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A Smoking Gun for Supermassive Binaries in Active Galactic Nuclei

Blazar Jet Variability probes precession caused by orbiting black holes in the centers of galaxies

An international research team led by Silke Britzen from the Max Planck Institute for Radio Astronomy in Bonn, Germany, has investigated blazars, accreting supermassive black holes in the centers of galaxies. Blazars show up when one of the emitted jets in the active galactic nucleus is pointing directly towards the Earth. The researchers present evidence that it is in fact the precession of the jet source, either caused by the presence of a second massive black hole close to the primary one or a warped accretion disk around a single black hole, that is responsible for the observed variability in blazars.

Their findings are presented in the Astrophysical Journal.

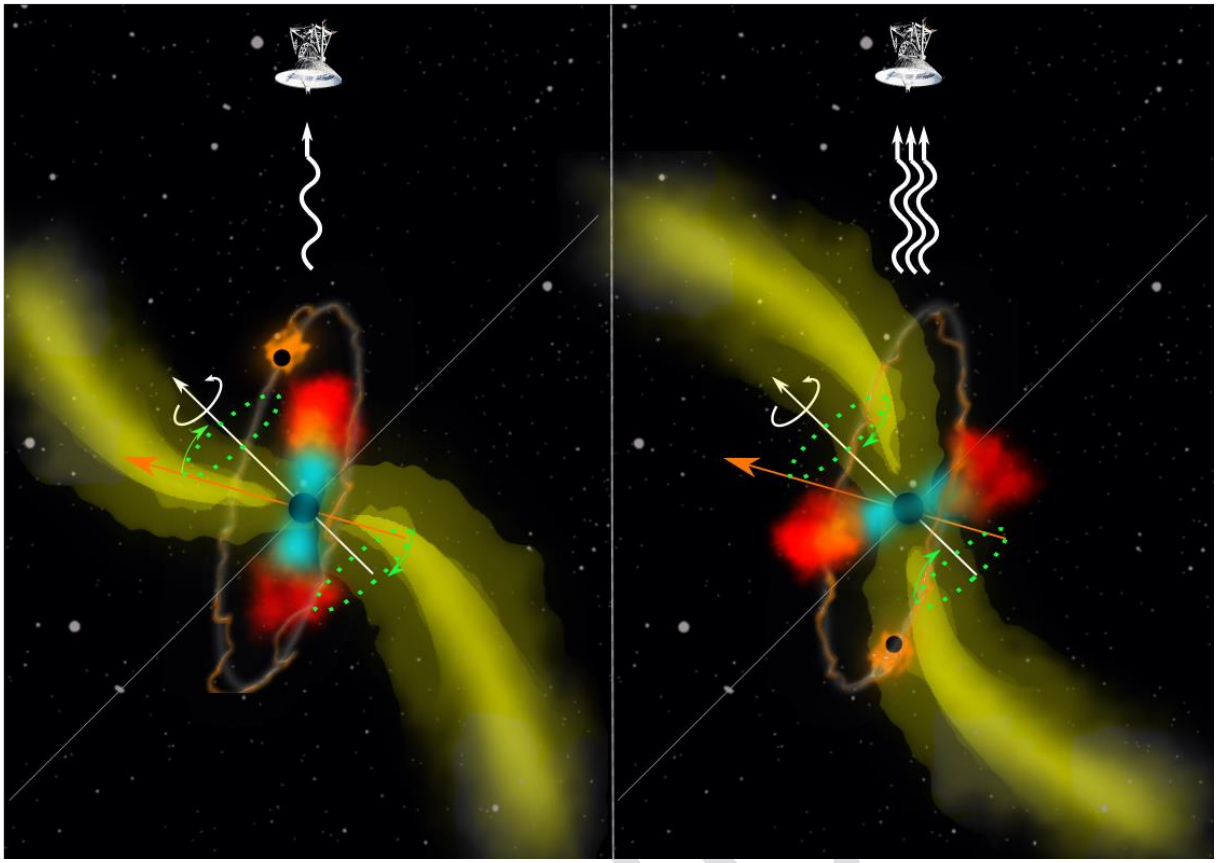

Fig. 1: *Illustration showing a magnetized radio jet (yellow), precessing due to a supermassive binary black hole at the center of the galaxy. The larger supermassive black hole is shown in black at the center within the accretion disk, that contains both warmer (blue) and cooler (red) gas. The white arrow indicates the spin of the larger black hole. The second black hole is orbiting (orange) around the central supermassive black hole and the orange arrow shows the orientation of its orbital angular momentum. Due to the misalignment, the torque from the secondary drives the precession of the accretion disk as well as the launched jet (green circle and arrows). Radio emission is indicated with white curved lines. A radio telescope points the direction towards the observer on Earth. The two images visualize how the jet swirls around and produces the variations in radio emission. The jet in the image on the right is turning towards the observer and thus appears brighter in the sky – hence stronger radio emission is seen.*

Credits: *Michal Zajaček/UTFA MUNI*

With the expression “Blazars” scientists denote the most dramatic examples in the zoo of active galactic nuclei (AGN), accreting supermassive black holes in the centers of galaxies. They show up when one of the emitted jets is pointing directly towards us, the Earth.

Results from decades of monitoring of blazars have always been interpreted in a way that the frequent and significant brightening of these sources, called flare activity, is associated with the ejection of jet components from the core into the jet, leading to a sudden enhanced emission.

Blazar jets are often curved and not as straight as one might expect. Meandering jet structures were thought to be connected to the component ejections from the core. Snaking jets as well

as the brightening of the AGN were both expected to be of stochastic origin – depending on the feeding of the black hole. However, over the years, more and more detailed observational results have cast doubt on this possibly too simple causal interrelation.

A new paper in the Astrophysical Journal questions this established ejection-flaring relation for the bright and strongly variable blazars. "*We present evidence and discuss the possibility that it is in fact the precession of the jet source, either caused by a supermassive binary black hole at the footpoint of the jet or – less likely – by a warped accretion disk around a single black hole, that is responsible for the observed variability*," says Silke Britzen from the Max Planck Institute for Radio Astronomy in Bonn, Germany, the leading author of the study.

When jets swirl around due to precession, this swirling motion naturally introduces periodic changes also in intensity, due to the effect of Doppler beaming, see Fig. 1 for a simplified schematic of this effect. This has been detected in a number of AGN jets over many years.

For OJ 287 – the best candidate for hosting a supermassive black hole binary - Silke Britzen and her team had established the precession origin of the strong variations in brightness and jet bending in their *Rosetta-paper* (MPIfR Press Release, July 21, 2018). Most recently, predictions from their work have been confirmed by Komossa et al. (MPIfR Press Release, February 23, 2023).

The team now applied the same model to other blazars. For a sample of 12 prominent AGN, their results demonstrate how the variability in brightness and jet curvature, can indeed be explained by the modulating power of precession.

The authors do not question that the underlying and hard-to-tackle jet physics can also be caused by internal interactions in the jet, explained by the so-called shock-in-jet model, by instabilities in the jet beam, or by energetic magnetic reconnection. However, they propose that the appearance of these jets, is strongly modulated and altered by the jet precession. Essentially, these jets would not appear as curvy and as bright, if not enhanced by the effect of precession.

By releasing the one-to-one correlation of the brightness enhancements with the ejection of jet components, allows to explore the interplay of a dynamical system that is essentially predictable, as it can be understood in geometrical terms.

"*Blazar variability in many galaxies might predominantly not be of stochastic, but of deterministic nature,*" continues Silke Britzen. "*It is fascinating to decode the inner workings of this black hole machinery with the help of variability studies.*"

One of the most important implications of this study is that the jet curvature is likely a telling signature of the existence of binary black holes at the center of these galaxies. Thus, the jet is forced to meander due to the gravitational influence of a second black hole on the jet-emitting black hole. In addition, the team managed to detect traces of a smaller-amplitude nutation motion in the radio light curves as well as in the kinematics of jet components – a second-order effect and additional proof of precession.

"*Physics of accretion disks and jets is rather complex but their bulk kinematics can be compared to simple gyroscopes – if you exert an external torque on an accretion disk, for instance by an orbiting secondary black hole, it will precess and nutate, and along with it the jet as well, similar to the Earth's rotation axis that is affected by the Moon and the Sun,*" adds

Michal Zajaček from the Masaryk University (Brno, Czech Republic), a co-author of the study.

Radio observations achieve the highest resolution in astronomical observations by connecting radio telescopes over very large distances with Very Long Baseline Radio Interferometry (VLBI). This is the same technique that allowed the Event Horizon Telescope (EHT) collaboration to image the shadow of a black hole for the first time, observing the 6.5 billion solar mass black hole in the galaxy M87 (MPIfR Press Release, April 10, 2019).

The search for these close pairs of supermassive binary black holes is ongoing since decades and resembles the effort necessary to find a needle in a haystack.

"*We still lack the sufficient resolution to probe the existence of supermassive binary black holes directly. But jet precession seems to provide the best signature of these objects, whose existence is expected not only by the black hole / AGN community, but also from the gravitational wave community who recently published evidence for the existence of a cosmic gravitational background due to the gravitational waves emitted by the mergers of massive black hole through cosmic history*," concludes Silke Britzen.

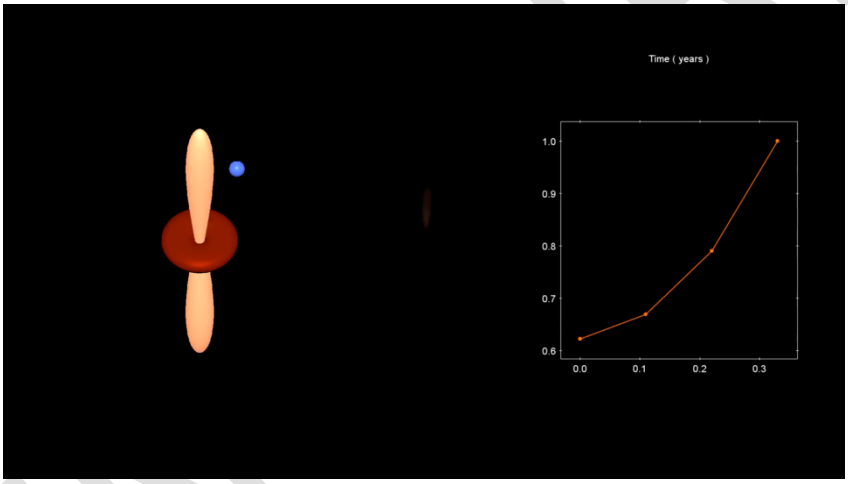

Fig. 2. *The animation shows how jet precession (left) leads to changing brightness of the radio emission (right).*

Credits: *Wolfgang Steffen (ilumbra AstroPhysical MediaStudio)*

Additional Information:

Supermassive black holes are typically found at the centers of galaxies. In active galaxies, accretion of matter onto the central black hole is thought to produce the enormous amounts of energy that may outshine the whole galaxy - making these central regions, denoted as Active Galactic Nuclei (AGN), the most luminous persistent sources in the Universe.

Extended, bipolar beams of plasma moving with relativistic speed, so-called jets, are launched from the central region of a supermassive black hole by means of a strong magnetic field.

Bright spots in the jet, so-called jet components, are observed to move along within the jets. The speed of these components may often appear as super-luminal, a geometrical effect which

seems to show velocities superseding the speed of light. This is, however, no contradiction to Einstein's special relativity as it can easily be explained as due to a well-known relativistic projection effect. As the jet material is moving at velocities close to the speed of light, and is directed towards the observer, the observed velocity appears enhanced since the observed time of arrival of the light is shortened as the component travels towards the observer. At the same time, the intensity is enhanced by so-called Doppler beaming which can be checked independently in various ways, i.e., by studying the brightness variability of the jets. The physical processes explaining how these components are initially produced, are still unknown.

The research team comprises Silke Britzen, Michal Zajaček, Gopal-Krishna, Christian Fendt, Emma Kun, Frédéric Jaron, Aimo Sillanpää, and Andreas Eckart. Silke Britzen and Andreas Eckart are both affiliated with the MPIfR.

Original Paper:

S. Britzen et al.: *"Precession-induced Variability in AGN Jets and OJ 287",* in The Astrophysical Journal, 951, 106. DOI: 0.3847/1538-4357/accbbc

https://doi.org/10.3847/1538-4357/accbbc

Further Information (Links):

MPIfR, Radio Astronomy / VLBI Research Department
https://www.mpifr-bonn.mpg.de/research/vlbi

Monitoring Of Jets in Active galactic nuclei with VLBA Experiments (MOJAVE)
https://www.cv.nrao.edu/MOJAVE/

Event Horizon Telescope (EHT)
https://eventhorizontelescope.org/

International Pulsar Timing Array (IPTA)
https://ipta4gw.org/

Parallel and Earlier Press Releases

The Rosetta stone of active galactic nuclei deciphered, MPIfR Press Release, July 21, 2018
https://www.mpifr-bonn.mpg.de/pressreleases/2018/9

Astronomers Capture First Image of a Black Hole, MPIfR Press Release, April 10, 2019
https://www.mpifr-bonn.mpg.de/pressreleases/2019/4

Weighing OJ 287 and the project MOMO, MPIfR Press Release, February 23, 2023
https://www.mpifr-bonn.mpg.de/pressreleases/2023/4

Contact:

Priv.-Doz. Dr. habil. Silke Britzen
Max-Planck-Institut für Radioastronomie, Bonn.
Fon: +49 228 525-280
Email: sbritzen@mpifr.de

Dr. Michal Zajaček
Masaryk University, Brno, Czech Republic.
Fon: +420 549 496-508
E-mail: zajacek@physics.muni.cz

Prof. Dr. Christian Fendt
Max-Planck-Institut für Astronomie, Heidelberg.
Fon: +49 6221 528-387
Email: fendt@mpia-hd.mpg.de

Dr. Norbert Junkes,
Press and Public Outreach,
Max-Planck-Institut für Radioastronomie, Bonn.
Fon: +49 228 525-399
E-mail: njunkes@mpifr-bonn.mpg.de