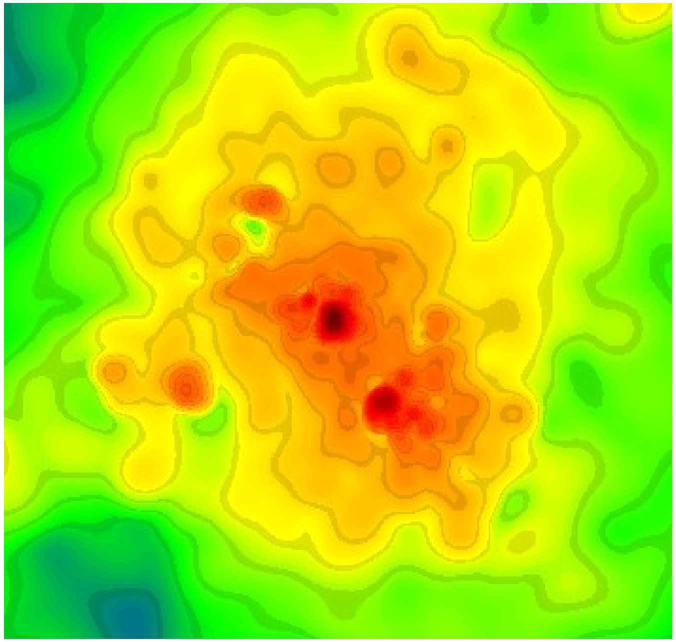
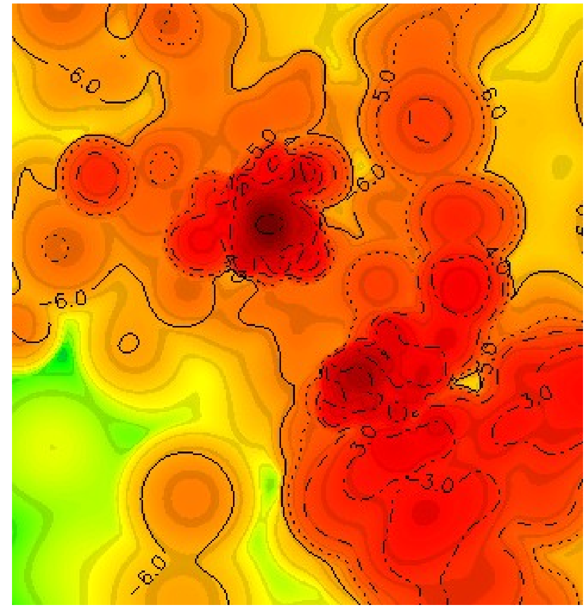
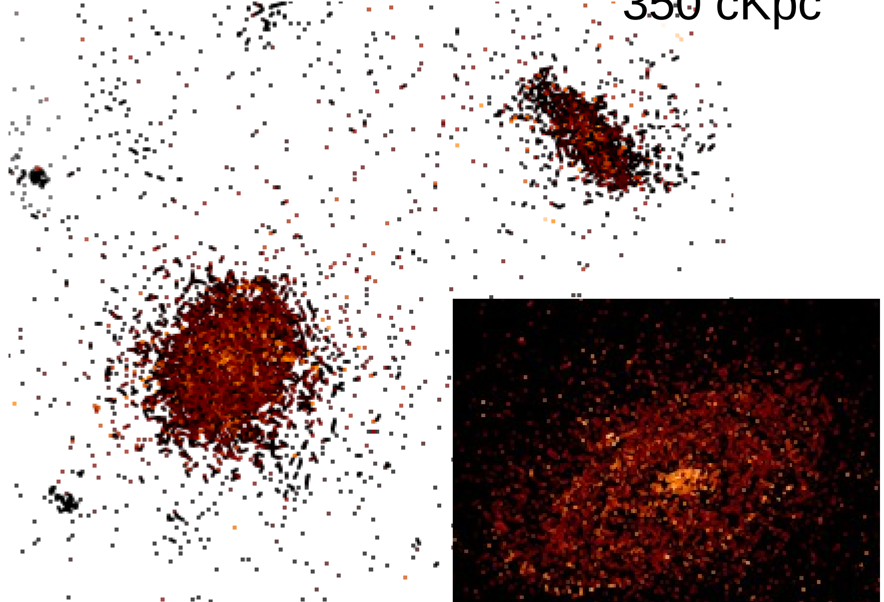
The assembly of dusty galaxies at z > 4





350 cKpc

700 cKpc



Luca Graziani

In collaboration with:

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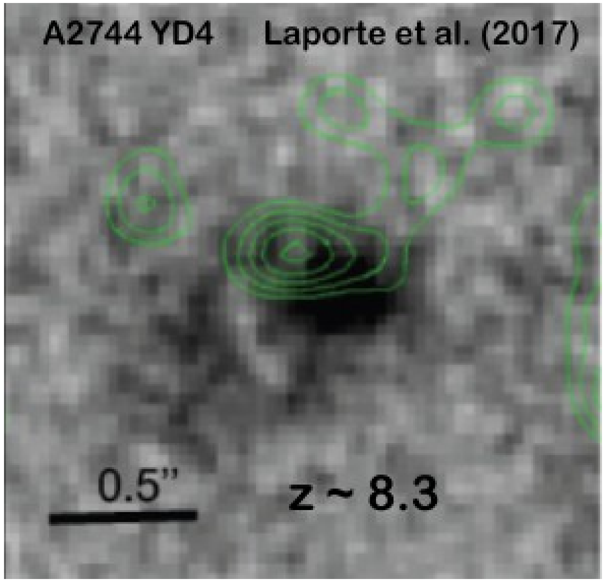
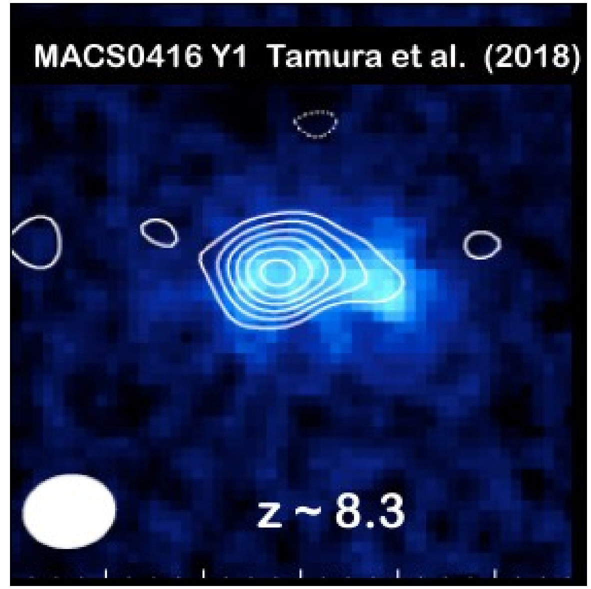
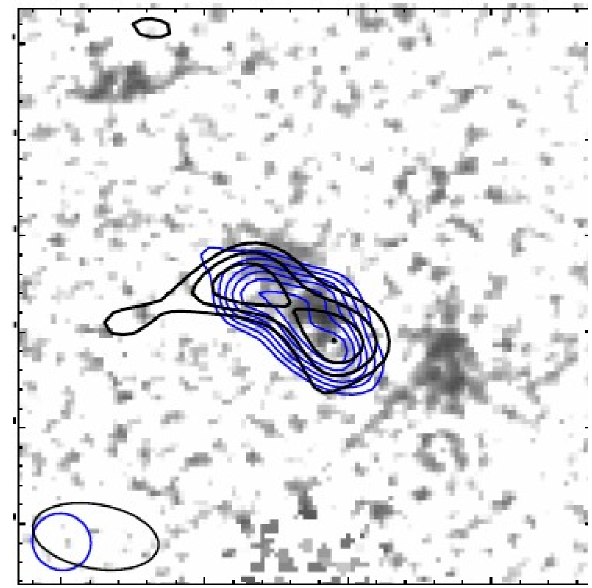
INFN ROMA Istituto Nazionale di Fisica Nucleare Sezione di Roma

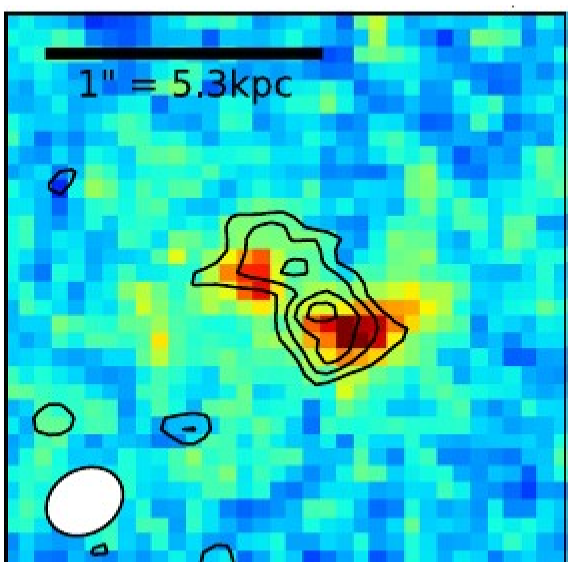
1st Moscow International Conference on mm/submm Astronomy, 12-16 April 2021, Online

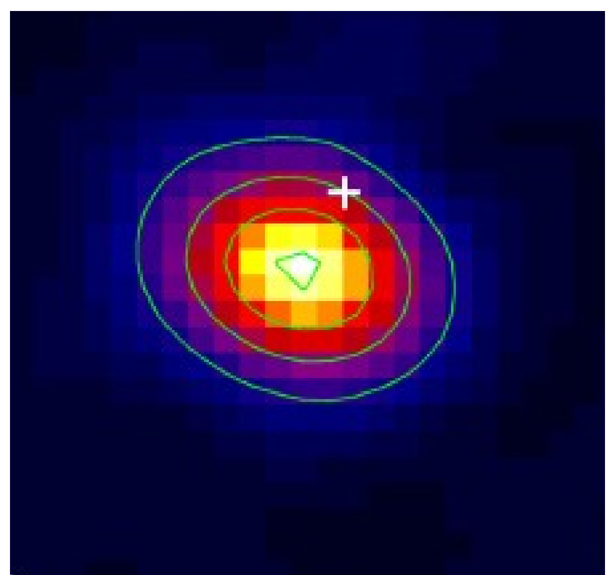


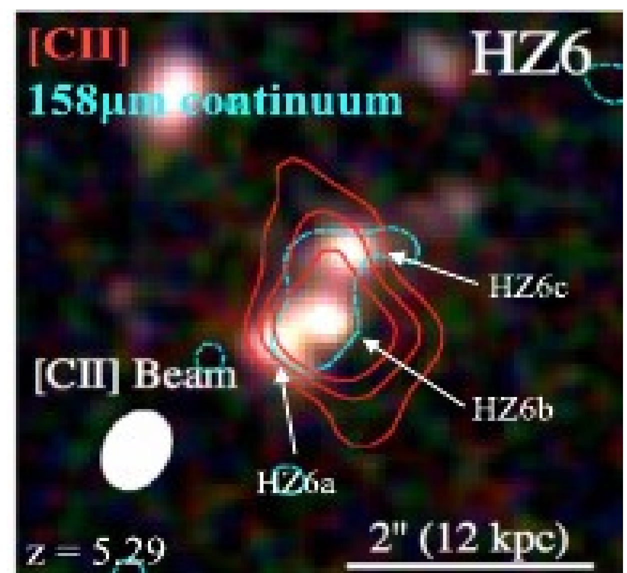




Part I: High-z dusty galaxies

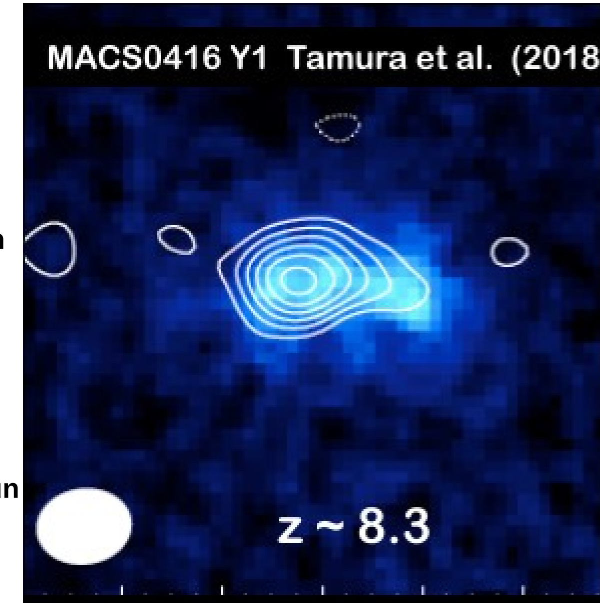






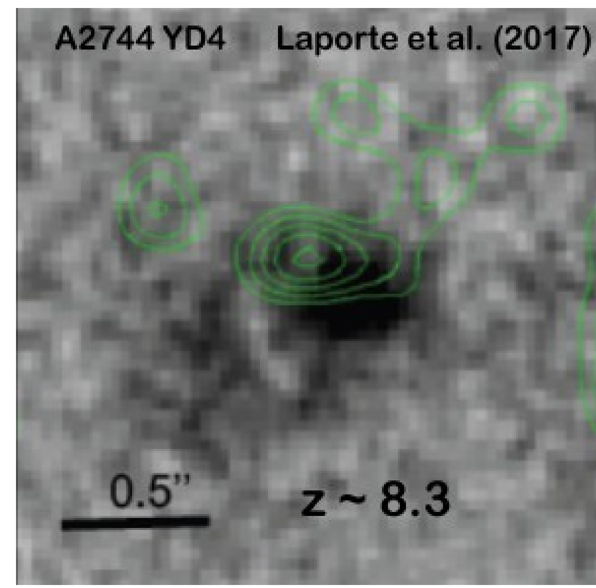
Signals from **dusty** galaxies in the EoR

- **Watson: z~7.5, M_d~ 10^7 M_{sun}, SFR~10 M_{sun}/yr, M_*~2 10^9 M_{sun}**
- **Laporte: z~8.3, M_d~6 10^6 M_{sun}, SFR~ 20 M_{sun}/yr, M_*~2 10^9 M_{sun}**
- **Tamura: z~8.3, M_d~4 10^6 M_{sun}, SFR~13 M_{sun}/yr, M_*~5 10^9 M_{sun}**
- **Tamura: z~9.11, M_d < 5 10^5 M_{sun}, SFR~13 M_{sun}/yr, M_*~ 10^9 M_{sun}**



Tamura et al. 2019

- **Does the dust evolution follow the stellar mass assembly?**
- **Effect of different assembly history?**
- **Dust evolution as a tracer of ISM evolution?**
- **Cold/Warm/Hot → T_d?**



Laporte et al., 2017

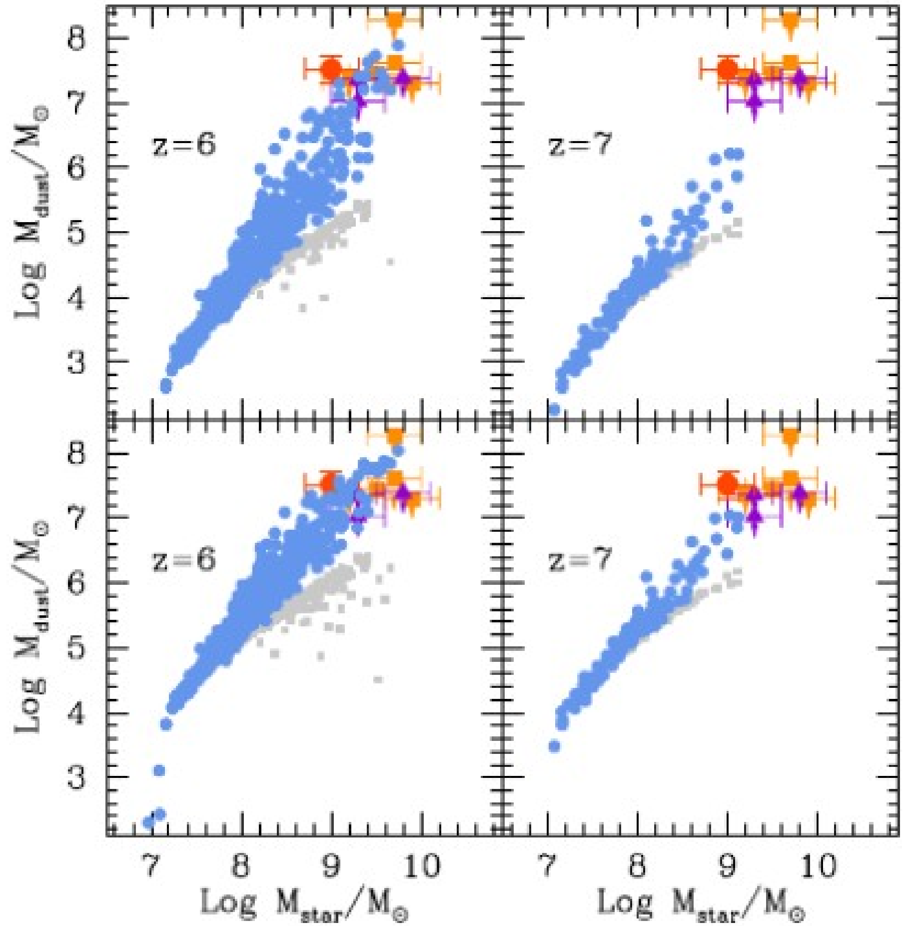
Interplay between feedback processes

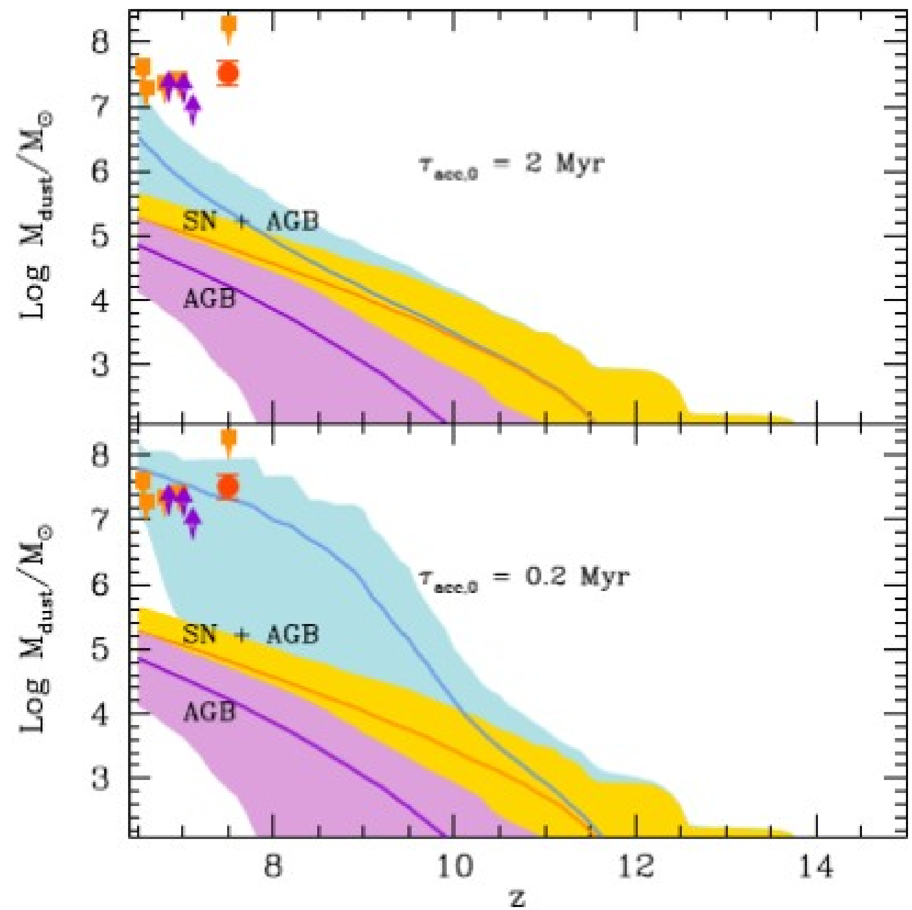
required to understand these galaxies as they assemble

→ Impact on reionization?

Simulating a high-z dusty Galaxy with semi-numerical models

Establish the right mass of dust by coupling simulations (Maio 2010) and SAM (Valiante 2007).





Mancini, Schneider, LG, et al., MNRAS 2015

Observed galaxies from **Schaerer** et al. (**2015**, squares), **Maiolino** et al. (**2015**, triangles) and **Watson** et al.(**2015**, circle point). Simulated galaxies with dust production and Evolution (blue points). Dust production only by SNI and AGB stars (gray points).

Strong assumptions on the evolution Timescales (mainly for grain growth) are required by SAM to match the observed Mass of dust. What is missing here? Assembly effect? Wrong Yields? Statistics?

Simulating high-z dusty galaxies with dustyGadget

$$\dot{M}_{\rm d} = -{\rm SFR}(t)\,\mathcal{D}_{\rm c} + \frac{x_{\rm c} M_{\rm d}}{\tau_{\rm gg}} - (1-x_{\rm c}) M_{\rm d}\left(\frac{1}{\tau_{\rm d}} + \frac{3}{\tau_{\rm sp}}\right) + \dot{Y}_{\rm d}(t).$$

Dust production and evolution simulated consistently with atomic metals in a 2-phase SPH, star-forming particles.

- **DETAILED STELLAR EVOLUTION**: (Tornatore 2007): **SNIa**, **SNII**, **AGB.**
  → Separate Stellar populations Pop III/Pop II can be followed and IMF assigned.
  → Precise stellar ages t_* , metallicity Z_* in stellar particles (Padovani&Matteucci, 1993).

- **METAL/DUST ENRICHMENT:** Tornatore 2007 + dust: **POP III**, **SNII,AGB**
  → Yields for both POPIII and POPII stars (Bianchi&Schneider 2007, Marassi et al., 2019).

- **DUST ASTRATION + GRAIN GROWTH + DUST DESTRUCTION + GRAIN SPUTTERING**
  Folllowed in each star-forming SPH particle.

  → time scales are modeled as environment dependent

.

x T_d requires assumptions
x mass resolution still a limit in cosmological simulations

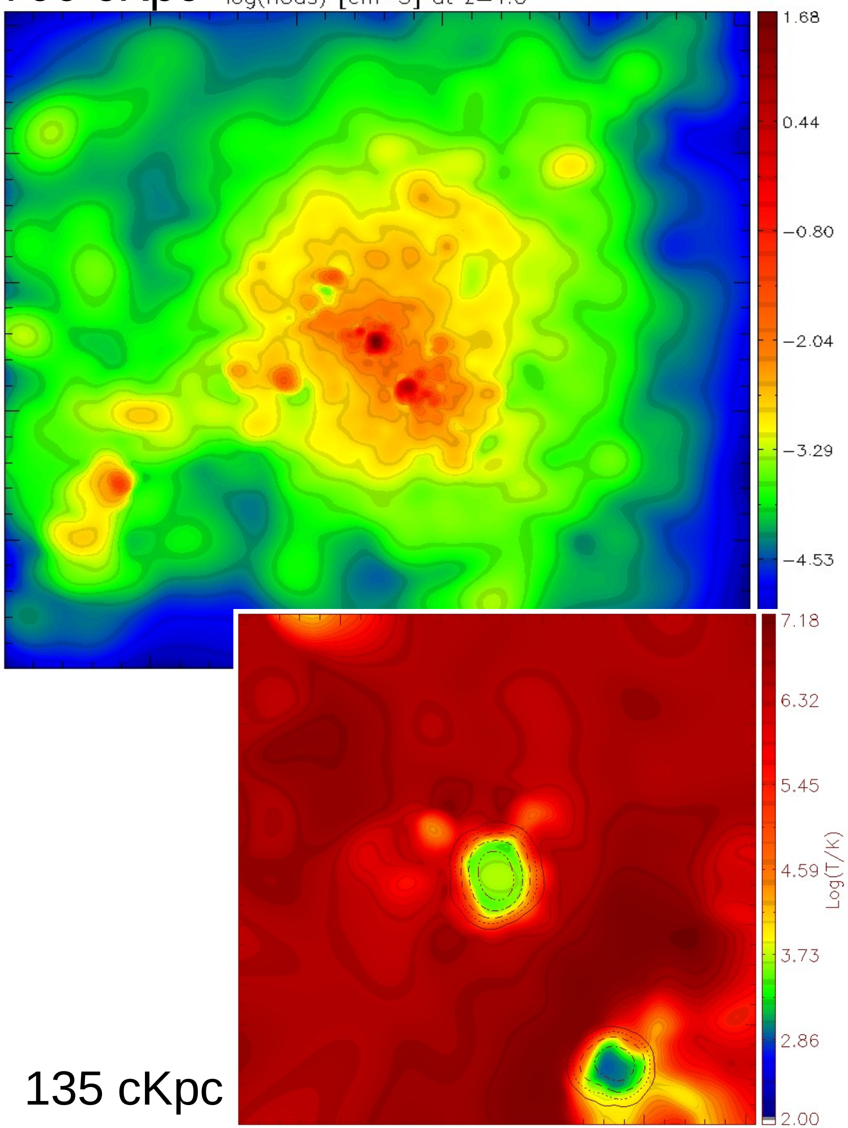
Processes regulating dust assembly are environment dependent !

LG, Schneider R., Ginolfi M., Hunt L. et al., MNRAS, 2020

Simulating high-z dusty galaxies with **dustyGadget**

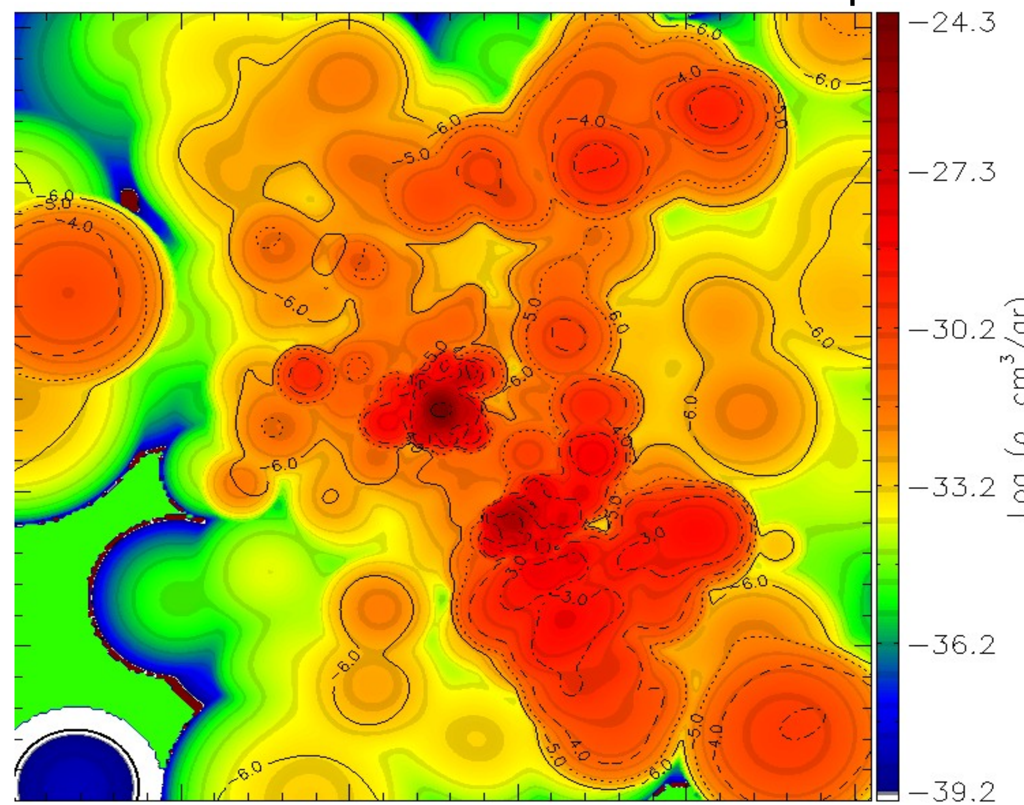
Dust production and evolution consistent with atomic metals in many galactic and extra-galactic environments.

700 cKpc



135 cKpc

350 cKpc

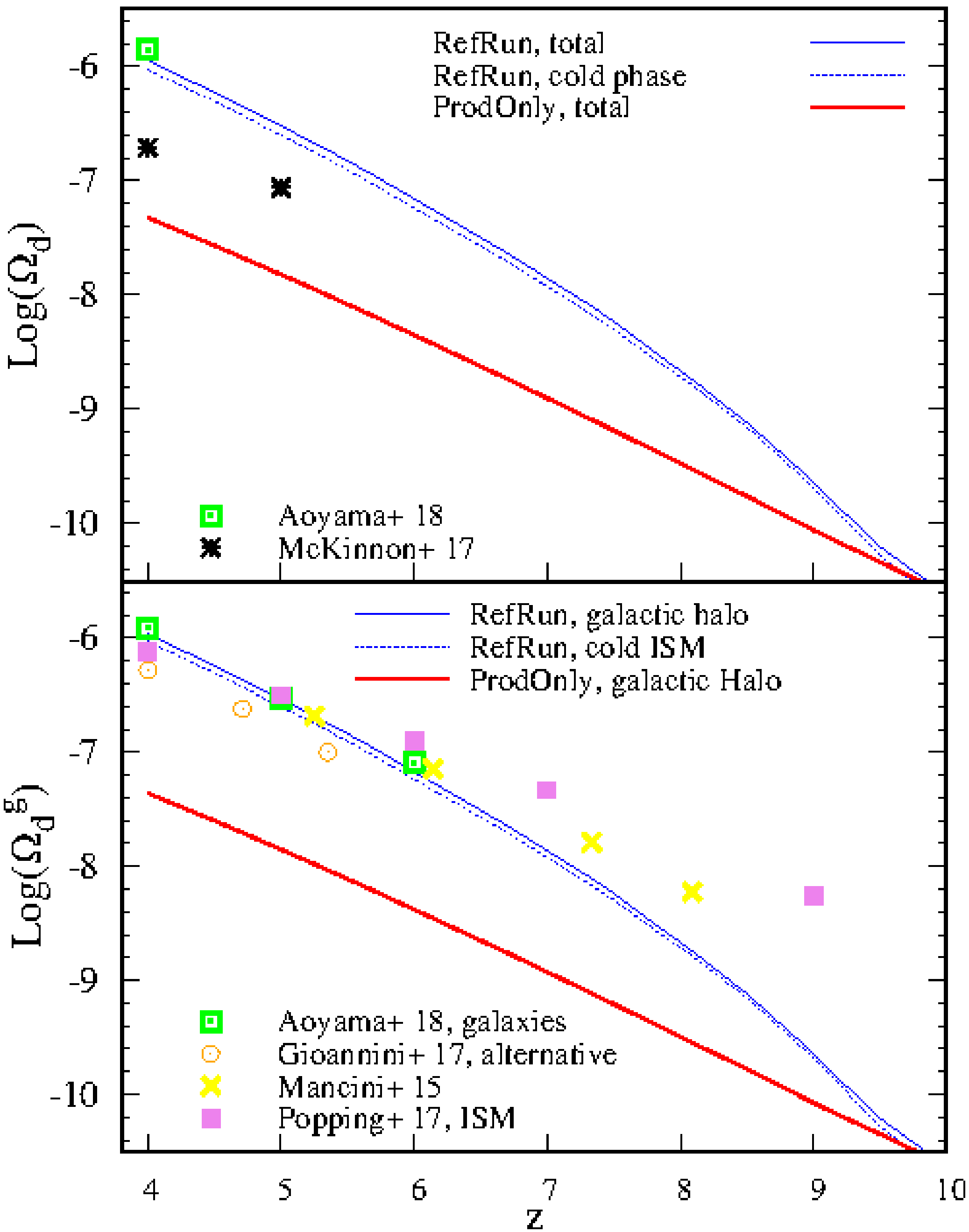


3D pattern of dust pollution shaped by winds **galaxies → CGM → IGM**.

LG, Schneider R., Ginolfi M., Hunt L. et al., MNRAS, 2020

Large scale environments show dust pollution

Statistical properties of simulated sample: $\Omega_d(z) \equiv \rho_d(z)/\rho_c, 0.$



Z > 9 Dust Mass → stellar origin

Z < 9 Dust Mass → ISM grain growth

Z ~ 4 Dust Mass in the volume agrees
With other SPH implementations.

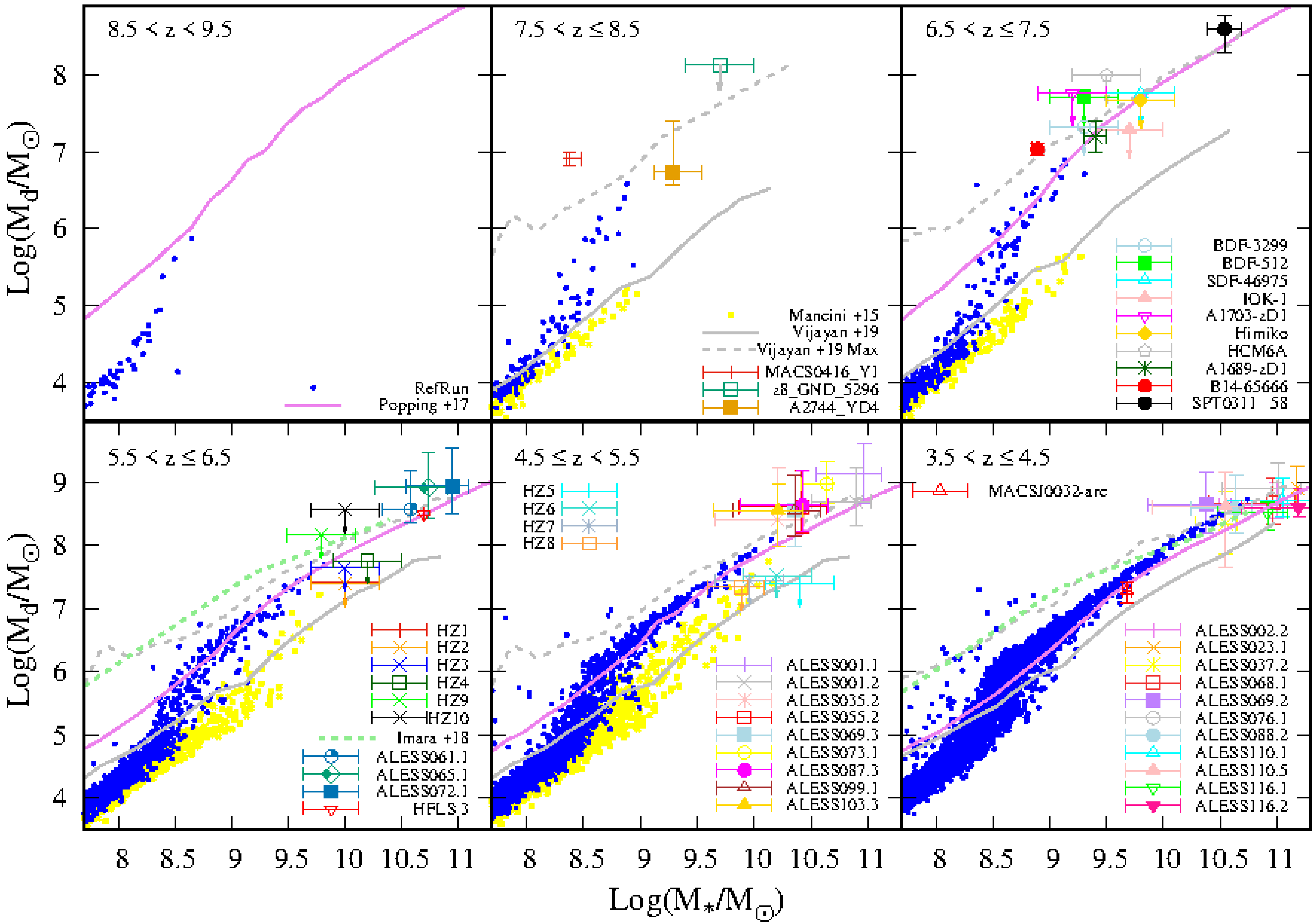
Z < 6 Dust Mass in galaxies agrees with
Both numerical and SAM models

Z > 7 Dust Mass in galaxies disagrees
Because of differences in process
Efficiencies and stellar yields

This is an integrated quantity.. across galaxy populations!

LG, Schneider R., Ginolfi M., Hunt L. et al., MNRAS, 2020

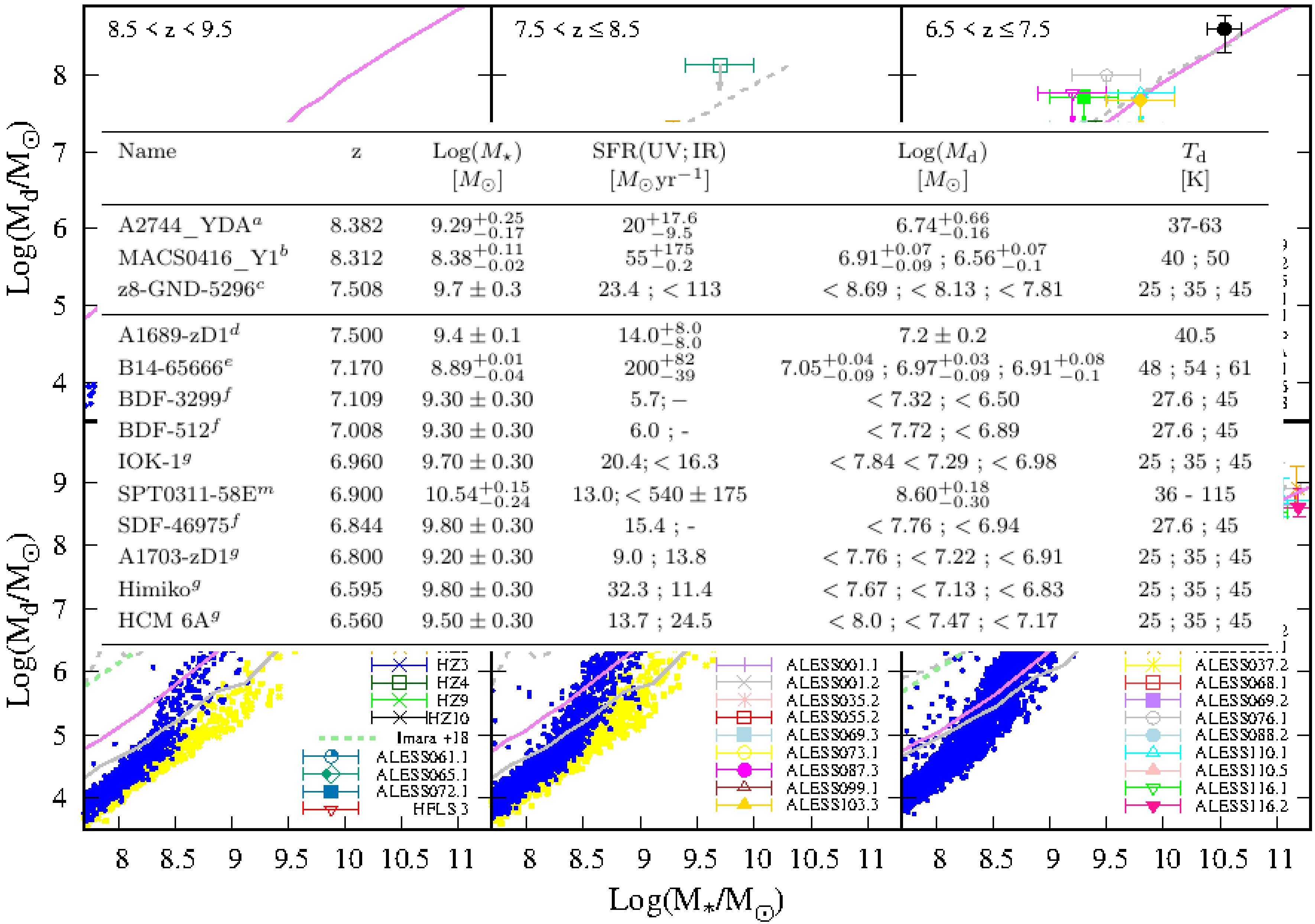
Statistical properties of simulated sample: $M_d(M_*)$



LG, Schneider R., Ginolfi M., Hunt L. et al., MNRAS, 2020

Correct environment → Agreement with $t_{gg,0}$ ~ 2 Myr

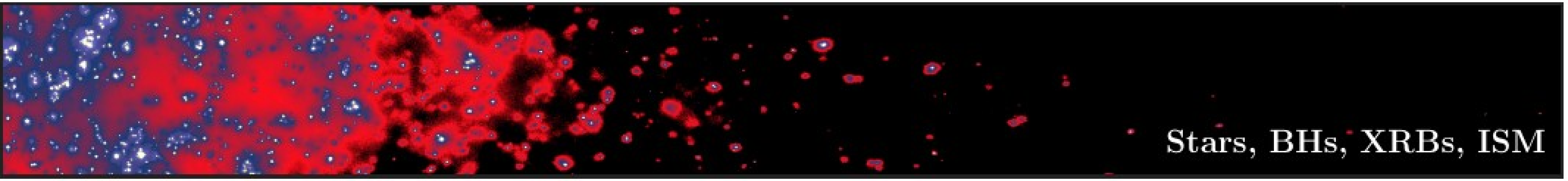
Statistical properties of simulated sample: $M_d(M_*)$



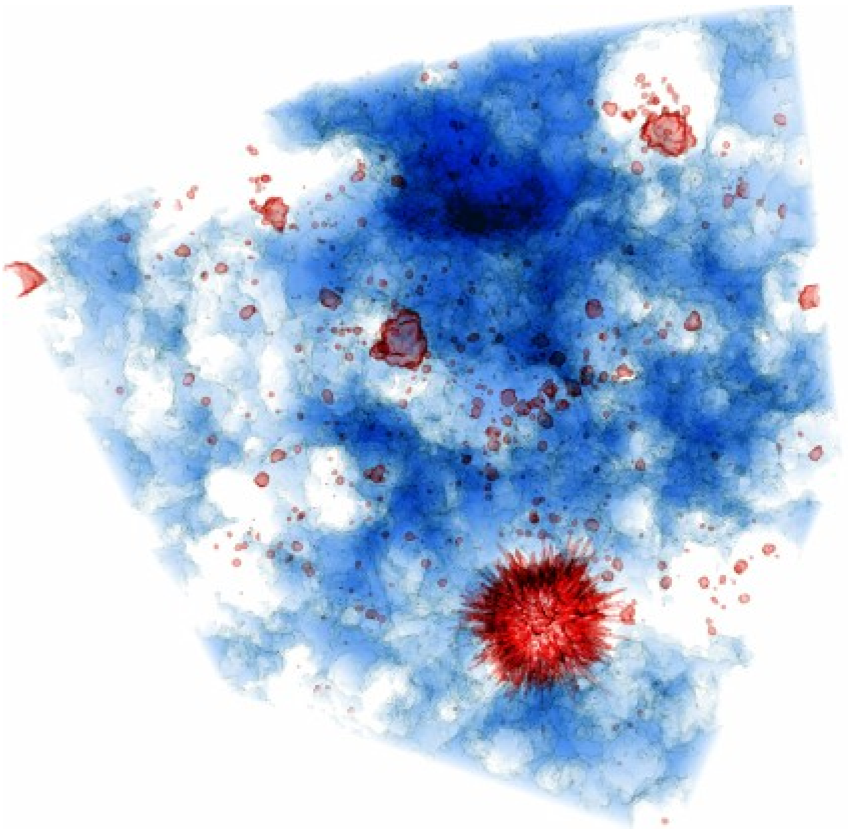
Name	z	$\log(M_\star)$ $[M_\odot]$	SFR(UV; IR) $[M_\odot \mathrm{yr}^{-1}]$	$\log(M_d)$ $[M_\odot]$	T_d [K]
A2744_YDA[a]	8.382	$9.29^{+0.25}_{-0.17}$	$20^{+17.6}_{-9.5}$	$6.74^{+0.66}_{-0.16}$	37-63
MACS0416_Y1[b]	8.312	$8.38^{+0.11}_{-0.02}$	$55^{+175}_{-0.2}$	$6.91^{+0.07}_{-0.09}$; $6.56^{+0.07}_{-0.1}$	40 ; 50
z8-GND-5296[c]	7.508	9.7 ± 0.3	23.4 ; < 113	< 8.69 ; < 8.13 ; < 7.81	25 ; 35 ; 45
A1689-zD1[d]	7.500	9.4 ± 0.1	$14.0^{+8.0}_{-8.0}$	7.2 ± 0.2	40.5
B14-65666[e]	7.170	$8.89^{+0.01}_{-0.04}$	200^{+82}_{-39}	$7.05^{+0.04}_{-0.09}$; $6.97^{+0.03}_{-0.09}$; $6.91^{+0.08}_{-0.1}$	48 ; 54 ; 61
BDF-3299[f]	7.109	9.30 ± 0.30	5.7; –	< 7.32 ; < 6.50	27.6 ; 45
BDF-512[f]	7.008	9.30 ± 0.30	6.0 ; -	< 7.72 ; < 6.89	27.6 ; 45
IOK-1[g]	6.960	9.70 ± 0.30	20.4; < 16.3	< 7.84 < 7.29 ; < 6.98	25 ; 35 ; 45
SPT0311-58E[m]	6.900	$10.54^{+0.15}_{-0.24}$	13.0; < 540 ± 175	$8.60^{+0.18}_{-0.30}$	36 - 115
SDF-46975[f]	6.844	9.80 ± 0.30	15.4 ; -	< 7.76 ; < 6.94	27.6 ; 45
A1703-zD1[g]	6.800	9.20 ± 0.30	9.0 ; 13.8	< 7.76 ; < 7.22 ; < 6.91	25 ; 35 ; 45
Himiko[g]	6.595	9.80 ± 0.30	32.3 ; 11.4	< 7.67 ; < 7.13 ; < 6.83	25 ; 35 ; 45
HCM 6A[g]	6.560	9.50 ± 0.30	13.7 ; 24.5	< 8.0 ; < 7.47 ; < 7.17	25 ; 35 ; 45

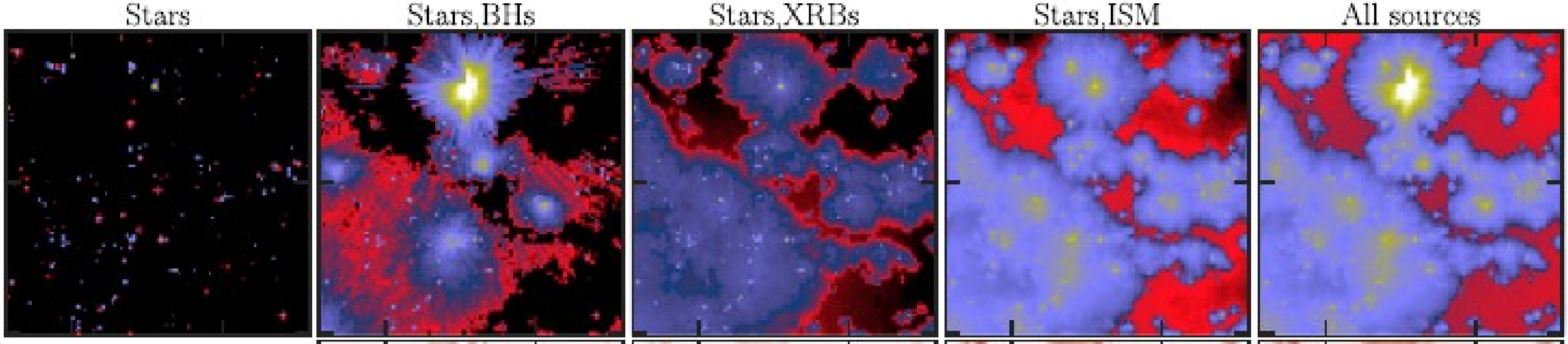
LG, Schneider R., Ginolfi M., Hunt L. et al., MNRAS, 2020

Dust masses are inferred → T_d is a critical !



Part II:
High-z dusty galaxies as sources of Cosmic Reionization

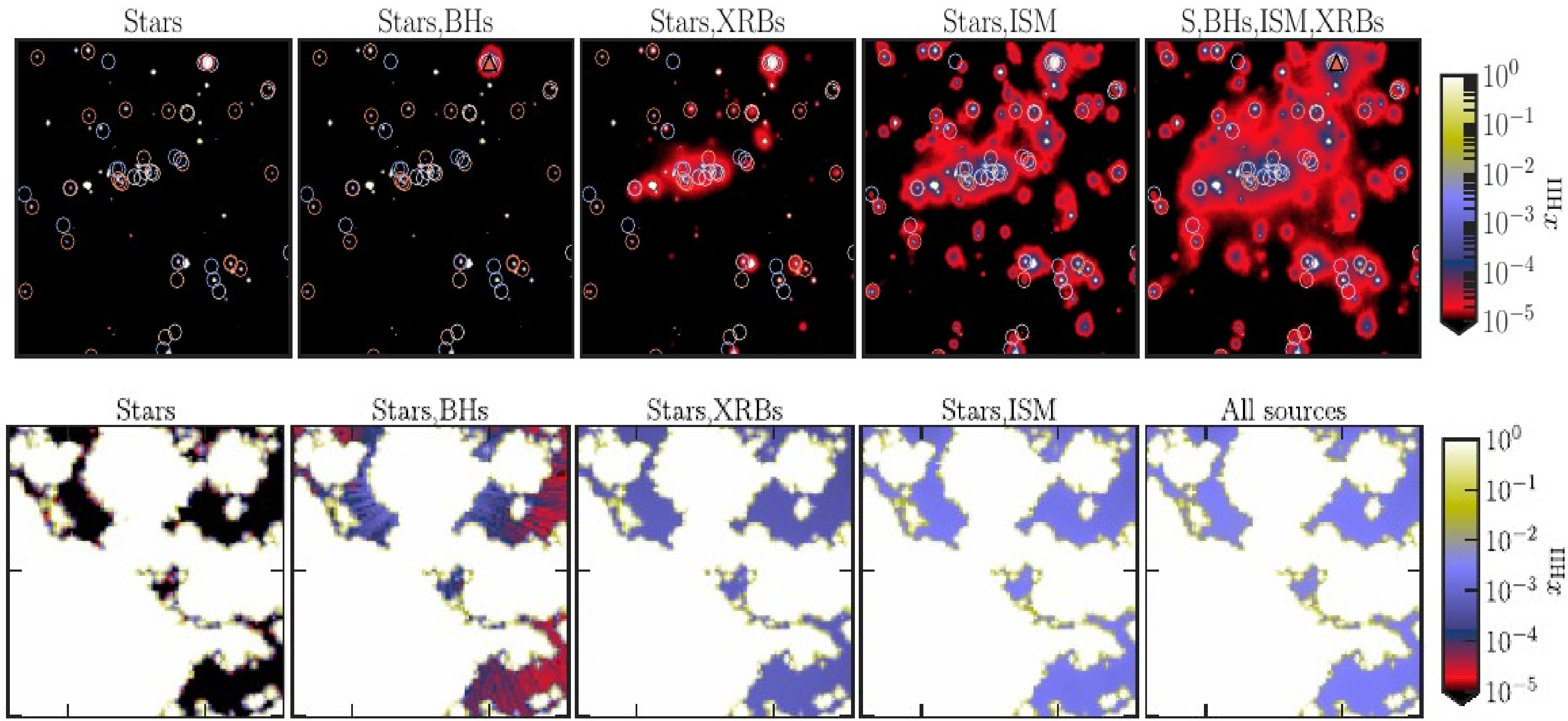




Understanding sources of H Reionization: ↔ escape fraction

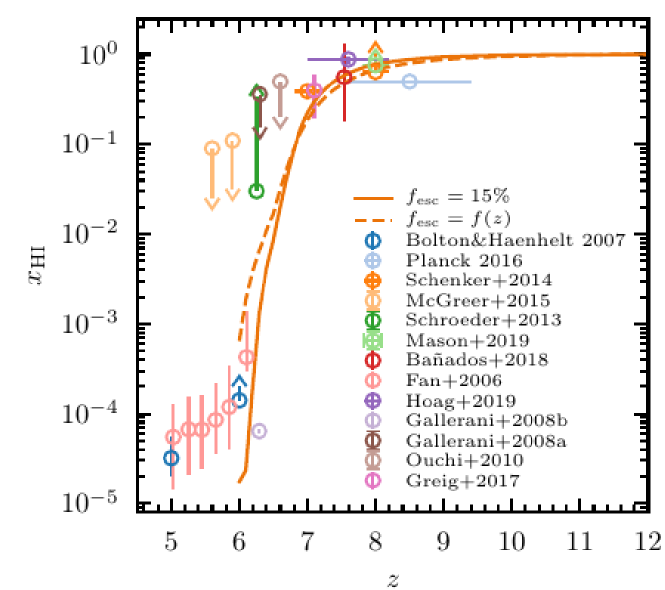
z~12

z~7.5



Eide M., LG/Ciardi B et al., MNRAS 2018, 2020

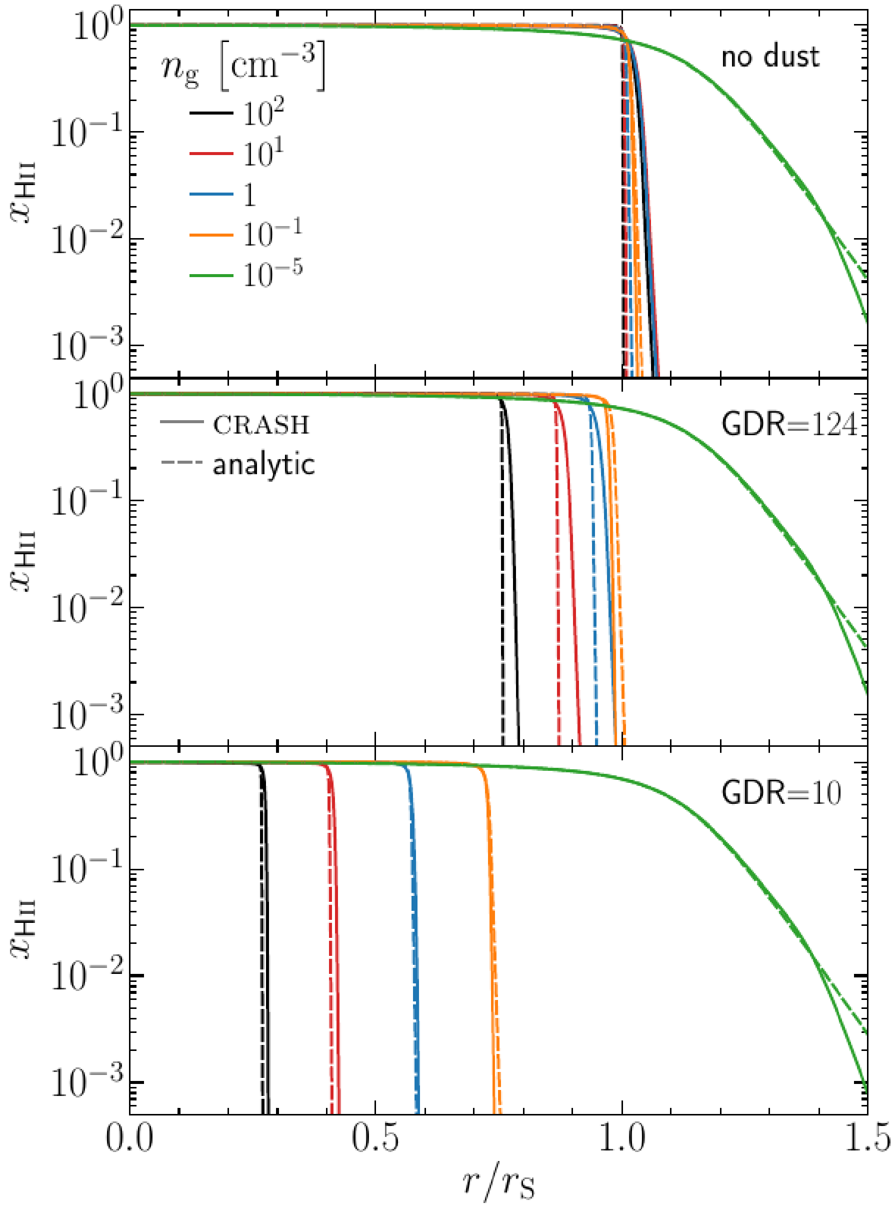
The process of **IGM Reionization** is captured at a **scales ≥ 100 cMpc** while the **escape fraction** of galaxies
Is constrained at **ckpc scales**.



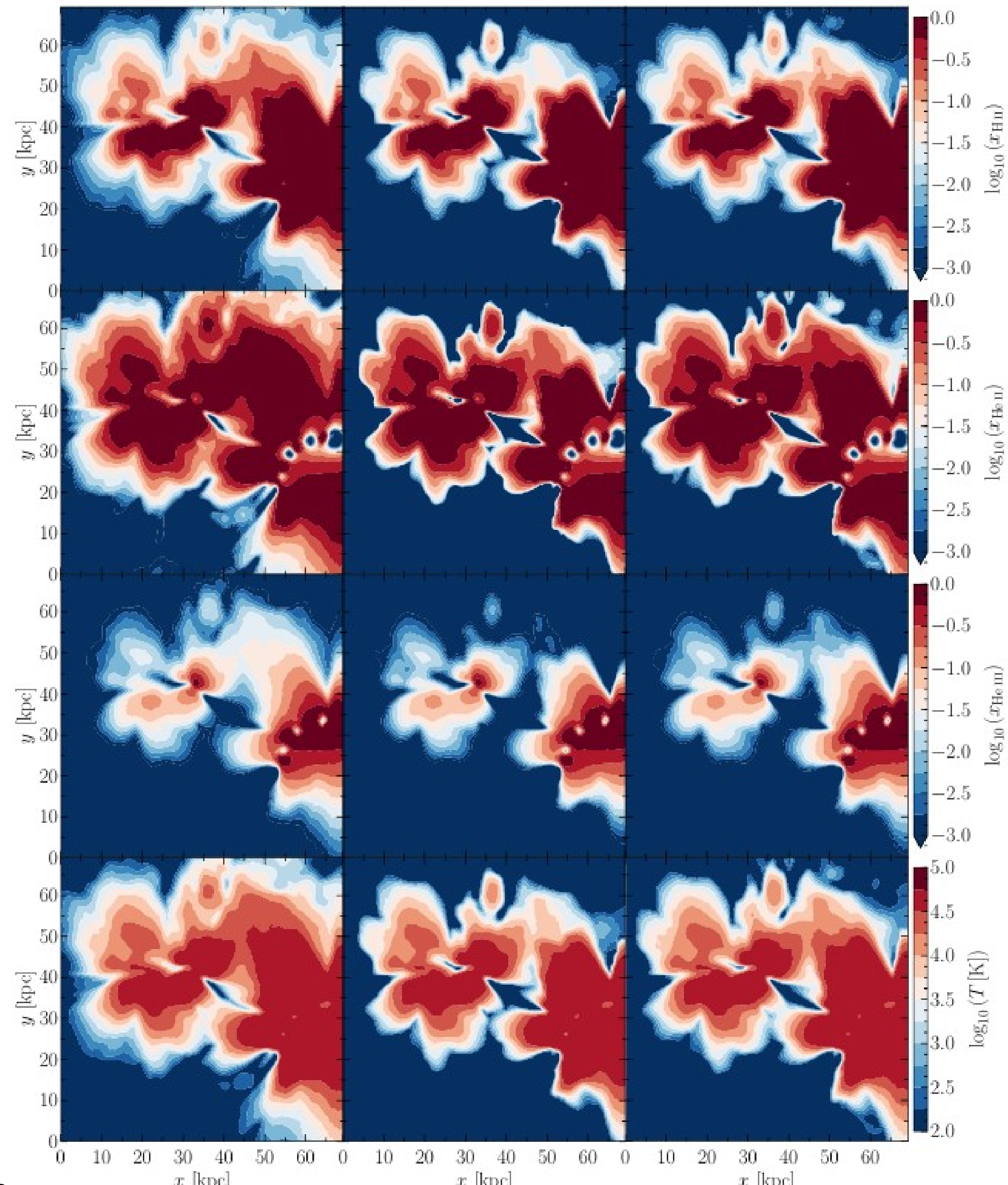
Galactic HII – dusty regions are crucial to understand f_{esc} !

Understand *extinction* → HII regions in a gas enriched by dust

A single HII region in different environments



A 0.5 cMpc cosmic web at z~9

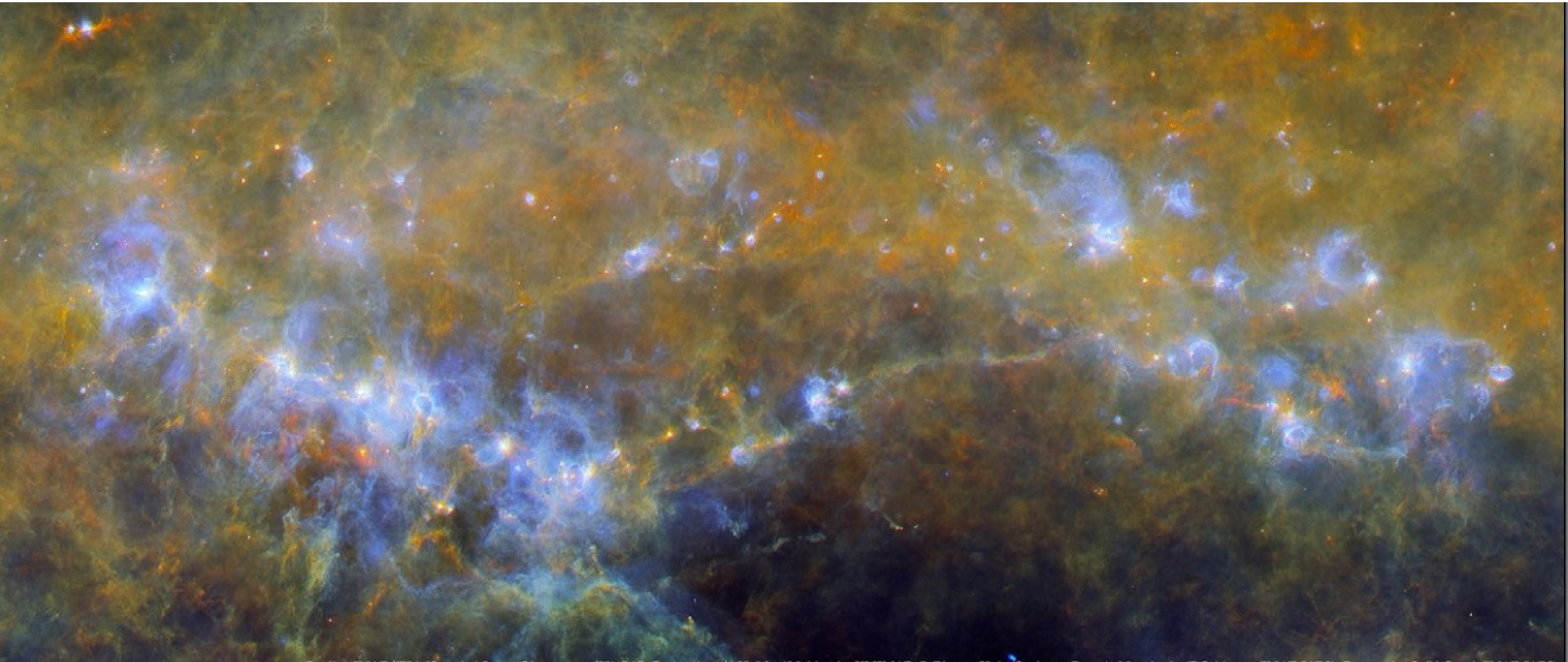


No dust Dust Dust-no PAH

Dust plays a significant role in the evolution of HII galactic regions → escape fraction

Glatzle M., Ciardi B., LG, et al., MNRAS 2019

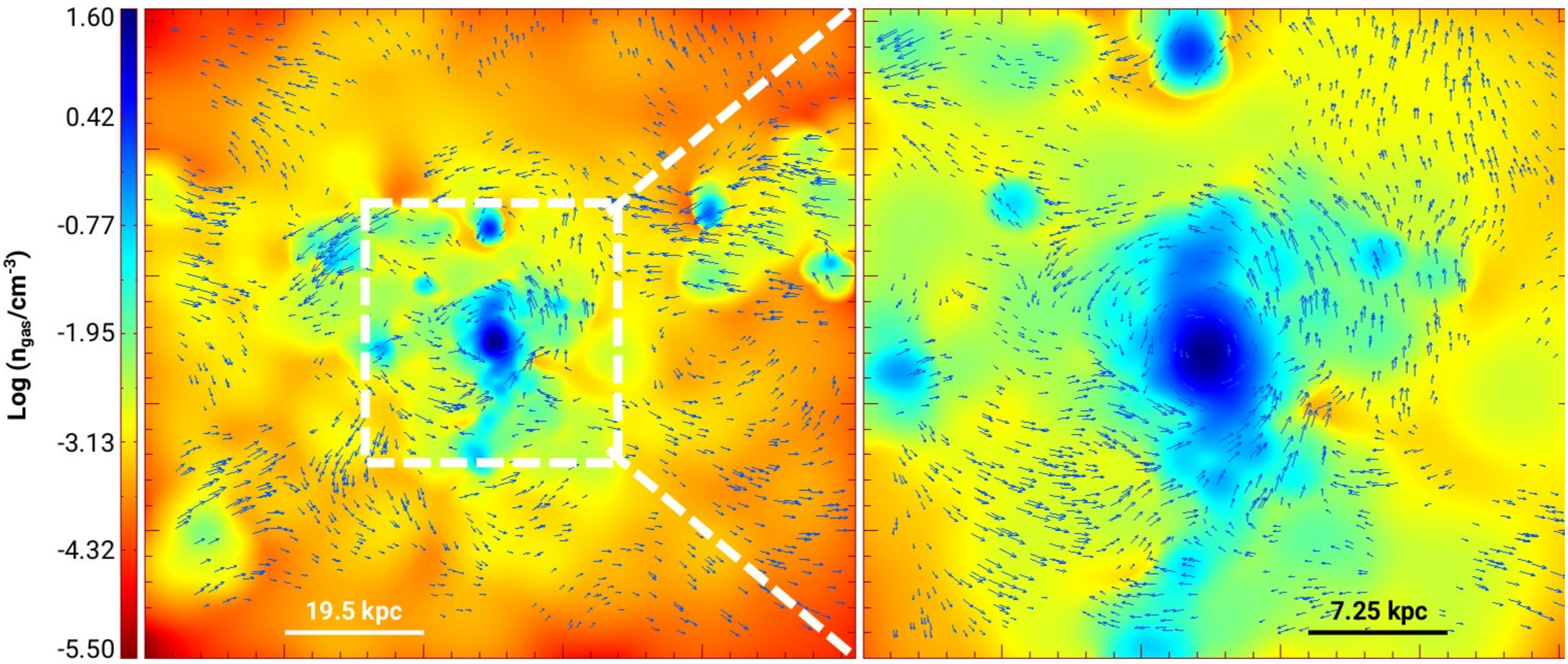
Part II:
Future Directions



Credits: INAF/ESA Herschel Space Observatory/Hi-GAL Consortium/ASI; Map-Making by UNIMAP (L.Piazzo, Univ. Sapienza Roma); Mosaics by E.Schisano (INAF-IAPS); Process by G. Li Causi (INAF-IAPS)

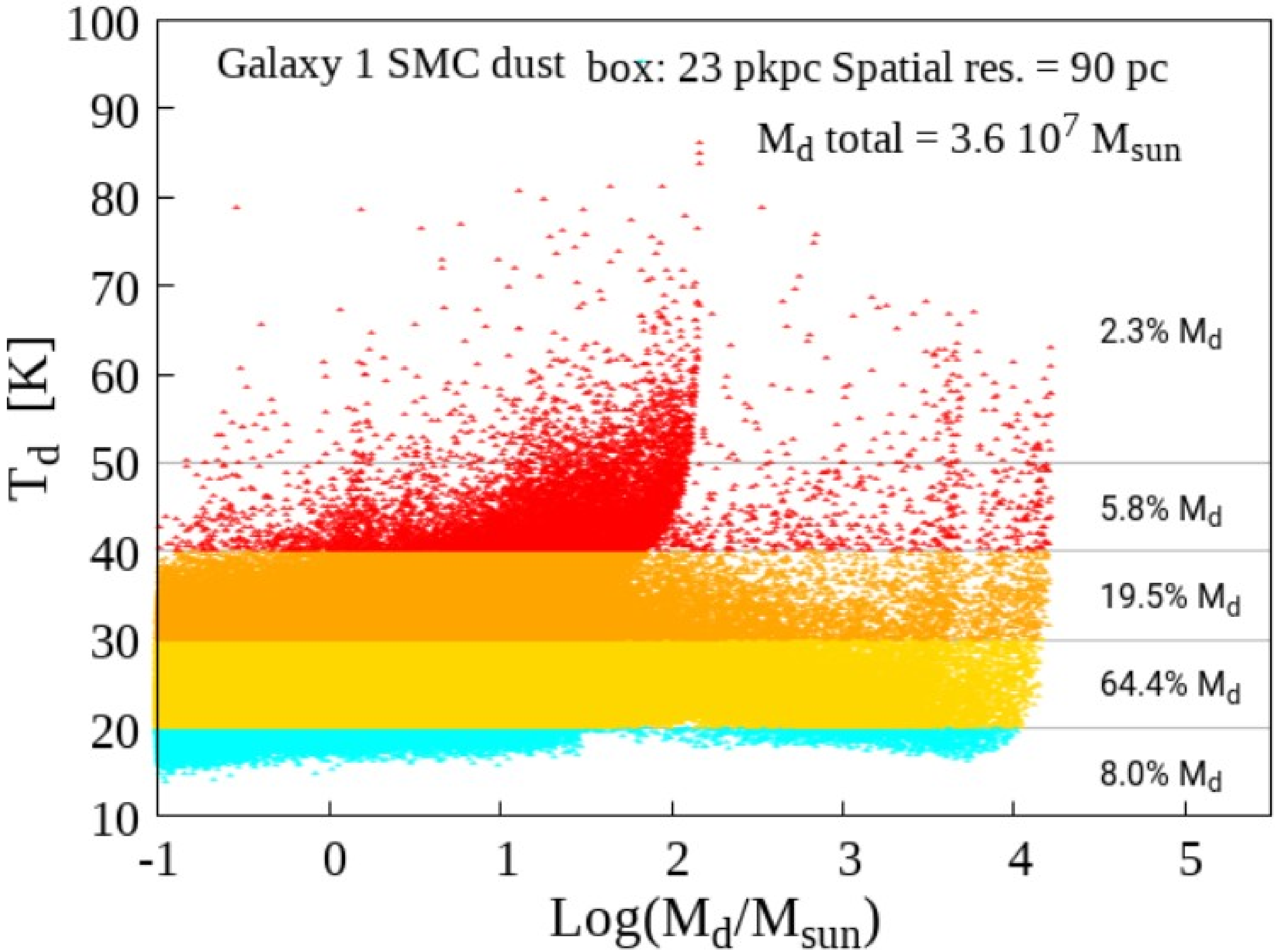
Statistics and environments of dusty galaxies $4 < z < 6$ constrained by ALPINE

(1) New simulations with better mass resolution.
(2) Scale 50/h cMpc
(3) 8 independent cubes evolved in $4 < z < 10$

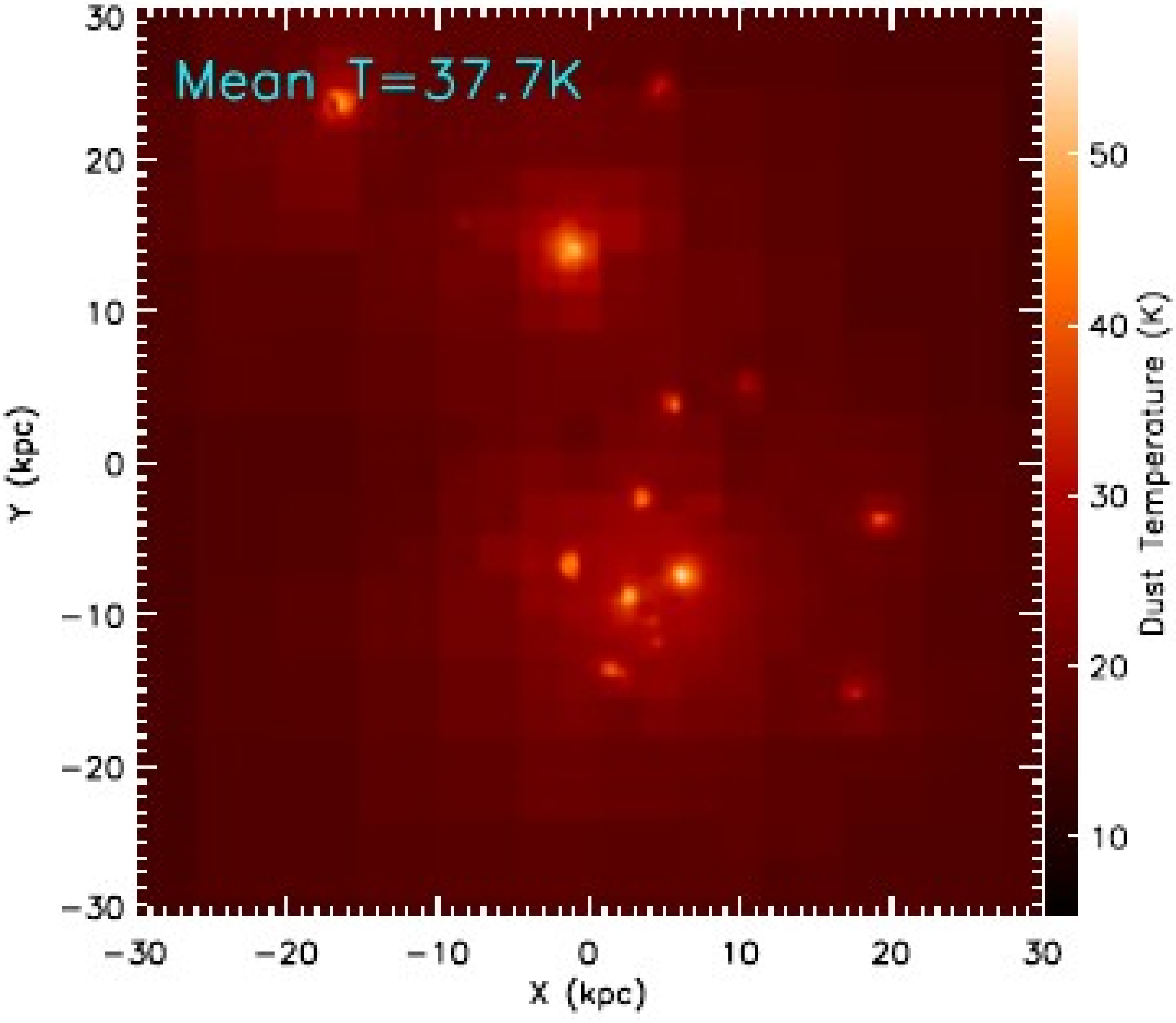


$M_{DM} \sim 10^{12}\ M_{sun}$, $M_g \sim 10^{11}\ M_{sun}$, $M_* \sim 10^{10}\ M_{sun}$, $M_d \sim 10^8\ M_{sun}$ → A kind of MW at z~4

RT Constraints on T_d derived from SKIRT8



RT Constraints on T_d derived from and ART[2]

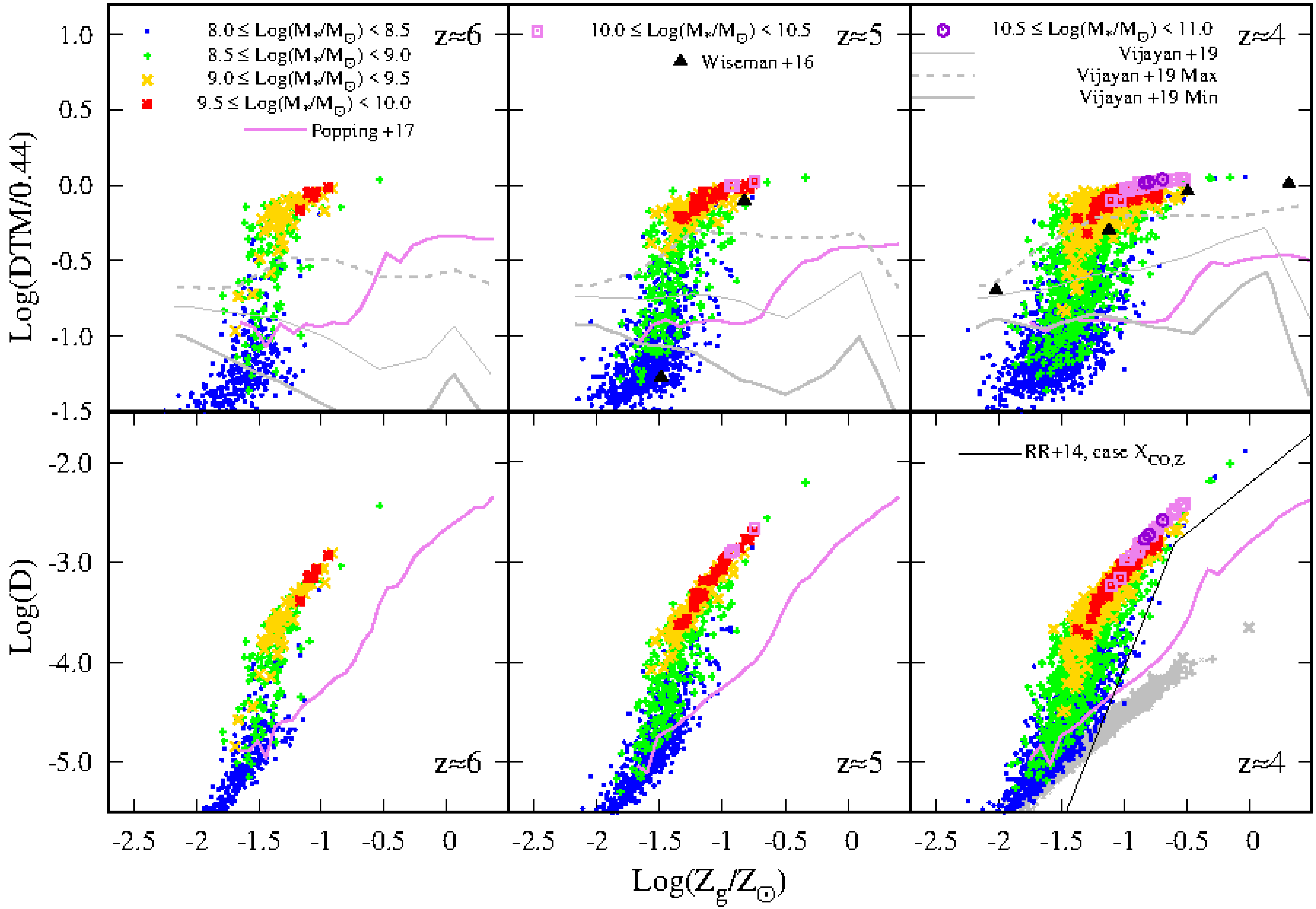


CONCLUSIONS

- Hydrodynamical simulations with dustyGadget can be successfully used to investigate **dust formation and evolution of high-z galaxies** providing their ISM multiphase and chemo-dynamical modeling is sufficiently accurate.
- **Dust is a fundamental tracer of galaxy evolution** through feedback: $M_d(M_*)(z)$, DTM(z) and *D* can be investigated both statistically and in their spatial distribution.
- **At z > 9 galactic dust is mainly of stellar origin**. Importance of metallicity corrections in regulating population transition.
- Process(es?) of **dust growth in the ISM** are of primary importance in tracing the many phases of the galactic ISM.

  → galactic environments deserve deep investigations.
- Dust has a deep impact on **observable quantities**: colours, beta slopes → Mancini et al., 2017
- **RT through dust and gas** (see Glatzle at al., 2019) necessary to understand the escape fraction of UV photons and cosmic reionization.

Statistical properties of simulated sample: DTM(Z_g)

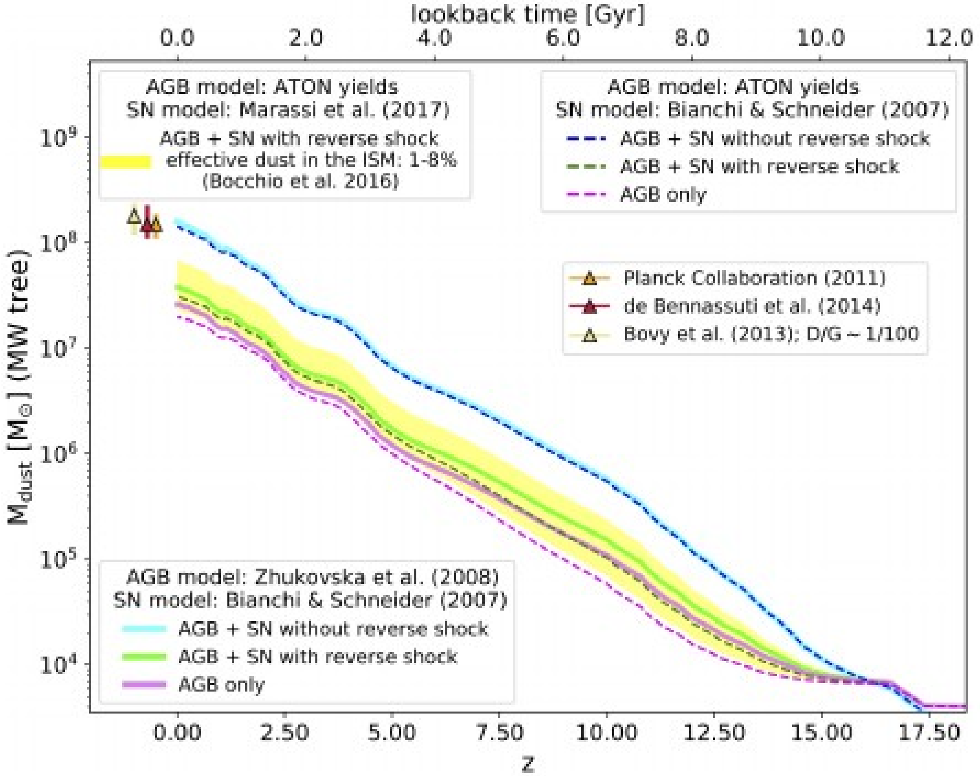


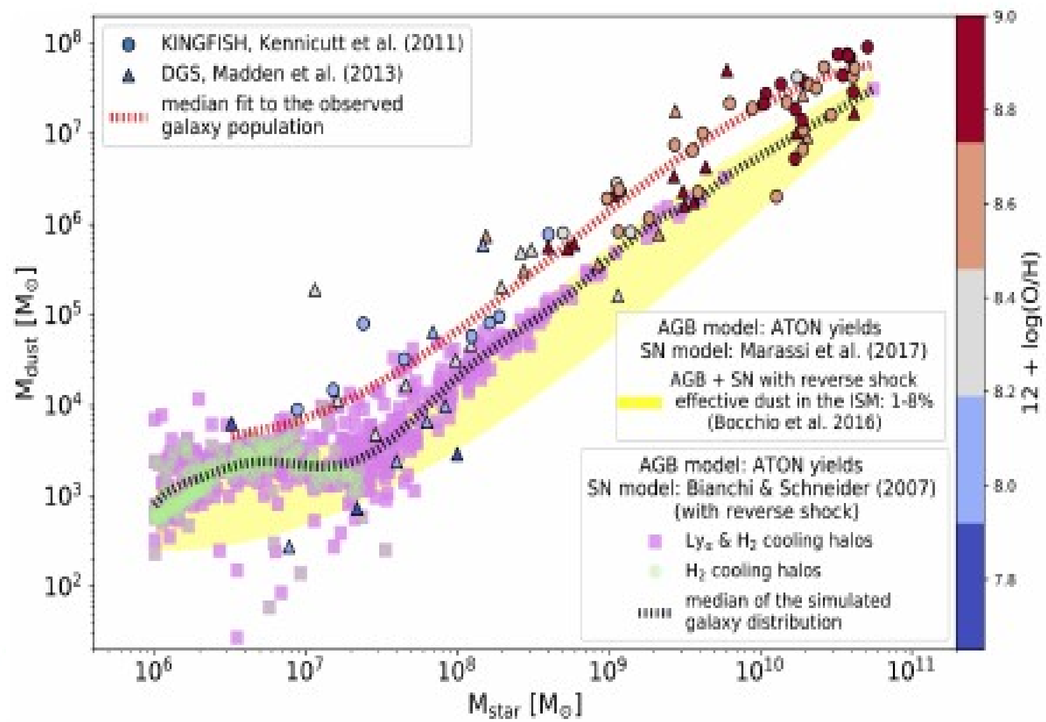
No evidence of *D*(Z_g)(z) evolution

LG, et al., submitted, arXiv:1909.07388

Simulating a dusty Milky Way-like galaxy with GAMESH

Establish the right mass of dust in the Milky Way and its satellites.





Stellar sources cannot produce suff. amount of dust in the Milky Way … or….

Same problem in the dwarfs at z=0 !

Reverse shock does not play a key role In removing dust around supernovae o_O

Dust production with stellar sources-only is not easy!

Ginolfi M., LG, Schneider R. et al., MNRAS 2018