Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 28 March 2016 (MN LaTeX style file v2.2)

Cooling Clouds by Varying Metallicities: Origin of Globular Cluster Bimodality

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ABSTRACT
Globular Clusters

Key words: globular clusters - methods:numerical

1 INTRODUCTION

2 BASIC IDEA

3 NUMERICAL MODELS

3.1 Numerical Method

This simulations were performed with the publicly available Eulerian three-dimensional hydrodynamical adaptive mesh refinement Enzo code (The Enzo Collaboration et al. 2013). The domain box size of the simulation was 150 pc with a top level root grid resolution of 128^3. Cell refinement was dictated by baryon mass and Jeans length with a maximum refinement level of 3. Our simulations included self gravity and radiative cooling using the Grackle library; details described in The Enzo Collaboration et al. (2013). The metal heating and cooling rates are provided from Haardt & Madau (2012).

3.2 Initial Conditions

Our initial conditions consisted of a cloud in pressure equilibrium with an ambient density and temperature background. The internal structure of the cloud is modeled by a Bonner-Ebert sphere Bonnor (1956); a self-gravitating isothermal gas sphere in hydrostatic equilibrium embedded in a pressurized medium. To fully describe a Bonner-Ebert sphere, a mass M_{BE}, temperature T_{BE}, and an external pressure P_{ext} must be chosen. Following our assumptions outlined in Section 2, we choosed $M_{BE} = 10^6$ M$_\odot$, $T_{BE} = 6000$ K, and $P_{ext} = 1.8 \times 10^5 \times k_B$ (k_B : Boltzmann constant). This corresponds to a cloud on the cusp where heating and cooling balance.

In addition, we add turbulence to the cloud following a power spectrum of $v_k^2 \propto k^{-4}$ for the velocity field.

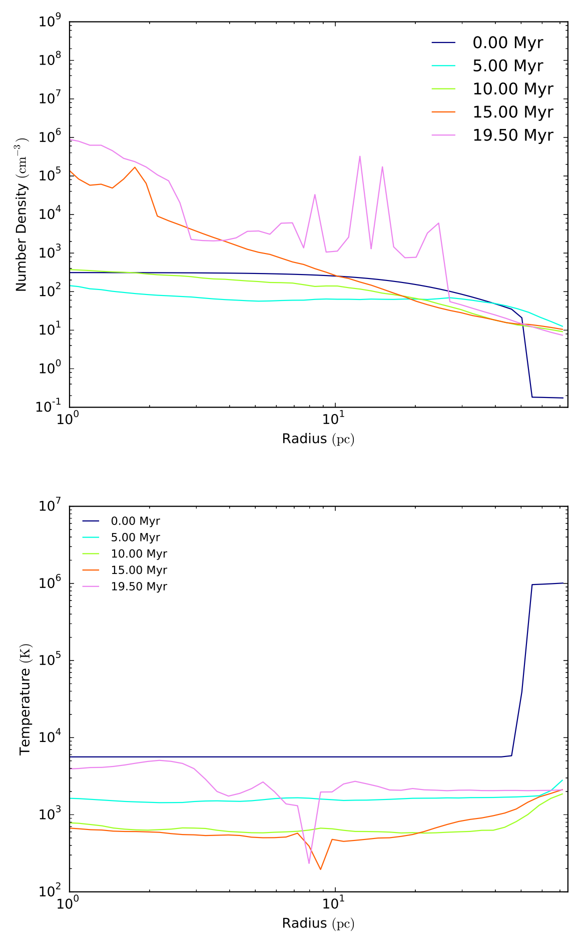

Figure 1.

Cell weighted profiles for density and temperature at give output times for run with cooling, turbulence, and metallicity of $Z = 10^{-3} Z_\odot$.

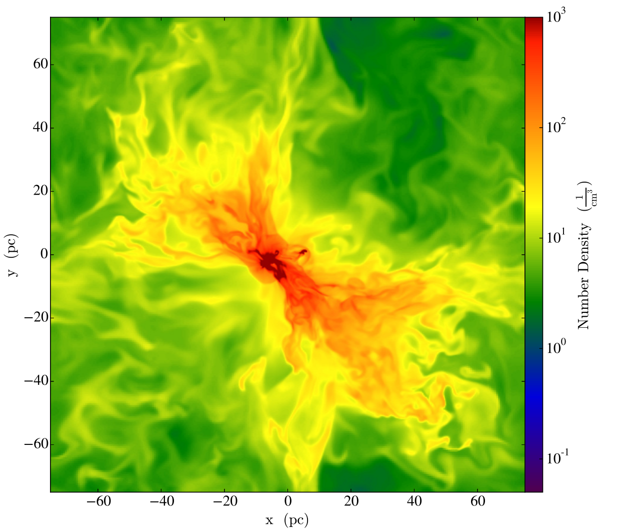

Figure 2.

Density slice at $t = 19.4$ Myr for run with cooling, turbulence, and metallicity of $Z = 10^{-3} Z_{\odot}$. In this run cooling is not efficient and gravity takes over forming a dense core.

4 RESULTS

4.1 No Heating Runs

In the left hand panel of Figure 1, are density profiles at given time steps. The cloud, which initially stable, starts to change dynamically due the added turbulence and cooling. The the free fall time of the cloud is $t_{ff} \approx 6$ Myr. However, the added pressure due to turbulence has prolonged any large scale collapse. Noting the several outputs, the cloud initially starts to drive mass outward. This is due the increase in pressure from turbulence. The outter rim of the cloud begins to drive outward decreasing the amount of mass in each radi. The expansion only last for ≈ 15 Myr. At this point, gravitational collapse sets in and the formation of a core begins, see Figure 2. The right hand panel of Figure 1, demonstrates the inability of the cloud to cool sufficiently. As expected from the one zone model, the cloud cannot efficiently cool before global gravitational collapse sets in.

4.2 Heating Runs

5 DISCUSSION

5.1 Analytic Model

5.2 Implications

5.3 Caveats

6 SUMMARY

ACKNOWLEDGMENTS

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