Jagdish Mehra: Ladies and Gentlemen, our speaker tonight in the continuing humanities series of SMTI [Southeastern Massachusetts Technological Institute, now University of Massachusetts, Dartmouth] is a theoretical physicist working mainly in the boundaries between cosmic rays and astronomy. Dr. Philip Morrison is professor of physics at the Massachusetts Institute of Technology, where he teaches both freshman and graduate physics courses. A native of Somerville, New Jersey, Professor Morrison received the BS degree from the Carnegie Institute of Technology, and the Ph.D. in theoretical physics in 1940 from the University of California, Berkeley. During the following two years, he taught physics, first at San Francisco State College and then at the University of Illinois. Beginning in 1943, he became associated with the Manhattan Project, through the University of Chicago Metallurgical Laboratory. From 1944 to 1946, he continued working on this project at Los Alamos, and later overseas on Tinian and Japan. In 1946 Professor Morrison joined the Physics faculty at Cornell University, where he remained until he came to MIT in 1964. He has lectured extensively at the Imperial College of Science and Technology in London, the Tata Institute of Fundamental Research in Bombay, and the University of Kyoto in Japan. Professor Morrison has written many articles for journals and books and is co-author with Hans Bethe on the Book of Nuclear Theory [actual title is Elementary Nuclear Theory]. Morrison became associated with the Physical Sciences Study Committee at its inception and is co-author of [?] School Textbook on Physics. Professor Morrison is a fellow at the American Physical Society, the American Association of Physics Teachers awarded him its 1965 Oersted Medal for Distinguished Teaching. He has received numerous other awards for his scientific writing and research. Professor Morrison has a reputation of being a great teacher and an eminently civilized mind. Ladies and gentlemen, it is with enormous pleasure that I present Philip Morrison to speak on interstellar communications.

[applause]

Philip Morrison: Thank you, Professor Mehra. I'm very pleased to be here to take part in the series, the names of the earlier  participants of which I find quite impressive. I remember that when I. I. Rabi was speaking at Cornell a few years ago, the distinguished physicist and Nobel Laureate, a man who has remarkable connection with Cornell because the Cornell Physics Department, with insight which I hope was, with a lack of insight which I hope is not characteristic of later times, in about 1920 discharged Mr. Rabi, then a young graduate student on the grounds he would never make a physicist. They were wrong. And ever since then, he has been delighted to point out how things at Cornell were not done very well. And he remarked

particularly when he came there, an elderly man full of honors and distinction, he said, "You know," he said, "things were done better in the old days." That was the line he took. He said, "For example, here I am talking to you from Baily Hall stage, but when I was a student here forty years ago, I didn't come to hear me, I came to hear men like Rabindranath Tagore. And things have gone down since that time." I feel that's the same way with your lecture series. But anyways I'll do what I can. I have an interesting topic and that may perhaps make up for the fact that I'm not going to talk about anything of direct moment to our world. Nothing in the headlines, really. But something which I think lies very deep in men, deep perhaps deeper than the headlines, and may in the long run have greater effect than some things which the newspapers may agitate from day to day.

If you were to ask, could we express to a renaissance scientist like Galileo the content of modern science. Perhaps I should not say it that way. Lets include Galileo as one of our company. Could we or Galileo, knowing what we know now in the Twentieth Century, explain to Aristotle what the content of modern science was, or even to a man more ancient than that, in a sentence, if we had a chance to transmit this notion to him. Of course it would make a nice discussion, it's like the books on a desert island, the idea of a compact talisman to contain the wisdom of many centuries. Of course, it's not easy to do. Nevertheless, it's entertaining to think about, and I would like for the purpose of this evening to put forward strong argument in favor of one simple sentence, a sentence which is so commonplace that when I tell you, you will feel mostly a little let down because we're so used to thinking of the truth of the statement that it doesn't appear to us in any way as being a statement of importance. But I maintain it's a statement of enormous importance. Not only because of what it implies, but also because of the way in which we know it, which is a way which contradicts the common sense experience to a very sharp degree, yet we don't doubt it at all. We have very good reason not to doubt it, because the chain of arguments on which it rests is much more secure and easily explains why our everyday experience does not jibe with it. The sentence is very simple. I could say, "The sun is a star, and all the stars are suns. The sun is a star and all the stars are suns." Everyone knows that or at least has learned it, I won't say that he believes and understands it. All too common in our time, as in every other time, is the acceptance of the common wisdom as a kind of mythology without an effort to assimilate what its content is, we are guilty of that. But I think it's quite plain why it's a deep statement. It's a statement which immediately puts a scale on the universe, far different from the scale of our geocentric fore-bearers. And at the same time it's a

statement that plainly contradicts the most obvious experience of daily life, namely the sun as a hot life-giving conspicuous object which dominates our whole sky, and is responsible the warmth from which we have existence. Whereas the stars are at best remote and beautiful ornaments to a night sky with which we have very little but intellectual connection. And the knowledge of the fact that simply the dilution by distance alone and nothing else makes the sun what it is and the stars what they are and that intrinsically each of them is more or less the same thing. That insight is so important, so characteristic, so clear in modern science that we simply couldn't overlook it. At the same time you will agree that naively it doesn't look that way at all. This stands for a great deal in the scientific world. It stands for atoms, it stands for nuclei, it stands for relativity theory, it stands for all the other things we know but which appear different from the everyday experience. And I don't think they stand on any different footing whatever. I strongly, I cast grave doubt upon the dualism, which was more popular a generation ago which it is today, which tended to say that the atoms of the physicist were one thing and the common sense table is another thing. I regard that in a sense, true, but in the most commonplace sense it almost says nothing, because the atoms are at least as real as the star-like nature of the sun, maybe more real, and they are at least as real as chairs. Now what reality is and what part chairs play in reality, I don't know for sure. But I'm prepared to say atoms and stars stand on exactly the same footing, we know as much about them as we know about the chairs in the auditorium and any other commonplace event. And that we know it is largely a consequence of the three-hundred year chain of modern science, which I could father upon Galileo, not because I insist upon this historically, but just as a reasonable staging point. Of course he had predecessors, but it's reasonable enough to say that his time is the time which our science began.

If I may have the first slide, I'd like to show you the title page of his first astronomical book, the most influential book perhaps ever published. Here it is, the Sidereus Nuncius. Messenger of the Stars, published by Florentines, as you see employee of the Florentines, philosopher, astronomer, making known to the learned world, indeed in Latin, in these works he hadn't yet gotten into the controversial stage of publishing his works in Italian, in Latin what he had found. And what he had found was plenty. The last line on the page, the right-hand words, you will see MDCX, that's the year 1610, it being late in the year of 1609 when he first turned his telescope on the heavens. And in this work, he made it quite plain to us what nowadays we all believe, what we learned in the daily papers, what we'll soon have the evidence of a young man standing his foot upon the moon and slapping it, banging it down there, striking the earth of the

moon if you will, with the sole of his shoe to be evidence to all in a few years time, and this first evidence was one which as securely as ever can be by Galileo in the next picture. If I may have that one.

These remarkable drawings, pen and ink drawings, were made by Galileo with that first little telescope which he turned on the skies, and you see them, you see the moon, you see the jagged edge, you see the light spots going into the dark parts, which were the tops of mountain peaks illuminated by the setting sun on the moon, more than the low country in between, so that the sunset line on the moon is not a straight line, these would not be anywhere were there would be mountain peaks, but some mountains remain in the sunshine after their valleys have gone into shadow. Here we have it, three hundred and fifty years old, the beginnings of modern science.

Galileo explained that the moon was like the earth, he said, "There's a place on the moon," and if you look at the newspapers in the last couple of days across the front of the New York Times, you'll see a magnificent photograph of that very same place, the crater of Copernicus, which said Galileo, "was like the plains of Bohemia." Now I've not been in the Czechoslovakian plains to compare it, and I don't think it's very much like Copernicus, but the daring of the statement was that instead of this being a mysterious place obeying no laws known to man, unlike everything we could possibly know, something that's shown by night, that was half-streaked with dark, half-bright by perpetual light, which was the ancient view of the moon, Galileo saw the moon as another large rocky ball, like enough to our Earth, not exactly like it but like enough to it so that he could say that in the center of it was a ringed plain and that plain reminded him of what travelers had told about the Erzgebirge mountains where in Bohemia you had large sort of crater like structures still visible to this day, and this is how he described the surface of the moon.

This then, I would say was the genuine beginning of the profound evidence that indeed the Moon is more or less like the Earth, like an airless, waterless, sterile Earth. But still another large rocky ball. Of course Galileo built upon the predecessor Copernicus, whose argument had been not indeed to show that the planets were Earthy, like the, like our globe, but that the planets were a starry company among which the Earth also sat. That we, too, moved. At the center was the sun, and the planets moved around it like a cortege, that we were no different

from them, and if they were shiny, why then the Earth must also be shiny, as of course we know it is, and again you can find this beautiful photograph on our newsstands today, the photograph of the bright Earth taken from just above the surface of the moon on Lunar Orbiter two. You can see the half-Earth there covered in cloud with the ring structure of the great cyclones of the Southern winter in the middle of the Atlantic Ocean showing on this photograph, the first magnificent photograph of our whole round Earth, a photograph I think of at least important for historical purposes, not quite as important but at least as interesting or romantic as historical purposes, as the photographs here, the drawings rather of Galileo made through the first telescope.

Now this is only to say then, that ever since then we have understood quite well the position which Copernicus and then Galileo brought us to understand; namely that the circumstances of the physical world are as far as possible uniform. That doesn't mean to say that everything is just the same. We know that New Bedford is not the same as Kansas, but nevertheless there is recognizable continuity between the two. We know the Earth is not like the moon, yet there is recognizable continuity between the two. We know that neither the Earth or the Moon are like the sun, which is a bright fiery globe quite different, gaseous, not solid. Nevertheless the same underlying laws go, it's not a remarkable, it's remarkable but not a magical thing; we can comprehend it. We can make fires ourselves, we can transmute the quantities to see that they are different, we can make nuclear energy just as the sun does. We have no doubt of the uniformity of nature in this respect.

Now the next step, of course, is to say, Galileo was able to take this next step, and it was demonstrated pretty well by Huygens, a young man when Galileo was an old man, Christiaan Huygens first made a good measurement of the brightness of the stars to compare to the sun and from this computed that the star Sirius was about 20 light years away. And was were it lived an object like our sun, perhaps ten times more splendid. This is the sense of the depths of space which we have. I think a few drawings might be worthwhile to bring it a little clearer. These are only textbook drawings which people have made to illustrate the scale. They are maps, not real photographs, not real evidence, they are the summary of evidence, but I can show to you as a summary, but mind you there lies behind them the evidence of the instrument and the reason which goes into it. Next slide please.

Here you see a familiar drawing of our solar system, one is the orbit of the Earth, two of Mars, the other planets are so small inside you can hardly see them, the elliptical object three is Haley's comet, so that you get some idea of the scale of the solar system, and you recognize this emptiness which is so characteristic of astronomical space. The dots that represent the planets are exaggerated in terms of scale, much exaggerated, because they have to be so in order for you to see the planets at all. When you look into the sky and see the planet Jupiter, a very bright object in our sky, just this hour in clear day, he looks very small indeed in the very large sky where he's swimming. Well that simply means there's a whole lot of black space and every once in a while there's a hunk of rock. And the next picture.

And in the next picture, the picture we have seen before is dwarfed, it's inside the square inside the square insides the square inside the square that's drawn there. You can't even see it. And what these dots are, again scattered out through space, are the nearby stars. The famous Alpha Centauri, Delta Cephei, Omicron Eridani and other stars in our neighborhood which we can point to in the sky, which look to us like bright points, but which logic and experiment allow us nothing other than to believe they are like our sun, more or less, great glowing balls, if we were near them, we would see them fuel the sky with their radiance and burn us with their heat and here they are scattered again through the depths of the space. You see them numbered there, these are the numbers of the nearby stars and they are plotted out to scale. Again I can hardly overemphasize how dwarfed by space is the matter. The stars are tiny points. We see them in the sky and think how enormous the black space which extends before them. The star image that we see by eye is enormously distorted by our eye, much greater in apparent size than the star image would be geometrically if we could see the disk of the star itself. A hundred times, five hundred times greater, so that we have mostly space and here and there studded a sun.

Now the argument which leads to the next step is a little more complicated argument. I shan't try to summarize here the astronomical arguments which lie behind all that I say. I hope that those of you who do not know these matters but are interested, will feel free to question me what is the nature of the evidence, and those of you who are not satisfied with that will consult the many excellent works which deal with this on all levels. And those of you who do know the evidence will be content to have me marshal before you the familiar numbers because it's on this that

really my entire discussion is based. We know today that the stars among which we live, which our sun is one, are not scattered out randomly forever through space, as was believed up until 50 or 75 years ago, but are in fact arranged in great islands, of which the next picture while give you some idea. This is a photograph, no longer an artist's conception, this is a photograph of a great whirling disk of stars. Let me make something quite plain, as the students of physics and optics will know. The central, spindle-shaped object, with black dust laying going across it, which is so characteristic, I must say found today on advertisements today from everything from automobiles to toothpaste, but still a beautiful and breathtaking object, is a distant galaxy. That light that you see, that glow, which you see in the center of it and all the way out to the edge, is not the glow of a luminous gas, as you might say, it is in fact the glow of billions upon billions of individual stars, individual suns. They are so far away from us, the telescope distorts their size such that instead of seeing them as individual spots, the spots merge and all we see is a bland, smooth distribution of light. But it is not at all a glowing gas, unless you think of gas as being a gas whose atoms are stars, which you can think if you'd like, a great leap of the imagination. But those are individual stars and in that object there are about a hundred stars for every human being alive. That is if you were allowed to name stars, every person would have a hundred stars named after him, there'd be enough to go around, no fights, plenty of abundance, plenty of nomens around. And a couple of hundred billion stars occupy that object. That's a fantastic thing because remember the stars are spaced out as far apart there as they are in our galaxy, for we, too, live in a galaxy, we cannot see our galaxy from the outside in this way. We shall never be able to see our galaxy  from this position, because of course this position is the position of an observer who is as far away from the galaxy as a hundred or five hundred times the size of the galaxy. The object in that picture is so big, as I say, it contains a hundred thousand million suns. It's so big it takes a hundred thousand years for light to go from one end of the diameter to the other. That's a fantastic size. To get outside of it would take tens of millions of years for light to move and since we don't have tens of millions of years to spend we shall never attain such a position with respect to our galaxy, or at least we shall not do it for tens of millions of years, even if we knew how, started right now with the speed of light, we couldn't do better than that. Next picture please.

Here is an artist's drawing, now this is no longer a map, no longer a photograph but it's a map. It tolerably represents the way we think our own island of stars looks. Now it's just the same as the one we saw in a picture, there was a small slide, perhaps if we could come back to that one

after this. The picture is the same spindle-shaped object, but think of the spindle-shaped object as a kind of disk, like a fried egg, to use a very homely simile indeed, with a bulge in the center and a flat disk. Now if I turn the egg face on I will see it as an elliptical or round disk. That's the way you are looking here in the artist's view. He's tried to simulate a hundred billion stars, of course he can't make a hundred billion dots, he's lucky to make ten thousand dots. He's merged dots together in the center with white ink, so that it looks very nice. But remember they are all stars and their size is very great, the outer square is a big square just to show about where we are, the inner square is another big square, inside that square is another square as small as the one you saw in the same proportion as the one that's there. And inside that square is another little square, and inside that one in turn, is that set of stars which I showed you before, which are all the stars of our neighborhood spaced so far in the starry sky as they were. See it all depends on scale. And that object, which is our own galaxy, contains a hundred thousand million stars tolerably like the sun. And up there inside the little square inside the big square is our sun itself. Now look at that object. That's our galaxy. Look at it objectively and calmly, and ask yourself, "Is there any special distinction at the place where we live? Is there a golden arrow in the sky? Is there an exclamation point either of dismay or pride?" None of those things are present. We live unmarked in this tiny corner of this gigantic island, and around us in all directions for thousand upon thousand of light years are spread stars tolerably like our own sun. Now if we adopt the position like Copernicus and Galileo that where we see no difference we will not assume a difference, then it becomes real wise of us to consider what is the nature of all those suns. Are they suns with Earths as well? And that's the topic I want to talk about this evening. That small slide, if possible, I think would be worth looking at.

Lets look at a small slide just for some sense of similarity. Now this takes a bit of imagination, because we cannot be as good in our own home as we are in distant galaxies. But I think if you look at that a little bit you might see a tolerable similarity to that big spindle disk that went across the screen some time ago. With a dark lane across the center of it. This however, is not a distant galaxy, but is instead our own Milky Way photographed from the Earth looking out from the edgewise disk, which we know the Milky Way to be, showing the dark lanes across it, exactly as the dark lanes spread across the distant Milky Way which we showed in the other picture. That's enough for this story. Now, if this, I shall not talk, of course its obvious that there is more than one galaxy, you have seen, we know we live in one galaxy, we have seen another picture of another one, I could show you, if I were patient enough two thousand pictures of

galaxies all of them looking tolerably similar, broadly similar. Most interesting pictures, those the ones that are close by. And if we looked for all of the images of all our telescopic plates that we could possible muster, we could muster up a thousand million galaxy pictures as well, each one of them being a collection of a couple of hundred thousand million stars. But I shan't bother to dwarf the issue with those numbers, I will consider for the rest of the evening, one and only one galaxy, our very own in which we live, an inconspicuous suburban location, somewhere out in the flanks of the galaxy in the sun, near the sun.

Now let me raise this question. The neighbors of our galaxy are lost, they are none of them closer than ten or twenty times away as far away as the size of the galaxy itself. They are islands in the sea. Let us talk about our own island in which the sun sits. Is it possible, is it plausible, that among those two hundred thousand million stars, there should be no stars closely enough to the sun to be recognizable? The answer is no. Stars we can detect very well with telescopes. We study them. We know their history to some extent, we know a great deal about their physical nature, so we can classify them and we can say for sure that there is perhaps no precise match to the sun, because no two things are similar as no two dandelions are exactly similar, but to very tolerable similarities, we can say a great deal about the stars in the solar system. And what we can say is there are plenty of them. I will eventually come to a number of about two hundred million which are very, very similar to our sun. In fact there are many, many more, but I shall discuss that in a moment. What is the situation with respect to this clearly burning question? If we are one star among many hundreds, as I say among thousands of millions in one galaxy, unless we see a physical difference about our condition which is not duplicated elsewhere, are we right in assuming that many circumstances of our common existence are not so duplicated?

Lets ask this question. What are the requirements for the evolution of life in the neighborhood of a star and see how many stars match those requirements? The first requirement is quite plain, anyone who looks at evolution recognizes immediately it's dominated by one fact: time. No use talking about if you do not have a star capable of enduring for billions of years, thousands of millions of years, without substantially changing. So that it warms its planets, if it has planets, with the light which alone can give rise to life as we know it. And that time is the first thing we must ask. We must ask how many stars in the sky have lasted or will last for a time like the sun? We can give an answer. We know how the stars shine. For example we know that the very

brightest stars, the most luminous stars in the sky burn out with prodigal swiftness. Their entire lives in a few millions of years. Around such stars there is no possibility to have life. Second, time must be available. Third, the star must be constant, one would think so. Therefore stars that are doubled so that two suns exist, and a planet if there were one, would now be bathed in the light of one and then be bathed in the light of another, perhaps in different color, a different strength. Such an environment we can't imagine, very difficult environment to imagine, anyway. And while we can't prove that it would be inimical and hostile to the evolution of life, let us simply exclude it boldly because it's not similar enough to our own. It may be interesting but it's not similar. So let us exclude it. We're not looking, you see, for all the possibilities. We are only being as conservative as possible and looking for those places that are just like home. Because home, we know at least was a favorable circumstance for the evolution of life. That would exclude all the double stars, which takes care of most of the stars. By most I mean two thirds of the stars, something like that. Well two thirds takes away most of them, but it leaves plenty. This of course is the nature of our discussion.


The third point you would want if you have a star that is constant and a star which endures through time, you have to ask how much is that star warming its surroundings. And this, too, we can calculate. I shan't bother to go through the mathematical discussion but its subject is quite amenable to our calculations. We can say the following things which can be put down in terms of common sense. It's only by common sense arguments, I can't get you the numbers alone, without taking more time, but I think you will quite agree with them. If we were much closer to sun than we now are, we would find an intolerable heat. So that liquid water, and with it all the substances of living matter that we know could not exist. Lets exclude such cases. That means of course, the hotter the star, the farther off you must be from the star in order to be, to persist. And the smaller the star, the closer you must be in order to persist at a temperature that would not boil water and yet would not freeze it. We ask for this water-based life. Therefore you see, that around a very bright star, there's a big room for planets that have the right temperature, because they can be very far away and still succeed. And the volume of the sphere or rather the area of the disk grows quite rapidly as the size of the sphere increases, and therefore large stars would have a hospitable volume to accommodate planets. I should say bright stars, not large stars. But very bright stars don't last very long. We must make some compromise, we must find stars enough room around stars that are not too short-lived to make the whole thing work. On the other hand, small stars turn out to be very numerous. That is stars of great

faintness are very numerous. You might well expect such stars to be possible sites. But again, there is no room around them. If they are very faint then you must live very close to it, therefore there is not much room for planets, planets form in some random way, or some way obeying the best laws we know, there are two or three possibilities for the formation of planets. We still have no sure theory. We will have to say there is not much room near small stars. So near small stars though numerous, there's not much room. Near bright stars, which aren't very numerous and don't last very long there's a lot of room, but the other two factors cut them down. So in consequence, the stars that last a long time that are neither too faint to have room for planets nor too bright to endure, nor multiple so as not to be constant, must be rather like the sun. And it turns out that if we make this plot we'll shortly see a curve that shows you about how many, what kind of stars might be hospitable in this respect. Calculating entirely mind you, from astronomical data, I say nothing whatever about life, nothing whatever about evolution, I only say at the moment, the precondition which is namely that we have the sunlight, which is the indispensable source of all life on Earth, and we want to find that sunlight among the hundreds of thousands of millions of external stars, are there any that produce that kind of sunlight? And this is the calculation I'm now embarked on by sketching. Next slide, please.

This slides is not to emphasize for you, oh that. That's the one. Very good. Now could I have the one you just passed up? Maybe they are out of order. This is the very slide that I was just describing. There you see a curve, a typical bell shaped curve, temperature plotted on the lower axis, very hot stars lie to the left, this is the probability of planets with sunshine like our own. The probability of very hot stars is very small, because while there is plenty of room for planets there is no time. And to the right, can we perhaps get the right hand on the screen? Very good. To the right, where the star is very cool, there are plenty of stars, but there's no room for planets. They must lie too close, there's no room close. I've taken into account all the room there is, I don't exclude them, it just doesn't add up to much. And in the middle then are the stars that are not too hot, uh, not too bright and not too faint, and while there is a modest amount of room and there are quite rather numerous stars, and it turns out that that's where the main contribution to sun-like stars would occur, and to confirm our calculations, merely to show the consistency, not because its something new, I plotted our sun in that very curve by calculating just in the same way, and it comes out to pretty close to center, which of course is consistent if you're looking for stars like the sun, the sun better be a star like the sun. And it is. It comes out very neatly in the same picture.

So let us ask a question, then. This has been my discussion, then, very sketchily put. Of all the stars in the galaxy, which stars are like enough to the sun so that there is room around them, that there is room around them for planets in the region say further from the star than Venus and closer to the star then Mars, not measured in miles but measured in Sun's radiation amounts, and that of course is just where the Earth is, between Venus and Mars, and if we had the same amount of radiation we'd have a situation tolerably recognizable like the Earth, with a climate presumably something like between the hottest Earth climates and the coldest Earth climates. And we might expect to find it not inimical, if everything else is right, to the existence of life. Now of course you say, it's rather well to have stars, but stars alone do not support life, and that of course is quite true. Our sun is a necessary condition of life, but another condition is a planet, for life cannot survive on the surface of the sun or out in the vacuum of space. It must have the hospitable, chemical surround of a planet, warmed by the star, in order to work. So the next question, I think you are entitled to ask is, "Are there any other planets, that is cold bodies warmed by indirect light around the suns of the galaxy?" If told you these are the kinds of suns we have, and we need to add one more number, which I have not computed, but which I can assure comes in the same calculation, fits the very curve, how many stars are there that come under this rubric, and the number of stars in our galaxy alone is three hundred million. About one and a half stars per American. And a star is not just a little piece of a little inconspicuous planet in the sky, it's a gigantic thing like the sun. Very close to the sun, indeed. And there is one of those in the galaxy for everybody in this country, and that's quite a few suns. Now you say, what is the evidence for this and of course the evidence for this is rather thin. The reason is quite clear. I am talking about what is perceivable, what we have perceived. And the fact of the matter is that if planets existed around any but the nearest stars, our best telescopes our best radio dishes, every other instrument we have, would be totally incapable of detecting their presence. Compare it for yourself, when you see the sun in the sky, is enormously blazing much easier to see than even the planet Jupiter of Venus at its brightest, right? If you imagine this whole situation at a place very far away from you, and the sun's blaze is reduced to that of a bright star, well the planets started out looking like a bright star, if you can imagine that the sun is reduced to a bright star, the planet is reduced to a completely inconspicuous object, dwarfed in the starlight on a photographic plate in a telescope. So there is no way whatever, directly to see the light of a planet, even if there were planets exactly like our own planets around all the stars in sight, with the possible exception of the nearest one or two, which we might be able to catch some glimpse of because chances are quite good at that distance.

On the other hand, there are means of detecting planets, available for the next nearest ten or twelve stars, not just seeing their light, which can't quite be done, once you get beyond the nearest one or two, but looking for the wobble in the stars position in the sky. You see we know very well that Jupiter goes round the sun and with him go the Earth, Mars, etc. Now you might naively think as Copernicus did in the first approximation, its a very good approximation, that sun is the very center of the solar system. That's not so. The center of mass of the solar system lies just a little bit off the mass of the sun, because the orbits of the planets as you know are not circles centering on the sun, but ellipses. There is a little bit of elongation in all those orbits, and so the Sun is not exactly in the center, only roughly in the center. And since it's only roughly in the center, it , too, moves in response to the motion of the planets. Since the sun is very heavy, it moves very little, the sun never moves in such a way that it goes around in orbit outside itself. It wobbles a little bit because it turns around just as all the others turn around, it turns around a point within itself. And if we can trace the path of the sun around the starry sky, there is a very tiny wobble in it. And we can see that wobble in the case of two or three of the nearest stars. And that wobble in the path demonstrates to us that these stars are accompanied by dark companions which we cannot see. These are not quite planets, I must admit that. They are too heavy to be planets. On the other hand the stars we are looking at are not very close in nature to the sun, they are rather far from the sun, much fainter stars than the sun. They just happen to be ones that are closest to the sun. You see, faint stars are more common than sun-like stars. And sun-like stars much more common than very much brighter stars. And these very common stars probably don't have any life. They don't' have any room for it, no planets. But they do have companions that are almost as big as themselves, one tenth or one hundredth as big as themselves. The biggest planet in our solar system is one thousandths as big as the sun. So while we can't be sure that there are any planets, we do have a couple of examples of object that are only a few thousandths as big as their local suns, and those are tolerably close to Jupiter. Of course we can't say that with it are a cortege of smaller planets and we don't expect life on anything like our own on anything but a rocky planet, a small rocky planet like our Earth, not a gigantic gaseous planet like Jupiter. Nevertheless the extension is very hard to resist. If you see some planets, there must be others, since the whole solar system seems to have reason to it. We don't expect independent origin, one from the other, we expect all planets were made together, there are many good arguments for that. They all go in the same direction, they have many elements in common, and therefore we like to say that if we see some planets we'd very likely see others. How many? We don't know know.

There is one clue. All of the stars that are brighter than the sun, hotter and brighter than the sun, spin furiously. The sun ought to be spinning furiously, too, because it was condensed out of gas in the galaxy. We're sure of that. And like the water that drains out of the bottom of the bathtub, which gets a slight spin and then spins faster and faster and faster, you see it whirling as it goes down the small drain orifice in a huge vortex, so the gas that comes from a rotating galaxy is collected into a very dense star from a very tenuous mass of gas must also begin to spin, it's already spinning. The whole galaxy is rotating very slowly, so it already has a slow rotation. Just as the water which imperceptibly rotates over the irregularities and edges of the tub. And as it gets turned into a smaller and smaller radius, it spins more furiously, so it should be with the gas that makes the stars. And so it is with the stars, they remember their origin in spinning gas and all stars spin furiously, except for those stars that are old enough and small enough without being too small to look like the sun. Those stars don't spin. Our sun doesn't spin. It spins a little bit, but instead of turning once every twentyseven days, if it held all the spin all the angular momentum that it once held, which the gas that made it once held, it would spin around once an hour, once every two hours. What has become of that spin, which we know from the laws of Newton is never destroyed and never created but must be preserved? That spin must have gone somewhere. Well, if we add up all the spin of all of the planets, that's where it is. They make up for their small mass by their big distances, so that the total effective rotation that they represent, the total momentum of rotation, of angular momentum, so called, is great. And the planets only have a thousandths of the mass, but they have ninety nine parts of a hundred of the spin. Now the stars we see like the sun have all lost their spin. The ones we see close enough to show planets or companions have got them. We don't know what's become of the spin of the others, we don't know if they have planets, but if they had planets they would have no spin. And they certainly have no spin. This is only circumstantial, it doesn't prove there are planets. But it enables us to say that unless circumstances are very different the loss of spin must have gone somewhere, into forming some type of gaseous discharge away from the sun, away from those distant suns, we don't know if it condensed into planets, but it certainly isn't there anymore, so it may well have condensed into planets, and depending on your point of view you could say planets are hard to form from this gas or easy to form, depends on your theory of the solar system, we don't have a good one yet. Such a one that we do have suggest to us that at least with a good probability it's a good bet that most of the stars whose spin is gone, most of the stars that lie in the center of that curve like the sun, maybe of the three hundred million maybe one hundred million of them have got planets at the right distance from

their star to be irradiated in an Earth-like way. So these are sun-like stars, with Earth-like planets, a hundred million of them spread out through our galaxy. We don't see any reason why they should not be just like where we live. Again, we have not seen a single example we can demonstrate. It was all an argument by our knowledge, an argument by uniformity exactly as was the argument by Copernicus and Galileo after him. Now the next slide, please.

This slide is a little dark, but I'd like for you to bear with it if you could, because it makes clearer than I can do with words what the distances are again. Because I point out to you the distances are enormous, we can see stars as faint telescopic objects, we have no chance of seeing planets. The left-hand part of the picture, that's fine, the left-hand part of the picture shows a symbolic  representation of  the same galaxy. That's our galaxy, and I drew a little square there to represent the region where we live in our galaxy. A little box. And in that box, that's a very small fraction of the galaxy, you see, in that box I've drawn to scale, are a hundred thousand sun-like stars. A hundred thousand in that tiny box, so you fill up the whole galaxy's space with those tiny boxes and that'd add you up to a hundred million or so, just as we say. Let me magnify that box by twenty times in all directions. The little box becomes like the box drawn in the middle of the figure. Now that box you must imagine with a hundred thousand dots in it. My draftsman is a patient associate and colleague, he can't draw a thousand dots but he can draw a few hundred which he did there, you must imagine that for every one of those there are a thousand like dust on the plate. Mind you the stars are very tiny in this picture. Don't think of the galaxy as shining bright with all stars, that's only an illusion of our imperfect eyes, our imperfect telescope. Between every set of stars is black sky, but our images distort and magnify the star so you don't see the black sky in between. But there's really black sky, just blackness in between the stars. And that's the same in that box. In that box, somewhere in there is our sun. It's so small that I can't even show it to you. So I magnify that, take a little piece of that box and magnify it by twenty into another box. And in that other box are only a few sites, I can't even read the number at the moment, though I can compute it. One hundred thousand divided by twenty cubed, I get to divide it by eight thousand, so there are about a hundred and  twenty no I guess about twelve, not a hundred and twenty, a dozen or so, a dozen or twenty stars in there which are sources. Now mind you this is a magnification of a little box inside the big box, and the big box a  magnification of a tiny box inside the galaxy, and we still have quite a few stars that are like the sun in that box. But I have drawn on that box a line, which perhaps you can see, a vertical line, and that line represents an interesting point, just to suggest how far along we are in space exploration. People talk about not the rockets of today, but the rockets of a generation

from now, run by ion motors. Driven by nuclear energy. You'll agree this is a far cry from burning liquid oxygen and gasoline, that sort of thing we have nowadays. This is what people are talking about and no doubt they will achieve it in ten years time or maybe twenty. Then if they take the best of such ion rockets, which is only twenty years in the future and they allow that thing to run for three hundred years it will then describe a line a path in the sky the size of that line which is drawn in that box, which was magnified by twenty to make that other box, which was magnified by twenty to make that that other box, which fits into the little tiny box in the galaxy over there. That's three hundred years of an advanced rocket which haven't yet seen. Just to give you an idea of how remote space is. Space is gigantic and all our physical means of looking into it are very limited. The only thing which carries for us across space with any kind of vigor and speed is one physical entity only, and that is light or its close parallel, radio waves. These things traveling at the speed of light dwarf all our mechanism and of course are capable of carrying information across the depths of space, exactly as well as material objects could ever do it.

Next picture please, I'd like to comment a little bit longer before we talk about this picture. You see what my argument now is so far, in these enormous depths of space there are a hundred million sites of star-like, of sun-like objects. Around these hundred million there is no reason to doubt that there are not very many Earth-like planets, we know of none of them, but the arguments I've given are fairly honest arguments as far as they go. These objects are so intensely far away compared to travel means that we can imagine or foresee, even late model flying saucers, that the hope of direct transport is really very small. I would not say zero, but I'd say it's very small. And it's fantastically wasteful and expensive of resources. The cost of a rocket to go to a star, a nearer star and back in just energy terms alone, just to buy the kilowatt hours of fuel energy, not to talk about any technical development or engineering or experiment, but just the sheer cost in power terms will be hundreds of thousands of millions of dollars. That is to say the whole gross income of a great nation to be spent on it. But if I want to send a message which will carry as much as I want by economical means, big radio transmitters and big radio receivers from star to star, I can get by with a dollar's worth of electric power. All the radio astronomy that's ever been done has been done with three cent's worth of electric power coming in from the stars. It's fantastically more economical to send power, to send signals than it is to transport.

In the old days, people traveled and exchange was important for the very stuff of life. In the

oldest time, the flint mines of England supplied the flint workers in France and all the way into Austria. In the mercantile time it was thought that trade and manufactured products were an indispensable means of foreign intercourse for nations. More and more are we clear that the dependence on resources is evening out. We have not yet reached that stage. Oil rich countries are oil rich. But the fact of the matter is that pretty soon, one day from now, the very sea water will be the source of energy. After that the need for oil will be much reduced. This is the whole tendency of technology, to substitute energy and understanding for any particular good. And if you ask, as the cost of transport goes up, for what reason transport would be economical, it becomes rarer and rarer. To go to Antarctica for any conceivable worldly good, coal or oil and so on, seems most unlikely today. It might just possibly be managed. To go to the moon seems improbable. The moon, mind you, is a twinkle of the eye away, compared to the nearest star which itself is very close compared to any sizable distance within the galaxy. So it seems to me that transport is simply remarkably improbable. There is only one thing that could get to a distant star which we cannot simply make for ourselves which it worth getting, which it is very economical to get if we use signals at the speed of light, and that is information. I believe interstellar travel will probably not be carried on ever, except conceivably for ceremonial reasons as the chief of state occasionally goes to shake the hands of another chief of state. Not because he's bringing anything with him, but just as a kind of gesture, a kind of symbol, a kind of sense of human intercourse which is better than any mere communication of messages. But we don't doubt that the presents with which the President takes to the Generalissimo are not in themselves worthy of the trip. And so it will be for interstellar transport. I think there is very little in that. But what I'm very much more concerned is, is it possible that there could be between sun and sun that there could be interstellar communication.

Now of course for communication its necessary that there be a live signal, a live transmitter, and a live receiver, something going on at the same time, allowing for the transit time difference, the light time difference between the two places. It does no good if we come into this world at a time which is different from our counterparts far away. If they live out their whole lives, their society's whole lives at a time different from ours, of course then we can never hope to communicate. We must cross time in order to communicate as well as space. This slide gives us some suggestion on what the time situation is like, and this is one of the remarkable parts of the entire argument which I am placing before you. I draw here against time, a very large scale of time, the horizontal axis, with a vertical curve of varying scales a few interesting phenomena concerning

our Earth as a function of time. The first of these, the outermost curve is the total mass of the planet Earth. Once upon a time there was no planet Earth, it was just some kind of gaseous region, then it condensed more or less gradually, formed the planet Earth and since that time the total mass of the planet Earth has remained more or less fixed, so you see the curve goes up, and then flattens out and nothing interesting happens. That's the most general thing of all, how much the planet weighs, how much stuff there is on Earth. All the earthquakes, changes of seasons, man's work, flows of ocean currents and so on, after all do not change the mass of the Earth, they just move material from one place to another, but it remains on Earth. We are changing the mass a little bit now by filling up some rockets, but you will understand that this doesn't change it very much.

Now let's ask another question, more interesting than mere mass, that's after all gross. Some of the mass on this Earth, some of the matter is a very different kind from the other matter. We recognize the two by describing them as quick and dead, as living and non-living. What about the living and non-living material on Earth? Well there was once upon a time where there was no living material on Earth, more than 3 or 4 billion years ago there was none. So on the bottom scale  at 5 billion B.C. at the extreme left and the present time 1960 A.D. on the right-hand edge of the scale, a very compressed scale indeed, I have represented time and a second curve shows the rise of life on Earth. We don't know exactly how, but it must have been something like this. There was nothing then something appeared, then it grew and inhabited all the oceans, and saturated all the oceans, that was the first step, and then about 350 million years ago in the Devonian time, life finally managed to come out of the seawater where it was born, and suddenly occupied the land. That was the second step. And that took a while and then the land was pretty well occupied and that hasn't changed much, the mass of life on land. That adds a little something to the sea, you'll notice the sea is still the principal seat of life, and then at the last moment, the grasses appeared and occupied the desert regions of the Earth, the steppe regions with dense forms of life and man finally tampered with that and added still more grasses in the form of the cereals, and all that makes the last little spike on the end there. This is about 50 million years ago, the beginning of modern biological time, when we have the fauna and the flora roughly similar to our selves, to our own time, the mammals and the grasses. So you see that curve is much tighter into the present. Life doesn't go as far back as the planet, of course. Now we go to the next curve, inside there, there I took a curve to represent something we might think of as being typical of life, typical indeed of man, fire. We think of man as having been given

fire long ago, the ancients thought by some giant Prometheus, we perhaps by some other means, but if you look into the question carefully it turns out, quite reasonably, fire is by no means man's invention. Of course not, forest fires, as long as there was only life on the sea, I think we could exclude fire from the Earth, and by fire I mean burning organic materials, I don't include volcanic heat, which is quite a different thing, they look very different when seen far away spectroscopically. But as long as there was only sea life, there was no fire. As soon as there was land life the danger of fire began and fire grew until finally when there were prairies full of grass, the forest fires were quite important. Nowadays we can estimate how much fire occurs each year that is not man-made in origin, and it's considerable, in fact most fire is of that kind. And fire from man's origin, arise as a sharp spike rather recently. So you notice the characteristic trend in these curves, the furthest from man, just the mass of the planet, that starts very early and is very steady. The second thing is life, that's closer to man but not very close, it started fairly long ago and rose rather rapidly, fire started still less long ago and rose much more rapidly. And now just to show something that is characteristically of man, I took telescopes. Now we know that in all the history of the Earth there were no telescopes, none at al l until 1600 A.D. which in that scale will not fit even as a pencil line from the right hand end, and then suddenly bang, there are all the telescope that there are, and the whole revolution from the first telescope to the present existence of telescope at every five and ten store, just in that large spike, we have no way of showing in that tiny three hundred year, which is one millionth, one ten millionth of the space, a draftsman is not able to draw a line fine enough to show just that, but that's an extremely sudden rise. Notice this characteristic feature, which I am trying to dwell on. Complex things, cultural things, arise on this Earth on the scale of geological time with terrifying suddenness, like an explosion. If you like, culture is explosively fast, it rises suddenly. Now we don't know how long we'll last, but it certainly rises with enormous suddenness. Now consider what this means, on all those other stars on all those other planets, if there is the evolution of culture, of course we can't say there is, I only appeal to the laws of Copernicus, to the point of view of Copernicus, if there are a hundred million places like this, why should we be so singled out? We can't prove that's not the case, but on the whole questions certain to be raised, I'm not here to discuss the probability of that point, what I'm really here to discuss is how we might find this out?

That is an important question. And what I'm saying is the rise of culture, technologically sophisticated culture, I shall not say intelligence for that's another problem, but culture, that is to

say, machinery to change the environment, telescopes, gasoline engines, computing machines, whatever you like, that would come to any society, to any planet if we are right with any of these arguments, with terrifying suddenness. Now the point is if there are 5 billion years to wait, why should that spike occur exactly 1604, that means 1604 years out of 5 billion, could anything we said that it did happen 1% faster somewhere else? If it was 1% faster somewhere else, then that curve, that right-hand curve would have occurred an eighth of an inch on that slide a little further to the left. Or suppose it rose with suddenness 1% later, then it would have occurred to the right an eighth of an inch. In either case, you see what that means. It means that given two stars that are not synchronized precisely by stopwatches, their lifetime is very long, the time when they arose to culture if they ever rose, any of their planets, will differ [in the star uniformity in time?] and you can quickly compute, then, that on the average if we can put all the places where culture will arrive, it will occur on the Earth most probably earlier than 50% of them, and later than 50% of them, and that's the best argument we can make. There is no reason to believe there's any kind of synchronization. The most powerful guess is that if there are a hundred million places where technology has or will arise, it already has arisen and gone on for a long time on 50% of them, about. Because there's no reason to be synchronized and the time of exchange is very rapid, compared to all the other changes, so spreading it about uniformly in time will make no difference in its history. And therefore we can be pretty sure, that if there are any sites worth communicating with, the expectation is they have long since attained our stage of interstellar communication, which is we have just about let ourselves be known by our best radio methods to stars ten and twenty and a hundred light years away from us. That's a tiny reach out into our galaxy.

But if all those other fellows, if they do exist, could probably let themselves be known very much farther than that because we know the extraordinary rate with which technological possibilities increase. Therefore we argue if they obey logical means of communication, it's most probable that already among the hundreds of millions of possibilities, there are some, we don't know how many, it might be none, it might be tens, it might be hundreds, it might be millions, it might be hundred million, already communicating. The only question left to ask is how long does this communicative state last? If it lasts zero time, then there are none but us, if last ten years as it has with us and we've lit us up since the ten years after we've discovered radio astronomy, or twenty years, [as the numbers aren't making it up?] That would account for why there's only one of us and no other colleagues. If our society lasts a thousand years we can compute there'd be

a hundred. If it were to last a million years, or ten million years, or hundred million years, always with the technical capacity at least as great as today, this would tell you how many more neighbors there would be at any coincident time, and yet existing in space in the same galaxy. And that's the question we can't answer.

So we raise the question, what are the physical means of communication, which is the best one, how could we communicate, what is the most economical means of communication, and when we learn that, when we decide upon that, let us bend our efforts to listen to those communications, to detect those communications, because very likely already exist in the communicating intergalactic community, long since established, waiting not very impatiently for an occasional new member. Probably the most excitement the anthropology departments of those distant places gets is when a new planet is heard from. Another Ph.D. in anthropology. Because of course it would not be the first time, if this is right, there must be a hundred million other examples, and there's no reason to think the next one is any more exciting, any more than the next thesis is very exciting. But it has some excitement. And think of the extraordinary galactic library that with communication would exist. Mind you, this is all predicated upon a problem we don't know, we've opened the question, let us search among the possible stars by the best technical means we can, to see how likely this number is, in other words the main uncertainty is first how likely is life to grow in an earth-like planet, how likely is life to evolve to technical capacity, and most difficult of all how long will technical capability last? And you can ask these questions as you will? I have no pat answers. I can give prejudices and arguments. But I think that all we can say with the principle of Copernicus, it seems most unlikely that there is none, that the hypothesis that there are some is worth making, and that the test is in our hands. We have but to find out the best means of looking and to look.

And of course the implication is we listen, since listening is much easier than sending. It's much cheaper to have a radio receiver than it is to have a broadcasting station. And all we do is listen, we listen for a while, effectively and we shall try it out. So far the total effort of the world has spent in competent listening has been about two weeks by one station, to three stars, and none of them happen to be sending. Well, we feel we should search a million sites before you give up, and a million is a long way away from three. So the situation is rather parallel to asking this question, "Are then any Americans who expect in the next few years to go to the moon?" And you ask your three neighbors and they all say no and you conclude therefore that no Americans

are going to go to the moon. But this is probably not right. If you ask enough Americans you'll find about twenty who expect to go to the moon, and that's just the number there is. So we feel unless you ask a few million there's no reason to give up the fight. And therefore since we've only asked about three, the investigation is just beginning.

Now let me make one further comment and end with just my statement of how things stand. The comment I'd like to make is how would you possibly communicate? Suppose there were technologically competent beings in another planet, not unlike our own, around a star not unlike our own, with technical capabilities very much better than our own, with a long history of use of radio and microwave, and laser and for all I know neutrino telescopes, how would they choose to send? The argument is very simple, they would choose the most rational, economical means which is earliest discovered by primitive beings like ourselves, because they'll want to communicate as soon as possible, no point in waiting for us to become very sophisticated. They could have helped us much in that effort, and what they probably used to is people not like themselves but people as different from themselves as they can find. They know all about stars, and evolution, and all about radio waves, and all about nuclear physics. What they don't know about, of course, is Japanese history, they've never heard about that at all. It will be fascinating for them, there is no way to make that up. It's easy to show on statistical grounds, that the number of possible histories of intelligent beings is very much greater than any possible theory of physics could lead to. So naturally that's the thing that will be novel to them and we believe that if they're anything like ourselves, if they have anywhere near the same technical capacities, they'll be interested in novelty, they'll be looking for novelties, so they'll be out looking for us in the simplest way. If we want to go to the shores of New Guinea and communicate with the people, we don't go there and set up a TV station and wait for them to set up a TV station to talk back to us, I think you'd go there and stand on the beach with a drum, you're quite sure they can detect a drum. And they'll pay some attention. That's what these people are doing, they are drumming for us in the most simple-minded way that is capable of reaching across space, and that is probably the radio band. So we think that from many stars beamed toward us as a likely site of life, but not yet sure, there may well be beamed radio signals containing a code that well make clear to us, that it's a technically competent, intelligent transmitter trying to make communication with us.

Let me ask the question, what kind of code could it possibly be? I think it'd be a code based on

mathematics. The argument is very straight-forward. The next slide will show something of what I mean. Here is the way you can send mathematics. Look at the general picture here. I want to make a convention, just for saving time, don't forget that pulses of radio or light can be sent very rapidly, much more rapidly than the human perception can possibly manage and still be quite well recorded. Even your very television set receives about two million signals per second, far more than we can ever detect. Now therefore I'm going to represent this, in order to make a long story short, I'm going to abbreviate the pulses by in the top line showing an arbitrary pattern of quick pulses, which I represent as a pattern block A, whenever you see Block A I imagine that that particular sequence of pulses has been repeated, there might be a hundred pulses in the characteristic pattern, it doesn't matter what pattern, just some characteristic pattern. A similar but distinct pattern would be block B, then block C, then so on. And every time you see Block A or B, you mean that collection of small pulses has been repeated. Now the other thing in the graph is a square pulse, of signal, just on, duration, then off. Dash dash. Look at the second line. Dash a dash dash b dash dash dash C is meaningless. The next slide, dash dash dash dash. Pattern b dash dash pattern A dash dash. Can anyone possibly give an interpretation of those, and mind you that's only two messages, it's clear if I sent a hundred, and that instead of just thinking here rapidly you get to talk to your colleagues and spend two days working it out there is simply no doubt you could decode this or many more abstruse patterns which I have bothered to give you, this is straightforward and could be done, and probably some of you by now have got a solution for this pair of patterns? Can anyone offer me a solution that works? Yes?

[unintelligible audience response]

That's right. I think it's very clear if A is read plus and B is read equals, then these two lines cover ordinary algebra just on the order of positive integers: 1 plus 2 equals 3. 4 equals 2 plus 2. And you see the AB and BA in the number pattern gives it to you right away. Now as I say with two it's not absolutely obvious, but that's just the exigencies of transmission by slide. But if you have radio and not just an amateur effort of 30 seconds during a lecture you can imagine the kind of interest to be surrounding this kind of thing, a hundred of the cleverest most experienced cryptographic people looking at this anti-cryptography, that is a coded message sent by someone not actually to conceal his thoughts, but anxious to reveal his thoughts by the best possible means, I call that anti-cryptography. It seems perfectly plain he could make very clear such algebraic messages. OK, you say, but it's not very interesting to learn 2 plus 2 equals

4 from a distant star, it's not worthwhile. Of course it's not worthwhile, but I think it reveals the main point. Signaling requires something in common and that one thing which may most be in common between one part of the universe and another, is mathematics, pure logic. And therefore if we send what we know, to each other we can establish a language by using it on the obvious common things. And then using that established language branch out into novelty, that's the whole idea. And we just worked through an example that would work quite well.

The next thing, having done ten of those, a hundred of those, a thousand of those, it would simply take a millisecond, until there's simply no doubt that it's algebra, and it's all clear, we have plus, minus, times, equals, anything else you want to put in to make it complicated, it's just a question of the economy, everything can be done with the four operations of arithmetic if I repeat them enough. So then these people send a series like the one down below, and send that series an infinite series indicated by the first twenty terms, and then another series, which doesn't mean the same thing, and another series, and another series, and another series, but when you look at all these series, you may for example find that all of the series are expressions of the number Pi, 2 pi, Pi over 4, pi squared, and so on. What would you think of if you saw that repeated ten or twelve times? Most everybody would say Pi has something probably to do with circles. Now the next step of my game is the following. Instead of sending algebraic symbols, the whole nature of the signals would change. Now the signals would consist, I'm afraid I didn't bring the right slide, is that the final slide? Can we see the last one if that's not it. OK, thank you, lights. The only difference in the picture would be this: these pictures are all characterized by one thing, a lot of pulses whose patterns are relatively non-repetitive, but the spacing in time was just the same. That looks like digital pulses always. Like symbolic stuff. But suddenly the picture changes, and I send you pulse pulse, very quickly, then no pulses at all, then pulse pulse, rather stretched far apart, then nothing at all, then a pulse and another pause and another pulse, and then still a longer pause between two pulses, then still a longer pause between two pulses, then still a longer pause between two pulses, and now a slightly shorter pause, a slightly shorter pause, two pulses, then slightly shorter, then slightly shorter, then slightly shorter, then very quick together pulse, pulse, then finally just one. Then none, then I start the whole thing over again. In between algebra with plenty of Pis in it. What do you think is going on? Not very hard to find out. I think every cryptographer would quickly jump, these pulses with space between them aren't meant to be interpreted not digitally, but geometrically. If you start plotting the space between the pulses, and very soon you would find that these two pulses correspond to a circle drawn by crossing it with a horizontal line. So I see two pulses

close together. That's how your television set draws a circle, it makes a pulse pulse, then jumps back and makes a pulse pulse a little further apart, then another a little further down, a little further apart and so on. Well that's just a trivial example. Now just imagine more formulae, a squared plus b squared equals c squared. What picture would you expect to see? You can imagine some squares within squares or a triangle, with squares on its three sides. And it's clear that a few such algebraically mathematical things would convert to geometry very nicely. But once you have converted to geometry you see what you have learned? You have learned how to convert pulses into pictures by a systematic rule, which you would follow every time, exactly like a television set follows a rule. I don't care what the rule is, it could be scanning straight lines like a TV set, make a spiral going outwards from the center like an imaginary TV set. It doesn't make any difference, any mathematical rule would work. Once you've seen many formulae and many graphs coming from those formulae, the chances are you'll understand the next thing you'd see, which are very complicated pulses, will not be mathematical formulae but something that is translated out by the geometrical rule of turning the pulses into a picture. And of course, once I have a picture, which could be 3-D for that matter, I leave the rest to the experts in elementary school teaching and kindergarten, who certainly will be able to tell me how to communicate a language by showing pictures of someone speaking, using objects, using mathematics, using all the means he can, and I feel rather sure that five years of watching such pulses we would be able to interpret that work better than we can interpret Sanskrit today.

And I think that's all it amounts to, and on that channel then would the remarkable lore, probably the first thing would be to show us how to build better transmitters and receivers, that's usually what's done. In fact you know how the signal would work; I think the signal would be interleaved, because we see that signal today. If you listen to a radio station quite objectively, pay no attention to the program, what do you hear on a radio station? I claim you'd hear the following sort of programming, and there's a very good reason for it. At regular intervals there is a stereotype pattern which occurs, I do not mean the used car commercial, but what I mean is the station identification, right? This is wnbm, New Bedford, if that's right, something like that and that would occur every fifty minutes or every half hour. Maybe every ten minutes will occur something else, rather perhaps every hour there comes a time signal, that sort of thing, and in between the wildest variety can occur, the signal repeats every once in a while to tell you what you're doing, to let you in on what's going on. And I think that's exactly how the signal would be. Every once in so often would be this simple algebra to give you the language, then in between would be more elaborate introductions into language, and in between that would be completely

new material, which you would have no chance of interpreting it the first time you hear it, but you store it away, you record it, by the time you've heard five consecutive years of the language lessons you could say, "Of course, I can go back and read that first material". Thus in this way no time is wasted, yet nobody spend an enormous time with material he can't possibly understand or recognize as an intelligent signal. So a simple recognition signal, this algebraic kind would occur very often, but would only occupy a short fraction of the time, in between a language lesson, in between that new material, in between that, most recondite of material, and finally after going through, you can work back to all your records, and you'll have a gigantic library displayed. This I think, is the kind of signal that I would rationally send, if I had such a channel.

Mind you such a channel will hardly brook of answers, it's one way communication as far as human life goes or even organism even rather remotely like human beings, because the time transit, if there are a million stations in the galaxy, a million of those stars, if one percent of all those possibilities hit, and hit our time, then there will be a million stations, that means the stations are a thousand years apart, and that means any signal would take two thousand years to get an answer, so an answer to someone that doesn't expect except socially. That I think is no great impediment. People often say, "That's impossible. No useful information can be transferred in such a channel." But I deny that, I can give an example. The library of all Greek thought is contained in about ten thousand books. We will never have any more ancient Grecian works. You will never be able to ask a single question to Socrates or Plato or Pericles, or any of the great writers of the past. That has not prevented them from having an important influence upon our very lives, transmitted to us through the benefit of a few scholars who study patiently and carefully those manuscripts and tell us what's in them, write them out, each generation in its time rereads them and re-interprets them and so on. If we had a constant growing body of material, thousands of times that rich, from people we could never answer, perhaps only in posterity could answer, I would say that's at least as rich a source as the Grecian writings. We'll never answer the Grecians, yet we find them interesting , important, and valuable guides. I think we could have a channel we could eventually interrogate, not us perhaps but our distant posterity, and I think that would not make it less valuable, but more valuable even, than the work of the past. So I feel that's no embarrassment, I don't regard that as serious at all. The real issue, then remains, is there a way, are we alone in this extraordinary galaxy, of all the two hundred million possibilities for suns and planets, are those two hundred million suns wasting away their radiance forever on empty space, are they wasting it forever on sterile planets, or

have those planets quickened to life, has life evolved in all its complex ways, have among those complex ways of life those developed who could modify their environment, a most successful way of life as we know? And has that complex way of life evolved to control its environment, again with great success? And has it maintained itself, has it lasted, has it endured for some time. The time of endurance determines the number, that's all. I make no brief; I don't claim to know the answer. I claim there's a logical connection and what we must do to find out is listen. Listening is not easy. It means establishing devices, finding out first the right way to listen, what frequency band, what kind of signals, we haven't established it yet though many people are talking about it. I think in a few more years' time we'll find people have a consensus about the best thing to try. Set up mechanical devices, probably automatic in part, which will search patiently week after week, star by star, millions of distant stars, looking for the kind of signal that would tell us that there is someone trying to gain our attention. That, I think, is the position this faces.

I'd like to close with two remarks. First, while logically speaking, I admit that the famous cause célèbre of our times, the flying saucer bears some kind of remote resemblance to these arguments, I myself feel it has absolutely nothing to do with it. I don't think the saucers, I think the saucers are real objects, in the sense that there are lights in the sky, planets, a thousand different distorted things, but I don't think there is any plausibility to any of the more fanciful stories which go to suggest that while I don't know that to be true, that's just a working hypothesis. But I believe firmly I'm prepared to see other evidence, so far I've seen none. But all I'll say is space is so deep this is not the communication which we'd expect. The communication we'd expect is a subtle one, an inexpensive one, a very rich one, bringing untold information. Much more than the gossip and the 1957 Buick design, which is all we've learned from the flying saucer enthusiasts. And this is about where I stand.

But it's clear to me that unless we make this effort to look, we shall never know the answer to the remarkable question, whether we are alone in this gigantic galaxy? Whether above us in the galactic sky there ought to be an arrows saying, "Here is something remarkable." Or whether we too are part of the same democratic emptiness of space, in which there are embedded here and there beings unlike and yet strangely like ourselves, with who we might someday hold useful intercourse. This is an old idea to dreamers and scholars, it is a new idea only in the sense that I think in modern times we raise the question not in philosophic speculation, but for a simple clear test, empirical test, can we find out? And we are beginning to suggest ways to find out. In

Prague, next summer, I hope the International Astronomic Union will take up the question of international program, slowly, cautiously, moderately beginning a search, which will take a long time, a search which will not be over in years, it will not be over in decades, we've gone so long without knowing, we may have to go another century or two without knowing, but sooner or later we will know either there is very little chance or else we will have made that important contact. In the thirteenth century, the Chinese scholar Thun Mu thought about these matters, and he said this, he said, "The stars are as many as the leaves in the tree, or the trees in the forest. If the, is it likely that there are no flowers in the forest, if we are a flowering plant among the trees? Is there no other world, no other tree like our own?" It was as absurd to think that, he thought, as it was to think there was but one person in the kingdom, or one leaf on a tree, as there would be but one world unto which a sun shone.

[applause]

Jadish Mehra: It is very exciting to speculate with Professor Morrison. There is a finite probability that life exist in other parts of this universe. That this life has already evolved its own Aristotle and perhaps the music of [Atusi?] Are there any questions, please? Yes?

Audience member: I have a pair of questions. First what is your theory of origins of the universe? The big bang theory or [inuadible]? And two, suppose that we ever contact life in the universe, what will happen to organized religion as we know it?

Philip Morrison: Well, those are certainly big questions. I'm not especially competent to discuss them, but I could make a few remarks. First in the question of cosmology, I like to emphasize that all that I've said tonight has nothing to do with that, would you agree? I don't care where the galaxy came from, from this point of view, here it is. There is no argument about it. Nobody disagrees that there are 10 to the eleventh stars and that's that. So the actual cosmology is not very important. I happen to favor, I don't know, I don't think we know what the cosmology is but I suspect we are not in a position to say which one is right. That's the only thing I would say. Probably a hypothesis we have not yet thought of is right. As for religion, I don't know, I guess it depends on the organized religion. I, uh, I'm sure that, I quoted from a Buddhist scholar from a thousand years ago. It's perfectly true that Thun Mu would have welcomed the whole proposition. Now up to you, professor [Vile?] said that its perfectly true that this sense that Earth is but one planet among many somewhat reduces the level, the notion that we are the footstool,

the very footstool of the deity that watches us very carefully as his only wards, it's perhaps hard to maintain. But I don't think anything very serious even in the tradition of the Western religions would change, if you said we are just one of the many possibilities open after all to a deity of infinite power. I think that I'm no theologian but I guarantee you'd be able to put that into anybody's theology. So it seems that it's not so much organized religion as human pride that stands in the way of accepting this point of view. But in any case, I'm not prepared to argue the question. I just say, "Let's find out." Then we'll know, you know. It's an empirical question, can be answered.

Jagdish Mehra: Yes, please?

Audience member: Would you say that the stars originated out of the thick blackness of space? And if so, could we say that the origin of life, that is to say life itself originated out of the darkness?

Philip Morrison: Yes, I think that's a very poetic way of putting it. An insight from the oldest literature we have says very much like that. But it's perhaps not quite so poetic from a physicist's point of view, the blackness of space that you talk about is a thin gas. And when a thin gas is brought together it's capable of glowing. And that is what we think happens in the stars. But if you like to relate that to the more metaphorical accounts from Mesopotamian literature, why certainly it's quite alright. It's a very nice way of putting it.

Audience member: Speaking about the probability involved, there are one hundred million stars, which could possibly have life-giving planets, and the probability that life will arrive given maximum conditions is one in a million, then you'd say the probability is pretty good then that we'd have life. Suppose that the probability that life can arise at maximum conditions is ten to the 15th, then you would say that there is only one chance in, what ten to the eighth that life will exist in our galaxy.

Philip Morrison: Yes.

Audience member: Is that right?

Philip Morrison: Right.

Audience member: Isn't there, I mean, I suppose there are people studying what are the probabilities that life will arise under maximum conditions. And the there's another probability that has to be considered. What is the probability that once life arises that a reasoning type of life like ours will, rather than an insect type life which perpetuates itself? It seems to me that the probability that this kind of activity will result in something good may be pretty small, when you take into consideration all the other possibilities.

Philip Morrison: Yes, it's an unsolved problem. I quite agree with you. Until we have a theory which tells us the answers to these questions, we can't make a sure calculation. So I agree with you, one of the things to find out is how probable is it for life to rise out of good conditions, how probable is it for life to evolve, and these are things under active study. I must say that if you ask around the experts in these fields you get of course different answers, but the consensus is if the conditions are favorable life will arise all the time. If the conditions are favorable, life will evolve elaborately. And the only place where we begin to fall off from probability one, is when you say will this life evolve to such complexity that they'll be able to manipulates the environment and have a technology. And there they begin to differ. But again, at least half the peopl e say, "Yes. It's extremely likely." The argument being, life seems to spread and do everything it can do to make a living. There is no place where it's stopped. You find life from the highest mountains to the depths of the sea. Right? You find it in all sizes from the [unintelligible] whale from two hundred tons, down to the bacterium of 10 to the minus 12 grams. And you find it from every level from the very slow lichens with last hundreds of years, and don't have any type of quick response, a symbiosis between alga and fungus, up to man, a very sentient, complex being. And my argument is simply this, the self-evolving tendency, which is characteristic, careful selection and transmission, works in all ways, and I see no reason for it to stop if it can work, and we know that making a living, in quotes, by having a powerful internal model of the surround and you can modify to outguess what the surround is going to do, is a very successful and powerful way of making a living. [unintelligible] for example, Gigi Simpson or David Devore at Harvard, debated this very often and they're good biologists and they say, "Nonsense, everything depends on some tiny chance. If the lungfish had had one more spine, he couldn't have walked out onto the African mud and there'd be no land-breathing animals." But I find that absurd. It's the same old question that arises in all kinds of studies of human history, like the history of the world. If Cleopatra's nose had been an inch longer, the whole world would have been different. Well no doubt the history of Cleopatra and Marc Anthony and

Rome would all have been different, but do you really think the whole thing would have been different? No. I think that fifty or a hundred years later, something else would have happened that would have been in a similar way. Same with the lungfish. There was the land, available for life, no life on it, not a bit, but weathering was producing nutrients and plenty, sunshine was there in plenty, living forms all about the sea being blown ashore, drifting ashore, sooner or later something was going to find a modification that favored expansion on that shore, and it was going to do it, it happened to be the lungfish, I couldn't predict it would be the lungfish, nobody could. It depended on a special trick, and you look backwards it looks like a miracle you see, you know how it goes, but it was a miracle only for that one case, but no one said how many cases were possible to do the same job? And I would argue that if there's a way of making a living, that's not barred by the continuity of life, you know, life has to evolve from previous life, so it has to have a continuity, if the continuity allows you to find your way to a new niche, a new environment, you're going to do so. There are innumerable examples of that. None of these people would predict the hummingbird, or the orchids that simulate moths, or moths that simulate orchids simulating moths. I know they wouldn't predict that, but there it is. Why did it occur, because it could occur. And I feel that pressure is very great, so on the whole I would doubt very much that there is any place were life is maintained for hundreds of millions of years, that has land and water, I think that's important, if you have just water, it probably doesn't work, if you have just land it probably doesn't work, mixed land and water I think your going to find beasts very like ourselves. No by very like ourselves, I don't mean five-fingered, six feet high and so on. I mean somewhere between three and fifteen feet high, somewhere between one and fifty tentacles, some color between violet and red, because all of those things are not essentials, but the essentials I think will be much the same. That's an opinion. I can't prove it, our theories of biology are not good enough, but everything in the Copernican point of view suggests this is right. It doesn't prove it, that's why I say this is an empirical matter, we ought to take a chance and spend a certain amount of effort to see who is right in this great debate.

Jagdish Mehra: We are holding a reception in honor of Professor Morrison. On behalf of the president of SMTI we invite you all to the north Dartmouth campus of SMTI in the north lobby, second floor. We are having coffee and donuts. See you there.