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Photometric variability of classical dwarf nova SS Cyg during outbursts

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Abstract. Brightness variations of dwarf nova SS Cyg in active states are studied using observations of different outbursts of the system in 2006-2008. The power spectrum analysis of the data reveals the presence of quasi-periodic oscillations in the light curves of SS Cyg near the maximum brightness and at the declinig part of the outburst light curves.

Key words. Stars: close binaries – Stars: cataclysmic variables – Stars: dwarf novae – Stars: SS Cyg – Stars: photometry – Stars: brightness variability

1. Introduction

SS Cyg is the brightest of the dwarf novae. This dwarf nova belongs to U Gem sub-type (classical dwarf novae showing a rapid brightening with large amplitude). The system consists of a white dwarf of the mean mass ($\simeq 0.66 M_{\odot}$) and a red dwarf that fills its Roche lobe and transfers mass to the white dwarf, forming an accretion disk around it. The orbital period of SS Cyg $0^{d}.275130$ was determined from spectral observations (Hessman et al. 1984). SS Cyg shows no eclipse, therefore its orbital inclination cannot be measured directly; the latest estimation of the binary inclination is $\approx 50^{o}$. Outbursts occur once every 52 days. During an outburst, SS Cyg brightens from 12^{m} to 8^{m}. After the outburst, the system remains in the quiescent state for a few weeks. Three types of outbursts are observed in this system depending on the outburst amplitude and duration: normal, long and anomalous ones. SS Cyg was the first dwarf nova detected as an X-ray source. Some of the SS Cyg parameters taken from Voloshina & Khruzina (2000) are collected in Table I.

The multifrequency behaviour of SS Cyg derived from many space and ground based observations is summarized in the fine review papers Giovannelli & Martinez-Pais (1991), Giovannelli (1996) and Giovannelli & Sabau-Graziati (1999).

The present paper is aimed at investigating short-term variability of this dwarf nova during the outbursts.

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2. Observations

Observations of SS Cyg were carried out during different outbursts in 2006, 2007 and 2008 using two 60-cm telescopes of Sternberg Astronomical Institute in Crimea:

In October 2006 and November-December 2007, CCD observations with Apogee-47 detector were carried out in V band with a time resolution of 1 s and 2 s.

Table 1. Parameters of SS Cyg

a	$(1.82 - 1.89)R_\odot$
i	52^o
M_{wd}	$0.66\ M_\odot$
M_{rd}	$0.46\ M_\odot$
R_{wd}	$(0.0110\text{-}0.0120)R_\odot$
R_{rd}	$(0.63\text{-}0.69)R_\odot$
T_{wd}	(24500-26200)K
T_{rd}	4500 (T_{eff})
R_{disk}	$0.22R_\odot$ (U band), $0.28R_\odot$ (B and V)
T_{disk}	3000-3200 K (outer disk)
T_{disk}	25000 K (inner layers of the disk)

In August and October 2007, photoelectric observations in V band were carried out with the UBV-photometer with a time resolution of 10 s.

In January 2008, high–speed photometry was carried out in V band using the UBV photometer with a time resolution less than 1 s.

CCD data were reduced using the MAXIM DL standard package, UBV data - with software developed by V. Lyuty. In Fig. 1 and 2 we show several individual light curves of SS Cyg for different outbursts observed.

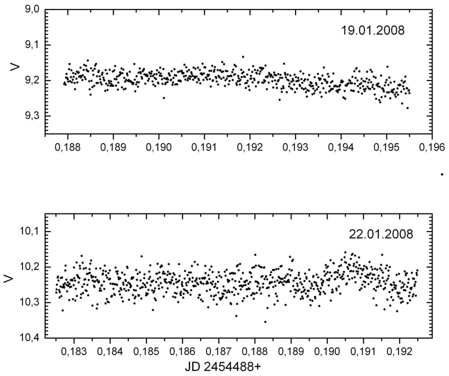

Fig. 1. Several daily light curves of SS Cyg obtained during the anomalous outburst in January 2008. Shown are the maximum of the outburst (the upper panel) and the declining part (the lower panel).

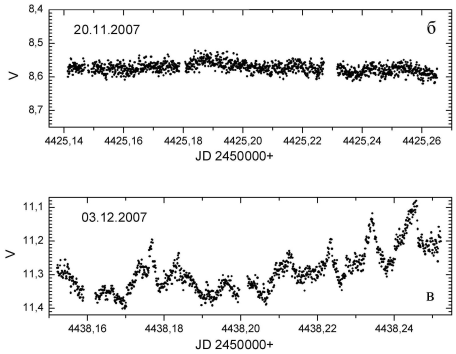

Fig. 2. The same is in Fig. 1 for the outburst observed in November 2007

3. Short-term variability of dwarf novae

Three distinct kinds of rapid variations are known to take place in the light curve of dwarf novae (Hack & La Dous 1993):

– **the coherent oscillations (DNO)** are brightness variations with short periods of a few tens of seconds and low amplitudes of the order of $0^m.002$. The coherence times are about 10^4–10^6 cycles. They are only seen during an outburst and are never observed in the quiescence and represent a transient phenomenon, lasting 1-5 days. The period decreases on the rising branch and increases on the declining branch;

– **the quasi-periodic oscillations (QPO)** are brightness variations with periods 3-4 times longer than those of the coherent oscillations, (typically between $\simeq$ 10 seconds and several hundred seconds); the amplitude of the QPOs are of the order of $0^m.01$. The coherence time is much shorter than in the case of the coherent oscillations. For a short interval of time a mean period can be determined. Like coherent oscillations, they only appear during eruptions. Several period ranges can exist simultaneously in the same system during different outbursts. The presence of the QPO does not depend on the subtype to which a dwarf nova belongs or on the morphology of the

individual eruptions (Robinson & Nather 1979). They may or may not appear simultaneously with the coherent oscillations. In SS Cyg quasi-periodic oscillations co-exist with the coherent oscillations;
- **the rapid flickering** - random light variations on time scales of a few minutes with amplitudes of tenths of a magnitude. The flickering is seen in the light curves of most dwarf novae.

4. The history of short-term variability in SS Cyg

Among the dwarf novae SS Cyg is unique in that its rapid oscillations has been found in both the optical and X-ray ranges. The different optical rapid oscillations were detected during outbursts of SS Cyg:

- the coherent oscillations were first detected in October 1976 by Patterson, Robinson, & Kiplinger (1978) with the period P=9.735 ± 0.002 s and mean semi-amplitude of 0.02%;
- two oscillations,- a coherent oscillation with 9.75 s and an amplitude of 0.1% and a quasi-periodic oscillation with a mean period of ≈ 32*s*,- were discovered by Robinson & Nather (1979) during the same eruption in October 1976;
- the coherent oscillations with 7.29 s period were found by Hildebrand, Spillar, & Stienning (1981) in the light curve of this dwarf nova during eruption of 1979 October;
- high-speed photometry during the 1978 September outburst revealed a small amplitude coherent oscillations with periods ranging from 8.23 to 8.50 s and an amplitude 0.07% (Horne & Gomer 1980);
- the coherent oscillations with periods 9.74–10.9 s and with an amplitude of up to ≈ 0.1% and quasi-periodic oscillations with periods ranging from 32 s to 36 s were found during the same outburst by Patterson (1981);
- the rapid coherent oscillations with periods ranged from a maximum of 9.91 s to a minimum of 8.96 s were revealed during an outburst in November 1973 by Giovannelli (1981) over an interval of four days;
- in 1988, the third group of quasi-periodic oscillations with P=86 s and a total amplitude of 1.5% were detected in SS Cyg by Voloshina & Lyuty (1988). The quasi-periodic oscillations of this type were also reported from other cataclysmic variables;
- quasi-coherent oscillations in the extreme ultraviolet were detected by EUVE, (Mauche 1997).

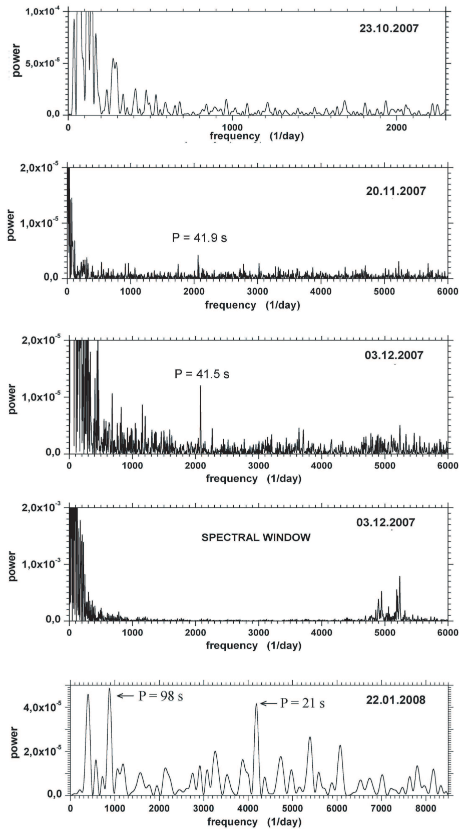

Fig. 3. Power spectra obtained for different nights from the analysis of SS Cyg observations in 2007–2008. The most prominent peaks are marked with arrows.

5. Results of analysis

A Fourier-analysis of our observations was made separately for each date. The obtained power-spectra clearly show the presence of rapid periodic oscillations in SS Cyg light curve during an outburst. The examination of the power density spectra related to outbursts observed in 2006-2008 reveals the presence of a few peaks. The most prominent peaks correspond to persistent oscillations:

- **the outburst observed in the fall 2006** shows oscillations with two periods 10.25 s and 76 s with a full amplitude of about $0^m.013 \pm 0.003$ and $0^m.016 \pm 0.003$, respectively;
- **the outburst observed in November 2007** shows oscillations with periods 41 s, 35 s and 72 s;
- **the outburst observed in January 2008** demonstrates oscillations with 98 s period.

The detected light variations can be interpreted in terms of the quasi–periodic oscillations. The oscillations with 10 s period belong to the first range of periods already found in this system; those with the period 35–41 s relate to the second one, and variations with period 72–98 s belongs to the third group of QPOs. Some of the power spectra calculated by our data are shown in Fig. 3, 4 and 5. The mean light curves of SS Cyg folded with some of the obtained periods are presented in Fig. 6, 7 and 8. Each point on these curves represents the mean value of all data in the 0.1 phase bin.

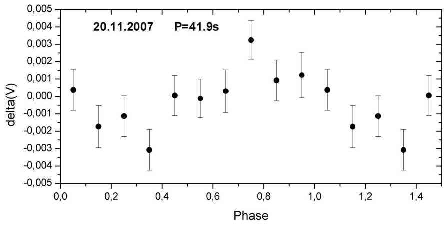

Fig. 4. Observations of SSCyg carried out in 2007 folded with the obtained period P=41.9 s. Observations are shown as filled circles, the vertical line denotes the mean σ

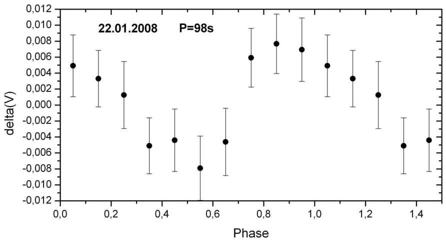

Fig. 5. Observations of SS Cyg folded with the P=98 s obtained in the 2008 data.

6. Summary

Our study of dwarf nova SS Cyg can be summarized as follows:

- High-speed photometric observations of dwarf nova SS Cyg were carried out during several outbursts in 2006, 2007 and 2008.
- Rapid periodic oscillations were detected in the light curve of SS Cyg both near the maximum outburst brightness and at the declining part after the maximum.
- Our data suggest that the oscillations are not always the same, i.e. oscillations with very different periods are observed in SS Cyg during different outbursts; several period ranges can also co-exist.
- The oscillations are not necessarily appear during each SS Cyg outburst. No periodic oscillations were found in the power spectra of earlier high-speed photometry of SS Cyg during outbursts observed in August 1996, October-November 1997 and July 2000.
- No correlation between these oscillations and the type of SS Cyg outburst (long, short or anomalous) has been found.
- The detected light variations of SS Cyg are most likely to be quasi-periodic oscillations.
- These QPOs seem to originate from the inner edge of the optically thick accretion disk which moves away from the white dwarf surface during an outburst.

7. Discussion

DMITRY KONONOV: You have reported many periods found in your power spectra. As I understand you obtain these spectra by only Fourier transforming your lights curves. How do you examine statistical relevance of the found periods ?

IRINA VOLOSHINA: We examine statistical relevance of the obtained periods by 3 σ criterium

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