Hermann Lecture Series 2022: Perry Phillips, Big Bang: The Beginning of the Universe (Part 2) – Elemental Abundance and the Cosmic Microwave Radiation

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Well, thank you very much. Very nice to see all of you here. I'm very happy to be here, just to use a hackneyed phrase that George Allen used to use.

At my age, I'm glad to be anywhere. Today, we are going to continue with the second part of the discussion on the Big Bang. And today, we will talk about the elemental abundance of the elements, primarily helium, hydrogen, and the ratio of those elements, and how that relates to the Big Bang.

And then we want to discuss the cosmic microwave background radiation. I know that's a mouthful, but basically, what we have is the universe filled with the glow of the embers of the Big Bang. And that gives us a lot of information and also is one of the classic of the three proofs that the hot Big Bang really is a valid theory that we can trust in terms of explaining on a physical basis how the universe began.

So with that in mind, we will move on. First of all, the evidence supporting the Big Bang. We looked at this yesterday with the threefold pillars.

And we have the hot Big Bang that is being supported on three pillars. And the first one is a universal expansion of the cosmos. We mentioned yesterday, as we look out, the farther out we look, the faster the objects are traveling away.

And we made the point that the best way to explain this is that the universe began very small and expanded. And we related how it is that, as a result of that, objects that are farther away are moving faster away from us than objects that are close by. And again, when we get out about 250 million light years, the objects that we observe moving away from us are not moving away from us in the sense of moving through space.

But space time itself is expanding. And I used the raisin bread analogy yesterday. That is, the raisin bread dough rises.

It takes the raisins with it. And this is what happens in the universe. As the universe expands, space-time pulls the galaxies along with it.

And with that particular analogy, the farther the raisins are, the faster they move away from one another. The farther the galaxies are away, the faster they move away from us. And with that, we determined we saw the expansion in terms of Hubble's law.

Today, what I want to discuss are the cinders of the Big Bang, if I may use that term. The cinders that were left as a result of the hot Big Bang that formed several elements early in the history of the universe. And we can actually measure what these elements were.

We can measure their proportion, one to the other. And that will give us another pillar of support for the idea of a hot Big Bang. And then the third thing that we want to look at is this cosmic glow that I call the microwave background radiation.

Why microwave? Oh, it deals with the wavelength of the radiation that we perceive. And I will relate how that ties in to the Big Bang and to the expansion of the universe as well. And what is so amazing about all this is we can come to these conclusions about the universe that is very large, very far away by using known physics that we have here on Earth.

And that is one of the wonderful things about the investigation of the universe. Well, first of all, what I want to discuss in terms of the elements of the Big Bang are going to be two elements, particularly, that were formed in the Big Bang. Actually, three: hydrogen, helium, and then a form of hydrogen called deuterium.

And I will illustrate what we mean by that. And what I'm going to propose is that with the known physics that we have and understanding the history of the universe, and by history, I mean the temperature and the pressure and the density of the universe in the past, our understanding of what that would be, we can determine what elements would have been created, how much would have been created at one time during the expansion that would have been created. I know that sounds like a tall order, but we can do that.

And then what we're going to do is we're going to go out, and we're going to take a look at the cosmos and see if our calculations are correct. And so what do we have? We have a good scientific method being applied to the universe as a whole. What do we do in science? We look at a phenomenon, and then we try to figure out what explains that phenomenon.

And we make a guess. And then with that guess, we say, if this is correct, I ought to be able to make a prediction that something else, if my analysis is correct, if my theory is correct, it should produce; I should be able to predict something else that would happen. And then we go out, and we see if that prediction is valid.

And if it's valid, then we have confidence in our theory, and that's what we're going to do here. So the first thing we want to look at is two elements. One is helium, and the other is hydrogen.

And here we have helium. This is a very interesting fellow who put a bunch of balloons together. I don't know, maybe he was watching the movie Up.

But he put a lot of balloons together, and he was able to rise to a certain altitude. I don't know how he got down. I don't know if he had a BB gun and then began to shoot the balloons, and then eventually came down or what.

But at least he was accomplishing what he wanted to with helium. We've all had experience with helium balloons. That's not a big deal.

But where did that helium come from? The second thing, what is proposed in terms of the origin of the elements is that hydrogen- that's what I mean by H- D is deuterium. It's just another form of hydrogen. Again, I'll explain that.

Along with helium and minor amounts of lithium, in other words, very light elements in what we call the periodic table, very light elements were formed shortly after the Big Bang. Now, we talked yesterday about the Big Bang beginning at time t equals 0, but you never get back there because of various factors. When would these elements have been formed? Basically, within about the first three minutes of the Big Bang.

And I know what you're going to say. Come on, nobody was back there. First three minutes of the Big Bang, how in the world can you figure out what's going on? Known physics, and we'll try to explain that.

So the idea is that these particular light elements were created during the Big Bang, but only these light elements. And I'll explain why we do not have heavier elements that were built up during that time. Other elements, like carbon, nitrogen, oxygen, which are absolutely essential for life, were produced in the middle of stars, in the center of stars.

And perhaps I'll have a little time to discuss that later on, how they were produced in the center of stars and then how they were incorporated here on Earth. I'll talk about that later on. If I don't, talk to me about it.

Let me know. Ask a question. But in other words, those light elements that I mentioned, the hydrogen, the helium, the deuterium, some lithium, they were created during the first three minutes of the Big Bang.

At least that's what we think. That's our theory. We're going to go out and see if that's true.

Well, here are some of the properties of helium and hydrogen. At one time, hydrogen was used in order to make balloons float and also to have what they called dirigibles that ferried people from Europe to America. And the famous one, of course, was the Hindenburg.

And one time, unfortunately, about 14 months after the Hindenburg was constructed, it was coming from Europe and went to dock at one of the towers in New Jersey. Unfortunately, there was an electrical charge that built up, caused a spark, and that was the end of the Hindenburg, as you see here. A few people survived, but it was just a catastrophe.

And people stopped using hydrogen for this particular reason. Helium is a lot safer, as we've already seen with this fellow ending up. But there's also not only filling balloons, party balloons, and all that with helium, there are also another very practical use for helium that I think you should see as well.

Here it is. Harden is, again, another one of my favorite cartoonists. Well, I mentioned hydrogen.

I mentioned deuterium. Hydrogen has evolved. We're going back to high school, well, maybe grade school science, OK, where we know that atoms are made of protons and neutrons in the nucleus and electrons on the outside.

OK, that's our simple, almost a planetary model of an atom. Well, hydrogen has one proton and one electron. Now, the proton, what charge does it have? Do you remember? Plus, right, a positive charge.

The electron is negative, and so you have neutrality here. Deuterium has a neutron in the nucleus. It's still hydrogen, because it still only has one proton, but it has a neutron in the nucleus, again, one electron.

And then you have tritium, which is another form of hydrogen. Unfortunately, that form of hydrogen decays with a half-life of about 13 minutes. And so what we're going to do, we're not even going to talk about that when it comes to discussing what's going on in the Big Bang, because even if it were formed, it would be totally destroyed.

So what we want to do, then, instead of talking about tritium, what we're going to do is talk about helium. And here is the challenge in the early part of the universe. How do we take hydrogen and form deuterium? And then how do we take hydrogen and form helium? Now, helium has two protons in the nucleus and two neutrons.

And you might think, well, that's fairly straightforward, actually. Here's all we have to do. We take a look at the early minutes, try to determine what is around.

We make calculations of the helium-to-hydrogen that we might think occurred. And what is interesting, the person who realized that the early part of the universe was hot enough to form elements was George Gamow. We saw him yesterday when it came to his understanding of the formation of things in the universe as well.

Here's what Gamow thought. During the early universe, the temperature is very hot. Atoms cannot exist as whole atoms.

What you would have is protons, and you would have electrons that would have independent existence. They would not be able to form hydrogen because the surroundings would be too hot. Now, here's what I mean by that.

Stick with me. In the early part of the universe, it's very hot. It's very bright.

We have a lot of radiation that's very energetic. And in talking about light, what I'm going to talk about is photons, photons of light, particles of light that are very energetic. And those particles are, those light photons are so energetic that even if a hydrogen atom were to think about forming, a photon would come along and break it apart.

And so what you have is this soup, this plasma of positive and negative particles. Now, how are you going to combine two protons into a substance that we call helium? Because helium has two protons. Hydrogen only has one proton.

How are we going to do it? What you need to do is take two protons and try to push them together. What's going to happen? They repel, right? Like charges repel. And they repel with such a strong force that the closer you push them, the repelling force grows without bounds.

We would say it approaches almost infinite repulsion. But something very interesting happens when they get close enough, and that is when they're very close, the strong nuclear force takes over, which is very attractive, almost 100 times more attractive than the repulsion of the electrical force. Boom, the two protons now fuse.

And something very interesting happens. So Gamow thought. And he got two individuals to help him by trying to make the calculations as to how this process would occur.

And here is one of the jokes of Gamow, because he himself was kind of a joker. He got somebody by the name of Ralph Alpher to help him. And his name is George Gamow.

And he said, well, Alpher is like alpha, the first letter of the Greek alphabet. Gamow is like gamma, the third letter of the Greek alphabet. He said, wouldn't it be interesting if we had another person with a name that sounded a little bit like beta? And then we could have a paper that we could call the alpha, beta, gamma paper.

And lo and behold, here's what happened. He got Alpher. That's alpha.

Gamow is gamma. And who's beta? Well, none other than Hans Bethe. And the interesting thing about this, Hans Bethe had absolutely nothing to do with writing the paper.

Gamow called him and said, hey, Hans, let's play a joke on people. I've got an alpha, and I've got a gamma. How would you like to be the beta? You don't have to do anything.

You don't even have to read the paper if you don't want to. And Hans Bethe had enough of a sense of humor that he decided to go along with this. And now, even to this day, this is called the alpha, beta, gamma paper that is a description of how these elements can come together.

Well, here's what happens. In order to form helium, what you've got to do is you've got to take four protons, put them together, then shazam, get a nucleus that has two protons and two neutrons. So somehow, what happens is you've got to change two of the protons to neutrons.

Well, this is a simplified diagram of what's going on. Here's what's really going on. And guess who devised this scheme? None other than Hans Bethe.

He is the one who won the Nobel Prize. And this is the process that goes on in the interior of our sun that converts hydrogen to helium and produces the energy that is necessary to power the sun, that produces the photons that eventually leave the center of the sun, where the reaction takes place, and come to Earth. You see, it's complicated.

The protons get together. They form deuterium. One of the protons becomes a neutron, et cetera.

It's a very complicated process. And this particular diagram is just a gestalt, just to understand that this is a very complicated process. And what is fascinating is that it was figured out.

And what I'm saying is that what goes on in the sun at about 50 million degrees is also what was going on in the early universe at that temperature, which was starting about 100 seconds after the Big Bang. The same thing was going on that was converting hydrogen to helium. Now, when did the cosmic helium form? I've already mentioned.

There's the Big Bang. There's one second. Helium formed during this particular time, from about 100 seconds to about three minutes.

Steven Weinberg has written a good book called The First Three Minutes. And he discusses this particular process that is going on at this particular time. Well, the process starts at about 100 seconds after the Big Bang.

It ends about three minutes after the Big Bang. After that, you can't produce any more helium. Before 100 seconds, you can't produce any more helium.

There is a window. Why? Why? Before this window, the temperature is too high. Photons are extremely energetic.

And any time one of these atomic nuclei tries to form, bang, a photon comes and breaks it apart. So you have to drop the temperature to the point where the particles condense without being torn apart by the photons that are energetic. Now, what's happening from 100 seconds to three minutes? The temperature of the universe is dropping.

Drops, drops, drops. It drops below the point where the photons are going to break up the nuclei. Nuclei begin to form.

But after three minutes, what happens? The temperature is too low for nuclei to form. Because how are the nuclei going to form? How are you going to get those two protons to come close enough for the strong nuclear force to grab them and to have that reaction take place where one turns into a neutron? You've got to give them a very, very high velocity so they crash together with enough force so that they overcome the repulsion and the strong nuclear force can grab them and combine them. But how are you going to get them to go that fast? How are you going to get them to have that much energy to be able to overcome that repulsion? Temperature: high temperature.

Temperature is a measure of how fast particles are moving. And if you have a high enough temperature, the protons can come close enough in order to fuse. Once the temperature drops below that, that's it.

The process stops. So what do we do? We say, we think we know what the density was of these particles at 100 seconds. We're pretty sure we know what the temperature was.

We know what the density is. Let us calculate what percentage of the protons that we have representing hydrogen can form helium during that window. And we can make our calculations, and this is what this chart shows.

This chart is not to wow us with mathematics or charts or anything like that. It's only to show that these kinds of calculations can be made. And what we find here is that the helium, by mass, should be about a quarter of the amount of material that is around after three minutes.

By mass, remember now helium is four times more massive than the hydrogen. If you're looking at numbers, and you pick numbers, number-wise, about one out of every 12 particles should be helium. That's the prediction.

Now we have to look at the observations as we go out into the universe. And here's what is fascinating. We look out into the universe, and we try to look out as far as we can at the earliest times of the universe.

Because what are we looking for? We are looking for helium that was formed some three minutes after the Big Bang. How are we going to get closer and closer and closer to the time of the Big Bang? Remember what I said yesterday: the farther out you look, the farther back in time we are looking. And so we look at galaxies that are very far away.

And this is shown by the deep field picture that we got from the Hubble telescope. And when you look at this and make your observations, what we find is the following. The vertical bars are the error bars in the measurements.

But what we find is that in looking at this point right here, the observation is 0.25, 1 quarter of the mass that we find is helium. In other words, the calculation is very much in keeping with the observation. And the observation is very much in keeping with the prediction that is being made.

This is an astounding fact that we find going on. Now, here's one of the problems. Helium was not created only during the Big Bang.

Helium is also created in stars, as I mentioned, stars like our Sun. Other stars that are larger also produce quite a bit of helium. What happens, however, with larger stars is that eventually they become unstable, and they explode.

What's going to happen to that helium that is in that particular star? It's going to be spread out in the surroundings. And so when people look at the helium that is present in the universe, they have to be very careful where they look so that the primordial helium is not contaminated with the helium that comes from exploding stars. And this is what these particular measurements show.

They basically show the progression of the ratio of helium as we go farther and farther out and look more and more into the distance where the helium is less likely to be contaminated with what comes from stars. The point, however, is that the prediction and the observation is pretty much the same. Well, there's one other thing that I want to look at.

We looked at the helium. There's one other thing I want to look at, and that is the deuterium. That, too, has been determined.

And I don't have diagrams for that, but all I can do is point to the observations that have been made. And in this particular paper, what you find is that the detection of deuterium in one system at the level predicted by primordial nucleosynthesis provides a direct confirmation of the standard cosmological model, which is the hot Big Bang. So those are the cinders of the Big Bang, and the prediction is in keeping with the observation.

So let's make a conclusion here. Universally, the observed ratios of helium to hydrogen and deuterium to hydrogen substantiate the theoretical predictions of the Big Bang theory. Only the Big Bang naturally accounts for these ratios.

You can't do it with stars later on. The only time you can do it is within that window of the Big Bang. Thus, the observed universal abundances of helium and of deuterium are used strongly for the Big Bang view of the universe.

That is our second pillar. And then people have gone on in order to make calculations of other elements that were formed at that time as well: helium-3 and lithium-7. And although there's a slight problem with the lithium, the helium-3 is working out.

So this becomes a very, very strong indication that we know what was going on during the Big Bang. Let's go to the third pillar that we had, the Cosmic Microwave Background Radiation, or the CMBR. In order to observe this, we not only observe it from the surface of the Earth, but we also use satellites.

And we'll see the importance of this particular satellite, the COBE satellite. Here's our friend again, George Gamow. This time, he engaged not only Alpha, Ralph Alpha, but Robert Herman.

And they had the following idea in the late 40s. I mentioned that the universe was very hot when it formed. It cools down as it expands.

But all those photons are still there. But what happens to them as the universe expands? Well, as the universe expands, the wavelength of the photons also expands. They lose energy as the universe expands.

So what starts out as a photon that has a very short wavelength, like an X-ray or a gamma ray or what have you, by the time it is finished, when the universe expands, that wavelength has lengthened out to a microwave wavelength, which is the light that we see. The wavelength is something like 10 to the minus 15 centimeters. Microwave is about 1 centimeter.

And it went from that very short wavelength to a very long wavelength because of the expansion of the universe. But they're still there. And so Gamow and Alpher and Herman tried to calculate what this radiation would look like at this particular time, 14 billion years after the Big Bang.

And they said, if it is there, we should be able to see photons whose wavelength now is about 1 centimeter because of the expansion. Well, there's George Gamow again. And there's Alpher.

And there's Herman. Very, very famous paper that was published in 4850 work. By the way, let me just do a parenthesis on George Gamow.

He has written Boku books. And they're very popular. And I remember as a teenager reading this one, 1, 2, 3, infinity.

And I always wanted to be a scientist. In fact, I wanted to be a scientist when I was in second grade, believe it or not. So I was about seven years old.

And I knew I wanted to be a scientist. When I was in third grade, I knew I wanted to be an astronomer, be an astronomer. One of my friends jokingly said it's because I had stars for my girlfriend.

But at that stage, who knows what was going on. But I remember reading 1, 2, 3, infinity. And that really gelled within me the desire to be a physicist.

And I recommend that book. If you have teenagers, if you know teenagers who are in any way interested in science, that's a great book. But anyway, the CMBR was proposed by him, Alpher, and Herman.

And we get back to them. And they said that the radiation should be there. The afterglow should be there.

But they made one very important prediction. And they said the radiation should be a special kind of radiation, so-called Planck radiation. And Planck radiation is the kind of radiation that is given off by any body that has a temperature.

And it has a very specific spectrum, which I will show you. Whether it's a very hot body, whether it's a very cool body, whether it's the radiation that is leftover from the universe's creation, it should be this particular kind of radiation, Planck radiation. Now, let me give an analogy here of a fireplace and a campfire.

How would you know if a fireplace has been used or a campfire has been used after the flames are gone? Well, you say, well, there must be some warmth. So I'll go, and I'll touch it and say, well, this is warmer than the surroundings. Somebody must have lit a fire here.

But here's a problem. You can only get within 100 feet of the fireplace. You can only get within 100 feet of the campfire.

How are you going to check then? Answer. What did I say about all objects that have a temperature? They emit radiation, and they emit Planck radiation. So what you do is you take a spectrum.

You take a spectrum of the fireplace. You take a spectrum of the stones around the campfire. And what you do with the spectrum, what is it? As we mentioned last time, what a spectrometer does is it takes the incoming radiation and breaks it up into various wavelengths.

And that's what we do. We measure that spectrum, and we can tell what the temperature is of the object. This is done all the time, by the way.

By the way, here's the paper that was written by Herman and Alfer that became a classic. Anyway, here's the shape of the radiation, Planck radiation. It has a specific spectrum.

It's named, by the way, after Max Planck, who figured out theoretically the formula for this kind of radiation. Here's what it looks like. This is, to the left, short wavelength.

To the right, long wavelength. Here's visible light. From blue to red.

And an object that was about 3,000 degrees Kelvin, and 3,000 degrees Kelvin is Fahrenheit. It's going to be roughly half that, if you like. But what it is, the sun that emits this visible light, the surface temperature is about 3,000 K. And you notice that if the temperature increases, the peak goes to shorter and shorter wavelengths.

Trying to find my, there it is. Shorter and shorter wavelengths. And as things cool down, notice what happens to the spectrum.

Notice what happens to the Planck radiation. All of a sudden, you get down to 100 K. You still have that characteristic shape, but it is lower down and more to the right. Now, this was a critical thing that Herman and Alpher figured out.

And that is the radiation is going to be blackbody radiation. Well, enter Penzias and Wilson in 1964. The previous calculations were done in the late 40s.

In 1964, Penzias and Wilson, that you find over on the left, their picture on the left, with an antenna that's behind them, were trying to improve signals coming from a satellite. And this is a time when the Echo satellite was launched. It was nothing but a big silver balloon.

And the idea was to have communications from the East Coast to the West Coast. And so the idea was that your signal would be beamed up to the Echo balloon. That would bounce off the Echo balloon, but it was high enough so that the signal would bounce off from the East and be received in the West.

And that was a check to see if communications could be done that way. And what they were doing with the special antenna, they were trying to pick up that signal that was bouncing off the Echo satellite, but they had to calibrate their antenna. So what they found, however, is that not only when they were pointing at the satellite, but wherever they pointed their antenna, they kept getting noise.

They hooked it up to a speaker, and they would hear sssss. Well, the Koran. OK, there are no snakes in here, or anything like that.

But no matter what they did, they thought maybe it was because there were power lines nearby. They excluded those. They thought maybe it was because of electrical interference with power generating stations.

They excluded that. that. They excluded everything but that was still there.

Well, they said, there's one more thing to do. By the way, this antenna is very large, as you can see from the two standing underneath it. One more thing to do, and that is they went and examined the interior of this big horn that you see that was collecting the radiation.

And in their paper, they say that it was covered with a white dielectric substance. That white dielectric substance was pigeon poop. And here is Penzias actually cleaning it out.

They tried to shoo the pigeons away. In fact, they captured them and gave them to somebody who actually grows pigeons, and they were thinking maybe they were unusual because, after all, what pigeon would want to live in a horned antenna like that? And the fellow said, no, there's nothing unusual about these pigeons. And so he released them.

Next thing I knew, they came back, and they did not want the white dielectric substance again to fill the antenna. So basically, as Robert Wilson says, he finally got a friend of his with a shotgun, and that ended the whole thing with the pigeons. But here's the thing.

They kept getting this radiation no matter where they pointed the antenna, and it was fairly constant. And this is what they found. And that point that you see right in the middle there, right here, it was from all over.

It was uniform. And they said, if this is cosmic microwave background, this is where it should be on the Planck curve. I remember I mentioned before that the peak gives you an indication of the temperature.

And the temperature here was going to be about 3.7 Kelvin. Zero Kelvin, by the way, is absolute zero. 3.7 Kelvin.

That is how much that radiation had cooled down. And you look at this, however, and you say, come on, that's one point. That's just one point.

We don't know where the peak is. How can you tell the temperature without knowing where the peak is? You've got one point. What are you talking about? Well, the people at that time, by the way, I was a graduate student at this time, people could not think of any other means by which this kind of radiation would be received.

But later on, in the 80s, people started looking at this even more. And in the late 80s, the Cosmic Background Explorer satellite was launched to go and look at this radiation above the Earth's atmosphere, looking specifically where that peak was in the blackbody radiation. And here's what it found.

Here are the points right near the peak over here. All these blue points are from the COBE satellite. And notice how they exactly follow a plane curve.

The prediction was exact. And the temperature turns out to be around 2.75 Kelvin. The prediction by Alpher and Herman was it would be someplace between about 3 and 7 degrees.

And it turns out to be up to 2.75. But the essential thing is it was Planck radiation. A rather, rather amazing calculation. There's Benzias and Wilsons.

Note how well the data matched the prediction. COBE confirmed the existence of universal background radiation just as predicted. What can we conclude? The universe is bathed in microwave radiation that is a remnant of the hot initial conditions of the universe, as predicted.

The CMBR was predicted to exist, and it would be Planck radiation. That's what we find. And I'll drink to that.

Only the Big Bang naturally explains the existence and the properties of the CMBR. Well, evidence supporting the Big Bang. Let's go back to our initial diagram.

We have the hot Big Bang. We saw how the expanding universe supports it. We saw how the light elemental abundance supports it.

And we saw how the cosmic background radiation supports the hot Big Bang. And it's all done with known physics, which again is amazing. Well, let me do a full disclosure here.

In spite of the evidence, some tensions still exist in terms of the Big Bang. Not everything has been solved. In fact, I guess I'll have to wait till next time to discuss it.

But let's make a couple of conclusions here. Very interesting passage in Ecclesiastes 4.12. And it says a threefold cord is not quickly broken. I think we have a threefold cord here that is not quickly broken.

People who deny that the hot Big Bang has occurred, whether it be for theological or for scientific reasons, to my mind have an enormous amount of evidence to overcome in order to deny it. And it's not just a matter of overcoming the evidence. It's not just a matter of picking a little thing here and a little thing there.

Give me an overall theory that is as good as this that explains everything. Okay? Don't just give me a little point here. Give me an overall theory that explains everything as well as these three pillars do of the hot Big Bang.

There's another verse. A good friend of mine, Dallas Kane, used to use this verse. And he said, it's the glory of God to conceal a thing, but the glory of kings, maybe cosmologists, scientists, et cetera, to search out a matter.

And he put the following interpretation down. It's the glory of God to conceal something, not because he wants to hide it from us forever and we're tampering in his field by trying to uncover it, but he hides things in a way that people hide eggs in an Easter egg hunt, which is coming up soon. You hide eggs for an Easter egg hunt.

Do you hide it because you want to totally frustrate the kids, not find them? No, we do it because we enjoy watching the kids find the eggs. And of course, they enjoy it too, especially if it's chocolate with cream filled inside. This is the sense in which God hides things because he enjoys watching his creatures understand these things and search them out.

And so it is the glory of God to conceal things, but I think it's the glory of humankind to be able to understand these things on a universal basis, to understand what is going on, not only way out there, but also way back there in time. That is absolutely amazing. Here's one of my favorite books, which came out in the late 70s.

I remember reading it in the early 80s: God and the Astronomers. Maybe some of you have already seen this and read this. And Robert Jastrow was with NASA, one of the heads of the NASA program.

And he writes the following. He starts out by writing the following. When an astronomer writes about God, his colleagues assume that he is either over the hill or going bonkers.

In my case, it should be understood from the start that I am a raving fundamentalist and believe everything in the Bible. Not quite. However, he's an agnostic.

However, I'm fascinated by some strange developments going on in astronomy, partly because of the religious implications and partly because of the peculiar reaction of my colleagues. Now we see the astronomical evidence leads to a biblical view of the origin of the world. And he spends the rest of the book describing this.

The details differ, but the essential elements in the astronomical and biblical accounts of Genesis are the same. The chain of events leading to man commenced suddenly and sharply at a definite moment in time in a flash of light and energy. Now consider this.

If an agnostic can see the connection between the Big Bang and Genesis, should Christians be far behind? I've actually written on this a while back. The article appeared in the Perspectives on Science and Christian Faith that the American Scientific Affiliation puts out. I get into more detail in terms of the creation not only of the elements but of other particles as well.

Not only are protons colliding together to form neutrons and hydrogen and deuterium and all that, but what we also find is quarks coming together to form the protons and the neutrons to begin with, etc. I discuss that, and the article is available either in the library or online at these particular sites if you are interested. And with that, I will end.

Thank you for your attention. Thank you. I made a promise, didn't I? That I would say something about the formation of the other elements? Okay, here goes.

Give me five minutes. Only the light elements formed during the Big Bang. When Gamow was making his proposal about elemental formation during the Big Bang, he thought he could explain the whole cluster of elements that we have.

The whole periodic table, starting from hydrogen going all the way to uranium at that point that they knew. But when they made the calculations, they realized that doesn't work. The process stops at lithium primarily.

So where do the other elements come from? What we have in the universe as a result of asymmetries and density when the universe was forming, we had large clumps of matter that had enough gravitational field to pull themselves together and to form stars and galaxies. Stars that form in the cosmos have various masses. Some are very large, very massive.

Some are very small, not very massive. The stars that are about three times more massive than the Sun and the Moon have a slightly different history. Here's what happens to them.

How do they start out? All stars start out by fusing hydrogen into helium along the process that I discussed. But the process doesn't stop there; the way the process stopped during the Big Bang. And the reason is that a star- what is it? It's a balance between gravity trying to pull it together and the nuclear reaction in the center, which causes pressure, which is trying to push it apart.

And a star like the Sun is stable. The gravitational field cannot overcome the pressure, and the pressure does not overcome the gravitational field. And it sits there very happy for about 10 billion years, but eventually it runs out of hydrogen.

The nuclear reaction cools down. Gravity says, here's my chance. I can squeeze it in.

But as it begins to squeeze in the star, the center becomes hotter and hotter. Not just 10 million degrees, which allows helium to form from hydrogen, but 100 million degrees, which now allows the helium that is there as ash to form carbon. Then eventually that reaction runs out.

Gravity has a chance to squeeze the star even more. Another reaction takes place at 500 million degrees. Carbon eventually turns to oxygen, and you get nitrogen, and you get other elements as well up until you get iron.

Once the core of the star becomes iron, there's no other reaction to overcome the gravitational pull of the center. And what does the star do? It collapses suddenly, the likes of which you would not believe. All this material comes into the center, bounces off, begins to expand, and then you get a bunch of neutrinos forming that take this material and spread it out light-years away from where the star was.

What happens now to this material? There are other gas clouds there that are going to collapse, that are going to form stars. And forming stars, by the way, we now know that process also forms planets. So those stars and those planets now have what? Carbon, nitrogen, oxygen, calcium, phosphorus, iron, or hemoglobin.

All those things now are in the planet, and it all came from the interior stars. What did God do to form man? Where did he form it from? Where did that come from? Think about it. Think about it.

Now you're going to say, oh no, Phillips is going to have a new age on me. No, this is really the way it seems to work. So you've heard the expression; you used to have bumper stickers that said, have you hugged a tree lately? I always wanted to put on, say, have you hugged a star lately? But you better have an asbestos suit on if you're going to try that.

Okay, with that I end. Let's have some questions. The term is the Big Bang.

How do we know that it was noisy? That's a good question. The term Big Bang was actually a pejorative term that was used by Fred Hoyle in a debate to try to, as I said, it was a pejorative term. And it's used not that there was sound there, but the fact that it was like an explosion.

And in terms of sound, interestingly enough, there were acoustic waves that were traveling through the universe at that particular time that condensed some parts and rarefied other parts that eventually became our galaxies and superclusters and all that. But that's a whole different story. There's no sound.

By the way, in empty space there's no sound. Regardless of what you see in Star Trek, the sound needs a medium to travel and there's no medium. But on the other hand, just think of all the silence you would have if you see the spaceship Enterprise, and it takes two minutes to get from one screen to the other side of the screen, and then it's total silence.

You got to put something in there. John Muir, a very famous naturalist, was helping Teddy Roosevelt establish some of our national parks and so on way back. Anyway, he made a comment about connectedness, and he says every flower is hitched to a star.

I thought that fits in quite well. Interesting, yes. Now we understand that there's something behind that.

By the way, I mentioned that there are some difficulties here, which I'll mention next time, but next time I will get into more detail in the cosmic background radiation because that gives us a lot of information in terms of the composition of the universe. And let me just tease you a little bit. We are made out of what is called baryonic material.

Protons, neutrons, okay, throw the electrons in there as well for neutrality. And everything that we touch, feel, is baryonic material. You say, well, what percentage of the universe is baryonic material? Well, I mean, it's 100%, right? I mean, this is it.

No. About four and a half percent of the universe is stuff like us. Another 20% is dark matter, which we know exists, but nobody can find what it is, but we know it exists.

And then remember the dark energy I mentioned, which is even more mysterious than I mentioned last time? About 73% of the universe is made out of that. So if you felt like a nobody before, you can feel like a special nobody after all this. So it says in scripture, what does it profit a person if they gain the whole cosmos? That's the word used there for world, and lose their soul.

So it's saying basically we're worth more than the whole cosmos, so we feel a little bit good about ourselves. Yeah, yes, yes. I mean, that's the other angle, that in spite of the vastness of the universe and the mighty objects that are there, God is still interested in us to the point where his son would come to die for us and be resurrected for us to have a relationship with him.

It's pretty amazing. I'm sure a lot of people in this room are probably pretty tuned into the Webb Space Telescope. It's going to be exciting to see.

It's going to be able to look so much further into the past. Yes. It's just amazing to think that the further we look, it's time travel.

You know, we're looking way back. Kind of exciting. Yes, and the point where Hubble is trying to look is about a half-billion years, light-years, half-billion years beyond the edge, beyond what Hubble could see.

By the way, the Webb Telescope- the nickname now is- we've had the Hubble Telescope; people are taking out the " e " and calling it the Webble. Anyways, what it's going to look at is a period of time where we think that galaxies form. So this is still going to be a good bit of time after the Big Bang.

I failed to mention that the universal background radiation, where it comes from, it comes from about 300,000 years after the Big Bang. So wait a minute. You were talking about protons and neutrons in the formation of helium 100 seconds to three minutes after the Big Bang.

I mean, how do you know? We can't see that. No, we can't, but we use our theories, and our theories seem to work. But here's what happens.

Here's why you can't see anything in the sense of receiving photons from that particular time: even though the temperature was low enough to keep nuclei from interacting and forming new nuclei, new elements, the electrons were free to roam. The electrons had too much energy to be able to form stable atoms. Now, so what, who cares, and what difference does it make? Okay, here's what difference it makes.

Free electrons scatter light in the same way that, on a very foggy day, if you take a flashlight and try to shine it, what happens? It doesn't go very far. The light just scatters all over. This is exactly what electrons do.

300,000 years after the Big Bang, the temperature cooled to the point where you could have stable atoms, where a proton and an electron could get together and form stable atoms. With stable atoms, photons are not blocked by the electrons. They go straight through.

And so this cosmic background radiation that we see- what we are seeing is what the universe was like 300,000 years after its formation. Pretty cool. And we can map that, and the mapping of that radiation, as I said, is going to give us an enormous amount of information that leads to, well, maybe a multiverse.

But we'll handle that on Thursday. Thank you all again. Appreciate your attendance.