Astronomers Capture First Image of a Black Hole

— Academia Sinica, Institute of Astronomy and Astrophysics (ASIAA) contribute to paradigm-shifting observations of the gargantuan black hole at the heart of distant galaxy Messier 87

**The Event Horizon Telescope (EHT) — a planet-scale array of eight ground-based radio telescopes forged through international collaboration — was designed to capture images of a black hole. Today, in coordinated press conferences across the globe, EHT researchers reveal that they have succeeded, unveiling the first direct visual evidence of a supermassive black hole and its shadow.**

This breakthrough was announced today in a series of six papers published in a special issue of The Astrophysical Journal Letters. The image reveals the black hole at the centre of Messier 87 [1], a massive galaxy in the nearby Virgo galaxy cluster. This black hole resides 55 million light-years from Earth and has a mass 6.5-billion times that of the Sun [2].

The EHT links telescopes around the globe to form an Earth-sized virtual telescope with unprecedented sensitivity and resolution [3]. The EHT is the result of years of international collaboration, and offers scientists a new way to study the most extreme objects in the Universe predicted by Einstein’s [general relativity](https://en.wikipedia.org/wiki/General_relativity) during the centennial year of the historic experiment that first confirmed the theory [4].

*"We have taken the first picture of a black hole,"* said EHT project director **Sheperd S. Doeleman** of the Center for Astrophysics | Harvard & Smithsonian. *"This is an extraordinary scientific feat accomplished by a team of more than 200 researchers."*

Black holes are extraordinary cosmic objects with enormous masses but extremely compact sizes. The presence of these objects affects their environment in extreme ways, warping spacetime and super-heating any surrounding material.

*"If immersed in a bright region, like a disc of glowing gas, we expect a black hole to create a dark region similar to a shadow — something predicted by Einstein’s general relativity that we’ve never seen before,"* explained chair of the EHT Science Council **Heino Falcke** of Radboud University, the Netherlands. *"This shadow, caused by the gravitational bending and capture of light by the event horizon, reveals a lot about the nature of these fascinating objects and allowed us to measure the enormous mass of M87’s black hole."*

Multiple calibration and imaging methods have revealed a ring-like structure with a dark central region — the black hole’s shadow — that persisted over multiple independent days of observations.

*"Once we were sure we had imaged the shadow, we could compare our observations to extensive computer models that include the physics of warped space, superheated matter and strong magnetic fields. Many of the features of the observed image match our theoretical understanding surprisingly well,"* remarks **Paul T.P. Ho**, EHT Board member and Director of the East Asian Observatory [5]. *"This makes us confident about the interpretation of our observations, including our estimation of the black hole’s mass."*

Creating the EHT was a formidable challenge which required upgrading and connecting a worldwide network of eight pre-existing telescopes deployed at a variety of challenging high-altitude sites. These locations included volcanoes in Hawaiʻi and Mexico, mountains in Arizona and the Spanish Sierra Nevada, the Chilean Atacama Desert, and Antarctica.

The EHT observations use a technique called very-long-baseline interferometry (VLBI) which synchronises telescope facilities around the world and exploits the rotation of our planet to form one huge, Earth-size telescope observing at a wavelength of 1.3mm. VLBI allows the EHT to achieve an angular resolution of 20 micro-arcseconds — enough to read a newspaper in New York from a sidewalk café in Paris [6].

The telescopes contributing to this result were [ALMA](https://www.almaobservatory.org/en/home/), [APEX](https://www.eso.org/public/teles-instr/apex/), the [IRAM 30-meter telescope](http://www.iram-institute.org/EN/30-meter-telescope.php), the [James Clerk Maxwell Telescope](https://www.eaobservatory.org/jcmt/), the [Large Millimeter Telescope Alfonso Serrano](http://www.lmtgtm.org/?lang=en), the [Submillimeter Array](https://www.cfa.harvard.edu/sma/), the [Submillimeter Telescope](http://aro.as.arizona.edu/), and the [South Pole Telescope](https://pole.uchicago.edu/) [7]. Petabytes of raw data from the telescopes were combined by highly specialised supercomputers hosted by the [Max Planck Institute for Radio Astronomy](http://www.mpifr-bonn.mpg.de/) and [MIT Haystack Observatory](https://www.haystack.mit.edu/).

The construction of the EHT and the observations announced today represent the culmination of decades of observational, technical, and theoretical work. This example of global teamwork required close collaboration by researchers from around the world. Thirteen partner institutions worked together to create the EHT, using both pre-existing infrastructure and support from a variety of agencies. Key funding was provided by the US National Science Foundation (NSF), the EU's European Research Council (ERC), and funding agencies in East Asia.

*"We have achieved something presumed to be impossible just a generation ago,"* concluded **Doeleman**. *"Breakthroughs in technology, connections between the world's best radio observatories, and innovative algorithms all came together to open an entirely new window on black holes and the event horizon."*

Notes

[1] The shadow of a black hole is the closest we can come to an image of the black hole itself, a completely dark object from which light cannot escape. The black hole’s boundary — the event horizon from which the EHT takes its name — is around 2.5 times smaller than the shadow it casts and measures just under 40 billion km across.

[2] Supermassive black holes are relatively tiny astronomical objects — which has made them impossible to directly observe until now. As a black hole’s size is proportional to its mass, the more massive a black hole, the larger the shadow. Thanks to its enormous mass and relative proximity, M87’s black hole was predicted to be one of the largest viewable from Earth — making it a perfect target for the EHT.

[3] Although the telescopes are not physically connected, they are able to synchronize their recorded data with atomic clocks — [hydrogen masers](https://en.wikipedia.org/wiki/Hydrogen_maser) — which precisely time their observations. These observations were collected at a wavelength of 1.3 mm during a 2017 global campaign. Each telescope of the EHT produced enormous amounts of data – roughly 350 terabytes per day – which was stored on high-performance helium-filled hard drives. These data were flown to highly specialised supercomputers — known as correlators — at the [Max Planck Institute for Radio Astronomy](https://www.mpifr-bonn.mpg.de/2169/en) and [MIT Haystack Observatory](https://www.haystack.mit.edu/) to be combined. They were then painstakingly converted into an image using novel computational tools developed by the collaboration.

[4] 100 years ago, two expeditions set out for the island of Príncipe off the coast of Africa and Sobra in Brazil to observe the [1919 solar eclipse](https://en.wikipedia.org/wiki/Solar_eclipse_of_May_29%2C_1919), with the goal of testing general relativity by seeing if starlight would be bent around the limb of the sun, as predicted by Einstein. In an echo of those observations, the EHT has sent team members to some of the world's highest and isolated radio facilities to once again test our understanding of gravity.

[5] The East Asian Observatory (EAO) partner on the EHT project represents the participation of many regions in Asia, including China, Japan, Korea, Taiwan, Vietnam, Thailand, Malaysia, India and Indonesia.

[6] Future EHT observations will see substantially increased sensitivity with the participation of the [IRAM NOEMA Observatory](http://iram-institute.org/EN/noema-project.php), the [Greenland Telescope](http://vlbi.asiaa.sinica.edu.tw/project.php) and the [Kitt Peak Telescope](https://en.wikipedia.org/wiki/Kitt_Peak_National_Observatory).

[7] [ALMA](https://www.almaobservatory.org/en/home/) is a partnership of the European Southern Observatory (ESO; Europe, representing its member states), the U.S. National Science Foundation (NSF), and the National Institutes of Natural Sciences(NINS) of Japan, together with the National Research Council (Canada), the Ministry of Science and Technology (MOST; Taiwan), Academia Sinica Institute of Astronomy and Astrophysics (ASIAA; Taiwan), and Korea Astronomy and Space Science Institute (KASI; Republic of Korea), in cooperation with the Republic of Chile. [APEX](https://www.eso.org/public/teles-instr/apex/) is operated by [ESO](https://www.eso.org/), the [30-meter telescope](http://www.iram-institute.org/EN/30-meter-telescope.php) is operated by [IRAM](http://www.iram-institute.org/) (the IRAM Partner Organizations are MPG (Germany), CNRS (France) and IGN (Spain)), the [James Clerk Maxwell Telescope](https://www.eaobservatory.org/jcmt/) is operated by the [EAO](https://www.eaobservatory.org/), the [Large Millimeter Telescope Alfonso Serrano](http://www.lmtgtm.org/?lang=en) is operated by [INAOE](https://www.inaoep.mx/) and [UMass](https://www.umass.edu/), the [Submillimeter Array](https://www.cfa.harvard.edu/sma/) is operated by [SAO](https://www.cfa.harvard.edu/sao) and [ASIAA](http://www.asiaa.sinica.edu.tw) and the [Submillimeter Telescope](http://aro.as.arizona.edu/) is operated by the Arizona Radio Observatory (ARO). The [South Pole Telescope](https://pole.uchicago.edu/) is operated by the [University of Chicago](https://www.uchicago.edu/) with specialized EHT instrumentation provided by the [University of Arizona](https://www.arizona.edu/).

More Information

This research was presented in a series of six papers published today in a [special issue](https://iopscience.iop.org/journal/2041-8205/page/Focus_on_EHT) of The Astrophysical Journal Letters.

The EHT collaboration involves more than 200 researchers from Africa, Asia, Europe, North and South America. The international collaboration is working to capture the most detailed black hole images ever by creating a virtual Earth-sized telescope. Supported by considerable international investment, the EHT links existing telescopes using novel systems — creating a fundamentally new instrument with the highest angular resolving power that has yet been achieved.

The individual telescopes involved are; ALMA, APEX, the IRAM 30-meter Telescope, the IRAM NOEMA Observatory, the James Clerk Maxwell Telescope (JCMT), the Large Millimeter Telescope Alfonso Serrano (LMT), the Submillimeter Array (SMA), the Submillimeter Telescope (SMT), the South Pole Telescope (SPT), the Kitt Peak Telescope, and the Greenland Telescope (GLT).

The EHT Collaboration consists of 13 stakeholder institutes; the Academia Sinica Institute of Astronomy and Astrophysics, the University of Arizona, the University of Chicago, the East Asian Observatory, Goethe-Universitaet Frankfurt, Institut de Radioastronomie Millimétrique, Large Millimeter Telescope, Max Planck Institute for Radio Astronomy, MIT Haystack Observatory, National Astronomical Observatory of Japan, Perimeter Institute for Theoretical Physics, Radboud University and the Smithsonian Astrophysical Observatory.

**Taiwanese Contribution to EHT**

Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) is a stakeholder institute, and is a partner of another stakeholder institute, the East Asian Observatory (EAO), within the 13-member Event Horizon Telescope (EHT) Collaboration.

The EHT Collaboration was established in 2017. Dr. Paul T.P. Ho (AS Academician and Distinguished Research Fellow) and Dr. Makoto Inoue (Distinguished Visiting Scholar and former Distinguished Research Fellow) are members of the EHT Board, which oversees the management and direction of the EHT. Dr. Keiichi Asada (Associate Research Fellow) and Dr. Geoffrey Bower (Adjunct Research Fellow and Research Scientist) are members of the EHT Science Council.

*“Eight telescopes have joined in this 2017 EHT observation. Starting in 2018, the Greenland Telescope (GLT) has also become an important element of the EHT, aiming at M87 from the beginning,”* said **Dr. Inoue**. “*The ASIAA supports four of the current key telescopes of the EHT, namely SMA, ALMA, JCMT, and GLT. ASIAA participated in the construction and operation of SMA, ALMA, and GLT from the very beginning.”*

“*Since 2015, JCMT became part of the East Asian Observatory (EAO),”* mentioned **Academician Ho**, who is the founding Director General of EAO and the Director of JCMT. *“EAO has incorporated all the East Asian VLBI communities into the EHT project via their participation on the JCMT VLBI efforts.”* He also led the construction of SMA and GLT, and the participation in ALMA project for Taiwan. Separation between SMA and JCMT provides the shortest baseline of EHT, while these two telescopes anchor the longest east-west baselines of EHT. ALMA provides the most important anchor because of its large collecting area, which enhances the sensitivity of every other telescope. GLT provides the northernmost station of the EHT.

*“In 2009, Makoto Inoue started the VLBI science team in ASIAA, and since then Keiichi Asada and I have led this science team to conduct the study of M87, starting from lower (mm to cm) frequencies,”* said **Dr. Masanori Nakamura**, the GLT/VLBI Project Research Scientist of ASIAA. *“Our previous results will be a key for further understanding the black hole spin in M87 with this EHT 2017 result. Our group is now internationally recognized as one of the leading research groups of the M87 research in the world.”*

Many GLT project members also worked for EHT [8], and many science and/or engineering faculties and staff members enabled us to construct our telescopes and instrument systems [9] that joined EHT. Furthermore, construction of SMA, ALMA, and GLT enjoyed the strong support of AS and MOST, and our long-term collaboration with the National Chung-Shan Institute of Science and Technology (NCSIST) [10]. Taiwan is therefore actively working on the EHT activities, and played a key role in the breakthrough we show this time.

**Next Step: the Greenland Telescope**

The angular resolution of a telescope “improves” (by getting smaller) with a larger mirror and a shorter wavelength. By adding the Greenland Telescope (GLT) [11], the “mirror size” of the EHT (the “baseline” or distance between the two most separated telescopes) becomes about 9000 km, and the angular resolution is improved significantly.

*“Based on the current EHT results from 2017, we now know that signals at longer baselines are fairly constant, while those at shorter baselines show rapid time variations based on the 4-day observations in a 7-day duration,”* **Dr. Keiichi Asada**, the first person who suggested to put a telescope at Greenland, pointed out. *“As we do not expect rapid time variation of the mass and spin of the supermassive black hole, this would indicate that the longer baselines (namely, fine structures) would tell more about the signature of general relativity from the very vicinity of the event horizon. As GLT will anchor the longest baselines, GLT will have a more essential role for the general relativity test in future.”*

For shorter wavelength (higher frequency) observations, moving the telescope to the Summit of Greenland is a necessity. Although the Thule Air Base is a good site, it is at sea level, with more atmosphere above the telescope. The Greenland Summit site is at 3200 m above the sea level, so the atmosphere is thinner and the water vapor content is less, which is greatly beneficial for higher frequency observations.

The Greenland Summit site is very cold (-60 ℃), where most of the water vapor in the atmosphere are frozen out. Lower water vapor content will allow most of the high frequency radio waves to be received at the telescope from the astronomical sources. Such excellent sites are very rare on the Earth, probably limited to the top of Mauna Kea in Hawaii, where JCMT and SMA are located, the Atacama Desert in Chile, where ALMA is located, the South Pole, where SPT is located, and the Greenland Summit. These very few telescopes, when observing with the highest frequencies, will provide highest angular resolution. We expect to image the black hole shadow with 10 times better resolution than the current results.

*“We are currently studying how to move the telescope to the Greenland Summit, and how to construct the telescope site at the Summit,”* explained **Dr. Ming-Tang Chen**, Research Fellow and the Deputy Director for Hawaii Operations of ASIAA. *“The Summit site is very remote with harsh conditions and very little infrastructures in place. At the current Thule site, we are testing the antenna and other components to improve reliability.”*

Denmark has indicated their intention to join our efforts. We will collaborate with the experienced Danish researchers on how to move and construct the telescope and support facilities at this remote site. We will also collaborate with Danish astronomers on the science with the GLT.

Notes

[8] Many GLT project members also worked for EHT on the theory of black hole jets and accretion flows (e.g., Dr. Masanori Nakamura), phase-up of ALMA into an equivalent 88m single telescope (e.g., Dr. Makoto Inoue, Prof. Cheng-Yu Kuo of the National Sun Yat-Sen University), formulating the EHT science proposals (e.g., Drs. Keiichi Asada, Masanori Nakamura), the execution of the EHT experiments (e.g., Drs. Satoki Matsushita, Keiichi Asada), and also on the calibration and imaging of the data (e.g., postdoctoral fellows Drs. Jun Yi Koay, Shoko Koyama, and NTU PhD student Wen-Ping Lo). They were among the first to actually see the image of the black hole shadow. Some of us also led teams to write the EHT papers that are published this time (Drs. Geoffrey Bower, Keiichi Asada).

[9] Many science and/or engineering faculties and staff members enabled the construction of our many telescopes and instrument systems (e.g., Drs. Ming-Tang Chen, Chih-Wei L. Huang, Patrick M. Koch, Satoki Matsushita, Ramprasad Rao, Ming-Jye Wang, and Mr./Ms. Shu-Hao Chang, Chung-Cheng Chen, Ryan Chilson, Chih-Chiang Han, Yau-De Huang, Homin Jiang, Derek Kubo, Chao-Te Li, Kuan-Yu Liu, Pierre Martin-Cocher, George Nystrom, Peter Oshiro, Philippe Raffin, Yang-Tai Shaw, Ranjani Srinivasan, Ta-Shun Wei, Chen-Yu Yu).

[10] NCSIST constructed the antennas and the receivers together with us, and delivered those with the world-class quality (e.g., Dr. Kuo-Chang Han, and Mr. Chih-Cheng Chang, Song-Chu Chang, Dr. Hao Jinchi, Ching-Tang Liu, Li-Ming Lu).

[11] The Greenland Telescope (GLT) was designed to recover the ALMA-Taiwan investments in the ALMA North America (ALMA-NA) partnership, as a Taiwan initiative. The ASIAA, together with the Smithsonian Astrophysical Observatory, was awarded the ALMA-NA 12 m Prototype Antenna in 2013. The telescope was retrofitted for polar conditions, and deployed to Greenland, in order to provide the highest angular resolution for ALMA, and also to establish the first Arctic observatory. The GLT was deployed to Thule Air Base on the west coast of Greenland in 2016. It achieved the first light in the winter of 2017, and joined the second EHT campaign in April 2018.