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LETTER

Letter to the Editor

A change in the variability properties of the intraday variable quasar 0917+624

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Abstract. We observed the quasar 0917+624 at three epochs at a wavelength of 6 cm in order to study its short-timescale variability. In December 1997 and February 1999, the source showed its usual characteristics: variations on a 10–15 % level have been found on timescales ≤ 1.5 days. In contrast, in September 1998 the source exhibited a monotonic increase of about 7 % during a five-day-observing campaign. Assuming an intrinsic origin of the variations, this corresponds to a change in brightness temperature of at least two orders of magnitude. We discuss shortly several mechanisms which may cause the observed change of the variability properties of 0917+624.

Key words: galaxies: active – galaxies: quasars: individual: 0917+624 – radio continuum: galaxies

1. Introduction

A remarkable property of the quasar 0917+624 is its pronounced radio variability on short timescales (Intraday Variability, IDV, e.g. Heeschen et al. 1987). This source was studied during several observations, in which it always showed amplitude variations on a 10–15 % level. Usually, these variations are quasi-periodic, with typical timescales in the range of 0.8–1.5 days (e.g. Quirrenbach et al. 1992, Kraus 1997, Kraus et al. 1999). Furthermore, fast variability is also observed in the linearly polarized flux density and the polarization angle, mostly with larger fractional amplitudes, reaching a factor of 2 in the polarized flux density. For the polarization angle, once a 180°-swing was observed (Quirrenbach et al. 1989).

Assuming an intrinsic origin of IDV, the fast variations imply brightness temperatures of up to 10^{21} K (e.g. Romero et al. 1994, Wagner & Witzel 1995, Kedziora-Chudczer et al. 1997, Quirrenbach et al. 1999). This fact represents a severe violation of the inverse Compton limit of 10^{12} K (Kellermann & Pauliny-Toth 1969), and challenges the existing models of AGN variability.

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Standke et al. (1996) investigated 0917+624 with VLBI, and found a compact core and a curved jet which extends to the northwest. Within the jet, superluminal motions with velocities of up to $\beta_{\rm app} \simeq 8$ were discovered.

In this paper we present the results from three observing campaigns (epochs 1997.98, 1998.71, 1999.10) aimed at studying short-timescale variations in 0917+624 at $\lambda = 6$ cm. In contrast to the earlier results (as described above), we observed only a moderate (amplitude of about 7 %) monotonic increase during a five-day-observing campaign in September 1998. During a recent observation in February 1999, the source appears to have returned to its "usual" (stronger) variability state. Here, we discuss in detail this change in the variability properties of 0917+624.

2. Observations and data reduction

We observed 0917+624 with the 100m telescope of the MPIfR in Effelsberg in December 1997 (25–31), in September 1998 (17–22), and in February 1999 (8–14), during observing campaigns performed in order to search for IDV in flat-spectrum blazars. Because all measured sources were point-like and moderately strong ($\gtrsim 0.5$ Jy) at the observed frequencies, we were able to perform the measurements with cross-scans (Quirrenbach et al. 1992, Kraus 1997).

We applied the data analysis procedure for reducing the IDV observations at the 100m telescope which was described by Quirrenbach et al. (1992) and Kraus (1997). Suitable secondary calibrators (which do not show any IDV) were observed as frequently as the program sources in order to correct for systematic elevation- and time-dependent effects. We linked our observations to the absolute flux density scale (Baars et al. 1977, Ott et al. 1994) by observing the sources 3C 286, 3C 48, and NGC 7027. The resulting measurement errors consist of the statistical errors from the reduction process and a contribution from uncertainties in the secondary calibrator measurements. The resulting errors lie in the range of 0.5–1 %.

Since the observed signal is split into the left- and right-circular polarization part, and fed into a polarimeter, we were also able to measure the linearly polarized emission of the

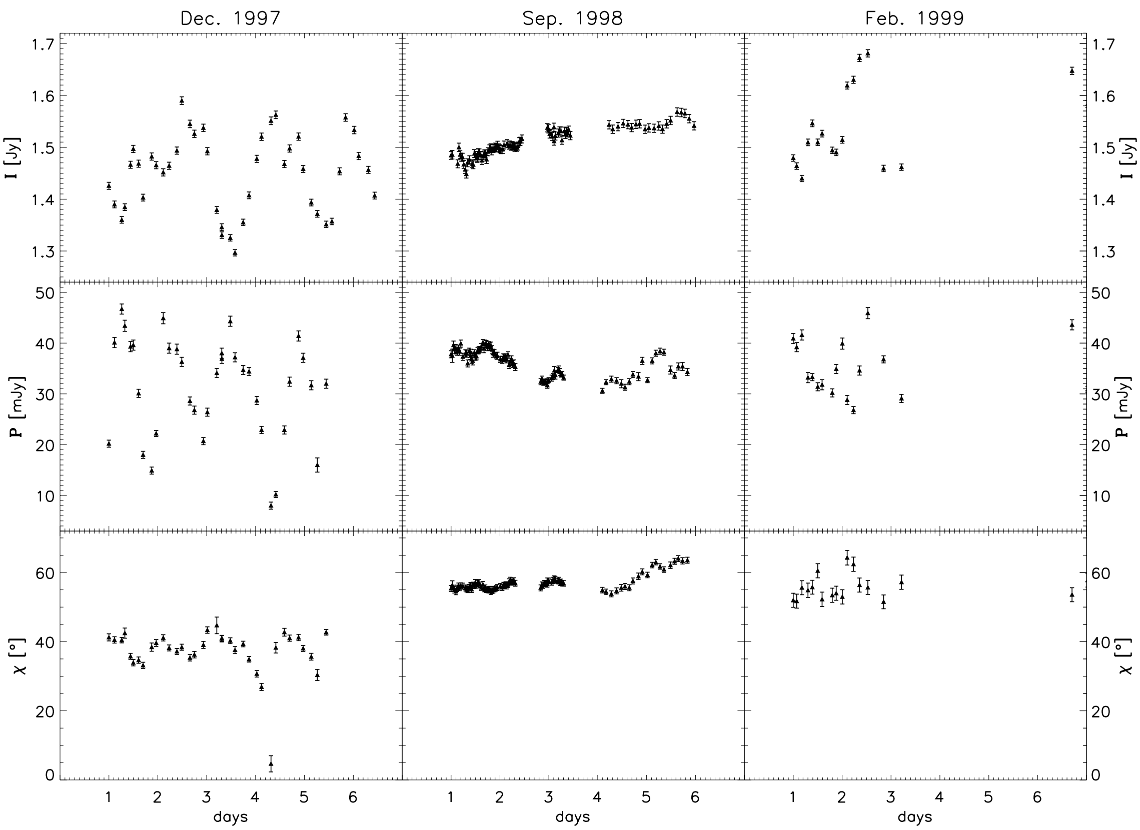

Fig. 1. Flux density and linear polarization variability in the quasar 0917+624 at 6 cm in December 1997, September 1998, and February 1999 (left to right). From top to bottom we plot the total flux density I, the polarized flux density P and the polarization angle χ against time (given in days from the beginning of the observation). At the end of the observation in December 1997 we were not able to achieve polarization data due to technical problems.

sources (Stokes-parameters Q and U). In addition to the analysis described above, we corrected the instrumental effects (e.g. parallactic rotation, instrumental polarization, etc.) using a matrix-method introduced by Turlo et al. (1985). The measurement errors usually are in the range of 3–5 % for the polarized flux density, and within 2–5° for the polarization angle.

3. Results

The lightcurves for 0917+624 at $\lambda = 6$ cm are plotted in Fig. 1. The change of the variability properties between the three epochs is evident. In December 1997, the source shows quasi-periodic variability on a timescale[1] of about 1 day with amplitudes of 15–20 % in the total intensity, of more than 100 % in the polarized intensity, and of about 20° in the polarization angle (neglecting the data point at day 4.3, although there is no evidence that it is spurious). In contrast to this, in September 1998, a steady increase over five days was seen in the total flux density, with an amplitude of ~7 %. The polarized flux density and the polarization angle show some additional variations, but the amplitudes are clearly smaller than in December 1997. In February 1999, the variations are again significantly stronger, although they look somewhat stochastic, especially in linear polarization. This may indicate the presence of even faster variability in the source.

[1] As "timescale", we denote here the time between a maximum and a minimum (or vice versa) of a lightcurve.

Table 1. Mean results for the three epochs.

Date	⟨I⟩ [Jy]	⟨P⟩ [mJy]	⟨χ⟩ [°]
Dec 1997	1.45 ± 0.08	31 ± 10	37.2 ± 6.8
Sep 1998	1.51 ± 0.03	36 ± 3	56.9 ± 2.3
Feb 1999	1.54 ± 0.08	35 ± 5	55.7 ± 3.6

It can be seen from Fig. 1 and Table 1 that neither the average of the total intensity nor the mean of the polarized intensity underwent large changes among the individual epochs. Only the average polarization angle rotated by about 20° between December 1997 and September 1998. In addition, we find from our flux density monitoring (at cm-wavelengths) that the spectrum of 0917+624 did not change significantly between the observing campaigns.

To compare the strength of the variability, we determined the "modulation index" $m = 100 \times \sigma_S / \langle S \rangle$ [%], and the "variability amplitude" $Y = 3 \times \sqrt{m^2 - m_0^2}$ [%], where σ_S is the rms flux density variation, and m_0 is the modulation index of a non-variable source (cf. Heeschen et al. 1987). Assuming an intrinsic origin of the variations, the brightness tempera-

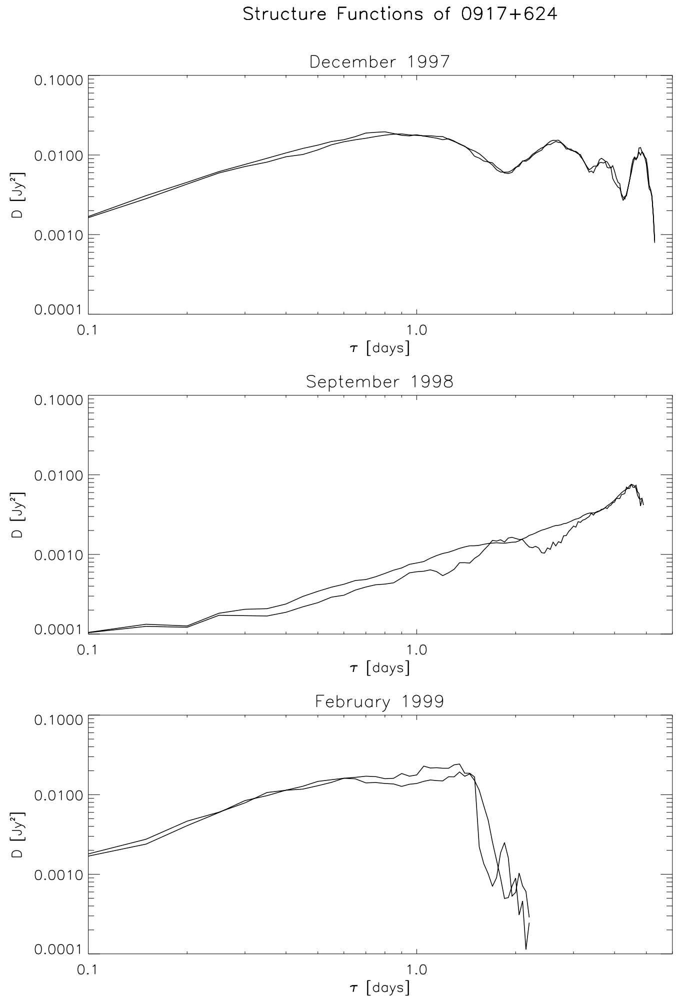

Fig. 2. From top to bottom we plotted the structure functions D of the total flux density from December 1997, September 1998, and February 1999 against the timelag τ. The structure functions are derived in two directions, starting at the beginning and at the end of the lightcurves, to avoid artificials caused by the sampling. Note that the structure functions become less well-defined for a time lag larger than half of the total length of the campaign.

ture T_B can be derived following Wagner & Witzel (1995): $T_B = 4.5 \times 10^{10} \times S \times \left(\frac{\lambda\, D_L}{\Delta t\,(1+z)}\right)^2$, with T_B in K, S in Jy, the observing wavelength λ in cm, the luminosity distance[2] D_L in Mpc, and the variability timescale Δt in days.

The values of m, Y, and T_B for all three epochs are listed in Table 2, showing that the variability was stronger by a factor of 3 in December 1997 and February 1999. This corresponds to a difference of the brightness temperatures by two orders of magnitude, between these two epochs and the observation in September 1998. However, even the slower variations in September 1998 would lead to a significant violation of the inverse Compton limit.

[2] For 0917+624 ($z = 1.446$) the luminosity distance is $D_L = 5289$ Mpc (using $H_0 = 100$ km/(s Mpc) and $q_0 = 0.5$).

Table 2. Modulation indices m, variability amplitudes Y, timescales, and brightness temperatures T_B for the three epochs.

Date	m [%]	Y [%]	Δt [days]	T_B [K]
Dec 1997	5.2	15.4	0.9	3×10^{18}
Sep 1998	1.8	5.1	> 5.0	$< 3 \times 10^{16}$
Feb 1999	5.1	15.1	1.3	1×10^{18}

In Fig. 2, we plot the structure functions $D(\tau) = <(S(t) - S(t+\tau))^2>_t$ (e.g., Simonetti et al. 1985) of the total flux density for all 3 epochs. It can be seen clearly that the strength of the variability (given by the value of D) on timescales $\tau \lesssim 3.5$ days is smaller in September 1998 than at the other two epochs. Additionally, no typical timescales (which should cause a maximum of D) are seen in September 1998 (except at $\tau \simeq 5.0$ days which is the duration of the campaign), while the structure functions from both other epochs show clear maxima at $\tau \simeq 0.9$ days (December 1997), and $\tau \simeq 1.3$ days (February 1999).

4. Discussion

The observations presented above suggest strongly that the variability characteristics of 0917+624 underwent significant changes between December 1997 and February 1999, corresponding to a change in the brightness temperature by two orders of magnitude. We note, that the BL Lac object 0716+714 showed a similar behavior during a three-week observation in February 1990, when a transition from fast to slow variations occurred within a few days (Quirrenbach et al. 1991, Quirrenbach et al. 1999). Kedziora-Chudczer et al. (1997) also reported on the disappearance of very fast variability in the quasar PKS 0405−385. Recently, this source exhibited fast variability again (Kedziora-Chudczer et al. 1998).

In general, there are two different categories of models to explain IDV, depending on the origin of the variability (Wagner & Witzel 1995). In the case of an extrinsic origin of IDV, the size of the emitting region is the most important parameter for the determination of the strength of the variability. Interstellar scintillations (e.g., Rickett et al. 1995) or gravitational microlensing (e.g., Schneider & Weiss 1987) both require small source sizes for producing fast variations. In other words, the sudden "stop" of the fast and strong quasi-periodic variability can be a hint for an increased size of the emitting region. (According to Wagner & Witzel 1995, gravitational microlensing is unlikely to be the sole cause of IDV.) In that context, one might think about the following scenario: the usual variations are caused by interstellar scattering enabled by the small size of the core of the source. During the formation of a new jet component, the size of the core increases, and the variations are becoming smaller (eventually, they even may vanish completely). Following the formalism of Rickett et al. (1995), the modulation index of a source with size θ can be described as

$$m_\theta = \frac{m_0}{\sqrt{1 + 4\,(\theta/\theta_{\rm scat})^2}} \quad , \qquad (1)$$

where $\theta_{\rm scat}$ is the scattering angle and m_0 is the modulation index for a point source. Hence, if $\theta = 2\theta_{\rm scat}$ the modulation index decreases by a factor $\sim \sqrt{17}$. After the ejection of the new component the core's size gets smaller again, and the variations re-appear. If this scenario is realized in 0917+624, VLBI monitoring should show a new jet feature, which should have an extrapolated "birth-date" close to September 1998. The emergence of the new component should be accompanied by a significant rise of the flux density in the mm-radio-regime, and subsequently also at cm-wavelengths (e.g. Marscher & Gear 1985, Zensus 1997). However, such a rise is not visible in our monitoring data until mid-1999.

Changes of the variability properties could also be caused by variations occurring in the the interstellar medium (e.g. variations of the particle density). Cordes et al. (1984) show that the scattering angle $\theta_{\rm scat} \propto (L\,\langle C_n^2\rangle)^{0.6}$ (where L is the effective path length and $\langle C_n^2\rangle$ the "level of turbulence" which is directly related to the electron density, e.g. Cordes et al. 1985). Hence, a decrease of the particle density (occurring on timescales of weeks to months) corresponds to a decrease of the scattering angle and therefore of the modulation index (cf. Eq. 1). Similarly, Fiedler et al. (1994) suggest that such changes of the ISM are responsible for flux variations of compact extragalactic sources on timescales of a few months ("extreme-scattering-events").

In the case of a purely intrinsic origin, the situation might be more complicated. In the framework of a shock-in-jet-model, the observed behavior would require a certain change of the physical conditions in the jet (i.e., the velocity of a jet component, the angle to the line of sight, or the particle density within the jet). Qian et al. (1996) explain the quasi-periodic variability observed in 0917+624 by the variation of the Lorentz-factor of a thin shock which travels through a jet with periodically varying boundaries (also Qian et al., in preparation). In the framework of this model an increasing shock thickness could lead to the disappearance of the intraday variability (Qian 1993). In that case, only a monotonic increase of the absolute flux density (as seen in September 1998) might remain.

The apparent brightness temperature derived above must be corrected for relativistic effects (e.g. Blandford & Königl 1979) to get the intrinsic brightness temperature: $T_B^{\rm intr} = T_B^{\rm obs}/\delta^3$ (with δ being the Doppler factor). In comparison, in the model of Qian et al. (1996) even a factor δ^5 has to be applied. Hence, in order to reconcile the observations of December 1997 and February 1999 with the inverse Compton limit, Doppler factors of the order of 100 ("standard" model) or 15 (model of Qian et al. 1996) are needed. With $\beta_{\rm app} \simeq 8$ (Standke et al. 1996) the corresponding angles to the line of sight (cf. Ghisellini et al. 1993) are $0\overset{\circ}{.}1$ and $2\overset{\circ}{.}9$, respectively. Taking into account that the values for $T_B^{\rm obs}$ and $\beta_{\rm app}$ are typical for a significant number of compact flat-spectrum radio sources, these angles seem to be uncomfortably small (at least for the "standard" model).

In an alternative approach, the observed changes can be explained by the superposition of two differently variable components. If these components have anti-correlated flux density variations, the observed total variability (i.e., the addition of both flux densities) might be very small. To explain the different behavior observed, a change in the variability characteristics in at least one of the two components must take place.

Subsequent studies of the variability properties and supporting VLBI observations of 0917+624 are needed for drawing more detailed conclusions. Monitoring closely the transition between the "rapid" and the "slow" phase of the variations may provide a unique opportunity to gain insight in the enigma of the rapid flux density variability.

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