Milliarcsecond-Scale Polarization Study of Compact Radio Sources 0223+341 and 0248+430 (Postprint)

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Abstract

Using the Very Long Baseline Array (VLBA), we conducted polarization observations at 4.6 GHz for the compact radio sources 0223+341 and 0248+430, obtaining intensity distribution images with an angular resolution as high as 2 milliarcseconds and, for the first time, acquiring the polarization vector distribution results for these two sources at 4.6 GHz. The compact steep-spectrum source 0223+341 shows no detected radio core; its radio structure is primarily composed of two components suspected to be hot spots, with polarized emission concentrated at one of the hot spots but exhibiting a relatively low degree of polarization, suggesting the presence of a relatively dense surrounding medium. In contrast, the gigahertz-peaked spectrum source 0248+430 displays a one-sided core-jet structure, with polarized emission concentrated near the radio core.

Full Text

VLBI Polarization Study of Compact Radio Sources 0223+341 and 0248+430

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Abstract: Using the Very Long Baseline Array (VLBA), we performed polarization observations of the compact radio sources 0223+341 and 0248+430 at 4.6 GHz, achieving an angular resolution of 2 mas. We present their total intensity distributions and, for the first time, their polarization vector maps

at this frequency. The compact steep-spectrum source 0223+341 shows no detectable radio core; its structure consists primarily of two components likely representing hot spots, with polarized emission concentrated near one of them at a low polarization degree, suggesting a dense surrounding medium. The gigahertz-peaked-spectrum source 0248+430 exhibits a one-sided core-jet morphology, with polarized emission concentrated near the radio core.

Keywords: Polarization observations; Compact radio sources; Polarization structure

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Introduction

Compact steep-spectrum (CSS) and gigahertz-peaked-spectrum (GPS) sources are defined as compact radio sources with spectral indices $\alpha \geq 0.5$ (where S ^{-α}) in the optically thin region, constituting approximately 30% and 10% of extragalactic radio sources, respectively. CSS sources have linear scales of 1-20 kpc, while GPS sources are generally smaller than 1 kpc. Their radio spectra exhibit low-frequency turnovers due to synchrotron self-absorption or free-free absorption, creating peaked structures. The peak frequency typically occurs below 500 MHz for CSS sources and between 500 MHz and 10 GHz for GPS sources [?]. Three main hypotheses currently explain CSS and GPS sources: (1) GPS sources are young radio sources in early evolutionary stages that will evolve into CSS sources; (2) both GPS and CSS sources interact strongly with dense surrounding media that limit their size; and (3) GPS sources may be transient or intermittent. Studying the radio structure and emission of CSS and GPS sources thus enhances our understanding of their morphology, evolution, and physical environments [?, ?]. Furthermore, because these sources interact strongly with galactic media, polarization observations can reveal their polarization properties and magnetic field structures, providing deeper insight into jet-medium interactions [?, ?].

We selected sources 0223+341 and 0248+430 from the 5 GHz VLBA observation project conducted by Fomalont et al. [?] in 1996. Their optical classifications and redshifts are listed in .

Source 0223+341 has a spectral turnover frequency _m of 250 MHz, with a spectral index of approximately 0.6 above the turnover (> _m) and an overall radio structure extending 8 kpc [?], classifying it as a CSS source. VLBI observations at 1.66 GHz revealed kpc-scale structure with a bright large-scale component and a more extended radio lobe approximately 500 mas to the southwest containing faint radio knots [?]. VLBA observations at 5 GHz showed the bright northeastern structure consists of two relatively distorted components with no detectable radio core [?, ?]. Observations at 8, 15, and 23 GHz with the VLBA and VLA indicated the radio core lies near the southwestern region, with the lobe extending southwestward and showing some polarized emission [?], while the bright northeastern structure resolved further into two hot spots [?]. Source 0248+430 has a spectral turnover frequency of 5 GHz, a spectral index of approximately 0.8 above turnover, and a radio structure size of 0.47 kpc [?], making it a GPS source. VLBA observations at 1.66 and 5 GHz revealed a one-sided core-jet structure extending southeastward with a distorted morphology and prominent knots, dominated by core emission [?, ?]. VLBA observations at 15 GHz resolved the large-scale jet into fine-scale structures with bright knots still visible along the jet direction [?]. VLA polarization observations at 5 and 15 GHz yielded polarization degrees of approximately 1% at both frequencies [?].

Both sources exhibit clear mas-scale jets with distorted morphologies, suggesting strong interactions with their surrounding media that facilitate studies of source-environment interactions. The NRAO VLA Sky Survey (NVSS) at 1.4 GHz detected polarized emission from both sources [?]. While previous 5 GHz polarization observations of these sources were limited, our VLBA 5 GHz polarization observations enable us to obtain mas-scale radio intensity and polarization maps to investigate their radio structures, polarization properties, magnetic field configurations, and jet-medium interactions. This paper adopts a Hubble constant $H_0 = 71$ km s^{-1} Mpc^{-1}, matter density parameter Ω_m = 0.27, and dark energy density parameter Ω_Λ = 0.73.

Observations and Data Processing

On February 25, 2004, we observed sources 0223+341 and 0248+430 with the 10 antennas of the VLBA under project code BZ031. Each source was observed three times for 7-8 minutes per scan in dual-polarization mode at 5 GHz. The observation employed four intermediate frequencies, each containing 16 channels with 8 MHz bandwidth per channel and 1-bit quantization. The data were correlated using the FX correlator in Socorro, USA, producing UVFITS data for subsequent processing [?].

Following the AIPS (Astronomical Image Processing System) cookbook [?], we processed the data using AIPS. The procedure included data editing, a priori amplitude calibration, parallactic angle correction, bandpass calibration, instrumental phase calibration, and fringe fitting. After averaging the data, we applied calibration and editing, followed by self-calibration and imaging. We then performed D-term correction using source DA193 and absolute polarization position angle calibration using source 1308+326 (referencing the VLBA/VLA polarization angle calibration website: http://www.aoc.nrao.edu/~smyers/calibration/) to obtain polarization distribution maps.

Results and Analysis

Data processing yielded total flux density and polarization measurements for both targets at 4.6 GHz, summarized in . The table columns list: (1) source name, (2) optical identification, (3) right ascension, (4) declination, (5) redshift, (6) total flux density, (7) polarized flux density, and (8) polarization degree.

Using the JMFIT command in AIPS, we performed Gaussian model fitting for both sources, with results presented in . The table columns include: (1) source name, (2) component identification, (3) major axis, (4) minor axis, (5) position angle, and (6) total flux density.

0223+341

[Figs. 1(a) and (b) display the polarized flux density grayscale and polarization vector distributions overlaid on total intensity images (1 mas = 7.898 pc). The flux structure consists primarily of two bright components, E1 and E2, located in the eastern and northern regions, contributing 79.6% and 10.9% of the total flux, respectively. Several radio spots are detected to the southwest, suggesting the radio structure extends in that direction, consistent with previous observations [?, ?]. The source exhibits a stable radio structure. Fomalont et al. [?] measured a total flux of 1.7 Jy in their 1996 VLBA observations, while Dallacasa et al. [?] obtained 1.5 Jy in 1991; our observation yields 1.52 Jy, showing little variation. Using 5 and 1.7 GHz data, they derived spectral indices of -0.3 and 0 for E1 and E2, respectively, and identified them as hot spots based on these indices and their distorted structures. Patnaik et al. [?] 15 GHz VLBA observations within a 14 mas^2 region retained only E1 and E2, with other features resolved out, confirming the radio core is not within the displayed structure. Mantovani et al. [?] 23 GHz observations located the core approximately 400 mas (3.16 kpc) southwest of the structure shown, outside the field of view.

Dallacasa et al. [?] detected no significant polarization structure in their 1991 VLA observations, with polarization degree <0.6%. This study presents the first mas-scale polarization structure of 0223+341 at 4.6 GHz. Fig. 1(a) shows polarized flux concentrated in the northeastern part of E1, with a peak brightness of 5.65 mJy/beam (13σ, rms = 0.43 mJy/beam). Fig. 1(b) reveals a simple polarization structure with vectors extending from E1 toward E2 in a northeast-southwest direction, showing no significant variation. The polarization degree is approximately 1%, relatively low, possibly due to limited resolution or depolarization effects from surrounding dense medium. Using the IVS observation database [?] and referencing the source's 1996 VLBA images at 2.3 and 8.3 GHz, we calculated the spectral index distribution in the polarized region, finding values ranging from -0.6 to 0.02, consistent with Dallacasa et al. [?]. No significant polarized emission is detected from most of E1 or from E2, suggesting dense surrounding medium causing strong depolarization, with limited resolution being another possible factor.

0248+430

[Figs. 2(a) and (b) show the polarized flux density grayscale and polarization vector distributions overlaid on total intensity images (1 mas = 8.448 pc). The radio structure consists primarily of a core region C, jet B, and knot A, displaying a typical one-sided core-jet morphology with a jet position angle of 150°. The radio emission is dominated by component C (the core), contributing 80.4% of the total flux, while A and B contribute 10.9% and 8.7%, respectively. This structure is consistent with previous results [**?**, **?**] and appears stable. In terms of flux density, Fomalont et al. [**?**] measured 1.4 Jy with the VLBA, while we obtain 1.12 Jy, showing little variation. Knot A likely results from jet-medium interaction, suggesting a more complex medium environment than at B.

This study presents the first mas-scale polarization structure of 0248+430 at 4.6 GHz. Fig. 2(a) shows polarized flux concentrated near the jet base adjacent to the core, with a peak of 7.12 mJy/beam (14σ, rms = 0.51 mJy/beam). Fig. 2(b) reveals a relatively simple polarization structure with polarization degree reaching 4% and polarization vectors essentially parallel to the jet direction. Using the IVS database [**?**] and referencing 1996 VLBA images at 2.3 and 8.3 GHz, we calculated spectral indices in the polarized region ranging from -0.3 to 0.1. The overall polarization degree is 3.87% (see), nearly three times higher than the 0.9% measured by Rudnick et al. [**?**] using VLA in 1981. The results show no significant magnetic field or polarization in the jet and knot, suggesting dense surrounding medium, while limited resolution may also contribute to low polarization measurements.

Conclusions and Outlook

Our 4.6 GHz VLBI polarization observations have investigated the radio structures and polarization properties of sources 0223+341 and 0248+430. Source 0223+341 consists primarily of two likely hot spot components with no detected radio core, with radio emission dominated by one hot spot. Source 0248+430 shows a one-sided core-jet structure with the core and jet nearly aligned but containing large-scale knots; the jet collimation appears improved compared to previous observations. Both sources' radio structures are largely consistent with earlier results, with total flux densities similar to previous measurements, indicating stable radio morphologies.

In polarization, we have obtained the first mas-scale polarization structures for both sources at 4.6 GHz. Source 0223+341 has a polarization degree of 1.18% with a simple structure concentrated at one hot spot, showing weak polarized emission and likely dense surrounding medium. Source 0248+430 shows polarized emission concentrated near the core with significant variation in polarized flux. Due to optical depth and rotation measure limitations at this observing frequency, we cannot precisely infer the intrinsic magnetic field structures of these sources. Further high-frequency polarization observations are needed for detailed analysis.

Both sources exhibit relatively low polarization degrees. O' Dea et al. [?, ?] compiled polarization results for CSS and GPS sources, noting that polarization degrees at 5 GHz are generally low and increase with observing frequency, suggesting that low polarization at low frequencies may result from limited resolution or depolarization by dense surrounding medium. Dallacasa et al. [?] also reported low polarization degrees for most CSS sources in their 5 GHz study. Our low polarization results are consistent with these findings.

Single-frequency observations provide limited information. Future work will present multi-frequency results to derive spectral index and rotation measure distributions from our data, enabling further investigation of these sources' physical properties and interactions with their environments.

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Note: Figure translations are in progress. See original paper for figures.