Honoring Charlotte Moore Sitterly: Astronomical Spectroscopy in the 21st Century
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Contribution of small telescopes at the Oukaïmden observatory in Morocco to study atmospheric dynamics and shocks waves in variables stars RR Lyr and R Scuti

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Abstract. Through Spectroscopy, we aim to develop the field of pulsating stars, especially the atmospheric dynamics of high amplitude pulsators such as RR Lyr and R Scuti, in order to establish new models of the mechanical and thermal behavior of their atmospheres (shock waves, relaxation time, energy loss...). We used high-resolution spectra over a total of 81 nights from made with the spectrograph Eshell during years 2013 and 2015 runs from Oukaïmeden observatory in the High Atlas mountains (Morocco) completed with made with the spectrograph ELODIE (Haute Provence observatory, France) during years 1994–1997. A detailed analysis of line profile variations over the whole pulsation cycle is performed. Shock wave velocity and lines intensity were used as indicators of atmospheric dynamics activities. We have obtained and compared our results with those obtained by the large telescopes, we have obtained thanks to our site very satisfactory results, Indeed : For RR lyr: For the first time the second apparition of Helium (D3) was detected using our Telescope (0.35m) at Oukaïmeden Observatory.

For the first time, during the phase of expansion of the star, the emission of the line D3 is visible on various phases Blazhko, including during the minimum of the cycle Blazhko.

Also, we presented the results of a long- term, high-resolution spectroscopic study of the variable star R Sct. We analyzed the features of the optical spectra of this object and found RSct shows irregular behavior in its slight variations for much of the time that it was observed. Its average period is close to 142 d, but some- times the irregularities are so strong that it is not possible to define a periodic variation.

Keywords. variable stars: RR Lyr, R Scuti, atmospheric dynamics, Small Telescops, Spectrophotometry

1. Introduction

RR Lyrae stars play a major astrophysical role as standard candles for distance determination and as witnesses of the evolution of the universe at a young age. These variables occupy a special place in the family of pulsating variable stars. They have been known for more than a century because of their large amplitude and pulsation period and were considered to be prototypes of pure radial pulsators, with periods ranging from a few hours up to a whole day. Their amplitude and phase modulations are well known as the Blazhko effect.

RV Tauri stars are pulsating variables named after the prototype RV Tau. They occupy the highest part of the instability strip of the Hertzsprung-Russell dia- gram between Cepheids and long-period variables. They are Population II objects, characterized by their high luminosity (L¿ 1500 $L_{\odot}$), low mass (M $\sim$ 0.6-0.7 $M_{\odot}$) and pulsation periods between 30 d and 150 d showing variations along the different cycles Wallerstein & Cox (1984).

The development of spectroscopy in astrophysics has experienced considerable growth thanks to the development of sophisticated instruments that equip large telescopes. However, important results can also be obtained with instruments linked to small telescopes. Indeed, the small spectrographs that equip observatories, such as the observatory of Oukaïmeden (Morocco), can prove to be very efficient in certain fields of astrophysics which require a long period of observations. The case of the study of pulsating variable stars is an example. Thus, the measurement campaign that we have started since 2013, at the Oukaïmeden observatory, on the pulsating star RR Lyr and recently on the star R Sct has made it possible to reveal important results on the atmospheric dynamics of these stars hitherto not yet observed by major observatories. These results that we present agree perfectly with those obtained at the observatory of Haute Provence (OHP) in France, that of Las Campagnas in Chile and that of Midi-Pyrénées observatory in France.

A collection of spectra obtained since 2013 on the pulsating star RR Lyr were analyzed and interpreted. We found the presence of maximum photometric brightness on 31 nights out of the 81 nights. On these 31 nights, we observe each time the emission of hydrogen line H_{α}. This made it possible to highlight important results concerning the dynamics of the atmosphere of the star RR Lyr and to emphasize the cooperation between these observatories.

Additionally, we present the results of a long-term, high-resolution spectroscopic study of the variable star R Sct. We have analyzed the characteristics of the optical spectra of this R Sct star, which has allowed us to correctly interpret the irregular behavior of the evolution of its luminosity curve, the average period of which is close to 142 days.

2. Spectrophotometry at Oukaïmden Observatory

Oukaïmden Observatory (J43)† is a research entity belonging to the Cadi Ayyad University in Morocco. It is located at an altitude of 2700 m on the High Atlas range 78 km south of Marrakech (7°52′5″ west and 31°12′32″ north). The observatory benefits from good observing conditions in a semi-desert area with a median seeing of 1 arcsec (Benkhaldoun (2018), and Benhida et al. (2018)).

The used instrument set-up includes two telescopes on a common mounting. For photometry, a 25-cm ASA 10N telescope was used with a QSI CCD camera with various color filters (Strömgren uvby). For spectroscopy, a 35.5-cm C14 telescope was used along with an eShel spectrograph (125mm F/5 collimator, R2 echelle Grating, cross-dispersing prism, 85mm F/1.8 objective) Thizy & Cochard (2010). We selected 25 consecutive spectra covering a large part of the visible domain (between orders 32 and 52, from 4100 to 7200 Å), and with a resolving power of about 12000. With an exposure time of 300 s, the signal-to-noise ratio (S/N) is about 30 Gillet et al. (2016).

† https://minorplanetcenter.net/mpc/obs_stats

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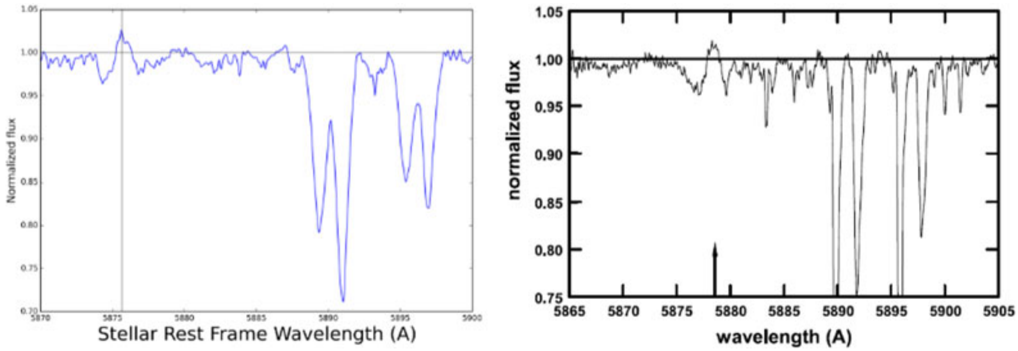

Figure 1. Comparison between the spectral profile of the Post maximum emission of the helium D3 line on the RR Lyr (left) Gillet et al. (2016). and on the RV Oct (right) Preston (2009).

3. Results of RR Lyr

3.1. *First detection of Post maximum D3 helium emission : P-Cygni profile*

The emissions of helium lines were detected on the star RRLyr for the first time by Gillet, Fabas & Lèbre (2013) just after a Blazhko maximum (ψ=0.1). The emission has been observed during the night of July 4, 2011 on the D3 HeI (5875.66Å), the HeI (6678.16 Å) and the HeII (4685.68Å) lines. Recently, we observed for the first time the 2nd emission of the D3 line of helium in the spectra of the RR Lyr star obtained at the Oukaïmeden observatory (Morocco) equipped with a spectrograph of resolution 12000 installed on a C14 Celestron telescope Gillet et al. (2016). This emission line has the shape of a P-Cygni profile, with the emission maximum centered at zero velocity in the stellar restframe and occurs at phase 1.00. We have suggested that this spectral profile is a natural consequence of the great extension of the expanding atmosphere induced by a violent shock that occurs with each pulsation cycle. Certainly because of the weak emission of this 2nd emission which occurs at the time of the doubling of the hydrogen $H\alpha$ line and its large spectral width which prevents its observation on this $H\alpha$ line. It is also possible that the shock wave arrives in the region of formation of the spectral lines of $H\alpha$ sufficiently attenuated not to produce any appreciable emission. The observation of this post maximum emission was carried out with this small 12000 resolution spectrograph installed on a telescope 14 inches in diameter Thizy & Cochard (2010). This D3 emission line was sufficiently well visible and strongly resembles that observed by Preston on the star RV Oct Preston (2009) with a 27000 resolution echelle spectrograph installed on the 2.5-m Pont telescope at Las Campanas Observatories (Fig. 1). Note that the measurement campaign that we started between 2013 and 2015 on the star RR Lyr made it possible to show that the emission of the D3 line is omnipresent in all Blazhko phases (Fig. 2) Benhida et al. (2018).

3.2. *Van Hoof effect linking the metallic lines*

In this year 2022, we conducted a new study on the Van Hoof effect which is an existing phase shift between the radial velocity curves of hydrogen and metallic lines along FeI λ 4920.509 Åand FeII λ 4923.921Å. We have tried to highlight this phenomenon, based on hundreds of spectra of the star RR Lyr collected at the OHP over a period ranging from 1994 to 1997. Other spectra from the observatory of Oukaïmeden were used for the same purpose (a series of 3 nights in 2015 and another series of 3 nights in 2016). This study that we will soon publish, allow us to reveal the presence of the Van Hoof effect between

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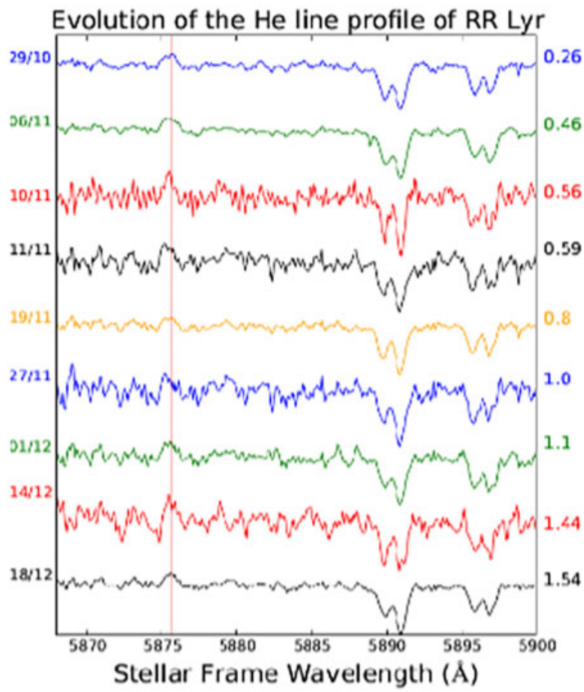

Figure 2. Emission of the line D3 (λ 5875.66Å) some helium, on various Blazhko phases Benhida et al. (2020).

hydrogen and the metallic lines on one hand, and between the metallic lines only on the other hand, that is to say in the lower atmosphere. In addition, we have also studied the influence of the Blazhko effect on the Van Hoof effect thanks to the spectra observed.

4. Results of R Sct: Evolution of the $H\alpha$ profile

R Sct is the brightest and one of the most irregular members of the RV Tauri class. It is also one of the longest known RV Tauri stars. Variations in the period of R Sct are known to exist large variations in the appearance of the H, Ti I, Ca I & Fe I profiles were noted Chafouai et al. (2019).

The spectra of the star R Sct obtained at the Oukaïmden Observatory and at the Midi-Pyrenees Observatory show irregular behavior in its luminous variations for a large part of the time it was observed. Its average period is close to 142 days, but sometimes the irregularities are so strong that it is not possible to define a periodic variation. We were able to show a correlation between the intensity $H\alpha$ and the velocity of the shock wave using a least squares modeling. The temperature generated behind the wake of the shock wave increases considerably when the shock wave velocity also increases. The hydrogen gas heats up accordingly, in turn, and generates the phenomenon of ionization. This leads to a decrease in the number of hydrogen atoms that will contribute to the emission of the $H\alpha$ line, and therefore to a decrease in the $H\alpha$ intensity. These variations can be indicative of differences in the intensity of the shock and the instantaneous state of the atmosphere, so that after one cycle the star does not return to exactly the same state.

In order to investigate the time variations and the peculiarities of the optical spectra of the RV Tauri star R Sct, high-resolution spectroscopic observations in the wavelength interval around the $H\alpha$ line (6540-6580Å) were obtained between 2014 and 2018.

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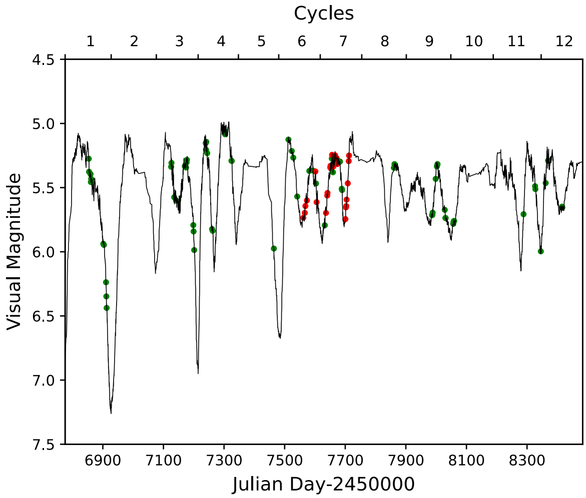

Figure 3. The light curve of R SCT from visual estimates of AAVSO from 2014 to 2018. The over printed single points corresponding to spectroscopic observations of Oukaïmden observatory (red points) and Narval database (green points), see The beginning of each new cycle (according to the photometric ephemeris) is also indicated.

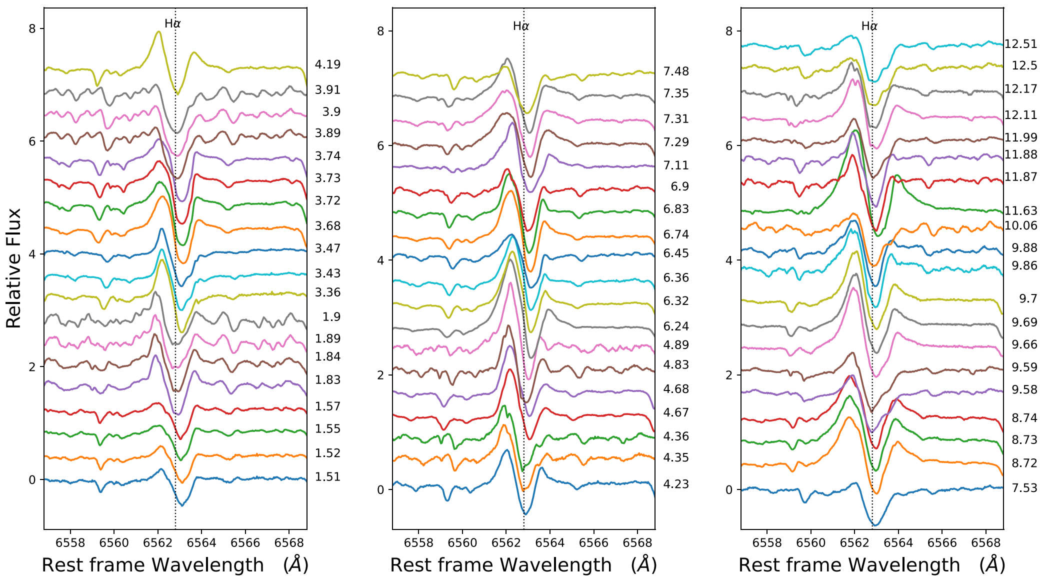

Figure 4. Evolution of the $H\alpha$ line in R Sct along several pulsation cycles. The cycle number and phase are indicated to the right of each spectrum (e.g., 12.51 means phase 0.51 in cycle 12). The dashed line represents the rest frame wavelength of the $H\alpha$ spacral line profile (λ6562.808Å).

The most striking feature in the visual spectral range is the strong $H\alpha$ line (see Fig. 3). The Balmer $H\alpha$ line changes in the spectrum of R Sct with the light variability (Fig. 4). Over the five-year period of observations of this object the resulting spectra show that the $H\alpha$ line has complex and variable profiles of various types: double-peaked emission line profiles with a stronger blue part and a central absorption and profiles with inverse P Cygni type.

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5. Conclusion

We presented the analysis and interpretation of results obtained at the Oukaïmeden observatory (Morocco). The results clearly show that small instruments have a role to play in tracking pulsating variable stars that require a long period of observation and tracking, this is only possible within small observatories. We were able to detect the presence of the 2nd emission on the helium line for the first time whose spectral profile was interpreted as a P-Cigny profile which expresses the presence of a shock wave which broke away of the photosphere. The results obtained on the R Sct star clearly show the perfect complementarity and concordance between the measurements carried out using the small spectrograph from the Oukaimeden observatory and the high-resolution spectrograph from Midi Pyrénée.

In Morocco, through the spectrophotometry instrumentation, we aim to develop the field of pulsating stars, especially the atmospheric dynamics of high amplitude pulsators such as RR Lyr and RV Tauri star, in order to establish new models of the mechanical and thermal behavior of their atmospheres (shock waves, relaxation time, energy loss...). We prove that with small telescopes we can realize campaigns and obtain good and interesting results for the study of variable stars. We continue to carry out a spectroscopic measurements campaign in parallel with the photometric measurements of the Tess satellite; we are currently over 220 nights and more than 5000 specters and we will present news results soon in a new artice.

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