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USNO Astronomer Leads Effort to Precisely Locate Sagittarius A* in the International Celestial Reference Frame Using Absolute Astrometry

In a new paper published in the February 2023 issue of *The Astronomical Journal*[1], a team led by astronomer David Gordon of the U.S. Naval Observatory report on precisely locating the black hole at the center of our galaxy for the first time in the International Astronomical Union's official celestial reference frame.

Located at the center of our Milky Way galaxy is a super-massive black hole, known as Sagittarius A* (Sgr A*), a strong radio source that has been known of and studied since the early 1950's. Gas and dust in the galactic plane obscures it in the visible part of the spectrum, but infrared observations of the motions of stars in its vicinity have shown it to have a mass of ~4 million solar masses[2]. And recently, its shadow has been imaged by the Event Horizon Telescope[3]. But in spite of the many studies made of it, locating it precisely in the sky has proven to be difficult. Accurately locating Sgr A* with respect to other sources in the celestial reference frame is important for defining the galactic coordinate system and for studies of galactic structure, kinematics and dynamics, and for registration between studies and images in the radio, millimeter and infrared. The best previous estimates of its position have been made using a radio interferometry technique called 'differential' astrometry, where its celestial coordinates are estimated with respect to one or two nearby calibrator radio sources. However, the coordinates of the calibrator sources used were known only to a few tens of milli-arc-seconds (mas) and could vary slightly over time, leading to similar uncertainties in the coordinates of Sgr A*. But now, a new study led by a U. S. Naval Observatory astronomer and published in the February 2023 issue of *The Astronomical Journal* [1] has for the first time determined Sgr A*'s precise position as well as its proper motion in the frame of the International Astronomical Union's official celestial reference frame, ICRF3[4].

ICRF3, the third realization of the International Celestial Reference Frame, is a celestial reference frame composed of the precise coordinates of ~4500 compact quasar radio sources determined by Very Long Baseline Interferometry (VLBI). For the past several years, David Gordon at the U. S. Naval Observatory and colleagues Aletha de Witt at the South African Radio Astronomy Observatory and Christopher Jacobs at the Jet Propulsion Laboratory have been making observations of Sgr A* using the radio interferometry technique called VLBI 'absolute' astrometry, in which its position is determined with

respect to hundreds of ICRF3 sources, thus fixing it firmly in the IAU's official celestial reference frame much more accurately than ever before.

Observations were made at a frequency of 24 GHz using the Very Long Baseline Array (VLBA), a facility of 10 radio telescopes operated by the National Radio Astronomy Observatory (NRAO) and funded jointly by NSF and USNO. The authors combined observations from 2006 through 2022 to determine Sgr A*'s position and proper motion in the ICRF3 frame, with a precision of ~0.5 mas and ~0.07 mas/year, respectively. In more human understandable terms, 0.5 mas is approximately how big a meter stick on the Moon would appear from Earth. Sgr A* is believed to be stationary at the galactic center, so the 6.4 mas/year proper motion measured in this study implies that our solar system is rotating around the galaxy at ~248 km/sec in the plane of the galaxy and ~9 km/sec perpendicular to the plane of the galaxy towards the north galactic pole.

References:

[1]*Position and Proper Motion of Sagittarius A* in the ICRF3 Frame from VLBI Absolute Astrometry*, David Gordon, Alet de Witt and Christopher. S. Jacobs, 2023, The Astronomical Journal, 165:49.

[2]The Astrophysical Journal, 689:1044-1062, 2008.

[3]The Astrophysical Journal, 930, L12, 2022.

[4]Astronomy and Astrophysics, 644, A159, 2020.