To See the Unseeable

Peter Galison in Conversation with Elizabeth Kessler

"A smoke ring framing a one-way portal to eternity" is how the *New York Times* described the first-ever image of a black hole, released last April. A staple more of science fiction than of reality, these bizarre objects have a gravitational force that consumes everything around them, including light. Their behavior is so unusual, so logic-defying, that even Albert Einstein doubted their existence. But last spring, a hazy picture of a glowing orange circle was viewed and shared by a billion earthlings, joining a history of epoch-defining photographs that elicit reflection on our place in the cosmos. How did scientists create an image of the strangest of celestial objects at the center of a distant galaxy, fifty-five million light-years away?

Peter Galison, a Harvard physicist and historian, worked on the project. Here, he recounts how astronomers, physicists, computer scientists, and others teamed up to allow us to see the unseeable.

Elizabeth Kessler: **You're a member of the Black Hole Initiative, an interdisciplinary science center at Harvard University that includes astronomers, physicists, mathematicians, and philosophers. How did you, as a philosopher and a historian of science, get involved with that work?**

Peter Galison: My career trajectory has been back and forth between physics and the history and philosophy of science. Back in the Pleistocene, I did two dissertations, one in theoretical particle physics and one in the history of science.

EK: **Through that initiative you got involved with working on the Event Horizon Telescope's first-ever image of a black hole, which was released with all sorts of enthusiasm and excitement in April 2019. I was really struck by how scientists describe black holes themselves; they use words like *mysterious* and *bizarre* and *exotic*. What are the qualities of black holes that make them so strange?**

PG: We're in a moment when astrophysical objects of enormous complexity and interest are legion. But black holes command this powerful imaginative. Physicists want to know how quantum theory and classical relativity can be reconciled there. Mathematicians are riveted by the equations that describe black holes. Astronomers want to understand how they shape galaxies and star formation. Philosophers are drawn to questions that arise about the knowability of these mysterious objects. Black holes are paradoxical: the darkest objects, hence their name. But they are also the brightest objects, sending beams of particles across not just galaxies, but vast *clusters* of galaxies. They appear to be the simplest objects, describable by just mass and rotation, but also the most complex, storing unimaginable amounts of information.

EK: **The process for making the image was so involved. It's an experiment in observing, but it's also an experiment in image making.**

PG: The first and most important challenge of making an image of a black hole is that they carve out a very small arc in the sky. It's as if you held up a quarter in Palo Alto, California, and I could read the date on it from Cambridge, Massachusetts. So it required a resolving power in magnification one thousand or two thousand times that of the Hubble Space Telescope. To do that, you need a radio-telescope dish the size of the Earth. You can't have that, so what do you do? Well, you take a group of existing radio telescopes scattered over the surface of Earth, and you record the signal that arrives at each of them in such a way that, when they combine, it's like having a huge mirror with most of it blacked out and only little bits of the mirror in play. In other words, you have a sparse image, but from a telescope that was as big as Earth. The effort took many years by a worldwide team, with 207 collaborators working from 18 countries.

EK: **You're talking about wavelengths of light that are invisible to the naked eye, so you have to have special radio telescopes.**

PG: That's right. In and of itself, using frequencies that we can't see with the eye is not new to science. X-ray images have done that since 1895. When you buy night-vision goggles and see a coyote outside your house in the middle of the night, those are images that are made outside frequencies directly visible to the eye. New here was a worldwide combination of radio-telescopes working with light at a wavelength of one millimeter. That required new electronics, an array of atomic clocks to register time with extraordinary precision, and a new ability to store and process information that accumulated at a rate of around 1.5 petabytes per night. For all these reasons, this image could not have been made even ten years ago.

EK: **And this network of radio telescopes collected tons of data that they shipped around to different places to calibrate and compress.**

PG: Yes. You might think—just send it over the Internet. Well, one of the telescopes is at the South Pole. You don't have Internet there. It turns out that the fastest way to get the data to the places where it's processed, in Massachusetts and in Germany, is to pack it into Federal Express trucks and the holds of 747s and send it. Old-fashioned, but effective. To be sure we had a robust image, we divided the image group into independent teams—to check each other.

EK: **Someone might ask "Is this a photograph?" And I think the answer is "Sort of." We think of a photograph in relationship to the idea of mechanical objectivity, which you and Lorraine Daston have written about—the idea that allowing a machine to generate an image guards against subjective interpretation. But there is so much more work that lies behind an image like this. It's part photograph, it's part algorithm, it's part statistics.**

PG: I think the meaning of the term *photograph* is not fixed. I don't think you can box in a concept like the photograph. In the early twentieth century, [Ludwig] Wittgenstein said that when we have a category like "game," that there is no way to say, "Here are the necessary and sufficient conditions that define all and only games."

I think what's true of games is true of what we mean by a photograph, too. We extend these concepts. What counts as a scientific image? What counts as a picture? We say we take a photograph with our cellphones. Those are highly processed. It's using all sorts of complicated algorithms to change things, to make them satisfactory to us as photographs. Yet, they are not the result of sunlight on photosensitive paper that uses silver iodide to undergo transformations and then is processed in chemicals. So the notion of a photograph changes. That said, I think it is true that the "scientific image" is a more capacious category than the photograph, and that the scientific image may be a better rubric under which to put this ringlike structure around the center of galaxy M87 [Messier 87].

EK: **So why make this picture? Why do we need to see the unseeable?**

PG: I think that it goes back to the beginning of our discussion. Black holes have this hold on our imagination, in the technical sciences, in philosophy, and in our fictional and artistic imagination—their very uncanniness, the strangeness of this phenomenon that left even Einstein completely unconvinced that such things could exist. The reality of black holes has been debated ferociously for one hundred years.

We want to see. We want to be able to say "There is a black hole." There, within that shadow, is the event horizon of a black hole larger than our solar system. That desire to attach sight, however processed, to the phenomenon of the black hole is enormously compelling. But now that we can make images, so much more begins: Can we test Einstein's theory of general relativity? Can we sort out how those enormous jets form just outside the event horizon?

EK: **I was thinking, too, about shadows, about William Henry Fox Talbot, and about how fixing a shadow—that most transitory of things—is part of the heritage of photography. We get to actually hold on to it. Even with this picture, as amazing as it is, we're close, but it seems that we would always be blocked from actually seeing a black hole.**

Page 72:
First image of a black hole, April 10, 2019
© EHT Collaboration/European Southern Observatory

Page 76:
Robert Gendler, *M31 image*, 2002
Courtesy the artist

This page:
Apollo 8 Mission image, Earth over the horizon of the moon, December 24, 1968
© NASA

There is something existential about facing the black hole. It seems tied to the great themes of myth.

PG: Well, there is a limit. I think we're seeing the silhouette of a black hole. We know silhouettes from seeing them in daily life, when someone is walking down the beach and toward you, or from the use of silhouettes in movies.

EK: **Right, the ominous is coming; the silhouette of the bad guy.**

PG: Indeed, an approaching gunslinger; a threatening, half-seen pursuer; a helicopter charging across the horizon. So there is this question of the black hole; we are seeing the silhouette of something. But that is kind of the limit of what we can see. That's the best we can do. Now, you could go into a black hole. But it would be the last thing you did, because you can't come back.

EK: **We've come to kind of expect that each new observing technology, or new telescope, or new camera, will give us a higher and higher resolution view. But the Event Horizon Telescope's image of the black hole is decidedly blurry.**

PG: It is. Some of that blur is due to the sparsity of our data. As the network of telescopes expands on Earth and, we hope, into space one day, as our algorithms improve, it will be possible to sharpen our results. But we also make sure to blur the results so that we are never claiming more precision than is merited. Then there are open questions: You can see in the south of the image a bright spot, and, over time, it seems to be changing over the course of the four to five days that our observing ran. No doubt the brightness is from swirling hot plasma. But what's exactly happening? What's shifting? What's the cause? Those are questions that we hope to resolve in subsequent, sharper runs, by making movies.

EK: **What does the color mean in the image? If it's light beyond the visible, then the astronomers are making a choice about whether to make this orange, or purple, or whatever.**

PG: We did have to choose. The significant part of the color choice is really the intensity of the brightness as it goes from the least bright to the brightest. That is physically significant. And you would see that, whether it was in blue, or black and white, or orange. So that is meaningful, and it tells you very roughly how many billions of degrees kelvin it is at these different places.

EK: **Why was orange the decision?**

PG: You might say the hot part of a flame is the blue part, not the orange part, so why not suggest real hotness with blue? We did have discussions about that, and I think people felt that, the hot part of flames notwithstanding, orange conveyed heat effectively and immediately.

EK: **That's interesting, because within a scientific context, the understanding of blue as hot would be immediate. But for the public, it might suggest cool. What you're talking about speaks to the varied audiences for an image like this.**

PG: All astronomical images—Elizabeth, you've written about this very effectively, I think—are embedded in a wider visual culture. People grow up in a visual culture, the way they grow up in a literary culture, and they write in ways that may have particularities to the scientific form of discourse, but it also has to reflect the vocabulary, and cadence, and structure of written language more generally. Science is not an island separated from the world of culture. It's located within a culture and, in this case, a visual culture that has long prized the outsize, the terrifying, and the sublime.

EK: **How might you situate the black-hole image within a larger history of image making?**

PG: I think within the history of astronomy, you could think about certain images that have really struck both the scientific community and the wider public. Images of galaxies, for example. Long-standing attempts, since the early nineteenth century, were made to try to figure out what these nebulae in galaxies were. These were huge nineteenth-century debates, and they captured the public attention. There are certain images in science that have become iconic in the sense that they came to stand for a realigned way of thinking about our relationship to the wider world. There's something very compelling about [Robert] Hooke's microscope image of the flea from the seventeenth century. His insects were both a wonder of nature in all their apparent detail, and a subject of a natural philosophy that aimed for explanation.

EK: **Using the microscope to look at something very small.**

PG: Yes. Using the microscope and showing that there were worlds inside the worlds that we knew about. Or Galileo's telescopic images, for instance, of the moons of Jupiter, made in 1610. Those images set us in scale in relationship to things far and things small. Another example, from the late nineteenth century, would be [Wilhelm] Röntgen's image of the bone structure of his wife Anna Bertha Röntgen's living hand—with a ring on it.

EK: **Sure, the X-ray.**

PG: X-ray photographs taught us to think about the living interior, the picturability of our human bodies.

And the Christmas Eve 1968 "Earthrise" image reset our relationship to the planet, looking at us from space in a way that had a different effect from looking at space from us—from Earth.

I think the black hole captured people's imagination in that way. It was a way to take this object, which seemed completely outside of our ability to image, and bring it to us. The estimates are that a billion people saw that image within a few days of its release, from sites around the world, at 9:07 AM on April 10, 2019.

EK: **The black hole as a concept, as a notion, has become such a touch point in science-fiction film, in science-fiction writing, and in the public imagination that it makes sense that it would grip people.**

PG: I think that's right. We've discussed how this is an image based on electromagnetic radiation that's not visible, and the image is sparse, and the image is noisy, and the image is limited in its resolution. It's an image that's mediated by techniques of mechanical objectivity and expert judgment, and then averaged to form a kind of idealized image that sums up what's in the other specific images. In all of these ways, it's highly processed, and yet there is something in the orange-ringed shadow that still stands for us as outside ourselves in a way that is different from a computer simulation, different from an artist's rendering.

EK: **The shadow image affects us.**

PG: Indeed, the robust image of this strangest of objects moves us, whether we're scientists, or the general public, or theorists, or philosophers, or science-fiction writers. In part, this builds on a long tradition of astronomical imagery that leaves us aware of the minute scale of us and our fragile planet. But perhaps there is also something existential about facing the black hole. It seems tied to the great themes of myth—standing at the center of a galaxy, reminiscent of origins and death, unseeable except through its effects on the world around it. There's still something about seeing this manifest but hidden power: *there*, at the center of M87. It still knocks me over that we've made an image of a black hole.

Elizabeth Kessler is a lecturer in American studies at Stanford University and the author of *Picturing the Cosmos: Hubble Space Telescope Images and the Astronomical Sublime* (2012).