Intraday Radio Variability in Active Galactic Nuclei

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Abstract

Rapid flux density variations on timescales of the order of a day or less (Intraday Variability, IDV) in the radio regime are a common phenomenon within the blazar class. Observations with the 100m telescope of the MPIfR showed that the variations occur not only in total intensity, but also in the polarized intensity and in polarization angle. Here we present an overview of our IDV-observations and discuss briefly some models which may explain the effect.

Key words: galaxies: active, radio continuum: galaxies
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1 Introduction

Flux density variations of extragalactic radio sources on timescales of the order of several weeks to years are well-known since the mid-sixties (e.g. Kellermann & Pauliny-Toth (1968) and references therein). They are used to study the physics of AGN, and have led – together with early VLBI results – to the development of the relativistic jet-model. In 1985, observations with the 100m telescope of the MPIfR in Effelsberg detected significantly faster intensity variations (on timescales of a few days down to several hours), the so-called IntraDay Variability (IDV) (Witzel et al., 1986; Heeschen et al., 1987). These rapid variations were studied in some detail in the following years, and it turned out that they are quite common in compact extragalactic radio sources. Recently, IDV was also discovered in sources in the southern hemisphere (Kedziora-Chudczer et al., 1998).
2 Observations and Results

Our observations of IDV in AGN have been carried out at the 100m telescope of the MPIfR in Effelsberg and at the VLA, studying variations of the total flux density, and — more recently — also of the (linear) polarization. For the total intensity, elevation- and time-dependent effects have been corrected using steep-spectrum sources, which do not show any IDV. For the polarization observations, we correct the instrumental polarization and the “cross-talk” between the Stokes-channels, applying the Matrix-Method proposed by Turlo et al. (1985). With these procedures, we are able to reach relative measurement errors of 0.3–1.2% (depending on the wavelength and the weather conditions) for the total flux density, 3–5% for the polarized flux density, and 2–5° for the polarization angle (for the rare highly polarized sources the measurement errors of the latter two quantities can be somewhat smaller).

Since 1985, we have observed 73 AGN (some repeatedly) in search for IDV; this includes the complete subsample of flat-spectrum sources of the 1-Jy-catalog north of δ = 50°. It turned out that the rapid variability is a common phenomenon in compact flat-spectrum radio sources: one third of the observed sources show variations with timescales of ≤ 2 days, one third show variability on longer timescales, and only one third of those sources never showed short timescale variations. Furthermore, the observations revealed that IDV is not only present in total intensity $I$, but is usually accompanied by variability of the linear polarization (intensity $P$ and position angle $\chi$). While total intensity variations range from a few percent up to 35% (e.g. in the case of the QSO 0804+499, Quirrenbach et al. (1992)), variability in the polarized intensity is usually larger and can reach a factor of two e.g. in the QSO 0917+624 (Kraus et al., 1999). So far, we have found no significant correlation between the strength of the variations or the timescales with either the redshift of the source, the galactic latitude, or the spectral index.

In Fig. 1, we show, as an example of the rapid variations, the variability observed in the quasar 0917+624 in total and polarized flux density and polarization angle (from top to bottom). An anti-correlation between the total and the polarized flux density is clearly present in the light curves. This can be supported further by the computation of the Cross-Correlation Function (CCF, e.g. Edelson & Krolik (1988)) between $I$ and $P$ which is plotted in Fig. 2. The minimum close to the timelag $\Delta \tau = 0$ confirms this anti-correlation. Due to the quasi-periodicity of both light curves, the polarized flux density variability seems to be phase-shifted with respect to the total intensity variations. This corresponds to the maximum of the CCF at $\Delta \tau \approx 0.7$ days. The anti-correlation between $I$ and $P$ is seen frequently in 0917+624, while other sources (e.g. the BL Lac object 0716+714) rather show a direct correlation between both values (e.g. Wagner & Witzel (1995), Kraus et al., in prepara-
Fig. 1. IDV in the Quasar 0917+624, observed in December 1997 at $\lambda = 6$ cm. We plotted the total flux density $I$ (upper panel), the polarized flux density $P$ (in the middle) and the polarization angle $\chi$ (lower panel) against Julian date. The variations in total and polarized flux density seem to be anti-correlated (see text and Fig. 2). At the end of the observation we could not achieve polarization data due to technical problems. Similar polarization angle variability was also observed in other sources. In 0917+624 the angular variations usually are larger than shown in Fig. 1 (e.g. Kraus et al. (1999)). Once, even a 180°-swing was observed (Quirrenbach et al., 1989).

In the BL Lac object 0716+714, we observed a direct correlation between the radio and the optical flux density variations (Quirrenbach et al., 1991), and discovered in April 1993 even faster variations (on timescales of two hours) than in any other source before (Fig. 3). It is unclear whether such rapid variability occurred only in this source, or has not been found before because of undersampling in time.
Fig. 2. Cross-Correlation analysis for the total and the polarized intensity of the light curve seen in Fig. 1. We plotted the Cross-Correlation Function (CCF) between $I$ and $P$ against the timelag $\Delta \tau$. This confirms the anti-correlation between both data series (minimum at $\Delta \tau \simeq 0$). The CCF reveals further that the total intensity precedes the polarized flux density by about $\Delta \tau \simeq 0.7$ days (see text).

Fig. 3. Rapid variability in the BL Lac object 0716+714. We plotted the flux density against the time in hours. Obviously, there are significant variations on timescales of about 1–2 hours, although on a low percentage level. This is the shortest timescale seen in our experiments.

3 Discussion and Conclusions

Thirteen years after its discovery, IDV is still not fully understood. In the case of an intrinsic origin, the timescale of the variations corresponds directly to the size of the emitting region, via the light travel time relation ($R \simeq c \cdot t_{\text{obs}}$). From this and the Rayleigh-Jeans law the brightness temperature of the variable component can be derived \cite{WagnerWitzel1995}, resulting in values for $T_B$ in the range of $10^{17}$–$10^{21}$ K, far in excess of the inverse Compton limit of $10^{12}$ K.
This fact seriously challenges existing models proposed to explain AGN variability. On the other hand, assuming an intrinsic origin of IDV, the investigation of IDV offers a method to study the physical properties of AGN on very small scales (in the order of light days or even smaller).

A correlation between the variations in the radio and the optical bands (seen e.g. in 0716+714 by Quirrenbach et al. (1991)) argues in favour of an intrinsic origin of IDV. In addition, the lack of a clear dependence of the strength or the timescale of IDV on the frequency or the galactic latitude speaks against interstellar scattering (ISS, Rickett et al. (1995)) as the exclusive cause of IDV. (Nevertheless, owing to the small source sizes $R \simeq c \cdot t_{\text{obs}}$ involved, ISS should be present as additional effect in the radio band.) Gravitational microlensing as an alternative extrinsic explanation is implausible because of the high duty cycle and short timescales of the variations and the fact that source sizes of the order of tens of $\mu$as are needed (Wagner & Witzel, 1995).

It is clear, that the variations of the linear polarization, especially the polarization angle variations, require special models. The easiest assumption might be a model with two or more independent components, taking into account the vector addition for the polarization vector. In fact, for extrinsic explanations like ISS or microlensing, this scheme is inevitable (e.g. Wagner & Witzel (1995)). In the light of the shock-in-jet models, Königl & Choudhuri (1985) explain changes of the polarization angle by the successive illumination of cross-sections with different magnetic field orientations in the jet. In the case of a small viewing angle of the jet, even 180°-swings (as observed in 0917+624 by Quirrenbach et al. (1989)) are possible. In an alternative model (Qian et al., in preparation), a thin sheet of relativistic electrons moves along magnetic field lines with a very high Lorentz factor ($\Gamma \simeq 20$–25). The observed variability is then explained by minor changes of the viewing angle (by only a few degrees) which give rise to large variations of the aberration angle and, therefore, of the observed synchrotron emission.

Adopting an intrinsic mechanism for IDV, Qian et al. (1991, 1996) considered the propagation of a thin shock through the jet plasma in a cylindrical geometry with periodic boundaries. They found this model capable of explaining the variations and the apparent high brightness temperatures by $T_B^{\text{app}} = \gamma_s^2 \delta^3 T_B^{\text{true}}$. Therefore, the high brightness temperatures can be reached easier, although even in this case Doppler factors higher than usually observed are needed. Recently, Spada et al. (in press) discussed a model in which the radiating electrons are accelerated by shocks in a conical geometry. If the injection times are shorter than the variability timescale, brightness temperatures of up to $10^{17}$ K can be explained with moderate Lorentz factors ($\Gamma \simeq 10$). Alternatively, collective emission processes proposed e.g. by Benford (1992) can avoid the violation of the inverse Compton limit. At present, however,
it is unclear whether this process can produce correlated broad-band (i.e., radio-optical) variations.

Thus, coordinated multifrequency observing campaigns covering a large range of the electromagnetic spectrum are needed to distinguish between the various models proposed.

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