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ALEXANDER ROSE: Good evening everybody. I'm Alexander Rose. I'm the Executive Director at the Long Now Foundation. Welcome to our first Chabot Center talk here in the planetarium. Thank you guys for coming all the way up here. As some of you know that come to the Long Now talks before know when we do the talks we often do something called the long/short which is a short film that exemplifies long-term thinking and we're trying to figure out which one we should show here tonight. It occurred to me that we are in a planetarium and for the very first time I can request a planetarium to do whatever I wanted. One of the things that [Inaudible] of the Long Now tracks is actually the slowest cycle that it tracks. If you could bring down the lights a little bit, actually you could bring them all the way down; you don't need to see me here. In the center there is the star field and all those pointers are pointing to the celestial pole, Polaris, which is currently at Polaris, but the celestial pole is not always pointing at Polaris. The last few thousand years we happen to be in a very lucky position for navigation where we had a nice bright star there. That dome of stars underneath those pointers also turns once every 25,771.5 years in what's called the processional cycle, the axial procession of the earth. So we actually have a demo of that from outside the planet. We could kill our projector actually, is that could be possible? So this is the processional cycle happening and you can see the North Pole there nicely indicated by the arrow. This is one processional cycle roughly 26,000 years happening in 30 seconds so it's that 23 degree tilt of the earth doing a little wobble. But then the thing that I've always wanted to see is what that looks like from one place on the planet. Now, the computer was having some trouble with this earlier we'll see if it actually pulls it off. I think it might have a deca-millennium bug in it. We'll see. Okay, so we're going to swing around first to bring Polaris into view. So we're looking right now at celestial north, that red dot which is Polaris and if you're looking at it that's the tail of Ursa Minor generally. And now we're doing a one minute full processional cycle. This would be basically your shot at midnight once a night for 26,000 years condensed to one minute. Vega's coming around, when the tail of Ursa Minor is up by that 80 roughly or about-- there's Vega right there swinging by the bright star. So Vega will be our north star in about 13,000 years if anyone's paying attention. Lovely, thank you guys so much. I'll hand you off to Alex Zwissler, the Director here at Chabot, to tell you about our evening's activities.

ALEXANDER ZWISSLER: Thanks a lot, Alexander. I'm Alex Zwissler, and I'm the Executive Director here at Chabot. I want to welcome everyone from Long Now and my friends and family from Chabot. That little moment exemplified-- I was watching and I was thinking that is exactly why I just love the Long Now Foundation. I had a chance to meet these folks several years ago in a previous life when I was the Executive Director of Fort Mason and we saw to it that they had their new home at Fort Mason Center. Now we have

a new home at Chabot and we might be continuing partnership. Just a quick commercial on Chabot. I know for some folks it's your first time here. We're a Space and Science Center. We see about 200,000 folks a year. Also, we are the largest publically accessible observatory in the country and with the skies inspiring in our favor later tonight. The telescopes will be open for your pleasure. Wow! Listen to that applause. I love these people. I'd like to introduce my friend, Stewart Brand, who will introduce the program tonight. Stewart.
STEWART BRAND: Twenty-six thousand years. We started with 10,000 years and we're getting up to the 26,000 years. We use the five digits for years to get by the deca-millennium bug and by about 8,000 years and now this is 02010. And I realize that not far off from that there's going to be what do you call the bug when you need six digits if we stay with the same year numeration. Then you can start wondering about what are the chances that we will keep the same year numeration and how long will we keep it? Another century? Another millennium? How many here have heard of a book called Star Maker? Of course, Martin Rees has. I recommend it. It has this context and it's basically a guy out on a field looking up at the night sky and then he ascends into it and he joins the life of the stars. It is one of the great visionary texts.
What Martin Rees brings is in a sense the Star Maker perspective. And what else he brings is our context and that context overlapping which in a way is what the Long Now Foundation is about. We sort of use 10,000 years as an indicator of a time, taking the long term very seriously, the long time past and the long time future. Martin Rees lives there. Please welcome our speaker.
MARTIN REES: Good evening, ladies and gentlemen. It is a great pleasure and privilege to be here. My lecture is about the future, but I'm going to start in an old fashioned way with a text. The famous closing words of the [Inaudible] species. "Was this planet recycling [Inaudible] of the fixed law of gravity from a simple beginning the most wonderful have been and are being evolved." Astronomers probe back before Darwin's simple beginning which after all is quite a complicated situation in our young climate. Astronomers trace how starting from some mysterious beginning nearly 14 billion years ago atoms, galaxies, stars and planets emerged. But indifferent especially to Stewart Brand, I'd like to describe astronomy as the grandest environmental science and it really is because the night sky is the one feature of our environment which has been shared by all cultures throughout all ages where humans have existed, though each culture has interpreted it in distinctive ways. As I'll describe in this lecture, origins lie in the stars and our remote descendants may row among them. My topic today, "Life in the Cosmos," fascinates astronomers. They would have fascinated Darwin, as well. I'm going to ask: What's the future of life and what's the chance of it being discovered elsewhere? I can't claim to be much of forecaster or visionary myself and I always have to say I'm not an astrologer. I don't give horoscopes. My next picture shows someone who was a visionary and many of you will recognize him, that's Arthur C. Clark. He said that his greatest wish was to see the discovery of alien life. Sadly, he didn't live to see that. He died in 2007 at age 90. But he did live long enough, of course, to see the human life venture beyond the Earth. To give a bit of history, he wasn't the first person to think about space travel. Among his precursors was the Great Newton. I gave him a plug for his most distinguished alumnus of my college in

Cambridge. I have to say, though, he is an unattractive character compared to Darwin: solitary and obsessive when young, vain and vindictive in his old age, so not a nice man. But he was, of course, the first to understand how in Darwin's phrase "planets go cycling on in their orbits." He must have thought about space travel. Indeed, this picture from the English edition of his principia is still the neatest way to explain to students the nature of orbital flight. He calculates that for the cannonball to achieve an orbital trajectory for it to curve in its trajectory no sharper than the earth curves way under it, its speed must be 18,000 miles an hour, far beyond what was then achievable, of course. And the first object to reach that orbital speed was of course Sputnik I. Only 12 years separated Sputnik and the first moon landing and. The moon landing was only 66 years after the Wright brother's first flight. Many of us who recall that expected a lunar base and even an expedition to Mars within 30 years, but 2001 didn't resemble Arthur C. Clark's vision any more than 1984 fortunately resembled Darwin's. The political importance for man's space flight was lost and only the middle aged can now remember seeing live the murky TV pictures of Neil Armstrong's "one small step." In fact, my students in England know that the Americans landed on the moon just as they know that the Egyptians built the pyramids, both enterprises seem to be driven by equally arcane national goals. But it was a heroic episode and I cherish this picture signed for me by seven of the Apollo astronauts. Since Apollo, hundreds of astronauts have circled the Earth in low orbit, activities that really seem neither practical nor inspiring. Meanwhile, of course, unmanned probes to other planets have beamed back pictures of many varied and distinctive worlds. I want to show you a picture of Mars. You've all seen pictures like this showing the extraordinary terrain on Mars. Here's a big crater there. And the next picture's going to show the place where those arrows are and this is a close up of Mars. This is the Phoenix spacecraft that landed there about two years ago and is going to dig up a sample and did not, of course, yet return it to Earth. Going further afield, the spacecraft have been to Jupiter. There are its four big moons. Europa is especially interesting. There is its icy surface beneath which there is probably an ocean and there's a close-up of the extraordinary surface. One of the most remarkable feats of space robotics was connected with Saturn's [Inaudible] moon Titan. The Cassini mission went to Saturn and then when it got there the small European probe called Hoigans broke loose and was aimed to land on Titan, the John Lunar Saturn. It was supposed to do this. This is an artist's impression of what it was supposed to do, open a parachute and land on the surface and indeed that is what it did. On the left, pictures taken on the way down, on the right where it landed. Now, this may look like rivers and lakes etc. but this is not a hospitable environment. These rivers are rivers of liquid methane. And the temperature here is minus 170 degrees centigrade. Well, I hope that during this century the entire solar system, all the planets and the main moons, will be explored and mapped by flotillas of tiny robotic craft far more sophisticated than the Hoigans probe. I think we can predict that. But will people follow? The practical case for sending people into space gets, in my view, ever weaker with each advance in robotics and miniaturization. Indeed, as a scientist or practical man I see no real case for sending people into space at all. As a human being I'm nonetheless in favor of man missions and I hope some people now living will walk on Mars and that it will be a long range adventure for at least a few humans. Of course, this goal is receding. NASA's firm plans now don't even include a return to the surface of the Moon and I think one problem actually is that NASA is constrained by public and political opinion to be too risk averse, therefore expensive. The shuttle failed twice in 120 launches, but each of those failures was presented as a national trauma causing extra delay and expense. So actually I don't think that future expeditions to the Moon and beyond will be politically and economically feasible unless they are as it were cut price ventures, perhaps even privately funded, spearheaded by individuals prepared to accept high risks, perhaps even one way tickets. The involvement of people like [Inaudible] and others in the high tech community, in launch and development is surely a positive step. And it's surely not unrealistic to envision multimillion dollar projects with private sponsorship. Even individuals could do it. Another calibration is that Formula One car racing involves the leading teams, Ferrari and McLaren, which each have sponsorship budgets of three or four hundred million dollars annually. So in that perspective a $10 million privately funded or sponsored project doesn't seem crazy although that cost is very cheap compared to what NASA would presently be doing. Of course, it's very important to realize that space travel is dangerous. We mustn't kid ourselves that it's routine. That's why I have things like Richard Branson present as space tourism, because there again the first disaster will be a real problem. It's got to be approached in the same spirit that drives test pilots, mountaineers, round the world sailors and the like. And remember that no way in our solar system offers an environment even as clement as the Antarctic or the top of Everest. Space doesn't offer an escape from the world's problems as some people claim, but they could, I suppose, in future centuries be self-sufficient groups of pioneers living away from the Earth. They would surely use all the resources of genetic technology to modify themselves to adapt to alien environments and the post human era would then have begun. Thereafter evolution would happen on the technological timescale far, far shorter than the timescale of Darwinian evolution. And, of course, these post humans could spread still further and machines of human intelligence could spread further still. Indeed, whether the future lies with organic post humans or with robots is a matter for real debate. In space exploration there are, of course, issues of environmental ethics. Would it be appropriate to exploit Mars as happened when the pioneers advanced westward across the United States? Is it okay to send seeds for plants to be modified to grow in alien environments like Mars, should [Inaudible] be thought about seriously? Or should the red planet be preserved as a natural wilderness like we think the Antarctic should be? This is an important debate and the answer I think will depend on what the pristine state of Mars actually is. If there were any life already on Mars, especially if it had different DNA, testifying to or apart separate origins from any life on Earth, then there would be widely voiced insistence that it should be preserved as unpolluted as possible. Whereas if there's nothing there it would seem to me it would matter less if we exploited it and ditto to the Moon it would matter less if we exploited it. Well, so much for the planets. Let's now widen our horizons to the stars. Widen our gaze beyond our solar system, far beyond the reach of any probe that we can now conceive. We can't foresee going to the stars, but could there be life already among the stars? We have certainly learned enough about stars to understand them and we understand how they evolved but we see places where they're born and where they die. Here in the famous Nebula about 7000 light years away there are hundreds of solar masses of dusty gas condensing into new stars and new solar systems, just as our own solar system once did. And we see stars dying. Some die elegantly like this as our sun will in about six billion years. Some die in a less symmetric way. This is another star like the Sun dying. Other stars, stars which are much heavier than the Sun to start with, die more explosively. This is as I'm sure many people know is the famous Crab Nebula which is expanding debris from an explosion witnessed and recorded by Chinese astronomers in the year 1054 A.D. The precursor of this was a star about ten times as heavy as the Sun. Why do these far away long ago phenomena affect us? They're very crucial to our very existence, that's because during the lifetime of the star that [Inaudible] and Crab Nebula it was fueled by fusion of hydrogen to helium, helium into carbon, oxygen and the rest of the periodic table. Then when it exploded this processed material was thrown back into space and eventually in about 10,000 years it will all have merged into interstellar gas. Our galaxy is a kind of ecosystem where gas is processed and recycled through successive generations of stars. If this lecture was two hours long I would explain all of this diagram in detail. I won't do that because it just indicates the various roots whereby pristine gas eventually condenses into stars and the low mass stars have long lifetimes, they're tie up to gas for a long time, but the high mass stars evolve quite quickly and then explode and throw the stuff out again so that new generations of stars can form. Indeed, all the carbon, oxygen and iron on Earth and in our bodies is ash from long dead stars, stars that died before our solar system was formed. Indeed, each of our bodies contains atoms that came from thousands of different stars all over the Milky Way. We are the nuclear waste, as it were, from the fusion power that makes stars shine. And if you look at it that way then the cosmos is part of our environment in the very intimate sense. We wouldn't be here were it not for these stars which lived and died far away and long ago. Stars in themselves are fascinating as part of our environment for just that reason. Well, you've now learned something that makes the night sky even more interesting than it was to our forbearers. Many stars, perhaps even most, are orbited by [Inaudible] of planets, just like the Sun is. Most of the planets that we know about are directly detected but they inferred and the prime technique is illustrated in this picture here. If a star is orbited by a planet then what actually happens is the star and the planet both orbit their center of mass, what's called the Barycenter. If the planets going around in a large circle orbit then the star goes around in a much smaller circular orbit, the radius being inversed proportional to the mass and the star being much more massive moves more slowly. But the small amplitude periodic changes in the Doppler Effect can be detected by amazing and precise spectroscopy of the star. You can detect an orbital motion of the star at any speed down to walking pace, that's about one in ten to the eighth to the speed of light, very precise spectroscopy indeed. By this technique, by looking for the periodic wobbles in stars induced by the pull of planets orbiting them. Several hundred planets have been found and, of course, Jeff Massey just down the road in Berkley is one of the leaders in this search. This is like the old slide. This just shows a list of stars which are known to have at least two planets by this technique and indeed one star has been found to have at least five planets by this technique. Now, the evidence about planets around other stars pertains mainly so far to giant planets, planets roughly the size of Jupiter or Saturn, the giants of our solar system. Detecting an Earth-like planet is much harder because that would induce motions of only a few centimeters per second in its parent star, too small to be detected by this technique if you look at the Doppler Effect. If you're especially interested in possible twins of our Earth, planets the same size as ours orbiting other Sun-like stars on orbits with temperatures such as water neither freezes all the time nor boils. Detecting these Earth-like planets, hundreds of times less matter than Jupiter, is a real challenge. As I said, it can't be done yet by this same technique as the big ones are, but there is another technique which can detect less massive planets. We can look for their shadow. And that's being done by the NASA Kepler mission. If a planet moved across in front of a star and we were looking at the star then the star would get slightly fainter because the planet in front of it blocks out a bit of its light. So if you're looking at the star then its brightness would behave as in this diagram here if the planet was in orbit in the plain of our level of sight so it would move across it. So this technique allows you to detect planets by looking for regular periodic dips in the light curve of the star. Now, the Kepler spacecraft, which was launched back in March of last year, is already finding dozens of planets not much bigger than the Earth by this technique. What Kepler does is it looks at a patch of sky about seven degrees across and measures the brightness of up to 100 thousand stars in that field to a position of about one part in 100 thousand and does it every half hour. It accumulates that data and it looks for cases where you see the slight dimming by a few parts in ten thousand where an Earth-like planet moves across. The hope is that in a year or two the Kepler team will announce a number of planets found by this technique. Now, of course, for every one they find with an Earth-like orbit around a Sun-like star you can expect at least fifty times more of simple geometry because clearly you've got to be very accurate in the plain of the orbit in order to see this effect at all. So in a couple of years time we will have fairly clear evidence on how many Earth-like planets there are around a typical field of stars. But we'd really, of course, like to see these planets directly not just their shadows as it were and that's hard. To realize how hard let's suppose that an alien astronomer with a powerful telescope and say 30 light years away, this is a nearby star, was looking at our solar system. The Sun from that distance would look like an ordinary star and our planet, the Earth, would seem in [Inaudible] phrase a pale blue dot. Very close to its star, our Sun, which would outshine it by many billions. So you're looking for a firefly next to a search light as it were and that's a big challenge. But if you could detect this pale blue dot then you could learn quite a bit about it by watching it because the shade of blue seen by the aliens if they looked at the Earth would be slightly different depending on whether the Pacific Ocean or the land mass of Asia was facing them. So by watching this dot the aliens could infer that there were continents, the length of the day, something of the seasons and the climate. They might even be able to infer something about the atmosphere and the oxygen and ozone in it. Well, within 20 years we will be making inferences like that about Earth-like planets around the nearest stars and that would involve either larger rays in space, this is a European project called Darwin. There's an American project called the

Terrestrial Planet Finder which is rather similar or maybe by even giant telescopes on the ground. This is a design for European giant telescopes; you need a truck to get to scale. Something like this would be able to resolve the image of a pale blue dot nearer to a much brighter star. Well, this is what we can expect 20 years from now to detect planets like the Earth. But will there be life on them? We still know very little about this question. I would say we know far too little to say whether alien life is likely or unlikely. That's basically because we don't know how life began on Earth. We know from Darwin how it evolved once it got started, but we don't even know whether life on Earth arose by some natural process or whether it was a rare fluke like shuffling a deck of cards into perfect order. We just don't know. We would, of course, like to find out if there is any life in our solar system before looking further and here are possible places to look. No one would expect any very advanced life but it would be very important to see if there is any vegetative life there and if there is as I said earlier in the case of Mars we'd like to be sure whether this life has an independent origin or whether the life, say, from Mars had gone to the Earth or vice versa. And that could be done by seeing if it has similar DNA. But clearly if there is life in any of these locations it's not going to be very exciting or very advanced life and so we do have to look further afield to planets around other stars. It makes sense, I suppose, to focus on other planets which are like the Earth because we know that life did start at least once in that particular environment and so it's sensible to look at Earth-like planets orbiting long live solar-type stars. But I think we shouldn't exclusively focus on that. There is an argument that there are a lot of special features about Earth which were required, some of them are listed here, and they're in a book called Rare Earth which has given a list of these things. I tend to feel that maybe being too proscriptive as it were because it's not clear these were prerequisites for life although we have clearly evolved in symbiosis with our environment. But to say that life could only exist when all of these conditions are fulfilled is rather misguiding perhaps like say isn't it amazing that our legs are just long enough to reach the ground. It's not amazing at all, and so we've evolved to fit in with this environment and that doesn't mean that life could not evolve in other environments. So I think we should be entirely open minded about where we look and less parochial. Indeed, we realize that life is found under extreme conditions on Earth, in hot springs and deep underground. And, of course, science fiction writers have other ideas. Balloon-like creatures floating in the dense atmosphere of Jupiter-like planets, swarms of intelligent insects, robots and all kinds of things. And incidentally about science fiction, I tell my students it's better to read first rate science fiction like Arthur C. Clark than second rate science. Second rate science may not be true either and is far less entertaining. I will put in a plug for the classic science fiction writer Olaf Stapleton who wrote not only Star Maker, but a book called Last and First Man. These were two classics and actually Last and First Man was one of the books that inspired Arthur C. Clark when he was a child. Well, even if simple life is common, and it is so many times around the stars, it's, of course, a separate question whether it is likely to evolve into anything we might recognize as intelligent or complex. That's a separate question. Of course, some people already know, those who've seen UFOs or been abducted and in the UK where I have the title of astronomer I get quite a lot of letters from these people and I tell them isn't it a pity that these aliens came here and all they did was destroy a few corn fields making corn circles, met a few well known cranks and went away again. And I tend to get these people to write to each other rather than to write to me. But perhaps someday we will have real evidence. Perhaps one day the city searches again being spear headed near here will succeed. I think this is very, very important that this is being done because even if the signal that is being detected is very boring, and it's the prime numbers or the digits of pi, it would carry the momentous message, the concept of logic and physics weren't limited to the hard weighed human skulls. It wouldn't prove there were consciences out there but it would prove that there was some kind of intelligence either organic or some sort of computer. Now, if there is anything out there which is sending such signals, would we have a common culture with them? Well, we would, not just mathematics but even if these aliens live on planet Zorg and have seven tentacles they would be made of the same kinds of atoms that we are. They'd gaze out if they had eyes at the same cosmos as us. They'd trace their origins back to the same big bang so we would have a lot in common. But, of course, as you know even if they are around and nearby a star signals would take many years to reach us so we would have plenty of time to compose a measured response if we wished but no scope for snappy red hot tea as it were. On the other hand, perhaps these searches will fail. The intricate biosphere may be unique and that may be disappointing. But it would have its upside which it would entitle us to be less cosmically modest because our tiny planet could then be the most important place in the galaxy, perhaps even a seed from its life could spread through the entire galaxy eventually. But it's an old saying that absent evidence isn't evidence of absence and, of course, even if the same searches reveal nothing there could be intelligences out there that are leading competitive lives and not trying to communicate. And there could be some that we couldn't recognize because they're so different from anything that we could conceive. There might even be such things in our solar system. And, of course, if there are aliens out there some of them may have insights which will advance anything that we can pose. They may have intelligence far ahead of ours, just as quantum theory would [Inaudible] a chimpanzee so there may be aspect of reality that humans will never grasp but which would be grasped by our remote descendants and may be grasped already by aliens if they are out there. Well, so much for possible alien life around stars in our galaxy. Let's now enlarge our horizons further. I'm going to describe briefly the large scale structure of our universe. If you could get two million light years away from the Earth and look back we would see something like this. This picture, of course, is as you know Andromeda the nearest big galaxy to ours. It's a spinning disk viewed obliquely where about 100 billion stars are orbiting around a central hub in the middle of which lurks a big black hole. This is a typical galaxy like ours. And our Sun if we could look at our galaxy from a great distance would be a very ordinary star located out towards the edge orbiting the central hub once every 200 million years long even by Long Now standards. Well, here's another galaxy, the whirlpool. Now, astronomers actually understand a lot about galaxies and you imagine how could they do this because they can't do any experiments on galaxies. They can just look at them. It might be hard to believe that we can be competent that we understand what they're made of and how they form. But we can do experiments in our computer. We can't crash together particles like a particle physicist can and [Inaudible] but we can crash galaxies together in our computers. And here are the results of one such calculation, two galaxies crashing together. What's happening is that the gravity of each star, one acts on the others and they pull out these sorts of tidal plumes. When these galaxies settle down they will have emerged into one single big amorphous bloated galaxy. Now, we can then look up in the sky and we see things like that and it's fairly clear that what's happened here is rather like in that movie, two galaxies have got dangerously close and each has pulled out a tidal plume on the other. By doing calculations with different assumptions about the masses, the dark matter, etc. we can firm up picture of galaxies by comparing the outcome of those calculations with things we see in the sky. So that's why there is quite a substantial basis for the understanding of galaxies. And, of course, there are huge numbers available for studying. This is a picture of the galaxies within about a few hundred million light years of ours that group together in clusters. One thing we know about galaxies is that they're moving away from us. We've known this ever since the work of Edwin Hubble. He is a heavy smoker as you can see and he discovered that distant galaxies are moving away from us and the further they are from us the faster they're moving, indicated by the longer arrows further away. Now, this doesn't imply that we're in a central position. The best way to envision the expanding universe is to think of a lattice like this. Supposing that you sit up on one of the vertices and all the logs lengthen and then the other vertices will move away from you with a speed depending on the number of intervening links. The whole network will expand. Now, that's a good picture for the expanding universe if you imagine galaxies or at least clusters of galaxies joined together by rods and all the rods lengthen in the same proportion and the galaxies get further away. There's no preferred center position. But there's one feature which isn't brought out by this picture and is better done by this other picture, angels and devils. Because when you look a very long way away at a galaxy you see it as it was a long time ago because it does take a long time and so if the universe is expanding you see distant galaxies at a time when they were close together when the worlds were shorter as it were. So what we actually see if we look back on our past light cone is something better resembling this picture here where as you look further out towards your horizon you see things more closely packed together. We can see very far back. This picture shows a patch of sky only a few minutes across. It would take more than 100 patches like this to cover the full moon and the sky. With the smallest telescope this would be a blank bit of sky but with the Hubble or the biggest ground based telescope you would see something like this. And each of these smudges is a galaxy, many of them fully the equal of our galaxy or Andromeda. Looking so small and faint because of the huge distance and many of these are so far away with their lights set out 10 or 11 billion years ago, long before our Earth formed. In fact, these galaxies look different from nearby galaxies because they contain more unprocessed gas that hasn't yet turned into stars and a lower proportion of elements like carbon and oxygen which you can look for spectroscopically. That's because 10 billion years ago there hadn't been enough time to process much material through stars to build up the heavy elements and therefore even though the mite on Andromeda be alien life to maybe astronomers on Andromeda looking back at us with bigger telescopes than ours, but you can say for sure that if there are such astronomers on these very distant galaxies because at the time in the light from these galaxies set out there would not have been enough carbon, oxygen and phosphorus to make a planet, there would be no planets and therefore scant the chance of life. Well, when we look at these distant galaxies we're looking back to when the universe was about a tenth of its present age and about five or more times more compressed. But what about still earlier times? I don't have time to go through all the arguments, but, again, as you probably know there is important evidence we've had for more than 40 years which is that intergalactic space isn't completely cold. It's warm to about 3 degrees above absolute zero by very weak microwaves. These microwaves if you measure their spectrum at different frequencies have an almost exact so-called black body spectrum indicating this is radiation which was once equilibrium. So this radiation filling all of space is a relic of when the entire universe was squeezed hot and dense, hot and dense as the center of the Sun. And as the universe expanded this radiation cooled and the wave lengths stretched but it's still around it because there is nowhere else to go and it's this weak background radiation. We have this evidence and others to give us confidence in extrapolating back to the time when the universe was a few seconds old. Astronomers are often accused of being often in error but never in doubt, so you may say how confident can they be about this, but actually the evidence for the universe at one second is in my view as compelling as anything a geologist could tell you about the earliest of Earth. We've got various fossils which we measured very exact. And so we do have this time chart of the evolution of the universe and that to one second or at least a modest fraction of a second is fairly well understood. But right back still earlier on it's rather mysterious. What we know is that at one second everything was in this bay of hot dense gas. Now, when you're told that the early universe was very hot and dense and a [Inaudible]. Now there's a tendency to be rather puzzled about how from something like that can our present complex and structured cosmos have arisen because most people have heard of a so-called second law of thermodynamics which says that structure tends to wash out. Structure tends to be eliminated rather than full. Whereas our present universe is clearly far more structured than the hypothetical early state which is almost smooth. How can we reconcile this emergence of structure with this law of thermodynamics? Well, the answer is a crucial role is played by gravity. Gravity enhances density contrast as the universe expands and regions slightly dense than average would lag behind as the universe expands with the extra gravity and eventually condense out. I'm going to show you a movie which shows a volume of the universe starting at the beginning and ending up now where the expansion is subtracted out so that it's a patch big enough to make several hundred galaxies look the same size all the way. On the bottom left you see the time measured in giga years, billions of years and you see there's a [Inaudible] that tends to contrast growth because gravity is enhancing them. And eventually after 30.7 million years we get something which actually is rather like the structures in our universe. And we have put into the initial conditions here fluctuations which are known to exist in the background radiation. And of this kind which have shown 16 thousand times faster than real time, of course, they show that galaxies can have emerged from an amorphous of the universe and because each of these galaxies then an arena in which stars, planets and perhaps life can emerge. We'd like to understand in fuller detail how these amorphous beginnings the cosmos evolved to its present complexities with life and planets. There has to be quite a few requirements in order for this to happen. Let me give a list of them first. You have to have particles at the beginning, protons and neutrons. You then have to have stars and planets. And then we've got to have the synthesis of the periodic table in stars and then planets forming around later generation stars. And then, of course, on at least one planet around at least one star life has to form and undergo Darwinian evolution and that evolution has led on at least one planet to creatures able to ponder the wonder and mystery of their origins. Well, what are the key prerequisites in the universe in order that all of these things can happen? Let me give you a list. The first thing is that we need to have gravity. If there wasn't any gravity then structures wouldn't condense out as the universe expands. Stars wouldn't pull themselves together. But gravity is a very weak force. Gravity is negligible between individual atoms. It's negligible where you have say a sugar cube or something like that. It's negligible for an asteroid, when you get something as big as a planet that makes it round and when its bigger it crushes it to make a star. So this picture here shows the various structures and it's because gravity is so weak that stars are so big compared to atoms. So gravity is crucial but we also need the [Inaudible] if the universe expanded but then collapsed almost straight away then nothing complicated ever happened. We need matter, anti-matter asymmetry, we need more matter and anti-matter of equal amounts then as the universe expands and then cooled it would annihilate and there would be lots of radiation but no atoms left behind. We need a [Inaudible] chemistry. We need a periodic table and that requires some other tuning between the nuclear force that holds the nuclei together and the electric force that disrupts them. We also need stars to form, probably second generation stars because one star makes heavy elements but then it's got to make second generation stars in order to have planets. And also the expansion rate must be tuned because if the universe were expanding too slowly it would collapse too soon, if it expanded too fast then gravity wouldn't be able to combat the kinetic energy and galaxies wouldn't form. So all those things are required and there must be some fluctuations in the early universe in order for there to be something to feed on for dense to contrast. A completely smooth universe would stay smooth forever. Now, what cosmos is trying to do is to understand and quantify these things and understand how they came about. These numbers which all are basic numbers, the physics, the strength of the forces, etc., they must have been imprinted at some very early stage in the universe. We don't know quite how early but I think very early indeed in most people's pictures. I like to show this picture. This shows the very early universe and this is actual size. This is the size of the universe when it is a trillionth of a trillionth of a trillionth second old and this is a time when it's thought that many of these key features were imprinted in it. The physics at that early stage is very uncertain. We can extrapolate back quite a long way but when we get back to that tiny, tiny fraction of a second where all of these important numbers were imprinted we still don't have any firm foothold because the physics is far beyond anything we can directly simulate in the lab or the accelerator. At this point I would like to insert a health warning, a hazard. I want to briefly mention some speculative issues. First, how big is our universe? Well, we can see this huge range of galaxies out to a distance of ten or twelve billion light years, which is the horizon around us, but there's no reason to think that's all there is. Just like if you're in the middle of an ocean, you climb the mast of your ship and you see a horizon around you, but you don't necessarily think the ocean finishes just beyond your horizon. And the same is probably true in the universe. We can't be sure of what happens beyond the horizon, but the expectation is that there is far, far more to our universe, it goes on far further than we can actually see. One reason for that is that if you look as far as you can in that direction and then in that direction, the conditions look the same to a precision of one part in 100 thousand so if its part of some finite structure then that structure must be much bigger than the state we can actually see. But some theory suggests that it goes on even further than that, maybe even so far that all combinatorial options are played out so there would be somewhere else another lecturer with similar people listening to a lecture. But the distance you have to go to find that replica is hugely greater, it's 10 to the pi, 10 to the 200th. A huge number so there's no possibility of seeing that replica because it would be far, far beyond the horizon. And, moreover, even this isn't all because what I'm talking about now is the aftermath of our big bang, but some theorists suspect that there could be other quite separate regions of space time. One idea is what is called brain worlds. The idea that there could be separate three dimensional cosmoses embedded in some common four dimensional substructure. To give an illustration supposing that you have ants on a sheet of paper, that's their two dimension universe, they might be unaware of another population of ants on a parallel sheet of paper. So likewise there could be another universe just that far away from ours, but if that distance is measured in the fourth spatial dimension we imprisoned in our three, we would know about it. That's one possibility. It's something we talk about with a straight face. This is a cartoon of an idea which is taken much more [Inaudible] inflation. We are in some region, shown bottom right, but that is just one bubble as it were in some infinite hierarchy. So these ideas are taken quite seriously and if there are many big bangs this raises another important question which is: Are the laws of physics the same in all of them? They may be but it could be that some of the laws of physics depend on how the big bang cooled down and it's different in different realms. That's very important for the apparent fine tuning which seems to have been required in order for our universe to exist. This is sort of a decision tree that we hope eventually to be able to settle. How many big bangs are there? One or many? If there are many are they all the same in the physical laws governing them or are some of them different and if we have the right hand then we can say our universe is governed by what we think of universal laws but really as it were by-laws in our cosmic patch and could be different elsewhere. We are in a universe that is governed by laws of a lot of complexity whereas it could be sterile or stillborn universes which are disconnected from ours. So remember the hazard warning sign is still on, this is still very speculative. If I needed a logo for my research group, I'd choose this, an Ouroboros. The image depicts the interconnectedness of the micro world on the left and the cosmos on the right, the inner space of atoms and the outer space of the universe. There are links between small and large, left and right and our everyday world of life and mountains is in the middle. It's determined by atoms and chemistry. And there are other links between left and right on this diagram. Where it is determined by atom chemistry but does it link half way up because stars fueled by the nuclei within those atoms and also they have had no time to scribe it. Galaxies are held together by dark matter which is believed to be some particles even smaller than atomic nuclei. So the links between left and right. The left is the domain of the quantum and on the right hand side, Einstein's theory of gravity holds sway. Generativity and quantum theory are the two great pillows of twentieth century physics. But they haven't yet been meshed together in a single unified theory. In most contexts this doesn't really impede scientific progress. That's because the remains of relevance of those two theories don't overlap. A chemist doesn't need to worry about the gravitational pull between the different atoms in a molecule. Conversely, an astronomer doesn't need to worry about the quantum fuzziness in your original planet because the planet is so big. But if we think of the very beginning of the universe everything was squeezed so dense that we have to worry about both these theories. Quantum fluctuates could unshape the entire universe where its compressed and so to understand the very beginning, to understand what banged and why it banged, were there many big bangs or one, we would have to understand the synthesis symbolized as it were gastronomically at the top here between the very small and the very large. But before leaving this picture there is a third front here at the bottom, neither the very large nor the very small but the very complex and the most complicated things are we ourselves. We're actually midway on the long scale between atoms and stars. We're big compared to atoms because layer upon layer of structure but we're small compared to stars, we're not so big that we could get crushed by gravity. Incidentally we are connected in the middle, a geometric mean as the mass of a proton and the mass of the sun is 50 kilograms. [Inaudible] two of the mass of most people here. We are midway between atom and stars and to understand ourselves we have to understand the atoms we're made of but we also have to understand the stars that made those atoms. The problem of this third front here is complexity. Even insects with layer upon layer of complexity is harder to understand than a star where intense heat and compression by gravity preclude complex chemistry. This picture incidentally is the famous drawing of a flea by Robert Hooke who was one of the first people to use a microscope and he published a book and he was actually a great enemy of Newton, newton's least favorite fellow of the world society, but he was not only a great scientist but a great draftsman and he produced this wonderful book. And you can imagine the fascination when the public saw these pictures for the very first time. But even a flea is much more complicated than a star. Finally, I want to draw back from the cosmos for what may even be a vast array of cosmoses and zoom back closer to the here and now to our planet orbiting a typical star in our galaxy. I want to emphasize first that even if there isn't any life out there it doesn't mean that life is forever a trivial afterthought of the cosmos. That's because of the vast time that lies ahead where life can spread from the earth far away. The stupendous time spent on the evolutionary past are now part of common culture, maybe not in Kansas or a few places like that but in most places this is a common culture that we have emerged over by four billion years and simple beginnings. But even people who are familiar with this tend all too often to somehow think that we are the culminations of process and no astronomer could honestly believe that. The reason for that is that the time lying ahead is even longer. This is a time lapse picture showing the Sun's origin, from a cloud its evolution and eventually it will become a [Inaudible]. It's less than halfway through its life and it's got six billion years before the fuel runs out and then flares up engulfing the inner planets. So the future of our Sun is longer than its past and the expanding universe will continue far longer, perhaps forever to quote Woody Allen, "eternity is very long, especially towards the end." So any creatures that witness the Sun's demise six billion years from now, they won't be humans, they'll be as different from us as we are from a bug. There has been as much time for evolution between now and then as there has been over the past history of the Earth and moreover as I said earlier evolution in the future is going to be far faster than Darwinian [Inaudible]. So post human evolution both here on Earth and beyond could be as prolonged as the Darwinian evolution that's led to us and even more wonderful. And Darwin himself recognizes this. He realized that not one living species would exist forever and there would be new species in the future. So we may be barely at the halfway stage in evolution and development. Finally, we're all familiar with these iconic pictures of our planet from space. Earth's delicate [Inaudible] contrasting with the sterile moonscape where the astronauts left their footprints and we've had these images, of course, for 40 years, an environmental icon. Now suppose that some aliens had been watching our planet, viewing it like that, not just 40 years but its entire four and a half billion year history. What would they have seen? Well, for nearly all that immense time Earth's appearance would have changed very gradually, continents drifted, the ice cover waxed and waned, successive species emerged, evolved and became extinct. But in just a tiny sliver of the Earth's history, the last one millionth part, just a few thousand years, the aliens would have seen a pattern of vegetation altering much faster than before. This signals the start of agriculture and the pace accelerated and soon the populations rose. And then there are other changes even more abrupt. Within 50 years, a little more than one hundredth of a millionth of the Earth's age, the carbon dioxide in the atmosphere began to rise and enormously fast, the planet became an intense emitter of radio waves, it took from TV, cell phones and radar transmissions. And then something unprecedented happened, small projectiles launched from the planets surface escaped the biosphere completely, some were propelled into orbit, some went to the Moon some beyond to the planets. Well, if they understood astrophysics the aliens could confidently predict that the biosphere would face doom in a few billion years when the Sun flares up and dies. But could they have predicted this unprecedented runaway fever, less than halfway through the Earth's life. Even in this [Inaudible] timeline extending millions of years into the future as well as the past, this century therefore may be a defining moment. It's the first in our planet's history where one species, ours, has Earth's future in its hands and it could be us who determine what happens in the future. Will life eventually stabilize? Will there be some spasm and disaster? Or will some of the planets, some of the projectiles launched from the Earth spawn new oasis of life elsewhere? So those decisions depend on us this century so we're the stewards of this planet at an especially crucial era and I think that's a message for all of us whether we are astronomers or not. Thank you very much.