The birth environment of the first stars and black holes

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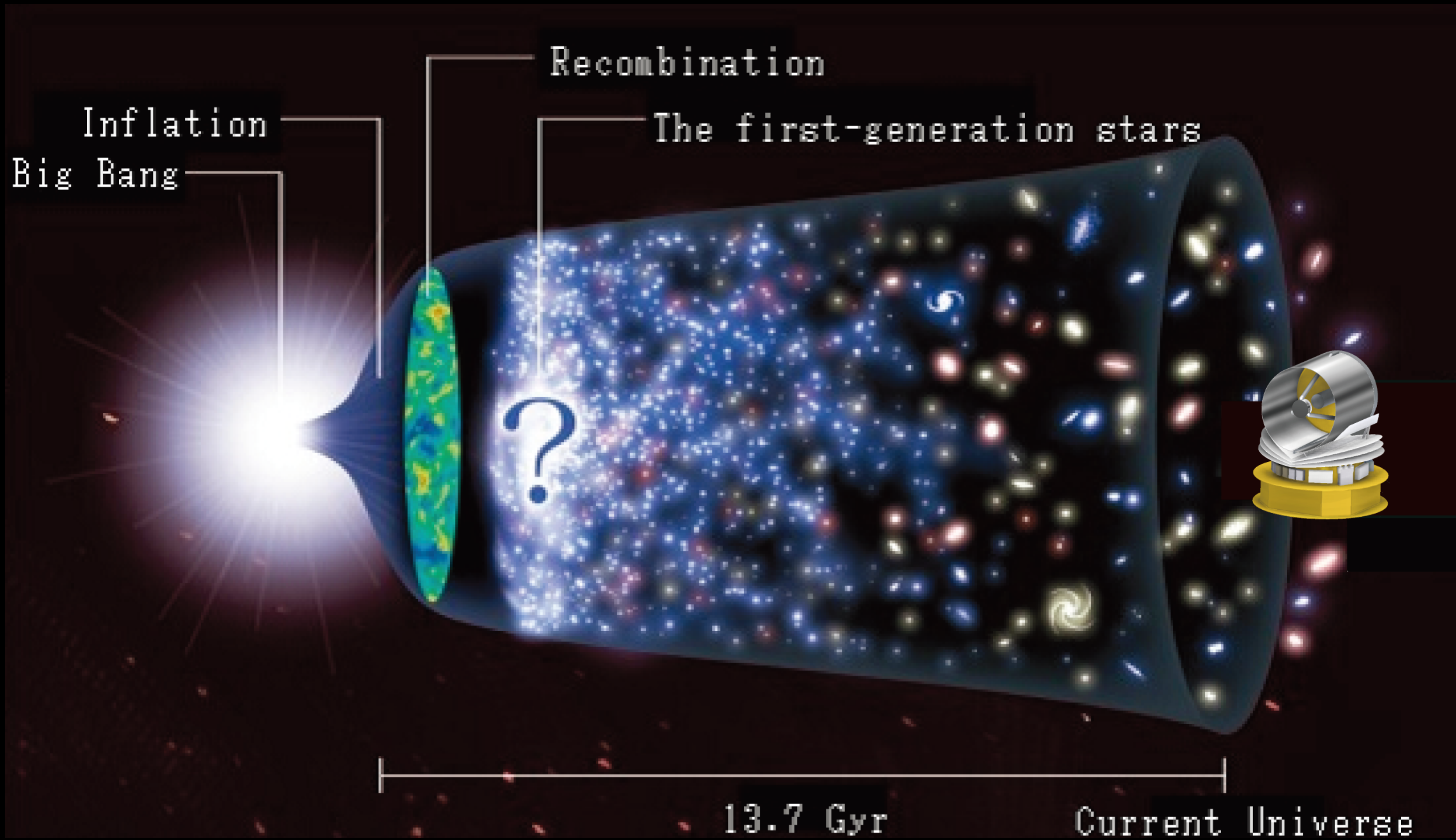


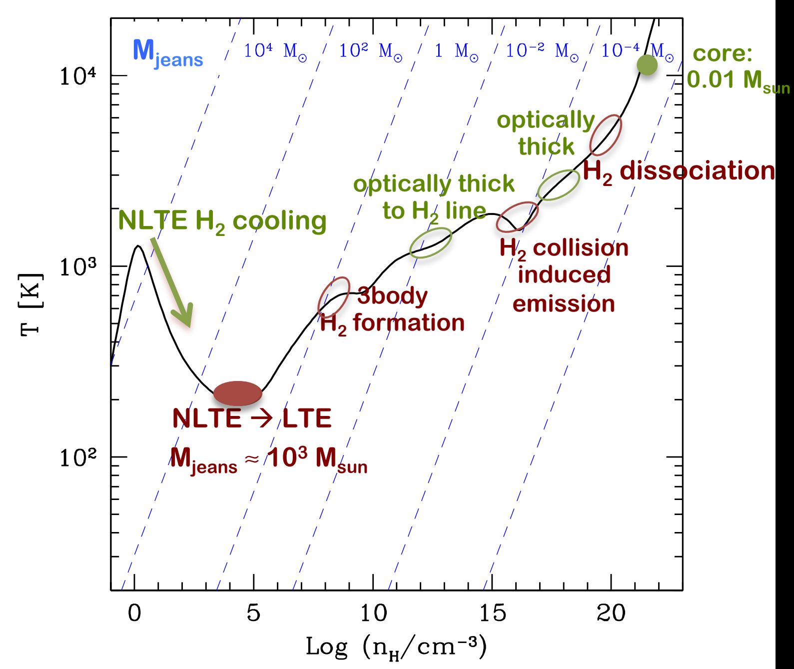
first (Pop III) star formation: in H_2-cooling mini-halos $M \sim 10^6\ M_{sun}$ at $20 < z < 30$

first proto-galaxies: in Lyman-α cooling halos $M \sim 10^8\ M_{sun}$ at $z \sim 10$

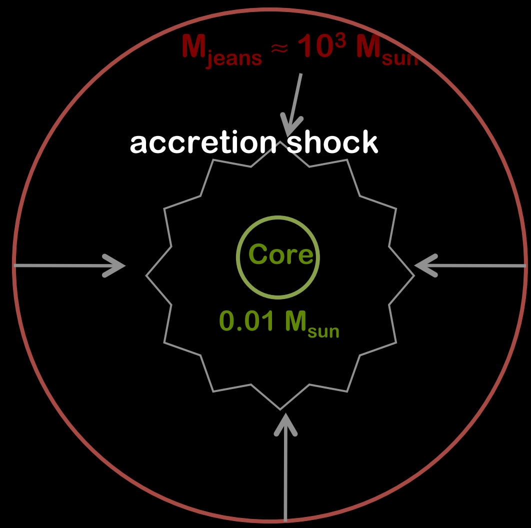
first (Pop III) star formation

H_2 cooling favors the formation of massive star

- collapse of ≈ $10^6\ M_{sun}$ mini-halos at $z \approx 20$
- H_2 cooling
- gas cloud becomes Jeans unstable $M_{jeans} \approx 10^3\ M_{sun}$



Omukai et al. 2005



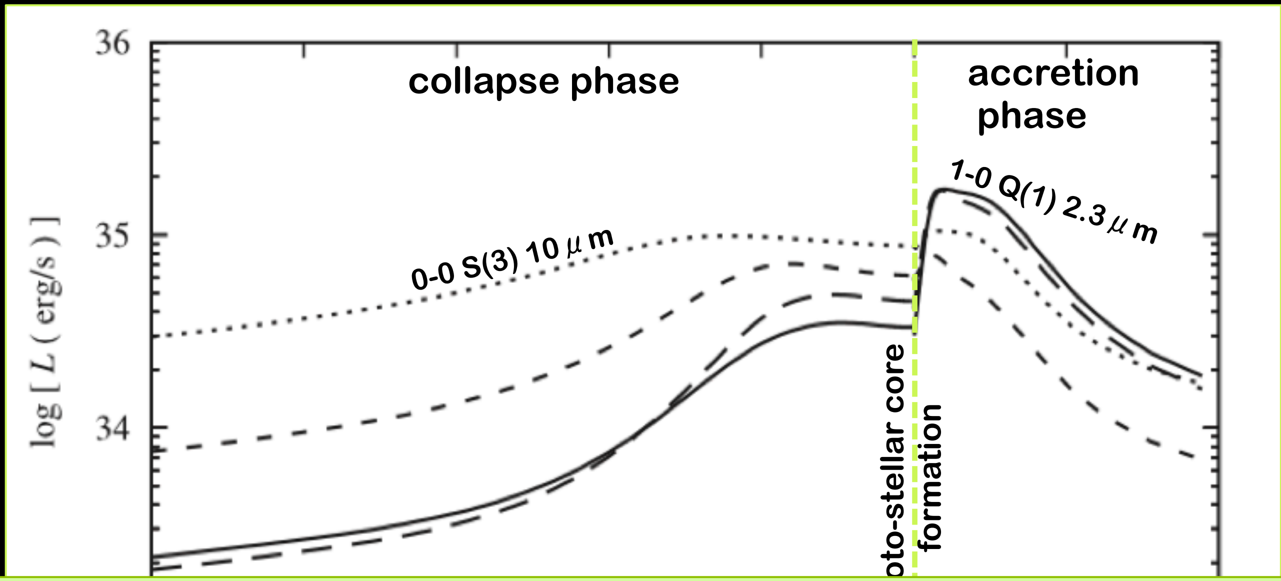
- ➡ accretion rate $dM/dt \approx M_J/t_{ff} \approx c_s^3/G \approx T^{3/2}$ (x 100 larger than @ Z_{sun})
- ➡ accreted gas mass $M_\star \cong$ [10 – 1000] M_{sun}

Omukai & Palla 2003; Bromm et al 2004; O'Shea et al. 2007; Tan & McKee 2004; McKee & Tan 2008; Hosokawa et al. 2011,2012; Hirano+14, Susa+14; Hirano+15

line luminosities from Pop III star formation in mini-halos

Kayama & Silk 2002; Ripamonti+ 2002; Mizusawa+2004

formation of a ~ 100 M_{sun} star @ z = 20



~ 10^8 stars should form in one mini-halo @ z = 20 to be visible by SPICA

(5σ – 1 hr) limiting flux: 5 10^{-20} W/m^2

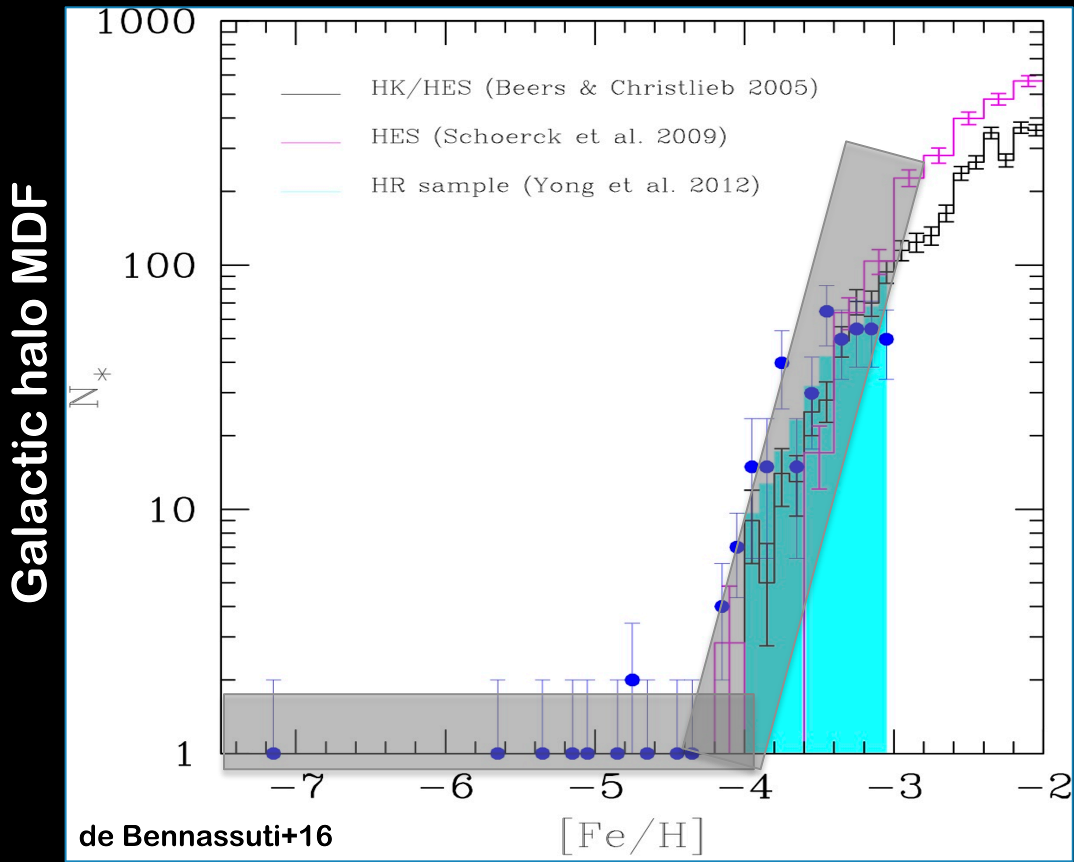
(5σ – 20 hr) line sensitivity: 2.6 10^{42} erg/s @ z = 5

1.3 10^{43} erg/s @ z = 10

6.5 10^{43} erg/s @ z = 20

probing high-z SF with stellar archaeology

low mass metal-poor stars are fossil remnants of early star formation:
their metallicity distribution function (MDF) and surface elemental abundances
encode information on their formation efficiency and on the sources of metal enrichment



Beers & Christlieb 2005;Schörck et al. 2009; Christlieb 2013; Yong+2013

probing high-z SF with stellar archaeology

low mass metal-poor stars are fossil remnants of early star formation:
their metallicity distribution function (MDF) and surface elemental abundances
encode information on their formation efficiency and on the sources of metal enrichment

the most iron-poor stars in the Galactic halo

8 out of the 9 currently known stars with [Fe/H] < - 4.5 are Carbon-enhanced (CEMP-no)

HE 0107—5240	[Fe/H] = -5.39	[C/Fe] = + 3.70	Christilieb+02
HE 1327—2326	[Fe/H] = -5.66	[C/Fe] = +4.26	Frebel+05
HE 0557—4840	[Fe/H] =-4.81	[C/Fe] = +1.65	Norris+07
SDSS J1069+1729	[Fe/H] = -4.73	[C/Fe] < 0.93	Caffau+11
SMSS 0313-0708	[Fe/H] < -7.30	[C/Fe] > 4.90	Keller+14
HE 0233—0343	[Fe/H] = -4.68	[C/Fe] = +3.46	Hansen+14
SDSS J1742+2531	[Fe/H] = -4.80	[C/Fe] = +3.56	Caffau+14
SDSS J1035+0641	[Fe/H] < - 5.07	[C/Fe] > 3.40	Bonifacio+15
SDSS J131326+0019	[Fe/H] = -5	[C/Fe] = + 3	Allende-Prieto +15

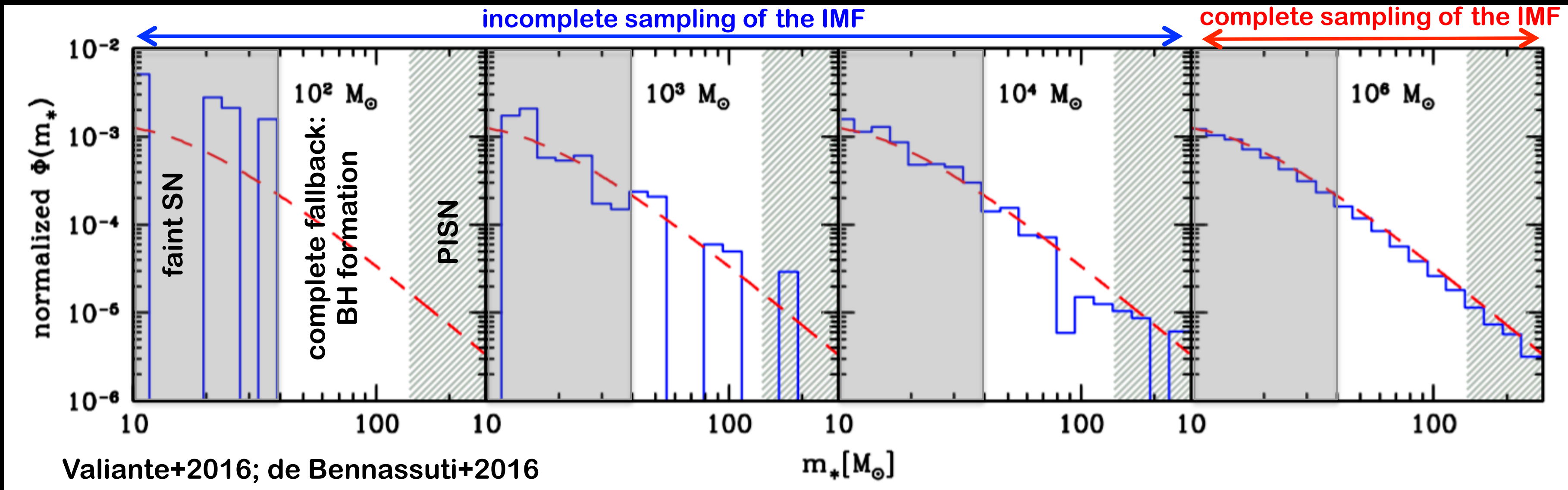
CEMP-no stars suggest that early metal/dust enrichment was dominated by faint SNe

de Bennassuti+2014,2016

initial mass function of Pop III stars in mini-halos

$$\Phi(m) = \frac{dN}{dm} \propto m^{\alpha-1}\exp\left(-\frac{m_{ch}}{m}\right)$$

$m_{ch} = 20\ M_{sun}$ $\alpha = 1.35$ $m_* = [10 - 300]\ M_{sun}$

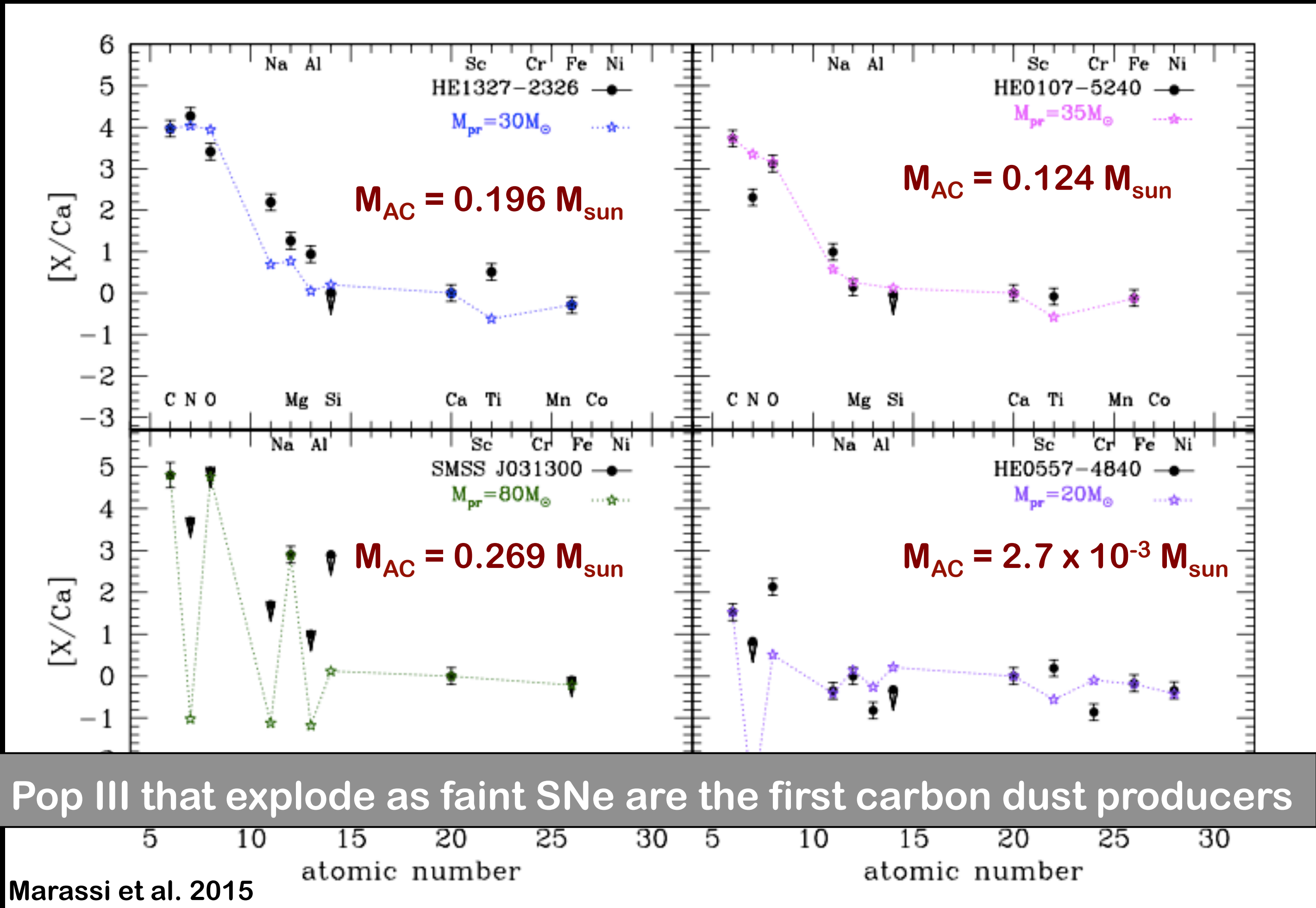


Pop III stars forming in mini-halos have a higher probability to explode as faint SNe than PISNe

de Bennassuti+2014,2016

Early dust enrichment: yields from faint Pop III SNe

1. FRANEC SN explosion models (Limongi & Chieffi 2012)
2. Mixing and mass-cut tailored to minimize the difference between $[X/Fe]_{model}$ and $[X/Fe]_{obs}$ of hyper-iron poor CEMP-no stars of Galactic halo

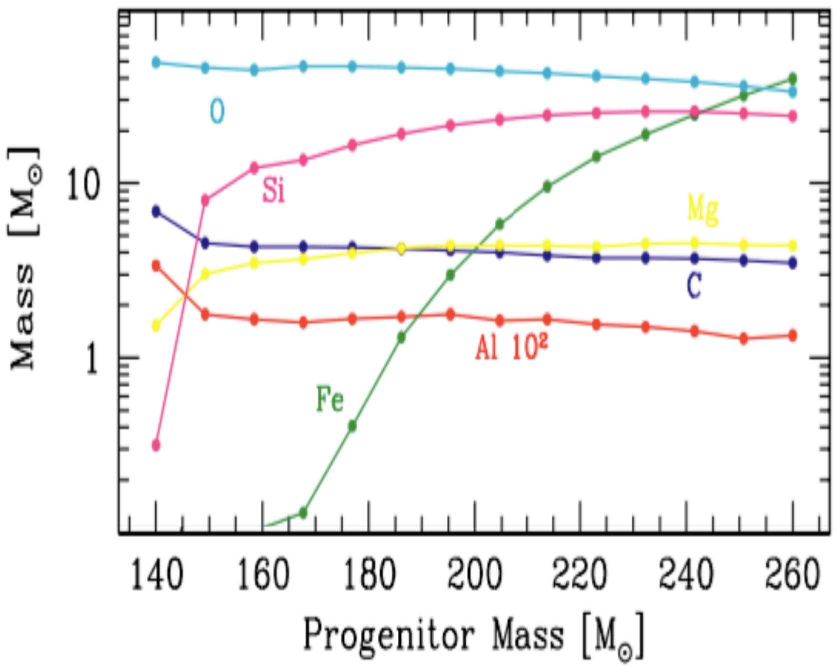


Pop III that explode as faint SNe are the first carbon dust producers

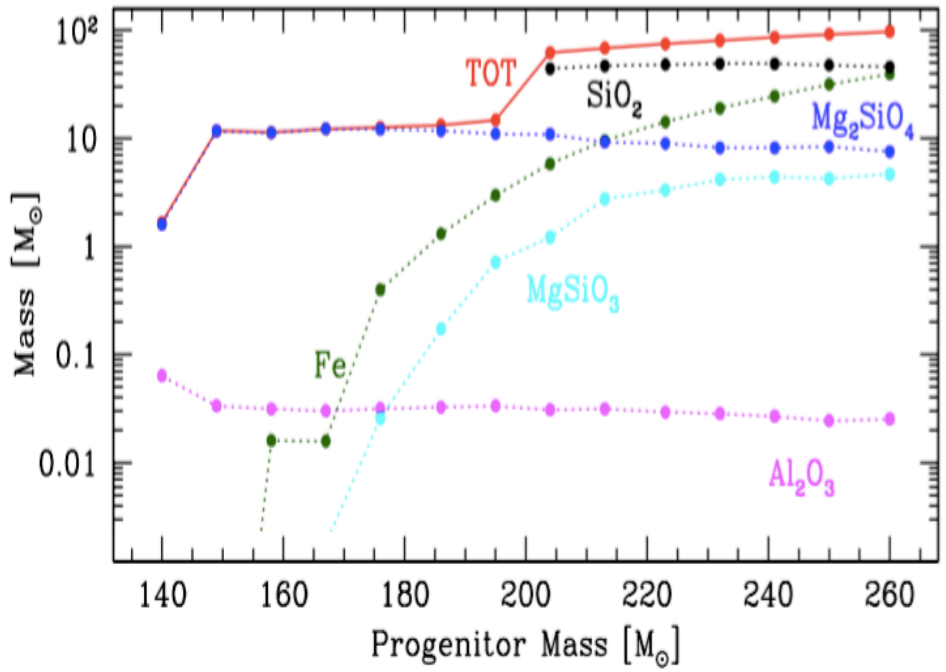
Marassi et al. 2015

chemical yields from the first SNe

metal and dust yields for Z = 0 non-rotating pair-instability SN models



Heger & Woosley 2002

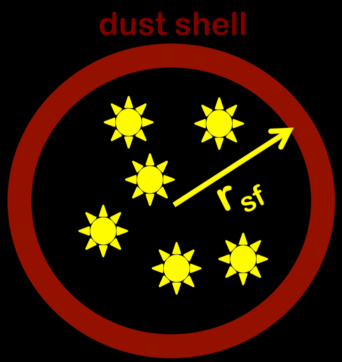


Schneider et al. 2004; Marassi et al. 2016

Pop III that explode as PISNe are the first silicate dust producers

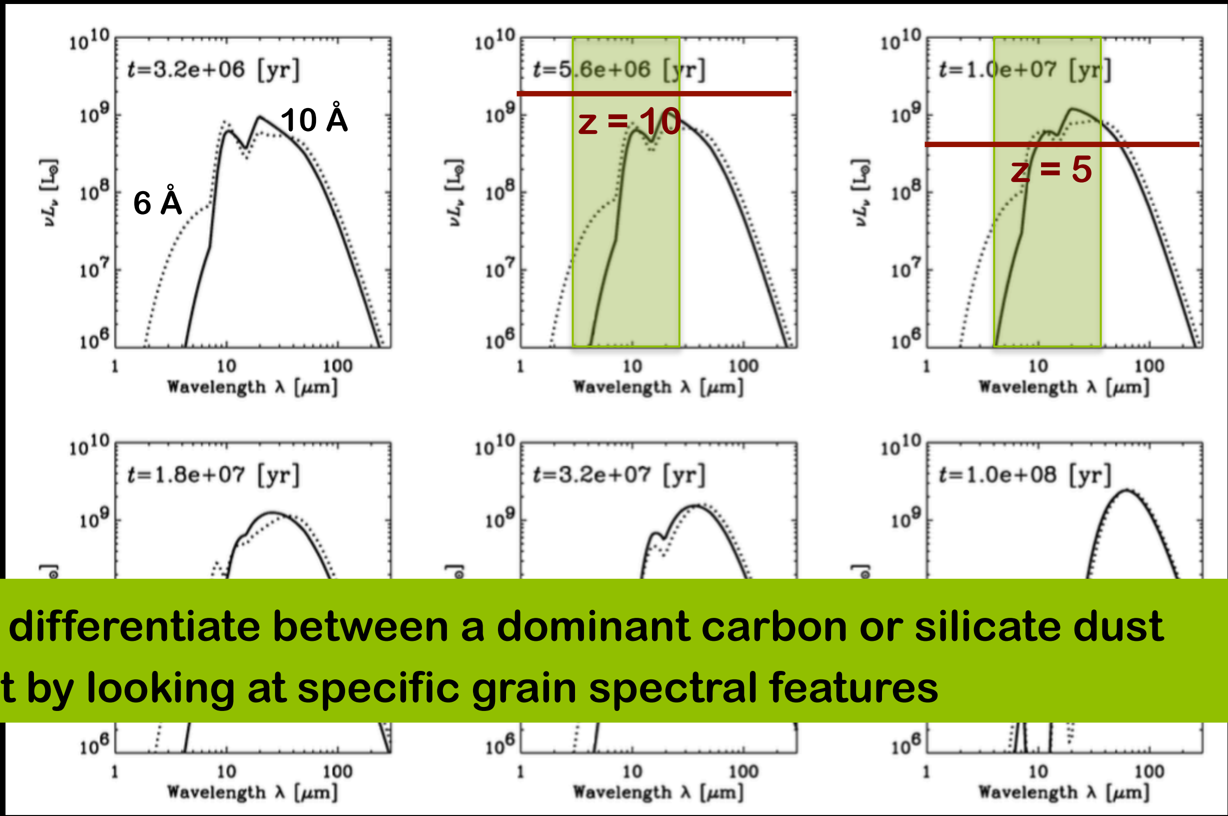
MIR SED from a young galaxy

Takeuchi+2003



time evolution of the SED for a SFR of 1 M_{sun}/yr and r_{sf} = 30 pc

carbon grains with a_c=300 Å and silicates with a_{Si}= 6 and 10 Å



SPICA may be able to differentiate between a dominant carbon or silicate dust enrichment by looking at specific grain spectral features

(5σ – 1 hr) limiting flux: 5 10^{-20} W/m^2

(5σ – 20 hr) line sensitivity:

6.8 10^8 L_{sun} @ z = 5

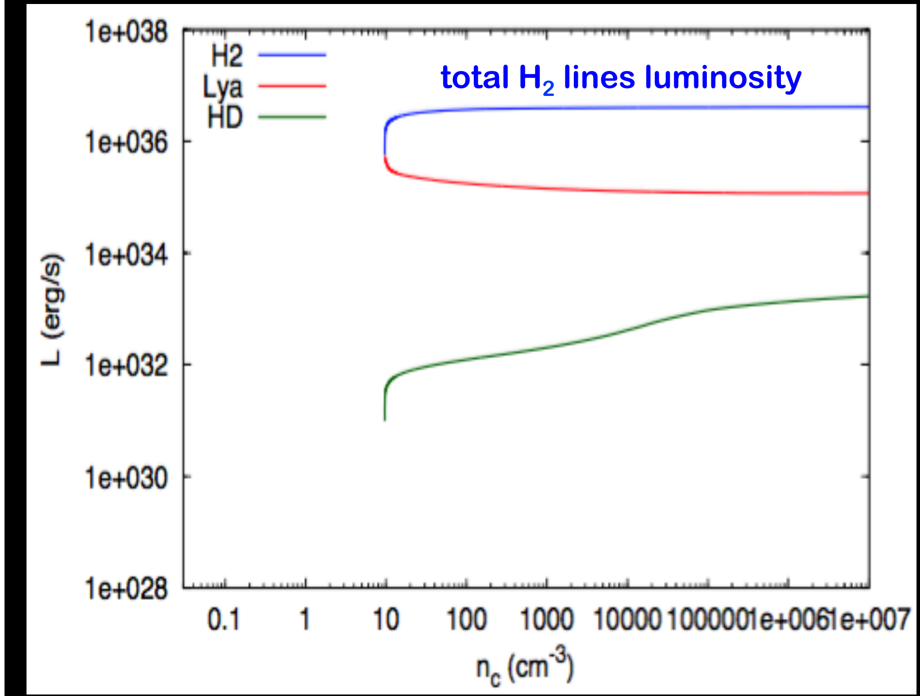
3.4 10^9 L_{sun} @ z = 10

1.7 10^{10} L_{sun} @ z = 20

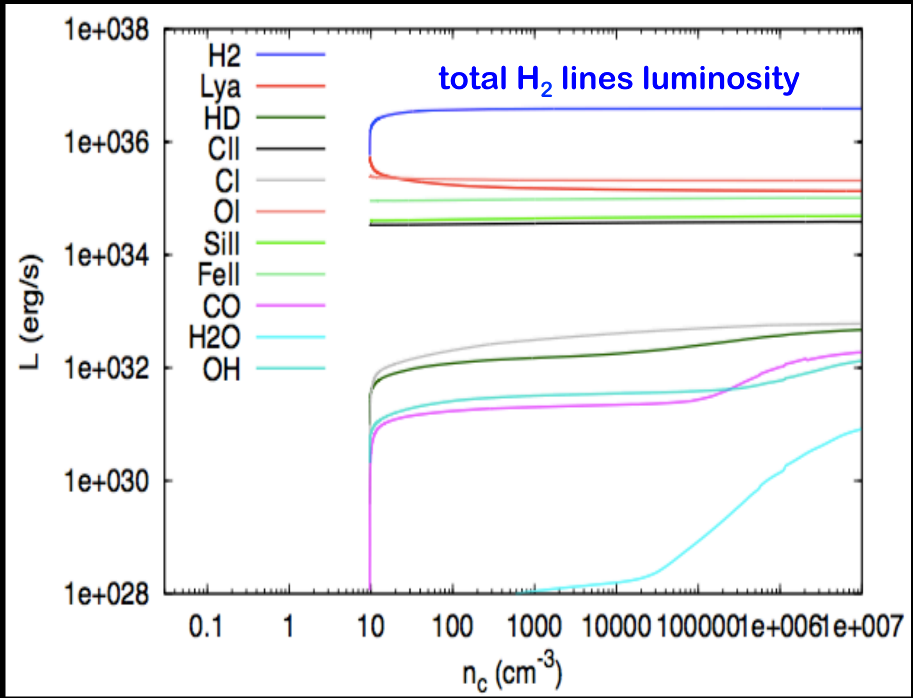
line luminosities from Pop III/II star formation in proto-galaxies

Mizusawa+2005; Omukai+2005

~ 10^8 M_{sun} metal-free gas collapse @ z = 10



~ 10^8 M_{sun} Z = 0.01 Z_{sun} gas collapse @ z = 10



- in z = 10 proto-galaxies the luminosity is dominated by H_2 lines
- the Pop III/II collapse phase in a proto-galaxy @ z = 10 is too faint to be visible

Conclusions

✓ SPICA may be able to differentiate between a dominant carbon or silicate dust enrichment by looking at specific grain spectral features

→ provide insights on the dominant dust sources at high-z and ultimately on the Pop III initial mass function

✓ predicted line luminosities during Pop III/II collapse phase in $z > 10$ mini-halos and proto-galaxies are too faint to be observed with SPICA

→ larger line luminosities expected from the cooling shells formed behind Pop III SNe (see Simona Gallerani's talk)