HELLENIC ASTRONOMICAL SOCIETY
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Population statistics of beamed sources

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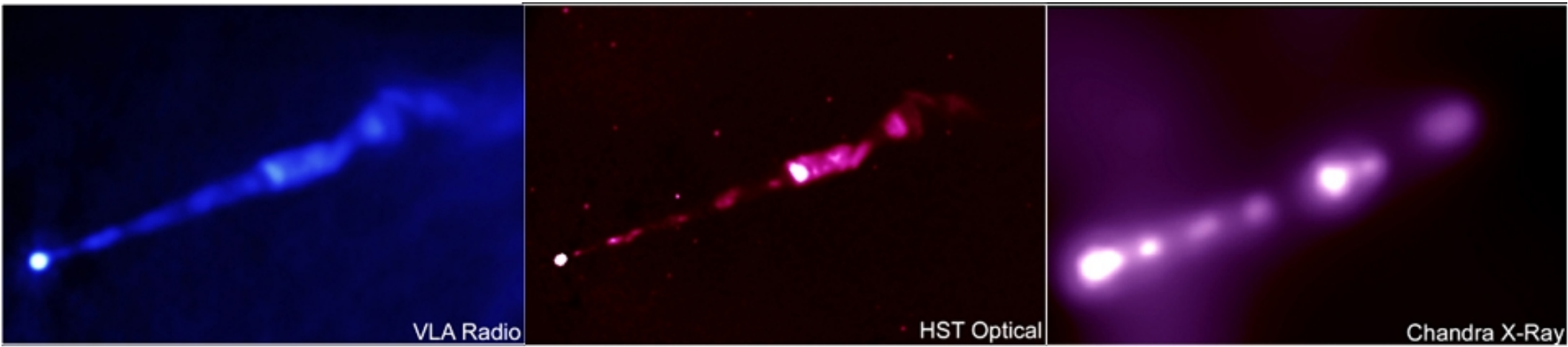


What is a Blazar?

Most Active of Galaxies:

- BL Lac objects (BL Lacs).

-Flat Spectrum Radio Quasars (FSRQs).

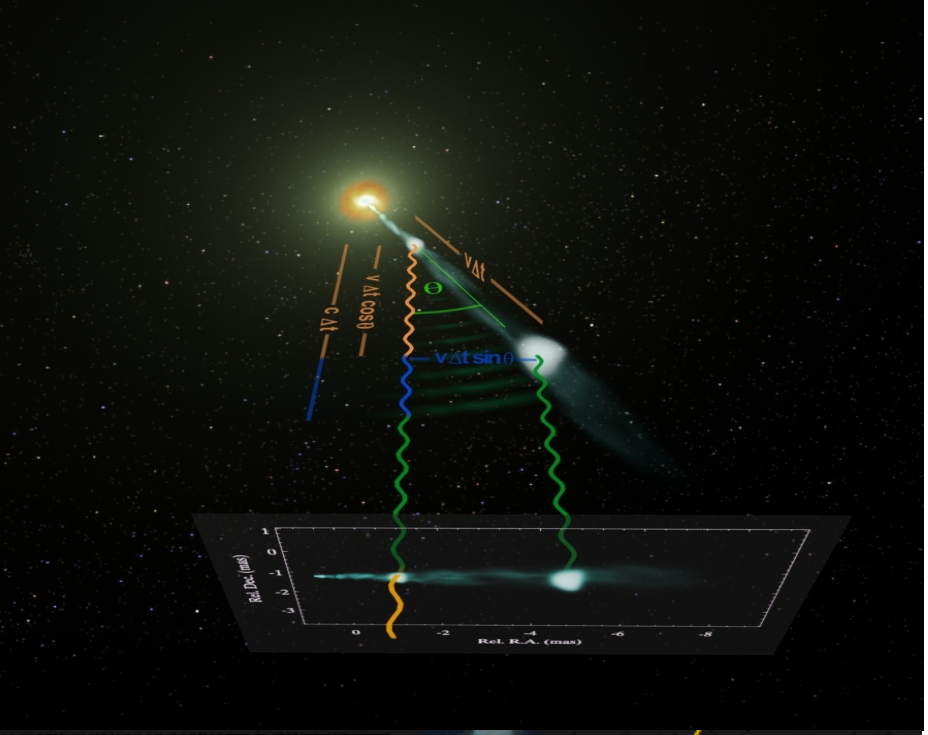
Jet oriented towards our line of sight:

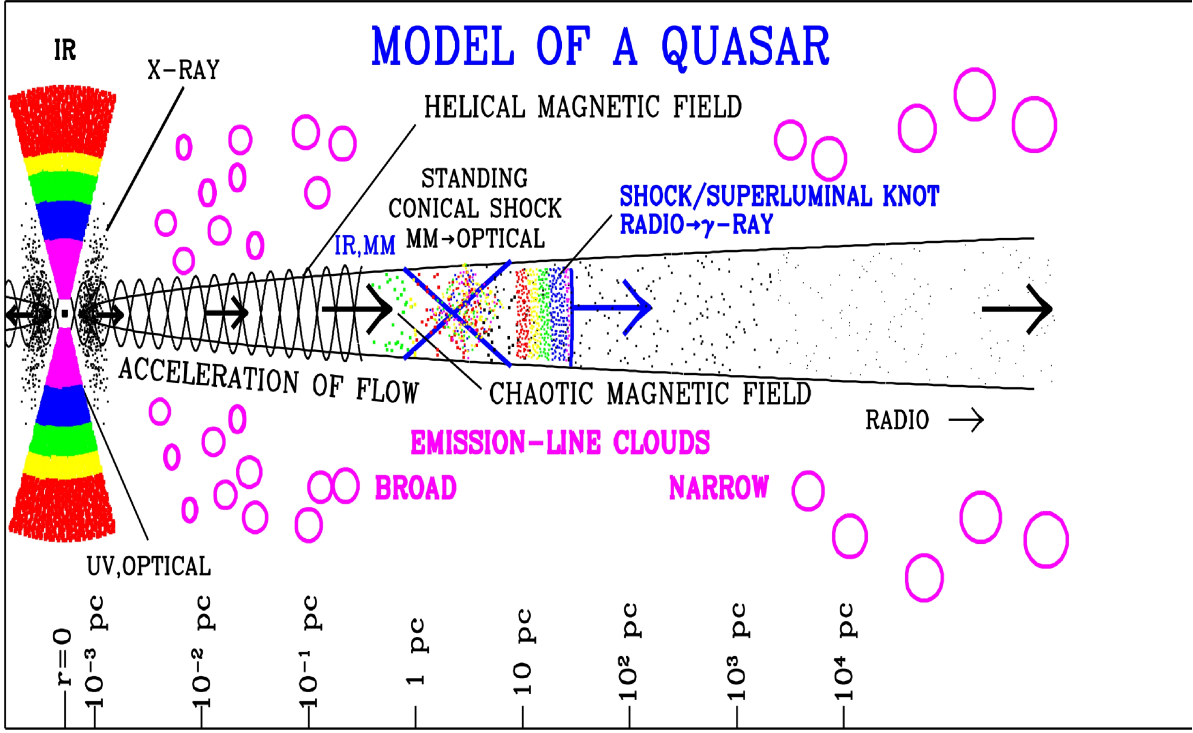
-Superluminal motion.

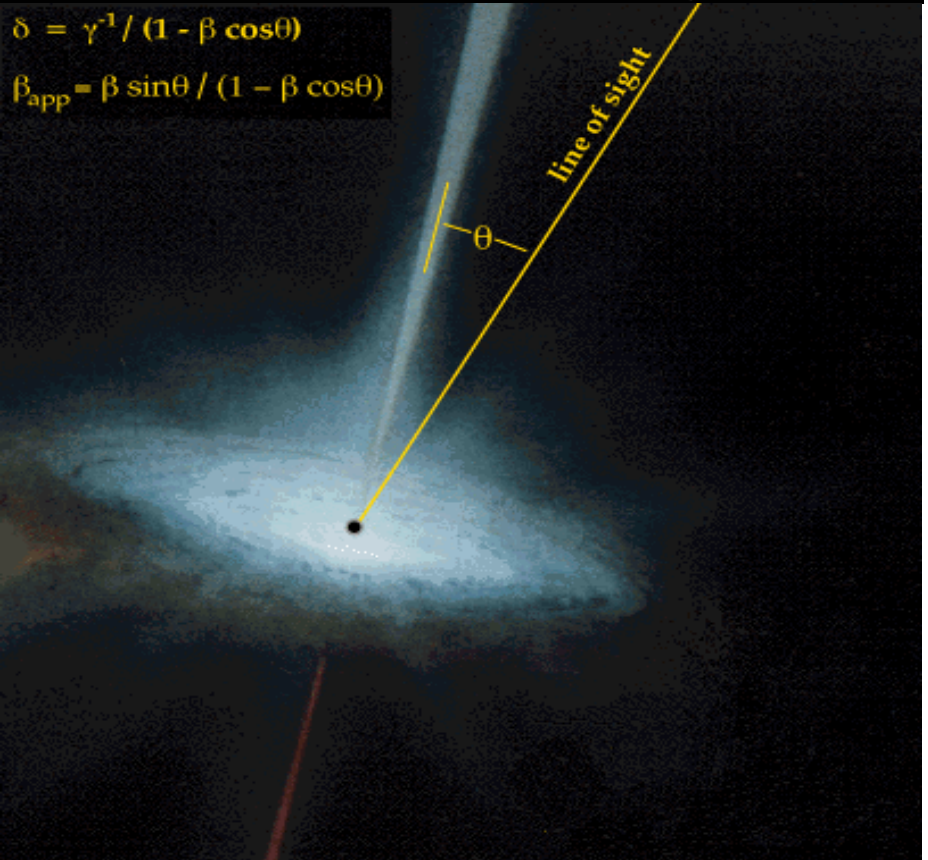
- Boosted emission.

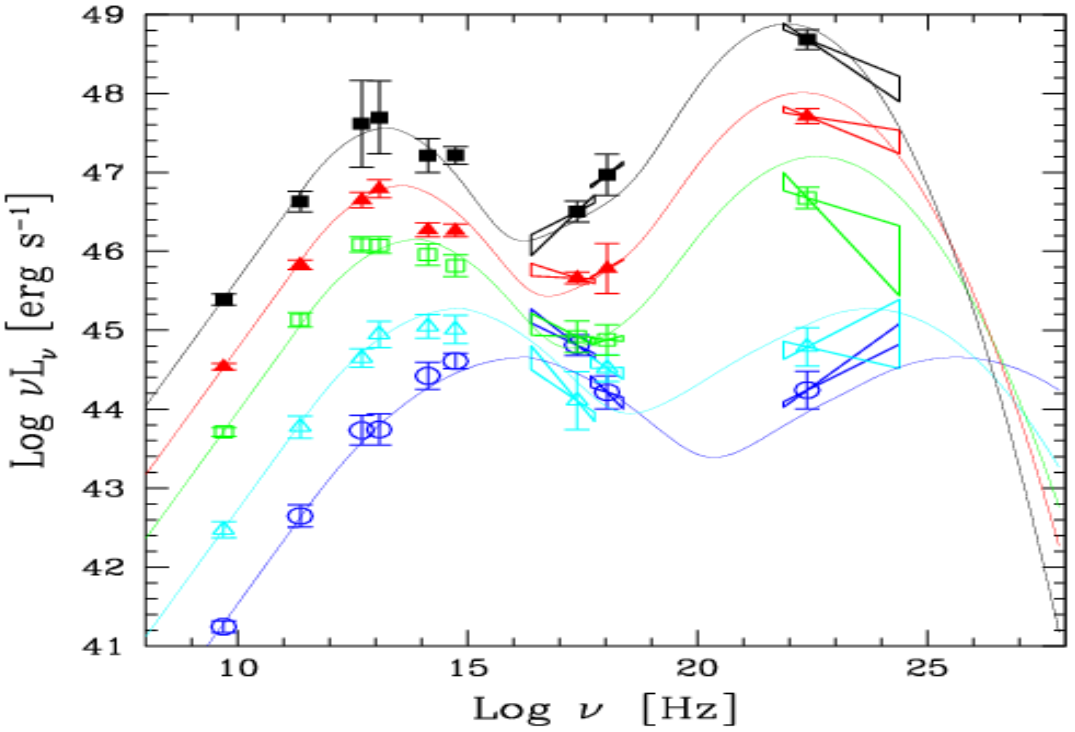
- Extreme variability across the electromagnetic spectrum.

-High degree of polarization in the jets


vΔt
vΔt cosθ
cΔt
θ
vΔt sinθ
Rel. Dec. (mas)
Rel. R.A. (mas)


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


δ = γ⁻¹ / (1 - β cosθ)
β_app = β sinθ / (1 – β cosθ)
line of sight
θ

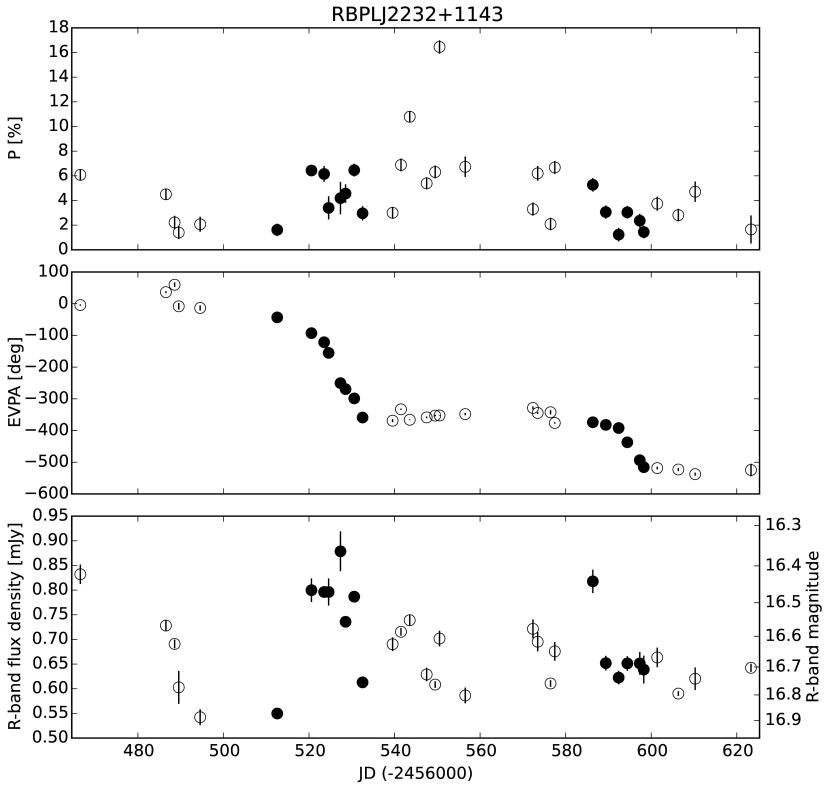

Log νL_ν [erg s⁻¹]
Log ν [Hz]
49
48
47
46
45
44
43
42
41
10
15
20
25

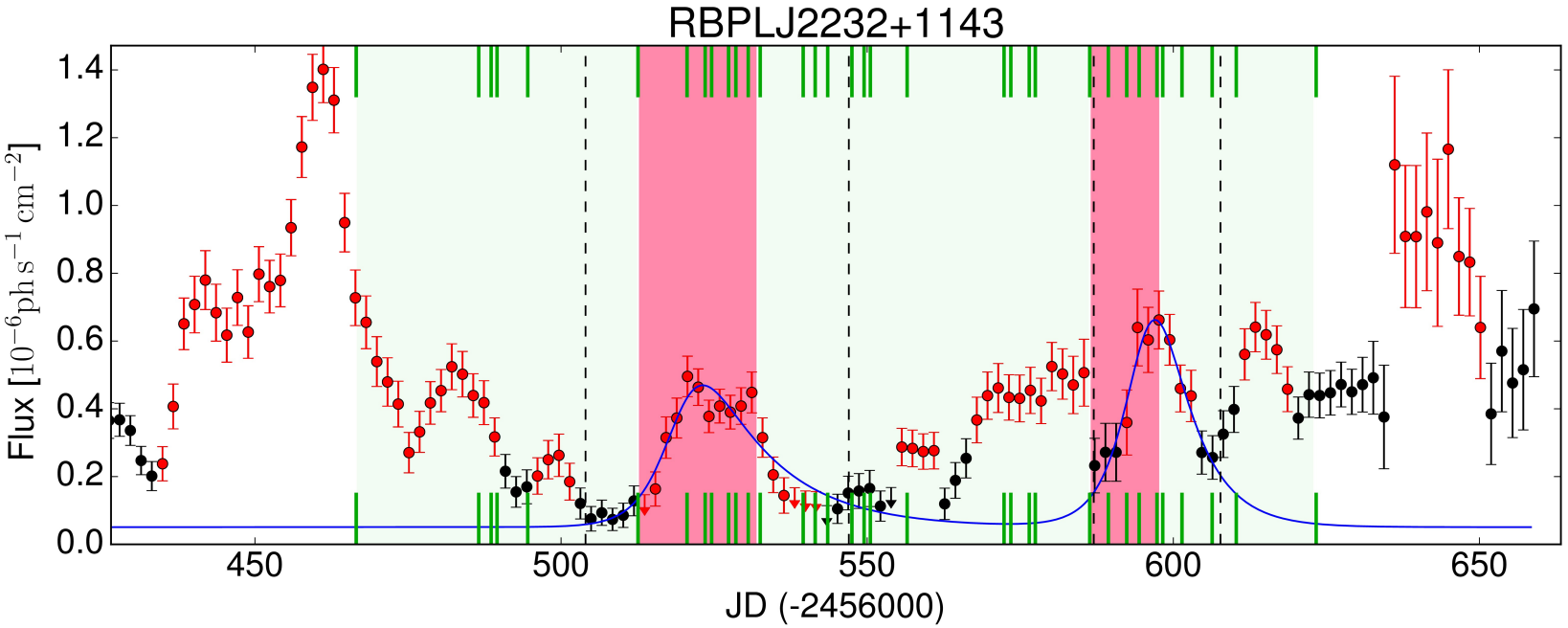
Motivation.

What is the relativistically induced spread of timescales in blazar jets?

Is there any difference in beaming between BL Lacs and FSRQs?

Are there reliable Doppler factor estimates?





A new model for Blazars.

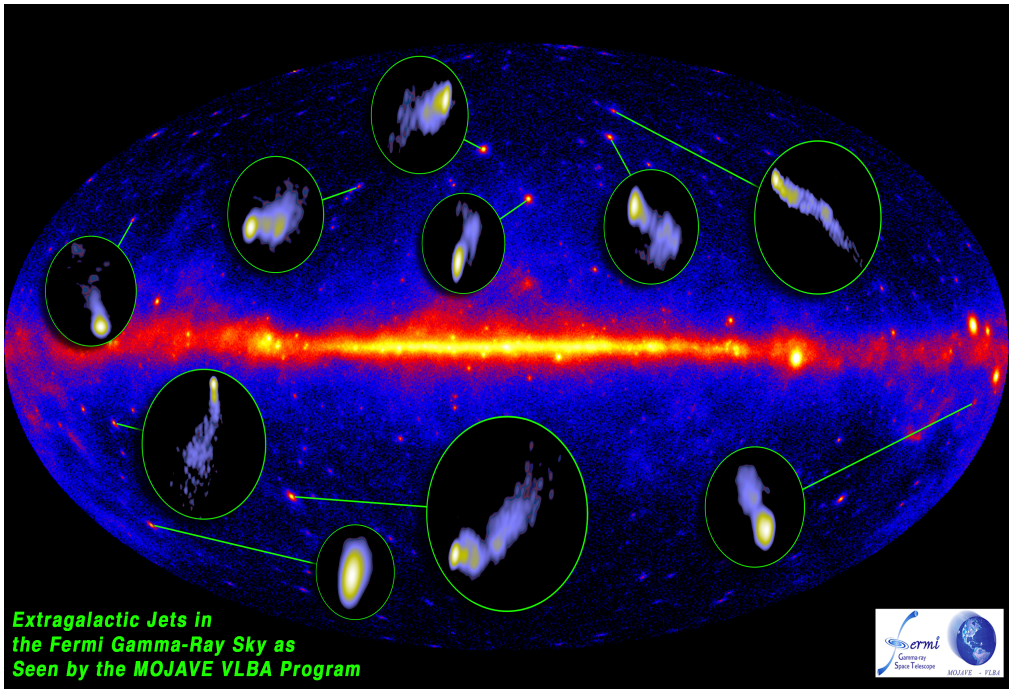
-Focus on simplicity and acceptability criteria

-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.

Intrinsic luminosity

p=2-s

Redshift

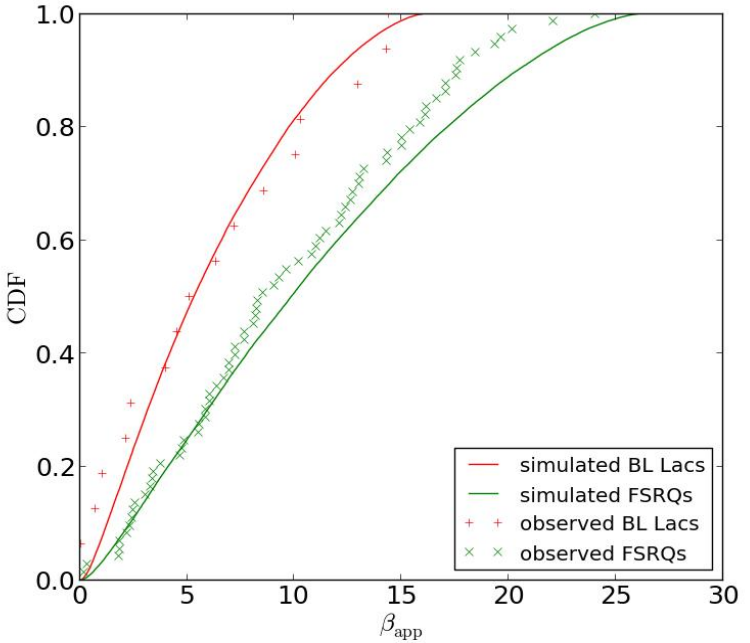
$$S = \frac{L D^{p} (1+z)^{1+s}}{4\pi d_L^{2}}$$

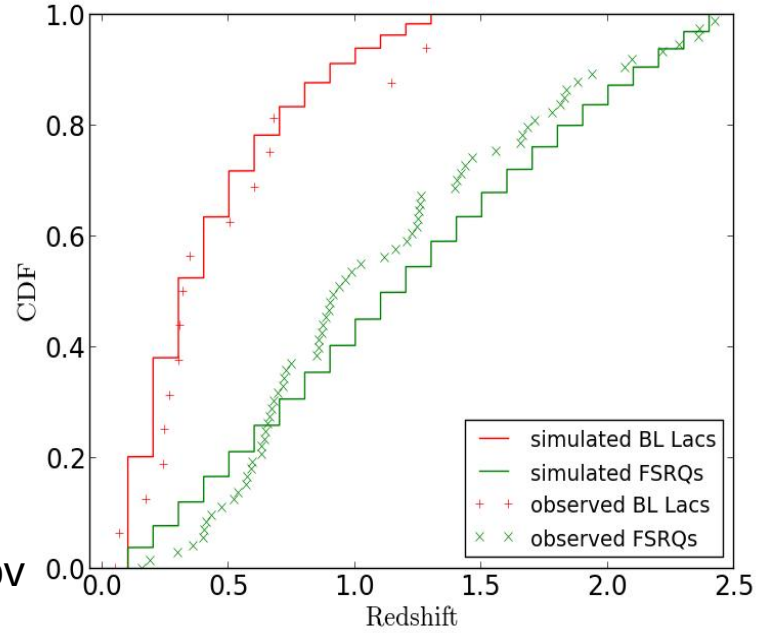
Spectral index

Flux density

Doppler factor

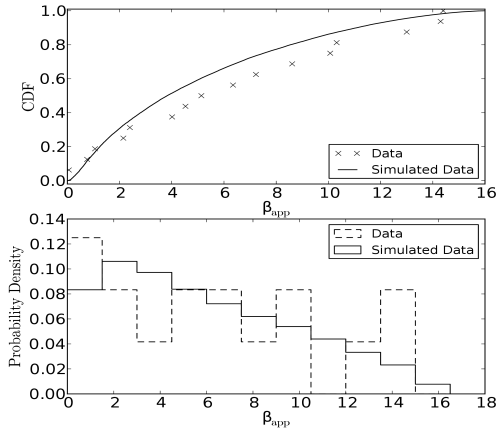
Luminosity distance

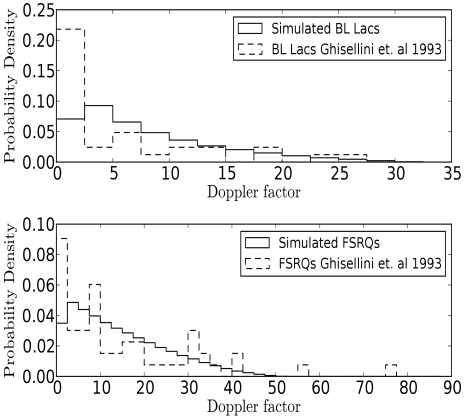


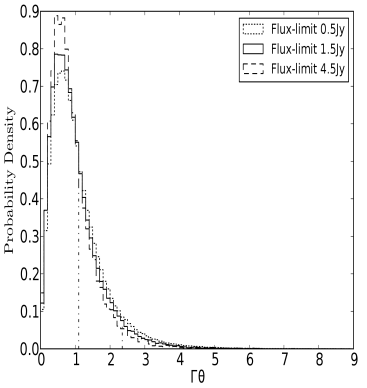


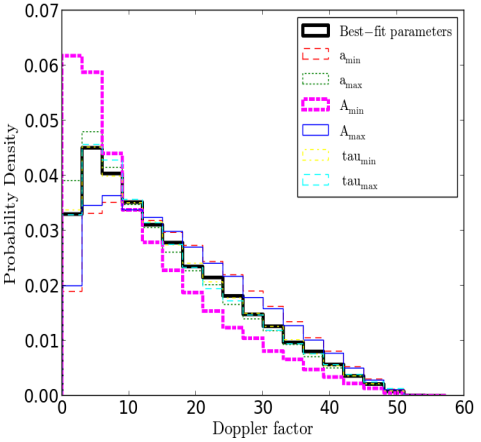
Step 4: Apply flux-limit (1.5 Jy).

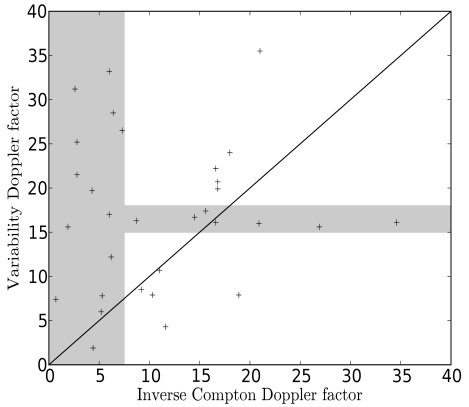
Step 5: Optimize models using the Kolmogorov- Smirnov test.


CDF
Data
Simulated Data
β_{app}
Probability Density
Data
Simulated Data
β_{app}

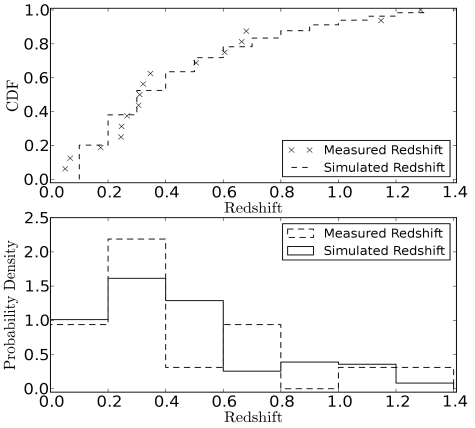

Probability Density
Simulated BL Lacs
BL Lacs Ghisellini et. al 1993
Doppler factor
Probability Density
Simulated FSRQs
FSRQs Ghisellini et. al 1993
Doppler factor

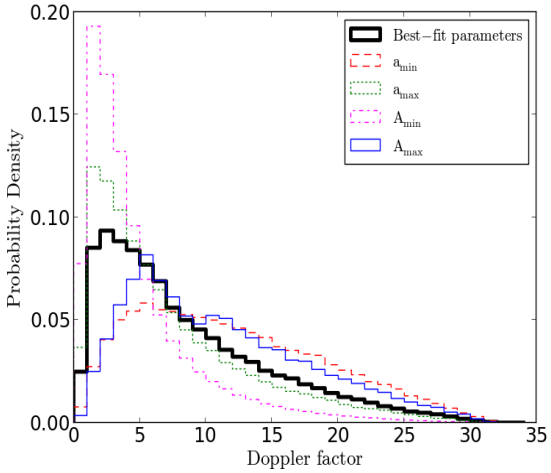

Probability Density
Flux-limit 0.5Jy
Flux-limit 1.5Jy
Flux-limit 4.5Jy
Γθ

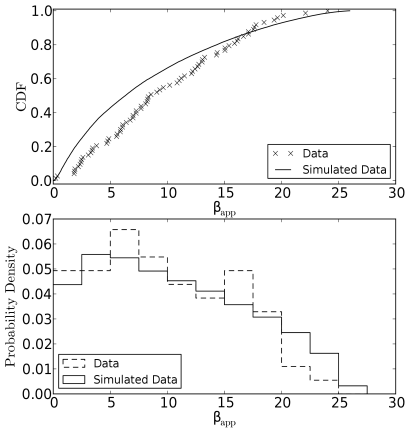

Probability Density
Best−fit parameters
a_{min}
a_{max}
A_{min}
A_{max}
tau_{min}
tau_{max}
Doppler factor

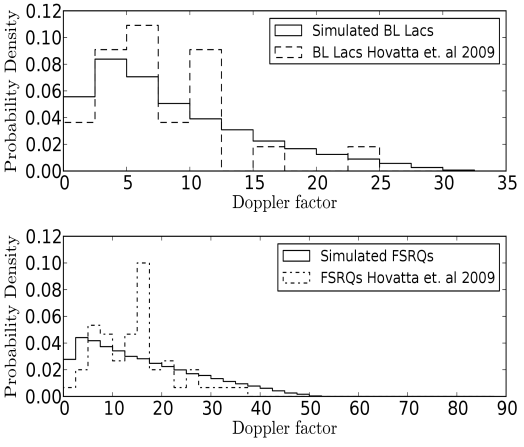

Variability Doppler factor
Inverse Compton Doppler factor

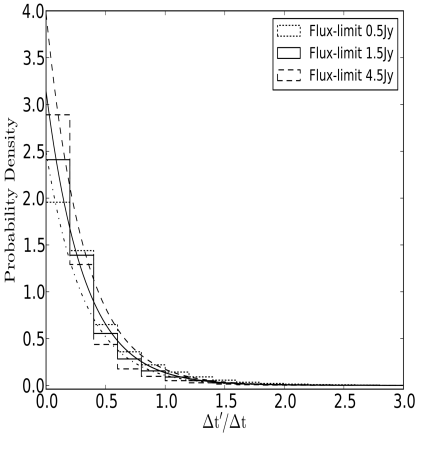
RESULTS


CDF
Measured Redshift
Simulated Redshift
Redshift
Probability Density
Measured Redshift
Simulated Redshift
Redshift


Probability Density
Best−fit parameters
a_{min}
a_{max}
A_{min}
A_{max}
Doppler factor


CDF
Data
Simulated Data
β_{app}
Probability Density
Data
Simulated Data
β_{app}


Probability Density
Simulated BL Lacs
BL Lacs Hovatta et. al 2009
Doppler factor
Probability Density
Simulated FSRQs
FSRQs Hovatta et. al 2009
Doppler factor


Probability Density
Flux-limit 0.5Jy
Flux-limit 1.5Jy
Flux-limit 4.5Jy
$\Delta t'/\Delta t$

What is the relativistically induced spread in observed event timescales?

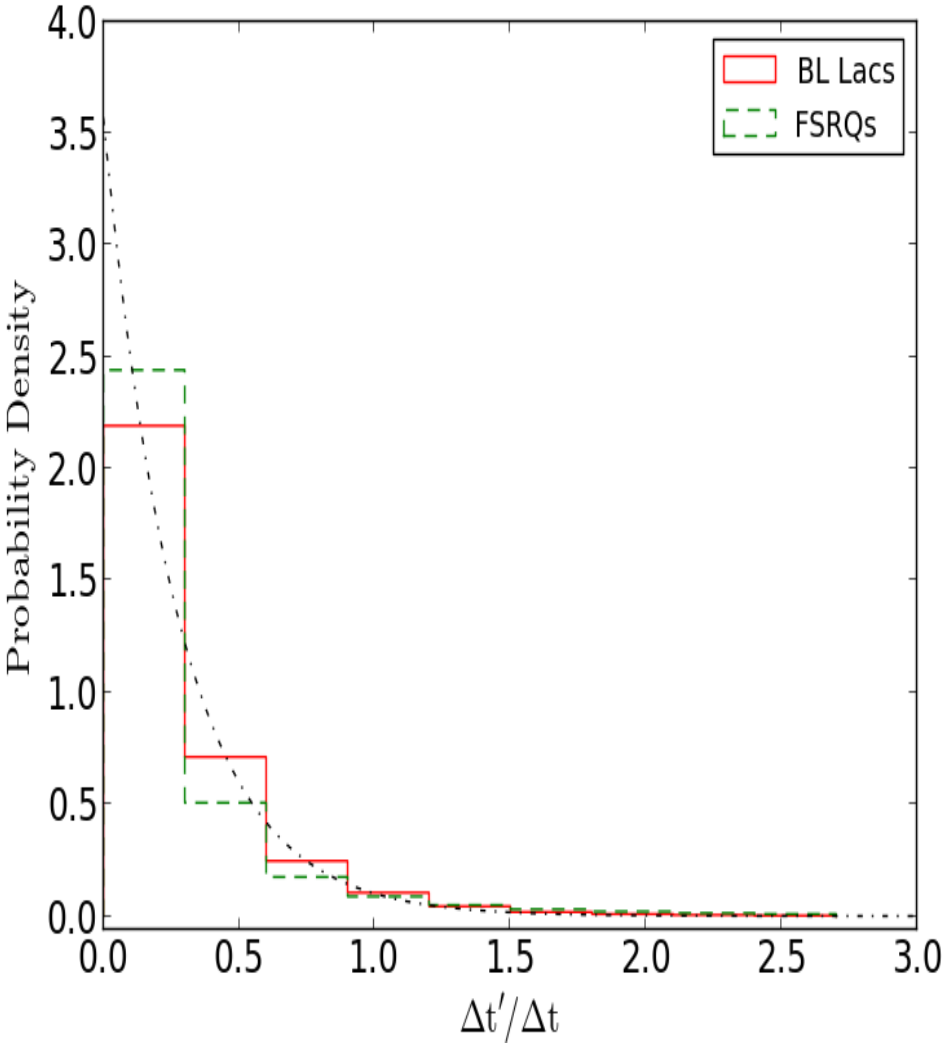
Observed timescale

Redshift

$$\frac{\Delta t'}{\Delta t} = \frac{1+z}{D}$$

Intrinsic timescale

Doppler factor

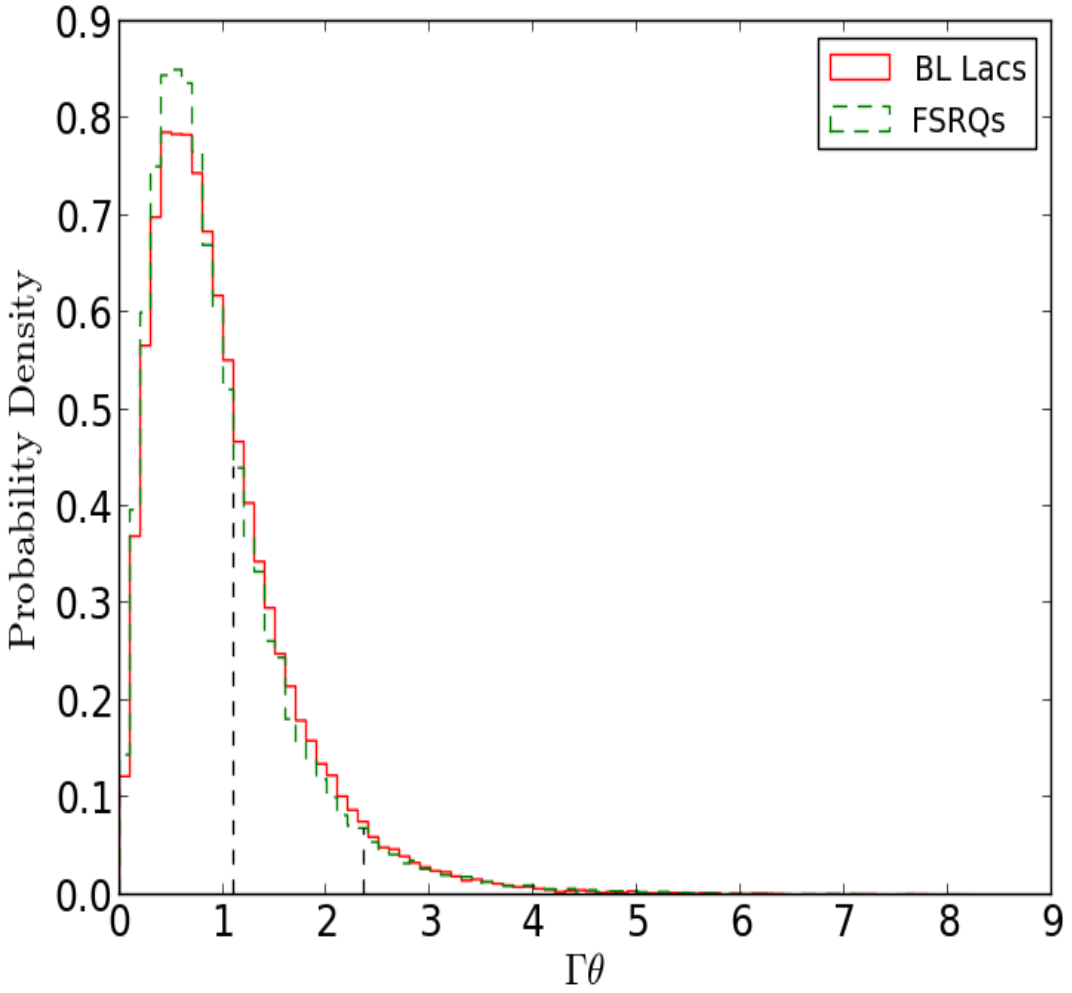


$\Delta t'/\Delta t$ *follows an exponential distribution with mean~0.28 for both classes!!!*

How big is the spread in the Γθ distribution?

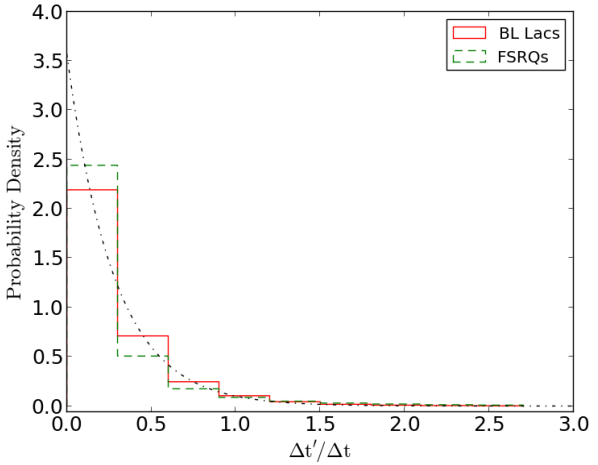
$0 < \Gamma\theta < 1.1 \sim 1\sigma$

Assuming $\Gamma\theta=1$ leads to **~50%** error!

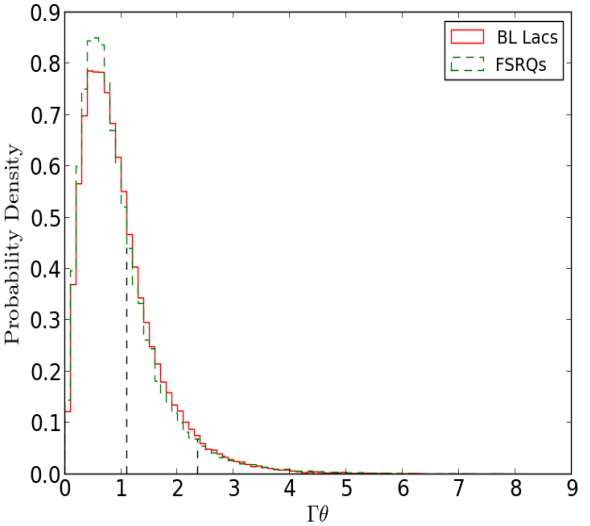


Do BL Lacs and FSRQs have different beaming properties?

-Timescales are modulated in the same way



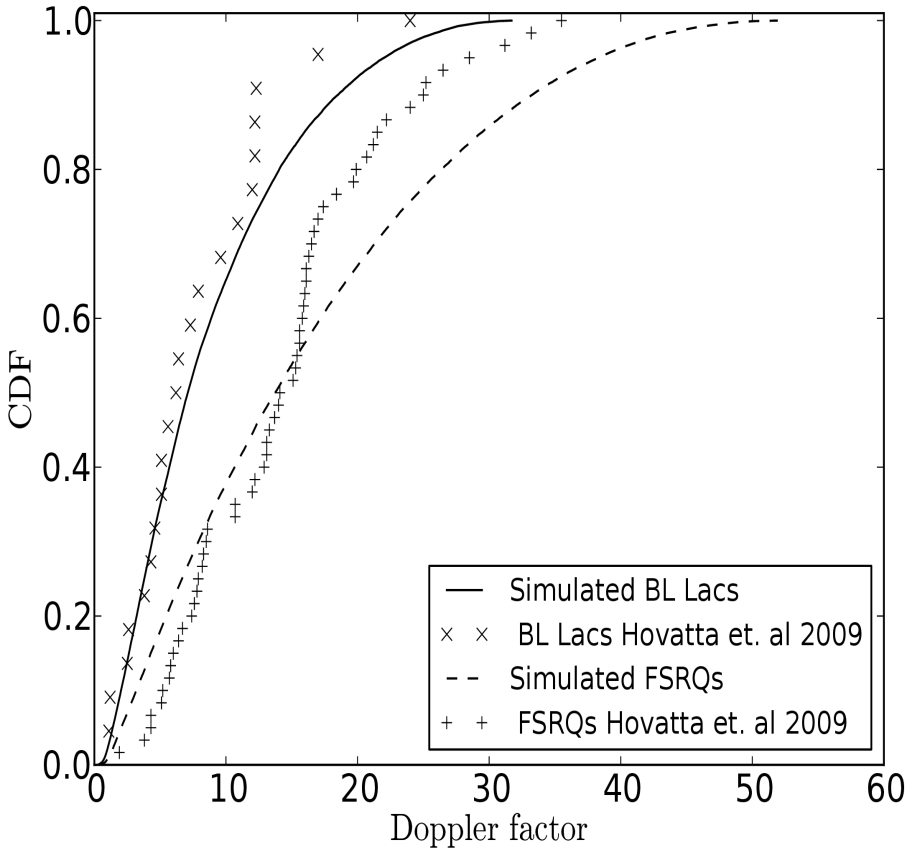
-Γθ distributions are identical



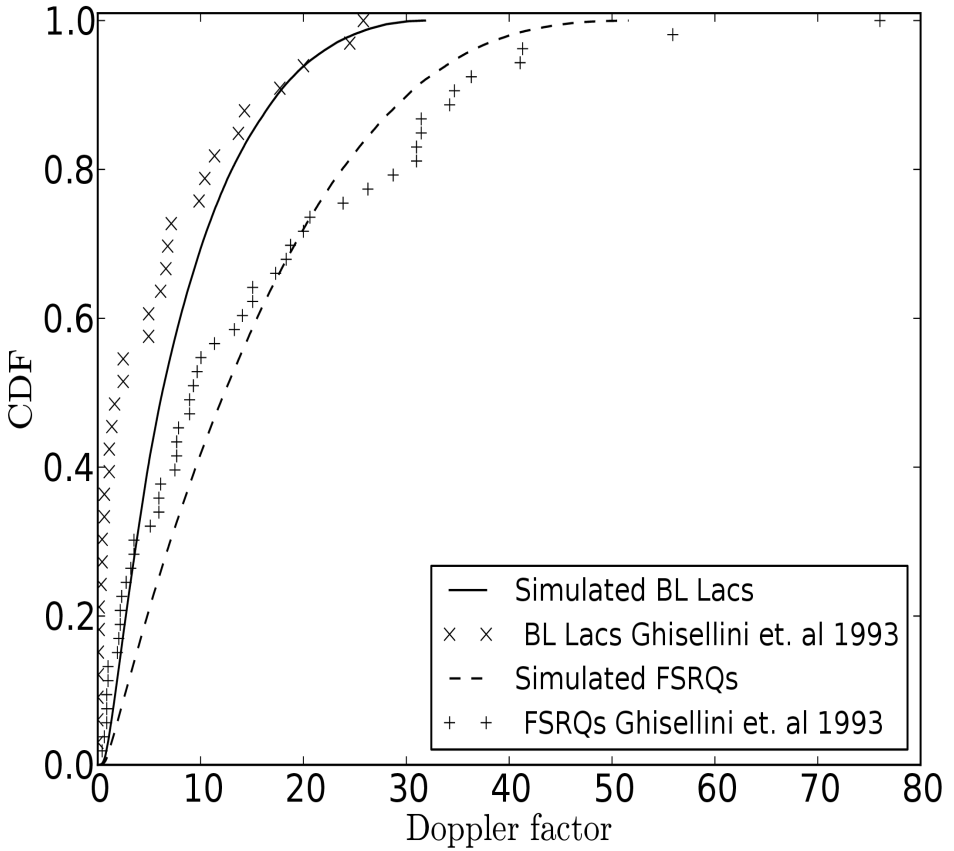
*BL Lacs and FSRQs do **NOT** have different beaming properties*

Differences in the time domain are intrinsic!!!

Which of the single-blazar Doppler factor methods can adequetely describe blazars as a population?



Variability Doppler factors (Hovatta et al. 2009)



Inverse Compton Doppler factors (Ghisellini et al. 1993)

We can recover the intrinsic distribution of timescales!!

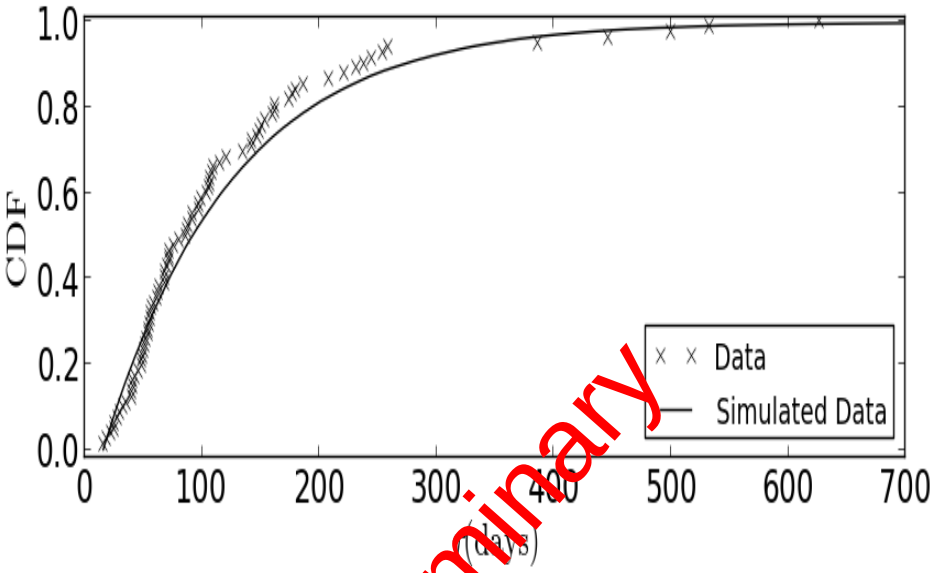
$$m = \frac{\Delta t'}{\Delta t}$$

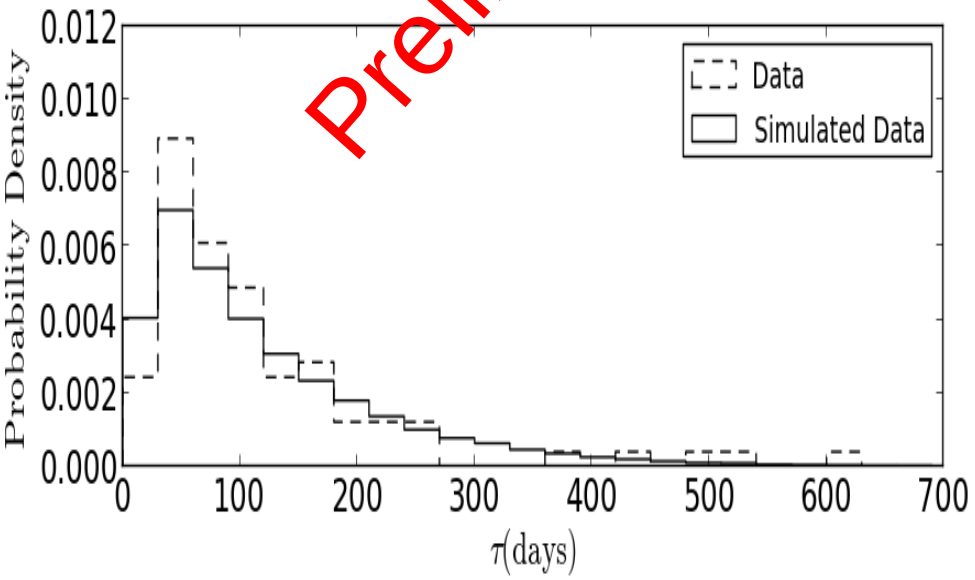
$$P(t_o) = \int_{m_{min}}^{m_{max}} P(t_i) P(m) \frac{1}{m} dm$$

Intrinsic probability density function

Observed probability density function

Exponential distribution





Preliminary

Conclusions.

1) Timescale modulation factor follows exponential distribution (mean~0.28) for both classes.

2) Different beaming between sources in a flux-limited sample: $\Gamma\theta \neq 1$

3) The differences of BL Lacs and FSRQs in the time-domain are **not** due to beaming!

4) The variability Doppler factor method is the most accurate for describing blazars.

Equipartition holds!

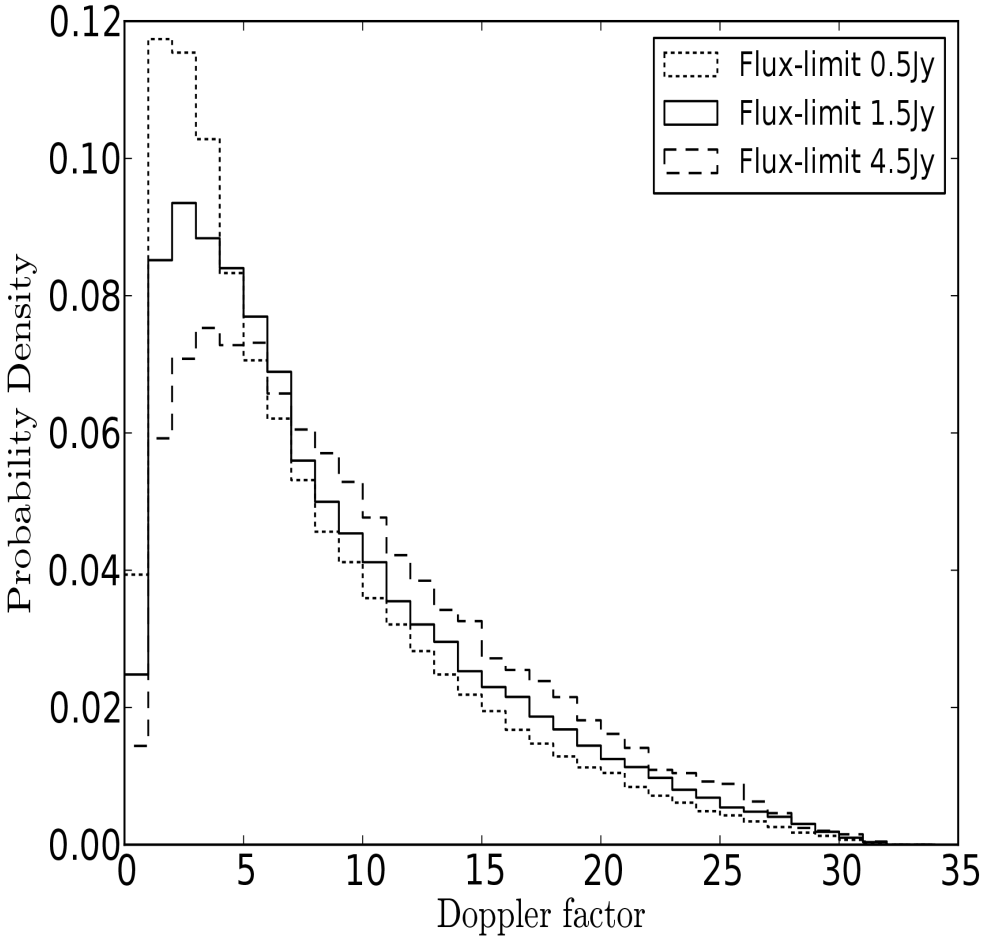
5) We can extract information about the distribution of time-like events in the rest-frame by fitting the observed probability density function.

arXiv:1412.2634 **arXiv:1412.2638**

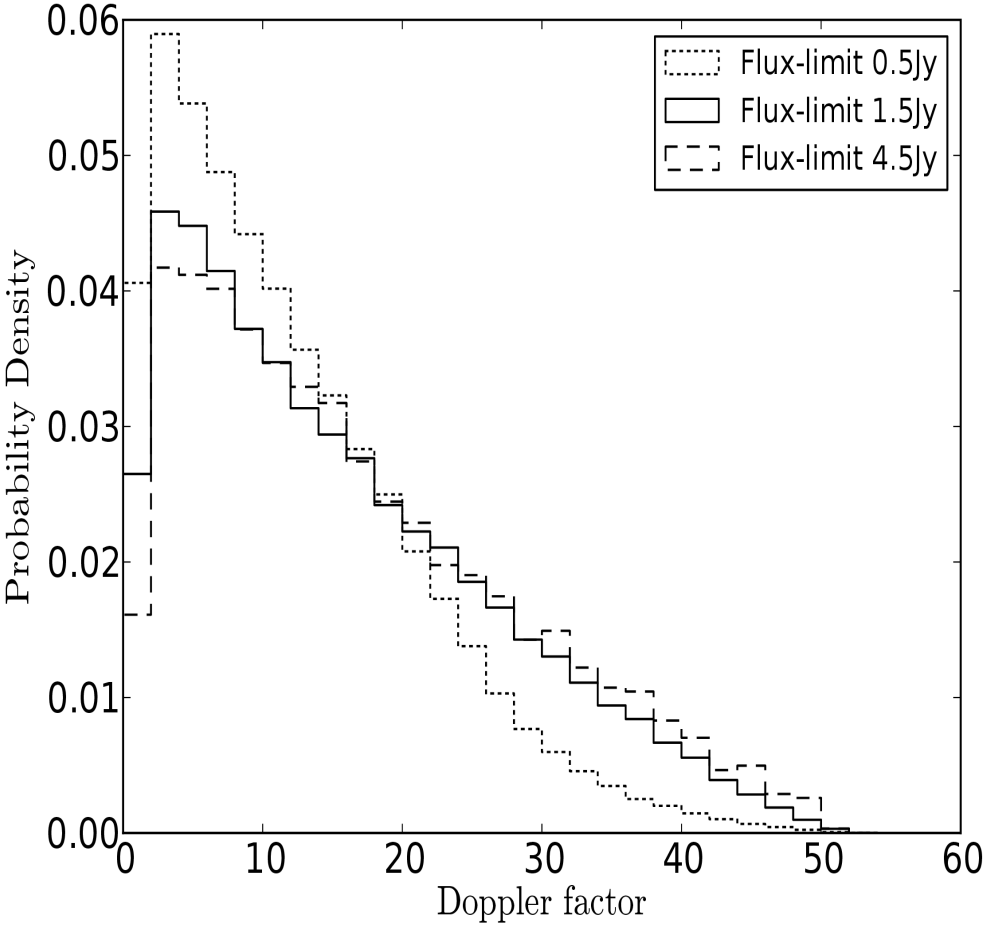
Additional slides

Doppler factor distributions.

BL Lacs

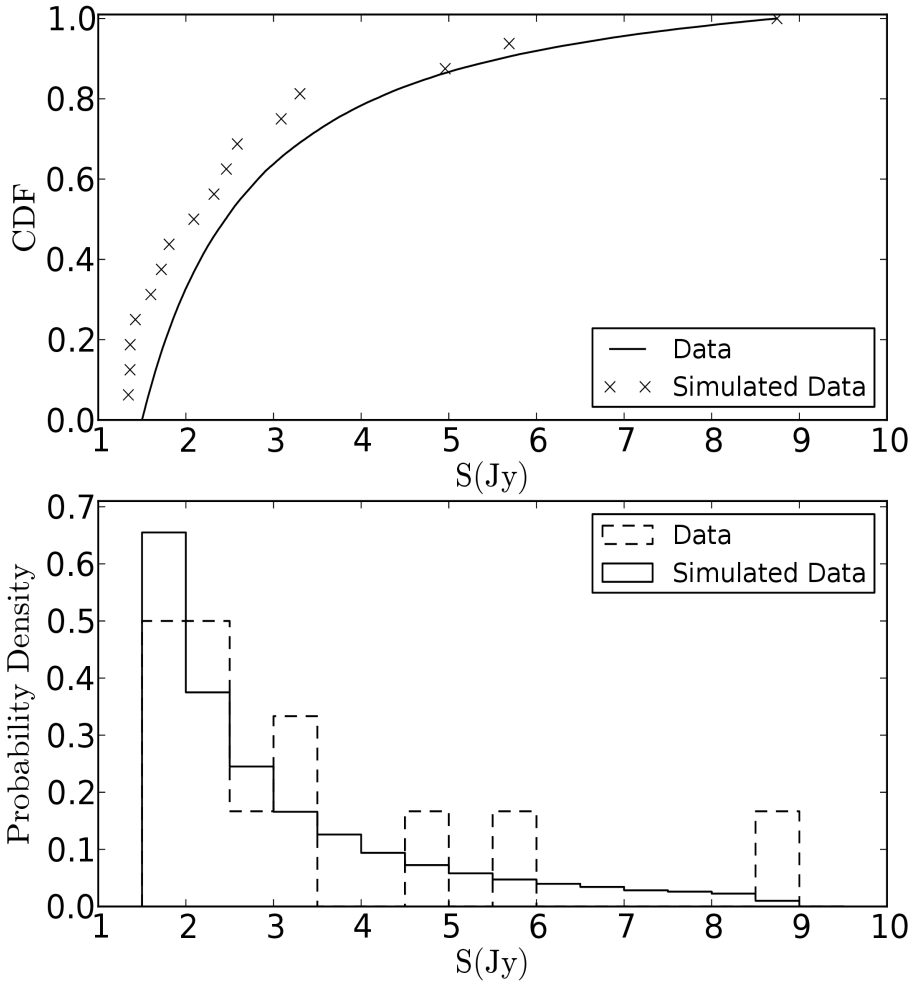


FSRQs

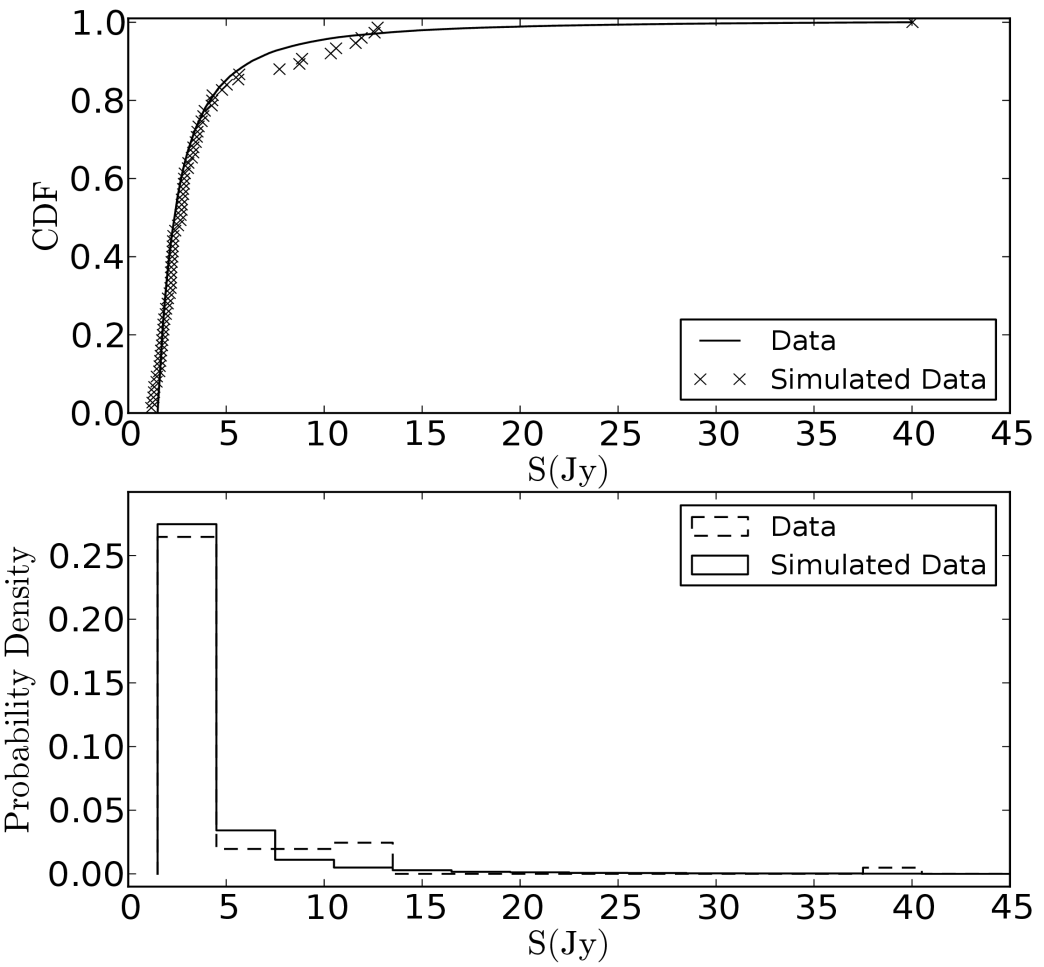


Flux density distribution

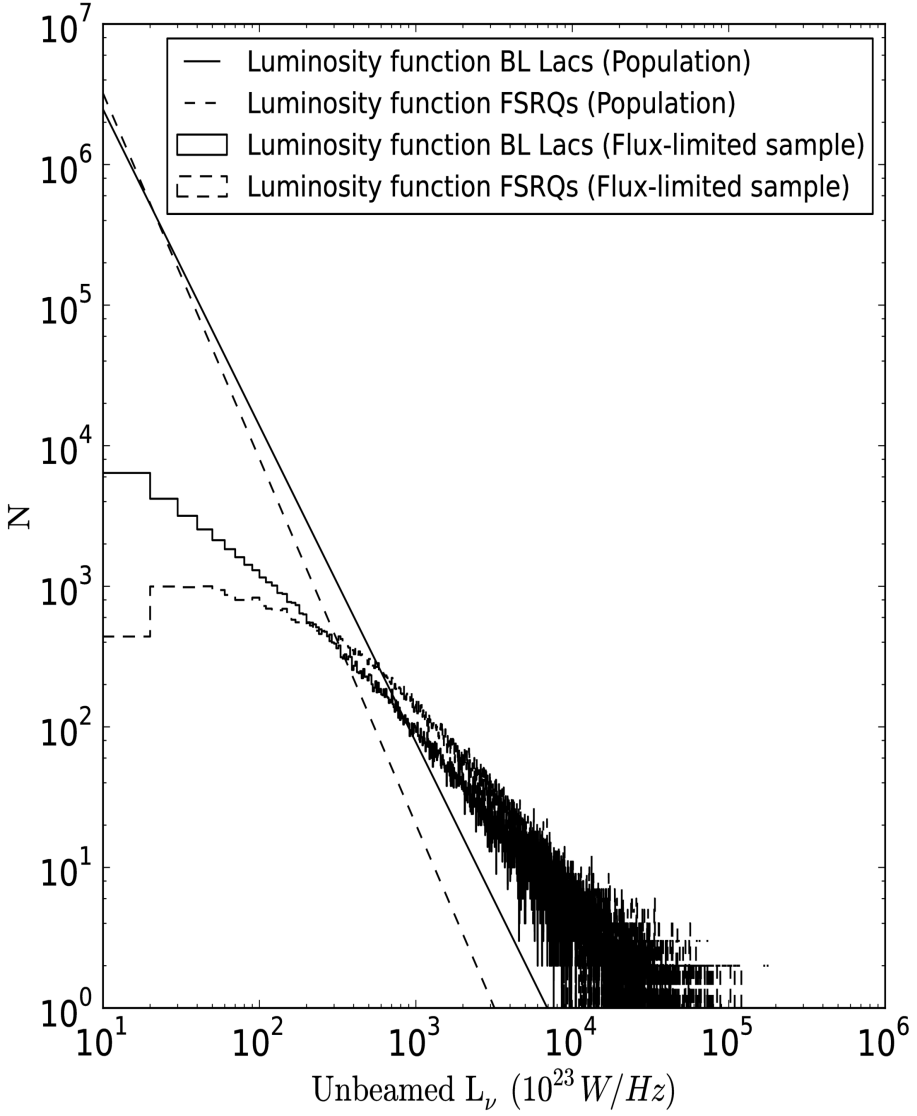
BL Lacs

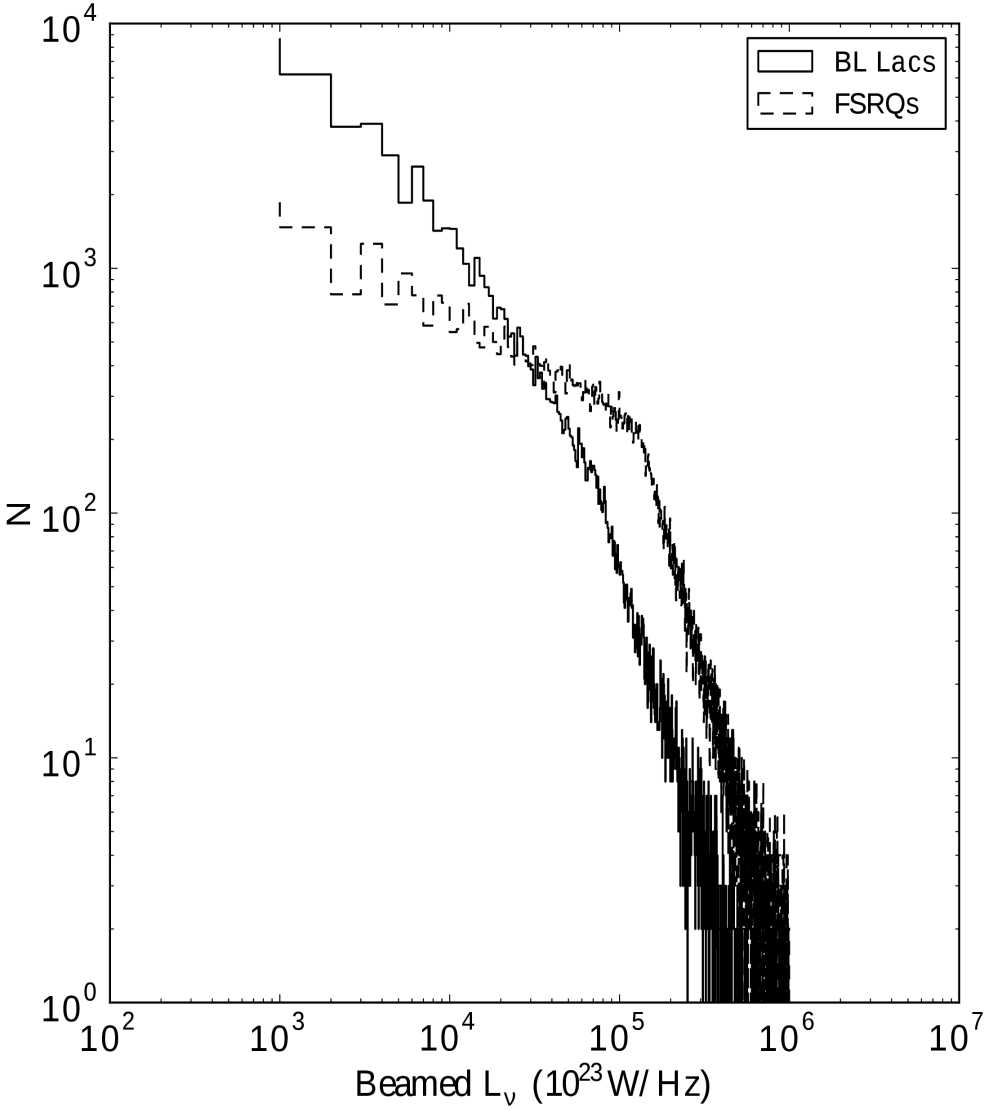


FSRQs



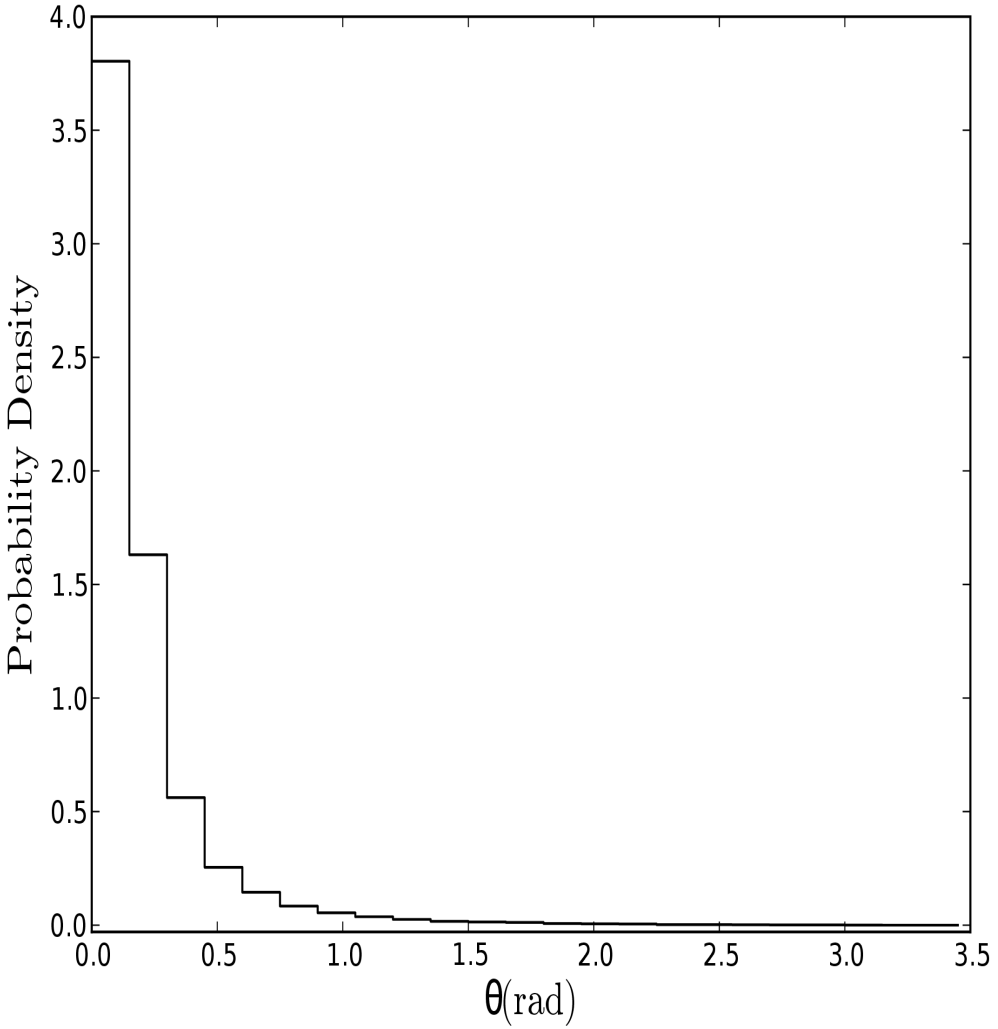
Luminosity function





Viewing angle distribution

BL Lacs $68.8\,\%\theta<0.2$



FSRQs $85\,\%\theta<0.2$