Models of Polarized and Variable Radio Emission for IDV Source 0917+624

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Abstract. We examine the power spectra of IDV and show the information, which is to be gained by wavelet analysis of light curves of the quasar 0917+624. Results for total and polarized flux at 11 cm are shown. Both interstellar scattering and intrinsic models have difficulties in explaining the 1 day period variations. A theoretical model for the time averaged emission is presented, which provides the basis for the analysis of possible variations.

1. Introduction

Intraday variability (IDV) in extragalactic radio sources has been found in sources like 0917+624 (Quirrenbach et al. 1989) with variations on time scales of about 1 day (fast IDV), showing amplitudes of 5-25% in total flux. The brightness temperatures of these sources range from 10^{18} K to 10^{21} K, if the variability time scale measures the source size. More recently ultrafast IDV sources PKS 0405-385 (Kedziora-Chudczer et al. 1997) and J1819+3845 (Dennett-Thorpe & de Bruyn 2000) showing time scales of half an hour to a few hours and much larger amplitudes have been found. While refractive interstellar scintillation (RISS) seems to be the only successful explanation for ultrafast IDV sources, the problem has not been solved for longer period IDVs.

We compared the results of Fourier power spectra and a wavelet analysis of light curves. Published data are used (e.g. Qian et al. 1991) from a 1989 multi-frequency campaign with the VLA and the 100 m Effelsberg antenna at 3.6, 6, 11 and 20 cm of total and polarized flux. The quasar 0917+624 has a determined redshift of 1.44 and shows superluminal motion up to[1] $h\beta_{app} \lesssim 8$ (Standke et al. 1996).

2. Comparing Fourier Power Spectra and Wavelet Analysis

While Fourier power spectra emphasizes periodic behaviour with the best frequency resolution possible, a wavelet analysis is able to show at what time intervals a typical time scale dominates the variations in the light curve. It allows

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[1]We assume a matter dominated universe with Hubble constant $H_0 = 100h$ km s^{-1} Mpc^{-1} and deceleration $q_0 = 0.5$.
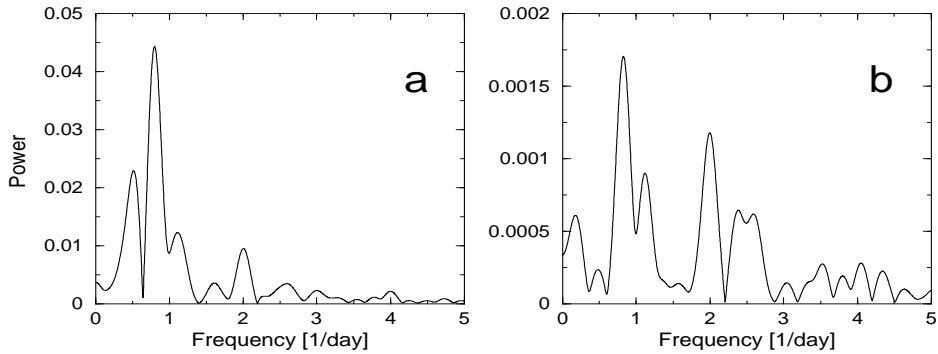
Figure 1.   The CLEAN power spectrum of variations of 0917+624 at
11cm in total (a) and polarized flux (b). Data have been taken from
the observing campaign in 1989. The peaks at 1.3 days and 0.5 days
must be considered as significant in (a) and (b).
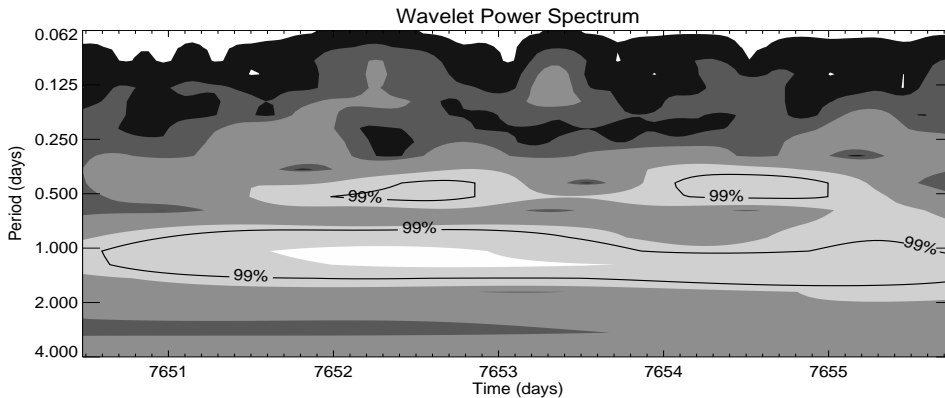

Figure 2.   Wavelet power spectrum for the same polarized flux data
at 11 cm as in Fig. 1. The 99% confidence level confirm the significance
of the two periods of 1.3 and 0.5 days.

to identify short periods with specific rise or decay times of individual bursts
and one can find phase and frequency shifts. For the 0917+624 data, we use the
CLEAN algorithm for the Fourier transforms and a Morlet wavelet family (e.g.
Torrence & Compo 1998). The spectra in Fig. 1 and 2 show two characteristic
periods of 1.3 and 0.5 days at 11 cm consistently with both methods. The addi-
tional periods of 2 and 0.9 days in Fig. 1a are too weak and close to the 1.3 day
period to be taken seriously. The 0.5 day period is more pronounced in polarized
than in total flux. In addition the wavelet method shows, that this period in
polarized flux P varies in amplitude, but not in frequency during the 7 days of
quasi-continuous observations.

3.   Interstellar Scintillation

Annual variations of the variability time scale of J1819+3845 (Dennett-Thorpe,
this volume) provide a strong argument in favour of RISS as the sole explana-

tion for ultrafast variations, when interpreted as due to the earth's motion with respect to the scattering medium. There is an indication of similar behaviour in 0917+624 as shown by Kraus et al. (1999), but changes in the characteristic time scale in the long-period IDV source 0716+714 have been found to occur quasi instantaneously (Wagner et al., 1996). Radio IDV in this source is correlated with variability at optical frequencies, which makes this explanation very unlikely for 0716+714. For 0917+624 we can approximate the variable component with 10-15% of Stokes I by a homogeneous ($\tau = 1$) source in the jet moving with a Lorentz factor of $\Gamma = 10$ at an viewing angle of $\vartheta = 0.5/\Gamma$ to the line of sight. This leads to the right apparent velocity $\beta_{app} = 8$ and a Doppler factor $\delta = 16$. This compact component can be steady over several years, if we assume energy equipartition and a corresponding intrinsic brightness temperature[2] of $T_B = 5 \cdot 10^{11} [\nu/1\text{GHz}]^{0.1}$. From the 11 cm data we derive a size of $4.3h^{-1}$ pc, which corresponds to 1 mas. For the scattering model of Rickett et al. (1995) with a distance to the scattering screen of 200 pc and a velocity of 50 km/s relative to the screen, the compact source has to be smaller than 0.1 mas at 11 cm, which is inconsistent with the equipartition temperature model. Reducing the distance to the scattering screen to only 20 pc as suggested by (Dennett-Thorpe & de Bruyn, 2000) reduces the discrepancy, but does not solve the problem. Only a particle dominated source with a brightness temperature of $5 \cdot 10^{12}$ K at 11 cm is so small, that it resolves the problem, but will violate the inverse Compton limit by $T_B = 8T_{IC}$ and predicts an unsteady source.

4. Intrinsic variability

A common feature of long period IDV sources like 0917+624 are the flat spectra of their cores, which requires an inhomogeneous jet model. The most promising model here is the propagation of a shock along the jet, at which electrons are accelerated and radiate in the post-shock gas. Variability is then caused either by density variations along the jet or by directional changes of the gas motion in a helical relativistic jet. In both cases the emission region must be small along the line of sight compared with its transversal width. If variations are expected predominantly along the jet, the viewing angle ϑ must be significantly smaller than $1/\Gamma$, so that the line of sight is still at a small angle to the jet direction in the jet rest frame.

Qian et al. (1991) argue that a shock can be naturally thin in a relativistic jet. The post-shock gas will leave the shock with its sound speed $\sim 0.6c$ in the shock rest frame. This implies that the shocked gas extents about

$$\Delta R = \left(1 - \sqrt{(\Gamma^2 - 4)/(\Gamma^2 - 1)}\right) R \qquad (1)$$

along the jet, where R is the position of the shock. For a jet with an opening angle of $0.9°$ moving with a Lorentz factor $\Gamma = 10$ the shock thickness and the jet width are equal. Effective cooling of the shocked gas is then required to keep the radiating layer of shocked gas sufficiently thin.

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[2] We assume a spectral index of $p = 2.5$ for the electron energy distribution.
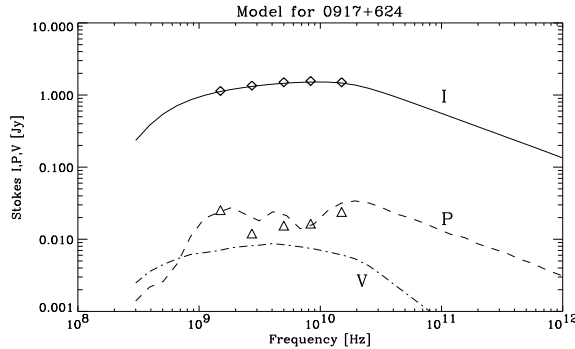
Figure 3. Averaged spectrum of the 1989 observing campaign for total (Stokes I: diamonds) and polarized flux (P: triangles). The model described in the text is shown as solid line for I, dashed for P, and dash-dotted for V. IDV in P is larger than the discrepancy of the modelled P and the averaged measurements.

For modelling the radiative transfer of polarized synchrotron radiation (Jones & O'Dell, 1977) we use a conical jet model with adiabatic particle cooling. The small degree of polarization is either due to a helical B-field structure seen face-on, or due to turbulence on top of a mean magnetic field as shown in Fig. 3. To reproduce the averaged spectrum, the shock is located $3 \cdot 10^{20}$ cm from the tip of the cone with an opening angle of $2°$ in a region with a mean magnetic field of 0.13 mG and a particle density of $N_e = 5 \cdot 10^{-5}$ cm^{-3}. The low energy cut-off of the electron distribution is at $\gamma = 15$ and determines the degree of internal Faraday rotation and conversion from linear to circular polarization. Both effects can be relevant in the region of interest,which extents down to $1 \cdot 10^{19}$ cm. The radiating gas is assumed to move with $\Gamma = 10$ at an angle of $\vartheta = 0.2/\Gamma$.

The model for the averaged emission can serve as a testbed for variability caused either by RISS or by thin shocks in the jet. It is not possible to determine the source of IDV in 0917+624 from present data.

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