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The Optical Variability of Some Blazars on Different Time Scales: Recent Results

V. V. Vlasyuk,[a,*] O. I. Spiridonova[a] and A. S. Moskvitin[a]

[a] *Special Astrophysical Observatory of RAS, Nizhny Arkhyz, Russia*

E-mail: vvlas@sao.ru

We present some results on the optical brightness variabilty of the blazars that were proposed as candidates for observation by N. S. Kardashev with colleagues about two decades ago. Intensive studies using the 1-m class telescopes of SAO RAS allowed us to discover numerous manifestations of flux variation on timescales from minutes to months. Together with some our earlier results, we present the new ones, not published yet. The opening for observations of the SAO RAS complex of small telescopes provided us with multiple increase of observing facilities. As a result of this development, we can detect many local and global brightness maxima for these violently variable sources as well as the intraday variation phenomena.

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[*]Speaker

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1. Introduction

Active Galactic Nuclei (AGNs) lie within the focus of interest of astrophysicists after M. Schmidt's discovery of the first quasar 3C273 in 1963. The most intensive studies of AGNs had been conducted at the end of the 90s – the beginning of the '00s, as they were the most distant sources in the Universe with huge energy release in a wide spectral range: from gamma radiation to radio waves. It is well known that the AGN phenomenon is caused by the presence of a supermassive black hole with a mass from few million to few billion solar masses. The accretion disk around the central engine together with relativistic jets is a source of powerful ionizing radiation. Till the beginning of the new century, AGNs kept record parameters among all sources in the Universe, afterwards they were partially superseded by gamma-ray bursts, which had been the most distant known objects for some years (for example, GRB090423 with z=8.2). But now the most distant sources are extremely young galaxies with z = 11–13.

Within the last years AGNs have become the objects of the main interest in extragalactic astronomy due to their possible nature as a source of high-energetic neutrinos. Between the many types of AGNs one should note the class of blazars, including BL Lacertae objects and high polarization quasars: a subclass of flat-spectrum radio quasars. The main feature that allow us to separate blazars from other AGNs is the presence of a relativistic jet which is oriented very close to the line of our sight. This peculiarity of blazars results in the strong variability of their radiation in a wide spectral range and on different timescales: from years and months to hours and even minutes.

2. Collaborative radio-optical observations of blazars till 2018

Being interested in solving the problem of blazar variability, N. S. Kardashev with colleagues about 20 years ago proposed our team to start collaborative studies of some blazars using the meter-class telescopes of SAO RAS. We started the observations of the blazar 2007+777 using the modest 60-cm telescope Zeiss-600. The first results for 2007+777 were obtained in the broadband B and R filters in 2000–2001 using a CCD camera which was designed and manufactured in SAO RAS and equipped with a Russian 1K×1K detector. They are presented in Fig. 1. We could not find any strong indication of intraday variation for the object, but confirmed the presence of long-term variability with characteristic timescales between 10 and 40 days with amplitudes $\sim 1^m$ [1].

A long-term optical monitoring campaign was initiated at the SAO RAS 1-meter reflector by N. S. Kardashev with colleagues in 2001 and had been continuing for about 20 years. Some observations were accompanied by simultaneous radio observations with the 22-m radio telescope of the Crimean Astrophysical Observatory at 22.2 and 36.8 GHz. The observing sample included about 10 blazars, which were distributed over the northern hemisphere and selected by their radio flux ($\sim$1 Jy).

We obtained the radio and optical light curves for these blazars and detected short-duration flares in the R band for [HB89] 0235+164 (shown in Fig. 2) and [HB89] 0954+658 in 2001–2003 [2] and for the blazar DA 55 and radio quasar 2134+004 in 2005–2006 [3]. Typical brightness variations reached 0.2^m over an interval of about 15 minutes. The radio flux variations for DA 55 and 2134+004 reached 1.5 Jy over about 15 minutes, and that for 2145+067 reached 2 Jy over 2 hours. For other objects from the sample we detected chaotic variation of radio flux, but without

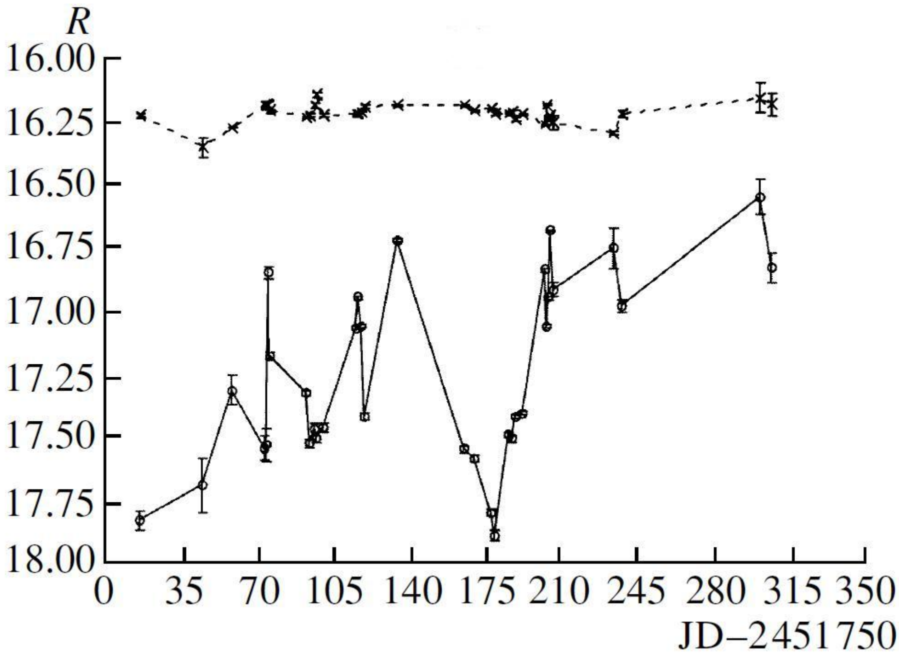

Figure 1: The long-term brightness variation for the blazar 2007+777 in the R band, observed within the 2000–2001 campaign with the SAO RAS 60-cm telescope. The upper curve at $R \sim 16.^m25$ presents the reference star measurements, the lower one is the flux variation for the blazar itself.

any optical features. Overall, we did not detect significant correlation between the radiation in the optical and radio bands in these observations.

2.1 Behaviour of the blazar S4 0954+658 in 2014–2015

The blazar S4 0954+658 is amongst the most interesting objects in our sample. This is a BL Lac object showing a smooth continuum and the absence of any appreciable emission or absorption features. It was discovered in radio surveys of the 70s, being brighter than 1 Jy at the 6 cm wavelength, and later was identified with an optical object (see [4] and references therein). It is very active in the gamma-ray range. As our own and literature data showed, its brightness was quite unstable, especially in 2011 [5]. The maximum variations in the B band reached 2^m, and the short-time brightness variations reached several tenths of a magnitude over several hours, thus confirming the activity of S4 0954+658 on both short and long-time scales. Evidence for correlation between flare events in the optical and radio bands in short time intervals has been noted, with a delay of several days.

Within the course of the photometrical monitoring of this source with the CCD photometer of the SAO RAS 1-meter reflector, we detected powerful optical flares between the end of 2014 and the beginning of 2015: the flux in the R band reached $\sim 13.3^m$ from the end of December to February 12, 2015 (see [6] and [7]). This maximum became most powerful for the 2010s decade. As following analysis showed, this event was accompanied by maxima in the mm radio waves, IR, and gamma radiation (see Figure 3) [4].

Joint analysis of the radio data in the range from 4.8 to 36.8 GHz with the optical and near-

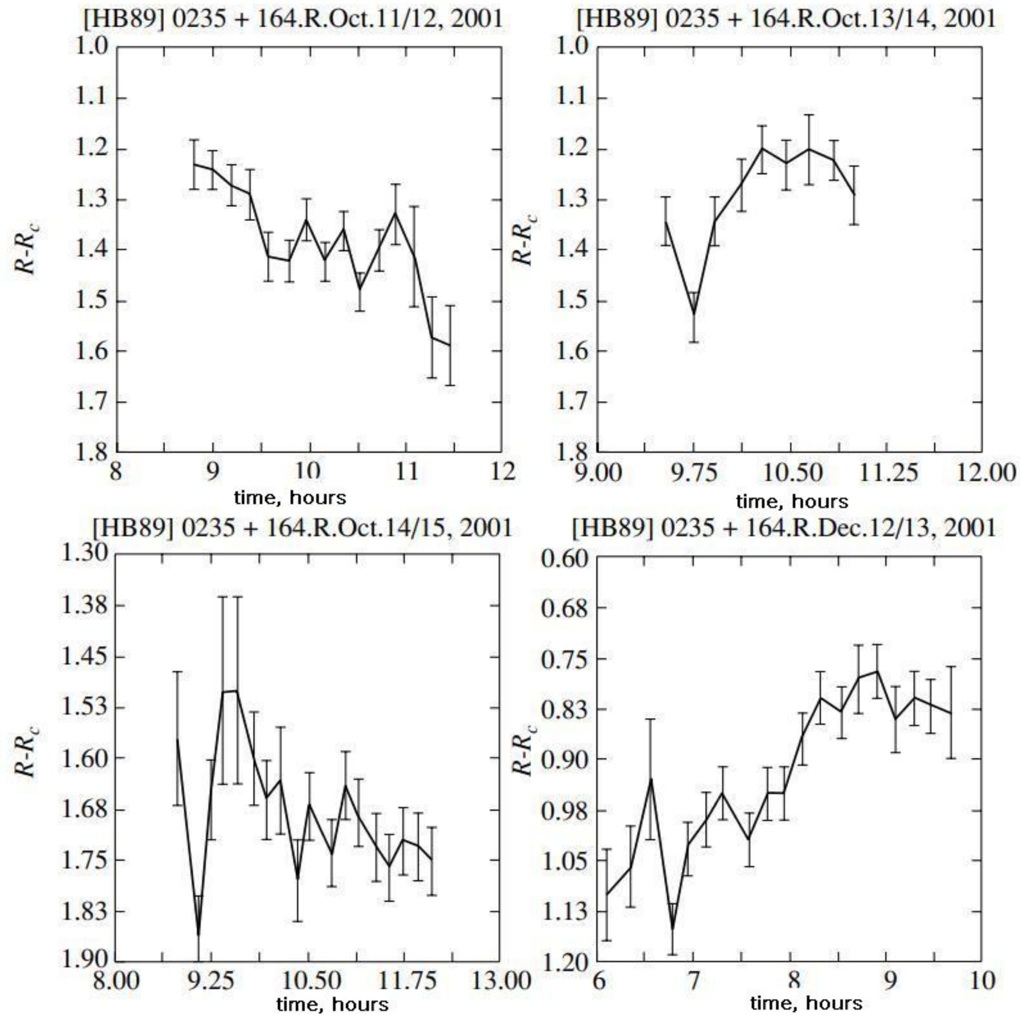

Figure 2: The examples of the intraday brightness variation for [HB89] 0235+164 in the R band in the October–November 2001 campaign with the 1-m telescope.

infrared data in broadband filters allowed us to make a conclusion about the parameters of the binary supermassive black hole in the center of the blazar. Below we show some new and even more powerful events in this extremely interesting object.

2.2 A unique multiple flare of the quasar TXS0917+624 in 2017–2018

Another interesting object from Kardashev's sample is the quasar TXS0917+624=OK630, identified with a powerful 1 Jy flat-spectrum radio source [8]. Its detailed studies with the 100-m Bonn reflector in the 80–90s gave some indications of significant variation on the day and intraday scales. The source was generally found to be strongly variable with the amplitude variation at a 10-–15% level and on time scales in the range of 0.8-–1.6 days. Surprisingly, the data from the same 100-m Bonn reflector which were obtained in 2000–2001 demonstrated the absolute disappearing of intraday variation at levels above few tenth parts of a percent [9]. A similar conclusion resulted from the studies with the 25-meter Urumqi radio telescope in 2005–2010 [10].

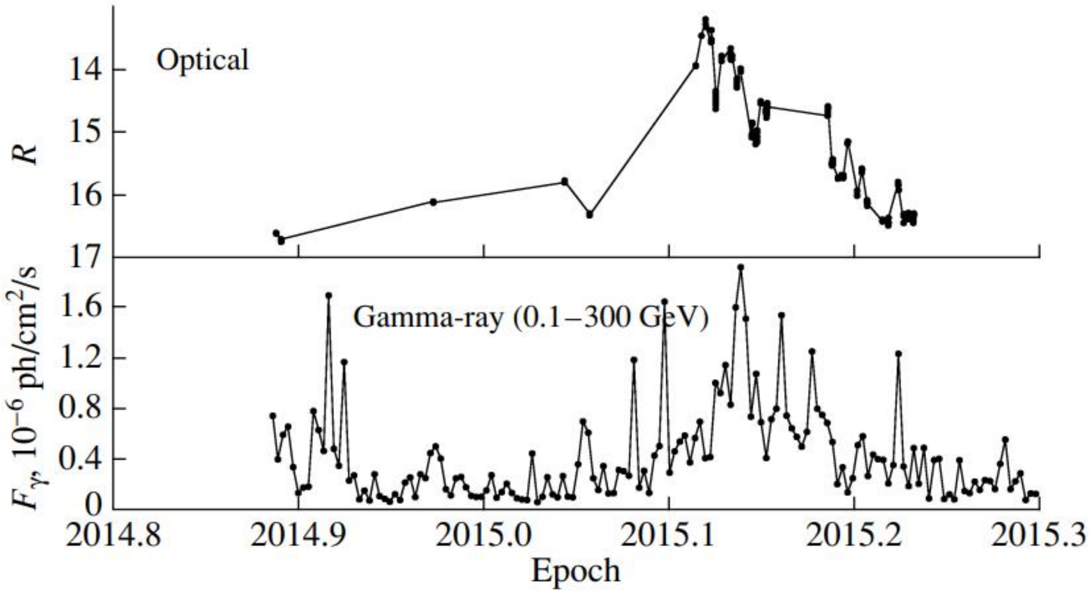

Figure 3: The light curve of S4 0954+658 in the optical (R) and gamma-ray bands during the December 2014 – February 2015 flare.

The optical studies of TXS0917+624 were not so intensive: the spectral investigation of the quasar with the 3.5-m Calar-Alto telescope made it possible to measure its redshift (z=1.44) and to detect some absorption systems from the matter along the line of sight [11]. Additional imaging with this telescope provided some indications on the presence of a faint companion to the East from the main source.

Only our own measurements of its brightness were published at the time [2]. Unfortunately, within that time interval TXS 0917+624 was at a low activity stage: its brightness (about 20^m in the R band) did not allow us to make any conclusion about the variation level. The photometrical monitoring with the 1-m reflector, nevertheless, was prolonged. We were lucky: after 15 years of flux fluctuation between 18^m and 19^m, the brightness of the quasar at the end of 2016 exceeded the 18^m level, and it became brighter.

The most interesting phenomenon dates back to the border between 2017 and 2018. Starting from the $R \sim 17.5^m$ level in mid-November, the brightness of the quasar increased up to $R \sim 15.2^m$ within 30 days. After the maximum near December 15th, the object started to dim and within 20 days returned to the level of $R \sim 18.0^m$. After a quiet state during 10 days, the flares of TXS0917+624 repeated twice but with smaller amplitudes and shorter durations (2.2^m and 1.5^m respectively). The distance between the peaks decreased sequentially from ~35 to ~25 days. One should note that the photometric measurements were obtained using different equipment of the SAO RAS 1-meter reflector. Moreover, some points were kindly provided to us by Kazakhstan colleagues from the Tien Shan Astronomical Observatory (see Fig. 4).

The deep imaging of TXS0917+624 performed with the CCD photometer of the SAO RAS 1-meter reflector under good weather conditions: excellent transparency and a seeing of about 1″, allowed us to confirm the presence of its faint eastern component that was suspected in [11]. We are going to publish a detailed analysis of the TXS0917+624 behaviour some time later.

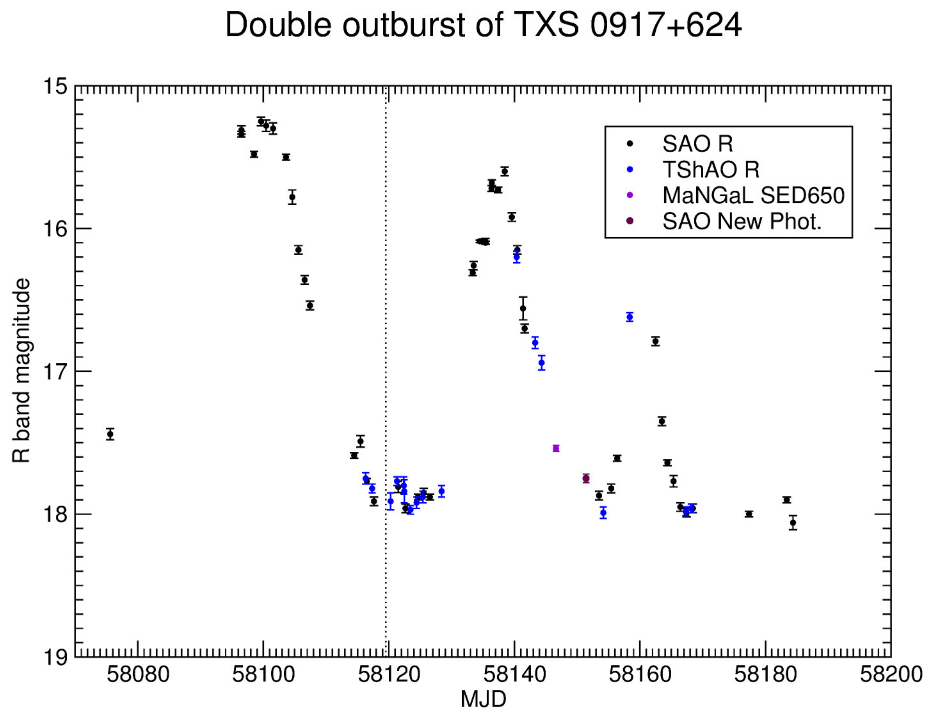

Figure 4: A unique multiple flare of the quasar TXS0917+624 during December 2017 – February 2018.

3. Studies of a blazars sample in 2021–2022

3.1 New SAO RAS complex of 0.5-m reflectors

Excellent additional possibilities in AGN studies appeared at SAO RAS after setting into operation of the complex of 0.5-m telescopes in 2019–2020. All these instruments aims at providing broadband photometrical investigations across one-degree fields. Let us briefly describe the main parameters of the telescopes: manufactured by Astrosib LLP (Russian Federation, Novosibirsk), the Ritchie-Chretien optical design, a primary mirror diameter of 0.5 meters, the focal ratio f:2.8 for the primary focus with a lens corrector and f:8 for the secondary focus.

The CCD camera based on the Kodak KAF16803 chip of 4K×4K 9 micron pixels provides a total field of view of about 1.5 degrees in diameter. All CCD photometers are equipped with sets of broadband filters: Johnson–Cousins BVR_cI_c and SDSS gri. The first telescope has been completed in 2019, and now fully operates in the program of exoplanet studies. The second telescope has been completed in 2020, and now is used for investigations of AGNs and, sometimes, exoplanets. After 16 months of operation in the primary focus mode, the second telescope was recombined to the Cassegrain mode with a smaller field of view but with higher image sampling: now one 9μm pixel of the CCD camera corresponds to 0.46″ on the sky instead of previous 1.35″.

3.2 First results

Among the first important results in the blazar studying using the 0.5-m reflector, one may note the identification of a gamma-ray burst dated 2021-Feb-27 with our favourite object:

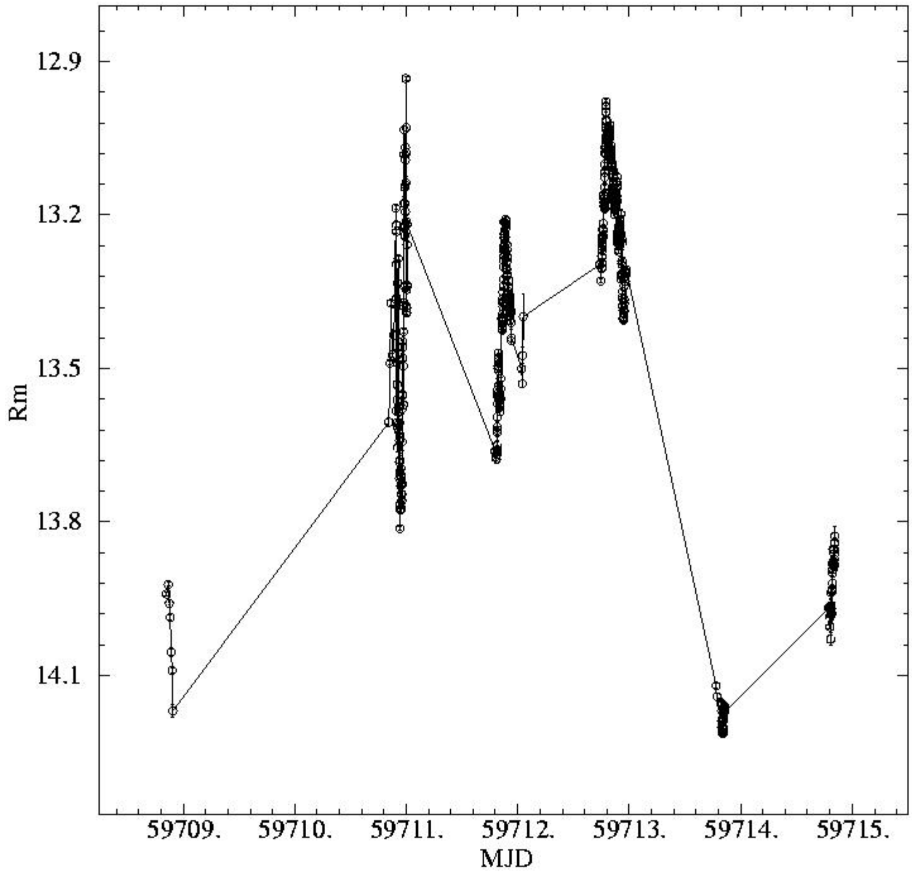

Figure 5: The behaviour of the [HB89] 0954+658 brightness during the absolute maximum flare in May 2022.

[HB89] 0965+658. Our data for this source gave its local maximum $R \sim 13.8^m$ over a 6-hour interval which corresponded to the maximum signal detected by the SWIFT cosmic mission [12].

Within the 200-day international campaign of WEBT (Whole Earth Blazar Telescope) in February-August, 2021, we obtained about 140 estimates of the blazar PG 1553+111 brightness in the B and R bands with an accuracy of about 0.01^m. Now these data are in preparation for publishing.

Very intensive studies of [HB89] 0954+658 since January 2021 till May 2022 provided about 2000 independent estimates of its brightness in the BVR bands. The analysis of the data, covering many hours and nights of observations, revealed tens examples of intraday flux variation. Now all these data are in preparation for publication. One should note the maximum brightness of $R \sim 12.9^m$ on May 11, 2022. Some observing runs for this blazar allowed us to detect fast flux variation at times of only few minutes.

4. Conclusions

The results of the intensive photometrical studies of the blazar sample proposed by N. S. Kardashev more than 20 years ago allowed us to note the importance of the comprehensive investigation of the AGN phenomenon. The use of a quite modest but specialized instrument gives important data which may disclose the enigma of Active Nuclei. We hope that the detailed and accurate analysis of the obtained data is going to give new principal information for solving the problems described above. One should also note the necessity for long-term radio observations of these objects. It is very likely that our collaborative efforts may result in the extension of the observing facilities in our country.

Acknowledgements

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