Pulsational Modeling and Projection Factor of RR Lyrae Stars

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We present in this paper the application of the SPIPS algorithm (SpectroPhoto-Interferometry of Pulsating Stars) on the RR Lyrae prototype RR Lyr. SPIPS is a modeling tool that combines all the available observables (radial velocimetry, interferometry, and photometry) to estimate the physical parameters of the star (ratio distance/p-factor, effective temperature, presence of infrared excess, color excess, etc.). Using the known distance of the RR Lyr prototype as an input, we derive the value of its projection factor: $p = 1.34 \pm 0.07$. The forthcoming *Gaia* DR2 will provide a considerable improvement in quantity and accuracy of the trigonometric parallaxes of variable stars. From this sample of RR Lyrae, the SPIPS modeling tool will enable a robust calibration of the distance scale.

1 Introduction

RR Lyrae variables are valuable distance indicators thanks to their relatively high brightness and number, but the accuracy of their distance scale is still not satisfactory. A common way to estimate distances of variable stars is the parallax-of-pulsation method which relies on the comparison of the linear amplitude of the pulsation (derived from spectroscopic radial velocities) and its angular amplitude (from interferometry, or surface brightness-color relations).

However, the accuracy of this method is limited by the projection factor (p-factor). This parameter permits us to convert the spectroscopic radial velocity integrated over the disk of the star into a pulsation velocity (corresponding to the velocity of the stellar photosphere). Unfortunately, there is a full degeneracy between the p-factor and the derived distance. Jurcsik & Hajdu (2017) estimated that the inaccuracy of the projection factor induces a systematic uncertainty of 3 to 10 % on the RR Lyrae distance scale calibrated using the parallax-of-pulsation technique in the galactic field and globular clusters. We present in section 2 the preliminary results of the application of the SPIPS method to RR Lyr.

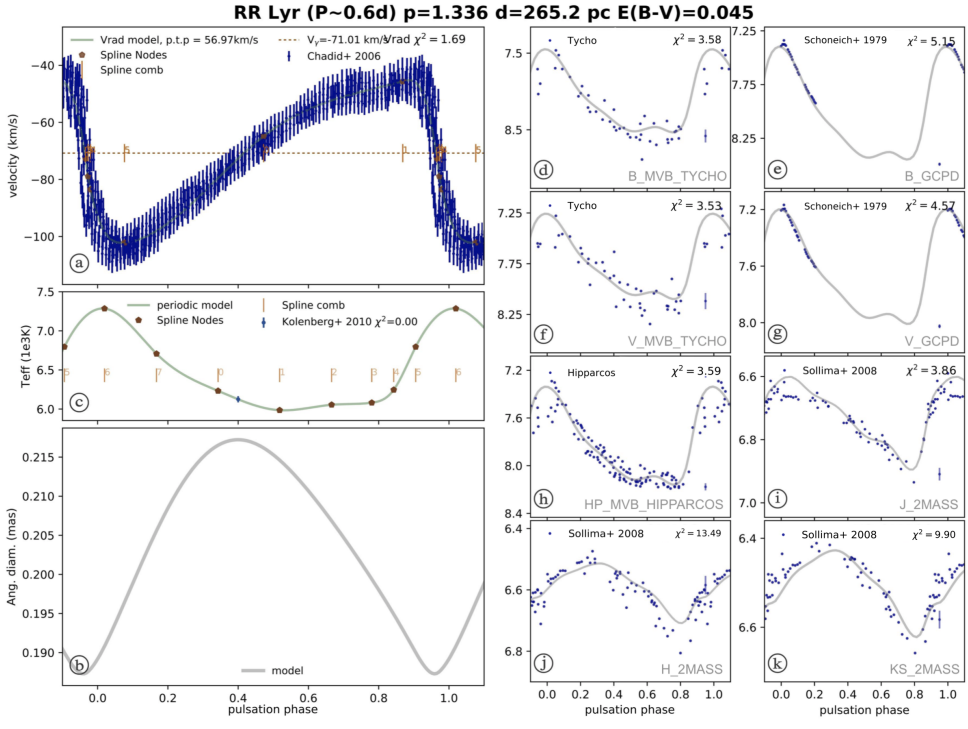

Fig. 1: SPIPS combined fit of the observations of RR Lyr. ⓐ Radial Velocity, ⓑ Angular diameter, ⓒ Effective Temperature, ⓓ-ⓛ Photometry.

2 Application of SPIPS to RR Lyr

The SPIPS method (Mérand et al., 2015) is inspired from the classical parallax-of-pulsation technique. The modeling code considers a pulsating star as a sphere with a changing effective temperature and radius, over which is superimposed a combination of atmospheric models from precomputed grids (ATLAS9, Neilson & Lester, 2013). This algorithm can take all the different types of data and observables that can be found in the literature into account, in particular, magnitudes and colors in all optical and infrared bands and filters, radial velocities, and interferometric angular diameters. The resulting redundancy in the observables and the combination with physical models ensure a high level of robustness and permits us to reach a better accuracy on the resulting parameters (such as the ratio distance/p-factor, the color excess $E(B-V)$, etc.). A preliminary overview of the SPIPS model of RR Lyr is presented in Fig. 1.

This star is the nearest and the best studied variable star of its class and therefore plays a crucial role in the calibration of the distance scale and the study of pulsating stars.

Benedict et al. (2011) derived a parallax $\pi = 3.77 \pm 0.13$ mas from the analysis of the *Hubble Space Telescope* FGS data. This is still the most accurately determined trigonometric parallax available for RR Lyrae stars. For this analysis, we used the B and V light curves from Schoneich & Lange (1979), the B and V photometric

data from *Hipparcos* and *Tycho* catalogs and near infrared JHK band photometry from Sollima et al. (2008). We also included the radial velocities measurements from Chadid & Chapellier (2006). In order to better constrain the SPIPS model, we added the effective temperature estimates derived by Kolenberg et al. (2010), based on high-resolution spectra.

A strong Blazhko effect is visible on this star (Kolenberg et al., 2011). This effect is characterized by an amplitude and a phase modulation of the pulsation of RR Lyr and might be due to a resonance between radial modes (Le Borgne et al., 2014; Buchler & Kolláth, 2011). Because of the great dispersion of the data on several Blazhko cycles, this effect is difficult to take into account in the SPIPS algorithm. The following analysis was made considering the mean radial velocities and photometric curves on several cycles.

The overall quality of the fit of the available observables is satisfying, with a resulting projection factor of $p = 1.34 \pm 0.07$ ($\pm 6\,\%$). This value is in agreement with some other works in the literature (Jones et al., 1992, $p = 1.32$). We also estimate some parameters such as the color excess of $E(B - V) = 0.045 \pm 0.004$, and we rule out the presence of a strong infrared excess coming from possible circumstellar envelopes.

3 Discussion and Perspectives

Some recent studies (Jurcsik & Hajdu, 2017; Skarka et al., 2018) concluded that the BW-method applied to RR Lyrae stars is sensitive to the Blazhko effect. On the contrary, this preliminary application of the SPIPS method to RR Lyr gave satisfying results. This difference can be due to smaller amplitude variations during a Blazhko cycle than those studied in the cited works and the good coverage of the Blazhko cycle of our dataset on RR Lyr.

An efficient way to improve these results is the collection of more recent datasets with a best coverage in phase. Another perspective is to use the results of this analysis on another sample of RR Lyrae pulsators in order to compare the derived parameters with some other recent studies.

Actually, only RR Lyr has a sufficiently accurate distance, and the precision of the RR Lyrae parallaxes released in the *Gaia* DR1 (Gaia Collaboration et al., 2017) is insufficient to constrain significantly their projection factors. The *Gaia* DR2 is expected to deliver more than a hundred thousand parallax measurements of RR Lyrae stars. According to Clementini (2016), a 10 μarcsec accuracy is expected for a hundred of them in the final *Gaia* data release. Fixing these distances in SPIPS and combining all types of new and archival observations, we will soon be able to resolve the distance/p-factor degeneracy for a larger sample of RR Lyrae, thus removing the major systematics of the parallax-of-pulsation technique.

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BBQ at the Podegrodzie Settlement, at the foot of the Royal Castle in Niepołomice. Emese Plachy, Róbert Szabó, Aliz Derekas, József Benkő and Zoltán Kolláth.