Blazar Jet Kinematics: Reloaded

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in collaboration with

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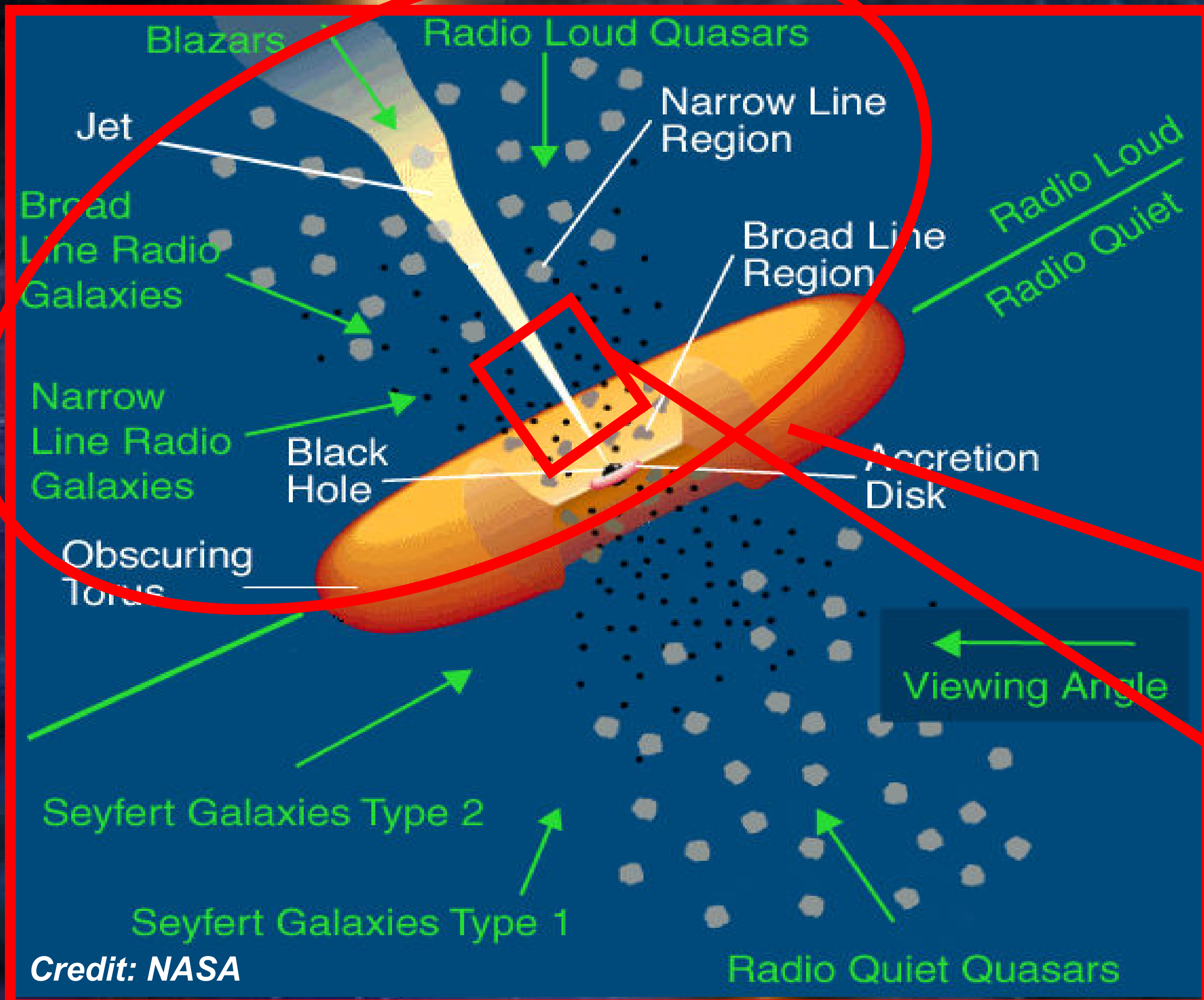
MAX-PLANCK-GESELLSCHAFT

Foreshadowing…
(,i.e. the outline!)

1. Introduction to AGN + jet kinematics
   (“all” what you wanted to know but were afraid to ask!)
2. **1803+784 and other peculiarities…**
   (=motivation!)
3. The Caltech-Jodrell Bank flat-spectrum (CJF) sample
   (the sandbox)
4. The Tools!
5. The Results!!
6. Conclusions
   (what you should keep)

Introduction to AGN…

(or, the picture you've probably already seen 10^5 times…today!)



Credit: NASA

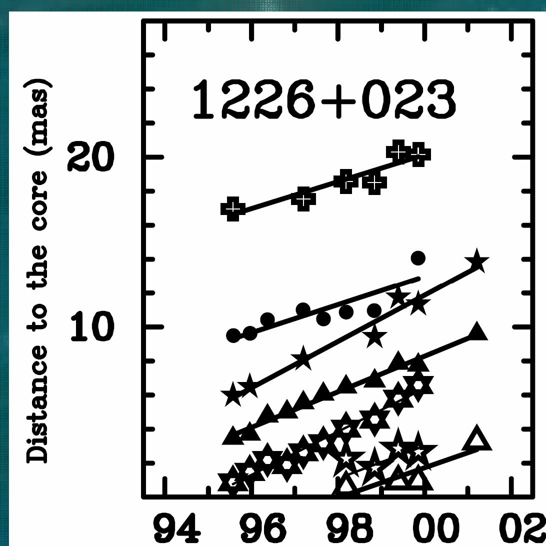
~ 5% of galaxies

~ 5 – 15% of AGN

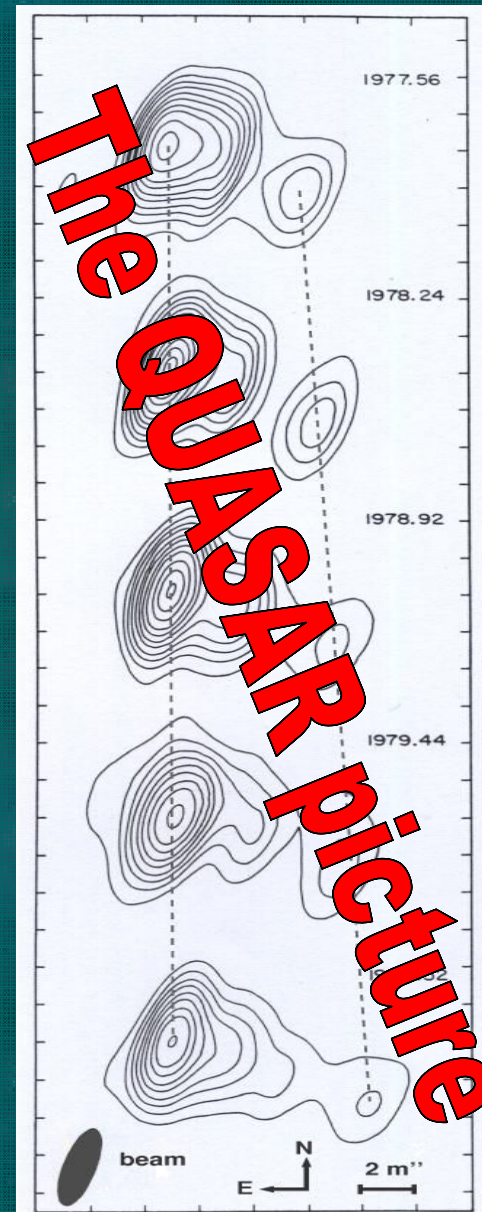
parsec-scale radio jet

…, and (classical) jet kinematics!

- steady and transient features
- **superluminal outward motion**
(e.g., Rees, Nature, 1966)
- shock-in-jet model
(e.g., Blandford & Koenigl, ApJ, 1979)
- bending effects
(by instabilities or geometry)

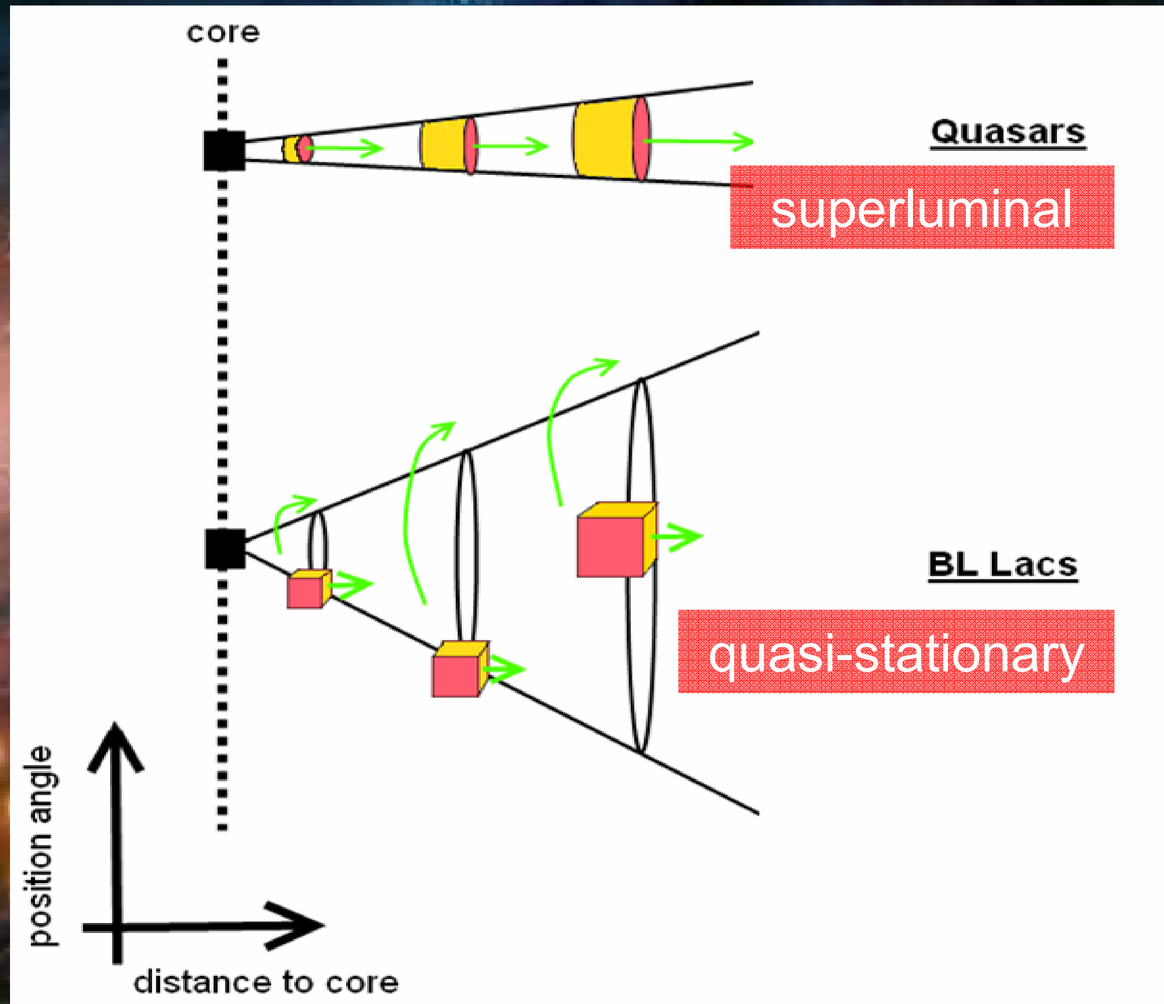


1226+023 @15GHz (VLBA);
Kellermann et al., ApJ, 2004



3C 273 @10GHz; Pearson et al., Nature, 1981

Setting the stage…
(,i.e. appetizers!)



As seen in:

- 1803+784
Britzen,..,Karouzos et al. 2010a
- 0716+714
Britzen,…,Karouzos et al. 2009
- 0735+178
Britzen et al. 2010b

We test a possibly different kinematic scheme between quasars and BL Lacs using a statistically complete sample of AGN.

3. The CJF sample

Caltech
Jodrell Bank
Flat-spectrum

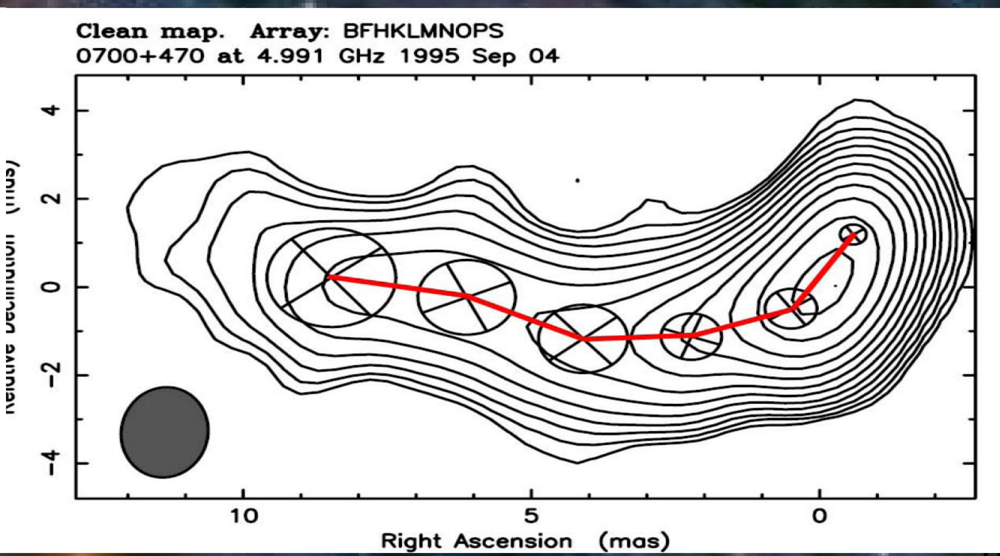
Frequency	**5GHz**
Flux @5GHz	**>350mJy**
Spectral Index	**$\alpha \geq -0.5$**
Declination	**$\delta \geq 35°$**
Galactic Latitude	**$\lvert b \rvert \geq 10°$**

Some references:

Taylor et al. (1996)
Britzen et al. (1999)
Britzen et al. (2007)
Britzen et al. (2008)
Karouzos et al. (2010)

The CJF sample…:

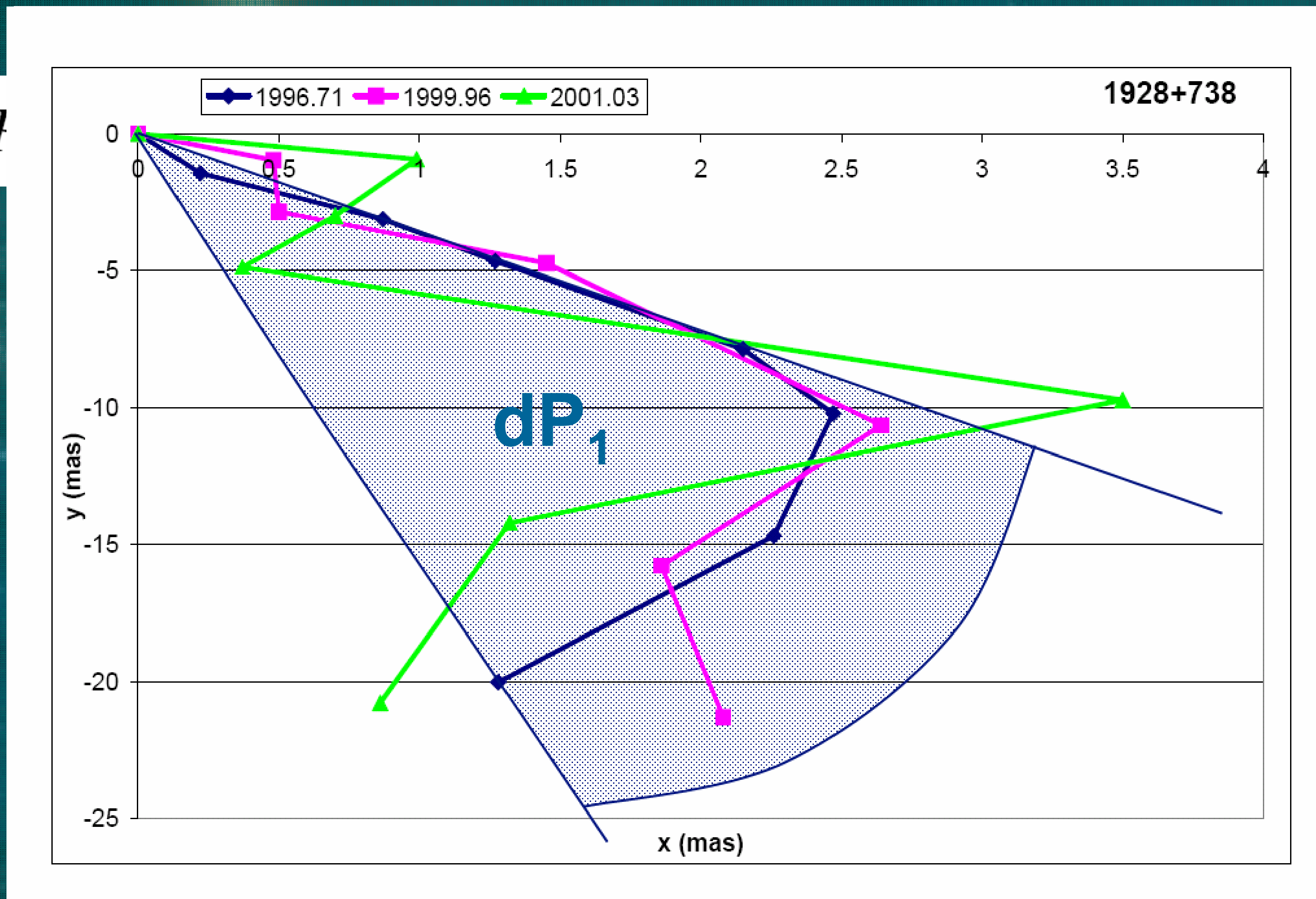
- contains 293 radio-loud active galaxies
  → 198 QSOs, 33 BL Lacs, 52 RGs
  → 264 sources with known z
- at least 3 epochs g-VLBI/VLBA @5GHz per source
- this sample is statistically complete in radio and X-rays



Britzen et al. (2007b)

4. The Tools

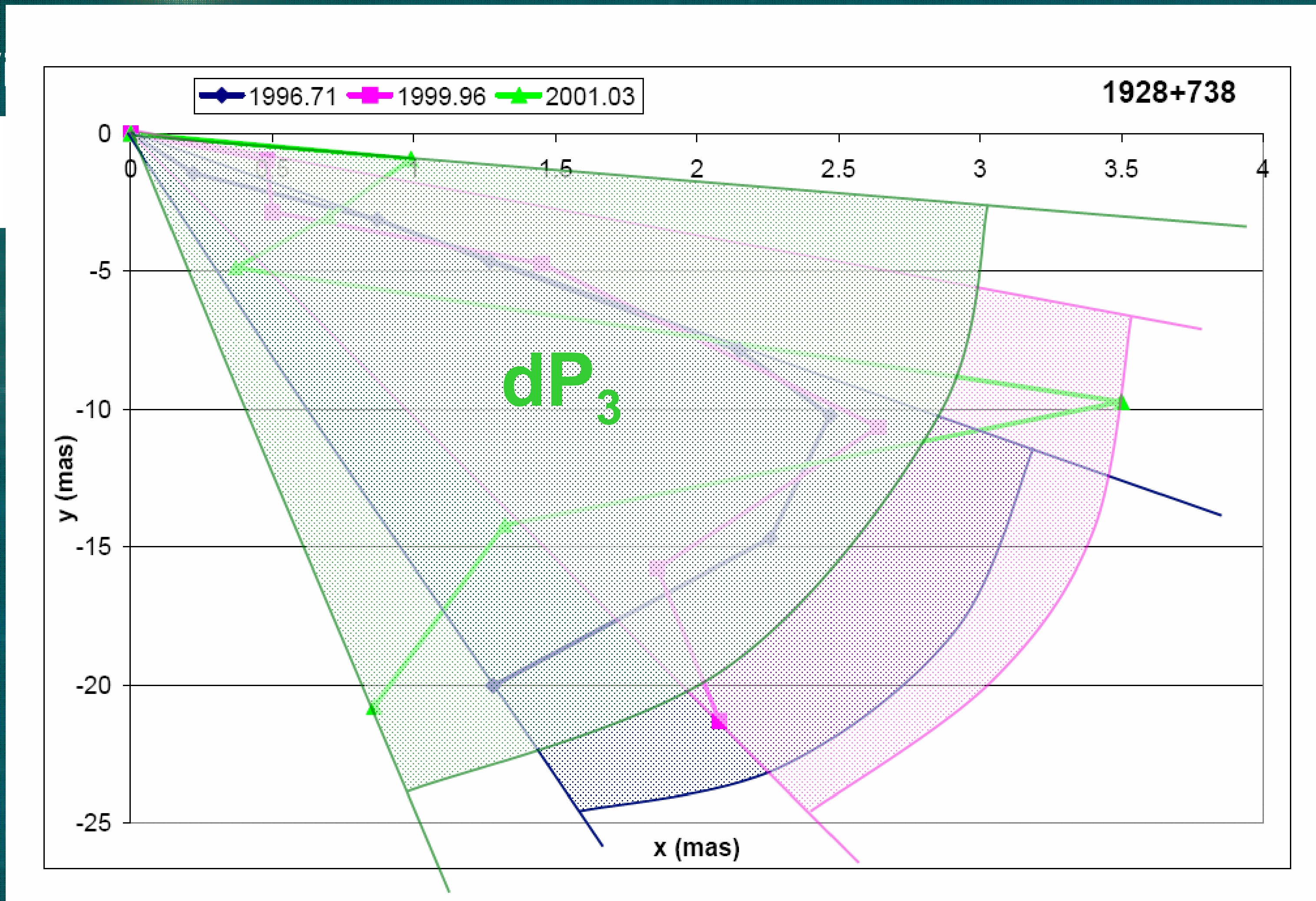
Jet



4. The Tools

Jet Wi

dP_i



4. The To

Jet Width:

$dP_i = \theta$

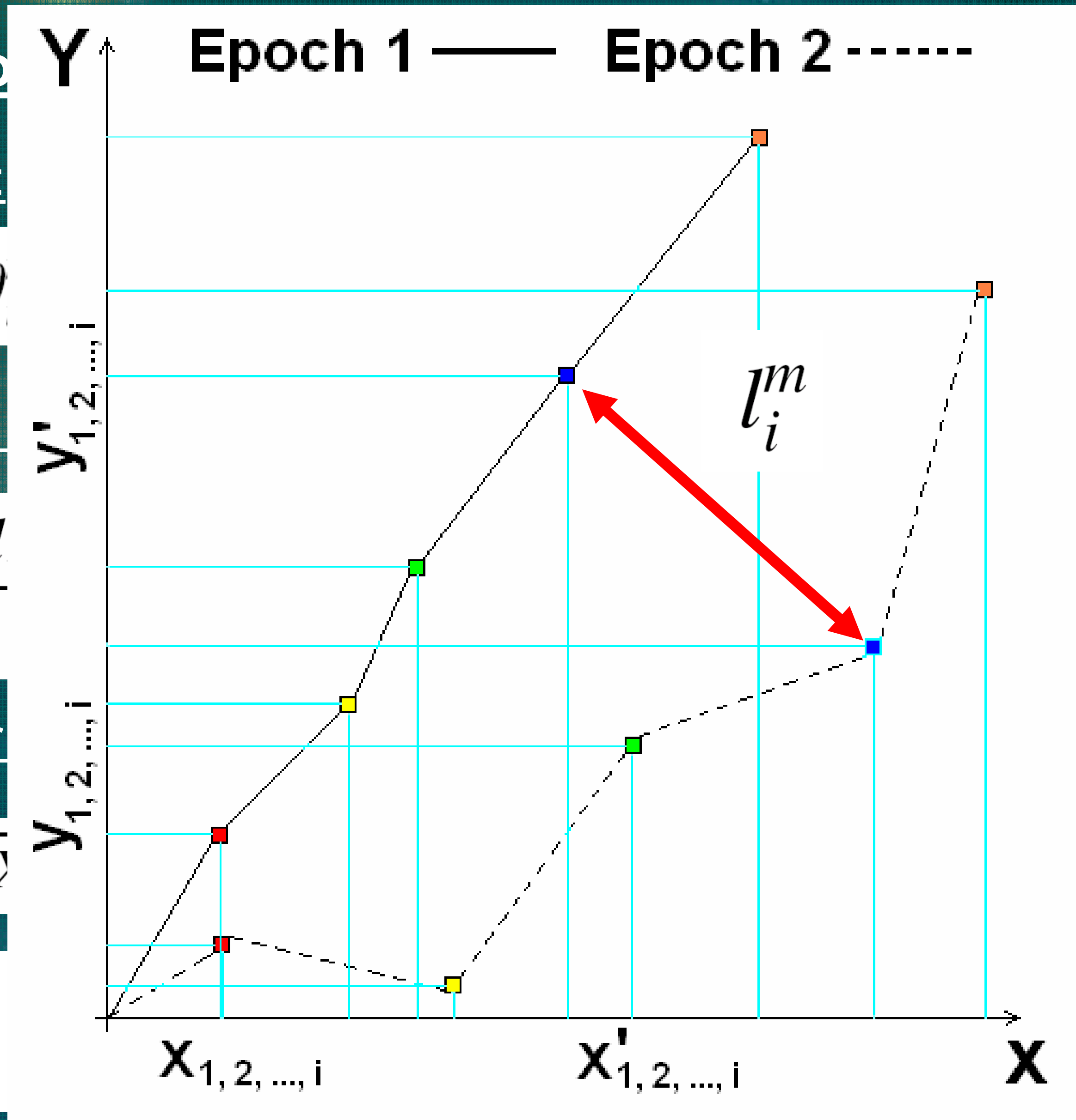
Jet Width

$\Delta P = \frac{d}{\ }$

Jet Linear

$l_i^m = \sqrt{\Delta}$

$L = \sum_{i-1}$



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$\frac{L}{NdT}$

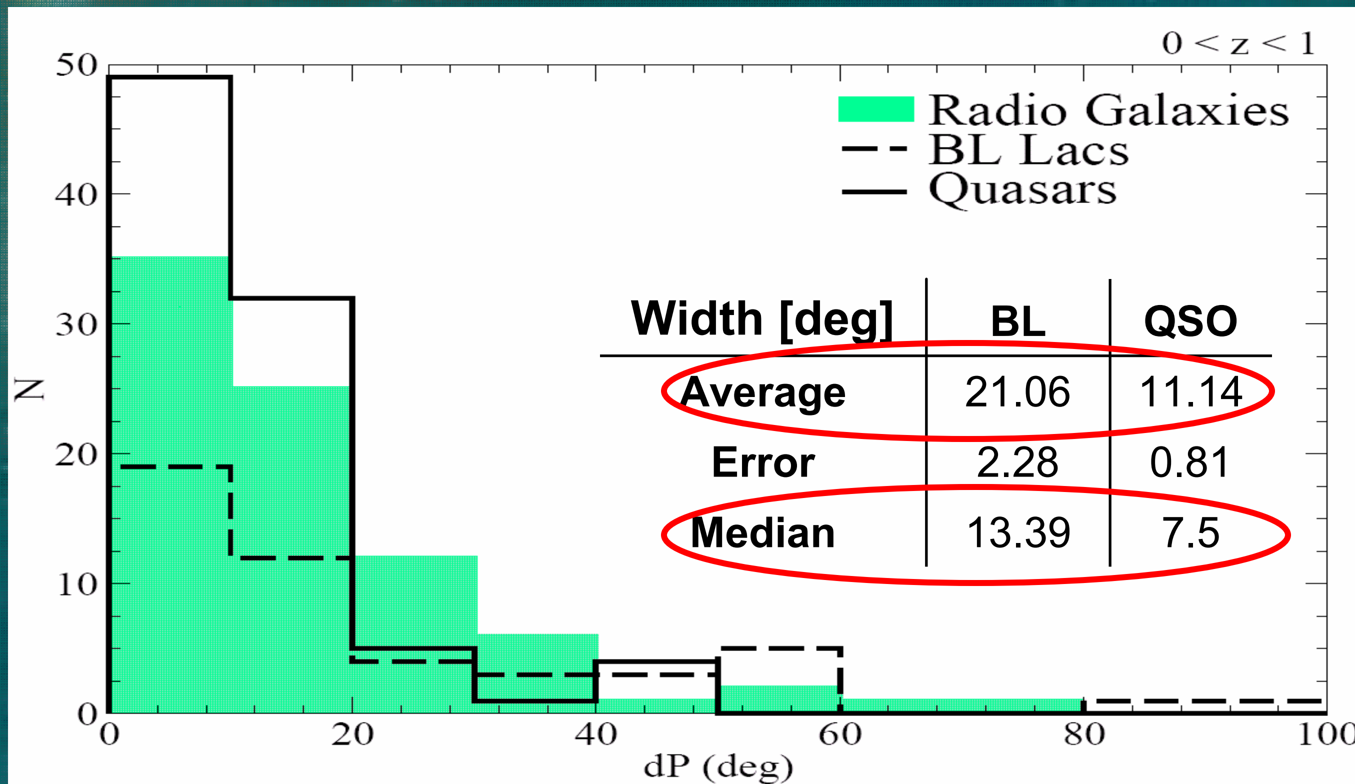
5. The Results…the width

(or the tools applied)

- according to 1803+784 we expect that BL Lacs show wider jets

Absolute distribution of dP

0 < z < 1



Width [deg]	BL	QSO
Average	21.06	11.14
Error	2.28	0.81
Median	13.39	7.5

BL Lacs show substantially wider jets than quasars

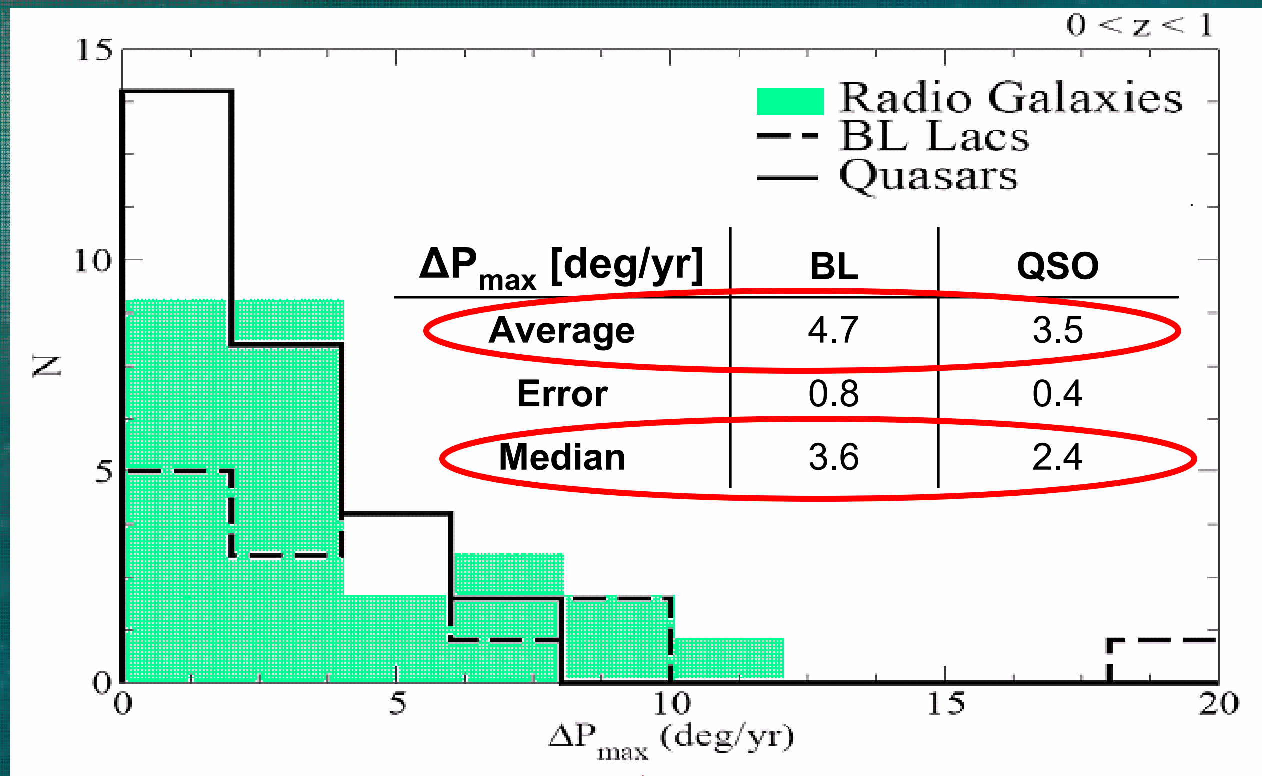
K-S test: **99%** significance
QSO different than BL Lacs

...the width evolution

• again according to 1803+784 we expect that BL Lacs show stronger changes in their jet widths

Normalized distribution of ΔP_{max}

0 < z < 1



ΔP_{max} [deg/yr]	BL	QSO
Average	4.7	3.5
Error	0.8	0.4
Median	3.6	2.4

BL Lacs show larger jet width changes than quasars

K-S ... ificance
QSO differen ... acs

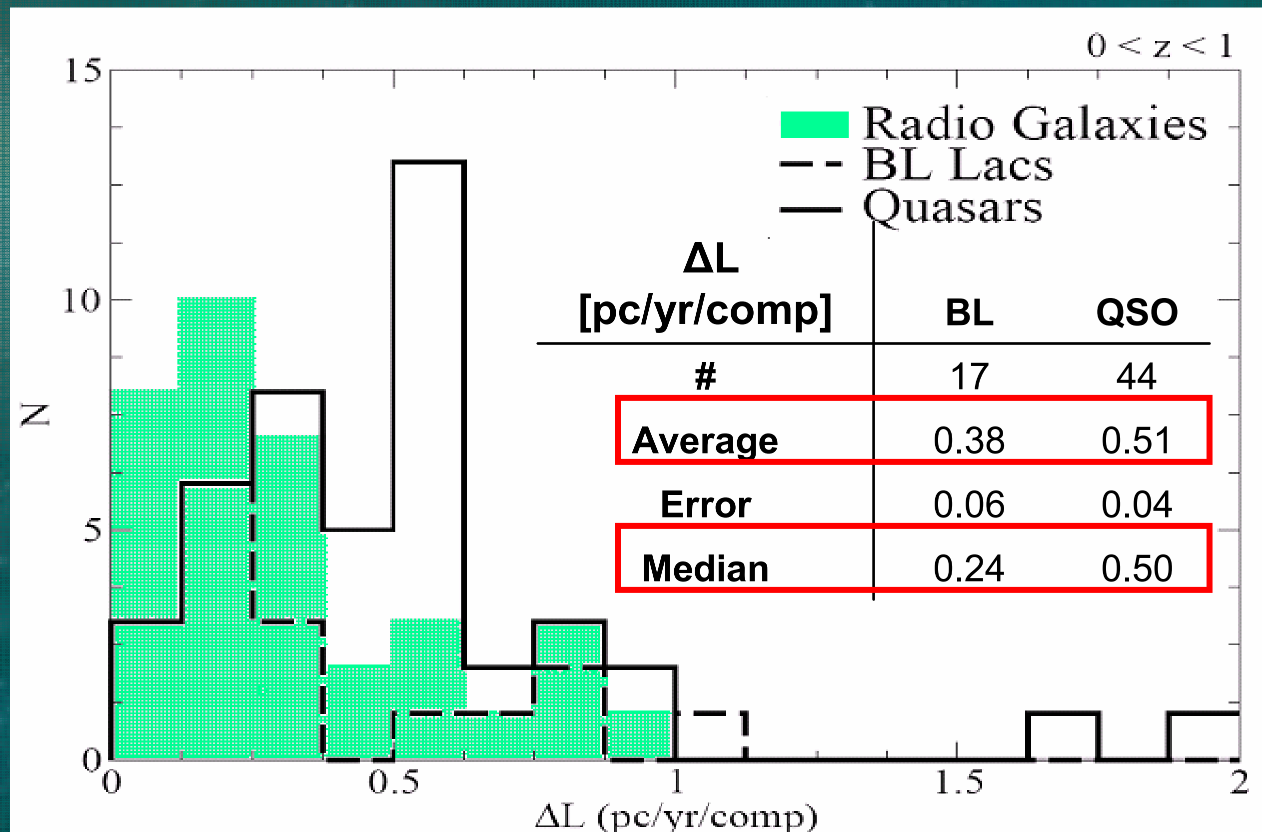
Inconclusive

…the linear evolution

- finally, we expect that BL Lacs show less total linear evolution than quasars

Normalized distribution of ΔL

0 < z < 1

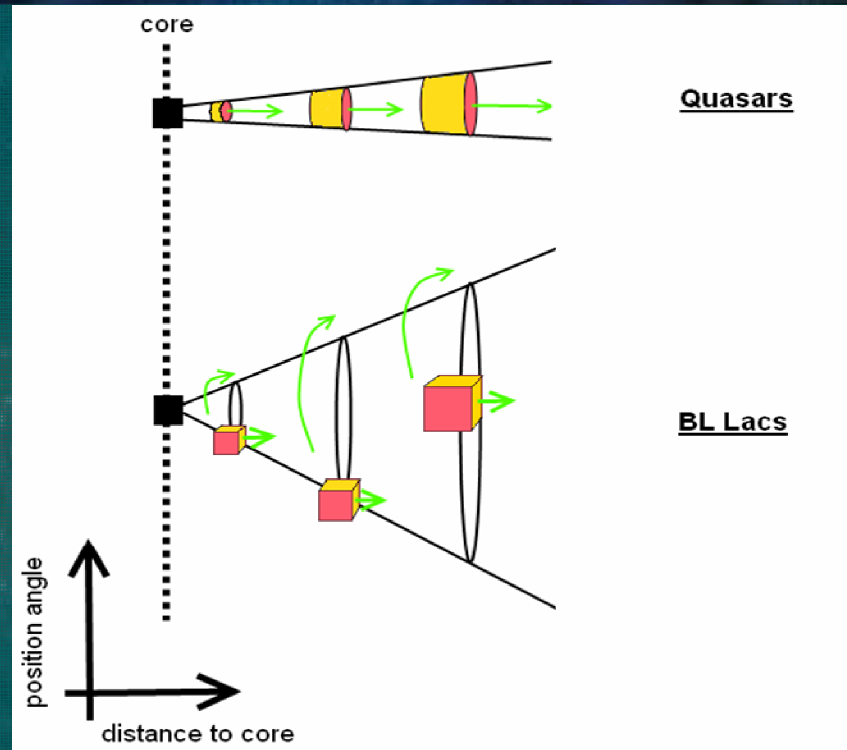


ΔL [pc/yr/comp]	BL	QSO
#	17	44
Average	0.38	0.51
Error	0.06	0.04
Median	0.24	0.50

BL Lacs show less outwards evolution than quasars

K-S test: **95%** significance QSO different than BL Lacs

6. Summary…



- BL Lacs → substantially wider jets
- BL Lacs → substantially less total linear evolution ΔL
- BL Lacs → stronger angular modulation

Conclusions…

New kinematic scenario as seen in 1803+784, 0716+714, etc.

→ **support from statistical evidence**

→ different kinematic behavior for BL Lacs

→ **oscillatory (non-radial) movement**

→ **stationarity w.r.t. the core**

THANK YOU!!

THANK YOU!!

THANK YOU!!

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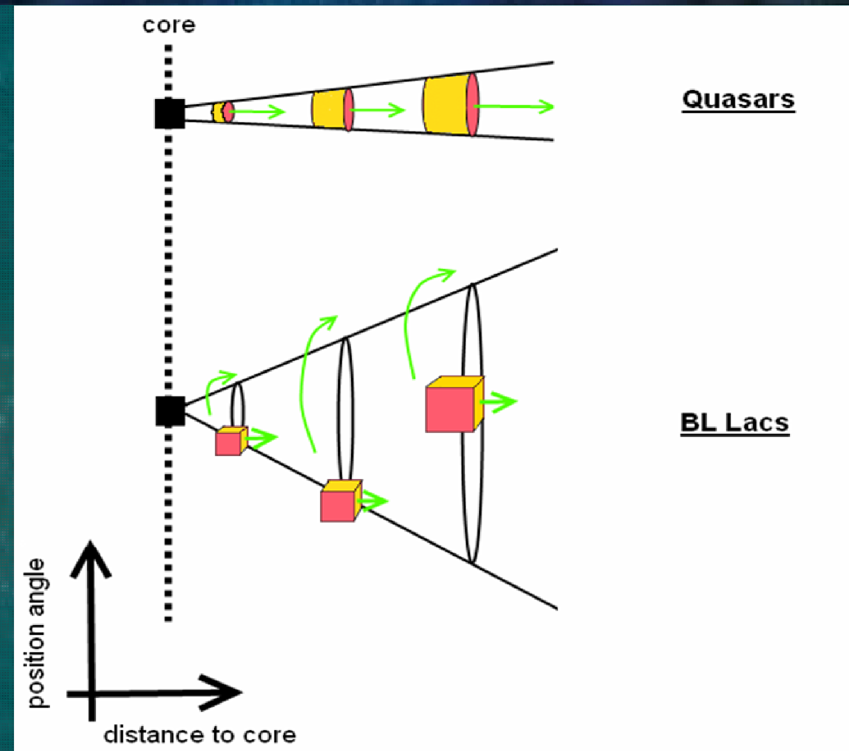

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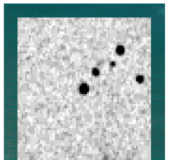
2. Case study: **1803+784**

Short CV



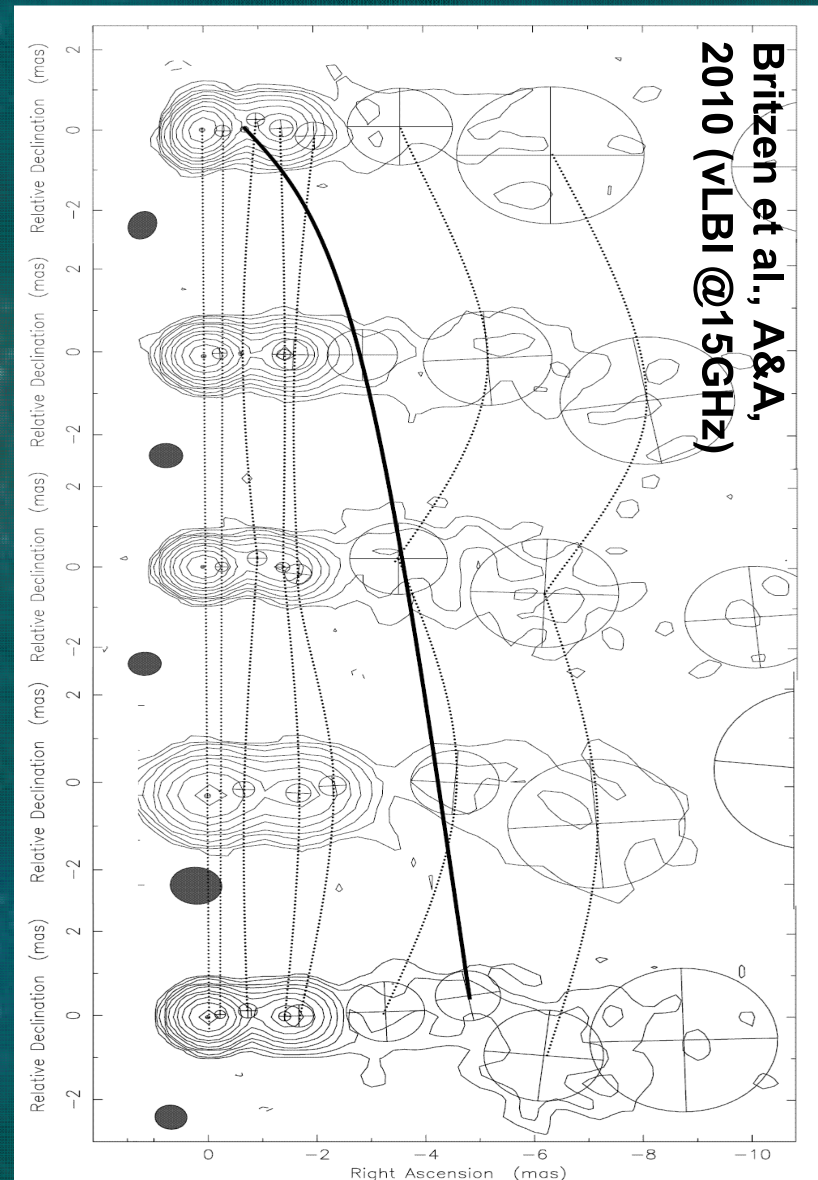
Name: S5 1803+784

Type: BL Lac

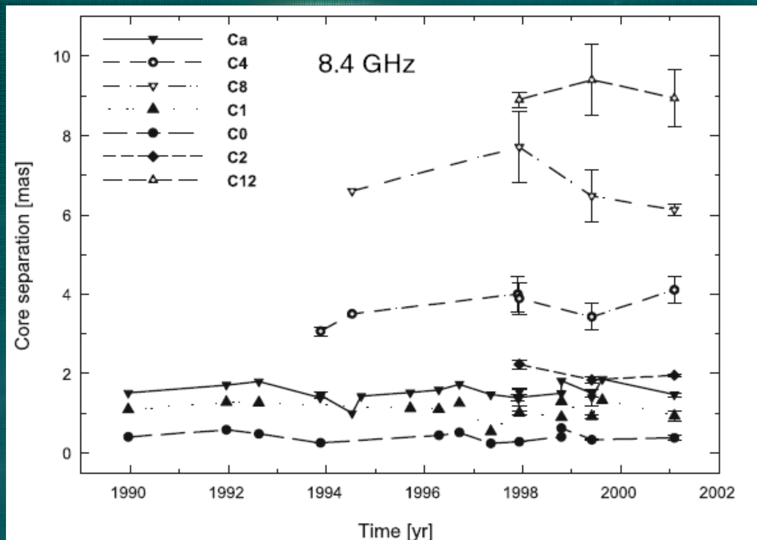
Redshift: 0.68 Occup.: AGN

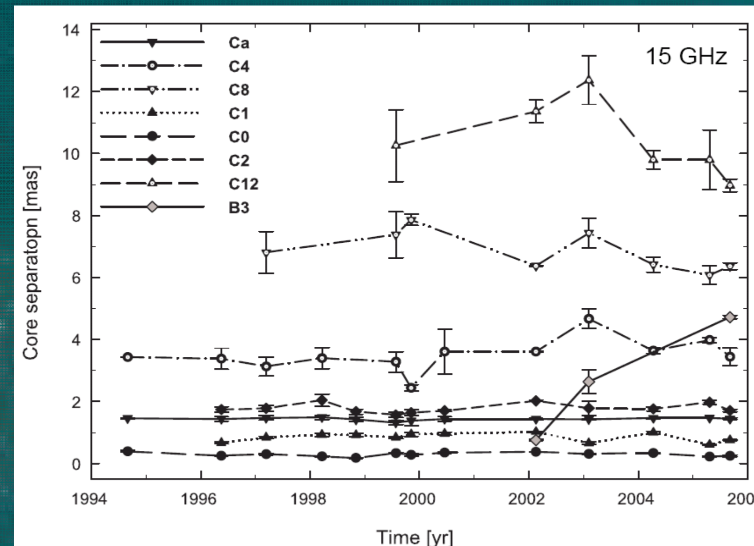
Host: unresolved

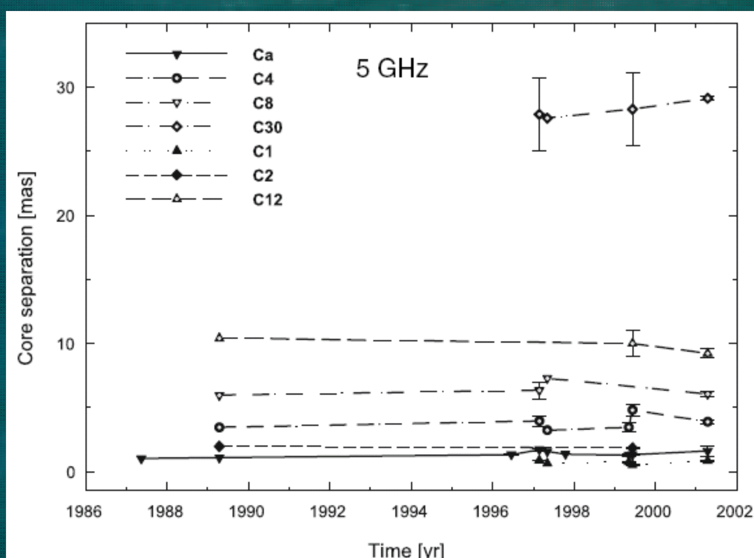
- 94 epochs @ different frequencies (1.6 - 15 GHz)
- VLBI observations with different arrays (e.g., VLBA)
- all epochs uniformly re-analyzed
- Britzen et al. (A&A, 2010) present a new kinematic scenario
→ most components appear stationary w.r.t. the core!

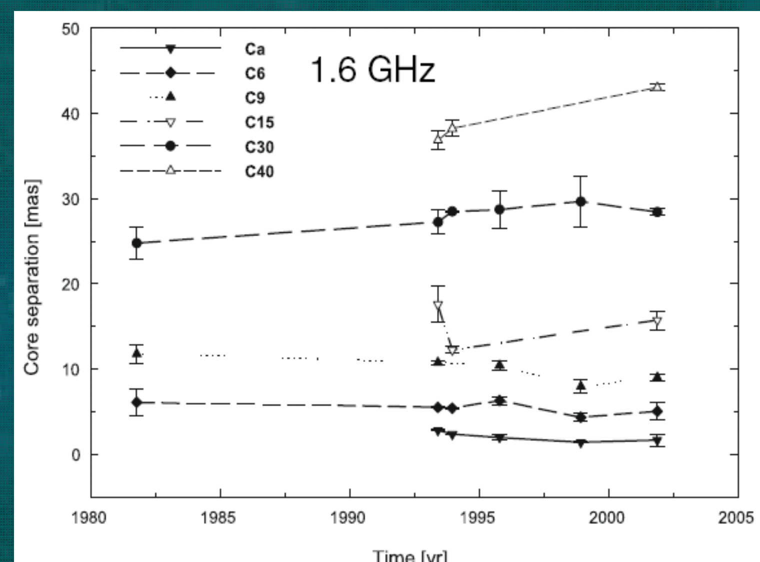


1803+784; Britzen et al., A&A, 2010







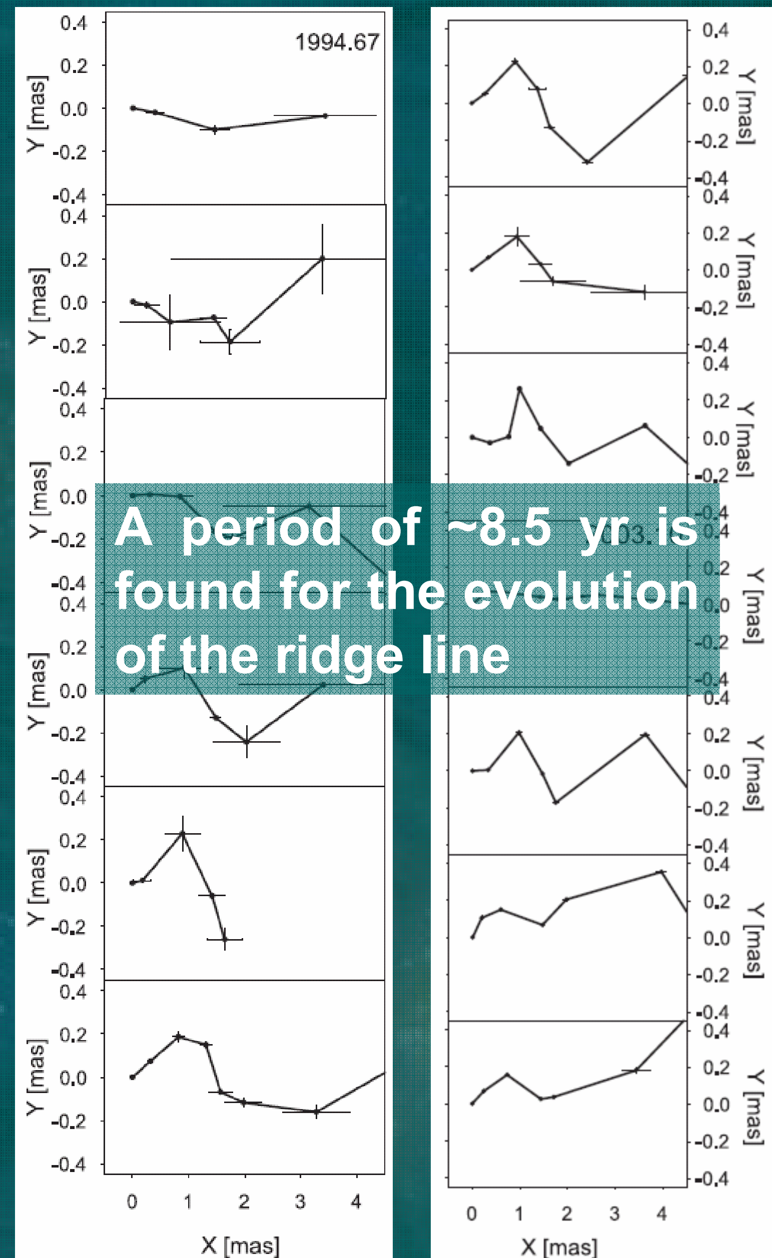


1803+784; Britzen et al., A&A, 2010

Britzen et al. also study the jet ridge line of 1803+784 and its evolution!

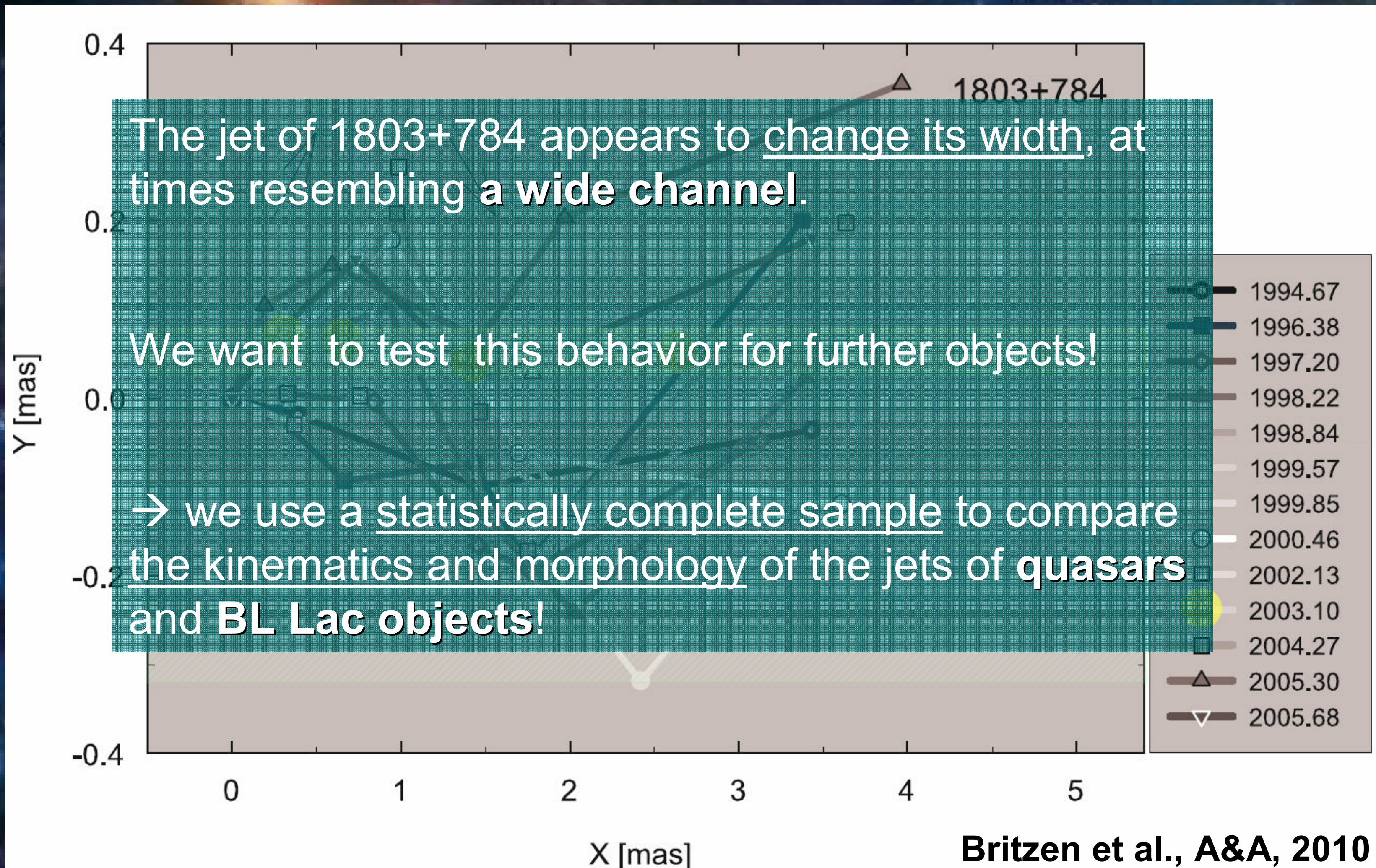
Jet ridge line, the: A line that linearly connects all component positions at a given epoch

- independent of component ID
- traces the "flux" spine of the jet
- characterizes the jet as a whole



A period of ~8.5 yr is found for the evolution of the ridge line

Britzen et al. also study the jet ridge line of 1803+784 and its evolution!



The jet of 1803+784 appears to change its width, at times resembling **a wide channel**.

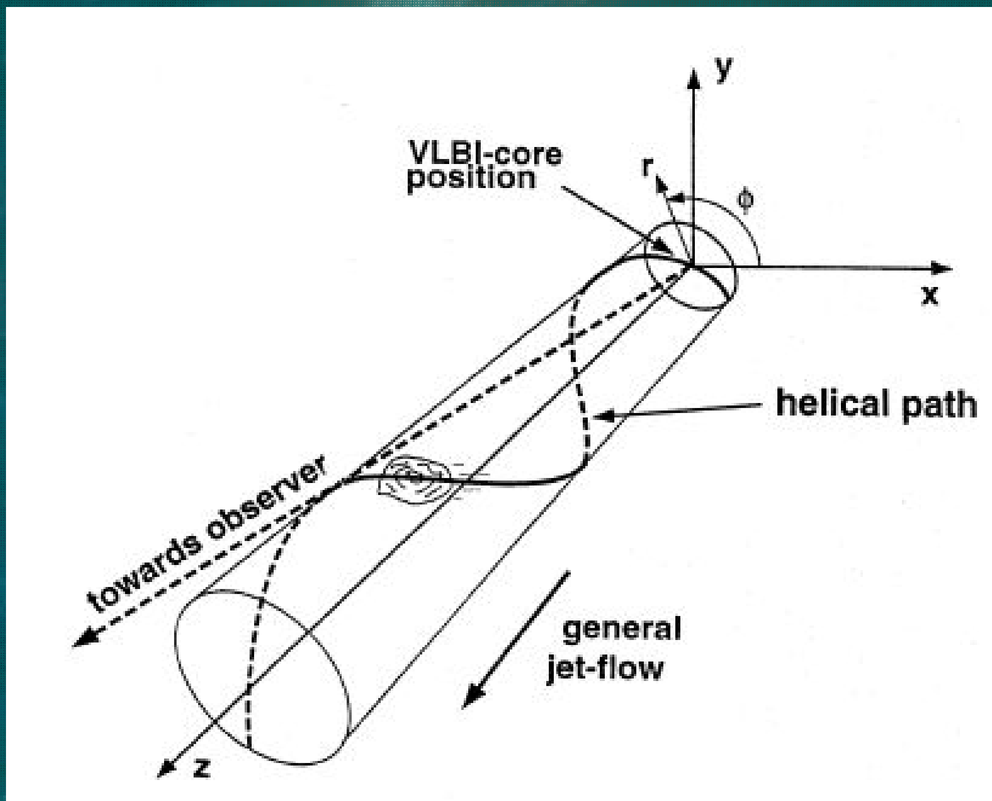
We want to test this behavior for further objects!

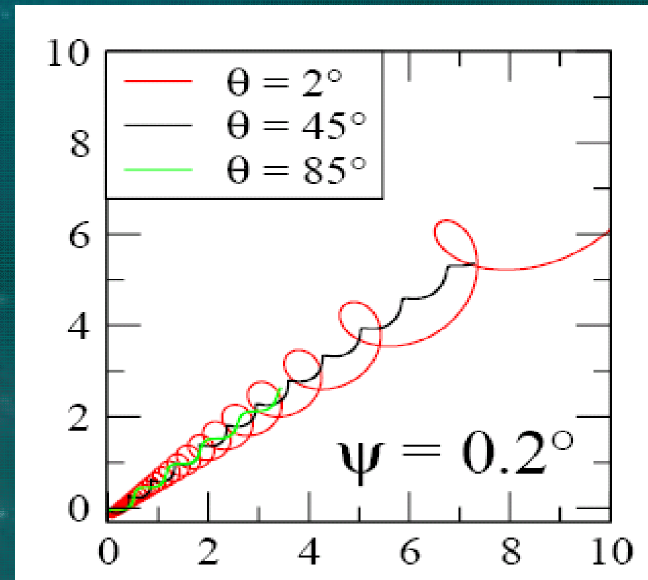
→ we use a statistically complete sample to compare the kinematics and morphology of the jets of **quasars** and **BL Lac objects**!

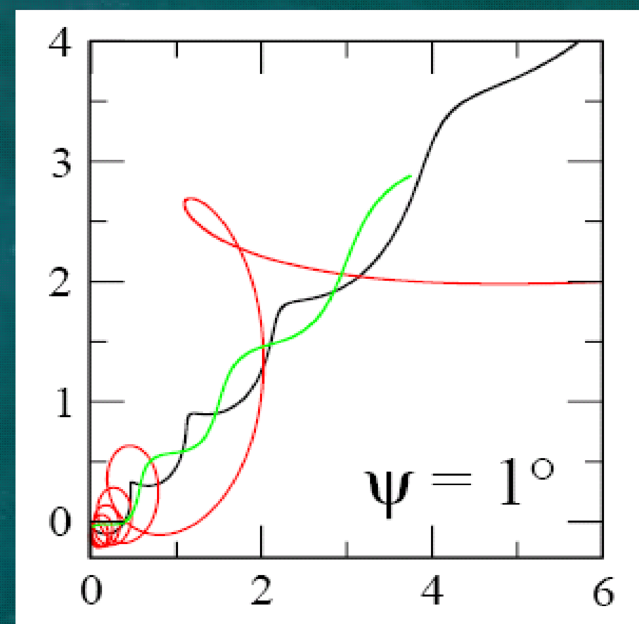
Britzen et al., A&A, 2010

Discussion…

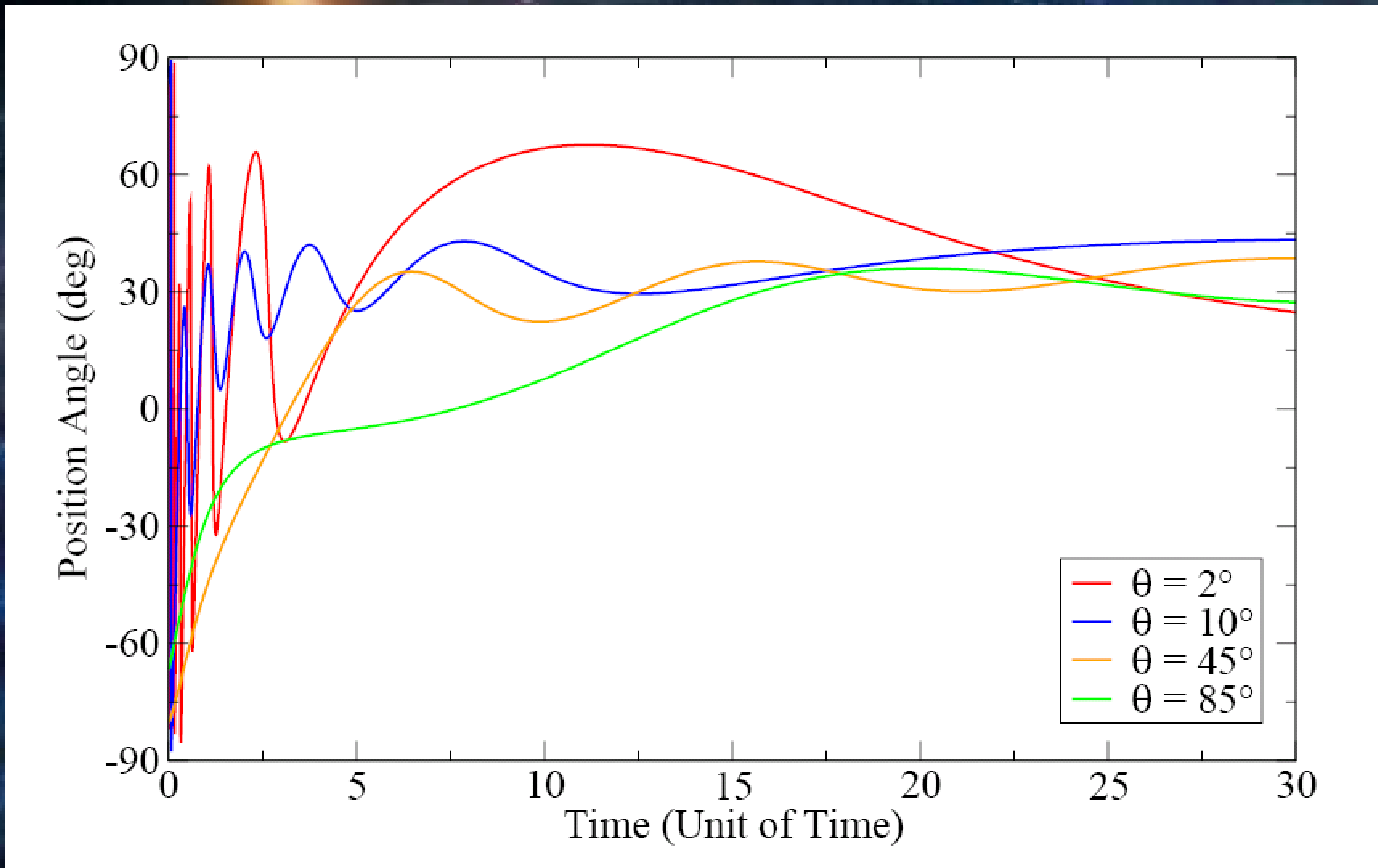
A helical model! (Steffen et al. 1995)







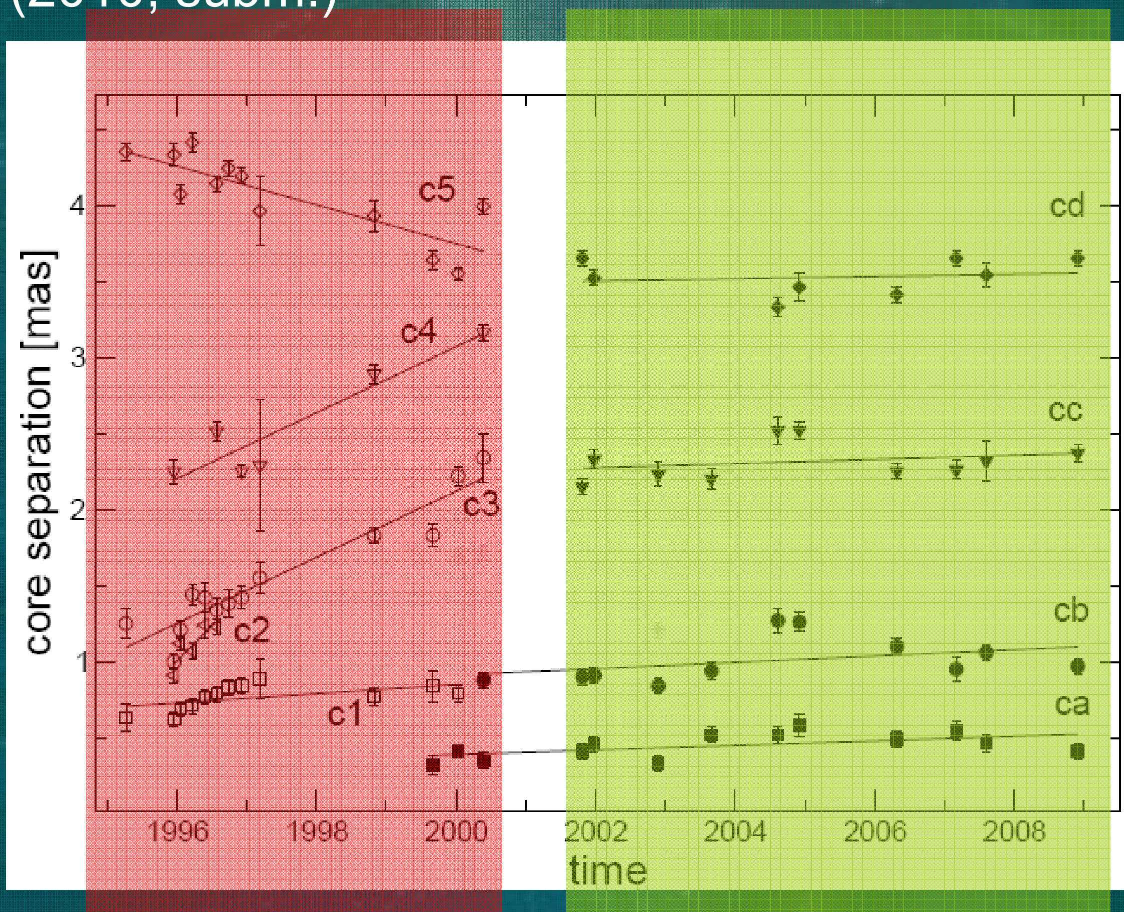
Discussion…(cont.)

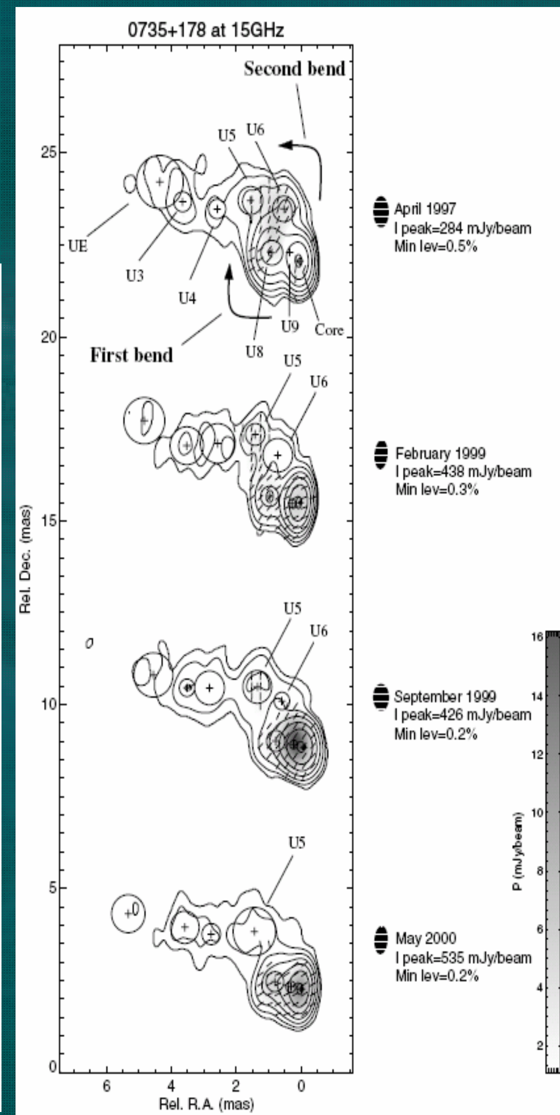


8. A case different than others…: 0735+178!

QSO / BL Lac (?), z = 0.424

VLBA @15 GHz (MOJAVE); Britzen et al. (2010, subm.)



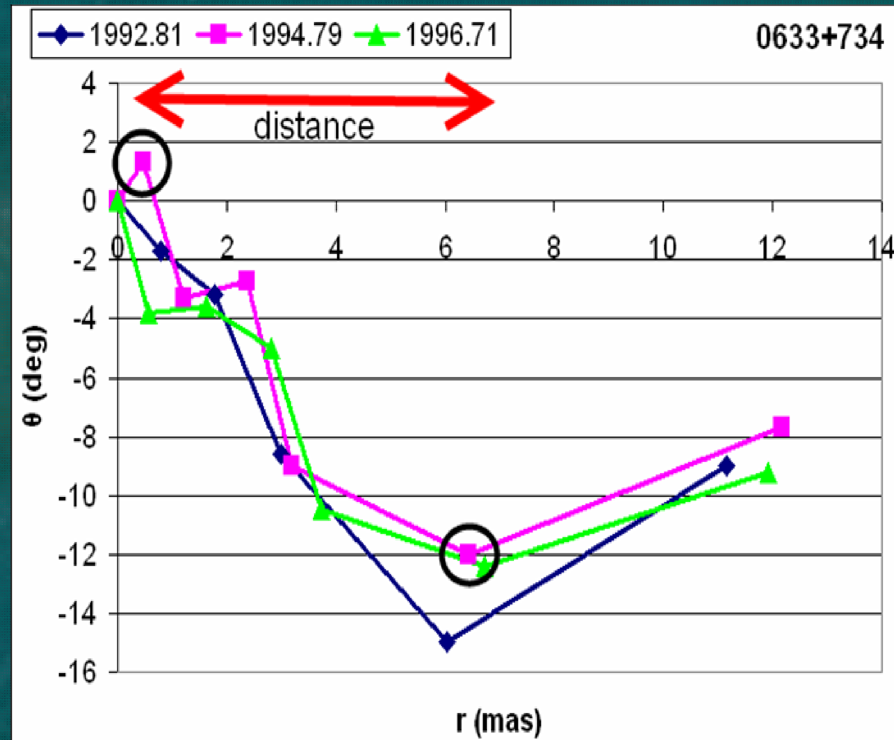


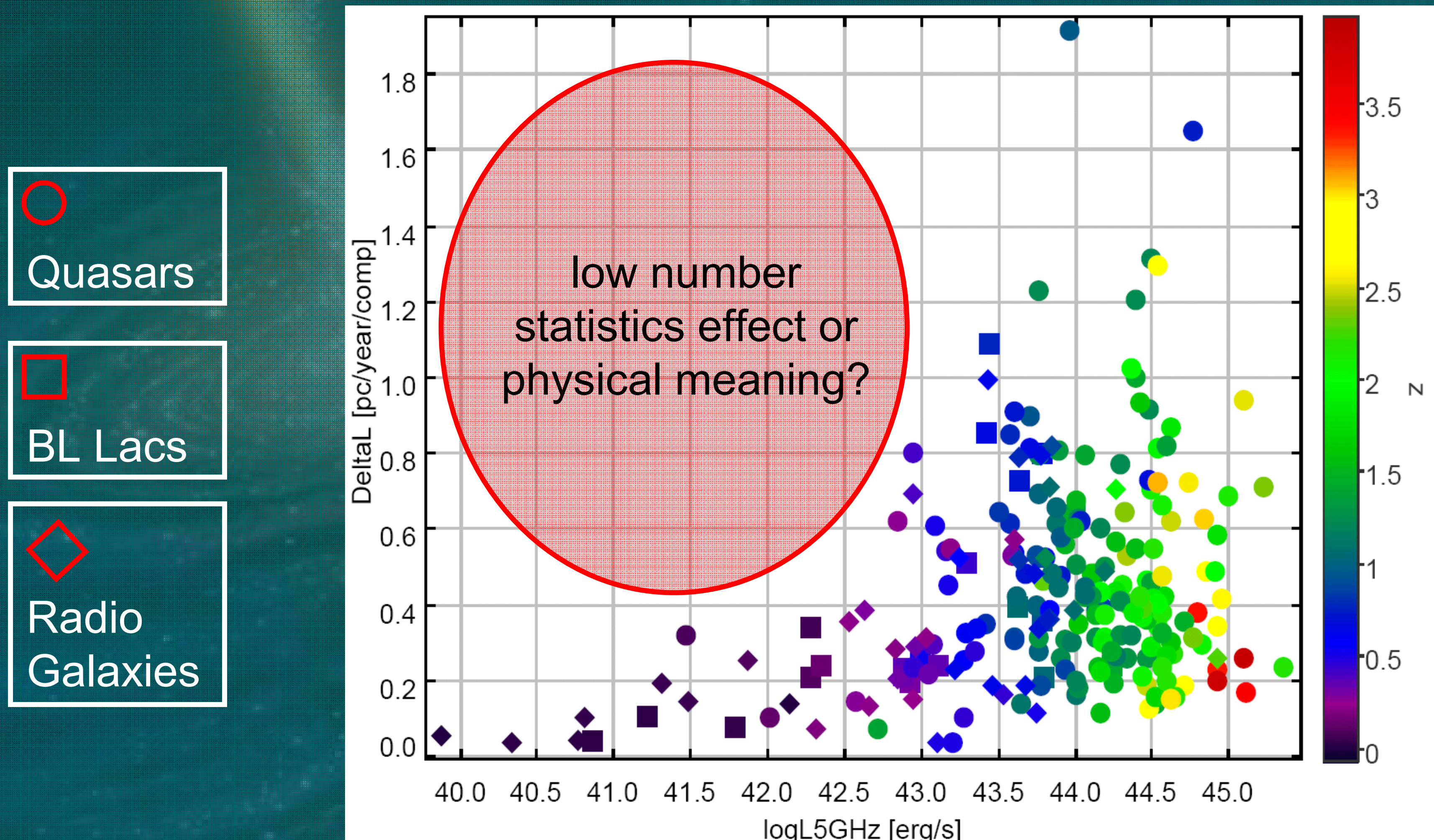
VLBA @15 GHz; Agudo et al. (2006)

Introducing further constraints:

- distance (w.r.t. the core) between the used components < 20 pc

Distance < 20 pc		
Width [deg]	BL	QSO
#	43	76
Average	21.93	10.46
Error	2.84	0.91
Median	10.6	6.45



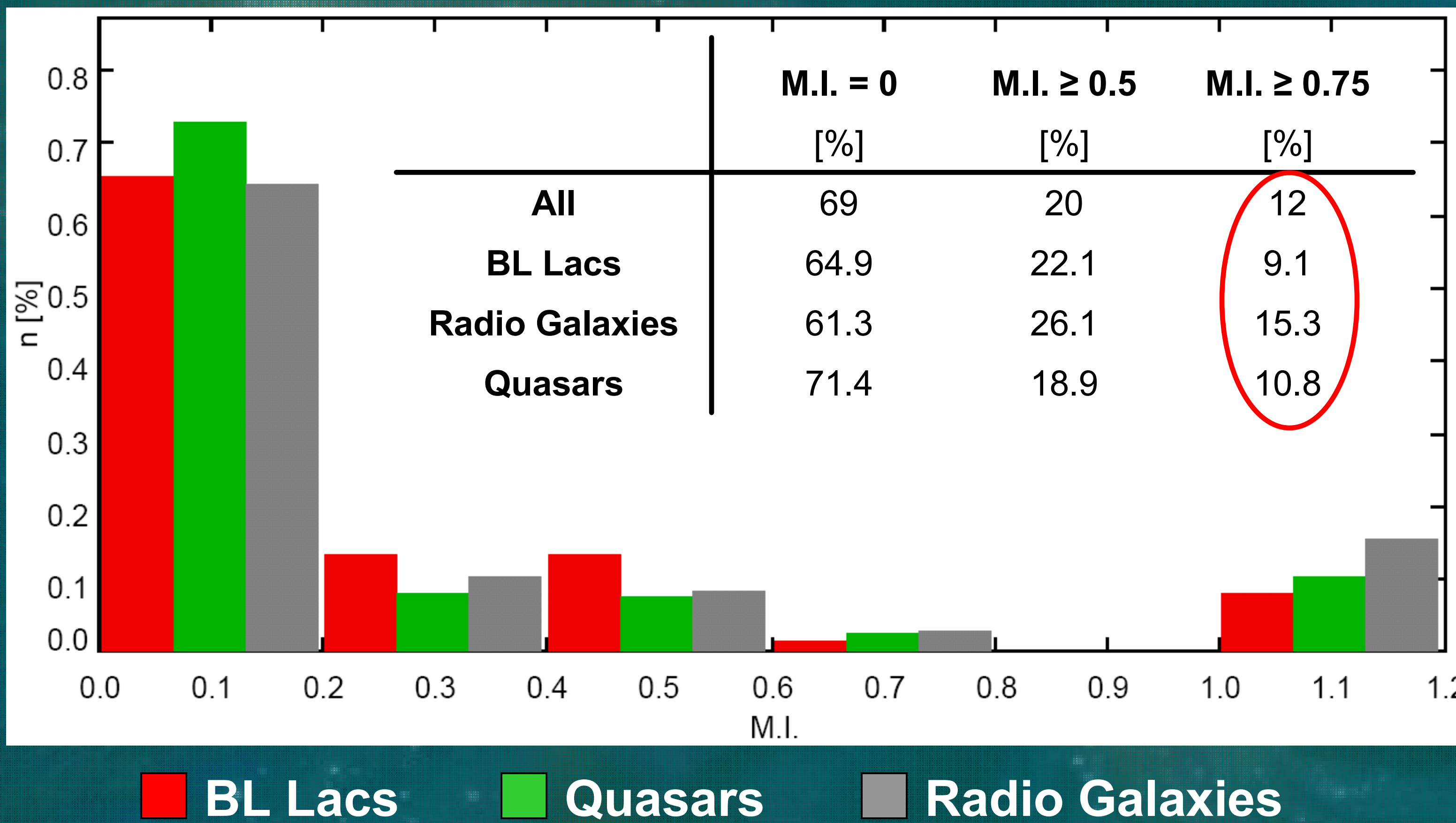


More luminous AGN appear to have stronger evolving jets related to Cohen et al. (2007), Lister et al. (2009) (?)

If N = # of components at a given epoch:

$$M.I. = \frac{number\ \ of\ \ extremas}{N-1}$$

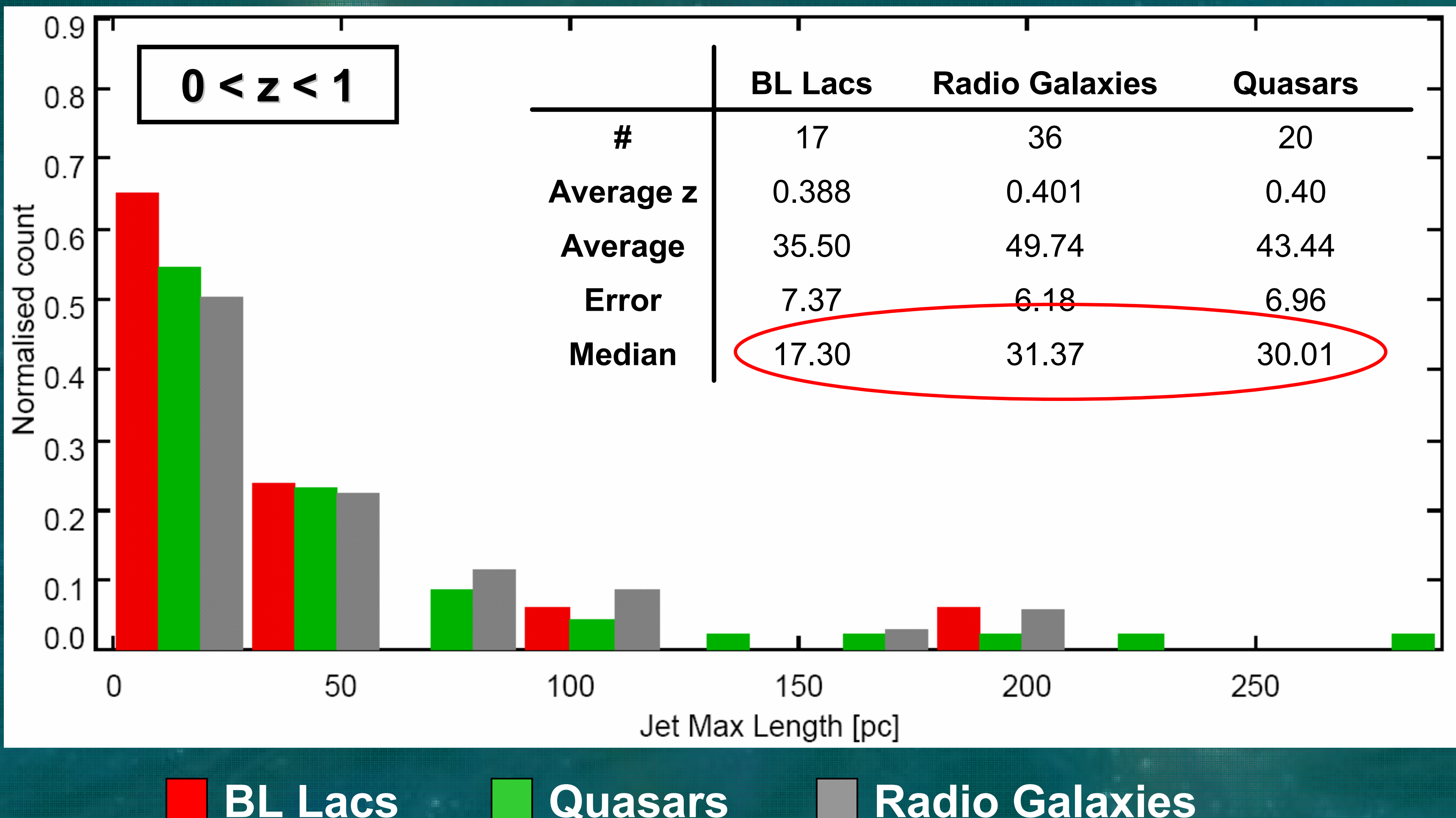
$$\theta_{i;extr} : |\theta_i - \theta_{i\pm1}| \geq 10(d\theta_i + d\theta_{i\pm1})$$



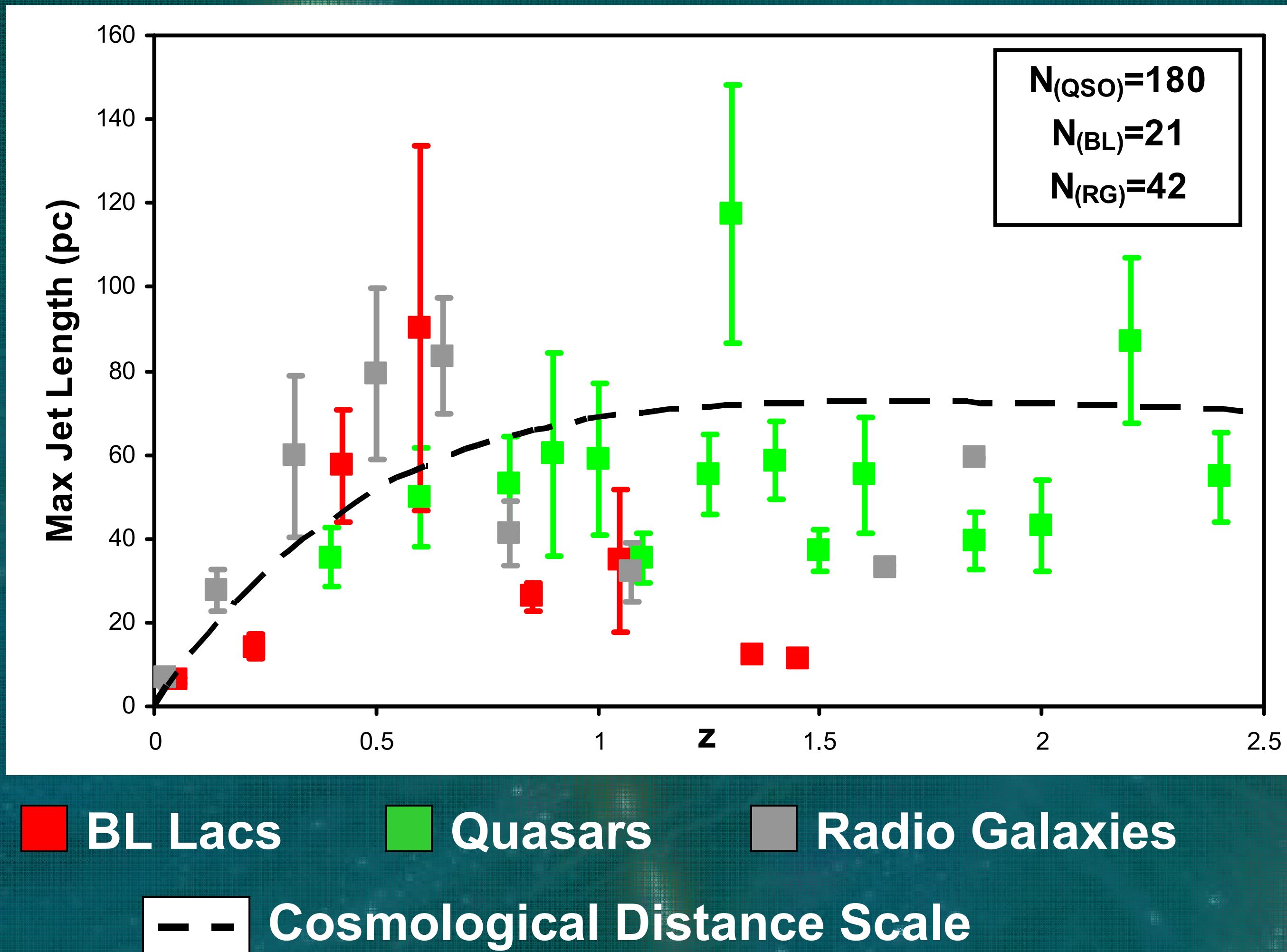
	M.I. = 0 [%]	M.I. ≥ 0.5 [%]	M.I. ≥ 0.75 [%]
All	69	20	12
BL Lacs	64.9	22.1	9.1
Radio Galaxies	61.3	26.1	15.3
Quasars	71.4	18.9	10.8

Jet length and morphology

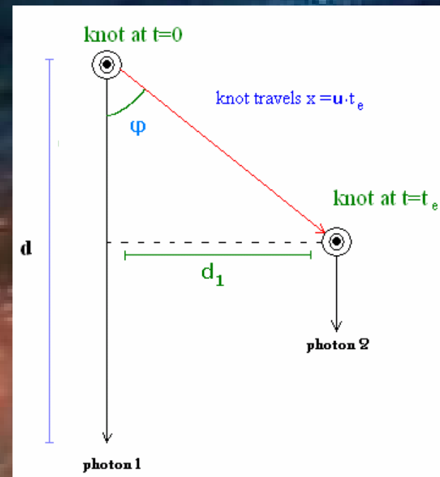
jet length = distance of the most distant identified component



	BL Lacs	Radio Galaxies	Quasars
#	17	36	20
Average z	0.388	0.401	0.40
Average	35.50	49.74	43.44
Error	7.37	6.18	6.96
Median	17.30	31.37	30.01



evolution of jet length with z ?



$$u_{app} = \frac{ut_e \sin\phi}{\Delta t} = \frac{u \sin\phi}{1-\beta\cos\phi}$$