Cosmic Rays and Meteorites

Lecture by James R. Arnold
February 8, 1961
32 minutes, 04 seconds

Speaker: James R. Arnold

Transcribed by: Sherry Yin

Time	Transcription
00:00	Dr. James R. Arnold: It’s pretty difficult to imagine that there’s anybody in this room anymore that, anybody in the United States who doesn't know something about America’s Space Program. Right now, we're spending money at a rate which only astronomers can possibly handle for the various objectives which go into this program of research and, and exploration of outer space. I’d like to begin really by describing an experiment I hope to have something to do with someday, for which is a little bit beyond our capacity at the present time, and then to come back from this experiment that, perhaps about the time you're in college, will be going on, to the workaday world of today and talk about the possibilities that are, that are available to us with beakers and the ordinary tools of the laboratory and some visitors from outer space which are already right here.
01:13	Dr. Arnold: The one experiment which of all the ones in the next decade I, I would most enjoy doing is this. The Moon, which is the nearest celestial object to the Earth, is a very pretty object. It’s also a very mysterious object and among the clues that we hope to get from the Moon is the whole history of the origin of the Moon and the Earth and the solar system. This is all part of the very big question, how did we get here? And it's certainly one chapter in that story how did the, how did the Earth, the Sun, the Moon, and the planets come to be? The story that at present is understood very very poorly indeed. One of the characteristic things about any science is that most excitement is generated and there’s most talk and most arguments about the things we don't know. I think you probably get the impression when you’re taking science courses in your school that science is made up of a lot of things which you only have to learn and when you’ve learned them you know it. In fact, there are very many things we know but the real fun is always in the things we don't know and certainly, one of the very important things we don't know is how the solar system came to be.
02:37	Dr. Arnold: Now, we have reason to think that the Moon has had a much less complicated later history after it was first made than the Earth. It has no oceans, which has no rain, has no atmosphere, it has no wind. It has none of the things which have changed the surface of the Earth so profoundly. We've had, not over the San Diego area but over more than half of the United States, glaciers, huge piles of ice within the last fifteen or 20,000 years which have just changed the whole topography completely. And the map just doesn’t look like what it looked like 20,000 years ago. The Moon does not have glaciers so that here’s a place to look at what things are like a long time ago, perhaps four and a half billion years ago when we think that the planets were formed. So what I would like to do sometime before too long is just to have a piece of the Moon in my laboratory and take a good look at it. This isn't beyond the realm of possibility. People at the Jet Propulsion Lab at Caltech [California Institute of Technology] are beginning to construct experimental devices already, which may return pieces of the Moon. But it's at any rate, something I certainly can't do right now. If I had these pieces of the moon, I could tell many

things, too many things perhaps to describe here quickly. But certainly one of the things I could tell, for instance, is whether the Moon was hot when it accumulated or whether it was cold.

04:02 Dr. Arnold: When I was a boy, the school book said that the Earth was originally a molten ball of lava, it cooled down and then there was a crust formed on the surface and then it got solid all the way down. One of my very famous colleagues, Harold Urey, is fond of pointing out that ice floats on water but that it's the only substance whose solid floats on its own liquid. Every kind of rock, every metal, everything that we know about, if a solid forms, it sinks to the bottom. So this story that I read about in school is certainly not right. It'll be nice to know what was right. Did the Earth accumulate hot or did it accumulate cold? Did the Moon accumulate hot or cold? This is one of the main questions and we don't know. If I had a piece of the Moon, I could tell, I think, but I don't. But if you look around you a little bit, you'd find that there are objects which have spent very long periods of time, perhaps about as long as the Moon has out in space, without an atmosphere, without tides, without winds or any of these sorts of things and which are sitting right here. In fact, I brought out the biggest one, which I have with me. This is a piece of a meteorite. Come up here and examine it later but I want it back.

05:33 Dr. Arnold: Came in to a place called Odessa, Texas we think about 50,000 years ago. It's a hunk of steel, nickel steel and it tells us a great deal. Some, these things are falling all the time. I also have some small pieces of meteorites, which have fallen much more recently. This is a piece of an object which fell in March of last year near Edmonton, Alberta, and which has told us some things I hope to find, to tell you about later. I can't forbear mentioning at this moment that one of our great current interests is a meteorite which fell in an area of California we can pinpoint fairly well on January 16th. I find that, if in an audience of this size, there are likely to be a fair number of people who saw a very bright fireball or shooting star at about 6 o'clock on that evening about two weeks, three weeks ago. There were enough phone calls to the various people who might have been called to jam all the switchboards in the San Diego area of people who did see it. We've been trying to recover this object. We know that it's somewhere in the northern part of Los Padres National Forest and that's about all we know about. It would be very interesting to us, it always is very interesting to us, to recover these pieces of meteorite from outer space.

06:58 Dr. Arnold: But what do they tell us? They tell us, first of all, what they are made of. They're made of the same chemical elements that the Earth is made of. That doesn't surprise us but since we don't really know too much about them perhaps we should say that first of all. The isotopes which they contain, which are the different kinds of atoms of each element, the lighter ones and the heavier, are also almost the same. Some very fascinating differences, they aren't quite the same. But if you analyze most of the common elements, they would be about the same. What proportions do they have? Well, this is quite a difference. You can search the whole world over and find lots of steel objects, tin cans so-called. Go up to the top of any mountains or any distant part of California where I've ever been and you will always find a few bottle tops made out of steel deposited there kindly by the people who came before you. Steel is very common all around us but before there was man, there was virtually no steel in the world. There’s one place in Greenland where apparently by natural processes some native iron was produced.

08:22 Dr. Arnold: The only other native iron that we know about is meteorites. And in fact, the oldest steel tool that we know to have been made by man, which is a knife recovered in an Egyptian tomb about 1500 B.C. is unquestionably a piece of meteorite. That is it was originally a piece of meteorite which has been beaten into this form. Probably the meteorites initiated the use of iron and steel in, in human society. They provided the first examples of it and led people probably although we don't really know it all to seek other ways to make this valuable substance. Not all meteorites are iron, however. In fact, most of the ones that we see come into fall or stone. If you come up and examine this piece of the Bruderheim Fall that I have with me, it'll probably look to you like almost any stone that you’ve seen. It’s a light gray in color. It has a little bit of a black crust on the outside. A lot of things that haven't happened to it that you might think. The night of January 16th when I was on the phone most of the night running up a big phone bill to all the police stations and Sheriff's offices all over California that had all the reports of it, the thing that kept happening was that I was told that say in Gilmore, California, fires have been set, shooting stars had come down and started the fires.

09:48 Dr. Arnold: It started fires 75 miles east of Las Vegas, west of Las Vegas. It started fires somewhere up in the Escondido area and it also started fires somewhere in the southern part of Los Angeles and none of these stories are true at all. People think that certain things are going to happen, and when they think they're going to happen they see them happen. Airplane pilots told us that they saw this streak of fire go below them. This doesn't happen either. What happens when a meteorite comes into the Earth's atmosphere is that it makes a very bright flash. People speak in the case of a pretty good-sized one, it's something that seems as bright to them as the full moon, bright enough to be seen in daylight. Then after it's moved through the air for a while like the nose cone of a rocket or satellite burning up, it’s slowed up by the tremendous pressure of the air against it. It's moving at rates of 10, 20, 50 miles a second and the wind is pretty hot. So, that after it, the air has a chance to really push against it, the air slows it up. When it has reached a height of about 10 miles above the Earth, it’s usually burned out. That is, it’s usually slowed down to the point that it's no longer glowing. Practically every bit of it that was ever hot has been blown away by the, by the wind, and from now on it's about the same thing as you would get if you went up in a DC8 [airplane] and dropped the rock out in free-fall. It comes down and strikes.

11:26 Dr. Arnold: Usually they're cold, sometimes they are a little warm. It's a good test when somebody says he's really found a meteorite. Again, he usually tells you I went and picked up the rock and it was red hot. You cross that one off the list. The rock itself, the usual sort of rock, this one in particular looks no different than others but it's very different. Perhaps I can illustrate one difference. I don't know how many of you are close enough to see this but here is this pebble and here is the magnet. That's not good, let's try again. It's got flecks of iron in it. About 10 percent of the rock is also made of metal. The iron has nickel in it. There's hardly any mistaking this type of creature. Now let me say some things that meteorites don't have in them that I think are very interesting. They don't have fossils. Maybe this doesn't prove a thing, a lot of people have thought that it was very important. One of the ideas about where they come from, in fact, an idea that I believe myself, up to a point, is the idea that they come from that part of the solar system which lies between Mars and Jupiter. If you remember the list of the planets which probably all of you learned sometime or other - Mercury, Venus, the Earth, Mars - then there's a gap where there's a lot of cosmic rubble. Some 2,000 minor planets, so-called, have been logged in there and then you come to the great big one Jupiter, Saturn, and so on out.

13:15 Dr. Arnold: Most of us think that these meteorites come from that part of the solar system. What isn't at all clear, is what that rubble is. A very popular idea is that it's an old planet that blew up. These days you can imagine somebody telling the story that it blew up in a particularly violent war between the people on the left side of the planet and the people on the right side of the planet. That is something that I don't particularly believe, but if one ever found a meteorite which had a fossil in it, why you'd be pretty much shaken up in your skepticism. If you imagine the Earth blowing up in the same way and I guess the way that nuclear weapons are going nowadays, why you shouldn't consider this to be absolutely impossible? If you imagine the Earth smashing to smithereens and leaving a collection of rubble like the asteroids, probably one piece of rubble, we once figured this out, probably one piece of rubble in about one or two thousand would have a fossil in it, a piece of fish, something that a, that a geologist could identify. This we don't see. We do see organic matter occasionally, complicated carbon-containing molecules. They don't seem to have anything to do with life, as far as we can tell. We don't think that the asteroids, that the meteorites represent something that came from a planet where there was life. In fact, I don't think that the asteroids ever were a planet. Again, many of the things I say here today, I'll probably live to regret.

14:55 Dr. Arnold: In their composition in general they very much resemble, the total composition of the meteorite so far as the elements like the metals and oxygen and carbon and so forth is concerned, very much resembles what we know about the composition of the sun except that the sun has lots of hydrogen in it and other gasses which, of course, are not present in a hunk of rock like that. This reinforces the idea that perhaps the solar system did form from the Sun and not from some other star that passed by. Another statement that we're not sure of, but it's another example of what we learned from the, from the meteor. Let me finish up with that topic now and turn around and talk about the other kind of visitor from cosmic space, cosmic rays. Now, I did not bring any samples of cosmic rays with me today. However, I don't particularly need to because there are samples of cosmic rays in this room at this moment. The cosmic rays are particles, very energetic nuclei of atoms that come through the atmosphere mashing nuclei as they go. Through about a space this big, every second a cosmic ray particle passes. If I had a Geiger counter here, I could demonstrate this to you pretty nicely. Although some of the radio, the counts I would get would be from the radioactivity of the rock and the radioactivity of you, and the radioactivity of me, but a good deal of what the in fact, what would be registered by a Geiger counter in this room will be due to the cosmic ray.

16:43 Dr. Arnold: Now, why are these interesting? Well, perhaps the main reason that they're interesting again is that we don't understand them. They are by far the most energetic particles in nature and man with his great big machines has only just begun to be able to make particles which are as energetic as the least energetic cosmic rays. I don't know whether I can put this into perspective for you. I'll take a minute to try. It's a kind of a hand-waving business like a trillion dollars. How can you make anybody really understand what a trillion dollars is? But let me try this, this game. If I take a molecule of water, H_2O, and boil it out of a liquid, the energy required to do this is some .02 electron volts. That's a unit that scientists often use to measure energy in, .02. If I take a molecule in your body and snap it in the middle - which I can't do very easily with my fingers, but there are ways of breaking carbon-carbon bond - that takes a lot more energy. It takes about four volts. I can imagine pulling a good deal harder. If I take one of the nuclei in your body or in the air of an air molecule and pull one of the particles out of it and this is nuclear forces of the strongest forces that we have on Earth, this will require approximately 8 million electron volts, about a million times as much as a chemical bond.

18:33 Dr. Arnold: Well, the lowest energy cosmic rays are about a thousand times as energetic as that. They're in the billions and after that, we go to trillions, quadrillions, quintillions, sextillion, and so forth. And if you ask me how high is the highest energy that they go, I don't know but at least a billion billion. That's a, that's a very much of a lower limit of electron volts. How are they made? Where are they, where do they come from? We don't know. We think they may have something to do with the galaxy, with the Milky Way. We're very far from sure. The one thing that we can do to study them is to look at how they're distributed around the world. For example, about ten years ago some people were arguing that the cosmic rays came from the Sun. If the cosmic rays come from the sun, then they should be more abundant near the Sun. Nowadays, there are rockets which are going towards the Sun and these rockets show that they're about the same near the sun, or closer to the Sun as they are out here. We can look further away, you can imagine a rocket going further out. The game that I'm engaged in playing is a little different and it's a game that can't be played with rockets. It consists in looking at the past history of the cosmic ray, I can, the one thing I don't think I will ever be able to do with a rocket is to go back a million years or a billion years in time.

20:08 Dr. Arnold: I can do it with a meteorite. I can take these objects which have been out there in cosmic space for billions of years and I can examine them to see what effects the cosmic rays have had on them. It's had quite a measurable effect. We have certain special interest, instruments we've developed for this purpose and we find out what things the cosmic rays have done to these meteorites. In this way, I can for example tell you that the cosmic rays that struck the meteorites a million years ago were just about the same as the cosmic rays that are striking them today. This is not entirely what we expect. There are some theories which would expect, lead us to expect, that they ought to be getting quite a bit more intense these days, these days on a million years scale than they did, than they were some time ago. If we can carry on with experiments of this kind, then I think that even before we get to the Moon and Jupiter and Saturn and where you will Alpha Centauri, we will probably know the answer to the origin of the cosmic rays and the answer to the origin of meteorites. Now perhaps in closing, I ought to say one word about what all this is good for. I don't really think it's good for anything. I can't think directly of an engineering application, anything that will make people wealthier or healthier or much less, wiser, which is the most difficult thing to imagine of all.

21:49 Dr. Arnold: There are, however, and this is worth repeating, there are always a set of processes that go on when a series of new scientific discoveries takes place. You have to develop new gadgets. You have to invent new instruments in order or improve old instruments in order to be able to do the things you're trying to do. It always turns out that these things are good for something you never dreamed of. In my own past history of about six or eight years ago, there's something called the liquid scintillation spectrometer, nice polysyllabic object, which we developed in order to look at that time at Carbon-14, it is one of the isotope that is made by cosmic rays, that's in all of it. The application I had in mind for it was rather a fiasco. There wasn't very much that could be done with it along that line. Now, I discover that when I turn up at a hospital, there is one of these shining gadgets blinking neon at me in almost every clinical laboratory, unexpected but it's one of those things that happens and it's worth mentioning because it's perhaps more, this kind of thing is perhaps more characteristic of modern science than anything else. Thank you.

23:06 [Audience Clapping]

23:14 Speaker 1: Do any of you people have questions you'd like to ask Dr. Arnold? We'll let you just go right ahead and take them.

23:23 Dr. Arnold: Okay, why don't I come back up here then. I will try if I hear him.

23:32 Speaker 2: [Unclear]

23:37 Dr. Arnold: The question was, where did I get the meteorites? We get meteorites from many sources. There's, there's some which are, have been found many many years ago because they made big craters. There's one in Arizona called Canyon Diablo, which made a crater three-quarters of a mile across. People are still hauling very large amounts of iron out of that, and those are very easy to get. There are others which have been collected by research scientists over many years. There are six or eight great collections in the world. People, there have been about 2,000 meteorites seemed to fall, or found. These are mostly in these collections. In a few cases, like this one Bruderheim that I displayed here, the one the recent fall, we've gotten wind of them rather quickly and have gotten them directly from the people who first collected them. I have yet to find my first meteorite, I hope that perhaps this one at Los Padres National Park might be it. Yes?

24:41 Speaker 3: Are cosmic rays in the form of gamma radiation or [unclear]

24:47 Dr. Arnold: The question was whether cosmic rays are in the form of gamma radiation or whether there are different types of radiation. No, they are particles. Gamma rays, as you probably know, are electromagnetic. They are like light, only much shorter wavelengths. Cosmic rays are nuclear particles, protons, alpha particles, nuclei of big atoms in a few cases. Yeah?

25:10 Speaker 4: [Unclear]

25:18 Dr. Arnold: Well, we've damaged it. The question was could we tell what was responsible for the chipping and the odd shape of the meteorites? I don't know. I don't know how many of you can see this very clearly. Some of this damage was done by us, we broke the meteorite at this point for analysis. If I hold my hand over this part, this is what the atmosphere did in sculpturing it. What happens, especially to irons, is it, that you get melting and they're edies. Sometimes you can see in the museums, places where it's gone right through and there's a big argument as to whether the holes were in the meteorite when it was still out there or whether they were made in the process of passing through the atmosphere. Some like this Bruderheim, especially some of the rocks, are just quite smooth on the outside. They don't, you'd walk right by it.

26:12 Speaker 5: Where are the great collections?

26:14 Dr. Arnold: Where are the great collections? The Smithsonian Institution in Washington [DC], the American Museum of Natural History in New York, the British Museum. The greatest private collection, the Nininger Collection had just been given to the University of Arizona and it's, or Arizona State rather, which is in Tempe, Arizona. That's at least as good as any of the others. Also, the Chicago Museum of Natural History has quite a large collection and the Russians. The, I might say by the way that a number of our samples have come from the Soviet Union and that they've been very cooperative in furnishing samples for our research. Yeah.

26:58 Speaker 6: [Unclear]

27:00 Dr. Arnold: How are cosmic rays discovered? Well, in a rather interesting way. Radioactivity was discovered about the time of the Curies [Marie Curie and Pierre Curie]. You, you probably know about this, the 1890s while [Antoine Henri] Becquerel was the man who did this in 1896 and this was the most exciting scientific discovery of that generation. Everybody started studying radioactivity, which is the decay of atoms, which give off nuclear particles. And around 1910, people got around to wondering why there was some radioactivity in the air and there are radioactive gases, radon, which comes out of the soil and into the air. A man named Victor Hess at Fordham [University], who is still a professor at Fordham fifty years later decided that he would study this by sending up a balloon with a counter in it, a radioactive counter. To his intense surprise, when he went up in this manned balloon with a counter, the higher up he got the more he saw. He thought that the Earth's atmosphere would shield him from the, from the radioactivity of the, of the ground but, and it did, but there was actually more of the stuff on the outside. So people began to realize that something was coming in from the outside. Yeah.

28:23 Speaker 7: [Unclear]

28:27 Dr. Arnold: The inner Van Allen Belt is almost certainly connected with the cosmic radiation. It's almost certainly due to neutrons which bounce back from the atmosphere in decay. The outer one is probably not. This isn’t quite clear. There was a question also.

28:41 Speaker 8: [Unclear]

28:54 Dr. Arnold: Yes. It's a little hard for me to do them justice since I don't agree with them. But there, there are ideas about, quite outside of cosmic wars which I don't think people take too seriously. There are ideas about the effect of a too, close approach to the planet Jupiter. I think that's a weak argument. There are other ideas about the possibility of impact, let’s say if there were an object the size of the Moon that ever crashed into a planet. There is some possibility if you stretch the arguments far enough that the whole planet might disintegrate. Harold Urey and I and a good many others are convinced that this would not work in practice, but this has been suggested. That perhaps there were two objects and they struck each other. Yes.

29:38 Speaker 9: [Unclear]

29:44 Dr. Arnold: No. It may be a little warm but it is not. It was on fire. Because the whole thing happened so fast, the time it takes from the outer space to on the ground is likely to be about ten seconds. In the course of this time, though for the first seven seconds or eight seconds of this, the thing is in violent flame. Everything that is burning, at this time is burned off, there’s a, there’s just a thin skin of material left. For the last three seconds, it's whistling through the air at a speed slow enough so that it doesn't burn. This tends to cool it off. Also, of course, it always takes a little while for somebody to, to get to it. You can imagine for instance that if I took a hunk of iron like this and I just had about the outer say 32nd of an inch, 64th of an inch red hot and it was in the ground. You saw it from here say over the other side of the, of the school, by the time you got over it, the cool, the cold of the inside would just soaked the whole thing up.

31:04 Speaker 1: One more question, we'll make this the last.

31:12 Speaker 10: [Unclear]

31:16 Dr. Arnold: The question is why the meteors caused ions to form, charged particles to form when they pass through the atmosphere. To the question of the, of the heat. The, any flame which is hot enough will make ions and, and when the, when the burning goes on in the outside, the temperature can be, is high enough at the beginning of any rate to actually produce ions.

31:43 Speaker 1: Thank you, Dr. Arnold. We appreciate it very much and I was impressed with the number of questions that we had here. I think they were real good. That will conclude this meeting. I would really like to have the teachers meet Dr. Arnold and that's all.

32:02 [Audience Clapping]