On the Origin of Dust in Galaxy Clusters at Low to Intermediate Redsfhift

Astro@Ts - Trieste, Italy

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WHAT IS DUST?

- Cosmic dust refers to small solid particles
  - $\sim$1% of the interstellar medium
  - with a range from $\sim$ 1nm to $\lesssim 1\mu$m.
  - mostly composed of **silicates** and **carbon** dust.

FIGURE: ©Hubble Space Telescope. Optical bands (left) Infrared bands (right).

- Dust reprocesses light (size, mass & composition dominant).
  - It is opaque in the UV and optical bands
  - But it is transparent and emits light in the IR.

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Why does dust matter?

- Observations of spectral energy distributions (SEDs)

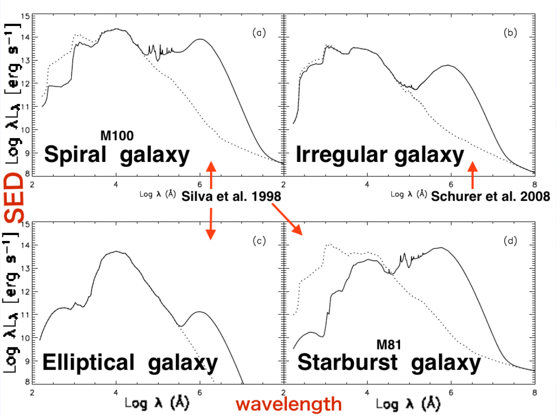
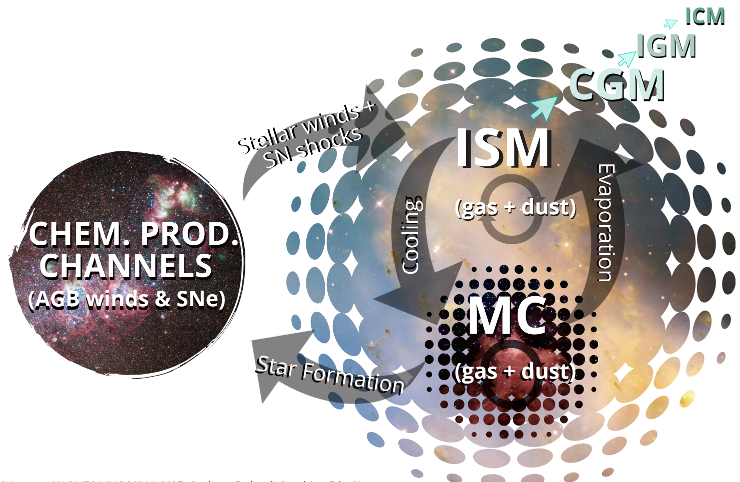


Figure: From Schurer A., PhD Thesis, 2009, Graph which shows the effect of dust on the SED of local galaxies. Solid lines: SED after dust reprocessing. Dashed lines: the intrinsic SED.

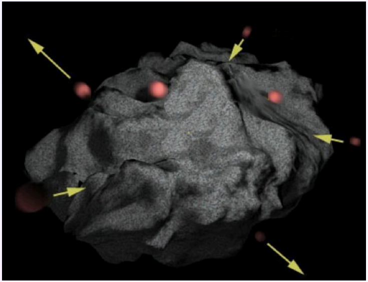
- H_2 catalysis → molecular cloud cooling → star formation → galaxy evolution → dust is important!

Dust Cycle

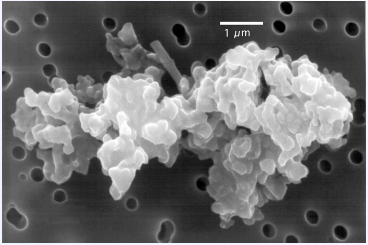


© Images: NASA/ESA (NGC4214, M27, Cepheus B cloud) Graphics: Eda Gjergo

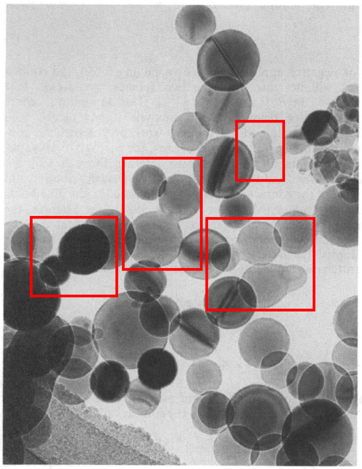
Dust Grain Physical Interactions



gas-grain (molecular cloud: accretion)



Scanning electron microscope image of an interplanetary dust (Brownlee & Jessberger, 2001).



grain-grain (molecular cloud: coagulation)

(Iijima et al., 1987): Electromicrograph showing coagulated spherical Si particles.

How is dust different in the ICM?

Hostile environment, permeated with highly energetic ions and radiation.

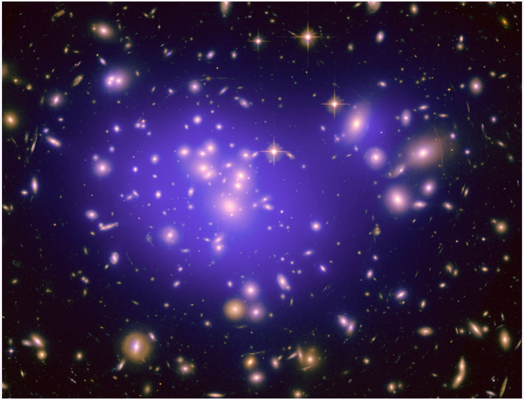


FIGURE: Galaxy Cluster Abell 1689. Credit: NASA, ESA, E. Jullo (JPL), P. Natarajan (Yale), & J.-P. Kneib (LAM, CNRS) Acknowledgment: H. Ford and N. Benetiz (JHU), & T. Broadhurst (Tel Aviv)

Dust does not affect Planck cosmology, but obscures up to 1/10 of clusters $z < 1$ (Melin+18), but as it disrupts easily through energetic particles it could serve as a probe for phys/dyn ISM/ICM matter interactions.

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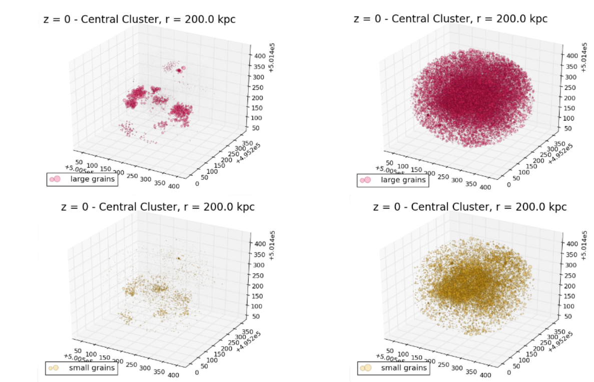
How is dust different in the ICM? Sputtering

$$\tau_{sp} = 5.5 \times 10^{7} \mathrm{yrs} \left(\frac{a}{0.1\,\mu\mathrm{m}} \right) \left(\frac{0.01\,\mathrm{cm}^{-3}}{n_g} \right) \left[\left(\frac{T_0}{T_g} \right)^{\omega} + 1 \right]$$

(Tsai & Mathews '95)



(a) Dust grain distribution in the central cluster.

(b) Dust grain distribution in the central cluster without sputtering.

Figure: From cosmological simulations, with and without sputtering, Gjergo+18.

Summary table of observational papers

Gal. Clus. Obs. Paper[1]	DtG[2]	r_{center}	z range / cluster[3]	Wavelength (instrument)[4]	Method[5]
GLC17	$< 9.5 \times 10^{-6}$	1-5'	$0.06 < z < 0.7$	250, 350, 500 μm (Herschel)	Stacked emission (clean)
PlanckXLIII-16	$(1.93 \pm 0.92)10^{-4}$	15'	$0.01 < z < 1.$	850-60 μm (IRAS/Planck)	Stacked emission (full)
GLC14	$\lesssim 8 \times 10^{-5}$	3 Mpc	$0.05 < z < 0.68$	g-r-i (SDSS-DR9)	Bkgd. extinction
GLC14	$\lesssim 2 \times 10^{-5}$	3 Mpc	$0.05 < z < 0.68$	g-r-i (SDSS-DR9)	Inferred FIR emission
McGee & Balogh (2010)	$\sim 3 \times 10^{-4}$	$\lesssim$ 43 Mpc	$0.1 < z < 0.2$	g-r-i-z/12-100 μm (SDSS/IRAS)	Bkgd. extinction
Roncarelli et al. (2010)	$\lesssim 5 \times 10^{-5}$	< 12'	$0.1 < z < 0.3$	u-g-r-i-z (SDSS-maxBCG)	SED-reconstruction
Kitayama et al. (2009)	$< 10^{-5}$	0.1 Mpc	(Coma cluster)	24, 70, 160 μm (Spitzer)	MIR/FIR emission
Giard et al. (2008)	$\lesssim 10^{-5}$	10'	$0.01 < z < 1$	12-100μm/0.1-2.4keV (IRAS/RASS)	Stacked emission (full)
Muller et al. (2008)	$\lesssim 2 \times 10^{-4}$	1.5 Mpc	$z < 0.5$	650, 910 μm (CFHT)	Bkgd. extinction
Chelouche et al. (2007)	$< 5 \times 10^{-4}$	~ 1 Mpc	$0.1 < z < 0.3$	u-g-r-i-z (SDSS)	Bkgd. extinction.
Stickel et al. (2002)	$\sim 10^{-6}$	0.2 Mpc	(Coma cluster+)	120, 185 μm (ISO)	I_{120}/I_{180}
Stickel et al. (1998)	$(1.66 \pm 1.53)10^{-4}$	0.2 Mpc	(Coma Cluster)	120, 180 μm (ISO)	I_{120}/I_{185}

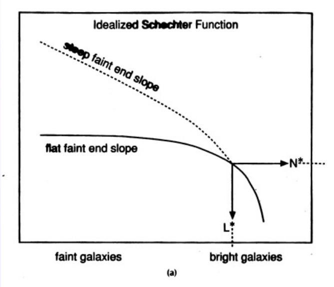
Notice:

- Some studies examine individual clusters, others perform statistics on large cluster samples.
- Notice the range in redshift, cluster radius, and observed wavelength for the various estimates.
- Estimates are based on:
  - Emission fitting of a modified black body spectrum.
  - Extinction in the UV/optical
- In bold are the papers considered in my work.

Methodology: integrate galaxy dust over luminosity functions I

Coauthors: Matteucci F., Palla M., Biviano A., Lacchin E.

- We consider sophisticated monolitic dust evolution models (i.e. Gioannini+17) for
  - elliptical galaxies
  - spiral galaxies
  - irregular galaxies
- We consider the Schechter Luminosity function $\Phi(L) = n^*(L/L^*)^\alpha \, \mathrm{e}^{-(L/L^*)}$ where * denotes its break.

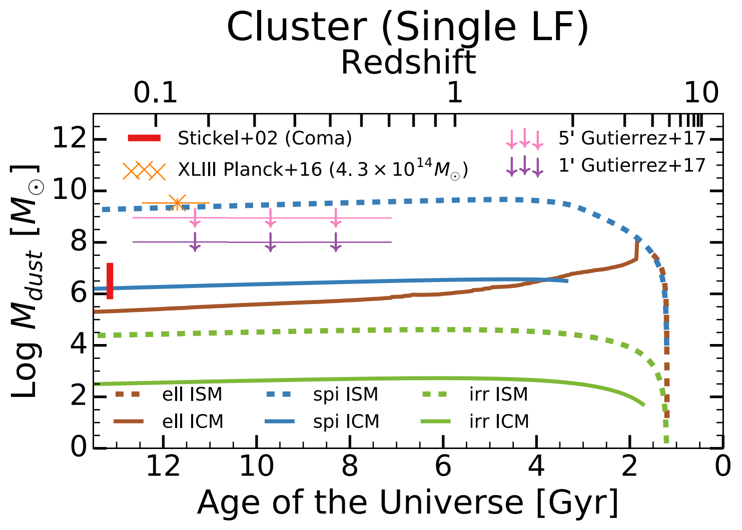


Methodology: integrate galaxy dust over luminosity functions II

- We interpolate, for a few galaxy mass iterations, the galaxy mass to dust mass relation: $M_d = E_i M_G^{\beta_i}$.
- We take advantage of the average galaxy mass-luminosity parameter $K = M/L$ (scalar for each morphology) to obtain the galaxy mass-luminosity relation.
- We integrate the dust masses over the whole luminosity function, following Matteucci & Vettolani (1988), starting from a minimum luminosity L_{min}:

$$M_i\,(> M_{G,min}) = f_{morph} M_i^* n^* \Gamma(1 + \beta_i + \alpha, L_{min}/L^*)$$

Comparison with cluster data



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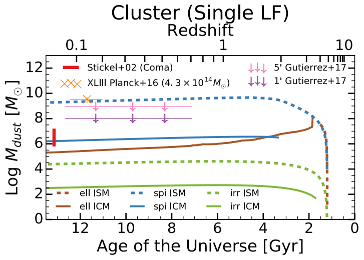
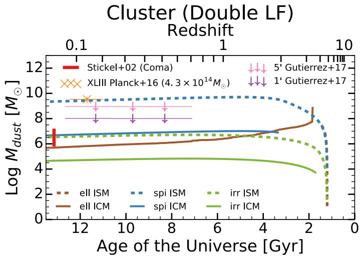
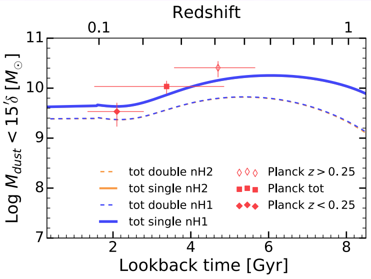
Comparison with cluster data (Single/Double LF)





- WINGs-like median cluster (Moretti+15)
- Gutierrez+17 for clusters of $M_{200} > 10^{14} M_\odot$
  - estimates based on the 350μm Herschel beam signal.
  - with three redshift bins centered around $z = 0.173$, 0.338, and 0.517.

Evolution with radius and redshift



- Evolution of a Coma-like cluster, as would be seen through a 15 arcmin fixed aperture.
  - Radius change follows the NFW profile, with a concentration $c = 0.85$ for spirals and irregulars, and $c = 4$ for ellipticals.
  - Slight redshift evolution that follows Andreon (2004).
  - Galaxy parameter dependence negligible.
- Planck data (XLIII Planck+16) – stacked signal integrated over a fixed aperture of 15':
  - $z < 0.25$: $M_{200} \simeq 4.3 \times 10^{14} M_\odot$
  - total: $M_{200} \simeq 5.6 \times 10^{14} M_\odot$
  - $z > 0.25$: $M_{200} \simeq 7.0 \times 10^{14} M_\odot$

Parameter dependence

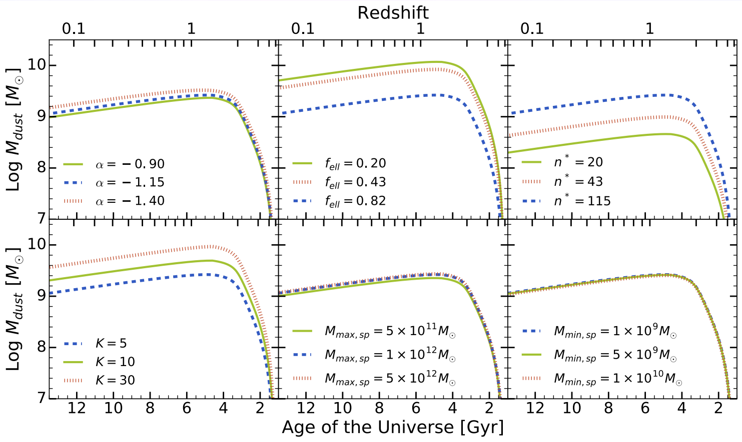


FIGURE: Parameter dependence of the dust mass evolution on the power of the luminosity function α (*top left*), the fraction of elliptical galaxies on the total (*top center*), the cluster richness n^* (*top right*), the mass-to-luminosity ratio K (*bottom left*), the upper (*bottom center*) and lower (*bottom right*) mass limit for spiral galaxies.

Summary and Future prospects

- There is very little dust in the intracluster medium of local clusters.
  - Dust abundance limits in individual clusters indistinguishable from our Galaxy's cirrus fluctuations.
- Stacked data analyses over large cluster samples at redshifts $0 < z < 1$ reveal there is a net dust mass in the intracluster medium.
  - Dust has to be of recent origin due to efficient destruction by sputtering in the harsh ICM environment.
- The bulk of cluster dust resides within spiral galaxies.
  - Contribution by irregular galaxies negligible even in steep double luminosity functions.
- Integrating dust (within galaxies or ejected/stripped) over luminosity functions produces results consistent with observations.
  - Results are stable within the acceptable parameter ranges.

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