Shapes of AGN jets on scales from pc to hecto-pc

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in collaboration with

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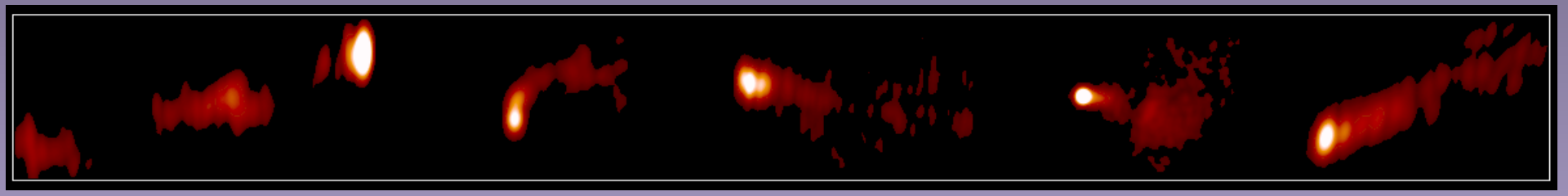
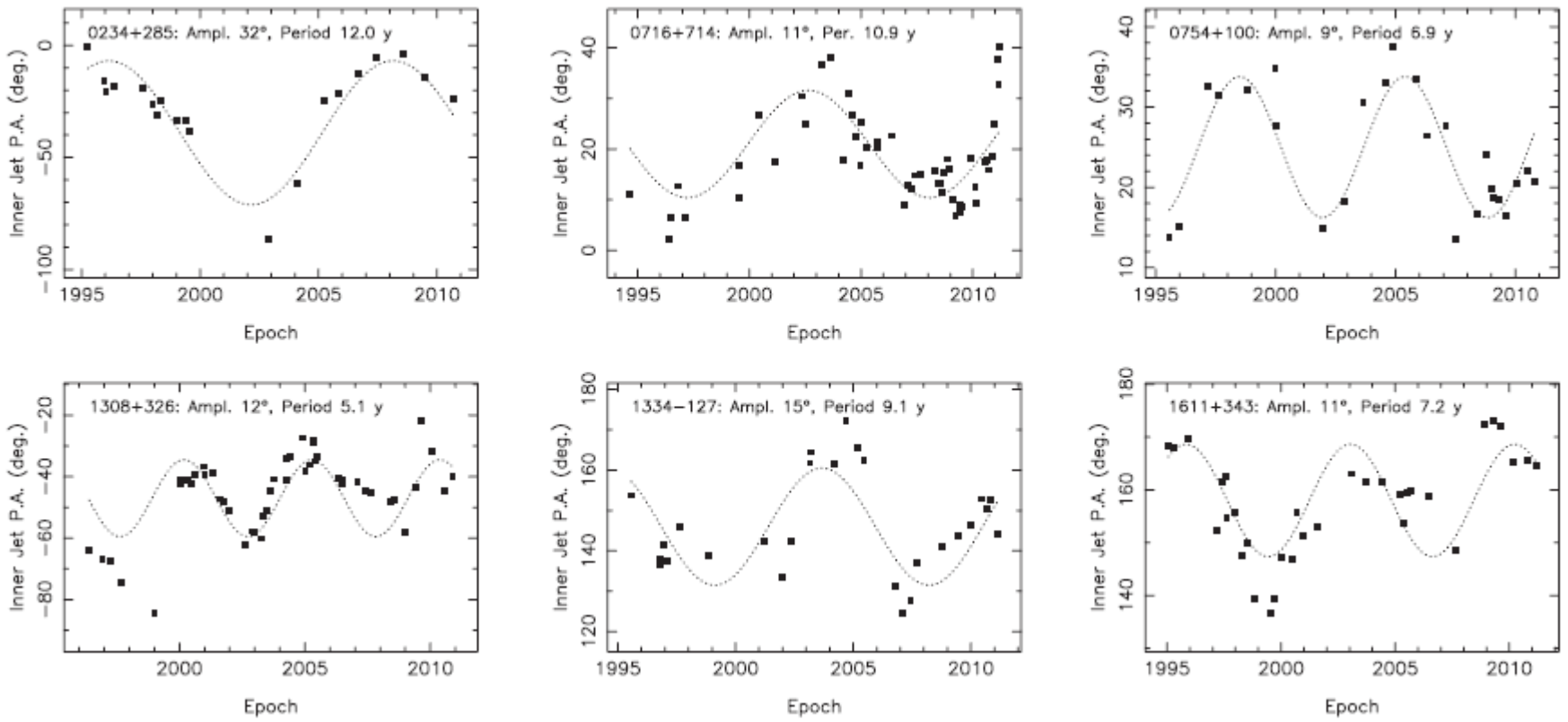


Blazars through Sharp Multi-Wavelength Eyes , Málaga, 30.05.2016

Innermost jet position angle variations

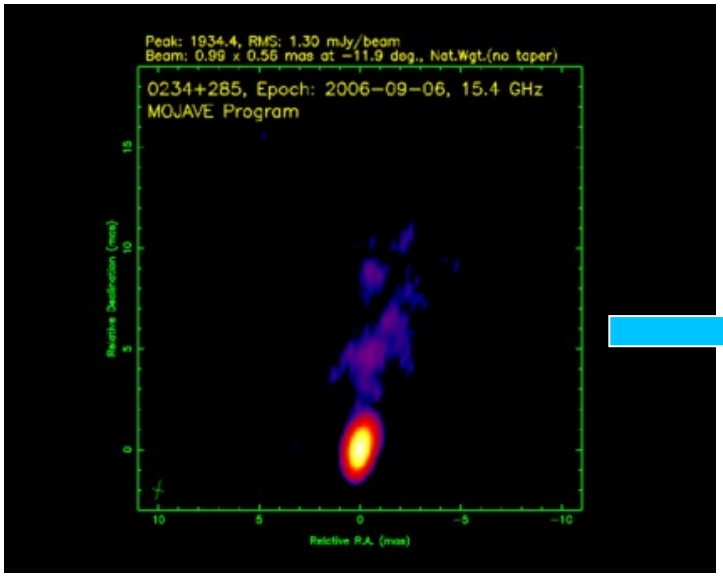


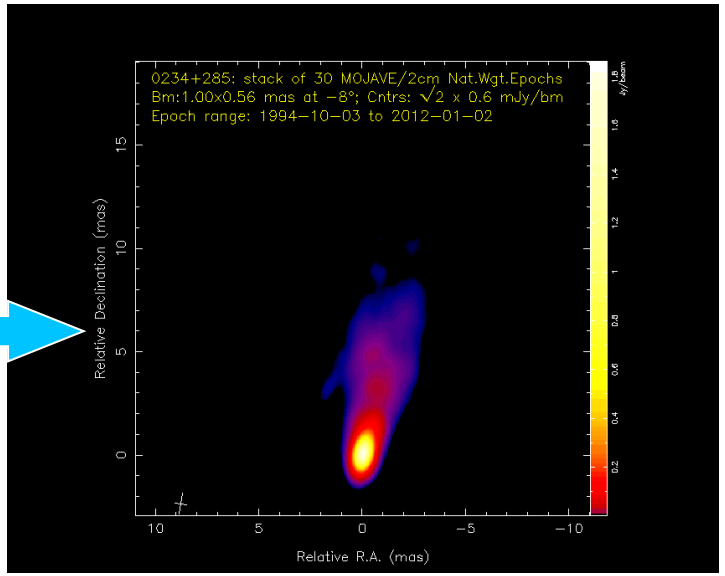
Lister et al. 2013

- Nearly all of 60 most heavily observed sources (12-16 yrs) show significant changes in their innermost jet PA

- About 1/3 of them show indications of oscillatory behavior with a fitted period from 5 through 12 yrs

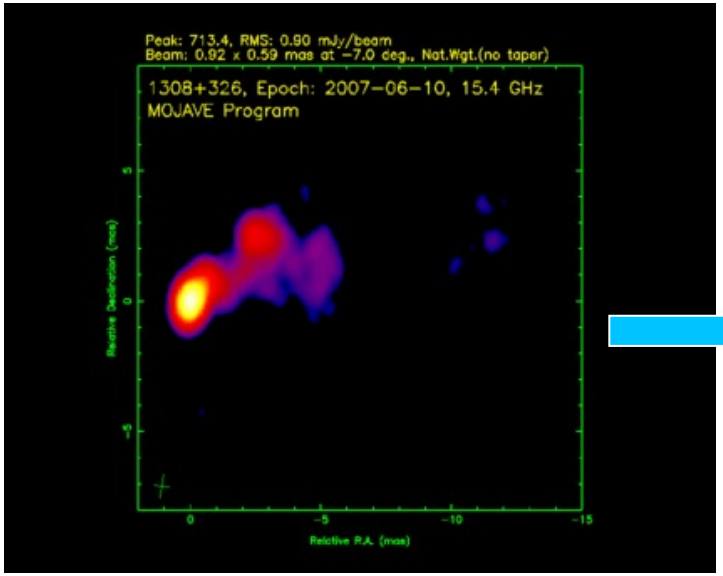
Multi-epoch stacked images

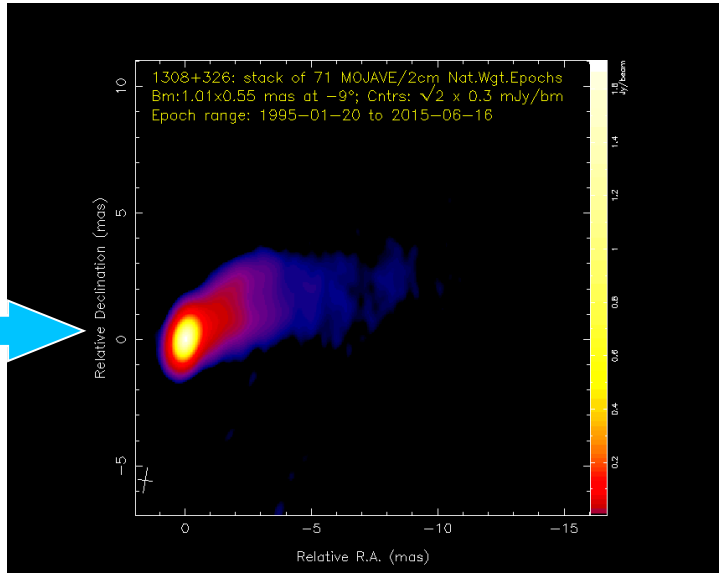




0234+285

30 epochs
17 yrs





1308+326

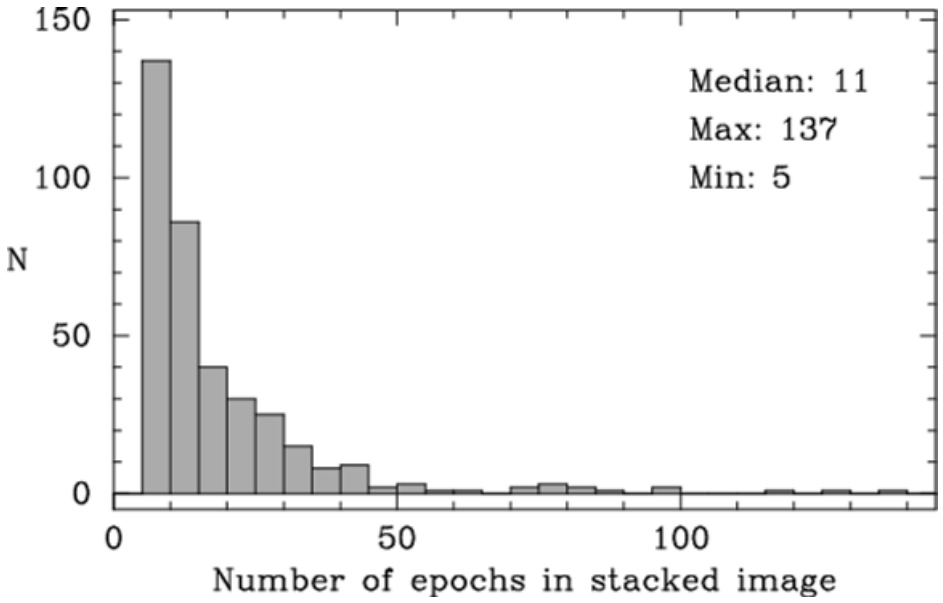
71 epochs
20 yrs

Stacked image statistics

Selection criteria:

- 2cm VLBA survey or MOJAVE programs
- at least 5 epochs since 1994-08-31
- the last epoch to include in the stack to be BL193AV, 2015-08-20

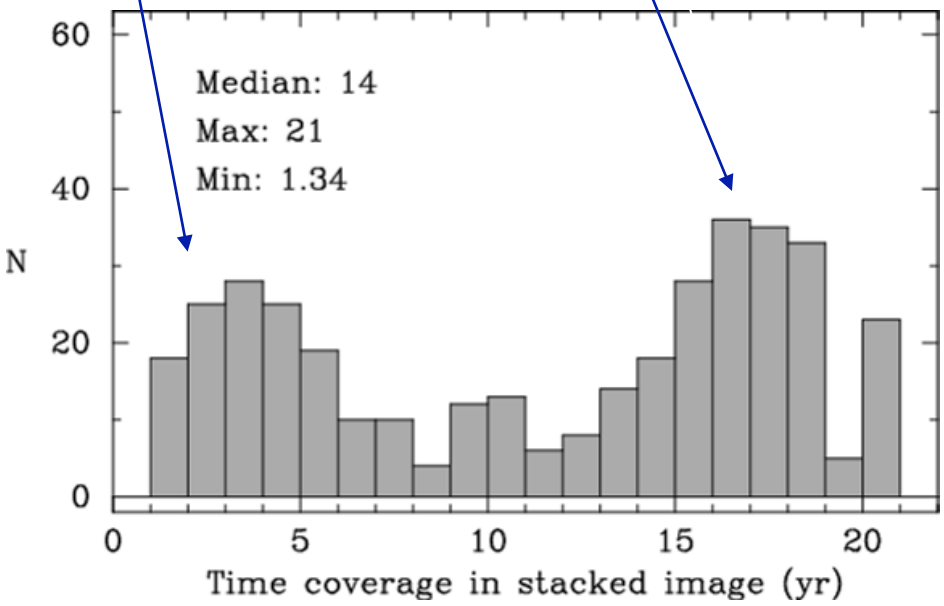
➔ a sample of 370 sources



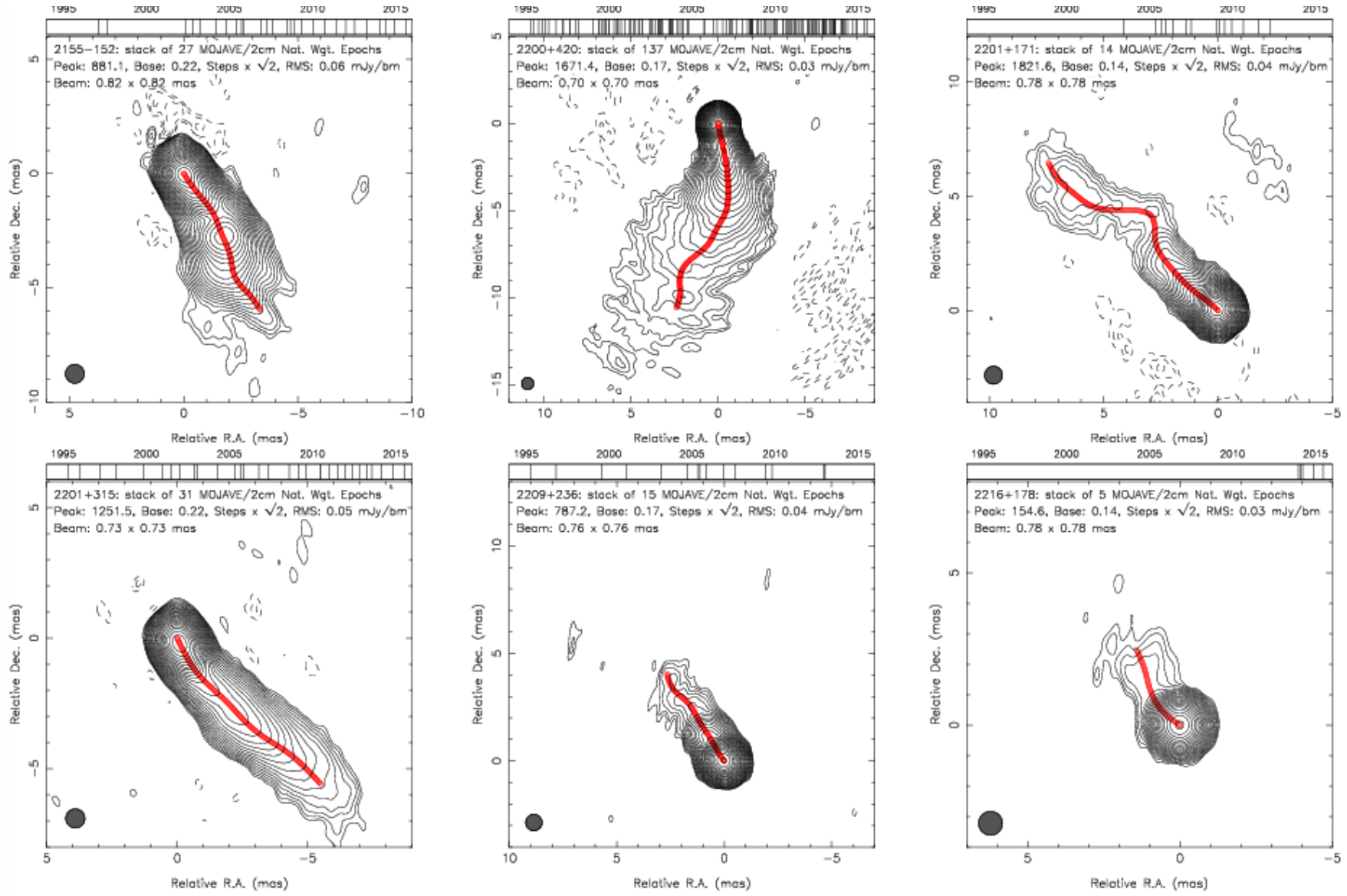
recently added:

- accel.
- HSP LAT blazars

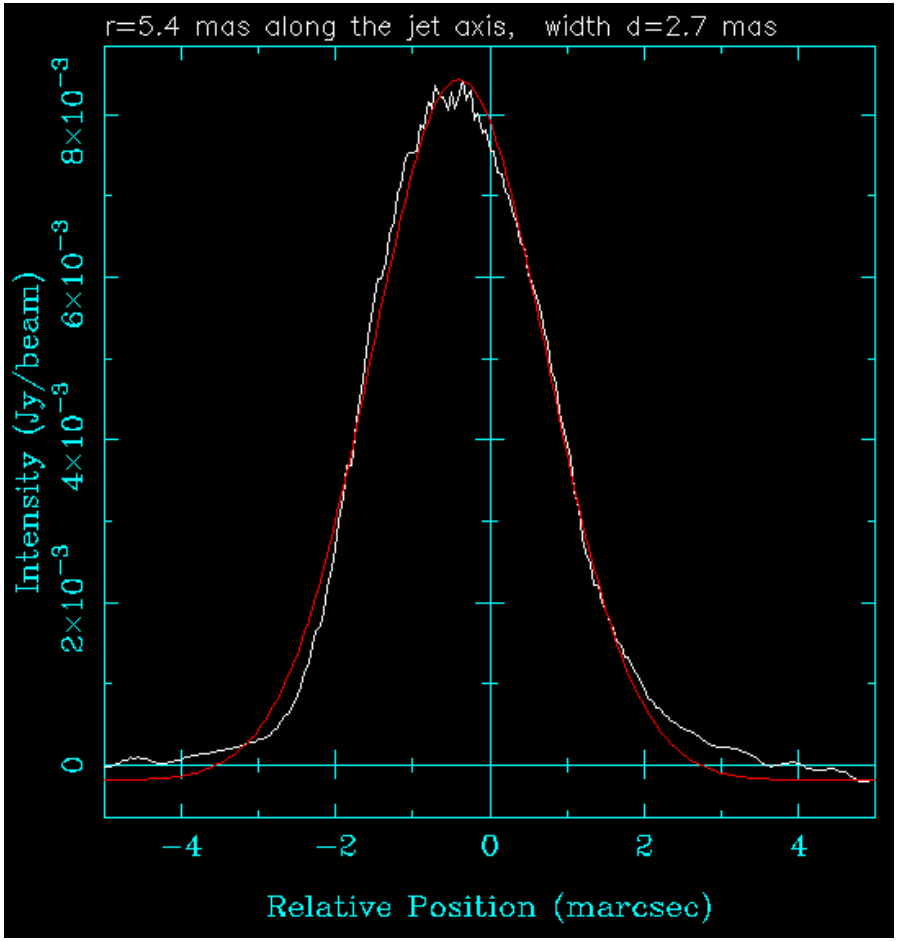
old friends

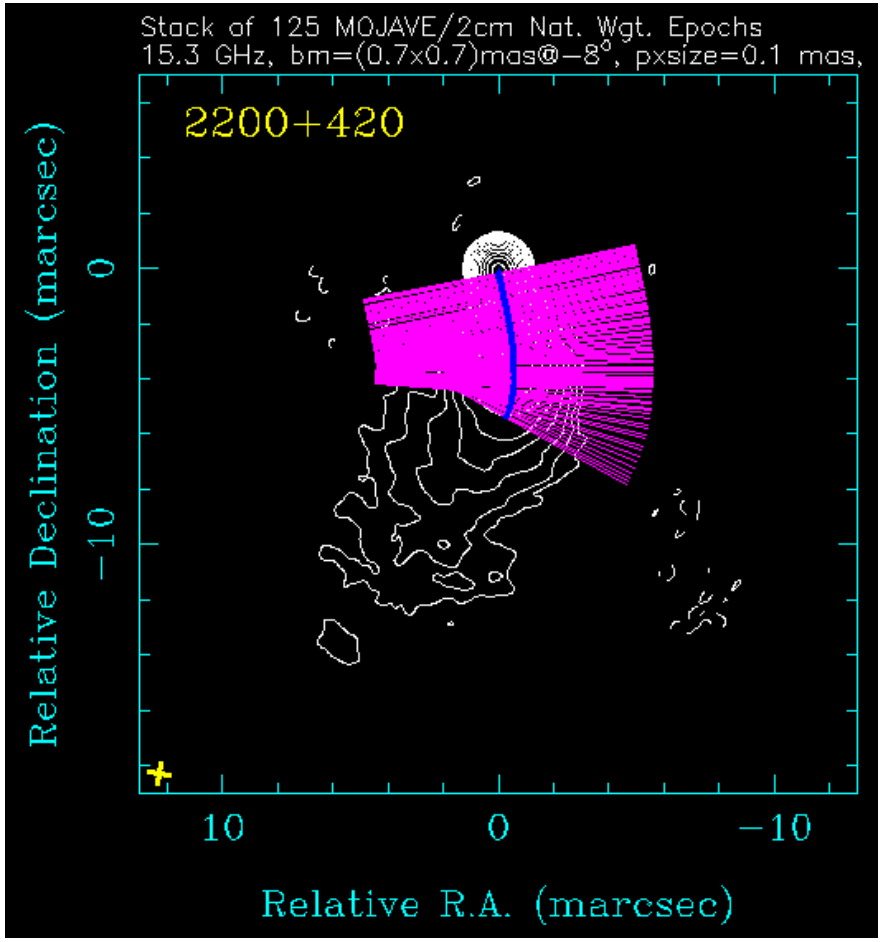


Ridgeline reconstruction (circ. beam)



Jet width & apparent opening angle measuring

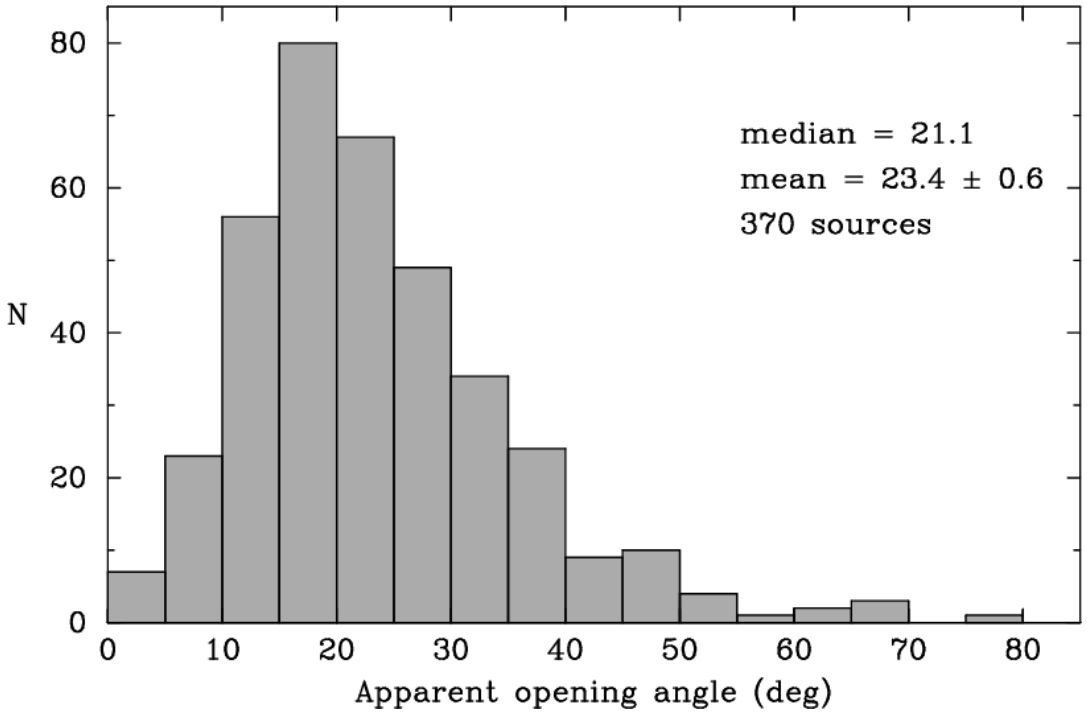


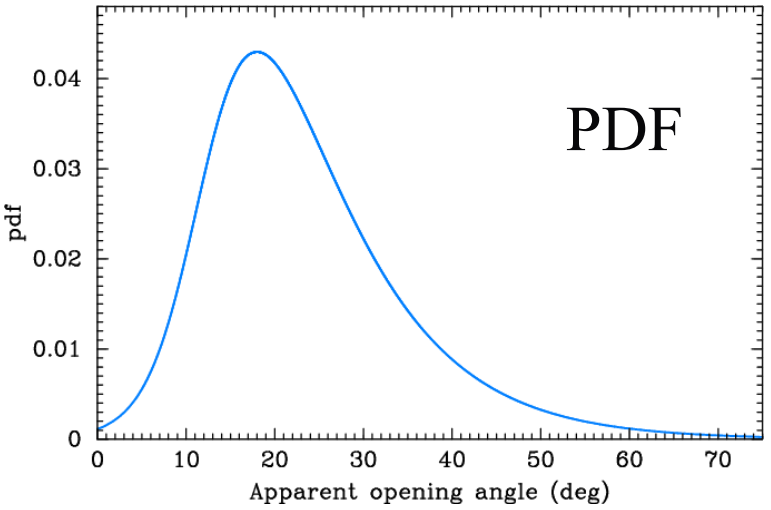


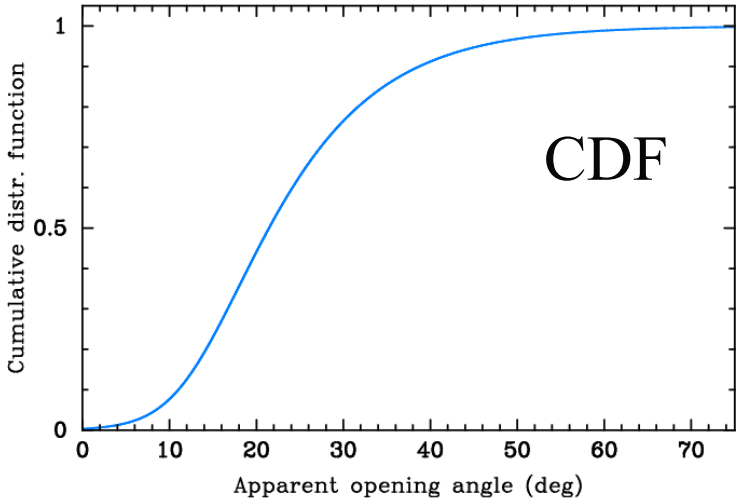
$$d = (D^2 - b_\varphi^2)^{1/2}$$

$$\alpha_{\rm app} = 2\arctan[0.5(D^2 - b_\varphi^2)^{1/2}/r]$$

Apparent jet opening angles distribution

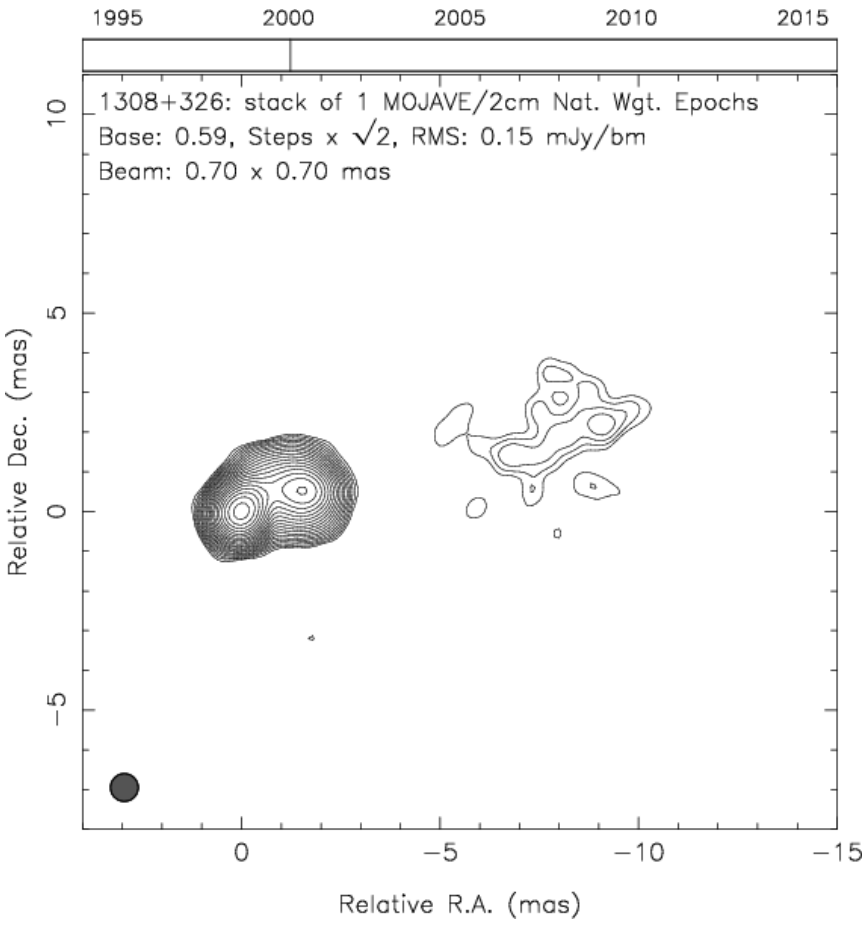


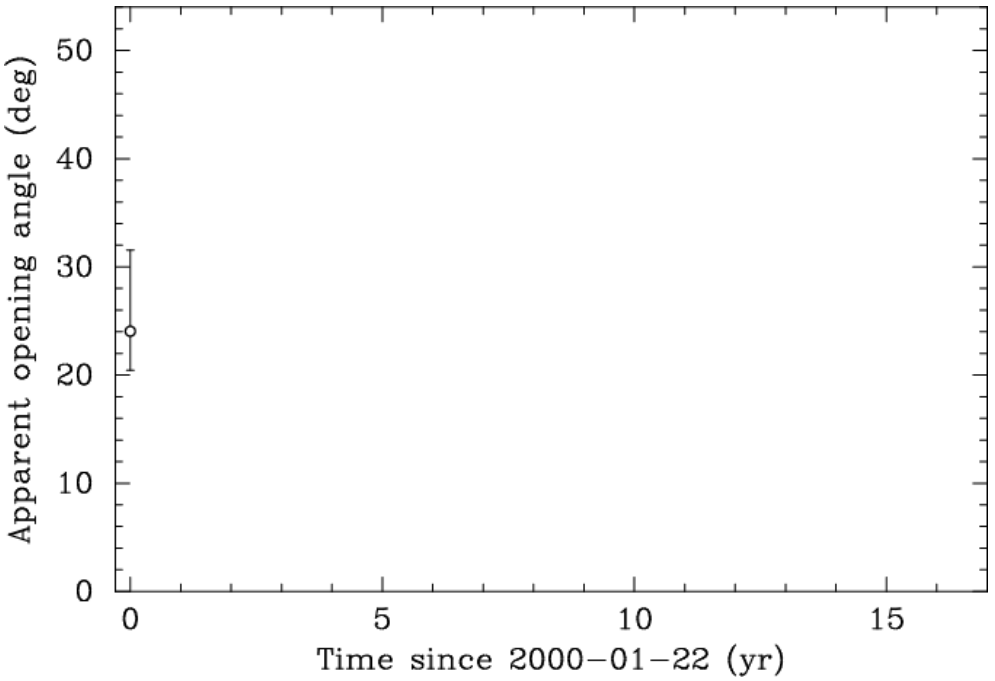




- wide distribution ranging from a few degrees through 77° (1520+319)
- peaks at ~20°

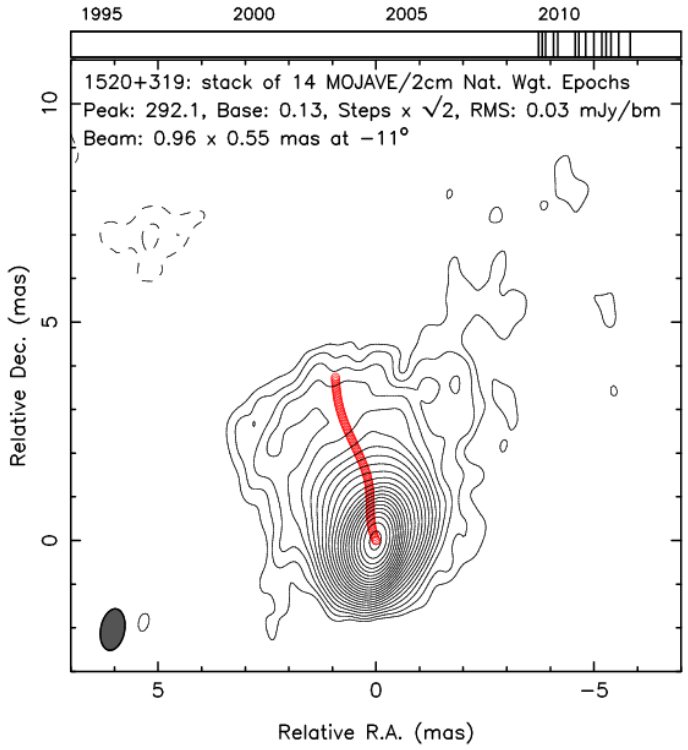
Stacked image and jet opening angle evolutions in BL Lac 1308+326

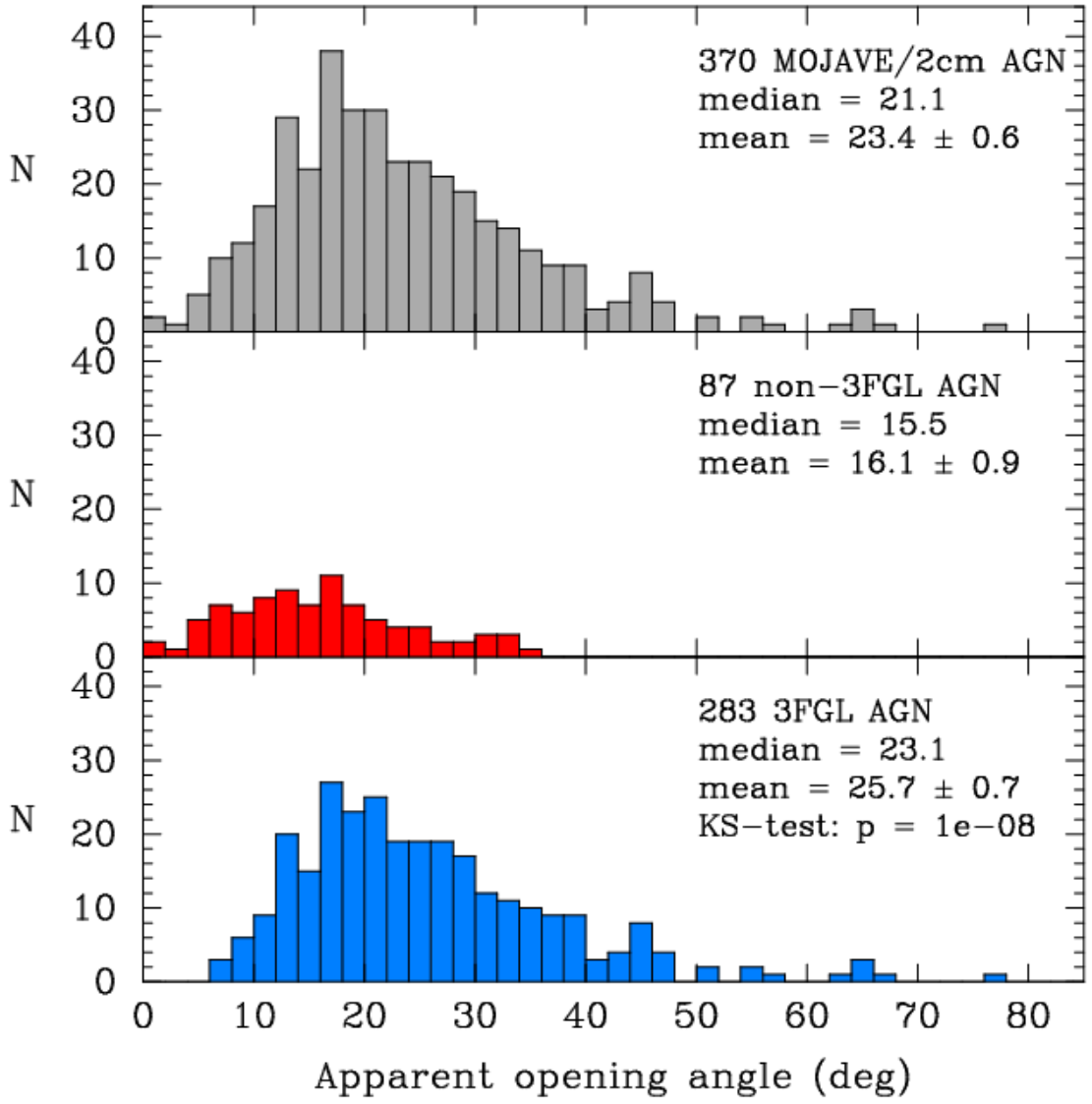




Apparent jet opening angles and γ-ray brightness

- LAT-detected AGN (3FGL) have on average wider opening angles
- sources with apparent opening angle exceeding 40° are all gamma-ray bright





Intrinsic opening angles

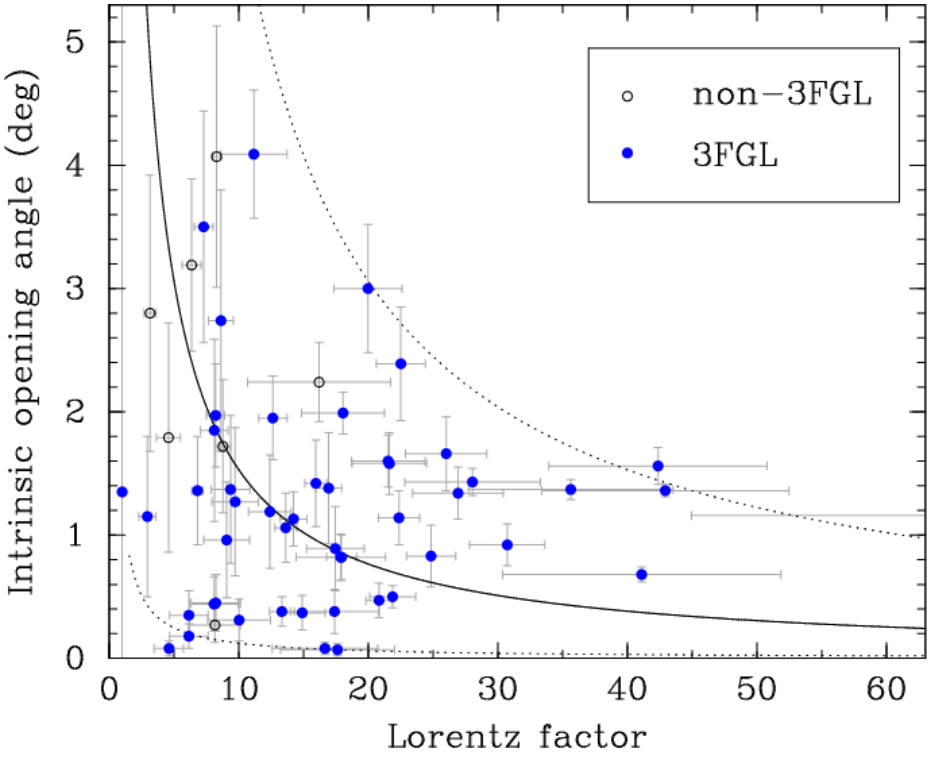
$$\Gamma = \frac{\beta_{app}^2 + \delta^2 + 1}{2\delta}$$

$$\theta = \mathrm{atan}\,\frac{2\beta_{app}}{\beta_{app}^2 + \delta^2 - 1}$$

$$\tan\left(\frac{\alpha_{int}}{2}\right) = \tan\left(\frac{\alpha_{app}}{2}\right)\sin\theta$$

max. radial apparent speeds (MOJAVE; Lister et al. 2013, 2016)

Doppler factors (Metsähovi AGN Monitoring Program; Hovatta+ 2009)
➔ 56 sources

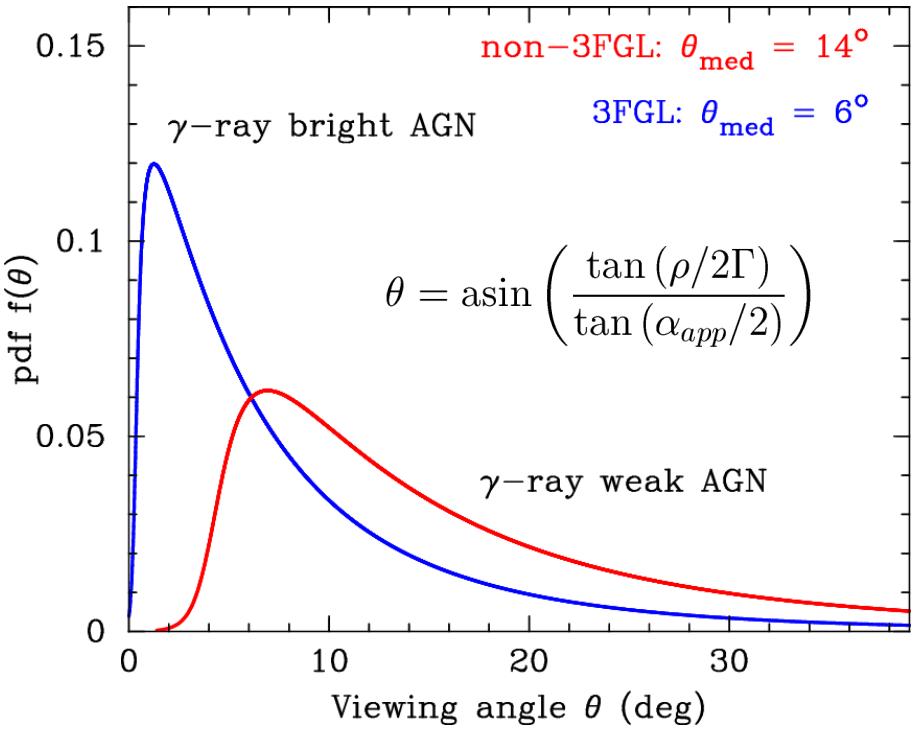


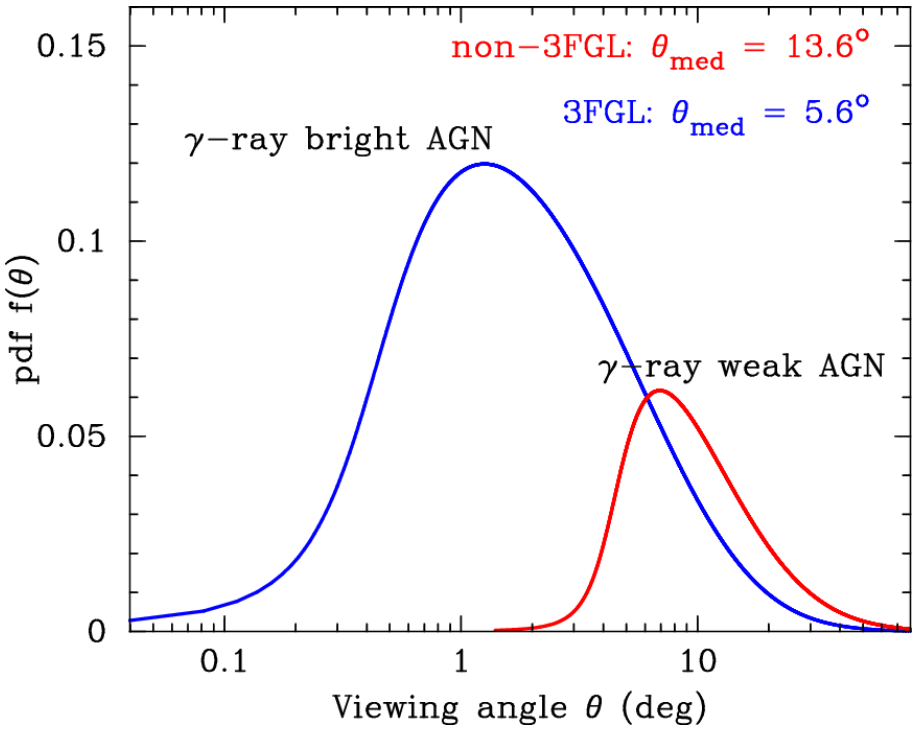
$\alpha_{int} = \rho / \Gamma$, where median ρ = 0.27 rad

- α_{int} and Γ are inversely prop., as predicted by models of relativistic jets (Blandford & Königl 1979; Daly & Marscher 1988; Komissarov 2007)

- LAT-detected AGN have narrower jets (with medians of 1.2° vs 2.2°)

Gamma-ray brightness and viewing angles





Gamma-ray bright AGN have on average smaller viewing angles

Consistent with

- higher apparent speeds (Lister et al. 2009)
- higher Tbs and variability index (Kovalev et al. 2009)
- higher Doppler factors (Savolainen et al. 2010)

Parsec-scale jet shapes

$$d \propto r^k$$

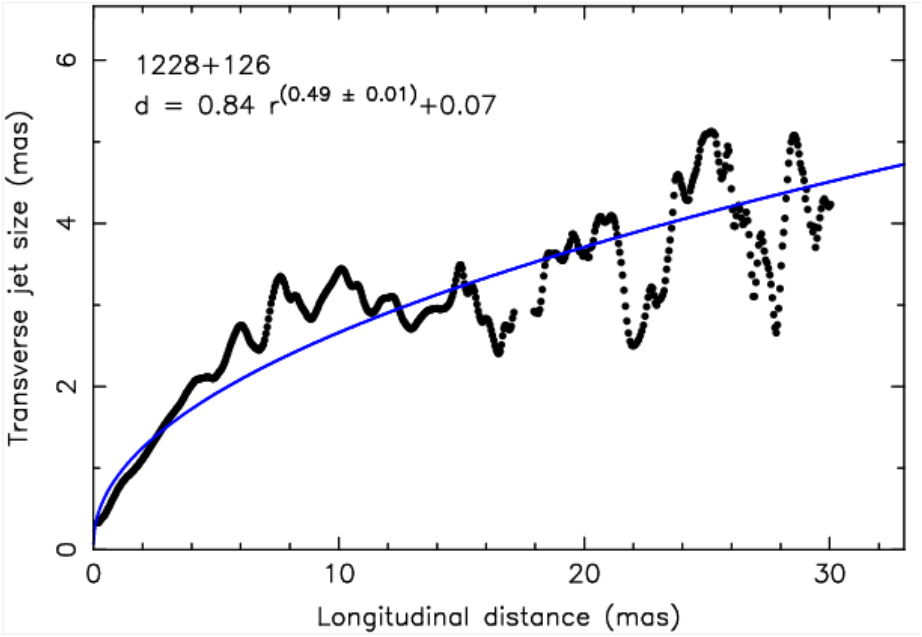
d – transverse jet width (deconvolved)

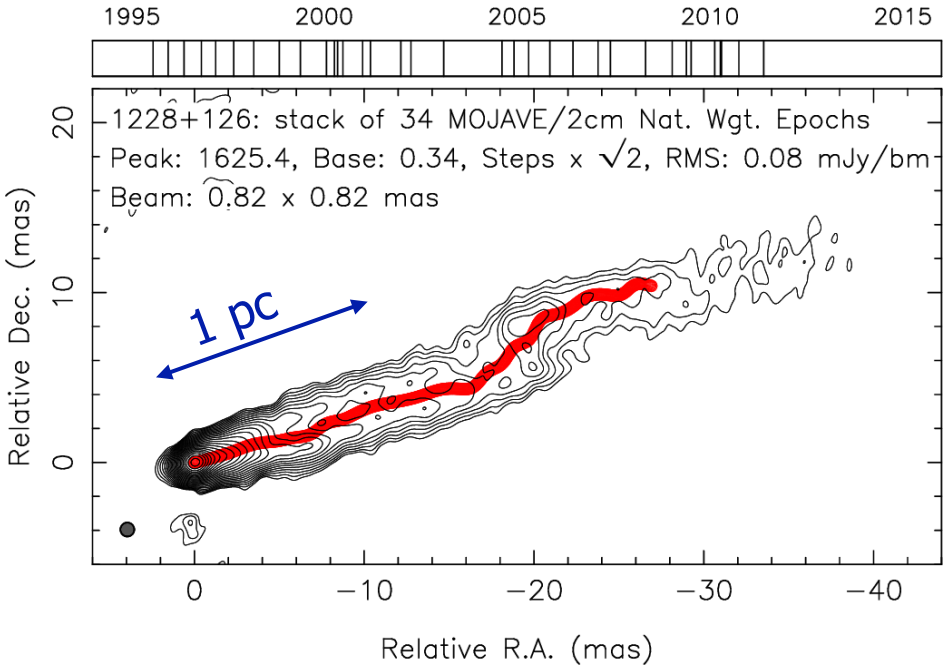
r – distance along the jet

k < 1 ➔ collimation (acceleration)

k = 1 ➔ conical (constant speed regime)

k > 1 ➔ more free expansion (deceleration)





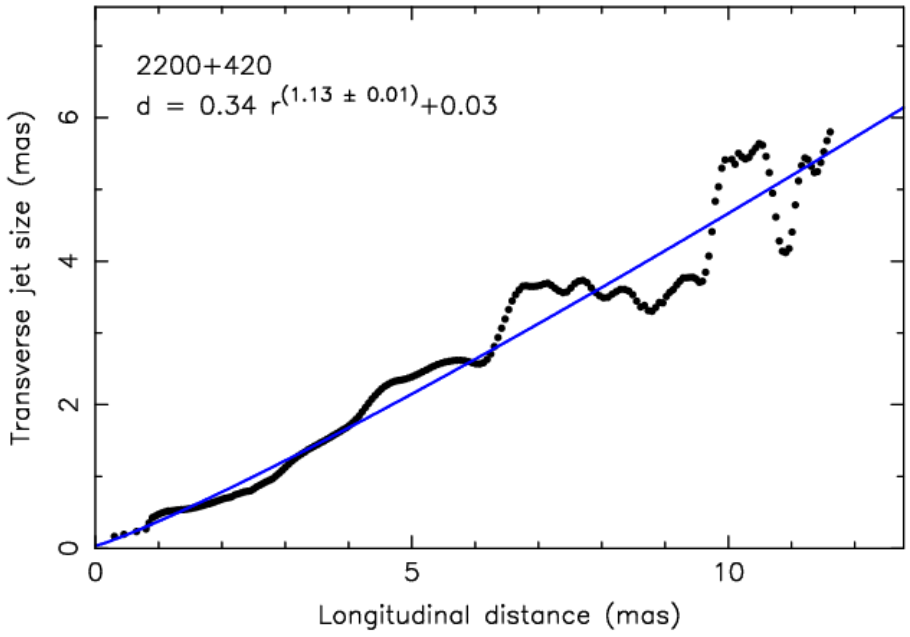
M87: k=0.5 ➔ close to parabolic

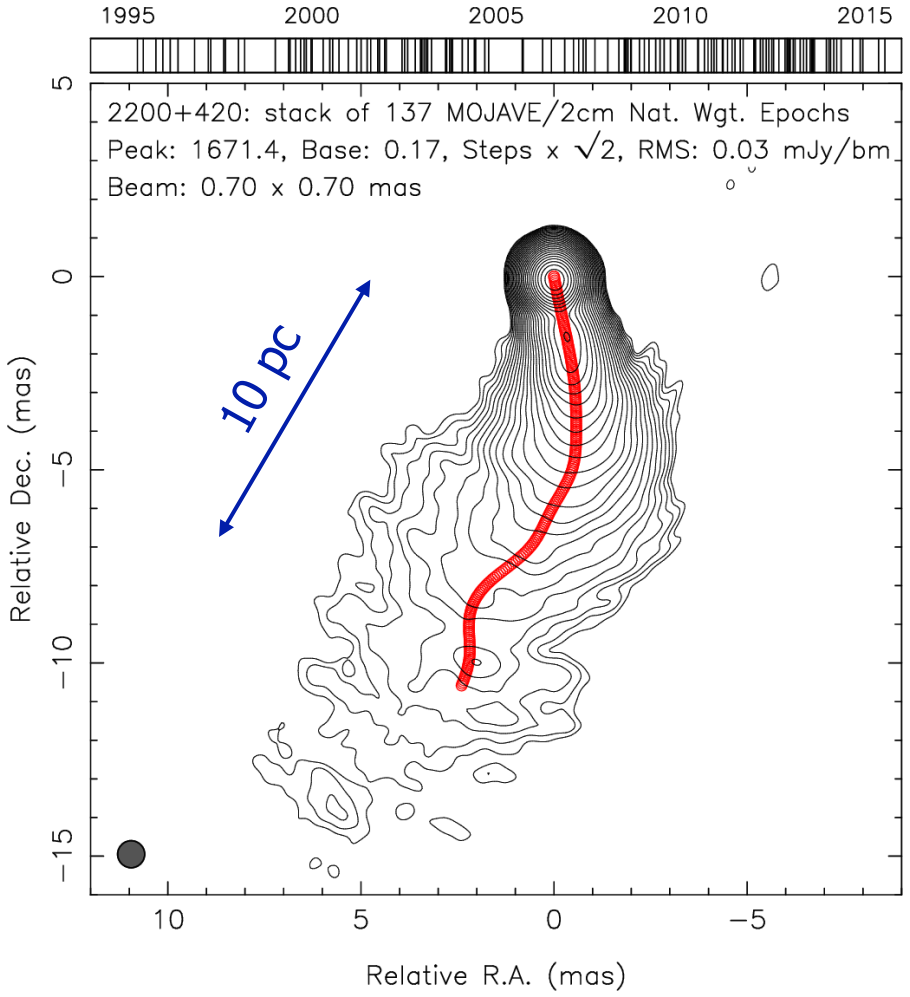
Parsec-scale jet shapes

$$d \propto r^k$$

d – transverse jet width (deconvolved)

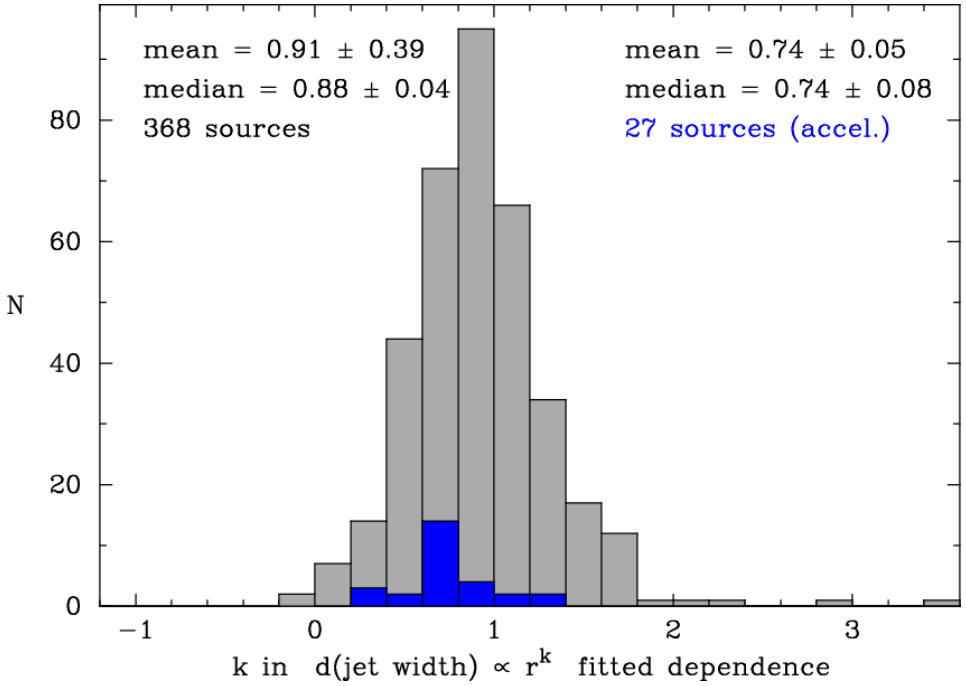
r – distance along the jet





BL Lac: k=1.1 ➔ close to conical

Parsec-scale jet shapes

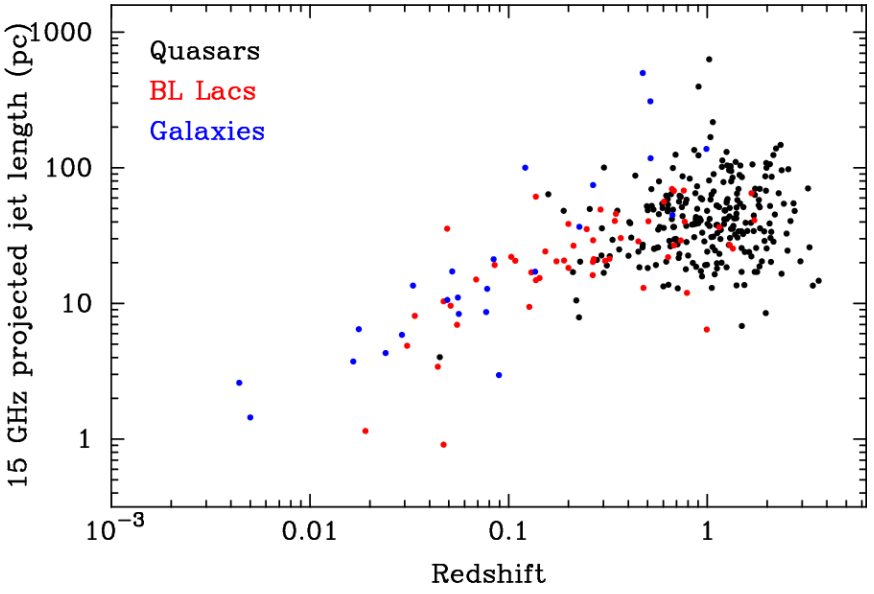


k ~ 1 ➔ typical shape is close to conical

consistent with a size-freq dependence $\theta \sim \nu^{-1}$ predicted by theory (Blandford & Königl, 1979) and statistically confirmed by observations (Pushkarev & Kovalev, 2015)

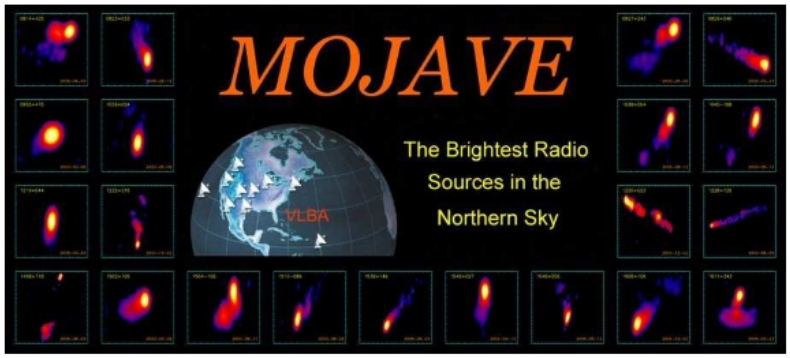
Median k-index for
all sources (368): 0.88 ± 0.04
BL Lacs (71): 0.99 ± 0.08
Quasars (241): 0.86 ± 0.04
Galaxies (22): 0.50 ± 0.18

Jets with accelerated motion (Homan et al., 2015) tend to be more actively collimated



18-22cm VLBA obs. of MOJAVE-1 sample

- 12 24h VLBA sessions during 2010 of single-epoch polarization sensitive observations
- 135 sources of the statistically complete MOJAVE-1 sample
- Aimed on Faraday rotation analysis. Our goal – jet shapes at larger scales
- Observing frequency: 1.4 GHz

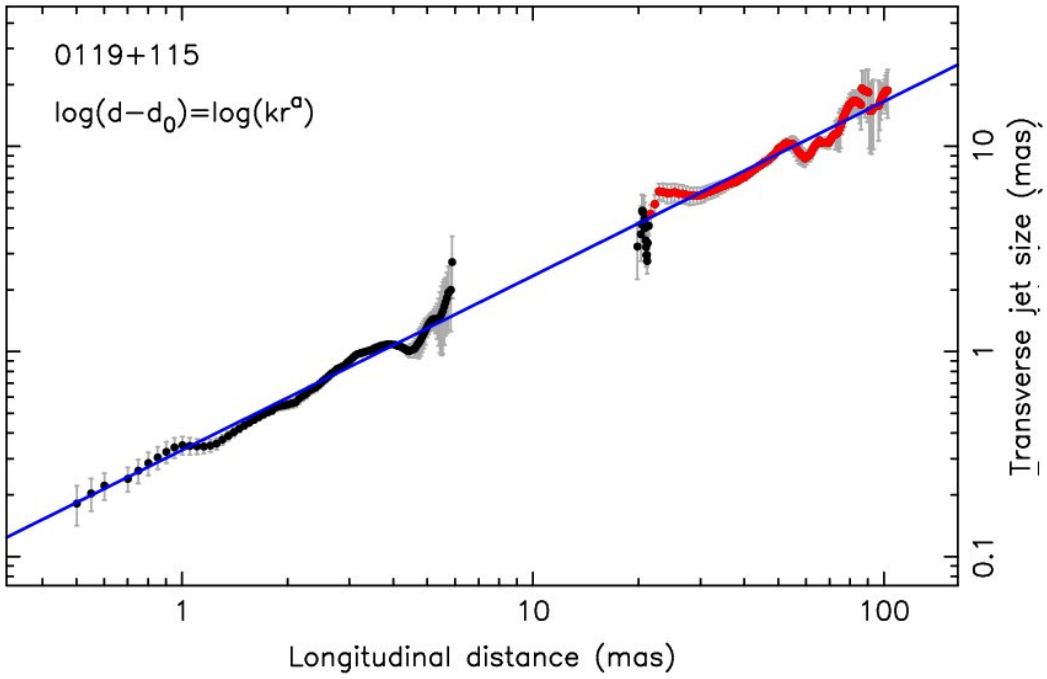


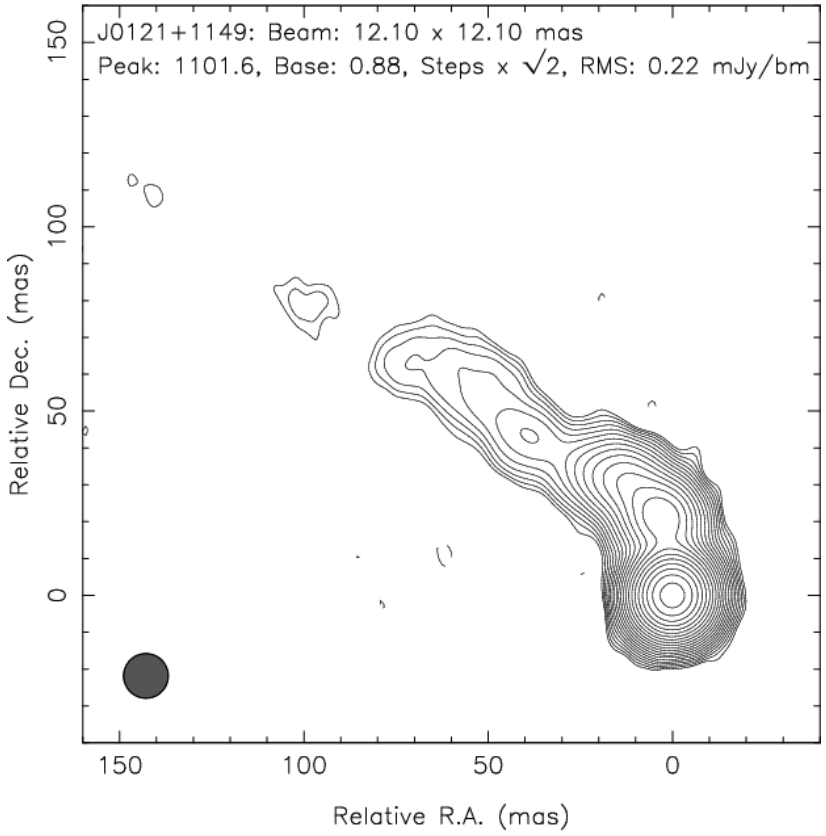
Jet shapes at larger scales

$$d \propto r^k$$

d – transverse jet width (deconvolved)

r – distance along the jet





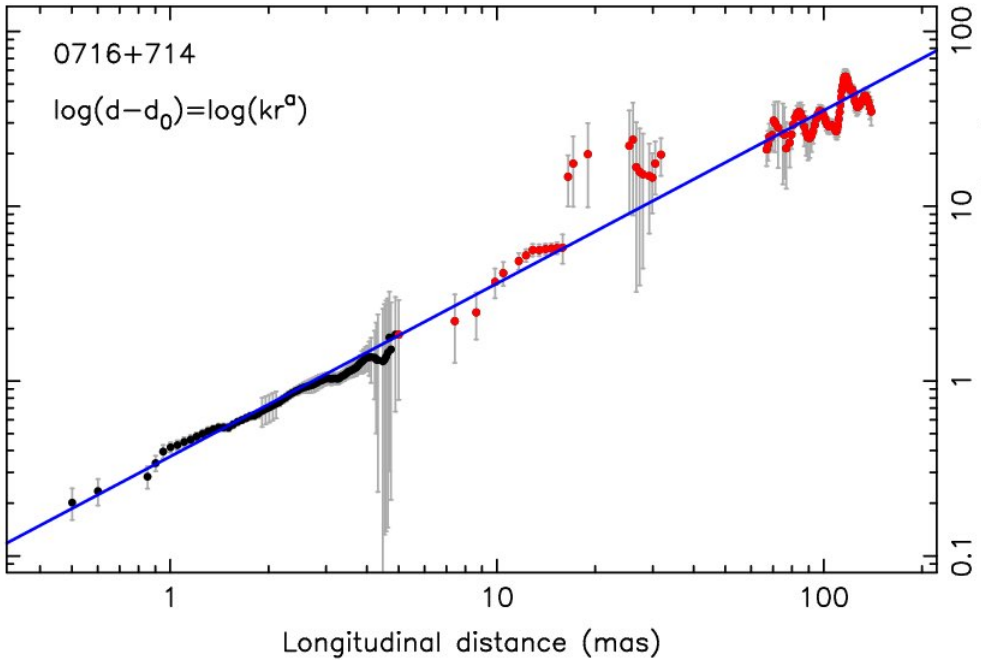
0119+115: k=0.85

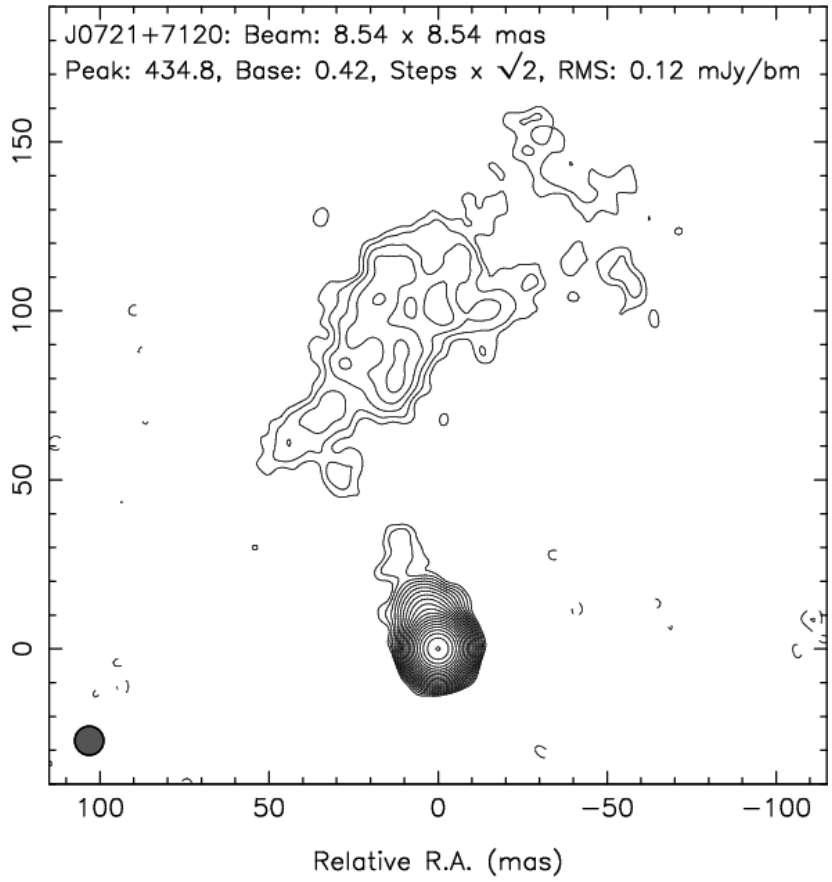
Jet shapes at larger scales

$$d \propto r^k$$

d – transverse jet width (deconvolved)

r – distance along the jet





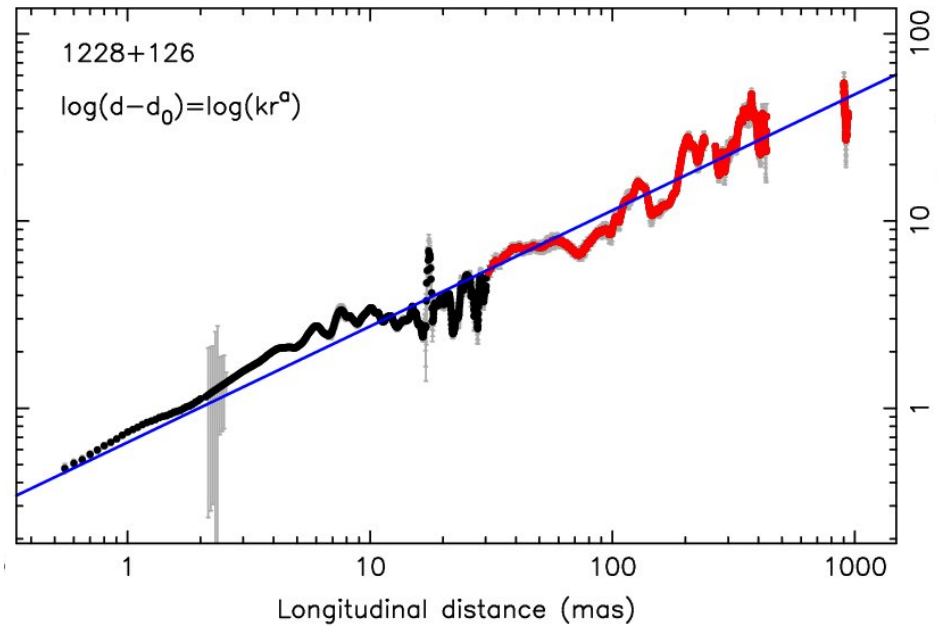
0716+714: k=0.99

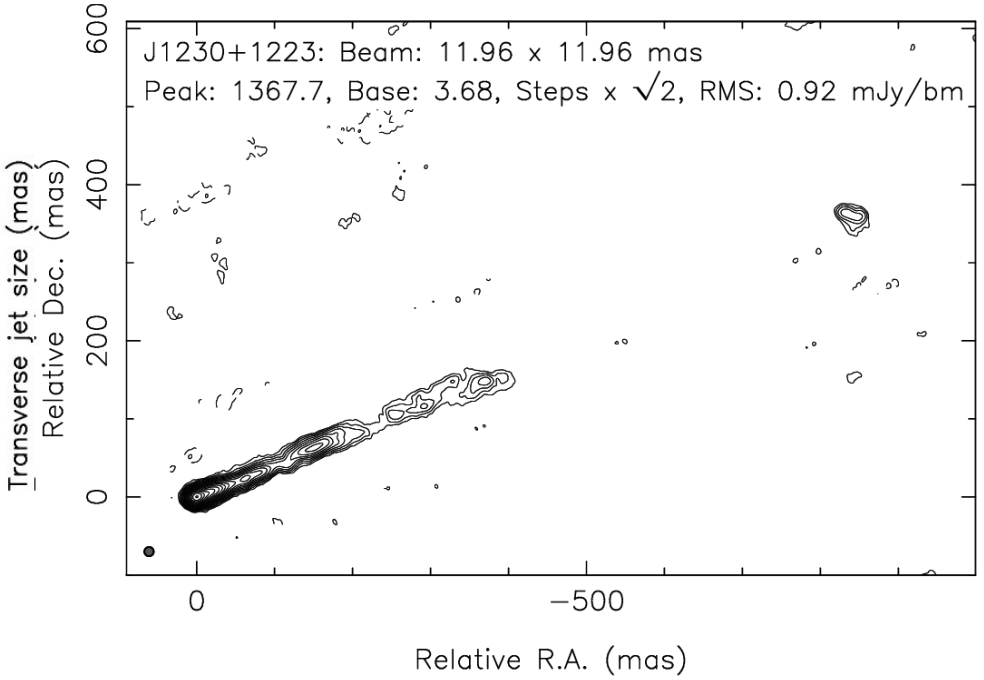
Jet shapes at larger scales

$$d \propto r^k$$

d – transverse jet width (deconvolved)

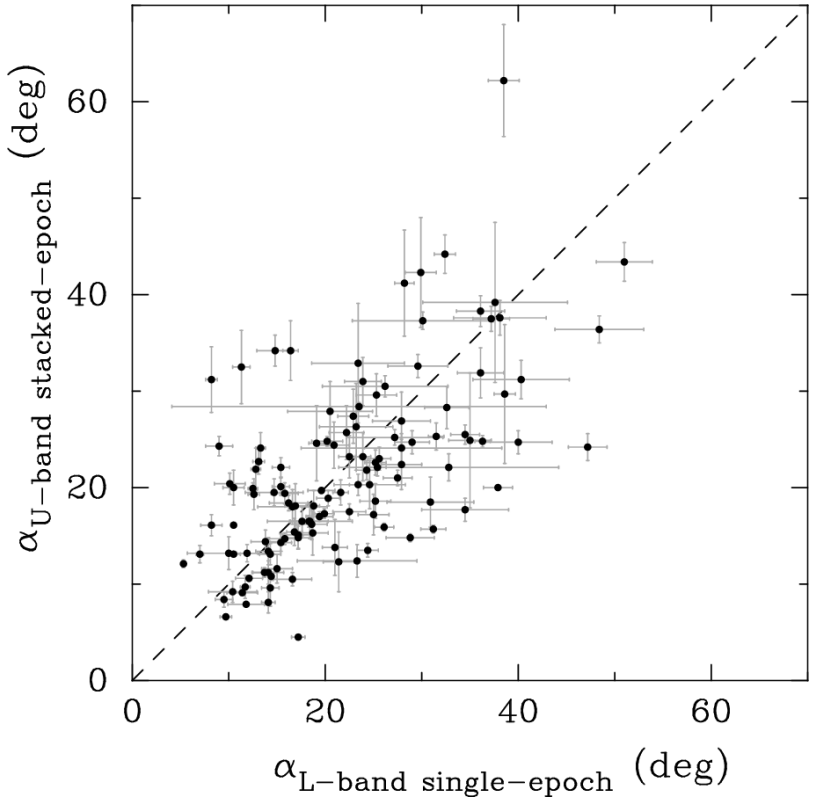
r – distance along the jet

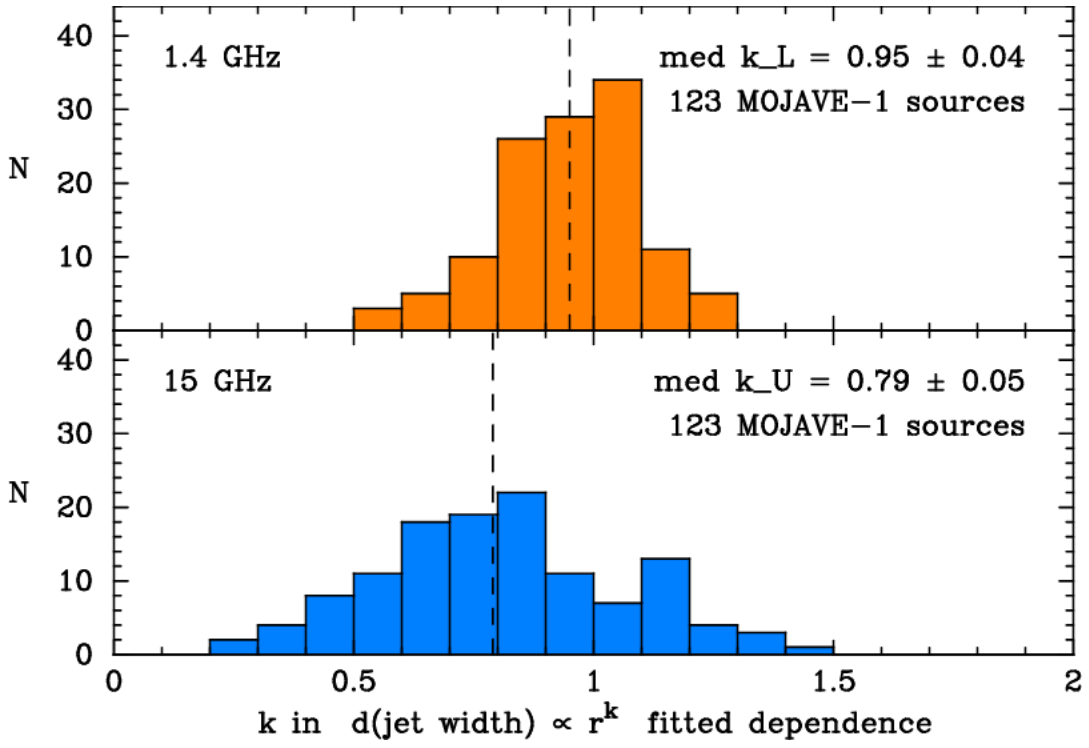




M87: k=0.62

Apparent jet opening angles at 15 vs 1.4 GHz





Opening angles are comparable, with median ratio of $\alpha_{1.4}/\alpha_{15}$~1.1

k ~ 1 ➔ typical jet shape is still close to conical at hecto-pc scales

median ratio: $k_{1.4}/k_{15}$~1.2

Summary

- Typical geometry of AGN jets on pc to hecto-pc scale is close to conical
- Intrinsic jet opening angles at parsec scales are small (~1°), inversely proportional to Lorenz factor
- Sources with radial accelerated motion tend to manifest more active collimation
- gamma-ray bright AGNs have statistically wider apparent opening angles and smaller viewing angles