Event Horizon Telescope

Background Material

Announcement on Breakthrough Results on the Milky Way

May 2022

The Event Horizon Telescope collaboration is announcing major results on the Milky Way on May 12th at 13:00 UT. These results will be presented at simultaneous press conferences world wide. As a service for enhancing the reporting, some background information is provided here.

The Event Horizon Telescope Collaboration

A long-standing goal in astrophysics is to directly observe the immediate environment of a black hole at angular resolution comparable to the dimensions of the event horizon. Such observations offer the best way to probe directly the strong gravity effects that are expected near a black hole and to trace the intricate dynamics of the matter which orbits the black hole nearly at the speed of light. This capability opens a new avenue for testing general relativity in the strong field regime, studying accretion and outflow processes at the edge of a black hole, and probing fundamental black hole physics and the very existence of the event horizons.

In pursuit of these goals, the international consortium of the Event Horizon Telescope (EHT) was formed in 2015, continuing the steady, long-term progress of improving and expanding the capabilities of Very Long Baseline Interferometry (VLBI) at short wavelengths. The VLBI technique of linking radio dishes across the globe to create an Earth-sized interferometer, has been used by the EHT to constrain the shape and the size of emitting regions surrounding the two supermassive black holes with the largest apparent event horizons: Sgr A* in the center of the Milky Way and M87 in the center of the Virgo A galaxy. Addition of key millimeter and submillimeter wavelength facilities at high altitude sites has now opened the possibility of imaging such features with an unprecedented fidelity and tracing the dynamic evolution of material accreted by black holes. In addition to performing such state-of-the-art astronomical measurements, the EHT collaboration also performs theoretical and simulation studies that are addressing physical conditions and fundamental processes occurring in the immediate vicinity of black hole event horizon.

By using novel systems for linking together existing telescopes, the EHT leverages considerable global investment to create a fundamentally new instrument with angular resolving power that is the highest possible from the surface of the Earth. Over the coming years, the international EHT team will mount observing campaigns of increasing resolving power and sensitivity, aiming to bring black holes into focus.

EHT Observing Campaign in April 2017

The technique applied for the EHT observations is called Very Long Baseline Interferometry (VLBI). VLBI enables the highest resolutions in astronomy by coupling a number of radio telescopes distributed across different countries on Earth. This method is used for the investigation of the direct environment of supermassive black holes in active galactic nuclei, in particular jets of high-energy particles emitted from the central regions. In the framework of the EHT project it will become possible to directly image the central black holes in addition to the jets. This is achieved by observations at shorter radio waves of only 1.3 mm wavelength. The resolution of the world-wide network of radio telescopes at that wavelength would allow us to resolve the size of a table tennis ball in the distance of the moon.

To minimize the impact of the Earth's atmosphere at that wavelength, the observations are only possible at high-altitude dry sites like the Atacama desert in Chile, the Sierra Nevada in southern Spain, high volcanoes in Hawaii or even the South Pole.

Including the Atacama Large Millimeter Arrays (ALMA) with its 64 dishes in total provides a very high sensitivity. In total it is synthesizing a radio telescope with an equivalent diameter of 84 meters, superior to the usual millimeter-wave radio telescopes with 15 to 30 meters in diameter. After a preparation phase of several years of observations within the EHT project, the first observing campaign took place between April 4 and 14, 2017.

VLBI data sets are analyzed in dedicated super computers, known as correlators. For the analysis of the EHT observations two correlators are used, at the Max Planck Institute for Radio Astronomy in Bonn and at Haystack Observatory in Haystack, Massachusetts, USA. These correlators are necessary due to the enormous data volume collected at each telescope, the equivalent of tens of thousands DVDs per site.

The telescopes which participated at the 2017 campaign were, in alphabetical order:

- Atacama Large Millimeter Array (ALMA) in Chile
- Atacama Pathfinder Experiment (APEX) in Chile

- IRAM 30-m Telescope at Pico Veleta, Spain
- James Clark Maxwell Telescope (JCMT) on Maunakea, Hawaii, USA
- Large Millimeter Telescope (LMT) Alfonso Serrano in Mexico
- South Pole Telescope (SPT)
- Submillimeter Array (SMA) on Maunakea, Hawaii, USA
- Submillimeter Telescope (SMT) on Mount Graham in Arizona, USA

Further observatories have joined the array since 2017, namely, the IRAM NOEMA telescope in the French Alps, the Greenland Telescope, and the University of Arizona 12-m telescope on Kitt Peak, AZ, USA. Two existing facilities at MIT Haystack Observatory and the Caltech Owens Valley Radio Observatory are being prepared to join future campaigns. New telescopes, such as the Africa Millimeter Telescope, are in the development phase.

The following astronomical targets were observed during the 2017 campaign:

- The Galactic Center, Sagittarius A* (Sgr A*), at a distance of 27,000 light years in the constellation „Sagittarius“ (EHT project)
- Active galaxy Virgo A (Messier 87 or M 87), at a distance of 53 million light years in the constellation „Virgo“ (EHT project). Results from these observations revealed the first image ever of a black hole (presented on April 10, 2019), For this result the EHT collaboration was awarded, among others, with the Breakthrough Prize for Fundamental Physics. Results on the detection of polarized light at the edge of the black hole were reported on March 24, 2021
- Southern Galaxy Centaurus A, at a distance of 13 million light years in the constellation “Centaurus”. Results from these observations were presented on July 19, 2021
- Quasar OJ 287, at a distance of 3.5 billion light years in the constellation “Cancer“
- Elliptical galaxy NGC 1052, in a distance of 63 million light years in the constellation “Cetus”
- Quasar 3C 279, at a distance of 5 billion light years in the constellation „Virgo“. Results from these observations were presented on April 7, 2020)
- Further active galaxies (like 3C 273) are used as calibration sources.

The Event Horizon Telescope has performed additional observing campaigns in 2018, 2021, and 2022. The 2019 campaign was canceled for operational reasons, and the 2020 one was postponed to 2021 due to the CoViD-19 pandemic. Results from these observations are now being processed and analysed.

Pictures from the observing campaign are available at the EHT webpage here.

Selected Frequently Asked Questions

What is known about the center of the Milky Way?

The central region of our Galaxy, in the direction of the constellations Sagittarius, Ophiuchus, and Scorpius, has about 10 million stars in the central 3 light years. The central region is obscured for visible light as seen from Earth due to the presence of interstellar dust. At radio wavelengths, a complex astronomical radio source appears at the Galactic Center. This complex structure contains a bright, compact radio source, labeled Sagittarius A* (A is the brightest source in radio for a given constellation, e.g., Messier 87 is Virgo A; the star is taken in analogy with atomic physics, where it denotes the excited state of an atom). This source has been under the scope of radio astronomers for the last five decades.
(See additional information below)

How far away is the event horizon of Sagittarius A*?

The distance between our Solar System and the center of our Galaxy, Sgr A*, is about 27,000 light-years. The Milky Way as a whole measures about 106,000 light-years in diameter. The Sun orbits the Galactic Center every 240 million years.

How big is the black hole in the Galactic Center?

The most recent observations of stars in the Galactic Center orbiting Sgr A*, presented by groups at UCLA and the MPE, yield a mass of about four million solar masses.
For this mass, the radius of the event horizon is about 6 million kilometers (which corresponds to an angular size in the sky of 5 micro-arcseconds; 6 million km is about 15 times the Earth-Moon distance).
Notice that for such a black hole size, the matter orbiting the black hole would have an innermost stable circular orbit which corresponds to a time of 4 minutes to 30 minutes, so that any variations in the gas emission around the very center may change at these time scales. Notice that those time scales are much shorter than a regular Event Horizon Telescope observing night, which takes several hours.
Compare: the black hole at the heart of the galaxy Messier 87 is roughly 1600 times more massive (6.5 billion solar masses), orbiting times are weeks.

What is the Event Horizon Telescope Project?

The Event Horizon Telescope is the name of a collaboration with the goal to obtain the first ever direct images of black holes. Since black holes do not emit any light, the goal is to image their "shadow" or "silhouette" caused by the gravitational bending of light under extreme gravity. This is only possible with a very sharp image of the black hole in the microwave region of the spectrum, virtually combining telescopes spread across the Earth into a single telescope as big as our globe. The individual telescopes are placed at remote locations, at high altitude with a dry atmosphere to avoid the effect of water vapor. Their recorded signal is combined and processed to obtain the final image. For this challenging enterprise, it is needed to team up different groups of scientists skilled in antenna optimization, receiver development, correlation of signals, calibration, deconvolution methods in imaging, theory of black holes, jets, and general relativity, numerical simulations, etc. Over 350 people conform the collaboration with the goal of imaging a black hole for the first time.

How international is the EHT collaboration?
The collaboration has members spread over the world. Thirteen stakeholder institutions constitute the core of the collaboration, and scientists of more than hundred institutions spread over North and South America, Europe, Southern Africa, and East Asia.

How many researchers contributed to this process?
The Event Horizon Telescope Collaboration counts with the participation of over 350 individual researchers distributed around the world. They have grouped in different expert teams to address the different challenges of the observations: e.g., phasing up the arrays of telescopes to work as a single dish, outfitting the telescopes at the different sites, post-processing the data in the correlator centers, calibrating the data, imaging, interpreting the images obtained, and producing numerical simulations to compare with the observations.

What is a black hole?
A region of spacetime with such intense gravity that nothing, not even light, can escape. For this reason, we call it “black”. Since matter that falls onto (into) it seems to disappear, is reminiscent of a “hole”.

What is an event horizon?
The event horizon is the boundary surface between space and the “inside” of the black hole. It is the “region of no return”, i.e. whatever crosses the event horizon will forever be unable to escape.

The Galactic Centre

The long history of Milky Way research can start with Galileo Galilei, who used his telescope in 1610 to discover that our galaxy, which appears as a diffuse cloudy band to the naked eye, actually is composed of stars. In 1785, British astronomer William Herschel produced a rudimentary map of the Milky Way.

In 1918, American astronomer Harlow Shapley located the Milky Way's center by using the newly discovered distance-measuring tool provided by Cepheid variable stars to determine that a halo of globular star clusters that surrounds the Milky Way is centered on a region in the constellation Sagittarius. That region is obscured from visible-light telescopes by thick clouds of gas and dust.

Karl Jansky, an engineer at Bell Telephone Laboratories, made the first discovery of radio waves coming from beyond Earth in 1932, earning the title of father of radio astronomy. Further work showed that the emission he detected is coming from the Milky Way's central region. That region later would be called Sagittarius A, as the brightest source of radio emission in that constellation. In 1951, Australian radio astronomers narrowed down the emission's location and indicated that it probably comes from the galaxy's center.

In 1960, Dutch astronomers Jan Oort and Wim Rougoor use radio and optical observations, including the rapidly rotation disk of neutral hydrogen and absorption lines at radio wavelengths to locate the direction and distance of the brightest source towards the Archer constellation, Sagittarius A. Based on these observations, they postulate it to be situated at the center of the Milky Way.

British astronomer Donal Lynden-Bell in 1969 suggested that very massive objects could live at the centers of some galaxies, such as those harboring active galactic nuclei (AGN). Such galaxies are extremely bright at many different wavelengths and also spew out powerful jets of charged particles. The British astronomer Martin Rees realized in 1974 that black holes could be the cause of this energetic turmoil, a fact that is now confirmed.

Bruce Balick and Robert Brown used in 1974 the National Radio Astronomy Observatory's Green Bank Interferometer to discover a very bright and compact object to which Brown later attached the name Sagittarius A* (adding the asterisk). A black hole became the leading explanation for what powers the bright radio emission of the object, abbreviated Sgr A*. In 1994, infrared and submillimeter studies estimated the object's mass at 3 million times that of the Sun.

In 2002, a team led by Reinhard Genzel of the Max Planck Institute for Extraterrestrial Physics reported on a 10-year study of the orbital motion of a star called S2 near Sgr A*. That study concluded that the central object is more than 4 million times more massive than the Sun. In 2009, another team reported on further observations of stellar orbits in the region and concluded that the central object probably is a black hole because no other phenomenon is known that can pack that much mass into such a small space. This work and other studies of Sgr A* earned the 2020 Nobel Prize in Physics for Genzel and Andrea Ghez of UCLA for producing "the most convincing evidence yet of a supermassive black hole at the center of the Milky Way."

Additional information:

- Scientific Background for the Nobel Prize in Physics 2020, granted to Andrea Ghez and Reinhard Genzel *for the discovery of a supermassive compact object at the centre of our galaxy*: Theoretical foundation for black holes and the supermassive compact object at the galactic centre
- ESO's blog Taking the First Picture of a Black Hole

Selected Links

- EHT Webpage
- EHT Organisation
- EHT Stakeholder Institutions
    - Academia Sinica Institute of Astronomy and Astrophysics (Board member: Satoki Matsushita)
    - Center for Astrophysics | Harvard & Smithsonian & Smithsonian Astrophysical Observatory (Board member: Raymond Blundell, also executive Group)
    - East Asian Observatory (Board member: Paul Ho, Executive Group)
    - Goethe-Universitaet Frankfurt (Board member: Luciano Rezzolla)
    - Institut de Radioastronomie Millimétrique (Board member: Karl Schuster)
    - Large Millimeter Telescope (Board Vice-Chair: David Hughes)
    - Max Planck Institute for Radio Astronomy (Board member and Founding Chair: J. Anton Zensus, Board Founding Chair)
    - MIT Haystack Observatory (Board chair, Colin Lonsdale,)
    - National Astronomical Observatory of Japan (Board member: Mareki Honma)
    - Perimeter Institute for Theoretical Physics (Board member: Avery Broderick)
    - Radboud University (Board member: Heino Falcke)
    - University of Arizona (Board member: Buell Jannuzi)
    - University of Chicago (Board member: John Carlstrom)

- Press Releases from the EHT:
    - First-ever Image of a Black Hole Published by the Event Horizon Telescope Collaboration, April 10, 2019
    - Something is Lurking in the Heart of Quasar 3C 279, April 7, 2020
    - Astronomers Image Magnetic Fields at the Edge of M87's Black Hole, March 24, 2021
    - Einstein's Theory Can Explain the Black Hole M87*, May 18, 2021
    - Einstein's Description of Gravity Just Got Much Harder to Beat, October 1st, 2021
    - Wobbling Shadow of the M87* Black Hole, September 23, 2021
    - EHT Pinpoints Dark Heart of the Nearest Radio Galaxy, July 19, 2021

Press Conferences - Media Advisories

Following press conferences are scheduled, in alphabetical order by location:

- Garching bei München, European Southern Observatory, see ESO Media Advisory (15:00 CEST) - Live streaming at ESO Website and ESO YouTube Channel
- Mexico City, CONACyT, see CONACyT Media Advisory (08:00 CDT) - Live streaming at CONACyT YouTube Channel
- Santiago de Chile, Joint ALMA Observatory, see ALMA Media Advisory (09:00 CLT)
- Shanghai, Shanghai Astronomical Observatory, see Shanghai Astronomical Observatory Media Advisory (21:00 CST)
- Taipei, Academia Sinica Institute for Astronomy and Astrophysics (21:00 CST)
- Tokyo, National Astronomical Observatory of Japan (22:00 JST)
- Washington D.C.,National Press Club, see National Science Foundation Media Advisory (09:00 EDT) - Live streaming at NSF website and Facebook. You can also view and embed using this live stream link.

Earlier Scientific Publications from the Event Horizon Telescope

- Satapathy et al., *The variability of the black-hole image in M87 at the dynamical time scale*, accepted for publication in The Astrophysical Journal, 01/2022
- Janssen et al., *Event Horizon observations of the jet launching and collimation in Centaurus A*, published in Nature Astronomy, 07/2021
- Kocherlakota et al., *Constraints on black-hole charges with the 2017 EHT observations of M87**, published in Physical Review D, 05/2021

- Narayan et al., *The Polarized Image of a Synchrotron Emitting Ring of Gas Orbiting a Black Hole* published in The Astrophysical Journal, 05/2021
- EHT MWL Science Working Group et al., *Broadband Multi-wavelength Properties of M87 During the 2017 Event Horizon Telescope Campaign*, published in The Astrophysical Journal Letters, 04/2021
- Event Horizon Telescope Collaboration et al., *First M87 Event Horizon Telescope Results VIII: Magnetic Field Structure Near The Event Horizon*, published in The Astrophysical Journal Letters, 03/2021
- Event Horizon Telescope Collaboration et al., *First M87 Event Horizon Telescope Results VII: Polarization Of The ring*, published in The Astrophysical Journal Letters, 03/2021
- Goddi et al., *Polarimetric properties of event horizon telescope targets from ALMA*, published in The Astrophysical Journal Letters, 03/2021
- Psaltis et al., *A gravitational test at the second Post-Newtonian order with the shadow of the M87 black hole*, published in Physical Review Letters 10/2020
- Wielgus et al., *Monitoring the Asymmetric Ring Morphology of M87* in 2009–2017 with the Event Horizon Telescope*, published in The Astrophysical Journal, 09/2020
- Kim et al., *Event Horizon Telescope imaging of the archetypical blazar 3C 279 at an extreme 20 microarcsecond resolution*, published in Astronomy & Astrophysics, 08/2020
- Gold et al., *Verification of Radiative Transfer Schemes for the EHT*, published in The Astrophysical Journal, 07/2020
- Broderick et al., *THEMIS: A Parameter Estimation Framework for the Event Horizon Telescope*, published by The Astrophysical Journal, 07/2020
- Roelofs et al., *SYMBA: An end-to-end VLBI synthetic data generation pipeline - Simulating Event Horizon Telescope observations of M87*, published in Astronomy & Astrophysics, 04/2020
- Event Horizon Telescope Collaboration et al., *First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole*, published in The Astrophysical Journal Letters, 04/2019
- Event Horizon Telescope Collaboration et al., *First M87 Event Horizon Telescope Results. V. Physical Origin of the Asymmetric Ring,* published in The Astrophysical Journal Letters, 04/2019
- Event Horizon Telescope Collaboration et al., *First M87 Event Horizon Telescope Results. IV. Imaging the Central Supermassive Black Hole*, published in The Astrophysical Journal Letters, 04/2019

- Event Horizon Telescope Collaboration et al., *First M87 Event Horizon Telescope Results. III. Data Processing and Calibration*, published in The Astrophysical Journal Letters, 04/2019
- Event Horizon Telescope Collaboration et al., *First M87 Event Horizon Telescope Results. II. Array and Instrumentation,* published in The Astrophysical Journal Letters, 04/2019
- Event Horizon Telescope Collaboration et al., *First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole*, published in The Astrophysical Journal Letters, 04/2019
- Porth et al., *The Event Horizon General Relativistic Magnetohydrodynamic Code Comparison Project*, published in The Astrophysical Journal Supplement, 08/2019