Article

JVLA wideband polarimetry observations on a sample of high Rotation Measure sources.

Alice Pasetto [1,*], Carlos Carrasco-González [2], Shane O'Sullivan [3], Aritra Basu [1], Gabriele Bruni [1], Alex Kraus [1] and Karl-Heinz Mack [4]

1 Max-Planck Institut für Radioastronomie (MPIfR), Auf dem Hügel 69, D-53121 Bonn, Germany;
2 Instituto de Radioastronomía y Astrofísica (IRyA-UNAM), Antigua Carretera a Pátzcuaro 8701, 58089 Morelia, Michoacán, México;
3 Instituto de Astronomía (IA-UNAM), San Jose Insurgentes, Ciudad de México, México;
4 Istituto di Radioastronomia (IRA-INAF), Via Gobetti 101, I-40129 Bologna, Italy;
* Correspondence: apasetto@mpifr-bonn.mpg.de

Abstract: We present preliminary results of JVLA wideband full polarization observations of a sample of Active Galactic Nuclei (AGN) with very high Rotation Measure (RM) values, sign of extreme environment. The polarization properties show a complex behaviour with the polarization angle (PA) and the fractional polarization (fp) that dramatically change within the wideband. The measured RM is not constant within the wide band. Its complex behaviour reflects the complexity of the medium with the presence of several Faraday components. The depolarization have been studied, modeling the Stokes parameters Q and U together with the polarization parameters (PA and fp) with wavelength by applying combinations of the simplest existing depolarisation models. With this JVLA study we could spectrally resolve multiple polarized components of unresolved AGN. These preliminary results reveal the complexity of these objects, still improvements have to be done on the depolairzation modeling to better understand the polarization structure of these sources.

Keywords: AGN; polarimetry

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1. Introduction

The polarized, non-thermal radiation of the powerful jets of relativistic plasma ejected from the radio-loud active galactic nuclei (AGN) can be used to probe the magneto-ionic material along the line of sight between us and the source of emission. The study and analysis of the polarization information in the radio band, i.e. the Faraday rotation and the depolarization, are powerful tools that can help to understand how the AGN media is characterized. The connection of the polarization properties, i.e. a very high rotation measure (RM) value and a strong depolarization, with the ambient medium, has been studied since years [e.g. 1,8,10]. Some observational works revealed sources with very high RM with single-dish and interferometric techniques [e.g. 4,5] and also with higher resolution VLBI technique [e.g. 3].

We show here JVLA polarimetric measurements of a sample of bright point-like AGN that show an essential characteristic: they are unpolarized at 1.4 GHz in the NRAO VLA Sky Survey (NVSS) [2]. These sources may suffer from strong in-band depolarization, i.e. a large rotation of the polarization angle at this frequency with the result of a final vector pair cancellation of the angles and the subsequent depolarization of the signal. The unpolarized AGN could be polarized at higher frequencies, sign of very dense medium and/or strong magnetic field.

We present preliminary results of wideband, polarimetry JVLA interferometric observations at L, C and X bands. Thanks to the wide band spectropolarimeters we could follow the dramatic changes of both the fractional polarization and the polarization angle of the targets. We studied the depolarization behaviour by modeling the Stokes parameters Q and U with wavelength. The JVLA observations and data reduction are shown in section 2, a brief description of the depolarization

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medels used in this work is presented in section 3 and preliminary results and discussion are shown in section 4.

2. Observations and data reduction

We observed in full polarization mode a sample of 14 sources by using the Karl. G. Jansky Very Large Array (JVLA) of the National Radioastronomy Observatory (NRAO)[1].

Observations were made at L (with 1 GHz bandwidth), C and X bands (with 4 GHz bandwidth). All the sources are bright enough for phase self-calibration and are unresolved at all the resolutions of the JVLA. The time on source was set around 1 minute per source/band; the time was considered enough for a good signal to noise both for the total intensity and the polarization flux density detection. Observations of a standard flux/polarization angle calibrator (e.g. 3C286, 3C48, 3C138), as well as the leakage calibrators were performed during all the observational sessions..

Data editing and calibration were made by using the data reduction package CASA (Common Astronomy Software Applications[2]; version 4.4.0) following standard VLA procedures (prior known corrections, bandpass, delay and gain calibrations and finally total flux and polarization calibration).

For the flux calibration of the Stokes I, we used resolved models of the flux calibrators provided by the CASA package. For the calibration of the stokes parameters Q and U we used the known values of the fractional polarization and polarization angle at different frequencies reported by [6]. Polynomial functions to these data fit the full Q and U spectrum in the 1 to 45 GHz frequency range. We used those modeling solution to calibrate our targets.

On the calibrated data, images of Stokes I, Q and U have been performed for all the targets for each 128 MHz spectral windows and for each band. On the individual spectral windows images we perform a Gaussian fit to the source, extracting information on the Stokes parameters I, Q and U. These high spectral resolution information allow us to well sample the SEDs and the polarization information, i.e. the polarization flux density, the fractional polarization and the polarization angle, for each target.

3. Depolarization models

Total intensity observations of these sources [5] have revealed complex radio spectra, which in most cases could be fitted with multiple synchrotron components. This can reflect a complex behaviour also in the polarization information with the presence of multiple interfering RM components. To study the complex polarization behaviour, we fitted the broad band Stokes Q and U spectra following the procedure proposed by [7]. We used a combination of three simple equations that explain the depolarization mechanism. Depolarization occurs when the media surrounding the radio source, not only produces a change in the polarization angle but also reduce the amount of its polarization flux density. It can also occurs that the synchrotron emitting and the Faraday rotating regions are mixed together. These different depolarization behaviours can be described by three known equations: (1) differential Faraday rotation (DFR), (2) internal Faraday dispersion (IFD) and (3) external Faraday dispersion (EDF) [see 1,7,9].

For a medium which is synchrotron emitting and rotating in the presence of a uniform magnetic field, i.e. the DFR, the complex degree of polarization is given by,

$$p = p_0 \frac{\sin R\lambda^2}{R\lambda^2} e^{2i\left(\phi_0 + \frac{1}{2}R\lambda^2\right)}, \quad (1)$$

[1] The NRAO is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

[2] https://science.nrao.edu/facilities/vla/data-processing

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where, p_0 and ϕ_0 are the intrinsic degree of polarization and polarization angle, respectively, and R is the Faraday depth through the region.

If the emitting region also contains a turbulent magnetic field together with a uniform magnetic field, i.e., the IFD, the degree of polarization is then given by,

$$p = p_0 e^{2i\phi_0} \left(\frac{1 - e^{-S}}{S} \right), \tag{2}$$

where $S = 2\sigma_{\mathrm{RM}}^2 \lambda^4 - 2iR\lambda^2$ and σ_{RM} is the internal Faraday dispersion of the random field within the volume traced by the telescope beam.

When the magneto-ionic medium contains turbulent magnetic field but does not emit synchrotron radiation, the EFD is represented by the equation:

$$p = p_0 e^{-2\sigma_{\mathrm{RM}}^2 \lambda^4} e^{2i(\phi_0 + RM\lambda^2)}. \tag{3}$$

When multiple emitting and/or rotating components exist and they are unresolved within the telescope beam, the complex polarization can be simply described as, $p = p_1 + p_2 + ... + p_N$ [7]. This is the approach we adopted for the modeling of the sources. We considered only the sum of the same model type, i.e. multiple of DFR, multiple of IFD or multiple of EFD.

The combination of these models have a strong interdependence of the different parameters and are highly non linear equations. To evaluate the goodness of the fit we performed the chi-squared-test to the data applying a function that provides a non-linear optimisation curve fitting for these kind of equations.

4. Preliminary results and discussion

We present preliminary results of this JVLA observational campaign. Examples of the radio spectra for three sources (0845+0439, 0958+3224 and 2245+0324) are shown in Fig. 1. The radio spectra fit were made by using our JVLA data at L, C and X bands, as well as data at lower frequencies reported in several surveys (i.e. the VLSS at 74 MHz, the 7C at 151 MHz, the WENSS at 325 MHz and the TEXAS at 365 surveys). We fitted the total intensity data with several synchrotron components following a similar approach performed during previous single dish fitting [5] on the same sample. The results of these new radio spectra fitting are consistent with previous single dish results.

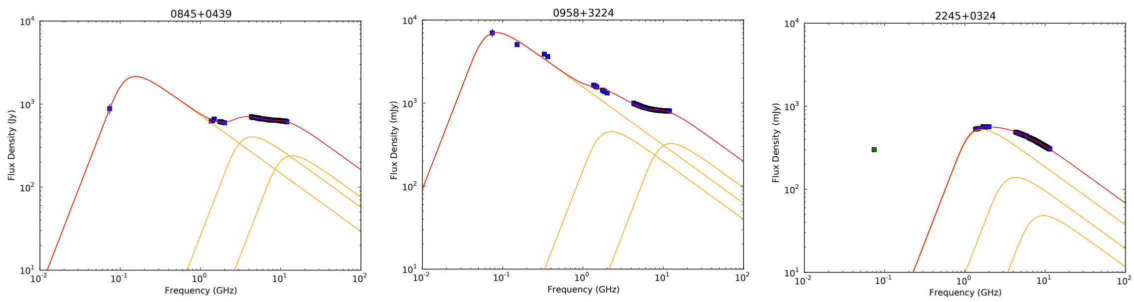

Figure 1. Radio spectra using L, C and X bands and literature. Total flux density is expressed in [mJy] and the frequency in [GHz]. Blue points are the JVLA and literature data and green points are upper limits.

In Fig. 2 we show the polarization properties of the three sources taken as an example. The plots show the Stokes Q and U together with the polarized flux density S_{pol}, the fractional polarization fp and the polarization angle χ within the C and X bands. These JVLA observations confirm previous results from the Effelsberg campaign [5]: the behaviour of the polarization angle deviates significantly from a simple linear trend. We cannot assign a single RM for these sources in the 4-12 GHz range; at

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different frequencies the RM have different values. The values of the RM with frequency are reported in Fig. 3. We calculated the RM at each frequency ν_0 by performing a local linear fit to the data points in a $\pm$512 MHz range around ν_0. We then plotted the derivative of the polarization angle, calculated in this way, as a function of frequency. The green stripe in the figures represent the 1σ error of the derivative.

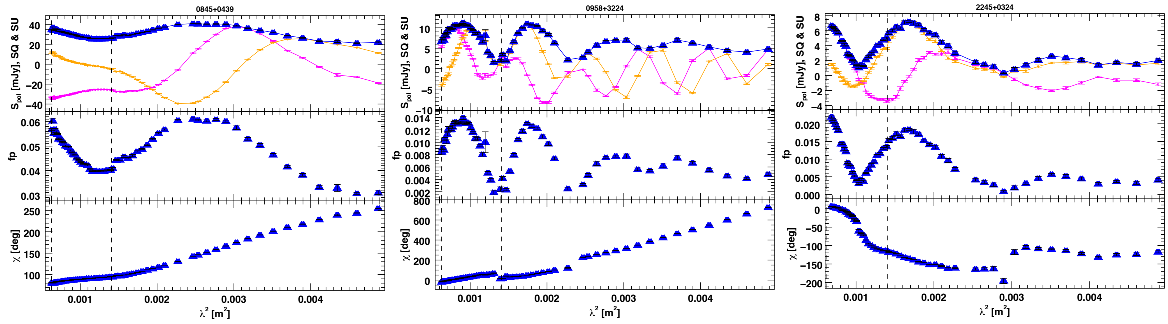

Figure 2. Polarization information of the sources at C and X bands.

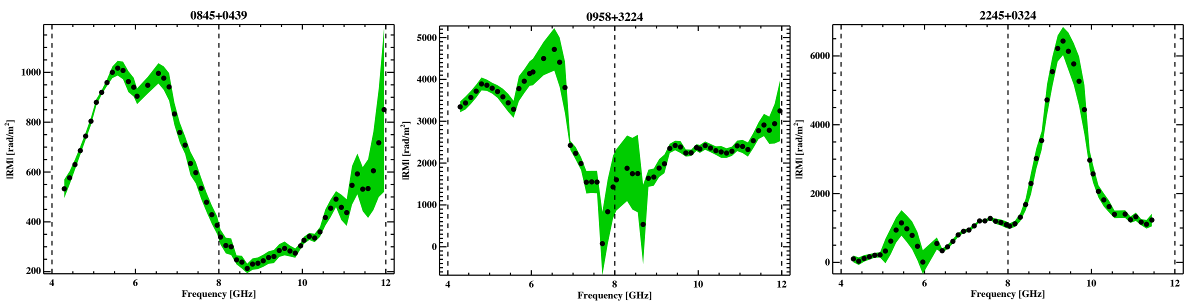

Figure 3. RM with frequency behaviour at C and X bands.

In Fig. 4 we report preliminary results of the depolarization modeling for the three sources taken as an example. Our modeling approach only could obtain a reasonable fit for roughly half of the sample. The RM values of the three sources corrected to the rest frame are reported in Tab. 1.

Table 1. RM of the modeling corrected in the rest frame (subscript RF).

Source	Model	z	RM_{1RF} [rad/m^2]	RM_{2RF} [rad/m^2]	RM_{3RF} [rad/m^2]
0845+0439	DED	0.3	1270 $\pm$ 10	2720 $\pm$ 20	–
0958+3224	T	0.5	8770 $\pm$ 30	1670 $\pm$ 110	2500 $\pm$ 120
2245+0324	DID	1.3	-14730 $\pm$ 140	-21340 $\pm$ 590	–

NOTE:
T: Triple model; DED: Double External Dispersion model; DID: Double Internal Dispersion model.

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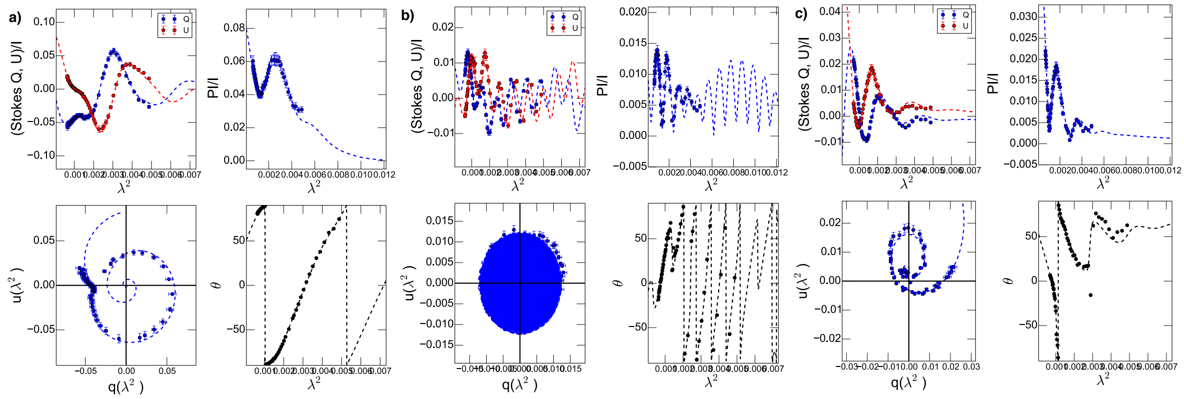

Figure 4. Depolarization models for the sources: (a) 0845+0439 fitted with a Double External Dispersion model, (b) 0958+3224 fitted with a Triple model and (c) 2245+0324 fitted with a Double Internal Dispersion model.

4.1. Some preliminary comments on the sources

- Source 0845+0439 (Fig.s 1, 2, 3 and 4a)
  The radio spectrum of this source (Fig. 1) could be fitted with an old component at low frequency and two synchrotron components at higher frequencies. However, also a flat spectrum with the whole frequency range could describe the spectrum. The polarization angle clearly does not follow a linear trend (see Fig. 2), with RM changing between 500 and 1000 rad/m^2 at C band (see Fig. 3).

  This source is very well fitted by a *Double External Dispersion* model (two times an external Faraday rotating screen that contains turbulent magnetic field), just few fractional polarization data points at long wavelength are not well represented by the fit. From the preliminary results of the depolarization modeling, the magnetic field could be characterized by a high presence of random cells of magnetic field.

  A possible scenario could be that the radio synchrotron emission is passing through two turbulent magnetized media that are not emitting synchrotron radiation but that are just responsible for the external Faraday depolarization. These media could be characterized by a high value of thermal electron density. Depending on the morphology of the source in the pc-scale, these media could be attributed to clumps surrounding the central engine and/or a dense wind that cover the jet spine of the AGN.

- Source 0958+3224 (Fig.s 1, 2, 3 and Fig. 4b)
  The spectrum of this source (Fig. 1) could be fitted with an old component at low frequency and two synchrotron components at higher frequencies. The RM seems to vary within the C and X bands with values $>$ 1000 rad/m^2 (see Fig. 3).

  For this source we found a *Triple* model to be the best model to fit the data. The depolarization comes from the presence of three external Faraday layers with regular magnetic field. One can visualize it with the presence of at least three clumpy regions producing a different RM each. The values of the resulting RMs are very high (indeed, note in Fig. 4(b) the large rotation of the Stokes parameters Q and U; see Tab. 1 for the values of the RM), suggesting a very dense magnetized media.

  From the literature, [11] classify this object as Seyfert 1.8 (Sy 1.8) therefore, the torus is obscuring the very central part of this galaxy. This suggests that the radio emission at high frequency comes from the central region of the galaxy and it goes through at least three external Faraday screens (that could be clumpy regions of the obscuring torus) that depolarize at C and X bands.

- Source 2245+0324 (Fig.s 1, 2, 3 and Fig. 4c)
  This source could be fitted with three synchrotron components and it is also consistent with a convex shape spectrum (Fig. 1) indicating a possible young nature of the source. The RM value increases towards high frequencies reaching a maximum at $\sim$ 9 GHz and it decreases again down to RM of $\sim$ 1000 rad/m^2 at $\sim$ 12 GHz (see Fig. 3).

  This source seems to be quite well fitted by a *Double Internal Dispersion* model: two times of the model that describes an emitting and rotating region having a turbulent and ordered magnetic fields coexisting together. If the young nature of this source is confirmed (with high angular resolution observations), the internal depolarization would be justified because of the presence in these objects of both non-thermal (responsible for the synchrotron emission) and thermal (responsible for the Faraday rotation measure) electrons in the same emitting region.

With this JVLA study we could spectrally resolve multiple polarized components of these unresolved AGN. The preliminary results reveal the complexity of these objects. However, we need to improve the depolairzation modeling to better understand the polarization structure of these sources and possibly give constraints on the physical parameters of the medium, i.e. magnetic field strength and thermal electron density.

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Conflicts of Interest: The authors declare no conflict of interest.

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