Precessing Radio Galaxy Jets: Simulations & Observable Signatures

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Introduction

Some radio galaxies show signs of changes in jet orientation or direction in the form of off-(current)axis lobes or S, X, or Z-shape radio morphology. One explanation for this is the precession of the AGN jet axis, possibly caused by a binary supermassive black hole companion. We performed jet simulations and generated synthetic radio maps understand the evolution of precessing jet dynamics and radio emissions.

Key Findings

Precessing radio galaxy jets take on a wide range of morphologies, highly dependent on viewing angle and projection effects

Reorientation events within the jets can cause sharp bending without external dynamics

Numerical Methods

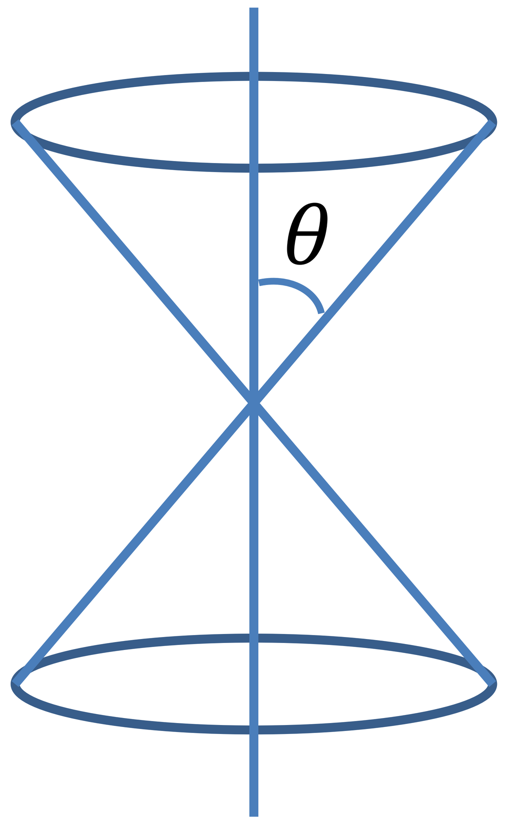
Using the Wombat MHD code (Mendygral 2011) we performed 3D jet simulations in which the jet axis precessed on Myr timescales. We utilized the 2nd order TVD solver with constrained transport of the magnetic fields (Ryu 1998). A ray electrons (CRe) was evolved along with the MHD plasma (Jones & Kang 2005) in order to model radio synchrotron emission from the jets. We included adiabatic and radiative effects (synchrotron & inverse Compton) in the evolution of the CRe energies.

The jets were injected into a static, uniform medium with density $\rho_{ICM} = 2.17\times10^{-28} g\ cm^{-3}$ and $T_{ICM} = 5\times10^{7}\ K$. The jets had $\rho_j = 1.1\times 10^{-29} g\ cm^{-3}$ and $v_j = 3\times10^{9} cm/s$ and were launched in pressure equilibrium with the undisturbed ICM plasma. Jets originated from a cylindrical volume with a radius of 3kpc. The cylinder axis was rotated each time step to create the precession.

Precession

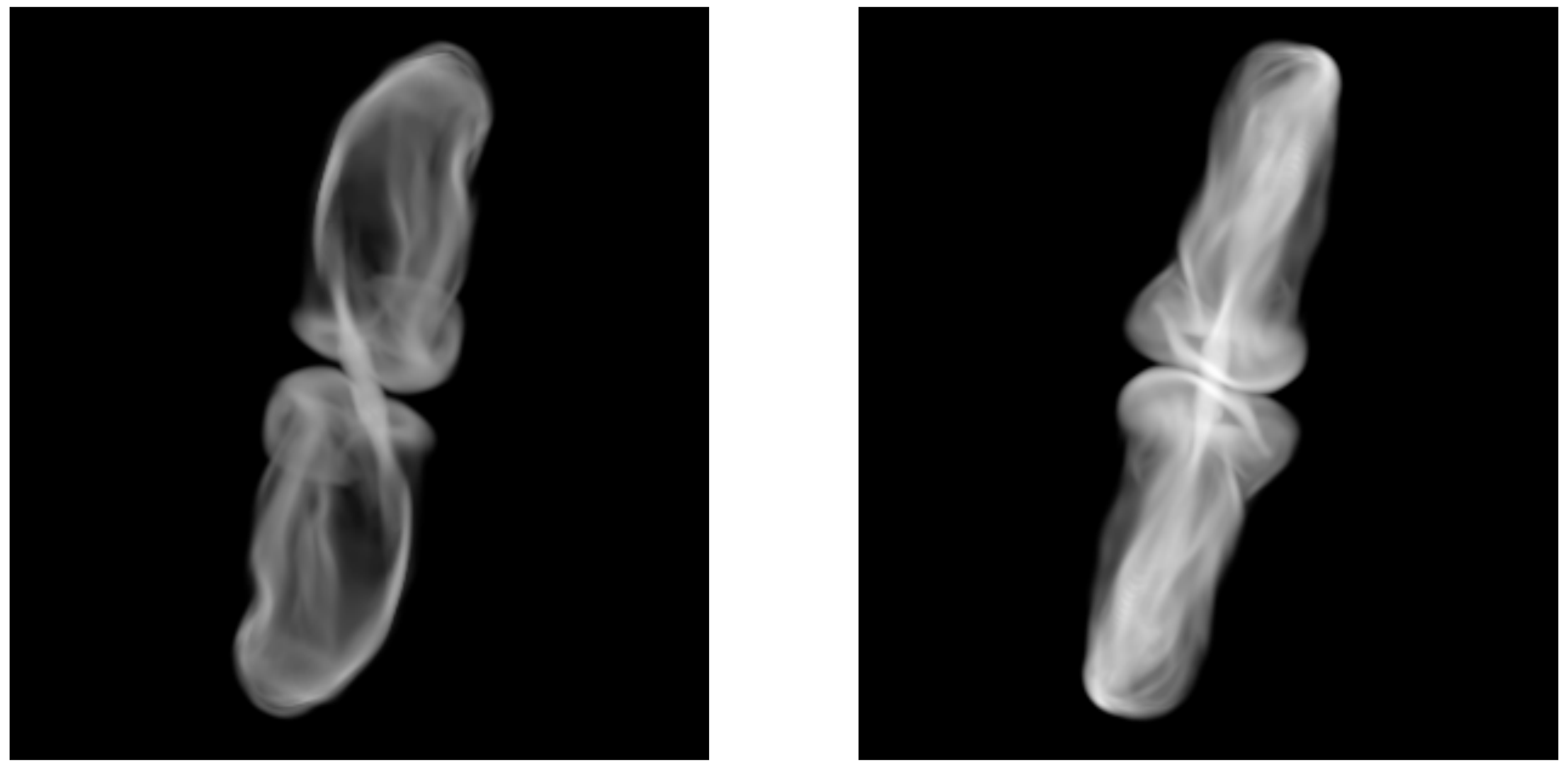
radio synchrotron @ 600MHz
32 Myr precession period, θ = 20°

We performed a series of simulations exploring different precession angles and periods.
We explored precession angles varying from $\theta = 10°$ - 30° and precession periods in the range of 1Myr – 100Myr.



Projection Effects

The viewing angle is very important for observing precessing jets. This has been pointed out recently by Horton et al. 2020. We confirm this in our simulations, as illustrated below. In particular, we note that depending on viewing angle, a precessing source could appear completely straight. These two images of the same source at the same stage in its evolution would likely be identified as different classes according to the classical FRI – FRII classification system. Similar confusion can result between two images of the same source at the same angle, but at different phases of the precession



radio synchrotron @ 600MHz, 32 Myr precession period, θ = 20°
Both images are at t=13Myr, but with a difference in viewing angle of 90°

Jet Reorientation

Despite the fact that our jet precession was smoothly varying in its angular velocity, we found that for some precession periods, the jet trajectory would become unstable and the jet would undergo a "reorientation event" in which the bent jet would break and the jet would become (relatively) straighter. After this point, the jet would begin again to bend as it precessed. These events seem to occur when the jet comes into contact with a region through which it has previously propagated, leaving behind a low density region and reducing the ram pressure that bend the jets. The sharp breaking of the jet is surprising in such a simple and uniform medium, as there where no external dynamics by which to induce this significant change. Often, in cluster environments, sharp discontinuities in radio galaxy sources or in jet direction are attributed to some interaction with the ICM, such as a shock, a wind, or a cold front. However, internal jet dynamics caused by precession can produce sharp bends and reordering of the jet in the absence of any external factors.

References

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