Dust production 680–850 million years after the Big Bang

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/me-how me-how-ov-ski/

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18.03.2015, Sintra

Background and motivation

What is the origin of dust?

- Stellar dust producers: AGB stars (3–8 $M_\odot$) and SNe (8–40 $M_\odot$)
- Theoretical dust yields: $< 4 \cdot 10^{-2}\, M_\odot$ per AGB star and $< 1.32\, M_\odot$ per SN (only $< 0.1\, M_\odot$ survives the shocks)
- SNR Cassiopeia A, Kepler, 1987A: $\sim 1\, M_\odot$ of dust, but other SNR reveal only 10^{-3}–$10^{-2}\, M_\odot$
- Dust grain growth in the interstellar medium
- Are stellar sources efficient enough to produce dust at $z > 6.3$?

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Method

- Millimeter emission $\rightarrow M_{\rm dust}$
- Optical/near-IR $\rightarrow M_{\rm star}$
- CO / C II line $\rightarrow M_{\rm gas}$ and $M_{\rm dyn}$
- $M_{\rm star} = M_{\rm dyn} - M_{\rm gas}$ or at least $M_{\rm star} < M_{\rm dyn}$
- Number of stars with masses M_0–M_1:

$$N(M_0 < M < M_1) = M_{\rm star} \frac{\int_{M_0}^{M_1} M^{-\alpha} dM}{\int_{M_{\rm min}}^{M_{\rm max}} M^{-\alpha} M dM}$$

- The required dust yield per star: $M_{\rm dust}/N(M_0 < M < M_1)$

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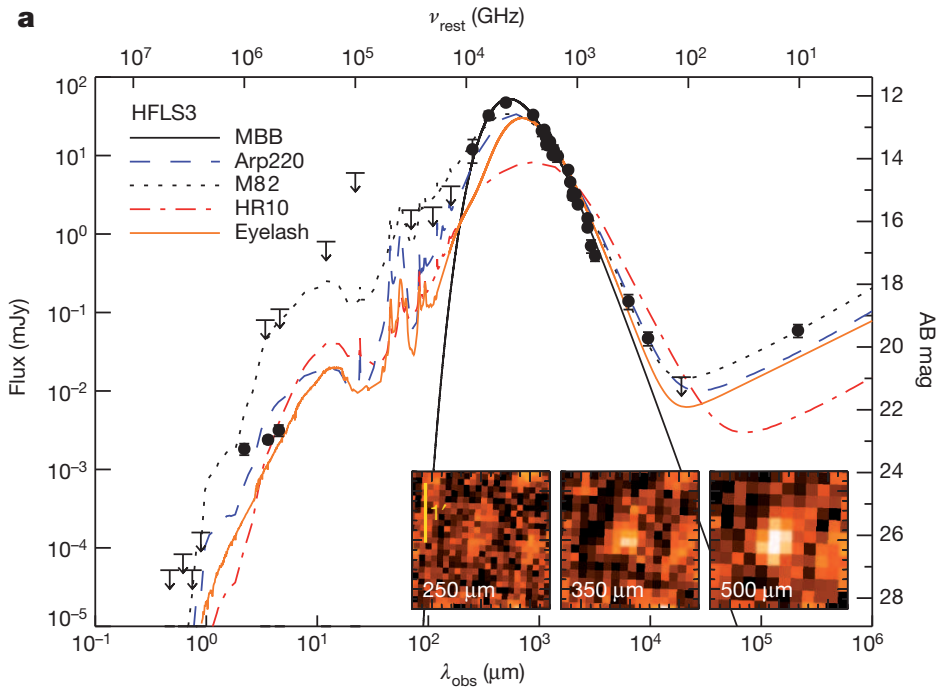
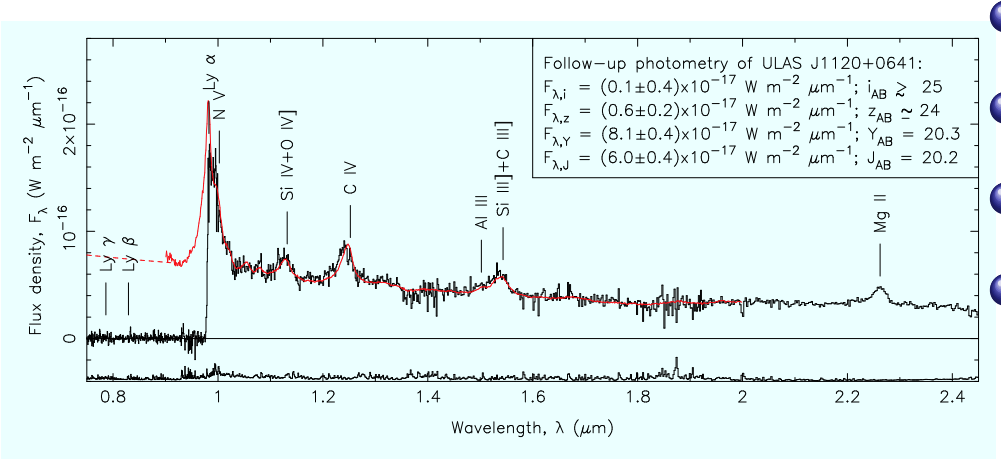
HFLS3



- $z = 6.34$
- red, *Herschel*-selected dusty starburst
- submm, optical/near-IR, CO
- Riechers et al. (2013, Nature, 496, 329)

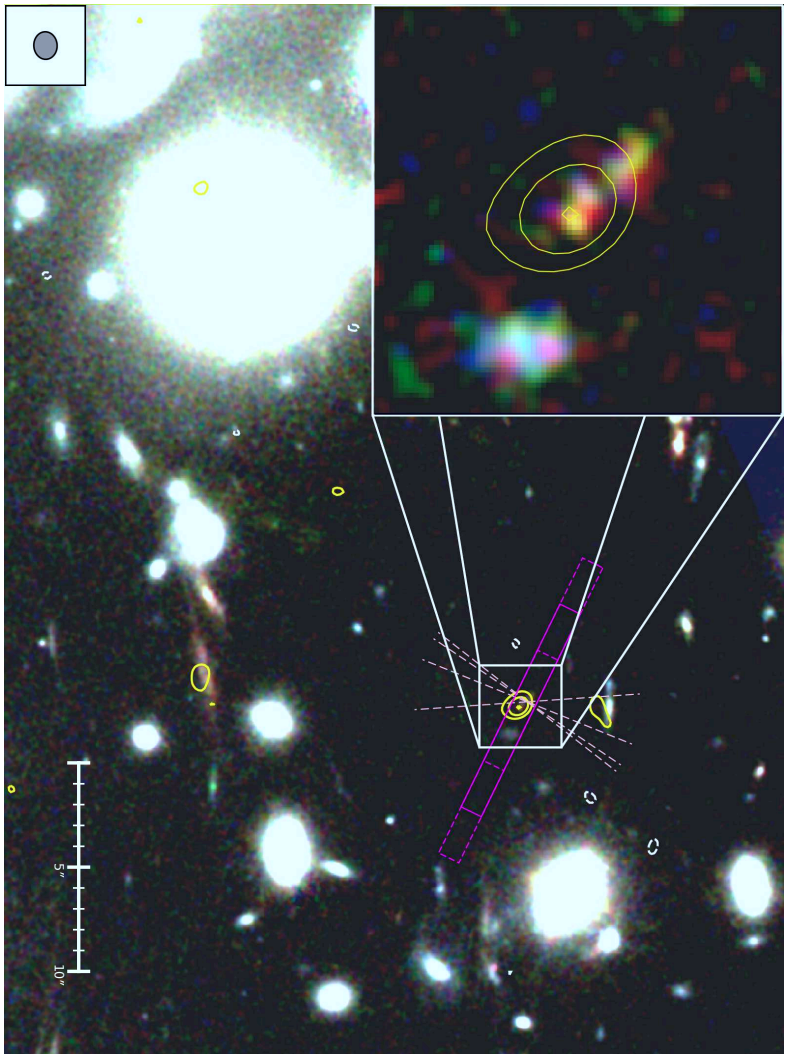
Sample

ULAS J1120+0641



- $z = 7.085$
- colour-selected quasar
- mm, CII
- Mortlock et al. (2011, Nature, 474, 616); Venemans et al. (2012, ApJL, 751, 25)

A1689-zD1



- $z = 7.5$
- lensed Lyman break galaxy (magnification factor: 9.3)
- submm, optical/near-IR
- Watson et al. (2015, Nature, in press, `arXiv:arXiv:1503.00002`)

Sample

Unsuccessful dust emission search at $z > 6.3$

- HCM6A
  - $z = 6.56$
  - lensed Lyα emitter (magnification factor: 4.5)
  - Hu et al. (2002, ApJL, 568, 75); Kanekar et al. (2013, ApJL, 771, 20)
- A1703-zD1
  - $z = 6.8$
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  - Bradley et al. (2012, ApJ, 747, 3); Schaerer et al. (2014, A&A, 574, 19)
- Himiko
  - $z = 6.595$
  - Lyα emitter
  - Ouchi et al. (2009, ApJ, 696, 1164; 2013, ApJ, 778, 102)
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  - Iye et al. (2006, Nature, 443, 186); Ota et al. (2014, ApJ, 792, 34)
- z8-GND-5296
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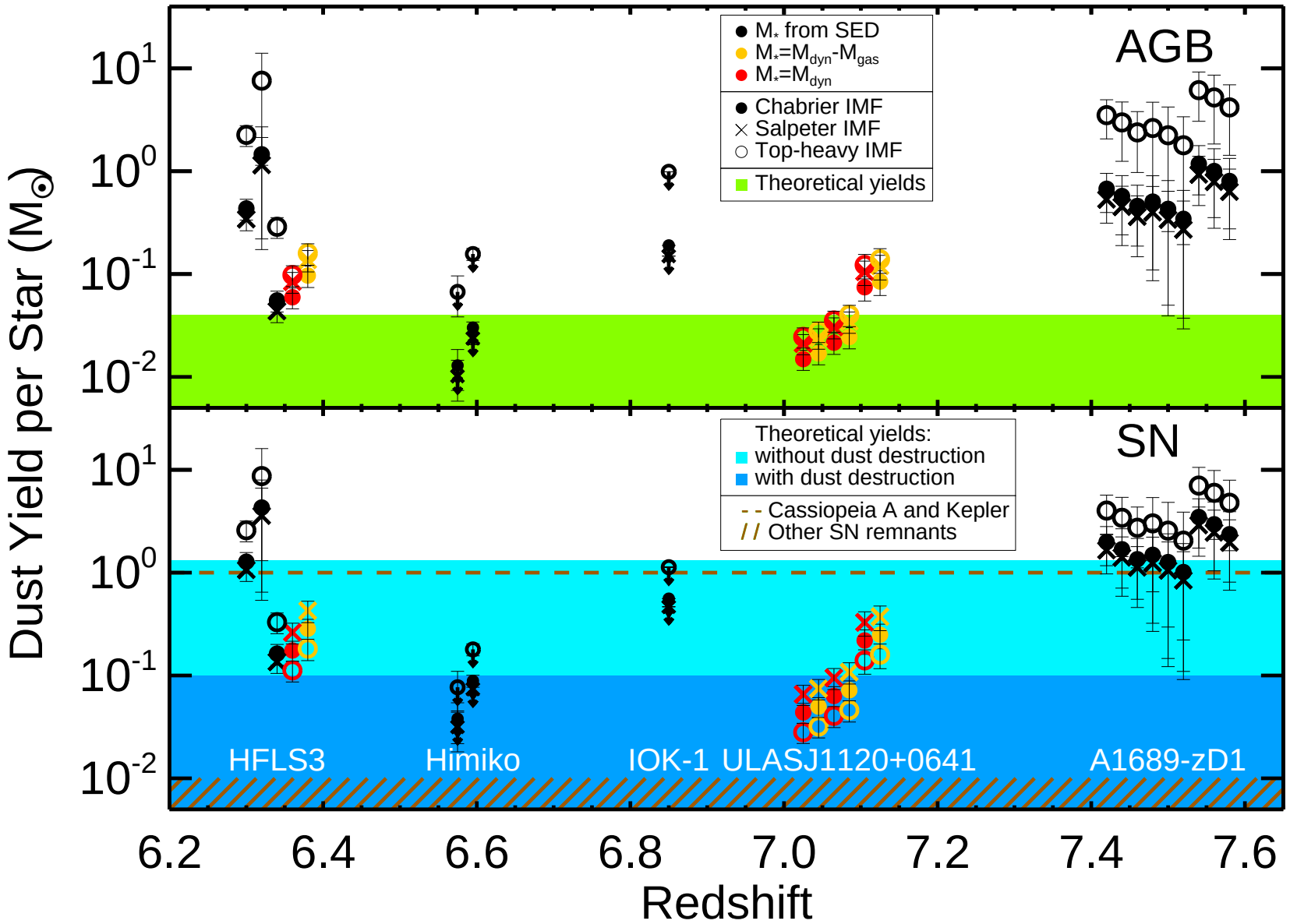
Dust Yields


AGB
SN
M* from SED
M*=Mdyn-Mgas
M*=Mdyn
Chabrier IMF
Salpeter IMF
Top-heavy IMF
Theoretical yields
Theoretical yields:
without dust destruction
with dust destruction
Cassiopeia A and Kepler
Other SN remnants
HFLS3
Himiko
IOK-1
ULASJ1120+0641
A1689-zD1
Dust Yield per Star (M⊙)
Redshift
10^1
10^0
10^-1
10^-2
6.2
6.4
6.6
6.8
7.0
7.2
7.4
7.6

Conclusions

Dust production at $z = 6.3$–7.5
(680–850 million years after the Big Bang)

- AGB stars could not contribute substantially
- SNe could explain measured dust masses, but only if they do not destroy majority of the dust they form (unlikely given the upper limits on the SN dust yields for dust non-detected galaxies)
- grain growth in the interstellar medium is likely required
- More details in Michałowski (2015, A&A, submitted)