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RAPID VARIATIONS IN RS Oph OBSERVED BY OMC/INTEGRAL

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RS Oph is a relatively bright symbiotic star with the orbital period $P_{\rm orb} = 460$ days, the inclination angle of $30^\circ - 40^\circ$ and the giant component underfilling its lobe (Dobrzycka and Kenyon 1994). RS Oph is a long-period cousin of cataclysmic variables (CVs) because in contains a white dwarf (WD), as suggested also from the fact that it is a recurrent nova with five observed explosions (e.g. Warner 1995). Beside these outbursts, the quiescent brightness fluctuates on time scales of months and years mostly between 11 and 12 $\rm mag_{vis}$, sometimes reaching 10 $\rm mag_{vis}$ (e.g. Dobrzycka and Kenyon 1994, Oppenheimer and Mattei 1996). Also the rapid optical variations on the time scale of tens of minutes, similar to those often seen in short-period CVs, were reported several times (e.g. Walker 1977, Dobrzycka et al. 1996).

RS Oph was repeatedly observed by the *INTEGRAL* satellite during its Galactic Plane Scans (GPS). Here we report on the observations of this object by the Optical Monitoring Camera (OMC) onboard *INTEGRAL*. This instrument, equipped with Johnson V filter and a CCD detector, is able to carry out rapid photometry (Mas-Hesse et al. 2003). The observing strategy used for GPS consists of so-called *science windows* during which a given region of the sky is observed by the co-aligned instruments for about 1.5 hours. OMC obtains a series of images during this period. Most images used for this study were secured with a 100 sec. exposure time. A smaller part was obtained with a 30 sec. exp. time; these measurements often possess slightly larger observational errors.

The observed light curves are displayed in Figure 1. It can be seen that both night to night and rapid variations of brightness occurred during our observations. In order to allow for a comparison of the amplitude of the variations in the individual science windows (hereafter abbreviated as sets ABCDE), the magnitudes were transformed into intensities, setting the intensity equal to unity at 11.4 mag(V).

A search for the cycle-lengths in the OMC data set was carried out using weighted wavelet Z-transform (WWZ) (Foster 1996). This method, based on the Morlet wavelet, enables one to determine period and amplitude of unevenly sampled time series. WWZ indicates whether or not there is a periodic fluctuation at a given time at a given frequency and is a measure of the confidence of a frequency at a given moment. This method is thus suitable for a search for the periods which undergo variations during the observation. It can be used for discovering possible temporarily existing periods in RS Oph. The value of the parameter c which determines how rapidly the analyzing wavelet decays was set to 0.0125, which is commonly used for variable star light curves. WWZ transform could be made for sets BCDE and the results are shown in Figure 2.

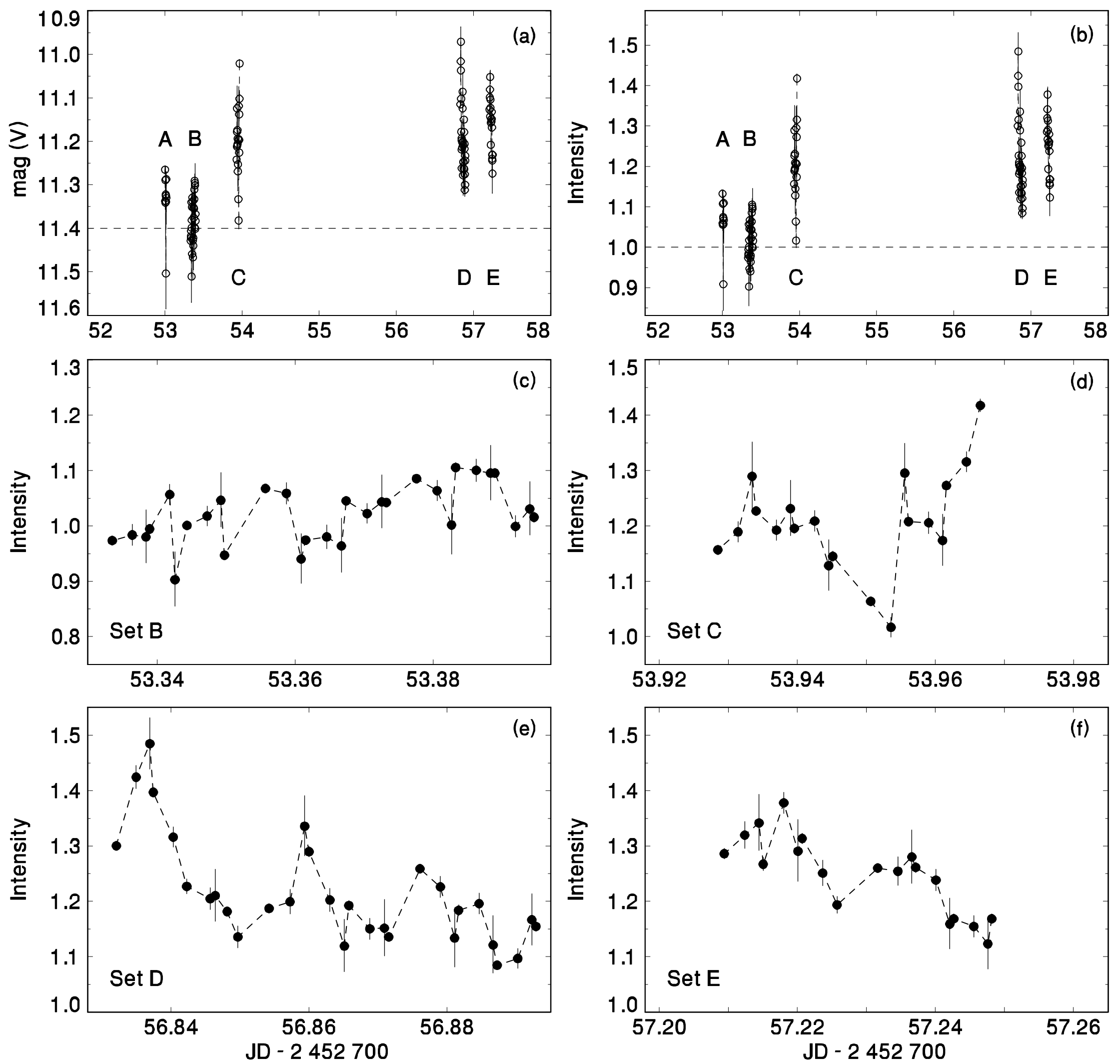

Figure 1. The V band light curve of RS Oph from OMC in the magnitude **(a)** and intensity scale **(b)**. The horizontal dashed line denotes the level in which the intensity was set to unity. The individual sets (science windows) are indicated by the capital letters ABCDE. These sets are plotted on expanded axes in **cdef**. The distances between the ticks on both the abscissa and ordinate are identical for all four panels. The points are connected by the dashed line for convenience to show the profile of the variations. The error bars of the individual measurements are also marked; in some cases the errors are smaller than the size of the symbols.

Our observations were obtained in the orbital phases $\phi = 0.9848 - 0.9935$ according to the ephemeris $T_{\rm icg} = 2450000 + 460\ E$ (Dobrzycka and Kenyon 1994) where $T_{\rm icg}$ refers to the inferior conjunction of the red giant. This implies that our observations were obtained at primary eclipse if RS Oph were an eclipsing system. In spite of the low inclination angle, this is still an important phase because for example the wind flow from the giant toward the WD can still influence our view into the vicinity of the WD.

We observed RS Oph at various levels of brightness, with the lower value close to 11.45 mag(V), the lowest one at which the flickering of this object was analysed previously, as summarized by Anupama and Mikolajewska (1999). We detect rapid variations of the brightness in all sets with sufficiently long coverage (BCDE). The largest peak-to-peak

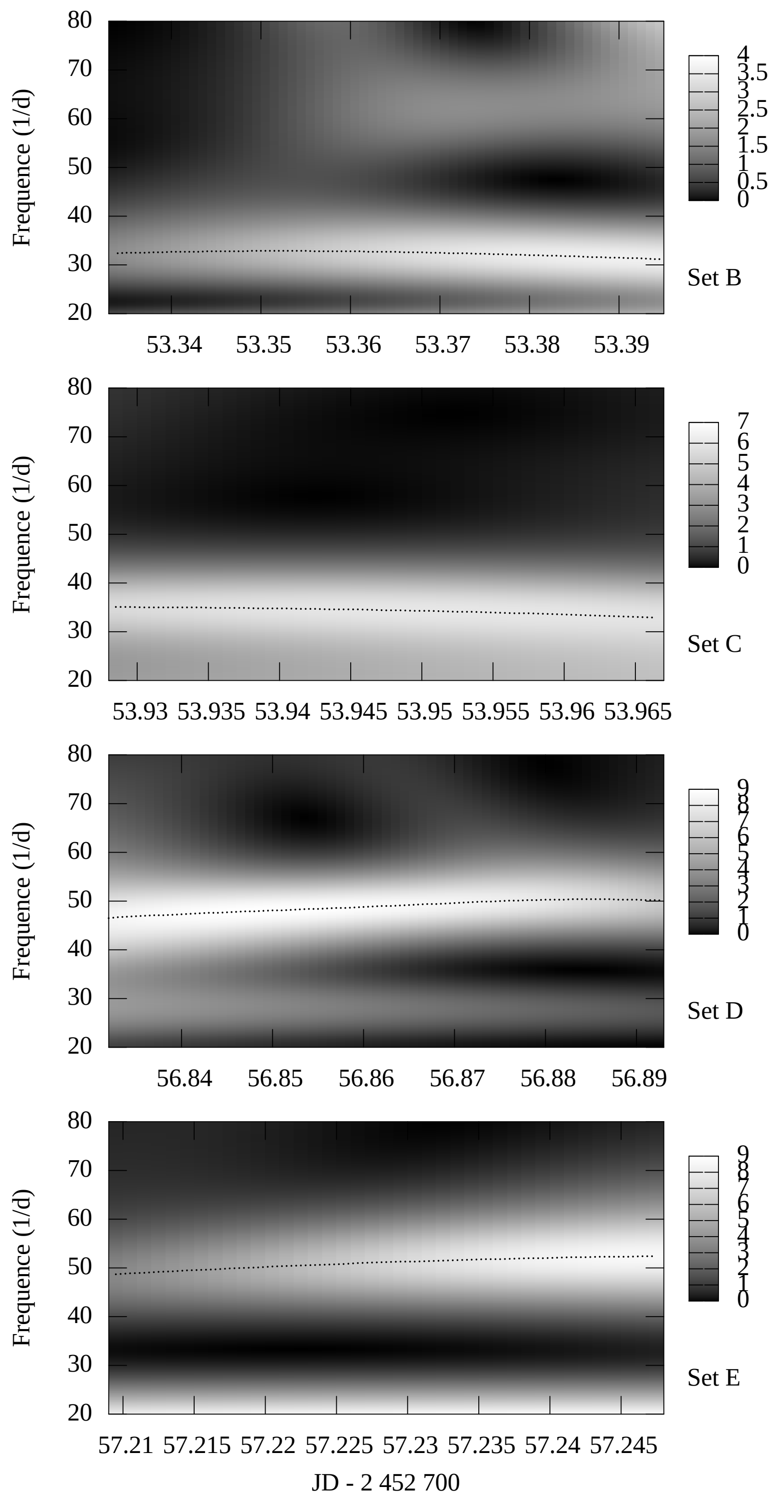

Figure 2. Weighted wavelet Z-transform of the individual sets of RS Oph. WWZ indicates whether or not there is a periodic fluctuation at a given time at a given frequency. The method of Foster (1996) was used. The dotted curves indicate the maximum of WWZ. The range of the ordinate is identical for all four panels while the length of the abscissa for each set corresponds to the length of the given science window of *INTEGRAL*.

amplitudes of about 0.3 mag(V) were observed for sets C and D. The amplitude of the flickering in RS Oph tends to increase with the increasing mean level of intensity. This speaks in favour of the origin of both the flickering and "constant" optical luminosity from the same source. The short time scale of the flickering places its most probable location to the close vicinity of the WD. The interpretation that the inner disk region is the source of the flickering is supported also by the rapid variations of the He II 4686 emission (Sokoloski 2002). We note that the relation between the amplitude of the rapid and long-term variations is in the same sense as the behaviour of CH Cyg (Sokoloski 2002, Sokoloski and Kenyon 2003) and T CrB (Anupama and Mikolajewska 1999). Our observations are also in agreement with Bruch (1992), i.e. that the luminosity of the flickering and "constant" source in CVs are correlated.

WWZ enabled us to detect a typical frequency of the flickering for each of sets BCDE. Although the duration of each set is not long enough to prove the coherence of the frequency over long time scales, we can state that the typical frequency was 30–50 cycles/day (i.e. period of 48–29 min) during our observations. The frequency tends to vary with the varying mean intensity of the sets – set B which possessed a lower mean intensity than sets CDE displayed the flickering with a lower frequency. The frequency displayed the variations also in the course of the set, as can be clearly seen for set D. All this contradicts the origin of the flickering from the rotation of the magnetized WD. We also stress that the typical periods of the flickering found here are quite discordant with the period of 81 ± 2 min reported by Dobrzycka et al. (1996).

We find a complicated relation between the amplitude of a flare in the flickering and its duration. The amplitude decreases with the decrease of the cycle-length (and hence the duration of the flare) in set D (compare Figures 1 and 2). On the contrary, set B which possesses a lower mean intensity level displays a longer cycle-length with a smaller amplitude in comparison with set D. The level of the "constant" intensity thus plays a role in this regard.

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References:

Anupama, G.C., Mikolajewska, J., 1999, *A&A*, **344**, 177
Bruch, A., 1992, *A&A*, **266**, 237
Dobrzycka, D., Kenyon, S.J., 1994, *AJ*, **108**, 2259
Dobrzycka, D., Kenyon, S.J., Milone, A.A.E., 1996, *AJ*, **111**, 414
Foster, G., 1996, *AJ*, **112**, 1709
Mas-Hesse, J.M., Gimenez, A., Culhane, J.L., et al., 2003, *A&A*, **411**, L261
Oppenheimer, B.D., Mattei, J.A., 1996, *IAU Symp. No.165*, p.457
Sokoloski, J.L., 2002, *Symbiotic Stars Probing Stellar Evolution*, astro-ph/0209101
Sokoloski, J.L., Kenyon, S.J., 2003, *ApJ*, **584**, 1027
Walker, A.R., 1977, *MNRAS*, **179**, 587
Warner, B., 1995, *Cataclysmic Variable Stars*, Cambridge Univ. Press, Cambridge