[SLICE OF MIT THEME MUSIC]

ANNOUNCER: You're listening to the Slice of MIT Podcast, a production of the MIT Alumni Association.

JOE MCGONEGAL: This is the MIT Alumni Books Podcast. I'm Joe McGonegal, director of alumni education. Priyamvada Natarajan earned degrees in Math and Physics at MIT in 1988 and '91, and a Master's in Science, Technology and Society in 2011. Now a professor of Astronomy and Physics at Yale University, Priya's new book is *Mapping the Heavens, the Radical* Scientific *Ideas That Reveal the Cosmos,* published by Yale University Press.

I reached Priya by phone and I asked her what prompted the occasion for writing this book.

PRIYAMVADA NATARAJAN: I've been always fascinated thinking about the process of science itself, and how is it that some theoretical ideas are so out there or crazy, but are yet accepted as plausible explanations. It comes out of being introspective about what I do on a day to day basis, but also comes from an appreciation of the history of science. And of course, you know, the changing conceptions of cosmos, right.

If you're living at this moment in time, I mean, we're so fortunate to be living at a time that the pace of discoveries is just so rapid, it's reshaping our view of the universe. Pretty much every decade, there's been a very dramatic change. It just seems to me that this was a moment to sort of sit back and think a little bit about how dramatic these changes have been and sort of where they leave us.

MCGONEGAL: It must be daunting to think of actually mapping the universe. We now know that the universe is expanding and it's expanding quickly. And to map it, is it a Sisyphean task?

NATARAJAN: When you work in cosmology, right, cosmic scales seem really natural to one. So for example, I often catch myself in real life, right, when I'm talking about something, someone asks me how long something takes. And it's harder for me, in a way, sometimes, to parse, OK, so this trip is going to take 15 and a half hours, or whatever. But somehow just saying, well, these two galaxies that you're seeing in this Hubble image, right, they look like they're going to be merging soon.

And for me, soon is, you know, like within five million years. So the way in which I think, there's a lot more comfort with these sort of abstract scales and numbers. And you know, I've found the task to be not so much daunting as exciting. I was like, oh my god, there's so many new ideas that the problem is figuring out what to put in and what to leave out. Because for each of these big idea, there were a lot of little refinements and things that were also very contested. And a lot of things happened to bring us to where we are in our current picture, many refinements and more sophisticated thinking other than just the original idea.

So I think the challenge, rather, was how to convey the simplicity and the complexity sort of simultaneously. You know, they're comprehensible to someone. They're very simple too even people who are not professionals, like the curious public.

MCGONEGAL: You pay due homage to the gods in the field of going back to the Middle Ages and then to Newton, Einstein. But what a diverse cast it is nowadays. It's a cast of characters. You seem attracted to the drama of the interpersonal relationships, the tensions. I was surprised, for instance, at all of the infighting among Einstein's circle, and his fallibility in going to dire lengths to stake his claims even when he was wrong and he knew he was wrong.

NATARAJAN: And you know, even after he publicly accepted that he was wrong, you could see that secretly, in private, he was really trying to recover a model, construct a model that would still be static and would somehow be in confidence with Hubble's data. And [INAUDIBLE] there was a mistake, he found a mistake himself so thankful he didn't admit it. You can't do it. But he didn't give up. I think that find in the Hebrew University archives is also pretty exciting for me, in a sense, it was very timely.

MCGONEGAL: Right, take us through that.

NATARAJAN: Right, so this is the contradiction, one of the contradictions I love about scientists, particularly Einstein is a real foil for this. You know, they come up with the most radical ideas, scientific ideas, come out of pure thought. General relativity came out of pure thought. He didn't come up with the theory to give an explanation to any phenomenon that was already observed. But here is this man with a profound creativity and originality.

And yet he was hung up. He had this belief. So he was open enough to come up with this, or he had an open mind, he came up with this radical reformulation. Yet there was some belief that he held very dear, sort of irrational attachment to the notion of a static universe because it's very disorienting to him to think of the entire universe as sort of expanding and moving. So he tried very hard to fix his model, the equations that predicted expansion by adding in extra terms to prevent adding any repulsive force by hand that would counterbalance gravity and therefore prevent the expansion, keep it all balanced.

So then it turns out that the evidence from Hubble of galaxies hurtling away from us and the further they were, were hurtling faster away, that was getting to be overwhelming. So you know, initially it was a small sample of galaxies. And then it was 24. And then, you know, they were just collecting data. At some point, Einstein was invited to Mount Wilson to see the latest data. And then there was a dramatic, as reported, it was a dramatic seminar, at the end of which Einstein stood up and said he was wrong and that, indeed, this was overwhelming evidence.

This was 1929. So recently, a few years ago, I think in 2014 or so in the Einstein papers, the archives in Hebrew University, a bunch of astronomers and physicists looked and they found sort of a dated manuscript, which looked like it hadn't been submitted anywhere, but it was a really good draft of a manuscript. And when they went through this, they found that this was an attempt in 1931, because it's dated by Einstein, to try to recover a static universe.

So this is, you know, after a couple of years after his public acknowledgment that the universe was actually expanding.

MCGONEGAL: He couldn't give it up.

NATARAJAN: He just couldn't give it up. And this is deeply psychological, right? I mean, there's nothing else. It's an emotional attachment to that notion that possibly came from the fact that this was sort of a historical view, right. And this was a little too radical for him, strangely. Reformulating entire Newtonian gravity was not as radical for his mind. But this notion, which he held really dear, was extremely radical and he couldn't give it up. This is the kind of thing about the minds of scientists that I am actually interested in.

Because I mean, at the end of the day, they are human. And although science as a methodology offers an objective, or as objective as possible way to understand and interpret nature, we have blind spots, even as scientists. And I think the blind spots are very, very interesting when there are blind spots in the minds of these hugely creative original people who come up with radical ideas all the time.

It's kind of interesting to see how they carry these conflicts.

MCGONEGAL: You also seem fascinated by the tricks our eyes play in observational physics when we look at the skies. Take us through the original-- was it the Greeks who plotted how Mars moved seemingly backwards. And then was it the lensing effects of-- almost makes it look like the universe is using Photoshop to reproduce one galaxy.

NATARAJAN: Exactly. Oh, I like that phrase very much.

MCGONEGAL: Digital imaging has saved us to a certain extent, no?

NATARAJAN: Right. I mean, I think, you know, I also make this argument throughout the book, that it's actually-- what is fascinating about the last 100 years in cosmology is this interplay of ideas and instruments, and the power that you get out of technology that has actually enabled us to see better, measure better, and capture better, and obtain-- so you know, in a way, astronomy was the original big data science. We've had like this huge amount of data of the night sky. And technology has actually enabled it.

So I mean, the role that technology has played in all of this is just remarkable and incredible.

MCGONEGAL: And helped theoretical physics catch up to observational physics.

NATARAJAN: Absolutely. And I think if you look at the open problems today, so for example two of the big open problems that I work on, dark matter and dark energy, at the moment, the impetus for both of them have come from data. They weren't theoretically predicted to be there. They were found empirically. And we are still kind of struggling for dark matter. We have a very plausible theory that appears to be supported along many lines of independent evidence that the universe is filled with dark matter. We are yet to discover the dark matter particle, though.

So it's not a done deal. I mean, it's a problem we've not fully solved. Alternatives, there have been no reasonable alternatives that pass the observational tests, all the tests. So we're kind of in a peculiar situation. And with dark energy, we kind of know what it does. We don't know what it is. That has to come from theory.

MCGONEGAL: You tell the story of Adam Riess, who's now at Johns Hopkins, a fellow alumnus and his work on dark energy. And tell them this story in brief, would you, of his specialty is dust and his contributions to that effort.

NATARAJAN: Adam was at MIT. We were contemporaries. I didn't know him too well but I did know of him and we took a couple of classes together in physics. He is a wonderful person. And a really, really good scientist. So for him, it was really-- he was at the right time at the right place. He got on this problem for his PhD, trying to understand whether, you know, supernovae-- supernovae are really like standard light bulbs.

Which means that if you buy a 60 watt bulb in Boston and you buy one in New Delhi, they will give you the same amount of light. And that's, you know, we know the calibration at 60 watts. Similarly, supernovae no matter where they go off they're basically the end states of stars, have this explosion and creates a supernova, very bright explosion in the sky. That explosion, no matter where it happens in the sky, has the same brightness.

And therefore, when we go out in the universe and see an explosion, if it is not very bright, we actually know that it is far away. So we actually have a measure of the distance. And so one of the projects that Adam got started in graduate school when he was working under Bob Kushner as his thesis advisor, was trying to characterize the supernovae.

There are many kinds of supernovae. So there's one class, which is a standard candle, and that's supernova type 1a. What he found was they were standard candles, but there was a little bit of variation. But it was a very systematic variation, though, which he found that you could look at the light curve, how the supernova gets brighter and then falls off, dims. From the shape of the light curve he knew that he could calibrate, do a better calibration of the wattage of the supernova.

And so that technique was crucial to the discovery of dark energy, which they did by looking at the brightnesses of distant supernovae. So you know, Einstein told us that the geometry, the fates, and the content of the universe are intricately related. By looking at the brightnesses of supernovae, our universe, which could have had one of three possible solutions, tracks that it could have followed over cosmic time but it ends up taking one track. With supernovae, they were able to pin down which track we were on.

And that track corresponded to a universe model that was dominated by dark energy and had, you know, 30% as matter and about 70% dark energy. So this was the effort that Adam had started doing. And his work was really critical because, you know, characterizing supernovae brightnesses through the dust and modeling the dust, and recovering the light curve shapes, that was the clincher to make them sort of standard candles.

MCGONEGAL: Until that point, the best we could do was measuring cepheids?

NATARAJAN: That's right, cepheids.

MCGONEGAL: Cepheids.

NATARAJAN: Yeah. But the thing is, it's very hard to find individual cepheids at large distances. We're limited, we have to-- because it's an individual star and it's not as bright. And the supernova is several orders of magnitude brighter than an individual star. They're some of the brightest objects in the universe. They can outshine an entire galaxy. So you know, the cepheid method could not take you far.

So in a way what Adam, and Brian Schmidt, and Perlmutter did as part of two independent groups is extended the Hubble diagram, they finished the job that Hubble started by looking at objects further and further away than Hubble was able to. And the objects that they were looking at now were no longer galaxies, but actually supernovae that out shown galaxies. They found that the solution corresponded to a sort of a very peculiar universe.

MCGONEGAL: Other alumni to shout out in this book, you've got a nice story on Roger Babson. You've got quotes from Dennis Overbye, Marcia Bartusiak. You've got some nice subtle references to LIGO. And I'm curious about your publication of this book around the LIGO announcement. I think it's chapter two you say that LIGO is poised to detect gravitational waves from emerging black holes.

And LIGO is a great example of this big science these days, right, of these massive international collaboration of scientists, versus the lone, Einsteinian, scribbling away in his ivory tower. You seem to argue for a balance of support, financial and otherwise, for both kinds of efforts these days, right?

NATARAJAN: Absolutely. I think we shouldn't lose sight of that. It's really important to encourage many different intellectual styles within science. There's a way in which individual scientists working in smaller groups can take creative risks that, you know, others cannot working in a large collaboration because there the science is sort of by consensus. Levels of funding involved there, right. So it's multimillion dollar investments.

MCGONEGAL: Well, you mentioned the James Webb telescope due to launch in 2018. Talk about your hopes for either your own research or for what that mission is going to teach us.

NATARAJAN: The James Webb Space Telescope carries onboard an amazing set of instruments. So it's going to open out the window from space for a wide range of wavelengths from which we have not had as much data, so sort of the emitted infrared, the far infrared, so the very, very long wave lengths.

These wavelengths, we are likely to see the exciting prospect is to see the first galaxies and the first black holes that ever formed. These super distant objects that formed when the universe was very dusty and violent. And the radiation from those times would get absorbed by dust because there's a lot of dust, UV radiation that is produced the hot stars, the first stars, or the secreting black holes, would produce UV radiation that would get, then, absorbed, reflected back and re-emitted in the infrared wavelengths.

So that's how we're going to be detecting these objects, which we couldn't see before. The prospect is of opening an entire new window into the universe and seeing things that we never even imagined we could see.

MCGONEGAL: How does your MIT education alive and well in this book.

NATARAJAN: I think it's a sense of curiosity that I just met up with MIT alum friends in San Francisco this weekend. We had brunch together, a whole bunch of classmates. And you know what was really exciting is we're all doing completely different things, but the sense of curiosity that we had and the desire to learn, and you know, and having learned how to learn at MIT has really served all of us well. And that's really-- we really treasure that.

MCGONEGAL: Tell us what else you're reading right now.

NATARAJAN: I read a lot of poetry and I read a lot of fiction as well as science. Right now I am trying-- I mean, but I'm reading-- there's a whole bunch of rash of physics books that have just come out. So I'm currently on my bookshelf to read, I have, Stefan Alexander's *Physics and Jazz,* and Sean Carrol's *The Big Picture.* And so you know, I review for the New York Review of Books, so I have a stash of books.

I keep getting sent a lot of books to take a look at. In terms of fiction, what I'm reading right now is the new Kazuo Ishiguro and the new Salman Rushdie. They're all jostling for my time. And I'm teaching, so until this semester finishes, it's kind of hard. But as soon as I finish teaching, I'm going to get on my reading.

MCGONEGAL: Amazon tells me that customers who bought *Mapping the Heavens* also bought books by Sean Carroll, as you mentioned, Richard Gott, Carlo Rovelli, Anna Frable, David Wooden, Alan Hershfield, does that seem like good company? Is the algorithm--

[INTERPOSING VOICES]

NATARAJAN: I think it's some pretty excellent company. This is a pretty crowded market for books in terms of the science niche. Lots of people are interested but there are lots of physicists who are writing, astronomers and physicists who are writing as well. But I felt very strongly that my take on it, really opening and unpacking the doing of the science as well as sharing of the scientific results. I think it was a story that's not been told as much.

MCGONEGAL: Priya Natarajan's *Mapping the Heavens, the Radical Scientific Ideas that Reveal the Cosmos* is available this month online or at your favorite local bookstore. Priya, thanks for joining me.

NATARAJAN: Yeah, thank you very much, Joe.

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