Active flaring states of GRS 1915+105 and Cyg X-3 in radio/X-ray monitoring

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Abstract

In multi-wavelength collaboration we studied the variability of the microquasars GRS1915+105 and Cyg X-3 during 2005 to May 2008 with the RATAN-600 radio telescope of SAO RAS. We detected clear correlation of the flaring radio fluxes and X-rays 'spikes' at 2-12 keV emission redundant in RXTE ASM from GRS1915+105 during eight relatively bright (200-600 mJy) radio flares in October 2005. Spectra of these flares at maximum are optically thick at frequencies lower than 2.3 GHz and optically thin at the higher frequencies. During the radio flares the spectra of the X-ray spikes become softer than those of the quiescent phase. Thus these data indicate the transitions from the very high/hard state to high/soft state during which massive ejections probably occur. These ejections are detected as radio flares. Such X-ray/radio events correlation detected later in 2006-2008. In December 2005 after of the 4-year quiescent radio state (100–200 mJy) Cyg X-3 entered the softer X-ray state with low level of hard (15-50 keV) X-ray and high ($\sim$0.5 crab) in the soft band (1-10 keV). In the following 500 days we have detected more 10 bright ($>$ 1Jy) flaring events correlated with rising phases of ASM-Swift-BAT intensity of Cyg X-3. A first 1 Jy-flare was detected on 3 February 2006 after 18 days of the quenched radio emission ($<$ 20mJy). The spectrum of the flare at the maximum is flat from 1 to 100 GHz, obtained the quasi-simultaneous observations with RT45m telescope and millimeter array (NMA) of Nobeyama Radio Observatory.

Key words: microquasars: variability — X-ray emission: — radio radiation

1. Introduction

The most important feature of the relativistic accretion process in the radio band are the jets – collimated outflows from a cosmic system of stellar mass as Galactic X-ray binaries (XRB) or galactic mass, active galactic nuclei (AGN). The relativistic jets discovered in the first time in SS433 (Spencer, 1979, Hjellming & Johnston 1981), then were detected in Cyg X-3 (Geldzahler et al. 1983), 1E1740-2942 (Mirabel, Rodriguz et al. 1992), GRS 1915+105 (Mirabel & Rodriguz, 1994), GRO 1655-40 (Hjellming et al. 1995) and then some others XRB. These jet-producing XRB are now named *microquasars* for analogy with the jets from quasars and blasars, VLBI-mapped a lot of times before XRB. Superluminal Galactic X-ray sources apparently accelerate radio-emitting material to relativistic speeds like jet sources observed in AGNs or quasars. The blobs of synchrotron-emitting electrons relativistically and ballistically move from host objects, which we see as the phenomenon of jets.

2. Observations program

The long-time monitoring sets of microquasars has systematically service, produced with the RATAN-600 radio telescope for years. Almost daily monitoring observations were carried out from September 2005 to May 2006, in July 2006, from November 2006 to March 2007 and from December 2007 to February 2008 and from June to August 2008 at frequencies at 1, 2.3, 4.8 7.7, 11.2, and 30 GHz. The multi-frequency light curves of the microquasars Cyg X-3, GRS 1915+10, SS433 have been measured at time scale to 100-150 days. We can directly compare them with time series of the X-ray observatory RXTE (Levine et al. 1996) and hard X-ray data from Swift/BAT (15-50 keV) (Barthelmy et al. 2005). The observations have been made with the 'Northern sector' antenna of the RATAN-600 radio telescope in a transit

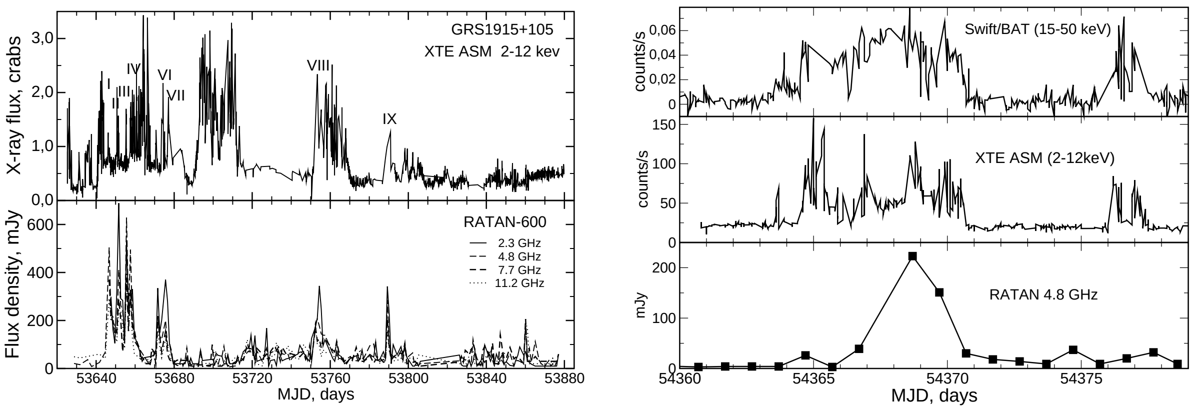

Fig. 1. Light curves of GRS1915+105 at radio frequencies and at 2-12 keV from September 2005 to March 2006 (*left*) and light curves of GRS1915+105 at radio frequencies and X-ray 2-12 keV and 15-50 keV fluxes in September 2007 (*right*)

mode. The errors of measured fluxes of the sources do not exceed 5-10 percent for sources with fluxes about and more 100 mJy. The details of the observations and the errors are given by Trushkin et al. (2006).

3. GRS 1915+105: X-ray – radio correlation

The bright and transient X-ray source, a low-mass binary, probably hosting a black hole $\sim 14M.$, GRS 1915+105 was discovered by Castro-Tirado et al. (1992) with the WATCH instrument on board GRANAT. An apparent super-luminous motion of the jet components was detected by Mirabel & Rodriguez (1994). Foster et al. (1996) detected that 2.3/8.5 GHz emission from GRS1915+105 correlated with X-rays with episodes of hard X-ray emission, detected with BATSE.

A phenomenological classification of the radio emission indicates two distinct emission modes; plateau and flaring. Plateau radio emission is caracterized as optically thick, flat-topped light curve beginning with a rapid onset followed by a decrease of flux density. In the radio flaring state, radio light curves are clustered with large flares, which are characterised by a rapid increase of the flux by two orders of magnitude in less than 18 hours, followed by an optically thin exponential decay. These observed large radio flares are considered as a propagation of plasmoids emitting synchrotron radiation.

Fender et al. (2002) discussed the alert observations of two flares (July 2000), when for the first time detected the quasi-periodical oscillations with P = 30.87 minutes at two frequencies; 4.8 and 8.64 GHz. Linear polarization was measured at a level of 1-2 percent at both frequencies.

Vadawale et al. (2003) have analyzed the short-time radio flares from GRS 1915+105 detected with Green Bank Interferometer (GBI) and All sky Monitoring (ASM) RXTE data (Levine et al. 1996) and found many cases of the X-ray and radio correlations.

In Fig.1(*left)* the radio and X-ray light curves are shown for the total set of 2005-2006. The nine radio flares have the counterparts in X-rays. The radio spectrum was optically thin in the first two flares, and optically thick in the third one (details are given by Namiki et al. 2006). In Fig.1 (*right)* the radio and soft and hard X-ray light curves during September-October 2007. Again we see detectable correlation between the radio flare and a soft X-ray 'spike' in the high state.

Most of radio flares show power-law spectra with index of -0.6 at the higher frequencies with a low-frequency turnover at 1 GHz, which can be interpreted as absorbed synchrotron emission.

The profiles of the X-ray spikes during the radio flares are clearly distinguishable from other spikes because its shape shows a fast-rise and a exponential-decay. The X-ray spikes, which reflect random activity of the accretion disk, show an irregular pattern. During a bright radio flare, the spectra of the X-ray spikes become softer than those of the quiescent phase, by a fraction of $\sim$30% (Namiki et al. 2006). But such rule is not applicable to all radio flares.

Miller at al. (2006) have detected a one-side large-scale radio jet from GRS1915+105 with VLBA mapping during an X-ray and radio outburst on 23 February 2006 (MJD53789.258). Then the optically thin flare with fluxes 340, 340, 342, 285, 206, and 153 mJy was detected at frequencies 1, 2.3, 4.8, 7.7, 11.2 and 21.7 GHz, respectively.

4. Cyg X-3: 2006-2007 – a new long-term active period

For $\sim$100 days (September – December 2005) Cyg X-3 was in a quiescent state of $\sim$100 mJy (Fig.4). In December 2005 its X-ray flux began to increase and the radio flux at 2-11 GHz increased also. Then the flux density of the source at 4.8 GHz was found to drop from 103 mJy

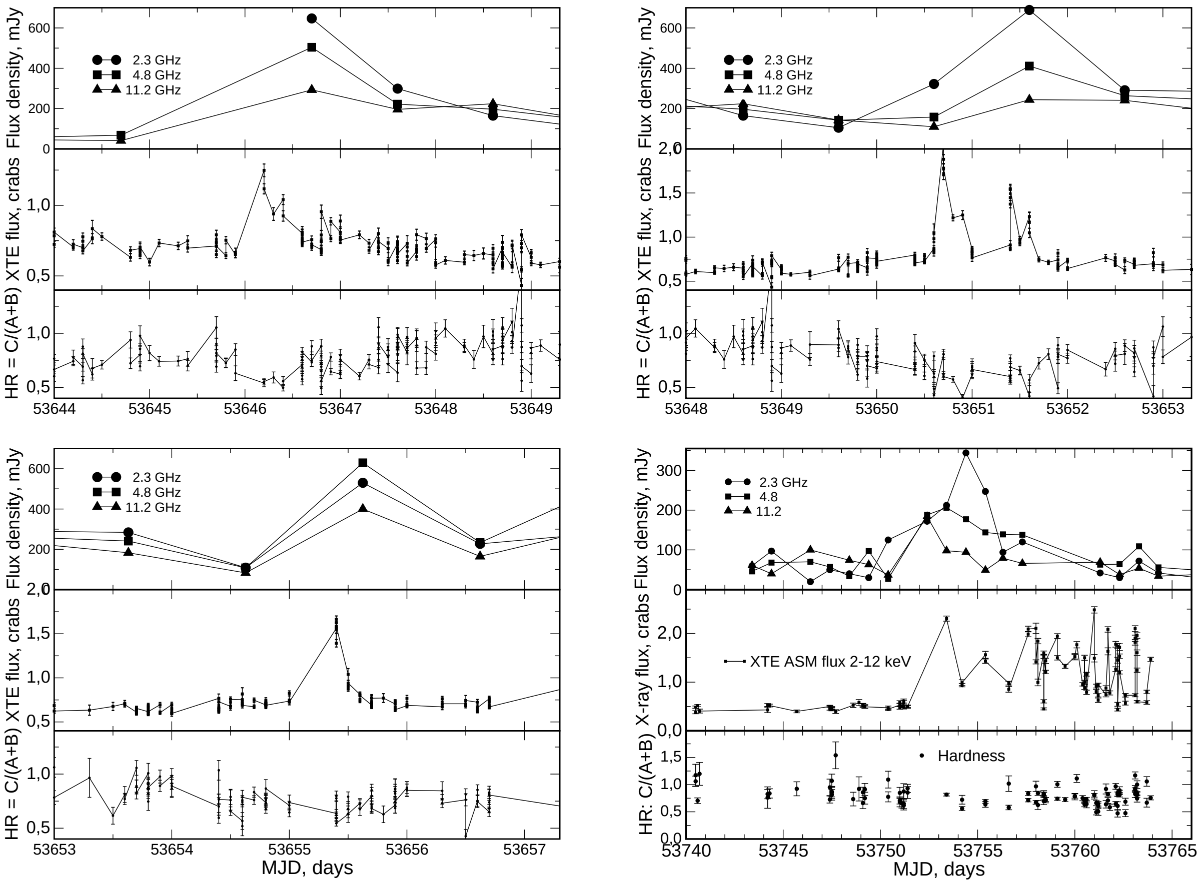

Fig. 2. The light curves of GRS 1915+105 around four most prominent X-ray 'spikes' (upper) and hard ratio C[12-5keV]/(A+B)[1.5-5keV] from XTE ASM data (bottom).

on 2006 Jan 14.4 (UT) to 43 mJy on Jan 15.4 (UT), and to 22 mJy on Jan 17.4 (UT). The source is known to exhibit radio flares typically with a few peaks exceeding 1-5 Jy following such a quenched state as Waltman et al. (1994) have showed in the intensive monitoring of Cyg X-3 with the Green Bank Interferometer at 2.25 and 8.3 GHz. The source has been monitored from 2006 Jan 25 (UT) with the Nobeyama Radio Observatory 45m Telescope (NRO45m Telescope), the Nobeyama Millimeter Array (NMA) and Japanese VLBI Network telescopes. On Feb 2.2 (UT), about 18 days after it entered the quenched state, the rise of a first peak is detected with the NRO45m Telescope and YRT32m. On Feb 3.2 (UT), the flux densities reached the first peak at all the sampling frequencies from 2.25 GHz to 110.10 GHz, (Tsuboi et al. 2006,2008). The spectrum at maximum (3 February) of the flare was flat as measured by RATAN, NRO RT45m and NMA from 2 to 110 GHz. The next peak of the active events on 10 February reached the level of near 1 Jy again with a similar flat spectrum. Then three short-time flares have happened during a week. The flare on 18 February had the inverted spectrum with the same spectral index α=+0.75 from 2.3 to 22 GHz. It is interesting that no jet structure has been detected with Japanese VLBI Network just after the first maximum of the flare. In other hand the following bright flares were jet ejections. For example the flare in 18 May 2006 have clear evidence of jet structure (Tudose et al. 2007)

In the active period (2006) there were two powerful flares, March 14 to 3-5 Jy and May 11 with flux densities of 12-16 Jy at 2-30 GHz. In the May flare fluxes have grown up by a factor $\sim$1000 within a day. The change of the spectrum during the flare on May 11-19 followed the model of a single ejection of the relativistic electrons, moving in thermal matter in the intensive WR-star wind. It stays in optically thin mode at higher frequencies, meanwhile at lower frequency 614 MHz Pal et al (2006) Cyg X-3 was in hard absorption. In the continuing active state of Cyg X-3 we detected a very fast-rise flare at 2.3 and 8.5 GHz with RT32 (IAA) on 5 June 2006 (MJD53891) (Trushkin et al. 2006). In three hours the fluxes changed from $\sim$ 1 Jy to 2 Jy and then decreased to 100-400 mJy during 15 hours. We detected the similar behaviour in the the Jan-Feb 2007, when maximum flux reached 14 Jy at 2.3 GHz (Fig:4).

In Fig.5 the light curves of the July flare are shown. The phase of the flux rising continued during 4-5 days. For the first time we could clearly see the evolution of the spectrum during the phase of the flare (Fig.5). And it was amazing that the low-frequency part of the spectra evolved from nearly flat optically thin (at 1 GHz) on the first day to optically thick after 3-4 days. In the standard model of the expansion of the compact sources (jets components) there is no any explanation for such behaviour.

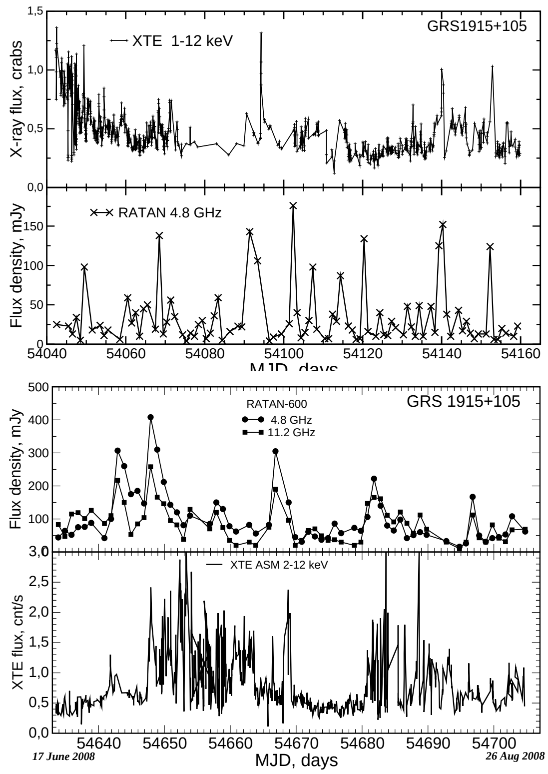

Fig. 3. Light curves of GRS1915+105 measured with RATAN-600 radio telescope and in ASM XTE in 2007 (*left*) and in 2008 (*right*)

We had to conclude that the thermal electron density, responsible for the low frequency absorption, grows up during grow-up of the relativistic electron density. The later stage of the spectral and temporal evolution could be fitted by the modified finite segments model by Marti et al. (1992) or Hjellming (1988) and Hjellming et al. (2000), which are modifications of the pioneer models by Shklovskij (1960) and van der Laan (1966).

Indeed in Fig.5 the radio spectra of the July flare evolved from the fourth day (MJD53942) as usual adiabatically expanding relativistic jets moving with $v_{jet} \sim 0.74c$, and thermal electron component has: $T_e = 10^4$ K, $n_{th} = 2\ 10^4 cm^{-3}$, magnetic field $B_0 = 0.07$ G, and energy index $\gamma = -1.85$. During the rising stage of the flare we should involve the intense internal shocks running through the jet (Vadawale et al. 2003).

5. SS433: new flaring events and their spectra

The first microquasar SS433, a bright variable emission star was identified with a rather bright compact radio source 1909+048 located in the center of a supernova remnant W50. In 1979 moving optical emission lines, Doppler-shifted due to precessing mass outflows with 78000 km/s, were discovered in the spectrum of SS433. At the same time in 1979 were discovered a unresolved compact core and 1 arcsec long aligned jets in the MER-

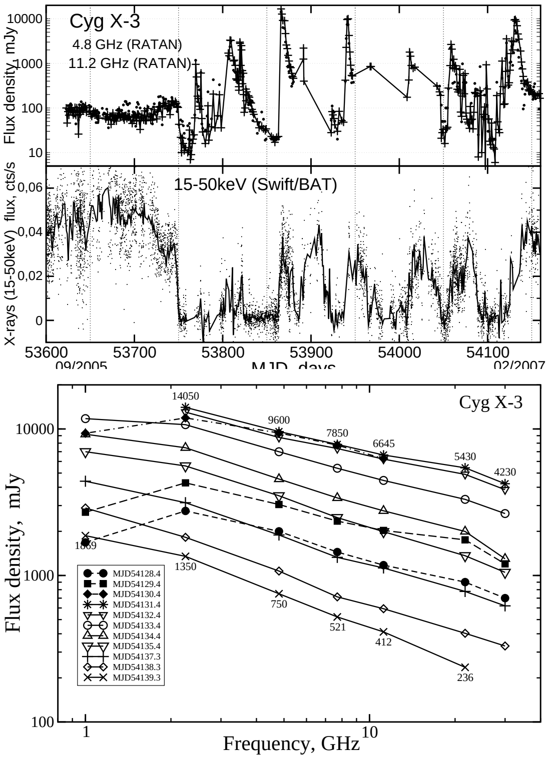

Fig. 4. (*top*) The RATAN and Swift/BAT light curves of Cyg X-3 from September 2005 to February 2007 and (*bottom*): The daily spectra of Cyg X-3 during the flare in Jan-Feb 2007.

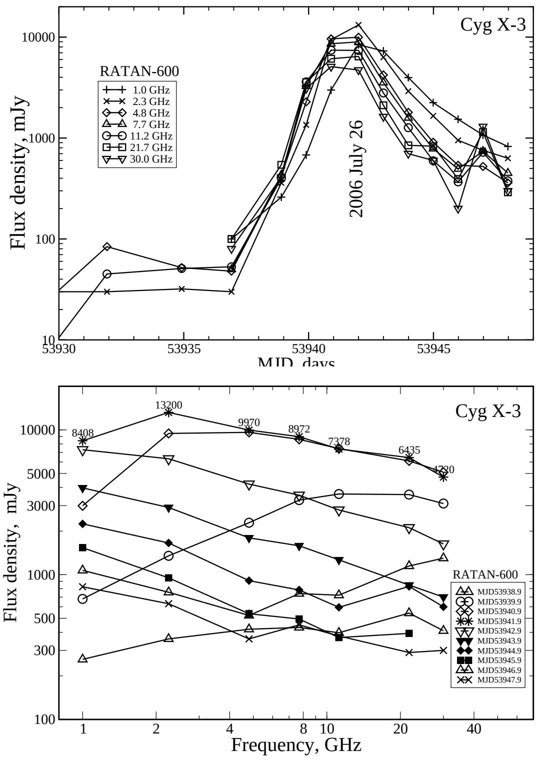

Fig. 5. The RATAN and RXTE ASM light curves of Cyg X-3 in July 2006 (*top*) and the daily spectra of Cyg X-3 during flare in July 2006 (*bottom*).

LIN radio image of SS433. Since 1979 many monitoring sets (e.g., with GBI (Waltman et al. 1994) , RATAN (Trushkin et al. 2006) were began. Different data do indicate a presence of a very narrow (about 1^o) collimated beam at least in X-ray and optical ranges. At present there is no doubt that SS433 is related to W50. A distance of near 5 kpc was later determined by different ways including the direct measurement of proper motions of the jets radio components.

Kotani et al. (2006) detected the fast variation in the X-ray emission of SS433 during the radio flares, and probably QPOs of 0.11 Hz. Massive ejections during this active period could be the reason of such behavior. The daily RATAN light curves are measured from September 2005 to May 2006. The activity of SS433 began during the second half of the monitoring set. Some flares happened just before and after the multi-band program of the studies of SS433 in April 2006 (Kotani et al. 2007).

In Fig.6(*top*) the light curves of SS433 during December 2007 - August 2008 are shown. 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.

In Fig.6(*bottom*) the light curves during the bright flares in December 2007 - February 2008 are showed. The both flares decayed with exponential law ($S_\nu \propto exp(-t/t_0)$, where $t_0 = 25$ days for the second flare.

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. (2005) discussed the periodicity of flaring events in ASM RXTE X-ray data, and found possible period about 368 days.

6. Conclusions

The long-time daily RATAN microquasar monitoring data give us fruitful material for comparison with the X-ray data from the ASM or ToO programs with RXTE, CHANDRA, Suzaku and INTEGRAL. We hope to continue such programs with MAXI in future.

The radio emission could be in two different optically thin and thick regimes at 1-2 and 10-20 GHz, and allows us to develop an adequate model of the flaring radio emission producing in the relativistic jets interacting with varying circumstellar medium or intense stellar wind.

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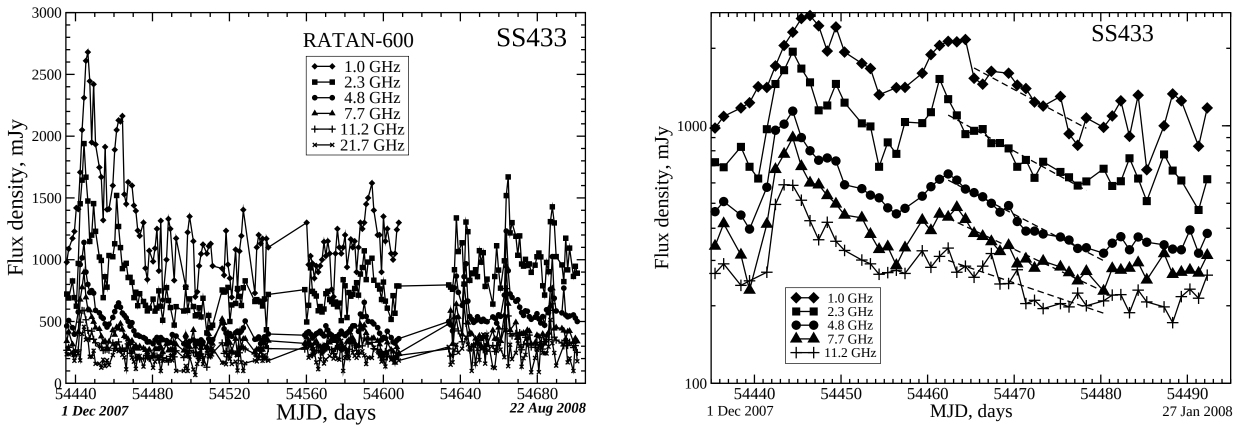

Fig. 6. The total light curves of SS433 in December 2007 - August 2008 (*left*) and during the powerful flaring events in December 2007 - January 2008 (*right*).

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