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Detection of polarized emission from SNR Cassiopeia A even at meter wavelengths

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Abstract. We report detection of weak but significant linear polarization in the emission from the Supernova Remnant (SNR) Cassiopeia A (Cas A) at 327 MHz using the GMRT. Our data in full Stokes parameters, benefiting from both high angular resolution and wide spectral span, reveal up to 5% linear polarization, despite the heavy internal depolarization expected at such low radio frequencies. Surprisingly, the intrinsic position angles (PA) are found to be nearly constant across the source.

Keywords : ISM: individual objects (Cassiopeia A) – ISM: magnetic fields – ISM: supernova remnants – techniques: polarimetric – X-rays: individual (Cassiopeia A)

1. Observations and data reduction

The 327 MHz GMRT observations of Cas A were carried out in November 2009. Data from ~ 9 hour synthesis observation in dual circular polarization channels (R & L) available through a hybrid were processed through the GMRT software correlator (Roy, Gupta, Pen, Peterson, Kudale & Kodilkar 2010) recording visibilities in all four Stokes (I,Q,U,V), with 256 spectral channels spanning the 16 MHz bandwidth. A short integration time of 2 seconds was used to minimize corruption of data from shorter time-scale RFIs. Observations for ~ 5 minutes every hour to sample a large range of parallactic angles ($> 150°$), needed for primary polarization calibration, were made on an unpolarized calibrator (3C468.1), which also provided useful phase calibration. The instrumental RL-phase spectra was estimated using the known RM of the polarized calibrator 3C345, and the consistency of the solutions was verified using another polarized calibrator 3C303 whose RM is also known[1] (Simard-Normandin,

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[1] de Bruyn, Private communication

Figure 1. GMRT 327 MHz Stokes-I image of Cas A.

Kronberg & Button 1997). The PAs of these polarized sources are not yet known, as far as could be ascertained from literature. However, the *relative* orientations in the images are well calibrated, and only a common reference offset in the orientations of the polarization vectors remains arbitrary at this stage.

While most of the standard imaging steps were performed in AIPS and MIRIAD, the final step to RM cube, *i.e.* performing Faraday tomography (Burn 1966; Ramkumar & Deshpande 1999; Brentjens & de Bruyn 2005), used locally developed software. The residual polarization leakage reduced to $< 0.5\%$ of Stokes-I, as a result of the primary polarization calibration. The data have been scaled assuming the integrated flux density of Cas A to be $\sim$ 7000 Jy at 327 MHz, consistent with a flux density of 2720 Jy at 30 cm, and a spectral index α of 0.77 (Green 2009), where $S_\nu \propto \nu^{-\alpha}$. A calibrated band-averaged image of Cas A (327 MHz Stokes-I) is shown in Fig. 1. The overall Stokes-I morphology, including the radio-bright ring (at $\sim 100''$ radius) and the knots/filaments, is strikingly similar to that in the VLA L-band images.

2. Key results

The RM of the dominant component in the Faraday tomographs is found to be $\sim 5 \pm 3$ rad m^{-2}.

The lack of correlation between the polarized intensity and Stokes-I (Fig. 2) rules out any instrumental origin of the observed polarized component. A clear anti-correlation of the degree of polarization with soft X-ray emission, assessed through a novel binning method, provides additional support for the polarization being intrinsic to the source (Fig. 3).

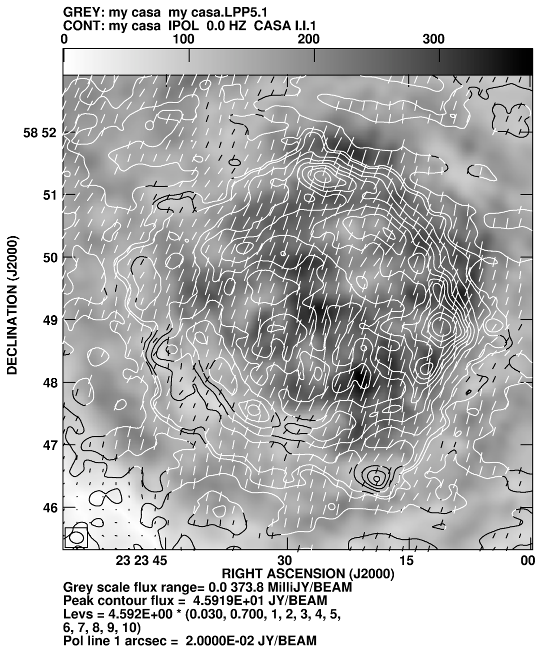

Figure 2. GMRT 327 MHz image of Cas A. The contours show Stokes-I intensity. Linearly polarized intensity is in grey scale. The polarization vectors are also plotted. The polarization position angle reference is arbitrary.

The dominant polarized emission component shows a nearly constant PA across the remnant, with the small dispersion ($\sim 5^\circ$) in the PA (Figure 2). This constancy of the PA is intriguing and is in direct contrast with the PA variation apparent in earlier studies of the remnant at higher frequencies (Mayer & Hollinger 1968; Rosenberg 1970; Downs & Thompson 1972; Gull 1973; Braun, Gull & Perley 1987; Jun & Norman 1996).

3. Discussion

Both the uniform orientation of the linear polarization and the constancy of the associated RM across the source as seen in our 327 MHz images are intriguing in light of the observations at higher frequencies where considerable spread in PA as well as RM is seen across the remnant. This would suggest that the observed polarized emission at 327 MHz must originate from the "outer regions" of the source, and that the magnetic field orientation therein, is uniform. Follow-up observations at higher frequencies (particularly at the 610 MHz band of the GMRT) would help clarify several of these intriguing features seen at 327 MHz.

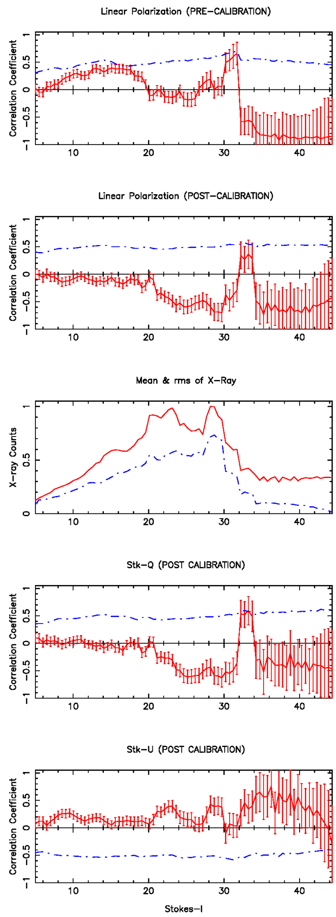

Figure 3. The top two panels show the profiles of the correlation between soft X-radiation and the linearly polarized intensity as a function of Stokes-I before and after primary polarization calibration respectively. The $\pm 1\sigma$ error bars on the correlation-coefficients are also shown. The central panel shows the profile of the mean (solid line) and the rms (dash-dot line) of X-ray counts (both the profiles have been normalized by the maxima of the profile corresponding to the mean X-ray count). Correlation profiles of calibrated Stokes-Q and Stokes-U with X-ray are shown in the 4th and the 5th panels respectively. The mean of the polarized intensities within the I-bins (dash-dot lines) are plotted in the respective panels. For ease of display, the magnitudes of the means within the I-bins are normalized by twice their global means ($\sim$ 360, 217, 168 & -130 mJy) for quantities in panels 1, 2, 4 & 5 respectively.

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