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Press Release

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USNO Astronomer Makes Major Breakthrough in Unifying the Celestial Reference Frame

In a new paper published in the November 2022 issue of *The Astrophysical Journal Letters*,[1] astronomer Nathan Secrest of the U.S. Naval Observatory reports the results of the first study of the relationship between variability in the luminosity of distant radio sources and their apparent positions on the sky.

The International Celestial Reference Frame (ICRF) is composed of 4,536 radio sources distributed across the sky. These sources, powered by the accretion of matter onto supermassive black holes at the centers of extremely distant galaxies ("active galactic nuclei" or "AGNs"), form a fixed frame of reference against which all other positions and motions can be defined. At radio wavelengths, the positions of these objects are measured using very long baseline interferometry (VLBI), a technique made possible with networks of radio telescopes spanning the globe. The orientation of the ICRF at radio wavelengths is extremely precise—with an uncertainty equivalent to the width of a human hair seen one thousand miles away—but extending the ICRF to other wavelengths has proven to be challenging.

One challenge has been apparent disagreements between the positions of many ICRF objects at radio and visual wavelengths, the latter measured by the European Space Agency's Gaia astrometric space mission. These "optical-radio offsets" affect about 11% of ICRF objects, and previous work has shown that these offsets are likely of astrophysical origin. Specifically, the radio emission in these distant AGNs is powered by jets: streams of matter ejected from near the supermassive black hole at speeds very close to that of light. These jets emit radiation at both radio and visual wavelengths, but the appearance (and therefore apparent position) of the jet changes with wavelength. Additionally, the matter falling into the supermassive black hole forms an extremely hot disk that emits very brightly at visual wavelengths, further contributing to differences in apparent position.

By analyzing variations in the apparent luminosity of the AGNs that comprise the ICRF using data from the recent Gaia DR3 release, Secrest found that the prevalence of optical-radio offsets in the most highly variable objects is only about 2%, a dramatic drop from the 11% prevalence in the full ICRF. Using color information from Gaia, as well as a comparison to known gamma ray emitters compiled in the Fermi Large Area Telescope catalog, Secrest showed that these highly variable objects are blazars, AGNs in which the powerful radio jet is pointing almost directly into our line of sight. In these objects,

the jet is brighter at visual wavelengths due to special relativity, and the projected offset between the radio and visual position of the AGN is minimized because of the jet orientation. These results indicate that using information about AGN variability provides a means of minimizing the effect of astrophysical misalignments between celestial reference frames created at different wavelengths, a major breakthrough in the effort to produce a unified, wavelength-independent frame.

[1] *Optical-Radio Position Offsets are Inversely Correlated with AGN Photometric Variability*
Secrest, N. 2022, ApJL, 939, 32