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On the occurrence of a shock wave in the atmosphere of ρ Puppis*

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Abstract. New high temporal and spectral resolution observations of the Ca II K absorption profile of the δ Scuti star ρ Puppis are presented. The data cover 1.2 pulsation cycle. Contrary to the result of Dravins et al. (1977), the line profile corresponding to the phase just before the maximum acceleration (monitored twice here), does not show any emission feature. Thus, the Ca II K emission may be of transient nature. Consequently, the intensity of the shock wave should be weak and strongly variable. This result is consistent with a previous study (Mathias et al. 1997) where no shock wave signature was present in the Hα and metallic line profiles observed. Thus, additional observations are required to specify the frequency of occurrence of the transient emission.

Key words: line: profiles – shock waves – stars: individual: ρ Pup – stars: oscillations – stars: variables: δ Sct

1. Introduction

It is now well known that the propagation of shock waves in the atmosphere of many classes of radially pulsating stars leads to the presence of an emission component in the absorption profile: Miras, RV Tauri, W Virginis, RR Lyrae, classical Cepheids ... This idea is supported by the large atmospheric motions measured in these stars, where the velocity peak-to-peak amplitude is of the order of a few tens of km.s^{-1}. For pulsating stars closer to the Main Sequence, such as the δ Scuti stars, the emission sometimes observed in UV Mg II h and k lines is not interpreted by means of shock waves but rather explained in terms of chromospheric activity (e.g. Fracassini et al. 1983). Thus, for these stars, it is necessary to take into account both chromospheric heating phenomena and transient heating due to pulsational shocks in order to build a realistic atmospheric model. The computation of such models, including non-linear and non-adiabatic effects, has not yet been carried out within the framework of a self-consistent approach. Up to now, Sasselov & Lester (1994) are the only ones who have constructed an atmospheric pulsating model including a chromosphere for classical Cepheids and assuming a driving piston.

However, the presence of shock waves in the atmosphere of δ Scuti stars is still unconfirmed. Dravins et al. (1977, hereafter DLS) report the presence of *transient* Ca II K emission in ρ Puppis (the largest amplitude known δ Scuti star) just before maximum acceleration.

DLS invoked a shock-wave mechanism to interpret this emission feature. Their observations were made with photographic plates having a reciprocal dispersion of 12.3 Å.mm^{-1}. The very brief emission (see their Fig. 3) observed in the blue wing of the Ca II K absorption line is indeed consistent with the presence of a shock wave emerging from the photospheric layers. But this emission was observed in only one of the two monitored pulsation cycles. Consequently, DLS concluded that this phenomenon was *transient*: the shock intensity is not always large enough to produce an emission component.

Until now, this observation is unique and there is no confirmation of the emission detection. In a recent paper (Mathias et al. 1997, hereafter Paper I), we made high resolution CCD observations of some metallic lines and Hα in order to find out whether shock waves exist within the atmosphere of ρ Puppis. Our observations were done over four consecutive nights, but the Ca II K absorption line was not in the spectral domain that we considered. Despite the very high quality of the data, no evidence was found for a shock wave associated with the star's pulsation.

In this paper, we present new high temporal and spectral resolution observations of the Ca II K line in order to detect whether or not an emission feature exists. Sect. 2 describes our observations and data reduction; the analysis of radial velocities and profile variations is given in Sect. 3. The last section is devoted to both a short discussion about the shock wave effect and some concluding remarks.

2. Observations and data reduction

The data were obtained with the 1.40 m CAT telecope at La Silla ESO Observatory using the Coudé Echelle Spectrograph (CES). The telescope was equipped with a CCD camera made of 2688 x 512 pixels, each having a size of 15 x 15 μm^2.

Observations were made during the night November 20, 1997. The spectral domain was centered on 3933 Å , i.e. around the Ca II K line. The resolving power was 60,000. The integra-

* Based on observations obtained at the European Southern Observatory (La Silla, Chile)

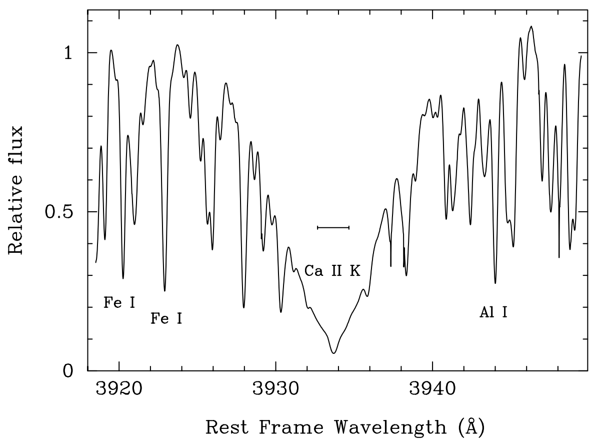

Fig. 1. Averaged spectrum taken over one pulsation period. Indicated are the Ca II K line, the two Fe I lines and the Al I line. The horizontal bar shows the domain covered in Figs. 3 and 4

Table 1. Mean-velocity γ and semi-amplitude K, together with their respective uncertainties in km.s^{-1}, for the four measured absorption lines.

line	γ	K
$\lambda\lambda$ 3933 Ca II K	51.0 ± 0.2	4.7 ± 0.3
$\lambda\lambda$ 3944 Al I	48.0 ± 0.1	4.8 ± 0.2
$\lambda\lambda$ 3920 Fe I	48.0 ± 0.1	4.8 ± 0.3
$\lambda\lambda$ 3922 Fe I	48.3 ± 0.1	4.7 ± 0.3

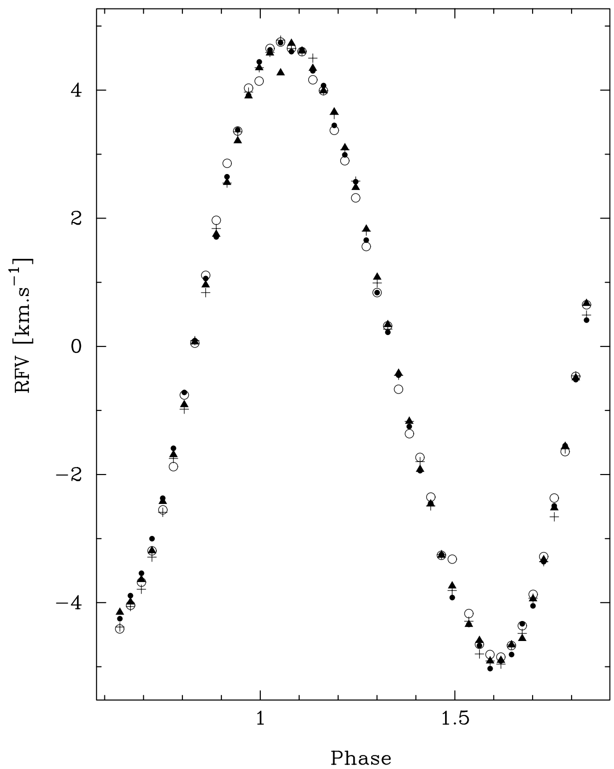

Fig. 2. Stellar rest frame velocity (RFV) associated with $\lambda\lambda$ 3933 Ca II K (circle), $\lambda\lambda$ 3944 Al I (dot), $\lambda\lambda$ 3920 Fe I (triangle) and $\lambda\lambda$ 3922 Fe I (cross). Note that we shifted the curve associated with Ca II K by about 3 km.s^{-1} in order to have the same mean-velocity. The uncertainty is less than 0.5 km.s^{-1}

tion time was 5 min or less, i.e. smaller than 2.5% of the pulsation period, providing a signal-to-noise ratio that we measured to be between 200 and 250 at a 2σ level. The total coverage of these observations was a little more than 4 hours, i.e. during 1.2 of a pulsation cycle. Our high spectral and temporal resolution observations are to be compared with DLS, who had a resolving power around 16,000 together with an integration time of about 9 min, i.e. 4.4% of the pulsation period. In addition, note that the time interval between consecutive spectra is about 12 min for DLS, while it is about 5.6 min for our observations.

Each spectrum was corrected for the pixel-to-pixel response through division by the mean of 5 flat field spectra obtained using a W-lamp. The wavelength calibration was done using about 40 lines of a thorium lamp. The spectra were then normalized to the continuum by a cubic spline function, and computed in the heliocentric frame.

To provide the variations as a function of phase, we used the basic period of the star, i.e. $P = 0.1408814$ d (see Paper I), and the phase origin given by HIPPARCOS, which is $T_0 = 2\,444\,995.91$ d. We ensured that the derived pulsation phases were coherent with the ones obtained by DLS.

3. Results

3.1. Radial velocities

The radial velocity curves were computed using a gaussian fit to the line. However, because many lines are blended (Fig. 1), including the Ca II K line which is very broad (FWHM$\simeq$8Å), we computed the gaussian fit only for the core of the line (the 5% deepest part of each line).

Then, due to the well-marked sinusoidal shape of the velocity curves (Fig. 2), a sine-fit was done, providing the mean-velocity γ and the projected semi-amplitude K. Table 1 summarises the results obtained for the best 4 lines.

The γ-velocity is close to 48 km.s^{-1} for two lines ($\lambda\lambda$ 3944 Al I and $\lambda\lambda$ 3920 Fe I). For the $\lambda\lambda$ 3922 Fe I line, the velocity is slightly larger, but this may be due to the uncertainty in the laboratory wavelength (Mathias 1994) since the difference is very small, corresponding to about 4 mÅ. On the other hand, the γ-velocity associated with the Ca II K line is appreciably larger by about 3 km.s^{-1}. It may be due to a blend, but the synthetic spectrum computed with a Kurucz model does not show any significant lines close to the core of the Ca II K line. It should also be noted that the γ-velocity is larger by about 1 km.s^{-1} than the one obtained in Paper I, which was already globally larger than previous values reported in the literature. This could be due to an additionnal velocity related to a binary system, as suspected by HIPPARCOS.

Concerning the pulsation amplitude, the value is 14% larger than those obtained in Paper I, and this can be attributed to a multiperiodicity effect. Note that the different values are compatible with each other, which implies that the projection factor

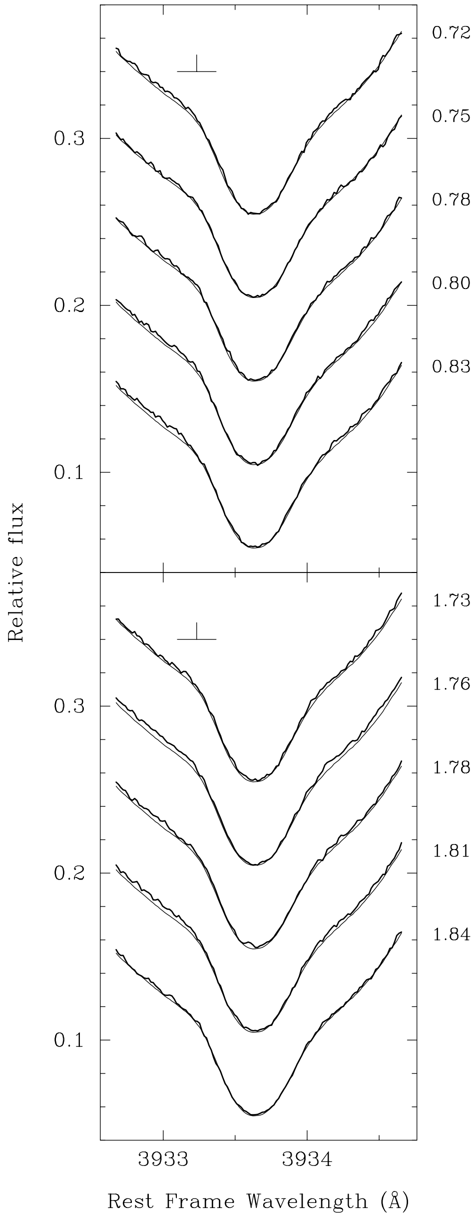

Fig. 3. The thin line is the average spectrum corresponding to Fig. 1. The thick lines represent the spectra of ρ Pup around pulsation phases $\varphi = 0.78$ and 1.78 (indicated on the right hand side of the figure). The width and the height of the emission detected by DLS is represented by the small inverse "T" symbol at our two expected emission phases $\varphi = 0.78$ and 1.78. The small shifts between the different spectra and the average one are mainly due to normalization process. Note that the scale is the same as the one used by DLS

(set to 1 for the computation of the rest frame velocity) is similar for the 4 lines.

Fig. 2 shows the radial velocities in the stellar rest frame versus phase. The four velocity curves have the same behavior, very close to a sine-wave. This is completely different from what DLS obtained where a bump is present around the pulsation phase $\varphi \sim 0.55$, and where the Ca II K line velocity curve differs from the other curves at two phases: $\varphi \sim 0.2$ and $\varphi \sim 1.4$

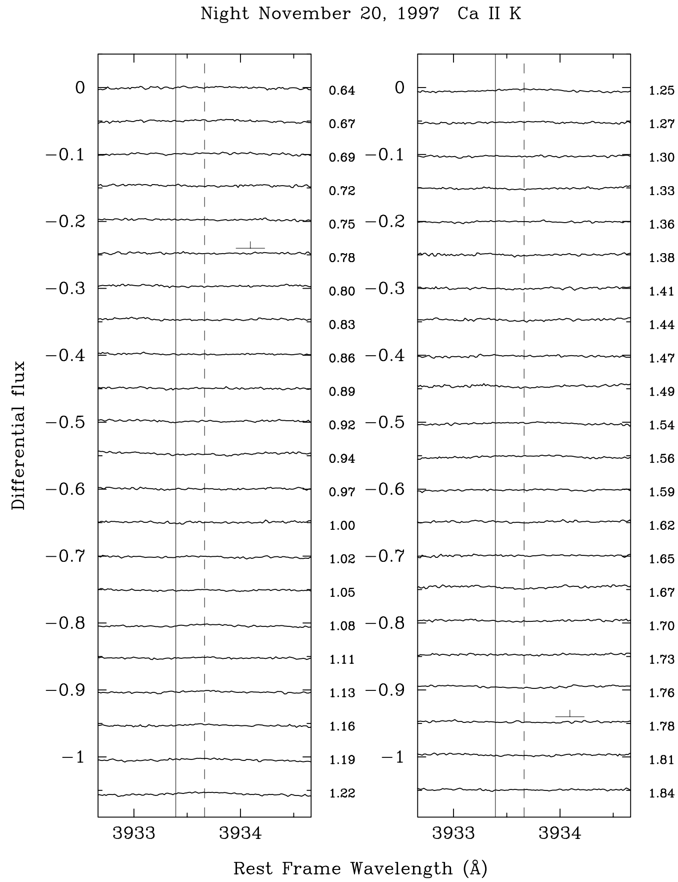

Fig. 4. All the differential spectra are presented, on the same scale as that of Fig. 3. The continuous vertical line corresponds to the wavelength at which the emission occurs in DLS. The dashed vertical line corresponds to the laboratory wavelength. The small inverse "T" symbol has the same meaning as in Fig. 3

by about 4 km.s^{-1}. In our data, no small variations larger than 0.5 km.s^{-1} are visible. Thus, contrary to DLS, we conclude that the radial velocity variation of the Ca II K line is identical to that of the other metallic lines that we considered.

3.2. Profile variations

DLS claim that on one spectrum they observed, a small emission around phase $\varphi \sim 0.78$ in the violet wing of the Ca II K line, but that this only occurred on one of the two consecutive pulsation cycles they monitored.

Fig. 3 shows that no particular emission, such as the one observed by DLS, is present. However, as mentioned in Paper I, the best way to detect the presence of the emission is to display the differential spectra, obtained by subtracting each spectrum from a mean spectrum representing their average over one pulsation cycle. Results are presented in Fig. 4. The changes between consecutive files are continuous and only reveal the atmospheric pulsation motion. It is clear that no emission feature is detected here.

4. Discussion and conclusion

Our new observations do not confirm the small Ca II K emission found by DLS. If we accept that the occurrence of a shock wave in the atmosphere of ρ Puppis is real, then the present results confirm its transient nature. Since in our previous study (Paper I) we did not detect any spectral signature induced by a shock wave within the profile of Hα and some of the metallic lines, we conclude that, when a shock is present within the atmosphere, its intensity must be small. Both from observations and pulsation models, it is known that the reproducibility of the dynamical motion of the different atmospheric layers is not the same over a few successive cycles (see e.g., Fokin et al. 1998). The shock intensities especially are strongly dependent on the dynamical state of the atmosphere. Consequently, it is quite plausible that the visibility of the weak shock detected by DLS in ρ Puppis is extremely variable and that its detection requires observations during several cycles and not one or two as done up to now. This means that new long time observations are necessary to determine the exact occurrence of the shock wave in ρ Puppis.

As shown by Fracassini et al. (1983), the permanent UV Mg II emission has a larger strength near maximum light (at phases ~ 0.96-0.12), i.e. when a shock wave induced by the classical κ-mechanism is crossing the photospheric layers (see e.g. Fokin & Gillet 1997). Because this emission is permanent, we must accept that a chromosphere exists in ρ Puppis and that the shock passage enhances the emission. Moreover Fracassini et al. (1983) put into evidence a variable violet-red asymmetry in the k1 and k2 Mg II components. Nevertheless, the quality of their observations is not high enough to confirm the presence of a blue asymetry which is symptomatic of outward propagating waves in the chromosphere. Further UV-observations are necessary to verify this important point which would give us an independent confirmation of the presence of the shock wave.

From the repeated observations of the UV Mg II lines of several classical Cepheids made by Schmidt & Parsons (1982), the pulsation appears to affect the mechanism of chromospheric heating. Moreover, these authors conclude that the mechanical energy of the pulsation seems to be at the origin of the chromospheric activity in this class of variable stars. Consequently, a strong coupling between the pulsation and the chromospheric state might take place and understanding it is certainly the basic step needed for a quantitative model. Although the calculation of a pulsation chromospheric model as done by Sasselov and Lester (1994) is beyond the scope of this paper, we suggest that, if future observations confirm the small Ca II K emission, a theoretical treatment of this problem would be required.

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References

Dravins D., Lind J., Särg K., 1977, A&A 54, 381 (DLS)
Fokin A.B., Gillet D., 1997, A&A 325, 1013
Fokin A.B., Gillet D., Chadid M., 1998, A&A in press
Fracassini M., Pasinetti L.E., Castelli F., Antonelli E., Pastori L., 1983, Ap&SS 97, 323
Mathias P., 1994, In: Sauval A.J., et al. (eds.) Workshop on “Laboratory and Astronomical High Resolution Spectra”, PASPC 81, 547
Mathias P., Gillet D., Aerts C., Breitfellner M.G., 1997, A&A 327, 1077 (Paper I)
Sasselov D., Lester J.B., 1994, ApJ 423, 795
Schmidt E.G., Parsons S.B., 1982, ApJS 48, 185