A Census of Dust in Optically Selected Galaxies: Evidence for Evolution from the Herschel-ATLAS and GAMA Surveys

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ABSTRACT

We use the largest ever sub-millimetre sky survey to explore how the dust content of optically selected galaxies depends on colour, stellar mass and redshift. Using a stacking technique we find that galaxies with blue and red optical colours have fundamentally different dust properties. The mass and temperature of cold dust in galaxies are found to depend on stellar mass and colour. We also find strong evolutionary trends in the dust luminosity of galaxies selected by stellar mass. Our results imply a significant increase in the dust content of all galaxies from redshift 0 – 0.35.

INTRODUCTION

The Herschel-ATLAS[1] is the first truly large-area survey of the sub-millimetre sky. It offers a unique opportunity to explore the dust content of an unprecedented sample of galaxies. We exploit H-ATLAS SPIRE imaging in three sub-mm bands covering 126 deg^2 at R.A. 9^h, 12^h & 15^h, Dec. 0°, coinciding with the GAMA survey[2,3] to provide redshifts and UV-NIR photometry from GALEX, SDSS and UKIDSS.

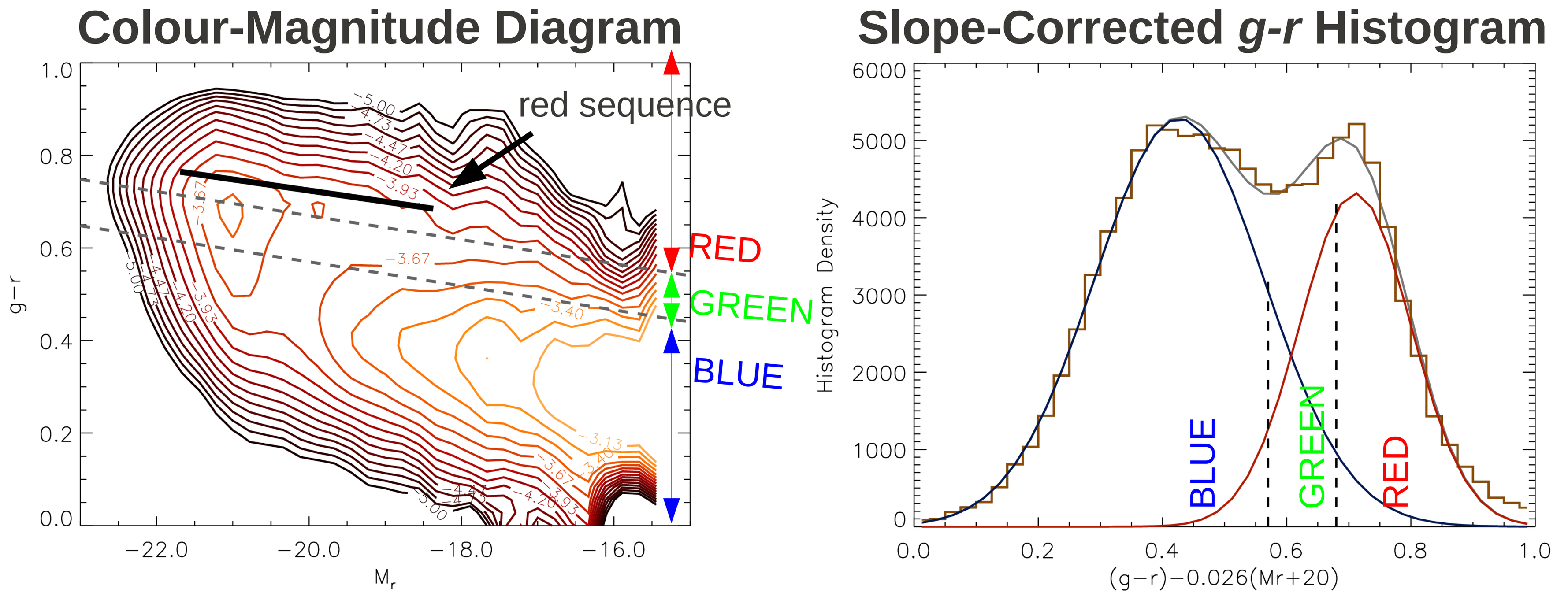

Figure 1: The $1/V_{max}$ weighted distribution of rest-frame *g-r* vs. absolute magnitude *Mr* (left) can be fitted by two Gaussian functions in *g-r*, whose means depend on *Mr*. Removing the slope and summing across *Mr* (right), we fit the functions to define red, green and blue colour bins.

STACKING OPTICALLY SELECTED GALAXIES

We select a galaxy sample limited to r < 19.8 from the GAMA catalogue, utilising GAMA spectroscopic redshifts where available and photometric redshifts otherwise. Our sample consists of 80,000 galaxies between redshifts of $0.01<z<0.35$. To investigate sub-mm properties of the full sample, we divide the sample in bins and stack galaxies in each bin. Stacking allows us to measure an average signal for sources beneath the noise and confusion limits of the SPIRE images. We use the median value of fluxes measured as point sources in the SPIRE maps, making reasonable assumptions to correct for blended flux in the stacks. The sample is divided into five redshift bins and three bins of optical colours (Fig.1, 2). Each of these is further split by stellar mass M_{star} (from GAMA[4]) before stacking.

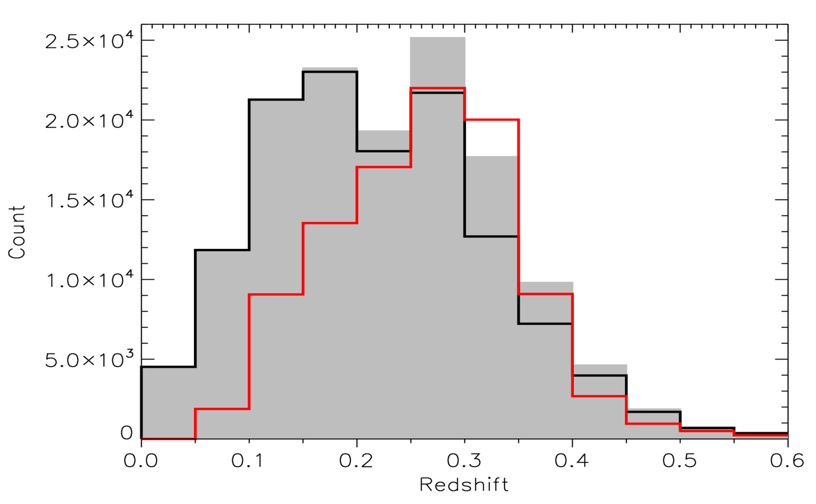

Figure 2: Histograms of spectroscopic (black line) and photometric (red line) redshifts available for our sample. The shaded histogram shows the final distribution of redshifts used (using spectroscopic where available). The sample was limited to z<0.35 due to incompleteness beyond this redshift.

RESULTS

Sub-mm fluxes at 250, 350 & 500µm are converted to rest-frame luminosities assuming a modified blackbody dust SED with a single temperature of 16K and emissivity β=2.0 (the median best-fits to stacked flux ratios). Stacked 250µm luminosities are shown in Fig. 3 as a function of redshift, colour and stellar mass (the other two bands display similar trends). The strong linear correlation between M_{star} and the sub-mm luminosities of blue galaxies extends from 3x10^{8}M$_\odot$ to 3x10^{10}M$_\odot$, but evolves with redshift and appears to flatten at the highest masses as redshift increases. For green galaxies the relation flattens at a lower mass and begins to resemble the relation followed by red galaxies, perhaps revealing a mixed population with different compositions at different stellar masses and/or redshifts.

$L_{250\mu m}$ vs. Stellar Mass as a Function of Redshift and *g-r* Colour

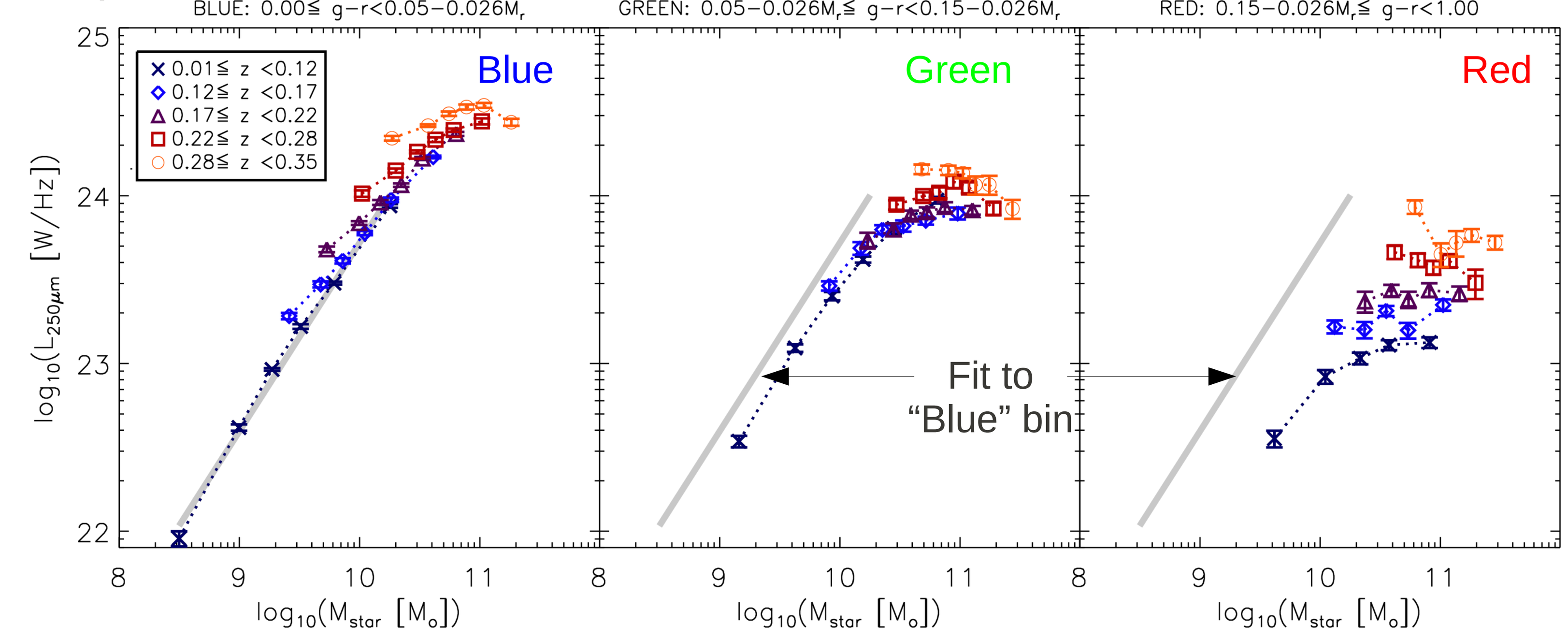

Figure 3: Stacked 250µm luminosities as a function of *g-r* colour (left to right), redshift (blue to orange) and M_{star} (x-axis) reveal trends in the dust emission (other SPIRE bands show consistent results). Blue galaxies at the lowest redshifts follow a strict correlation between (median) M_{star} and sub-mm luminosity, but the correlation breaks down for the largest blue galaxies as well as for green and red. Red galaxies have much lower sub-mm luminosities, and all colours show some evolution with redshift.

Luminosities of red galaxies lie on a different relation to those of blue and green, and they are fainter in the sub-mm, so must either have less dust or colder dust than blue galaxies of the same stellar mass. This is consistent with the picture that optically red galaxies are passive. The dust luminosity of all (especially red) galaxies of a fixed stellar mass increases with redshift over the range 0.01-0.35.

ANALYSIS

To understand the reason for the luminosity evolution we compare the data at 250, 350 and 500µm to model SEDs. Fitting single-component SEDs (assuming β=2) to stacked fluxes in each bin, we estimate dust temperatures and dust masses (Fig.4) that vary significantly across the range of galaxy properties. We notice that the dust in red galaxies is colder than in blue, and that the dust temperature increases with increasing stellar mass of blue galaxies. This is the cause for the difference in the luminosities of red and blue galaxies; in fact the *amount* of dust present appears to be fairly independent of the optical colour. However, dust mass increases by a factor 10 as stellar mass increases by a factor 100, so that the average dust-to-stellar mass ratio is around 10 times higher at M_{star} = 10^9 M$_\odot$ compared with 10^{11}M$_\odot$. Typical dust masses for a given stellar mass also evolve with redshift for galaxies of all stellar masses and optical colours.

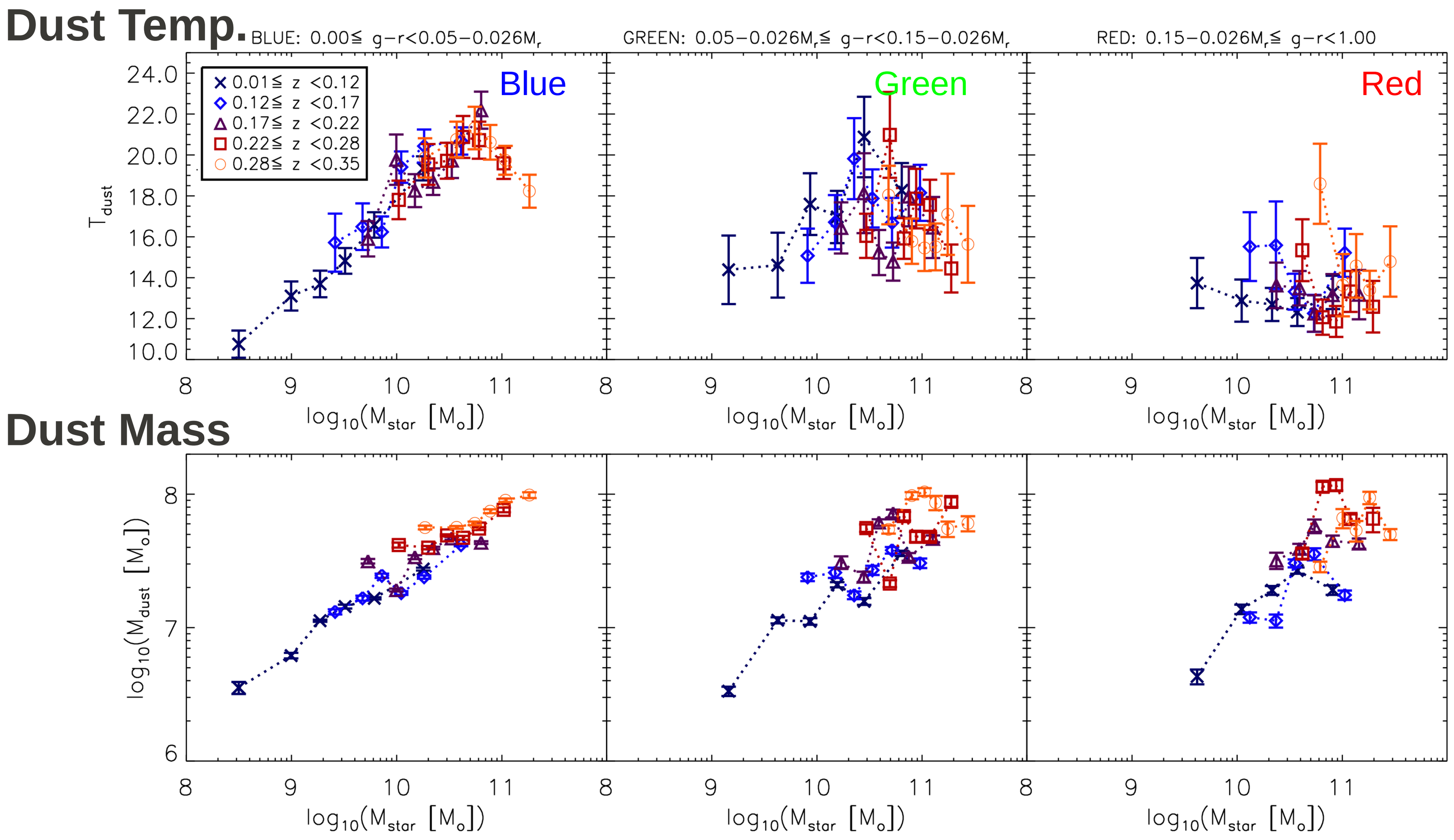

Figure 4: Dust temperatures inferred from SED fits (top) are strongly correlated with optical colour and stellar mass, while dust masses (bottom) show little dependence on colour but do evolve with redshift.

CONCLUSIONS

Our results reveal systematic differences between the dust properties of red and blue optically-selected galaxies. Red galaxies are much fainter in the sub-mm than blue galaxies of comparable stellar mass, indicating a passive nature. Blue galaxies tend to have warmer dust, and their dust temperature depends on stellar mass. All samples undergo a significant increase in dust mass from z~0.01 to z~0.35, implying higher rates of star formation and dust production at higher redshifts, looking back over this relatively short range of cosmic time.

* NB supported by an RAS grant. [1] Eales et al. 2010, PASP, 122, 499; [2] Driver et al. 2009, A&G, 50, 12; [3] Hill et al. 2011, MNRAS, 412, 765; [4] Taylor et al. 2011, MNRAS submitted.