



Daily observations of blazars in the RATAN-600 Western Sector surveys

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Abstract. We present the results of a daily monitoring of blazars observed in survey mode with the RATAN-600 Western Sector in 2018–2019. Twelve blazars were observed in the survey at the declination of the Crab Pulsar and their light curves have been measured at 4.7 GHz. All the sources but one showed a radio variability level below 15%. The flux density of the blazar B2 1324+22 increased by a factor of two during the observing year. In 2019–2020, during a generally active state, a monitoring of the blazar PKS 1614+051 was conducted at 2.3 and 4.7 GHz. The flux density variability was low ($\sim 3\%$) at both frequencies. At 4.7 GHz the source was variable on a timescale of 25 days in its reference frame. A daily monitoring of the blazar AO 0235+164 was carried out at 2.3 and 4.7 GHz in 2021–2022. The light curves showed three repeating flares with a timescale of 57 days, and a periodicity of 52 days in the source’s frame was found at 4.7 GHz.

Keywords: active galaxies; blazars; radio continuum

1. Introduction

Blazars are a class of active galactic nuclei (AGNs), known for their Doppler-boosted relativistic jets pointing nearly toward the observer’s line of sight (Urry & Padovani 1995). Blazars exhibit emission and variability across the entire electromagnetic spectrum. They are divided into two subclasses: BL Lacertae objects (BL Lacs) and flat-spectrum radio quasars (FSRQs). In the radio band their emission is produced by the synchrotron and free-free radiation mechanisms. Studying the variability enables estimation of typical sizes of radiating regions and the distances between them. In this work we present a study of 14 blazars observed on a daily basis at 2.3 and 4.7 GHz with the RATAN-600 Western Sector.

The light curves of these blazars were examined as part of the sample in Kudryashova (2024). Additionally, two bright blazars, PKS 1614+051 and AO 0235+164, were studied in greater detail. General characteristics of the studied blazars, taken from the literature, are presented in Table 1.

The objects of the sample are in the redshift range from 0.3 to 4.2, the flux densities at 4.7 GHz are 34–1270 mJy with a median value of 230 mJy, the average spectral index $\alpha = -0.12$, the median radio luminosity of the FSRQ-type blazars is 1.5×10^{44} erg/s, while it is only 2.0×10^{42} erg/s for the rest of the objects.

2. Observations

The observations were carried out with the RATAN-600 Western Sector in round-the-clock radio survey mode using secondary mirror No. 5. The surveys were performed during a year at each of the three declinations: 22°0, 16°5, and 05°0. Three or four identical four-channel radiometers at 4.7 GHz were used in all the observations, and an additional radiometer at 2.3 GHz was used in the surveys at 16°5 and 05°0.

The observed data were processed and analyzed as described in Kudryashova (2024). To increase the signal-to-noise ratio (S/N , where S is a signal in terms of antenna temperature, T_a), the data at 4.7 GHz were averaged over each radiometer channel and, if necessary, over several days. As a result, datasets for each object over 12 months were obtained. Further data processing resulted in the light curves with a daily or a three-day resolution for the sources with the highest S/N .

The obtained light curves at 4.7 GHz for the weaker (with lower S/N) and bright (with higher S/N) sources are presented in Figs. 1 and 2, respectively.

3. Radio variability analysis

The radio survey at Dec = 22°0 was conducted in 2018–2019 at 4.7 GHz. A list of 205 bright sources has been obtained by Kudryashova (2024). Twelve of the radio sources are classified as blazars in the literature. In this work we improved the accuracy of their light curves and measured the variability.

To measure the variability level, we used the variability index defined in Alleret al. (1992):

$$V_S = \frac{(S_{\max} - \sigma_{S_{\max}}) - (S_{\min} + \sigma_{S_{\min}})}{(S_{\max} - \sigma_{S_{\max}}) + (S_{\min} + \sigma_{S_{\min}})}, \quad (1)$$

where S_{\max} and S_{\min} are the maximum and minimum flux densities, and $\sigma_{S_{\max}}$ and $\sigma_{S_{\min}}$ are their measurement errors.

The left panel of Fig. 3 shows the measured variability indices at 4.7 GHz compared to those for the sources of other types from Kudryashova (2024) depending on the measured flux densities. The distribution of the variability indices for 205 sources is shown in the right panel. It may be concluded that the blazar J132700+221050 (B2 1324+22) had the highest variability index

Table 1. General characteristics of studied blazars: col. 1 – the NVSS source name; col. 2 – redshift; col. 3 – type of the source; col. 4 – measured flux density with its error, in mJy; col. 5 – variability index with its error; col. 6 – two-frequency (1.4–4.7 GHz) spectral index with its error; col. 7 – luminosity of the source, in erg/s; col. 8 – reference: [1] – Ahumada et al. (2020); [2] – Gaia Collaboration et al. (2023); [3] – D’Abrusco et al. (2014); [4] – Massaro et al. (2009); [5] – Higley et al. (2020); [6] – D’Abrusco et al. (2019); [7] – Healey et al. (2008) [8] – Wilkes et al. (1983); [9] – Kudryashova (2024); [10] – Sotnikova et al. (2021); [11] – Cohen et al. (1987).

NVSS name	redshift	type	$S_{4.7} \pm \Delta S$	$V_S \pm \Delta V_S$	$\alpha \pm \Delta\alpha$	$L_{4.7}$	reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
J015218+220707	1.321	FSRQ	900±37	0.12±0.03	-0.10±0.04	2.26e+44	[1,4,9]
J023004+215909	0.529	bl.cand.	66±5	0.0±0.105	0.01±0.07	2.55e+42	[2,3,9]
J060351+215937	–	bl.cand.	1270±56	0.02±0.01	-0.64±0.04	-	[3,9]
J072614+215320	1.882	FSRQ	442±30	0.08±0.08	0.48±0.06	1.58e+44	[2,4,9]
J102016+220940	0.314	bl.cand.	61±4	0.0±0.125	0.11±0.06	7.32e+41	[5,6,9]
J103633+220312	0.595	FSRQ	265±20	0.11±0.03	0.01±0.02	1.02e+43	[4,5,9]
J105430+221055	4.161	BL Lac	52±4	0.10±0.07	-0.19±0.07	1.34e+44	[2,4,9]
J125433+221103	0.509	BL Lac	45±3	0.11±0.07	-0.67±0.07	2.00e+41	[4,5,9]
J132700+221050	1.398	FSRQ	690±23	0.29±0.01	-0.15±0.05	1.65e+44	[4,5,9]
J161847+215921	0.334	Unc.type	34±2	0.09±0.04	-0.69±0.06	5.61e+41	[4,5,9]
J171611+215214	2.380	FSRQ	298±14	0.04±0.07	-0.69±0.05	4.50e+44	[2,4,9]
J180738+220456	0.798	FSRQ	187±8	0.11±0.03	0.83±0.05	1.28e+43	[4,7,9]
PKS 1614+051	3.21	FSRQ	1100±30	0.02±0.001	0.51±0.09	8.63e+44	[4,8,9,10]
AO 0235+164	0.94	BL Lac	1560	0.32±0.07	0.37±0.07	1.79e+44	[4,9,11]

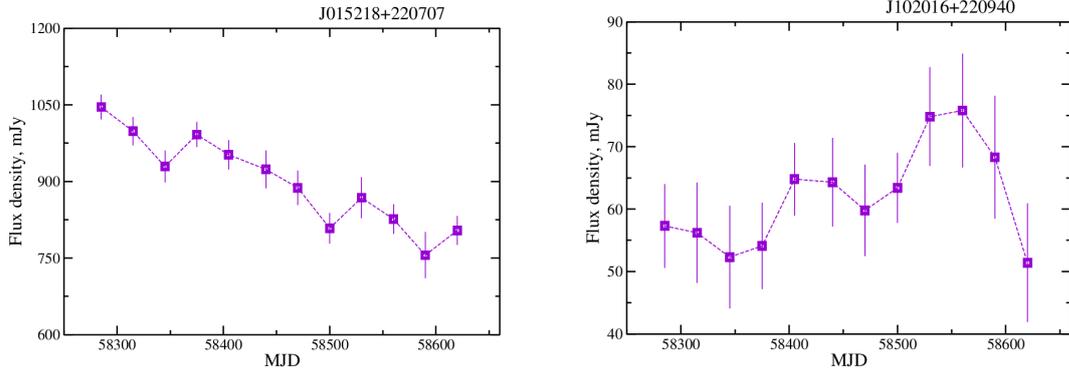


Figure 1. Light curves for the blazars NVSS J015218+220707 and NVSS J102016+220940 obtained by averaging daily records over 30 days.

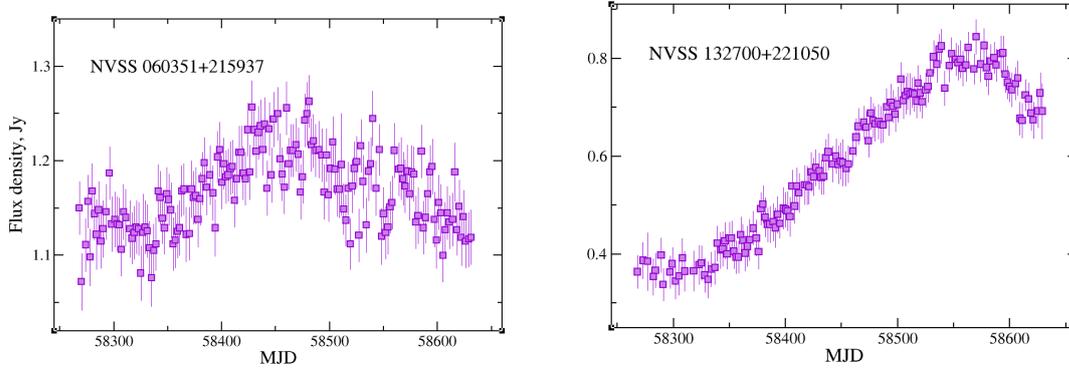


Figure 2. Light curves at 4.7 GHz for the blazars J060351+215937 and J132700+221050 obtained by averaging the observed data over 3 days.

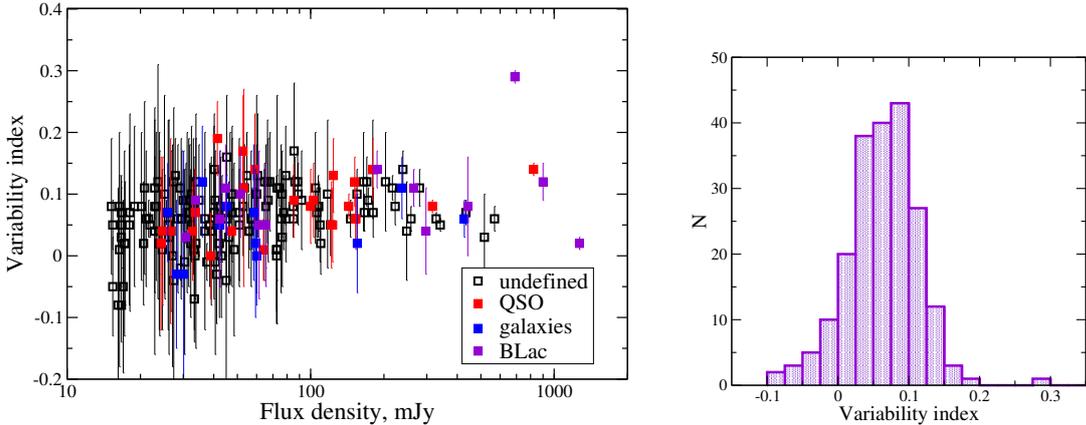


Figure 3. *Left:* the variability indices of the studied blazars compared to the sources of other types from Kudryashova (2024); *right:* the variability indices distribution.

$V_S = 0.3$. Its flux density increased by a factor of two during the observing year. For other sources, the variability indices $V_S < 0.2$.

Structure function (SF) analysis and the Lomb–Scargle (LS) periodogram were used for a more detailed study of the light curve variability properties. The SF analysis was developed by Kolmogorov in the turbulent plasma theory (Kolmogorov 1941a) and adopted by Simonetti, Cordes & Heeschen (1985) to search for typical timescales in astrophysical time series.

For the blazar B2 1324+22, SF analysis did not show any timescales, therefore it can be concluded that the timescales and periods, if exist, are significantly longer than the time span of our observations.

4. PKS 1614+051

The blazar PKS 1614+051 is of special interest due to its high redshift $z = 3.21$ (corresponding to about 15% of the current age of the Universe), peaked spectrum in the radio band, and compact VLBI structure. It is classified as a gigahertz-peaked spectrum (GPS) radio source by O’Dea (1990) and later as a high-frequency-peaked (HFP) source by Dallacasa et al. (2000). One of the explanations for the nature of this class of radio sources is their young age. In this scenario, radio emission is produced inside the host galaxy and is affected by its interstellar medium. PKS 1614+051 was observed at 2.3 and 4.7 GHz in radio survey mode at RATAN-600 from May 2019 to June 2020. To improve the accuracy of the flux density measurements, we averaged three daily observations. The measured light curves are presented in Fig. 4 and indicate a slow decrease of flux density at 4.7 GHz throughout the period of observations. The median flux density uncertainty is $\sim 12\%$ for the data at 2.3 GHz and $\sim 2\%$ for 4.7 GHz.

The estimated variability level was quite low: $V_S = 0.03$. Using SF analysis, we found a typical timescale of 25 days in the source’s reference frame. It gives a constraint on the emitting region size of less than a parsec. The LS periodogram did not reveal any significant periods.

5. AO 0235+164

The blazar AO 0235+164 at $z = 0.94$ is an object of various studies because of its brightness and the small angle between its jet and the observer’s line of sight $\Theta = 1.7^\circ$ (Kutkin et al. 2018) with an opening angle of $\sim 50^\circ$ that makes it a useful object for investigating the jet properties. AO 0235+164 was observed with RATAN-600 daily from May 2021 to June 2022 at 2.3 and 4.7

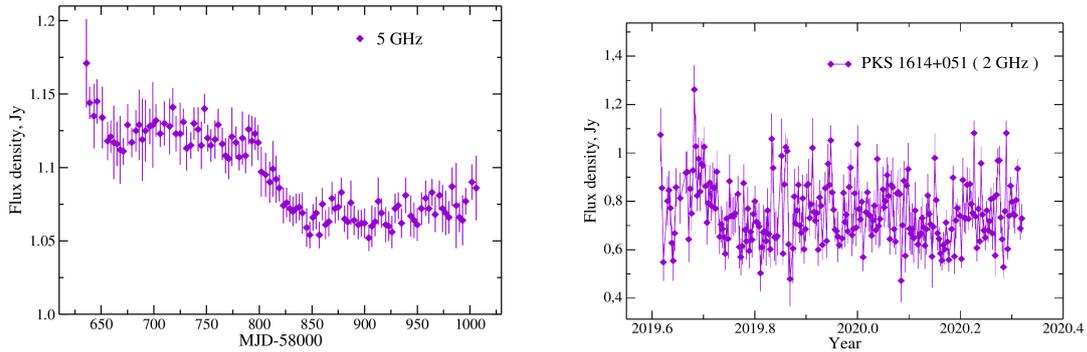


Figure 4. Light curve for blazar PKS 1614+051 obtained at 4.7 GHz (*left*) and 2.3 GHz (*right*) in a radio survey mode during from May 2019 to June 2020.

GHz. The measured light curves are presented in the left panel of Fig. 5. Their variability indices are $V_S = 0.22$ at 2.3 GHz and $V_S = 0.32$ at 4.7 GHz. The light curves exhibit three low-amplitude flares. To investigate their timescales and periodicity, we used SF analysis and the Lomb-Scargle periodogram. With the additional data at 5 GHz from Vlasyuk et al. (2024) (Fig. 5, right panel), four flares progressing in duration and amplitude are apparent. Outbursts lasting 3–5 days preceded each flare maximum.

We obtained a period of ~ 52 days in the source’s reference frame with a false alarm probability of less than 1%. Thus, we can conclude about an episode of quasi-periodic behavior of AO 0235+164 from May 2021 to June 2022.

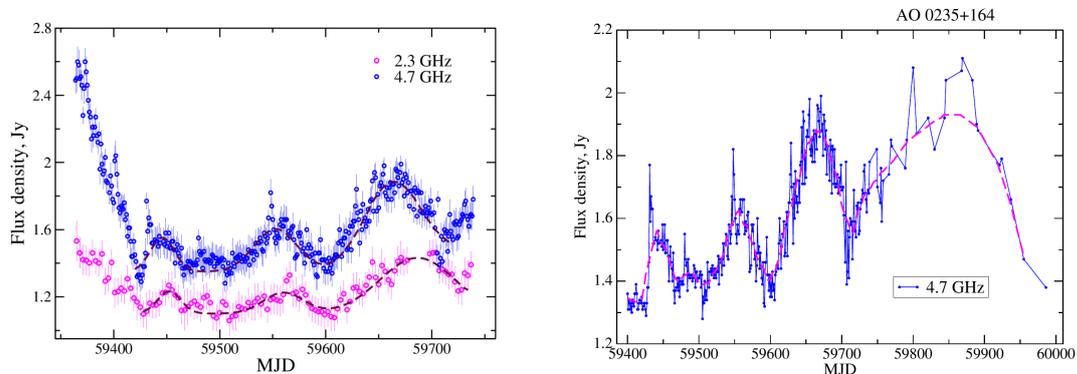


Figure 5. Light curves for the blazar AO 0235+164 obtained in 05.2021–06.2022 at 2.3 and 4.7 GHz.

SF analysis gave us a variability timescale of 57 days in the source’s reference frame. Using discrete correlation function analysis, we obtained a time lag of 7 ± 1 days between the light curves at 2.3 and 4.7 GHz. Such a variability timescale and a time lag between 2.3 and 4.7 GHz give constraints on the emitting region radius $R \ll 1$ pc and on the distance between the emitting regions at the two frequencies of < 0.1 pc.

6. Summary

Daily observations at 2.3 and 4.7 GHz presented in this work give an opportunity to study shorter timescales and periods of the blazars variability. In this paper we analyzed the light curves of 14 blazars observed in radio survey mode at RATAN-600.

1. Among the 12 blazars observed at 4.7 GHz in 2018–2019, only B2 1324+22 showed significant variability with monotonic flux density growth without any timescales within the period of observations.
2. During daily observations in 2019–2020, the HFP blazar PKS 1614+051 showed at 2.3 and 4.7 GHz a low variability $V_S = 0.03$. At 4.7 GHz a variability timescale of 25 days in the source’s reference frame was found, without any significant periodicity. The size of emitting region is estimated as less than 1 parsec.
3. The extremely compact blazar AO 0235+164, observed on a daily basis at 2.3 and 4.7 GHz, showed complex variability behavior during 2021–2022. Repeating flares with a period of ~ 52 days and a timescale of 57 days were found. By DCF analysis a time lag of 7 ± 1 days between the emission at 2.3 and 4.7 GHz was measured. This corresponds to a radius of the emitting region $R \ll 1$ parsec and a distance between the emitting regions at the two frequencies of < 0.1 pc.

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