A Survey of Dust in the Low Redshift Universe

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with
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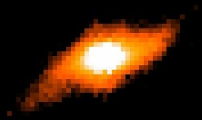
GAMA



Outline

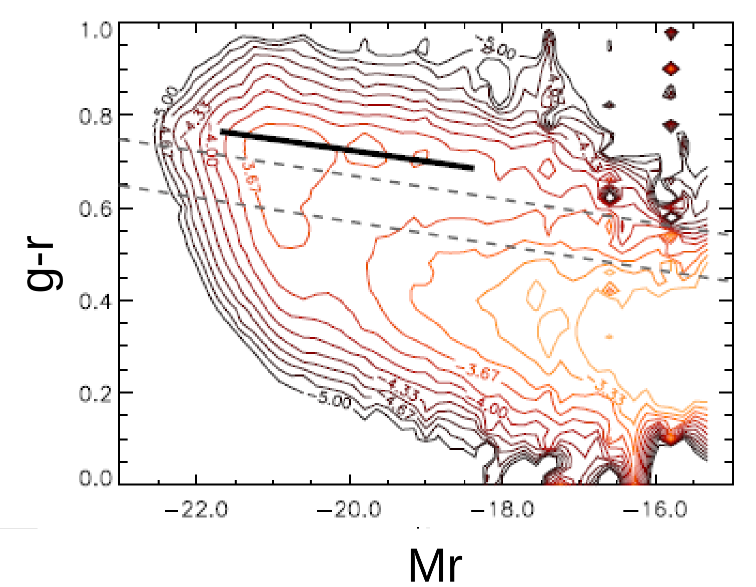
- Introduction to the surveys
- Stacking methods
- Correcting for bias
- The Cosmic Infrared Background
- The Cosmic SED
- Evolution of Infrared Luminosities
- Characteristics of dust in optically selected galaxies – temperature and mass
- Obscuration in galaxies
- The nature of red galaxies

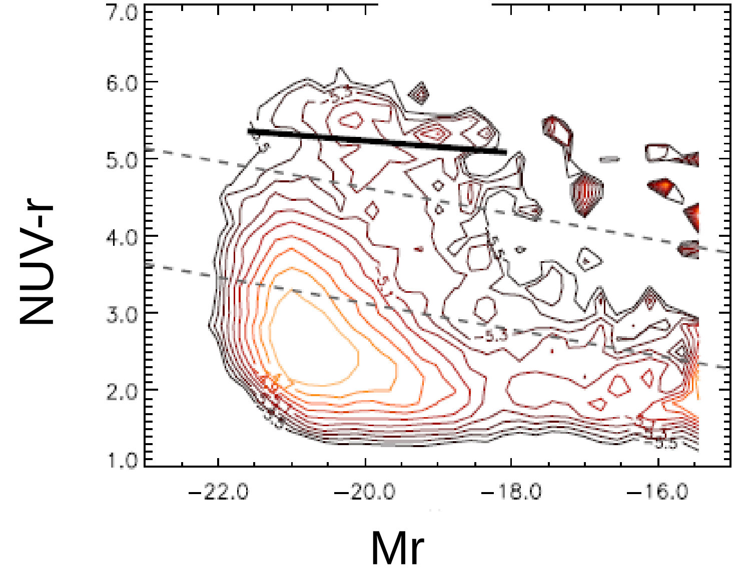
Herschel-ATLAS & GAMA

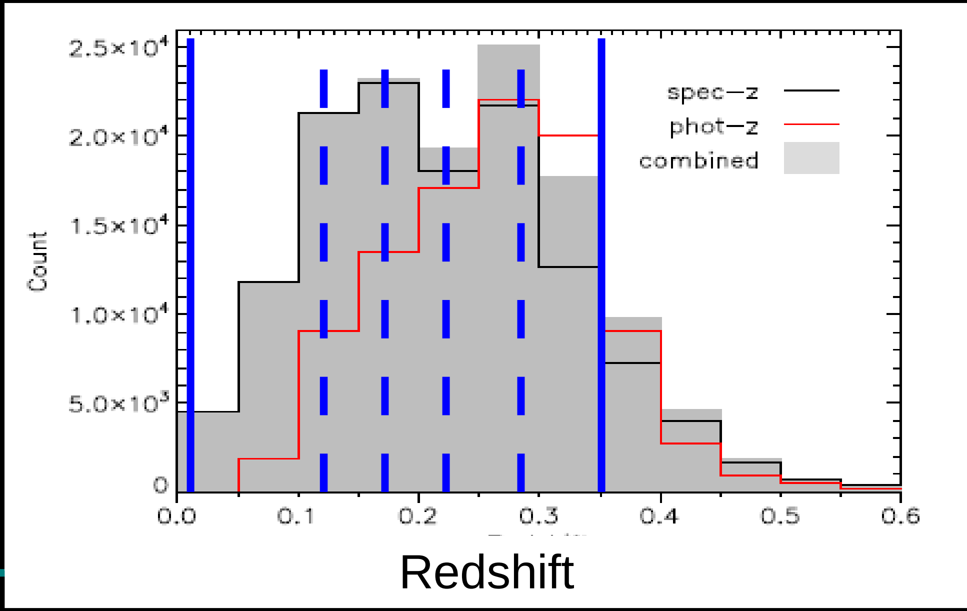
- 550 deg^2 imaging at 100, 160, 250, 350, 500μm with PACS and SPIRE instruments
- Reaching an rms noise level close to the confusion limit
- Equatorial fields:
    - ~130 deg^2 H-ATLAS/GAMA overlap at 9^h, 12^h, 15^h
    - GAMA photometry in *NUV,FUV,ugrizYJHK* (Hill+11)
    - ~99.9% complete down to r=19.8 (Baldry+11)
    - Spectroscopic redshifts for 90% of sample down to r=19.8
    - Photometric redshifts otherwise
    - Stellar masses from *ugriz* (Taylor+11)

Stacking Methods

- Split sample into:
  - 3 colour bins (to isolate red sequence and blue cloud)
  - 5 M_r bins / 5 M_{star} bins
  - 6 z bins

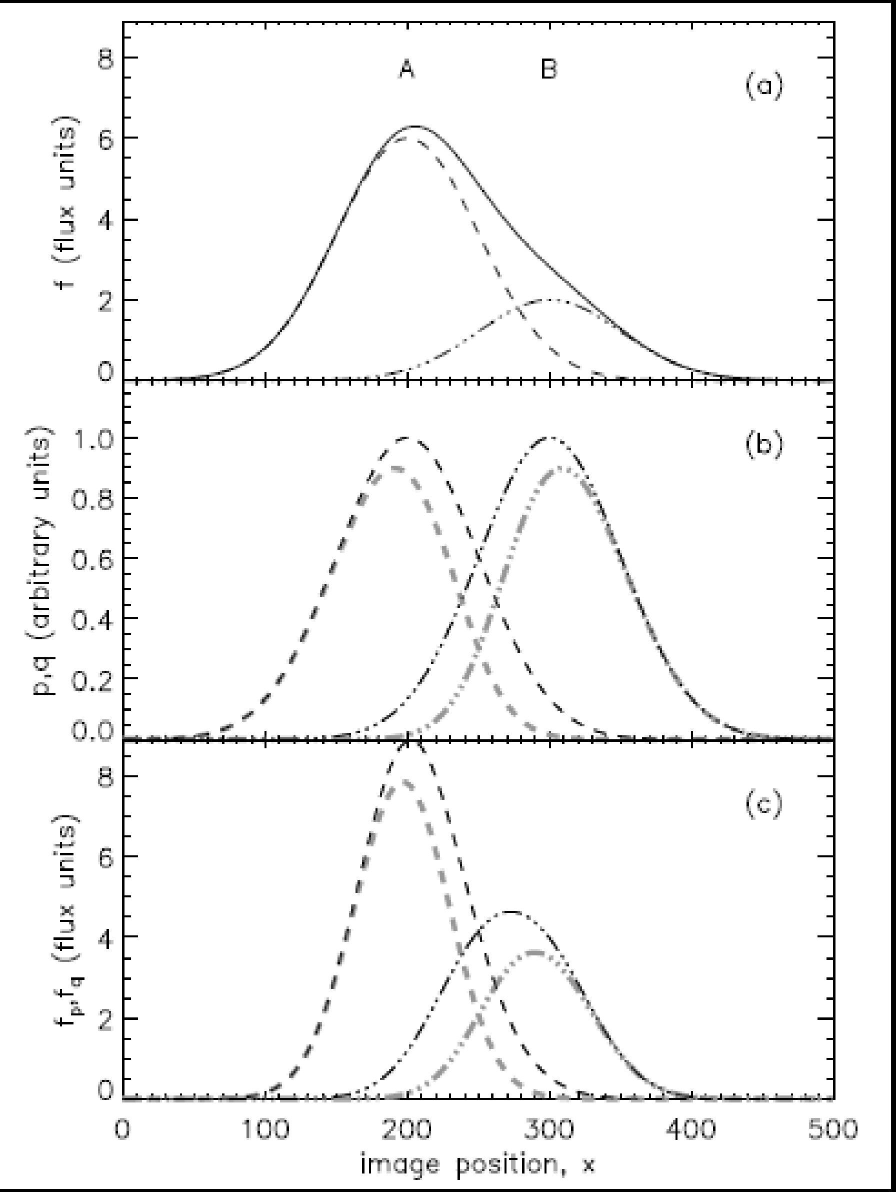


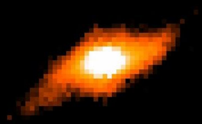




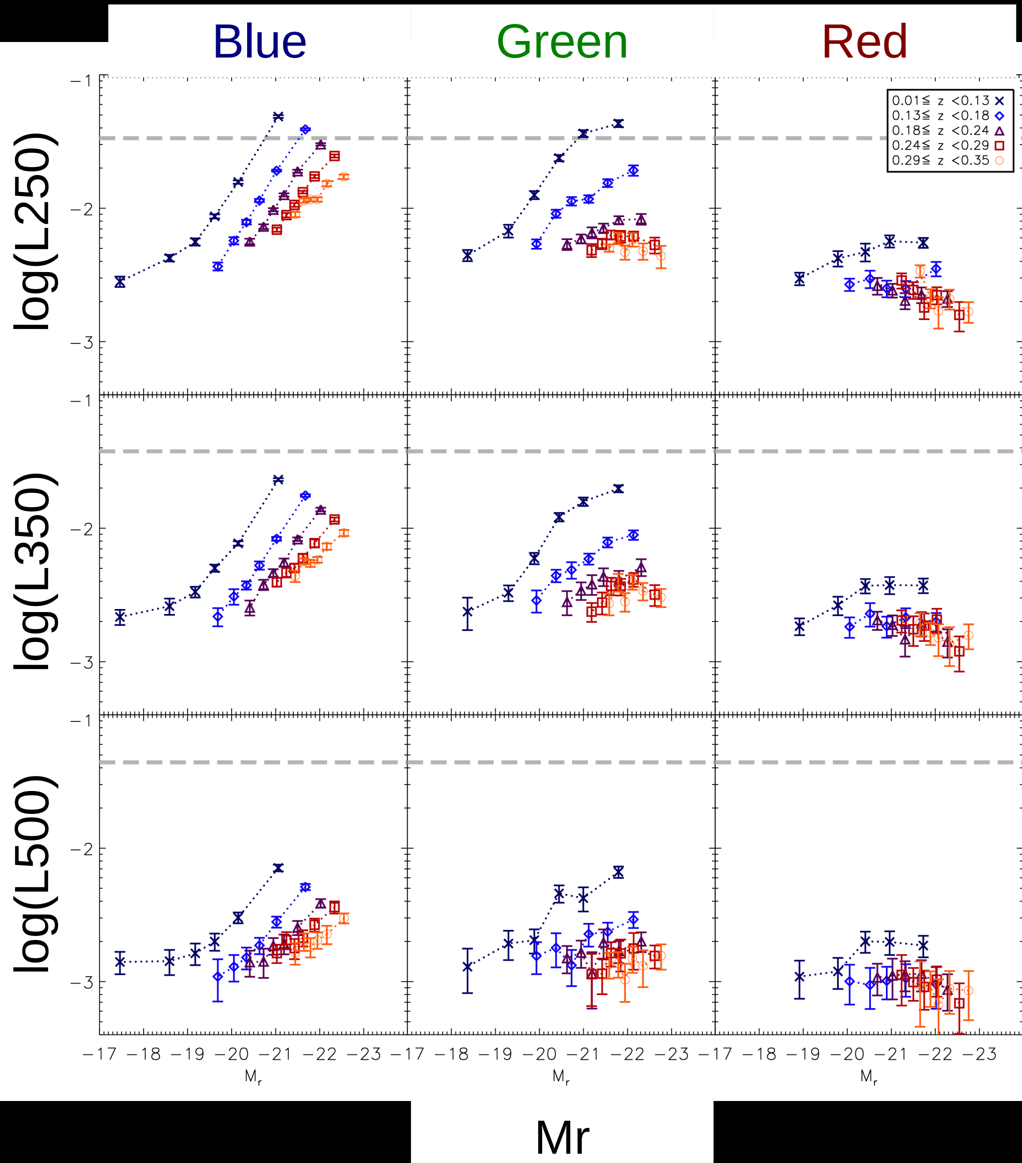
Simultaneous stacking & deblending

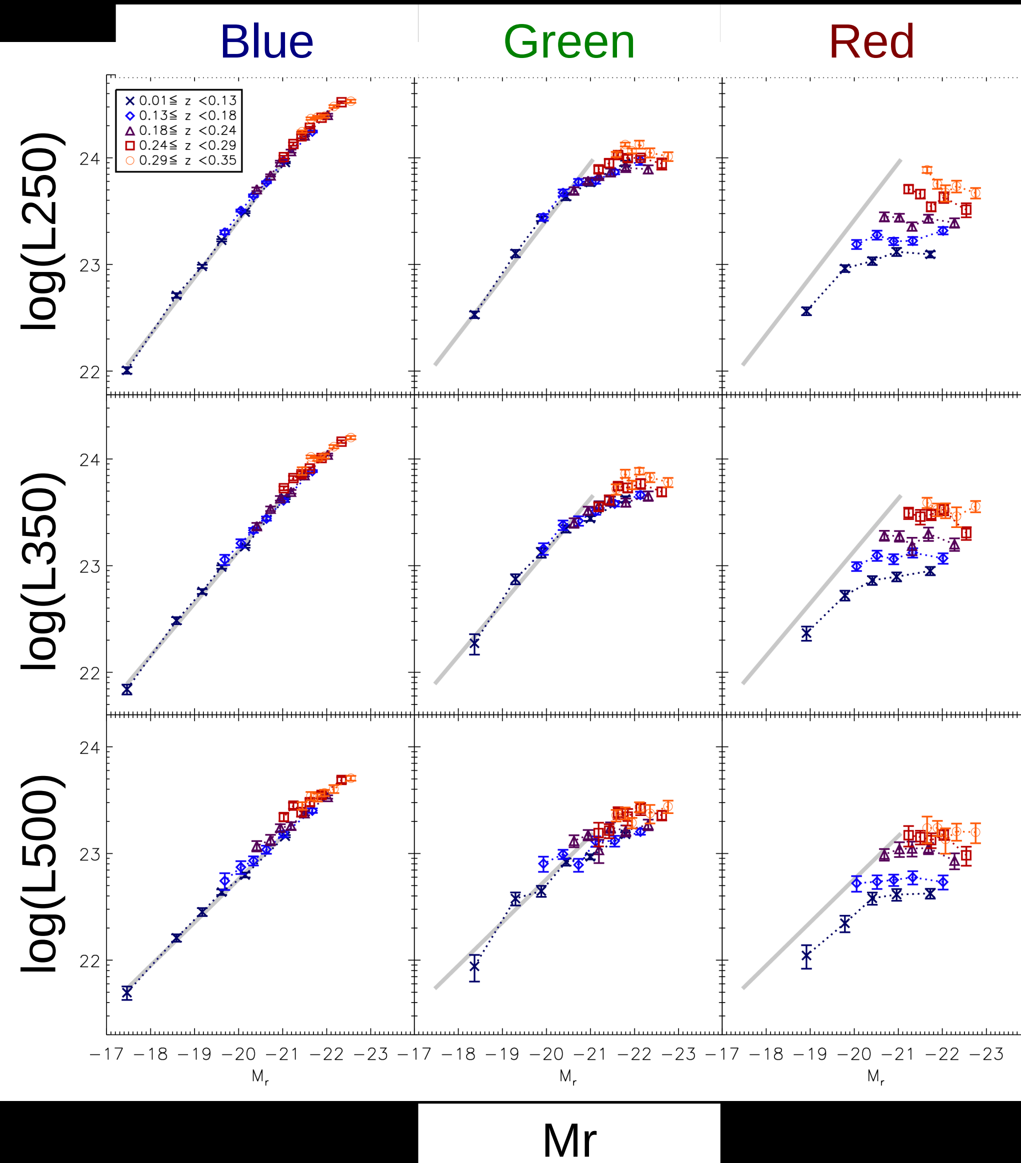
- Normally would convolve the map with the PSF
- Each position in the convolved map then represents total flux of a point source
- But blending can lead to over-estimate of flux this way
- So we weight the PSF kernel to deblend fluxes





Sub-mm fluxes of optically selected galaxies





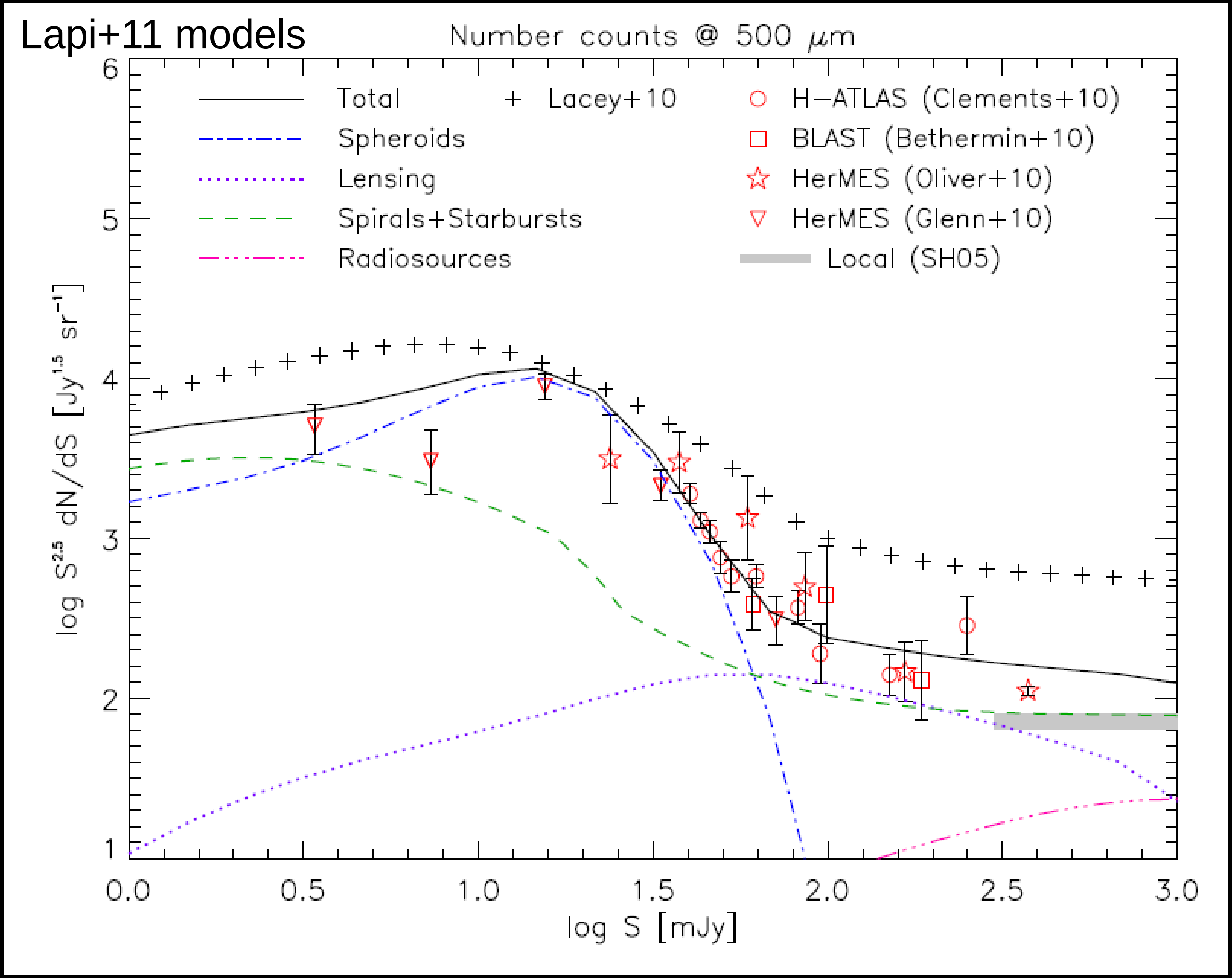
Could the fluxes by biased by lensing?

- We know that some galaxies can be aligned with background sources, and if the alignment is close enough then there will be strong lensing
- The foreground galaxy magnifies the flux from the background source and an image can appear close enough to the target position to boost the measured flux
- In general the foreground lenses must...

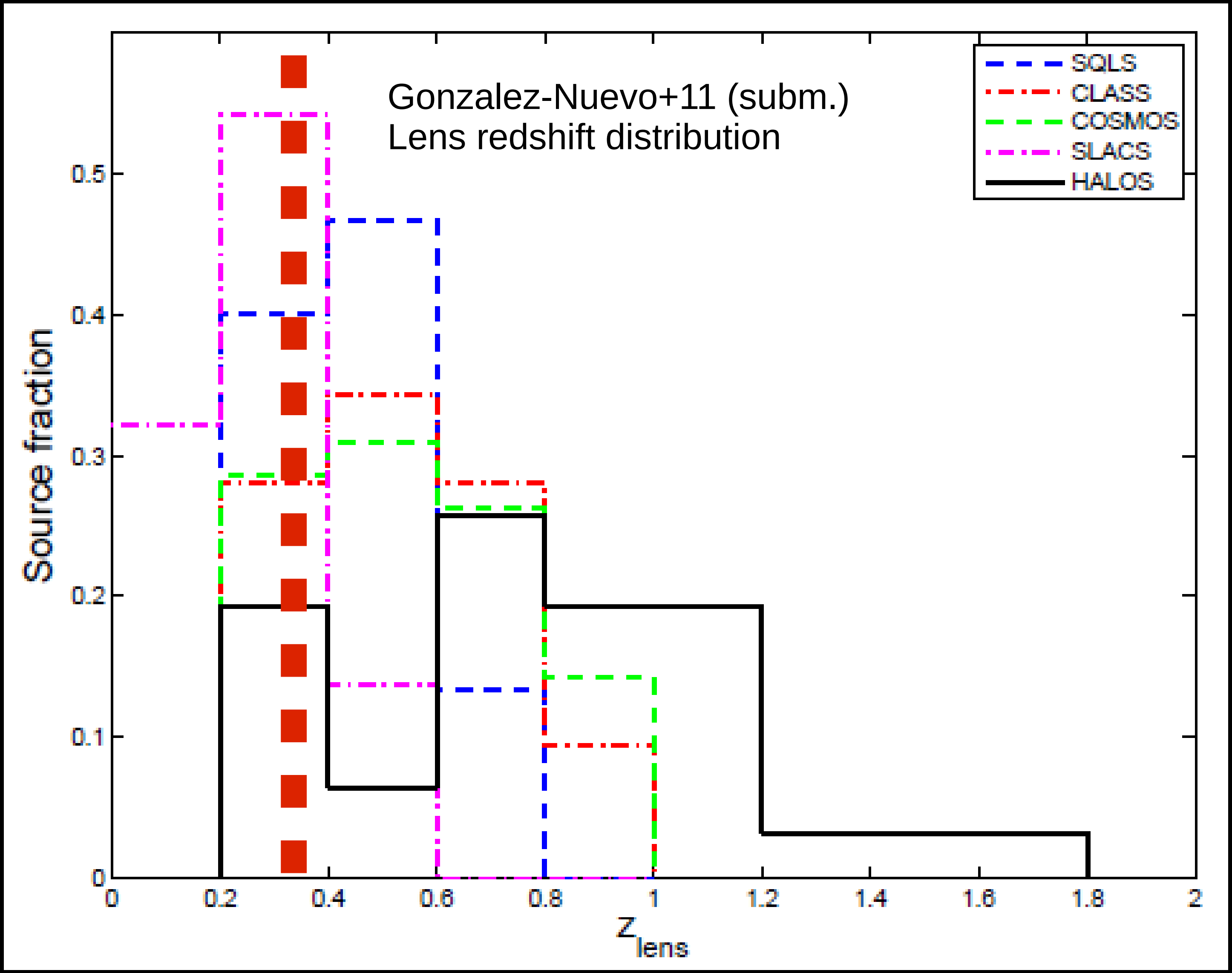
    i. be intrinsically faint in comparison to the lensed source

    ii. have a gravitating mass profile that provides a strong magnification factor (e.g. spheroids)

Estimating the lensing contamination to red galaxies



Estimating the lensing contamination to red galaxies

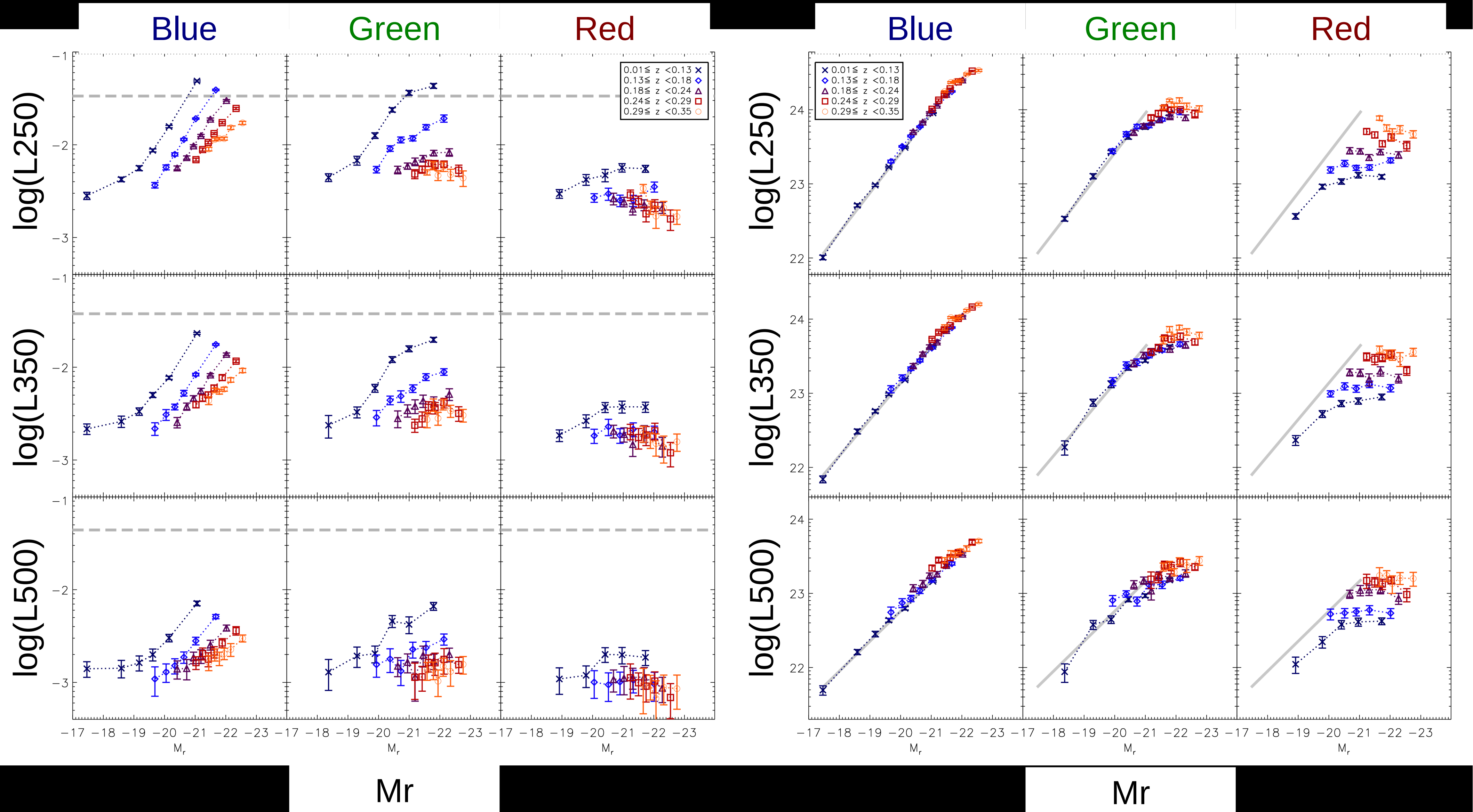


Estimating the lensing contamination to red galaxies

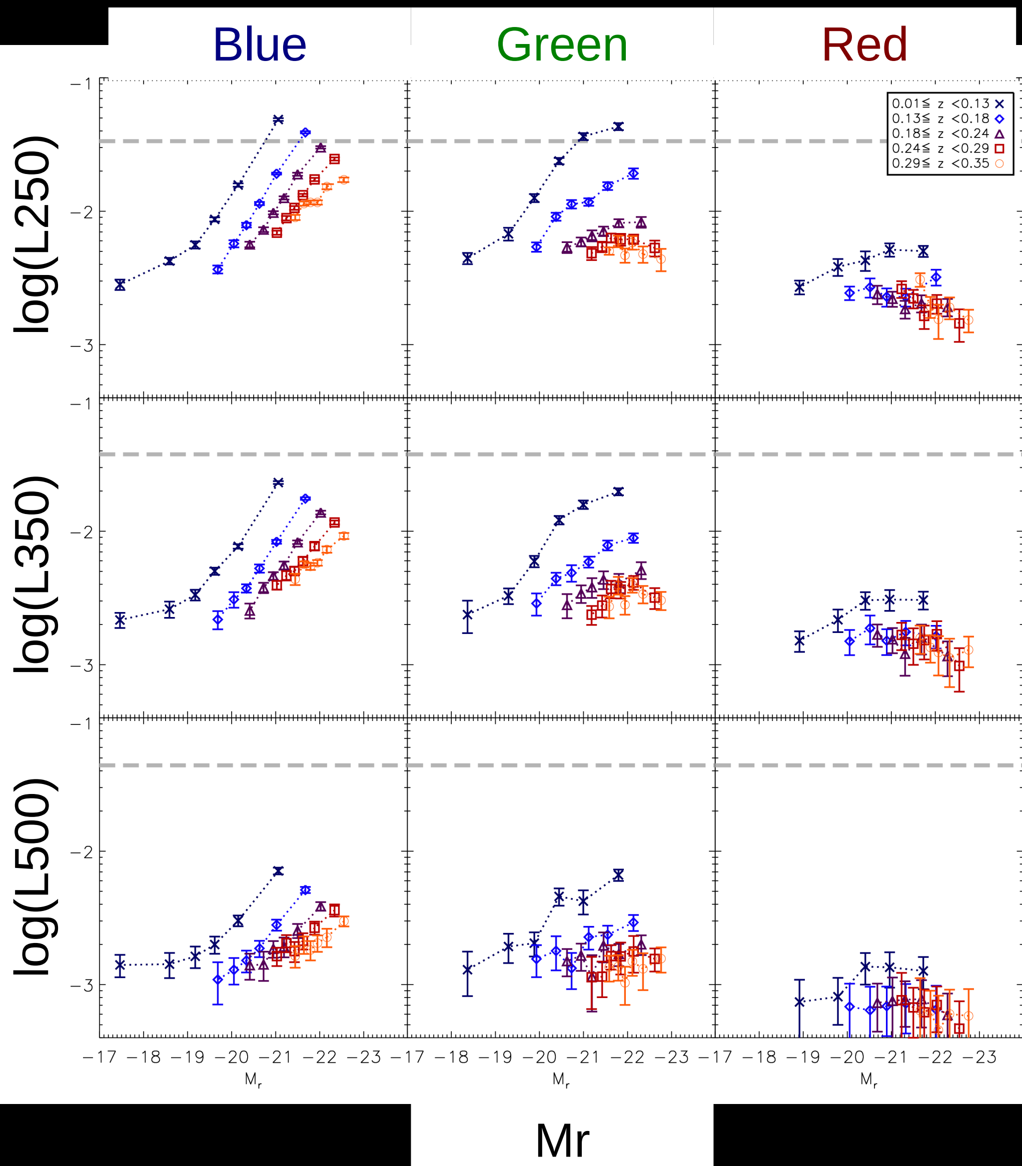
- Integrate the source counts of strong lenses (Lapi+11) to obtain total lensed flux by square degree
- Use HALOS redshift distribution to estimate how much of this flux is lensed by low redshift galaxies ($z<0.35$)
- Compare to measured flux from red galaxies

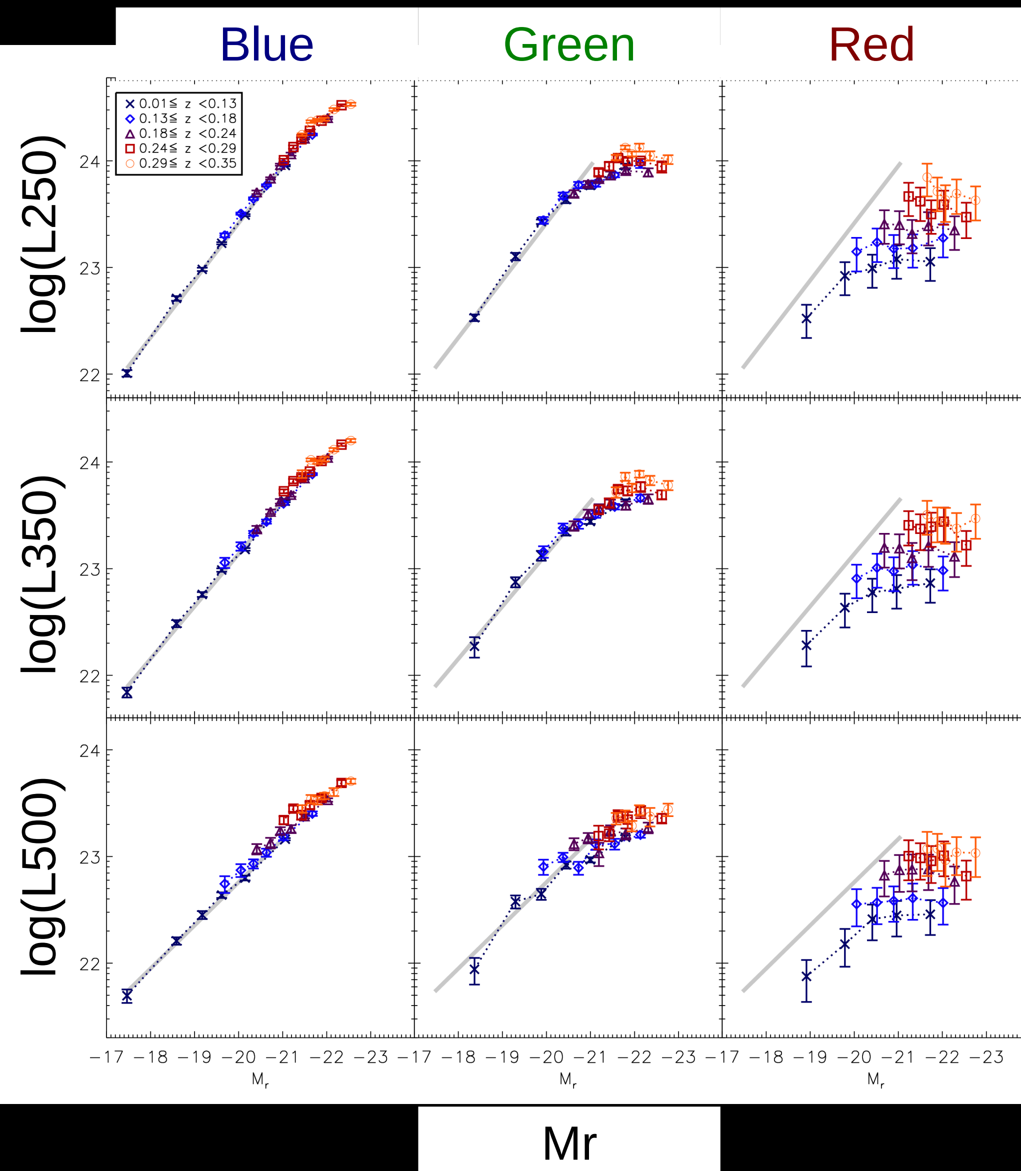
	Total surface brightness (Jy $\deg^{-2}$)		
	250 μm	350 μm	500 μm
All lensed flux	1.09	1.34	1.22
Lenses at $z < 0.35$	$0.23^{+0.09}_{-0.06}$	$0.28^{+0.12}_{-0.07}$	$0.26^{+0.11}_{-0.07}$
3-σ upper limit	(0.50)	(0.62)	(0.56)
Red galaxies	2.6 ± 0.5	1.6 ± 0.2	0.8 ± 0.1
Fraction	$0.09^{+0.04}_{-0.03}$	$0.18^{+0.08}_{-0.05}$	$0.32^{+0.14}_{-0.09}$
3-σ upper limit	(0.19)	(0.39)	(0.68)

Original results



Lensing-subtracted Results





The Cosmic Infrared Background

- Total stacked intensity, completeness-corrected, of all r<19.8 galaxies up to z=0.35
- Contribution to the CIB:

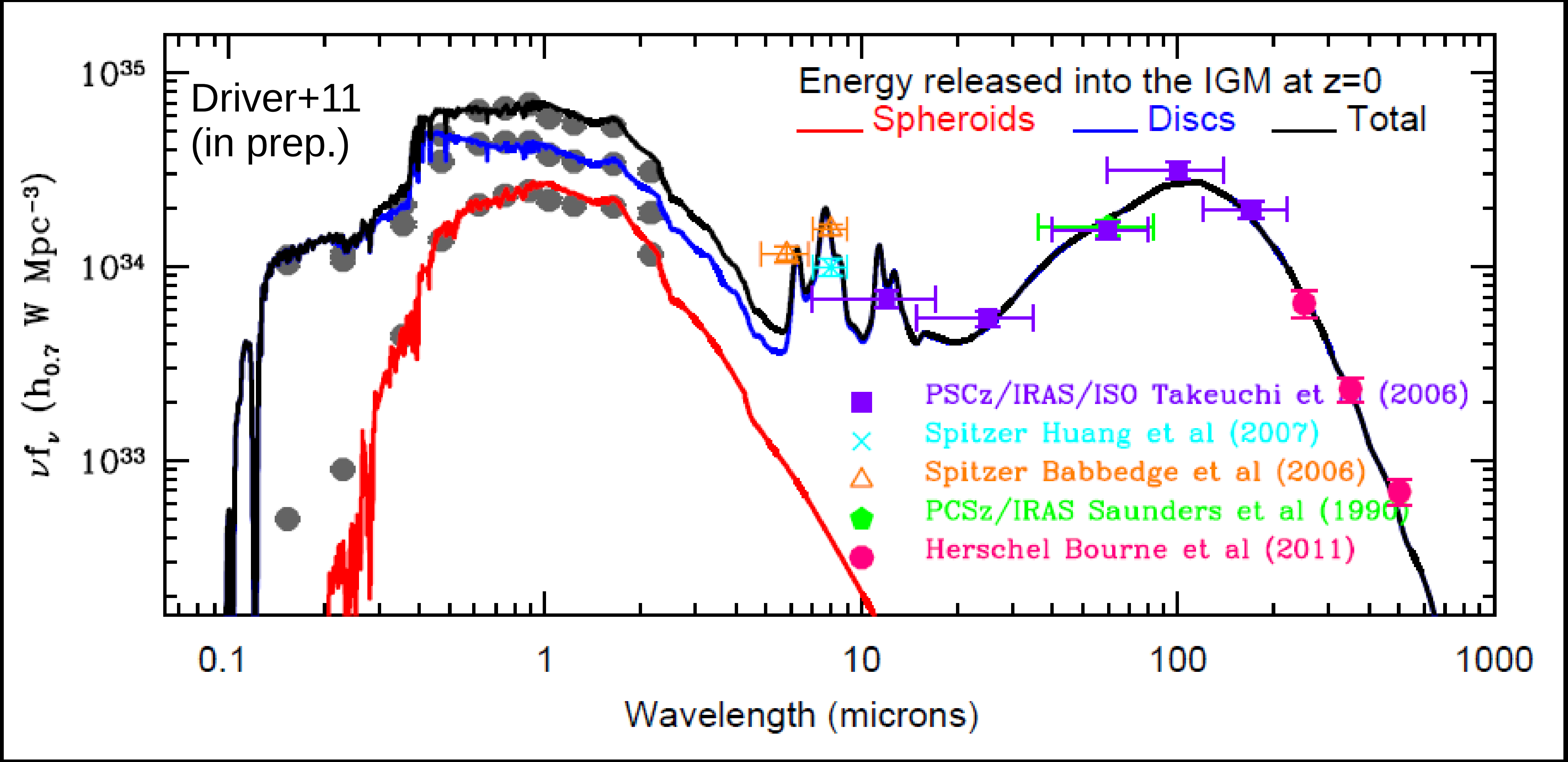
Complete to M_r* =-21.4

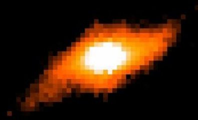
	250 μm	350 μm	500 μm
		% of CIB	
Total Stack	5.27 ± 0.42	3.89 ± 0.32	2.94 ± 0.23
$0.01 < z < 0.28$	4.42 ± 0.36	3.20 ± 0.27	2.42 ± 0.20
$0.01 < z < 0.12$	1.64 ± 0.18	1.12 ± 0.14	0.81 ± 0.09
$0.12 < z < 0.17$	1.03 ± 0.11	0.74 ± 0.08	0.55 ± 0.06
$0.17 < z < 0.22$	0.90 ± 0.09	0.67 ± 0.08	0.52 ± 0.05
$0.22 < z < 0.28$	0.86 ± 0.09	0.68 ± 0.08	0.54 ± 0.06
$0.28 < z < 0.35$	0.85 ± 0.08	0.68 ± 0.08	0.52 ± 0.05
Blue	3.21 ± 0.28	2.36 ± 0.22	1.78 ± 0.16
Green	1.19 ± 0.10	0.88 ± 0.08	0.68 ± 0.06
Red	0.87 ± 0.10	0.65 ± 0.08	0.47 ± 0.05

60% = blue cloud
20% = green valley
20% = red galaxies

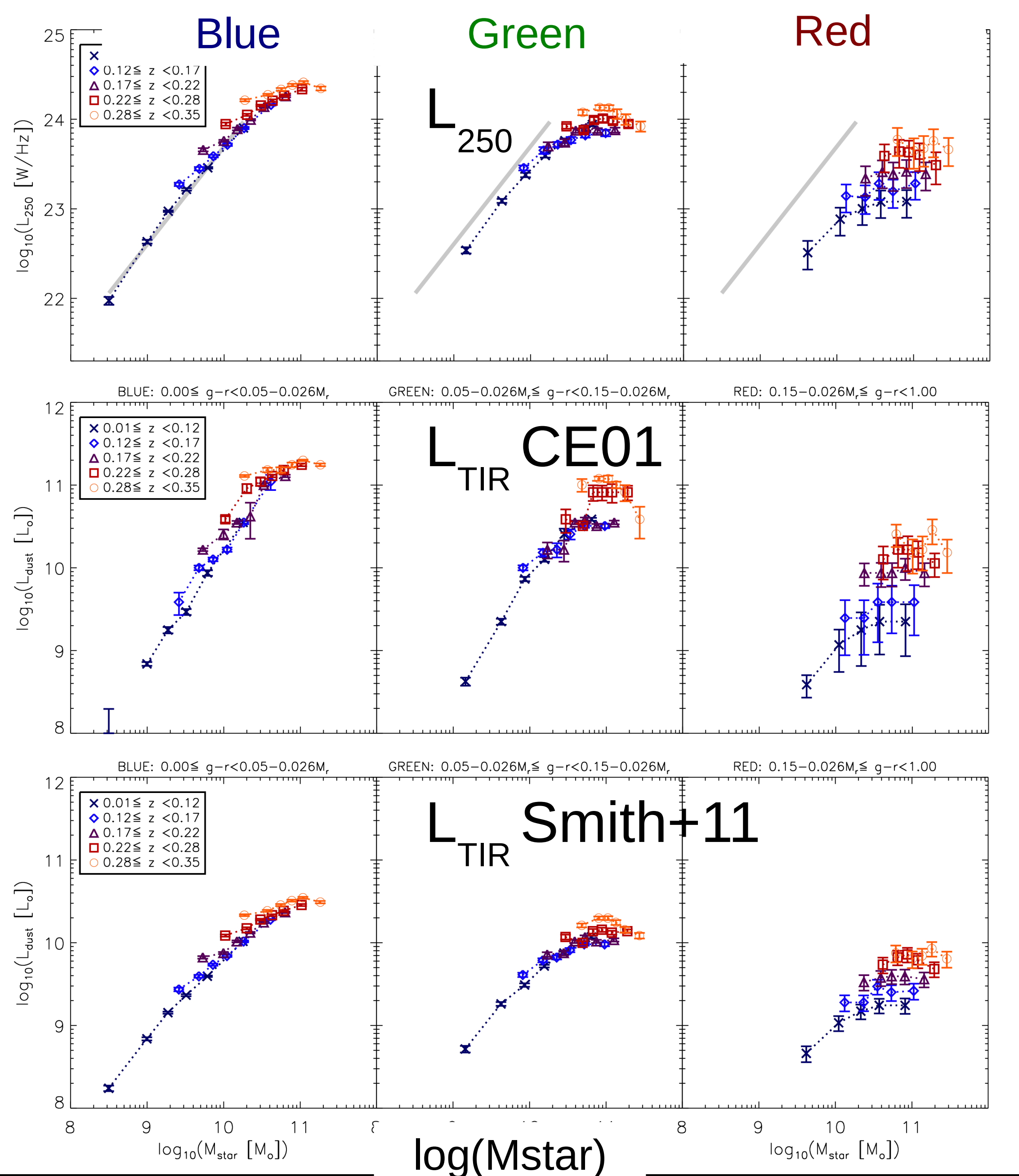
The Cosmic SED

- Predictions vs. observations of the total luminosity density of the universe at z=0





Evolution of Infrared Luminosities of normal galaxies



250μm luminosities at a given M_{star}

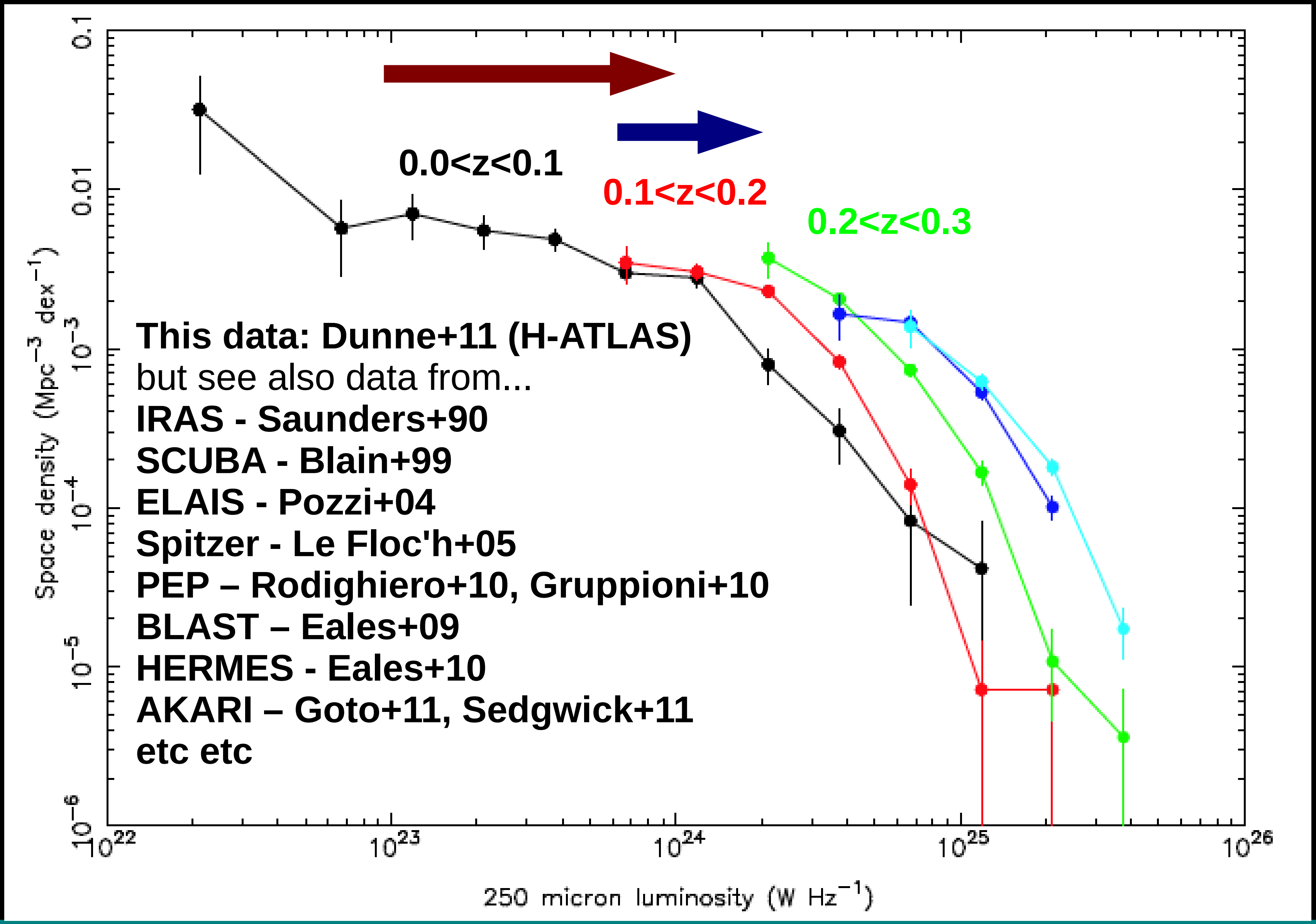
- blue ~$(1+z)^{3.9}$
- green ~$(1+z)^{1.1}$
- red ~$(1+z)^{\sim 10}$

Total IR luminosities dependent on template but evolution consistent:

- Blue ~$(1+z)^{3.9}$
- green ~$(1+z)^{1.6}$
- red ~$(1+z)^{\sim 9}$

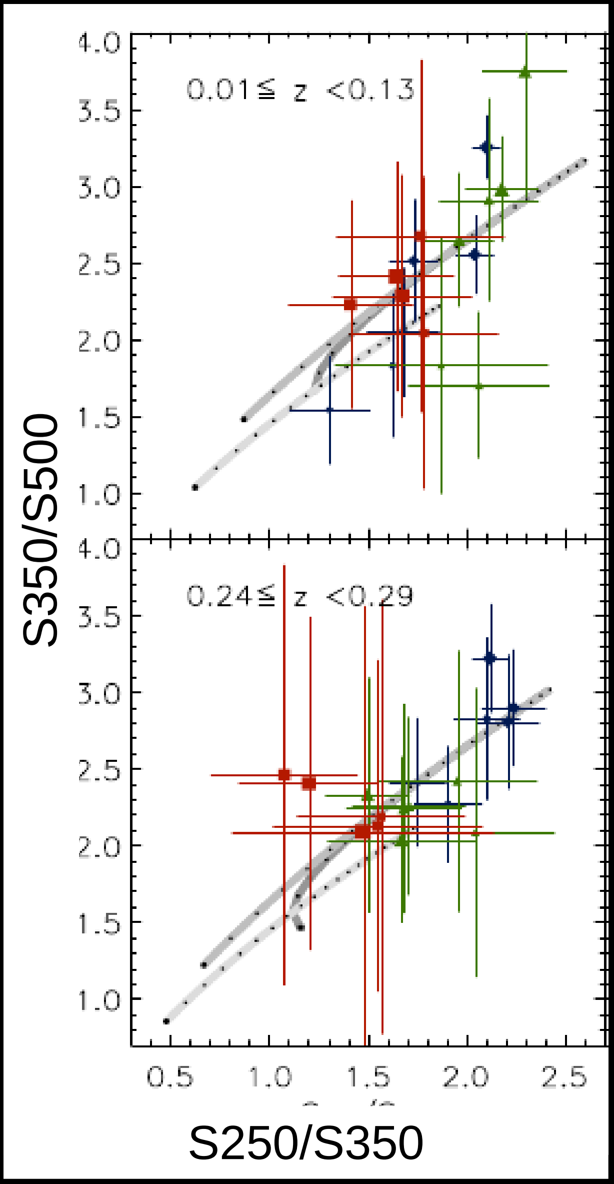
Agrees with Oliver+10; and Magnelli+09, Damen+09, Dunne+09, Pannella+09, Karim+11, etc etc (radio and FIR luminosity evolution)

Evolution of the FIR/sub-mm LF

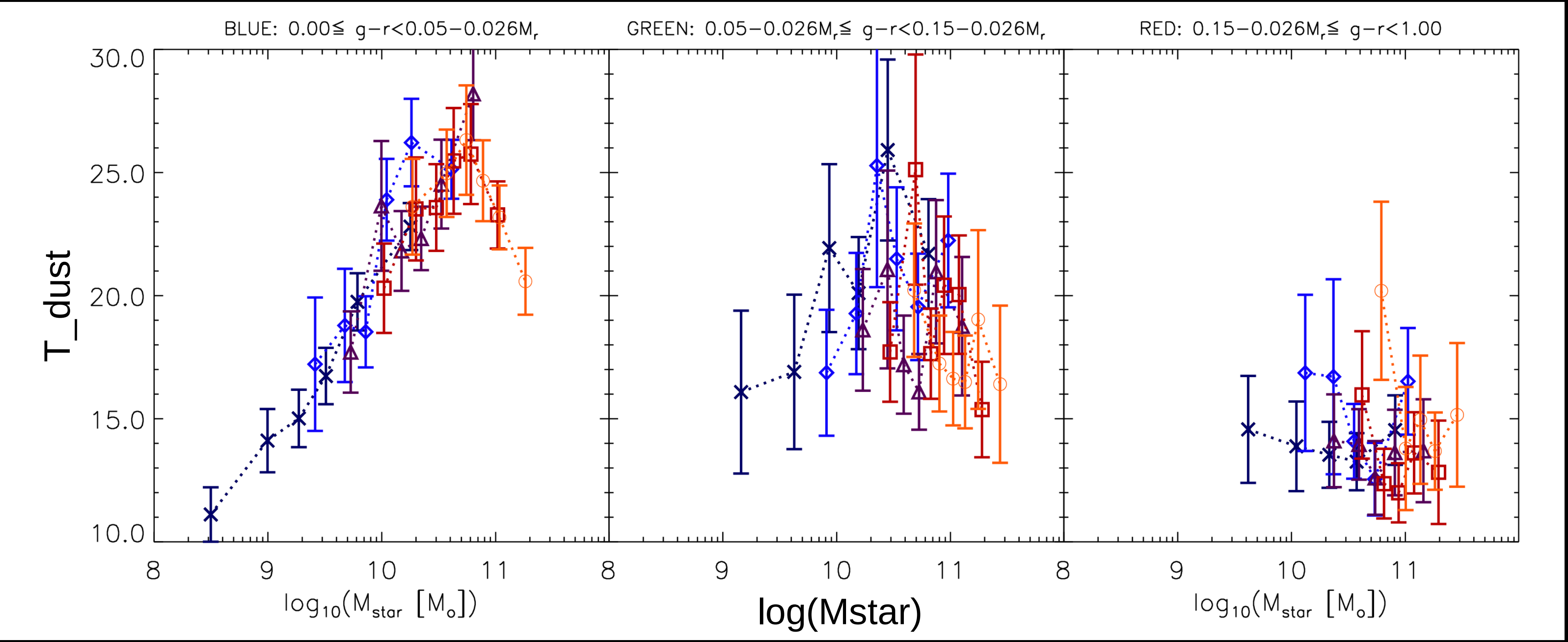


SED Fitting

- Fit greybody SEDs to the three stacked fluxes in each bin (250, 350, 500 µm points)
    - $S_\nu \sim \nu^\beta B(\nu,T)$
- Must assume constant β but then can constrain temperatures
- Significant difference between dust temperatures of red and blue galaxies
- Blue galaxies show correlation with mass
- Doesn't appear to be due to lensing (at 2.4σ level)
- Robust to contamination of 500µm band by additional confusion or extended flux



Dust Temperatures



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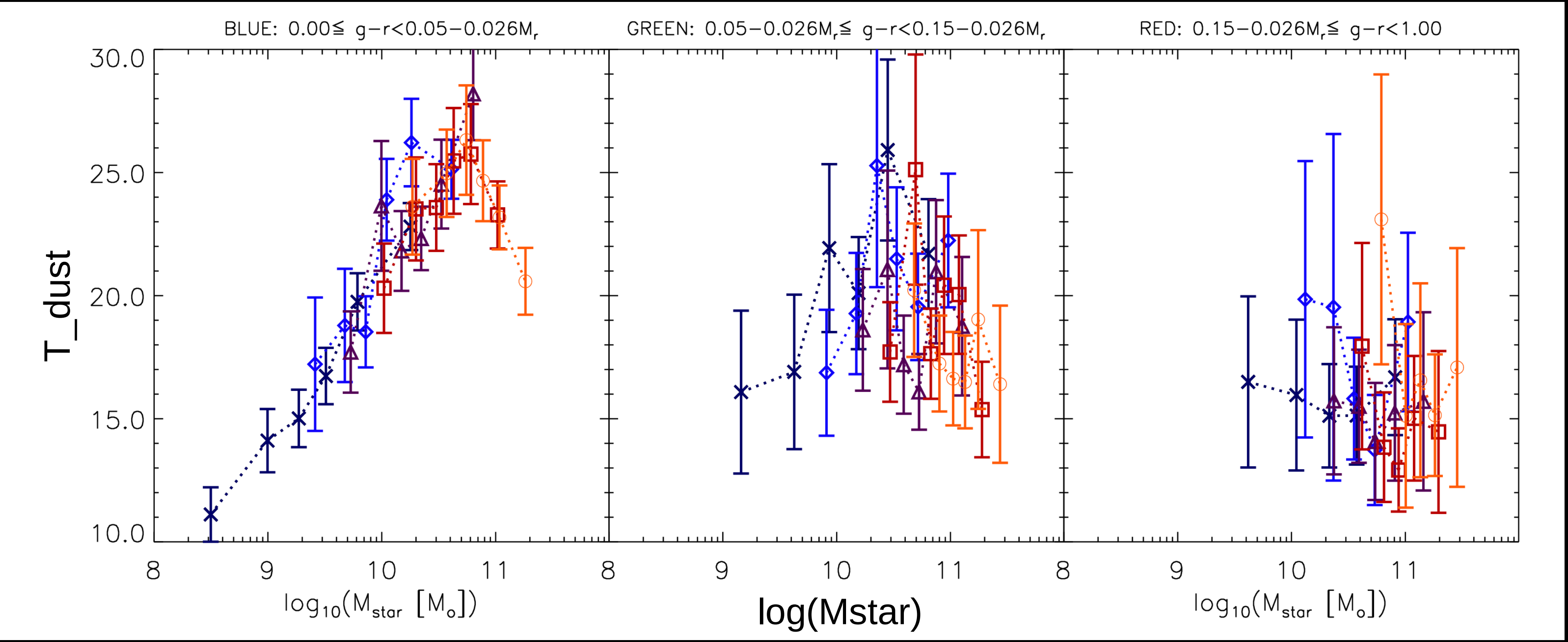
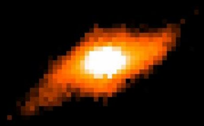
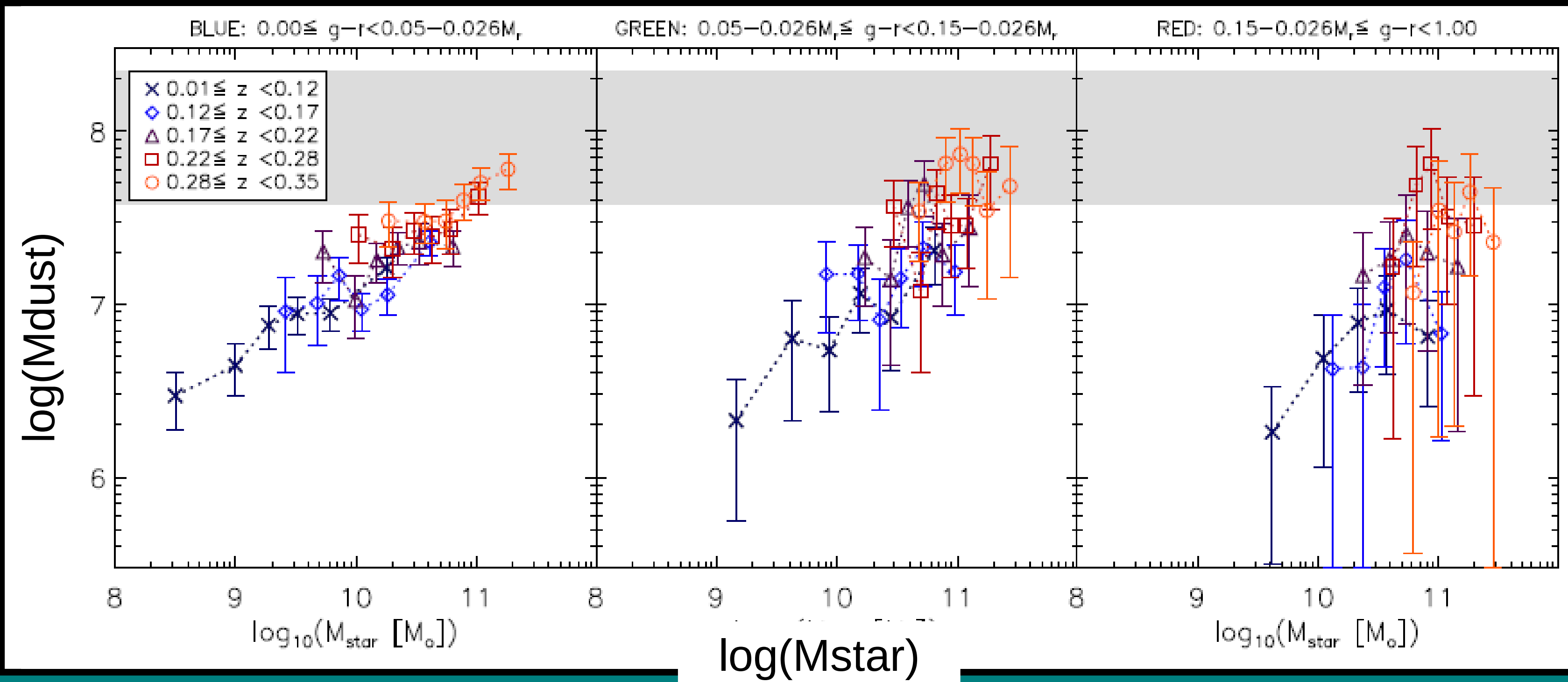




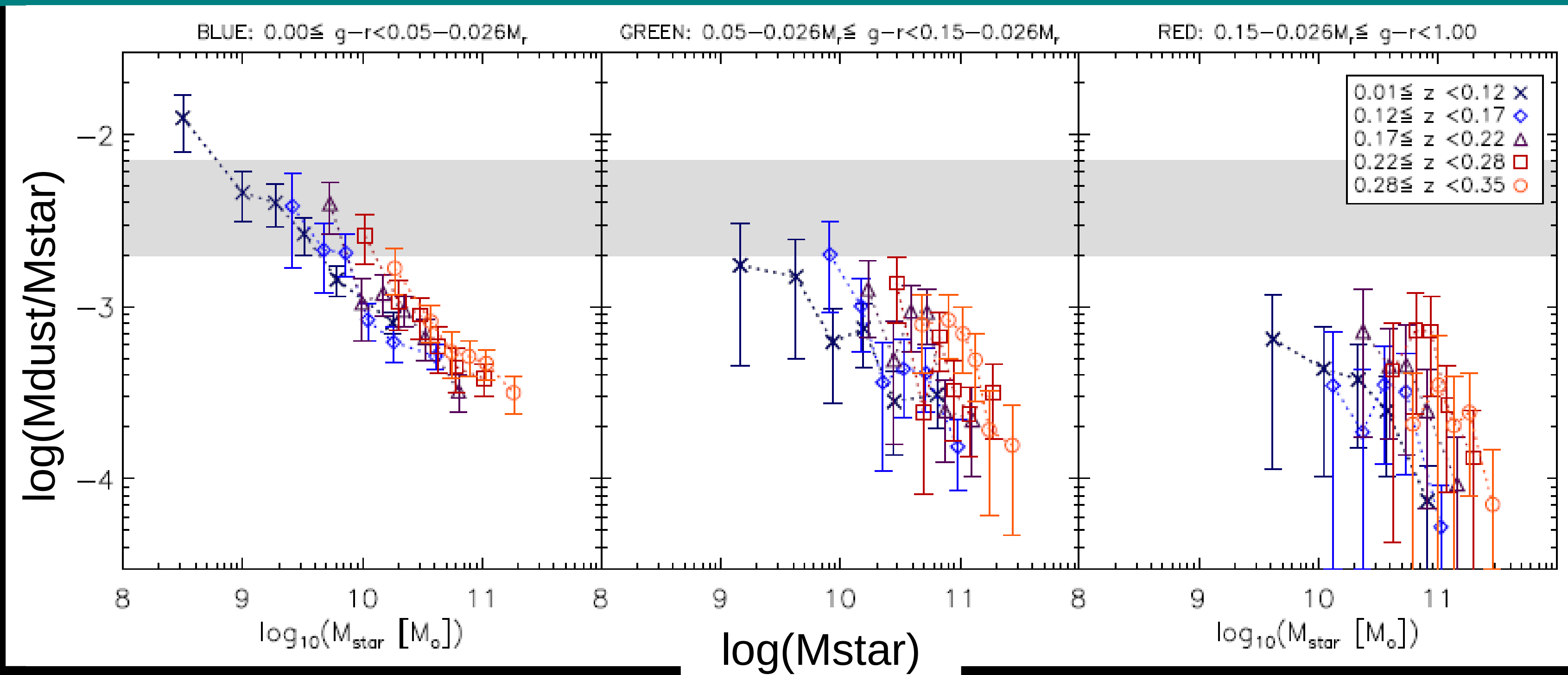
Dust Masses

$$M_{\rm dust} = \frac{S_{250}\, D_{\rm L}^2\, K(z)}{\kappa_{250}\, B(\nu_{250}, T_{\rm dust})\,(1+z)}$$

- M_{dust} dependent on *T*
- *L* dependence partly due to *T*, partly due to *M*
- *M* responsible for evolution with *z*
- Hence evolution of DMF
- *T* (& *M*?) responsible for colour dependence



Dust Masses

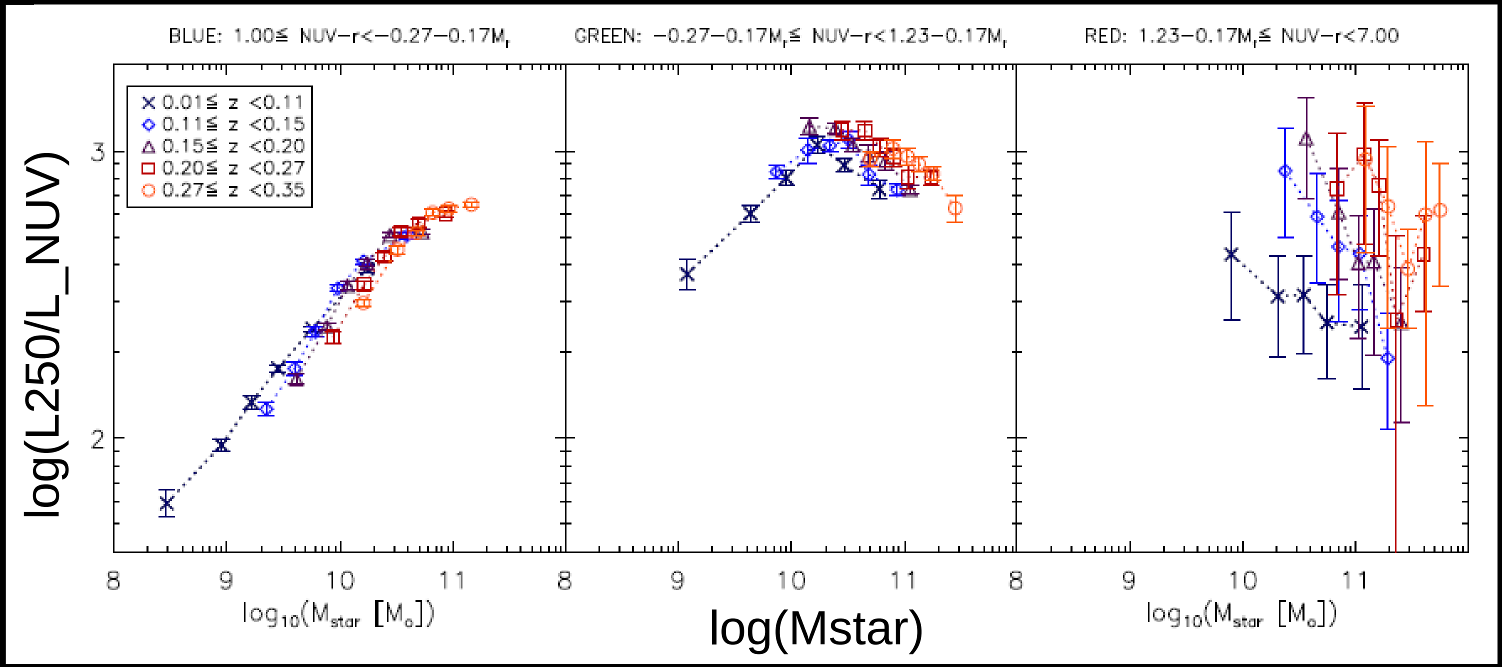


- M_{dust}/M_{star} strongly anti-correlated with M_{star}
- For dust to remain in ISM, 'dwarfs' must be less efficient at turning gas into stars...
- and high dust masses in dwarfs imply dust must be produced in SNe and probably in the ISM (unless a top-heavy IMF) – H.Gomez+ (in prep)

Dust Masses

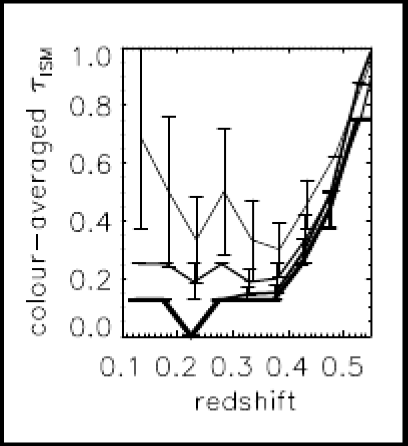
- Dust masses of red and blue galaxies *typically* differ by factors 2-3, according to these results – could be a little more if lensing is stronger effect, but we tried to be conservative in estimating that.
- Red galaxies also appear to have colder dust than blue
- Contrast with literature data on spiral versus elliptical samples: ellipticals have at least an order of magnitude less dust than spirals, but similar dust temperatures (e.g. HRS – M. Smith+11 subm.;
- Also Rowlands+11: median dust mass of Herschel-undetected ellipticals much lower than our red sample
- *M* and *T* results are not independent, so must take care
- HRS (Smith+11) also found environmental dependence

Obscuration of Star Formation

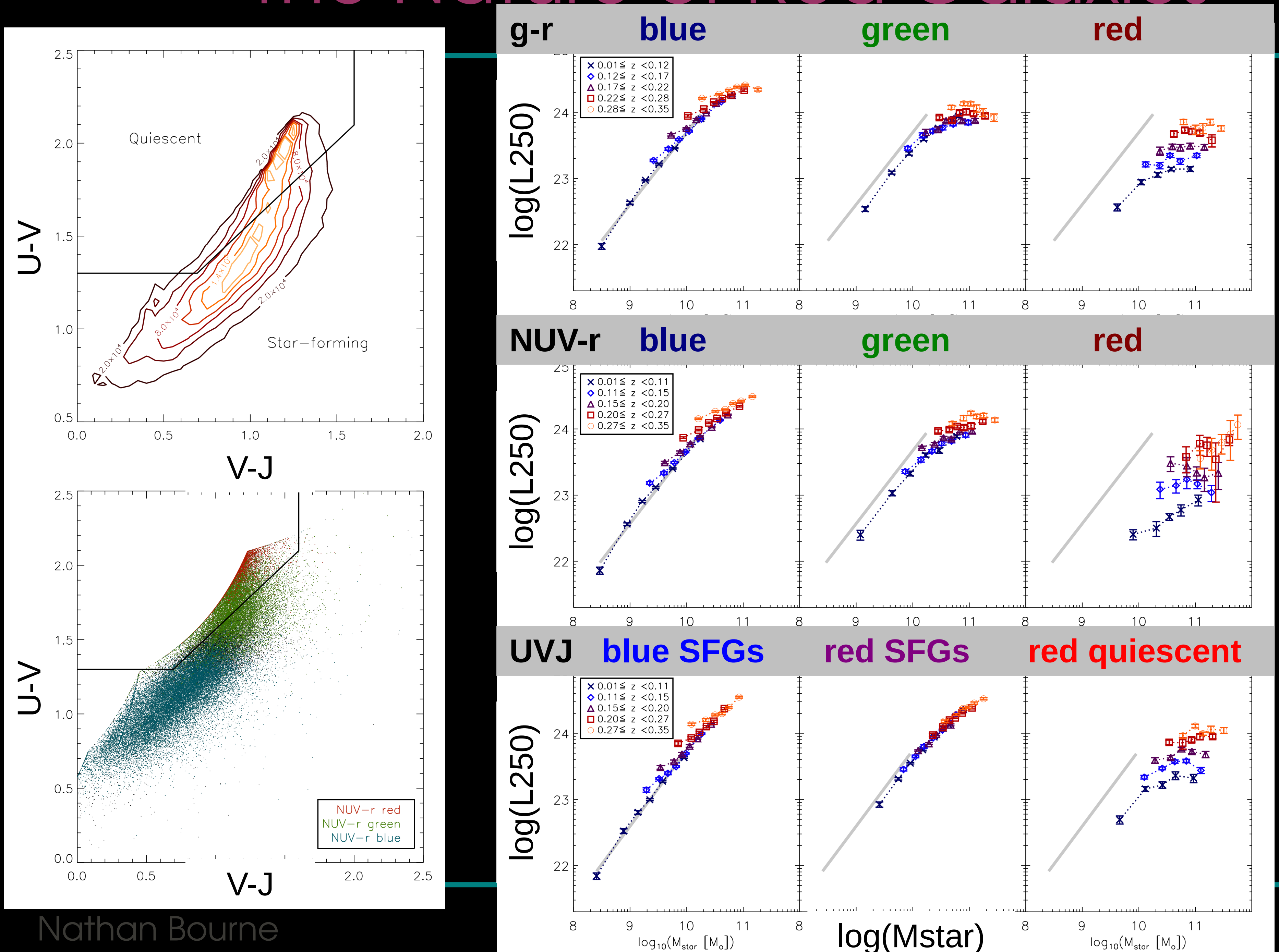


- Luminous red galaxies have increasing levels of obscuration as go to higher z and lower luminosity/mass
- This probably also applies to blue galaxies

Tojeiro+11:



The Nature of Red Galaxies



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Conclusions

- Stacking optically-selected galaxies we can recover the predicted total luminosity density of the Universe (Cosmic SED) at z=0
- Low redshift galaxies only account for about 5% of the 250μm CIB at z<~0.3 – most extragalactic sub-mm light comes from high redshifts
- Stacked fluxes of red galaxies can be significantly contaminated by lensing (~10% at 250μm; ~30% at 500μm) – but we can correct for this
- Blue galaxies are up to 10x more luminous in the sub-mm than red galaxies, probably due to higher dust temperatures which may result from higher SFRs
- Red and blue galaxies show different relationships between dust luminosity and stellar luminosity due to warmer dust in massive blue g's
- Red galaxies have colder dust and probably less dust mass – but not by a lot – in contrast with recent results for elliptical galaxies
- High dust/stellar mass ratios in low-mass galaxies imply dust must form in SNe and probably in the ISM
- Red (and blue?) galaxies are more obscured at higher z and lower M

A sample of "normal" galaxies at low redshift

- *What do I mean by normal and why (historically much of our understanding of dust in galaxies has been based on IR luminous samples)*