The Philosophical Society of Texas

PROCEEDINGS

1994

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OF THE ANNUAL MEETING

AT AUSTIN

DECEMBER 2–4, 1994

LVIII

AUSTIN

THE PHILOSOPHICAL SOCIETY OF TEXAS

1995

THE PHILOSOPHICAL SOCIETY OF TEXAS FOR THE COLLECTION AND DIFFUSION OF KNOWLEDGE *was founded December 5, 1837, in the Capitol of the Republic of Texas at Houston by* MIRABEAU B. LAMAR, ASHBEL SMITH, THOMAS J. RUSK, WILLIAM H. WHARTON, JOSEPH ROWE, ANGUS MCNEILL, AUGUSTUS C. ALLEN, GEORGE W. BONNELL, JOSEPH BAKER, PATRICK C. JACK, W. FAIRFAX GRAY, JOHN A. WHARTON, DAVID S. KAUFMAN, JAMES COLLINSWORTH, ANSON JONES, LITTLETON FOWLER, A. C. HORTON, I. W. BURTON, EDWARD T. BRANCH, HENRY SMITH, HUGH MCLEOD, THOMAS JEFFERSON CHAMBERS, SAM HOUSTON, R. A. IRION, DAVID G. BURNET, and JOHN BIRDSALL.

The Society was incorporated as a non-profit, educational institution on January 18, 1936, by GEORGE WAVERLY BRIGGS, JAMES QUAYLE DEALEY, HERBERT PICKENS GAMBRELL, SAMUEL WOOD GEISER, LUCIUS MIRABEAU LAMAR III, UMPHREY LEE, CHARLES SHIRLEY POTTS, WILLIAM ALEXANDER RHEA, IRA KENDRICK STEPHENS, AND WILLIAM EMBREY WRATHER. On December 5, 1936, formal reorganization was completed.

The office of the Society is located at 2.306 Sid Richardson Hall, Austin, 78712.

Edited by Ron Tyler, Janice Pinney, and Colleen Kain

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Three hundred and three members, spouses, and guests gathered at the Four Seasons Hotel in Austin on December 2–4, 1994, for the Society's 157th anniversary meeting. President Steven Weinberg had organized a superb program on "The Controversial Cosmos." The Friday evening reception and dinner was held at the Lyndon Baines Johnson Presidential Library, during which President Weinberg announced the new members of the Society and presented them their certificates of membership. The new members of the Society are: Philip C. Bobbitt; Charles M. Bonjean; Charles C. Butt; Joaquin G. Cigarroa Jr.; Mary Elizabeth Crook; Jean Houston Baldwin Daniel; Wilhelmina Delco; J. Chrys Dougherty IV; James K. Galbraith; Malcolm Gillis; E. Ernest Goldstein; William B. Hilgers; Joseph D. Jamail Jr.; William W. Justice; Lowell H. Lebermann Jr.; Prudence M. Mackintosh; Gwendolyn O. Marsh; Judith D. Moyers; Burl Osborne; Bernard Rapoport; Allan Shivers Jr.; Marshall T. Steves; Stephen W. Sullivan; Charles W. Thomasson; Billy Bob Trotter; David C. Warner; Jon S. Whitmore; C. G. Whitten; and C. Kern Wildenthal.

President Weinberg had planned a fascinating program with a number of distinguished speakers invited to share their insight into the Controversial Cosmos with the membership. We paused for lunch at the Four Seasons Hotel, and the annual banquet was held that evening at the Austin Club with the Showcase band playing throughout the evening.

At the annual business meeting, Vice President Bill Crook read the names of the eight members of the Society who had died during the previous year: Randolph Lee Clark, Ezra William Doty, Franklin Israel Harbach, John Tilford Jones, Bernice Milburn Moore, A. Frank Smith Jr., Gail Whitcomb, and Frank McReynolds Wozencraft.

Secretary Tyler announced that our membership stood at 181 active members, 66 associate members, and 44 emeritus members. Treasurer Dougherty reported that we had invested some of our funds in the hope of earning sufficient interest to help support our annual meeting and other programs.

The following officers were elected for the coming year: Bill Crook, president; Charles Sprague, first vice president; Jack Blanton, second vice president;.Chrys Dougherty, treasurer; and Ron Tyler, secretary.

President Weinberg announced that we had received five entries in the President's Award contest, but the judges decided not to award the prize.

Following the Sunday morning discussion, President Weinberg declared the annual meeting adjourned, to be reconvened on December 1, 1995, in Corpus Christi.

ATTENDANCE AT THE 1994 MEETING

Members registered included: Misses Hayes, Hollaman, Lee, Natalicio; Mesdames Brinkerhoff, Crook, Daniel, Hershey, Diana Hobby, Hutchison, Johnson, Johnston, Kempner, Krier, Lancaster, Mackintosh, Marsh, McCorquodale, McDermott, Porter, Randel, Rhodes, Rostow, Temple, Vick, Weddington, Wilhelm, Isabel Brown Wilson, Zachry; Messrs. Anderson, Arnold, Ashby, Barrow, Henry M. Bell Jr., Paul Gervais Bell, Berdahl, Bobbitt, Bonjean, Caldwell, Calgaard, Carson, Christian, Cigarroa Jr., Cook, Crook, Curtis, Denman, Dick, Dobie Jr., Dougherty III, Dougherty IV, A. Baker Duncan, Farabee, Fehrenbach, Joe J. Fisher, Flawn, Galbraith, Garner, Garrett, Goldstein, Gordon, Greenhill, Guest, Hamm, Hargrove, Harrigan, Harrison, Harte, Hershey, Hilgers, Hill, Hobby, Holtzman, Hughes, Inman, James, Jordan, Justice, Kelsey, Kessler, Kempner, King, Kilgore, Kozmetsky, Law, Lawrence, Lebermann, LeMaistre, Levin, Lochridge, Locke, Lord, Love, Luce, Maguire, Mark, Martin, McCombs, McKnight, Middleton, Moody Jr., Moore Jr., Moseley, Mullins, Murphy Jr., Phillips, Pope, Pressler, Ramey Jr., Reavley, Rostow, Rutford, Schwitters, Seybold, Shilling Jr., Shivers Jr., Shuffler, Smith, Sparkman, Spence, Sprague, Steves Sr., Storey Sr., Storey Jr., Sullivan, Sutton Jr., Temple, Thomasson, Trotter, Trotti, Tyler, Vandiver, Wainerdi, Walker, Warner, Weinberg, Whitmore, Whitten, Whittenburg, Winfrey, Woodruff, Worsham, Charles Wright, James Wright, Lawrence Wright, William Wright, Yudof.

Guests included: Mrs. Thomas D. Anderson, Mrs. Daniel Arnold, Mrs. Lynn Ashby, Charles Barnes, Mr. and Mrs. Thomas G. Barnes III, Mrs. Thomas Barrow, Sharon Begley, Mrs. Henry M. Bell Jr., Mrs. Paul Gervais Bell, Mrs. Robert Berdahl, Mrs. John R. Brown, Mrs. Clifton Caldwell, Mrs. Ronald Calgaard, Mrs. Ronald Carson, Patsy Chaney, Mrs. Joaquin Cigarroa Jr., Mrs. C. W. W. Cook, France Cordova, Mrs. William Crook, Mrs. Gregory Curtis, Mrs. Dudley Dobie Jr., Mrs. J. Chrys Dougherty III, Ann Druyan, Mrs. A. Baker Duncan, Mrs. Ray Farabee, Mrs. T. R. Fehrenbach, Mrs. Joe J. Fisher, Maverick Fisher, Mrs. Peter Flawn, Mrs. Joe B. Frantz, Mrs. Bryan Garner, Mrs. Jenkins Garrett, Margaret Geller, Mrs. E. Ernest Goldstein, Mrs. William Gordon, Mrs. Joe Greenhill Sr., Joe Greenhill Jr., Mrs. William Guest, James Gunn, Greg Ham, Mrs. George Hamm, Mrs. James Hargrove, Mrs. Stephen Harrigan, Mr. and Mrs. Harold Harris, Mrs. Edward Harte, Beth Hedrick, Mrs. William Hilgers, Mrs. John Hill, Mrs. Wayne Holtzman, Susan Hornstein, William Hornstein, Ann Hotung, Bruce Hunt, Mr. and Mrs. Richard Jacobs, Mrs. Thomas James, T. Mark James, Mrs. Bryce Jordan, Mrs. William Justice, Mrs. Harris Kempner, Mrs. Jimmy Kessler, Mrs. Dan Kilgore, Jerianne Kolber, Mrs. George Kozmetsky, Olin Lancaster, Mrs. Thomas Law, Mrs. F. Lee Lawrence, Mrs. Charles LeMaistre, Mrs. William Levin, Marc Lewis, Mrs. Lloyd Lochridge, Mrs. John Locke, Mrs. Grogan Lord, Mrs. Ben Love, John Mackintosh, Mrs. Jack Maguire, Mrs. Hans Mark, Mrs. B. J. McCombs, Mrs. Harry Middleton, Mr. and Mrs. Jon Moline, Colby Moore, Mrs. J. Sam Moore Jr., Mrs. John Moseley, Mrs. Charles Mullins, Mr. and Mrs. Leo Newman, Lynda Obst, Mrs. Thomas Phillips, Mrs. Edmund Pincoffs, E. Peter Pincoffs, Mrs. Jack Pope, Mr. and Mrs. Boone Powell, Mrs. Paul Pressler, Mrs. Thomas Ramey Jr., Mrs. Thomas Reavley, Alec Rhodes, Carl Sagan, Mr. and Mrs. Melvin Salveson, Lawrence Scott, Linda Schele, Mrs. Roy Schwitters Jr., Mrs. William Seybold, Josephine Shanks, Mrs. Roy Shilling Jr., Mrs. Allan Shivers Jr., Mrs. Ralph Shuffler, Mr. and Mrs. Bill Shuffler, Mrs. Frank Smith, Mrs. Robert Sparkman, Mrs. Ralph Spence, Louise Spurgin, Mrs. Charles Sprague, Mrs. Marshall Steves Sr., Mrs. Charles P. Storey Sr., Mrs. Charles P. Storey Jr., Mr. and Mrs. Richard Stream, Mrs. John Sutton Jr., Ying Tang, Mrs. Larry Temple, Mrs. Charles Thomasson, Mrs. Bob Trotter, Mrs. Robert Trotti, Scott Van De Mark, Mrs. Frank Vandiver, Ross Vick, Mr. and Mrs. Curtis Vaughn, Mrs. Richard Wainerdi, Mrs. Raul Walker, Mr. and Mrs. George Ward, Mrs. David Warner, Mrs. Steven Weinberg, Mary Pearl Williams, Mrs. Jon Whitmore, Mrs. C. G. Whitten, Mrs. Gail Whitcomb, Mrs. George Whittenburg, Wallace Wilson, Mrs. Iron Worsham, Mrs. Shirley Wozencraft, Mrs. Charles Wright, Mr. and Mrs. Don Wright, Mrs. James Wright, Mrs. Lawrence Wright, Mrs. William Wright, Mr. and Mrs. Paul Youngdale, Mrs. Mark Yudof.

WHAT DO WE KNOW ABOUT THE UNIVERSE? MODERN COSMOLOGICAL KNOWLEDGE

STEVEN WEINBERG

IN PLANNING THIS YEAR'S PROGRAM, WE SPENT SOME TIME CONSIDERING THE possibility of taking our subject as "Problems Of Higher Education." But as the year went on, those problems seemed larger and larger, and I began to think that higher education was too difficult a topic. We have therefore decided to pick an easy topic for this year. It is, "What is the Universe?"

To be a little bit more specific, we have divided this into three sections, each dealing with particular aspects of that question. The first session this morning really does ask "What is the Universe?"—that is, what do we know scientifically about the universe? Then after a coffee break, we will have a second session, which considers "How We Know It?" This sessions deals with the problems of funding and science policy that underlie the scientific discoveries. The third session, this afternoon, will deal with the "Impact of Cosmology on General Culture."

There will be time after each of the panel's talks to have a general discussion. I would like to suggest that this general discussion be focused on the particular topics being discussed in each session. So, for example, if this morning you think that you don't like the universe, I would suggest you raise that point in the third panel rather than in the first panel.

To start, we have a message from last year's president of the Society, Ambassador Bob Krueger. He regrets that he couldn't get here, but the plane connections from Burundi were difficult. He is in Burundi without his library, but out of the depths of his learning, he recalled for us a quotation from John Donne, which I think is appropriate. It is in "An Anatomy of the World," and goes as follows:

> The sun is lost and the Earth and no man's wit can well
> direct him where to look for it.

We're not here so much concerned about the Sun and the Earth, we think we know a fair amount about them, but rather with the larger universe of stars, and galaxies—the whole thing. We don't know whether our wit will direct us where to look for it, but this is a good place to find out.

So, I will now call for the first speaker. She is Margaret Geller, Professor of Astronomy at Harvard University and Senior Scientist at the Smithsonian Astrophysical Observatory. Margaret is—this is me talking now, not reading what she submitted—Margaret is one of the young leaders of observational astronomy. Together with some colleagues, she was the one who found large structures in the universe—great walls and other great voids and other things out there—an amazing amount of structure where most astronomers would have expected the galaxies to form a more or less homogeneous soup. This has started a long chain of subsequent work in cosmology and astronomy.

Her work has been honored in many ways. In particular, she is one of the youngest members of the National Academy of Sciences, she is a MacArthur Fellow, and she has won national and international film prizes. Her topic is "The Present Universe."

THE PRESENT UNIVERSE

MARGARET GELLER

Thank you. It's a pleasure to be here. When growing up in New Jersey, I thought Texas was unimaginably large! And the first time I drove across it, I found that it was unimaginably large. But I finally found something that makes Texas look puny—that's the universe.

The attempt to explore the universe and to understand its history is perhaps one of the most audacious of human adventures. Those of us who work in this field have the chutzpah to assume that by observing ancient light which travels to us for hundreds of millions, or even billions, of years before ending its journey in our telescopes, we can find out what the universe looks like and how it came to be.

I'd like to tell you a little bit about what we know so far—a little bit about the little bit that we know. And I'd like to start on a fairly large scale with our own galaxy, the Milky Way.

If you look up at the sky on a clear night, you see a band of stars running across the sky. That band of stars is the plane of our galaxy, the Milky Way. If you could get outside our galaxy, it might look something like our nearest neighbor, Andromeda, which is some two million light years from us. The light which hits a photographic plate to make a picture of Andromeda travels for two million years before it ends its journey and makes a picture.

Galaxies like Andromeda and the Milky Way are enormous systems. The diameter of a galaxy is about 100,000 light years. Light traveling from the center of our galaxy to the Sun, for example, takes about 25,000 years to get there. These distances are enormous. For comparison, it takes eight minutes for light to reach us from the Sun. The Sun orbits the center of the galaxy once every hundred million years or so.

Andromeda is accompanied by some small friends—galaxies have an enormous range of sizes. You might ask, how massive is a galaxy like Andromeda? The mass of Andromeda is about a trillion times the mass of the Sun. A way to remember this number is that there's about a solar mass in Andromeda for every dollar in the federal deficit.

Galaxies don't have well-defined edges. If you measure the mass of a galaxy by looking at the motions of stars in the galaxy, you find that there's much more mass than you can explain if you just put together stars to make up the light you see. In fact, you find that ninety percent of the mass of galaxies is dark and doesn't give out any light.

Nature has played a rather unkind trick on those of us who attempt to discover the ways of the universe. Ninety percent, or perhaps even ninety-nine percent, of the mass in the universe is dark. As a result, we don't know really what the matter is or where it is. We can only detect dark matter by looking at motions in the universe and by applying Newton's laws.

The visible portion of the universe contains about 10 billion big galaxies similar to our own Milky Way. Because they have mass, galaxies cluster together. The nearest cluster of galaxies—the Virgo cluster—is about 45 million light years from us. We see this cluster as it was 45 million years ago.

The galaxies in the Virgo cluster look very different from Andromeda and other spirals. The elliptical galaxies in Virgo are just big piles of stars. Elliptical galaxies are much more common in clusters than in less dense regions of the universe. These clusters can contain hundreds to thousands of galaxies comparable in mass with the Milky Way.

I glibly specified a distance to the Virgo cluster. In fact, when we do cosmology, we don't really measure distances directly. We cheat. What we measure is velocity.

In 1929, Hubble made one of the most remarkable discoveries of the twentieth century. He discovered that the universe is dynamic—that galaxies appear to be flowing apart from each other with velocities just proportional to their distances. This expansion law enables us to measure the distances to galaxies by measuring their velocities, which are, it turns out, a lot easier to measure than distances. We measure the velocity, and the Hubble constant (related to the age of the universe) enables us to convert velocities to distances.

To understand the Hubble expansion, imagine a piece of elastic with galaxies sewn to it at regular intervals. If I stretch the elastic, the galaxies move apart from each other, with exactly the Hubble law: velocity is proportional to separation. Any galaxy I sit on sees the same law. You have to imagine the elastic going on and on forever. Another remarkable property of this law is that I start with the galaxies uniformly spaced, and I end that way. This law is a special one which preserves the arrangement of galaxies.

The Hubble law enables us to map the universe. We live in the first age when this mapping has been possible. Advances in detector technology enable us to detect, record, and interpret a large fraction of the photons which arrive after their hundred-million- or billion-year journeys.

The first step in making a map of the universe, or finding out what the universe looks like, is to find the positions of galaxies on the sky. We take pictures of the sky, and find these objects. We measure their latitudes and longitudes, or their positions, on the sky.

Fortunately, for the beginning of this kind of project, positions of galaxies were catalogued in the 1950s and 1960s by Zwicky and his collaborators working at Cal Tech. They looked by eye at 1,000 photographic plates and found the positions of 30,000 nearby galaxies. The galaxies in Zwicky's map are comparable with the Milky Way; they are nearer to us than about 500 million light years.

Even the two-dimensional map shows clearly that there are clusters of galaxies. However, there is no obvious pattern in the two-dimensional map.

Of course, the universe is a three-dimensional, not a two-dimensional, place. What we'd really like to know is the distribution of galaxies in three dimensions. What does the universe look like? Are there patterns on very large scales? We know there are objects, galaxies, which have radii of 100,000 light years or so. We know there are clusters of galaxies containing thousands of galaxies within a region of light years across. But are there larger patterns? And, if so, how large are they?

In the 1970s, everyone was quite confident that, if you observed a piece of the universe, a hundred million light years on a side, every piece would look the same. In other words, everyone thought there were no patterns larger than a few tens of millions of light years. It turns out that this conclusion is patently false. We now know from measurements of the redshifts or equivalently, for these purposes, distances to thousands of galaxies in the universe that the universe contains patterns with a scale of more than a hundred million light years.

One of the first steps in discovering these remarkable patterns was the project which John Huchra and I and our student, Valerie de Lapparent, carried out in 1985. We measured the redshifts for galaxies in a strip across the sky. We wanted to see whether there were any large-scale patterns. It turns out that for the nearby universe, you can use a rather small telescope—1.5 meters—to do your exploring. Our observatory is on Mount Hopkins, just south of Tucson.

We measure these redshifts by dispersing the light from each galaxy. We spread the light out into its colors and then we examine the spectrum. We look for characteristic features which tell us the velocity of the galaxy. For example, lines of hydrogen and nitrogen form a characteristic pattern. For more distant galaxies we see this pattern at longer wavelength. A more distant galaxy often appears more distant: it has a smaller angular size. But because galaxies have a wide range of intrinsic sizes, the difference in angular size is inadequate for really knowing the distance. We measure the spectrum: the lines for a more distant galaxy are at longer wavelength. This longer wavelength is a consequence of the larger velocity of this galaxy. This effect is very similar to the Doppler effect that you hear when a siren goes by you. The annoying noise gets to be somewhat less annoying because the pitch drops. This Doppler effect causes the lines to shift to the red (to longer wavelength) for galaxies with larger velocities. After you measure redshifts for a thousand galaxies or so, you obtain this remarkable picture.

The map of our first slice of the universe is often called, "the stick man." We look out into the universe to a depth of some 500 million light years. The galaxies are distributed in very thin structures surrounding, or nearly surrounding, what appear to be empty—or at least dark—regions. The diameter of the largest low density, or dark, region is 150 million light years. You could put a box inside a dark region, a box 100 million light years on a side. The box would have nothing in it. Other boxes the same size would have lots and lots of galaxies, because they might contain a cluster. The patterns in our first slice are as large as the map.

On the basis of our first slice, we suggested that the galaxies might be distributed on two-dimensional structures—that they were distributed as though they were on the surfaces of bubbles. We assume that our first slice is a typical slice. And we asked ourselves, "What kind of distribution in galaxies in the universe would make our slice typical?"

If you think about this question you can imagine making a slice through the soap suds in your kitchen sink. If the slice is thin compared to the size of the bubbles, the soap film surrounds the interiors of the bubble. It's just that the bubbles in the universe are 150 million light years across, not a centimeter.

After we made this suggestion, we got quite a bit of help from the media. For example, one headline proclaimed, "Lawrence Welk Universe Theory." The description continued: "Imagine Lawrence Welk playing God, blowing those bubbles while the band plays 'Stardust.' Who knows? Maybe the universe is just one big puff piece." We and others have gone on to continue to discover whether the structure we saw in the first thousand galaxies is typical of the nearby universe.

With 10,000 galaxies, in a map of portions of the northern and the southern galactic hemispheres, we see more of these enormous patterns. The most impressive of these structures is the Great Wall—a sheet of galaxies which extends across the entire northern galactic hemisphere. The instructions to get there are: leave our galaxy, travel for 300 million light years or so, look around you—you're in the Great Wall. Everywhere you look, there are galaxies. In the southern hemisphere, we find the same kind of structure—empty regions and thin walls populated by thousands of galaxies like the Milky Way.

The largest surveys taken together now contain 100,000 galaxies reaching one-and-a-half billion light years into the universe—an enormous map. These maps contain many large empty regions, and walls similar to the Great Wall. All of the surveys show the same kind of pattern. But, 100,000 galaxies is a still a small number compared to the contents of the visible universe—some 10 or 100 billion galaxies.

The universe is highly structured today. It has an age of somewhere between ten and fifteen billion years. One of the puzzles facing us is that although the universe today is highly structured, the universe at an age of 200,000 years was very uniform. The three-degree radiation which fills the universe carries with it a picture of the universe at this ripe young age. There is structure in the most recent maps of the very young universe. There are places where the temperature is slightly warmer than three degrees, and there are patches where it's slightly colder. This picture shows the little lumps and bumps which were in the universe at that early epic; they grew under the action of gravity to become the spectacular structure we see today. The difference between the hot regions and the cold regions is a few parts in a hundred thousand, whereas the variations in density of galaxies today can be as much as factors of a thousand!

The early universe was very smooth. Now, at least the matter that emits light, shows us a highly structured pattern. We have very little information about what happened in between. With new big telescopes being constructed on the ground, we hope to be able to observe the younger universe at intermediate times. So far, the data are very patchy.

Our situation now is little bit like going to the movies after a difficult day. You are awake for the first few seconds, you fall to sleep, to wake up only at the very end. You see the last few frames. You wonder—what happened? Well, a lot can happen in ten or fifteen billion years. How do we get a highly structured universe in a mere ten to fifteen billion years?

We have some theoretical understanding of the development of structure in the universe. Gravity has a lot to do with it. Computer simulations start with millions of particles—say 32 million particles interacting gravitationally in an expanding universe. In the beginning there is little structure—as time passes, structure develops.

The problem remains that the structures produced in these computer models are often not as large or as coherent, or as well defined, as those that we see in the data. One of the most profound problems we have today is to understand the origin of structure in the universe. How did these huge structures originate? How did our galaxy form, and how did we get here?

With state-of-the-art graphics, we can now "travel" through a portion of the survey. The graphics as part of a film called, "So Many Galaxies—So Little Time" (available from the Astronomical Society of the Pacific [415-337-1100]). The goal of the film is to show young and old alike the aesthetics of science and to share the excitement of discovery with a broad audience.

THE EARLY UNIVERSE

STEVEN WEINBERG

The next speaker needs no introduction. It's me. I may not know much, but I know enough not to show graphics right after Margaret Geller, so I will stay here at the microphone. The title of my contribution is "The Early Universe."

This title suggests that there was a time when the universe was different from what it is now. This is certainly true; the universe has not existed in its present state—the state that was described by Margaret—for an infinitely long time. You can see this just from the expansion of the universe that Margaret talked about—all the galaxies rushing apart from each other. It follows without much thinking that they were much closer together in the past.

In fact, there must have been a time in the past when all the galaxies were crunched together—not separate galaxies at all. To be specific, if you look at the galaxies in the Virgo cluster that Margaret showed, the cluster of galaxies in one of her early slides, she said they are believed to be about 45 million light years away. By the way, since the title of the meeting is "The Controversial Cosmos," I should say that number is very controversial. I suspect it's probably about right, but there are some distinguished astronomers who think it may be half that, a mere 20 million light years or so away. The difference does matter, but it doesn't affect the overall picture very much.

To be definite, let's say that the Virgo cluster galaxies are 45 million light years away. We know that they are traveling away from us (you could just as well say we're traveling away from them) at a speed of 1,000 kilometers per second. Now if something is moving away from you at 1,000 kilometers per second, and you know how far away it is now, then you can figure when it must have been close to you in the past. And if you just divide 45 million light years by 1,000 kilometers per second (and you happen to know how many kilometers are in a light year), you can figure that these galaxies must have been close to each other about fourteen billion years ago.

Actually, it must have been more recently than that. The calculation I just did assumes that the speed of the galaxies has been constant during this period. There is an obvious reason to believe that the expansion is slowing down: it is the force of gravity. Everything in the universe is being attracted to everything else by that force. So, the expansion must have been faster in the past than it is now, and, therefore, the expansion must have started more recently than fourteen billion years ago. Our best guess is that because of gravity the present expanding state of the universe has only lasted about two-thirds of that time. (The number two-thirds is actually more precise than the 14 billion.) That's a guess with which not everyone would agree, but it is pretty well founded theoretically. In this way, we conclude that the age of the universe is about nine billion years.

As I said, we don't have a great deal of confidence in the precise values of these distances and times, but I think most astronomers would agree that somewhere in the range from nine to, perhaps, fifteen billion years ago, the matter of the universe was tightly crunched together. The galaxies and even the stars could not have existed then. Rather, we think that the universe must have been filled with a gas of hydrogen and helium atoms.

If you go back far enough, even atoms could not have existed separately. You can see this by thinking a little about how the refrigerator in your kitchen works. Freon in the refrigerator is compressed (that's what your compressor is for), and then it's allowed to expand. In a free expansion, any gas will cool down, because some heat energy goes into pushing the gas outward. The cold freon then takes the heat out of your butter and eggs. The universe is in a state of expansion, and therefore it is cooling. The cooling doesn't affect the stars, because they have nuclear reactions going, which keep them hot. But it does affect the gas that fills the voids between the stars and the galaxies, and it affects the radiation that Margaret Geller mentioned that fills the universe. This faint radio static was discovered in 1964 in New Jersey, but it fills the universe more or less uniformly, with only slight variations in different directions, mentioned by Margaret Geller. The intensity of this radiation can be described by saying that it's the same intensity of radiation you would get if you pointed a radio antenna into a bath of liquid helium at a temperature of three degrees above absolute zero, and listened to the faint whisper of radio waves from the motion of the helium atoms. It is not easy to detect, as you can imagine.

But, the universe is expanding, and so this radiation has been cooling. And, again, without any difficult chain of reasoning, you can see that if it's cooling, it must have been hotter in the past. In fact, it cools in proportion to the size of the universe. So, when the universe was a thousand times smaller than it is now, it was a thousand times hotter. We think that this was at a time when the universe was about a million years old.

We need theory to carry the story any earlier than that. The reason is very simple: not until the temperature of the universe dropped to a few thousand degrees could atoms hold together, so before that time the universe was filled with free electrons, which made it opaque to radiation. I'll come back to this point.

Because the universe was opaque during its first million years, there's not much chance (although it's not impossible) that we'll detect any sort of signal showing us directly what happened during that period. But our theories work pretty well. We can test them in various ways, not relying on pure thought, but also relying on observation, and we find that the theories do give a coherent picture of the early evolution of the universe, starting at a moment which is about a trillionth of a second after a real beginning.

I mentioned a real beginning, though in fact I don't know that there was a beginning. (I'm sure that we'll come back to this point.) If you mathematically extrapolate the equations governing matter and gravitation backward in time, you find that there was a moment when the universe was infinitely hot and infinitely dense. This is what I'm calling a beginning—the mathematical moment at which our equations tell us the universe was infinitely hot and infinitely dense. For reasons I'll explain in a minute, we don't really know if there was such a moment, but it's good to have a benchmark to reckon time from. So this mathematical moment is what I have in mind when I say that something happened a million years or a trillionth of a second after the beginning.

Our present physical theories allow us to go back in time to about one-trillionth of a second after the supposed beginning, when the temperature of the universe was 10,000 trillion degrees. At that time, not only were there no galaxies or stars or astronomers, there were no atoms; the nuclei of atoms did not exist; and even the protons and neutrons, which are the particles inside the nuclei of atoms today, did not exist. The universe was filled with a nearly smooth undifferentiated soup of the particles that are studied in today's elementary particle physics laboratories—some of them familiar particles like electrons, some much less familiar like quarks, and other particles whose names I won't burden you with, together with their antiparticles.

I should say a word about antiparticles because they played a very important part in this story. One of the great discoveries of twentieth-century physics (originally a theoretical discovery of Paul Dirac) is that for every kind of particle that can exist, there is another kind of particle known as the antiparticle, which has the same mass and spins in the same way, but has an opposite electric charge.

So, for example, just as there are electrons that flow through electric wires and an electric current and have a certain mass and a certain negative electric charge, there are other particles called antielectrons (they are important enough to have a special name—they are known as positrons—but I will call them antielectrons), that have just the same mass and just the same spin as electrons, but opposite electric charge. Antielectrons are not abundant in the present universe. In fact, it was not until some years after Dirac's prediction that antielectrons were found in cosmic rays. Today antielectrons are produced as a matter of routine in our laboratories. They have stopped being exotic and are used as a tool not only in particle physics but even in medicine.

The universe at this very early time was filled with nearly equal numbers of particles and antiparticles—quarks and antiquarks, electrons and antielectrons, and so on—plus radiation filling the universe, all making large contributions to the energy and pushing out and making the expansion go. Then as the universe cooled, at a certain moment about a hundredth of a second after the beginning, the quarks joined together to form the particles, the protons and neutrons, that make up atomic nuclei.

When the universe was about a second old, the electrons and the antielectrons started to annihilate each other because it was so cold, only about 10,000 billion degrees. To be accurate, they had been hitting each other and annihilating all along, but during the first second it had been hot enough so that particle-antiparticle pairs would be continually created out of radiation, maintaining the numbers of particles and antiparticles. But then when the universe was a second old and the temperature dropped to about 10,000 billion degrees, it was cold enough so that particles and antiparticles were no longer being produced from radiation. And so almost all of the contents of the universe disappeared into a blast of radiation, leaving over only a tiny residue, an excess of about one part in ten billion of quarks and electrons, which couldn't find an antiquark or antielectron with which to annihilate, because there were one part in ten billion more quarks than antiquarks and electrons than antielectrons.

That's a big mystery. Why is there anything left? Why are we here? We are here because the amount of matter in the early universe exceeded the amount of antimatter by about one part in ten billion. Many physicists would like to be able to calculate that number and explain why it is what it is. And many of us have tried, without success so far.

We have now reached the end of the first second. The universe went on expanding and cooling. At this time, it was filled with radiation and electrons and quarks, the quarks now fused into protons and neutrons. These are the particles that make up the nuclei of the atoms that make up ordinary matter. But the protons and neutrons had still not fused into atomic nuclei—it was still too hot for nuclei to form. Nuclei formed, but were immediately blasted apart by the radiation.

Then at the time the universe was three minutes old, it became cool enough so that a nucleus, when formed, would no longer be blasted apart. And at that moment, the basic recipe for the universe was frozen: about 75 percent hydrogen, 25 percent helium, and a small amount of light elements.

One of the great triumphs of this whole theoretical picture is that it is possible to calculate these abundances, not only of hydrogen and helium, but also of their rare isotopes like deuterium and helium 3, and of a few other light elements like lithium, beryllium, and so on. The numbers fit—the abundances of the light elements that we see in the stars and interstellar gas match the numbers that are calculated from our theory of the early universe. This is really one of the most impressive triumphs of mathematical science, applied to an era tremendously remote from us in time.

After the first three minutes the contents of the universe, now consisting of hydrogen and helium nuclei and a trace amount of other things, went on expanding and cooling. When the universe was about a million years old, it began to be cool enough so that electrons and nuclei would hang together as atoms, and not be immediately blasted apart by the radiation. The disappearance of free electrons made the universe transparent to radiation. This is the epoch when the radio static discovered in 1964, the cosmic microwave background, was emitted. Not too long after (as these things go) the force of gravity began to attract the matter of the universe toward the little seeds, the slight inhomogeneities, that had been present since earlier times. And as more matter clumped together, it became more attractive gravitationally, and then attracted more matter. This instability produced stars and galaxies and clusters of galaxies (not necessarily in that order). The stars began cooking the light elements with which they started. All of the heavy elements beyond lithium and beryllium were produced in the stars. A first generation of stars burned very rapidly, fusing the hydrogen and helium into heavy elements like carbon, oxygen and nitrogen, out of which we are formed, providing the subject of the next speaker.

Now, of course, all this makes an interesting story, but it does not tell us the thing that probably interests people the most. What everyone really wants to know is what happened at the very beginning. There are many views about this. I used to say that one just had to accept that time began then, and questions about what happened before then are simply impermissible questions, although of course they get asked anyway. St. Augustine took this view—he explained that part of the creation of the universe was the creation of time. But this is no longer the view of many astronomers and astrophysicists. Many of us now think that what I have been calling the beginning of the universe may not have been a real beginning. This is in part because we now understand that at the moment of one trillionth of a second after what I have been calling the beginning, when the temperature was roughly 10,000 trillion degrees, something strange happened in the universe.

All of the particles that I have been talking about have mass. Electrons have mass, quarks have mass, and so on. Where did they get that mass? Our theories tell us they got that mass at that moment of a trillionth of a second after the beginning—that before that, they were massless.

We don't know the details of how that happened. Our theories tell us it happened, and that it happened when the temperature was roughly 10,000 trillion degrees, but we don't know the details of how it happened. This is one of the main questions that the supercollider had aimed at answering, and which we hope now may be answered by another accelerator in Europe.

According to one view of what produced the mass of the quarks and electrons and so on at this very early moment, there are fields analogous to magnetic fields, but which have never been detected, and that fill the universe. Just as iron, at a temperature of 770 degrees centigrade spontaneously develops a magnetic field, so also as the universe cooled below a temperature of about 10,000 trillion degrees, it spontaneously developed these other fields, which pervade the universe today, and are responsible for the masses of the particles we see.

Now we don't know that this is true. As I said, this is one of the things we had hoped to learn about at the supercollider. But, if it is true, then at even earlier times although the average value of these fields was zero, they would have been in a state of violent fluctuation. When a field like this fluctuates beyond a certain value, it creates a local expansion which can then run away and produce something very much like what we saw in Margaret Geller's pictures—a universe, an expanding cloud of matter that grows to 10 billion light years across, or even larger. This is called chaotic inflation.

So, in other words, according to this picture of chaotic inflation, what we have been calling the Big Bang may be, in fact, only a little bang—only a local fluctuation in a very much larger megauniverse, which is continually experiencing these fluctuations and creating "universes." This may very well have been going on for eternity, so that it may not be necessary to answer any question about what happened before the beginning.

These ideas are so far highly speculative and should not be taken away as an established scientific doctrine. But fortunately these matters can be addressed by the methods of mathematical physics and also observational astronomy. If these ideas about chaotic inflation are correct, then the fluctuations occurring when the universe was hotter than about 10,000 trillion degrees would have left certain imprints in the present universe in the form of gravitational waves, which might be detected in our laboratories. We don't know whether the universe had a beginning, but we have a real chance of finding out.

Steven Weinberg: Our next speaker needs no introduction, but for a different reason—it is because everyone has heard of him. Carl Sagan is the Duncan Professor of Astronomy and Space Sciences at Cornell, and he is the Director of the Laboratory for Planetary Studies at Cornell. He's a distinguished scientist who has worked in many areas of astrophysics and in exobiology. He has also done much to bring science to the general public, to fulfill our aim of making the work of science part of the general culture of our time.

Carl has won the Pulitzer Prize. He just recently received the Public Welfare Medal, the highest award of the National Academy of Sciences. And although it's not in the printed program, he is the author of a new book, a Book-of-the-Month Club selection called *Pale Blue Dot*.

I hope that you will get to meet some of the out-of-state speakers here in our coffee breaks and lunches and so on, and in connection with Carl's talk I particularly want to mention that I hope you will get to meet him and his wife, Ann Druyan, who is here with him. Ann is a distinguished author, and has recently been elected as the general secretary of the Federation of American Scientists. Ann and Carl are writing the script of a movie based on an earlier novel, *Contact*, which I remember reading and finding fascinating. And with them, also as their guest, is Linda Obst, who is going to be the producer of this movie. It will star Jodie Foster and will be shown in theaters near you some time in the next billion years.

LIFE IN THE UNIVERSE

CARL SAGAN

Thanks very much, Steve. I just want to give Margaret her expanding universe back.

Well, my job is to describe the possibility of life elsewhere. This is, in a way, a new problem, a new question, because for most of human history, there was no elsewhere. This was the only world. There wasn't any other world. There wasn't any other place for life like us. And so the issue never arose. Yes, there were gods or demons who come from the sky—demons from the interior of the Earth is a very new idea. It used to be that the demons lived up in the sky, too.

Also, when we thought that the world was only a few thousand years old, the idea of evolution was silly, because if one species had evolved from another over a few thousand years, you should be able to see it happening. I mean, just watch this dog and see it turn into a cat. Doesn't happen? Forget about evolution. It's a ridiculous idea.

But now that we know that the world is four-and-a-half billion years old, extremely slow changes in heredity can build up to enormous differences from organism to organism, and evolution has to be taken seriously.

And this idea—and the grander idea that life on Earth arose by chemical processes about four billion years ago, which, while certainly not absolutely confirmed, is certainly the prevailing view, and there's much to support it—indicates that the laws of nature permit order to be extracted from chaos without divine intervention. The divine intervention, if you like, is in the establishment of the laws of nature that permit these processes in the first place. But the idea of a micro-interventionist deity who has to fix things, in a way, is an impious idea. If a deity is omnipotent and omniscient, why does she or he have to fix things? Why not get it right in the first place? This meddling is a sign of incompetence. And it's a much grander idea, I believe, to imagine a deity, if you want, if there was the kind of beginning that Steve talked about, who gets it right in the first place, establishes the laws of nature in the physical cosmos, lets it roll, and then goes and does something else, maybe with those infinite number of other universes that she or he may have to deal with.

If we look at life on Earth, we find astonishing similarities. For example, we and the chimpanzees share 99.6 percent of our active genes, which means either that 0.4 percent is a larger number than we had hitherto understood, or that we have a lot to learn about ourselves from studying those guys.

And the apparent gross differences between us and oak trees, slime molds, killer whales, viruses—I mean, that's a big range. Right? But, yet, you look closely and you find that all of those beings, all the beings on Earth use nucleic acids to encode the heredity material—it's the language of life—use amino acids, the building blocks of proteins, as the catalysts that control the chemistry going on inside and in the vicinity of the organism, and use essentially the same code book to translate nucleic acid information into protein information. How could those impressive, formidable, awesome similarities occur unless all life on Earth has evolved from a single common ancestor?

If that is true, and that is certainly the prevailing understanding, then we know almost nothing about life, because we have only one example of it. All the differences are superficial. Down deep there's only one kind of life on Earth. If there's life elsewhere, does it have nucleic acids, does it have proteins, does it have the same code book? Never mind if they look ugly. What are they based on? How do they work? Where did they come from? We don't know. And do they have to be based on carbon or water as we are? I confess to you I am personally a carbon and a water chauvinist, but that may be an accident of birth or a failure of the imagination. I can give you arguments why everybody else has to be based on the same molecules as me. But it's a suspect argument, because I have a vested interest.

Now, something happened to our ancestors who studied the stars. They saw as an everyday occurrence the Sun, the Moon, the planets, and the stars rising in the east and setting in the west. And then somehow, tomorrow they went under the Earth, and there they are, ready to come up again.

That seems to mean we are at the center of the universe. It's as clear as anything. We're at the center. What's more, we use the stars for calendrical and other purposes. Nobody else—none of those slime molds or oak trees did. The stars clearly were made for us. The universe was made for us.

Every human culture bought into this delusion. It wasn't until the fifteenth century that we slowly began extricating ourselves from it. We still have trouble doing that. Think about how poetic and reasonable the words sunrise and sunset are. But, of course, that's a pre-Copernican phrasing. The Sun is not rising and setting. The Earth is turning. Think of how hard it is to parse haliocentrism into ordinary English. You know, something like, Billy, be sure to be home before the rotation of the Earth makes the local horizon occult the Sun. Billy's long gone before you're done. The language doesn't permit us to utilize the Copernican perspective. And, by the way, something approaching half of American adults do not know that the Earth goes around the Sun and takes a year to do it. Speaking about the more difficult problems in education.

Now I would like to just give a quick visual perspective on the idea that we are at the center of the universe. Here is a recent Hubble space telescope photograph of an obscure edge of the very cluster of galaxies that Margaret told us about, the Virgo cluster, some 45 million light years away.

This is a giant elliptical galaxy in the Virgo cluster. But almost everything else you see, all these other things, are not stars in our galaxy and not galaxies in the Virgo cluster, but galaxies behind the Virgo cluster. And there are some hundred billion other galaxies in the known universe.

Now suppose you were an intergalactic traveler seeking interesting galaxies, and you were told that the beings who are the point of the universe live on one of these galaxies. See that little one right there? That's the center of the universe, and they are the reason the whole universe of a hundred billion galaxies was made. Just ask them. What's your sense of them?

Now you pick out one of these galaxies. This is a painting by John Lomberg. It's the most accurate rendition of the Milky Way galaxy as seen from the outside that's been done so far. You're seeing a few hot stars and regions illuminated by hot stars. Some clusters, but no stars like the Sun. Suppose you were told that right there, according to the beings who live there, is the center of the universe—the fourth spiral arm out in the galactic boondocks, where it's not even well lit. That's the center of the universe. You might think that these guys are on the planet of the idiots.

And now, suppose you plunged into that part of the galaxy. See that star right there? There are 400 billion stars in the Milky Way galaxy alone, and the beings for whom the universe was made live here.

It's a pathetic conceit, which we should not castigate our ancestors for, because they had only their everyday commonsense notion about stars rising and setting, and their aspirations to be important through no effort of their own. We, today, are in a very different position. For us to think that we are the point of the universe today is, I believe, truly reprehensible.

Here is a very nice U.S. Geological Survey montage of some of the results of NASA's heroic three decades of planetary exploration and discovery. Some worlds are shown thrice—three different central meridian longitudes. The solar system—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune—a range of the moons of the Jovian planets, one comet, and if this were done lately, there would be three asteroids added that have been examined close up.

There is a gorgeous, beautiful array of worlds in the solar system. We live on one quite minor world. There are four big ones. Isaac Asimov described an extraterrestrial observer entering the solar system and describing it as four planets plus debris. We live on one of the hunks of debris.

How did life arise on our planet, and is there any elsewhere? I should confess straight out that nobody knows the answer, certainly, to the latter question. And, to the former, we have some very interesting hints. I will, in a moment, describe some of them. But we don't really know that either.

What we do know is that there are circumstances in which the very molecules that we are made of, the building blocks of the proteins, the building blocks of the nucleic acids, spontaneously form, and that is surely a hint that making us was not that difficult. Moreover, the Earth was uninhabitable because of impacts until something like four billion years ago. By 3.6 billion years ago, the Earth had abundant microbial life, and from the fossil forms we can tell that those could not have been the first life. It was too complex. Therefore, the origin of life had a very narrow window available for it, maybe something like a hundred million years. That means, I think, that it was a probable event, and I'll come back to that in a second on Mars.

The outer solar system, all these worlds, are loaded with organic matter—the carbon-based stuff that all life on Earth is made of. In the interest of time, I want to concentrate on one such world. This is a montage of the Saturn system. This picture was made, by the way, by the *Voyager* spacecraft, using scissors and glue technology. Each picture was taken separately, and then we pasted them on a black background to make this pretty picture. There is a moon of Saturn called Titan. It's the biggest moon in the Saturn system, second biggest moon in the solar system, an absolutely extraordinary world relevant to our question.

Here is the limb or horizon of Titan. You can see that the world itself is covered with a kind of orange smog, haze layers above the planet. *Voyager I* was in part dedicated to trying to take high resolution photographs to see breaks in the haze and cloud. Could we see the underlying surface? We could not. The idea of a moon with an atmosphere—clearly this has an atmosphere—a moon with red clouds, that's sort of weird. What is happening there? What is that stuff?

Here is a diagram of the pressure, which corresponds to altitude, versus temperature. It looks very much like the Earth's.

But as *Voyager I* and *II* discovered, the surface temperature is about 95 degrees above absolute zero, far below the freezing point of water. This is a very cold world. The surface pressure, however, is high. There's about ten times as much air above a square centimeter of surface on Titan than on Earth. And that air, as on Earth, is made mainly of nitrogen. The second constituent is methane, CH_4. *Voyager* discovered about eight simple organic molecules in the gas phase, already telling us that there is organic chemistry going on today in the upper atmosphere of this planet.

There are sources of energy pouring in to the Titan atmosphere, each of which reaches a certain depth, including electrons from the magnetosphere of Saturn through which Titan plows, ultraviolet light from the Sun, cosmic rays, and other sources.

Here is an early experiment in our lab in which we simulated the atmosphere of Titan at low pressure, supplied energy in the form of electrons simulating the Saturn magnetosphere, and you can see that the reaction vessel is coated with a kind of tawny solid powder. There is a picture of Titan on the wall just behind. And you can see it looks alike. This is, however, not a detailed scientific identification. But that can be done.

We can measure for Titan—you can see it here in color—what is called the imaginary part of the complex refractive index. It's essentially an absorption coefficient, a means of telling what parts of the spectrum of light are absorbed best by this material.

We can also measure the stuff I just showed you that's made in the laboratory, and that's this solid line. And you can see it matches really very nicely over many orders of magnitude of variation, both in wavelength and in that absorption coefficient. Whereas, other materials—this is something called poly-HCN, this is something called polyacetylene—that have been proposed don't match at all.

So we think we have bottled the haze of Titan. Since we have it in our laboratory, we can analyze it to see what it is. Without asking you to spend any time on the details, it is loaded with amino acids to the tune of one percent of it, and there's an enormous range of other organic molecules.

Chemists will recognize some of the purine and pyrimidine bases of nucleic acids. So, here we have this extremely curious circumstance that an obscure world in the outer solar system minding its own business, being irradiated by charged particles from nearby Saturn and light from the Sun, is producing organic molecules which are raining down like manna from heaven. We can calculate, if the same process had been going on for the last four billion years, the amount of stuff accumulated on the surface ought to be tens, maybe hundreds, of meters thick. That's an awful lot of stuff. It would be great to analyze it directly.

The NASA-ESA (European Space Agency) joint mission called Cassini, is designed to arrive in 2004. An entry probe is to enter through the haze and examine what's happening there. In this artist's impression, here is the entry probe, called Huygens, resting on the surface of Titan—of course, nobody knows what the surface of Titan actually looks like. In fact, you would not see Saturn from the surface of Titan, unless you had infrared eyes. The artist may be imagining what it looks like in the infrared. And we will have *in situ* organic chemistry done then.

The one thing about Titan that doesn't match the Earth with regard to simulating early conditions on Earth is, of course, liquid water. It's too cold there. Except that it turns out when there is a hypervelocity impact by a comet, it liquefies, it makes a kind of slurry of the snows on the surface, and it takes a long time to refreeze. It looks as if about half of the surface of Titan, over geological time, has seen liquid water for something like a thousand years. Whether all of that organic matter in liquid water for a thousand years has taken us far beyond the chemistry I just described to you, is an interesting open question for which we should hold our breath until 2004.

The one other world I want to briefly mention, with regard to life, is Mars.

It's a world of wonders. It is the place that the *Viking* spacecraft, a glory of the U.S. space program, landed in 1976. There were experiments to dig in the Martian soil—look, we're doing civil engineering in other worlds—extract soil samples back into the spacecraft and look for microbes. No microbes were found in two places, 5000 kilometers apart, by a variety of sensitive instruments. Funny results were obtained, not fully understood. The bulk of the scientific opinion is, whatever it is, it's not life.

But now, at the same time—where the spacecraft taketh away, they also giveth—there is extraordinary evidence that Mars, which today has no liquid water—too cold, atmospheric pressure too low—once had abundant running water. Look at these river basins. There were also lakes and conceivably some—this is disputed—oceans. When was that? That was about four billion years ago. That is, at the very moment when the origin of life was happening on the Earth, Martian conditions were extremely Earth-like. Is it possible that life arose on one of those worlds and not the other? Or did life arise on both, and then deteriorating climatic conditions on Mars made that life go underground, or become extinct, and on Earth, to survive and prosper? We don't know the answer, but Mars is clearly a very important place to explore.

We now have increasing evidence that there are planets of other stars. This is an accretion disk surrounding a nearby star called Beta Pictoris. This is just the sort of thing that has been hypothesized for the early history of the solar system as the Sun was forming, the planets condensing, accreting out of a circumstellar disk of gas and dust.

Here is a Hubble Space Telescope picture in the Orion nebula of, in fact, dozens of very young stars in which that's happening. And here a picture of our solar system—Mercury, Venus, Earth. And here the system of the pulsar 1257 + 12, which has at least three planets of recognizable similarity to Earth, both in mass and in distance from the star, suggesting that there are enormous numbers of planets throughout the Milky Way galaxy, and that we are on the verge of being able to detect them. And that, of course, means there are lots of potential abodes for life.

I want to conclude with just a word or two about my favorite planet in this entire glorious universe—this universe of a hundred billion galaxies, each with maybe a hundred billion stars, and that is ours. It's again a chauvinism to which I freely confess. I like the Earth, in part because I am beautifully adapted to it and to no other world. I appreciate it. Of course, this is a confusion of cause and effect. Nevertheless, it's something deeply felt.

When the two *Voyager* spacecraft were beyond Neptune, it was possible to turn the cameras of one of them back to look at the planets that we had long passed. And, of course, you would not see any detail. There would be a single pixel, a single picture element, but I thought it might be useful to get that, not for scientific reasons, but for other reasons.

We turn the camera back and we're able to photograph from beyond the outermost planet six of the nine planets of our solar system. And here, momentarily in a sunbeam, is the Earth, a pale, blue dot. That's here. That's home. That's us. That's where we live. That's where everyone you love, everybody you know, everybody you ever heard of, lived out their days. Every cattleman and rancher, every hunter and gatherer, every teacher and student, every prince and pauper, every young couple in love, every hopeful child, every king and peasant, every revered religious leader, every corrupt politician, every one of us lived out their lives there on a mote of dust suspended in a sunbeam.

The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that in glory and in triumph, they could become the momentary masters of a fraction of a dot.

Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of another corner of the pixel—how frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds. Our posturings, our imagined self-importance, the delusion that we have some privileged place in this universe, are challenged by this point of pale light.

It's been said that astronomy is a humbling, and even character-building experience. For me, there's no better demonstration of the folly of human conceits than this distant image of our tiny world. For me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot that is the only home our species has ever known.
Steven Weinberg: Not entirely surprisingly, we have run a bit over our scheduled time. I am going to exercise my prerogative as chairman today to extend this session so that we can have questions and answers. The coffee break is hereby put back by, let's say, twenty minutes. I don't want to take time from the next session, so I am hereby informing the people who are really running this meeting—I don't see them—oh, there you are, Ron—that we will put off the lunch for twenty minutes.

The subject of this meeting is "The Controversial Cosmos," and we do want to try to uncover the possible controversies that these talks may give rise to. Things similar to what Carl Sagan said in his talk were said four hundred years ago by Giordano Bruno, for which he was burned to death. We are not going to burn anyone, so I would like to call not only for questions but also comments and arguments. To do this, go to that microphone, please, and also, please give your name when you start.

There's always a problem of getting someone to ask the first question, so I will start things going by asking Margaret Geller a question. Margaret, you showed us all this structure, but when you look at sufficiently large scales, like a billion light years, you don't see anything that large, do you? I mean, the universe ultimately at sufficiently large scales is pretty homogeneous, isn't it?

Margaret Geller: The microwave background tells us that at least at early stages, the universe was quite uniform. And the maps of the distribution of galaxies shows huge holes all over the place. It's not really clear yet whether there are structures on the scale of the deepest maps of the galaxy distribution because of the way in which the maps are made.

The nearby maps, which John Huchra and I have made, are complete in the sense that we measured the redshift or the velocity for each galaxy. The deeper maps, although they cover a very large volume, are not complete. Thus the contrast of the structures is suppressed. Your first impressions of the deeper maps is that you have reached the scale where the patterns are smaller than the map. However, one has to analyze that carefully. We've been wrong about the presence (or absence) of large patterns before.

Steven Weinberg: Okay. Next question. Someone, please. Thank you very much, sir. Could you give your—everyone, please, give your name. This is not for my edification, but so that it'll be in the tape record. It's impossible to tell from the tape who was asking the question.

Tom Barrow: I am Tom Barrow from Houston. And I have first a comment. As a geologist, I always have trouble communicating with people because my sense of time is so different. You're having trouble communicating with me because your sense of time is even greater. But just one question. You mentioned Virgo in 45 million years might—somewhere in the back of my mind tells me that that point in time on Earth, we had dinosaurs.

Carl Sagan: No. Sixty-five million years ago, they all disappeared.

Tom Barrow: All right. Thank you. The point being is that the human species appeared much later. And if we're trying to think, as you were, Dr. Sagan, about life, and we're measuring it as we do, is there ever any chance with, in your opinion, with radio waves or any other mechanism that we will ever, because of the time of travel between galaxies, ever get a signal back or from them?

Carl Sagan: Thank you. I didn't have time to say anything about the fact that we live in the first moment in human history when serious searches for signals from civilizations on planets of other stars is going on. The idea is you use a large radiotelescope and a sensitive receiver, and if someone somewhere else wants to make their presence known, there's a very good chance that you might be able to pick it up.

Now if you pick up a signal from, let's say, the Virgo cluster, then that signal had to have left 45 million years ago. And so if the moment you get it, you answer, they will hear back in another 45 million years. It's not what you might call a snappy conversation.

Nevertheless, we are used to one-way communication, which we consider useful. Socrates talks to us. We do not talk to Socrates. We don't consider that a complete waste of time. We have something to learn from him. Nobody knows if there are other intelligent beings, and if there are, if they are devoted to trying to communicate with more backward civilizations by radio. But, if there is a smattering of them in the Milky Way galaxy, then the distance to the nearest one is maybe a few hundred light years, something like that. And so it would take a few hundred years for the message to come to us.

One last thing. How would anyone know that we are here? You can't tell just by looking at the Sun. The only way they could know we are here, unless they have scouting expeditions, is to pick up our own radio transmissions. And the most effective kinds of such transmissions are radar and commercial television.

To think for a second about commercial television, here is the Earth sitting in space and no radio waves except from lightning and so on, come out of it for four-and-a-half billion years. And then, suddenly, around the late 1940s there is this spherical wave that expands at the speed of light out from the Earth and eventually, we hope, will encompass an inhabited planet. They listen, and what do they hear? They hear Howdy Doody, Milton Berle, the Army-McCarthy hearings, and other signs of high intelligence on the planet Earth. On the oft-asked question about if they're out there, how come they haven't come here? —now we know.

Bill Guest: For the record, Bill Guest from planet Houston. First, I want to thank all of you for a very lucid and very exciting presentation. My question is for you, Steve. You talk about the first second, or the first three minutes, from the beginning. What do you mean by second or three minutes?

Steven Weinberg: Bill's question, I imagine, comes up because there was no Earth going around the Sun at that time, and so in a sense there were no years. But there are things that were going on even during the first three minutes that provide perfectly good time standards. In fact, even here and now we no longer use the Earth going around the Sun to define the second; we use a certain frequency of light emitted by an atom.

Now, I have to admit that when the universe was three minutes old, there weren't any atoms either, so strictly speaking I can't call on atomic clocks. But there are other things that were going on then that provide a definition of time. For example, the quantum mechanical wave function, a mathematical object that describes how a particle moves in quantum mechanics, oscillates at a certain frequency. The period of this oscillation is a very tiny fraction of a second—much shorter than any time we've been talking about here—and a certain number of these periods could perfectly well provide a definition of what we mean by a second.

No one was around in the first few minutes, of course. But the laws of nature were there—they don't just exist in our minds. They are really something built into the universe, and they define what you mean by a second even when there was no one to measure it. There are philosophers of science who would disagree with me about this, and perhaps someone here would disagree. But Jamie probably isn't going to argue with me about this. Jamie, why don't you give your name for the record?

James Galbraith: James Galbraith of Austin. I suppose every kid has questions about the cosmos that you forget about. And one of the wonderful things about this morning is not only does it remind you, but you actually get a chance to ask them.

And one of my questions has been why are galaxies that we know of, such as the Milky Way, and every other galaxy that I think you showed today, aligned in a plane? Why are they not spheres, like the stars, or some other irregular shape? So my first question, Is that true that galaxies characteristically aligned along a plane? And, if it is true, do we observe the alignments of galaxies in relation to each other in such a way that they would be appear to be aligned along the surface of the bubbles that you have observed?

Margaret Geller: Galaxies like our galaxy have a disk. Spiral galaxies have a disk. Not all galaxies have these disks. It's believed that they have these disks because there's gas left over when stars form in the galaxy. This gas cools and condenses to a disk.

There are galaxies, like the big elliptical galaxies in the core of the Virgo cluster, which have no disk. They're just huge piles of stars.

The biggest galaxies in the universe and the smallest galaxies in the universe don't have any disks—they are ellipticals.

James Galbraith: What about the ones that do? Do we know anything about the way in which the disks are aligned?

Margaret Geller: There was a period when people tried to discover whether galaxies were oriented in some systematic way. People wondered: was there a net spin of the universe? I don't think there's really any good evidence that nearby galaxies are oriented in some particular way—certainly not with respect to the structures that we see.

We think, in fact, that most of the mass in the galaxy is not in that disk. The disk is very misleading. In fact, it's a small fraction of the mass. We think most of the mass is distributed in this dark halo which might look more or less like an elliptical galaxy (if we could only see it). The spirals—all this pretty structure we see—is just the flotsam and jetsam which sits inside the great big halo. The lights we see as galaxies are just the beacons to tell us where the concentrations of mass are in the universe. We use galaxies to mark our path through the universe.

Steven Weinberg: Maybe I'll add to what Margaret said, something that I think she takes for granted, that the galaxies are rotating. And possibly the difference between the spiral nebulae and the others has to do with their rotation. And it's the rotation that defines a definite plane. It's the plane that's perpendicular to the axis of rotation. Although much of the matter is so hot that it doesn't fall into that plane, the plane is still there because there is an axis of rotation.

There's another famous example of this sort with which I think you are familiar. Our own solar system is nearly a plane. All the planets are close to this plane, known as the plane of the ecliptic. You can see this if you look at the sky when there are three or more planets visible. They line up in a straight line, with this line always in the same position relative to the stars. This line is the projection on the sky of the plane of the ecliptic. When the protostellar nebula out of which the Sun and planets formed collapsed, it collapsed into the plane perpendicular to the axis of rotation of the cloud.

Carl Sagan: Can I just make a comment on that? The fact that the planets go around the Sun in the same plane—it's essentially the equatorial plane of the Sun—how does that come about? Isaac Newton, no intellectual slouch, in dealing with that problem, essentially, threw up his hands. He said it was in the initial conditions. God must have started out the solar system with the planets in the same plane.

Laplace, using no more physics than Newton had available to him, said, no, no. There's a perfectly understandable way in which you could start with an irregular, rotating, condensing cloud, and wind up with all the planets in the same plane. Namely, as it contracts under self-gravity, it speeds up by the conservation of angular momentum, the same idea of the ice skater who brings her arms in and spins faster in her pirouette. As it spins up faster, you can think of it as centrifugal force eventually counteracts the gravity that's tending to pull things together in the plane of rotation. But along the axis, there's no centrifugal force, and this irregular cloud condenses into a disk. Therefore, simple Newtonian physics can extract order out of chaos.

And when Napoleon—Laplace and Napoleon were buddies—asked Laplace, That's how you make a solar system? Where does God come in? Laplace said, "Sire, I have no need of that hypothesis."

Steve Bobbin: Steve Bobbin. I'm in Austin. Recognizing that this ought to be the last one for you, given the vast uncertainties that you've all dealt with for us today, but a critical question I've asked as transition for the next session. For each of the panel quickly. What are the most critical sources, sensors, tools to reduce the uncertainties in what you are now doing?

Steven Weinberg: Margaret, you're first.

Margaret Geller: I think the real problem that I see is that we've come quite a long way in understanding something about how the nearby universe looks. What we don't know, and what we *can* look at, is what the universe *was* like. When we look out in space, we look back in time. We can observe the universe as it was billions of years ago. We can make a lot of these observations from the ground. Many large telescopes are now being constructed. One of the great difficulties with these telescopes is that, although capital funding has been raised to support the construction of the telescopes, funding is limited for the support of the science that will come out of them, and, also, perhaps, even more serious, for the instruments that really enable the telescope to make the observation.

Steven Weinberg: I guess I'm next. My perspective is that of an elementary-particle physicist rather than an astronomer. As far as I can see, the astronomers these days are in hog heaven, wallowing in a sea of data. They do need additional instruments, but even without them they are in a very rich period when data is flooding in, partly from new satellites like the Hubble Space Telescope and the COBE satellite.

I think the greatest need for astronomy is to build something like the supercollider. And I say that partly for reasons I mentioned in my talk, but also in connection with something Margaret talked about. The universe is filled with dark matter. There are some reasons to believe (although it's still controversial) that dark matter is not ordinary matter, it is not made up of ordinary atoms, but consists of some kind of exotic particle that has not yet been discovered.

The particle physicists have various candidates for what kind of exotic particle may make up the dark matter, and will be able to discover at least some of these types of particle, if we build accelerator facilities with sufficient energy and intensity. So I think that building the next generation of accelerator is the highest priority for understanding the universe.

Carl?

Carl Sagan: For what I was talking about, I would say that spacecraft missions looking for organic matter and, who knows, life on nearby worlds is clearly something that we have the technology for. The use of radio telescopes to listen for signals being sent to us from the depths of space is happening—even by contributions of members of the Planetary Society, or, in another project, a few wealthy individuals. That is in the range of hundreds of thousands to a few millions of dollars a year. The technology has gotten so good that we can really do pioneering work for very little money there.

Beyond those, it seems to me that the pace of work on the geological record, the antiquity of life, are proceeding at a very active pace. In terms of planetary exploration and the search for life elsewhere, this also is a kind of golden age.

Steven Weinberg: Thank you. That was a good provocative question. I hereby declare the coffee break beginning. We should reassemble at ten after the hour—ten after eleven.

HOW DO WE KNOW IT? PROBLEMS OF FUNDING AND POLICY

STEVEN WEINBERG

The scientific progress described in the first session was not all made by people just sitting at their desks and scratching their heads. This work needs large machines—telescopes on Earth, telescopes on satellites going around the Earth, telescopes that operate in radio, optical, X ray, other wavelengths.

All this costs money. Some of this money comes from private philanthropy. Increasingly, it has to come from government, and it has to compete with other possible uses of that money. And even when allocated to science, it has to compete with other branches of science, other ways of doing science, other ways of doing astronomy.

This gets controversial. Congresspersons argue about this, and journalists argue, and scientists argue. We don't all agree with each other.

I'm glad that this morning we have three people representing three different kinds of experience in the support of scientific research. The first speaker is Dr. France Cordova. She is the chief scientist of NASA. But she is not an inside-the-beltway bureaucrat. She was, and in fact continues to be, a working astronomer. Her work is in studying compact cosmic sources of various wavelengths in the spectrum. She was the head of the Department of Astronomy and Astrophysics at Penn State, which, incidentally, is the sister university of UT-Austin in running the big new telescope of McDonald Observatory, about which the following speaker will talk. France is a deputy group leader at Los Alamos, and is a member of various federal advisory boards. I'm very happy to welcome her. I was a little worried because at one point, it looked like weather delays would make her late for this session, but the skies cleared, and here she is—France Cordova.

STUDYING THE UNIVERSE FROM SPACE

FRANCE CORDOVA

Hello. I'm very pleased to be here; I keep discovering among your membership more old friends from different parts of my past life. So I'm really thrilled to see you and renew those acquaintances.

The first thing that we have to establish here is why we observe from space at all, given that it's expensive and risky. My first slide addresses that question. This image shows a thin band around the Earth. This is the atmosphere that shelters life from damaging ultraviolet radiation and permits it to thrive. But in absorbing much of the cosmic radiation, the atmosphere also hides most of the information content of the universe.

You see in this next figure that the visible band is one small part of the electromagnetic spectrum that is accessible on Earth. But, even there, the turbulence of the atmosphere disturbs our view. There are parcels of air continually moving above us. And that turbulence makes the stars twinkle. The twinkling hides lots of information. It makes very dim and faint things impossible to pick out from the background light. And it makes it impossible to separate objects that are very close together in the sky. And so that's why, even in the optical band where we have telescopes on the Earth observing, we still need to get above the atmosphere to observe very faint objects, especially those in crowded fields.

So who, then, is going to enable and fund observing from space? For ground-based telescope observations, there are many different financiers of astronomy; the government, industry, and private citizens participate and contribute to building telescopes and instruments, and funding observations and data analysis.

In contrast, space observations, because of their appreciable cost, are enabled principally by the government, especially the National Aeronautics and Space Administration, as part of the Space Act of 1958. The expansion of human knowledge, observing phenomena in air and space, is one of the charges in that Act. NASA's the only agency, really, that observes the cosmos from space.

So then the next question is, "How well is NASA utilizing space as a platform for observing the cosmos?" Last night at your dinner, I was sitting next to a very lively group of folks, and someone said, "I haven't been paying attention to NASA lately. What has NASA accomplished of late?" That is the right question to ask, isn't it?

I'm going to just tell you, therefore, a little bit about what NASA has accomplished recently. And this is only as it concerns the cosmos, because that is the theme for today. I want to focus on three NASA-funded missions of the 1990s and what they are contributing to scientific controversies about the cosmos.

My first example is the Cosmic Background Explorer Mission, also known as COBE; you heard about it briefly this morning in Dr. Geller's speech. This beautiful image, taken in the near infrared wavelengths, is what our own galaxy looks like when viewed by the COBE mission. So this is "home."

The next figure is a spectrum of the black body radiation—the very cold three-degree-Kelvin radiation that permeates the universe—the remnant radiation left over from, we think, the "Big Bang." Now before the COBE mission there were a number of spotty observations in different parts of the broad spectrum that the curve covers—some rocket observations, some from the ground. And it was thought, previous to COBE, that if a satellite had the capacity to measure this spectrum well, this plot of intensity versus wavelength is what it would detect. But it was suspected, based on some early rocket-based observations, that the satellite might see at some places on this curve departures from this smooth line.

When this figure, representing the first nine minutes of COBE data, was first presented to an audience of two thousand astronomers in January of 1991, there was a standing ovation in the crowd. That's how much it meant to scientists to establish the character of the spectrum of the big bang remnant background radiation. The uncertainties on the COBE spectrum are smaller than the width of the line that delineates the shape of the spectrum: That's how precise the satellite's sensors were!

The other thing that the COBE satellite did with a different experiment—and you saw this picture, slightly different version, earlier this morning—was to detect minute differences from a uniform temperature background. These are microkelvin fluctuations. Those differences, we think, reflect the "seeds" of future galaxy formation.

And now, my second example: We jump from the cool part of the electromagnetic spectrum, the microwave and infrared, to the hottest, most energetic part of the spectrum, the gamma ray.

This satellite, named the Compton Gamma Ray Observatory after Arthur Compton, was launched in April of 1991 by the space shuttle. It's an interesting little fact to note that when it was first deployed, the high gain antenna that communicates data to the tracking and data relay satellite, which in turn communicates the data back down to the ground, was stuck. It could not be deployed remotely from the ground. In an unanticipated space walk, two astronauts got out and unstuck it.

What did that satellite discover? Well, I showed you the beautiful picture from the near infrared that the Cosmic Background Explorer yielded, in which you saw the Milky Way disk and the bulge in the center of the galaxy. This picture from GRO is much different. This is taken from one of the instruments called EGRET. It shows the band that is the Milky Way emitting very high-energy radiation, above a hundred million electron volts. The bright discrete sources along the band are mostly pulsars—neutron stars beaming radiation. And above the plane is the brightest source: it is not from our own galaxy at all, but is from another entire galaxy whose additional brightness may be due to a high rate of star formation or the accretion of stars onto a central black hole. This is the map, if you could look, if your eyes were sensitive to a hundred-million electron volts. The

GRO satellite continues to yield a lot of new information about the highest energy sources in our universe.

This satellite was reboosted into a higher orbit in December of 1993, and thus it will continue to take data for at least a few more years. This longer-lived capability is important to assemble more statistics on what is one of nature's most exciting and unexplained phenomena: gamma-ray bursts. This figure shows a map of the universe. All those little points of light on it—I think there are about a thousand—represent detections of gamma ray bursts. These are very short, very energetic bursts of lights that last a few seconds or less.

They were first discovered, by the way, in the group that I was in at Los Alamos National Laboratory, using surveillance satellites to monitor the nuclear test ban treaty. That was in 1970. And here we are in 1995, almost, and we still do not know the origin and nature of these great, short bursts of light.

What the BATSE instrument on the Gamma Ray Observatory revealed was that the distribution of the bursts on the sky is uniform. So you can't say that the bursts are coming only from the plane of the Milky Way or its center, or from nearby galaxies like the Magellanic clouds.

And the other very important observation from BATSE is that the number of weak bursts is smaller than you would expect if the distribution from strong to weak bursts conformed to a smooth distribution in space and time. This observation implies a finite size for the distribution of the bursters.

Scientists trying to understand the causes of this phenomenon are bewildered. Originally, we thought that the bursts were the result of activity associated with neutron stars, the dying remnants of supernovae. That hypothesis looks less certain in view of the new GRO data.

Instead, a number of astronomers (but not all!) think that the origin of the bursts is cosmological, that they are coming from other, far-off active galaxies. The origin of the bursts is one of the great debates among high-energy astronomers.

A third example that reflects NASA's great recent accomplishments, and introduces many more controversies about the cosmos, is the Hubble Space Telescope. One of the very first results that it provided after the mirror problem was corrected is that, at the center of one of the galaxies in the Virgo cluster, M-87, is a pancake-shaped object which, when observed with a spectrograph, reveals high-velocity rotation of gas about the center. The mass can be deduced from this observation, and the conclusion is that there must be a black hole at the center, or else something more exotic than a black hole.

Another galaxy in the Virgo cluster is M-100. This composite figure from the Hubble Space Telescope reveals the interior part of that beautiful spiral galaxy. Detailed observations of Cepheid variables in M-100 yielded an exciting result, a revised age for the universe!

Cepheid variables are yellow, supergiant stars. There's a well-known relationship between their period and their luminosity, which has been verified using Cepheids in galaxies that are close to us, much closer than the 56 million light years that M-100 is. The Hubble Space Telescope made twelve observations, at one month intervals, of twenty Cepheids in M-100. This figure shows the observations of just one object. You can see how, over time, it brightens, then dims, and then brightens again.

The result of all these observations is that we can use the Cepheid period-luminosity relationship to measure the distance to this faint galaxy. This is very important in establishing the distance scale that you heard about this morning. This particular observation has revolutionized our thinking about the value of the Hubble constant because it suggests that the universe may be very much younger than previous models suggested. In fact, the universe may be between eight and twelve billion years younger! This observation is expected to be refined in the next couple of years with the measurement of Cepheid stars in more and fainter galaxies. It's a critical measurement that can be done very effectively with the Hubble telescope.

A third Hubble observation that was announced only about two weeks ago has to do with the dark matter that you've heard a little bit about. On the left is an image of a globular cluster in our Milky Way Galaxy, taken with a ground-based telescope. One scientist, when first looking at this image, imagined that out away from the center there should have been more stars, yet the field looked empty to him, as if you could see through the cluster. So, he used the Hubble Space Telescope to take a deep image of the outer regions of the cluster. The result is shown on the right-hand side of this figure.

The next figure shows, by means of little yellow triangles, what one would have expected for the distribution of stars in a globular cluster, when one does simulations estimating the number of red stars whose mass is a couple of tenths of a solar mass. And you see that there are no observed stars at the density level of the predicted stars (yellow triangles).

One of the hypotheses for the nature of dark matter is that it is made up of very small, and therefore faint, stars of a couple of tenths of a solar mass, perhaps even smaller. This is the most simple of the speculations about what comprises dark matter. And since these stars couldn't be detected from the ground, scientists were hopeful that the Hubble telescope would provide evidence of the existence of these objects. However, indications from Hubble are that they are simply not there!

One can then hypothesize that perhaps the internal dynamics of these clusters are such that the low-mass stars are kicked out of the cluster by the big "bully" stars.

Another astronomer, however, took an observation with Hubble of a remote region far away from the star cluster and also far removed from the plane of the galaxy. That result is shown on the right-hand side of the next slide. The picture on the left-hand side is a simulation of how many low-mass stars should have been seen. Again, the speculated stars are not there! They haven't been kicked out of the star clusters after all.

The conclusions from these two observations are first, that dark matter is probably not comprised of very small stars, and second, our theories of stellar evolution are now challenged because we do not see the predicted number of low-mass stars.

So the Hubble Space Telescope is yielding observations and posing new controversies all the time.

Thus far I've told you a little bit about what NASA has accomplished in space in just the past few years. Certainly one metric for the success of NASA is accomplishments like these.

Another metric, one that's becoming increasingly important, especially inside the Capitol Beltway, is dollar value. During the Cold War, science was funded for its undeniable excellence; everyone believed that achievement in science and technology would be an excellent defense posture.

But today, in an era of downturning budgets, we're being scrutinized much more closely by Congress and the public, who are looking at the value that they're getting for our investment in space. They are asking us to do more (science, technology, applications) with less money. NASA is responding to that challenge.

I want to use the Hubble Space Telescope as an example because it's a mission that's gotten a lot of public attention. Scientists like to say that we can't put a price on the kind of knowledge that I've just illustrated. Yet it's the cost of Hubble that rendered the mistake in its mirror fabrication, when it was discovered shortly after launch, so visible and so tragic.

Space is a very high-risk business. I've just completed a tour of all of NASA's centers—ten centers around the country—and talked to the people there about what kind of science they do, what's the role of science at their center, how do the scientists fit in, what was it like before, what is it like now. And one thing that our NASA Center people always talk about is risk. They said, "Oh, in the sixties, we used to just throw it up there, you know . . . And a lot of it failed at launch, but today we remember just the stuff that worked. We're less ready to take those chances today."

Well, the Hubble telescope is a good reason—it's a good example of where Americans do draw the line in the sand. We spent $2 billion—that's your money—to launch the Hubble Space Telescope. We continue to spend $260 million a year to operate it, and will do so for at least the fifteen years that we promised that this space observatory would stay operational. The total life-cycle cost of Hubble, given a fifteen-year lifetime, is over $6 billion. This slide shows the astronauts going into space in December of 1993 and inserting corrective optics in front of the telescope's main mirror. They also fixed the solar panels, gyros, power supplies, a lots of other things. We think that the $86 million extra money we spent for the reservicing is small compared to the added value.

The Hubble "rescue" is a great example of what NASA does very well, which is reacting under great pressure. When something happens, NASA gathers all the forces of its brilliant men and women, both within the Agency and in the external community of space scientists and engineers. The scientists proposed thirty-some solutions for how to fix the optics problem. The engineers narrowed that down to about three feasible ones. And then all agreed on a plan to fix the telescope. Congress stepped up to funding NASA's plan, and after only two-and-a-half years, the astronauts went up there with the new corrective optics and, I mean, everything worked brilliantly.

We have to change from this model though. We can't afford to have spacecraft that cost several billion dollars in one shot; we can't afford to put costly spacecraft on top of launchers that do not have 100-percent success rate. And there is no vehicle, no launcher, that does. In fact, the space shuttle has now, in spite of its tragedy of 1986, the best launch vehicle record in the world.

NASA has done a lot of soul-searching in the past couple of years under new leadership, and is completely reengineering itself—the way it does business, its management, streamlining the work force, putting into place a lot of changes so that the country can have much more frequent access to space: instead of a couple of launches per decade, perhaps twenty-five to fifty per decade.

This is our vision. We've challenged our NASA Centers, like the Jet Propulsion Laboratory and the Goddard Space Flight Center, to reduce the mass of spacecraft, because that's where most of the cost is in the development and launch.

You've all seen the pictures of giant spacecraft that fill up the bays of our Center warehouses at Goddard. We are replacing this picture with one of an engineer who is building the spacecraft of the next century on a desktop.

If we were just trying to get the mass of the spacecraft down, we could readily ask ourselves, what about the science yield? Doesn't less mass and less cost mean less science? Our reengineering efforts demand that we do more for less. We are trying to incorporate the most innovative of new technologies—new architectures and microdevices in order to get more output with a lot less expenditure.

We're working on miniaturizing a lot of the subsystems—the command and data subsystem, the attitude control subsystem, telecommunications, computer systems. One of the models we use is a spacecraft on a chip. That's the challenge. The technologies that need to be created are micro-electromechanical systems and micro power sources for telecommunications.

For outer planetary flybys, we're working on micro-thrusters that have fifteen times longer lifetimes and a thousand times lower leak rates. We're working on micro-gyros that are five times less massive than the gyros we use today. We're working on wave guides that are less massive.

For small-body sample returns, we're looking at how to make active pixel sensors that are much smaller than the ones that we flew on *Voyager*. And very small star-trackers.

The President's signed into effect a national space transportation policy this August, and NASA is trying to step up to the challenge. We hope that Congress will approve us to develop the wherewithal, the research program, for a reusable launch vehicle by the year 2000 that industry would then step up to building.

We've suffered at NASA a 30-percent reduction in our overall budget in the past two years. We are now at a level of $14 billion. Yet, we're trying to do more. We're trying to build a space station. We have new initiatives in aerospace. We believe—the country believes—that it needs a new high-speed civil transport.

We're trying to do more space science initiatives. We're trying to send a series of landers and orbiters to Mars. In order to do all of this, we have to really do things differently. So we've been looking at implementing a lot of management changes, at doing a lot through international collaborations, and also at setting long-range goals to get us out of the reactive mode that I described. We're trying to look ahead to ten, fifteen, twenty years, and ask: What do we want to be doing at that point? And look back to the present and ask: What can we do to get ready for that vision?

I want to come back just for a minute at the end of my remarks to a larger view of NASA. As Steve mentioned, science is just a part of what NASA does. It's one of five main activities that we've identified as comprising what NASA is all about. Science happens to comprise thirty percent of NASA's budget, so it's a big activity. It's an activity that looks at planets and also at more local phenomena in our own galaxy. We have space physics missions. We have solar missions, exploring the Earth-Sun connection.

Among our other activities is aeronautics. We're all customers of the aerospace industry. We all want to be in better, faster, cheaper, and certainly safer, airplanes.

Mission to Planet Earth is another big initiative of NASA's. We've stepped up to the whole U.S. global change imperative, which was inspired by that wonderful iconography that we got when *Apollo-8* looked back and saw this beautiful planet, Earth. What can we do to preserve it for the future? This year alone, in 1995, NASA will spend $1.25 billion on Mission to Planet Earth. We will launch, up through the early part of the next decade, something like thirty satellites, in a constellation looking at all the different aspects of global change—the forests, the winds, the effects of clouds and the ocean, and the tropical rainfall, to put together a total picture of the influences on climate.

A fourth activity of NASA is space technology. Advanced technology is what underlies and enables us to do the work that we are doing.

And a fifth NASA activity is human exploration and development of space. At the foundation of this activity are the many life sciences and microgravity research activities like biomedical science and biotechnology, and experiments that utilize an environment where the gravity is much reduced from what we have on Earth, in order to do research on the physics of materials. To grow protein crystals in space that will be of use to pharmaceutical industries. To grow larger samples of tissues than one can grow on the ground, for medical research. To look at combustion and how it is affected in a microgravity environment, and fluid physics, and even renormalization theory.

This enterprise is one that we have joined with the National Institute of Health, and the American Medical Association. It's enabled by our space shuttle and, in the future, by our space station. These provide the architectural wherewithal to be able to do new research.

And this brings in a whole other dimension of NASA's activity, which is the role of humans in exploration and development of space.

So you can see that space science is just one of five principal activities at NASA, all of them competing for funding in a downsizing economy, all driven by different customers with different needs. We respond to the president, we respond to the Congress, we respond to the Office of White House Technology Policy and the Office of Management and Budget, the aerospace and non-aerospace industries, universities, the general public, scientists, educators, and students.

The fact is that space belongs to everyone. And all sectors of our economy want to be part of its utilization and its development. Some of us want to use it as an observatory to look at the cosmos. And some as a place for experimentation in altered gravity.

And some of us even imagine that our species, for whatever reasons—reasons related to getting more economic resources, or safety from extra-solar-system hazards, or simply because there is adventure in our genes—will want to explore it.

It's NASA that's been charged with finding the wherewithal to fulfill the dreams of the people who use space and have ideas about how this usage should be conducted—how to make it flourish.

We're trying to find a better means to access space faster and cheaper. Our goal is that eventually space is not something that just NASA does, but that it's a partnership in which everyone has a stake. We are working much more closely, I think, than we have in the past with industries for their bright ideas. We're working closer with scientists and their students in universities. We're trying to get those partnerships going so that we're reinventing, not only spacecraft, not only a new kind of launch vehicle, but the whole way that we conduct science. Because our eventual dream is that, just as highways on Earth today are accessible to all, that space will be accessible to all. That it will be a new venue for commerce, and for pleasure, and for continual inquiry into why we occupy our present geography out of all the space in the universe.

Steven Weinberg: Thank you. Well, as you have heard, very important things are going on above the Earth's atmosphere. Some interesting things are also going on in astronomy within the Earth's atmosphere. The tradition of looking up at the sky from our surface continues, and we're very proud that, here in Texas, we have one of the leading astronomical observatories of the world—the McDonald Observatory out in West Texas. Many of us in this room have visited there, and if you haven't, I recommend it.

Tom Barnes is the Associate Director of the McDonald Observatory and an important scientist in his own right, an active astronomer and astrophysicist and author of many important scientific articles. He's a member of peer review committees for NASA and for the National Science Foundation. We're very glad to have him tell us about "Looking at the Universe from Texas."

STUDYING THE UNIVERSE FROM TEXAS

Thomas Barnes

Thank you, Steven. I want to tell you about a large telescope project that we have in progress at McDonald Observatory, about some of the controversies of the cosmos that this project will attack and about some of the controversies that we had to endure in achieving this telescope project. This is a timely season to speak about McDonald Observatory. On December 21, there will be the 150th anniversary of the birth of a Paris, Texas, banker named William Johnson McDonald. McDonald died in 1926. In his will, leaving out all the whereases and wheretofores, he said the following: All the rest of my estate I give to the University of Texas to be used in erecting and equipping an astronomical observatory for the study and the promotion of the study of astronomical science.

This bequest founded the McDonald Observatory in the Davis Mountains of West Texas. From the McDonald Observatory grew the Department of Astronomy of the University of Texas at Austin. Our astronomy program is now the largest research and teaching program in astronomy of any university in the nation, and, by any measure that one uses to rank competitive programs in the nation, ranks in the top five. It's an outstanding collection of astronomical talent founded on the bequest of a visionary Texan in 1926. Astronomy has a long tradition of honoring its benefactors, as in the naming of the McDonald Observatory for William Johnson McDonald.

Earlier this year, two other individuals were honored in a similar way. Your fellow philosopher, the Honorable William P. Hobby, and Pennsylvania philanthropist, Robert E. Eberly, were honored in the naming of the Hobby-Eberly Telescope for them in ceremonies in West Texas in March of this year. Through their contributions to astronomy, to their universities, and to their states, they have acted in the same tradition as W. J. McDonald. And, through their contributions, they will enable the astronomy programs at Texas and at Pennsylvania State University to endure and to continue "the study and the promotion of the study of astronomical sciences" well into the next century. I know that Bob Eberly is not here today, and that Governor Hobby is. Would Bill Hobby please stand and be recognized? (applause)

To begin I will give you a quick introduction to the McDonald Observatory. There are five optical telescopes in operation at McDonald: a 107-inch telescope, an 82-inch telescope, a 36-inch telescope, and a 30-inch telescope. Not shown in the slide is another 30-inch telescope dedicated to NASA laser-ranging programs which is on another peak.

When it was dedicated in 1939, the 82-inch telescope was the second largest telescope in the world. This is the telescope created through the bequest of W. J. McDonald. It has made tremendous contributions to our understanding of the evolution of stars and the properties of galaxies. When the 107-inch telescope was dedicated in 1969, it was third largest in the world. It has also made significant contributions to the study of the evolution of stars and additionally to the inventory of our solar system through ground-base support of NASA space missions.

Today, those two telescopes, instead of ranking second and third, rank thirty-sixth and seventeenth in the world. And, within ten years, they will rank forty-ninth and twenty-eighth. Some years ago we astronomers recognized that if Texas were to continue in the tradition of excellence established by William J. McDonald, we had to equip ourselves with a much greater telescope.

I'm not going to burden you with the entire fifteen-year history of that effort, but it led to a partnership of institutions including the University of Texas at Austin, which will have approximately fifty percent of the telescope time on the Hobby-Eberly Telescope, Pennsylvania State University (thirty percent of the telescope time), Stanford University (about ten percent), and two German institutions, Ludwig-Maximilians-Universitat in Munich and Georg-August-Universitat in Göttingen, which will have approximately five percent of the telescope time each.

The telescope itself is a radically new design in order to keep the cost down. The construction cost for this telescope is $13.5 million. This may be compared with the construction cost for the similarly sized Keck telescope constructed in Hawaii, which exceeded $100 million.

One of the aspects that makes Hobby-Eberly Telescope novel is the primary mirror. The primary mirror is composed of 91 individual hexagonal mirrors. These 91 mirrors are each 40 inches across, flat to flat. Together, they simulate an optical surface in the form of a large hexagon. The size of the large hexagon, from flat to flat, is 400 inches, and from point to point is 440 inches. This may be compared with the 107-inch telescope, our largest telescope at the present time, and with the 400-inch Keck telescope. There is no other telescope with a primary mirror larger than this one planned or under construction in the world.

Last March, we had groundbreaking ceremonies for the telescope, as shown in this slide. You'll recognize a number of the people in this picture; indeed some of them are here. The telescope is now well under construction. We expect to have "first light" through the telescope in less than two years, and full scientific operation of the telescope in less than three years.

I want to turn now to the scientific niche that the Hobby-Eberly Telescope will occupy before mentioning some of the problems that were encountered in achieving this telescope. There are three things that control the science that will be done with this great telescope. The first is its large aperture—the size of the primary mirror. It is the large aperture which permits us to look at objects in much greater detail than is possible with our existing telescopes because more light is available. And, it enables us to look at objects that are beyond the grasp of our current facilities.

The second aspect is that the telescope is optimized for spectroscopy. You saw photographs of spectra in Margaret Geller's presentation this morning. This telescope will do spectroscopy exclusively. It will focus on the one aspect of astronomical research which gives us the most information per photon that we receive.

The third thing that controls the science we will do with it is that it will be queue-scheduled, similar to the Hubble Space Telescope. At one moment, it may do my observation; the next observation may be France Cordova's observation; the next observation may be Jim Gunn's. These will be completely interleaved for efficiency of operation. Now, this will take a lot of the romance out of telescope observing for us astronomers. There will be no point for me to go to the telescope while my observations are taken, because I won't know when they will be taken. That will be up to a computer program—unless I specify that they must be taken at specific instants of time for astronomical reasons. But, even then, there's no point for me to travel to West Texas to watch a thirty-minute exposure and then go home again.

It will be a very different kind of astronomy—much more like the astronomy done with space satellites than that done with our present telescopes. But, it makes for very efficient astronomy. When I go to the telescope now, as I will on Sunday night for a seven-night session with the 82-inch telescope, there are times when the sky is unsuitable to my research. So the telescope sits idle. But, it might be suitable to somebody else's research. But, it still sits idle because only I have access to the telescope for those seven nights.

With the Hobby-Eberly Telescope, that will not be the case. If the sky is unsuitable for my observation, the computer will switch it to somebody else's observation for which the sky is suitable. The efficiency of operation will be much greater than with existing telescopes.

Some of the controversies of the cosmos that we'll attack with this great telescope were mentioned already this morning. One is the evolution of the universe. This telescope is going to permit us to do large-scale surveys of quasi-stellar objects to much, much fainter magnitudes than can be done with any other telescope. That means we'll be looking at quasi-stellar objects that are extremely distant and, therefore, extremely young in terms of the history of the universe. We'll be looking far back in time. That will give us an angle on the conditions in those QSOs and in the universe at very young ages.

By looking at the light absorbed between the quasi-stellar object and ourselves by the intervening gas, we can examine the conditions when galaxies first formed. As you heard this morning, the formation of galaxies is a very poorly understood phenomenon. We don't know how the galaxies came into existence in these great sheets and surfaces of bubbles. But, by looking at very distant, very faint quasars, and seeing in their light the spectroscopic evidence of the intervening gas, from which galaxies form, we can examine the question of their origin.

There is also the dark matter controversy. You saw photographs of spiral galaxies this morning and other photographs of elliptical galaxies—the ones which are round and mostly full of stars. You saw that galaxies clump together in clusters. We know, from looking at the motions of the galaxies in the clusters, and from looking at the motions of the interstellar gas in the spirals, that perhaps ninety percent of the matter in our universe is invisible to our telescopes. This is very disconcerting; it's as if ninety percent of the contents of this room were invisible to us.

We'd like to know *what is* the dark matter and *where is* the dark matter. To a large extent, learning *what it is* depends on learning *where it is*. We know dark matter exists in clusters of galaxies. We know it's in spiral galaxies. But, we don't know for sure that it's in elliptical galaxies because they're devoid of the gas that is used as a probe of the motions inside the galaxy. These motions tell us the existence of dark matter.

With the Hobby-Eberly Telescope, we will examine hundreds of individual stars—these very faint stars—in elliptical galaxies to determine their motions, and discern whether or not dark matter is present there. We will have a new angle on where is it, and, perhaps, therefore, what is it.

There is also the age of the stars controversy. France Cordova mentioned it a few minutes ago, and you have probably read about it in the newspapers. Recent measures of the Hubble expansion constant for our universe, if you interpret them in the standard way, lead to an age of the universe that is less than the age of the stars according to standard stellar evolution theory. It's as if your children were older than you! As a stellar astrophysicist, I'm more inclined to believe the astronomy of the stars and less inclined to believe the astronomy of the cosmos, but, perhaps, Steven Weinberg has a different view of that.

We can attack this problem in a new way with the Hobby-Eberly Telescope. We will use it to look at some of the dimmest, most distant, dying stars in our galaxy—so-called white dwarf stars. Far away from the disk of bright stars in which our Sun is immersed (the Milky Way), far out in the outer reaches of the galaxy, there exist some of the oldest white dwarf stars. The Hobby-Eberly Telescope will look faint enough to study these stars.

Such stars get dimmer with time in a way that's dictated by their internal structure. They no longer have nuclear reactions energizing them; they're just hot bodies cooling off with time. Well-understood physics tells us how rapidly they cool, and, therefore, for a given age of our galaxy, how many of them there should be at each temperature. This in turn leads to a prediction that, by measuring how many of them there are at each temperature, we can infer their age.

So, we can get an age for some of the oldest stars in our galaxy in a different way than from standard stellar evolution calculations on everyday stars. This gives us a different perspective on the problem of how old are the oldest stars. We will understand better whether it's the stellar evolution calculations that are wrong or whether it's our interpretation of the expansion age of the universe that's wrong.

Another controversy that this telescope will help us resolve concerns the existence of other planetary systems. We have evidence for planets outside of our solar system only from that pulsar that Carl Sagan showed earlier. Those three are the only known planets outside our own nine. Because of the nature of the pulsar, it's highly unlikely that those planets involve life. In fact, it's highly unlikely that those planets were there from the beginning of the history of that pulsar. They probably formed after the original star died and became a pulsar.

Those are the only planets we know about, because planets are very hard to find around other stars. Our theories for the origin of the solar system and for the evolution of stars say that the universe should be filled with planets. But, they're so small, compared to their stars, that they're very hard to find.

Researchers here in Austin, one using the Hubble Space Telescope, another using our 107-inch telescope, are attacking that problem. They have achieved interesting limits on how large the planets may be around Alpha Centauri, our nearest stellar neighbor, and around stars similar to the Sun which are near us in space. Neither experiment has yet detected planets, though. The Hobby-Eberly Telescope will enable us to extend those investigations to a much larger, statistically significant sample of stars and to extend the precision of those measurements to much smaller planets. It may well detect the first planets around normal stars. Now, I will bet on the existence of lots of planets, but as an astronomer, I want to see it demonstrated, rather than just wished. That's an issue which this telescope will address.

Now, how did this telescope project come to pass? There are lots of hurdles to overcome for a project of this magnitude in astronomy today: there are problems with the telescope design; there are problems having to do with the telescope's location; and there are problems having to do with money. You'll not be surprised to hear that money dominates all the other problems.

How to afford it. The era when a single university, like the University of

Texas, can accept the funds from a benefactor, like W. J. McDonald, and build the second-largest telescope in the world, are over. It's not possible to do that any more. Every major telescope project in the world today, save one, is a consortium undertaking.

The 400-inch Keck telescope in Hawaii is a collaboration of the California Institute of Technology and the University of California System.

The Gemini telescopes, one of which will be in Hawaii, a 320-inch telescope, the other on Cerro Pachon in Chile, another 320-inch telescope, are being built by the United States, Canada, Great Britain, Argentina, Brazil, and Chile.

The European nations have joined together to build four 320-inch telescopes on a single mountain in northern Chile.

And, we have joined with four other universities to build an even larger one on a mountain in West Texas.

These projects are all consortiums. The only exception is the Japanese national telescope, a 340-inch telescope being constructed in Hawaii. Partnerships are how astronomers have solved the problem of funding these large telescopes—join with other astronomers. That's something a little foreign to us Texans.

We've all heard the story of the town that called on the Texas Rangers to quell a riot. One Ranger showed up, and the town said, "where's the help?" The Ranger said, "One riot, one Ranger." That's been our philosophy in Texas. But we cannot do that any more. We have to have the collaboration and the cooperation of other institutions to be in these large projects.

In consortia, new problems arise. I want to mention some of the difficulties that we went through in our consortium. Penn State and Texas are the founding partners in this enterprise. The other three institutions are important but smaller partners. The bulk of the funding came from Texas and Penn State and the bulk of the observing time will go to Texas and Penn State. From the beginning this enterprise involved a negotiation between the University of Texas and Penn State University.

The Hobby-Eberly Telescope was a Penn State invention, but the location is in Texas. The engineers who are designing it are in Texas. Texas has ten times the number of active astronomers in its program as exist in the Penn State program. This asymmetry led to difficulties in the collaboration. I know that France would attest to this, as she and I participated in lots of energetic negotiations during the early years of this project.

From the Texas angle, we were the big fish in the pond, and it would have been very easy to say, let's go full speed ahead and drag the rest of them with us. (France says that they were the smart fish.) From the Penn State angle, it was essential to avoid being swallowed up by the bigger fish. It took seven years for us to resolve these issues and form a true partnership where we recognize each other's strengths, we recognize what each institution brings to the enterprise, and we recognize that, without the other one, the project would not exist.

If France hadn't been head of the Department of Astronomy at Penn State during the late 1980s when these discussions were critical, this project might not exist. If Bryce Jordan, one of your fellow philosophers here, had not been President of Penn State University with his Texas connections and his understanding of McDonald Observatory, this project might not exist.

Eventually, we achieved true teamwork between the two institutions. But, then, the price escalated. It became clear that we needed more partners; the two institutions couldn't do it alone. This project started in 1985 as a $3 million telescope project. In 1987, it was a $6 million telescope project. In 1989, it was a $9 million telescope project. Today, it's $13.5 million. And I swear on the Bible here before me that it will not go above $13.5 million!

Stanford and Munich and Göttingen joined us. Now, their interaction with this partnership reminds me of a quote from Pierre Trudeau, who was Prime Minister of Canada when I was a graduate student at the University of Toronto. He remarked upon U.S.-Canadian relations and said, "When you sleep next to an elephant, you are aware of every twitch." The astronomers at Stanford, Munich and Göttingen are aware of every twitch at Texas and Penn State. And rightly they should be. They have gone out on a tremendous limb, each of them, to get into this project. Without them, there is no project. And, yet, they're small enough that, like the elephant, we could inadvertently roll over and crush them.

The Stanford collaboration in this project is maintained by a single assistant professor. His institution has provided him with tremendous resources. They are participating at $1.4 million in the project. This is quite a vote of confidence in him and his future research. But, I don't care how bright you are, and my Stanford colleague is very bright, assistant professors have a hard time getting the attention of university presidents. As a result, we had great difficulties coming to legal agreement with Stanford in this project.

Our German partners are in a different culture. Their law is different; the way they're funded is different; the way their universities work is different. We had to learn how to communicate across this cultural gap. That was difficult at times. There were legal delays while we argued over nuances in the agreement, as it was translated back and forth.

Then there was the exchange rate. At one time, the U.S. dollar got strong, and the university in Göttingen said, "We're out of here. Our money is in deutsche Marks, and we don't have enough to participate now." Then the dollar became weak, and we all cheered, as Göttingen was back in. Without Göttingen, there would not have been a project.

There were difficulties other than creating partnership among these five institutions. Perhaps we can talk about some of them later or at another time in the round table tomorrow. But to me, the key thing was establishing the partnership. Partnerships of this sort are absolutely essential for the future of astronomy and for the future of large telescope projects in the world.

There is a statement that the prophet said in Proverbs: "Where there is no vision, the people perish." I believe that visionary leadership is crucial in all human endeavors. Where there is no vision, an astronomy program will die. Where there is no vision, a great university will wither. Where there is no vision, a proud state will be diminished. We have had the good fortune to have had great vision in the astronomy programs at these institutions, in their university administrations and in their state governments.

Astronomers Dan Weedman and Larry Ramsey of Penn State University invented the concept. They had the vision that a simple telescope of huge aperture and great effectiveness could be built cheaply. They were right. My friend and mentor, the late Harlan Smith, had a vision that this great telescope would be located in Texas in the Davis Mountains. He was proved right.

There were the visions of institutional excellence seen by Bryce Jordan at Penn State, by Peter Flawn and Gerry Fonken and Hans Mark and Bill Cunningham and Bob Berdahl here at Texas; the vision of Texas leading the nation in technological endeavors of our legislative friends, and the vision—the glorious imaginator—of those of you sitting in this audience who provided the funds to make the Hobby-Eberly Telescope come to pass.

I'm reminded of a quote by the philosopher Goethe, "Whatever you can do or dream you can, begin it. Boldness has genius and power and magic to it." We have been blessed with bold leadership in the astronomy programs of these institutions and in the states that are participating in this project.

I look forward to seeing all of you at the dedication of this telescope in 1996. Thank you.

Steven Weinberg: Thanks, Tom. Our next speaker comes to us from New Jersey, but, in fact, he is a native Texan, born in Livingston, Texas. I should add that in addition to that distinction, Jim Gunn is one of the most distinguished astronomers in the world.

Jim is a member of the National Academy of Sciences and has many honors and many accomplishments. He is presently the Eugene Higgins Professor of Astronomy at Princeton University. The name Eugene Higgins is familiar to me because I was the Eugene Higgins Professor of Physics at Harvard University, which raises the question: who was Eugene Higgins?

Eugene Higgins was an eccentric American recluse who in the later part of his life moved to London. When he died, it was found that, since he didn't like anyone he knew, in his will he had left all his money to four universities—Harvard, Princeton, Yale, and Columbia—for endowed professorships, from which both Jim and I benefited. I hope that today, somewhere in Europe, there is an eccentric recluse who is going to leave all his money to the University of Texas at Austin.

Jim sent a very short autobiographical blurb, but I can add to it that Jim is incredibly versatile. Most astrophysicists or astronomers these days can be clearly classified as theorists or observers. (This is even more true in my own field of physics.) There are astronomers who spend their working life collecting light and preparing and then interpreting their measurements, and other astrophysical theorists who interact with the observers and develop fancy mathematical theories.

Jim is one of the few who operates with complete effectiveness on both levels. Some of the most important papers in astrophysical theory are due to Jim and his collaborators, and he's also a major figure in astronomical observation. In fact, though I didn't know in advance what the other speakers here would say, I could pretty well guess what would be the general area of their talks. In Jim's case, I really have no idea what topics he's going to address, which is why I assigned his talk the rather noncommittal title, "Overview." I look forward to finding out what he has to say.

OVERVIEW

JAMES GUNN

Thank you, Steve. I feel a little bit like the prodigal son, actually. I grew up in Texas. I was born here, grew up here, went to school at Rice. Unfortunately, not the University of Texas at Austin, and I'm back very seldom, but always enjoy it, and certainly happy to be here today.

Steve, when he asked me to come and give this talk, asked me to talk about the real issues that this session addresses—that is sort of the sociology of science—issues of fundings, problems that exist in the field. And I'm going to divide the talk into two parts.

The first one is not so different from the first two talks. I would like to talk about my own experiences with two very, very different kinds of projects. I was involved for fifteen years as the deputy principal investigator on the camera-in-space telescope and became very familiar with the workings of NASA.

Then, in 1991, I decided that life was too short to go on that way, and began working on a project that will reach fruition at about the same time as the telescope that Tom Barnes told you about, and what is, it seems at least to us, a rather ambitious effort to map the northern sky. It will be done in an entirely different way with a very large component of private funding and so on. The latter project is of the same sort of size scale as the McDonald telescope. The whole project, not just the cost of the telescope, but the whole project is around $25 million as opposed to the $2 billion on Space Telescope. And it's not surprising that the methods, the style, everything is very, very different in these two regimes. And I hope, a little illuminating.

Let me start by saying a few wishy-washy words about the health of science and how it can be measured. It is, of course, a very difficult thing to come to grips with whether a science is healthy or not. You measure it in terms of its output. And, I think, on any measure, American science in general, and American astronomy in particular, are really quite spectacularly successful things. But, if one is concerned about the future, one has to look a little bit at the infrastructure and see whether things are rotting at the bottom or not, because that rot will only become apparent as you go on into the future.

In order for science (or for that matter any other endeavor OR any organism) to remain healthy, it must stay in balance in whatever sense is appropriate for it. Clearly a science, however spectacular may be its output today, will die tomorrow if it is not training young people to take the place of today's researchers. Likewise, if today's results are built upon yesterday's innovative experiments and/or observations and the support for those basic things has disappeared, it is dubious whether tomorrow will be so glorious. Generally (though not always), education and the basic infrastructure are much cheaper and involve many more people than the biggest, most spectacular experiments. In science, the big things are built by the little things and feed upon them . . . and, very importantly, cannot survive without them.

My department chairman, Jerry Ostriker, is not only a very good scientist, but something of an amateur sociologist of science as well, and has proposed a model for the distribution of resources in a science which he regards as a viable and desirable norm—and one from which one should deviate strongly only at one's peril. The idea is, basically, that if one has a list of projects which constitute the activities of a science and each of these has a yearly cost attached, one should order this list from most expensive to least and divide the list into (say) factors of ten in cost. Thus, for astronomy, the very most expensive projects (all NASA space missions) might be in the 100 million to 1 billion dollars per year, the next from 10 million to 100 million, next 1 to 10 million, next 100 thousand to 1 million, last, perhaps, 10 thousand to 100 thousand. The Ostriker model calls for the number in each of these categories to be such that approximately the same amount of MONEY is spent on each one. This clearly implies that there are many more small projects than big ones, and that, in fact, there are roughly ten times as many in a given category as in the one just above it, each of which costs ten times as much. The argument is that if one only does small things, it is impossible to be ambitious and do very large, difficult projects which, in general, offer great rewards in the pursuit of knowledge, and if one does no little ones it is impossible to train people and to maintain the infrastructure of often very unglamorous research and measurement without which great leaps cannot be made, and that the above balance insures that roughly equal amounts of total effort are expended across the very wide scale of sizes of scientific endeavor.

The real distribution in astronomy is not like this at all; it is terrifically top-heavy, due partly to the fact that the NASA research budget is so big compared to that of the National Science Foundation and partly to the fact that the distribution *within* the NSF, for various arcane reasons, is also very top-heavy. There are no NSF projects in the top bins at all. There is ONE NSF project underway now, the telescope that Tom Barnes mentioned, which is of the order of $100 million total cost, but it's runout time is something like ten years. So, the average annual expenditure is considerably smaller. And, of course, there are not 10,000 active astronomers in this country, each of whom would need to expect at least $10,000 per year to do anything. So there is very much less yet in the smallest bin. So the total skew is much more than a factor of ten over this range.

This top-heaviness is, to my mind and to many of my colleagues, exceedingly unhealthy. Technological strides have made most of the wonderful advances which we have enjoyed in the last few years possible, but the number of technically expert young scientists we have trained during this period is very small. Vast amounts of money have been poured into the aerospace industry and into the National Observatories, not any of which has gone into educating people who can assess the quality of the work and instruments returned, much less who can design the next generations of those instruments. This whole issue of balance is, of course, part and parcel of the "Big Science - Little Science" controversy, about which I expected to hear much more from my colleagues this morning than I did. I think the evils of a completely dominant Big Science, from which astronomy suffers more and more as time goes on, are so well known that the issue is not worth dwelling on, but I would like to give you my particular slant on the issue from my recent perspective from both sides of the fence.

I want to talk about two projects that I have been myself heavily involved in. HST, the Hubble Space Telescope, about a $2 billion project, and the smaller project that will be getting underway in a couple of years, the Sloan Digital Sky Survey, which is about a $25 million project in total runout.

France mentioned that, in fact, the popular newspaper costs for HST of $2 billion is really only its launch cost, and the runout cost is actually considerably larger than this, partly because it's expected that the project will last fifteen or twenty years. It was funded entirely from national resources. It was an international collaboration. Far and away the largest part of the money for the project came from the U.S., but there was substantial European collaboration. There was no private money involved at all, and the money came entirely from space agencies, NASA in this country, and the European space agency in Europe.

It involved a few hundred scientists. And the amount of money involved was very, very large compared to the research money that the scientists involved in the project actually saw, because most of the money fueled the construction of the spacecraft, which was done in the aerospace industry, the launch of the spacecraft, which was done by the NASA organization, and so on.

So, it can't really be said that the scientists in the project spent this $2 billion. And, in fact, one of the real tragedies of the space telescope project, I think, was that scientists were not involved in several quite crucial areas in the project. And I became, I'm afraid, a little bit notorious slightly after Space Telescope was launched, when a letter that I wrote that I intended for one pair of eyes only got distributed quite widely, in which I had the temerity to suggest that the failure of the Space Telescope, which I thought was not too strong a word when its optics were discovered to be so flawed, was, perhaps, to be laid on our own doorstep. That it was our own inattention, our own willingness to believe the NASA hype machine, our own unwillingness to stand out of the spotlight long enough to actually look and see what was happening at the places that this enormous instrument that was being built for our benefit . . . what was really going on. And I still very strongly believe that that's true.

Now, the issue of value for money is one that is exceedingly intangible. France addressed this already this morning. And I don't know, I don't begin to know, how you can place a value—you can certainly place a cost—

how you place a value I don't know. Space Telescope has already done wonderful things that we could not begin to do from the ground. Whether those things are worth $7 billion is something that both the scientific community and, of course, the taxpayers, in the end, have to grapple with. And I have no idea how that will come down. It will only come down, of course, in the future funding of similar kinds of things, because this instrument is a fait accompli.

Everybody has shown pretty slides, and I have to show a few of my own. We don't have to have an artist's conception, because the space telescope is launched. This is the beast in question. It's a 2.4-meter telescope with, now, exquisite optical performance. And what can it do that we can't do from the ground? Well, you've seen some of this already.

This is a picture of the largest spiral galaxy in the Virgo cluster. France already showed this picture. And it was in this galaxy that the Cepheids were seen, which gave the first taste of a really exquisitely accurate way of measuring the distances to distant galaxies. You've all seen this in the newspaper, and the initial results that the distance scale is such that the universe is younger than things in it. This has all been alluded to before.

These were things which might be done with enormous difficulty from the ground. And, in fact, there was a group just before the Space Telescope announcement was made that claimed they had done such a thing. But, I think one would always doubt the measurements, because it is so very, very difficult to see exactly what you are doing because of the very important thing that France mentioned—that from the ground one is always subject to the motions in the atmosphere that make the stars twinkle. And those motions blur the images. Whereas, if you get above the atmosphere, that blurring goes away, and the optical quality, if the optical system is any good, is limited entirely by the size of the telescope. And so the number that one thinks about for the Space Telescope is something like a factor of ten better than you can do from the ground.

You've seen some other pictures of clusters of galaxies this morning. I don't think you have seen anywhere thus far a comparison of what ST will do with what can be done from the ground. This is a really quite superb picture of a cluster of galaxies taken from the ground. This is a quite distant cluster of galaxies, at roughly the largest distance of the sample that Margaret talked about this morning. It's something like a billion light years away.

And, already, from this ground-based picture, you get the idea that there are some very funny things in this cluster of galaxies. Notice that there are galaxies, and then there are these long things. And you see three or four of them, perhaps. And it's been known for some time that these long things, these so-called arcs, are the result of gravitational lensing. It was an effect that Einstein first predicted, in fact that gravitation—that the presence of mass and the existence of gravitation bends light. Light bends in a gravitational field, much as particles fall in a gravitational field.

And this cluster is acting as a lens on the universe behind it, the very distant universe behind it. Now, there's very little you can say from the ground-based picture except that these arcs probably exist. And, in fact, the evidence was not compelling for a very long time that the phenomenon had anything to do with lensing.

Now, let me show you a picture—a quite long exposure, about ten hours—taken with the space telescope of this same cluster. I think the results are sufficiently dramatic that they really need little comment. In the first place, you notice that the arcs are not *hardly* visible any more. They are really quite visible. And, in fact, if you count very carefully in this picture, you see not four but thirty-six of these arcs.

And it really seems very likely that data like this will tell us how big the universe really is. One of the problems that was not mentioned in discussing the distance scale earlier this morning was that it is all tied, in some way, to some astronomical distance. It depends on how nearby some star is whose distance you may or may not know very well. But we think that from pictures like this and looking at the physics of what's going on, in particular if one can see time-variable events in these things, that purely from the very simple laws of physics, one can measure distances with no further assumptions.

And so, we may, in fact, from observations like this, be able to get a quite unequivocal view of how big the universe is without any astronomical assumptions, with really only the errors of the observation. This would be a quite wonderful thing to do.

Now, let's talk about something perhaps no less innovative, but a very different way of doing science. This is a project which I have been involved with for the last five years, a project of roughly the same scale as the one that Tom Barnes talked about this morning.

This is called the Sloan Digital Sky Survey, and, as its name suggests, a fair amount of the money to fund the project did not come from national sources, but from private sources, because the Sloan Foundation was nice enough to give us $8.5 million at the beginning to get this project underway. There have been quite a number of other donors. In fact, at the moment, we are still lacking. It's going to cost $25 million. We have enough money to build it, not to operate it; we're still short about $5 million. We have been able to get five of the twenty we have from the National Science Foundation, by far the largest part of the money has come from private philanthropy.

Margaret has told you basically what this telescope was about this morning, because the telescope came about because (and I say only partly in jest) that we decided that Margaret and John Huchra should not be able to map the universe all by themselves, that we would get together and try to do them one better, and to build a telescope which was specifically adapted to this task.

The telescope we are building is fairly small. It's only a 100-inch telescope, a 2.5-meter one. But it's a telescope which is made specifically to do mapping. It's not a general purpose telescope. It's a very large departure from the norm in astronomy, in which you build a telescope that's supposed to do everything. And, in order to save money and to do the job best, we have tried to build one which is specifically adapted to this job.

We want to map the northern sky—a quarter of the whole sky, about 10,000 square degrees. We will go out to a depth of about two billion light years. And the hope is—Margaret told you this morning that it was difficult to actually judge what was going on in her most distant samples because they were not complete—the object of this is to make a complete sample out to this distance.

In the project we will measure a million galaxy redshifts. We will get redshifts for about 100,000 quasars out to redshifts out to about five. That's looking back about ninety-five percent of the way to the Big Bang, which, admittedly, is a long way from the trillionth of a second that Steve talked about. But it's still a very, very large chunk—by far the largest chunk of the visible universe. We will measure brightnesses for about 100 million galaxies and slightly more stars for about $25 million.

Now, one of the challenges of this, and, in fact, one of the great problems that we've had in setting this up, is that not only the large numbers—these numbers sound large for the numbers of objects, but when you talk about the number of bits that the project will produce and the data-handling that's involved, it becomes really quite daunting. The data base the project will produce is something like ten terrabytes, 10,000 gigabytes, of data. Even ten years ago, it would have been unthinkable to try to deal with this. And so this is a project very much like the others you've heard, which has very much been enabled by technological advances just in the last ten years or so.

Our aim is to take this data and to distribute it very, very widely—to make it available on media so that basically every working astronomer can have a copy of the nearby (out to two billion light years) universe on his desk on CD ROM. But those same data can be distributed to active amateurs, to high schools. It will be a really quite terrific educational tool about astronomy in very much the same way that the Palomar Sky Survey would have been had only it been affordable. But copies of the Palomar Sky Survey cost tens of thousands of dollars for the individual photographic plates.

Part of the information revolution has made this a very much cheaper thing to do, and also very much better, because one can take a CD ROM, plug it into one's PC on one's desk, and ask whatever questions you want to ask about the objects on the disk, because the data are taken digitally, they're very accurate data, and you can answer any question that you could ask of an image of the galaxy.

Now, which is the way to go? Well, I think that's a meaningless question. The aim of the survey that I just told you about is to take an accurate census of the nearby universe. Two billion light years doesn't sound so nearby, but, as Margaret said earlier in talking about the distance to Virgo 45 million years away, two billion years is only twenty percent of the age of the universe. And, although evolution has occurred in that, we expect the sample that we see to be pretty much like the universe today.

It's big enough, we hope, to answer questions about what the largest structures are really quite unequivocally. Those questions may have been answered before, but I think this survey will answer them quite unequivocally. But, if, at the same time, we do not build large instruments on the ground and telescopes in space which enable us to look to very, very great distances, from which light has traveled most of the age of the universe to get to us, we can't answer the really fundamental questions about evolution. How did the universe come to be the way it is today?

So, the answer, of course, and all of you know that all scientists, when asked, what do you want?, to first order they say, Everything. And I think that's what I'm saying.

However, let me now move to the second part, which is the crux of the talk. I think we know that the era in which we can say we want everything is very rapidly drawing to a close, if, in fact, it did not close, perhaps, about twenty years ago. And so I want to say a little bit about something that is certainly related to science funding, but is, I think, rather more far reaching.

It's related to the "Big Science-Little Science" debate. Astronomy, as we've seen, is rather top-heavy. Perhaps Ostriker's law is not applicable, perhaps that's not the way you want funding at all. I think that's arguable. I don't think it's at all arguable that astronomy, at least, and probably all science, is rather top-heavy.

The things at the top are very visible. The infrastructure, the small grants, the small investigators, are not being funded at anything like the level that they need to be. That has very important sociological effects as well as educational ones, and I'll come back to those in a little bit.

Large science has very pernicious effects. I think France would probably disagree with me. She's the chief scientist of NASA, after all, and she has to defend her turf. But, NASA is injecting a great deal more money at the present time into astronomy than the NSF does. The NSF's charge is basic research. The National Aeronautics and Space Administration is a very mission-oriented agency. And so the question is the fact that they are putting ten times as many dollars, roughly, into astronomy as the NSF, what effect does that have? It not only fosters the development of these very large projects, but it fosters, I think, a very unfortunate change in one's mind view away from exploring really quite fundamental things to going along with where one thinks the money goes. Sometimes this is successful and sometimes it's not.

Space Telescope, I think, was regarded by many people as a bribe—the offer of a space telescope was regarded as a bribe by NASA many, many years ago, in order for the astronomical community to support the development of the shuttle. Most scientists agreed that the right way to put up satellites was not with expensive manned vehicles, but with rockets. But, nevertheless, NASA basically told us that you can have the space telescope if you will let us launch it on the shuttle.

There have been similar efforts to try to build astronomical things in the environment of the space station, which, I think, is entirely inappropriate for astronomical research. So there are very many pernicious things that are imposed from the top by completely nonscientific (and often blatantly political) priorities.

But one of the most serious things is that I think our credibility suffers enormously when we allow ourselves to do this. For a very, very long time, this country, and much of the western world, has been having a love affair with science. Scientists have been exceedingly respected members of the society. We have comported ourselves, in general, satisfactorily.

But, of late, that seems to be less and less true. There are very many reasons for this, and the response that we're getting, particularly from the Government, is also varied, and I think can be really quite easily understood.

It's clear that this society is falling out of love with science. That has been reflected, actually, for some time in the fact that the scientific research budgets have been going up rather slowly. This is a fact which academia has not noticed very much. They have noticed it in the sense that it is much more difficult to get funding now, I think, than it was some time ago. No one would deny that. But, we have not adapted. We have not changed our lifestyle at all.

Now, of course, one of the fingers that's pointed at this phenomenon has always been the breakout of peace. I don't think anyone in the academic community would not have been a supporter of world peace. And, yet, it is clear that the desire to remain scientifically competitive at the national level largely came from the desire to remain militarily competitive, and the realization that science was necessary to maintain the military edge.

There is a wonderful book by David Holloway that just came out called *Stalin and the Bomb*, in which there is a conversation—exactly how these records were produced, I have no idea—which is supposed to have taken place between Stalin and Beria. Beria was, of course, the chief of the secret police. But, he was also the only one in Stalin's close circle who had any scientific background at all. Stalin leaned on him very heavily for advice regarding scientific matters, and Stalin was in the process of developing the H-bomb at that time. He wanted the H-bomb more than almost anything else. And I think that's easy to believe.

At that time there was a movement afoot, basically as to physics in the Soviet Union that Lysenko had done to biology, to make physicists think like proper socialists and less like the free-thinking scientists that they were. Beria pointed out, very forcefully, to Stalin that if he did this thing, he would almost certainly not get his bomb, because everyone in the top level of the Soviet hierarchy, knew that this was not the way science worked. It was simply a convenient political mold to try to force on people. Stalin thought about this. And his reply was, "Ah, yes. The physicists. Leave them be. We can always shoot them later."

Now, I think that's probably not going to happen to Steve Weinberg because our society works a little bit differently. But, the effect could actually be very much the same, that, if support for science dries up at the top, or even if it stays constant, that science as we know it is in very, very grave danger of dying.

Now, I'm not going to stand up here and say that the way out of this dilemma is to give science more money. My colleagues have stood on their hind legs for many, many years and said the way out of this dilemma is to give science more money. The real roots of the problem are the same as the roots of problems in many areas.

David Goodstein, in a Sigma Xi lecture a couple of years ago called "Scientific Elites and Scientific Illiterates," I think, addressed the problem rather better than I have seen it done anywhere else. David remarks that the growth of science, as measured by any one of a very large number of indices, is about a factor of ten per fifty years, and has been so from about 1700 to about 1970.

And, if extrapolated (these are always fun extrapolations, like the Club of Rome extrapolations) one of the extrapolations is that if this growth kept up at the rate it was going, there would be a million scientific journals published in the world by the year 2000. Now, the rate at which new scientific journals come into being has already deviated enormously from this curve. There are about 40,000 scientific journals in the world, and we will be lucky, I think, if there are 40,000 scientific journals in the year 2000. There will certainly not be a million of them.

The rate of growth of financial support of science has followed. It's rather difficult to measure, of course, since 1700, but it follows this curve also roughly until about 1970, where there is an abrupt discontinuity. Now peace didn't break out in 1970. It broke out much later. And so it's perhaps a little unfair to blame the breakout of peace. What's really going on is that if science kept growing at the rate it was going, there would be more scientists in the world than people very shortly. And that seems a rather unusual and not a highly likely thing to happen. So, it is simply the fact that exponential growth can go on as long as the thing which is growing is small, but not any more when it gets very large. There can be a large variety of things that actually cap it, that cut it off. But, those are simply symptomatic. The real problem is that science, in particular, and the economy and many other things we're seeing across the country, cannot continue to grow exponentially.

The scientific community is not adapting to this at all well. We have had a number of little things that have helped us along, as American scholars, American students, have come along and realized that the scientific pot is not growing as rapidly as the field is. They have been dropping out like flies and going to do other things, which is a measure of their intelligence. But, the third world is supplying our universities with lots of students, and so the number of students keeps growing as the number of professors keep growing, largely fueled by the infusion of talent from outside in the world. But, when they get out, not even the best American students are finding jobs. And certainly the foreign students are not finding jobs.

The effect of this on the community itself is very bad. One is that people scramble very, very hard to find research money. To such an extent that it is not unusual, if you ask a fellow faculty member, what he does with his time, that he spends fifty percent, or perhaps more, writing proposals—not doing physics, not doing astronomy, but writing proposals. That's not a very profitable way, I think, to spend our time.

The other problem is that, if you spend all your time soliciting, I think it's not long before you start thinking like a prostitute. And that is anathema to the very ideas upon which science is based, the very ideas upon which we want to gain our view of the world. We must be intellectually honest. We must seek not money to support our army of students and to build our machines. We must seek knowledge.

Now, it's been widely proposed that the solution to this dilemma is to double the federal research budget. Well, that growth of ten per fifty years corresponds to about two in about fifteen, and so, if they double the amount of money, that would keep us going in the style to which we are accustomed and would like to remain accustomed for another fifteen years. To be sure, the people proposing this mostly have only about fifteen years left in their scientific careers, and so that's just fine with them, but is, perhaps, not the final solution to the problem. I think it rather more important that we in the field adapt to a situation which has gone from untrammeled growth to one of near stasis.

One of the things that Goodstein noted and, in fact, came down rather hard upon (the "scientific illiterates" part of his lecture) was the fact that America produces the best scientists in the world from the least-well scientifically educated group of students anywhere in the western world. And, I think, by all measures, that's true.

He attributes this fact to the fact that scientists propagate themselves in a very narrow way, and I think that that's undeniably true. I think that one of the things that scientists must do is spread this knowledge about. The education really has to start at a very much lower level. We must live with slightly smaller growth. We must dispel the mathematical and scientific phobia that plagues the American public.

The mood that I would like to convey is a little gloomy. My view is that even though astronomy is in a golden age, I don't think there is any doubt that our future, and, in fact, the future of all real scientific research, is in very dire danger from these social effects. And the effects are not to be laid at the feet of the Government. They are really to be laid at our own feet.

William Wordsworth, a poet whose works I don't care for very much in general, said it very, very much better than I can do. This is a poem that you've probably all heard; the first line is very famous:

> The world is too much with us; late and soon,
> Getting and spending, we lay waste our powers;
> Little we see in Nature that is ours;
> We have given our hearts away, a sordid boon!
> The Sea that bears her bosom to the moon;
> The winds that will be howling at all hours,
> And are up-gathered now like sleeping flowers;
> For this, for everything, we are out of tune;
> It move us not—Great God! I'd rather be
> A pagan, sucked in a creed outworn,
> So might I, standing on this pleasant lea,
> Have glimpses that would make me less forlorn;
> Have sight of Proteus rising from the sea;
> Or hear old Triton blow his wreathed horn.

Thank you.

Steven Weinberg: We have about fifteen minutes for discussion. I'm sorry that time is so short, but there will be more time tomorrow when we have our traditional general discussion among us philosophers and some of the speakers.

Before I open this for general questions, I note that some of the things Jim said were gentle criticisms of NASA, and I wondered if France wanted to respond to anything that Jim said.

France Cordova: We have the same criticisms of ourselves. I think that NASA is very aware of this, and that's why we are trying so hard to re-invent ourselves. We have new leadership under the direction of administrator Dan Goldin, who comes from industry, from TRW's research division. He completely turned the agency on its head. I mean, think of an agency that is on the order of $15 billion downsizing in two years by more than thirty percent, and what that does to the work force and to the initiatives and so forth.

The comments on Hubble and the station are well taken. When Darwin wrote his *Origin of the Species*, he said natural selection was the most important thing in evolution of the species, but it wasn't the only thing. He also made a strong pitch for adaptation as an important component. Science has always adapted to the architectural infrastructure that it has, sometimes with fantastic results. You heard this morning an allusion to the discovery of extra-solar-system planets that was very much an adaptation to a telescope (Arecibo) that was broken down temporarily for repairs. Dr. Alex Wolszczan of Penn State University made a fantastic discovery with that telescope, even in its disrepair.

I certainly agree that the shuttle, being as expensive as it is, and being the one major launch vehicle that we have for heavy payloads, was an architectural constraint that drove the designs of science projects. Now, that is something that we scientists live with; we know how to utilize what is available. And, to some extent, of course, the space station will do that, too. The space station is not just built for science. It's built for a lot of customers. It is the highest priority of the White House for many reasons that transcend just science. But good science will be done nevertheless with the space station; even good fundamental physics, it turns out, has been proposed recently and is definitely being considered for the space station.

So, I'm optimistic with our new directions, especially towards developing smaller spacecraft, reducing risk, and involving a broader range of customers in our space projects, we will be able to do science as excellent as that of the Hubble Space Telescope, but for a very much smaller cost.

I want to just leave you with one example of change at NASA. Most of the observatories that were mentioned today in space were part of something called "the great observatory program," which was sort of like the giant savings and loan program of the 1980s. It got us in a big predicament, because we made these Battleship Gallacticas with everything on them, because we thought this was the only bus going out of town. Today we're really trying to move away from this model, which was expensive, risky, and took too long in development of missions.

There are two great observatories that haven't been launched yet. One is an x-ray one to be launched at the end of this decade, but its design has changed a lot since its original conception and now it is much less expensive, but still expensive by the standards that we are driving towards. The one example that really illustrates what we're trying to do is about is an infrared telescope called the Space Infrared Telescope Facility, or SIRTF. It's the last of the great observatories; we hope it will be flown too.

SIRTF started off just a few years ago at a projected cost of $2 to $3 billion. Today, that mission has been redesigned to be on the order of $300 million. This is by incentivizing the scientists, the same scientists that Jim's talking about, to say, "No, we can't afford to do this any more this way. We can't afford to make it so risky and to drag out the development forever." Because it's the dragging out, more than any factor, the continual changes, losing the management and the continuity of management and the people that really have their hands on the project, that make our endeavors so much more expensive and risky.

And, so the SIRTF scientists applied their talents and their innovations so that the detectors now being proposed are much more sensitive than the original concept. And the whole model of the way NASA is working presently is right in line with the illustrations of smaller, faster, and cheaper, that Tom and Jim gave you from the ground-based astronomy experience.

The point is that you don't try to do everything with one mission, or one telescope, or one instrument. Instead, the SIRTF telescope, and many of the other missions that NASA has tremendously downsized, have focused on one essential fundamental area of parameter space, in the case of the infrared telescope, on sensitivity—getting the sensitivity down by a factor of 10 to 100,000 better than has been done in the past from space. And just focusing on that one thing, doing that one thing well, still yields the ability to do key fundamental discoveries in several major areas of fundamental astrophysics; it also still allows for serendipitous discoveries about the cosmos. All of this will make this infrared telescope an important contributor to science—just as important as the Hubble telescope, but at a tiny fraction of the cost of Hubble.

So, we're on board, Jim.

Steven Weinberg: Okay. I'm sympathetic with a lot of what France says, although, I must say that the space station is pretty expensive. I remember testifying in Congress about the supercollider and having a congressman say, "Well, I understand how the space station is going to help us learn more about the universe, but I don't understand that about the supercollider." There are still hungry looks on the faces of scientists when they think of the money going into the space station.

We have the microphone open for questions. Hans? You have to give your name for the record.

Hans Mark: I'm Hans Mark. I used to be important. First, let me say that I'm very, very pleased that Dr. Cordova is with my old agency, NASA. She's a wonderful representative of what we're trying to do.

Tomorrow morning, I'm listed on the program with Carl Sagan and et cetera. Carl, do you know who et cetera is?

Steven Weinberg: I'm et cetera.

Hans Mark: You're et cetera. Okay. I'd like to prepare a little bit for that by asking two scientific questions of Jim Gunn and Margaret and Steve, because our job is going to be to wrap-up somehow.

The question of the paradox of your children being older than you are was mentioned. Is it possible that the phenomenon of time isn't what we think it is over such very long time scales and very long distances that we're talking about? That's my first question.

And my second question has to do with the paradox of dark matter—the fact that the universe is expanding more slowly than it should, apparently. I'm sorry. How does it go? My mind is not working quite well. But, anyway, something is wrong. Is it possible that instead of dark matter, since we haven't been able to find it, there's something wrong with the law of gravitation, because the two are clearly related? You put the mass in and you say, Well, if the law of gravitation may be different, then maybe there isn't any dark matter and that there's another law that governs the expansion of the universe.

I'd like to ask for just a couple of comments on those two questions from the three individuals, and France, of course, you also. I'm sorry. I missed you. On where you come down on these. Whether people have thought about it and whether there is a possibility that something very fundamental is going on.

Steven Weinberg: I think anyone who wants to answer should. Jim, do you want to say anything?

James Gunn: Well, I think you could probably speak much more eloquently on the first question. The question about whether time behaves the way we think it does—time is really part and parcel of the physical laws. So, if time doesn't behave the way we think it does, we have the wrong physical laws. In fact, it's possible to think about the expansion of the universe not as a real expansion, but as the notion of length changing. And it's been shown—many people have shown—that you really can't tell the difference. It's just language, but it does not alter the physical laws; it does not alter any observable phenomena.

But, if you want to make the universe older than the Hubble age in a substantial way, you have to change the way in which the universe expands. It has to expand more slowly in the past. We think gravity makes it expand more rapidly in the past, and that makes it younger than the Hubble extrapolation.

Now, there is a way to do that. Einstein invented, much to his dismay, a very long time ago a constant called the cosmological constant, which is a kind of force that the vacuum exerts on itself. It has recently come back into vogue. It's very hard to understand why it's the size it is, if it, in fact, exists, but Nature is cleverer than we are.

But basically, as Steve said this morning, there is much to suggest that our views are basically correct . . . the light-element synthesis, the COBE maps, I don't think this was really brought out, but from the fluctuations in the universe one sees today, you expect roughly the fluctuations that you see in these COBE maps of the microwave background. That is an enormous triumph of the idea of the way structure grows, I think. It could have been anything. It could have been perfectly smooth. It could have been very, very lumpy. We knew it wasn't very lumpy to begin with. But, the fact that it came out about right, that the behavior with scale was about right, is an enormous triumph of the way we think about the growth of structure in the universe today. There are, perhaps, ways around that. I am not sure.

But, certainly, the light-element synthesis that Steve talked about is, I think, a really very compelling reason to believe that the laws of physics we have today are correct back to at least the era of nuclear synthesis.

Steven Weinberg: Okay. Let me just take advantage of my prerogative as chairman to give a brief additional reply, and then go on to another subject.

When you look at these distant galaxies with a spectroscope, and when you look in a flame here in your fireplace on Earth with a spectroscope, you see the same pattern of spectral lines. It's wonderful to see in the distant galaxies the same familiar sodium lines that you can see in any flame. The pattern of spectral lines is shifted to the red, but is otherwise identical to what we see on Earth. But the light we see today from a galaxy that is a billion light years away left that galaxy when the universe was a billion years younger. This shows that the laws of physics haven't changed very much over the billions of year that we have been calling the age of the universe.

With regard to the force of gravity, there's a physicist in Israel named Milgrom, who has seriously considered possible departures from Newton's law of gravitation at distances which would be relevant to this question, of, say, galactic sizes. The consensus is that it doesn't work. In fact, the latest issue of *Physical Review Letters* has an article on just this subject analyzing the motions of things in the galaxy, and concluding that changing the law of gravitation cannot be done in such a way as to fit the observations.

Yes, sir. Give your name, please.

Melvin Salveson: I am Melvin Salveson. I am here as a guest of George Kozmetsky. My affiliations were UCLA and Pepperdine. I am not an astronomer, but I have a question that arose from Dr. Sagan's remarks, repetitively about the center of the universe. And, also, learning from Socrates, I learned from Euclid that with a string and a circle, I can find the center of the circle.

Can you astronomers find the center of the universe?

Steven Weinberg: Well, Tom, you're a working astronomer these days.

Tom Barnes: The answer to that is "no we cannot" because there isn't one. The analogy that I like best to explain why that is so uses a balloon with dots painted on its surface. As the balloon is blown up, the dots on the surface of the balloon get ever farther apart, simply because there's more surface to the balloon than there was before. So the dots get farther apart as the surface stretches.

Now, imagine a microbe on one of those dots with a telescope looking along the surface of the balloon. Imagine the microbe is constrained to look only along the surface. It doesn't have the ability to look perpendicular to the surface of the balloon. Every dot that the microbe sees is getting farther away. And from the perspective of the microbe, it is at the center of the universe, because all of the other dots are rushing away from it as the balloon expands.

So where is the center on the surface of the balloon? There is none. The very fabric of the microbe's space is getting larger, and so everything is getting farther apart. In three dimensions, as we sit at our telescopes and look out, the very fabric of the space between us and all the other galaxies is enlarging. And so we see them all rushing away from us. But, there is no center to that expansion. It's the space itself that's getting bigger.

Melvin Salveson: I'll let others answer whether that's an answer. Thank you very much.

Steven Weinberg: Is there another question? I think we're all getting hungry, so why don't we go on to lunch? We can discuss these questions of funding and policy tomorrow morning.

WHO CARES? THE IMPACT OF COSMOLOGY ON GENERAL CULTURE

Steven Weinberg

We have been describing results of scientific observation and theory and how these observations are done and where the money comes from. But the aim of this work is not to develop new weapons or new technologies or new cures for diseases, but to develop understanding. It would be a disappointment if it were only the understanding of the scientists that we were developing. In the end, for scientific understanding to be really valuable, it has to become part of general culture.

And, so, our third topic here, the one we take up this afternoon, is "The Impact of Cosmology on General Culture." This session is organized to run in chronological order. The three speakers will discuss three periods in human history.

The first period is the time of the Mayans. We are fortunate to have with us in the University of Texas at Austin one of the great experts on this subject, perhaps the greatest expert. She is Linda Schele, who holds the John Murchison Professorship of Art at the University of Texas at Austin. She is the author of a number of books, and, I think is generally regarded as the leading specialist on the writing, art, and cultural history of the ancient Mayans.

MAYAN TIMES

Linda Schele

I am grateful for that great introduction. Now I've got to live up to it.

Before I start, I have to tell you I'm an art historian, which means I cannot speak without pictures, so my presentation will be mostly pictures. And, second of all, I want to start out speaking a little bit about what cosmology and world view is. We of the West live inside the box of our own cosmology. And when we speak about other people's cosmologies or world views in the world, we privilege our own as true, and we penalize other people's according to how close they get to us in the way they understand the world.

For instance, most of the cosmologies of the rest of the world are equated to religion. In our world view, religion is something personal, non-public, and has nothing to do with public policies. We even have a government that separates religion from government.

What I want you to begin contemplating, as I show you what the Maya did with their cosmology, is an equation, not between religion in the modern world and what the ancient Maya did with their world view, but between what we do with science and their world view. If you listen to the stated agendas of many of the talks this morning, beginning with Dr. Sagan's description of the large forms in the universe, the speakers focused on questions like, "How did the world get to be the way it is; what processes led to it, and, as human beings, where do we belong in it, and how do we operate with it." Human beings have been asking those questions for as long as we have the archaeology of art, which is at least thirty thousand years ago.

And the Maya came to their own solution. Now, it would be very easy for us in this room to dismiss the Maya solution as fantasy and child stories, or as things we don't want to think about. But the Maya essentially faced the same problems that we do. How do you create some overarching understanding of the world that explains the phenomena that you see in the world? We have a special group of people called scientists who use scientific language and jargon to describe and explain our universe. Therefore, we have a meeting like this with a room full of people who come together to learn about cosmological questions from professional translators, such as Dr. Sagan, who explained to us why all of these new discoveries are important. We have to have translators because if ninety percent of us in this room picked up one of the professional papers by these people, we wouldn't understand much more than "the" and "a." Right?

The Maya, like many other peoples in the world, took a different tactic. Instead of inventing a special language to explain how they understood the world, they used stories and metaphors. The advantage of stories and metaphors is you don't have to have a professional class of translators. Everybody can understand them. And, so, what I'm going to do very quickly in this short, twenty-minute presentation is to explain their major myth of creation as we have recovered it from Maya writing. But, the point here is not the "story" of creation. If we just deal with it as the story of creation, then it would just be another little fantasy story to entertain you, and you would go home and say, "Well, isn't that quaint." No, we have something more.

The Maya story of creation is a map of the cosmos as they understood it. And every single member of Maya society, from young children to the highest king, could walk outside their doors and confirm the truth of the metaphor by simply looking at the sky.

The Maya lived on the Yucatan Peninsula and parts of modern Mexico, Belize, Guatemala, and Honduras. There are about twelve million people there today who speak a Mayan language as their first language. That's probably near the population, perhaps a little bit more, at the time of the conquest.

The story I'm going to be telling you about we can document archaeologically back to 900 B.C., and parts of it were shared by other peoples all over Meso-America and even North America.

The Maya turned to the major activity of their lives as a source of metaphor. For women, it is the making of food from maize. For men, it is the planting of maize. Now, it's not just maize that I'm talking about here. It is the natural history of the plant—how you put it in the ground, what happens when it grows, what happens as it dries out, what you do with it when you harvest it, how you turn it into food for human beings, how you cook it. All of this got turned into the basic stuff of metaphor describing how creation works.

Okay. This slide is an image of the maize god himself, usually a beautiful young male with corn growing out of his head. His wife is the moon goddess. And from the actions of these two beings came all of the living creatures of the world and the cosmos itself. The Maya didn't believe in a one-time creation. In fact, we live in the fourth creation, so the universe has formed, been destroyed, and reformed at least four times. This concept of recurrent creation is a theme in all Meso-American thought.

This slide shows a chachak ritual today in Yucatan where the h'men or chief priest is, making a huge tamale out of all of the maize dough that was brought by the participants from the town to create the sacred food that will be given back to the gods as the ceremony progresses.

Now, in the ancient story of creation, two days in the tropical year were terribly important. One is August the 13th. The other's February the 5th. If you correlate their calendar to our calendar, they will tell you that the fourth creation began on August the 13th, 3114 B.C. But in their way of thinking, this day also recurs every year. The human community responds to it through ritual, and through reenactments that bring back into the Earth and into the lives of human beings this generating energy of creation. It's like a supercollider that creates conditions close to an earlier time in the cosmos.

Now, the story of creation focuses on the rebirth of the maize god, who was killed by the gods of death. After death, he generated twin sons, who had to go to the Underworld and resurrect their dead father. The myth was also associated with the pattern of the Milky Way on these two days. Now, this slide shows sunset on the first of the two days, August the 12th. The slide reconstructs August 13 in the year 690, because this is when one of the texts describing it was written. The Big Dipper here is a great bird whose name was Twelve Macaw or Magic Revealed. He is the false sun of the third creation, and, before the fourth creation can begin, he must be killed.

As the Milky Way rotates (you can see this is two hours later), the Big Dipper moves towards the horizon. When the Milky Way moves into this orientation from the southwest to the northeast, it matches a scene from Maya imagery in which the twin sons of the maize god—known as the Hero Twins—shoot the bird, the false sun, out of the tree. And, as the sky is here, Ursa Major, or the big bird, now disappears into the horizon as if it fell out of the tree. And with the Milky Way in this position, it represented the great crocodile tree in which the bird sat. You can see the Milky Way literally has the crocodile head right there (in the dark cleft). With the defeat of the bird, their world is prepared for the fourth creation.

Now, in the story, the maize god is then reborn. You can see in this slide, there is a snake right there, and the maize god is being reborn out of the mouth of the snake. As he grows into adulthood very quickly—this is a fast story—it's like Star Trek—beautiful, naked young women dress the maize god and prepare him for his duty. Even today, Maya women go into the corn field to nourish the maize by speaking to it and talking to it. This is the nourishing, mothering role of women within Maya society.

Once the maize god is an adult, and he is fully dressed again, he is put into a canoe, where he is rowed by canoe gods, to the place of creation. The canoe, like the crocodile tree, is in the Milky Way. As the crocodile tree rotates till it goes from the east to west horizon across the sky. This happens between midnight and two o'clock in the morning, on the day of creation. Here, the slide shows the two paddlers. The maize god sits in the middle of the canoe. Here (slide) is the canoe rotating up into position.

The next thing that happens to the canoe is that it sinks beneath the surface of the primordial sea. The sinking of the canoe is actually the rotation of the Milky Way as it moves down to the northeast. Now, there are two critical places in Maya creation. One is the belt of Orion, which is right there and the lower three stars of Orion, which forms a great hearth at the center of the universe, where the first fire of the universe occurs. The maize god is going to jump out of the middle of Orion and create the world, create the sky on the day as this position in the sky rotates up to the zenith position in the sky. The sinking of the canoe—the very action where the canoe sinks beneath the water—brings up this place of creation—Orion—up above the horizon and takes it to the zenith position at dawn.

This slide is in a stunning flint that's at the Dallas Art Museum that shows exactly the sinking of the canoe. Here is the canoe arcing down into the sea. This is the position of the canoe itself as it arcs there, bringing up the point of creation to the heavens.

Now, in Maya cosmology, the belt of Orion is a turtle. Even today, they call the belt of Orion a turtle. The lower three stars, the star of Alnitak, Saiph, and Rigel are today called the three stones of the hearth by Maya people. Gemini up here are copulating peccaries, so when the Sun goes through Gemini, it is riding peccaries.

Here's a gorgeous pot that shows the turtle of Orion being cracked open—and this is the maize god coming up out of the crack in the back of the turtle as he comes into the world to begin creation. Here's that image placed against the constellation of Orion.

Now, the point I want you to get here is not the story. It's a cute story but it is not a story that carries meaning for us. But if we look beyond the story, we see that it's encoding the sky. Anybody could walk out at night and, rather than seeing random patterns that are meaningless to human beings, all of a sudden the sky is patterned by the story and it's related not only to the creation of the world, but to the everyday lives of people. If NASA wants money, that's what it's got to do.

Here's another picture from a Maya codex. Here's the ecliptic. Here are cords holding the turtle to the ecliptic, and there are the three stones of the hearth right immediately on top of the table.

We even have a picture of the selling of the hearth. This pot shows one of the three stones that are set. This is a god who has the lovely prosaic name of God L. We don't know what his real name was. But he's sitting on one of these first three stones that were set in creation, and these are the six gods who helped. In Maya cosmology, everything was done by the community of beings. It's like a council. It's like the Senate of the United States, although God help us if the Senate of the United States runs the cosmos.

Now, we also have pots (slides) that show the reborn maize god in the middle of the three stones of creation. This is an image that's all over Maya art, and I just want you to know it's the world's greatest chip-and-dip plate.

Now, on the opposite side of the year—on February the 5th. Remember the first act of creation (on August 13) was to center the world by creating a great hearth in the sky. That's like our own cosmology. Right? We centered the world first, and even whether you want to do it in terms of the Greeks or the expanding universe, ideologically, it has a center. Right? The Maya centered the world and prepared the first fire.

Then once the universe was centered the gods had to separate the heavens from the Earth. And this action is also written into the sky. We start out at sunset on February 4, but notice that the Milky Way is in exactly the same position it was at dawn on August 13. Here's Orion, here are the copulating peccaries, and what's going to happen now is they're going to rotate towards the west. This is at eight o'clock, where they cross the zenith position. They fall towards the western horizon.

There are all sorts of other myths connected with this movement of the

Milky Way. For instance, the Pleiades are four hundred young boys that the lords of death killed, and that are resurrected by the Hero Twins. These are the four hundred boys falling towards the horizon. Here the Milky Way moves a little bit closer to the horizon until, in the next two hours, we go through time of the night, when the Milky Way rims the horizon in the tropics. This they call the "Great Dreaming Place," or the "Great Place of Transformation" in which the world was remade.

Then, at four o'clock in the morning, out of the entire eastern horizon, the Milky Way begins to rise. The word for the Milky Way in Mayan languages, by the way, is the Sak Bey or the "White Road." It rotates until at dawn it's right over the top of the sky. The Milky Way in this north-south orientation is the great tree at the center of the cosmos. By erecting the tree, the gods lifted the sky from the Earth and created the structure of the universe.

Now, those of you that know anything about astronomy are going to say, Well, they can't see the Milky Way at sunset and dawn. But they could see Scorpius, which is one of the two brightest places in the sky, and they could see Orion. These are the most intense areas of the sky, and, if it's not cloudy, you can see those stars almost immediately when the Sun has gone beyond the horizon or comes up above it.

So here is creation. Now, to let you see how this works, here is the tree imprinted over the Milky Way. The Lakandous today call this region of the Milky Way the root of a great tree. And as this Mayan print shows (slide), the Maya saw a little scorpion near the great root of the tree. We now have information from at least five different Mayan languages, and from pre-Columbian sources, that they called our constellation of Scorpius "Sinan," which is the word for "scorpion." The scorpion is right there at the base of the tree right where our Scorpius is.

Now, this (slide) is perhaps the most famous piece of art known from the Maya. This is the tomb of the great king Pecal at Palinque. He is shown inside the skeletal opening to the Other World. He rides atop a plate. There's the great bird that got knocked out of the tree that's on top of it. This is, in fact, a great tree. This is the ecliptic crossing the tree, and you're seeing Pecal in the moment he falls into the other world at the moment of his death.

The verb that's recorded on this sarcophagus to describe what is happening to him is *och bey*. "He entered the road." Remember that the Milky Way is called the "White Road." This is a map of the sky on the night he died. So that this image is not only a metaphorical picture of death that includes all of the ideas of resurrection and where human beings come from and where we go and what happens to us after life, but it is also a map of the sky on the night he died.

Now, the myth, as we believe it, was probably invented and attached to the sky and these great motions of the Milky Way around 1000 B.C., where the cultivation of corn was joined to it. This (slide) is a picture of the night on the sunset position of the two days. This (slide) is the sunrise position on August the 13th and the sunset position on February the 5th. This is the sunrise position on February the 5th and the sunset position on August the 13th at 1000 B.C., at La Venta, one of the first cities to be built in Mesoamerica. And, if you look, there's Orion dead straight at the zenith position. So that as these objects, or these particular areas of the sky, move from zenith to zenith, they map the actions and timing of creation.

Now, to give you some idea of how ancient this may be, all of the people in the Amazonian basin, or the great majority of them, have a myth of creation in which the Milky Way is a great canoe rowed to the place of creation by a one-legged paddler. And the place of creation is the nexus between Hyades, the Pleiades, and the belt of Orion. For that to get to South America means this is a very ancient human myth indeed. If it is, in fact, diffusion that is the result of both of these myths being in the same place.

Now, finally, because Steven asked me to do it, I'm going to do a little bit with Venus. When the maize god came out of the Turtle, he and his helper not only painted on the constellations of creation, but they organized the ecliptic, by painting images along its path. These are their zodiacal constellations of the ecliptic. Now someone was talking earlier about the planets moving along the band. This is the band. Our people historically organized this band into twelve zones. The Maya organized it into thirteen zones. And these (slide) are the surviving pictures of the relative zones in the sky that each of these represented.

Now, the famous pictures in the Dresden Codex of the Venus pages, I can now use to show you a little bit how creation interacted with all of this. These are five pages, six pages actually, reading across to here. These are pictures and the means of counting that the Maya used to keep track of the planet Venus. They knew that it had an approximate period, an average period, of 584 days, and they wanted to be able to predict where it would show up so that they could time their actions to it.

The Maya did not believe in a kind of prediction that allows you to change the future. Instead, they believed that if they could understand the patterns of the universe, then they could join their actions to it so that they had the best chance of getting the responses and the results that they wanted. Now if this is not a good description of what we're trying to do at this conference. So they studied the patterns of the universe, exactly like our scientists do. The difference is they didn't have telescopes. All they had was their eyes. And so what they tried to do was make the greatest sense of patterns they saw.

Now, you can see (slide) that there are three pictures on each page. The top picture is the god of the Morning Star. The middle picture is a god that they called the Spearer, and the bottom picture is a picture of the victim of the Spearer. These are probably constellations in the sky.

In the four rows of glyphs that you see here, there are 584 days. There are 584 days here, 584 here, 584 here, 584 there. Five Venus cycles in total. But what they discovered is five Venus cycles is the same as eight tropical years. So if they started here with Venus in Scorpius, exactly the whole run of this table later (5 x 584; 8 x 365; or 2920 days) Venus would come back to Scorpius.

If you run vertically through the entire table, there are thirteen runs of this cycle. This is the Grand Venus cycle of 104 years. The next Grand Venus cycle would go to the next constellation, then the next, until it goes all the way around the ecliptic. On the twelfth run, it came back to Scorpius again, and on the thirteenth it went to the next constellation. By using that system, they could cast Venus 10,000 years into the future, 104,000 years into the future, 204,000 into the future, and they did it, simply by knowing how the tropical year interacted with the Venus year.

These numbers (slide) give you the base data, the understanding of how this all starts. The columns of glyphs here (I'm not going to read them to you), tell you the status and the orientation, the pattern of Venus, in the first moment of creation. And from that first moment of creation all of the subsequent motion of Venus unfolded.

This is the base date of the Venus calendar. This is the number that casts it into historical time. And then these are the numbers that count the days that run up through the thirteen runs of the entire table. Each time you run thirteen times through here, it's 104 years.

Not only do these numbers take you back before creation, but they commensurate many different cycles. They commensurated Venus, the 52-year cycle and the celestial year, with the visible behaviors of Mercury and Mars.

So the three inner planets, the three planets that dance across the sky in the fastest motion, are all brought together in one great numerical pattern that is, in fact, describing the symmetry of the universe the way they understood it. That is exactly what these people in this room have spent their lives trying to do. I thank you.

Steven Weinberg: Wow! And now for something completely different. Here in the University of Texas at Austin, we were very glad when Bruce Hunt joined our faculty a few years ago and immediately gave us a presence in the history of science, which we had not had previously.

He is a specialist in the history of science and technology, and, although his own research field is nineteenth-century physics and he is the author of a book *The Maxwellians* on that subject, he has for several years taught a course on the scientific revolution of the sixteenth and seventeenth centuries, in which modern science arguably was born. He is therefore very well equipped to tell us about the impact of that great moment in the history of our species on the general culture of the part of the world that knew about it. Bruce Hunt.

THE SCIENTIFIC REVOLUTION

BRUCE HUNT

I'll just talk. No slides. Just over 450 years ago, in 1543, arguably the greatest revolution in western cosmological thought occurred, or at least began, when Nicholas Copernicus published his great book on the *Revolutions of the Heavenly Spheres*. According to Copernicus, the Earth was not the center of the universe, as virtually everyone everywhere had always thought; instead, he said, the Earth was basically a big rock circling the Sun. This was very hard for most people to believe. It went against the most obvious appearances. We don't feel like we're moving. We don't feel like we're just a speck off on the edge of things. To all appearances, we are the center around which everything turns.

Moreover, Copernicus's evidence for this surprising claim was not particularly direct or, at that time, very convincing—at least not to those who were not as deep into astronomical theory as Copernicus himself was. He had virtually no direct empirical evidence. When we look closely at the predictions his theory made, we find that they did not really fit observations very much better than the old Earth-centered Ptolemaic system did. Copernicus's main argument was essentially aesthetic—that once you grasp the real inner nature of his theory, it was, in some fairly abstract sense, simpler and more pleasing to the mind. But this sort of aesthetic appeal was not accessible to most people without very long study.

The impact of Copernicus's work was not immediate by any means. Copernicus himself had waited a long time before publishing his work. In fact, he was literally on his death bed when it was published. He was basically talked into publishing it by an enthusiastic younger scholar, Rheticus. Rheticus was supposed to see the book through to press, quite a big obligation to have in 1543 when printing was still relatively new. But he was offered a better academic job, and left Nuremberg to go to Leipzig. So Rheticus handed it over to a Lutheran theologian, Andreas Osiander, who saw it through the press.

Copernicus, incidentally, was a Catholic church official—not a priest, but a Catholic church official. But he had good relations with a number of Protestant astronomers.

Well, Osiander saw the book through the press, but he added an anonymous preface which many people, particularly those who didn't make a careful study of the book, took to have been Copernicus's own. In this preface, Osiander essentially said, "don't take this book literally. It gives an interesting and useful mathematical hypothesis that makes astronomical calculations somewhat simpler or more elegant, but you shouldn't believe it—you shouldn't think that the Earth is really going around the Sun. That would be absurd."

And, in fact, Copernicus's work was taken in this "hypothetical" sense by astronomers in Europe for the next fifty years or more. It's been well established by recent scholarship that Copernicus's book was widely read and intensively used. Many annotated copies with quite extensive and interconnected annotations have been found. But it was used primarily as a calculational device not meant to be taken literally.

In fact, careful study has been able to identify only about ten true Copernicans before 1600 or so—only ten active thinkers who seem to have really believed Copernicus's argument that the Earth moved.

The real impact of Copernicus's work and the main controversy over this new theory of the cosmos came in the early part of the seventeenth century after Johannes Kepler in Germany had extended and revised the theory, and especially after Galileo Galilei in Italy had turned his telescope on the skies in 1609. Galileo made a number of discoveries and then, strengthened by those, launched a very aggressive intellectual campaign, not just for the new Copernicanism, but for a whole new approach to philosophy—what we would now call science—and to the question of how we should understand the world.

I want to emphasize that the evidence for Copernicanism, even after Galileo's telescope, was rather indirect. You can't look up in the sky and see that the Earth moves around the Sun, and Galileo certainly didn't. But he did see a number of interesting things—the rugged surface of the Moon, suggesting that it was another Earth-like body, a huge number of stars, including many, many in the Milky Way that had been previously invisible, and the moons of Jupiter, his most sensational discovery, the one that really made him very famous. He publishes these results in 1610.

A bit later Galileo discovered the phases of Venus. He found that Venus shows the same kind of phases, from full to crescent, as the Moon does. But that does not establish that the Earth goes around the Sun. It establishes that Venus goes around the Sun, which is a rather different thing, and there was in fact a widely held theory at that time which said the Earth was stationary, while the other planets went around the Sun, and the whole thing cranked around the Earth.

But Galileo did discover enough suggestive evidence to indicate that there was something wrong with the old astronomical and cosmological system, that there was a need for something new. The impact that this had on the broader culture of thinking people in Europe is, I think, very well reflected in some lines from a poem by John Donne. Steve Weinberg quoted a bit of it this morning after Bob Krueger, the former president of the Society, had mentioned it to him. I'll quote a few more lines from Donne's 1611 poem, "The Anatomy of the World," written just after Galileo's work had been published and had made a sensation throughout Europe:

> [The] new philosophy calls all in doubt,
> The element of fire is quite put out;
> The sun is lost, and the Earth, and no man's wit
> can well direct him where to look for it.
> And freely men confess that this world is spent,
> when in the planets, and the firmament
> they seek so many new; Then see that this
> is crumbled out again to his atomies.
> 'Tis all in pieces, all coherence gone;
> all just supply, and all relation.

What I think Donne's words reflect is that, as Linda Schele has said, a cosmology provides an ordering picture for individuals and for a society. As the old Earth-centered cosmology was undercut by the work of Copernicus, Kepler, Galileo, and the rest, people felt a sense, reflected in Donne's words, of a collapse of order, a collapse of old verities, a collapse of what was obviously true and important to them. I will return to Donne in a minute. He was responding to a revolution, not just in astronomy and cosmology, but, in the largest sense, in world view, in people's view, literally, of where they stood in the world.

I want to emphasize another point, too. This cosmological revolution was connected to a lot of other things in the way people viewed the world. In Europe, in the Middle Ages and the early modern period, there was a well-developed, quite coherent, cohesive view of the world and where everything fit together, a view basically derived from Aristotle's writings as they had been recovered and interpreted in the Middle Ages. It was a commonsensical view in a lot of ways, and quite tightly integrated. You couldn't change one thing very much without having to change a lot else. The Earth was at the center of the universe. The universe had a definite center. There was no confusion about that. There was a center, and the Earth was at it.

Everything in the physical world that we encounter was, the Aristotelians said, made up of combinations of the four elements: earth, water, air, and fire. Those four elements constitute all of us and everything around us. They are subject to change, development, birth, death, decay. Each has its natural place. Everything in the world, everything in the universe, has its natural place relative to the center of the universe. And the whole Aristotelian theory of the motion of bodies was predicated on this theory of natural place and the elements.

Aristotelians made a strict separation between the eternal Heavens and the changeable Earth. Nothing in the Heavens ever really changes; it just moves around and comes back in cycles. The Heavens were very different from the changing, changeable world we live in, from the Earth we live on.

This was an ordered hierarchy, an ordered world, in the literal sense of the Greek word, a *cosmos*: an *ordered* world. Almost all of this ordered, cohesive cosmos, this ordered view of the world, would have to be thrown out the window if one accepted Copernicus's claim, based on his learned astronomical studies, that the Earth was not actually at the center, but was zipping around through space at some enormous speed—that it wasn't even in the same place from one moment to the next.

The new astronomy would require a new theory of motion. It would require a new theory of matter, since the old theory of the elements, of the four elements, didn't hold up very well on a moving Earth. Certainly the notion of natural place didn't hold together very well if we weren't in the same place from moment to moment.

One response to this, reflected in passing in Donne's poem, was a resurgence in the seventeenth century of atomism, of the view that all matter was essentially the same, different only in its size, shape, motion. It was a very different view of the world, of its nature and in a sense of our own.

Much else was also called into doubt by "the new philosophy." The authority of Aristotelianism in general was called into doubt—if Aristotle had been wrong about something as straightforward and big as where the world is and how the universe is put together, perhaps he had been wrong about a lot of other things as well. Of course, other people had raised questions about Aristotelianism before, but it was still quite a strong philosophy in the early 1600s. It certainly still dominated the universities.

Moreover, since the Middle Ages, large parts of Aristotelianism had been incorporated into Christian theology. To question the Aristotelian cosmology, and by extension Aristotelian methods of reasoning, was thus also to question deeply held Christian beliefs.

Galileo, as I said, was one of the first, perhaps *the* first, to pursue this tack in favor of the new philosophy really aggressively. His first opponents were not churchmen, but Aristotelian philosophers. They were the ones who were most directly threatened by Galileo's attacks.

Incidentally, once Galileo had used his telescope, he parlayed it into a big career move. He got himself appointed mathematician and philosopher—he particularly insisted on the title of philosopher—to the Grand Duke of Tuscany in Florence, a much more prestigious position than his old job as a mathematics professor in Padua. Moreover, it gave him a much better position from which to carry on his prospective intellectual revolution.

Galileo's opponents among the Aristotelian philosophers attacked him on a number of grounds between 1611 and 1613. Galileo was a skilled debater who knew the tricks of the trade very well. His Aristotelian opponents weren't able to make a lot of direct headway against him, so a number of them then brought in what was essentially the doomsday weapon of early-seventeenth-century intellectual debate—accusations of heresy. It was the Aristotelian philosophers who first raised directly the question with the Roman Catholic Inquisition: Are these not heretical beliefs?

What did they say was heretical about Copernicanism? At one level, it conflicted with traditional standard interpretations of certain Biblical passages. At one point in the book of Joshua, Joshua commented, "Sun, stand thou still." He wanted more time, more daylight, to slaughter his enemies, so he said, "Sun, stand thou still." He didn't say, "Earth, stop rotating on your axis for a while." He said, "Sun, stand thou still," and the almost universal interpretation of this by theologians was that it was a direct statement that the Sun moved around the Earth rather than vice versa.

Another interesting objection that was raised against Copernicanism concerned not a direct implication of the theory, but rather an extrapolation that many people soon made. Remember that before Copernicus, the Earth was not a planet. It was Earth and the other things up there were planets. If you look up in the night sky and you see a point of light, what does that have in common with the Earth? Nothing, as far as people could see and as far as they could think. But if now the Earth was a rock going around the Sun, then presumably the other planets were Earth-like. And if the purpose of the Earth was to be a home for man, as most people believed, then certainly these other planets must be home to beings as well. And we find arguments about the plurality of worlds and the inhabitants of other worlds appearing very soon in the late-sixteenth and early-seventeenth centuries.

All of this raised enormous theological problems: Did these creatures on other planets have souls? Had Christ lived, died, and been resurrected on these other planets? Can the creatures on these other planets be saved? These were all enormous problems, and were raised quite early on.

To cut to the chase on this part of the story, in 1616, the Inquisition in Rome examined the question of whether the motion of the Earth and the stability of the Sun were heretical beliefs, and determined that they were.

Copernicus's book was put on the index of prohibited books until "corrected," which was later done by putting in little annotations basically saying, "Don't take this seriously, he just doesn't really mean it." Galileo was not directly condemned at that time, but he was told, in no uncertain terms, to cool it, to pull back and not to push his case. And he did keep fairly quiet for some years. He pursued other interests, shall we say.

After a series of events in the 1620s, things looked more hopeful to Galileo, and in 1632 he tried again. He published a big *Dialogue on the Two Chief World Systems*, comparing the Ptolemaic and Copernican cosmologies. It was lively and well written, and was quite widely read. Formally Galileo didn't come down on one side or the other, but you didn't have to be a very careful reader to see that it was strongly pro-Copernican. It is framed as a conversation among three characters: Salviati and Segrado, who were named for friends of Galileo who died recently, and the Aristotelian mouthpiece Simplicio, who is often made the butt of jokes in the course of the book.

Galileo didn't fool anybody with this book, and he was called before the Inquisition in 1633, though he was by then nearly seventy, and forced to recant and abjure his belief—forced literally to kneel down and renounce any belief that the Earth moved. He was then placed under house arrest back in Florence for the rest of his life.

But, of course, that wasn't the end of the story. It wasn't just a clash of cultures in which Galileo lost out. Though Galileo did, in a sense, lose out, Copernicanism continued to spread. It was a hollow victory for the Aristotelians. In many ways, the Inquisition's condemnation of Galileo just increased his prestige in Protestant countries. If the Church had condemned it, maybe there was something to it—that was the attitude in many Protestant countries. Copernicanism advanced rapidly in northern Europe through the middle of the seventeenth century, culminating in the work of Isaac Newton in the 1680s.

To repeat, all of this clearly was not just about astronomy and cosmology. It wasn't just about arcane questions of how the planets moved around each other. It was about questions of world view, questions of what the natural order was, and questions, ultimately, of what our relationship to that natural order was. It was a controversy over truth, over authority, over access to truth, and other methods of finding truth.

I think the connection between natural order and human order is very clear for the Mayan cases, as Linda Schele has talked about. I think it is also quite clear for the Aristotelians. It may be harder for us to see such connections when we look at the post-Copernican world or at the modern cosmology, but I think, ultimately, once we gaze into them we see that there are deep connections.

I'd like to close by returning to the next few lines of Donne's poem:

> 'Tis all in pieces, all coherence gone.
> All just supply and all relation.
> Prince, subject, father, son are things forgot,
> For every man alone thinks he hath got
> to be a Phoenix. And that there can be
> none of that kind, of which he is, but he.

Donne is making the point that the old cosmology had provided a foundation, a justification for a view not only of the natural order, but of the human order, of the social and personal hierarchy. In Donne's eyes, that had been upset, that had been torn down, that had been called into doubt by the new philosophy and the new cosmology.

Donne, at least, did not seem to see a new basis for human life and thought emerging. And I think the construction not of a comprehensive new basis, but of a new way of organizing human society in terms that people had to make for themselves was, in many ways, the largest legacy of the cosmological revolution of the seventeenth century.

Steven Weinberg: Finally, we come up to today. Of course, we can't look back at the present moment. So we shall hear from someone who I suppose could be called a historian of the present—a journalist. We scientists spent a fair amount of time talking to journalists, because they report what we do to the public, and without that our work would lose much of its relevance.

At the same time, we often suffer from this interaction, because, although the press has no particular bias for a closed universe or an open universe or for a lot of dark matter or less dark matter, they have a bias for the news they are reporting to be sensational. They would like to be reporting on great breakthroughs, whereas, in fact, as we know, scientific discoveries are very often just incremental improvements.

One of the journalists who is greatly respected by scientists for resisting this temptation toward sensationalism is Sharon Begley. She is the science editor at *Newsweek*. Reading her articles over the years, a few of which were based in part on conversations with me, I found that she provides a very sensible screen which keeps the hype (and I have to admit, sometimes this hype originates with the scientists themselves) from the public and gives scientific developments no more than their just importance. So I have come to admire her very much.

As I said, she is the science editor and a senior writer at *Newsweek*. She has been an adjunct professor of the Columbia School of Journalism, and she has written widely for many journals, including the *New York Times*, *National Wildlife*, *McCall's*, and *Family Circle*. We are very glad to welcome her here to Texas. Sharon Begley.

TODAY

SHARON BEGLEY

Thank you very much, and thank you for putting me on a panel that you've called "Who Cares?" Because whenever I go to my editor and say, they've discovered this or they've discovered that, that's the response I get. "Who cares? Why do we want to write about this?"

And by all rights, the general public, and hence the press, which considers itself the public's surrogate, should have no interest at all in the subject of cosmology. Often it's very hard to understand, an idea you might have come away with after this morning. They talk about quarks and anti-particles and the era of recombination and whether the universe was transparent and things like that. It's just not the kind of language that we ordinarily use day-to-day.

For another, whatever answers they come up with aren't directly relevant to anyone's daily life, and that's a question we writers always get, of what relevance is it. No one dies from it, and, as you also all know, we are prone to write about subjects that are going to threaten either us or the planet we live on. And if you are swayed by the news climate that started this summer, the practitioners of cosmology don't go leading police posses around the L.A. freeways in white Broncos, so why should we care about it at all?

But the subject does get a good deal of coverage in at least the major metropolitan newspapers and the newsweeklies, though hardly at all on TV, which, I guess, you can attribute to the difficulty of getting good footage of the Big Bang, although Dr. Geller's wonderful graphics would sort of belie that.

Why journalistic interest is so high tells a lot about journalism, I think, and its assumptions about whether the public cares, and maybe a little bit about cosmology also. So why do we care?

Even when the subject is as weighty as cosmology, you have to remember that the press is more and more in the business of entertainment. For all of its constitutional protections and self-importance, we seek to entertain. And, luckily for the practitioners of cosmology, cosmology is the Hollywood of science. You couldn't make up a lot of this stuff.

Look at the discovery of the three-degree background radiation thirty years ago that was alluded to this morning, which provided the first strong experimental proof of a Big Bang model. Arno Penzias and Robert Wilson at Bell Labs were preparing this big horn receiver—this was in Holmdel, New Jersey—so they could begin a program of radio astronomy. First they had to clear it of all the microwave interference. So they spent months scraping pigeon droppings off their microwave antenna. One of the astronomers here will have to explain why pigeon droppings cause microwave signals. But, anyway, apparently they do.

So they're scraping and scraping and scraping, but couldn't get rid of this annoying hiss. It turns out, of course, that the microwave hiss came not from what the pigeons had left behind, but what the Big Bang had. It was the radiation left over from the beginning of the universe. And they end up with a Nobel Prize. And I don't think there are too many other Nobels that started out with pigeon guano. But in cosmology, these things happen.

Also, cosmologists are forever inventing whole new concepts, strange objects and ideas to explain how the universe came to be. Black holes we've all heard of. Well, these are tame compared to some of the other things they've come up with. There are white holes. There are worm holes. An eminent physicist, one of the leaders in understanding and extending Einstein's general theory of relativity, came out with a book this summer that, among other things, spoke very seriously about time travel.

There are these things called cosmic strings, supposedly leftovers from the Big Bang, that supposedly acted as seeds to make galaxies form. Has anyone seen one of these? Of course not. But it's the closest you can get to science fiction in science journalism, so we write about it a lot.

Mark Twain described science as an endeavor in which "one gets such wholesome returns of conjecture out of such a trifling investment in fact," which, I think, describes modern cosmology to a tee.

When Professor Geller and her colleagues discover some huge structure out there, as one newspaper story put it, "it could not be explained by any existing theory." But that was true for about as long as it took for the ink to dry on that newsprint. Theorists hate a vacuum even more than nature does. So they rushed in to explain her great wall and the soap-bubble-like way that galaxies are scattered across the sky. They said primordial explosions blew out the galaxies, or the stuff called hot dark matter shepherded the primordial mass into these galaxies. Or, no; wait, it was cold dark matter or it was a mixture of hot and cold.

But of all the wonderful ideas that cosmology brings us, perhaps the best is the idea that our telescopes are time machines. This, again, was alluded to this morning, but wasn't made too much of. But the idea that when you look out at something far, far away, you are looking at something long ago I think has an amazing appeal to people. It's extremely counterintuitive and also sort of wonderful.

There's a long tradition in theoretical physics of doing back-of-the-envelope calculations and coming up with explanations for what experimentalists have found. The story is told of the eminent theoretician Arnold Sommerfeld, who lived from 1868 to 1954, and, for part of his life, in Munich. In those days, the trolleys were cooled by two fans set in the top of the cars. And as the trolley rolled along, air flow would turn the fans, pulling warm air out of the trolley so everybody would stay nice and comfortable.

One of Sommerfeld's students noticed that although the fans could turn either clockwise or counterclockwise, the two fans in any given car nearly always rotated in opposite directions. So he asks the great Sommerfeld, Why is this? This is easy to explain, he said. Air hits the fan at the front of the car first, giving it a random motion in one direction. But once the trolley begins to move, a vortex created by the first fan travels down the top of the car and sets the second fan moving in precisely the same direction. But, Professor, the student protested, what happens is in fact the opposite. The two fans nearly always rotate in different directions. Ah, ha, said Sommerfeld. But, of course, that is even easier to explain.

Among today's cosmologists, you have to wonder what the theoreticians would come up with if the observers had discovered not a great wall but a great star shape, and maybe not soap bubbles, but a great waterfall shape. I don't think they'd have trouble explaining any of these things. Anyway, this is entertainment.

More seriously, journalists and the people we write for have a soft spot for cosmology because the observations are forever pointing out how little we understand. Scientists, for all the ambivalence with which people treat their discoveries and inventions, are at least acknowledged to be pretty smart, and maybe too smart. Since the days when [Alexis] de Tocqueville was writing about the citizens of this new country, Americans have delighted in cutting icons down to size. And these brilliant people who speak in an arcane language that few people outside the field understand

and about abstruse concepts that seem divorced from everyday life are forever being humbled. Other people bring pretty pictures of galaxies and things, but I bring slides of newspaper headlines. "Where is the Rest of the Universe?" This is a story about the missing matter that we heard about this morning. "Physicist Aims to Create a Universe." Literally, one of the originators of the inflation theory of Genesis, now that he's done that, is holed up at MIT and trying to make more bubble universes pop out in the basement of MIT. But that's okay, because he has tenure so he can keep doing it.

This is from the *New York Times* of 1984. "Most of the Universe is Missing." Again, a very humbling idea. These smart people don't know where ninety or ninety-nine percent of the universe is. Always good when theorists are confounded.

"Massive Clusters of Galaxies Defy Concepts of the Universe. The Dark Side of the Cosmos." This is from *Time*. I thought I should, you know, give equal treatment here. As astronomers struggle to illuminate the nature of dark matter, a new report hints that as much as ninety-seven percent of the universe could be made of the mystery stuff.

"The Shadow Universe" is another dark matter story. Again, there's something out there, we have no idea where it is, what it's made of, and, in fact, until a few years ago, we didn't even know it was out there.

And "Heavens." This is *Newsweek*. That's the kind of headlines we do.

So we have the entertainment factor and we have the humbling factor for why readers like to read about cosmology and why journalists like to write about it.

Let me move on to a third reason. Since the title of your meeting is "The Controversial Cosmos," I'll tackle that one. It will come as no surprise to anyone who gets his or her news from anything other than *The Weekly Reader* that journalists are drawn to controversy like scientists to grants. If somebody says the Earth is round, then we find somebody who says it's flat. If somebody says that DNA evidence is the greatest thing since fingerprinting, we find people who say it's unreliable. And so on.

Well, when it comes to cosmology, we do not have to move a muscle to find controversy. "The Big Bang Never Happened." This is an idea that not gravity, as we heard about this morning, but electric currents gave structure to the universe.

"Novel Theory Challenges the Big Bang." This is another electromagnetism piece. This is another *New York Times* headline.

"Findings Indicate a Younger Universe." This, too, was alluded to this morning. We have the paradox that some of the oldest galaxies and stars seem to be sixteen billion years old. But some other observations, using the

Hubble constant, suggest a universe only eight billion or so years. So this is a problem.

"Jolt To a Vital Part of the Big Bang Theory." Always good to challenge convention.

"Nothing Fits the Theories Any More." Force astronomers to rethink the nature of the universe. I don't know why Steve said something about inflating things and making things more than they are.

But, anyway, "Recent Findings Appear to Challenge Some Basic Assumptions. Big Bang Bashers."

These go back to 1984. And it almost doesn't matter which particular experiment or whatever they're talking about. These things just get recycled and recycled. They're just endlessly entertaining.

"The Big Bang has Arrived" and "A New View of the Universe." This, again, is the universe is older than some thought.

"Big Bang Under Fire." I think you get the idea by now.

And this is a good one. "The Big Bang Theory May Be Shot." We are going to rewrite the history of the universe.

Lately, there's been a new wrinkle in cosmology's appeal—one that extends the ideas that Linda and Bruce were talking about. As scientific cosmology closes in on a complete theory of creation, one which requires only the laws of nature as researchers have discovered them and no divine creator, cosmology is beginning to offer a modern creation myth, myth not in the sense of fiction, but in the sense that Linda would use it, of a suitable, coherent story on which a culture can hang its understandings of its origins and evolution.

The speakers this morning described the current version of scientific cosmology. And what's amazing as, you know, you sort of go home and think about this, is that there is no appeal made, nor is one necessary, to any supernatural agency. The universe as we observe it, cosmologists believe, can be explained completely through the laws of nature. That is a pretty amazing thing, that the laws of physics are enough to create time and space, to cause there to exist something where before there was nothing.

This has proved fodder for many people's search for, or at least curiosity about, the sacred. There's this old notion in theology, more current in years past than today, but still it has some currency, called the God of the Gaps. This was the practice of appealing to a deity to explain that which science could not. The trouble was for people whose faith rested, at least in part, on this notion the gaps kept shrinking. Long ago, God was invoked to explain the creation of the Earth, but then smart planetary geologists came along and pretty much explained that. God was invoked to explain how life could have arisen from inanimate matter. But now the RNA biologists are pretty much plugging that gap. You get the idea. There are fewer and fewer things in the natural world that you have to invoke a deity to explain.

You can get the sense, as you listen to this, that cosmologists are closing what may be the final gap of all—how the cosmos came to be. And what we are left with is: the notion of God, however you define that concept, is the laws of physics. And if you accept that, there is the final unanswerable "why" to the beginning of the universe. There is a question beyond which science cannot go. If the universe exists, thanks to the laws of physics, then the question is: why are the laws what they are? Scientists are fond of saying they do not answer "why" questions, they answer only "how."

This sort of story addresses that. "Our Universe Created from Nothing. Forces that Predated the Cosmos May Have Let there be Light:" not an accidental allusion to scripture.

"The Handwriting of God." This comes from, again, the COBE results that we heard about this morning—the satellite that discovered these little temperature inhomogeneities in the universe that seemed to be relics from the Big Bang and may explain how structure came to be what it is. A physicist said this—"the handwriting of God." So we don't make it all up.

So, again, my last reason for why journalists and the public are intrigued by cosmology is that cosmology, more and more lately, is inspiring thoughts of the sacred or a deity. As an aside, I'll just mention that this is a fairly curious thing for journalism because if you were to think of the two subjects that American journalists know the least about, it's got to be science and religion. But somehow when the two converge, there's some synergy there or something and it has an unbeatable appeal.

As I said, cosmologists themselves more and more are appealing to religious terms and images. Stephen Hawking, the British cosmologist, in his best-selling book, *A Brief History of Time*, closed with the thought that one day we will truly know, as he put it, "the mind of God."

Leon Letterman, a Nobel Laureate in physics, who recently stepped down as director of the Firme National Accelerator Lab, named his book on particle physics, *The God Particle*.

And there is a lot of God talk swelling around last year's discovery of the inhomogeneities in the cosmic background radiation. These slight temperature differences in what was otherwise a perfectly smooth sea of the primordial background radiation—this was the same stuff that turned out not to be pigeon droppings—those inhomogeneities have been sought for years, and they're thought to bear on the question of how structure in the universe, the galaxies, formed billions of years ago.

"Holy Grail of the Cosmos." This was another COBE story. Again, it's not an accident that people are using religious metaphors and terminology.

"A Physicist Ponders God and Fame." That physicist is George Smoot, who was the principal investigator on the instrument that found the inhomogeneities.

Let me hold that one. I don't know how we existed before Nexus searches, but I just pulled out a few clips. One University of Chicago physicist, talking about the COBE discovery, said they found the Holy Grail of cosmology. Smoot himself said it was "like looking at the face of God."

One astronomer at Harvard, who is quite devout, a fundamentalist, talked about how billions of dollars a year for science is "not because we want Teflon frying pans or better golf clubs. It's because of people's basic wonder and desire to know where we stand in the universe."

A cosmologist at U.C. Santa Cruz talked about reading God's journal of the first day in those COBE results.

Let me just read you a little bit more. This was from an *Omni* magazine interview with George Smoot. He was asked why he invoked God—this face of God—because he caught a lot of flack for it among other scientists. And this was his answer. "I invoked God because it's a cultural icon people can understand. But there's something deeper. Talking about cosmology, you can't help making the connection to religion. In all regions, all cultures, there's always 'in the beginning.' Either you started from something or you didn't. I got letters from religious people. About half said, That's great, it's wonderful what you've done. The others said, You don't need those experiments. You should read the Bible and et cetera. You'll know the truth."

One last example. There was another all-sky plot that we heard about this morning. And as one writer described it, the galaxies looked like they're lined up along spokes. And he called it the "fingers-of-God" effect.

Now you could say that the researchers are invoking God only metaphorically. But I think there's something more substantive here than metaphor. Another important thread in cosmology today is the observation that the constants of nature, things like the strength of the gravitational force, or the likelihood that nuclei will fuse in stars like the Sun—all of these constants have to be incredibly fine-tuned in order for stars to be born, for planets to form, and for life to arise.

Several theologians have picked up on this. And they are arguing, as do some scientists, that the Big Bang can become, in a profound sense, consciousness—human consciousness. And, if this is so, if human life and consciousness is an inevitable outgrowth of the universe, then it makes the emergence of sentient, self-aware, self-reflecting life on this planet of enormous significance. There are too many coincidences for life to have happened by chance.

This is maybe a reaction against the four hundred years of the Copernican viewpoint. It's sort of comforting, after being told that we're just on this speck of dust in an insignificant solar system out in the boondocks of the galaxy and the cosmos. And people seem to be seizing on this. It somehow makes them feel part of something greater than themselves. And by people, I mean, to some extent, journalists. But we reflect only what people tell us.

You're beginning to see the emergence of several institutes of science and religion. There is one in Chicago. There's one in Berkeley. Many theology departments are looking at the connections between science and religion more and more.

Let me sum up. Journalists flatter themselves that they serve as mirrors of an age. Chalk it up to millenarianism or to the aging of baby boomers who've decided that there's more to life than material consumption, or even working in a soup kitchen. But, anyway, they seem to be seeking some sort of spiritual anchor. Whatever the reason, cosmology has become a new religion for some seekers, in that it addresses the same fundamental questions that ancient religions arose to address. And so it makes sense that of all the sciences, it does inspire a sense of awe and wonder that have to underlie any fundamental religious experience.

Finally, I'd like to leave you with the last thought that, although journalists have this rap that we only write about bad news, I think we also like cosmology because it is, at bottom, profoundly optimistic. Cosmology teaches that, thanks to the Doppler effect, if you drive fast enough toward a red light, it turns green. And it also offers the hope that, since the universe is expanding, one day there will be a parking space even in Manhattan.

Steven Weinberg: That was a wonderful session. There is time for questions and I see some people approaching the microphone. Let me make a comment and a question while they are in motion.

The comment is for Sharon Begley. The picture of chaotic inflation that I described this morning in a way makes it unnecessary to reach conclusions about the universe being carefully arranged to make it possible for us to be here. If there are many bangs going off all over the megauniverse, each bang with somewhat different rules we would call laws of nature, then, naturally, intelligent beings, when they finally turn to look at the sky and study the laws of nature, will find themselves in one of the bangs where the laws of nature are suitable for the appearance of life.

After all, it's not surprising that out of all the planets and moons in the solar system, we live on the only one on which we could live. In the same way, it may not require any unnaturalistic interpretation to explain why we live in a universe with laws of nature which allow us to live. I rush to answer this point because Vaclav Havel, the well-known Czech poet and statesman, gave a perfectly dreadful speech in Philadelphia last July, in which he pointed to the idea about the fine-tuning of the laws of nature as showing a rapprochement between science and a human-centered view of nature. Any such conclusion is quite premature.

There's a question. (I knew if I talked long enough there would be.) Please give your name for the record.

Charlotte Rhodes: Thank you, all three of you, for fine, illuminated, and interesting presentations. We surely do appreciate what you gave to us today. My question is for you, Dr. Hunt. It's just a small factual question, and I'm happy with approximations.

Most of the big theories that come along, like Copernicus's, are taken up really by a very small circle at first. For example, even thirty years after Galileo was under house arrest and published, Milton still used the Ptolemaic universe as the basis for *Paradise Lost* simply because of his lay audience. How long, approximately, did it take for the general laity like me to accept the idea of this really violent change in our way of thinking?

Bruce Hunt: That's much more difficult to establish than you might think.

Charlotte Rhodes: I said approximate.

Bruce Hunt: It's difficult to know what people who don't write down their beliefs think. But I think as far as we can tell, Copernicanism was widely accepted among generally educated folk in Europe, by the late 1600s, certainly by the time Newton was writing in the 1680s.

Charlotte Rhodes: Okay. So fifty years.

Bruce Hunt: Even earlier in the seventeenth century, it was an idea people had heard about and knew about, but perhaps didn't themselves literally accept. By the eighteenth century, you find very few educated people in northwestern Europe who continued to believe in an Earth-centered system.

The Roman Catholic church didn't remove Copernicus from the index until late in the eighteenth century and, in some regards, even into the nineteenth century. In many areas, including eastern Europe, Copernicanism met with quite a lot of resistance. But in, say, France and England, it was generally accepted by the late 1600s.

One thing I might add: I mentioned that Copernicus's own theory did not provide any great advantage in the accuracy of its predictions. Through the work of Kepler and his successors in the 1600s, however, the moving-Earth approach came to have a very substantial observational advantage over the old geocentric system.

Charlotte Rhodes: Thank you. Steven, thank you so much for putting together such a really fine program.

Steven Weinberg: I was just going to say I visited the University of Salamanca a few years ago, and I was told that until well into the eighteenth century, they were not allowed to teach Newtonian physics.

Amy Freeman Lee: Amy Freeman Lee from San Antonio. J. Robert Oppenheimer often referred to the fact that if one wanted to be whole, one had to be a combination of scientist and artist. So I particularly want to salute all the scientists today who quoted poetry. That, in my view, makes you not all wrong, anyway, at least if not all right.

I really have a two-part question. While we all, I'm sure, admire and respect knowledge and the pursuit thereof, and certainly understanding beyond that, if we're graced with long life and we look back on our own life, we see small patterns which we can recognize. But no individual ever lives long enough to see the whole, what I like to refer to as the divine blueprint. So my question is this. Do scientists, in your opinion, really believe that in the end you will know it all? And if so, part two, if you know it all, is the price too much, the price being to erase much of the magic and the mystery that makes life worthwhile?

Steven Weinberg: Okay. Since this is not a panel of professional astronomers, if I may I would like to modify your question slightly, and ask, do you think that science erased the mystery that makes life worthwhile?

Bruce Hunt: I'd divide that even more. I'm not convinced that it's the mystery that makes life worthwhile. I think there are a lot of things that make life worthwhile besides mystery. Steven has written a book on *Dreams of a Final Theory*, so I think he can talk more about what scientists believe about the possibility of a sort of final theory.

I don't think it is a necessary conclusion for scientists to draw that they're heading towards or converging on one final theory, though many take that view.

Steven Weinberg: Linda, what's your feeling about the relative merits of the Mayan view of the heavens and the modern view of the heavens? Or are they just two views that have to be taken each in its own terms and not compared?

Linda Schele: My own feeling is that it's like apples and oranges. If you want to evaluate whether one works better or not, then we could use the yardstick of survival. Right? The Maya made it through two thousand years without very much change, and we're still counting.

But the other thing that I think is important for all of us to think about here is science. In the last talk, science and religion came back together a little bit. But when you talk about world view, it is not a voluntary endeavor. This is the way in which we, as social beings, and people who belong to a particular cultural tradition, generate the way we understand the world. There is no voluntary, you know, I'll accept this or not accept it. And whether or not we as individuals accept it or not accept it, it still drives our world.

And I have a wonderful example of it. I don't see Carl Sagan here now. But all of you remember his series several years ago, "Cosmos," where he was trying to pull us into their revolution. And the line that he used on us over and over and over again to make us believers is, We are star stuff. Well, I watched "Babylon Five" last Saturday night, and the wise alien turned to the captain and said, "We are star stuff." That's the making of myth in world view. And it will happen whether we want it to or not.

Amy Freeman Lee: Thank you very much. Dr. Weinberg, since the title for the afternoon session is "The Impact of Cosmology on General Culture," I will stand on the definitive definition of poetry.

Steven Weinberg: Question? Margaret, do you have a question?

Margaret Geller: I'd like to make two very brief comments. One is a coincidence that I noticed. Orion, the central star in Orion's belt, is a star-forming region.

Linda Schele: Yes. And you do not know the warm feeling in the center of my heart that gives me. And even in terms of the theory of intelligence that just came up also, the myth of why human beings were created in the Maya mode, this is wonderful because human beings were generated by the living force of the universe in order to observe and acknowledge the wonder of the order that gave it existence in the first place. And if that's not what we're doing in this room . . .

Margaret Geller: I wanted to make one more brief comment about news in science and what's news and what isn't, and how we repeat stories to ourselves. In fact, we've been talking about dark matter all day. I just wanted to point out that this problem was discovered in 1933. It's not new. It's only changed its name recently from missing mass or missing light to dark matter. The change of the name makes us think we've been making progress.

Steven Weinberg: Carl, we're very rigid. You'll have to get up and come to the microphone and then say who you are. But I want you to know that while you were out of the room, someone said something nice about "Cosmos."

Carl Sagan: I'm extremely grateful. I wanted to ask two points for Professor Schele. I absolutely agree with you about cosmogonic and cosmological myths, serving useful social functions. It seems to me that the big difference between modern science and Mayan myth is that there is critical self-scrutiny in which people would ask, Why do you think that myth is true? Here is an alternative myth that explains the orientation of the Milky Way equally well. How do you know my myth isn't better than your myth?

To the best of my knowledge, that never happens in pre-scientific times. That's the absolute critical step to merely having something that makes us feel good and having something that actually corresponds to the world. Would you disagree with that?

Linda Schele: Yes. I would. I've had this argument many times. I think if you work internally with them and try not to set up a comparison which privileges my world view and puts theirs at a disadvantage, they do have trial and error. They do adjust world view. The difference is their trial and error of whether they—the tests that they place upon the model that they have made of the universe is at a much closer scale. It's whether the rain comes or not. It's whether the migrations of the birds operate. It's whether or not the universe responds in the way the model predicts.

Carl Sagan: I don't think it's a canoe. I think it's a jaguar.

Linda Schele: It is possible that they did that. Okay?

Carl Sagan: But there's no record of that.

Linda Schele: Well, the problem is, I have finally, after all of these years,

figured out how to describe what I do. I'm a paleontologist of the human mind. And as a paleontologist of the human mind, all I have left are the fossils in the ground. I do not have a core of human beings that I can go ask. So, like a guy who's working with the bones, trying to put the dinosaur back together, I've got to put together this entire mental construct of the world from essentially—and I don't even, like the dinosaur guys, I don't even have the full record, you know. It's where nature happens, you know, the accident of history happened to leave a record in the ground.
Carl Sagan: Well, as you know, many of us think you've done a fantastic job in the reconstruction. Different question. What we call the Big Dipper, the ancient British call Charles's Wagon, native Americans call the Big Bear, the Chinese had some wagon with bureaucrats on it. It's remarkable how many different cultures saw different things.

You just said that the Mayan Scorpio is a scorpion. That constellation doesn't, to my eye, look much like s scorpion. I wonder if this is a cultural diffusion with the West. And the only reason I think that is because of this weird fact that Teotihuacan is the city of the gods, "teo" is the Nahuatl word for god, and it's also the Indo-European "rout." Maybe just a wild coincidence. But what do you think about that?

Linda Schele: Okay. The problem of diffusion of language, as you know, is far more complex. One word doth not make a relationship. The word in English for a hole in the ground is "hole." And the word in Yucatec for a hole in the ground is "hol." But one word doesn't count. You've got to have systematic relationships, just like you do in science.

In fact, Scorpius—if you think about the places that I talked about in their cosmology myths, Orion, Gemini, the Big Dipper, and Scorpius, these are the brightest areas in the sky. These have the largest concentration of first-magnitude stars.

I went out to Utah when we started working on it and we got the connection to South America, realizing that I may be dealing here with a fundamental myth that came across the Bering Strait. So, depending on how the Bering Strait migrations come out in archaeology, we could be dealing from 10,000 years ago to 50,000 years ago in the migration of a myth that may have come across the Strait.

I had to find out if these are the important constellations, were the same 20,000 years ago? There's one planetarium in this country that can move the P stars, and that's Utah. At Provo, Utah, there is a planetarium that's run totally by computer, and it's not mechanical. I went out there, worked with them, they moved it back 15,000 years, and the only star in any of those constellations moved is one star in the tail of Scorpius that moved in a little bit and straightened out the tail, so it wasn't quite as curvy.

Which means that we've got minimum 15,000 years where the same patterns are essentially there for human beings to work with. Scorpius is Scorpius. All across the Middle East, it's a scorpion, and Europe, because we inherited the Middle Eastern system. I'm not sure what it is in China. Someone will know that. In the South Pacific, it's a great fishhook.

But all of it is based on that great curving shape that, when you are in the tropics, gets very high and dips to the horizon. And, if it is diffusion, it appears to be a diffusion that has to go back at least 15,000 years and is not within the historical period of human beings, say within the last 4,000 years.

Steven Weinberg: Question?

Jimmy Kessler: My name is Jimmy Kessler. I'm curious if, whichever of the three of you would like to comment to, that maybe what we are witnessing is the fact that there is so much scientific data, there is such a speed of communication, and, with all due respect to the scientists in the room, there is a certain degree of unintelligibleness to the data that's being handed to the public, that what we are witnessing is people returning once again to what they were capable of understanding, which were stories.

I sat mystified by the Mayan stories. I listened to what Professor Hunt had to say and heard a great deal more of the encounter of the human beings than some of the particulars of the dates and times—that is, the stories. And that, perhaps, the return to cosmology is an attempt by us mere mortals who are not scientists who may be perceived as the high priests of a certain jargon, to understand the world around us. And that, perhaps, what Dr. Sagan has done over the years to kind of bring it home is that step. But, so far, what's happened is that we're grasping, those of us out in the boondocks, are grasping for something to hold on to that science doesn't provide. Any general comment?

Steven Weinberg: I think this is probably a question for Sharon Begley.

Sharon Begley: I think there is a great deal to that. I mean, people take from science what they will to construct their myths, whatever they may be, which is why the essential scientific validity of what they take is almost not the point. I mean, Steve's pointing out that the chaotic inflation theory does not really say that we are special. People are going to filter that out.

I can just tell you from the letters we received after we did a story about science and the sacred, people are seizing on this. You know, whether it's scientifically justified or not, people are looking for some, not justification, connectedness; that "only connect" idea. And whether you take it from the idea that we are star stuff or we are an inevitable consequence of the forces that unleash the—whatever, I think that's very important. People are looking for myths by which to order their lives even today.

Steven Weinberg: I think there's a tendency which I see in many different directions, as for instance in the speech of Vaclav Havel that I mentioned, to try to get away from the old-fashioned question of whether some idea is true and ask instead, what affect does this have on our lives? This is a tendency about which I'm not entirely enthusiastic. Any more questions? Yes. Another question. Would you come up to the microphone and give your name please?

Unknown: I'm reminded by this thing, and also by your comment about truth and myths, that myths are only—someone used a wonderful word today, matrices. And they don't claim to be much more than a matrix, a way to look at something, a focus, a little checkmark. Nobody claims that the myth is true. What the myth looks at and analyzes is no more true than anybody would claim a corollary or an axiom in the Euclidean geometry was true. It's just a way to look at it. And we get to debunking like a twelve-year-old that realizes that mother is not exactly the all-knowing, all-providing person we hoped she might be.

Linda Schele: Can I make a comment on this?

Steven Weinberg: I wish you would, Linda.

Linda Schele: I'm sort of the only one in this room whose job it is to study human beings. That's what I do, right? I do it—well, okay. I'll let the historian in on this, right?

I study non-Western cultures, and I have a tremendous problem when I deal with them because of the way that we think about them—the way we think about the mythology and the stories of other people. And I'm not pleading here, or even advocating the replacement of science by storytelling, but what I want to say is that we should, if we can, stop dividing these things as if they're two utterly unrelated human endeavors.

I have a friend named Johannes Wolbert who has studied the Warao in the Orinoco Basin for fifty years. The Warao are what we would call a very primitive people who don't even make art. But they have the most stunningly complex cosmology that's based on the effects of the pharmacology of tobacco, and it's based upon animals and objects in their world. What Johannes has done, unlike most of the other ethnographers who work in the other worlds on the planet, is to go beyond the story, he doesn't stop with recording the story. He asks them, Can you show me? Can you take me to it? And almost always they can. They take him to a wasp nest or they take him to a bee or they take him to a tree or they take him to something in their world that these stories encode.

What I'm saying here to you is that human beings across the planet, not like us, we're colonialsts, right? Our ancestors have been here for no more, unless there's a native American in this room, have been here for only a couple of hundred years. People like the Warao have been living where they live for 10,000 to 20,000 years. And their myths and their stories encode what they have observed in their world.

If we go to them and we say, Well, gee, this is just a story, it's not worth much, it's fantasy, what we lose is we lose 10,000 to 20,000 years of human observation of how our world works. If we go there, instead, humbly and we turn our science to try and understand what natural phenomena those stories are encoding, we not only have before us the wealth of the tropical forest and the weather patterns of the Earth and all sorts of things we can't even begin to imagine.

And that's simply my plea—to separate off these two ways that human strategies, that human beings have evolved in social experience to deal with our natural world. If we choose one and reject the other, on either side, we lose enormous capacities that our species have spent tens of thousand of years constructing.

Steven Weinberg: Since our topic is "The Controversial Cosmos," I feel impelled to give an answer that I think is somewhat in the spirit of Carl Sagan's earlier remarks. It is, that if you want to know how to live in the Amazon jungle, then the Warao probably know much more than we do, and if you want to know about human emotions, then there may not be much to choose between them and us, but if you want to know what the Milky Way is, or how the Sun was formed, then they are wrong and we are right.

Linda Schele: Yes. But wait a minute. If you want to find the drug that's going to save your life from cancer, you better go ask the guy that's working in the forest.

Steven Weinberg: Absolutely. That was the point I was making. Okay. Is there another question? Well, I think we're well prepared then for the business meeting. And we'll take a short coffee break and come back here in about fifteen minutes.

ROUND TABLE DISCUSSION

Steven Weinberg: Linda, please come to the table. It turns out that Linda is the designated "et cetera" in the program. She's here to represent the non-physical scientists—I don't say non-scientists, because I think what she does is a science. She has assured me that she's in favor of generous funding for astronomy. Otherwise, I wouldn't have invited her to the table.

Well, as I was saying, none of the people at the table need an introduction, but one of them hasn't been introduced yet in this meeting, so I will introduce him now. Hans Mark holds the McKetta Centennial Chair in Engineering, and is a professor in the Department of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin. He also was a superb chancellor of the University of Texas system.

Hans has had many other positions of great responsibility. He was the secretary of the Air Force. And, what is more pertinent to this meeting, is that he was the deputy administrator of NASA and the director of the NASA-Ames Research Center. And so he has seen many of the things we were talking about in NASA from the inside. Also, although perhaps this is not the most important of his accomplishments, he and I were on the Berkeley faculty together years ago. Hans told me this morning that he has two minutes of remarks about yesterday's discussion. And then I'll ask if any of the other people at the front table have any short remarks and turn it over to the audience, because this is really your morning.

Hans Mark: I thought it would be worthwhile just to summarize a couple of things that were said yesterday. I hesitate to do this. The last time I talked to this group, it was about the SSC and we lost it shortly thereafter. And so I hope that nothing I say today has a similar effect.

I think, if you look at what was said yesterday, there were really two issues at the top. And let me summarize them. One was a discussion of the scientific mysteries that still remain with respect to the cosmos and cosmology, the origin of the universe. I think the problem of dark matter is, even though it's an old problem, probably the single most important one. Something is wrong there. And I would put that at a very high level of priority to find the answer to that, and I think that it's going to require a change in how we think about things.

The question of the age of the universe is a more recent thing, but I think there's also a problem there, and it may even be related to dark matter somehow. But the whole question of time scales and how this whole thing works is not, I think, clear.

A second question that came up is a political one, really, and that has to do with the funding for science—Big Science versus Little Science, all these things. I'd have to take issue with what Jim Gunn said yesterday about the funding for science. I am sorry he is no longer here. I don't think any society has ever funded science for its own sake.

If you look at the history of scientific academies, the first one was the Royal Society of London, and it very quickly evolved into an arm of the Royal Navy. The Greenwich Observatory was funded by the Royal Navy for three hundred years almost before the funding was changed, I think, a few years ago to something else. And so I think that the question of funding for science really depends on finding political imperatives that are compelling enough to justify the support of scientific research. And it was mentioned yesterday that we had the Cold War, and I think we need some new political imperatives that we ought to look at to continue to justify our funding for scientific research.

The last thing I want to say is a personal opinion. And, you know, my friend here, Carl Sagan, yesterday talked about the insignificance of the world and the cosmos. I don't agree with that.

Carl Sagan: I didn't say the cosmos was insignificant.

Hans Mark: No, no. But you said the world was insignificant within the cosmos. I think the fact that we occupy this world makes it important, and makes it the central issue. I can't listen to Linda, for example, without wondering about this miracle that we call the human mind and how it works. I disagree with the implication that because the Earth is a small dot in the vast sky it is not important. We really are very important. Human life is unique. So, with that, let me leave it.

Steven Weinberg: I think everyone would agree we're important. The question is important to whom?

Hans Mark: Ourselves.

Carl Sagan: Bacteria makes similar remarks.

Steven Weinberg: Carl, do you have any remarks that you'd like to make?

Carl Sagan: On the kind of apparent crisis in cosmology that we heard at least hinted at yesterday, this is not a crisis, but an opportunity. If the cosmological theories matched the observations within the probable errors, and everybody was happy, and then, through the advance of technology, along comes some new observations that absolutely don't match the theories, this is fantastic good news. I mean, the people who proposed the theories will be grumpy. That's just human nature. But, here is an opportunity to learn absolutely new and wonderful things.

It'll be a moment of turmoil where it'll look as if we're uprooted. We don't know what the answers are. And then the answers, if the history of science is any guide, the answers will come and people will say, oh, how could we have been so ignorant as we were in 1994 not to realize that. And then whatever the answers are, maybe it's prosaic as neutrinos having mass, maybe something much more interesting.

There have been many such crises in the history of cosmology. I'm old enough to remember the crisis of the mid-'40s in which the age of the Earth was older than the age of the cosmos. People understood that to be awkward. It even led to what is called the steady state cosmology, the idea that the universe had no beginning and no end and that matter was being spontaneously made out of nothing all the time on a very small scale. When you'd ask the steady staters, Where does this new matter come from?, they'd say, where did your Big Bang come from? But steady state turns out to be wrong. An error had been made, in fact, in the Hubble constant and also in the age of the Earth and the contradiction helped to spur both geochronology and cosmology.

I think part of the reason that there's a kind of glee in the press about this is because scientists might be wrong. And if scientists are wrong, then that justifies us for not understanding what they were saying in the first place. If it's all wrong, then it showed quite prudent judgment to not understand anything they were saying.

That, then, takes me to the second issue about science education, which was touched on briefly yesterday by Jim Gunn and others. For me, there are three or four reasons why science education is important. I'm not talking about the production of professional scientists. That will, I believe, always occur. I think everybody starts out as a natural-born scientist. Society then beats the science out of them, but a few are lucky enough to make it through and retain their initial enthusiasm—with scars.

No, the problem is to have a scientifically literate public. That's important for many reasons. One is the economy. Technological industries are moving out of the United States. By many standards, we're moving from a production to a service economy. All of this is connected with science and technology. Performance of U.S. kids on the standardized science tests with other countries is dreadful. Furniture factories can't hire apprentices because they can't measure, they can't do simple arithmetic, the apprentice journeymen. That is a serious aspect of science that touches on everyday life.

Secondly, there are major issues, for example, environmental issues. How are we to instruct our representatives in Congress? Should we ban CFCs? Should we encourage CFCs? Is global warming a hoax or is it a potential disaster? What about AIDS, the information superhighway? The list is as long as my arm.

If we don't understand those issues, how can we instruct our representatives? And if they don't understand those issues, how can they vote intelligently on this? We have arranged things so that we have a society based on science and technology and have worked it out that nobody understands science and technology. That's a prescription for catastrophe as clear as you can imagine. We might get away with it for a time, but eventually this mix of ignorance and power is going to blow up in our faces.

Third, every human culture, as Linda Schele reminded us yesterday, has tried to understand our circumstances in the cosmos, our significance, if any, our place in the universe, where we come from. There's no culture that hasn't made an attempt in myth, superstition, folklore, religion, to try to answer that question. They're very innovative and fascinating. My view is that almost none of them have come anywhere near the realities, neither in getting it right nor even in matching the reverence and awe that the universe truly elicits.

But, today, we are in a remarkable time where we really are beginning to get some of the answers. On all of these origins questions, from the human species, all the way up to the cosmos, every human being hungers for answers. That is a kind of service that science provides to inquisitive human beings.

The method of thinking that science involves is a delicate mix of openness to all ideas, no matter how bizarre, and rigorous skepticism. The things that the president of the Philosophical Society of Texas routinely worries about in his illuminations on quantum chromodynamics are impossibly counterintuitive. They simply don't correspond to common sense, but they do correspond to reality.

The openness to the most apparently bizarre ideas is an essential aspect of science. But, at the same time, there is an element of rigorous, critical scrutiny of all ideas, old and new. It's that delicate balance of openness and rigorous skepticism that propels science on its way. You can't get by with one or the other. You need both. I fear we do not see enough of that mixture in economics, in the way we organize our society, in politics, in religion. Science is a tried-and-true way of understanding things. I sure would like to see those general methods more generally applied.

Put those four reasons together and I think it's absolutely central that every citizen of the United States have some understanding of the results and methods of science. We are just amazingly far from that ideal.

The last thing Hans Mark said was that *we* make the Earth important. Well, you know, there're ten million species, and, if any of them could speak, I'm sure they would say the same thing about themselves. We could also say that about whatever particular ethnic or geographical group we belong to.

This is more the contortionist patting himself on the back rather than anything corresponding to reality. We desperately want to be important. If we want to be important, let's do something important. Let's not just say we're important because we were born on the Earth, or because we're humans, or because we have a particular degree of melanin, or we come from a particular country, or we have a particular amount of wealth. That doesn't make us important. Let's be important in how we cherish each other. Let's be important in how we make the world a safer place. Let's be important in how we make a planet worthy of our children and our grandchildren. Then we'd have a right to pat ourselves on the back.

Steven Weinberg: Linda, do you have any remarks that you'd like to make now?

Linda Schele: Yes. I find myself in a moment of extreme deja vu. Three years ago, I sat on a stage like this in Provo, Utah, with Jared Diamond on one side of me and about three ecologists and anthropologists on the other side of me who were sitting in front of an audience like this made up of Utah people instead of Texas people.

And Jared had been talking about the loss of all of the animal species after the Bering Strait migrations. And all of the people at the table were calling for rational response to ecology. And, once again, I found myself the odd man out. And I said, wait a minute. You can educate people all you want to. You can tell them what is the rational reaction. You can explain to them why this is for their better good. But until you change what's programmed up here, until you change world view, you're speaking to the walls. And it seems like to me that if we want to talk about science in the way that will affect society, we have to begin talking about it from that point of view, not just what we ought to do or what the science tells us we should do, but how it affects world view.

Now, in my defense of what these guys do, and I don't understand very much about what they say either. They speak a special language that is unintelligible to me and most of us in the room. But I pretty well trust them because they're my high priests, right? I was just talking to someone out in the hall yesterday about if you take the Mall, the Capitol of the United States and the Mall and NASA, as reflections that the American people have materialized in symbols to explain to the world who and what we are, if you go up to 1945, every building built in the mall, every building that this nation commissioned as a symbol to represent what we are, reflects the past. It is either Greece or it's Rome.

If you look at everything that we've built after 1945, we have built buildings that say we are modern, that say we lead technology, that say we are the heart of the world in the United States. That's what NASA was. NASA wasn't about pure science. NASA was about putting a man on the Moon, and being the first person to do it. It was a symbolic act.

Now, what Carl is calling for, and I'm sure that what Steve's going to call for, involves a symbolic act. Do we sit back away from the edge of what our species does, or do we place our nation on the edge? Now, to put our people on the edge, we can't have just high priests. We've got to have at least laymen in the audience that can understand the language the high priest is using. And if we want to compete with the Japanese and the Taiwanese and the Europeans, we're going to have to do it. I mean, it's not a question.

It's okay if we want to drop back off the edge and become a second or a third world nation. Within the next fifty years, unless we make the commitment to exactly what they're asking for in our own, you know—as a symbolic act of culture, the declaration of who and what we are as a people, we're going to become what Mexico and Guatemala are, period.

Carl Sagan: Mexico's getting better.

Linda Schele: Getting a little better.

Steven Weinberg: I agree with everything the three previous speakers have said, so I will pass on making any remarks of my own.

Carl Sagan: I have to pick up on "high priest." The analogy, Linda, I claim, fails. We're not high priests, medium priests, or low priests. We're not priests, because we welcome challenges to the doctrine. We give our highest awards to those who prove that what we believed was wrong. One of the reasons we venerate Einstein is because he disproved no less a figure than Newton. And there are all sorts of scientists today who are trying to disprove Einstein, unsuccessfully so far.

That's because we recognize human fallibility. We recognize the complexity of nature. We recognize how hard it is, even asymptotically to approach the external world. This, I claim, is the exact opposite of the attitude of high, low and medium priests who don't want any challenges to their doctrines, who say, "Believe or beat it." What do you say to that?

Linda Schele: I quote Peter Jennings. When all of us in this room have sat for thirty years and listened to pronouncements—now, I'm not talking about you, okay? There's a difference between the people who do the science and what happens to the science when it hits the media, and then when it hits us, which is people telling us, Well, don't do this because it's scientifically proven that this is going to hurt you. Or, don't do this because it's scientifically proven that it's going to help you, and five years later it gets reversed.

Now, we know why that happens. Look, I'm an archaeologist and I live in this teeny little insignificant world which doesn't get any funding at all. So my issues about funding are, you know, I'll do with $5,000 a year. I don't need the $500 million. But I live in a world which is—it's about as maximum state of fluxes it can be.

I'm one of five or six people in the world that is in the process of deciphering the Maya hieroglyphic writing system and who, you know, is trying to reconstruct the history. And I hear all the time from the archaeologists, Would you quit changing your mind? Would you just tell us what the truth is and stop? We can't. Every time there's a new text, it changes. It's like science.

Carl Sagan: It *is* science.

Linda Schele: Whenever a new piece of data comes in, you have to change the way you explain everything. You have to go back to the beginning.

Steven Weinberg: I'm going to exercise some prerogative here. This is fascinating, but there are a lot of people . . .

Linda Schele: It's not what you wanted.

Steven Weinberg: No, it's just what I wanted. But I wanted to involve the audience, too. And so I'm going to start calling on people in the audience now. The usual rules, please. Come up to the middle aisle and state your name and then ask your question.

Margaret Geller: Probably I'm not really a bona fide member of the audience, but for this morning's purposes I am. I'm Margaret Geller. I'd like to make a comment about science. The title of the symposium has been "The Controversial Cosmos" and I'd like to make a comment about this business of the age of the universe and the age of the objects in it, which, I think, has been vastly overblown by the press. I think the controversy has been vastly exaggerated here.

I have the misfortune of having read the scientific papers in detail. I'd like to comment on the fact that the apparent discrepancy is not a serious problem. And the reason it's not a serious problem is that the errors and the determination of both the ages of stars and of the expansion age of the universe are large. In particular, the Space Telescope result for the Hubble constant is exaggerated.

Steven Weinberg: You mean the accuracy is exaggerated?

Margaret Geller: And the reason it's exaggerated is that they are making the same mistake Hubble did when he discovered, but didn't discover, the Hubble law. Hubble discovered the Hubble law in a part of the universe where it doesn't apply.

Steven Weinberg: That's right.

Margaret Geller: One of the peculiarities of science is that many times people claim to know what the answer is. They fit the simplest model to their data and they get it sort of right. It turns out that we live on the edge of a vast cluster of galaxies, the Virgo Cluster. We're falling into it because there's a lot of mass in it. Our motion, relative to the center of this cluster, is not a simple cosmological flow. When we measure the motion of the center of the Virgo Cluster, we must understand the detailed dynamic of that cluster in order to get the Hubble constant. The Space Telescope measurements only reach Virgo. To obtain a reliable value for the age, we must reach far beyond Virgo to a scale larger than the largest patterns in the distribution of galaxies—however large they may be.

Steven Weinberg: I agree that the accuracy was tremendously exaggerated in the press.

Margaret Geller: Well, I would differ with you because there's a systematic problem. If you measure the Hubble constant, you have underestimated it.

Steven Weinberg: But it doesn't imply that the people who did the work didn't know about the problem you are quoting.

Margaret Geller: No, but they exaggerate the accuracy and don't point out the systematics.

Steven Weinberg: Well, I think what they did was to be very technical, and they published the result which was only one standard deviation accuracy.

That is, the thing has 63-percent chance of being right within the error that they chose. And that fact got lost in the press.

Margaret Geller: Well, I would differ with you because there's a systematic problem, which is that if you measure the Hubble constant, you have underestimated.

Steven Weinberg: But, they also went beyond the Virgo Cluster. We better not get further into this. Here we have a non-priest.

Chrys Dougherty: I'm glad you recognize it. Chrys Dougherty, Austin. I want to get back to the small boys' problem. I'd like to, and I may have missed it yesterday, an explanation of why there has to be, or is thought there has to be dark matter. Is it—and if it exists, why didn't we find it when we got beyond the atmosphere? Why is it thought that there's a necessity to have something like dark matter? Is it that because radio waves or light is transmitted only through matter? What am I missing? Point one.

Point two was suggested to me yesterday. Mr. Gunn said that there wasn't any center of the universe. And I wonder what happened at the Big Bang—that had to be a point in time, wherever that occurred. Didn't that have to be the original center? Child's question.

Carl Sagan: Let me try using a metaphor a little bit to answer these questions. First of all, dark matter, by its definition, isn't something you can see. But if it's there, it has to be discovered some way.

The Earth is dark matter in the sense that it is almost non-self-luminous. It shines if you're in the solar system by reflected light. If you're an immense distance away, you cannot see the Earth. It's too dim.

Now, by tracking the motion of stars and the rotation of galaxies, and the motion of galaxies in a cluster of galaxies, you can deduce the presence of matter that's holding things up or speeding things around. Then you see if there is enough matter that we've already inventoried to explain these motions. If the answer is no, you say there is some matter there that does not reveal itself by giving off light that I can see, but, nevertheless, is there. What kind of matter it is, there's no way to know from just those observations. So that's an incomplete answer to the first half of your question.

Second half of the question: Let me try, once again, with our balloon. But what you have to remember about the balloon is that the observers, you, let's say, and me, are absolutely flat. Not just thin in the vertical direction, but with no height whatever. We know about left-right. We know about forward-back. But up-down is gibberish to us. We don't know what it means. We can't point in that direction. Someone says, okay, here's forward-back, here's left-right. Now, point in the direction at right angles to those two. What are you talking about? You've lost your marbles. There isn't any direction at right angles. We're two-dimensional beings in a two-dimensional universe.

If you can imagine that, and I don't say it's easy, now imagine that, unbeknownst to you, you live on the surface of a three-dimensional sphere, a ball. Suppose someone, a balloon god, is blowing up the balloon. So the distance from each two-dimensional galaxy on the surface of the balloon to every other is increasing with time. Then you say, look, galaxies are getting further and further apart from each other. Backwards in time, they had to be closer and closer. There was a time when they were all together. Show me where that point is. Look, all the galaxies are running away from each other. There has to be some center to the universe that they're all fleeing from. Where is that center? Show it to me.

And now you, since you're really a three-dimensional being, can recognize that the center of that expansion is inaccessible to the universe of those two-dimensional beings, because it's in that third dimension, the radial direction at right angles to the surface of the sphere. It's not going to do any good to say, "Tell me where it is. Point to it." What are you talking about? It's in that inaccessible third dimension.

Now, up everything I've just said by one dimension and you have a flavor of the answer to your second question.

Steven Weinberg: I would add one remark that may help a little. I don't know if Carl said it, but the influence that the dark matter has on the stars and the galaxies and the clusters of galaxies is exerted of course through gravity. This matter is being detected through its gravitational effects. Everything is a source of gravity. You are, I am, the Earth is, the Sun is, and the dark matter is. But it's not detected yet through any other means.

And it isn't a matter of getting above the Earth. I mean, in fact, the dark matter is everywhere. It's above the Earth's atmosphere. It's also in this room. But it doesn't interact very strongly with anything. In fact, the jargon name for the most popular type of dark matter is WIMPS, which stands for Weakly Interacting Massive Particles. They are here, just like the neutrinos are here, in large numbers in this room. But they interact so weakly that we don't see them. But in vast numbers, in astronomical volumes, these particles produce a large gravitational field which we do detect through its effect on the motions of stars, et cetera. That's why we think there is dark matter, even though we haven't detected it directly.

With regard to the balloon, there's one further thing (which unfortunately won't help explain what is going on), and that is that many astronomers and physicists think that the balloon is probably infinite. If this is correct, then not only is there no center, there's also no circumference—the thing just goes on and on forever.

Carl Sagan: Not just that. There's an infinite number of balloons.

Steven Weinberg: Well, that's true according to the new idea of chaotic inflation. Another question.

Porter Story: Well, I'm Porter Story from Houston. And I guess the high priest analogy really comes home to me. I'm a physician, and physicians have had the same accusations of being sort of high priests. And we really thought we knew what we were doing, and things got higher and higher tech and more and more expensive, and now society's not nearly as willing to pay for intensive-care-unit-like medicine, at least as they used to be.

And I guess I'm kind of concerned about the survival of this species on this planet. I mean, we, in a sense, have adopted the scientific method that science is truth. And yet I look around and the rain forests are being cut down, the population's growing dramatically, half of black males between eighteen and twenty-four in prison, you get robbed if you walk up Capitol Street. I mean, there are a lot of problems here that the scientific method doesn't seem to be successfully addressing.

And I'm wondering how a further effort at clarifying some of the things that we've been talking about today, the dark matter, the age of the universe, is going to help with the survival of the species.

Carl Sagan: Science does not purport, for example, to be able to lay down codes of behavior. Conceivably it could tell you the consequences, or something of the consequences, of adopting this versus that moral code. But, science is about what is. You can't make an "ought" out of an "is." Something else has to come in to carry "is" to "ought." Traditionally religions have tried to do that. Where religions had a monopoly on the "is," then they had much greater authority on the "ought." But when religions turned out to be backing the wrong horse on the "is," then their authority, their moral authority on the "ought," started to decline.

This is part of the post-Newtonian complaint about the universe is collapsing all around us. There's no rudder to steer by. We had many poems yesterday of John Donne and others. You can see it also in Mathew Arnold's "Dover Beach" in which he mourns the absence of a time when we really knew what was true. What he's saying is, it didn't matter what was true. What matters is that we all thought it was true.

You referred to crime. It is very efficient to have a policeman inside of each of our heads, much better than to have a policeman on every corner. If there were a god who metes out punishment and reward, then there's a policeman working inside our heads. If the idea of that god is tied to us at the center of the universe and then the nation is undone, then that policeman is also, to some extent, undone. Then we have the kind of problems you're talking about.

While I am a very strong proponent of the magnificent subtlety, glory of the universe and its ability, as I said before, to elicit reverence and awe, that doesn't supply what the old religions do. It is emotionally unsatisfying to worship the Newtonian law of gravity. It is a force higher than ourselves. It permeates the universe. It makes solar systems and galaxies. But it is not a convenient object of prayer.

There are some things that humans need that science doesn't provide, although science certainly has relevant things to say about that. My personal view is that what we are lacking is a religion that provides the things you are missing, but is also honest and conforms to the universe of science. That religion has yet to come, in my view.

Hans Mark: Let me add something there. I have to change Carl's title. He's not a priest, he's not even a high priest, he's a Rabbi.

Carl Sagan: Rabbi only means teacher.

Hans Mark: That's exactly right. I'm glad you explained that. And that's the point. Look, I would respond as follows to your—it really wasn't a question. It was a comment. I really believe things are better than you imply. You know, the world is really not going to Hell in a handbasket. And I think that, to some extent, the things you quoted tend to be at the edge of where things are.

I was asked to make a commencement address at our College of Education a few years ago. To prepare, I looked up the numbers. The truth of the matter is that most people do graduate from high school. Most people do pretty well. And when I said these things, the audience got angry at me. Yet, the numbers tell you that and many people seem not to believe it.

So there's a disconnect, I think, between public impression and what is really happening. Take the "increasing" crime rate. Crime is being reported more often now than it used to be and more activities are now counted as "crimes." The "decline" of SAT scores is another example. More people are taking the SAT tests now than in the past. In the beginning (circa 1945) only ten percent of high school graduates took SAT tests. Today seventy-five to eighty percent take the tests. That is why SAT scores have declined. When the figure seventy-five percent or eighty percent of the people was reached back in 1970, the scores leveled off. Since then there has been little decline.

Please don't take what I think are edge phenomena and treat them as the average. They're not.

Roy Schwitters: Roy Schwitters, Austin. I think this question really is at the heart of the meeting. I must say I want to congratulate Steve and the panel and the speakers because I think you've really hit the issues of late-twentieth-century science, where we are in science.

First of all, the scientific questions are clearly exciting. Now, in my minute stage, have gone around and listened to other scientists outside of my field of physics to understand what's going on. I think the message is fairly clear that the questions are there, the mystery is there, the horizon of questions that we don't know the answers to is opening faster than our ability to answer those questions. And that's great. And Carl Sagan said it just right. You want controversy. You want noise and excitement. It's great.

What's the problem? The problem is just really, in some sense, what you just said, and I think what Linda said, is a world view now to take us into the twenty-first century of why should society support science. Fact is, there wasn't much, at least public-sector, support before World War II, and we rode a very exciting time up until about 1970, I think Gunn was right on that, of increasing money, increasing expectations, technologies, and so forth, and we're still seeing the fruits of that. It's tremendously exciting everywhere.

Money leveled off at about that point. And then what we've seen is another very positive development in the discussion of the telescope. In order to make progress, you need new instruments, and people have now banded together to collect the resources. To do that has many positive aspects and some negative that Gunn referred to of some of the other sociological aspects. But, by and large, it's been very positive.

However, you know, where do we go from here? Is it the role of government, of our society, to fund the future of the question of the cosmos and my area, particle physics? And we've clearly seen the past couple of years a very tough debate on that issue. My view is that we have to have the faith that more knowledge of these kinds of questions which seem so far removed from ordinary experience will, somehow, be good. Knowledge is power. Knowing more about our universe will help us as it clearly has in the past. But that's an act of faith in my view about the future of science, and I strongly believe it.

Now, where do we go? I think we do have problems now. I think there are problems within our communities. I just love the touches of this yesterday. But I think there are serious responsibilities of the scientific community that we need to act out and think out ourselves. And in my case and one of the things that is more sensitive, I think, in the collider issue, is responsibility of the scientist. I mean, we are taking public funds or other private funds. I think there is a real responsibility there, (a) to be accountable for those funds and (b) to do what Carl's done, to try every way we can to tell our supporters what we're doing and why it's important. I think that's very important.

And one can no longer hide behind, if you will, the shield of academic freedom. I think it just won't work. And I think it's wrong. And that's a tough sell within our community, and I think something's going to have to be argued out.

The larger question of society and what is the world view that will have society, frankly, fund these things, pay for them. They're damned expensive. We heard yesterday the statement from the woman from NASA that the country has drawn a line in the sand beyond which they're not willing to spend any more. I think that's a terrible tragedy. I think it's a problem that may be true right now, but that's an issue we've got to debate. Is that what our society wants to do, draw the line in the sand and say we can't afford to know any more? I'm very troubled by that.

My view, this is not big science versus small science. It's not a choice. You're trying to understand the world around you. In some cases, you don't have any options. It costs a lot of money, and this is what it's going to take.

Now, I completely agree with Hans's point, though, is that I do not believe, now, the way we're going in the Government, of pushing technology, of defining the roads of discovery. That's not going to fly either. You need to have a strong mission. We had a mission with NASA to put man in space. It had a lot of collateral benefit for science. We had a mission in atomic energy to protect the country. It had a lot of collateral benefits in high energy physics.

Where we go from here, I think, is not clear, and I think is very much the subject of society and, you know, this kind of organization. So I would like to hear more comments on that.

Steven Weinberg: I would say that there probably are people here today with us, members of the society and guests, who think that our society, which, for example, finds itself unable to fund drug rehabilitation centers for drug addicts who want to be rehabilitated, and misses out in many other ways in providing for various desperate needs, has no business putting money into learning the laws of nature and the secrets of the universe.

I don't feel that way, evidently, and I suspect those of us at this table don't feel that way. (I made Linda swear she didn't feel that way.) But, you know, we're very polite in Texas and especially in this Society, so there may be some in the room who do feel that way but don't want to get into an argument about it. I hope that if anyone in the room thinks we should not be spending the taxpayer's money on studying the universe, that they not be hesitant in standing up at the microphone and saying so.

Peggy Goldstein: Peggy Goldstein. This is a very small point, but I was thinking yesterday about Linda's canoe and the various things that were seen in similar ways by different societies, and the others that are seen in different ways by different societies. And I think there may be a comparison to the way everything is blowing apart in the universe, and also in our own little world.

But there are some things that are seen the same way. And Scorpius was one of the things that was mentioned. And I looked it up in Chinese. And in Chinese the character for "scorpion" is used for Scorpius. They put the character of the sky before it, and the character for place after it. And it just made me think a little bit about the way that things were coming together and couldn't they do it more.

Steven Weinberg: Do you want to respond to that?

Linda Schele: Yes. The point that I was trying to make is that when the Maya used their stories and their myths the way I talked yesterday, is they're like we are. They can't live in a universe, or couldn't live in a universe that was random. And one of the ways in which human beings orient themselves for what's around them is we find order. And there are lots of different ways which we have invented, around the world and throughout history, to encode that order so that we can transmit it to each other and find common ground to talk about.

Now, I wasn't attempting to say, at all, that the Maya had a greater truth or a lesser truth, but so much as a different truth. The difference that I see between what the Maya did and what these guys are doing is that I don't live in the Maya box, and you guys don't live in the Maya box. You live in their box. And it's their game that makes our world view now.

Now what's the huge difference, other than the differences and the methods of inquiry that we talk about when we talk about what science is. It's a special way of seeing that we invented in our own cultural past. It's distance. I mean, the Maya didn't even know what a light year was. These guys are talking about billions of light years. And so, what they have done is that they have changed the scale of our vision so enormously in the last hundred years that we can't find our—what Carl is telling us is that we are so teeny in the vastness of all of this that to think of ourselves as the center is an act of almost madness.

And that scale for us, as human beings, is terrifically difficult to deal with. And what's going on in this room and what's going on between physicists and astronomers and cosmologists and people like us all around the world is we're trying to forge a new way of understanding the world that will let us be comfortable and let their truths exist in one whole united world view. I don't know how long it's going to take us to do it, but that's the business that's going on in this room right now.

Carl Sagan: I entirely agree with what Linda just said. The idea that science is something invented recently, I think is clearly untrue. Some think that, let's say, the Greeks were the first to glimpse. There's a book by a man named Cromer in which this is argued. In *Cosmos*, I did argue that the Ionian intellectual revolution was the pathway to modern science.

But take a look at hunter-gatherers. Hunter-gatherers are what we humans were for 99.9 percent of our history—until the invention of civilization ten thousand years ago. There are a few, or were until recent, a few remaining hunter-gatherers moderately untouched by the corrupting world of scientific civilization. It was possible for anthropologists to live among them and to find out what they were like.

What I'm about to say is true of, as far as I know, of all hunter-gatherers, but my particular data comes from work on the !Kung San people in the Kalahari Desert in Botswana and Namibia. Richard Lee is my particular source on this. They are astonishing. Here they are. There's a group of five of them loping along at high speed with their bows and poison arrows, following a track. The track is now intercepted by another track which goes in a different direction.

They pause momentarily, take a brief glance, and agree among themselves on what animals made this new track, how many of them there were, ages, and in some cases, sexes of the animals, was anybody injured among them, how long ago they passed, how fast they are traveling, and whether it is possible for us to diverge from following this bunch to following this new bunch, whether we're more likely to catch up with the new bunch than the old bunch.

And they are perfect at it. What's more, they will recognize the footprints of individual members of their group. "Oh, look, Oley is here, but where is his grandson? He's not with him." Now how do they do it? You ask them and you find the following.

Hoofprints degrade with time. The walls slump in. Bits of detritis get blown in. And from the ratio of diameter to depth of the hoofprint, knowing the strength of the soil, which differs from place to place, and the humidity, you can make an accurate estimate of how old this crater is—this footprint is. I said crater because this is exactly what planetary scientists do with impact craters on other worlds. We date the craters, we determine how old they are. We date the craters in part by how degraded they are, having calibrated the rate of degradation.

What's more, the hunter-gatherers determine when the herd last passed by the fact that there is often a swerve from the linear direction in the vicinity of a stand of trees. Why is there such a swerve? Because in the scrub desert of the Kalahari, even a momentary respite in shadow is better than in sun. And so the herd make this deviation.

But now you can ask, When did this stand of trees cast a shadow into this place into which the herd swerved? That depends on the solar motion across the sky, which is different in different seasons. You have to have a kind of solar motion algorithm in your head to be able to make that calculation.

Well, all of this is science. And if you go and ask a hunter-gatherer, Where did you learn that, he doesn't say, I spent three weeks of apprenticeship just watching craters degrade. It's not like that. He says, I learned what my fathers did. But someone had to figure this out. That person was a scientist. Science goes all the way back. We are a scientific species, and the problem is that we are discouraged from pursuing our natural scientific inclinations by the imperfections of child-rearing and the schools and the media.

Hans Mark: Mr. Chairman, I wonder if I could respond to Roy Schwitters's question, because he did ask one which we kind of ignored. And that is, to bring us back to our current problem, what is it that justifies spending taxpayers' money or private funds on scientific research.

There is, of course, the desire to know. And I want to subtract that because that's always been with us, as Carl says, and I think that that will continue to be there. But the truth of the matter is that there is a utility to doing science which multiplies what the society is willing to spend on it.

The question is what is that utility. What are the reasons that we use to justify doing science? Carl mentioned yesterday that Napoleon and Laplace were friends. Actually, the reason why they were friends is that Napoleon started his career as an artillery officer. Laplace was very, very good at calculating ballistic trajectories, and he started an institute, in fact, to do that. The point I am making, of course, is that warfare has been something that has historically multiplied expenditures on science and technology.

I think there are other things that a modern society could systematically use to multiply spending on science and technology. And usually the most effective way to do that is to look at a crisis. Now, I spent sixteen years working in NASA. The first A in NASA stands for Aeronautics. One of the things that we spent a lot of research money on was aviation. The public generally does not hear much about this, but we spent about two billion dollars a year as taxpayers on aviation. This was concentrated particularly on aviation safety, how we regulate aviation to be safe. I can give you a hundred examples of fundamental stuff that came out of that, fundamental research in computer science and other things that were funded because of what was perceived by the public to be a problem, a societal problem: How do you make air travel safe?

I think there are a hundred other things like that. You mentioned the environmental problems. We are clearly funding things today to deal with environmental issues. We have a program here at the University of Texas at Austin to look at the weather pattern changes due to ocean currents and the behavior of oceans. This is a part of the global change question.

I think in terms of cosmology, NASA, for example, was tied to American foreign policy. Our foreign policy was to compete with something called the Soviet Union. And there was a perception in the late 1950s and the early 1960s that the Russians were ahead of us. And so we established NASA to get to the Moon, as somebody said, and to establish a competitive position with respect to the Soviet Union. That was, at the time, a compelling political reason to justify the scientific spin-offs from the lunar trip.

From my point of view, in terms of exploring the universe, I like to do it step by step. I think we need to go back to the Moon. I think one of these days we're going to go to Mars. Carl talked eloquently about the scientific reasons for doing that yesterday, namely, did life ever originate on Mars or not? But that question will not justify the expense to go there. And the question is what will? What is a political argument that you can make to go to Mars? Carl and I have for years argued and talked about this. I think one can make an argument that, today, the exploration of the solar system could be tied to a foreign policy. In addition to the other things we do, the application of some resources that we used to spend on competing with each other militarily could be spent on the cooperative exploration of the solar system. This would create jobs for Russian scientists with whom we used to compete.

President Bush almost said it in 1989 but not quite. I would guess, Roy, that if we do it right, one could establish an atmosphere, a political atmosphere where these arguments would be compelling. It doesn't exist now, but it might.

Steven Weinberg: Roy, do you want to respond? By the way, I should have said earlier that some of our earlier speakers, Tom Barnes and Bruce Hunt, are with us. And if any of the audience have questions that would be appropriately directed to them, we'd also welcome those questions. Roy?

Roy Schwitters: Well, I'd like to say that I agree with the thrust of your remarks. I think it's going to take a grand vision to do this. What I'm concerned about, you know, and I guess in looking at the history of the last fifty years, we have two of those basically—put man in space and protect ourselves from the Russians. Obviously, the second one, fortunately, is gone. We solved that problem, I think, in some sense.

And so, however, what we're seeing, of course, is, again, I think Jim Gunn was right on the money on this, of course, a lot of fifty-year-old institutions, a lot of fifty-year-old scientists, you know, looking ahead to the next fifteen years, that ain't a vision. We're seeing a lot of, again, great institutions and laboratories doing things at a different level, which seem to be policy of making the U.S. competitive, and so on. And I think we really have to analyze those things and ask ourselves honestly, Is this the right way for science to go. Because a lot of money is going there. And I think it's troublesome.

I tend to agree with you. I don't know if I would agree on the same grand vision, but I would like to hear if other people agree with that, because I personally think that's the way for us to, so to speak, spin off our science as we pursue this grander vision.

Carl Sagan: A couple of comments on the last two remarks. I would say that it wasn't two grand goals, put humans in space and beat the Russians. It was only one grand goal. Those two were the same. And it's not just beat the Russians. It's demonstrate rocket potency, because rockets carry nuclear weapons and they can be used to annihilate—it's not just a random choice of technology. It's the technology of death. It's intimidation in the public arena. Russians put up *Sputnik*. U.S. puts up *Explorer 1*. Gagarin, John Glenn. And so on. And it's much more impressive than just firing a dummy warhead into an exclusion zone in the Pacific Ocean.

Then the United States beats the Russians to the Moon. We win the race. We demonstrate rocket prowess. Shortly thereafter, the Apollo program ends. It ends because it has served its purpose. It has no continuing purpose.

The symbolic aspect of that for me is that the last human being to set foot on the Moon was the first scientist. As soon as the scientist gets there, clearly we're wasting our time.

The Apollo program was not about science. Although, as several people have said, piggyback, squeezing into the interstices, were all those glorious interplanetary robotic missions, the *Mariner*s and the *Viking*s and the *Voyager*s and all of that. We got something quite unexpected, and also we got that magnificent view of the Earth from the Moon on that same *Apollo 17* mission which awakened people's consciousness about the fragility of the Earth's environment.

Let's find something else like that, that's what Hans is saying, something else which has political uumph, but which scientists can use to do their science. Is this really proper? Is there something a little worrisome about this? It sounds as if, and I'm caricaturing what Hans said, but you do hear this from scientists, nothing matters except us getting supported. Let's find a reason, good, bad, or indifferent, and hitch our wagon to that star.

I think it should be the other way. What is in the interest of society? Science is one of many aspects of this society where things are lacking. And let us, from that point of view, see what ought to be done.

Now, the issue that Steve Weinberg raised before: People say, Look, we don't have enough money to help drug addicts who want to get off the drugs. What are you doing spending money in superconducting supercolliders? I think you do have to look at how money is spent on science compared to how much money is spent on other things.

The Department of Defense, in overt and covert expenditures, is well above $300 billion a year. I think it's a very fair question, Is that in the national interest? Is that the best expenditure of those funds in the time when the Soviet Union does not exist any more, and when there is no superpower on the horizon, when the U.S. is by far the most formidable force on the planet.

Why do people say we've got to take the money from science when there is this other behemoth that is just loaded with money that does not seem to have nearly as much national purpose any more, unless we're going to go around and intimidate and annihilate other nations? If that's not our goal, we can save a great deal of money.

Finally, on the question of going to Mars, yes, that is kind of a policy of the present administration. Let's cooperate in space with the Russians, and that keeps them from doing bad things. But why cooperate in space? Why not cooperate in building a superconducting supercollider or any one of a thousand other things that might be a lot cheaper down on Earth? What's special about space for that cooperative goal?

There are historical reasons. The exploration of the solar system can be very neatly done by robotic missions. We don't have to send humans. If it's science, if it's exploration we're talking about you don't need humans. If you want to justify it, there have to be other reasons. And, I agree with Hans, they are political or social or historical reasons. This issue is the focus of my latest book, *Pale Blue Dot*. Is there a legitimate justification for the long-term presence of humans in space?

Steven Weinberg: Available in bookstores presently. I would say, by the way, that the Republican contract with America calls for an increase in defense spending and a decrease in spending for the National Science Foundation. And if anyone in the audience would like to argue and defend that, I think it would make an interesting discussion.

T. R. Fehrenbach: T. R. Fehrenbach, San Antonio. I have a question, actually generic, for the whole panel. And if you'll forgive me for making one comment to show our archaeologist there is some support out here. For several years I headed the Texas State Archaeological Regulatory Agency, responsibility and protection of all public properties in the state, with a budget of less than $200,000. And the only way we bought a computer was that we had a boat, you know, for marine exploration, and we rented it to Texas A&M University. I think they had beer parties on it. And concealed it in our budget and bought a computer system.

But, anyway, my question is simply this. One of the really driving forces of the present age—you know, for the moment, we are past the mutual destruction, you know, the rockets poised and this thing—is, frankly, economics. You go into any government around the world and that's ninety percent of what they're talking about. Huge amounts of investment, you know, are flying around the world like rockets might have done.

And I wonder, going back to give you a historical analogy, you look at the exploration, and I know this is tortured, but you look at the exploration by Europeans of the world and the New World, even the Massachusetts Bay Colony was organized as an economic venture, you know, in England. We obscure that. We keep just thinking about the Puritans in this. The only one, I think, that was ever organized, like for refugees, was Maryland, and that didn't last long. Of course, Massachusetts Bay failed as an economic enterprise for the investors in England.

But what I'd like to ask, particularly our science physicists, archaeology, we just have a problem with economics and archaeology, but do you feel that there is any possibility in the age in which what seems to be happening, Hans, is this age you and I grew up and came through where you had the political thrust, you know what I mean, government political, you use political influence and you got the budgets. That seems to be ending.

Is there any push-pull thing where there can be an economical interest in space in which we can get like, you know—$40 billions go into mutual funds, you know, for this and that, if you watch the play, that we can get $40 billions into space. I believe in the space program, but I do not believe governments will continue to support this anything like we've had in the past.

Hans Mark: Ted, the current situation is that we spend about, loosely defined, $120 billion a year as a society on research and development. Of that, half is public money and the other half is private. The private $60 billion is justified economically. It is spent, in most cases, by profit-making enterprises and there is science there. No question about it. So the answer to your point that, can you use economics to justify spending on research, is, yes, we do. Of the public $60 billion spent on research, half is justified in terms of national defense. That is what Carl talked about.

Paul Woodruff: Paul Woodruff, Austin, Texas. My question has to do with education. I notice several people referred to defects in our science-education delivery system, so to speak. I'm not sure that there's a defect in education. I think that the problem is much deeper and cultural. There are plenty of scientists around. Plenty of money is being spent on science education.

But I notice, both in the students for whom I am responsible, who are very bright and have had all sorts of advantages for science education, a deep resistance to studying science. They don't feel that science is relevant to their lives. Even people who are going to be doctors and engineers are reluctant to accept our requirement to learn about general relativity. What does this have to do with me and what I'm going to do, they say.

And, at the same time, there's a deep reluctance on the part of the scientific community to step outside of their circle and teach real science to non-scientists. What is the reason for this partition in our cultural lives? I remember Linda Schele yesterday saying something quite nice about how the science of the Mayans really connected with their lives in a way that the science of our day doesn't seem to connect with the lives of our own students.

Even this great outpouring of poetic despair at the success of science has quieted. This was still being heard in the nineteenth century and perhaps early in the twentieth century. But in our own part of the twentieth century, you don't see poets worrying about what science is doing to the mysteries of the universe. It's no longer relevant in the way that it was.

What's the matter and what can be done about it?

Carl Sagan: Saturday morning television is replete with mad-scientist cartoons. What's that about? Why is that a mode of entertaining and instructing the young? What is it expressing? What's it responsive to? What are its consequences?

It's responsive, I believe, to widespread fears about science gone wrong. It comes from nuclear weapons, it comes from toxic waste, it comes from Agent Orange, it comes from global environmental issues where the scientists were late in recognizing that there was something to be worried about. People understand that science is a tool of formidable, maybe even awesome, powers, and that we don't really understand all we have to, to prudently and safely use it.

People are scared of scientists. That's surely part of the reason for the morally crippled scientists that you see in cartoons. And every now and then there's a scientist who comes along, Edward Teller, for example, who will confirm this kind of fear. That's part of the reason that people are worried about science.

Secondly, science is hard. It's quantitative. It involves, as I was saying before, counter-intuitive ideas. It's not true that anything you have to say is right, as is true in English classes. You can be dead wrong. There's such a thing as just completely wrong.

Then there is the fact that science and religion are perceived, whether correctly or not, as in some conflict. Certainly there are religious people of fundamentalist persuasion who are busy attacking science, certainly biology, evolution. These, I think, are some of the reasons for the disquiet about science.

Now, the issue of what do we do about it and who are the culprits, I quite agree with the implication in your question that the responsibility is very broad. Take a look at your local newspaper. Does it have a daily astrology column? I suspect the answer is yes. Does it have even a weekly science column? I suspect the answer is no. Who made this decision that daily portraying pseudo-science bunk, a hoax, without a disclaimer "for entertainment purposes only," that that's good, but even a weekly column on science, not technology, not medicine, science, that's bad? Who decided that?

When's the last time you heard an intelligent remark by a president of the United States about science? When's the last time that Sunday morning pundit shows—in which white, middle-aged, insiders agree with each other on every channel—when's the last time that they talked about science? When's the last show on television in which the hero was somebody dedicated to finding out how the universe works?

Why are school bond issues routinely voted down by voters? Why are there spiffy jackets with school letters on them given to those who make the varsity team in basketball, baseball, or football, but not those who are exceedingly good in science or history or mathematics? Who decided that that was the right way to invest jacket money or letter money?

Why is it that when Nobel Prizes are announced the networks can't spend five minutes per Nobel Prize to say what it was about? Instead, it's something like, "may some day lead to a cure for cancer. Today in Sarajevo . . ." What a wonderful news hook. Why don't they do it?

Here's the O. J. Simpson trial, which clearly is going to have a lot depending on DNA sequencing. Where is the network special on DNA sequencing? For that matter, where is the network special on television? Have we ever heard an hour-long program on how television works? Or James Clark Maxwell, because of whom we have television. Has anyone ever heard of him? Have the television networks acknowledged their patron saint? No.

Is anybody in the networks devoted to reading *Science* or *Nature* each week to see if there's anything newsworthy? None of this happens. Our society is decoupled in many significant ways from understanding science. It's not surprising that, when kids come to college, they are not primed to study science.

Steven Weinberg: We're already past the time at which the program called for an adjournment. So I'll take this last question and then I'll have a word and then we'll be adjourned.

Terry Hershey: All right. This kind of follows up on what Carl was saying and also a question I asked him yesterday. Terry Hershey, Houston.

Knowledge also lives in books in libraries. And I have a friend who was the lead investigator on the Condon Report, which was an investigation of UFO's commissioned by the Air Force some years ago. And he wrote a book about it, which is about to be published by France Vick next year.

When he started looking for copies of the Condon Report, and Dr. Condon was a noted physicist that I'm sure many of you know, and the result of all these investigations was a zero. I mean he said they didn't—wasn't saying there wasn't anything out there, but they were saying they didn't find anything. And so, therefore, it wasn't very sensational for a book, and so the book didn't get published.

But the Condon Report did. And when he started trying to find copies of the Condon Report a little later to check some things, he found that they had mysteriously disappeared from libraries. They had been "checked out and not returned." And when I mentioned that to Carl yesterday, you said, "Oh, well that is not unusual." What did you mean? Do you mean that somebody's out there filching scientific stuff out of libraries? I'm not saying that it's the UFO people that don't really want us to know they're around.

Carl Sagan: I wasn't saying that it was aliens stalking American libraries.

Terry Hershey: But are things disappearing from our libraries?

Carl Sagan: There are people who believe that the way to engage in substantive debate is simply to censor the arguments of the opponent. I know of cases where books on evolution have mysteriously disappeared. So there's only one side of the issue to read.

But it's much worse than that. Because, never mind people destroying books in book stores or in libraries, what is published is absurdly skewed towards pseudo-science and the fantastic. So, how many books are published on the lost continent of Atlantis and its crystals? Hundreds. How many books are published on the evidence that Atlantis is a complete fantasy? Plato passed on some legend from much earlier than his time, and people can't let go. There are almost no books published like that. Maybe Dorothy Vitaliano's *Legends of the Earth* has a chapter on it.

Likewise on UFOs. The ratio of the number of books that say we're being visited to the number of books that say this is ridiculous is a hundred to one. Go into a library and ask for a book on UFOs, you are a hundred times more likely to get a credulous, unskeptical, gullible, pandering book with no intellectual integrity than you are to get a book that critically assesses the evidence.

That's part of a much more serious problem in this country, it's the lack of skeptical and critical thinking.

Bill Gordon: Mr. Chairman, I know you don't want any more questions, but I would like to add a postscript. May I have your permission?

Steven Weinberg: Please. You have to give your name, though.

Bill Gordon: Well, I'm Bill Gordon, Houston. I would like to say that there are two very good reasons why you and the Philosophical Society and other taxpayers should invest in curiosity-driven research.

First, it's a good investment. The returns on your investment are something like thirty percent. That's hard to find in many places these days. A thirty-percent return is a good investment.

The second is that investing in curiosity-driven research makes jobs. It creates industries, and those industries create many jobs. Now there are a couple of problems in all of this. The first problem is that the utility of the curiosity-driven research can't be predicted. You simply have to accept the fact that you're making an investment in something that will produce a return. No one can tell you what the utility will be, but there will be one.

The second point in making jobs. We've heard a lot about the Mayan culture and what astronomy, cosmology had to say to those people, particularly with respect to farming, and what they could do with crops. There's a second aspect in astronomy that really hasn't been mentioned, and that has to do with navigation.

If you go back to the beginnings of time almost, people looked at the stars as a means of finding their way. What's going on today in navigation is that there's an enormous new industry developing around a piece of technology you can hold in your hand that's called GPS. It's a global positioning system. What it will do is tell you where you are on this Earth in latitude, longitude and elevation. And it will tell you that to about one hundred feet.

If you take the hand-held system that costs five hundred dollars, that's fine for your sailboat, it's good enough for navigating an airplane from Boston to New York, but it can be far better than that if you had two of those devices, one of which you knew the location precisely, and the second one, you can determine where you are to within about ten feet. And that's good enough to make a blind landing when you get to Washington, D.C., and be sure that you're on the right runway and at the right end of it.

Now, that comes from developments that no one thought about when developments were being worked out. The first has to do with making a good clock, because the navigation system that involves the GPS involves stars in the sky that are man-made. They're satellites. What those satellites do is broadcast the time and their position. And if you can tune into two or three or four of those satellites, you know exactly where you are to a matter of feet.

And that's a fallout from studies that have nothing to do with navigating airplanes, with navigating your automobile through the city, looking exactly where you are, your sailboat, your hunters, your hikers. Those things are all fallouts and those are creating an industry which will be billions of dollars. And I'm not trying to imitate Carl Sagan. Billions of dollars, in terms of income, in terms of jobs, and those are new fallouts.

Steven Weinberg: Amen to that. I agree.

Bill Gordon: It's a good investment. And it does create industries and jobs.

Steven Weinberg: Thank you for those good words. In closing, I'd like to repeat something I said at the business meeting yesterday. The members of the Society showed their good sense in not attending the business meeting in large numbers, so I think this bears repetition now. I want to express my thanks to the staff of the Philosophical Society, especially Colleen Kain and Ron Tyler, who, in order to make this meeting possible, did a million things that you can't even imagine. But it all worked, and I'm very grateful to them.

Bill Guest: Steve, Bill Guest. I just wanted to say we also want to thank you for an extremely well-run meeting.

Steven Weinberg: But don't go away yet, because I found in conversations with many of the speakers who came from out of town and some of the guests who came from out of town, that they felt very warmly received here, and that they enjoyed their interactions with the members of the Society—in some cases, perhaps, even more than they expected they would. So I'd like to thank the members of the Society and their guests for being so hospitable and friendly and interacting so well.

Finally, I'd like to end by going back to an issue that was raised yesterday, particularly by Amy Freeman Lee. There is something that is a little chilling about the science we do. It used to be that when we looked at the sky we saw things that cared about us, whether it was great canoes or maize gods or Orion, the great hunter, or, as the psalm says, that the heavens proclaim the glory of God. We saw in the sky evidence of a concern for human beings. Science has to some extent replaced this with a rather chilling view. The stars are balls of glowing gas and they exist in vast numbers, far more than you can see with the naked eye in our own galaxy, and then billions of galaxies beyond that. As Carl emphasized yesterday, this view of the universe does not give us a starring role. Some like Vaclav Havel respond to this aspect of the scientific worldview with a hostility to science. I found a very different and quite wonderful response in a poem (since we've all been reciting poems) by W. H. Auden, called "The More Loving One."

> . . . Looking up at the stars, I can tell quite well
> That for all they care I can go to Hell.
> But on Earth indifference is the least
> We have to dread from man or beast.
> How should we like it if the stars were to burn
> With a passion for us that we could not return.
> If equal affection cannot be
> Let the more loving one be me.

Thank you very much, and I will see you in Corpus Christi.

MEMORIALS

John R. Brown
1909–1993

John R. (Robert) Brown was one of the ablest judges in the federal judiciary. He was chief judge of the Fifth Circuit Court of Appeals. He was appointed to the court in 1955 and served as chief judge from 1967 to 1979. While on the court, he was the Fifth Circuit representative to the Judicial Conference of the United States from 1967 to 1979.

Judge Brown was a bright and witty man. He wrote many scholarly opinions, but his unique style always rendered them colorful and interesting. On suitable occasions, he wore colorful sports shirts to match his wit. He loved and related "Dear Abby" stories from the newspaper such as, "My boyfriend is chewing on my ear, what does it mean?"

Judge Brown was born in Funk, Nebraska, on December 10, 1909. He received a B.A. degree from the University of Nebraska in 1932 and LL.D.'s from the universities of Michigan (1932), Nebraska (1965), and Tulane (1979). He was admitted to the Texas Bar in 1932 and was a partner in Royston & Razor, Houston and Galveston from 1932 to 1955, specializing in admiralty law. He married Mary Lou Murray on May 30, 1936, and they had one son, John R. After her death in 1972, he married Vera Smith Riley on September 14, 1979.

Judge Brown served from Lieutenant to Major in the Transportation Corps, USAAF from 1942 to 1946. He was chairman of the Harris County Republican Committee from 1953 to 1958 and belonged to the Texas, Houston, and American Bar Associations, the American Judicature Society, and the American Law Institute. He was also a member of the Order of the Coif, Phi Delta Phi, and Sigma Chi. He was an elder in the Presbyterian Church, and a member of both the Houston Club and the Houston Country Club.

I had the privilege of being his guest at several meetings of the judges of the Fifth Circuit. When it met in Miami, we fished together in the Atlantic. He was a skilled fisherman and landed a fine sailfish, which, as a sportsman, he returned, alive and well, to the sea. I was glad he caught it instead of me, and enjoyed watching the size of the fish grow with each retelling of the story.

In addition to being a brilliant man, Judge Brown was thoughtful and sensitive to others, a person that I was glad to know and proud to have as a friend.

J.R.G.

Mary Joe Carroll
1914–1995

Mary Joe Durning Carroll, distinguished attorney and longtime member of the Society, died at Austin, Texas, on March 17, 1995.

Mary Joe Carroll faithfully served the Philosophical Society of Texas for over twenty years, joining in 1970 and holding the positions of secretary from 1971 to 1975 and treasurer from 1976 to 1987.

Mary Joe was born on June 25, 1914, in Wichita Falls, Texas, the daughter of Mary Douglas Durning and Joseph H. Durning, for whom she was named. At the age of two, Mary Joe's family moved to Sherman, Texas, where she became an avid participant in extracurricular activities and graduated second in her high school class. Her accomplishment as a debater, winning the Interscholastic League State Championship in Debate, earned her scholarships to attend the University of Texas and honed her skills as an advocate that would distinguish her later in life.

The recipient of both B.A. and M.A. degrees with honors, she began a long relationship with the University of Texas. It was there that she met her husband, H. Bailey Carroll, then an instructor in the Department of History. He became a Distinguished Professor of Texas History at the University and served there until his death in 1966. Professor Carroll served as executive director of the Texas State Historical Association, in which capacity he was managing editor of the original two-volume *Handbook of Texas*. Mary Joe was associate editor.

Becoming a lawyer had been Mary Joe's ambition since high school when she first read an account of Clarence Darrow's landmark defense of Darwin's theory of evolution. Mary Joe began the journey to realize her goal in 1944 by enrolling in one course at the University of Texas School of Law. She continued to take courses, usually managing one or two at a time around family duties, until 1955, when she was awarded the LL.B. degree.

Mary Joe ranked first among the applicants taking the June 1955 Bar Exam. Newspapers reported that she was the first woman to do so. Shortly thereafter, and just six days before her 41st birthday, Mary Joe began working with the Austin firm then known as Looney, Clark & Moorehead, where she would serve until her death.

Starting out in a unique way, Mary Joe began her practice of law as personal assistant to Judge Everett L. Looney, the firm's top attorney in both appellate and trial matters. Judge Looney was widely recognized for his abilities and had served as president of the State Bar of Texas.

Assisting Judge Looney in preparing to defend landowners involved in the veterans' land scandals, Mary Joe began her career poring over records in the General Land Office. She gained fame in Lubbock papers, first as a woman escorting the locked file cabinet, full of her research, into the courtroom, and second, as the woman who argued several points of law in front of the judge. Although the trial ended in a conviction for Judge Looney's client, Mary Joe produced a two-volume appeal, probably still the longest brief ever submitted to an appellate court, and helped to obtain a reversal in the Court of Criminal Appeals.

In 1961, Mary Joe served in the Texas Senate as parliamentarian for Lieutenant Governor Ben Ramsey. Her valuable experience with Ramsey led to Mary Joe's being selected to draft legislation of all kinds. Expertise in legislation caused Mary Joe to be employed to draft both the Open Meetings Act and the Open Records Act. These measures were sponsored by the Texas Press Association and the Texas Daily Newspaper Association, both of which procured her as general counsel.

Following her experience in the Texas Senate, Mary Joe received the task of writing an education code for the State of Texas. Though the code she drafted failed to pass at the last minute, her basic plan was used thereafter, and the format was duplicated in the measure which ultimately passed and became the first of the Texas Codes.

For many years, Mary Joe did the appellate work in the firm, most notably handling all appellate matters for the Trinity River Authority's acquisition of land for Lake Livingston and drafting briefs and appeals in cases before the Savings and Loan Administration. Over the course of her career, Mary Joe participated in many landmark decisions, such as *Myers v. Martinez* which ended county dominance by holding that there could be a wet city within a dry county.

The most constant aspect of Mary Joe's legal career was appellate briefing and arguing. Her proficiency in this area enabled her to serve her alma mater as a board member of the *Texas Law Review*. Her first solo court appearance was made in the Texas Supreme Court and she won her last two appeals, one shortly before her eightieth birthday and one right after.

Mary Joe disliked being called a "woman lawyer" and insisted that she was a woman who happened to be a lawyer. She never considered her sex relevant to her practice of law. In describing herself, though, she often said that she was born before women could vote; that she had a license to practice law before women could sit on a state court jury in Texas; and that she was a partner in a major law firm before women had any civil rights.

Mary Joe was an advocate par excellence and she loved the practice of law. She is survived by her son, J. Speed Carroll and her grandson, Charles Durning Carroll.

S.W.

John Bowden Connally Jr.
1917–1993

"HE LEFT HIS FOOTPRINTS ON THE HISTORY OF OUR GENERATION."

Three-term Governor of Texas. Secretary of the Treasury of the United States. Secretary of the Navy of the United States. U.S. Presidential Candidate. Confidant to five U.S. presidents. John Connally created a large part of the public and political history of his time.

John Connally was born in Floresville on February 27, 1917. He got his introduction to politics while attending and graduating from the University of Texas at Austin and the UT Law School. His first political campaign was the election of future Congressman Jake Pickle as UT student body president. The following year, Connally was elected president himself.

John Connally was always interested in theater. His contemporaries and colleagues on campus at the time included Zachary Scott and Eli Wallach. It was in his campus theater activities that John Connally met Idanell Brill. John and Nellie Connally married in 1940 and began one of the most remarkably productive partnerships in the history of Texas. Nellie Connally has her own indelible footprints on the pages of twentieth-century history. In 1937, John Connally assisted and participated in the election of Lyndon Johnson as congressman from Austin in a special election. That began an unparalleled relationship between perhaps the two most significant Texas political giants of the twentieth century. Connally worked for then Congressman Johnson in Washington in the late 1930s before returning to Austin to complete his law degree and begin to practice law.

World War II changed his plans. Connally volunteered for military service at the outset of the war and was commissioned an officer in the United States Navy. He served with honor, valor, and distinction until after the war had been concluded, receiving the Bronze Star and Legion of Merit.

Returning to Austin after the war, Connally organized and served as the initial president and general manager of Radio Station KVET. He managed Johnson's successful campaign for the United States Senate in 1948, and went (albeit briefly) to Washington in 1949 to organize Senator Johnson's office. He returned to Austin later that year to a private practice of law.

In 1952, Connally was hired by famed millionaire Sid W. Richardson to be his personal lawyer. He lived in Fort Worth and counseled Mr. Richardson and his nephew and business associate Perry Bass until 1960.

Always interested in and always active in politics, Connally managed Johnson's campaign for the Democratic nomination for president in 1960, urged him to accept the vice-presidential nomination on the ticket with John Kennedy, and then played a key leadership role in the Kennedy-Johnson presidential campaign in 1960. In 1961, President Kennedy appointed John Connally to serve as secretary of the navy. He resigned after a year to run for governor of Texas. John Connally took office for the first of his three terms as governor of Texas in January, 1963. On November 22, 1963, he was critically wounded by the assassin's bullets that killed President Kennedy as they rode together in the presidential limousine in Dallas. That tragedy in no way deterred John Connally from what became his lasting achievements as governor. Connally earned the reputation and the perpetual legacy of being the Education Governor of Texas. Long before the importance and benefits of an enhanced education system were perceived and understood in the public and political arenas, advancement of the quality of and access to education were the hallmarks of Governor Connally's administration. He set the tone on his first day in office when he said:

> The talisman of this new age is education. Throughout history, man has always searched for the uncommon ingredient or objective, whether it be new lands, gold and silver, or oil. Today, this uncommon ingredient is brain power, the coin of the realm of this new age.

While it would be impossible to chronicle all of the advancements in education initiated under Governor Connally, some stand out. Elementary and secondary education, after scrutiny by disinterested but committed civic and business leaders, was modernized. The curriculum was made more relevant, needed equipment and teaching tools were made available, teacher salaries were increased, and administration of public education was made more efficient and less burdensome.

It was in higher education, however, that John Connally's leadership had the most lasting impact. Probably the most notable accomplishment was broadening the public's understanding of the critical role higher education plays in our society. There were specifics which undergirded that new awareness. Following a year-long study by a blue ribbon committee of prominent citizens, the Texas Higher Education Coordinating Board was created to eliminate unnecessary duplication in public higher education and to permit an enhancement of quality. That concept was so well received that it was copied by other states. A state-operated student loan program funded by state bonds was created. That enormously successful program permitted literally tens of thousands of Texans to attend college. It has been the prototype of a program copied by other states. A master plan for higher education in Texas was developed. A formula funding-system to assure parity and equity of funding of all public higher education institutions was established.

Governor Connally placed special emphasis on our junior colleges or community colleges. For the first time, there was coordination of their role and an emphasis on quality and accessibility. Both through the community colleges and through separate programs, Governor Connally demanded that technical-vocational programs be expanded, modified, and upgraded to meet the job needs of Texas. He wanted to make certain that youths who did not get a four-year degree would be prepared for the job market.

Using abandoned military bases, Governor Connally established a central state-wide technical-vocational education facility. The Texas State Technical College System continues to be successfully operated and is the envy of other industrial states.

Faculty salaries in Texas went from being below national average to among the highest in the country. Libraries and research were satisfactorily funded for the first time.

With adequate funding, new loan programs, and perhaps the lowest tuition of any of the fifty states, Connally opened the doors of higher education for generations of young Texans. He also brought higher education to the population centers to make it more accessible. New senior colleges and new community colleges were created during his tenure.

John Connally had a vision for Texas and the country. He saw the need to enhance the quality and expand the accessibility of education in Texas. He had the drive and the ability to sell the state on his vision. He succeeded. No one has ever done more for any state.

When Connally voluntarily left the Governor's office at the end of his third term in 1969, he once again entered the private practice of law, this time as a senior partner with the Houston law firm of Vinson & Elkins.

In 1971, President Richard Nixon appointed him secretary of the treasury. Given the fact that a Republican president was appointing a renowned Democrat to one of the key Cabinet positions, the selection was a rarity in American politics. As secretary of the treasury, Connally played a major role both in the economic policy of the United States and in the determination of national fiscal and economic policies related to foreign allies and adversaries. He is generally regarded as one of the strongest and most effective Cabinet members in the history of this country.

Connally left the Treasury in 1972 to resume law practice. Under the appointment of President Nixon and the re-appointment of President Gerald Ford, he served on the Foreign Intelligence Advisory Board.

After joining the Republican Party in 1973, Connally became an active candidate in 1980 for his party's nomination for president. Although he did not secure the nomination, he shaped the debate and advanced the issues of the campaign. The word retirement never fit John Connally. After stepping down from an active law-firm law practice in 1985, be continued, until his death, to serve on public corporate boards and to take leadership in civic and human causes too numerous to recount.

John Connally died on June 15, 1993.

Few public leaders in the history of our country have demonstrated the adherence to conviction and belief that John Connally did. Few politicians have left our scene with the almost universal admiration that John Connally enjoyed. Few individuals have been on both the giving and receiving end of such a magnitude of affection and friendship as John Connally. John B. Connally was a human being nonpareil.

L.T.

Ezra William Doty
1907–1994

Texas lost one of its pioneer leaders in the arts and arts education when E. William Doty died on June 16, 1994. He had been a member of the Philosophical Society of Texas since 1952.

"Bill," as he was known to his friends and colleagues, founded the

University of Texas at Austin College of Fine Arts and served as its dean for thirty-four years beginning in 1938. Born in Grand Ledge, Michigan, he received bachelor's degrees in education and music and the M.A. and Ph.D. degrees in philosophy, all from the University of Michigan. He also pursued advanced study in organ, conducting, and philosophy in Paris, Salzburg, and Leipzig. He is survived by his wife of sixty years, Elinor. They were the parents of three children: Ruth Joan Doty, now Mrs. Allen Killam of Durham, North Carolina; William Wortley Doty of Colorado Springs, Colorado; and Martha Elinor Doty, now Mrs. Joe Freeman of Austin.

In 1938 Bill Doty was a 31-year-old assistant professor of music at the University of Michigan when a University of Texas faculty committee recommended his appointment as dean of the newly authorized College of Fine Arts, chairman of the new Department of Music, and professor of music. UT's interim president, John W. Calhoun, had been concerned about the relative youth of this appointee, but reckoned that the new dean "would soon overcome the liability of his youth." When he arrived in Austin in the spring of 1938, Bill faced a daunting challenge and a remarkable opportunity. He was asked to plan, organize, and implement a comprehensive College of Fine Arts at a university where formalized instruction in the fine and performing arts had not existed since the music department was eliminated by Governor Miriam ("Ma") Ferguson in April, 1925. There was no fine arts faculty; nor were there facilities in which to implement the new curricula in music, visual arts, and drama. But, responding to the opportunity and to his own vision, Bill began to assemble outstanding faculties in music, art, and drama; and, in 1942, a state-of-the-art music building, with offices for the College of Fine Arts, was dedicated.

Over the years of his deanship and in the years since, the correctness of his vision, and the artistic and academic soundness of the means by which that vision was carried out, have been manifest over and over. By the time of his retirement, the College had nationally ranked programs and faculties in all of its disciplines. And, because of the admirable way he originated and nurtured every aspect of the College, it now serves over 2,000 students who major in the arts while also providing instruction for many thousands of other students who seek simply to broaden their understanding of music, theatre, dance, or the visual arts.

Were the telling of Bill Doty's stewardship to higher education and the arts to stop there, the record would be a splendid one. But there is more to be said. He was a first class organist and recitalist, and the teacher of a number of organists who have achieved national prominence. Further, he was an active teacher of music theory and music literature in his own department, a lecturer in church music at the Episcopal Seminary of the

Southwest, and a teacher of aesthetics in UT's Department of Philosophy.

At the national level, he served from 1955 to 1958 as president of the National Association of Schools of Music, the organization that sets standards and determines accreditation in college and university music. He also organized the first national conference of fine arts deans, which led to the formation of the International Council of Fine Arts Deans. And such was his reputation as a leader in the arts that he was appointed executive director of the Office of Cultural Affairs of the City of New York in 1964–65 and took a leave of absence from the University to serve in that position.

In his educational philosophy, Bill urged, first and foremost, that the fine and performing arts had an essential role in the university. He believed that the arts should be analyzed and understood; but he also insisted that the university was a place where they should be created, performed, and enjoyed.

B.J.

J. Conrad Dunagan
1914–1995

John Conrad Dunagan, long a leader in regional and national business circles as well as educational and historical philanthropy, died on February 10, 1995. Born in Midland on December 31, 1914, Conrad, as he was known to his friends, spent his early childhood years on a Gains County ranch before moving to Midland in 1925. He graduated from Midland High School in 1931 and later attended the University of Texas at Austin. In 1933 he married Kathlyn Cosper, and the couple moved to Monahans.

From 1933 to 1983, Conrad worked as manager, partner, and, finally, president of the Monahans Coca-Cola Bottling Company (later Permian Coca-Cola Bottling Company). He was prominent in the bottling industry on the state and national levels, and wrote a history of the Texas soft drink industry for the forthcoming *New Handbook of Texas*. Conrad helped organize the First State Bank in Monahans, moving from assistant cashier in 1937 to chairman of the board in 1967. He was also a co-founder of Kermit State Bank in 1944 and remained active in both banks until his death. His other business interests included Midessa TV, Inc. (KMID-TV), of which he was president from 1954 to 1983; Texas Savings and Loan, which he headed from 1965 to 1982; and Southwest Canners of Portales, New Mexico, which he co-founded in the early 1970s.

Conrad seemed to be involved in every phase of civic, educational, and historical affairs in the state. He served as a member of the Monahans City Council in 1939 and the Texas Good Neighbor Commission from 1955 to 1961, was a charter member of the Monahans Rotary Club (receiving the Paul Harris Fellow Award from Rotary International in 1980), and was instrumental in the creation of the Monahans Sandhills State Park (serving as president of the park association from 1958 to 1961). The Monahans Chamber of Commerce named him as its Outstanding Citizen in 1964, and he was elected to the United States Jaycees' Hall of Leadership in 1983.

Conrad served on President Eisenshower's Council on Education. He played an important role in the formation of the University of Texas of the Permian Basin and, beginning in 1976, served on its development board. He founded the Permian Honor Scholarship Foundation that year, which has awarded more than 1,700 scholarships to area students, and endowed a professorship in regional and business history at UTPB. He served as a member of the Executive Committee of the University of Texas System Chancelor's Council and received the Distinguished Patron Award from UTPB in 1991.

I knew Conrad best as an avid local historian, writing extensively on Ward County and business history topics. He was an active member of the West Texas Historical Association, the Permian Historical Society, and the Texas State Historical Association, serving on the governing boards and as president of all three organizations. He was elected to the Permian Academy of History and as an honorary life member of the TSHA Executive Council. He also served on the board of the Historical Association of Ward County and supported the creation of the Million Barrell Museum in Monahans. He wrote a short biographical study of Eugene Holman, a Monahans native who became president of Standard Oil Company (New Jersey) and in whose restored childhood home the Million Barrell Museum is located.

Conrad received numerous other honors, such as the Southwest Conference of Foundations Founder Spirit Award in 1991 and the Community Statesman Award for Philanthropy from the Heritage of Odessa Foundation in 1994.

He is survived by his wife and by five children, ten grandchildren, four great grandchildren, his mother, and three sisters.

R.C.T.

Robert C. McGinnis
1918–1995

Bob McGinnis was born January 1, 1918, in Dallas to E. Karl and Helen Campbell McGinnis. He died at his home in Austin on February 22, 1995.

The E. Karl McGinnis family moved to Austin shortly after his birth. There he grew up, attending Wooldridge School and Austin High School with one year of study in France at the École Chateau de Bures. At the University of Texas in Austin Bob majored in business administration, was a member of the varsity tennis team, enjoyed the company of his Phi Delta Theta fraternity brothers and graduated Phi Beta Kappa in 1938. In 1941 he received his law degree from Yale Law School and practiced law briefly in Cleveland, Ohio, before our country entered World War II in 1941.

Upon joining the United States Navy Bob attended Officer's Candidate School at Dartmouth College in New Hampshire, was commissioned an ensign in Naval Intelligence and sent to Washington, D.C., for duty. In 1942 he was ordered to service in the Pacific at Noumea, New Caledonia, a French colony, where his proficiency in French served all well. Following a tour of duty in Guadalcanal he returned to the United States where he wooed and won Ethel Clift, to whom he was married in May of 1945. He was transferred to the Navy's Russian language school in Boulder, Colorado, where proximity to the Rocky Mountains made climbing an irresistible attraction when time permitted. At the end of World War II Bob resumed his career as a lawyer practicing for three years with the Dallas firm of Carrington, Gowan, Johnson and Walker and teaching law, part time, at the Southern Methodist University Law School.

In 1949 he and his family moved to Austin where he joined the law firm of Powell, Wirtz and Rauhut which subsequently became McGinnis, Lochridge & Kilgore. He was this firm's senior partner until his health required him to give up the profession and practice to which he gave so much.

He was an enormously capable and successful lawyer dealing with transactional matters, family-law matters, property disputes and many other areas of the law. However, his specialty became involvement in oil and gas disputes and representation of clients before the Texas Railroad Commission and the courts in various matters of a conservation nature. He truly became the dean of the lawyers engaged in that type of work. One of the more challenging and interesting matters was his representation of one of the world's largest oil companies in an arbitration involving the ownership of oil reserves under the North Slope of Alaska, this work being done chiefly at Seattle over a period of two or more years. He served on the Interstate Oil Compact Commission. He chaired the Texas Commission for Judicial Conduct. He was president of the Travis County Bar Association and chaired the Administrative Law Committee of the State Bar of Texas and its Section on Real Estate, Probate and Trust law.

His interest in the University of Texas never lessened. He was a member of the Chancellor's Council and the President's Associates there. As a member of the Philosophical Society of Texas, Town & Gown, and the Headliner's Club in Austin he enjoyed the fellowship with their members and participation in their programs.

Tennis was both his game and outlet and a source of great enjoyment for him and even more particularly for those with whom he played over the years. Travel abroad in later years became more frequent, although the demanding schedule of his law practice sometimes required cancellation of such trips. He was no ordinary tourist as he and Ethel picked unique places of the world to visit.

His was a distinguished career at the law made possible by his great legal ability, his determination, his willingness to work to reach satisfactory solutions, and by the respect which all of this earned him from his clients, his colleagues, the judges and examiners before whom he appeared, and his opponents. He had an uncanny sense of how present events and courses of action would affect outcomes and the future. Despite his superior intelligence, no one would find him to be intellectually impatient or overbearing.

Besides his wife of nearly fifty years, Bob is survived by his daughter, Mary Blair Moredock, and four sons, Edward Campbell McGinnis, John Montgomery McGinnis, Robert Clift McGinnis, and Michael J. McGinnis, and ten grandchildren.

Those of us who have known this gentle, kind, ethical, friendly, and modest man have been fortunate indeed.

L.L.

Ralph Spence
1919–1995

Tyler oilman Ralph Spence died June 24 leaving a remarkable record of service to Tyler, East Texas, and the entire state, exemplified by extensive involvement in the oil and gas industry, the Episcopal Church, education, and community development.

This eloquent and persuasive East Texan will long be remembered as a gallant leader, undaunted by challenges separating him from goals he deemed essential to the betterment of his fellow citizens. The beneficiaries of his extraordinary commitment and energy are his legacy to Texas and America.

Ralph Spence especially cherished his family, whom he loved and inspired. His partner in virtually every endeavor was Mary John Spence, his wife of 52° years.

Ralph Spence was born January 4, 1919, in Yorktown, Texas; however, he lived most of his life in Tyler, where he was buried in Rose Hill Cemetery. He received a bachelor of business administration degree from the University of Texas at Austin. This lifelong patriot served in the U.S. Navy during World War II, participating in the invasions of Normandy, Southern France, Okinawa, and the Philippines.

An independent oil operator, Ralph Spence made many contributions as an oil and gas industry leader, including service as vice president of the Independent Petroleum Association of America and as a member of its Executive Committee. He contributed to the discovery of several fields. He was the founder of the Tyler Petroleum Club. In recognition of his record of achievement, he was presented the Pioneer Award by the East Texas Association of Petroleum Landmen.

Ralph Spence was a devoted member of Christ Episcopal Church in Tyler, serving as senior warden, junior warden, vestryman, licensed lay reader under four bishops, and was named lifetime vestry member. He further served as principal presenter of the New Prayer Book of the Episcopal Church to the General Convention of the national church; was elected by the Diocese of Texas to serve as deputy or alternate to General Convention for thirty years; was elected by General Convention to the Executive Council of the National Episcopal Church; and was a member of the Executive Board of the Episcopal Diocese of Texas. He was a representative to Diocesan Council for 40 years.

Ralph Spence's support of education at all levels demonstrates his unwavering commitment to helping others.

He served as a member of the Texas Higher Education Coordinating Board, appointed by Governor Dolph Briscoe. At the time of his death, Ralph Spence was chairman of the development board of the University of Texas at Tyler. He was the only man to serve on five University of Texas development boards including: the University of Texas at Austin, the University of Texas at Tyler, the University of Texas Medical Branch at

Galveston, the College of Business Administration at the University of Texas at Austin, and the University of Texas Health Center at Tyler.

As chairman of the University of Texas Chancellor's Council he led a successful solicitation campaign for the acquisition of the Gutenberg Bible for the University.

He was named Distinguished Alumnus by the University of Texas Ex-Students' Association, as well as Distinguished Alumnus of the University of Texas College of Business Administration. Also, he was named "The Centennial Dad" by the University of Texas Dads' Association, was unanimously voted into the College of Business Administration Hall of Fame at the University of Texas at Austin, and received the Community Service Award as chairman of Earl Campbell Day in Tyler.

His support of education extended to many institutions. He was a president of the Robert E. Lee High School PTA in Tyler and was awarded life membership in the Texas Congress of PTA for service to youth. Also, he was presented with a Public Service Award from Texas College in Tyler. He initiated the Ralph Spence YMCA Leadership Award more than twenty years ago to honor students at ten East Texas middle schools. Along with Mrs. Spence, he received the Flame of Excellence Award from All Saints Episcopal School in Tyler. Ralph Spence shared his expertise in fundraising in many areas including the Tyler-Smith County Public Library. He originated the Eisenhower Golf Classic Society to help provide international scholarships for deserving students.

Among his numerous additional contributions to the community, he was director of the former Citizens First National Bank, a life member and chairman of the Salvation Army Board, president of the Texas Rose Festival and Order of the Rose, president of the East Texas Symphony Association, director of the East Texas Hospital Foundation, and member and vice-chairman of the Federal Bi-Racial Committee for twelve years. For his extensive record of professional and community service he was listed in *Men of Achievement in Texas*.

In addition to his wife, Mary John, survivors include one son and daughter-in-law, Ralph Spence Jr. and Tancy, Billings, Montana; two daughters and sons-in law, Louise and Guy Griffeth, Dallas; Judy and Charles Tate, Houston; two brothers and sisters-in law, Charles and Carolyn Spence, Raymondville; J. H. and Pat Spence, Tyler; nine grandchildren, Spence and Teal Griffeth, Benjamin, Nash, and Ralph Spence III, Mary John and Louise Frank, Carver and Jamie Tate; and several nieces and nephews.

H.B.

MARGARET LYNN BATTS TOBIN
1898–1989

Much of the nine decades that comprised the life span of Margaret Batts Tobin was devoted to giving. Her prodigious philanthropy encompassed everything from the gift of a heliport to Santa Rosa Hospital in memory of her husband to the underwriting of the Metropolitan Opera production of George Gershwin's *Porgy and Bess*. Her generosity was as expansive as her interests.

Born in Bastrop, Texas, she was the daughter of Robert Lynn Batts, University Law professor and judge of the Fifth U.S. Circuit Court of Appeals.

She attended the University of Texas where she later served on the Board of Regents of the University of Texas System.

In 1926, she married Edgar A. Tobin, a World War I flying ace, who founded Tobin-Surveys, Inc., engaged in worldwide petroleum exploration.

She sustained her passionate love of music throughout her life and manifested this feeling both nationally and internationally through her philanthropy. She not only became a founding member of the San Antonio Symphony in 1939 and its opera series in 1944 but also was a member of the Metropolitan Opera's Managing Board of Directors for twenty years.

For a quarter of a century, she served as regional chairman of the National Council of the Metropolitan Opera Association. In addition, she was a board member of the National Opera Institute, member of the national Advisory Board of The Sante Fe Opera and a member of the Houston Grand Opera Association. In summary, her life was one long song.

However, there were many other melodies in her own repertory. A major chorus was devoted to a life membership on the Board of Trustees of the McNay Art Museum beginning in 1953, a dozen years of which she served as its president.

Her life's composition was not devoted exclusively to the fine arts. Among her other memberships in local, regional and national organizations, she was a member of the Board of Trustees of Colonial Williamsburg, Inc., and the Garden Club of America. Such regional groups as the Southwest Conference of Foundations and Trusts and the Southwest Foundation for Research and Education counted her as a loyal member. Locally, she belonged to the Community Chest as a founding member, the American Red Cross of Bexar County, Santa Rosa Children's Hospital, Protestant Children's Home, German-English School, San Antonio

Conservation Society, Charity Ball, Chrysanthemum Ball Association, the Assembly, Junior League, San Antonio Country Club, the Argyle, Club Giraud, and St. Mark's Episcopal Church.

"Mag" Tobin was the recipient of numerous honors. In 1953, she was named Woman of the Year in Music by the San Antonio *Express-News*, and in 1974, she received the Diamond Jubilee Award of the National Jewish Hospital and Research Center in Denver, Colorado. The Conservation Society of San Antonio gave her its highest honor, the Amanda Cartwright Taylor Award, in 1985.

No portrait of Mrs. Tobin would be complete without the inclusion of animals, especially dogs and horses. She was an accomplished equestrian. In her own art collection, the work of Rosa Bonheur was a favorite.

She is survived by her son, Robert Lynn Batts Tobin, who is carrying on the family tradition of philanthropy *per se* and specifically of generous support of the arts.

Margaret Tobin was richly endowed in all aspects of life, and her life clearly records the fact that "to whom the most is given, the most is demanded." Her song was truly operatic.

A.F.L.

Gail Whitcomb
1907–1994

Gail Whitcomb was born October 29, 1907, in San Antonio, Texas, the son of Josephine Rowena Thompson and Gail Hiram Whitcomb, and died in Houston on April 7th, 1994.

In 1924 Gail graduated from Webster (Texas) High School. In 1931 he received both B.A. and LL.B. degrees from the University of Texas before moving to Houston where he lived and maintained a law office during the remainder of his life. In 1934, Gail married Geraldine Coad and they had two children. Less than a month before his death, the Whitcombs celebrated their sixtieth wedding anniversary.

The offices, appointments, and positions Gail held and the honors he received reflect the leadership he provided to his profession, to his city, to his state, and to his country. He served as a Director of the Houston Lighting and Power Co., the Continental Bank, Allied Bank, Houston First Savings Association, Houston First Financial Corporation and the Southland Life and Southland Financial Corporation of Dallas for over twenty-five years. He was also chairman of the board of the Federal Home Loan Bank, Ninth District, 1954–64.

Gail served as director of the Southwest Research Institute of San Antonio, a founding director of the Benjamin Franklin Savings and Loan Association, and a founding director of Channel 13 Television Station in Houston.

In 1961–62, he served as president of the Houston Rotary Club. In other years, he was chairman of the Houston Chapter of the American Red Cross, chairman of the board of the Houston Chamber of Commerce, president of the Houston Museum of Natural Science, president of the Houston Club, the Houston Committee on Foreign Relations, a member of the Board of Directors of the Salvation Army, the Houston Symphony Society, the Boy Scouts of America, and the Clear Creek Independent School District.

He organized and was chairman of the board of Community Effort, Inc., a Houston Cooperative Crime Prevention Program, 1966–1968. Earlier during the governorship of Allan Shivers, he was chairman of the Harris County Home Rule Committee for the study of local government coordination and consolidation.

Beginning in 1930, he devoted much interest and time to the cattle industry, and was president of the American Brahman Breeders Association, the Houston Farm and Ranch Club, and the Houston Live Stock and Rodeo.

His involvements also included the Museum of Medical Science of which he was a Founding Trustee.

In 1968, Gail was named the Rotary Distinguished Citizen, and received the Distinguished Alumnus Award of the University of Texas at Austin. In 1969, the Houston Board of Realtors honored him with the Key Houstonian of the Year.

His service to the University of Texas was unfailing: a director of the University Foundation, a member of the Executive Committee of the Chancellor's Council, a Life-Time Vice President of the U.T. Dad's Association, a Life Member of the Ex-Student Association. He also served on the Development Board of the University of Texas Health Science Center in Houston. His service to medicine included membership in the Board of Directors of Baylor College of Medicine.

He served as a member of Board #294 of the Selective Service System from 1966 to 1971, and in the 1950s was a campaign manager for Dwight Eisenhower.

His professional organizational memberships included the Houston Bar Association, the Texas State Bar Association, and the American Bar

Association. Club memberships included the Houston Club, Houston Petroleum Club, San Antonio Argyle Club, the St. Charles Bay Club of Rockport, and the Philosophical Society of Texas.

Gail Whitcomb is survived by his wife; his son, Thomas Leland Whitcomb; daughter, Jerianne Whitcomb Kolber and her husband, Otmar Kolber; and three grandsons, Gail Thomas "Ty" Whitcomb, Mark Whitcomb Kolber, and Briton Leland Kolber. He is also survived by a niece and her family, and by a host of friends and admirers.

W.D.S.

OFFICERS OF THE SOCIETY

For the Year 1995

President
WILLIAM H. CROOK

First Vice-President
CHARLES C. SPRAGUE

Second Vice-President
JACK S. BLANTON

Secretary
RON TYLER

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WILLIAM C. LEVIN
J. CHRYS DOUGHERTY
JOHN CLIFTON CALDWELL
ELSPETH ROSTOW

PAST PRESIDENTS

*Mirabeau Buonaparte Lamar	1837–59
*Ira Kendrick Stephens	1936
*Charles Shirley Potts	1937
*Edgar Odell Lovett	1938
*George Bannerman Dealey	1939
*George Waverley Briggs	1940
*William James	1941
*George Alfred Hill Jr.	1942
*Edward Henry Cary	1943
*Edward Randall	1944
*Umphrey Lee	1944
*Eugene Perry Locke	1945
*Louis Herman Hubbard	1946
*Pat Ireland Nixon	1947
*Ima Hogg	1948
*Albert Perley Brogan	1949
*William Lockhart Clayton	1950
*A. Frank Smith	1951
*Ernest Lynn Kurth	1952
*Dudley Kezer Woodward Jr.	1953
*Burke Baker	1954
*Jesse Andrews	1955
*James Pinckney Hart	1956
*Robert Gerald Storey	1957
*Lewis Randolph Bryan Jr.	1958
*W. St. John Garwood	1959
George Crews McGhee	1960
*Harry Hunt Ransom	1961
*Eugene Benjamin Germany	1962
*Rupert Norval Richardson	1963
*Mrs. George Alfred Hill Jr.	1964
*Edward Randall Jr.	1965
*McGruder Ellis Sadler	1966
*William Alexander Kirkland	1967
*Richard Tudor Fleming	1968
*Herbert Pickens Gambrell	1969
*Harris Leon Kempner	1970
*Carey Croneis	1971
*Willis McDonald Tate	1972

*Dillon Anderson 1973
*Logan Wilson 1974
*Edward Clark 1975
Thomas Hart Law 1976
*Truman G. Blocker Jr. 1977
Frank E. Vandiver 1978
*Price Daniel 1979
Durwood Fleming 1980
Charles A. LeMaistre 1981
*Abner V. McCall 1982
*Leon Jaworski 1983
Wayne H. Holtzman 1983
Jenkins Garrett 1984
Joe R. Greenhill 1985
William Pettus Hobby 1986
Elspeth Rostow 1987
John Clifton Caldwell 1988
J. Chrys Dougherty 1989
*Frank McReynolds Wozencraft 1990
William C. Levin 1991
William D. Seybold 1992
Robert Krueger 1993
Steven Weinberg 1994
William H. Crook 1995

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*Deceased

MEETINGS OF THE PHILOSOPHICAL SOCIETY OF TEXAS

December 5, 1837	Founded at Houston
January 29, 1839	Austin
January 18, 1936	Chartered
December 5, 1936	Reorganizational meeting - Dallas
January 29, 1937	Meeting and inaugural banquet - Dallas
December 4, 1937	Liendo and Houston
1938	Dallas
1939	Dallas
1940	San Antonio
1941	Austin
1942	Dallas
1943	Dallas
1944	Dallas
1945	Dallas
1946	Dallas
1947	San Antonio
1948	Houston
1949	Austin
1950	Houston
1951	Lufkin
1952	College Station
1953	Dallas
1954	Austin
1955	Nacogdoches
1956	Austin
1957	Dallas
1958	Austin
1959	San Antonio
1960	Fort Clark
1961	Salado
1962	Salado
1963	Nacogdoches
1964	Austin
1965	Salado
1966	Salado
1967	Arlington
1968	San Antonio
1969	Salado
1970	Salado
1971	Nacogdoches
1972	Dallas
1973	Austin (Lakeway Inn)
1974	Austin
1975	Fort Worth
1976	San Antonio
1977	Galveston
1978	Houston
1979	Austin
1980	San Antonio
1981	Dallas
1982	Galveston
1983	Fort Worth
1984	Houston
1985	College Station
1986	Austin
1987	Kerrville
1988	Dallas
1989	San Antonio
1990	Houston
1991	Galveston
1992	Dallas
1993	Laredo
1994	Austin
1995	Corpus Christi
1996	Dallas

MEMBERS OF THE SOCIETY

(As of August, 1995)

(name of spouse appears in parentheses)

Adkisson, Perry L. (Frances), chancellor, Texas A&M University System, distinguished professor of entomology, Texas A&M University .... *College Station*

Allbritton, Joe Lewis (Barbara), lawyer; board chairman, Riggs National Corporation .... *Houston*

Anderson, Thomas D. (Helen), lawyer .... *Houston*

Armstrong, Anne Legendre (Mrs. Tobin), former U.S. ambassador to Great Britain .... *Armstrong*

Arnold, Daniel C. (Beverly), director Farm & Home Financial Corporation .... *Houston*

Ashby, Lynn Cox (Dorothy), former editor editorial page *Houston Post*; member, Houston Philosophical Society and Houston Economic Development Council; author .... *Houston*

Ashworth, Kenneth H., commissioner of higher education, Texas College and University System .... *Austin*

Atlas, Morris (Rita), lawyer, senior partner, Atlas and Hall .... *McAllen*

Baker, James Addison, III (Susan), U.S. secretary of state; former U.S. secretary of the treasury; White House chief of staff .... *Houston* and *Washington, D.C.*

Baker, Rex. G., Jr., lawyer .... *Houston*

Barrow, Thomas D. (Janice), vice-chairman, Standard Oil Company (Ohio) .... *Houston*

Barton, Derek Harold Richard (Christiane), professor of chemistry, Texas A&M University; Nobel Prize in chemistry .... *College Station*

Bash, Frank (Susan), director, McDonald Observatory, The University of Texas at Austin .... *Austin*

Bass, George Fletcher (Ann), scientific director, Institute of Nautical Archaeology, Texas A&M University .... *College Station*

Bell, Henry M., Jr. (Nell), senior chairman of the board, First City Texas, Tyler N.A.; chairman of the board, East Texas Medical Center Foundation .... *Tyler*

Bell, Paul Gervais (Sue), president, Bell Construction Company; president, San Jacinto Museum of History .... *Houston*

Bentsen, Lloyd, (Beryl Ann; "B.A."), United States senator .... *Houston* and *Washington, D.C.*

Berdahl, Robert (Margaret), president, The University of Texas at Austin; author; historian. .... *Austin*

Blanton, Jack S. (Laura Lee), president, Scurlock Oil Company .... *Houston*

Bobbitt, Philip C., professor of law, The University of Texas at Austin; author .... *Austin*

Bolton, Frank C., Jr., lawyer; former head of legal department of Mobil Oil Company .... *Houston*

Bonjean, Charles M., professor of Sociology and director of the Hogg Foundation for Mental Health, The University of Texas at Austin .... *Austin*

Bowen, Ray M., president, Texas A&M University .... *College Station*

Brandt, Edward N., Jr. (Patricia), physician—medical educator; executive dean, Oklahoma City Campus—Health Sciences Center, University of Oklahoma .... *Oklahoma City, OK*

Brinkerhoff, Ann Barber, chair, UTMB Centennial Commission .... *Houston*

Bryan, J. P., Jr. (Mary Jon), president, Schroeder Torch; former president, Texas State Historical Association .... *Houston*

Bush, George (Barbara), president of the United States; former director, Central Intelligence Agency; former ambassador to United Nations; former congressman .... *Houston* and *Washington, D.C.*

BUTT, CHARLES C., chairman of the board and president, H.E. Butt Grocery Company ..... *San Antonio*

CALDWELL, JOHN CLIFTON (SHIRLEY), rancher; former chairman, Texas Historical Commission; director, Texas Historical Foundation ..... *Albany*

CALGAARD, RONALD KEITH (GENIE), president of Trinity University ..... *San Antonio*

CARMACK, GEORGE (BONNIE), former editor, Houston *Press*, *Albuquerque Tribune and Travel*, and editorial writer San Antonio *Express-News* ..... *San Antonio*

CARPENTER, ELIZABETH "LIZ," former assistant secretary of education, Washington correspondent, White House press secretary; consultant, LBJ Library; author ..... *Austin*

CARSON, RONALD (UTA), Harris L. Kempner Professor in the Humanities in Medicine and Director of the Institute for Medical Humanities, University of Texas Medical Branch at Galveston ..... *Galveston*

CASEY, ALBERT V., former United States postmaster general; chairman and C.E.O., AMR Corp. and American Airlines, Inc.; director, Colgate-Palmolive Co. ..... *Dallas*

CAVAZOS, LAURO F. (PEGGY ANN), former secretary of education; former president, Texas Tech University and Texas Tech University Health Sciences Center ..... *Washington, D.C.*

CHRISTIAN, GEORGE (JO ANN), writer and political consultant; former press secretary and special assistant to President Lyndon B. Johnson ..... *Austin*

CIGARROA, JOAQUIN G., JR. (BARBARA), physician, internal medicine and cardiology ..... *Laredo*

CISNEROS, HENRY G. (MARY ALICE), former mayor, San Antonio, faculty member, Trinity University ..... *San Antonio*

CLEMENTS, WILLIAM P., JR. (RITA), former governor of Texas; former chairman, SEDCO, Inc.; former deputy secretary of defense ..... *Dallas*

CONGER, ROGER N. (LACY ROSE), retired executive; former mayor of Waco; former president, Texas State Historical Association ..... *Waco*

COOK, C. W. W. (FRANCES), company director, former chairman, General Foods Corp. ..... *Austin*

COUSINS, MARGARET, writer and editor ..... *San Antonio*

CRAVEN, JUDITH LYNN BERWICK (MORITZ), professor of public health administration, University of Texas Health Science Center, Houston; Director of Public Health, Houston ..... *Houston*

CRIM, WILLIAM ROBERT (MARGARET), investments ..... *Kilgore*

CROOK, MARY ELIZABETH (MARC LEWIS), author; member, Texas Institute of Letters ..... *Austin*

CROOK, WILLIAM HERBERT, former U.S. ambassador to Australia; former president San Marcos Academy; commissioner, U.S.-Mexican Border Development ..... *San Marcos*

CUNNINGHAM, WILLIAM H. (ISABELLA), former president, University of Texas at Austin; chancellor, University of Texas at Austin ..... *Austin*

CURTIS, GREGORY (TRACY), editor, *Texas Monthly*; author ..... *Austin*

DANIEL, JEAN BALDWIN, former first lady of Texas; author ..... *Liberty*

DARDEN, WILLIAM E., president, William E. Darden Lumber Company; former regent, University of Texas ..... *Waco*

DEAN, DAVID (MARIE), lawyer; former Secretary of State of Texas ..... *Dallas*

DEBAKEY, MICHAEL E., surgeon; chancellor, Baylor College of Medicine ..... *Houston*

DECHERD, ROBERT W. (MAUREEN), president, A. H. Belo Corporation ..... *Dallas*

DELCO, WILHELMINA (EXALTON), former member of the Texas House of Representatives; civic leader ..... *Austin*

DENIUS, FRANKLIN W. (CHARMAINE), lawyer; former president, University of Texas Ex-Students' Association; member, Constitutional Revision Committee ..... *Austin*

DENMAN, GILBERT M., JR., lawyer, partner Denman, Franklin & Denman; chairman of the board, Southwest Texas Corporation and Ewing Halsell Foundation .... *San Antonio*

DICK, JAMES, founder-director of the International Festival-Institute at Round Top; concert pianist and teacher .... *Round Top*

DOBIE, DUDLEY R., JR. (SAZA), lawyer, The Unviersity of Texas System .... *Austin*

DOUGHERTY, J. CHRYS III (SARAH), attorney; Honorary French Consul in Austin; trustee, St. Stephen's Episcopal School, Austin; University of Texas Law School Foundation .... *Austin*

DOUGHERTY, J. CHRYS IV (MARY ANN), assistant professor in the Lyndon Baines Johnson School of Public Affairs .... *Austin*

DOYLE, GERRY (KATHERINE), former chairman, foreign trade committee, Rice Millers Association .... *Beaumont*

DUGGER, RONNIE E. (PATRICIA BLAKE), publisher, *The Texas Observer*; author .... *Wellfleet, MA*

DUNCAN, A. BAKER (SALLY), president, Duncan-Smith Company .... *San Antonio*

DUNCAN, CHARLES WILLIAM, JR. (ANNE), chairman, Duncan Interests; former secretary of U.S. Energy Department, deputy secretary of U.S. Defense Department; president of The Coca-Cola Company, and chairman of Rotan Mosle Financial Corp. .... *Houston*

DUNCAN, JOHN HOUSE (BRENDA), businessman; chairman, Board of Trustees, Southwestern University .... *Houston*

ELKINS, JAMES A., JR., chairman, First City Bancorporation of Texas, Inc.; trustee, Baylor College of Medicine .... *Houston*

ERICKSON, JOHN R. (KRISTINE), author, lecturer; owner of Maverick Books publishing company .... *Perryton*

EVANS, STERLING C., ranching and investments .... *Castroville*

FARABEE, KENNETH RAY (MARY MARGARET), vice chancellor and general counsel, University of Texas System; former member, Texas State Senate .... *Austin*

FEHRENBACH, T. R. (LILLIAN), author, historian; former chairman, Texas Historical Commission; former chairman, Texas Antiquities Committee; member, Texas State Historical Association .... *San Antonio*

FINCH, WILLIAM CARRINGTON, retired dean, Vanderbilt Divinity School; former president, Southwestern University .... *Nashville, TN*

FISHER, JOE J. (KATHLEEN), chief judge emeritus of the U.S. District Court for the Eastern District of Texas, former district attorney and state district judge for the First Judicial District of Texas .... *Beaumont*

FISHER, RICHARD (NANCY), managing partner, Fisher Capital Management; former executive assistnat to U.S. Secretary of the Treasury .... *Dallas*

FLAWN, PETER T. (PRISCILLA), president emeritus, University of Texas at Austin .... *Austin*

FLEMING, DURWOOD (LURLYN), former president and chancellor, Southwestern University .... *Dallas*

FLEMING, JON HUGH, educator, consultant, businessman; former president, Texas Wesleyan College; former member, Governor's Select Committee on Public Education, trustee, Oklahoma City University .... *Oklahoma City*

FONKEN, GERHARD JOSEPH (CAROLYN), executive vice-president and provost, University of Texas at Austin .... *Austin*

FROST, TOM C. (PAT), chairman of the board, Cullen/Frost Bankers, Inc. .... *San Antonio*

GALBRAITH, JAMES K. (YING TANG), professor in the Lyndon Baines Johnson School of Public Affairs .... *Austin*

GALVIN, CHARLES O'NEILL (MARGARET), professor, School of Law, Vanderbilt University .... *Nashville, TN*

GARNER, BRYAN ANDREW (PAN), lawyer, president, of Law Prose ... *Dallas*

GARRETT, JENKINS (VIRGINIA), lawyer; member, Governor's Committee on Education Beyond High School; newspaper publisher ... *Fort Worth*

GARWOOD, WILLIAM L. (MERLE), judge, U.S. Court of Appeals, Fifth Circuit ... *Austin*

GILLIS, MALCOLM (ELIZABETH), president, Rice University ... *Houston*

GOLDSTEIN, E. ERNEST (PEGGY), former Special Assistant to President Lyndon B. Johnson; retired senior partner Coudert Freres, Paris, France ... *Austin*

GORDON, WILLIAM EDWIN (ELVA), distinguished professor emeritus, Rice University; foreign secretary, National Academy of Sciences ... *Houston*

GRANT, JOSEPH M., banker, former chairman and C.E.O., Texas American Bank/Fort Worth ... *Houston*

GRAY, JOHN E. (MARY), president emeritus, Lamar University; chairman emeritus, First City National Bank—Beaumont; former chairman, Coordinating Board, Texas College and University System ... *Beaumont*

GREENHILL, JOE R. (MARTHA), lawyer, former chief justice, Supreme Court of Texas ... *Austin*

GUEST, WILLIAM F. (AMY), attorney; chairman, American Capitol Insurance Company ... *Houston*

HACKERMAN, NORMAN (JEAN), former president, Rice University; former president and vice chancellor, University of Texas ... *Austin*

HALL, WALTER GARDNER, chairman of the board, Citizens State Bank, Dickinson; former president, San Jacinto River Authority ... *Dickinson*

HAMM, GEORGE FRANCIS (JANE), president of the University of Texas at Tyler ... *Tyler*

HARDESTY, ROBERT L. (MARY), former president, Southwest Texas State University; former assistant to the president of the United States; former chairman of the Board of Governors, United States Postal Service ... *Washington, D.C.*

HARGROVE, JAMES W. (MARION), investment counselor; former United States ambassador to Australia ... *Houston*

HARRIGAN, STEHEN MICHAEL (SUE ELLEN), author; contributing editor to *Texas Monthly* ... *Austin*

HARRISON, FRANK, physician; former president, University of Texas Health Science Center at San Antonio; former president, University of Texas at Arlington ... *Dallas*

HARTE, CHRISTOPHER M., president and publisher, *Centre Daily Times* ... *State College, PA*

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