Focus on the First Event Horizon Telescope Results

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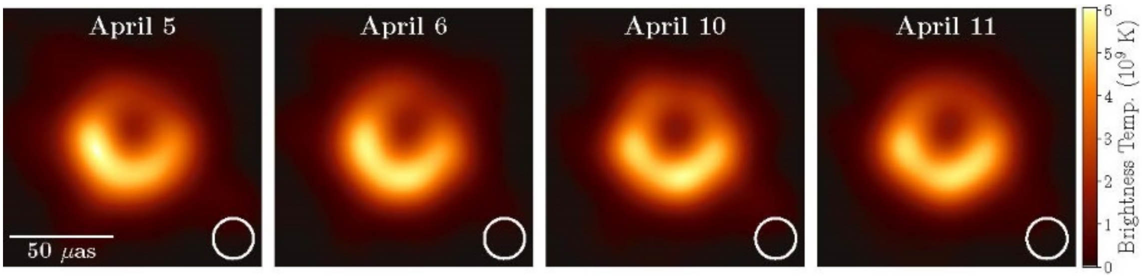

Figure 1. EHT images of M87 on four different observing nights. In each panel, the white circle shows the resolution of the EHT. All four images are dominated by a bright ring with enhanced emission in the south. From Paper IV (Figure 15).

We report the first image of a black hole.

This Focus Issue shows ultra-high angular resolution images of radio emission from the supermassive black hole believed to lie at the heart of galaxy M87 (Figure 1). A defining feature of the images is an irregular but clear bright ring, whose size and shape agree closely with the expected lensed photon orbit of a 6.5 billion solar mass black hole. Soon after Einstein introduced general relativity, theorists derived the full analytic form of the photon orbit, and first simulated its lensed appearance in the 1970s. By the 2000s, it was possible to sketch the "shadow" formed in the image when synchrotron emission from an optically thin accretion flow is lensed in the black hole's gravity. During this time, observational evidence began to build for the existence of black holes at the centers of active galaxies, and in our own Milky Way. In particular, a steady progression in radio astronomy enabled very long baseline interferometry (VLBI) observations at ever-shorter wavelengths, targeting supermassive black holes with the largest apparent event horizons: M87, and Sgr A* in the Galactic Center. The compact sizes of these two sources were confirmed by studies at 1.3mm, first exploiting baselines that ran from Hawai'i to the mainland US, then with increased resolution on baselines to Spain and Chile.

Over the past decade, the EHT extended these first measurements of size to mount the more ambitious campaign of imaging the shadow itself. During 5-11 April 2017, the Event Horizon Telescope (EHT) observed M87 and calibrators on four separate days using an array that included eight radio telescopes at six geographic locations: Arizona (USA), Chile, Hawai'i (USA), Mexico, the South Pole, and Spain (Figure 2). Years of preparation (and an astonishing spate of planet-wide good weather) paid off with an extraordinary multi-petabyte yield of data. The results presented here, from observations through images to interpretation, issue from a team of instrument, algorithm, software, modeling, and theoretical experts, following a tremendous effort by a group of scientists that span all career stages, from undergraduates to senior members of the field. More than 200 members from 59 institutes in 20 countries and regions have devoted years to the effort, all unified by a common scientific vision.

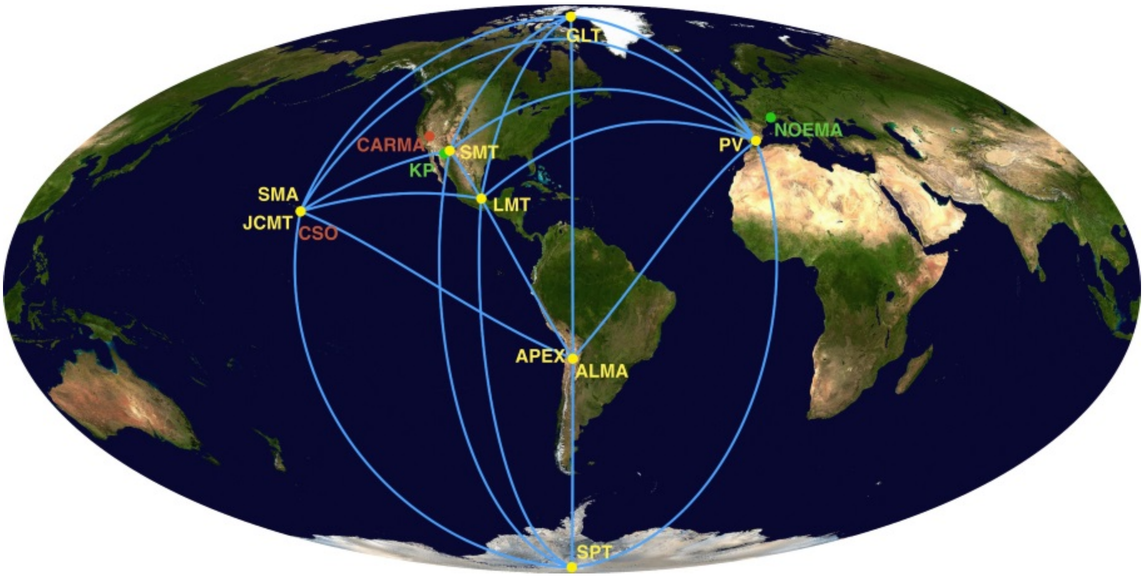

Figure 2. A map of the EHT. Stations active in 2017 and 2018 are shown with connecting lines and labeled in yellow, sites in commission are labeled in green, and legacy sites are labeled in red. From Paper II (Figure 1).

The sequence of Letters in this issue provides the full scope of the project and the conclusions drawn to date. Paper II opens with a description of the EHT array, the technical developments that enabled precursor detections, and the full range of observations reported here. Through the deployment of novel instrumentation at existing facilities, the collaboration created a new telescope with unique capabilities for black hole imaging. Paper III details the observations, data processing, calibration algorithms, and rigorous validation protocols for the final data products used for analysis. Paper IV gives the full process and approach to image reconstruction. The final images emerged after a rigorous evaluation of traditional imaging algorithms and new techniques tailored to the EHT instrument--alongside many months of testing the imaging algorithms through the analysis of synthetic data sets. Paper V uses newly assembled libraries of general relativistic magnetohydrodynamic (GRMHD) simulations and advanced ray-tracing to analyze the images and data in the context of black hole accretion and jet-launching. Paper VI employs model fits, comparison of simulations to data, and feature extraction from images to derive formal estimates of the lensed emission ring size and shape, black hole mass, and constraints on the nature of the black hole and the space-time surrounding it. Paper I is a concise summary.

Our image of the shadow confines the mass of M87 to within its photon orbit, providing the strongest case for the existence of supermassive black holes. These observations are consistent with Doppler brightening of relativistically moving plasma close to the black hole lensed around the photon orbit. They strengthen the fundamental connection between active galactic nuclei and central engines powered by accreting black holes through an entirely new approach. In the coming years, the EHT Collaboration will extend efforts to include full polarimetry, mapping of magnetic fields on horizon scales, investigations of time variability, and increased resolution through shorter wavelength observations.

In short, this work signals the development of a new field of research in astronomy and physics as we zero in on precision images of black holes on horizon scales. The prospects for sharpening our focus even further are excellent.

First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole

The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L1

First M87 Event Horizon Telescope Results. II. Array and Instrumentation

The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L2

First M87 Event Horizon Telescope Results. III. Data Processing and Calibration

The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L3

First M87 Event Horizon Telescope Results. IV. Imaging the Central Supermassive Black Hole

The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L4

First M87 Event Horizon Telescope Results. V. Physical Origin of the Asymmetric Ring

The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L5

First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole

The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L6