Detecting the elusive blazar counter-jets

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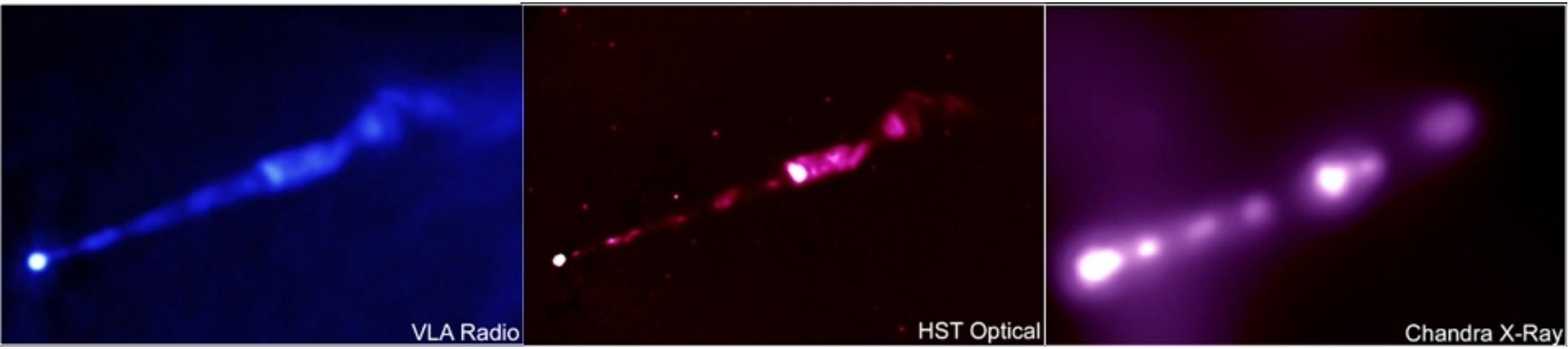
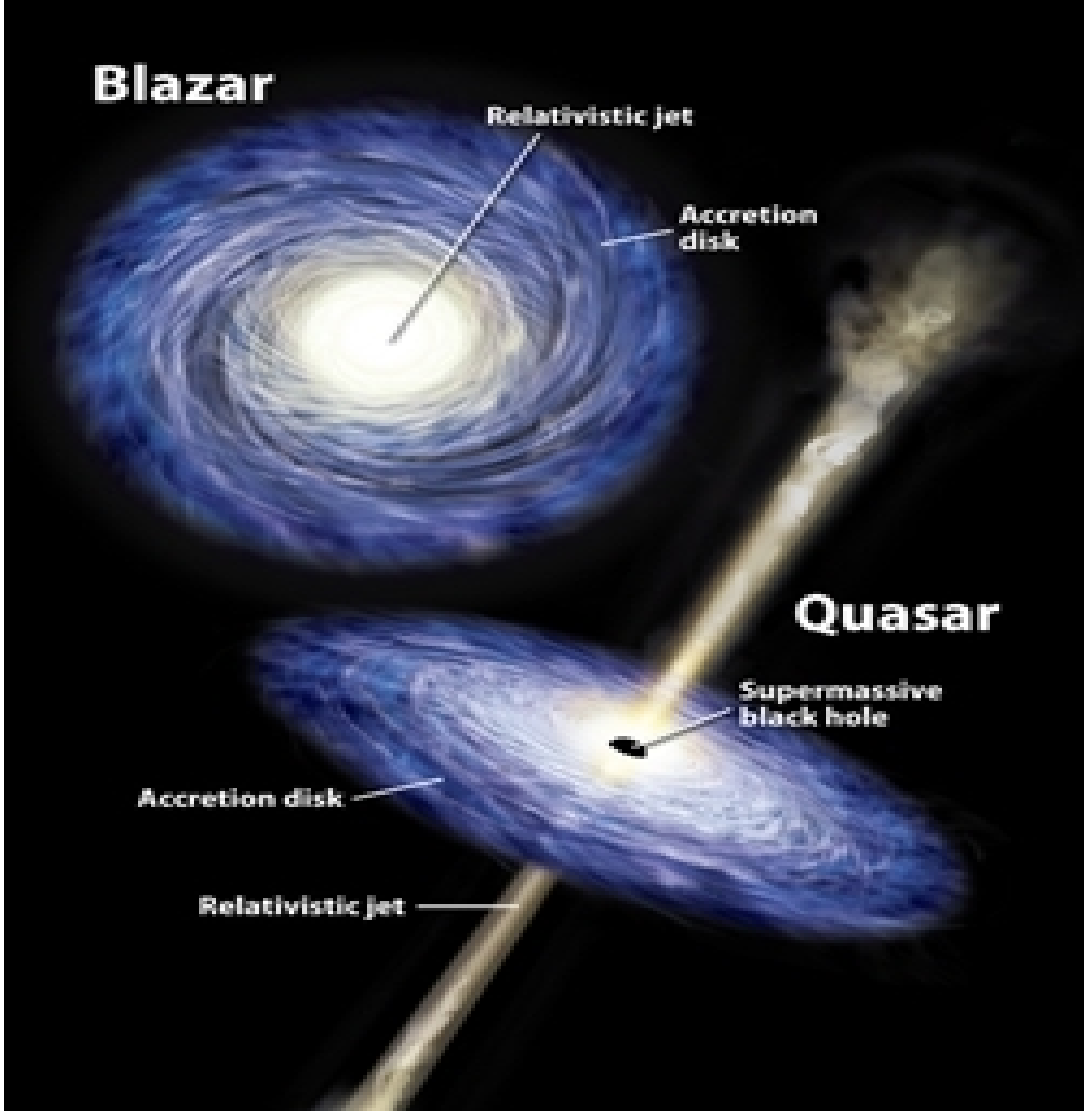


Nuclear Activity in Galaxies, Hel.A.S.
Athens, July 2016

What is a Blazar?



Most Active of Galaxies:

- BL Lac objects (BL Lacs).

-Flat Spectrum Radio Quasars (FSRQs).

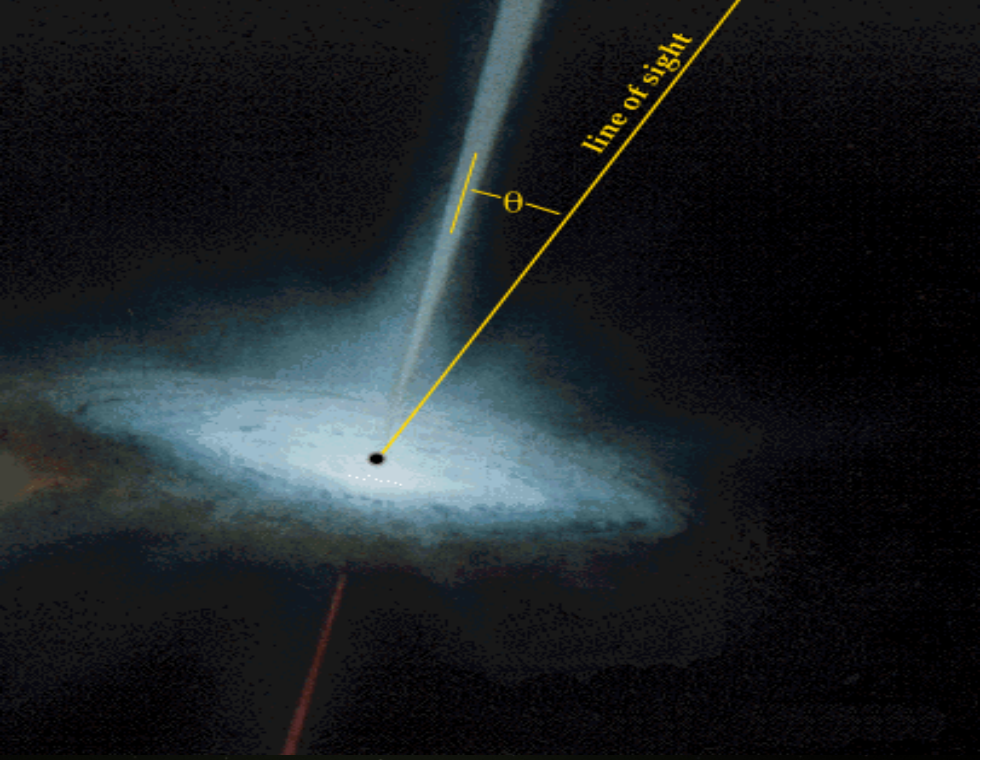
Jet oriented towards our line of sight:

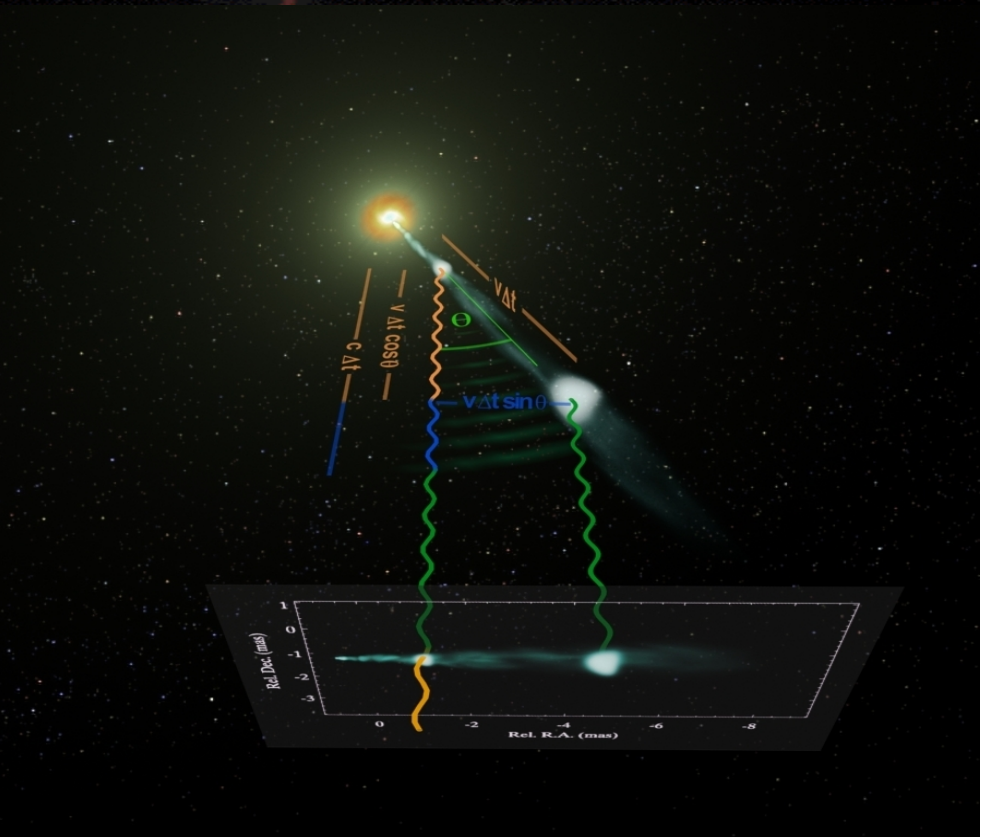
-Superluminal motion.

- Boosted emission.

- Extreme variability across the electromagnetic spectrum.

-High degree of polarization in the jets





Doppler factor (δ)

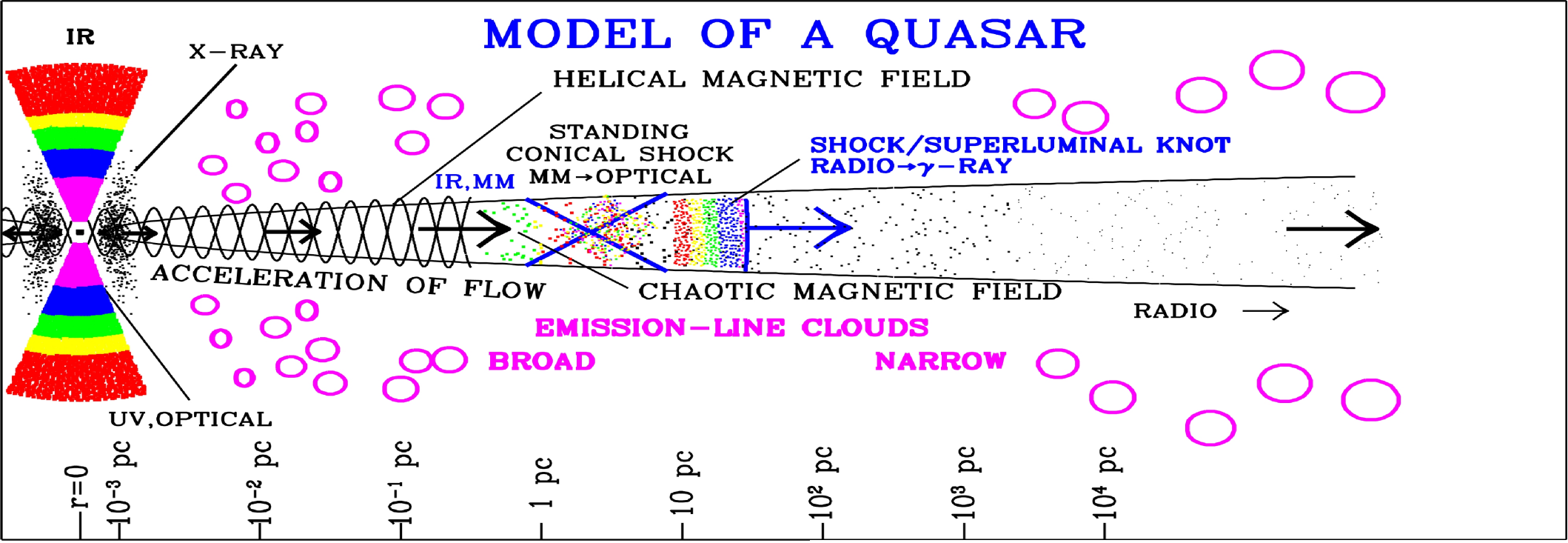
$$\delta = \frac{1}{\Gamma\left(1-\beta\cos\theta\right)}$$

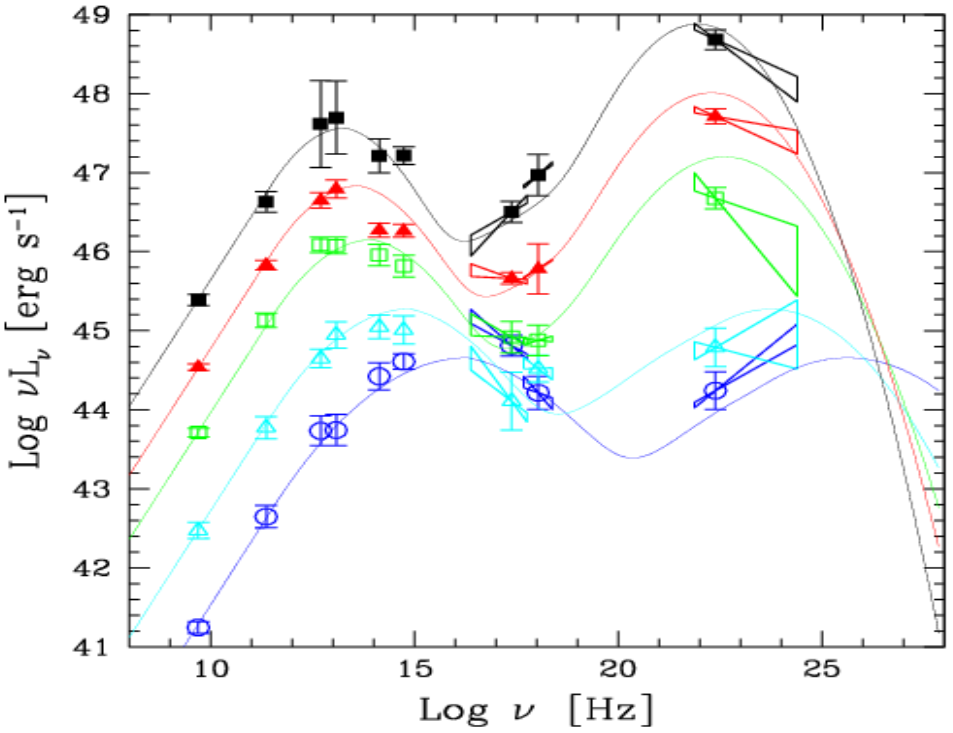
Lorentz factor (Γ)

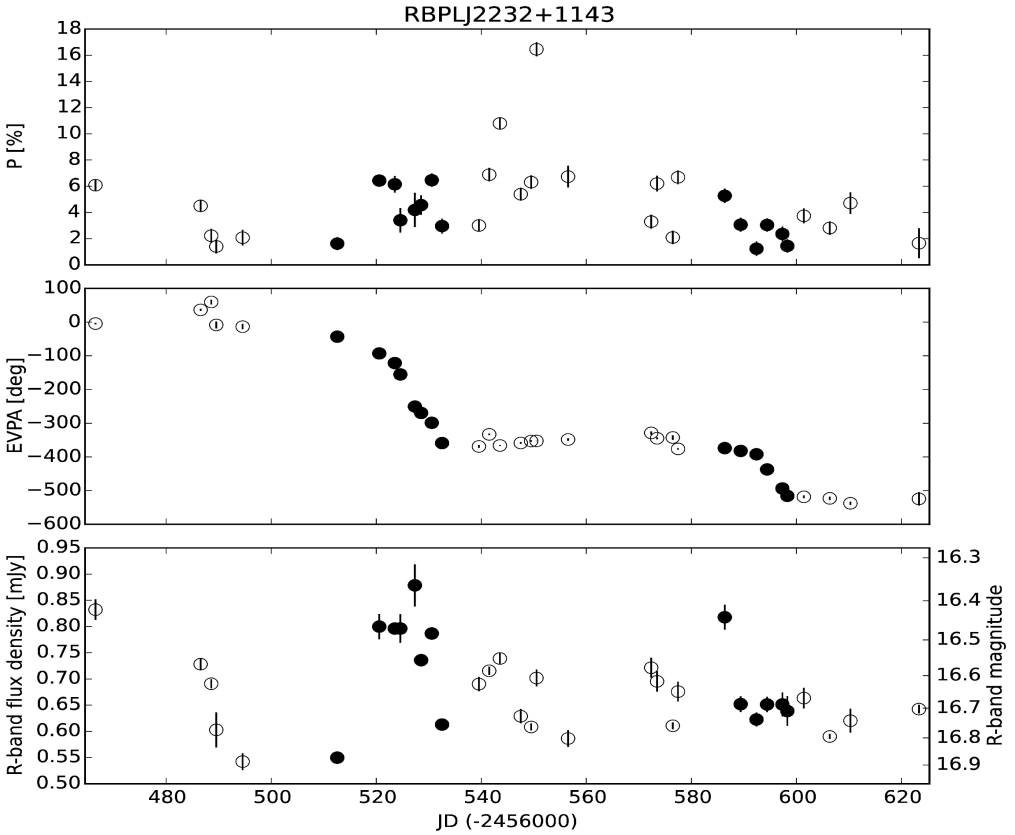
$$\Gamma = \frac{1}{\sqrt{1-\beta^2}}, \qquad \beta = \frac{u}{c}$$

Apparent velocity (β_{app})

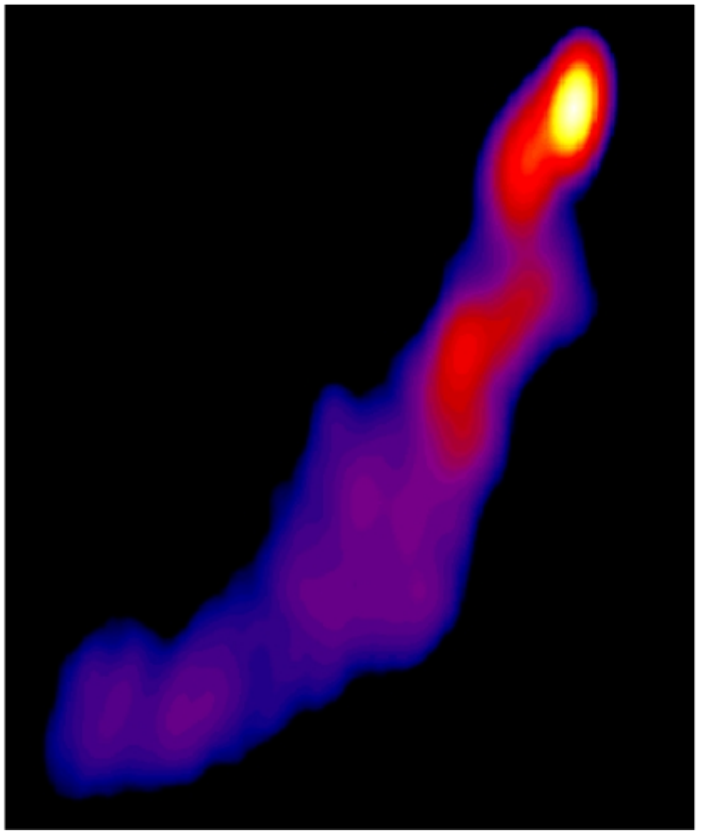
$$\beta_{app} = \frac{\beta\sin\theta}{1-\beta\cos\theta}$$


MODEL OF A QUASAR
IR
X−RAY
HELICAL MAGNETIC FIELD
STANDING
CONICAL SHOCK
MM→OPTICAL
IR,MM
SHOCK/SUPERLUMINAL KNOT
RADIO→γ−RAY
ACCELERATION OF FLOW
CHAOTIC MAGNETIC FIELD
RADIO
EMISSION−LINE CLOUDS
BROAD
NARROW
UV,OPTICAL
r=0
10⁻³ pc
10⁻² pc
10⁻¹ pc
1 pc
10 pc
10² pc
10³ pc
10⁴ pc

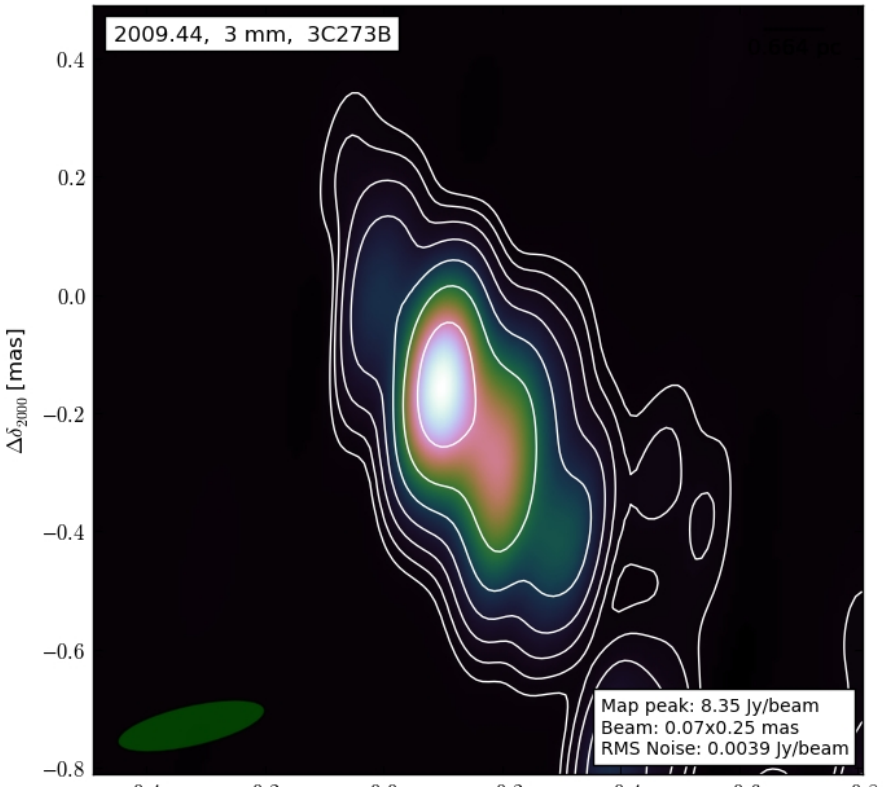

Log νL_ν [erg s⁻¹]
Log ν [Hz]


RBPLJ2232+1143
P [%]
EVPA [deg]
R-band flux density [mJy]
R-band magnitude
JD (-2456000)

Counter-jets.



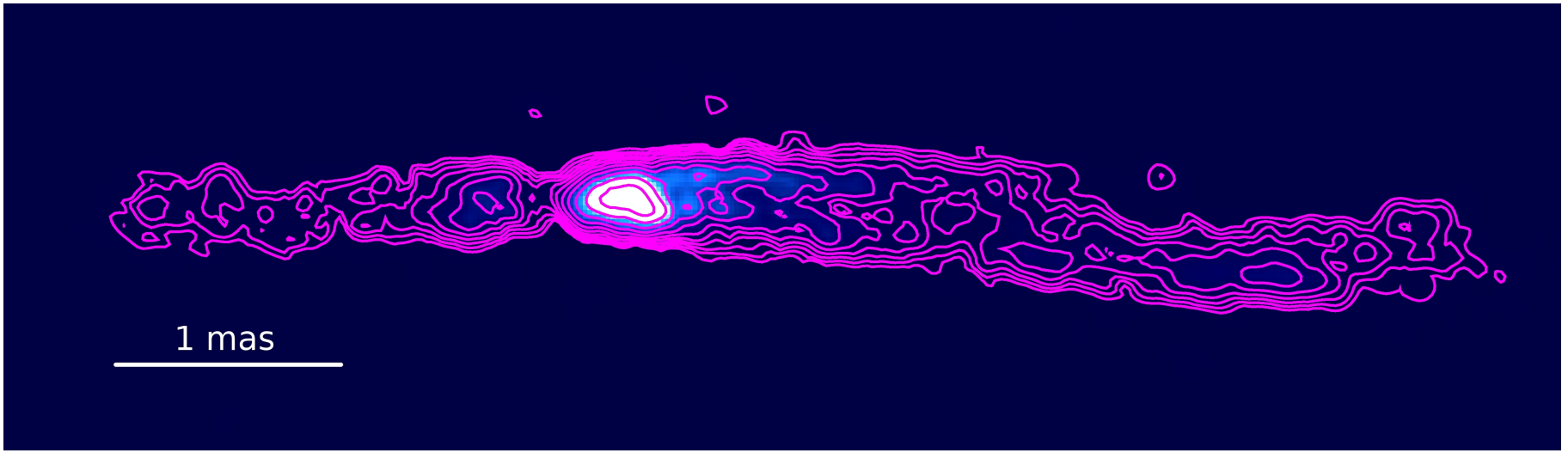
CTA 102
Credit: Eduardo Ros



3C273
Credit: Jeff Hodgson

Counter-jets.

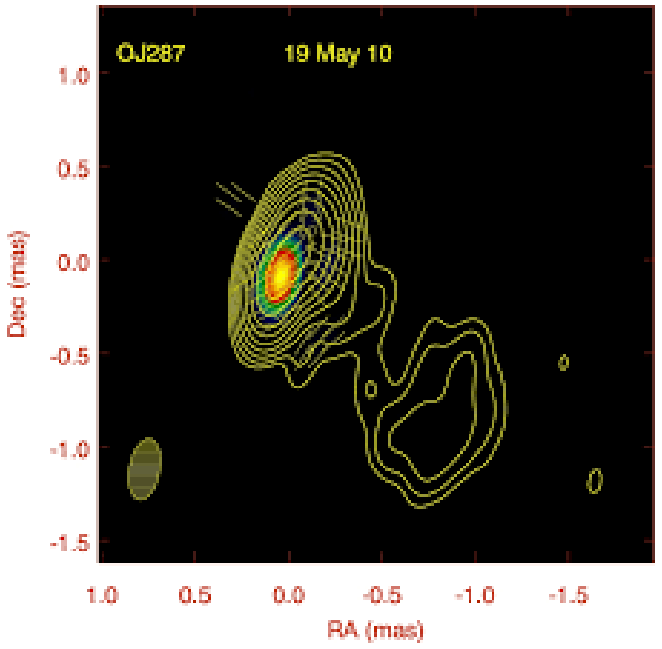
Cyg A, Boccardi et al (2015)

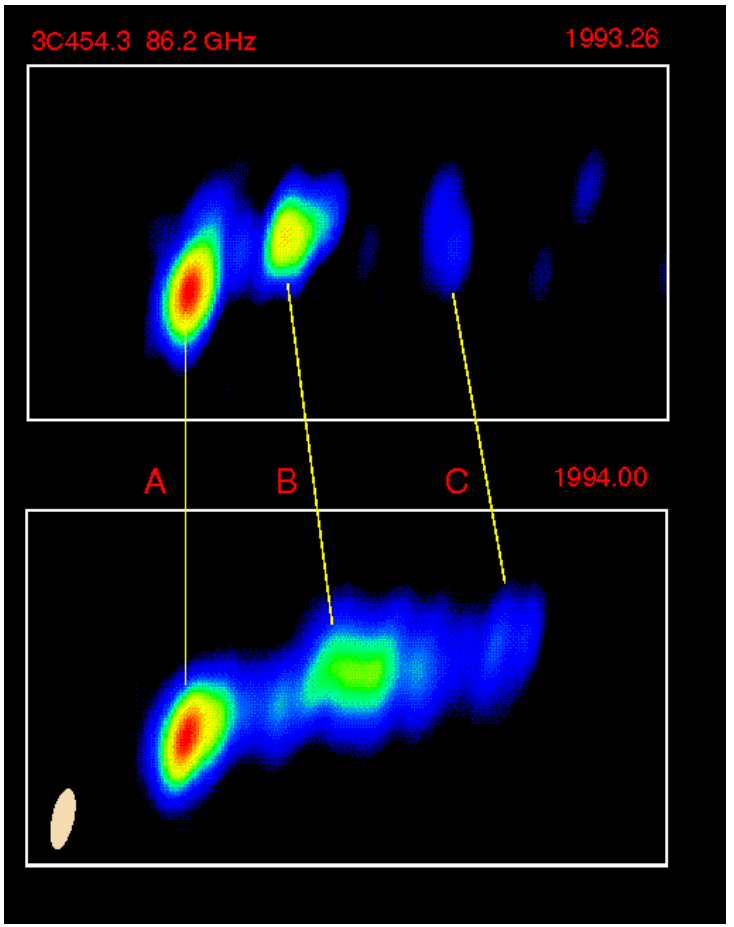


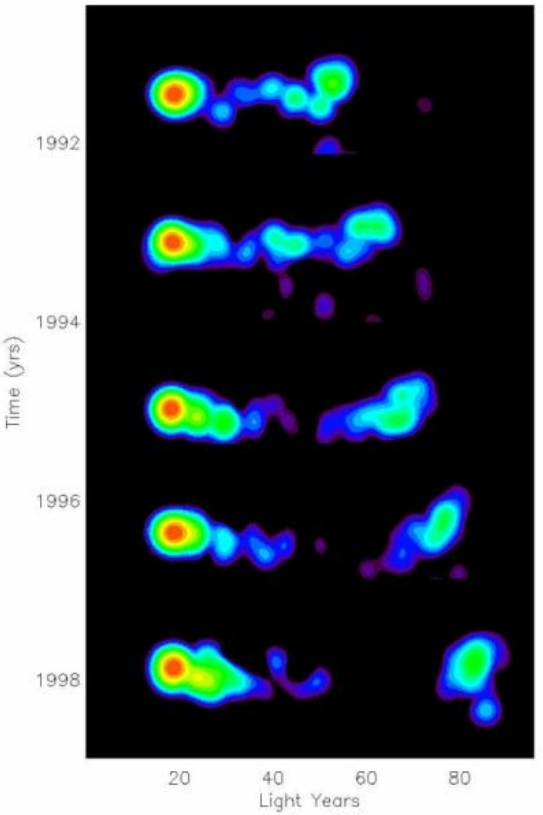
$$j = \frac{S_{jet}}{S_{counterjet}} = \left(\frac{\delta_{jet}}{\delta_{counterjet}}\right)^{p=2-a} = \left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right)^{p} \Rightarrow \theta = \arctan\left(\frac{2\beta_{app}}{j^{1/p}-1}\right)$$

Blazar counter-jets and Doppler favoritism.

$j >> 1$







OJ287

3C454.3

3C279

A new model for Blazars.

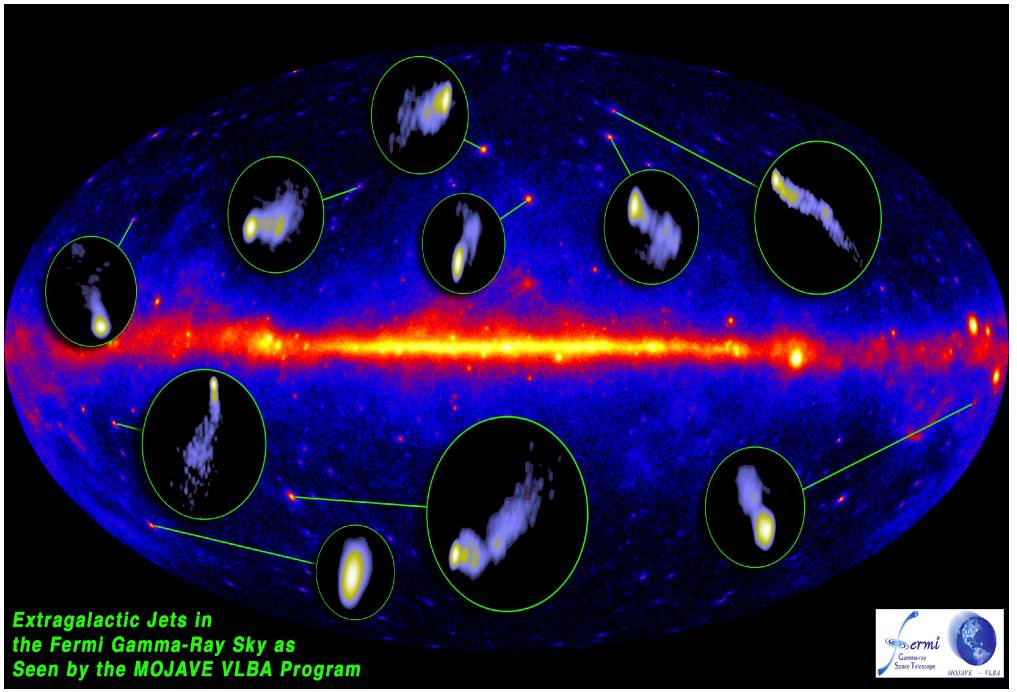
-Focus on simplicity and acceptability criteria

-Rely on trustworthy observables such as apparent velocity and redshift.

-Treat BL Lacs and FSRQs as distinct populations.

-Simultaneously fit the unbeamed luminosity and bulk Lorentz factor distributions.

Final Sample: *FSRQs : 76*
BL Lacs : 16



M.O.J.A.V.E sample:

- Statistically complete

- Flux-limited (1.5 Jy)

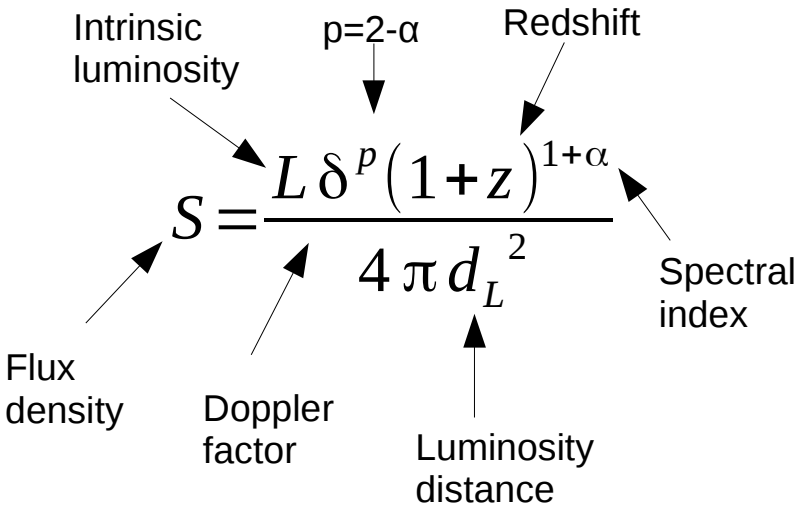
(Lister & Homan 2005)

Calculations:

Step 1: Determine the number of sources in each redshift bin.

Step 2: Draw random values for the:
1) viewing angle
2) bulk Lorentz factor
3) unbeamed luminosity
for each source.

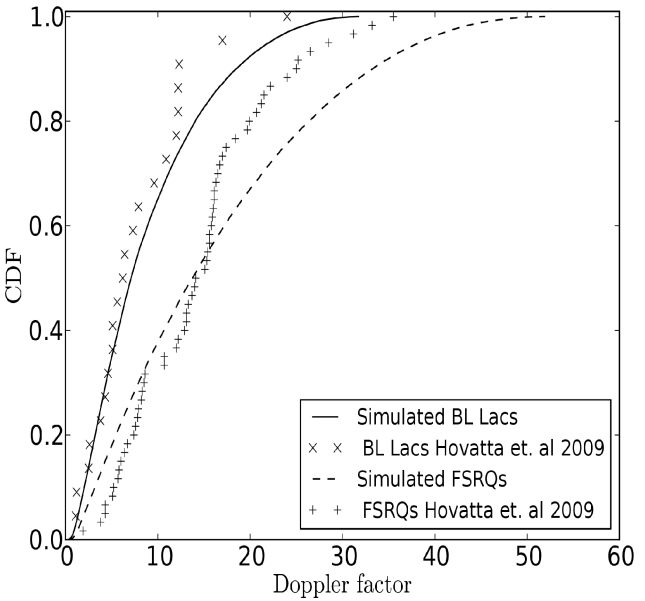
Step 3: Use flux density equation.



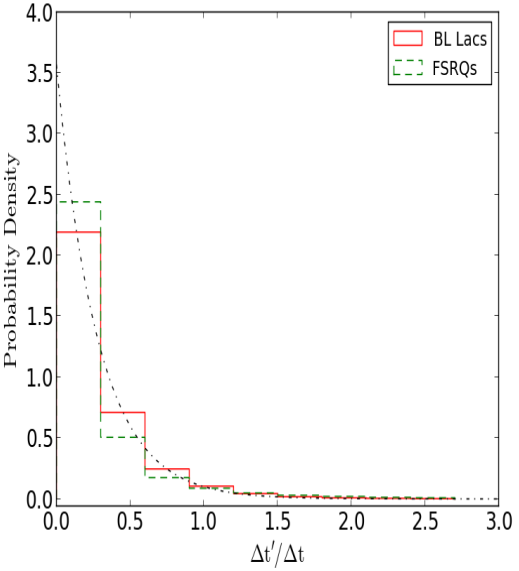
Step 4: Apply flux-limit (1.5 Jy).

Step 5: Optimize models using the Kolmogorov- Smirnov test (K-S test).

(Liodakis & Pavlidou 2015a)



(Liodakis & Pavlidou 2015b)



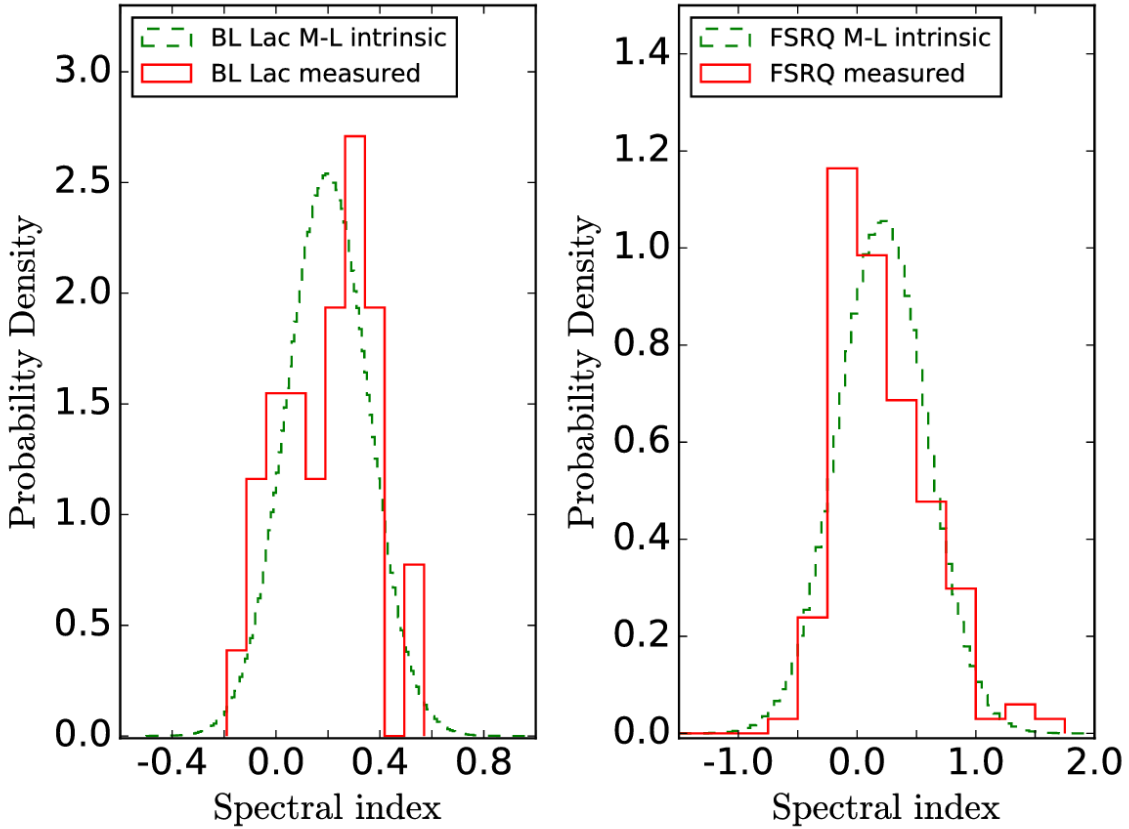
(Liodakis, Blinov and Pavlidou, *MNRAS submitted*)

Spectral index distribution.

Maximum likelihood approach, **Venters & Pavlidou (2009)**

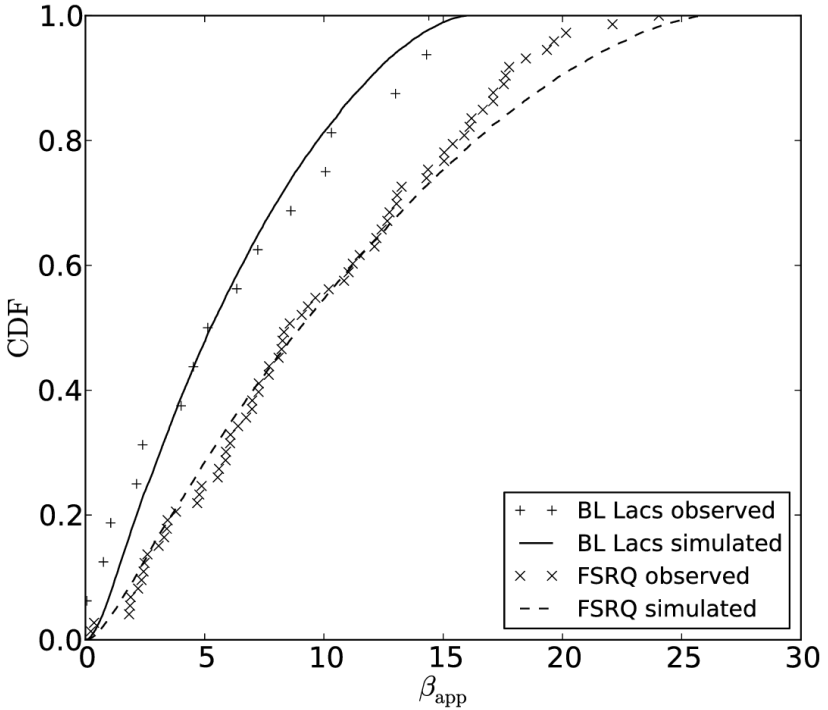
BL Lacs:
Mean ~0.19
Standard deviation~0.15

FSRQs:
Mean ~ 0.21
Standard deviation ~ 0.37

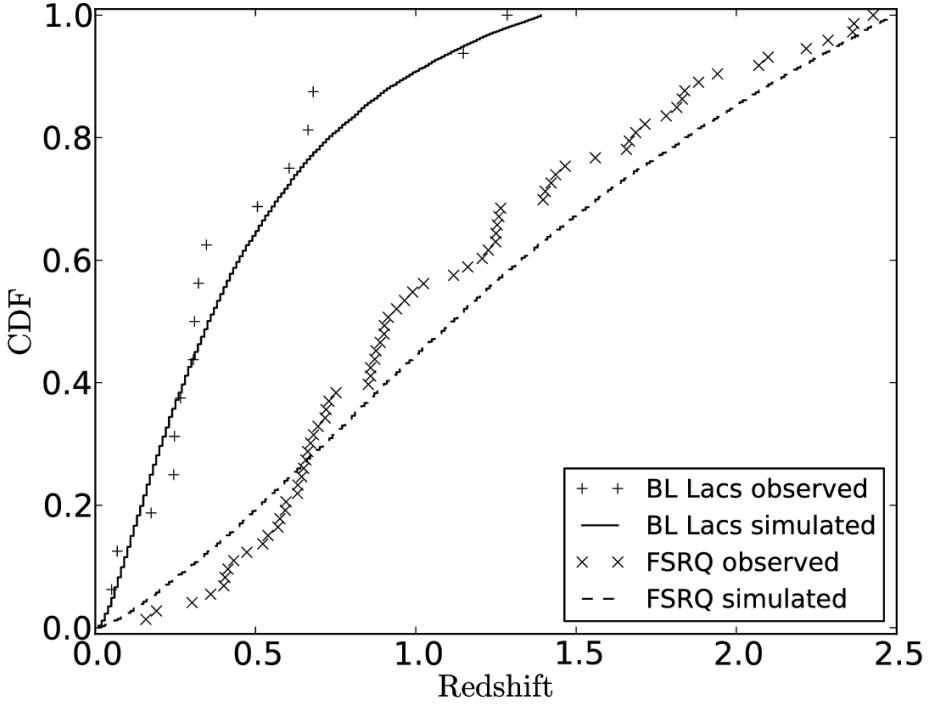


A re-optimized model.

BL Lacs:
Apparent velocity ~93.5%
Redshift ~70.4%



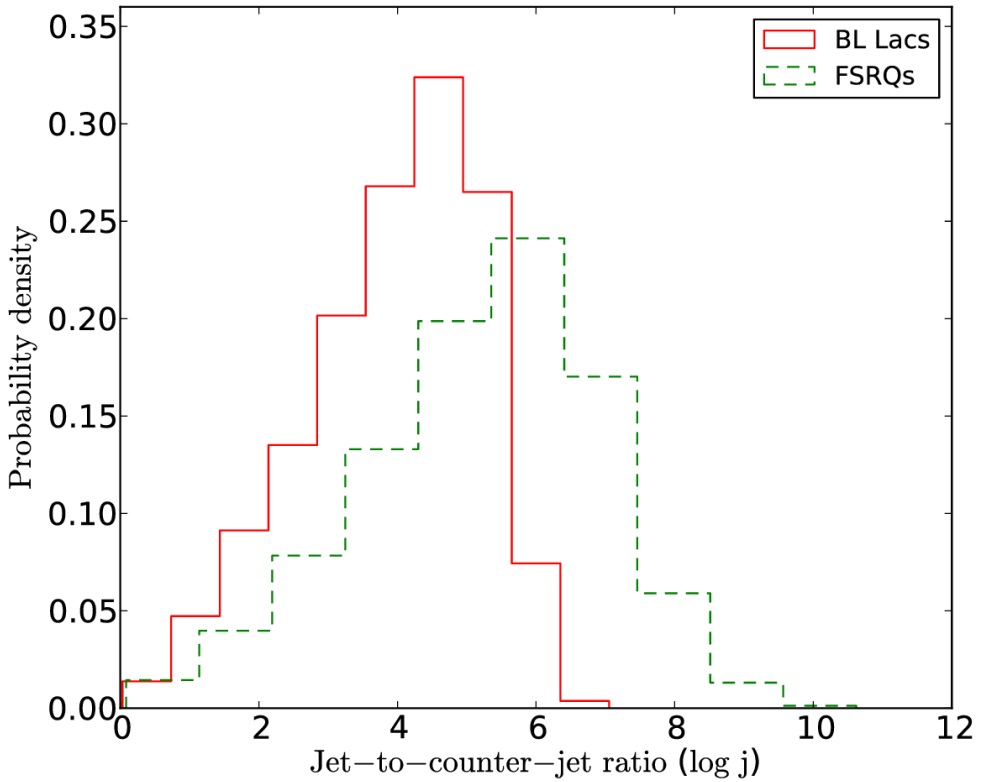
FSRQs:
Apparent velocity ~ 81.3%
Redshift ~ 29.1%



Jet-to-counter-jet ratio.

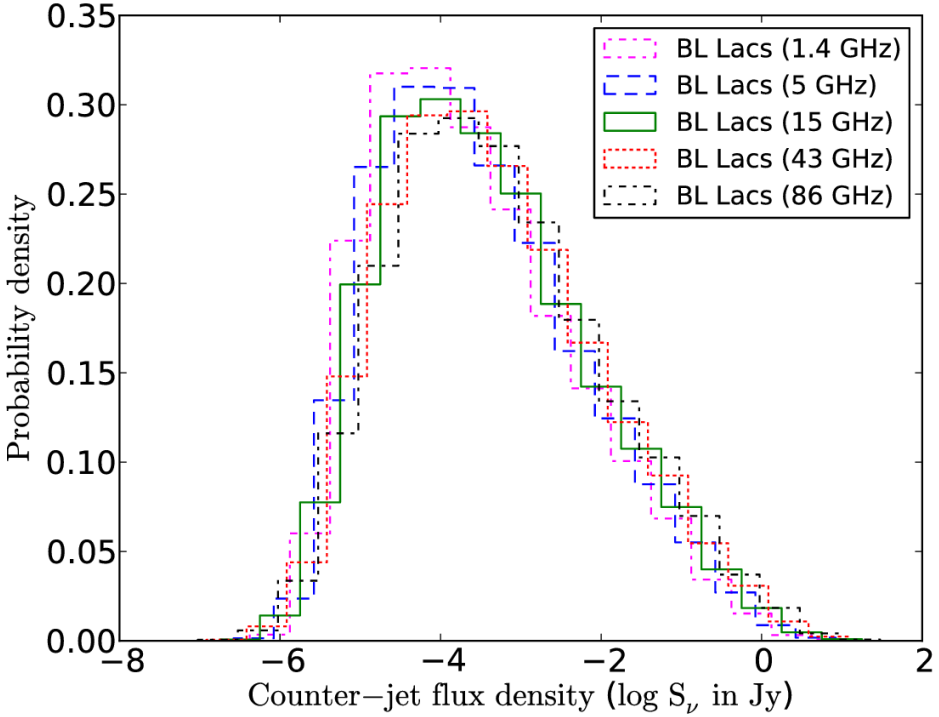
BL Lacs:
Peak ~ $10^{4.5}$
Mean ~ $10^{3.9}$

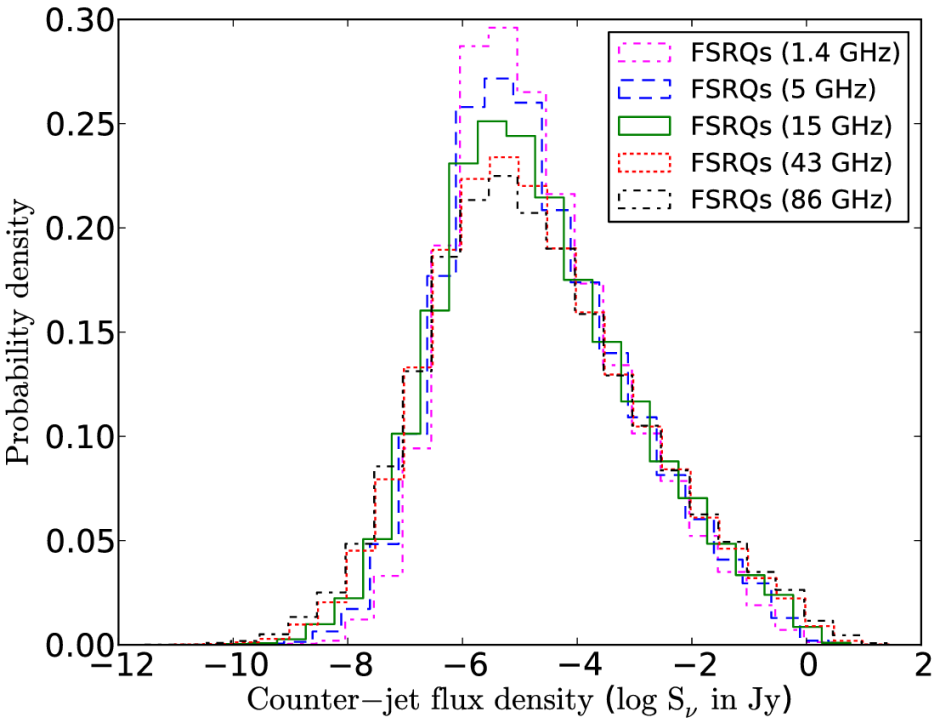
FSRQs:
Peak ~ $10^{5.8}$
Mean ~ $10^{5.2}$



Best dynamic range so far ~**47000** (Leon et al 2016)

Counter-jet flux-density.





SKA, e-Merlin expected to reach ~**1μJy** sensitivity

>99% of BL Lac and **>77%** of FSRQ counter-jet

Observational constrains.

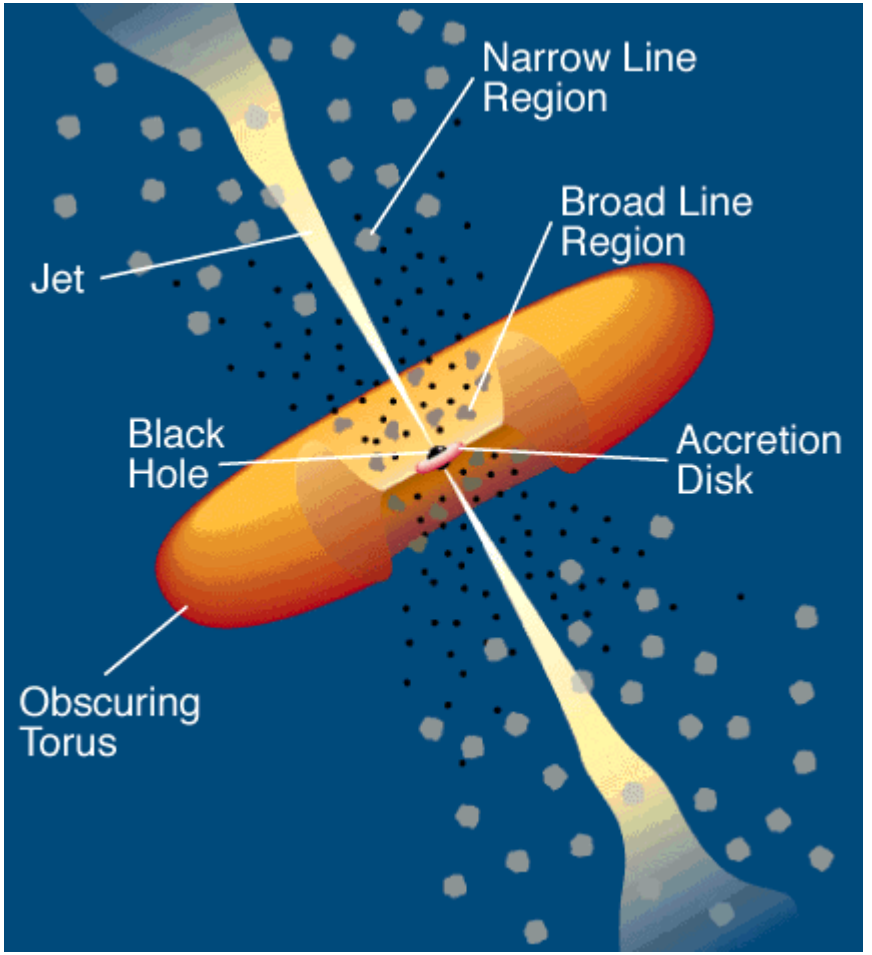
-System related constrains (weather, atmospheric turbulence, poor u-v coverage)

-Free-free absorption (**Vermuelen et al. 1994**)

-Bents in the jet (**Homan et al 2002**)

Working in our favor:

-Black hole microlensing (**Bao & Wiita 1997**)



Candidates.

-low Doppler factor $(\lesssim 5)$
(Hovatta et al 2009, Liodakis et al. *MNRAS submitted*)

-low apparent velocity **(MOJAVE)** $(\lesssim 3)$

PKS0735+17

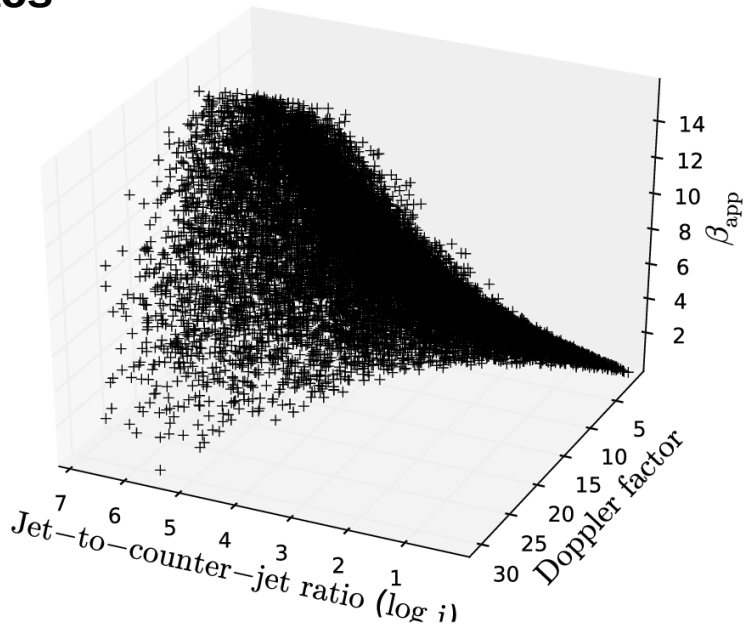
4C39.25

PKS1101+384

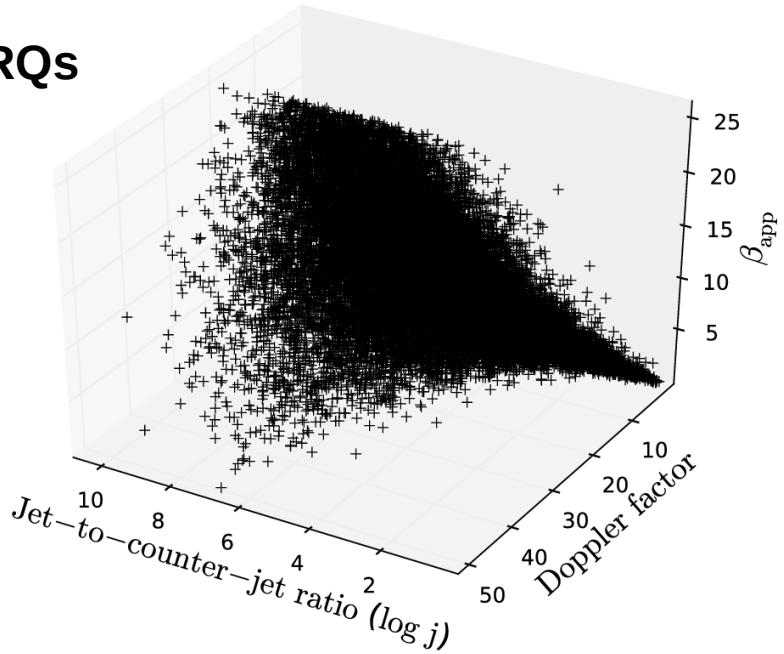
2021+614

PKS2254+074

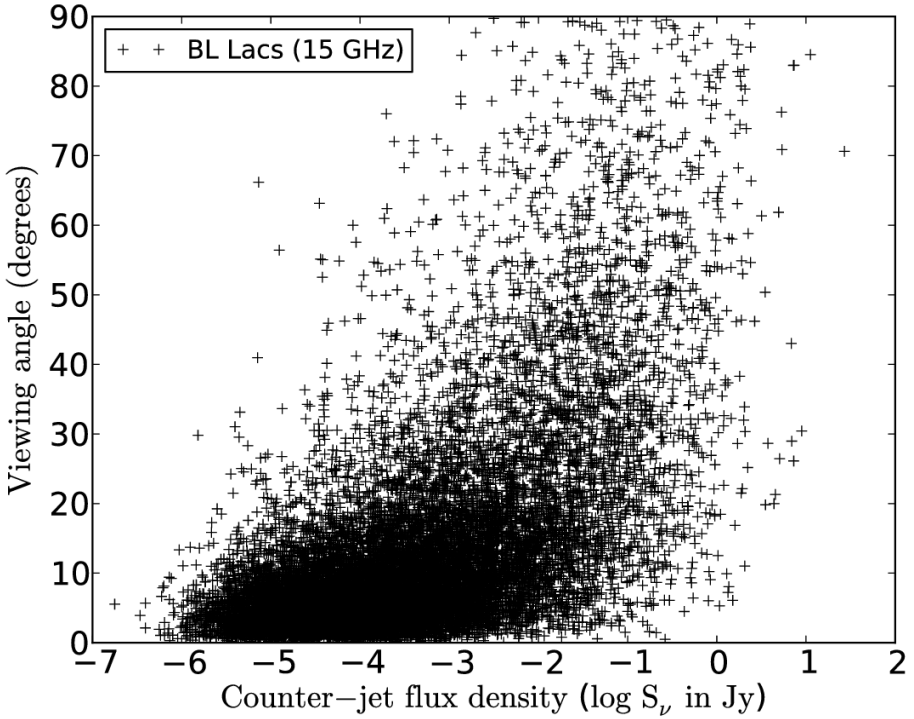
BL Lacs

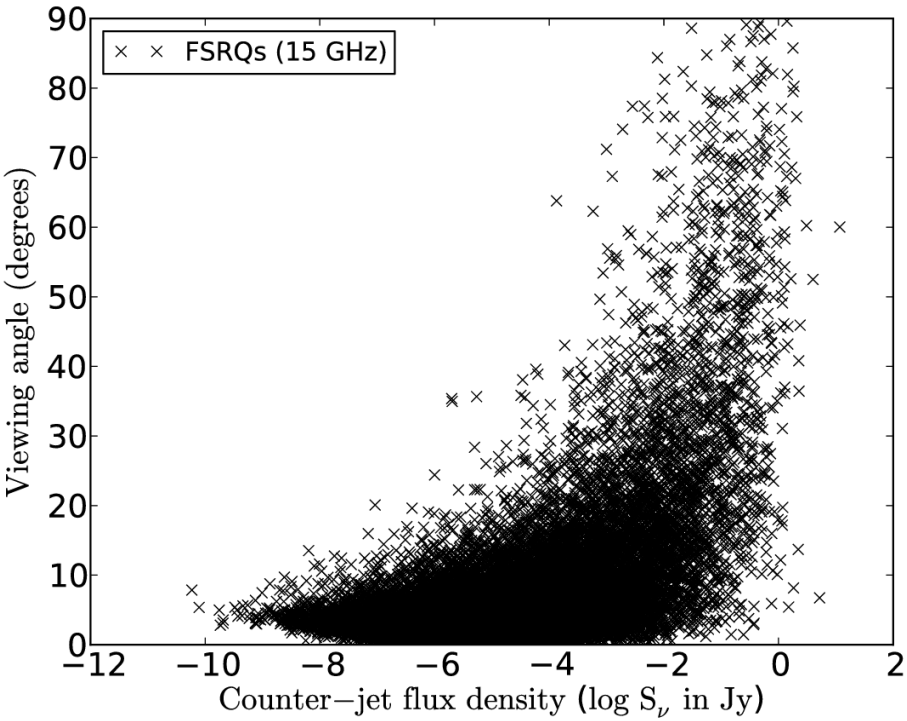


FSRQs



Misclassified radio galaxies?





5% of radio selected & **15**% X-ray selected BL Lacs are misclassified as radio galaxies!
(Giommi et al 2012)

Summary.

- We created realistic models that describe the blazars populations.

- Set the theoretical sensitivity limits for future telescopes in order to detect blazar counter-jets. Future telescope arrays may detect > **99%** BL Lacs and **> 77%** FSRQ counter-jets.

- Established criteria for counter-jet detection, as well as **identified 5 candidates** from the existing estimates.

-BL Lacs may be **misclassified** as radio galaxies due to their bulk Lorentz factor