Hydrodynamic Simulations of Clumps and Clump Interactions in Planetary Nebulae

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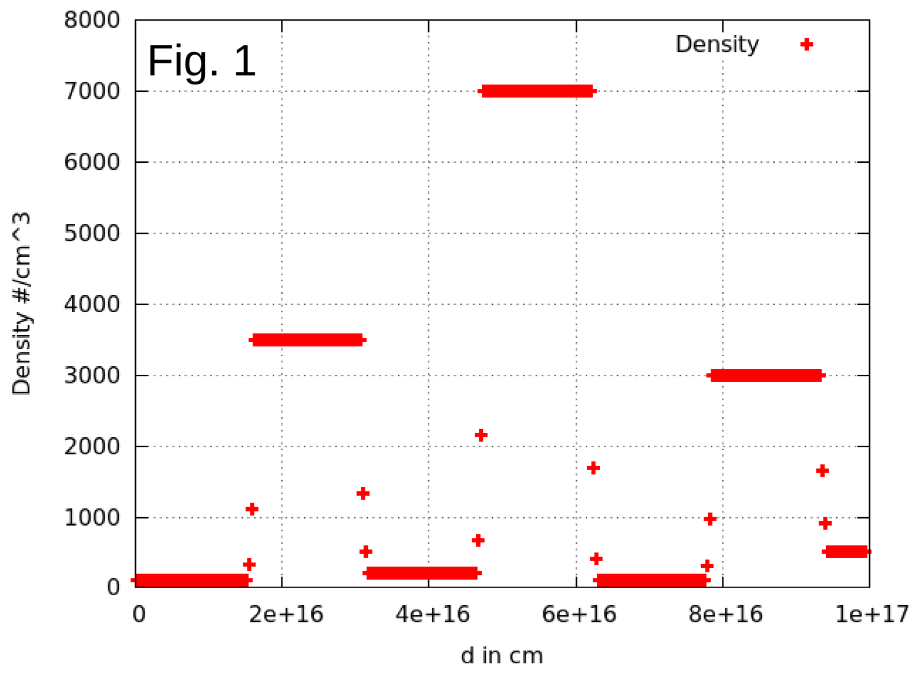
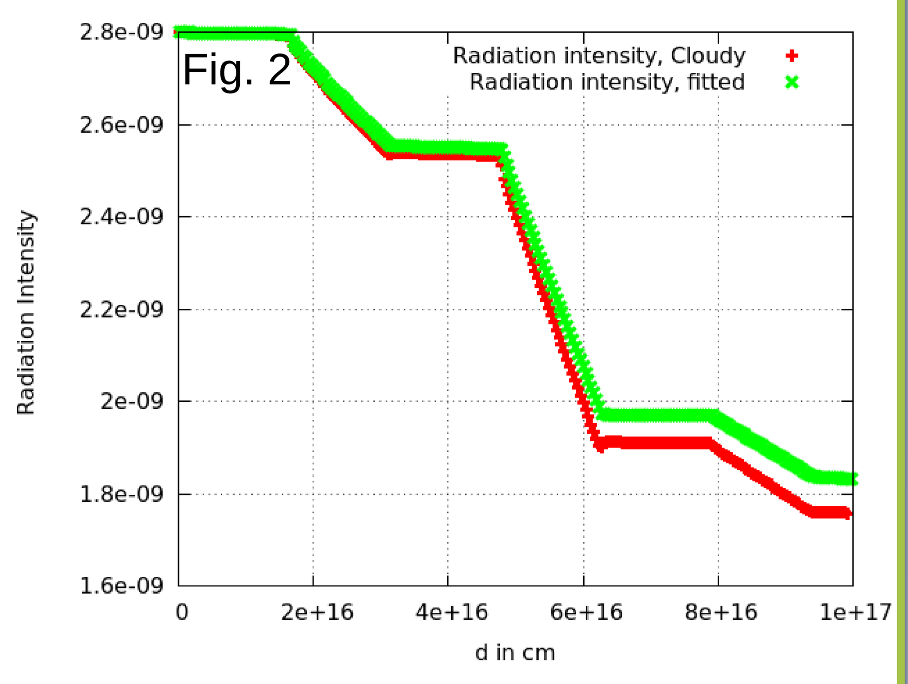
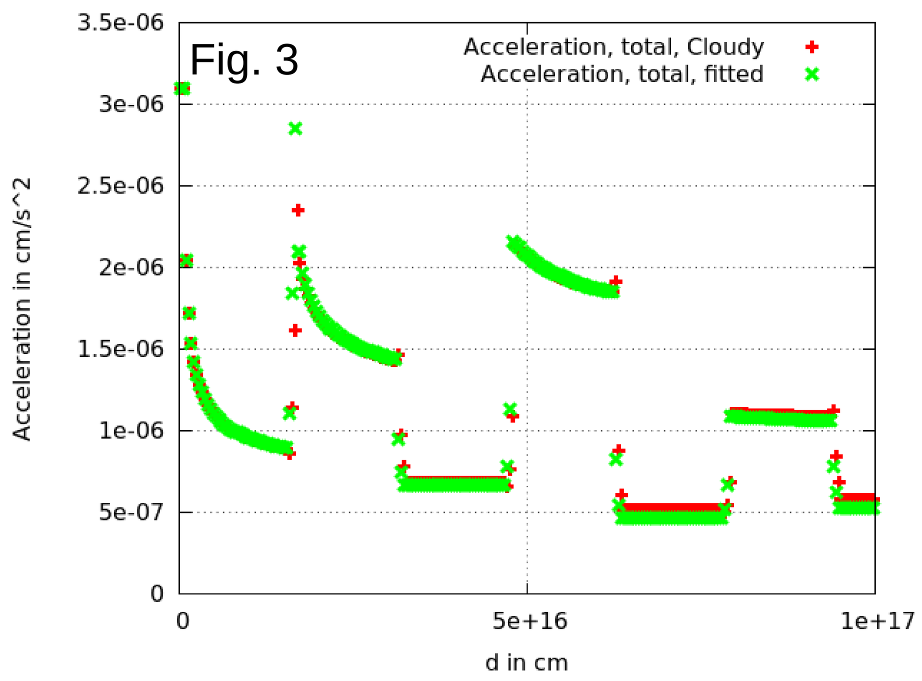
Abstract:

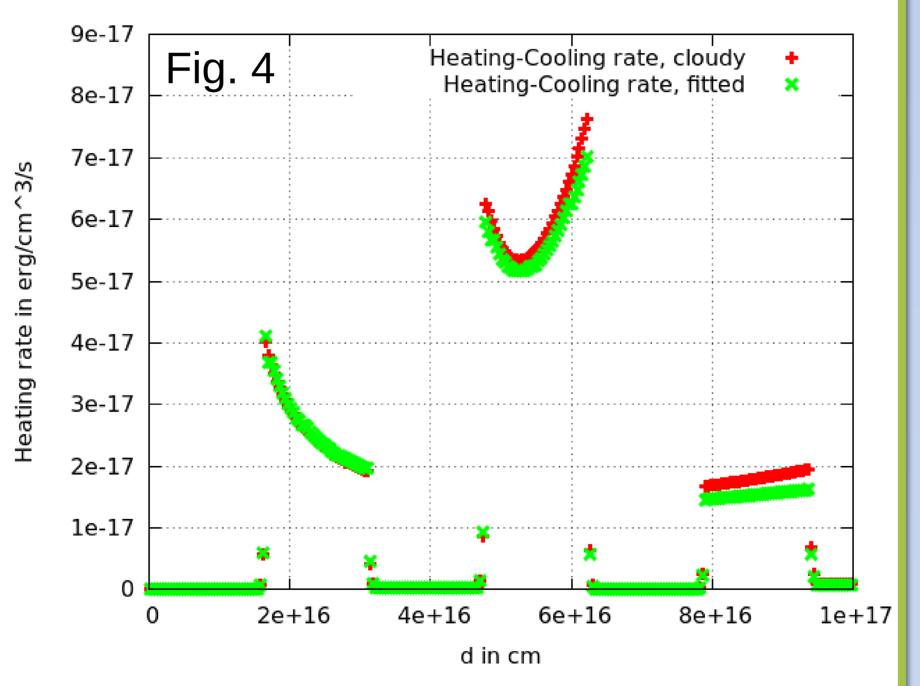
Cometary knots are a poorly understood feature seen in some Planetary Nebulae (PN). The most prominently studied knots are in the Helix Nebula [1]. These knots consist of overdensities, up to 100 times denser than the material of the surrounding nebular rim. We study the stability of these knots using extensive physics and complex initial conditions. For our studies we use multiple components to make the physical model as complete as possible. We perform the 3D hydrodynamic simulations with the FLASH hydrocode [2]. In these simulations we aim for a sophisticated radiation treatment. For this avail, we use the photoionization code Cloudy [3]. Its extensive atomic database and elaborate treatment of physical processes makes it very well suited for our purpose. A realistic model of the stellar radiation is provided by Thomas Rauch's theoretical stellar spectra [4]. This is, to our knowledge, one of the first PN hydrodynamic simulations with an accurate description of the photoionization by using Cloudy. We also take the effects of stellar and self gravity into account. The density of the inflowing wind is modelled as a random field with a power-law spectral density distribution created by our own code TBARF [5]. With this model we study the stability of single clumps, and the interaction and shadowing effects of multiple clumps in the PN environment as introduced by Lim & Mellema [6]. We will extend this by varying the clump size, clump distribution, wind speed, wind density fluctuation spectrum, and stellar temperature to explore the full parameter space. We will also investigate multi-clump interactions similar to Raga et al. [7].

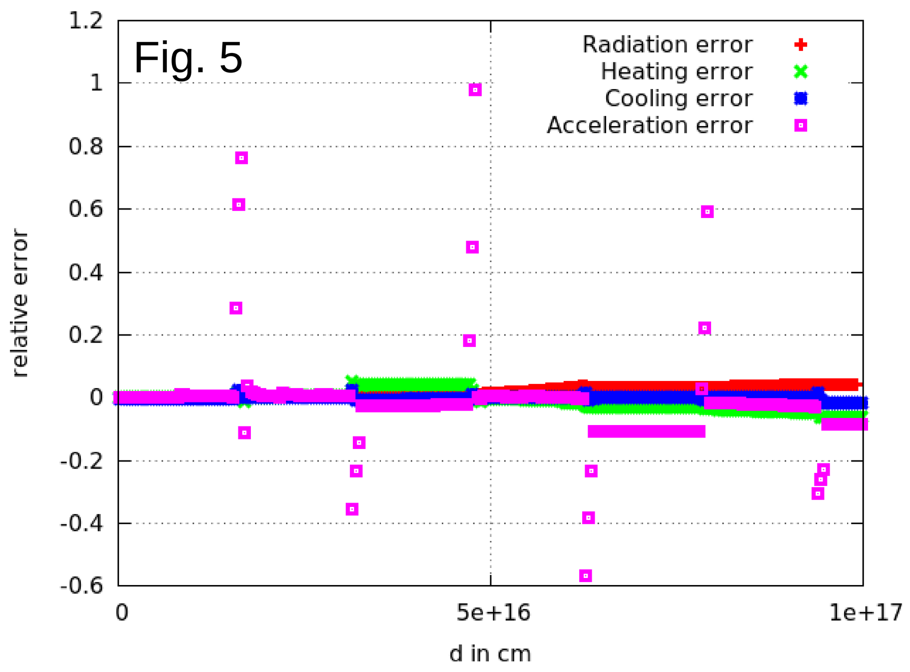
Radiative Transfer with Cloudy







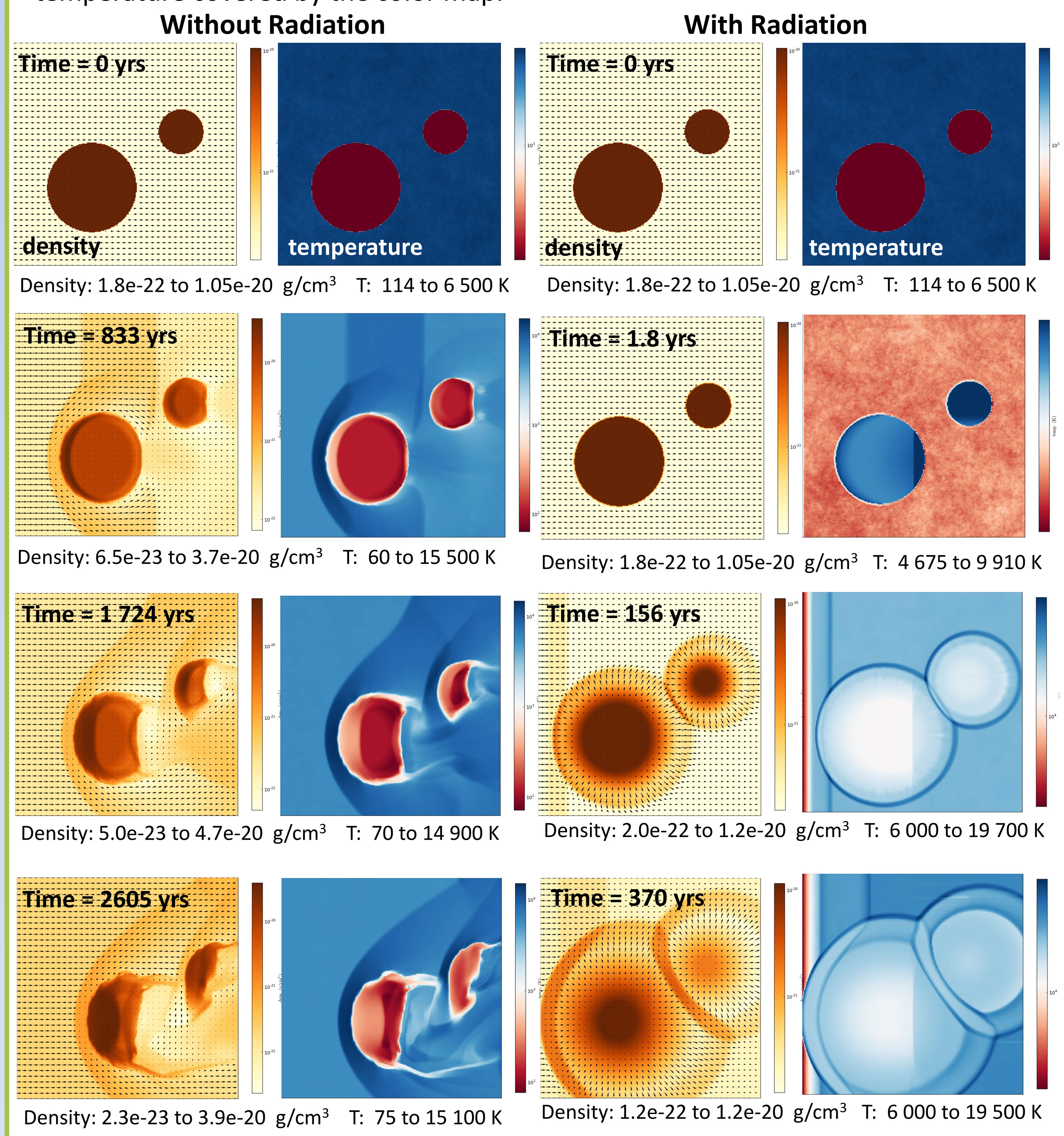




In our hydrodynamic simulations we use Cloudy [3] to treat the radiation and radiative transfer. For this purpose, we create a database of Cloudy simulations. This database consists of tabulated intensity, acceleration and heating values calculated by propagating white dwarf radiation [4] along extended lines of constant temperature and density. Later, in our hydrodynamic simulations, we track the intensity of the propagating radiation by using the tabulated values. Finally we look up the correct heating, cooling and acceleration values for the current intensity, density, and temperature and move on to the next cell. In **Fig.1** we show a sample density profile. **Fig.2** shows the corresponding radiation profile calculated with Cloudy and our reconstructed profile. There are problems in the high density regions, which can be reduced by increasing the resolution of the high density lines. **Fig.3** shows the radiative acceleration due to radiation effects and our reconstruction. **Fig.4** shows the sum of heating and cooling calculated by Cloudy alongside our reconstruction. In **Fig.5** we show the relative errors for radiation, heating, cooling and acceleration. Generally, the formal errors are quite small. There are only discrepancies in the transition regions where a too steep density gradient chosen. We plan on refining our database with higher resolution lines for the final scientific simulations.

Hydrodynamic Simulations

The left two columns in the figure below show density and temperature slices of a simulation cube (size: 0.03 pc^3 with resolution 256^3) without radiation. The right columns show the same for a simulation with the radiation treatment described on the left panel. The density plots have velocity arrows superimposed on them. Both simulations start with the same initial conditions (t=0 yrs). The outside gas is modelled by a Gaussian random field generated by TBARF with a mean density of 100 cm^{-3}. It moves with a speed of 10 km s^{-1}. The clumps are in a pressure equilibrium with the surrounding medium and have a density of 5000 cm^{-3}, their radii are 0.003 pc and 0.006 pc. At t=0 a low density (100 cm^{-3}) wind at 25 km s^{-1} flows into the simulation domain. The radiation case is illuminated from the left side with an intensity of 50 erg cm^{-2} s^{-1} by radiation following a white dwarf star spectrum (T=100 000K) [4]. For each figure we show the range in density and temperature covered by the color map.



We see that in the non-radiation case both clumps get slowly destroyed by the inflowing wind. In the radiation case the clumps photo-evaporate which happens on a much shorter timescale than the destruction by the wind. This evaporation happens quicker than would be expected with our parameters. We can see a slight shading effect on the smaller clump at the t=1.8 yrs snapshot, but generally the shading effects are much weaker than we would expect from observations. These issues will have to be adressed further before we start detailed scientific simulations.

References:

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