The Parsec-Scale Circular Polarisation of BL Lac Objects and Related Blazars

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Abstract

We present results of circular polarisation measurements based on Very Long Baseline Array data for a sample of 1-Jy Northern BL Lac objects, including two-epoch measurements for some of the sources. We discuss results obtained by applying the gain-transfer method of Homan and Wardle (1999), as well as new methods developed by ourselves. The degrees of circular polarisation for the VLBI core region are similar to those detected for compact AGN in previous studies, with typical values of a few tenths of a percent. The most plausible origin of this polarisation is probably the conversion of linear to circular polarisation during the propagation of the radiation through a thermal or relativistic plasma. We find evidence for consistency of the sign of the circular polarisation at a given observing frequency across epochs separated by roughly five years for some sources, supporting the existence of some long-term properties of the inner jets, such as the magnetic field orientation.

Introduction

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BL Lac objects are a subset of Active Galactic Nuclei (AGN) that are observationally similar to radio-loud quasars in many respects, but display systematically weaker optical line emission. BL Lac objects are also characterised by strong and variable polarisation at ultraviolet through radio wavelengths. The radio emission and much of the higher-frequency emission is almost certainly synchrotron radiation. BL Lac objects together with optically violently variable quasars are sometimes referred to as "blazars."

VLBI polarization observations of radio-loud BL Lac objects have shown a tendency for the dominant ordered magnetic (B) fields in the parsec-scale jets to be transverse to the local jet direction (Gabuzda, Pushkarev, & Cawthorne 2000 & references therein). Recent analyses of VLBI polarization observations have yielded evidence that these transverse B field structures correspond to toroidal or helical fields associated with these jets (Gabuzda, Murray & Cronin 2004 and references therein).

Techniques for producing maps of the circular polarisation of compact AGN have been pioneered by Dan Homan and his colleagues (Homan & Wardle 1999, Homan, Attridge & Wardle 2001, Homan & Wardle 2004). The main technique developed for the accurate calibration of the R/L gain ratios, as is required for circular-polarisation (CP) imaging, is essentially a statistical approach, in which individual estimates of the R/L gain ratios obtained for various sources at various times are collated and smoothed to obtain a master R/L gain
calibration table, which is then applied to the data for each source. We present here CP images of several BL Lac objects and the blazar 3C279 produced using this technique, and also discuss possible methods that can be used to refine and verify such results.

Observations & Reduction I

We consider here primarily 15 GHz data obtained during multi-frequency VLBA polarisation observations of sources from the sample of 1-Jy Northern radio-loud BL Lac objects defined by Kühr & Schmidt (1990) in February 1997, June 1999, August 2002 and March 2003. We also present results for 22 GHz data obtained in August 2002. These data were calibrated and imaged in the NRAO AIPS package following standard techniques. from these observations.

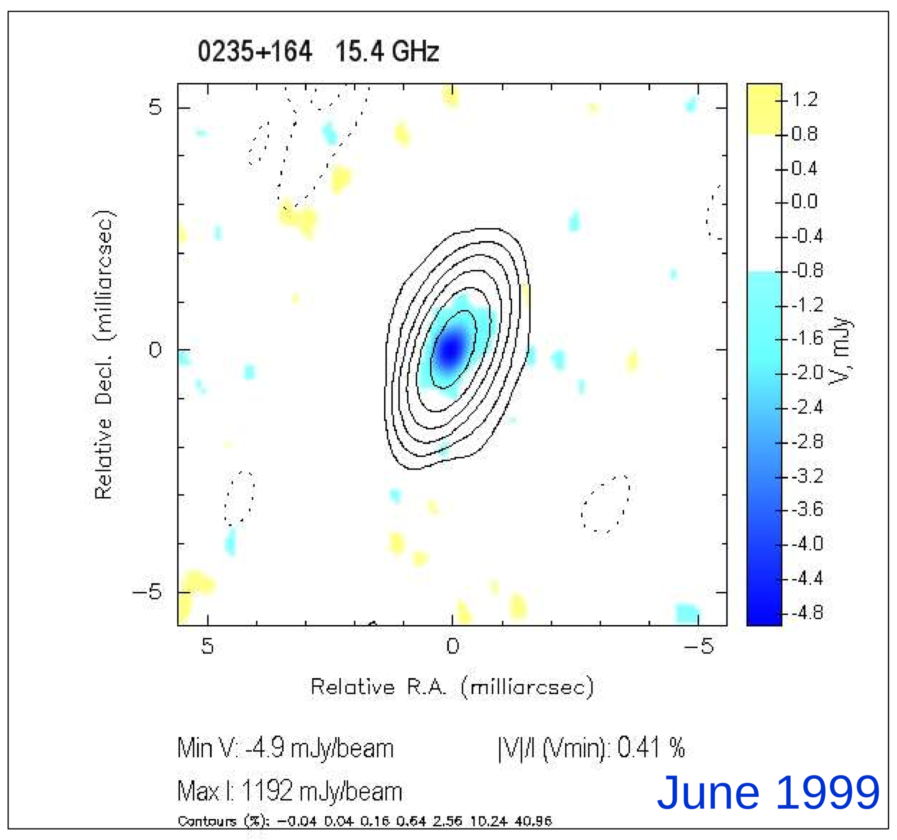
When applying the statistical "gain-transfer" method of Homan & Wardle (1999), ideally one would determine the R/L gain ratios for sources that were known not to have detectable CP and apply these solutions to other sources that were known or suspected of having CP. In practice, it is very often not possible *a priori* to know whether a given source has potentially detectable CP on parsec scales. Thus, the smoothed master table of R/L gain ratios will typically include some sources that have CP on parsec scales, whose R/L ratios will be slightly higher or lower than their instrumental values. This is not a serious problem if a series of observations includes a sufficiently large number of sources, since, on average, equal numbers of sources can be expected to have positive and negative CP: R/L gain ratios that are slightly overestimated will be smoothed with those that are slightly underestimated, yielded values for the smoothed gain ratios that are close to their instrumental values. The results can then be refined in an iterative fashion by excluding sources found to have detectable CP and constructing a new master gain calibration table.

The successful application of this technique, thus, depends on observing a sufficiently large number of sources over a sufficiently long time. This criterion was best met by our February 1997 observations (24 objects observed over about 42 hours) and August 2002/March 2003 observations (10—12 sources in 24 hours), and somewhat less well by our June 1999 observations (6 sources in 12 hours).

Figure. Detections of circular polarisation in several BL Lac objects and the blazar 3C279. Results for each of thee epochs are presented in individual boxes, with the epoch indicated in each.

The results for 1334-127 for February 1997 and March 2003 both display positive circular polarisation at a level of about 0.25%.

Our results for 3C279 for March 2003 and August 2002 both display positive circular polarisation of 0.60%, in good consistency with the results of Homan & Wardle (1999) for 1996.



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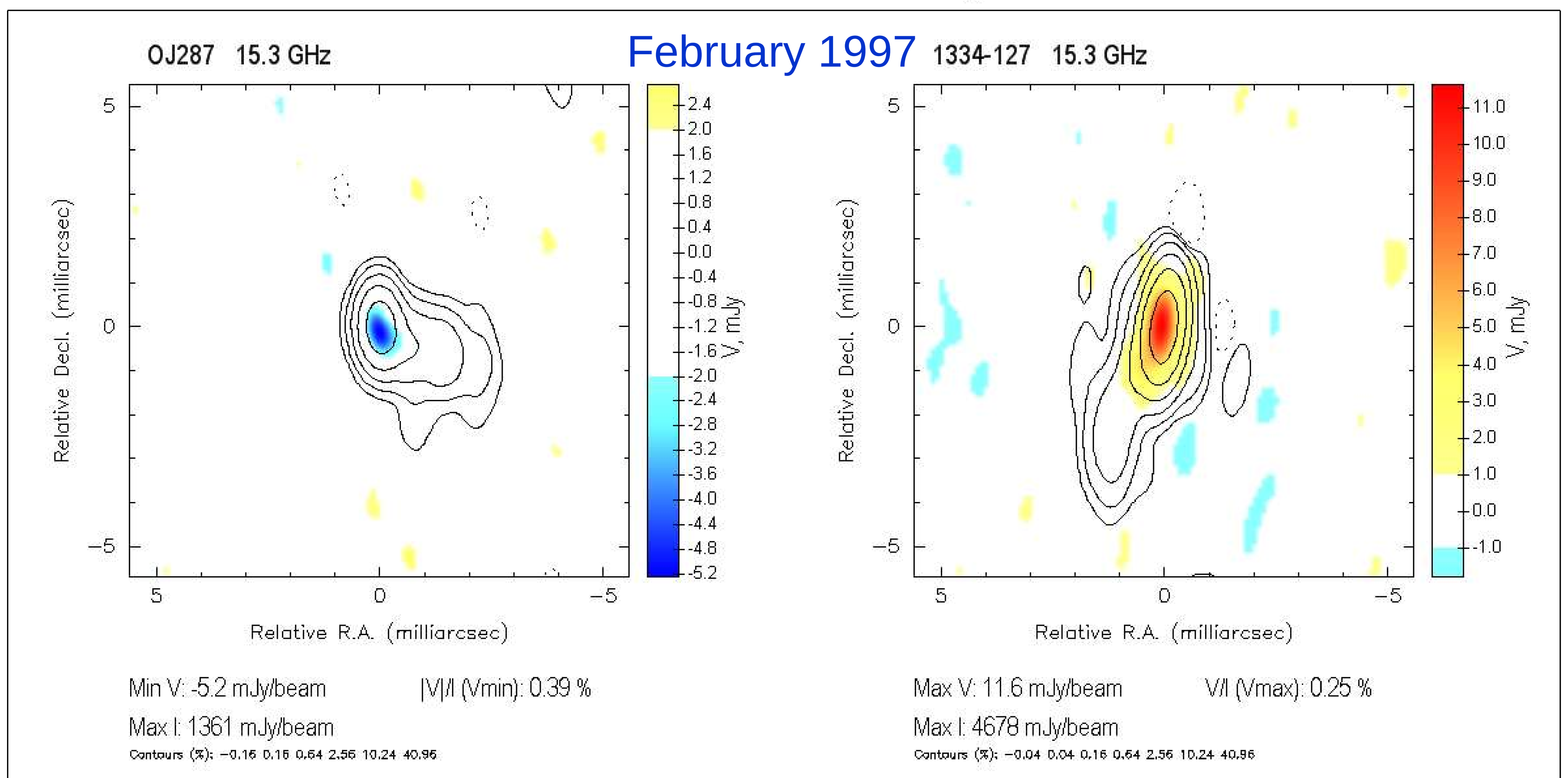
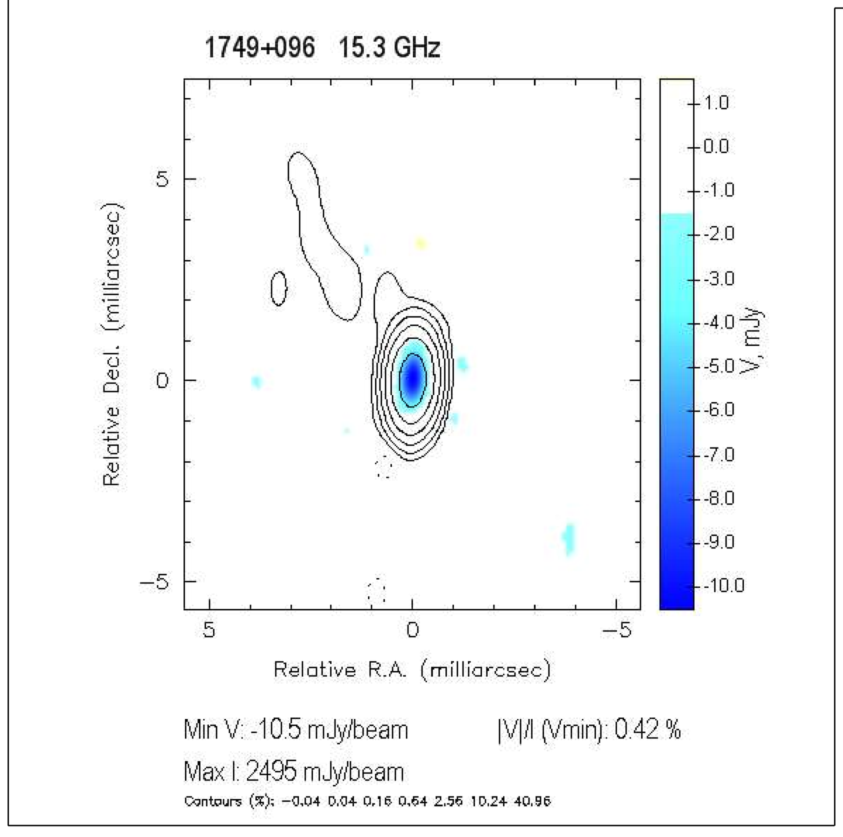
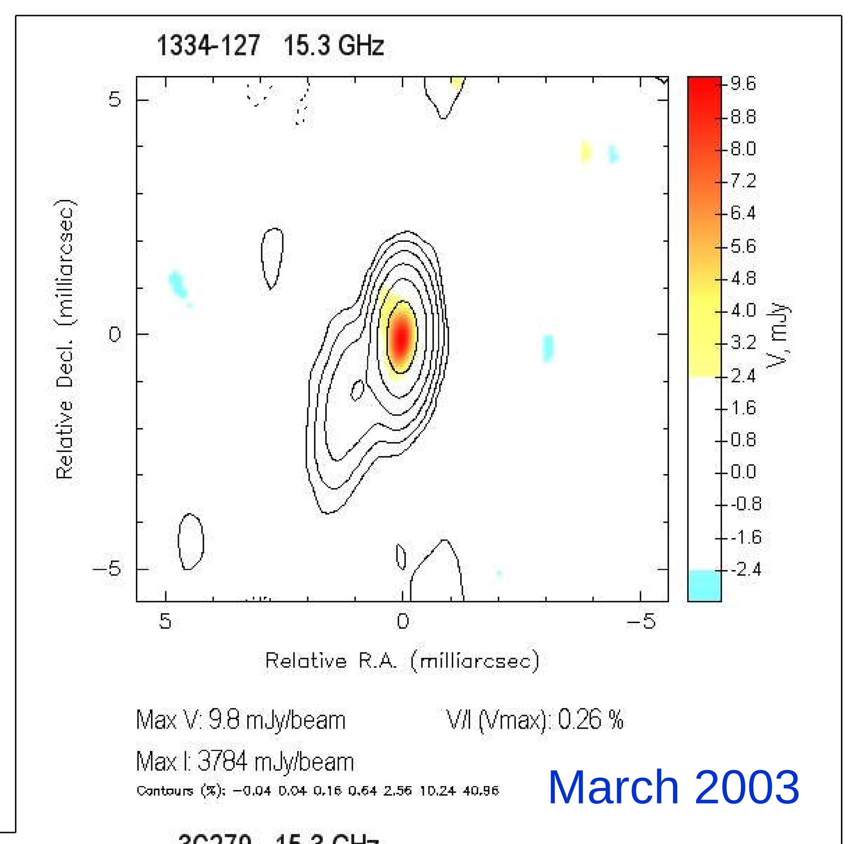


February 1997





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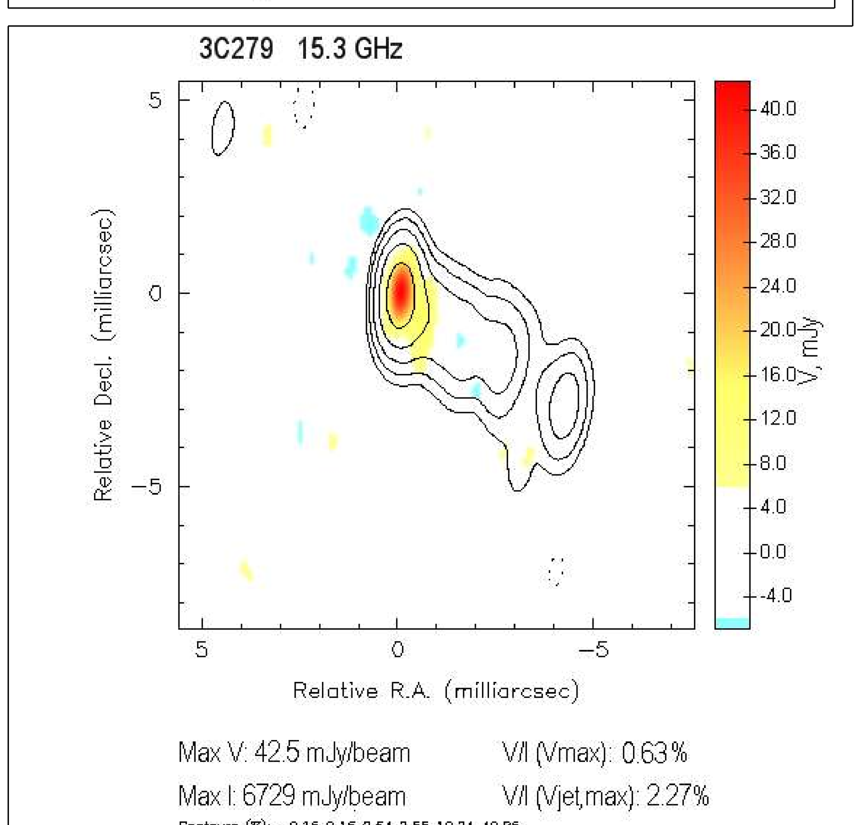
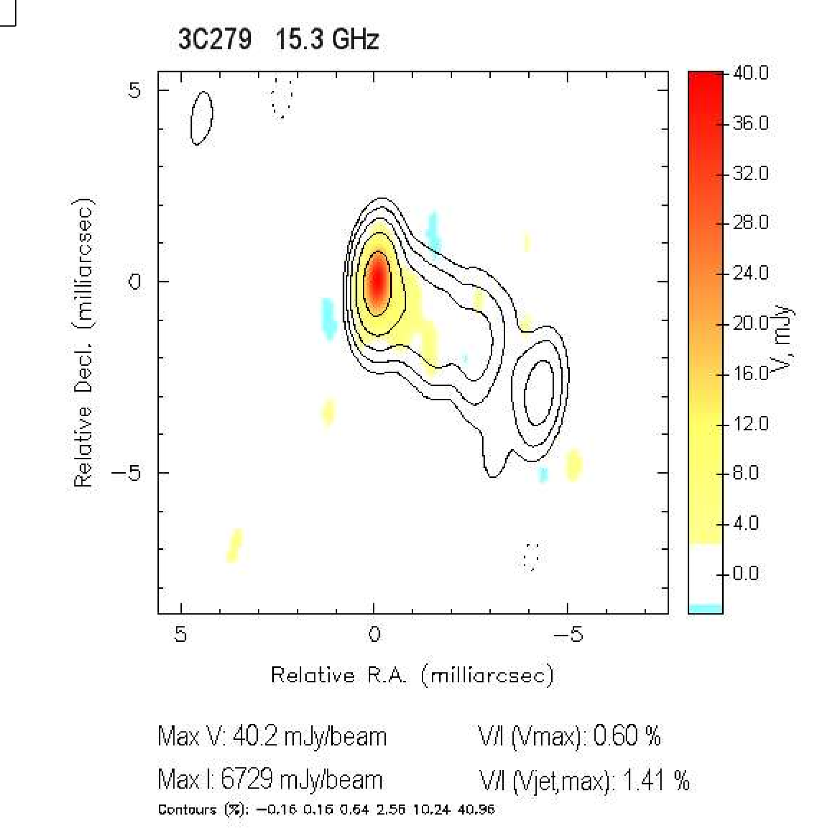
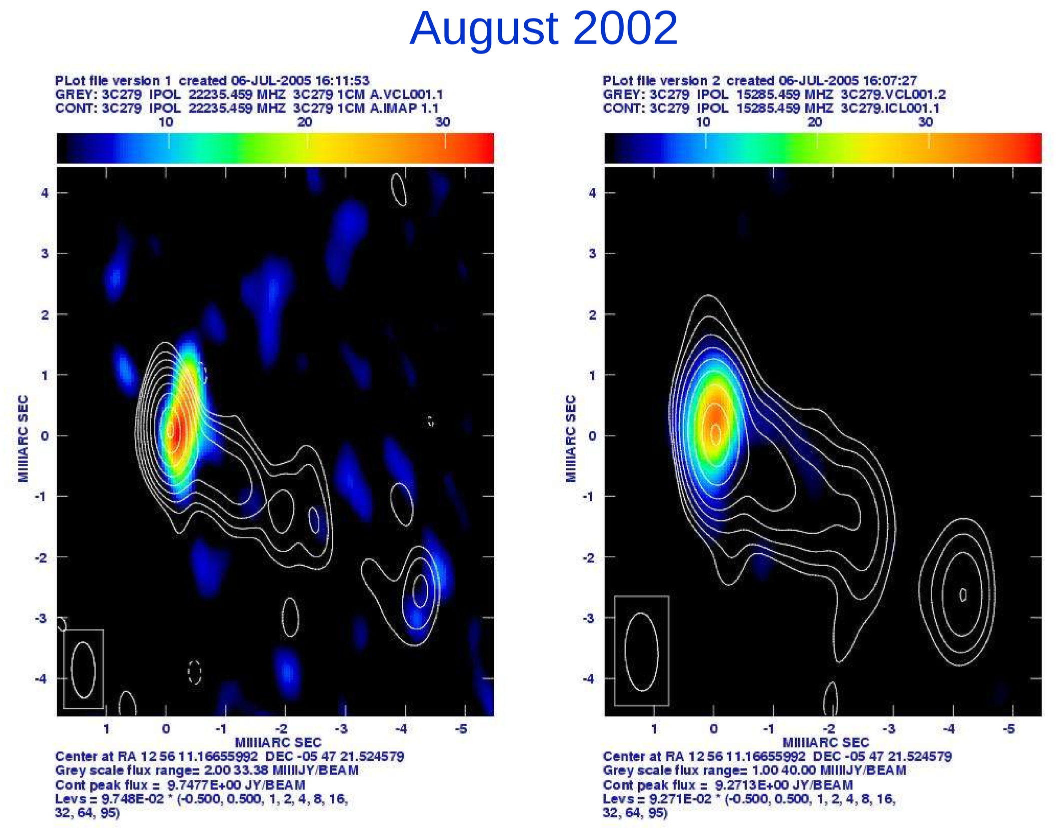


3C279 - Before independent RR/LL calibration

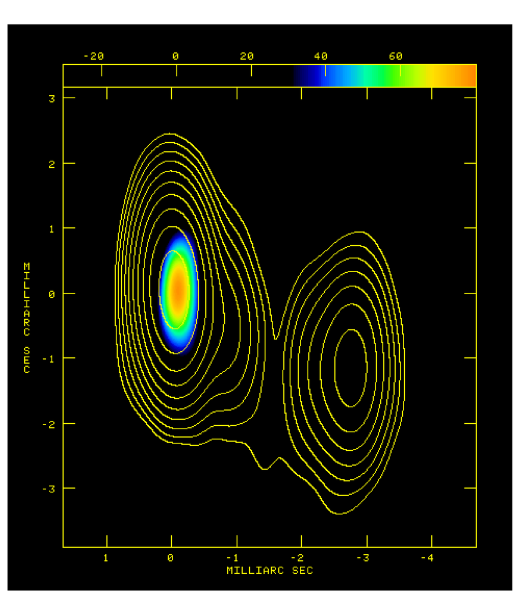


3C279 - After independent RR/LL calibration

August 2002



22 GHz 15 GHz



15 GHz map of Homan & Wardle (1999)

Observations & Reduction II

We refined the results obtained using the gain-transfer method by performing a final self-calibration of the RR and LL visibility data separately using the final total intensity (I) image and the CP (V) image obtained in this way:

$$RR = (I+V)/2$$

$$LL = (I-V)/2$$

Further, the Fourier transform of these refined visibility data is taken in order to produce a refined V map.

In virtually all cases, this changed the value of the CP peak only slightly, but substantially lowered the noise level in the CP map. This technique provides a useful means to improve the quality of CP maps that are initially obtained using some other technique, such as the gain-transfer method; but we emphasize that this requires that the initial CP map already be considered reliable.

Results & Discussion

The figure shows I contours with the V images superposed in colour. The scale for the colour plots has been chosen so that positive CP is in yellow—red tones and negative CP is in blue tones. The results for each of the four epochs are collected in individual boxes. At 15 GHz, we detected CP in 3/24 sources observed in February 1997, 1/6 sources in June 1999, 2/10 sources in August 2002 and 1/12 sources in March 2003.

We obtained preliminary estimates of the degrees of CP by taking the ratio of the peaks of the CP and intensity images; the resulting values are similar to those found in earlier parsec-scale studies (Homan & Wardle 1999; Homan et al. 2001), typically a few tenths of a percent.

CP was detected in the BL Lac object 1334—127 at 15 GHz in both February 1997 and March 2003; in both cases, the CP is coincident with the VLBI core and is +0.25%, despite the fact that the VLBI core intensity changed appreciably between these two epochs (middle two right-hand images in the figure).

15 GHz CP was detected in the blazar 3C279 in both August 2002 and March 2003; again, the CP is coincident with the VLBI core. The value of the CP is +0.60%, consistent with the independent measurements of Homan & Wardle (1999) for 1996 [lowest two rows of plots]. The figure shows 15 GHz March 2003 images for 3C279 both before and after applying a final separate RR and LL self-calibration as described above; a suggestion of faint extended positive CP appears in the inner jet in the refined image, but this must be verified.

The sign consistency of the core CP for 1334—127 and 3C279 over intervals of five years or more suggests constancy of some long-term properties of the inner jets, such as the magnetic field orientation (see also Homan et al. 2001).

22 GHz CP was also detected in 3C279 in August 2002 (left plot in lowest row); the CP peak appears to be shifted from the I peak toward the inner jet, suggestive that the CP is associated with a newly emerging jet component. However, this result must be considered tentative and requires verification.

Final words

Parsec-scale CP measurements are still technically challenging, and little information is available about the time variability and frequency dependence of the detected CP. Nevertheless, the excellent consistency between our own results and those of Homan for 3C279 and 3C84 (see also the poster by Homan et al.) and between our own results for 1334—127 at two different epochs clearly demonstrate the reliability of the gain-transfer technique. The high potential of parsec-scale CP observations for providing new and unique information about the compact relativistic jets of AGN, particularly when analysed together with other data, such as the core rotation measures, makes this a fruitful field for further work.

We are investigating alternative methods for obtaining VLBI circular-polarisation images based on an analysis of the noise levels in the I and V images produced using a series of models for the VLBI core CP. In addition, we are in the process of carrying out a CP analysis for further 15, 22 and 43 GHz VLBA polarisation data for Kühr & Schmidt (1990) BL Lac objects, which will provide further information about their core CP at 22 GHz, the time variability of the 15 GHz core CP and the spectrum of the CP, which can help distinguish between various possible mechanisms for the generation of the circular polarisation [e.g., directly via the synchrotron mechanism or as a result of Faraday conversion of linear to circular polarization during propagation through a cold or hot plasma (Legg & Westfold 1968; Jones and O'Dell 1977)].

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