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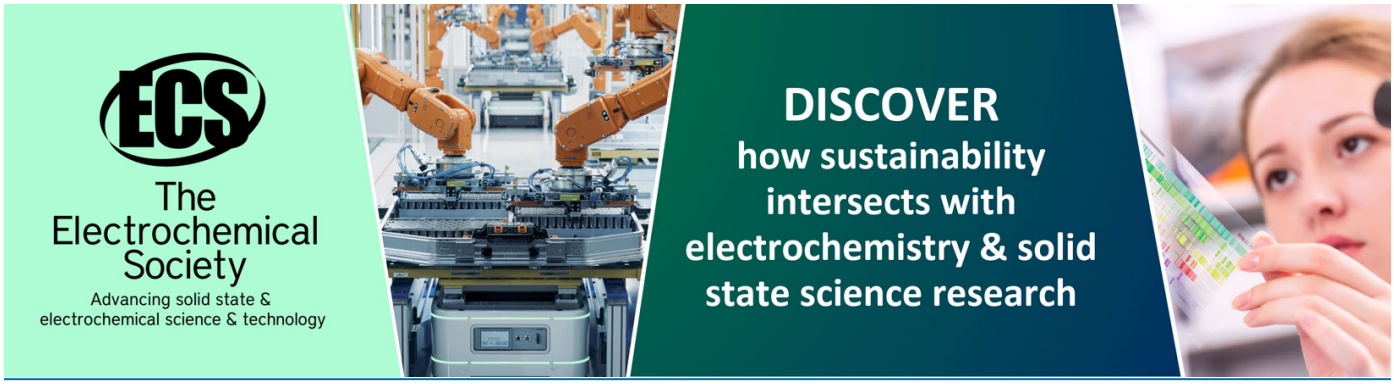

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Metallic line doubling in the spectra of the variable RR Lyrae star

F L Sefyani[1], A Benhida[1], Z Benkhaldoun[2], T De France[3], D Gillet[4], P Mathias[5], M Lazrek[2], Y Eljariri[2], K Chafouai[2], A Daassou[2]

[1]Oukaimeden Observatory, LPHEA FSTG, Cadi Ayyad University, BP 549 Marrakech, Morocco
[2]Oukaimeden Observatory, LPHEA FSSM, Cadi Ayyad University, BP 2390 Marrakech, Morocco
[3]AAVSO (American Association of Variable Star Observers), 49 Bay State Rd, Cambridge, MA
[4]Observatoire de Haute-Provence - CNRS/PYTHEAS/Université d'Aix-Marseille, 04870 Saint Michel l'Observatoire
[5]CNRS UMR5277 Institut de Recherche en Astrophysique et Planétologie, 14 Avenue Edouard Belin, 31400 Toulouse, France

E-mail: sefyani@uca.ma

Abstract. We present the observation of line doubling absorption in the spectra of the RR Lyrae variable star on the metal lines of FeII ($\lambda = 4923.921$Å) as well as of D1 and D2 lines of sodium. For the emission, we observed the lines of hydrogen H_α and H_β with a very high intensity and the two lines of HeI ($\lambda = 5875.66$ Å and $\lambda = 6678.15$Å). This transmission/helium I remission [1, 2] is directly related to the intensity of the shock wave through the atmosphere of the star during the phase of maximum Blazhko cycle [3]. During the expansion phase of the photosphere of the star and during the passage of the shock wave we witnessed a disappearance of the absorption lines of neutral FeI ($\lambda = 4934.006$Å and $\lambda = 4920.503$Å) and their reappearance in phase 1.00. These observations were made with a spectrograph resolution scale of about 12,000 installed on the C14 telescope at the Oukaimeden observatory (J43) during the different star pulsation cycle. We noticed that some of them almost coincide with the maximum Blazhko cycle. The doubling line were interpreted by Schwarzschild [4] on the basis of a two-layer atmosphere. This interpretation could measure the speed of the shock wave derived from the difference between the two red and blue spectral components on H_α hydrogen lines, D3 helium, D1 and D2 lines of sodium and FeII during the observed doubling of lines. At phase 1.00, the shock wave reached the maximum speed of 160 km.s^{-1} confirming the hypersonic regime occur during this maximum Blazhko cycle.

1. Introduction

The Astronomical Observatory of Oukaimeden (J43) is a research entity belonging to the Cadi Ayyad University. It is located at an altitude of 2700 m on the High Atlas range 78 km south of Marrakech ($7°52'52''$ west and $31°12'32''$ north).

RR Lyrae (HD 182989) is the brightest star of the sky in its class. It is also the most observed star in spectroscopy and photometry. Its light curve shows a period of 0.5668 days and is subject to amplitude and phase modulation discovered by Bazhko in 1907 [3]. At present, it is well established that the shock waves pass through the atmosphere of the pulsating variable

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star RR Lyrae during the periodic pulsation movements. Among the observational facts in favor of these waves, there is the discontinuity in the radial velocity curve, the doubling of absorption lines, the appearance of emission lines and the Van Hoof phenomenon [5]. The doubling of lines was interpreted by Schwarzschild in 1952 [4] on the basis of a two-layer atmosphere: during compression (decreasing curve of light), all the layers of the atmosphere move inwards, the front of shock wave penetrates the lower layer of the atmosphere and a reversal of direction of motion occurs. This results in a rapid movement of the atmospheric layers from the inside to the outside in the phase interval $[0.9-0.1]$. Historically, the doubling of metal lines was observed for the first time by Sanford in 1952 [6] on W. Virginis. In 1992, Lbre and Gillet [7] observed the doubling of the sodium D lines.

In 1996, Chadid and Gillet [8] detected the doubling on metallic lines of FeI ($\lambda = 4934.006$Å) and TiII ($\lambda = 5188.700$Å), the physical interpretation of which was presented by Fokin and Gillet in 1997 [9]. Phenomenon results from the passage of the shock wave in the atmosphere of the star during phase 0.9 at the beginning of the expansion of its atmosphere. In 1997, Chadid and Gillet [10] also detected the doubling in the metallic lines of FeII ($\lambda = 4923.921$Å) and MgI ($\lambda = 5183.604$Å). In 2008, Chadid *et al* [11] detected for the first time the disappearance of the metallic FeI lines and their reappearances during the pulsation cycle of the star S Area. As for us, we have observed this doubling on the FeII line ($\lambda = 4923.921$Å) at phase 0.13 of Blazhko Cycle.

2. Observations and data Reduction

Measurements of the spectra of the star RR Lyrae were performed on 12 October 2013 and 28-29-30 October 2015 as well as during the night of 6 November 2015. The period of each pulse is 0.566835616 day ie 13 h 36 min. The spectra were acquired using the C14 telescope. The Scale Spectrograph, connected to the 50 μm diameter optical fiber telescope, has a resolution of 12000 with a dispersion of 16Å / pixel and is equipped with a QSI camera using a 3.2 meg pixel CCD at 6.8 μm per pixel. Calibration is performed with a Thorium-Argon lamp. The camera is cooled to $-20C$ throughout the measurements. The exposure time is $300s$ for each recording. The spectra were filtered with a Gaussian filter at $\sigma = 0.6$ pixels. The spectral dispersion is about 0.1 Å/pixel. The measured signal-to-noise ratio is about 30 dB. The time resolution is: $\Delta t/P \approx 0.6\%$. The spectrograph is equipped with a diffraction grating for dispersing light between 4100 Å and 7200 Å between orders 32 and 52. The curves of the line profiles established according to Stellar Rest Frame. The velocities presented are taken with respect to the barycenter of the star established in the heliocentric reference frame. The value of the barycentric velocity of the star in the heliocentric reference frame is -73.5 km/s from the results of Chadid & Gillet [8]

3. Metallic Line Doubling

It is well established that the shock waves pass through the strip formation zone during each pulsation cycle of the star atmosphere. These shock waves generate a phenomenon of overall motion of the atmospheric layers. Once these layers arrive at the level of the photosphere, they rebound and give rise to a migration of the metal lines of absorption of red to blue. The measurements carried out by Chadid and Gillet in 1996 [8] confirm, for the first time, the presence of doubling of metal lines on the star rr-lyrae at phase 0.926. These are the neutral FeI ($\lambda = 4394.006$Å) and ionic TiII ($\lambda = 5188.700$Å) lines. They also observed the doubling in the form of broadening of lines on the FeII ($\lambda = 4923.921$Å) and on the MgI ($\lambda = 5183.604$Å). The intensity of these duplications depends on the Blazhko phase according to the study made by Chadid and Gillet in 1997 [10]. This suggests that the doubling on the FeII is synonymous with the presence of a very strong shock wave observable at the maximum of the Blazhko cycle. During the night of 12 October 2013 and at phase 0.853, at the beginning of the observations,

the doubling of the FeII metallic lines had indeed begun (figure 1). The ion FeII absorption line (λ = 4923.921Å) reached the middle of the doubling at phase 0.941. On the other hand, no duplication of metal lines is observed on the spectra corresponding to phases 0.38 and 0.58 of the Blazhko cycle, just a phenomenon on broadening occur at this phase. Moreover, we observed the phenomenon of disappearance of the neutral FeI lines (λ = 4934.006Å and λ = 4920.503Å) and their reappearances in phase 1.00.

The doubling of metal lines detected by Preston in 2011 [12] on the RR-lyrae type stars shows that the emission of HeII (λ = 4685.68Å) appears during the pulsation cycles in which the doubling of the metal lines occurs. This suggests that this phenomenon of doubling is physically synonymous with intense dynamic activity of the pulsating movements of the star's atmosphere. On the other hand, Chadid *et al* observed for the first time on the star S Arae [11] the disappearance of absorption lines of FeI (λ = 4920.503Å), FeI (λ = 4934.006Å) and neutral TiI (λ = 4918.6Å) during the passage of the shock wave. This same phenomenon was observed also on the star RR-lyrae but concerning just the lines of the FeI neutral (λ = 4934.006Å and λ = 4920.503Å). Thus, it appears that the ionization of the FeI (λ = 4934.006Å and λ = 4920.503Å) during the expansion phase of the star photosphere reflects the intensity of the shock wave that passes through this atmosphere (figure 2).

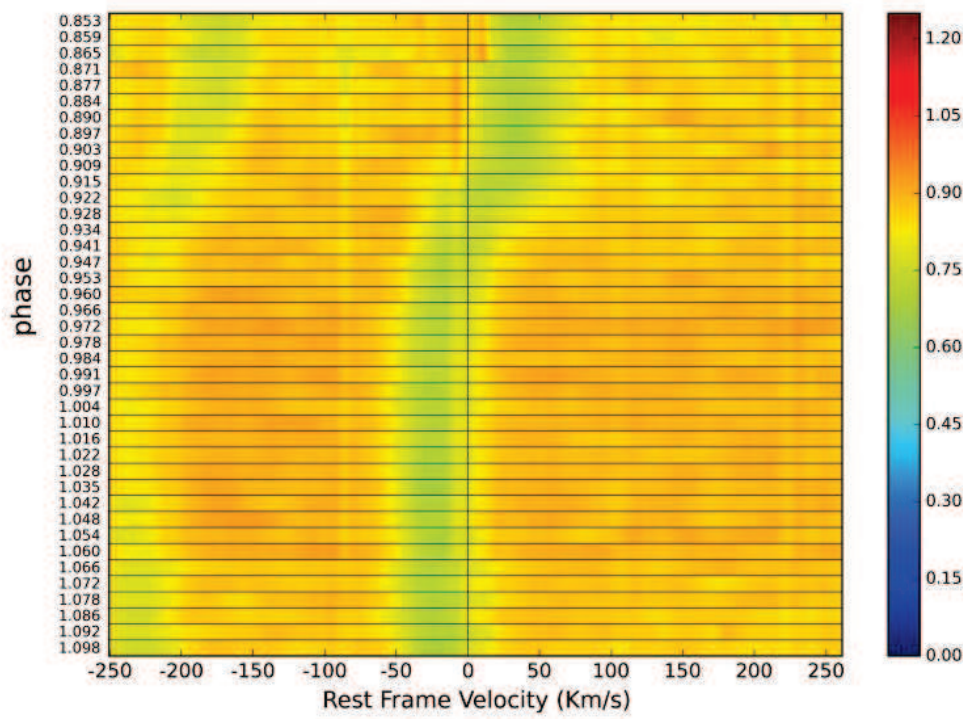

Figure 1. Time series of FeII (λ = 4923.921Å) line of RR Lyr, ordered by increasing phase from top to bottom. On the left, time series of FeI (λ = 4920.503Å). Spectra are interpolated to provide a 2-dimensional map of the (λ = 4923.921Å) profile in the [-250; 250] km /s velocity range. Velocities are given in the stellar rest frame with positive velocities corresponding to inward motion (toward the photosphere). The pulsation phase is given on the left side. On the right side, the color bar representing the flux is from 0.0 to 1.2.

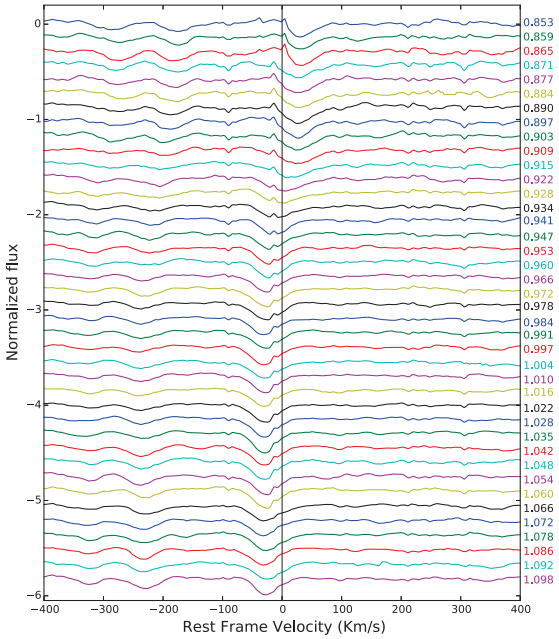

Figure 2. Evolution of the (λ = 4923.921Å) line profile of RR Lyrae at phase 0.13 of Blazhko Cycle. The pulsation phases are indicated on the right side. The vertical line represents the zero velocity in the stellar rest frame. The profiles are arbitrarily shifted in flux.

4. Conclusion

We have observed that the doubling of the ionic FeII line (λ = 4923.921 Å) occurs in phase 0.941 during the night of 12 October 2013 corresponding to the Blazhko phase 0.13. On the other hand, we did not observe any doubling of metal lines in the spectra corresponding to phases 0.38 and 0.58 of the Blazhko cycle. Neutral FeI lines at (λ = 4934.006 et) and (λ = 4920.503Å) showed broadening at the time of transition from the red component of the line to the blue component due to the low amplitude intensity compared to the intensity of the ionic FeII lines. The shock wave is sufficiently intense to ionize the majority of iron atoms involved in the process of line doubling. During the passage of the shock wave we witnessed a disappearance of the absorption line of the neutral FeI (λ = 4934.006Å and λ = 4920.503Å) in favor of an increase in the intensity of the ionic FeII line (λ = 4923.921Å). From phase 1.00, the neutral FeI line reappears (λ = 4934.006Å and λ = 4920.503Å).

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