Clumping in Hot Star Winds
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Discussion: Magnetic fields, variability

Moderator: Joe Cassinelli

Owocki: We intuitively associate increased absorption with a high spatial density, since this leads to an increased column density. But for line opacity the absorption at any frequency scales with the column density within a Sobolev length about the resonance point for that frequency, and that in turn depends on the inverse of the velocity gradient. In hydrodynamic models of wind structure, for example of corotating interaction regions (CIRs, see, e.g. Cranmer and Owocki 1996), discrete absorption features tend to come from regions of a relative velocity plateau, not from dense compressions as had been anticipated.Such plateaus form behind discontinuities in the positive velocity gradient, i.e. at "kinks" in the velocity law. They represent a new and interesting feature of line-driven outflows, wherein the driving force depends on the velocity gradient, and often arise upstream from a barrier, such as a slower moving dense compression. As such, discrete absorption components (DACs) in UV wind lines from hot stars may be providing a diagnostic of a new hydrodynamical phenomenon that we are still trying to fully understand.

Feldmeier: As for the propagation properties of these kinks: as we recently found analytically (Feldmeier, Raetzel, & Owocki, 2008, ApJ), kinks propagate upstream faster than Abbott waves. A pronounced kink like in the Cranmer & Owocki (1996, ApJ) CIR simulations propagates roughly at twice the Abbott speed. Due to this fast upstream motion of kinks, their outward evolution through the wind, and that of the associated velocity plateau causing DACs, is rather slow and may indeed match the slow, observed DAC evolution timescale.
Regarding Wolf-Rainer Hamann's criticism towards the Sobolev approximation: someone should really generalize the amazing Greens function analysis by Owocki & Rybicki (1986, ApJ) for the pure absorption case, to include line scattering, if only in some simplified fashion. This would once and for all do away with any qualms about the existence of Abbott waves.
Finally, with regard to the temperature stratification of the X-ray emitting gas: the exact run of temperature, density, and ionization in the postshock region of a radiatively cooling shock is well know, e.g. from the analytical calculations by Chevalier & Imamura (1982, ApJ). We (Feldmeier et al. 1997, A&A) applied this to obtain fits to ROSAT spectra, which were clearly better than from corresponding isothermal-shock fits.

Massa: I hear a lot about velocity plateaus. But these enhance the absorption for a fixed column density. So am I being told that the mass loss rates are even lower because the column density is less?

Puls: May it be that the maximum observed infall velocity (which could be observed on the red side of the profile) is related to the magnetic parameter η_*?

ud-Doula: The infall velocity of dense material is always smaller than the free fall velocity. Assuming no rotation, the magnetic confinement parameter decides how far away from the stellar surface the material is collected. The further out this happens, the higher is the infall velocity.

Massa: A result from our 2003 paper is that the ion fraction of O VI is correlated with terminal velocity. To me, this suggests that shocks and not magnetic fields are dominating the clumping.

Blomme: We indeed require that the spot velocity is different from the rotational velocity. The fact that the spot is not fixed on the surface makes it difficult to attribute it to magnetic fields, which are expected to be fixed on the surface.

Hamann: Can somebody make clear the relation between the periods of DACs and modulations? For ζ Pup, as far as I remember, the IUE MEGA campain data gave the DAC repetition time equal to the rotation period of $\sim$ five days, and a modulation period that is much shorter (19 h) and not an integer fraction of the former.

Blomme: These are the correct values for ζ Pup. But for HD 64760, we have a recurrence time for the DAC of 10.3 d and a rotational period of 4.1 d (or 4.8 d if you believe that the rotational modulations are stuck on the surface). The values are not compatible, so you need a spot velocity that is lower than the rotation velocity.

Lobel: The shape of the DAC is very much dependent on the spot velocity with respect to the surface rotation velocity. It is determined by the velocity plateaus behind the CIR and how they are geometrically distributed over time with respect to an observer. The DAC optical depth estimated by the Sobolev approximation is $\tau = \rho q_i / |\mathrm{d}v/\mathrm{d}r|$, so if $|\mathrm{d}v/\mathrm{d}r|$ is small there is large line optical depth in the DAC. Close to the surface that approximation may break down, however, because there is also the projection effect in the observer's line of sight which will determine the morphology of the DAC.