The jet of the LLAGN of M81: Evidence of Precession

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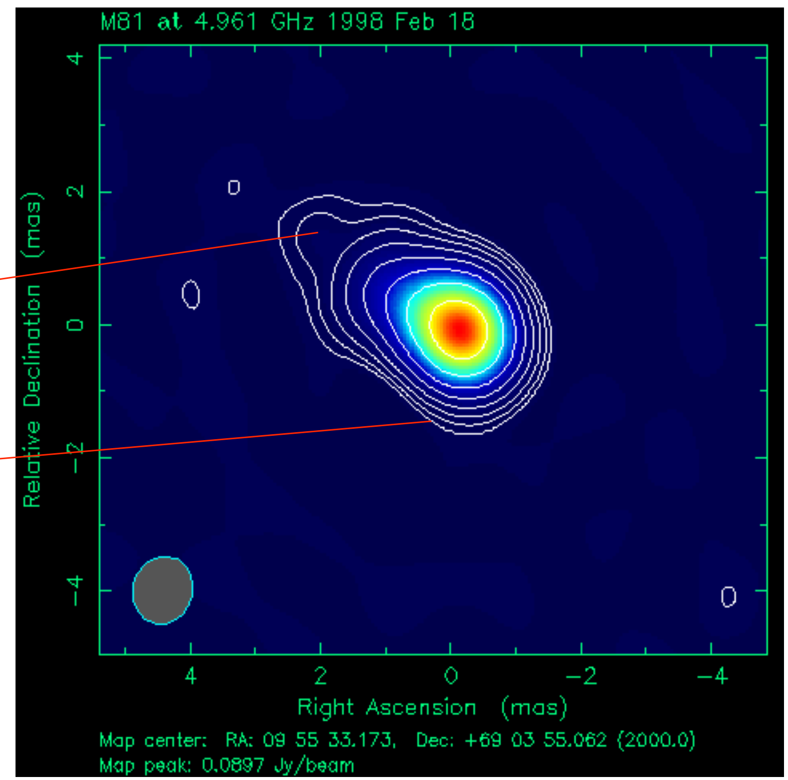
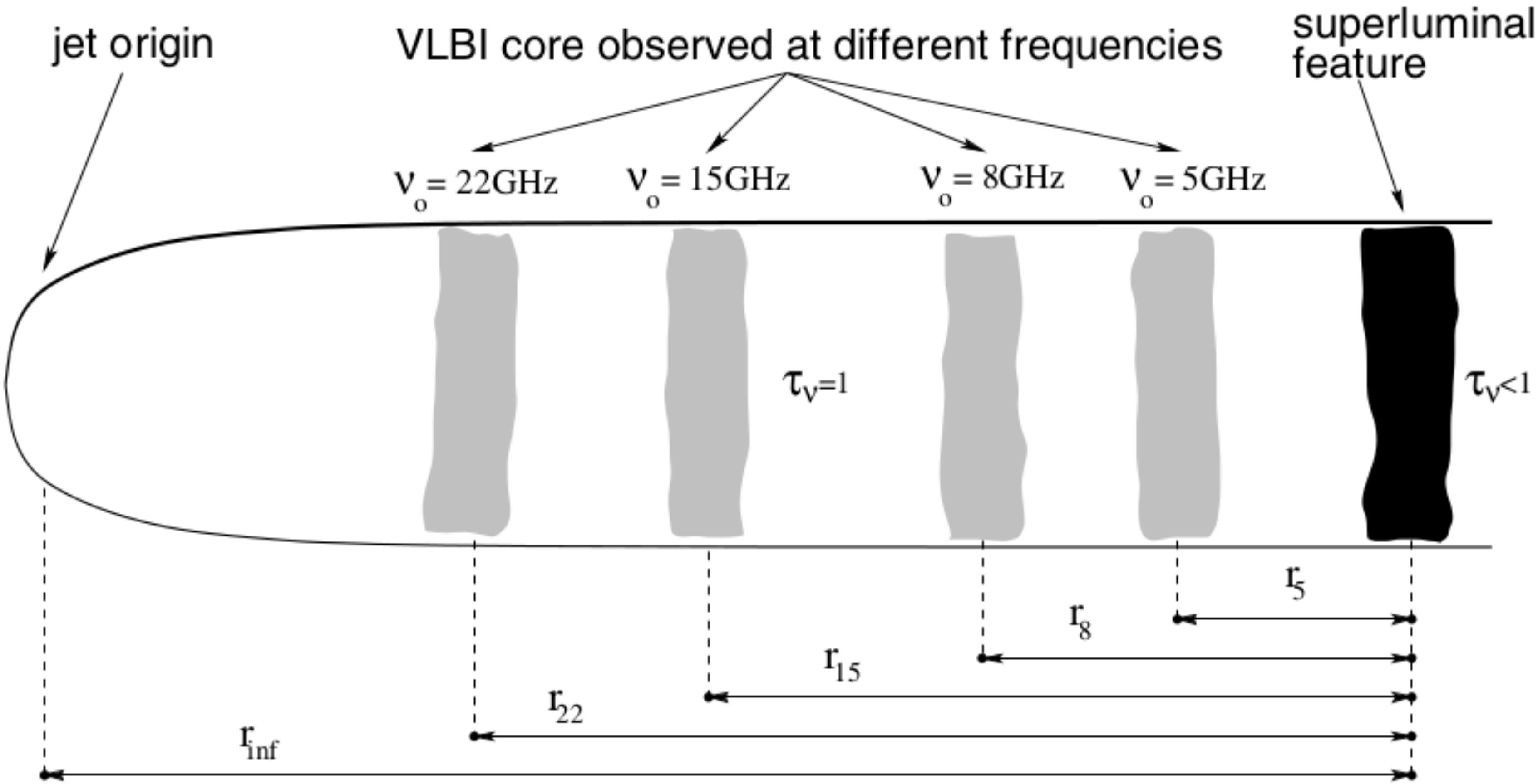


Active Galactic Nuclei



Kovalev et al. (2008)

B and N decrease with distance to the jet origin. Hence, frequency-dependent position of the τ_ν =1 surface (VLBI core).

Core shifts with VLBI

THE SUBTLE PROBLEM OF PHASE REFERENCING

In a phase-referencing experiment at two frequencies, it is impossible to decouple the core shift in the calibrator from the core shift in the target.

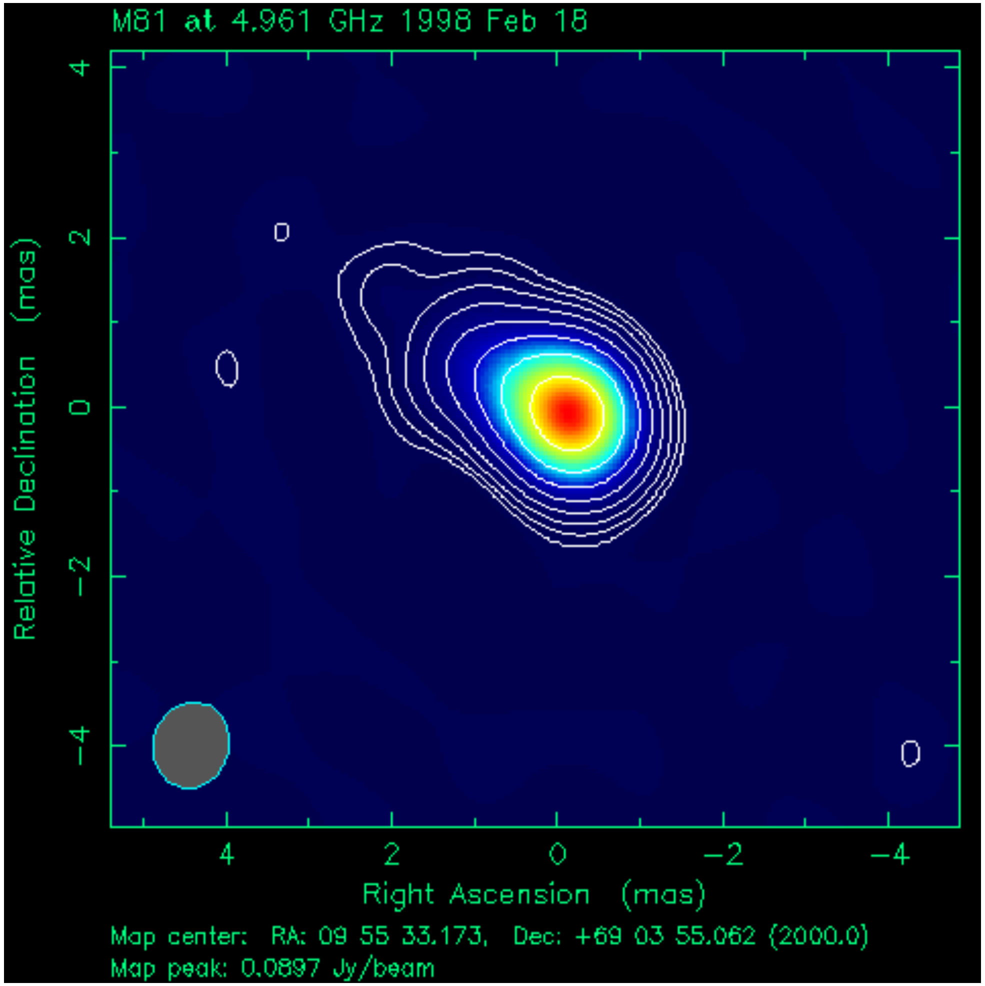
THERE ARE ONLY TWO EXCEPTIONS:

1.- Sources that have shifts (i.e., jets) in perpendicular directions (and are located close by). Any tangential shift in one source would map into a wrong estimate of the shift in the other source.

2.- One of the sources (or prominent source component) is optically thin (i.e., there is no core-shift).

Optically-thin sources are the *Desideratum* of VLBI astrometry!

The LLAGN in M81



1 mas ⌧ 0.016 pc ⌧ 3000 R sch

- Distance: **3.63 ± 0.34 Mpc** (Freeman et al. 1994); 3.96 ± 0.29 Mpc (Bartel et al. 2013)

- Radio luminosity ~ **10^{37} erg/s** (e.g., Ho et al. 1999).

- Spectral index **+0.3** up to ~200GHz (Reuter & Lesch 1996).

- X-ray luminosity ~ **10^{40} erg/s** (e.g., Reynolds et al. 2009).

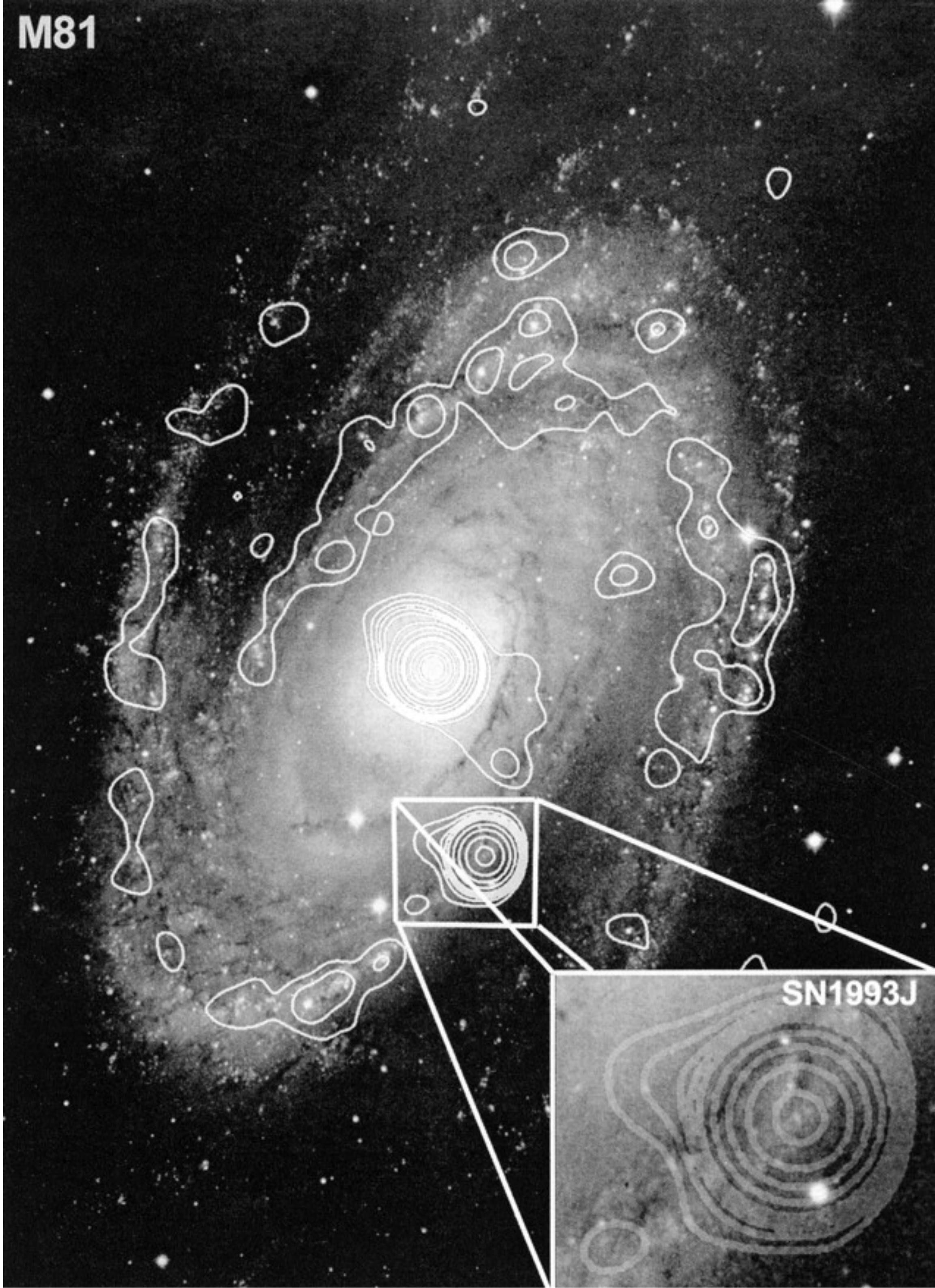
- Estimated mass of SMBH: **~7×10^7 Solar masses** (e.g., Deveraux et al. 2003).

- **R_{sch} = 1-3 x 10^{-5} pc**

M81 and SN1993J

- SN1993J was an extremely strong radio-loud supernova, located in M81 (host of a LLAGN).

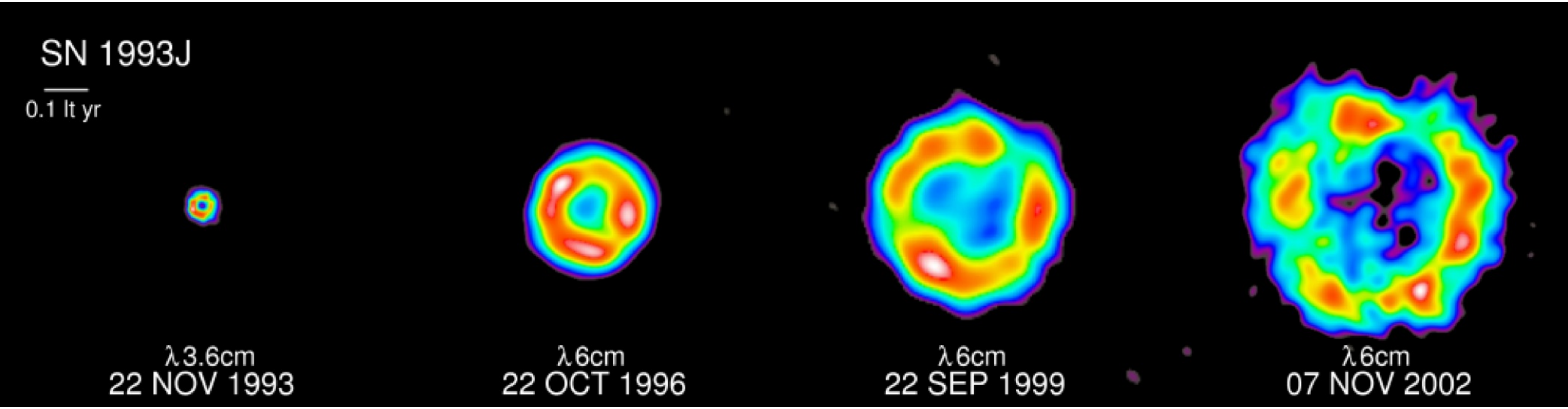
- Angular Distance between M81* and SN93J: 2.8 arcmin



M81 and SN1993J

- SN1993J was an extremely strong radio-loud supernova, located in M81 (host of a LLAGN). It shows a high degree of isotropy of the radio shell's expansion.

- There is no core-shift in the radio emission of a supernova. Hence, this was a unique opportunity to monitor the (absolute) kinematics of the jet of an AGN.



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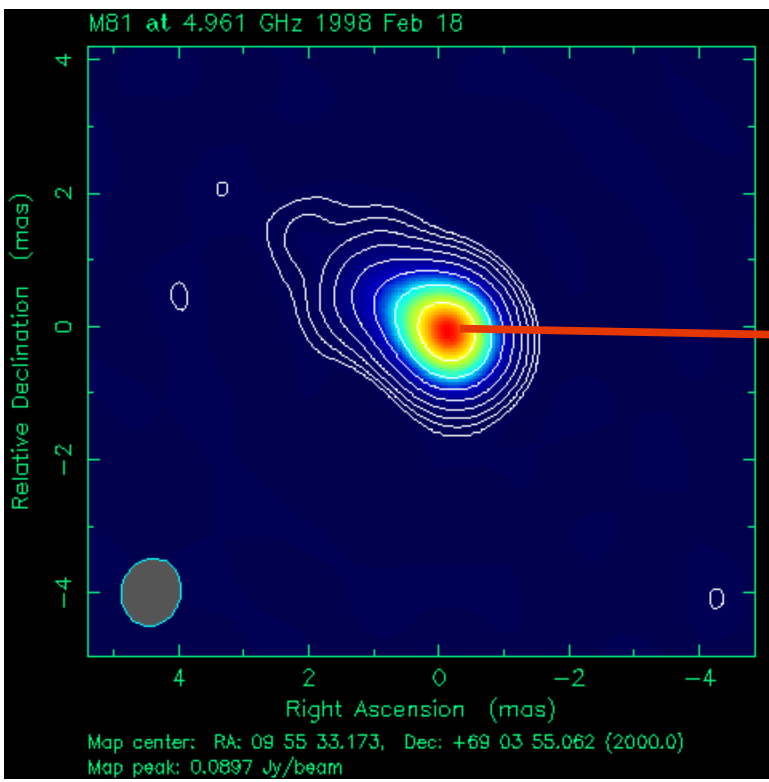
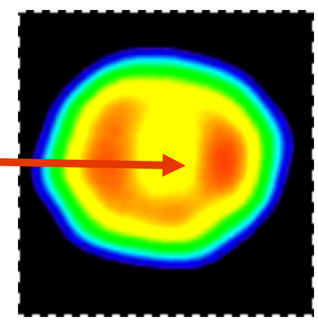
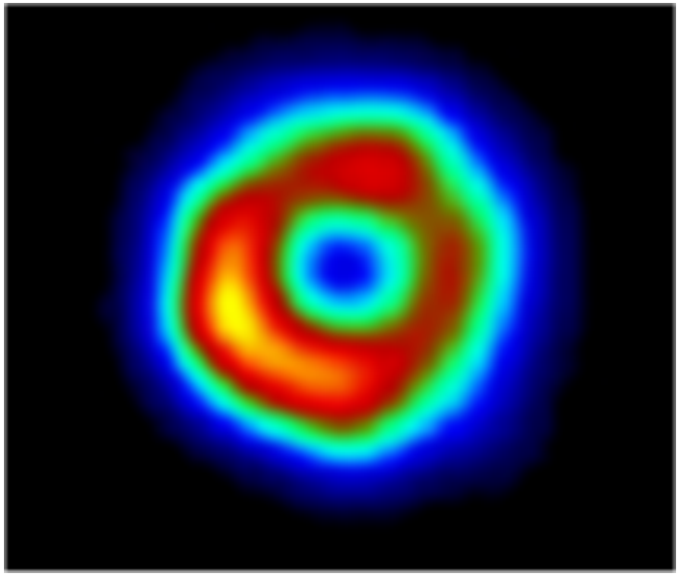


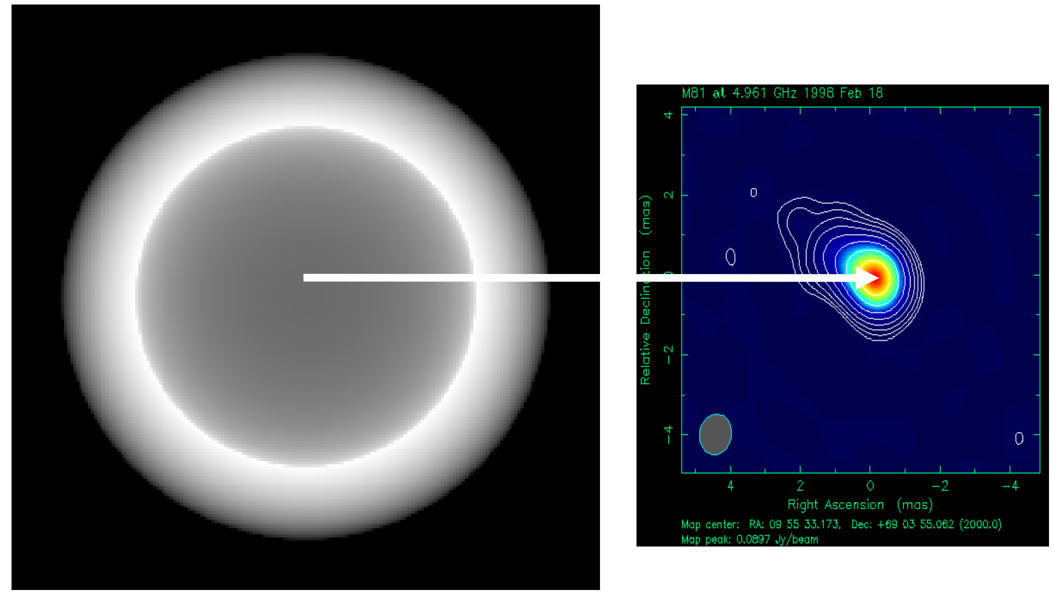


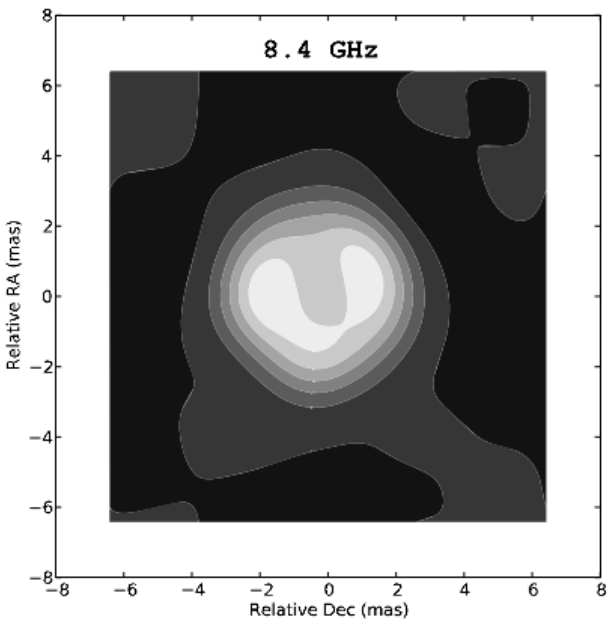
1 mas ☒ 0.016 pc ☒ 3000 R_{SCH}

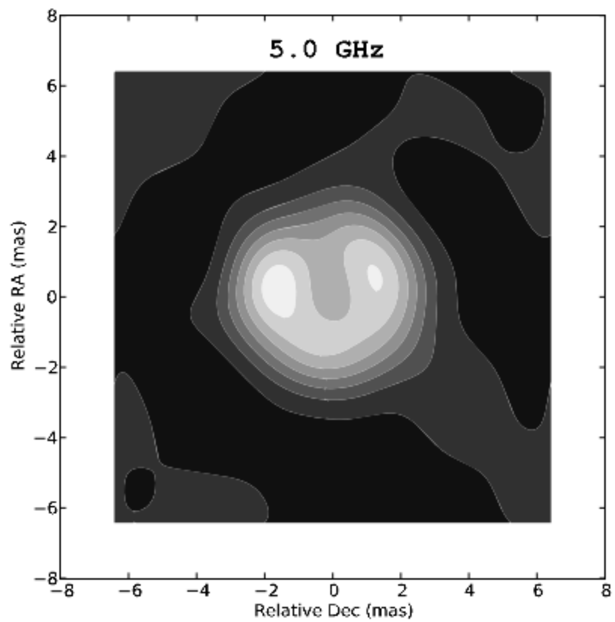
M81. Multi-frequency astrometry

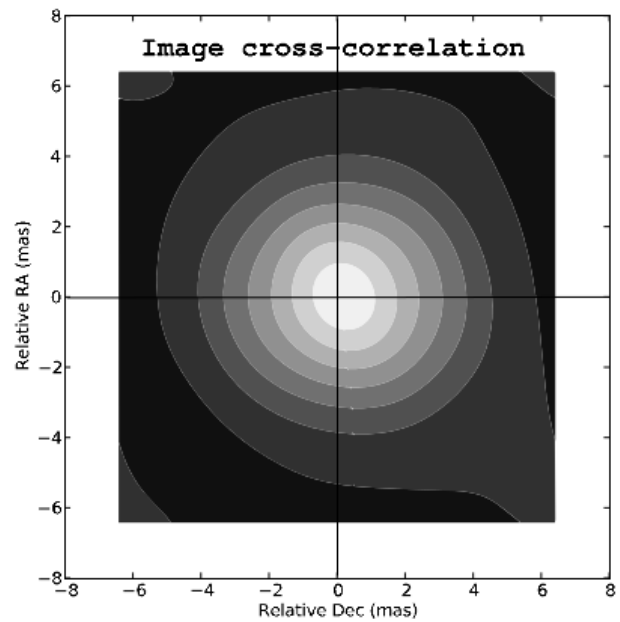


Fit









M81. Multi-frequency astrometry

COMPARISON 1-2

	Frequency pair (GHz)					
	1.7–5.0	1.7–8.4	5.0–8.4	1.7–2.3	2.3–5.0	2.3–8.4
Method	Shift (mas)					
Shell center[a]	0.57 ± 0.21	0.74 ± 0.19	0.18 ± 0.13	0.31 ± 0.17	0.42 ± 0.14	0.59 ± 0.09
Cross-corr.[b]	0.68 ± 0.22	0.77 ± 0.50	0.21 ± 0.10	0.35 ± 0.05	0.43 ± 0.25	0.65 ± 0.14

- Very similar results for the core-shift with both methods (although large uncertainties).

- Smooth & compact jet; equipartition:

$$\Delta r = \Omega \left(\frac{\nu_1 - \nu_2}{\nu_1 \nu_2} \right)^{\kappa}$$

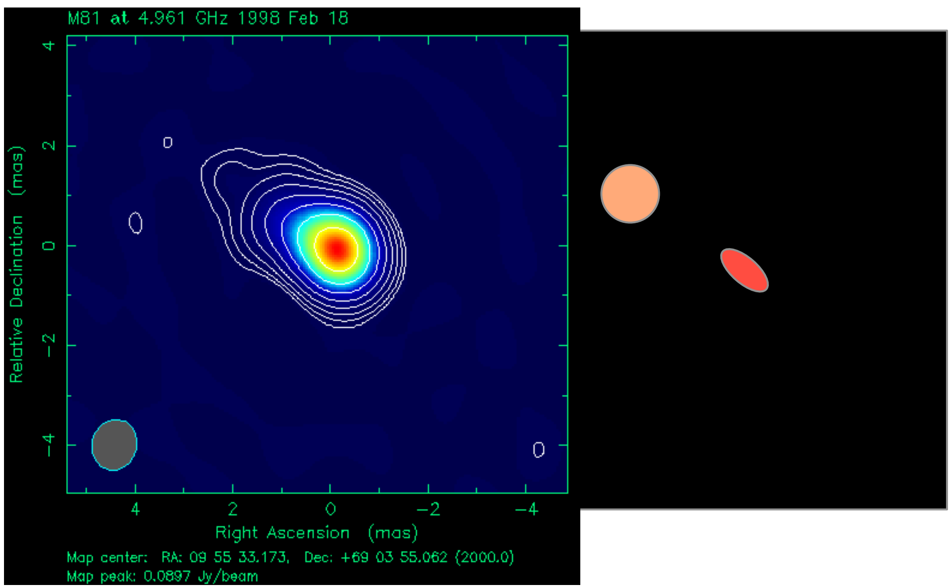
(Lobanov 1998)

$$\Omega = 1.75 \pm 0.20 \, \mathrm{mas\,GHz}.$$

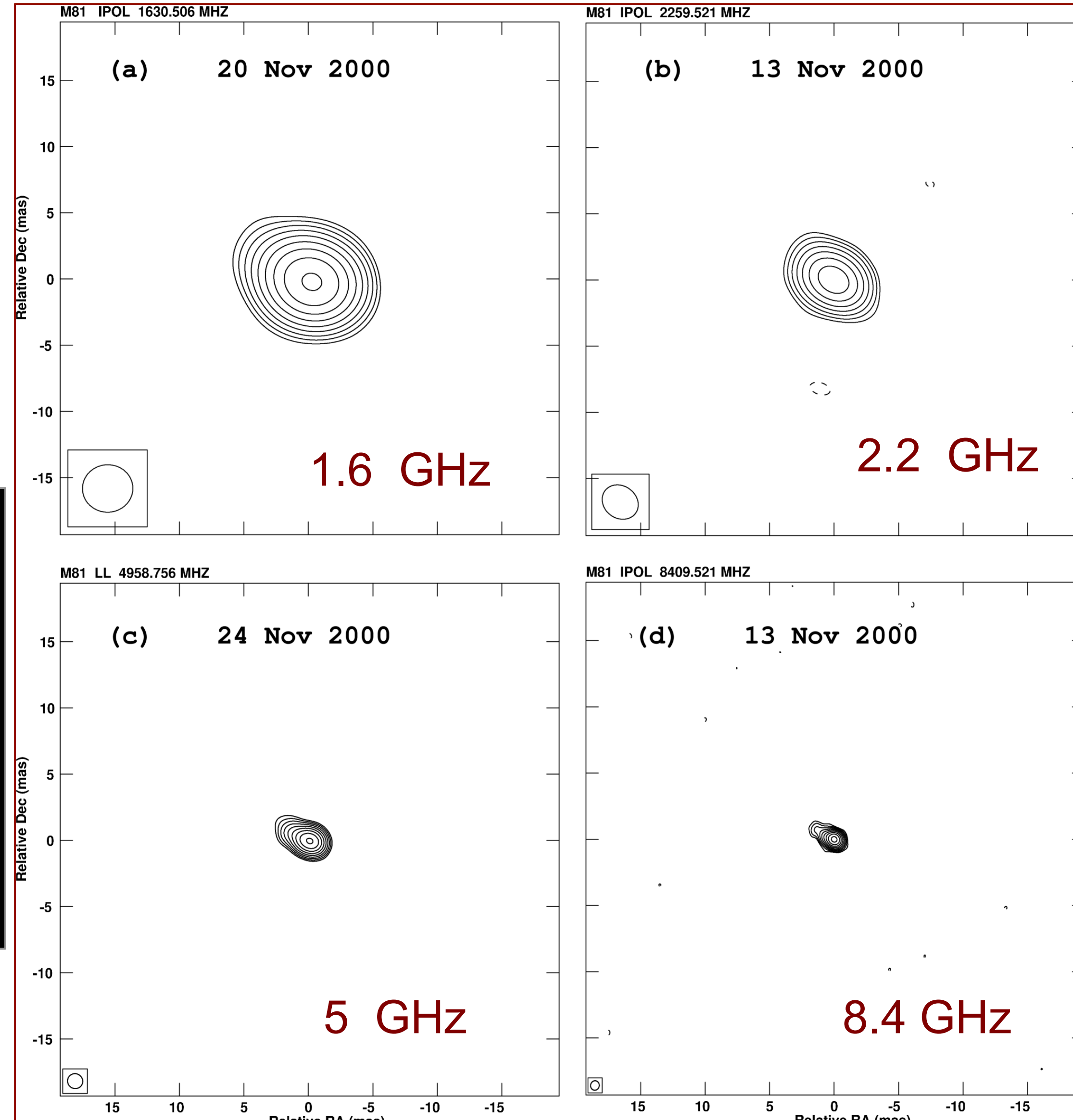
M81. Model fitting

- Elliptical Gaussian to fit the (slightly resolved) core.

- Circular Gaussian to fit the extended close-by jet emission.



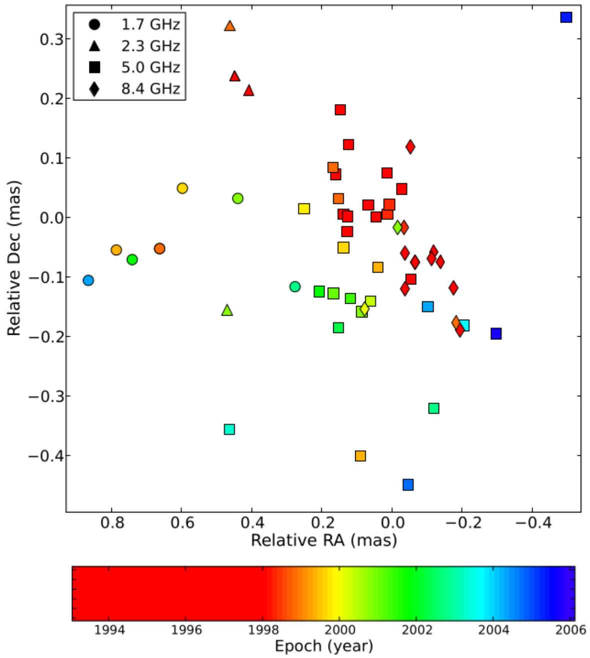
1 mas 3000 R_{SCH}

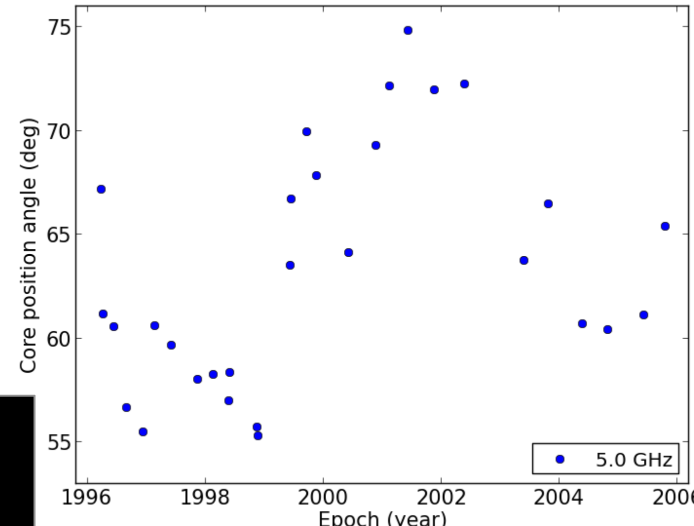


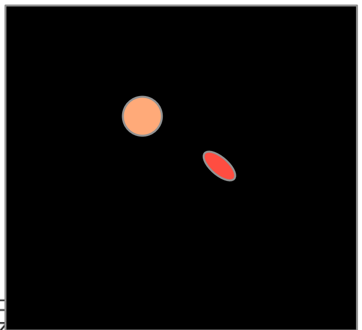
Martí-Vidal et al. A&A 533, A111 (2011)

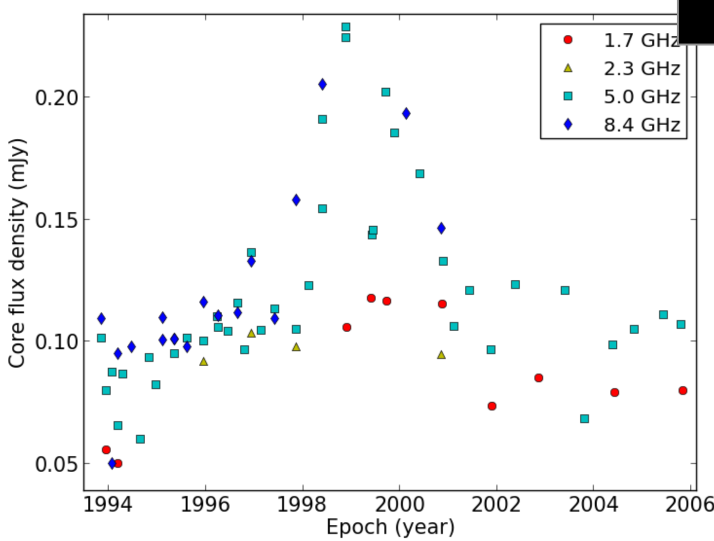
M81. VLBI results

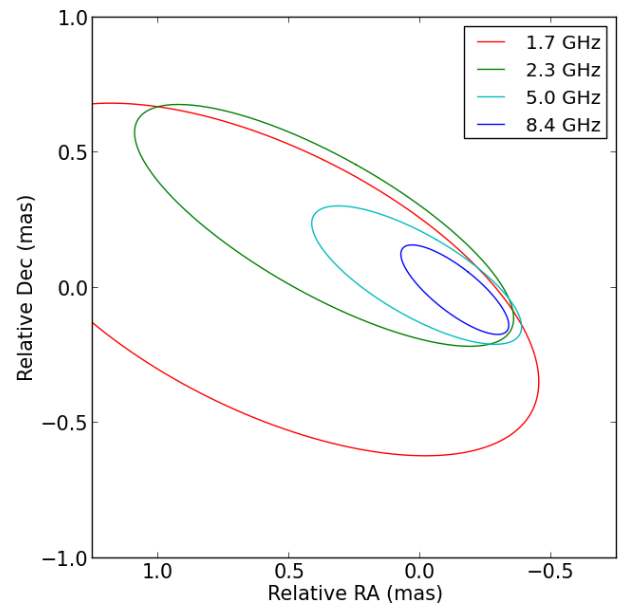
EVOLVING CORE INCLINATION AND LUMINOSITY

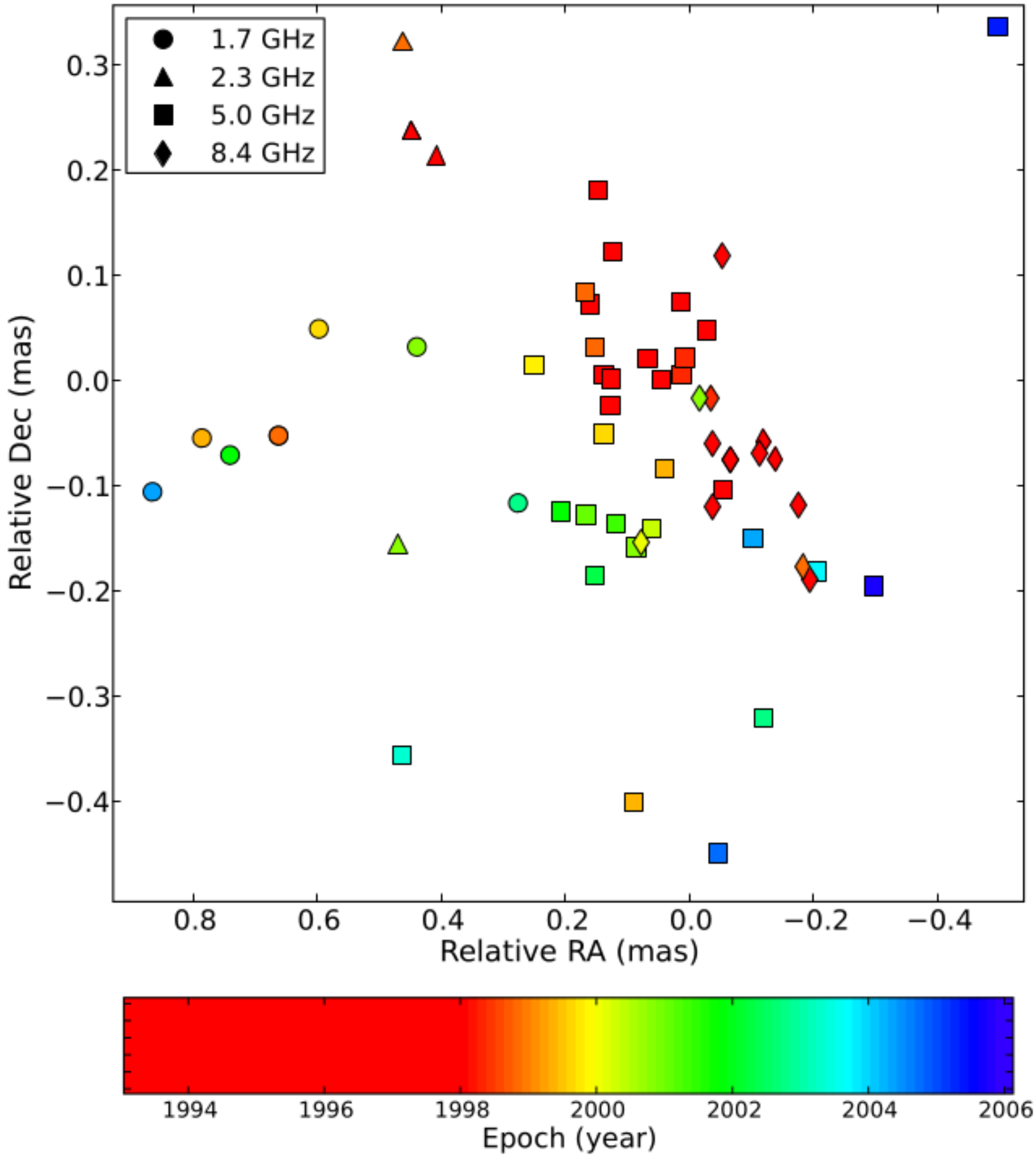




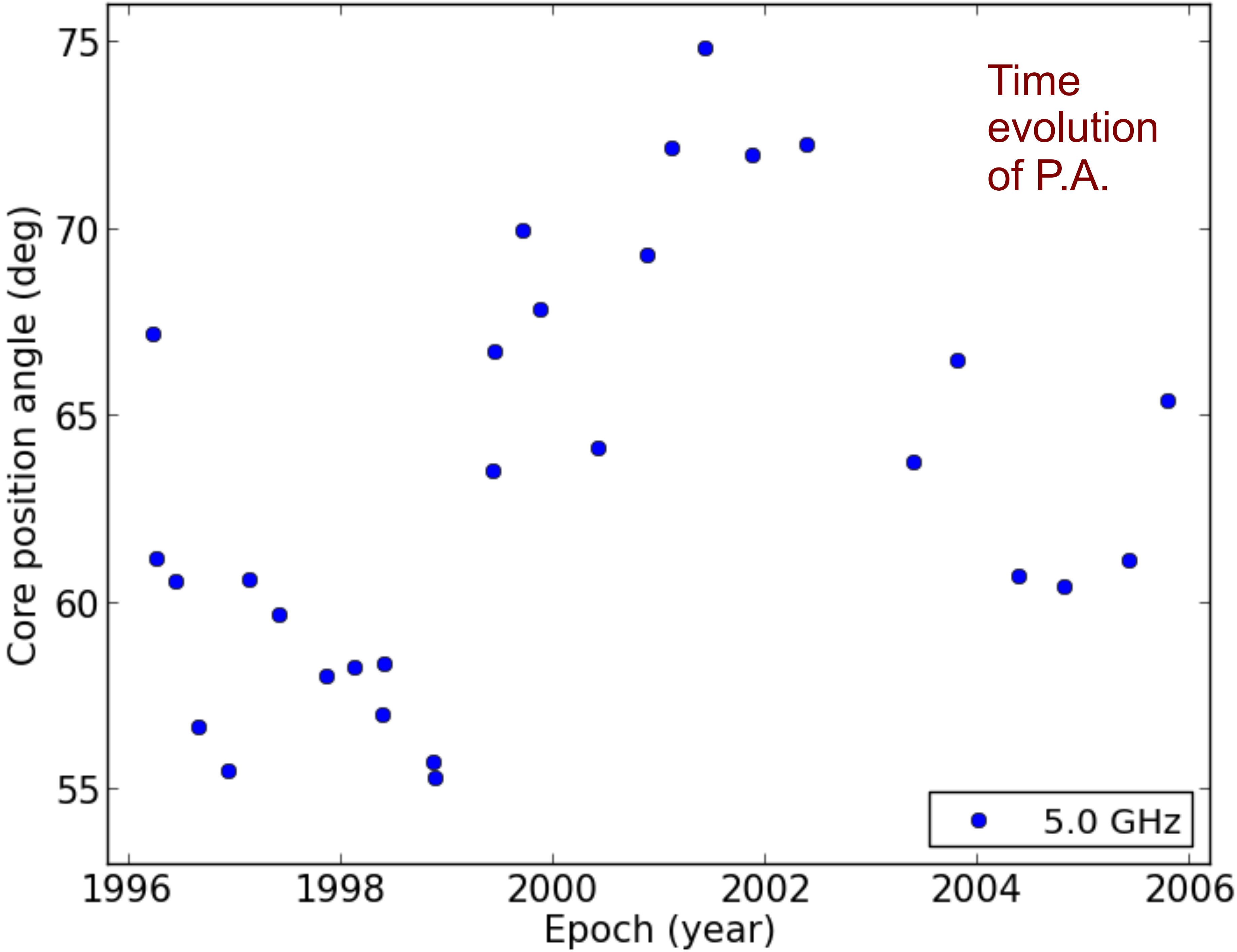




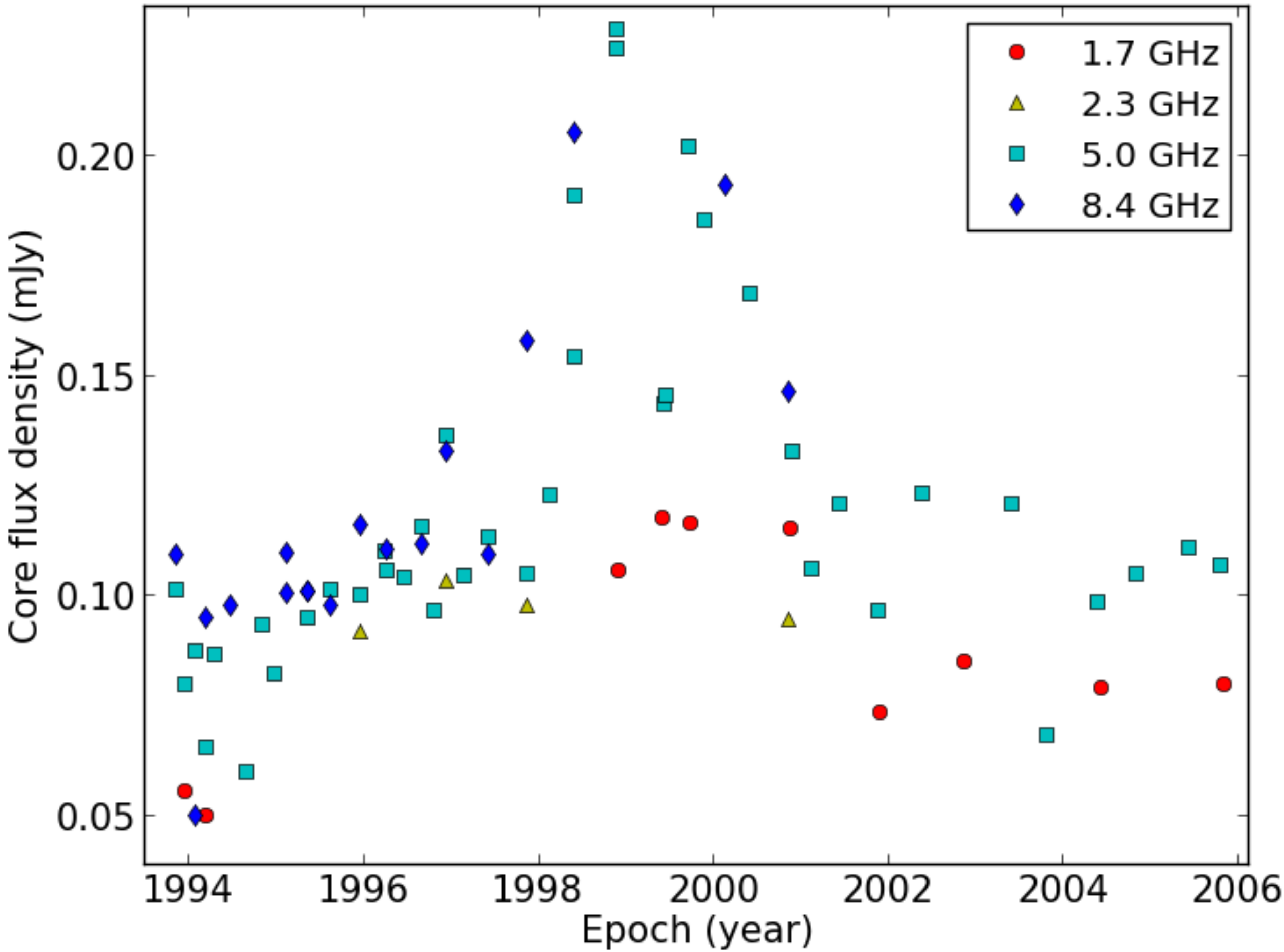


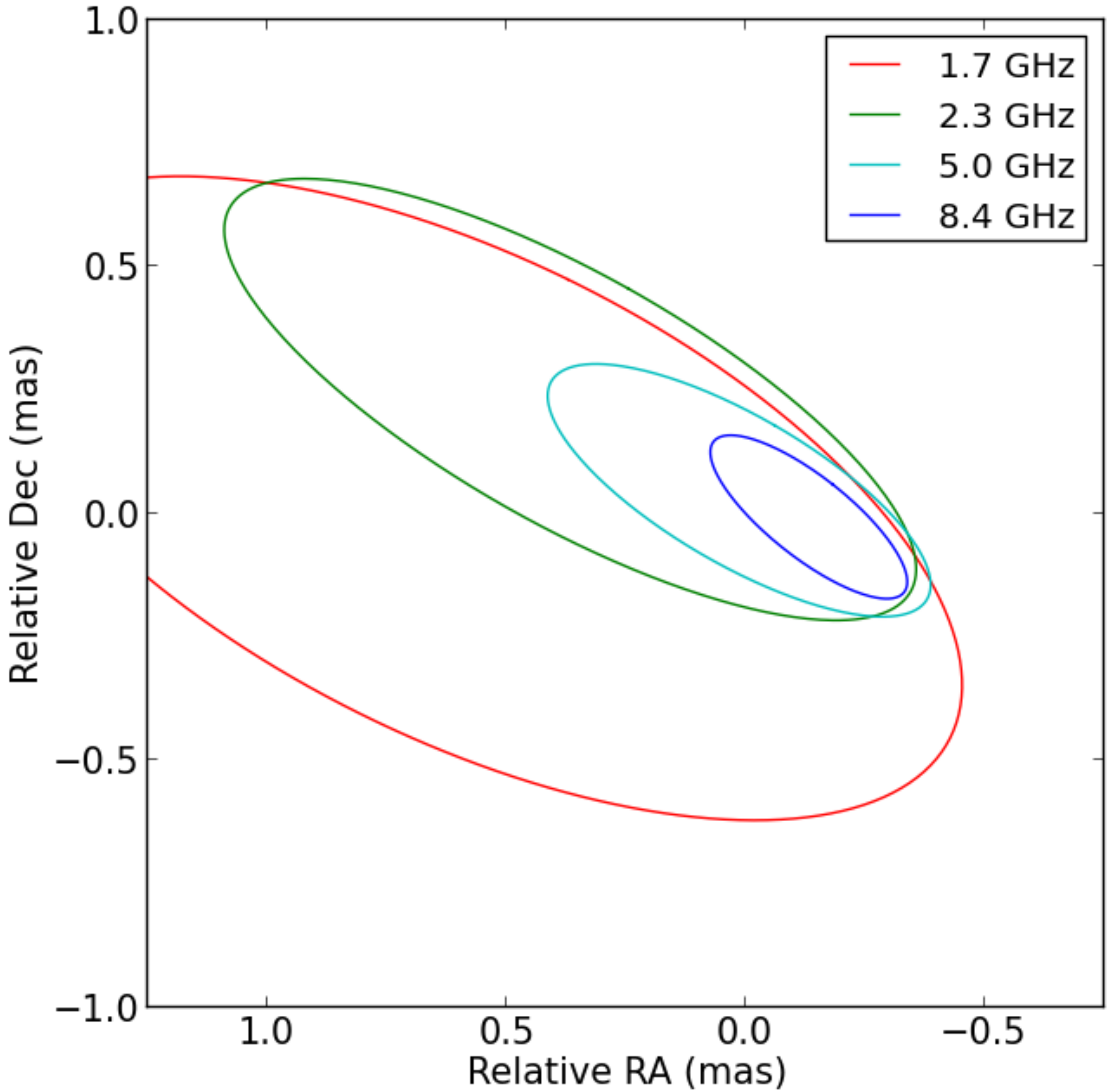


Position of the brightness peak


Time
evolution
of P.A.
Core position angle (deg)
Epoch (year)
5.0 GHz
75
70
65
60
55
1996
1998
2000
2002
2004
2006

Core Flux Density

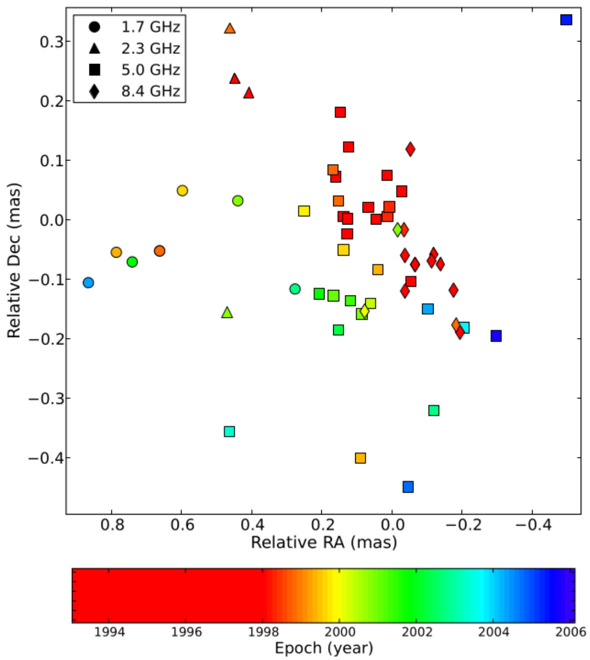


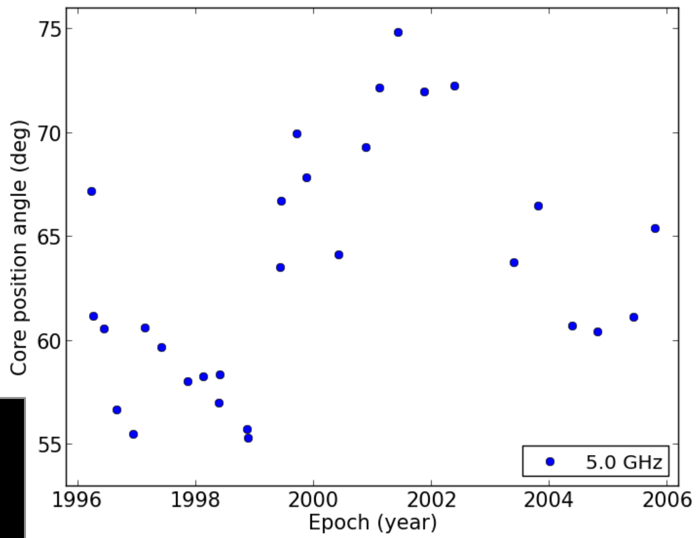


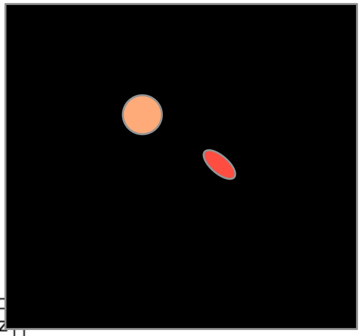
1.7 GHz
2.3 GHz
5.0 GHz
8.4 GHz
Relative Dec (mas)
Relative RA (mas)
1.0
0.5
0.0
−0.5
−1.0
1.0
0.5
0.0
−0.5

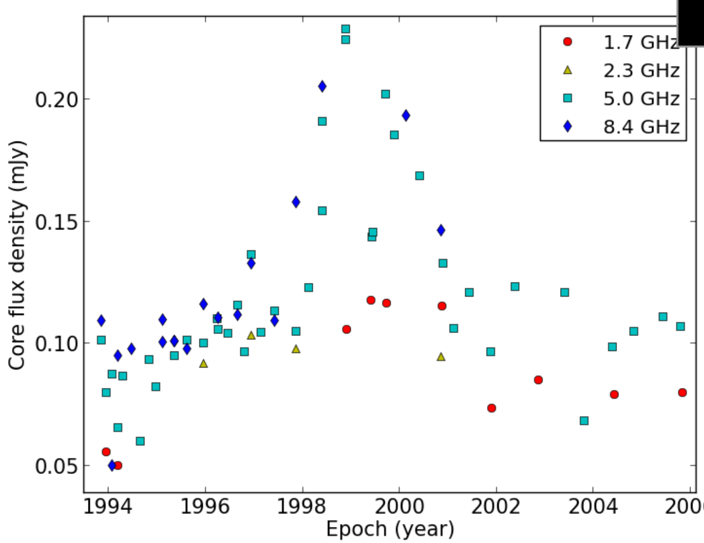
M81. VLBI results

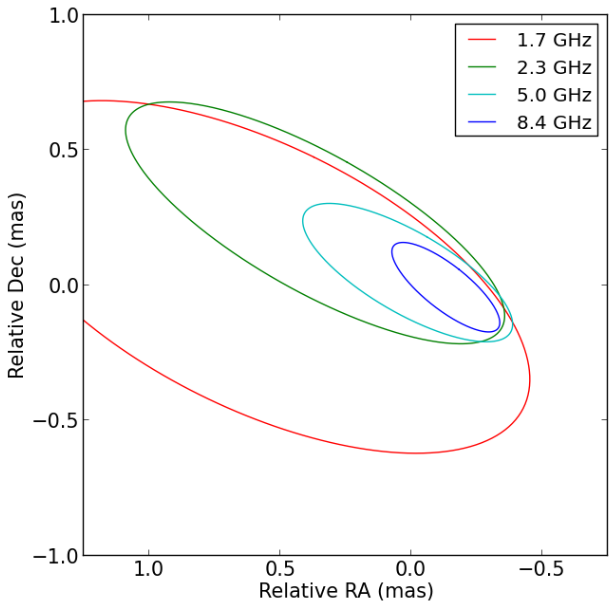
EVOLVING CORE INCLINATION AND LUMINOSITY





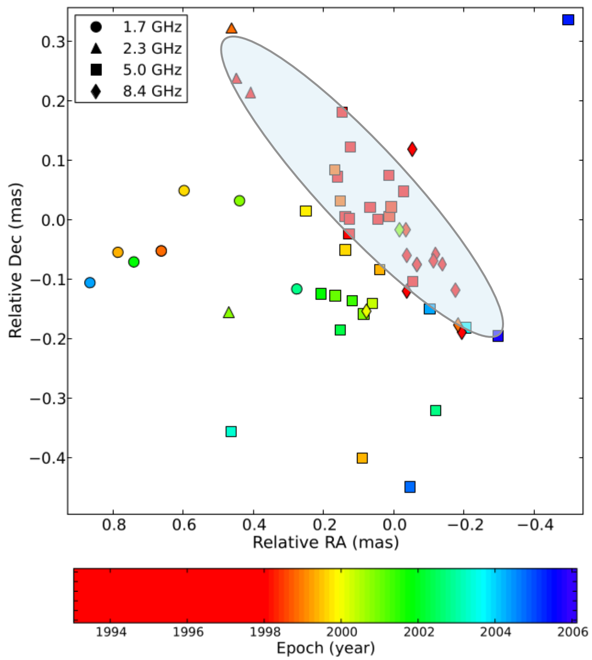


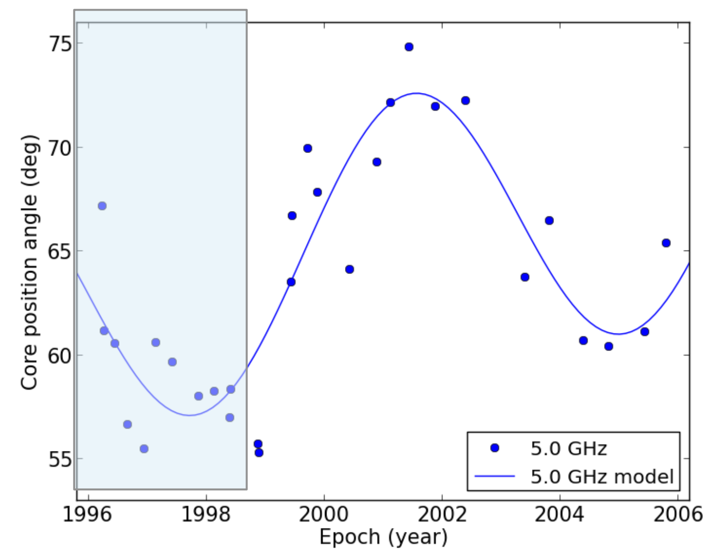


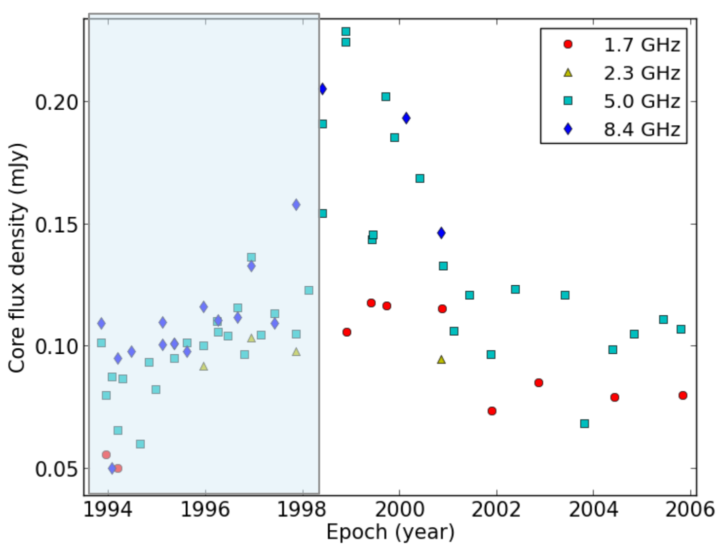


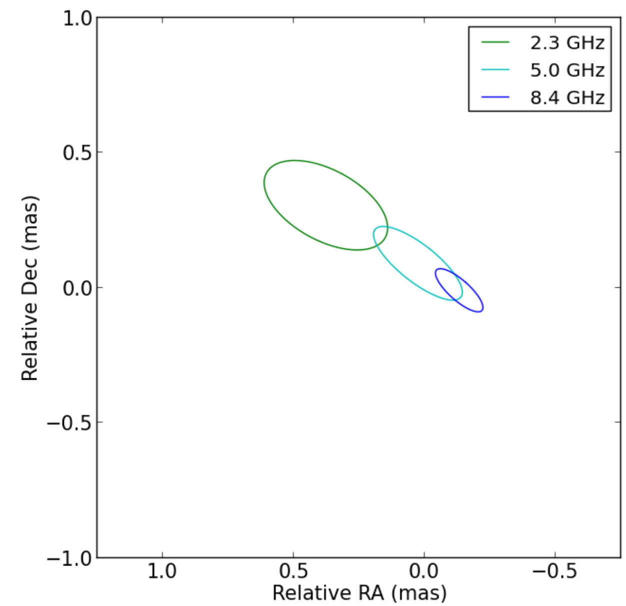
M81. VLBI results

EVOLVING CORE INCLINATION AND LUMINOSITY



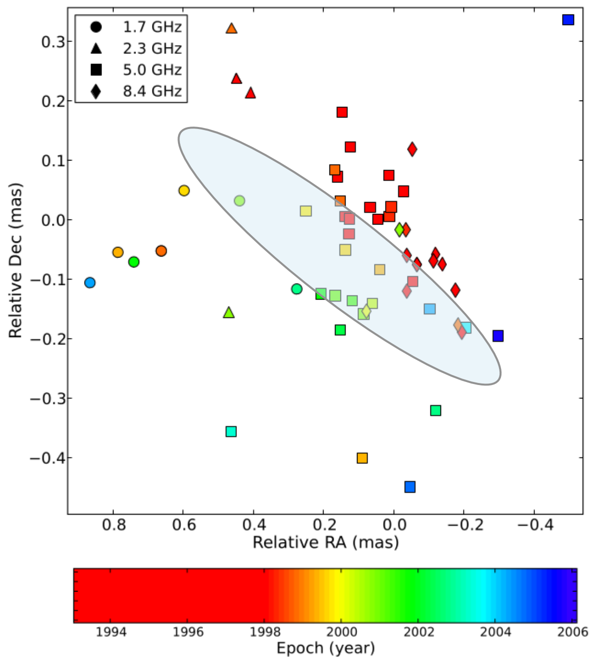


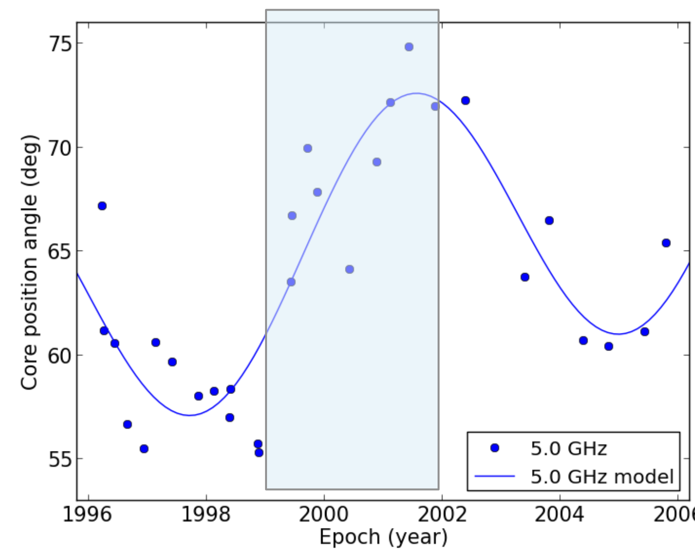


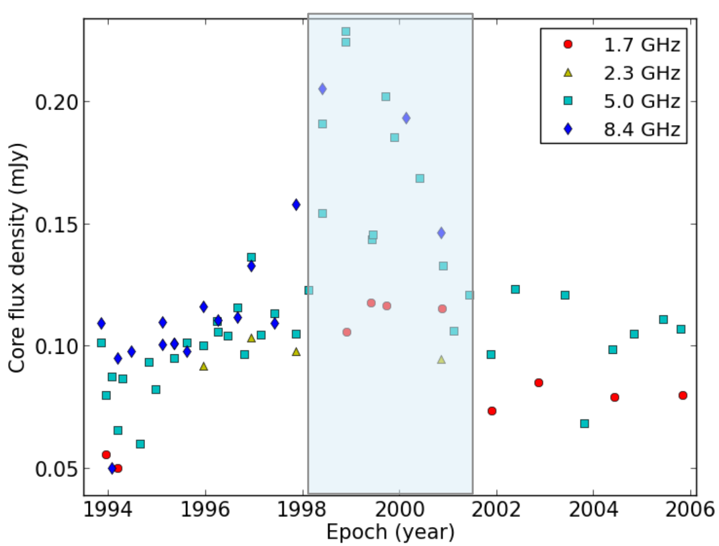


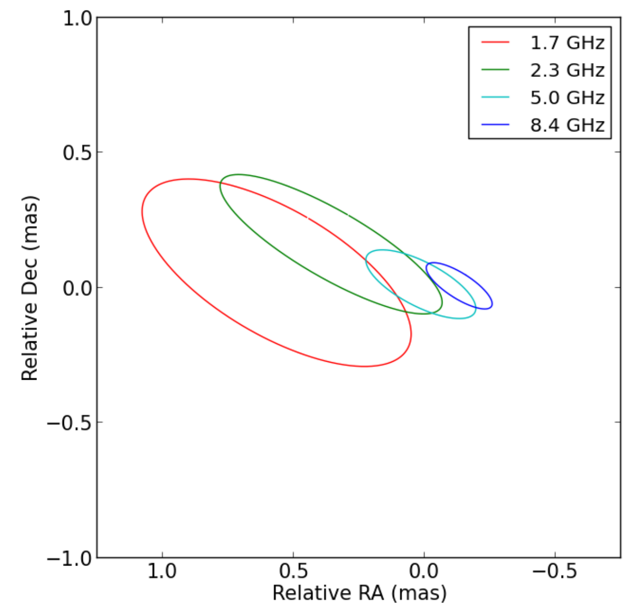
M81. VLBI results

EVOLVING CORE INCLINATION AND LUMINOSITY









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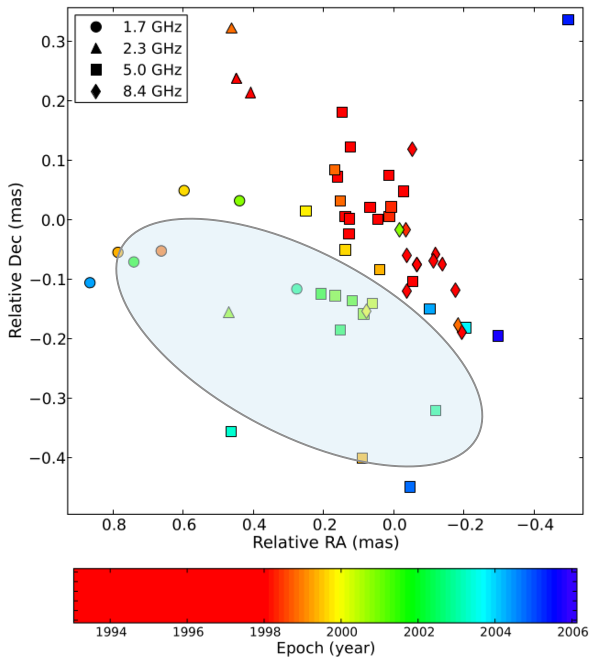

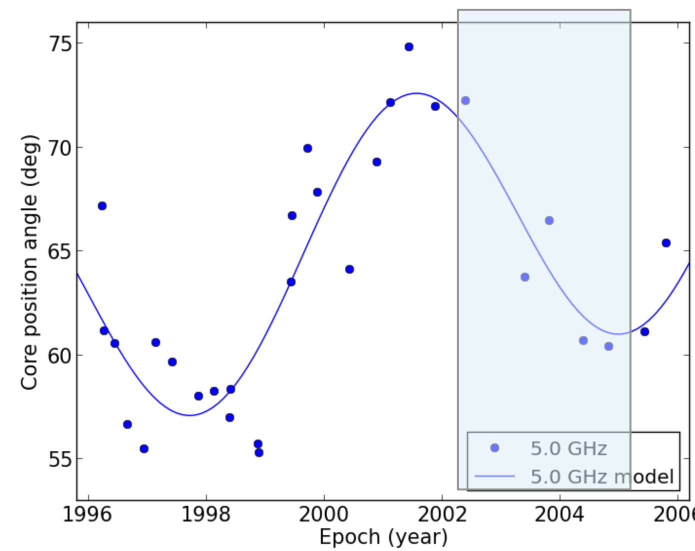

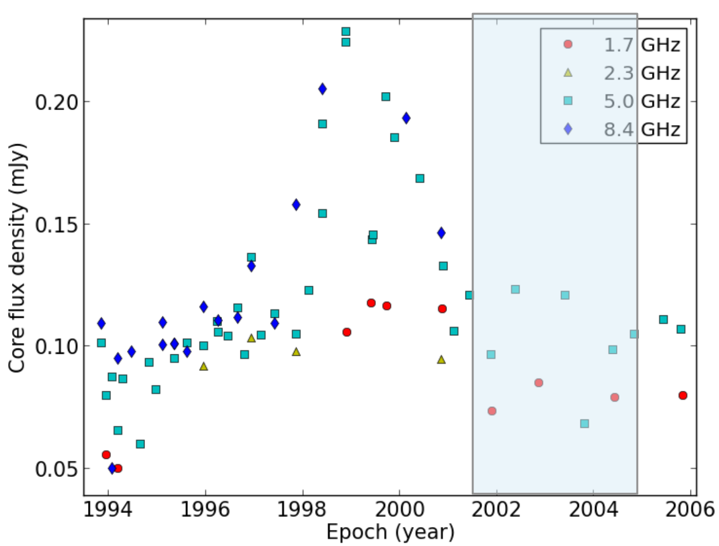

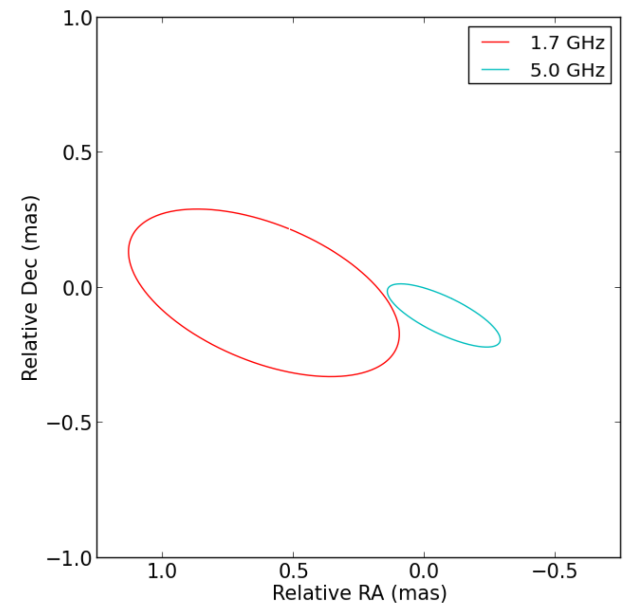

M81. VLBI results

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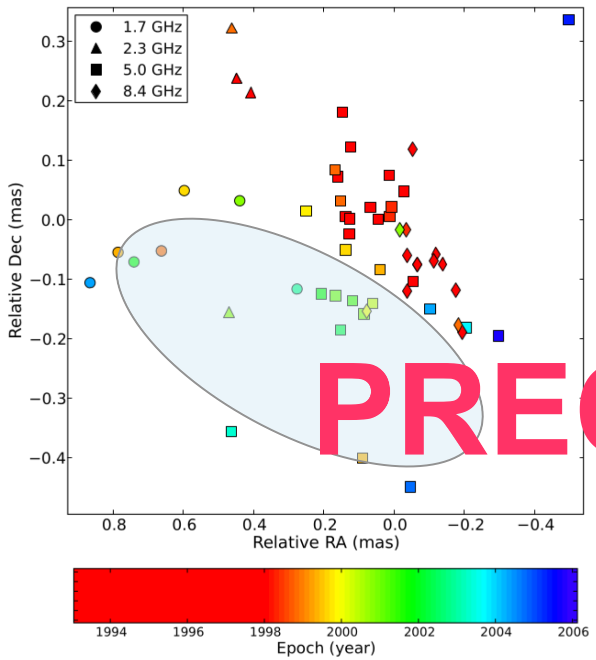
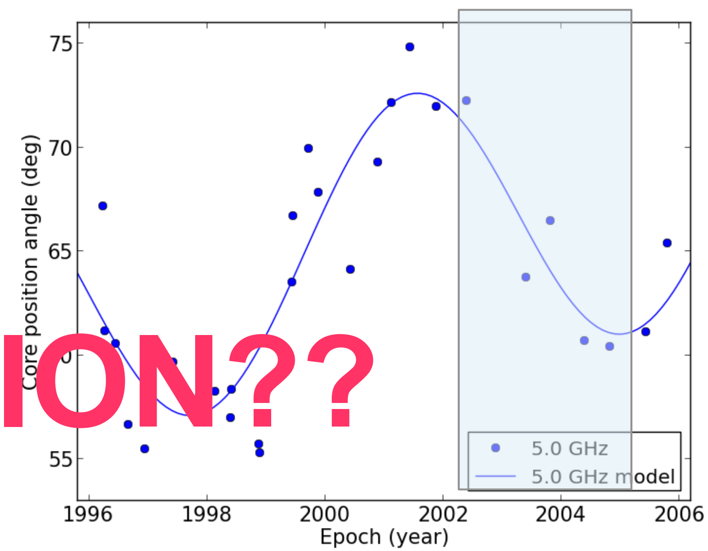
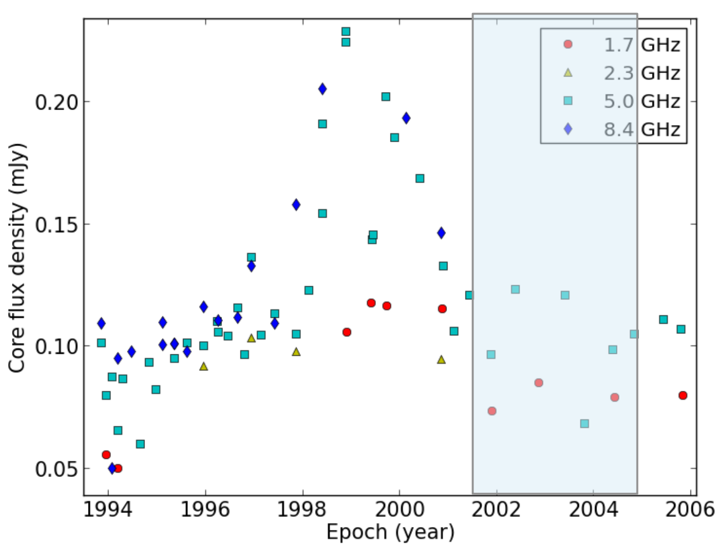
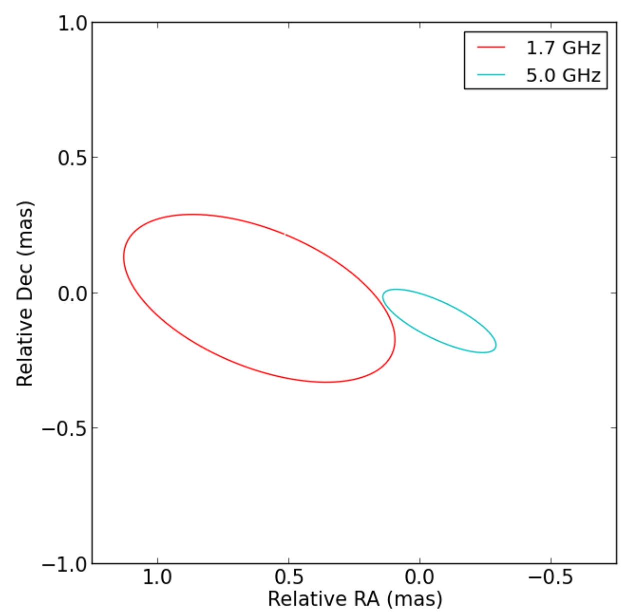




PRECESSION??





M81. JET PHYSICAL CONDITIONS

(see eqs. in, e.g., Lobanov 1998)

-Knowing the distance (3.63 Mpc), we derive the *linear* core-shift:

$$\Omega \sim 0.031\,\mathrm{pc\,GHz}$$

-Knowing the galaxy inclination (~14 deg.), the AGN flux density, and the jet opening angle, we derive the (equipartition) magnetic field at the core :

$B_{\mathrm{core}}(\nu) \approx \nu^{m/k_{\mathrm{r}}} \left[\frac{\Omega_{r\nu}}{(1+z)\sin\theta}\right]^{\zeta} F^{-1/k_{\mathrm{b}}}$ 7, 10, 21, and 34 mG (1.7, 2.3, 5.0, 8.4 GHz)

-Extrapolating these magnetic fields to 1pc: $B_1 \approx 2.92 \cdot 10^{-9} \left[\frac{\Omega_{r\nu}^3 (1+z)^3}{k_{\mathrm{e}} \delta_{\mathrm{j}}^2 \phi \sin^5\theta}\right]^{1/4}$

… and assuming a magnetized black hole (critical B), we derive its mass:

$M_{\mathrm{bh}} \sim 2.7 \times 10^9 B_1\ M_\odot$ → M = 2 x 10^7 solar masses

M81. JET PHYSICAL CONDITIONS

-The magnetic fields is of the order of 10-50 mG.

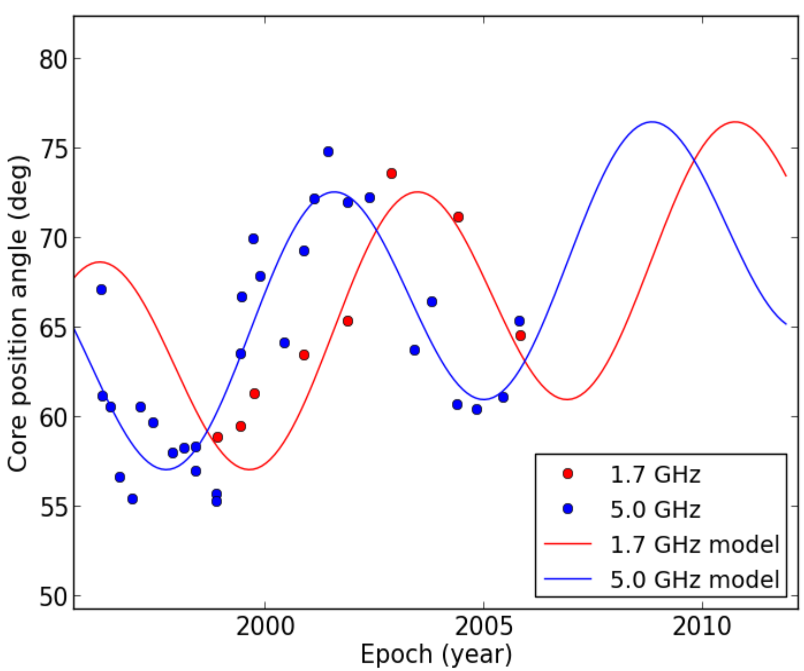
However, 10s of Gauss are necessary to model the inverted spectrum, provided it is optically thick (Reuter & Lesch 1996). Much lower B can be fitted if the emission Is optically-thin (i.e., mono-energetic electron distribution), but this model is not consistent with the core-shift scenario.

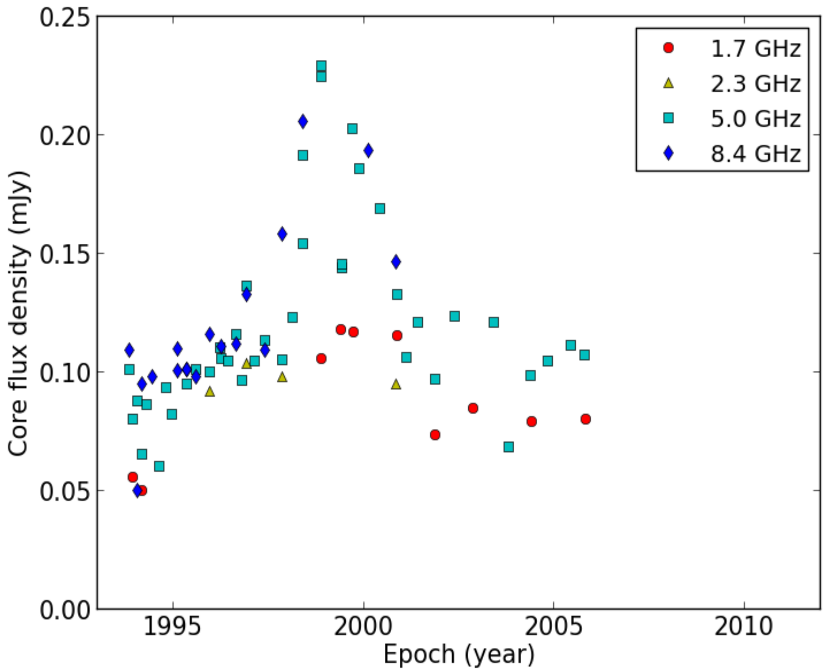
- **A mass of 2 x 10^7 solar masses** is in good agreement with that derived from the kinematics of the central disc of gas (7 x 10^7 solar masses, Devereux et al. 2003) and that derived from the stellar velocity dispersion at the bulge (5.5 x 10^7 solar masses, Schorr-Muller et al. 2011).

Morever, our mass estimate should be considered, indeed, as a lower limit, obtained by imposing a critical magnetic field to the SMBH neighborhood.

M81. Jet Precession (i)

We have shown there is evidence of Jet Precession → The observed range of changes in PA and flux density variability can be explained with γ=10-20 and deprojected variations of 2-4 deg in the θ_{LOS} (between 12 and 16 degrees).





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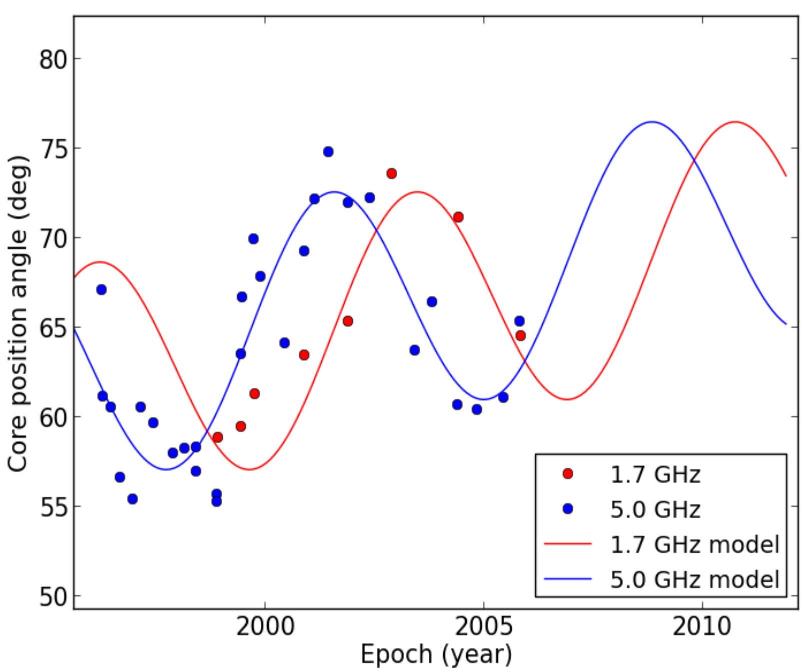
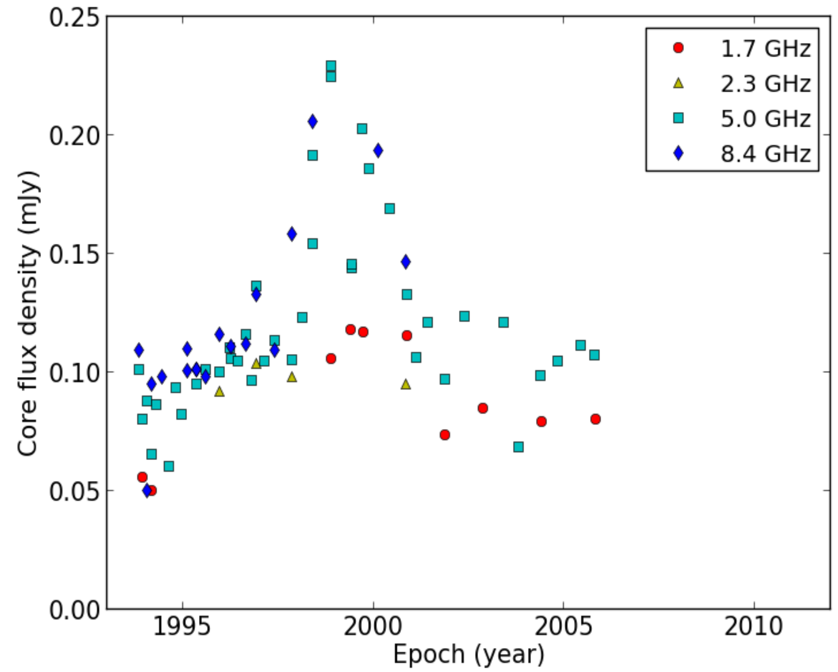
M81. Jet Precession (ii)

The fitted period of 7.3±0.1 yrs cannot be properly established (it is comparable to the dataset). In any case, it is very short compared with typical precession timescales.





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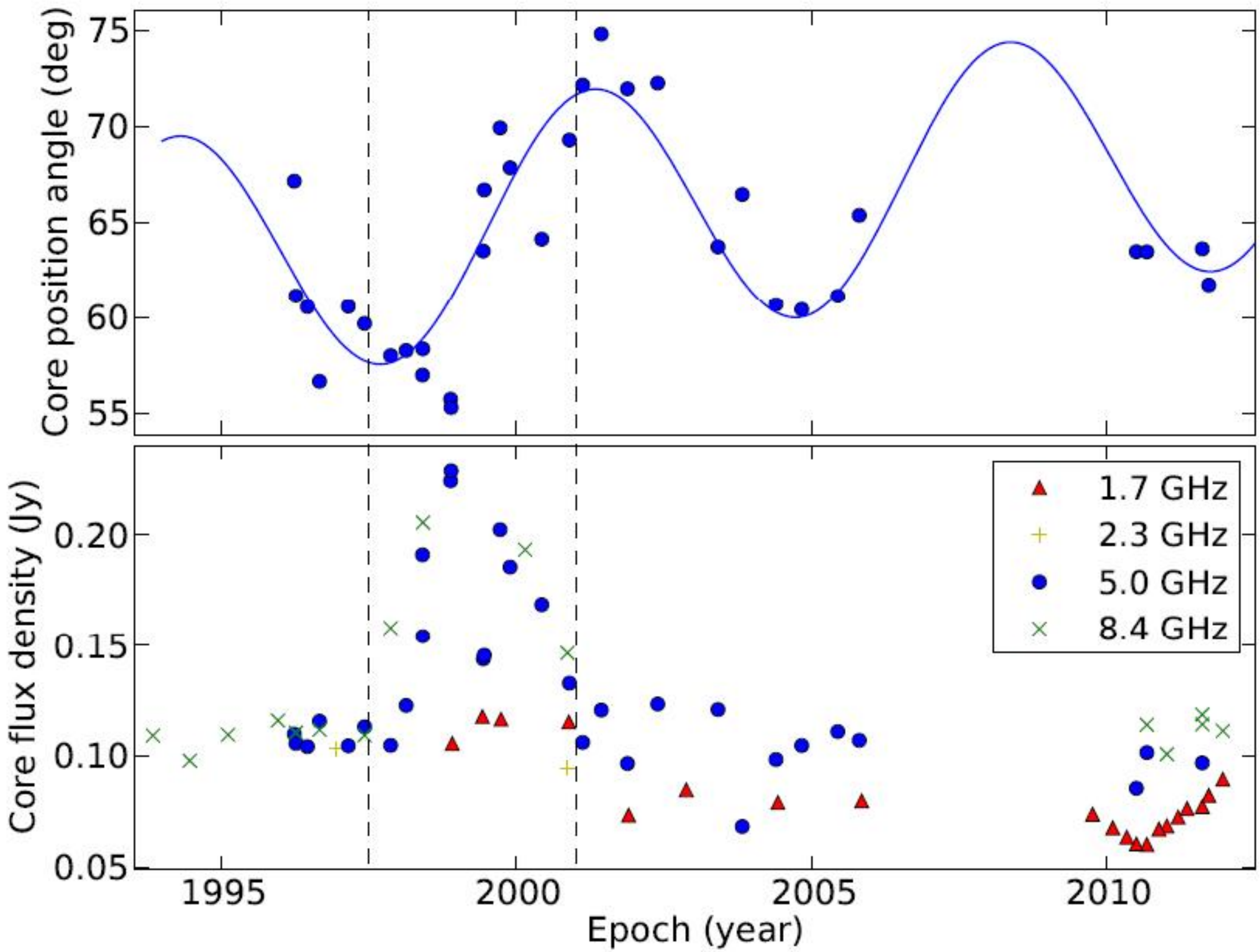
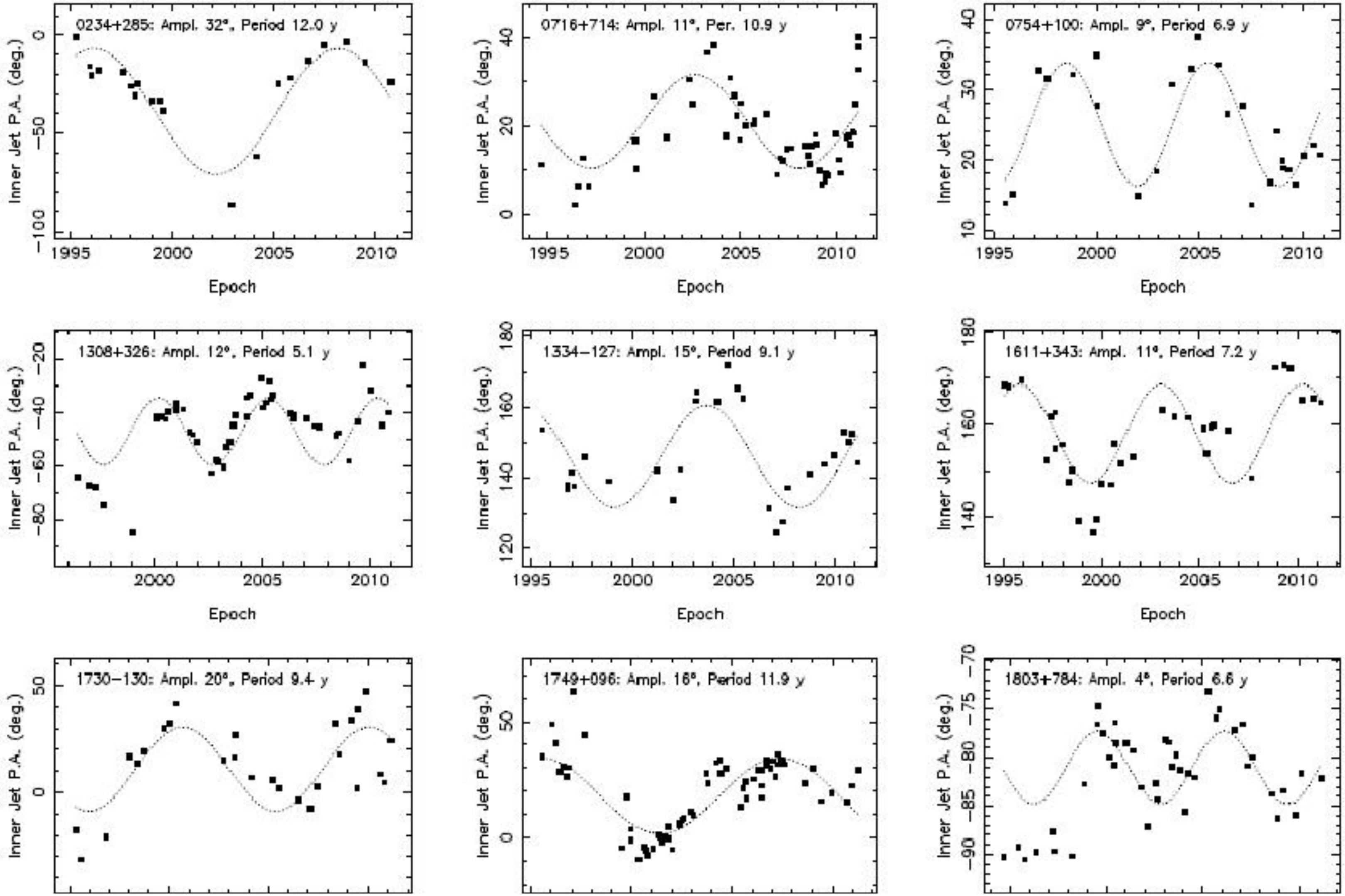
M81. Jet Precession (iii)

We have extra VLBI observations, phase-referenced to supernova SN2008iz in M82. Monitoring is ongoing at several frequencies.



MOJAVE Jets displaying oscillatory trends



“We favor a conical jet model in which emerging features do not fill the entire cross-section of the flow. […] What is typically visible are lit up portions of thin-ribbon like structures embedded within a broader conical outflow. […] According to Perucho (2012) these ribbon structures may arise from helical Kelvin-Helmholtz pressure maxima within the jet.” (Lister et al. 2013)

Conclusions

-We have analyzed a complete set (12 years; multifrequency) of VLBI observations of M81*, phase-referenced to SN1993J

- We find a clear and long (~3-4 years) flare in the radio emission of M81 that seems to be directly related to changes in the source geometry (hence independent of the disc-jet connexion).

-The flare happens to occur on a time range where the position angle of the cores at all frequencies (referred to a fiducial point on the sky) increase systematically.

-- The position angle of the Gaussian fitted to the core evolves in a sinusoidal way (period of 7.3 years) plus a long-term component.

-- We have obtained estimates of the mass (based on a strongly magnetized BH scenario) and the magnetic field (based on the derived (linear) core-shift and jet opening angle).