URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Imaging Supermassive Black Holes and Blazar Jets with Millimeter and Space VLBI Observations

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On April 10, 2019, after decades of technical development, the Event Horizon Telescope Collaboration presented the first image of a black hole [1], thus transforming these elusive objects from the realms of science fiction to science fact. The central compact radio source in the radio galaxy M87 has been resolved out into an asymmetric bright emission ring with a diameter of 42 μas, which is circular and encompasses a central depression in brightness with a flux ratio >10:1. The emission ring is recovered using different calibration and imaging schemes, and remains stable over four different observations carried out in different days. Comparison of the Event Horionz Telescope (EHT) to an extensive library of ray-traced GRMHD simulations shows that they are consistent in size and shape with the lensed photon orbit encircling a dark shadow caused by photon capture at the event horizon of a 6.5 billion solar masses black hole, as predicted by general relativity. EHT observations thus provide confirmation for the presence of supermassive black holes powering active galaxies (AGN), and present a new tool to explore gravity in its most extreme limit via repeated astronomical observations. The extension of the EHT to include new antennas on the ground and in Earth orbit will allow us to make the first real-time movies of supermassive black holes and their emanating jets.

Thanks to the extremely high angular resolution that the very long baseline interferometry (VLBI) technique provides, we have studied AGN for the past decades at centimeter wavelengths (cm-VLBI), probing into their cores with sub-milliarcsecond angular resolutions. Mass accretion onto SMBHs leads to the formation of an accretion disk that surrounds its event horizon. Magnetic fields either anchored in the innermost accretion disk or black hole ergosphere extract -- through a process that is still largely unknown -- some of this material forming a pair of very powerful and highly collimated relativistic jets that extend far beyond the size of the host galaxy. Relativistic electrons in the jet, threaded by large scale magnetic fields, radiate most of their energy as synchrotron and perhaps inverse Compton emission across the entire spectrum, from radio to γ-rays.

We have therefore a broad idea of how accretion onto SMBHs works, what ignites a galactic nuclei, and how the relativistic jets propagate, but looking deeper into the SMBH vicinity, where all these processes take place, was just a step beyond the angular resolution we could achieve with cm-VLBI from the surface of Earth. Two recent technological improvements have overcome this limitation, providing a first glimpse into the inner works of SMBHs. On one side, the space VLBI mission RadioAstron has allowed to increase the virtual size of our VLBI telescopes to as large as the distance to the Moon, achieving angular resolutions as small as 20 microarcseconds [2]. On the other side, the participation of ALMA as a phased array in VLBI observations at millimeter wavelengths (mm-VLBI) has allowed the Event Horizon Telescope (EHT) to reconstruct images with similar angular resolutions, but at higher frequencies and therefore lifting the opacity blurring curtain that affects longer wavelengths, providing the first clear look into a black hole.

Combining the EHT, RadioAstron, and the GMVA, plus other cm-VLBI arrays worldwide and observations across the whole electromagnetic spectrum, we can for the first time, after decades of study actually address the fundamental questions of how gravity works in the strong-field regime near the event horizon, how accretion leads to the formation of relativistic jets, and how they propagate to drive galaxy evolution at cosmological scales.

References

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