Dust obscured cosmological simulations

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Plan:

- A few words on dust in astrophysics
- The problem with radiative transfer in dusty ISM for cosmological simulations
- A sample application of our solution: GRASIL3D
- Next step: incorporating dust evolution in simulations

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What is cosmic "dust"?

Typically from 0.5 to 1% of *Interstellar Medium* mass in galaxies is in small solid particles=dust. about ½ of heavy elements are *depleted* to dust

Grain size ranges from a few Å (PAH molecules) to 1-10 μm

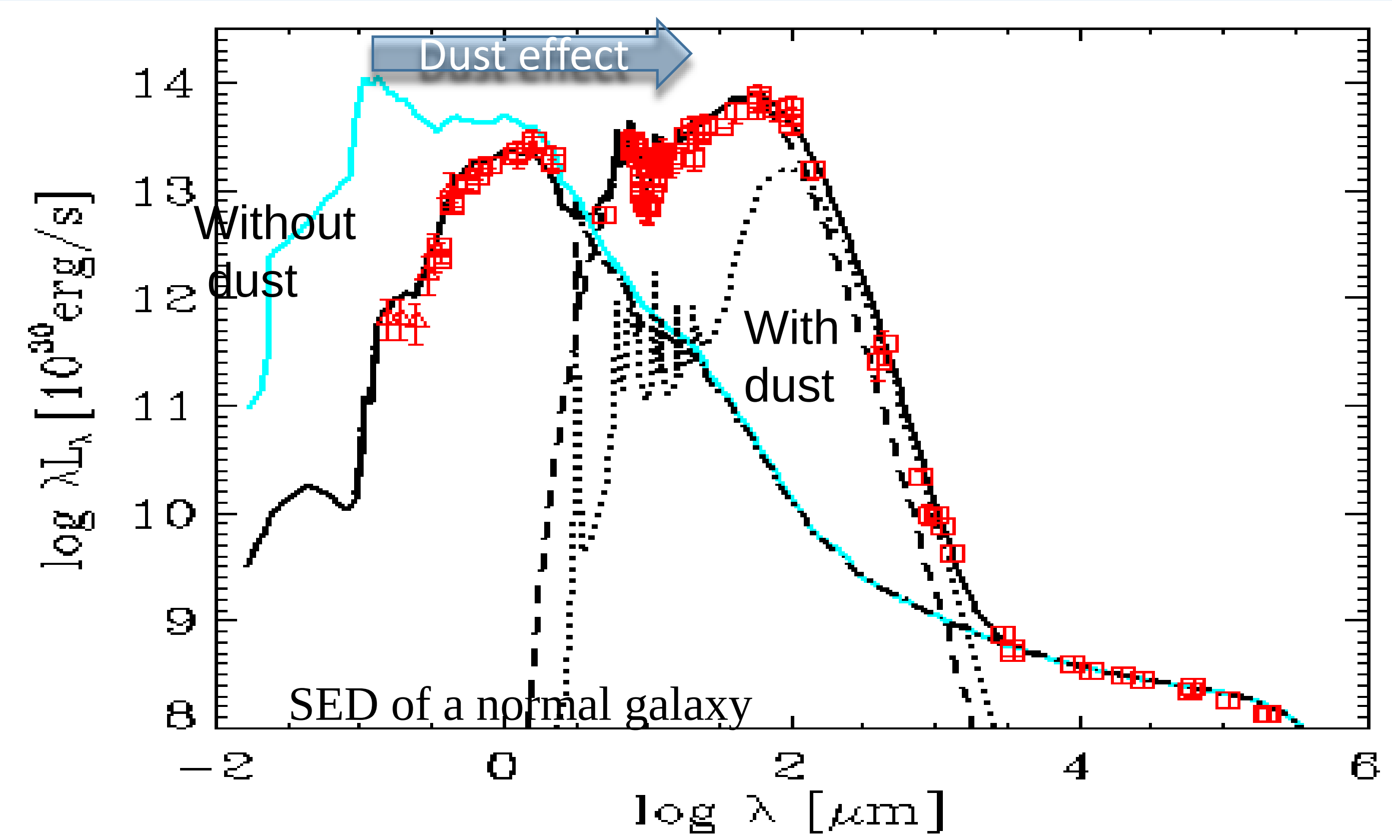
Composition: two main chemical groups: carbonaceous (graphite and/or amorphous C) and silicate (Mg+Fe+Si+0, eg olivine) grains

Dust is an interesting active element of ISM life: heats or cool the gas, catalyses the formation of molecules, increases the importance of radiation pressure…..

Problem: due to its effective interactions with the radiation field, dust strongly affects the perception of astrophysical objects

Effects of "dust" on the SED

Dust particles interact with photons (absorb, scatter, polarize) emitted by stars or other primary sources. This is particularly effective in optical-UV (λ < 1 μm). The energy is thermally reradiated at λ > a few μm. This is because grains are destroyed at T > 1000-2000 K



Dust reprocessing in simulations

In general, a direct comparison of galaxy models with most observations calls for a radiative transfer treatment of reprocessing in the dusty ISM.

A complex, time-consuming and to some extent uncertain numerical task.

As for simulations, it is by now feasible only in post-processing.
A few tolls already exist for this:

1. SUNRISE (Jonnson+ 2006,2009);
2. RADISHE (Chakrabarti + 2008, 2009);
3. SKIRT (the new version: Baes+ 2011; Steinacker+ 2013);
4. Art2 (+2007, 2008; Yajima+ 2012);
5. GRASIL3D (Dominguez-Tenreiro+ 2014)

There is one important complication, usually overlooked……

Dust reprocessing in simulations

Cosmological simulations do not provide enough information to perform sensible dust radiative transfer (RT).

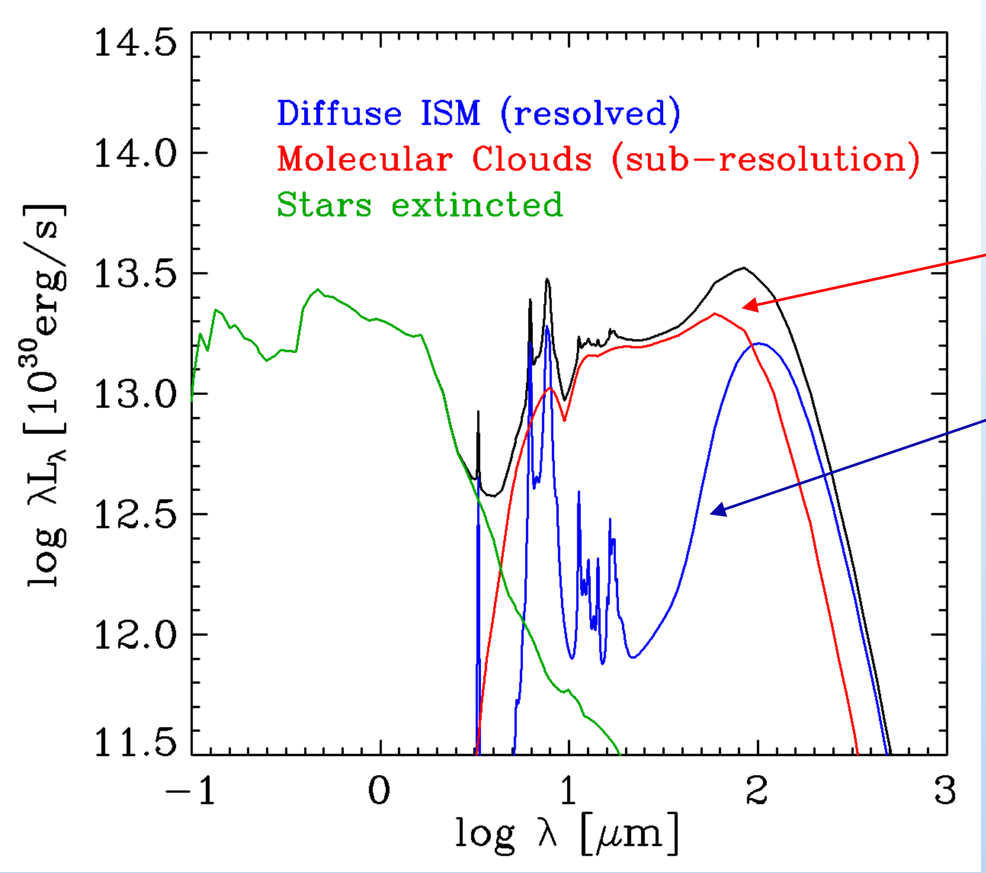
Most of the reprocessing occur on the unresolved scales of Molecular Clouds, ($M < 10^5 - 10^6\, M_\odot$; $R < 50\, pc$), i.e. orders of magnitude below typical resolution;

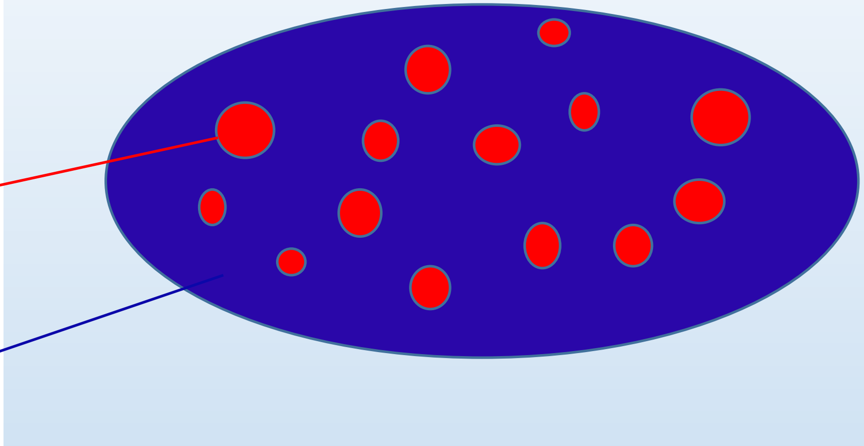
Thus further "sub-resolution" RT modelling is unavoidable (with associated free parameters).

Orion Nebula
visible light

Orion Nebula
visible + sub-mm
(orange)

Dust reprocessing in simulations





The GRASIL3D infrared SED is the sum of two components:

- a cooler one due to diffuse ISM (cirrus), computed using the <u>resolved density fields</u> of dusty gas and stars
- a warmer one due to unresolved Molecular Clouds (MCs), computed with additional <u>sub-resolution modelling</u> (2 to 4 parameters)

Applications of GRASIL3D dusty radiative transfer to cosmological simulations

(in chronological order)

- Obreja+2014, MNRAS (8 zoom simulations of ET galaxies. Evolution of M*-SFR and M*-Z relations)
- Granato+2014, MNRAS (Galaxiy clusters zoom in. Proto-cluster stage)
- Buck+2017, MNRAS accepted (100 high resolution zoom simulations. Nature of clumpy disks at high-z)
- Santos+2017, A&A accepted (dwarf galaxies in the CLUES local group zoom simulation. The diversity of IR-submm emission.)
- Goz+2017, MNRAS submitted (MUPPI small cosmological box)

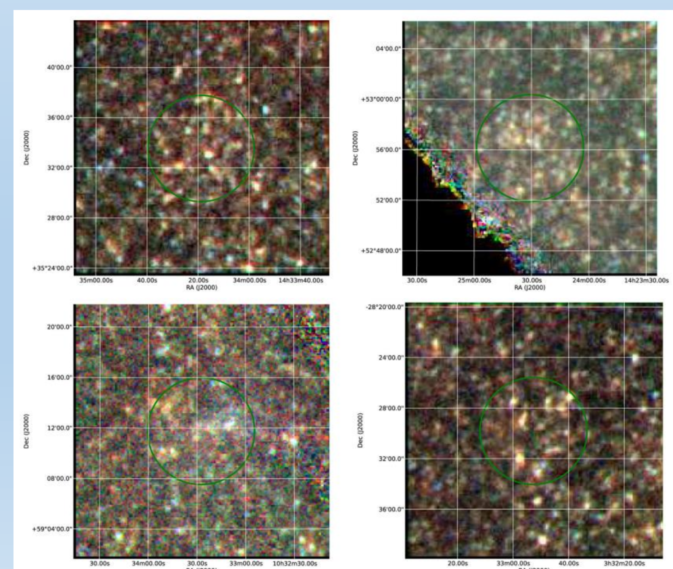
Galaxy (proto)cluster at high z > 1.5

At z<1 relatively large samples of galaxy clusters are known and their properties well understood.

At z>1.5, close to their epoch of formation, few (proto)clusters are safely known. Ideal to construct high-z samples selected with techniques catching (proto)clusters in different evolutionary stages.
Recently exploited possibility: dust emission in infrared or sub-mm, during intense phases of Star Formation

Planck+Herschel satellites identified hundreds of "clumps" suggesting SFRD > 1000 $M_{\odot}$ yr^{-1} Mpc^{-3}

Question: are these objects predicted by present day cosmological simulations?



2° sample application of GRASIL3D: Granato+ MNRAS 2015

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The early phases of galaxy clusters formation in IR: coupling hydrodynamical simulations with GRASIL-3D

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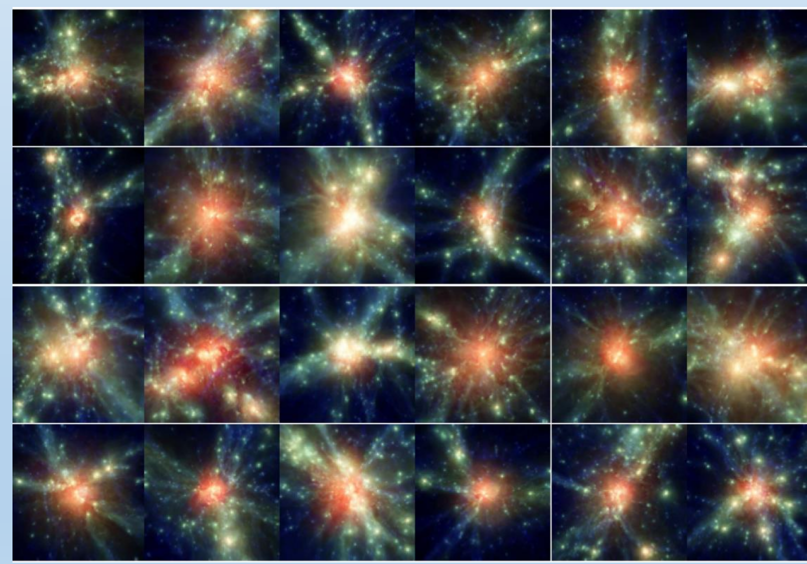
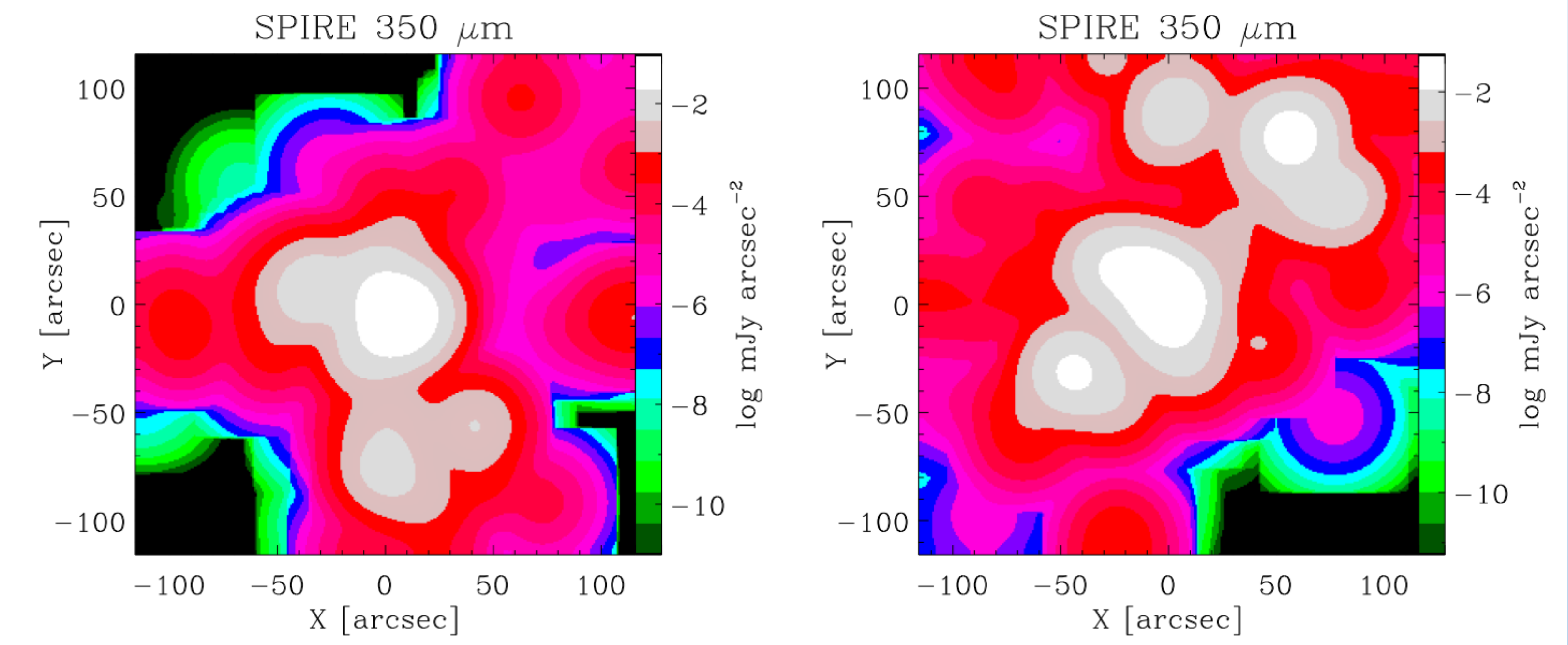
DIANOGA SET: 24 most massive clusters (M_{200} > 1e15 h^{-1} $M_{\odot}$ at z=0) selected from Parent gravity only sims, box 1 Gpc h^{-1}, re-simulated at higher resolution in boxes of about 60 Mpc, including baryonic physics



The proto-cluster regions of 2 Mpc (~ Planck beam) from snapshots at z 0.75 to 4 (where SF and thus dust reprocessing is high), postprocessd with GRASIL3D to produce images and SEDs

Granato+ MNRAS 2015

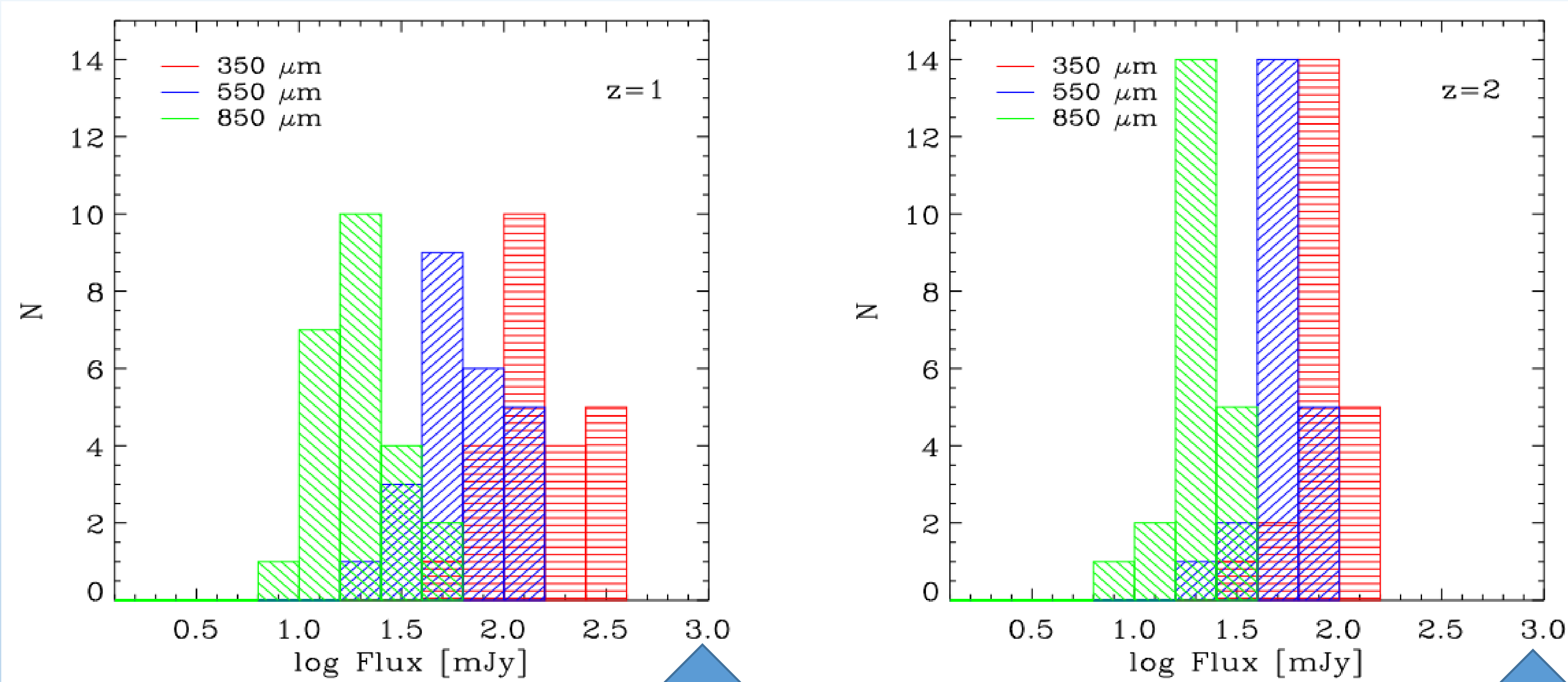
Radiative transfer GRASIL3D images of the two brightest simulated clusters at z=2 and $350\ \mu m$, convolved with Herschel PSF (25 arcsec)



Only white spots are slightly above Herschel survey limit

At odd with hints from observations (e.g. Clements+2014; Planck collaboration XXVII 2015)

Predicted distributions of sub-mm fluxes with GRASIL-3D



Well below the ~1 Jy fluxes @350 μm of the 4 clusters (or “clumps”) identified by Clements+14 over 90 sq. degrees, with photo-z 0.8 to 2.2

Too gentle SF (and little variance among clusters) at high z but (still) too much stellar mass at z=0

Result independent of details of radiative transfer

(Ragone-Figueroa+ 2013)

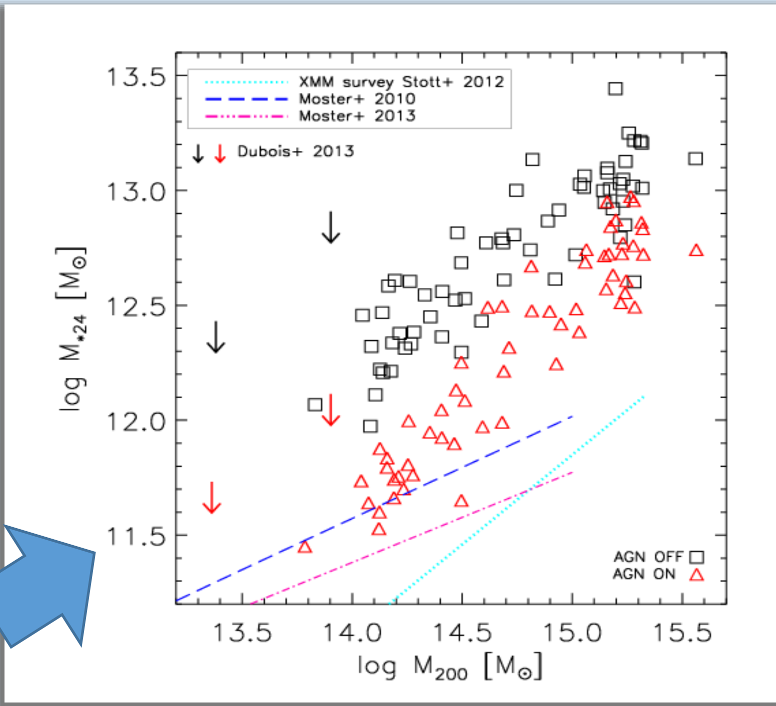
Insufficient peaks of SF of the simulated (proto)cluster:

data suggest up to $1.5 \times 10^4\ M_\odot/yr$

in simulation $< 2 \times 10^3\ M_\odot/yr$

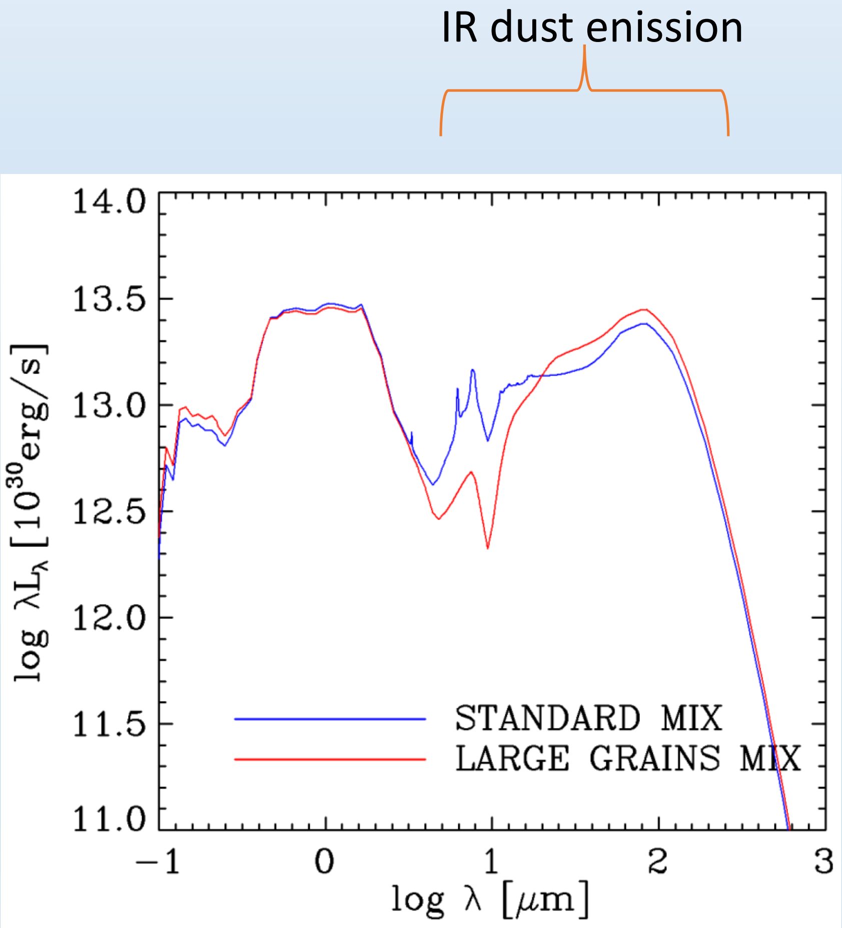
Independent indications of such SFRD

Despite this, final mass in BCGs is too large, even with AGN FB



Next step: including a treatment of evolution of dust properties in the simulation

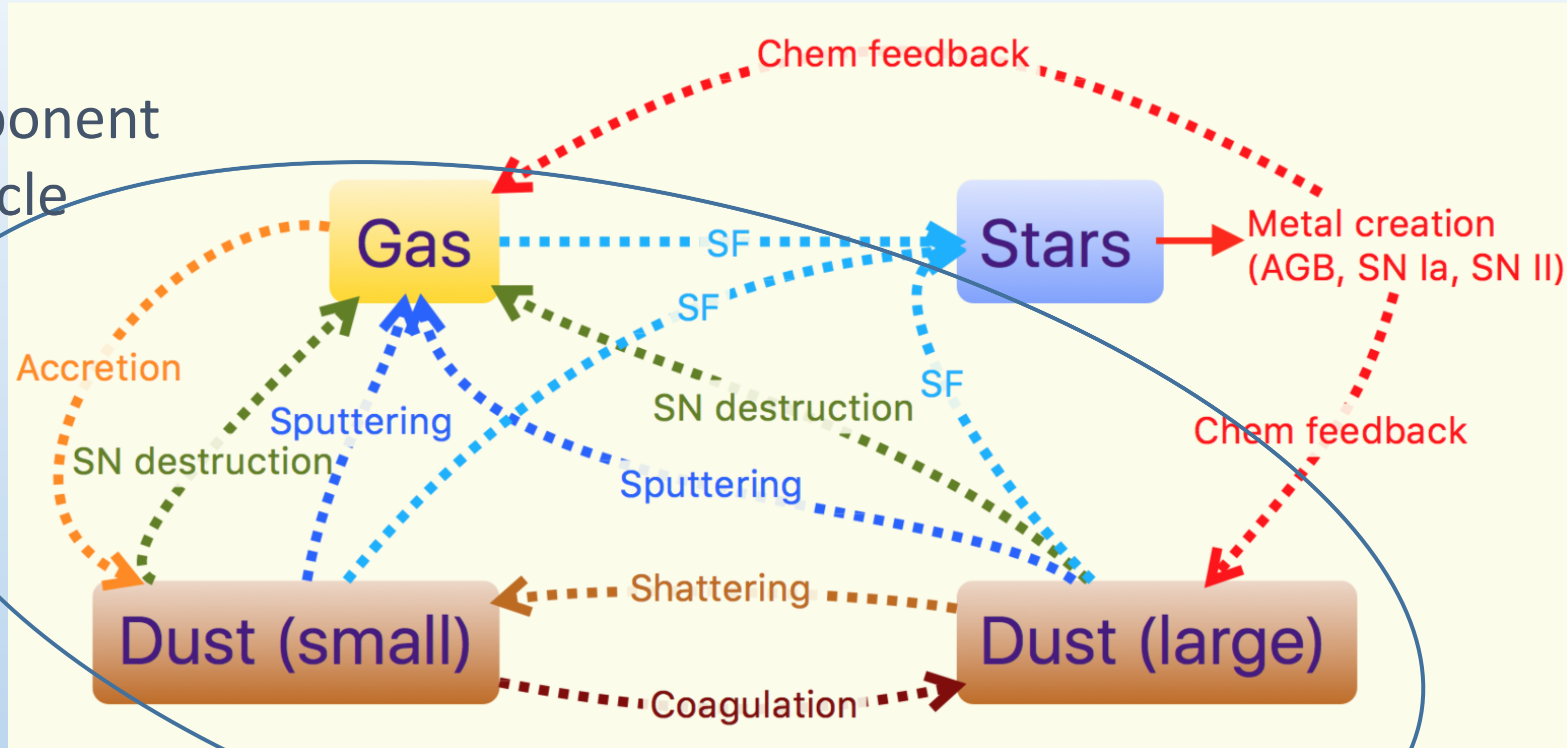
- The radiative effects of dust strongly depend on the physical and chemical properties of dust grains
- Most computations adopt models of the dust grain mixture (composition and size distribution) derived to explain some “average” properties of MW dust
- However it is expected and observed that these properties change from galaxy to galaxy and even within different environments of the MW



Modeling Dust Evolution in P-GADGET3

Eda Gjergo[1,2], Gian Luigi Granato[1], Cinthia Ragone-Figueroa[1,3], Giuseppe Murante[1].

Multicomponent "gas" particle



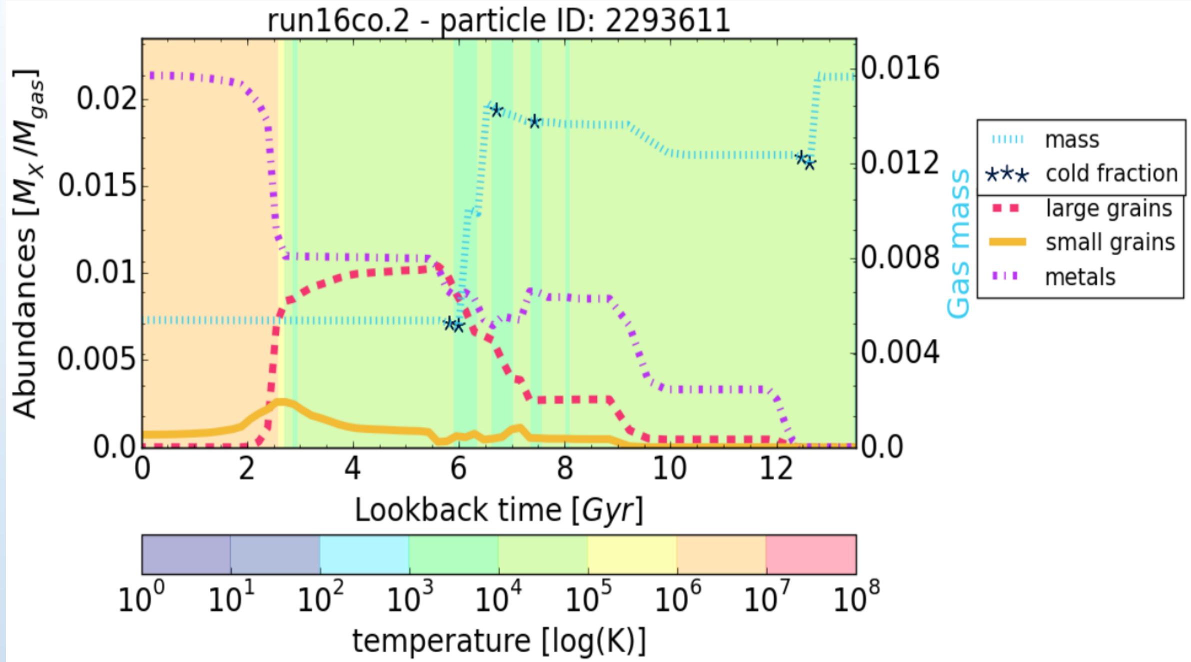
- We recently completed an implementation of dust evolution in our version of P-Gadget3.
- Evolution of "gas" particles over code time-steps with SAM methods;
- We predict abundances of small and large, carbon and silicate dust grains (2x2=4 dust abundances)

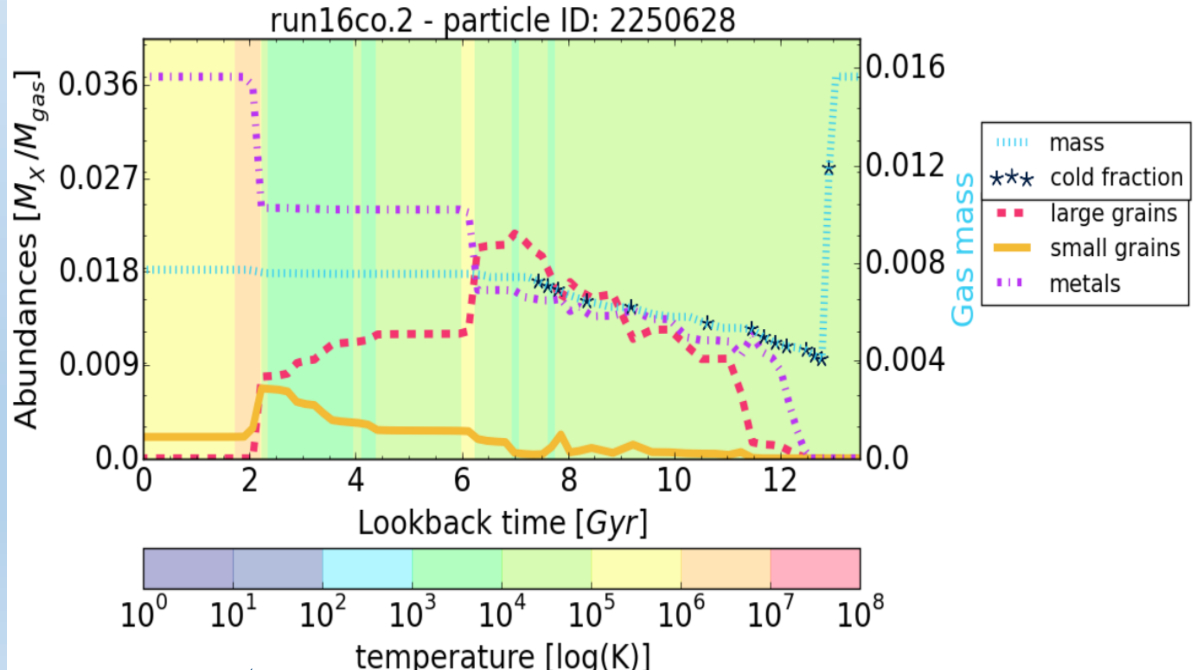
Examples of evolution of the various components in 2 gas particles

At times the dust abundance grows more than the metallicity due to the important role of accretion in the ISM

When particles are dense and star forming, small grains disappears due to efficient coagulation. If not, shattering can win.

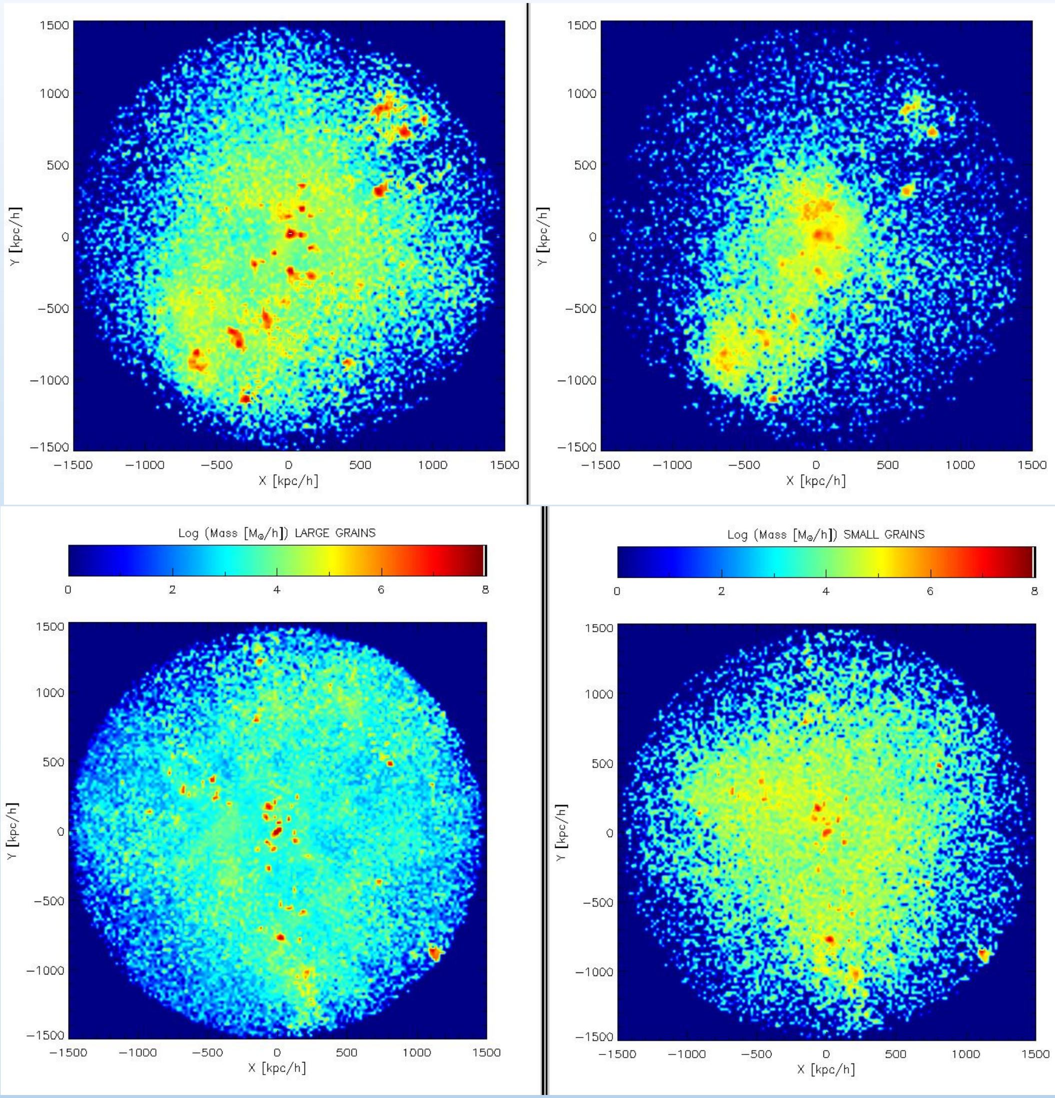
Thermal sputtering destroys grains at T>1E6 K





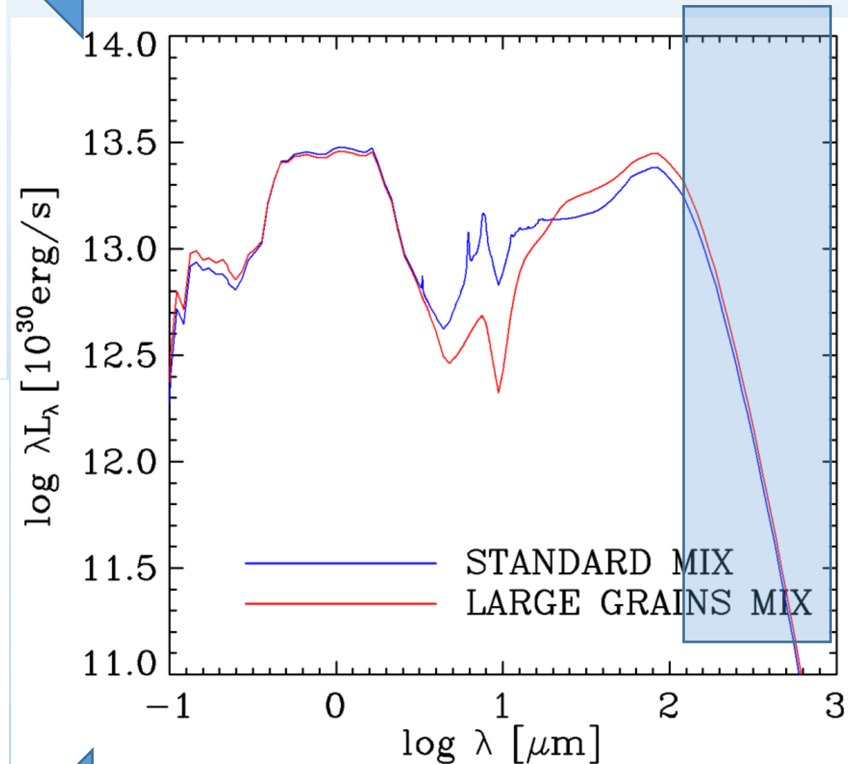
arrow of time

DUST MASS DENSITY MAPS WITHIN Rvir



Z=1

IR dust emission



Z=0

LARGE GRAINS

SMALL GRAINS

Small grains abundant only at late time

SED below 100 μm is affected

Conclusion

A proper treatment of dust effects in galaxy formation simulations is in its infancy, but it is strongly required and rapidly evolving

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