A search and multi-frequency investigation of the parsec-scale structure of curved jets in AGN

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What is done?

Analysed 123 000 images of about **17 000 AGNs** at various radio frequencies.

Filtered images with resolved extended jet structure.

Revealed ridgelines of jets for each image.

Identified 546 sources with significantly bent jets (Fig. 1).

Modelled jets with helix models to constrain possible bending hypotheses.

Estimated possible precession periods.

Tested 3 models of jet's precession (incl. black hole binary) and Kelvin-Helmholtz instability model.

The Challenge

It is observed that many active galactic nuclei (AGN) jets exhibit bending even at parsec scales. Our task is to perform multi-frequency analysis of AGN VLBI images, find sources that exhibit some degree of bending (fig. 1) and suggest possible physical mechanisms in charge.

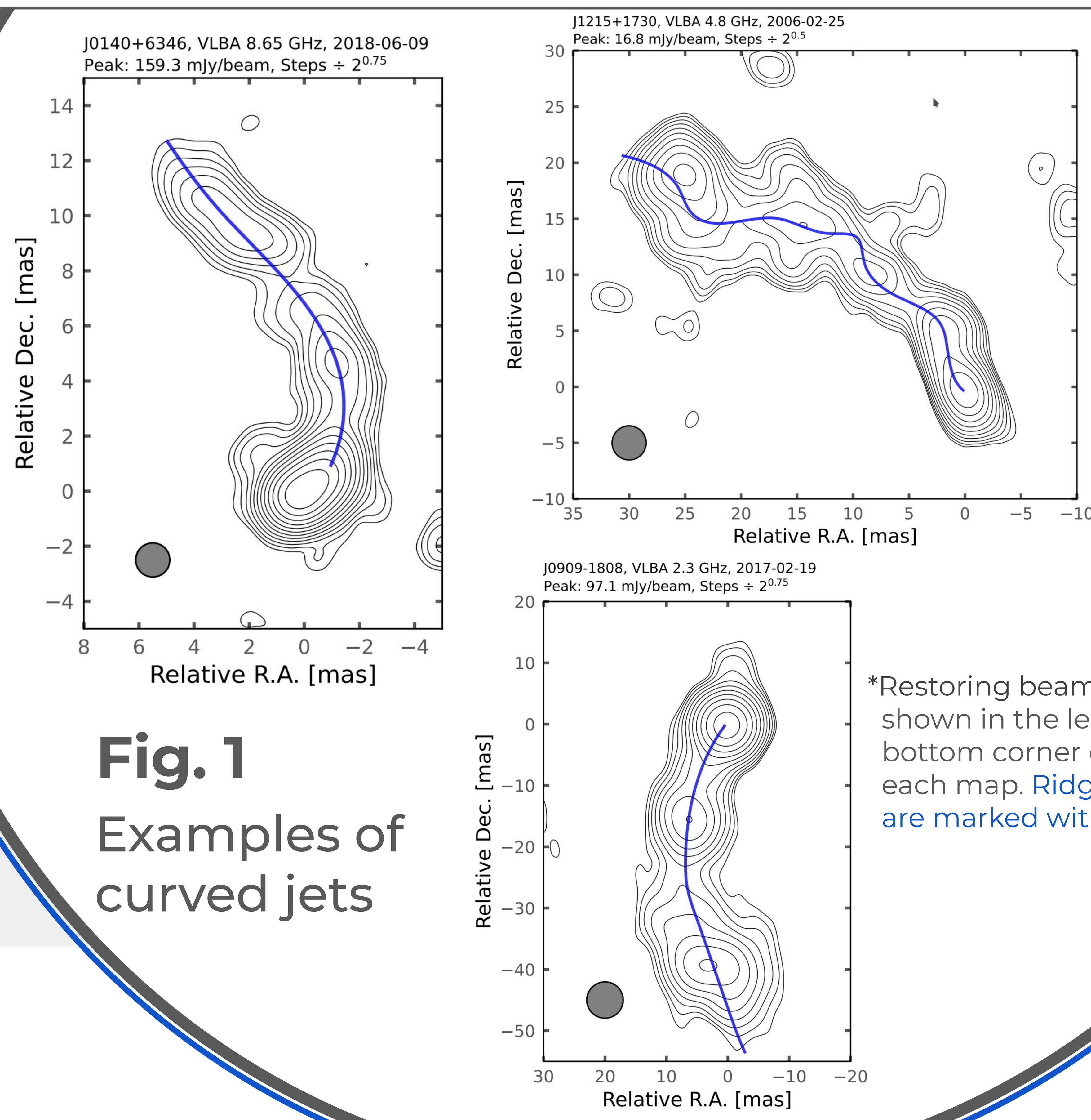

Fig. 1

Examples of curved jets

*Restoring beam is shown in the left bottom corner of each map. Ridgelines are marked with blue

The Data

In our research, we use the Astrogeo VLBI FITS image database, analyzing 123,000 images of 17,000 AGNs. We fit all images with 2D Gaussian and by after-fit residual filter out those that have no extended source.

The dataset after filtering contained 64 000 images of 8 000 sources

To extract AGNs with bent jets we stacked their ridgelines, fitted them with linear helix and calculated the angle of helix rotation. Each source with helix rotation angle > 20 deg became candidate. The number of candidates was ~ 2000. Then we manually chose AGNs with bent jets (**546 objects**).

Precession

We modelled ridge lines of each jet with the model of precessing jet, where substance moves with highly relativistic velocities along ballistic trajectories (which is a linear helix model).

Using estimated parameters and distributions of velocity, inclination angles and redshift provided by MOJAVE and OCARS teams we performed Monte-Carlo modelling of **precession periods posterior distribution** (Fig. 2). The periods span from decades to thousands of years.

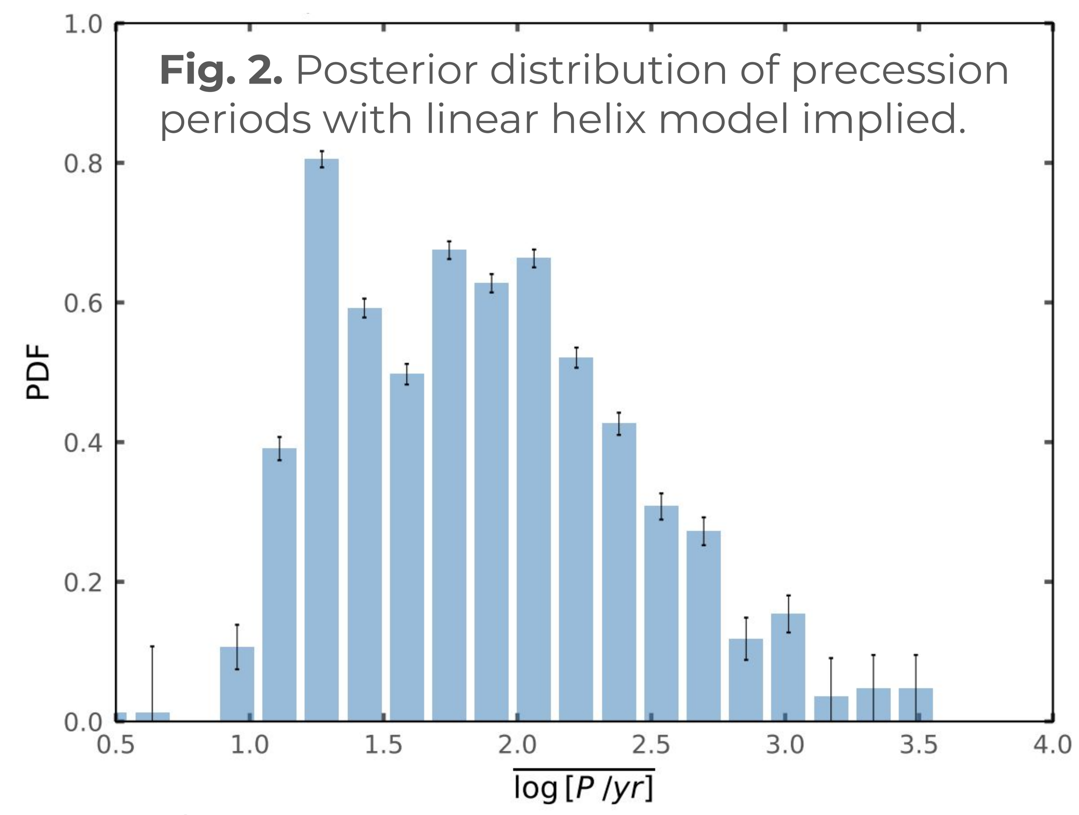

Fig. 2. Posterior distribution of precession periods with linear helix model implied.

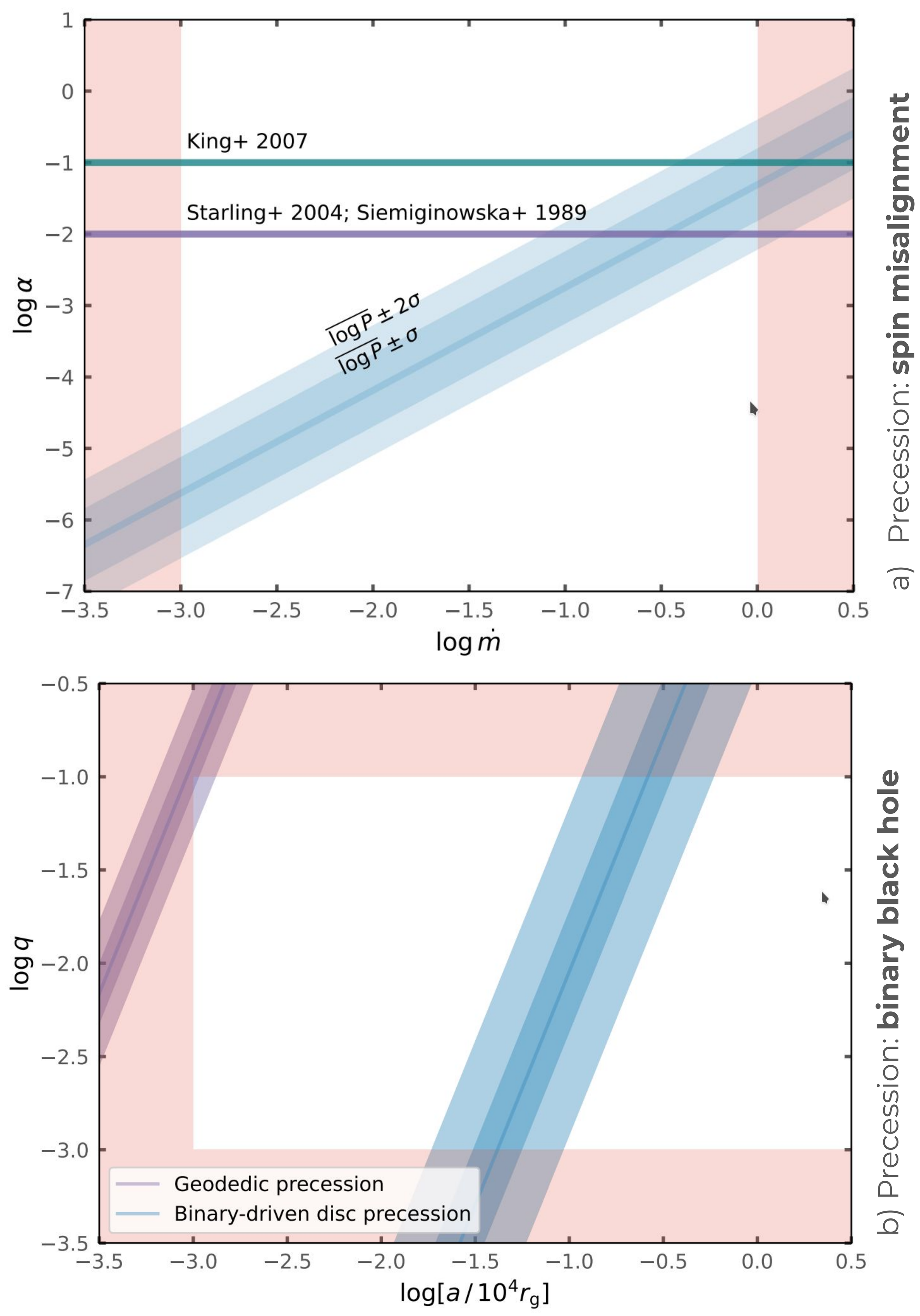

Fig. 3. Parameter spaces for different precession models. Red-shaded areas represent unlikely values. Blue and purple areas correspond to the estimated periods distribution (± 2σ).

Physical origin of precession

We investigate 3 precession models:

Single supermassive black hole:

- ➔ Precession driven by spin misalignment of a BH and accretion disk. (1)

Supermassive black hole binary (SMBHB) involved:

- ➔ Geodetic precession (2)
- ➔ Accretion disk-driven precession (3)

Given the periods distribution we investigate parameter space these models. (Fig. 3). Eddington accretion rate and disc viscosity for (1). Mass ratio and separation for (2) and (3).

Conclusions

- **Misaligned spin-driven precession:** Viable in AGNs with high Eddington accretion rates ($\dot{m} > 0.1$) (Fig. 3a).
- **SMBHB:** Geodetic model is not viable, because it predicts extremely small separations. Accretion disc-driven precession works well with separations of $10^{1.5} r_s$ to $10^3 r_s$ and mass ratios between 10^{-3} and 10^{-1} (Fig. 3b).

In addition, we tested the **Kelvin-Helmholtz instability** model (logarithmic helix). The model was capable of describing curved jets with realistic values of parameters.