The early phases of galaxy clusters formation in IR: coupling hydrodynamical simulations with GRASIL3D

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Brightest cluster galaxies in cosmological simulations: achievements and limitations of active galactic nuclei feedback models

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GRASIL-3D: an implementation of dust effects in the SEDs of simulated galaxies

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SIMULATIONS
The Clusters Sample

The 24 most massive clusters (masses $M_{200} > 1e15\ h^{-1}\ M_{\odot}$) extracted from a parent simulation (gravity only) having box of 1 Gpc h^{-1}

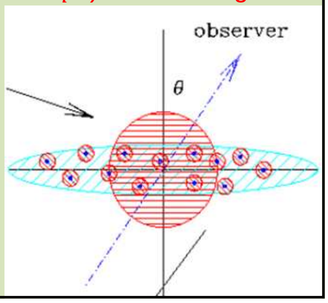
Re-simulated with custom version of Gadget-3, including hydrodynamics and sub-resolution baryonic physics:
Cooling, Star Formation, SN Feedback, AGN Thermal Feedback

softening 5 h^{-1} kpc; $M_{DM} = 8.5e8\ h^{-1}\ M_{\odot}$; $M_{gas,ini}=1.5e8\ h^{-1}\ M_{\odot}$

(proto)cluster regions of physical sizes of 2000 kpc from snapshots at z 0.75 to 3 (where SF and thus dust reprocessing is high) post-processed with GRASIL3D, to produce images and SEDs

Dust reprocessing in simulations

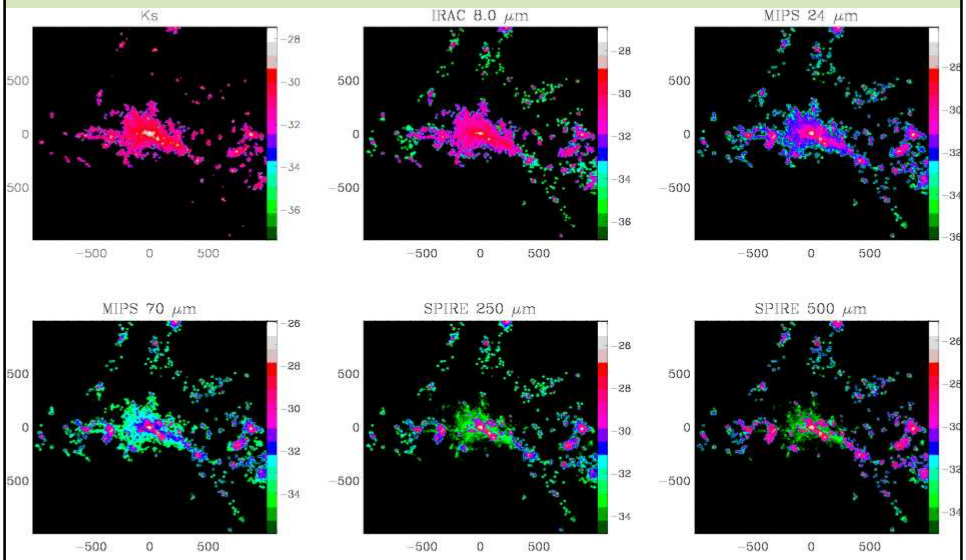
- Radiative transfer treatment of dust reprocessing in simulations demands further “sub-resolution” modelling:
- Stars are born within dense, optically thick Molecular Clouds (MCs) and gradually escape over timescales of 3-30 10^6 ys;
- Bright stars younger than this very much affected by dust reprocessing within MCs;
- Stars older than this, much less affected by dust associated with diffuse ISM (cirrus);
- Stellar radiation suffers and age-dependent reprocessing, which is the reason why dust reprocessing increases with specific star formation;
- But no hope to resolve MCs ($M < 10^5 - 10^6\ M_\odot$; $R < 50\ pc$) in cosmological simulations;



“sub-resolution” radiative transfer with GRASIL3D: 4 more parameters

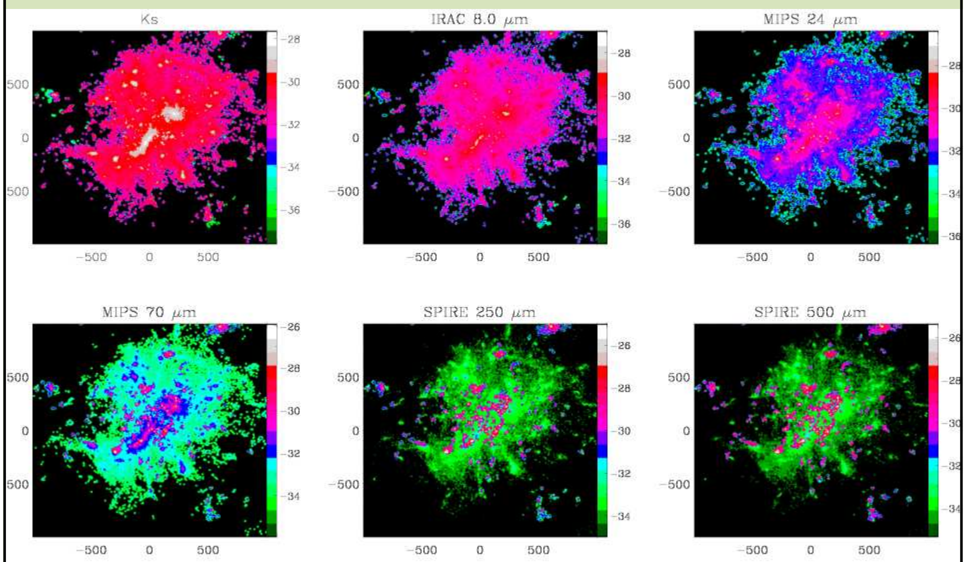
- Assume a log-normal PDF for un-resolved gas densities, with mean given by the local gas density from the simulation and $\sigma \sim 2-3$ (a first parameter); Suggested by very high resolution studies;
- Assume that gas above a given density threshold in this distribution (a second parameter) is in MCs;
- This allows to compute the fraction of gas which is in MCs.
- Stars particles younger than a certain age (a third parameter) are assumed to radiate inside molecular clouds of mass *M* and radius *R*. The fourth parameter is M/R^2, which sets the MC optical depth
- Radiative transfer is treated separately in the MCs and in the cirrus (resolved)

Images of one cluster at z=2 in various NIR to sub-mm bands



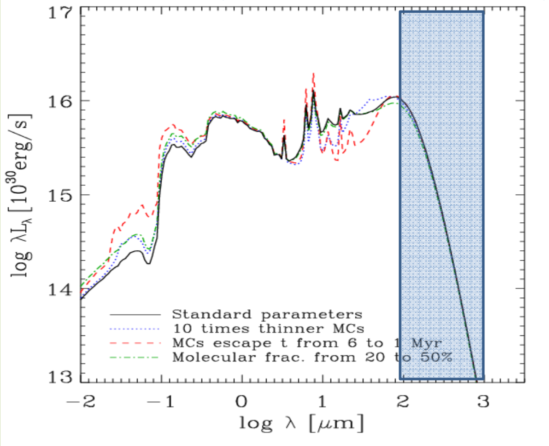
Flux units log10 of erg/s/Hz/arcsec^2. Box size 2000 kpc physical, close to the Planck HFI beam at z 1 to 3. No telescope effects.

Same cluster at z=1 in various NIR to sub-mm bands



Flux units log10 of erg/s/Hz/arcsec^2. Box size 2000 kpc physical, close to the Planck HFI beam at z 1 to 3. No telescope effects.

Dependence on G3D parameters



Above ~ $100\ \mu m$ very little dependence on uncertain parameters introduced to describe "sub-resolution radiative transfer".

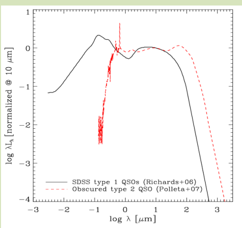
Below ~ $100\ \mu m$ instead proper care is required

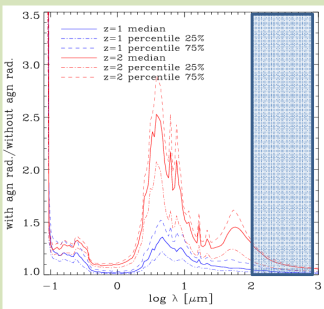
Parameter	Adopted value	Reasonable range	Short description
t_0	6 Myr	1 to 30 Myr	Escape timescale of stars from parent MCs
M_{MC}/R^2_{MC}	$5\,10^5\,M_\odot/(10\,pc)^2$	10^5 to $10^6\,M_\odot/(10\,pc)^2$	Determines MCs optical depth
$\rho_{MC,thres}$	$1\,M_\odot/pc^3$	0.3 to 3 $M_\odot/pc^3$	Threshold density for gas to be considered in MC phase
σ	2.5	2 to 3	Dispersion of the sub-resolution PDF of gas densities

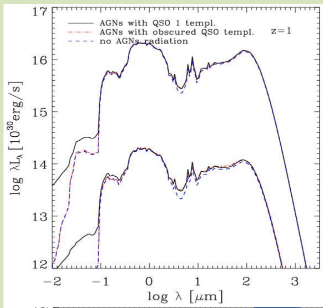
The radiative effect of AGN activity

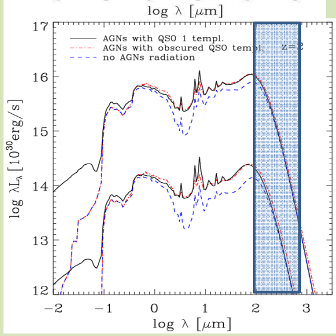
Above ~ $100\ \mu m$ the dust emission is powered by stars.

Below ~ $100\ \mu m$ the contribution from accretion onto SMBH may be important at high z



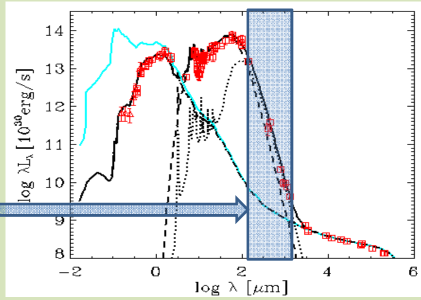




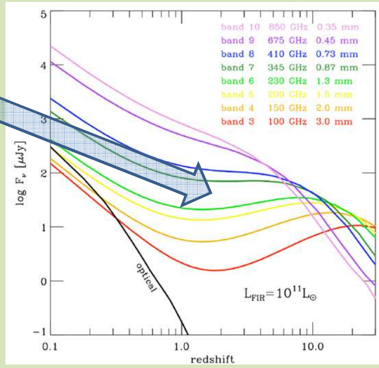


Comparison with observations
Why far-IR and sub-mm?

Sub-mm surveys are very effective in detecting obscured star formation at high-z, due to the expected steep shape of the SED from about 100 to 1000 micron rest frame



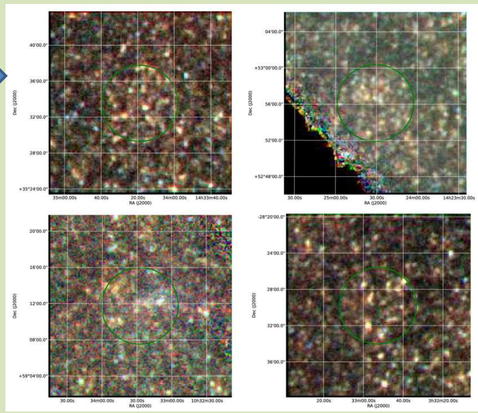
The “k-correction” compensates for cosmological dimming, so that the observed flux nearly constant between z=1 and 10



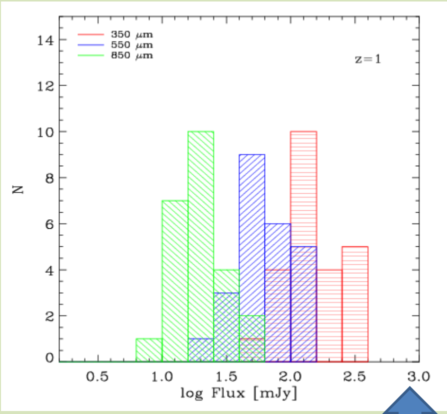
Comparison with observations?

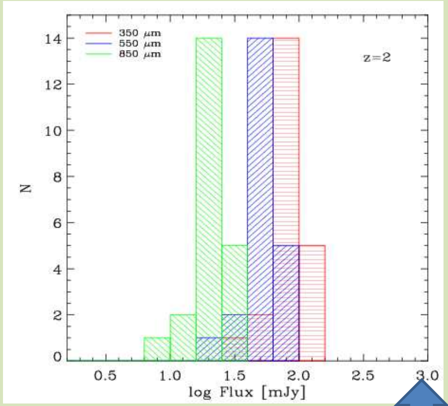
- Clements+2014 identified 4 candidate proto-clusters undergoing a violent phase of very obscured star formation (estimated from a few 10^3 to 10^4 M/yr over regions of 2 Mpc), combining sub-mm Planck and Herschel maps (250 to 850 micron), over an area of 90 sq degrees;
- Their photo-z are between z=0.76 and z=2.2
- Are such sources expected on the basis of cosmological simulations?

Three colour Herschel images for Planck clumps. Blue = 250 μm, Green = 350 μm and Red = 500 μm



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

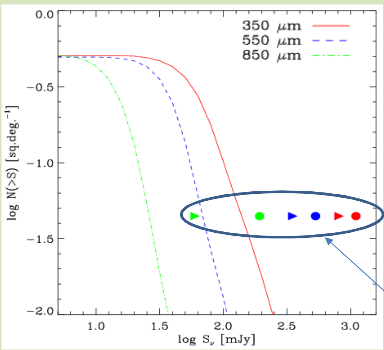




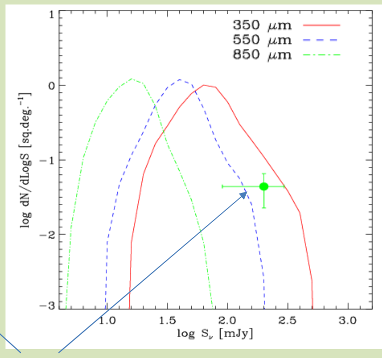
Well below the Jy level of the 4 clusters ("clumps") identified by Clements+14 over 90 sq. degrees, with photo-z 0.8 to 2.2

Predicted contribution to number counts in the Planck-HFI beam

Integral number counts



differential number counts



data

no way to find "our" simulated proto-clusters at flux levels of 1 Jy at sub-mm.

Too gentle SF at high z
but (still) too much stellar mass at z=0

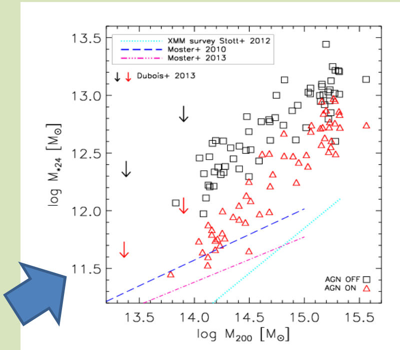
Result independent of details of radiative transfer

AGN cannot help in raising far-IR and sub-mm

It is due to insufficient peaks of SF of the simulated (proto)cluster:
data suggest up to $1.5 \times 10^4\ M_{\odot}/yr$
in simulation < $2 \times 10^3\ M_{\odot}/yr$

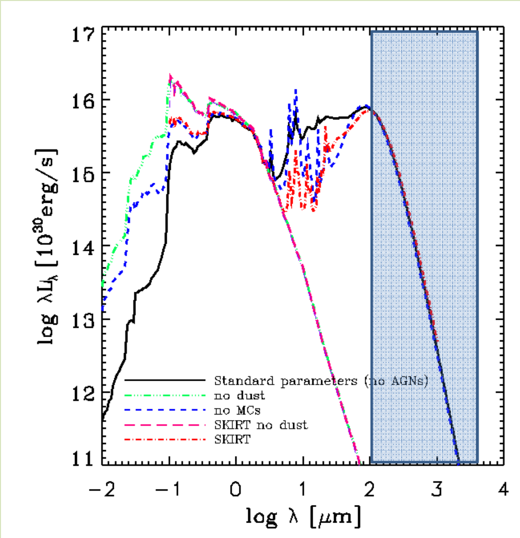
Problem worsened by the fact that final mass in BCGs is too large, even with AGN FB

(Ragone-Figueroa+ 2013;
Her talk on Friday



Summary and conclusions

- Cosmological simulations of massive galaxy cluster formation post-processed with GRASIL-3D to predict their panchromatic properties, focusing on IR arising from dust reprocessing, expected to be important in the high z actively star forming phase;
- Above 100 micron, weak dependence on additional assumptions required by the post-processing. Also AGN contribution it minor: emission powered by stars;
- Predicted sub-mm fluxes too low by a factor > a few to explain recent findings. Simulated (proto)clusters regions never attain SFR rates > several thousands, suggested by some observation;
- Problem exacerbated by the persisting overproduction of stars at z=0 in massive systems (Ragone-Figueroa+ 2014).
- Observations suggests that z > 1.5 pop of clusters contains examples with both extreme as well as very low star formation activity, while in our simulated clusters these two cases are clearly under-represented.
- Problem likely shared by most if not all cosmological simulations



log λL_λ [10^{30}erg/s]
log λ [μm]
Standard parameters (no AGNs)
no dust
no MCs
SKIRT no dust
SKIRT