1. Abstract

We present 3D simulations of the formation of a massive star using Monte-Carlo radiation-hydrodynamics (RHD) scheme that treats the radiation transport with a high level of microphysical detail, including both absorption and scattering by dust and photoionisation of gas. We find that massive star formation occurs via stochastic disc accretion accompanied by radiatively-driven high-speed bipolar outflows, leading to a 25 solar-mass protostar after 30 kyr. Dynamically our simulations are reminiscent of those presented by Kuper et al. (2012) or Klassen et al. (2016). Our method allows us to produce synthetic observables, such as SEDs and molecular line databases directly from the RHD simulations that can then be compared with observations.

2. Numerical method

We have developed an AMR Monte-Carlo RHD method that treats the radiation transport (RT) at a level of microphysical detail comparable to that of selected RT codes such as CLOUDY. The salient points are:

- the stellar luminosity is split into a large number of photon packets that follow a random walk through the computational domain, undergoing scatterings, absorptions and emissions
- Monte-Carlo path-length estimators are used to determine dust absorption rates, photoionisation rates, and radiation-pressure source terms
- radiation hydrodynamics is performed on the same AMR mesh as the RT, self-gravity is calculated using a multi-grid Poisson solver, and Hydrodynamics is performed on the same AMR mesh as the RT, self-gravity is calculated using a multi-grid Poisson solver, and Dirichlet boundary conditions were used with a minimum cell depth of 7 and a maximum of 12, meaning the smallest AMR cell has linear dimension of 13AU. Outflow/no expansion. We used silicate dust grains, assumed to sublimate at 1500 K, and a 0.1pc radiation, 100 solar-mass cloud with an inclination of 5 degrees. The 10 micron silicate feature is seen strongly in absorption. The central object is still strongly obscured even at 30 kyr.

3. Initial conditions

We assumed a 0.1pc radiation, 100 solar-mass cloud with an exponential density profile and a solid body rotation with an angular velocity 5x10^{-19} rads. An AMR grid of 8x10^4 cells on a side was used, with a minimum cell depth of 7 and a maximum of 12, meaning the smallest AMR cell has linear dimension of 13AU. Outflow/no boundary conditions were adopted for the hydrodynamics, and Dirichlet boundary conditions were used for the Poisson solver, formed from a low-order multipole expansion. We used silicate dust grains, assumed to sublimate at a temperature of 1500K. The protostellar radius and luminosity were calculated from the 10^4 track of Hosokawa and Omukai (2009).

4. Results

The protostellar accretion rate shows substantial variability and quickly peaks after 5 kyr at 2x10^{40} solar-masses/year. It then declines as the radiation pressure starts to establish outflow cavities along the rotational axis, although a high-level of variability remains (see Figure 1). The outflow cavities are broadly symmetric, fast (~100km/s) low-density (<10^{-17} g/cc) and warm (~10000K) (see Figure 2). We do not see any evidence of rotating-driven Rayleigh-Taylor instabilities (Cif. Krumholz et al. 2009). By 30 kyr the protostar has reached 25 solar-masses and is surrounded by a substantial protostellar disc that displays strong spiral features (see Figure 3).

We are able to compute synthetic observables directly from the RHD simulations, using the gas and dust temperatures and photoionisation state of the gas. For example we can use the SEDs (Figure 4) to predict the position of the object in colour-colour space and compare with cuts used to identify massive young stellar objects (Figures 5 and 6). We are also able to calculate ISRF level populations for molecules and hence dust cubes for particular transitions (see Figure 7 for an example).

References