BALMER EMISSION PROFILES IN RADIALLY PULSATING STARS : THE CASE OF THE DOUBLE Hα EMISSION

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ABSTRACT. We present new high resolution profiles of Hα emissions in radially pulsating stars (RR Lyrae, W Virginis, RV Tauri, Mira stars and Classical Cepheids). Depending on phase, these profiles can show an apparent absorption within the emission close to the Hα laboratory wavelength. The origin of this feature is discussed in the framework : (a) of a composite of a single emission and a deep photospheric absorption (RR Lyrae, W Virginis and RV Tauri stars); (b) of a true absorption caused by cool hydrogen above the shock wave producing the emission; (c) of a geometric model in which the absorption is a lack of emission. Recent observations (Hα profiles of Mira stars S Car and T Cen), which show that the absorption dip is below the continuum level, are in favour of the true absorption model.

1. INTRODUCTION

The existence of shock waves in the atmospheres of radially pulsating stars is a well-known phenomenon. They are characterized by a discontinuity in the radial velocity curve due to double absorption lines, by hydrogen and metallic emissions and sometimes by the presence of fluorescence lines. Hydrogen emissions in Classical Cepheids (pulsating stars of population I) is weak and shock waves have been suggested only in a few cases (for instance in β Doradus by Hutchinson et al., 1975). In Cepheids of population II, only RV Tauri and W Vir stars show both helium and hydrogen emission (Preston, 1962; Abt, 1954 and Wallerstein, 1959 respectively) while RR Lyrae stars have only weak hydrogen emission (Preston, 1964). Finally, Mira stars (both populations I and II) present during a large fraction of their periods strong Balmer emission lines (Joy, 1947), but helium emission is never observed.

In all these stars, atmospheric motions are the consequence of radial pulsations although the cause of pulsation can be different (Cox, 1974). Thus, we must expect to observe some spectral similarities between these different kinds of stars; namely double absorption lines. Are there also similarities in observed emission profiles ? This is certainly affected by the disparity of stellar parameters (gravity, T_{eff}., atmospheric composition,...) between these stars. The aim of this paper is to show that the double Hα emission must be observed in all classes of radially pulsating stars and to suspect a similar origin (§ 2). The different explanations for the emission are then discussed in the case of Mira stars (§ 3) for which a large number of profiles are already available.

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2. DOUBLE Hα EMISSION IN RADIALLY PULSATING STARS

The double Hα emission is only observed around or after the luminosity maximum. It is characterized by an absorption close to the Hα laboratory wavelength within an apparent broad emission. In the case of cool stars (Mira or RV Tauri stars), other smaller absorptions at different wavelengths can also be observed (see fig. 1b).

Fig. 1a shows the double Hα emisson observed in the spectrum of the RR Lyrae star X Ari at the Canada-France-Hawaii (CFH) Coudé Spectrograph equipped with a 1,872-diode Reticon as detector. The resolution is 0.2 Å ($R \equiv \lambda/\Delta\lambda = 33{,}000$) and the signal-to-noise ratio 60. The phase of this observation is $\varphi = 0.93$, i.e. just before the luminosity maximum. A comparison with the profile (dashed line) without emission ($\varphi = 0.86$, i.e. 1 hour earlier) shows conspicuous double emission components. The blueshifted contribution is stronger than the redshifted one. These observations suggest that the double emission is only apparent and is the consequence of a composite between a single large emission and a strong photospheric absorption. This is consistent with an absorption dip, smaller at phase 0.93 than at phase 0.86.

The Hα profile of the hot Mira star S Car (population II) in fig.1b is more complex because other absorptions are also visible within the emission. The resolution is close to 0.11 Å ($R = 60{,}000$) and the signal-to-noise ratio at the continuum level is approximately 200. The Coudé Echelle Spectrometer (CES) of the European Southern Observatory (ESO) equipped with a 640 x 1,024 RCA-CCD detector has been used. The AAVSO predicted phase is 0.79, i.e. before the luminosity maximum. Since a large number of absorptions is visible, it is not easy to give an accurate position of the continuum level. Nevertheless, in contrast with X Ari, the central absorption is not obviously below the continuum. Its origin will be discussed in the next section.

The following profile (fig. 1c) was obtained with the same spectrometer at the same resolution. The double Hα emission profile of the relatively faint star ($V \sim 10.0$, corresponding to phase 0.21) W Vir (the prototype of W Virginis stars) is very easily visible. As with S Car, the blueshifted emission component is stronger than the redshifted one and the central absorption is above the continuum level.

Finally, the last profile (fig. 1d) concerns the bright RV Tauri star R Sct at its second luminosity maximum. The CES equipped with a 1,872-diode Reticon was used ($R = 60{,}000$ and $S/N \sim 300$). This profile is similar to that of X Ari. The central absorption is clearly below the continuum level. Unfortunately, it is not possible, as in X Ari, to observe the normal absorption profile without emission but we must accept that the main contribution to the central absorption is due to the photospheric absorption.

All these stars are of population II and at the moment of their observation their spectral types were respectively A8 II (X Ari), K5e III (S Car), F0 Ib (W Vir) and G0eIa (R Sct). In Mira stars, the Hα absorption is never observed from luminosity maximum to luminosity minimum (for S Car see profiles in Gillet et al. 1985). The strong TiO band-head and TiO lines of the γ-system in the Hα region affect considerably the spectral visibility (Hänni, 1987). The lack of high resolution Hα profiles of W Vir does not allow one to appreciate the intensity of the photospheric absorption although it is easily visible at phase 0.395 within the Hδ profile (Abt, 1954). Thus, quantitative estimates of the photospheric contributions would be useful.

Classical Cepheids show large distortions of the Hα profile (for instance, Wallerstein, 1972) while visible emissions remain weak. In other words, the intensity of the photospheric absorption compared to that of emission always dominates. Thus, no manifest double emission profiles are observed.

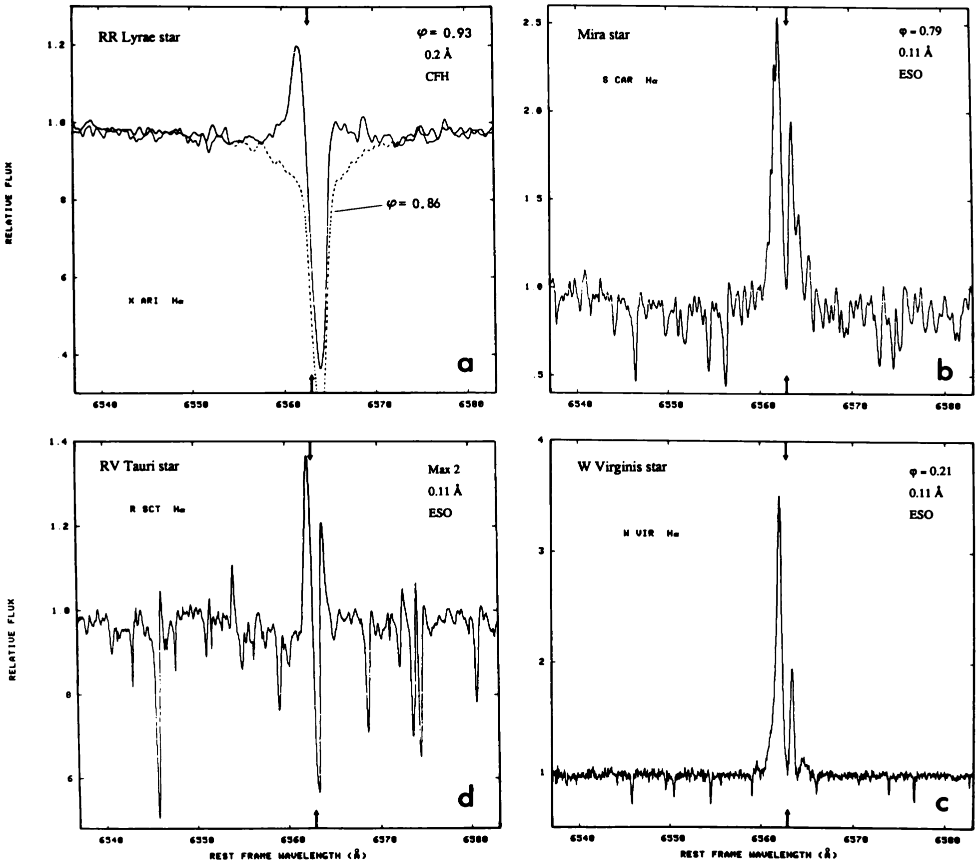

Fig. 1 High resolution profiles of Hα lines in four different radially pulsating stars. The resolution, the observatory and the phase φ (at luminosity maximum φ ≡ 0.0) are given. The position of the Hα laboratory line is marked by an arrow on the stellar rest frame wavelength axis. All the profiles show a double emission structure which is not always present.

3. THE CASE OF MIRA STARS

Because of their very low effective temperature (< 3000 K), the visibility of the double Hα emission profile is unusual. Up to now, approximately twenty stars with this kind of profile have been reported (Gillet, 1987). In S-type and very hot (early M2) M-type Mira stars the double profile is quite visible from luminosity maximum, while it appears only around phase 0.4 in typical (i.e. cool) M-type Mira stars. Untill now, no double emission has been observed in C-type Mira stars. Thus, this suggests that TiO absorption is not the cause of the observed double structure although the R1a (~ 6562.8 Å) TiO band-head of the γ-system at the Hα laboratory wavelength (6562.817 Å) can contribute in some cases to this structure (Hänni, 1987).

Two kinds of explanations have been proposed. The first, due to Bidelman and Ratcliffe (1954), claims that the absorption is a true absorption caused by cool hydrogen above the shock wave. The problem is to show how a cool gas (T < 2000 K) can absorb Hα-photons. Wallerstein and Cox (1984) in their discussion on W Virginis stars, suggest that Lα-photons produced in the shock wake would be absorbed in the umperturbed atmosphere above the shock. This Lα scattering with the help of the metastability of the 2S state, would provide the overpopulation of the n = 2 level, inducing the observed Hα absorption.

The second explanation has first been proposed by Willson (1976) and later refined by Gillet et al. (1983,1985). It assumes that the shock is far from the photosphere. Thus, we can see emission from the far side of the star (the receding part of the shock) giving the redshifted component while the advancing part of the shock produces the blueshifted component. This geometrical interpretation shows that the central absorption could be only a lack of emission. The ratio of the thickness of the de-excitation zone behind the shock front to the photospheric radius is very much smaller than 10^{-4}. The profile resulting from this narrow and radially moving shell has been investigated by Wagenblast et al. (1983) and Bertout and Magnan (1987). Due to the photospheric occultation, the width of the redshifted contribution may be smaller than the blueshifted one as observed. The larger column density for photons coming from the receding part of the shock explains the weaker intensity of the redshifted component. As shown by Wagenblast et al. (1983), the absorption dip is not necessarily at the Hα laboratory wavelength.

In the last model, the central absorption cannot be below the continuum except if the photospheric absorption is visible, but this does not seem to be the case in Mira stars. All double emissions previously reported have their absorption dip above the continuum (see Gillet, 1987). Figure 2 presents two recent observations which prove that the absorption dip can be below the continuum. As phase advances, the intensity of the central absorption decreases and becomes higher than the continuum level (fig. 3). All these observations have been done with the CES at ESO La Silla (R = 60,000 and S/N ~ 200-400). Since T Cen is a very hot (up to K0 at luminosity maximum) M-type Mira star of population I, its true continuum level is close to a relative flux of unity. This is not the case for S Car (fig. 1b) which was observed at phase 0.68. Indeed, with a spectral type close to M5, molecular absorptions are very concentrated and the true continuum level may be around 1.1-1.2 in relative flux (Piccirillo et al., 1981).

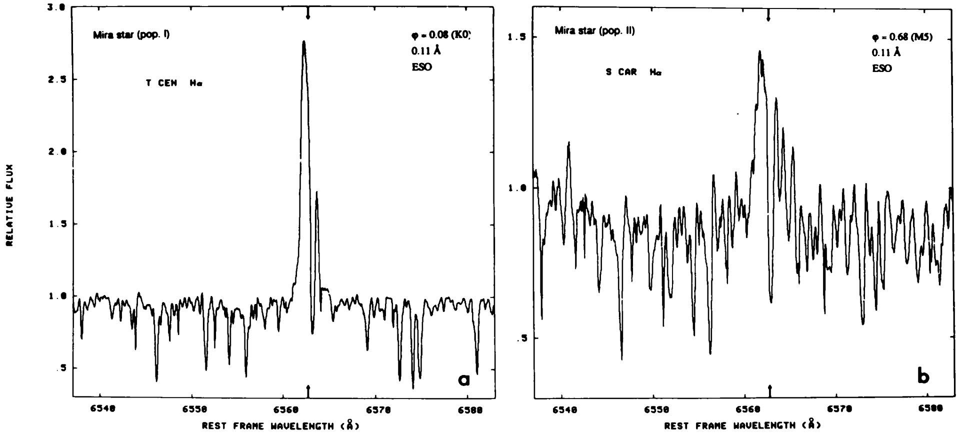

Fig. 2 Double emission structure of two Mira stars. The striking feature is that the central absorption dip is under the stellar continuum level, in contrast to previous observations (Gillet, 1987).

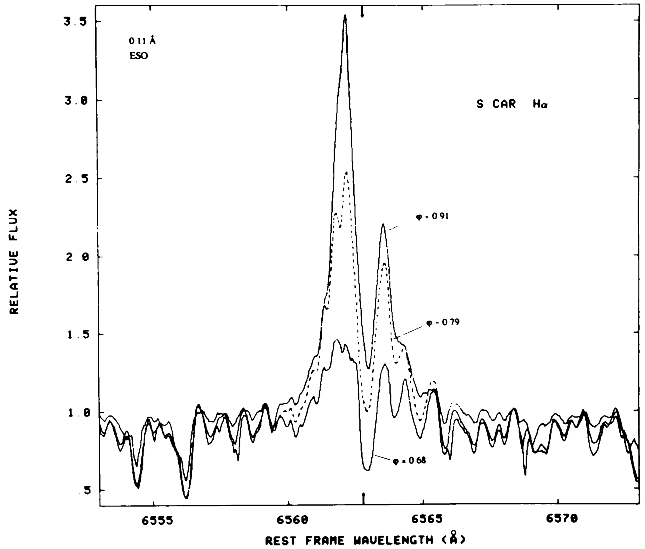

Fig. 3 Evolution in phase of the double Hα emission of S Car. At φ = 0.91 (luminosity maximum φ ≡ 0.0), the central absorption dip is above the continuum, in contrast to that at phase 0.68.

4. CONCLUSION

The high resolution Hα-profiles of the Mira stars T Cen and S Car show that the central absorption can be below the stellar continuum. Since the Hα photospheric absorption is not observed in these kinds of stars, this is not in favour of the geometric model. Thus, the central absorption dip could be explained by the self-absorption of the cool hydrogen above the shock wave.

In RR Lyrae and RV Tauri stars the contribution of the photospheric absorption to the double emission profile is certainly significant. The same conclusion applies to Classical Cepheids and perhaps also to W Virginis stars but further observations would be useful. The case of Mira stars seems different because the evaluation of the photospheric contribution, which is never observed, is difficult to estimate. It would be also useful to consider if the hydrogen self-absorption can contribute to double emission profiles in RR Lyrae, RV Tauri, W Virginis and Classical Cepheid variables.

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REFERENCES

Abt, H.A. : 1954, Astrophys. J. Suppl. **1**, 63
Bertout, C., Magnan, C. : 1987, Astron. Astrophys. in press
Bidelman, W.P., Ratcliffe, A.E. : 1954, Publ. Astron. Soc. Pacific **66**, 255
Cox, J.P. : 1974, Rep. Prog. Phys. **37**, 563
Gillet, D., Maurice, E., Baade, D. : 1983, Astron. Astrophys. **128**, 384
Gillet, D., Maurice, E., Bouchet, P., Ferlet, R. : 1985, Astron. Astrophys. **148**, 155
Gillet, D. : 1987, Astron. Astrophys. in press
Hänni, L. : 1987, private communication
Hutchinson, J.L., Hill, S.J., Lillie, C.F. : 1975, Astron. J. **80**, 1044
Joy, A.H. : 1947, Astrophys. J. **106**, 288
Piccirillo, J., Bernat, A.P., Johnson, H.R. : 1981, Astrophys. J. **246**, 246
Preston, G.W. : 1962, Astrophys. J. **136**, 866
Preston, G.W. : 1964, Ann. Rev. Astron. Astrophys. **2**, 23
Wagenblast, R., Bertout, C., Bastian, U. : 1983, Astron. Astrophys. **120**, 6
Wallerstein, G. : 1959, Astrophys. J. **130**, 560
Wallerstein, G. : 1972, Publ. Astron. Soc. Pacific **84**, 656
Wallersein, G. Cox, A.N. : 1984, Publ. Astron. Soc. Pacific **96**, 677
Willson, L.A. : 1976, Astrophys. J. **205**, 172