Hydrogen Emission Lines from Extended Pulsating Atmospheres

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Abstract

In order to study the basic radiative mechanisms in the extended envelopes of evolved stars (e.g. Long Period Variables), we determine the spectrum emerging from a very optically thick Non-LTE hydrogen layer surrounding a core of high temperature (see figure 1). Such a model was first proposed by Sobolev (1960) and Menzel (1946). It is consistent with the fact that LPVs are likely evolving toward planetary nebulae. The main parameters of the model are the temperature of the illuminating star (T_r), the dilution factor (ω) and the Lyman continuum optical depth of the envelope (τ_{1c}). We examine their influence upon the emerging intensities in the lines and in the continua.
The model could explain some observations related to evolved stars and especially the presence of emission features in an otherwise cold environment. Furthermore atmospheric pulsation phenomena produce large variations in the emerging spectra: reddening, emission/absorption transition of the hydrogen lines, profile deformations...

We assume that the only energy deposited in the envelope is the ionizing radiation of the stellar core. We reject the Local Thermodynamical Equilibrium hypothesis in the medium. The lines thus result from purely radiative processes via a fluorescence mechanism. We solve the radiative transfer equations in the lines (including the Lyman transitions) and in the continua together with the equations of statistical equilibrium of a hydrogen atom with 4 levels and a continuum. This system is linearized and solved by the method of addition of layers in an iterative way. (Gros and Magnan, 1981; Magnan, 1992). A typical model of a mira is obtained with a core of temperature $T_r = 30000K$, a dilution factor of 10^{-2} and an envelope optical depth in the Lyman continuum $\tau_{1c} = 100$. The geometric thickness of the envelope is thus $\simeq 1R_\odot$ for a star which radius is close to $200R_\odot$. The calculated emerging spectrum shows that the illuminating radiation is extremely reddened by the envelope. Moreover the Lyman and Balmer lines are strong in emission with central reversal profiles due to a strong decrease of the source function in the most external layers of the envelope.
We mimic an atmospheric pulsation by varying the envelope radius. If δR is assumed to be constant, a variation of R leads to a change of the parameters $\omega \simeq R^{-2}$ and $\tau \simeq R^{-2}$ since $n_e^2 R^2 \delta R$ is constant. In figure 2 is shown the effects of a +/- 25%

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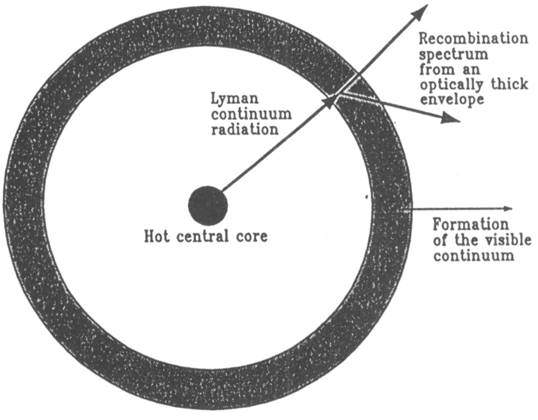
variation of the envelope radius on the emerging $H\alpha$ profile. We may notice that the higher is the envelope radius, the stronger are the lines in emission, the wider are the lines, and the bluer is the emerging spectrum.



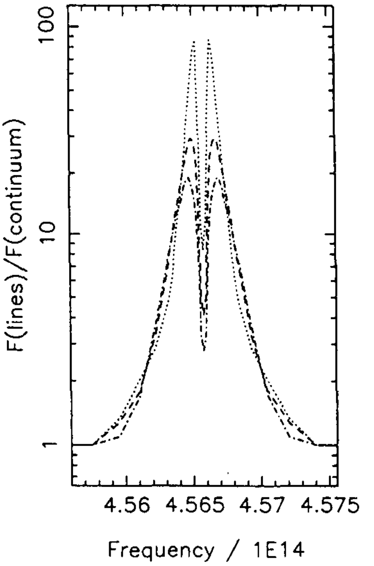


Figure 1 (left) Schematic modeling of the radiative transfer in an evolved star.
Figure 2 (right) H_α emerging profiles from 3 envelopes of different radius.

This study suggests that emission lines in diluted envelopes could result from a recombination mechanism and not from thermal processes through a temperature rise. Moreover atmospheric pulsations produce changes in the emerging spectrum. They lead to variations of the intensity of the emerging lines with corresponding emission/absorption passages, to variations of the emerging profiles, and to a reddening of the emerging continuum.
This model can be applied to evolved pulsating stars like the Mira variables which show similar variations during their cycle (for more details see de Laverny and Magnan, 1992).

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