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The Diverse Properties of GPS Sources

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Abstract. We discuss the morphology and kinematics of five gigahertz-peaked spectrum (GPS) sources that have been observed with the VLBA. We find a wide range of observed properties including core-jet structure, superluminal motion, variability, extended structure, and polarization, all of which appear to deviate from commonly-accepted GPS paradigms (e.g., O'Dea 1998). We suggest that the observed low frequency cutoff in GPS sources may be primarily due to free-free absorption rather than synchrotron self-absorption.

1. Introduction

GPS sources are characterized by their sharp low-frequency spectral cutoff and the absence of large scale structure. Previous observations have suggested a simple double morphology with no evidence for significant relative component motions. In this paper, we present new VLBA observations of five well-known GPS sources whose diverse properties are difficult to understand in terms of simple conventional models where the GPS sources are classical self-absorbed synchrotron sources that are the precursors of double-lobed radio galaxies.

2. Individual GPS sources

2.1. CTA 102 (2230+114)

The quasar CTA 102 (z = 1.04) was one of the first radio sources found to have a pronounced cutoff at low frequencies (Kellermann et al. 1962). This was later interpreted by Slysh (1963) and Williams (1966) as the result of synchrotron self-absorption (SSA), and provided the first evidence for highly compact structure in extragalactic radio sources. Observations by Sholomitsky (1965) showed remarkable variations in the decimeter wavelength flux density of CTA 102 which were difficult to understand in the framework of conventional synchrotron theory. Subsequently, many other quasars and a few AGN with flat radio spectra were found to show similar variability, but the discovery of superluminal motion in many quasars appeared to provide a simple interpretation in terms of relativistic beaming.

Recent multi-wavelength observations of CTA 102 have continued to show large variations in flux density (Aller and Aller, private communication). Indeed, in recent years the spectrum is no longer recognizable as a GPS source, and VLBA observations made at 2 cm since 1995 show a characteristic core-jet structure which we typically associate with flat spectrum radio sources (Fig. 1).

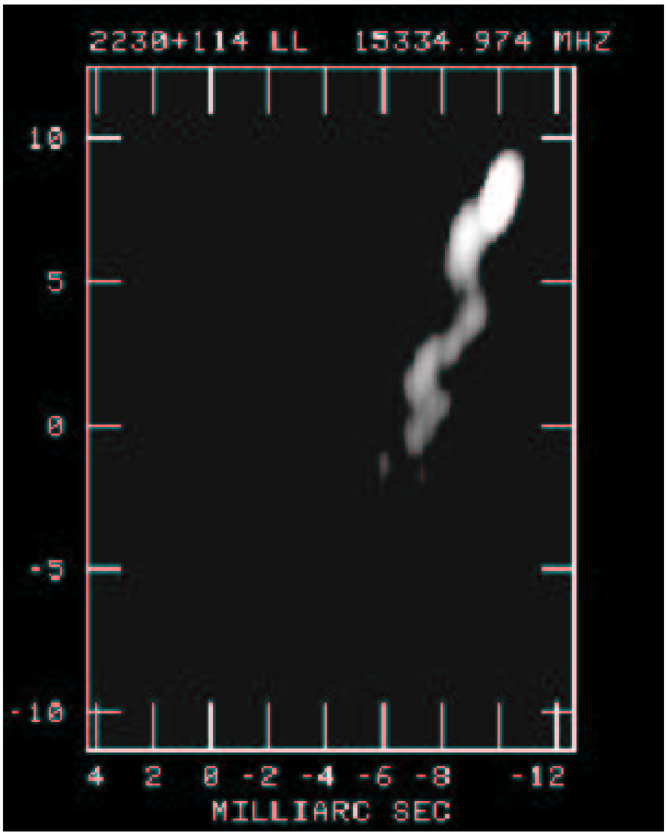

Fig. 1. VLBA 2cm image of CTA 102 at epoch 1996 October. The greyscale indicates total intensity.

In spite of CTA 102's rapid flux density variability, our multi-epoch VLBA observations show no evidence of any component motions. It is possible that the relativistic fluid is moving smoothly along the jet, and is not reflected in observable pattern motions described by the bright features seen in Fig. 1. Rather, these features may merely mark apparent brightness enhancements at the location of each bend, as would be expected from a relativistic helical jet at locations where the fluid velocity vector is directed at the observer.

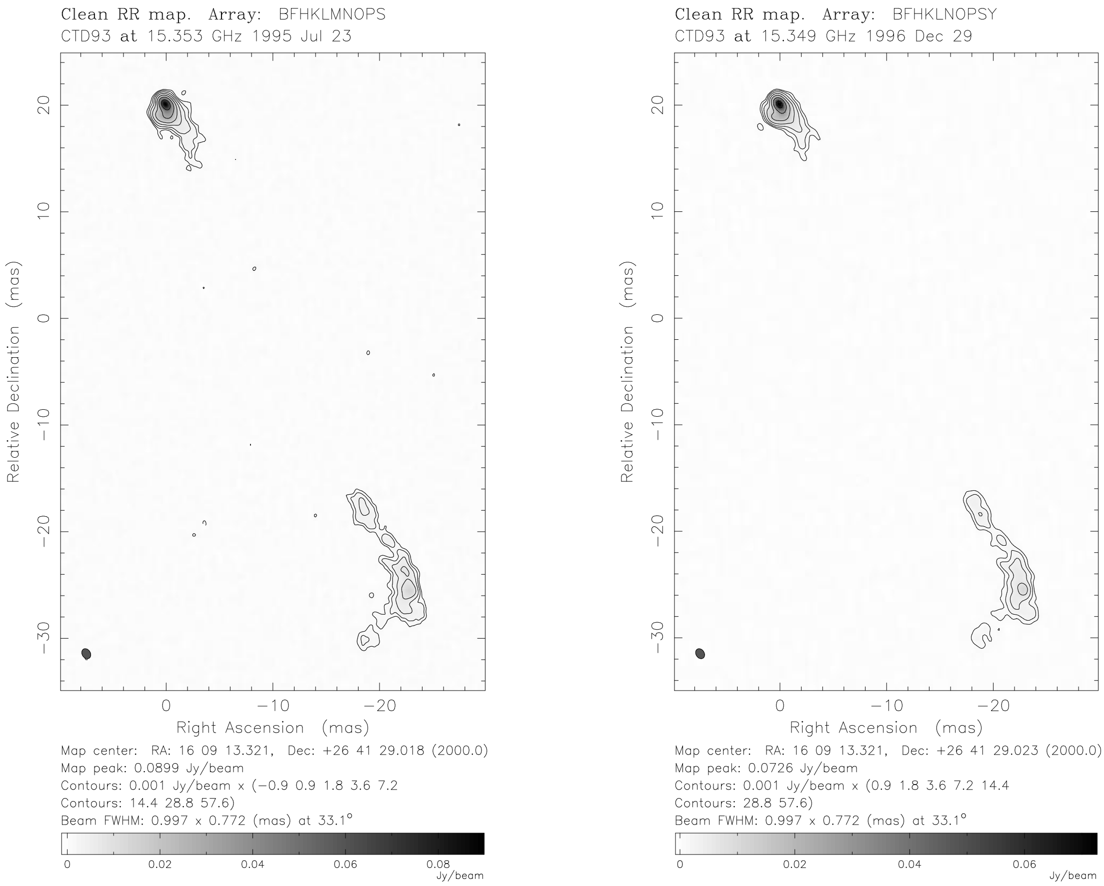

Fig. 2. VLBA images at 2 cm of CTD 93 at epochs 1995 July (left) and 1996 Dec. (right) drawn with the same contour levels.

2.2. CTD 93 (1607+268)

CTD 93 is an AGN identified with a $m_V = 20.3$ galaxy at $z = 0.47$. With a radio luminosity of 3×10^{27} W Hz^{-1}, it is one of the brightest radio galaxies known. It was first discovered in a 20 cm survey (Kellermann & Read 1963) and was later found to be a GPS source by Kellermann (1966). Early VLBI observations (Phillips & Mutel 1980, Phillips & Shaffer 1983) indicated an apparently simple symmetric double structure with an unusually large component separation. Subsequent VLBI observations of other GPS sources led to the paradigm which associates GPS sources with symmetric double structure rather than classical core-jet structure (Phillips & Mutel 1982). However, higher-resolution VLBA observations of CTD 93 made in July 1995 (Fig. 2) revealed that the southern component was in fact a narrow, sharply bent jet, while the northern component was a compact feature likely to be the core (Shaffer, Kellermann, & Cornwell 1999). Multi-frequency observations showed, surprisingly, that the southern low-surface-brightness jet has a similar spectrum to the presumed core component. This is contrary to what would be expected if the low frequency spectral cutoff is a result of SSA, and suggests that the low frequency cutoff may be the result of free-free absorption (FFA) from a surrounding ionized medium. We have re-observed CTD 93 with the VLBA on 29 Dec 1996, and find identical structure to the earlier observations, with no evidence for any change in component separation during the 18 month period between the two epochs. Our observations place an upper limit to the relative component motion of 0.5c.

2.3. 2134+004

This quasar is similar to CTD 93 in that it was one of the earliest-recognized GPS sources (Shimmins et al. 1967), and is exceedingly luminous at centimeter wavelengths. It is identified with a $m_V = 18$ quasar at z=1.93 and is highly variable in the optical (Gottlieb & Liller 1978), with occasional flarings of more than three magnitudes. Its flux density is relatively constant, however, at radio wavelengths (Aller et al. 1985)[1]. Like CTD 93, it was also thought to be a symmetric double, but our multi-wavelength VLBA observations indicate that the more compact easternmost component is associated with the base of a one-sided jet. There is a faint bridge that reaches towards the western component (see Fig. 3) which we associate with highly beamed radiation from a portion of a highly curved jet that is directed toward the observer. Multi-epoch VLBA observations at 2 cm provide marginal evidence that the

[1] http://www.astro.lsa.umich.edu/obs/radiotel/umrao.html

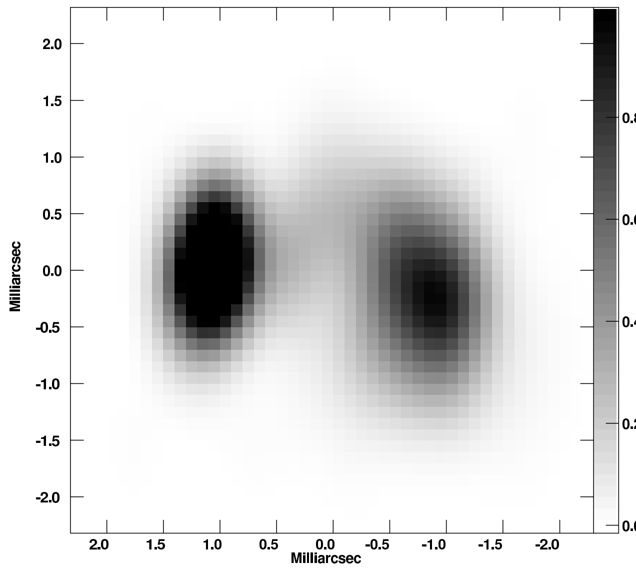

Fig. 3. VLBA 2cm image of 2134+004 at epoch 1995 May.

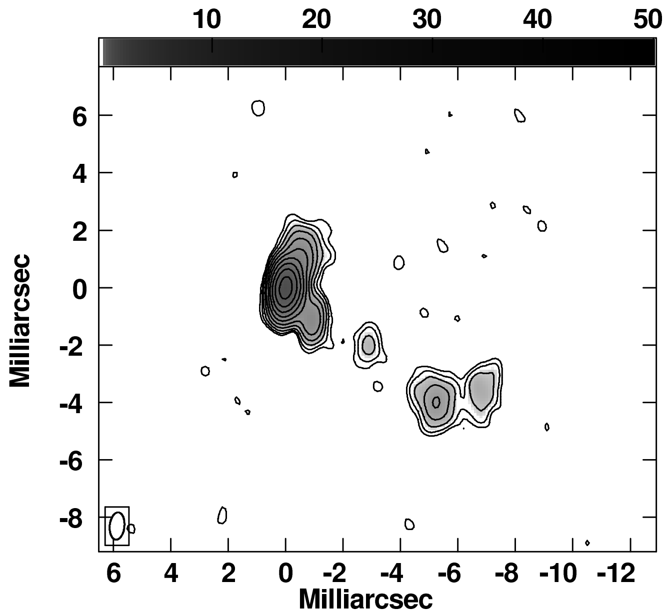

Fig. 4. VLBA 2cm image of OQ 208 at epoch 1997 Aug. The contour levels are 1, 2, 4, 8, 16, 32, 64, 128, 256, and 512 mJy beam^{-1}.

two components are drawing closer in time. However, our fitted core positions may be affected by blending of components below the resolution level of our images (see, e.g., Lister and Smith 2000).

2.4. OQ 208 (1404+286)

OQ 208 is one of the closest known GPS sources (z = 0.08), and is associated with the broad line radio galaxy Mkn 668. Its radio morphology is characterized by a very weak central core and two sharply bent jets (Fig. 4). The core appears to have a variable flux density, and is evident at only some of our VLBA epochs. The eastern jet undergoes a ninety degree bend similar to the southern component of CTD 93. There is no apparent motion of the jet components with respect to the presumed core with an upper limit of about 0.5c.

2.5. PKS 1345+125 (4C +12.50)

The host galaxy of PKS 1345+125 is an ultra luminous infra-red galaxy (ULIRG) at z=0.12 that is rich in both molecular and atomic gas (Evans et al. 1999, Mirabel 1989). The host contains two optical nuclei separated by $\sim$ 3.5 kpc that appear to have undergone a recent merger, as evidenced by its tidal tail structure and distorted isophotes (Gilmore & Shaw 1986). The western nucleus harbors an obscured quasar and a powerful compact radio source with a GPS spectrum and a sharp spectral cutoff near 400 MHz. VLBA observations reveal a well-defined jet structure with a total extent of $\sim$ 100 mas = 220 pc (Fig. 5). The brightest feature in our full-track VLBA image has an inverted spectrum and was identified as the core by Stanghellini et al. (2001). Although the core is weakly polarized ($m = 0.3\%$), the fractional polarization reaches very high levels in the southern jet, with $m = 30\%$ at the major bend and $m = 60\%$ at the very tip of the jet. The electric vectors in both regions are perpendicular to the total intensity contours, which suggests that shocks in the flow have ordered the magnetic field of the jet.

The presence of a relatively bright northern counter-jet and mild superluminal motion (1.2c) in the southern jet (Lister et al. 2002) imply that the jet axis of this source lies fairly close to the plane of the sky. The overall bent morphology suggests that the jet nozzle direction may be slowly changing with time, perhaps as a result of the merger event. Lister et al. (2002) were able to obtain a good fit to both the ridge lines and brightness distributions of the jet and counter-jet using a simple precessing jet model. The viewing angle to the inner jet in their best-fit model (62 deg.) is consistent with the angle inferred from the observed superluminal speed and jet/counter-jet flux density ratio.

3. Summary

All five of the sources we have studied have sharply bent jet structure. We find no other systematic properties which distinguish these GPS sources other than their peaked radio spectrum, which may be due to a combination of SSA and FFA from a surrounding ionized medium. CTA 102, 2134+004, and CTD 93 have bright cores plus fainter bent jets typical of what is observed in other quasars and AGN, whereas PKS 1345+125 and OQ 208 have double-sided jet structures that end in sharp bends. The identically-peaked spectra of the separate components of individual GPS sources implies little differential Doppler shift of the spectral components if the cutoff is from SSA. This interpreta-

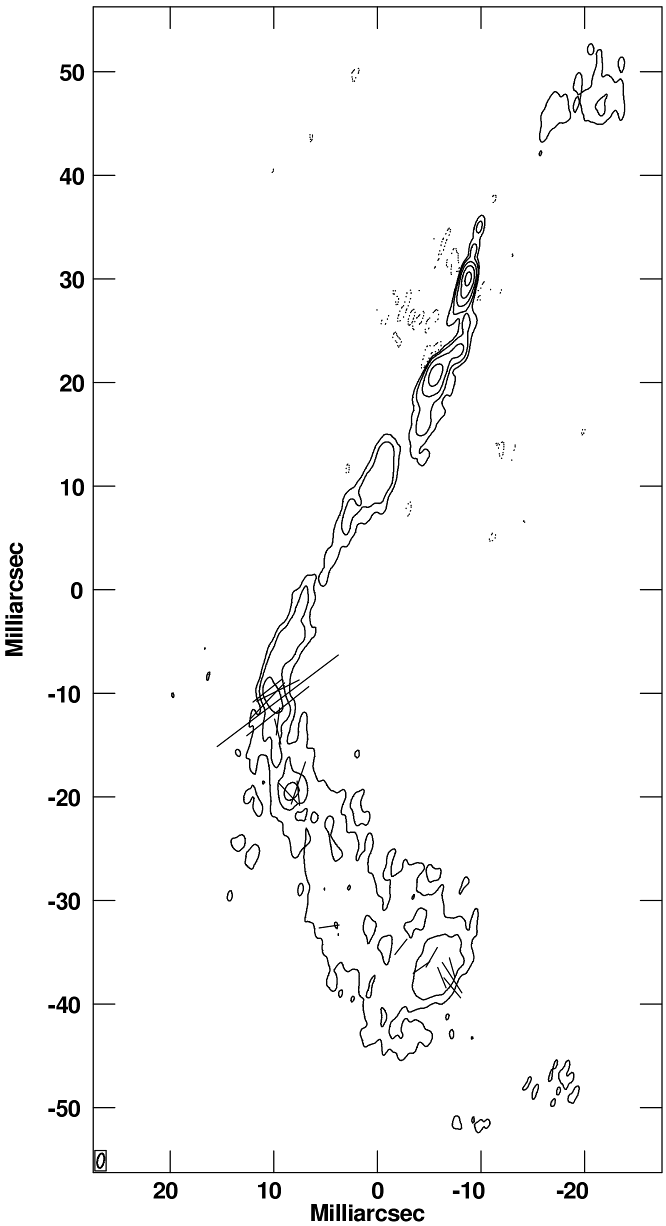

Fig. 5. 2 cm VLBA image of PKS 1345+125 at epoch 4 Jan 2001, with electric vectors superimposed. The lowest I contour is ±0.4 mJy beam^{-1}, with successive contours increasing by factors of 4.

tion is supported by the absence of any differential component motions, possibly because all the components we are observing are moving at the same velocity with respect to an unidentified core below our level of detection. But this interpretation is not consistent with the observed highly bent structure which would appear to require changes in the Lorenz factor corresponding to changes in the direction of the flow.

The common cutoff frequency across components of widely different surface brightness therefore suggests that some or all of the low frequency cutoff may be due to FFA rather than SSA. In this case the small angular size predicted from the early spectral observations and the assumption of SSA would be coincidental.

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