Radio Loud Black Holes

An observational perspective

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Overview of the first lesson

1) **Synchrotron emission and radio spectra of AGN**

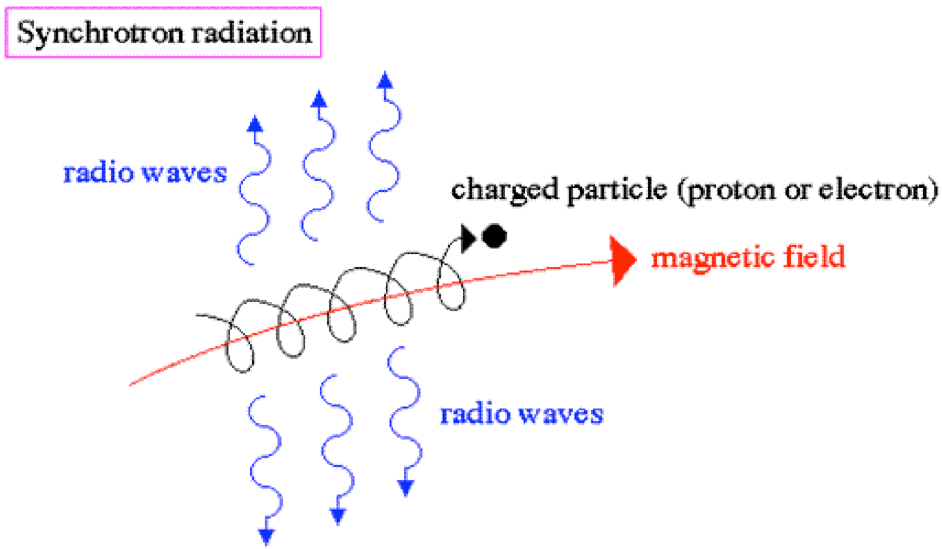
2) **Classification of radio galaxies and large scale morphology**

3) **A unified view of radio galaxies**

4) **Parsec-scale radio observations of AGN** - *Lorentz factors and viewing angles*

5) **Compact flat spectrum radio sources** – *variability and statistics of beaming parameters*

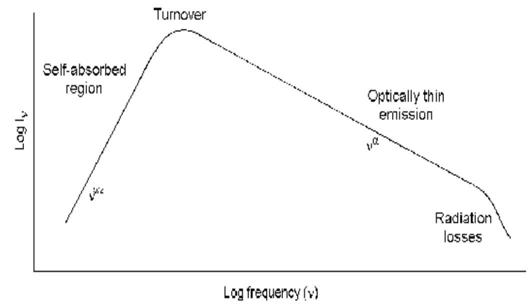
Synchrotron Emission and Spectra of Extragalactic Radio Sources



For a population of electrons with:

$$\mathbf{N}=\mathbf{N}_o e^{-\delta}$$

The resulting spectrum has the form:



$$\mathbf{S} \propto \nu^{-\alpha}$$ **with** $$\alpha = \frac{\delta - 1}{2}$$

Radio Loudness and AGN hosts

Radio Loudness parameter defined as:

$$R = F_{5\ \mathrm{GHz}}/F_{\mathrm{B}}$$

R > 10 *(Kellermann et al. 1989)*

R > 2 - 3 *(Capetti et al. 2006)*

Radio loud AGN are located in elliptical galaxies, but only

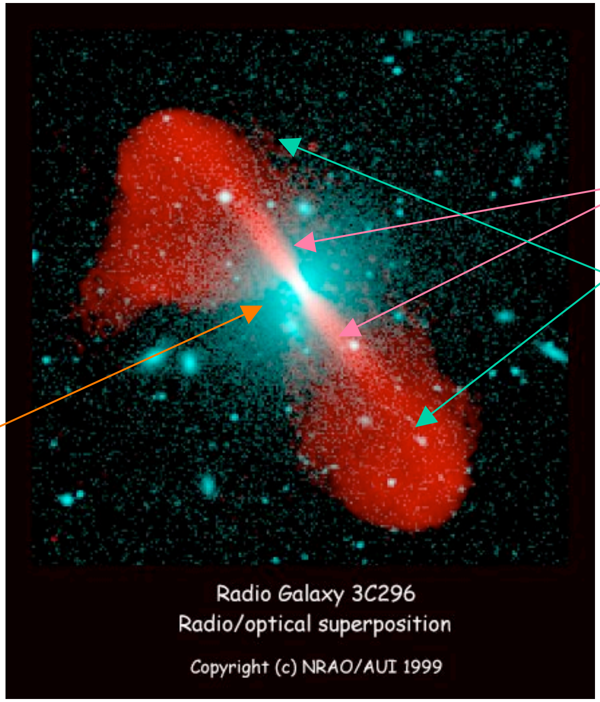
~ 10% of such galaxies hosts a radio source of nuclear origin

Classification of AGN from the power and morphology of the radio emission

Radio loud AGN are classified into two classes of radio power, which also correspond to different morphological classes

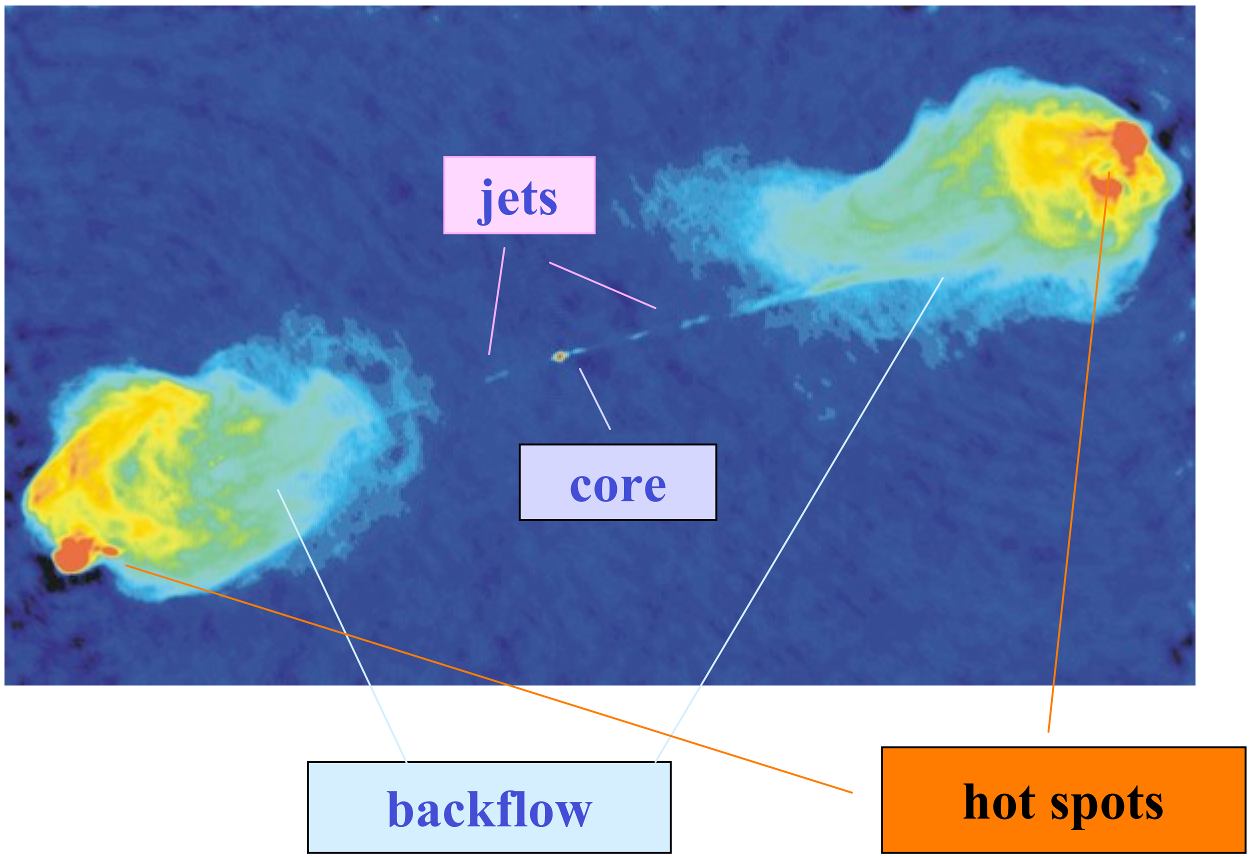
FR I radio galaxies typically have radio power

$$P_{178\ \mathrm{MHz}} < 10^{25}\ \mathrm{W/Hz}$$

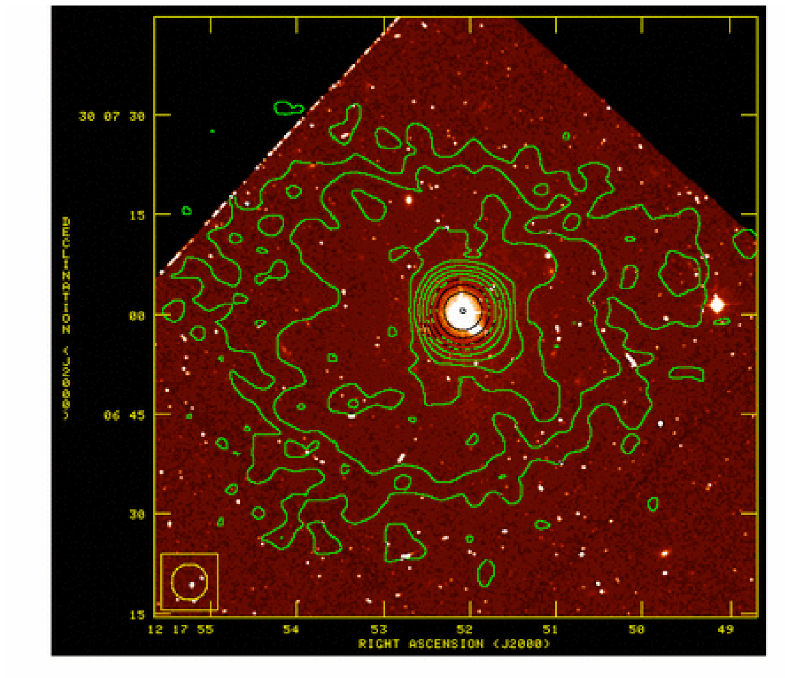


FR II radio galaxies typicall have radio power

$$P_{178\ \mathrm{MHz}} \geq 10^{25}\ \mathrm{W/Hz}$$

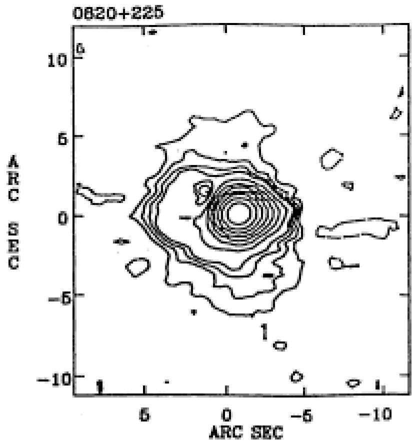


Both low power and high power classes host also compact sources



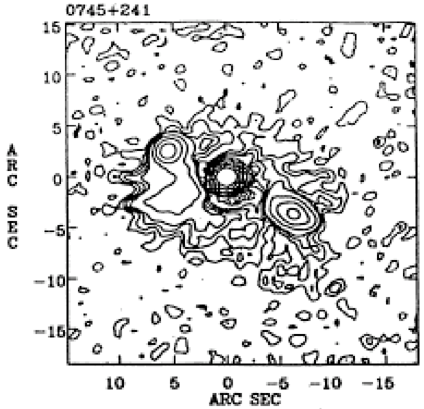
BL Lac 1215+303

Giroletti et al. 2005



QSOs

Murphy et al. 1993

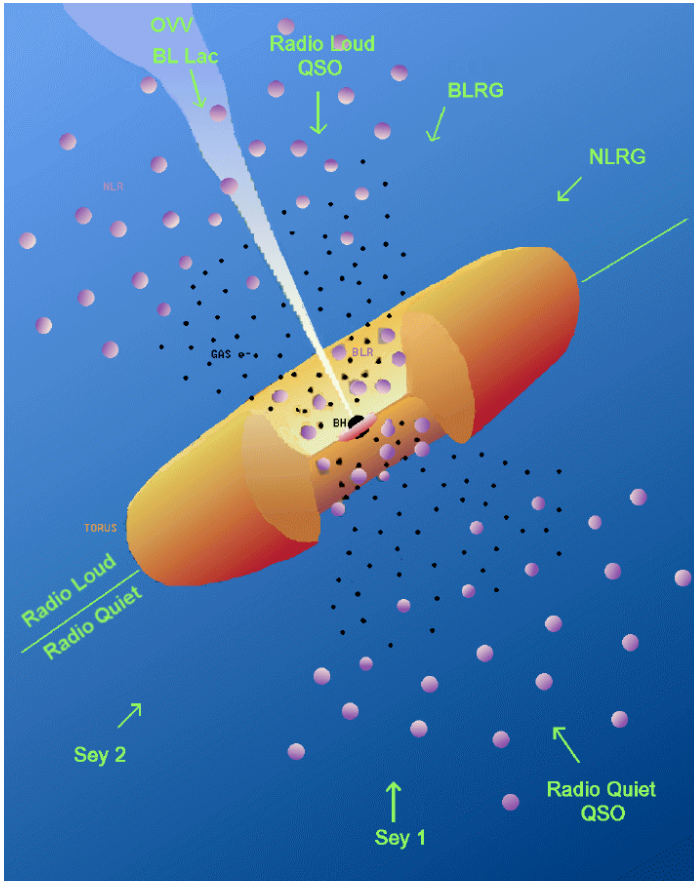


Unified view of Radio Loud AGN

Low power

$P_{178\ \mathrm{MHz}} < 10^{25}\ \mathrm{W/Hz}$

Are FR I radio galaxies the parent population of BL Lacs seen at large viewing angles?



High power

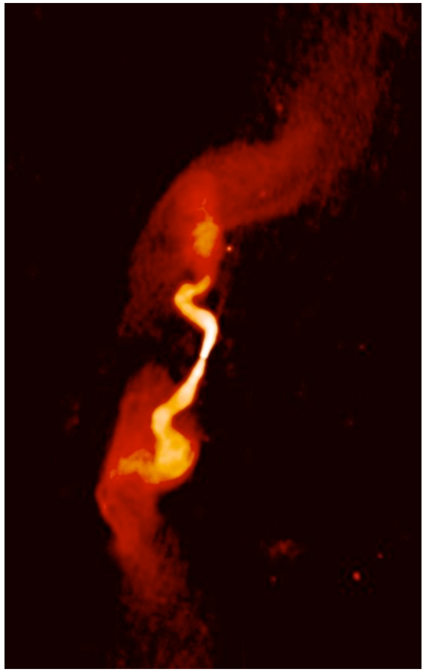
$P_{178\ \mathrm{MHz}} \geq 10^{25}\ \mathrm{W/Hz}$

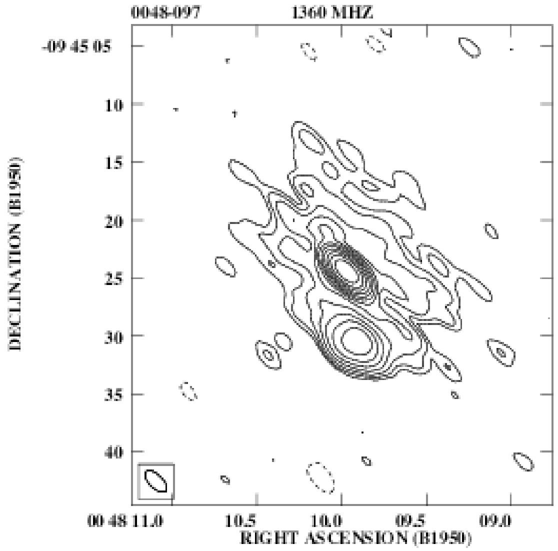
Are FR II radio galaxies the parent population of flat spectrum radio quasar seen at large viewing angles?

If the answer is YES, then we expect the two populations in each class to share similar intrinsic properties, i.e. same Lorentz factor , same polarization properties, …

FR I

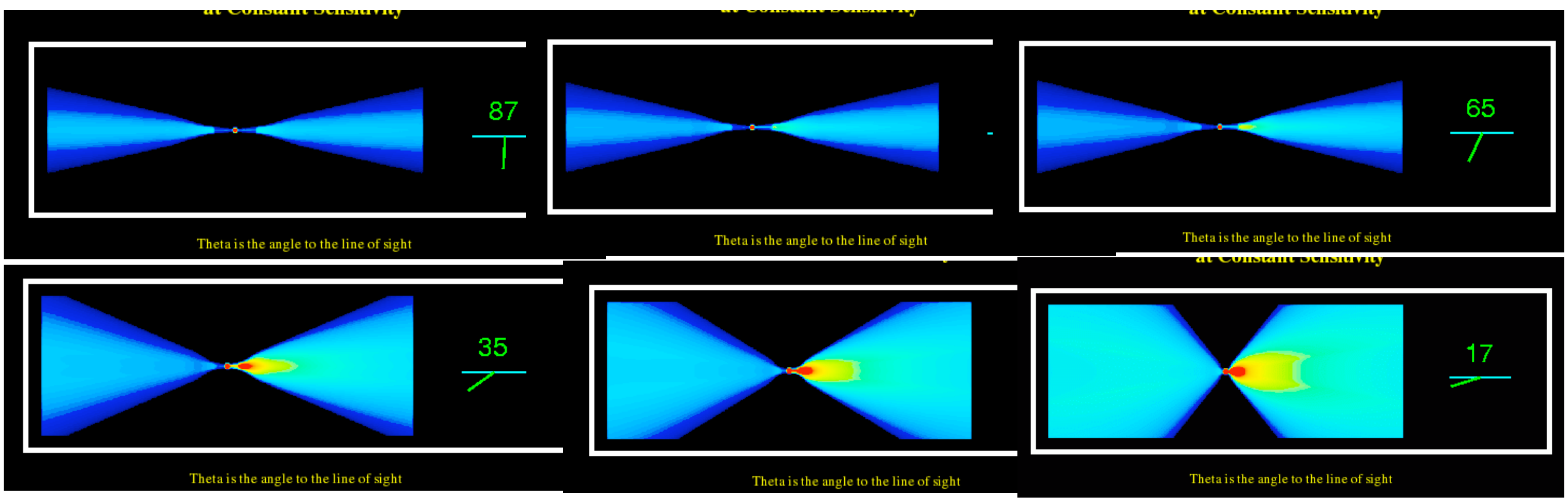
3C31



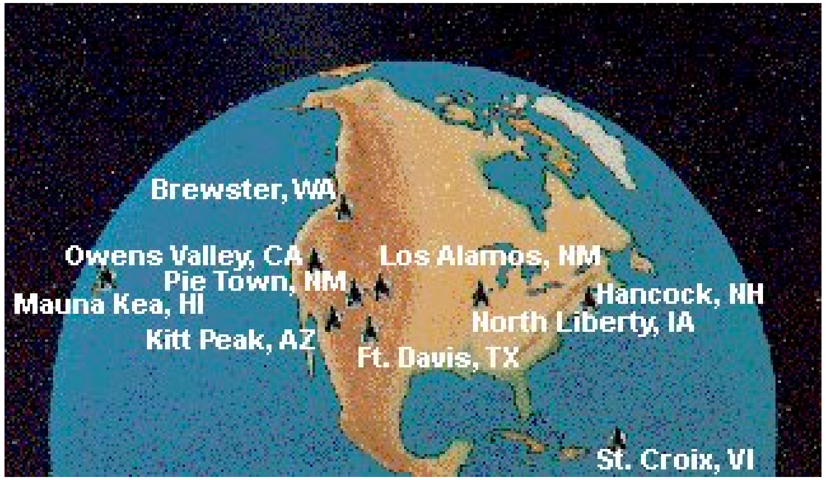


BL Lac

0048-097



Very Long Baseline Interferometry probes the parsec-scale region in radio loud AGN



European VLBI Network

1.6 GHz – 22 GHz (6 GHz also)

5 to 0.3 mas

z=0.01	->	1 mas = 0.2 pc
z=0.1	->	1 mas = 1.8 pc
z=2	->	1 mas = 8 pc

Very Long Baseline Array

327 MHz – 43 GHz

22 to 0.17 mas

VLBI Observations as tools to

a) Test the unification model for radio loud AGN

b) Investigate the central regions of FRI and FRII radio galaxies

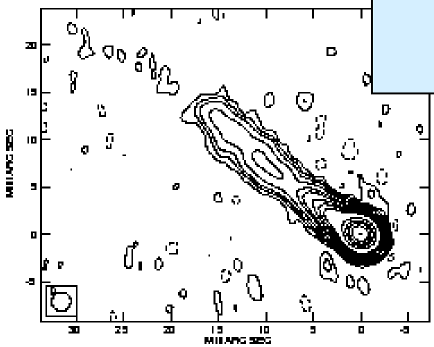
c) Study the medium surrounding the black hole

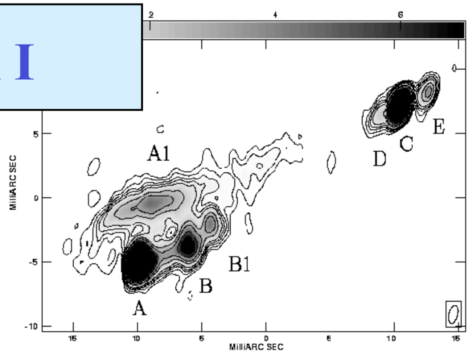
d) Study the "extreme" radio loud AGNs in the proximity of the central black hole

e) …

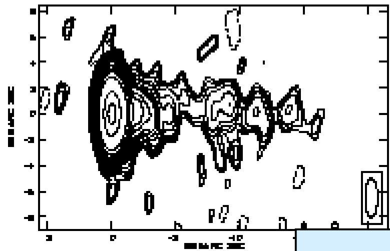
Central regions in FR I and FR II radio galaxies, radio loud QSOs and BL Lacs and unification models. The morphology

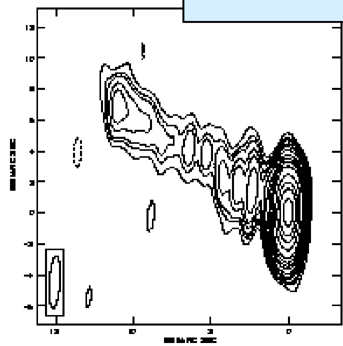
FR I

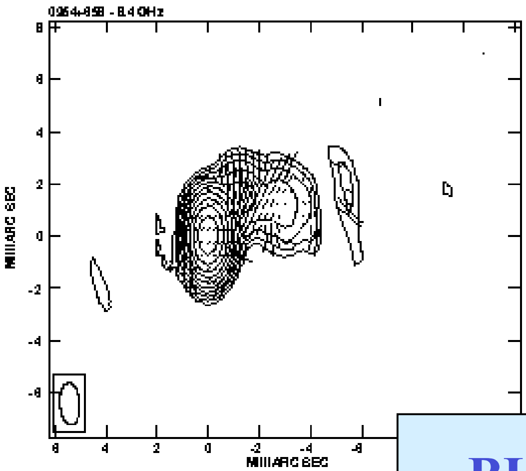


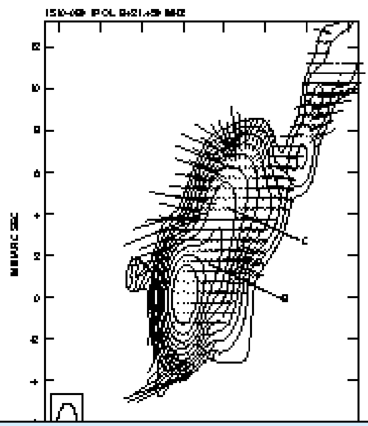


FR II





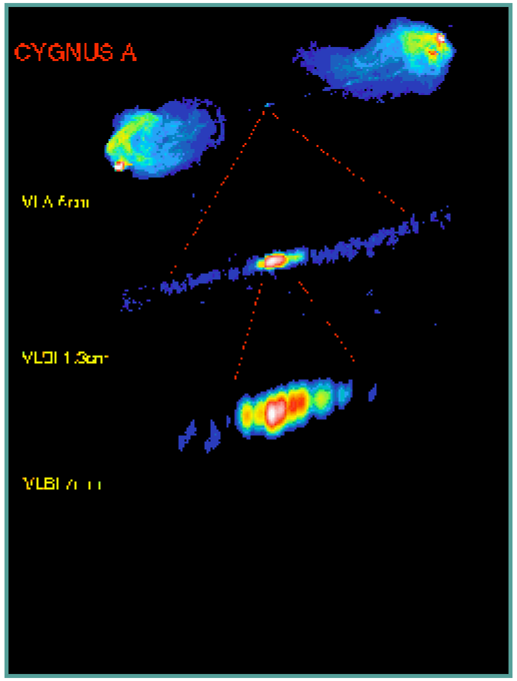




BL Lacs and RL-QSO

(Giovannini et al. 2001)

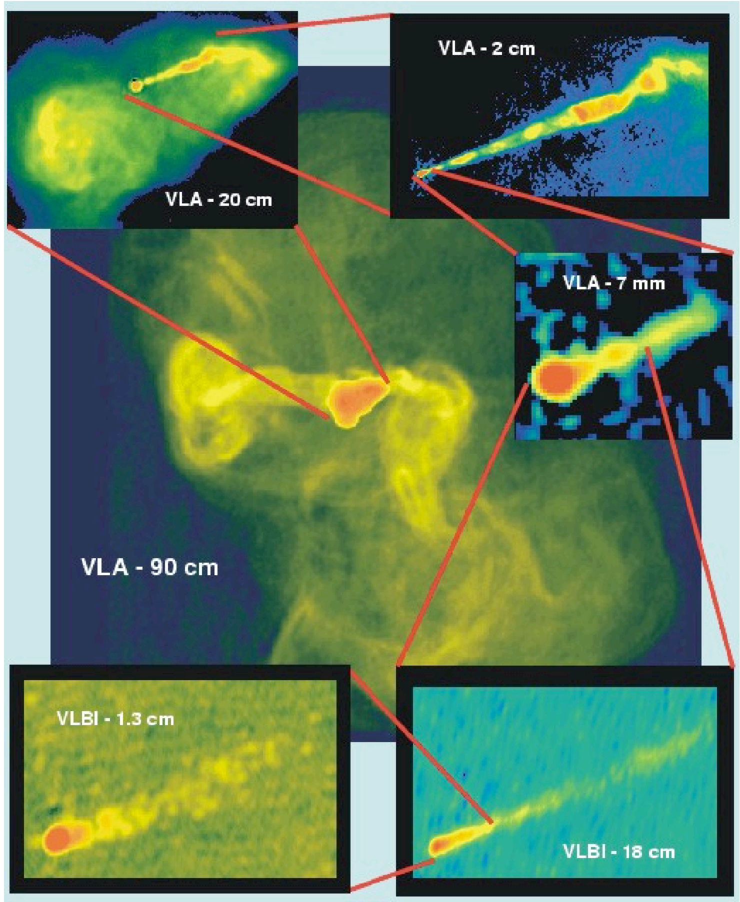
(Venturi et al. 2003)

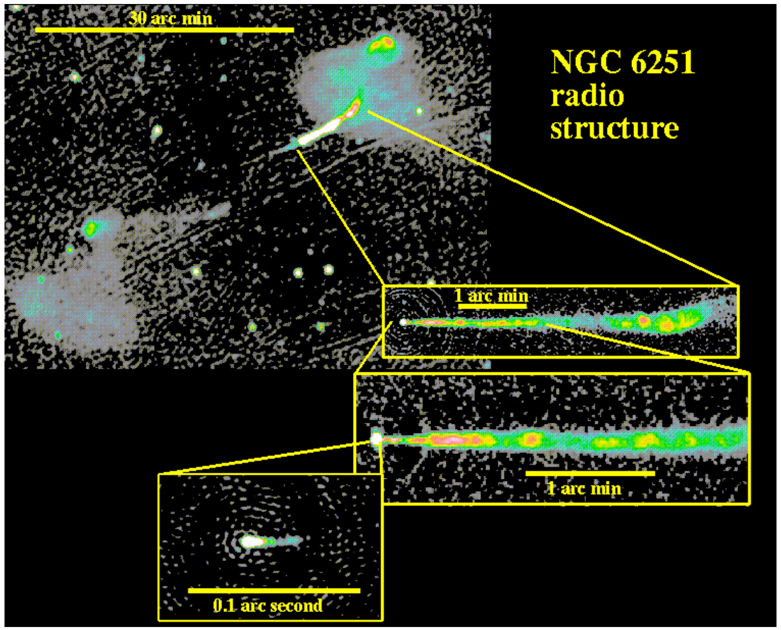


Cygnus A

FRII

M87 - FRI

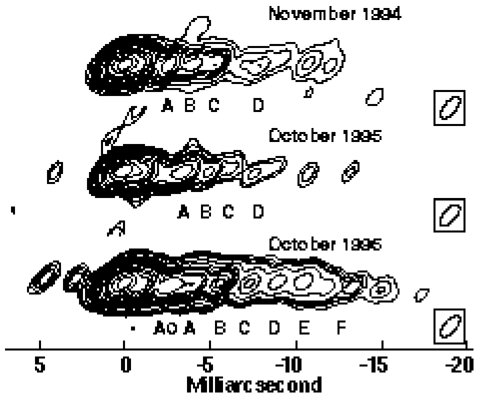


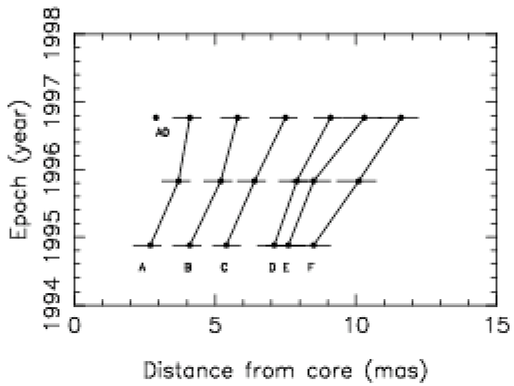


NGC6251

Central regions in FR I and FR II radio galaxies, radio loud QSOs and BL Lacs and unification models.

Proper motions in radio galaxies

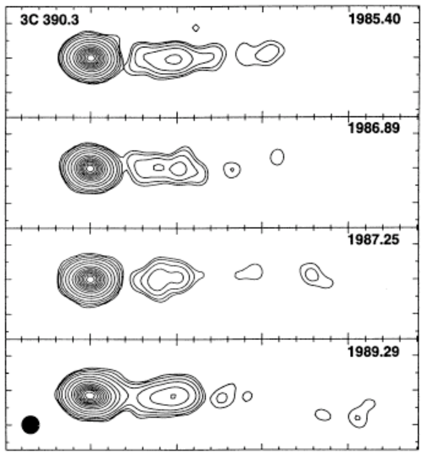


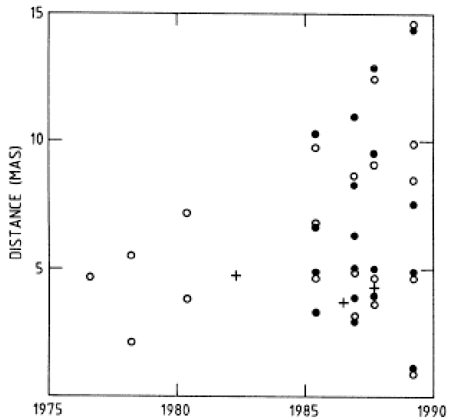


FRI NGC315

$$\beta(app) \approx 1.1 - 2.5h$$

Cotton et 1999





FRII 3C390.3

$$\beta(app) \approx 3.5h$$

Alef et al 1996

Information from the multiepoch parsec-scale radio imaging

Under the assumption that what we see is the result of relativistic beaming in an intrinsically symmetric source:

Apparent speed $$\beta_{app} = (\beta sin\theta)/(1 - \beta cos\theta)$$

Brightness ratio $$\beta_i cos\theta = (R^{1/(2+\alpha)} - 1)/(R^{1/(2+\alpha)} + 1)$$

↓

Lorentz Factor $$\gamma = (1 - \beta)^{-1/2}$$

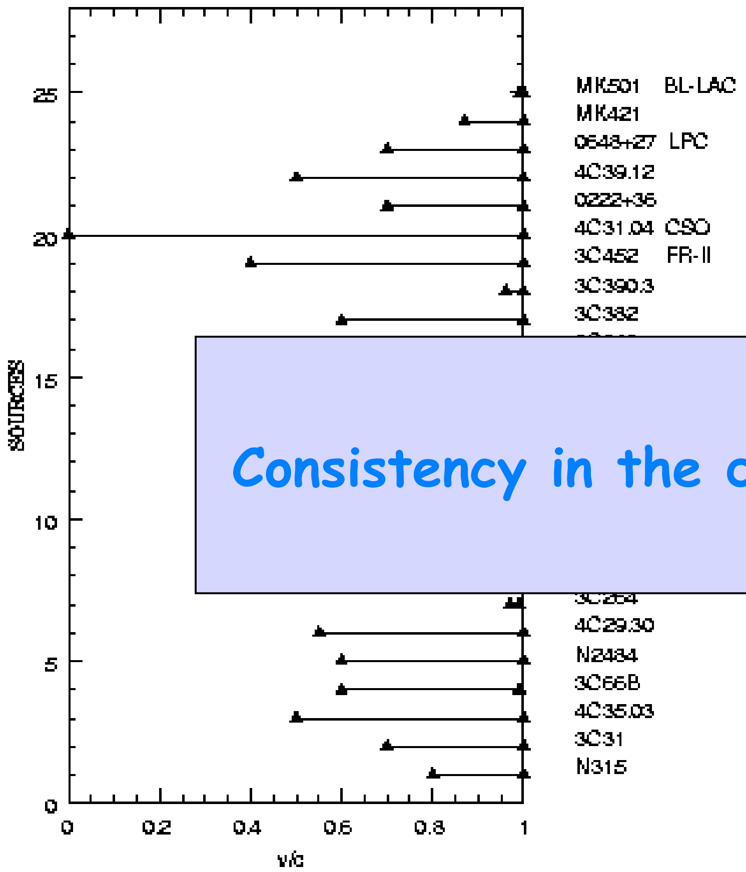
Doppler Factor $$\delta = [\gamma - (1 - \beta cos\theta)]^{-1}$$

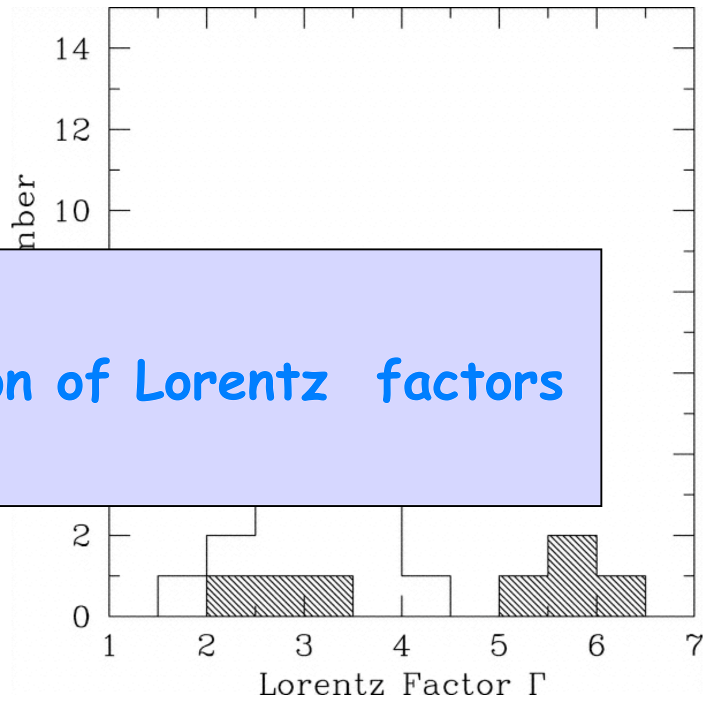
Sample of low power radio galaxies

(Giovannini et al. 2001)

Sample of neraby BLLacs

(Giroletti et al. 2004)

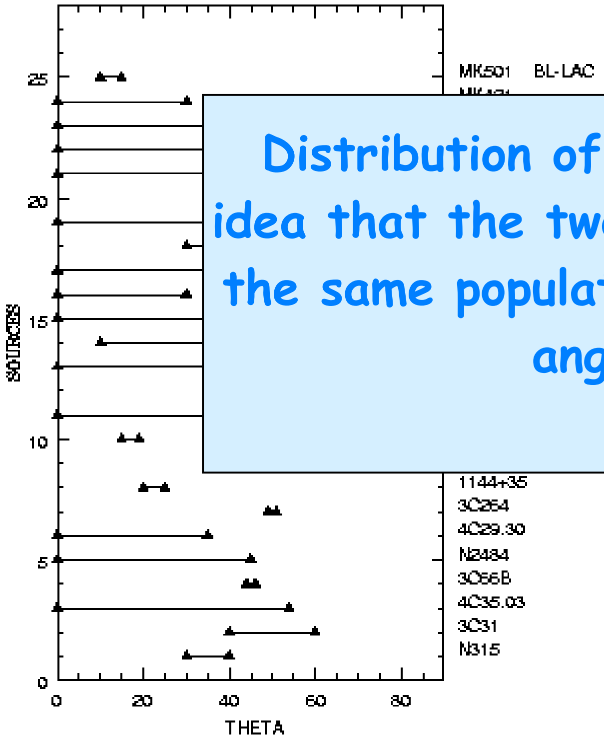




Consistency in the distribution of Lorentz factors

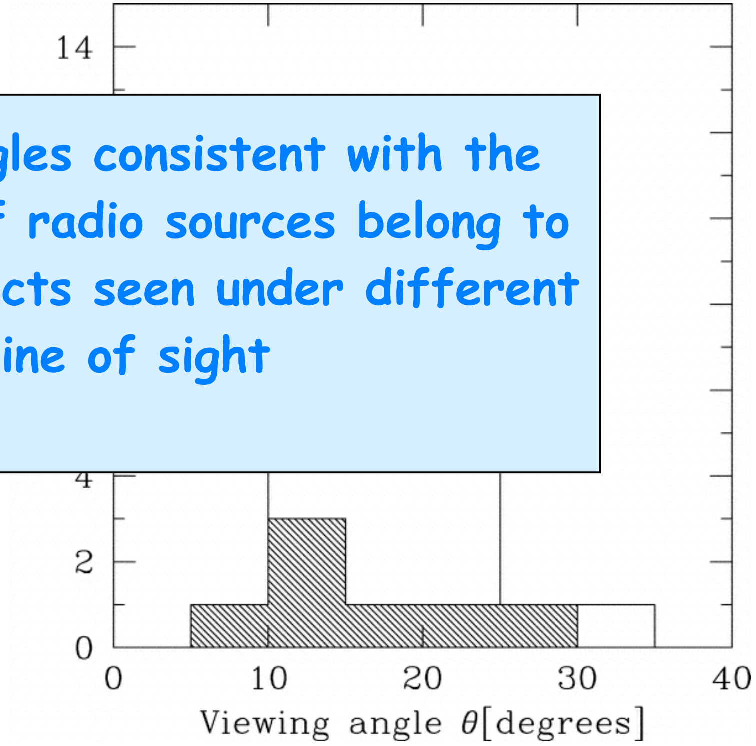
Sample of low power radio galaxies

(Giovannini et al. 2001)



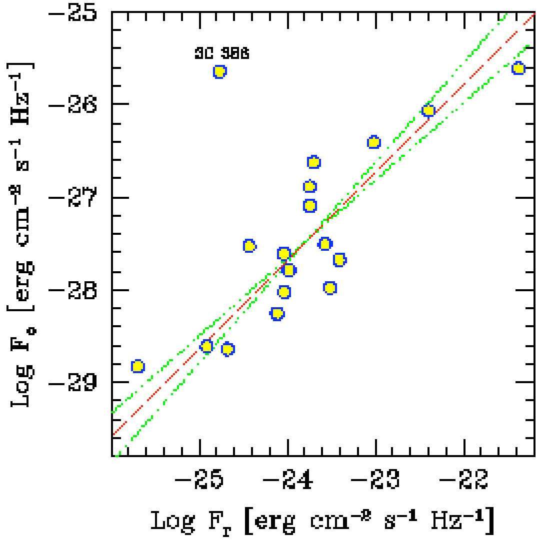
Sample of nearby BLLacs

(Giroletti et al. 2004)

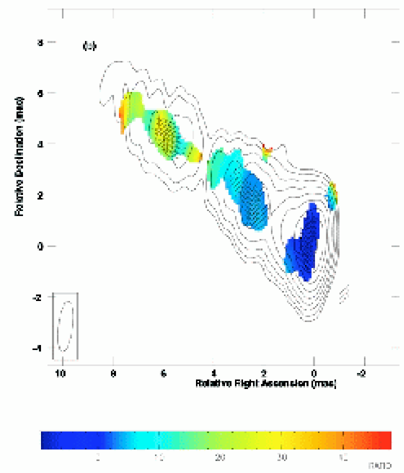


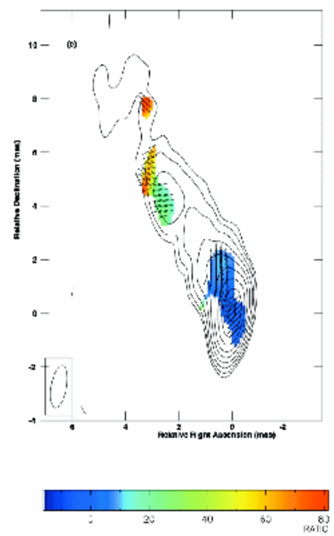
Distribution of viewing angles consistent with the idea that the two classes of radio sources belong to the same population of objects seen under different angles to the line of sight

Radio Polarimetry and the nuclear environment



HST observation of FRI nuclei suggset that no obscuring torus is present in such sources and that the BLR is indeed missing *(Chiaberge et al. 1999)*

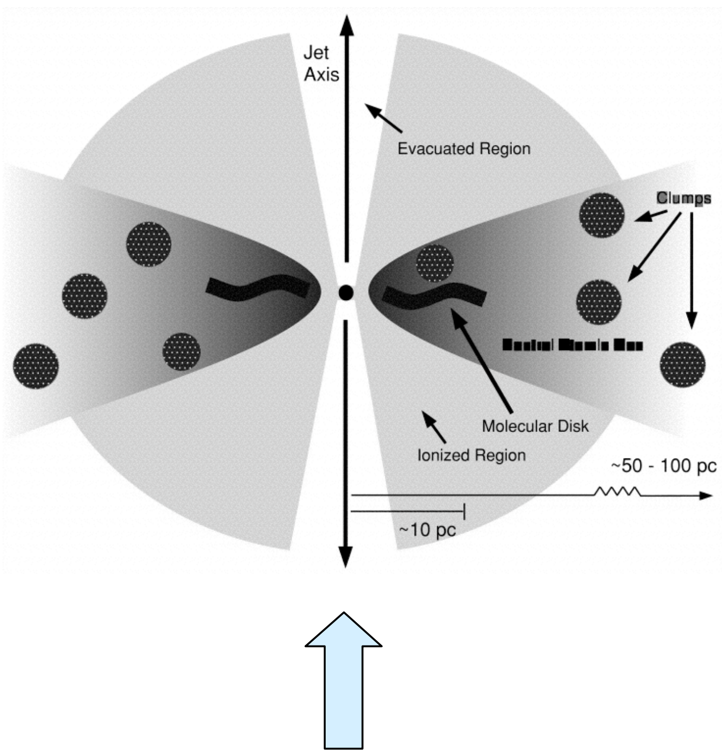




Polarimetric VLBI shows that the inner parsecs of FRI are polarized and this suggests the lack of a dense medium surrounding the core *(Kharb et al. 2005)*

The nuclear radio properties of highly beamed sources.

The Blazars World

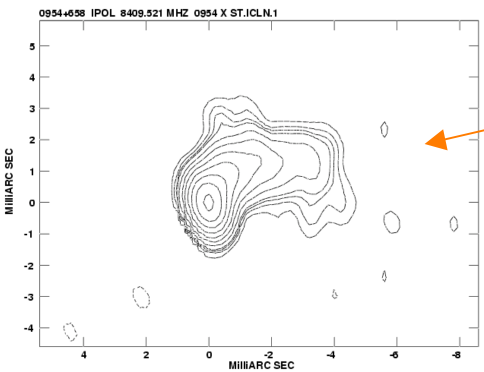


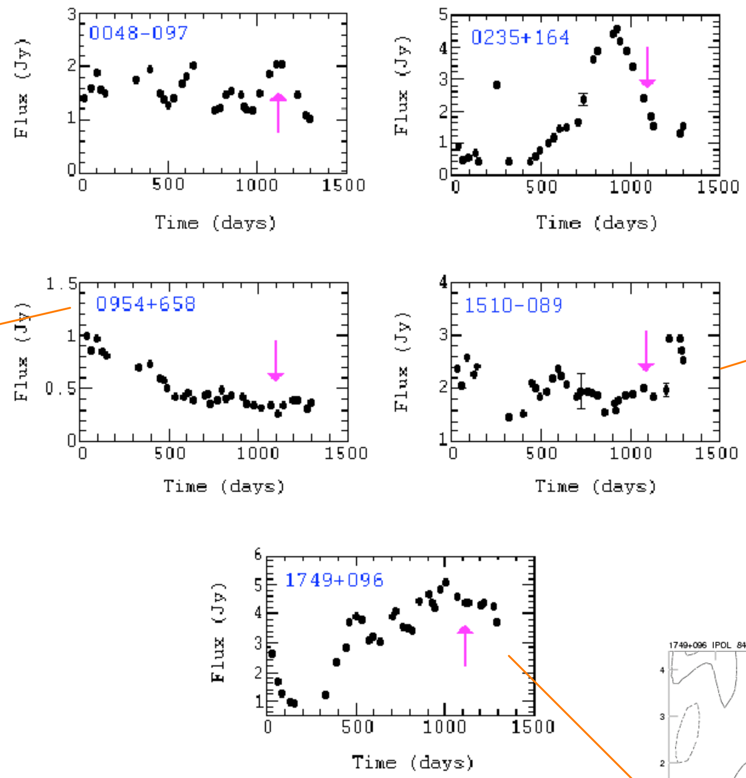
Observer

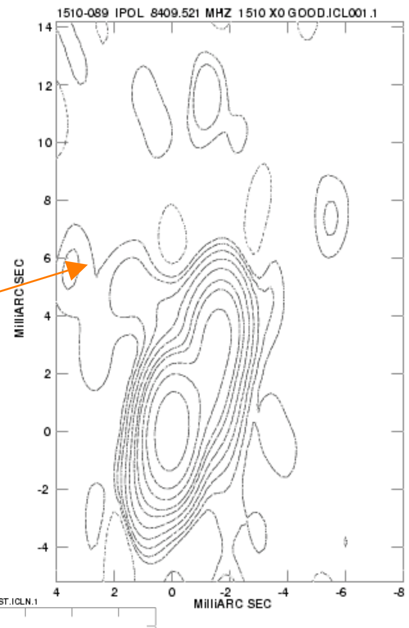
When we look at the powerful radio sources aligned at small angles to the line of sight, the most extreme properties are found:

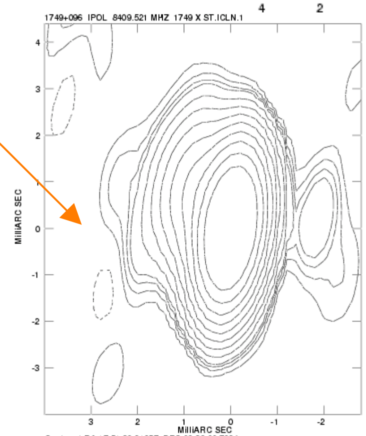
- Strong flux density variability
- Morphological changes implying superluminal speeds
- Instabilities in the radio jet

Flux density variability









Venturi et al. 2001 & 2003

Flux density variability in compact sources is expected from an expanding cloud of relativistic electrons initially thick at some frequency at a small angle to the line of sight. During the expansion the magnetic field and electron energy decrease, and the cloud becomes optically thick at progressively shorter frequencies.

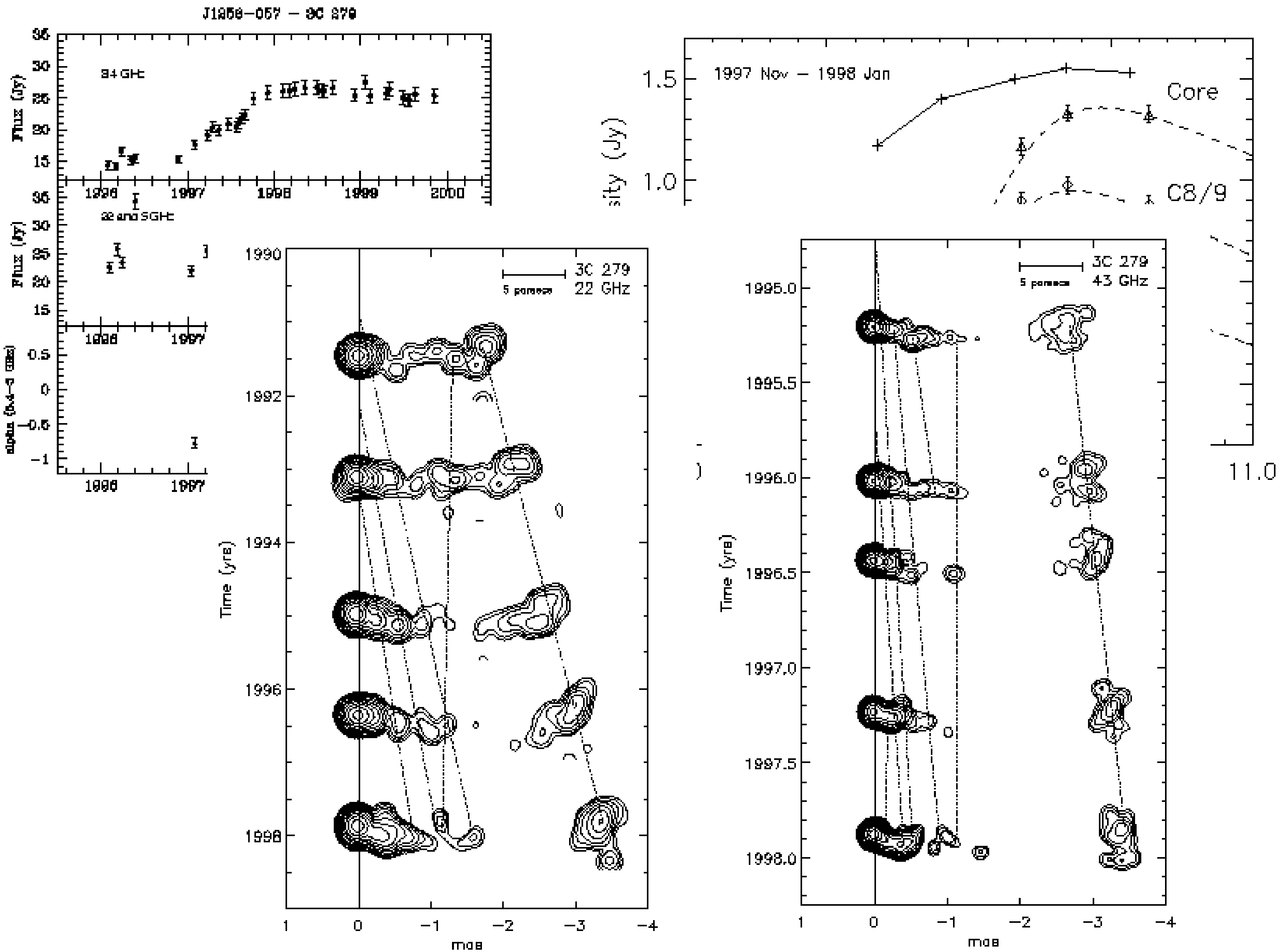
↓

Link between variability and ejecta of new components is expected

↓

Superluminal motion of components is expected in FSRS

3C279

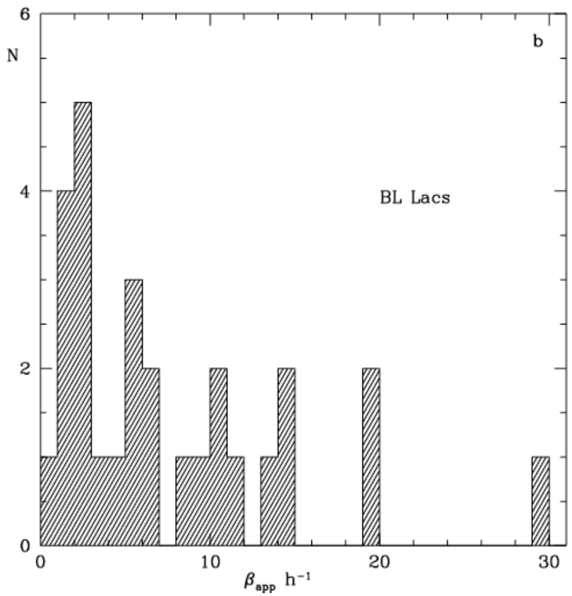


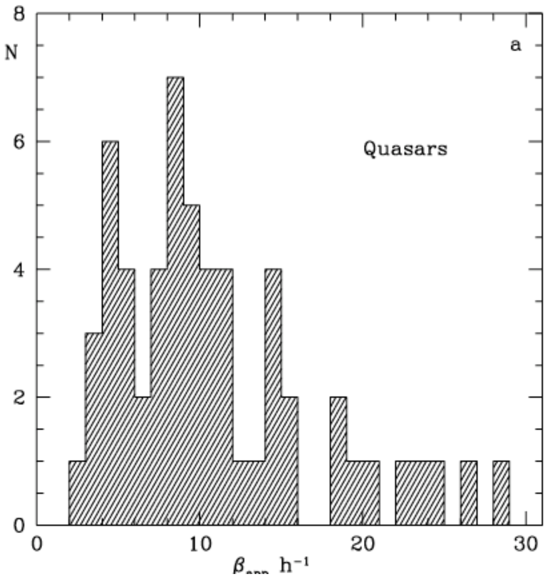
J1256-057 — 3C 279
Flux (Jy)
Time (yrs)
mas
3C 279
22 GHz
3C 279
43 GHz
5 parsecs
1997 Nov — 1998 Jan
Core
C8/9

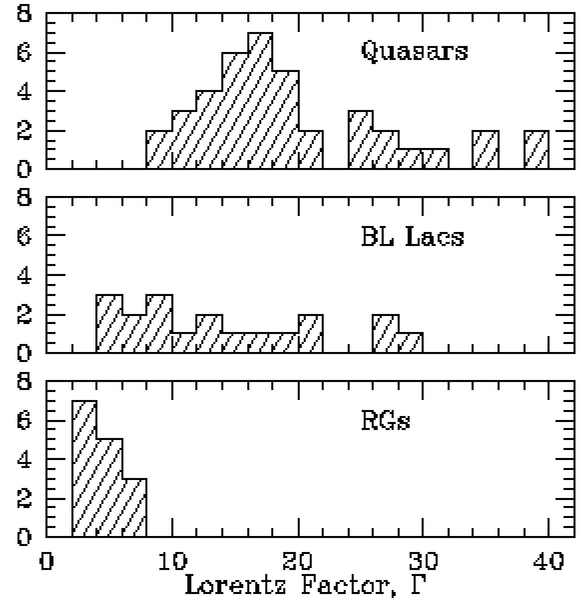
Multiepoch campaigns of VLBI observations

at 22 and 43 GHz

(Jorstad, Marscher et al. 2001, 2004, 2005 …)



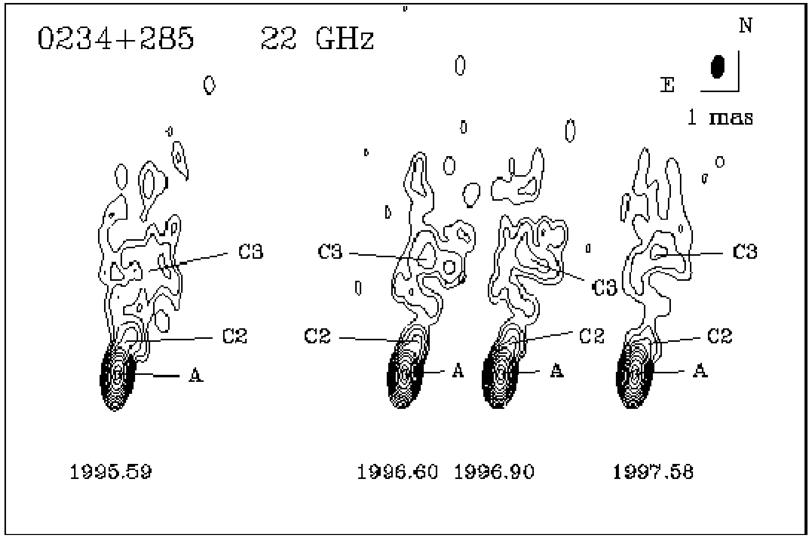


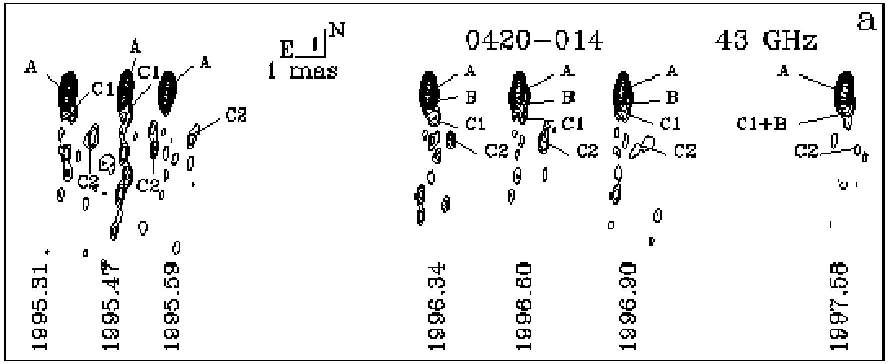


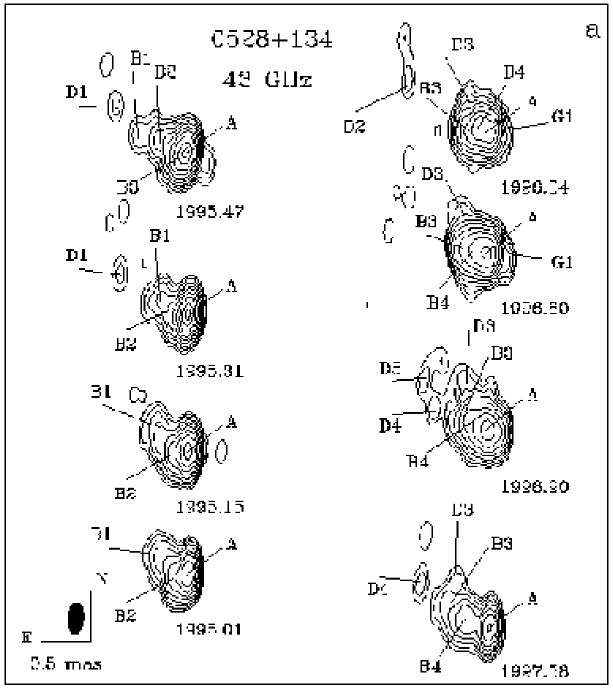
Distribution of apparent speeds in BLLac and QSO

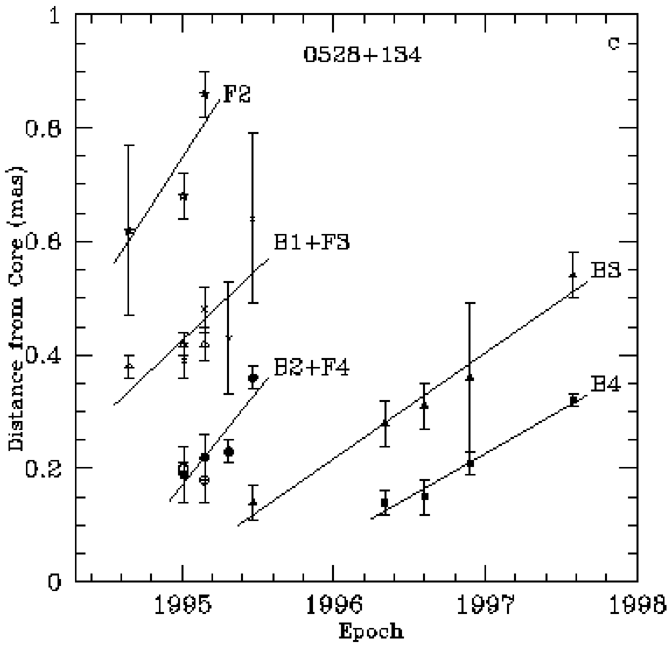
Distribution of Lorenz factors

From Jorstad, Marscher et al. 2001



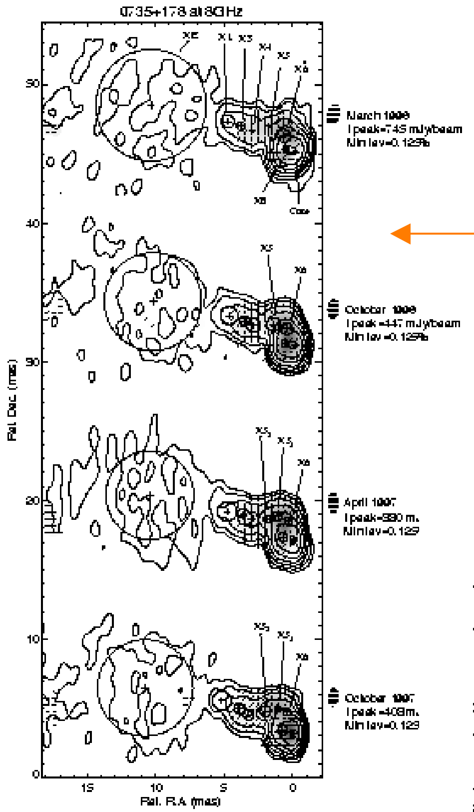


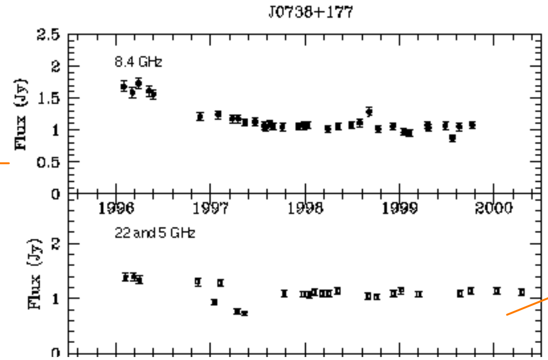


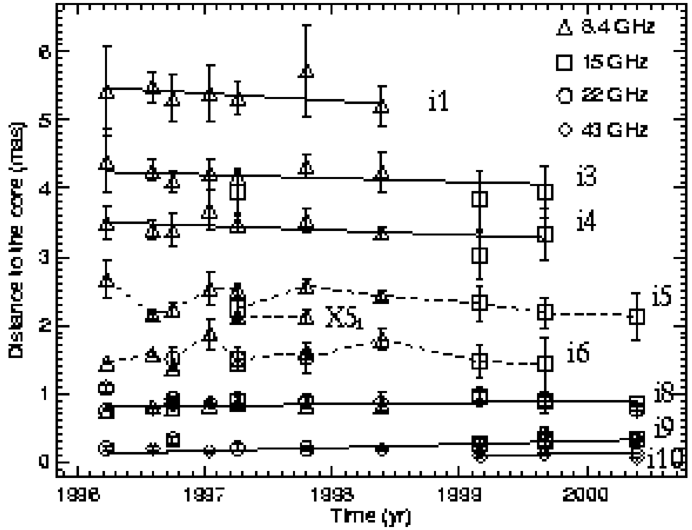


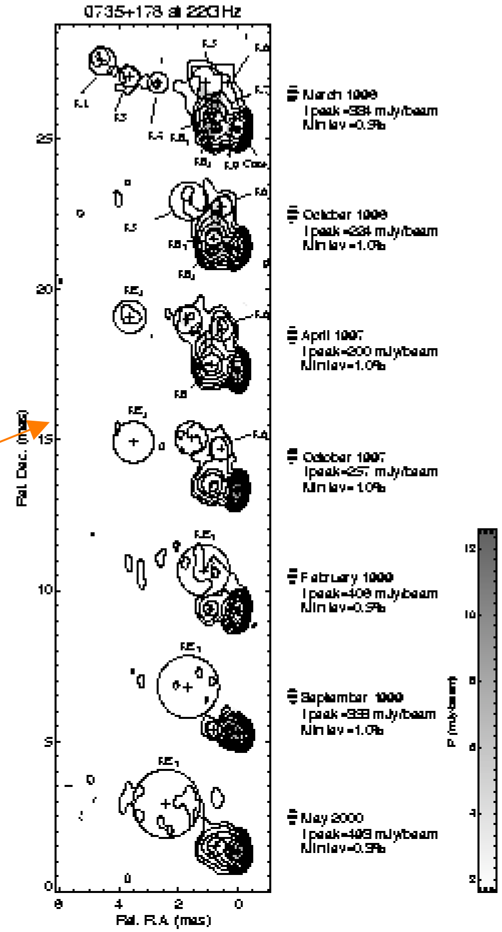
Study of the quiescent stage in the BL Lac 0735+178

(Agudo, Marscher et al. 2006)



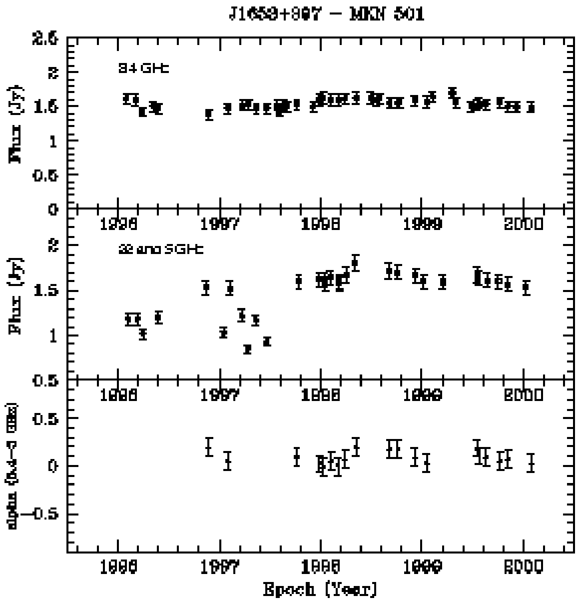






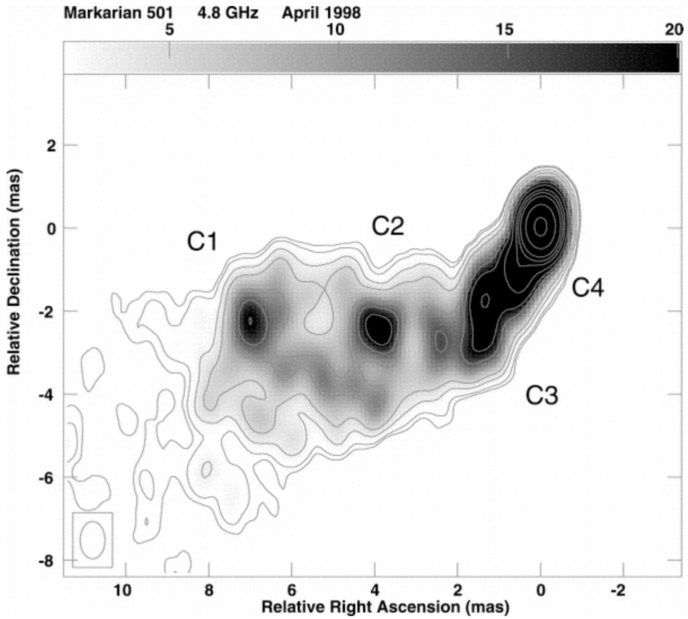
Superluminal motions and gamma-ray loudness

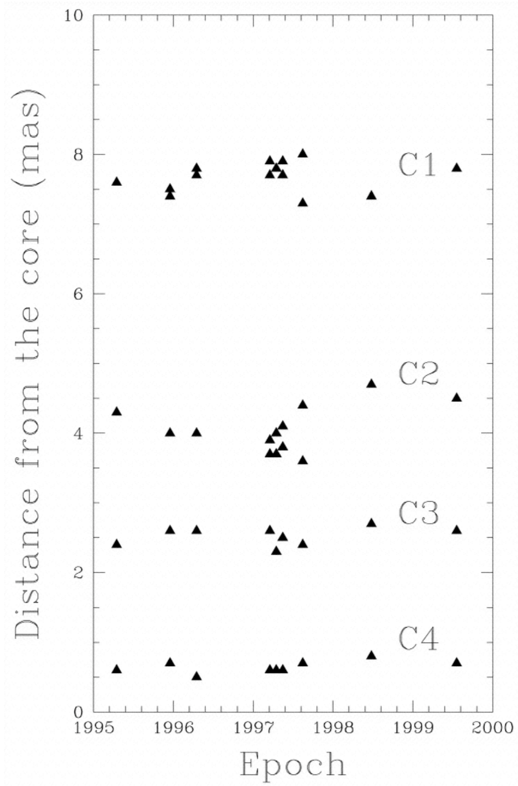
The case of Mkn 501



No flux density variability from single dish monitoring

(Venturi et al 2001)

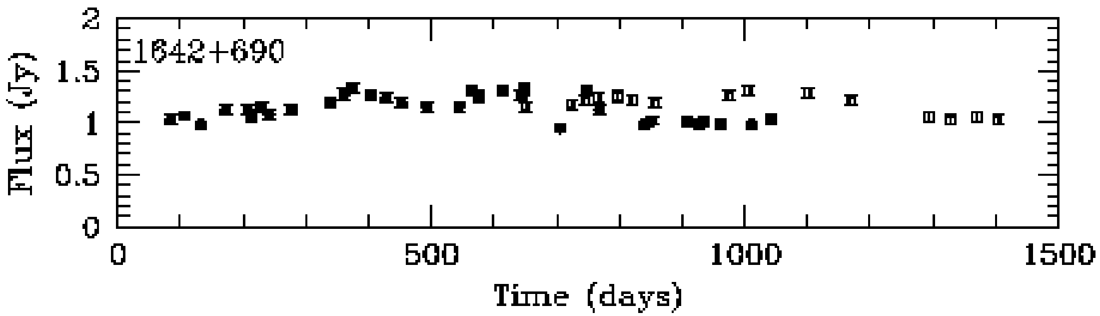


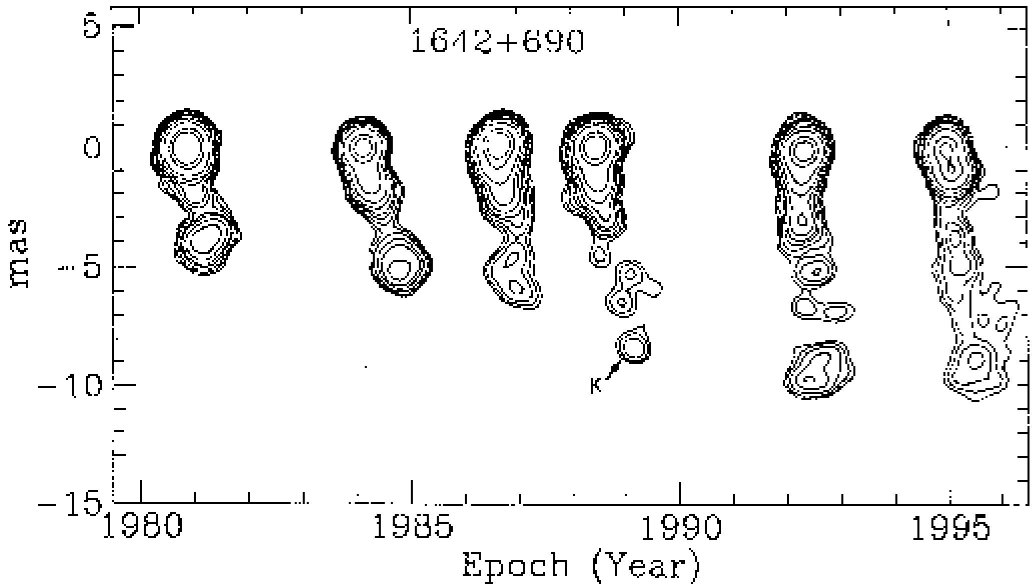


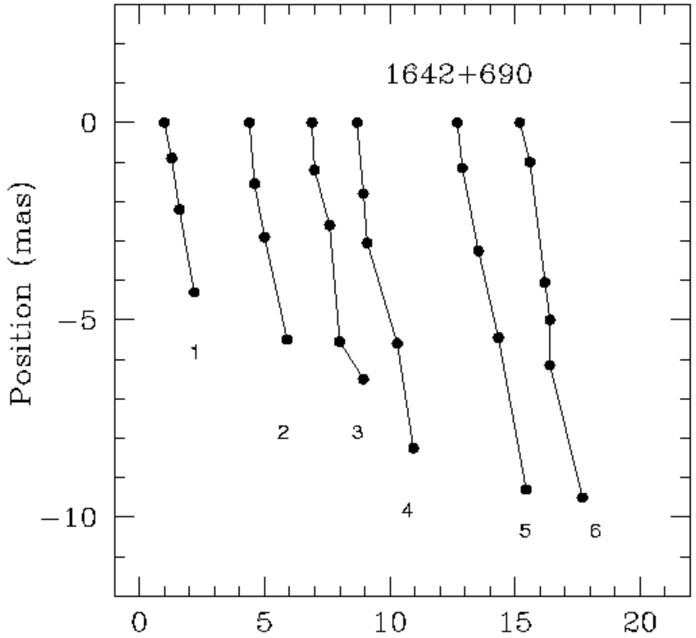
No morphological changes over the same period

(Giroletti et al. 2004)

The case of 1642+690

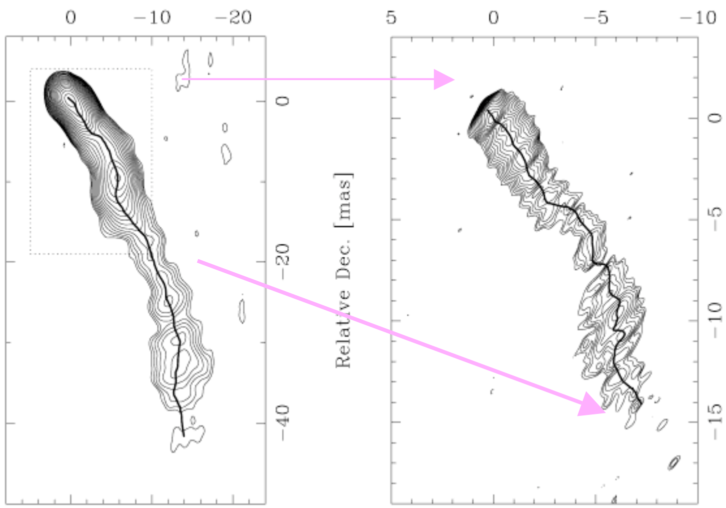




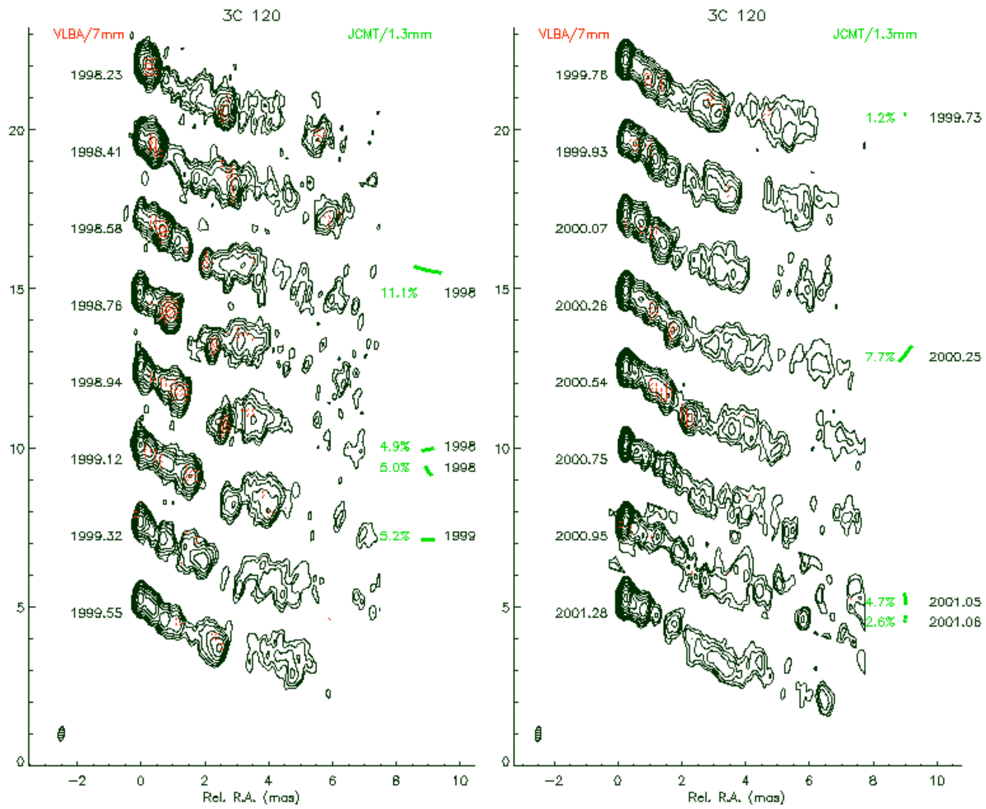


Instabilities in the parsec scale jets of blazars

0836+710 *(Lobanov et al. 1998)*



Precessing jet seen at a very small angle to the line of sight



3C120

(Gomez et al 2000)