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"Planetary Exploration (Lecture Two)"

Carl Sagan

Carl Sagan, "Planetary Exploration, Lecture 2"
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RALPH STEETLE: Good evening, I am Ralph Steetle, a member of the Condon lecture committee and along with Dean Carl Dittmer and the faculty of science at Portland State College, one of your hosts for the Condon lecture committee. Those of you who were in this hall last night, heard a full and complete and proper introduction of our Condon lecturer, Dr. Carl Sagan, from Condon committee member Dean Dittmer. But I would like to remind those of you who were unfortunate enough to have missed last night, some of the background that our lecturer brings to Oregon with him.

After receiving his doctorate from the University of Chicago in astronomy and astrophysics, he has been among other things a Miller research fellow at the University of California, assistant professor of genetics at Stanford Medical School, Alfred P. Sloan Fellow at Harvard, an experimenter with the Mariner 2 mission to Venus, a consultant to NASA and the National Academy of Sciences, and during the past six years he has lent his wisdom and knowledge to Harvard and the Smithsonian Astrophysical Observatory. The geologists here in the hall tonight honor the man for whom these lectures are named, Thomas Condon, because his influence brought Oregon geology into the public domain out of the exclusive interest of the scientists, and into the general interest of the public as a whole. Our Condon lecturer tonight, Dr. Carl Sagan, by his thoughtful and human scholarship, is helping to bring the planets into the public domain. Dr. Carl Sagan will continue his lecture on planetary exploration.

[applause]

CARL SAGAN: Thank you very much, Mr. Steetle. Well, yesterday we only got as far as the moon and today I want to zoom through all the planets. I will start at Mercury, might just as well start with the nearest and go outwards, and I will try to give a brief description on what it is we know, what some of the major mysteries are about Mercury, Venus, Mars and Jupiter. And I will then try to summarize the sorts of scientific knowledge which planetary explorations can be expected to bring us, and the kinds of social and political significance that such an age of planetary exploration implies.

Well, let's start with Mercury. Mercury is very close to the sun, is a difficult object to see, certainly with the naked eye, even with a telescope, simply because it’s so close to the sun. It’s even said that Nicholas Copernicus died without ever having seen the planet Mercury, which… whose orbit he had calculated. The first slide shows you three drawings of the planet Mercury. These are made by the same observer of the essentially same regions of the planet. This feature, is this feature, is this feature. And notice that there are some significant differences even from drawing to drawing. Well, these are hard drawings to make, yet if you observe how long it takes for a feature to appear over one planetary limn or edge, and reappear over the other, you should be able to get an idea of what the period of rotation is. Lights, please.

In this way the Italian astronomer Giovanni Schiaparelli made a calculation and determined what the period of rotation is on Mercury, and he came out with a period of 88 days, which is just the period of revolution. Put another way, he concluded that the day and the year were of equal length on Mercury, and therefore that Mercury always kept the same face to the sun. And this then led to all sorts of nice statements in encyclopedias and astronomy textbooks about Mercury being both the hottest and the coldest place in the solar system, the side facing the sun of course being the hottest, because it was so near to the sun and always received the sunlight, and the side away from the sun being heated essentially by starlight and so it's kind of cold. Well, it turns out… we can have this light off. It turns out that Mercury is neither the hottest nor the coldest place in the solar system. And in fact, it doesn't always keep the same face to the sun.

Well, what's wrong?

It was understood why Mercury *should* always keep the same face to the sun. It has to do with the kind of tidal breaking which the sun exerts on Mercury. It's the same kind of thing that's responsible for the fact that the moon always keeps the same face to the Earth. George Darwin, the son of Charles Darwin, had calculated these tidal couplings, and it was clear from theory that the answer had to be 88 days, the observation supported 88 days. Several generations of French astronomers demonstrated that it was 88 days. If there was sort of one sure fact in astronomy, it was that Mercury was in synchronous rotation, the period of the day equaling the year.

Well, the development of radar astronomy permits periods of rotation of planets to be determined in totally different ways. For example, a radar pulse can be sent out to a planet and as the planet rotates, the Doppler effect changes the wavelength of a narrow pulse, so that one edge because it's coming towards you, shifts the wavelength in one direction, the other edge of the planet because it's moving away from you, shifts the wavelength in the other direction. And so an initially narrow pulse is spread out in frequency. Well, when this was done at the Arecibo observatory in Puerto Rico, it turned out that Venus—that Mercury had a period of rotation of 56 days and not 88 days. And what's more, the error bars were small. Well, clearly the radar people had made some mistake because everyone knew it was 88 days. And so all the radar people had to scratch their head. It was very embarrassing, but the more they looked the cleaner the 56 days seemed. Then it became necessary to look back over the old optical stuff, and then it turned out that all the drawings that have ever been published were *also* consistent with 56 days. The visual astronomers had neglected to mention that this was also a solution of the observations. So this kind of gives an indication of the question of uniqueness in science. The mere fact that a certain hypothesis is consistent with a certain set of observations doesn't prove it's true.

And it's most important to see which other hypotheses are consistent with the same set of data, because it might be possible to make an experiment to distinguish one hypothesis from another. Well, 56 days turns out to be also a kind of tidal locking and involves a 2 to 3 ratio of the periods of rotation and revolution. And that means that there's a kind of periodicity in how the sun rises and sets. Also, the orbit of Mercury is very eccentric. It's not a circle, as the orbit of the Earth is, but it's very elongated, which means sometimes Mercury is rather close to the sun and sometimes it's rather farther away. As a result, what Mercury does in the sky—that is, what the sun does in the sky of Mercury—is different from what the sun does in the sky of the Earth. Let's imagine that we live on Mercury. Now, we're going to look up and see the sun rising and setting, of course, it will take some time for it. But let's think about what happens during a day on Mercury. Suppose you live at the place where the sun is overhead at perihelion. That is when Mercury is closest to the sun. You then will observe the following: the sun will rise small, and gradually swell as it rises. It will initially be moving fast as it reaches the zenith over your head. It gets the largest it gets, quite large, several times larger than here. Then it stops in the sky, like the Joshua scene… after stopping… [laughter] it then moves a few degrees in the sky back, stops again, then continues on in the initial direction moving more and more rapidly, shrinking, and then it sets.

Now suppose you live at the place on Mercury that's 90 degrees away in longitude. What do you see? The sun rises big, pauses, and then sets. Then it rises again, kind of in earnest, and shrinking in size as it moves to the zenith, moves faster and faster, absolutely bombs right through the zenith, slows down as it reaches the other horizon, gets very large as it sets, then it sets. Then it rises again… [laughter] looks over to see what's happening, and then satisfied, it sets again. So now you can imagine. It's very unlikely that there's life on Mercury, but it's fun to imagine that there's intelligent life on Mercury you see, and some guys live at the one longitude and some guys live at the other longitude; each of them, of course, has their own cosmology… and then they begin to expand, and then they meet and they say, “The sun does this.” The other one says, “Nonsense, the sun does this.” Can you imagine what a terrific dialogue that would be? [laughter] And you know, each group would execute the other and they'd be a holy inquisition and all like that.

Well, at intermediate longitudes the sun does even more complicated things in the sky, right? These are the two simplest cases I've mentioned. Now the heating of the surface of Mercury depends on how long the sun is in different parts of the sky. If the sun is overhead and large for a long period of time, it's going to get pretty hot, and if the sun is small and moves fast, it's not going to get so hot. So the kinds of temperatures are going to be different from here. It's not going to be so simple. It's gonna be complicated.

We can calculate the insolation, the amount of sunlight that's going to be absorbed by the surface material on Mercury, and we can solve the heat conduction equation and see how this sunlight, due to this complex motion of the sun in the sky, will penetrate the surface of Mercury. We can then test these calculations, because Mercury is a source of radio emission, and the radio radiation that comes out of Mercury at different wavelengths comes from different depths. The longer the wavelength the greater the depth underneath Mercury’s surface that the radiation comes from.

So in this way, we've been able to reach some fair agreement between theory and observation. The next slide shows us a graph of the brightness temperature, the vertical axis. That's the apparent temperature at Mercury, at the subsurface level from which the radiation is coming. This is radiation of wavelength two centimeters, it’s short radio waves. And along this axis is the phase angle. It tells you what phase Mercury is in. Full Mercury, crescent Mercury and so on.

The vertical lines are the observations at 2 centimeters wavelength on a particular time of a particular year and the solid curves are the theoretical calculations for three values of a certain quantity which characterizes how well heat is conducted on the surface. You can see that the middle curve matches the data pretty well, certainly not perfectly but well enough. Two-thirds of the points fall on the error bars. Well, that then tells us something about the conductivity of Mercury, the surface of Mercury. It turns out it can't be anything solid. It must be dust; fine particulate matter in a vacuum, and that suggests that Mercury is quite similar to the moon. In fact, Mercury has a very low reflectivity. It's extremely dark, just as the moon, and it has other optical properties quite similar to the moon. The surface of the moon and the surface of Mercury are probably quite similar.

The next slide shows the predicted temperatures over the disk of Mercury at the surface. Infrared radiation comes from essentially the surface. These are in degrees Kelvin; 273

degrees Kelvin is the freezing point of water. Well, the only point I want to mention is that the coldest spot is right under this arrow down here. It's 92 Kelvin. The hottest spot is right under here, 694 Kelvin, and these turn out to be neither the hottest nor the coldest spots in the solar system.

Lights, please.

Well, Mercury has no atmosphere so far as we can tell, no reason to believe there's any liquid water or any other kind of liquid anywhere on it. The prospects for life on Mercury are very grim, but it's certainly a very fascinating place, in part because of the peculiar sort of choreography that's responsible for the motion of the sun across the sky.

If we move on from Mercury to Venus, we come to a rather different sort of situation. The next slide compares two terrestrial planets, Venus on the left and the Earth on the right, both in crescent phase. And you can see, these are rather comparable pictures, not exactly, there are differences in various photographic parameters, but they're reasonably close. You can see that in the case of the Earth, the cloud cover is about 50% and underlying surface detail can be made out. In the case of Venus, the cloud cover is essentially a hundred percent, and no detail at all has ever been visible at ordinary… at the frequencies of ordinary light. This is a 200-inch telescope photograph of Venus. Terrifically high resolution. You can see what an awful waste of time it is photographing Venus in ordinary life. You could spend your whole life getting terrific pictures and never learn a thing about Venus.

Lights, please.

Well, there's a long history of speculation about Venus. For example… for example a Swedish chemist about the turn of the century argued as follows. He said, Look, you can't see a thing on Venus, so there must be terrific clouds with absolutely huge cloud cover. What's the clouds made of? Well, everybody knows clouds are made of water. It's an absolutely huge amount of water. Since there is an absolutely huge amount of water in the clouds, there must be a huge amount of water on the surface, so the surface is a swamp. Right? What else. If there's swamps, there have to be dinosaurs, right? [laughter] So he deduced dinosaurs. Okay, so it's a terrific tour de force, right, of logic. You can't see a thing, and from that you deduce dinosaurs. [laughter]

Well, in fact, we now know a great deal about Venus, and it's unlikely that there are any dinosaurs around. The kind of information we have is spectroscopic. That is, we know the composition of the atmosphere and something about the composition of the clouds from ground-based and balloon-borne spectroscopy. We know a great deal about the surface conditions from the radio emission from the surface; see, the radio emission goes through the clouds and reaches us, although the optical radiation reflected from the surface does not manage to penetrate the clouds while preserving an image, and so we can't optically see through the clouds, but in radio frequencies we can. And the radio telescopes have for twelve years now been telling us that the surface of Venus is just awfully hot. Even though the temperature at the clouds is quite low, about 40 degrees below zero centigrade, and the average temperature of the planet ought to be about what the clouds are, and not the kind of high temperature that the radio emission indicates. We now have, due to the really brilliant successes of the United States Mariner 5 and the Soviet Union Venera 4 space vehicles, more direct evidence both on the composition of the atmosphere, on the clouds, and on the surface of Venus.

What kind of place is Venus? The atmospheric pressure at the surface is something like 20 to 60 times what it is here on Earth. The atmosphere is about eighty or ninety percent carbon dioxide. There's some question as to what the remainder is. It may be nitrogen. There is a small amount of water vapor in the atmosphere amounting to slightly under one percent. The surface temperatures are something like, well, a good average over the entire disk of the planet is something like 700 Fahrenheit.

However, there is evidence that the temperature varies very much from place to place. So that the temperature at the subsolar point, okay, when the sun is directly overhead, may approaches high as a thousand Kelvin, and the temperature at the poles may be as low as say, 400 Kelvin, still above the normal boiling point of water. The clouds are, particularly from the Russian measurements, almost certainly made of water, they're ordinary ice clouds. So it's a complete cover of cirrus, unbroken cover, and the cloud layer is extremely high, about 50 kilometers above the surface, something like that. And if you are standing on the surface of Venus, there would be about as much light as there is on an overcast day on the Earth, maybe slightly less.

Now people have been uncomfortable about these high temperatures, first of all about their source, and second of all about their implications. It seems likely now that the high temperatures are due to a greenhouse effect in which visible light penetrates the clouds and the atmosphere heats up the surface. The surface tries to radiate back to space in the infrared but the atmosphere is now quite opaque due to the water and carbon dioxide. So it doesn't let the heat out. Such an effect works on the Earth, but only to the tune of about 20 or 30 degrees. In the case of Venus it works to a tune of about 400 degrees, and that's due to the larger amounts of carbon dioxide and water in the Venus atmosphere.

The implications of the high surface temperature seemed to be, first of all, that they excluded life. And so people tried to make a way out of that. Some people said, Well, maybe the radio emission wasn't from the surface, but now there are all sorts of reasons to think that it is, including direct measurements by the Soviet entry probe. Then people said, Well, maybe the poles are cold enough, so there could be life, terrestrial-type life there, but the poles aren't that cold. They're well above the normal boiling point of water. Well, people said, maybe there could be a high mountain somewhere, and at the top of it there could be temperatures that would be like on the Earth… and that's really scratching… and you can calculate, take an average spot on Venus, and and ask how high does the mountain have to be so they could have a reasonable temperature at its top? The mountain has to be like 45 kilometers tall. And that's not just, you know, some kind of rare mountain, that's an impossible mountain, because the pressures at its base would exceed the tensile and yield strengths of material. The stuff couldn't support that amount of pressure above it and would just collapse. So the idea that there is on the surface of Venus conditions which are favorable for terrestrial-type organisms is not such a good idea.

On the other hand, that's not the same thing as saying there can't be any life on Venus.

Certainly, it doesn't say there is any life on Venus, but it certainly doesn't say there isn't any life on Venus either. That's because there are lots of molecules, including most of the molecules we're made out of, which fundamentally are stable at these high temperatures. Although the weaker bonds, which conform the thing into three-dimensional structures, would fall apart.

The conditions in the clouds of Venus are much more Earth-like. In fact, the bottoms of the Venus clouds of the most Earth-like place in the solar system, except of course for the Earth, and it certainly… I mean, it's so Earth-like that you can imagine some time in the future a spacecraft, a manned spacecraft which ejects a balloon, a constant pressure level balloon which hangs just at the bottom of the clouds. And in there, there'll be astronauts who will just have a little face mask and that's all because the pressure is one atmosphere and the atmosphere is room temperature. Just like the old-time balloonists, and they'd have little leather goggles, and they'd float along, the clouds would be above, and they would look down below and take pictures of things and study meteorological conditions. Then of course there would be a problem of how to get them back. [laughter] But the conditions are clement enough so that such a thing could be fantasized, if not actually planned.

What about the surface of Venus, what's it like? There's a number of funny things on the surface, one of which is that the pressures are so large that you are in a region where there is something called supercritical refraction. Light is bent, merely by the density and the density gradient in the atmosphere. So that if this were a lecture hall on Venus and I attempted to look at someone in mid-audience, by looking at him, I could not see him, because instead, it would be light from a few feet in front of me that would come up in a bent path right to my eyes. If I wanted to look at that fellow in the middle of the audience I would look up like this to see him, because his photons would be coming in like that. And in fact there would be a little cone above my head into which would be poured the entire horizon.

Let's say we're outdoors from horizon to horizon. It would be… and in fact below the horizon, to a significant extent, all of that reflected light would be neatly poured into a little cone above my head. So if I wanted to see what was happening somewhere on the other side of Venus, of course the resolution would be poor, I would simply look up in the air and I would be able to see. Photons are coming right into my eyes. [laughter]

Whereas, if I were to look anywhere below that cone, I would be getting photons from just a few feet away. Okay, and I would be seeing an enormous ground which would surround me. In fact, if you're on Venus and walking, you would seem to be in a large hole, which would move with you. The hole would move along with you. [laughter] That's not so great. Well, it's easy anyway, and seems a perfectly… perfectly reliable conclusion about what it would be like on the surface. It would be overcast, extremely hot. So hot that in the shadows you would see things shining by their own red heat in the daytime. There's also a little hydrofluoric and hydrochloric acid in the atmosphere just floating around. In fact, Venus is very much like classical descriptions of hell. [laughter]

That doesn't mean that it's not an interesting place. And in fact, the exploration of Venus is… we're certainly bound to learn a great deal from, even if the analogy with hell is not exact. Well, if we now move outward from the Sun and pass by the Earth-moon system, which we talked about… Oh, you know, about Venus. Let's not move out so fast, I forgot to mention that the radar studies of Venus are now so sophisticated that we have maps of Venus obtained in reflected radio light. And these maps show things which look like long mountain chains, a few things which are round and seem to be depressions which look very much like big impact craters or maria, like on the moon. And in fact, there are pictures of Venus which are comparable to what you can see with the naked eye by looking at the full moon. That's about the detail we now have on the surface of Venus through radio techniques, and of course someday, it'll be possible to do much better than this by sending probes through the cloud layer and actually have them photograph and send things back.

Okay. *Now* let's move outward pass the Earth-moon system and go to to Mars, which is certainly been widely touted as the planet most likely to harbor life, and let's spend a few minutes on what the environment of Mars is, whether it could support life, and whether the claims that have been made in the past of observational evidence for life on Mars are in fact reliable.

The next slide is a very good color photograph of Mars. You will see that Mars is divided into bright areas and dark areas and a very bright polar cap, which has a composition that's being debated. There are those who think it's ordinary frost, ordinary ice. There are some who think it's condensed carbon dioxide, dry ice, and some who think it's both. I think it's both. The polar cap waxes and wanes with the seasons. In the winter it's big, as I'll show you shortly. In the summer It's small and sometimes goes away altogether. The reddish coloration of the planet is entirely real and in fact can be easily confirmed by going out on a clear night. If you have a clear night, and looking at Mars and it's red. Now on the earth there is one unique substance which colors rocks red, and that is ferric oxide or rust. Therefore it has been believed for 40 years that Mars is covered with rust. And the most recent studies confirm this view. The dark areas of Mars look to the eye to be, as you can see here, a kind of neutral gray. In fact, the dark areas are also red, but they're not as red as the bright areas. Now in the older literature, there are frequent reports of the dark areas being bluish or greenish. As you can see from this picture, this is generally not the case. There are two effects which tend to make people see blues or greens for the dark areas. One, is a well-known optical effect. If you have a very brightly colored patch of something and you put next to it something which has a neutral color, you tend to attribute to the neutral color, the complementary color to the brightly colored area. Well, the complementary colors to reds and oranges are blues and greens, and particularly under the unsteady scene conditions in, while looking through a telescope, there is a distinct tendency to see blues and greens. Second point is that the older observers used refracting telescopes which… the different wavelengths of light are focused at different distances, have different foci within the telescope, and therefore there is a kind of bluing or greening of the entire image due to this extra focal blue or green light.

Well… lights, please. I'll come back in a moment to the sorts of arguments that developed from the supposed observations of green coloration on Mars. What's the physical environment of Mars like? The surface pressure is about a percent of what it is here. The amount of water vapor in the atmosphere is about a tenth of a percent of what we have here. So it's a thin, dry atmosphere. The atmosphere of Mars, like that of Venus, is composed largely if not exclusively of carbon dioxide. There is no oxygen or ozone in the atmosphere, and this then provides a very interesting limitation on possible life on Mars. The sun puts out radiation from very short to very long wavelengths. It puts out an awful lot of radiation in the ultraviolet part of the spectrum. These ultraviolet rays penetrate through space to the upper atmosphere of the Earth where they are absorbed by ozone and oxygen, and so they generally speaking do not reach the surface of the Earth.

Were there no such ozone or oxygen, these ultraviolet photons would penetrate our atmosphere to the surface of the Earth. These wavelengths of light are just the ones used in germicidal lamps to kill things. And in fact, the nucleic acids, the genetic material of terrestrial organisms, is extremely sensitive to this kind of ultraviolet light at a wavelength of about twenty six hundred angstroms. So, in the case of Mars, there is no oxygen or ozone absorption, and ultraviolet light must also penetrate to the Martian surface, and there is independent evidence from rocket ultraviolet spectroscopy of Mars that this is the case.

So you say, Aha, life on Mars is therefore impossible, because everybody will get fried. In fact, at Mars, a typical terrestrial microorganism—never mind a typical—a very radiation-resistant terrestrial microorganism which isn't shielded by anything gets killed by the ultraviolet light in a matter of hours. Well, there are two kinds of objections to this, to the contention that this excludes life on Mars. One objection is that after all life arose on the Earth in the absence of oxygen. Okay, so at the most critical and labile time in the history of life, there was lots of ultraviolet light around. So maybe our ultraviolet lability is only a sort of later evolutionary development, or maybe earlier organisms had ultraviolet defense mechanisms that we don't have today. In fact, there are very potent protection mechanisms against ultraviolet damage, which most organisms on the earth have today.

The second objection is the composition of the Martian surface. Mars is red; that means light of lots of colors falls on Mars. Other wavelengths are absorbed, red light is not absorbed but is reflected back. Well, if red light is reflected, blue light is absorbed. And if things absorb in the blue, they generally speaking absorb in the violet and the ultraviolet. If the Martian surface material is in fact iron oxides, it has an absolutely huge ability to absorb ultraviolet light. That means that if you're a microorganism on Mars, other things being equal, you'll do fine if you just hide under a little rock, maybe a very small rock like 20 microns thick.

Well, what about temperatures on Mars? The average noon equatorial temperature is about what it is in this room right now. So that sounds terrific, right? That evening, the temperature will have dropped about a hundred and fifty degrees Fahrenheit. It has been called an extreme continental climate. Now, it's certainly clear that this combination of environmental parameters is uncomfortable for human beings, right? Wide ranges in temperature, no oxygen, huge amounts of ultraviolet light, low pressures, and small amounts of water. My goodness, it's hard to imagine a less likely place for life.

But of course that's just people, there's lots of places that people can't live where organisms do fine. There are lots of organisms, for example, not only that can do without oxygen, but they are poisoned by oxygen. Maybe there are organisms which do fine on Mars. Well, such experiments are possible. You construct a chamber which simulates all of these properties of Mars. Such chambers are of course called “Mars jars.” [laughter] And you then inoculate these Mars jars with terrestrial microorganisms and you see if they survive. The experiments that we've done were many years ago, we don't do these things anymore. We found that every sample of soil that we picked from, you know, your garden, to some exotic mountaintop. In every sample there were some microorganisms which did perfectly well indefinitely under the Martian conditions. Now that's that's survival, that's different from growth. But it turns out that if small amounts of water vapor are present even for a small fraction of a day, say 10 minutes a day on Mars in little micro environments, and this seems likely, then growth of terrestrial microorganisms is also possible.

Well, this has two implications. First of all, it says that if terrestrial microorganisms can do it, Martian microorganisms, if any, oughta be able to do it even better. It says there are no physical or chemical objections to the presence of life on Mars. It of course does not *prove* life on Mars. Secondly, it implies that there is a serious hazard in the contamination of Mars if we unwittingly carried terrestrial microorganisms to Mars, and they there survive and reproduce. And then we at some later time go to Mars with a very sophisticated system and go look for life on Mars, we'll find life. It will be the most expensive way of detecting terrestrial microbes ever invented. [laughter] And therefore it's extremely important, for this reason and also because if there are Martian organisms, terrestrial organisms might not like them and you might disturb things up there. Therefore it's very important to sterilize space vehicles bound for Mars. Such a thing is expensive, but feasible. Both the United States and the Soviet Union have claimed that they will scrupulously avoid contaminating the planet. The first likely instrumented soft landing on Mars will be in 1969 by the Russians, and a lot of us hope that they will take the appropriate precautions. There's some reason to… on the basis of performance of the Soviet Union in the entry vehicle in the atmosphere of Venus, to worry a little about the… about how scrupulous they will be. One the other hand we weren't very scrupulous about avoiding contamination of the Moon, and well, I'm not suggesting that there should be any pointing of fingers, but it's a very important thing to avoid such contamination.

Now, so the conclusion is that so far as we know about the Martian environment, there might be life on Mars, there might not be. And you're not going to know just by sitting around the laboratory and putting together Mars jars. Well, we can always… we can always look at Mars. A variety of observations of Mars have suggested to previous observers the presence of life. What are these observations? Well, one is the green coloration, which I already mentioned. The idea was that if the dark areas have more areas of green, then there have to be plants there, because what else is green aside from plants? That's, you know, a scientific argument. At least an argument in the scientific literature. That's not the same thing.

Aside from the kinds of objections that I made before, like, Mars isn't green, there's something wrong with this argument, and that is it implies that plants have to be green. But it's a very interesting question to ask, why are plants green, what's it do for the plant? Doesn't do much for the plant.

The sun is putting out a lot of light, at yellow and green wavelengths, and the plant is saying, I don't want any of that stuff, by reflecting back yellow and green light. Okay, so it's kind of being stupid, you might say. And in fact there have been evolutionary developments in plants to undo this error and start absorbing some yellow and green light.

Well, it seems awfully unlikely that the Martian organisms would by evolutionary accident make the same mistake that terrestrial organisms have made. And in fact Mars being cooler, if you believe that the organisms want to stay warm, then they would be very smart to absorb all wavelengths and therefore they be black. So, this is a small example, but it indicates the kind of hazards that are involved in assuming that what we have is what's up there. First of all what we have, the observations may be wrong, and secondly the argument might be wrong, and this sort of thing pervades the literature.

The next slide shows us two photographs of Mars. MD here means Martian Day, and that means that for the 687-day Martian year, we invented a calendar so that by the date you'll get a feeling for what season it is. So here, it's April 7th and here it's July first. If there are any Martians, they'll have different calendrical conventions.

Well, here it is spring, you can see that the big polar cap is a certain contrast between bright and dark areas. Here it is summer. The polar cap has shrunk, water vapor and carbon dioxide has been released into the atmosphere, and the contrast between bright and dark areas has increased.

This progressive increase in contrast as winter fades into summer is called the wave of darkening. It's absolutely clear and evident, measured visually, photographically, photometrically, and it has been used to argue for life on Mars.

Lights, please.

Along with these visual changes, there are… which can be measured photometrically, there are polarimetric changes in the polarization of the light reflected from Mars. These changes suggest a change in the particle size of small grains on Mars. The traditional view has been that the changes in darkness and the changes in particle size are due to the growth of organisms on Mars during Martian spring and that the wave of darkening is of biological origin. However, there are alternative explanations having to do with windblown dust and elevation differences, which explain the same observations without invoking life.

So it may be that the wave of darkening is of biological origin, but there certainly is an alternative explanation which seems to work very well and quantitatively. Well, there's another set of observations about Mars, next slide please. These are the canals. On the left is a drawing by Schiaparelli who discovered the canals; you can see this network of single and double straight lines, which he called *canale* which mean channels or grooves, but which was translated, mistranslated into English as channels. Sorry, as "canals," which implies canals. Now these observations of Schiaparelli were extended by the American astronomer Percival Lowell, who in fact invented a whole observatory to study this and other problems. And Lowell argued from the unerring straightness of these lines—for thousands of kilometers, you can see the scale—that these were not natural objects but artificial objects; that the canals of Mars were in fact canals, and that they were the products of an advanced civilization on the Martian surface that was channeling the water from the melting polar cap to the thirsty inhabitants of the equatorial cities.

In fact, this thing went so far that there is a text on the hydraulic engineering involved. [laughter] And there's also a suggestion on the international politics of the Martians, since the canals obviously cross international boundaries. Well, all this is fine, and in fact the argument as you recall from yesterday, lots of straight lines are in fact a good sign of life. If only the straight lines are really there. Well, on the right is the exact same area of Mars as on the left, however seen under better seeing conditions. What happens is that ordinarily when you look at Mars, there are no canals, as on the first photograph. When the seeing improves, there suddenly flash out these straight lines like the lines on a fine steel etching, as one astronomer said. But when the seeing gets even better, and this is a very rare occurrence, these straight lines break up into an array of disconnected fine detail.

Which I can’t show you, because the background is white and so is the arrow. It's like foreign movies when the subtitles are there against a white background. You never make them out. Well, what I want to indicate is, you see the straight line right below this arrow? That's the same thing as this right here. Well, nobody can see that, that's obvious. Anyway, there's a one-to-one correspondence between what's on the left and what's on the right. If you squint, I think you'll see what I mean. Well, so you would think that this is the story about the canals of Mars; not an astronomical, but a psychophysiological problem. But there's one problem with that. How is it that the little disconnected fine model details on Mars are arranged in straight lines? Here they are. Why are they arranged in a straight line? After all we look at the moon, we look at Mercury, the seeing conditions change. Why don't we see canals there? So there is something on Mars that doesn't exist on Mercury or the moon. What is it?

We've done some radar studies of Mars which indicate among other things that several of the classical canals are ridges. And they may be ridges which are interrupted by dust so that in fact, it looks like a series of hills, but arranged in a perfectly straight line. Other evidence to support this can be obtained from the Mariner 4 photography of Mars. The next slide shows frame 11 of the Mariner 4 photography. You can see there are craters on Mars produced by impact, as just the same story as on the moon, here is an absolutely huge crater, this thing right in the middle, it is about 150 kilometers across, and its entire western ramparts have been thoroughly eroded. Now in addition there are straight lines which can be seen in this picture. They are indicated by the two pairs of arrows.

The bottom straight line in here is so thin it's hard to make out much detail except to see that it's a straight line. The upper straight line right here is thick enough so it's possible to see that its upper part is brighter than its lower part. From the lighting of the craters it's clear that the sun is towards the upper part of the picture so that the creators are illuminated towards their bottoms. That means that this straight line in the upper right hand corner has its sunward side illuminated. The side away from the sun is in darkness and therefore it's a ridge. Now why are there ridges of this sort completely covering Mars when we don't have any on the Earth? Lights, please.

We do have them on the Earth. If you remove the oceans, you will find that there is a network of submarine ridges which lace the surface of the Earth. And in fact, we have proposed that the dark areas of Mars are analogous to the continents, the bright areas to the ocean basins with ridges running through them, except that the basins of Mars are filled with dust and not with water.

Well, therefore, there remains no evidence for life on Mars, no evidence for it, but also no evidence against it. We saw yesterday the difficulties of detecting life on Earth from the vantage point of Mars. Well, there's a difficulty doing it the other way around, and we're not going to really know until we can actually land a space vehicle on Mars and make a more direct and careful examination.

Let's now just momentarily go outwards once again and take a look at Jupiter. The next slide is a small one. This is a color photograph of Jupiter. This thing here… no, I'm sorry, this thing here is the great red spot. You can see how un-red it is. In fact, it's sometimes not even there. Now it's hard photographically to reproduce the colors on Jupiter. They are subtle, variegated, changing from moment to moment. The axis of rotation of the planet is like this. The thing is rotating that direction and these things are equatorial bands and belts which are surely related to the meteorology of the planet. This is an enormous thing many times larger than the earth. In fact, the red spot is many times larger than the earth, and yet it rotates once every nine hours 55 minutes. The colors on Jupiter are a very interesting problem. We know that the atmosphere is composed of hydrogen, helium, methane, ammonia, and probably some water below the clouds. We're only looking at the clouds here.

If you supply energy to such a mixture of gases, you will produce a wide variety of organic molecules. And in fact a very similar process is thought to be responsible for the production of organic chemicals leading to the origin of life early in the history of the Earth. When we had an atmosphere which was rich in hydrogen, as the present atmosphere of Jupiter is. Some of the organic molecules produced in this way are very highly colored. And in fact the coloration of Jupiter that we see here may be due to organic molecules. There is also some evidence from ultraviolet spectra of Jupiter, additional evidence for organic molecules there. In fact, Jupiter may be a vast planetary laboratory in which the kinds of organic chemistry involved in the origin of life have been going on for the last 5 billion years. And if you view the solar system from afar, Jupiter seems the most likely place for life. Certainly more so than the Earth. Oxygen atmosphere is very hot. Well, Saturn, Uranus, and Neptune are very much like Jupiter so far as we know, I won't say very much about them.

Lights, please.

The Jovian planets, as you can see, are very different kind of set of objects, than the terrestrial planets. These are enormous, distended, swollen gas bags of enormous dimensions much closer in chemical composition to the rest of the universe than the terrestrial planets are. They are extremely different places, much different from any of the terrestrial planets, and are very much worth exploring. Now, the general scientific returns from planetary exploration are absolutely huge. Let's take a few fields and just think momentarily what's involved. It's no secret to you that there are problems in meteorology, and exact weather prediction is certainly not a thing which is with us yet. This is not especially a fault of the meteorologists. It's an extremely difficult problem to understand the motions of winds on a planet which has big elevation differences on it, and oceans, and is rapidly spinning. These are extremely difficult fluid dynamical problems.

The meteorologist has up to now only one object of study: the Earth. Wouldn't it be terrific if he could change some things on the Earth and see what happens? Stop it from rotating, see what the circulation is, that's hard. Or suppose he could take away all the oceans and see what influence that would have. Okay, that's not as hard, but it's still hard. Well, in effect, he can do this. Venus essentially doesn't rotate, it rotates so slowly that all the Coriolis forces aren't working, and that's an example of what circulation there is when rotation stops. We don't know what the circulation of Venus is, but we could find out. Mars is a place with no oceans. That could certainly give us some evidence as to what circulation is like in the absence of oceans. The day on Mars is 24 hours long, so that is very neatly arranged to be quite comparable with here.

We don't know much about the meteorology of Mars, but we could find out. Well, you see this is an example, there are many sciences which are stuck to a single case. But if we could go to some other planets, we can get some more cases, we can make a more general subject. The most, the science in which this is most profoundly true is biology. All of us organisms on the Earth are the same organism, in a very fundamental sense.

We all use nucleic acids for the genetic code. We all use proteins for catalysis. We even have the same genetic code, the same sequence of nucleotides translates to the same sequence of amino acids. The same language is used by paramecia, poodles, and people. Now how could such a thing ever occur? I mean, for example: suppose you are an anthropologist and you are going around looking at languages for all the groups of the Earth. Suppose you find that everybody speaks English. That would be very strange. What would you conclude?

Would you conclude that English spontaneously arose in all these isolated communities? No, you certainly wouldn't. You would conclude that a bunch of English guys went around and made everybody talk English. Which is the way it happened. Well the fact that the same genetic code is used by all the organisms of the Earth, means that there is a common origin of all the organisms of the earth. We are all descended from a single instance of the origin of life. That means that the biologist is only studying one case. He doesn't know what kind of things are general—biology has to have them everywhere—and what kind of things are contingent—dependent on evolutionary accident and could have gone just as well one way as another. It seems to me that biology will never come into its own and will never be a true general science until we have some examples of life from elsewhere. This could be an extremely simple kind of life. It needn't be something complex. A microorganism truly from Mars would probably do it for the biologist.

There are similar advantages that lots of other sciences could have; there's a kind of spin off, the practical everyday benefits of the space program. There is a fundamental approach to problems of origins, the origin of life, the universe, the origin of the solar system, which can be obtained by space exploration in a way which would not otherwise be accomplished.

I now want to talk about just in the few remaining minutes about some of the other less tangible, but I believe even more important benefits of space exploration. First of all, let's consider the question of adventure. We live in a time when adventures become less and less possible. It used to be that a young person of adventuresome spirit could set off for a place where nobody else had ever been. In fact some of that same spirit probably motivated the first settlers in Oregon. It used to be that there were for all you knew new places. New kinds of human beings just, you know, over the hill. There was always the possibility of something totally unexpected, something marvelously exciting. In a fundamental sense that time has passed; because of the advances in communications and in transportation, the entire world has become unified in some sense a useful, but in some sense a very frightened way. You can travel from one end of the United States to the other and encounter the same dismal sequence of hamburger stands serving the same stuff with the same waitresses who speak same way. The same lousy service. The diversity is disappearing. The planet is getting homogenized.

Now, at just this moment, the possibility of space exploration comes along. At just this moment, it's possible to send, of course at first a very few people, as in the the early explorations of this continent, but at least to send some people out on voyages of exploration where we can keep in much better contact with these voyages, then we could at the time of the voyages of Columbus, where we can find out in some direct sense what's happening up there. We don't even have to do it with people. Let me ask you to imagine the following situation.

We land, as we could if we wanted to in the middle 1970s, a roving automatic vehicle on Mars. It lands, it has television cameras, it starts walking. The roving vehicle is controlled from the Earth. There are communications from Earth to vehicle, from vehicle back to Earth. Because of the finite time for light to travel which we talked about yesterday, there would be a delay of about 15 to 20 minutes. So you'd want to be sure that the little tank could do some things by itself. For example, if you are on the Earth viewing the television screen and you saw a gorge approaching and you said, Hey, tank! Stop. 20 minutes later, the news would get there, and meanwhile the tank would have tumbled into the gorge. So you want the tank to be able to know to avoid gorges and so on, but that can certainly be built into the thing. Now suppose that the television pictures from this vehicle on Mars would be transmitted to your home television screens, you know when the Ranger series started, it had this set of pictures live from the moon. I mean, that's an absolutely stunning thing, live from the moon. Well, it'll be possible to have something that we'd say, Live from Mars.

You would sit there glued to your television set, because there's no telling what might be up there. We don't know enough to say what's there and what's not there. I mean, it might just be sand dunes and deserts, occasional ridges and plateaus, but it could be other things, could be little, you know, kangaroo rats hopping all over the landscape. [laughter] It could be the relics and monuments and citadels of some now vanished civilization. We don't know that that's not the case. I think it will be just extraordinarily exciting. In fact, I think the whole space program could be paid for by subscription TV.

Well, I mention this to indicate that it's not necessary to go there in order to share in the spirit of adventure which would accompany any exploration of another place. It's a whole other world. The land area, the total surface area of Mars is larger than the total area of North and South America. Now, there are some other implications of planetary exploration. One of them is this: the question of group identification. It started out, I guess, that people's identification were with themselves. Then people evolved and got families, and so there was identification with the family group, and then the tribe, and then some small principality, and some state, and then some nation. In each stage of this evolutionary process, our group identification got larger and larger and larger. So with the exception of a few states in this country, most people are willing to think of themselves as Americans rather than as members of a particular state. This process has stopped at national identification, but there's another step, another obvious step which hasn't happened yet. And that is the fundamental identification of us as citizens of the Earth.

Now, I think part of the reason that this fundamental identification hasn't happened yet has to do with all sorts of problems of the human psyche, but part of it results from an absence of perspective. But now imagine it's kind of easy. It's an everyday event to see the Earth from some camera on board a spacecraft, gradually dwindling until it fades to a faint crescent and then indistinguishable from thousands of other planets or stars. The idea that there's something fundamental in these small group identifications begins to erode. I think even the most fervent of nationalists would have kind of a second pause at seeing the Earth just disappear.

The exploration of the planets is clearly an endeavor of all of mankind and what I think there certainly will be, it will matter which nation does the exploring. The critical event, as the critical event in the 15th and early 16th century, was that the exploration occurred. It's mankind that's doing the exploration. There are other aspects to this. It has to do with what William James called the moral equivalent of war. Konrad Lorenz and lots of other people have suggested that warfare on the earth occurs in part because people have aggressive instincts. William James suggested, Okay, terrific, let's use those aggressive instincts in something where the rest of us don't get knocked off. Some people have more aggressive instincts than other people.

Now, I think there are excellent reasons for believing that people with aggressive instincts tend to migrate towards military occupations if they do it voluntarily. The world has gotten too small for this sort of working out at one's own hostilities. On the other hand, if space flight became a kind of going concern, then I think the same sorts of energies which of course are very useful aspects, I mean most of the exploration of the new world was done by military guys, and, except for some mistakes like Cortez and Montezuma… they did a pretty good job, that is as long as they weren't any other people to contact, they did fine. Well, it seems to me that all the energies and abilities that are involved in the military mind might be very usefully applied to space exploration. All of this business of long-term planning and coordination of activities is ideally suited; not only is the military mind so suited, but so is the the kind of military industrial complex that's involved in the preparation for war. So in short, my feeling here is, let's send those guys up there because the more of them up there, the less of them down here. [applause]

There's another kind of perspective that planetary exploration provides, and that has to do with the uniqueness of mankind. Not just with the identification we have with our planet, with the identification we have with other people. Because human beings are the product of a unique—I don't mean better, but I just mean unique—evolutionary sequence. There's a lot of things about us which are clearly the result of evolutionary accidents. Let me explain what I mean. We have five fingers. Okay? Everybody thinks that's terrific. Very reasonable. What other number of fingers could you have? But *why* do we have five fingers? We could have four or six, we'd do just as well provided that one was opposable. Why five? There's a reason why we have five, and that goes back to Devonian times. Whatever that is, 400 million years ago.

There was a remote relative of ours which crawled out of the water onto the land. This primitive amphibian had five phalanges, which are the ancestors of our fingers. Now, there are other guys swimming around the primitive oceans that had four and six phalanges, but they weren't the ones that crawled out onto the land. So here we have five, and we think base 10 arithmetic is reasonable, and so on. But if the guys with seven phalanges crawled out we'd all have base 14 arithmetic, and base 10 would be taught in the new math. Well, that's an example of how the kinds of things that we consider to be, of course, obvious, reasonable, aren't. Human beings… there are much more profound examples of this general thesis, about things that we have, the way we are, the way we think, which we think is the only way we can be, which are obviously the result of evolutionary accidents. But what this means is that if there are intelligent organisms elsewhere, they're not going to be like people.

And I'd like to read to you a short but very lyrical passage by Loren Eiseley. He says, "Lights come and go in the night sky. Men troubled at last by the things they build may toss in their sleep and dream bad dreams, or lie awake while the meteors whisper greenly overhead. But nowhere in all space or on a thousand worlds will there be men to share our loneliness. There may be wisdom. There may be power. Somewhere across space, great instruments handled by strange manipulative organs may stare vainly at our floating cloud wrack, their owners yearning as we yearn. Nevertheless, in the nature of life and in the principles of evolution, we have had our answer. Of men elsewhere and beyond, there will be none forever."

What this means is that the similarities among various kinds of people on this planet are so much larger than the minor differences which seem to separate them, as to be almost a kind of joke, to be a kind of compulsive searching for absolutely infinitesimally differences when the real differences are absolutely enormous. In this sense, I think that there is a very interesting feedback on problems here on Earth, which this planetary perspective can provide.

Well, finally I think it's important to think about the historical perspective. The planets are going to be explored only once, there's only going to be one generation in the history of the world which is going to start out wondering about the planets, but is going to end up really knowing about them because they will have been there. It is a very sobering fact that the same techniques, namely rocketry and nuclear power, which can send us to the planets, can also be used to destroy us. I think the choice of which sort of applications we want to make is really upon us at the moment, and I think that if we make the appropriate choice we will have the pleasure of knowing that there was a time where it was possible to do something which had greatness associated with it, and we chose to do it.

Thank you.

[applause]

SAGAN: I understand I'm supposed to entertain questions. Yes, sir. How do I distinguish between what's living and what isn't?
[another speaker whispering] This gentleman said it took him 15 years to learn it, and only 1 hour to understand it.

SAGAN: Thank you very much. This gentleman has said it took me fifteen years to learn it, and it took me only one hour to understand it. Thank you. [applause]

The question is how do I distinguish what's alive from what's not? Well, this is a fairly profound question. I mean on the one hand, you can say that any child can distinguish the difference between a live puppy, a dead puppy, and a toy puppy, and so it's a trivial problem, but that's puppies. There are a variety of possible definitions of life, each kind of invented by a particular biological subspecialty, and the definition is always in the terms of their own specialty. I think the most significant definition of life is the following: a living system is one which is capable of evolution by natural selection. If you take that, you'll find that there are really no cases—and that means it has to be able to reproduce, and mutate, and reproduce its mutations, and have some interaction with the environment. If you take that example, you'll find there are no cases where a thing is called alive, when you would disagree; there are no cases the other way around. It seems to fit every single case and it's not bound to any particular kind of chemistry, it's a functional and not a molecular definition.

Yes. [question in background]

Right. I've been asked a very straightforward and simple question. Which is of the three possibilities for the origin of the universe, which I mentioned yesterday, the question of which is to concentrate on the one in which 13 billion years ago, everything emerged from nothing, and he just wants to know what do I… what am I talking about when I say nothing, and how did the universe emerge from nothing? I can only say to you, sir: beats me. [laughter]

And as you know, that's a well-known hard problem.

[question in background]

Right. Two questions. One, is there any major discrepancy between U.S. and Soviet space vehicle results about Venus, and two, what about the exchange of information between the two countries: is it open or not? There were some newspaper reports about conflicts between the two sets of space experiments. They turned out to be based upon the usual sort of newspaper misunderstanding of what's being said and were not fundamental. There actually is one remaining area of disagreement having to do with the question of the Lyman-alpha flux density in the interplanetary part of the voyage, but an actual confrontation between the U.S. and Soviet scientists on this hasn't been accomplished yet. So we don't know if it's a real discrepancy or just an apparent one. The exchange of information between the two countries is excellent. There is a certain tendency of the United States to say what it's going to do before it does it, and for the Soviet Union to say what it’s going to do only after it does it, but apart from that the exchange is pretty good. The kinds of areas where the exchange is very constrained has to do with the actual detail of the boosters involved, because those same boosters are of course used for nuclear annihilation and mutual terror, and so it wouldn't be cricket to exchange data on that. But with that exception it is a very good exchange. There's a yearly meeting of an organization called COSPAR, the Committee on Space Research, and there is participation both in the United States and the Soviet Union, you know, each of us knows our opposite numbers there. The exchange is very good.

Yes.

[question in background]

Something like 1% of the amount of money which is going down the drain in Vietnam, would serve for everything I'm talking about.

[applause]

Yes, sir.

[question in background]

Right, if the distance of the Earth from the sun is called one astronomical unit, then Jupiter is something like 10 astronomical units away, it’s about ten times further from the sun than we are. Well, 93 million times ten… 93 million miles times ten, 930 million miles roughly. Okay, it's far away. But on the other hand, that doesn't mean it's hard to get to, and a typical voyage to Jupiter using minimum energy trajectories would take a few years, something like that. If… that's a minimum energy trajectory. It's possible to be slightly more sophisticated. One can use, as you mentioned, nuclear power, and then go not on minimum energy trajectories, but on much faster trajectories. And it's also possible to do a thing called… well, it’s a kind of cosmic billiards that can be played. It's possible to send a space vehicle so close to a planet that it's bent into a kind of hairpin trajectory, but like the whip at, you know, amusement parks, and so it really exchanges momentum very rapidly with the planet. The planet loses a little, but the planet has a lot. And the thing goes absolutely bombing out of there and therefore it's possible to get from here to some other place if you choose your moment, in much shorter periods of time than you might expect. In fact in the late 1970s there is an opportunity to do what's called the Grand Tour, which is to go to Jupiter, have Jupiter do a swing-by mode to Saturn, Saturn to Uranus, and Uranus to Neptune, and do all that in not too many years. Just a moment, I'll look up the date of the next time that that's possible…

Yeah, you can do it in 1977, and the next moment is 2153. So, that suggests that there is another rather interesting opportunity which is coming up in the 70s and is not likely to recur in the next century or two.

Yes. [question in background] Right. No, I don't. Let me repeat the question. There's a theory by a fellow named Uffen that… we know that the Earth's magnetic field flips, the north magnetic pole becomes the south magnetic pole. And the reason for this is under debate. It's a very exciting geophysical discovery, and during the period of these flips, the Earth's magnetic field goes pretty close to zero. A suggestion has been made that at those moments, protons from the sun and cosmic rays which are ordinarily deflected from the Earth by the magnetic field, penetrate through the atmosphere. Okay, down to the surface, and then some organisms get it and that increases the mutation rate, and maybe explains the death of the dinosaurs and so on. The reason this is no good is because it forgets that the atmosphere absorbs the same particles, even if you turn off the magnetic field it never gets down to the surface and the organisms never know anything about it. And so it's not such a hot idea.

Yes. [question in background] What's the theory of relativity? Not in one or two minutes, baby. [laughter]

Yes. All the way in the back. [question in background] Yeah, that's a good question. Could life evolve under very different conditions from our own? Let me answer that first. Yeah, I mean, I think so. I think that you didn't have to have the very same conditions that we have right here on Earth right now. In fact, we know that the conditions early in the history of the Earth were very different from what they are now, and probably general, that is the kind of conditions under which life first arose on the Earth are probably very similar to the early conditions on practically every place. As for life evolving totally in the atmosphere, I don't know. I don't see any strong objection to that, particularly if the surface for some reason were prohibitive; say it was too hot and if the atmosphere were dense. For example, on Jupiter, that's not… it's been suggested that life is evolving in dense regions of the atmosphere which aren't, however, the surface. As for life down in the depths of a planet, in the interior of the planet, the main problem there is one of the source of energy. If you're surrounded by stuff which is all at the same temperature and there's no source of light because you're down so deep, then you can't make… you can't thermodynamically make things more complicated, and evolution is impossible. So I don't think that in the interiors of planets evolution of life is likely; in just a little bit below the surface I think it is, though.

Yes. [question in background] Yep, this is an old red herring. No. I'm just saying that nucleic acids and proteins are terrific for us, but after all we just discovered that they were terrific only a little time ago. And so maybe there are some other things which are terrific for some other kind of organisms on some other planet, and we don't know about it yet. There's a lot of chemistry that hasn't been examined in this context for reasons which are kind of too long to go into. I don't think… silicon is not as good as carbon. One reason is its cosmic abundance is much less. There's a lot more carbon around than there is silicon, particularly at the time of the origins of things, and there are also reasons why silicon isn't quite as good as carbon. I'm mostly talking about other kinds of organic molecules based on carbon, other than nucleic acids and proteins.

Yes. [question in background] I can answer that very simply. Yes. I have been presented with such evidence. No, I have never been presented with good evidence. [laughter] Okay, I mean, the audience has been remarkably restrained in not raising this issue before. Let me say a word about flying saucers. I didn't talk about this last night, did I? All right. People see things, okay, in the sky, and they're said to be flying saucers. By which it is meant that they are space vehicles from some other planet, intelligently guided or… well, manned, isn't, for reasons I've mentioned, quite the right word, but populated. Now, what should we do about this? Well, first of all, it's important not to say that the thing is ridiculous on the face of it. Okay, because you know, we're ignorant, and even though it's hard for us to travel from here to some other star, there might be civilizations millions of years in advance of us and it might be trivial for them. In fact, there are even… it is even possible to imagine now, using the kinds of physics we know today, ways of doing this in reasonable periods of time for the occupants. After all, there are going to be new laws of physics discovered in the next few million years also, in addition to new engineering applications.

Well, so that's the first point. The second point is that there are strong emotional predispositions on this subject which it would be a mistake to ignore. There are people who desperately want to believe that we are being visited, that there are beings, intelligent supermen from elsewhere that have come here to save us from ourselves just at the time that somebody's finger is on the nuclear trigger. Now that has a very clear element of wish fulfillment in it. I mean it would be so terrific if it were true, you'd better be very careful about anybody who says it's true.

Then there are strong emotional predispositions the other way; people who are you know covert geocentrists, who want to believe that we are the pinnacle of creation, and that there can't be advanced beings elsewhere, and so they'd just as soon not hear about this stuff. Okay. So that's a caution that suggests that both claims and denials may be based more on emotion and logic. Now, what about the evidence? First of all, it's interesting to take a look at what sort of things have been claimed to be flying saucers and have been then reliably demonstrated to be something else. What are these misapprehended natural objects?

The moon. You might say, how could anybody possibly mistake the moon for a flying saucer? It happens all the time. Somebody, you know, some housewife is out in her garden. She looks up, just… My God. What's that? [laughter] Never having seriously looked up in the sky before, she runs to her to her telephone and calls the police and, and well, you know it. You know how interested the local police forces are in this stuff. Well, so, the mere existence of a few of these lunar, so to say, flying saucers indicates that you know, it used to be when we were all shepherds or whatever we all were, that we would look up in the sky. We were very familiar with what the night sky looked like and objects there. We knew that's a star, that's a planet. That's a bird, and so on. But people don't know that anymore. Who looks up anymore? In the large cities, even if you wanted to look up, there was nothing to see, there's just all this smog, and even out here, you know, I say out here… even in places where the weather is good… [laughter] there are still very few people who look up. Well, the list of misapprehended natural objects is really terrific. Venus, bright stars, aurora borealis. Aircraft; conventional aircraft with unconventional lighting patterns, like strategic air command refueling operations, and then unconventional aircraft, and then… like there's an overcast. There's a hill, and there is a car going up the hill and the headlights, see, zoom across the sky in parallel, and the report is, you know, there were two of them, officer, in there going 50,000 miles an hour! Then there's that classic case of a firefly that was trapped between two adjacent panes of glass in an airplane cockpit window. Okay? And they said, you know, it made fantastic right angle turns defying the laws of inertia. These are our reliable airline pilots. And well, so, after you've gone through, you know a few dozen of these cases, you then aren't so surprised to hear that there are large numbers, say 30 or 40 percent or something like that, of these observations that haven't been tracked out, because you know, look how many how many peculiar and bizarre incidents occur and are called flying saucers. So you'll then want to have a really hard and fast example, something which is really clear. Now, it's very interesting how it turns out. There are lots of cases of exotic objects, but seen under very unreliable conditions. One old lady who's now institutionalized told you about it. That's a real case. Then there's lots of cases which are very reliably seen. A dozen people see them or something, but they're not least bit exotic. It's a moving light, it disappeared over the trees. Well, maybe it's an airplane. It's a headlight on a cloud or something. There are no cases of extremely exotic objects, which are seen under extremely reliable conditions. Let me give you an example of what I'm talking about. After this meeting is over and you all file out of this building, as you're milling around outside this lecture hall, a large, 40 foot in diameter, flying saucer lands right on Broadway out here and a turret goes up, and a mechanical arm comes out and grabs a passerby and withdraws it into the space vehicle and then several people with cameras photograph this whole thing and the thing takes off, okay? And a hundred people see it. That's what I would call an exotic sighting. [laughter] Seen under reliable circumstances. Now, there are no such cases. You know, how is it that there aren't metallic sheening things which hover over Portland which are seen on a Thursday afternoon by 10,000 residents? You know, why aren’t there any such cases? Why is it always somebody in lower Monongahela County who is you know, hoeing and this thing landed on the lawn and then left and there’s this char pattern on the lawn. That's the evidence. Well, so until there is something quite exotic and seen under reliable circumstances, I prefer to withhold judgment. That's a very long answer and the time is late. I think I'll leave you with this kind of unscientific, but at the same time provocative and interesting and sort of opening-to-the-future sort of issue. Thank you. Good night.

[applause]

STEETLE: I’d like to thank Dr. Sagan, on behalf of the faculty and students in the University of Oregon, Oregon State, and Portland State, and the public in Corvallis and Eugene and Portland. Thank you very much.

[program ends]