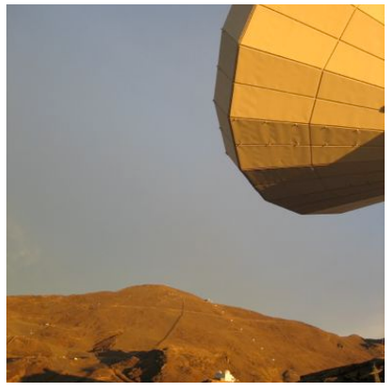
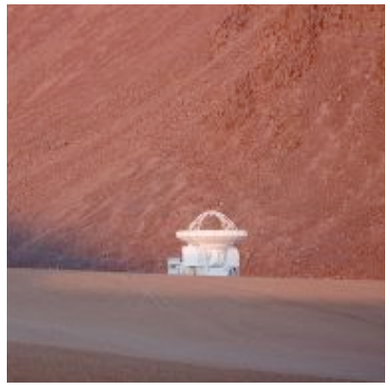
Max-Planck-Institut für Radioastronomie

100-m Effelsberg


30-m IRAM


12-m APEX

F-GAMMA program: 5 years of cm to sort-mm monitoring of Fermi blazars

Emmanouil (Manolis) Angelakis

and L. Fuhrmann[1], N. Marchili[1], I. Nestoras[1], V. Pavlidou[1], I. Myserlis[1], C. M. Fromm[1], M. Perucho[3], J. A. Zensus[1], T. P. Krichbaum[1], H. Ungerechts[2], A. Sievers[2]

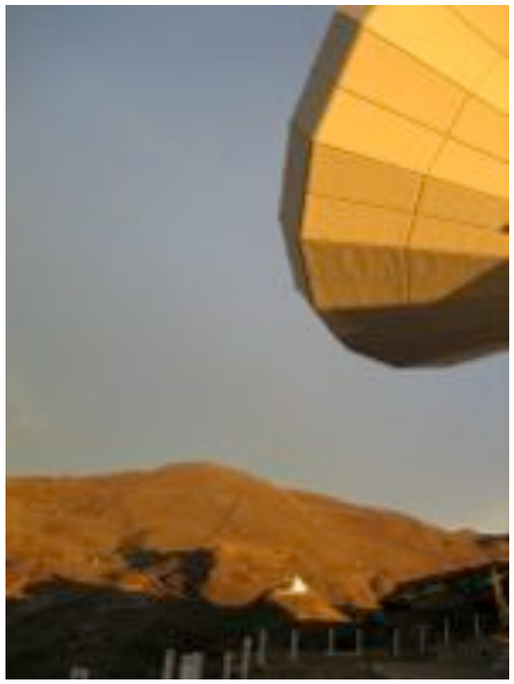
1 Max-Planck-Institut für Radioastronomie, Auf dem Hgel 69, Bonn 53121, Germany
2 Instituto de Radio Astronomía Milimétrica (IRAM), Avenida Divina Pastora 7, Local 20, E 18012 Granada, Spain
3 Departament d'Astronomia i Astrof ısica. Universitat de Valencia. C/Dr. Moliner 50, 46100 Burjassot (Valencia), Spain

F-GAMMA program

cm to sub-mm monitoring of *Fermi* blazars

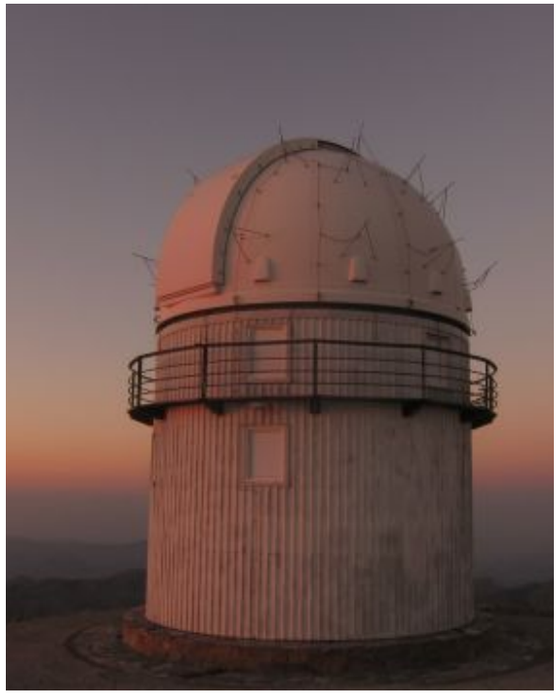
Effelsberg 100-m telescope

IRAM 30-m telescope



APEX telescope

Skinakas 1.3 m telescope



- monitoring ~60 *Fermi* blazars since January 2007

(sample revised in 2009.5; total: 97 sources observed)

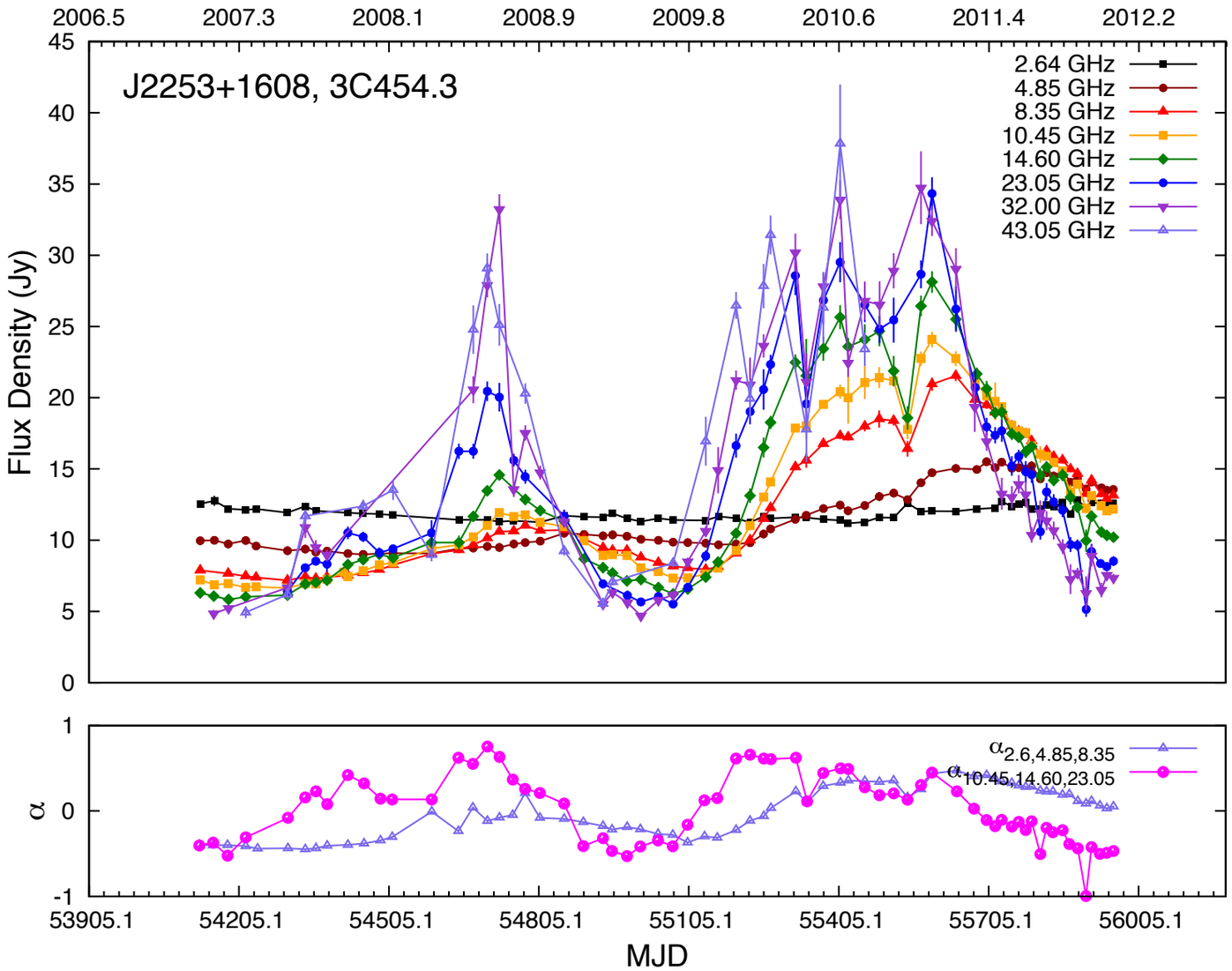
- at 2.6 - 345 GHz at **12 frequencies**, optical and gamma-rays
- linear and circular **polarization** of the Effelsberg data
- **optical polarimetry** (expected spring 2013)

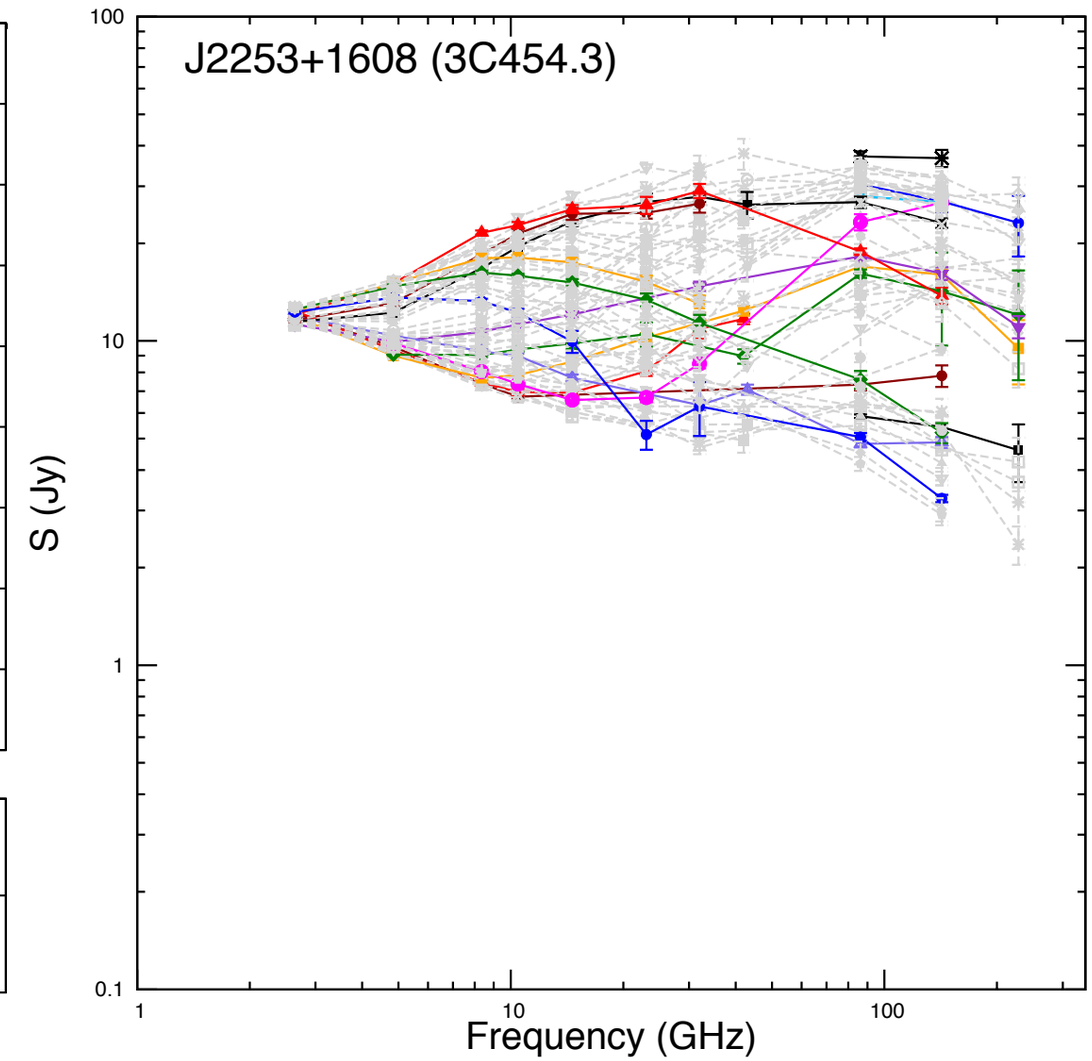
F-GAMMA PROJECT

FERMI-GST AGN MULTI-FREQUENCY MONITORING ALLIANCE

F-GAMMA program

cm to sub-mm monitoring of *Fermi* blazars





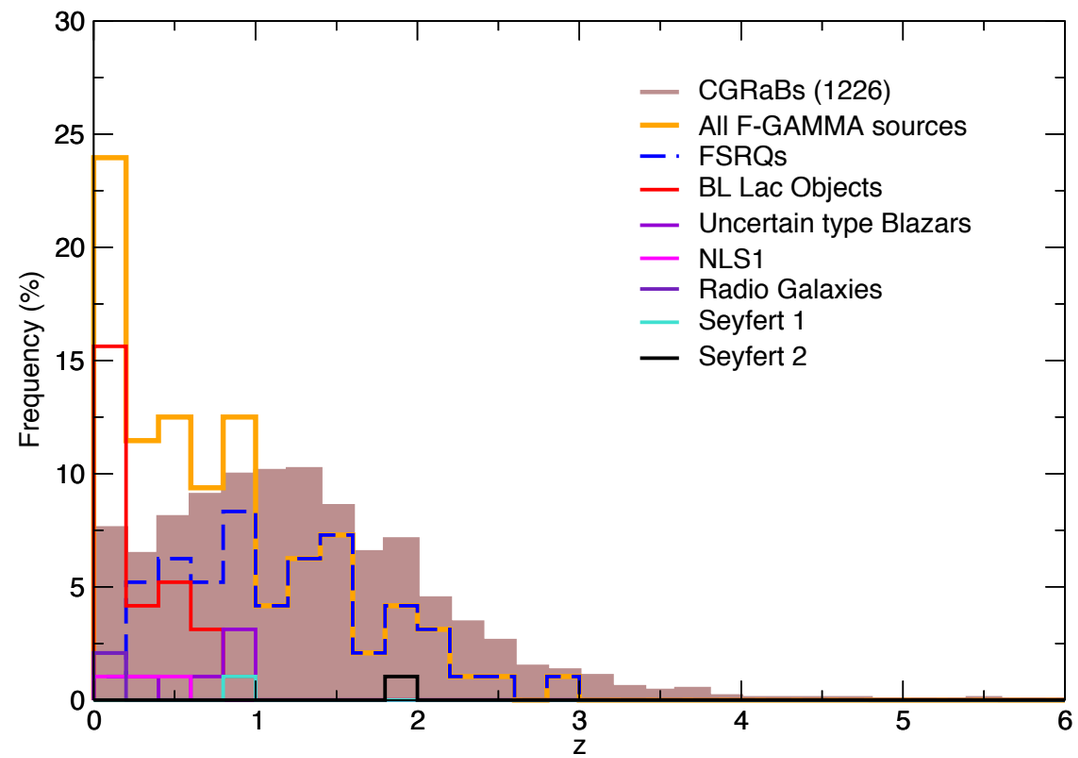
- cross-telescope **coherency ~ 2 days**
- mean **cadence: 1/(1.3 months)**

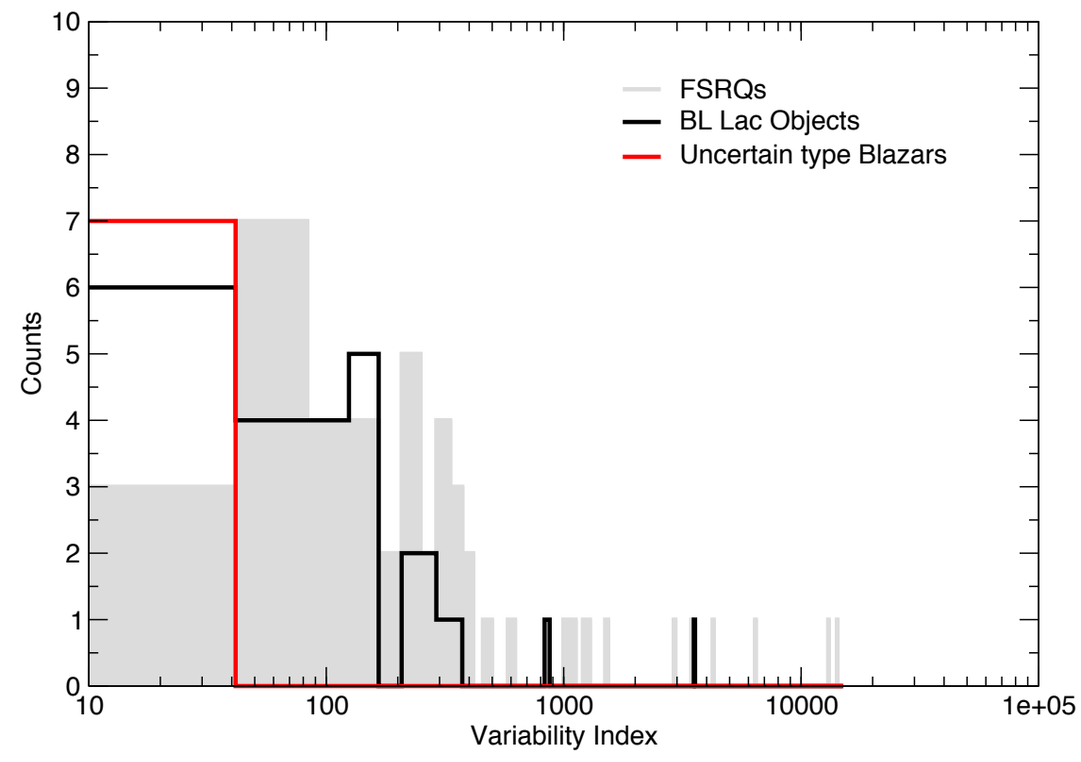
F-GAMMA program

the sample discussed here

- 55 FSRQs
- 28 BL Lacs
- 7 unclassified blazars
- 3 Narrow Line Seyfert 1 galaxies
- 1 Seyfert type 1
- 1 Seyfert type 2
- 2 radio galaxies

(classification of Massaro et al. 2009)

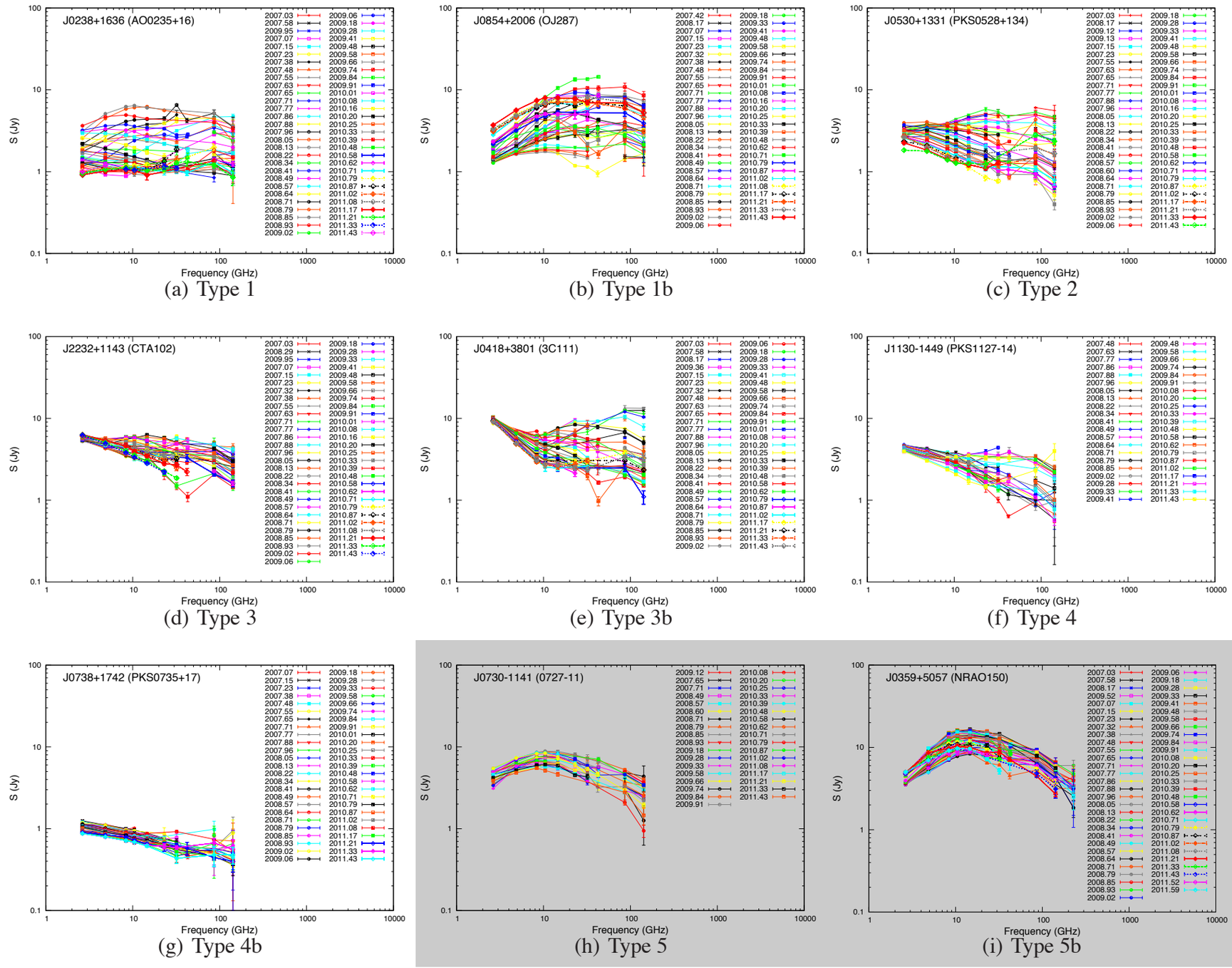




Angelakis et al. in prep.

Testing Variability Models

reproducing the spectrum variability pattern



(a) Type 1 (b) Type 1b (c) Type 2

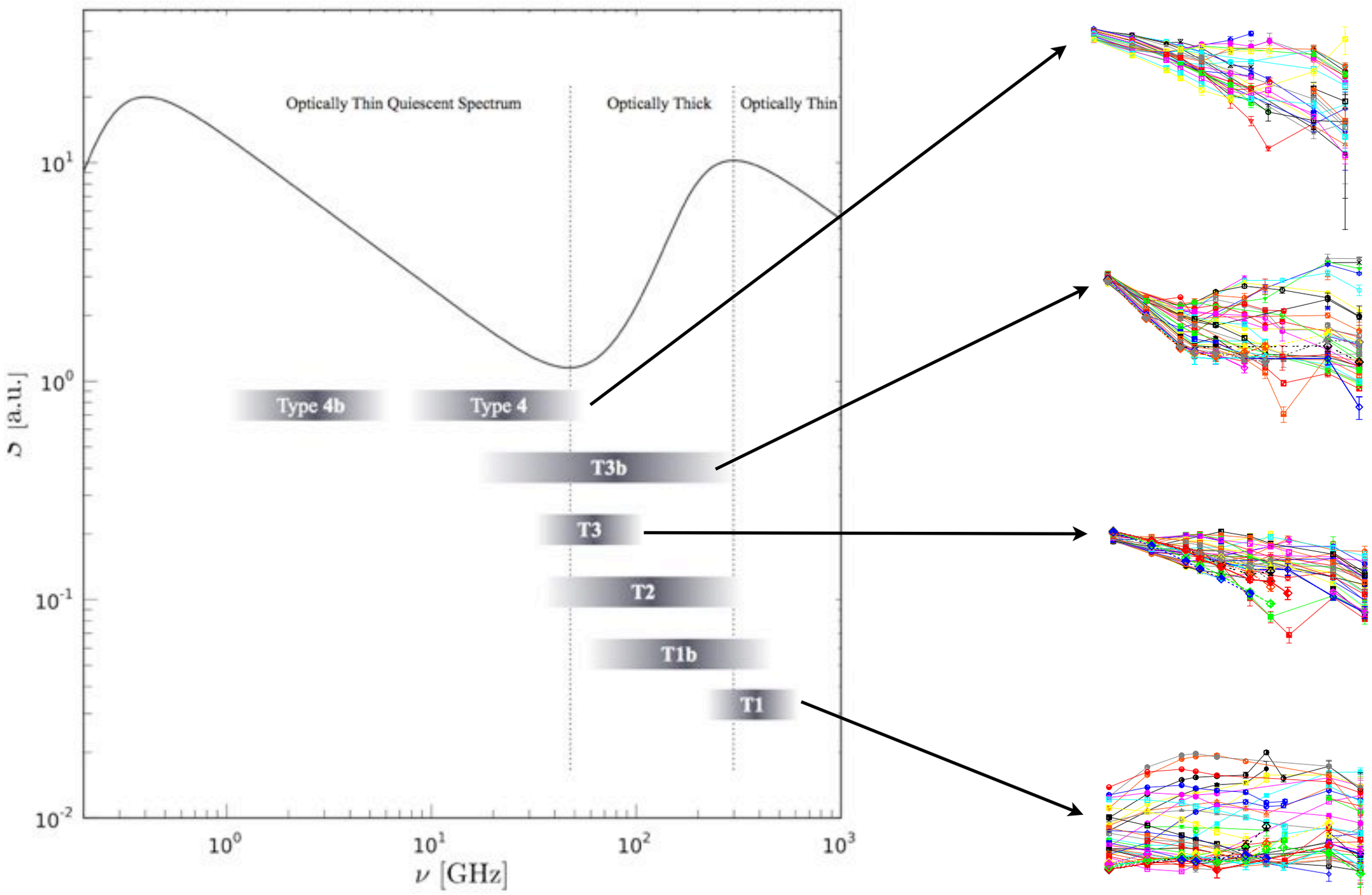
(d) Type 3 (e) Type 3b (f) Type 4

(g) Type 4b (h) Type 5 (i) Type 5b

Angelakis et al. in prep.; 2012JPhCS.372a2007A; 2011arXiv1111.6992A

Testing Variability Models

reproducing the spectrum variability pattern



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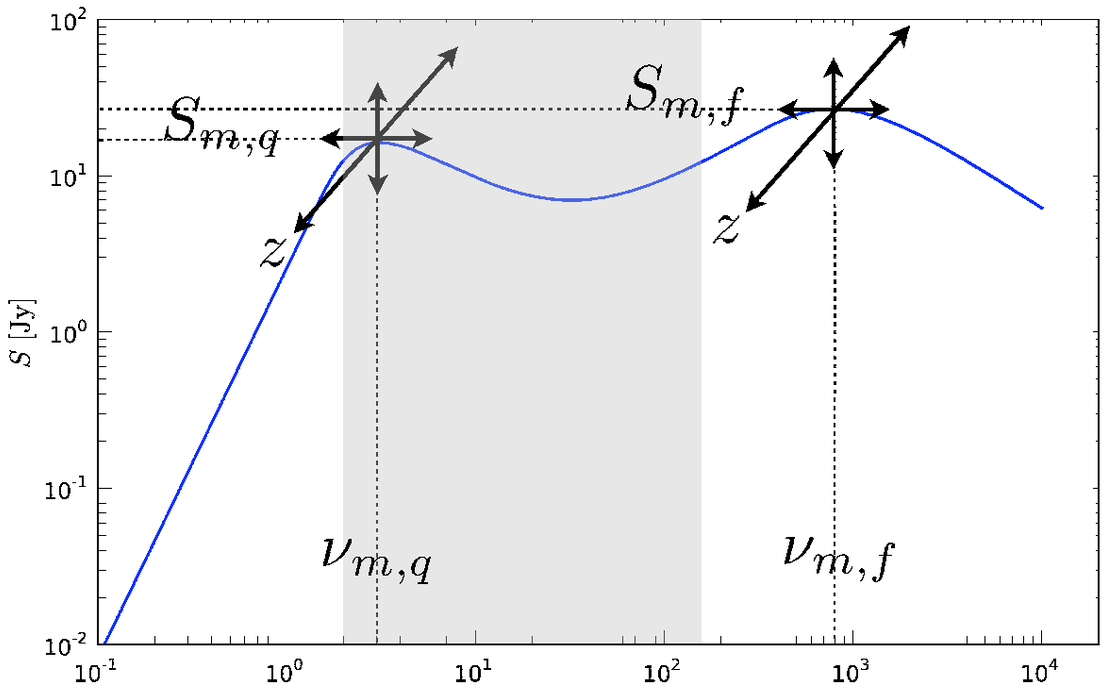
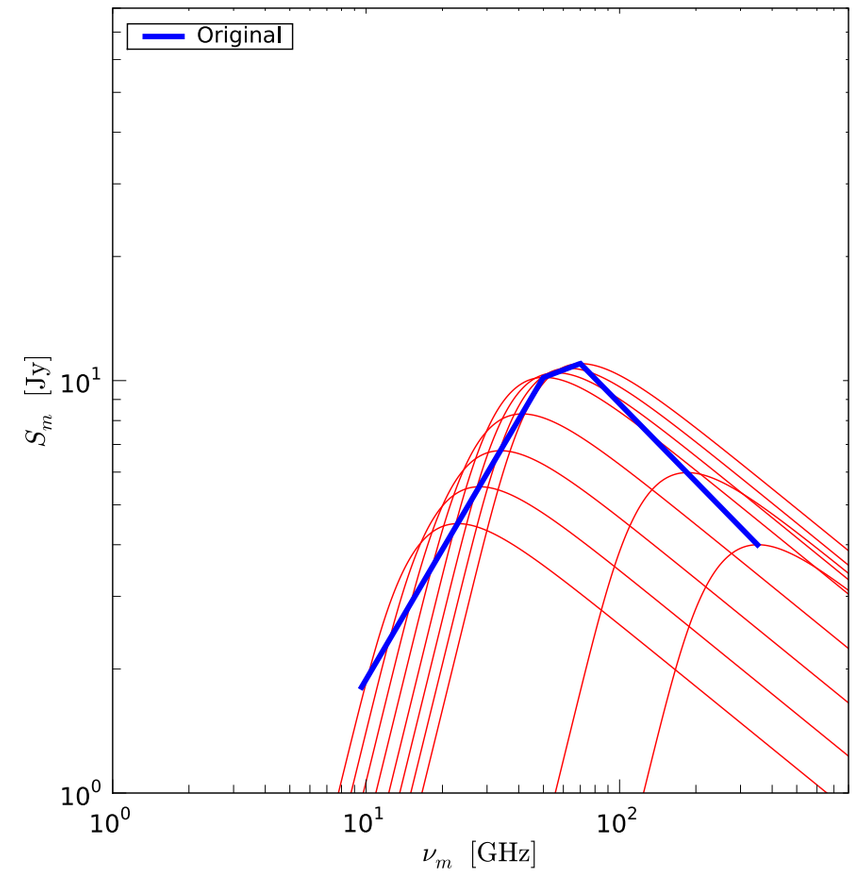
Testing Variability Models

reproducing the spectrum variability pattern



- redshift
- intrinsic properties (peak frequency of the SSA spectrum, outburst excess, broadness of the SSA, broadness of the valley)
- spectral evolution

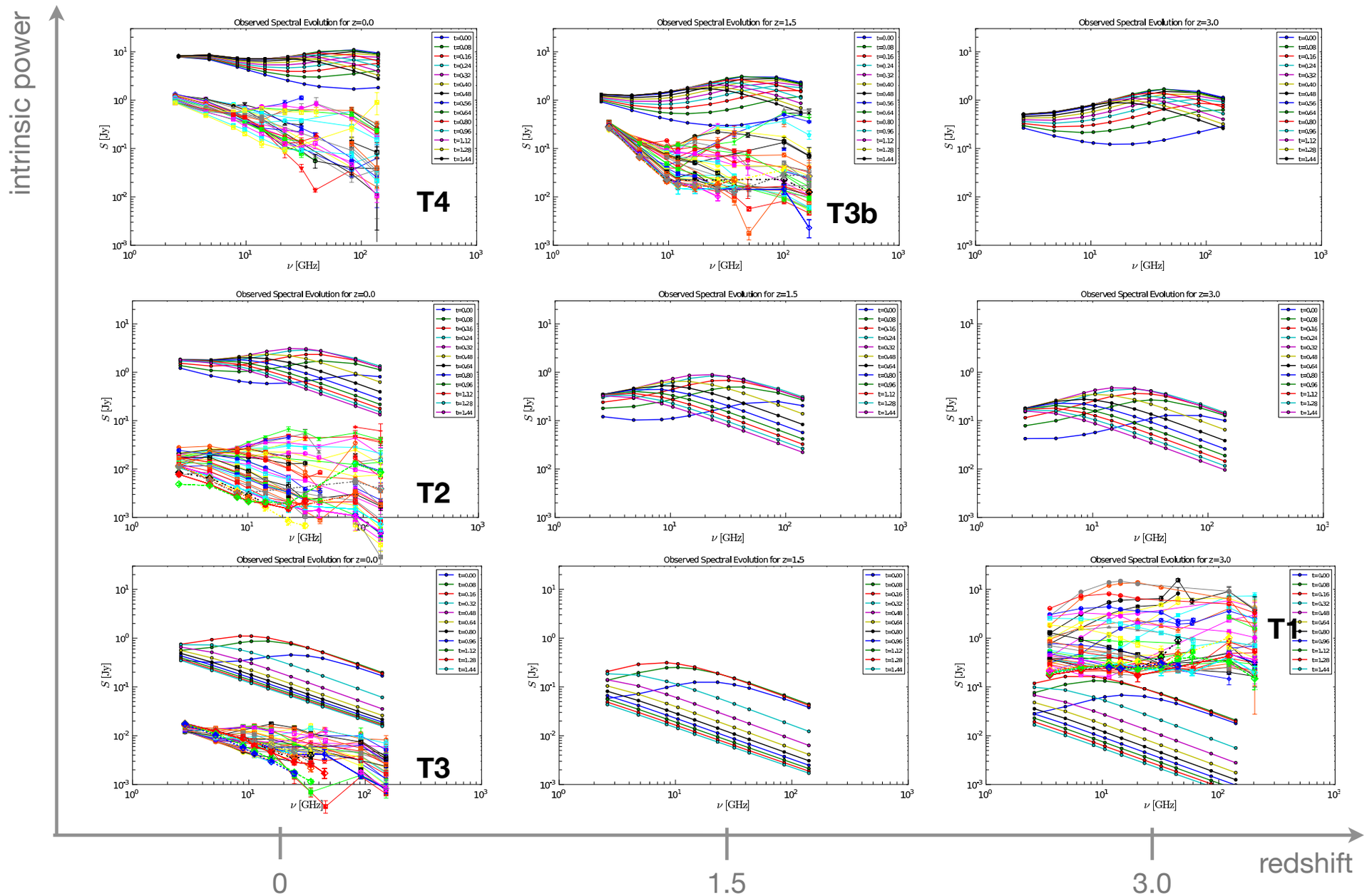
following Marscher & Gear 1985ApJ... 298..114M; Türler et al. 2000AnA...361..850T



- evolution of the magnetic field
- evolution of the Doppler factor
- jet opening angle
- spectral index (estimated from quiescent spec.)
- normalization parameter

Testing Variability Models

reproducing the spectrum variability pattern



Angelakis et al. in prep.; 2012JPhCS.372a2007A; 2011arXiv1111.6992A

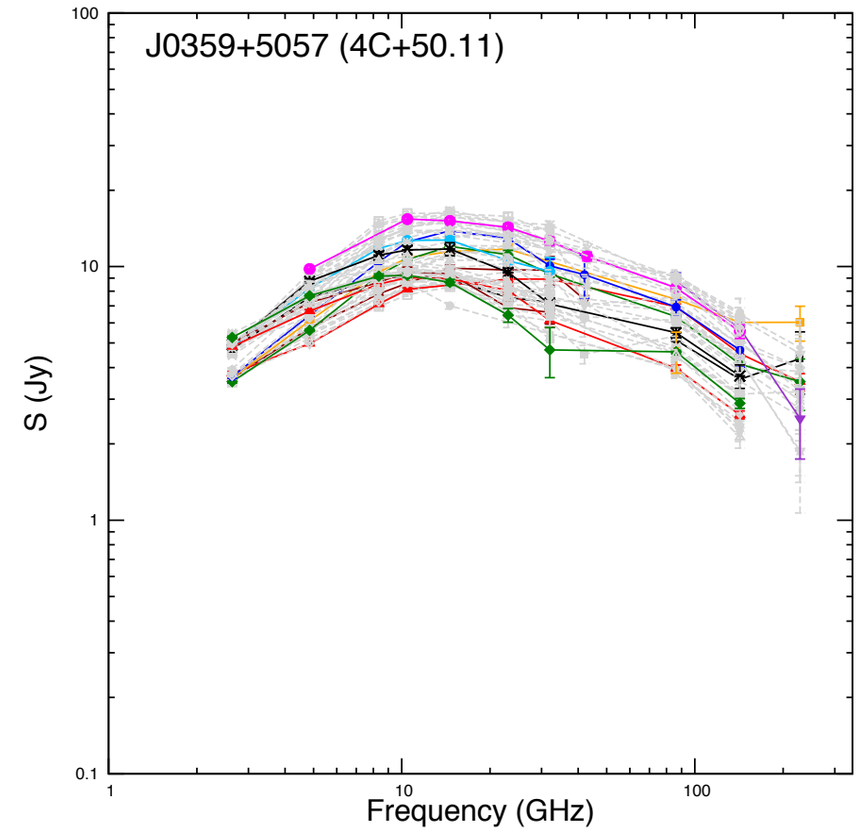
Testing Variability Models

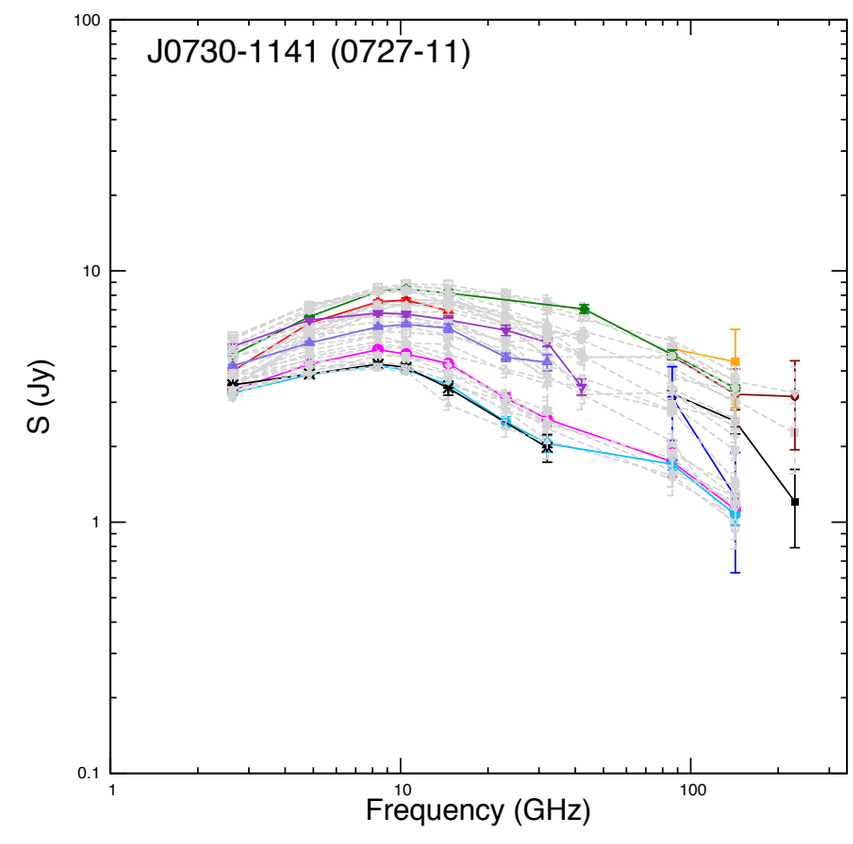
reproducing the spectrum variability pattern

- convex spectrum
- changing self-similarly

caused by:

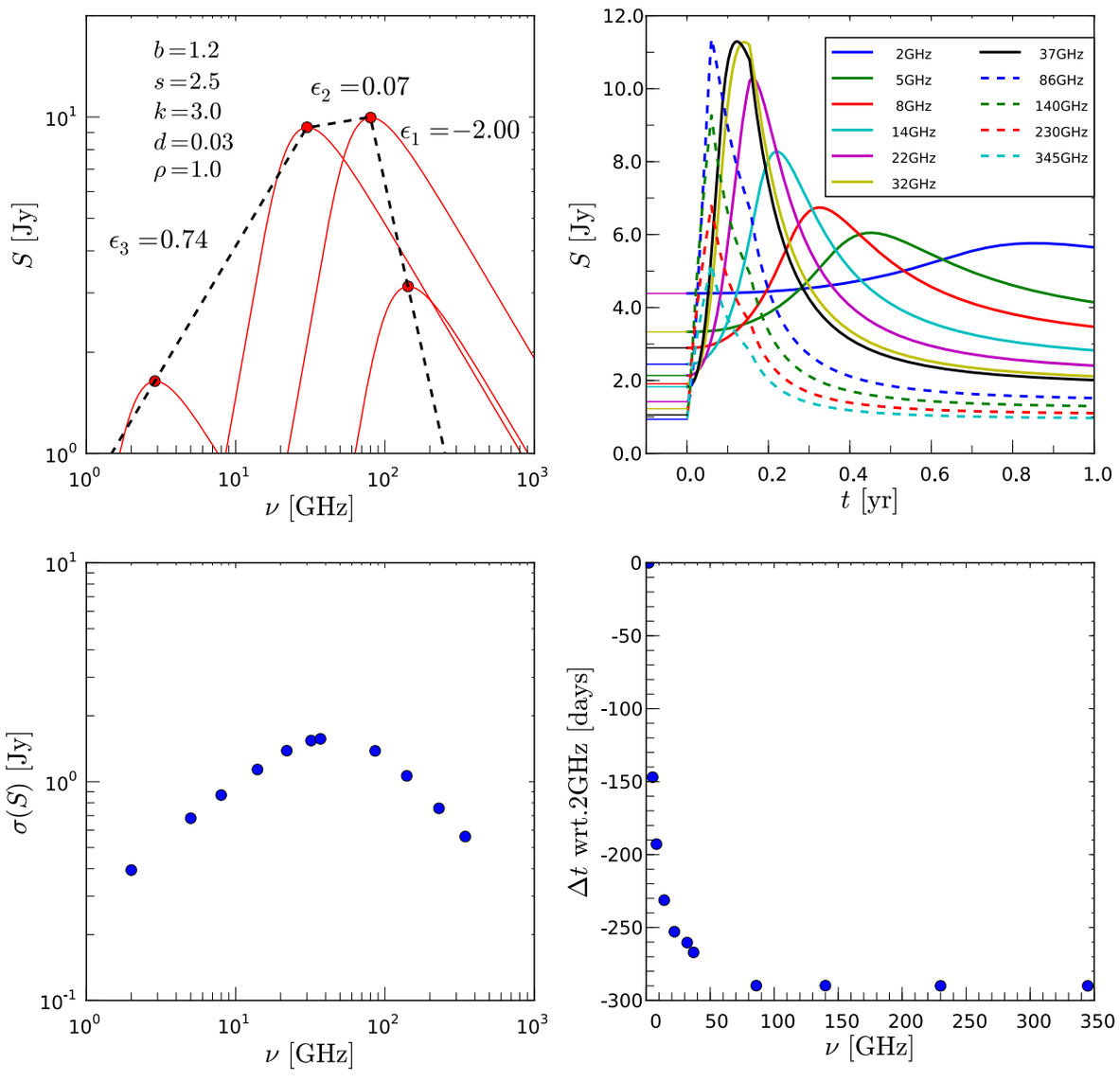
- changes in D? - Unlikely
- geometry?
- changes in the B topology?
- opacity effects?
- combination of a mild change of the LoS and the change in the particles density?





Testing Variability Models

variability amplitude in the frequency domain



- shock model (Marscher & Gear 1985)
- study case CTA102:
  - a conical jet (p = 1)
  - a toroidal magnetic field (b = 1.2)
  - constant Doppler factor
- if all follow same pattern: increase - max: ~ 60-80 GHz - then plateau - decrease

calculations done by C. Fromm

Testing Variability Models

variability amplitude in the frequency domain

A Likelihood Analysis Obtains the *Intrinsic Modulation Index,* we assume:

- normally distributed "true" flux densities (S_0, σ_0)
- intrinsic modulation index $\bar{m} = \sigma_0 / S_0$
- For N measurements of the flux density (S_j, σ_j)

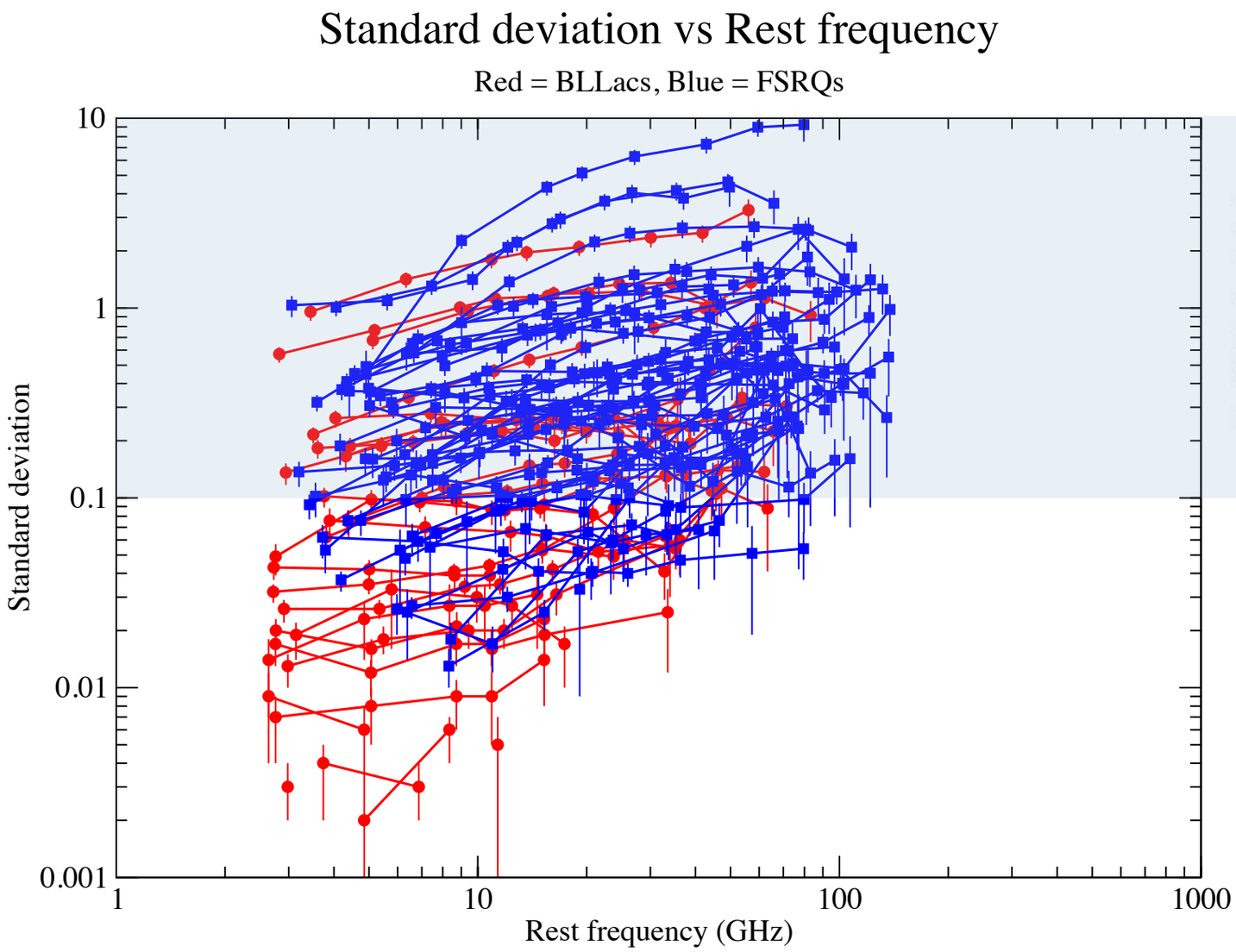
the most likely value of $\bar{m}$ and the associated uncertainties obtain the marginalized likelihood as a function of only $\bar{m}$:

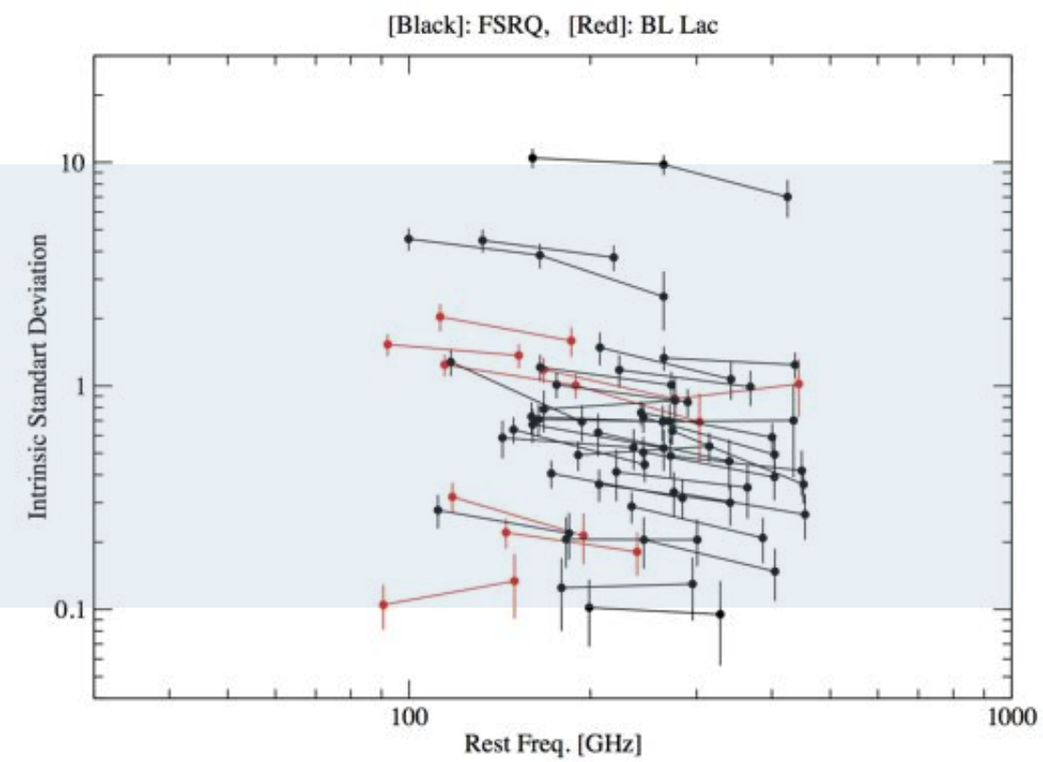
$$\mathcal{L}(\overline{m}) = \int_{\text{all } S_0} dS_0 S_0 \left\{ \left(\prod_{j=1}^{N} \frac{1}{\sqrt{2\pi \left(\overline{m}^2 S_0^2 + \sigma_j^2 \right)}} \right) \times \exp \left[-\frac{1}{2} \sum_{j=1}^{N} \frac{(S_j - S_0)^2}{\sigma_j^2 + \overline{m}^2 S_0^2} \right] \right\}$$

Richards et al. 2011ApJS..194...29R

Testing Variability Models

variability amplitude in the frequency domain





Nestoras et al. in prep.

Angelakis et al. in prep.

Testing Variability Models

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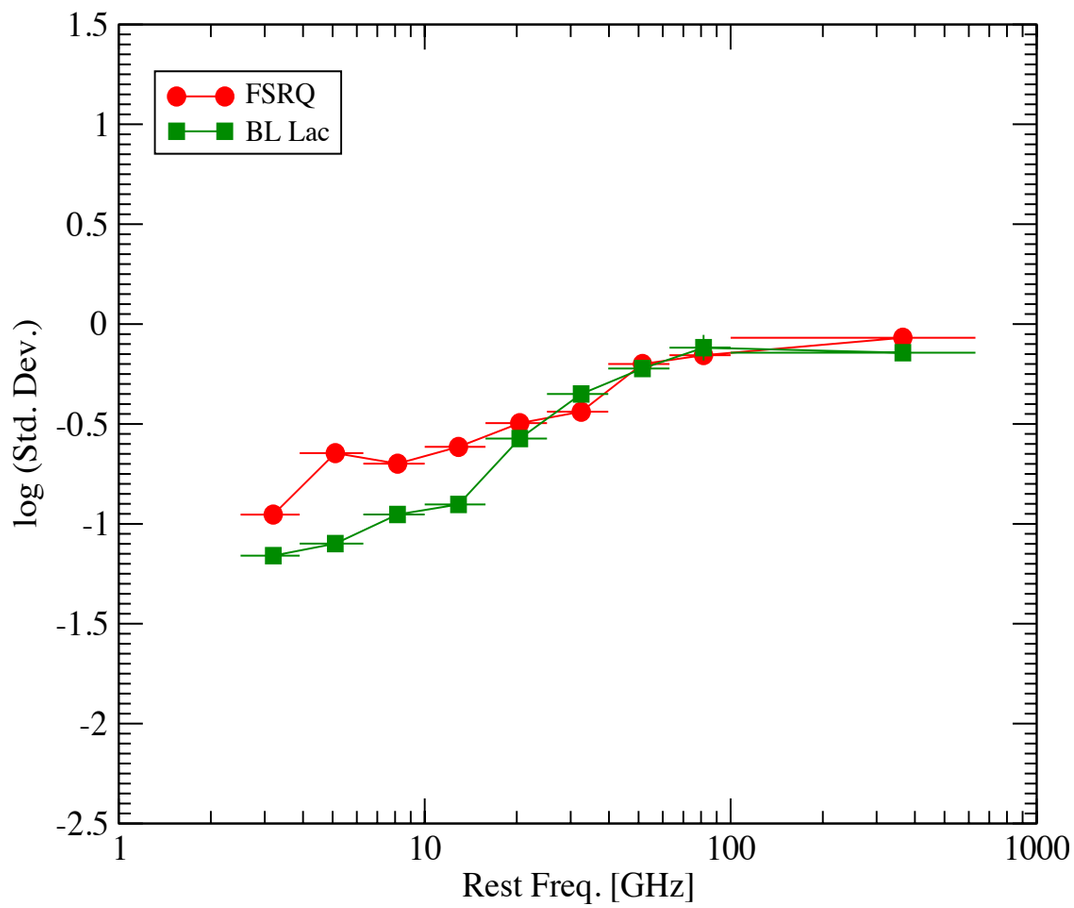
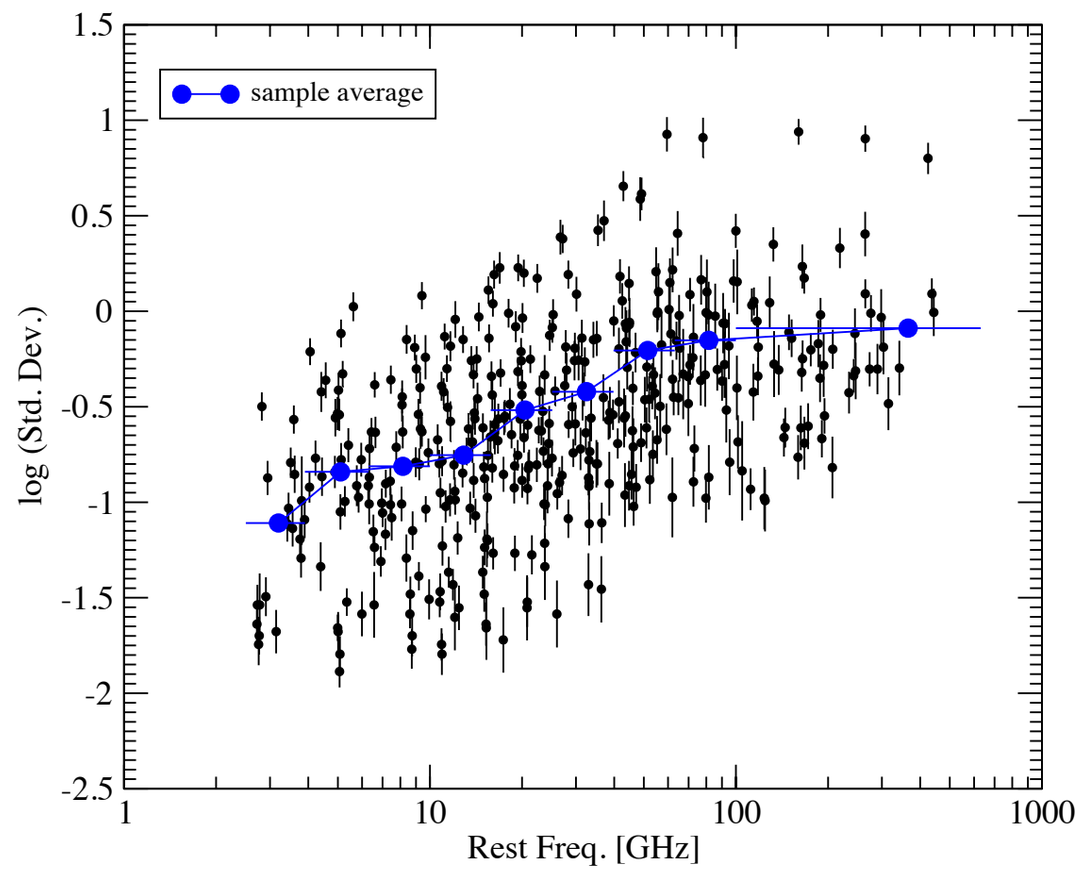




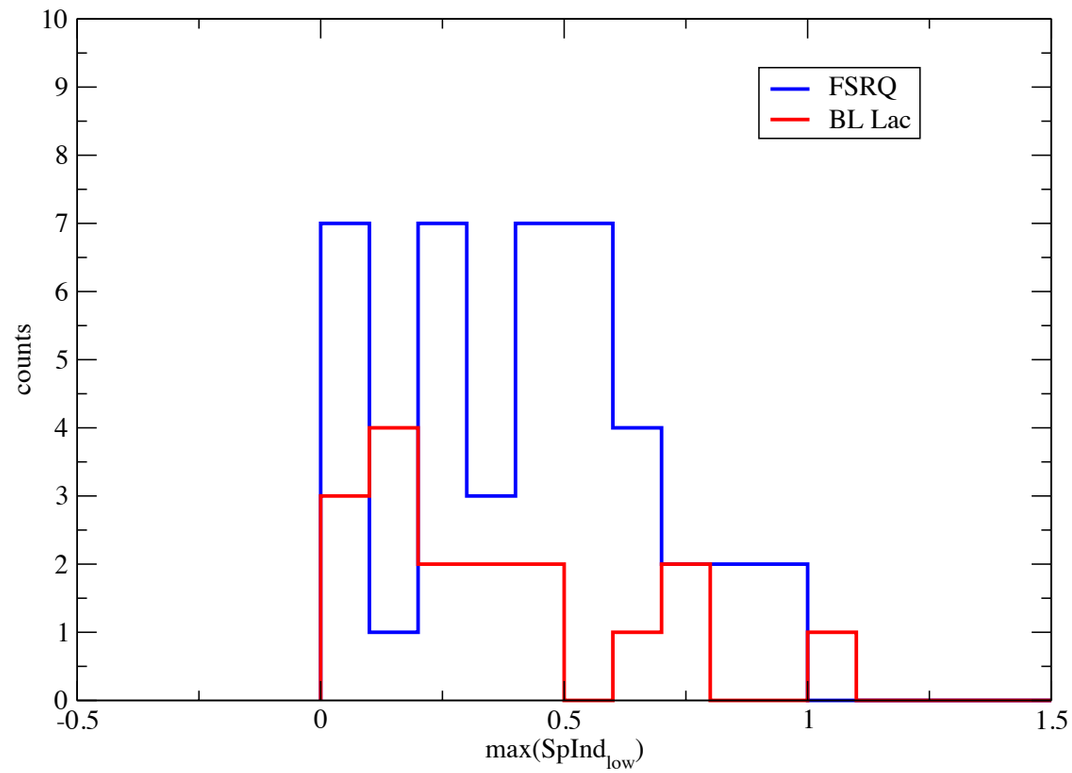
Fuhrmann et al. in prep.

Testing Variability Models

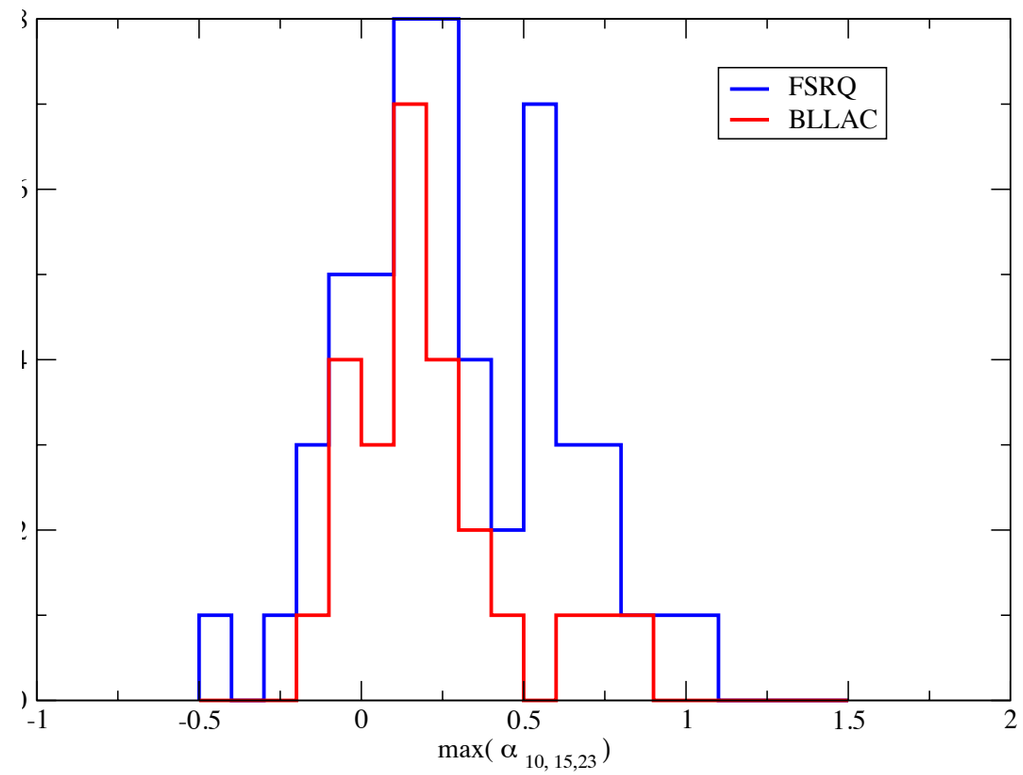
variability amplitude in the frequency domain

$$S \propto \nu^{\alpha}$$

$\alpha_{2.6,4.9,8.4}$



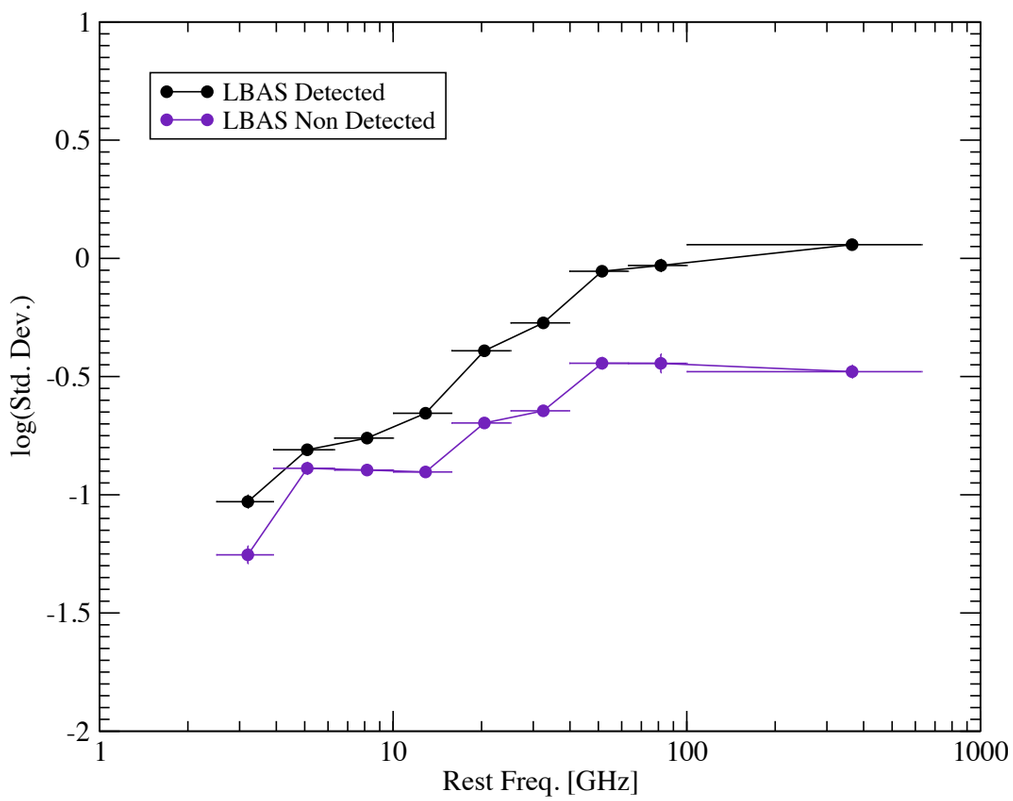
$\alpha_{10,15,23}$

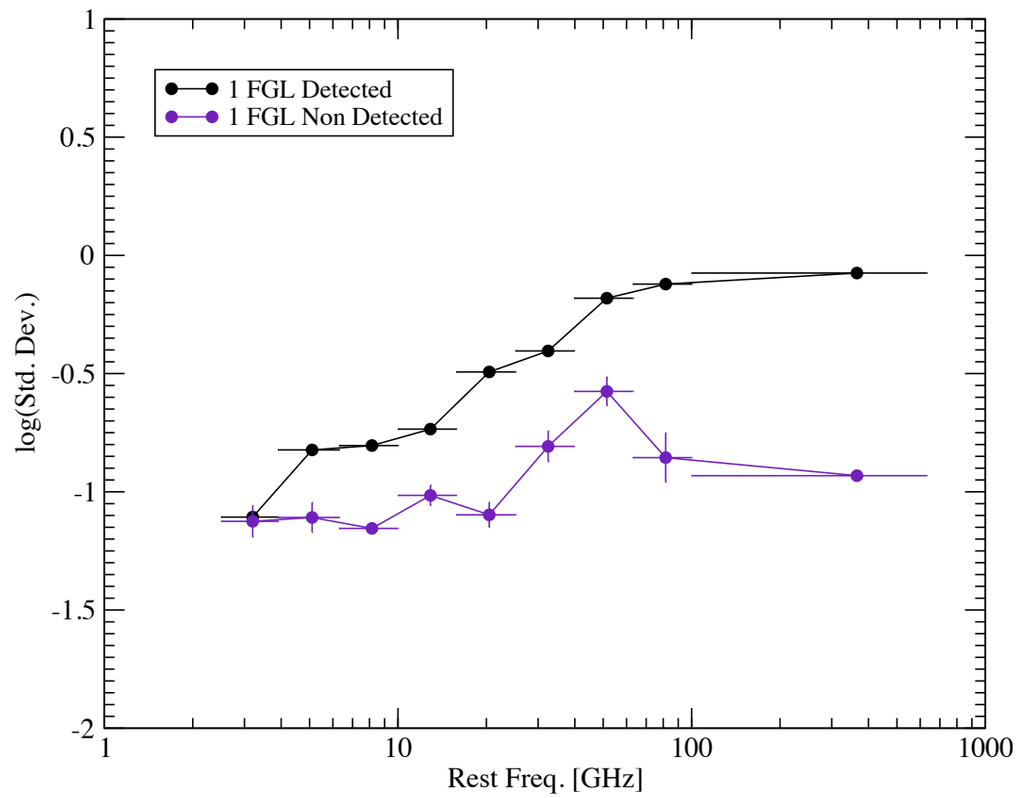


Angelakis et al. in prep.

Radio Variability

LAT detectability





Radio Variability

T_B and Doppler factors - class

Variability amplitude measures brightness temperature:

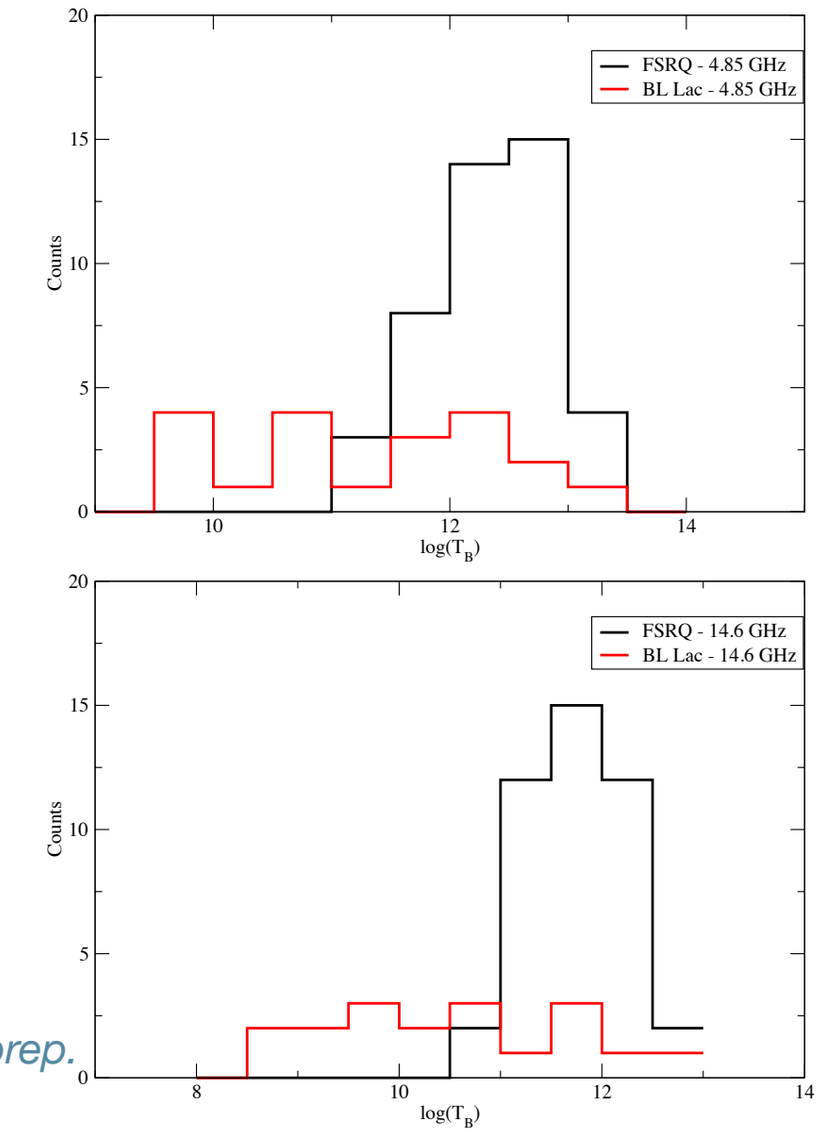
$$T_B = 4.5 \cdot 10^{10} \cdot \Delta S_\lambda \left(\frac{\lambda \cdot d_\lambda}{\Delta t_\lambda \cdot (1+z)^2} \right)^2$$

Assuming Equipartition brightness temperature limit:

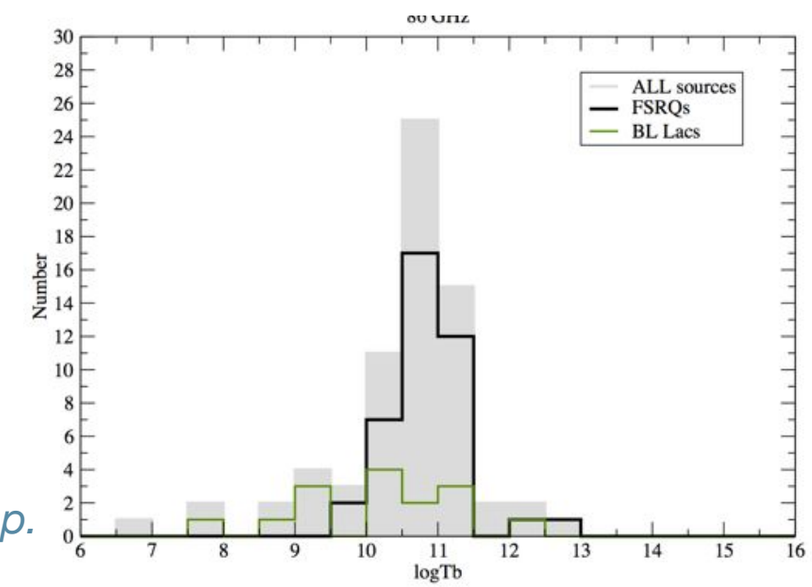
$$T_B \simeq 5 \cdot 10^{10} \cdot \left(\frac{\delta_{var,IC}}{1+z} \right)^{3+\alpha}$$

Hence, Equipartition Doppler factor:

$$\delta_{var} = (1+z) \sqrt[3+\alpha]{T_B / 5 \cdot 10^{10}}$$



Angelakis et al. in prep.



Nestoras et al. in prep.

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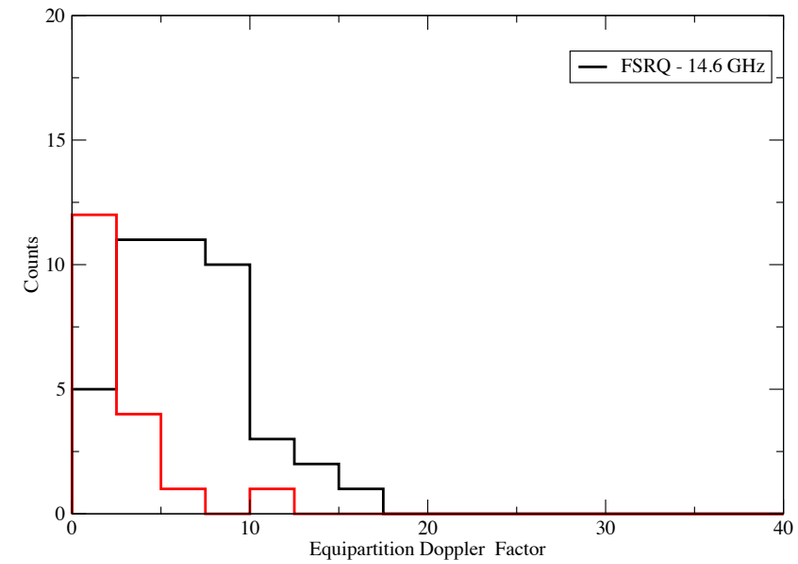
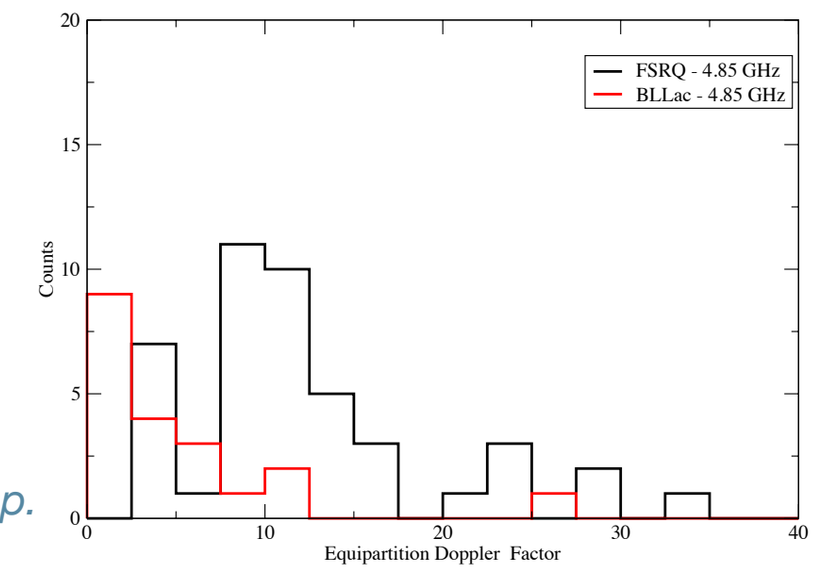
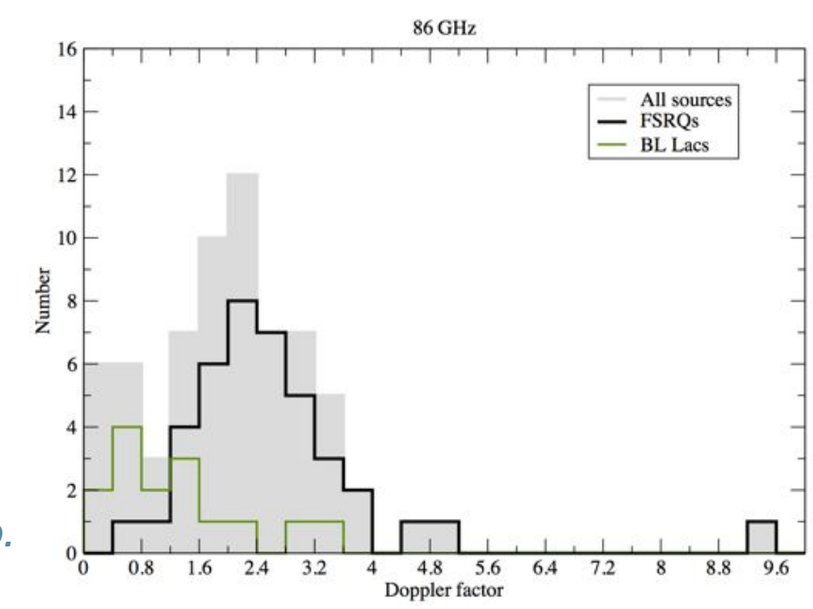




Angelakis et al. in prep.



Nestoras et al. in prep.

Radio Variability

T_B and Doppler factors - LAT detectability

	LBAS			1FGL		
	$\langle T_B \rangle$ (K)			$\langle T_B \rangle$ (K)		
Frequency (GHz)	Detected	Non-Detected	ratio	Detected	Non-Detected	ratio
86	3.98E+11	1.56E+11	**2.6**			
14.60	4.79E+12	2.66E+12	**1.8**	3.99E+12	1.48E+12	**2.7**
10.45	6.24E+12	4.43E+12	**1.4**	2.96E+11	1.18E+11	**2.5**
	D (from average Tb)			D (from average Tb)		
86	2.4	2.2	**1.1**	2.3	1.9	**1.2**
14.60	5.1	4.6	**1.1**	5.0	3.4	**1.5**

gamma - radio connection

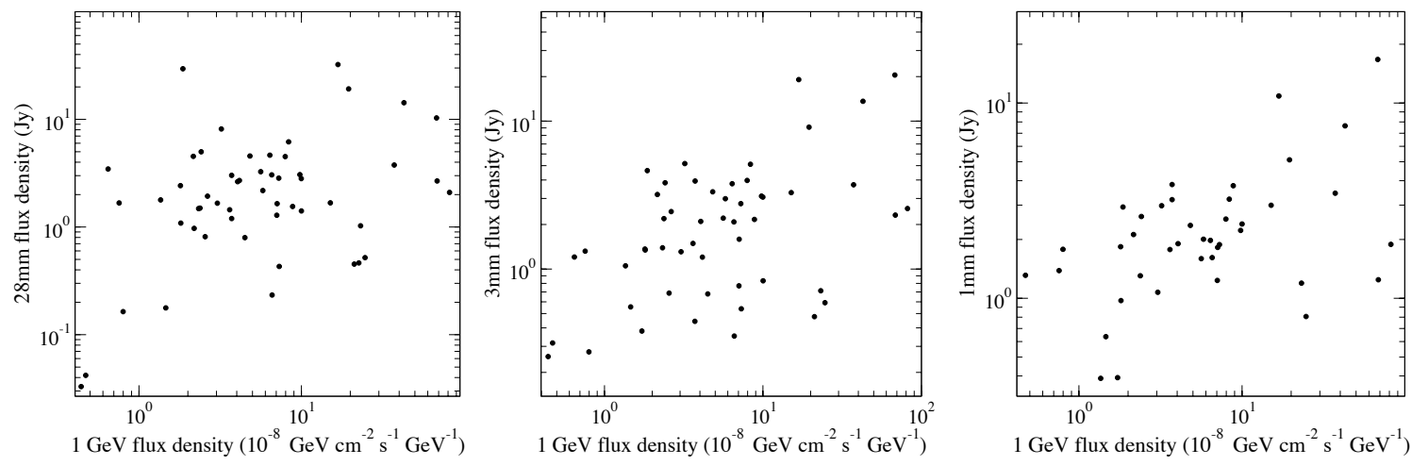
the flux-flux correlations

common distance effect, from:

- preferred L
- detection in both wavebands as selection criteria
- small luminosity dynamical range isetc..

advantages of F-GAMMA data:

- F-GAMMA: multi-frequency
- concurrent radio - gamma
- concurrent radio spectral index



analysis shows:

- below 7mm significant correlation, better than 2σ
- at 2 mm and 3mm, better than 3σ
- longer wavelengths do not show a significant correlation

suggesting:

- physical connection between the radio and high-energy emission
- co-spatial gamma and mm emission region
- fluxes averaged over timescales comparable to length of single flare, correlate more significantly than those over longer timescales

Fuhrmann et al in prep.; Pavlidou et al. 2012ApJ...751..149P

Conclusions

- F-GAMMA:
  - data accessible at: **www.mpifr-bonn.mpg.de/div/vlbi/fgamma**
  - provides dynamic broadband spectra
  - covers the “heart” of the radio activity

- Testing Variability Models:
  - in most cases the variability can be reproduced assuming a 2-component system:
    - steady quiescent component
    - high frequency component (internal shock)
  - sampling only a small part of the parameter space can reproduce most of the phenomenologies
  - no type switches:
    - variability mechanism source fingerprint
    - variability mechanism changes with slow pace
  - the variability amplitude over frequency agrees with the shock-in-jet scenario

Conclusions

- FSRQ - BL Lac dichotomy:
  - FSRQs show larger intrinsic variability amplitudes
    - outbursts in BL Lacs do not reach low frequencies.
      - less energetic events? (de-boosted fluxes in prep.)
      - BL Lacs more self absorbed
  - BL Lacs appear systematically at lower TB , and Equipartition D

- radio variability and gamma loudness (of individual events or overall):
  - LAT detected sources show higher intrinsic variability amplitudes
  - LAT detected sources show higher TB and D

- S-S correlation
  - significant below 7mm, vanishes towards lower frequencies
  - physical connection between the radio and high-energy emission
  - co-spatial gamma and mm emission region