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Modelling feedback from massive stars using Monte Carlo radiation hydrodynamics

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Abstract

We conduct numerical simulations of photoionization and radiation pressure feedback from stars in clusters using our Monte Carlo radiation hydrodynamics code, TORUS. We present our fiducial model of a 1000 $M_\odot$ cloud containing a 34 $M_\odot$ O-star. We also present synthetic observations of recombination lines and forbidden lines calculated directly from the RHD simulations.

1. Introduction

Massive OB stars can drastically alter the dynamics of the molecular clouds in which they are born via processes such as photoionization (whereby ejected electrons heat up the ISM, creating a pressure gradient which causes expansion) and radiation pressure onto dust grains. Material is collected into dense neutral shells, which may trigger further star formation – but material is also dispersed, eventually leaving behind an open cluster of exposed stars.

2. Numerical methods

TORUS is a 3D RHD grid code which uses a Monte Carlo (MC) method for the radiation field [1,2]. MC photon packets of different frequencies are emitted from stars which are Lagrangian sink particles. Packets enter cells, get scattered/absorbed, and are then reemitted as diffuse field packets, which continue propagating until they escape the grid. The change in momentum of a cell gives the radiation pressure exerted on that cell; this is added onto the momentum equation in the hydro step.
Grids contain dust, hydrogen, helium, and the first few ionized states of C, N, O, Ne, and S. Dust grains are also present and are thermally decoupled from gas. We include dust heating and heating due to photoionization of H and He, and gas-dust collisions. Sources of cooling are recombination lines of H and He, free-free emission, and collisionally excited forbidden lines from metals. [3,4]
Since temperature affects pressure which affects dynamics, we carry out a full radiation calculation for every hydrodynamics timestep.

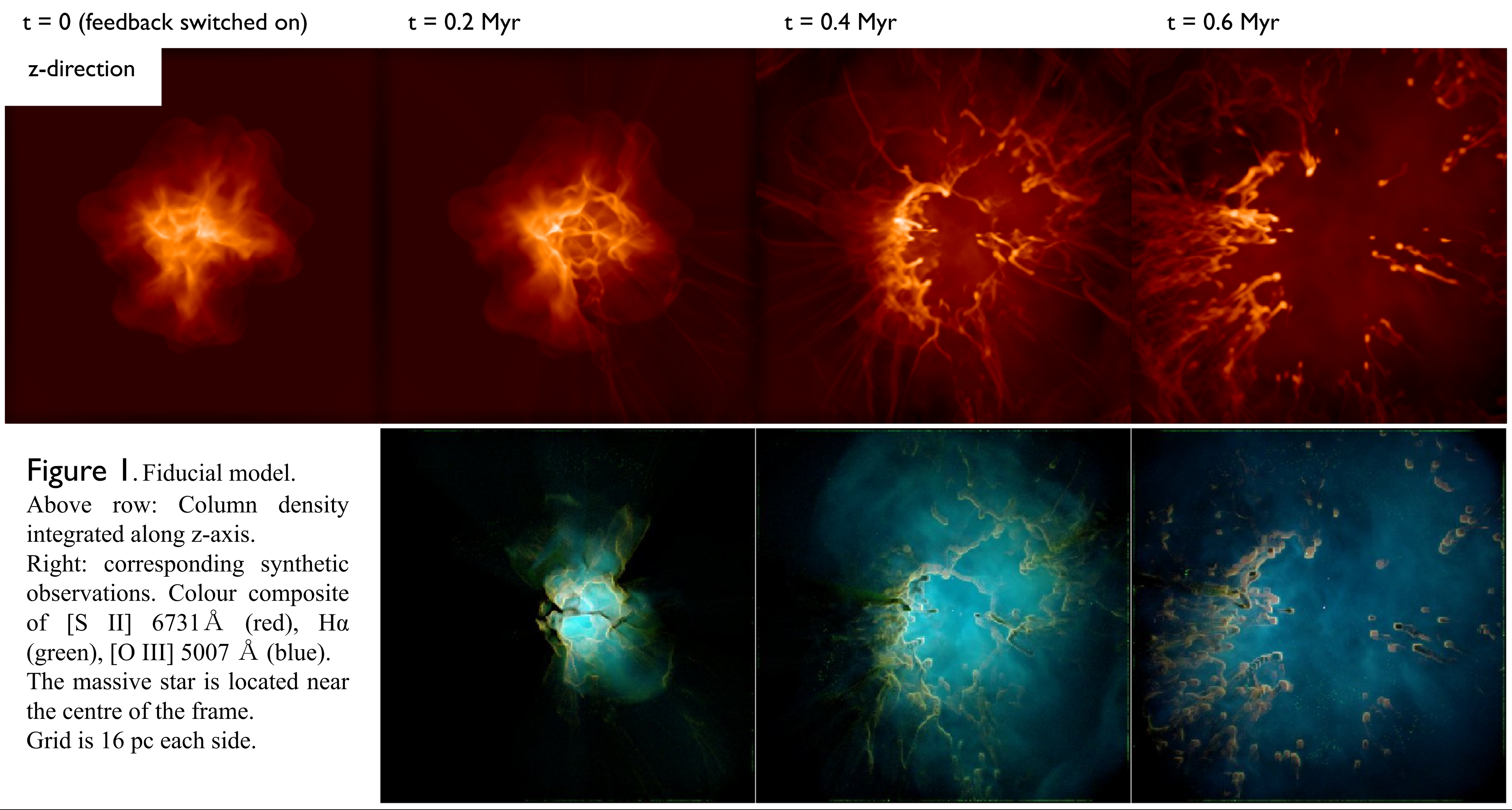

Figure 1. Fiducial model. Above row: Column density integrated along z-axis. Right: corresponding synthetic observations. Colour composite of [S II] 6731 Å (red), Hα (green), [O III] 5007 Å (blue). The massive star is located near the centre of the frame. Grid is 16 pc each side.

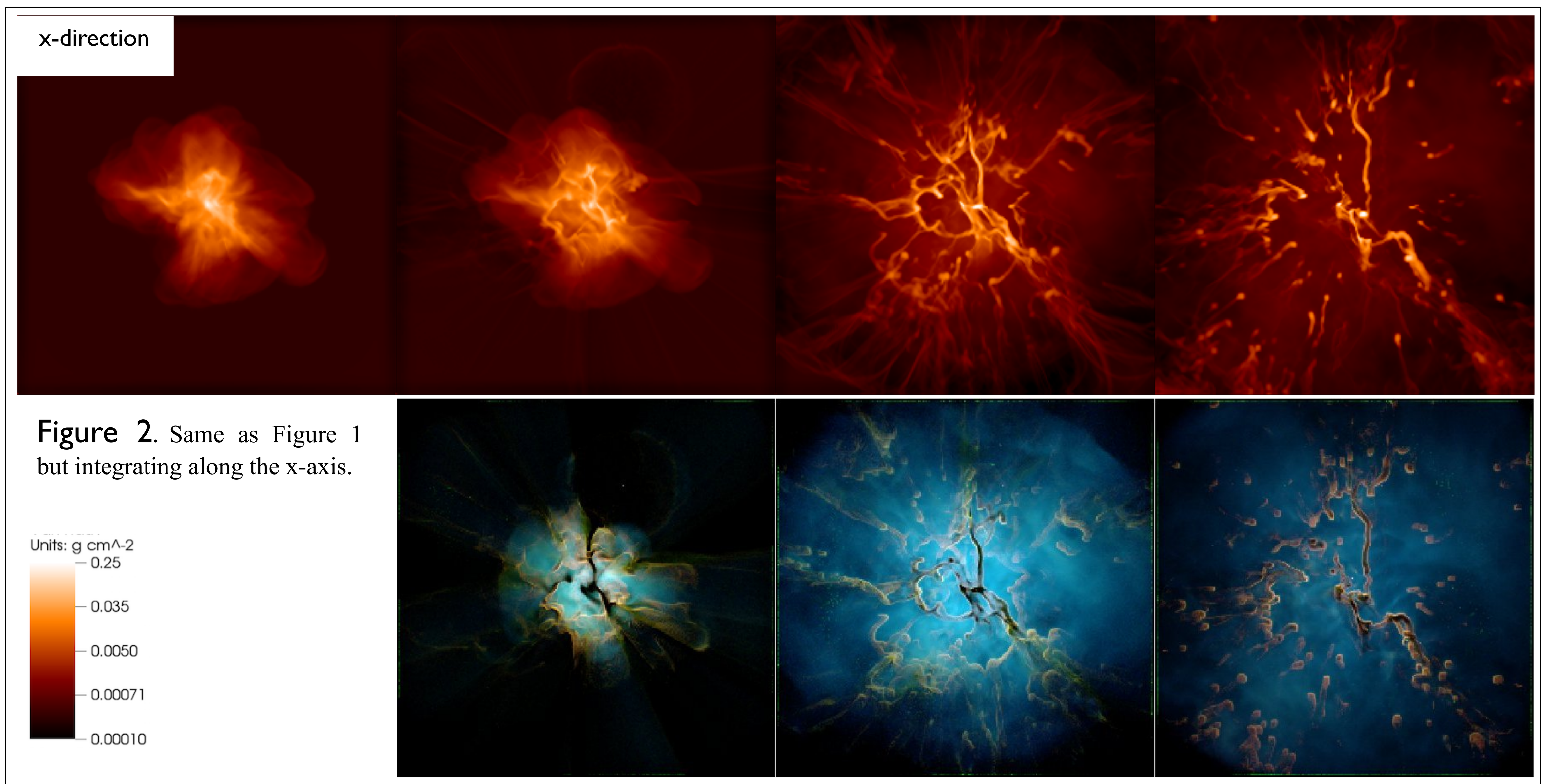

Figure 2. Same as Figure 1 but integrating along the x-axis.

3. Initial conditions – fiducial model

Our fiducial model uses a 3D grid at resolution 256^3, starting with a spherical cloud of 1000 $M_\odot$ with a uniform-density inner core up to half the sphere radius, beyond which an $r^{-1.5}$ density profile extends to the edge. The mean surface density is $\Sigma = 0.01$ g cm^{-2} ($R = 2.66$ pc). A turbulent velocity field is applied such the virial parameter $\alpha = 2$.
The cloud collapses under self-gravity and turbulence without stars up to 0.75 t_{ff}, at which point stars are inserted from a Salpeter IMF with star formation efficiency 10%. The most massive star (34 $M_\odot$) is placed in the most massive clump, while the other stars are placed with probability that a star is at position $r \propto \rho(r)^{1.5}$. Feedback is then switched on.

4. Synthetic observations

From the RHD models, we can obtain images using recombination lines (e.g. Hα), forbidden lines (e.g. [O III] 5007 Å), dust continuum emission, and free-free emission. Some examples are shown in Figure 1. These will allow us to directly compare with observations and test diagnostics of temperature and density (e.g. forbidden line ratios). We also calculate the interstellar UV flux as a function of time and distance from stars, as well as the escape fraction of ionizing photons.

5. Results

Our fiducial model is shown in Figures 1 and 2. The 34 $M_\odot$ star rapidly ionizes and disperses the low-density surroundings, with some high-density knots and filaments resisting the ionization front. Over time, their edges get carved by the front into pillars and eventually globules of high-density neutral gas. On a large scale, the material gets pushed radially away from the star and off the simulation volume; bulk grid properties of a lower-resolution (128^3) version of the fiducial model are plotted in Figure 4 (blue line).
We also carry out preliminary models of higher-mass clouds (but same surface density) at low resolution to investigate the dependence of initial conditions on cloud dispersal. The current status of a 10^4 $M_\odot$ cloud is shown in Figure 3 with grid properties in Figure 4 (green line). Going forward, we intend to use masses of 10^3 to 10^6 $M_\odot$ at 256^3 resolution. For longer-lived clouds, we will also include supernovae.

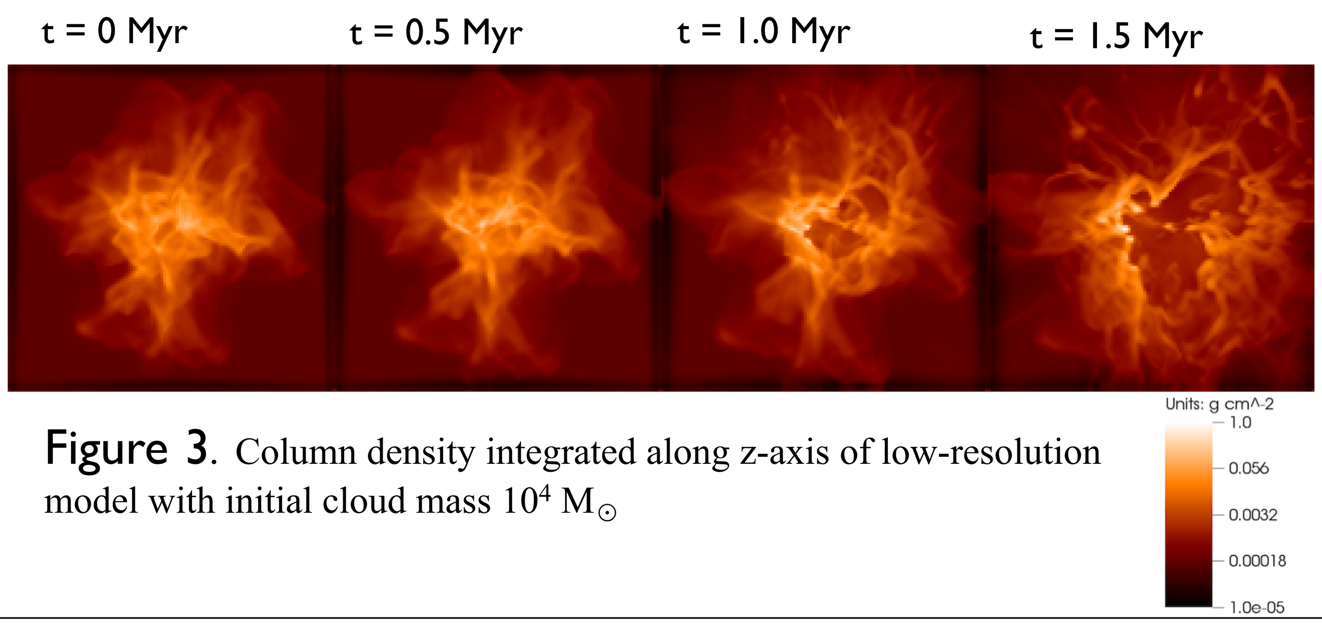

Figure 3. Column density integrated along z-axis of low-resolution model with initial cloud mass 10^4 $M_\odot$

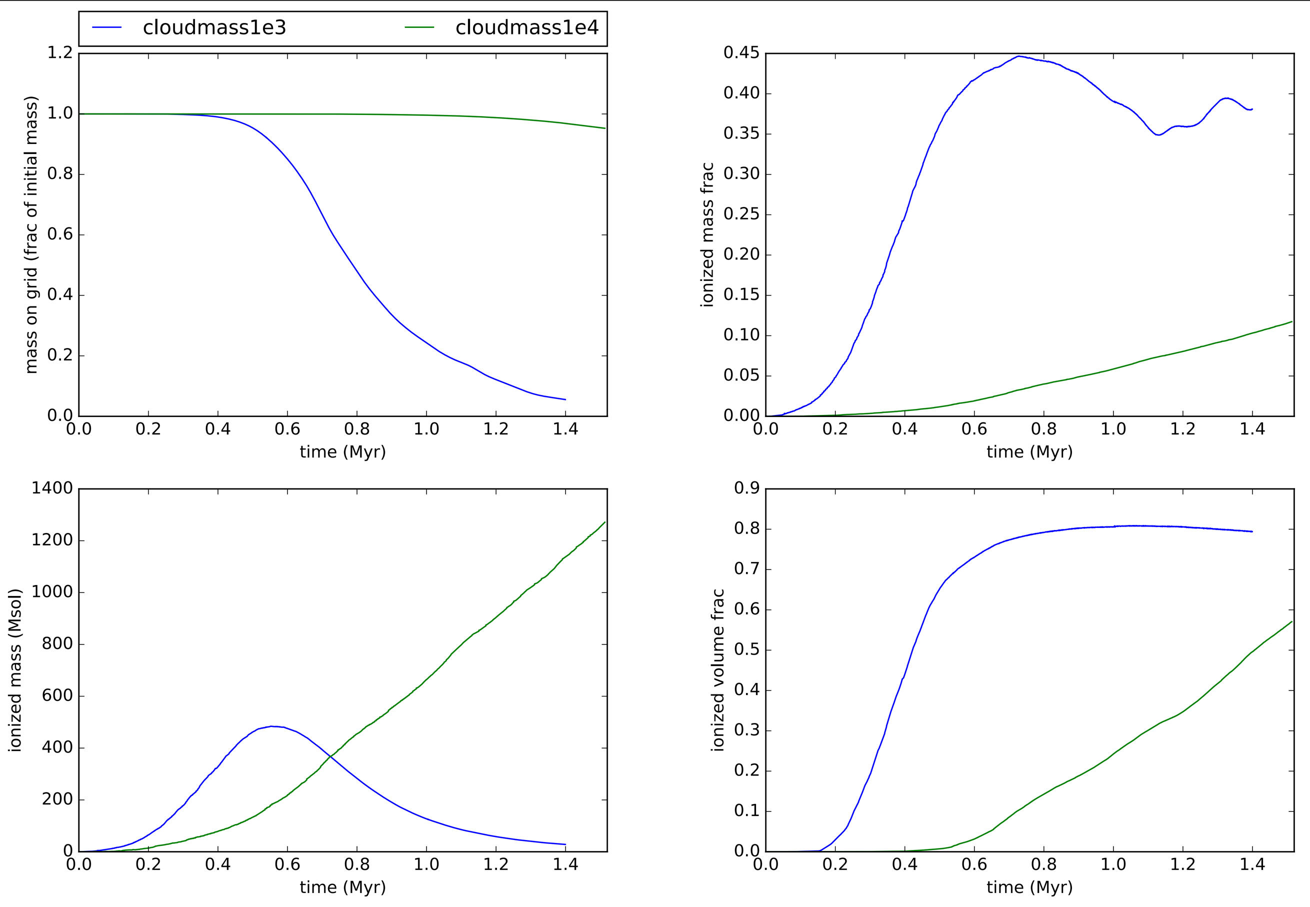

Figure 4. Bulk grid properties for low-resolution models of the fiducial cloud (10^3 $M_\odot$; blue line) and higher mass cloud (10^4 $M_\odot$; green line)

[1] Lucy L. B., 1999, A&A, 344, 282 [2] Harries T. J., 2015, MNRAS, 448, 3156 [3] Wood K. et al, 2004, MNRAS, 348, 1337 [4] Haworth T. J., & Harries T. J., 2012, MNRAS, 420, 562