The metal and dust build-up in the Universe: constraints from LBGs at the epoch of reionization

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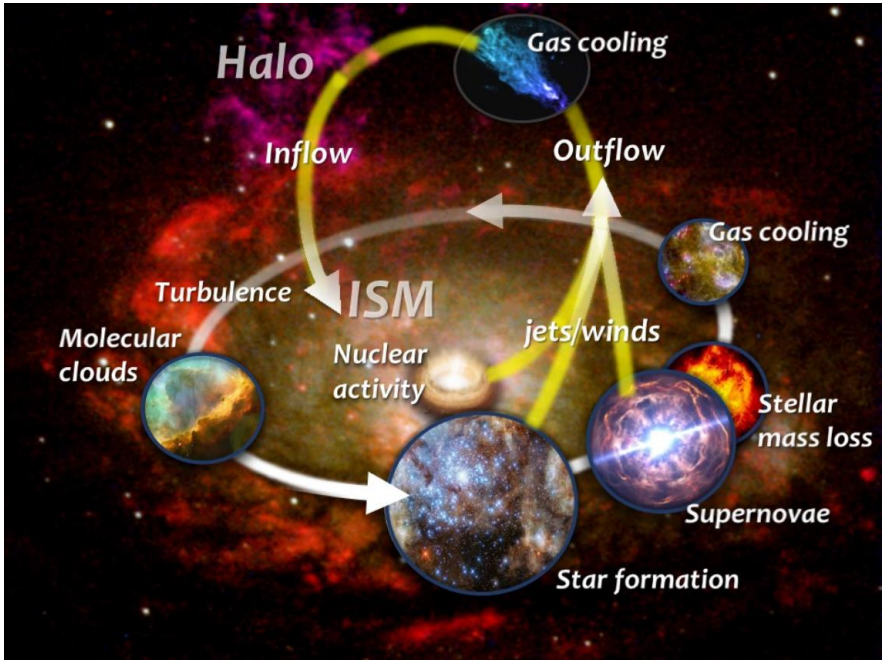
The evolution of baryons in galaxies



- **Different evolutionary time-scale of stars according to the initial stellar mass**:
  - >8-10 $M_{\odot}$ → evolve in <30 Myrs; explode as Type II supernovae (SNe II).
  - ~<6-8 $M_{\odot}$ → evolve in >100 Myrs; lose their envelope (mass-loss) during the thermally pulsing asymptotic giant branch (TP-AGB) phase.
- **Gas, metal and dust in galaxies change because of different physical processes:**
  - Star formation and evolution (metal & dust enrichment).
  - Grain evolution in the ISM of galaxies.
  - Galactic inflows and outflows.

Dust evolution and uncertainties

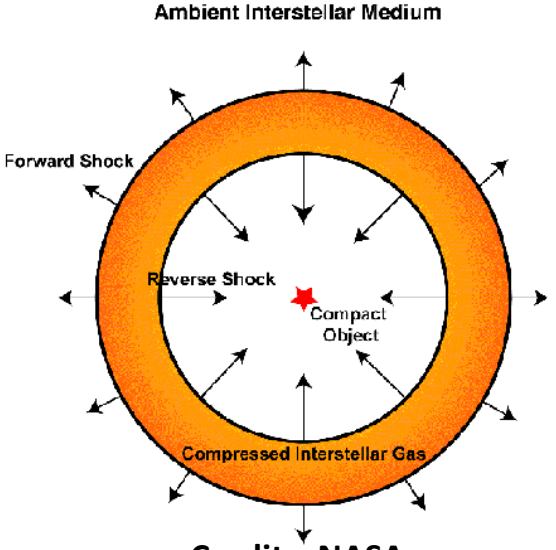
- **Type II SNe → uncertain metal yields, dust production/destruction/reformation** (e.g. Bianchi&Schneider07; Gall+14; Matsuura+19; Slavin+20).

- **Low & intermediate-mass stars: uncertain mass-loss rates, 3rd dredge-up, HBB**

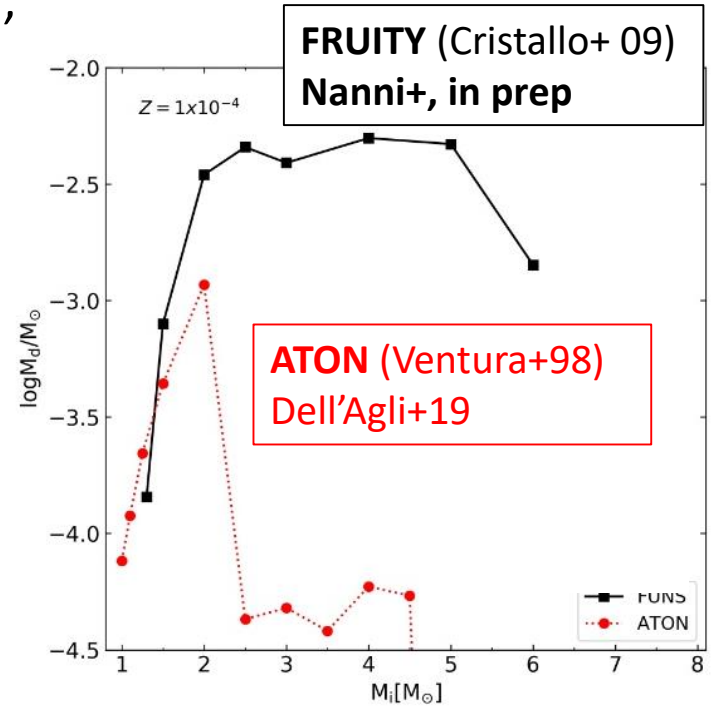
→ **uncertain metal & dust yields** (e.g. Ventura+12; Nanni+13).

- **Grain accretion in the ISM**

→ **uncertain efficiency** (e.g. Asano+13; Zhukowska+16; Priestley+21).



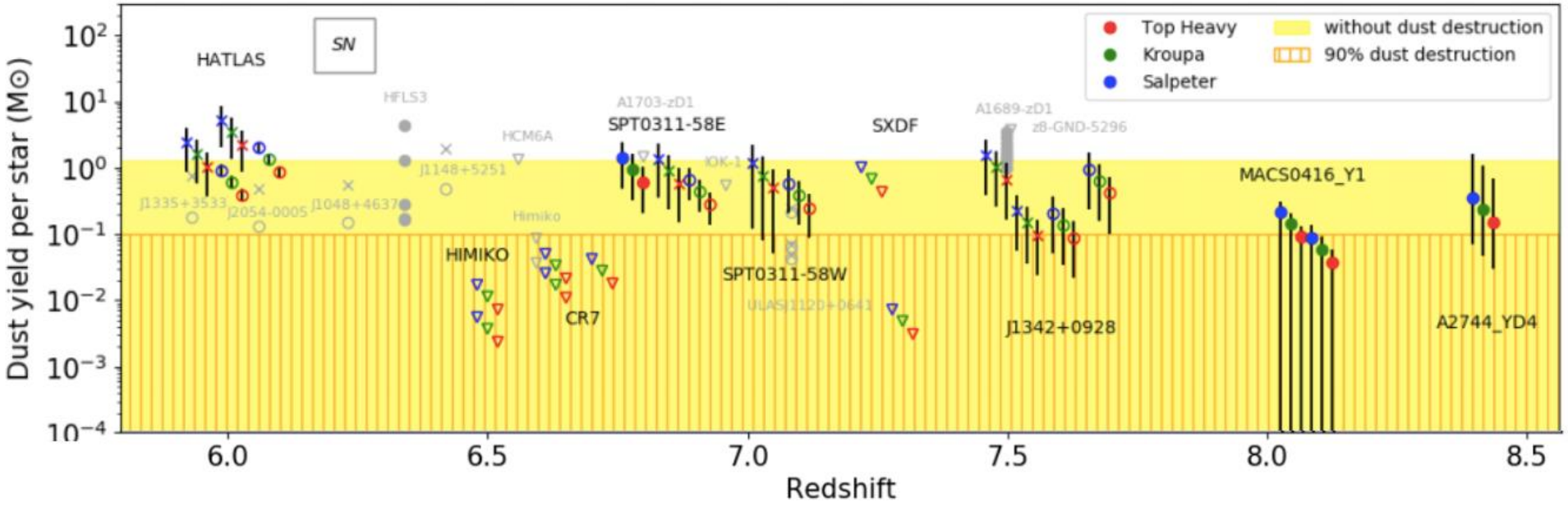
Credits: NASA



1. Are we able to explain the dust content in galaxies?

2. Can we constrain the baryon cycle in galaxies?

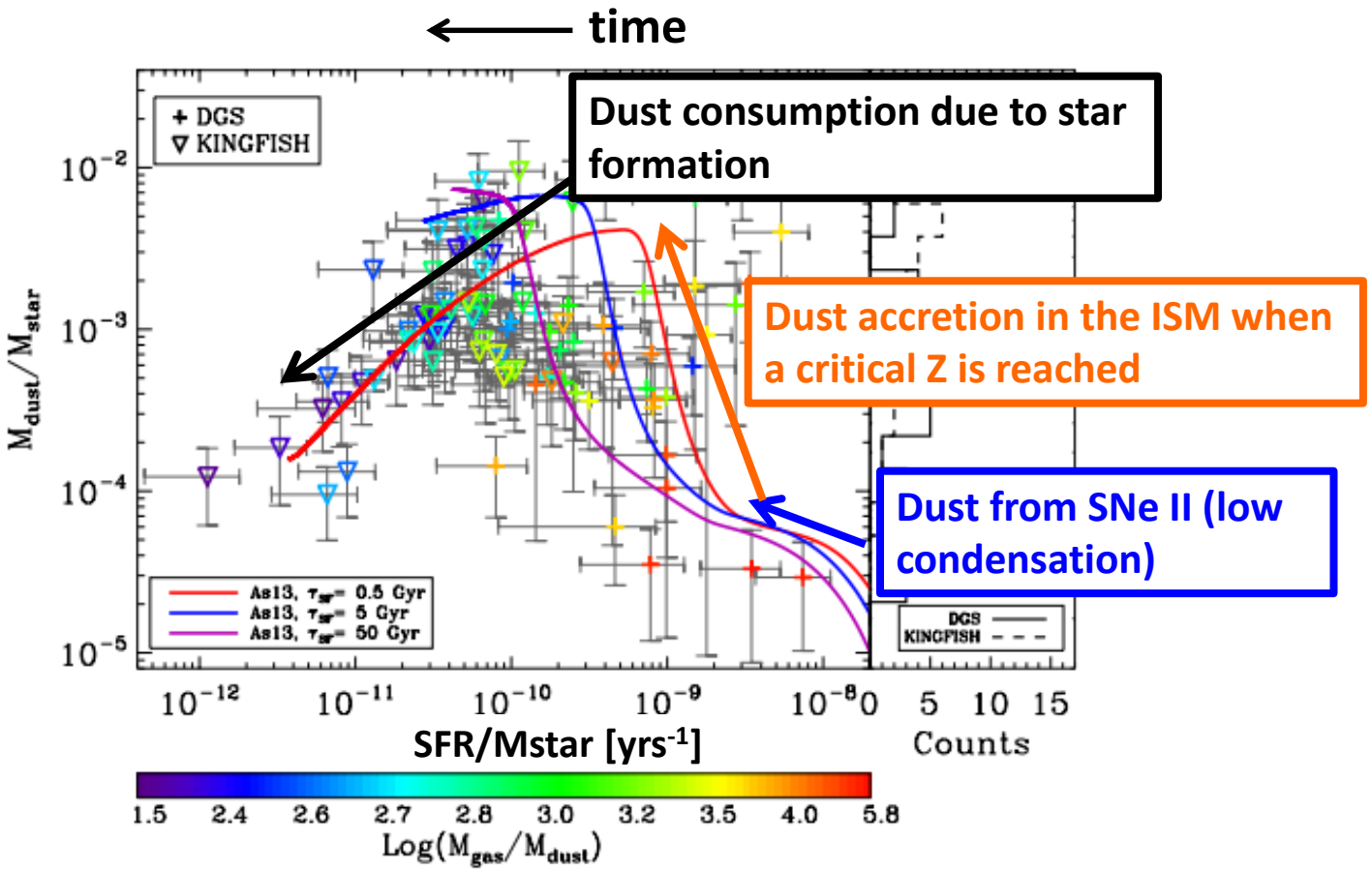
Dust in high redshift galaxies



Leśniewska & Michałowski 2019

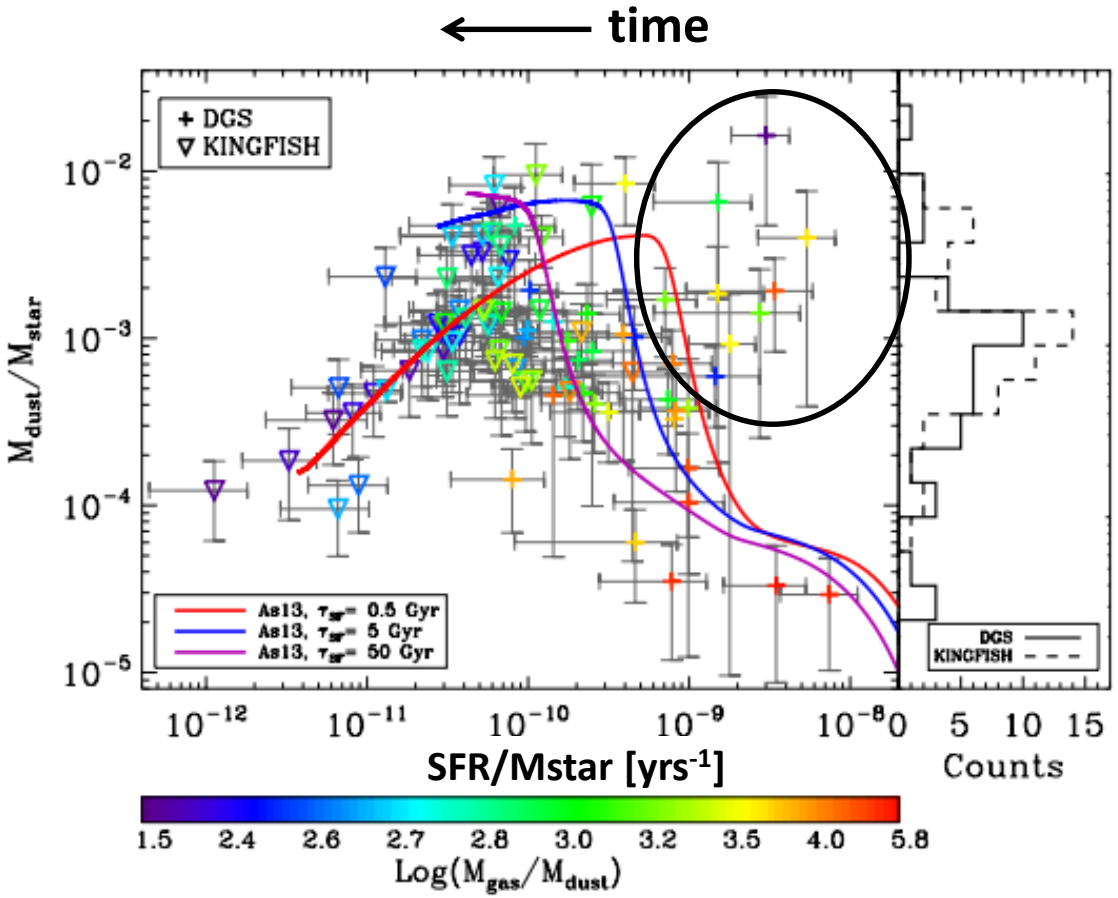
- Dust accretion in the ISM?
- Efficient dust production by SNe?
- Low- and intermediate-mass stars are not efficient enough (plus, they require at least 100 Myrs to evolve).

Dust in local galaxies



Remy-Ruyer+15 (models from Asano+13); see also De Vis+17, +19

Dust evolution and uncertainties: local galaxies



Remy-Ruyer+15 (models from Asano+13); see also De Vis+17; +19; Galliano+21

The largest values of M_{dust}/M_{star} vs SFR/M_{star} are not reproduced!

Constraining baryon evolution in low-Z galaxies

The gas, metal and dust evolution in low-metallicity local and high-redshift galaxies

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Observational and theoretical constraints on the formation and early evolution of the first dust grains in galaxies at 5 < z < 10

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Local and high-z galaxies: available information

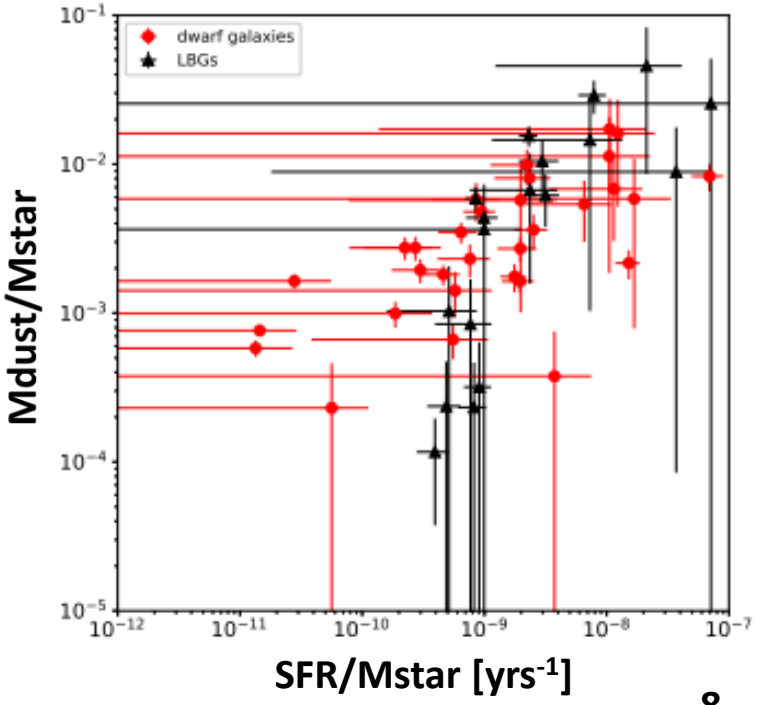
Lyman-Break Galaxies
(Burgarella+20)

Local dwarf galaxies
(Madden+13)

SED fitting
(CIGALE)
Boquien+19

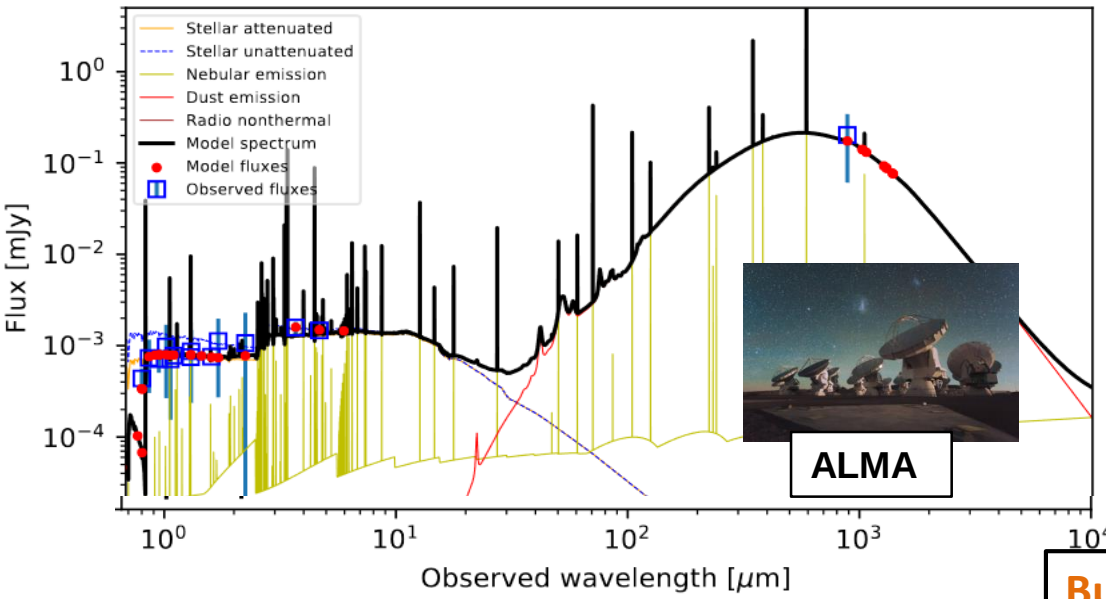
- **Mdust**
- **Mstar**
- **Age**
- **SFR**

- **Metallicity** (Rémy-Ruyer+13)
- **Gas fraction** (Rémy-Ruyer+14)
- **Circumgalactic dust** (McCormick+18)

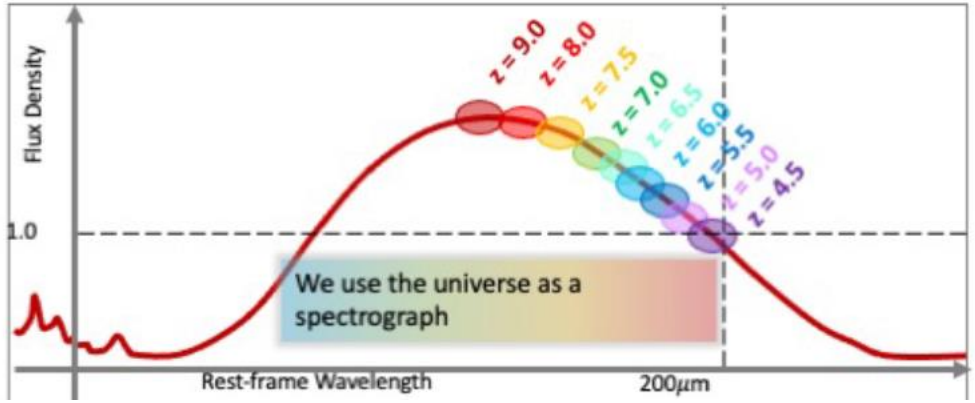


Dust mass estimates for LBGs

LBG

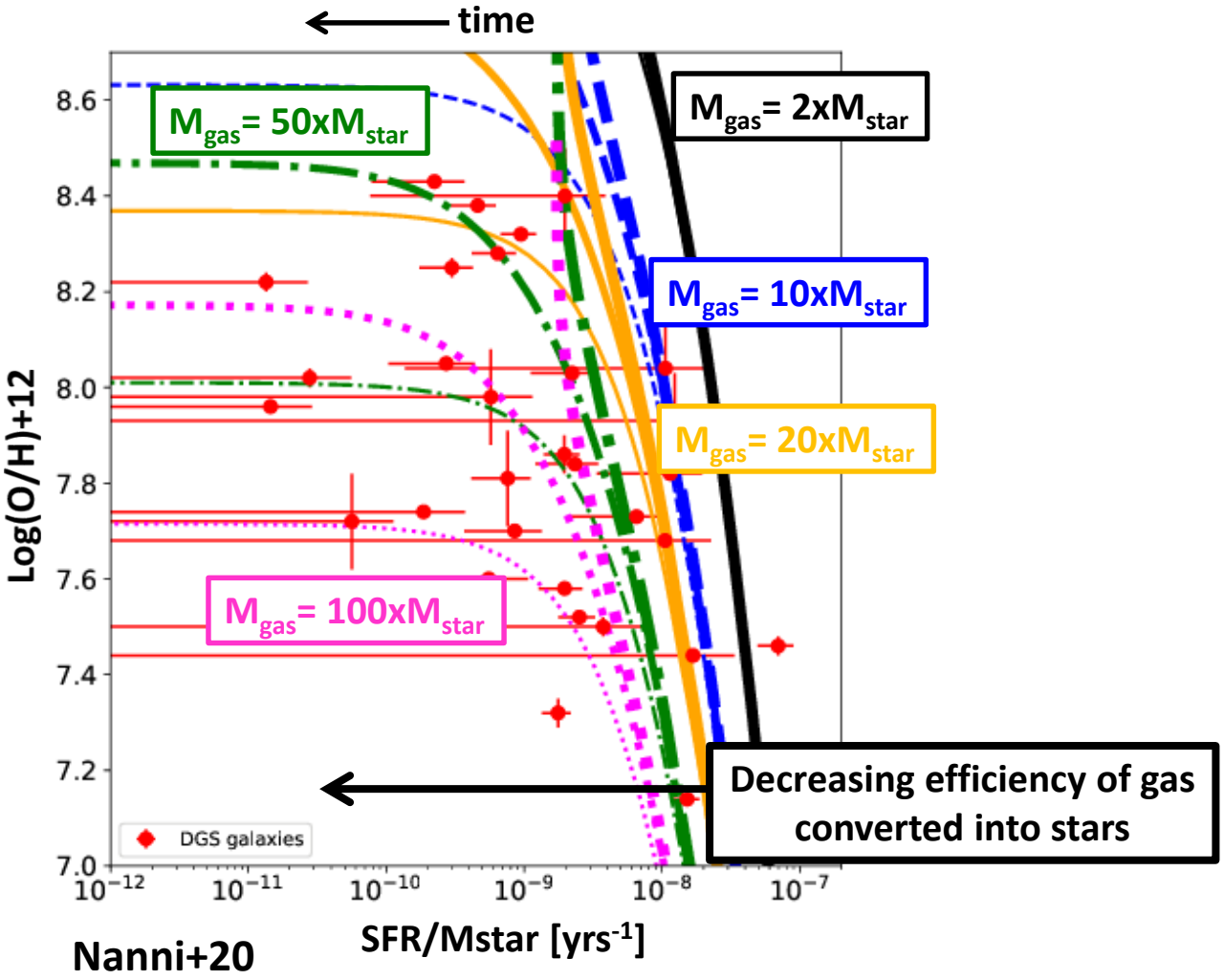


Burgarella, Nanni+20



Burgarella+21

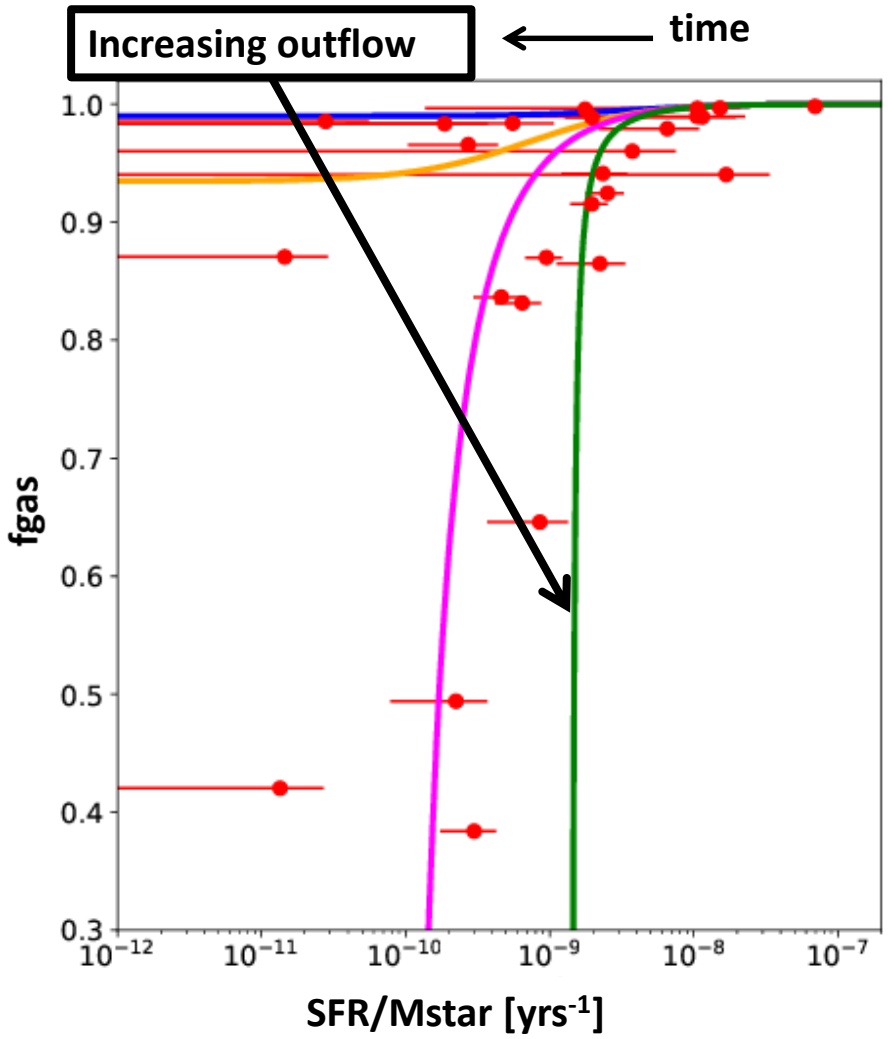
Constraints for local dwarf galaxies: metallicity



Metallicity: provides constraints on the typical **efficiency of gas conversion into stars (~few %).**

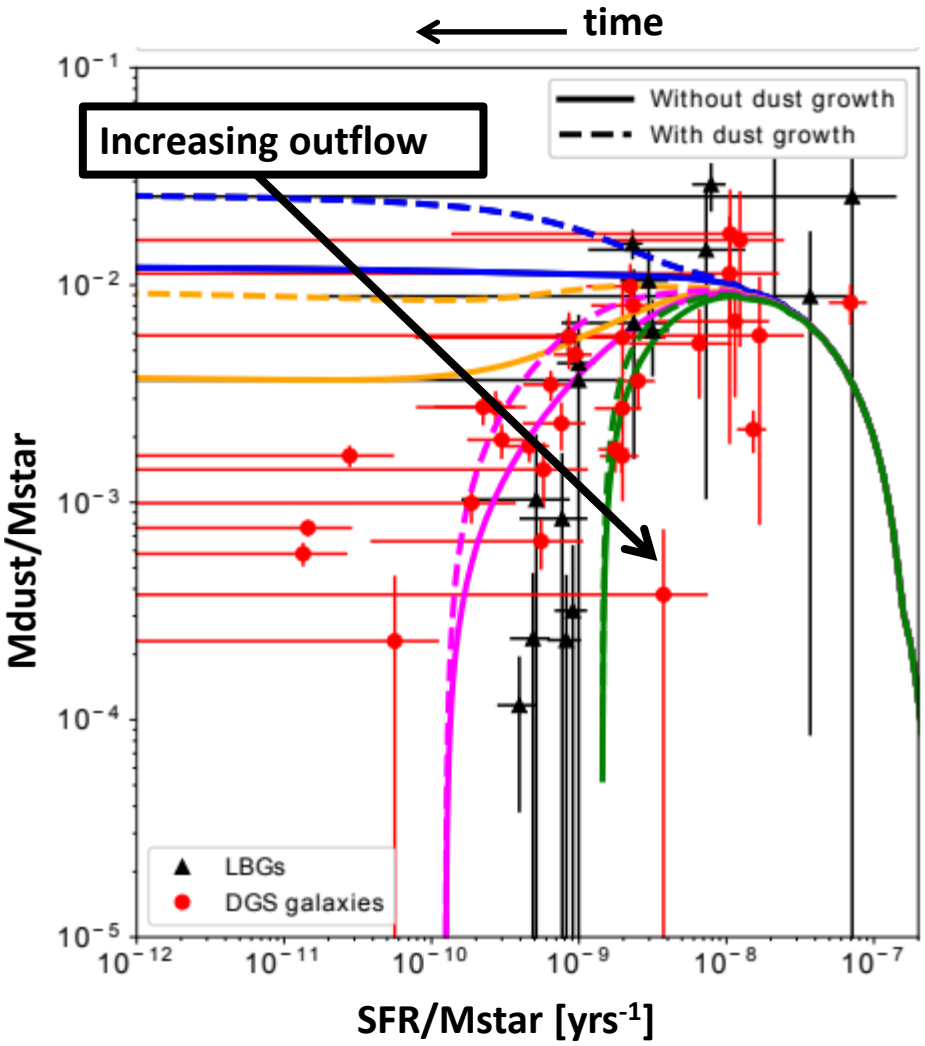
→ Implies low efficiency for dust destruction in the ISM from SNe **(τ_d α M_{gas}/M_{swept})**.

Constraints for local dwarf galaxies: gas fraction



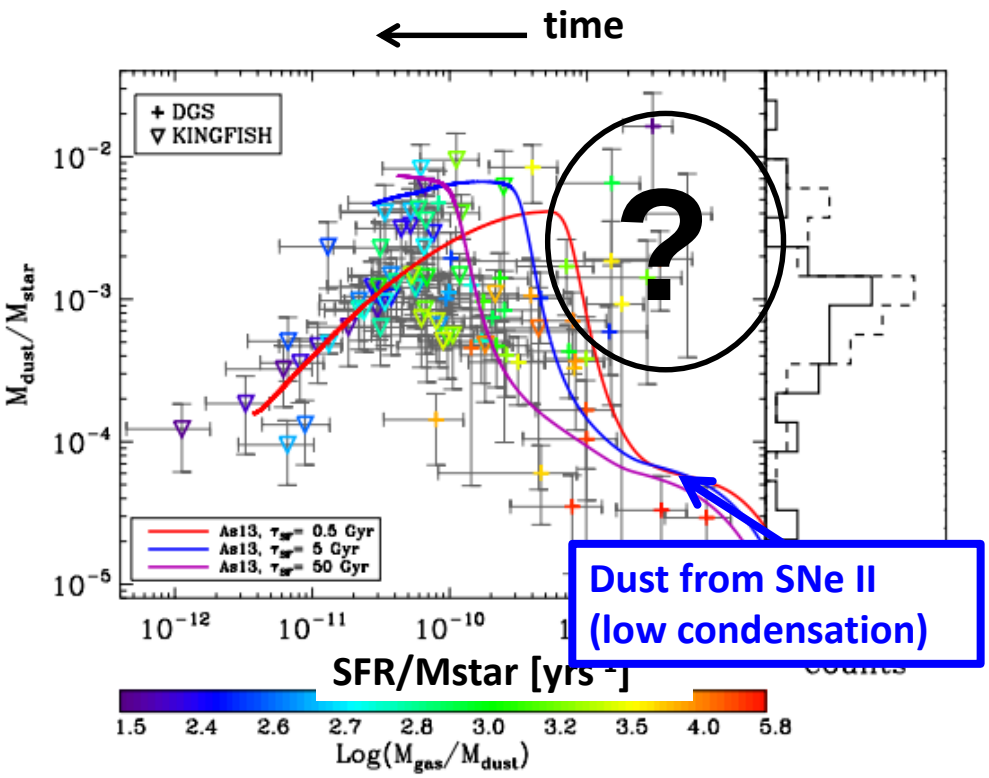
- Galactic outflow is needed to reproduce the gas fraction if the star formation efficiency is low.
- Not enough decrease of the gas content by star formation alone.

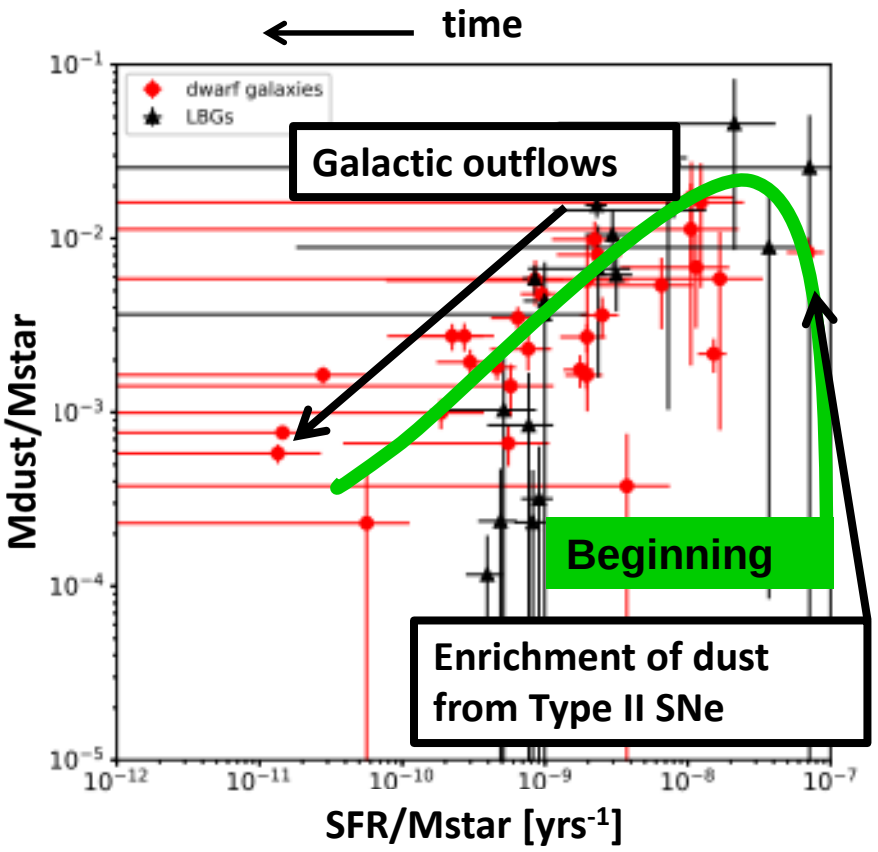
Constraints for local dwarf & high-z galaxies: dust



- **The model assumptions for local dwarf galaxies are employed to study LBGs.**
- **Dust accretion in the ISM is not necessary to reproduce the observations of these galaxies.**

How to get large mass of dust «early» enough?





Remy-Ruyer+15 (models from Asano+13)

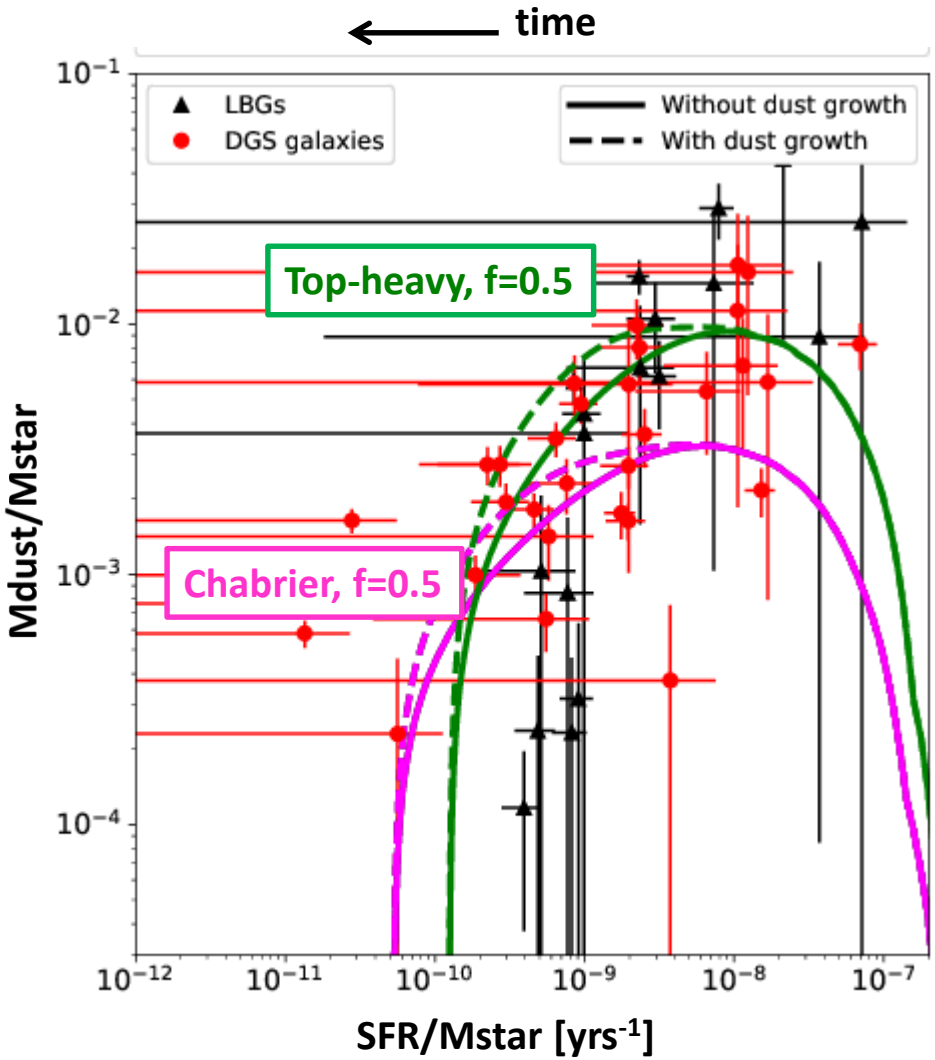
→ **Too low dust at the beginning of the baryon cycle.**

→ **We need to "change the trajectory" of the dust evolution model.**

→ **A lot of metal and dust from Type II SNe is needed!**

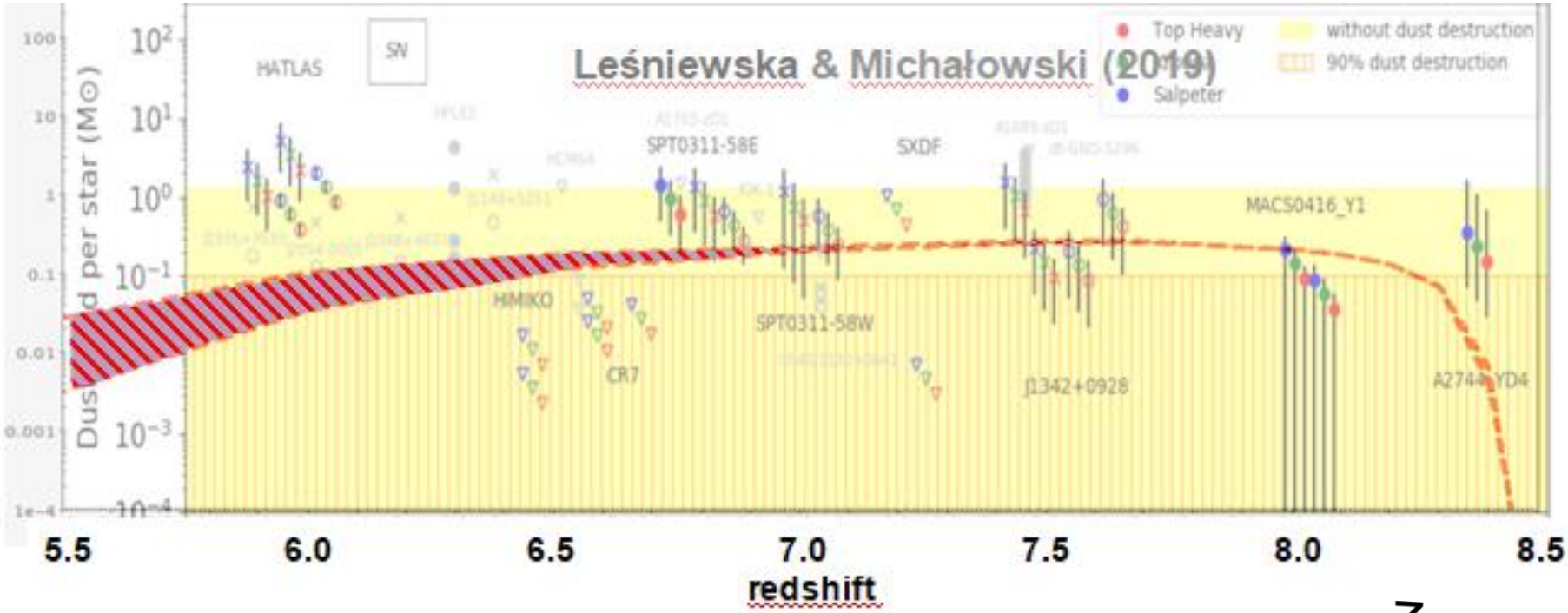
→ **Given the low efficiency of SNe destruction for grains in the ISM, we need the outflow to efficiently remove dust.**

Initial mass function & dust condensation fraction



- Top-heavy IMF helps to reproduce the observations.
- Condensation fraction ~50% (see also De Looze+2020).
- Low contribution from low- and intermediate mass stars.
- A large gas mass helps to reduce dust destruction from SNe.

Dust in the early Universe?



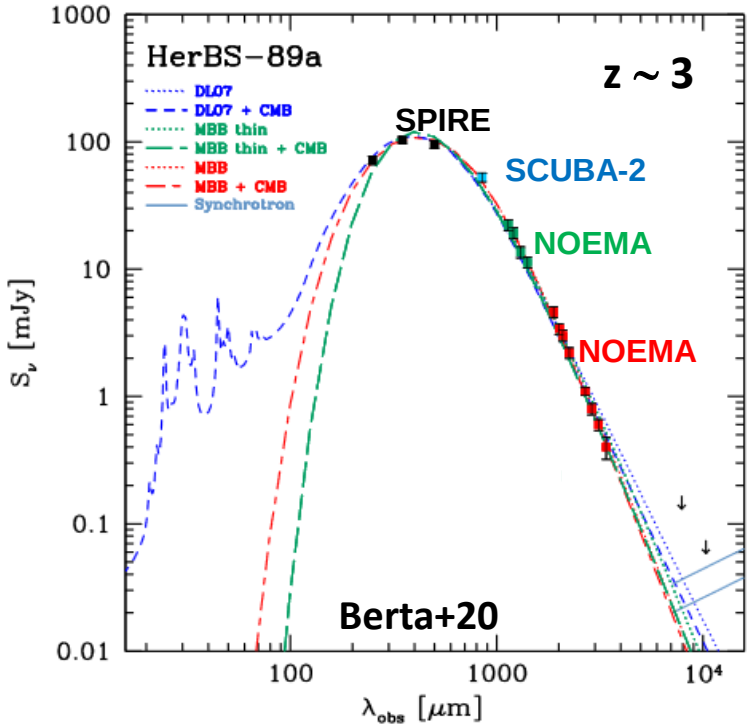
Curtesy of Denis Burgarella

$z_{formation}$

Future plans

- **Observationally constrain the outflow of local dwarf galaxies** (Romano+, in prep)

- **z-GAL NOEMA Large Program**, Herschel-selected high-z luminous galaxies (PI: Pierre Cox, IAP)



- **JWST:**
  - constraints of the metallicity for LBGs at z ~ 7
  - constraints on the mid-IR (PAH emission) for galaxies at z ~ 3

Conclusions

In order to reproduce different observations of low-Z galaxies we need:

- **A low efficiency of gas converted into stars** (~few%) to reproduce the metallicity of local galaxies.
- **An efficient outflow** to reproduce the decrease of the gas fraction of local galaxies and the dust content of local and high-z galaxies.
- **A top-heavy IMF & high dust condensation (~ 50%) favours a fast enrichment of metals and dust**.
- **Dust accretion in the ISM is not strictly** required to reproduce the observations.