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Approaching the Speed Limit: Explaining the Powerful Acceleration of the Jets that Stream out of Supermassive Black Holes

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An international team led by Drs. Keiichi Asada and Masanori Nakamura from the Institute of Astronomy and Astrophysics (ASIAA) has revealed for the first time how the mysterious jets that stream out from the the very vicinity of black holes approach 99% of the speed of light after being launched. How the flows obtain such an extremely fast speed has been one of the big unanswered questions in astrophysics for over 40 years. The discovery was made by observing the jet from the supermassive black hole at the heart of active galaxy Messier 87 (M 87). Resolving the site of the acceleration was made possible by the sensitive observations obtained using the European VLBI Network (EVN) (an interferometric radio telescope spread throughout Europe and beyond). The results of this discovery were published in The Astrophysical Journal Letters on December 23, 2013.

Extragalactic jets are powerful bipolar streams, consisting of ionized plasma. The jets emanate from active galactic nuclei (AGNs) from regions in the vicinity of supermassive black holes (SMBH) and have a mass between a million and ten billon solar masses. Some of the jets travel more than ten million light-years, well beyond the physical extent of their host galaxies, at more than 99% of the speed of light. Such a relativistic outflow has been observed as the superluminal motion with Very Long Baseline Interferometry (VLBI) since the 1970s. Apparent velocities exceed the speed of light when the relativistic outflow aligns within a small viewing angle along the line of sight. Magnetically driven outflows around the SMBH are theoretically a promising mechanism for producing extragalactic jets. However, up until now it has remained unclear how the jet velocity approaches the speed of light.

M 87 is a giant elliptical galaxy in the Virgo cluster of galaxies about 50 million light-years away from the Earth, and it is one of the nearest AGNs which exhibits relativistic outflows extending up to about 5,000 light-years. The galaxy hosts an enormous black hole about six billion times more massive than the sun, with a Schwarzschild radius or event horizon of R_s ~ 64 AU (astronomical units: the mean distance between the Earth and the Sun). Proper motions of the M 87 jet have been probed by VLBI, the Very Large Array (VLA), and the Hubble Space Telescope (HST) during the last two decades and a curious picture has been derived in the M 87 jet: there is no evidence for highly relativistic velocities around the SMBH, and then, suddenly, they appear further downstream. This issue has been highlighted by inspecting observed proper motions associated with the M 87 jet over two decades, together with recent remarkable observations using EVN. The team finally discovered the missing link in the velocity field of the M 87 jet, which lies in the intermediate region between ten thousand and several hundred thousand R_s, and concluded that these results necessitate continuous acceleration and collimation processes from non-relativistic (1% of the speed of light) to relativistic speed (99 % of the speed of light) over an extremely large spatial scale.

The team also analyzed the structure and velocity field of the M 87 jet, and found fundamental properties by the magnetohydrodynamic (MHD) jet acceleration, which constitute the solid foundation of an MHD paradigm for the extragalactic jets. Highly relativistic outflows are

fundamental in the universe. How the flow obtains such an extremely fast speed is one of big unanswered questions that high-energy astrophysicists have been facing for over 40 years. It was previously believed that the jets, initiated at nearby SMBHs, would be ejected with almost the speed of light like shotgun bullets. The new observation results in M 87, instead, reveal a long-lasting, continuous acceleration toward the speed of light.

Dr. Paul Ho, ASIAA Director noted, "Currently, ASIAA is conducting the 'Greenland Telescope' (GLT) project with international collaborators. The 12-meter telescope is anticipated to operate in Greenland from late 2015. Astrophysicists are seeking the first exciting opportunity to image the shadow of the SMBH in the galaxy M 87 (a size close to ~ 5 R_s) as well as the jet launching region, using sub-millimeter VLBI observations including GLT with an ultra-high angular resolution. How is the VLBI technique superior? It allows you to see a *xiao long bao* (Chinese steamed dumpling) clearly on the moon. This will be the highest angular resolution in astronomy. With this challenging project, the GLT team will bring the black hole into our real world in the near future."

The full article entitled "Discovery of Sub- to Superluminal Motions in the M 87 Jet: An Implication of Acceleration from Sub-relativistic to Relativistic Speeds" is available at *The Astrophysical Journal Letters* website.

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