The central region in SS 433 supercritical disk and origin of flares

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Abstract. Mean orbital light curves of SS433 in different precessional phases are analysed for active and passive states separately. In passive states the mean brightness depends strongly on the disk orientation, the star is fainter by a factor $\approx 2.2$ in the disk edge-on positions. In active states the brightness does not depend significantly on the precessional phase. We suggest that in active states hot gas cocoons surrounding the inner jets grow and can not be shielded by the disk rim in the edge-on phases. Brightest optical flares are clear separated in two groups in orbital phases, it is considered as indication of orbital eccentricity. Bright flares prefer specific precession and nodding phases, it favours the slaved disk model and the flares as disk perturbations by a torque applied to outer parts of the accretion disk.

1. Active and passive states of SS 433

Active states of SS 433 were isolated using the GBI radio monitoring program data [http://www.gb.nrao.edu/fgdoss/gbi/gbint.html] and direct inspection of

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Radio and optical data in 1985 when SS 433 was mainly in quiet state and in 1980 when it was mainly active. The radio flux (GBI radio monitoring data) in Jy, optical flux in V magnitudes.}
\end{figure}
the optical data. Fig. 1 shows radio and optical data in two observational seasons (1980 and 1985). Active states are clearly seen in radio. In visible region flares destroy the regular orbital and precessional variabilities. Orbital variability is seen as deep primary eclipses of the accretion disk by the donor–star (Min I, $\phi_{\text{orb}} = 0$,

\[ P_{\text{orb}} = 13^d 08 \). Precessional variability is a brightening when the accretion disk is the most open to observer ($T_3$ moment, $\psi_{\text{pr}} = 0$, $P_{\text{pr}} = 162^{d4}$) and weakening when the disk is in edge–on positions ($T_{1,2}$ moments, $\psi_{\text{pr}} = 0.34, 0.66$).
We analyse the orbital light curves of SS 433 in different precessional phases for active and passive states separately. Both original and all published data of optical V–band photometry for 1979–1996 were used. The data–base consists of 2200 individual observations collected in Sternberg Institute. We used 1491 observations in passive states of SS 433 and 584 observations in active states, where obvious flares were excluded. We find that the light curve in active state is about the same as that of in passive with primary and secondary minima (Fig. 2, Fig. 3). However, it is very important that in active states the brightness does not depend significantly on precessional phase and the primary minima are not so deep as they are in passive states. We suggest a geometry of the inner disk parts as two hot gas cocoons surrounding the two inner jets. In active states the cocoons grow and they can not be shielded by the disk rim when the disk is edge–on. In Fig. 4 we show a sketch of the disk and cocoons in active and passive periods.

![Figure 3. Mean precessional light curves for passive (circles, down curves) and active (crosses, upper curves) states in a middle of the primary minimum (left) and in elongations (right) in phase intervals $\Delta \phi = \pm 0.05$.](image)

When the disk is the most open to observer the mean brightness in elongations is the same in active and passive states. Probably the cocoon surrounding the approaching jet is not shaded up to its base by the disk rim in these precession phases and luminosity of the cocoon does not depend notably on its size. This may be in a case if the cocoon scatters ($\tau_T \sim 1$) inner radiation coming from the accretion disk funnel. The cocoons can be identified with a source of the UV radiation of SS 433, where Dolan et al. [1] have detected the strong linear polarization directed along jets. The cocoons can be also identified with a source of the double–peaked He II $\lambda 4686$ line observed in the disk [2].

In passive states an amplitude of precessional modulation ($\Delta I \approx 0.4$) is about the same as amplitude of primary minima ($\Delta I \approx 0.5$). This means that the projected sizes of the outer disk rim and the companion star are the same.
2. Phasing of flares

We have selected optical flares as short (about one day) increases of brightness over the mean passive state flux in corresponding phases. 14 super–bright flares ($\Delta I_f = 0.7 - 1.2$) and 16 bright flares ($\Delta I_f = 0.57 - 0.7$) were isolated and studied in the phase diagrams (Fig. 5). Fainter flares show about the same behaviour as bright ones, but their distributions are more scattered.

All the super flares (save for one) are located in two isolated orbital phases. The only possibility to produce flares in specific orbital phase is a noncircular orbit. We suggest that it is the case. If a periastron passage occurs close to $\phi_{orb} \approx 0.28$, the second group of flares delays for $\Delta \phi \approx 0.1$ to expected apoastron passage ($\phi_{orb} \approx 0.78$). The mass transfer rate in SS 433 is highly supercritical $\dot{M} \sim 10^{-4} M_\odot$ yr$^{-1}$ [3], and flares have to be related not to the mass transfer rate variations, but rather to the accretion disk perturbations.

The eccentricity in SS 433 is less than $e < 0.05$ [4]. However even an eccentricity $e \approx 0.01$ can produce the critical Roche volume variation of 2% [5]. Such an eccentricity may dominate the effect of the primary’s Roche volume variation appearing because of primary’s spin misalignment with the orbital axis (twice per orbit, the slaved disk model).

A real moment of the periastron passage has to be earlier than the flares on the time of matter transfer through the disk ($\Delta t_{tr}$), $\phi_{orb} = 0.28 - \Delta \phi_{tr}$. The specific orbital phase specifies precession phases for flares depending on mechanism of flares. They are $\psi_{pr} \approx 0.22(0.72) + \Delta \phi_{tr}$, if perturbations occur because of (i) a torque applied to outer parts of accretion disk (the nodding motions, [6]) or $\psi_{pr} = 0.47(0.97) + \Delta \phi_{tr}$, if the perturbations occur because of (ii) the Roche lobe

*Figure 4.* A sketch of the accretion disk with cocoons surrounding inner jet bases in active and passive states in two extreme precessional orientations

![Figure 4](image-url)
The central region in SS 433

Figure 5. Phase diagrams for super–bright flares (filled and open circles) and bright flares (triangles). Two vertical lines mark location of the super–flares at $\phi_{\text{orb}} = 0.28 \pm 0.05$ and $0.886 \pm 0.004$, two horizontal lines mark location of the cluster of bright flares at $\psi_{\text{pr}} = 0.32 \pm 0.05$ and $+0.5$ in precession phase. In the right diagram with nodding phases ($\omega_{\text{nod}} = 2\omega_{\text{orb}} + 2\omega_{\text{pr}}$) two diagonal lines represent the best linear fits for super flares only with slopes $0.57(\pm 9)$ and $0.58(\pm 9)$.

... squeezing [3]. Observed location of the super flares allows for any of the two models, however the bright flares and some super flares are crowded in precessional phase $\psi_{\text{pr}} \approx 0.3$, what favours the nodding model (i), if $\Delta t_{\text{tr}} \sim 1$ day.

In the diagram $\psi_{\text{pr}} - \phi_{\text{nod}}$ (Fig. 5) the super flares show quite expected behaviour as flares in fixed orbital phases ($\psi_{\text{pr}} \propto 0.5 \phi_{\text{nod}}$). The phases $\phi_{\text{nod}} = 0.25, 0.75$ correspond here to location of companions in the line of nodes. The bright flares, which do not follow the diagonal lines, delay for $1.0 \pm 0.4$ days from nodding phases $\phi_{\text{nod}} = 0.0(0.5)$. Such a behaviour could be understood, if the nodding (i) mechanism does work and the time of matter transfer across the perturbed disk is $\Delta t_{\text{tr}} \sim 1$ day.

Acknowledgments

The authors thank G. Valyavin for a help in preparation of the paper. This work has been partly supported by the RFBR grant N00-02-16588 and the Russian Federal Program “Astronomy”.

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