The Evolution of Dust in Optically-Selected Galaxies

over the last 4 billion years

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GAMA Galaxy And Mass Assembly

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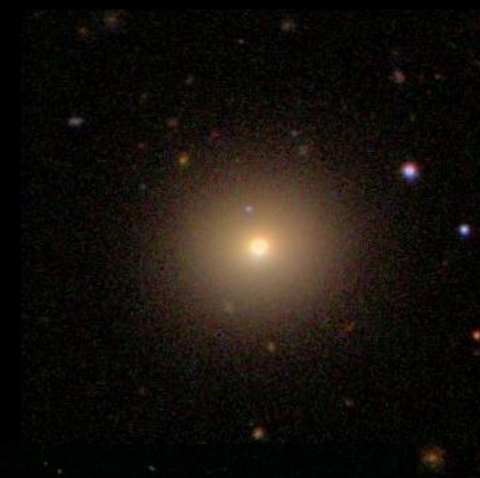
UNITED KINGDOM · CHINA · MALAYSIA

Outline

- Introduction
- Stacking
- Sub-mm fluxes of ordinary galaxies
- Analysis and Interpretation
- Dust temperature and mass
- Obscuration of star-formation
- The nature of red galaxies



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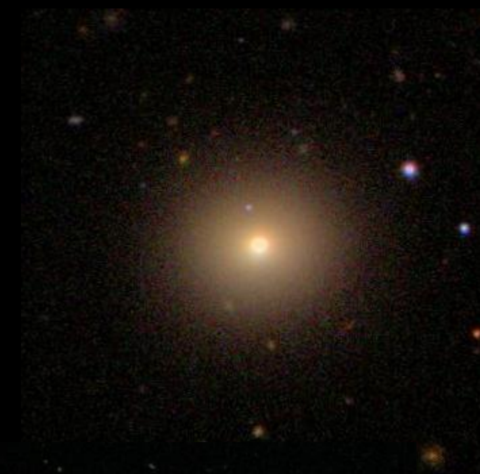
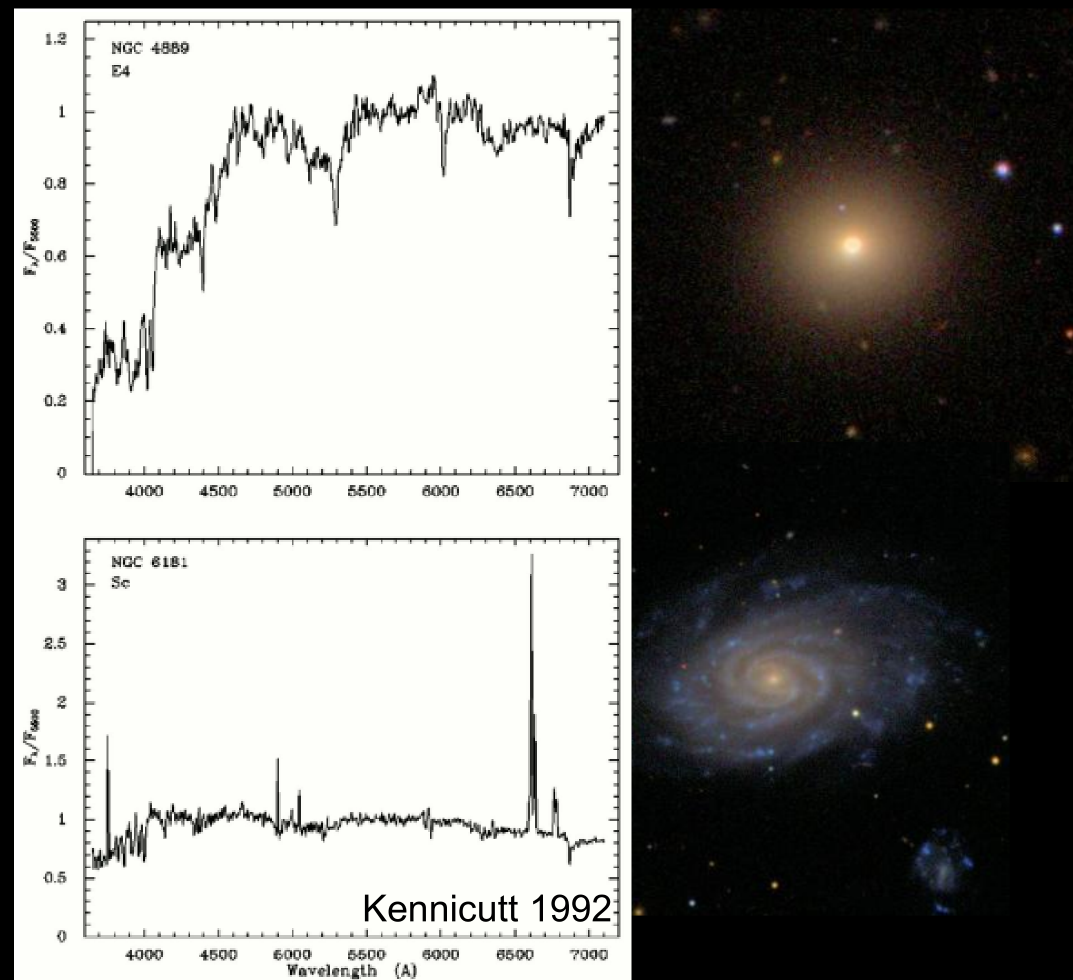


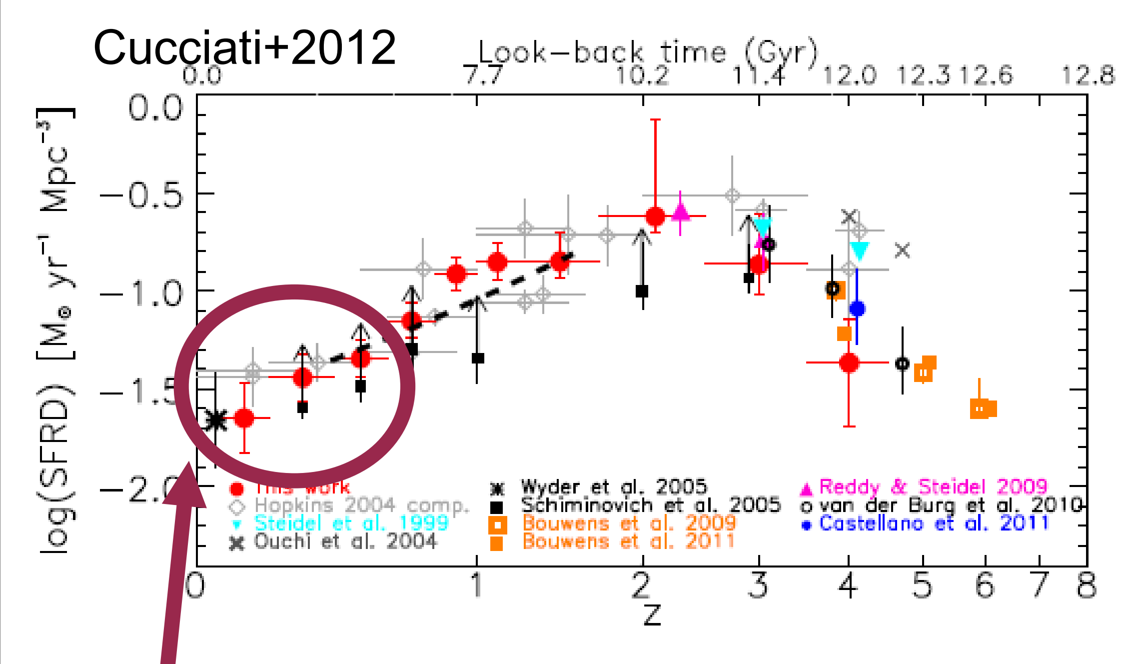
Motivation

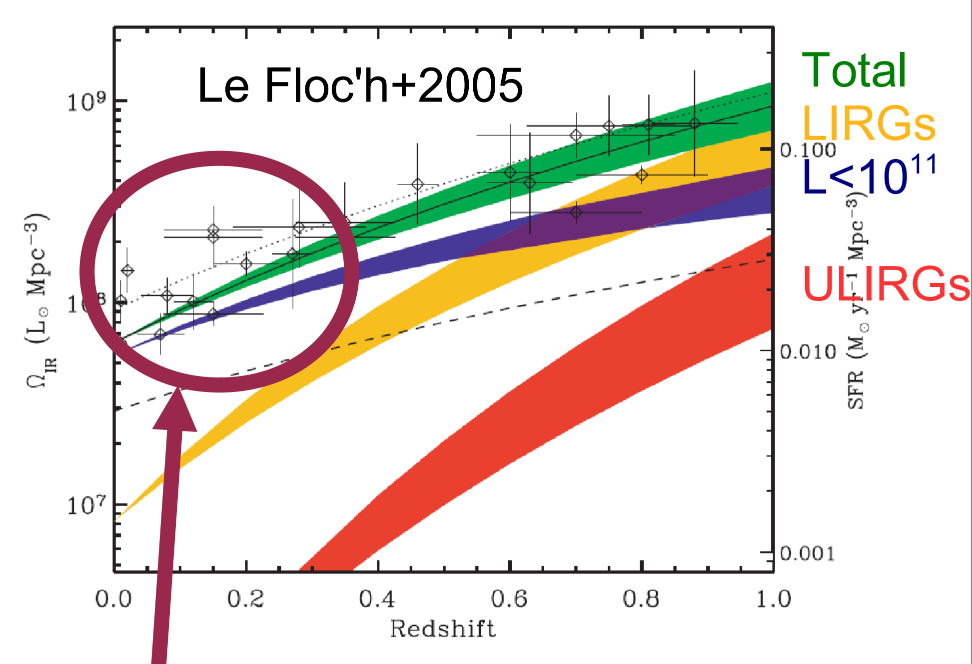
- Bimodality of galaxies
  - red vs. blue
  - elliptical/spiral
  - emission lines
  - … dust content?
- Dust traces SFR...?



- Warm dust
  - IRAS, Spitzer
- Cold dust
  - SCUBA, Herschel

Motivation





SFR Density at Low redshifts:

- Strong evolution with z
- Dominated by low-luminosity systems:
  disk-mode star-formation in ordinary spirals

Herschel-ATLAS & GAMA

- 550 deg^2 imaging at 100, 160, 250, 350, 500μm with PACS and SPIRE instruments
- Noise level close to confusion limit
- 135 deg^2 H-ATLAS/GAMA overlap in equatorial fields 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 at r<19.8
- Photometric redshifts otherwise
- Stellar masses from *ugriz* (Taylor+11)

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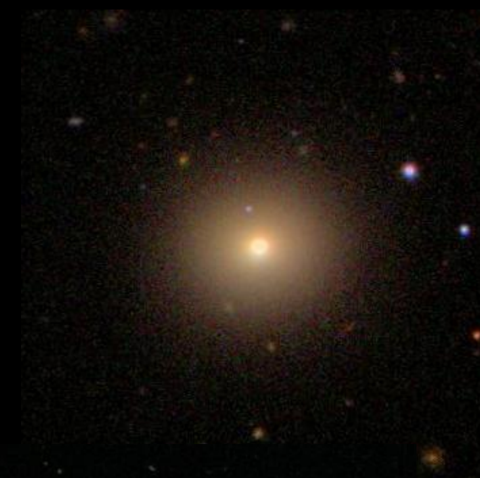
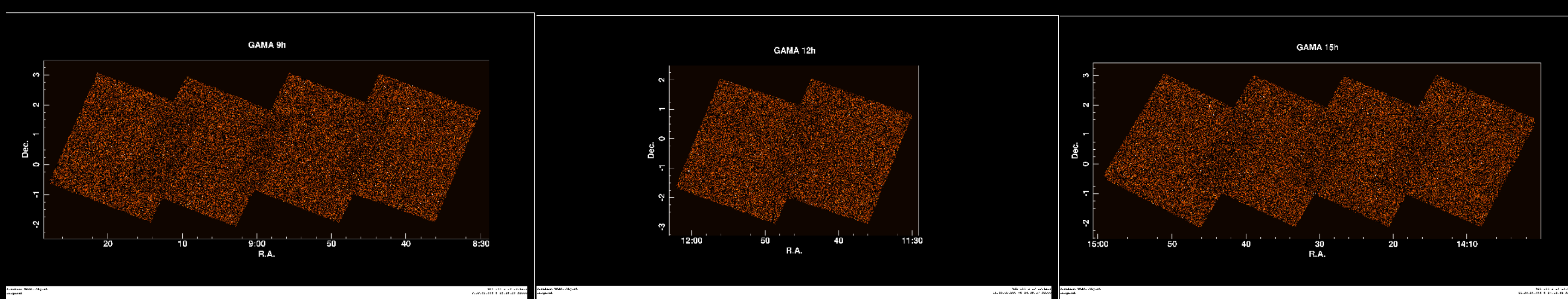


Stacking 86,000 SDSS galaxies in the sub-mm

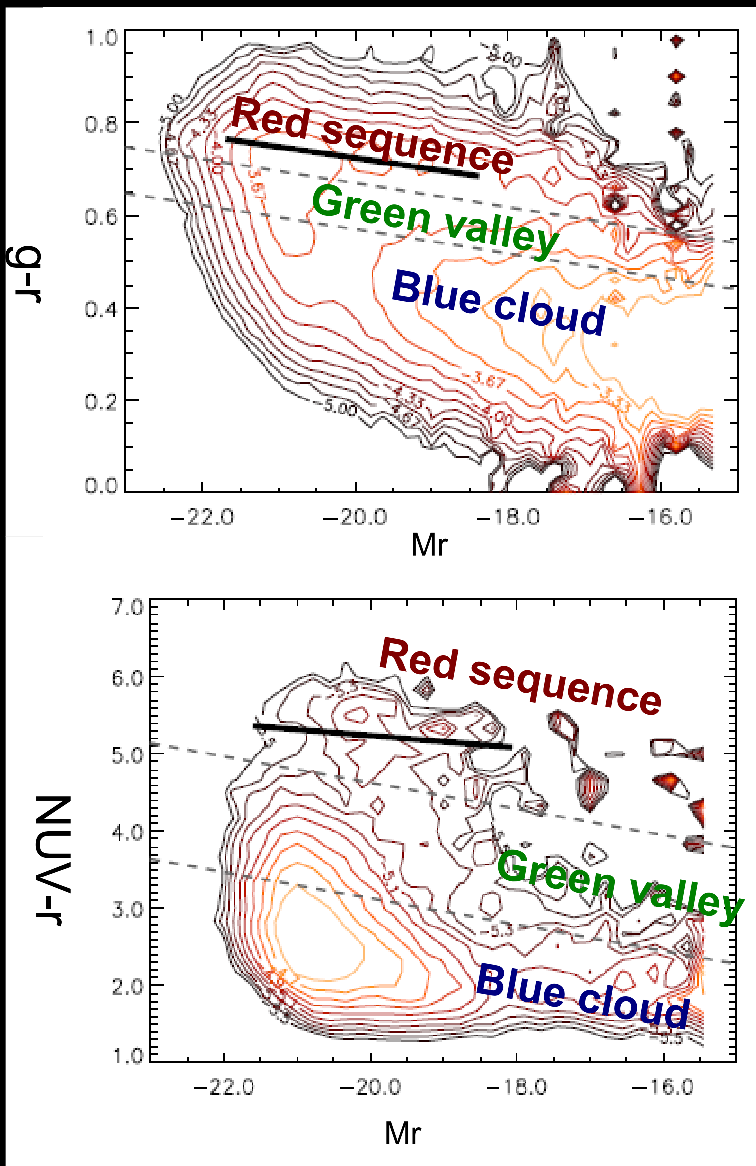
- Optical selection unbiased by dust properties
- Unprecedented sub-mm sky coverage providing large number statistics at low redshift
- UV-NIR photometry aids classification of sample to explore dependencies

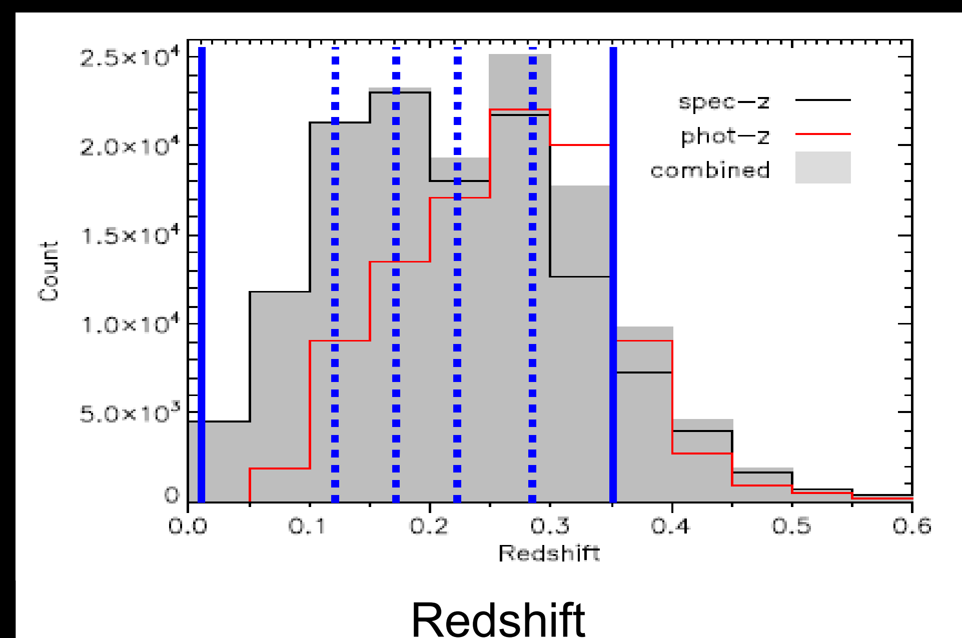


The First Large-Scale Census of Dust in Normal Galaxies at Low Redshift

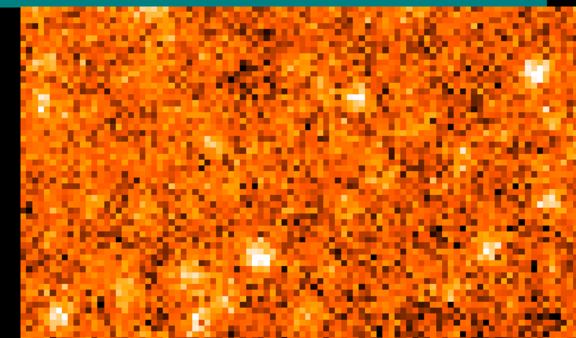
Stacking strategy

- 3 colour bins - to isolate red sequence and blue cloud
- 5 bins of absolute magnitude (M_r) or stellar mass
- 6 redshift bins – test for evolution





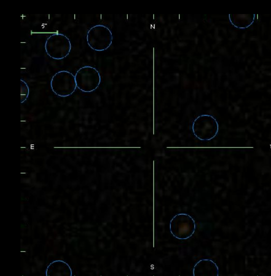
Confusion and blending

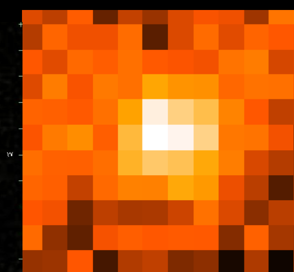


Three problems to consider:

- Unresolved background (faint high-z sources)

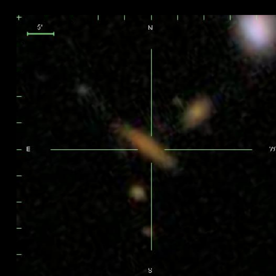
  → subtract a flat sky background

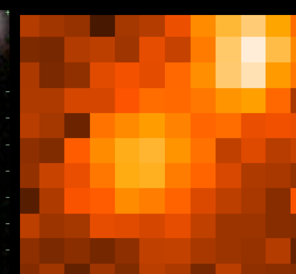




- Blending with detected background sources (mostly bright high z sources)

  → fit & subtract





- Blending between sources in the GAMA catalogue

  → divide flux in map between the blended sources and PSF-convolve

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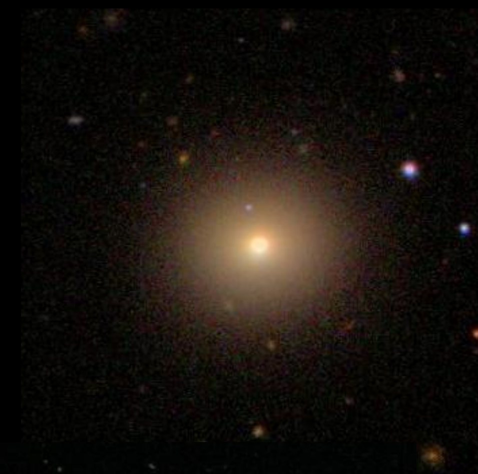
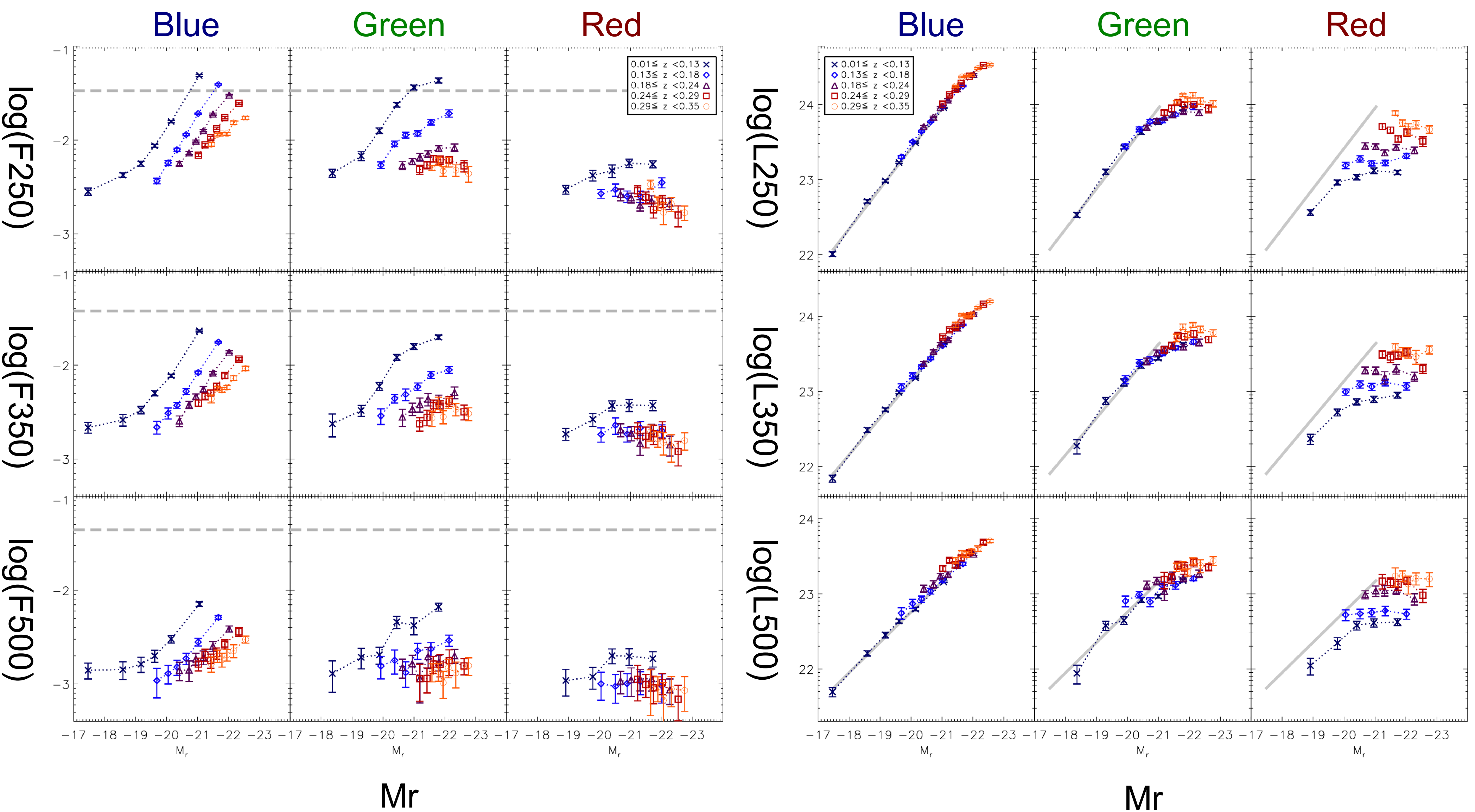
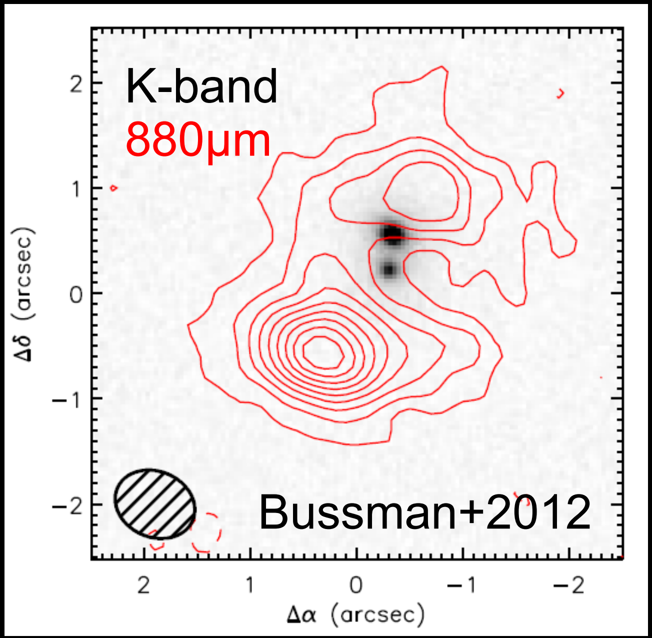


Sub-mm fluxes of optically selected galaxies



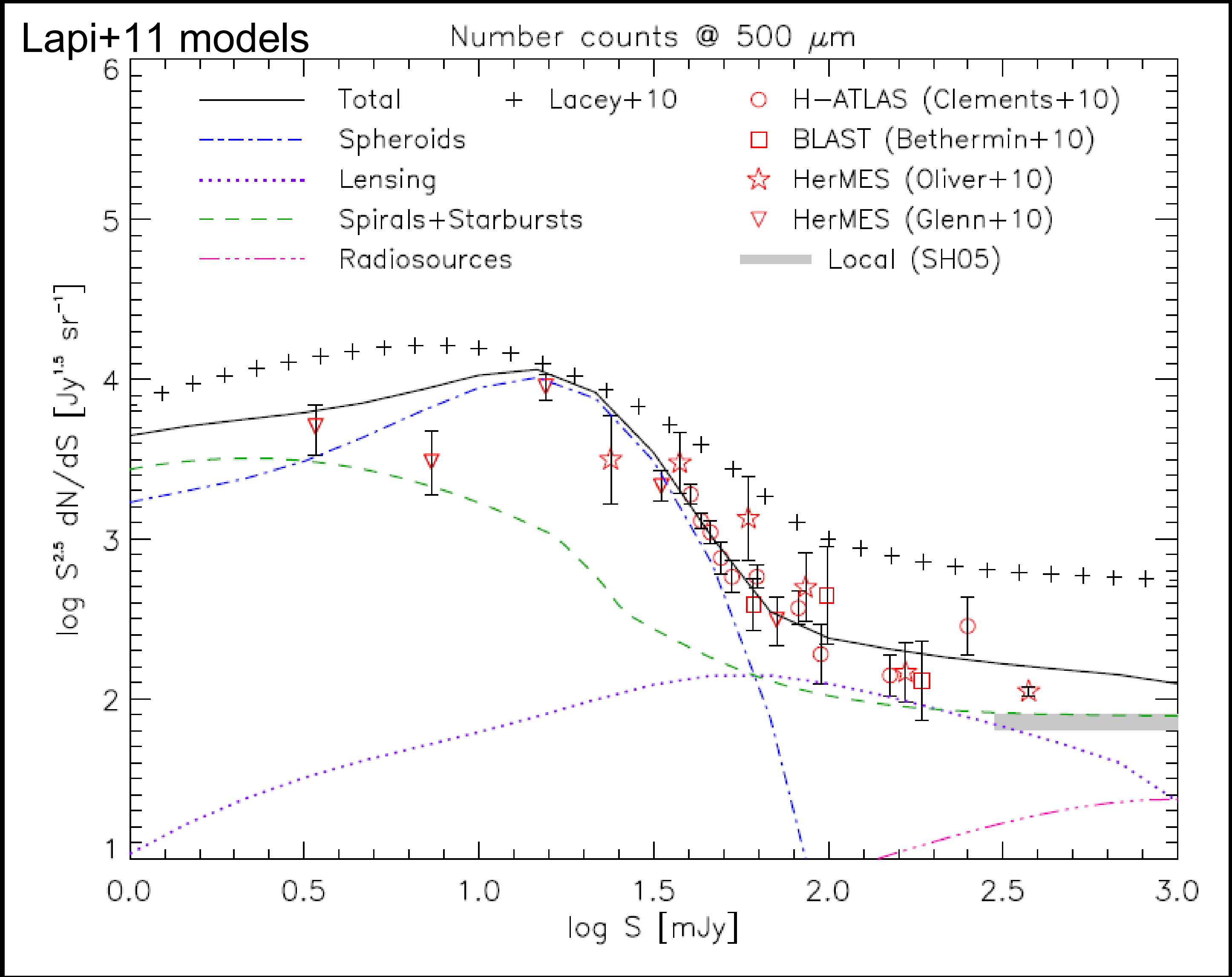
Fluxes can be biased by lensing

- Galaxies that are aligned with background sources will act as strong gravitational lenses
- The magnified flux of the high-z lensed source (SMG) can significantly boost the sub-mm flux of the low-z target, due to negative k-correction and low resolution in the sub-mm

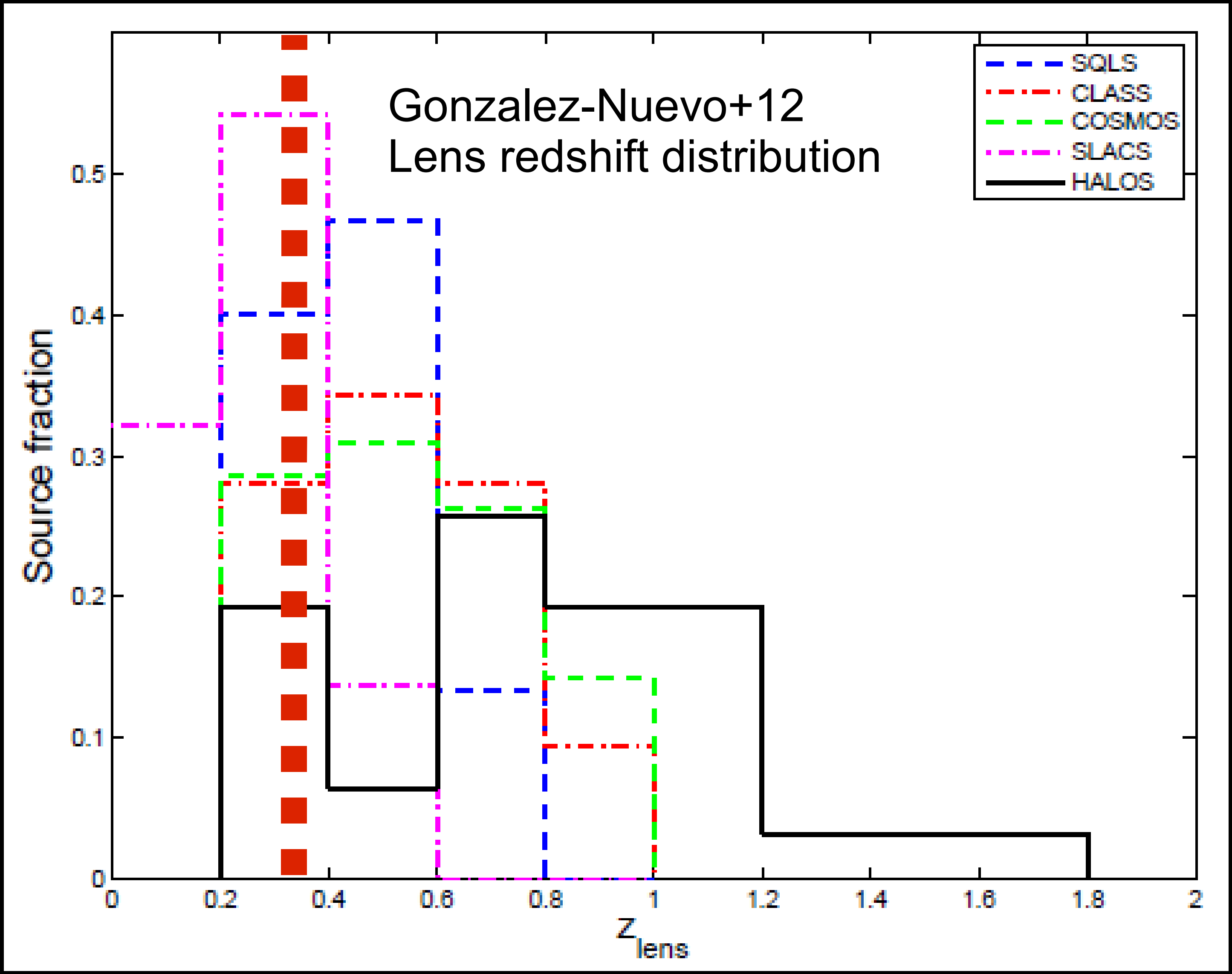


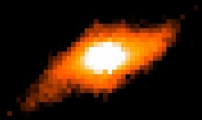
- Can be a problem if we stack many foreground galaxies which...
  - are intrinsically faint in comparison to the lensed sources
  - have a gravitating mass profile that provides a strong magnification factor (e.g. spheroids)

Estimating the lensing contamination to red galaxies



Estimating the lensing contamination to red galaxies



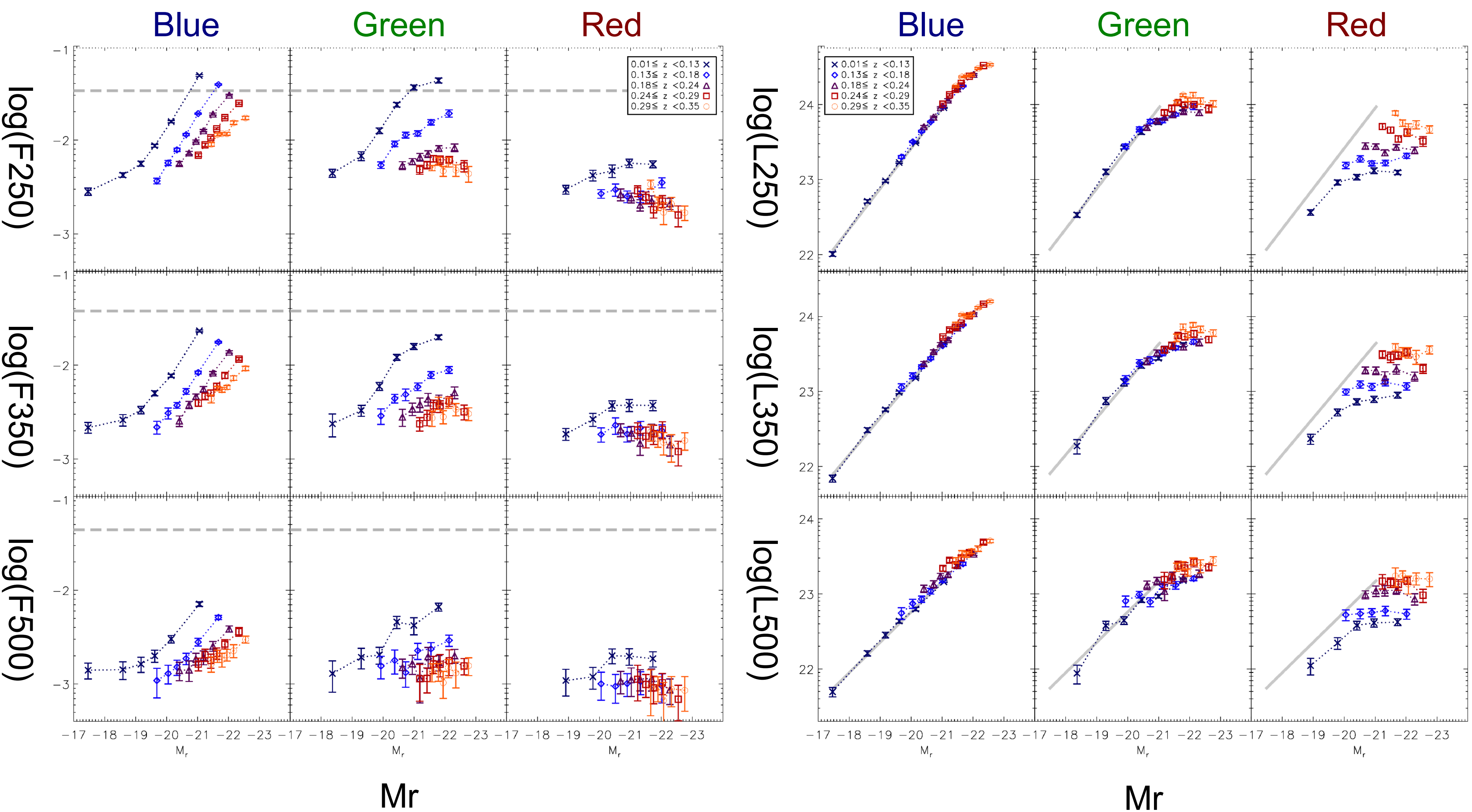


Estimating the lensing contamination to red galaxies

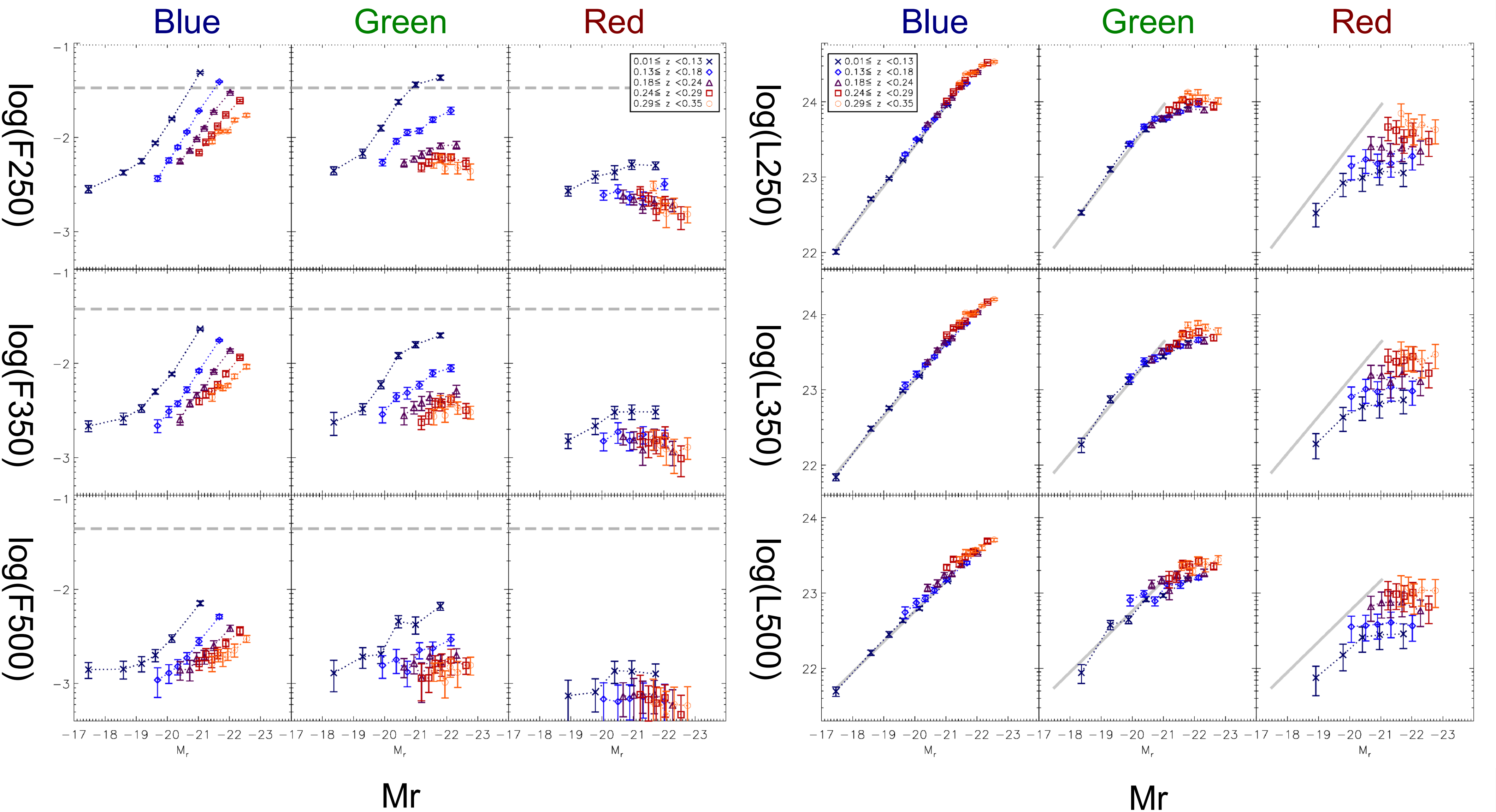
- Integrate the source counts of strong lenses (Lapi+11) to obtain total lensed flux per square degree
- Use HALOS (Gonzalez-Nuevo+12)redshift distribution to estimate how much of this flux is lensed by low redshift galaxies (z<0.35)
- Compare to measured flux from red galaxies

	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)

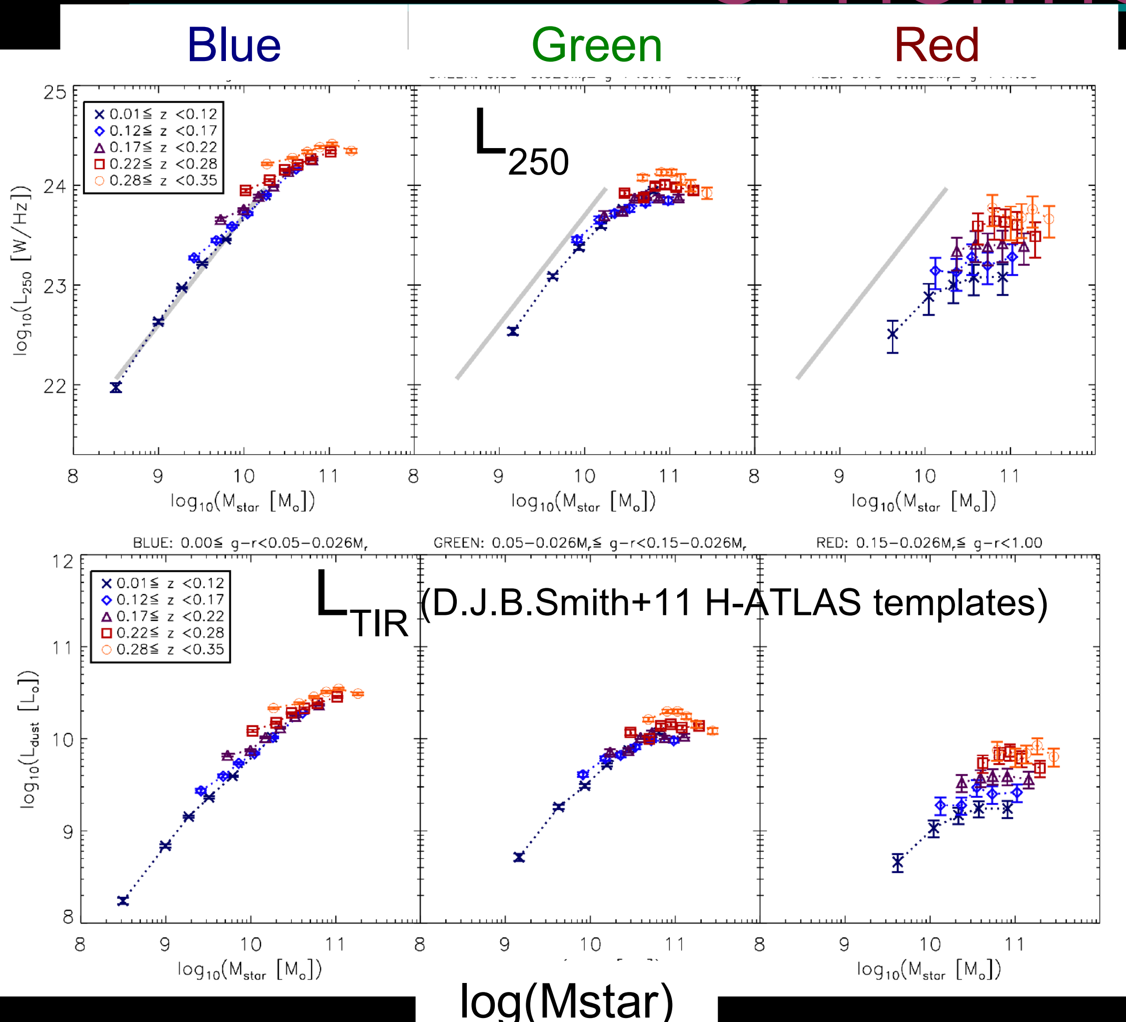
Original results



Lensing-subtracted Results



Evolution of Infrared Luminosities of normal galaxies

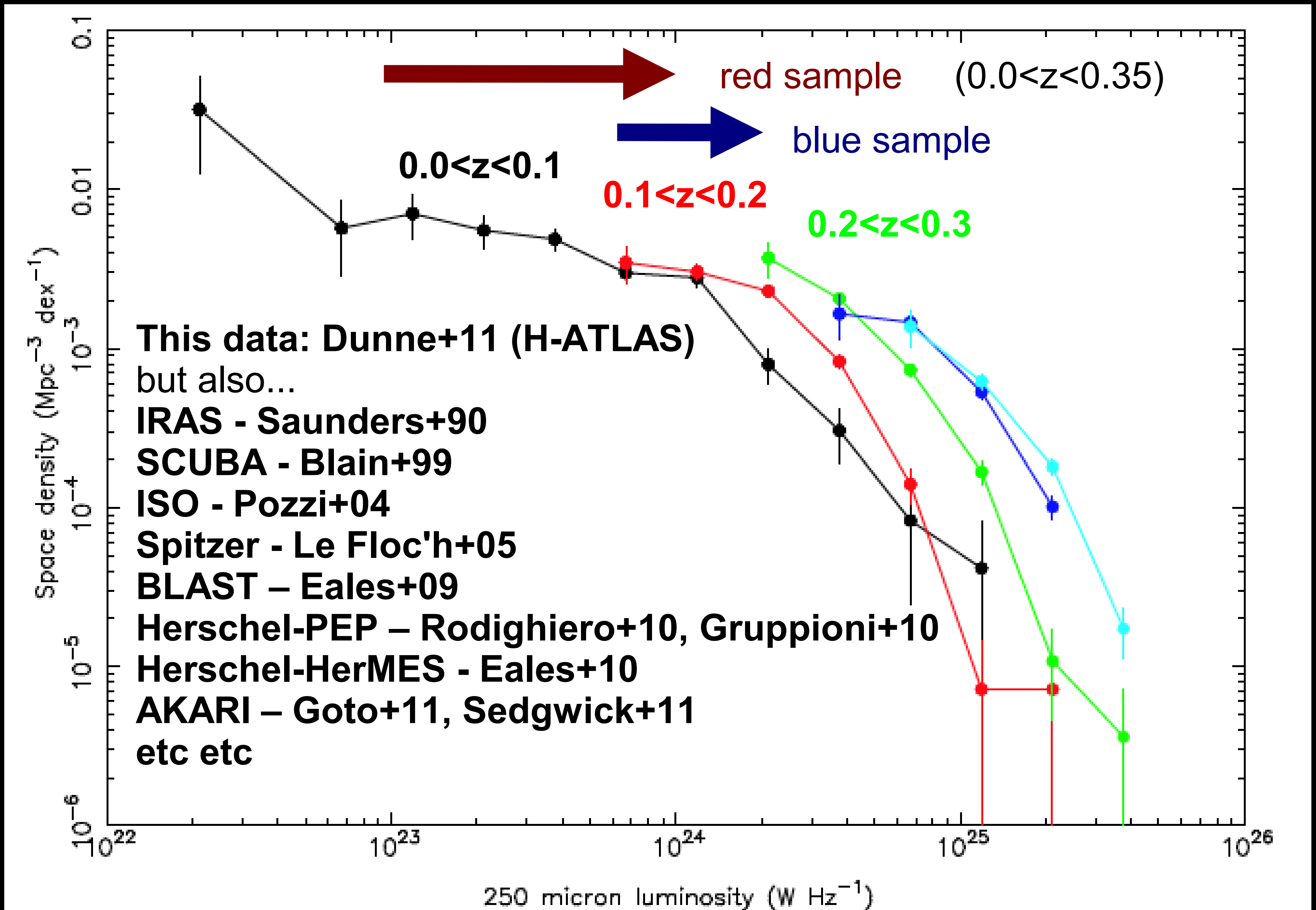


250µm or total IR luminosities evolve with redshift at fixed M_{star}

- blue $\sim(1+z)^4$
- green $\sim(1+z)^3$
- red $\sim(1+z)^6$

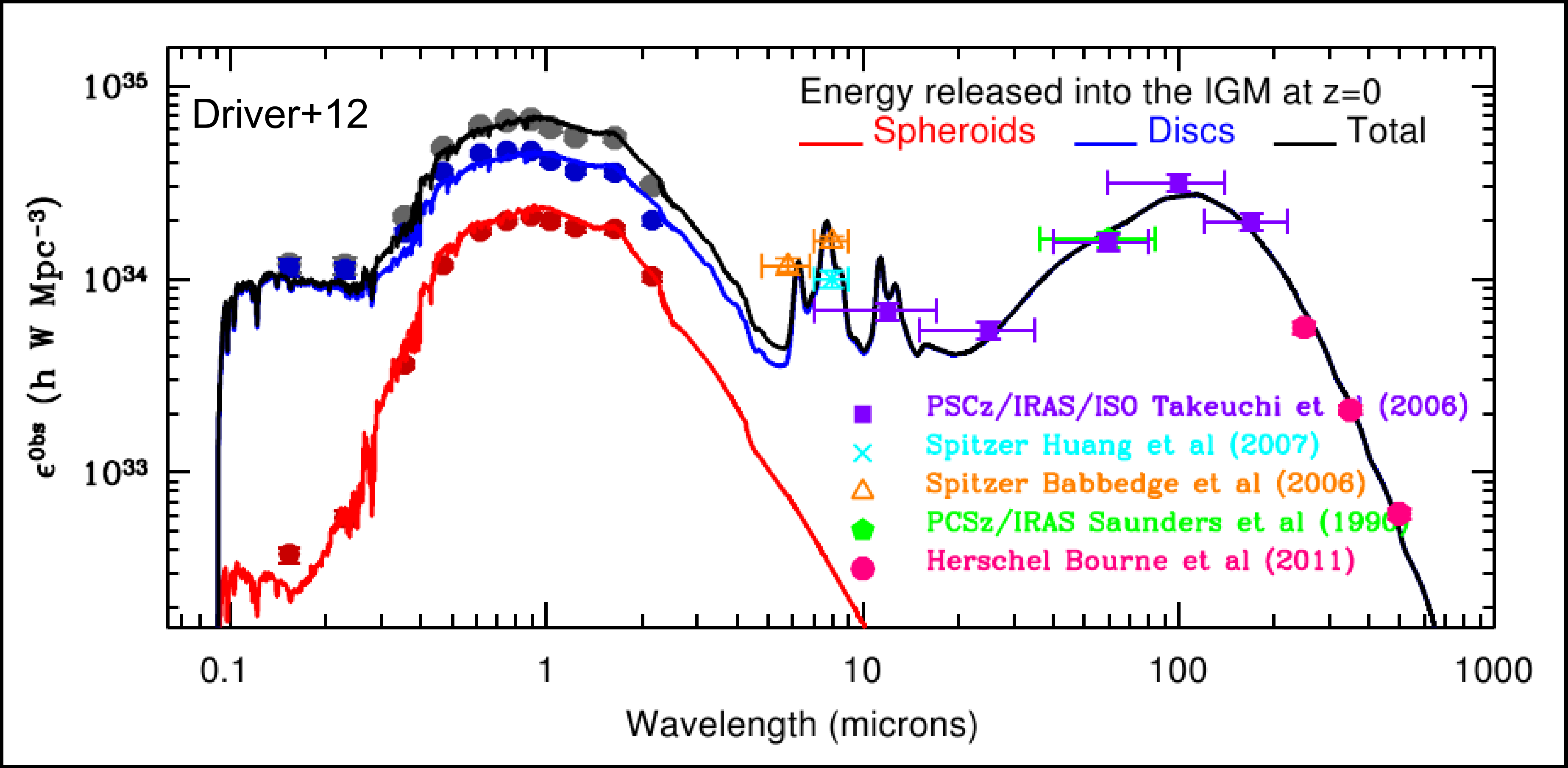
- Agrees with previous results for radio and FIR luminosity evolution over larger z ranges: Oliver+10; and Magnelli+09, Damen+09, Dunne+09, Pannella+09, Karim+11, etc etc

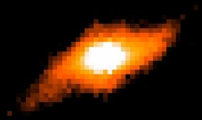
Evolution of the FIR/sub-mm LF



The Cosmic SED

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





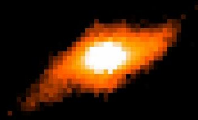
The Cosmic Infrared Background

- 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

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

	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



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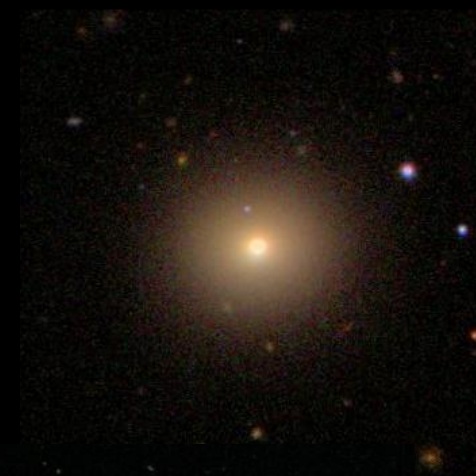
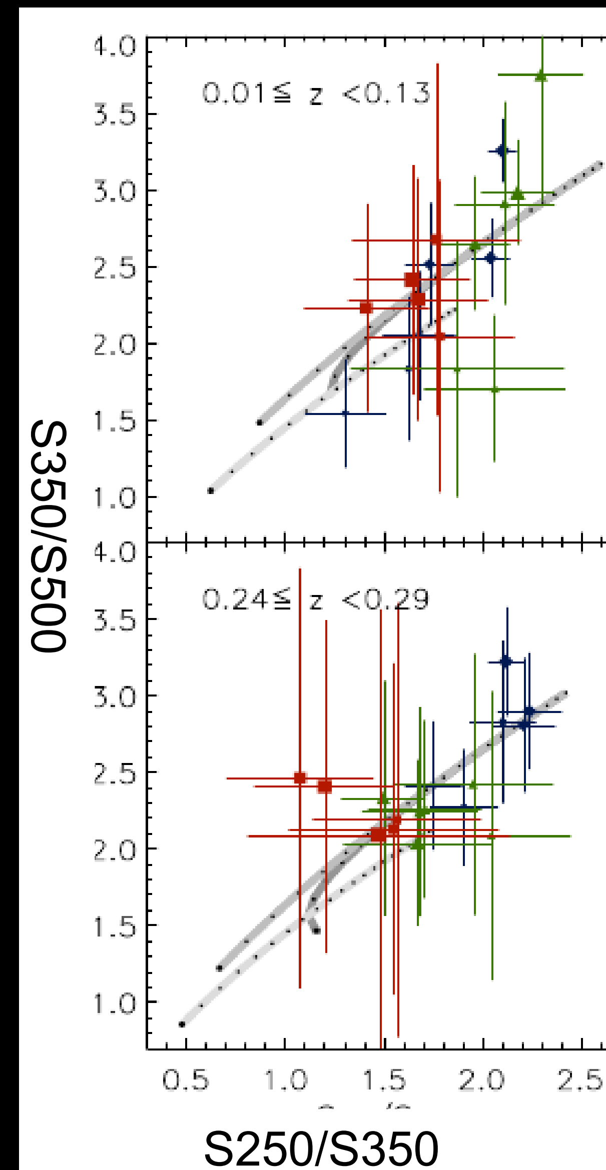


SED Fitting

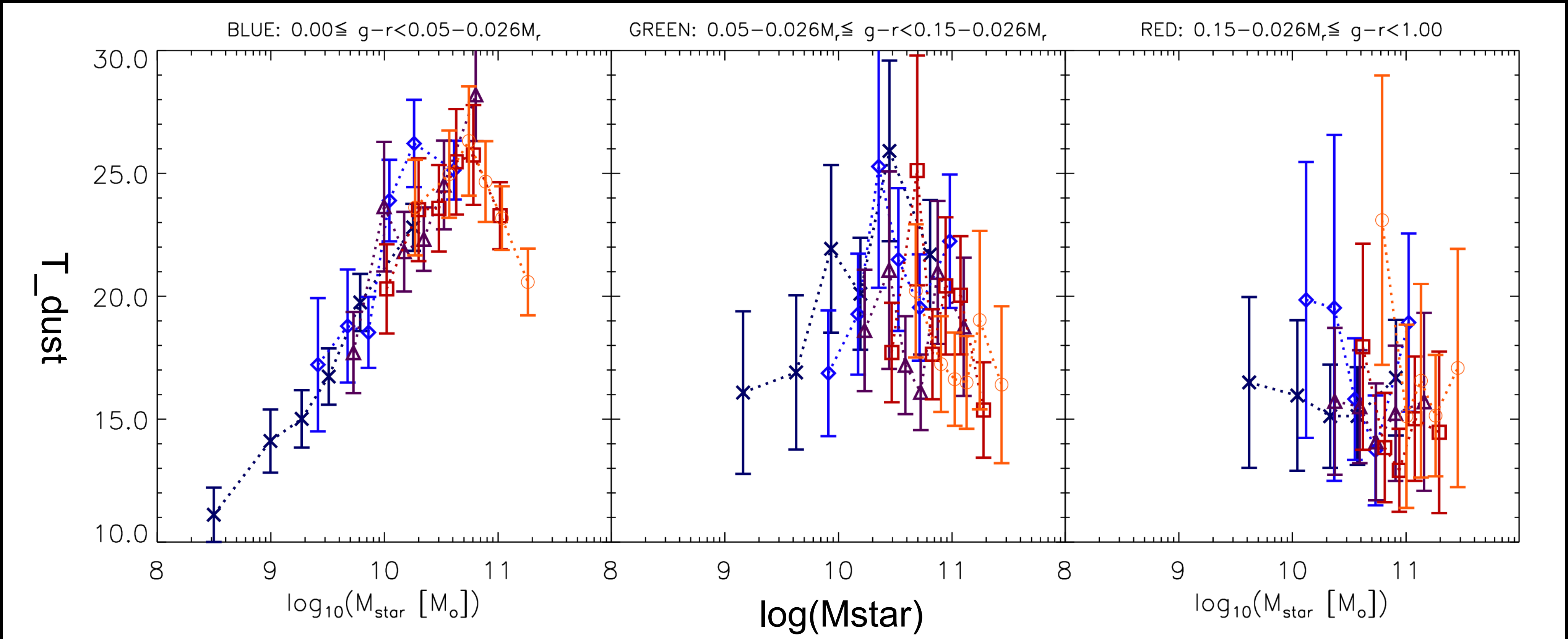
- Fit greybody SEDs to the three stacked fluxes in each bin (250, 350, 500 μm points)

$$S_\nu \sim \nu^\beta B(\nu,T)$$

- Must assume constant β but then can constrain temperatures
- Blue galaxies show correlation with mass
- Significant difference between dust temperatures of red and blue galaxies
- Doesn't appear to be due to lensing (at 2.4σ level)
- Robust to contamination of 500μm band by additional confusion or extended flux



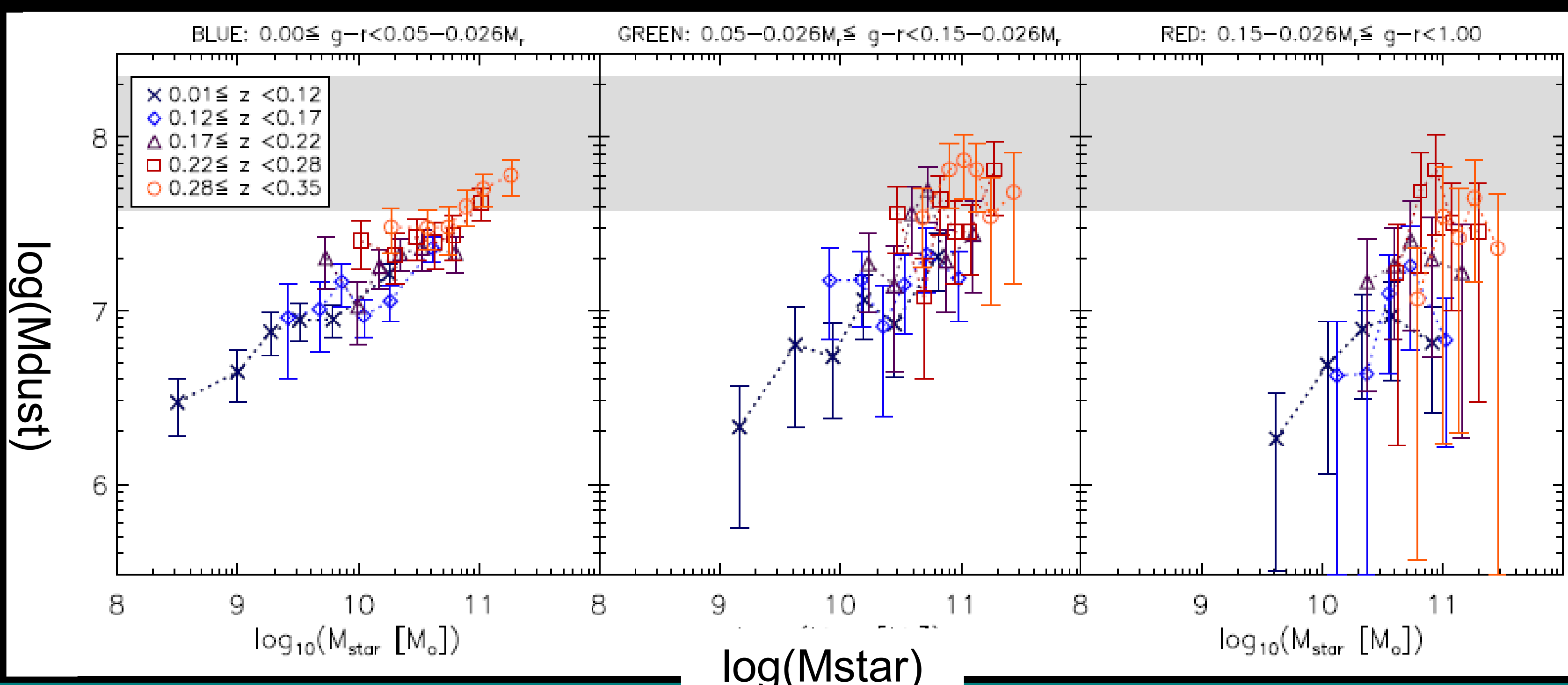
Dust Temperatures

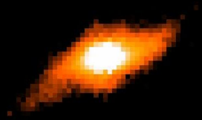


Dust Masses

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

- 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





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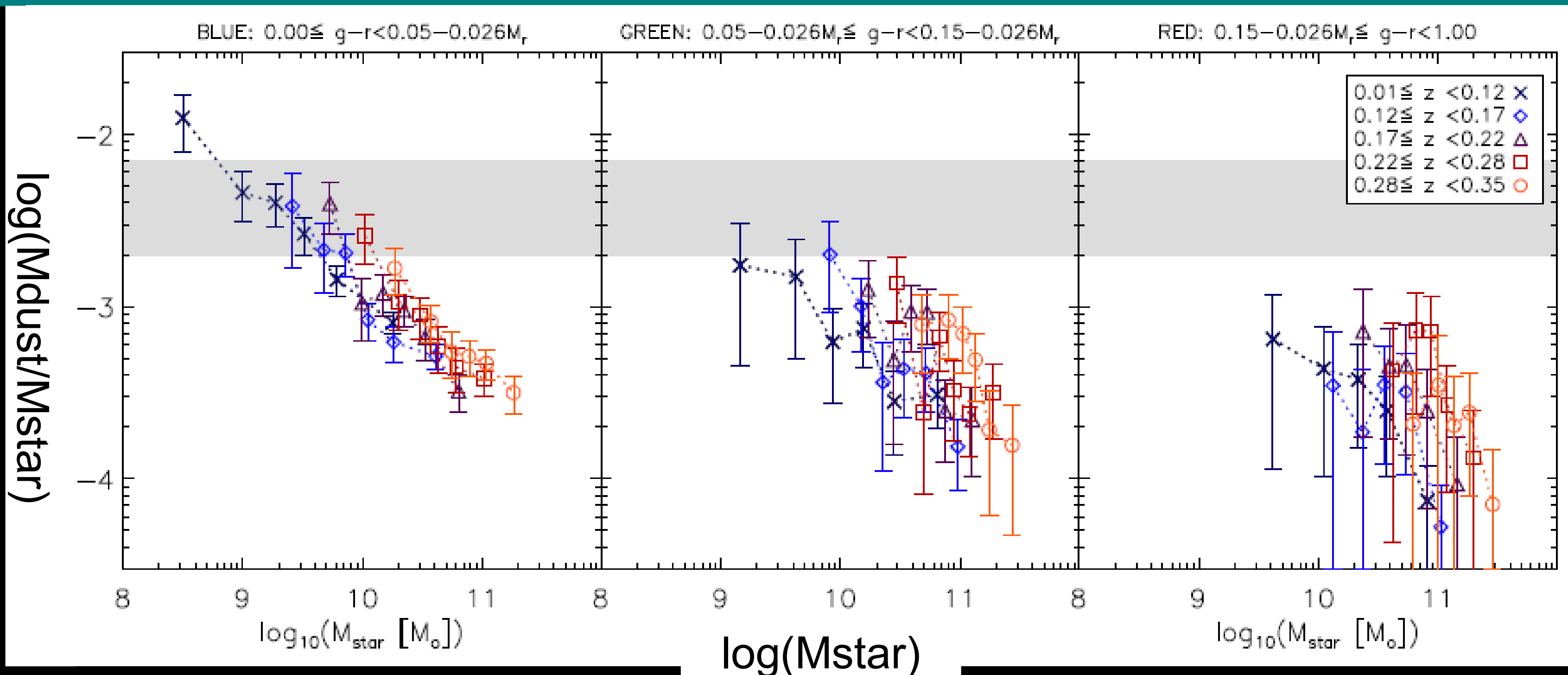
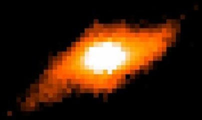


- M_{dust}/M_{star} strongly anti-correlated with M_{star}
- If dust mass traces gas mass, 'dwarfs' have converted less of their gas into stars
- and high dust masses in dwarfs imply dust must be produced in SN (and grow in the ISM) - unless a top-heavy IMF – H.Gomez+ (in prep)



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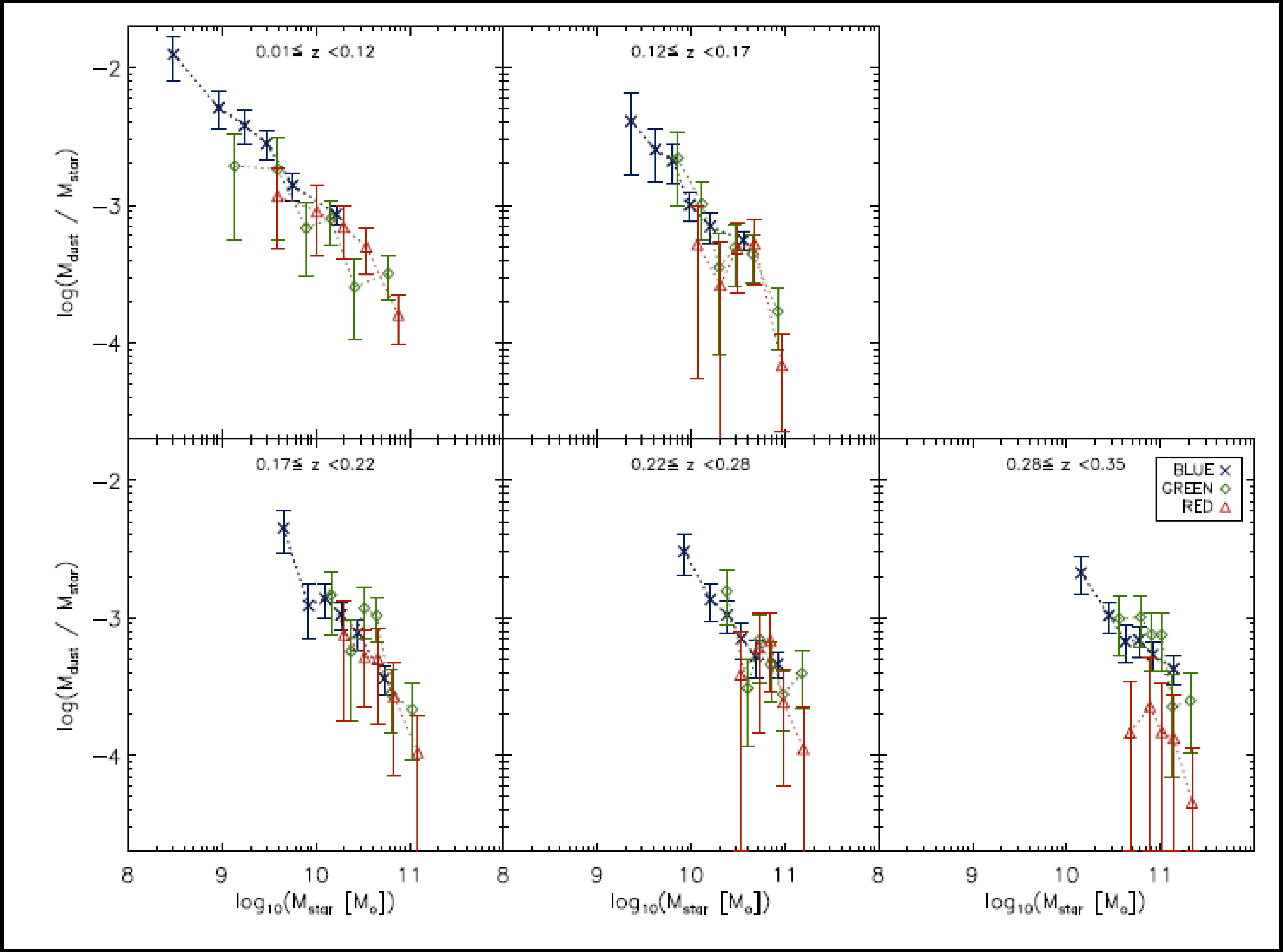
0.01≤ z <0.12
0.12≤ z <0.17
0.17≤ z <0.22
0.22≤ z <0.28
0.28≤ z <0.35
BLUE
GREEN
RED
log(M_dust / M_star)
log_10(M_star [M_o])
−2
−3
−4
8
9
10
11

Dust Masses

- Dust masses of red and blue galaxies *typically* differ by factors 2-3
- Red galaxies also appear to have colder dust than blue
- Contrast with literature data on spiral versus elliptical samples: typical ellipticals have at least an order of magnitude less dust than spirals, but similar dust temperatures (e.g. HRS – M.W.L. Smith+12)
- Also Rowlands+12: median dust mass of Herschel-undetected ellipticals much lower than our red sample
  - red galaxies != ellipticals
- Also possibility of environmental dependence of dust masses - see HRS, HeViCS, HeFoCS...

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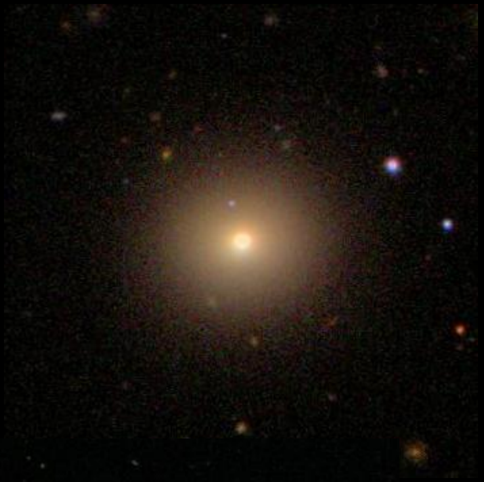
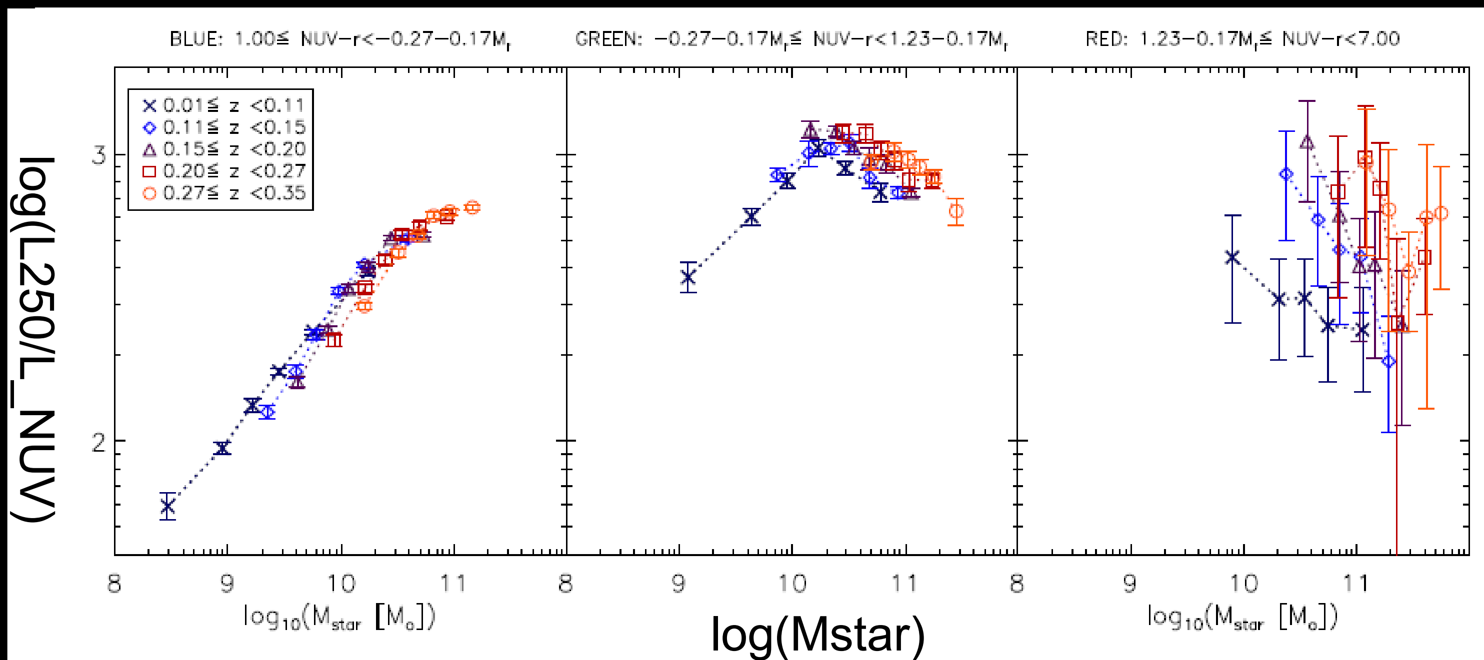
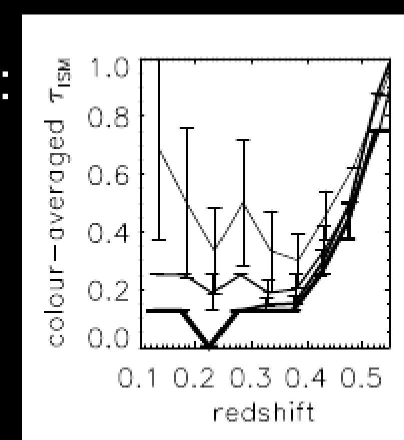


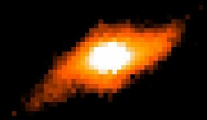
Obscuration of Star Formation



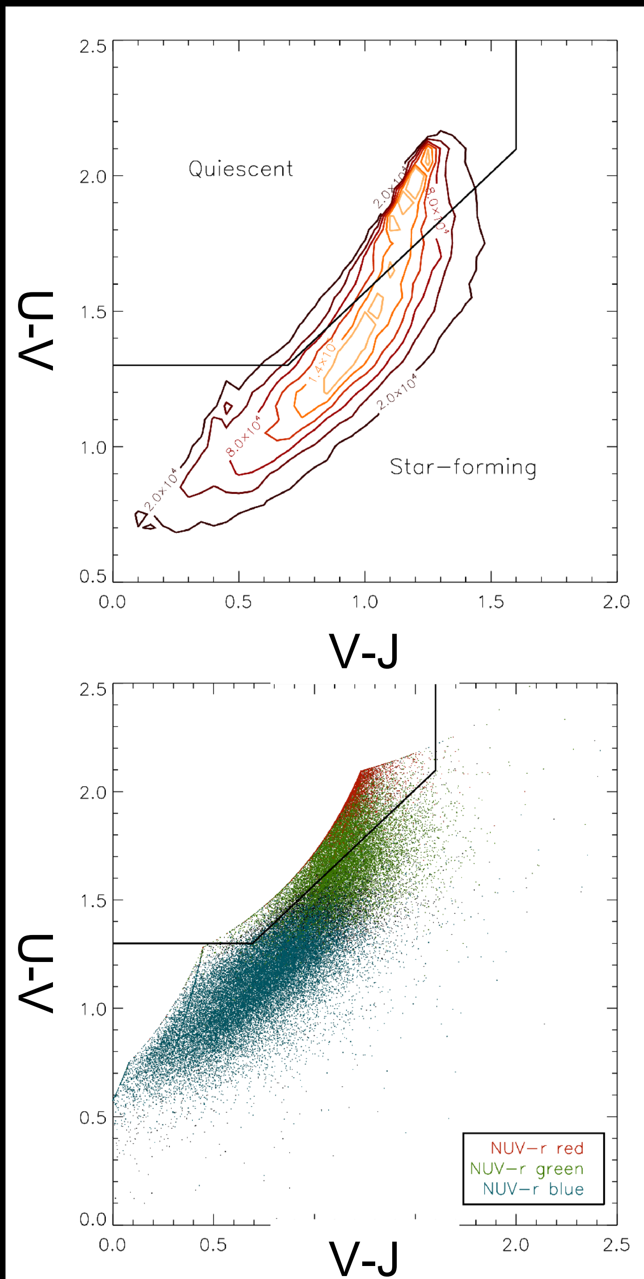
Tojeiro+11:

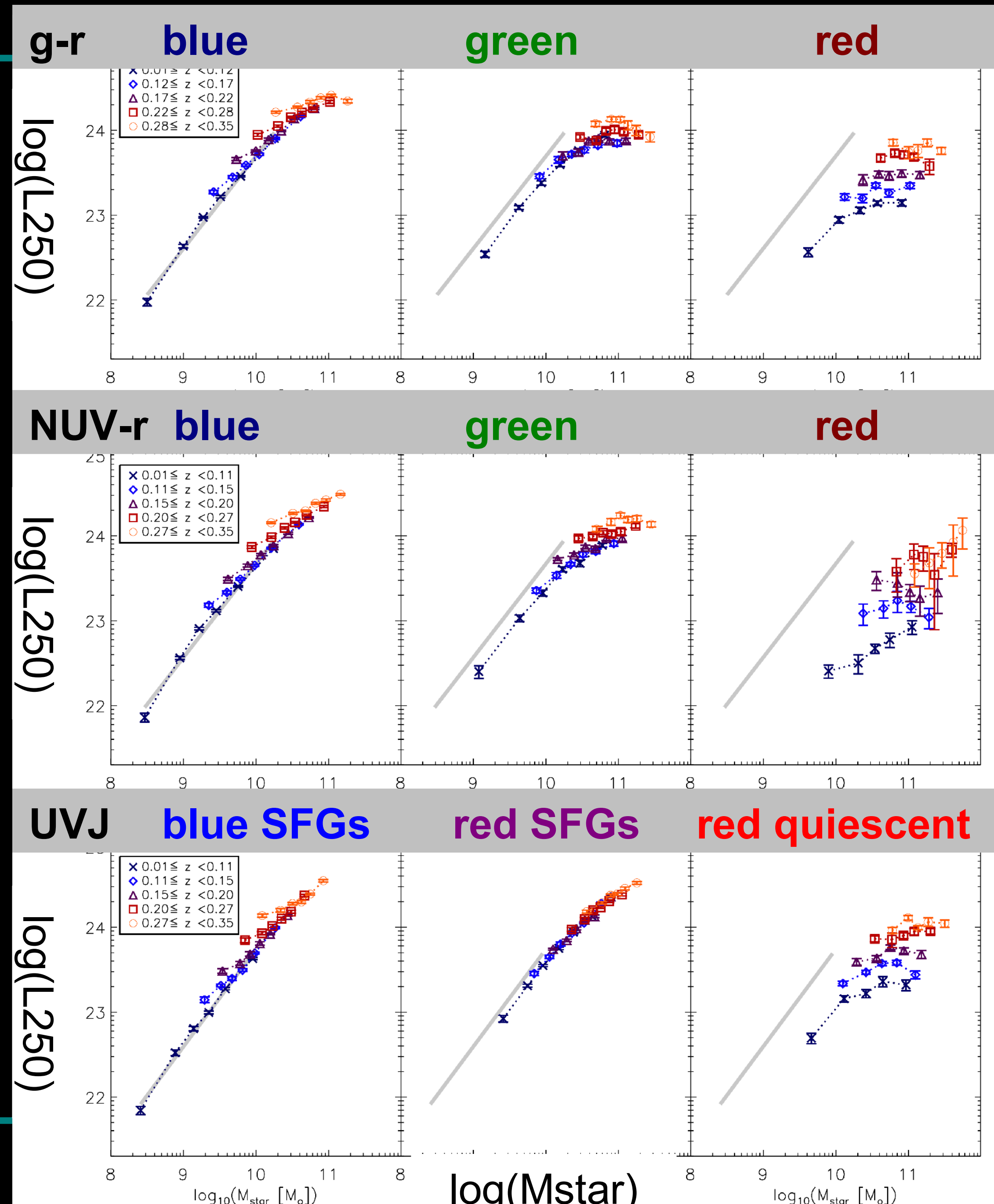


- Luminous red galaxies have increasing levels of obscuration at higher z and lower luminosity or mass



The Nature of Red Galaxies





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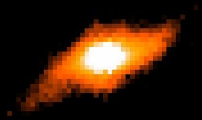

Conclusions

- Low redshift galaxies (z<0.3) account for about 5% of the 250μm CIB - ~60% of this from the blue cloud, ~20% from red sequence – 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, apparently due to higher dust temperatures which may result from higher SFRs
- Red galaxies have colder dust and probably less dust mass, but only by a factor ~2-3, typically
- Red (and blue?) galaxies are more obscured at higher z and lower mass