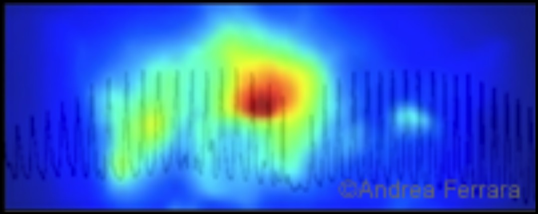

Molecules and dust as fuel to star formation
KITP June 21 – 24 2016

first stars and dust

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INAF/Osservatorio Astronomico di Roma

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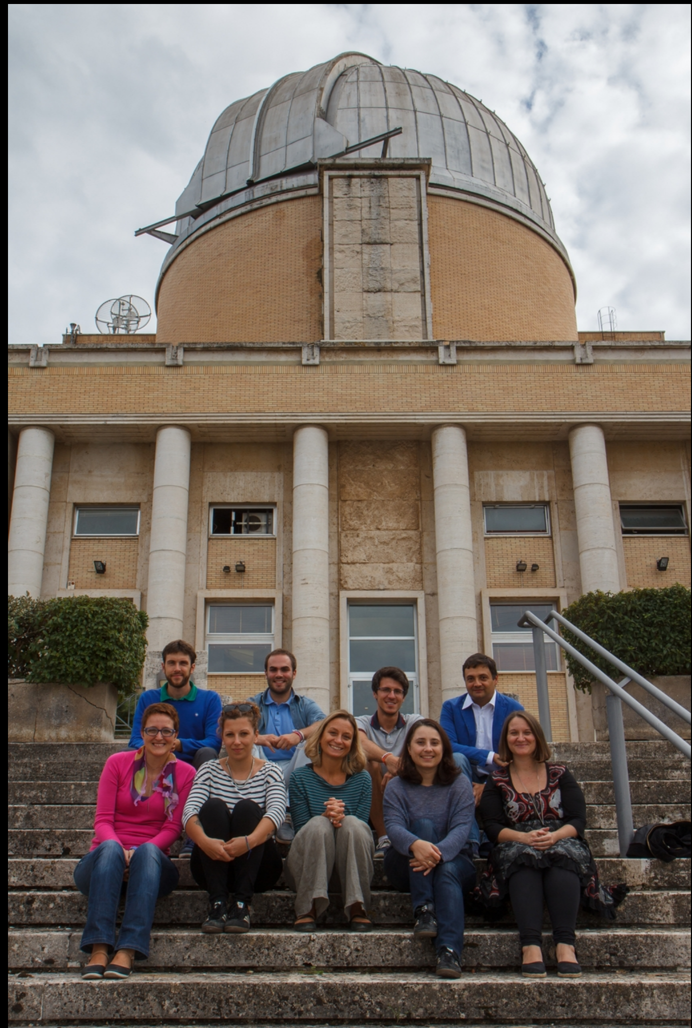


http://www.oa-roma.inaf.it/FIRST/

Evolution of star forming clouds at low-metallicities

H_2, metal and dust cooling: 3 different mass scales

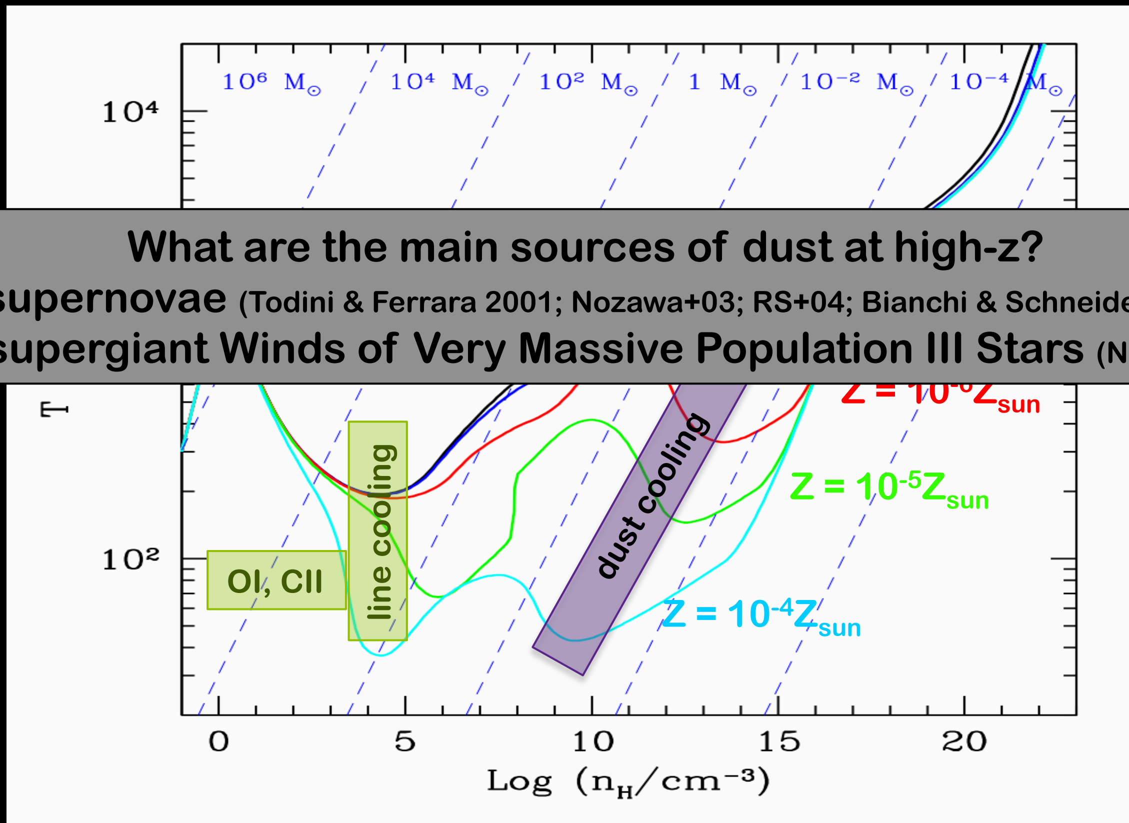
H_2-line cooling:

$M_{jeans} \sim 10^3\ M_{sun}$

What are the main sources of dust at high-z?

Population III supernovae (Todini & Ferrara 2001; Nozawa+03; RS+04; Bianchi & Schneider 2007; Marassi+14, 15)

Red-supergiant Winds of Very Massive Population III Stars (Nozawa+14)



metal-line cooling:

$Z > 10^{-4}\ Z_{sun}$

$M_{jeans} > 10\ M_{sun}$

Bromm et al. (2001)
Bromm & Loeb (2003)
Santoro & Shull (2004)

dust cooling:

$Z > 10^{-6}\ Z_{sun}$ $D_{cr} > 4.4\ 10^{-9}$

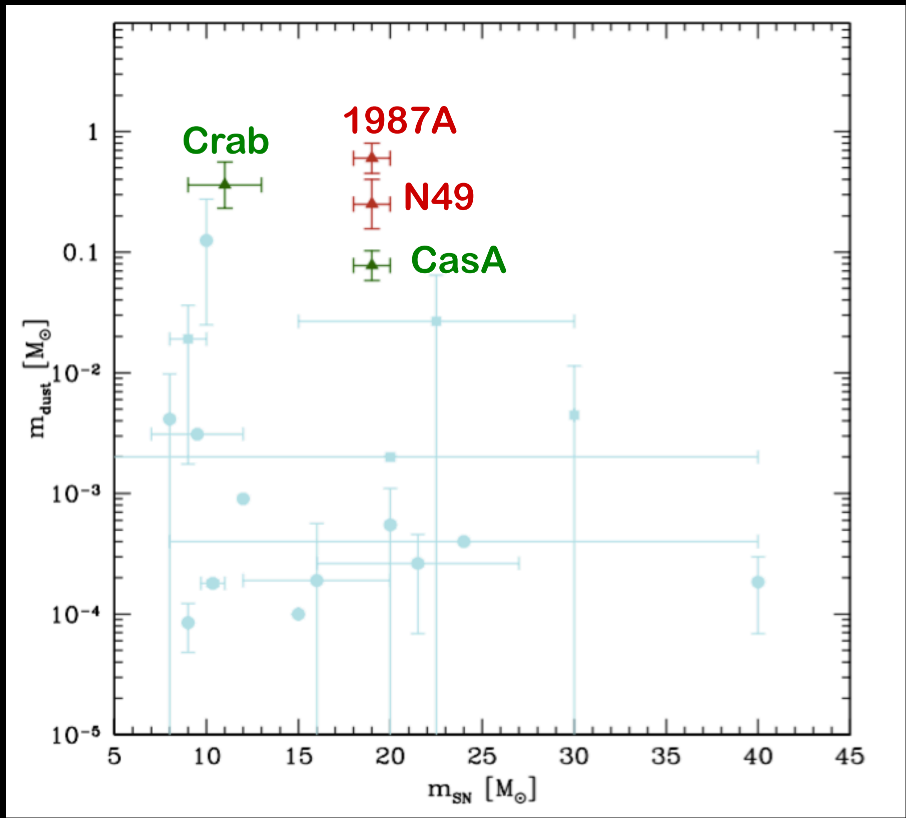
$M_{jeans} < 1\ M_{sun}$

RS et al. (2002,2003,2006),
Omukai et al. (2005)

stellar sources of dust: SNe

observations of SNe and SN remnants show signatures of the presence of dust associated with the ejecta

Schneider+14



Gall+11 Gomez+12, Dunne+09, Barlow+10, Matsuura+11, Otsuka+10

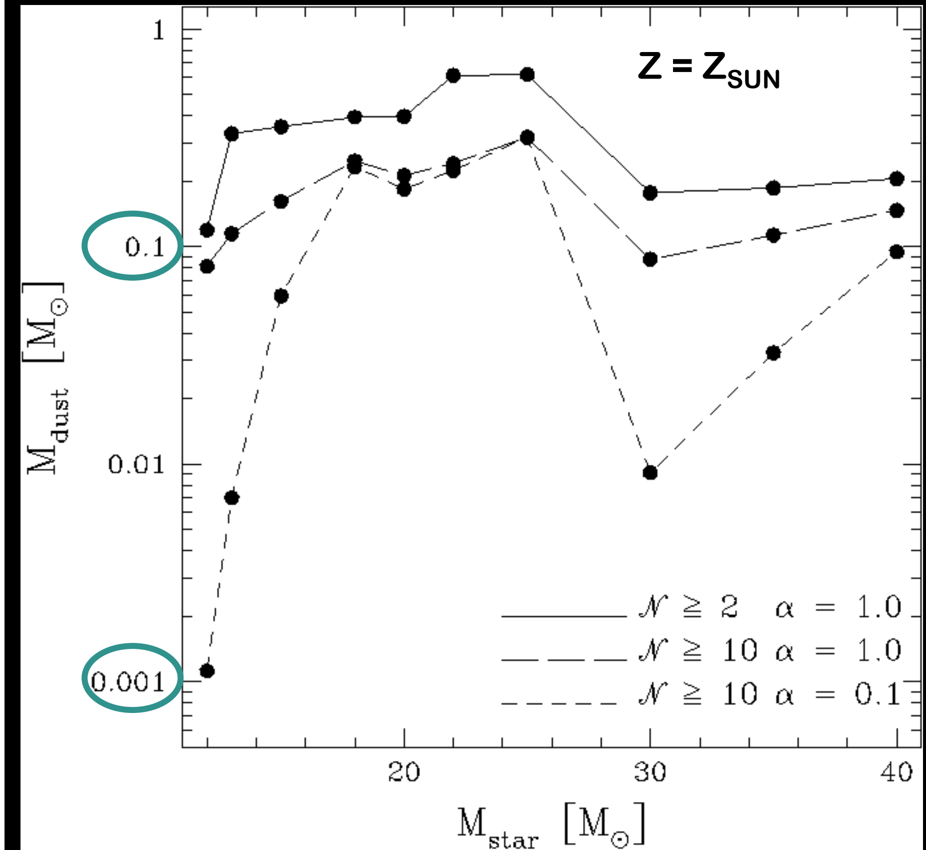
Kozasa & Hasegawa 1987; Todini & Ferrara 2001; Nozawa et al 2003; Schneider, Ferrara & Salvaterra 2004;
Bianchi & Schneider 2007; Cherchneff & Dwek 2010; Fallest et al. 2011; Sarangi & Cherchneff 2013; Marassi+2014, 2015, 2016; Bocchio+2016

SN dust yields

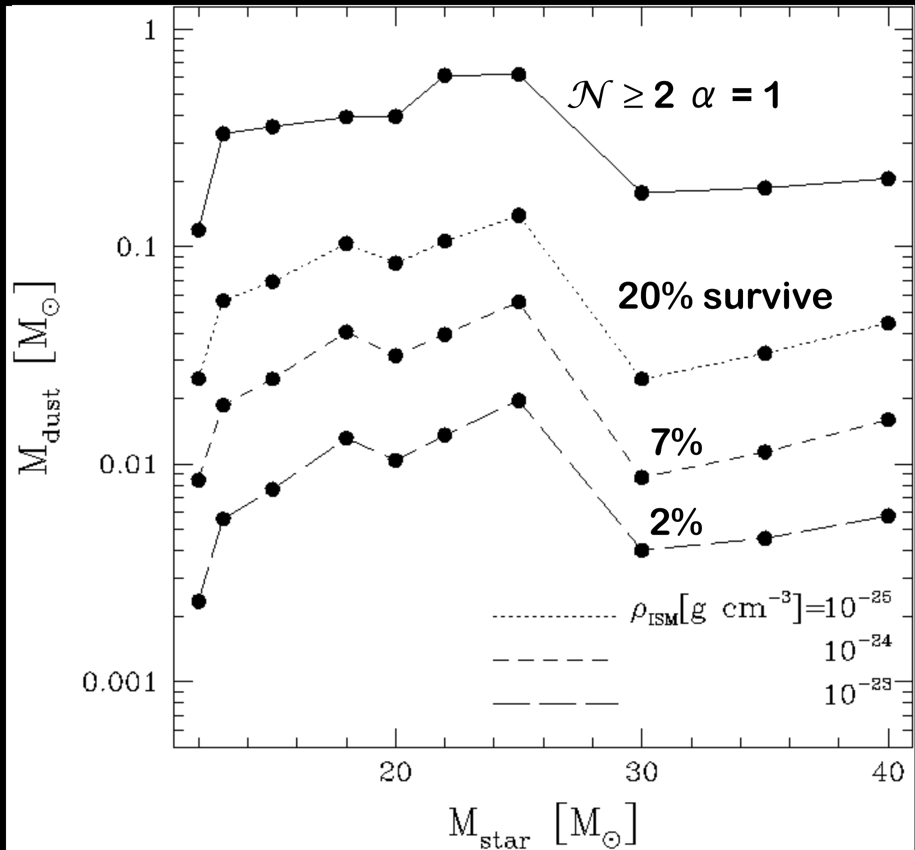
Kozasa & Hasegawa 1987; Todini & Ferrara 2001; Nozawa et al 2003, 2007; Schneider, Ferrara & Salvaterra 2004; Bianchi & Schneider 2007; Chercheneff & Dwek 2010; Fallest et al. 2011; Sarangi & Cherchneff 2013; Marassi+2014, 2015, 2016

fixed energy explosion models (1.2 10^{51} erg) and fully mixed ejecta

dependence on mass and parameters



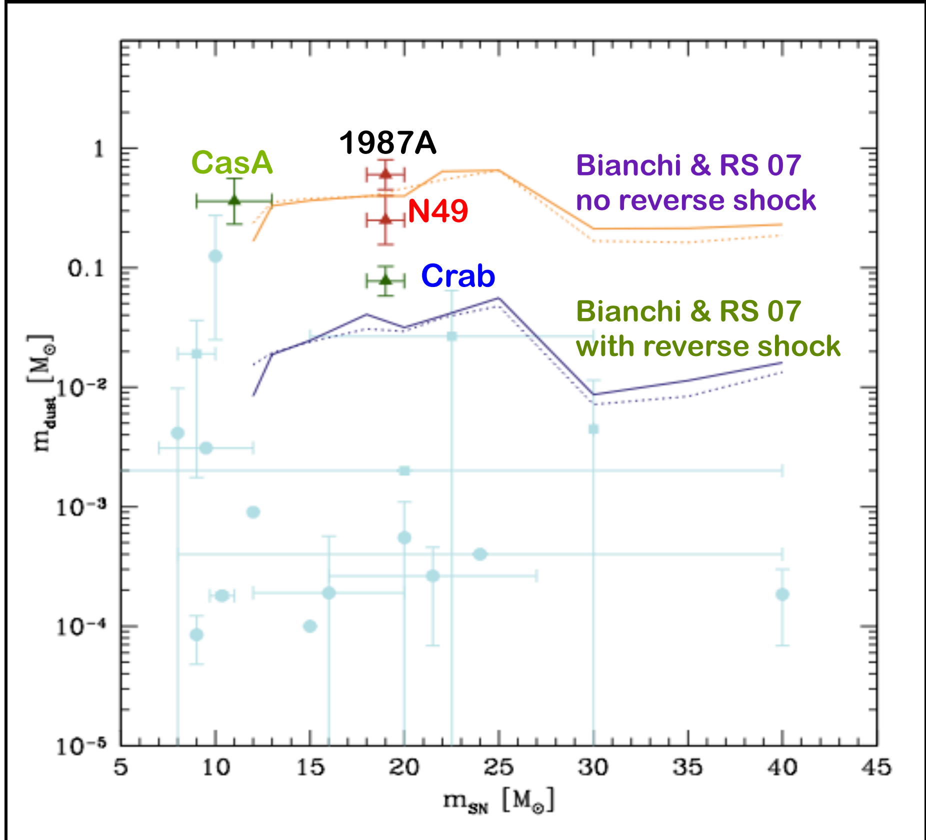
dependence on the strength of the reverse shock



Bianchi & Schneider (2007)

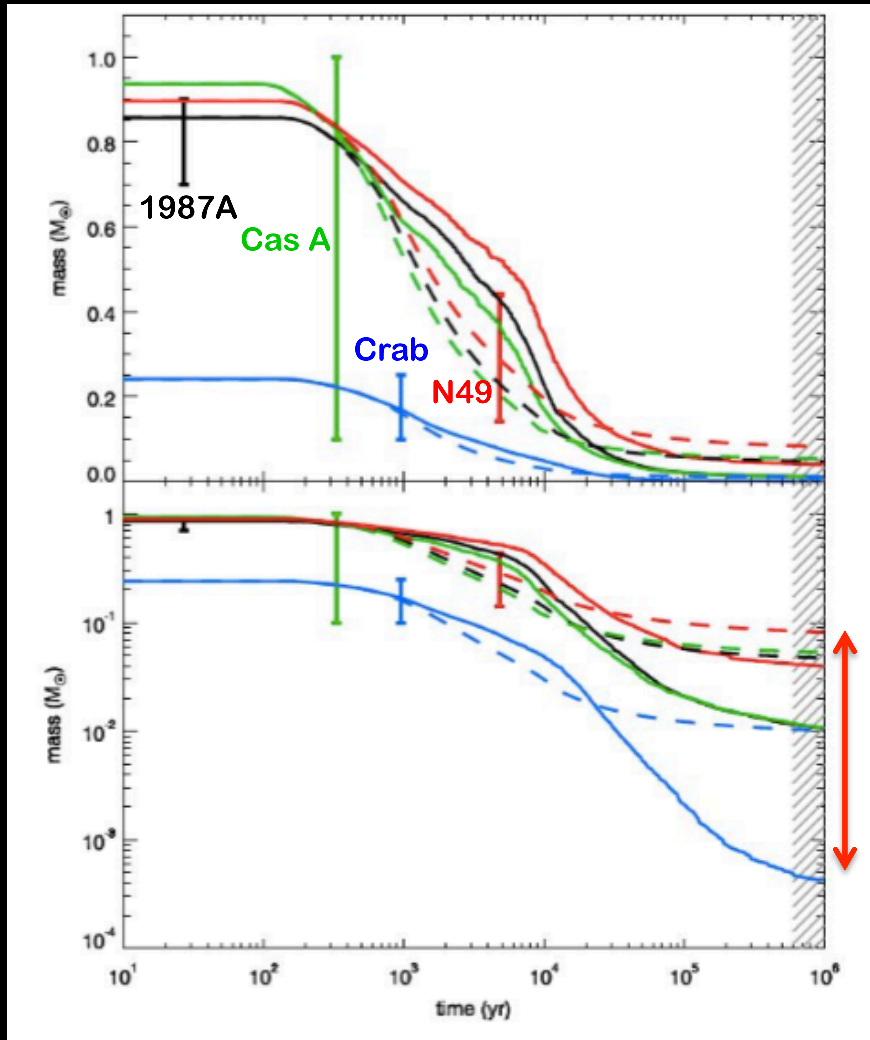
SN dust yields: comparison with observations

Schneider+14



Gall+11 Gomez+12 Dunne+09 Barlow+10
Matsuura+11 Otsuka+10

Bocchio+16



theoretical SN dust yields are in broad agreement with available data

the mass of SN dust that will enrich the ISM << than observed in SN remnants with $t_{age} < 10^4$ yr

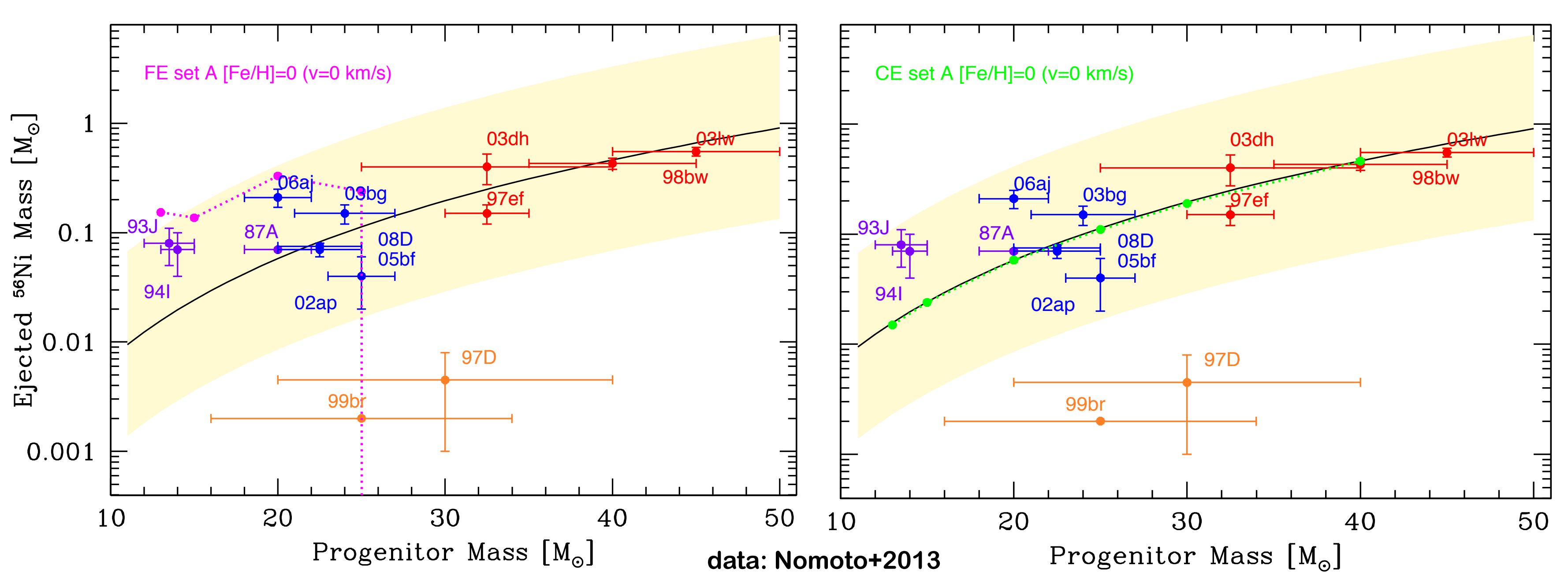
SN dust yields: importance of fallback, metallicity and rotation

Marassi, RS, Limongi, Chieffi, Graziani, Bianchi in preparation

Grid of SN progenitor models with $13\ M_{sun} \leq M_{star} \leq 120\ M_{sun}$ $10^{-3} \leq Z/Z_{sun} \leq 1$ and different v_{rot}

models with fixed explosion energy: $E_{sn} = 1.2\ 10^{51}$ erg

calibrated explosion models



data: Nomoto+2013

SN dust yields: importance of fallback, metallicity and rotation

Marassi, RS, Limongi, Chieffi, Graziani, Bianchi in preparation

Grid of SN progenitor models with $13\ M_{sun} \leq M_{star} \leq 120\ M_{sun}$ $10^{-3} \leq Z/Z_{sun} \leq 1$ and different v_{rot}

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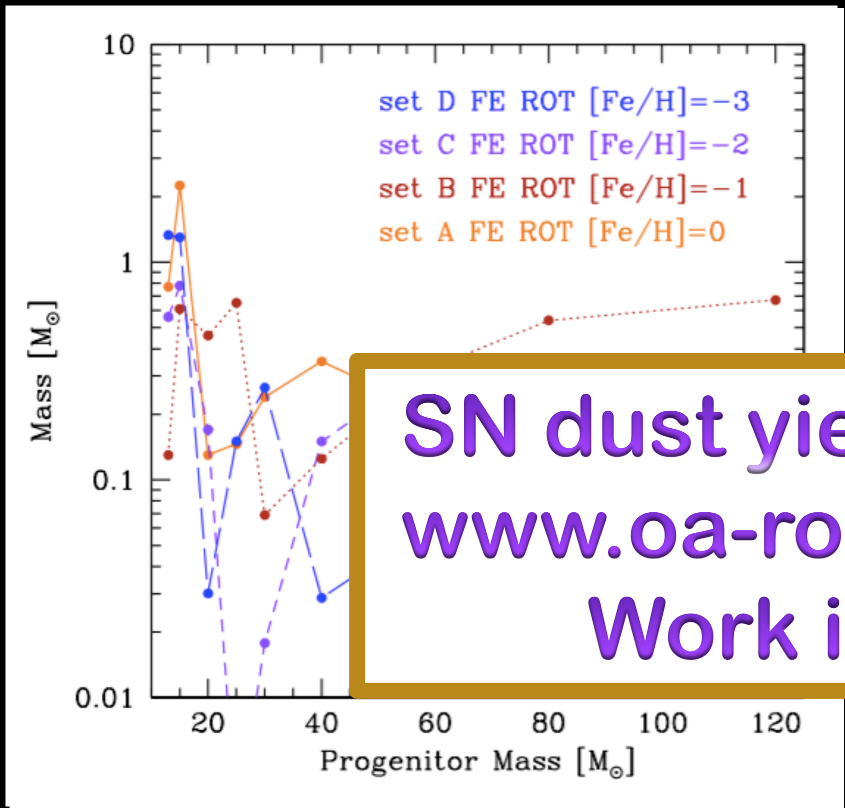
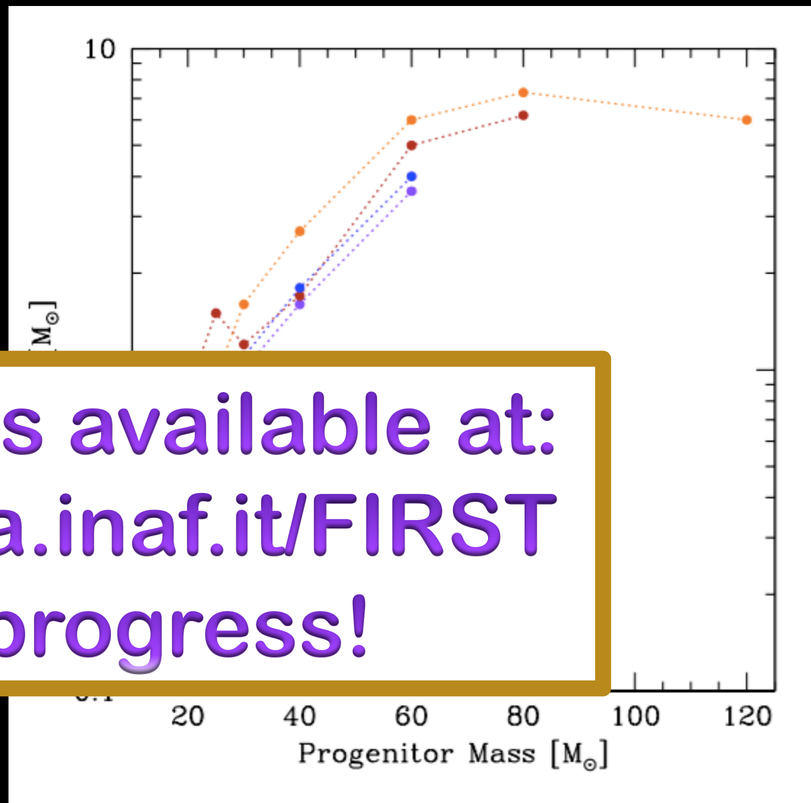


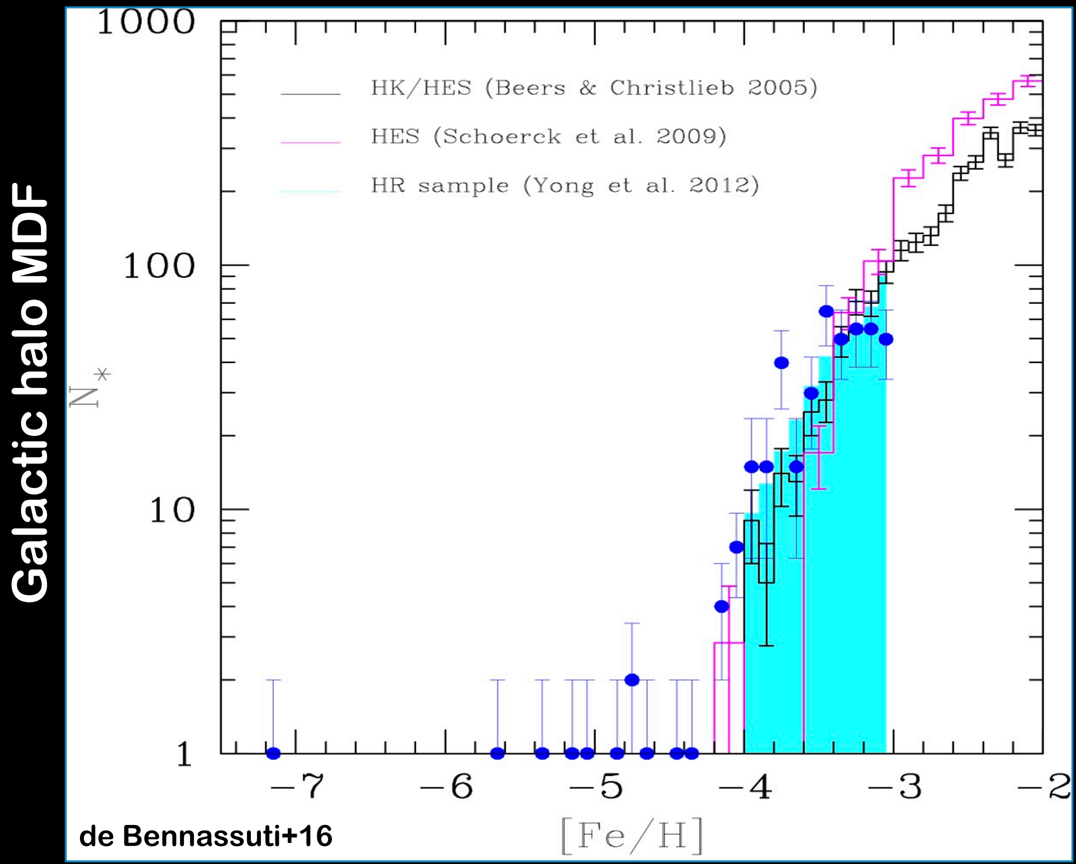
calibrated explosion models



SN dust yields available at:
www.oa-roma.inaf.it/FIRST
Work in progress!

probing low-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 low-Z SF with stellar archaeology

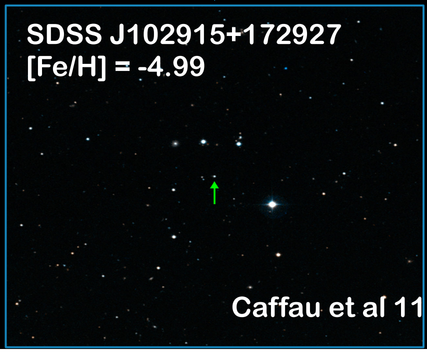
low mass metal-poor stars are fossil remnants of early star formation:
their metallicity distribution function (MDF) and surface elemental abundances
encode information on their formation efficiency and on the sources of metal enrichment

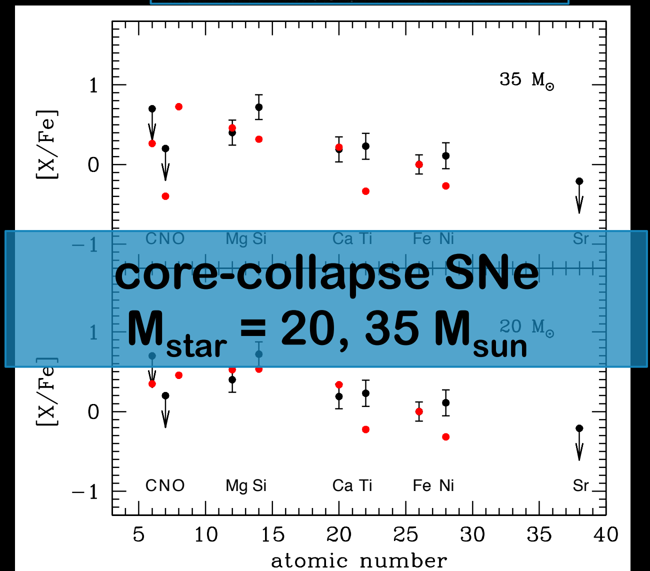
the most iron-poor stars in the Galactic halo

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

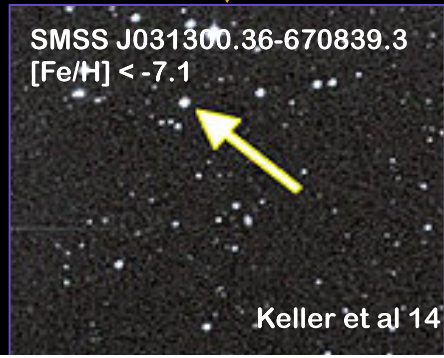
HE 0107—5240	[Fe/H] = -5.39	[C/Fe] = + 3.70	Christilieb+02
HE 1327—2326	[Fe/H] = -5.66	[C/Fe] = +4.26	Frebel+05
HE 0557—4840	[Fe/H] =-4.81	[C/Fe] = +1.65	Norris+07
SDSS J1069+1729	[Fe/H] = -4.73	[C/Fe] < 0.93	Caffau+11
SMSS 0313-0708	[Fe/H] < -7.30	[C/Fe] > 4.90	Keller+14
HE 0233—0343	[Fe/H] = -4.68	[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

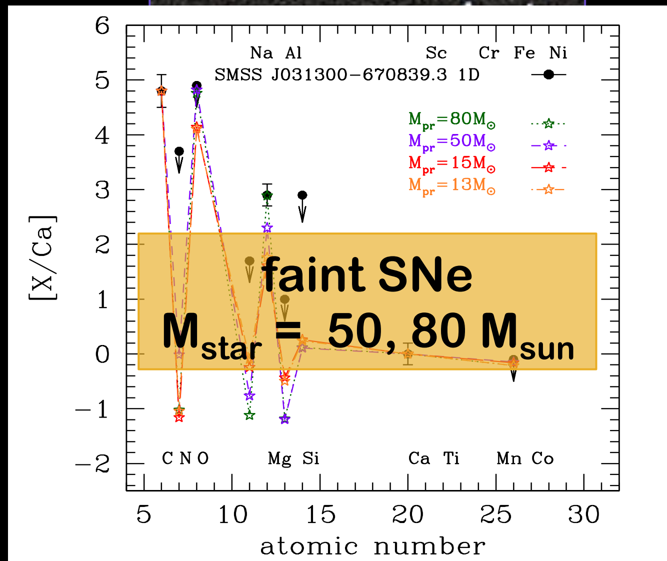
simulating the birth environment of C-normal and C-rich stars





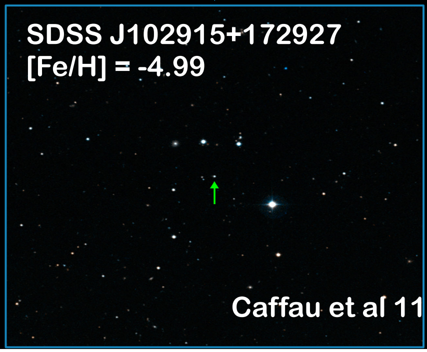
Schneider et al. 2012

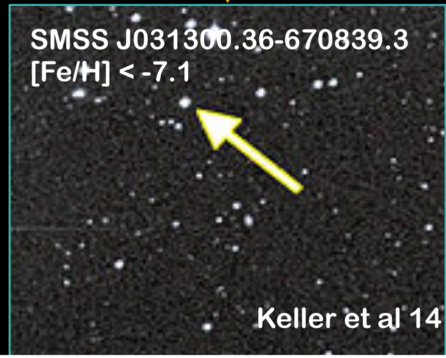


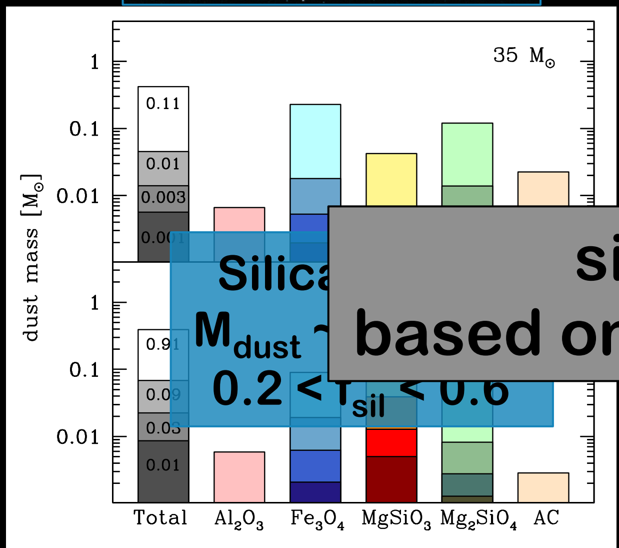


Marassi et al. 2014

simulating the birth environment of C-normal and C-rich stars







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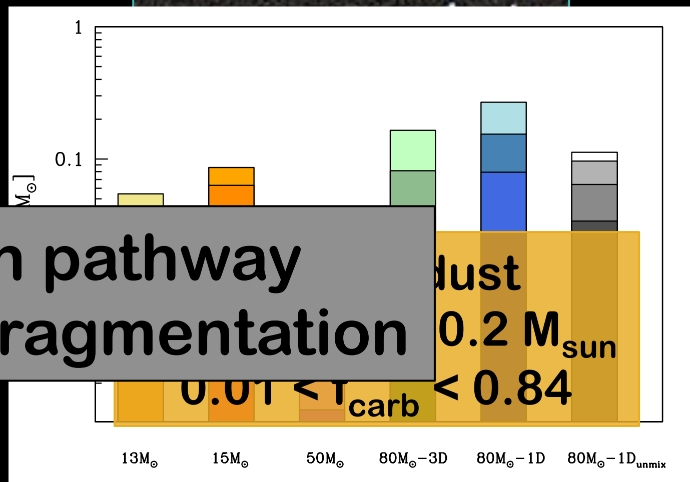


Marassi et al. 2014

Silica…

M_{dust} ~ …

$0.2 < f_{sil} < 0.6$

…dust

… 0.2 M_{sun}

$0.01 < f_{carb} < 0.84$

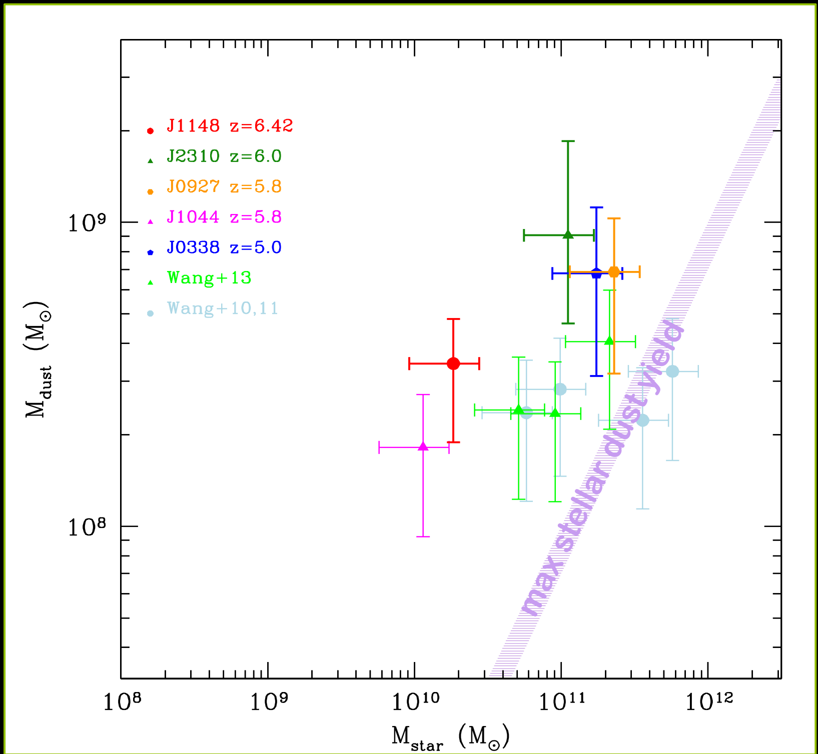
single formation pathway based on dust-driven fragmentation

the dust mass in "extreme" galaxies at z ~ 6: quasar hosts

are stellar sources enough to produce ~ 10^8 M_{sun} of dust in < 1 Gyr?

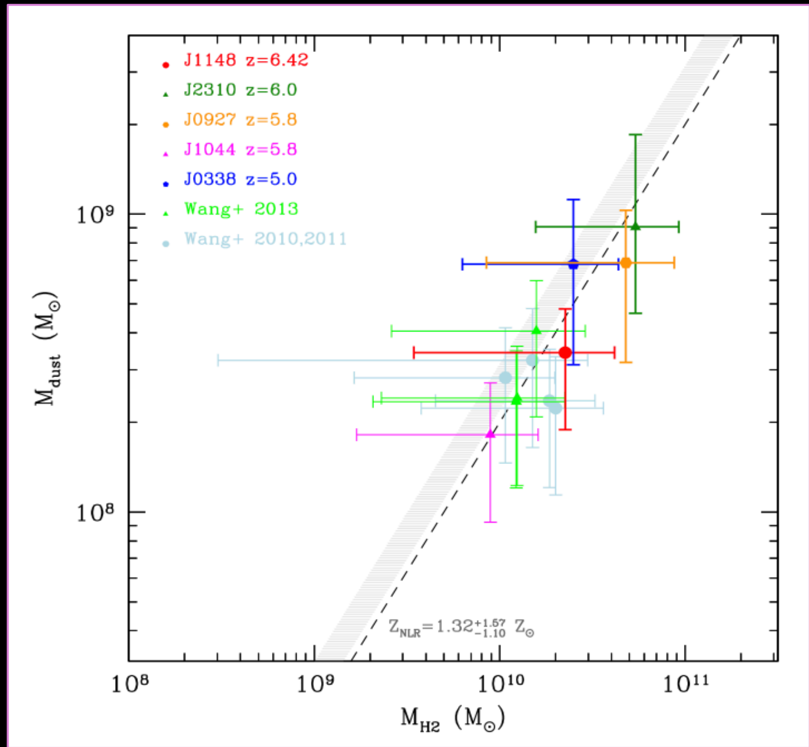
Valiante et al. 2009, 2011, 2014; Gall et al. 2010, 2011; Dwek & Cherchneff 2011; Mattsson 2011; Pipino et al 2011; Calura et al. 2013

M_{dust} *does not* correlate with M_{star}



stellar dust is not enough to reproduce the observed M_{dust}

M_{dust} *does* correlate with M_{H2}



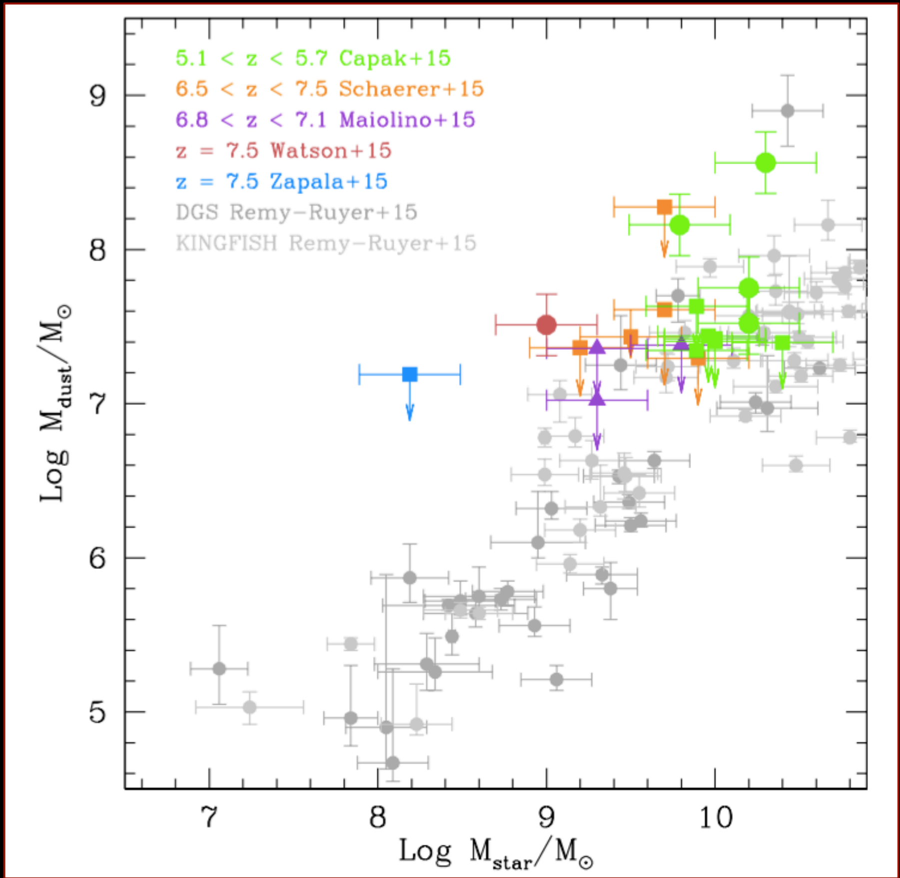
the observed M_{dust} require super-solar metallicities and very efficient grain growth in dense gas

Valiante et al. 2014, 2015

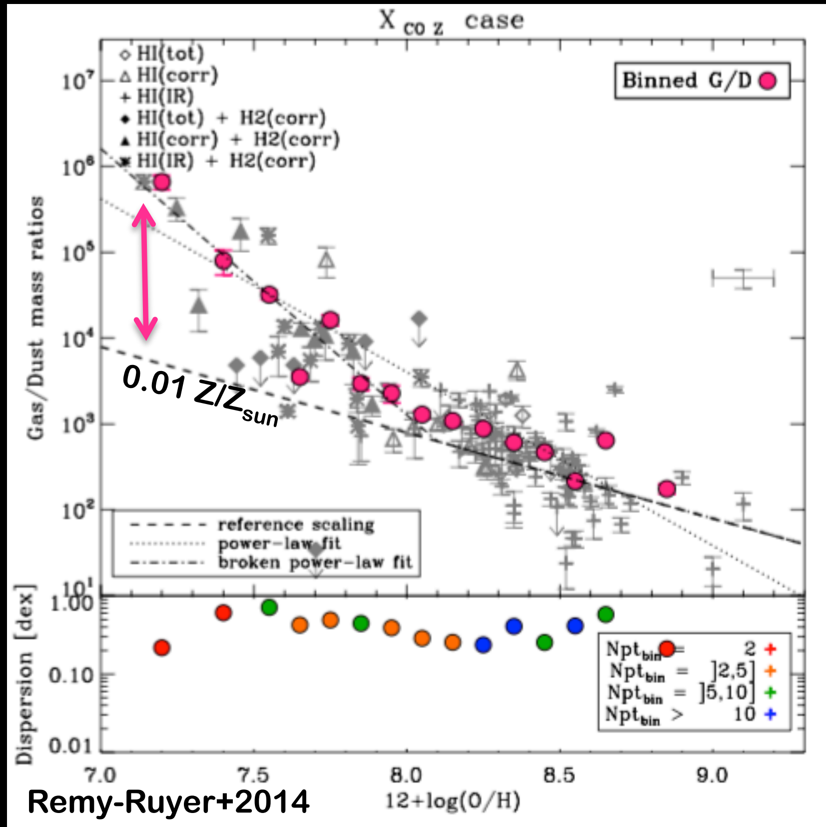
the dust mass in “normal” SF galaxies at z ~ 6

Shimizu+14; Mancini, RS+2015, 2016; Khakaleva-Li & Gnedin 2016; Aoyama+ in prep; Graziani+ in prep

the dust mass in “normal” galaxies at 5 < z < 7 compared to local galaxies



Gas-to-dust mass ratios in local galaxies over a 2 dex metallicity range



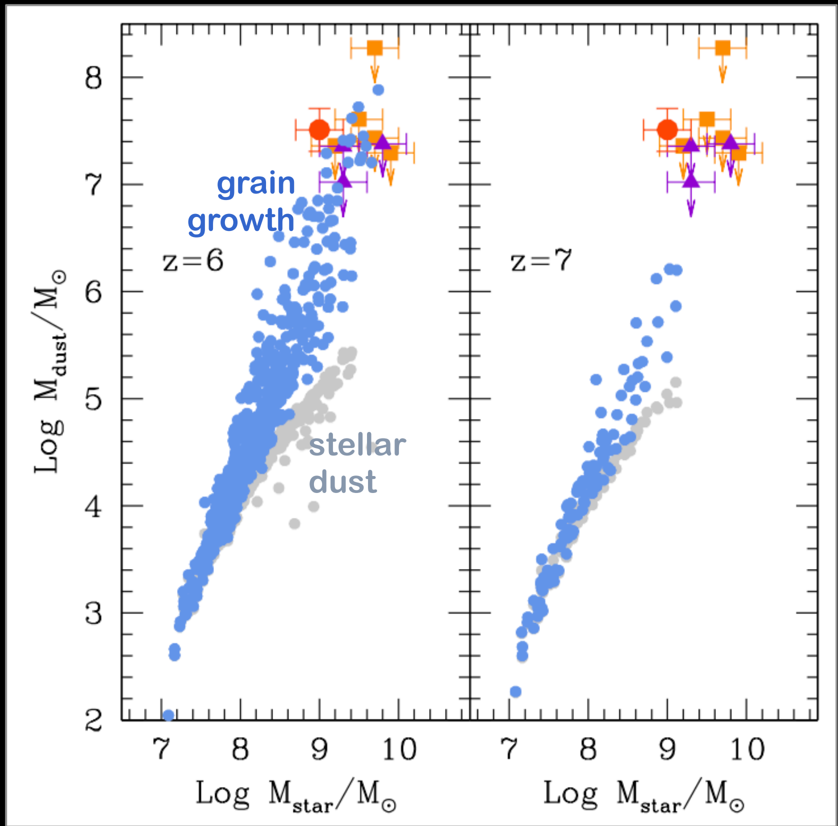
Asano+2013; Hirashita+2014

$$\tau_{acc} = 20\,\mathrm{Myr} \times \left(\frac{n_{mol}}{100\,\mathrm{cm}^{-3}}\right)^{-1} \left(\frac{T_{mol}}{50\,\mathrm{K}}\right)^{-1/2} \left(\frac{Z}{Z_\odot}\right)^{-1}$$

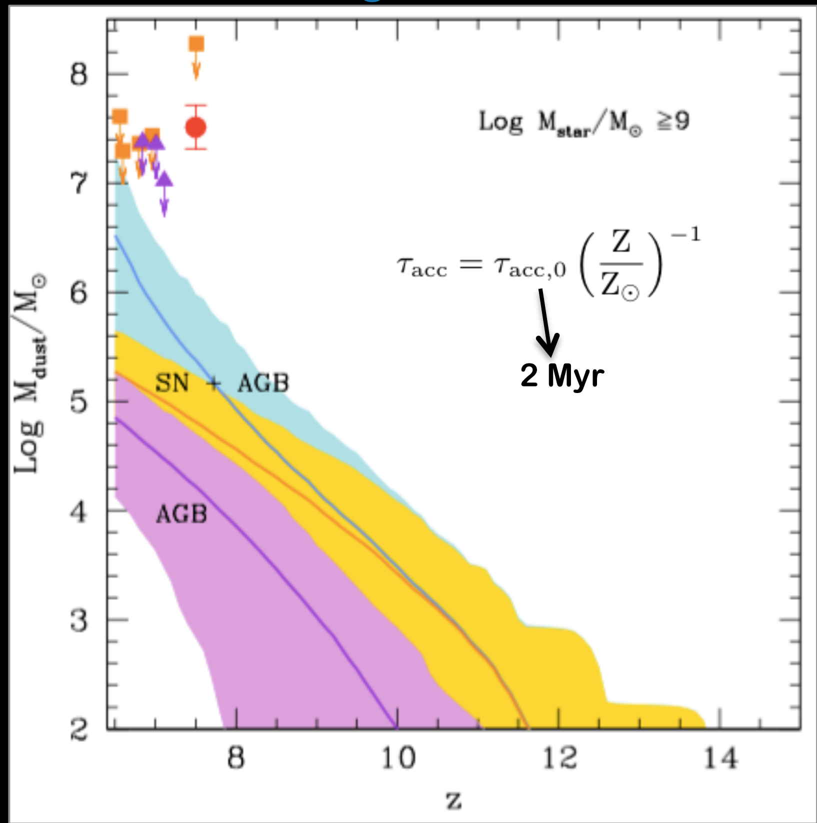
the dust mass in z ~ 6 "normal" SF galaxies

Ouchi+2013; Kanekar+2013; Ota+2014; Schaerer+2014; Maiolino+2015; Watson+2015, 2016

dust vs stellar mass: simulation results vs observations



dust evolution of the most massive galaxies



Mancini et al. (2015)

the dust mass in z ~ 6 “normal” SF galaxies

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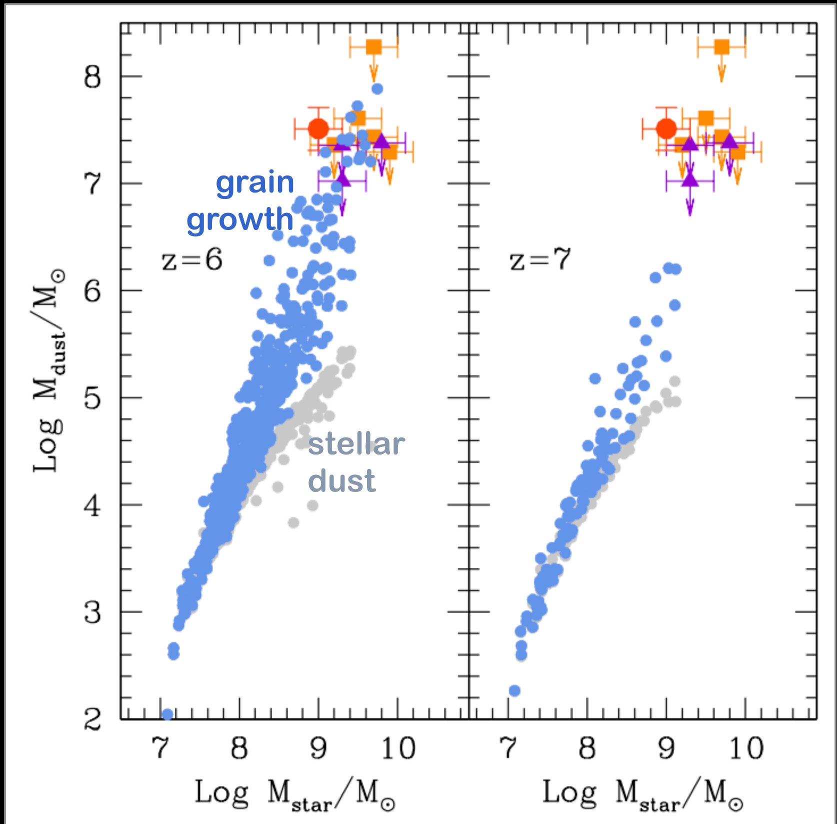

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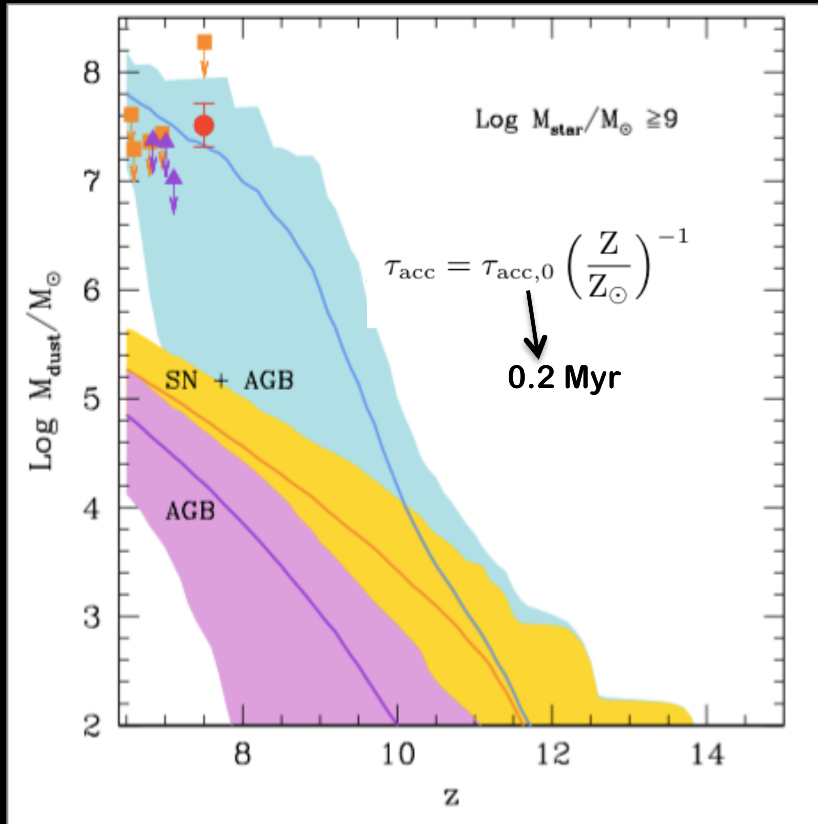
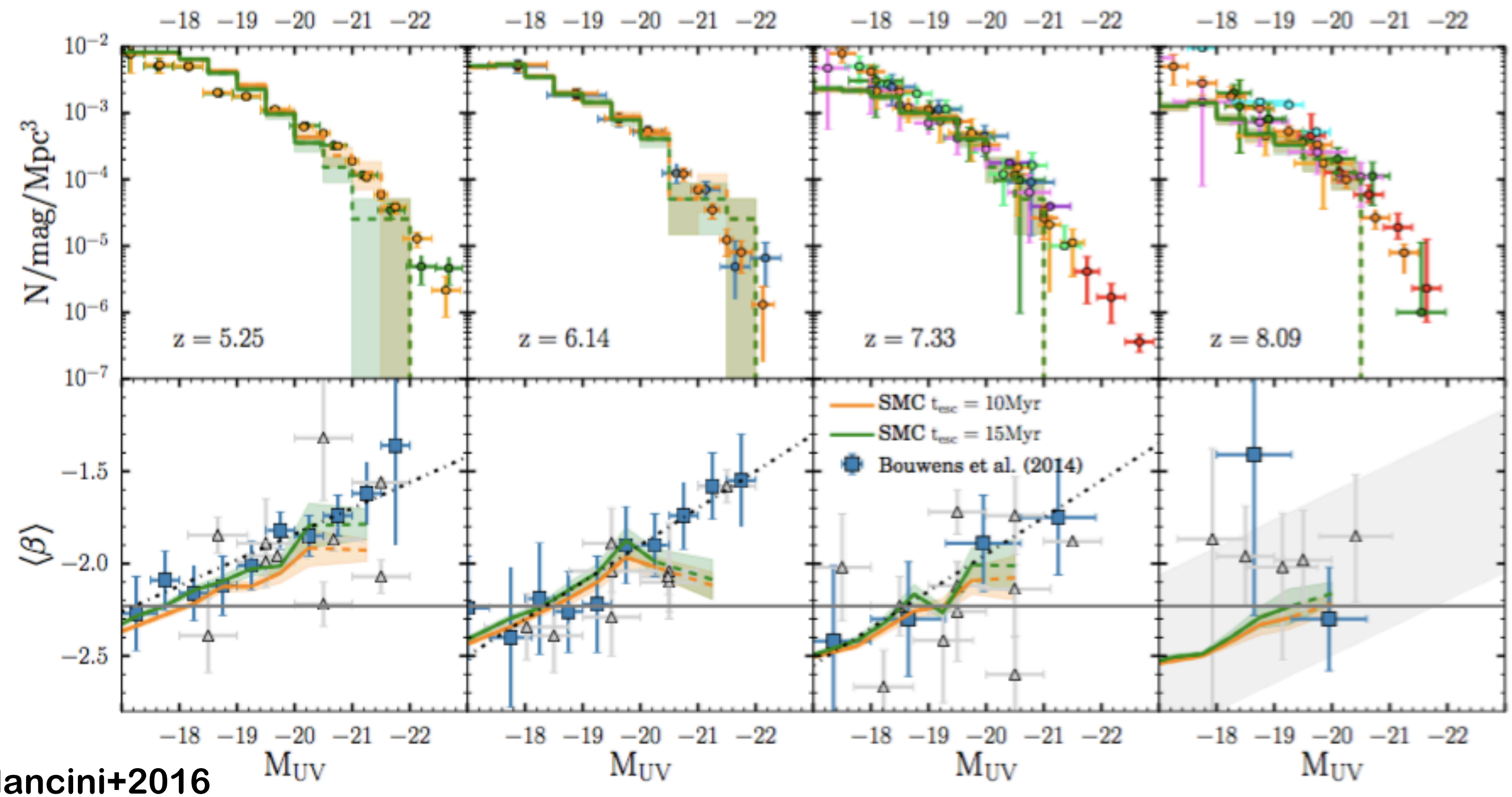


efficient grain growth is required to account for the observed dust mass

Mancini et al. (2015)

effects on the evolution of the UV colours at z ~ 5 -10

Mancini, RS+2015, 2016; Khakaleva-Li & Gnedin 2016; Graziani+ in prep

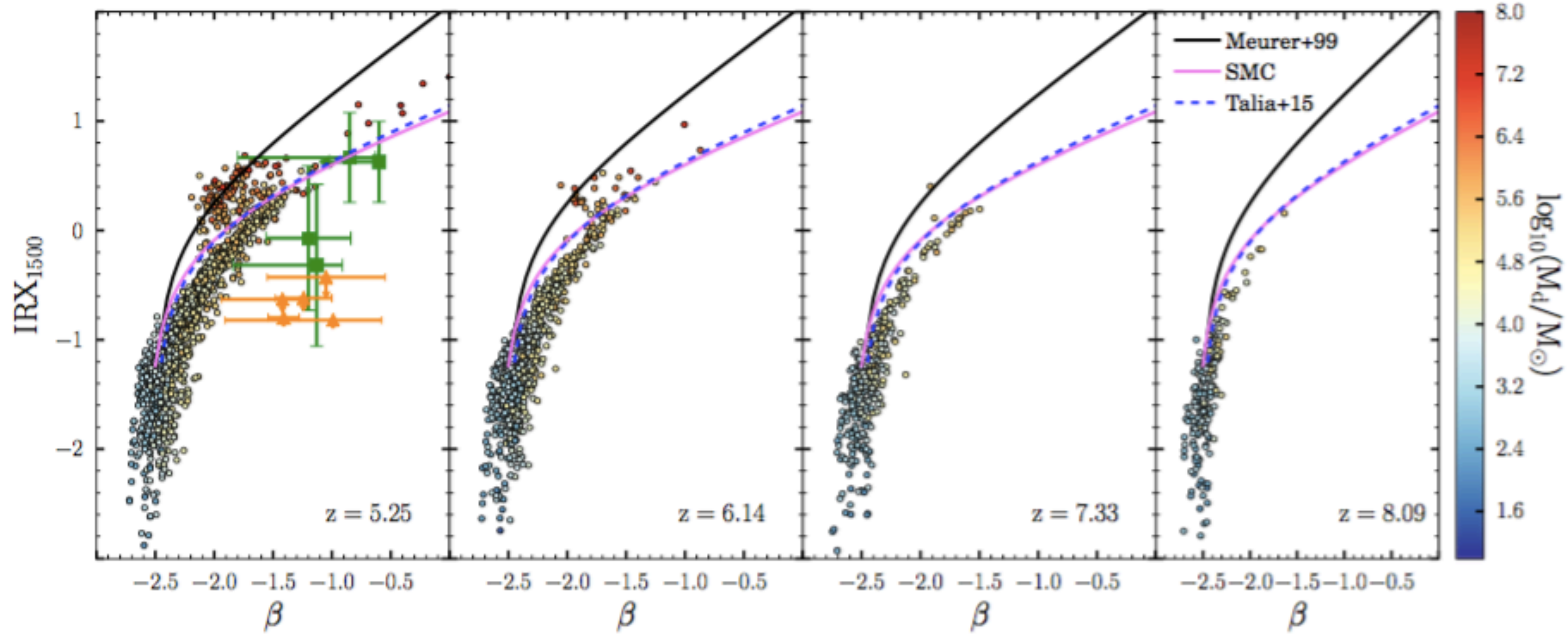


Mancini+2016

dust has an important effect on the UV LF at z < 7 and on galaxy colours

effects on the evolution of the UV colours at z ~ 5 -10

Mancini, RS+2015, 2016; Khakaleva-Li & Gnedin 2016; Graziani+ in prep



simulated galaxies are consistent with modest reddening at z > 7

SFRs at z > 5 may be over-estimated if dust-correction based on local relations (Meurer+99) are applied

see posters of Mattia Mancini and Luca Graziani

Summary

Insights on the formation epoch of the first dust and its impact on high-z star formation from a combination of theoretical models and observations in the Local Universe and the highest redshifts accessible with current facilities.

- constraints from stellar archaeology on the nature and properties of the first supernovae and the (dust-induced) formation mode of the first low-mass stars

- observed properties of $z > 6$ quasars hosts require efficient dust enrichment by stellar sources and grain growth in dense gas

- dust enrichment in normal star forming galaxies affect the UV LF at $z < 7$ and galaxy colours → ALMA and JWST will be able to probe the emergence of dust-enriched galaxies at high-z

TBD: including dust in numerical simulations of high-z galaxies (dustyGADGET Graziani et al. in prep)