The Structure of High-Redshift Star-Forming Galaxies: Implications on Far-IR SED and SFR

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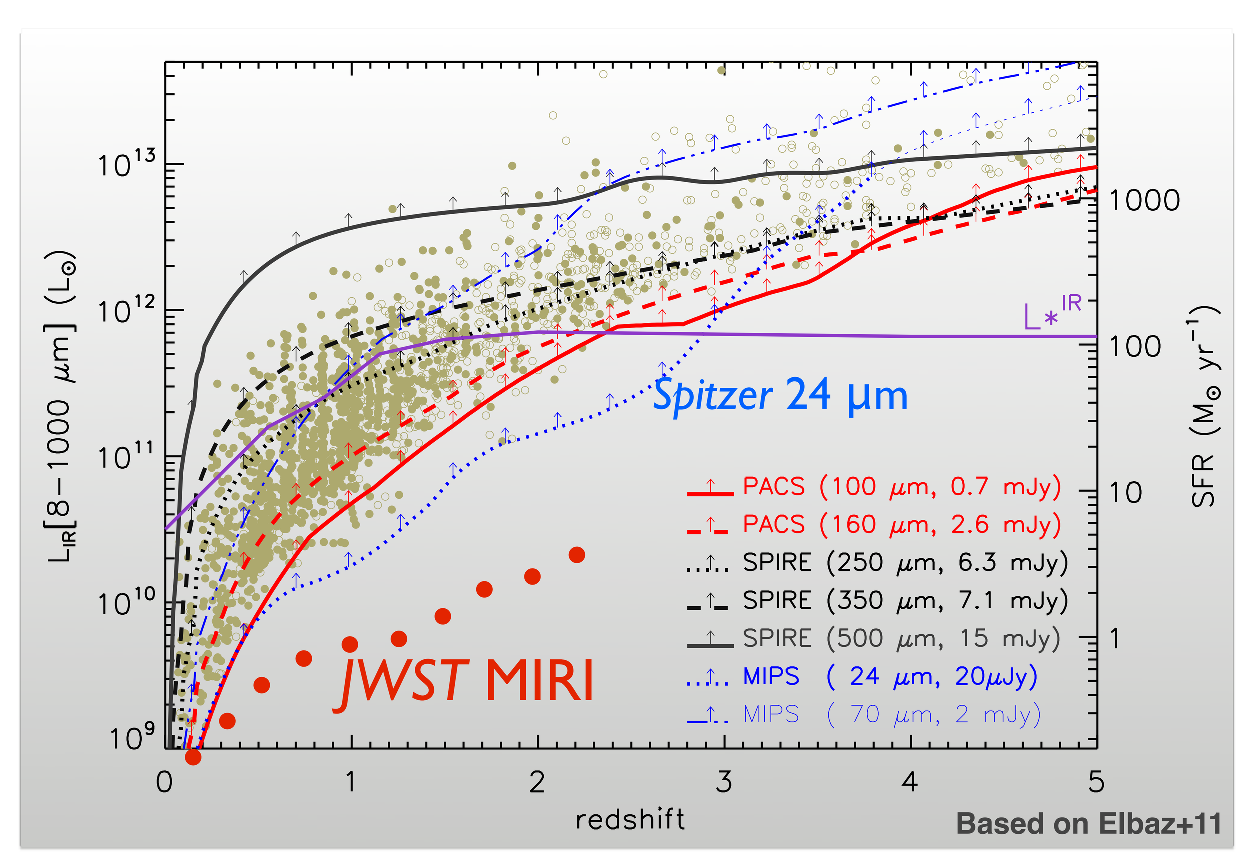
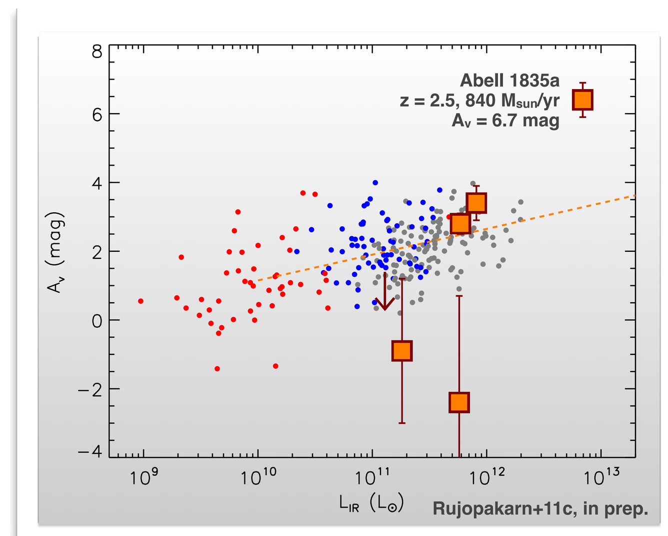


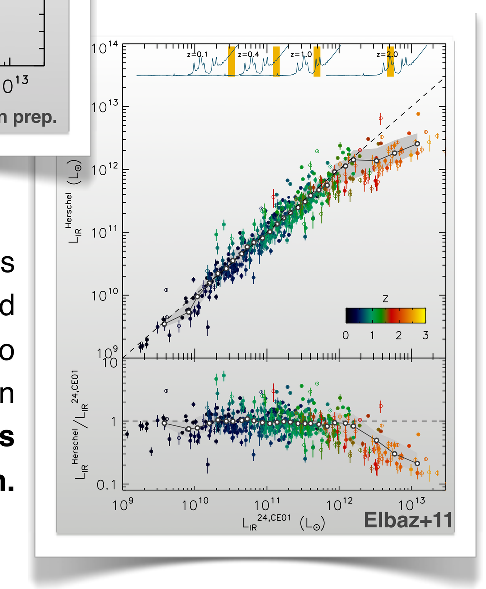
***Spitzer* 24 μm observations will be an important probe of the luminous star-forming galaxy population until *JWST*. But to utilize them, we need to understand the apparent evolution in IR galaxy spectral energy distributions (SEDs) with redshift.**

This evolution can be understood almost entirely in terms of the larger size of the high redshift U/LIRGs and their resulting lower star formation surface density than is typical for local examples.

This result in itself has interesting implications for galaxy evolution
- **Indicates there is a route besides major mergers to trigger very high levels of SF activity at $z \sim 2$**
- **This indication is supported by morphology studies**
- **There is simple procedure that gives accurate LIR from observed 24 μm flux densities**

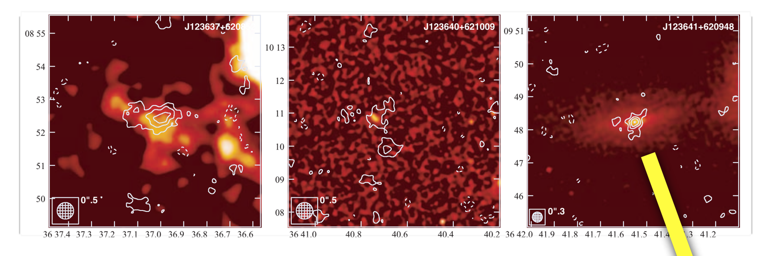


Our separate study using LBT/LUCIFER and *Spitzer* IRS to measure optical extinction by comparing Hα to Paα and Brα emissions shows that star-forming galaxies at $1 < z < 3$ have a large range of extinction. An IR SFR indicator is critical in these systems.

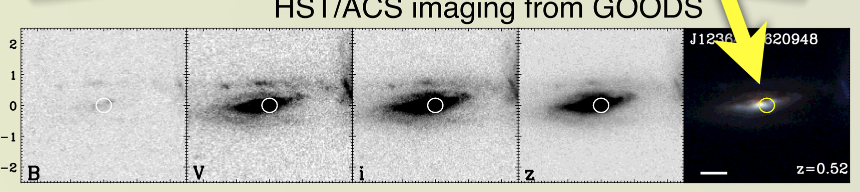


Applying local IR SEDs to high-z galaxies to estimate LIR and SFR from single-band 24 μm observations without taking into account the SED evolution results in an overestimation of LIR and SFR. **This is known as the "mid-IR excess" problem.**

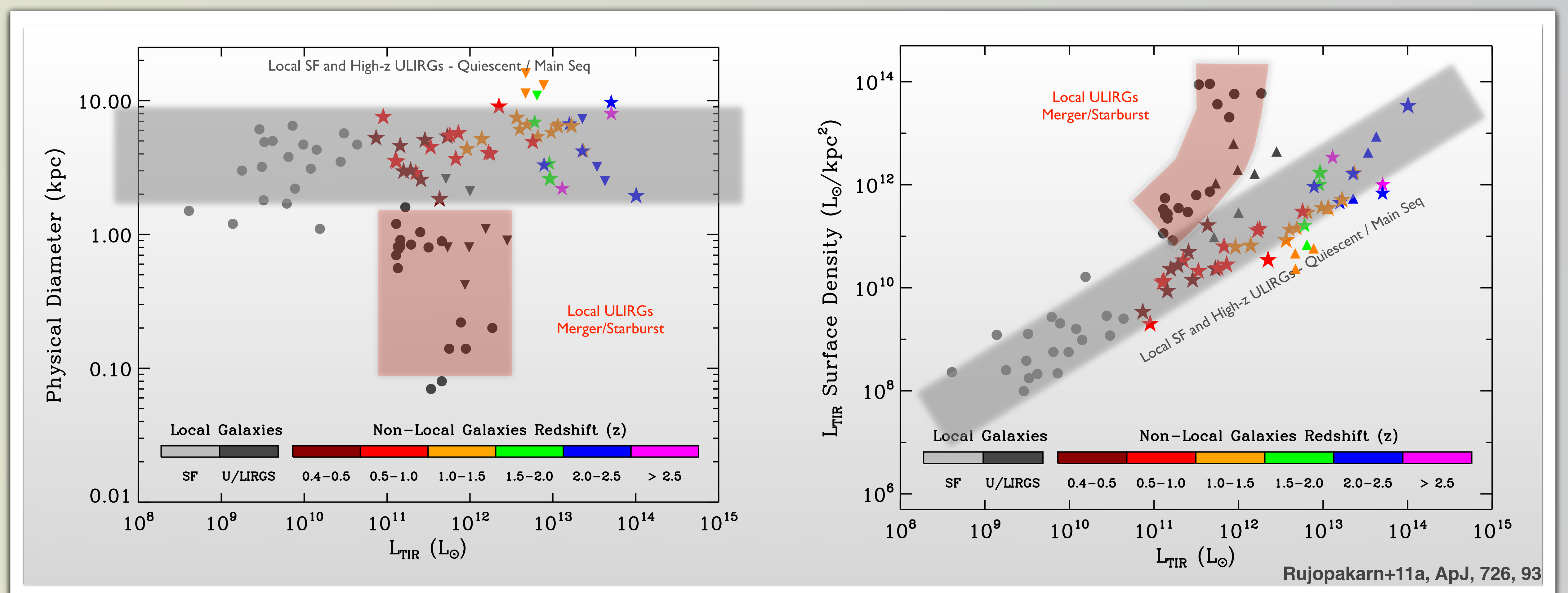
Muxlow+05 MERLIN/VLA radio survey of the HDF



HST/ACS imaging from GOODS



We have used complete samples at 1.4 GHz that resolve the IR-emitting galaxies to measure physical sizes of galaxies both in the local Universe and at high-z. **The galaxy diameters are 2-10 kpc, almost independent of redshift and luminosity, except for local U/LIRGs that are ~100x smaller in surface area.**



The star-forming regions in non-local U/LIRGs and SMGs have similar physical sizes to those in local normal star-forming galaxies.

Excepting local U/LIRGs, there is a tight relationship between total infrared luminosity, L_{IR}, and infrared luminosity surface density, Σ_{IR}, for nearly all infrared-luminous galaxies.

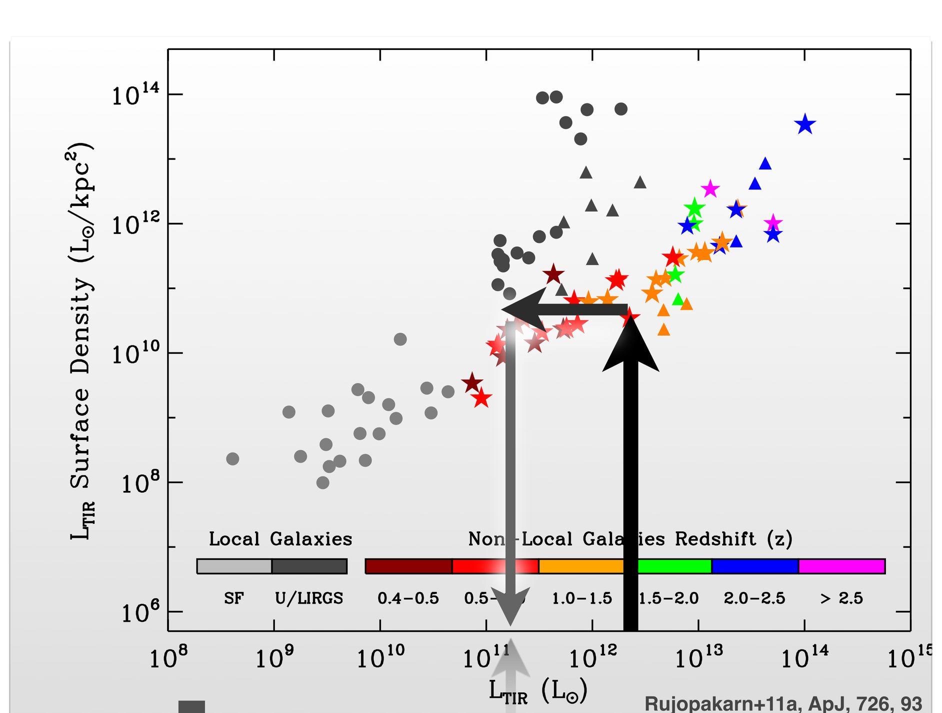
This relationship allows relating local SEDs to high-z galaxies on the basis of luminosity surface density not luminosity.

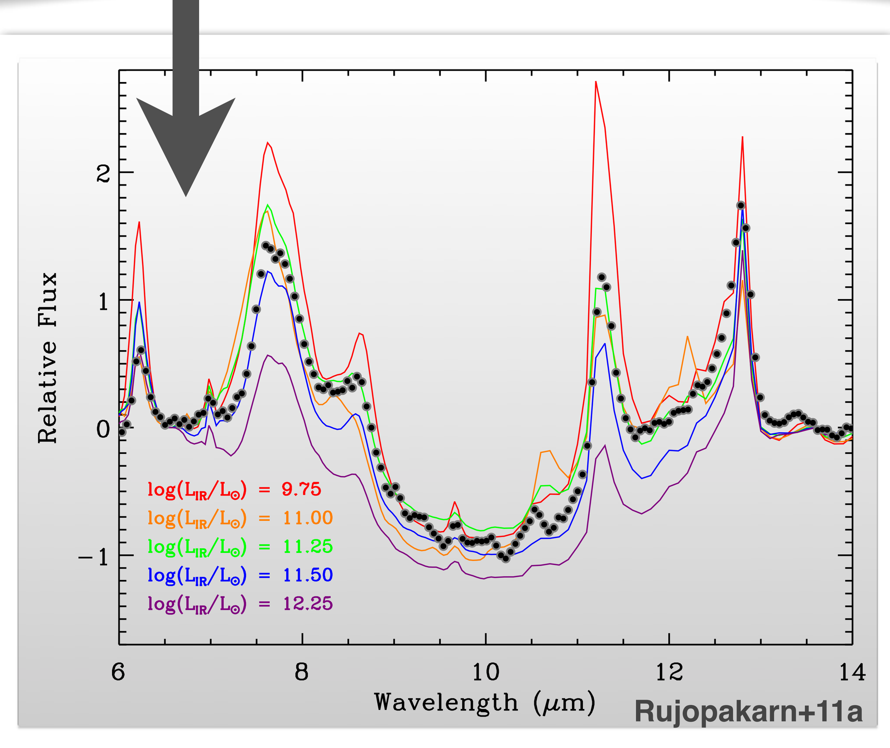
Assuming the IR SED is a function of surface density, Σ_{IR}, (as would be expected if it depends on optical depth effects), there is a simple, predictive procedure to select the appropriate local SED template to use with any high-z U/LIRG.

For example, SED features of a $10^{12.3}$ L_{sun} ULIRG at $z \sim 1$ should be similar to the SED of a local galaxy with LIR of ~$10^{11.2}$ L_{sun} that has identical Σ_{IR}

A comparison of the stacked IRS spectra of ULIRGs at $z \sim 1$ with LIR of $10^{12.3}$ L_{sun} (Dasyra+09) to the local SED templates from Rieke+09 shows that the SED of a $z \sim 1$ ULIRG can indeed be described by the local SED with LIR of $10^{11.00}$ - $10^{11.25}$ L_{sun}.

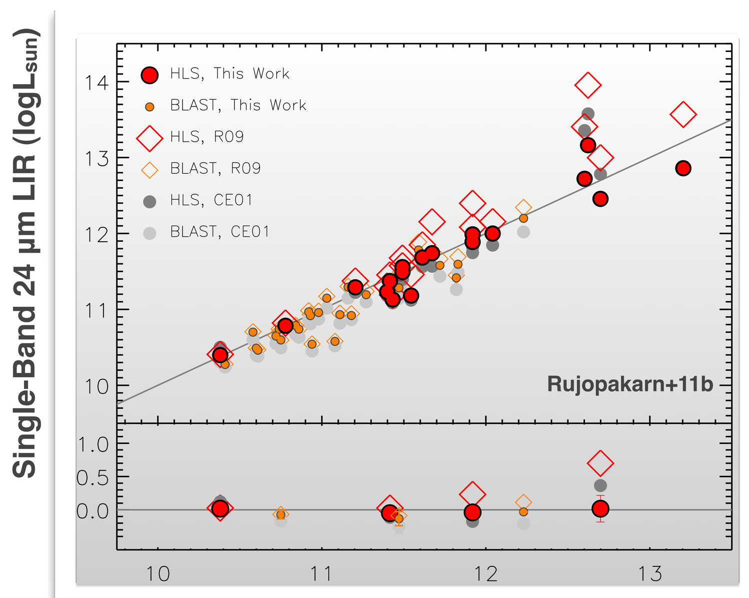
There is an evolution of star forming infrared spectral energy distributions (SEDs) with redshift that we show is virtually entirely due to the larger sizes of high-z U/LIRGs





A simple procedure allows estimating the total infrared luminosity of star forming galaxies solely from the redshift and the observed 24 μm flux density out to z ~ 2.5

The results accurately reproduce the actual total infrared luminosities determined from *Herschel* and BLAST observations (bottom) as well as LIR from stacked samples (right). The averages (bottom panels) imply the offsets are less than 0.1 dex.



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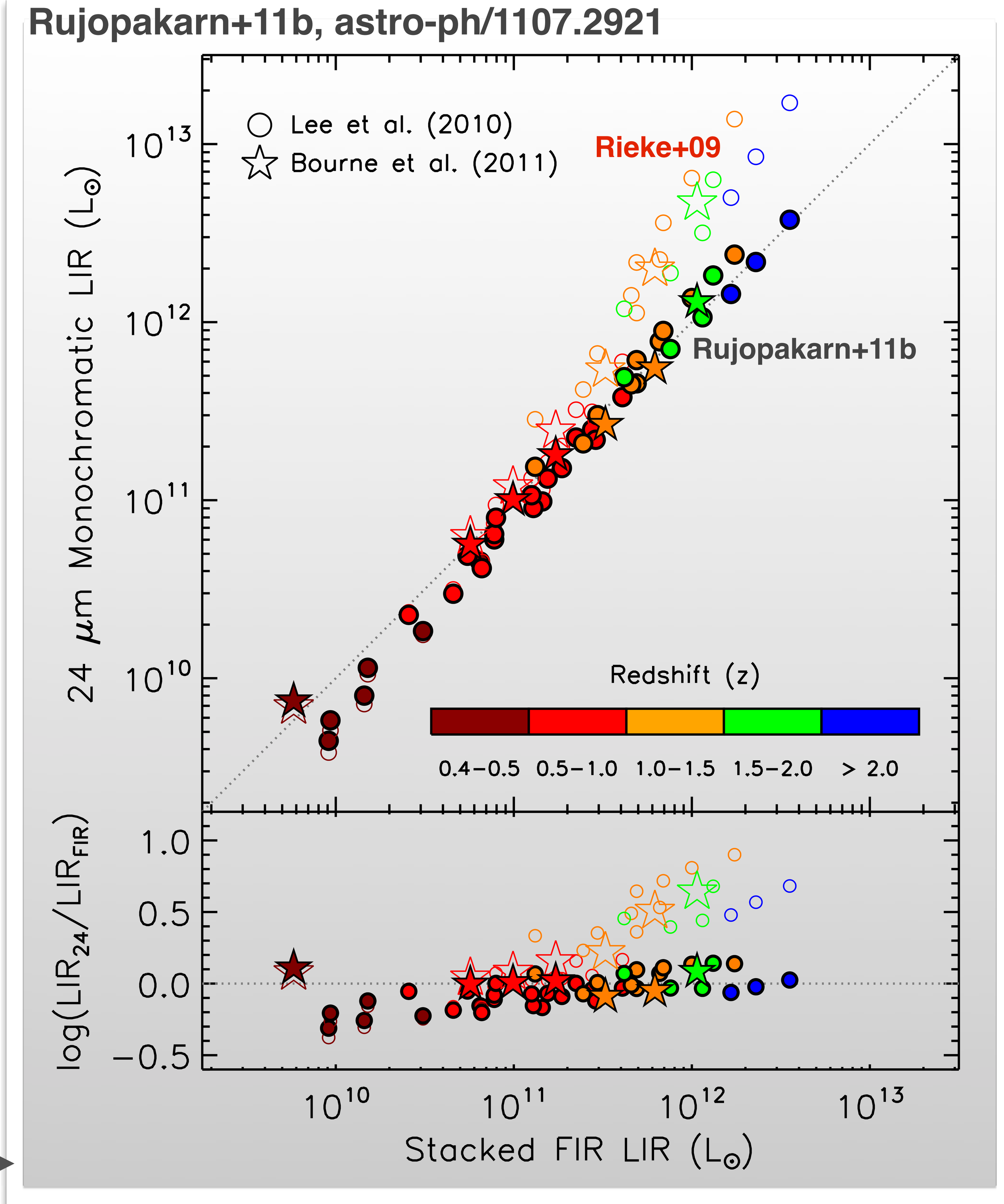
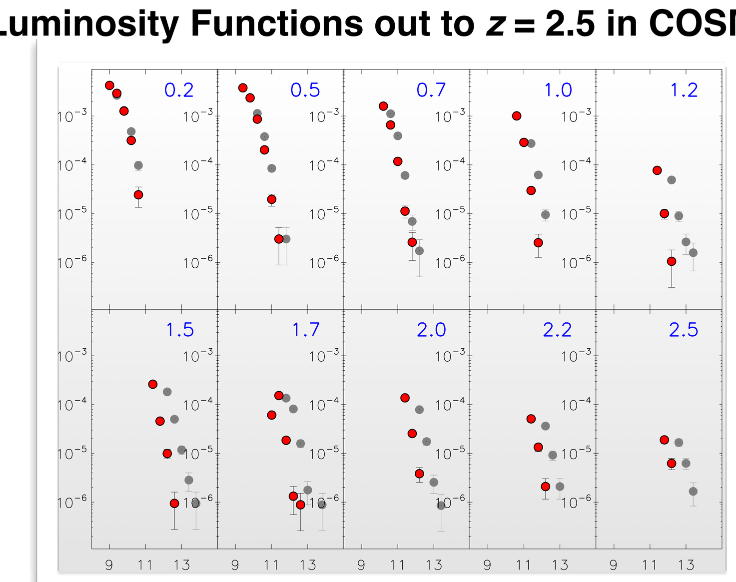


Effects of the new LIR indicator on IR Luminosity Functions out to $z = 2.5$ in COSMOS



Rieke+09 Rujopakarn+11b

Further implications:

- **Inspection of the HST/ACS images indicates that only a minority of the high-z IR galaxies are major mergers. This is consistent with their radio morphologies**
- The SED selection procedure also results in substantial reductions in the maximum star forming luminosity estimate
- **The COSMOS LFs above suggest an upper limit of LIR of star-forming galaxies to be ~ 10^{13} L_{sun}**