

Full Stokes Polarimetry Science Collaboration

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ABSTRACT

Stokes V has been recently included in the polarimetric observing sessions at the Effelsberg 100-m radiotelescope, at 11, 6, 3.6 and 2.8 cm wavelength. This paper collects possible science cases based on this technique.

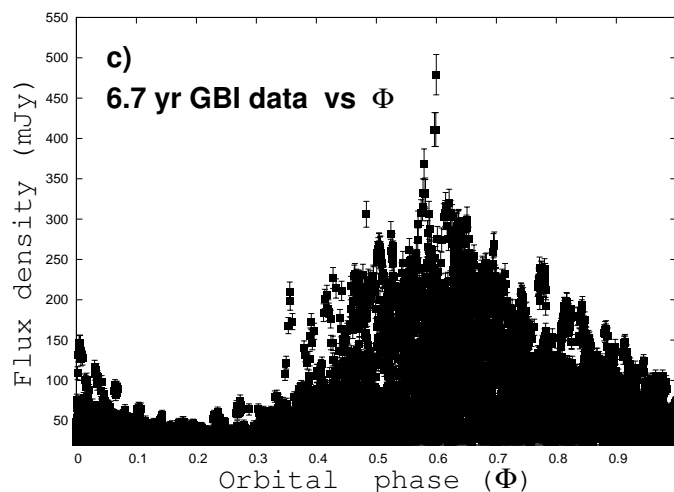
1. Galactic Astronomy

1.1. Multi-frequency linear and circular polarization study of the microquasar LSI+61°303

LSI+61°303 is a periodic source, with outbursts coincident with the orbital period of $P=26.5$ days, in both gamma-ray and radio emission. The system is formed by a massive Be star and a compact object (neutron star or black hole). The periodic radio-outbursts have flux densities ranging from 50 to 350 mJy at frequencies from 2.5 to 10.5 GHz. The source exhibits a complex radio flaring sequence, where the periodic outburst consists indeed of two consecutive outbursts with different spectral characteristics: the first outburst is optically thick, whereas the second outburst, with a delay of few days from the first outburst and stronger, is optically thin. This complex outburst of LSI+61°303 has the typical non-thermal spectrum of microquasars where the behavior of the spectral index during the flaring phase, i.e. optically thick/optically thin emission, is strictly linked to a change of the morphology of the radio emission, i.e. from a steady jet to a transient jet (Fender et al. 2004; Hannikainen et al. 2006; Massi & Kaufman Bernadó 2009). So far there are few polarization study of this source. An higher level of LP when the source is optically thin is expected, then LP should diminish while approaching the optically thick phase of the following outburst. On Sept. 13th, 1993, 4 days after the peak emission, a linear polarization between 1% and 2% has been detected at 5 GHz, using the VLA, and an upper limit of 0.4% of circular polarization has been derived (Peracaula et al. 1997). Circular polarization observations (no detections above 3 sigma) has been performed by Estalella et al. (1983) at 8.4 GHz with the 70 m telescope at the Madrid Deep Space Communication Complex (INTA-NASA).

A multi-frequency full Stokes study of this source, carried out for 1 week across the peak emission, would supply an interesting picture of the spectral behavior of the source while crossing the optically thick/thin stage. It would be very important to establish if circular polarization is also present in LSI+61°303 as in the other microquasar SS433 where is also observed a sign change in Stokes V (McCormick et al. 2003).

Fig. 1. Radio light curve (8.3 GHz) vs. the orbital phase Φ from Massi & Kaufman Bernadó (2009)

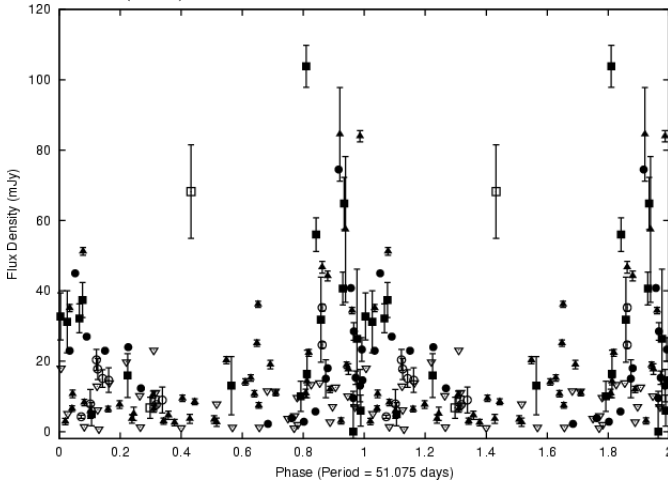


1.2. Multi-frequency linear and circular polarization study of the binary V773 Tauri

V773 Tauri is a young pre-main-sequence binary system, with a period of 51 days (Boden et al. 2007) and a radio emission from 30 to 100 mJy in the range 8-10 GHz. The two components are separated by tenth of stellar radii, are fast rotating around their axis and undergo a strong magnetic activity, with flares from three to six order of magnitudes brighter than the solar flares.

The periodic radio flaring of nearly 51 days has been explained as due to the collision of giant-sized magnetic solar-like streamers belonging to the two components. Magnetic structures of almost 20 stellar radii associated to each of the two stars have been indeed recently imaged with VLBA+EB (Massi et al. 2002, 2008). Up to 2% of linear polarization and 4% of circular polarization have been detected at 5 and 8 GHz, suggesting the presence of an electron energy distribution which spans both moderate and high-energy regimes (Phillips et al. 1996; Massi et al.

Fig. 2. Radio observations of V773 Tau folded with the orbital period of 51.075 days. Phase 0(1, 2) refers to the passage at periastron. From Massi et al. (2002)



2006) The observation of linearly and circularly polarized levels are related respectively to the synchrotron and gyro-synchrotron emissions that are both present in this source, unique example in the field of stellar coronae where only gyro-synchrotron and circular polarization are otherwise observed.

Multi-frequency full Stokes observations could be carried out during the predictable flaring phase at periastron passage where the minimum distance between the two stars give rise to the strongest interbinary collision among the streamers. Observation of linear polarization would confirm the up to now unique detection of Phillips et al. (1996).

1.3. Spectral Line Polarimetry

Spectral line polarization observations are an important tool for studying the strength and morphology of magnetic fields, both galactic as well as extra-galactic. The circular polarization arising from Zeeman splitting of paramagnetic molecules and of strong (maser) transitions of non-paramagnetic molecules can directly be used to the magnetic field strength in the region where the lines in question are emitted. Additionally, the linear polarization, arising due to radiation anisotropy when exciting the different magnetic substates (the Goldreich-Kylafis or GK-effect, Goldreich & Kylafis (1981)), allows observations of the projected direction of the magnetic field on the plane of the sky.

The majority of the spectral line polarization observations, specifically those in the radio-wavelength regime, have been aimed at masers. While due to their very nature, the analysis of maser polarization needs special treatment beyond the regular GK-effect, maser polarization observations have in recent years provided important insights in the magnetic fields during star-formation (e.g. Vlemmings (2008)), in AGN and ULIRGs (Vlemmings et al. 2007; Robishaw et al. 2008) and around evolved stars (e.g. Vlemmings (2008)). Still, even the maser observations are often still limited to small samples. Full Stokes polarimetry with large single dish telescopes could greatly increase sample sizes of all the types of astronomical objects mentioned earlier. And as most of the current single dish studies have only been used to obtain one (typically circular) of the polarizations, full Stokes polarimetry would add important further information. Additionally, full Stokes maser polarimetry would be able to directly test the robustness of the single-dish polarization

calibration schemes due to the prescribed dependence of the circular polarization to the derivative of the total power (in case of the regular Zeeman effect).

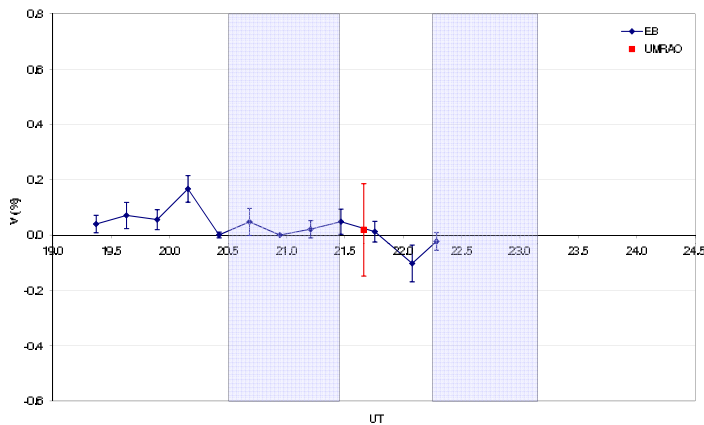
2. Extragalactic Astronomy

2.1. Rapid polarization variability of extragalactic sources across the Radio-Bands

A relatively large fraction (30-50%) of compact flat spectrum radio sources show in the cm-radio-band variations in intensity and polarization on time-scales of hours to days. This so called intra-day variability (IDV) has at least two main physical causes. At long cm-wavelengths it is dominated by the interstellar scattering effect, induced by the clumpy and turbulent interstellar medium. Depending on source size and observing wavelength, the interstellar scattering (ISS) can be weak or strong, refractive or diffractive, showing different signatures in intensity and polarization. The IDV observed at 5 GHz is mainly weak refractive. At 1 GHz strong diffractive effects have been observed in a few cases. Interstellar scattering shows a strong wavelength dependence, with variability amplitudes decreasing with increasing frequency. At short radio-wavelength and in the mm- to optical bands, rapid variability is still present and is caused by source intrinsic effects, related to the variable and often extreme physical conditions in the (very small) emission region (e.g. QPOs). In the case of the IDV source 0917+62, multi-frequency polarimetry has been used to disentangle between scattering induced and source intrinsic effects (Qian et al. 2002). An observed break in the wavelength dependence of the EVPA of the BL Lac 0716+71 let us suspect that at least two Faraday screens are present, one from the ISM and another one possibly intrinsic to the source. VLBI polarimetry in J1128+56 suggests time variable RMs, related to the orbital motion of the Earth (Gabányi et al. 2009). Polarization angle swings observed in 0917+62 and 1150+81 indicate polarized sub-structure on scales of 10-100 micro-arcseconds. All this gives plenty of room for astrophysical interpretation and modeling, which due to the still limited understanding of polarization variability presently must remain hypothetical.

Therefore a monitoring of the IDV in intensity and polarization of blazars with good time and broad frequency coverage (1-90 GHz) is required, to disentangle between source intrinsic and source extrinsic effects, and to provide high quality polarization data for more thorough astrophysical modeling. When using the available (and planned) multi-channel polarimeters of the EB-telescope, the frequency dependence of the RM measure and its possible variability can be determined. Polarimetry at the higher frequencies (above 10 GHz) is less affected by Faraday-rotation and external depolarization and therefore can be used to access the source intrinsic origin of the rapid variability. This demands coordinated polarimetric monitoring at different telescopes, each of which observes in different radio bands (decimeter, centimeter, millimeter, optical). The study of the circular polarization and search for possible CP variability even on the shortest time scales (less than days) in IDV sources would allow to test more exotic models, which are based on partly coherent emission processes, and which predict high and more variable CP than in the standard incoherent synchrotron emission scenario of AGN.

Fig. 3. Stokes V from 3C 84. Data from the Effelsberg and the UMRAO telescopes taken on Feb. 20th. The grey areas indicate the UMRAO observing time intervals.



2.2. CP Target of Opportunity at Effelsberg from UMRAO long monitoring program

In the last 30 years, the 26-m telescope of the University of Michigan has been the only single-dish radiotelescope used to carry out multi-frequency full-Stokes observations of extragalactic radio sources Aller et al. (2003).

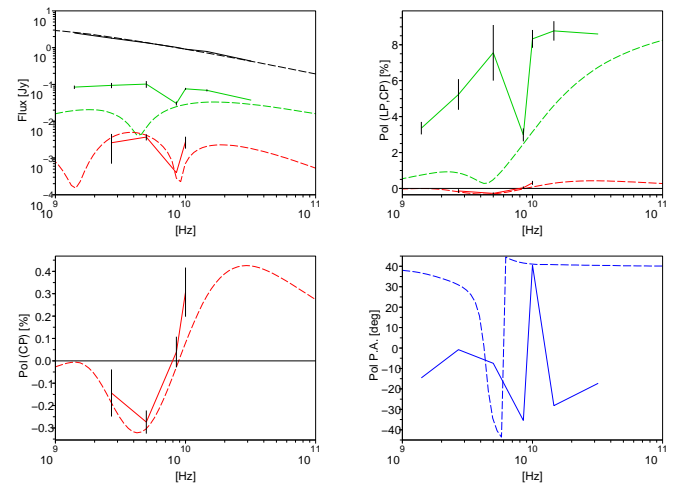
During 2007, at Effelsberg, CP from a sample of 39 extragalactic sources has been repeatedly observed at 6 cm as part of the new polarimetric calibration test phase. During the same period the University of Michigan was carrying on a full Stokes polarimetric monitoring program, which covers several years, at 6, 3.6 and 2 cm. At the beginning of 2009 a comparison between the past observed values has been performed for the sources 3C 279, 3C 84 and 2145+06 at 6 cm. The measurements from the two instruments are in very good agreement, anyhow the measurements were carried out independently and typically are not contemporary. The time gap between an Effelsberg observation and a Michigan one ranges from 1 to 20 days. During February 2010 a contemporary observation of 3C84 and 3C345, observed at the same time by Effelsberg and the UMRAO, has been performed. The sources were observed for nearly 5 hours per day, for 5 days, and the comparison between the data set confirms a very good agreement between the instruments (Cenacchi E. et al, in prep.).

Because of the high variability that typically characterizes CP, it is hard to plan an Effelsberg CP observation with large advance, hence a further common observation within a triggering procedure would be an ideal solution. Sources belonging to the UMRAO monitoring program which exhibit an increasing value of CP could be observed at Effelsberg upon notice by the UMRAO, as target of opportunity. The higher accuracy offered by the 100-m telescope and the better time resolution will allow a detailed full Stokes study of the sources during the peak emission phase.

2.3. Full Stokes observations of AGNs at frequency ≥ 10.5 GHz

Radio emission from radio-loud AGNs is typically ascribed to synchrotron radiation from relativistic electron flowing in jets emerging from a central super-massive black-hole that is accreting material from the host galaxy. The synchrotron emission is intrinsically highly linearly polarized and significantly circularly

Fig. 4. 0056-00, full Stokes spectra observed in 2008. Each plot contains a comparison of the observed radio continuum flux (continuous line) and the simulated one (dashed line). Upper left, top to bottom: flux density I, LP, CP (absolute value); upper right, top to bottom: LP, CP; lower left: CP; lower right: polarization angle. From Cenacchi et al. (2009a)



polarized, anyhow, the levels of local CP, measured with interferometric techniques, are too high to be compatible with the estimated magnetic field strength along the jet (Vitrishchak & Gabuzda 2007). Hence the Faraday conversion, internal or external, is generally accepted as the dominant mechanism that produces CP. Both the intrinsic emission and the Faraday conversion predict a decreasing level of CP with frequency, with different trends (Jones & O'Dell 1977), hence a reliable identification of the specific mechanism involved requires multi-frequency full Stokes observations.

In a recent paper, Vitrishchak et al. (2008) published the VLBA data for 41 AGNs observed at 15, 22 and 43 GHz and surprisingly found that, for half of the detections, the degree of CP was increasing with frequency, instead of decreasing as expected. Most of the sources listed in the paper have already been observed at Effelsberg at lower frequencies. We would like to extend the full Stokes calibration technique (Cenacchi et al. 2009b) at higher frequencies at Effelsberg and repeat the observations carried out by Vitrishchak et al. (2008). Although with a single-dish antenna the observed CP is the integrated value, from the whole source, the authors generally attribute the CP emission from the source core region only, or from a compact region at the base of the jet. Although a proper study of the CP emission along the jet structure at intermediate resolutions is still missing, we should be able to detect the increasing trend of CP with Effelsberg also.

3. Techniques

3.1. Aspects for the usage of the Italian radio telescopes for full Stokes polarisation observations

The Italian radio telescopes are two 32-m antennas at Medicina, close to Bologna, and at Noto, in Sicily. A new 64-m antenna is currently being completed in Sardinia and expected to become operational during 2011. In the past, these antennas were mainly used for VLBI and to a minor extent for spectroscopic single-dish observations. We are currently upgrading hard- and software facilities for the time being at Medicina to allow for the usage for deep continuum measurements. Once developed we expect that at least the software part can easily be exported to

Noto and the SRT. This would then provide us with observing facilities, especially suited for observations at high frequencies, given that at least two (Nt, SRT) of these three antennas possess an active primary mirror and are situated at relatively well-suited sites. The installation of polarimetric receivers forms a critical milestone in these upgrade efforts, as these observations require well-calibrated receiver systems and profound knowledge of the antenna optical conditions. First tests are currently being performed at Medicina. The final goal will be the calibration of the systems for circular polarisation measurements. We expect that the suite of Italian radio telescope will provide optimum observing grounds, in particular for monitoring efforts, for future CP studies.

Scientifically, high-frequency (≥ 10 GHz) observations of suited sources, in particular Giant Radio Galaxies, are an optimum application for single-dish telescopes, as interferometers tend to loose considerable amount of flux density and structural information for very extended sources. Linear polarisation information is crucial as e.g. the magnetic field structure can be directly mapped without depending on additional modelling from Rotation Measures, as would be necessary at lower frequencies (Mack et al. 1997; Saripalli et al. 1996).

The characteristics of Circular Polarisation in these sources, e.g. around hot spots, are hardly known.

In addition to the high-frequency observations, also low-frequency single-dish maps of such sources become more and more important to provide full-Stokes zero-spacing information for the growing amount of low-frequency observations expected from the GMRT, Lofar or other new low-frequency arrays.

3.2. Looking for Faraday rotation and conversion along relativistic jets using the VLA

The production of circular polarization (CP) in radio sources is typically ascribed either to intrinsic synchrotron emission or to Faraday conversion: a birefringence effect that converts linear polarization (LP) into CP (Wardle & Homan 2003). In a relativistic plasma the normal polarization modes are elliptical and both Faraday rotation and conversion are present.

When observed, a significant detection of Faraday rotation is linked the presence of an high concentration of magnetized plasma within the emitting region or around it (Faraday screen), or more - in general - along the line of sight. When intrinsic to the source host, when the geometry of the magnetic field is favourable to the line of sight, it could also trigger the Faraday conversion of Stokes U into V.

A VLA multi-frequency and multi-epoch observation of a couple of selected sources with jets directed far from the line of sight (e.g. broad line radio galaxies such as 3C120, Gómez et al. (2008) or highly bent QSOs, Cotton et al. (2003)) would allow the study of the evolution of the Faraday gradients along the jet features. The implementation of a reliable full Stokes calibration with the VLA, analogous to the gain transfer technique developed by Homan & Wardle (1999) for the VLBI, would allow Stokes V measurements and the simultaneous study of CP and LP at different frequencies. Rotation measure gradients, the spatial dependancy of the degree of polarization and the detection of circular polarization are often associated with the presence of helical magnetic fields and/or with jet bends changing the Doppler factor.

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