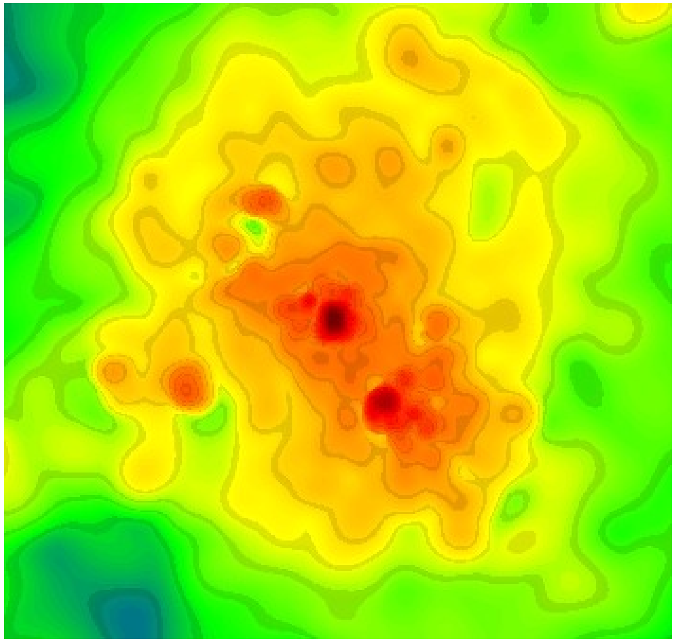
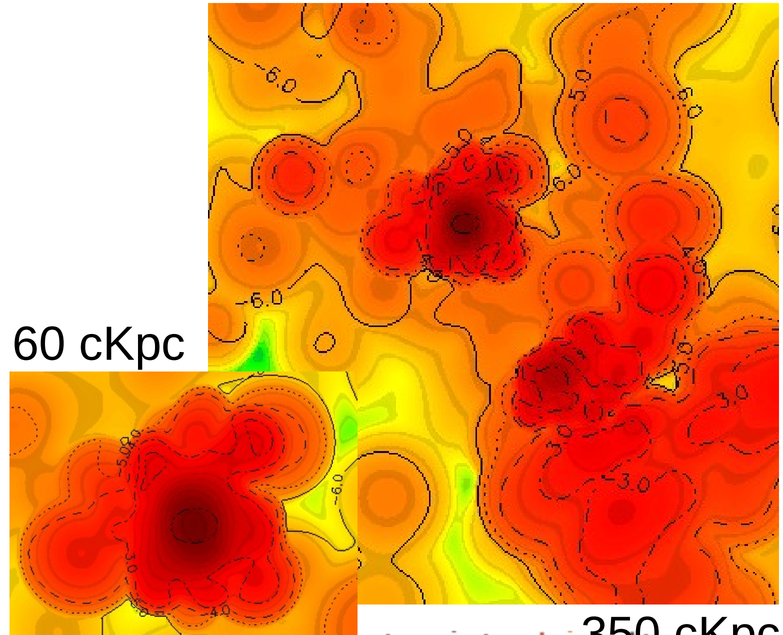
The assembly of high-z dusty galaxies

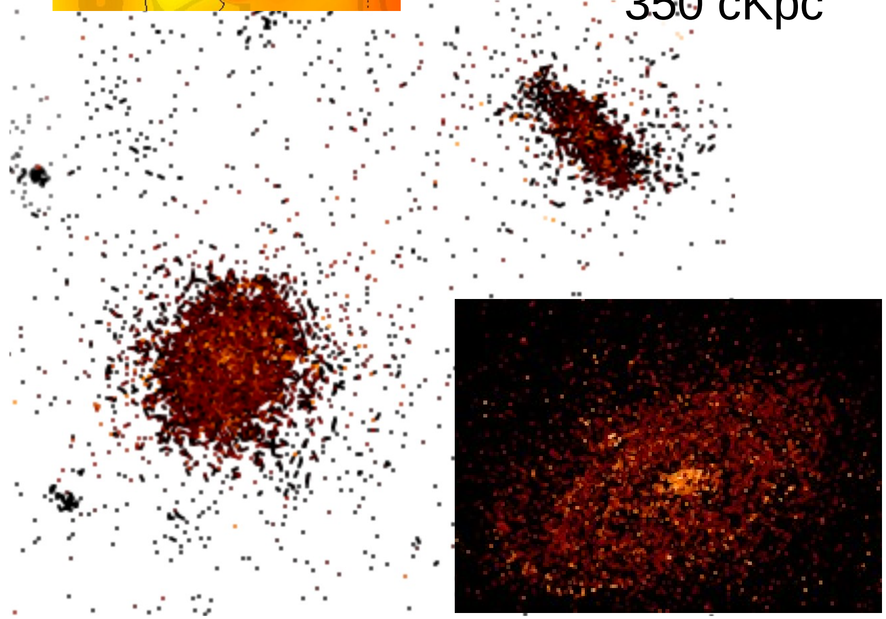


700 cKpc

60 cKpc



350 cKpc



Luca Graziani

In collaboration with:

R. Schneider (Un. La Sapienza)
M. Ginolfi (Un. Ginevra)
L. Hunt (INAF, Arcetri)
U. Maio (AIP)
M. Glatzle, B. Ciardi (MPG)

AMALDI RESEARCH CENTER

DIPARTIMENTO DI FISICA SAPIENZA UNIVERSITÀ DI ROMA

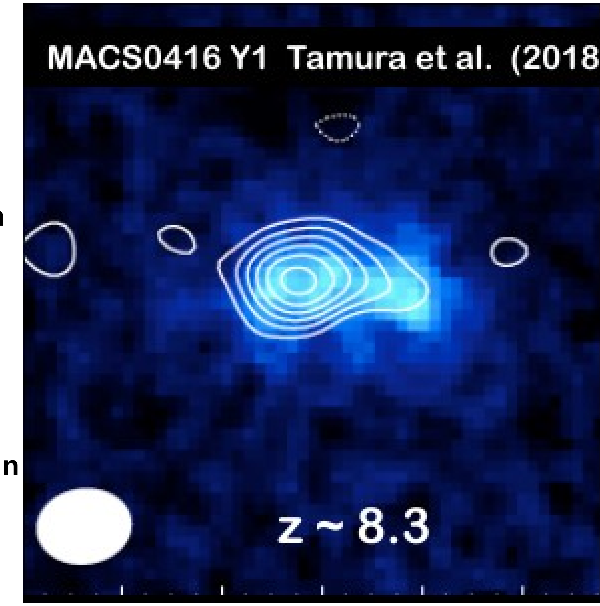
ISTITUTO NAZIONALE DI ASTROFISICA INAF

INFN ROMA Istituto Nazionale di Fisica Nucleare Sezione di Roma

Extremely Big Eyes on the Early Universe, 9-13 September 2019, Roma, Italy

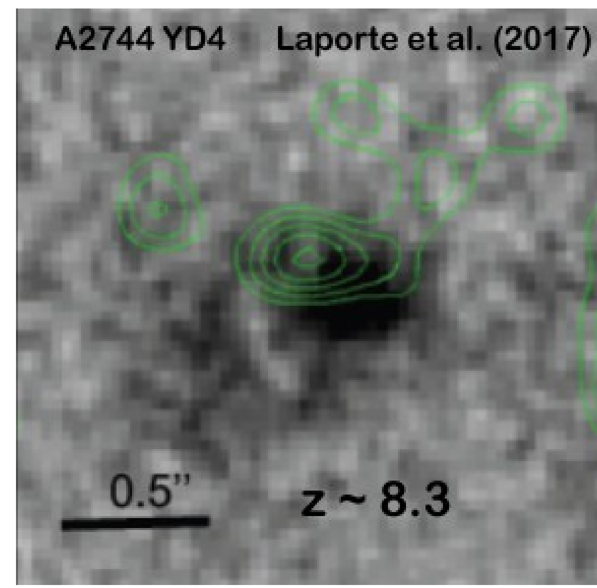
Signals from High redshift (z > 6) **dusty** galaxies

- **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. 2018

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



Laporte et al., 2017

Interplay between feedback processes required to understand these galaxies as they assemble

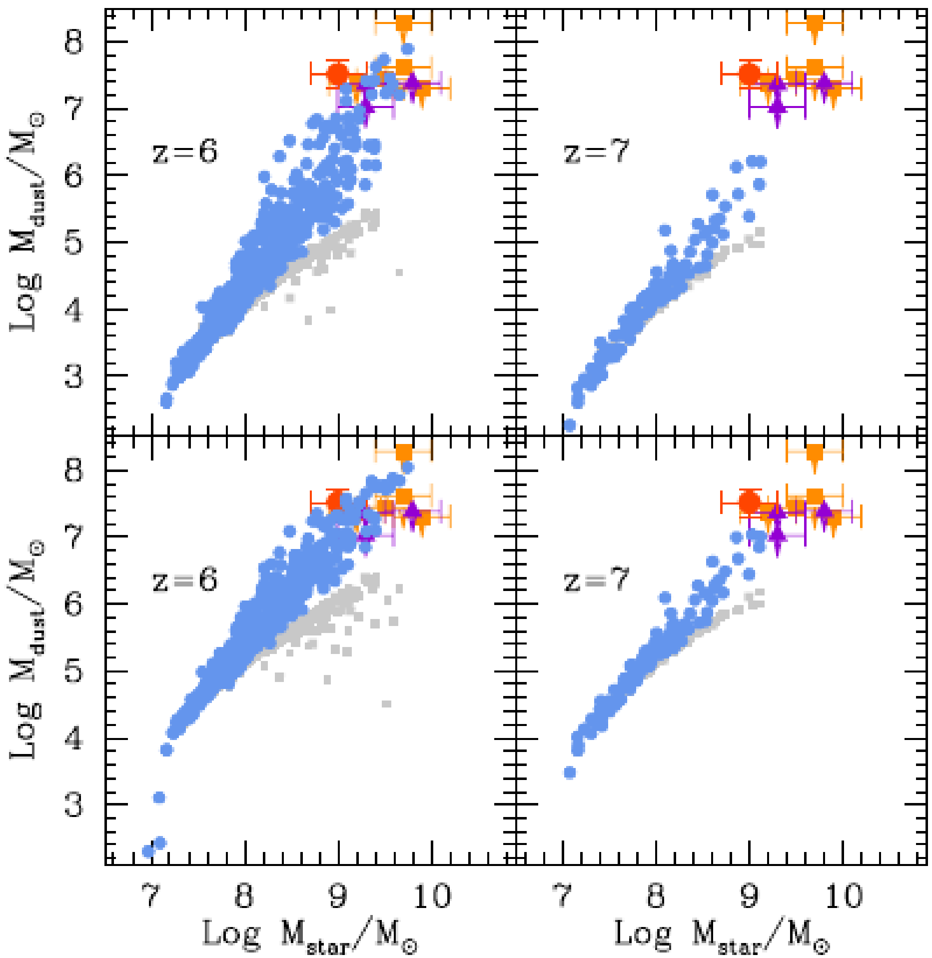
Modelling *dust formation*, *evolution* → Understand extinction

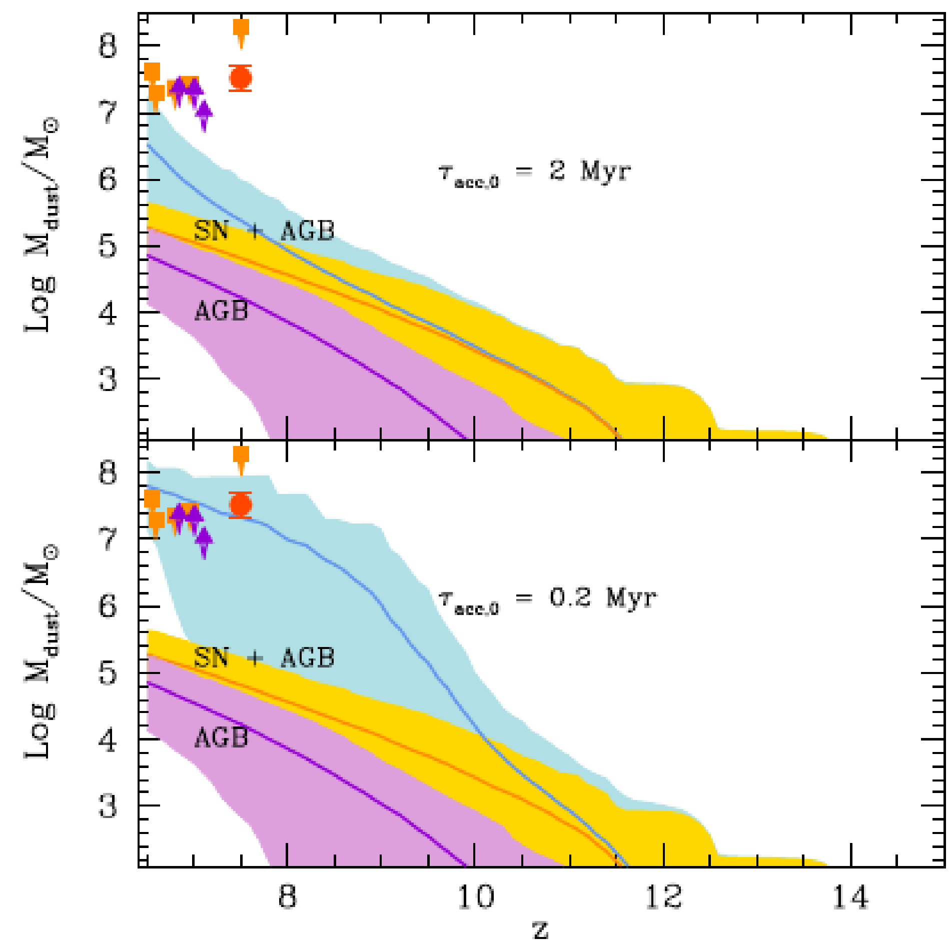
- **Dust is an old topic as the Milky Way ISM is enriched by dust D_c ~1/150**
- **Models / codes for dust extinction: absorption/scattering exist and reproduce the Milky Way extinction curve**
- **But….**
  - **Dust formation still unconstrained especially in low-metallicity stars**
    → *Effective* stellar yields (Y_d) for metals and dust are required for both AGB stars and SNe (Marassi et al., MNRAS 2019)
  - **Galactic environments in which dust can grow are NOT clear**
    → What is the time scale for dust grains to grow? (t_{gg})
    → Gas conditions? n_{gas}, T_g, Z_g ? Cold/Hot phase (x_c)?
    (Hirashita et al., MNRAS 2014)
  - **Processes destroying dust grains have specific time scales**
    → Destruction by stellar shocks (t_d) (de Bennassuti et al., MNRAS 2014)
    → Grain sputtering in hot gas (t_{sp}) (Tsai & Mathews, ApJ, 1995)

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

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**

LG, et al., submitted

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

Dust production and evolution simulated consistently with atomic metals in multi-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 can be modelled as largely environment dependent
  x T_d requires assumptions
  x mass resolution still a limit in cosmological simulations

These processes are environment dependent !

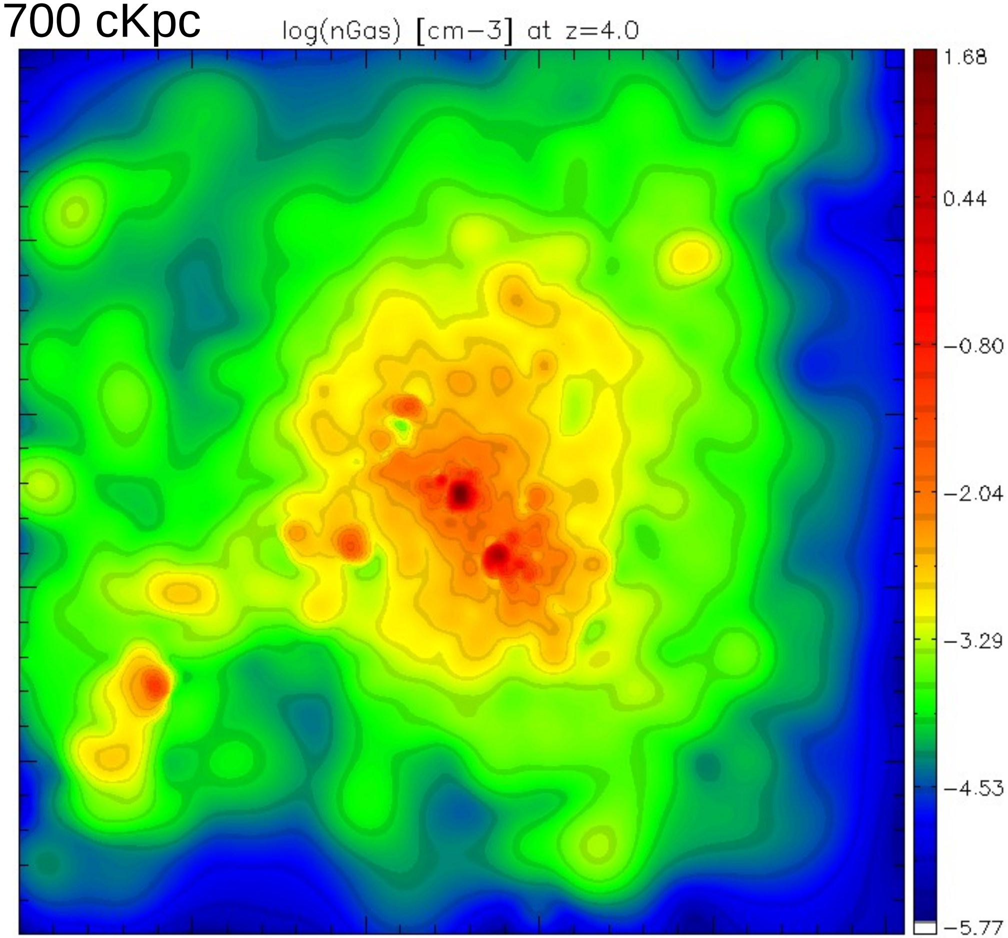
Simulating high-z dusty galaxies with dustyGadget

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

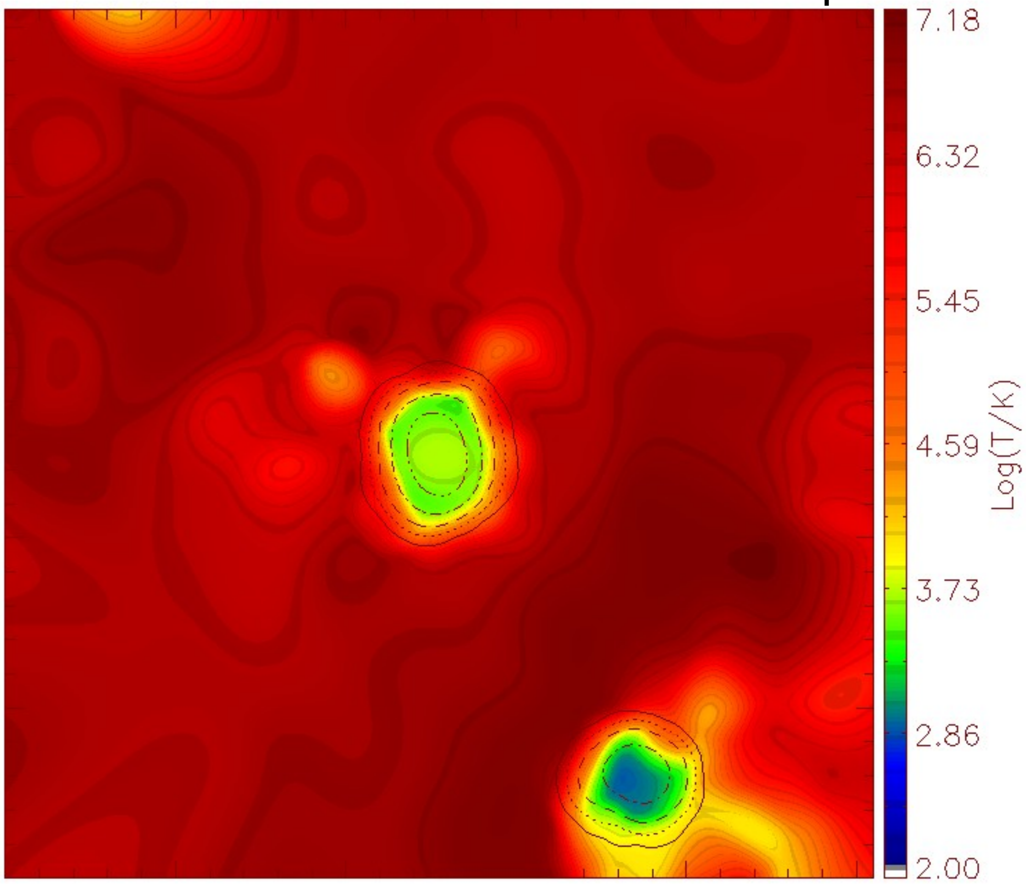
Dust production and evolution simulated consistently with atomic metals in multi-phase SPH, star-forming particles.

LG, et al., submitted

700 cKpc



135 cKpc

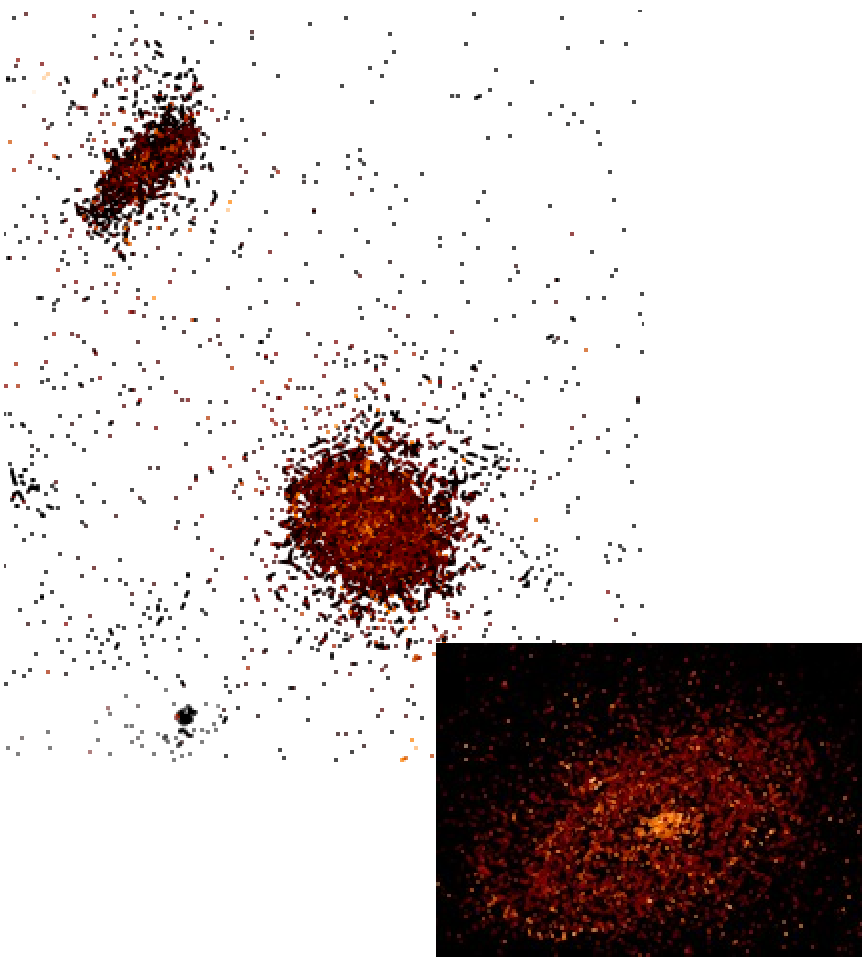


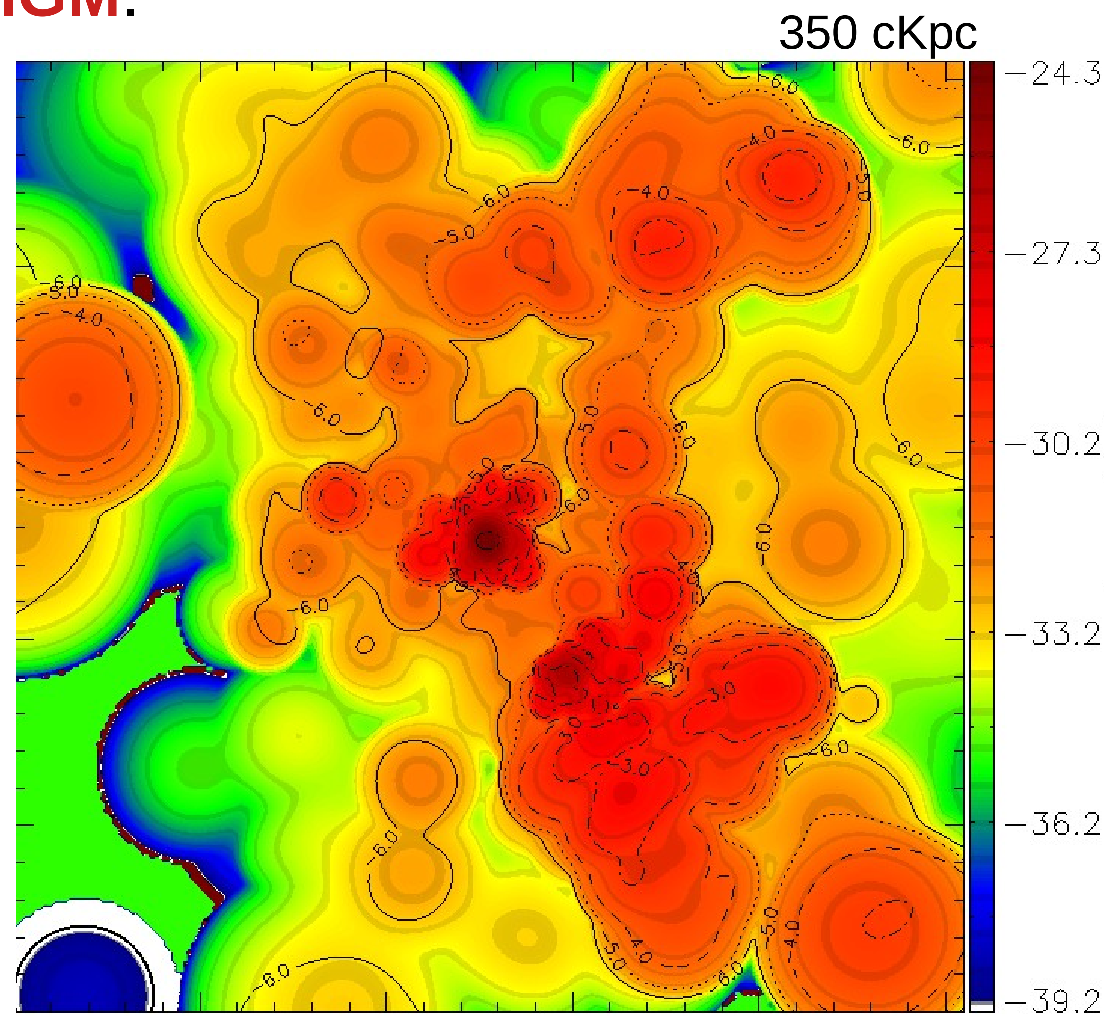
Environment dependence & Spreading by winds

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

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

3D pattern of dust pollution but the **problem becomes strictly scale-dependent: galaxies + CGM+IGM**.





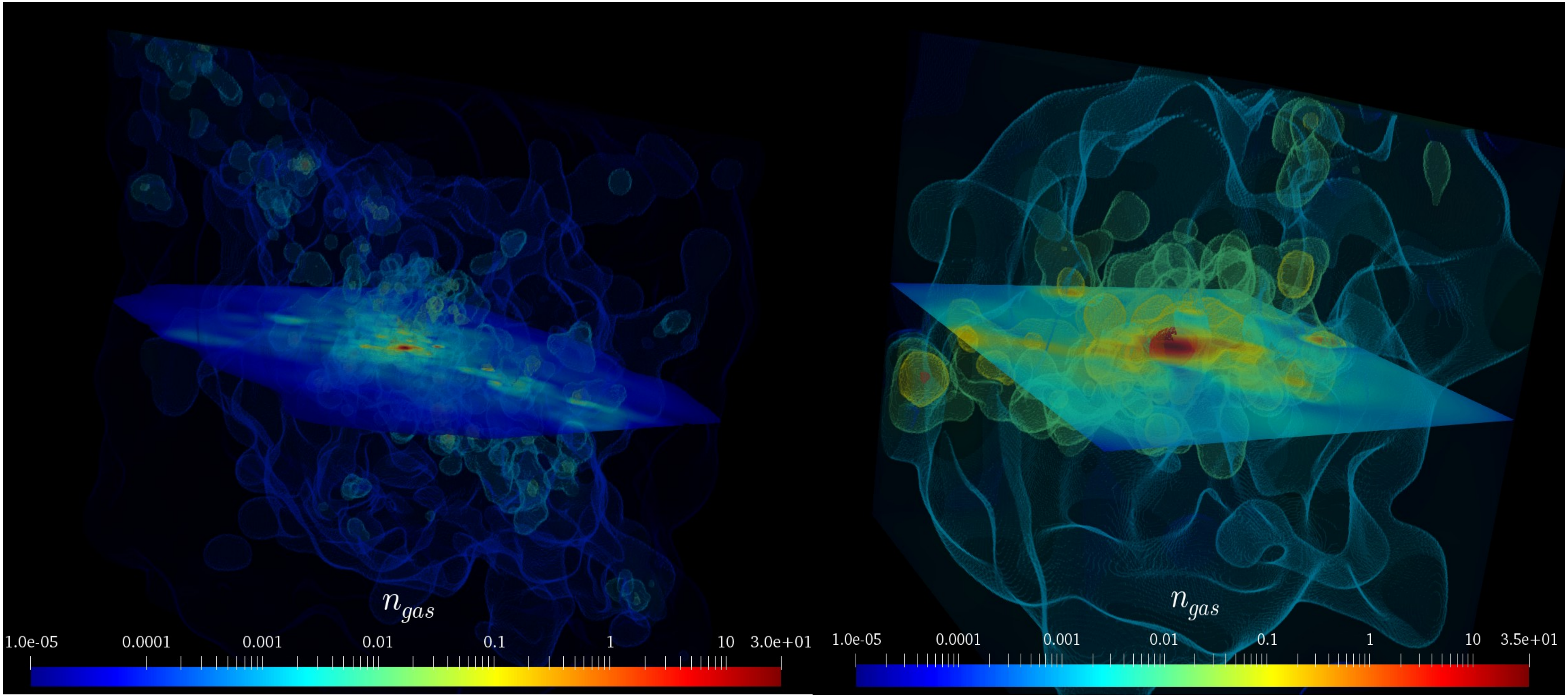
Environment dependence → scale dependence

LG, et al., submitted

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

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

3D pattern of dust pollution but the **problem becomes strictly scale-dependent: galaxies + CGM+IGM**.

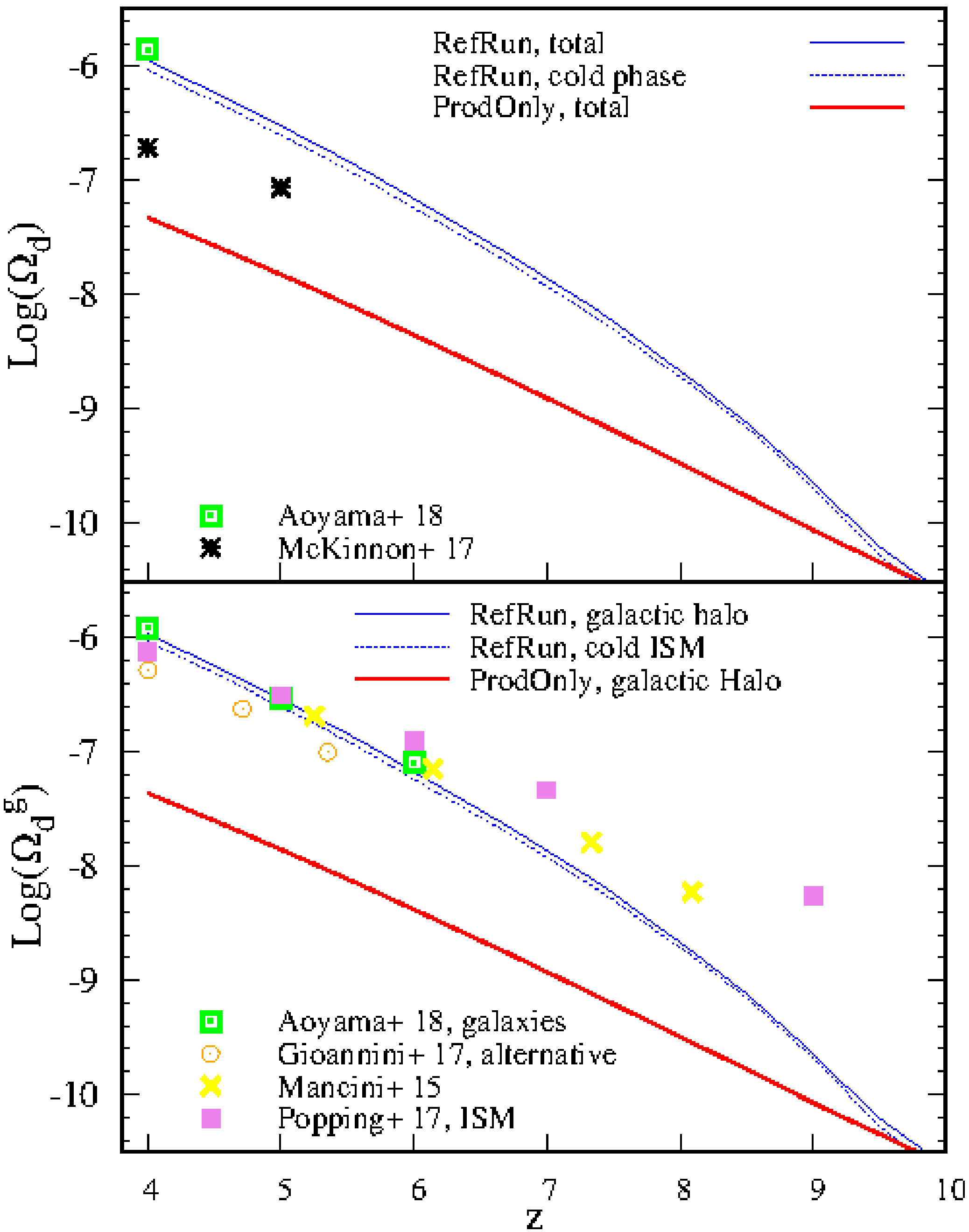


Environment dependence → scale dependence

LG, et al., submitted

Statistical properties of simulated sample: $\Omega_{\rm d}(z) \equiv \rho_{\rm d}(z)/\rho_{\rm c,0}$

LG, et al., submitted



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.

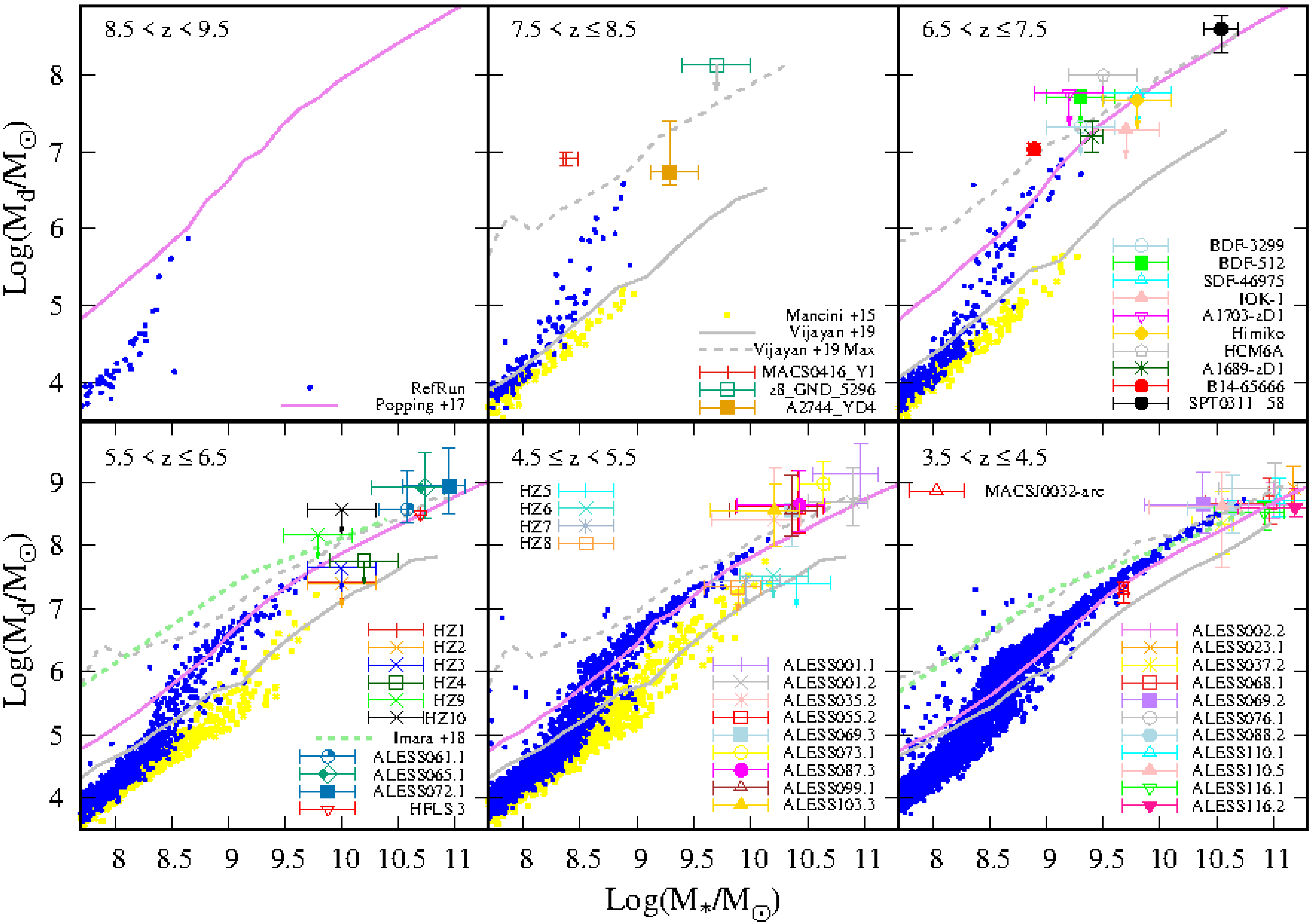
Z < 6 Dust Mass in galaxies agrees with
Both numerical and SAM models

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

This is an integrated quantity.. across galaxy populations!

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

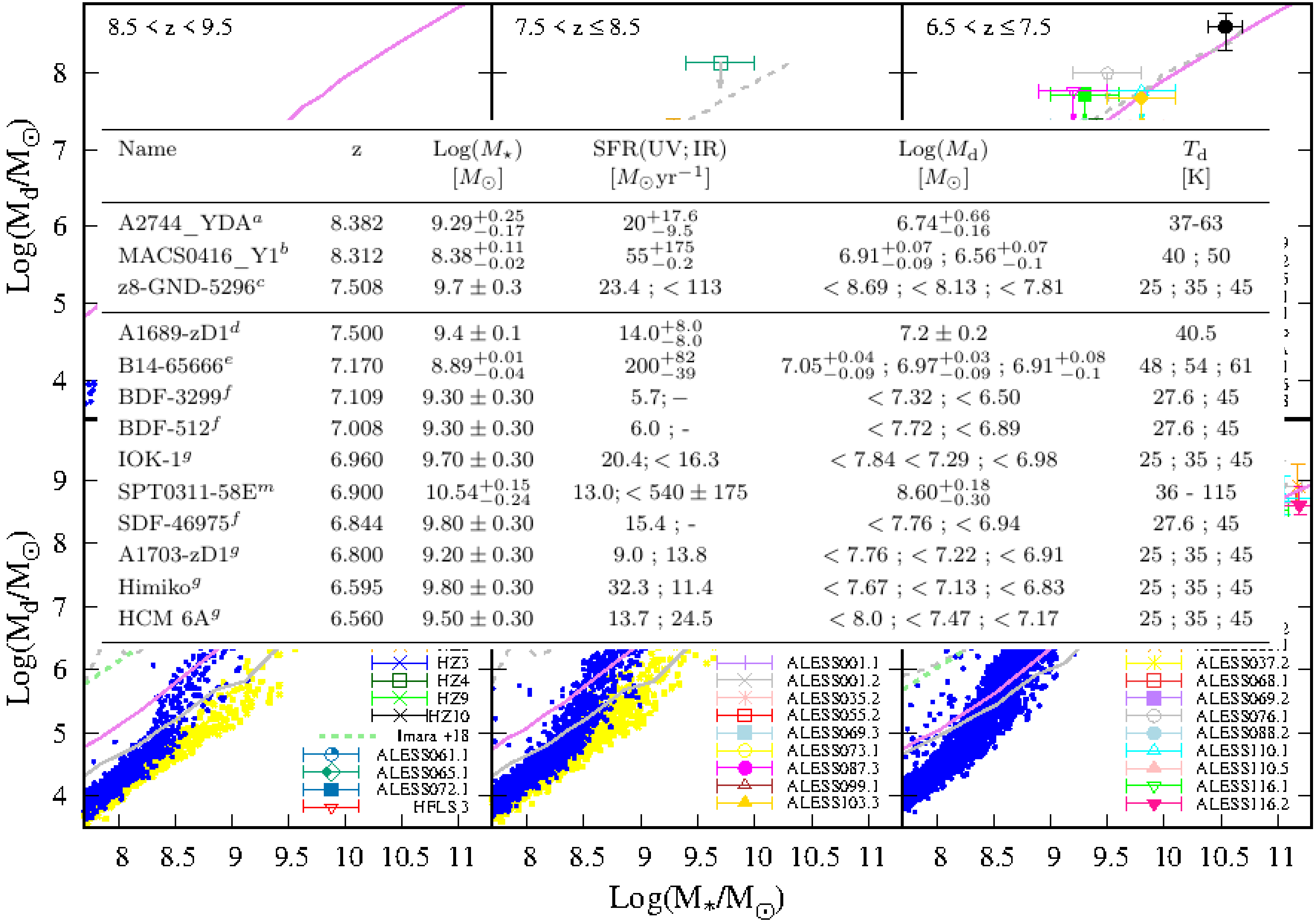
LG, et al., submitted



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

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

LG, et al., submitted

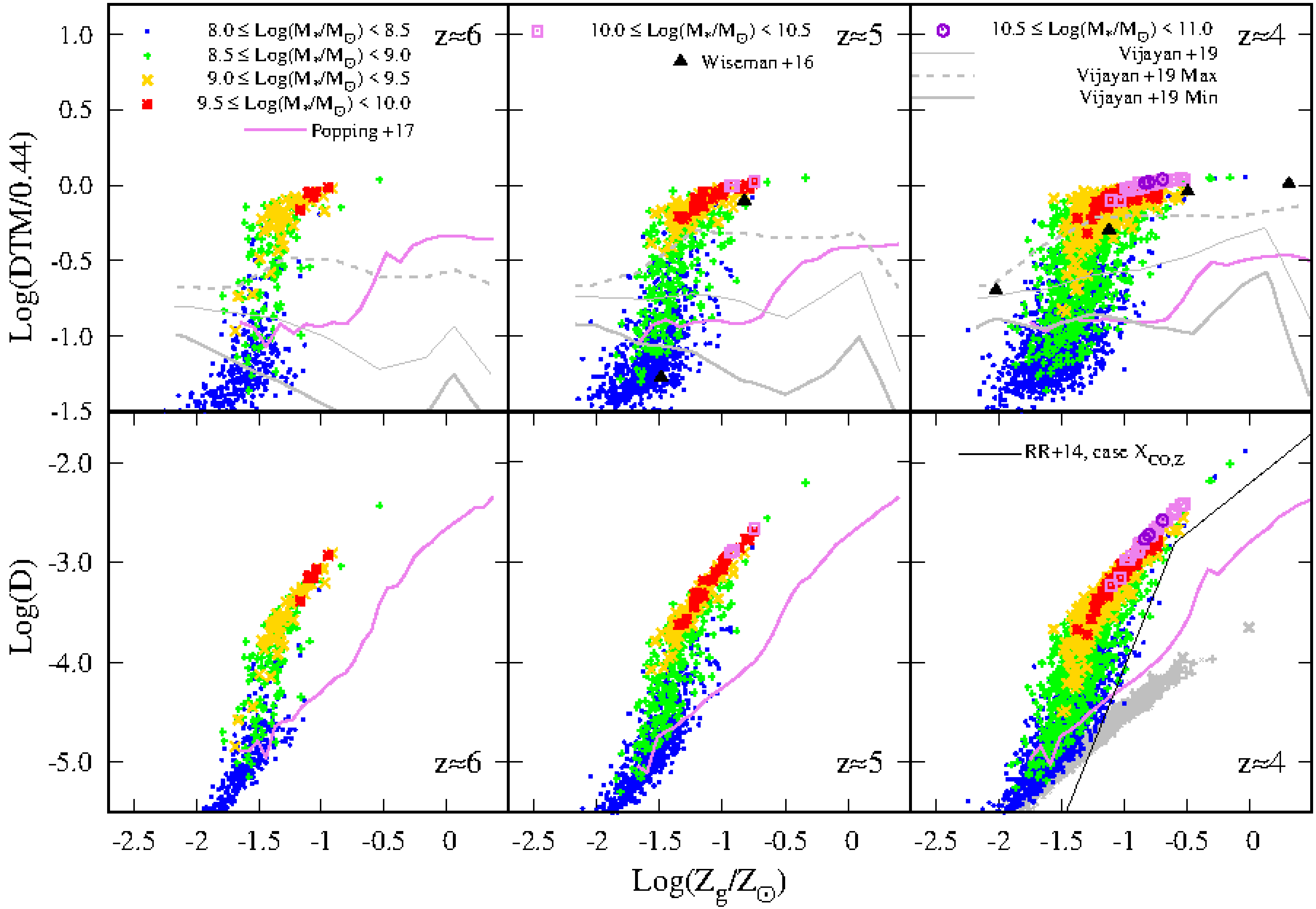


Name	z	$\log(M_\star)$ $[M_\odot]$	SFR(UV; IR) $[M_\odot \mathrm{yr}^{-1}]$	$\log(M_d)$ $[M_\odot]$	T_d [K]
A2744_YDA[a]	8.382	$9.29^{+0.25}_{-0.17}$	$20^{+17.6}_{-9.5}$	$6.74^{+0.66}_{-0.16}$	37-63
MACS0416_Y1[b]	8.312	$8.38^{+0.11}_{-0.02}$	$55^{+175}_{-0.2}$	$6.91^{+0.07}_{-0.09}$; $6.56^{+0.07}_{-0.1}$	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

Dust masses are inferred → T_d is a critical !

Statistical properties of simulated sample: DTM(Z_g)

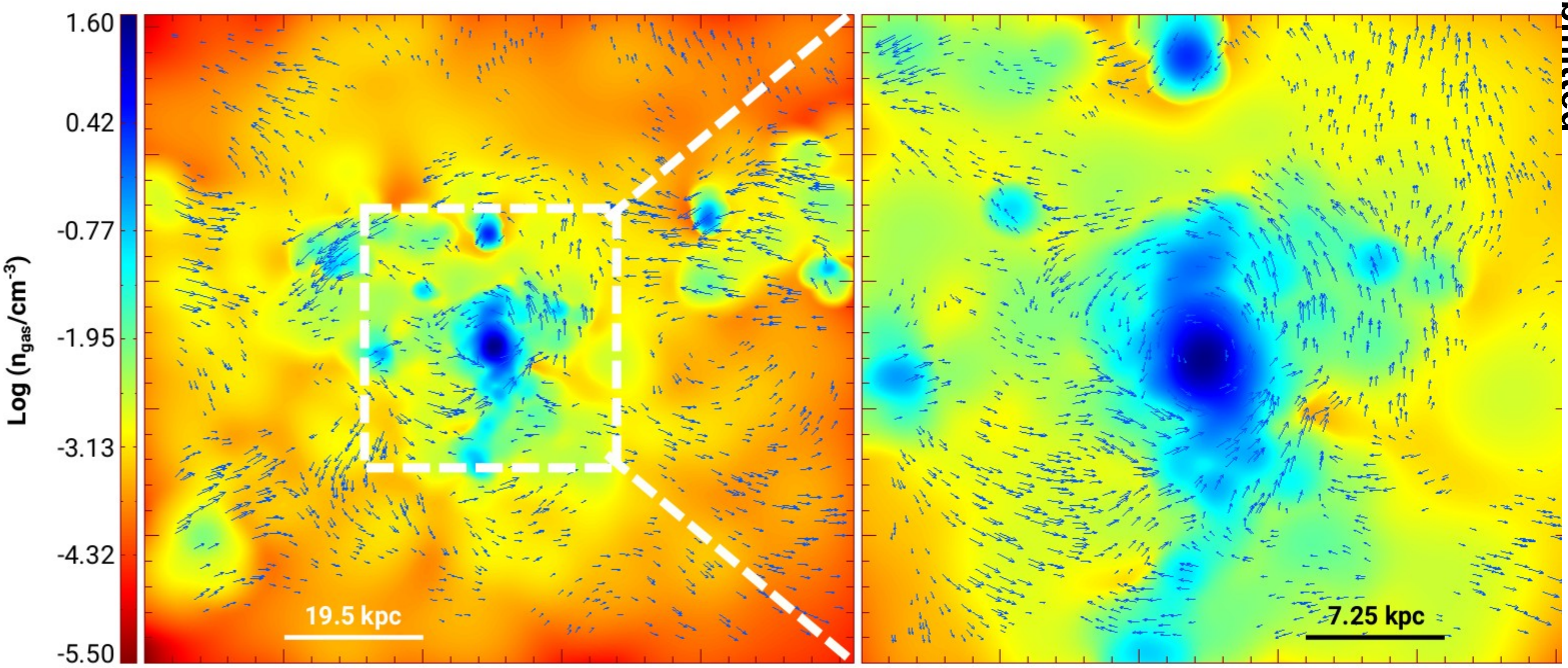
LG, et al., submitted



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

The environment of a massive halo at z~4: gas distribution

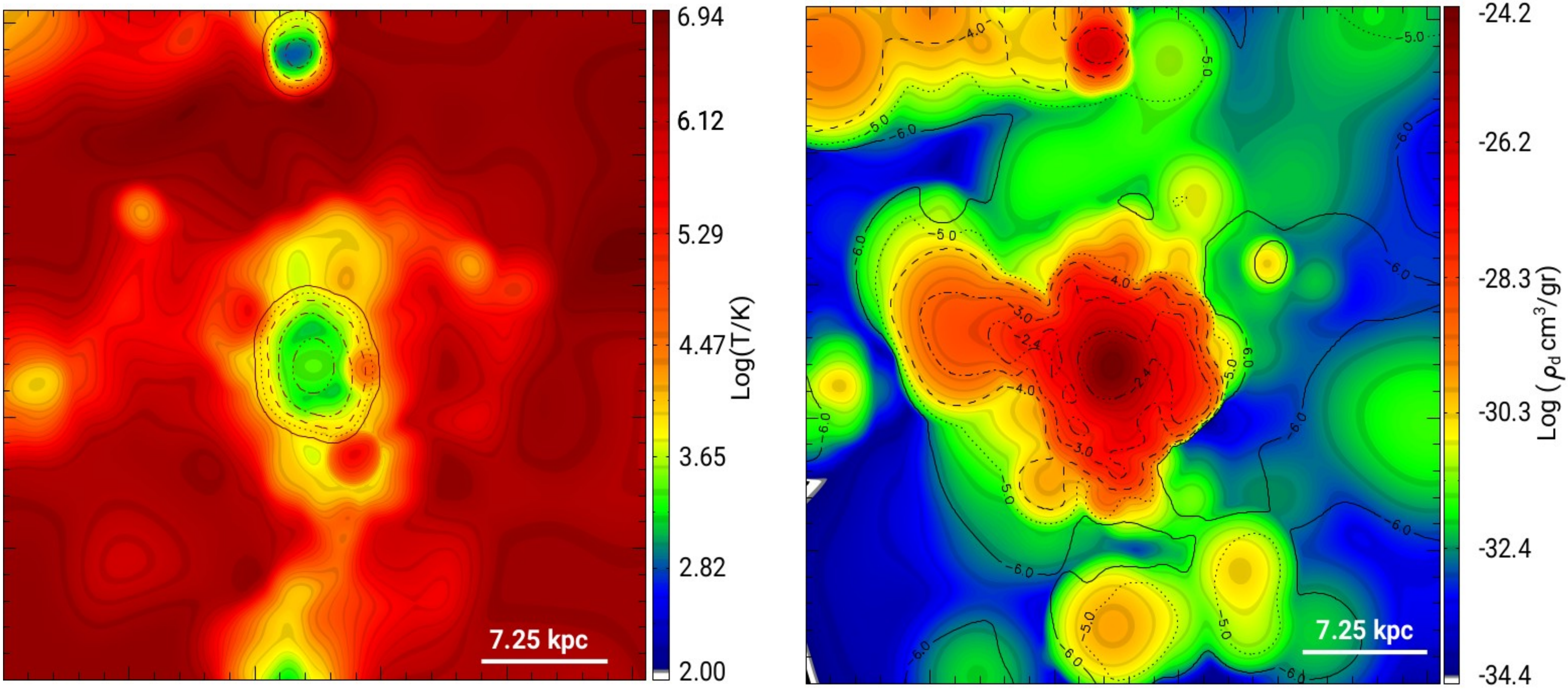
LG, et al., submitted



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

Mechanical feedback by galactic winds

The environment of a massive halo at z~4: gas temperature and dust density



At smaller physical scales evidence of chemical feedback in dust grains. No dust at d > 30 kpc??

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.