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LIGHT AND RADIAL VELOCITY CURVES SYNTHESIS: MASSES OF STARS AND RELATIVISTIC OBJECTS

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Abstract. We present the results of light-curve analyses, which allow us to determine stellar masses for three interesting massive binary systems containing early-type components. The analysis was carried out in the framework of the Roche model at an eccentric orbit. We also present the results of modeling theoretical absorption-line profiles and radial velocity curves for optical components in X-ray binary systems. Heating of the optical star by the incident X-ray radiation is taken into account by model atmosphere calculations. Comparing observed line profiles and the radial velocity curves with the model ones provides a possibility to correctly determine masses of relativistic objects.

1. INTRODUCTION

Synthesis methods for close binary systems are a powerful tool for determination of the fundamental parameters of stars and relativistic objects. These methods were suggested in the 1970s by several authors: Hill and Huchings (1970), Wilson and Devinney (1971), Wood (1971) and others. The ones most widely used nowadays are based on the Wilson-Devinney computer code (Wilson, 1979).

We have our own set of computer codes for light and radial velocity synthesis for different binary models: Roche model at an eccentric orbit, a model with spheroidal accretion disk, a model with precessing thick accretion disk, a model for X-ray binaries etc. (Antokhina, 1988, 1996; Antokhina and Cherepashchuk, 1987, 1994; Antokhina et al., 2005).

The main idea of the synthesis methods is to approximate the tidally distorted surface of a star by thousands small elements and to compute their emission at each orbital phase. Summing the surface elements we can calculate the total flux of the stars for any orbital phase and so the whole light curve. For obtaining a radial velocity curve the absoption line profiles and local velocities of surface elements are calculated and integrated over the visible part of the star. The effects of gravitational darkening, limb darkening and heating of stellar surfaces by the incident radiation from the companion (including X-ray radiation from a relativistic object) are taken into account.

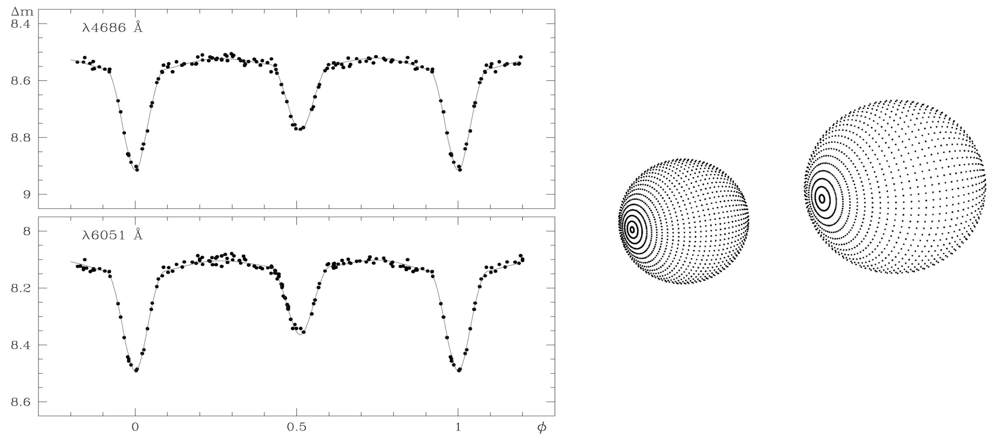

Figure 1: The light curves and geometrical model of CPD-41°7742.

By comparing the model light and radial velocity curves with observations, one can derive important stellar parameters, such as masses, temperatures, radii and others.

In the current paper we present the results of the light curve analysis for three interesting massive early type binaries (Sect. 2). Obtaining the masses of their components is important for advancing the theory of stellar evolution.

Modeling theoretical absorption-line profiles and radial velocity curves for optical components in X-ray binary systems and deriving the masses of relativistic objects is discussed in Sect. 3.

2. LIGHT CURVE ANALYSIS: SOME INTERESTING MASSIVE EARLY TYPE BINARIES

2. 1. CPD-41°7742

This is a spectroscopic binary (O9+B1) with massive hot components on slightly eccentric orbit. It is located in the young open cluster NGC 6231. XMM-Newton observations for this system show clear phase-locked X-ray variability from wind-wind collision. Light curve analysis (Fig. 1) allows one to obtain the most important absolute parameters of the system (Sana et al., 2005).

2. 2. HD 93205

A massive spectroscopic binary HD 93205 (O3V+O8V) contains one of the earliest known star in a binary. It has highly eccentric orbit ($e \sim 0.46$). A precise light curve with a very small amplitude ($\sim 0.02^m$) covering all orbital phases was obtained for the first time by our team at CTIO and has an unusual form. Our analysis by the synthesis method shows that the orbital inclination is about 60° and there are no

Table 1: Main parameters of the studied binaries.

Parameter	$CPD-41°7742$	$HD\,93205$	$A1$
$M_1(M_\odot)$	17.97	45.0	30–90
$M_2(M_\odot)$	9.96	20.0	25–50
$R_1(R_\odot)$	7.45	8.0	6.5–15
$R_2(R_\odot)$	5.39	6.3	11–18
$T_1(K)$	34000	49000	43000
$T_2(K)$	26260	36500	46000
i	77.°4	60°	70°
e	0.020	0.46	0
ω	33°	17°.4	0
$P(d)$	2.44	6.08	3.77

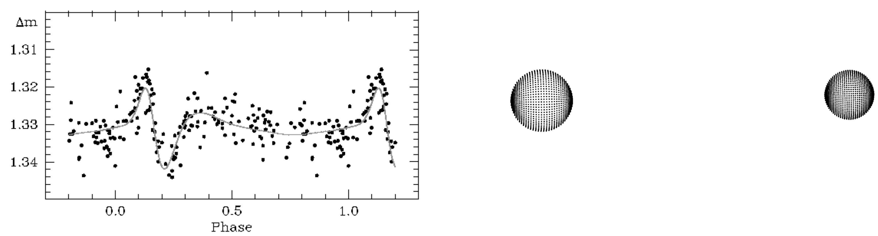

Figure 2: The light curve and geometrical model of HD 93205.

eclipses. Light curve variability (Fig. 2) is caused only by small tidal deformation of stars during orbital motion (Antoknina et al., 2000).

2. 3. A1 IN NGC 3603

The binary A1 (WN6+O) is located in the most massive visible cluster NGC 3603. From the analysis of spectral features it was suggested that one component is the most massive H-rich WR star in our Galaxy (total binary mass $\sim 100 - 150 M_\odot$). A good infrared light curve with the amplitude $\sim 0.1^m$ was obtained by the Hubble telescope (Fig. 3). Our light curve analysis allows us to estimate the orbital inclination, masses and radii of the components, which almost fill their Roche lobes (Moffat et al., 2004).

3. RADIAL VELOCITY SYNTHESIS FOR X-RAY BINARIES

The standard method for analysis of radial velocity curves of a binary is the point mass approach. However stars in binaries can be very distorted. Synthesis method gives a possibility to take into account the complicated shape of the components, to calculate true radial velocity curve, and to obtain the correct masses of the components. This is especially important for X-ray binaries, in which additional complication is high X-ray heating (Fig. 4). In our computer code, we use stellar atmosphere models to compute local line profiles, sum them to obtain a full line profile and then compute the RV curve (Antokhina et al., 2005).

Using this approach, we refined the mass of the black hole in the X-ray binary Cyg X-1 (Abubekerov et al., 2004b) and the masses of neutron stars in the X-ray binaries Cen X-3, LMC X-4, SMC X-1, 4U 1538-52 and Vela X-1 (Abubekerov et el., 2004a).

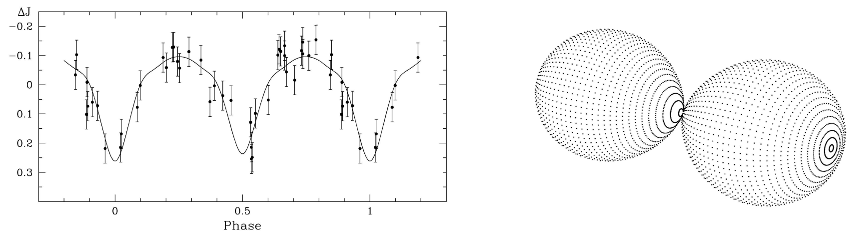

Figure 3: The light curve and geometrical model of binary A1.

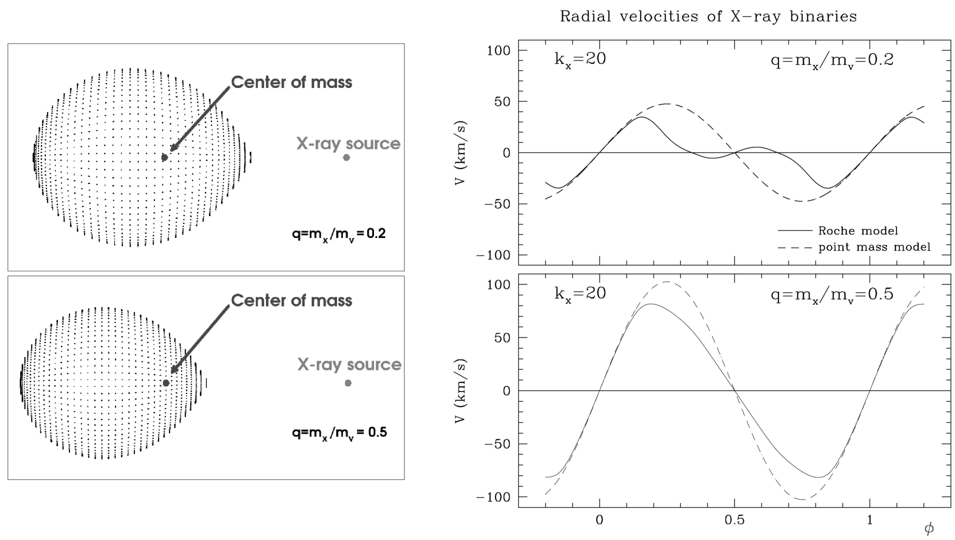

Figure 4: X-ray binary models and corresponding radial velocities (the parameter k_x characterizes the power of the incident X-ray flux).

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