Parsec-scale Jet in the Distant Gigahertz-Peaked Spectrum Quasar PKS 0858−279

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The high redshift GPS quasar PKS 0858−279 exhibits the following properties which make the source unusual. Our RATAN-600 monitoring of 1–22 GHz spectrum has detected broad-band radio variability with high amplitude and relatively short time scale. In the same time, the milliarcsecond scale structure observed in a snapshot VLBA survey turned out to be very resolved which is not expected from the fast flux density variations. We performed 1.4–22 GHz VLBA observations of this quasar in 2005–2007. It has revealed a core-jet morphology. A high Doppler factor $\delta$ is suggested for the jet, its nature is discussed in this report on the basis of the multi-frequency VLBA and RATAN data collected. Synchrotron self-absorption was confirmed to be dominating at low frequencies, the magnetic field strength of the dominating jet feature is estimated of an order of 0.1\,\mu G.

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1 Introduction

At RATAN-600 we monitor more than 600 extragalactic objects North of declination $−30\,°$ since 1997 (Kovalev et al. 1999). We have identified and analyzed a subsample of objects which permanently show gigahertz-peaked spectra (GPS; see Sokolovsky et al. 2009). One of the GPS sources in the sample, high redshift quasar PKS 0858−279 ($z = 2.152$, Stickel et al. 1993) was already identified as a GPS source and studied in many papers including Spoelstra et al. (1985); O’Dea et al. (1991); Cersosimo et al. (1994); de Vries et al. (1995, 1997); Edwards & Tingay (2004). This distant object has drawn our attention because of several properties which are unusual for both, a typical GPS source and a typical quasar. First results of a study of this interesting quasar are presented in this paper.

We adopt for this paper the Friedmann-Robertson-Walker cosmology with the following parameters: $H_0 = 72$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_M = 0.3$, and $\Omega_L = 0.7$. For a source at a redshift $z = 2.152$, the luminosity distance $d_L = 16.5$ Gpc, one milliarcsecond corresponds to 8 pc.

2 Properties of the GPS quasar 0858−279

2.1 Variable radio spectrum

The quasar 0858−279 shows GPS-like spectral shape at all observing epochs (Figure 1). Our analysis of variability properties has selected this quasar as one of the most variable objects among the identified subsample of GPS sources.

This finding is supported by ATCA monitoring results (Edwards & Tingay 2004). They have shown that the variability index for this object is the highest one among the GPS sample investigated (we do not consider 1519−273 which is known to be a strong IDV and NGC 1052 which is not a “true” GPS). Most of GPS sources which possess a simple convex spectrum at any observing epoch are not variable significantly.

We also note that this object is reported by Ricci et al. (2004) to have $(106 \pm 7)$ mJy of linearly polarized total flux density at 18.5 GHz which makes its fractional polarization $(7.1 \pm 0.5)$ per cent. Such high degree of linear polarization is quite unusual for a flat spectrum radio source and even more unusual for a GPS one.

2.2 Characteristic milliarcsecond-scale size and morphology

We have used data from the VLBA Calibrator Survey program (Beasley et al. 2002; Fomalont et al. 2003; Petrov et al. 2005, 2006; Kovalev et al. 2007; Petrov et al. 2008) to analyze the milliarcsecond scale structure of the quasar. It did not show the expected core-jet morphology and was found to be significantly resolved: the dominating component is 1.3 mas at 8.6 GHz and 12 mas at 2.3 GHz in size (width at half-power level of a Gaussian model component). In opposite, the shortest time scale of the radio variability observed is of the order of several months (Figure 2) which gives an estimation of the size of the varying component from light-travel time arguments in the absence of coherence (Marscher et al. 1979) to be much smaller than the measured sizes! The amplitude of the radio variability is about or greater than 1 Jy.
Figure 1  Variability of the broad-band spectrum of the GPS quasar PKS 0858−279. Filled circles are RATAN observations in 1997–2008 at frequencies 1.0, 2.3, 3.9, 4.8, 7.7, 11, & 22 GHz, filled squares come from the literature (collected by the CATS database). RATAN light curves are presented in Figure 2.

3 Revealing the jet at parsec scales

In order to resolve the obvious inconsistency between the variability and milliarcsecond-scale structure, a dedicated VLBI experiment was organized by us. We have observed the GPS quasar simultaneously in six frequency bands (1.6, 2.3, 5, 8.6, 15, 22 GHz) with the NRAO VLBA array in a dual circular polarization mode during four observing epochs in 2005–2007. First epoch results are presented in Figure 3 (Stokes I), the spectral index image for the highest frequency range observed — in Figure 4. We have found the following.

It is confirmed that the structure is heavily resolved at all observing frequencies. It becomes more compact at higher frequencies while the dominating component of the emission becomes optically thin. The size of the dominating feature A is measured from a uv-data analysis. It changes from 26 mas at 1.6 GHz (optically thick case) to about 0.5 mas at 22 GHz (optically thin case). This evolution of size with frequency is well illustrated by the correlated flux density data presented in Figure 3. It is important to note that in this particular case different VLBA resolution at different frequencies did not significantly affect or limit accuracy of our size estimates.

The spectral index distribution calculated between 15 and 22 GHz shows a compact component C with inverted spectrum ($\alpha \sim +1, S \propto \nu^\alpha$) which is most probably an opaque core region while the dominating component A with $\alpha \sim -1$ must be a jet region of the quasar (Figure 4). The high resolution high frequency observations have finally revealed a typical core-jet structure at mas scale for this quasar; the jet appears highly curved.

Electric vectors of linear polarization are found to be parallel to the apparent inner jet direction at high radio frequencies and rotate by about 90 degrees from 15 to 8.5 GHz. At the same time, fractional linear polarization of A drops from 10 to 20 per cent at high frequencies to about or less than 4 per cent at 8 GHz and below. This suggests the synchrotron radiation with self-absorption from a blob with highly ordered magnetic field. Magnetic field lines are therefore perpendicular to the direction from C to A.

We have measured the true angular size of the dominating component at frequencies above the synchrotron self-absorption turnover frequency which appeared to be 0.5–0.6 mas. The observed strong variability of the total flux density with the variability time scale between two years and 100 days requires a very high Doppler factor $\delta > 10$ (calculated following Marscher et al. 1979; Burbidge et al. 1974; Agudo et al. 2006) and, from a probability argument (e.g., Cohen et al. 2007), a small viewing angle for this distant quasar.

VLBA monitoring of the structure of this quasar during about two years in 2005-2007 did not allow us to detect any significant motion in the structure. The distance between the core and the dominating jet component remained about constant at 15 and 22 GHz. Assuming a “standard” model for a compact synchrotron source (following the original idea by Slysh 1963) we estimate the magnetic field strength of the dominating jet component A having Doppler factor $\delta$ (Marscher 1983, 1987) to be of an order of $0.1 \delta$ mG.

4 Summary

An unusual combination of properties of the high redshift GPS quasar PKS 0858−279, namely relatively fast flux density variations and “amorphous” parsec-scale structure was resolved by VLBA observations at high radio frequencies which revealed a parsec-scale core-jet morphology for this
Figure 3 From top to bottom. First and third row: Naturally weighted CLEAN images of the quasar 0858−279 from 1.6 to 22 GHz. The lowest contour is plotted at the level given by "clev" in each panel title (Jy/beam), the peak brightness is given by "max" (Jy/beam). The contour levels increase by factors of two. The dashed contours indicate negative flux. The beam is shown in the bottom left corner of the images. Second and fourth row: Dependence of the correlated flux density on projected spacing from 1.6 to 22 GHz. Each point represents a coherent average over one several minute observation on an individual interferometer baseline. The error bars represent only the statistical errors.
AGN. The dominating jet component (A) responsible for the GPS-type spectrum became optically thin above 15 GHz and was resolved out from the core (C). From fast variations it is suggested that the jet Doppler factor $\delta$ may be about or greater than 10. Linear polarization analysis has confirmed that the turnover in the spectrum of the dominating jet feature A is caused by the synchrotron self-absorption, its magnetic field strength is estimated to be of an order of $0.1 \delta_m$ G.

The nature of the dominating jet component A with synchrotron self-absorption still remains unclear. A feature with such properties is unusual for the majority of the radio loud quasar jets. What causes this change of jet properties, does interaction with the surrounding medium play a role? How may short time scale variations occur in the optically thick part of the spectrum in this quasar? Further investigations will shed light on this.

Although formally this object can be classified as GPS source both based on the spectral as well as on the linear-size definition, the new observations reveal that this classification can probably no longer be maintained based on the high boosting factor, core-jet morphology, and other characteristics, which are unusual for a typical GPS source, but not uncommon for a quasar.

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