Relativistic jets from stellar-mass accreting black holes

STEP'UP 2024 PhD Congress

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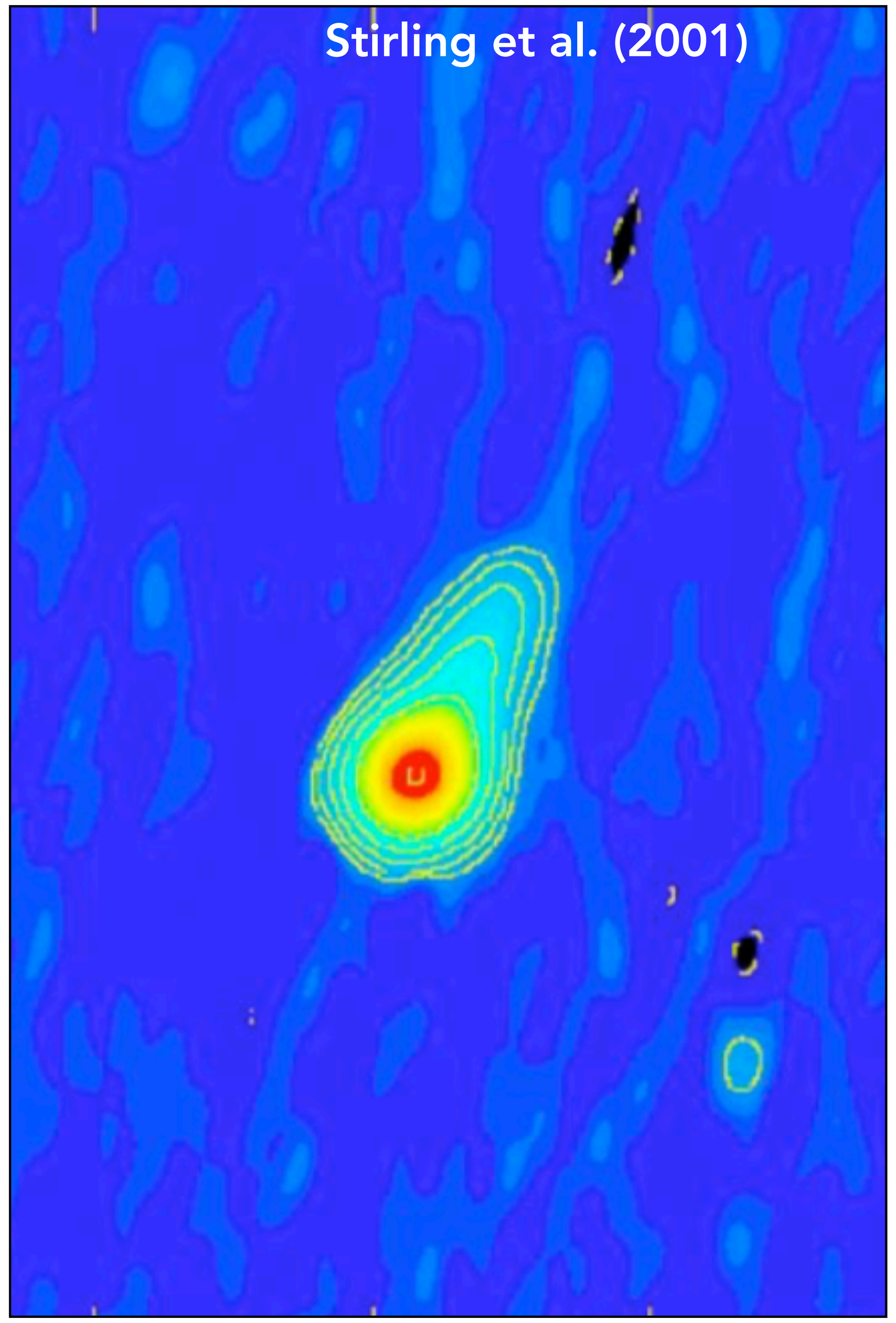
X-ray binaries

Credits: NASA/CXC/M.Weiss

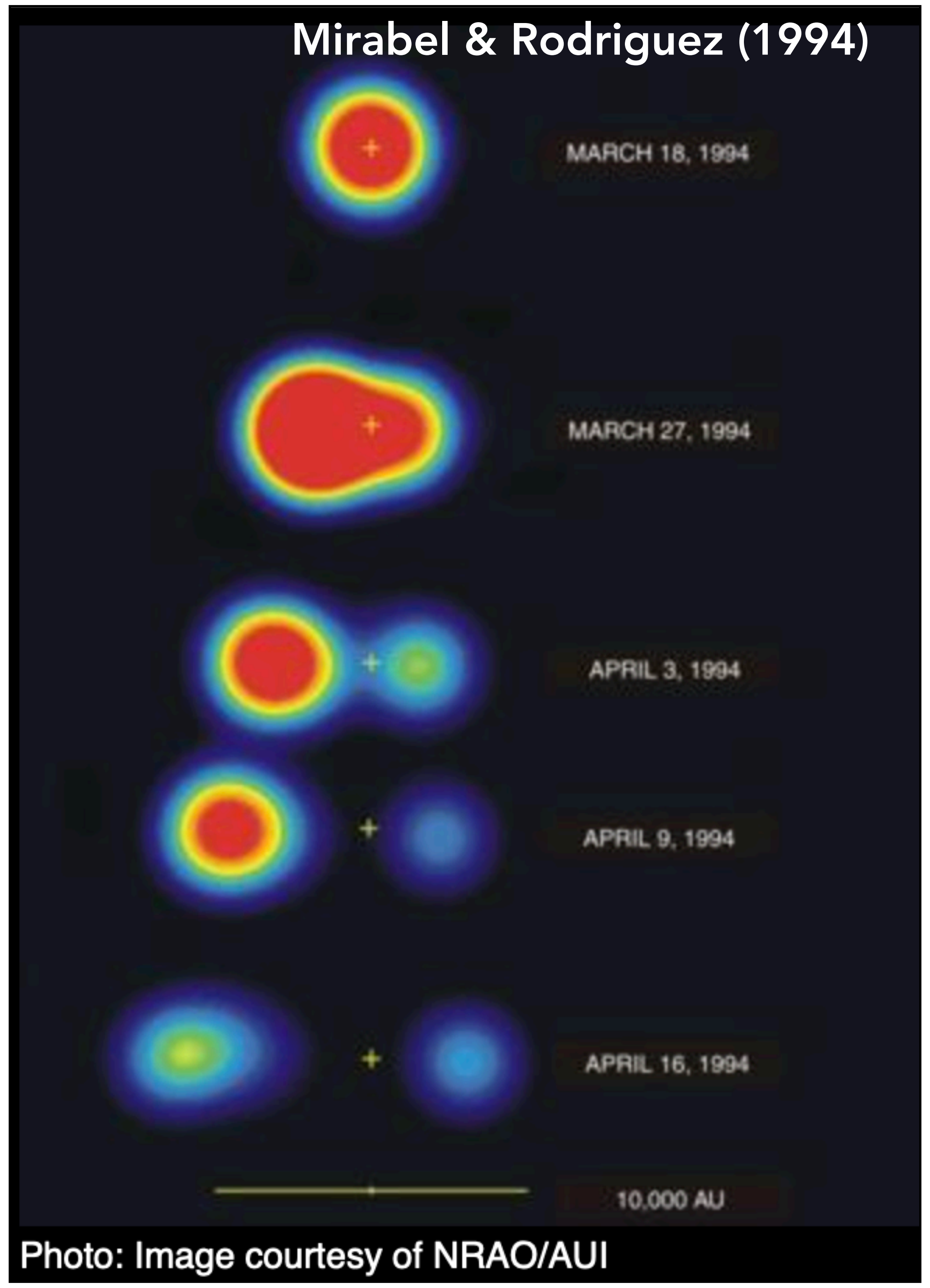
Different kinds of jets

Compacts jets



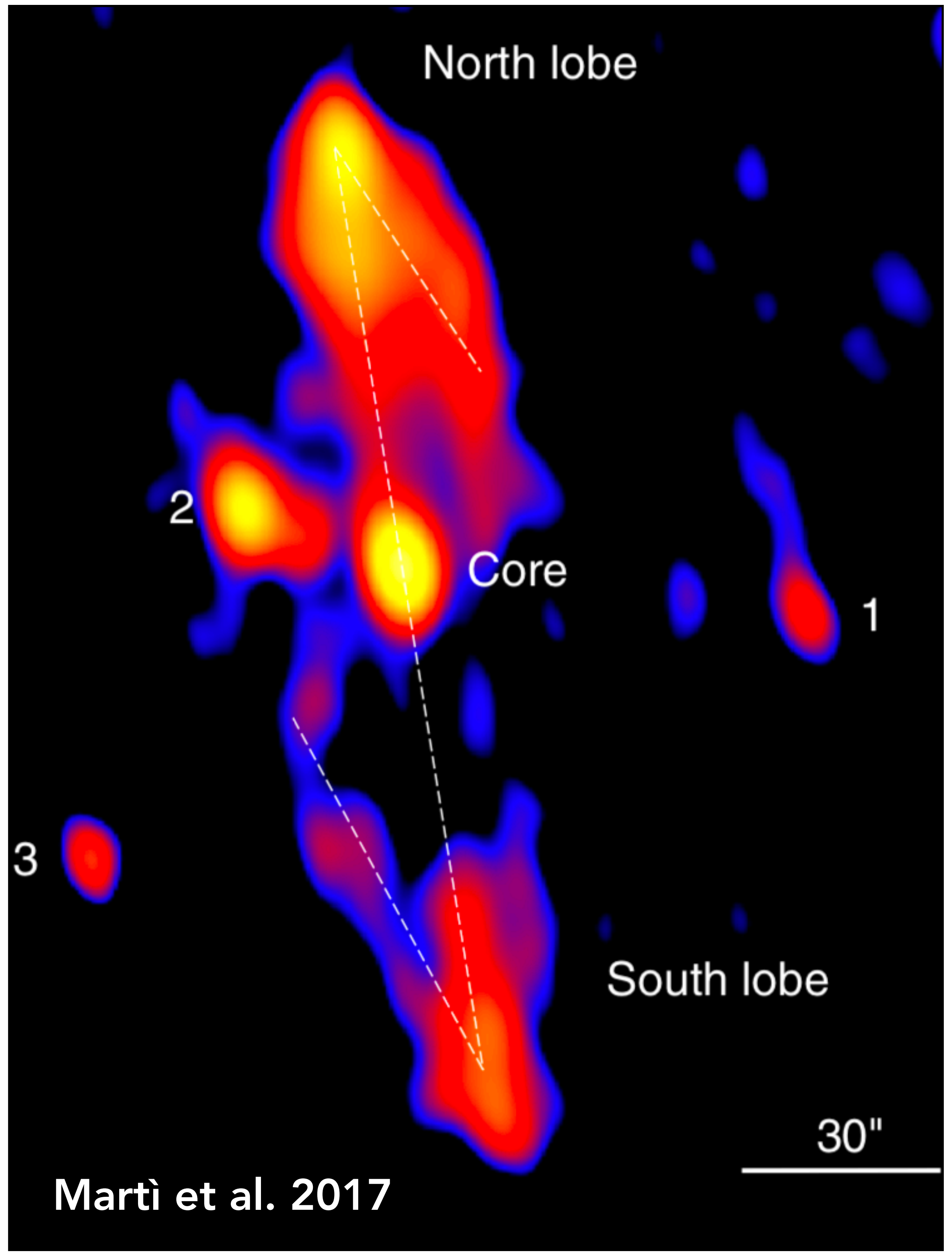
- Continuous and collimated jets
- Strong coupling between accretion and ejection
- Typical scale: ~1 AU

Discrete ejecta



- Bipolar plasma bubbles
- Apparent motion often superluminal
- Typical scale: ~10^4 AU

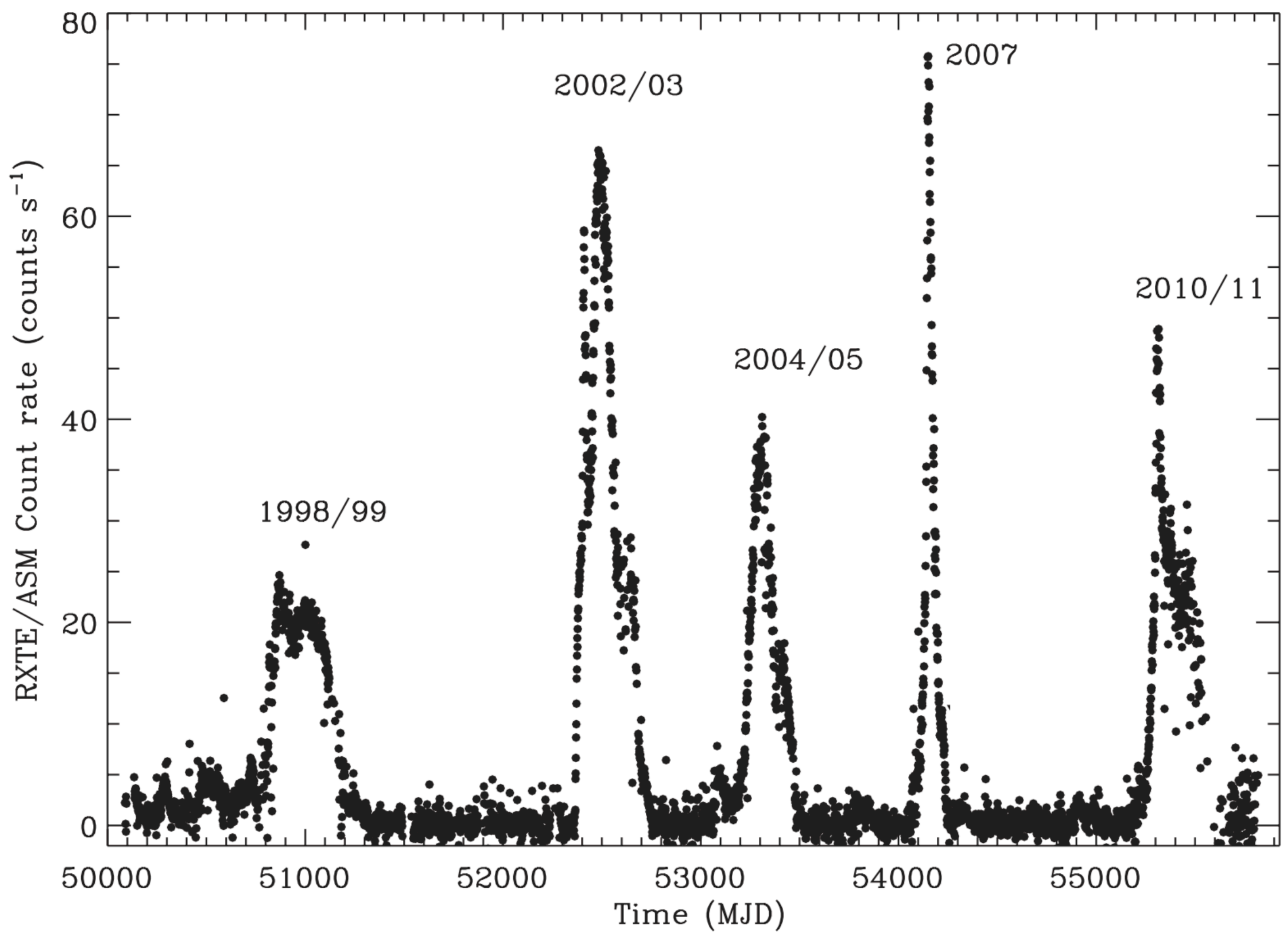
Large scale jets



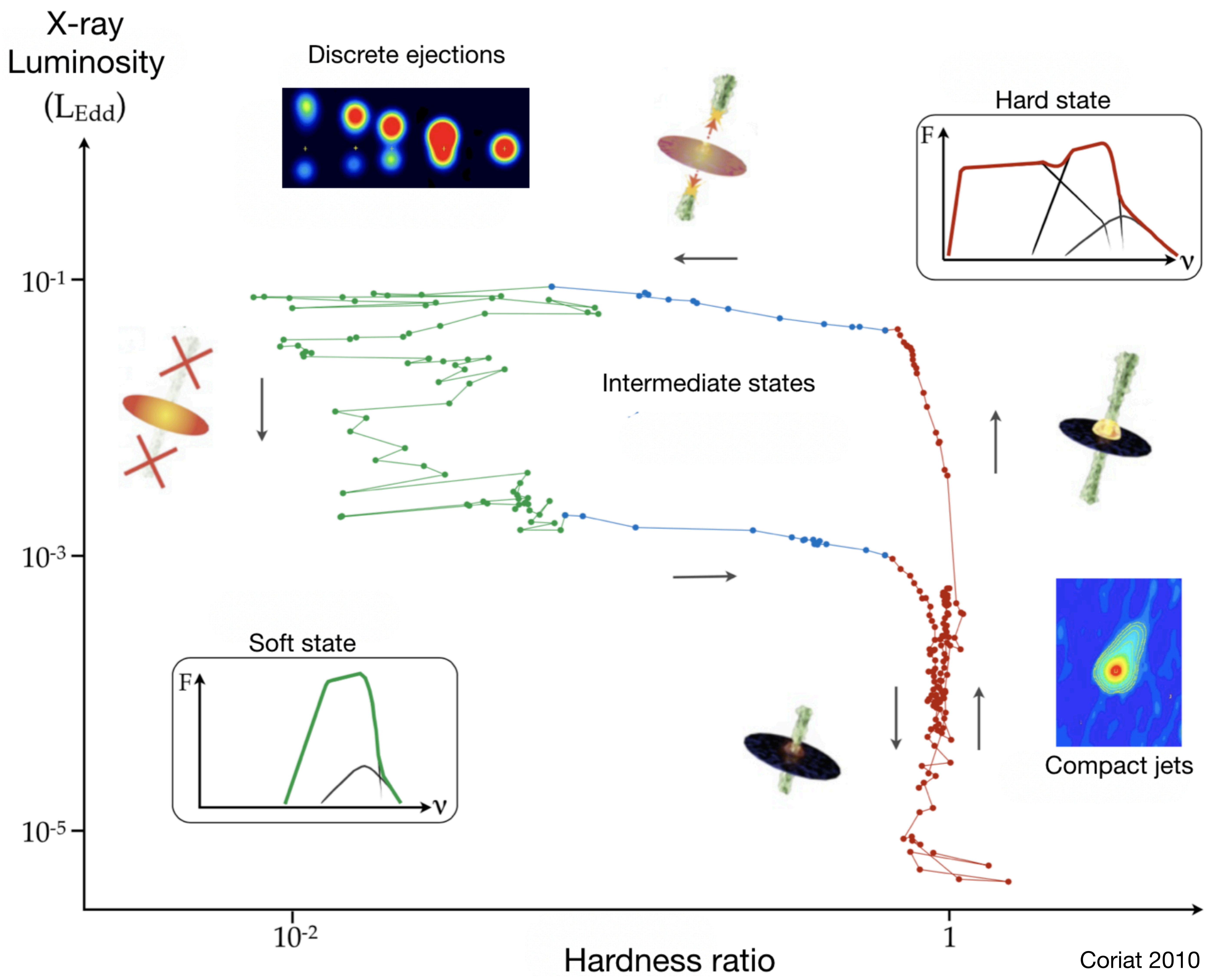
- Discrete ejecta detected up to parsec scales (~10^5 AU)
- Strong interaction with the surrounding environment
- Observed in a few sources

Life of a black hole X-ray binary

- Transient = object evolving on human timescales (minutes to years)
- Phases of quiescence and outburst
- X-ray spectral states: hard, soft, intermediate
- Presence/absence of compact jets, discrete ejection events



Corbel 2013



Coriat 2010

How to track discrete ejecta?

Need for:

- Detecting radio emission: radio-telescope
- High angular resolution: astronomical interferometer (or telescope array)

→ Radio-interferometers
(VLA, ATCA, MeerKAT,…)

Principle: sampling the Fourier transform of the sky with an array of antennas

Radio-interferometer

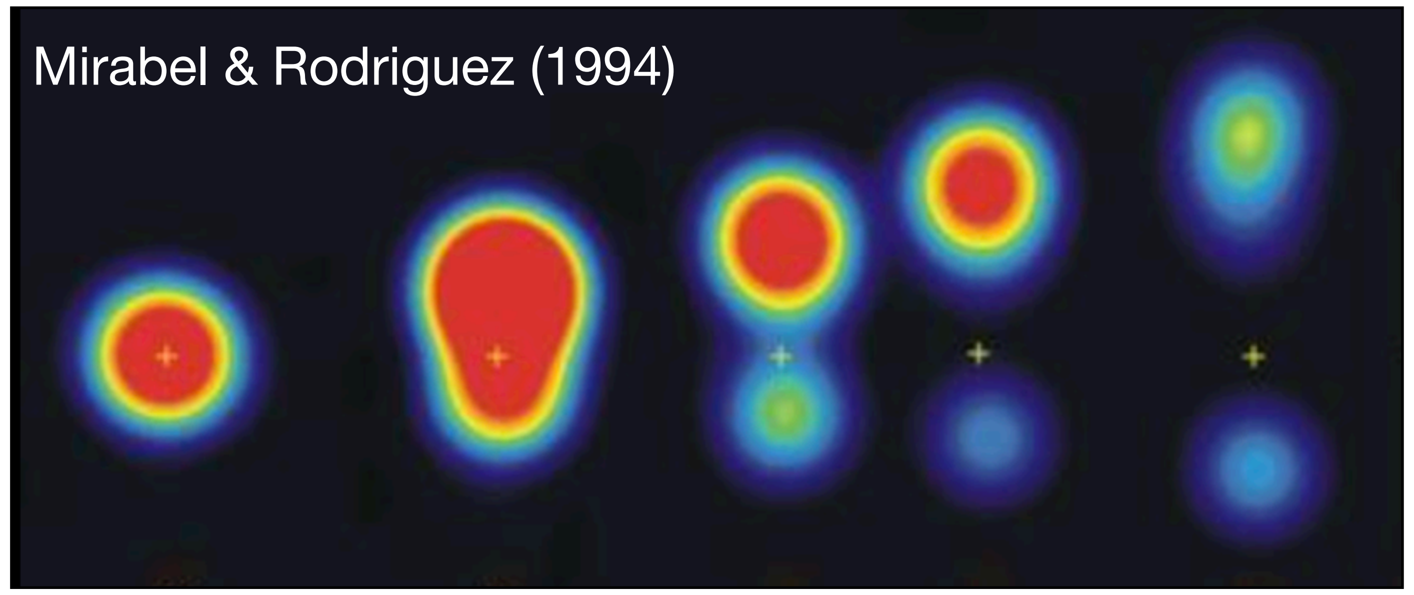
Angular resolution

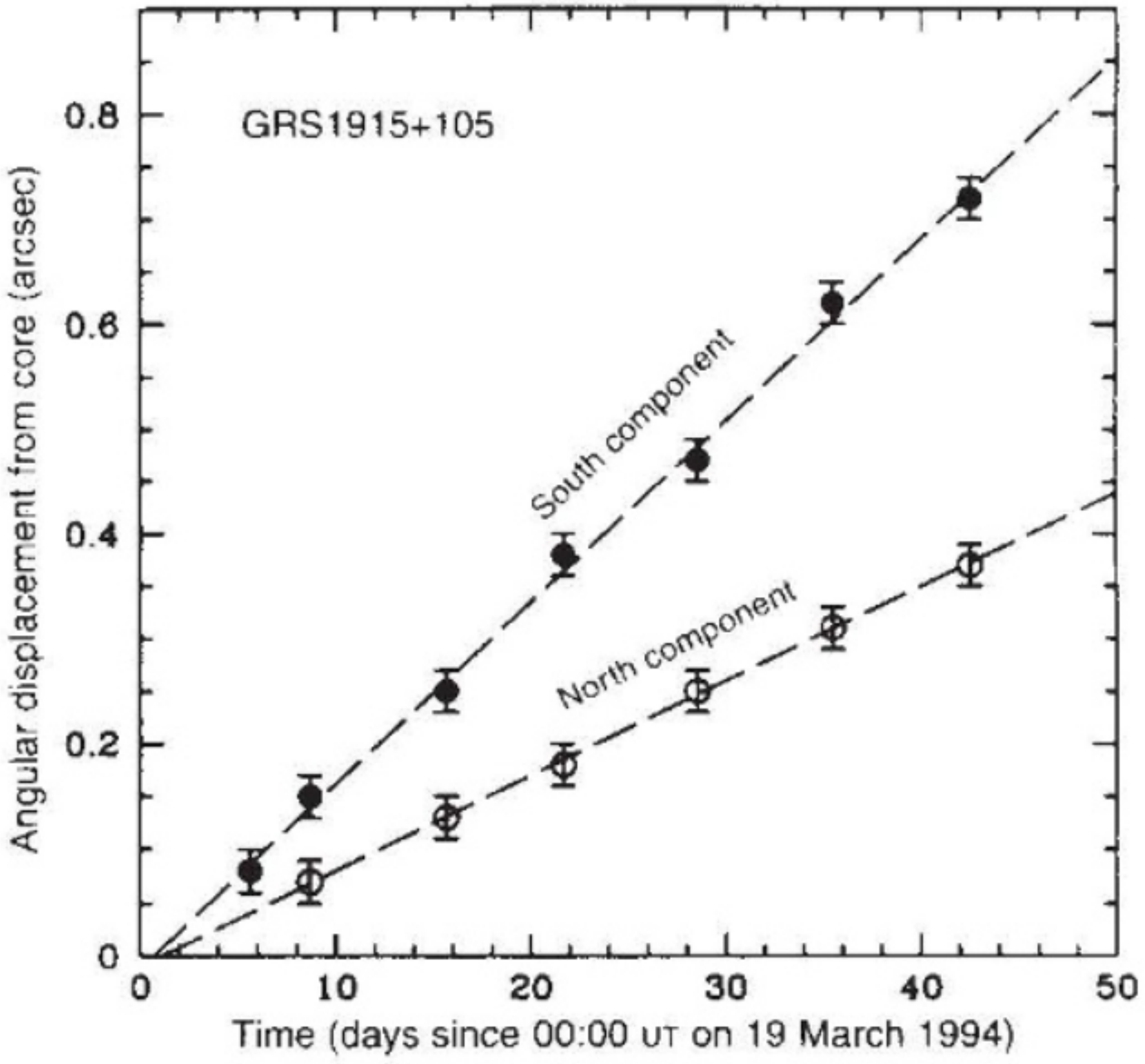
Single-dish telescope: $\theta = \lambda / \mathbf{D}$

Array of antennas: $\theta = \lambda / \mathbf{B}$

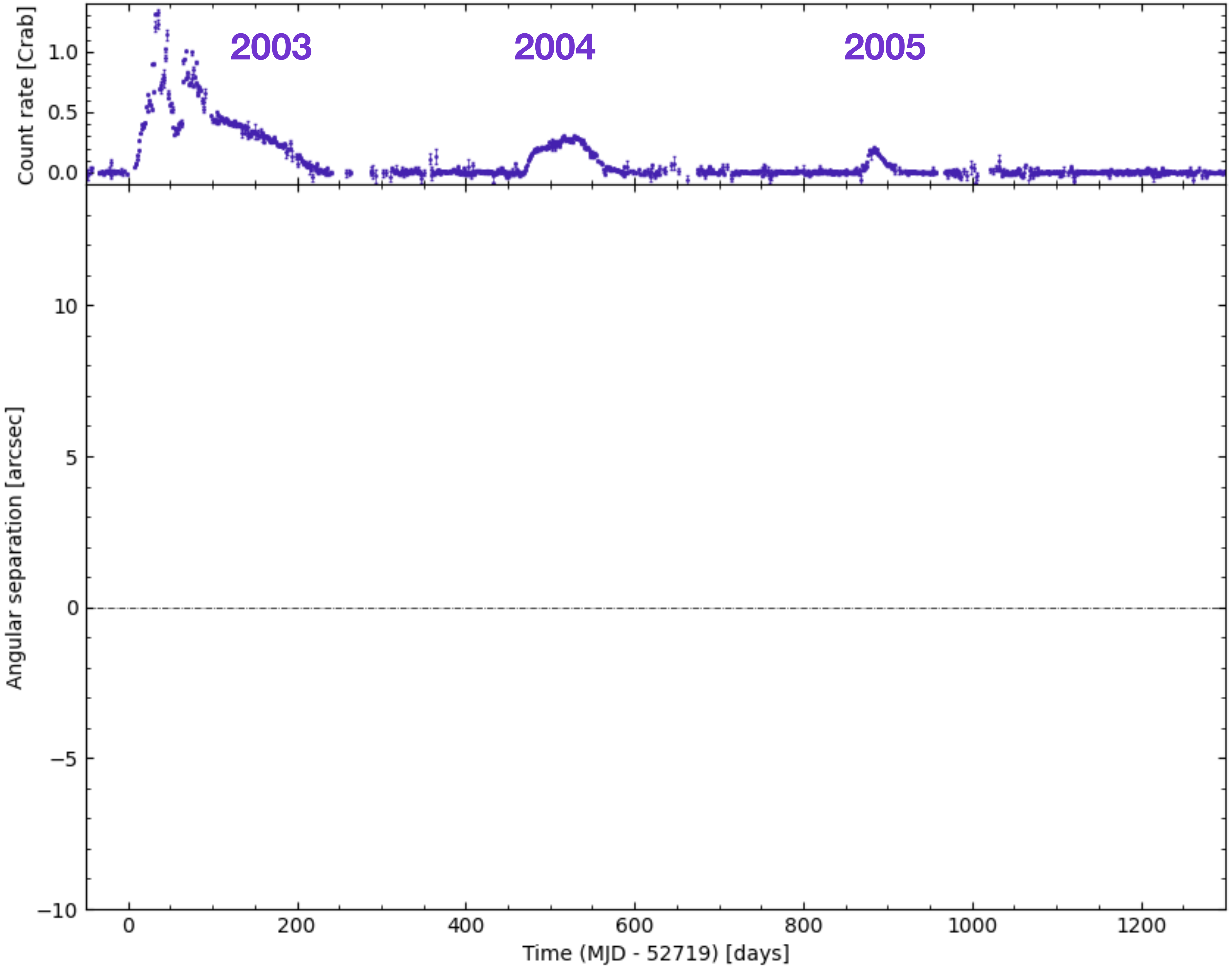
Jets of the XRB H1743-322

Typical example



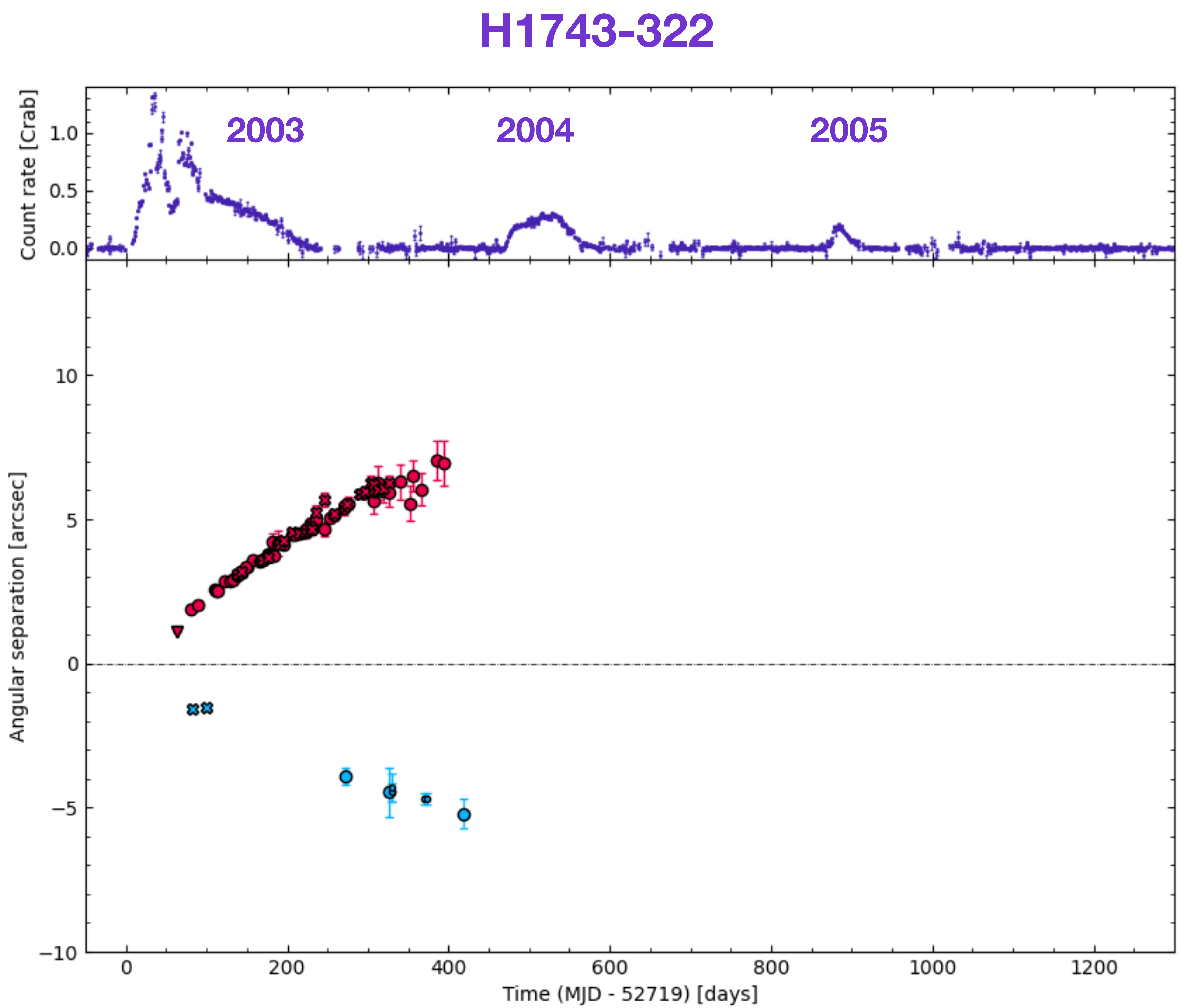


H1743-322



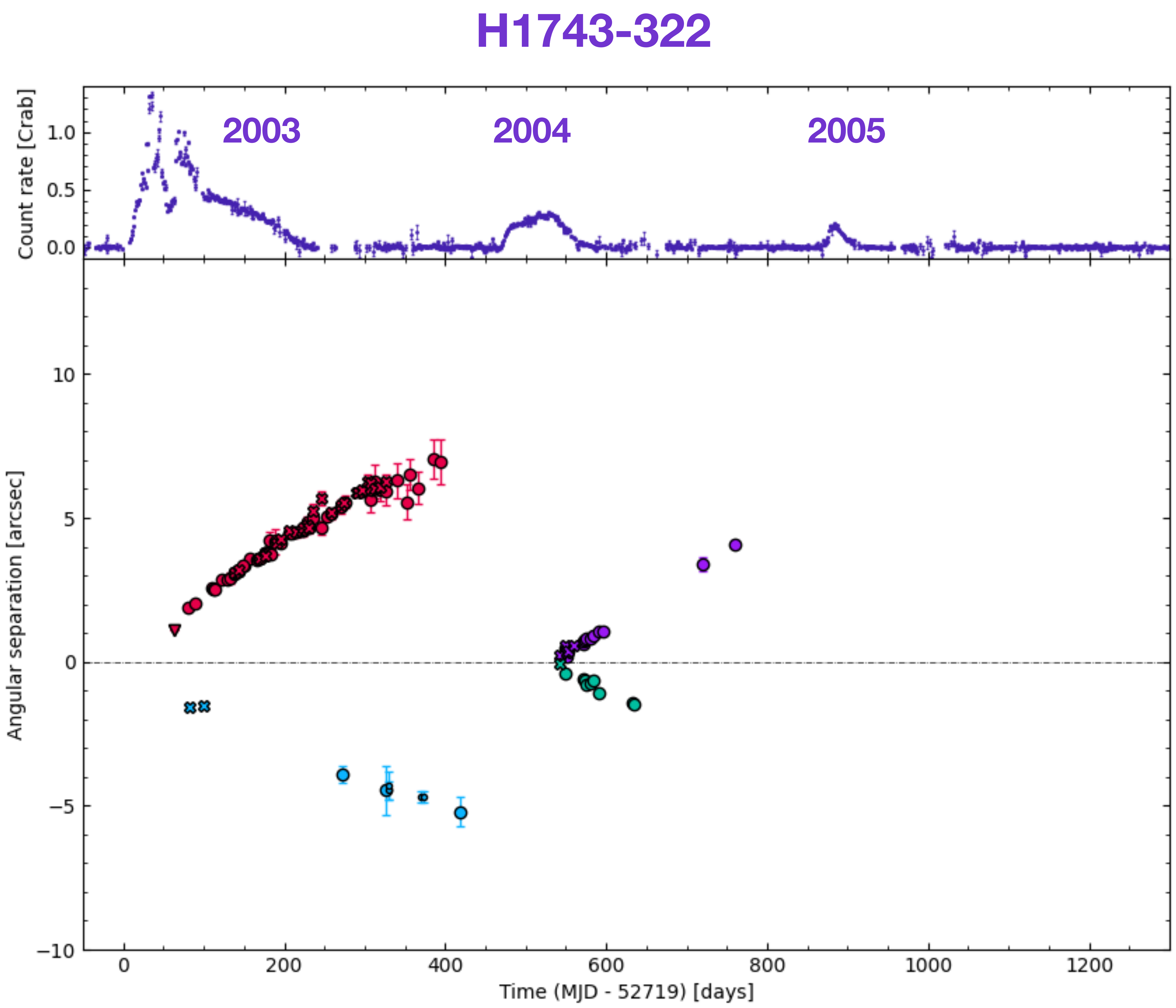
Jets of the XRB H1743-322

- 2003 outburst: eastern and western jets



Jets of the XRB H1743-322

- 2003 outburst: eastern and western jets
- 2004 outburst: eastern and western jets



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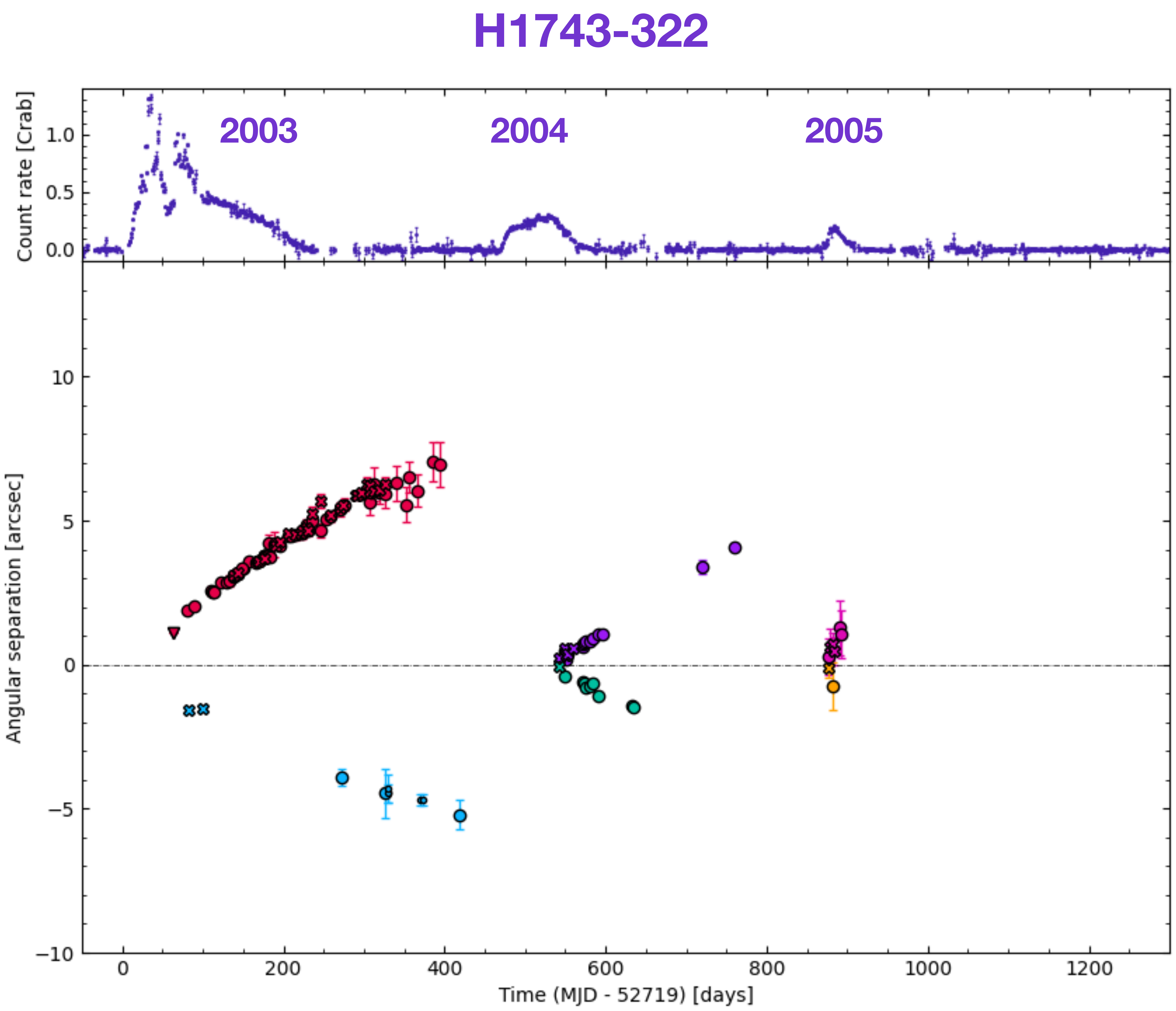

Jets of the XRB H1743-322

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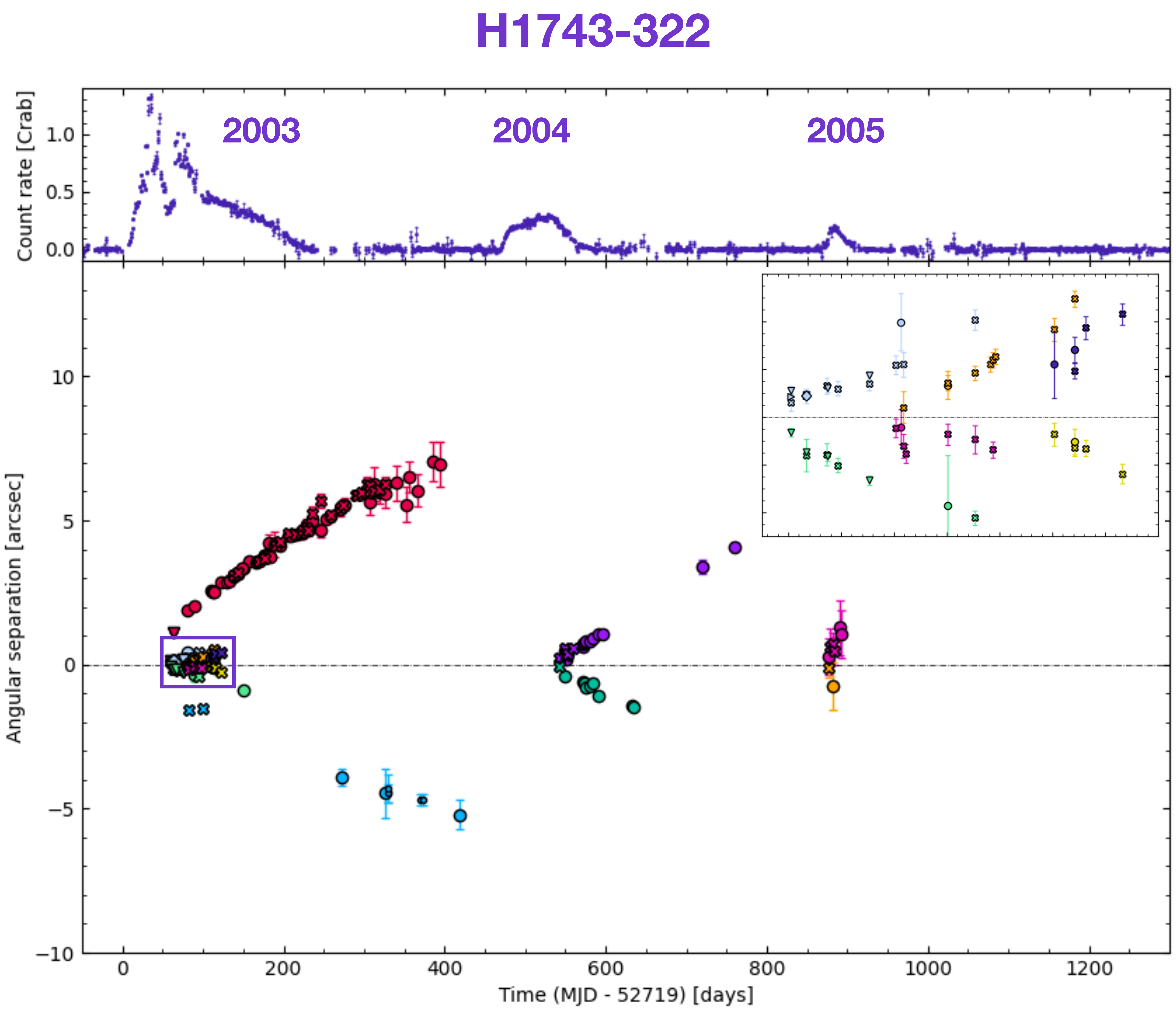
- 2003 outburst: micro-ejections



Jets of the XRB H1743-322

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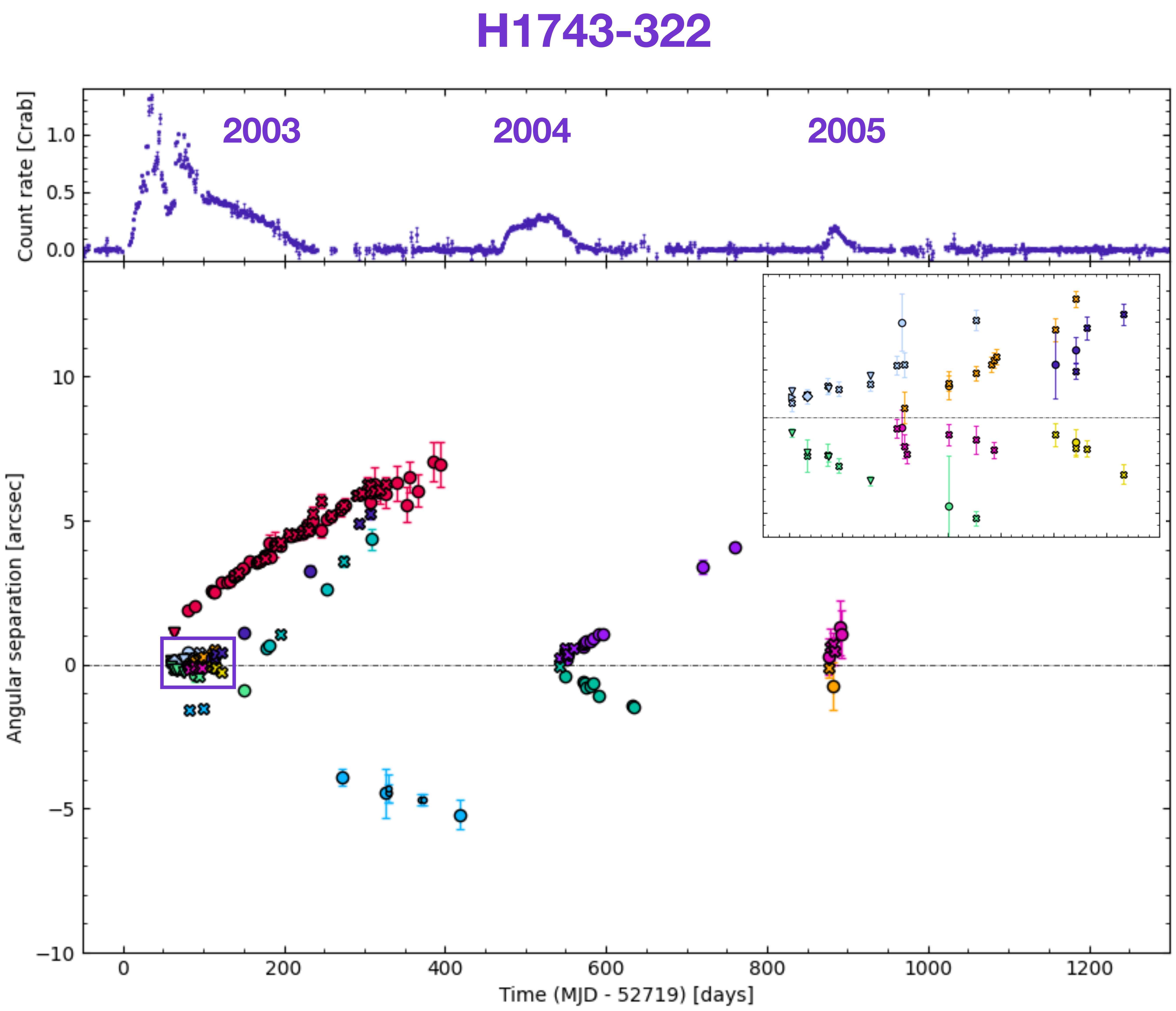
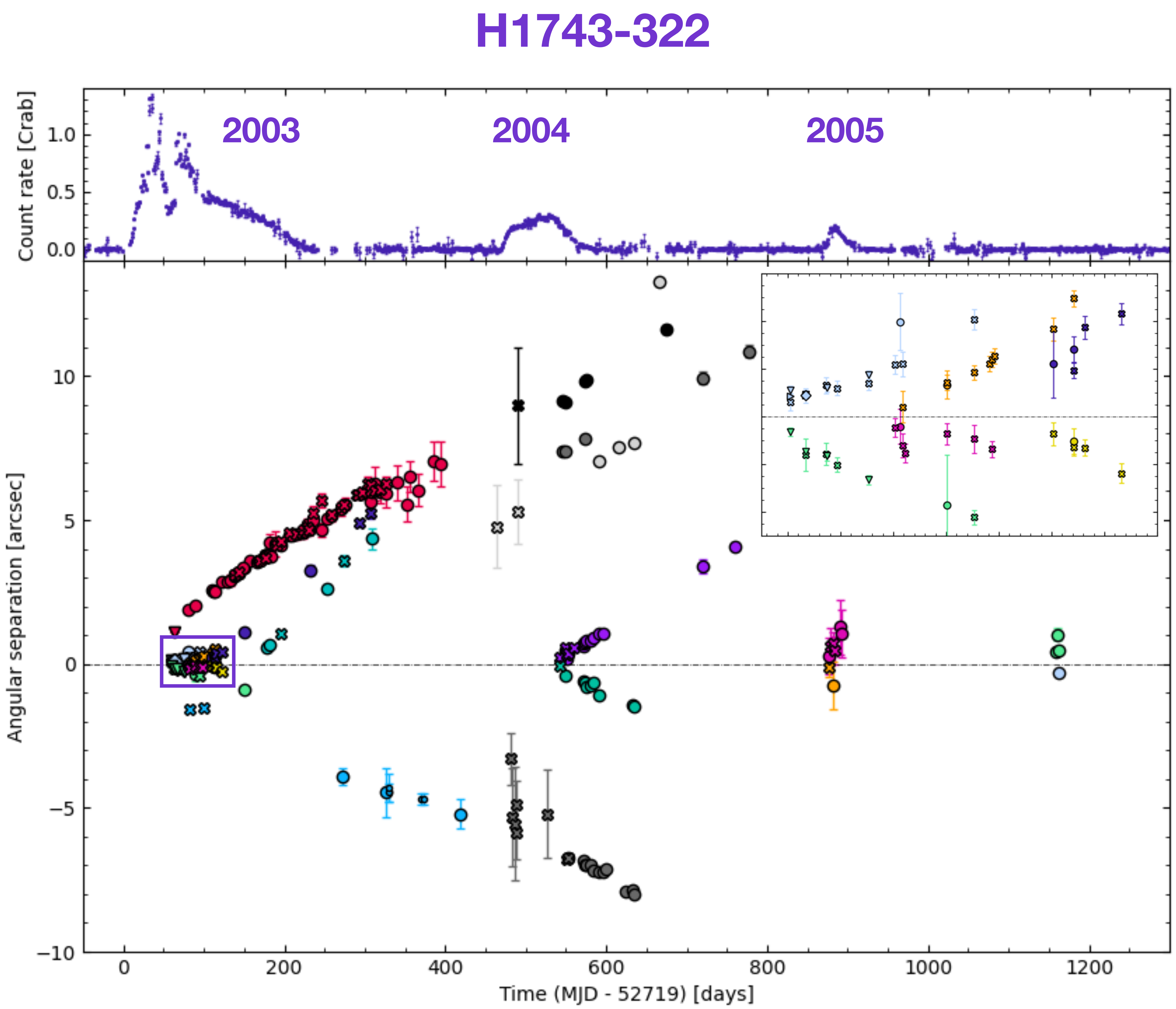
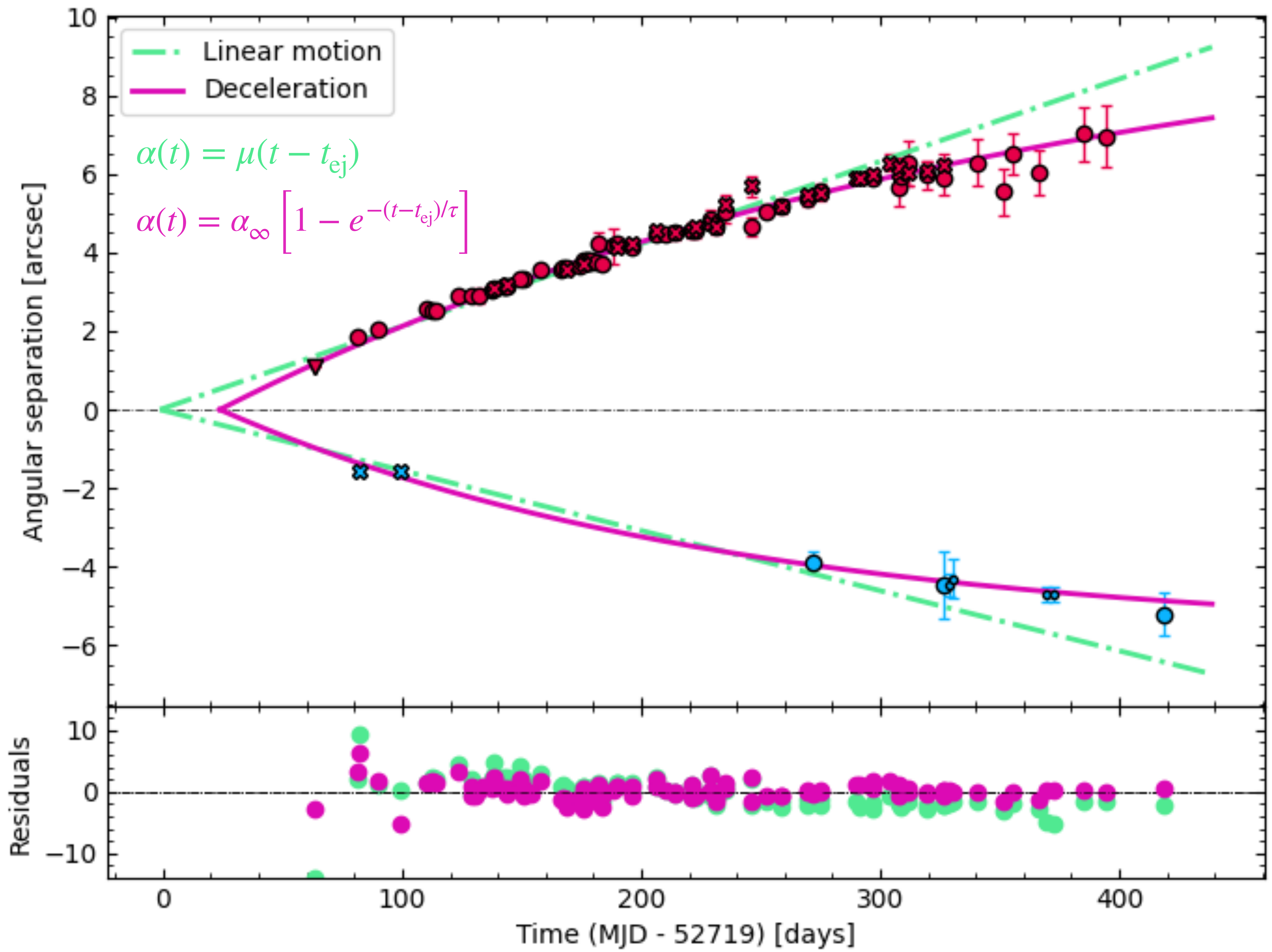


Jets of the XRB H1743-322

- 2003 outburst: eastern and western jets
- 2004 outburst: eastern and western jets
- 2005 outburst: eastern and western jets
- 2003 outburst: micro-ejections
- Additional moving ejecta



Constrained parameters



Interaction with the interstellar medium

- Deceleration
- Reactivation of the jets

Kinematics

If D in unknown: $\beta \geq 0.112$ $\theta \leq 83.6\,\mathrm{deg}$

$D \leq 7.4\ \mathrm{kpc}$

If $D = 7.0\ \mathrm{kpc}$, $\beta = 0.95$ $\theta = 83.2\,\mathrm{deg}$

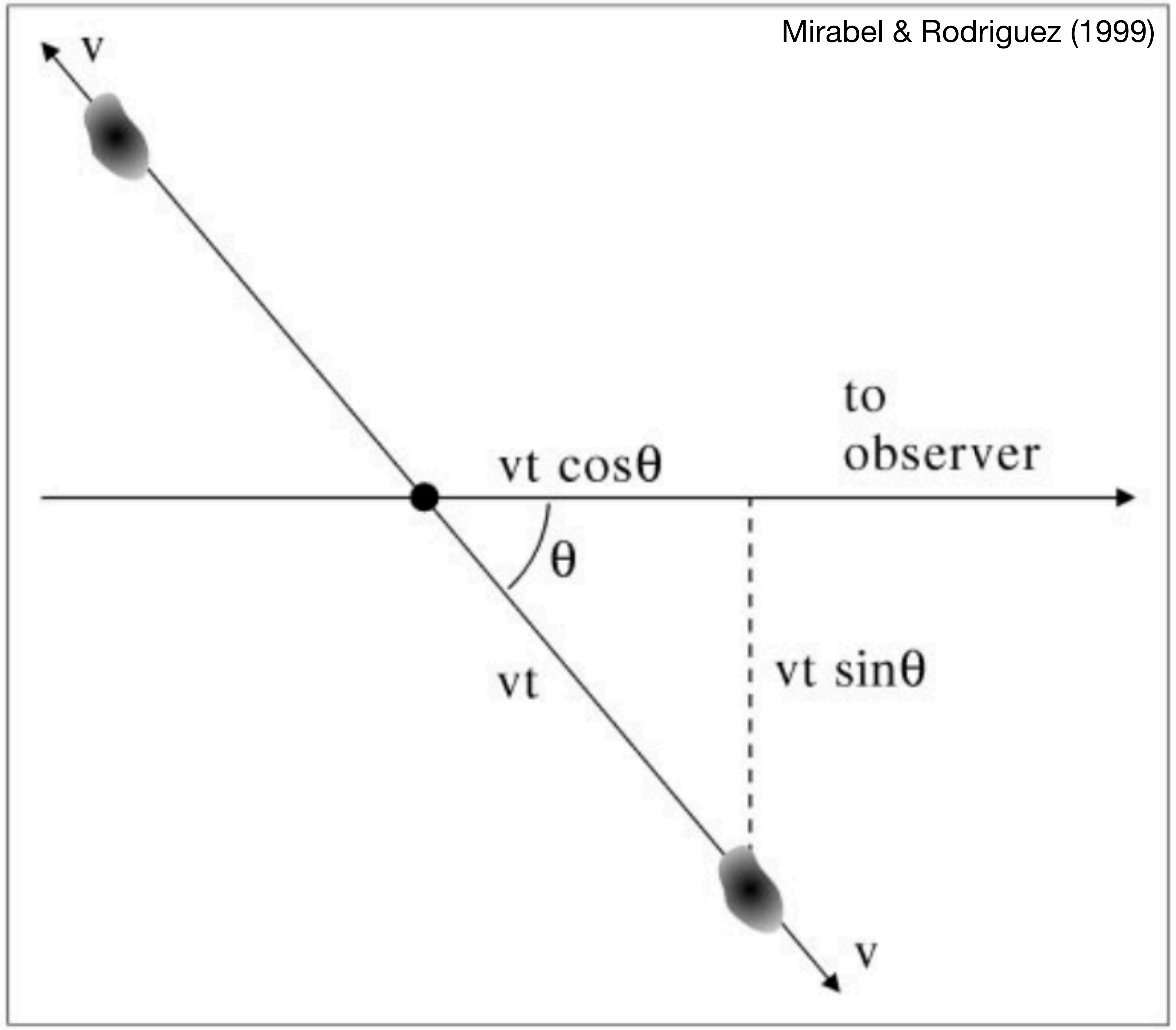
Radio emission of the jets

Minimum energy $E_{\mathrm{min}} \sim 2 \cdot 10^{43}\ \mathrm{erg}$

Thank you!

Backup slides

Speed, inclinaison and distance



Apparent speed

$$\beta_{r,a} = \frac{\beta \sin\theta}{1 \pm \beta\cos\theta}$$

$$\beta\cos\theta = \frac{\mu_a - \mu_r}{\mu_a + \mu_r}$$

$$D = \frac{c\tan\theta}{2}\frac{\mu_a - \mu_r}{\mu_a \mu_r}$$

Degeneracy
between β et θ
if D is unknown

Fit of the proper motion (deceleration model)

$\mu_a = 26.3 \pm 5.6$ mas/day $\mu_r = 21.0 \pm 2.4$ mas/day

$$\beta\cos\theta = 0.112 \pm 0.027$$

Corbel et al. (2005)
$\beta\cos\theta = 0.23 \pm 0.05$

Without knowledge on the distance:

$\beta \geq 0.112$ $\theta \leq 83.6$ deg $D \leq 7.4$ kpc

If $D = 7.0$ kpc

$\beta = 0.95$ $(\gamma = 3.2)$ $\theta = 83.2$ deg

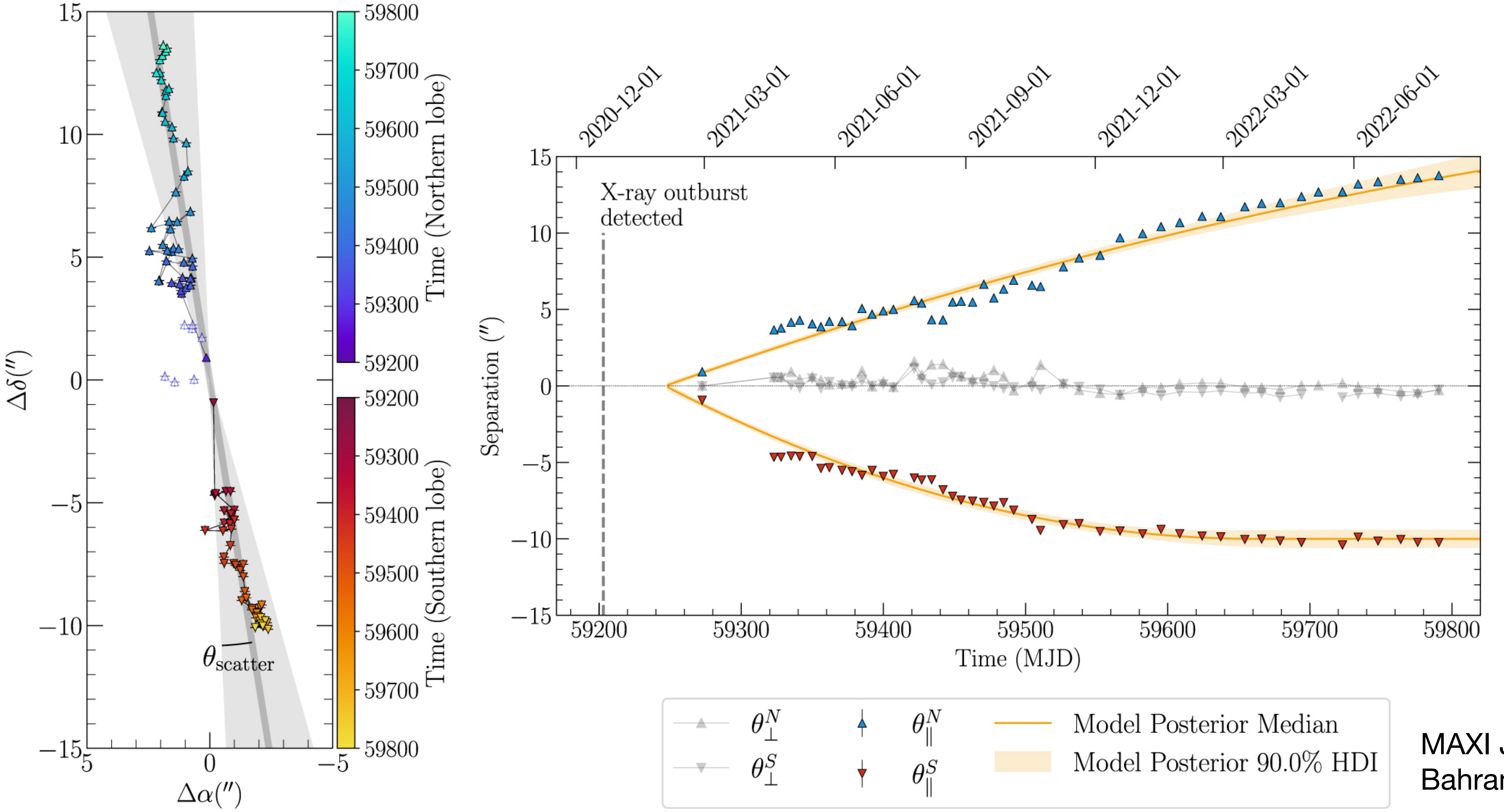
Big questions

1) **Powering mechanism**? **Composition** of the jets: leptonic? baryonic?

2) Contrains on the **physical parameters** of the jets? **Energetic content**?

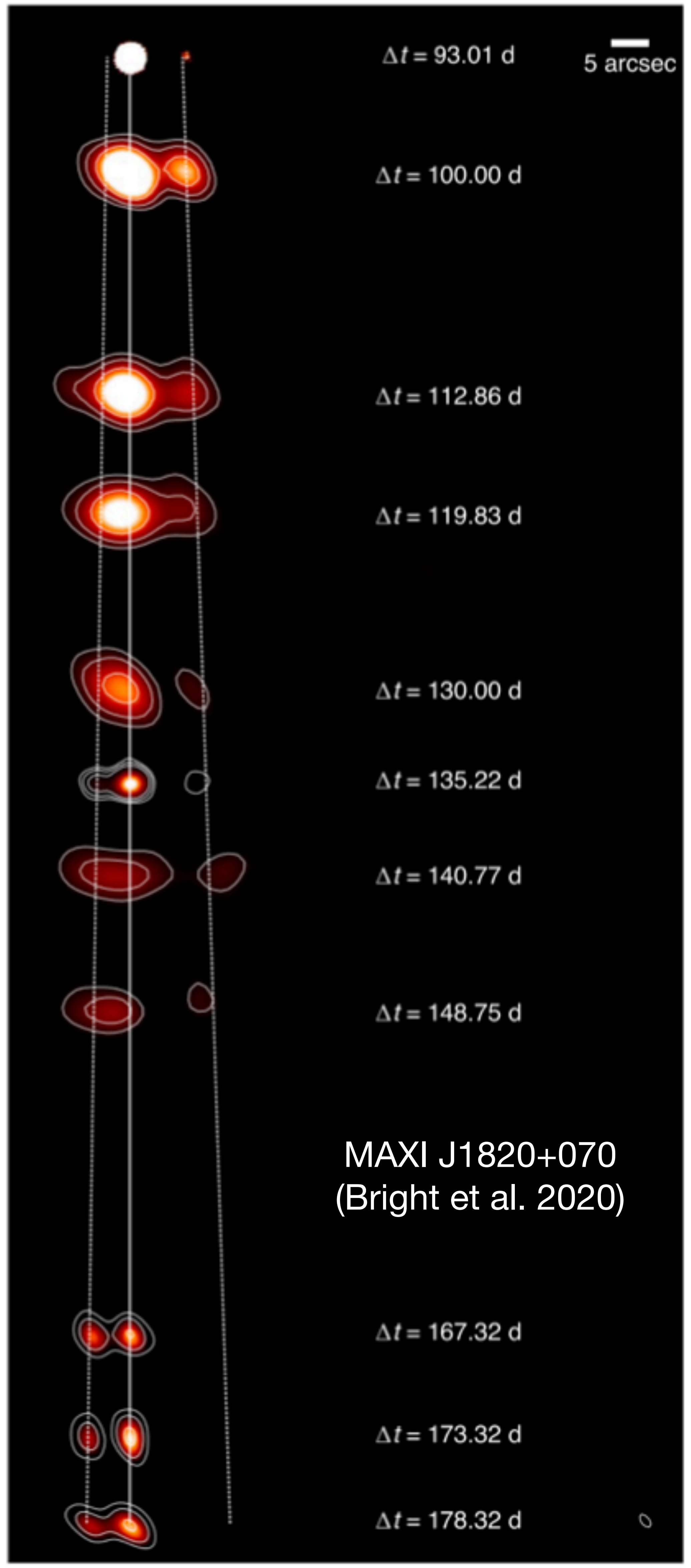
3) **Observational signatures** announcing discrete ejections? **Causality** in the disk?

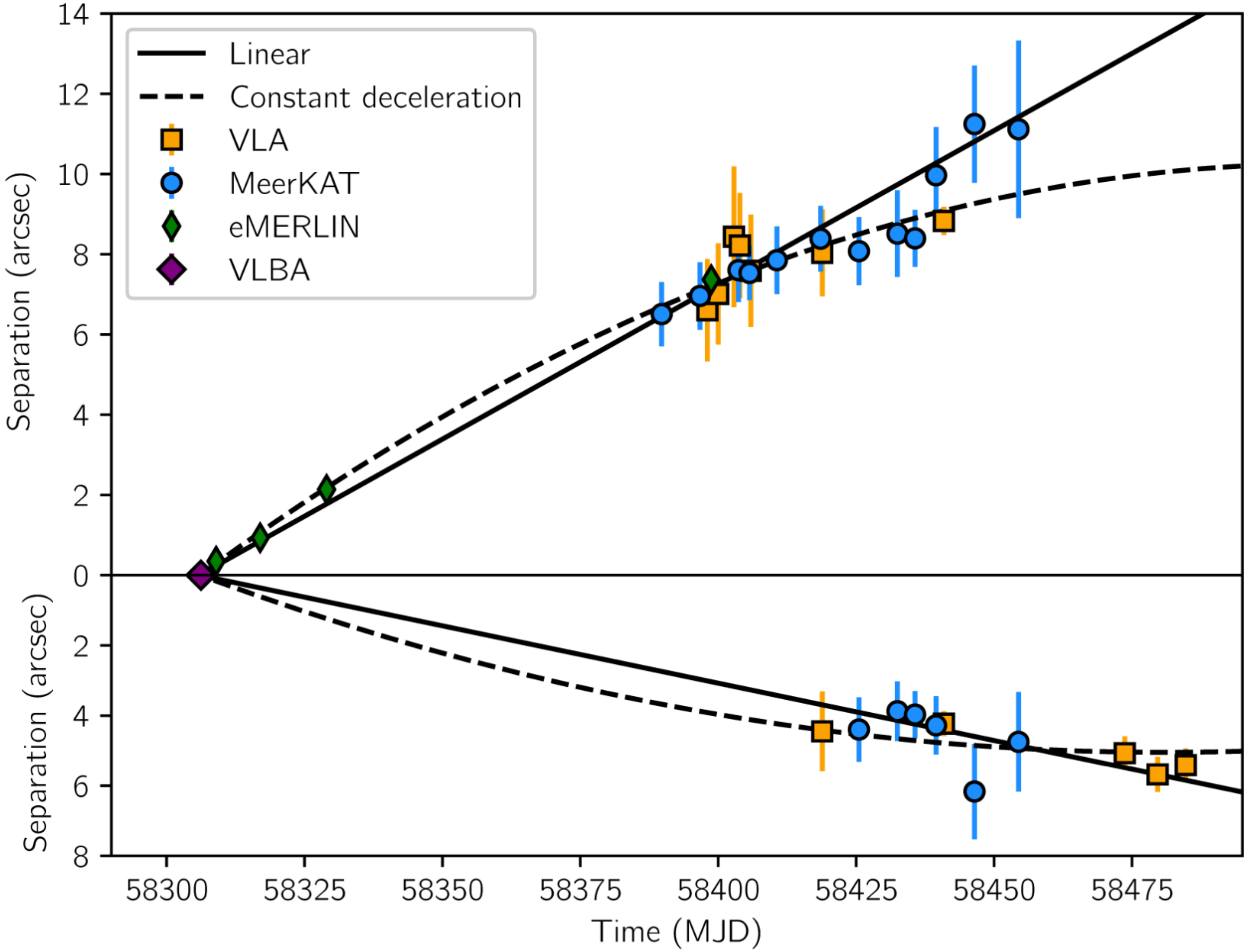
4) **Jet-ISM interaction**?



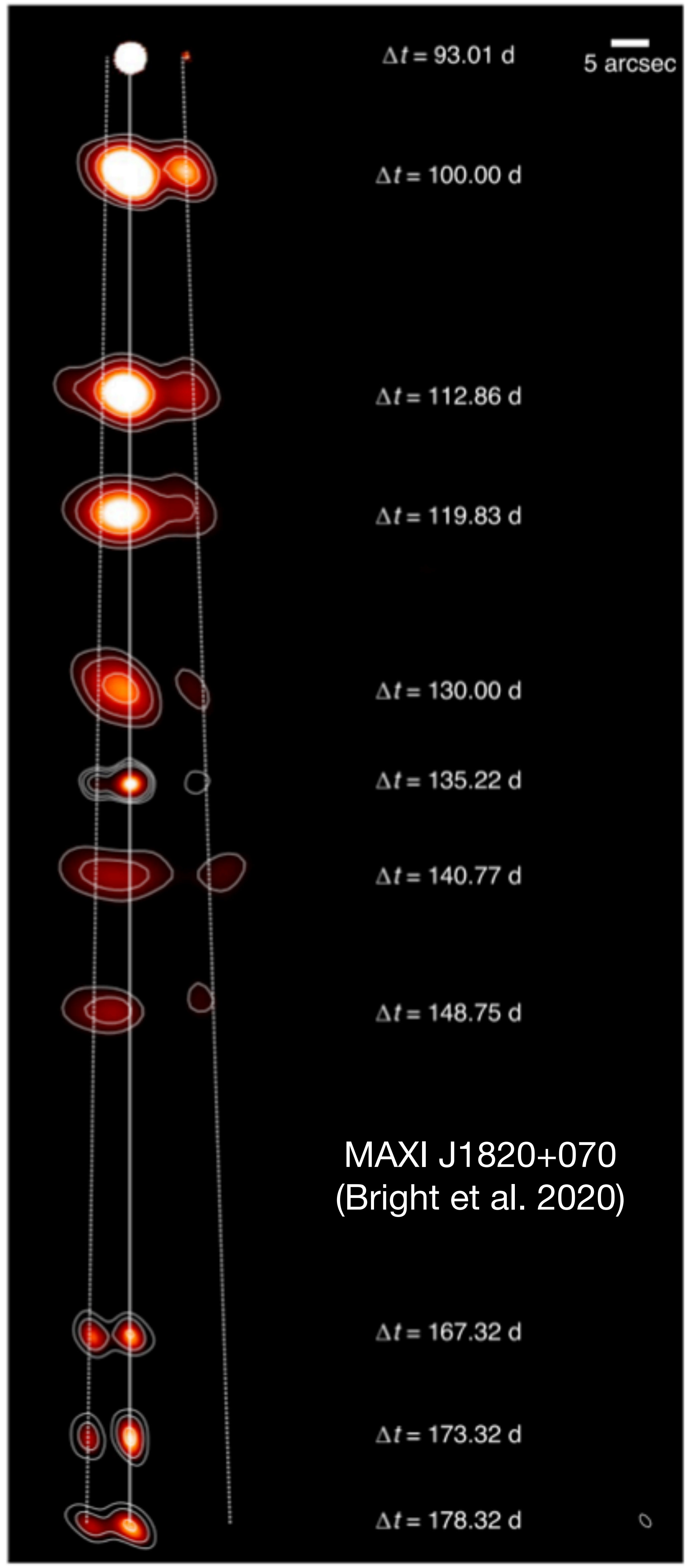
MAXI J1848-015
Bahramian et al. 2023

Large-scale jets and interaction with the ISM

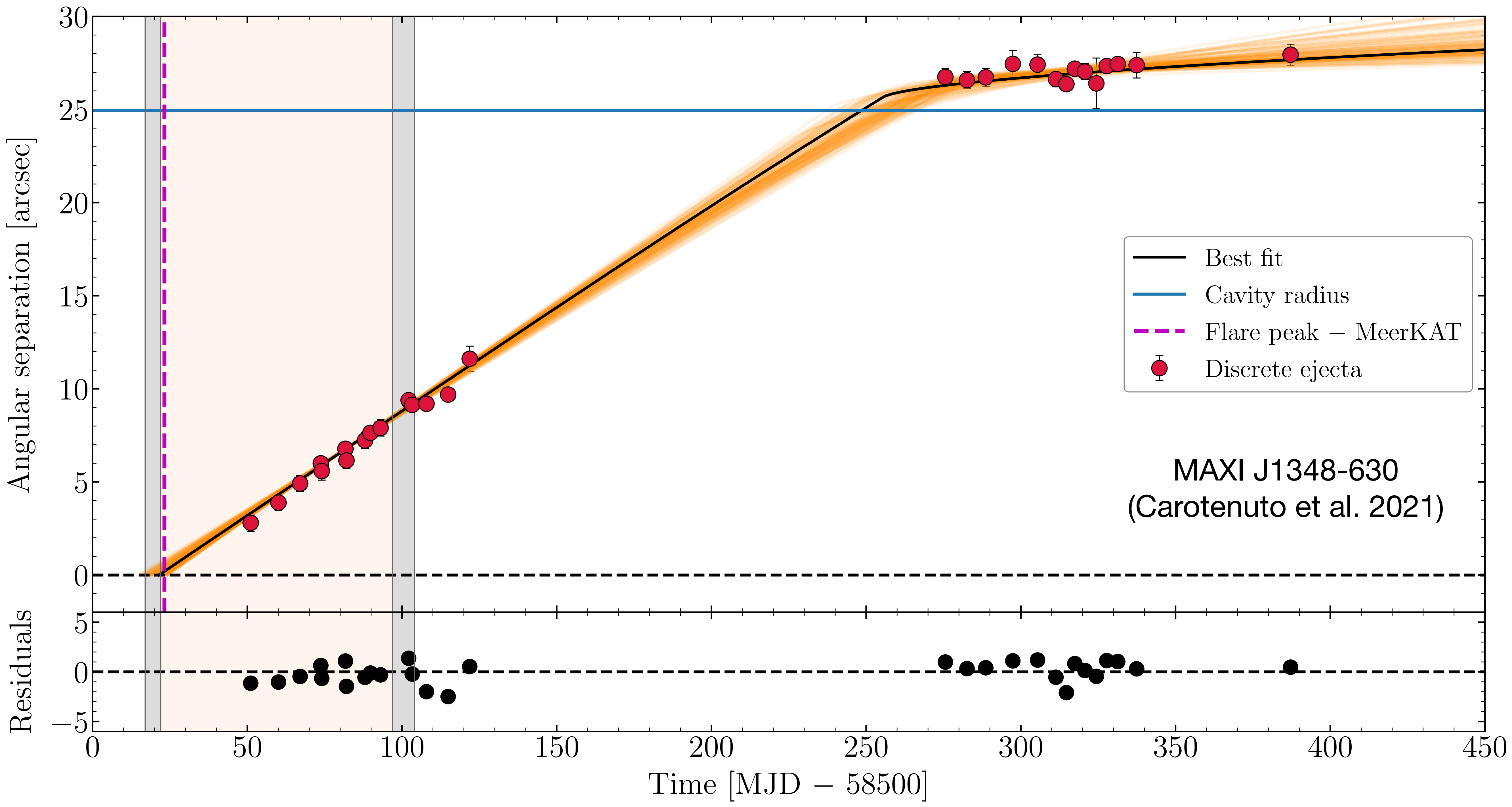




Large-scale jets and interaction with the ISM



- MeerKAT (SKA-mid precursor) observations suggest the omnipresence of the large-scale jets.
- Detection up to parsec scales.
- Interaction with the interstellar medium: reactivation of the jets + deceleration
- Wideband synchrotron emission by high energy (up to TeV) particles
- Properties of the jets and the environment inferred from the kinematics



Radio interferometry

The Very Large Array (VLA)

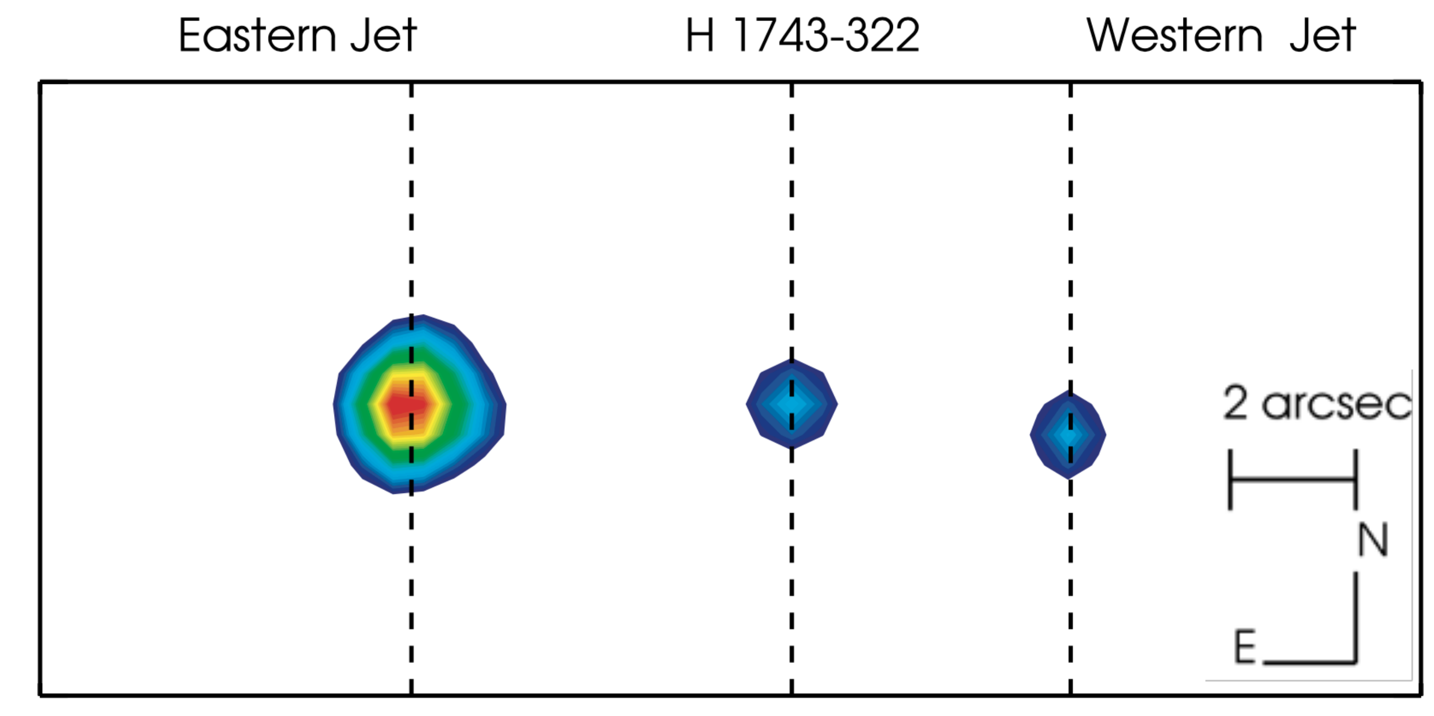
Principle: sampling the Fourier transform of the sky with an array of antennas

Reduction and analysis of radio data:

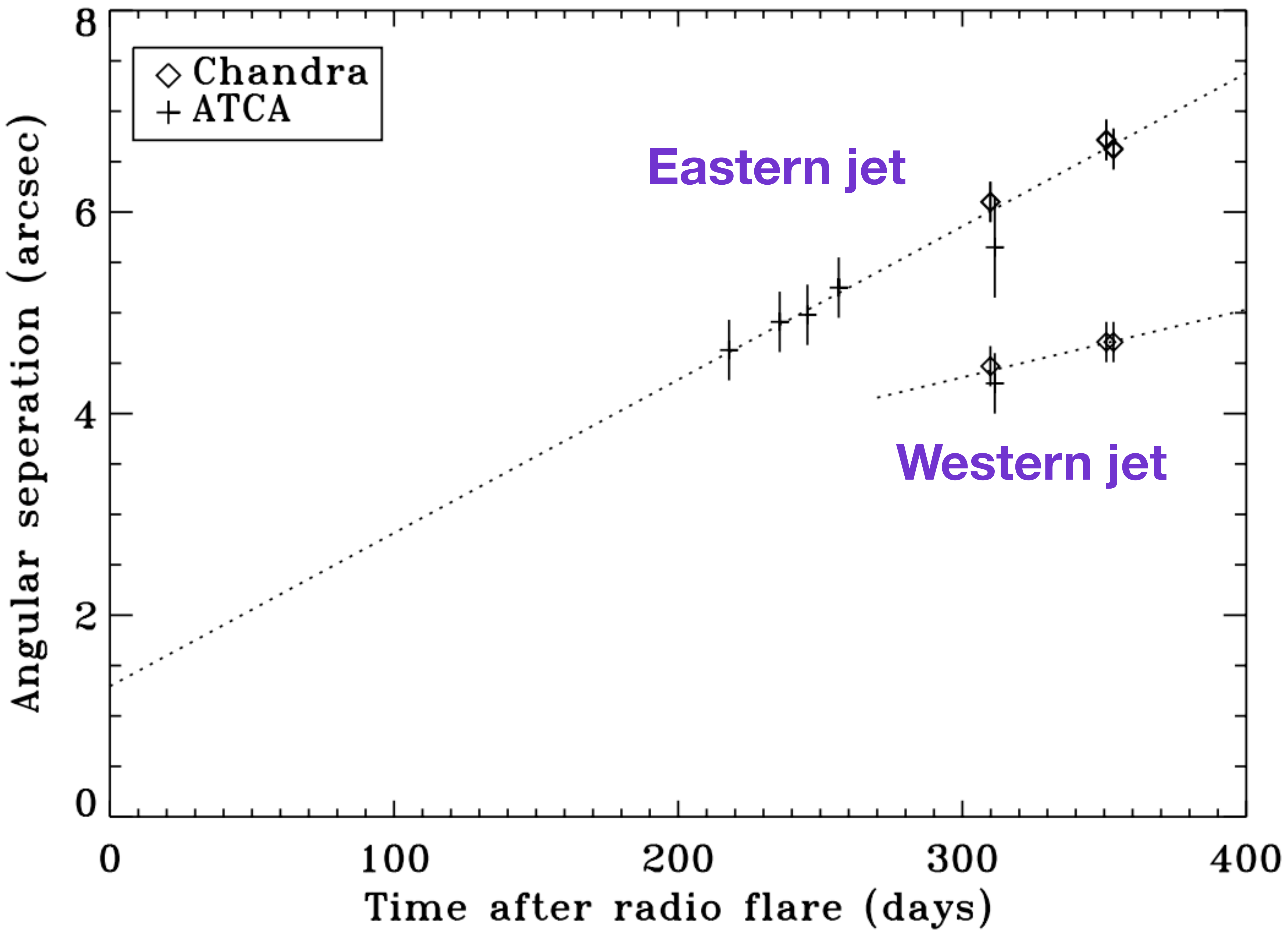
- Flagging: excluding aberrant and/or corrupted data
- Calibration of the visibilities
- Imaging: reconstruction via inverse Fourier transform
- Deconvolution: « cleaning » of the image by iterative subtraction of the PSF
- Fit of the point sources by bidimensional gaussian functions

The microquasar H1743-322

- X-ray binary discovered in 1977, localized towards the galactic bulge
- First detection of the discrete ejecta by Corbel et al. during the 2003 outburst
- Since then, regular outbursts (2004, 2005, 2008,…, 2018)



Corbel et al. (2005)



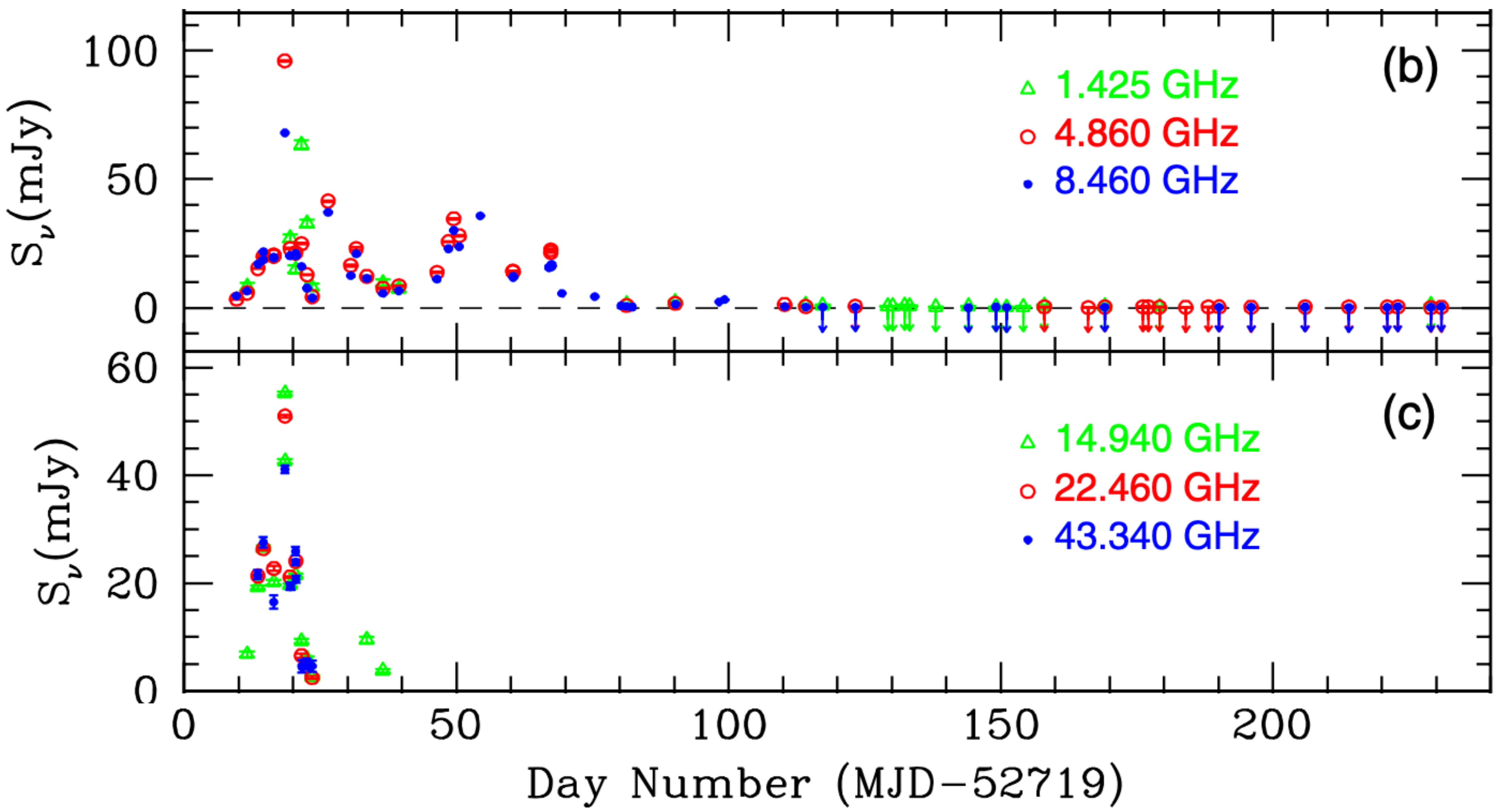
Corbel et al. (2005)

- Extremely dense and comprehensive VLA dataset: 200+ multifrequency observations (up to 6 bands)

Energy of the transient jets

- Estimate of the minimum energy of the jets using the radio flare
- Hypothesis: equipartition between magnetic energy and energy of the electrons in the plasma bubble

$$E_{\min} = 3 \cdot 10^{33}\, \eta^{4/7} \left(\frac{\Delta t}{\mathrm{s}}\right)^{9/7} \left(\frac{\nu}{\mathrm{GHz}}\right)^{2/7} \left(\frac{S_\nu}{\mathrm{mJy}}\right)^{4/7} \left(\frac{D}{\mathrm{kpc}}\right)^{8/7} \mathrm{erg}$$



McClintock et al. (2009)

- Peak flux density during the flare $S_\nu = 93.37 \pm 0.28$ mJy $(\nu = 4.860$ GHz$)$
- Distance of the microquasar $D = 7$ kpc
- Ejection timescale (rise time of the flare) $\Delta t \simeq 10$ jours

$\rightarrow$

$$E_{\min} \sim 2 \cdot 10^{43} \text{ erg}$$

$$P_{\min} \sim 3 \cdot 10^{37} \text{ erg/s}$$