Cyclic Variations in the Periods of RR Lyrae Stars

Ennio Poretti[1·2·3], Jean-François Le Borgne[4·5·2], Alain Klotz[4·5·2], Monica Rainer[1·6] and Mercedes Correa[7·2]

1. INAF-Osservatorio Astronomico di Brera, Via E. Bianchi 46, 23807 Merate (LC), Italy
2. Groupe Européen d'Observations Stellaires (GEOS), Bailleau l'Evéque, France
3. INAF – Fundación Galileo Galilei, Rambla José Ana Fernandez Pérez 7, 38712 – Breña Baja, Spain
4. Université de Toulouse, UPS-OMP, IRAP, Toulouse, France
5. CNRS, IRAP, Toulouse, France
6. INAF-Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy
7. Agrupació Astronòmica de Sabadell, Sabadell, Spain

We report here on two types of cyclic variations that can be observed in the periods of RR Lyrae stars, i.e., the Blazhko and the light-time effects. The former has been investigated by studying the amplitude variations recorded in RR Lyr itself, firstly by *Kepler* and then by the network of the "Very Tiny Telescopes" (VTTs), the latter on the basis of the new spectroscopic observations of the most promising candidate, KIC 2831097. The start of the search for binary candidates in the RR Lyrae stars observed with the TAROT telescopes is also announced.

1 Introduction

The RR Lyrae variables are subjected to many other periodicities overlapped to the main pulsation cycle. The evolutionary changes, the excitation of other radial and nonradial modes, the modulation in amplitude and phase known as the Blazhko effect, and period doubling are extensively reported in the literature. Unfortunately, many theoretical aspects are not well understood yet. Recently, many efforts have been made to detect the light-time effect, i.e., periodic variations of the O−C (*Observed* minus *Calculated*) values of the times of maximum brightness ($T_{\max}$) due to the orbital motion of the RR Lyrae component in a binary system.

In the present contribution, we report on the new observational efforts made jointly with the Brera team in Italy, the IRAP team in France, and by the amateur astronomers composing the *Groupe Européen d'Observations Stellaires* (GEOS).

2 The Pulsation Period of RR Lyr

The analysis of all the $T_{\max}$ epochs listed in the GEOS database allowed the careful reconstruction of the changes in the pulsation period of RR Lyr (Le Borgne et al., 2014), i.e., the alternation of two states characterized by the pulsation over a period longer than 0.56684 d and over another shorter than 0.56682 d. We emphasize the importance of continuing to monitor RR Lyr: it is not only the eponym of the class

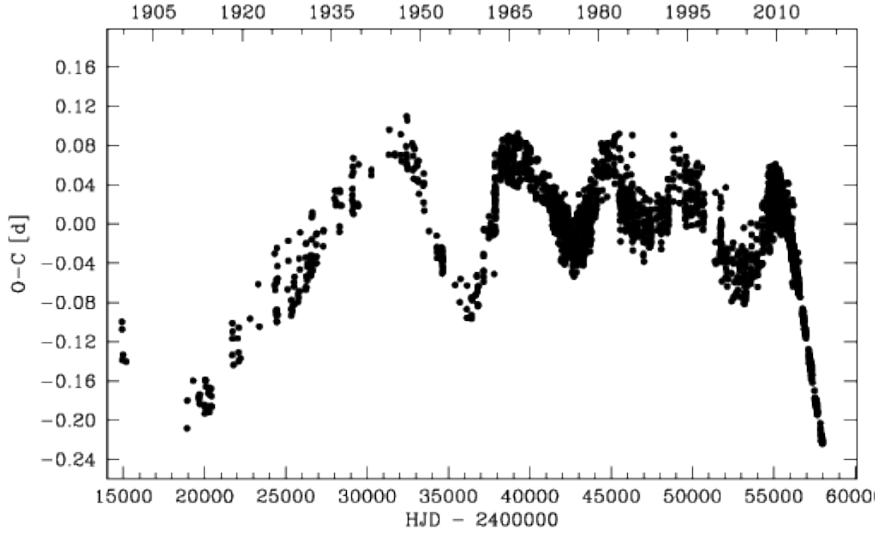

Fig. 1: The historical behaviour of the O−C values of RR Lyr. The new $T_{\max}$ measured by VTTs in 2015, 2016 and 2017 are on the extreme right side.

of variable stars, but the ideal laboratory where all the tests of the modelling of the pulsation on horizontal branch stars can be performed. The persistence of the current pulsation period in the low status was established by the new $T_{\max}$ values obtained in 2015 (Poretti et al., 2016). The survey with the "Very Tiny Telescopes" (VTTs; Le Borgne et al., 2014) has continued in 2016 and 2017. Figure 1 shows the development of the pulsation period in the last three years: the new $T_{\max}$ values indicate that the pulsation is still in the short-period status. The pulsation period is actually the shortest ever experienced by the star.

3 The Blazhko Period of RR Lyr

We also determined the Blazhko period since 1910 to verify how it follows the changes in the pulsation period (Le Borgne et al., 2014). We could infer that the variations of the pulsation and Blazhko periods are completely decoupled, since the Blazhko period had just one sudden decrease from 40.8 d to 39.0 d in 1975.

We remind the reader that the measurements obtained by the VTTs and by *Kepler* have also been extensively used to record the monotonic long-term decrease in the amplitude of the Blazhko effect (Le Borgne et al., 2014). Such a decrease resulted in an almost final damping in 2014. The subsequent $T_{\max}$ values collected with the VTTs in 2015 showed a slight increase in the amplitude of the O−C values (Poretti et al., 2016). The new values collected in 2016-17 confirm that the Blazhko effect has resumed at a measurable amplitude (Fig. 2). However, the amplitudes in 2015 and 2016-17 look very similar (Fig. 3) and hence the effect is still weak.

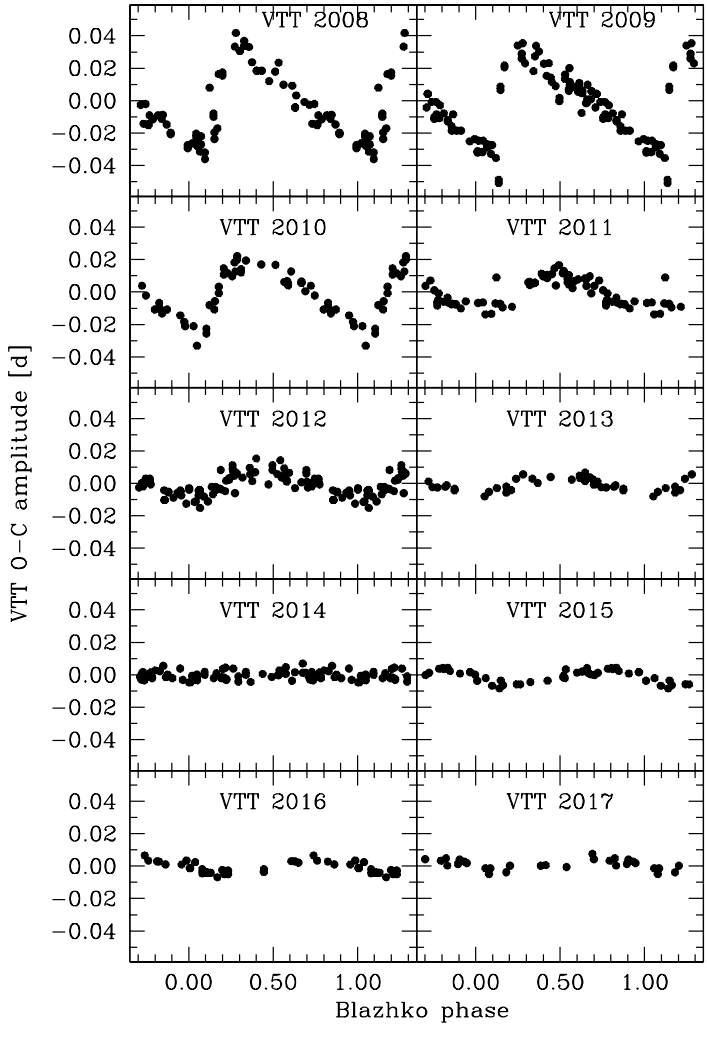

Fig. 2: The behaviour of the amplitude of the Blazhko effect of RR Lyr. The new determinations in 2016 and 2017 are shown in the bottom panels.

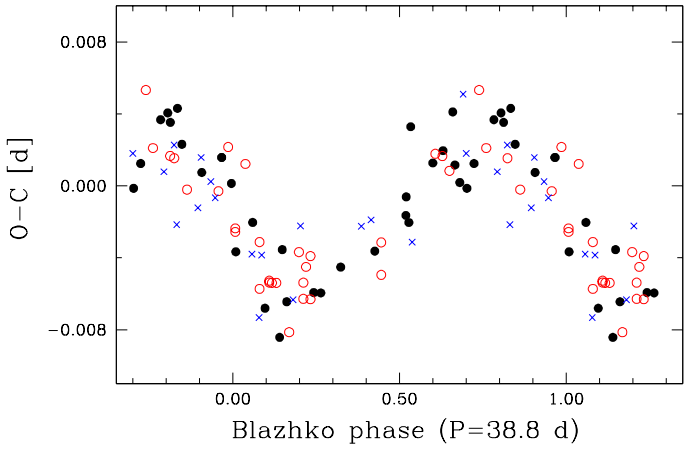

Fig. 3: The O−C values obtained in 2015 (filled black circles), 2016 (empty red circles) and 2017 (blue crosses) folded with the Blazhko period P_B=38.8 d.

4 Hunting for the First RR Lyrae Star in a Binary System

We do not know of any binary system in which one of the components is an RR Lyrae variable. Searching for such a system is not only an observational exercise. Our knowledge on the masses of RR Lyrae stars is based on evolutionary and pulsation models. A direct measure is still lacking. As in the case of many fields of stellar astronomy, binary stars can provide the laboratory where this measure can be extracted.

The *Kepler* field includes many RR Lyrae variables, new and old (Benkö et al., 2010). The almost continuous light curves supply a testbed for the careful analysis of the O−C values in the search for cyclic patterns due to the light-time effect. Such an analysis is particularly powerful in the case of *Kepler* stars since they have been observed for 4 years, investigating a wide range of orbital periods. A very promising candidate has been recently proposed: KIC 2831097 (Sódor et al., 2017). It is a first-overtone RR Lyrae variable with a period P=0.337 d and a light amplitude of ΔK_p=0.40 mag.

The O−C curve shows two overlapping effects: a linear decrease of the pulsation period, as observed in many RR Lyrae variables (Le Borgne et al., 2007) and a well-defined periodicity of 753 d with a full-amplitude of 0.04 d. This periodicity seems to be a well-established fact since it has been followed for almost two full cycles and repeats itself in a very regular way (fig. 2, top panel, in Sódor et al., 2017). We can look at KIC 2831097 as the current best target for hunting the first RR Lyrae star in a binary system.

In our collaboration, we obtained a clear radial-velocity curve from the Hα line by using the FIES instrument mounted at the Nordic Optical Telescope (Roque de Los Muchachos, La Palma, Canary Islands, Spain). Figure 4 (left panel) shows the radial velocity obtained from the Hα line, folded over the pulsation period; the mean systemic velocity has been subtracted. The spectra were taken in August 2017, near one of the quadratures. A similar campaign is planned in May 2018 to obtain the

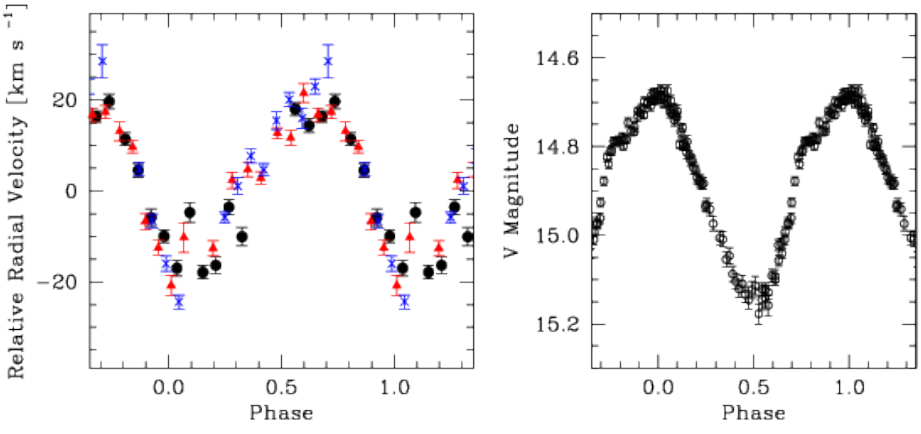

Fig. 4: *Left panel:* the radial velocity curve over the pulsation period obtained with FIES in August 2017. Different symbols for different nights. *Right panel:* the light curve from simultaneous CCD photometry.

pulsation radial velocity at the other quadrature.

The GEOS collaboration also ensured the simultaneous photometric coverage: Fig. 4 (right panel) shows the V light-curve obtained by the Agrupació Astronòmica de Sabadell (Spain) with a Meade 12" telescope equipped with a CCD Moravian G2 1600.

5 Searching for Binary RR Lyrae Stars in the GEOS Survey

Since 2004, the GEOS survey uses the TAROT telescopes to measure the O−Cs of $T_{\max}$ values of hundreds of Galactic RR Lyrae stars (Le Borgne et al., 2007). The O−C accuracy is about 3 minutes, and some stars are observed many times per year. As a consequence, such a density of O−C values leads to identify new variations with periods longer than ten years. They could be due to a companion of the RR Lyrae star, thus invoking a light-time effect. The baseline of only 13 years of the GEOS survey introduces a bias leading to find suspect companions nearer than 20 AU from their RR Lyrae star. It remains difficult to distinguish if the variations are due to the light-time effect or to a very long Blazhko period from photometric data only. Taking into account the large distance of the stars from the Earth, the apparent angular separation is typically lower than 10 mas, making it very challenging for direct confirmation by using adaptive optics. We plan to continue the TAROT observations to confirm the suspected periodicities and to find other stars with longer periods.

6 Conclusions

The VTT monitoring showed that the pulsation of RR Lyr has continued in its short-period status in 2016 and 2017. Moreover, the VTT still measured a weak amplitude of the Blazhko effect, but larger than in 2014. Both facts confirm the importance

of continuing the observation of this star, since its behaviour through the ages can bring important information on the evolution of horizontal-branch stars.

As a new topic in the GEOS research, we investigated the TAROT database to identify RR Lyrae stars in binary systems. At the moment, KIC 2831097 remains the best candidate for such a system. We started an observational project to obtain the radial velocity curves of this star at the predicted quadratures. The first campaign was successful, while the second is programmed in 2018.

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Conference dinner in the Wieliczka Salt Mine, Jan Haluszka Chamber. From left to right: Jean-François Le Borgne, Fouad Sefyani, Abdelmjid Benhida, Jan Kare Trandem Qvam, Erika Pakstiene and Ennio Poretti.