The role of heat conduction to the formation of Planetary Nebulæ with H-deficient fast winds

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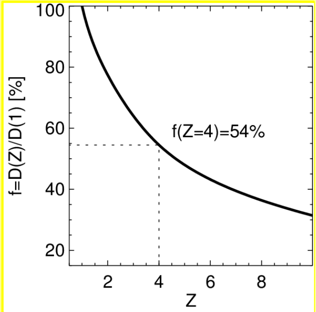
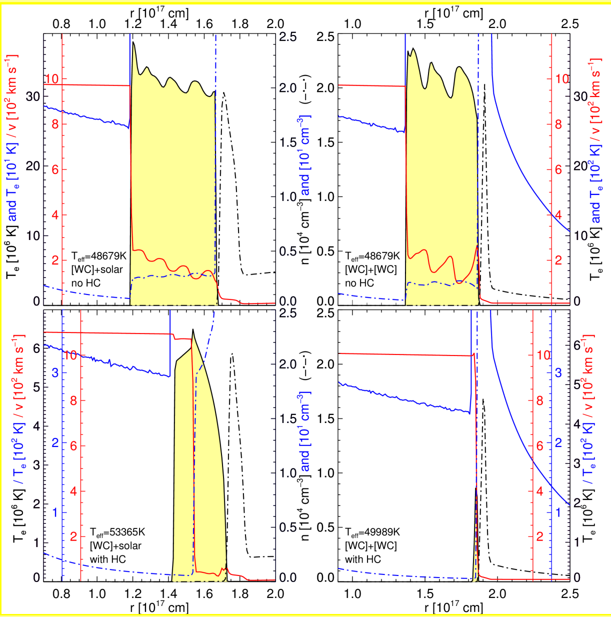
X-ray observations of young Planetary Nebulæ (PNe) have revealed diffuse emission in an extended region, around both H-rich and H-deficient central stars. In order to also reproduce physical properties of H-deficient objects such as BD+30º3639, we have, at first, extended our time-dependent Radiation Hydrodynamics models with heat conduction for such conditions. We have then calculated an extensive set of models to match observed properties of both the wind-blown bubble and the surrounding nebula of BD+30º3639. Here we present some of the important physical concepts, which determine how and when a hot wind-blown bubble forms. In this study we have had to consider the, largely unknown, evolution of the CSPN, the slow (AGB) wind, the fast hot-CSPN wind, and the abundances. The main conclusion of our work is that heat conduction is needed to explain X-ray properties of wind-blown bubbles also in H-deficient objects.

The general Fokker-Planck-based plasma theory of Spitzer (1962), to good accuracy, applies to both pure hydrogen and other compositions. Heat conduction is modeled through an additional heat-flux term; this can be written as a diffusion coefficient multiplied with the temperature gradient:

$$q = D\nabla T$$

The charge-dependent component of the diffusion coefficient *D* decreases modestly with an increasing effective charge (Z). Our tests with models that use H-deficient abundances show that Z≤4.0; the highest values are reached inside the hot wind-blown bubble. A figure of D(Z) shows that, under H-deficient conditions, it is about a factor two smaller than in a pure hydrogen plasma of the same temperature– a rather insignificant change.

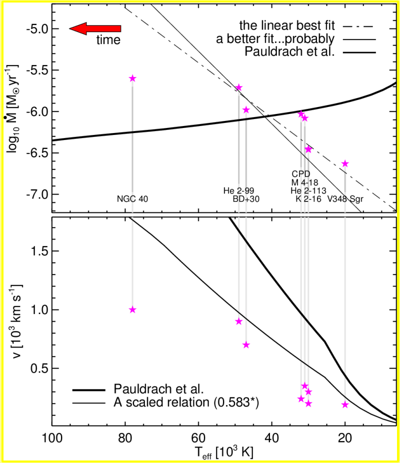




Here the fast wind – and therefore also the region where the wind-blown bubble forms – always has a H-deficient composition that is typical of [WC] stars.

- Without heat conduction a hot bubble forms (eventually) between the shock and the contact discontinuity (upper panels) – regardless of the composition. The bubble is in this case very hot, $T \geq 10^7$K, which is also much higher than what X-ray observations show.
- With heat conduction heat is transported out of the bubble, causing an increased rate of evaporation, which in turn leads to a lower temperature in the bubble. The bubble structure is also different (lower left panel).
- No bubble seems to form if also the nebula is H-deficient (lower right panel). If the heat-conduction flux is lowered by magnetic fields a bubble should be possible to form in this case as well – although, the temperature will increase.

The stellar evolution is a crucial component in time-dependent models of the ionization structure in PNe. The quality of the models increases with more accurate predictions of the changes in the slow wind (of the previous AGB stage), the fast wind, the central star (CS), and the abundances. Either wind is characterized by its mass-loss rate, outflow velocity and abundances, and the CS by its effective temperature ($\mathbf{T_{eff}}$), luminosity (**L**), and mass (**M**).



For H-rich compositions Pauldrach et al. (1988,2004) find that the mass-loss rate of the fast wind decreases with time. For CSPNe with a H-deficient composition, i.e. [WC] stars, empirical data show that the mass-loss rate instead increases with time (e.g. Leuenhagen et al. 1996). Simultaneously the fast-wind expansion velocity (**v**) is better fitted with a downscaled velocity-relation of Pauldrach et al. (1988). The fast-wind outflow velocity is the most decisive factor to the formation of a hot wind-blown bubble. Our studies with [WC] stars require an outflow velocity of about 1000 km/s to form a bubble.

This is work in progress that will be presented in Sandin et al. (2011), in prep.

In a direct followup to this work we will present a study where we match a model with the X-ray-bright PN BD+30º3639.