Chin. J. Astron. Astrophys. Vol. 6 (2006), **Suppl. 2**, 337–340
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

5 GHz Observations of Intraday Variability in AGNs

Hua-Gang Song[1,2] ⋆ and Xiang Liu[1]
[1] Urumqi Astronomical Observatory, NAOC, CAS, Urumqi 830011, China
[2] Graduate University of Chinese Academy of Sciences, Beijing 100049, China

Abstract We present the results of intraday variability observations in compact extragalactic radio sources with the 25 m radio telescope of Urumqi Astronomical Observatory at 5 GHz. In total we have observed 116 flat-spectrum sources, of these, 17 show IDV. We present here a summary table of the results, as well as the light curves and structure functions of a few sources. Either interstellar scintillation or an intrinsic origin could be the cause of the variability in these IDV sources. Further observations over a longer time scale are needed to explain the IDV.

Key words: galaxies: active galactic nuclei — intraday variability

1 INTRODUCTION

Intraday variability (IDV) has been seen in some compact flat-spectrum radio sources since it was discovered in 1985 (Witzel et al. 1986). The variability of total flux density, polarized flux density and the polarization angle are observed frequently in some sources. Both correlation (e.g. in 0716+714) and anti-correlation (e.g. in 0917+624) between the total and polarized flux variations have been found (Wagner et al. 1994). However, this behavior can change between different observations of the same sources. More complete and frequent search and monitoring of IDVs are much needed for understanding IDV properties.

In Aug. 2004, a new 5 GHz receiver of high sensitivity and stability was installed at Urumqi Observatory. With this instrument we searched for IDVs in the PR sample (Pearson & Readhead 1988) and the Michigan Radio Source Flux Database.

2 OBSERVATIONS AND DATA REDUCTION

We selected 59 compact sources from the 65 PR sources and 57 compact sources from the Michigan sample. The sources observed consist of 31 QSOs, 5 BL Lacs and 23 galaxies in the PR sample, and 52 QSOs and 5 galaxies in the Michigan sample. For most sources, the observing time in one session was between 10 and 20 hours.

Flux densities were measured with 'cross - scans' in azimuth and elevation, twice in each coordinate in 60 seconds. A Gaussian fit was performed on each scan. The amplitude of the fit is a measure of the source's flux density. After applying a correction for small pointing offsets, the amplitudes of both AZ and EL in one 'cross - scan' were averaged. We corrected the measurements for the antenna gain (the elevation-dependent effects), using secondary calibrators which are known to be non-variable on short timescales. Finally, we linked our observations to an absolute flux density scale by the primary calibrator 3C 286.

We carried out statistical analysis on the following quantities.

The modulation index *m*

$$m[\%] = 100 \times \frac{\sigma_I}{\langle S \rangle} \,, \tag{1}$$

σ_I denotes the standard deviation of flux density, $\langle S \rangle$ denotes the average in time. *m* provides a measure of the variation strength. The relative variability amplitude is defined as

$$Y[\%] = 3\sqrt{m^2 - m_0^2} \,. \tag{2}$$

⋆ E-mail: songhg@ms.xjb.ac.cn

Table 1 The parameters of IDV sources. The table lists source name, optical identification, redshift, observation date, the number of data points, the mean value of the flux density, modulation index *m*, relative variability amplitude *Y*, χ_r^2 value, structure function type, and Galactic latitude *b*. C: calibrator; P: PR sample; M: Michigan sample.

Source	id	z	date	N	$\overline{S}$ (Jy)	*m* [%]	*Y* [%]	χ_r^2	Type	b
3C309.1(C)	Q	0.91	05 Jan 24	21	3.37	0.45		1.63	0	42
0109+224 (M)	Q		04 Dec 13	26	0.55	4.33	12.58	3.52	I	–39
0133+476 (P)	Q	0.86	04 Dec 12	20	2.46	2.96	8.38	9.82	II	–13.9
0422+004 (M)	Q	0.31	05 Jan 9	33	0.73	2.95	8.82	6.52	I	–31
0804+499(P)	BL	1.43	05 Aug 11	28	1.08	3.74	10.77	8.83	I	33
			05 Aug 31	38	1.01	3.32	9.73	16.78	II	33
0814+425 (P)	Q	0.25	04 Dec 14	23	0.84	2.78	6.67	2.64	I	34
0954+658 (P)	BL	0.37	04 Dec 14	26	0.88	1.16		2.24	0	43.6
			05 Jul 21	32	0.88	3.62	10.3	9.88	II	43.6
			05 Aug 30	44	0.92	2.82	8.32	3.06	II	43.6
			05 Aug 31	43	0.91	4.34	12.83	18.07	I	43.6
0957+227 (M)	Q	0.42	05 Jan 25	13	0.41	5.0	14.29	2.22	I	51.7
1039+811 (M)	Q	1.26	05 Aug 8	32	1.34	4.34	12.58	29.95	II	35
			05 Aug 31	43	1.31	2.83	8.2	16.28	I	35
1150+812(M)	Q	1.25	05 Aug 31	41	1.99	2.54	7.3	18.33	I	36
1156+295(M)	Q	0.73	05 Jan 12	32	0.81	2.82	8.24	4.1	II	76
			05 Jan 25	37	0.83	2.97	8.67	10.2	I	76
1717+178(M)	Q		05 Jan 11	26	0.85	3.32	9.91	5.39	I	27.6
1739+522(P)	Q	1.38	04 Dec 12	24	1.75	2.0	5.41	10.64	II	31.6
			05 Aug 30	44	1.4	2.28		9.21	0	31.6
			05 Aug 31	27	1.37	1.67		2.86	0	31.6
1749+701(P)	BL	0.77	04 Dec 21	19	0.91	5.18	10.36	15.14	II	30.8
1803+784(P)	BL	0.68	04 Dec 21	19	1.91	5.32	10.98	14.23	II	29.2
1823+568(P)	BL	0.66	04 Dec 21	19	1.46	4.18	5.8	27.53	II	26
1928+738(P)	Q	0.3	05 Aug 30	43	3.94	1.86	5.35	32.76	II	23.6
			05 Aug 31	40	3.93	2.52	7.24	22.97	I	23.6
2351+456(P)	Q	1.99	04 Dec 13	25	2.77	2.77	13.4	29.1	I	–15.7

where m_0 is the modulation index of the secondary calibrator observed in the same experiment. We also do a χ_r^2 test to see whether a source is variable or not

$$\chi_r^2 = \frac{1}{N-1}\Sigma_{i=1}^{N}\left(\frac{S_i - \langle S\rangle}{\Delta S_i}\right)^2 . \tag{3}$$

where N is the number of measurements, S_i is the individual flux density, and ΔS_i is its error.

Structure functions can be used for the analysis of the characteristics of variability, and to search for typical timescales and periodicities. The structure function D(τ) is defined as (see Simonetti et al. 1985):

$$D(\tau) = \langle (S(t) - S(t+\tau))^2 \rangle_t . \tag{4}$$

with '$\langle\ \rangle_t$' denoting average in time. For any time lag τ, the value of $S(t+\tau)$ is calculated by linear interpolation between two adjacent data points. The τ ranges from the minimum time of adjacent data to the whole observation time. Sources whose structure function reaches a maximum within the observing period are called type II, sources with increasing structure function are assigned type I. Non-variable sources are assigned type 0.

3 RESULTS AND DISCUSSION

We find IDV sources based on their light curves, modulation index *m*, relative variability amplitude *Y*, χ_r^2 and the structure function. The sources which show IDV are presented in table 1. 17 of the 116 observed flat-spectrum sources show IDV in our observations. 7 out of 57 Michigan sources show IDV, and 10 (nearly one third) QSOs and BL Lacs from the PR sample show it. We show the light curve of 3C309.1 in Figure 1 as an example of a non-variable source. Its modulation index was 0.45%. Here we report briefly on the properties of 3 sources.

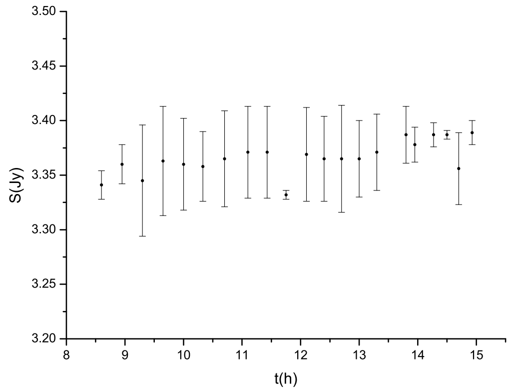

Fig. 1 Light curve and structure function of quasar 3C309.1 on Jan 24, 2005.

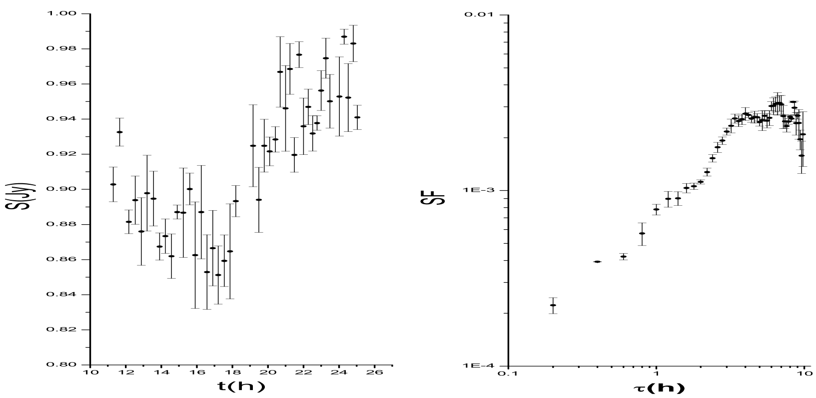

Fig. 2 Light curve and structure function of quasar 0954+658 on Aug 31, 2005.

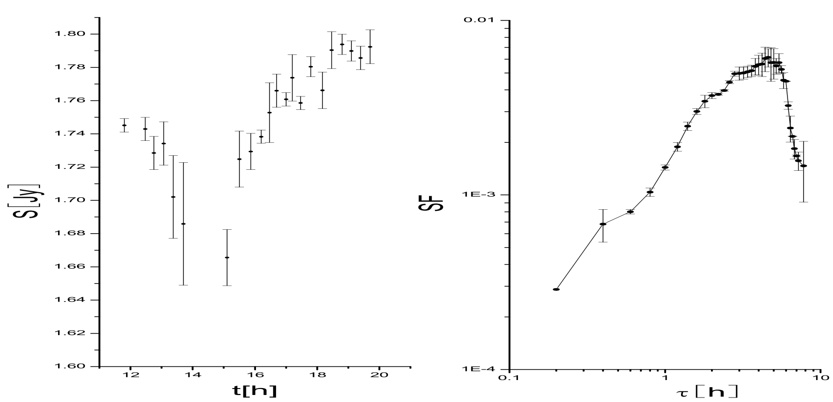

Fig. 3 Light curve and structure function of quasar 1739+522 on Dec 12, 2004.

0954+658: VLA point source, VLBI core-jet source. It displays variability on a level of 12.8% in Figure 2. It was observed 4 times and showed different structure function types at different epochs. RISS-induced variations are present in this IDV source (Fiedler et al. 1987), and a very rapid flux density dip (nearly 10% within one day) resembling an extreme scattering event was observed in this object (Fiedler et al. 1994).

1739+522: VLA point source, VLBI point source. It was observed 3 times and showed IDV only once. Besides the variations of about 10% shown in Figure 3, a rapid flux density dip has been seen. This source showed a dip in May 1991 which could be explained as an extreme scattering event (Kraus et al. 2003).

2351+456: VLA point source, VLBI core-jet structure. This source displays strong variation of about 13%. See Figure 4. This is the first time that it showed IDV.

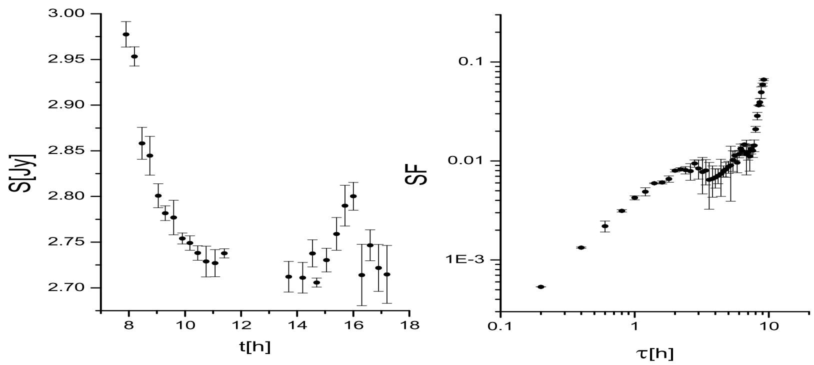

Fig. 4 Light curve and structure function of quasar 2351+456 on Dec 21, 2004.

Assuming an intrinsic origin for IDV, the size of a variable source can be derived from the variability time-scale using the light travel time. In this case, the linear size cannot be much larger than $c \times t$ (Kraus et al. 2003). According to the synchrotron theory, with the brightness temperature of a source, $T_{\rm b} \simeq 4.5 \times 10^{10} S[\mathrm{Jy}](\frac{\lambda[\mathrm{cm}] D_L[\mathrm{Mpc}]}{\Delta t[\mathrm{d}](1+z)})^2$, intraday variation on time-scales shorter than 0.5 days would imply brightness temperatures of 10^{19}-10^{21} K (e.g. Wagner & Witzel 1995). Therefore, IDV would indicate a severe violation of the inverse Compton limit of 10^{12} K (Kellermann & Plauliny-Toth 1969). Intrinsic explanations have been invoked, e.g. the motion of compact structure (a shock) in an underlying relativistic jet or the reconnection of magnetic field lines and coherent emission processes (Quirrenbach et al. 2000). However, some IDVs could be caused by an extrinsic effect, e.g. scattering in the interstellar medium (Rickett 1995). It is also likely that both intrinsic and extrinsic effects together cause intraday variation in some cases.

Future observations on longer time scale have been planned at Urumqi observatory in order to understand the possible causes of the IDV activity.

Acknowledgements We thank Richard Strom for valuable comments.

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