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Origin of the Blazhko effect:

(im)possible mission ?

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Abstract. A century ago after its discovery, the Blazhko effect still remains a mystery. In this short paper, we summarize some of the new spectroscopic results concerning the properties of the modulation of RR Lyrae, giving new insight towards an understanding the Blazhko enigma. The results are based on a detailed anlysis of high precision spectroscopic observation sets spread continuously over an entire Blazhko period (41 days).

Key words. Line: profiles–Stars: variables: RR Lyrae–Stars: oscillations – Stars: Blazhko effect – stars: individual: RR Lyrae–techniques: spectroscopy

1. Introduction

A century ago, S.N. Blazhko discoverd a periodic modulation of both the amplitude and the phase of the main pulsation on timescales typically varying from dozens of days to hundreds of days. This phenomenon, so-called Blazhko effect (Blazhko 1907), is exhibited by some 25–30% of the RRab and 5% of the RRc population of the Galactic Bulge.

The Blazhko effect does not yet have a generally accepted explanation. Several explanations have been put forward, but there is still no consensus on the mechanism underlying the Blazhko effect (Kovàcs 2001). Both groups of competing Blazhko models that exist today involve nonradial pulsational modes. The first observational detection that the Blazhko phenomenon is caused by nonradial mode excitation comes from analysis of RR Lyrae high precision spectroscopic observations (Chadid et al. 1999), showing a triplet frequency structure with a separation equal to the Blazhko frequency around the pulsation frequency. The left sidepeak being higher than the right one. Chadid et al. (1999) claimed a quintuplet structure as well. Later, Smith et al. (2003), based on CCD photometric observations, confirmed the triplet frequency structure in RR Lyrae, but with a right sidepeak higher than the left one. They did not detect any quintuplet structure. Nevertheless, it has still been hard to identify exactly which nonradial pulsation modes are excited in RR Lyrae, based primarily on observations poorly spread over both the pulsation and the Blazhko period, in combination with the time spacing of the observations, which introduces alias frequencies and can bias the observed amplitudes of the detected frequencies.

2. Frequency analysis and discussion

The spectroscopic observations used in this study were obtained at the Observatoire de

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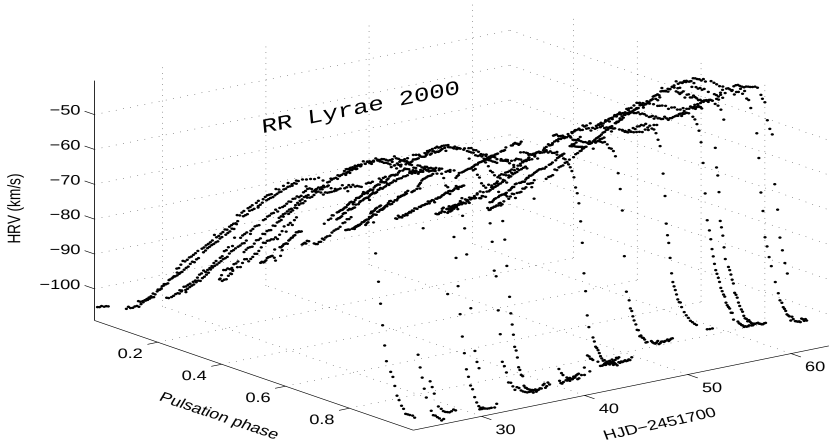

Fig. 1. Two-dimensional radial velocity curve (in km/s) calculated from the AURELIE spectra and folded with the pulsation period (0.5669 d) over a whole Blazhko cycle. The variations in the radial velocity curve due to the Blazhko effect are clearly visible.

Haute-Provence from June to August 2000, using the AURELIE spectrograph attached to the 1.52 m telescope. The spectral domain covers the range from 484 nm to 494 nm with a resolving power R ≃ 60 000. A signal–to–noise ratio (S/N) of around 90 was obtained for a time resolution around 0.5 % of the pulsation period of 13 h36 mn. Figure 1 shows the two-dimensional radial velocity curve of the single ionized metallic absorption line Fe II $\lambda\lambda$ 4923.921. As can be seen from Figure 1, the data sampling provides a homogeneous coverage of all Blazhko phases. The variation in both heights of maxima and minima of the radial velocity curves indicated a modulation period of about 41 days. The frequency analysis study is carried out using the Fourier transform analysis on the heliocentric radial velocity data. The frequency analysis showed a pulsation frequency $f_0 = 1.7637$ c/d ($P_P = 0.5669$ d) as the dominant frequency with its first fourteen harmonics. The Fourier spectra prewhitened with the pulsation frequency and its harmonics are shown in Fig. 2 (the second panel from the top). Prominent peaks are seen at frequencies of 1.7914, 3.5538, 5.3157, 7.0771, 8.8412, 10.6051, 12.3668, 14.0768, and 15.9002 c/day. These frequencies beat against f_0 with beat periods of 36.10, 37.88, 40.65, 44.84, 44.05, 43.67, 47.85, 36.76, and 37.17 days, consistent with a 41 day Blazhko period. The third panel from the top of Fig. 2 shows the results of the Fourier transform analysis after a second prewhitening of the modulation frequencies. Peaks are now selected at frequencies of 1.7343, 3.4985, 5.2671, 7.0336, 8.7998, 10.5574, and 12.3170 c/day beating against f_0 with periods of 34.01, 34.60, 41.67, 47.17, 53.48, 40.32, and 34.60 days, with an average of around 40.84 days, which is consistent with the Blazhko period as well. A third prewhitening of the all modulation frequencies gave a flat spectrum, showing that there are no other components present above the noise level (see the bottom panel in Fig. 2)

The new spectroscopic results show, (1) a triplet structure with an equidistant frequency spacing and a large asymmetry in the modulation amplitudes, (2) the main pulsation amplitudes of the harmonic components are decreasing exponentially, whereas the decrease is linear for the right and left modulation components, (3) there is no quintuplet structure detected within a median 1 σ radial velocity uncertainty of 250 m/s, (4) there is a residual scatter occuring during a small phase interval corresponding to the phase of the main shock passage across the photosphere, (5) the scatter is more important during the middle of the de-

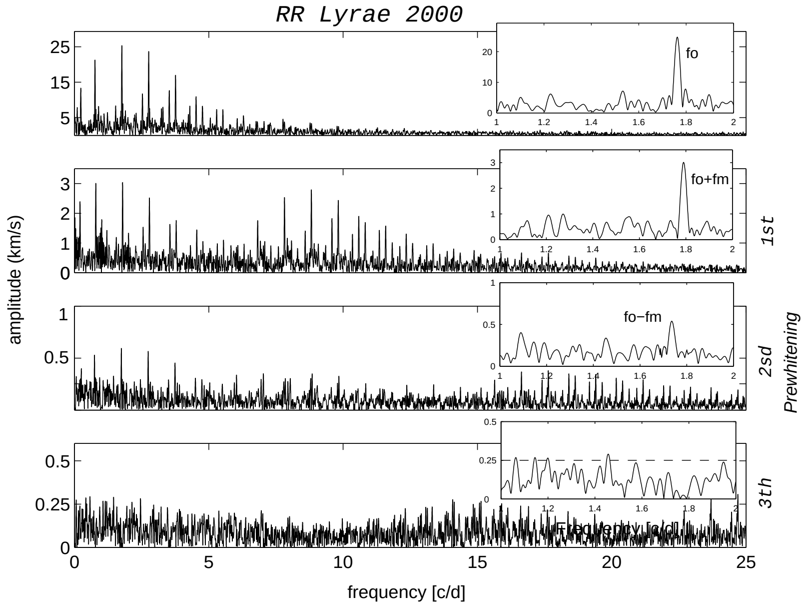

Fig. 2. Fourier spectra on the heliocentric radial velocity. The upper panel shows the amplitude spectrum, the other three panels are the residual spectrum after prewhitening with the main frequency f_0 and its harmonics, the $kf_0 + f_m$ frequency and the $kf_0 - f_m$ frequency respectively. The insert panels show the enlargements between the frequencies 1.00 c/d and 2.00 c/d. The dashed curve shows the noise level that corresponds to the level of the weakest amplitude in the data.

scending branch of the radial velocity curve, when the shock intensity is maximum, and finally (6) The radial velocity curves exhibit a Blazhko periodic variation in both heights of maxima and minima, in contradiction with photometric results, which indicate a Blazhko variation only in maxima of the light curves (Smith et al. 2003). These observational results put constraints on any proposed explanation of the Blazhko enigma. The most popular hypotheses nowadays for explaining the observed properties of the Blazhko stars are focused on two groups. The *magnetic models* wich require a strong magnetic field and predict a quintuplet structure in the frequency spectrum. Based on high-precision observations of the longitudinal magnetic field, Chadid et al. (2004) concluded that RR Lyrae is in fact a *bona fide* non–magnetic star, providing the strongest argument yet against the oblique magnetic rotator models. Furthermore, our analysis does not show any quintuplet structures in the frequency spectrum below the 250 m/s level. This is another argument against the magnetic models, which predict such structures. The *resonance models* based on a nonlinear resonant coupling between the dominant radial mode and non–radial modes. The dipole modes have the highest probability of being nonlinearly excited (Dziembowski and Mizerski 2005). These models predict a triplet frequency structure with sidelobes of similar amplitudes, symetrically placed around the fundamental radial mode frequency and its harmonics.

Neverthless, the results presented above also seem to rule out the resonance models, which are the only models still available to explain Blazhko phenomenon. In fact: One major problem for the resonance models is the production of strongly asymmetric modulation components detected in our data, since they predict approximate equality of the amplitude ratios between the symmetrically spaced side lobe frequencies of the different order components. On the other hand, it is important to recall that according to the nonlinear coupling

Fig. 3. Sergei Nikolaevich Blazhko (1870 - 1956) Memory of a Century of the Blazhko effect (1907)

theory, the nonradial modes are highly nonlinear in evolved stars. Thus, it is probably not easy for the resonance models, which involve nonradial pulsational modes, to explain why the high order nonlinear coupling terms show amplitudes commensurable with the first order types in our data. There are significant differences between the order dependence of the amplitudes of the modulation component frequencies and the radial mode frequency. The origin of these differences cannot be explained by nonlinear coupling. In fact, since the harmonic terms of the radial mode, invoked by nonlinear coupling, decrease nonlinearly, it is expected that the nonlinear coupling terms of nonradial modes have to decrease nonlinearly as well. Then, the nonlinear coupling can not explain the linear decrease of the amplitude modulation components. There are irregular changes in the RR Lyrae atmosphere during the Blazhko cycle. The residual scatter is most intense where the nonlinear effects are most important (shock wave passages). Therefore, the connection between temporal hydrodynamic phenomena and such modulation has to be taken into account in Blazhko models.

3. Conclusions

We conclude that the physical origin of the Blazhko phenomenon is still poorly understood. Our detailed spectroscopic observations of RR Lyrae, obtained over an entire Blazhko period, make it more difficult to explain the Blazhko effect with the current resonance models, which are the only theoretical models available that explain the Blazhko enigma, and provide new insight for understanding this long-standing puzzle. The connection of the atmospheric dynamics of RR Lyrae and the cycle modulations has to be seriously considered in future Blazhko theoretical investigations.

Observations from Space constitute the natural development in the description of the stellar interiors and to introduce dramatic increases in the number of identified frequencies. The CoRoT mission is expected to help to identify the suspected nonradial modes among RR Lyrae stars towards to understanding of Blazhko enigma. An international CoRoT programme, '*Blazhko effect and double mode in RR Lyrae stars, Chadid et al.* ' is in progress (See http://www-luan.unice.fr/ chadid/projetcorot.pdf)

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