

# On the Interpretation of the Long-Term Cyclic Period Variations in RR Lyrae Stars

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Many RR Lyrae stars show long-term variations of their pulsation period, some of them in a cyclic way. Such behaviour can be attributed to the light-travel time effect (LTTE) caused by an unseen companion. Solutions of the LTTE often suggest very eccentric orbits and minimal mass of the companion on the order of several solar masses, thus, in the black hole range. We discuss the possibility of the occurrence of the RR Lyrae-black hole pairs, and on the case of Z CVn, demonstrate that the LTTE hypothesis can be false in some of the binary candidates.

## 1 Introduction

It is generally accepted that a large portion of the stars in the Universe is bound in binary and multiple systems. For example, Raghavan et al. (2010) found that among A-type main sequence stars, at least 70 % of them have a companion. If we consider the progenitor of an RR Lyrae (RRL) type star as a low-mass star of G-type, we still should observe about 40 – 50 % as binaries. Of course, RRL stars are old stars that already passed the red-giant evolutionary phase, which would definitely affect the incidence rate of binaries with RRL stars.

However, depending on the mass ( $0.1 - 1.3 M_{\odot}$ ), the percentage of population II stars in binaries ranges from about 20 % to 40 % (Duchêne & Kraus, 2013). The orbital period of G-type main sequence stars peaks at  $\log(P)(\text{days}) = 4$ , suggesting a large number of stars with very wide orbits preventing mass transfer (Duchêne & Kraus, 2013). Although there are no available RRL binary statistics, we could basically expect that many of RRL stars untouched by the evolution of a close companion would be found in binary systems.

This is in clear contrast with what we observe. There are about 100 000 RRL known in our Galaxy, LMC, and SMC (Watson et al., 2006; Soszyński et al., 2014, 2016), but only 82 candidates for binary systems (Liška & Skarka, 2016)<sup>1</sup> and only one (almost) confirmed binary (TU UMa, Wade et al., 1999; Liška et al., 2016b). Thus, the binarity of RRL stars remains puzzling, which leaves us with the RRL mass estimated only roughly from the evolutionary and pulsation models.

## 2 The Light-Travel Time Effect and Minimal Masses for the Companions

According to discussion in Skarka et al. (2016), it is hard to discover an RRL star in a binary system using direct methods (e.g., eclipses, colour excess, radial velocity measurements) due to the large luminosity of RRL stars. Thus, the most promising, and so far the most effective, method is the investigation of cyclic period variations that are considered to be a result of the orbital motion and finite speed of light – the well known Light-Travel Time Effect, LTTE.

A big advantage of this method is that low-mass companions can be detected, and by modelling the period variations (usually in the form of  $O-C$  diagrams<sup>2</sup>), we can get orbital parameters, orientation of the orbit in space, and a mass function. Thus, the investigation of cyclic period variations of binary systems is a full alternative to radial velocity observations. On the other hand, it is very time consuming, and only binaries with orbital periods longer than hundreds of days can be investigated.

Based on the investigation of LTTE, 52 stars have been discovered (see the online list by Liška & Skarka, 2016, and references therein), and additional candidates have been announced at this conference (see Hajdu et al., 2017; Greer, 2017; Poretti et al., 2017, this proceedings). The function of mass or minimal mass was estimated in a few studies (for example, Hajdu et al., 2015; Liška et al., 2016a). A very disturbing fact is that in some of the candidates, the calculated minimal mass is in the range of black holes (Liška et al., 2016a; Sódor et al., 2017), and in some cases with masses significantly above  $10 M_{\odot}$  (Derekas et al., 2004). Our analysis of the  $O-C$  in Z CVn suggests even larger minimal mass.

## 3 Z CVn

In Skarka et al. (2018), we performed an extensive study of Z CVn employing various methods and approaches: from photometry (53 nights during four observing seasons) and spectroscopy (eleven nights during two seasons) to LTTE analysis (227 maximum times, 72 new). We also used archival data, when available. Besides the deep analysis of the Blazhko effect and physical characteristics, the cornerstone of our study was the investigation of period variations.

<sup>1</sup>See the online version of the list at <http://rrlyrbincan.physics.muni.cz/>.

<sup>2</sup>'O' stands for observed and 'C' stands for calculated.

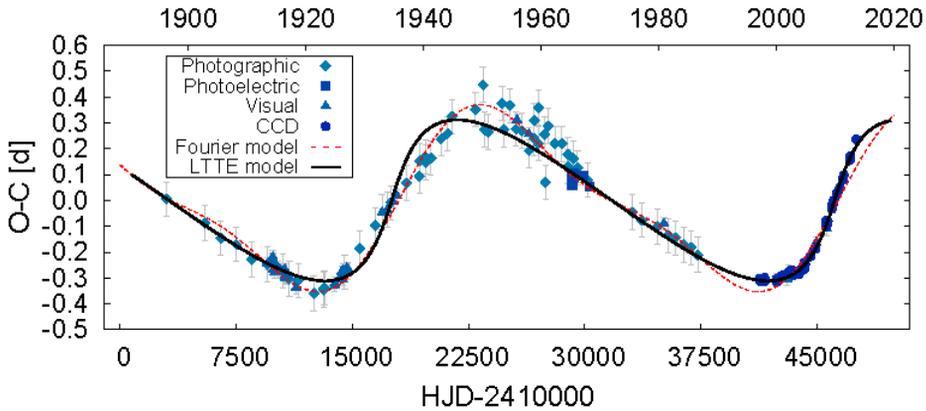


Fig. 1: The  $O-C$  diagram of Z CVn consisting of our measurements and archival times of maximum light. The meaning of different symbols and lines is clear from the legend.

The spectacular cyclic period variation is apparent from the  $O-C$  diagram shown in Fig. 1. The data gathered using various methods (shown with different symbols) are complemented with the model when the LTTE is considered (black continuous line) and a Fourier fit with two harmonics with period of 78 years (for comparison).

The full set of orbital parameters that we obtained can be found in Skarka et al. (2018). The most important issue for us now is the minimal mass that was estimated as  $56.5 M_{\odot}$ , which is very suspicious.

#### 4 Discussion

First, we asked a question whether such a massive black hole could exist. Due to the discovery of the merging black holes detected by the LIGO experiment, when two black holes with masses of  $29$  and  $36 M_{\odot}$  coalesced into one object (Abbott et al., 2016), we now know that such objects can exist. Also from the theory of formation of black holes, it is clear that massive black holes can come to existence from very massive stars that have strong magnetic fields and low metallicity causing reduction of the stellar wind (Spera et al., 2015; Petit et al., 2017).

The second question to ask is whether we can detect some (X-ray) radiation from the material falling onto the black hole. The classical mass transfer known from close binary systems can be ruled out in such a wide system. Thus, the only source of material could be the stellar wind from the RRL component and the surrounding interstellar matter. The accretion would take place via the Bondi-Hoyle-Lyttleton accretion (Hoyle & Lyttleton, 1939; Bondi & Hoyle, 1944; Bondi, 1952), which is inversely proportional to  $(v_s^2 + v_r^2)^{3/2}$ , where  $v_s$  is the speed of sound in the material and  $v_r$  is the relative speed of the black hole with respect to the surrounding material.

Unfortunately, we do not know the density of the stellar wind from RRL stars and temperature (both define  $v_s$ ) of the surrounding material. Thus, the resulting luminosity of the black hole could be orders of magnitude lower, but also orders of magnitude larger than the luminosity of Z CVn itself (depending on the input density, temperature, and relative speed). In any case, there is no X-ray source

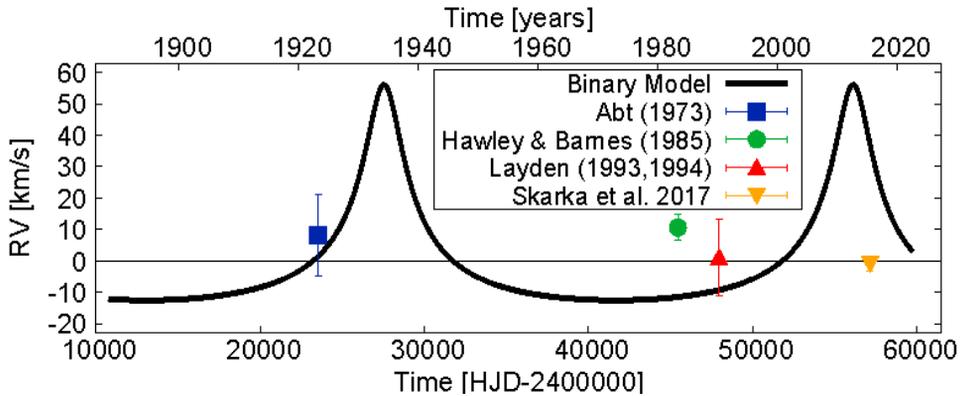


Fig. 2: RV measurements (points) versus RV model based on LTTE assumption.

detected in the direction to Z CVn.

Another chance to detect a black hole is via the supernova remnant. The problem is that the remnants survive maximally for tens of thousands of years. If the progenitor of the black hole exploded, it necessarily had to happen billions of years ago. In addition, we do not know whether Z CVn corotates with the Galactic halo and, thus, whether the possible remnant follows Z CVn. Theoretical studies show that massive stars may not explode as a supernova, but collapse directly to a black hole (Fryer, 1999). In any case, there are no signs of the remnant.

However, the most important evidence against binarity of Z CVn are the spectroscopic measurements. We complemented our 11 RV measurements (Skarka et al., 2018) with available observations from the literature (Abt, 1973; Hawley & Barnes, 1985; Layden, 1993, 1994) and got the systemic radial velocities (Fig. 2). It is seen that the measurements do not match the model based on LTTE at all, which, without any doubt, rejects the binary hypothesis.

## 5 Conclusions

In Skarka et al. (2018), we showed that although massive black holes can exist, the period variations of Z CVn cannot be caused by an unseen companion implying existence of some unknown long-term effect that is intrinsic to the star.

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