An extensive analysis of the sub-parsec region of 3C84

Max-Planck-Institut für Radioastronomie

IMPRS astronomy & astrophysics Bonn and Cologne

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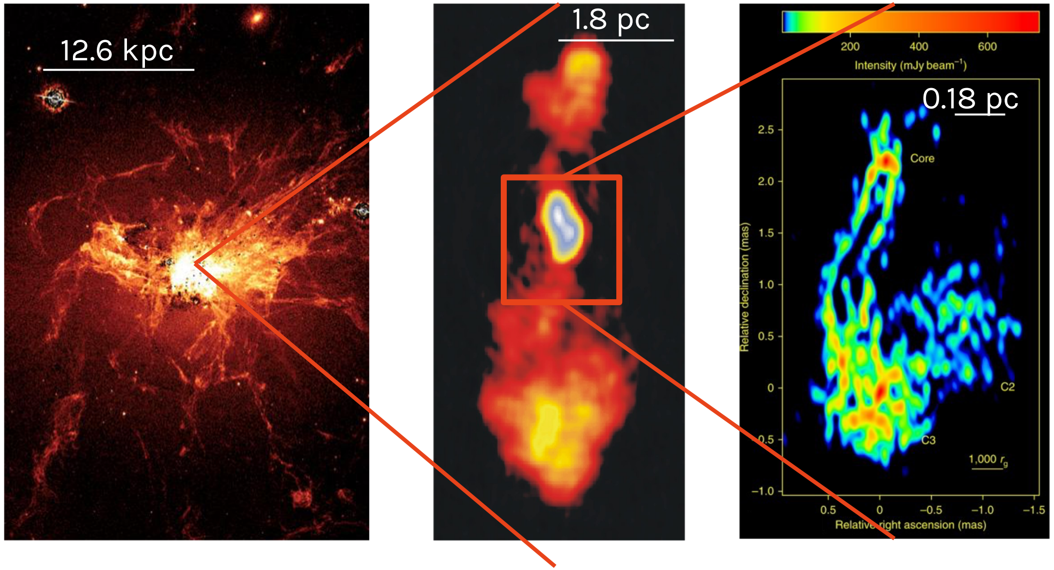
3C84's prominent characteristics

- 3 major brightening events/flares: 1959, 1990s, 2003-2005
- Northern counter-jet detection:
  - 1994: 8, 22 GHz (Walker+94, Vermeulen+94)
  - 2017: 43 GHz (Fujita+17)
  - 2020: 86 GHz (Wajima+20)
- Free-free absorption for accretion disk; obscures counter-jet (Vermeulen+94, Walker+94, Kim+19)
- Ridge brightening before 2000 (Walker00), limb brightening after 2010 at 22, 43 GHz (Nagai+14)
- 0.1c near jet base, 0.3c-0.5c acceleration downstream (Vermeulen+94, Krichbaum+92)
- Jet follows asymmetric, S-shaped path, curved trajectories (Krichbaum+92, Dhawan+98)
- Inverted sp. i. in counter-jet, flat spectrum in core, steep spectrum downstream (Walker+94)
- C. P. up to 3% in core (Homan+04), L. P. 2% at 86 GHz, increase with ν (Kim+19)
- High energy γ-ray emission, correlation with radio lacking (Abdo+09, Nagai+12, Nagai+14)

Overview of 3C84



HST (red filter) + HI line
Fabian+2008

22 GHz ground-based
Walker+2000

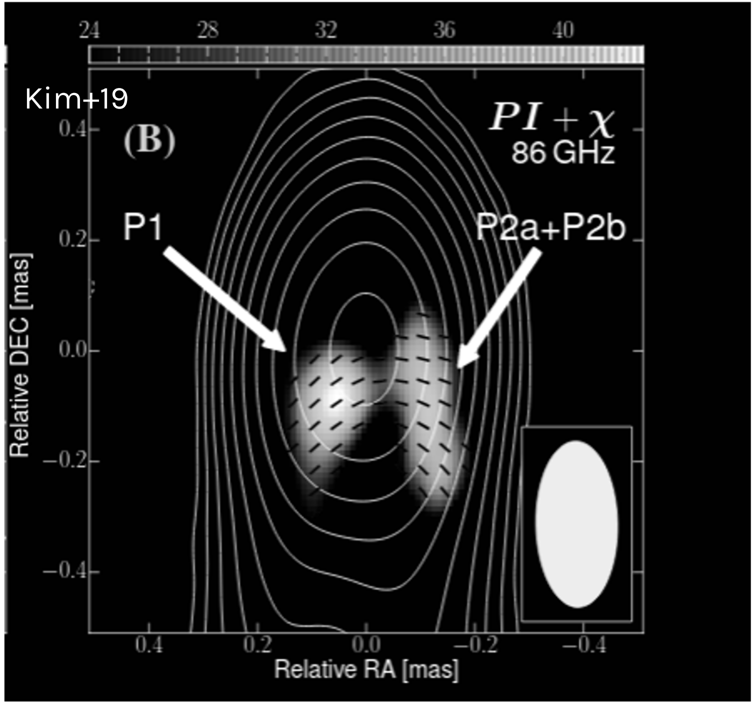
22 GHz from space
Giovannini+2018

- NGC1275, central galaxy of Perseus cluster
- Elliptical, Seyfert 1.5 / FR I, peculiar
- $M_{BH} \leq 2 \times 10^9 M_o$

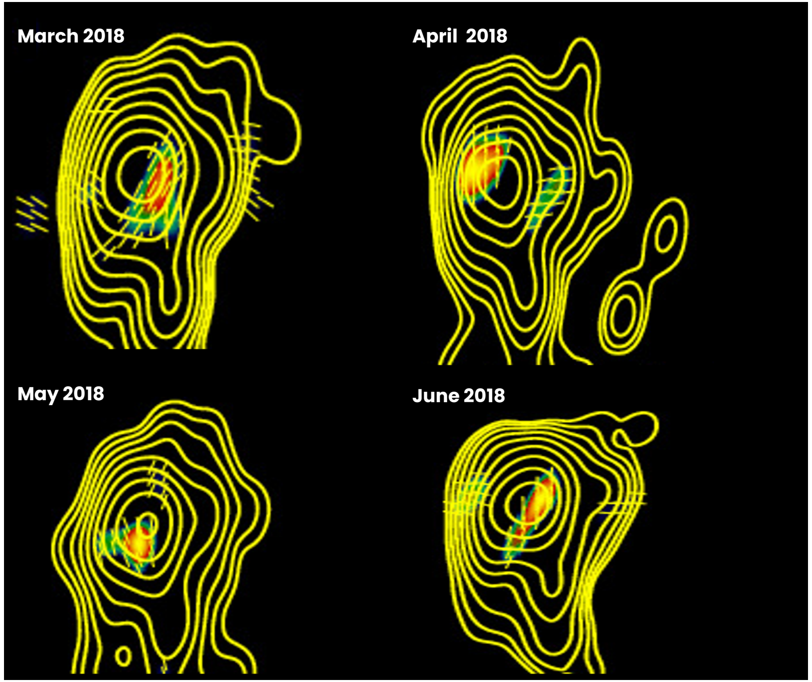
RadioAstron revealed:

- Core elongation ⊥ to the bulk jet flow
- Limb brightening

3C84 polarisation



Limb brightening continues into sub-mas region

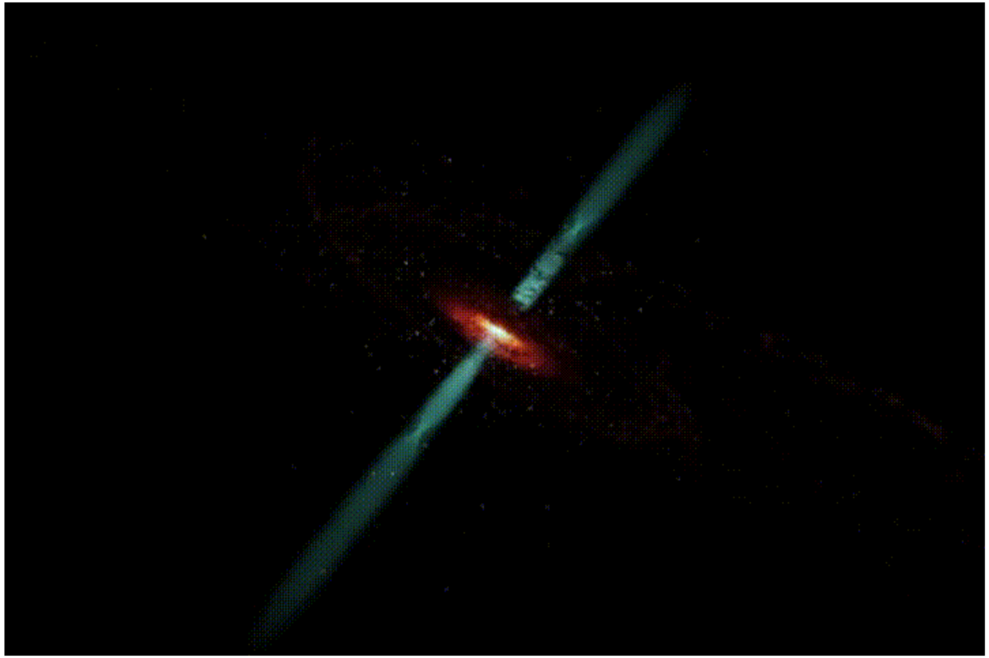


Pol. Images of 3C84 at 43 GHz (BU, Jorstad+17)

Highly variable with time, linear polarisation

Motivation & Jet Basics

- **Origin of E-W elongation?**
  - Broad jet base
  - Jet bending
  - Stationary (recollimation shock)



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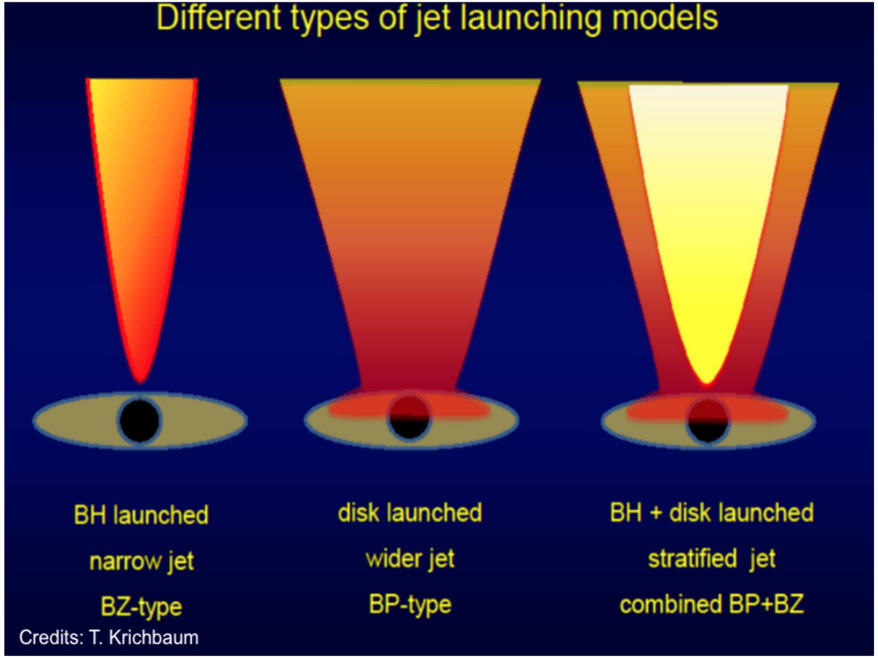
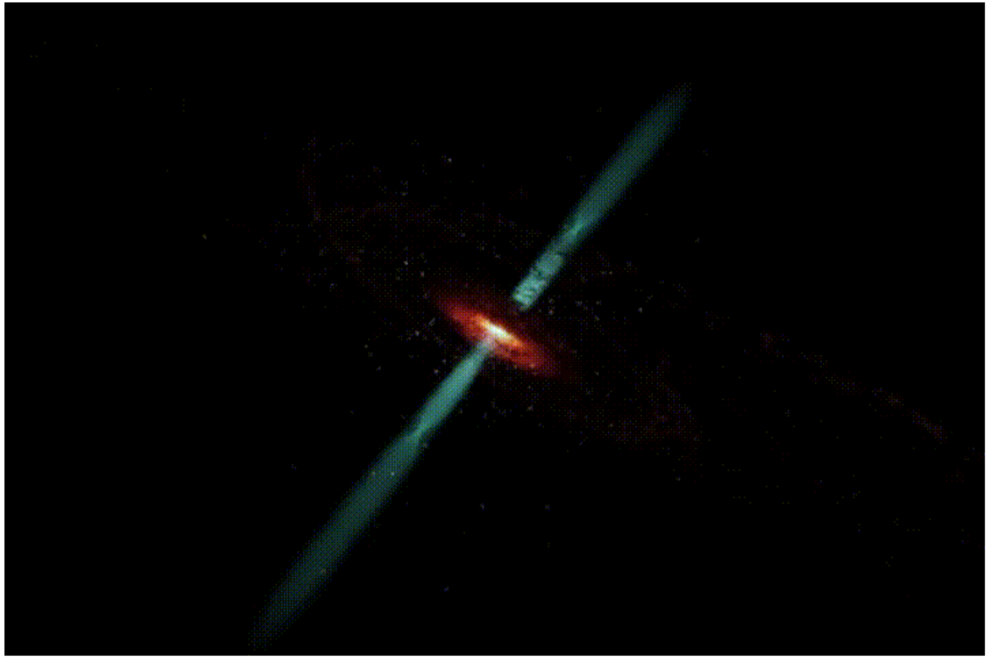
Motivation & Jet Basics





Jet launch

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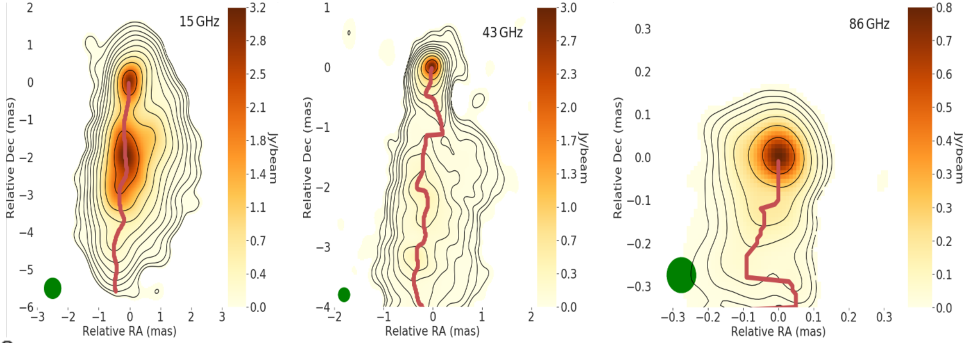
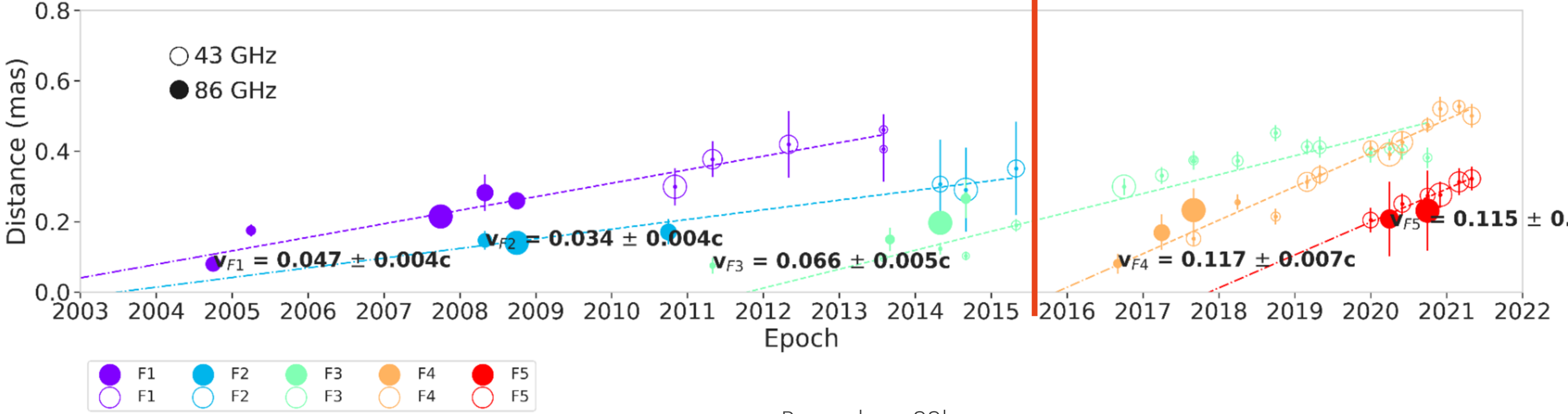
3C84 kinematics



- Stacked images at 15, 43 & 86 GHz
- Subluminal motion (0.05-0.1c)
- Newer components move quicker
- High **ν** components marginally faster (2σ)



Paraschos+22b

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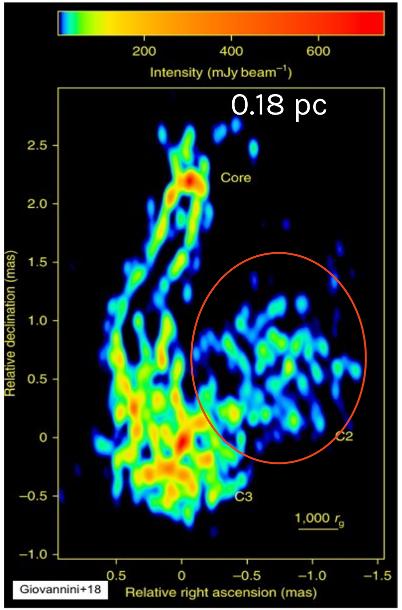
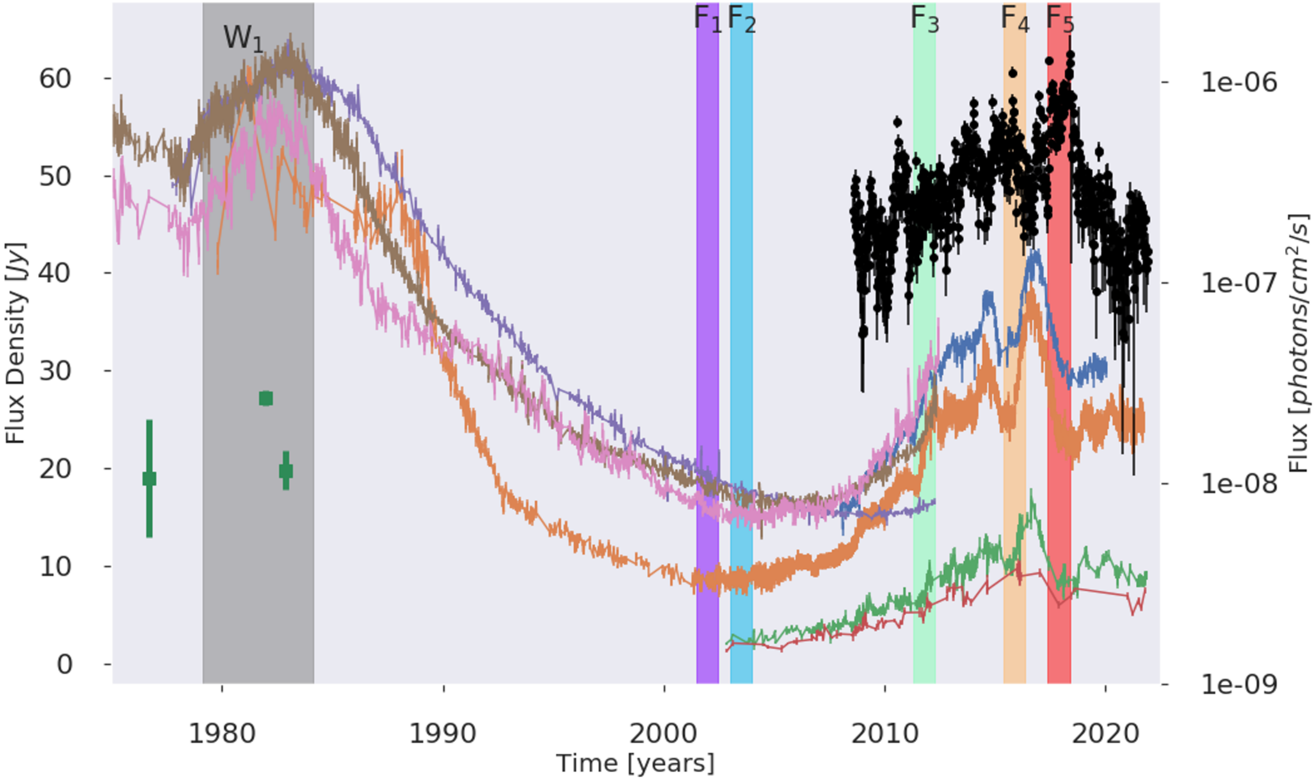
Component ejection - flux variability correlation





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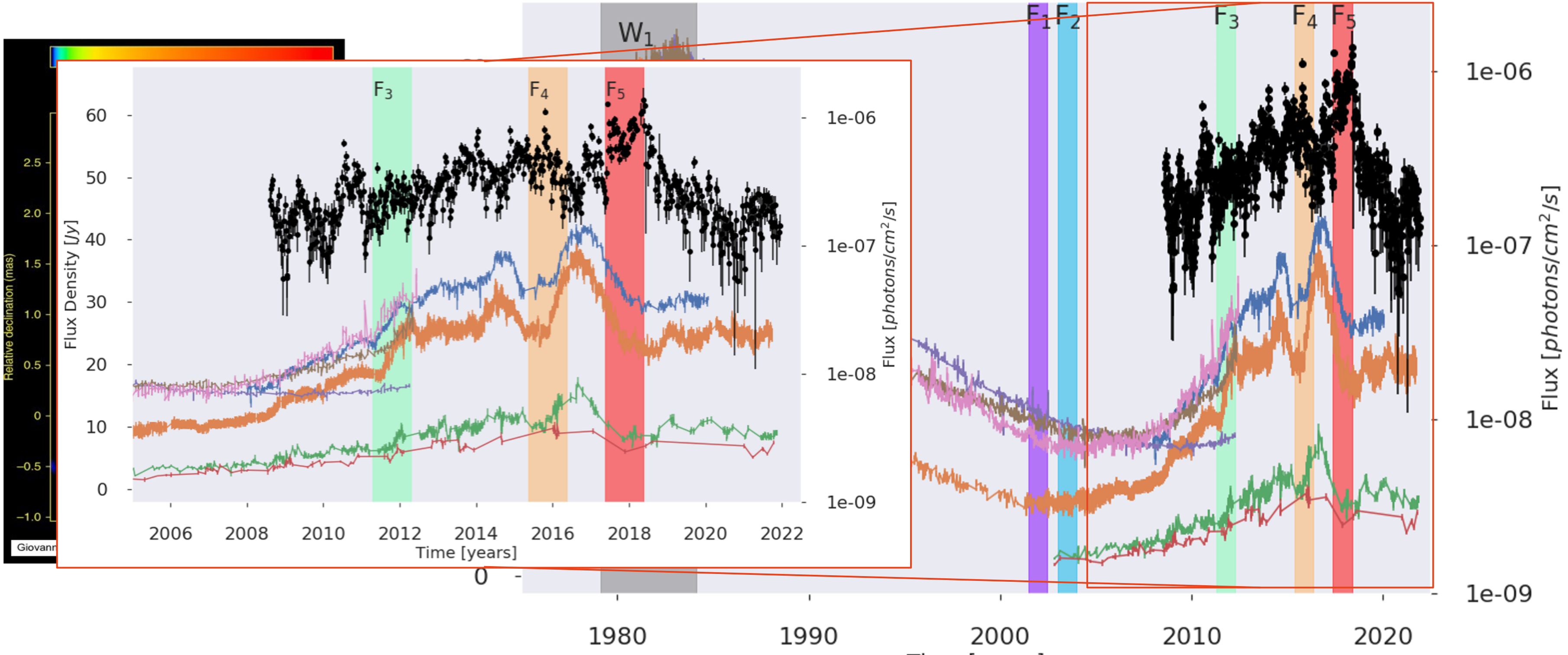
Component ejection - flux variability correlation



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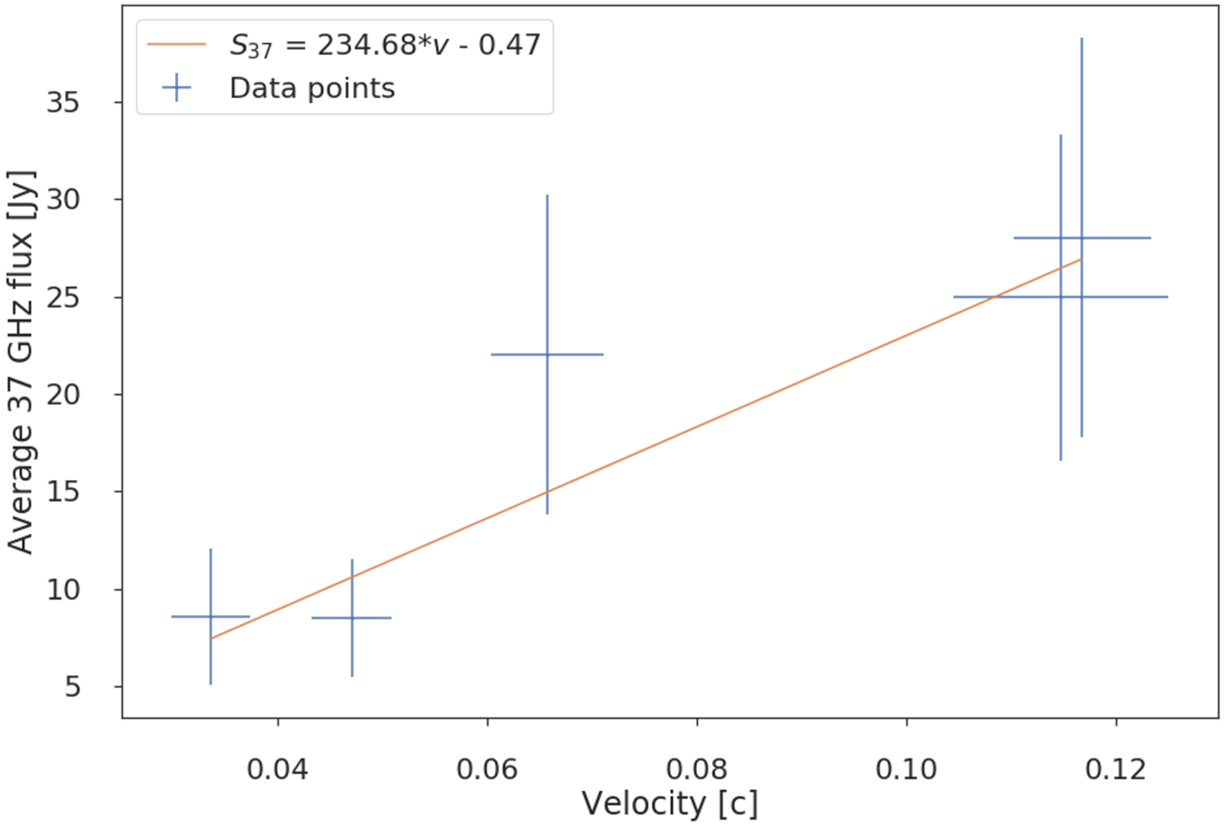
Component speed - flux variability correlation

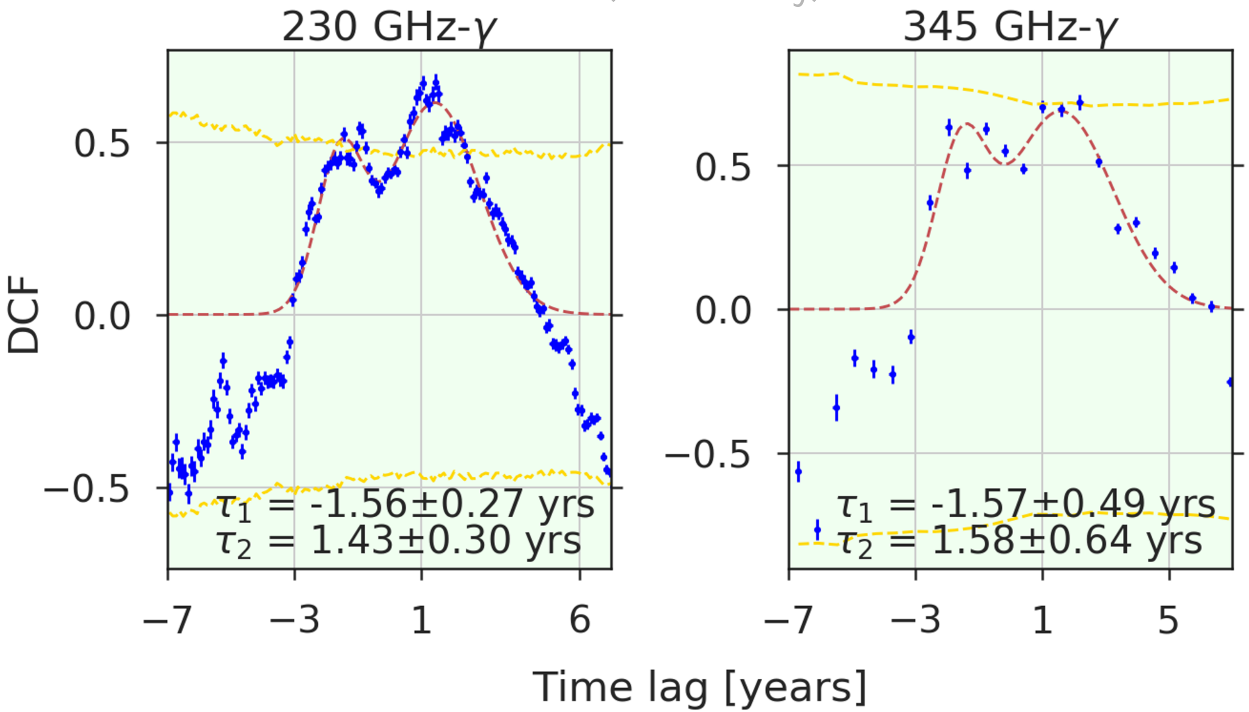
Faster moving features were ejected during higher flux periods



γ-radio correlation

- 2 peaks indicate multiple ejection regions
- Random turbulent noise within a shocked region?

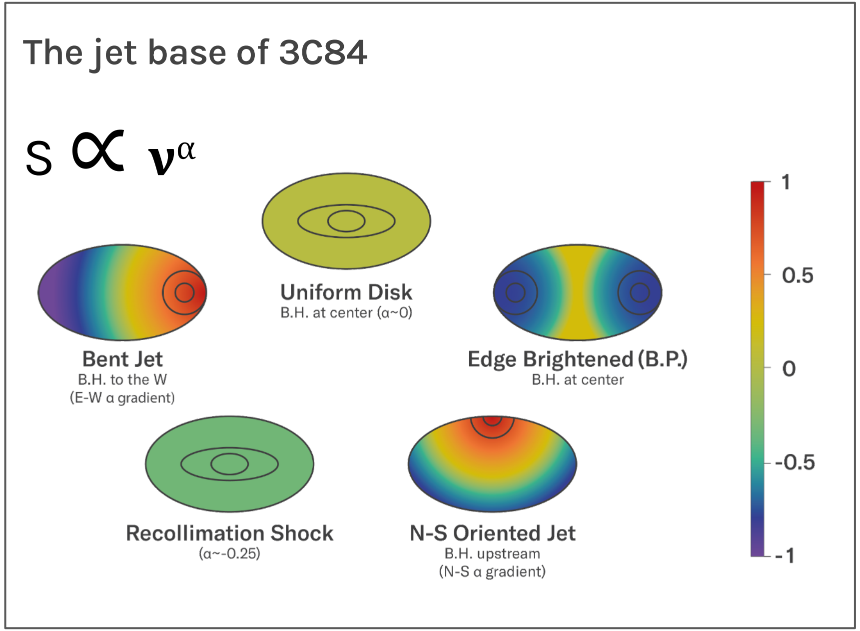
(Preliminary)



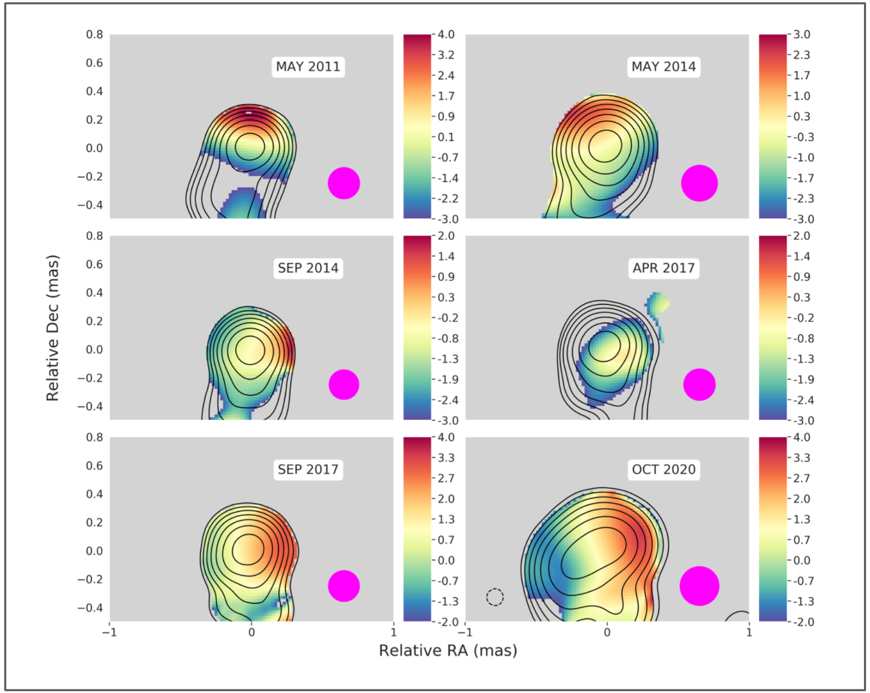
Paraschos+ in prep.

Spectral index maps

Spectral index gradient orientation changes with time



Paraschos+22a



Paraschos+22b

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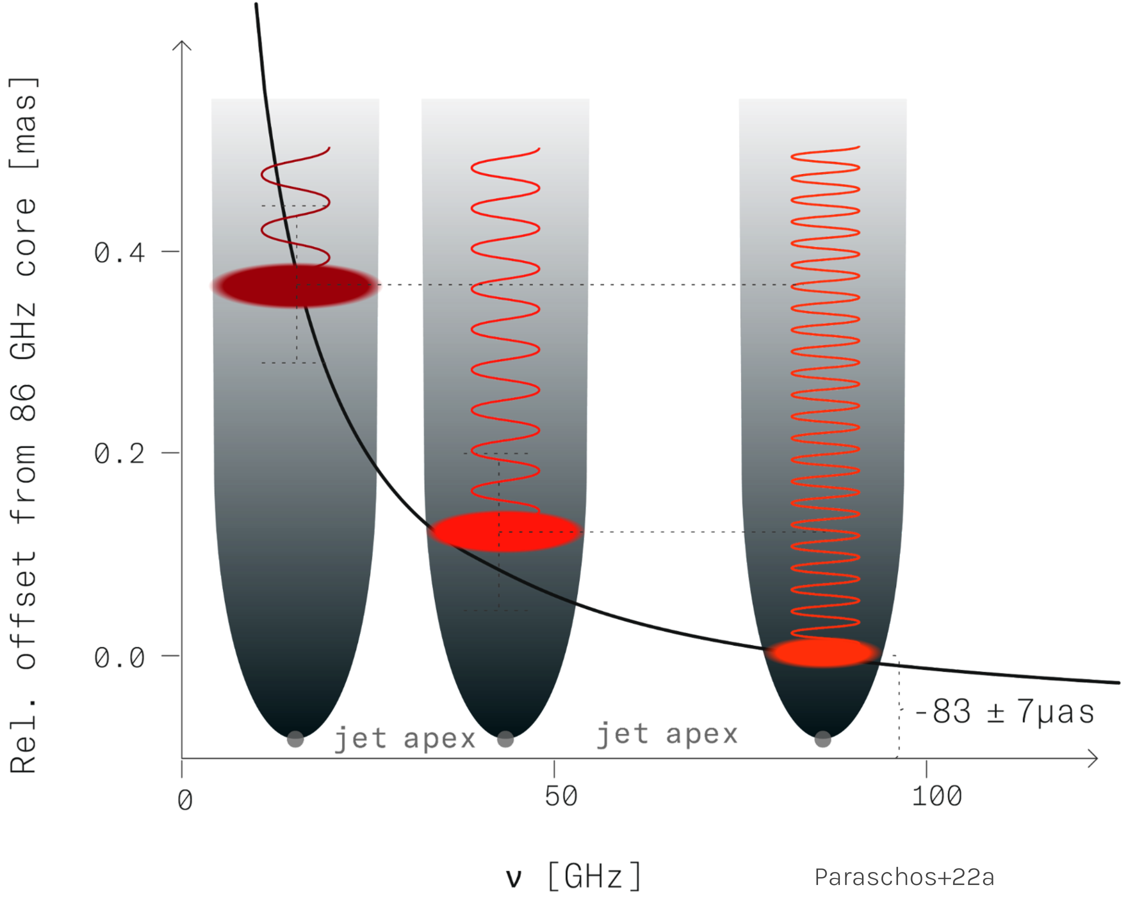
Core shift

via 2D X-corr

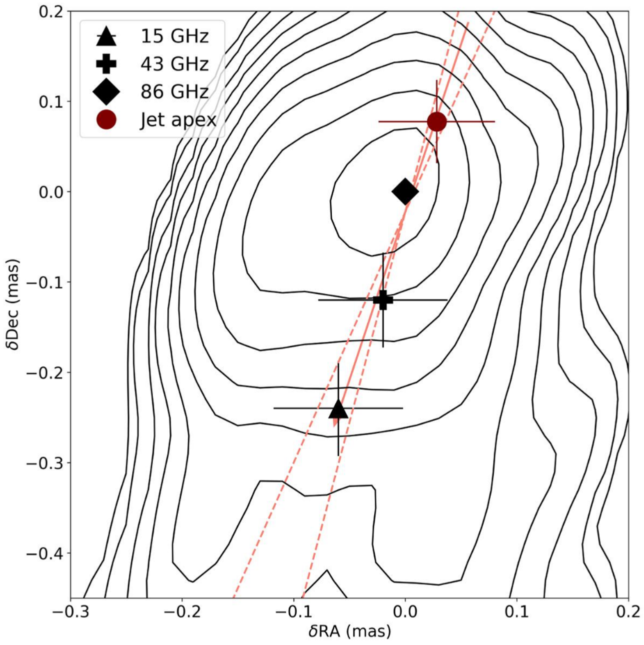
Apparent position of jet apex

is frequency dependent

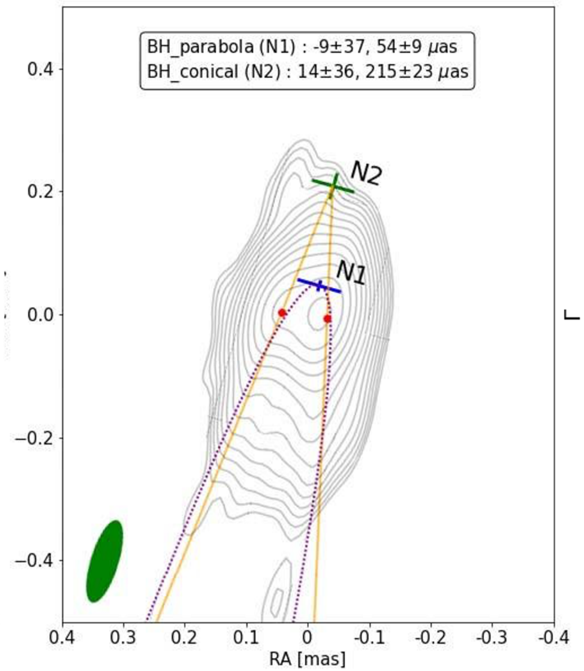


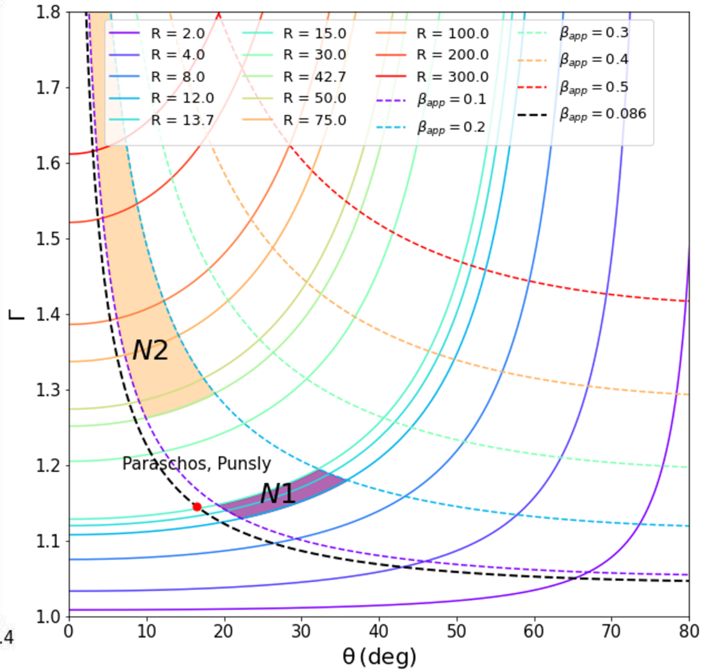
Paraschos+22a

3C84 Jet Apex Position Via Jet Profile Modelling & Core-Shift



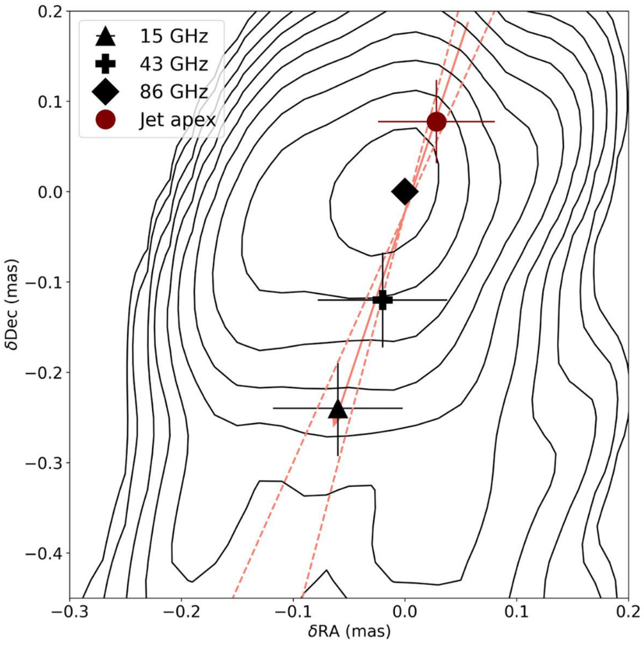
Paraschos+21

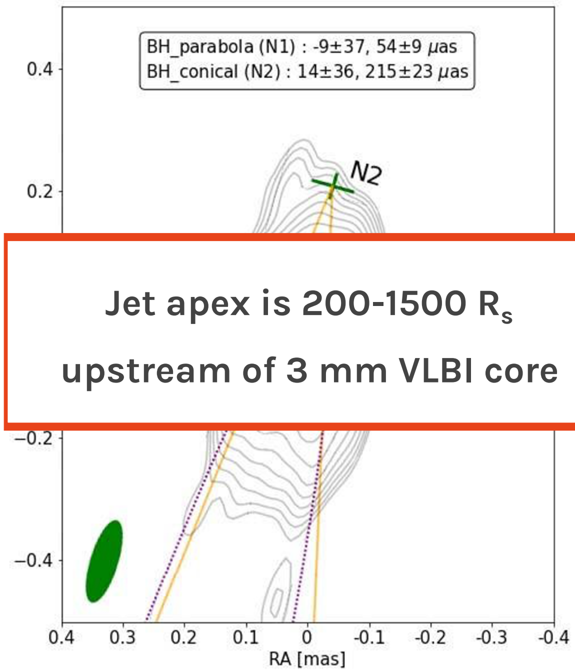




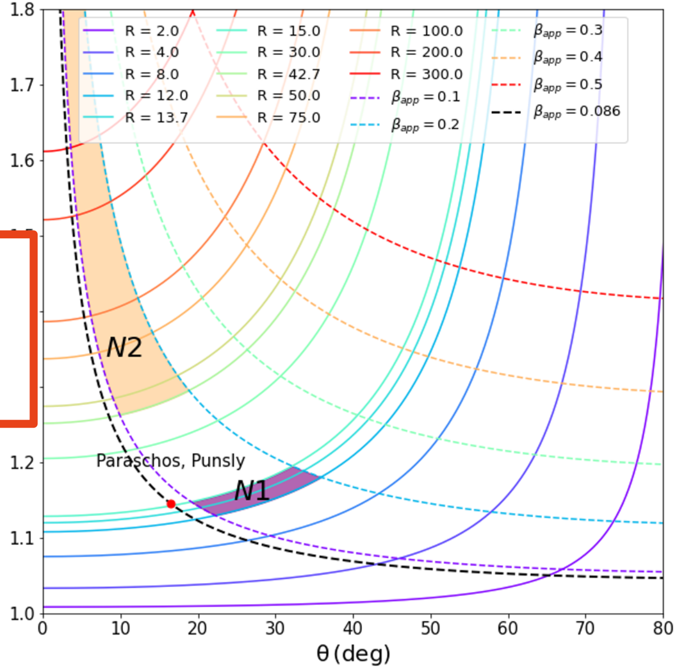
Oh+22

3C84 Jet Apex Position Via Jet Profile Modelling & Core-Shift





Jet apex is 200-1500 R_s upstream of 3 mm VLBI core



Paraschos+21

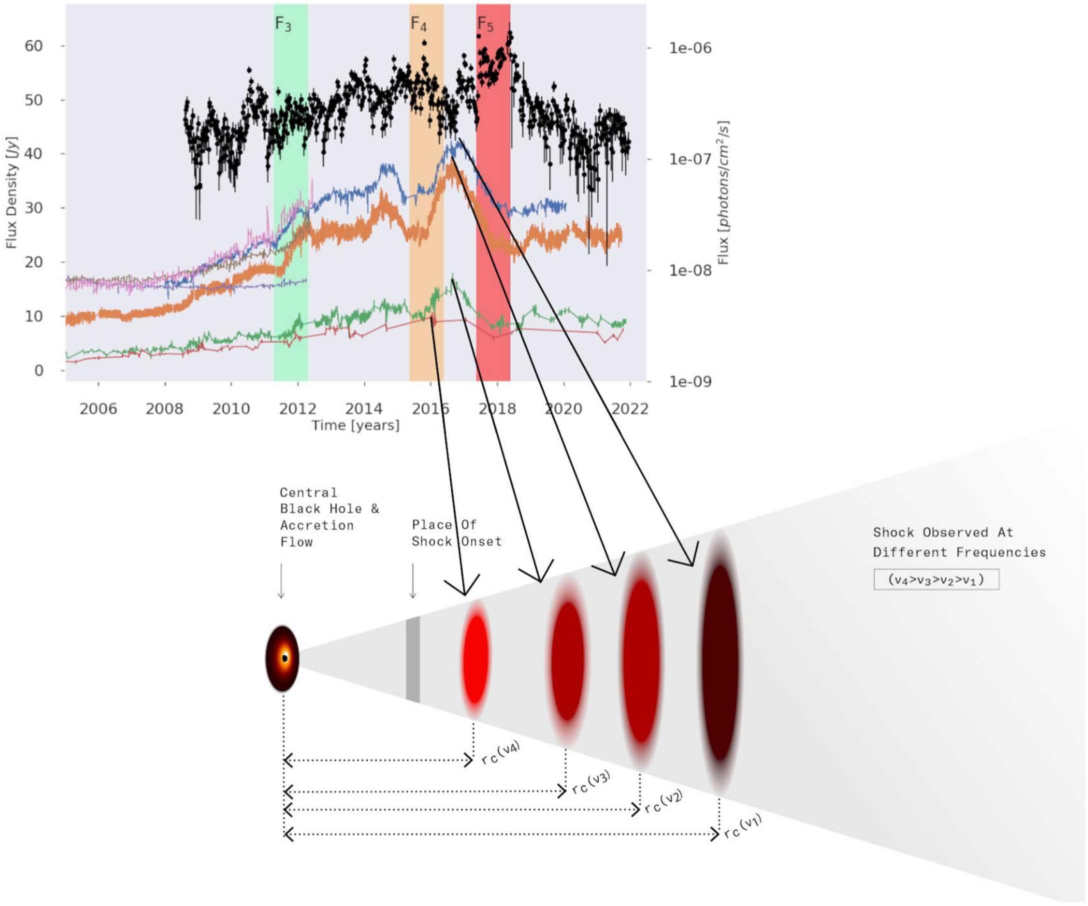
Oh+22

Core shift

via flare onset

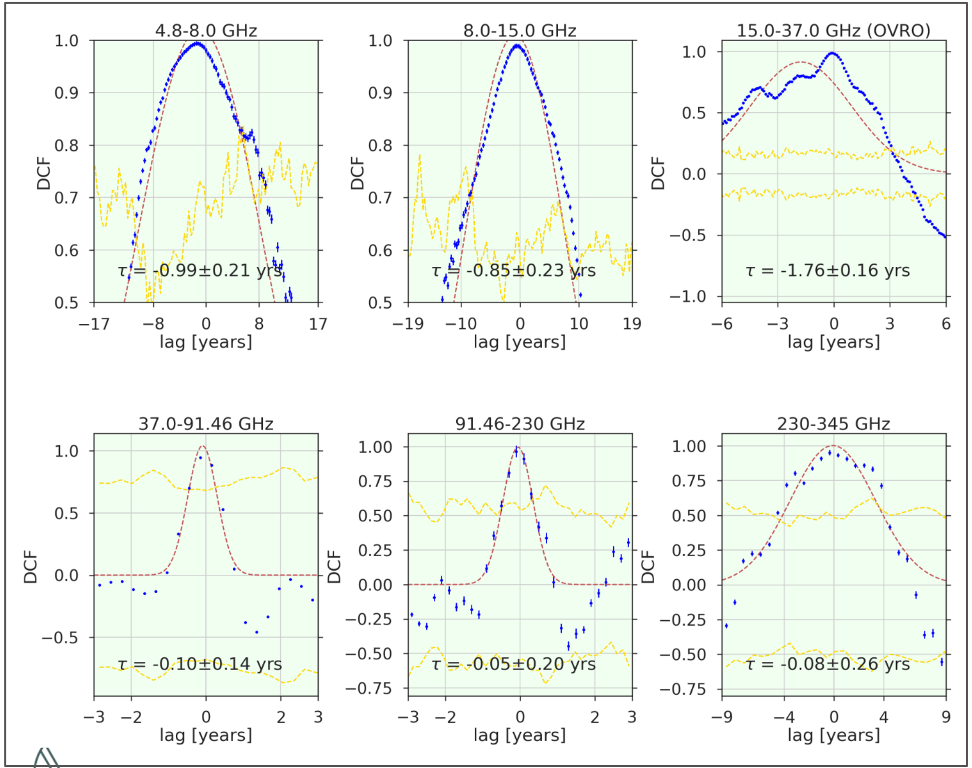
Temporal flare appearance

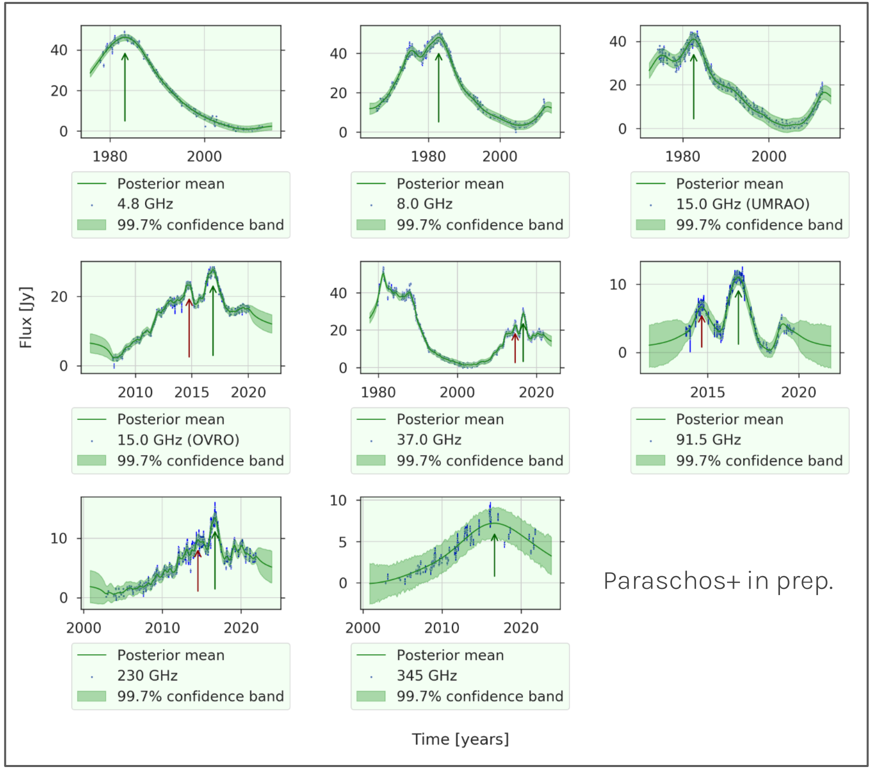
is frequency dependent



Core shift via time lags

DCF (Preliminary) GPR



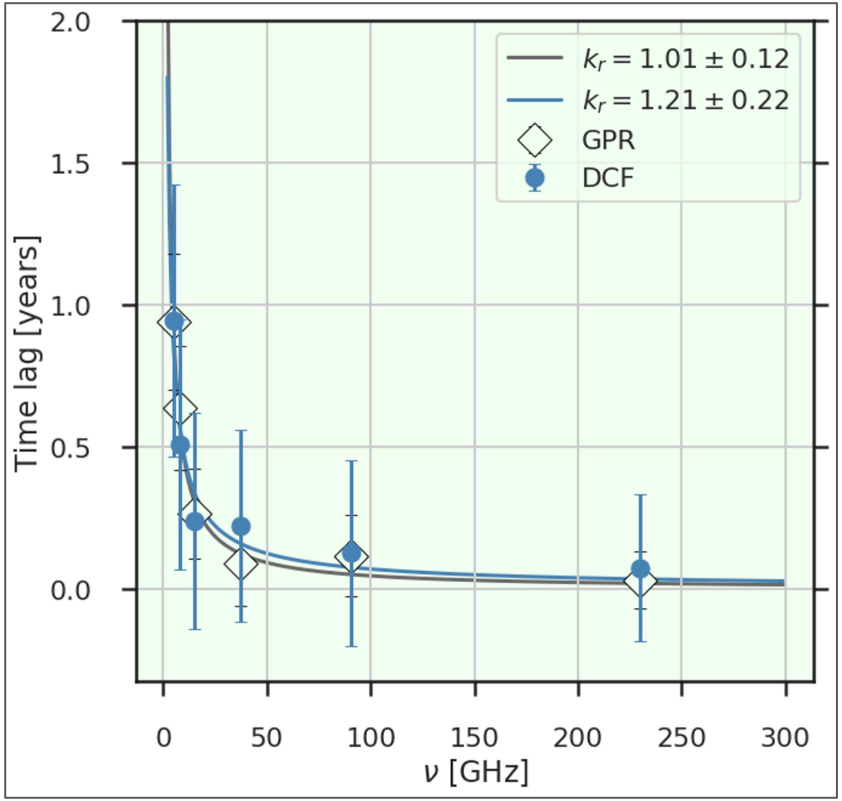


Paraschos+ in prep.

Jet apex location

- System in equipartition
- Jet apex is up to 630 R_s upstream of 3 mm core

(Preliminary)



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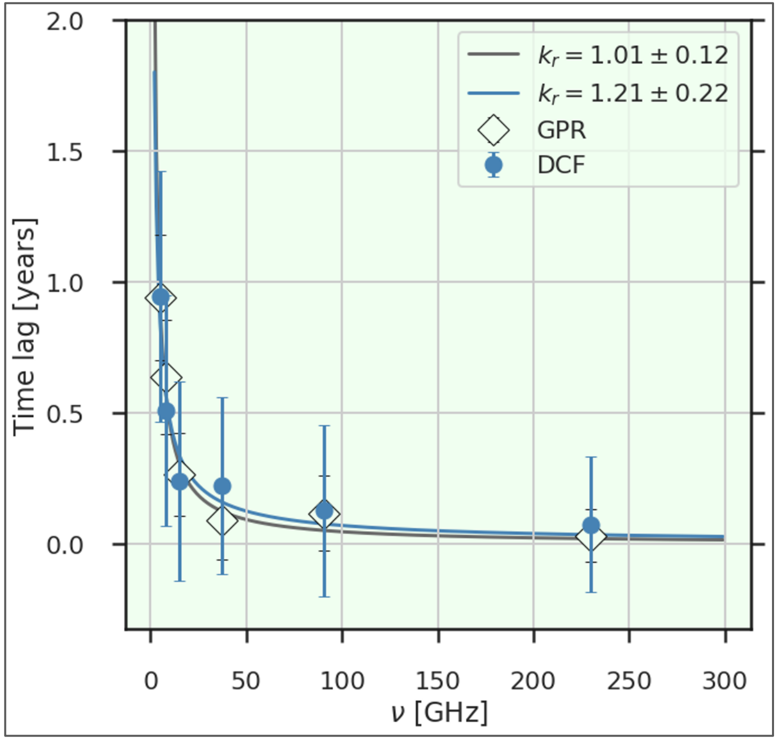
Magnetic field

(Preliminary)

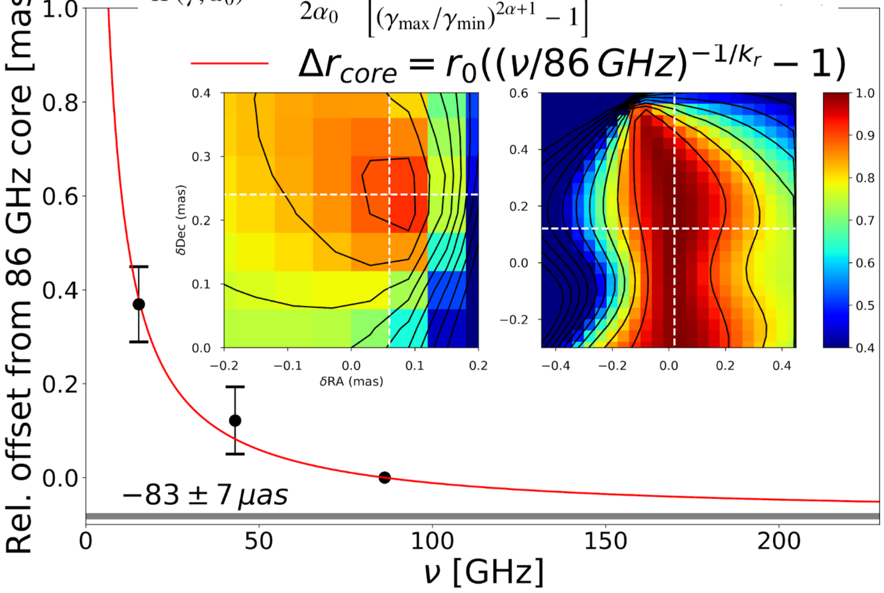


Via time lags

$$B_0 \approx \frac{2\pi m_e^2 c^4}{e^3}\left[\frac{e^2}{m_e c^3}\left(\frac{\Omega_r^\nu}{r_0 \sin\vartheta}\right)^{k_r}\right]^{\frac{5-2\alpha_0}{7-2\alpha_0}}\left[\pi C(\alpha_0)\frac{r_0 m_e c^2}{e^2}\frac{-2\alpha_0}{\gamma_{\min}^{2\alpha_0+1}} \times \frac{\varphi}{\sin\vartheta}K(\gamma,\alpha_0)\left(\frac{\delta}{1+z}\right)^{\frac{3}{2}-\alpha_0}\right]^{\frac{-2}{7-2\alpha_0}} \text{[G]},$$

with

$$K(\gamma,\alpha_0) = \frac{2\alpha_0+1}{2\alpha_0}\frac{\left[(\gamma_{\max}/\gamma_{\min})^{2\alpha}-1\right]}{\left[(\gamma_{\max}/\gamma_{\min})^{2\alpha+1}-1\right]}$$



Via 2D X-corr

Magnetic field & Topology

Assumptions:

- Blandford & Königl jet
- synchrotron self-absorbed jet

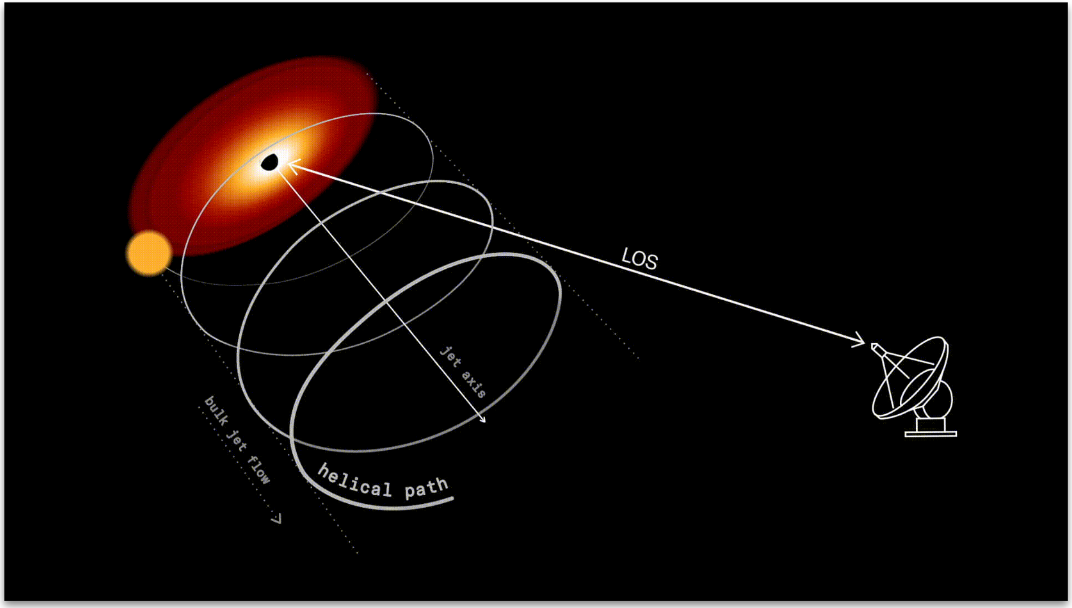
Magnetic field at the extrapolated jet apex location: ~ 2 - 10 G

- ❑ Extrapolating to ≤10 R_s: 70-600G; compares well to M87 & NGC 1052
- ❑ Extrapolating to 1pc: 0.06-0.2 G; 4-6 times lower than BL Lacs and quasars, indicating possibly intrinsic differences

Magnetic field configuration: toroidal/mixed toroidal-poloidal, depending on particle density p. l. index assumption → stratified combination of BP + BZ?

Open questions

- Precessing jet (Lense-Thirring)?
- Helical jet?
- Binary black hole?



Conclusions

RA revealed a core structure perpendicularly oriented to the bulk jet flow

- Sub-luminal motion in core region, newer components faster
- Time variable spectral index gradient orientation
- Jet apex is 200-1500 R_s upstream of the 3mm VLBI core
- Magnetic field at jet apex: 2-10 G