R. de Vos and R. Blomme

Can wind variability in early-type stars mimic turbulence?

Abstract

In order to explain the P Cygni profiles observed in early-type stars, Groenewegen and Lamers (1989) had to introduce a large "turbulent" velocity in the stellar wind. As the physical basis for this turbulence is not known however, we investigated another possible explanation. Assuming that short-term variability exists in the wind, the observed line profile is a time-average. Our results calculated with this model agree very well with the time - independent profiles calculated with a large turbulent Doppler-broadening.

Introduction

Early-type stars show a significant stellar wind with mass loss rates up to a few times 10^{-6} $M_{\odot}$ yr^{-1}, and even higher ones for Wolf-Rayet stars or during outbursts of Luminous Blue Variables. One of the spectral signatures of these winds are the P Cygni profiles seen in the ultraviolet. Early theoretical models for calculating these profiles assumed the Sobolev-approximation, in which thermal and turbulent velocities are neglected with respect to the outflow velocity (e.g. Castor and Lamers, 1979; Olson, 1982). However, Groenewegen and Lamers (1989) showed that for a sample of 27 stars the inclusion of large "turbulent" velocities (100-400 km/s) resulted in theoretical profiles that agree much better with the observations than the Sobolev-profiles.

An alternative

The exact nature and origin of what they call "turbulence" remains a problem. In their model it's just a velocity-broadening with a Gaussian distribution but the physical reason for it is not well known. Possibly there's a connection with the instabilities found in the time-dependent hydrodynamical study of Owocki et al. (1988). However, the uncertainty about the origin of this turbulence made us look for alternatives to explain the observed P Cygni profiles.

Early-type stars show variability in the radiation they emit. This influences the stellar wind which is largely driven by the absorption of photons (and the resulting transfer of momentum). So the stellar wind is variable as well, on similar time-scales as the variability of the star. Observationally a spectrum is obtained by integration over a certain time. Typical integration times with the IUE satellite are of the order of 1 min. Variations with periods below that integration-time will not be detected but will influence the profiles nevertheless.

Models

To test the above idea we calculated a time-averaged spectrum, where we varied either the terminal velocity (which is the mean velocity of the material at large distances from the star) or the velocity up to which the relevant ions are present in the wind (which is not necessarily the same as the terminal velocity). The variations were taken to be sinusoidally with time. We did not include any turbulent broadening but only thermal broadening (20 km s^{-1}) in our model. For this calculation we also need to specify an ionization law. We compared our results with a similar profile calculated using the method of Groenewegen and Lamers (1989), i.e. with a high turbulent velocity.

Results and conclusions

The comparison (Fig. 1 and 2) shows that our models can explain the observations as well as the Groenewegen and Lamers model - at least for the parameters specified here. They show that, in principle, our alternative is feasible. The real test will come of course when, in future, we'll try to apply our model to a range of early-type stars which show a large variation in their P Cygni profiles. Possibly another ionization law or a variable one will be necessary, especially to

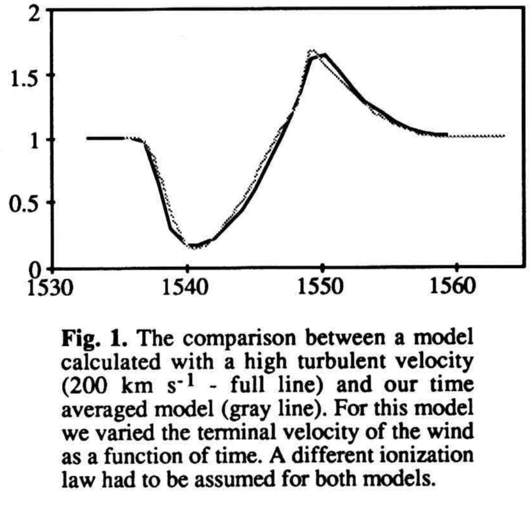

Fig. 1. The comparison between a model calculated with a high turbulent velocity (200 km s^{-1} - full line) and our time averaged model (gray line). For this model we varied the terminal velocity of the wind as a function of time. A different ionization law had to be assumed for both models.

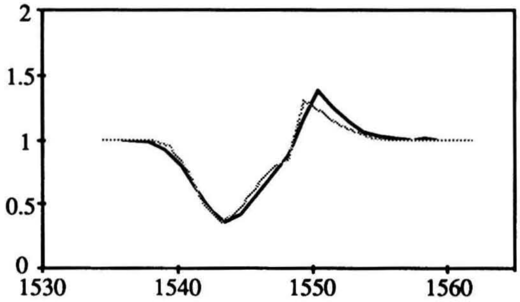

Fig. 2. The same as Fig. 1, but this time we let the velocity up to which the C IV ions are present vary with time.

explain the deep absorption troughs observed in the profiles of certain stars.

An important consequence of our models is that the ionization fraction we find is very different (by a factor of about 10) from the ones found by Groenewegen and Lamers (1990). This could be relevant to the comparison they made between the ratios of observed ionization fractions and those derived from the theoretical (hydrodynamical) models made by Pauldrach (1987). This comparison (Fig.1 and 2) revealed discrepancies of a factor 10-100. At this moment it is not clear how our model will influence their conclusion.

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