Changes in the angular separation of the lensed images PKS 1830-211 NE & SW

Jin Chengjin\textsuperscript{a,b,c} M.A. Garrett\textsuperscript{b} S Nair\textsuperscript{d} R.W. Porcas\textsuperscript{c} A.R. Patnaik\textsuperscript{c}

\textsuperscript{a}Beijing Astronomical Observatory, Chinese Academy of Sciences, A20 Datun Road, Chaoyang District, Beijing 100012, China
\textsuperscript{b}Joint Institute for VLBI in Europe, Postbus 2, 7990 AA Dwingeloo, The Netherlands
\textsuperscript{c}Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
\textsuperscript{d}Raman Research Institute, C.V. Raman Avenue, Bangalore 560080, India

Abstract

We present 8 epochs of 7 mm dual-polarization VLBA observations of the gravitational lens system PKS 1830-211 made over the course of 14 weeks. Clear changes in the relative positions of the cores of up to 80 μarcseconds (μas) were observed between epochs (each separated by ≈ 2 weeks). A comparison with previous 7 mm VLBA maps shows that the separation of the cores has changed by almost 280 μas over 12 months. This leads us to conclude that changes in the brightness distribution of the mm-VLBI core of the background source must be occurring rapidly. This is the first clear observation of significant radio source evolution in a gravitational lens system. It is also the first time that changes in source structure have been detected in a distant extra-galactic source on such short time-scales. This is partly accounted for by the magnification provided by the lens system.

Key words: cosmology: gravitational lensing: individual (PKS 1830-211)
PACS: 98.62.Sb, 98.54.Cm, 98.70.Dk

1 Introduction

PKS 1830-211 is a very bright and highly variable radio source at cm- and mm-wavelengths. As well as being a highly probable gravitational lens system (Rao & Subrahmanyan, 1988), it is also identified by the EGRET instrument
as a strong source of gamma-rays (Mattox et al., 1997). PKS 1830-211 is one of only two known lens systems (the other is B0218+357) which are bright and compact enough to be detected and imaged with mm-VLBI. All these observations suggest that the background source in this system is uncommon in many respects and can probably be best classified as a blazar.

Relatively rapid changes in the brightness distribution of the images had been reported earlier (Garrett et al., 1997), an effect that may be partly explained by the magnification provided by the lens system. In the case of PKS 1830-211, this magnification may be as large as 5–10 (Kochanek & Narayan, 1992; Nair et al., 1993). Recent spectroscopic observations in the near-IR using the NTT with clear detections of both the $\text{H}_\alpha$ and $\text{H}_\beta$ emission lines (see Lidman et al. (1999)) have finally revealed the redshift of the source to be $z_s = 2.507$. In this paper we present multi-epoch VLBA 7 mm maps of both lensed radio images, in both polarised and total intensity.

2 Observations and Data Reduction

We made eight epochs of 7 mm, dual-polarisation VLBA observations of PKS 1830-211 between 1997 January 19 and 1997 April 30. Each epoch was separated in time by about 14 days. The data were correlated at NRAO, Socorro. For the sixth epoch (1997 April 03), the data quality was very poor partly due to bad weather at KP and weak fringes at BR. Since the SW and NE images are separated by about 1” on the sky, wide-field techniques were used to make maps of both images simultaneously from a single data-set (see Garrett et al. (1999)). The polarisation data analysis followed Leppänen et al. (1995).

3 Results & Discussion

Contour maps of both PKS 1830-211 NE and SW, in total and polarised intensity, for each epoch except the sixth (1997 April 03) are shown in Fig. 1. Superimposed on these maps are the positions and sizes of the Gaussian fits as determined by the AIPS task IMFIT. The size of the crosses represent the major and minor axes of the Gaussian components.

Our wide-field approach to the data analysis permits us to produce maps of both lensed images simultaneously, thus allowing us to measure with high precision the angular separation between the central peaks in the radio images.

We have measured the angular separation of the NE and SW image (NE–SW) by fitting Gaussian components to our highest-resolution, uniformly-weighted,
Fig. 1. From left to right we present: (i) total intensity maps of the NE image, (ii) polarised intensity maps of the NE image, (iii) total intensity maps of the SW image and (iv) polarised intensity maps of the SW image. The epoch of observation increases from top to bottom. All the maps are naturally weighted and the FWHM of the circular restoring beam is 0.5 mas. Contours are spaced by factors of two in brightness, with the lowest at three times the rms noise 4 mJy per beam (for the total intensity maps) and 1.5 mJy per beam (for the polarised intensity maps).
total-intensity maps. In Fig. 2 we present the position of the peak in the NE image relative to the peak in the SW image. We have also included the results of previous 7 mm VLBI observations made by Garrett et al. (1997) in 1996.

Fig. 2. The position of the total intensity peak in the NE image relative to the total intensity peak in the SW image. The origin on the plot is at a nominal position (642000,728000) in microarcsec with respect to SW core, which is the separation of the two sub-fields of the NE and SW images.

We have estimated the errors on all these separation measurements by comparing measurements from sub-sets of the data for a given epoch. These suggest the separation measurements are accurate to 1/10 of the major axis of the uniformly weighted fitted beam i.e. \( \sim 30 \mu\text{as} \).

What are the possible explanations for this change in the image separation?

First let us consider effects that are intrinsic to the background source. (In this case changes will appear in both images, separated by the time delay, and the angular separation changes result from a combination of both). In this context it is useful to note that for a simple FRW universe \((q_0 = 0, \Lambda = 0, H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1})\), a shift of \( \sim 80 \mu\text{as} \) (the largest shift measured between epochs separated by \( \sim 2 \) weeks) corresponds to a linear distance of \( \sim 0.8 \text{ pc} \) at \( z_s = 2.507 \). If one assumes that the lens provides a magnification factor of \( \sim 10 \) (Kochanek & Narayan, 1992, Nair et al., 1993), the linear distance...
then scales to $\sim 0.08$ pc. Given PKS 1830-211’s blazar characteristics, the most obvious interpretation is that the centroid of the peak in the brightness distribution of the core is changing on relatively short time-scales, perhaps, for example, as shock fronts propagate along a continuous jet, appearing as bright and (later) fading regions of radio emission. A less conventional scenario is that it is the mm-VLBI “core” (i.e. the base of the jet) itself that is moving, as the effectiveness of the collimation mechanism changes. Since this area of jet physics remains poorly understood (see Marscher (1995) for a recent review), and since measurements with this sort of linear resolution have not previously been possible in this type of source, it is not clear to us whether movements of the order of $\sim 0.08$ pc are reasonable or not.

Extrinsic explanations might include the effect of scattering by ionised gas encountered along the line of sight, specifically in the lens galaxy or our own galaxy. Since PKS 1830-211 lies close to the galactic plane, the effect of the ISM in our own galaxy is expected to dominate (Walker, 1996). Jones et al. (1996) have measured the interstellar broadening of the SW image between 18 and 1.3 cm and estimate that the SW deconvolved core size is proportional to $\lambda^{-2}$, as predicted by Interstellar Scattering (ISS) theory. At 1.3 cm they measure a size of the SW image of $\sim 0.6 \times 0.2$ mas. In our observations the size of the SW (and the NE) image change with epoch. However, a typical value for the core size is $\sim 0.26 \times 0.13$ which is much larger than we might expect assuming a $\lambda^2$ relation. Indeed the scaling in size between 1.3 cm and 0.7 mm is almost linear with $\lambda$, as expected from simple models of synchrotron radio emission. Hence, we suspect that the measured source size is dominated by its internal radio structure, rather than scattering effects.

However, in addition to image broadening, the effect of ISS can, in principle, also produce “image wander” — an apparent shift in the position of a source (Rickett, 1990). This effect is considered to be small: an order of magnitude smaller than the scattering size itself. Indeed, observations of compact sources lying close to the galactic centre (where the effects of ISS should be severe) bear this out: for example, $\lambda$18 cm VLBI observations of masers located close to the galactic centre (Gwinn et al., 1988) show that for water masers the r.m.s. wander of individual spots is $< 18 \mu$as over the course of 6 months. Since the effect of image-wander would also scale as $\lambda^{-2}$, we suspect that conventional ISS is not a compelling explanation for the changes in image separation that we measure. We also observe changes in the image separation with respect to the peaks in polarised intensity. These changes are less reliable than those observed in total intensity (since the polarised flux is very much fainter) but the initial indications are that the changes in the image separation in total intensity and polarised intensity are unrelated.

Milli-lensing produced by massive ($10^3$–$10^4 M_\odot$) compact objects in the halo of the lens can certainly introduce shifts of $\sim 80 \mu$as, but changes in the
separation would be measured on relatively long time-scales: hundreds of years rather than the weeks or months observed here.

Another possibility is that the transverse velocity of the lens galaxy across the sky could introduce a relative proper motion between the NE and SW images. For highly magnified four-image lens systems the proper motions are expected to be a ~ few tens \(\mu\)as yr\(^{-1}\) \cite{Kochanek1996}, but for two-image systems such as PKS 1830-211 the motion is expected to be an order of magnitude smaller.

In summary, the changes in the measured image separation are most likely due to changes in the brightness distribution of the background radio source. The detection of source evolution on these short time-scales would be impossible if it were not for the fact that this is a lensed system which provides us with a magnified view and closely spaced multiple images that allow accurate relative position measurements to be made. If, as we strongly suspect, the changes we observe are due to internal motions in the radio structure on scales of \(> 0.08\) pc in ~ 2 weeks, this implies (unlensed) superluminal velocities in the rest frame of the background source of \(> 3c\).

References

Garrett, M.A., Nair, S., Porcas, R.W., & Patnaik, A.R., 1997, Vistas in Astronomy, 41, 281.
Garrett, M.A., Porcas, R.W., Pedlar, A., et al., 1999, NewAR, XX, xxx. These Proceedings.
Gwinn, C.R., Moran, J.M., Reid, M.J., & Schneps, M.H., 1988, ApJ, 330, 817.
Jones, D.L., Preston, R. A., Murphy, D.W., et al., 1996, ApJL, 470, L23.
Kochanek C.S., & Narayan R., 1992, ApJ, 401, 461.
Kochanek, C.S., Kollat, T.S., & Bartelman, M., 1996, ApJ, 473, 610.
Leppänen, K.J., Zensus, J.A., & Diamond, P.J., 1995, AJ, 110, 2479.
Lidman, C., Courbin, F., Meylan, G., Frye, B., Welch, W.J.W., 1999, ApJL, 514, L57-L60.
Mattox, J.R., Schachter, J., Molnar, L., Hartman, R.C. & Patnaik, A.R., 1997, ApJ, 481, 95.
Marscher, A.P., 1995, in: Cohen, M.H., Kellermann, K.I. (eds), Proc. Natl. Acad. Sci., 92, 11439.
Rao, A.P. & Subrahmanyan, R., 1988, MNRAS, 231, 229.
Nair S., Narasimha D., & Rao A.P., 1993, ApJ, 407, 46.
Rickett, B.J., 1990, ARA&A, 28, 561.
Walker, M.A., 1996,111. in: Ekers, R., Fanti, C., & Padrielli, L. (eds), IAU Symposium 175, Extragalactic Radio Sources, Kluwer Academic Publishers, p 111.