Constraining jet physics using total intensity and polarimetric radio observations

Talvikki Hovatta
Aalto University, Metsähovi Radio Observatory
Finland

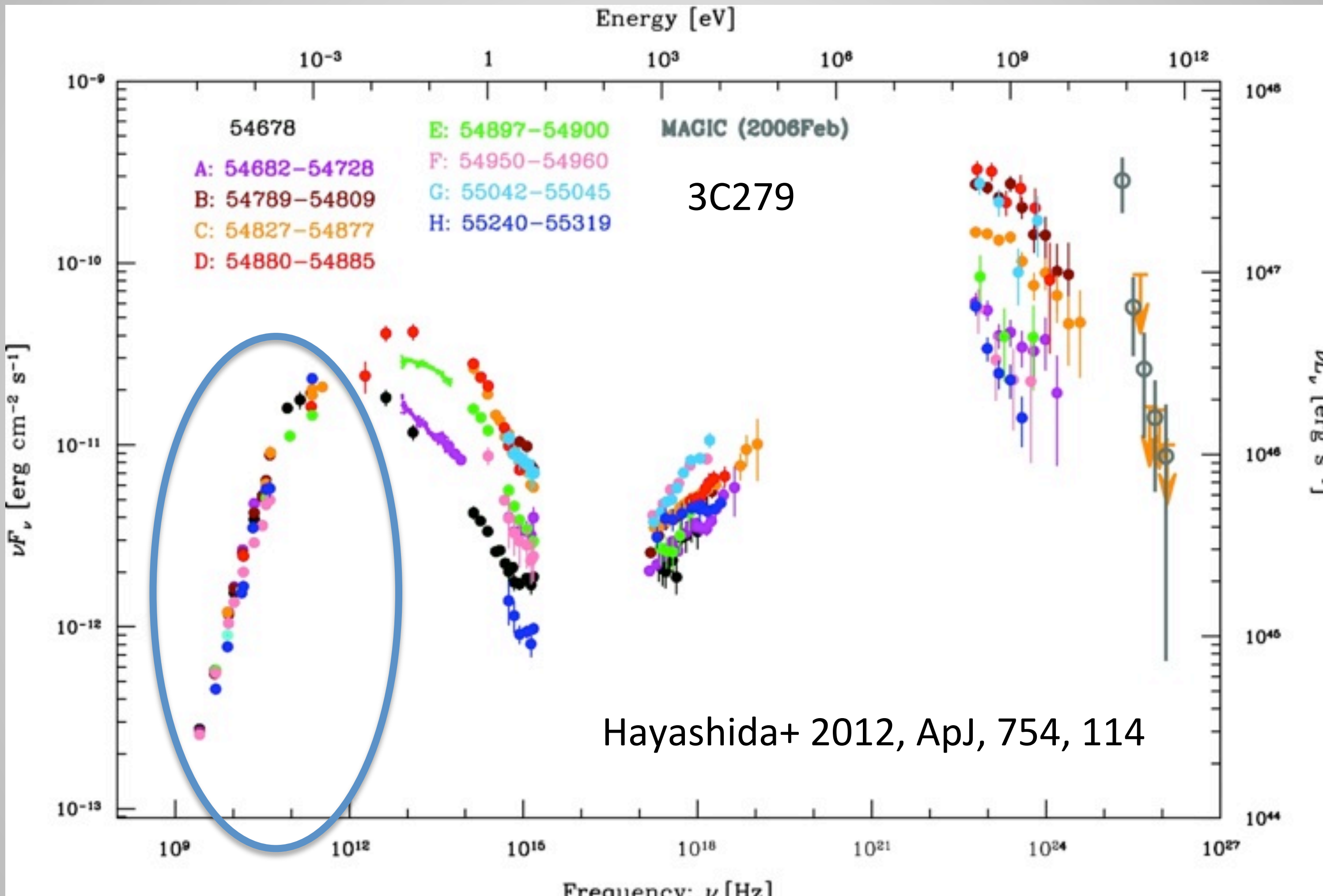
Many thanks to M. Aller, H. Aller, E. Angelakis, P. Hughes, I. Liodakis, I. Myserlis, V. Ramakrishnan et al. for material presented in this talk

Aalto-yliopisto

Motivation / Outline

- Lots of radio data available from various long-term (decades!) monitoring programs
- How can single-dish radio observations be used to constrain jet physics?
  - E.g., Doppler beaming, flow parameters, viewing angle, magnetic field order, shock structure…
- Multifrequency and polarization data are the key

Spectral energy distribution



Blazar monitoring programs

Major Blazar Monitoring Programs

Monitoring Program / Sample	Frequencies/Bands	Homepage
MOJAVE-1 (flux density-limited 1.5 Jy sample)	15 GHz VLBI	http://www.physics.purdue.edu/MOJAVE/MOJAVEtable.html
MOJAVE-4 (current monitoring sample)	15 GHz VLBI	http://www.physics.purdue.edu/MOJAVE/MOJAVEIVtable.html
TANAMI	8.4, 22 GHz VLBI	http://pulsar.sternwarte.uni-erlangen.de/tanami/
BOSTON U.	43 GHz VLBI, optical	http://www.bu.edu/blazars/VLBAproject.html
F-GAMMA	2 - 200 GHz, IR, optical	http://www.mpifr-bonn.mpg.de/div/vlbi/fgamma/fgamma.html
OVRO	15 GHz	http://www.astro.caltech.edu/ovroblazars/
UMRAO	4.8, 8, 15 GHz	http://www.astro.lsa.umich.edu/obs/radiotel/umrao.php
METSAHOVI	22, 37 GHz	http://www.metsahovi.fi/quasar/
MEDICINA/NOTO	5, 8, 22, 43 GHz	http://www.mpifr-bonn.mpg.de/staff/ubach/bmonit/
SIMEIZ	22, 37 GHz	
MARMOT	86 GHz, optical	http://www.astro.caltech.edu/marmot
SMA Calibrator List	86, 300, 350 GHz	http://sma1.sma.hawaii.edu/callist/callist.html
TUORLA	Optical	http://users.utu.fi/kani/1m/index.html
STEWARD	Optical	http://james.as.arizona.edu/~psmith/Fermi/
MAPCAT	Optical	http://w3.iaa.es/~iagudo/research/MAPCAT/
PERUGIA	Optical	http://astro.fisica.unipg.it/PGblazar/tabella2000.htm
SMARTS	Optical	http://www.astro.yale.edu/smarts/glast/
ST. PETERSBURG	Optical	http://www.astro.spbu.ru/staff/vlar/OPTlist.html
GASP	Optical	http://www.oato.inaf.it/blazars/webt/
CATALINA SKY SURVEY	Optical	http://nesssi.cacr.caltech.edu/catalina/Blazars/Blazar.html
KAIT	Optical	http://128.32.15.133/kait/agn/
ROBOPOL	Optical	http://robopol.org/
SWIFT XRT	X-ray	http://www.swift.psu.edu/monitoring/
1LAC (1st Fermi AGN Catalog)	>100 MeV	http://www.asdc.asi.it/fermi1lac/
2LAC (2nd Fermi AGN Catalog)	>100 MeV	http://www.asdc.asi.it/fermi2lac/
TeVCAT	TeV	http://tevcat.uchicago.edu/

http://www.physics.purdue.edu/MOJAVE/blazarprogramlist.html
List maintained by Matt Lister

Various observatories

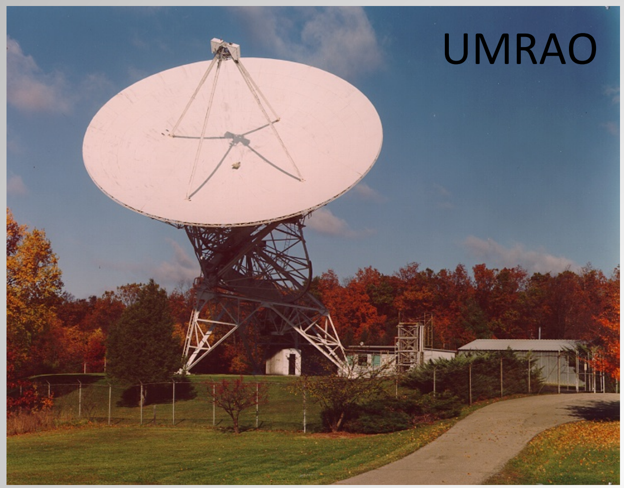
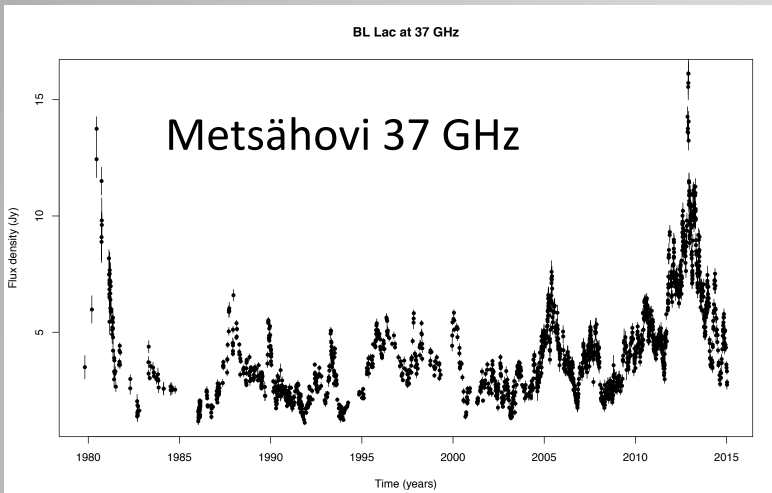
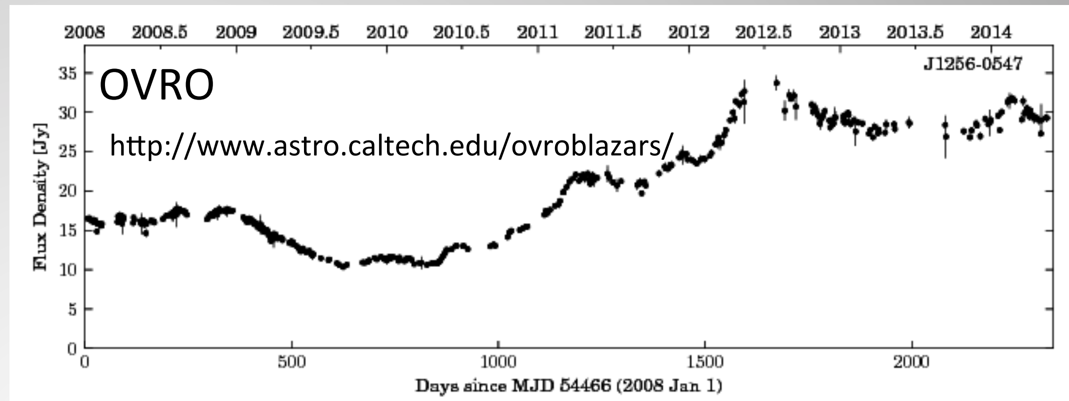
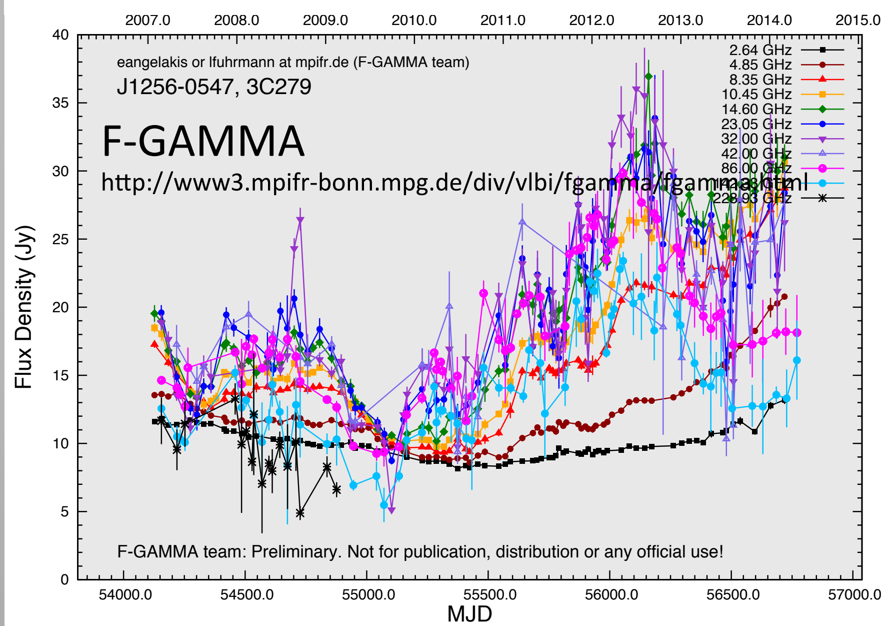


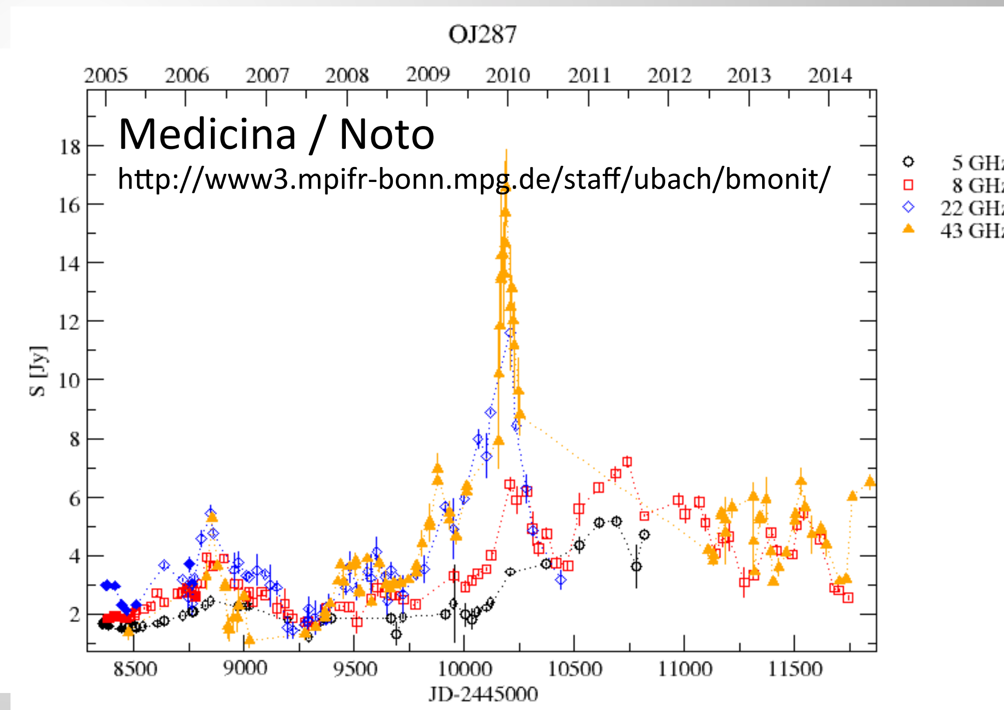
Image credits:
TH, UMRAO, Metsähovi

Multifrequency radio light curves

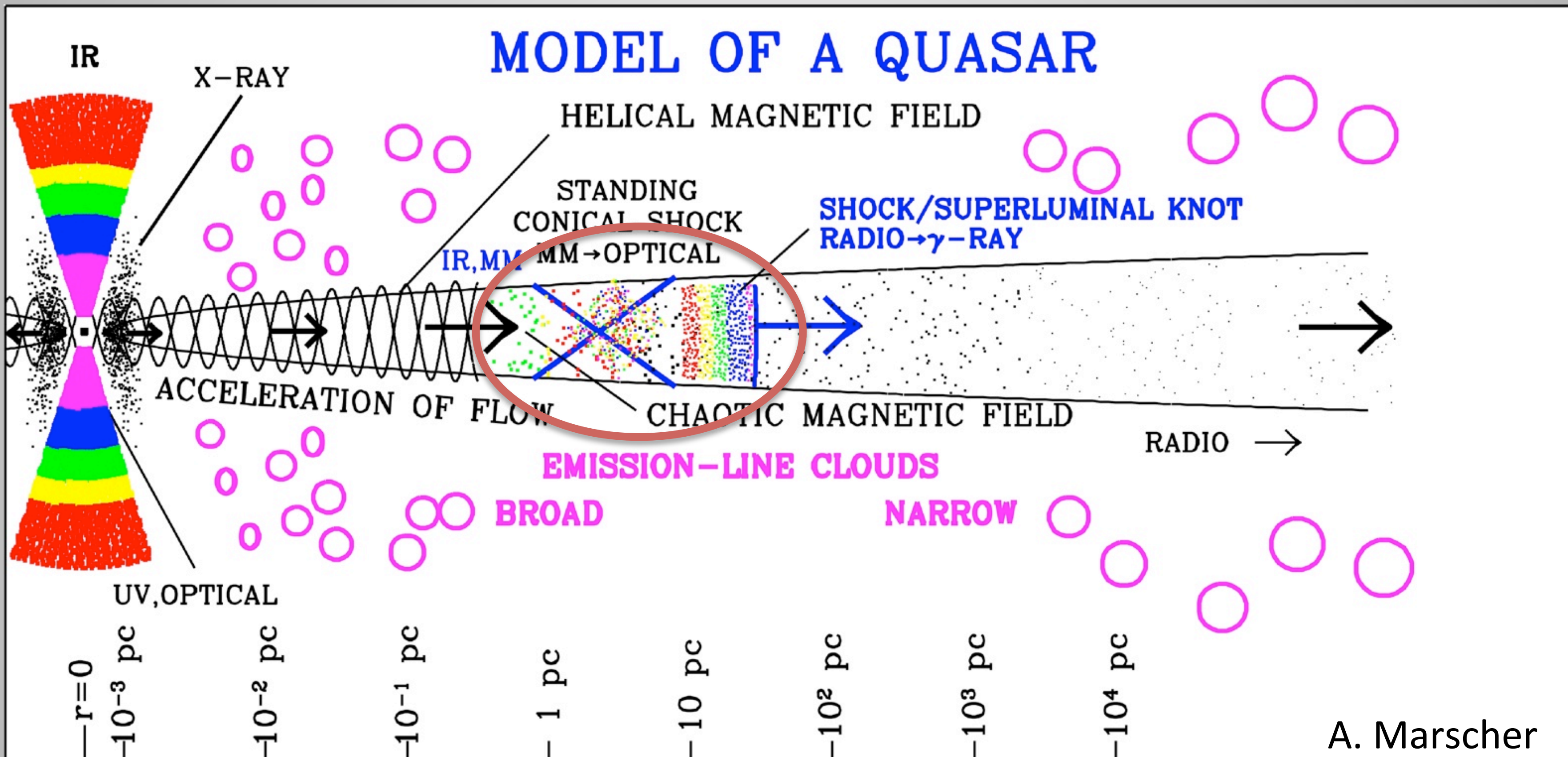








Variability dominated by the radio core

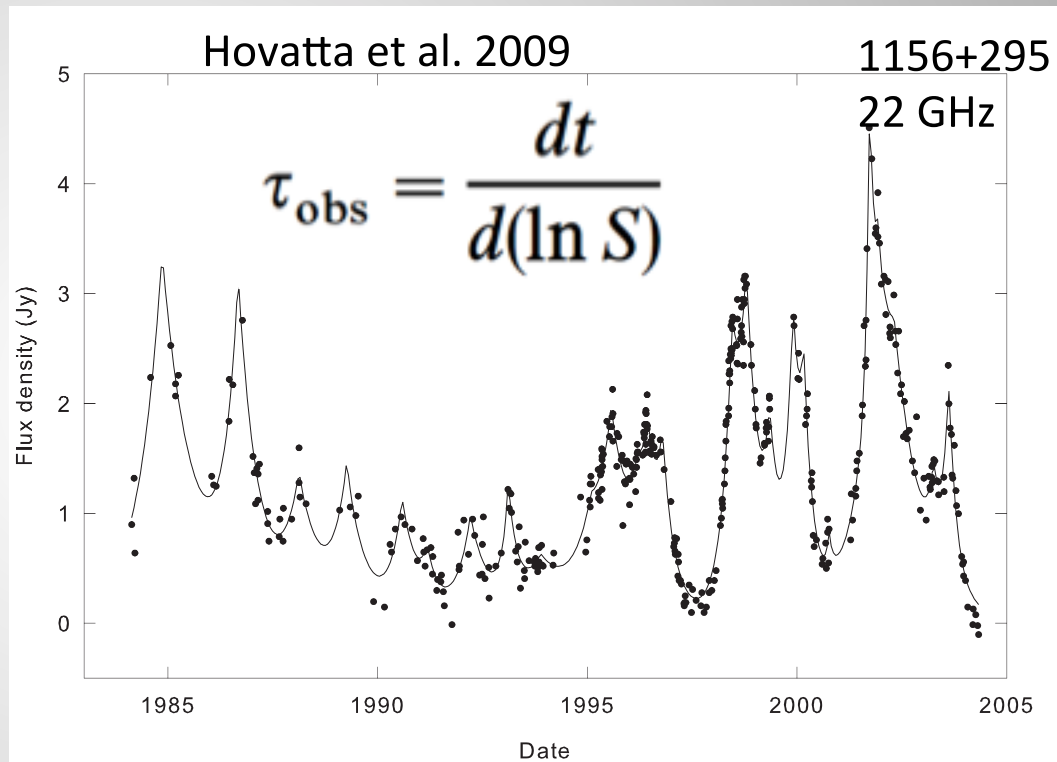


talvikki.hovatta@aalto.fi

Doppler boosting factors

Assumptions:

- Logarithmic variability timescale stays constant during flares (Teräsranta & Valtaoja 1994)
- Flare rise time = size of the emission region (Lähteenmäki et al. 1999)
- Emission region is in equipartition $T_{int} = T_{eq} = 10^{11}$K (Readhead 1994)



$$\tau_{\rm obs} = \frac{dt}{d(\ln S)}$$

$$T_{\rm b,var} = 1.548 \times 10^{-32} \frac{\Delta S_{\rm max} d_{\rm L}^2}{\nu^2 \tau^2 (1+z)}$$

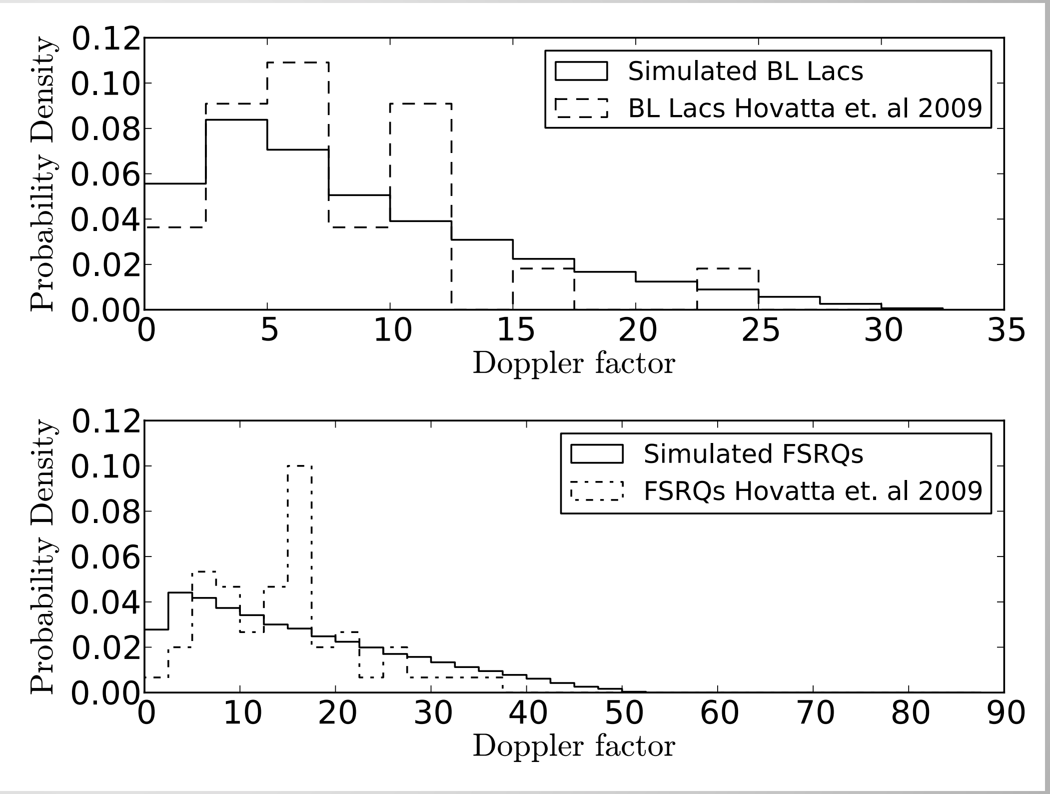
$$D_{\rm var} = \left[\frac{T_{\rm b,var}}{T_{\rm b,int}} \right]^{1/3}$$

Different assumptions

Assumptions:

- Jet Lorentz factors follow a power law distribution (Lister & Marscher 1997)
- Pure luminosity evolution function (Padovani & Urry 1992)
- Simulations used to match apparent speed and redshift distributions
- Comparison of various Doppler factor estimates

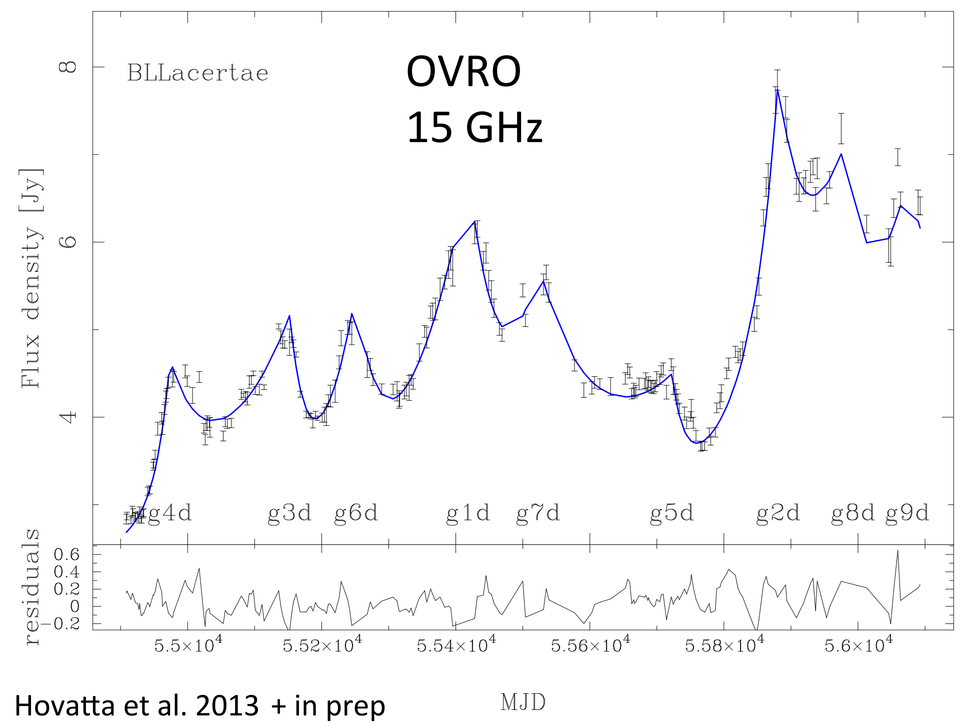
Liodakis & Pavlidou, 2015



See Poster by I. Liodakis!

Obtaining Doppler factors for more sources

- OVRO 40-m program is observing ~1800 sources at 15 GHz since 2008
- Twice / week sampling
- All Fermi sources from 1FGL and 2FGL
- MCMC approach to obtain uncertainties for D_{var}
- MOJAVE 15 GHz observations to constrain T_{int}



Hovatta et al. 2013 + in prep

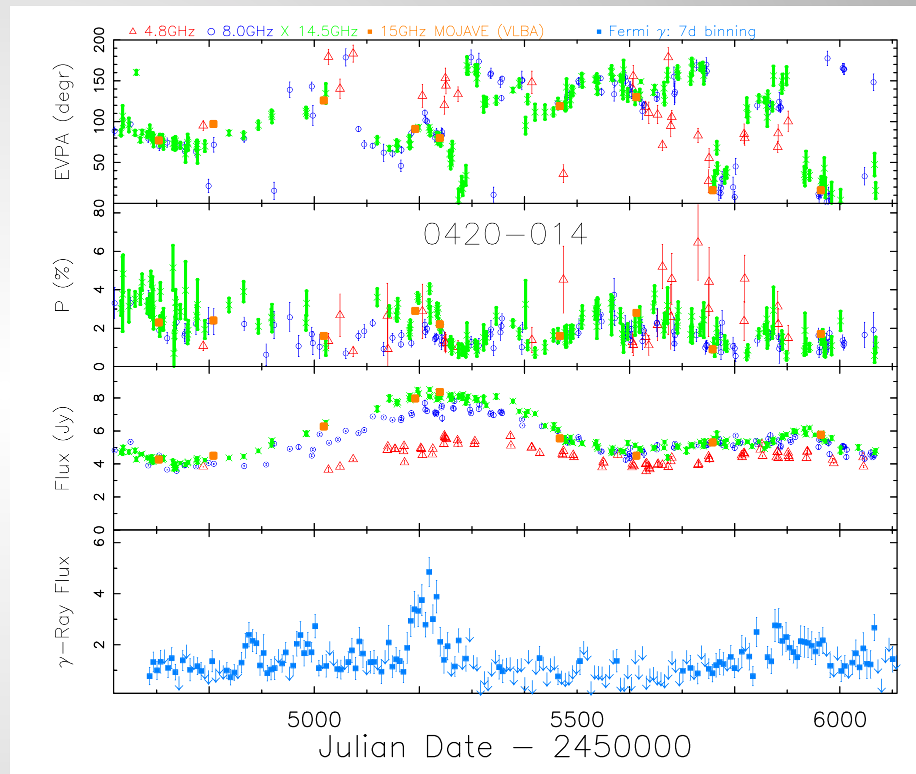
Physical modeling

- Radiative transfer modeling (Hughes, Aller & Aller, 2015)
- 3 frequencies (4.8, 8, 14.5 GHz)
- Includes polarization!

Parameter	Constraint
Low energy cutoff (γ_i)	EVPA spectral behavior
Axial B field (**B**z)	EVPA and P%
Bulk Lorentz Factor (γ_f)	P%
Viewing Angle (θ)	P%
Shock obliquity (η)	ΔEVPA
Shock sense (F or R)	Doppler Factor and β_{app}
Shock length (l)	duration of flare in S
Shock Compression (κ)	ΔS and P%
Shock onset (t_0)	start of flare in S or P

See Poster by M. Aller!

Aller et al. 2014

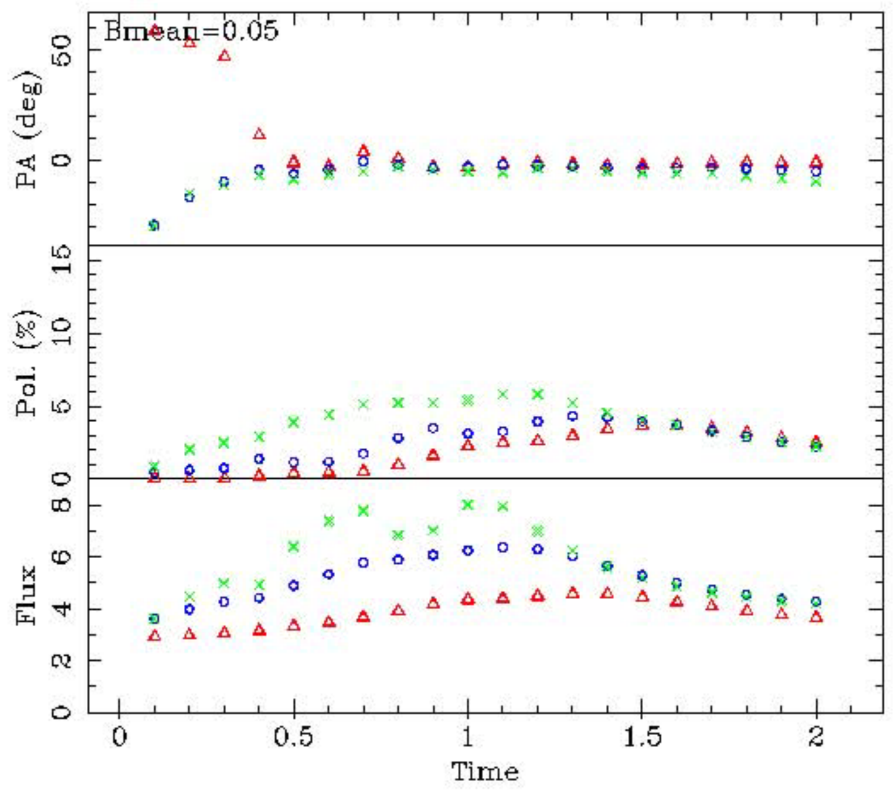


talvikki.hovatta@aalto.fi

Constraining parameters (1)

Different amount of axial magnetic field

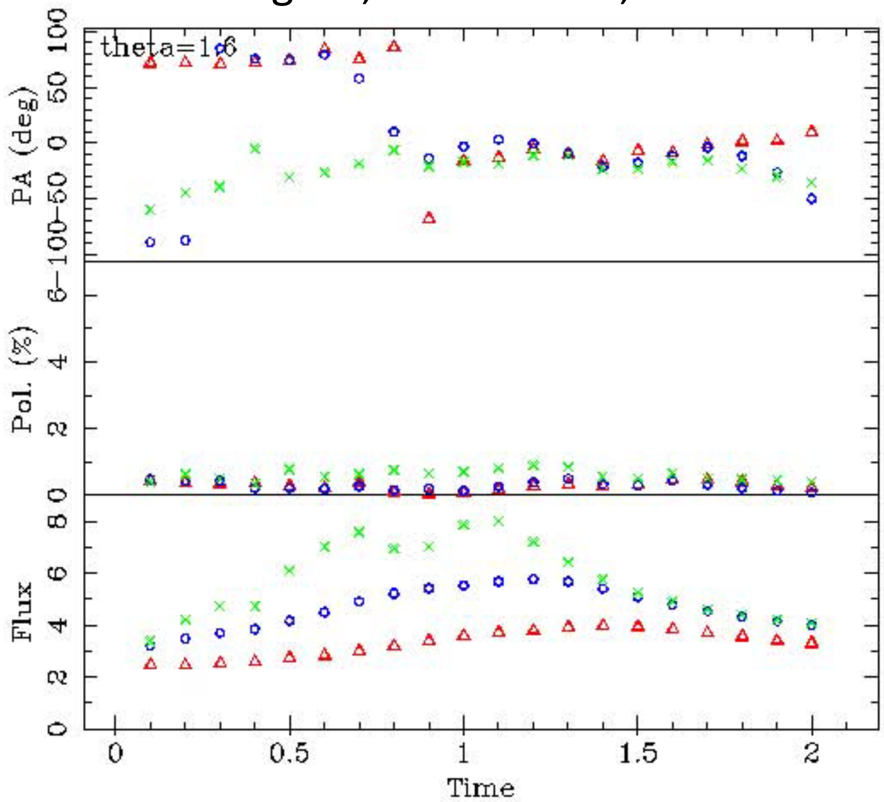
Hughes, Aller & Aller, 2015



Constraining parameters (2)

Change in the viewing angle

Hughes, Aller & Aller, 2015



Best-fit model

THE ASTROPHYSICAL JOURNAL, 791:53 (14pp), 2014 August 10 ALLER ET AL.

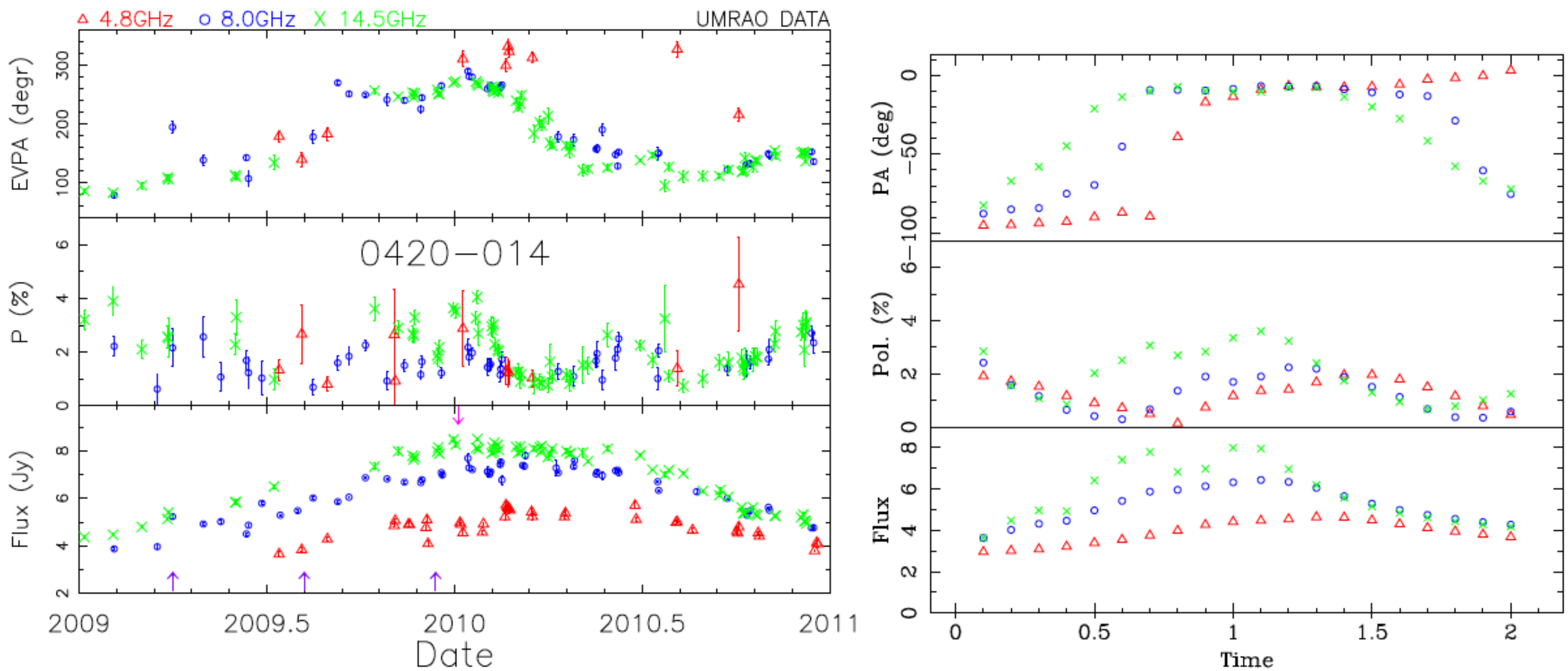


Figure 4. Comparison of the data and the simulation for the 2009–2010 event in 0420−014. Left: daily averages of the total flux density, fractional linear polarization, and EVPA. Upward arrows along the time axis mark the shock start times. A downward arrow at the top of the lower panel marks the time of peak γ-ray photon flux. Right: simulated light curves. The computations have been carried out at three harmonically related frequencies separated by $\sqrt{3}$ that correspond to the UMRAO observing frequencies of 14.5, 8.0, and 4.8 GHz; the symbols follow the convention used for plotting the UMRAO data.

See Poster by M. Aller!

Table 2
Parameters for Individual Shocks: 0420−014

Shock	1	2	3
Start (t_0)	2009.25	2009.6	2009.95
Length (l)	10.0	15.0	10.0
Compression (κ)	0.8	0.66	0.65
Location of S_{max}	0.22	0.64	1.06

Parameter	0420−014
Spectral index (α)	0.25
Fiducial Lorentz factor (γ_c)	1000
Cutoff Lorentz factor (γ_i)	50
Bulk Lorentz factor	5.0
Number of shocks	3
Shock obliquity	90°
Shock sense	F
Viewing angle (θ_{obs})	4°
β_{app}	11c
Axial magnetic field*	16%

Wider spectral coverage

- F-GAMMA
  - Almost 90 Fermi sources
  - 2.64 – 142 GHz at 10 bands
  - Cadence 1/1.3 months
- RadioPol
  - Linear polarization at **2.64, 4.85, 8.35, 10.45** and 14.6 GHz
  - Circular polarization at 2.64, **4.85**, 8.35, 10.45, 14.6, 23.05 GHz

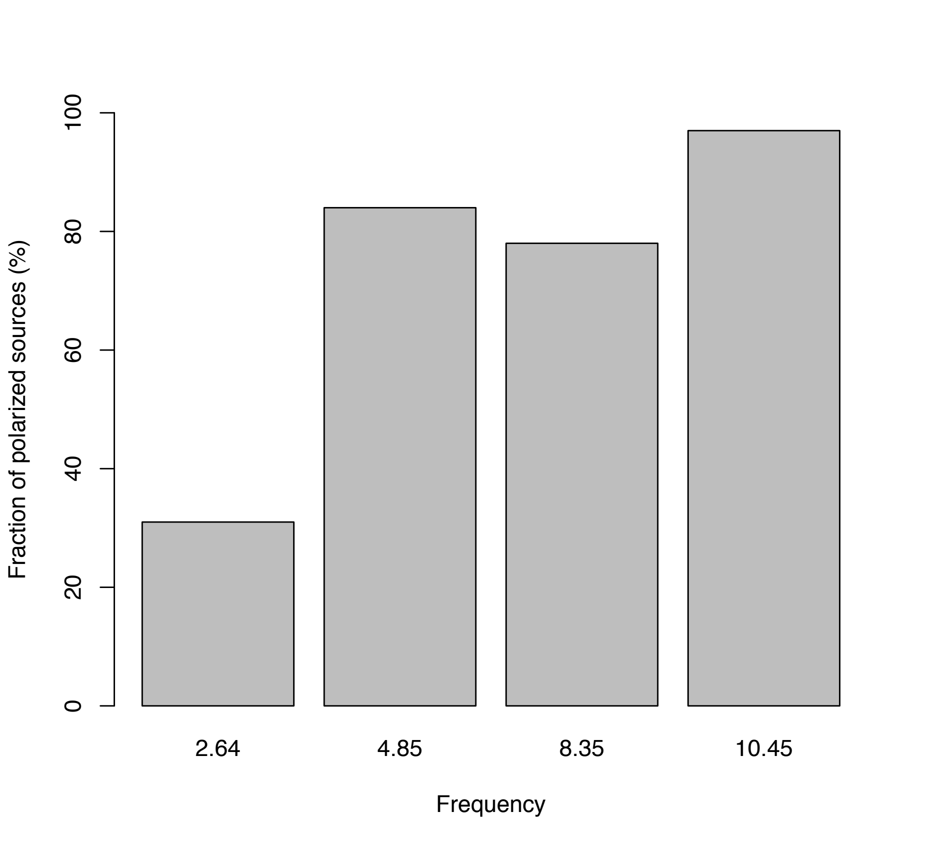
Angelakis et al. 2010, astro-ph.CO/1006.5610

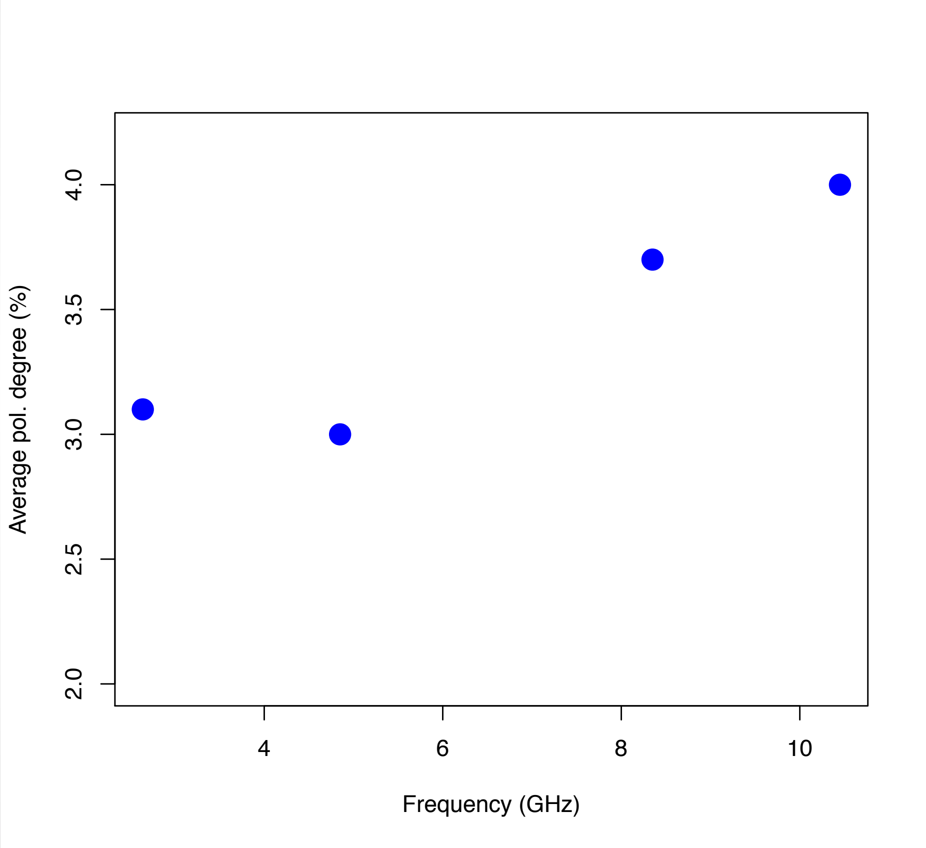
Fuhrmann et al. 2007, 2007, AIP Conf. Series, Vol. 921, 249–251

Myserlis et al 2014, arXiv1401.2072M

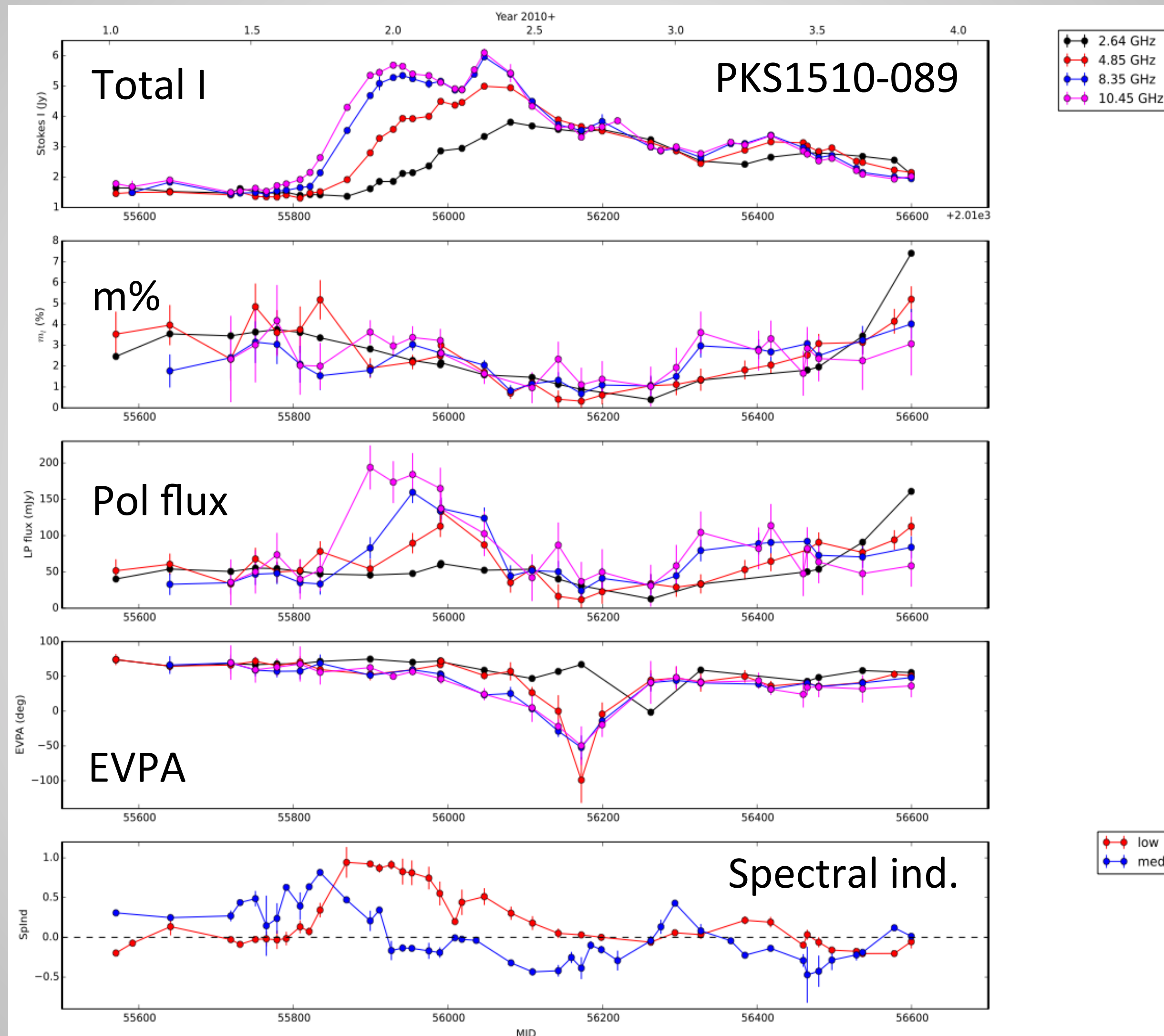
RadioPol statistics

Data courtesy of I. Myserlis





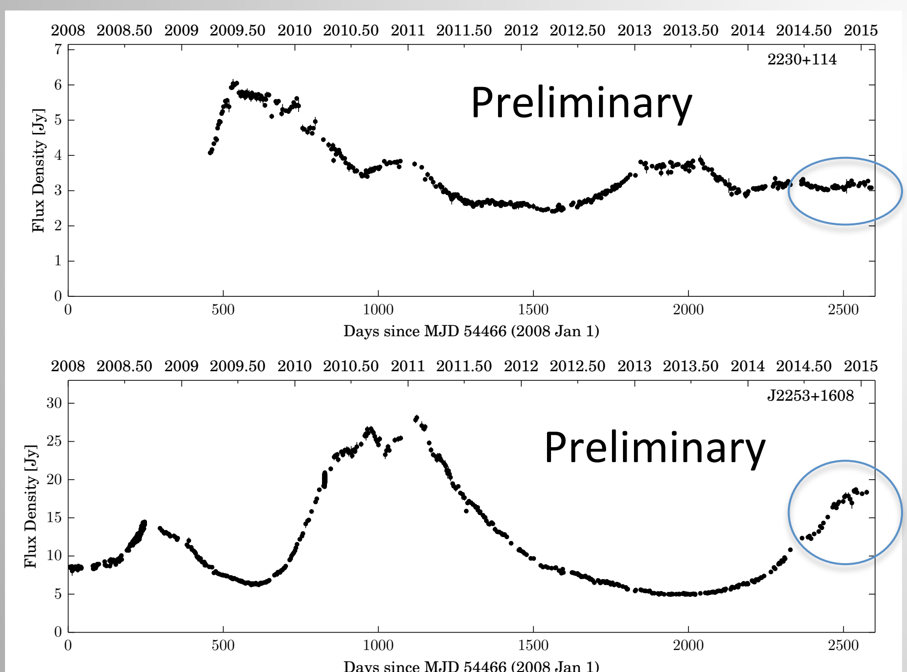
Linear polarization event



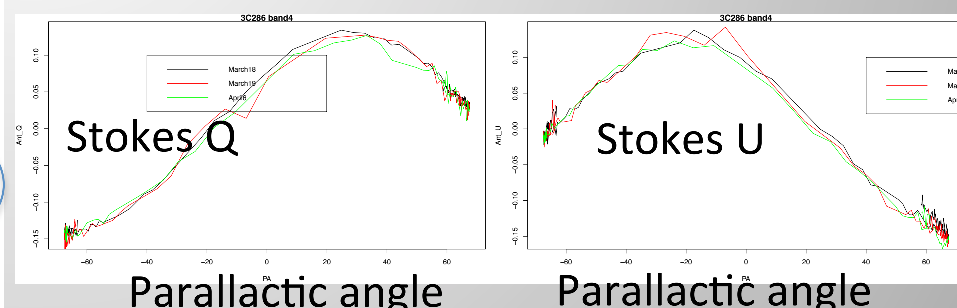
Myserlis et al. 2014

Polarization is the key

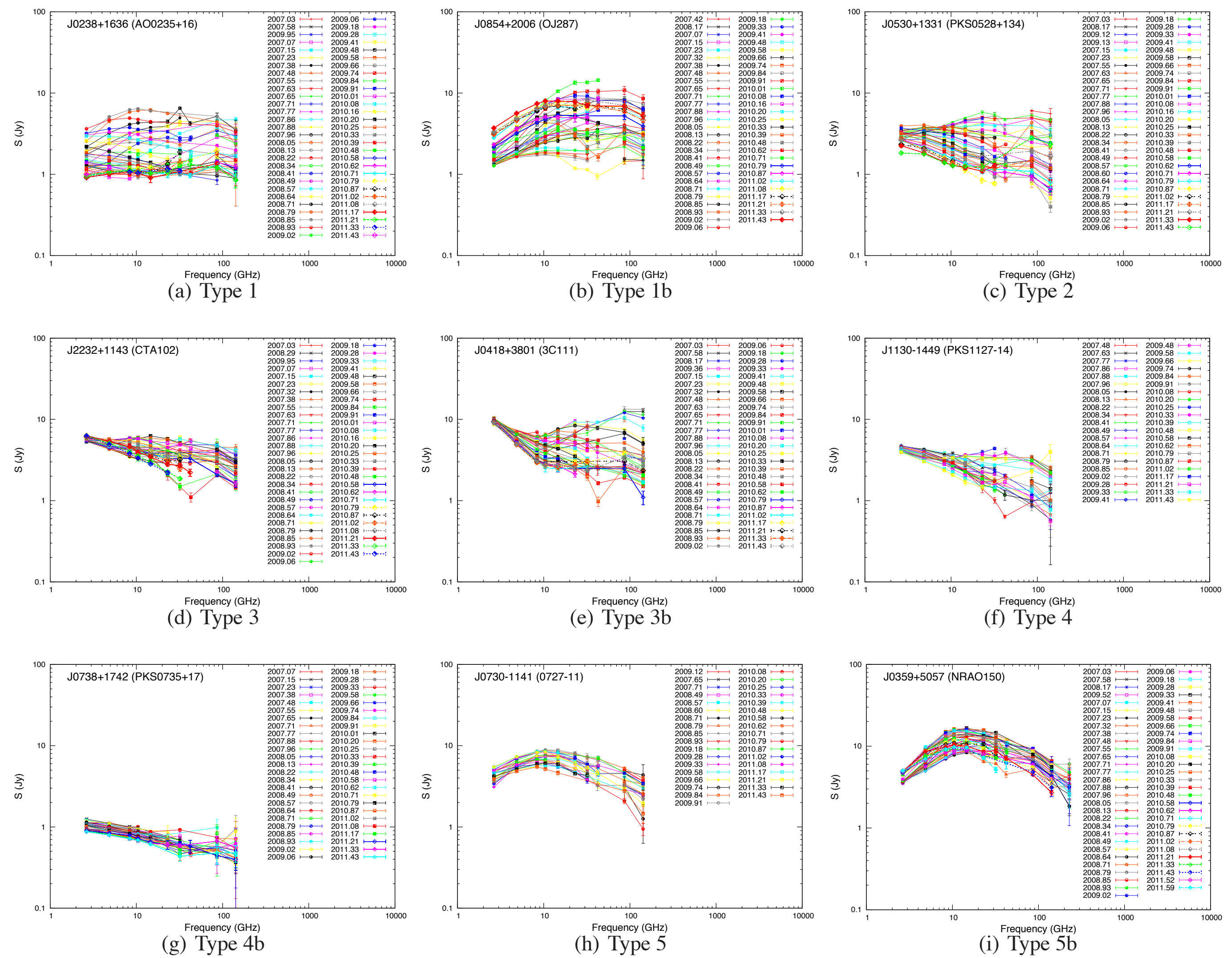
- New Polarization receiver installed on the OVRO 40-m in May 2014
- 13-18 GHz, 1800 sources
- Calibration on-going



3C286



Spectral types and evolution



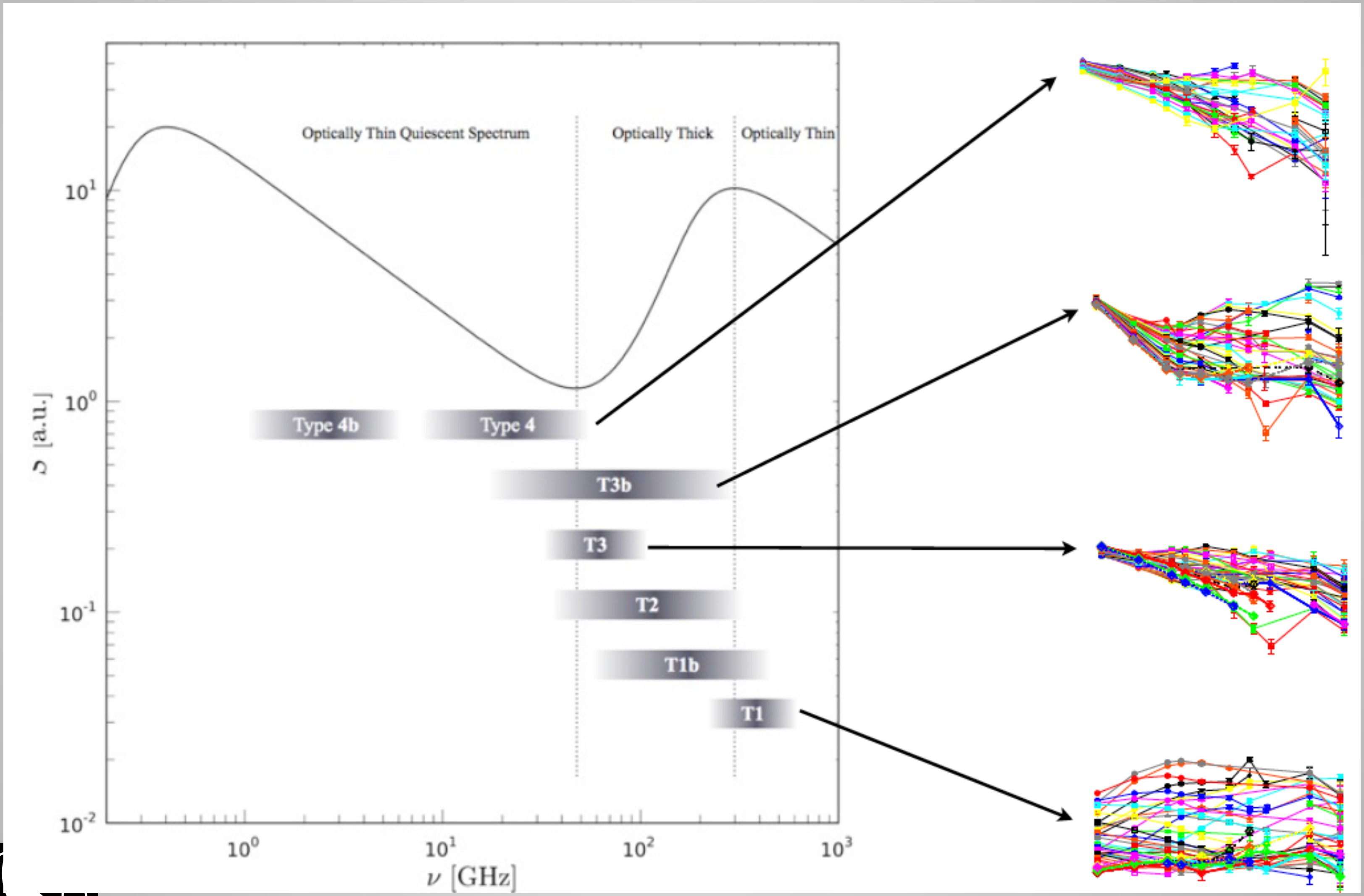
(a) Type 1 (b) Type 1b (c) Type 2
(d) Type 3 (e) Type 3b (f) Type 4
(g) Type 4b (h) Type 5 (i) Type 5b

F-GAMMA

Angelakis et al.
In prep.

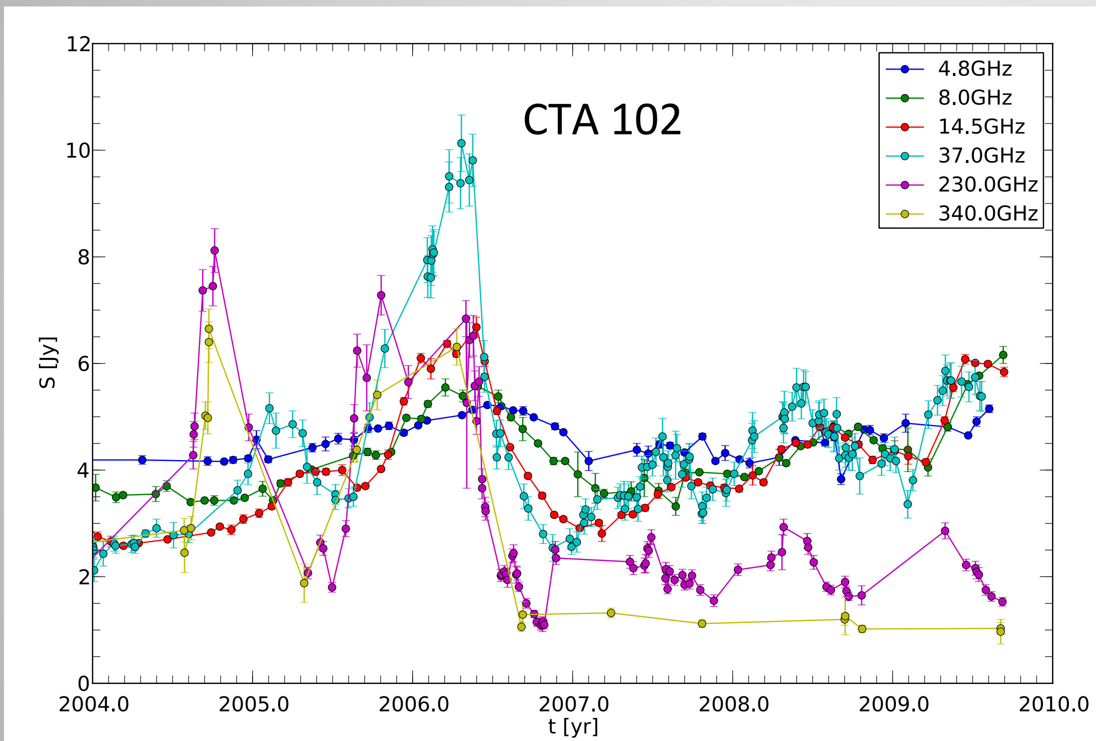
Physical picture

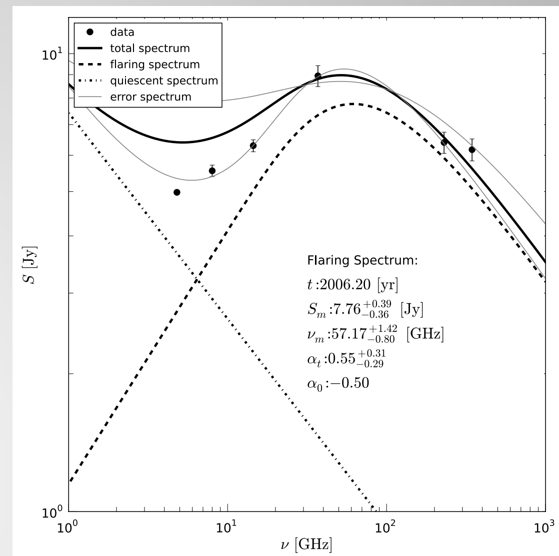
Courtesy of E. Angelakis

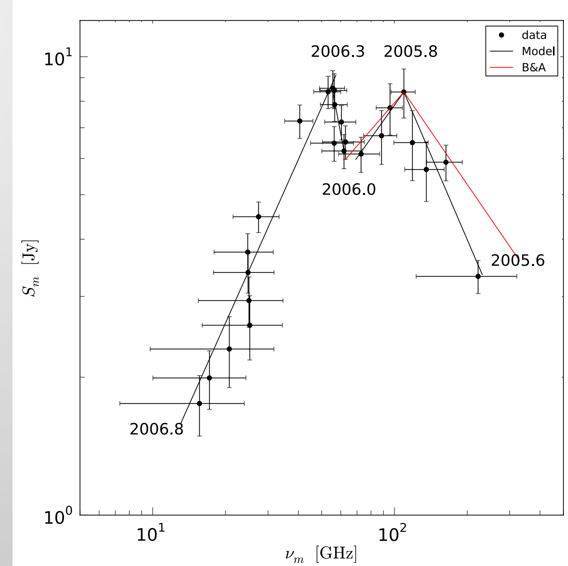


Modeling of flare evolution

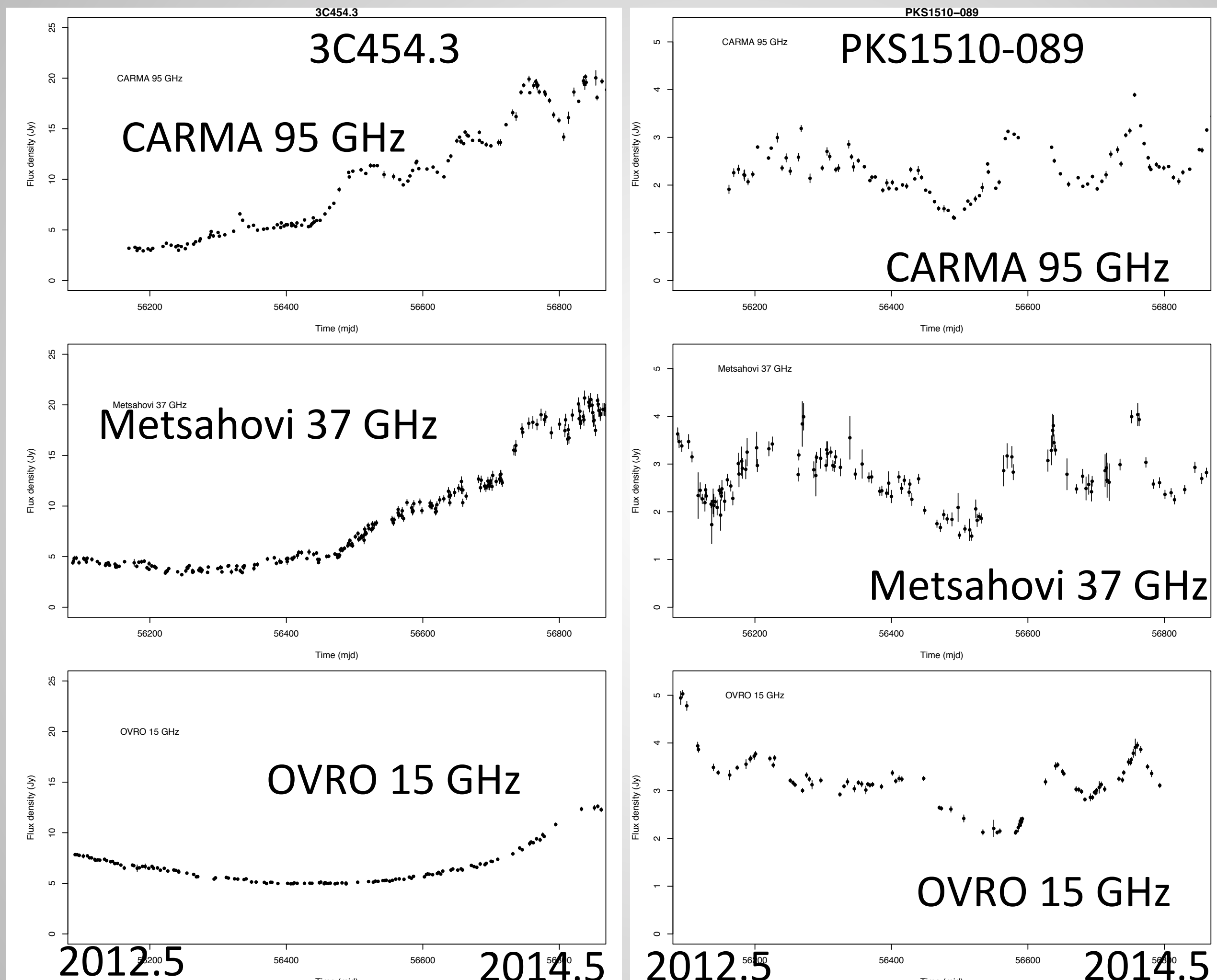
Fromm et al. 2011







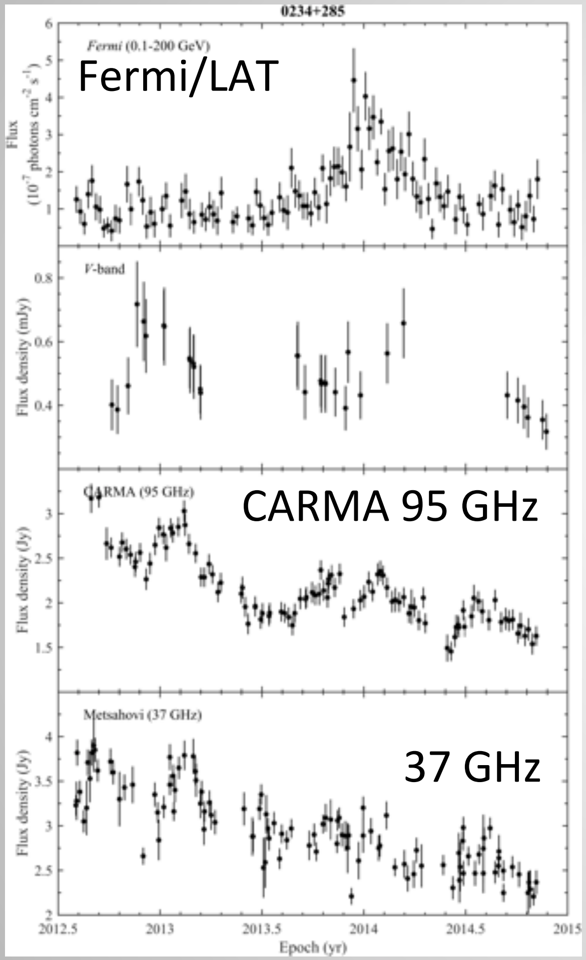
Dense sampling shows details



talvikki.hovatta@aalto.fi

Gamma-ray connection

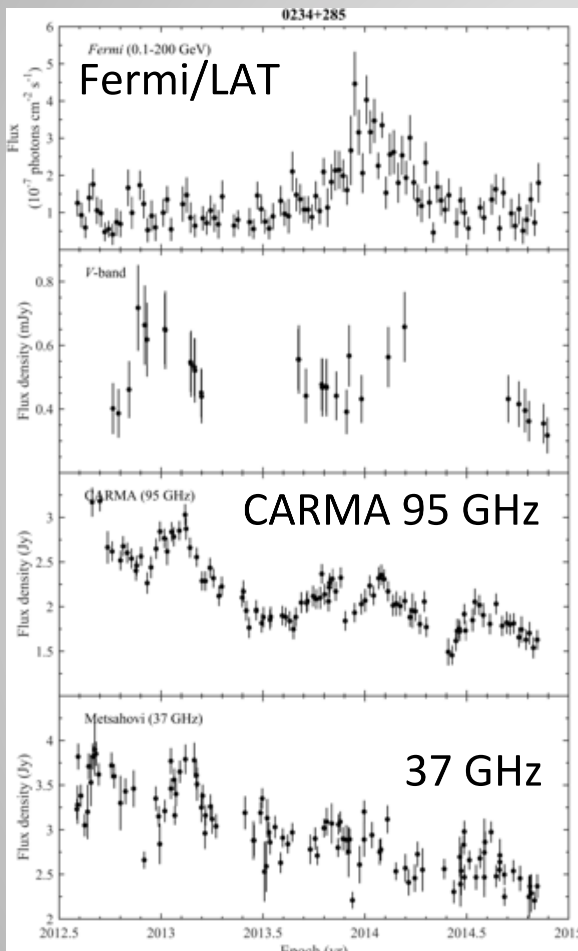
See Poster by
V. Ramakrishnan!



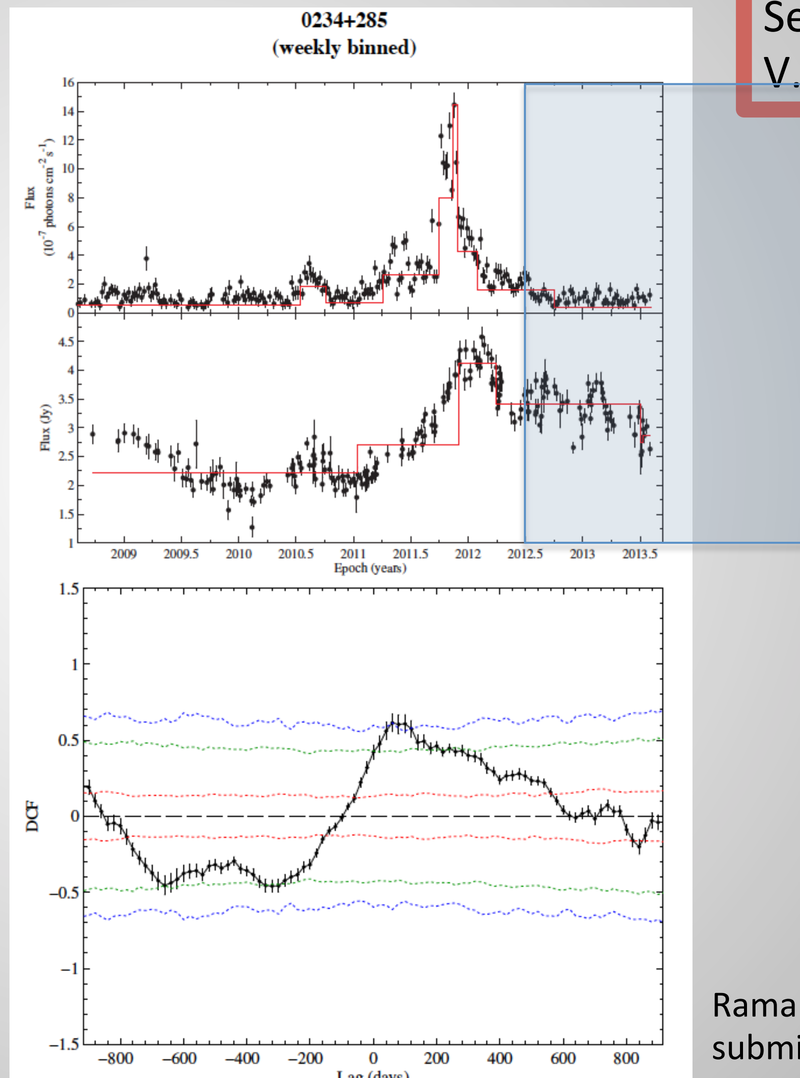
Ramakrishnan+ in prep.

Gamma-ray connection

See Poster by V. Ramakrishnan!



Ramakrishnan+ in prep.



Ramakrishnan+ 2015, submitted

Summary

- Single-dish radio observations CAN be used to constrain jet physics
- Modeling the variations in total intensity and polarization allow constraining:
  - Doppler beaming factors, magnetic field structure, viewing angle, shock parameters etc.
- These can be used to aid the multifrequency modeling of the sources