KENNETH BRECHER
(joined by Owen Gingerich)

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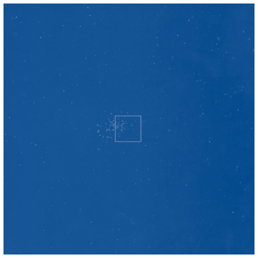

Kenneth suggested having the picnic inside The Great Refractor at Harvard, but said that he would need to coordinate with the "key holder." We had several exchanges with a man named Owen, but had not realized that the "key holder" was Owen Gingerich, professor emeritus of Astronomy and History of Science at Harvard (FIG. 1). While in his office preparing for the picnic with Kenneth, he humbly mentioned that he had consulted with the Eames on several aspects on the film: "I provided the Eames office with the relevant chart from the Lick Sky Survey Atlas, so that as they moved into the night sky, the stars were all correct. Then I calculated the three-dimensional coordinates of the Magellanic Clouds, nearby galaxies of the local family, then key nearby field galaxies, the Virgo cluster of galaxies, etc. These went by very rapidly in the film because with steps of ten in each interval, the film was soon moving faster than light! I have a feeling that I probably helped decide the direction of the astronomical trajectory to maximize interesting objects en route to the edge of the universe. You may have noticed that my name was one of four people explicitly acknowledged at the end of the film." As he opened a filing cabinet titled "P" to the file for his work on Powers of Ten, *we saw a file for Pope John Paul. It turns out he consulted with the Pope too, on the celestial calendar.*

Once Kenneth arrived, a particular burst of conversation unfolded between him and Owen. They bantered back and forth, sharing inside references, debating details, negotiating reasoning of refractory use and abuse. It was the kind of exchange that can only happen between close colleagues, impassioned and informed across the same field of inquiry. Their quick minds and playful demeanors drew us in to a quick intimacy (FIG. 2).

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<u>Kenneth</u>: One of your questions was "why here?" Do you know why?

<u>Amy</u>: I presume because this is the site of the first large telescope in the United States, and …

<u>Kenneth</u>: That's a true statement. And maybe there's a cause and effect for what we're going to get to, but that's not why.

<u>Michael</u>: I presume that maybe there's a connection with Philip Morrison.

<u>Kenneth</u>: Phil lived two blocks from here. The real reason is that this is where modern cosmology began. It all began with Henrietta Swan Leavitt, right here. Even Edwin Hubble, for whom the space telescope is named, said she should have won the Nobel Prize. Of course, she didn't. We're here at the Harvard College observatory because in the mid-nineteenth century, this was where American large-scale astronomy began. And in the early twentieth century, a piece of work was done here that was the first piece of solid work to tell you about the size of the universe. *Powers of Ten* scaled out to ten to the twenty-fifth meters, ten billion light years away. And the first indicator of such a large scale came from work that was done right here at this observatory. This year's Nobel Prize in physics, coincidentally, was also for learning about the large-scale structure of the universe, new things that were not in *Powers of Ten*, so there is this nice connection over this hundred-year period.

<u>Michael</u>: Can you tell us more about Henrietta Leavitt?

<u>Kenneth</u>: She was hired here by Edward Charles Pickering, the director of Harvard Observatory at the time, along with other women who would never be hired as professors, to analyze the huge volume of data being produced in the form of photographic plates here. These women were not given proper research jobs; they were called "human calculators" *(FIG. 3)*. She analyzed photographic plates of stars in a nearby galaxy called the Magellenic Clouds, and she had noticed that there were stars there that varied in brightness; and that the longer the period of brightness variation, the brighter the star. So she found the first correlation that allowed us to begin to figure out how big the universe is by using time instead of brightness as an indicator of distance. You see, if you don't know the distance to a star, how do you know how intrinsically bright it is? You just know its relative brightness. But what she did was calibrate the correlation between time variation and intrinsic brightness of some variable stars. Then she could determine a star's distance from its time variation. So she turned time into distance.

<u>Amy</u>: This idea of astronomers across hundreds of years trying to understand the scale of the universe, this it is exciting … but how do we explore this vast knowledge while staying on the blanket?

<u>Kenneth</u>: That's an interesting question. *Powers of Ten* fits into a tradition of popularizing science, of trying to discuss many things for a broader audience. Particularly in twentieth-century astronomy, scientists like James Jeans, Arthur Eddington, and particularly George Gamow (who is one of the inventors of the Big Bang model of cosmology) wrote wonderful books for the public to try to explain many pieces of astronomy. And in particular, *One Two Three … Infinity* by Gamow is much like *Powers of Ten* in the sense that it similarly talks about little things and big things, going from atoms to the universe and comparing their scale. And it talks about the whole range of biology, chemistry, physics, astronomy, even some geology. It does not get into neuroscience, which is interesting. And in all of that spread, it tries to make one feel your own scale – compared to that of the universe (very small),

compared to the nucleus of an atom (quite big) – and makes all those points nicely. But it is interesting – none of those early books talked about the human mind as a real frontier, and that's the thing that's come in recently, neuroscience! It used to be psychology, neuroanatomy, or neurobiology. But now there's a more general term: neuroscience. But it wasn't touched on in *Powers of Ten*, although it did go right down into cells.

Amy: It only paused for a second on the human scale, and then it went onwards.

Kenneth: It's interesting that it starts on the human scale and spends more than half of the movie out in space. Of course, we have a lot of powers of ten to cover, more than going down to the nucleus, but it spends an inordinate amount of time on astronomy. You know that there are now about seven billion people in the world, but there are about 7,000 professional astronomers. There's only one astronomer in a million. Seems like a lot of time to spend on astronomy, but people are interested in astronomy!

Amy: Can you talk about how this public interest in astronomy, and the public imagination of it, affects culture?

Kenneth: In the 1960s, I was a student of Phil Morrison's when this was all going on, the development of *Powers of Ten*. At the time, we talked about the things that you see out there as most of what's there – the galaxies, the gas, the stars, the nebulae. But we know now that it's only 4 percent, the other 96 percent is totally something else, split between dark matter and dark energy. So that's one paradigm shift, in the sense that we once believed we were studying the whole universe, but now we know we're just studying little traces. Most of the stuff, the dark matter, the dark energy, we don't have a clue about it. If you ask the more general question, what does that have to do with the general culture, the general mindset of people? First of all, it's pretty humbling to realize that what you see is not what you get. Your eyes and your hands are just not the best or only measure of it. So eyes, or cameras, they can deceive you. How that fits into a more general framework of thinking, well, it tells you that you can't just trust your senses when you're trying to understand whatever the subject is. And at the other end, particle physics, which was dealt with in *Powers of Ten*, you have to probe things at very high energies, and what do you wind up learning there? Well, we're still waiting to see. We need another movie because we're waiting to see if they find the Higgs boson that gives rise to the mass that we feel gravitationally. What does this do for culture? What does poetry do for culture? What does art do for culture? What's the point of existing if it isn't for art, science? Well, there is a third thing that's important, and that's playing. Playing is the really important thing.

Michael: Maybe that's a nice segue into your relationship with Philip Morrison. From the little we know of him, it seems like he was someone who enjoyed life in that kind of wonderful, exploring way.

Kenneth: I first met Phil Morrison in the spring of 1964 when he came to MIT from Cornell. I was then a junior, and he gave a series of lectures on theoretical physics for undergraduates. It was so unbelievable, so exciting, so dynamic. Everybody was dumbfounded at his intellect, the range of topics that he would connect, his encyclopedic knowledge of anything and everything. I stayed at MIT and did a Ph.D. in physics with him, and we collaborated on several projects in astrophysics. I was not one born to do astronomy; I was much more interested in using the universe to test physics than using physics to test something about the universe. Working with Phil, my introduction to astronomy was through physics. In fact, I never have taken an astronomy course in my entire life, even though I have by now taught about a hundred of them. Interestingly, I knew Phil (at least about him) well before I had actually met him, because like every geek in high school in the 1950s, I got *Scientific American*. And before he became book editor of the magazine, he wrote many articles on a wide range of topics: cosmic rays, nuclear physics. He could write about anything.

Amy: It's an unexpected, fortuitous event to have you with us too, Owen. You must have known the Morrisons, too?

Owen: Yes, I met them when Phil and Phylis were working on various educational projects, and there was a general brainstorming meeting to which I was invited. And Phylis was interested in a certain kind of historical imagery of the stars, and I helped her with access to the libraries at Harvard, where she could see some of these very early atlases that contained those images. And because they lived only a few blocks from me, I also saw them at home, completely surrounded by the books flowing in for review from the *Scientific American*. They had a space problem, so they considered it a great favor for us to come in and write our names in the books we might want. Then, when they cleared their house every so often, we would get a call from his assistant saying there were books for us. They decided which person should match with which book, since more than one person might write their name in a book.

KENNETH: Pull one of those big brown volumes out.

OWEN: This is the kind of thing I got from him: Egyptian astronomical texts.

KENNETH: Can I quantify this, Owen? It's my understanding that about 5,000 books a year were coming into their *Scientific American* "office." But it's not that they just came in. Every month, Phil skimmed many, if not most, of the books, read thoroughly perhaps fifty, and then wrote ten book reviews, which were usually better written than the books were.

AMY: One of the things we've heard is that Philip Morrison actually carried the atomic bomb in his lap. Do you know anything about this?

KENNETH: He did. He was J. Robert Oppenheimer's student, so he joined the project. The core was only ten or twenty pounds of uranium; that's not all that big. So he was handcuffed to the box that contained it, in the car that went from Los Alamos to the Trinity site. But I never talked with him about those things. Phil did not like to discuss that period. I don't know if you talked to him much about it, Owen?

OWEN: We got him to talk about it in my class, on a panel discussion of Los Alamos veterans. They talked about whether we should have made the bomb and whether we should have dropped it. He was always very forthcoming when describing that period. He said it was a totally different time, and that students today cannot really appreciate what it was like.

KENNETH: Phil was also accused of being a spy for the Russians by this guy Jeremy Stone. Phil denied it in writing; that happened near the end of his life.

AMY: Looking around this space, it feels surprisingly unclinical. There's even an upholstered love-seat at the controls. Who would those two people sitting there be?

KENNETH: One of the things that you might want to do with a telescope like this is to measure the time of transits of things, when a star moves across a particular position in the sky. So you might be looking through the telescope, and your partner would be writing things down *(FIG. 4)*. This telescope was built at the dawn of photography. Photography starts in 1840, and this was built in 1850. So they took one of the first, if not the first, photographs of astronomical objects here: pictures of the sun, the moon. A daguerreotype of the moon taken here won a competition in France as the best daguerreotype ever done.

OWEN: Speaking of photographs, I just wanted you to see this. Here's my picture of Charles Eames, when he was in Uppsala, Sweden photographing the Copernicus books *(FIG. 5)*.

AMY: Oh, that's great! So you were at Uppsala? I went to Uppsala last year to see some of Linnaeus's drawings. I went deep in the library, where they had one of his diaries that he drew in when he went to Lapland the first time, and he had made some beautiful drawings in it. He would draw figures to help him remember the flowers. They're really crude drawings.

OWEN: This too, it's a great picture that I took and put into the proceedings of the National Academy of Sciences. This is that book, *Calendarium Romanum Magnum*, by Johannes

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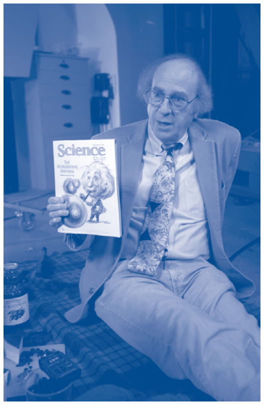

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Stoeffler, that was owned by Copernicus for many years, and in which they found the hairs that gave them the DNA for Copernicus *(FIG. 6)*.

Amy: My God, that's amazing! Wow!

Michael: Have they tracked any relatives?

Owen: No, they've tried really, really hard, and the bloodline seemed to vanish about 1700. They did a lot of archival work.

Amy: And did you find the hair?

Owen: I did not find the hair in it. But there were nine hairs found, four of which were good enough to do DNA enhancement, and two matched each other and matched the tooth in the cranium that they thought was Copernicus. So I got this wonderful email from Frances Collins saying, "isn't DNA wonderful?" And I emailed him back and I said, "but I was photographing this book, do you think one of the other hairs is mine? Should I have a DNA analysis?" And he said, "but of course." But I haven't done it yet.

Amy: You might be related.

Owen: To the hair, not to Copernicus!

Amy: Let's talk about some of the publications you brought, Kenneth.

Kenneth: This issue of *Science* came out at the end of 1998 as the science story of the year *(FIG. 7)*. I would say personally it's the most important thing in all of science in the 1990s. It summarized research findings by two separate groups, who had simultaneously discovered that the universe is expanding at the present time at an accelerating rate. Now, the expansion of the universe had been discovered in the 1920s, and everyone expected that the universe's expansion would be slowing down. Some people believed that the universe would expand and contract, and expand and contract. And that's almost a philosophical or religious belief, something like a Buddhist view, where there is no beginning and there is no end of time, and the universe expands and contracts and just goes on forever. But there was an alternative view that also comes out of Einstein's theory of relativity that the universe is a one-shot affair – that it starts at a particular time and expands forever. This article talks about the discoveries that seem to prove that, and even more startlingly, shows that the rate of expansion is increasing, meaning that something is pushing it out, some kind of cosmic repulsion.

(FIG. 8) Using dark balloons to demonstrate the accelerating rate of the expanding universe.

Michael: And this *Scientific American*?

Kenneth: This is the current issue, October 2011. As I mentioned before, Phil was the book reviewer for them, and he wrote many articles throughout the 1950s through the 1970s and into the 1980s, so it's totally appropriate. And Phylis wrote with him, too. But also this is one of many articles that have come out in the last decades about the dark matter, which I talked about briefly before. It's part of the 96 percent of the universe that you can feel through gravity, but that you can't see. This article happens to be about dark matter affecting the shape of our own galaxy, an idea that goes back really to the 1930s. The idea that there's matter out there that you don't see, but whose gravitational effects you feel, has its start with a really interesting character at Caltech named Fritz Zwicky. He was a Swiss physicist with a wide range of interests and an understanding of thermodynamics, of general relativity, and most all, of physics. At Caltech, he encountered Walter Baade, who was an observational astronomer, and the two of them together invented both the word and idea of supernovae.

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Before them, no one knew there were such large, explosive events. People had reported that occasionally stars appeared and disappeared, and they were called novae, new stars. But there hadn't been one in our galaxy for 300 years. Zwicky and Baade showed that a number of these exploding stars, historical ones, were not much brighter than novae that can repeat. These supernovae represented the death of stars.

After that, he was the first one to have reported there was something affecting the motions of galaxies that was not seen. When we look at a whole cluster of galaxies, maybe a hundred galaxies in the group, he noticed they were moving around too quickly for their spatial distributions with respect to the other galaxies, as if something was holding them together, but you couldn't see it. So he's the one who first talked about dark matter in a serious way: It is matter, it gravitates – it sucks but it doesn't push, but you can't see it. So what's the relevance of these two magazines to *Powers of Ten*? When the movie was made, we thought we knew what the universe was about: stars and galaxies, which you see. If you listen to *Powers of Ten*, it says, "look around us and you see these bright objects with empty space in between." It's really interesting, because we know now most of the universe isn't empty space. It's full of dark matter and dark energy, and at most, the stars and galaxies represent only about 4 percent of the content of the universe. So that's a tremendous change in our knowledge since that period.

Amy: That's beautiful. It's interesting to look at shifts in understanding, how people can be so skeptical of ideas that later turn out to be true.

Kenneth: You always come to things with your own prejudices, especially if you're talking about the universe. We could get off into all the stuff I'm skeptical about now, too, but then I'd be offending my colleagues.

Michael: You don't want to talk about current crackpots?

Kenneth: All right, I'll put my foot in my mouth. For my money, the current crackpot thing is what's called string theory. You have a whole world of, I'll say it, otherwise unemployable particle physicists who are speculating about an ultimate theory of matter. Just as a side note, there are four fundamental interactions in physics: the strong interaction that holds nuclei together, the weak interaction that can lead to the decay of nuclei, electromagnetism that leads to light, and gravity. Three of these have already been unified into a theory, the standard model: the strong, weak, and electromagnetic interactions. And there's a fantastic amount of evidence supporting the standard model. It's made no wrong predictions; this is a great theory. But, you need a quantum theory of gravity, and this aim for a grand, unified theory of gravity with the other forces has taken various courses, one of which is this string theory. There isn't one single string theory, but there're probably hundred or thousands or millions of versions of them. So that's very popular in particle physics and people would like to talk about interesting issues about the universe. Not all questions in cosmology are settled, but most are. But string theory is one thing where it's not like normal science. In normal science, you test things, you make predictions. Or, as Karl Popper says, you have to have theories that are falsifiable. To be falsifiable, you've got to get out there and predict something and then do an experiment. So if they make no predictions or they make an infinite number of predictions, you can't show that string theory is false. Well, then it isn't physics. It's what Alfred Jarry called "pataphysics."

MICHAEL: Pataphysics?

KENNETH: Pataphysics is to metaphysics what metaphysics is to physics. It's not science, not in the normal sense. But on the other hand, if you're talking about the universe, there's only one universe, so how do you know normal science ideas apply to the one universe? Science is of the general.

MICHAEL: And it's as impressive for a non-scientist. That's another one of those words that makes it onto magazine covers, so you know people are talking about it. String theory. It's got a really nice name. One thing that we haven't asked you yet is where you would place yourself along the spectrum of the *Powers of Ten*.

KENNETH: I noticed something last night: The book and the movie don't end on the same power, and I'm curious about that. There was one power difference.

AMY: Yeah, the movie ends at 10^{25}, and the book at 10^{26}, I think.

KENNETH: Anyway, so the answer is this is my power. At the time, you could see that most distant quasars were a little further than this, although there was a good group of galaxies in here. So this is one-tenth of the size of the universe, quote end quote, leave aside if it's infinitely big. So I was identifying with this or a little above this. This is one billion light years or so, but the whole Hubble scale for the universe is about ten billion light years, roughly speaking.

AMY: It's interesting that it's only gone up one increment in the macro direction, but I wonder how the limits of the known have changes on the microscale.

KENNETH: Well, that's the domain of the Large Hadron Collider, the largest particle accelerator ever. The experiment that's going on now, it's the most expensive experiment that's ever been done in the history of the universe. It's a ten-billion-dollar experiment. You're trying to get down inside of a nucleus. So the nucleus we normally talk about is about one fermi?

MICHAEL: They're saying 10^{-16}, so point one fermi.

KENNETH: So now you're trying to go a little deeper than one fermi – down to the level of a tenth, for the sake of argument. You may think that's nothing in forty years, but either way, on the big and the small end, each factor of ten is more than one factor of ten in money, effort, and time. Here's a way to think about it: You have this telescope up here, which has a fifteen-inch cross section.

MICHAEL: Right, I wonder how much it cost?

KENNETH: At the time, it was twenty-five thousand dollars. I don't know how to translate from 1850 to now, but I can say it was a lot, even for a really rich university like Harvard; they had to get donors and so forth. Now you're talking about telescopes on the ground that are at the level of a billion dollars, the largest ones that are multimirror telescopes and so forth. Or the Hubble Space Telescope was two billion dollars, so let's pick on that. You've gone up an astronomical factor in cost, and then it gets back to your question about society. What is society willing to do to find out these questions? How much is it worth? Like the movie *Titanic*, which took in a billion dollars or so. As a society, did we get as much bang for the buck from that as from the Hubble Space Telescope? Which gave us more?

MICHAEL: I love your comparison.

KENNETH: Well, they're comparable amounts of money. And just now we are going up another factor of ten in money. The Webb telescope, the one that will replace Hubble, is up to a cost of ten billion dollars or so. It wasn't supposed to be that expensive.

AMY: When's the last time you went on a picnic?

KENNETH: Two months ago, south of France, near the caves of Lascaux. We had a picnic there, near where the prehistoric artists painted.

Amy: When's the last time you used this telescope?

OWEN: The last time we tried it was a complete disaster, because the chains that open the shutter somehow jumped in such a way that the shutter dropped and sheared several bolts as it went down. So it was impossible to get it closed. Fortunately, there was not a hurricane or anything, otherwise this area would have been pretty wet. That was a few years ago, but ever since then, we've been so intimidated that we haven't tried it.