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Variability Study of the S5 Sample

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Abstract. We present the results of flux density monitoring of the S5 sample at 5 GHz with the Urumqi 25-m radio telescope during Dec. 2008 and Nov. 2009. Most sources exhibited $>2\%$ rms variation in our one-year monitoring. Twenty-five highly variable sources were detected at a confidence level of 99%. Weaker sources show larger amplitude of variability. Sources that have a steep spectral index are not as variable in flux density as the flat spectrum objects. No galactic dependent variability was found. Supplemental IDV observations for several strong variables were performed in order to search for possible rapid variability, and to compare variability on different time-scales. The absence of short time-scale variability in S5 0633 + 73 indicates that mid time-scale variability is a main source of intrinsic origin.

Key words. Galaxies: active—quasars: general—radio continuum: galaxies.

1. Introduction

AGN often exhibits variability on diverse time-scales across the whole electromagnetic spectrum. The observed variability can be explained with source-intrinsic (e.g. shock-in-jet) and/or extrinsic (e.g. ISS) effects. Aiming at a statistical study of AGN variability, we performed single dish observations for the S5 sample.

The S5 sample (Kühr *et al*. 1981) is the most complete sample (185 radio sources) in the northernmost sky with $S_{5\,\mathrm{GHz}} > 250$ mJy. It provides excellent targets for statistical study of variability of different types of AGNs.

2. Observation, results and discussion

Monthly flux density monitoring for the S5 sample was carried out during Dec. 2009 and Nov. 2010, containing a total of 10 observing sessions (observations were cancelled in March and June for poor weather conditions). According to the monitoring results, in Dec. 2010 and Jan. 2011, seven sources were selected for IDV observations, which were much denser in sampling ($\sim 1\,\mathrm{h}^{-1}$) and longer in duration (3∼5 days). All the observations were made in 'cross-scan' mode at 5 GHz, each scan consisting of 8 sub-scans (4 in azimuth and 4 in elevation). This observing mode allows the evaluation and correction of the pointing offsets. It turned out to provide data with high signal-to-noise ratio (SNR) for sources with $S_{5\,\mathrm{GHz}} > 0.3$ Jy. Such observation methods were also performed at Effelsberg. A detailed description of data calibration procedure can be found in Kraus *et al.* (2003).

In order to keep data with higher SNR and to achieve more convinced statistical results, 60 sources with $S_{5\,\mathrm{GHz}} < 0.3$ Jy were excluded, which leads to a list comprising 125 strong radio sources. A comparison between the total flux density of the entire sample measured by us (pilot run in Dec. 2009) and by Kühr (in 1977 and 1978) is shown in Fig. 1, which shows a high degree of agreement with ∼82% sources in 3σ level.

According to χ^2 tests, twenty-five sources, which were classified as highly variable sources, showed large amplitude of variability at a confidence level of 99% (see Table 1), while the rest were less variable. All the highly variable sources were either FSRQs or BL Lacs, except one radio galaxy S5 2116 + 81. Our result showed that ∼50% of quasars/BL Lacs exhibited significant variability, while radio galaxies were relatively stable. It is worthy to note that the modulation index (in Table 1), which is defined by $m[\%] = 100 \cdot \Delta S / \langle S \rangle$ represents the variability strength.

Table 1. Twenty-five highly variable sources detected in the S5 sample.

Source	id	Scans	$\alpha_{2.7-5\,\mathrm{GHz}}$	$\langle S \rangle$ (Jy)	ΔS (Jy)	M (%)	χ^2
0016 + 731	Q	14	0.16	1.287	0.096	7.46	88.722
0159 + 723	BL	19	0.05	0.465	0.022	4.77	50.342
0205 + 722	Q	14	−0.38	0.456	0.03	6.52	49.182
0615 + 820	Q	10	−0.03	0.878	0.065	7.36	72.214
0633 + 734	Q	9	−0.32	0.652	0.05	7.73	56.19
0716 + 714	BL	13	0.23	1.261	0.236	18.74	767.983
0743 + 744	Q	10	−0.05	0.41	0.023	5.62	32.281
0925 + 745	FS	10	0.09	0.327	0.018	5.65	30.282
1003 + 830	Q	10	−0.14	0.483	0.025	5.28	29.38
1039 + 811	Q	11	0.4	0.931	0.084	8.97	86.878
1044 + 719	Q	11	−0.08	1.332	0.112	8.42	97.388
1053 + 704	Q	10	0.16	0.309	0.026	8.29	71.47
1053 + 815	Q	11	−0.36	0.739	0.053	7.13	66.221
1322 + 835	FS	10	0.24	0.323	0.02	6.07	29.141
1323 + 799	Q	11	0.22	0.65	0.038	5.85	40.194
1357 + 769	Q	11	0.61	0.56	0.065	11.67	134.871
1448 + 762	Q	10	0.32	0.474	0.025	5.31	31.108
1531 + 722	Q	10	−0.04	0.333	0.027	7.98	48.511
1726 + 769	Q	9	−0.11	0.329	0.055	16.57	233.062
1749 + 701	BL	13	−0.26	0.631	0.028	4.51	34.482
1856 + 737	Q	10	−0.02	0.418	0.024	5.8	30.439
2007 + 777	BL	12	0.71	1.07	0.149	13.95	249.014
2010 + 723	BL	12	−0.26	0.983	0.045	4.56	27.299
2023 + 760	BL	11	−0.13	0.529	0.039	7.37	56.404
2116 + 818	G	9	−0.22	0.368	0.019	5.23	20.813

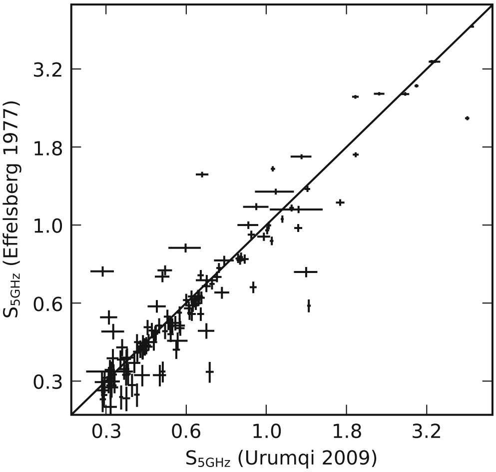

Figure 1. Comparison of flux density.

The modulation index tends to decrease with increasing source flux density as shown in Fig. 2. Similar trend was also found by Lovell *et al.* (2003) and Liu *et al.* (2011). As interpreted by the former, such a trend is ISS effect expected. Given the assumption that the compact emission region have a maximum brightness temperature T_B, the angular diameter of the emission region is then related to source flux density $D_l \propto S^{1/2}$ (Wagner & Witzel 1995). Thus the stronger in flux density, the larger is the angular size. If the size of variability component is larger than the first Fresnel scale, the ISS-induced variability can be reduced or even quenched. However, Liu *et al.* (2011) suggested that the source structure should be taken into account. Supposing the variability comes from the central core of AGN, for core-dominated sources, the flux fluctuations of the core dominate the observed variability in the total flux density, while for jet-dominated ones, such fluctuations can be suppressed by the radio jets.

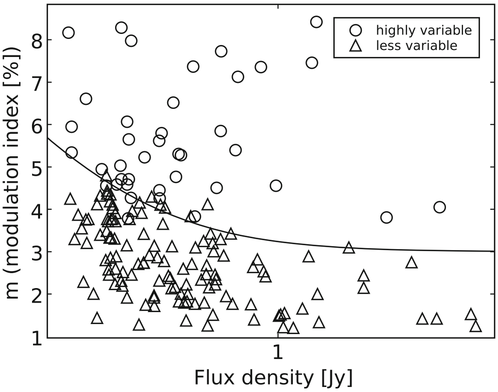

Figure 2. Flux density dependent variability.

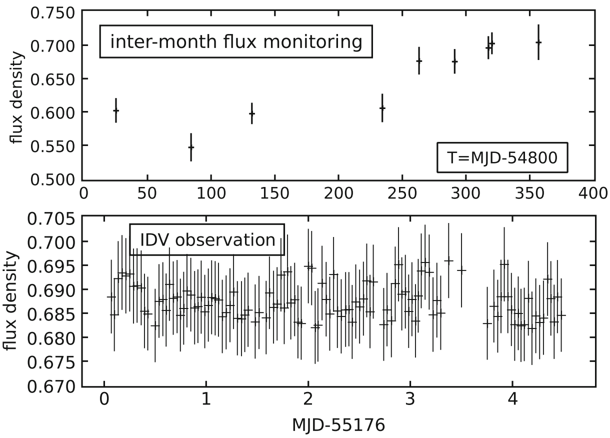

Figure 3. Light-curve of S5 0633 + 73.

In order to understand how intrinsic and extrinsic sources contribute to AGN variability according to the above explanations, we (i) checked the radio morphology of our sample, (ii) performed supplemental IDV observations for 7 strong variables. We found that almost all highly variable sources show unresolved point structure in VLA images at 5 GHz, while by contrast, the rest are more extended (see Kühr *et al.* 1987). All of the seven selected variables showed rapid variability except S5 0633 + 73 (see Fig. 3), which exhibits compact double structure with south-east lobes. Concerning the angular size, flux density and mid/short time-scale variability at 5 GHz for these sources, we suggest that IDV is mostly ISS-induced, while the mid time-scale variability is mainly of source intrinsic origin. A mixture of strong intrinsic and weak extrinsic effects may also be possible for the mid time-scale variability. However, the discrimination between these two effects may require multi-wavelength (especially high frequency) or even VLBI observations, which is far beyond the scope of this paper.

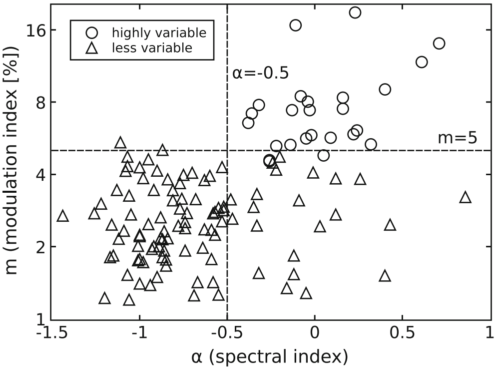

Figure 4. Spectral index distribution.

No evident correlation was found between the spectral index (between 2.7 and 5 GHz from Kühr *et al.* 1981) and variability strength for the sample (Fig. 4). However, the distribution of highly variable and less variable sources in the $\alpha - m$ domain is so distinct that most of the former is located in the upper right and the latter on the lower left region of Fig. 4. This suggests that the highly variable sources tend to have flat or even inverted spectral indices in general. The horizontal dotted line $m = 5$ almost separates the sample into highly variable and less variable, demonstrating modulation index as a good cross-check for source variability classification.

A comparison of the fraction of variables at different galactic latitudes was applied in order to search for possible galactic latitude dependent variability. However, no such dependence was found, implying ISS is of less importance for mid time-scale variability.

Acknowledgements

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References

Kraus, A., Krichbaum, T. P., Wegner, R., Witzel, A. *et al.* 2003, *A&A*, **401**, 161.
Kühr, H., Johnston, K. J., Odenwald, S., Adlhoch, J. 1987, *AAS*, **71**, 493.
Kühr, H., Pauliny-Toth, I. I. K., Witzel, A., Schmidt, J. 1981, *Astron. J*, **86**, 854.
Liu, X., Ding, Z., Liu, J., Marchili, N., Krichbaum, T. P. 2011, *JAA*, **12**, 147.
Lovell, J. E. J., Jauncey, D. L., Bignall, H. E., Kedziora-Chudczer, L., Macquart, J.-P., Rickett, B. J., Tzioumis, A. K. 2003, *ApJ*, **126**, 1699.
Wagner, S. J., Witzel, A. 1995, *ARAA*, **33**, 163.