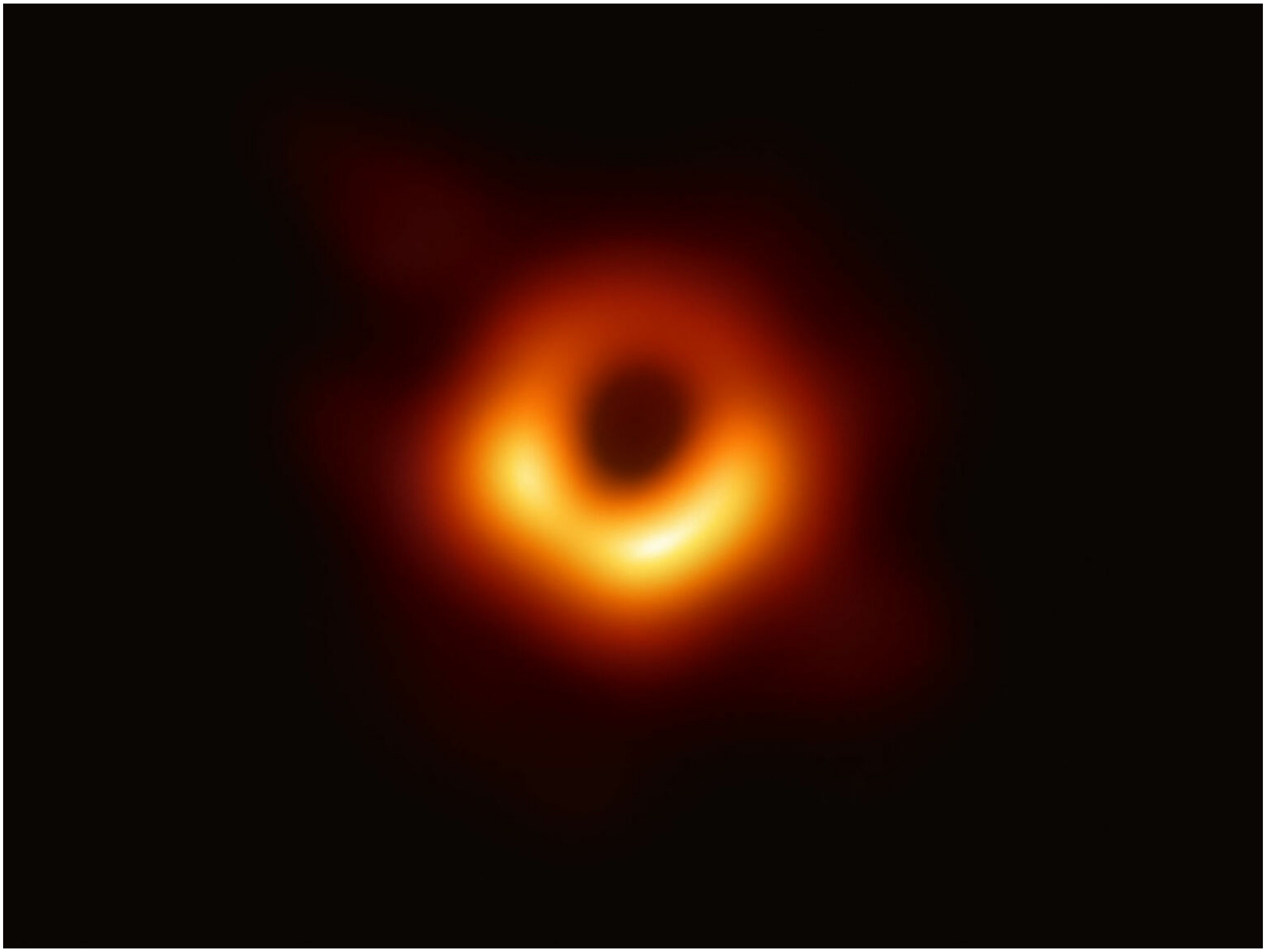


How Do You Photograph a Black Hole?

A scholar who helped make the historic image of the shyest astronomical celebrity discusses the art and science behind the picture.
Peter Galison May 17, 2021

On April 10, 2019, at 9:07 a.m. Eastern time, the first-ever picture of a black hole burst onto oversized screens in six cities around the world, from Taipei and Tokyo, through Santiago, Mexico, and Washington, DC, to Brussels and Madrid. It had taken years for the global Event Horizon Telescope Collaboration—then more than 200 scientists—along with a planet-size instrument, to produce that image. Though in many ways a technical-scientific result, the image resonated beyond laboratories and observatories. Down the street from where I work, black (donut) holes were the flavor of the day, joining front page news. In the following few days, press analysts reported that a billion people saw the image on screens and paper.

Black (donut) holes

Black holes capture us. They have a cultural resonance like nothing else in the world of physics. True, there are objects that have transformed these disciplines (scientists certainly care about the Higgs particle or neutron stars, for example), but they aren't the stuff of dreams, films, and fiction. But black holes are different. Astronomical celebrities, these dramatic distensions of space and time star in Hollywood films. Think of Gary Nelson's *Black Hole*, Paul S. W. Anderson's *Event Horizon*, or Christopher Nolan's *Interstellar*. They feature in the science fiction of Carl Sagan's *Contact* and Joe Haldeman's *Forever War*; they course through everyday talk about unrequited friendship, secretive governments, and futile actions. How can one not be fascinated by an invisible barrier, the horizon, a point of no return as absolute as a law of nature can have it? Black holes evoke loss.

Interstellar. 2014. USA. Directed by Christopher Nolan

Physically, black holes are regions of space where the inward pull of gravity is so powerful that nothing, no object, not even light, can escape. Smallish black holes—the size of a modest city—can form when stars of the right size run out of fuel to burn and collapse under the force of their own gravity. Much bigger, supermassive black holes sit at the center of most every galaxy, including our own, the Milky Way, with masses ranging from millions to billions of times that of our sun.

But since black holes do not reflect light and do not emit light, how does one capture in a picture this shyest of all things? Happily for us imagers, black holes are surrounded by orbiting gases that glow with heat. Still, the challenge of imaging is immense: not a pixel would exist without the combined efforts of telescope operators, instrument designers, theorists, data experts, and engineers, from early-career to senior scientists. Public silence was necessary: we agreed to an absolutely strict embargo, not a word, and certainly not a preliminary picture to be shared with outside colleagues, even family. Why secrecy? Because a leak, before we were confident in the image, would have allowed no second chance: a retracted image would shatter confidence in the whole enterprise. Haunting us was the fear that we had missed something, and that bred a furious care. One senior theorist on the EHT put it this way: "I'd love to see that thing…that makes me very suspicious about myself and what I see." More tests.

Even the hardboiled among us wonder
what it would be like to fall past the horizon.

I made a film along the way (*Black Holes: The Edge of All We Know*), over four years, not knowing where it would end—the attempt by such a far-flung collaboration to image a farther-flung black hole seemed so audacious. Black holes, with their one-way horizons, are nothing like other objects. Launching jets of hot gas from the swirl around them, black holes anchor the brightest objects in the universe. They are also the darkest, swallowing light, dust, even stars, a physical, looming stand-in for death. Even the hardboiled among us wonder what it would be like to fall past the horizon.

To bolster confidence in the emerging image, we divided up the image group into four teams, with strict orders not to talk to one another, a discretion bolstered by closed doors and frosted paper tacked on windows. It was a battle against our own hopes. Each team had a different method for extracting a picture from the data. The struggle began. How to get rid of unphysical quirks that arose along the way, mere artifacts? What were the best settings for making an image, the high-tech analogue of choosing the right aperture or shutter speed on a camera?

This time the image was real: a solar system–sized hole
in space and time weighing 6.5 billion times our sun.

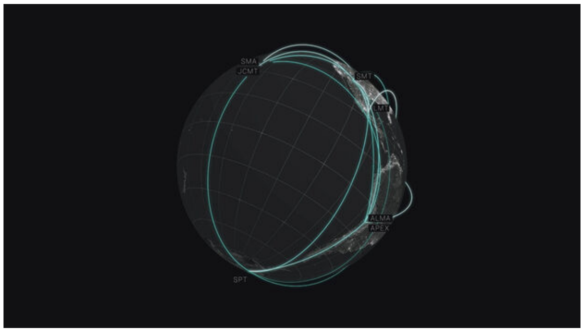
First, all four teams received test data sets created from unknown images. Some were astronomical objects, others were simulations, one was even an image of Frosty the Snowman. Running blind, each team had to reconstruct the original test image. When all teams could successfully pass the tests, then—and only then—did we tackle real data. Still in isolation, the teams began peering, in awe, at the first real black hole images. A month later (July 2018), the four teams gathered to compare their catch, pixel by pixel. Sitting together in a room, the tension was palpable. One student began beating a desk drumroll as the comparison slide was readied. When it went up on the screen, showing an astonishing match among teams, everyone burst out in applause.

One EHT colleague told me she couldn't peel herself away from her cell phone, where a copy of the orange ring appeared in a confidential email; she stared, absorbed, for hours. Another found the picture terrifying—though the collaboration, and indeed the wider community, had been simulating black hole images for decades. This time it was real. I felt that too, looking into a solar system-sized hole in space and time weighing 6.5 billion times our sun. But for nine all-in months the question remained: was the image robust, was it an artifact? Could we interpret it theoretically? With test after test we tried to knock it down, hoping it would stand up.

The EHT Collaboration Joint Meeting of
the Imaging Working Groups, July 2018

Suppose you were falling toward the particular supermassive black hole, M87, whose portrait we took. If you imagine it centered on our sun, its horizon would be out by Pluto. If you floated across that horizon you would, just then, sense nothing; no shattering break at the horizon, no drama. But once past the fateful last surface, you would not be able to send a message out: even your flashlight's beam could not outrun the infalling space. If feet first, your feet would be pulled toward the center with ever greater force than your head, sides pressed harder and harder toward each other. Eventually, inexorably, this voyage leads to (dreadful word) spaghettification.

A happier thought: The instrument that made the image was formed by a kind of jiu-jitsu of science. The task was to link some of the most sophisticated and massive radio telescopes in the world (in Chile, Hawaii, Mexico, Arizona, Spain, and the South Pole) in a cat's cradle of connections. Each baseline connecting two telescopes picks out a different aspect of the image: long baselines grab small image features, short baselines pick out the big features. Taken together, the network allows a fineness of resolution never before achieved—one able to image the black hole.



Network of EHT telescopes, from *Black Holes: The Edge of All We Know*. 2021

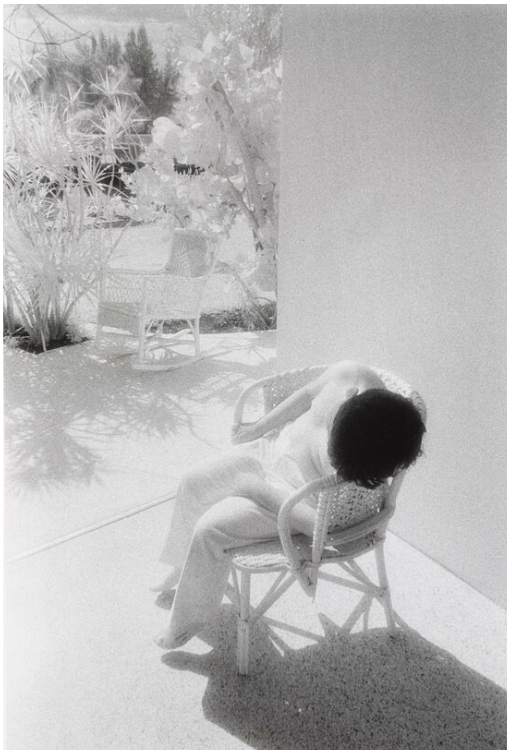
Observatories perch on mountain tops—almost halfway up the atmosphere. Once connected, these dishes acted like a single Earth-sized dish. An optical telescope uses a mirror to collect light—the bigger the mirror, the more magnification. Imagine that you could precisely break up the mirror, scattering pieces far and wide so they formed a much larger mirror (with gaping holes between the instruments). If each shard captured the light that fell on it, and if the shards could be reassembled, one could extract a hugely blown-up image. The bound-together dishes of the EHT were sufficient to make M87 visible, equivalent in resolution to reading page numbers in a book in MoMA's Design Store…from the Eiffel Tower.

The photons—bits of light—registered in the image of M87 left the neighborhood of the black hole "just" a few million years after the last dinosaurs laid down their heads for the last time. Those photons traveled all this way, were seized by the telescopes, and registered on hard drives as data. Those data were then correlated in supercomputers, distributed to analysis groups and, after a vast processing effort, emerged as an image.

But what is this image? Is it a photograph? That prompts an eternal question photographers and critics and curators have been posing for a century and a half: What defines a photograph? Must it be made with a camera? Even a century ago, that would not have held: Man Ray produced his *Rayograph* (1922) with no camera in sight. Ray and his lover, Kiki de Montparnasse, leaned their heads directly on photosensitive paper.

Man Ray (Emmanuel Radnitzky). *Rayograph*. 1922

Nor do we need film to count as a photograph. These days we take pictures with our phones, digital cameras, helmet cams, and door cameras, with not a single crystal of silver halide in sight. Ah, but maybe the M87 image shouldn't count as a photograph because the light gathered by the telescopes is not visible—it is at the edge of the "far infrared." Humans cannot see in the infrared (though bullfrogs, mosquitoes, and piranhas do). Perhaps that disqualifies it from the annals of photography? No. MoMA has prints made with black-and-white infrared film, including Abigail Perlmutter's luminous *Untitled*, from 1974. Indeed, you can buy an infrared crittercam to snap midnight doings of wildlife in the backyard. Says one ad: "2 color LCD screen lets you easily setup the camera and instantly view photos."

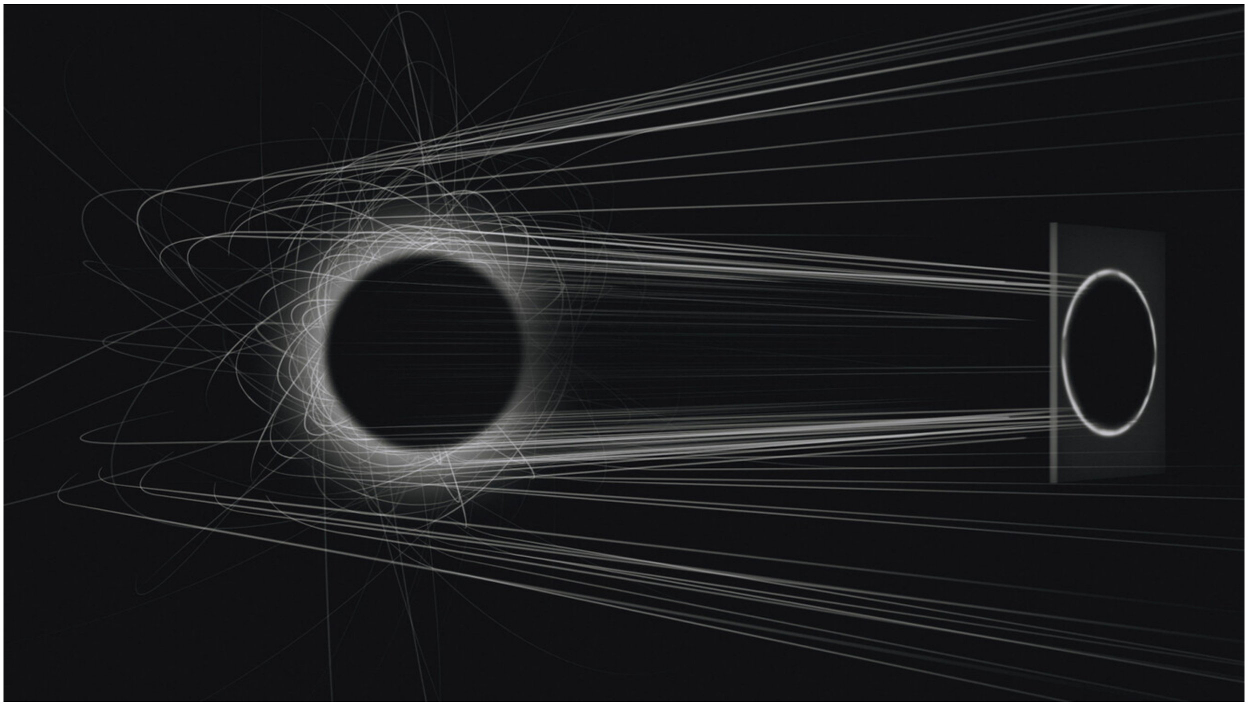


Abigail Perlmutter. *Untitled*. 1974

Julio Agostinelli. *Circus (Circense)*. 1951.

Or maybe the silhouette of the black hole makes it not of the object being seized. But we certainly see the stunning silhouettes in Julio Agostinelli's *Circus* (1951), currently on view at MoMA: backlit people watching the show.

M87 pulls some photons through the horizon, never to emerge. Yet other bits of light from behind the black hole are yanked around and flung toward Earth by its huge gravitational field. Still others orbit M87 before escaping to our watchful eyes. So the shadow M87 casts is more complex than those by a circus visitor. We are nonetheless observing the black hole.



How the Shadow Is Captured, from *Black Holes: The Edge of All We Know*. 2021

What about color? From the data, the relative brightness of the ring, including the brighter sector in the south, is given. Since the light itself from M87 is not in the visible spectrum, any representation of it is “false color.” We could have picked black and white or dayglo pink. I remember a group of us sitting around our computers, talking. The blue tip of a candle flame is hotter than the orange at the wick; blue giant stars are hotter than red giants. We returned to the everyday—red hot, blue cold. Would you stick a blue warning note on a stove? An orange one on a freezer? The gas around M87 is 10 billion degrees: we chose orange.

So what do we mean when we say we have taken a picture of a black hole? It seems that chasing after a fixed definition of photography, with a once-and-forever set of criteria, is a losing proposition. Photographers and curators, artists and scientists, won’t stay still. Happily enough, they are always asking for more. That restlessness may well be what makes photography such a vibrant medium.

One last thought. Of all the scientific images in MoMA’s collection that join artistic works, there are a few that shift our sense of place and scale. NASA’s *Untitled photograph from the Apollo 11 mission, July 1969* certainly has that effect. Not that one couldn’t have imagined the Earth seen from near the moon in advance, but seeing it jarred our sense of centrality and dominance.

Maybe part of the impact of the M87 image is something like that. Simulations might have anticipated its form, but seeing it, really peering at the edge of accessible space and time—that was something else. Call it a photograph? A picture? Under any name, all of us in the Event Horizon Telescope Collaboration are greatly honored to have this image of M87, archivally printed in large format, in the collection of The Museum of Modern Art.

NASA. *Untitled photograph from the Apollo 11 mission, July 1969*.

The Event Horizon Telescope Collaboration. *Galaxy M87*. April 10, 2019

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