CAN NONSTATIONARY VELOCITY PLATEAUS ACCOUNT FOR SLOWLY MOVING DISCRETE ABSORPTION COMPONENTS?

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ABSTRACT We use radiation hydrodynamics simulations to illustrate the formation of a time-variable velocity plateau in a model of the stellar wind of an O-type star. The presence and evolution of such plateaus might explain the formation and slow acceleration of discrete absorption components in P Cygni profiles of OB stars.

THE PROBLEM

Discrete absorption components (DAC) are frequently observed in spectral features that form in the winds of O stars, especially the P Cygni profiles of UV resonance lines. Time-resolved observations have shown that the DAC accelerate blueward through the absorption trough of such profiles, usually starting from velocities near 0.4\(v_\infty\) and ending at \(v_\infty\). Curiously, the observed accelerations of the DAC are always less than the acceleration expected for the mass flux of the steady wind. In terms of the standard \(\beta\)-law parameterization of the wind velocity as a function of radius (where larger values of \(\beta\) correspond to more slowly accelerating outflows), the accelerations of DAC are characterized by \(\beta > 1\) (and often \(\beta > 2\); see Prinja, Howarth, and Henrichs 1987; Prinja and Howarth 1988; Prinja et al. 1991; Fullerton, Gies, and Bolton 1992). In contrast, both theory (e.g., Pauldrach, Puls, and Kudritzki 1986) and observations of the overall shape of P Cygni profiles (e.g., Groenewegen and Lamers 1989) indicate that the mass flux in the time-steady wind follows a velocity law characterized by \(\beta \approx 0.8\). How can estimates of \(\beta\) appropriate to the overall mass flux of the wind be reconciled with estimates derived from the motion of the DAC?

A POSSIBLE SOLUTION

We have been using an improved version of the Owocki, Castor, and Rybicki (1988) 1-D radiation hydrodynamics program to explore the effects of various perturbations on the formation of structure in line-driven stellar winds. On several occasions, arbitrary initial perturbations have produced a spatially extended structure over which the velocity gradient is comparatively flat—a plateau. As noted by many previous investigators (e.g., Mihalas 1979), such a structure produces an absorption enhancement at the mean velocity
of the plateau, simply because excess column density accumulates along its length. In our simulations, the position and radial extent of the plateau change with time, so that the absorption enhancement associated with it becomes progressively blueshifted, much as the DAC are observed to do. It appears that the time scales associated with these structural changes in the plateau are not directly related to the mass flux of the wind, but are instead determined by the propagation of fast inward-facing and slow outward-facing radiative acoustic waves. Thus, the acceleration of the absorption enhancement caused by a plateau can be very much slower than would otherwise be expected.

AN EXAMPLE OF A NONSTATIONARY PLATEAU

The development of a velocity plateau is illustrated in Fig. 1 for a model appropriate to an O6–O8 supergiant. The formation of this plateau was triggered by arbitrarily decreasing the wind density over a small region near the base ($r = 1.05 R_\odot$) of a steady-state model. The left-hand panel shows the behavior of the velocity law $v_r(r)$ over the duration of the simulation. The plateau appears as the flat region at a velocity of $\sim 500 \text{ km s}^{-1}$ that stretches from near the site of the initial perturbation to $r \approx 2 R_\odot$ and persists for about 10 hours. The right-hand panel illustrates the variation of optical depth as a function of frequency and time. This plot, which serves as a proxy for a more rigorous line profile calculation, clearly shows the progressive motion of the strong absorption enhancement produced by the changing structure of the velocity plateau. Other enhancements in optical depth are due to material that is compressed into dense clumps by the action of the line-driven instability, which accelerates small amounts of rarified gas to very large velocities (cf. left-hand panel).

We measured the radial velocity of selected absorption enhancements in order to quantify their acceleration. These velocities are plotted as a
function of time in Fig. 2. The slope of the velocity curve of the absorption enhancement from the plateau is substantially smaller than the slope of any of the enhancements caused by clumps, which clearly indicates that the "plateau" enhancement accelerated more slowly than the "clump" enhancements.

This slow acceleration is further emphasized in Fig. 3, which shows the acceleration as a function of velocity for several of the enhancements. To permit comparison, the curve appropriate to a standard $\beta = 0.8$ velocity law (as determined by fitting the parameterized curve to $v_r(r)$ at $t = 0$) is also shown. The acceleration of the enhancement from the plateau is 2–6 times smaller than expected on the basis of the standard curve; and, in general, the $a_r(v_r)$ curves from the clumped absorption enhancements differ substantially from the standard contour. These results are in qualitative agreement with the observed behavior of DAC. Although UV observations usually diagnose accelerations only for velocities in excess of about 1000 km s$^{-1}$, the optical observations reported by Fullerton, Gies, and Bolton (1992) are directly comparable.

SUMMARY

We have suggested that at least some DAC might be produced by velocity plateaus in stellar winds, and that the slow acceleration of these features is caused by the structural evolution of the plateau, not the mass flux. Although this interpretation is attractive, it is highly schematic and suffers from several drawbacks. In the first place, we do not yet know whether plateaus will be a frequent occurrence or whether their formation involves special combinations of circumstances. Secondly, although the line-driven instability affords many possibilities for generating structure, a source of seed perturbations (as yet unidentified) from deep in the wind seems to be required. Finally, the structures we have produced so far do not persist long enough to explain the observations. We conjecture that longer-lived structures might result once the restrictive assumption of 1-D geometry is relaxed and rotational effects are incorporated in the calculations.

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REFERENCES

FIG. 2  Radial velocities of the absorption enhancements as a function of time. Different enhancement episodes are labeled with different letters.

FIG. 3  Radial acceleration of absorption enhancements as a function of velocity, compared with that expected from a $\beta = 0.8$ velocity law.