The effect of dust-cooling in the fragmentation of star-forming clouds for the transition from Pop. III to Pop. II

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Introduction

The first burst of star formation in the Universe is thought to give rise to massive stars, with current theory predicting masses in the range 20-150 solar masses. This contrasts with the mode of star formation we see today, which tends to yield stars with masses less than 1 solar mass, and so at some point in the evolution of the Universe there was a transition from primordial (Pop III) star formation to the mode of star formation that we see today (Pop II/I). The most widely accepted cause for this transition is metal enrichment of the interstellar medium by the previous generations of stars, and suggests that there may be a 'critical metallicity' at which the mode of star formation changes.

Questions

What is the expected mass spectrum of stars in metal free and metal poor conditions?

At what metallicity do we expect the transition from forming predominantly high-mass stars to the IMF we observe today, which is dominated by low-mass stars?

What are the dominant physical processes that govern fragmentation and determine the mass spectrum (feedback, chemistry & cooling, environmental & initial conditions)?

Approach

We investigate the effects of the cooling due to dust grains on the collapse of low metallicity star forming clouds and the Pop III/II transition. Making use of 3D numerical models to follow the thermal evolution of clouds with different metallicities, we study self-consistently the evolution of the gas and dust temperatures during the collapse, and determine the properties of the cloud at the point at which it undergoes gravitational fragmentation.

This allows us to investigate the role that dust cooling may play in the transition from a Pop III IMF composed predominantly of high-mass stars to the IMF we observe today.

Results

The simulations were made using the Gadget2 SPH code, employing 40 and 2 million particles. The clouds start at a number density of 10^5 cm^{-3} and temperature of 300 K. We test two metallicities: 10^{-4} and 10^{-5} $Z_{\odot}$.

And we were able to reproduce previous 1D results with a simple core collapse. By adding rotation and turbulence, the collapse was slower, and so the PdV heating smaller, permitting the gas to cool more.

Conclusions

We conclude that the dust can start to become an efficient coolant at around metallicities of 10^{-5} - $10^{-4}Z_{\odot}$, in agreement with the results of Omukai et al. (2005). We hence support the idea that dust cooling can play an important role in the fragmentation of molecular clouds and the evolution of the stellar IMF (Clark et al. 2008), and may help to bring about the transition from Pop III to Pop II star formation.

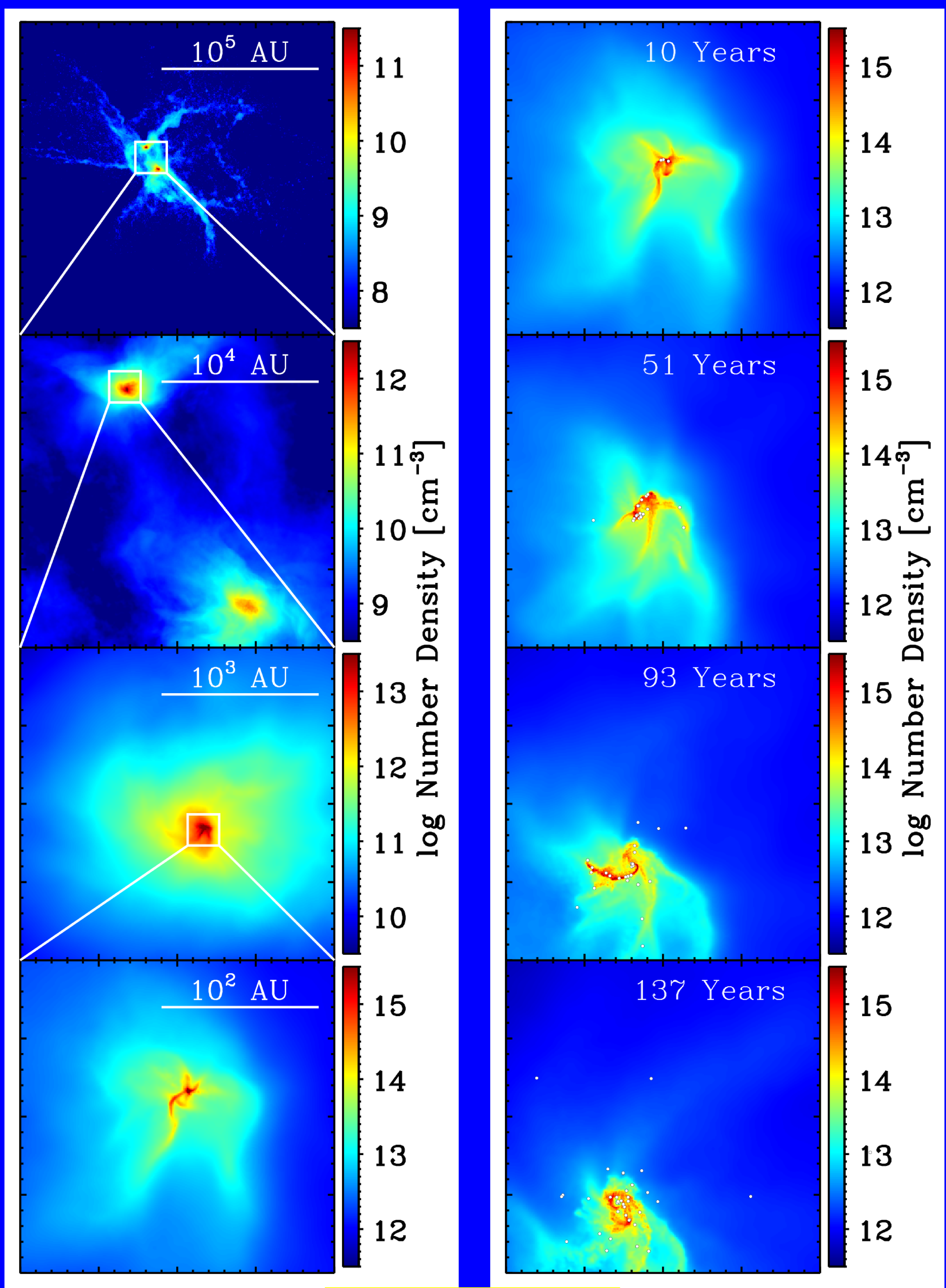

Figure 1

Number density chart for 40 million SPH particles and $Z = 10^{-4}$ $Z_{\odot}$. Left: Zoom in the simulation snapshot just before forming the first sink particle. Right: Time evolution of the sink particles creation.

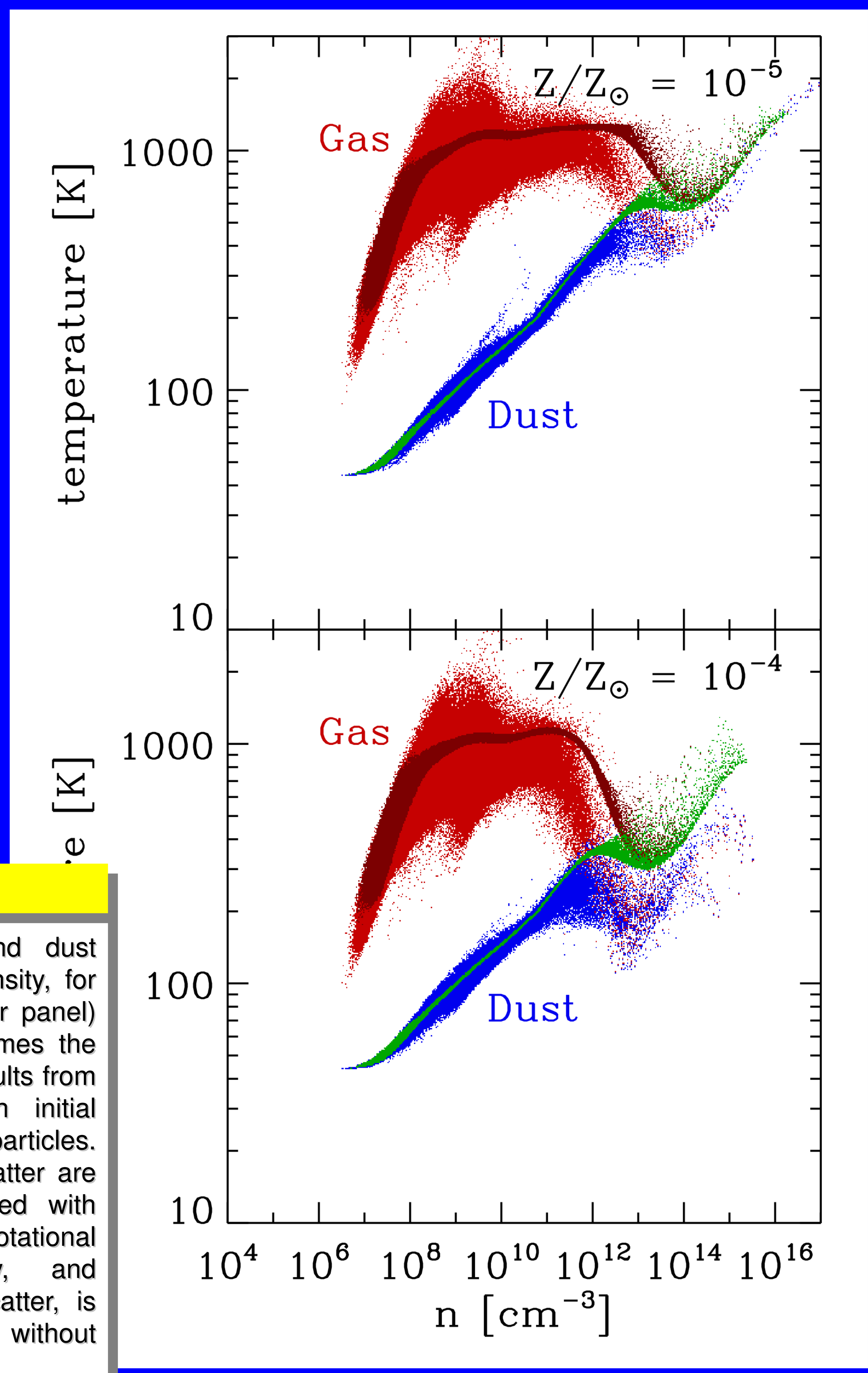

Figure 2

Dependence of gas and dust temperatures on gas density, for metallicities of 10^{-4} (upper panel) and 10^{-5} (lower panel) times the solar value. We show results from simulations with smooth initial conditions for 2 million particles. The points with more scatter are from simulations initialized with small amounts of initial rotational and turbulent energy, and overplotted, with less scatter, is the core collapse without turbulence nor rotation.

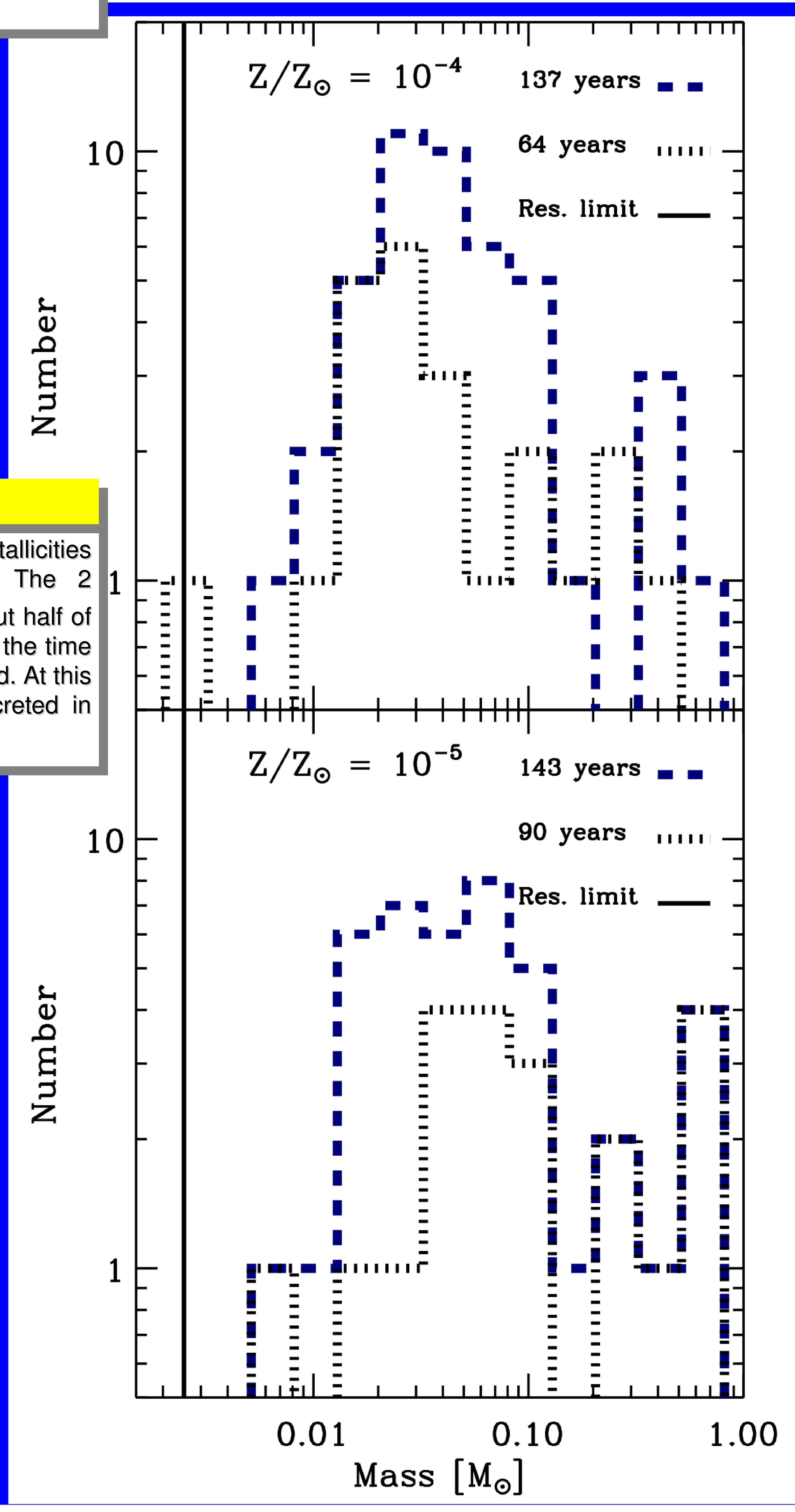

Figure 3

Sink particles IMF for metallicities of 10^{-4} and 10^{-5} $Z_{\odot}$. The 2 histograms are when about half of the sinks are formed, and the time after the first sink is formed. At this point, about 5 $M_{\odot}$ is accreted in the sink particles.