ATOMS FOR PEACE + 50
Nuclear Energy & Science for the 21st Century

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Panel Chairman:
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ORBACH: The next speaker, with his wonderful colleague, David Tram who is no longer with us, was one of the pioneers in creating the link between the very small and the very large. His name is Dr. Michael Turner and he was recently named the Assistant Director for Mathematical and Physical Sciences at the National Science Foundation. Prior to his appointment he was the Bruce V. and Diana M Rauner Distinguished Served Professor at the University of Chicago, with appointments in the Department of Physics and Enrico Fermi Institute at Chicago and a member of the scientific staff at the Fermi National Accelerator Laboratory. The recipient of numerous awards and distinctions during three decades of research, Dr. Turner is a member of the National Academy of Sciences and a Fellow of the American Physical Society and the American Academy of Arts and Sciences.

He's served on or chaired many advisory committees for the NRC, DOE, the NSF and NASA. And since 1984 he has been involved in the governance of the Aspen Center for Physics, serving as president from 1989 to 1993. He is the author of several monographs and books as well as more than 300 research papers. His research focuses on the earliest moments of the universe. He received his Ph.D. and M.S. degrees in physics from Stanford University and his B.S. degree in Physics from the California Institute of Technology.

He was the Chair of the Committee on the Physics of the Universe that developed the national research council report, "Connecting Quarks to the Cosmos, 11 Science Questions for the New Century." And, indeed, the document being circulated to you today, owes a great deal to Michael, "The History and Fate of the Universe." Dr. Michael Turner.

TURNER: It's a pleasure to be here today. A good idea produces the expected good outcomes. A great idea produces a plethora of unexpected great consequences. I think after today, we can all agree that the Atoms for Peace idea was a great idea. Astrophysics and cosmology is a case in point. In 1953 no one would have thought, or few would have thought that particle physics and nuclear played much of a role in studying the universe. And my message today is that has completely changed, that the two are intertwined. In fact, in trying to prepare our talks today, Jonathan and I are going to echo many of the same themes because you just cannot separate them.

So, let's go back to 1953, two very big questions in cosmology were, number one, the origin of the chemical elements, the Periodic Table from hydrogen to uranium. Where did those elements come from? Where were they produced? The second big cosmic question of the time was, did the universe have a beginning? And there was a raging debate at the time between the Big Bang Theory, a theory where there was a beginning and the Steady State Theory where the universe always was the way it was.

It's interesting to look at the tools of the time in astronomy and the tools of the time in astronomy were optical telescopes, mostly, almost all privately operated, using photographic plates that captured about 1% of the light. The biggest telescope was the 200-inch Hale Telescope on Mt. Palomar. Those two big questions have been answered and in both cases the answer involves nuclear and particle physics. The universe began from hot Big Bang from the soup of the elementary particles, some 14 billion years ago and, time permitting, I will trace the entire history, next. Do I have that long? No.

The chemical elements were made by nuclear reactions, both in the Big Bang and in stars. And I think in pausing to think about this, the peaceful use of what Eisenhower called the nuclear secret, the free exchange of information by scientists around the world on both sides of the Iron Curtain, contributed to this understanding that we now have to these two big questions. So, on to the quark soup--

So this connection between the very big and the very small is most simply illustrated by this can of soup that, at least in the Midwest, you can find in the supermarkets. I don't know out here. I haven't been here that long. It's the most basic connection. Our universe started much more simply, a soup of the elementary particles. And here, starting in the upper left hand corner, I'll just walk you through very quickly, not in the 14 billion years it actually took, the history of the universe from quarks to us.

The quark soup that existed very early on changed into a soup of more familiar neutrons and protons when the universe was about ten microseconds old. When the universe was seconds old, I don't think anyone can dispute this, cosmology ran the first nuclear reactors and they were fusion reactors. And this epoch or Big Bang nuclear synthesis produced the lightest elements in the periodic table, the helium, the lithium, the helium 3, and deuterium. And the helium and particularly the deuterium that's with us today, the deuterium in the neutrino detector, came from the Big Bang.

Moving right along, when the universe was about 400 thousand years old, the atoms were formed. So, until then, matter was ionized and at this time, it was cool enough for the atoms to form and we have a record of that formation of atoms in the cosmic microwave background that I'll talk a little bit more about in a moment. And that represents how far we can see today with our scientific instruments. And then the story continues to the formation of the first galaxies, stars, clusters of galaxies, on up to the structure that we see today.

So this is the story that we put together and a key feature of this story is the nuclear and particle physics input. Skip that slide. In terms of optical telescopes, this is as far as you can see on a clear day. This is the Hubble deep field. This image of the universe that I think probably everyone has seen, maybe you don't appreciate the dimensions, this is one-forty millionth of the sky, one-forty millionth of the sky. In this one-forty millionth of the sky are more galaxies than Hubble studied in his entire lifetime. There are about 15 hundred galaxies. Those are the extended objects. There is one star in the Hubble deep field, which you can see shining brightly there.

The image would be filled with more galaxies except for the fact when you look out in space you look back in time and this image is taking us to back to the time when galaxies formed. So you literally are seeing the birth of galaxies in this image. So that is the Hubble Space Telescope. Ground based telescopes play an important role also. This is a project that involved the National Science Foundation, the Sloan Foundation, NASA and DOE. The Sloan Digital Sky Survey, a project whose goal was to digitize the sky and look on bigger scales. When you look on bigger scales, you can find the needles in the haystack, especially because there always seem to be arrows pointing at them. (Laughter)

These are-- I'm a theorist so I thought the arrows were there. These are two of the most distant objects ever seen and it's really breathtaking to think about these objects. These are quasars. The light left these objects when the universe was less than a billion years old. And when the universe was seven times smaller. And these objects actually by astronomical standards are fairly bright. It is just that they are rare and you have to look at a whole bunch of the sky to find these needles in the haystack. And as John Bacall could tell you, quasars are galaxies in their terrible twos. The quasar phenomenon is a phenomenon associated with young galaxies when the black holes in their center are gobbling up a lot of material.

The farthest that we can see with radiation that I mentioned earlier is the cosmic microwave background. We call this radiation, the echo of the Big Bang. This is the radiation that takes us back to a time before galaxies, before stars, takes us back to when the universe was about 400 thousand years old. And these microwaves give us an image of the universe when it was very young. And the way that we have to get at these microwaves involves space, so the Kobi satellite is illustrated here, instruments on the ground, there's a microwave detector that operates at the South Pole called Daisy, and then balloons to get above the atmosphere.

This is the best image that we have of the microwave--

END OF SIDE A, TAPE 5

TURNER: --As far as we can see with photons and this is a false color image of the microwave sky, hot and cold, and this is a trace of the matter that existed in the universe before stars and galaxies and the difference between the hottest and the coldest points is only about a hundred micro-Kelvin. The temperature of the microwave background is about 3o Kelvin and the variations that existed in the universe and the distribution of matter were quite small. And those variations and the distribution of the matter seeded all the structure that we see today, raised the question, where did those seeds come from, where did those variations come from. And I'll come back to that.

What are the new questions that we're asking in the year 2003? And these questions involve both the quarks and the cosmos. So my list of questions and James' and Jonathan's list of questions are very similar. They are just displayed differently here. They're very rich questions. The first one, I've organized them into three categories-- The first one has to do with the stuff of the universe, what is the universe made out of, a very, very simple question.

There's what we know about the stuff of the universe. As John said, most of the stuff of the universe is not visible; it's dark. Percentage-wise, stars only account for a half a percent. There's a pyramid diagram constructed here to get us close to the top because this 4% number is small. At the very top are the photons in the microwave background. The atoms account for about 4%. Of that 4%, the stars are only about a half a percent. Most of it exists in the form of gas, which never settled down to make a star.

Black holes, which people think as being exotic, and maybe part of the dark matter, account for one-ten thousandths of a percent of the universe. Of course, there's a lot of universe so there are a lot of black holes out there. As Jonathan mentioned, a big chunk of the universe, 33%, or 30% by mass, exists in a form of matter that we can't identify yet. We call this the exotic dark matter or the cold dark matter.

A great success of this collaboration between astronomers and nuclear physicists and particle physicists is to now know that some of it is neutrinos. We know the neutrinos have mass. The masses are not pinned down but neutrinos account for, in round numbers about what stars do. So there are a lot of neutrinos in the universe. They don't weigh much but they contribute about as much as stars do. The bulk of that dark matter we believe is in a new form of matter. The two particles that were most focused on are the axion and the neutrolino. The neutrolino is a particle whose existence is predicted by this string theory. And then at the bottom of the pyramid is the dark energy.

In terms of the opportunities for further discovery, although we have this inventory, 96% of the universe is in new forms of matter and energy that we are yet to completely identify. In terms of the dark matter, I show you to two pictures here. Fritz Wicke(?), an astronomer who made the first discovery of dark matter and Vera Rubin who I think may be here tonight. And here is an image of dark matter, again, through our instruments we're able to image the dark matter. This is a Hubble Space Telescope image. The orange fuzzy images are galaxies and a cluster of galaxies.

Wicke studied the cluster of galaxies and notice that the galaxies were moving fast and the gravity of the stars in the galaxies didn't produce a strong enough gravitational field to keep the cluster bound, and coined the phrase dark matter. In this image, if you look at the bluish galaxies that looked funny, there's a bunch of them that looked like they are ring shaped and there are some of them that look distorted, those are galaxies that are much further away and light has had to pass through this cluster and the gravitational affects of dark matter has created multiple images and has distorted the galaxies and allows us to study its distribution and be confident that the dark matter is there.

Dark energy-- In 1998, it was discovered that the expansion of the universe, which we had expected for some 70 years, should be slowing down due to the attractive force of gravity, was actually speeding up. And at the end of the year, this was called the breakthrough discovery of the year by Science magazine. Again, this discovery involved teamwork between astronomers and physicists, some of the physicists working at Lawrence Berkeley Laboratory.

And you might ask yourself, how the heck can the universe be speeding up and, fortunately, I'm running out of time so I don't have to tell you. It is the big question but here are two answers, notice not just one answer. One possibility is that it is due to the gravitational force associated with the quantumcy of the virtual particles that fill the vacuum. We're not certain that that's the correct answer. This is one of these problems that inspires the next generation of scientists including my son.

And the lower image there is his model for why the universe is speeding up. In the corner there-- That's what he thinks dark energy is, when he was six. His ideas are getting more sophisticated. I show these because puzzles do inspire the next generation of scientists and this truly is a puzzle and I can say about these two possible solutions to this problem, that they are both equally likely to be true. And, in fact, I think both are probably wrong.

The next set of questions involves the beginning of the universe. So there was a Big Bang, what powered that Big Bang? Our best idea has to do with something called inflationary cosmology, the idea that the universe underwent a tremendous burst of expansion when it was very young. And we're able to test this idea and this comes back to the cosmic microwave background. This is a blowup of part of W-Map. This is about ten degrees across the sky. And this tests this idea that when the universe was very young, when it was 10-32 seconds old, it went through at tremendous burst of expansion due to forces of the elementary particles.

If this idea is correct, then the patterns that we see on the microwave sky represent the inhomogeneity and the distribution of matter that seeded all of structure arose from quantum discreteness. And if that idea is correct, and the evidence so far looks good, then what we're seeing here, courtesy of the expansion of the universe, is the sub-atomic quantum world and the size scale here-- Remember it's ten degrees across our sky, what we're actually seeing back to is a size a billionth the size of a proton, which the expansion of the universe serving as a microscope and the sky serving as a screen.

Space and time-- What is space? What is time? And how did they come about? Those are questions that we're now able to ask and string theory plays an important role, again, the connections between the two. Our cosmic destiny-- Because the universe is speeding up and that speed up is caused by a form of energy we don't understand, we don't understand if the universe will continue to speed up, if it will start slowing down or even if it will recollapse. These are big questions.

And in order to answer these questions, we have to break down the barriers between the traditional fields. We have broken those barriers down. I think that is one of the themes here. And astronomers and physicists around the world are going to have to work together using both accelerators and telescopes. So, accelerators as Jonathan said, are absolutely important because they give us the controlled conditions. The telescopes are important because they give us access to conditions that we cannot recreate on the earth. In addition there are tools that were not dreamed of in 1953, computers operating at teraclop(?) speeds, eyes on the universe that we didn't have in 1953, X-Ray eyes, gamma ray eyes, we hope gravity-wave eyes soon to be able to see the collision of black holes through gravity waves.

So this is a great scientific adventure, wonderful possibilities for discovery that require a change in the culture, astronomers and physicists working together and the science cuts across three federal agencies, NASA, DOE, and NSF. Thank you.

[applause]

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Questions and Answers:
ORBACH: The floor is now open for questions.

QUISH: My name is Alan Quish. I'm a physics professor at the University of Michigan. One important benefit of the Atoms for Peace Proposal was the start of exchange visits between Russian and American scientists and students, especially in high energy and nuclear physics. This seemed an excellent and successful example of what Susan Eisenhower this morning mentioned as her father's hope that the Atoms for Peace Program would build good relations between scientists and students who would later become scientific leaders and help this, to have better relations between the two sides of the Iron Curtain. I think this had worked.

I've been involved in this program since the late 1960s. Unfortunately, this mutually beneficial exchange was significantly reduced when the now expired Department of Energy "Min(?) Atom Peaceful Use of Atomic Energy, Memorandum of Cooperation" was not signed when it was expired in February 2002. Has any progress been made in getting this signed again so this can continue.

ORBACH: I think the question was addressed at me and not the panel. Would any members of the panel like to respond to that? (laughter) Yes there is progress made an, in fact, in today's newspaper you will see one of the reasons why that progress will now accelerate. Thank you.

Are there other questions addressed to the panel? Yes.

GERKY: Bob Gerky, INNEL, to one of the three panelists. We've heard a lot about, where did the water come from on earth. And I'd be curious as to what the latest thinking is. There are some who have said the water on earth has come from comets. Does that hold any water?

ORBACH: Michael?

TURNER: I'm looking for an astronomer or planetary side on my left side here but I don't see one. Well, it certainly came from the quarks (laughter) in the Big Bang and it went through the Big Bang nucleus synthesis. I cannot tell you what the best idea for where the water on earth came from. I can only tell you the early origin of water, which is extremely exciting.

__: Is there any reason that it should have come from any different than all the rest of the elements that we have here on earth?

TURNER: Well, chemistry plays an important role in the formation of the solar system because some of the elements are more volatile than other elements. So, here on earth we don't see the primordial mix. Most of the universe is-- Most of the atoms in the universe are hydrogen. We certainly don't see that here on earth. But the earth's gravity isn't strong enough to hold the hydrogen and the helium, whereas in the sun and in the giant planets it's possible. So, chemistry plays a very important role in what we see here.

ORBACH: Questions? As Chairman, then, I am going to take the liberty of asking my own, which has been driving me nuts for five years. I would like to ask the panel to speculate on just what this dark energy is.

TURNER: Well, I think my son's idea's pretty good.

ORBACH: Are we really that bereft of ideas?

TURNER: No, I think we are at the phase right now where we need a really crazy idea. One of the exciting things about science is that when you get the very toughest problems, they involve some creative break, thinking outside of the box and so I tell this to graduate students and undergraduates and I also put a footnote saying, "Not every crazy idea is a solution to a profound problem. Some of them are just crazy ideas."

The range of things that we're thinking about run from something as mundane as the energy of the quantum vacuum. The problem there is that Jonathan and his friends can't calculate how much the quantum vacuum weighs. When they try to calculate it they get an absurdly large number before they say it must be zero.

(Laughter) It could be-- I describe very, very briefly inflation, speed up in the early universe. Maybe this is a milder form of inflation. And an idea that I really, really like, because it seems crazy enough to be correct is that there is no dark energy; we just don't understand gravity. And that a theme, again, that Jonathan was talking about, was that this marriage between gravity and quantum mechanics will require a modification of general relativity. If you'd ask Jonathan and his colleagues five years ago where that modification would be, they would say, "Oh, it is going to be at very, very short distances. It's not going to affect the cosmos."

But you never know where the clues are going to come from and this could be the clue that tells us about how we have to modify general relativity. And so I think that the solution to this problem that we go back and look at Jonathan's paper and find in page five that there is a two that should have been a 1.5. I think it's that we find something out very profound about matter, space, time and energy.

BAGGER: Mike is completely right about that. I showed a graph, which showed quarks and leptons and so forth, but that is really just a schematic for a whole structure which allows you to do calculations that are tested at experiments to better than a tenth of a percent level. And that whole structure completely breaks down on the subject of dark energy. As Mike was saying, if you use that, basically, you calculate that the dark energy should be infinite and in particle theory if it is infinite, well, maybe it's zero; you missed something.

The fact that it's not zero and it's not infinite, is something that is just completely beyond anything that we can understand and so something brand new has to happen and we just don't have a clue what it is.

ORBACH: Are there other questions?

__: Well, it is sort of a comment. I'm an experimenter so I don't really believe much of anything that can't be measured. There was an article in Scientific American within the last year and I'm bad with names so I forget the guy's name but he proposed a good solution would be to have a very small extra term to Newton's Law that deviated from it at large distances. As far as I know there is no direct experiment that shows that you can't have something which would only cause 1020 deviations from Newton's Law nearby.

And a bunch of my theory colleagues dumped on me and started explaining why that couldn't work but I think it is something to look at.

__: The problem is that the violence that you have to do to the theory has to be consistent with that suite of precisions measurements that you have made so far. And so that imposes constraints. You have to be consistent. Yet, I agree. The answer has got to be crazy. So there is not much wiggle room but there is a hole somewhere and we have to find it.

ORBACH: I think one has to be careful of empirical fits. I mean you can play games with the laws but why, and are the microscopics behind them was my response with I read the article. It was certainly a clever argument but it doesn't answer anything. In the same way that the cosmological constant can change the sign and it gives you expansion, it doesn't tell you where it comes from and that is what these gentlemen have been struggling with. But you actually said something, Michael, that was quite, and, again, Jonathan, quite extraordinary. You believe that the structure of general relativity may be inaccurate.

TURNER: Well, certainly in science we know that in any give point in time, our description of the natural world is just an approximation and what's exciting about the scientific process is that it is never over. Newton wasn't wrong; he just didn't get the whole story. Einstein's theory encompasses-- In science successive theories eat their predecessors whole if we are doing our job right. And so, Einstein just didn't get the whole story. He got a big, big, chunk that we're still trying to swallow. We're still trying to understand black holes and their meaning and we're still trying to understand the Big Bang.

But I think if you took a poll among physicists, I think most of us would say, Einstein didn't get it all. He did not have the last word on gravity and we have more to learn and we're looking for clues and maybe the cosmic speed-up is a clue to tell us which direction to go.

BAGGER: Also it's quite possible, that because ...(inaudible) constant is related to the extra dimension, because it's a question of how our four-dimensional world is embedded in this higher dimensional space, it could be just related to that as well. Again, we don't know.

ORBACH: In the spirit of experiment, can you give us some clues as to how these extra dimensions might actually be observed?

__: Well, in particle physics, everything is a particle. So, actually, if they are the right size, the could be seen as a set of new particles that-- New accelerators like the LHC, or they could be seen through deviations from Newton's Laws and table top experiments, depending exactly on what variety of new dimensions we are talking about or they might be so small that they are only seen indirectly here or there. We don't know.

The great advance in the last few years-- Previously, people thought that these extra dimensions had to be so small that, well, you basically can't see them. But recently theorists have figured out how they can be infinitely large and you still wouldn't know that they're there. And so the story is wide, wide open.

ORBACH: Further questions? Yes.

DOWNEY: Jim Downey, again, at Harvard. And I would have to say I'm not much of a string theorist except for what it involves in tying my shoes. My question is a follow-on to that. It seems from what I have read about string theory that one of the flaws is that it's heavily on the word theory and that experiments to validate it are extremely limited. I'm wondering if we have to find multiple universes or if we can be comfortable at some point with the fact that this may, in fact, be the only universe that ever was.

__: String theory is, at this point, so-- It's so early in the development of string theory that one can't even say, really, what it predicts. How it connects to experiments, we don't know. It's more of also a paradigm at this point, than an actual precise theory with predictions. We'll have to see. Time will tell how it fits in, how it is detected, if it's detected.

__: To comment on your multi-verse possibility, I think what intrigues people are the questions that string theory addresses and the mathematical beauty. Then if you marry string theory with this idea of inflation that I was talking about, you could have had multiple Big Bangs and the rules, what we call the laws of physics, the local bylaws of physics, could be different in the different inflationary events and so the universe could have a structure that is infinitely larger than we can imagine and, if this is so, this would be a breakthrough on the same level of Copernicus getting us out of the center of the universe and the idea that there a multi-verse structure would bring us back down to earth.

As you say, we can't test that yet. So it's this intriguing idea because the hallmark of science is testability. And so I think even you find the string theorists who are desperate to find little ways to test the theory because you have to test these ideas in science.

__: Is that idea giving up this universe-- There are billions of universes and this one is the way it is just because it is? Are we giving up to say that?

__: Well, you're talking about the anthropic principle, which I'm not a fan of--

__: Well, it's related to what you are saying.

__: If the universe has this multi-universe structure that you asked about, and we're very far from saying that, then it's a fact of nature that we have to accept. So, let's wait and see if we have to accept that fact.

ORBACH: There's a book by Martin Reese called The Six Numbers that Determine the Universe, which raises this question, pointing out that these six number, which are the cause for existence, are accurate to an incredible limit for us to exist. And, therefore, why those six, which forms the basis for the second book that he wrote, and I refer you to that.

Burt--

RHICHTER: Burt Richter from Stanford. The whole history of physics is the history of metaphysics turning into physics because of experiments. And right now what we are suffering from is a dearth of experiments because the experiments are getting more complicated, bigger, and more expensive. My poor theory colleagues don't have any data to anchor them and so they are floating in the ether multi-verses and strings and all the rest of that sort of thing.

But sitting up there is one person controlling the budget of the Department of Energy, another person controlling the budget in certain areas of the National Science Foundation and what we've got coming along now are not only things like the LHC, this great accelerator, but we're going to have new telescopes, we're going to have new X-Ray satellites. And I think in the next ten or 15 years, I wish it were faster, we're going to have some new facts and new facts are going to bring some of theory friends back from floating around in the ether to having to make contact, once again, with the real world and then we're going to start to move to a new concept.

__: I hate to dispute. I hate to disagree with Burt Richter. You're absolutely right. We have wonderful possibilities in front of us and we have a plate that is very, very full and we will have a hard time getting everything done. But I think what's very exciting in this connection between the quarks and the cosmos, is that this astronomical fact that the universe is speeding up is not just of interest to astronomers but it's of great interest, as you well know, to your theorists and it may be--

Maybe it's not the clue that they wanted. Maybe they wanted the Hink's particle first but science is always orderly and so we've go other clues coming in, the dark matter, the dark energy. But I take you point on the possibilities before us and finding a way to carry out the experiments and realize our dreams.

ORBACH: I'm going to have Rob Goldsten ask the last question.

GOLDSTEN: Since some areas of particle physics are deferring from making predictions yet and there are these 17 or 19, depending on how you want to count them, basic numbers that are behind the standard theory, we had Roger Penrose come to Princeton to take the occasion to go after string theory as being irrelevant. That was kind of an interesting experience at Princeton. But I asked him this question and his answer-- And I'm curious how your response is, what your answer is-- Since we can't have a prediction, how about a meta-prediction, so to speak, a prediction about the predictions. When will one of these numbers come out of string theory? The first one?

[pause]

ORBACH: Would you like me to predict when Jonathan will answer this question? (Laughter)

__: So to speak, a meta, meta-prediction.

BAGGER: To be honest, I'm not a string theorist. I'm backpedaling fast. I actually believe in effective field theory. I'm more like a condensed matter physicist, mucking around with my effective Hamiltonian of the standard model and I can look further and see that either great things coming in the next factor ten in energy. To get all the way to the string theory scale, is more than I can imagine. But I can use string theory for inspiration and to take the big picture of string theory and use it as a guide, but actually detailed calculations, it's like trying to drive, perhaps chemistry from first principles of quarks and leptons. There are many steps in between. It may be very hard.

ORBACH: As one of those guys who mucks around with materials, let me thank the members of the panel and all of you in the audience. I think Burt Richter's plea, that this will come faster than 15 years, is upon us. We have four to five more years of operation of Fermilab. These issues, these new particles, the experiments that have been called for may well emerge from that. One has, as you saw the large hadron collider at Cern, the possibility of the linear collider in parallel. We have in front of us machines and theories that address the very fundamentals of our existence. It's an exciting time to be alive and I thank you all for joining us this afternoon.

[applause]

END OF SESSION 4