Single-Dish Polarimetry with the 100-m Effelsberg Radio Telescope – the Radio Galaxy 3C 111 –

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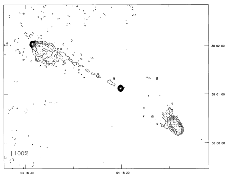
Abstract

Studying the variability of polarized AGN jet emission in the radio band is crucial to understand the dynamics of moving shocks as well as the structure of the underlying magnetic field. The 100-m Effelsberg telescope is a high quality instrument to study the long-term variability of both total and polarized intensity as well as the electric-vector position angle. Since 2007, the F-GAMMA program has been monitoring the linear polarized emission of 60 blazars at several frequencies. Here, we present a method of calibrating and correcting instrumentally biased polarimetric data at 2.8 and 6 cm as well as the resulting F-GAMMA full-Stokes light-curves of the radio galaxy 3C 111 along with VLBI-polarimetric images from the MOJAVE program. We find strong variability due to the beamed NE-jet at 2.8 cm while at 6 cm 3C 111 is no longer a point-source for the Effelsberg beam and extended non-variable lobe-emission is dominating. Furthermore MOJAVE light-curves at 2 cm match very well to Effelsberg ones at 2.8 cm.

F-GAMMA Project at MPIfR and 3C 111

The **F-GAMMA project** (Fuhrmann et al., 2007; Angelakis et al., 2008) is monitoring over **60 blazars** each month with the 100-m Effelsberg Radio telescope from 2007 on. Coordinated observations are being conducted with the IRAM 30-m telescope, APEX and *Fermi*-GST. For the first time we calibrate and analyze Effelsberg F-GAMMA polarization data at two wavelengths of 6 and 2.8 cm.



Left: **3C 111** mapped with **VLA** at 3.6 cm (Leahy et al., 1997). 3C 111 is a nearby FR II broad-line radio galaxy with an angle of ≈ 19° between jet and line-of-sight (Linfield & Perley, 1984; Kadler et al., 2008). It exhibits a broad SED with activity in the radio, optical/UV/X-rays (Chatterjee et al., 2011; Tombesi et al., 2012) and the gamma-rays (Hartman et al., 2008). The parsec-scale jet morphology is discussed in detail by Kadler et al. (2008).

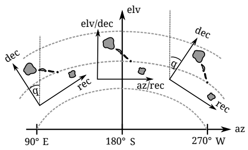
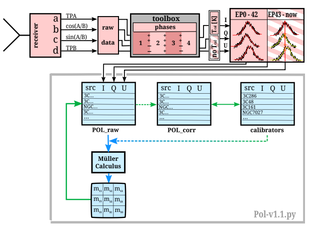


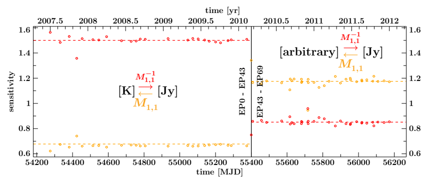
Diagram of the arcsecond structure of 3C 111 moving through the Effelsberg az/elv coordinate system with changing parallactic angle $q(t)$. 3C 111 is cross-scanned in azimuth and elevation mostly at $q(t_{obs}) \approx -50°$ and 50° according to the first and third position in the diagram. Hence, az/elv-scans are mostly driven nearly across and parallel to the jet structure resulting in partly broadened scans.

Müller Calculus – Calibration



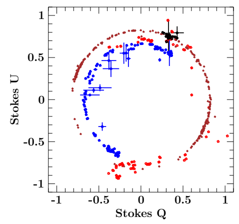
Scheme of receiving, splitting, processing and calibrating (Angelakis, 2007; Fuhrmann, 2004) full-Stokes (I-LCP/I-RCP/Q/U) raw data. Raw-data are either pre-calibrated to Kelvins or left at arbitrary units. Cross scan profiles yield Stokes I, Q and U values. **One Müller matrix per epoch** is **fitted** to measured raw data in a **successive loop** (Turlo et al., 1985; Kraus, 1997; Kraus et al., 2003). The Müller matrix is a 3×3 matrix translating between source-intrinsic and measured Stokes parameters. When applied to calibrators, it harbors calibration factors also describing instrumental influence on measured (linear) polarimetry data.

Results – Stokes I



Evolution of the derived total power calibration factors (m_{11}). Total power calibration is a stable byproduct of the full-Stokes Müller matrix derivation.

Results – Stokes Q/U

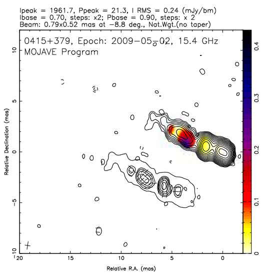


Q–U plot for all data of the *calibrator 3C286* since 2007 with: **corrected polarimetry data**, **corrected data rotated** with the appropriate parallactic angles, **uncorrected raw data** (red points are due to a less stable system).

$$\begin{pmatrix} I \\ Q \\ U \end{pmatrix}_{obs} = \begin{pmatrix} m_{1,1} & m_{1,2} & m_{1,3} \\ m_{2,1} & m_{2,2} & m_{2,3} \\ m_{3,1} & m_{3,2} & m_{3,3} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(2q) & \sin(2q) \\ 0 & -\sin(2q) & \cos(2q) \end{pmatrix} \begin{pmatrix} I \\ Q \\ U \end{pmatrix}_{cal}$$

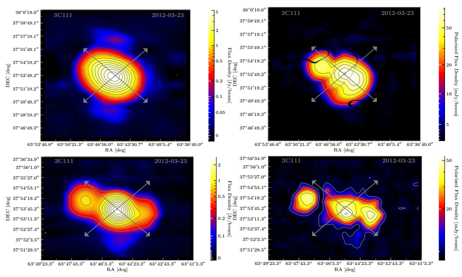
$$P = I_{pol}/I = \sqrt{Q^2 + U^2}/I \qquad \chi = 0.5 \arctan(U/Q)$$

MOJAVE – VLBI mapping



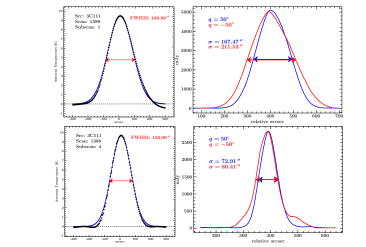
Example MOJAVE image of 3C 111 at 2 cm in total intensity and linear polarization. See `http://www.physics.purdue.edu/astro/MOJAVE`. Due to longer baselines compared to the VLA, this map shows the innermost part of the NE-jet introduced above. The jet is the only visible jet due to relativistic beaming.

100-m Effelsberg Maps



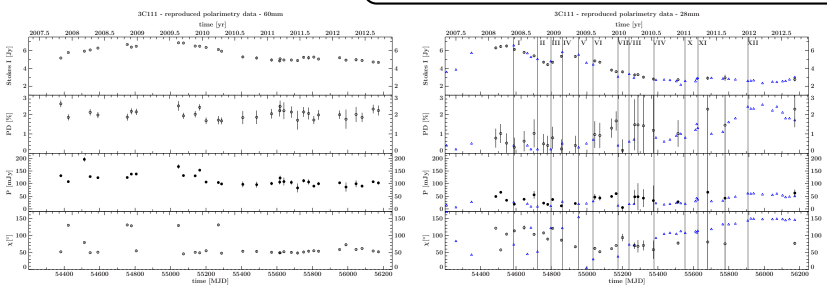
Mosaic maps of 3C 111 at 6 cm (top) and 2.8 cm (bottom). **Left:** total, **right:** polarized intensity. Gray arrows denote scanning directions.

Cross Scans



Effelsberg cross-scan data at 6 cm (**left column**) along (*top*) and across (*bottom*) the jet-axis of 3C 111 versus map-profiles (**right column**) at 6 cm (*top*) and 2.8 cm (*bottom*) both **along** and **across** 3C 111 single-dish maps.

Product of calibration – Full Stokes 6 cm / 2.8 cm light-curves



Long-term light-curves of the extended radio source 3C 111 at 6 cm (**left**) and 2.8 cm (**right**). From top to bottom: total intensity, fractional polarization, polarized flux, electric vector position angle. In the 2.8 cm light-curves, blue triangles mark 2 cm data from the MOJAVE project, gray vertical lines with roman numbers mark events in interferometry maps. Light-curves at 2.8 cm show a more pronounced variability than at 6 cm.

Total intensity flares at 2.8 cm are leading the one at 6 cm as appropriate jet-components are gradually getting optically thin at longer wavelength. Although the degree of polarization stays quite constant at 6 cm, it shows strong variability at 2.8 cm. The evolution of MOJAVE images, total intensity and linear polarization match well to calibrated Effelsberg light-curves at 2.8 cm. Hence it is shown that the Effelsberg 2.8 cm beam is sensitive to the core of the 3C 111 jet without getting influenced by the lobes.

Acknowledgements & References

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This research is based on observations with the 100-m telescope of the MPIfR and the VLBA of the NRAO. It has been supported by the MPIfR (Max-Planck-Institut für Radioastronomie) at Effelsberg, the NRAO (National Radio Astronomy Observatory), the Spanish MINECO projects AYA2009-13036-C02-02 and AYA2012-38491-C02-01 and by the Generalitat Valenciana project PROMETEO/2009/104, as well as by the COST MP0905 action ‘Black Holes in a Violent Universe’.