Physical conditions and processes in AGN jets

through multi-frequency linear and circular radio polarization monitoring

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100-m Effelsberg
monthly cadence of ~60 sources at 4 frequency bands between 2.64 and 10.45 GHz

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Motivation

The polarization parameters carry information for the **physical conditions and processes** in the regions where the radiation is emitted and propagated through, both in the jet and along the line of sight e.g. through the galactic content of magnetized plasma. We have recovered the **multi-wavelength polarization parameters** of 87 AGNs measured by the F-GAMMA program. Our analysis eliminates a number of systematics bringing the uncertainty to levels as low as **0.1%**, essential for the **inherently low circular polarization** degree. In order to constrain the physical conditions of the jet plasma, we implement a **polarized radiative transfer model** that attributes the variability to evolving internal shocks to reproduce the **observed polarization behavior** for the case study of the blazar 3C 454.3.

High-precision linear and circular polarimetry with the 100-m telescope

Our polarimetric data analysis methodology can be used to recover the linear and circular polarization parameters of point-like sources in the radio window and it is directly applicable to receivers equipped with circularly polarized feeds. It eliminates a number of systematics bringing the uncertainty to levels as low as **0.1%** for linear polarization degree, **0.5°** for polarization angle and **0.2%** for circular polarization degree measurements. The most important features of our methodology are:

Instrumental linear polarization correction

The observing system introduces **spurious signals** in the receiver channels responsible for the Stokes Q and U measurements. We use the Stokes Q and U datasets obtained from linearly unpolarized sources to create an **instrument model for every observing session** (Fig. 1). This model is then used to recreated the expected instrumental polarization signals which are then subtracted from each measurement.

Careful treatment of the telescope response

The observables are extracted by fitting a beam pattern model to the obtain telescope response. We investigated different models in order to optimize this procedure. Our results show that the **Airy disk pattern** describes the whole area of the dataset with high accuracy. This approach is essential for the inherently low **Stokes V measurements (~0.5%)** using circularly polarized feeds.

Instrumental circular polarization correction

The instrumental circular polarization is manifested by a **systematic offset** of the Stokes V measurements as well as the **significant correlation** between the Stokes V light curves of stable sources. Under the assumption that the instrumental circular polarization is caused by an **imbalance between the LCP and RCP receiver channel gains**, we use the Stokes V measurements of stable sources to restore the gain balance.

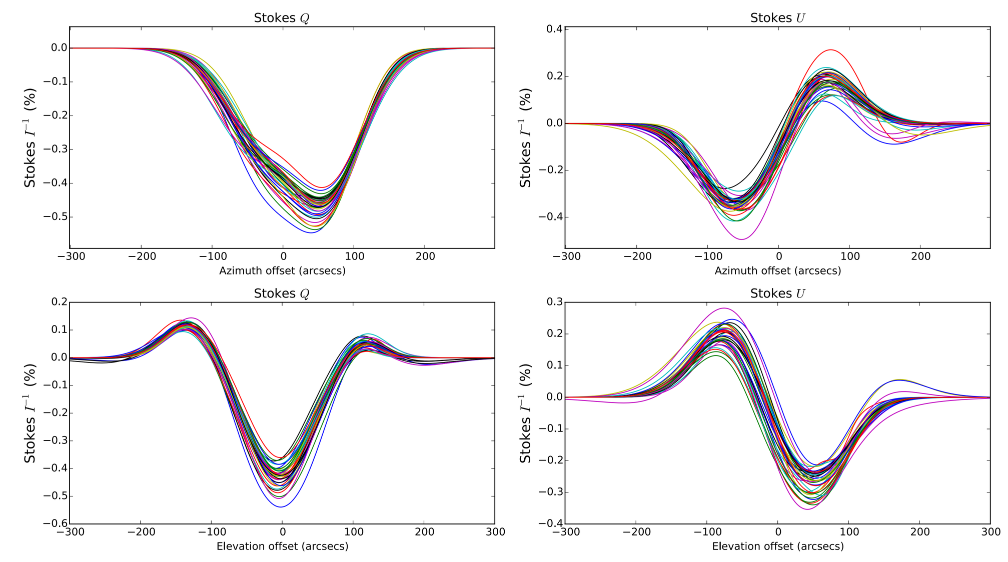
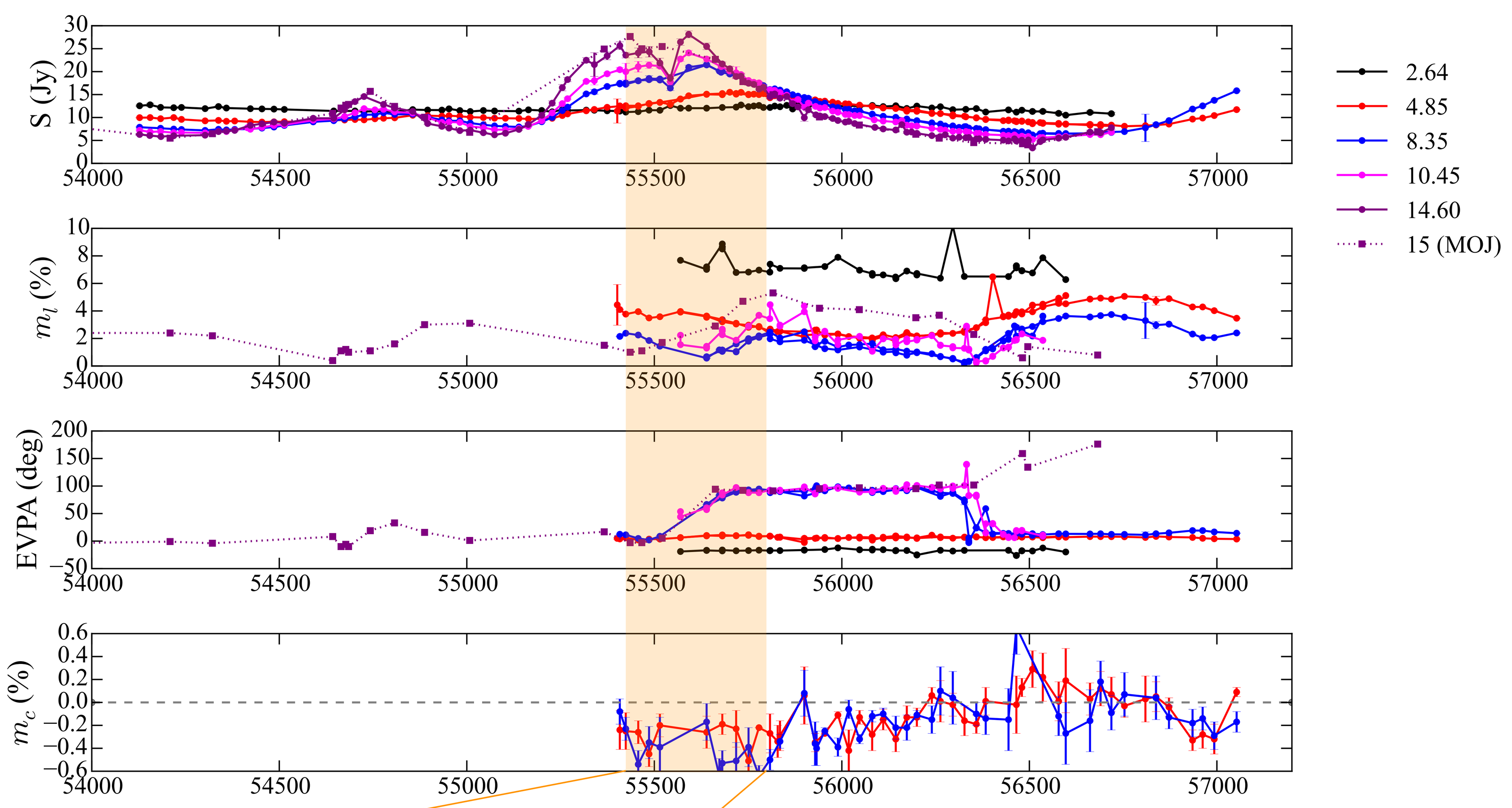


Figure 1.
The generated instrument models of the instrumental Stokes Q and U signals in the two scanning directions of each measurement, the azimuth in the top and the elevation in the bottom panels. The models were generated for 38 sessions.



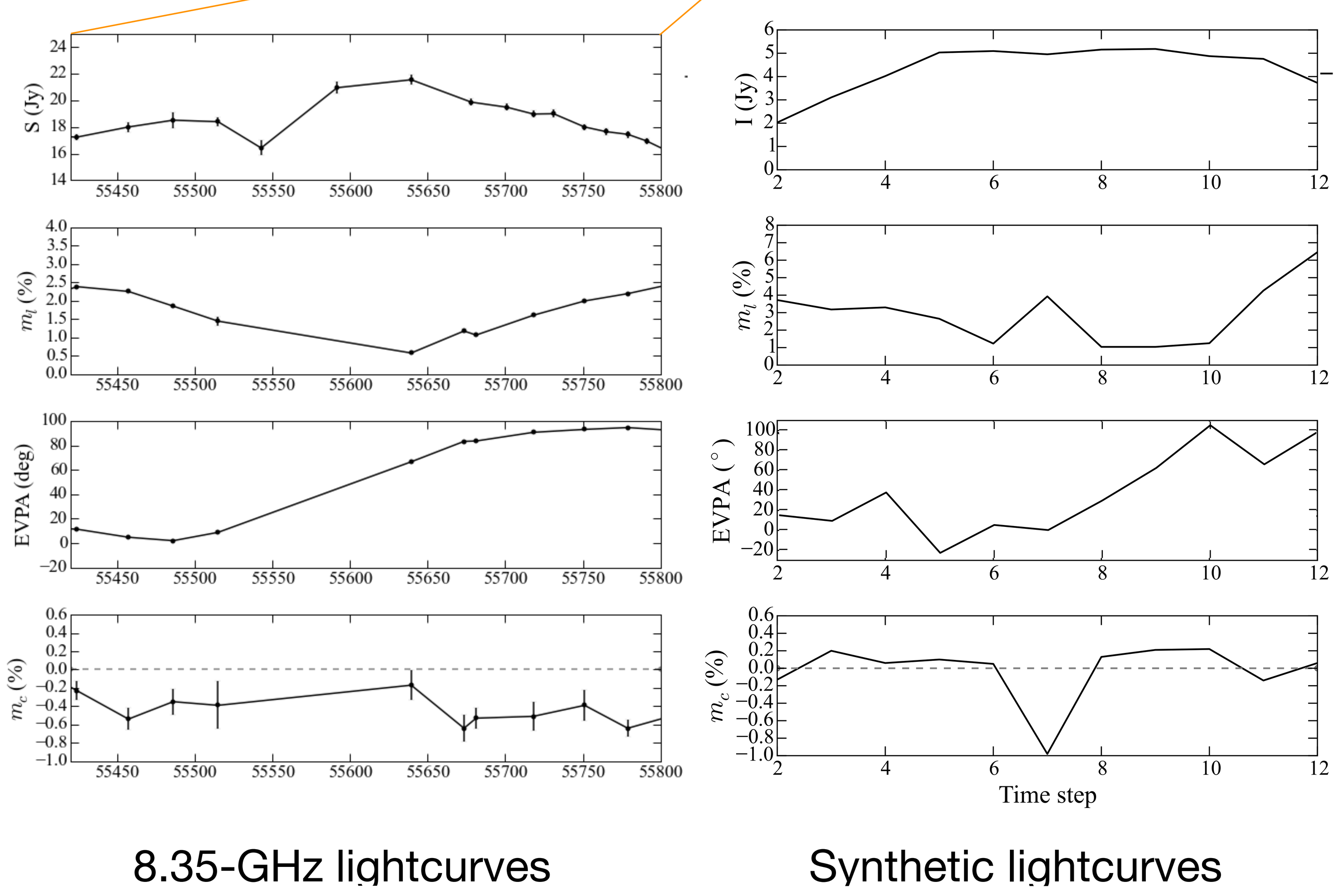


Figure 2. *(Left, top)*
Full-Stokes lightcurves for the blazar 3C 454.3. From top to bottom: (1) Stokes I at 2.64, 4.85, 8.35, 10.45 and 14.6 GHz; (2) the degree of linear polarization m_l; (3) the linear polarization angle (EVPA) and (4) the degree of circular polarization m_c. In the Stokes I, m_l and EVPA plots, we have included the information at 15 GHz, taken from the MOJAVE monitoring program.

Figure 3. *(Left, bottom)*
Left: The 8.35-GHz Full-Stokes lightcurves of 3C 454.3 for the MJD range of ~55400 to 55800. *Right:* A qualitative reproduction of the 8.35-GHz total flux density and polarization variability (left). The synthetic full-Stokes lightcurves were generated by a full-Stokes radiative transfer model.

Figure 4. *(Right)*
A modeled jet profile and some key parameters of the radiative transfer code. The density gradient along the jet axis is demonstrated by the color shading of the cells. The orange arrows show the projection of magnetic field on the plane of the sky. The radius and distance along the jet, r, are expressed in arbitrary units.

3C 454.3: a case study

Linear and circular polarization variability

The multi-frequency radio variability of the blazar 3C 454.3 exhibit repeating patterns in the flux density - frequency domain which can be attributed to the **propagation of synchrotron self-absorbed (SSA) components** as predicted by the "shock-in-jet" model. As we observe first **the optically thick and then then thin regimes** we expect to observe the following **characteristic changes** in the polarization parameters:

1. A **minimization** of the linear polarization degree, concurrent with an EVPA **rotation** of exactly 90°.
2. A **minimization** of the circular polarization degree, followed by a change in the circular polarization **handedness**.
3. A **maximization** of the total flux when the peak of the SSA spectrum matches the observing frequency.

In the polarimetric dataset of 3C 454.3 we found two polarization angle (EVPA) rotations of exactly 90° at MJD ~55650 and 56350 (Fig. 2, 3rd panel), concurrent with a minimization of the linear polarization degree (2nd panel) at the corresponding observing frequencies. An indication of a change in the handedness of the circular polarization (4th panel) is also evident close to those dates.

Variability modeling and constrained physical parameters

We used a full-Stokes radiative transfer code which **emulates the emission** for both the unshocked and shocked regions of the plasma flow (Fig. 4) to reproduce the total flux and polarization variability observed in the blazar 3C 454.3 between MJD ~55400 and 56500 (Fig. 3). Using the model, we managed to constrain:

- the **coherence length of the jet magnetic field** to ~9 pc, in agreement with polarization variability estimates of ~6 pc
- the **shock compression factor**, k ~ 0.8, and
- the **shock Doppler factor**, *D* ~ 30, in agreement with independent previous estimates in the literature (*Hovatta et al. 2009, A&A, 494, 527*; *Sasada et al. 2014, ApJ, 784, 141*; *Zhou et al. 2015, New Astron.,36, 19*)