SIMULATING METAL-POOR STAR FORMATION IN THE FIRST GALAXIES

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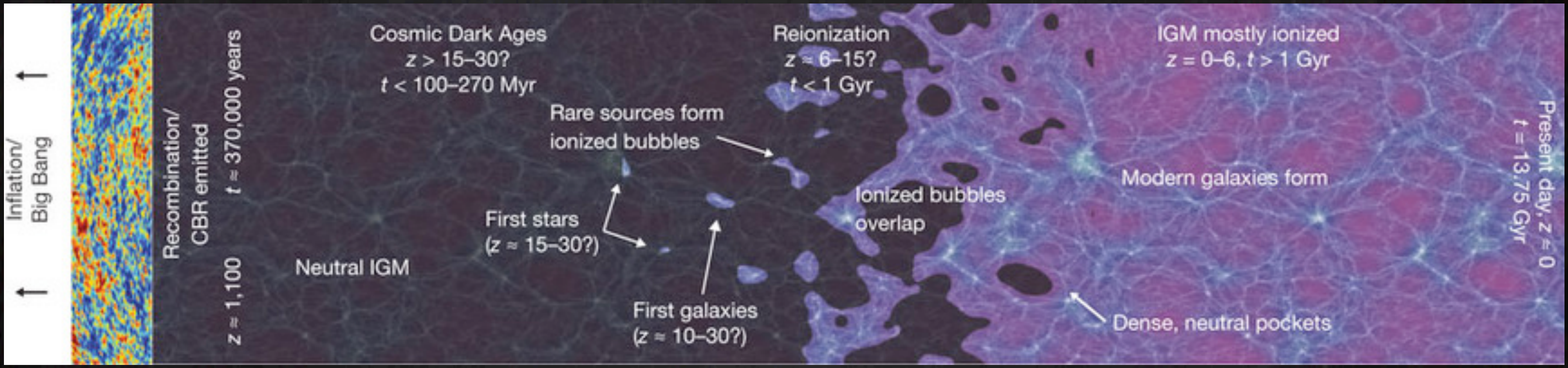
with Volker Bromm and Milos Milosavljevic

1. What theory and simulations have taught us about Population III star formation

2. The Pop III-II star formation mode transition

3. Current work: Simulating metal-poor, clustered star formation in the first galaxies

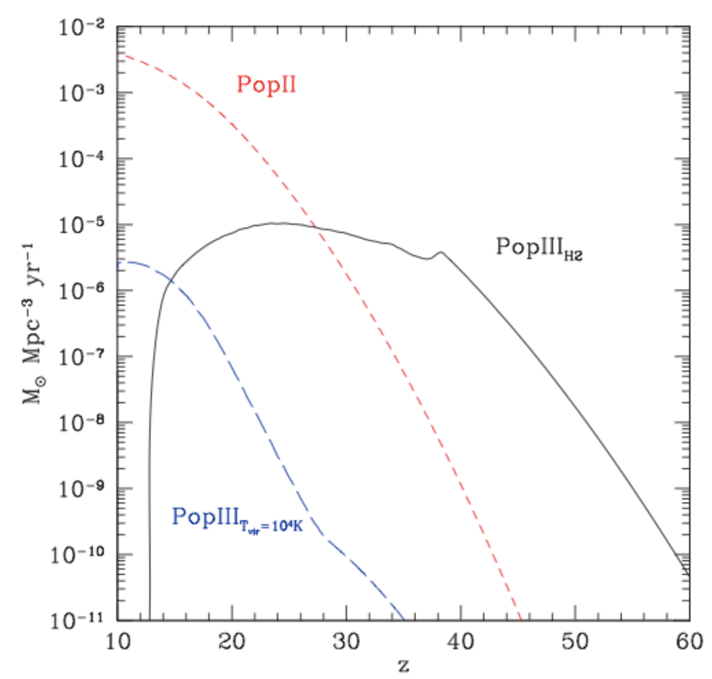
First Stars – Population III



Formed at high redshifts: $z \approx 15$-40

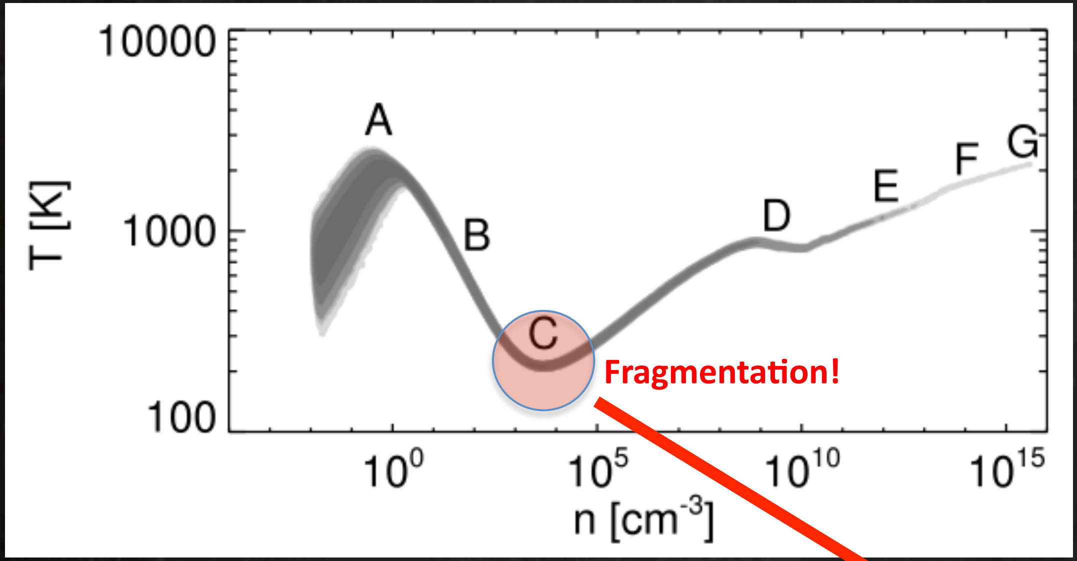
Birth site: $10^6\ M_\odot$ dark matter 'minihalos'

Couchman & Rees (1986); Tegmark et al. (1997)



Trenti & Stiavelli (2009)

First Stars – Population III



Yoshida et al. (2006)

Complete lack of heavy elements significantly affects thermal evolution as gas collapses

Overall behavior controlled by physics of H_2 molecule

Fragmentation sets in at $n \sim 10^4$ cm^{-3} and $T \sim 200$ K

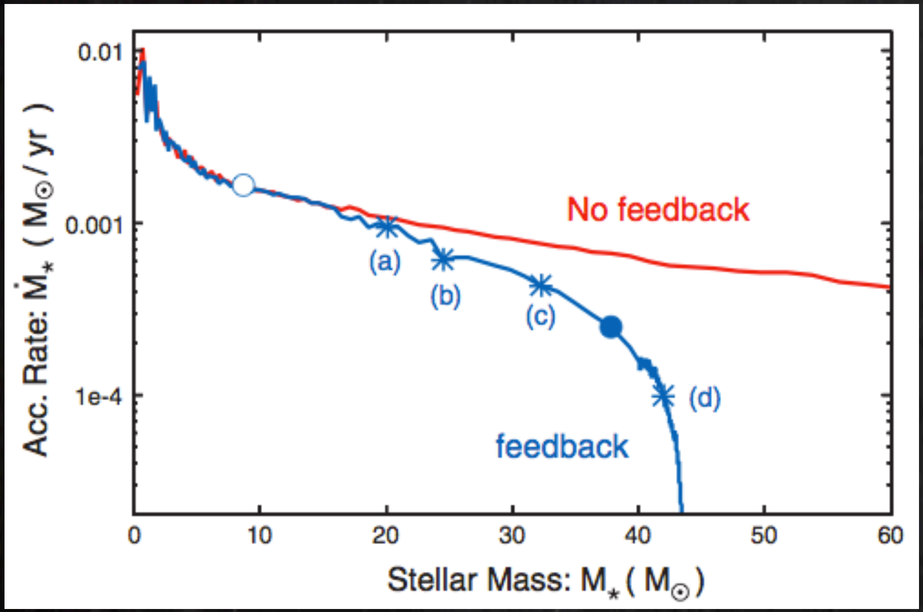
$\rightarrow M_J \sim 1000\ M_\odot$

Abel, Bryan, & Norman (2000); Bromm, Coppi, & Larson (2002)

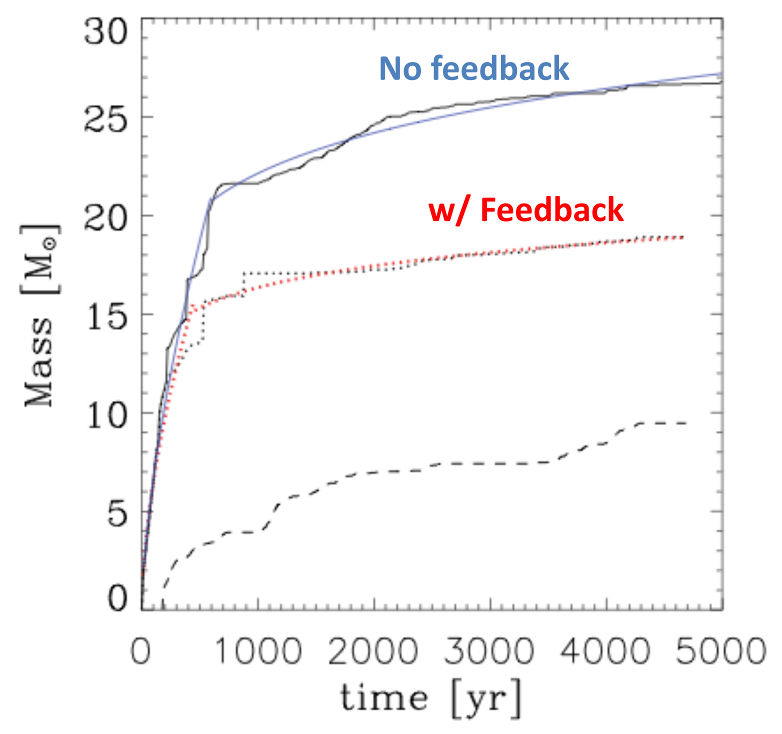
Stellar mass determined by accretion of Jeans unstable clump onto protostellar core

First Stars – Population III
Maybe not so massive…

1. Protostellar radiative feedback can suppress gas accretion



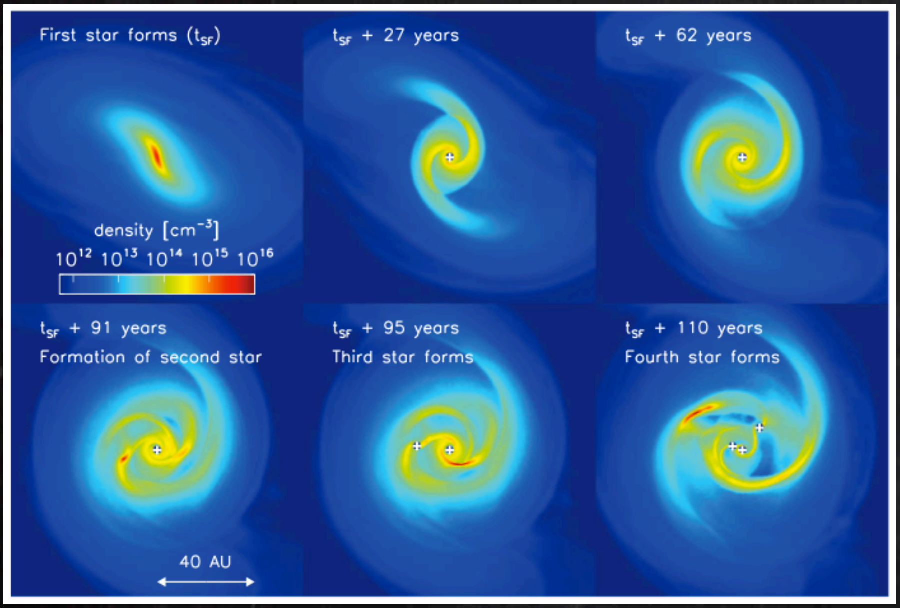
Hosokawa et al. (2012)



Stacy, Greif, & Bromm (2012)

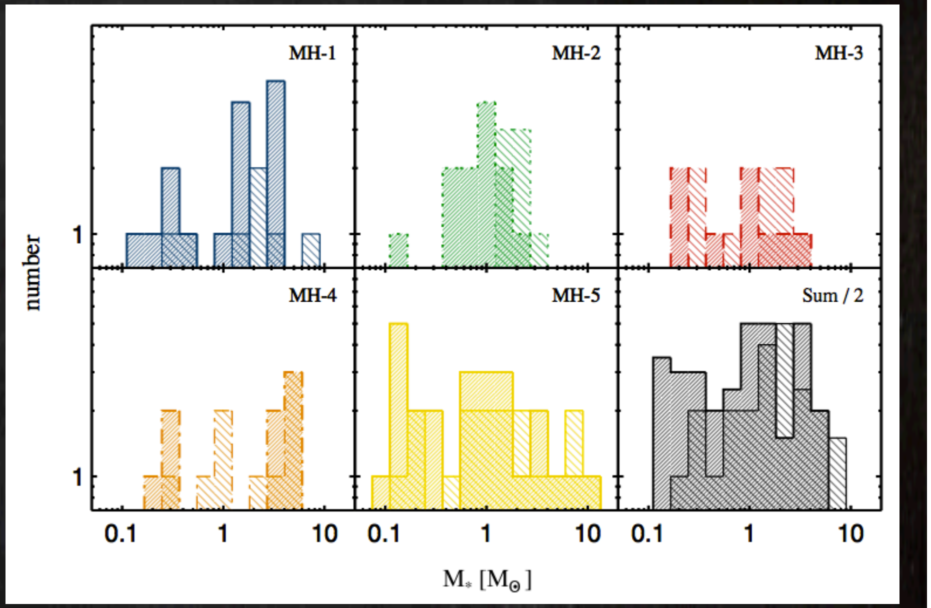
First Stars – Population III
Maybe not so massive…

2. Pop III disks are unstable to fragmentation



Clark et al. (2012)

Greif et al. (2011)



Much more broad, less top-heavy mass function, but almost certainly more massive than Population II/I

What drives the Pop III/II star formation mode transition?

Answer: Metals

Fine-structure lines:

$n \sim 10^3 - 10^6$ cm^{-3}

$M_{frag} \sim 10 - 100\ M_\odot$

$Z_{crit} \sim 10^{-3.5}\ Z_\odot$

Bromm et al. (2001); Bromm & Loeb (2003); Santoro & Shull (2006); Smith et al. (2008)

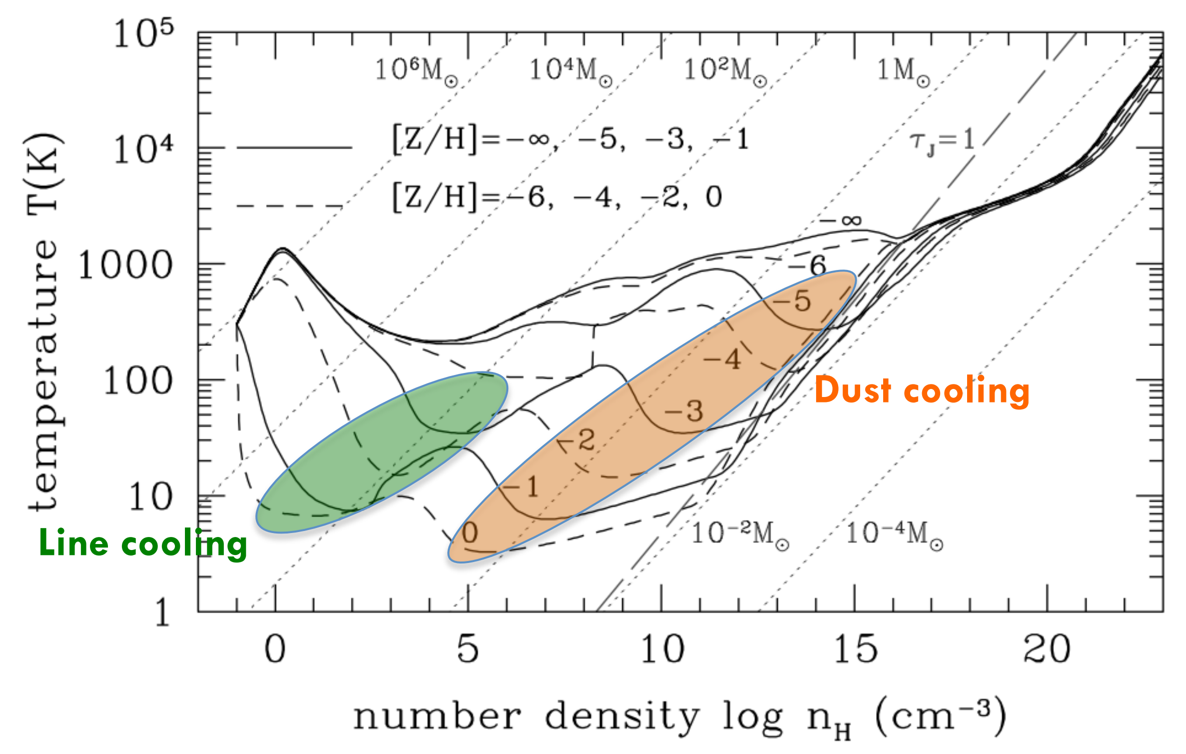
Dust thermal emission:

$n \sim 10^{7\text{-}14}$ cm^{-3}

$M_{frag} \sim 0.1 - 1\ M_\odot$

$Z_{crit} \sim 10^{-6}\ Z_\odot$

Schneider et al. (2006); Omukai et al. (2005); Tsuribe & Omukai (2006); Clark et al. (2008)



Omukai et al. (2005)

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My focus:

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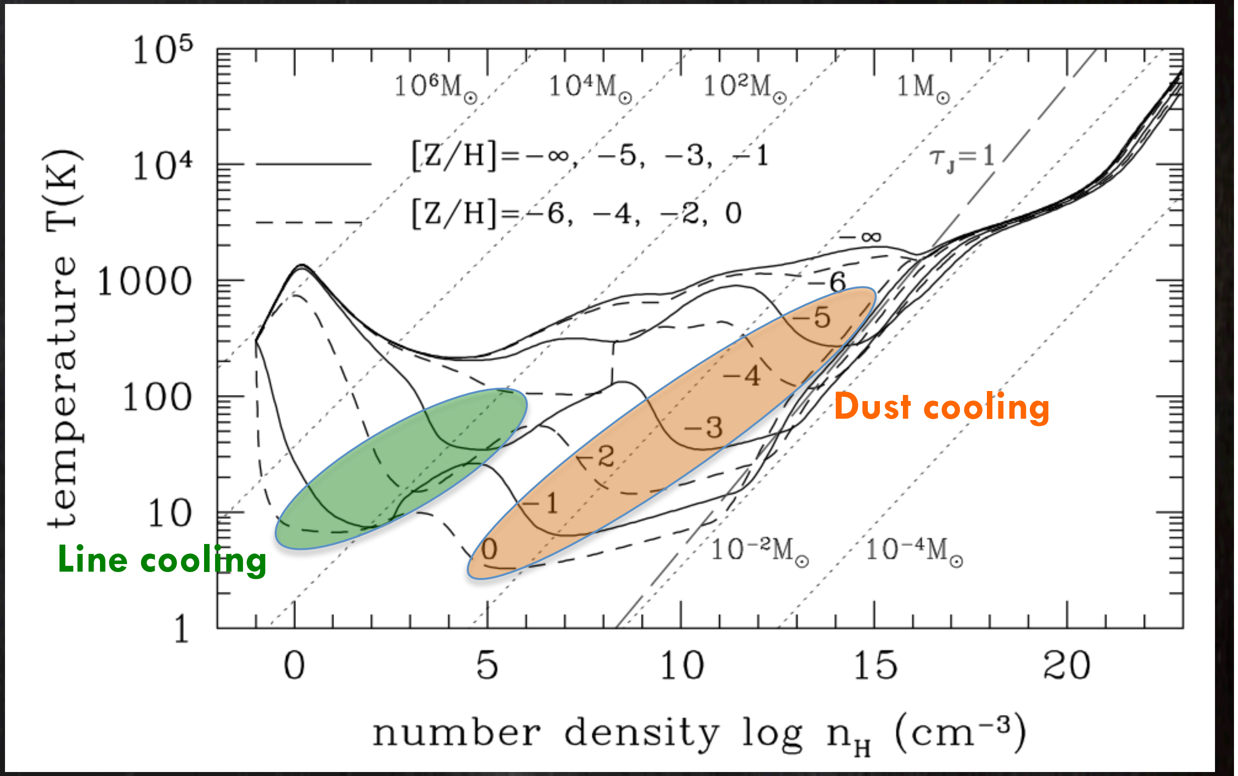
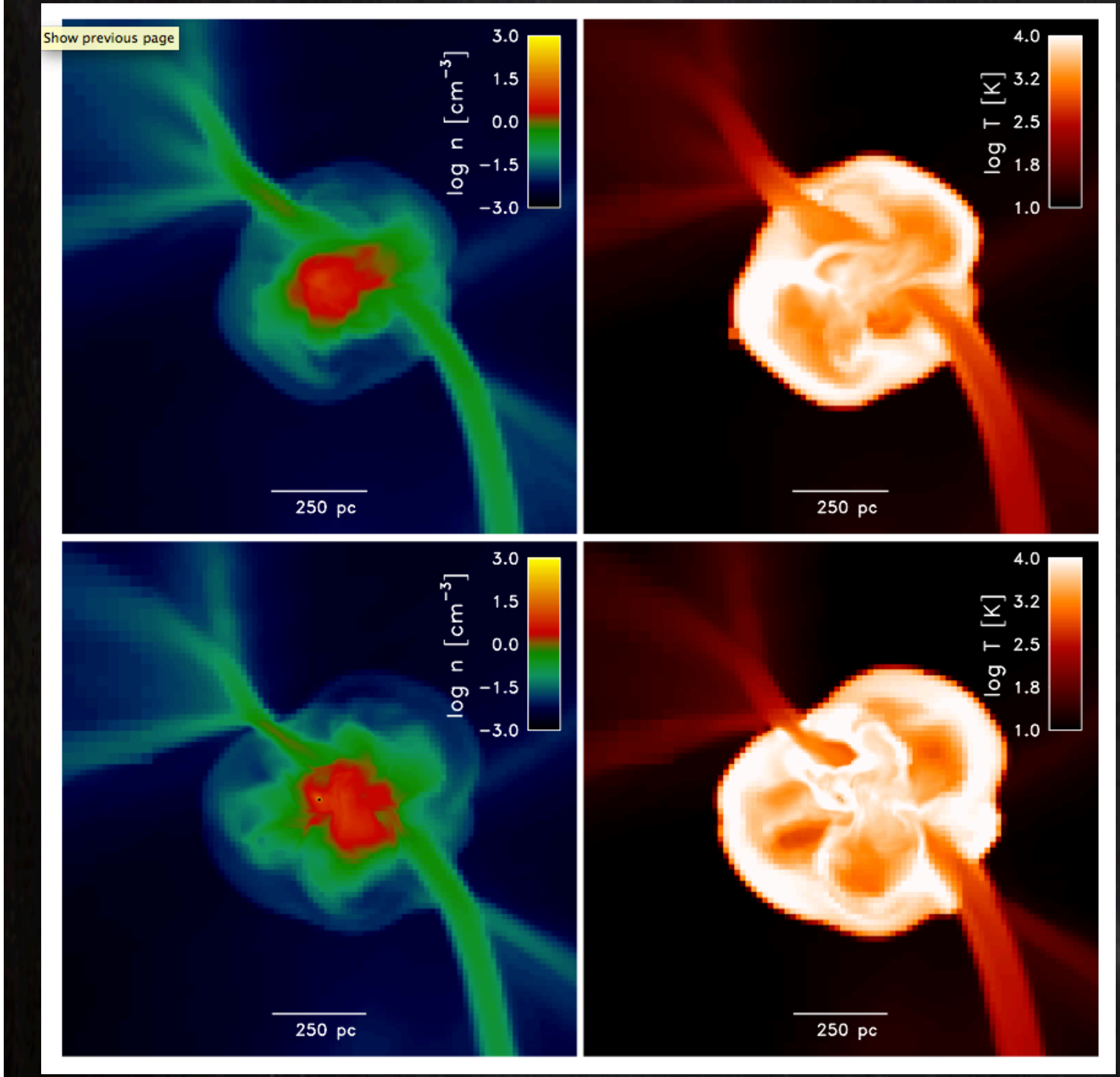


Omukai et al. (2005)

Metal-enriched star formation in the first galaxies

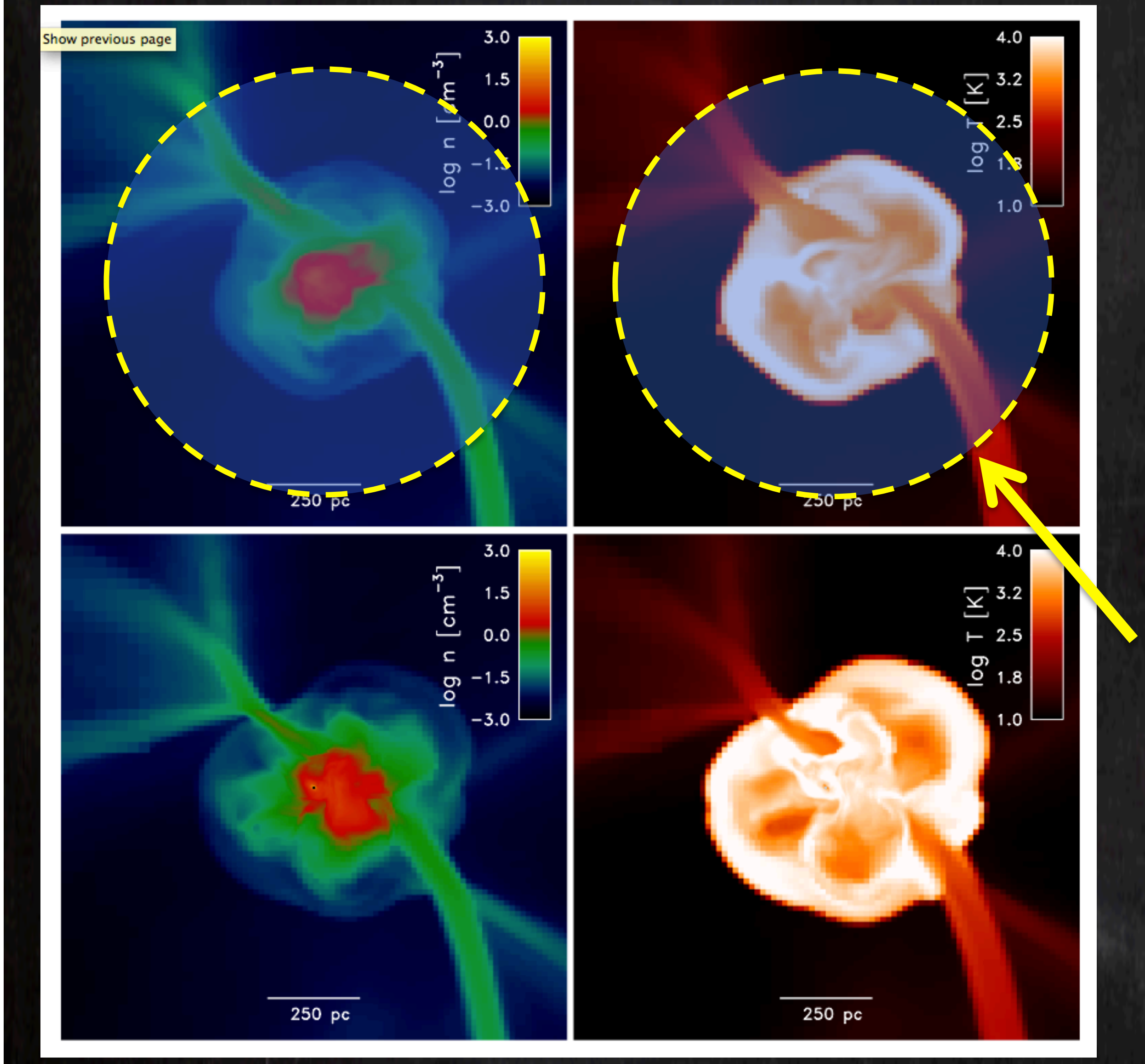


Cosmological simulation in 1 Mpc^3 comoving box

Molecular hydrogen and minihalos suppressed by strong Lyman-Werner background

Approximate the point of atomic cooling halo virilization by onset of high-density Lyman-alpha cooling aided contraction.

Metal-enriched star formation in the first galaxies



Cosmological simulation in 1 Mpc^3 comoving box

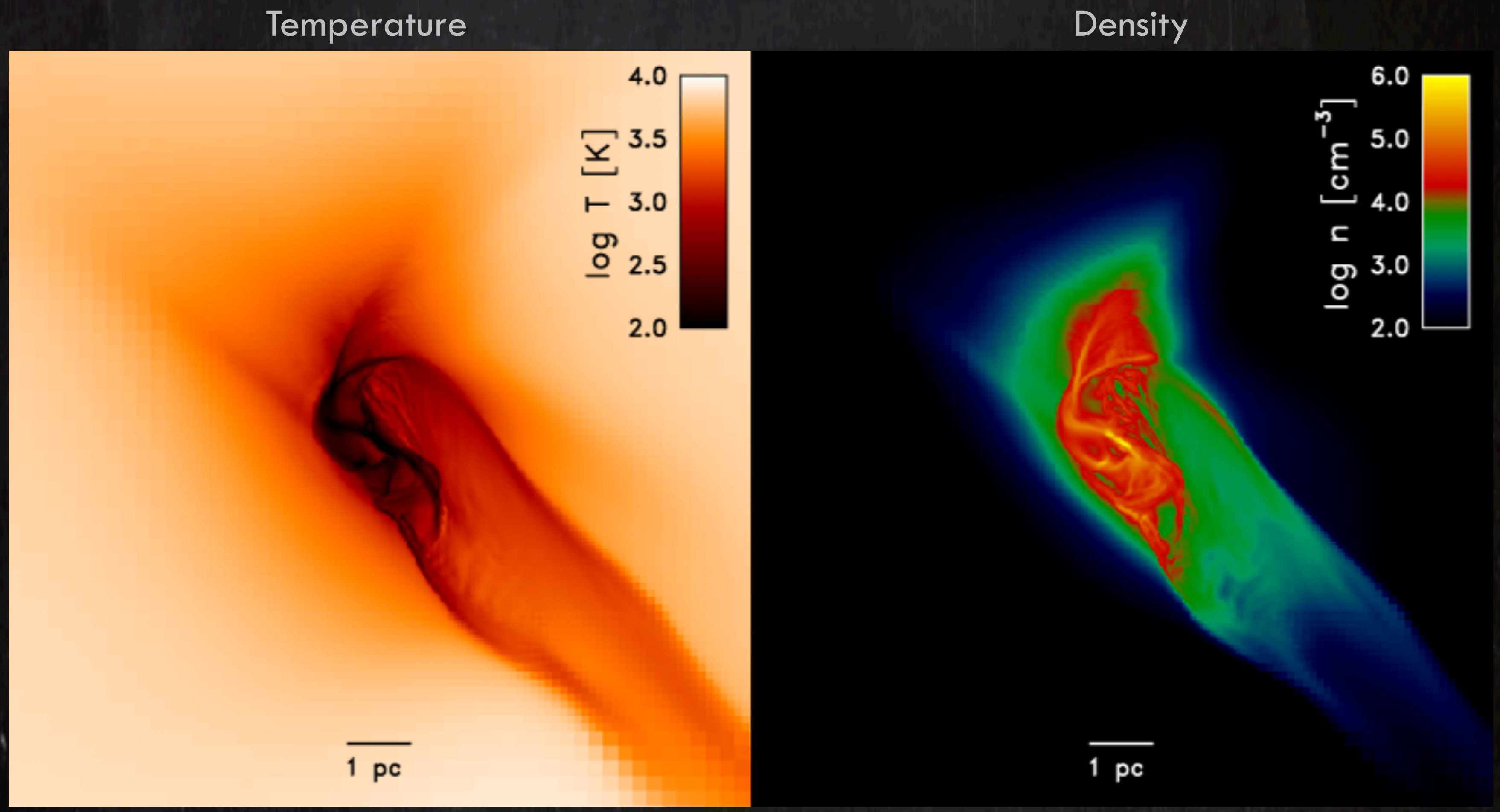
Molecular hydrogen and minihalos suppressed by strong Lyman-Werner background

Approximate the point of atomic cooling halo virilization by onset of high-density Lyman-alpha cooling aided contraction.

At this point, 'paint on' a uniform metallicity around virial extent of halo.
$Z = 10^{-2}$, 10^{-3}, and 10^{-4} $Z_\odot$

Replicates the result of more complicated simulations that include SNe metal-dispersal.

$Z/Z_{\odot} = 10^{-2}$


Temperature

Density

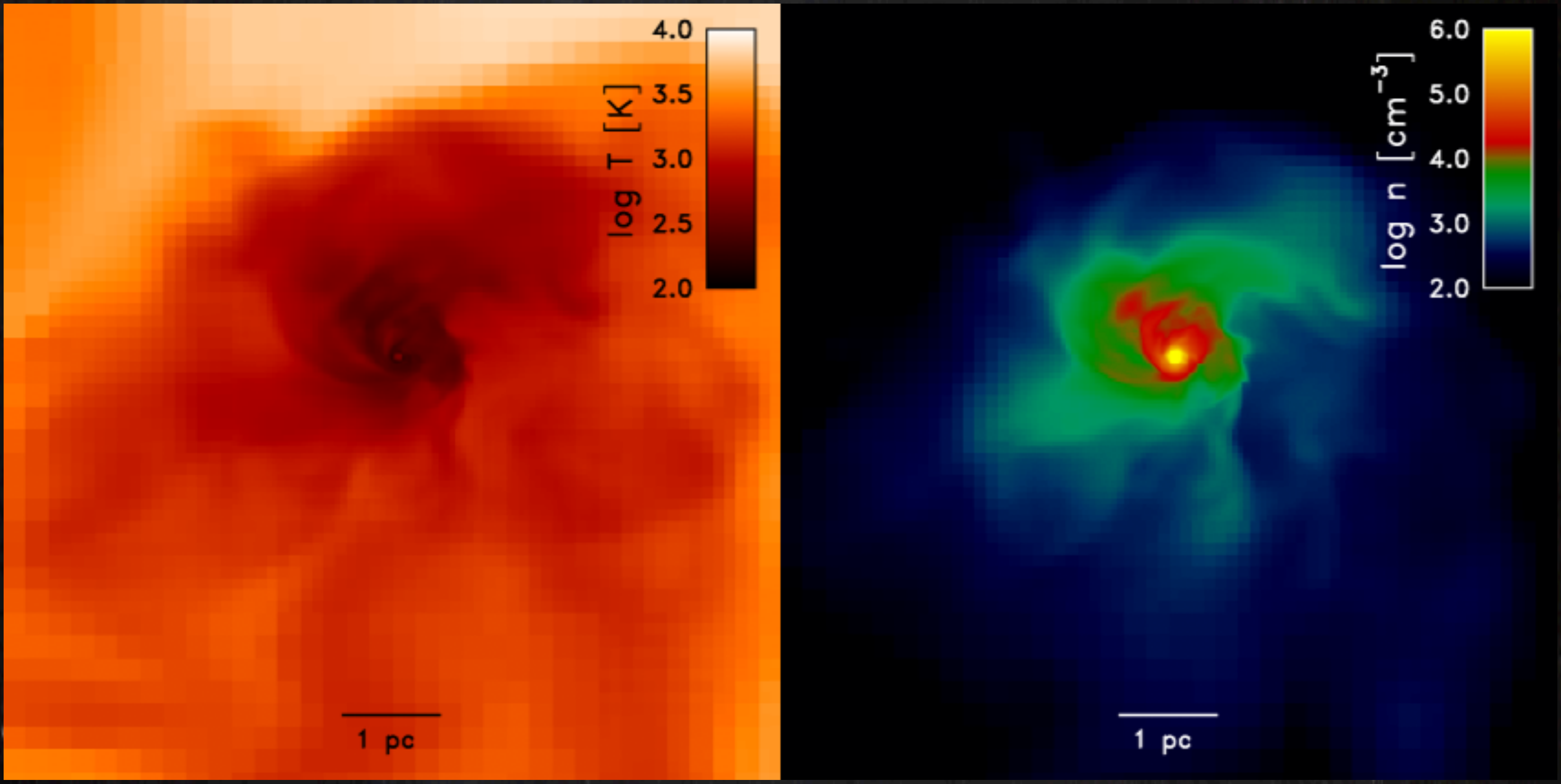
Mass-weighted line-of-sight projections.
Time extent: 4 Myr.
Black circles represent sink particles.
Sink particle creation threshold: $n \sim 2\text{x}10^{6}$ cm^{-3}.

Final mass in sinks: 1600 M_{sun}
Number of sinks: 12

$Z/Z_\odot = 10^{-4}$

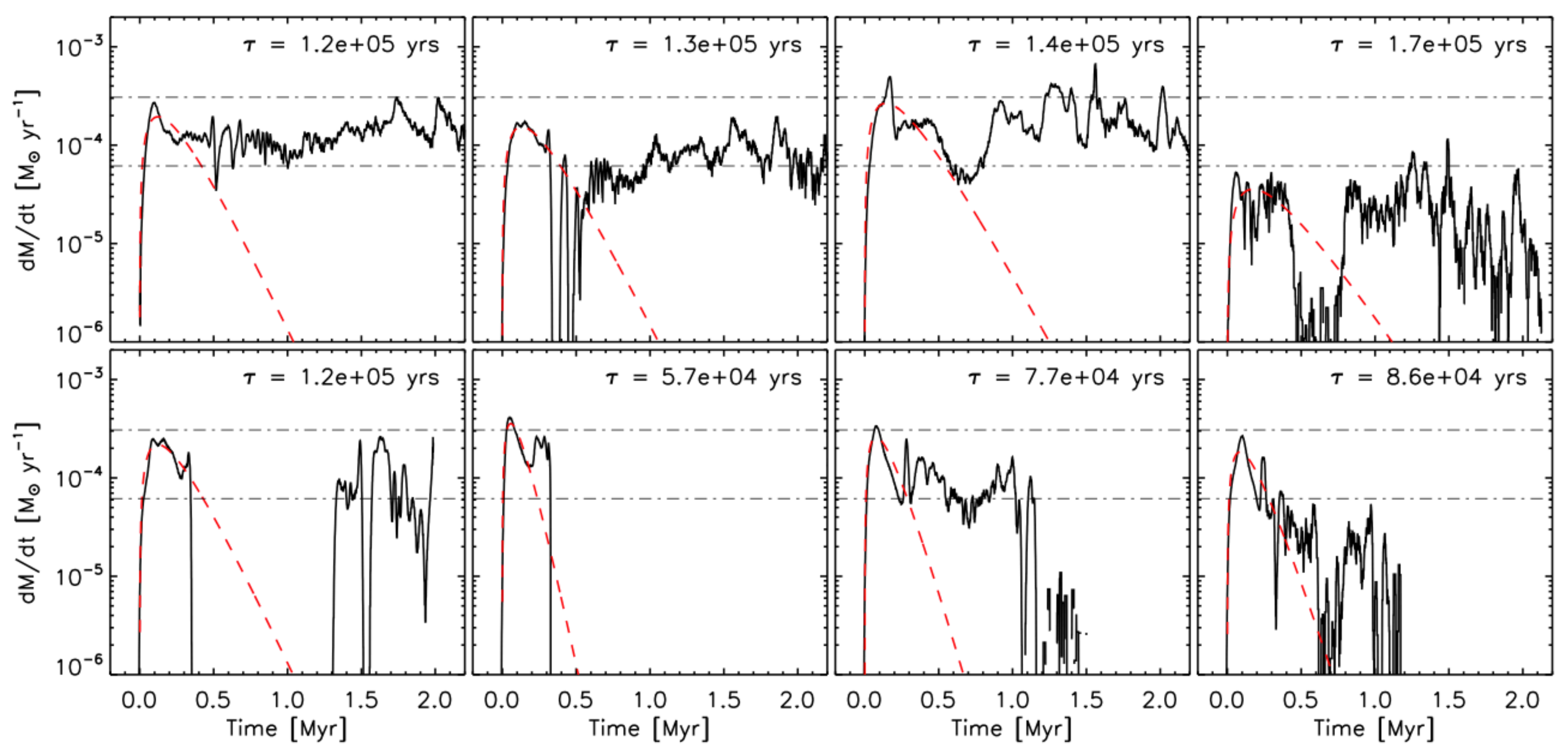
Temperature

Density



Final mass of lone sink: 500 M_{sun}

Sink particle accretion histories



Rapid rise to maximum represents accretion of initial Jeans unstable clump.

$Z/Z_\odot = 10^{-2}$

Higher mass objects gain mass through ‘competitive accretion’, accreting from a shared reservoir of gas e.g., Bonnell & Bate 2006

Lower mass sinks have accretion shut off by close encounters with larger sink particles.

Conclusions

Between metallicities of 10^{-4} and 10^{-3} Z_{sun} there is a fundamental difference in the evolution of star formation environment.

Supersonic collisions between cool collapsed gas and hot halo gas is responsible for generation of filamentary density perturbations that are the sites of gravitational collapse.

Sink particle, and likely stellar, gas accretion controlled by a process of 'competitive accretion', where the first and most massive particles preferentially accrete the most gas. Dynamic encounters between sinks are extremely important.

Solar mass fragments must be produced at higher density, likely due to dust-gas coupling (future work).