Colin J. Lonsdale

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Colin Lonsdale is a radio astronomer who has worked at the Haystack Observatory of the Massachusetts Institute of Technology for 32 years, and for the past decade has led the Observatory as Director.

He specializes in radio interferometric techniques using a variety of national and international facilities, and has published extensively on a wide variety of astronomy research topics. These include the jets and lobes of extragalactic radio sources, supernovae and hydroxyl masers in star forming galaxies, the relationship between star formation and active galactic nuclei, and masers in the extended atmospheres of young stars. More recently he has worked on solar and heliospheric studies at low radio frequencies.

He has also been heavily engaged in the development of new techniques and instruments in radio astronomy, including very long baseline interferometry (VLBI) and multiple, novel low frequency imaging arrays.

He has been involved in the Event Horizon Telescope project since its inception, and much of the technical development for the project was conducted at Haystack under NSF funding during his tenure as Observatory Director. He serves on the governing Board of the international EHT Collaboration as vice-Chair and member of the Board Executive Group.

Professional Preparation:

St. Andrews Univ., Scotland	Applied Mathematics & Astronomy	BSc. Hons., 1978
Nuffield Radio Astronomy Labs, England	Radio Astronomy	Ph.D., Fall 1981
Nuffield Radio Astronomy Lab, England	Radio Astronomy Postdoc Fellow	1981 - 1983

Appointments:

2008-present	Director, MIT Haystack Observatory
2006-2007	Assistant Director, MIT Haystack Observatory
2001-present	Principal Research Scientist, MIT Haystack Observatory
1986-2001	Research Scientist, MIT Haystack Observatory
1983-1986	Research Associate at the Pennsylvania State University
1981-1983	Postdoctoral Fellow at the Nuffield Radio Astronomy Laboratories

Written Statement of

Colin J. Lonsdale, PhD
Director, MIT Haystack Observatory
and
Vice-Chair of the Governing Board,
Event Horizon Telescope Collaboration

before the
Committee on Science, Space, and Technology
United States House of Representatives

Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, thank you for the opportunity to describe the Event Horizon Telescope (EHT) and its truly extraordinary capabilities that have enabled this milestone scientific result.

A different kind of telescope

The EHT operates on the principle of interferometry. Rather than describe this in technical detail, it is useful instead to start with the mental image of a conventional telescope, creating an image by focusing light from a distant object onto a sensor array – like a digital camera with a really long telephoto lens attached.

Generally, the bigger the lens, the more light is gathered, the fainter the objects that can be seen, and the greater the magnification that can in principle be achieved. If the telescope optics are literally perfect, the amount of detail that can be seen, or equivalently the amount of magnification of an area of sky that can be applied, depends only on how big the lens is on the front of the telescope.

The black hole in the galaxy M87 is billions of times more massive than our Sun, which means that its event horizon is comparable in size to the extent of our entire solar system. This is a scale so huge that it defies human imagination to fully grasp. And yet, it lies so far away, 55 million light years, that it appears to us as something extremely tiny on the sky[1]. So tiny in fact that no optical telescope ever built, either on the ground or in space, has anything close to the magnification required to see what the EHT has seen. Such a telescope would need a lens, or a mirror, several miles across to achieve that level of detail, and the optics would have to be perfect.

We cannot physically build such a telescope, but by using a range of key, recently available technologies, we are now able to reproduce the capabilities of one. An optical telescope would need to be several miles across, but at the radio wavelengths used by the EHT we must synthesize a virtual telescope that is instead the size of the earth, many *thousands* of miles across. How is this done?

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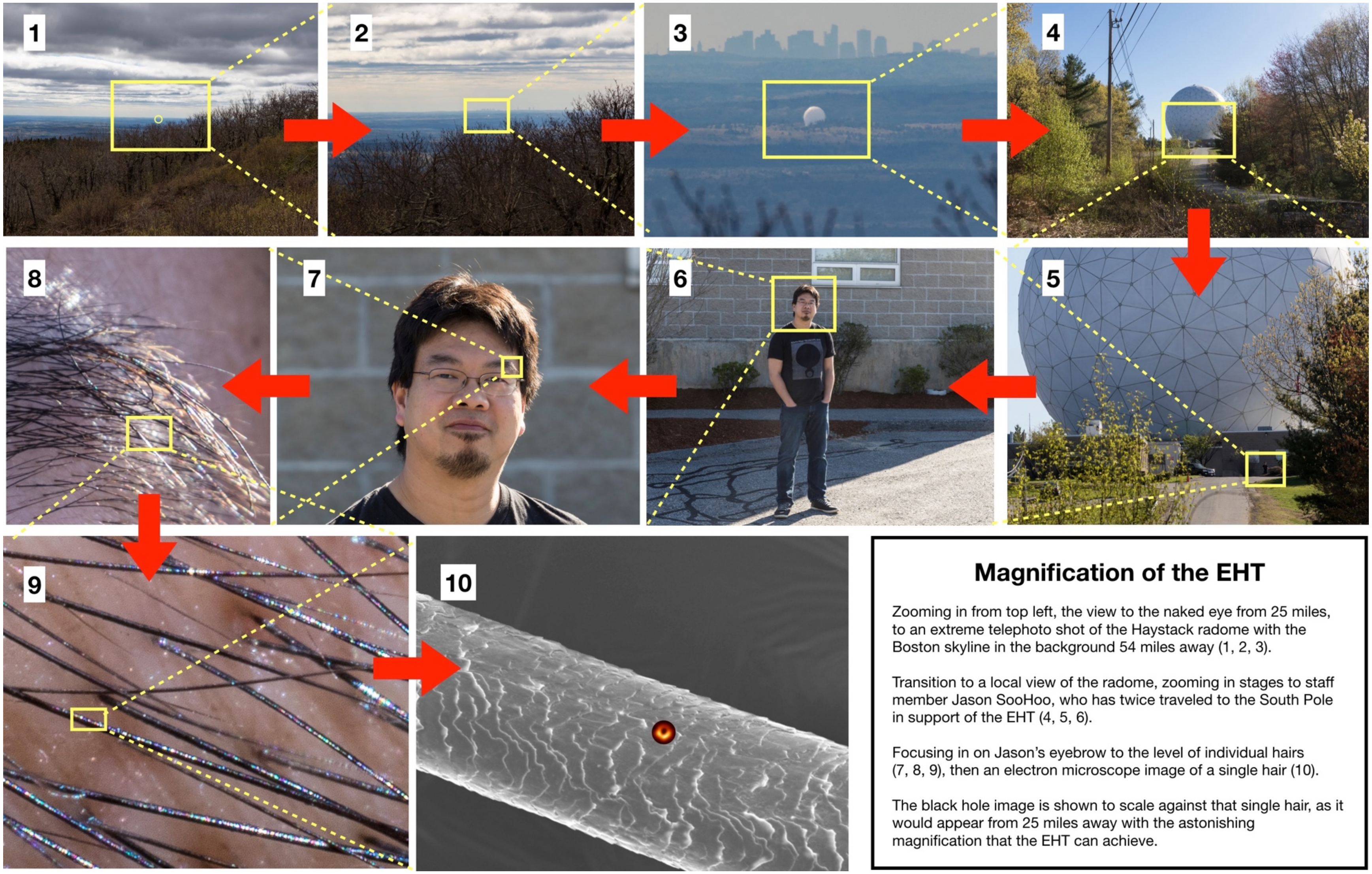
[1] A sense of the enormous level of magnification required for black hole imaging, and achieved by the EHT, is provided by the graphic on the next page.



Magnification of the EHT

Zooming in from top left, the view to the naked eye from 25 miles, to an extreme telephoto shot of the Haystack radome with the Boston skyline in the background 54 miles away (1, 2, 3).

Transition to a local view of the radome, zooming in stages to staff member Jason SooHoo, who has twice traveled to the South Pole in support of the EHT (4, 5, 6).

Focusing in on Jason's eyebrow to the level of individual hairs (7, 8, 9), then an electron microscope image of a single hair (10).

The black hole image is shown to scale against that single hair, as it would appear from 25 miles away with the astonishing magnification that the EHT can achieve.

Capturing and storing photons

The radio dishes of the EHT sit atop mountains around the world, and in one case on top of a massive ice sheet at the South Pole. Each of these dishes can be thought of as sitting directly in front of an imaginary earth-sized lens. If that lens were real, radio photon paths would be bent by it, and come to a focus point somewhere in space where we could place a sensor array to capture an image. Instead, we capture the photons that strike the radio dishes, and store them as digital data on ordinary computer hard disks – lots of them. A radio photon is a little bundle of energy, just like a photon of visible light, so more radio photons equates to more energy that can be measured. A key technical challenge of the EHT was to collect enough of these photons so that a faint object like a distant black hole could be detected.

One way to get more photons is to use bigger dishes, and to use dishes on mountaintops so that the earth's atmosphere does not bury those photon signals in unwanted noise. A major part of the recent success was an NSF-funded project, leading an extensive international effort to combine the signals from dozens of dishes of the Atacama Large Millimeter Array (ALMA) high in the Chilean Andes, allowing them act together as one much larger dish.

The other way to get more photons is simply to capture and record enormous amounts of digital data, by opening up the range of radio frequencies received by each telescope (like listening to many radio stations at once), and sending the resulting torrent of bits and bytes to a high-speed recording device. The more data that gets recorded, the more photons get captured, and the fainter the objects that can be seen.

Using modern disk drives with massive storage capacities, and specially designed electronics and systems to feed up to 128 spinning disks at once, the EHT systems are already capable of recording 64 gigabits per second at each radio dish. To put this in perspective, this is the equivalent of streaming more than 11,000 full HD movies at the same time. A full EHT observing campaign fills up thousands of high capacity disks, weighing several tons.

Capturing such data volumes at many sites takes extensive preparation, attention to detail, and extraordinary efforts by individuals, who travel to the far corners of the world and deploy their energies and talents to oversee the correct operation of the radio dishes and EHT equipment. The global nature of the telescope is mirrored by the international nature of the dedicated team of scientists, engineers and operational staff who make these remarkable observations possible from some of the most remote and inhospitable locations on the planet.

This work is difficult and demanding, but EHT staff engage in it with energy and enthusiasm for a truly inspiring research mission that exemplifies human curiosity and the quest for knowledge. It is a great privilege to be witness to, and in some measure to facilitate, the process of discovery pursued by a diverse team inspired by the prospect of opening a new window onto the most extreme environments known to science – the domain of warped spacetime, relativistic motions and prodigious energy release surrounding the event horizons of black holes.

Their efforts, and those of others with varied and essential responsibilities throughout the project, deserve our recognition and profound gratitude. It is my intent that today, with this testimony, we fully represent the contributions of the more than 200 members of the international EHT collaboration.

A computational lens

Photons that strike the dishes are detected, converted into digital data and stored, effectively capturing them. Those that miss the dishes are lost forever and never reach our imaginary planet-sized lens. But for those photons that were "captured", we can transport them to a central location using ordinary shipping methods, play them back from the disks, and manipulate them in such a way that they come to the same point at the same time, just as they would have done if the lens was real.

This is done by a process known as "correlation" which takes account both of ultraprecise synchronization of the recorded data as derived from atomic clocks at each dish, and of exquisitely detailed modeling of the imperfect rotation of the Earth which determines the precise positions and velocities of the dishes at any given instant, relative to the target on the sky. It then mathematically compares the properties of the signals coming from each of the dishes.

This is the essence of "radio interferometry", in which signals from widely separated dishes are combined and, provided they have been perfectly lined up with each other, compared in order to precisely measure how much they differ from each other from nanosecond to nanosecond. It is a complex and extremely computationally intensive phase of EHT operation, supported by teams of scientists, correlator operators and software engineers. And it has become technically and financially feasible for the massive quantities of data required by the EHT only in recent years due to relentless and dramatic advancements in the computing industry.

The EHT systems from the dishes all the way through to recorded data are complex, with behaviors that are not always wholly predictable. In addition, the data are affected by weather conditions at the various dish sites. Correlator operations at both the MIT Haystack Observatory in the USA and the Max Planck Institut für Radioastronomie in Germany are where such issues are diagnosed and corrected to the extent possible by experienced, expert staff. The data undergo a range of rigorous quality checks, sometimes taking many months, before being released to the broader EHT collaboration for further analysis.

Reproducing the function of a giant lens, at these short wavelengths and with such data volumes, represents a formidable achievement for our collaboration. It is testament to more than a decade of NSF-supported developments, on diverse and challenging technical fronts, and all of us here today are proud to have participated in this work. Without vision and risk-taking on the part of NSF, and the support and collaboration of our international partners, this result would not have been possible.

Nevertheless, because the dishes we use are few and far between, we can build only a miniscule portion of our ideal earth-sized computational lens. Given such sparsity of information, it has been necessary to develop advanced new techniques that take the correlated data and convert them into an image whose properties are well understood, and whose reliability can be objectively and quantitatively established. That is the topic of the testimony to follow, by Dr. Bouman.

The future

The results we are celebrating here today are just the beginning for our black hole imaging endeavor, and for this field of science. With data already in hand we will pursue Sagittarius A* at the center of our Milky Way galaxy, which is the only other black hole which appears big enough on the sky to be imaged with the current EHT.

But the technology will continue to advance on many fronts, and the path to additional rapid scientific progress is already clear. More dishes will be used to create increasingly precise images revealing subtle details and fainter features. Dishes will be sent into space to create a telescope even bigger than the Earth with even more magnifying power, putting other black holes with different environments, orientations and parameters within reach, and allowing us to explore the ones we are currently studying on ever finer scales. Movies of material spiraling into black holes will become possible, and some of the mysteries surrounding the generation of the remarkable jets of material emanating from these objects at close to light speed will start to be unraveled for the first time.

The black hole image, already iconic across the globe, will also surely fire the imaginations both of young scientists pursuing advanced degrees or starting their first postdoctoral appointments, and of high school students or undergraduates who may aspire one day to participate in groundbreaking discoveries. Such unique, high-profile and accessible scientific breakthroughs provide beacons with which to attract our brightest young minds from all backgrounds into science and technology, enriching and diversifying our national STEM workforce.

But we need not wait to see the impact of the EHT project, because even before the image was generated, the mere possibility of achieving such a result inspired a cadre of talented young researchers and students to join the project, in dozens of institutes all over the world. And this is epitomized by Dr. Bouman’s story.

From a scientist’s perspective, these are exciting times indeed!