Physics of extragalactic plasma elements

through multi-frequency linear and circular radio polarization monitoring

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Emmanouil Angelakis
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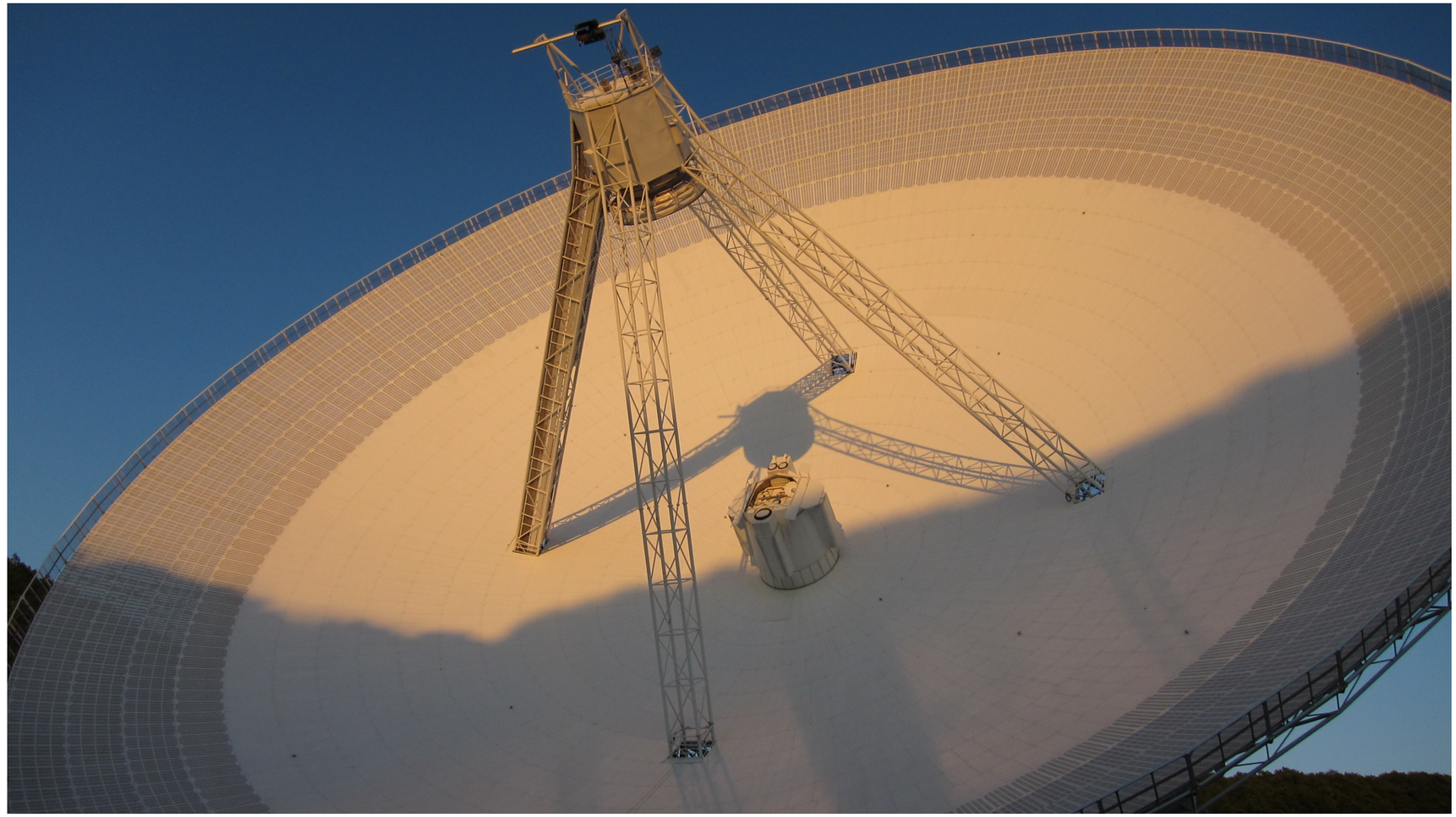
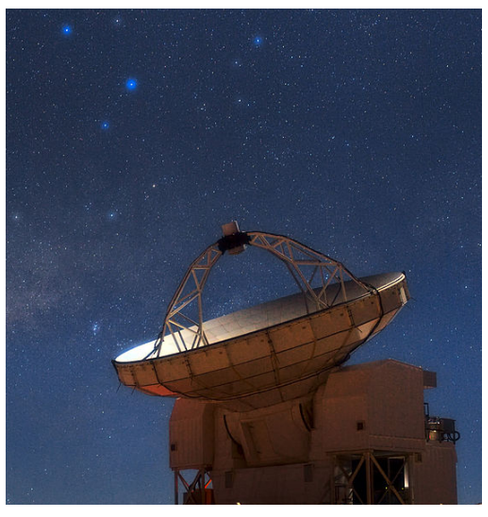
für Radioastronomie





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
- **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**
- **Current status: 2010.5 - 2015**

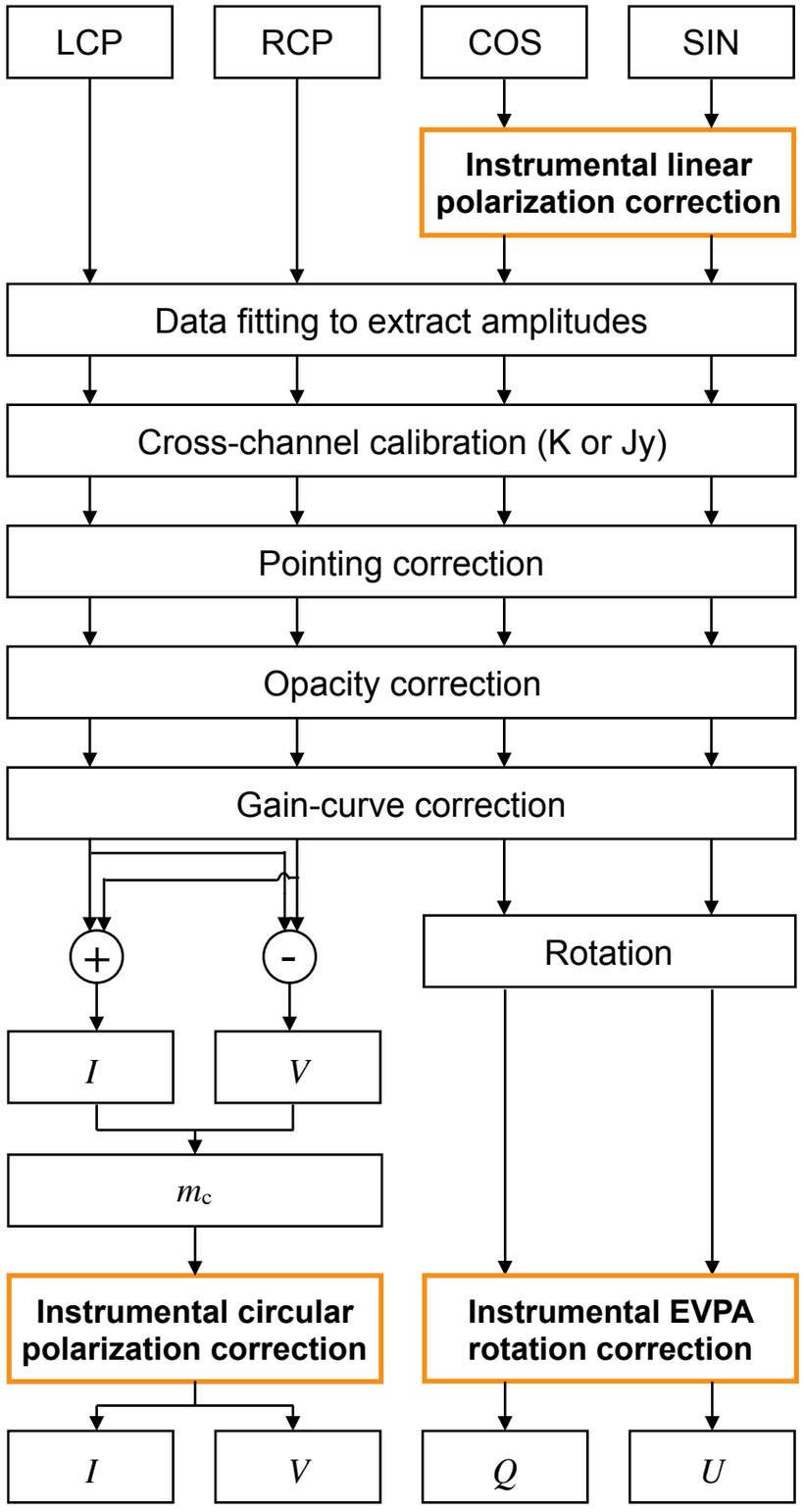
Fuhrmann, Angelakis et al. submitted
Angelakis et al. 2010, astro-ph.CO/1006.5610
Fuhrmann et al. 2007, AIP Conf. Series, Vol. 921, 249–251

Linear and circular polarimetry with Effelsberg

new, high-precision data analysis pipeline

Detailed correction of instrumental effects:
LP, CP, EVPA

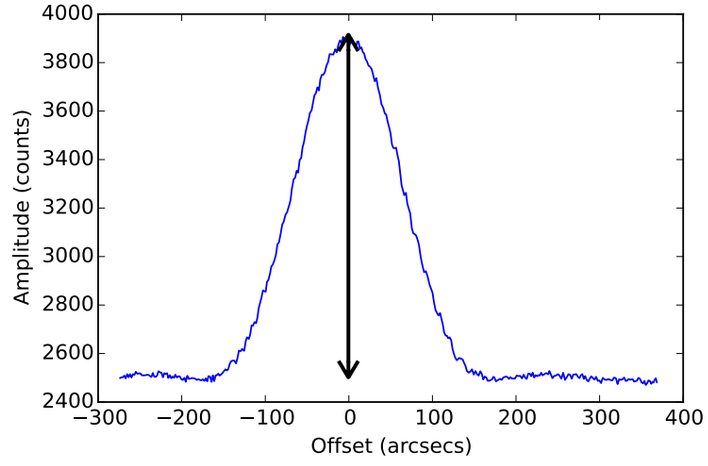
Careful treatment of telescope response



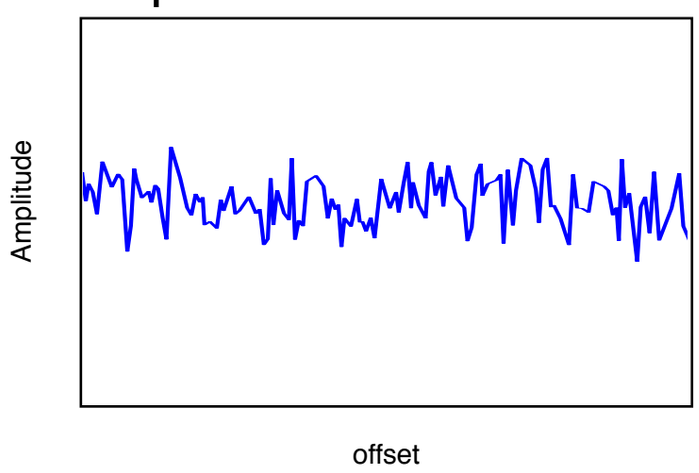
Myserlis, Angelakis et al.,in prep.
Myserlis et al., Galaxies, vol. 4, issue 4, p. 58

Instrumental LP correction

Stokes Q
Polarized source



Stokes Q
Unpolarized source



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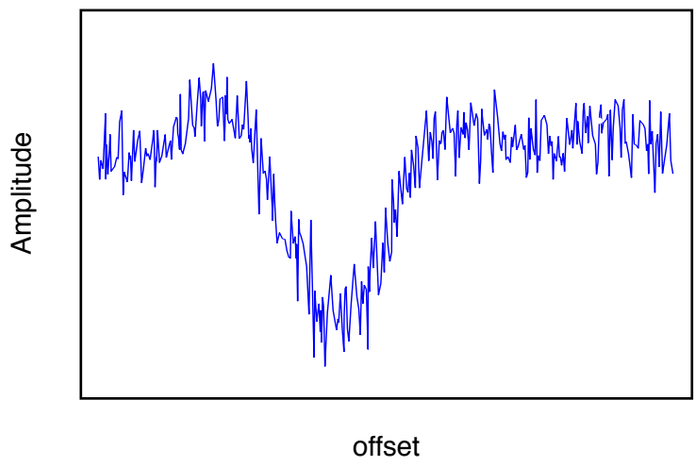

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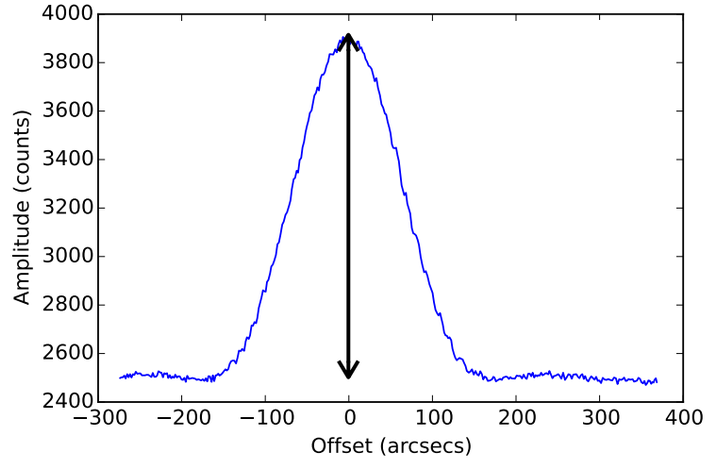


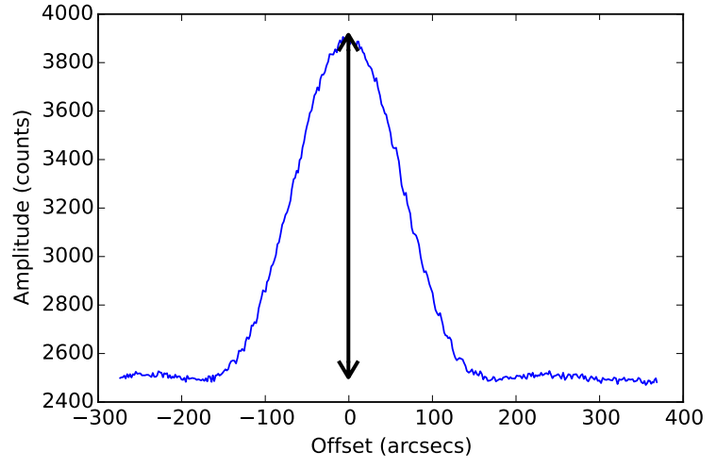
Myserlis, Angelakis et al.,in prep.

Instrumental LP correction

Instrument model

- Parametrization with smooth functions

Stokes Q
Polarized source



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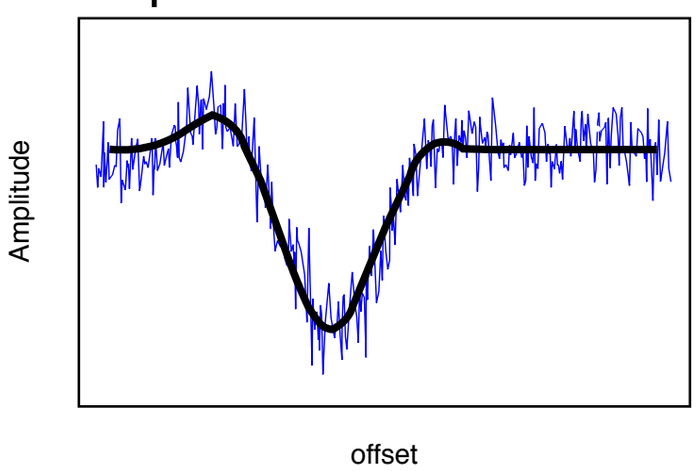

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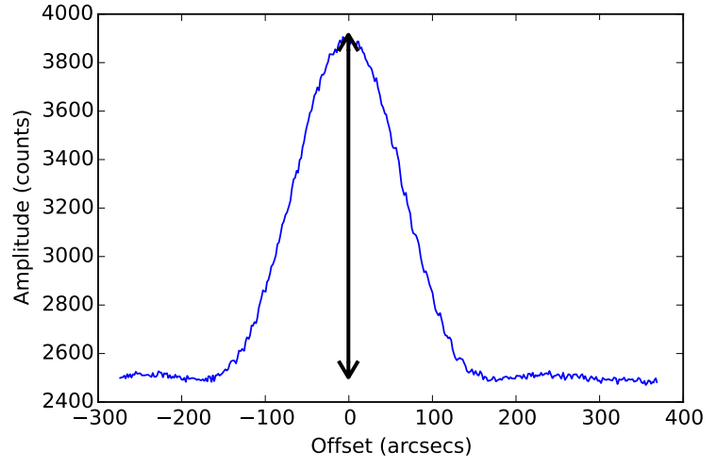

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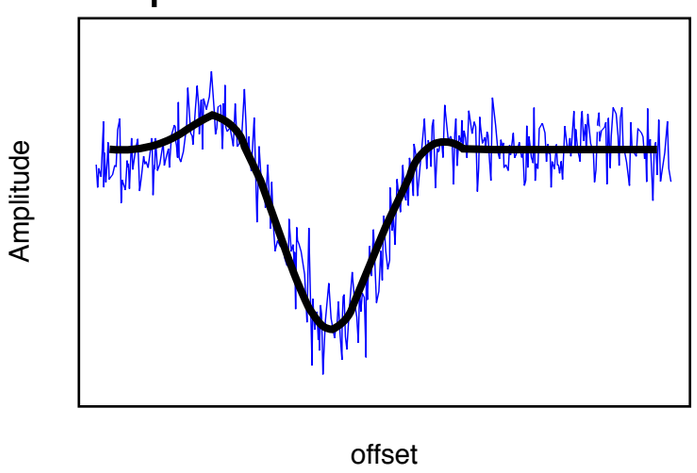
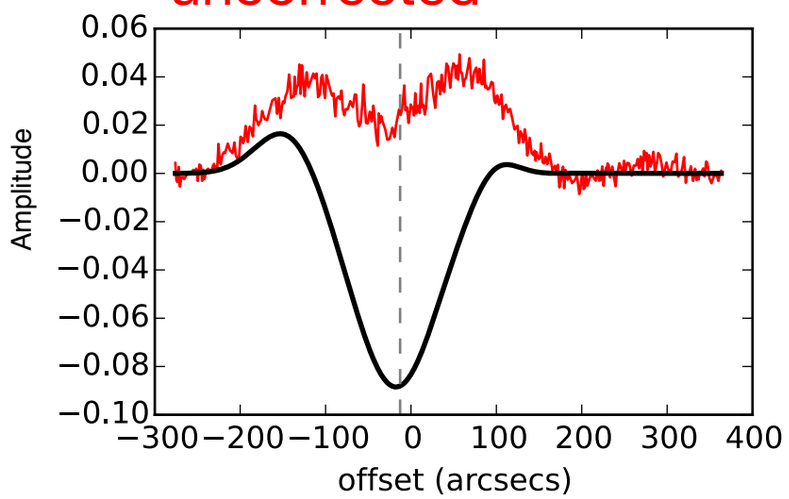


Weakly polarized source
uncorrected



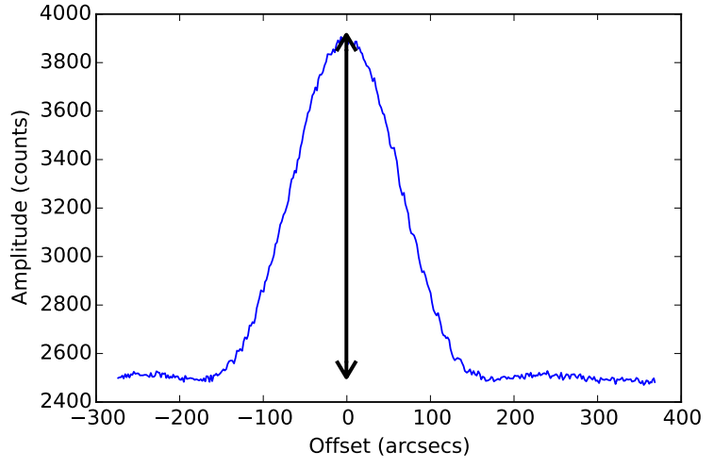
Myserlis, Angelakis et al.,in prep.

Instrumental LP correction

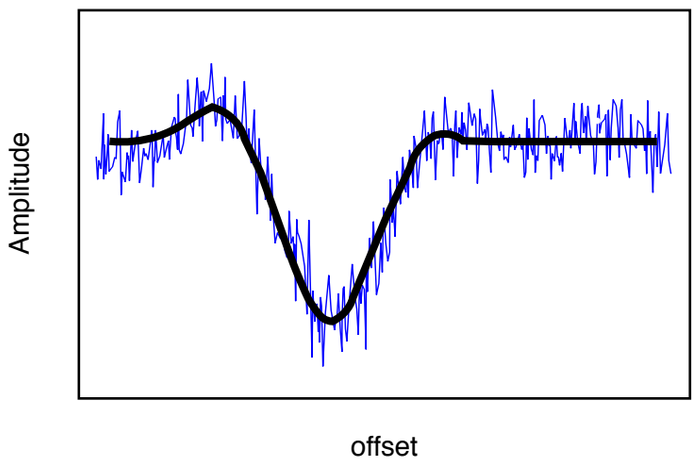
Instrument model

- Parametrization with smooth functions
- We recover significant Q and U from corrupted measurements

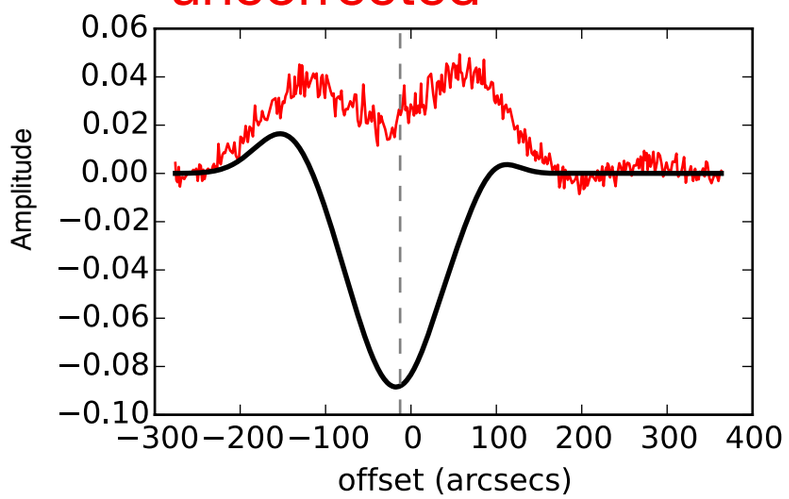
Stokes Q
Polarized source



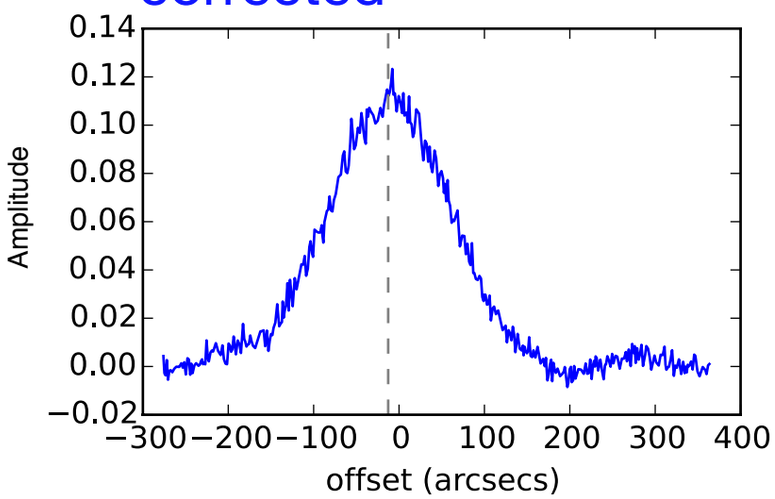
Stokes Q
Unpolarized source



Weakly polarized source
uncorrected



Weakly polarized source
corrected



Myserlis, Angelakis et al.,in prep.

Instrumental EVPA rotation correction

Moon's linear polarization

- LP degree maximized towards limb

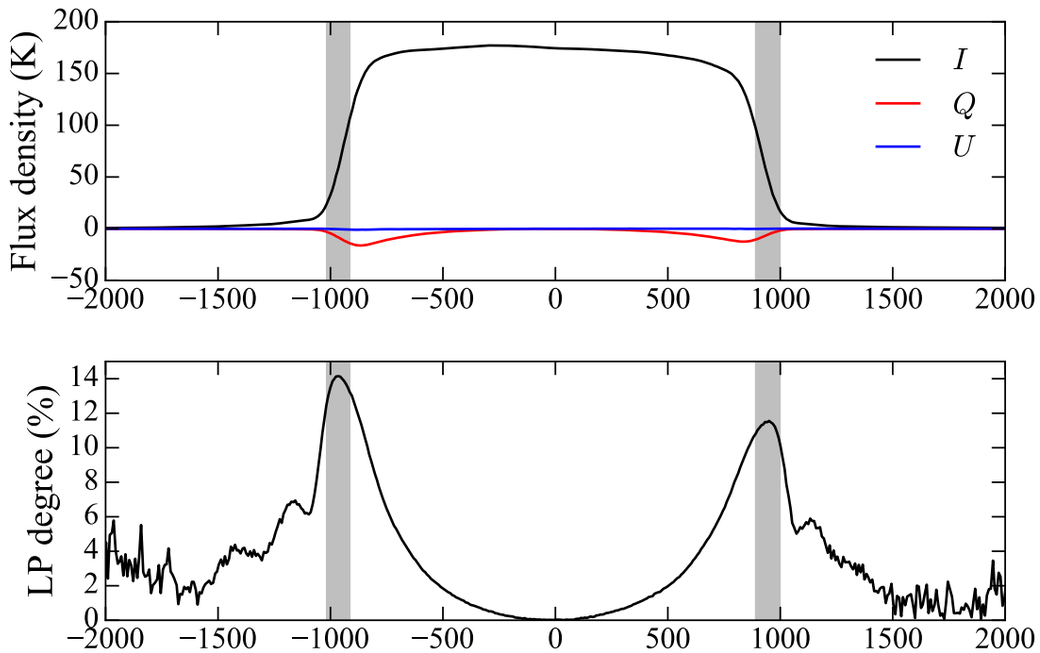
- Radially oriented EVPA

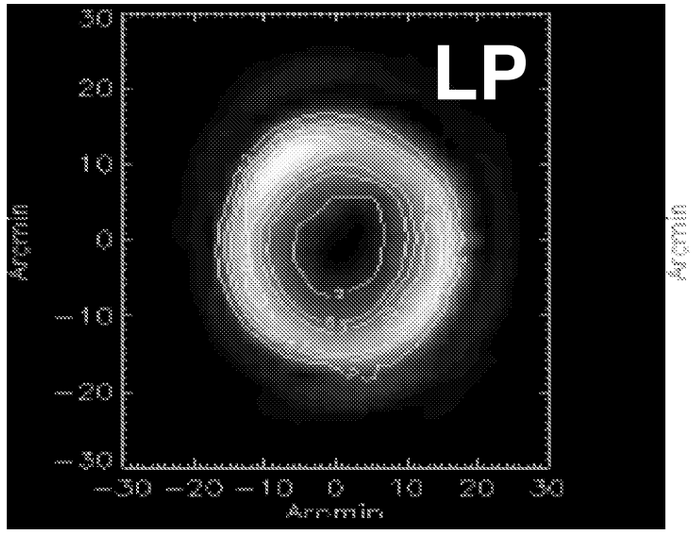
Scanning directions: 0°, 30°, 45°, 60°, 90°, 120°, 135°, 150°

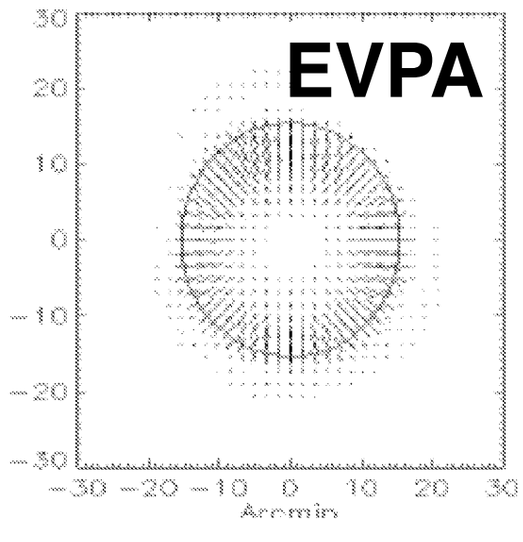
Instrumental rotation

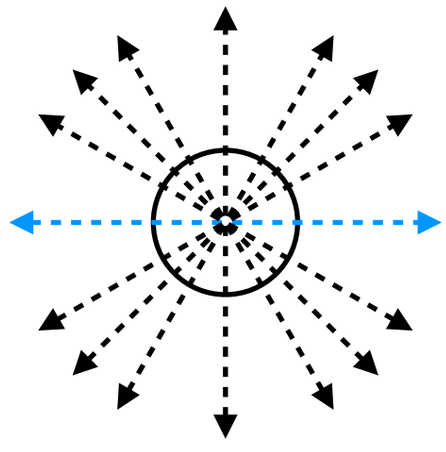
- 4.85 GHz: 1.26 ± 0.11°

- 8.35 GHz: -0.50 ± 0.12°









Poppi et al. 2002, AIP Conf. Proceedings, Vol. 609, 187–192
Myserlis, Angelakis et al.,in prep.

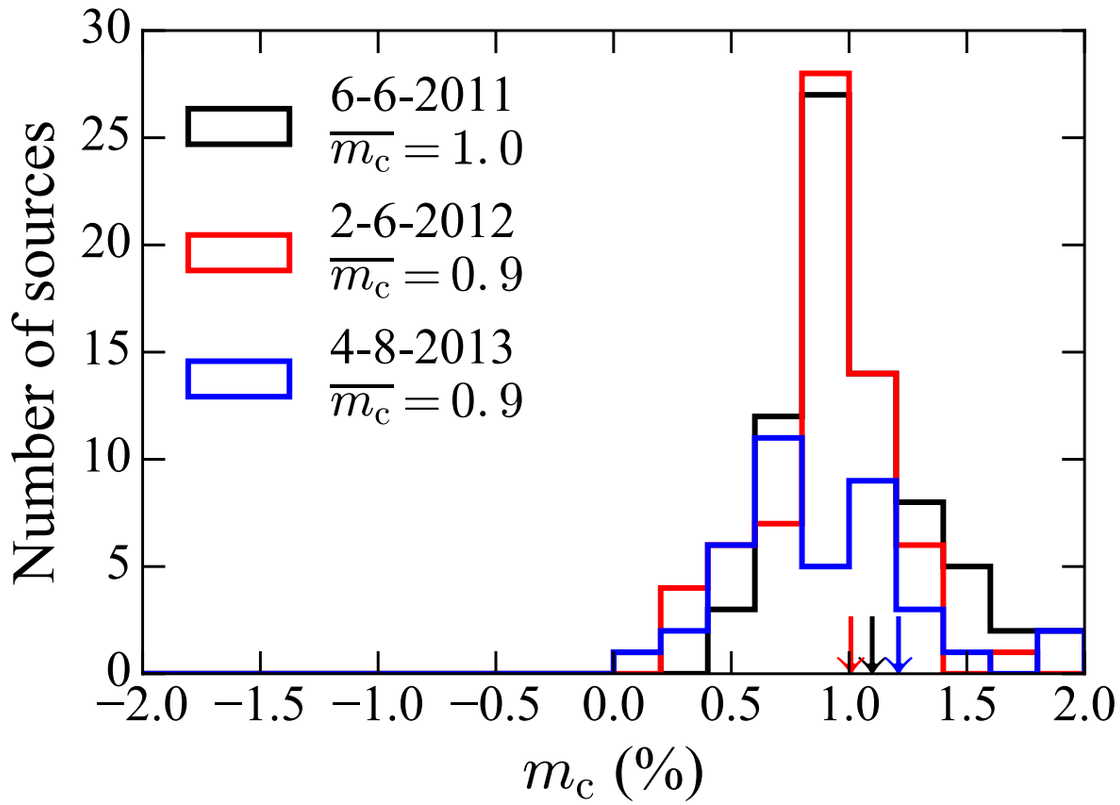
Instrumental CP correction

Indications of instrumental CP

- CP degree distributions centered at non-zero value
- Non-zero CP measurements of unpolarized sources

Sensitivity imbalance between left- and right-circularly polarized feeds, r

$$m_{\rm c} = \frac{m'_{\rm c} r + m'_{\rm c} + r - 1}{m'_{\rm c} r - m'_{\rm c} + r + 1}$$



Myserlis, Angelakis et al.,in prep.

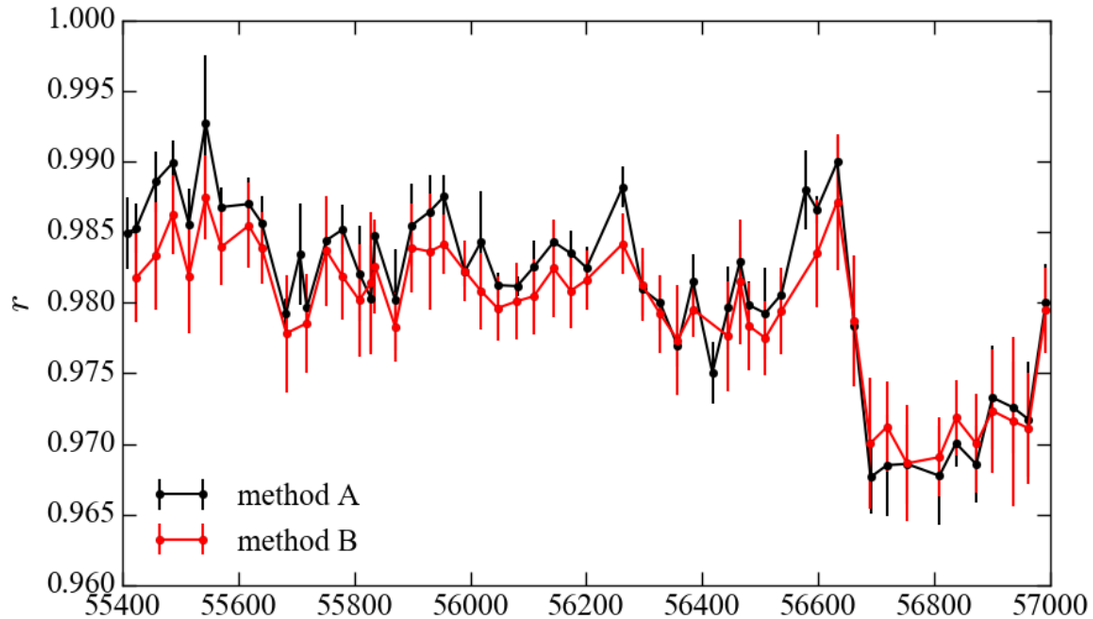
Instrumental CP correction

r estimation methods:

A. Unpolarized sources

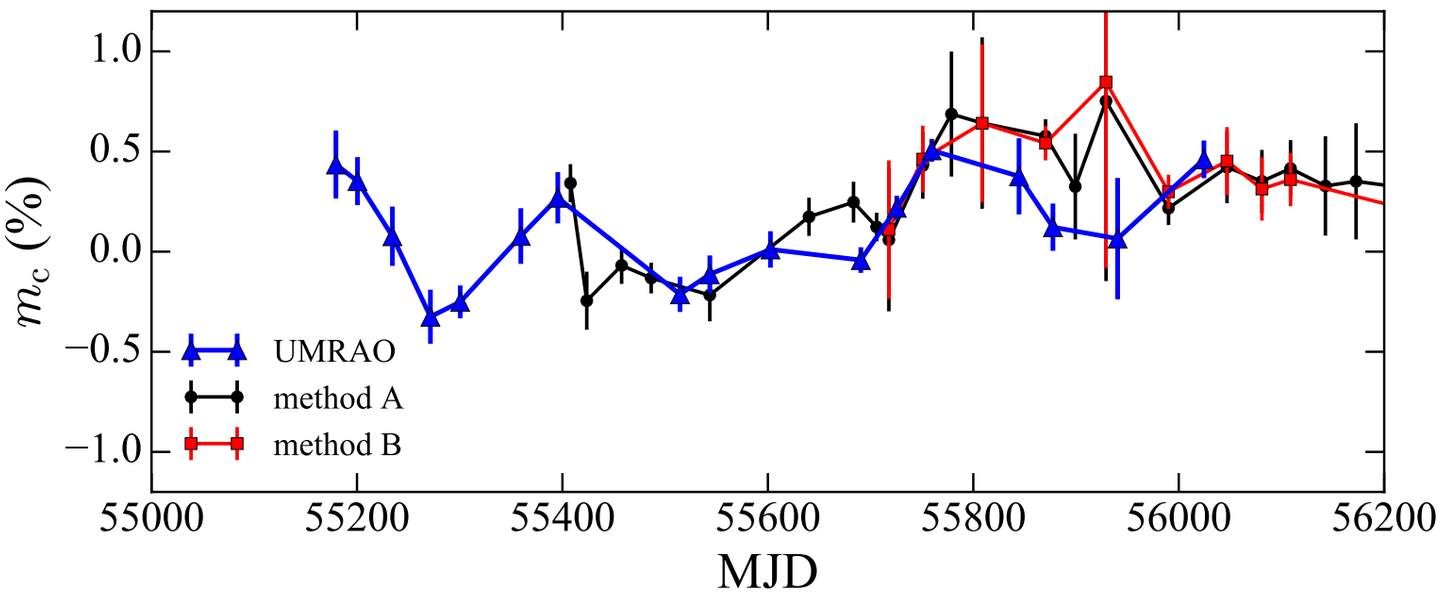
B. Sources with stable CP

- Singular value decomposition (SVD)
- No need to know their CP *a priori*



Comparison with UMRAO dataset

- 169 concurrent measurements
- 5 sources
- median $|\Delta m_c|$: 0.2 %



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Comparison with Müller matrix correction

Principle

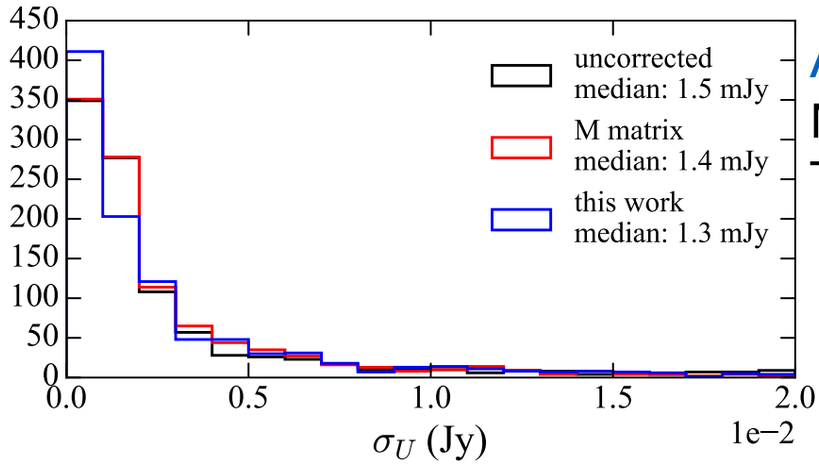
$$S_{\mathrm{corr}} = \mathbf{M}^{-1} \cdot S_{\mathrm{obs}}$$

Fundamental advantages of our method

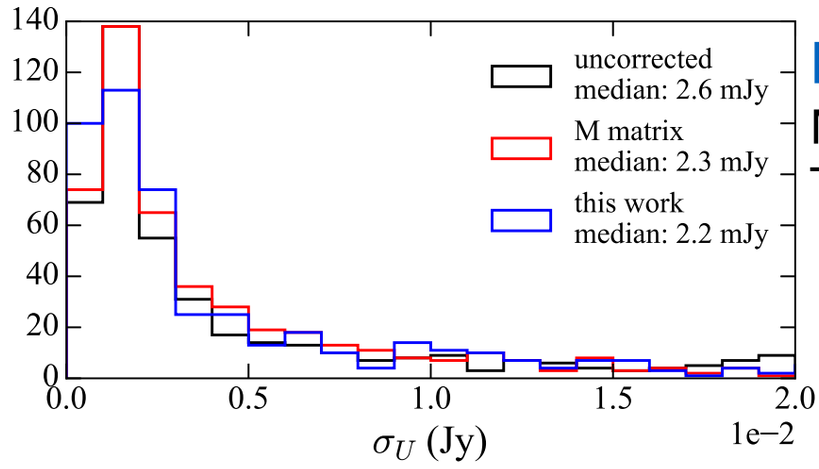
- Correct the spatial dependence of instrumental LP
- No need to know the CP of stable sources *a priori*

Comparison measure

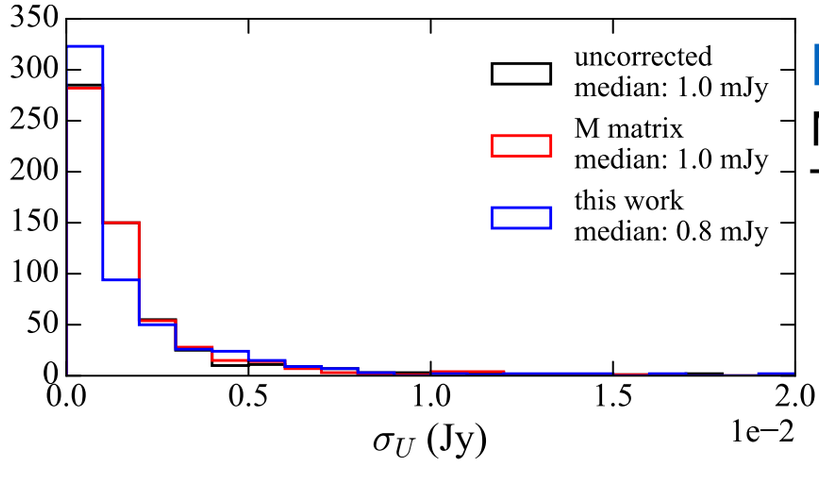
- Intra-session variability of Stokes I, Q and U
- 4—20 % less intra-session variability
- Improved performance for the low LP data



All sources
Müller: -6.7 %
This work: -13.3 %



High LP
Müller: -11.5 %
This work: -15.4 %



Low LP
Müller: -0.0 %
This work: -20.0 %

Myserlis, Angelakis et al.,in prep.

Linear and circular polarimetry with Effelsberg

new, high-precision data analysis pipeline

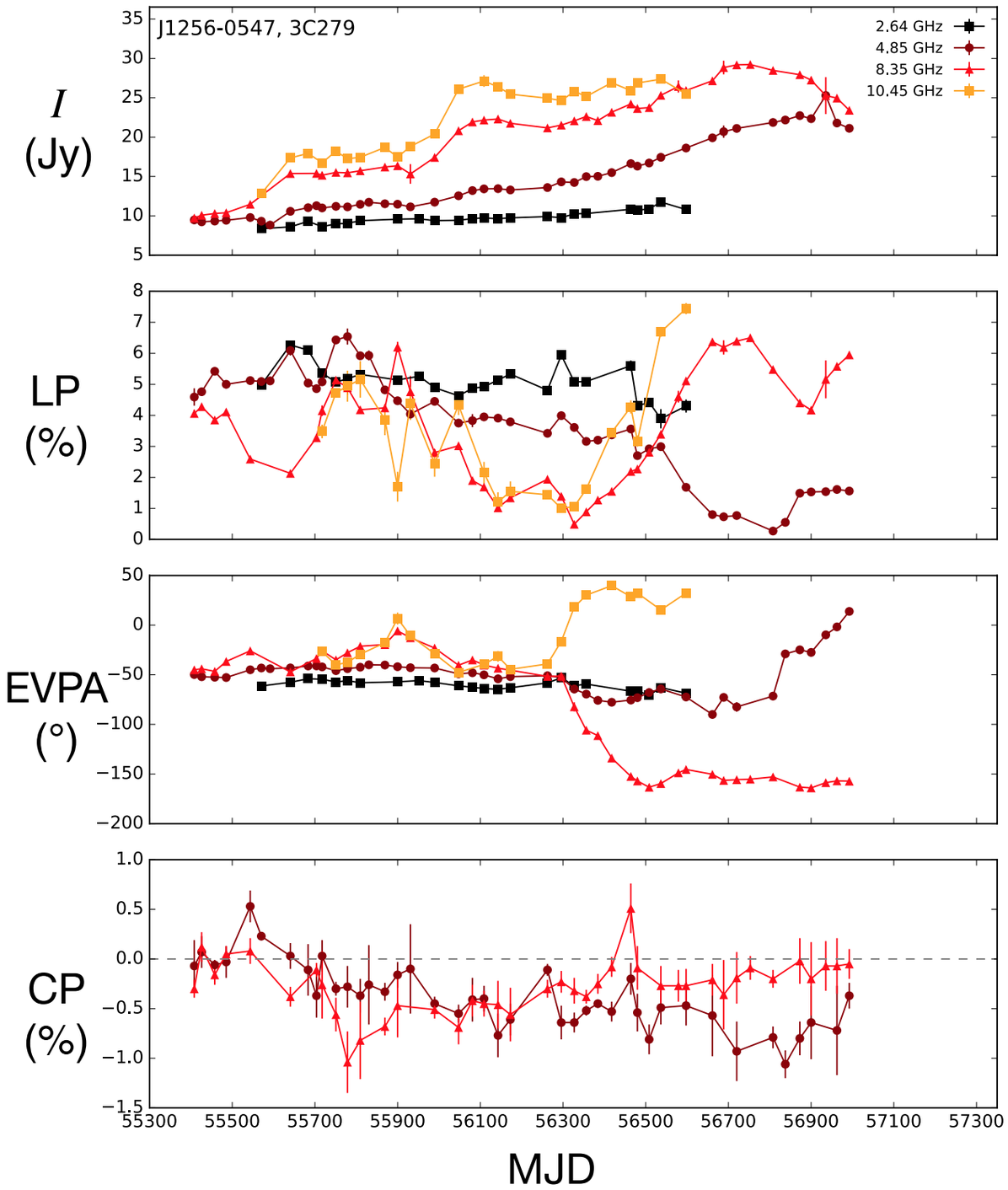
Uncertainties:

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

High-cadence, Full-Stokes lightcurves

Polarimetric standards:

- LP degree: 5 sources
- CP degree: 4 sources
- EVPA: 8 sources



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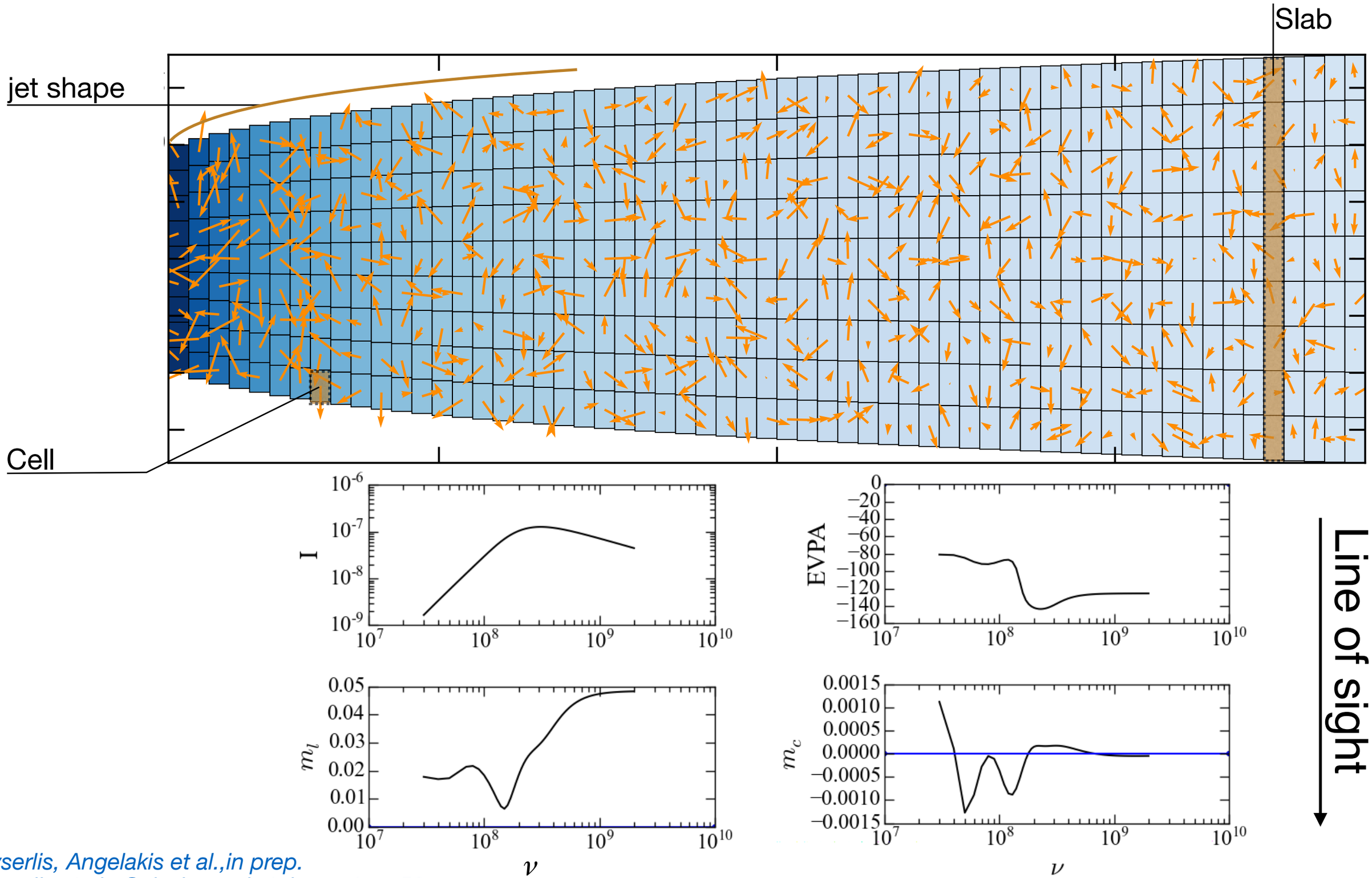
Constraining the jet physical conditions

by modeling the linear and circular polarization variability



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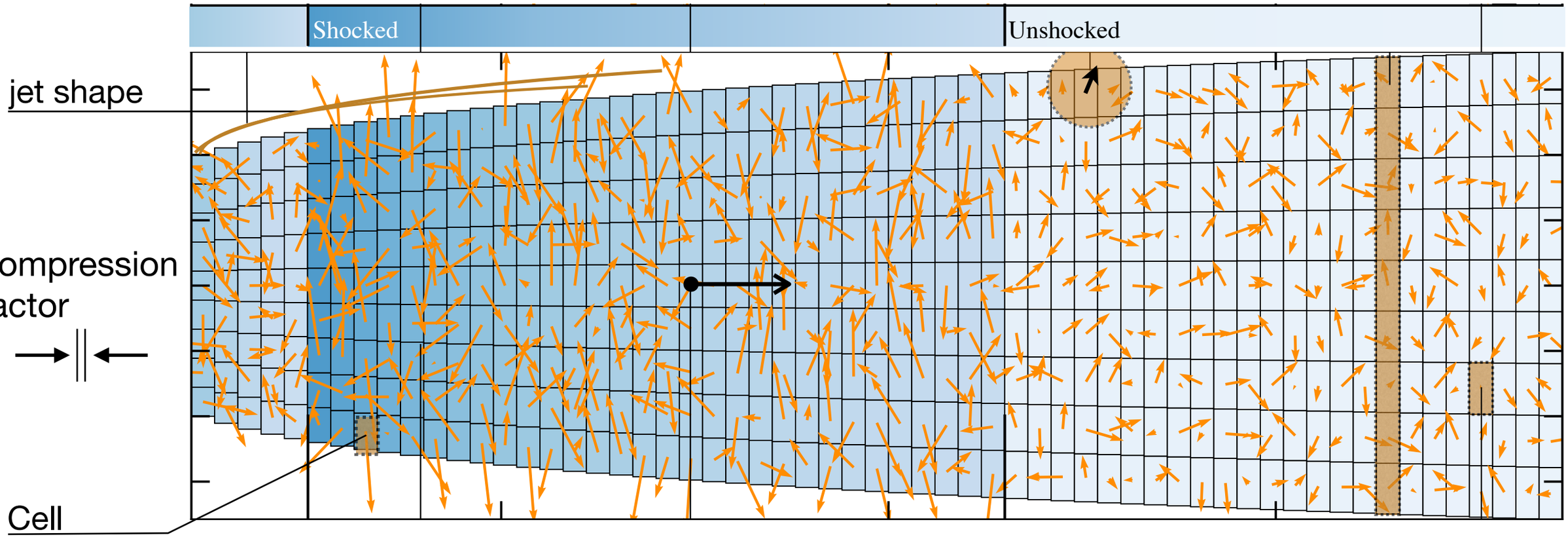

Density

$$n'_0 = n_0 k^{-\frac{s+3}{6}}$$

Lower energy cutoff

$$E'_{\rm min} = E_{\rm min} k^{-\frac{1}{3}}$$

B-field strength

$$B' \sim kB$$

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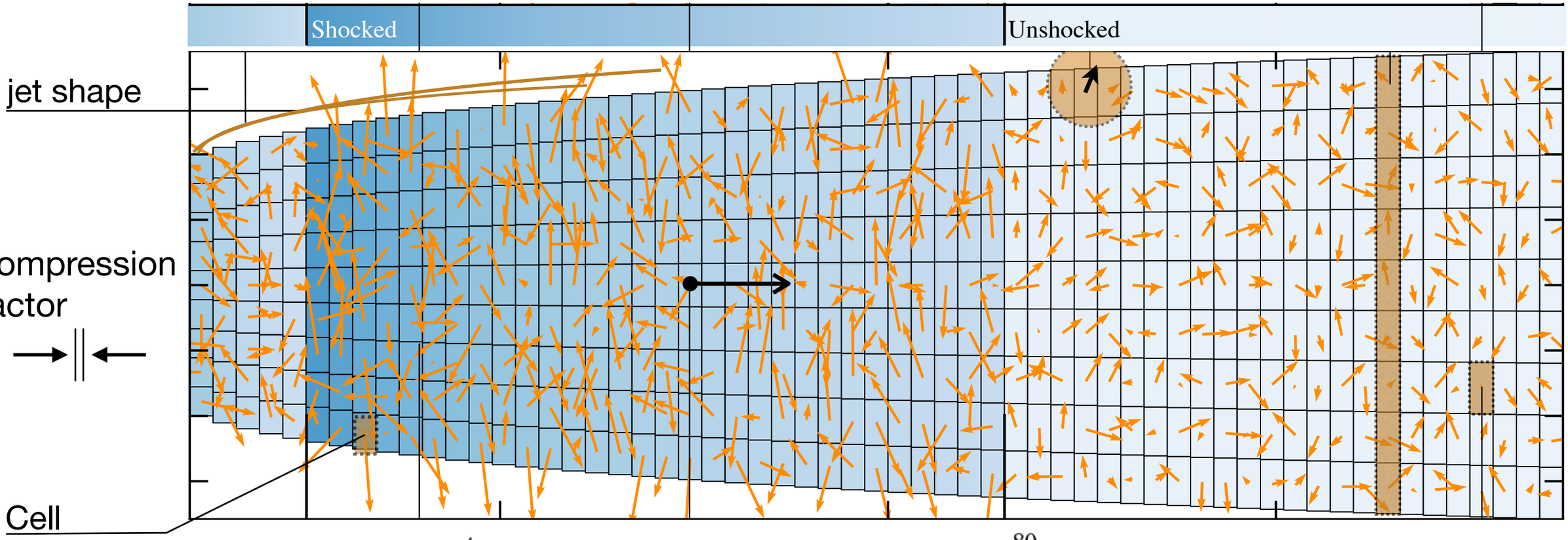

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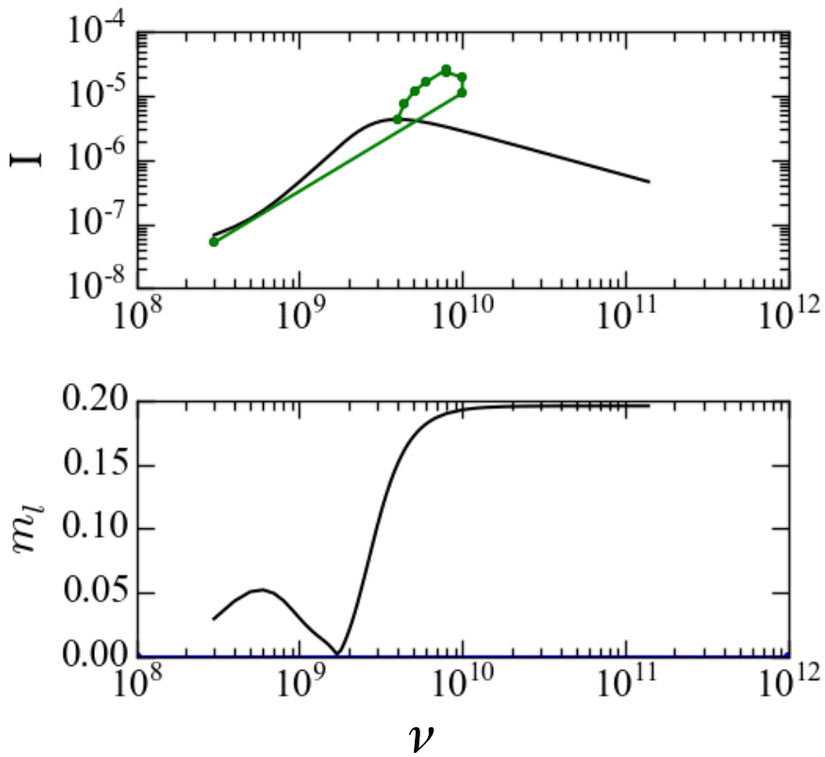

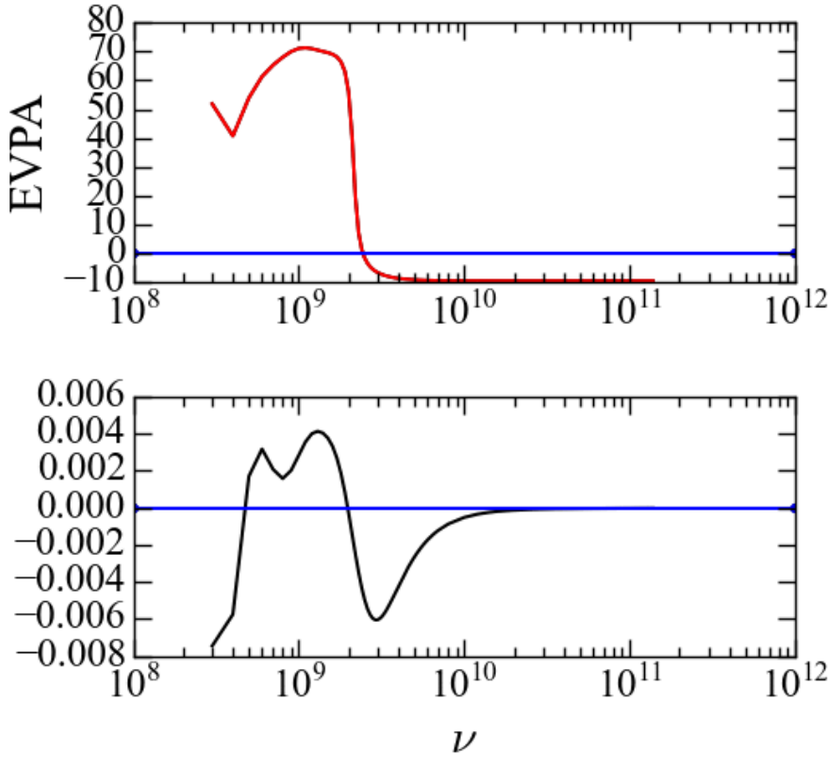

Line of sight

Constraining the jet physical conditions

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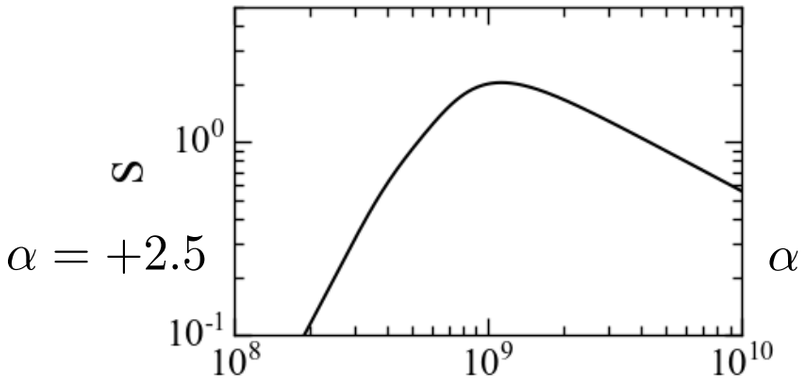
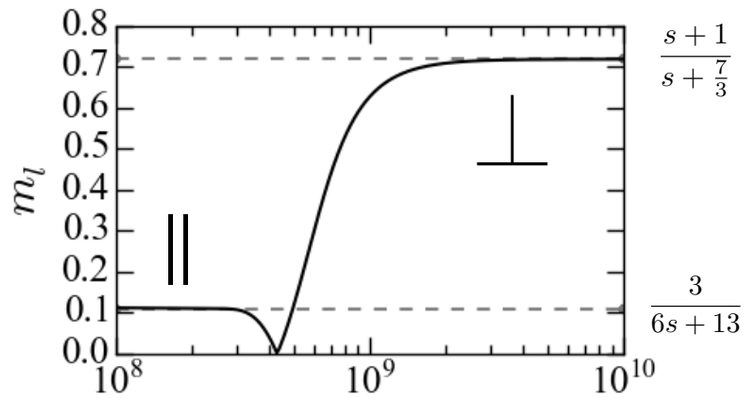
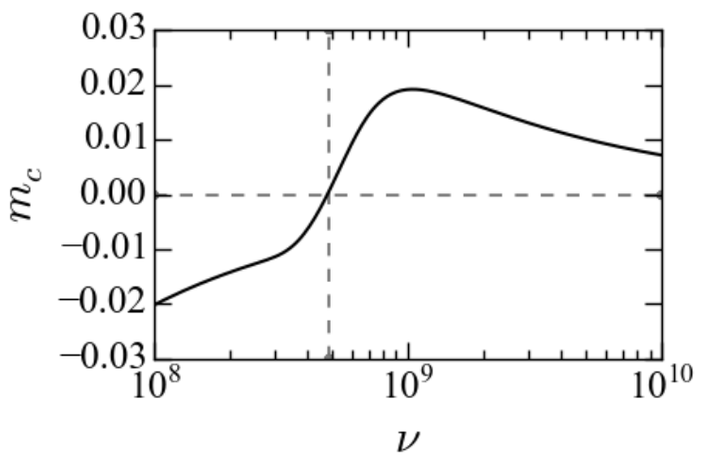
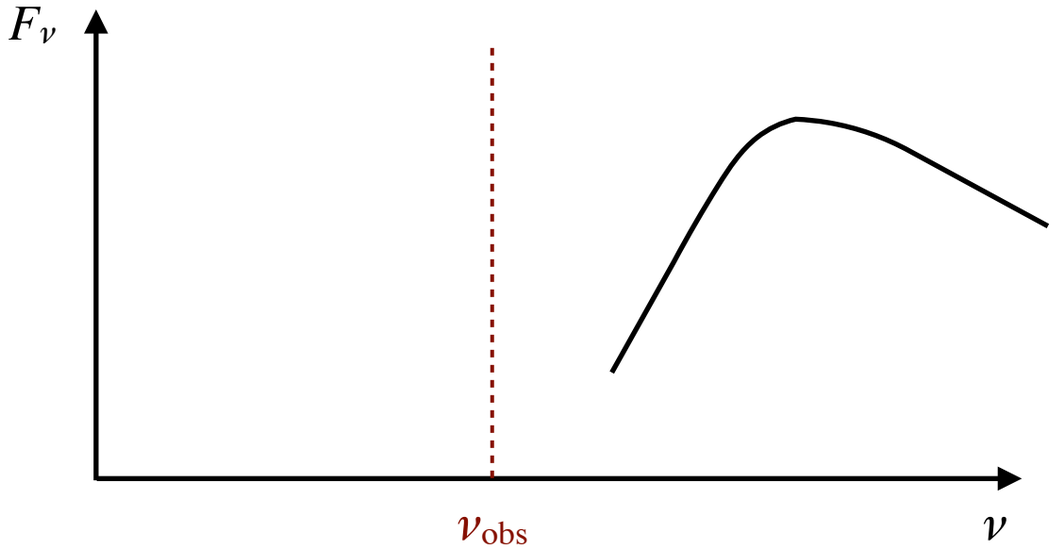


$\alpha = +2.5$

$\alpha = -\dfrac{s-1}{2}$







optical depth

χ 90°-flip

$m_l \to 0$

$m_c \to 0$

$S \to S_{max}$

frequency, time

Constraining the jet physical conditions

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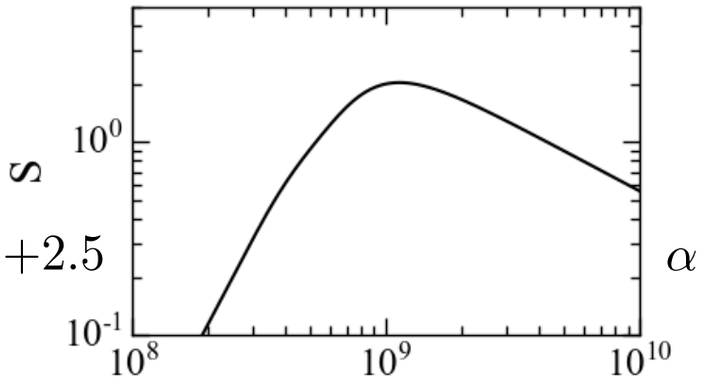

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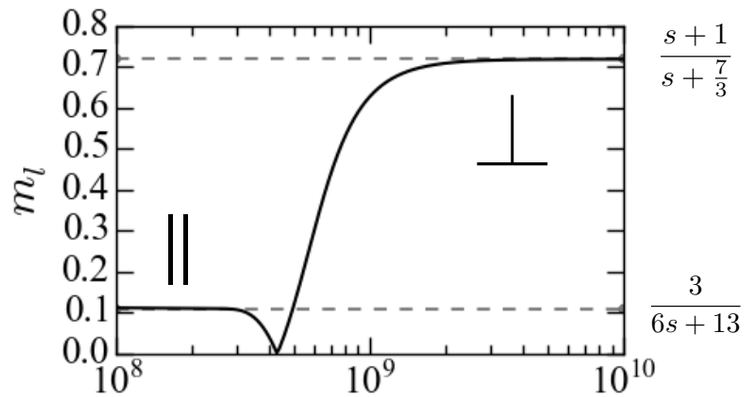

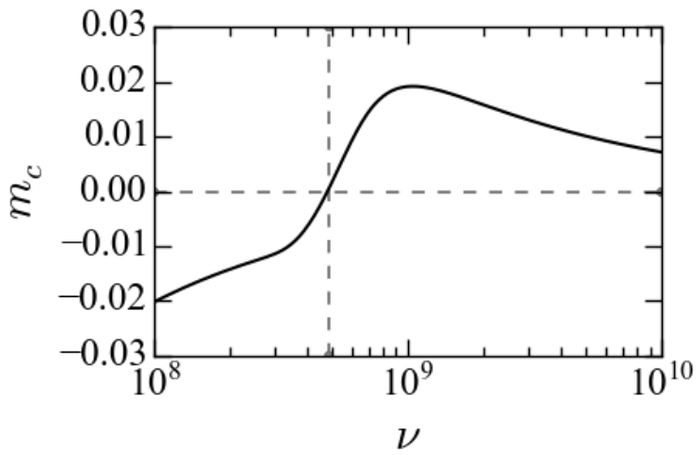

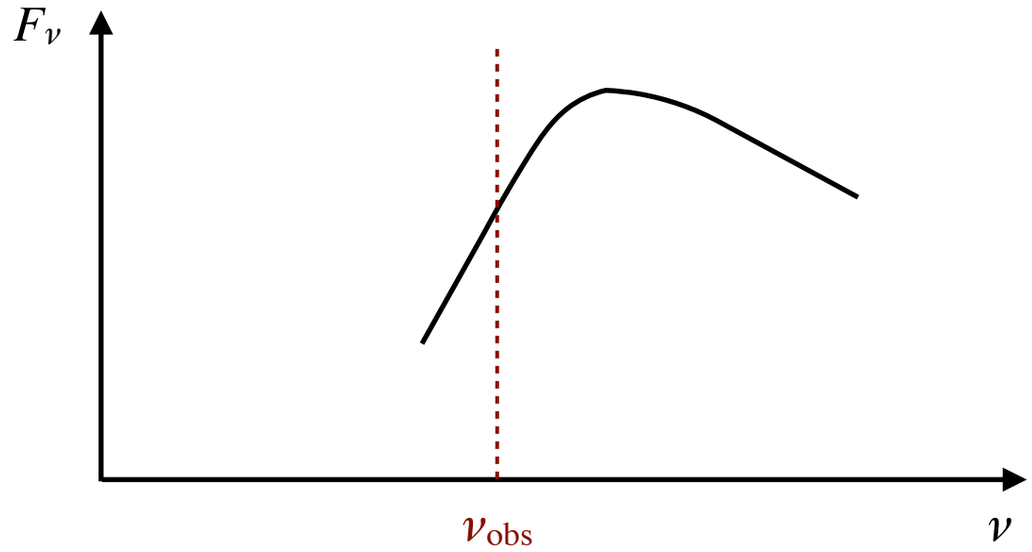

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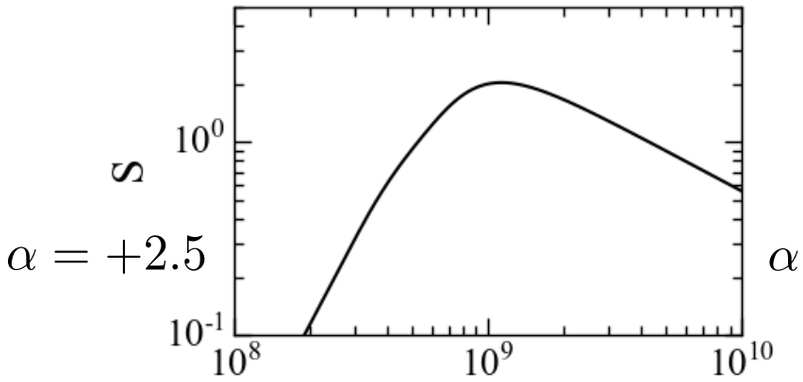

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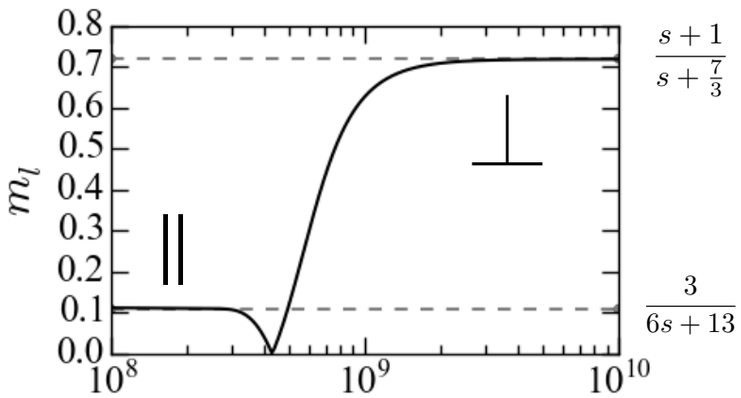

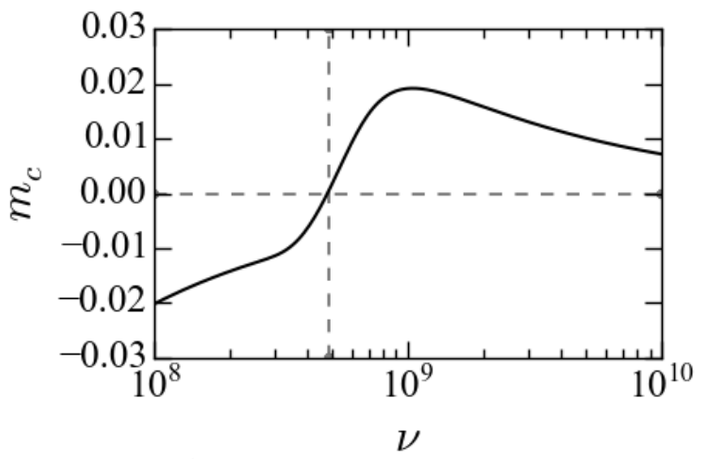

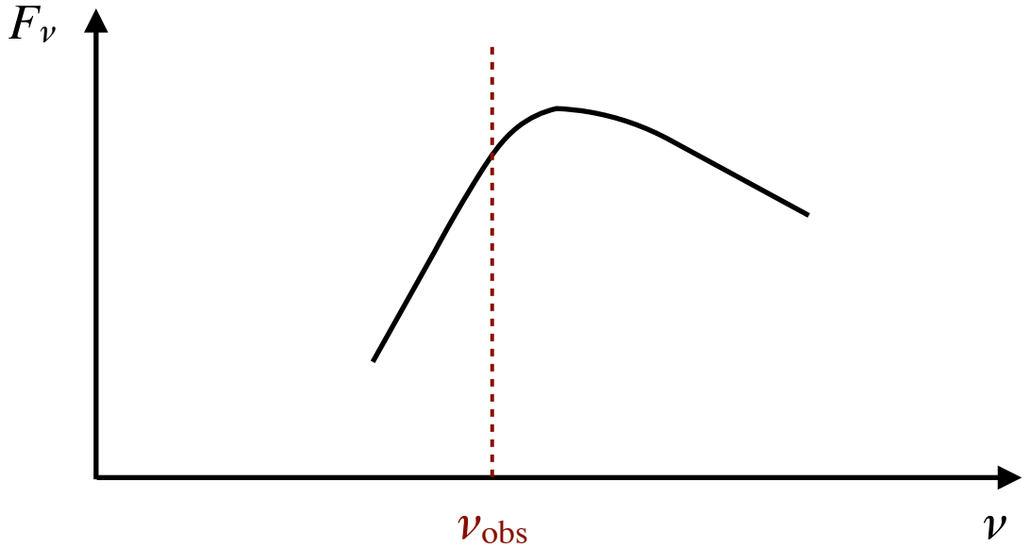

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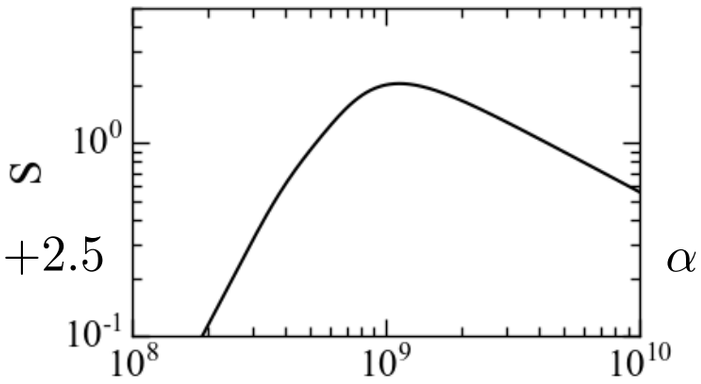

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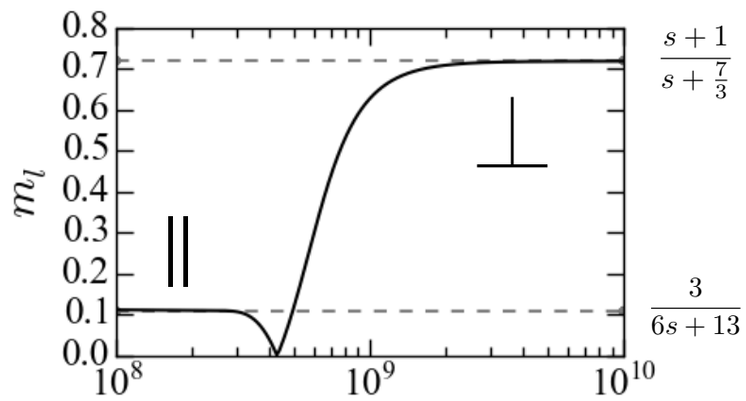

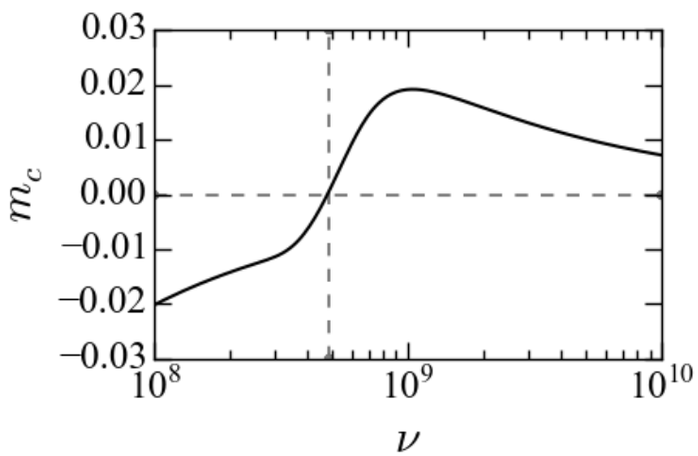

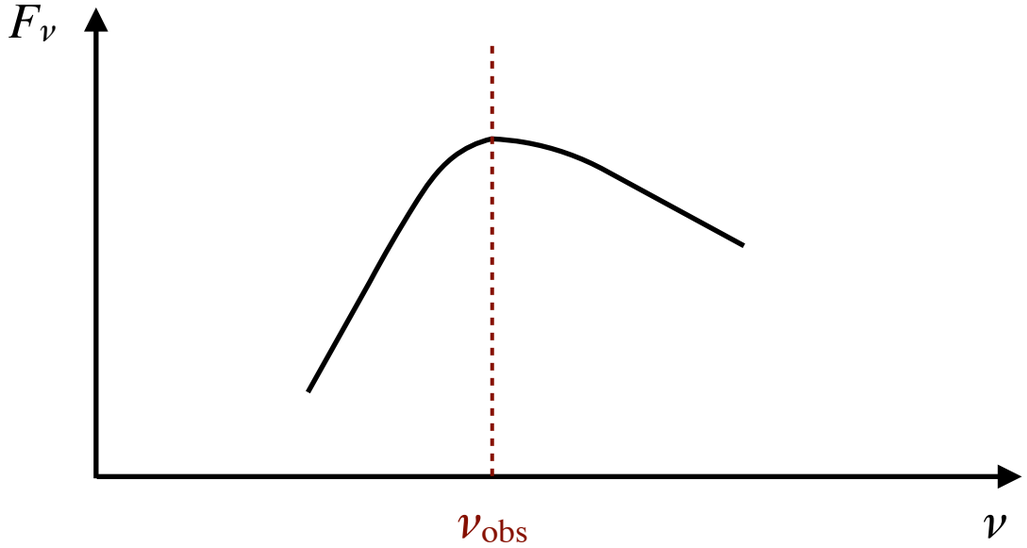

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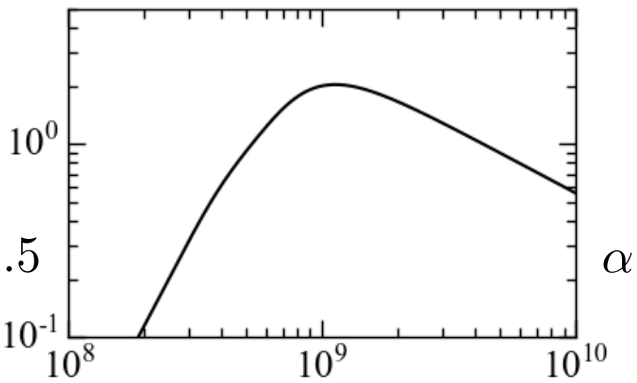
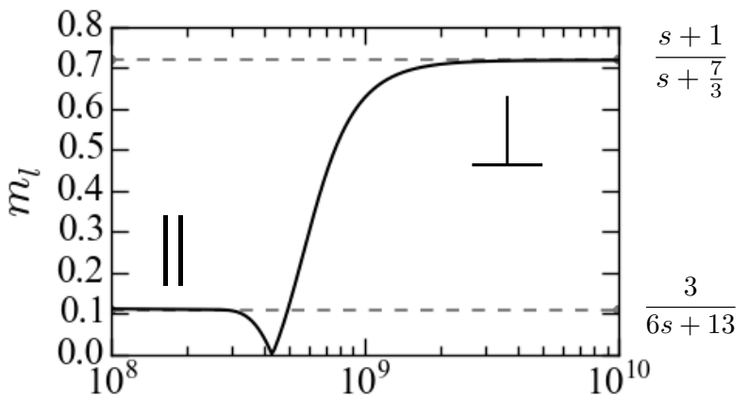
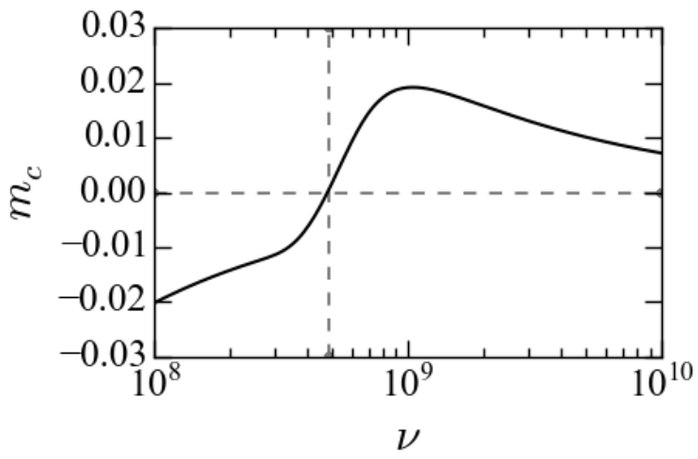
by modeling the linear and circular polarization variability

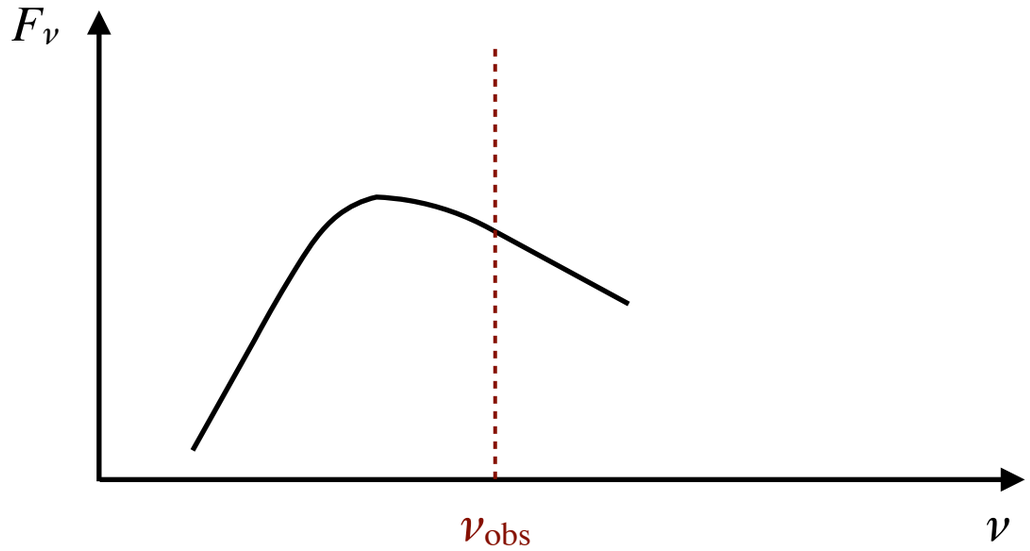
$\alpha = +2.5$



$\alpha = -\frac{s-1}{2}$







optical depth

χ 90°-flip

$m_l \to 0$

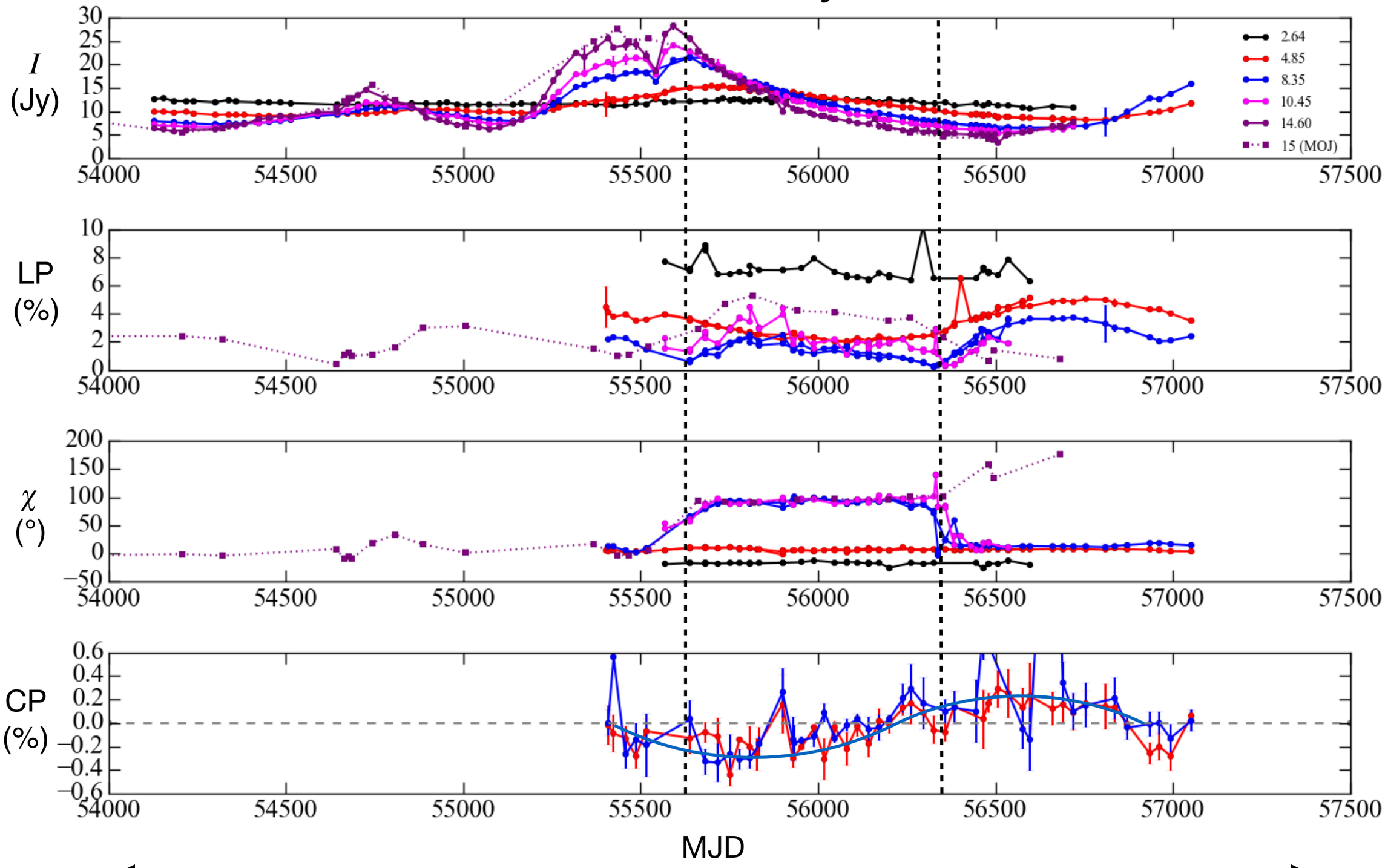
$m_c \to 0$

$S \to S_{max}$

frequency, time

3C 454.3

a case study



optical depth

χ 90°-flip

$m_l \to 0$

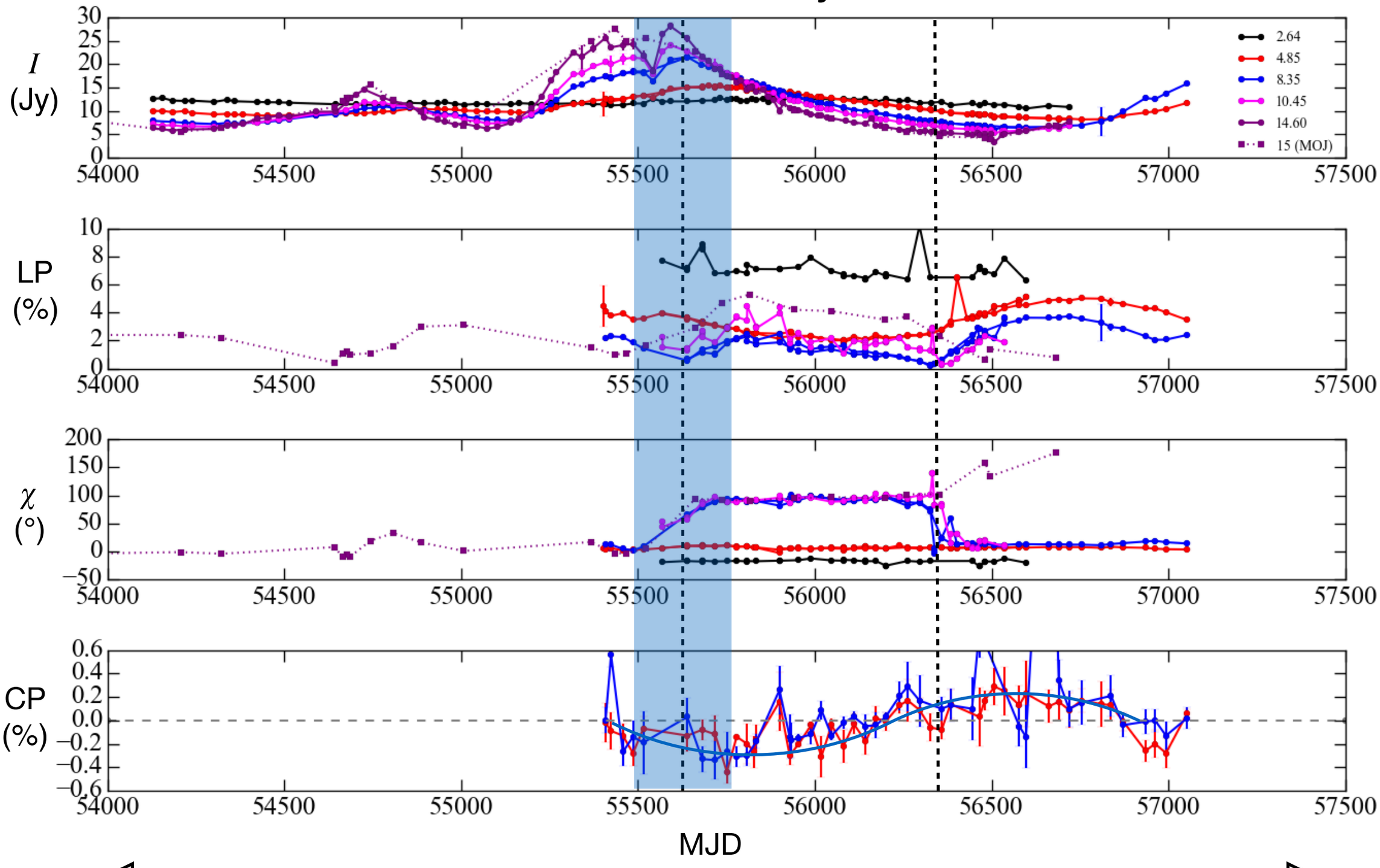
$m_c \to 0$

$S \to S_{max}$

frequency, time

3C 454.3

a case study



optical depth

χ 90°-flip

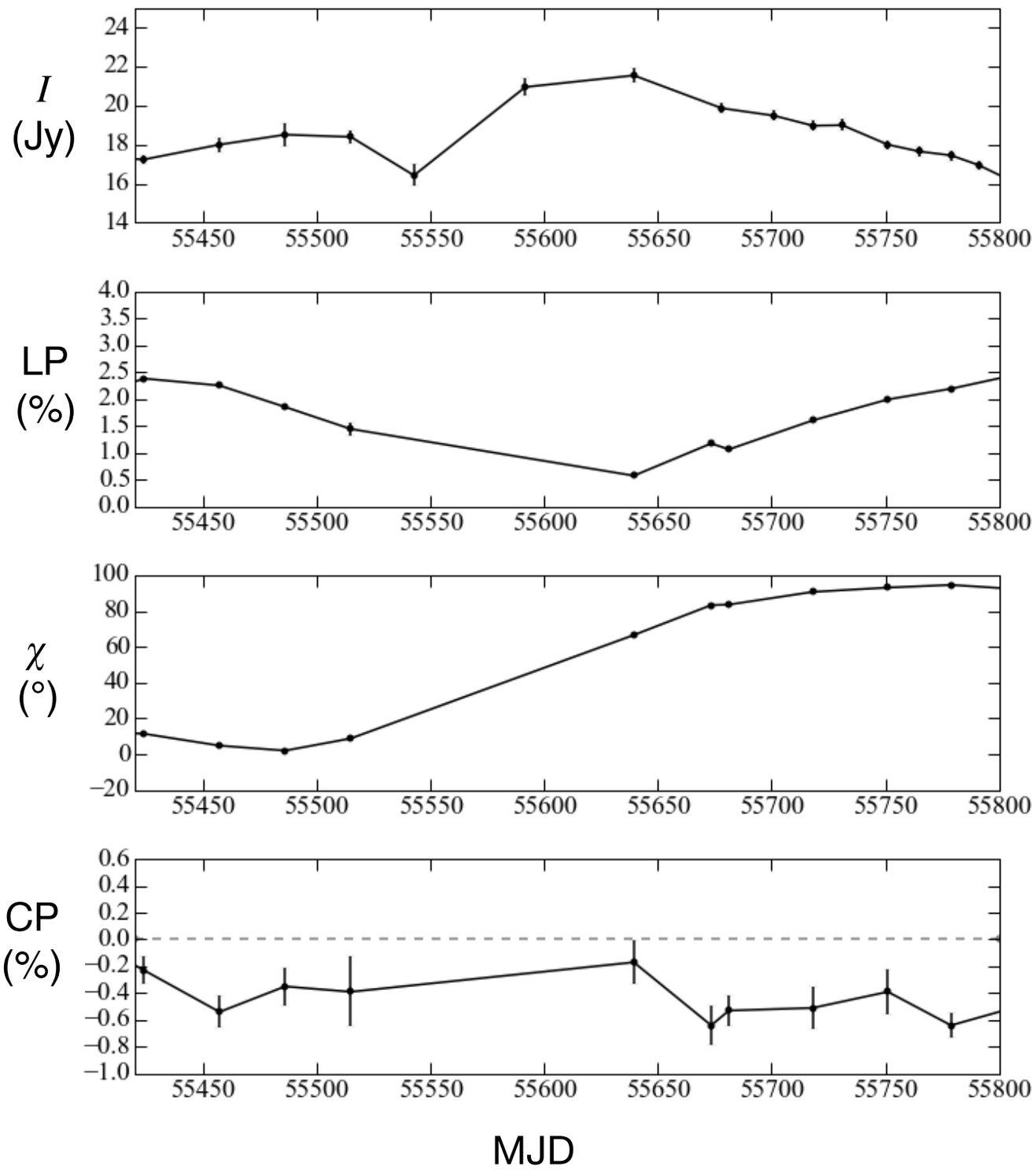
$m_l \to 0$

$m_c \to 0$

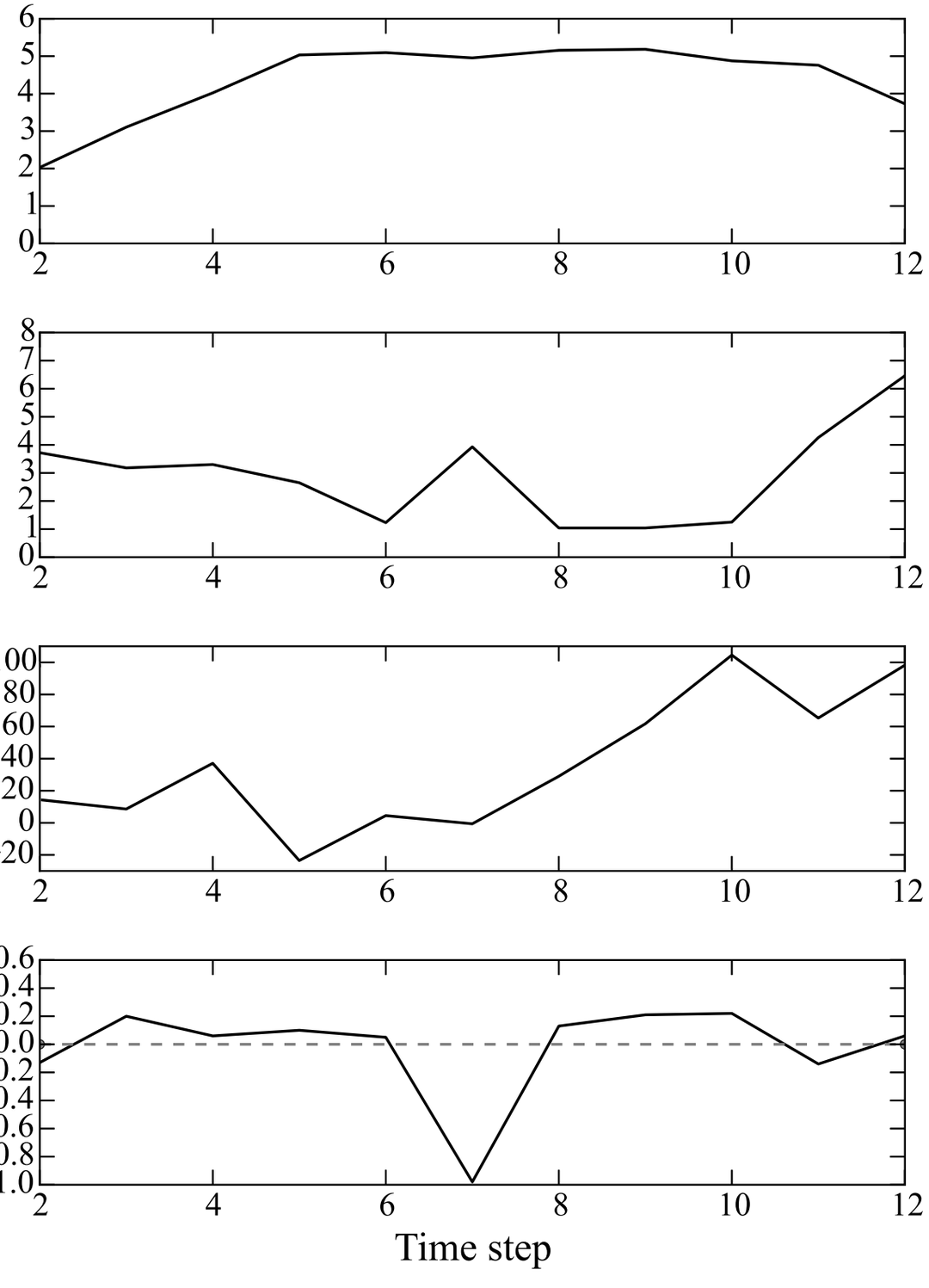
$S \to S_{max}$

frequency, time

Observed lightcurves
8.35 GHz



Synthetic lightcurves
8.35 GHz



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

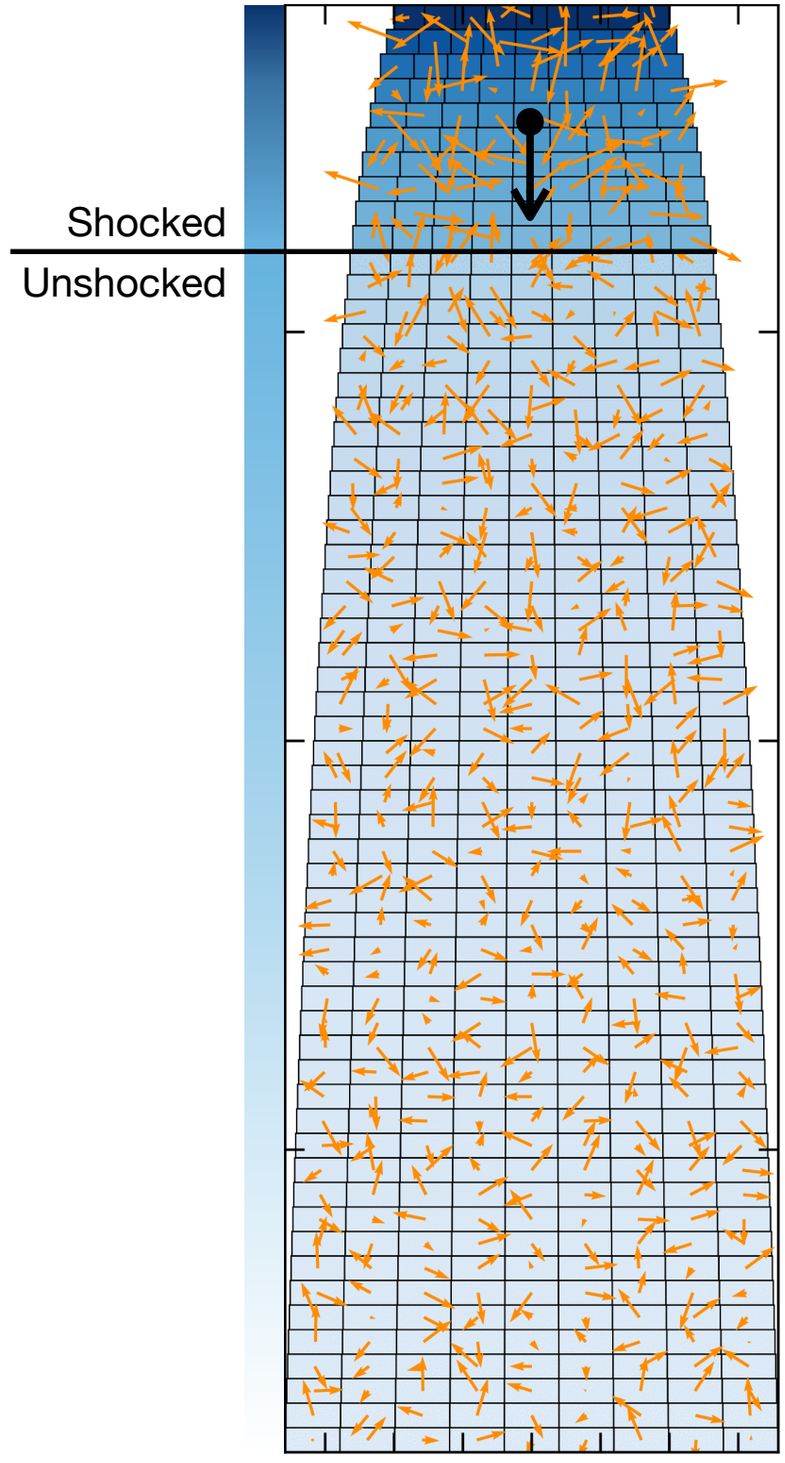
Constraining the jet physical conditions
by modeling the linear and circular polarization variability

Shocked flow parameters

- Compression factor: $k = 0.8$
- Doppler factor: D ~ 30, consistent with D_{var} at 37 GHz
  Hovatta et al. 2009, A&A, 494, 527

Unshocked flow 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

Summary

Radio monitoring → physical conditions of AGN jets

F-GAMMA monitoring program

- multi-frequency, high-cadence, Full-Stokes dataset

- ~90 sources

- 8 years

New, high-precision LP and CP calibration for the Effelsberg telescope

LP and CP variability → constrain physical conditions of the jet plasma

Future work

Extend polarization database in time (2007–2015) and frequency (2.64–23.05 GHz)

Further applications of LP and CP modeling: AGN jets, low velocity outflows, micro-quasars, X-ray binaries, supernova remnants

Comparison with polarized VLBI maps