Blazar physics

through multi-frequency circular and linear polarization monitoring

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Linear and Circular polarimetry

powerful tool but challenging endeavor

Investigate

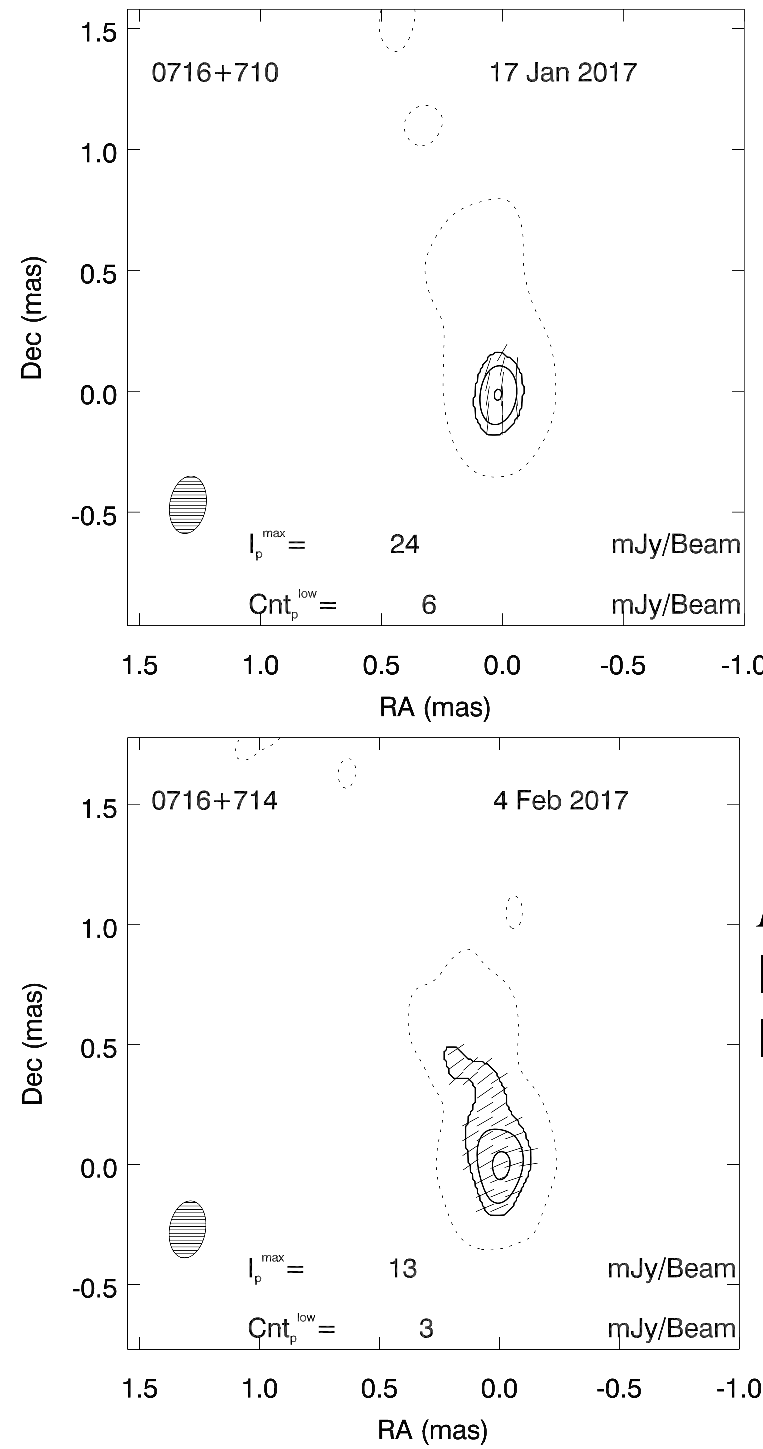
- physical conditions
- emission processes
- variability mechanisms

Challenging due to

- low levels of LP and especially CP
- high levels of variability
- instruments specialize on either LP or CP

Design and development of an **end-to-end framework**

- novel **LP and CP** data reduction pipeline
- **full-Stokes radiative transfer model** of astrophysical plasma systems (e.g. AGN jets)

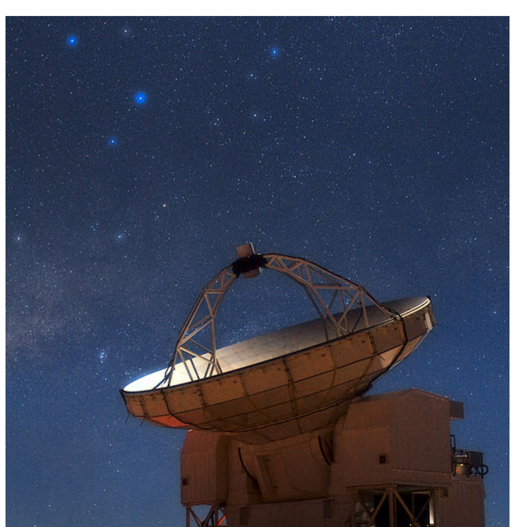


I_{peak} = 749 mJy
LP_{peak} = 25 mJy
EVPA = -6°

dT = 18 days

I_{peak} = 860 mJy
LP_{peak} = 13 mJy
EVPA = -68°

credit: VLBA-BU Blazar Monitoring Program



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

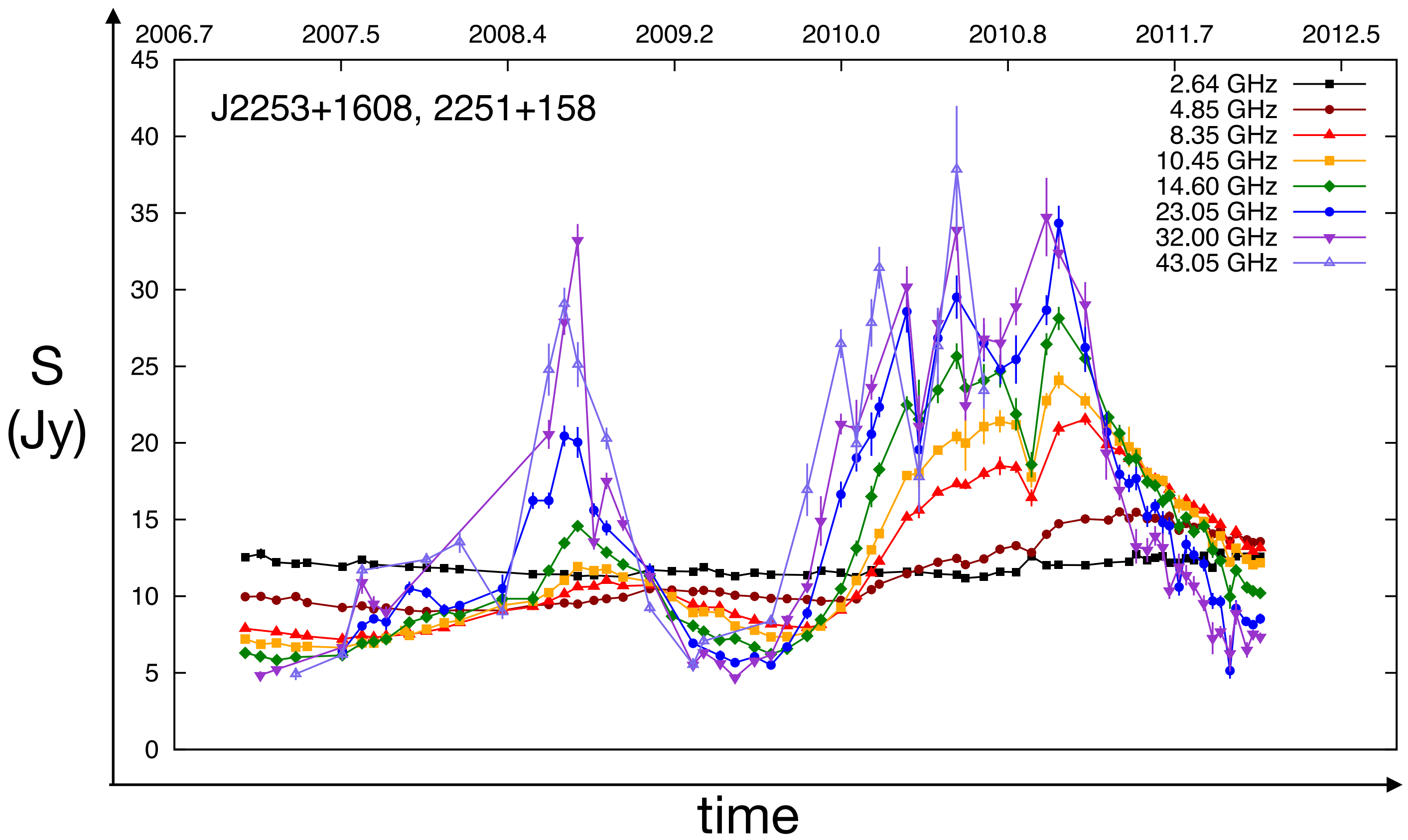
- almost 90 mostly ***Fermi*** sources
- mean cadence ~ **1.3** months
- 2.64–345 GHz at **11** frequency steps
- 8yr data release soon

see also poster:
“F-GAMMA: monthly light curves of Fermi blazars”

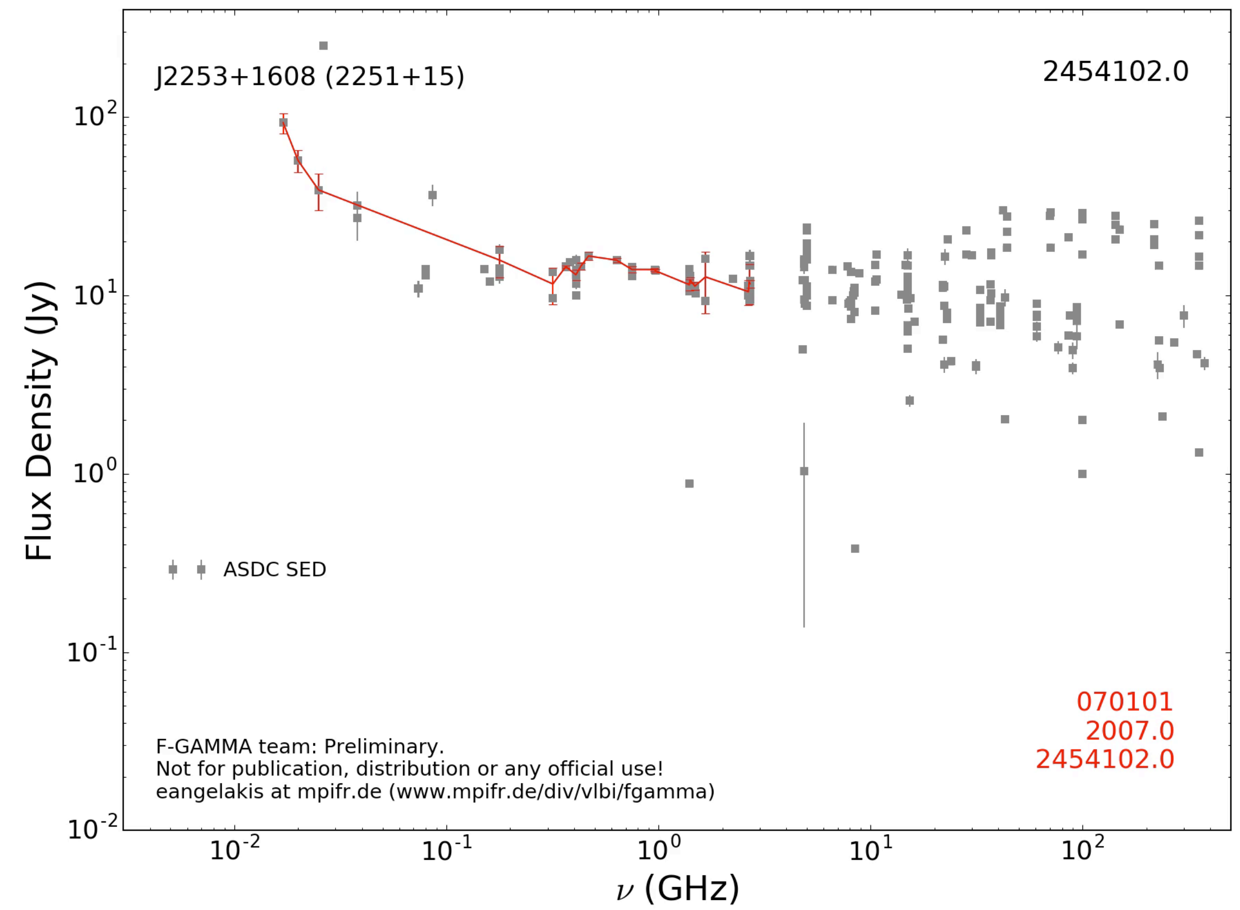
\+ follow-up monitoring with Effelsberg

- 2.64–43 GHz at **8** frequency steps
- mean cadence ~ **10** days

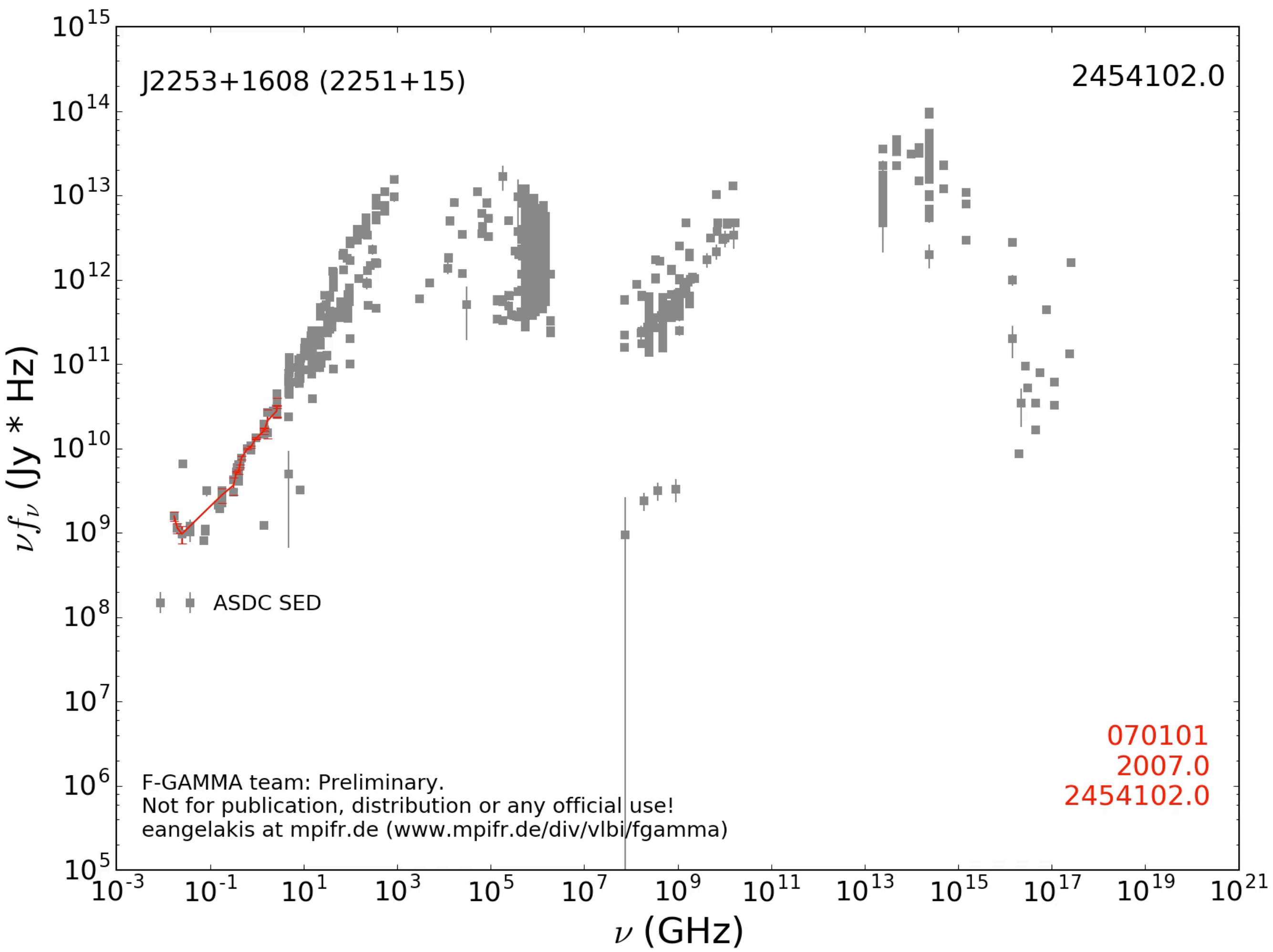
Fuhrmann et al. 2016A&A...596A..45F
Angelakis et al. 2010, astro-ph.CO/1006.5610



J2253+1608, 2251+158
2.64 GHz
4.85 GHz
8.35 GHz
10.45 GHz
14.60 GHz
23.05 GHz
32.00 GHz
43.05 GHz
S (Jy)
time
2006.7
2007.5
2008.4
2009.2
2010.0
2010.8
2011.7
2012.5



J2253+1608 (2251+15)
2454102.0
ASDC SED
F-GAMMA team: Preliminary.
Not for publication, distribution or any official use!
eangelakis at mpifr.de (www.mpifr.de/div/vlbi/fgamma)
070101
2007.0
2454102.0
Flux Density (Jy)
ν (GHz)



J2253+1608 (2251+15)
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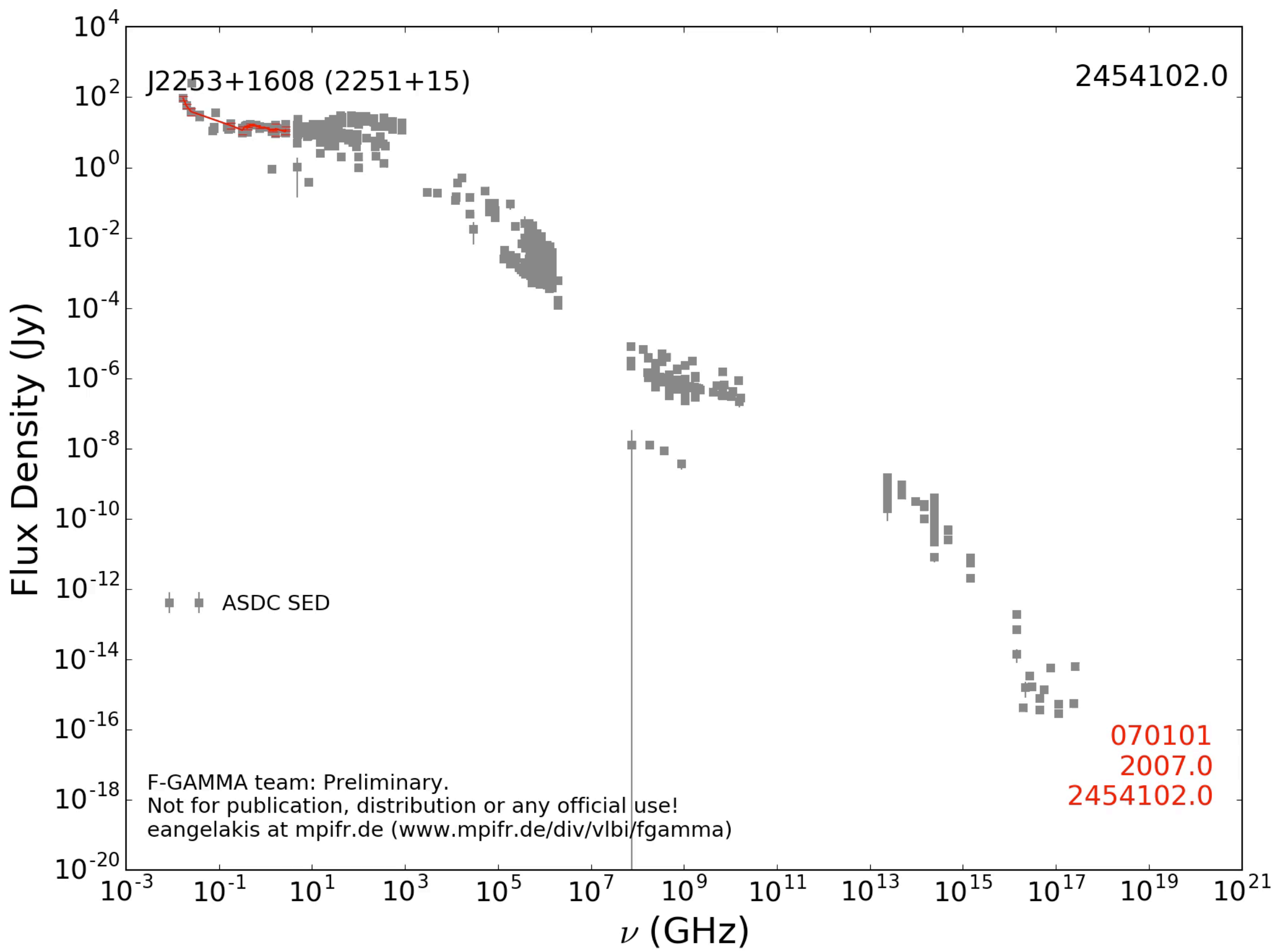
070101
2007.0
2454102.0
νf_ν (Jy * Hz)
ν (GHz)



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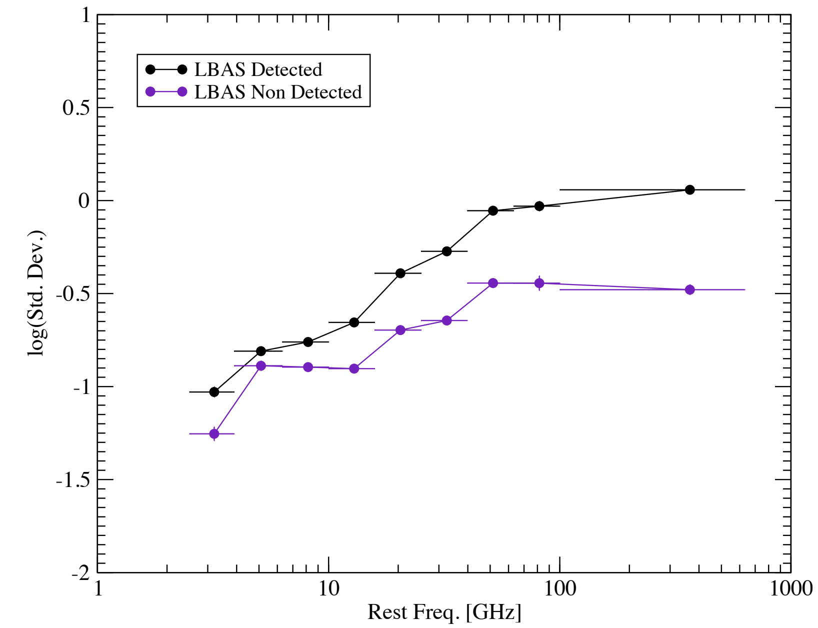
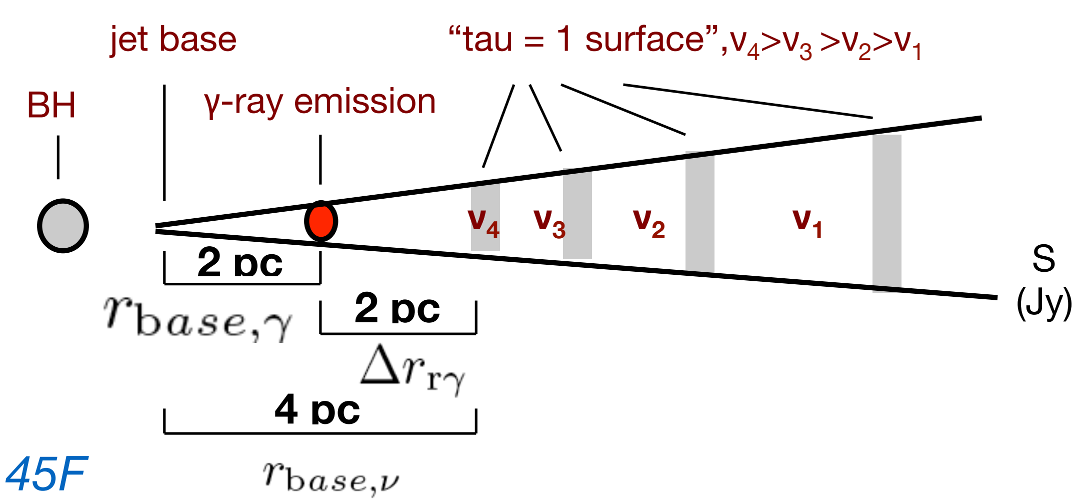
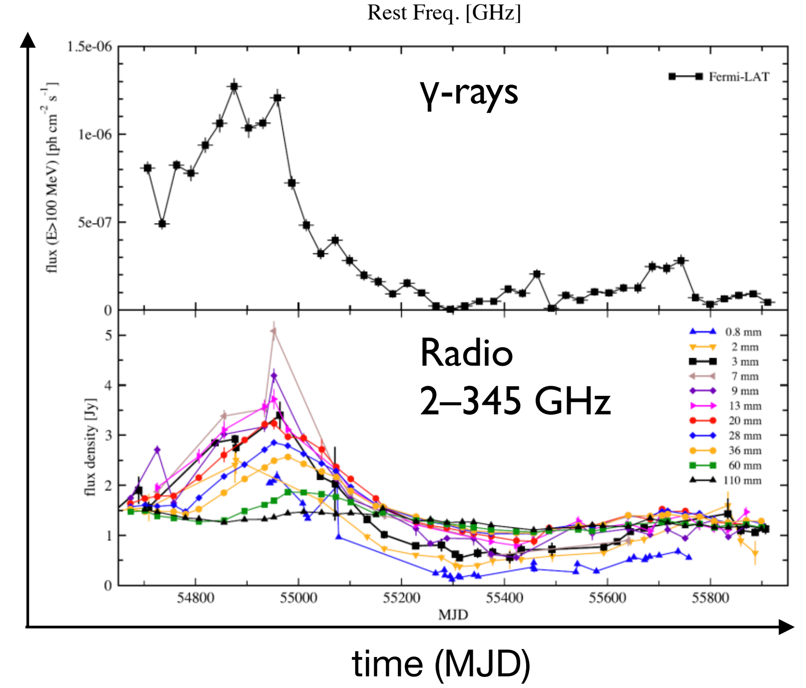
070101
2007.0
2454102.0
Flux Density (Jy)
ν (GHz)

F-GAMMA
science highlights

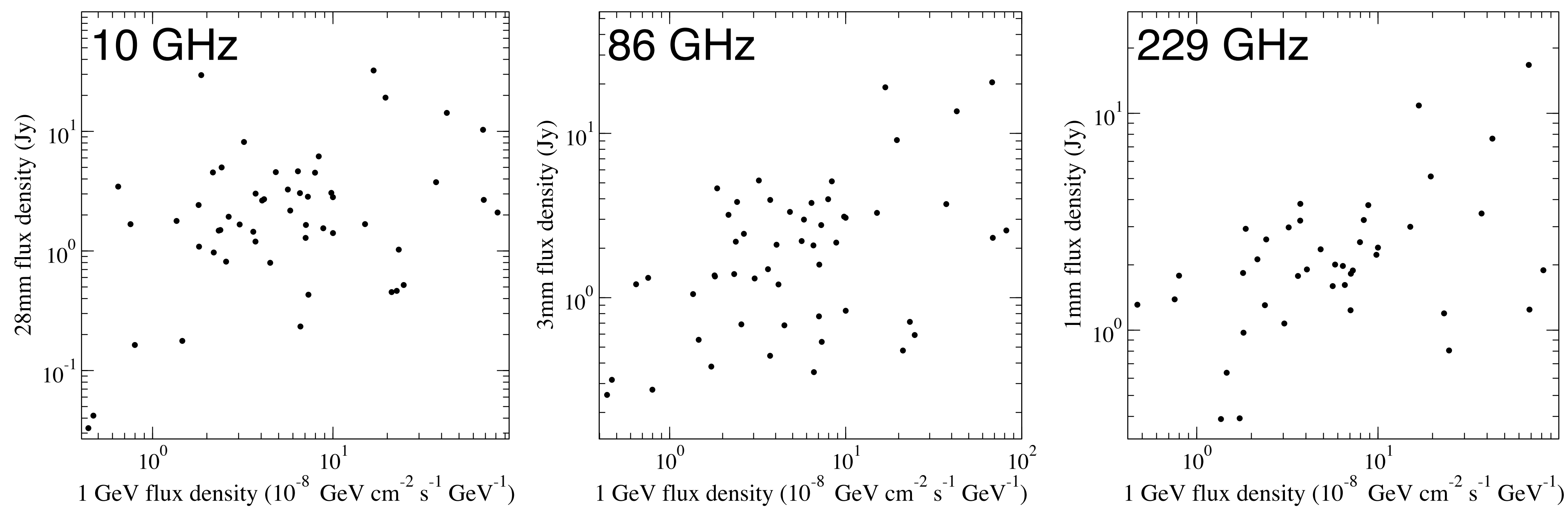


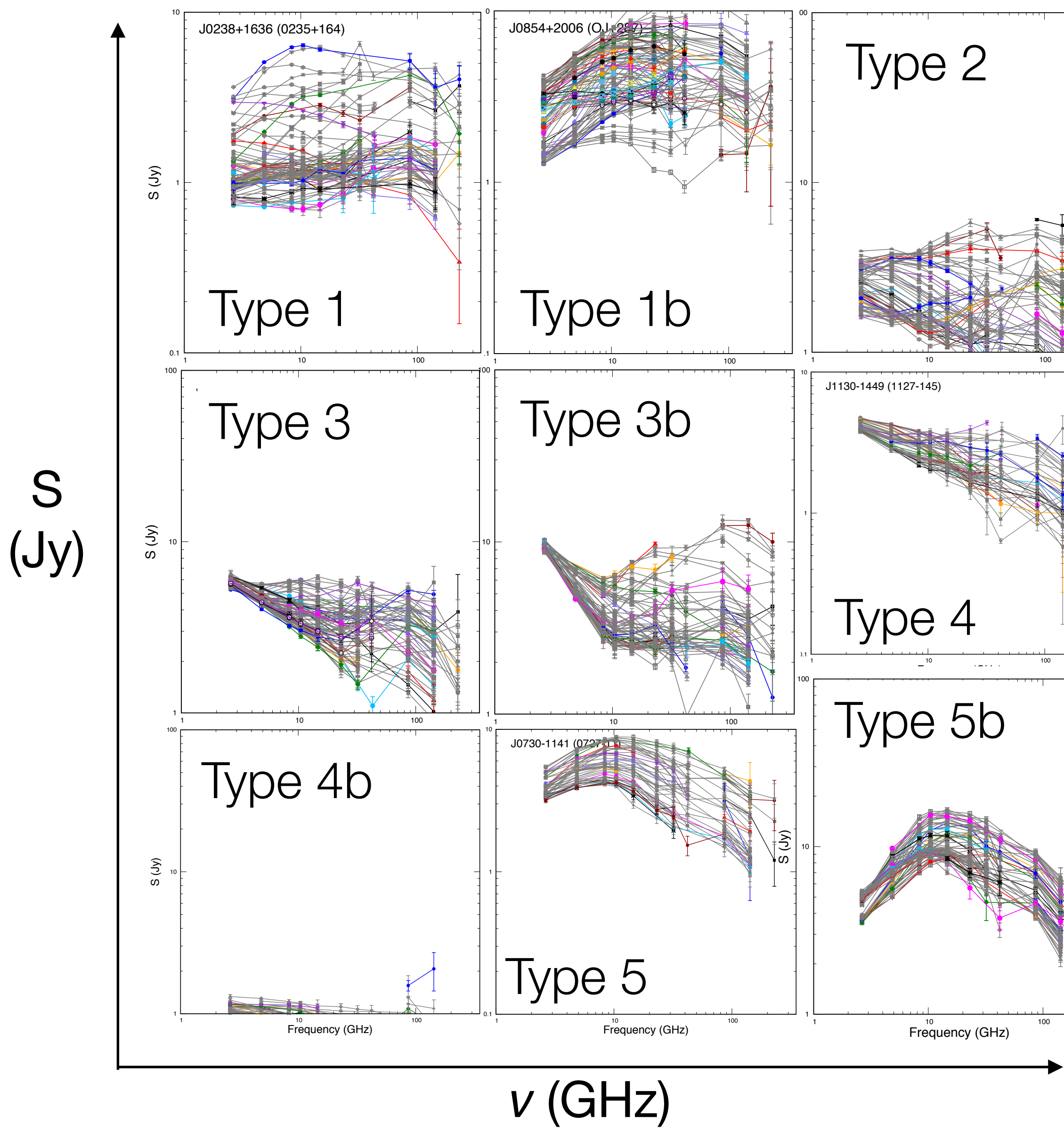
- γ-ray loudness and radio variability
- γ-ray emission site
- radio vs γ-ray fluxes (S-S correlations)





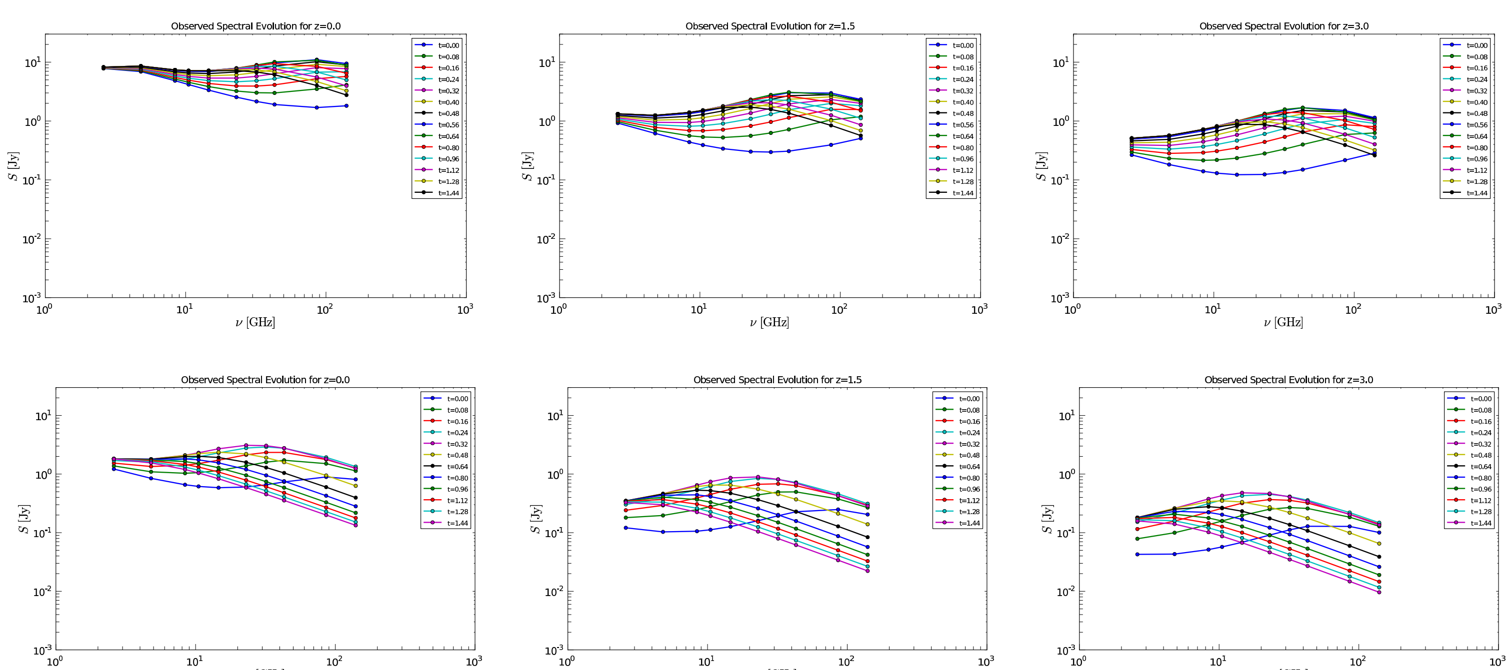
Fuhrmann et al. 2016A&A...596A..45F
Fuhrmann et al. 2014, MNRAS, 441, 1899
Karamanavis et al. 201 6,A&A, 590, 48

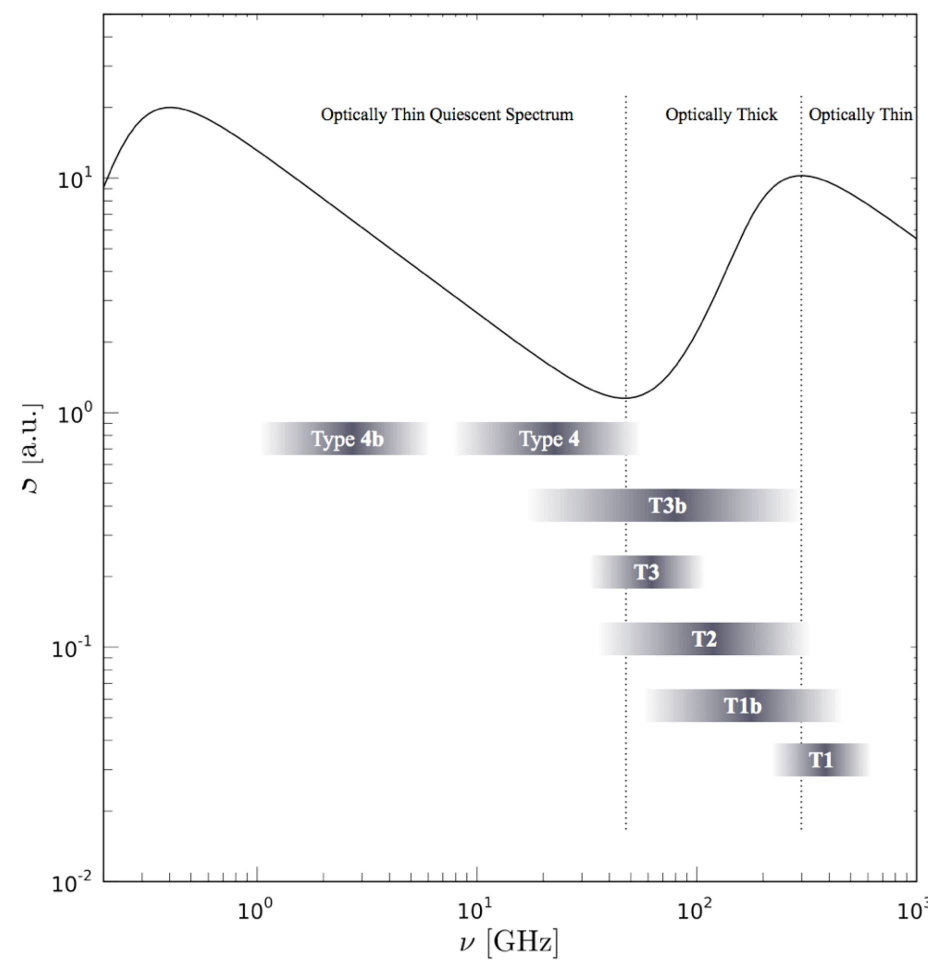




SED variability patterns can be reproduced by the combination of:

- 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

New LP and CP data reduction pipeline

high-precision radio polarimetry

Complete pipeline
- from telescope observables to I, Q, U, V

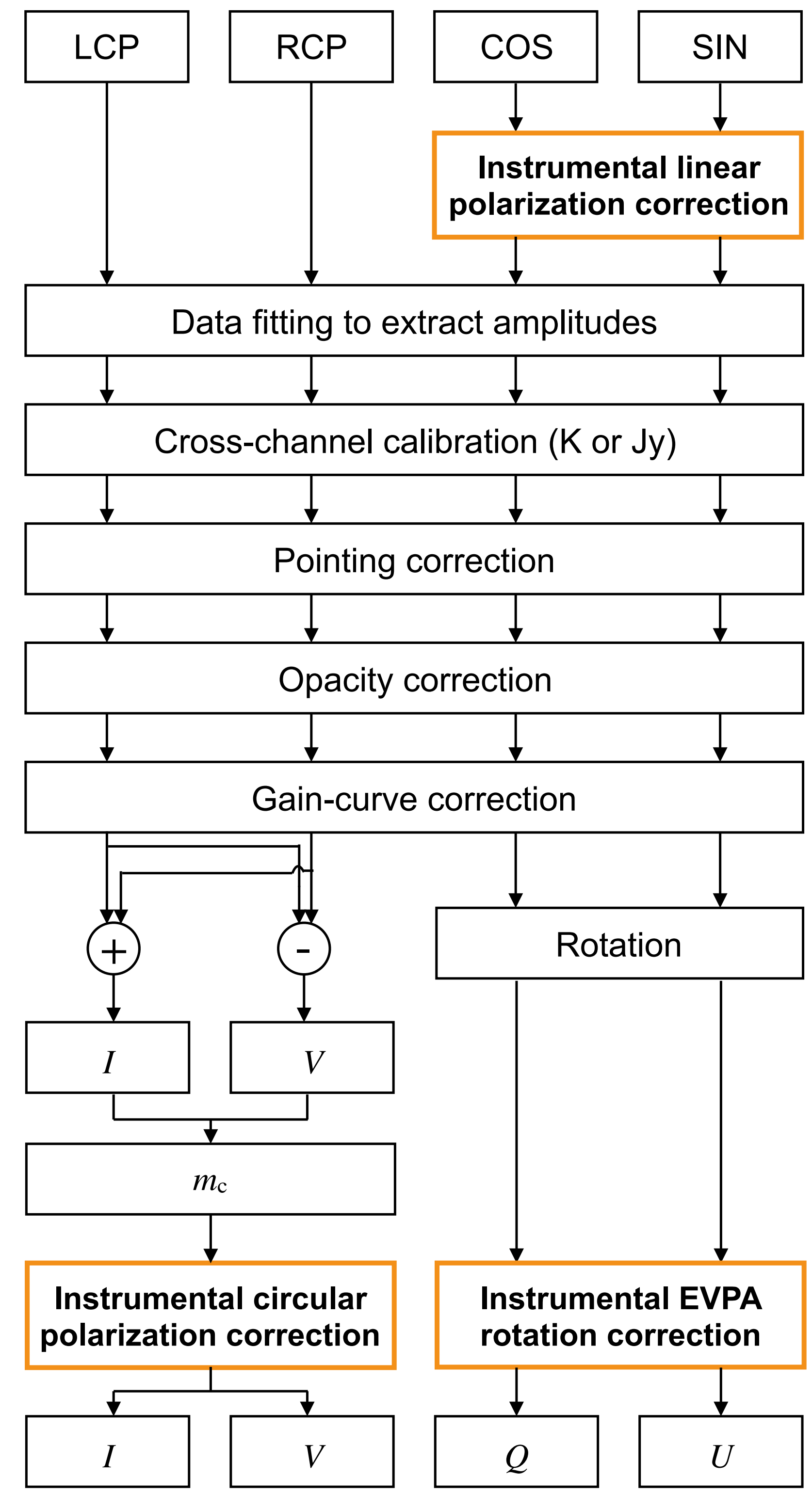
Several correction steps
- pointing, opacity, elevation-dependent gain

Careful treatment of telescope response
- Airy disk instead of gaussian beam pattern

Minimization of instrumental effects:
- instrumental LP correction **across the telescope beam**
- absolute EVPA calibration with **Lunar** observations
- instrumental CP correction with **two** independent methods

Designed for CP feeds but easily applicable also to LP feeds

see also poster:
"Linear and circular polarization standard sources in the GHz regime"



Myserlis et al. 2018, A&A, 609A, 68M
Myserlis et al., Galaxies, vol. 4, issue 4, p. 58

Linear and circular polarimetry with Effelsberg

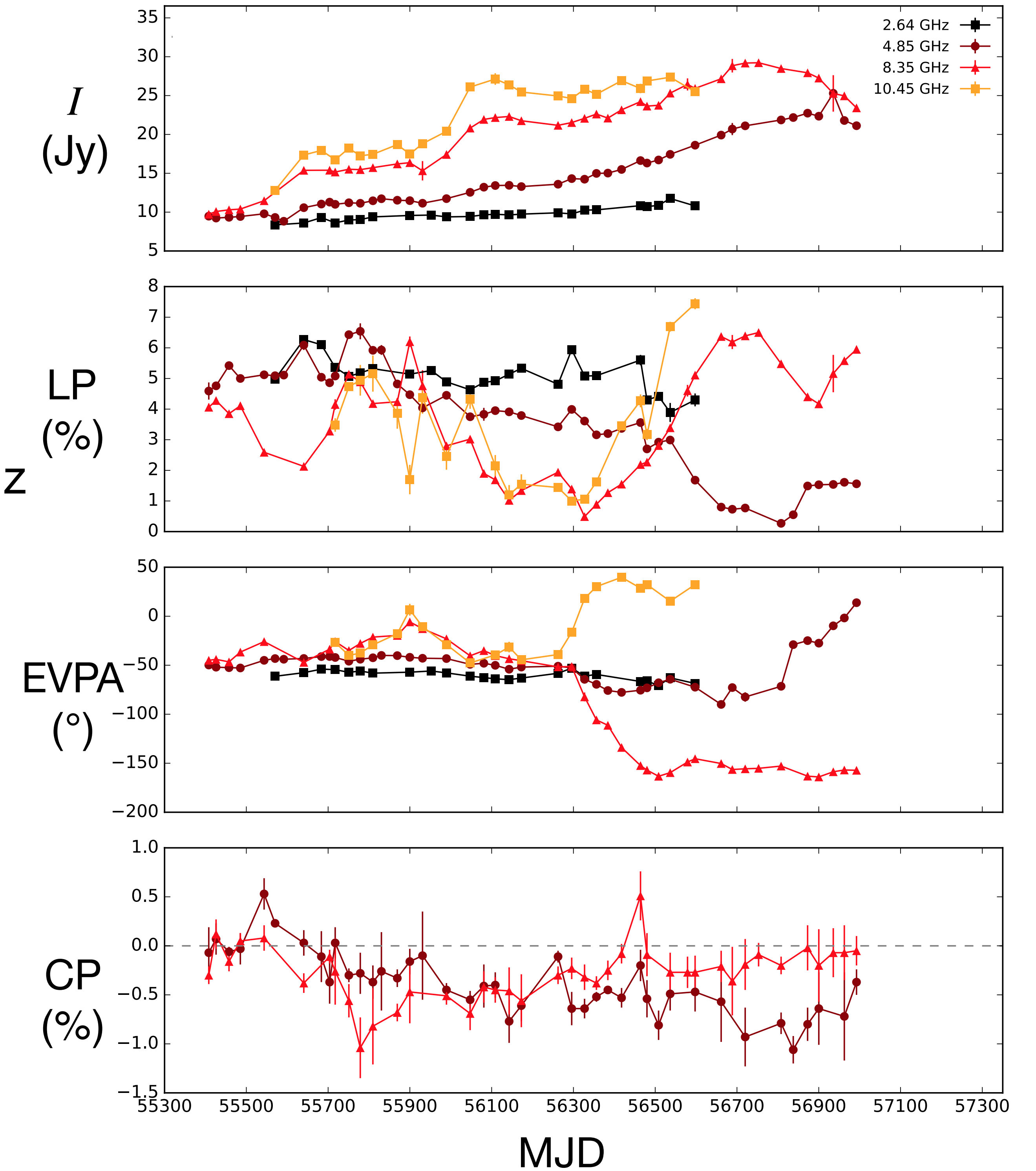
new, high-precision data analysis methodology

Uncertainties:

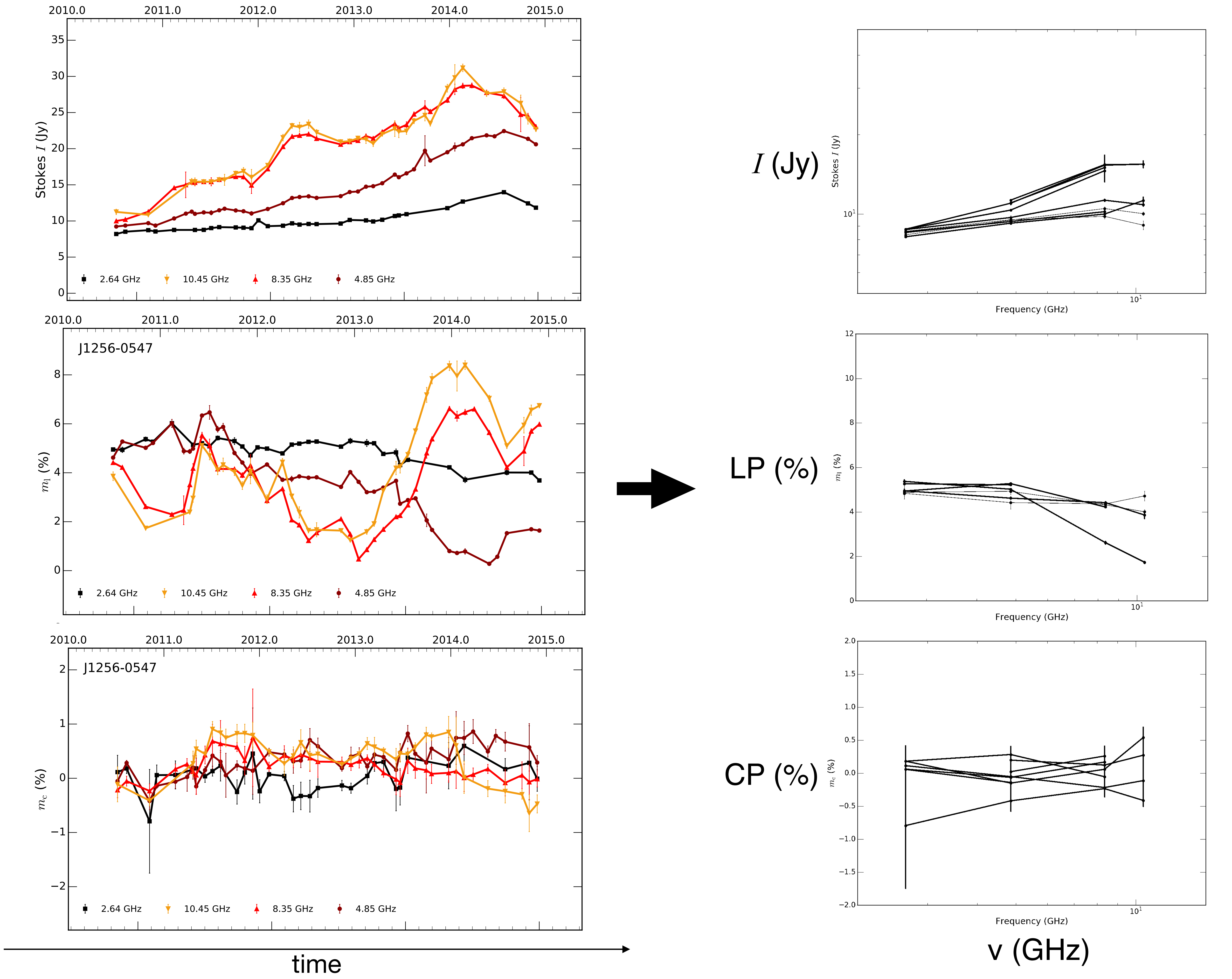
- LP degree: **0.1 %**
- CP degree: **0.1—0.2 %**
- EVPA: **1°**

High-cadence, full-Stokes light curves

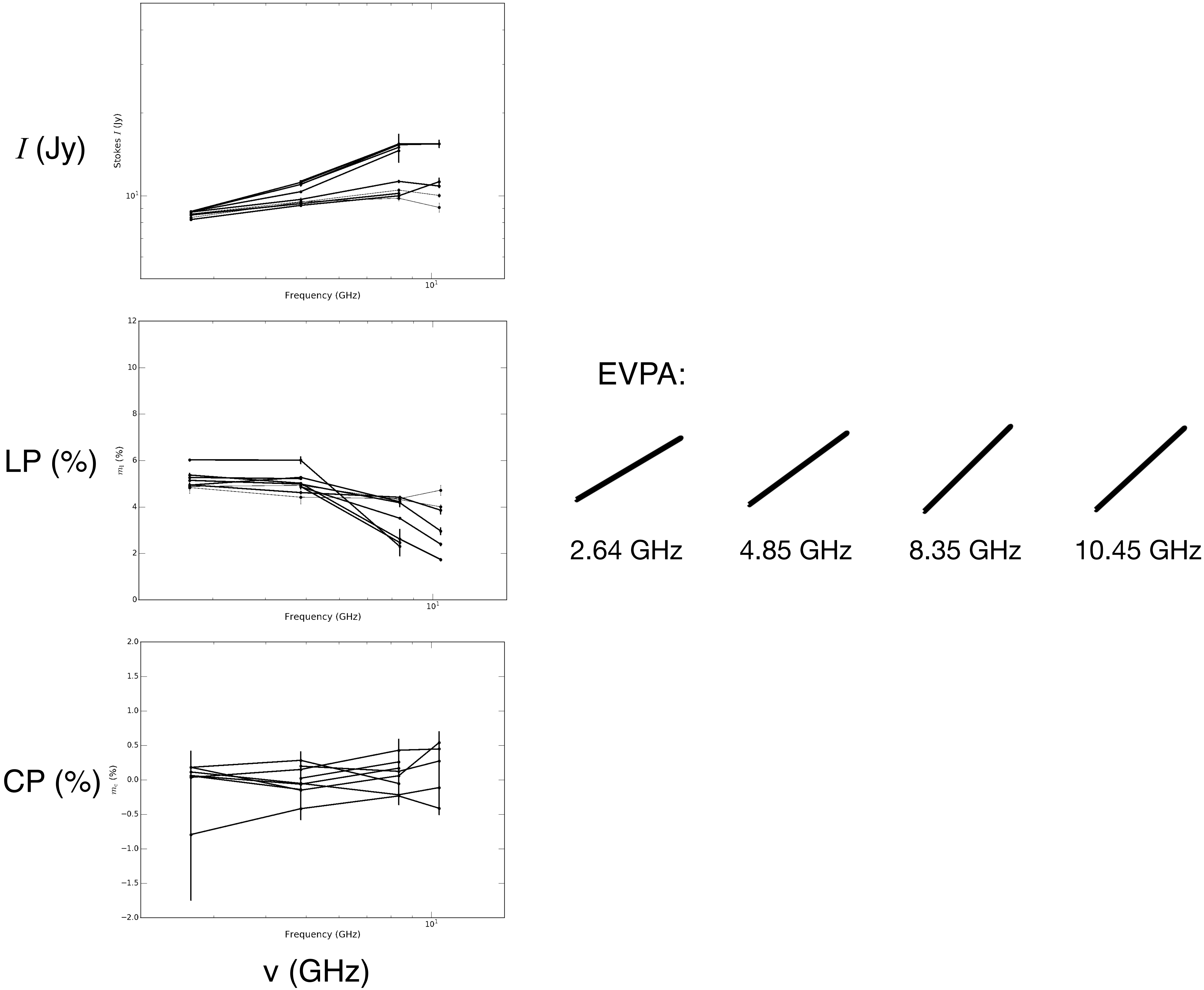
- LP at **2.64, 4.85, 8.35, 10.45** and **14.6** GHz
- CP at **2.64, 4.85, 8.35, 10.45**, **14.6, 23.05** GHz
- mean cadence: ~ **1 month**
- time baseline: **2010.5 - now**



Myserlis et al. 2018, A&A, 609A, 68M



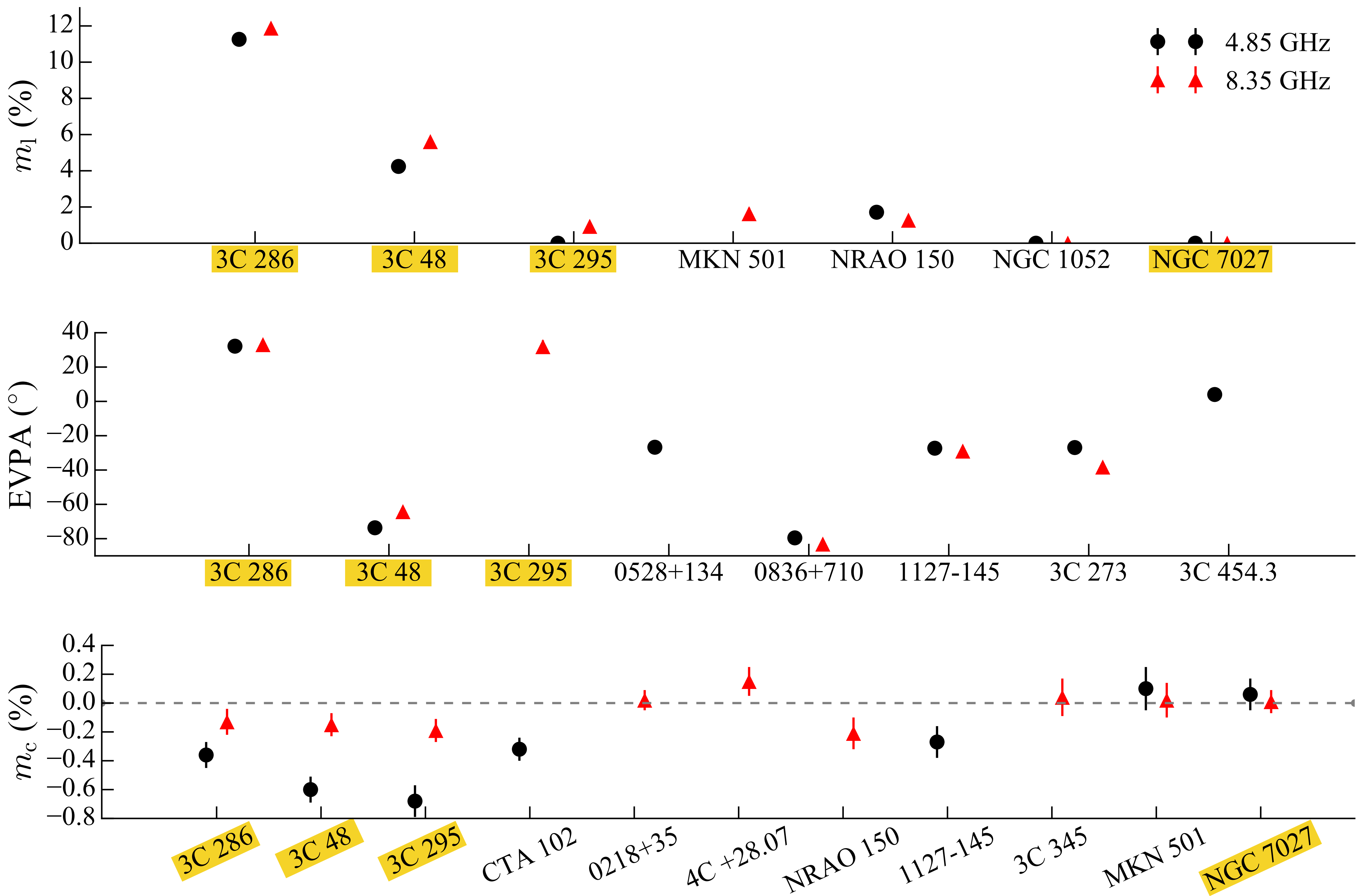
Stokes I (Jy)
2.64 GHz
10.45 GHz
8.35 GHz
4.85 GHz
J1256-0547
m_l (%)
m_c (%)
time
I (Jy)
LP (%)
CP (%)
Frequency (GHz)
v (GHz)



I (Jy)
Stokes I (Jy)
Frequency (GHz)
LP (%)
Frequency (GHz)
CP (%)
Frequency (GHz)
ν (GHz)
EVPA:
2.64 GHz
4.85 GHz
8.35 GHz
10.45 GHz

Sources with stable polarization over 5.5 yrs

July 2010 – April 2016



<σ> = 0.1 %

<σ> = 1.7°

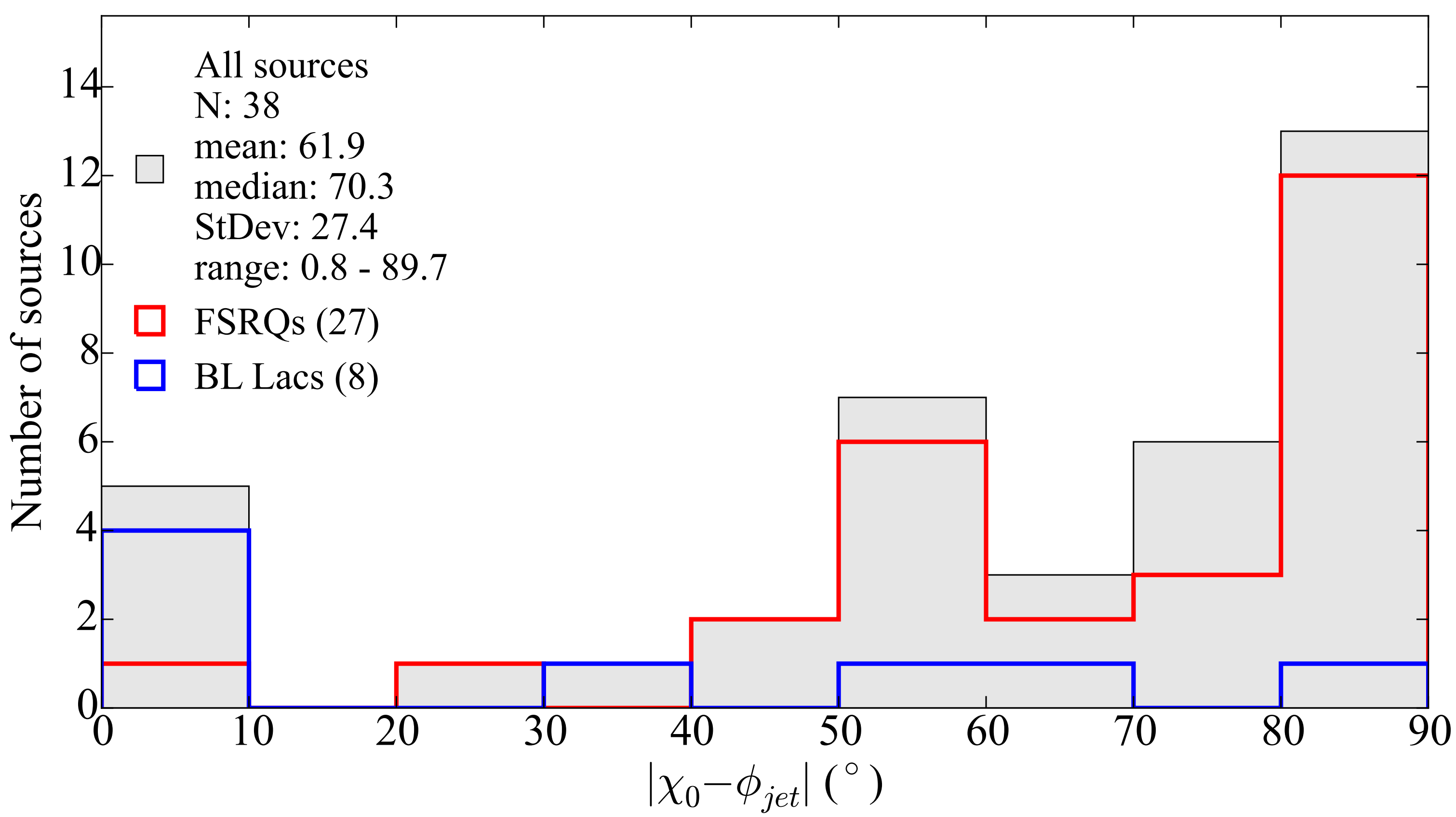
<σ> = 0.1 %

Myserlis et al. 2018, A&A, 609A, 68M

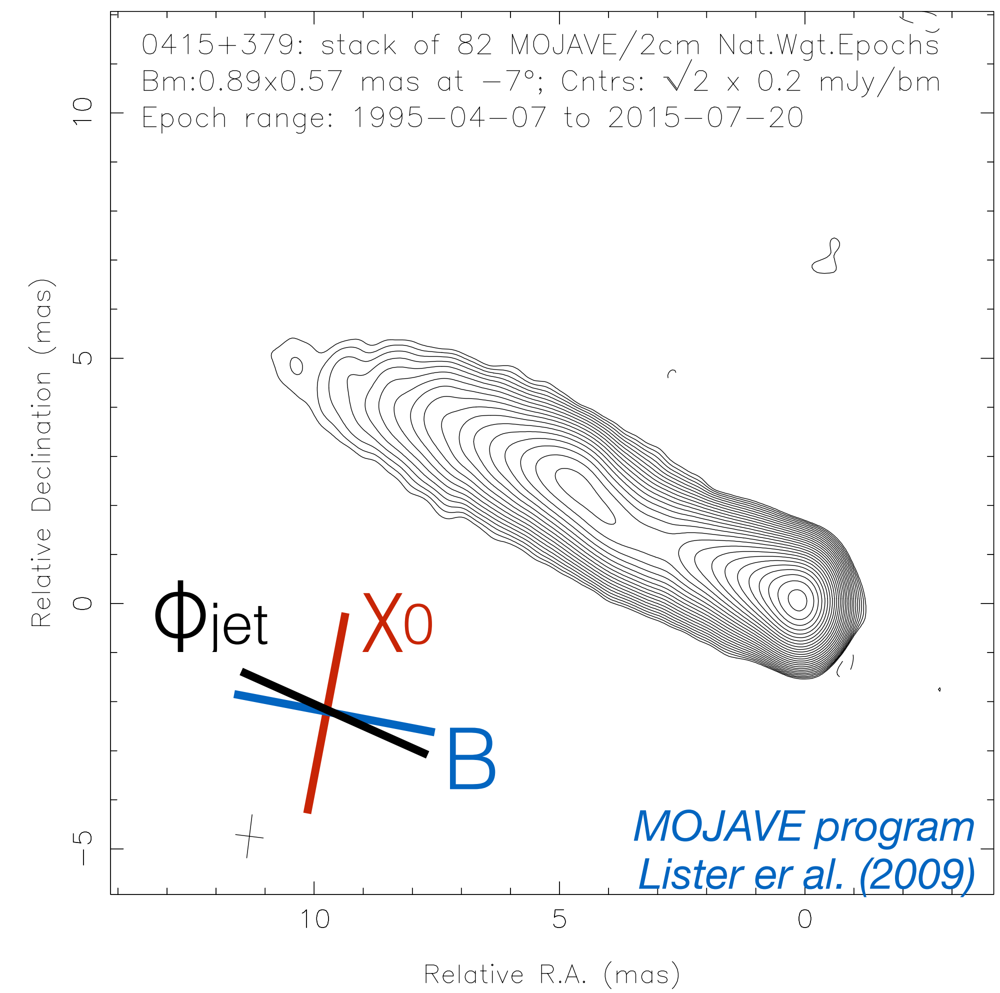
Static results / Population studies

using median values

- B-field strength: **~ 5 mG**
- plasma composition: **~ 1:2** (e^- vs e^+)
- faraday rotation levels consistent with **galactic** low-energy plasma content
- **poloidal** B-field component dominance



3C 111

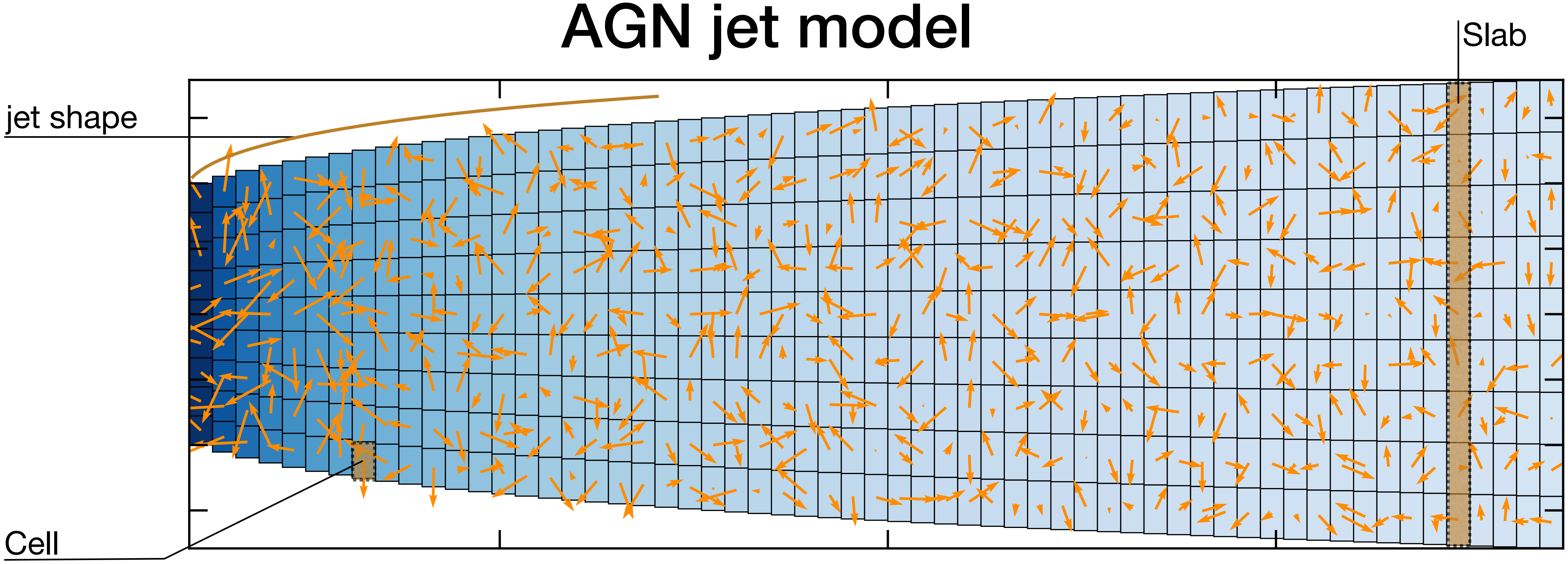


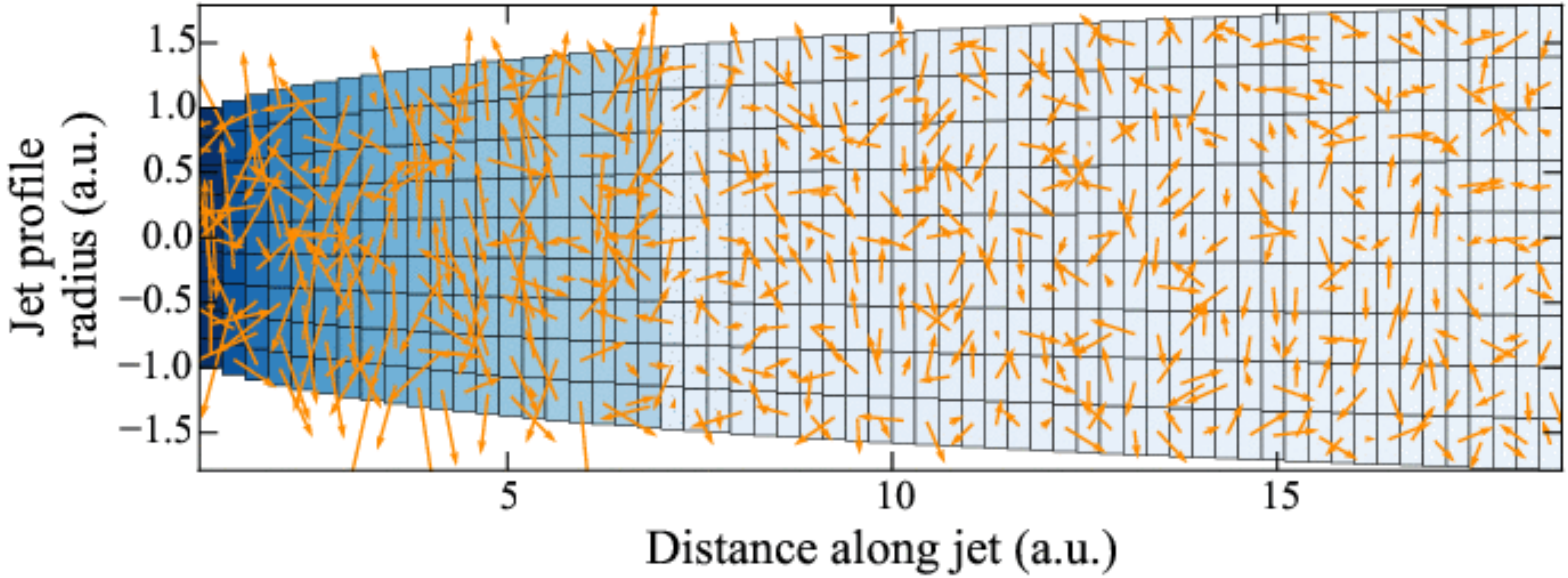
Dynamic results / Time domain studies

using multi-frequency, LP and CP variarility

- **full-Stokes radiative transfer model** of astrophysical plasma systems
- AGN jet modeling with **turbulent** B-field configuration
- variability induced by **shocks propagating** downstream
- tested in both **low and high γ_{min}** regimes

AGN jet model

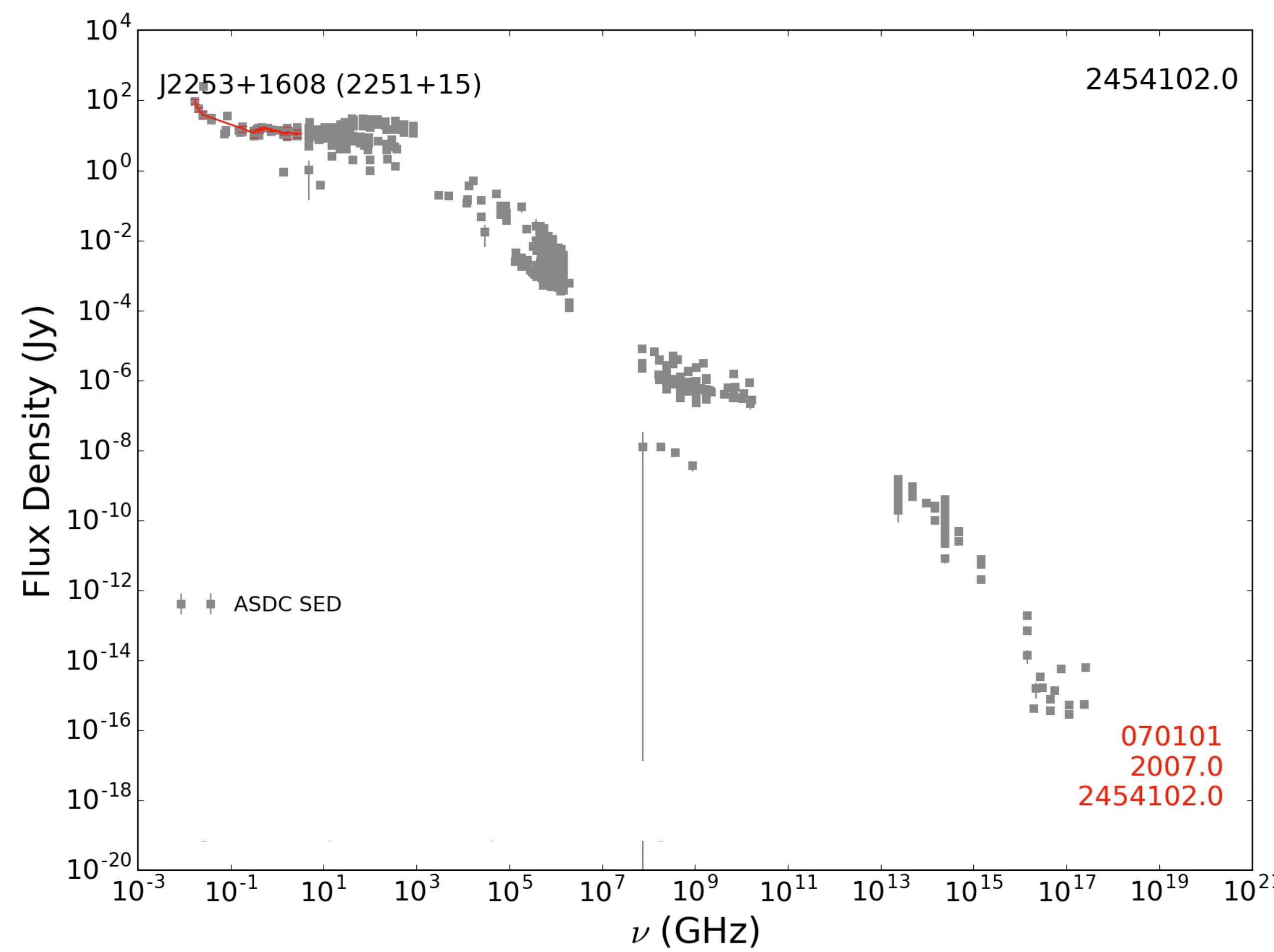




the high-γ_{min} *regime:*

Shock parameters

- ➡ Compression factor: k = 0.8
- ➡ γ_{min}~10^4
- ➡ Doppler factor: D ~ 30
  Consistent with D_{var} at 37 GHz
  Hovatta et al. (2009)
- ➡ Jet plasma parameters
  - Density: $n_0 = 10^1$ - 10^2 cm^{-3}
  - Magnetic field coherence length: 9 pc



Myserlis, Angelakis et al.,in prep.
Myserlis et al., Galaxies, vol. 4, issue 4, p. 58

the low-γ_{min} *regime:* NGC 4845

Irwin et al, 2015,ApJ…809..172I

- SSA spectrum with $\nu_{\max}$ ~ 1.8 GHz ✔
- LP practically zero (0.1–0.5 %) ✘
- CP
    - extremely high at 1.5 GHz: 2–3 % ✔
    - zero at 6 GHz ✔

Realisation

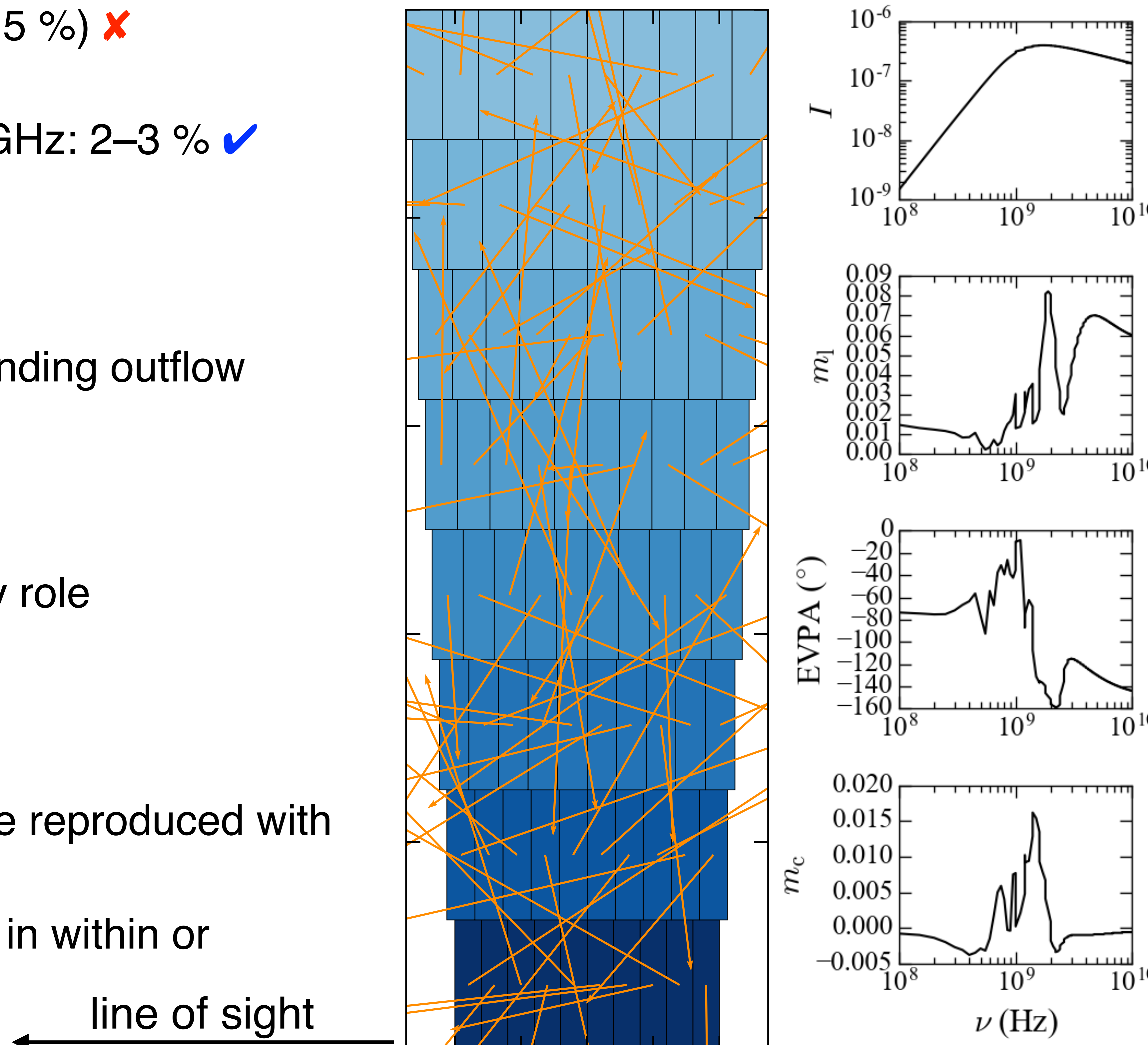
- conical adiabatically expanding outflow
- random B-field

We find:

- Faraday effects play a key role
    - decrease LP at 1 GHz
    - increase CP 1 GHz

Low LP at 6 GHz **cannot** be reproduced with this realisation

- excess of thermal plasma in within or around the outflow



Summary

LP and CP are powerful tools to study blazar physics: physical conditions, emission processes and variability mechanisms

Broadband radio data (F-GAMMA + beyond): spectral variability due to evolving SSA components
- **track** expected coordinated LP and CP changes
- **constrain** physical conditions

Developed an end-to-end framework for LP and CP studies
- high precision polarimetry
- recovered LP and CP data for four frequencies (2.64, 4.85, 8.35 and 10.45 GHz): **LP and CP light curves and spectra**
- spin-off result: **LP and CP calibrators**

Static results / population studies
- B-field: **~ 5 mG**
- plasma composition: **~ 1:2** (e^- vs e^+)
- faraday rotation due to **galactic** low-energy plasma
- **poloidal** B-field component dominance (with FSRQ and BLLac dichotomy)

Dynamic results / time domain studies
- **full-Stokes radiative transfer model** of astrophysical plasma systems
- AGN jet modeling with turbulent B-field configuration and variability by propagating shocks
- successfully tested in both **low and high γ_{min}** regimes
- constraints for Doppler factor, compression factor, plasma density and B-field coherence length