Interpretation of Light Curves of the Cataclysmic Variable OY Car in a Model with Shockless Interaction between a Gaseous Stream and the Disk

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Abstract—To determine the parameters of the accretion disk and shock-wave region responsible for the formation of the orbital peak in the light curve of the binary system OY Car (an SU UMa-type variable), we have analyzed its UBVR and JK light curves using two gas-dynamical models with different regions of shock interaction: one with a hot line along the stream from the Lagrange point L₁ and one with a hot spot on the accretion disk. The hot-line model can better describe the quiescent state of the system: the maximum $\chi^2$ for the optical light curves does not exceed 207, whereas the minimum residual for the hot-spot model is $\chi^2 > 290$. The shape of the eclipse is almost identical in both models; the main differences are in interpreting out-of-eclipse portions of the light curves, whose shape can vary in the transition from one orbital cycle to another. The hot-spot model is not able to describe variations of the system’s brightness at orbital phases $\varphi \sim 0.1–0.6$. The rather complex behavior of the observed flux in this phase interval can be explained in the hot-line model as being due to variations of the temperature and size of the system. Based on the analysis of a sequence of 20 B curves of OY Car, we conclude that the flux variations in the primary minimum are due to variations of the luminosity of the accretion disk, whereas the flux variability in the vicinity of the orbital peak is due to the combined effect of the radiation of the disk and hot line. The JK light curves of OY Car in the quiescent state and during a small flare also indicate preference for the hot-line model, since the primary minimum and the flux near quadratures calculated using the hot-spot model are not consistent with the observations. © 2003 MAIK “Nauka/Interperiodica”.

1. INTRODUCTION

Cataclysmic close binary systems are among the most interesting non-steady-state astrophysical objects, due to the intense mass transfer between the components. Their short orbital periods enable the determination of the characteristics and parameters of the system over comparatively short observational times.

The light curves and radial-velocity curves of these systems indicate that they consist of a white dwarf and cool main-sequence star. The latter fills its Roche lobe, resulting in an outflow of matter through the vicinity of the inner Lagrange point L₁. Further, this matter is captured by the white dwarf’s gravitation and forms an accretion disk, halo, and intercomponent envelope. The existence of the accretion disk is confirmed by the profile of the eclipse of the white dwarf and the surrounding material by the cool component of the system. However, light curves of eclipsing close binaries display some additional features that cannot be described in simple “cool star—white dwarf—accretion disk” models. In particular, the vast majority of light curves of eclipsing close binaries display a so-called “orbital peak.” Gorbatskii [1] and Smak [2] suggested that this is due to a hot spot at the edge of the accretion disk, where the stream from L₁ collides with the disk. Over the last 30 years, the hot-spot model has been widely used to interpret the light curves of cataclysmic binaries (see, for example, [3]).

Gas-dynamical studies of the mass transfer in close binaries [4–9] showed that the stream and accretion disk are morphologically a single formation and that their interaction is shockless. Naturally, in this case, the temperature at the point of contact between the stream and disk does not increase, so that the hypothesis that there is a hot spot on the accretion disk must be abandoned. Three-dimensional gas-dynamical calculations of mass transfer in an interacting close binary [4–9] have indicated that, in the steady-state case, a shock interaction resulting
in a temperature increase occurs when the matter flowing around the accretor but not yet captured by the disk collides with the stream from \( L_1 \). This interaction forms an extended shock wave oriented along the stream \([4–6, 10]\) (the “hot line”), whose radiation makes it possible to understand certain observed effects in the light curves of cataclysmic variables \([11, 12]\), in particular, the occurrence of regular and irregular peaks during eclipses of the accretion disk by the donor star. Comparisons between models with a hot spot and a hot line \([11, 12]\) have presented conclusive evidence in favor of the latter type of model for the interpretation of close-binary light curves.

Eclipsing close binaries, whose light curves can be used to investigate the flow structure, are rare and do not form a homogeneous group. Therefore, it is of interest to consider close binaries with various features in their light curves and to analyze the suitability of various gas–dynamical models for their interpretation. Here, we present our analysis of light curves of the SU UMa cataclysmic variable OY Car.

### 2. GENERAL INFORMATION ABOUT OY Car

The variability of OY Car \((= S6302)\) was discovered by Hoffmeister \([13]\) in 1959; however, this star was observed little in the subsequent two decades. In the beginning of the 1980s, interest in this system increased substantially, leading to intense observations. Comprehensive summaries of the photometric observations are given by Vogt et al. \([14]\), Vogt \([15]\), Schoembs et al. \([16, 17]\), and Cook \([18]\), of IR photometric observations by Berriman \([19, 20]\) and Sherrington et al. \([21]\), and of spectral observations by Bailey and Ward \([22]\), Hessman et al. \([23]\), and Harlaftis and Marsh \([24]\).

The light curve of the system in the inactive state is typical of eclipsing close binaries. A pronounced peak with its maximum at phase \( \sim 0.75 \) is observed in each orbital cycle prior to the eclipse of the primary. The times of the onset and end of the ingress into eclipse for the white dwarf, disk, and hot region of the shock are clearly visible in the eclipse curve.

In the active state, the system displays a number of peculiarities. The flare activity of OY Car classifies it as an SU UMa variable; these are dwarf novae with orbital periods shorter than \( 3 \) h. Flares of this type of star are divided into two separate classes: regular flares, which are brief and irregularly distributed in time, and superflares. The latter are more prolonged, brighter, and less frequent; however, at the same time, they are more predictable. In the case of OY Car, the regular flares occur every \( 25–50 \) days and have amplitudes up to \( \approx 3^m \) and durations of about \( 3 \) days. Superflares occur approximately once a year. Their amplitude reaches \( 4^m \), and they may last for up to \( 2 \) weeks. Photometric observations of the system in these periods have been carried out by Krzeminski and Vogt \([25]\), Schoembs \([26]\), and Bruch et al. \([27]\).

Observations of OY Car are analyzed in \([18, 22, 23, 28, 29]\). The orbital parameters and mass ratio of the components were derived from radial-velocity measurements. The size of the disk and the white dwarf, as well as the orbital inclination, were estimated based on the shape of the primary minimum. The spectrum and comparisons of the photometric parameters of the system in various colors have been used to determine the effective temperature of the cool component and, with lower accuracy, the temperature of the hot star. The mass of the white dwarf was estimated based on its radius using the Hamada–Salpeter relation \([30]\); later, the mass of the cool component was also derived. The period of the system was determined with good accuracy from an extensive set of photometric observations. Table 1 presents some parameters of OY Car.