Sweeping up the dust in the low-redshift Universe: Stacking in the Herschel-ATLAS

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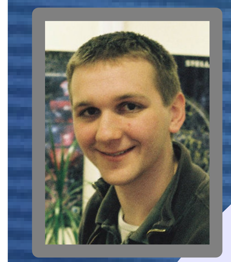
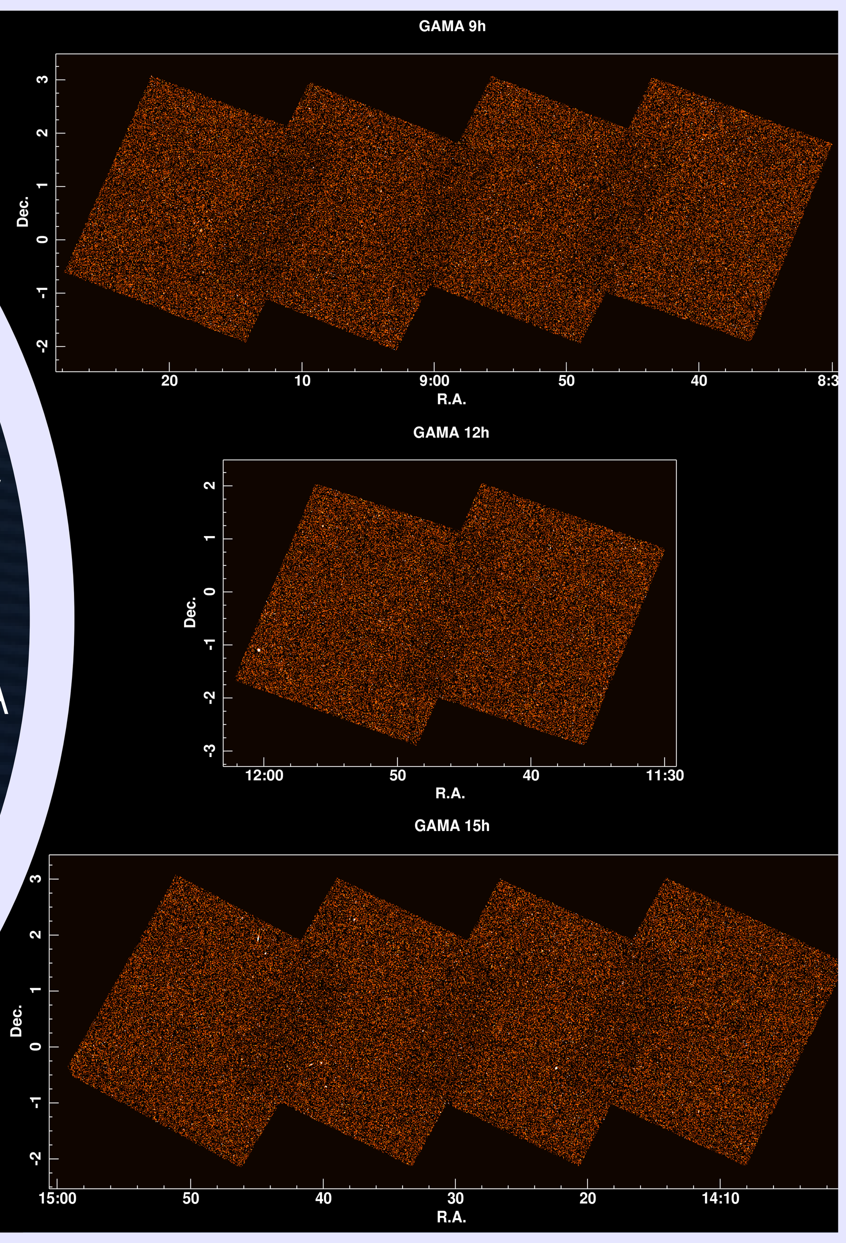


The Herschel-ATLAS survey provides the largest ever map of the sub-mm sky. We have used over 100 square degrees of this revolutionary data set, with multi-wavelength photometry & redshifts from GAMA, to conduct an unbiased census of the dust mass in optically selected galaxies up to z=0.35, using stacking to reach below the noise and confusion limits (Bourne et al. 2012).

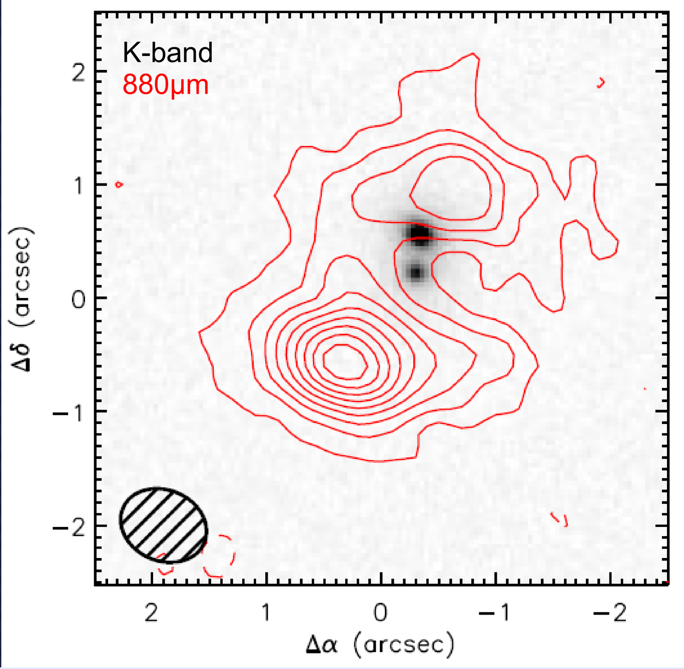
Stacking 80,000 galaxies in the sub-mm

We stack SPIRE images of the three equatorial GAMA fields (right) at 250, 350 & 500μm, binning the galaxy sample by redshift, stellar mass and colour, and measure the relationships between typical dust and stellar properties of normal galaxies across the optical colour-magnitude diagram. We carefully take account of confusion issues resulting from clustering and lensing.



Lensing bias

We statistically correct our results for the expected contamination from strong lensing by red galaxies; this leads to corrections of 10-30% but more importantly increased errors. For example, this SMA image from Bussmann et al. (2012) demonstrates a lensing system in H-ATLAS. All of the sub-millimetre emission in this image (red contours) comes from the high-redshift lensed SMG, but in the SPIRE beam it is indistinguishable from the foreground elliptical galaxies (shown in greyscale) which in fact contribute negligible sub-mm flux.



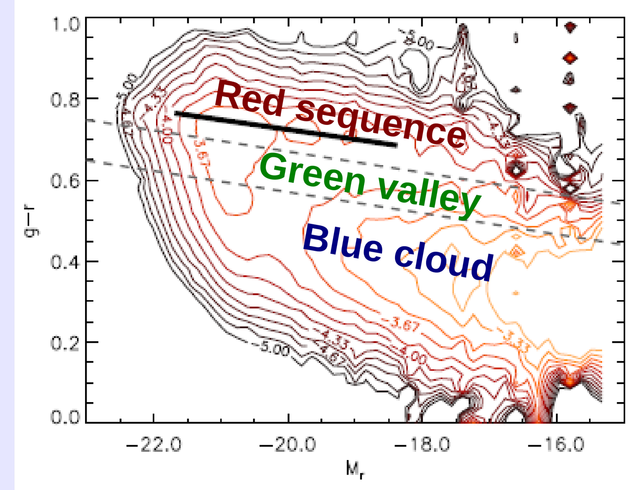
How much dust does a typical galaxy hold?

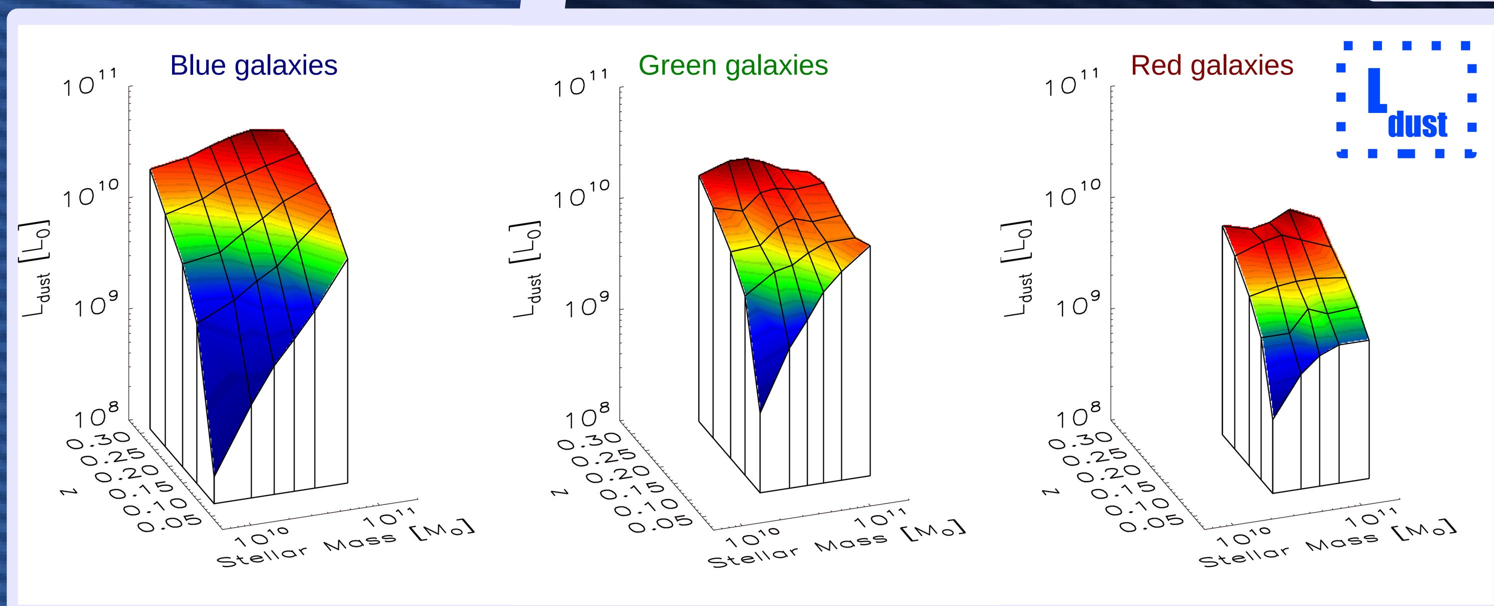
Dust comprises just a fraction of a percent of the mass density of the Universe, yet it holds the key to our understanding of some of the most important astrophysical processes - star formation and galaxy evolution.

IRAS and Spitzer have allowed us to understand emission from warm dust heated by young stars in luminous star-forming galaxies, but sub-mm instruments like SCUBA have shown us that most of the dust mass is colder and emits at longer wavelengths (Dunne et al. 2000). However, it has always been too difficult to map a large volume of the low-redshift Universe in the sub-mm, and our knowledge of cold dust in galaxies has been restricted to small samples suffering from selection bias. Now for the first time Herschel provides the capability to map large areas of the sky in far-IR to sub-mm wavebands spanning the peak of the SED.

Sub-mm luminosities across the colour-magnitude diagram

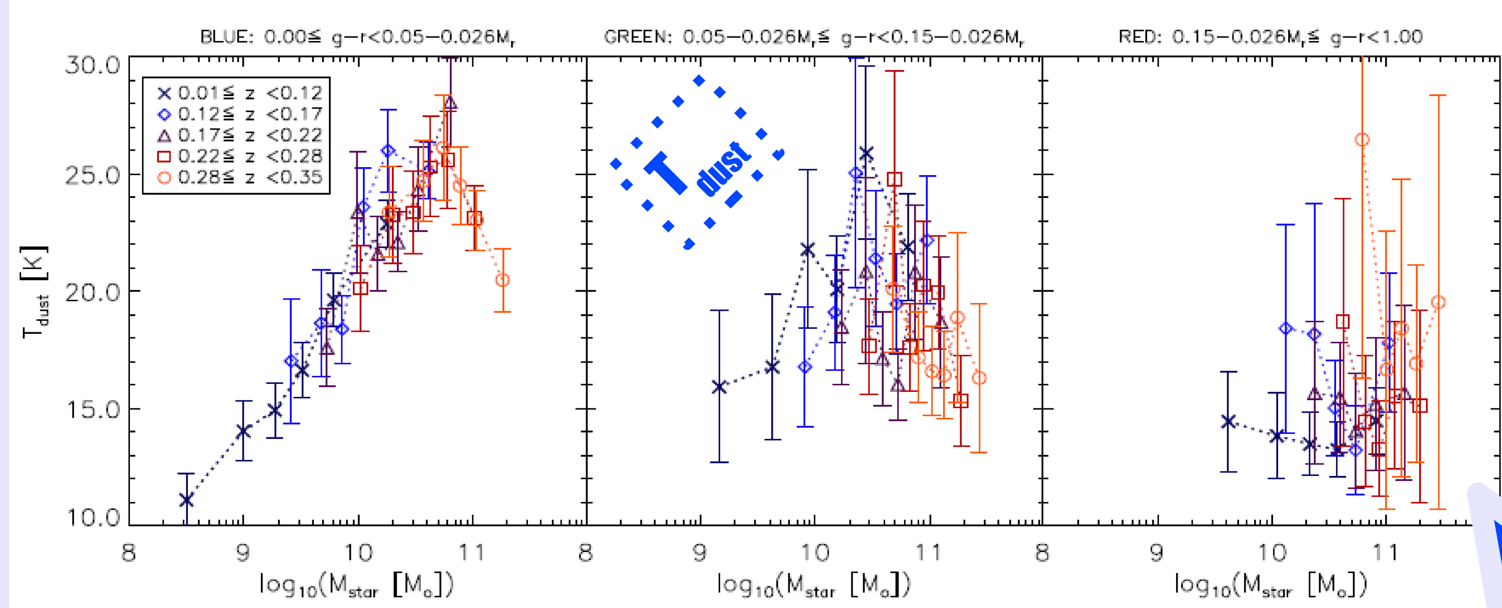
Stacking sub-mm luminosities in bins of redshift, stellar mass and optical colour, we fit models for total dust luminosity. Normalisation is highly dependent on the dust temperature and the templates assumed. Results below use templates derived from H-ATLAS detected sources (Smith et al. 2012).





Luminosities may be higher than these in galaxies with more warm dust that is poorly constrained by SPIRE. Results show:

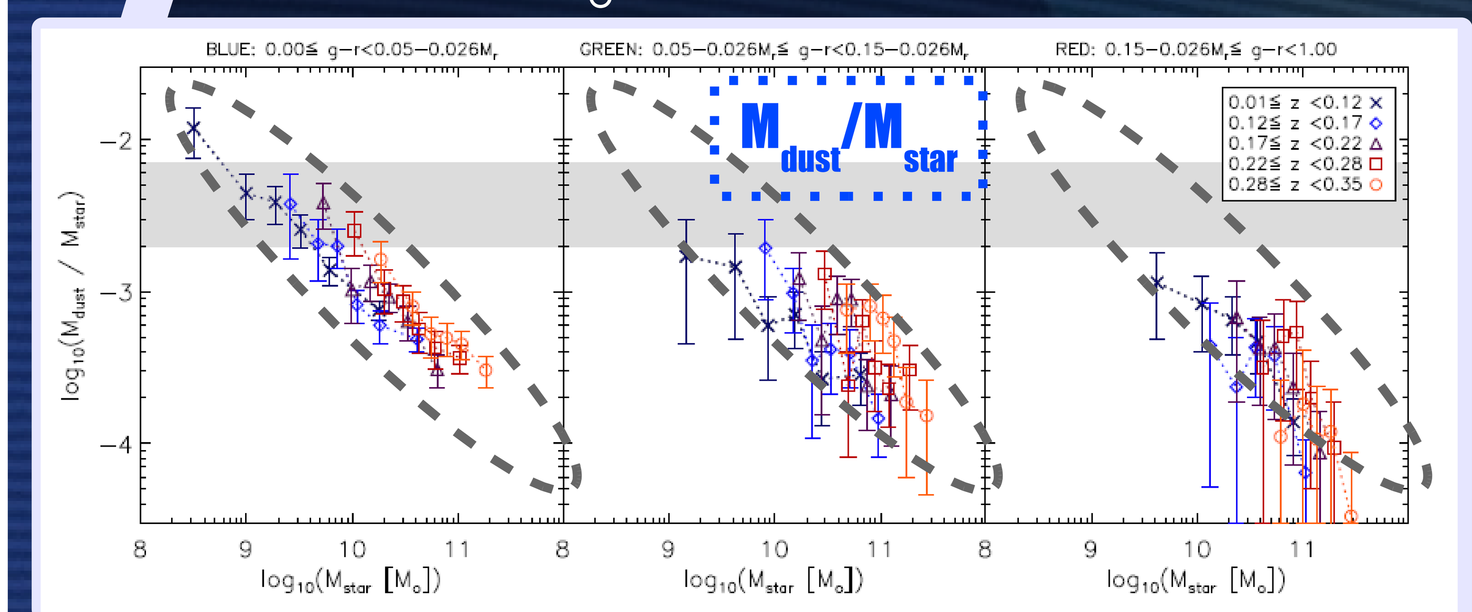
- Luminosities increase with stellar mass for blue and green galaxies at low stellar mass/low z
- Luminosities evolve strongly with redshift for all bins
- Red galaxies are up to an order of magnitude less luminous than blue galaxies of the same mass



Strong evolution in the dust masses of all galaxies

Dust masses can be calculated assuming that the SED at wavelengths >200μm is described by a single grey-body β =2 and temperatures given by the fits shown to the right. The figure below shows the stacked dust-to-stellar mass ratio in bins. Main results:

- The typical dust fraction is low compared to H-ATLAS detected sources in the same redshift range (shaded grey; Dunne et al. 2011).
- It is strongly anti-correlated with stellar mass, but appears to be less dependent on colour than might be expected – it is not as large as the order-of-magnitude difference in luminosities of red and blue galaxies.



Errors for red galaxies in the higher redshift bins are increased by the uncertainty of the lensing contamination (see box above), and scatter is introduced by a variable temperature in the fit, but assuming a non-evolving temperature (see right)...

- The dust fraction in galaxies of all colours & masses evolves strongly.

Do red galaxies have less dust, or simply colder dust?

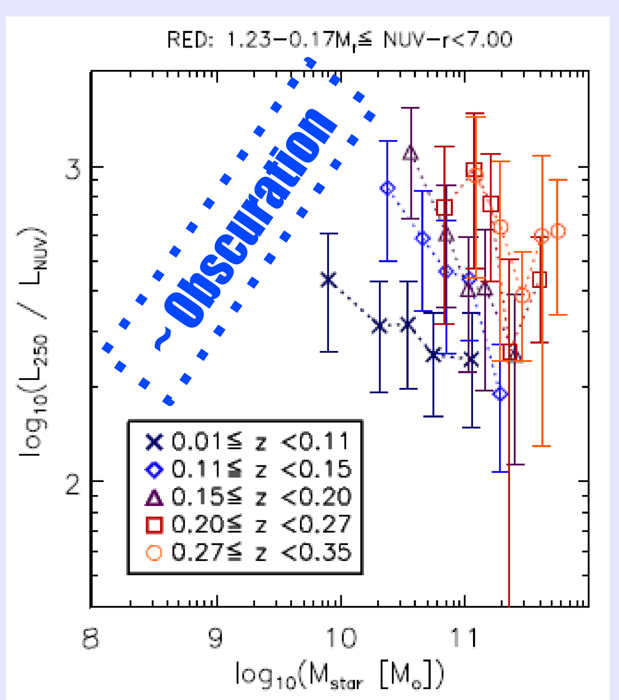
The conversion from sub-mm luminosity to dust mass depends on the shape of the SED. We assumed constant emissivity index β =2 and fitted temperatures to observed fluxes as shown in the plot above. We find:

- Dust temperature depends strongly on colour (from blue galaxies in the left panel to red on the right)
- A clear correlation of temperature with stellar mass in blue galaxies (left panel).
- No evidence for any dependence on redshift, indicating that luminosity evolution is driven by dust mass evolution.

However, large errors on the red stacks due to lensing uncertainties may hide weak temperature evolution caused by a change in the nature of the red sample (see discussion at left).

The dual personalities of red galaxies

All of this raises the question of whether the red galaxies sampled are quiescent red-sequence systems or obscured star-forming systems. UV-optical colours are better for dividing star-forming (blue) from passive (red) galaxies, and using these we confirmed the results obtained from optical colours. We also found that red galaxies in our sample occupy the "quiescent" region of the UVJ colour-colour diagram. On the other hand, it appears that the obscuration of star-formation in red galaxies may increase with redshift, as shown by the stacked 250μm/NUV luminosity ratio (see right); however this may not be a good tracer of obscured star-formation if the 250μm-emitting dust is heated by older stellar populations.



Bourne, N., et al. (2012), MN in press. ArXiv 1201.1916
Bussmann, S., et al. (2012), ApJ submitted
Dunne, L., et al. (2000) MNRAS 315, 115
Dunne, L., et al. (2011) MNRAS 417, 1510
Smith, D.J.B., et al. (2012), MNRAS submitted