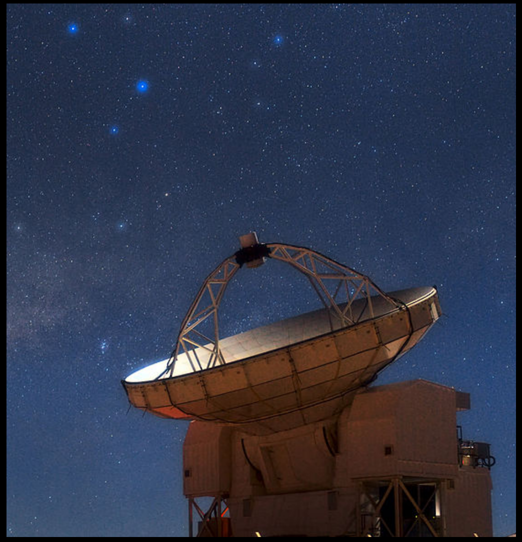
F-GAMMA program

multi-frequency radio monitoring of Fermi blazars

Emmanouil Angelakis
Max-Planck-Institut für Radioastronomie, Auf dem Huegel 69, Bonn 53121, Germany

MAX-PLANCK-GESELLSCHAFT

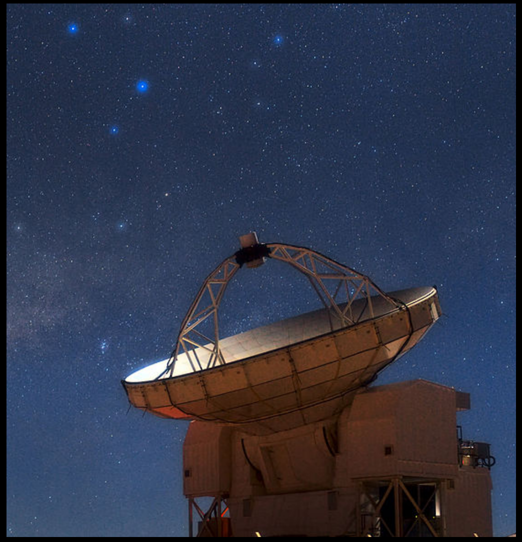
Max-Planck-Institut für Radioastronomie



the F-GAMMA program (Jan. 2007 — Jan. 2015):

- understand the broad-band variability (emission and variability mechanisms)
- localise the gamma-ray emission site
- conduct population studies of HE emitters
- investigate what drives the HE emission
- physics of the emitting elements

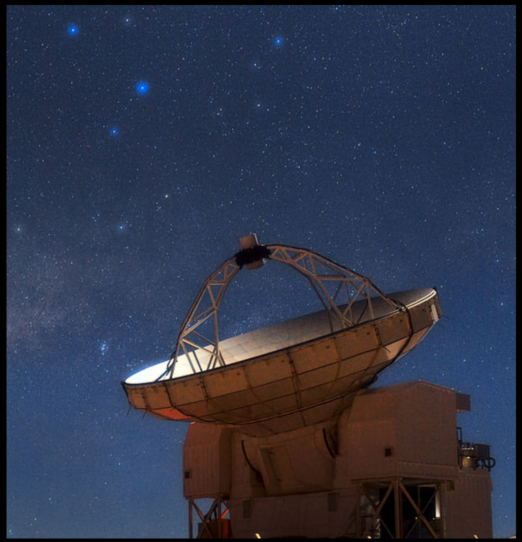
Fuhrmann, Angelakis et al. A&A, accepted, 2016arXiv160802580F
Angelakis et al. 2010, astro-ph.CO/1006.5610
Fuhrmann et al. 2007, AIP Conf. Series, Vol. 921, 249–251



the F-GAMMA program (Jan. 2007 — Jan. 2015):

- ~90 mostly *Fermi*-detected and candidate sources
- Effelsberg: 2.6, 4.9, 8.4, 10.5, 14.6, 23, 32, 43
  - linear polarisation: 2.6, 4.9, 8.4, 10.5 and 14.6
  - circular polarisation: at 2.6, 4.9, 8.4, 10.5, 14.6, 23
- 30-m IRAM: 86.24, 142.3, 228.9,
- APEX 12 m: 345 GHz

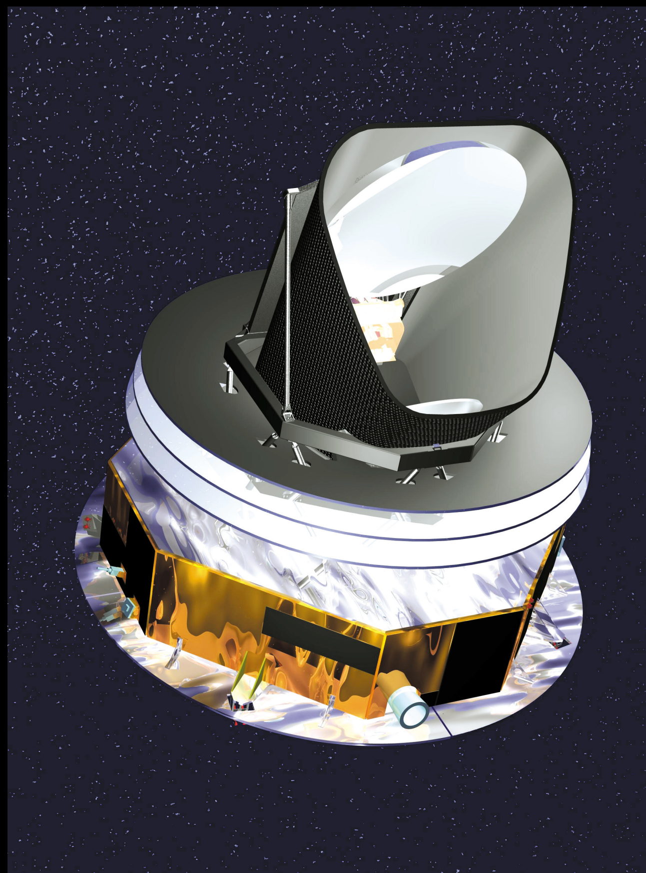
Fuhrmann, Angelakis et al. A&A, accepted, 2016arXiv160802580F
Nestoras et al. submitted



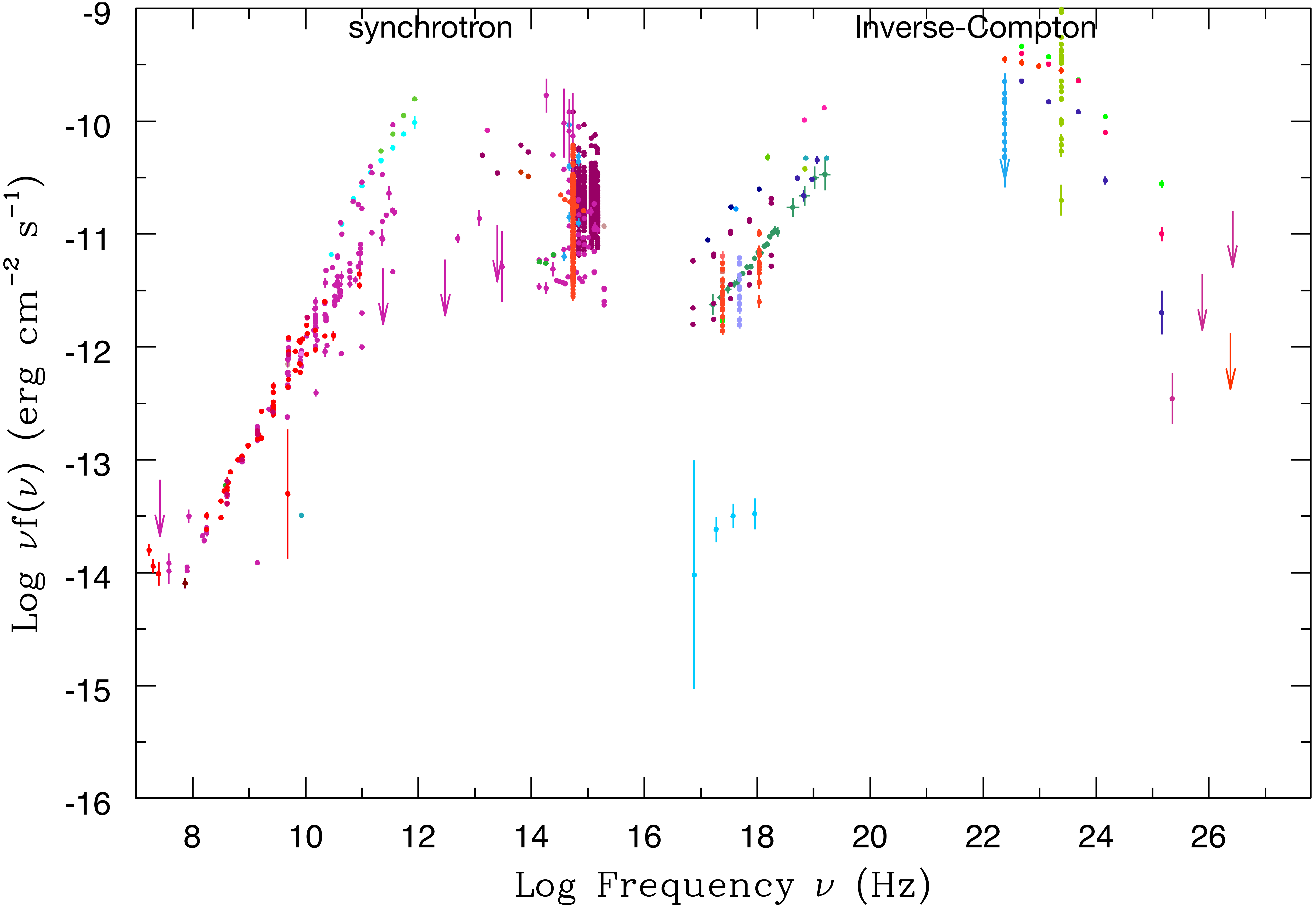
the F-GAMMA program (Jan. 2007 — Jan. 2015):

- Effelsberg:
  - cadence: 1-1.3 months
  - fractional uncertainty: <5%
- 30-m IRAM:
  - cadence: 1-1.7 months
  - fractional uncertainty: : <11%
- APEX 12 m: 345 GHz

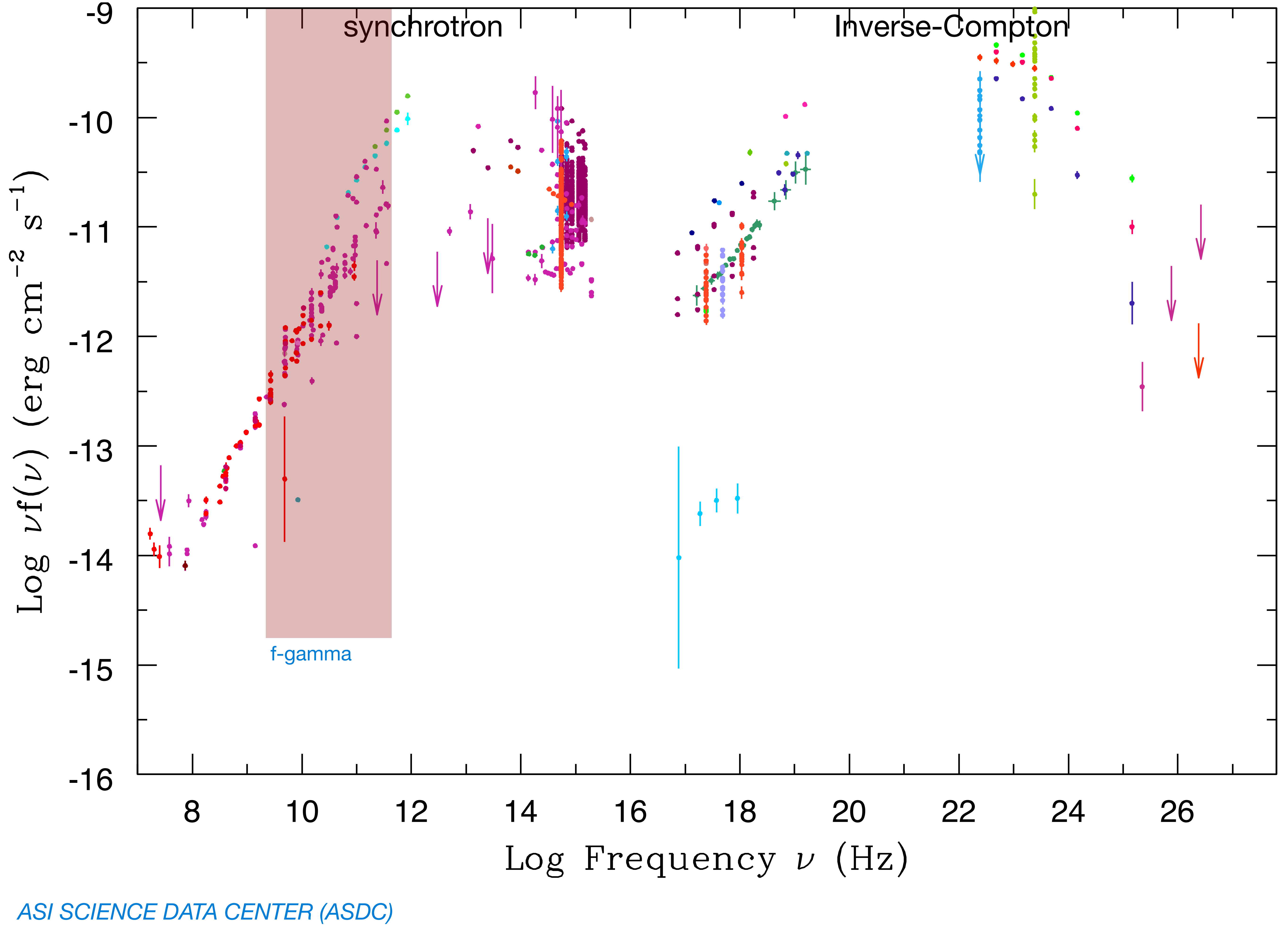
Fuhrmann, Angelakis et al. A&A, accepted, 2016arXiv160802580F
Nestoras et al. submitted

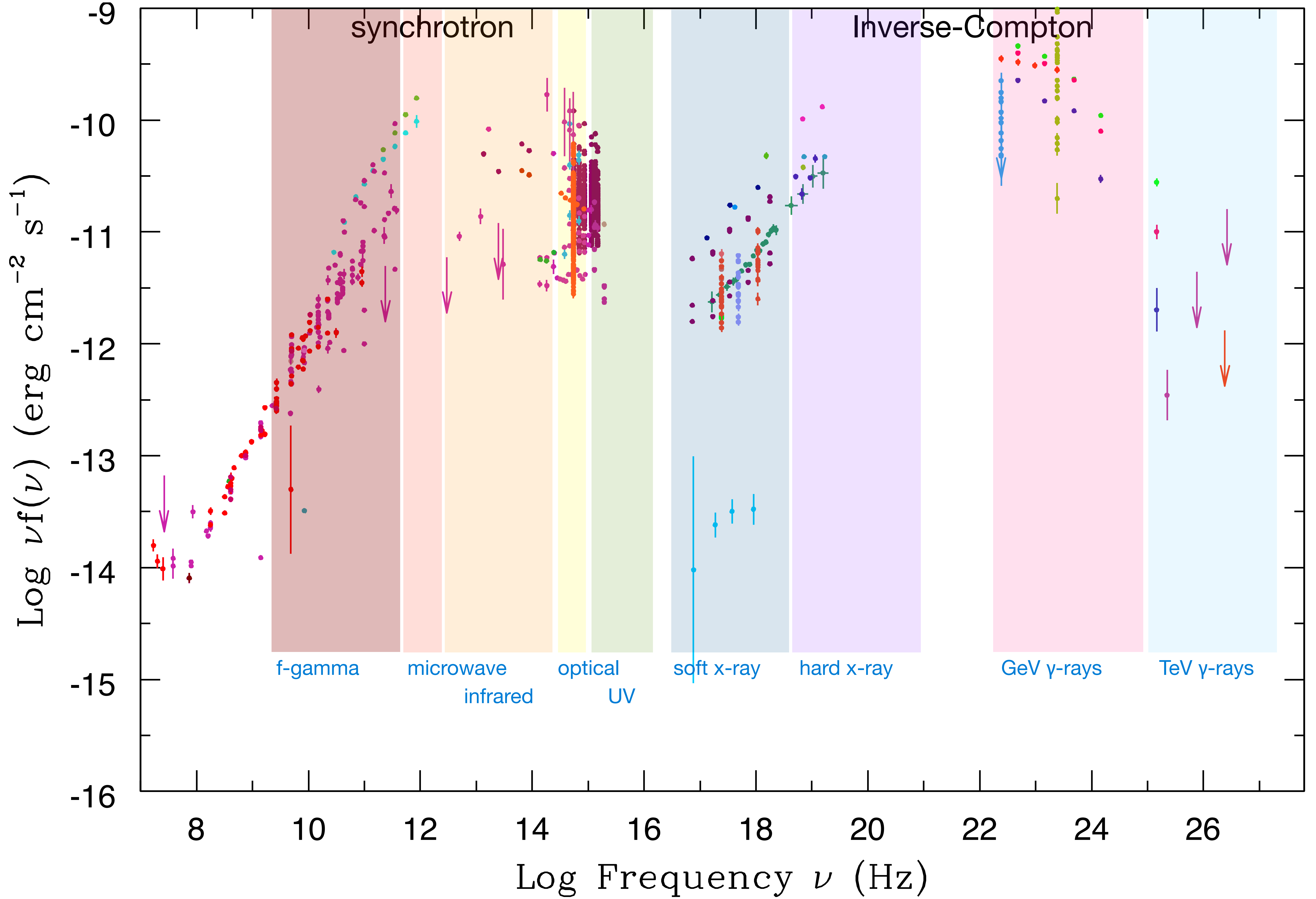



- OVRO monitoring *(Richards et al., 2011, ApJS, 194, 29)*:
  - 15 GHz
  - 1800 sources
  - cadence: ~2 days
- KVN *(Fuhrmann, Angelakis et al. A&A, accepted, 2016arXiv160802580F)*:
  - cadence: ~1 month
  - ~90 sources at 13 , 7 mm
- RoboPol (polarisation) *(Angelakis et al., 2016, MNRAS, 463, 3365)*:
  - 60 GL and 15 GQ sources
  - 1-3 days in R-band

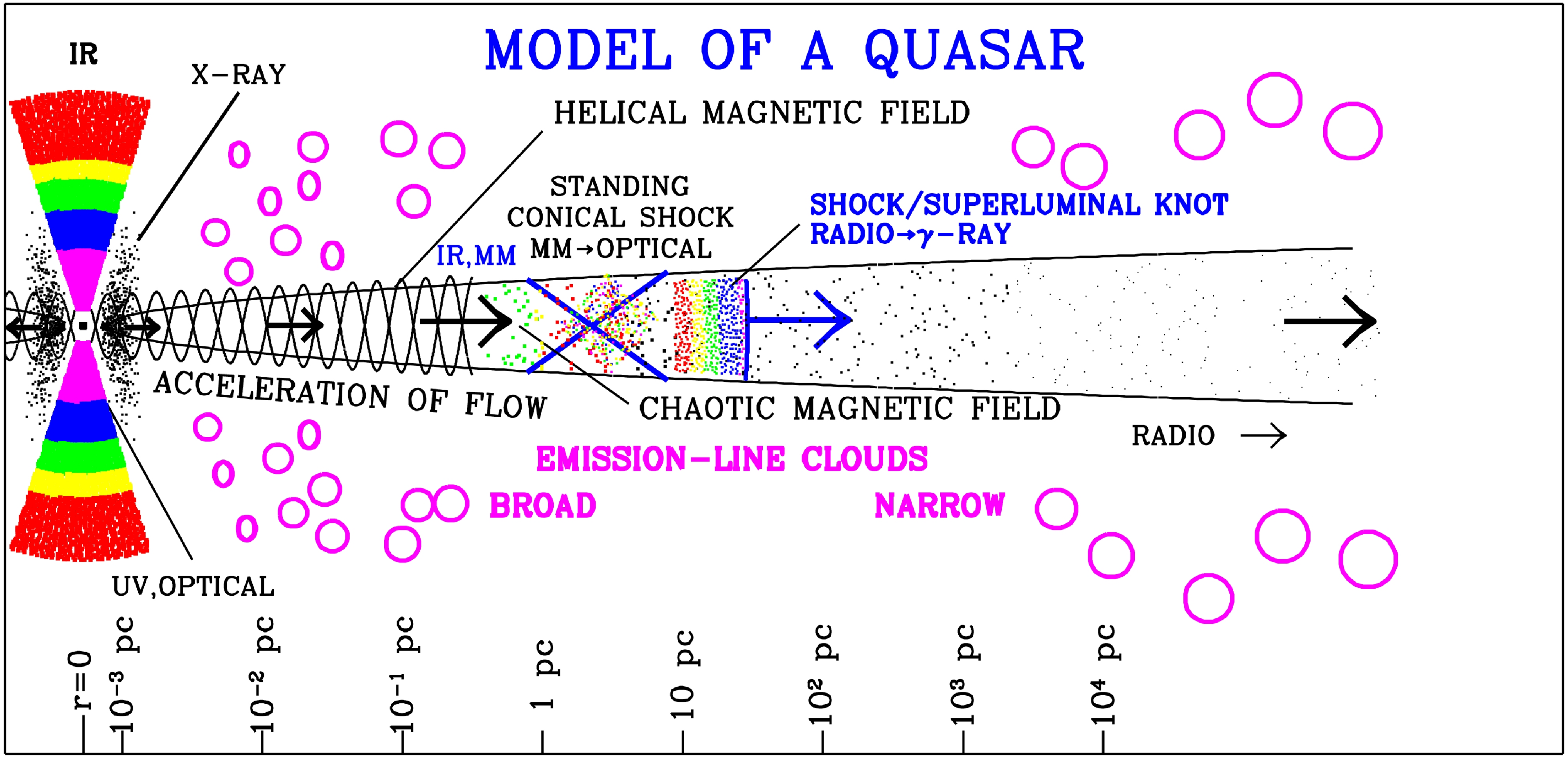


ASI SCIENCE DATA CENTER (ASDC)

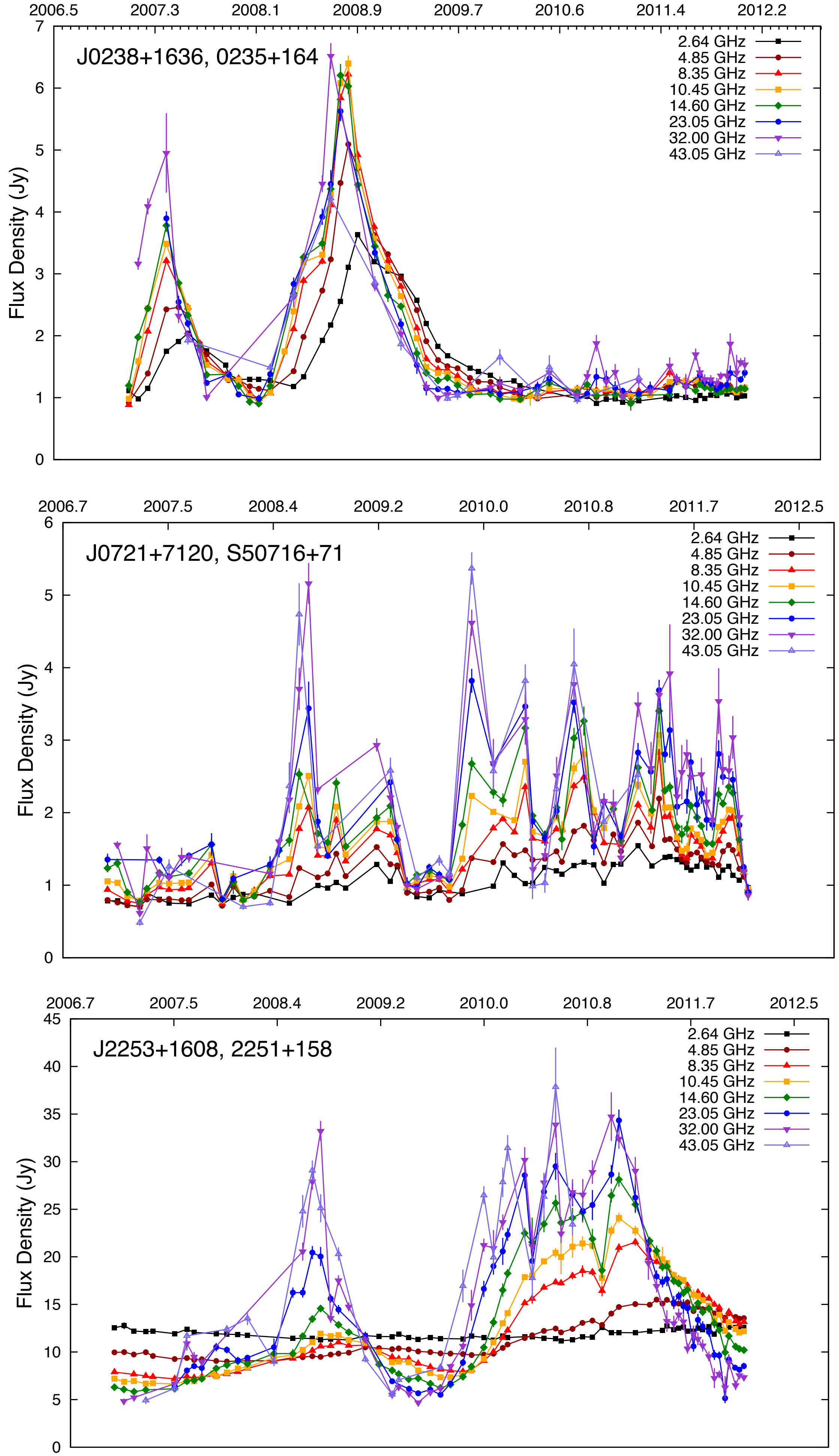

synchrotron
Inverse-Compton
f-gamma
Log νf(ν) (erg cm⁻² s⁻¹)
Log Frequency ν (Hz)
-9
-10
-11
-12
-13
-14
-15
-16
8
10
12
14
16
18
20
22
24
26
ASI SCIENCE DATA CENTER (ASDC)

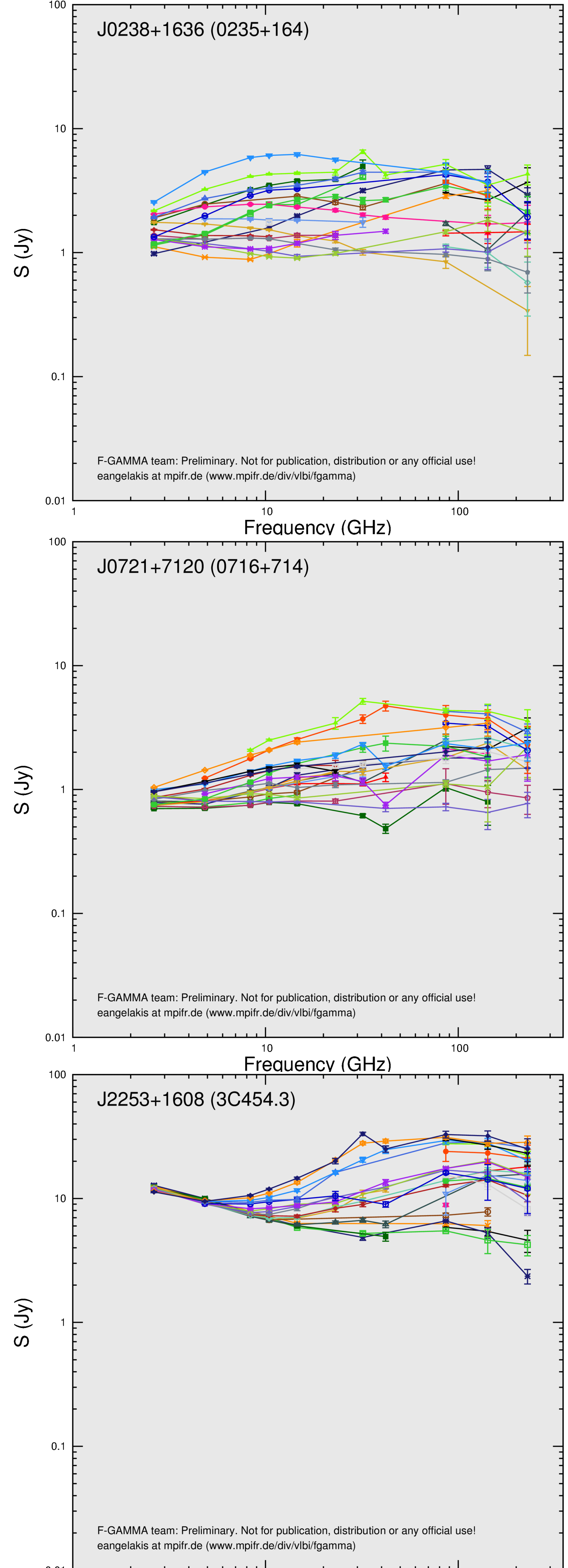


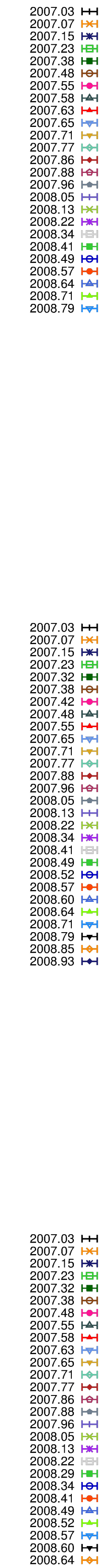
ASI SCIENCE DATA CENTER (ASDC)


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

A. Marscher





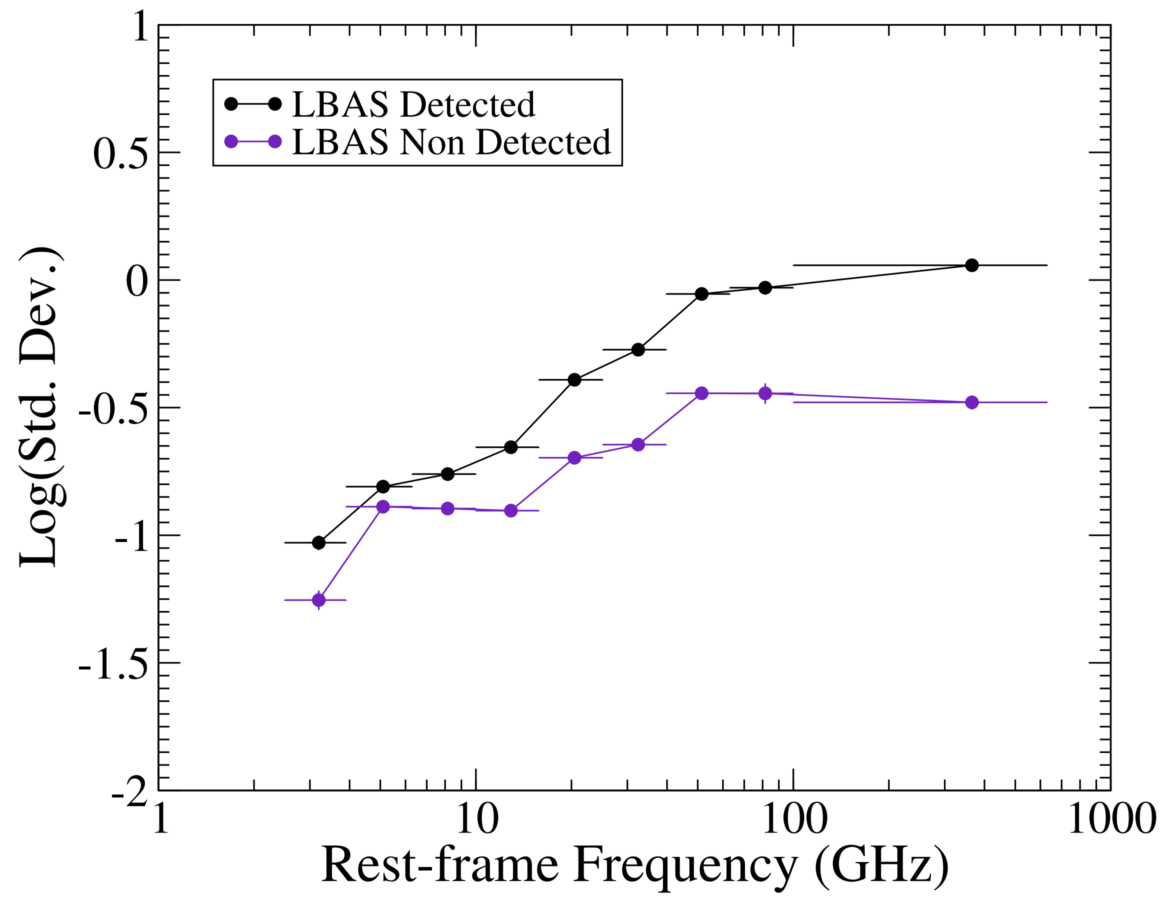


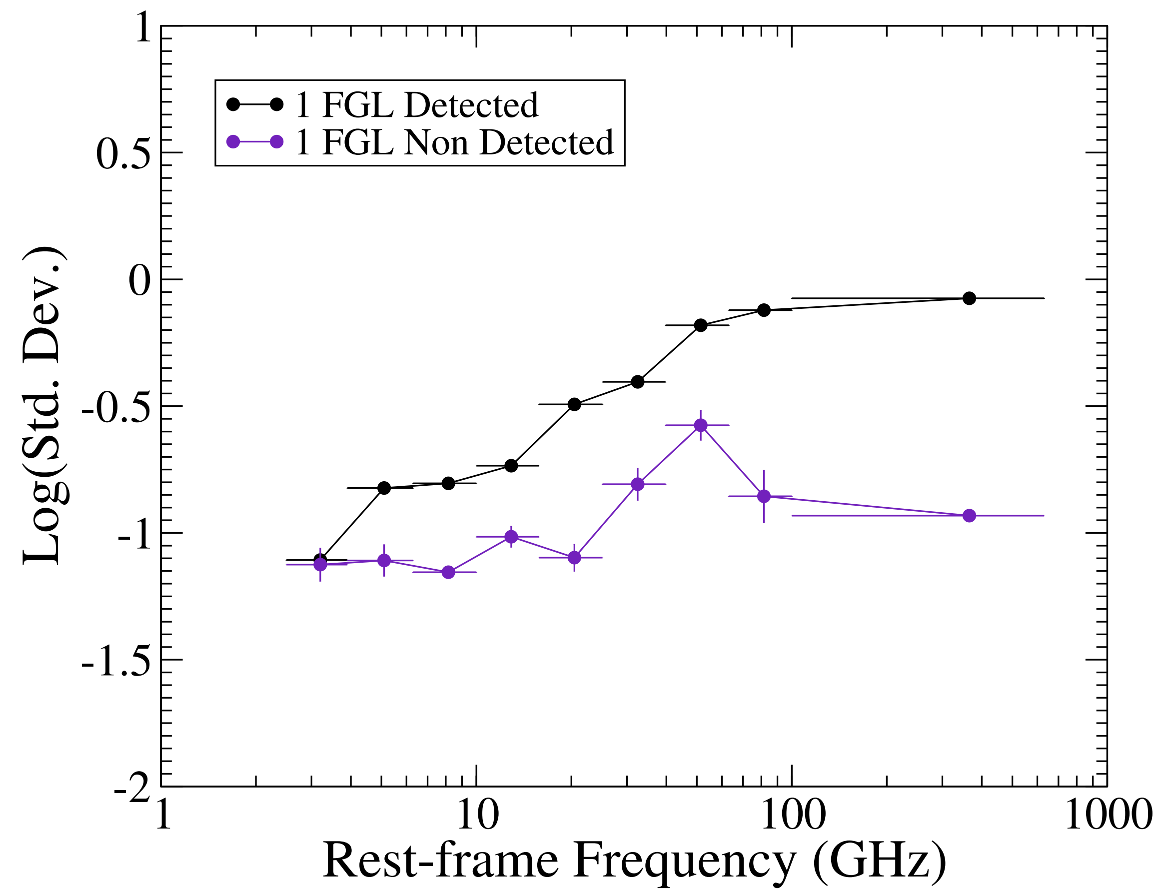
Angelakis et al. in prep.

radio - gamma-ray activity

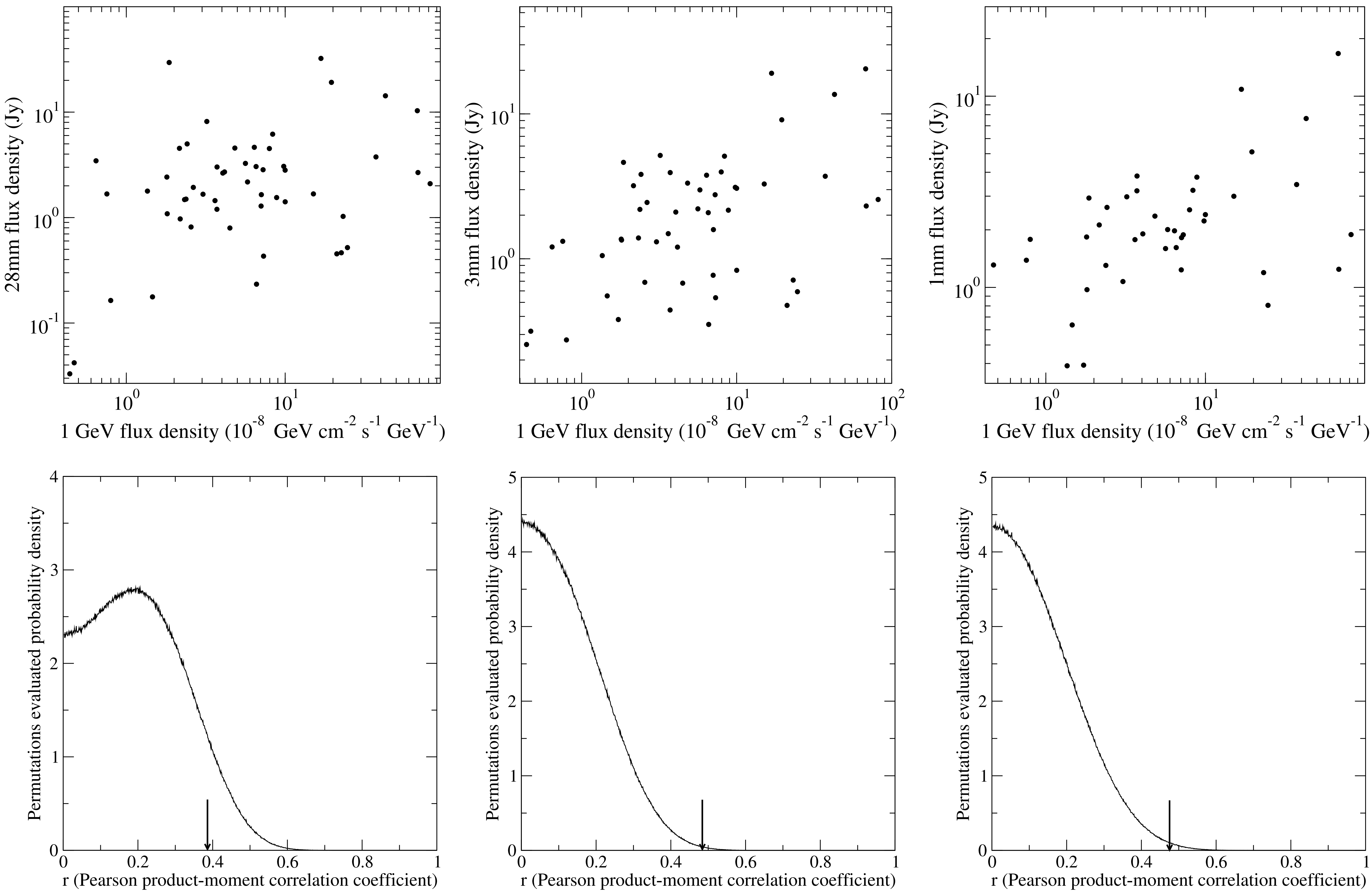
Radio variability amplitude and Fermi detectability:

- ➡ γ-ray detected sources display larger variability amplitudes
  - more than a factor of 3 at the highest frequencies
- ➡ clear increase in the separation towards higher frequencies





Fuhrmann et al., 2016, in press A&A, arXiv:1608.02580

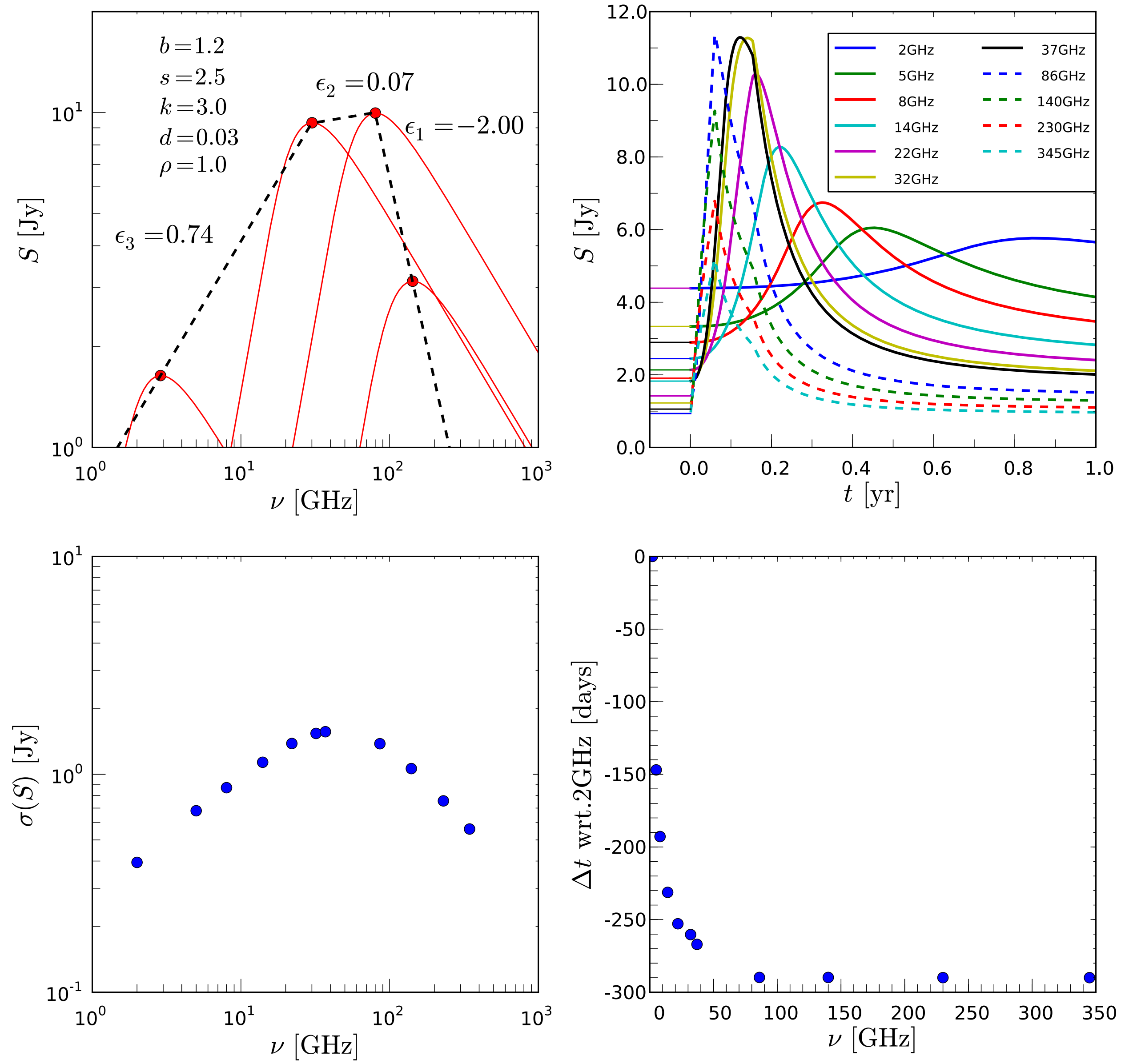


Fuhrmann et al., 2016, in press A&A, arXiv:1608.02580 testing the shock in jet: variability amplitude vs frequency and classification testing the predictions of the shock-in-jet (*Marscher & Gear 2985*)

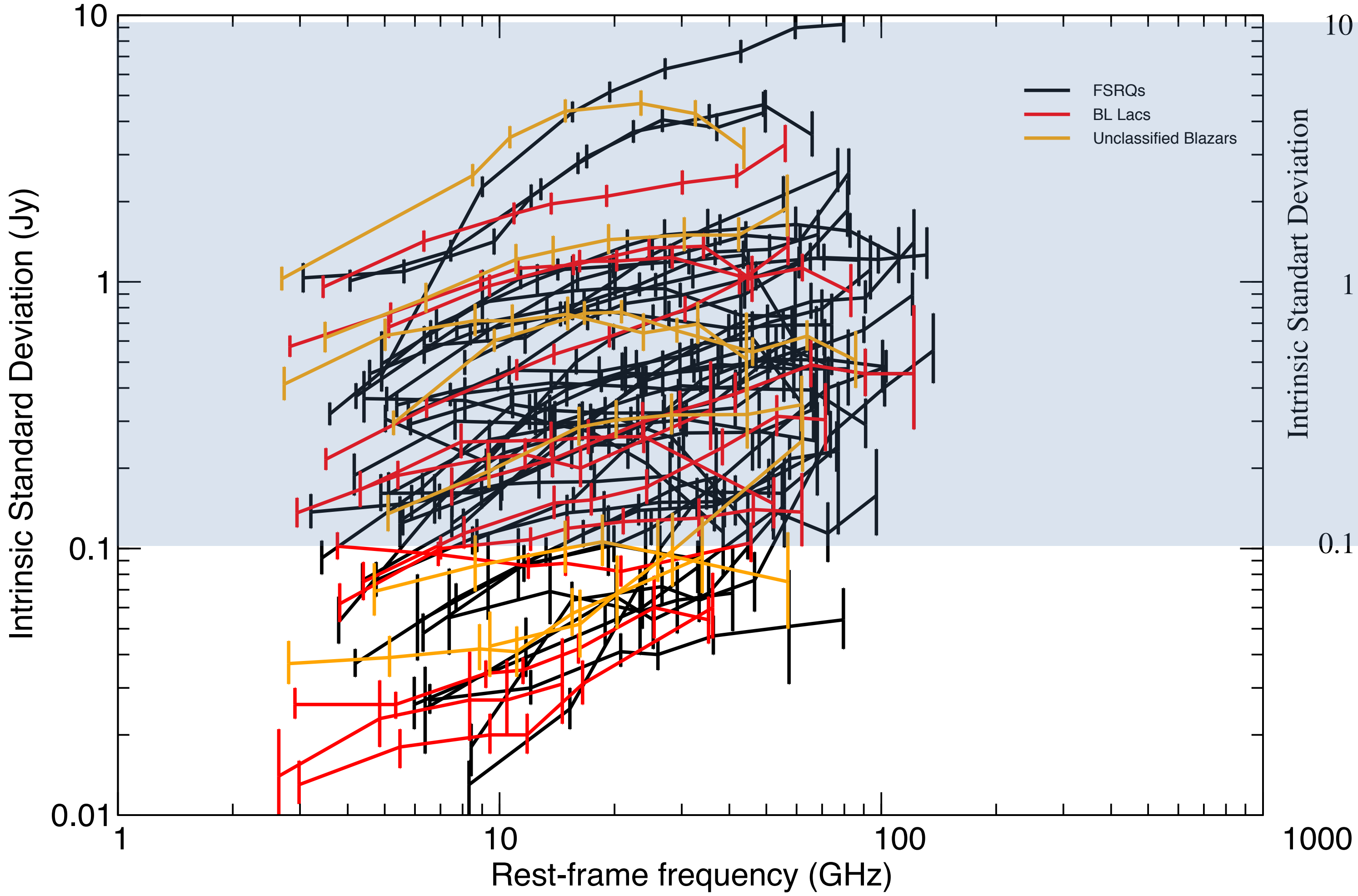
A Likelihood Analysis obtains the Intrinsic Modulation Index, we assume:

- normally distributed “true” flux densities (S_0 , σ_0)
- intrinsic modulation index $m=\sigma_0/S_0$
- For N measurements of the flux density (S_j, σ_j)
- the most likely value of m and the associated uncertainties obtain the marginalised likelihood as a function of only m:

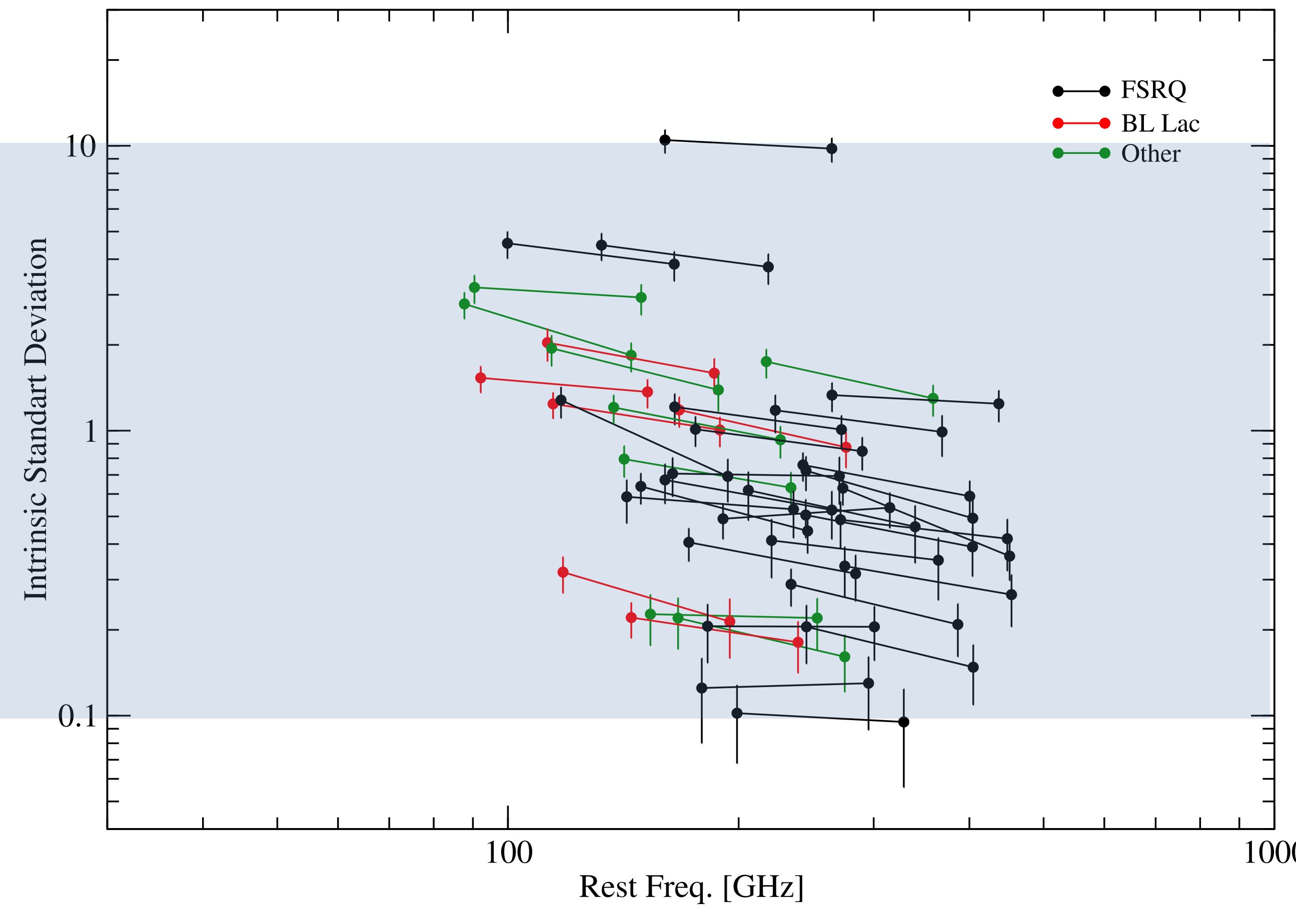
$$\mathcal{L}(\overline{m}) = \int_{\text{all } S_0} dS_0 S_0 \left\{ \left(\prod_{j=1}^{N} \frac{1}{\sqrt{2\pi\left(\overline{m}^2 S_0^2 + \sigma_j^2\right)}} \right) \times \exp\left[-\frac{1}{2} \sum_{j=1}^{N} \frac{(S_j - S_0)^2}{\sigma_j^2 + \overline{m}^2 S_0^2} \right] \right\}$$



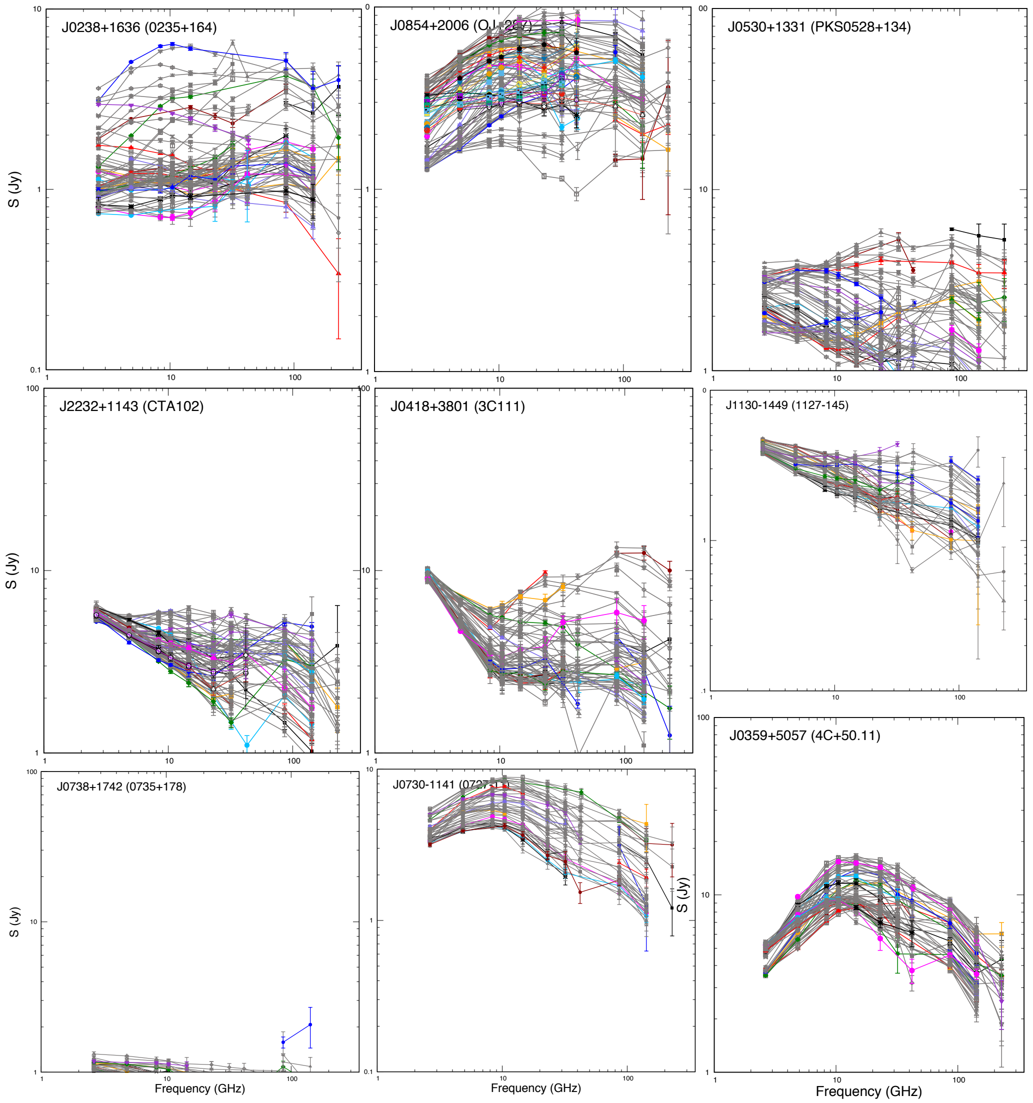
Richards et al. 2011ApJS..194...29R



Angelakis et al. in prep.

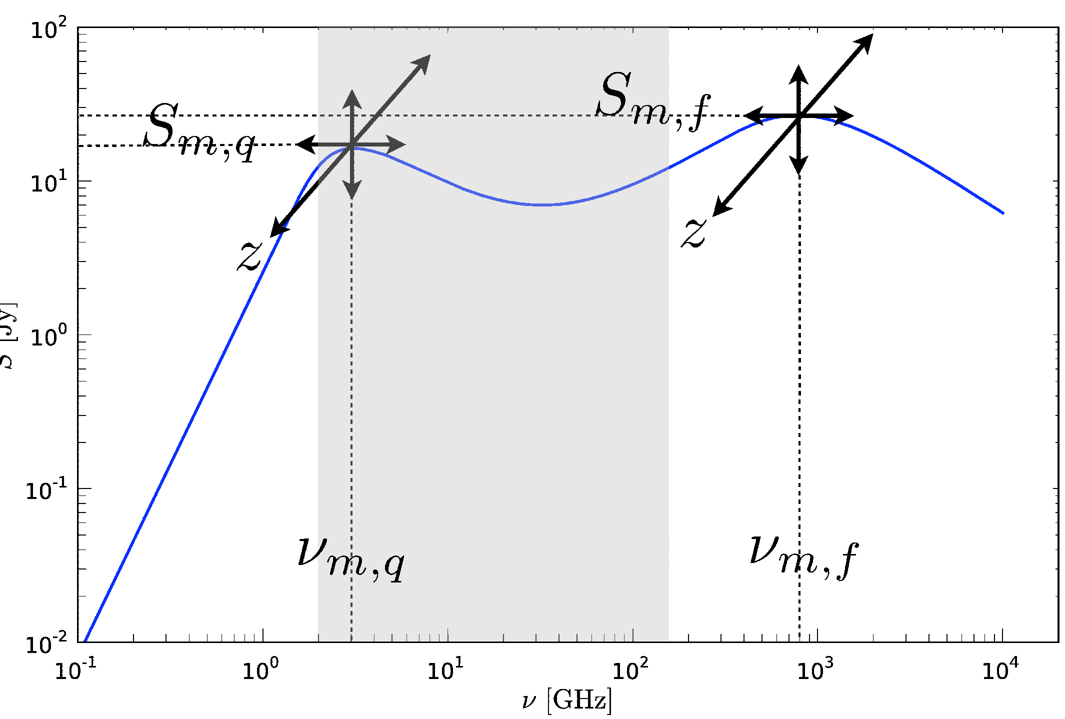


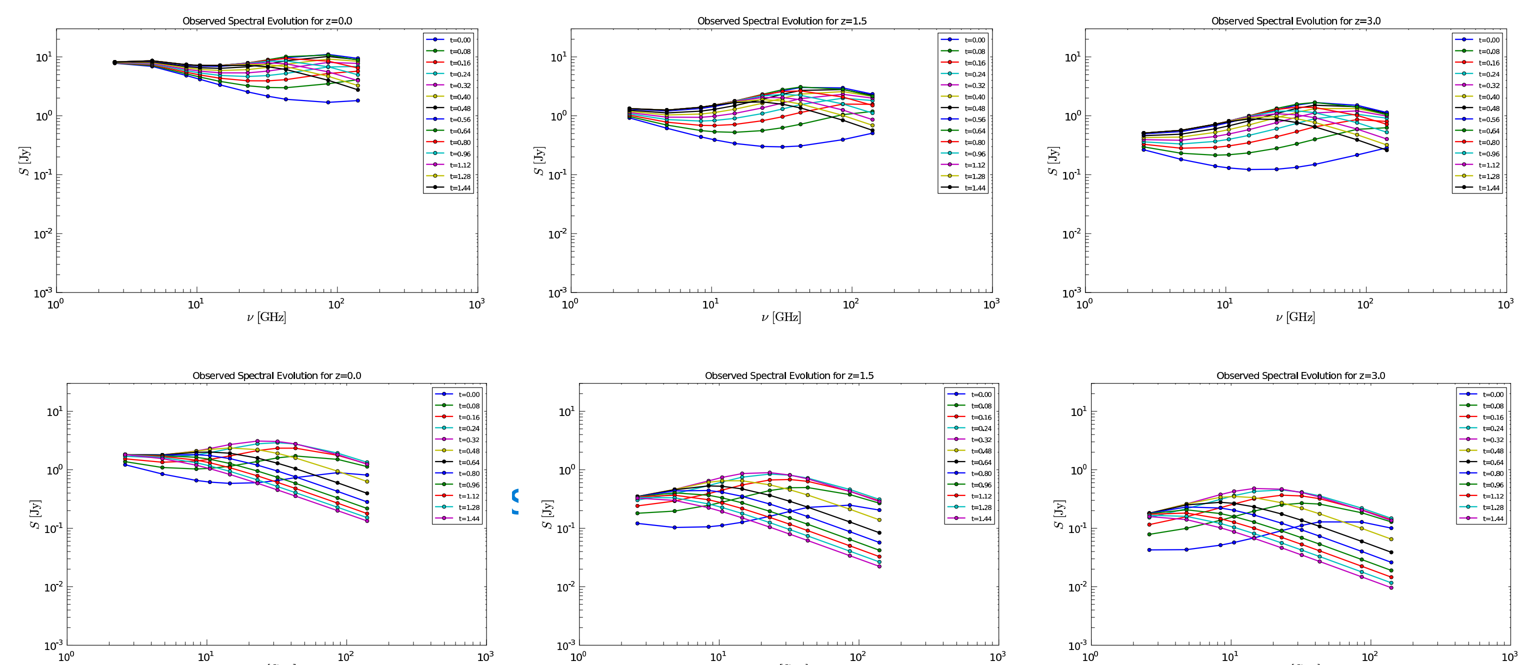
Nestoras et al. in prep.



the plurality seen in the radio SED variability patterns can be naturally reproduced by the mere combination of:

- a power-law quiescent spectrum with S ~ ν^{α} attributed to the optically thin emission of a large scale jet
- a convex synchrotron self-absorbed spectrum caused by recent outbursting superimposed on the quiescent part.



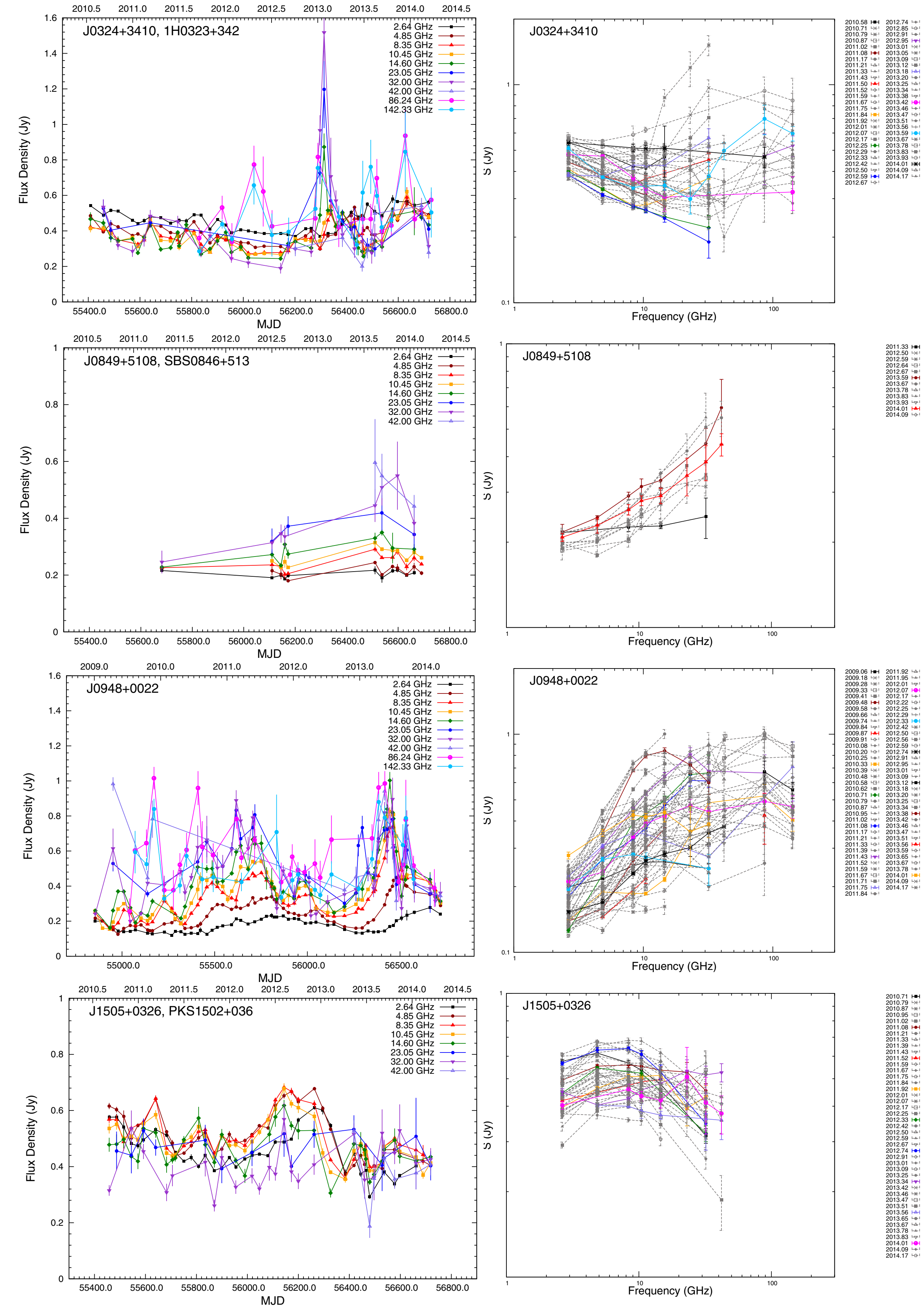


Angelakis et al. 2012, arXiv:1205.1961
Angelakis et al. in preparation

NLSY1s

the radio jet emission of Narrow line Seyfert 1 galaxies:

- ➡ light curves phenomenology typical of blazars (lower flux densities),
- ➡ “flare decomposition” method showed moderate brightness temperatures implying:
  - Doppler factors that do not exceed about 10
  - moderately relativistic jets
- ➡ jet power similar to the least energetic blazars (BL Lac objects),
- ➡ spectral evolution occurs at a faster pace, involving shorter timescales:
  - probably related to the smaller black-hole masses or higher accretion rates



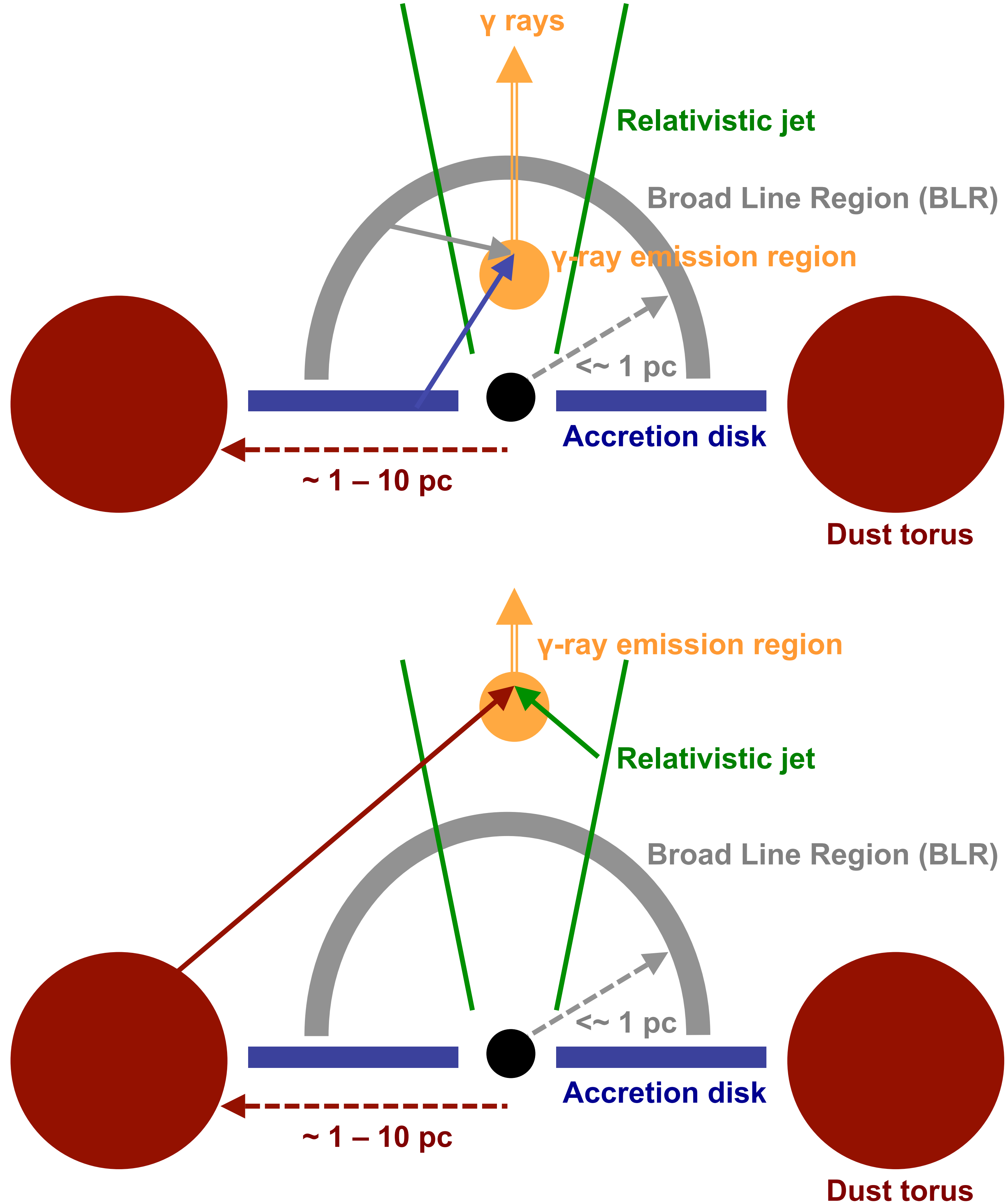
Angelakis et al. A&A 575, A55 (2015)

gamma-ray emission site

➡ where in the jet are the gamma rays produced?:

- close to SMBH in the Broad Line Region
- on down the jet at pc-scales

(e.g. Blandford & Levinson 1995, Valtaoja et al. 1992, Jorstad et al. 2001, Agudo et al. 2011, Leon-Tavares et al. 2011)



Fuhrmann et al MNRAS 441, 1899

Locating the γ-ray emission site
using multi-band variability

PKS 1502+106

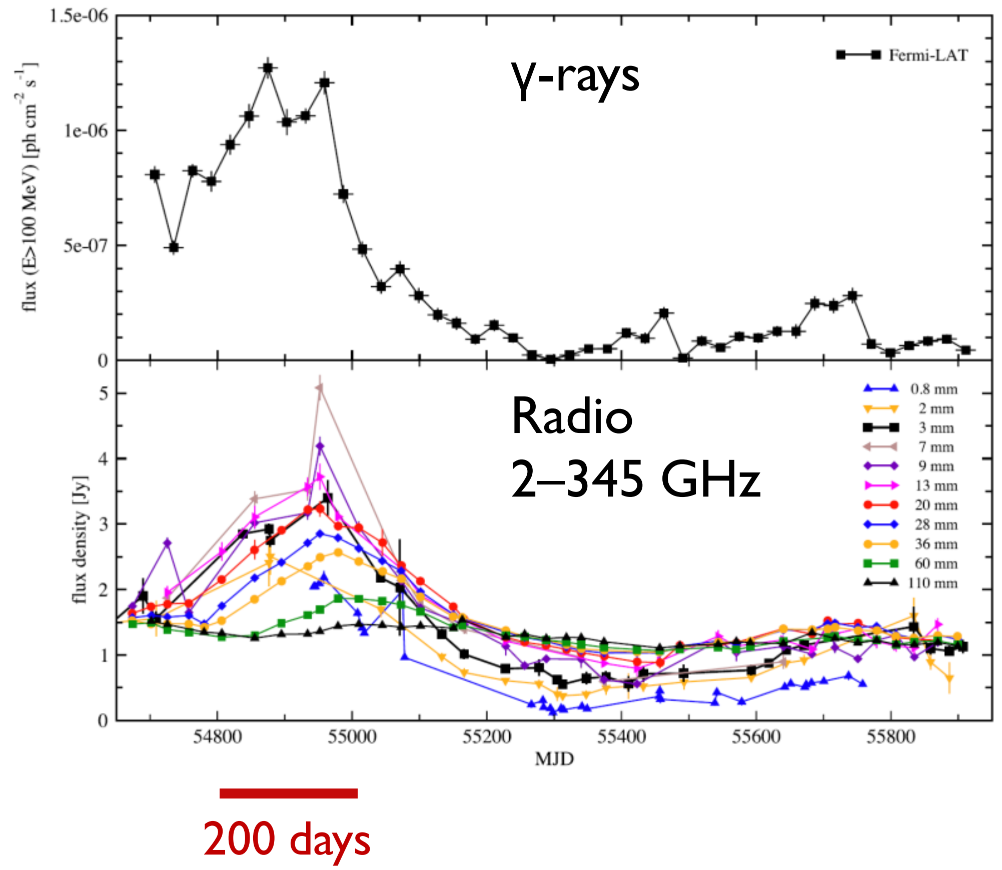
Delay origin: opacity of the synchrotron self-absorbed jet

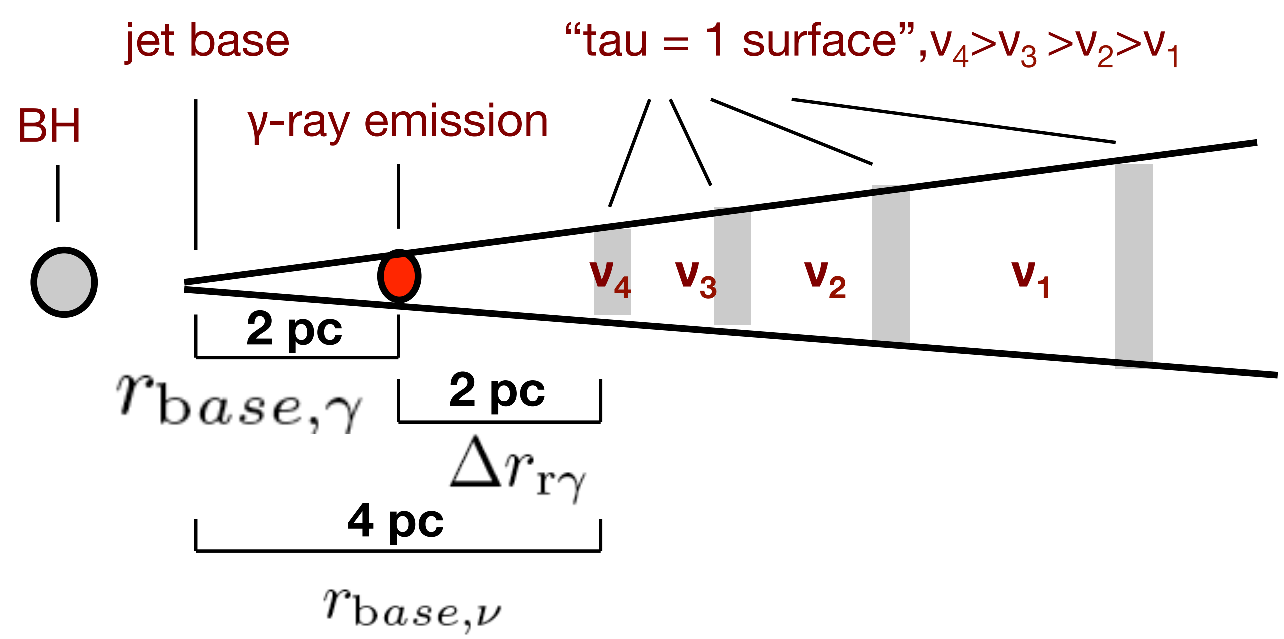
Relative timing of flares (DCCF)

Knot kinematics (mm-VLBI)

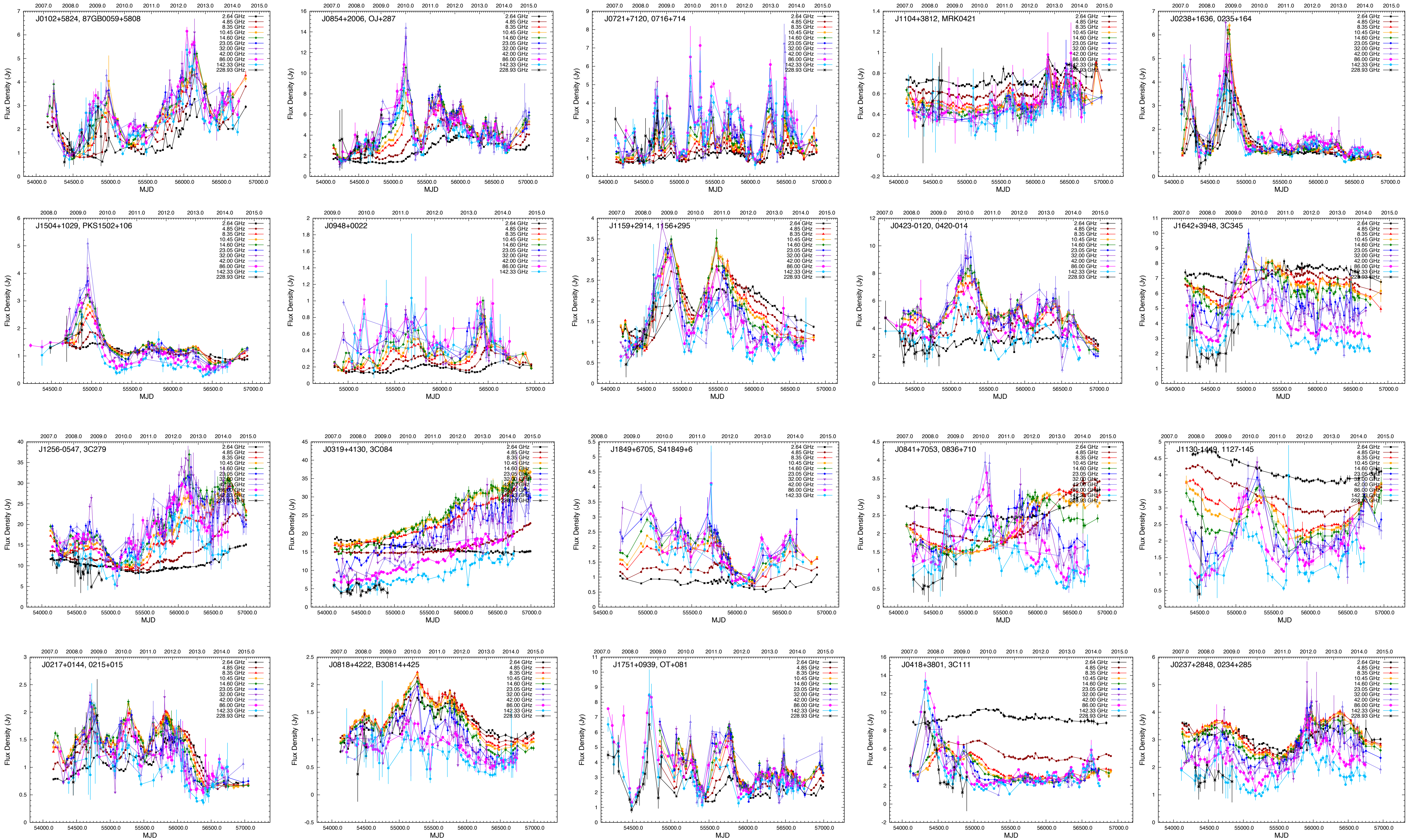
- precise core-shifts

- γ-ray emission site





Karamanavis et al 2016 A&A 590, 48
Fuhrmann et al 2014 MNRAS 441, 1899



data requests *eangelakis@mpifr.de*

www3.mpifr-bonn.mpg.de/div/vlbi/fgamma/