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Multi-frequency Event Horizon Telescope: the Sharpest Color Camera of the Universe

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The Event Horizon Telescope (EHT) is a global millimeter-wavelength Very Long Baseline Interferometry (VLBI) array assembled and operated by the international EHT Collaboration (EHTC). The current EHT array comprises 11 telescopes at 9 geographic locations across the globe, from Greenland to the South Pole, and from Hawai'i to Europe. With a global array and the current observing wavelength of 1.3 mm/230 GHz, the EHT achieves an extremely high angular resolution of $\sim$20 μas, providing the sharpest view of the universe. The EHT resolution will improve to $\sim 15\,\mu$as in 2023 with the first science observations at 0.8 mm/345 GHz. With unprecedented capabilities, the EHTC has provided the first event-horizon-scale images of black holes for the supermassive black hole Messier 87* (M87*) and the Galactic supermassive black hole Sagittarius A* (Sgr A*). The first images of M87* and Sgr A* both revealed a bright ring of photons enclosing the gravitational-lensed shadow of the black hole. These breakthroughs have provided direct constraints on the physics of black hole accretion and outflows, and new tests of Einstein's general theory of relativity (GR) in the strong field regime. EHT further revealed the deepest view of the cores in other active galactic nuclei, temporally and spatially resolving the complex plasma flow of their inner jets.

Here, we present the current development vision of the EHTC toward mid- and late-2020s. The EHTC envisions a transformational upgrade to the current EHT, to form a multi-frequency Event Horizon Telescope (mEHT) array. The mEHT concept aims to overcome limitations in current EHT capabilities and significantly broaden the scientific applications of high-frequency VLBI. Significant hardware upgrades across the existing array, and the addition of new stations including the Haystack 37-m telescope and the Owens Valley Radio Observatory, will enable the use of frequency phase transfer (FPT) in simultaneous multifrequency observing (the "m" in mEHT) at 90/230 GHz or 230/345 GHz (Figure 1). With FPT, high SNR measurements of atmospheric perturbations, which limit current EHT coherence and sensitivity, are obtained at lower frequencies and used to correct the greater corruption at high frequencies. The implementation of FPT will dramatically reduce atmospheric decoherence at 230/345 GHz, which will substantially increase the number of robustly detected interferometric fringes, enhance imaging dynamic range, and enable detections of much fainter emission. With the wider coverage of the observational frequencies and the high angular dynamic range, multi-frequency mEHT observations, which may involve partner sites at 90 GHz (e.g., Global Millimeter VLBI Array), allow new science capabilities inaccessible with the current monochromatic EHT. With the planned extension, the EHT will be the highest-resolution color video camera ever made, and will open up a new window on the dynamic universe to address fundamental questions in gravitational physics, accretion and jet astrophysics, and drivers of galaxy growth.

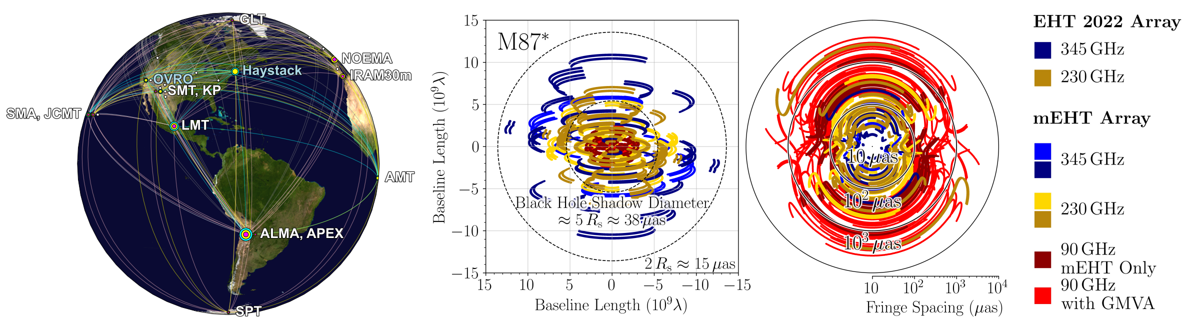

Figure 1. (Left) The mEHT array. Sites with 90/230/345 GHz capability are marked cyan/yellow/magenta circles, with diameters proportional to effective telescope diameters. The additional international partner sites at 90 GHz are marked in white. (Middle and Right) Fourier coverage of the mEHT at all frequencies for M87* (middle), and the equivalent coverage of fringe spacing (right). The mEHT array will achieve a large angular dynamic range capturing structures over two orders of magnitudes in spatial scales from $\sim 10\,\mu$as to $\sim 10^3\,\mu$as.