PROCEEDINGS OF SCIENCE

Long-term multi-frequency monitoring of microquasars

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We discuss the results of the radio studies of the X-ray binaries with relativistic jets. We carried out a multi-frequency (1-30 GHz) daily monitoring of the radio flux variability of the microquasars SS433, GRS1915+105, and Cyg X-3 with the RATAN-600 radio telescope during the recent sets from 1 November 2006 to 31 August 2008. From December 2005 radio emission of Cyg X-3 after four years relatively quiescent levels (100-200 mJy) dropped down to ∼20 mJy, and then we detected a lot of bright radio flaring events (1-20 Jy) followed the very variable (from 0 to 0.5 crabs) 15-50 keV X-ray emission, which was monitored in the Swift/BAT ASM program. Again from December 2007 to March 2008 we have daily measured almost quiescent fluxes from Cyg X-3 but in April 2008 a bright radio flare with clear synchrotron self-absorption was detected. We detected several bright short-term flares from GRS 1915+105 which could be associated with active soft X-ray events. In intense measurements of SS433 fluxes (often mutually with X-ray and optical observations) we detected massive ejections during powerful flares. We discuss the various spectral and temporal characteristics of the light curves from the microquasars. Monitoring of the flaring radio emission is a good tracer of jet activity X-ray binaries.

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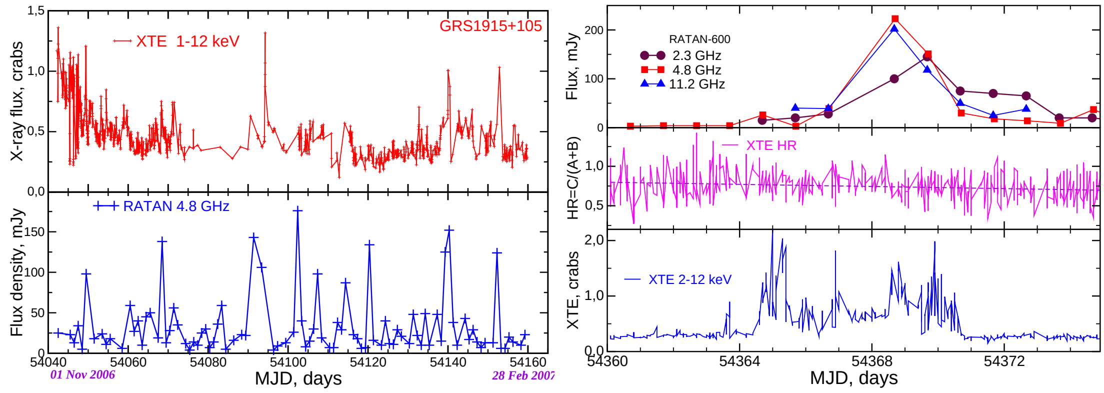

Figure 1: *Left:* XTE X-ray and 4.8 GHz light curves of GRS1915+105 from 1 November 2006 to 28 February 2007. *Right:* radio light curves and at XTE data: the total flux $A+B+C$ and hardness intensity $C/(A+B)$ in September 2007.

1. Introduction

The variable synchrotron radio emission is a good tracer of active processes in relativistic jets in the Galactic X-ray binaries (XRB) – microquasars. We continued the multi-frequency monitoring of SS433, Cyg X-3 and GRS 1915+105 in order to follow the jets activity and compare the radio light curves with X-ray light curves receiving in the ASM programs of cosmic satellites RXTE [1] and Swift [2]. Here we accepted flux unites: 1 crab = 75 counts/s for ASM XTE data, and 1 crab = 0.22 counts/s for ASM Swift data.

2. Observations

The all sets of the monitoring program were carried out with North sector RATAN-600 radio telescope on radio continuum radiometers in range 1 - 30 GHz. Usually we have daily observed three microquasars at 3-4 frequencies (2.3, 4.8, 7.7 and 11.2 GHz), but during powerful flares we can use also 1.0 and 30 GHz radiometers with relatively worse sensitivities. The details of the observations are given by Trushkin et al.[3]. In Table 1 we give the duration of the observational sets of the microquasars during from 1 November 2006 to 1 September 2008. The last column is the total number of daily measurements of the flux densities in the given set. Thus we have measured more than 1000 daily spectra of microquasars during two years. Of course we have observed 3-5 secondary calibrators daily for accurate calibration of the measured flux densities at different frequencies.

3. Discussion

3.1 GRS 1915+105: X-ray – radio correlation

The soft/hard X-ray - radio flaring correlation of GRS1 1915+105 was discussed a lot of times [4, 5, 6, 7, 8]. In Fig.1(left) the 4.8GHz and X-ray light curves are shown during the set in 2006-2007. The frequent bright radio flares have the associated bright events from X-ray light curves received in ASM RXTE at 2-12 keV.

Table 1: Observational sets with RATAN-600 from 1 November 2006 to 1 September 2008

dd.mm.yy – dd.mm.yy	Source	N_{obs}
03.11.06 – 28.02.07	V4641 Sgr	92
03.11.06 – 28.02.07	SS433	99
03.11.06 – 28.02.07	GRS1915+105	94
03.11.06 – 28.02.07	Cyg X-1	69
03.11.06 – 28.02.07	Cyg X-3	103
01.06.07 – 07.06.07	Cyg X-3	5
12.06.07 – 04.07.07	SS433	11
21.06.07 – 04.07.07	GRS1915+105	9
13.09.07 – 05.10.07	GRS1915+105	22
29.09.07 – 05.10.07	SS433	7
30.10.07 – 18.11.07	SS433	18
30.10.07 – 18.11.07	GRS1915+105	18
01.12.07 – 03.03.08	LS 5039	92
01.12.07 – 03.03.08	SS433	78
01.12.07 – 03.03.08	GRS1915+105	78
01.12.07 – 03.03.08	Cyg X-1	76
01.12.07 – 03.03.08	Cyg X-3	76
08.03.08 – 22.05.08	SS433	54
07.04.08 – 22.05.08	GRS1915+105	44
13.04.08 – 27.05.08	Cyg X-3	10
17.06.08 – 31.08.08	SS433	68
17.06.08 – 31.08.08	GRS1915+105	61

Fig.1(right) shows radio light curves of the bright flare and at XTE data: the total flux $S = A+B+C$ (1.5-3, 3-5, 5-12keV) bands of ASM XTE and the X-ray hardness ratio $HR = C/(A+B)$ in the set of September 2007. Clearly that radio flare associated with X-ray event and we did not detected any changes in HR as were discussed by Namiki et al. [9] and Trushkin [10, 11]. The radio spectrum was optically thick at frequencies lower 4.8 GHz during the flare.

In Fig.2(left) the light curves of GRS1915+105 at 4.8 GHz, at 2-12 keV and at 15-50 keV bands from 1 December 2007 to 2 March 2008 are shown. GRS 1915+105 was in quiet state, and unusual changes of X-ray fluxes near MJD54470 are probably connected with close solar elongation of the source. Thus the microquasar has fluxes lower than 30 mJy and was relatively stable in all bands.

But already in April 2008 GRS1915+105 passed in active state with high levels of sort and hard X-ray emission. After that we detected two bright radio optically thin flares and then the source stayed on fluxes about 100 mJy with flat or even inverted radio spectra, as shown in Fig.2(right).

Al last during summer months 2008 GRS1915+105 was very active and four flare with peak fluxes higher 200 mJy were detected (Fig.3). Again these bright flares have the associated bright

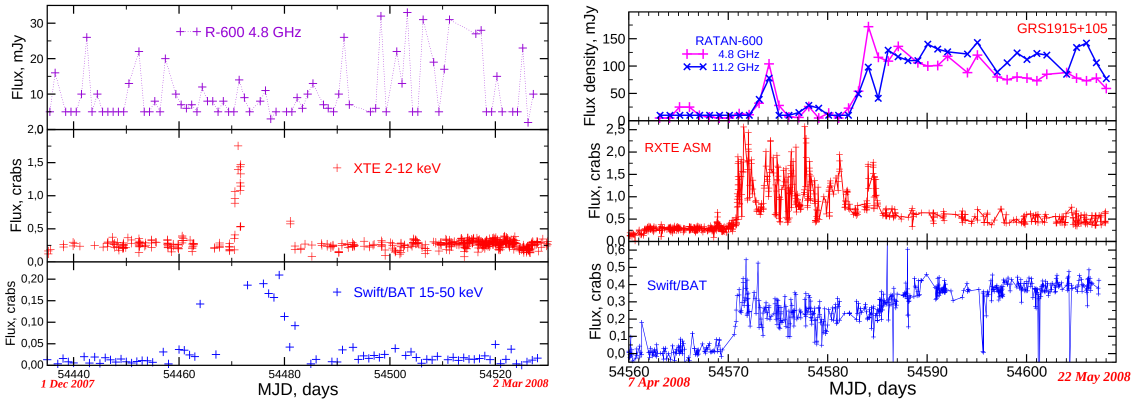

Figure 2: *Left:* Light curves of GRS1915+105 at 4.8 GHz/11.2GHz, at 2-12 keV and 15-50 keV from 1 December 2007 to 2 March 2008. *Right:* the same from 7 April to 22 May 2008.

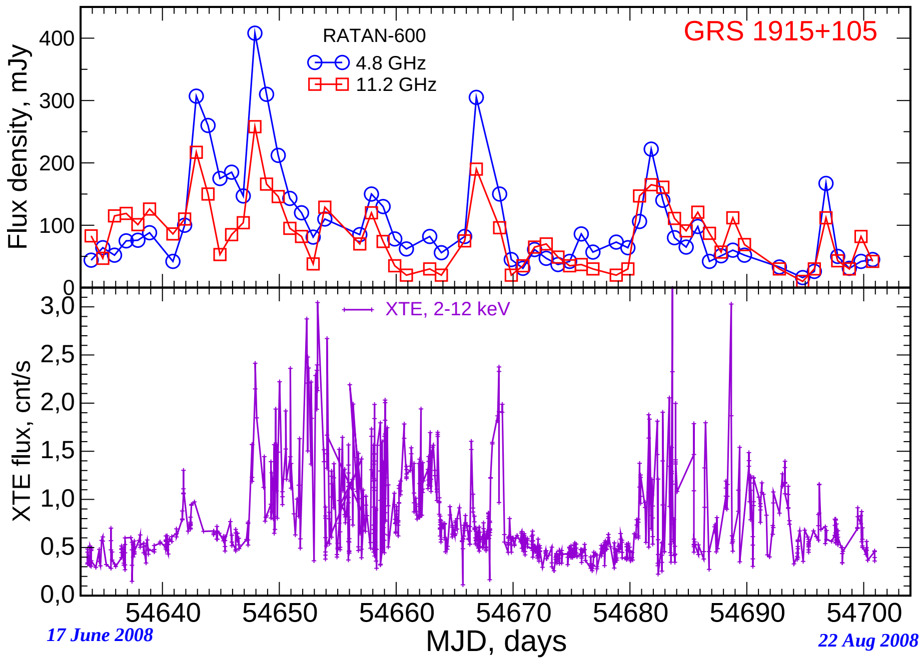

Figure 3: Light curves of GRS1915+105 at radio frequencies, at 2-12 keV from 17 June to 22 Aug 2008.

soft X-ray events at 2-12 keV.

3.2 Cyg X-3: 2006 – new long-term active period

Recently Szostek et al. [12] discussed the long-term correlations of the X-ray and radio states, using BATSE, XTE and GBI ([13, 14] data. In [12] was presented the detailed classification of the mutual states.

Trushkin et al.[3, 11] and Tsuboi et al.[15, 16] discussed the beginning of the active period of Cyg X-3 in December 2005 – March 2006. The activity continued to 2008 (Fig.4) and a lot of strong flares were detected in March, May and Jule 2006, with peak fluxes 3-5, 12-18 and 8-12 Jy

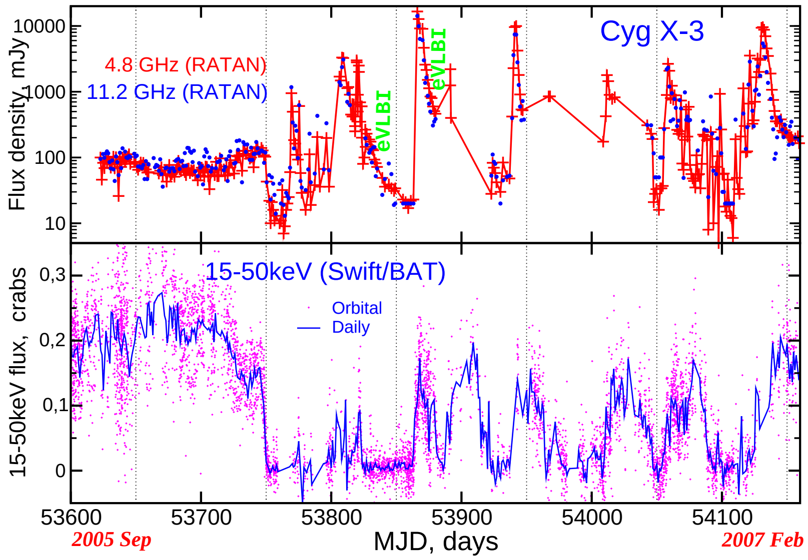

Figure 4: The RATAN 4.8/11.2 GHz and Swift/BAT ASM light curves of Cyg X-3 from September 2005 to February 2007.

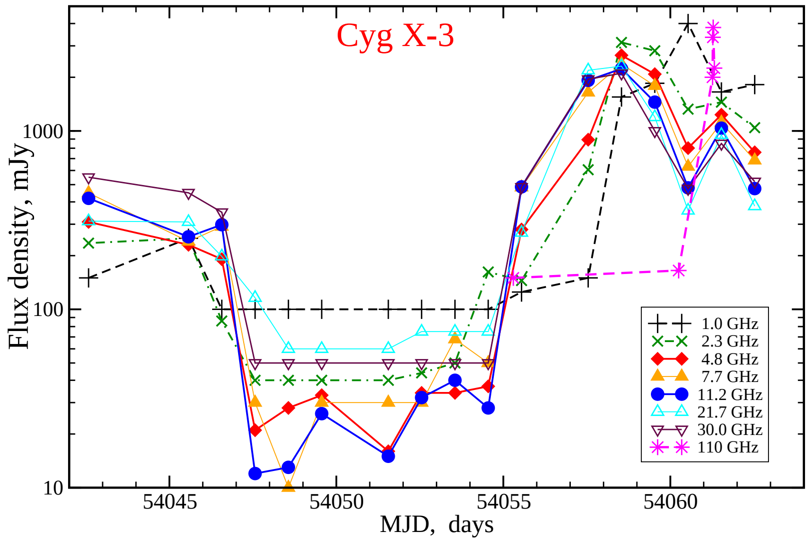

Figure 5: Radio light curves of Cyg X-3 before and during the bright flare in November 2006.

respectively. In the May 2006 flare fluxes have grown up by a factor ∼1000 during a day. Just 20 April and 18 May were received the first eVLBI maps of Cyg X-3 [17].

In November 2006 we found new evidence of the activity of Cyg X-3 with a flare typically with peak exceeding 3-5 Jy following a quenched state (< 20mJy)(Waltman et al. [13]). In Fig.5 the milti-frequency RATAN light curves are given with some observations with Nobeyama Radio observatory interferometer (NMA). We detected very variable mm-band (110 GHz) emission after maxima at lower frequencies, which was evolved from 150 mJy to 3 Jy and then 2 Jy during 1-2 hours. The RATAN spectrum on Nov 22.53UT (MJD54061.5) is well fitted by a power-law with spectral index -0.19 from 1 to 30 GHz. The total spectrum from 1 GHz to 100 GHz on Nov 22 can

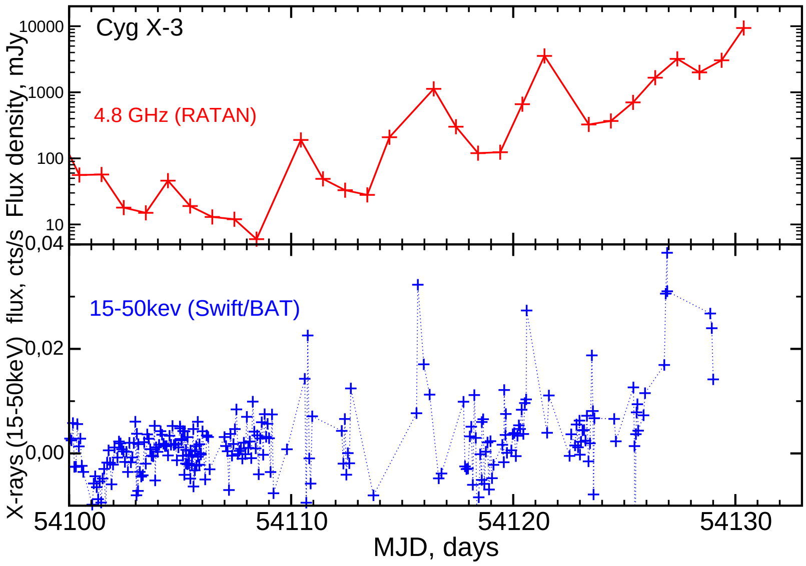

Figure 6: The radio and X-ray light curves of the Cyg X-3 during flare in January 2007.

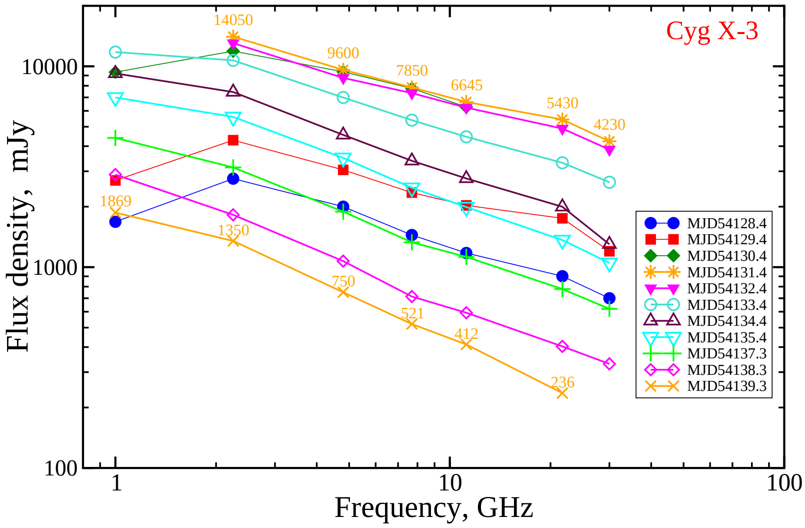

Figure 7: The daily spectra of Cyg X-3 during the flare in February 2007.

not be expressed with an optically thin power-low model but shows a high-frequency component with a peak above 100 GHz and/or with a short lifetime, less than 6-8 hours. The mm-band flare have probably weaker counterparts at the lower RATAN-600 frequencies (Tosaki el al.[18]). Before we have detected the fluxes changed from ~ 1 Jy to 2 Jy during 3 hours and then decreased to 100-400 mJy during 15 hours with at 2.3 and 8.5 GHz with RT32 (IAA) on 5 June 2006 (MJD53891) [19].

In Fig.6 the 4.8 GHz and Swift 15-50 keV light curves of the beginning of January 2007 flare are shown. We can clearly see that all four radio small flares have X-ray counterparts – short-time spikes, just before ($\sim$ 1day) radio local maxima.

After this increase stage in January 2007 we plotted the daily spectra of Cyg X-3 in February

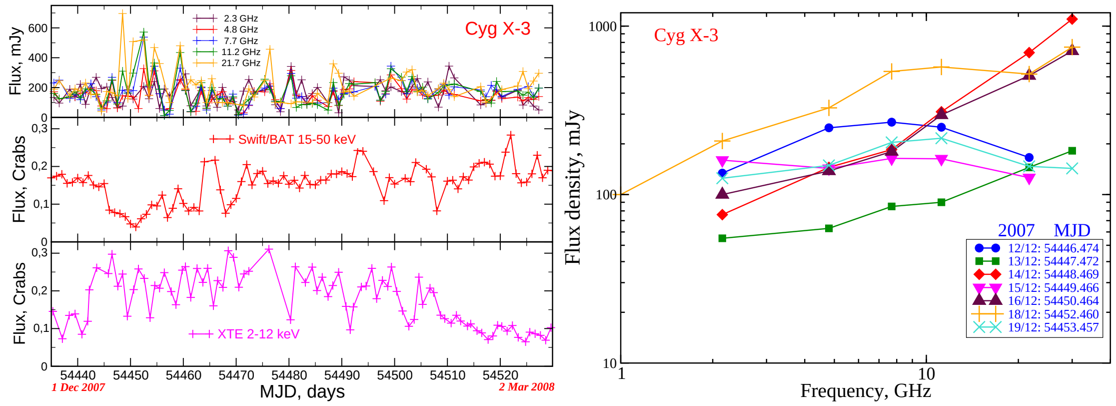

Figure 8: *Left:* The radio and X-ray light curves of Cyg X-3 from 1 December 2007 to 2 March 2008. *Right:* the daily spectra of Cyg X-3 during flaring events in December 2007.

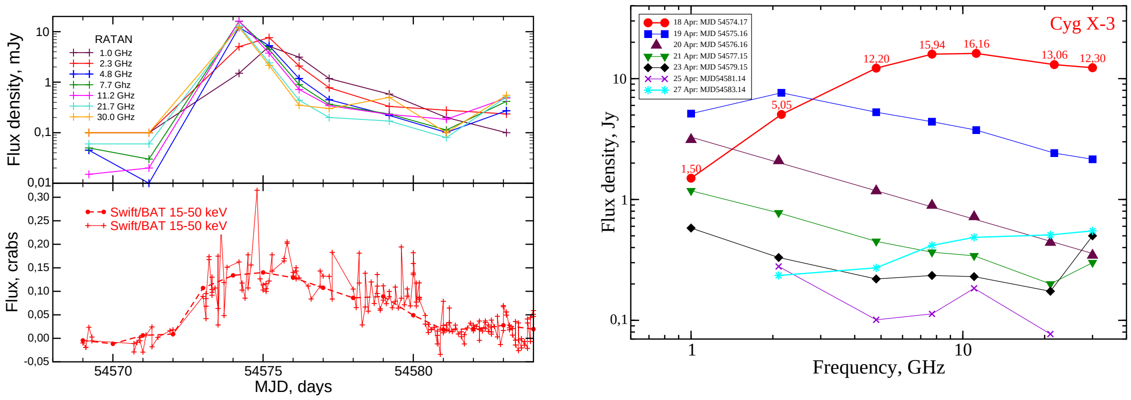

Figure 9: *Left:* The RATAN and Swift light curves of Cyg X-3 in April 2008. *Right:* the daily spectra of Cyg X-3 during the flare in April 2008.

2007 (Fig.7). A a rule only during first drop-up stage their spectra have turn-overs at frequencies, lower than 2 GHz. The spectral and temporal evolution of such flares could be successfully fitted with the modified finite segments model by Hjellming et al.[20] and developed by Marti et al. [21]. Trushkin et al. [3, 11] have fitted spectra of the July 2007 flare. In the first stage of such a flare we should involve the intense internal shocks running through the jet as proposed Watanabe et al. [14]. The former flare in September 2001 was successfully fitted by Lindfords et al. [22].

In Fig.8(left) the radio (RATAN) and X-ray light curves (XTE, Swift) of Cyg X-3 from 1 December 2007 to 2 March 2008 are shown. Only in the beginning of the set Cyg X-3 was in active state with relatively small hard X-ray emission (MJD54450). Then spectra of Cyg X-3 were inverted with positive spectral indices, as shown in Fig.8(right).

In April 2008 we detected the bright flare from Cyg X-3 again after a quenched state. In Fig.9(left) the radio (RATAN) and X-ray light curve (Swift/BAT) of the flare are shown. In Fig.9(right) the daily radio spectra are plotted. The 18 April spectrum give clear evidence of the optically thick regime at lower frequencies. With GRMT points at 614 and 244 MHz [23, 24] the quasi-simultaneous spectra could be well fitted by or a synchrotron self-absorption model, when

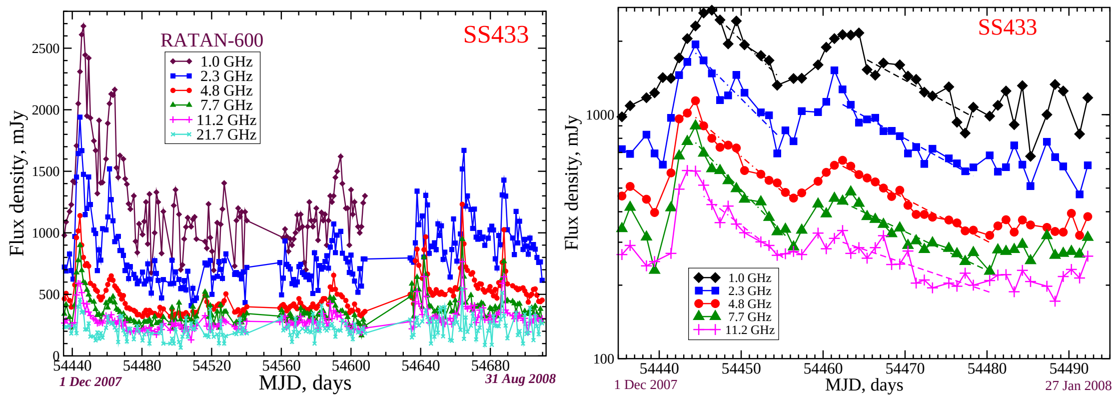

Figure 10: *Left:* The RATAN and Swift light curves of SS433 from 1 December 2007 to 31 August 2008. *Right:* radio light curves from 1 December 2007 to 22 January 2008 in log scale (right).

spectral index is equal to -2.5 or a external absorbed screen model. The turn-over frequency is shifted towards lower frequency day by day.

3.3 SS433: a intense set in 2007-2008

We continue studies multi-frequency variability of the first microquasar SS433 in order to detect the massive ejections in the flaring states [26, 27, 28]. Many monitoring sets (e.g., with GBI ([25]), RATAN (Trushkin et al.[29]) were began in 1970-80ths. In Fig.10(left) the light curves of SS433 during 1 December 2007 - 31 August 2008 are shown.

In Fig.10(right) the light curves during the bright flares in December 2007 - February 2008 are shown. The both flares decayed with exponential law ($S_\nu \propto exp(-t/t_0)$, where $t_0 = 16$days and $t_0 = 25$days for the both flares respectively. The delay of the maximum flux of the bright flare in December 2007 at 1 GHz is about 2 days and 1 day at 2.3 GHz relative to the maxima at higher frequencies. We detected the surprising coincident dates (6-7 Dec) of the bright flares in 2006 and 2007. Probably the 1-year periodicity of activity exit in radiation of SS433. Recently Nandi et al. [30] discussed the periodicity of flaring events in ASM RXTE X-ray data, and found possible period about 368 days.

4. Conclusions

In 2006-2008 the RATAN microquasar monitoring data (1200 radio spectra) give us abundant material for detailed comparison with the X-ray data from the ASM or ToO programs with RXTE, CHANDRA, Suzaku and INTEGRAL. The 1-30 GHz emission originates often from different optically thin and thick regions. That could give us a key for adequate modelling of the flaring radio radiation formed in the relativistic jets interacting with varying circumstellar medium or stellar winds.

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