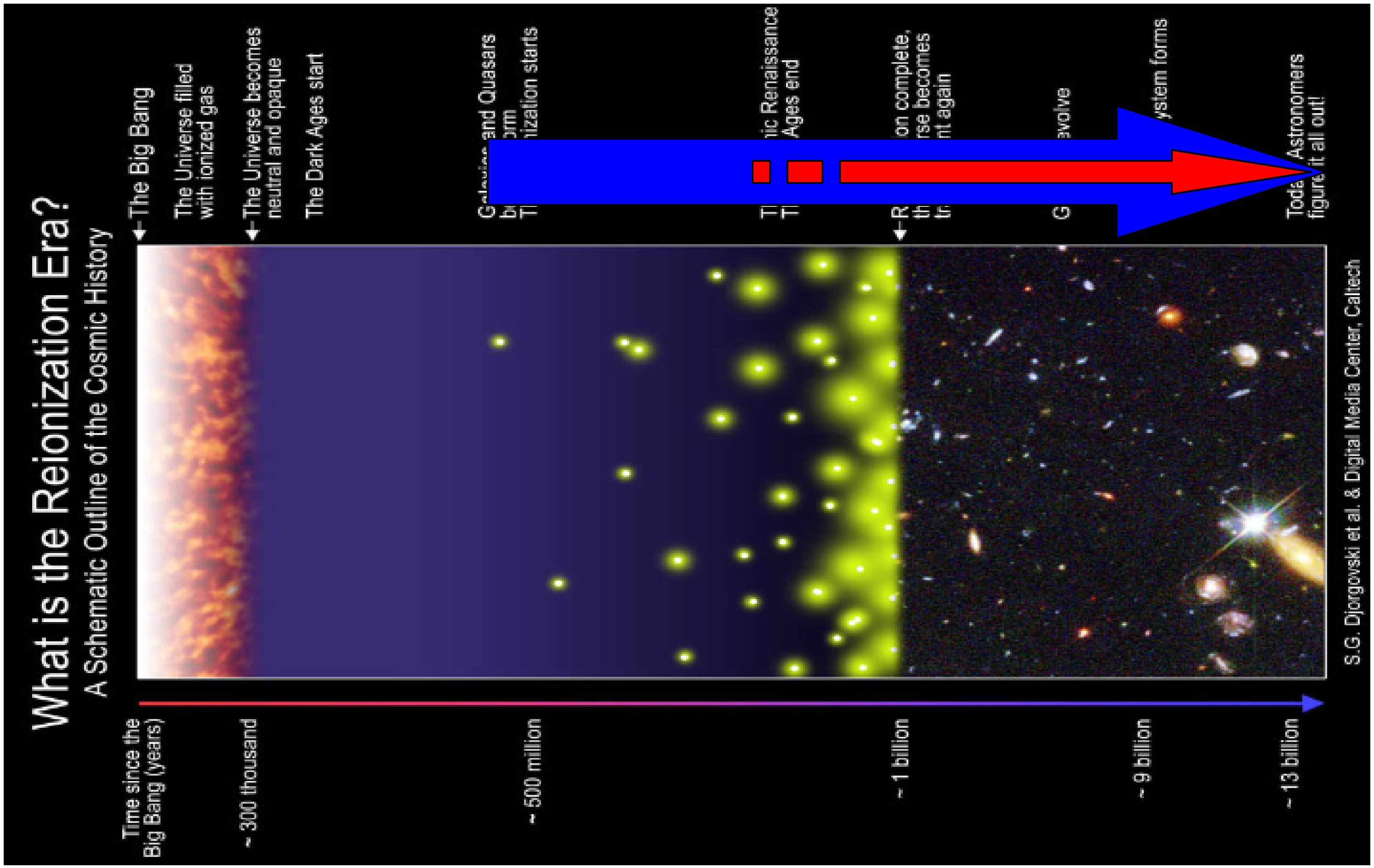
The Cosmic Evolution of Dust ?

Ranga Ram Chary, Planck/Spitzer Science Center, Caltech



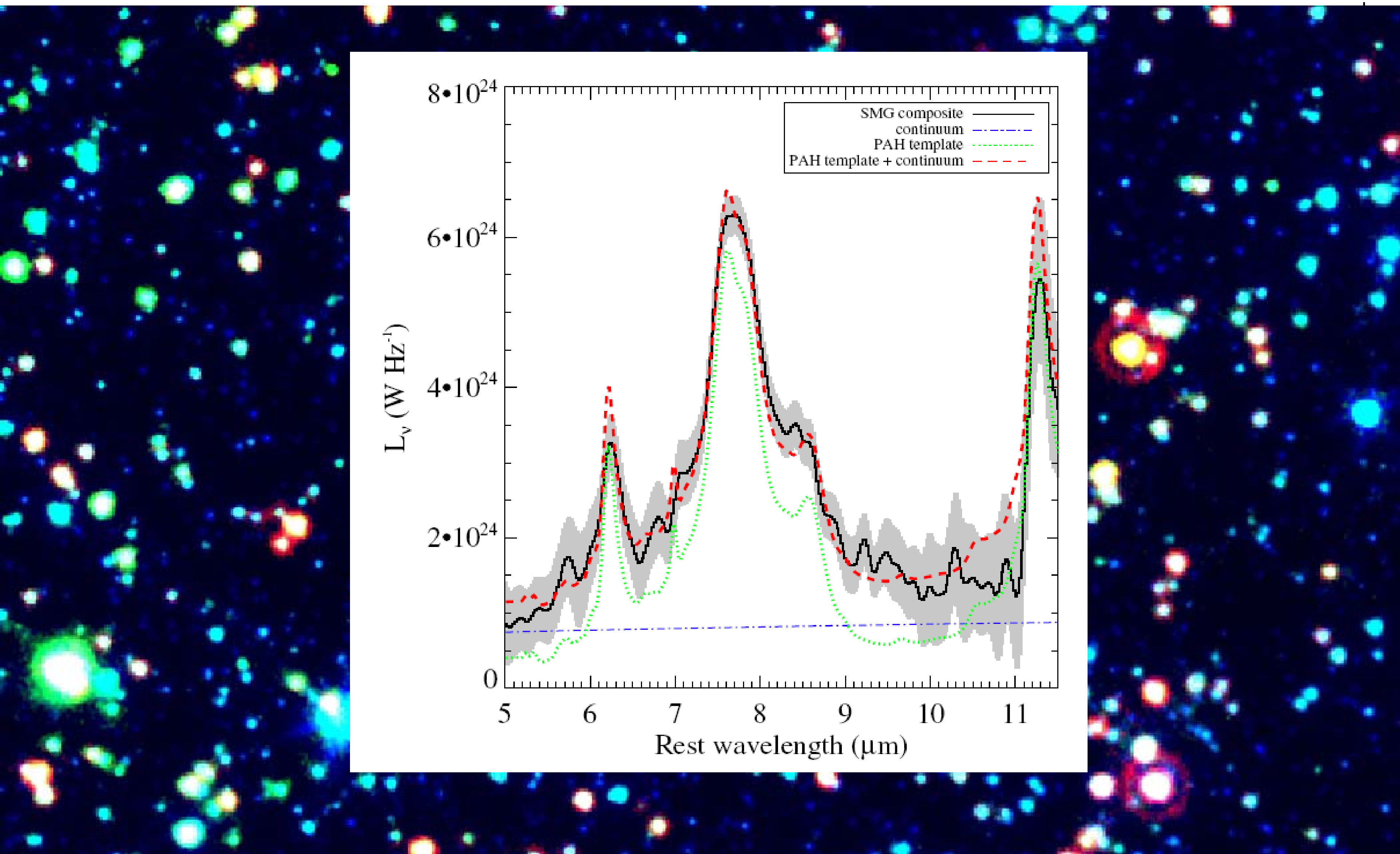
z=1000

z=6

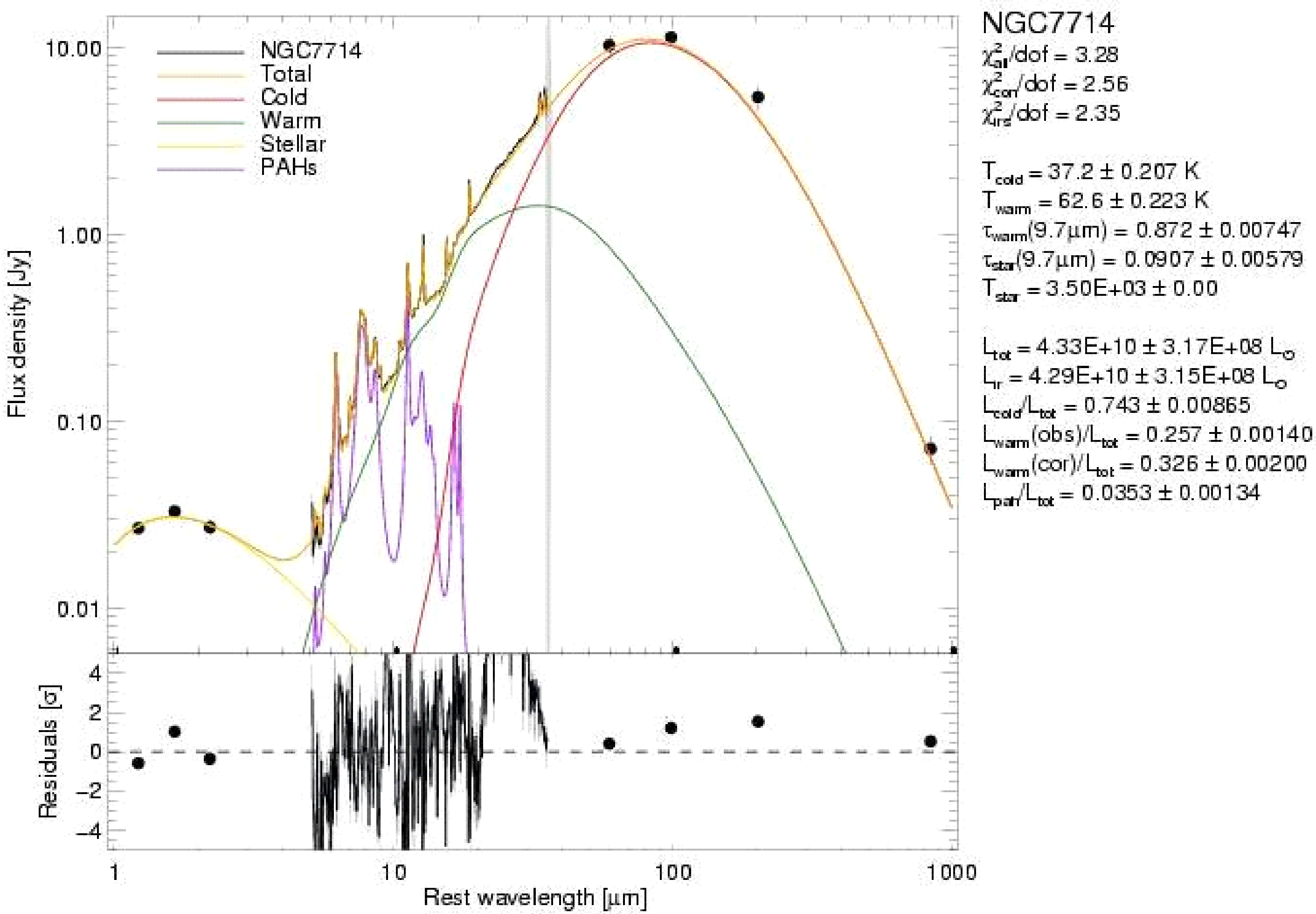
z=1.5

z=0

Cosmic Dust:
How do we know its there ?

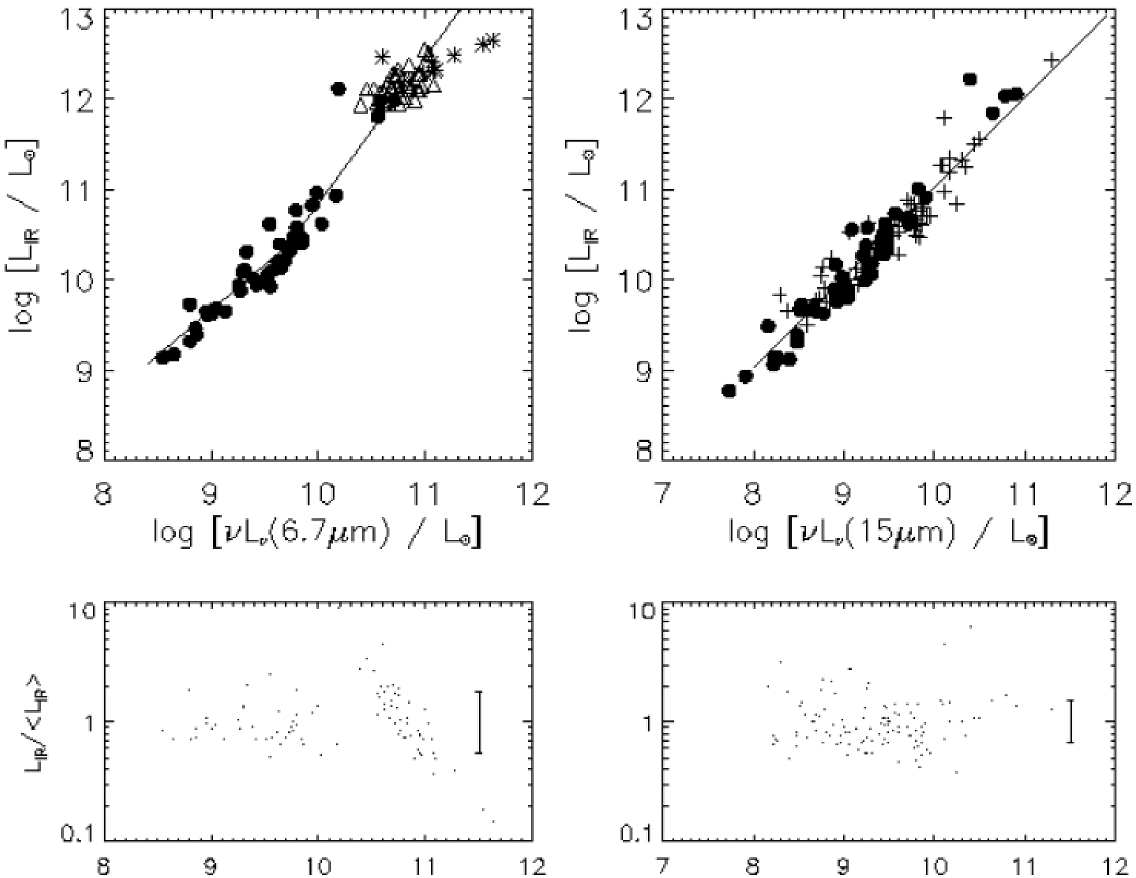


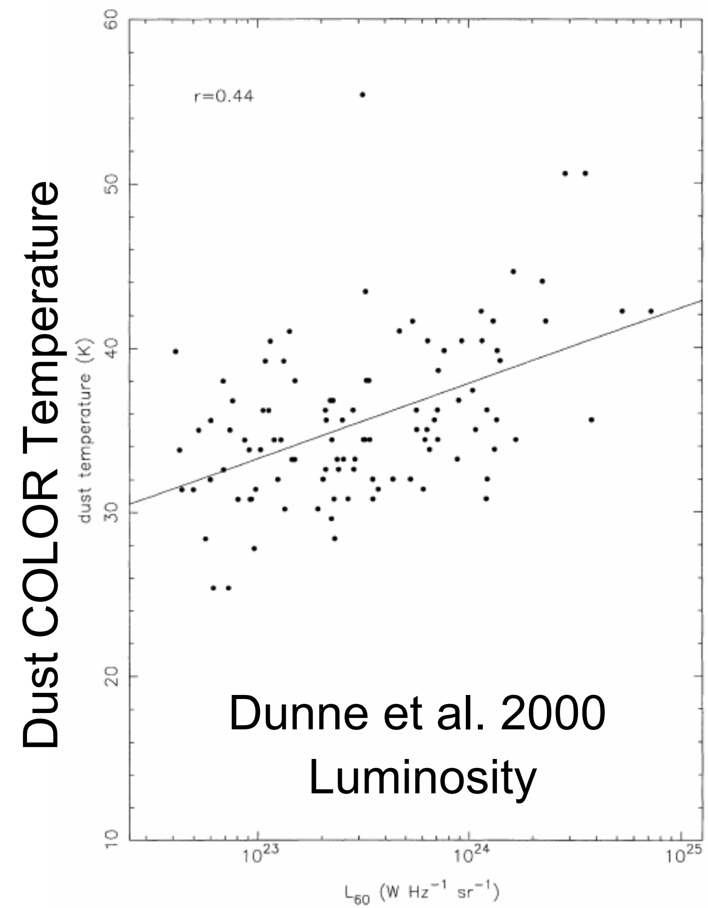
But there is dust in different phases



Jason Marshall and IRS GTO Team

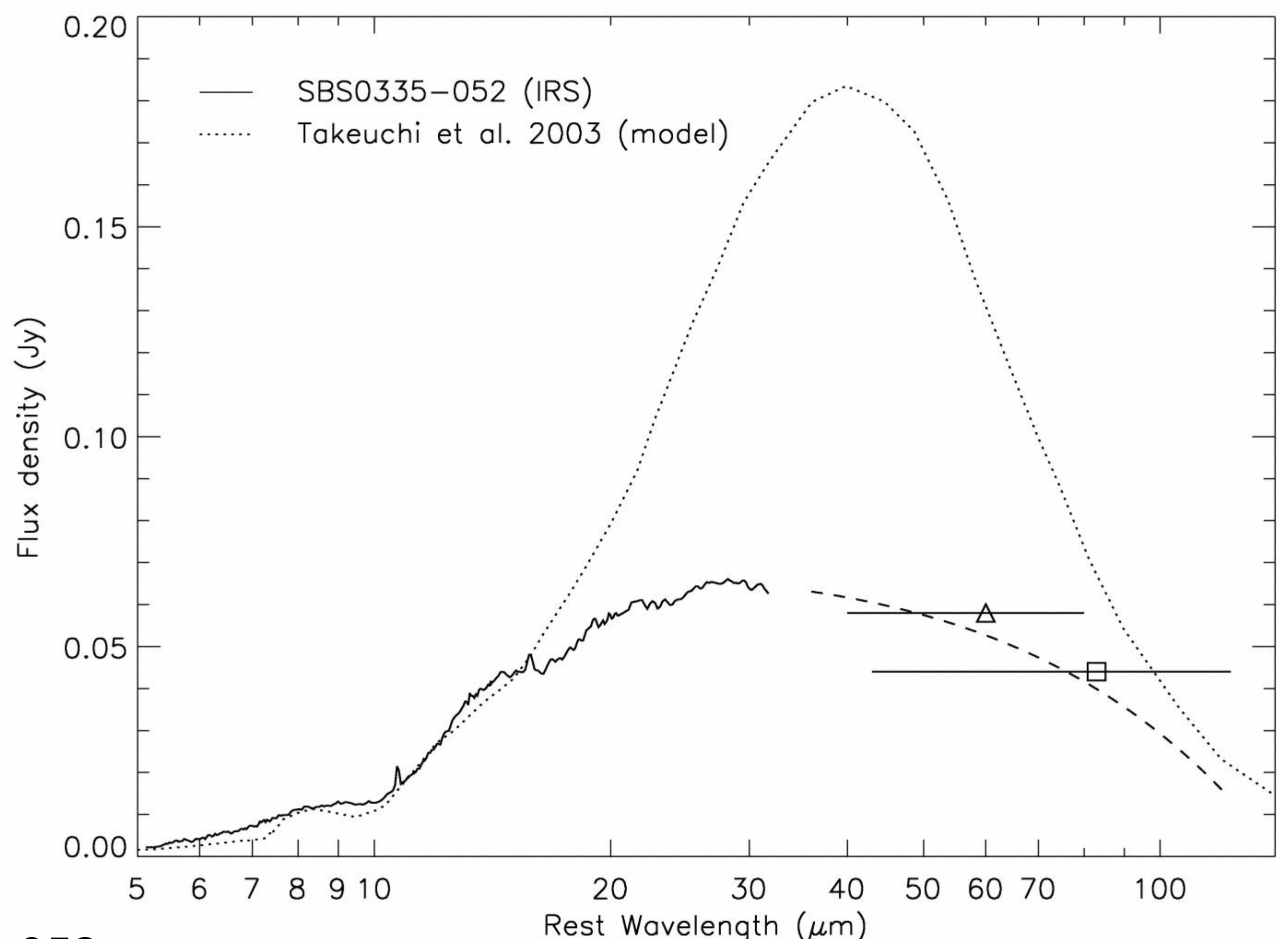
Remarkably there are tight correlations





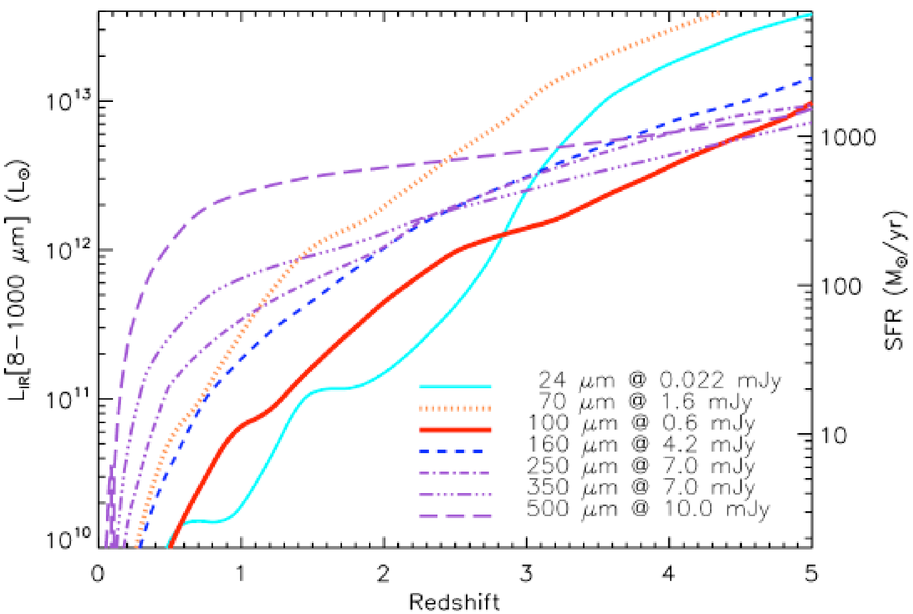
But large Luminosity-Temperature scatter even in the Local Universe introduces strong wavelength dependent biases

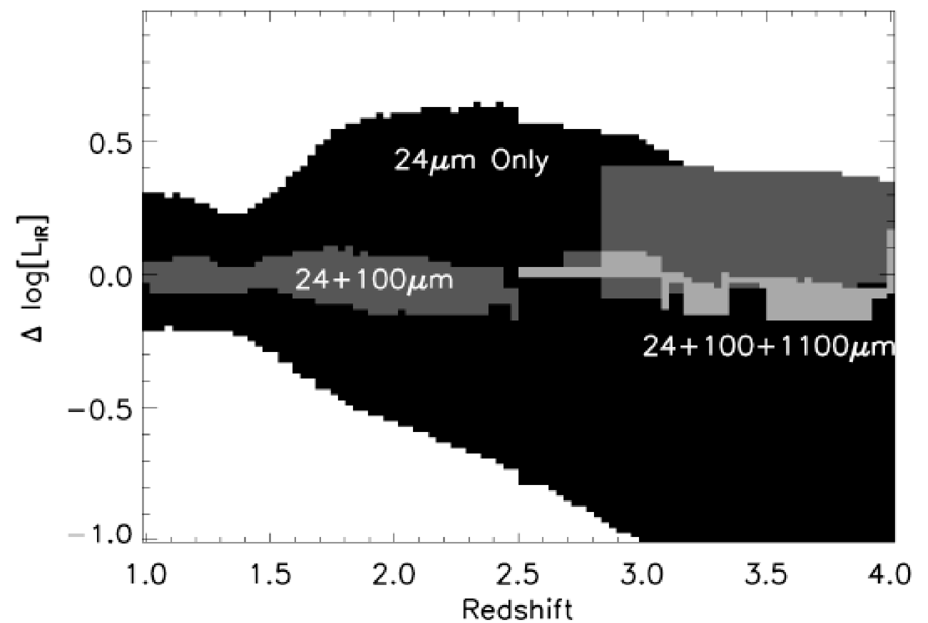
There are some nightmare sources!



SBS 0335−052
1/40 $Z_{\odot}$
Houck et al. 2004

Sensitivity of Different Wavelengths to Dust Obscured Star-Formation

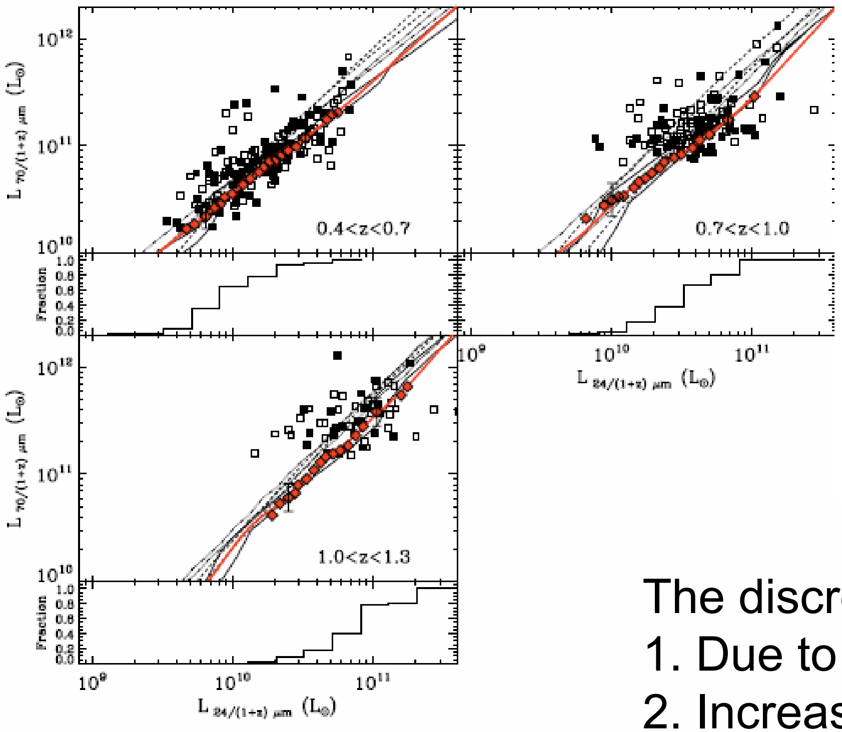


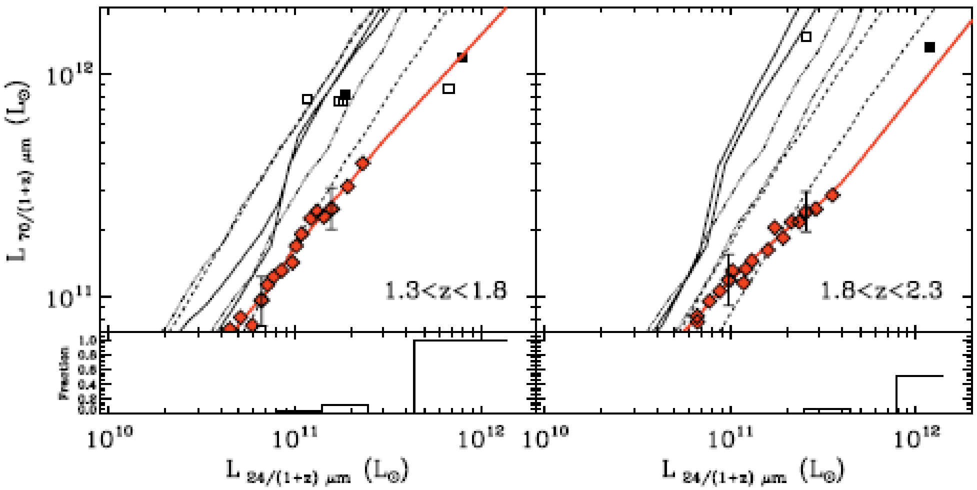


From GOODS-H (Elbaz et al.)

Mid-Infrared wavelengths are the most sensitive and least affected by confusion. However, requires large bolometric corrections.

Can use FIR data+stacking to assess these correlations at high-z

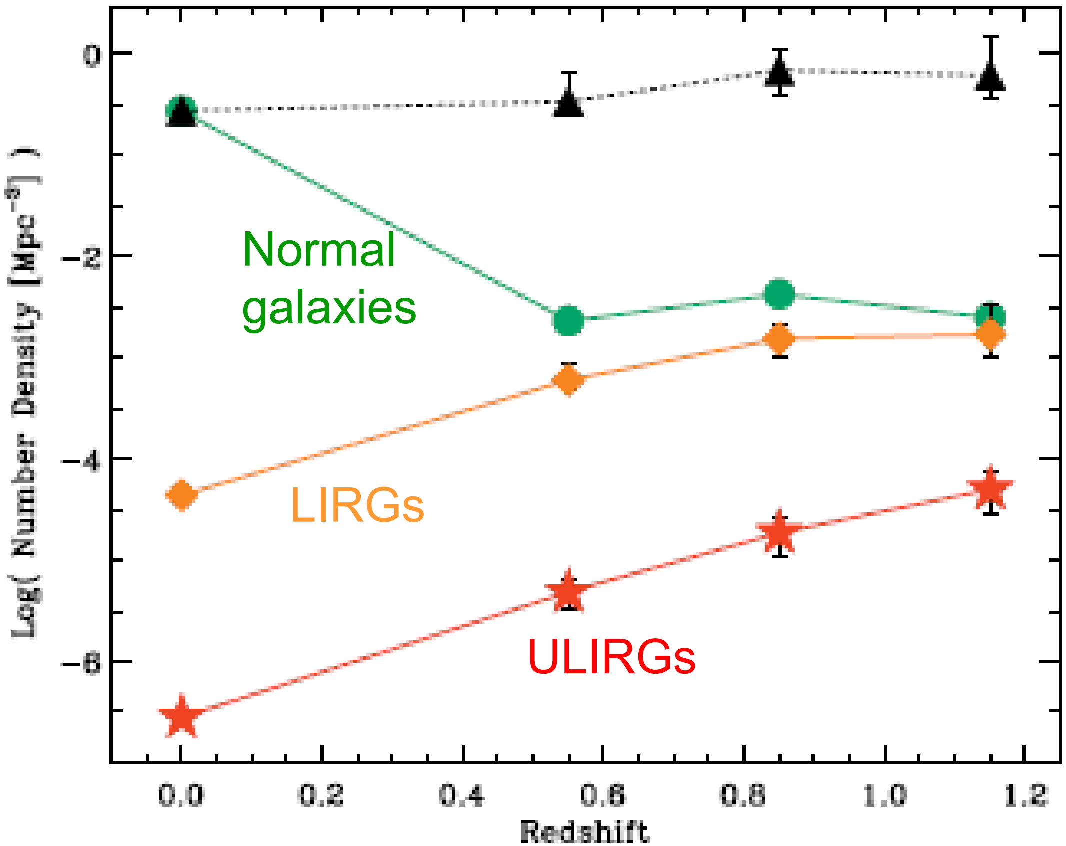




The discrepancy at high redshift could be:
1. Due to phot-z uncertainty
2. Increasing AGN contribution
3. Change in temperature/emissivity of dust due to decreasing metallicity

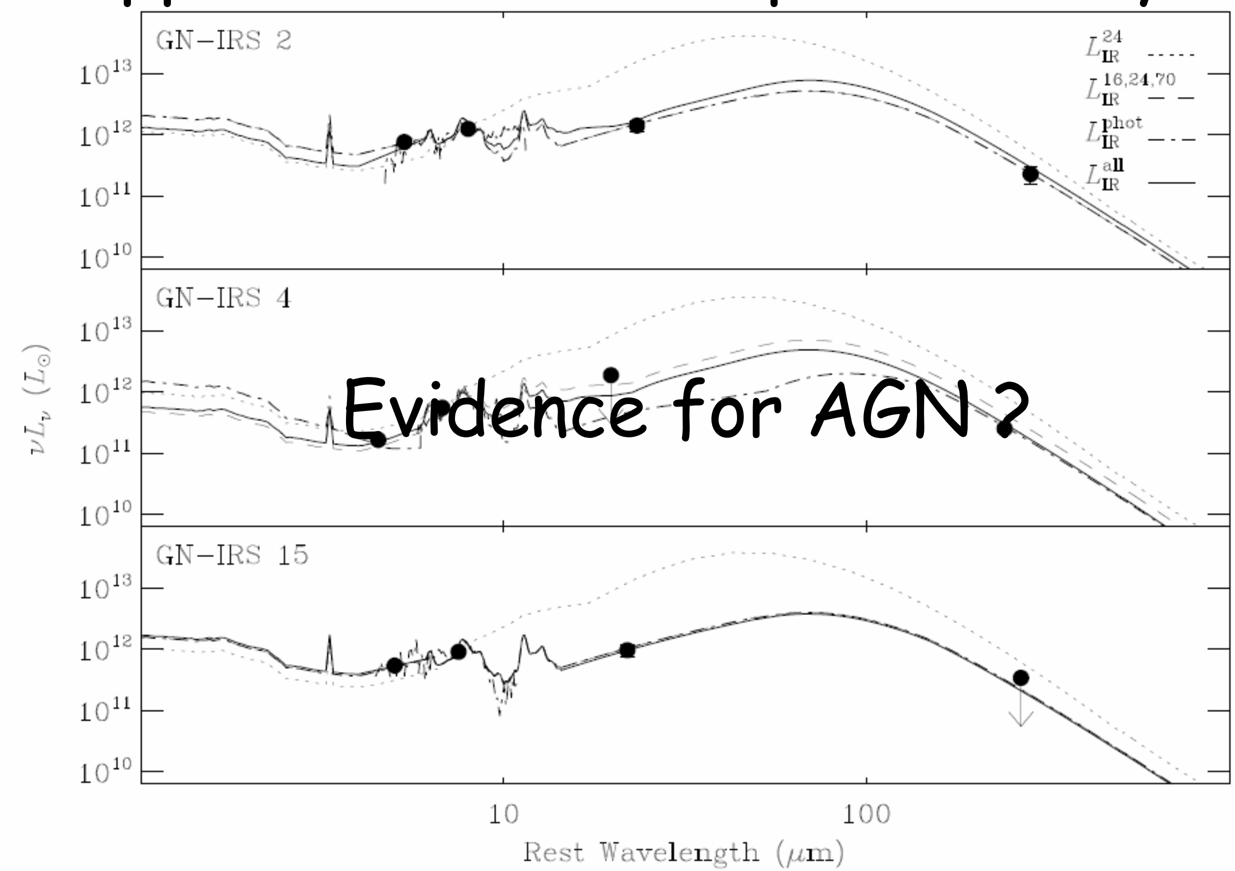
Magnelli et al. 2009a, b

LIRGs and ULIRGs increase by x50-100 between 0<z<1



Magnelli et al. 2009

Even for objects with spec-z, some violate upper limits or FIR photometry

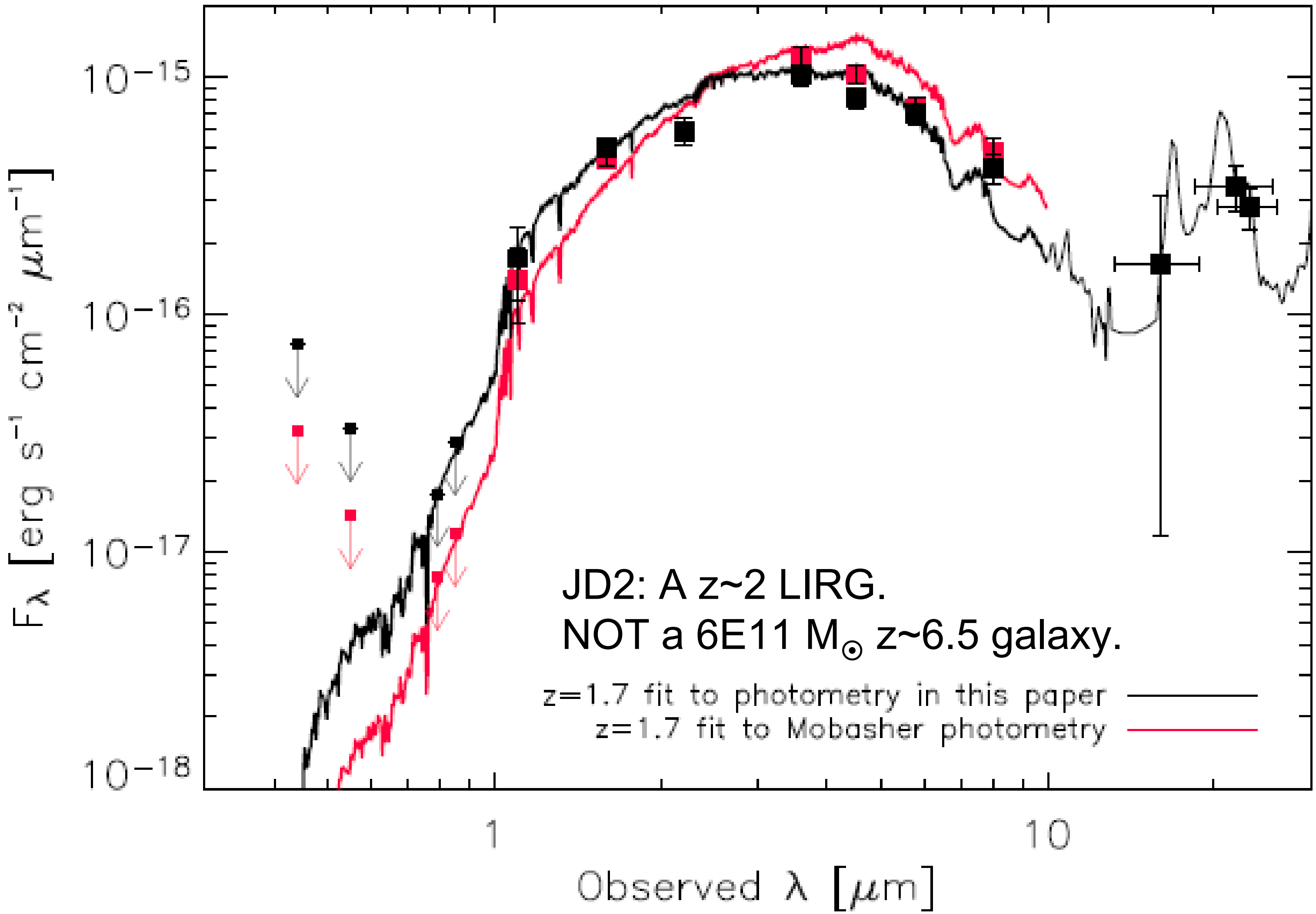


Evidence for AGN ?

Intriguingly, this happens at LIR>3E12 L☉
which is the most extreme source in the local Universe

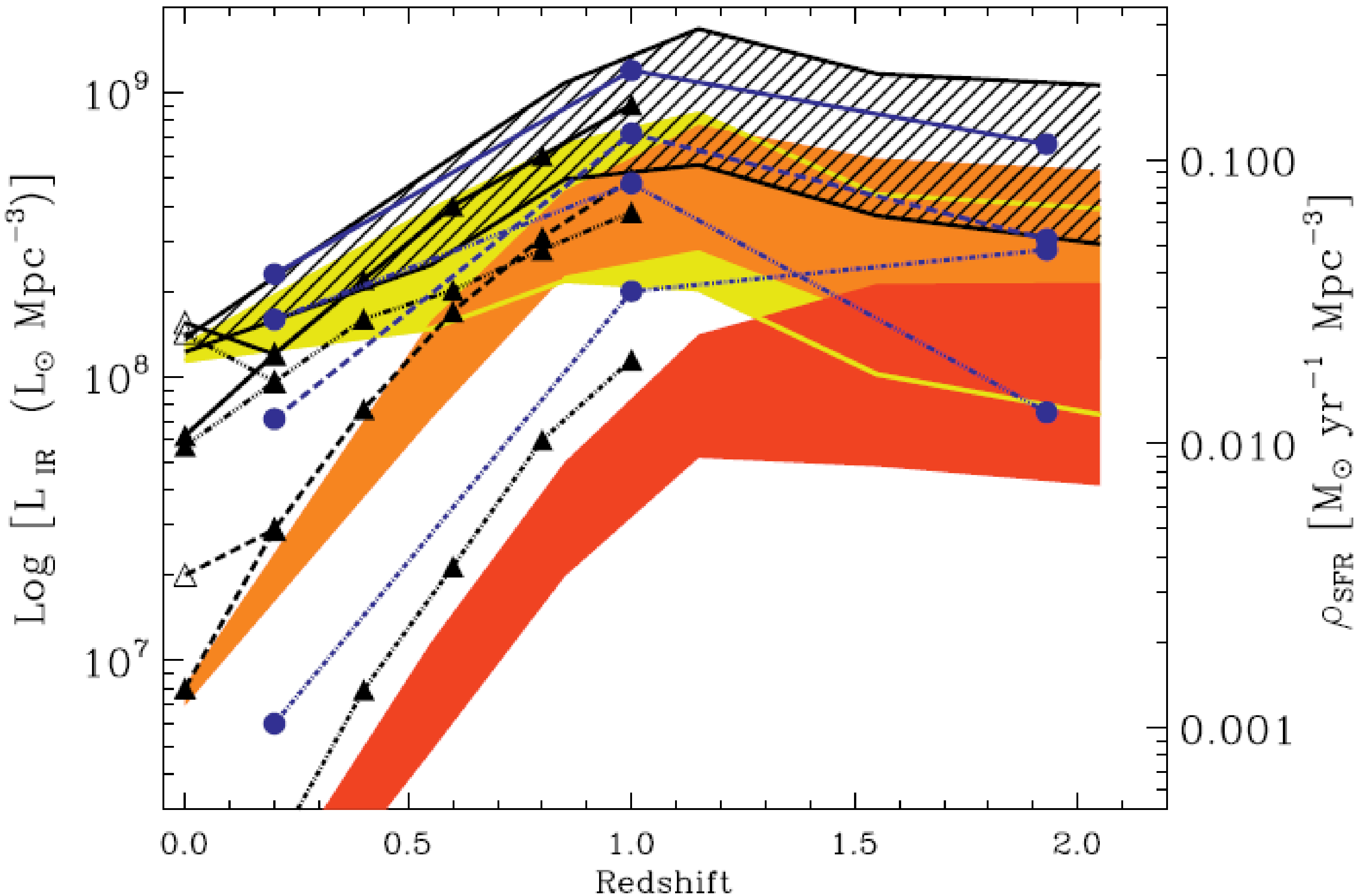
E. Murphy et al. 2009

Are We Missing the z~2-3 LIRGs ?



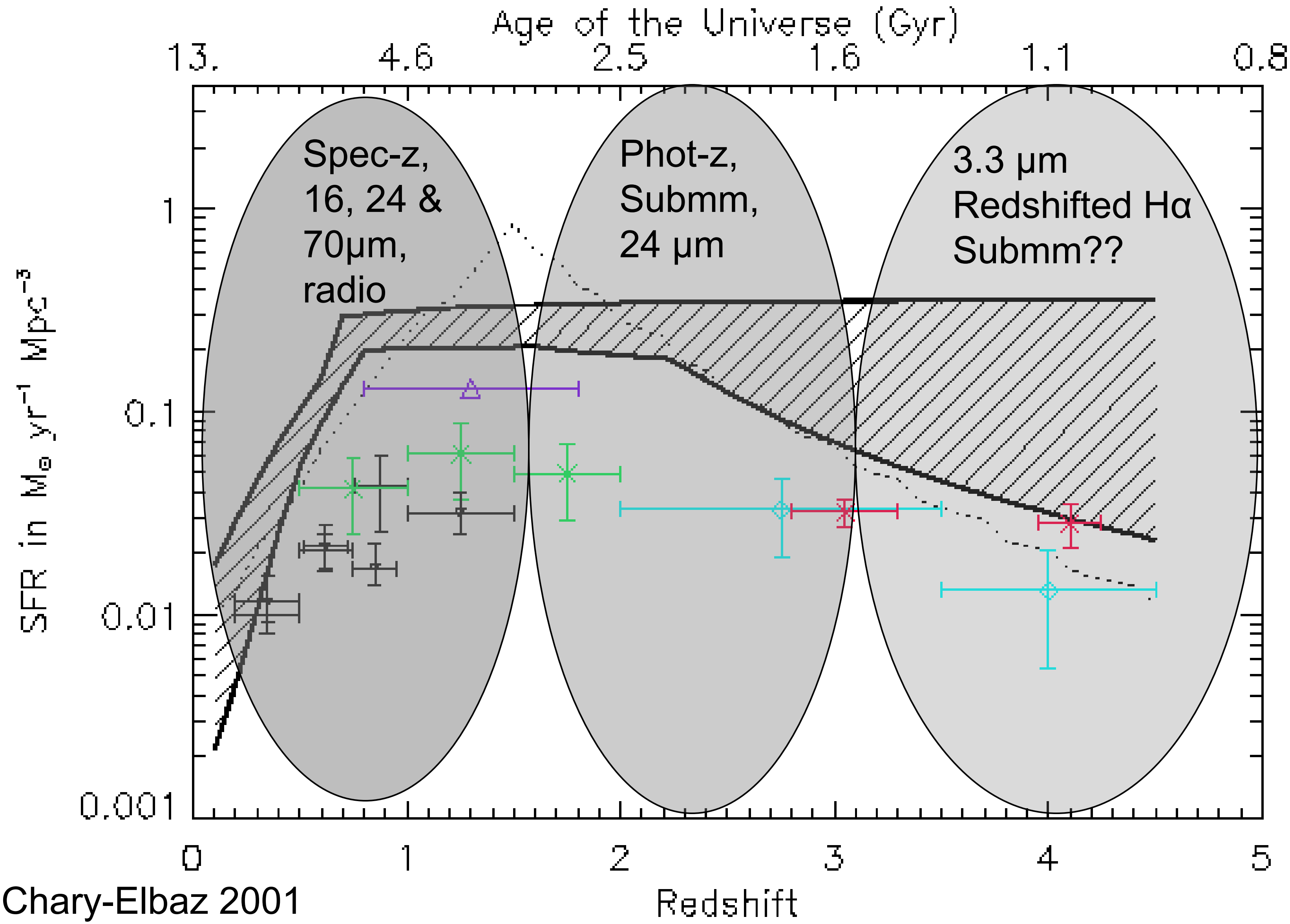
Chary et al. 2007

SFR at z<2 is known to x4



Magnelli et al. 2009

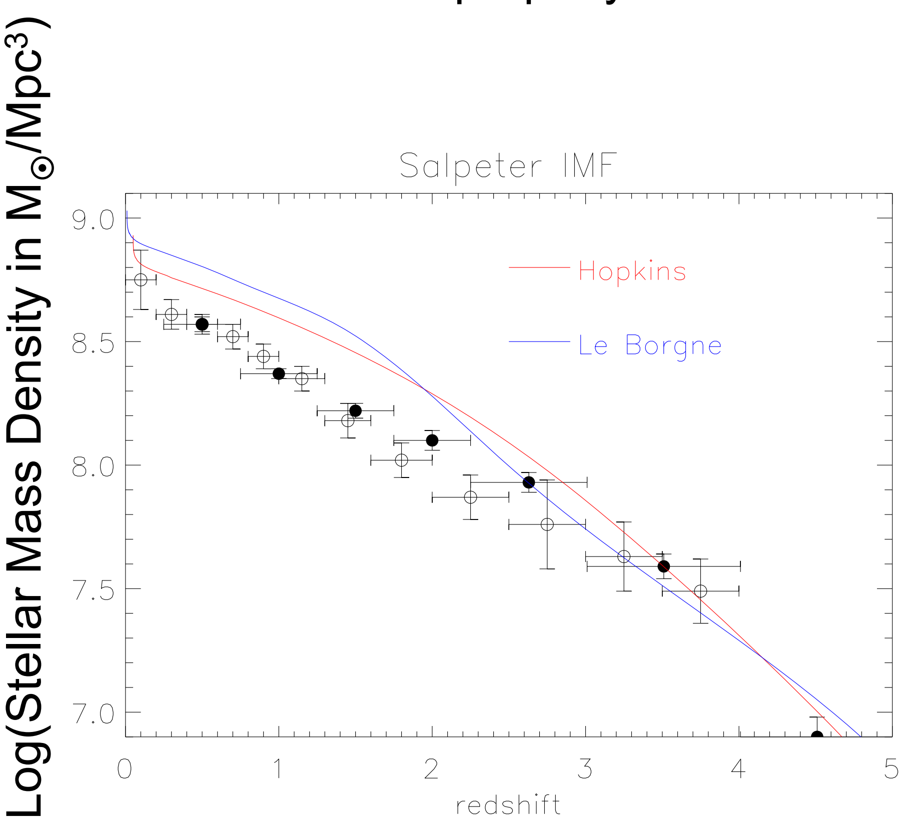
Different Techniques Give About the Same Answer: To within x2

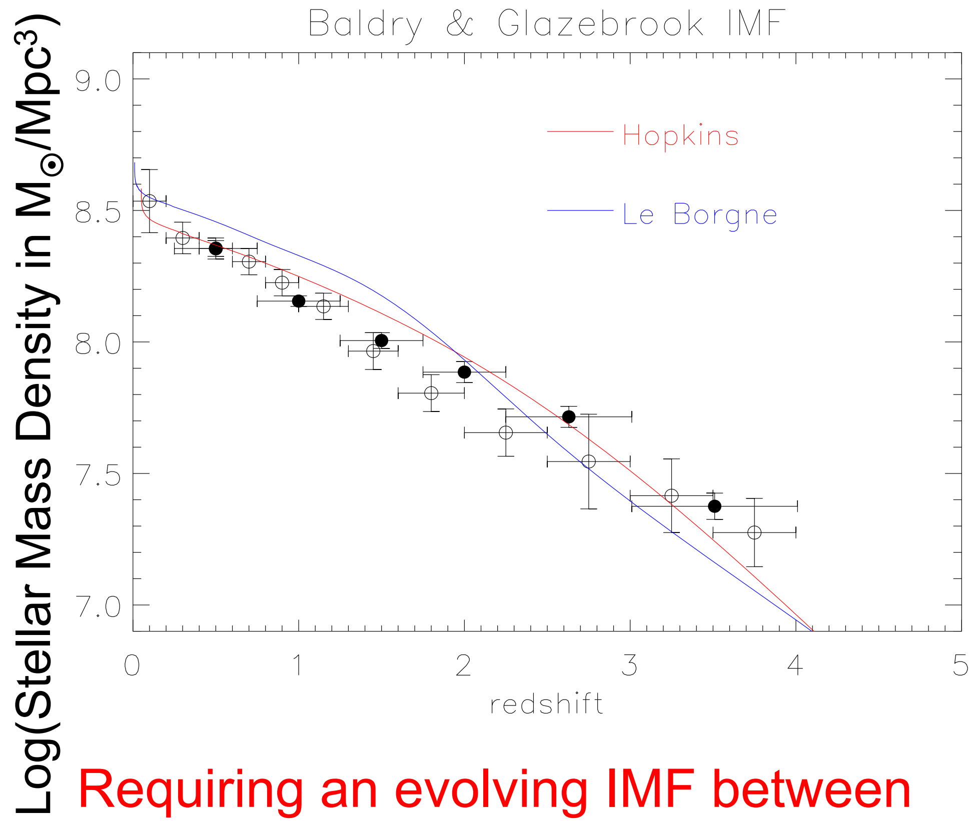


Chary-Elbaz 2001

A Discrepancy between ∫SFR and Stellar Mass Density ?

No – less than x2 discrepancy ! One needs to account for stellar remnants properly.

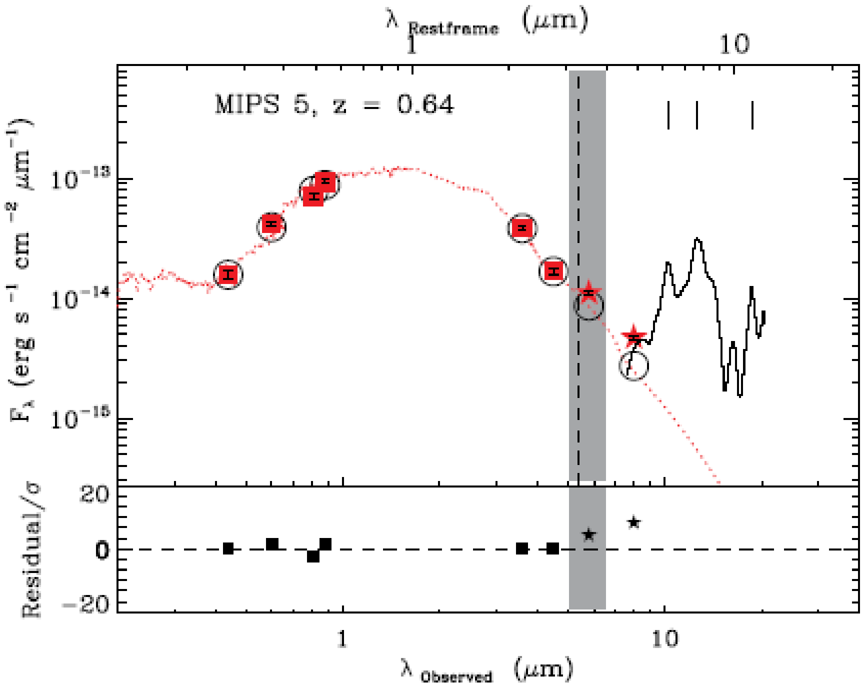




Requiring an evolving IMF between 0<z<3 is being too hasty.

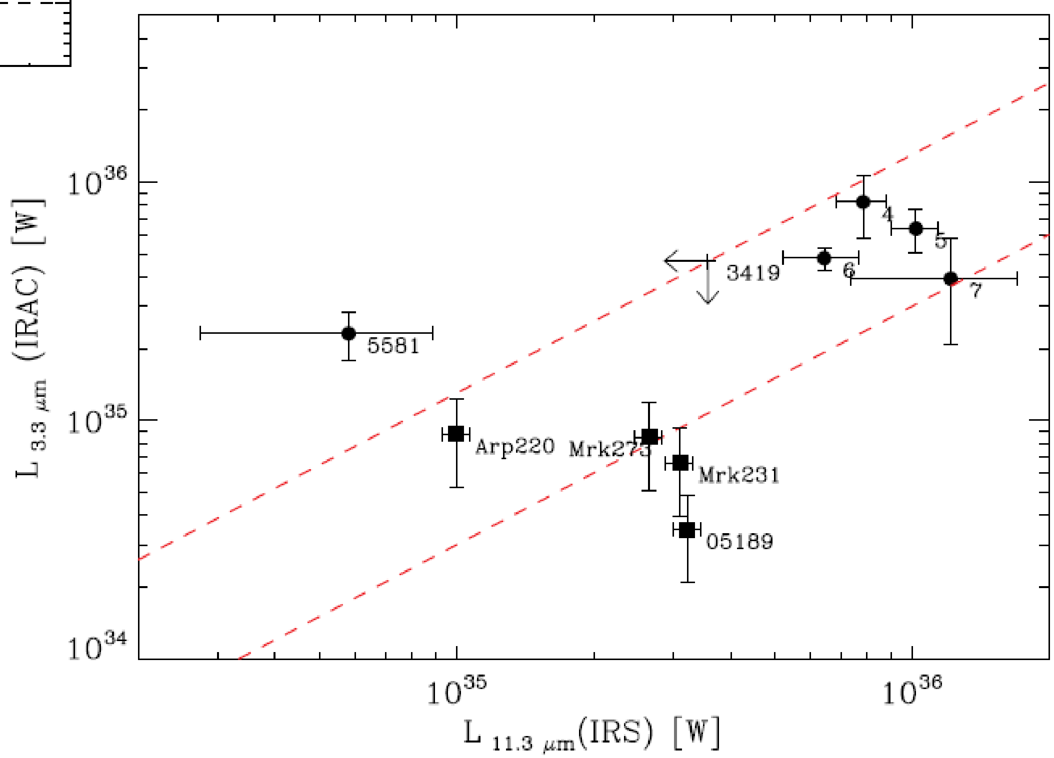
Le Borgne et al. 2008
A&A in press

Pushing out to z>2
Ignorance is bliss ?

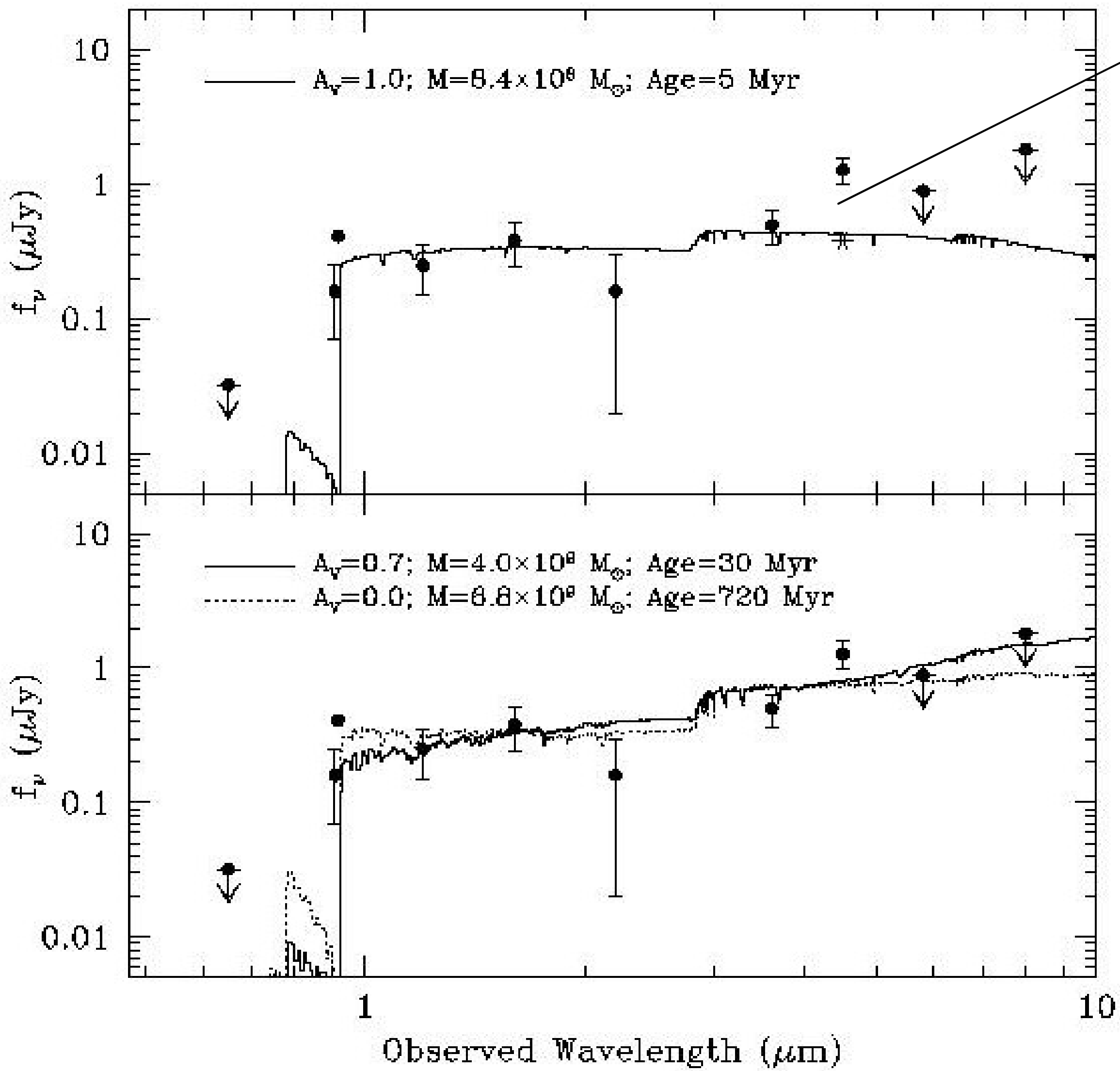


Moving on to z>3, besides the UV, we are just discovering the utility/reliability of the 3.3μm PAH feature as a SFR indicator.

Magnelli et al. 2008



Can fit SEDs and calculate SF History



Difference is from Hα in emission ?

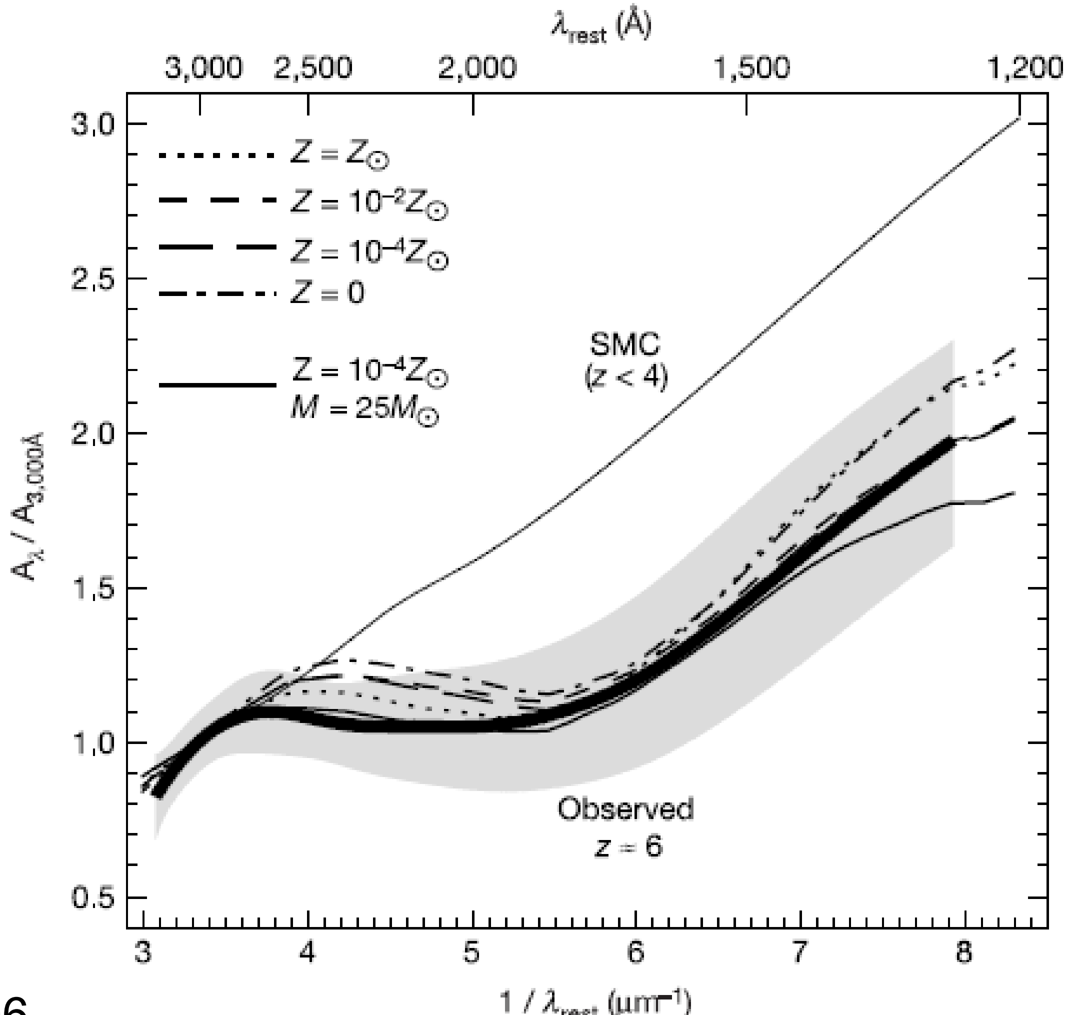
UV SFR<10 $M_\odot$/yr
Hα SFR~100 $M_\odot$/yr

Hα EW~0.2μm

Indirect evidence for A_V~1 mag of dust within 1 Gyr of the Big Bang. But jury is out since no mm detection (Combes group).

Chary et al. 05
Hu et al. 02
Schaerer et al.

Evidence for SN dust at high-z ?



Maiolino et al. 2006

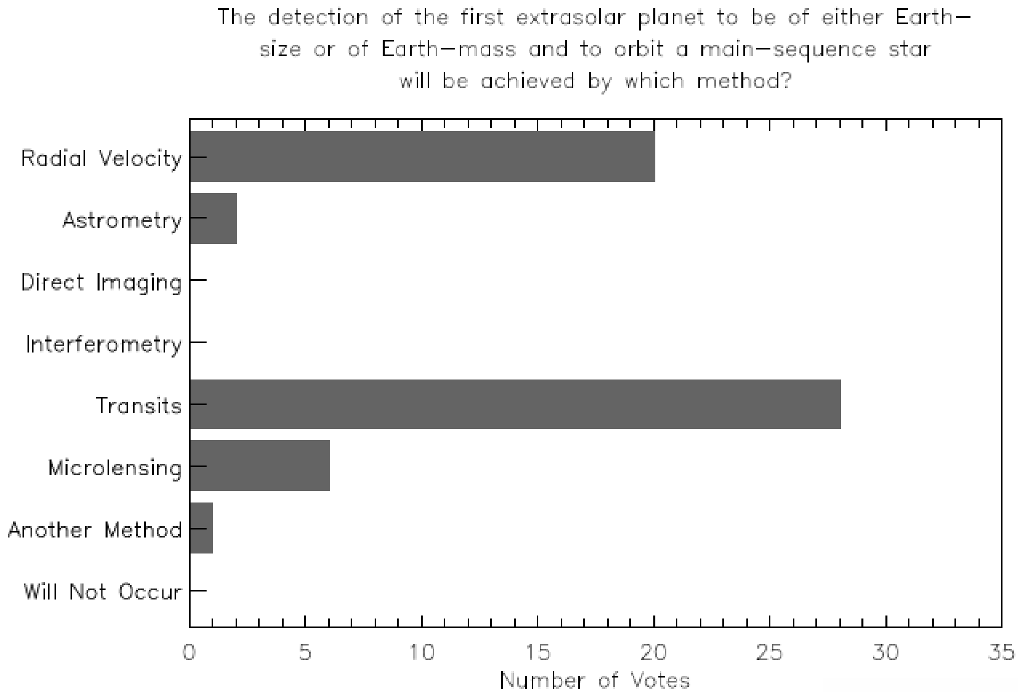
Conclusions

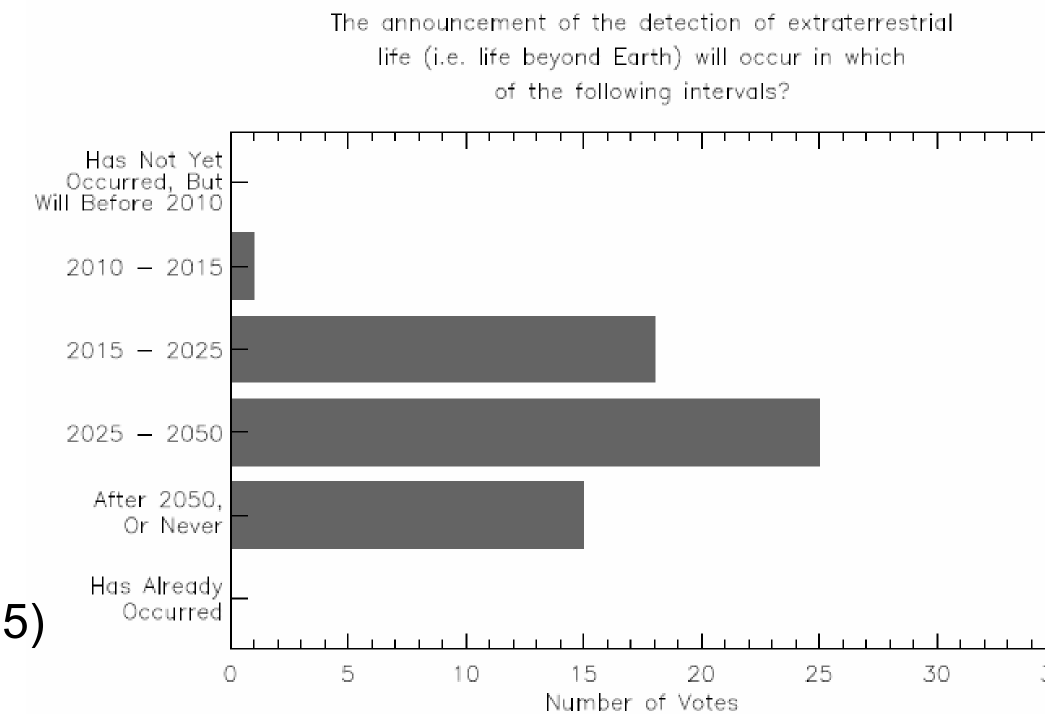
- SFR between 0<z<1.3 is known to within x2, from MIR, FIR and radio surveys
- Strong evolution of LIRGs and ULIRGs by x100. Unclear if this is bursty or quiescent star-formation.
- At z>1.4, phot-z errors, metallicity, AGN contribution might play a role. Unclear what is happening. GOODS-Herschel will provide clues among the ULIRGs.
- However, MIR spectra indicate AGN are not responsible for bulk of error. Mostly due to error in PAH equivalent widths – NO local analogs exist. Errors are mostly at high luminosities which might overestimate ULIRG contribution.
- At z>3, time is ripe for alternate techniques to measure dusty SFR. Dust formed very early in the Universe – might have different characteristics at high-z. BUT ALL THIS IS EXPENSIVE !

A Complete Census of Planets in the Habitable Zone out to 100 pc

Ranga-Ram Chary

Spitzer Science Center



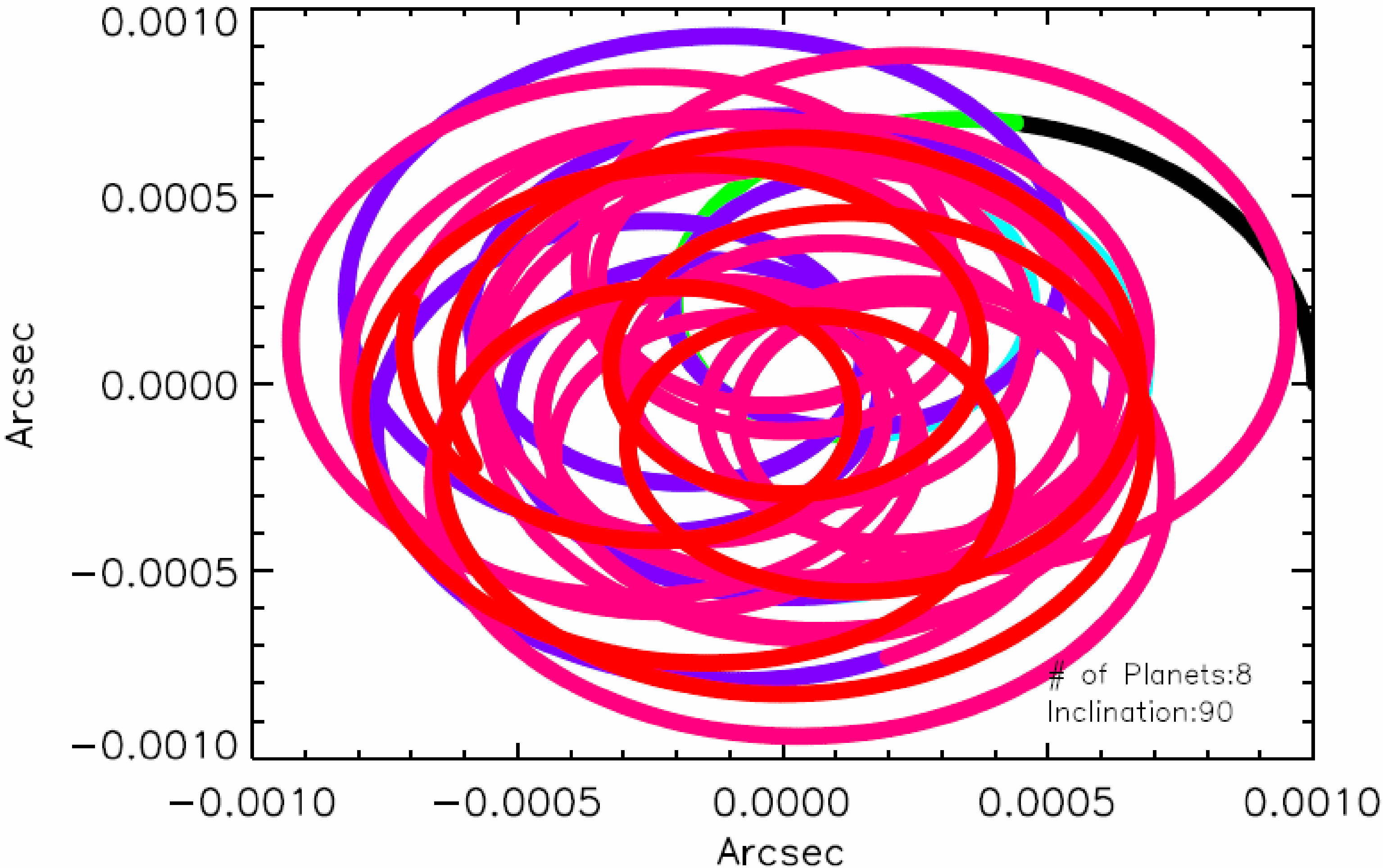


Charbonneau poll astro-ph/0511583,
"10 years of 51 Peg" Conference (2005)

Pros and Cons

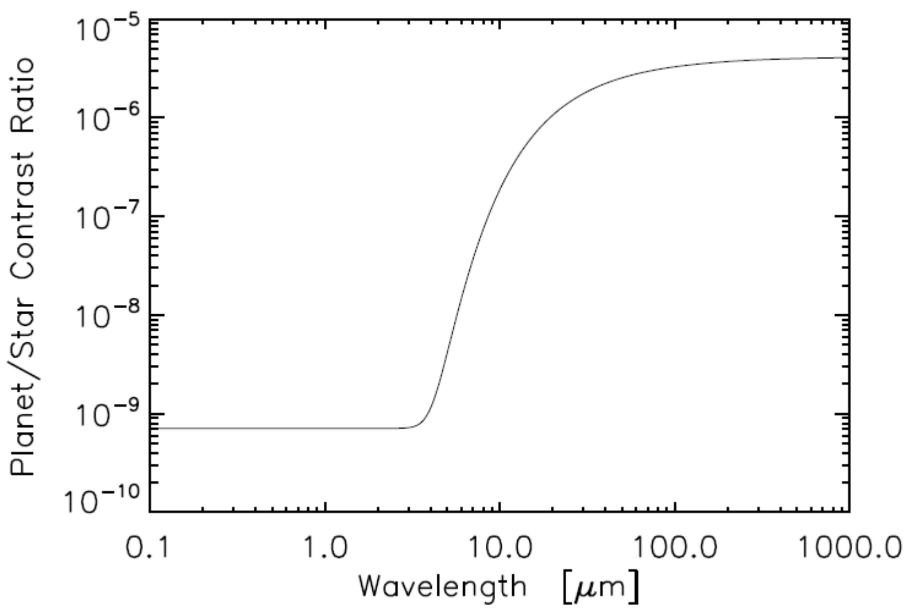
- Radial Velocity
  - Jupiter at 5 AU is 13 m/s
  - Earth at 1 AU is 0.09 m/s
  - Measures $M_p\sin(i)$. $i<45°$ becomes increasingly difficult.
  - Multiple harmonics if multiple planets
- Transit
  - Probability is 2.2E-5. So we cannot be complete.
  - S/N of transit decreases for non-edge on systems
  - COROT 7b ($2R_{\oplus}$ at ~0.2 AU – needs peer-review)
- Microlensing
  - Most successful technique yet, but follow-up impossible ($5.5M_{\oplus}$ at 2.6 AU – Beaulieu 2006)

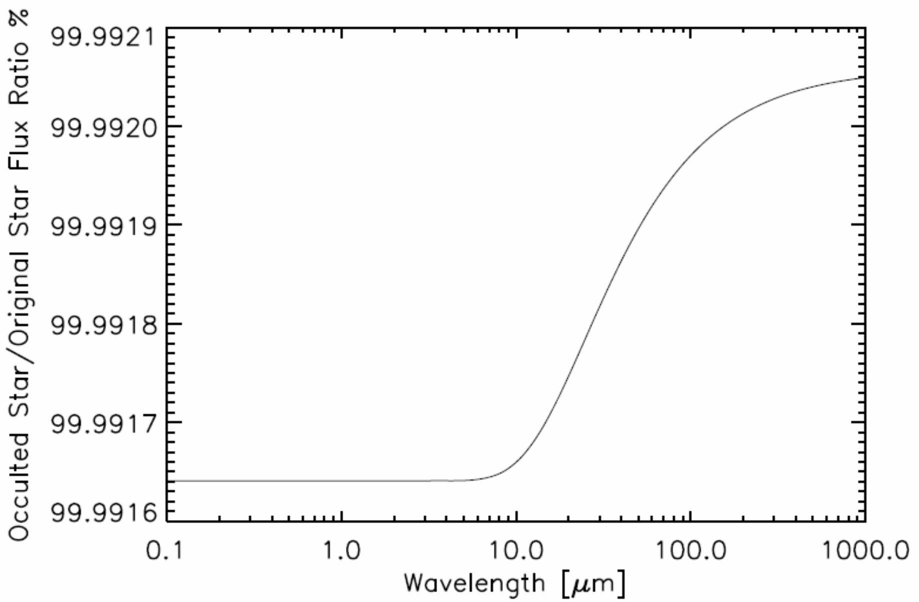
Astrometry is hopeless



- The Earth only has an effect of 0.3μas
- Below SIM (1-4μas) and GAIA (20μas) capabilities
- Decomposition of individual components is difficult.

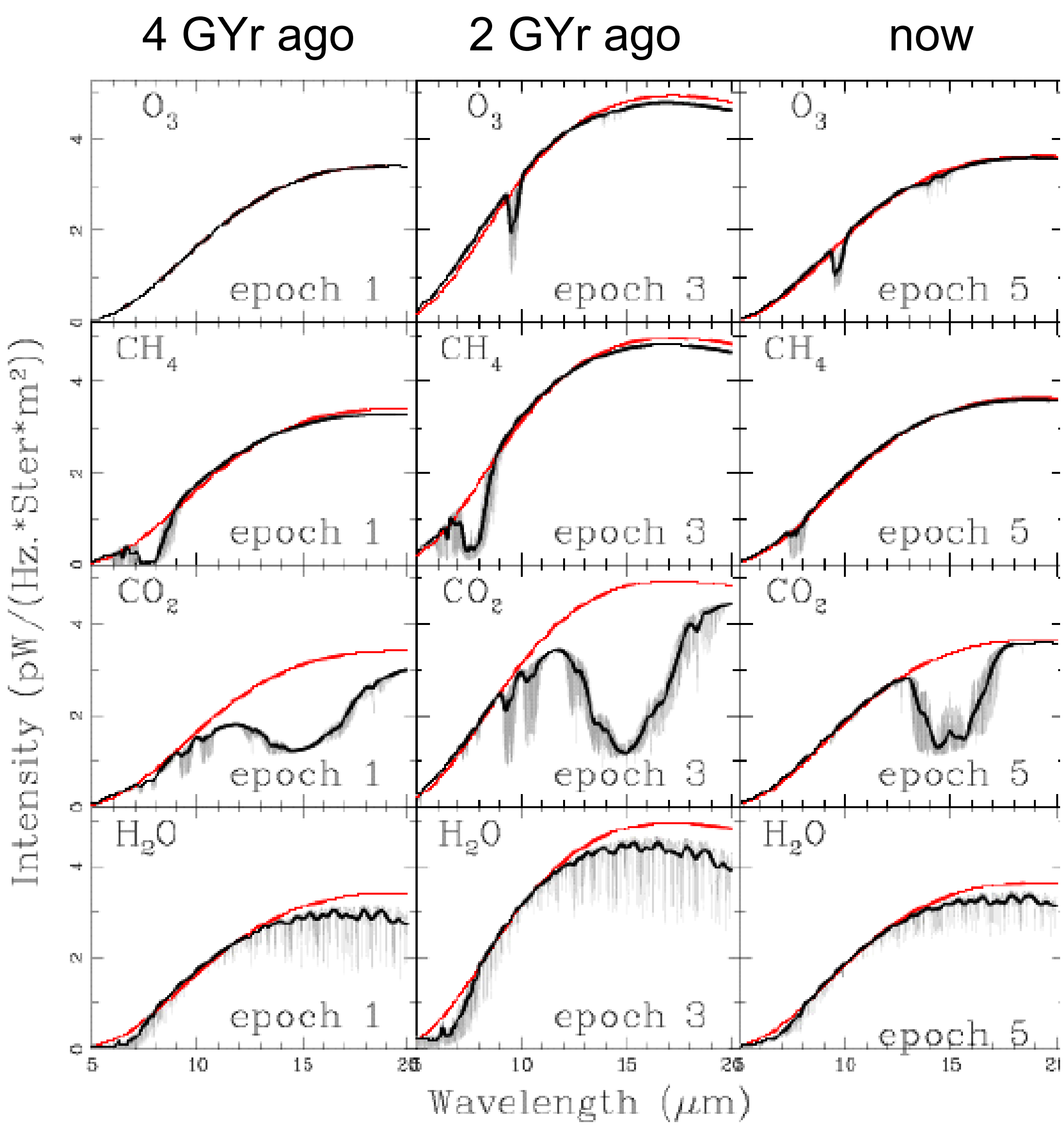
The Primary Advantage of the IR





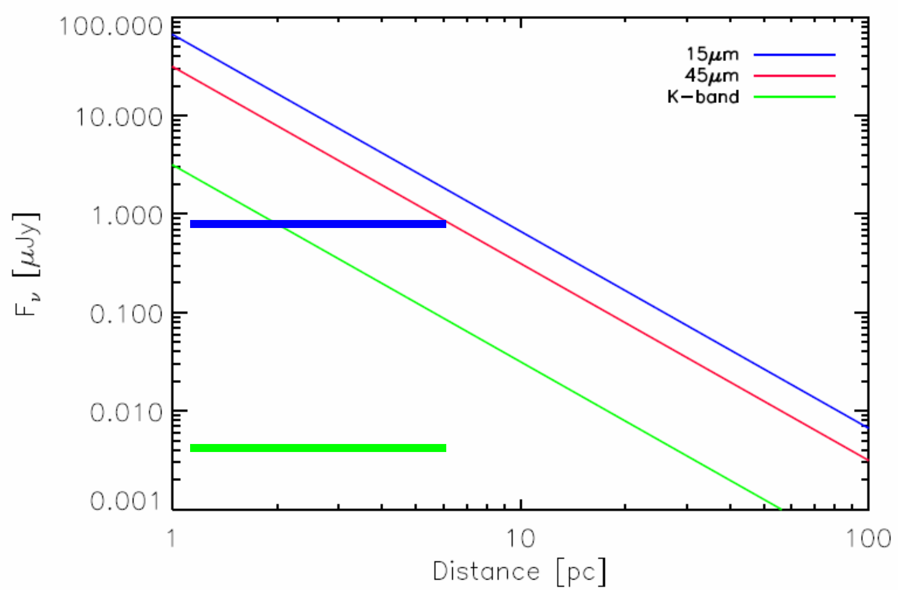
- The contrast with the star is maximized
- Although this doesn't help transit experiments, it provides 3 orders of magnitude gain (!) for direct imaging.
- Assumes Earth albedo of 0.39, Earth T~300 K
- That's why TPF-I goes out to ~15 μm

Furthermore, a radiance measurement can reveal climate/habitability

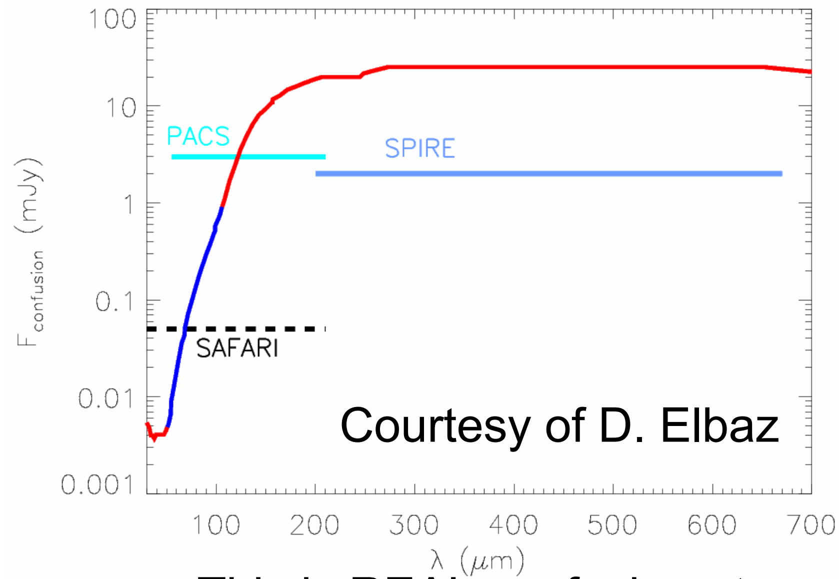


Kaltenegger Traub & Jucks

Need to get very faint ~10 nJy at 100 pc



Confusion becomes an issue

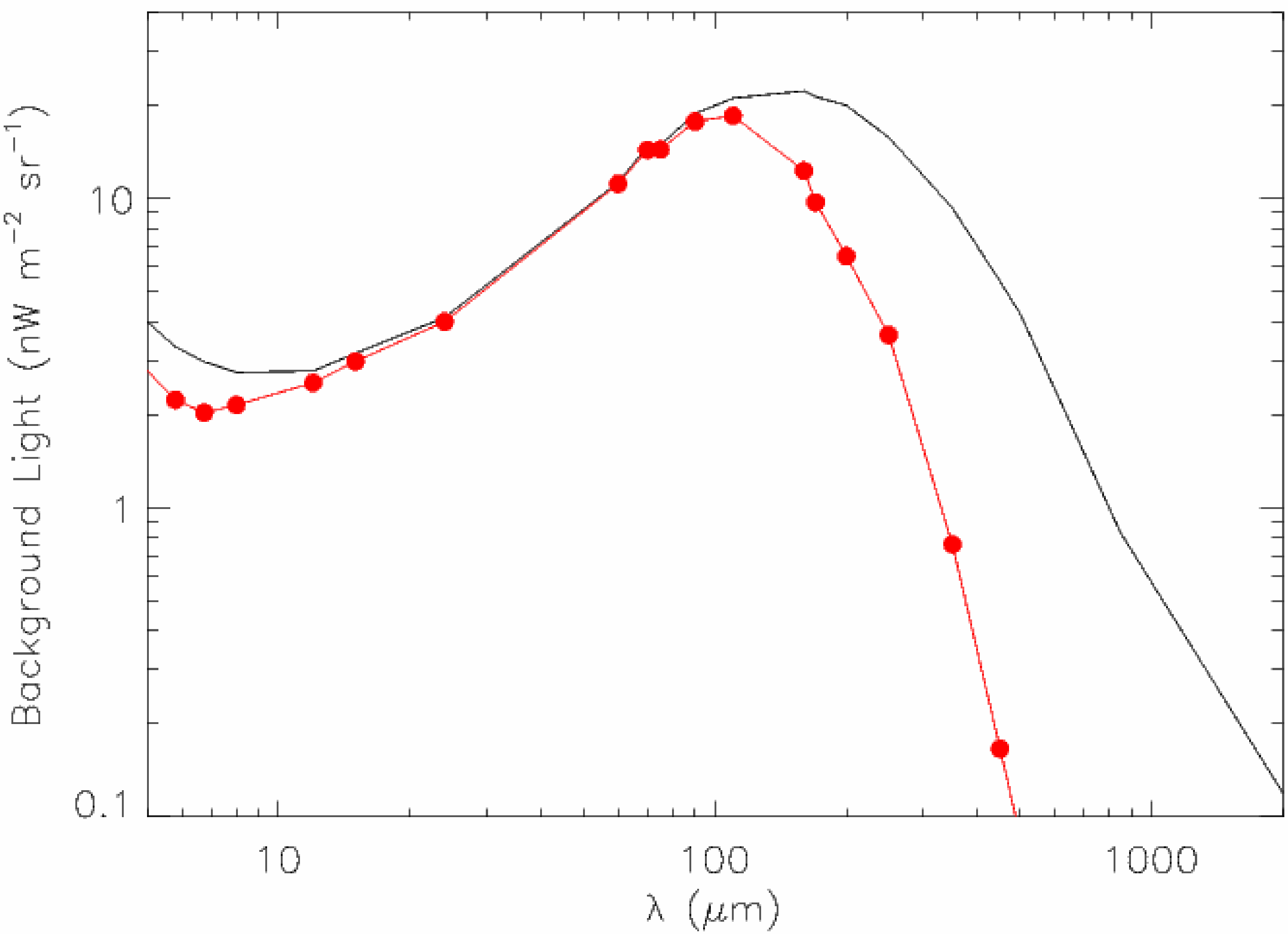


This is REAL confusion at
7 beams/src

JWST: 1E4s, 5sigma at 15μm = 0.9μJy
5sigma at 2μm = 5nJy

So maybe <10-20pc as IR excess (1part in 1E9) since it wont be able to physically separate Earth-light from starlight even at optical/NIR wavelengths

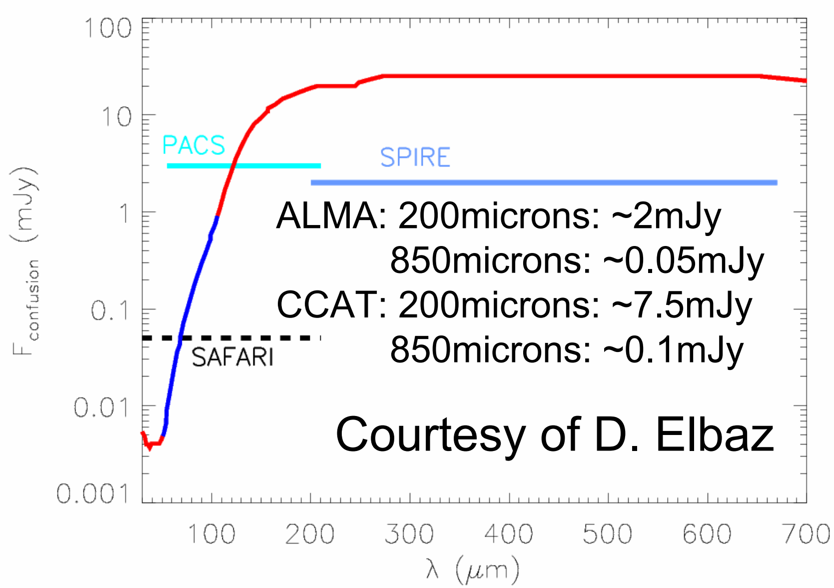
Fraction of EBL resolved through direct detections with 3.5m aperture down to the confusion limit

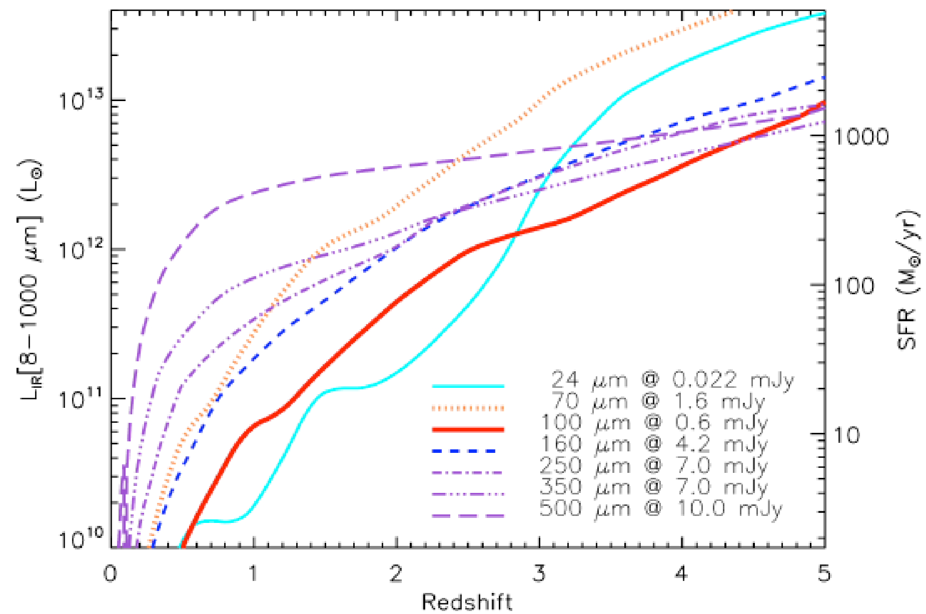


So, we need a 10-50μm interferometer

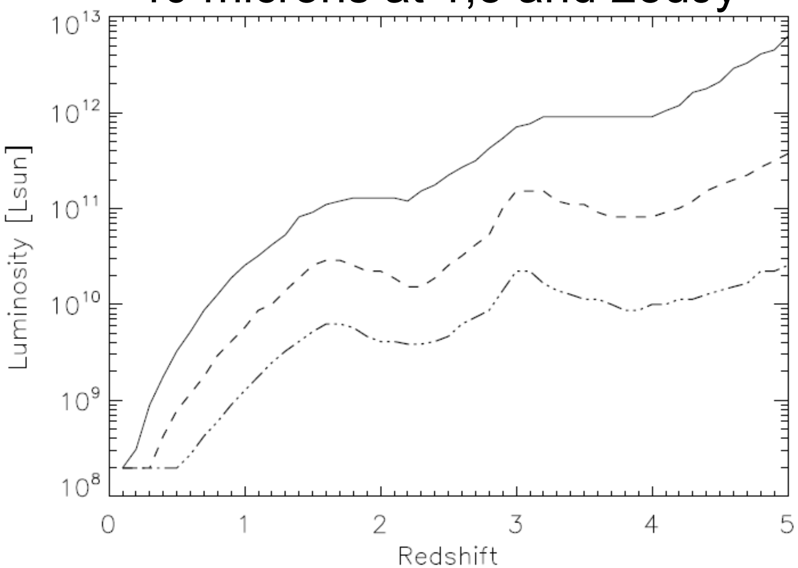
- Baselines of 1km at 10μm, 5km at 50μm
  - Leverage technology off LISA
- Current detector technology with interferometry and ~1m class telescopes will allow a complete census out to ~10 pc.
- Reaching 100 pc requires significant effort expended in small format (10*10), high QE arrays.

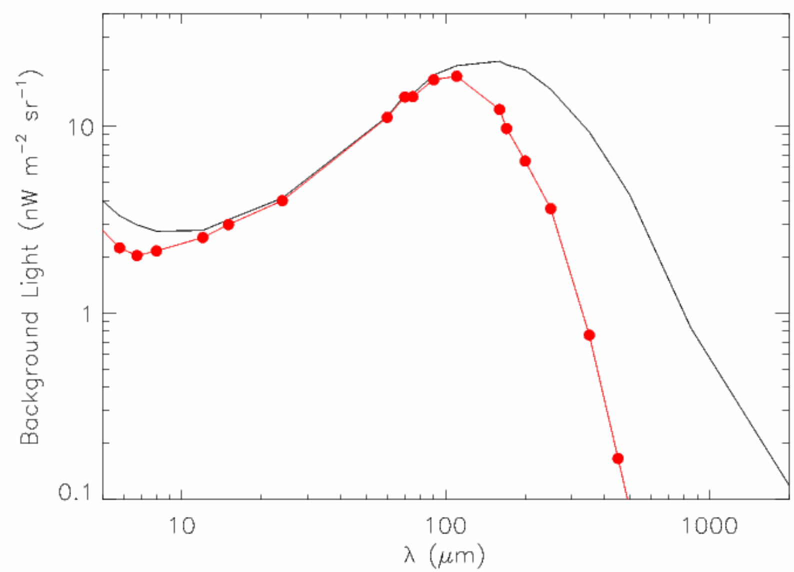
A Recommendation ?





40 microns at 1,5 and 25uJy





A 25-40 microns, 2m telescope would be really nice.