How Weird Is the Cosmos?

ALAN GUTH: One of these pieces that split, when it split off it was about the size of, well it was probably a large region, but within that there was something the size of a marble that's going to become everything that we observe today. Once it splits off, it's been expanding, so it coasts, slowed after that by ordinary gravity.

ROBERT L. KUHN: But there's no new universe that comes out of our universe then, it's that original stuff. A marble came out of that and we're the marble.

ALAN GUTH: That's right. Exactly right. That's right.

ROBERT L. KUHN: Now I understand.

SHOW OPEN

ROBERT L. KUHN: Every few months it seems, something comes out in the newspaper or in journals that is an absolutely shocking discovery or revelation in astrophysics and cosmology, I'm shocked. Are you guys, the professionals, shocked?

DAVID GOODSTEIN: That's the most amazing thing, I know as an outsider that it was just a few years ago that black holes were considered a mathematical fantasy, there was no proof that any such thing existed, and now I think it's believed, my colleagues, they can, they can disagree if they want, that every galaxy is condensed on a black hole the way every rain drop is condensed on a particle of dust and this only happened just a few years and, in those few years, it's become so ordinary that we don't even mention it in a discussion like this.

ROGER BLANDFORD: That's right.

NEIL DEGRASSE TYSON: I agree 100%, that's how quickly it came on and how rightly skeptical many people were, but as the observations kept rolling in, there was no doubt about it.

ROGER BLANDFORD: Another big surprise is that we've discovered, uh, very high energy cosmic rays, these are subatomic particles that have the energy of a well hit baseball and these are being detected.

ALAN GUTH: Well, I, for example, was genuinely surprised with the results that came out a few years ago that the universe appears to be accelerating.

ROBERT L. KUHN: The expansion of the universe.

ALAN GUTH: Not the expansion, the acceleration.

ROBERT L. KUHN: The expansion was getting faster, right.

ALAN GUTH: The expansion of the universe is speeding up, and the best candidate for that, by far, really the only sensible explanation that I think is currently on the table is an energy that just permeates empty space, and that's exactly the kind of energy that causes acceleration, and the amount of acceleration that it would cause is exactly what's seen in the supernova observations and, when I use this word exact, I really mean to an accuracy of about 10%.

DAVID GOODSTEIN: An accuracy of 10% is a big improvement in astrophysics, I can remember when they used to tell us that the most important equation in astrophysics is one is approximately equal to 10.

THEY LAUGH.

NEIL DEGRASSE TYSON: One of our biggest challenges in astrophysics, since we can't take a tape measure and measure distances to stars, we can't travel there and read our odometer, we need to be much more clever about it, and one of the ways, one of the most successful ways that have been developed is to look around the galaxy and try to find a thing, a star, an event, something that, every time it happens, or every time you see it, it's the same, whether it be here or in another galaxy. And, if you do that, and you know the one up close very well, then that means you can judge how far away the other one is by how much dimmer it shows up to be, compared with the one you know.

ROBERT L. KUHN: If their absolute level is the same…

NEIL DEGRASSE TYSON: Exactly, so if I have a world of a 100-watt light bulbs and I put a 100-watt light bulb in another galaxy and I see how much dimmer it is, I know how far away it has to be to be that dim. Supernovi are brighter than the entire galaxy in which they explode, so, they become our best known standard candle that enable us to get accurate distances to the most distant galaxies. And by doing this, you can say, all right we can measure the expansion of the universe, and based on that model, my standard candle equations tell me how bright that supernova ought to be, and it's not, it's got a different brightness, and so does that one and so does that one. And the only way you can fit your curve through these candles is to admit to yourself that we live in an accelerating universe.

ALAN GUTH: it's incredibly shocking, in terms of what it says about fundamental physics because from the point of view of fundamental physics, we just have no explanation of what we call this dark energy might actually be. It should be brought out, the situation now appears to be that if we talk about the total energy density of the universe…

ROBERT L. KUHN: Which is all the mass, all the energy, all together.

ALAN GUTH: Yeah, mass is a form of energy in this language, so it's all the mass plus anything else, about 30% of that probably is what we call dark matter, and about 60 or 70 or almost 70% is this dark energy, the stuff that's causing the acceleration. Not only do we have no idea what the component is that's the dominant contribution to the universe, we don't even know the second dominant. We're only the third dominant and that's what we think we know something about, so there's a tremendous amount of mystery here.

ROGER BLANDFORD: I think one of the things that you learn about the subject is that you are, there's a thrill a minute you're getting new discoveries all the time. And we're very fortunate to be living at a time when these discoveries are coming out at such a tremendous rate. This is a golden age of discovery in astronomy and it's been going on for about 40 years, and it's largely driven by technology, new technology being applied to observation.

NEIL DEGRASSE TYSON: The cosmos comes to us through telescopes, through particle accelerators, and there's a whole aspect of the universe that our senses had no access to, for us to declare that it makes sense or not. We discovered neutron stars, pulsars, that have the density equivalent, if you take a herd of 50 million elephants and cram them into a thimble, that will weigh the same as a thimble worth of a neutron star. And, we have to contend with this all the time. THEY LAUGH. We're already primed for wild and crazy thoughts that, in fact, come out of the cosmos. The threshold for what is ridiculous has to necessarily be quite low in the community of astrophysicists when you just look at the history of the kinds of things we've discovered. Just look at how often we have been baffled and stumped and had to sort of grow out of that baffledness to get ready for the next turn of events that comes our way

ROBERT L. KUHN: Alan, all of the things we're discussing regarding the expansion of the universe reflect on a theory that you came up with in the early 1980s that really revolutionized everyone's understanding about how the universe began. Could you just give us a brief summary of that.

ALAN GUTH: Sure, the theory you're talking about is called the inflationary universe theory. It addresses the question which the conventional form of the big bang theory really just left out, which is the question of what banged, what started this enormous expansion. Inflation proposes that there would be a form of matter which would actually turn gravity on its head and make it repulsive, and that's exactly what you need to start the universe expanding

ROBERT L. KUHN: Let's go into a little bit more. When does inflation start and when does it end?

ALAN GUTH: Inflation lasted probably about 10^{-30} seconds or something like that, although it's a number we're not very certain about, 10^{-30} maybe actually explains a decimal point, 29 zeros and a one.

NEIL DEGRASSE TYSON: If can't imagine it, there's nothing wrong with you THEY LAUGH. You're still an okay person.

ROBERT L. KUHN: Now during that time, space expanded faster than the speed of light.

ALAN GUTH: That's right, the speed of light is an absolute barrier for a race. If any object has a race with a light beam, the light beam always wins, and that says nothing goes faster than light. But, nonetheless if you imagine space as a plastic medium that's stretching, general relativity in fact, places no limit whatever to how fast it can stretch, so this stretching does occur far faster than light. So, during this brief time that I'm talking about the region that we've now observe, everything that we can see goes from being at the start of that time smaller than the size of a single proton, and, at the end of that time, it's about the size of a marble and then it continues to expand up until the present day.

ROBERT L. KUHN: Well us about human beings that we can look back 12, 13, 14 billion years and describe events that are a billionth the size of a proton in the space of time of 10^{-30} a second.

DAVID GOODSTEIN: We have a deep faith in physics. LAUGHTER.

ROGER BLANDFORD: I think it's a long, historical pattern though of people looking at these questions and asking these questions. If you go back to ancient Greece, there were certainly analogous questions being asked and, in some sense analogous tools being employed, albeit in the extremely primitive manner to try and get the answers to these questions and it's something perhaps deep in humaning, in the human spirit if you like to make these enquiries and I think Neil is very right in that we're forever being shocked by the universe and what it throws up in our faces, but we shouldn't forget that when we're thinking about the Greeks or we're thinking about theoretical speculation, ultimately, we're doing science. And the hard test of these theories is going to be observational predictions that come home.

ROBERT L. KUHN: Let's look at dark matter. Of the matter in the universe, 90% is dark. Tell me what that means.

NEIL DEGRASSE TYSON: In fact, I'd rather word that slightly differently. To even assert that it's matter assumes that you know something about it that we don't. 90% of the gravity that we see has no basis in matter that we know or understand.

ROBERT L. KUHN: Yeah, how do we know it's there if we can't see it?

NEIL DEGRASSE TYSON: "The Missing Matter" how do you know what's missing if it's not there. It's a very simple experiment, actually, there are two classic measurements of this. You measure how fast these galaxies are moving and that tells you how much mass is there, holding them together. And, because, if there's not enough mass, those speeds would have the cause to fly apart. And, so, you infer how much mass is there from the speeds, then write that down and put a pin in it. Now, you say, well let me just count up the galaxies, you can do that, too, count them up, estimate how much mass would be per galaxy and you compare these two numbers and one is a hundred times the size of the other. And so there's extra matter there that we can't account for, protons, neutrons, electrons, none of these classic particles you learn about in chemistry class.

ALAN GUTH: Another I think important piece of evidence is that, from measurements of the non-uniformities in the cosmic background radiation, which we view as the afterglow of the heat of the big bang. They can measure these non-uniformities at the level of one part in a hundred thousand, and because these have evolved as the universe has evolved, they have a lot of clues in them about the evolution and history of the universe.

NEIL DEGRASSE TYSON: I would add that in the map satellite right now, the Microwave Anisotropy Probe, it will map this cosmic microwave background with such precision that it'll enable you to compare the pattern in one part of the sky, with another, and there's something we don't yet know, and that is whether space is sort of ordinary or whether it has sort of multiple connections to it, because if it does, then the pattern over here will be exactly the pattern over here, and that tells us that the universe curves back in some loop, a donut or some sort of three dimensional Möbius strip, and this are the fanciful side of what that analysis might bring

ALAN GUTH: It will be a pretzel universe, that is sort of strange. THEY LAUGH

NEIL DEGRASSE TYSON: It's just strange. And we like strange things.

DAVID GOODSTEIN: Not stranger than any of the other things.

NEIL DEGRASSE TYSON: But equally as strange.

NEIL DEGRASSE TYSON: And keep trying to think what discovery in our near future could be as astounding to us as Hubble's discovery that we lived in an expanding universe, and something like that, for me, would be quite extraordinary.

DAVID GOODSTEIN: Just think of what happened. Albert Einstein works a theory, all by himself, 1916, that has a natural prediction that the universe is expanding, he doesn't believe this, so he puts in, artificially, something he called the cosmological constant, it's supposed to prevent the universe from expanding. Then it's discovered, Hubble, that the universe is, in fact, expanding, and so he calls that the biggest mistake of his scientific career, and now we've got it back again to explain this acceleration of the universe that Alan was talking about.

NEIL DEGRASSE TYSON: So his biggest blunder was saying that it was his biggest blunder.

DAVID GOODSTEIN: THEY LAUGH Exactly, exactly.

ROBERT L. KUHN: Clearly all that we're talking about requires a set of fundamental laws of physics. Has there been some recent data suggesting that some of these fundamental laws, some of these constants may be changing over time?

ROGER BLANDFORD: Well, there have been reports that one of the famous constants of nature, which is called the fine structure constant, may be changing slightly over time.

ROBERT L. KUHN: What is the fine structure, what is it composed of?

ROGER BLANDFORD: Oh, it's, it's a, it's a combination of the speed of light and the charge on the electron and a famous constant that every physicist knows.

DAVID GOODSTEIN: Well, if the fine structure constant is changing, it means that the charge on the electron is not constant, and then that means that chemistry is changing all the time. We tend to think that, well, we say the laws of physics are eternal, and this says not even the laws of chemistry are eternal, and that would come as quite a shock, I think, speaking of shocking things about cosmology.

ROBERT L. KUHN: What will the implications be?

DAVID GOODSTEIN: There has to be a fine balance among the constants of nature for lots of things, including us to exist in the world. If the fine structure constant were to change by very much, we would probably become impossible. And, of course, we would prefer that that not be, be the case.

THEY LAUGH.

NEIL DEGRASSE TYSON: But there's an important point here though. We're talking about a difference in the fine structure constant from long ago. Whatever it is today, we're here, so, we're okay with its current value. If it had a different value back then, that would fly in the face of our expectations, but there's nothing in principle that would prevent us from modeling the way in which it has changed over time and then reinterpret the statements we've made about the early universe. And by the way, just to put that in historical perspective, I think it's important to realize science advances not by throwing a successful theory out the window, it advances by recognizing the successful theories being a subset of a larger, deeper, understanding. People often refer to the period of Einstein as that which threw Newton out the window and now we have a new way of thinking of the universe. I think that doesn't quite capture it as accurately as possible. If you look at Einstein's equations of motion and of gravity, if you put in low gravity and low speeds, all of his equations then look exactly like those of Newton.

DAVID GOODSTEIN: That's a very good point. It's not true that Einstein, both relativity and quantum mechanics, showed that Newton was wrong, instead it showed why he was right. It showed that Newton's laws arise out of even more fundamental laws that cover a wider range of experience.

ROBERT L. KUHN: Let's go forward now. We've been looking back to the beginning, last 14, 13 ½, 14 billion years, how far can we look ahead? What are the kinds of predictions we can say about the future of the universe and, indeed, the end of the universe?

NEIL DEGRASSE TYSON: I gotta put one in first and then, then you all can take the table. Consider that after our galaxy merges with the Andromeda Galaxy, that'll happen in five or six billion years, and that'll be fun, you know, watching the galaxy get closer and closer, Titanic, collisional ballet, the acceleration of the universe will increase to the point where all nearby galaxies that are currently undergoing the expansion will have accelerated beyond our horizon to the point where we will be sitting in a collection, in a mass collection of stars, or whatever they are at that time, and we'll see nothing else in the universe outside of us, because they would have been accelerated beyond our horizon. And I wonder if we were around then, how would that simple fact have influenced our theories of the universe. There would be no other galaxies, there'd be nothing else, just our local system.

ROBERT L. KUHN: But how do we know that hasn't already happened?

NEIL DEGRASSE TYSON: Well, I was wondering that, this is the scary part, this is the scary part, in what state are we in now that's the consequence of some other catastrophic phenomenon that these guys are cooking up on his…

ROGER BLANDFORD: Blame him.

NEIL DEGRASSE TYSON: So that's my two cents for the fascinating future.

ALAN GUTH: Let me answer that wild question by also taking a jump of maybe 10, maybe 10^{10} billion light years off to the side, as well. Uh, one of the curious things about inflation, which I think we might as well mention, since we're talking about the ultimate future, is that, once this inflationary process that I've talked about starts, it never really stops, there's this peculiar material that's driving the exponential expansion, due to repulsive gravity that it creates. What happens is the material that's driving the expansion is unstable so, in the case in places it decays and forms normal matter and then those regions become normal universes. But it decays like a radioactive substance with a half-life, so if you wait half-life of this material, half of it will have decayed, in a sense it become normal matter. But unlike normal radioactive material, it's exponentially expanding at the same time, so in the same half-life, the half that remains gets to be much larger than what was there in the first place. It goes on literally producing new universes forever. So our universe will, very likely, have the fate of ultimate emptiness, there's our region of the universe, but meanwhile, elsewhere, new, young universes are sprouting up,

ROBERT L. KUHN: You made a jump and I missed how you got there, and that is, we, we had inflation going when suddenly we had a lot of new universes coming out of that. LAUGHTER.

ROBERT L. KUHN: I was listening carefully and I missed how that happened.

ALAN GUTH: Okay, well, it's undergoing exponential expansion, which every so often is doubling and the doubling time is about 10^{-37} seconds or something ridiculous like that. So, every 10^{-37} seconds, it doubles in time. Every so often, in a much longer time scale, 10^{-34} seconds, a piece of it breaks off and becomes a universe while the rest of it goes on exponentially expanding, and then another piece breaks off and becomes a universe. And because it's continuing to double and double, even though pieces of it are constantly breaking off, it continues to get bigger and bigger, instead of smaller and. This would be the very history of our universe during the inflationary period.

ROBERT L. KUHN: And so what's happening now to that?

ALAN GUTH: We're one of these pieces that split off, when it split off it was about the size of, well, it was probably a large region, but, within that, there was something the size of a marble that's going to become everything that we observe today. Once it splits off, it's been expanding, so, it coasts, slowed after that by ordinary gravity.

ROBERT L. KUHN: But there's no new universe to come out of our universe, then? It's that original stuff. The original stuff that had this inflation, a marble came out of that and we're the marble.

ALAN GUTH: That's right. Exactly right.

ROBERT L. KUHN: Now I understand it!

NEIL DEGRASSE TYSON: This allows us to invoke, correct me if I'm wrong, this allows us to invoke the Copernican principle for our own existence. If you're spawning universes, like it's rabbits, some universes would be inhospitable to life, because the carbon life as we know it, the carbon atom wouldn't be as sticky as we know it is in chemistry, or whatever, am, am I correct with that? And, so you can have a multitude of cosmoses, of universes, only one of which is suitable for life and we happen to be in that one, of course, otherwise we wouldn't …

DAVID GOODSTEIN: Or there may be many of them, there maybe other kinds of life, silicon life based life rather than carbon based life.

ALAN GUTH: So, it could be a very small fraction that's suitable for life, but since there's an infinite number, whatever that fraction is…

NEIL DEGRASSE TYSON: Yeah, but every time we play around with the fundamental constants, we get something that we know wouldn't reproduce life as we know it.

ALAN GUTH: Yeah, that's true, what always bothered me though is the necessity of tacking on that phrase "As We Know It" at the end.

NEIL DEGRASSE TYSON: Okay, why does that bother you?

ALAN GUTH: Well, because, if we're trying to ask why is the universe the way it is, some people say it has to be the way it is or else life, as we know it, would not exist, but, if life, of a different form existed. Life as we don't know it, that can still form a perfectly plausible universe.

ROGER BLANDFORD: Well, we've already demonstrated that, as far as inanimate things are concerned, our imagination has been rather limited, so, there's no reason why we shouldn't be equally limited as far as animate things are concerned.

ALAN GUTH:, There's a strong tendency to just define the word universe to mean anything that's look like everything that we see. And, in theories like inflation, strongly suggest that every little thing we see is just a tiny fraction of everything that exists,

ROBERT L. KUHN: How do you see the next ten years in this time of dramatic observations and new data in astronomy?

ROGER BLANDFORD: I think there's still a tremendous amount of discovery space, as we say, out there to be opened up. One of the opportunities is in gravitational radiation. These are, if you like, waves, rather like the light in this studio or radio waves, but, they're waves of gravity that have ripples, if you like, in space and time and they're very weak in their interactions. They interact very weakly with matter but they can be detected, essentially, by moving mirrors and so on around. And there are telescopes being built under construction at the moment on the ground and plans for putting similar telescopes in space, which we hope will one day soon measure this gravitational radiation, and perhaps a sescond or third generation telescope will be able to see gravitational radiation produced from the very earliest times of the big bang, perhaps even going back to the time of inflation.

NEIL DEGRASSE TYSON: Fifty years, a hundred years?

ROGER BLANDFORD: Oh, I wouldn't dare put a number on it. There's one other way, that, in fact, is, it probably is, sooner than that, and that is trying to look at these microwave background fluctuations from when the universe was about half a million years old, but look at them in a new way, look at them in a way that you might look at the sun through Polaroid sunglasses. That it turns out is a messenger from the very early universe, too. And if the right sort of patterns are seen in that polarization, that could also be confirmatory evidence for the stories that are told about the very early universe.

ALAN GUTH: In terms of observations, there are, I guess, two other, well, one thing going on now, which is very exciting which is the Sloan Digital Sky Survey, which is just a much more massive survey of galaxies and their positions, and that does allows us to do a lot of statistical tests in terms of the distribution of matter in the universe . This is also a tool for finding exotic objects, which can be a lot of fun. For example, one type of exotic occurrence that they're look for is the presence of two very nearby quasars and, then what that allows you to do is to observe the light coming along the line of sight from these quasars and you can measure the absorption of light by atoms in between. And that gives you not only the description of the matter everywhere along one line of sight with the other, but it also allows you to see left to right, to see if there's a cloud of a certain type that you're seeing in one beam, is it also seen in the other beam? And, statistically, then you can learn, for example, how big these clouds are, and that allows you to tell a lot about where they are and what their apparent size is telling you about the geometry of the universe, as a whole, and it's really very exciting.

NEIL DEGRASSE TYSON: I would add that, if you look at the old days of the classical explorers, well the Renaissance explorers mapping Earth's surface, coming to some understanding of the nature of our backyard, I see this enterprise, the Sloan Digital Sky Survey, and those that came before it that were smaller in scope, I see those as the inevitable extension of this effort that first occupied us in our attempt to map the Earth and now it is occupying our time, energy, and resources to map the cosmos.

DAVID GOODSTEIN: That brings up another point. With all of the astonishing things that we've talked about today, this is not the biggest revolution in the history of cosmology. There was a time when we believed that we were the center of the universe, the universe existed for us. And we had a set of laws of physics that made sense, but it only made sense so long as that was true. And then Copernicus came along and ripped us out of the center of the Universe, destroyed everything we understood, there was no basis for any physics of any kind, much more evolutionary than changing, the changes with time and the constants of nature or anything like that. And in a very short period of time, a hundred and fifty years to be sure, but only five or six scientists lives, we had put it all back together again, and we were no longer the center of the universe, we were living on a speck of dust in an undistinguished galaxy somewhere in some corner of one of the many universe.

THEY LAUGH.

ROGER BLANDFORD: Out in the suburbs.

NEIL DEGRASSE TYSON: There might be some theory yet to emerge that will give us an understanding of the dark matter, the dark energy, your "rabbit" universes in the early times, something might come forth that connects all of that and we will then be looking back on these times, laughing at how quaint our ignorance was.

DAVID GOODSTEIN: Right, how little imagination we had.

ROBERT L. KUHN: Don't we feel grand in the process, even though we're not part of, we're not in the center, we are part of this enormity?

NEIL DEGRASSE TYSON: I feel grand. THEY LAUGH. I do because, I don't feel smaller, I feel bigger, because it's the collective minds of we, the human species, that figured this stuff out and that's extraordinary. One of the, for me, the unheralded discoveries of the 20th century, which I carry with me every waking moment, is the recognition that the very chemistry of our bodies were forged in the centers of supernovae, that exploded, gave their lives to the enrichment of the galaxy, out of which we formed stars and planets and people. So, it's not so much that we're in the universe, the universe is in us.

ROBERT L. KUHN: And that's the last word.

THEY LAUGH.