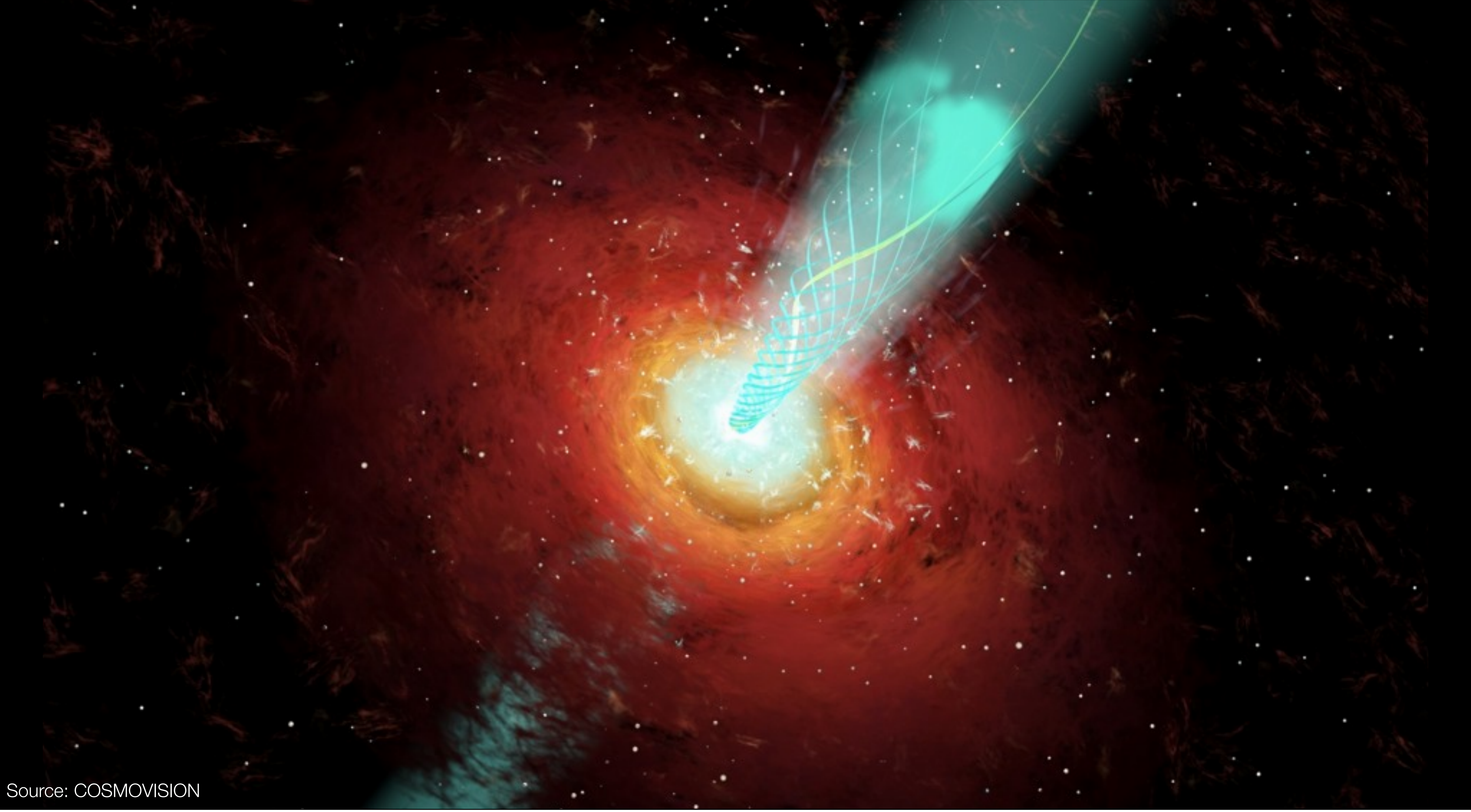

Blazar physics through multi-band linear and circular polarization monitoring

I. Myserlis

PhD Advisor: Dr. E. Angelakis

Collaborators:
Dr. L. Fuhrmann, Prof. V. Pavlidou, I. Nestoras,
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Max-Planck Institut für Radioastronomie

Blazars

Jet on the line of sight

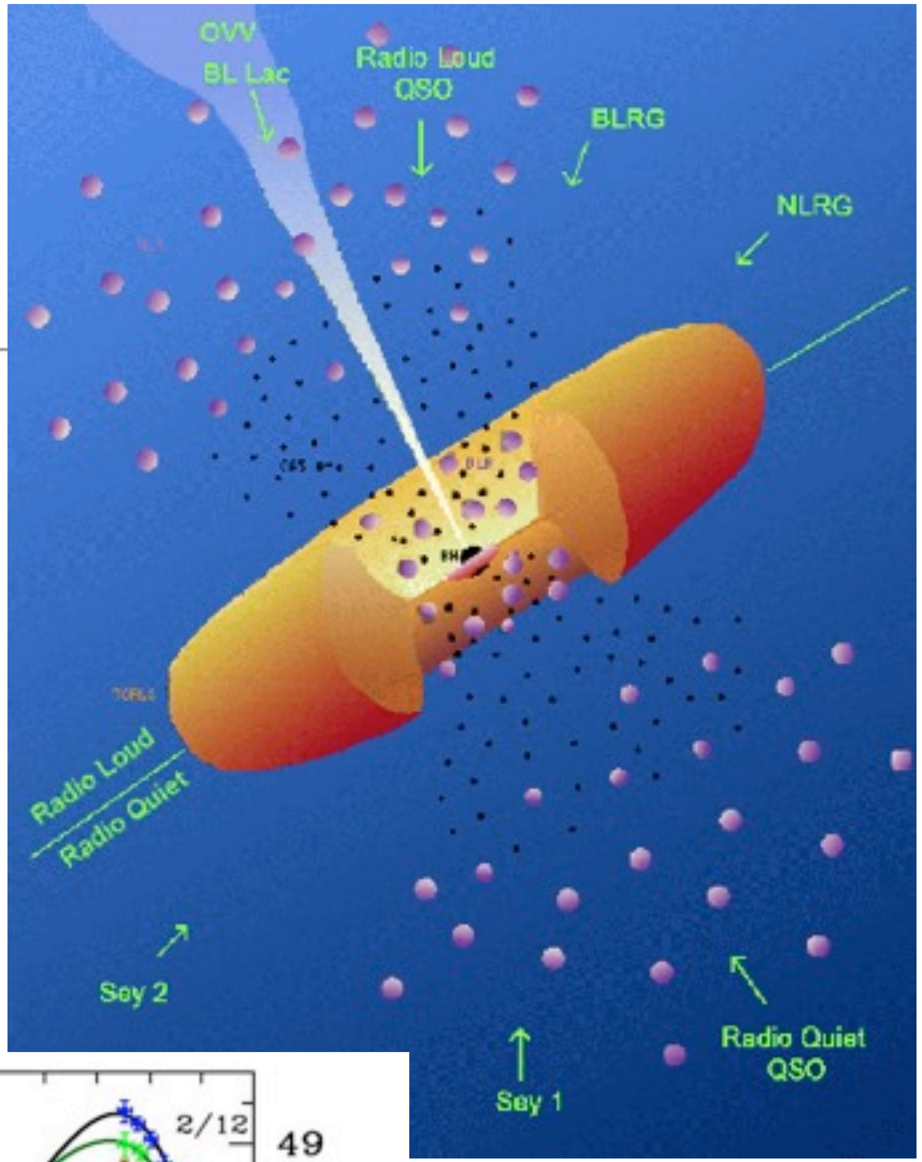
Broadband 2 humped SED

Extreme variability

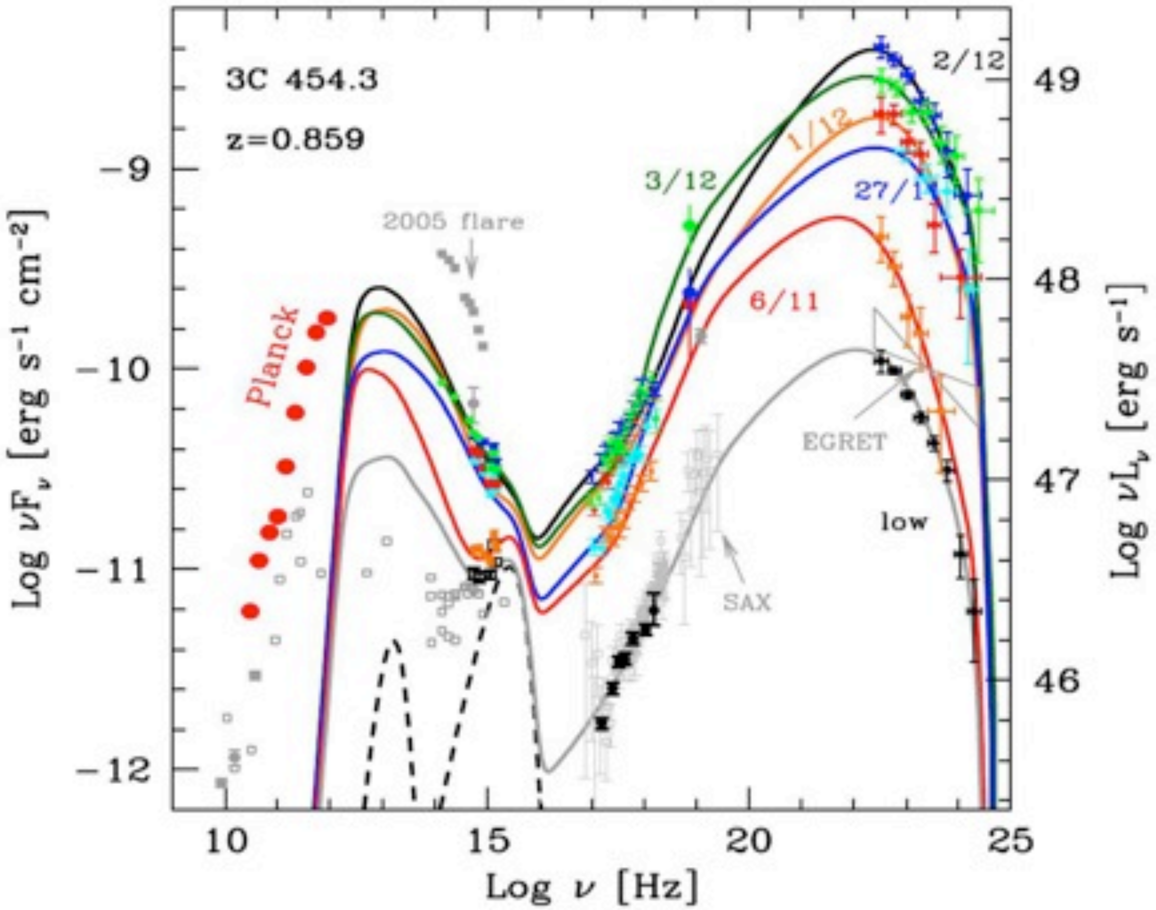
Short timescales

Relativistic boosting

Superluminal motions



Urry & Padovani



Bonnoli et al., 2011

Polarization production mechanisms in AGN

"static" studies

Incoherent synchrotron emission

Synchrotron Self Absorbed (SSA) spectrum

$$N(E)dE = \kappa E^{-s} dE \rightarrow S_\nu \propto \nu^{-\frac{s-1}{2}} = \nu^{-a}$$

Canonical value for AGN: $\alpha \approx 0.7$

Self absorbed $S_\nu \propto \nu^{+2.5}$

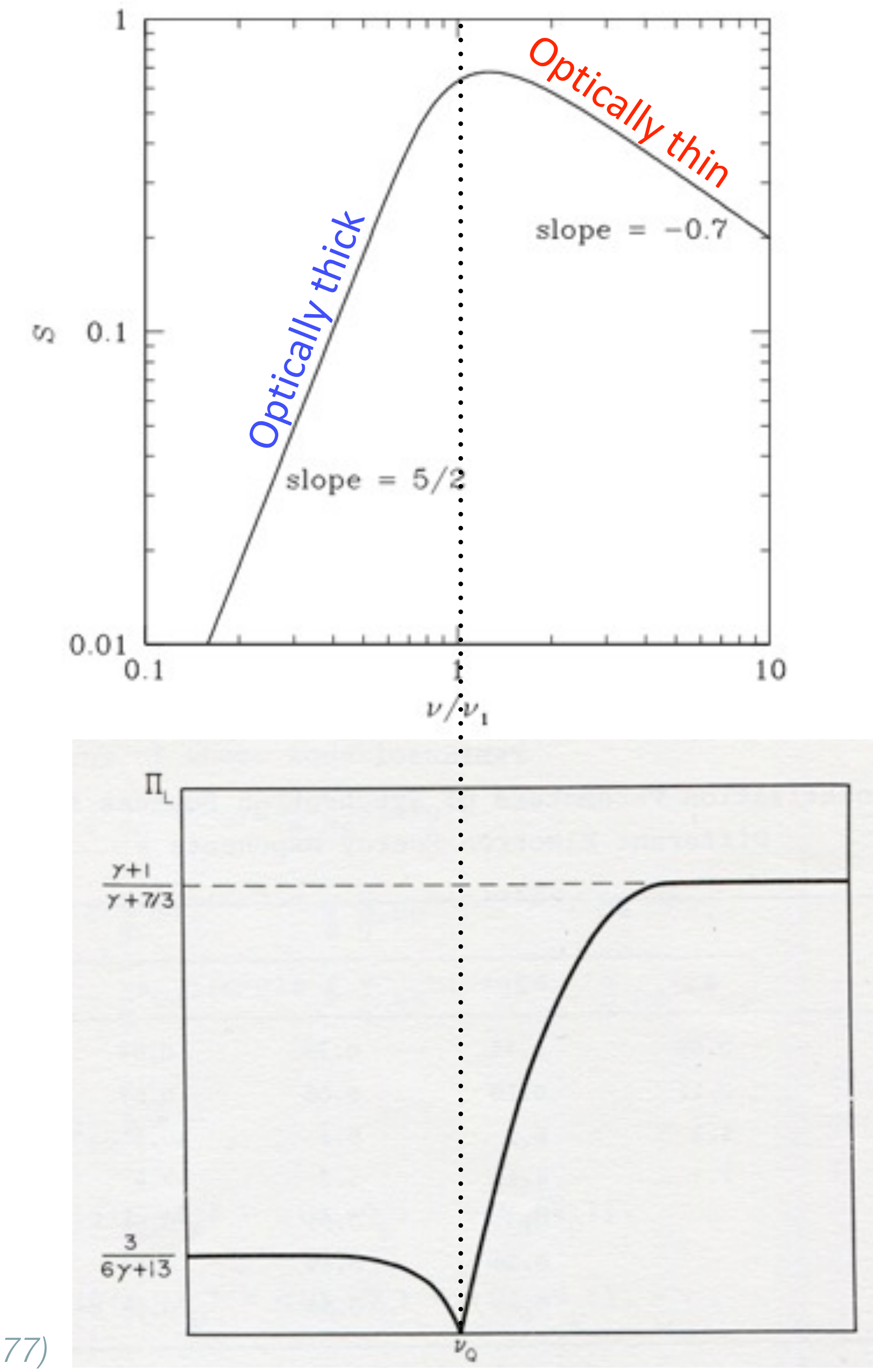
Linear polarization component of synchrotron sources

Optically thin: $m_l = \frac{s+1}{s+\frac{7}{3}} = \frac{a+1}{a+\frac{5}{3}} \approx 72\%$

Perpendicular to the projected magnetic field

Optically thick: $m_l = \frac{3}{6s+13} = \frac{3}{12a+19} \approx 11\%$

Parallel to the projected magnetic field



Pacholczyk A.G. (1977)

Polarization production mechanisms in AGN

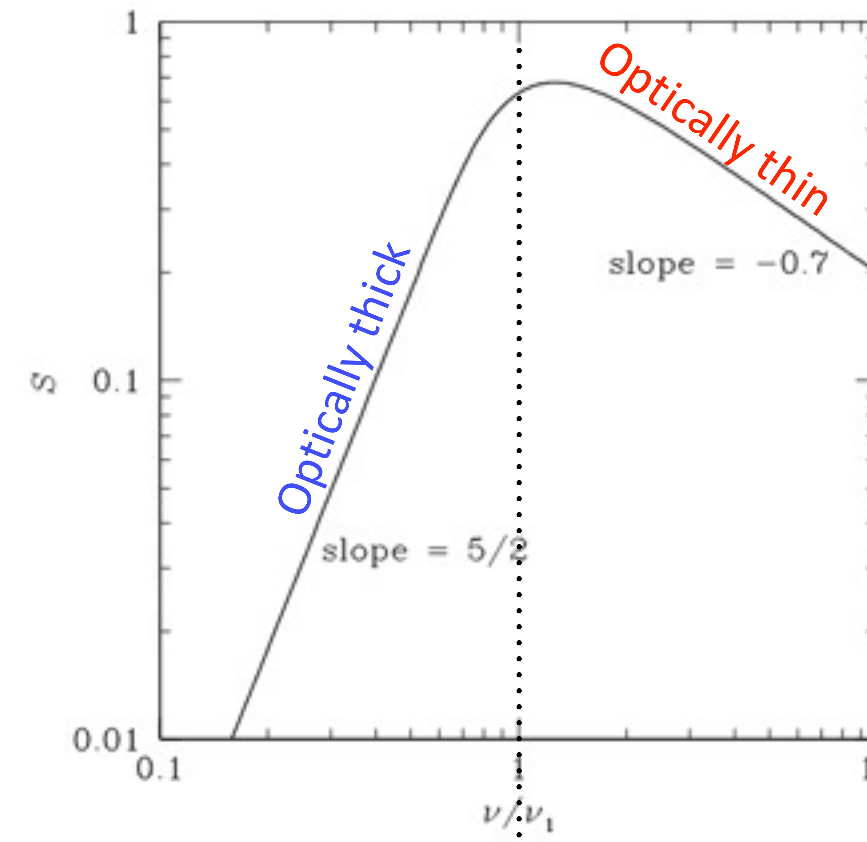
"static" studies

Circular polarization component of synchrotron sources

Low values of circular polarization

$$m_c \approx 0.01 m_l$$

Different number of electrons on either side of the velocity cone



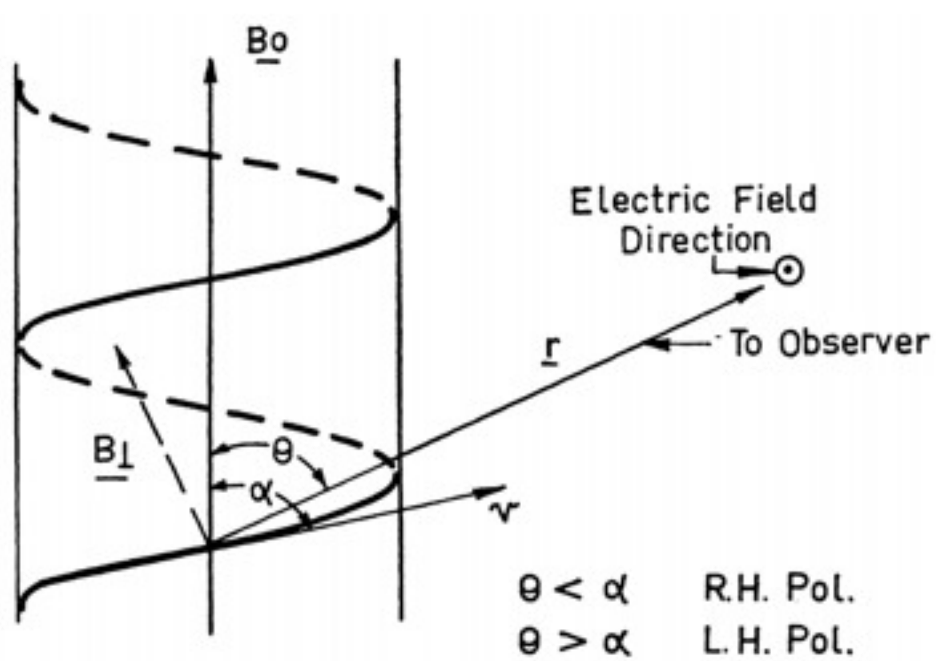
Optically thin

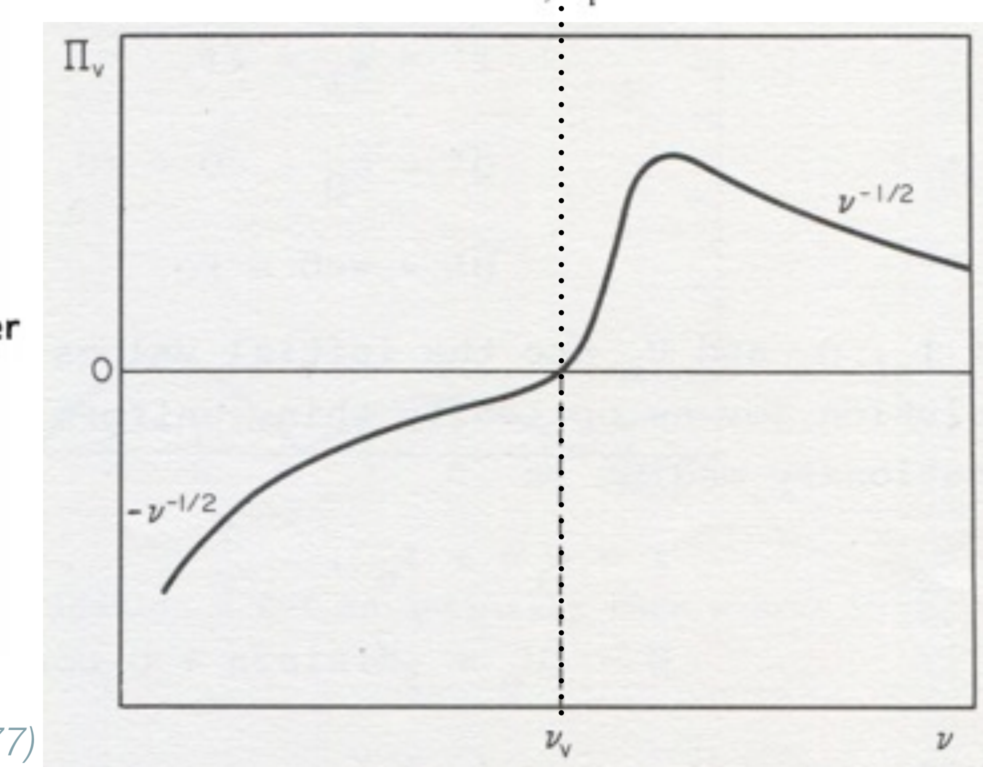
$$m_c \propto \nu^{-\frac{1}{2}}$$

Optically thick

$$m_c \propto -\nu^{-\frac{1}{2}}$$

Gardner & Whiteoak (1966)





Pacholczyk A.G. (1977)

Polarization production mechanisms in AGN

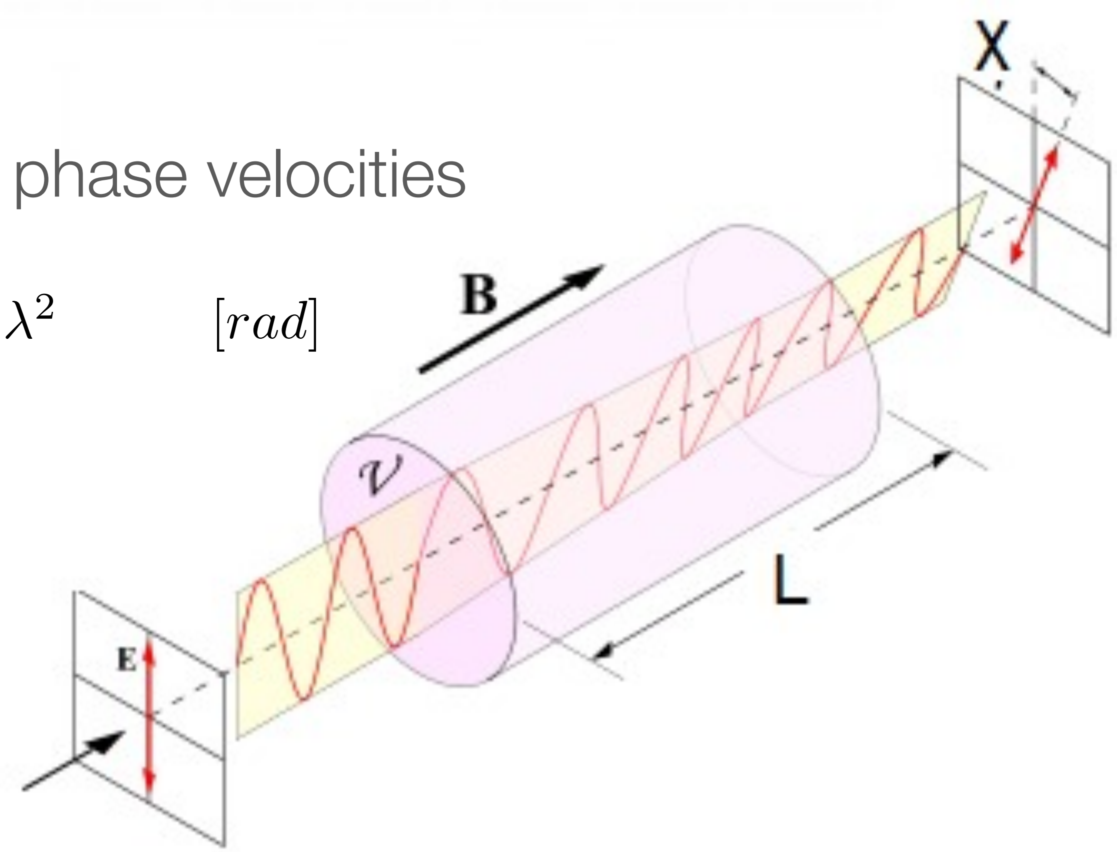
"static" studies

Second order effects when traveling through a magneto-ioninc material

Faraday rotation

LCP and RCP components have different phase velocities

$$\Delta\chi = 8.1 \cdot 10^5 \cdot \left(\int_L n_e B_{\|} cos\theta dL\right) \cdot \lambda^2 = RM \cdot \lambda^2 \qquad [rad]$$



Faraday depolarization

Faraday conversion

Linear to circular polarization

In the presence of low energy relativistic electrons

Birefringence of the two orthogonal LP modes: $\perp$ & $\|$ to the magnetic field

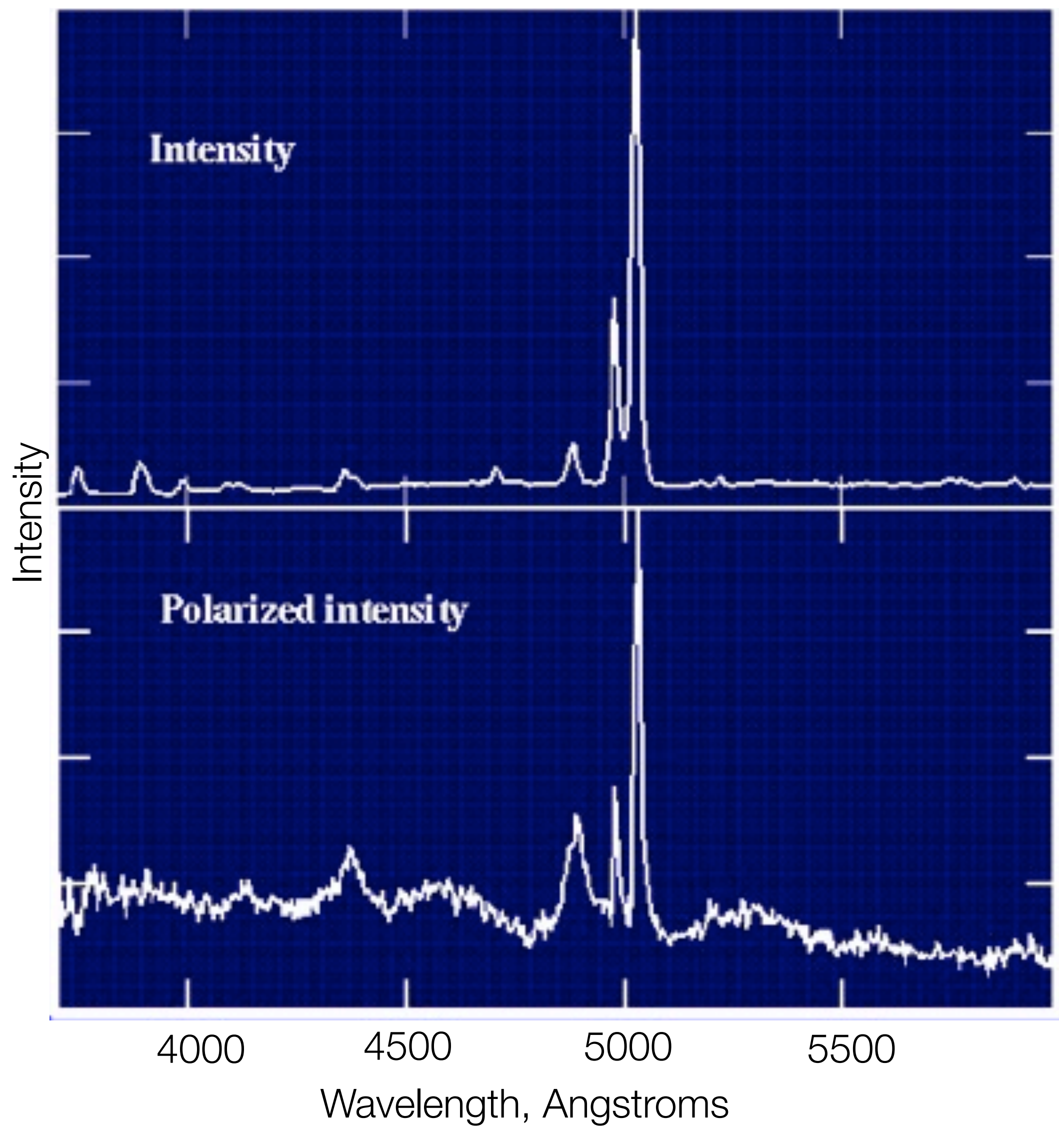
Estimate electron density ratios within the magneto-ionic material

Polarization production mechanisms in AGN

"static" studies

Scattering

Spectropolarimetry helped the unification scheme of AGN



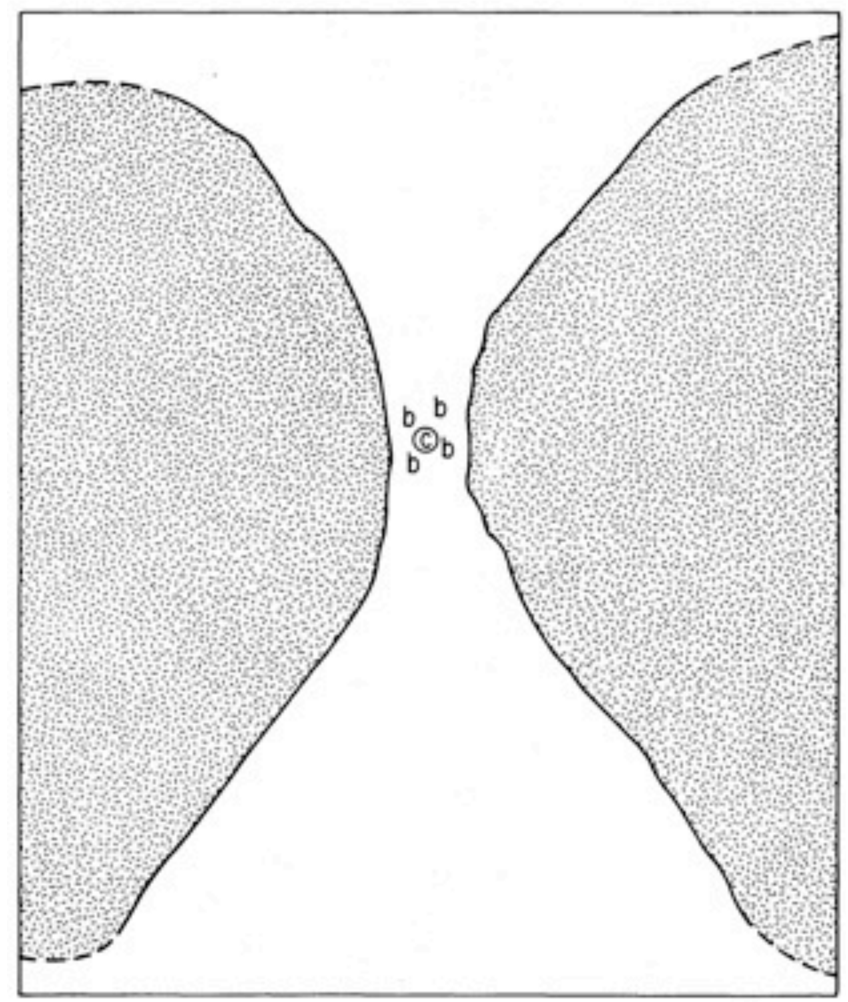


FIG. 5.—Cutaway drawing of a continuum source and broad-line clouds surrounded by a geometrically and optically thick disk. Only photons traveling out along the polar directions can scatter into the line of sight. We would observe a high polarization in the plane perpendicular to the symmetry axis, which we presume to be the radio structure axis.

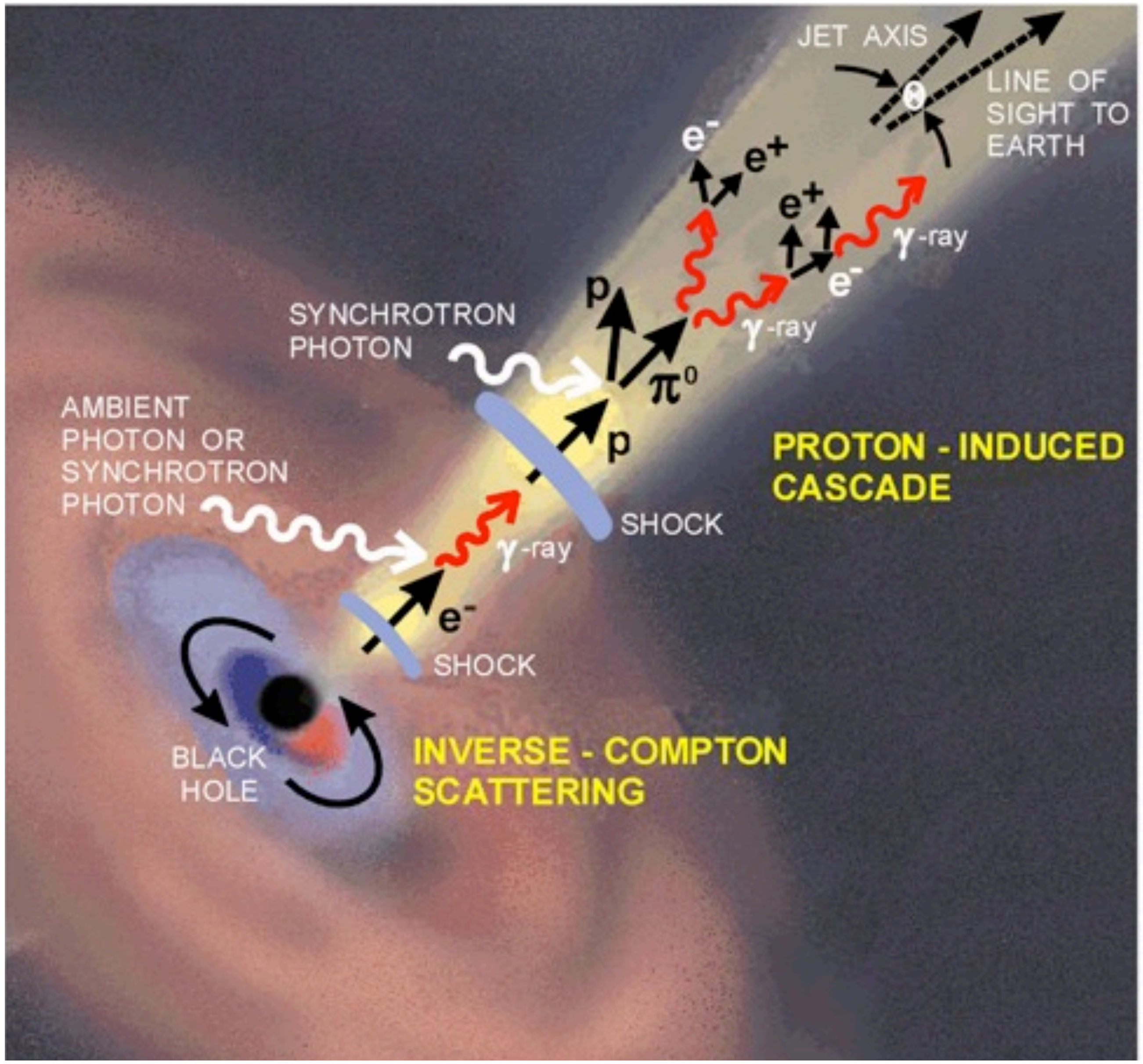
Antonucci & Miller, 1985

Polarization production mechanisms in AGN

"static" studies

High energy polarization studies

Diagnostic for leptonic or hadronic emission at the high energies



Polarization production mechanisms in AGN

dynamic studies

Trace the evolution of the aforementioned characteristics

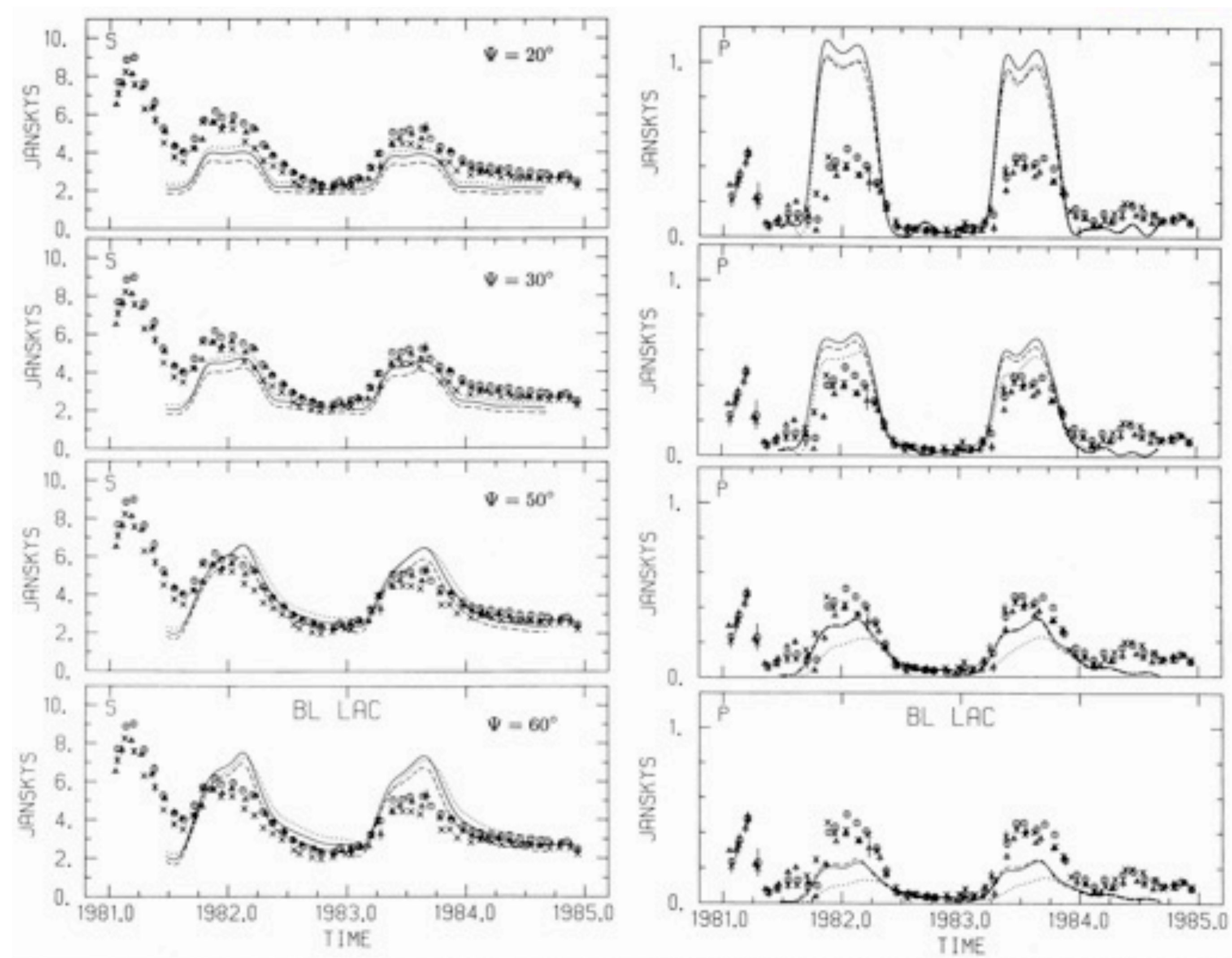
- Development and testing of new or existing models (e.g. shock-in-jet model)

Multi-frequency polarization monitoring

- Rotation measure studies
- Opacity studies

Simultaneous radio and optical polarization monitoring

- Connection between the radio and optical emitting regions



Hughes & Allers, 1989

The F-GAMMA program

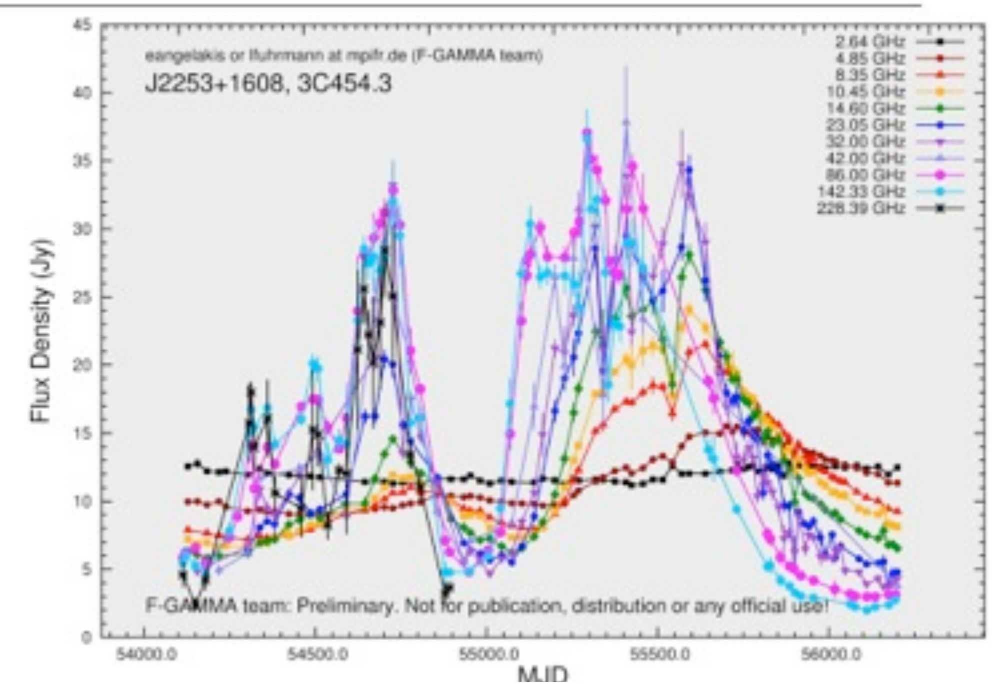
brief description

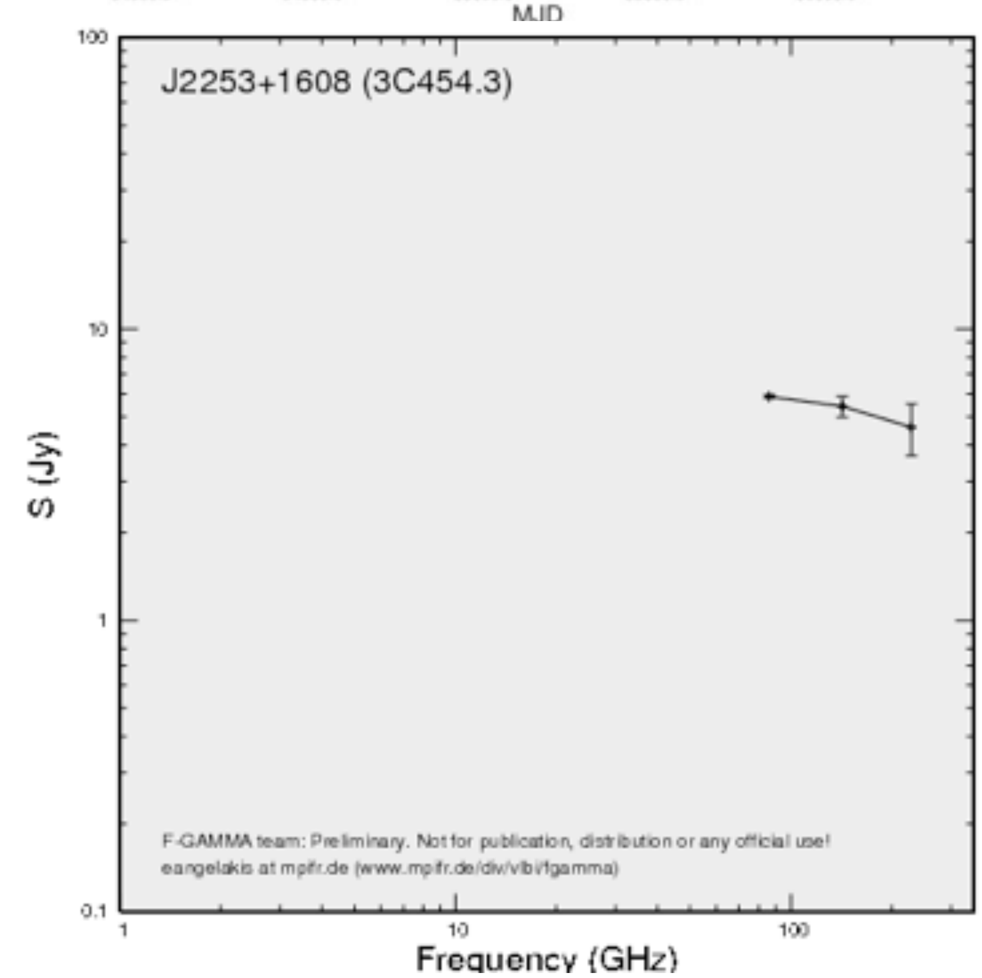
Multifrequency monthly monitoring of 60 γ-ray blazars

- Flux density variability
- Spectral evolution
- Polarization variability

Main facilities

- 100m Effelsberg telescope (Germany)
    - 2.64, 4.85, 8.35, 10.45, 14.60, 23.05, 32.00, 42.90 GHz
- 30m Pico Veleta IRAM (Spain)
    - 88.24, 142.33, 228.39 GHz
- 12m APEX
    - 345 GHz





The RoboPol program

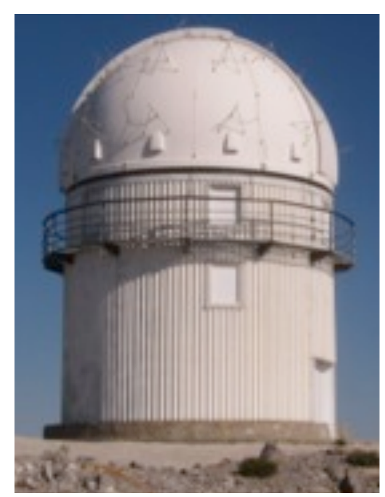
Chasing optical polarization swing events

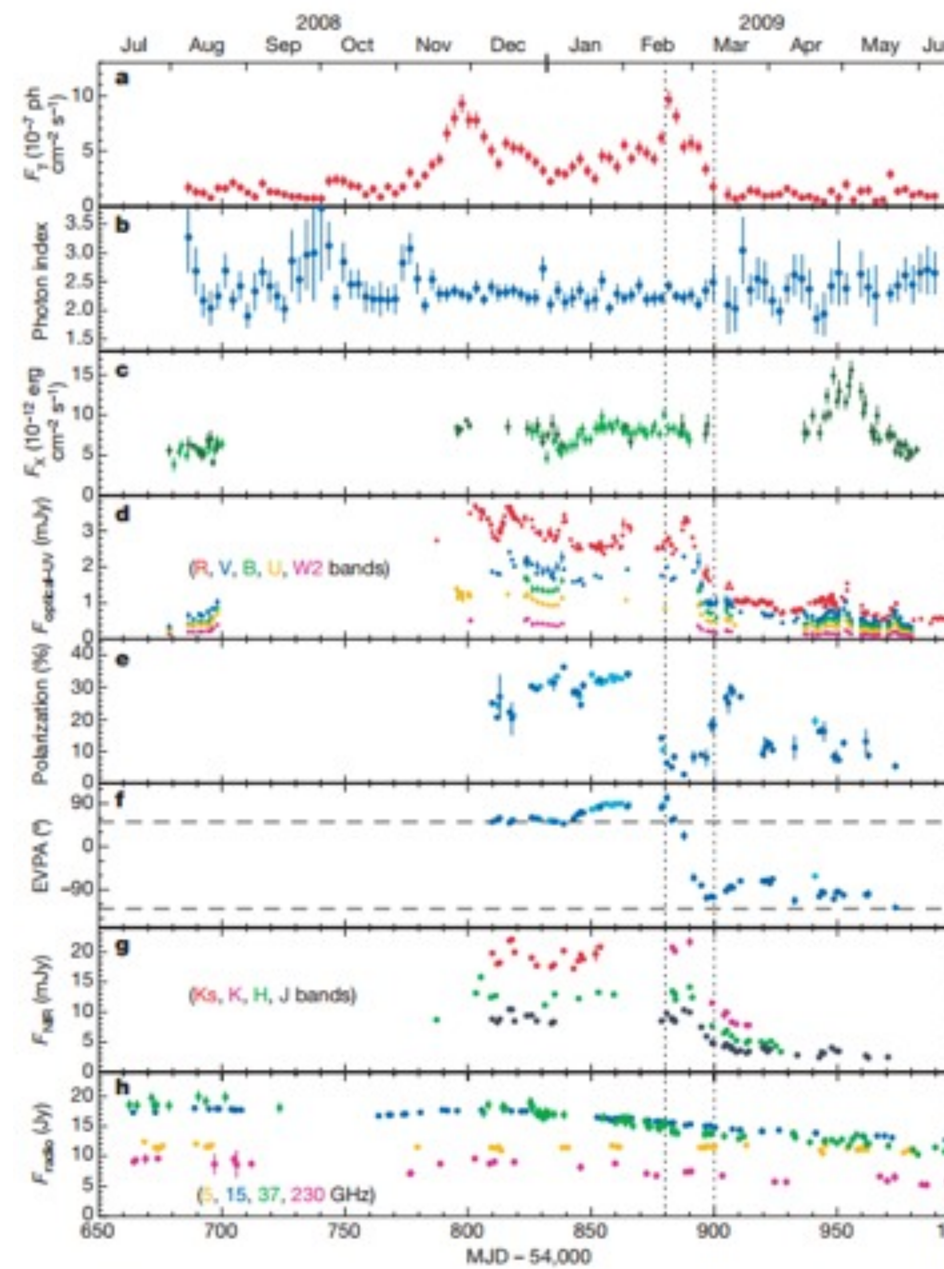
Optical polarimeter on Skinakas telescope (UoC)

- Instrument built specifically for the telescope
- Fully automated, on-the-spot data reduction pipeline

Observing strategy

- Observe *massively*: ~ 100 sources
- Observe *frequently*: 3–night cycles
- Observe *dynamically*: Dynamic observing schedule by real-time data reduction





Abdo et al., 2010, Nature, 463, 919

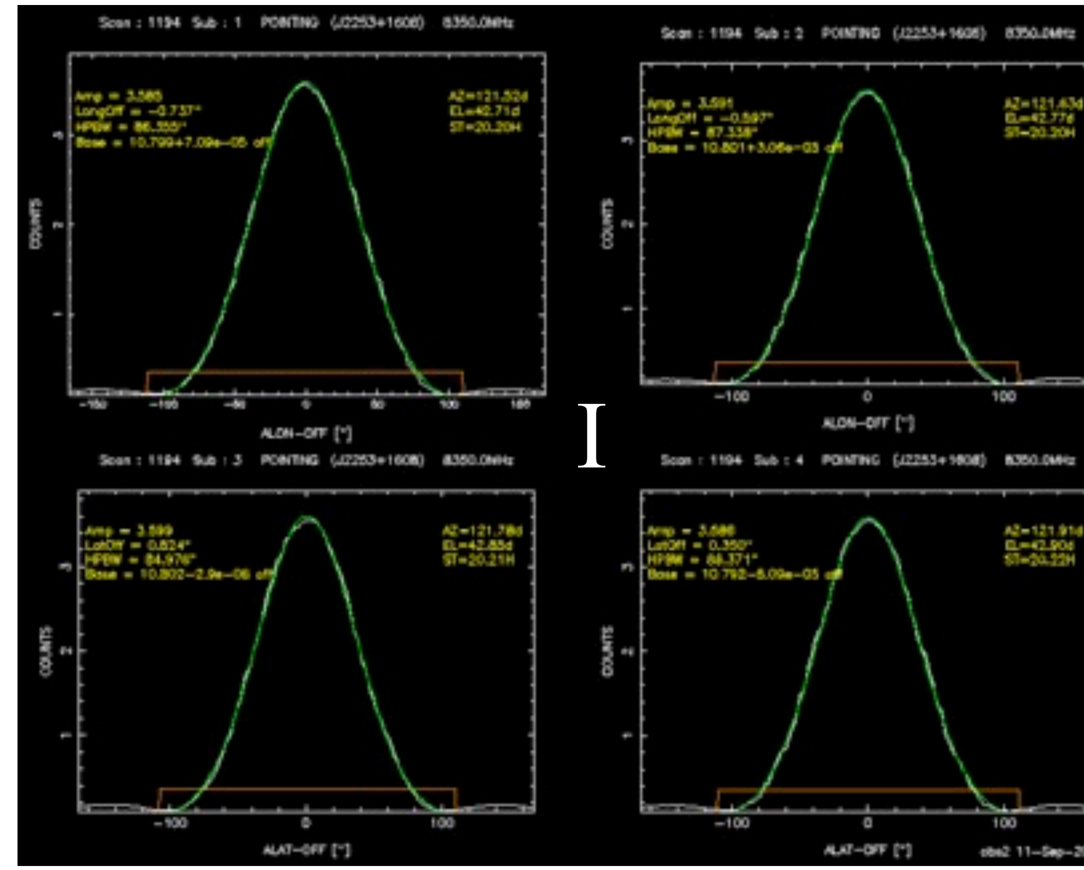
Radio polarization measurements

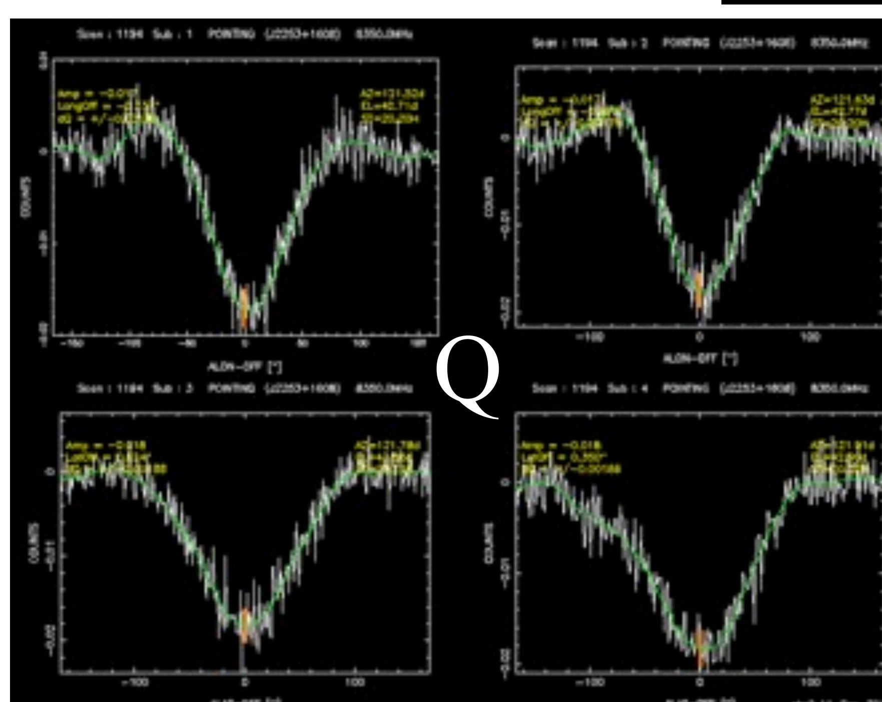
Observations & data acquisition

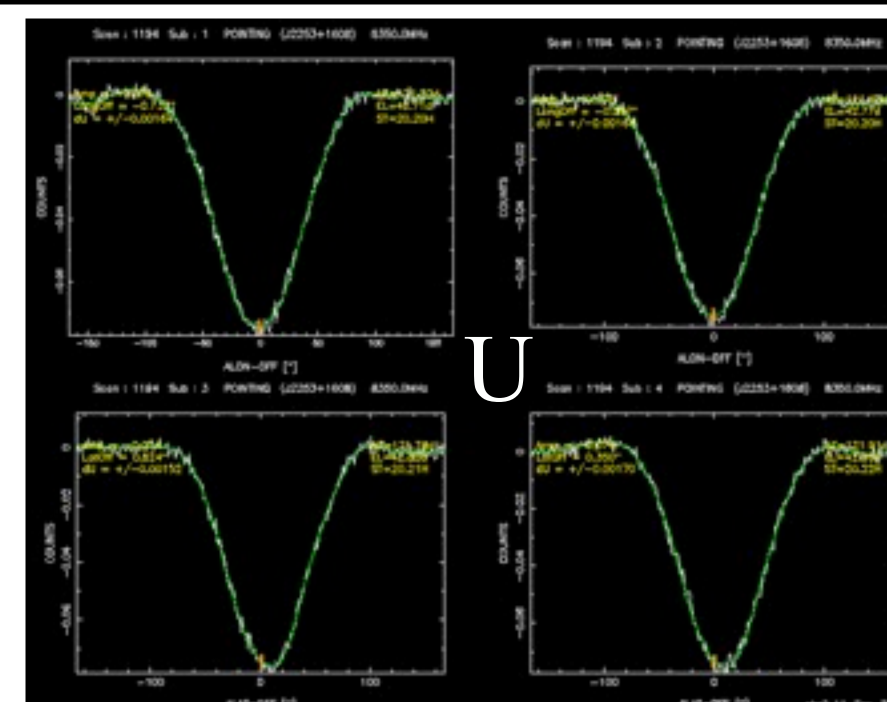
- Instrument: Effelsberg 100-m radio telescope
- Frequencies: 2.64, 4.85, 8.35, 10.45 and 14.60 GHz
- Cadence: 1.3 months

"Standard" corrections

- Pointing
- Opacity
- Gain curve
- Sensitivity







Radio polarization measurements

instrumental polarization correction

$$\begin{pmatrix} I_{obs} \\ Q_{obs} \\ U_{obs} \\ V_{obs} \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \cdot \begin{pmatrix} I_{real} \\ Q_{real} \\ U_{real} \\ V_{real} \end{pmatrix}$$

$$\begin{aligned} I_{obs} &= m_{11} \cdot I_{real} + m_{12} \cdot Q_{real} + m_{13} \cdot U_{real} + m_{14} \cdot V_{real} \\ Q_{obs} &= m_{21} \cdot I_{real} + m_{22} \cdot Q_{real} + m_{23} \cdot U_{real} + m_{24} \cdot V_{real} \\ U_{obs} &= m_{31} \cdot I_{real} + m_{32} \cdot Q_{real} + m_{33} \cdot U_{real} + m_{34} \cdot V_{real} \\ V_{obs} &= m_{41} \cdot I_{real} + m_{42} \cdot Q_{real} + m_{43} \cdot U_{real} + m_{44} \cdot V_{real} \end{aligned} \qquad [1]$$

Method

1. Observe sources with known polarization characteristics
2. Solve the system of equations [1] by fitting our measurements
3. Apply the instrumental polarization correction to our target sources

Radio polarization measurements

instrumental polarization correction

$$\begin{pmatrix} I_{obs} \\ Q_{obs} \\ U_{obs} \\ V_{obs} \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \cdot \begin{pmatrix} I_{real} \\ Q_{real} \\ U_{real} \\ V_{real} \end{pmatrix}$$

$$\begin{aligned} I_{obs} &= m_{11} \cdot I_{real} + m_{12} \cdot Q_{real} + m_{13} \cdot U_{real} + m_{14} \cdot V_{real} \\ Q_{obs} &= m_{21} \cdot I_{real} + m_{22} \cdot Q_{real} + m_{23} \cdot U_{real} + m_{24} \cdot V_{real} \\ U_{obs} &= m_{31} \cdot I_{real} + m_{32} \cdot Q_{real} + m_{33} \cdot U_{real} + m_{34} \cdot V_{real} \\ V_{obs} &= m_{41} \cdot I_{real} + m_{42} \cdot Q_{real} + m_{43} \cdot U_{real} + m_{44} \cdot V_{real} \end{aligned} \qquad [1]$$

Method

1. Observe sources with known polarization characteristics
2. Solve the system of equations [1] by fitting our measurements
3. Apply the instrumental polarization correction to our target sources

Full Stokes calibration

Circular polarization calibrator(s)

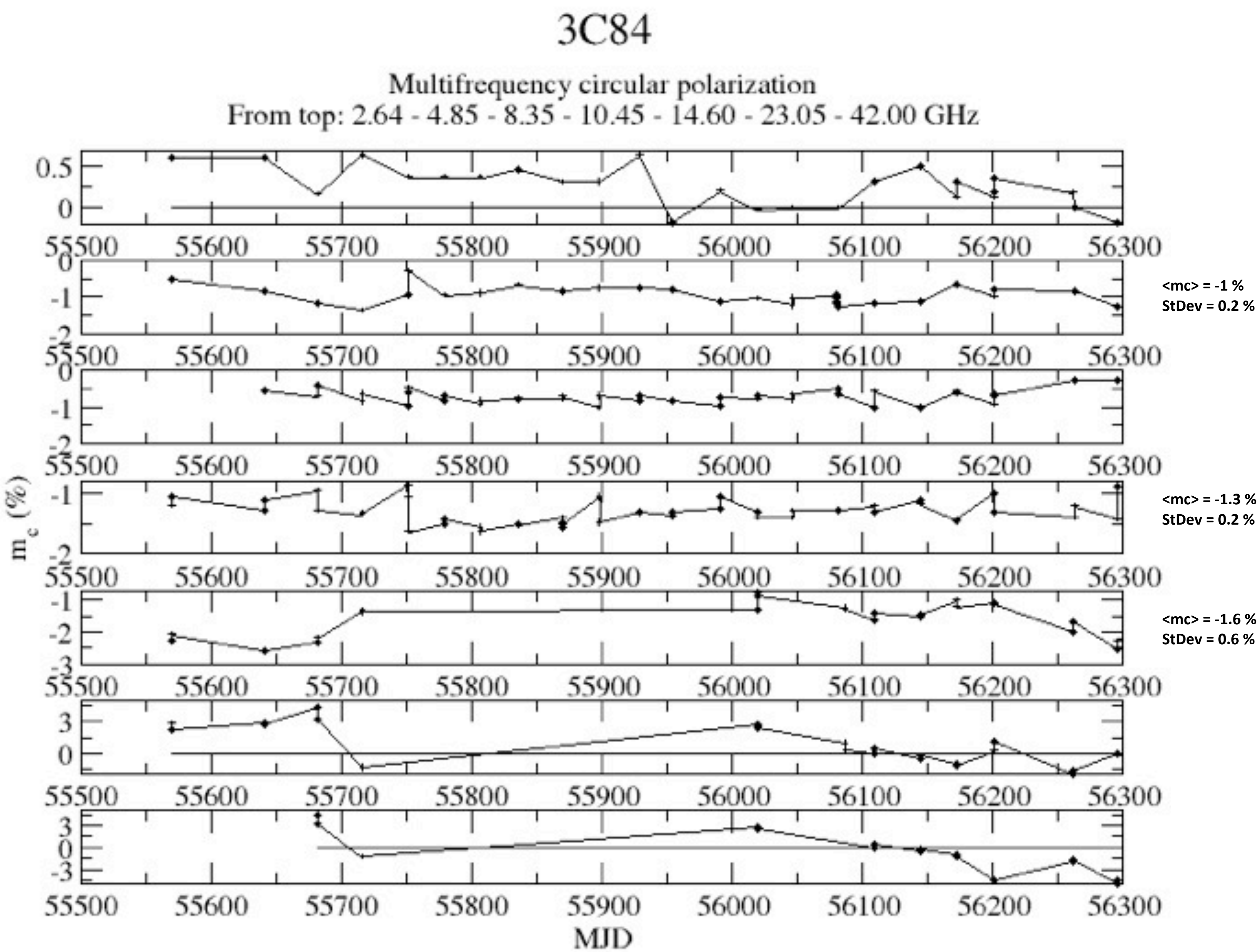
4th row and column from high SNR circular polarization measurements (masers, pulsars?)

Relations between Müller matrix elements from theory

Radio polarization measurements

instrumental polarization correction

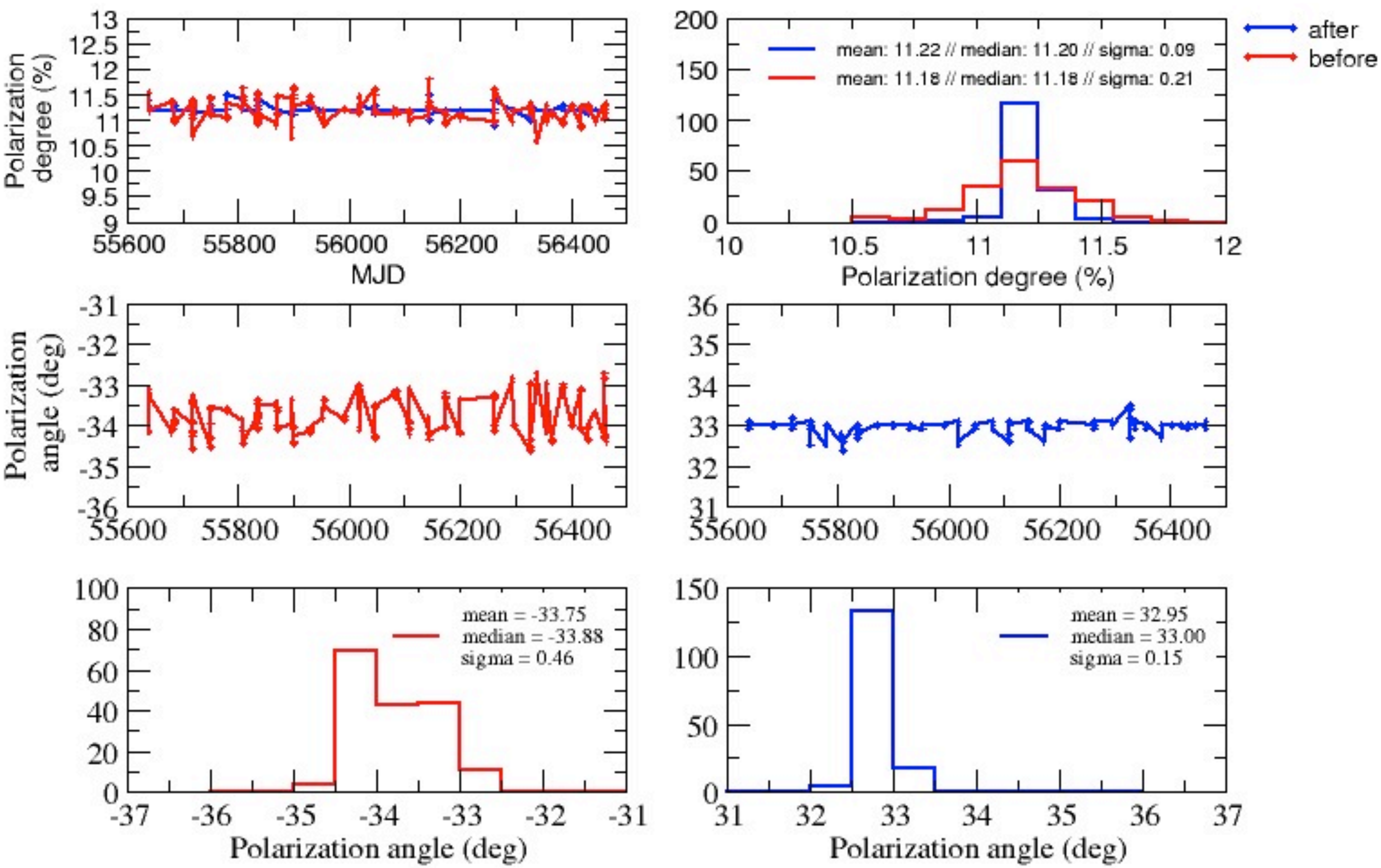
Finding circular polarization calibrators



Myserlis, Angelakis et al. (in prep.)

Calibrator data as a quality check for de-rotation

3C286 at 8.35 GHz



Myserlis, Angelakis et al. (in prep.)

Radio polarization results

linear polarization histograms

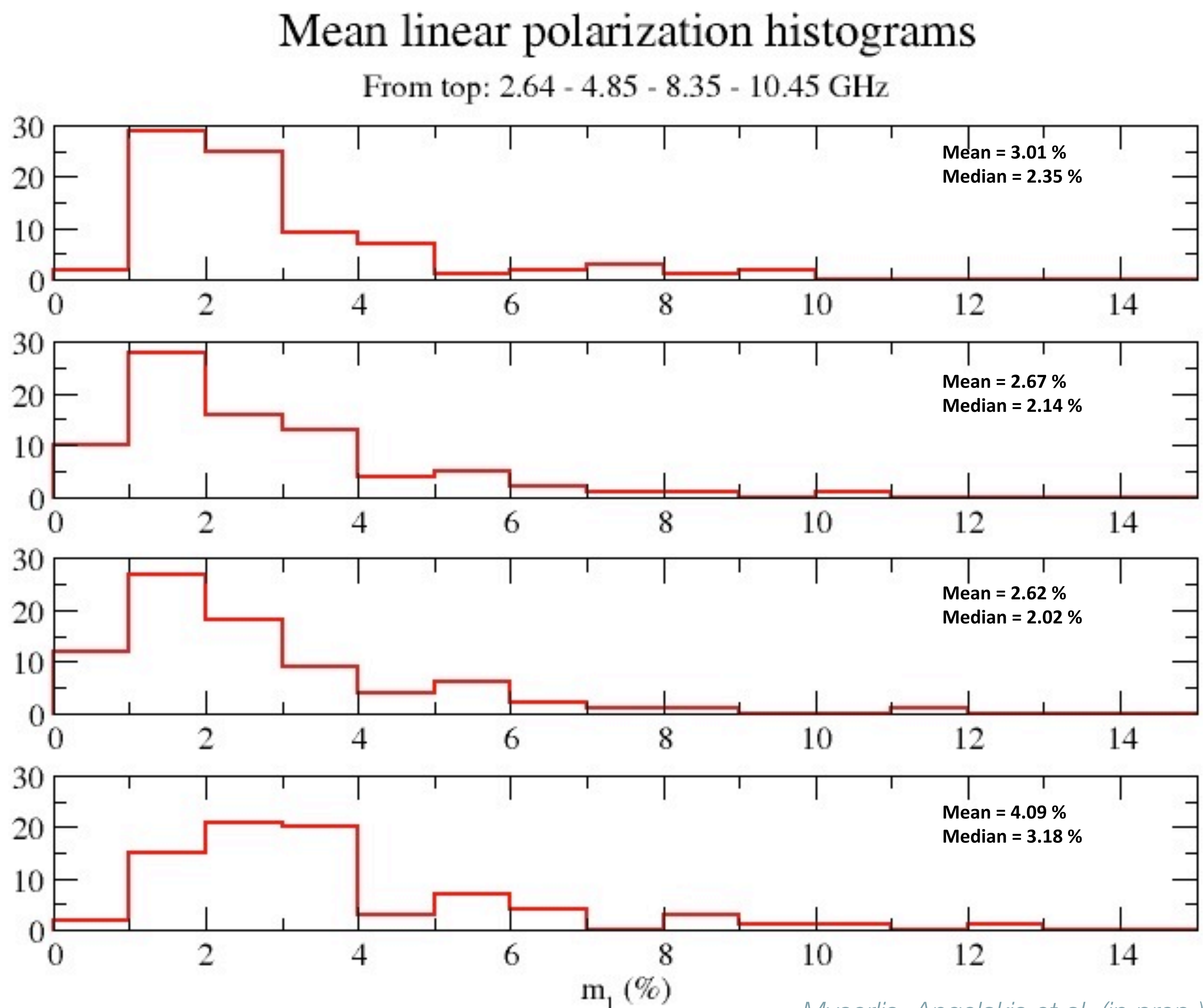
January 2011 - now

4/5 frequencies

Polarized flux

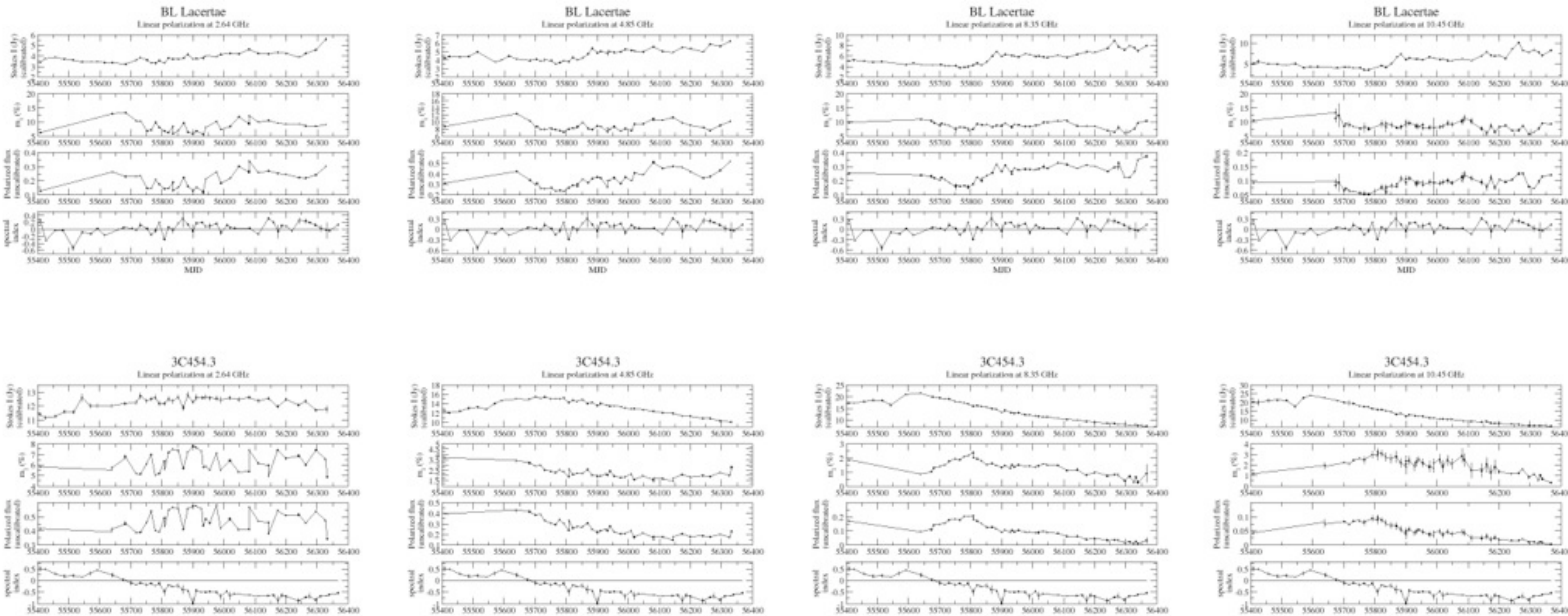
Polarization degree

Polarization angle



Myserlis, Angelakis et al. (in prep.)

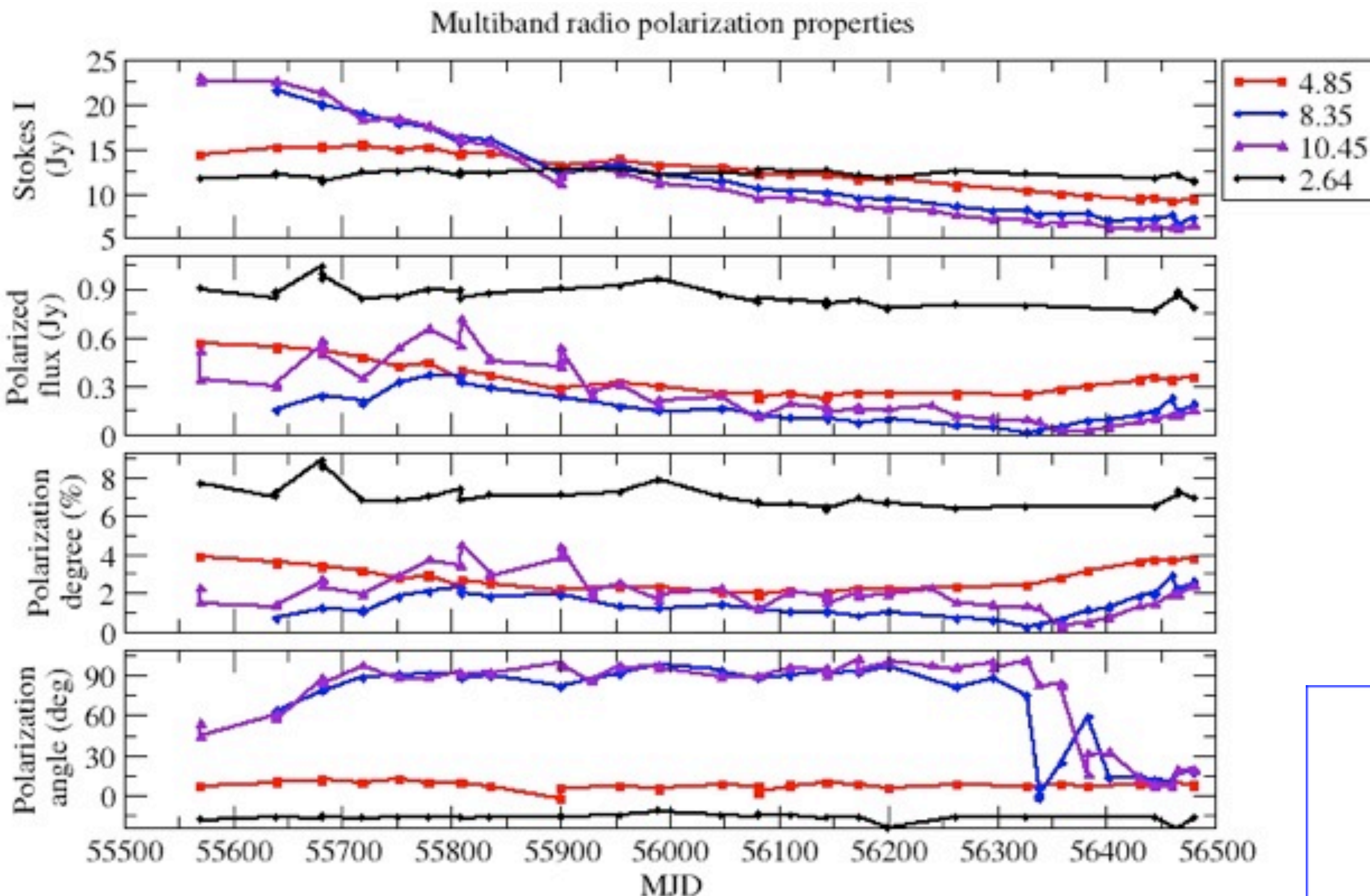
Radio polarization results

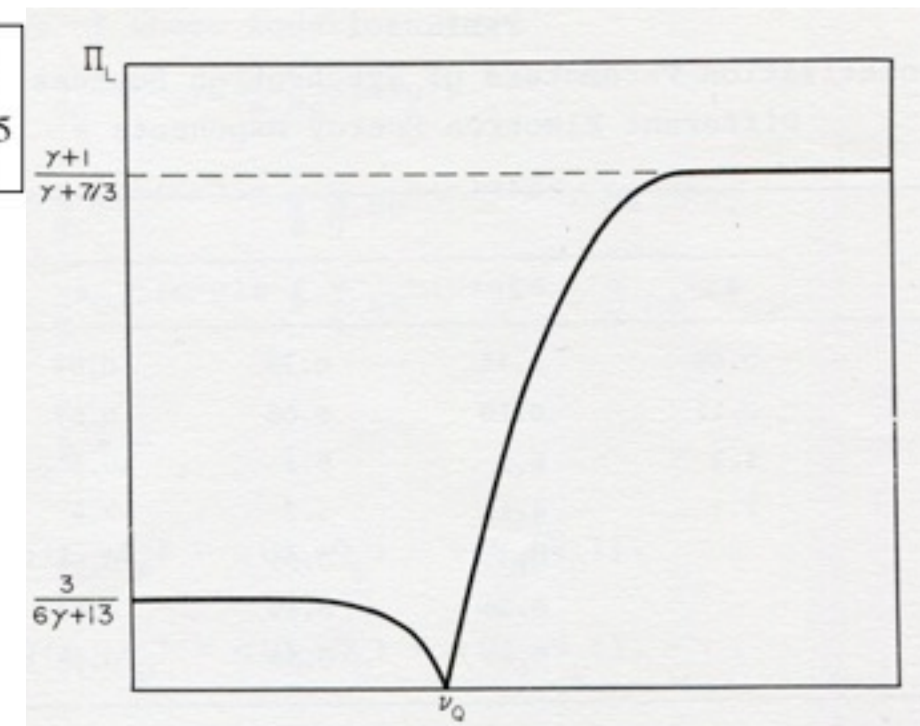


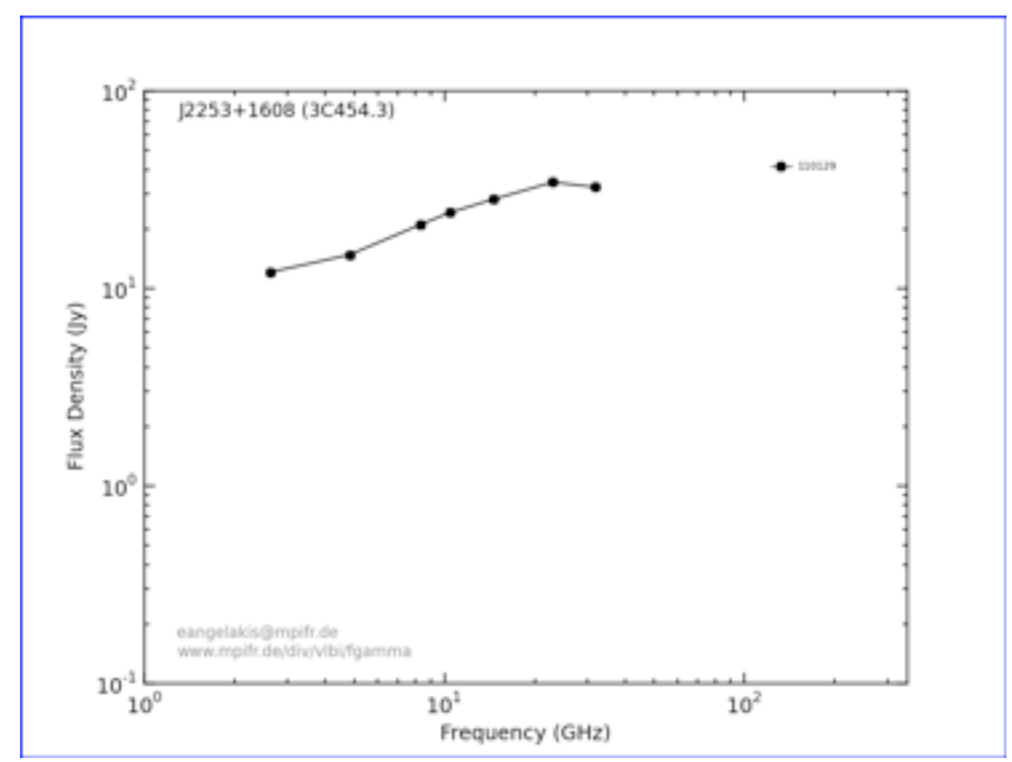
Myserlis, Angelakis et al. (in prep.)

Radio polarization results

3C 454.3 polarization angle swing



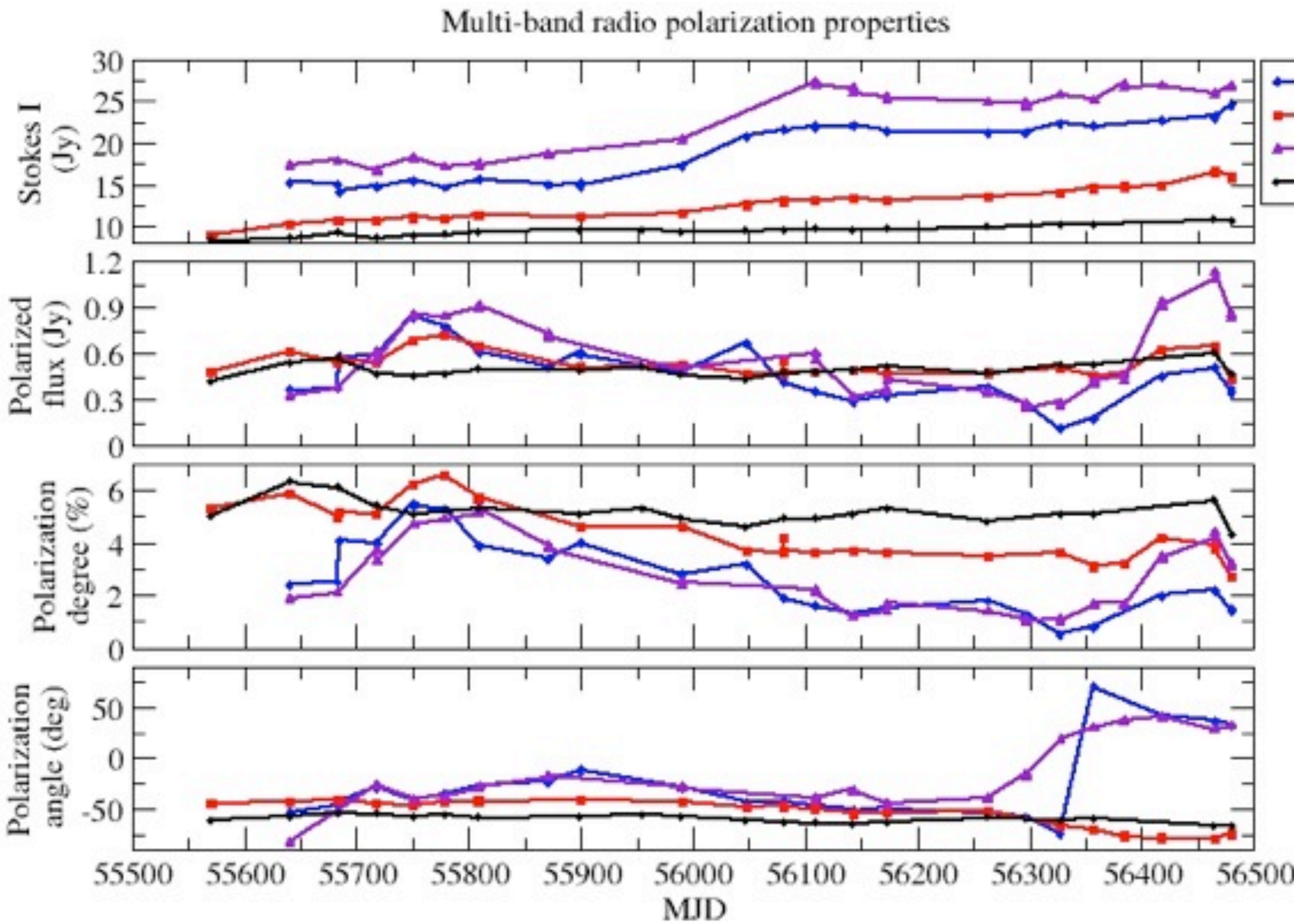


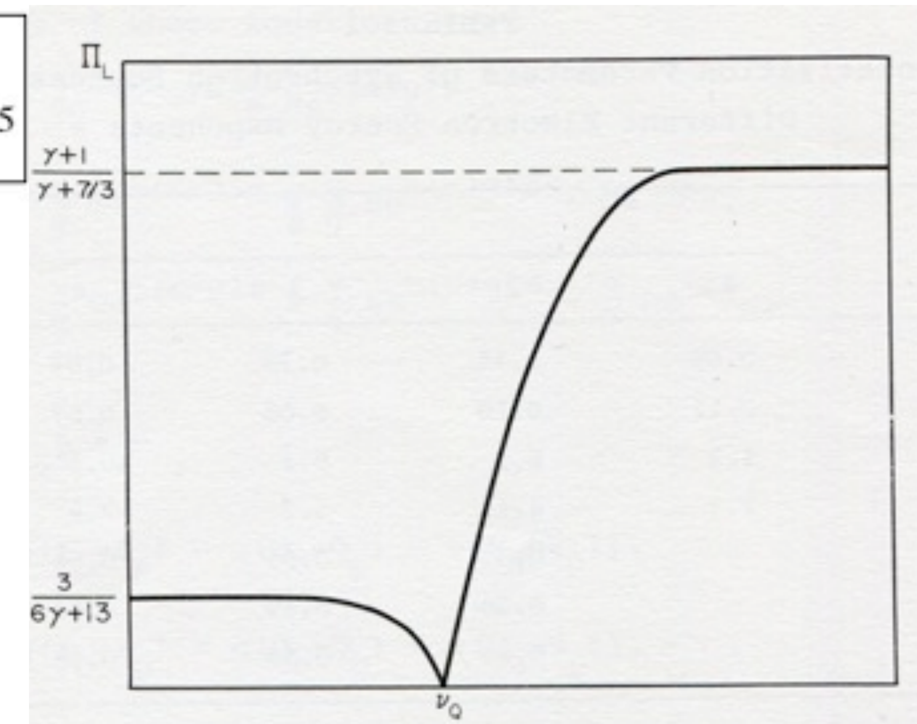


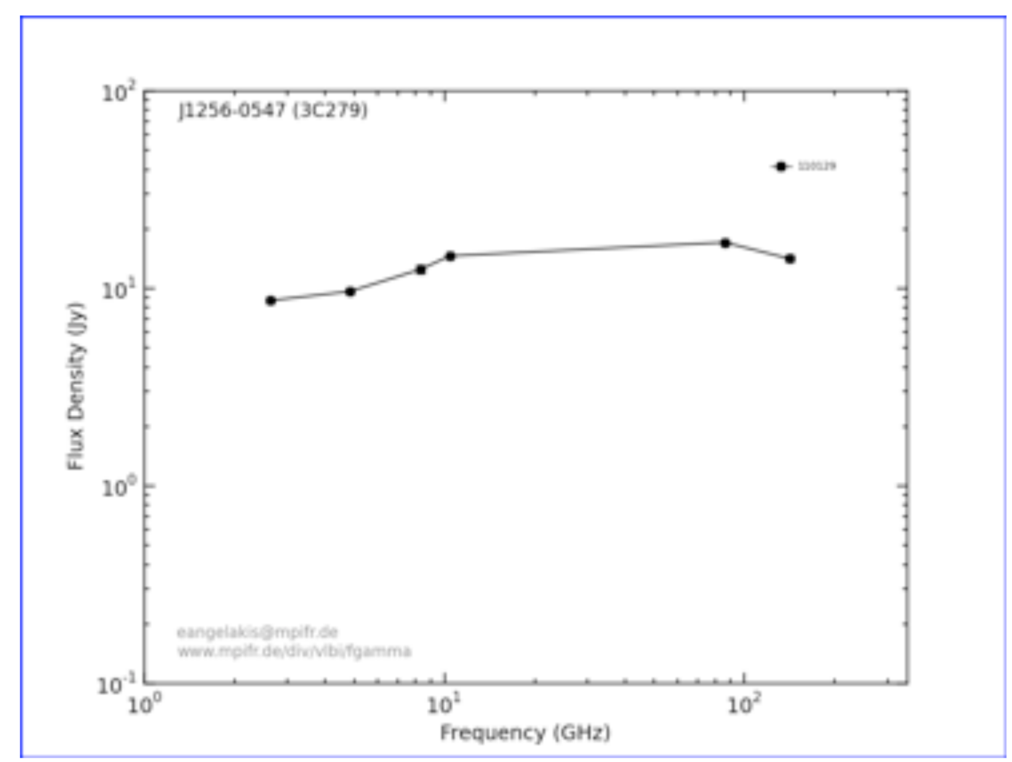
Myserlis, Angelakis et al. (in prep.)

Radio polarization results

3C 279 polarization angle swing







Myserlis, Angelakis et al. (in prep.)

Conclusions & future steps

Polarization measurements are a powerful tool for the investigation of the different phenomena that take place in blazars

On-going data reduction of radio polarization measurements at 5 frequencies (2.64 - 14.6 GHz)

Future improvements of our data reduction scheme

- LP: 3x more accurate polarization angle measurements
- CP: Investigation and study of CP calibrators

Connection with optical polarization monitoring measurements

We have already found 2 radio polarization swing events and much more are coming soon...

Thank you!