High redshift dust and the PopIII/PopII transition

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DAVID

The **D**ark **A**ges **VI**rtual **D**epartment

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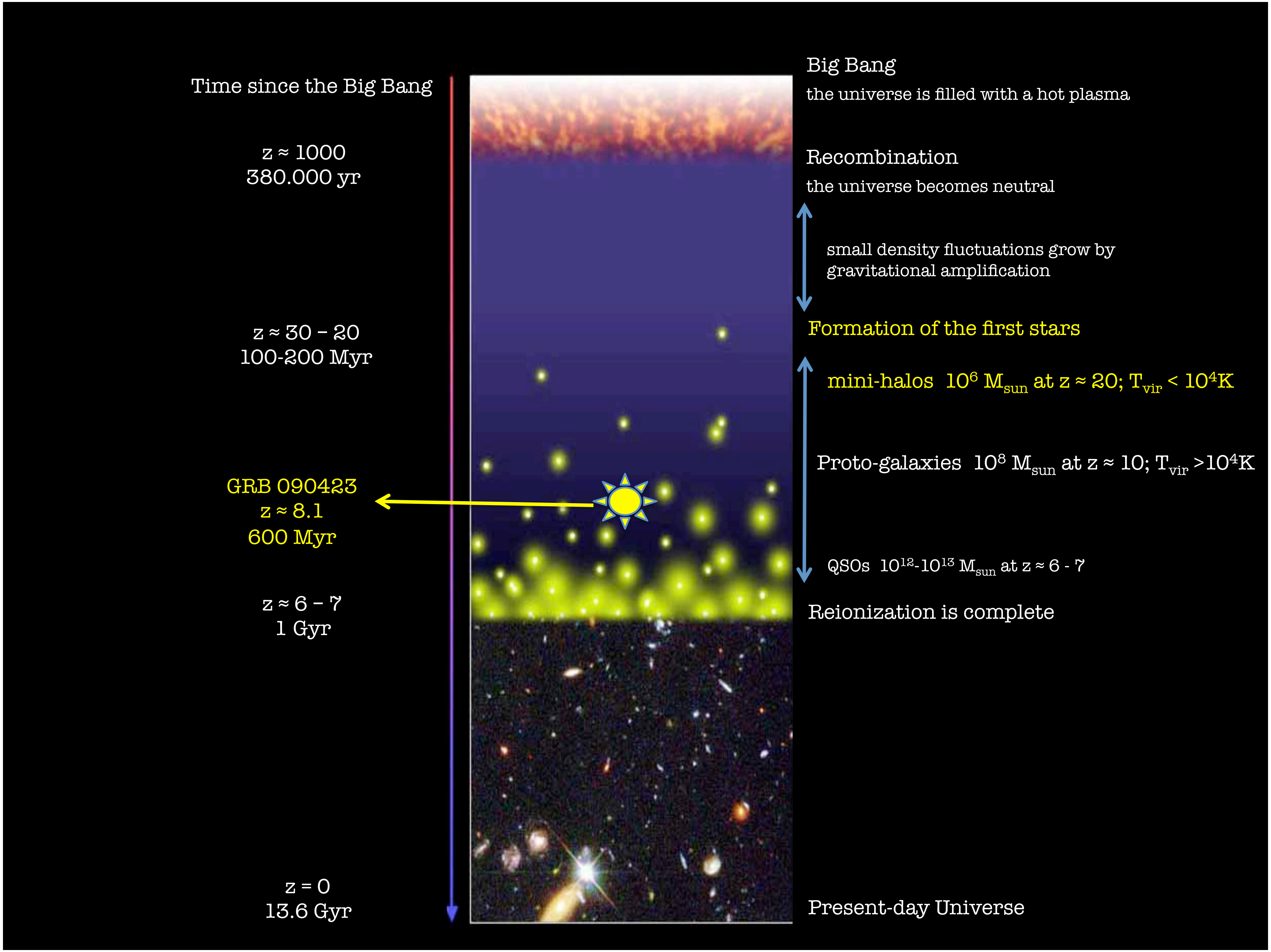
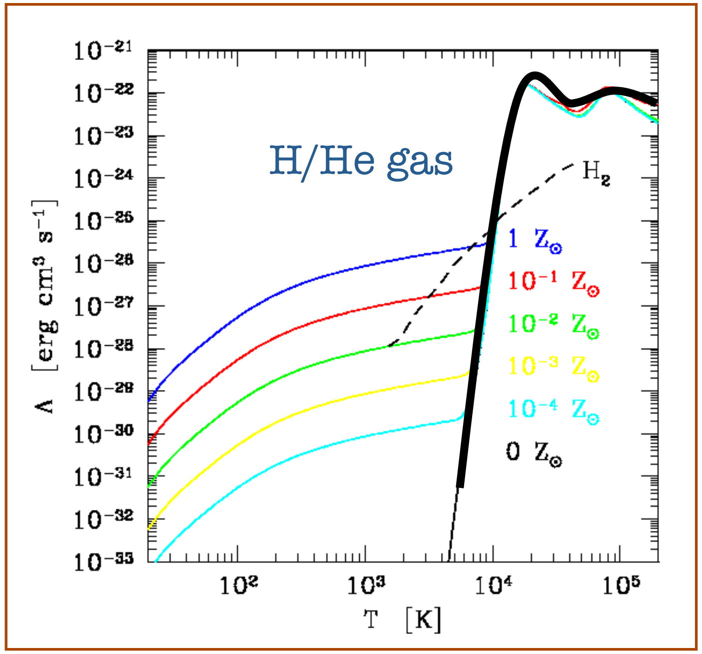

Time since the Big Bang
z ≈ 1000
380.000 yr
z ≈ 30 – 20
100-200 Myr
GRB 090423
z ≈ 8.1
600 Myr
z ≈ 6 – 7
1 Gyr
z = 0
13.6 Gyr
Big Bang
the universe is filled with a hot plasma
Recombination
the universe becomes neutral
small density fluctuations grow by gravitational amplification
Formation of the first stars
mini-halos $10^6 M_{sun}$ at $z \approx 20$; $T_{vir} < 10^4$K
Proto-galaxies $10^8 M_{sun}$ at $z \approx 10$; $T_{vir} > 10^4$K
QSOs 10^{12}-$10^{13} M_{sun}$ at $z \approx 6 - 7$
Reionization is complete
Present-day Universe

First Star formation



Very peculiar environment:

- o Gas of primordial composition: H, He, Li
- o No heavier elements (metals) are present
- o No metals are locked into solid dust grains

➡ Inhibit strong fragmentation

$$M_J \approx 700\ M_{sun}\ (T/200\ K)^{3/2}\ (n/10^4 cm^{-3})^{-1/2}$$

➡ Favor gas accretion

$$\dot{M}_{acc} \approx M_J/t_{ff} \approx c_s^3/G \approx T^{3/2}$$

➡ Feedback effects from the forming star

$$60\ M_{sun} < M_* < 100\text{-}300\ M_{sun}$$

Tan & McKee '03-'08

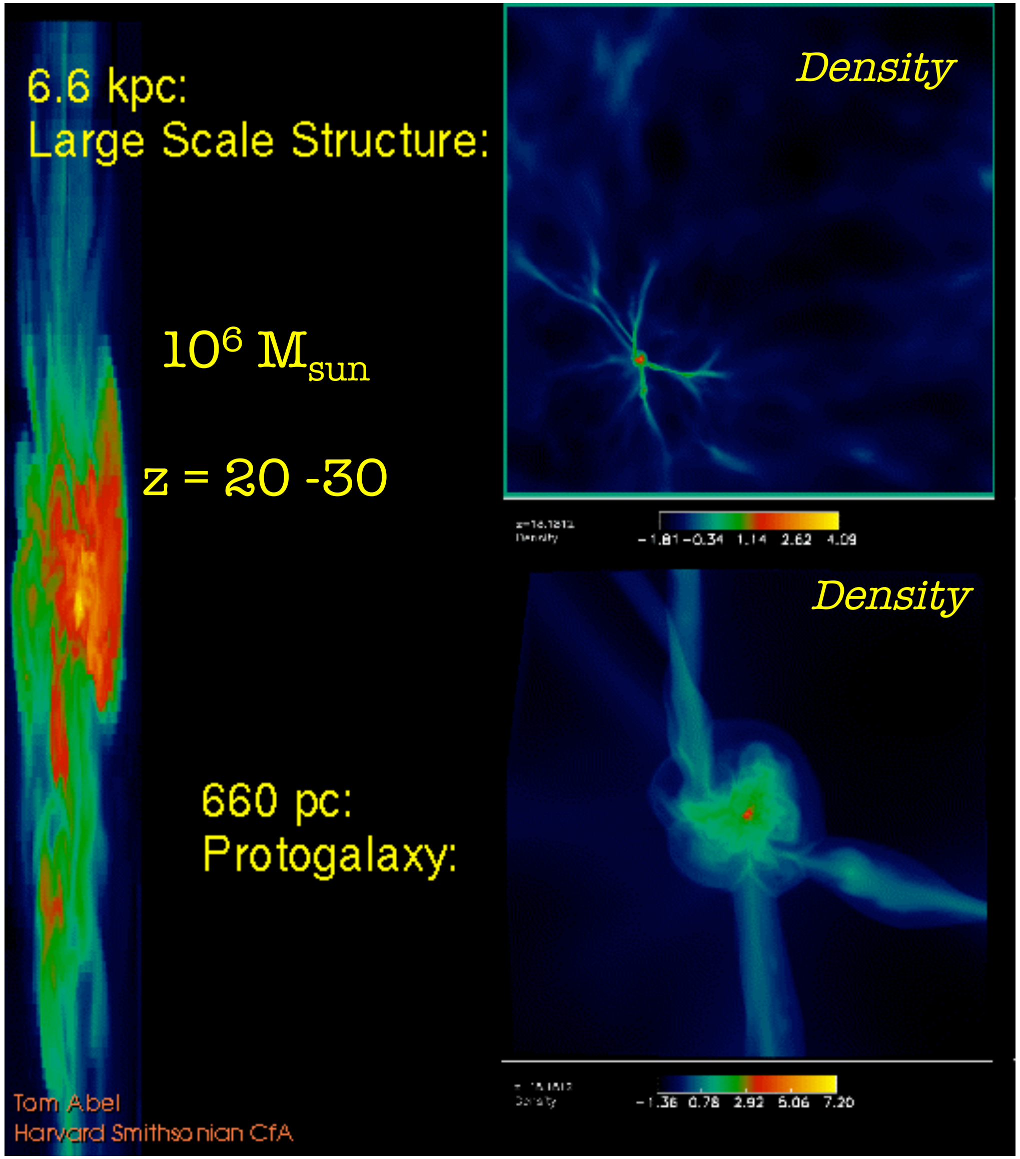
Very massive stars

100 Msun – 700 Msun

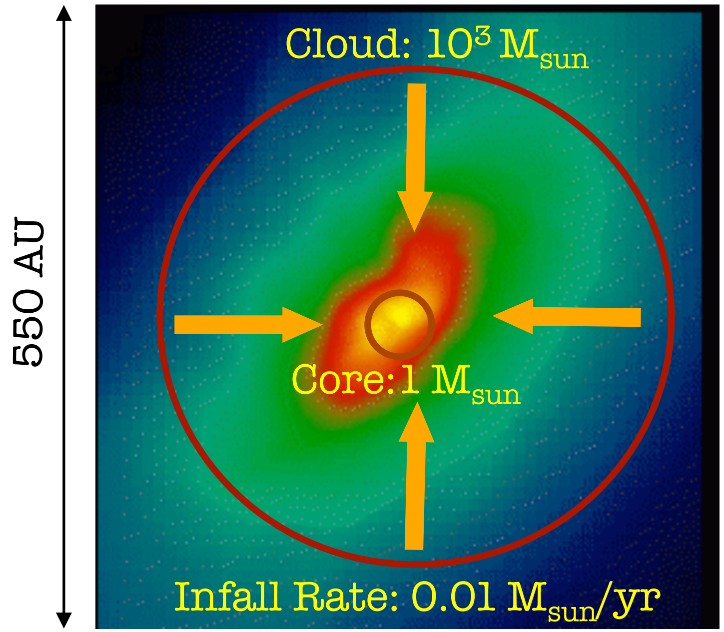
Omukai & Nishi '98, Nakamura & Umemura '02, Omukai & Inutsuka '02, Ripamonti et al 02, Schneider et al '02, Omukai & Palla '03

Simulating the Cosmic Dawn

From the Large Scale Structure to the protostars in 3D

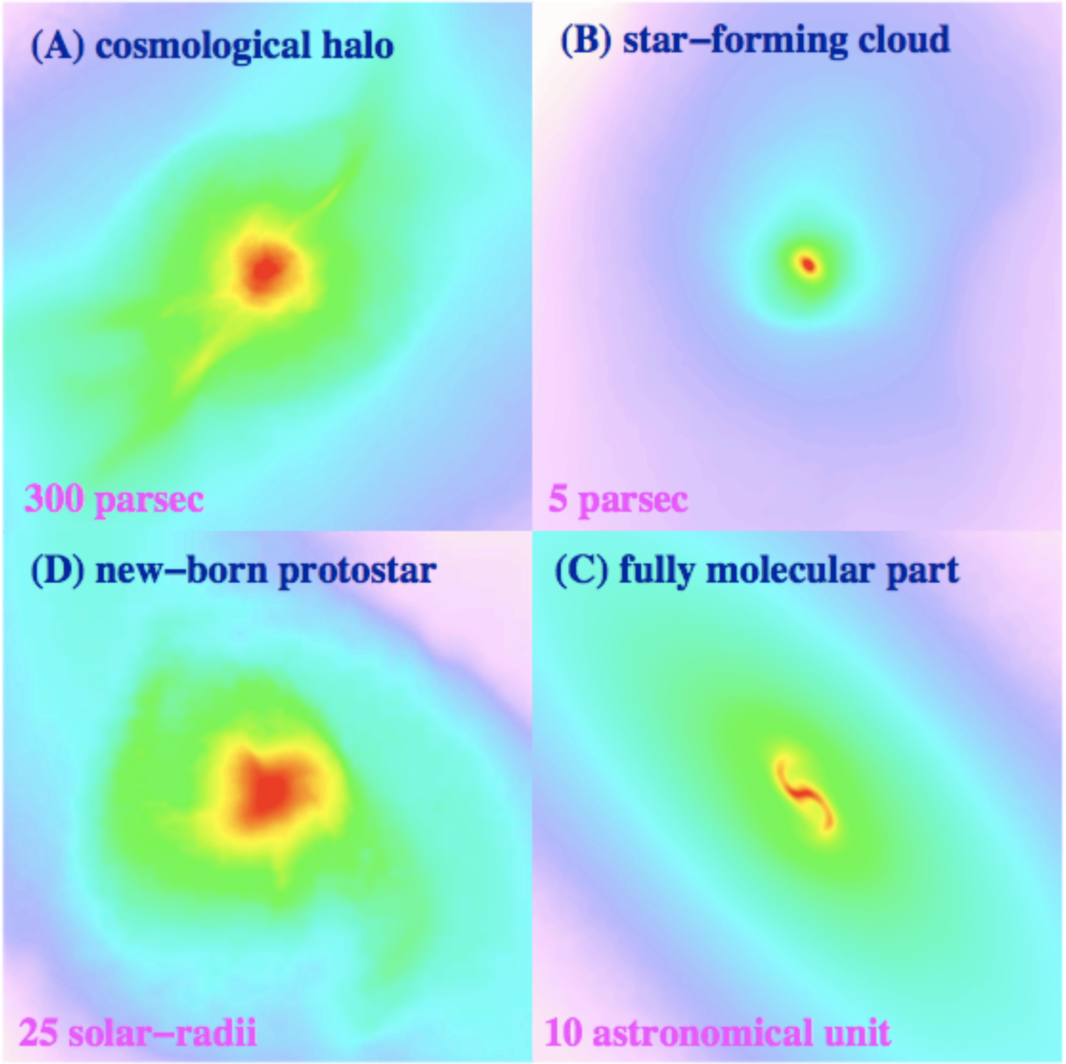


protostellar cloud



Abel, Bryan & Norman (2000-2002)

Ultra-high-resolution numerical simulation



Yoshida, Omukai & Hernquist 2008

but see also O'Shea & Norman (2007); Gao et al. (2007); Turk et al. (2008)

Star formation with the first metals and dust: motivations

(I) Indications for an IMF transition from PopIII to PopII/I stars

Population III

- $Z \sim 10^{-12}$-10^{-10}
- Very Massive Stars

30-60 Msun < M < 600 Msun

Mch ~ 100-300 Msun

Bromm et al 01
Schneider et al 02,03,06
Bromm & Loeb 04
Santoro & Shull '04
Omukai et al 05

$Z > Z_{cr}$ →

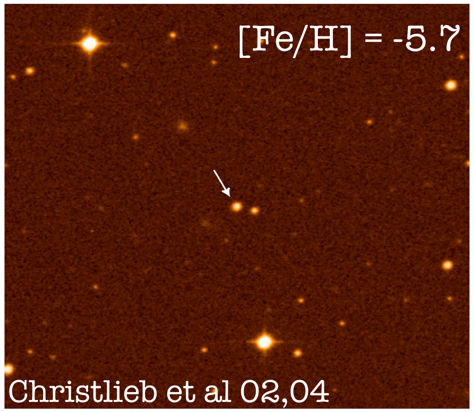
Population II/I

- $Z \sim 10^{-5}$-10^{-4} / $Z \sim 0.02$
- "Normal" stars

0.1 Msun < M < 100 Msun

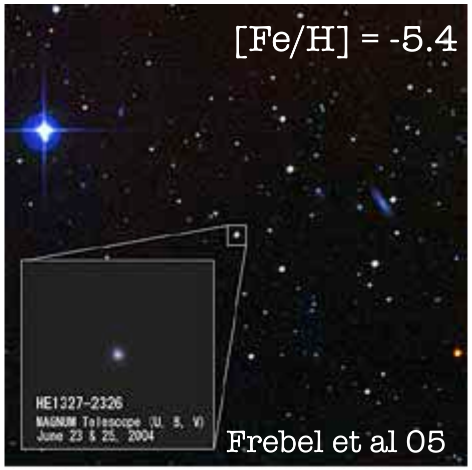
Mch ~ 1 Msun

(II) Discovery of Hyper Metal-Poor Stars (HMP)



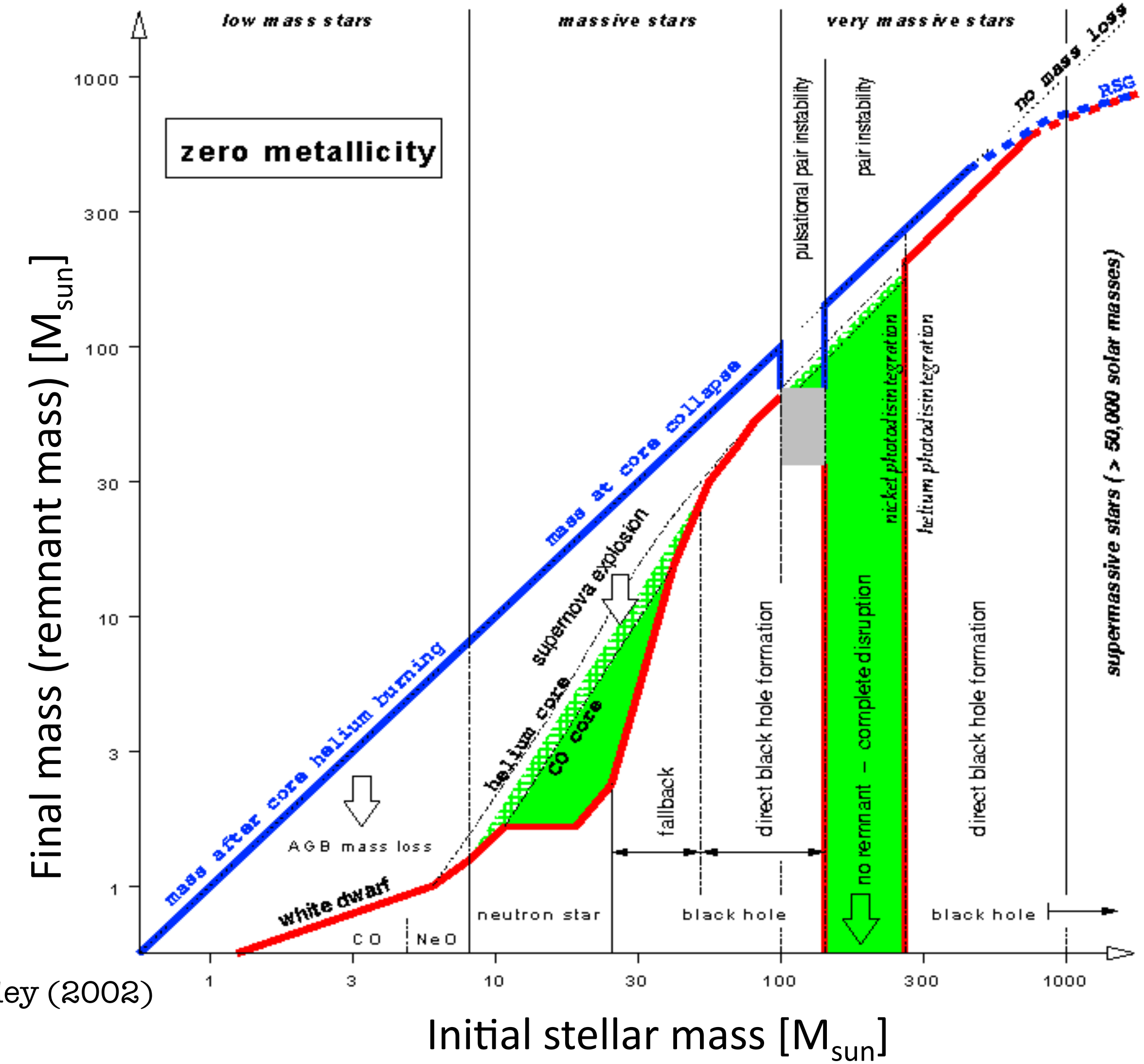
The Very Metal-Deficient Star HE 0107-5240

ESO PR Photo 25a/02 (30 October 2002) ©European Southern Observatory



Are these stars low-mass Pop III ?

Final fate of PopIII stars

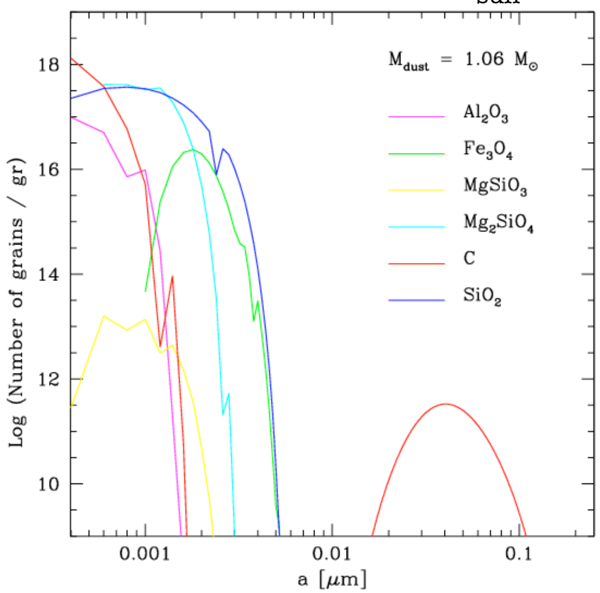


Heger & Woosley (2002)

dust production in the first SNe

Kozasa & Hasegawa 1987; Todini & Ferrara 2001;
Nozawa et al 2003; Schneider, Ferrara & Salvaterra 2004

SNII Z=0 $M=22\ M_{sun}$



Todini & Ferrara 2002

$M_{met,in} = 2.8\ M_{sun}$

$M_{met,fin} = M_O = 1.47\ M_{sun}$

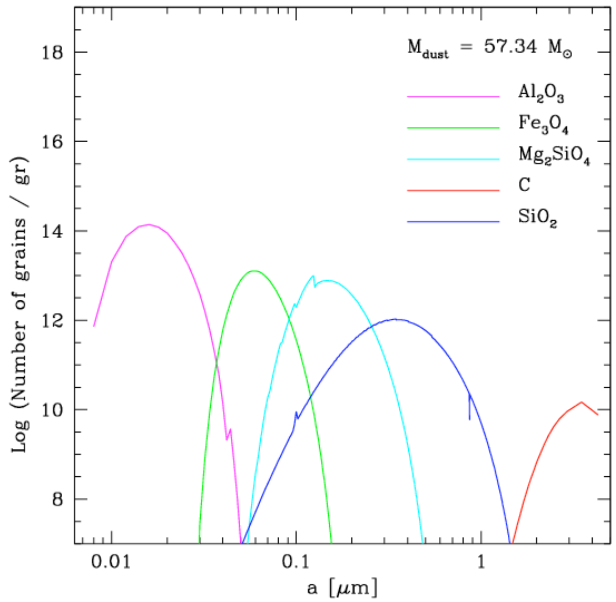
$f_{dep} = M_{dust}/M_{met} = 0.38$

$M_{dust} \leq 5\%\ M_{prog}$

$f_{dep} > 20\%$

$12\ M_{sun} < M_{prog} < 40\ M_{sun}$

PISN Z=0 $M=195\ M_{sun}$



Schneider, Salvaterra & Ferrara 2004

$M_{met,in} = 87.75\ M_{sun}$

$M_{met,fin} = M_O = 17.23\ M_{sun}$

$f_{dep} = M_{dust}/M_{met} = 0.65$

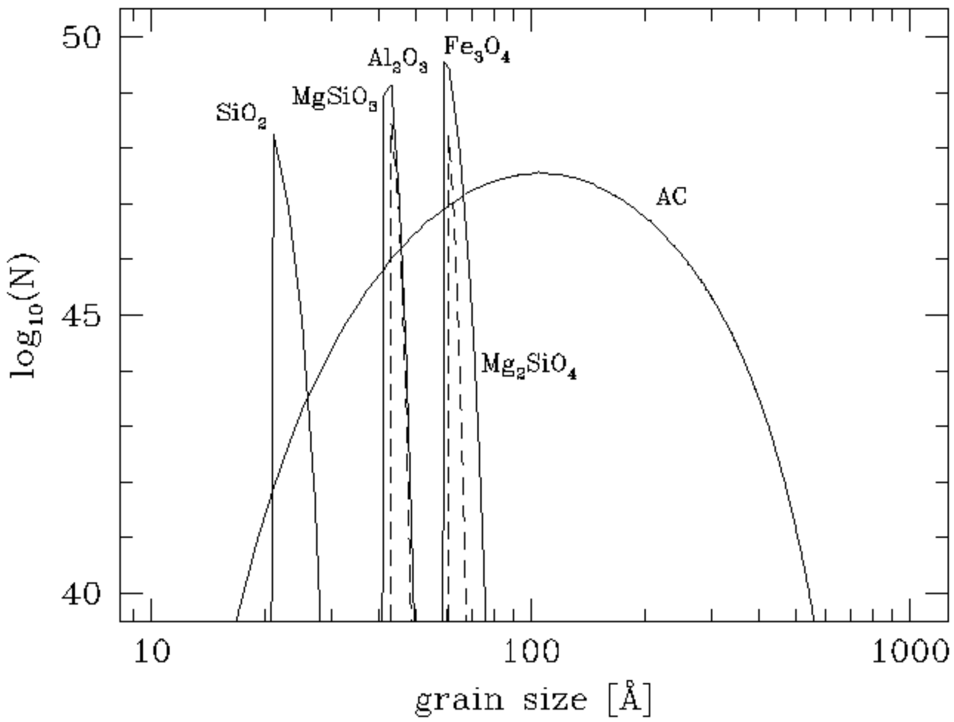
$M_{dust} \approx 20\text{-}30\%\ M_{prog}$

$f_{dep} = 60\text{-}70\%$

$140\ M_{sun} < M_{prog} < 260\ M_{sun}$

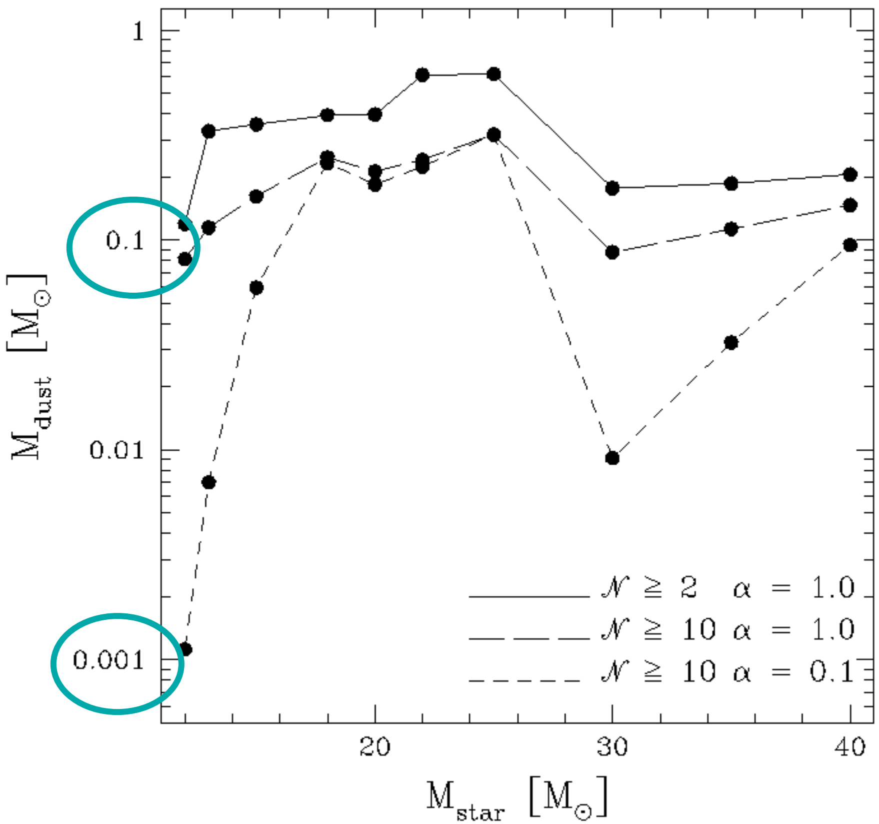
Model Uncertainties

Bianchi & Schneider (2007)



Sticking coefficient
1 (models) vs 0.1 (experiments)

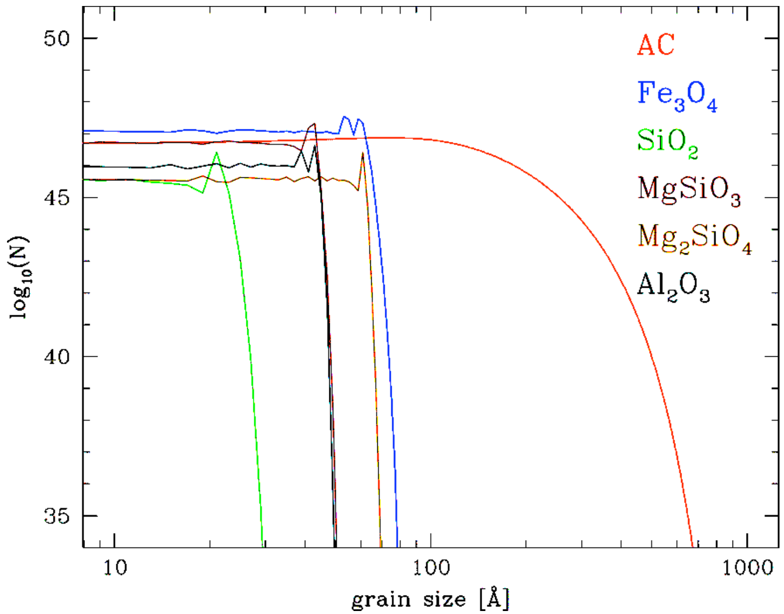
Discretization & limits of standard nucleation theory

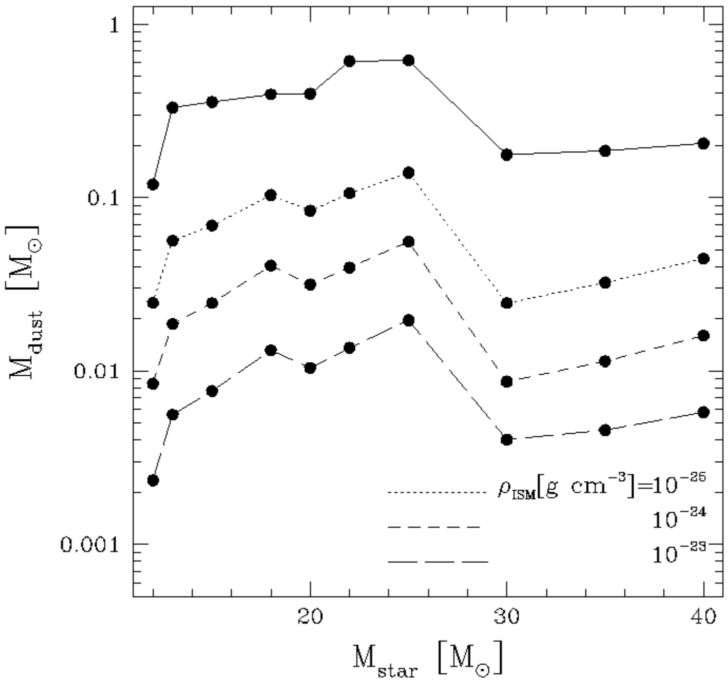


SN dust survival through the reverse shock

Bianchi & Schneider 2007

Dust erosion by collisions with gas particles



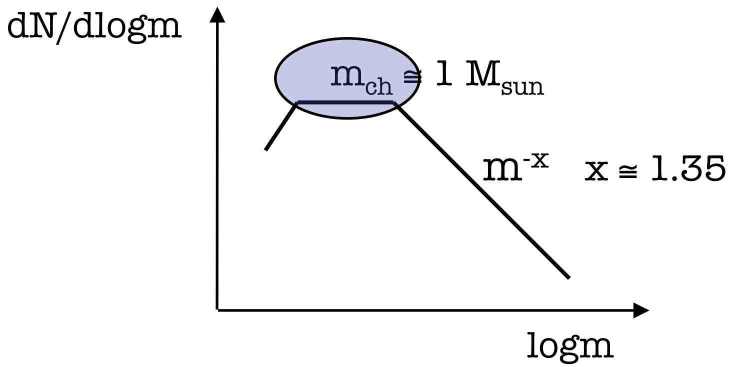


20% survives

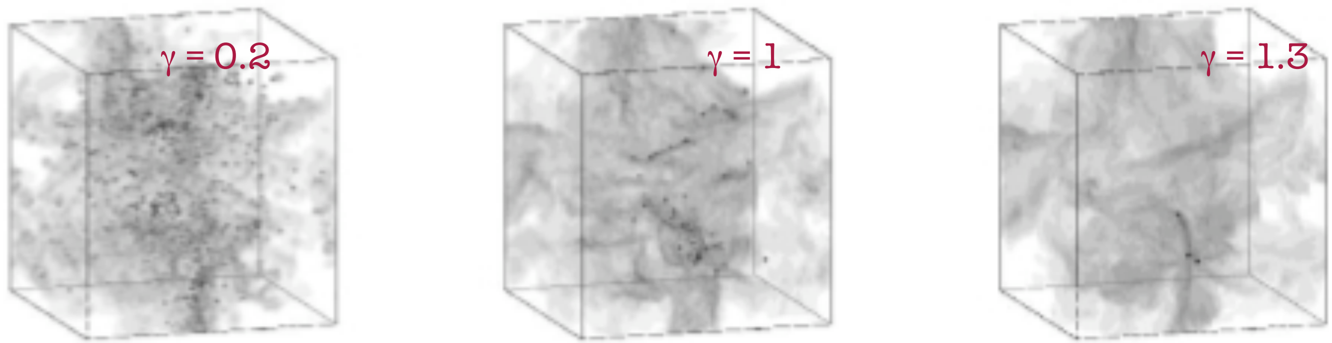
7%

2%

thermal physics and the origin of the characteristic stellar mass



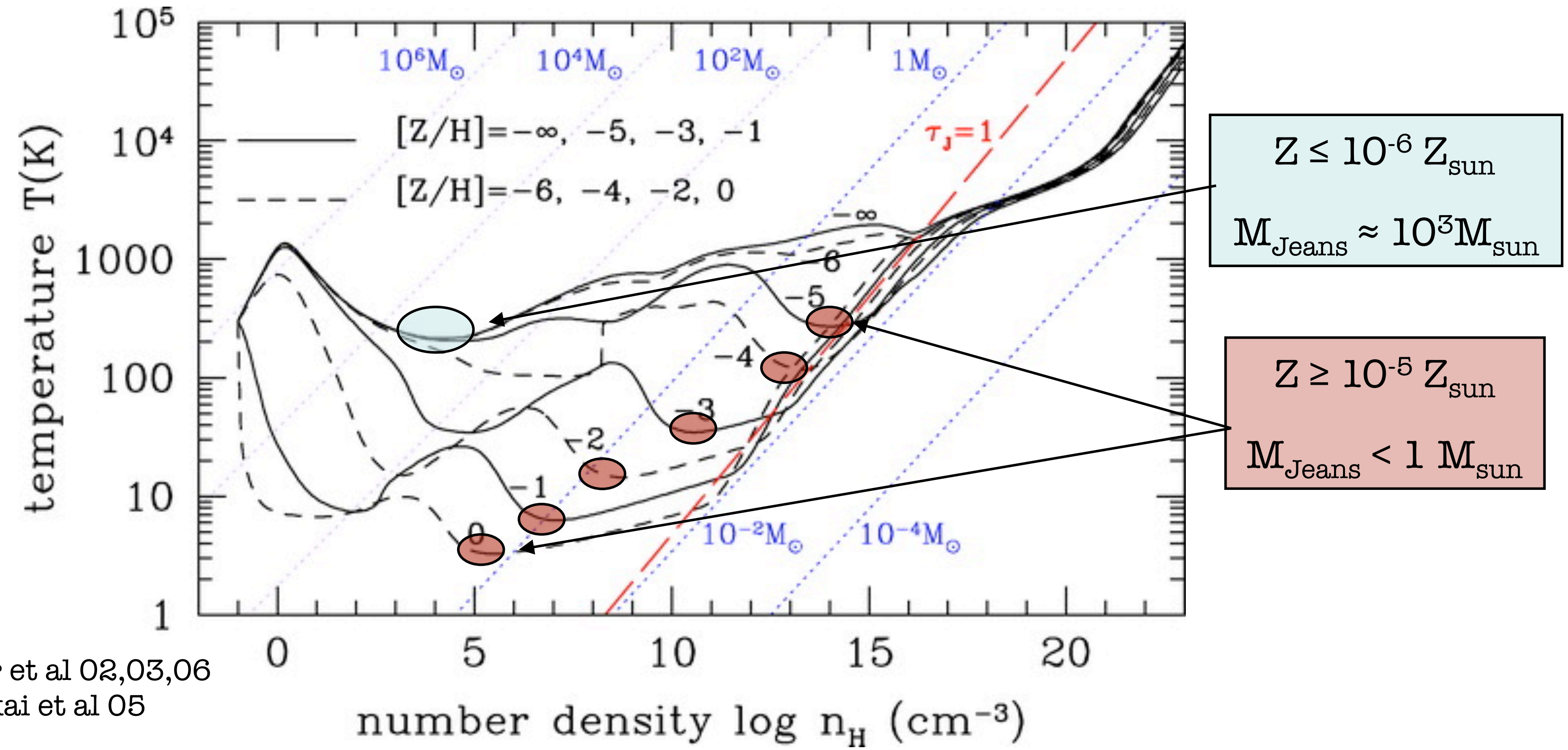
Gravitational fragmentation



Li, Klessen & Mac Low (2003)
Jappsen et al. (2005)

metallicity Z ⟶ gas cooling ⟶ characteristic mass M_{ch}

evolution of star-forming clouds at low Z



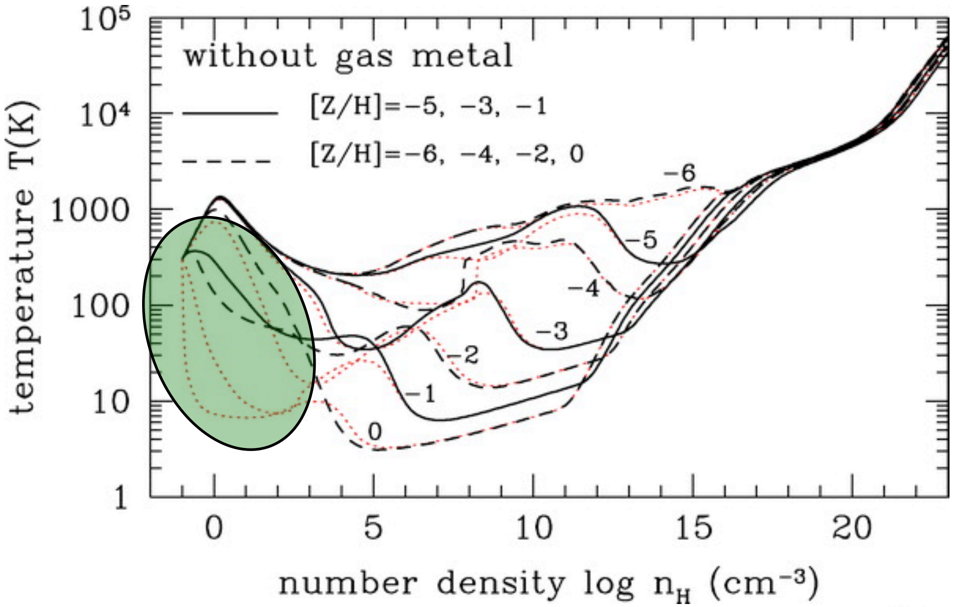
Schneider et al 02,03,06
Omukai et al 05

✓One-zone mod … n

✓ D chemistry a

TRANSITION IN FRAGMENTATION SCALES
for $Z_{cr} = 10^{-5\pm1} Z_{sun}$

roles of metals and dust

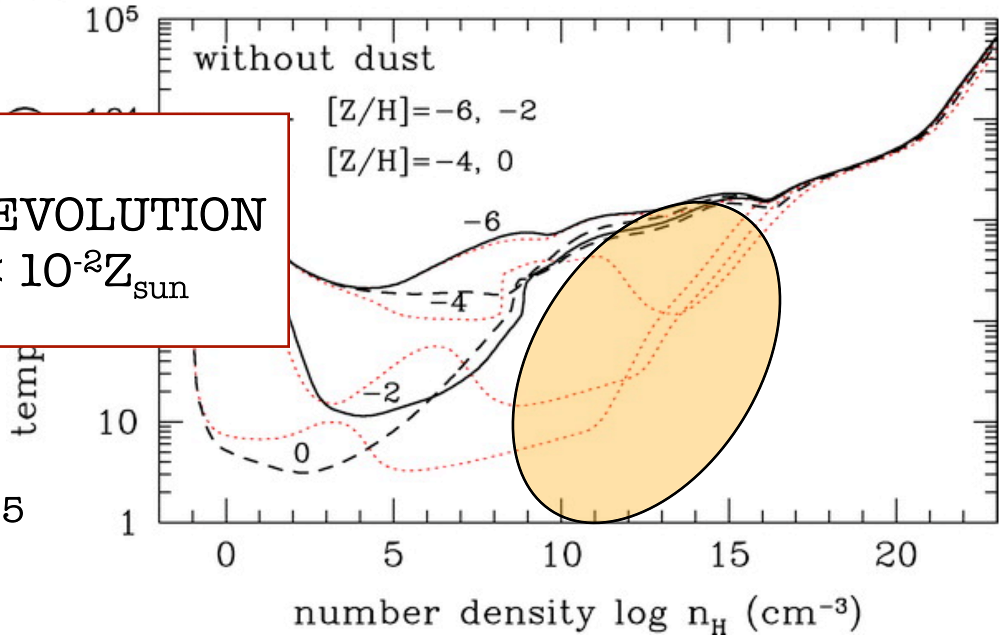


Dust grains:

- cooling by grains
- H_2 formation on grains

fiducial model

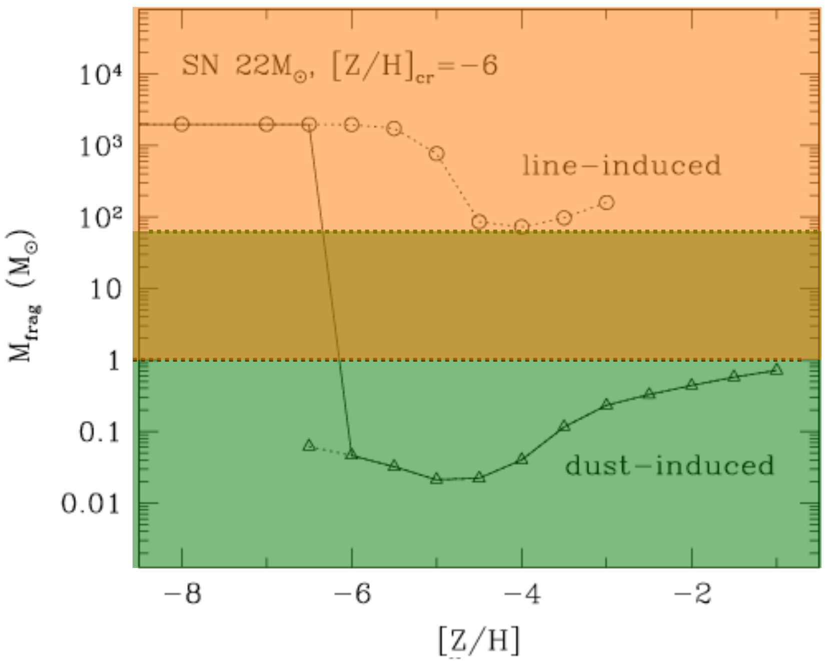
DUST GRAINS DOMINATE THE EVOLUTION AT LOW METALLICITIES: $Z < 10^{-2} Z_{sun}$

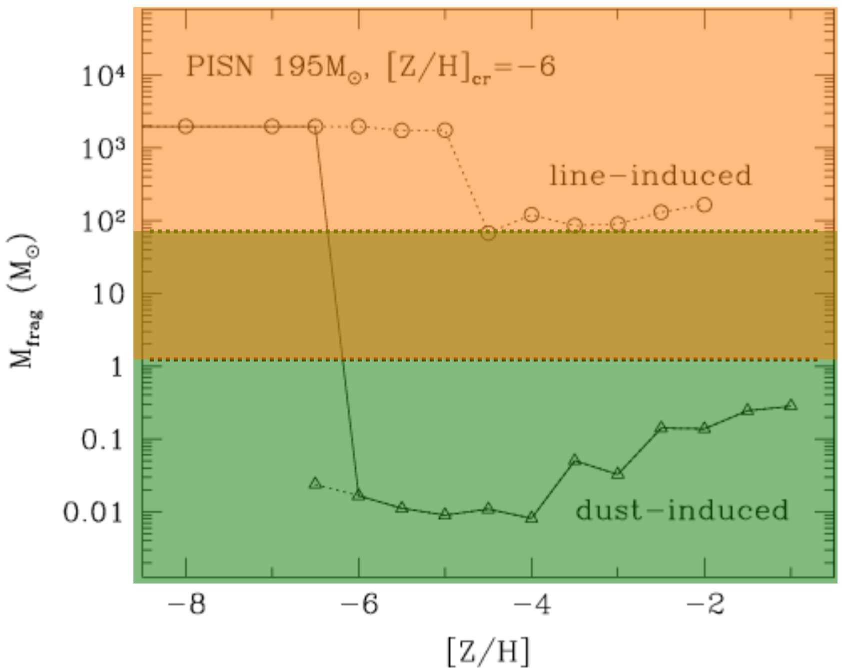


Schneider et al 2003; Omukai et al 2005

fragmentation of pre-stellar clouds enriched by the first SNe

Schneider, Omukai, Inoue & Ferrara 2006



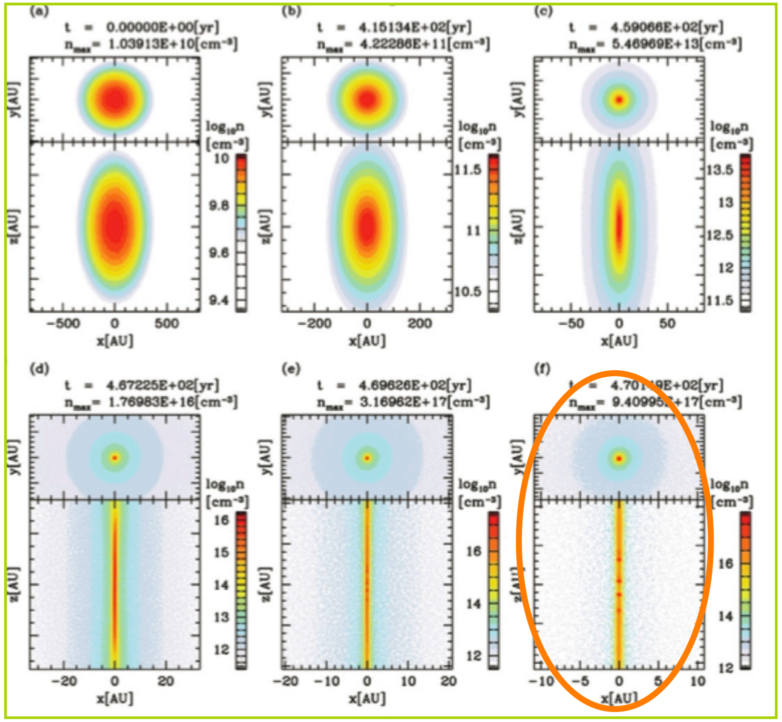


- dust-induced fragmentation leads to subsolar mass fragments at $Z_{cr} \approx 10^{-6}\ Z_{sun}$

- line-induced cooling leads to fragment masses ≈ 100 M_{sun} up to $Z \leq 10^{-2} Z_{sun}$

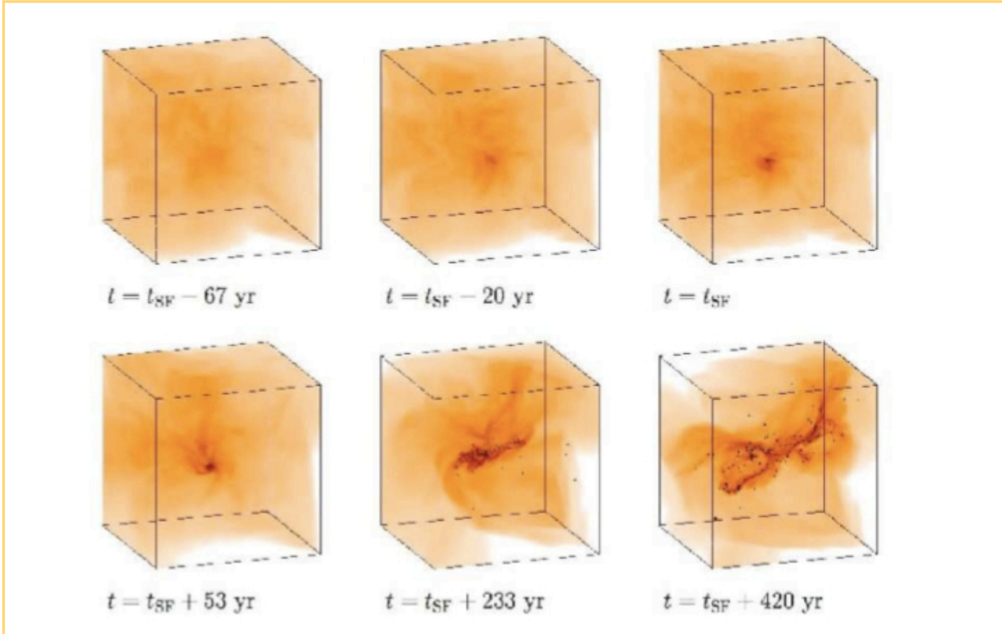
3D numerical simulations

$Z = 10^{-6}\,Z_{sun}$ $\varepsilon = 2$



Tsuribe & Omukai 2006

$Z = 10^{-6}\,Z_{sun}$ cloud including the effect of rotation

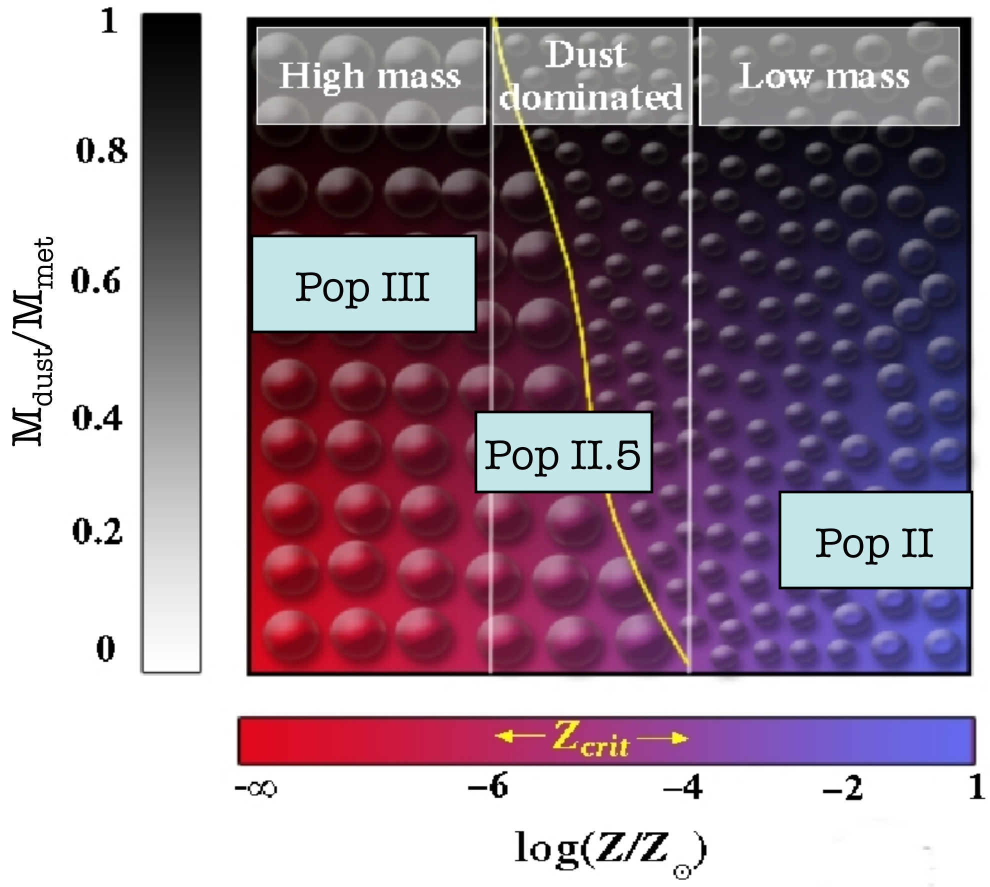


Clark, Glover & Klessen 2008

at $10^{-6}\,Z_{sun}$ dust-driven fragmentation leads to the formation of a cluster of stars with $M_{ch} \sim 1\,M_{sun}$

critical metallicity scenario

dust grains and metals drive a transition in mass scales of prestellar gas clouds



Dear Anja, Darach and Sarah,

Thank-you!