Dust in High Redshift Galaxies

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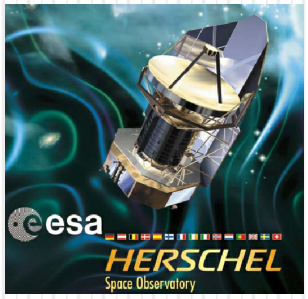
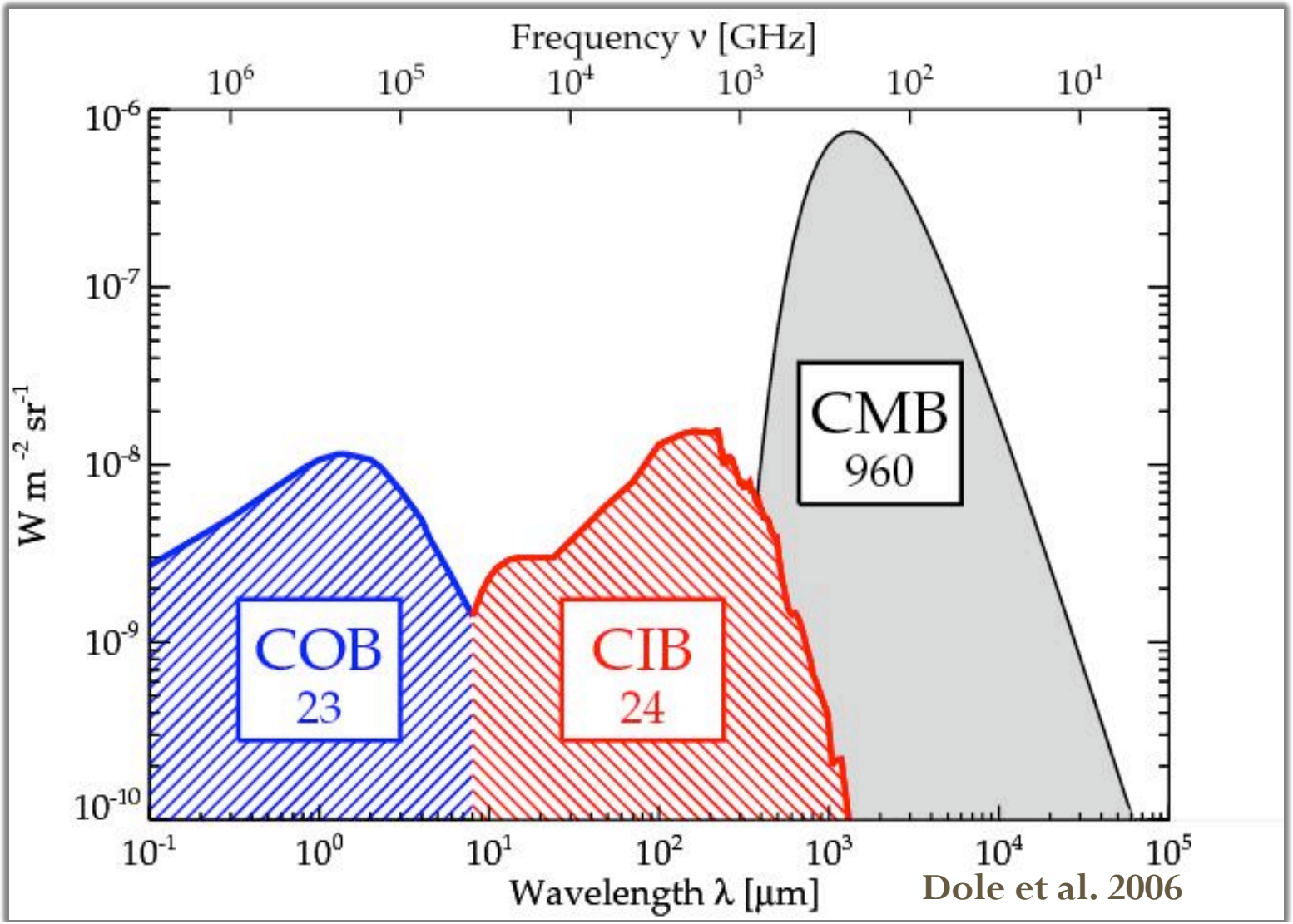
ISM conference – ESO Santiago

June 29, 2011

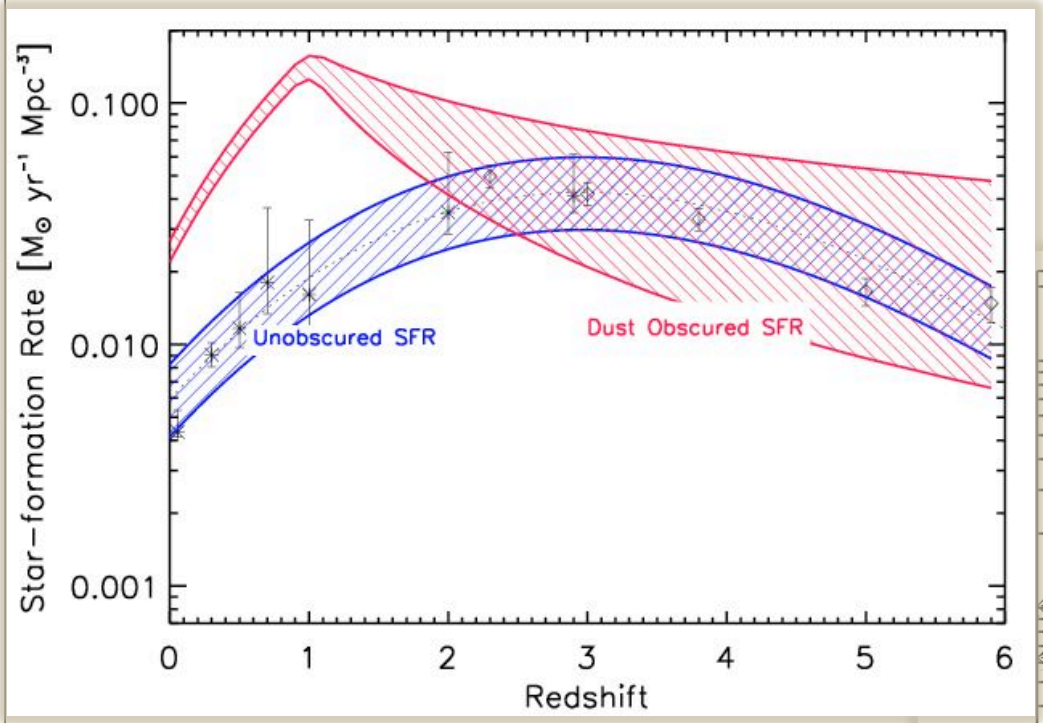


Cosmic Infrared Background*



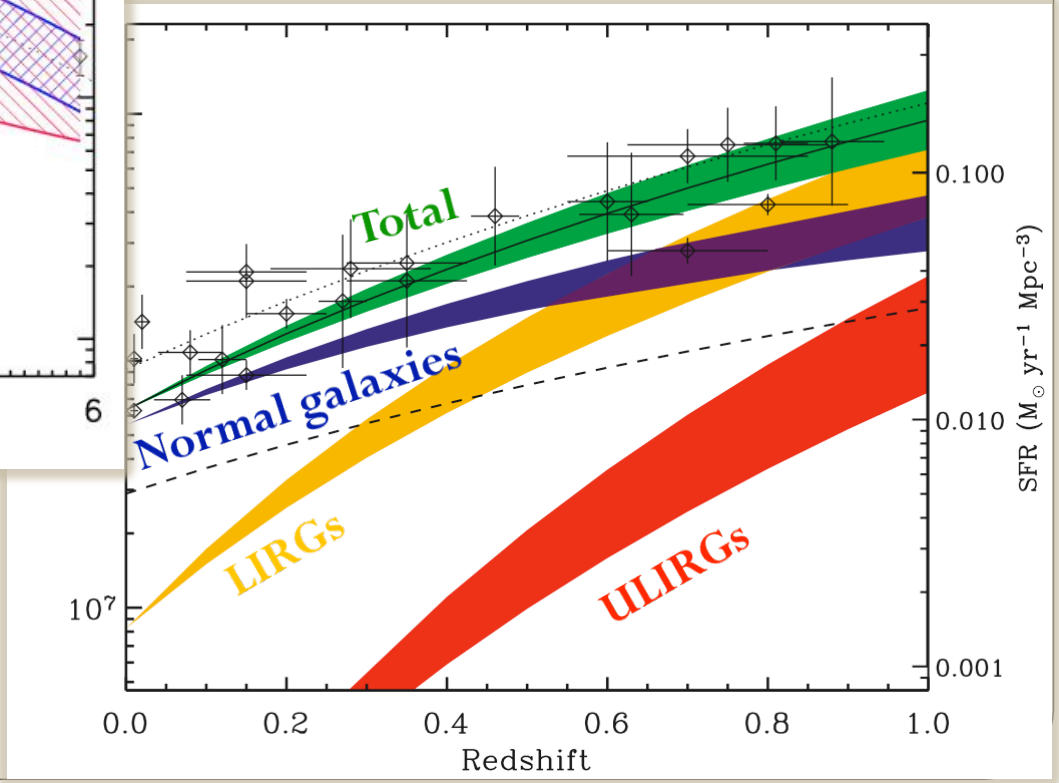
*** Cosmic Infrared Background (CIB) = Extragalactic Background Light (EBL)**

Dust-obscured activity dominates the build-up of stellar mass and black holes in galaxies

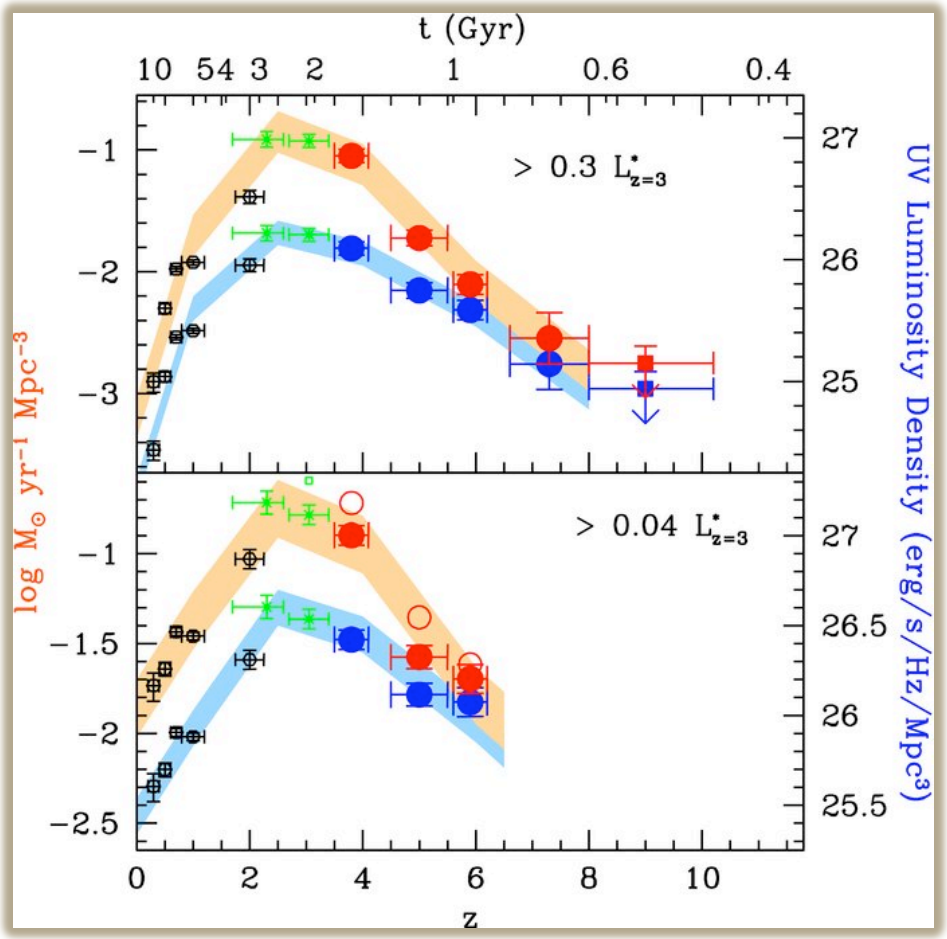


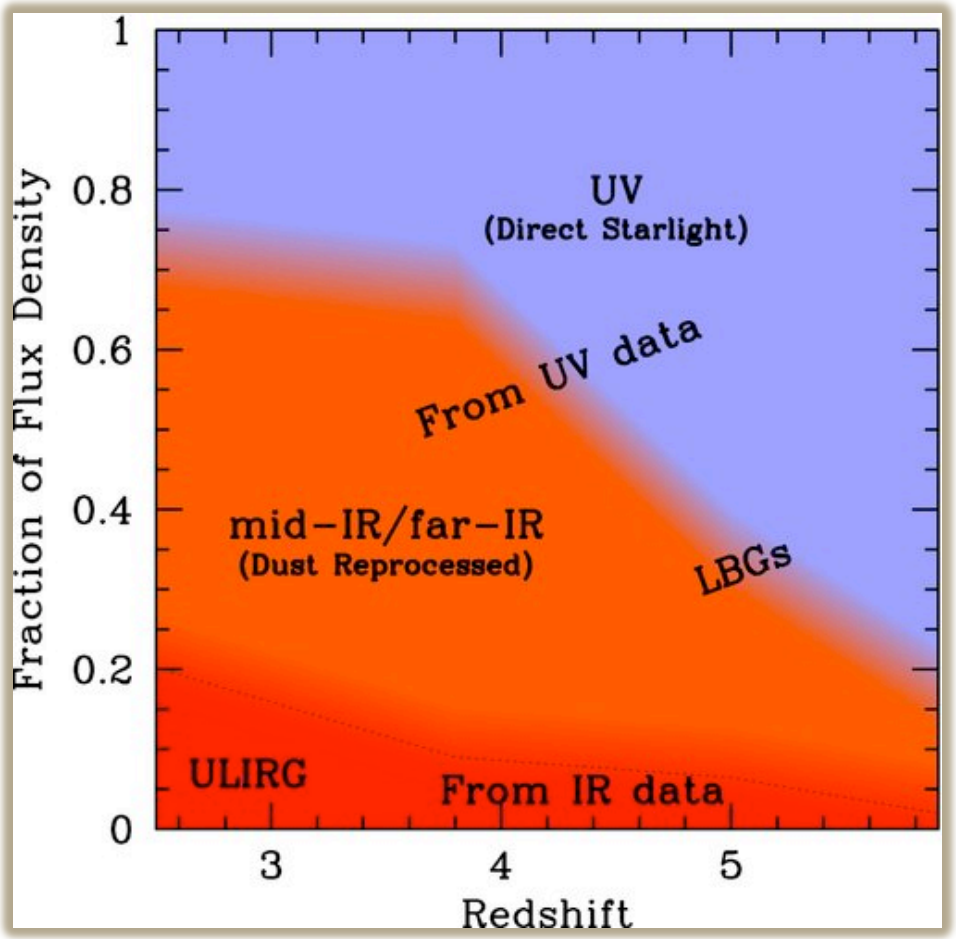
Chary & Pope 2011

Le Floc'h et al. 2005



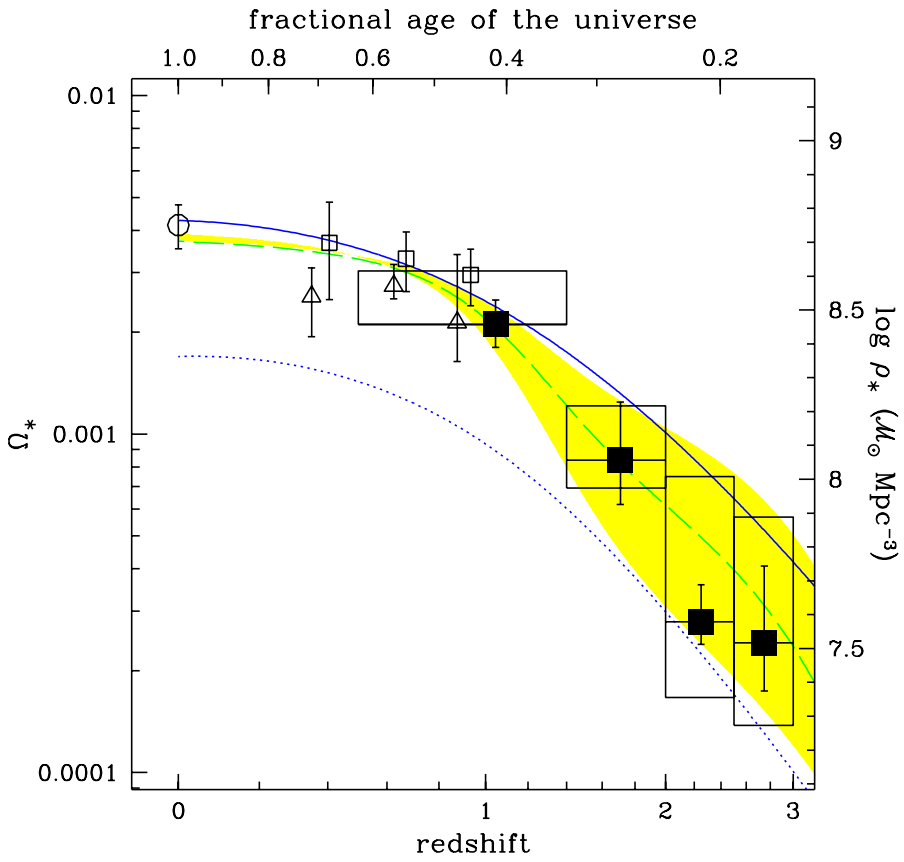
Dust-obscured activity dominates the build-up of stellar mass and black holes in galaxies



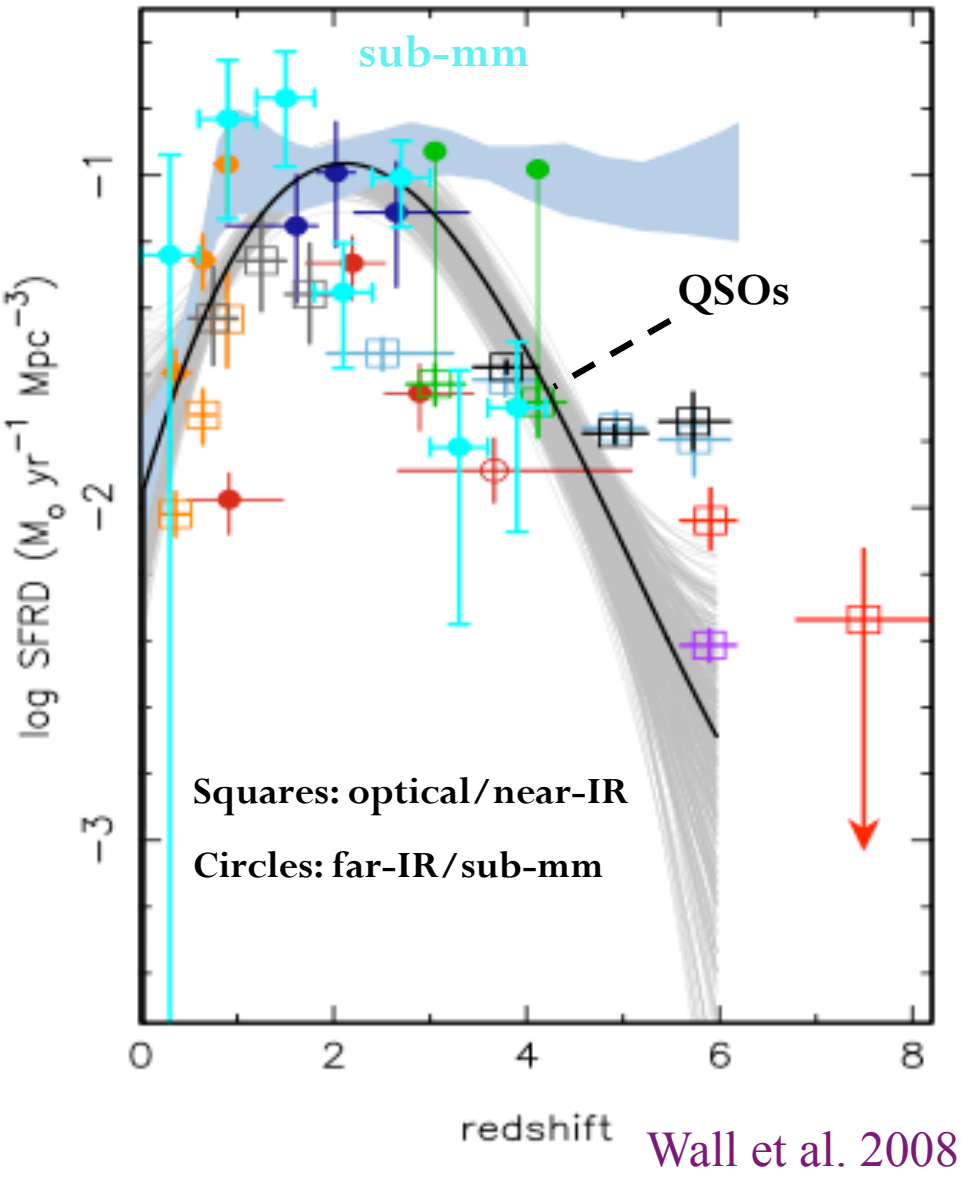


Bouwens+2009

Most stellar mass and AGN growth occurs at z~1-3

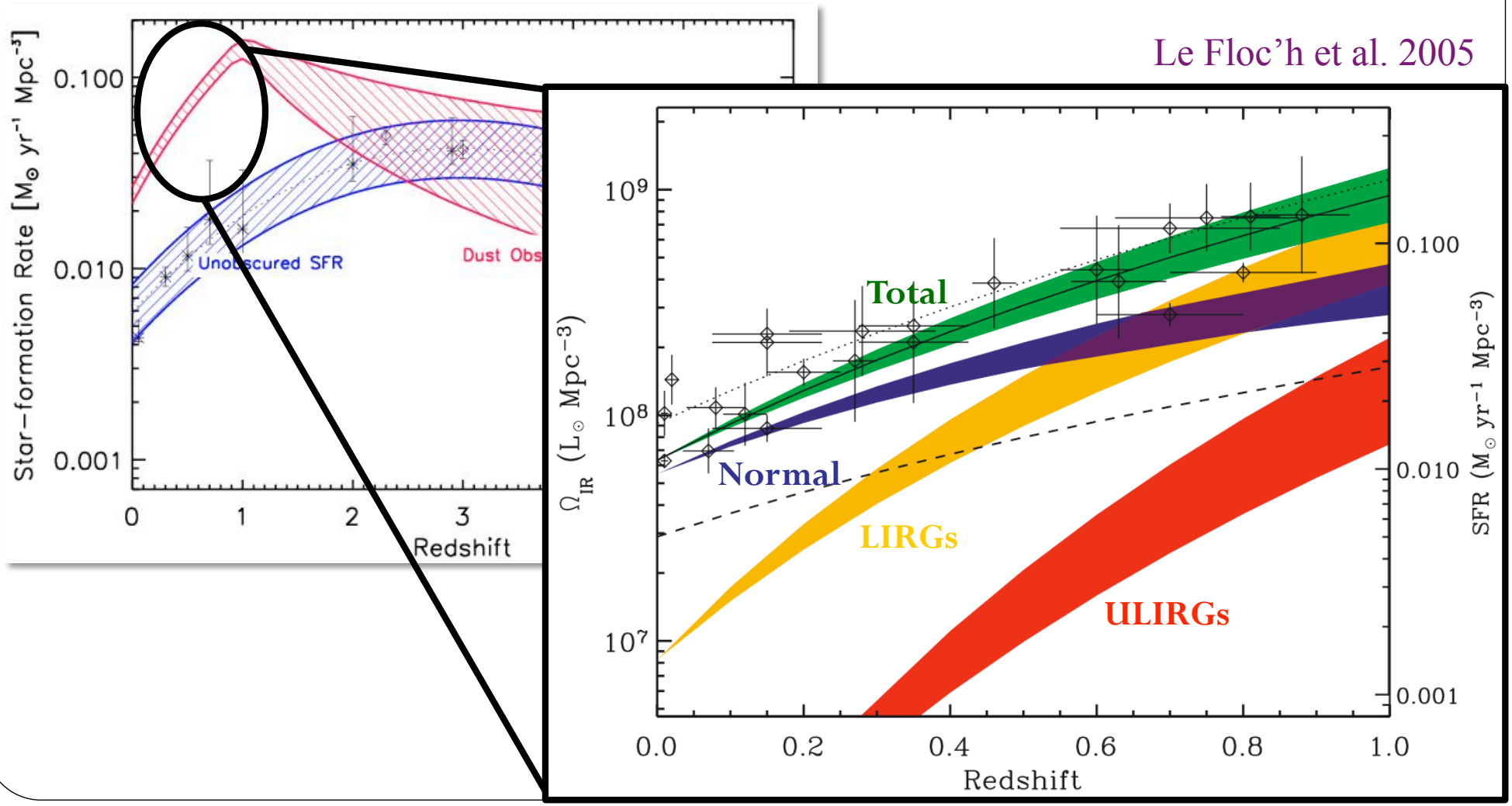


Dickinson et al. 2003



Wall et al. 2008

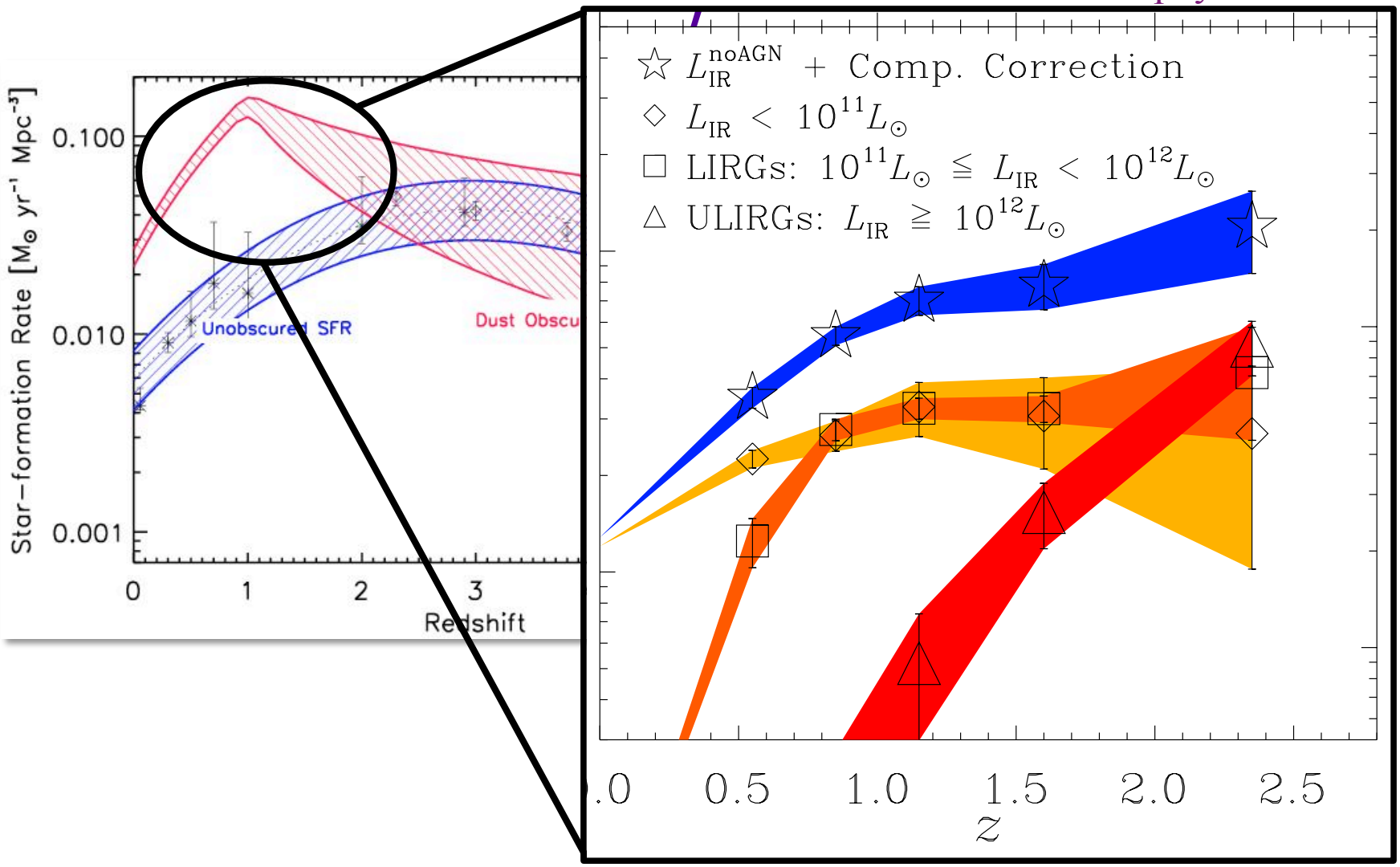
Most of the z~1-3 stellar mass growth occurs in LIRGs (and ULIRGs)



Le Floc'h et al. 2005

Most of the z~1-3 stellar mass growth occurs in LIRGs (and ULIRGs)

Murphy et al. 2011

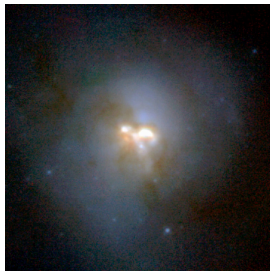


Ultra-luminous infrared galaxies (ULIRGs)

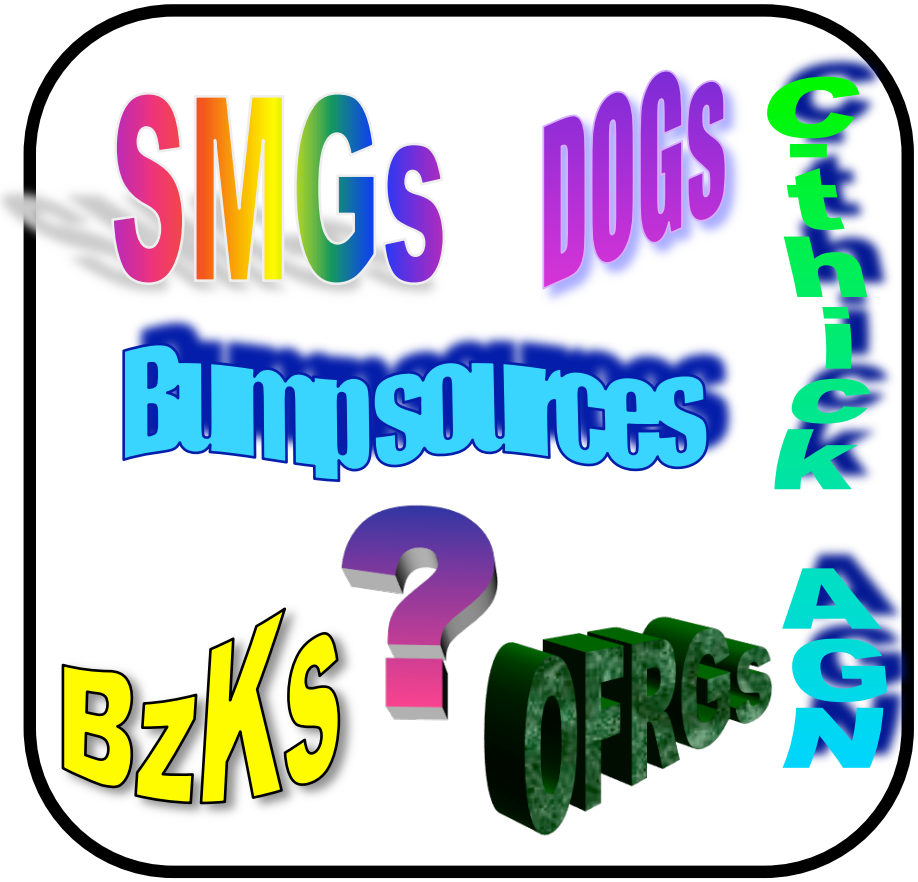
"A rose by any other name would smell as sweet "

Local

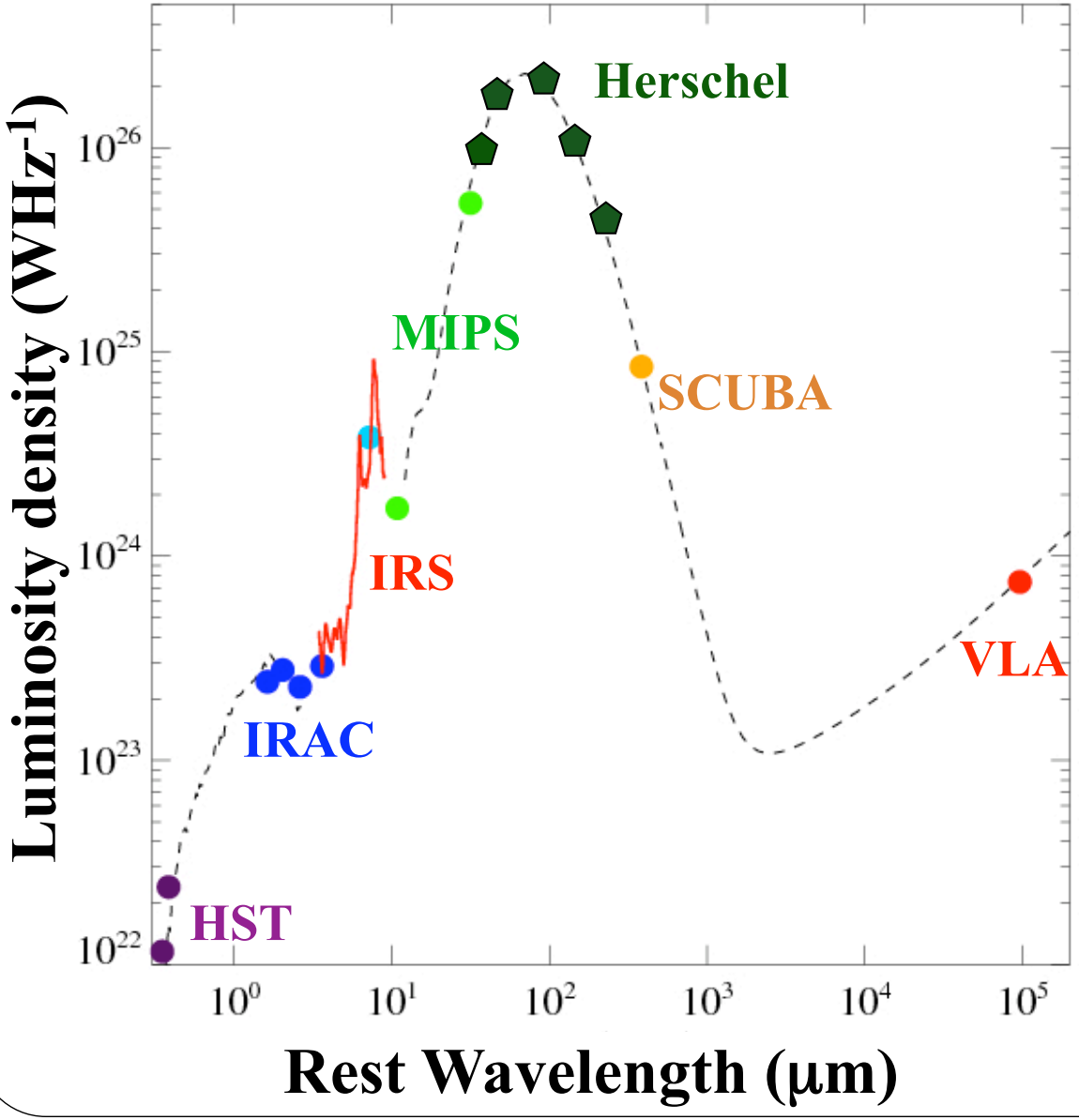
- **Complete samples of galaxies down to a given L_{IR}**
- **Not biased by AGN, dust temperature, detection limit, etc.**
- **Mostly major mergers**



z ~ 2



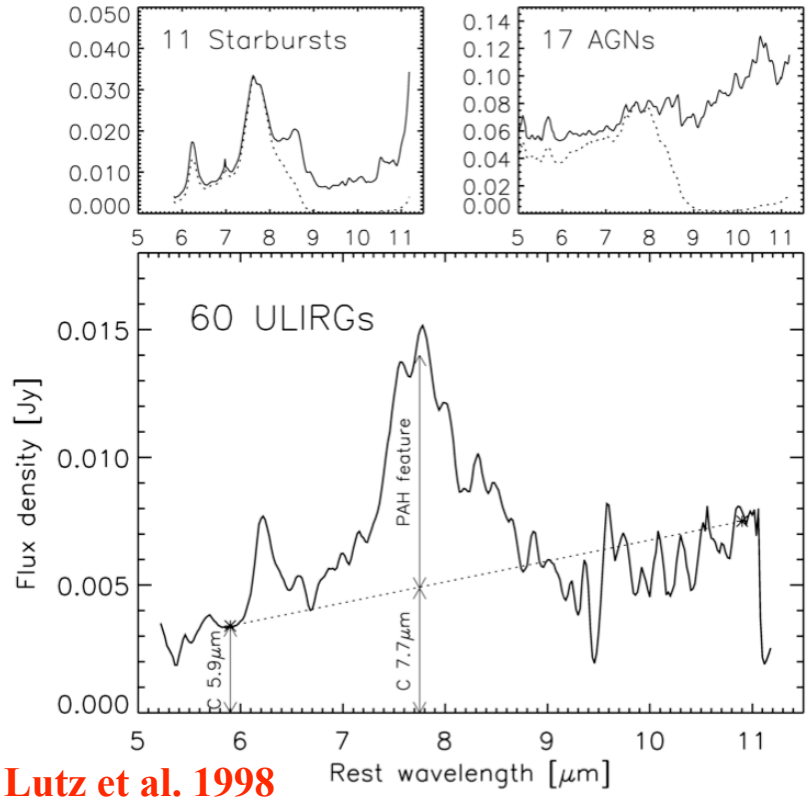
Spectral energy distribution (SED) of high redshift submillimeter galaxies (SMGs)



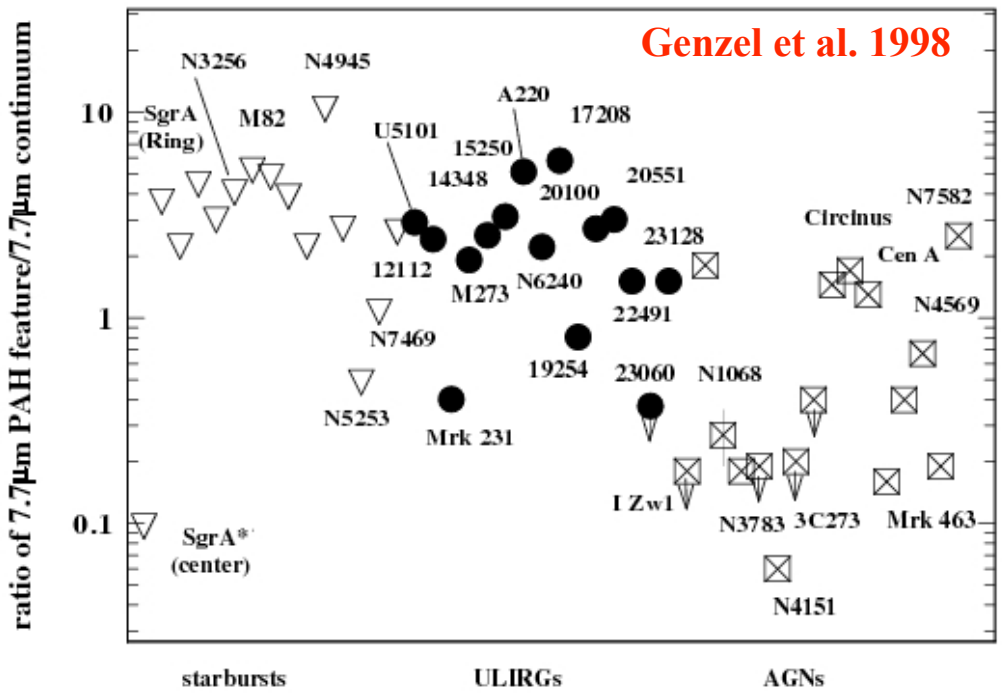
- Circa 2011: Well sampled SED for ULIRGs z~1-3
- *Herschel* data probes the peak of the dust emission: dust masses, temperatures, emissivity
- Spectroscopy can provide a probe of the underlying radiation field and ISM coditions
- Mid-IR spectroscopy is sensitive to dust which is dominating the SFRD

(ISO) Mid-infrared Spectroscopy

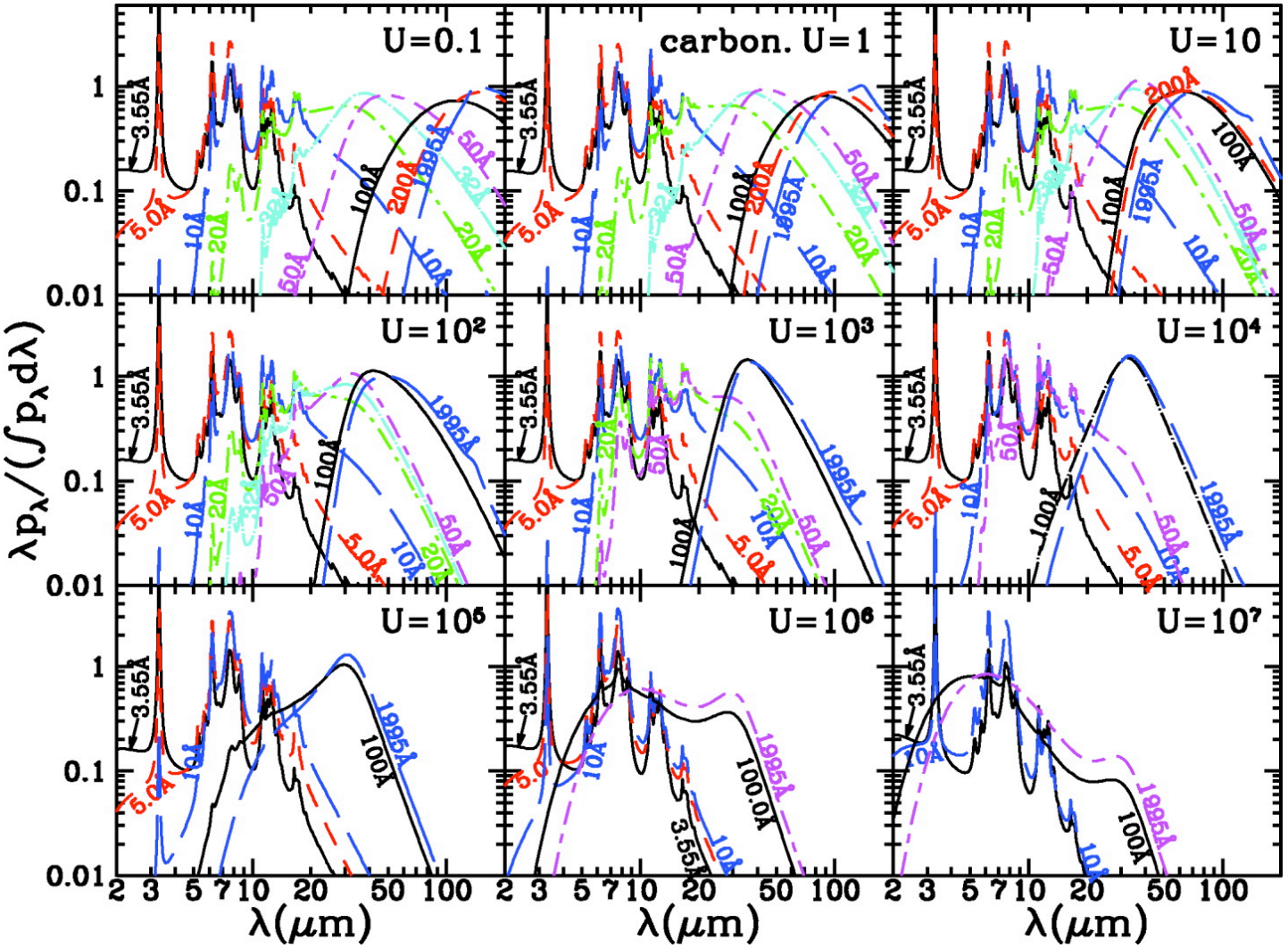
Local ULIRGs



Lutz et al. 1998

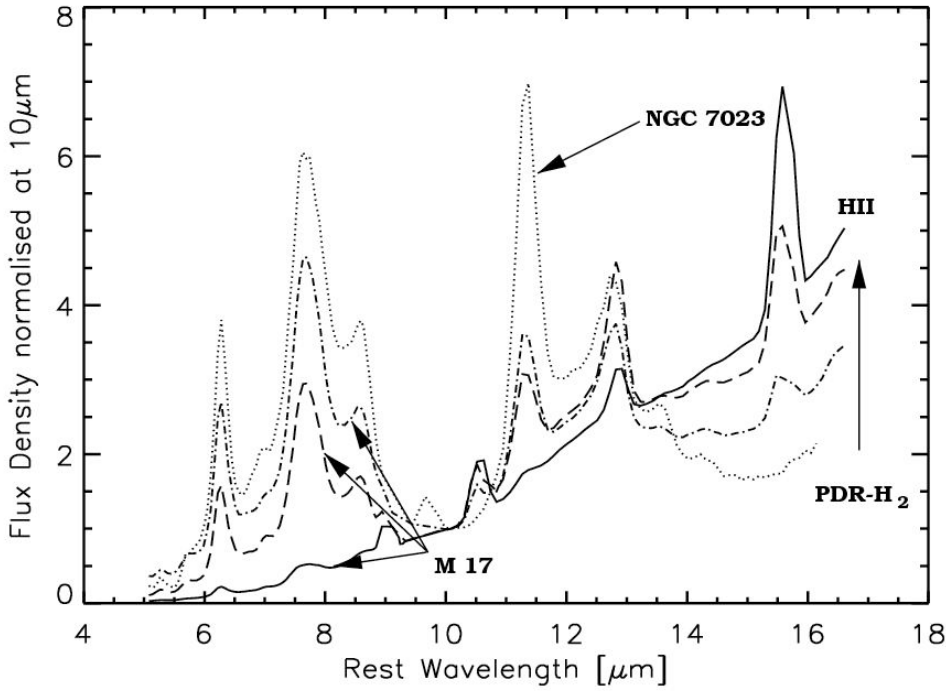


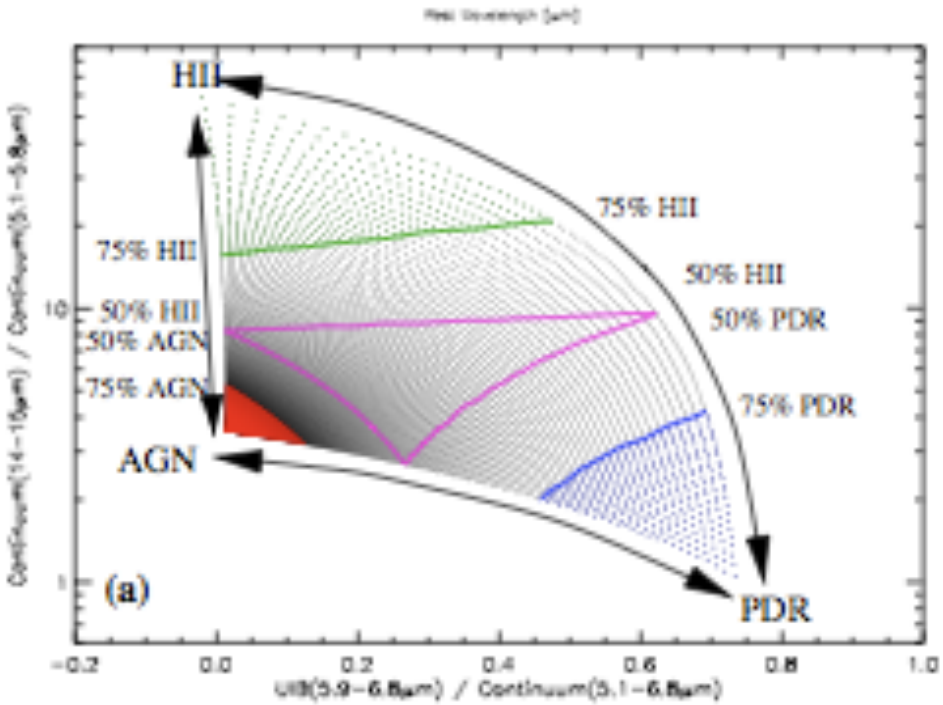
PAHs are sensitive to the radiation field and the dust grain size distribution



Draine & Li 2007

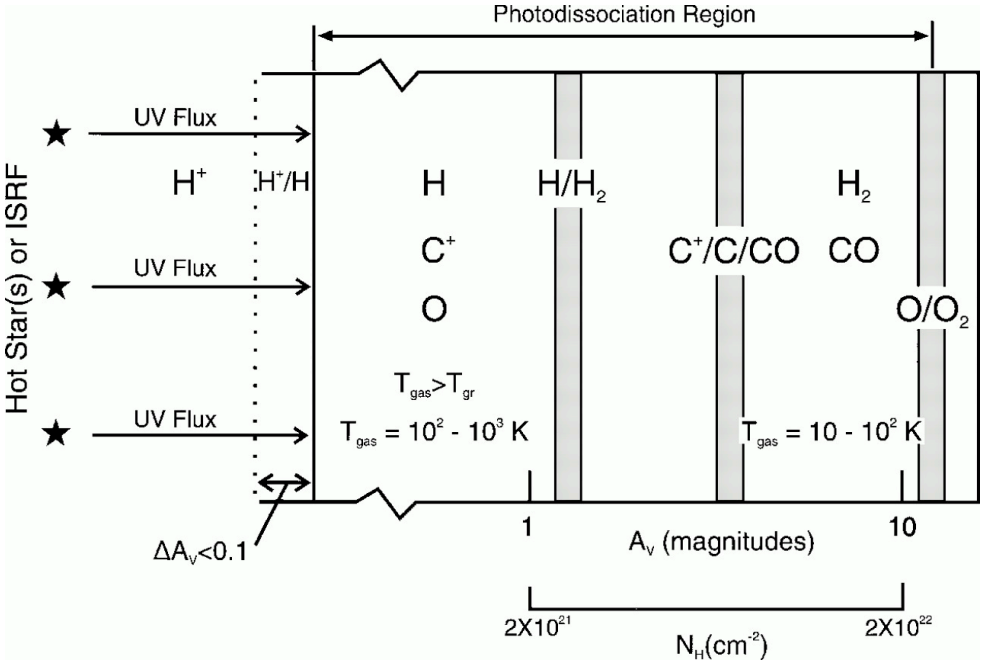
PAHs as an ISM diagnostic

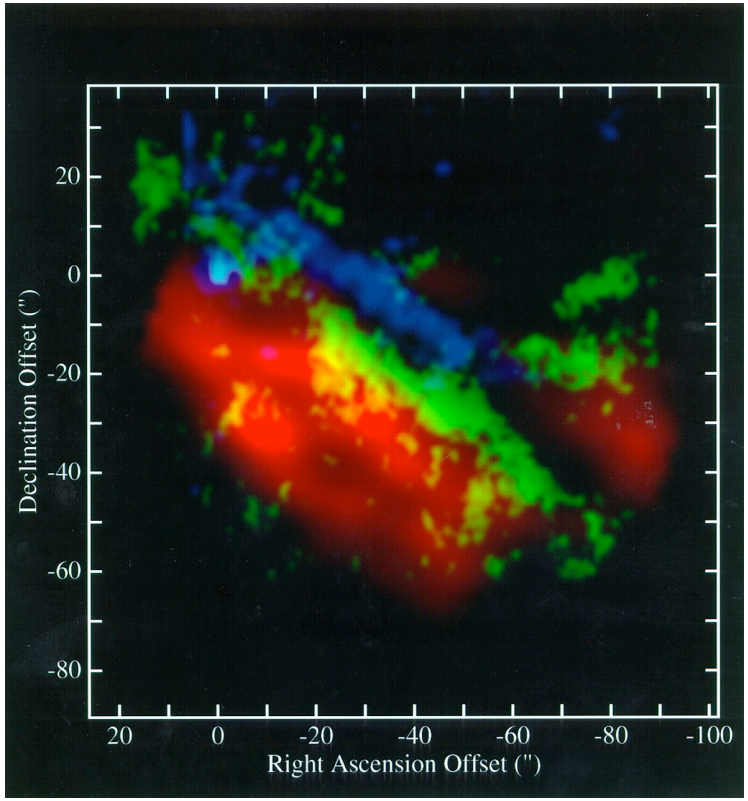




Laurent et al. 2000

PAHs as an ISM diagnostic

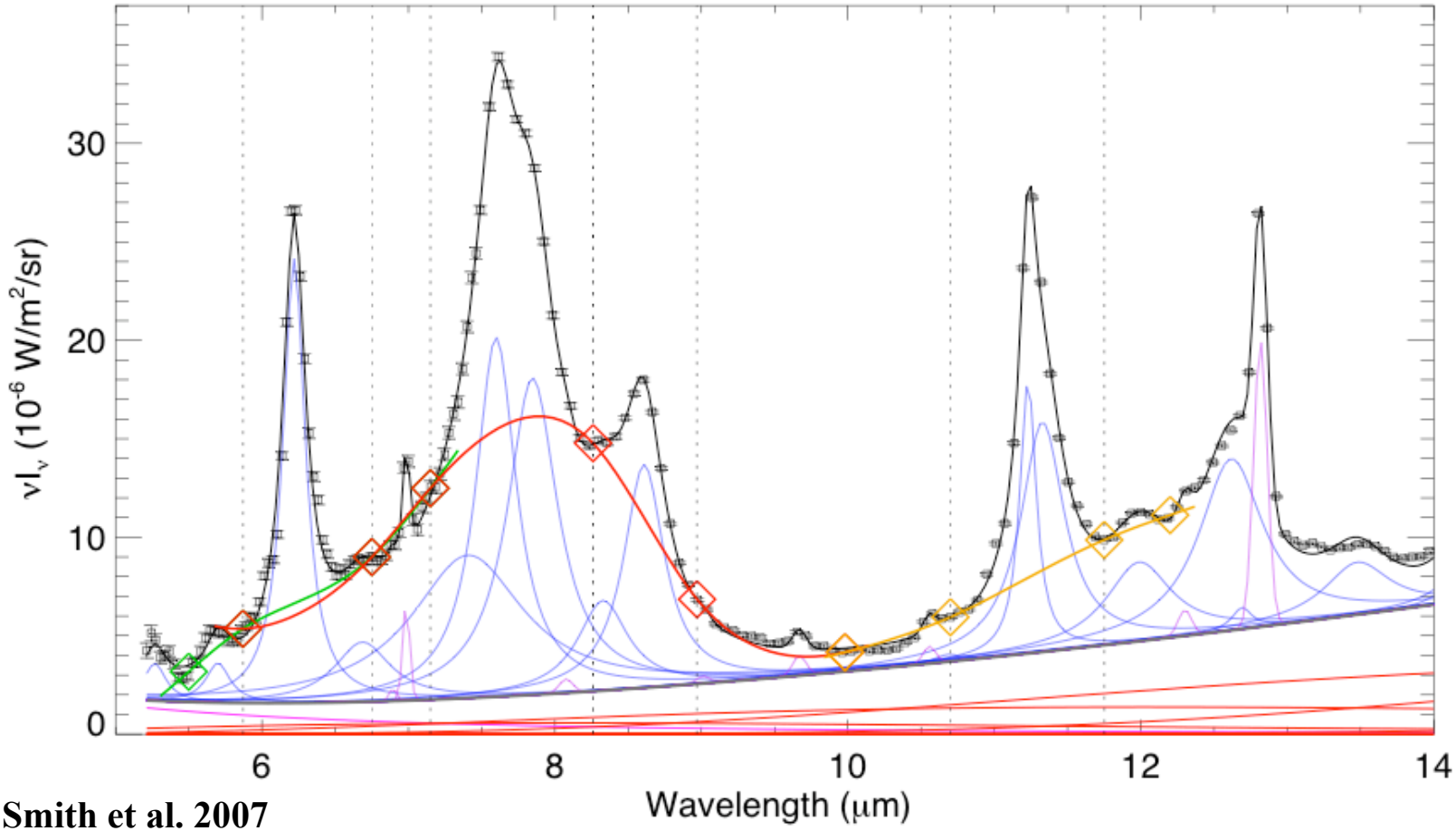




Hollenbach &Tielens 1997

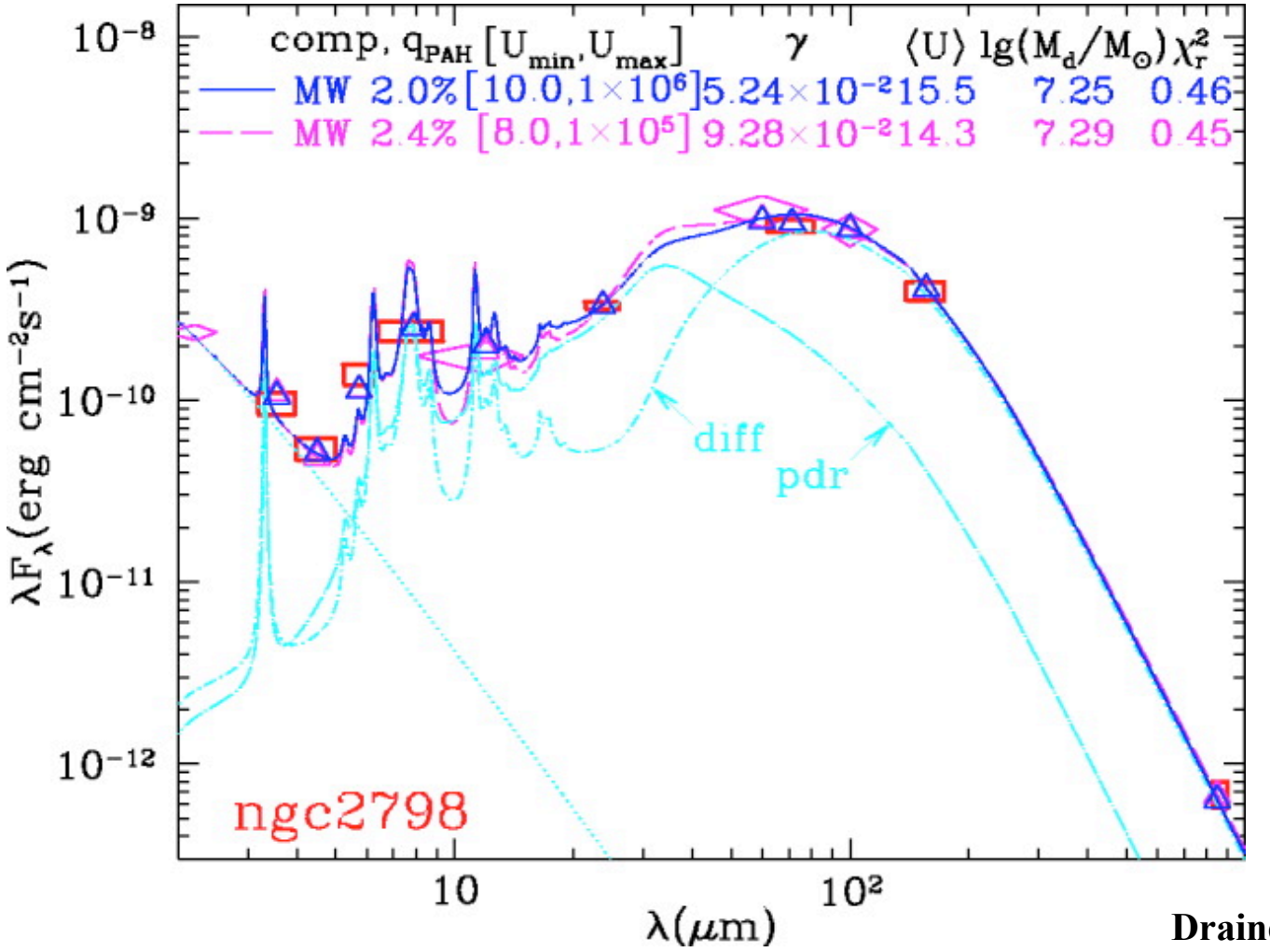
Spitzer IRS spectroscopy

Detailed studies of local galaxies



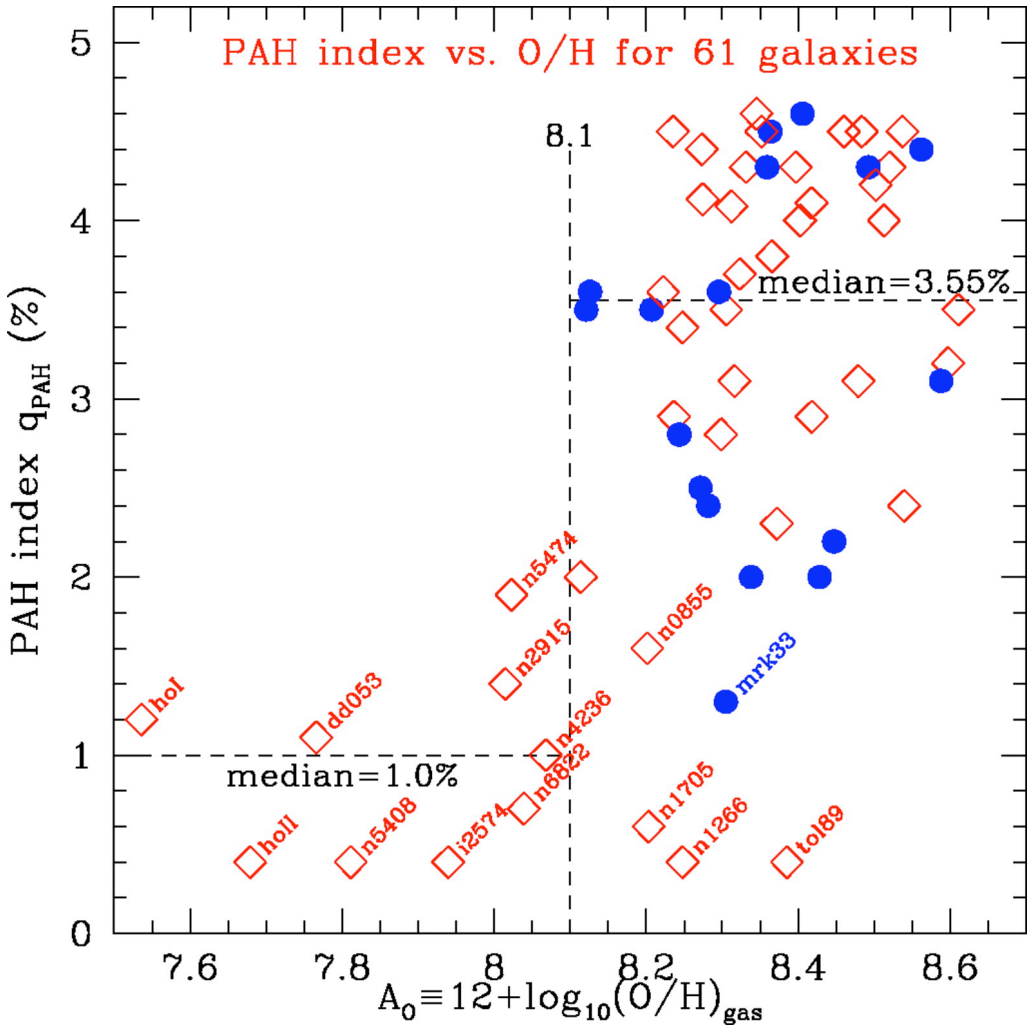
Smith et al. 2007

PAHs are found in PDRs and diffuse regions of star forming galaxies



Draine et al. 2007

PAH/L_{IR} ratio depends on metallicity



Draine et al. 2007

Spitzer Mid-IR Spectroscopy

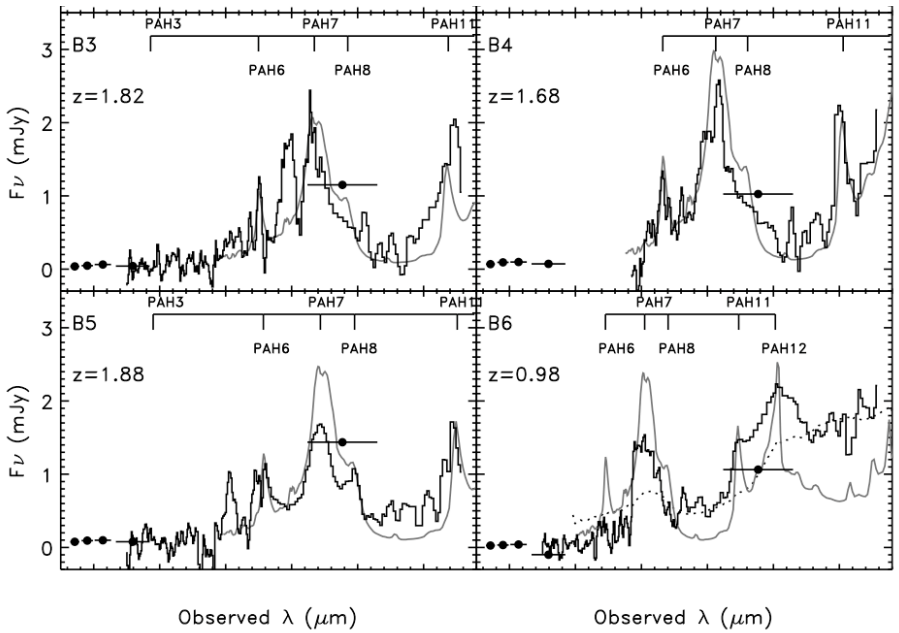
Extending out to high redshift

The mid-IR spectrum can be decomposed into two main components:

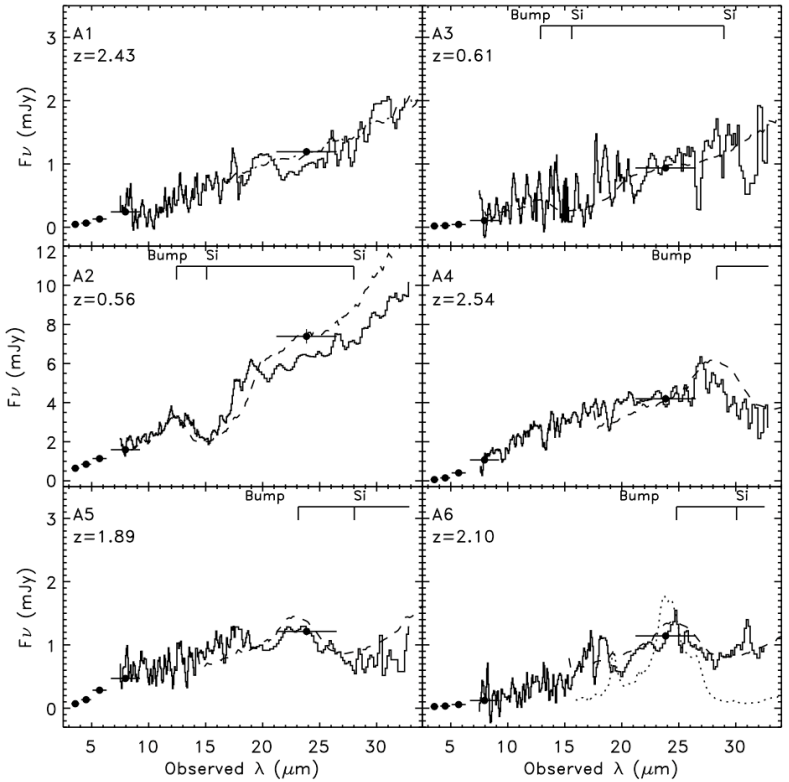
1. Starburst:

Polycyclic aromatic hydrocarbons (PAH) emission lines + extinction

Main lines at 6.2, 7.7, 8.6 and 11.3μm



2. AGN: power-law + extinction



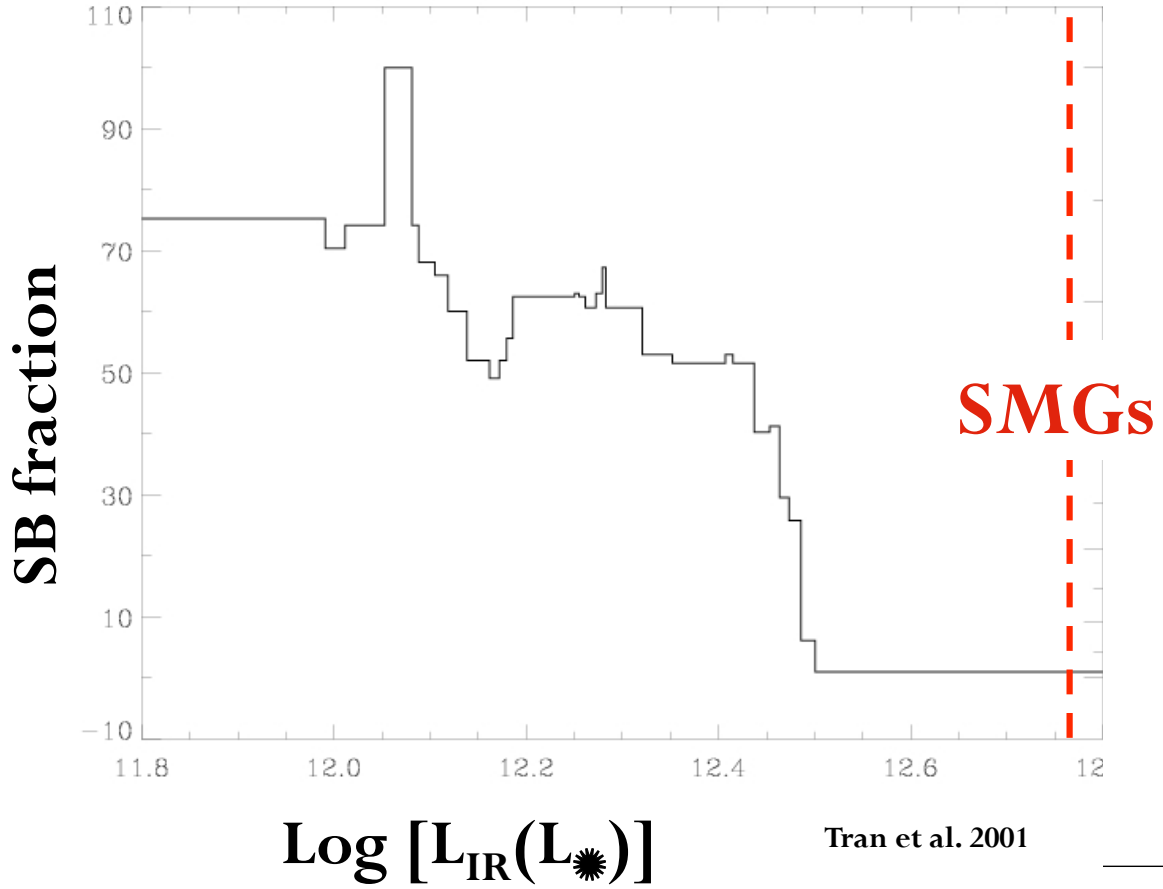
Weedman et al. 2006

z~2 Submillimeter Galaxies (SMGs)

- high IR luminosities

=> SFR~1000$M_{\odot}yr^{-1}$

...assuming no AGN!



Tran et al. 2001

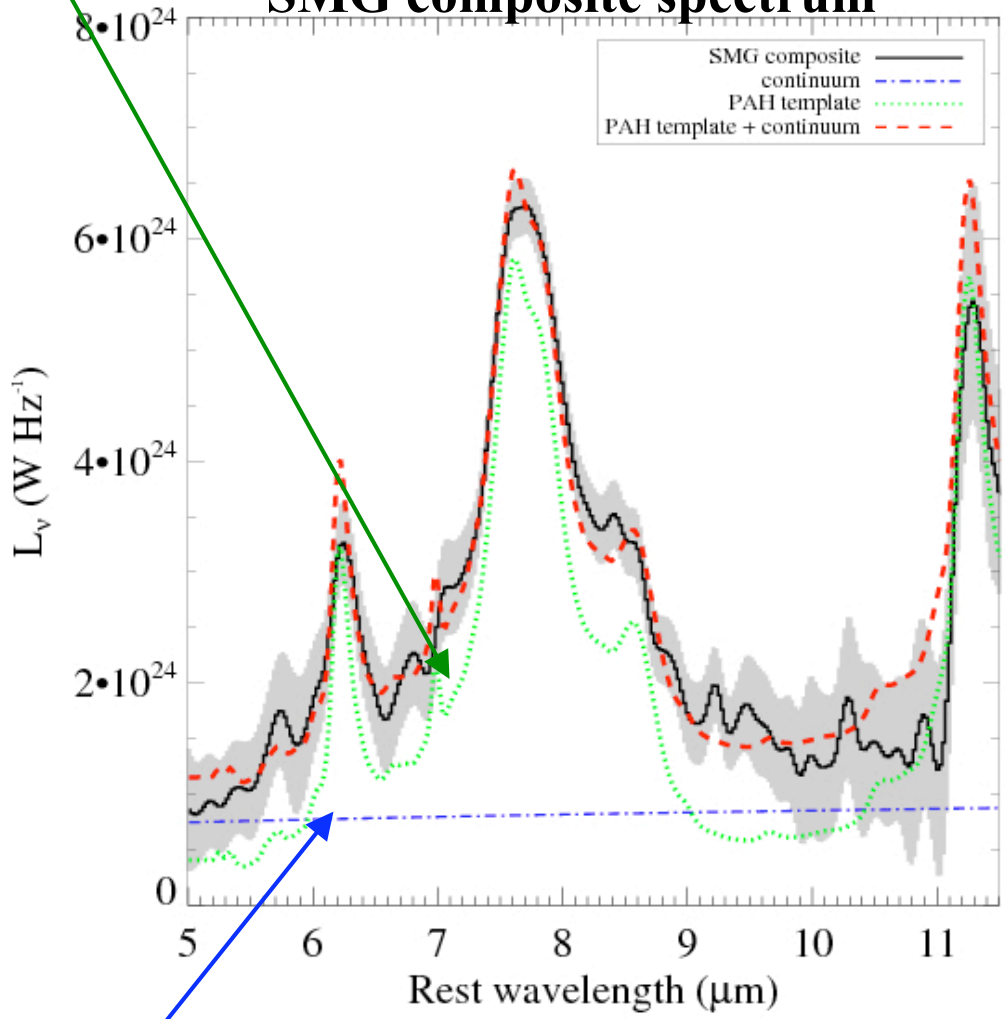
Local ULIRGs show increasing AGN contribution with L_{IR}

=> Does this mean SMGs are AGN dominated ?

Spitzer Mid-IR Spectroscopy of SMGs

Starburst: Polycyclic aromatic hydrocarbons (PAH) + extinction

SMG composite spectrum



Mid-IR SED of SMGs is starburst dominated :

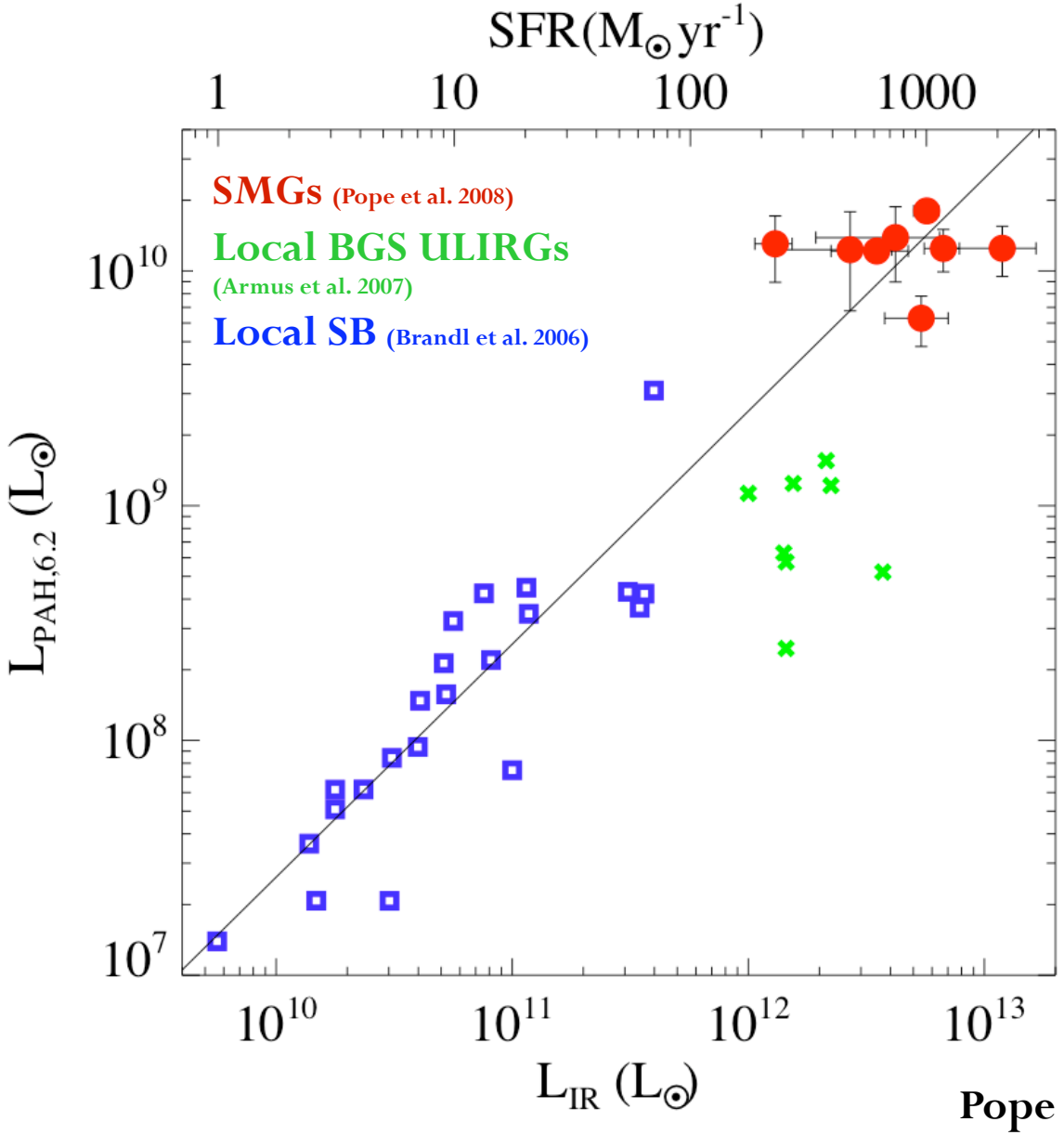
small contribution from AGN (<30% at these wavelengths)

Scaled up M82 – not like local ULIRGs (e.g. Arp220)

Pope et al. 2008
see also Valiante et al. 2007,
Menendez-Delmestre et al. 2009

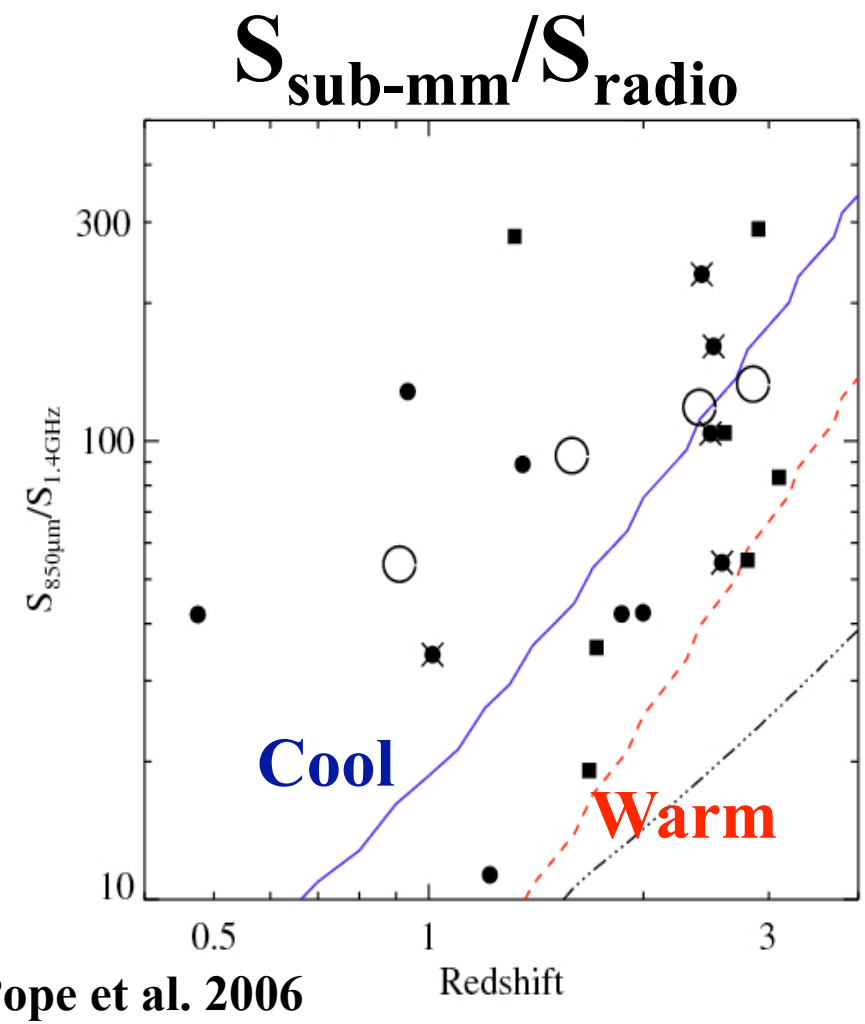
AGN: power-law + extinction

SMGs are scaled up local starbursts



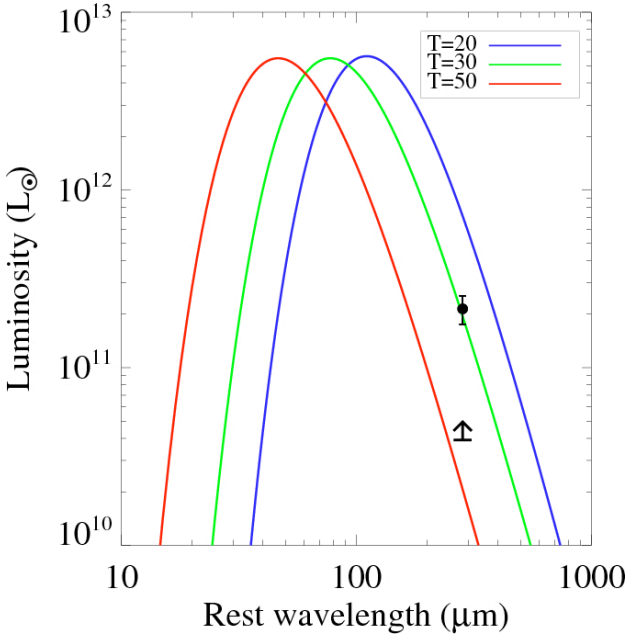
Pope et al. 2008

SMGs: Dust temperature bias

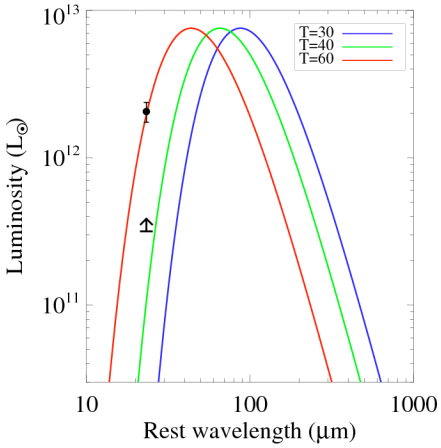


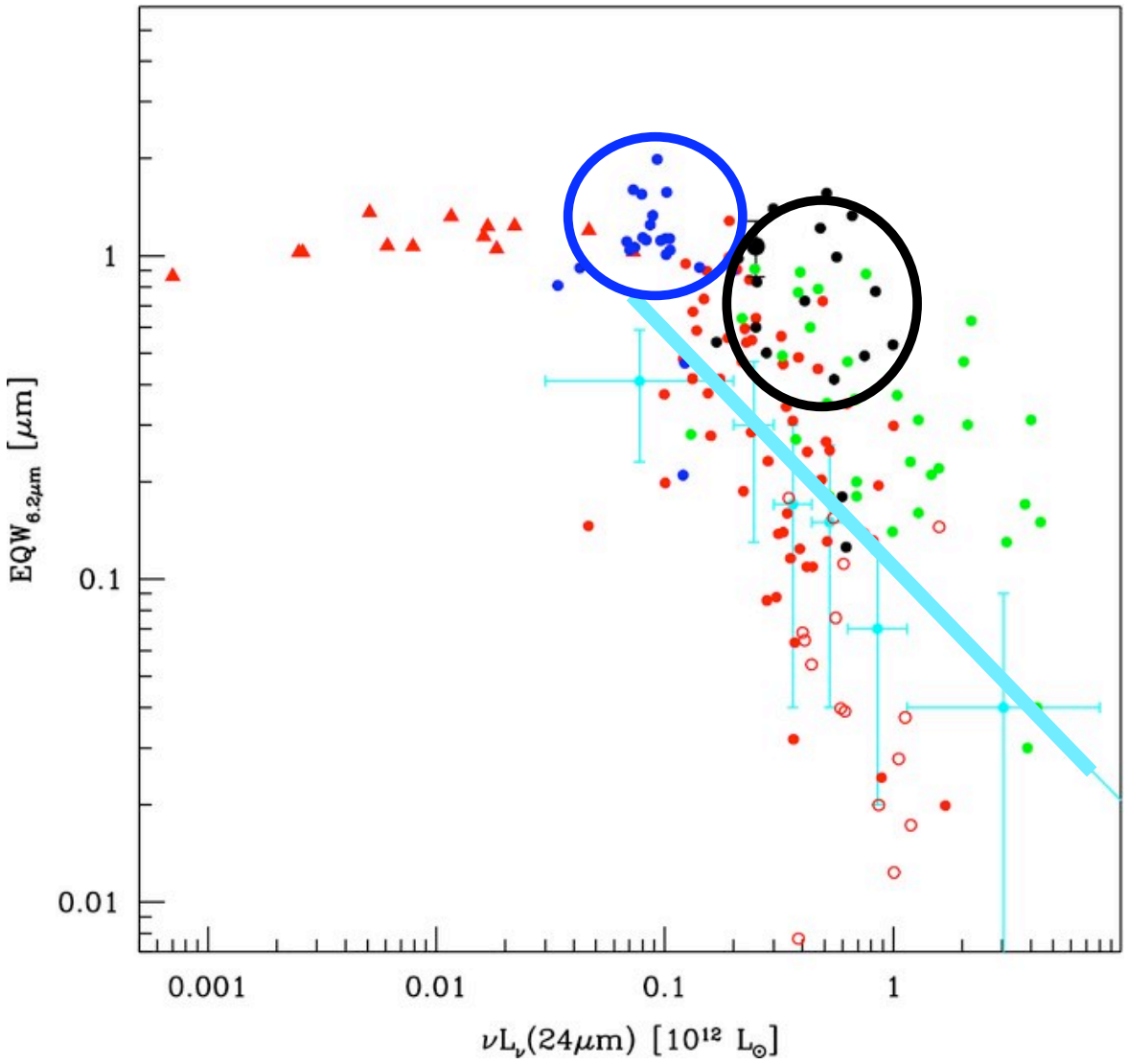
Pope et al. 2006

SMGs are cooler than local galaxies of the same luminosity



Spitzer-selected ULIRGs



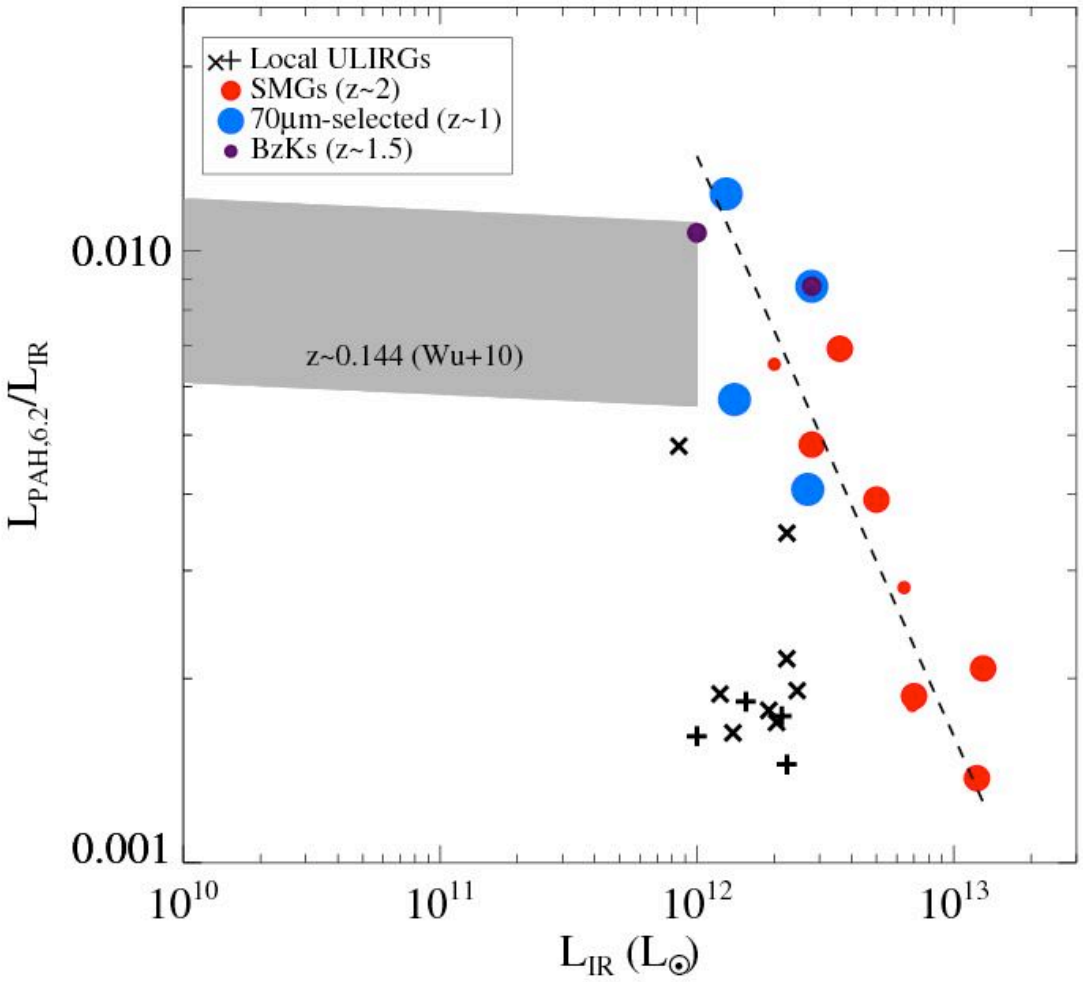


Spitzer-selected (U)LIRGs at z=1 and z=2 also show higher PAH EW than local ULIRGS

Stronger PAH emission at high redshift

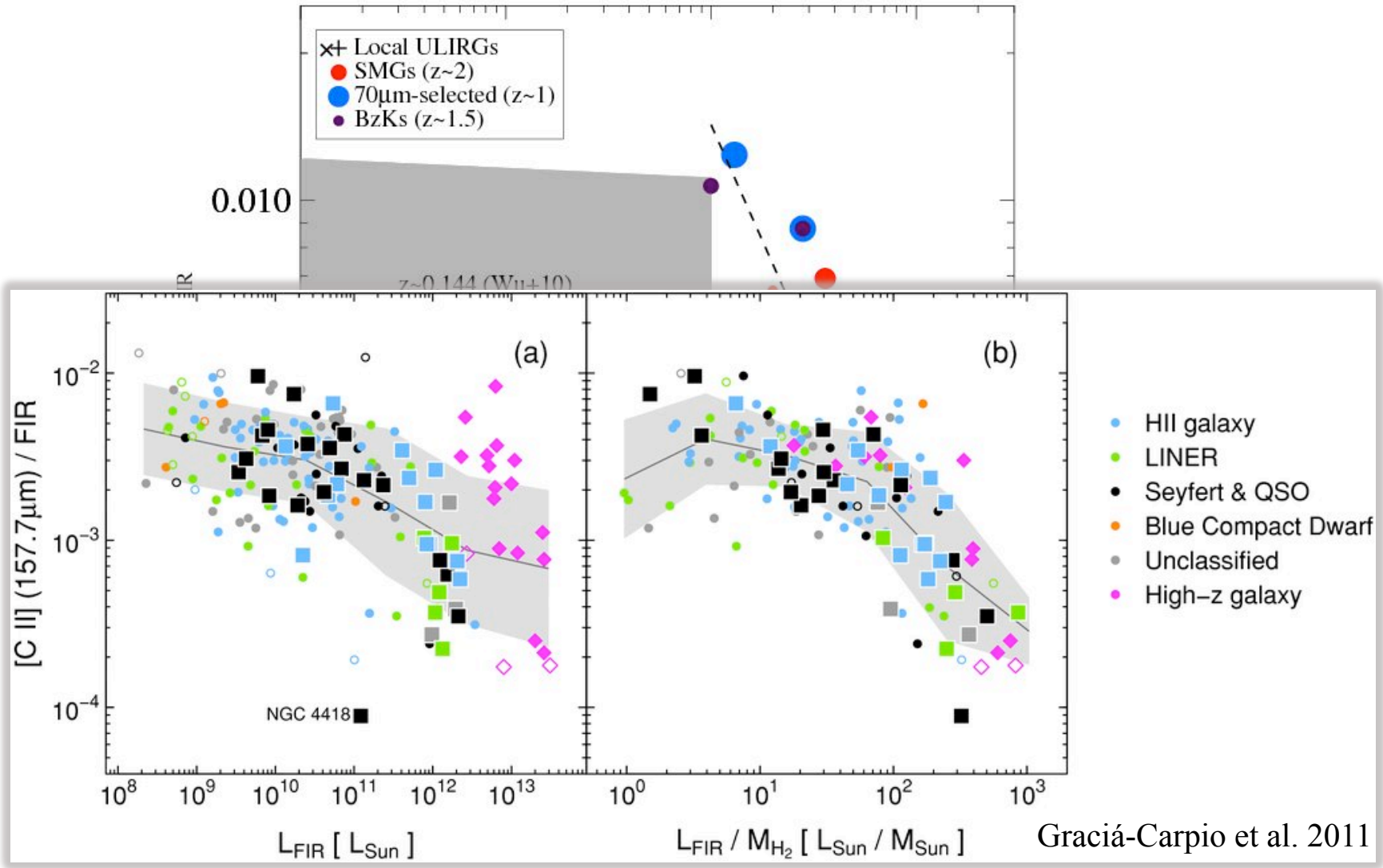
Fadda et al. 2010

Link between dust and gas



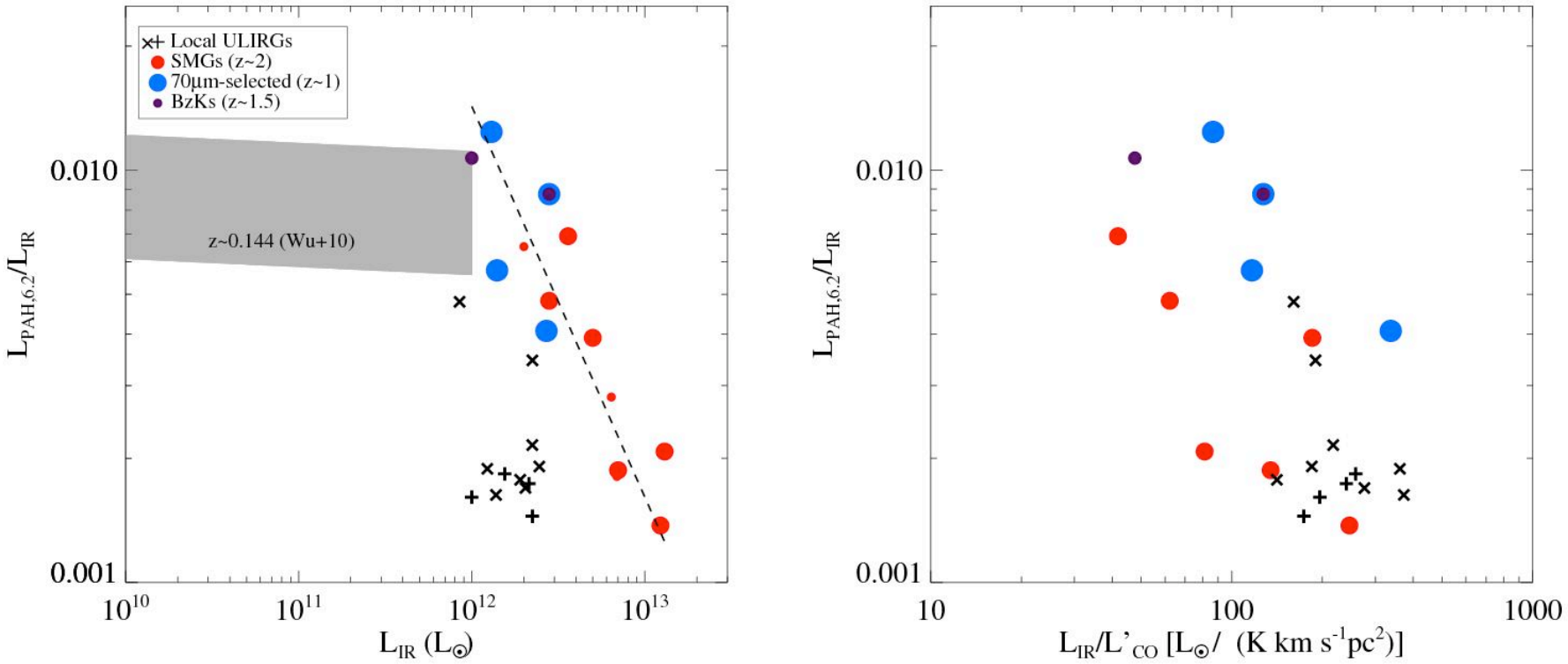
Pope et al. 2011

Link between dust and gas



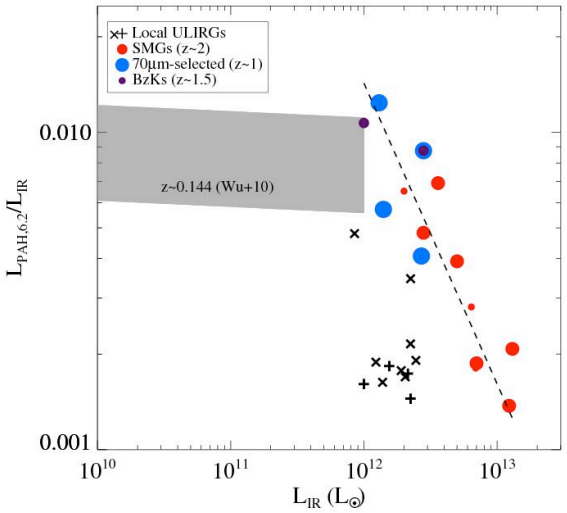
Graciá-Carpio et al. 2011

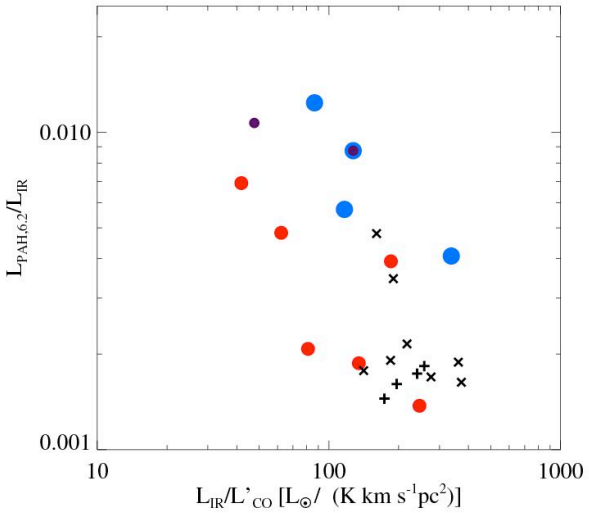
Link between dust and gas

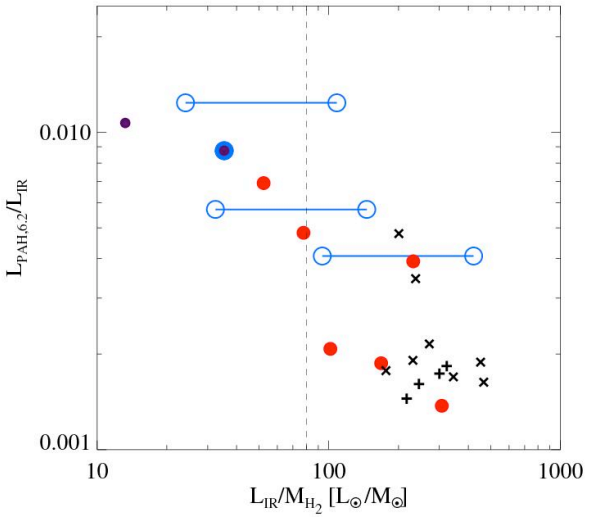


Pope et al. 2011

Link between dust and gas

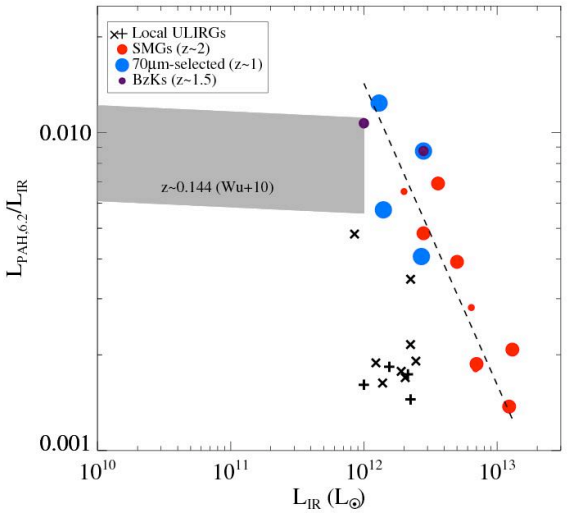


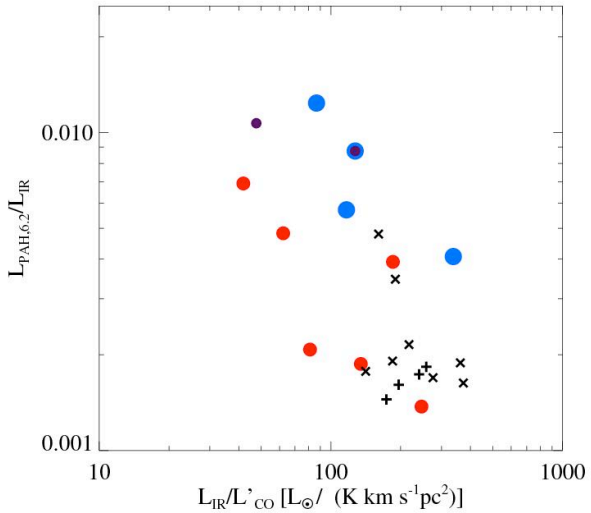


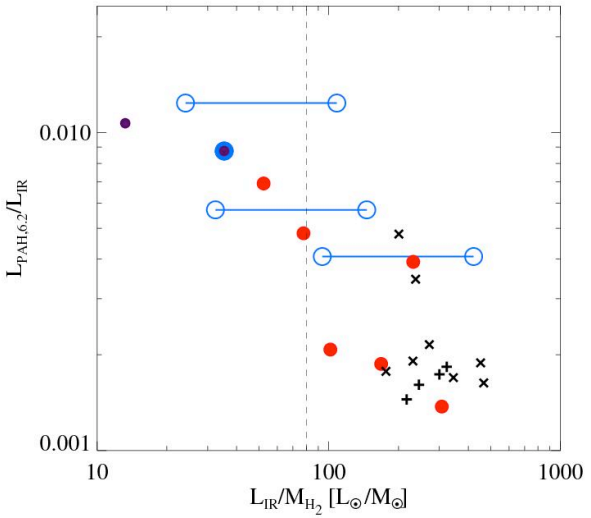


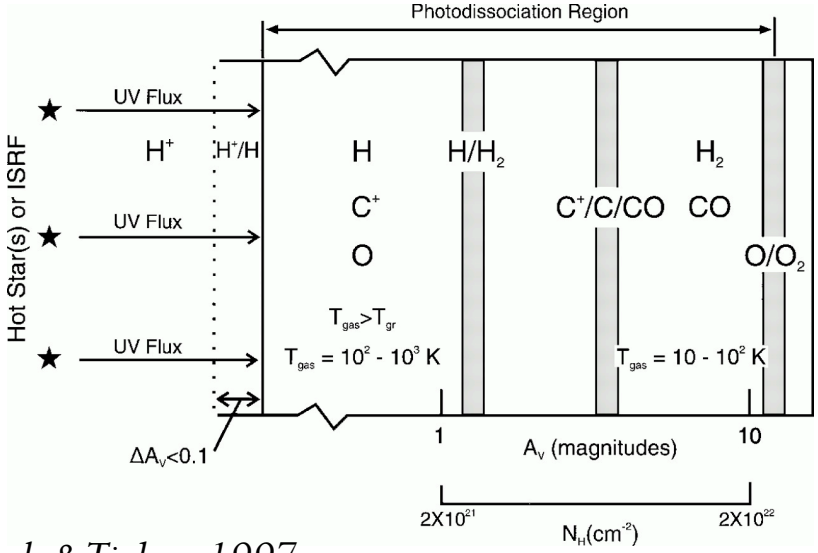
Pope et al. 2011

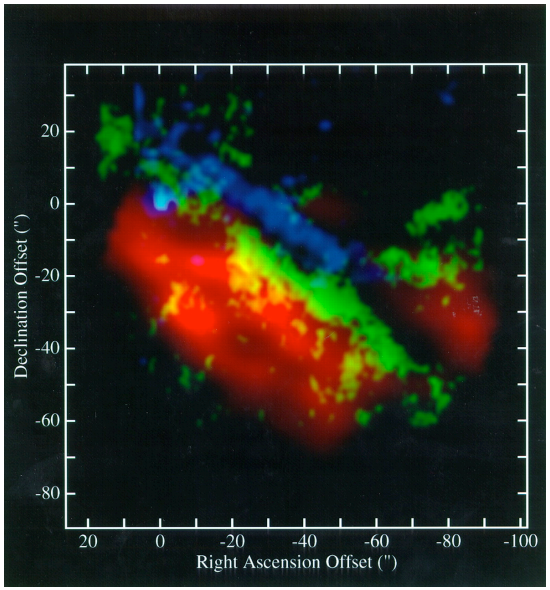
Link between dust and gas











Hollenbach &Tielens 1997

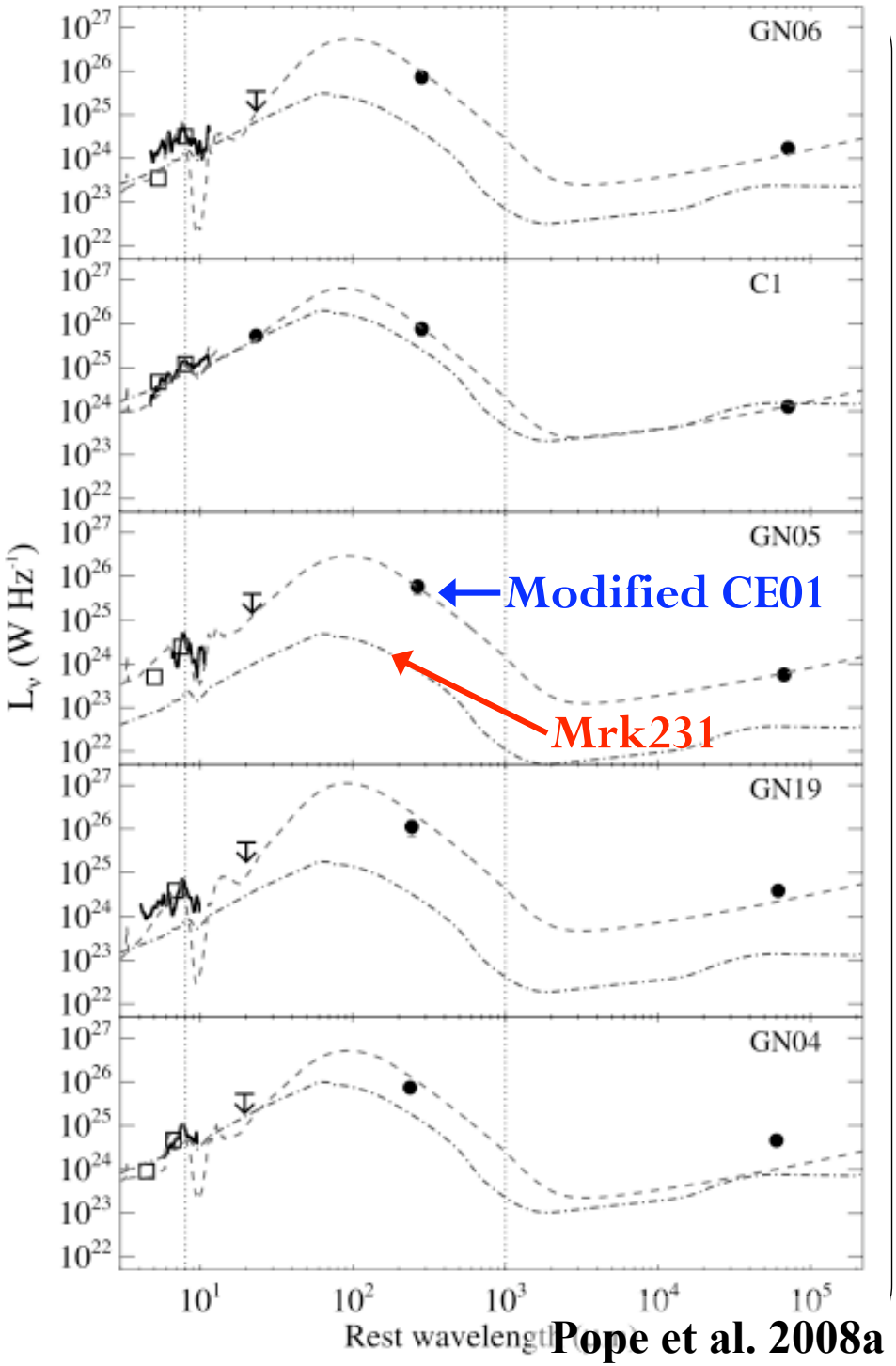
IR SED

- IRS gives a good estimate of $AGN_{mid\text{-}IR}$ but we care about the AGN contribution to $L_{IR}(8\text{-}1000\mu m)$
- Extrapolate to far-IR:

e.g. $AGN_{mid\text{-}IR} \sim 50\%$

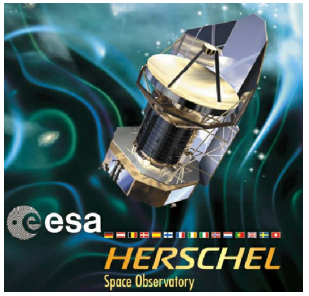
$\Rightarrow AGN_{total\ IR} \sim 10\text{-}20\%$

- AGN rarely dominate bolometric luminosity



Pope et al. 2008a

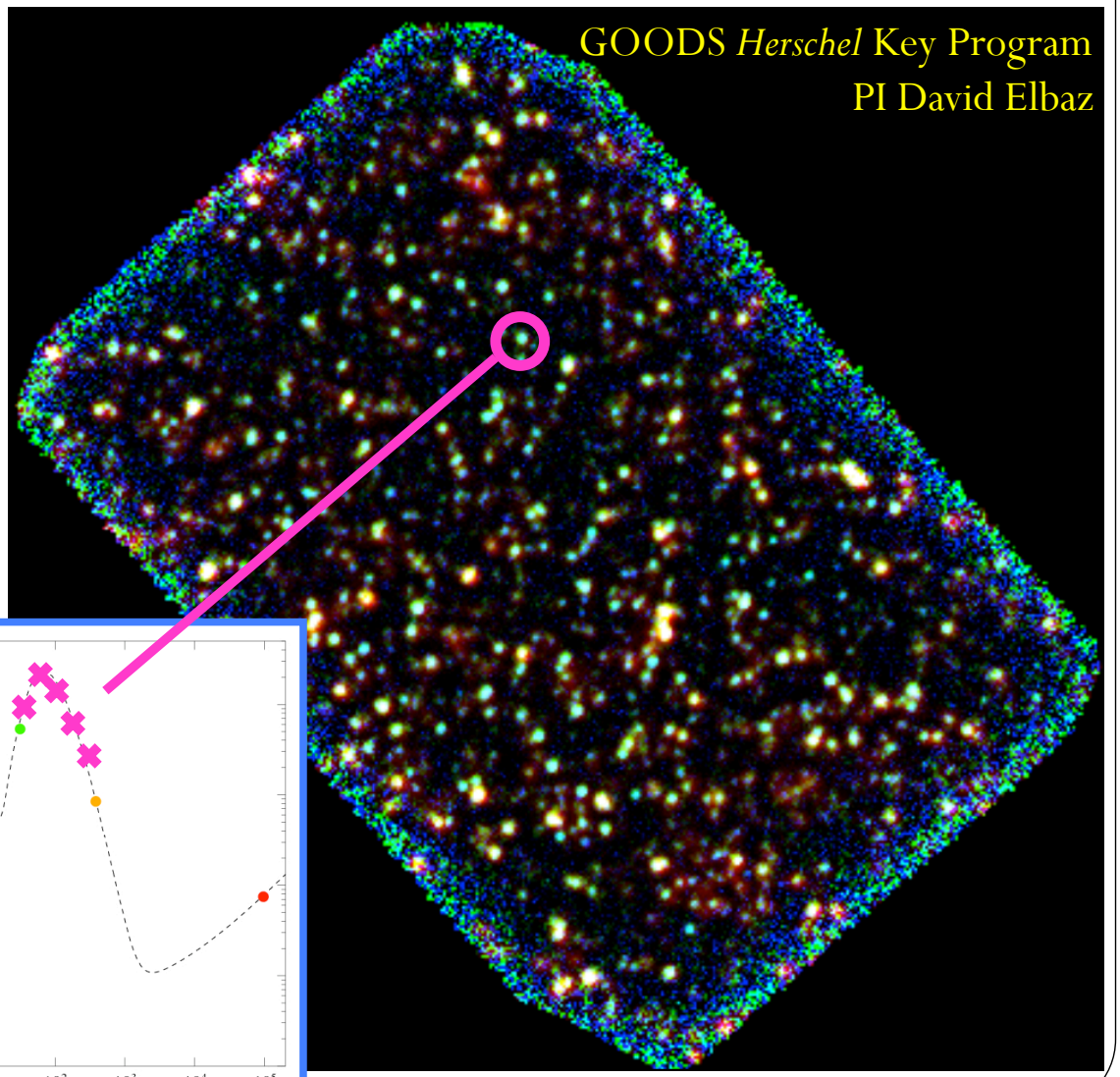
Herschel Space Observatory

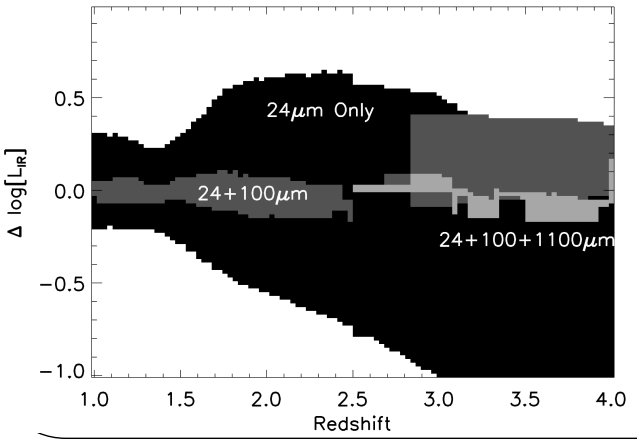


Deep high(er) resolution far-IR imaging at:

70, 100, 160, 250, 350, 500μm

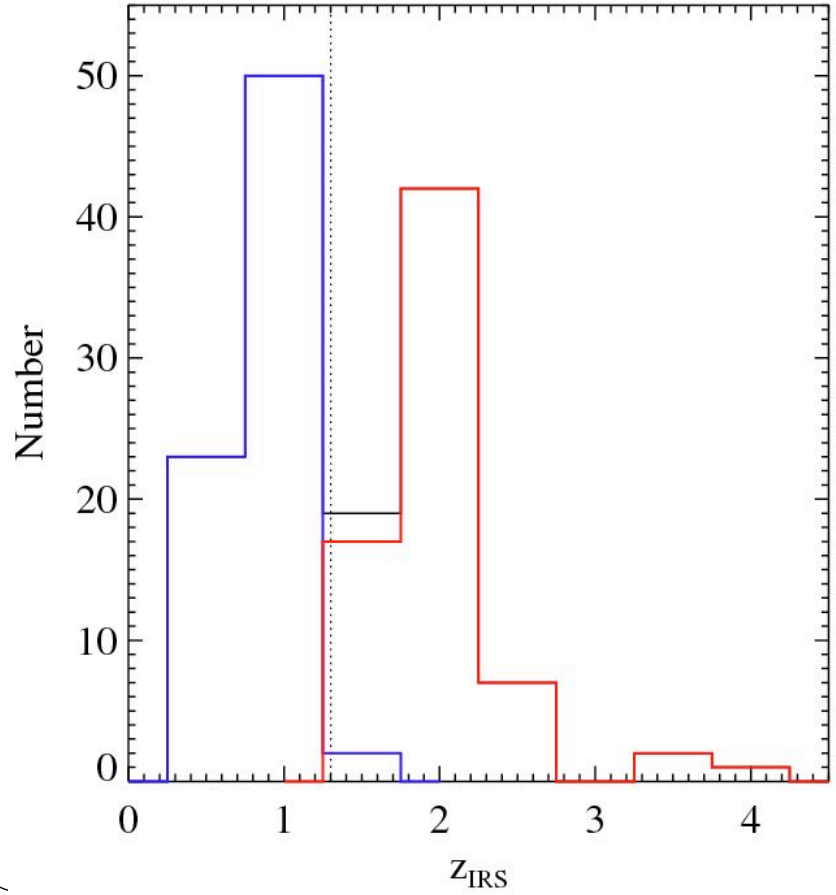
- **Accurate L_{IR} and SFR for individual galaxies**
- **Dust properties: T_{dust}, β, M_{dust}**

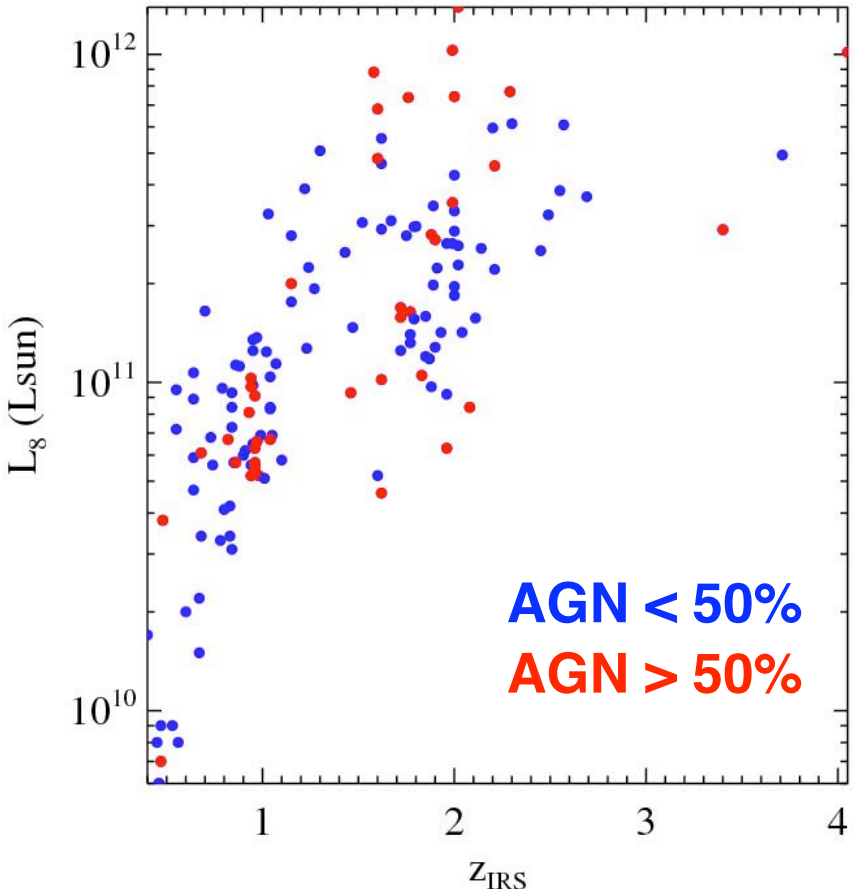




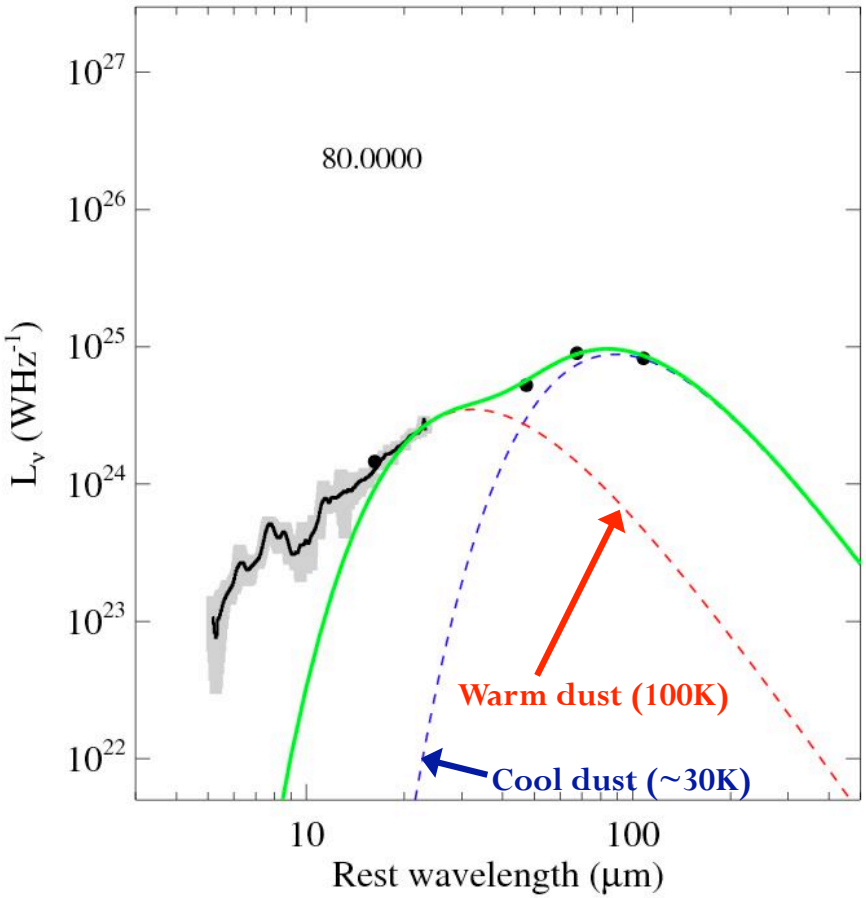
GOODS Extragalactic Mid-IR Spectral Library

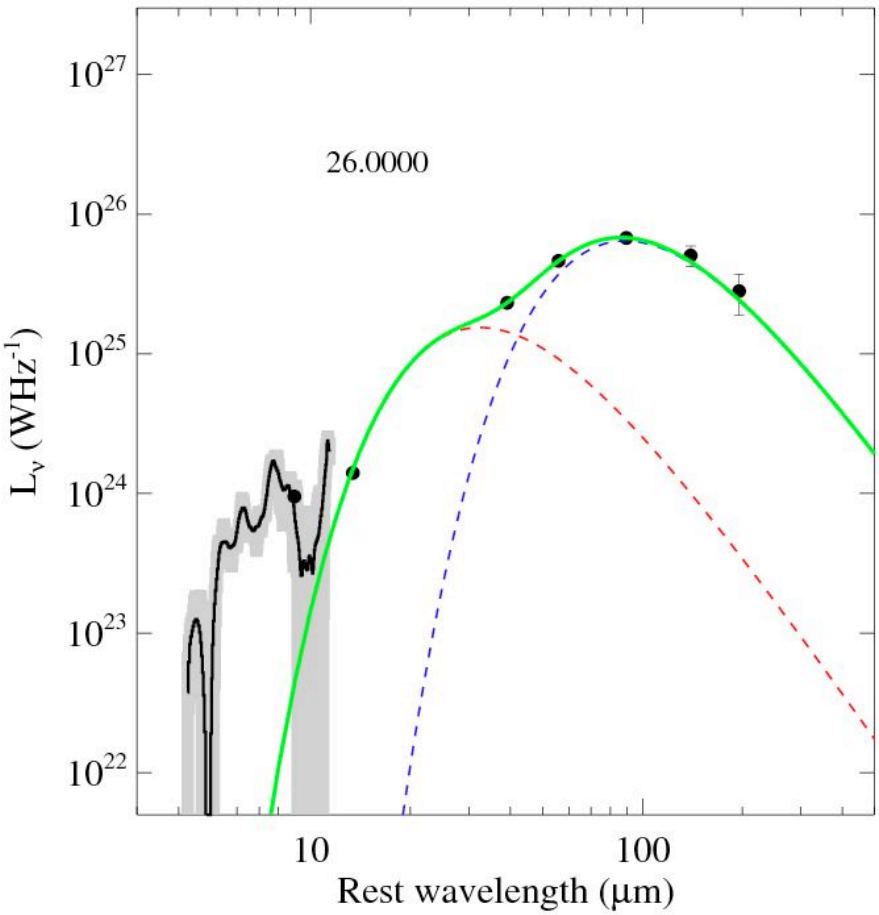
- 150 sources in GOODS-N and ECDFS observed with *Spitzer*/IRS
- All data reduced and lines measured in a uniform way
- Spectral decomposition to get AGN fraction, L_{PAH}, L_8, etc.



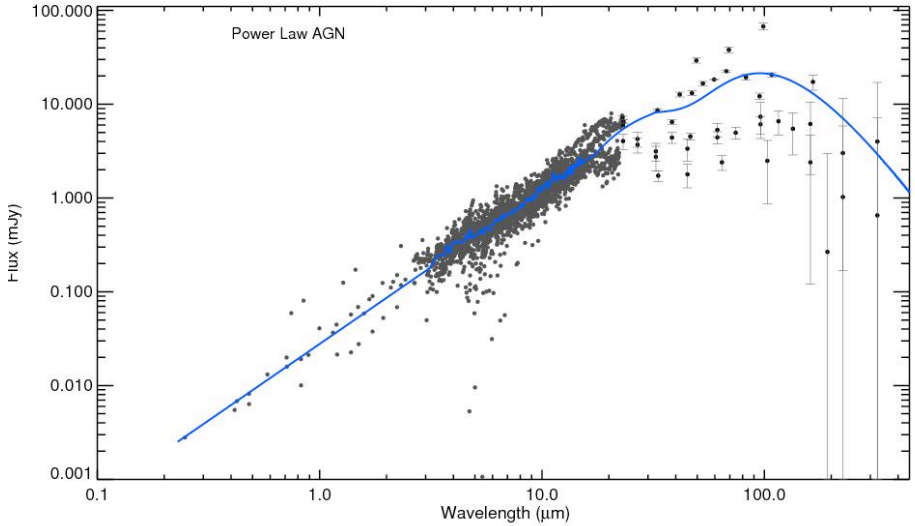


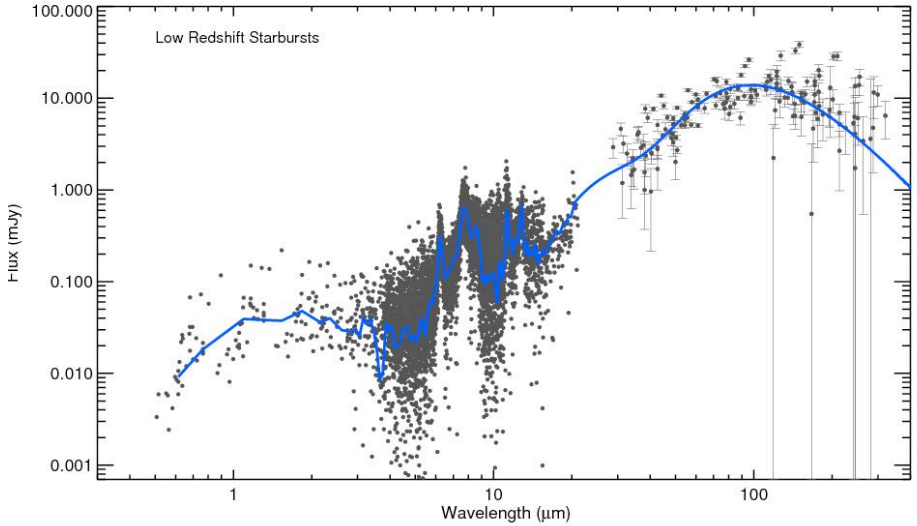
SED fitting with *Spitzer*/IRS + *Herschel*

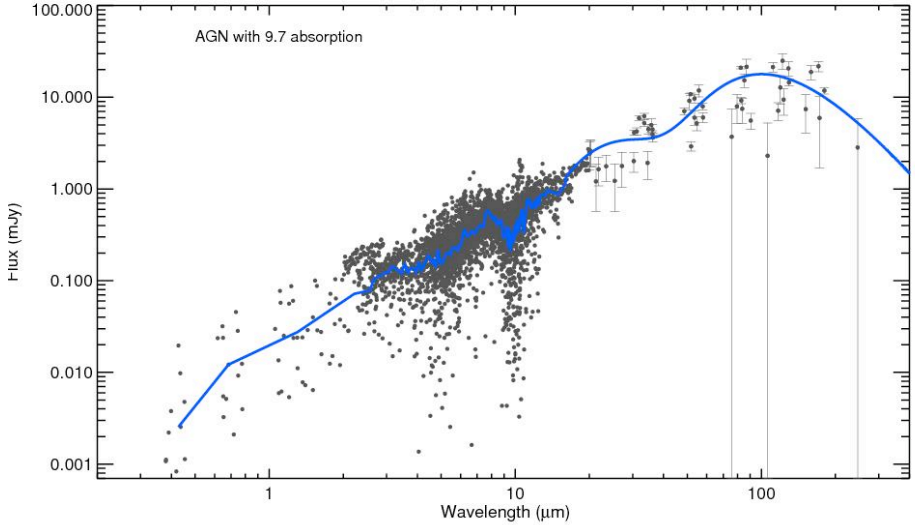


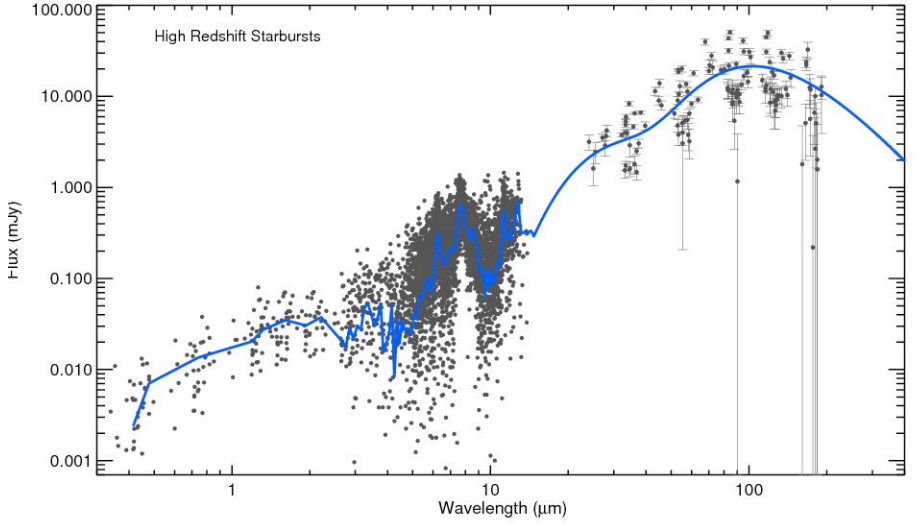


Composite SEDs



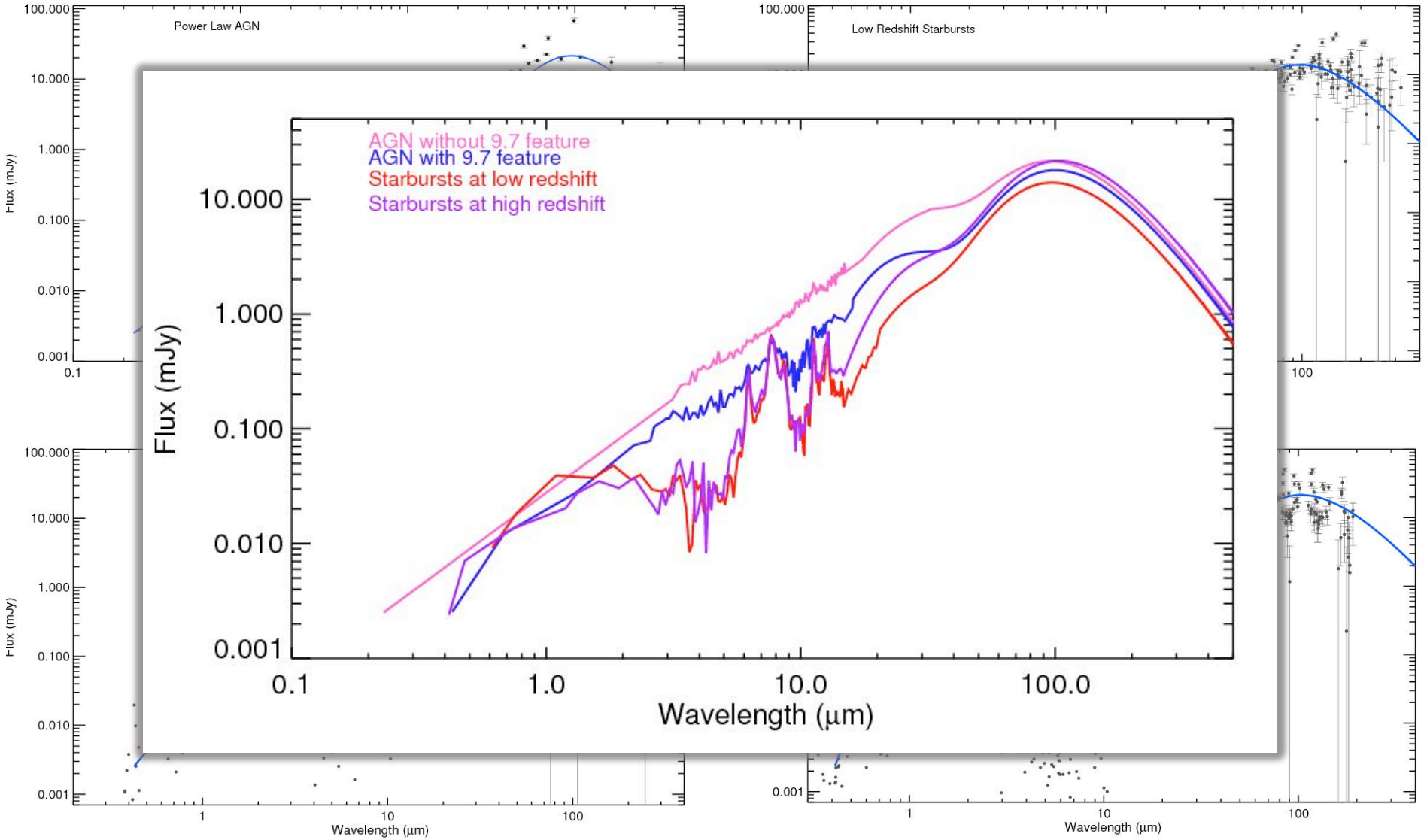






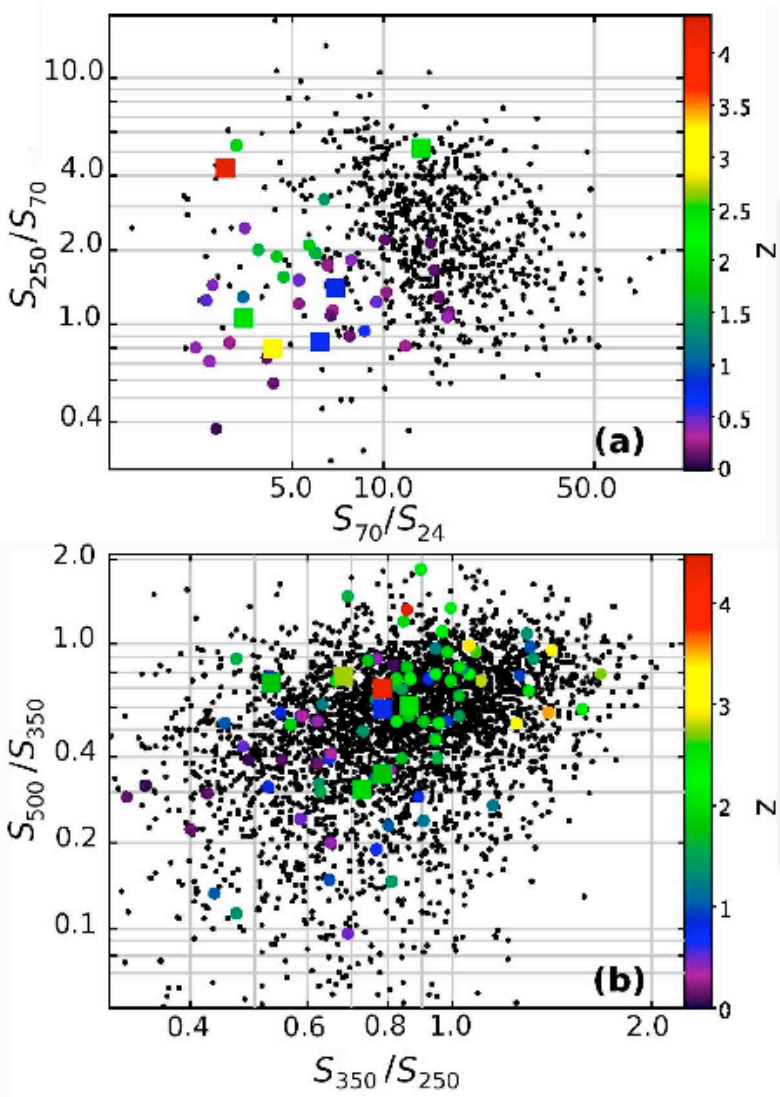
Kirkpatrick et al. in prep

Composite SEDs

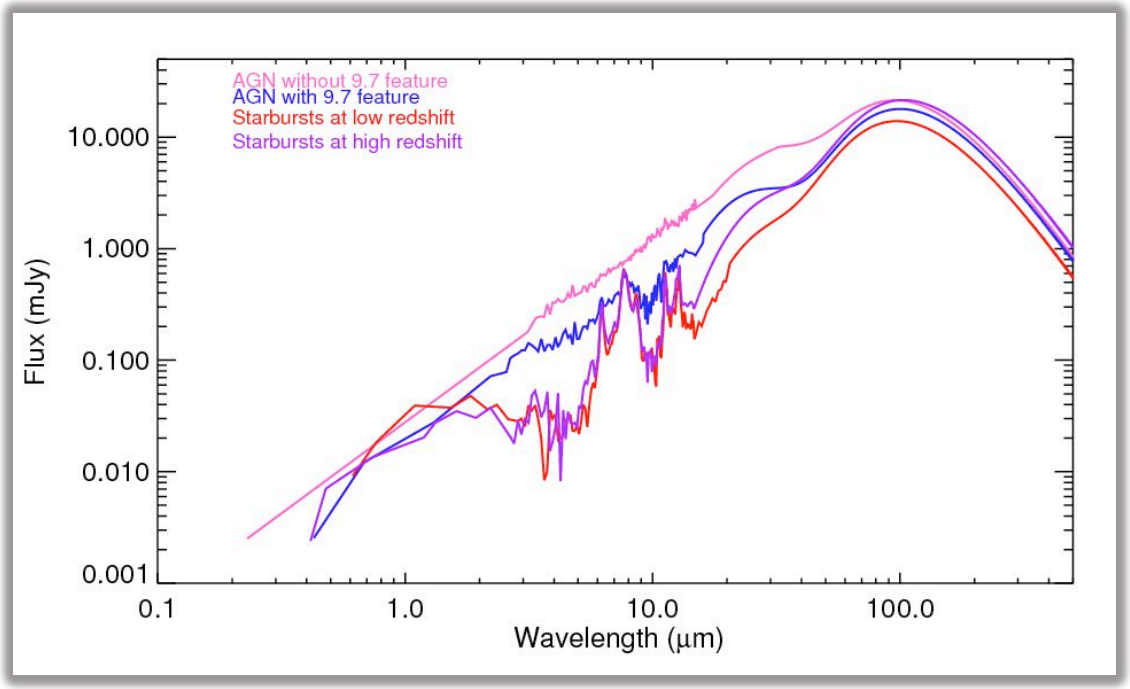


Kirkpatrick et al. in prep

Influence of the AGN on IR colors



Hatziminaoglou al. 2010



Kirkpatrick et al. in prep

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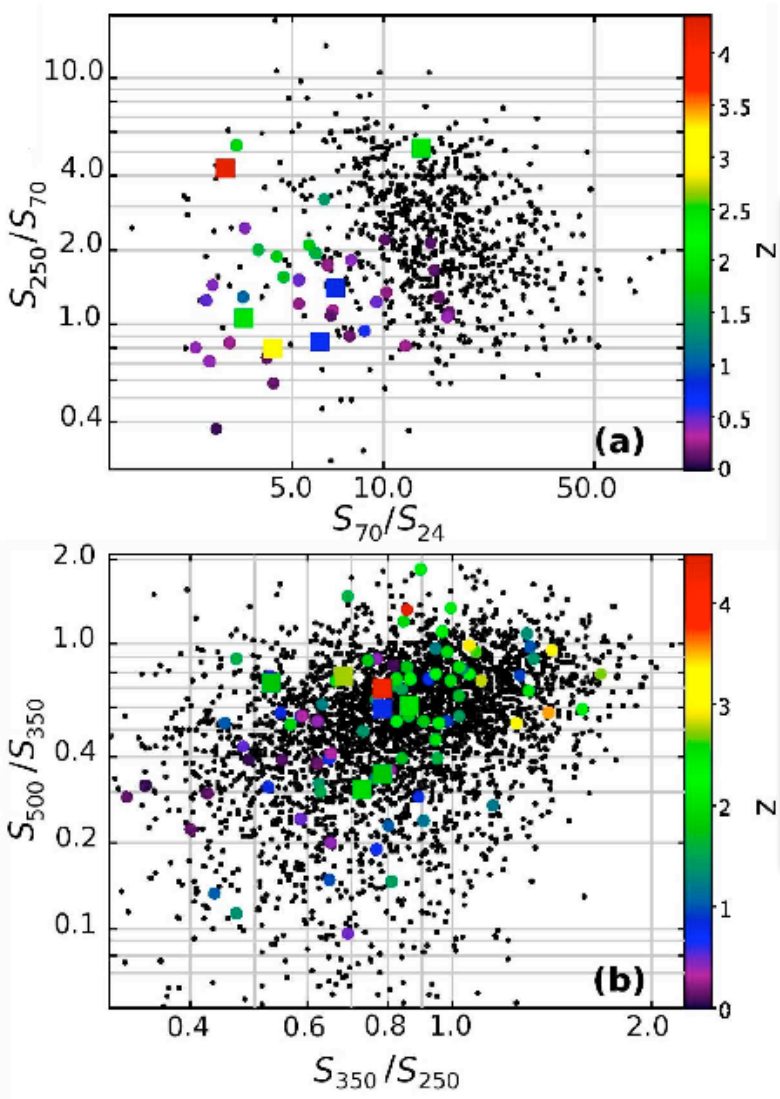
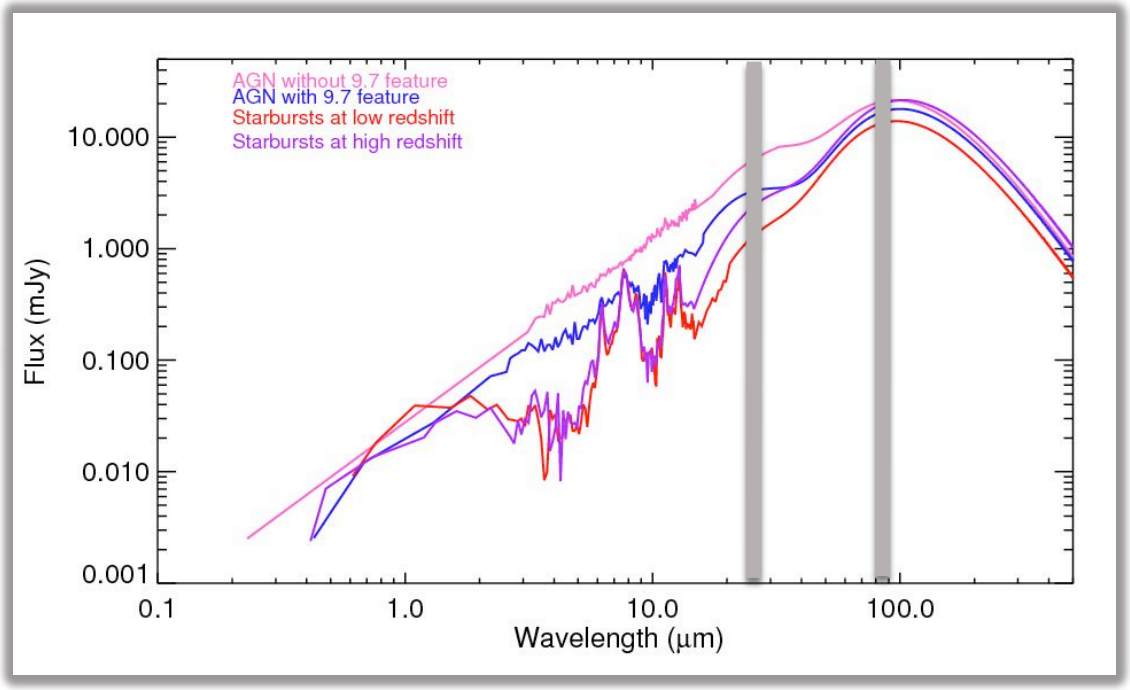
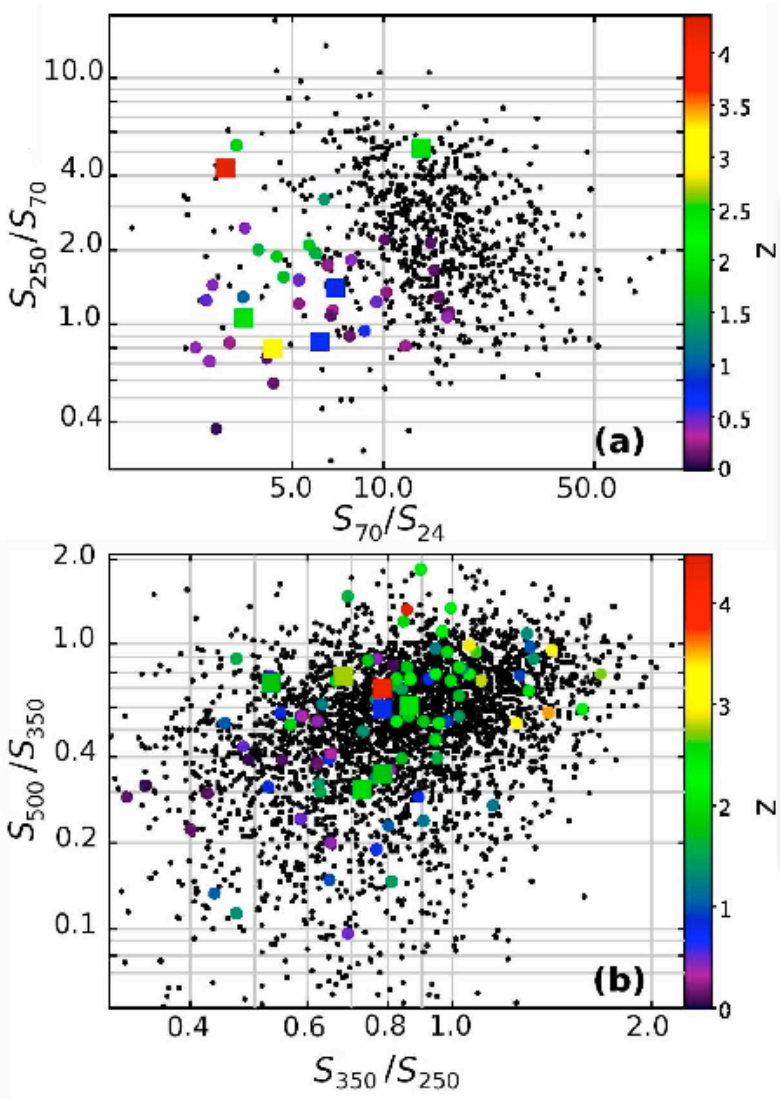


Hatziminaoglou al. 2010

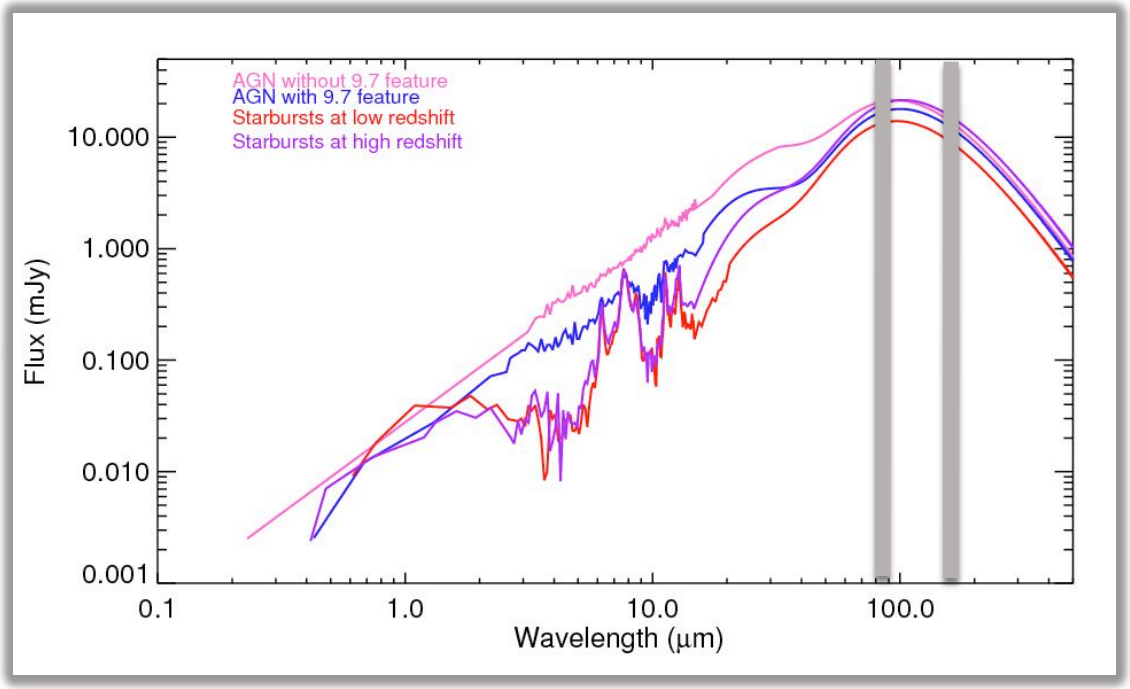


Kirkpatrick et al. in prep

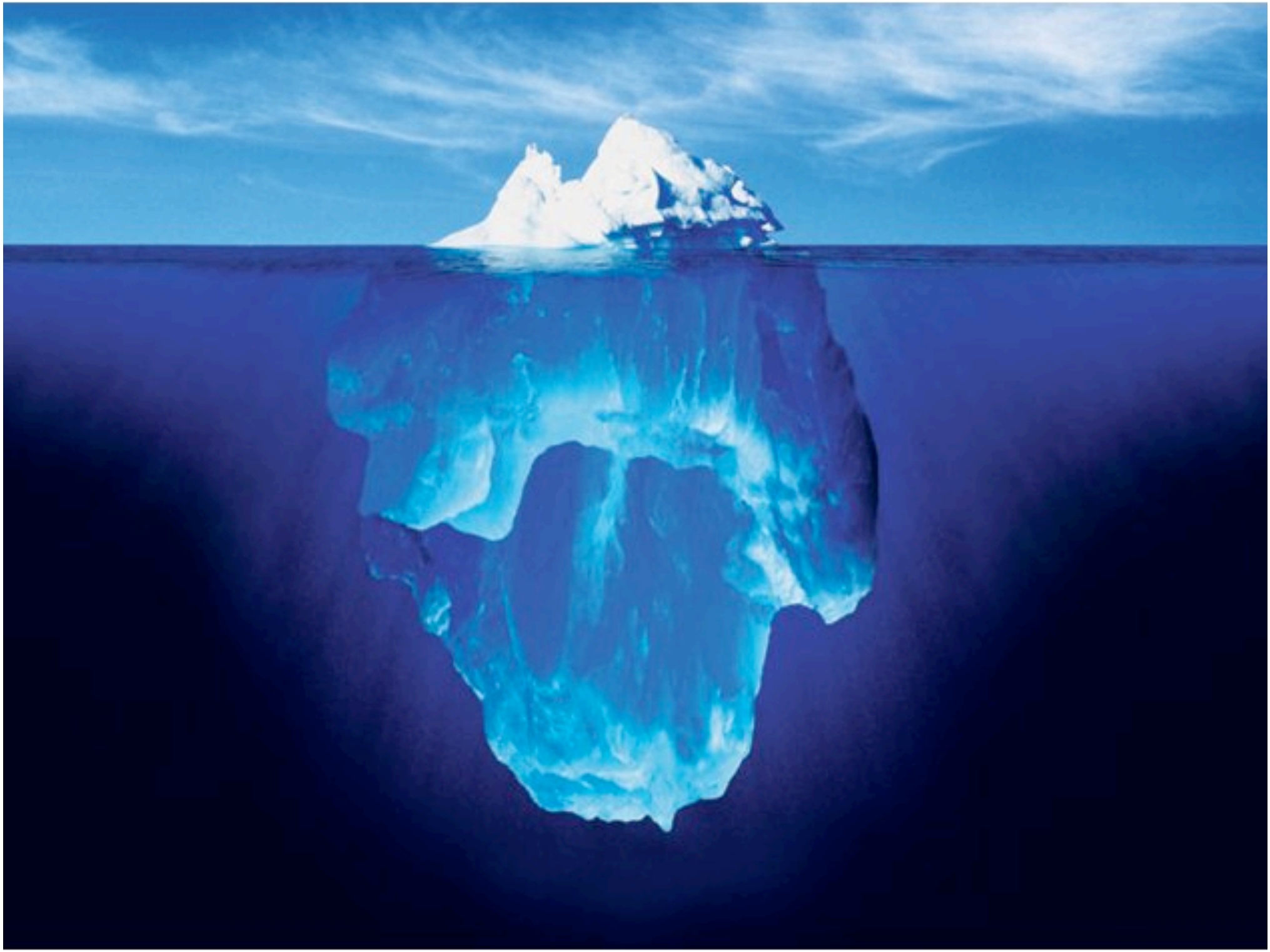
Influence of the AGN on IR colors

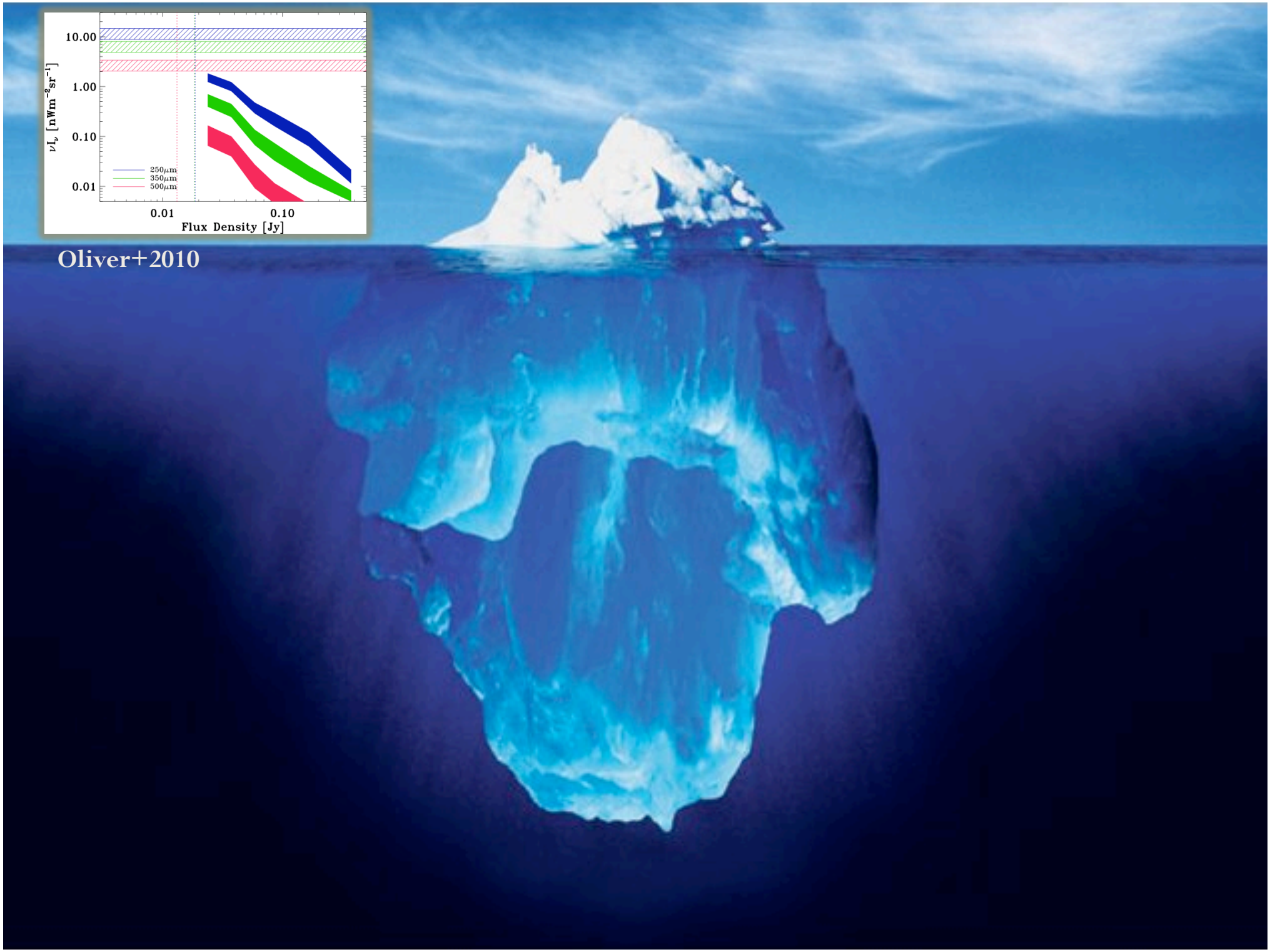


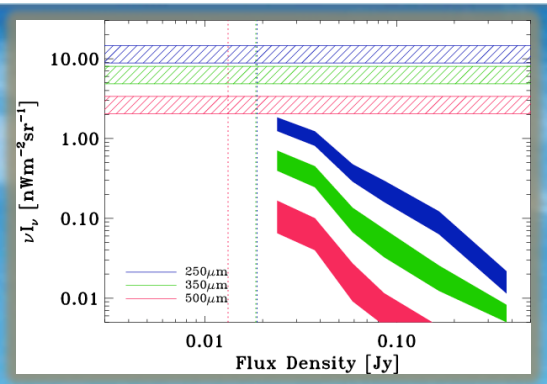
Hatziminaoglou al. 2010



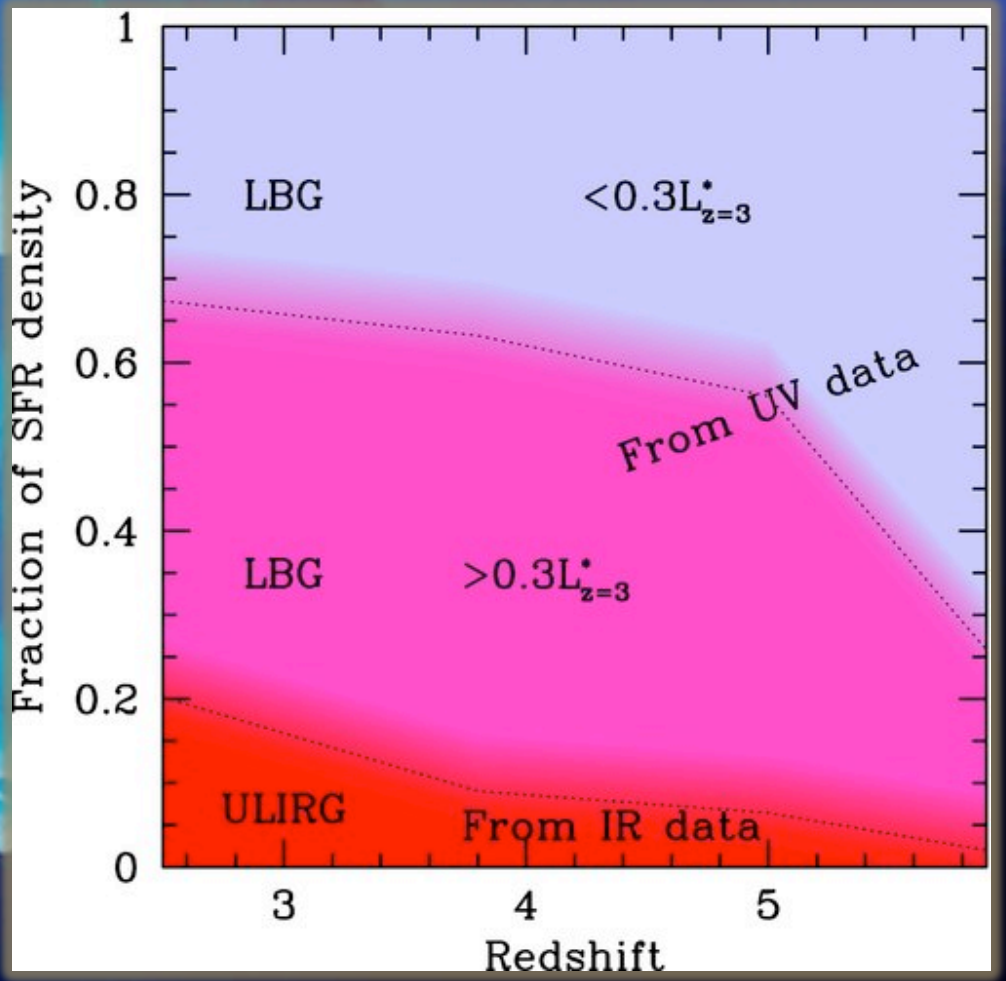
Kirkpatrick et al. in prep



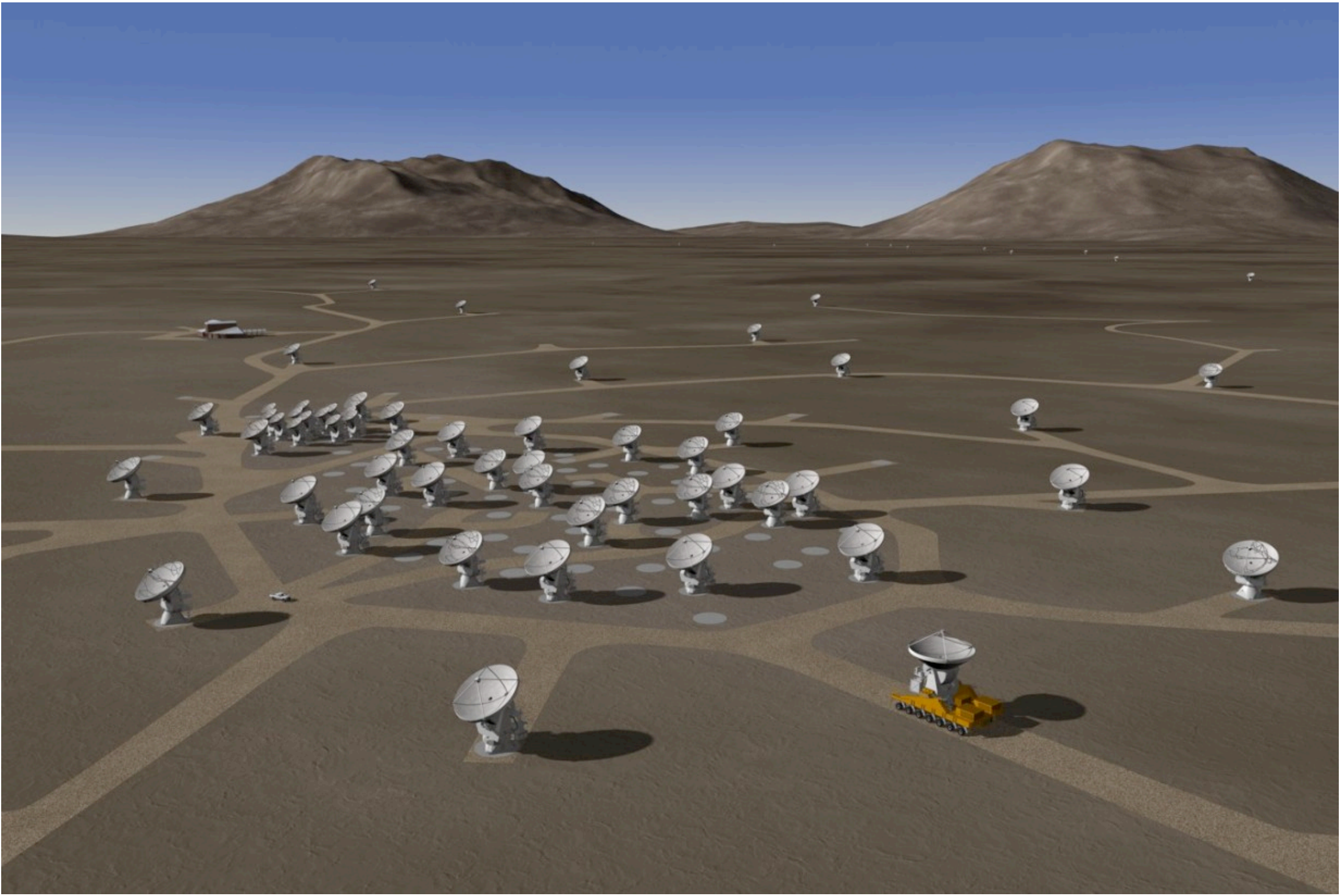

10.00
1.00
0.10
0.01
νI_ν [nWm^{-2}sr^{-1}]
250μm
350μm
500μm
0.01
0.10
Flux Density [Jy]
Oliver+2010



Oliver+2010



Bouwens+2009



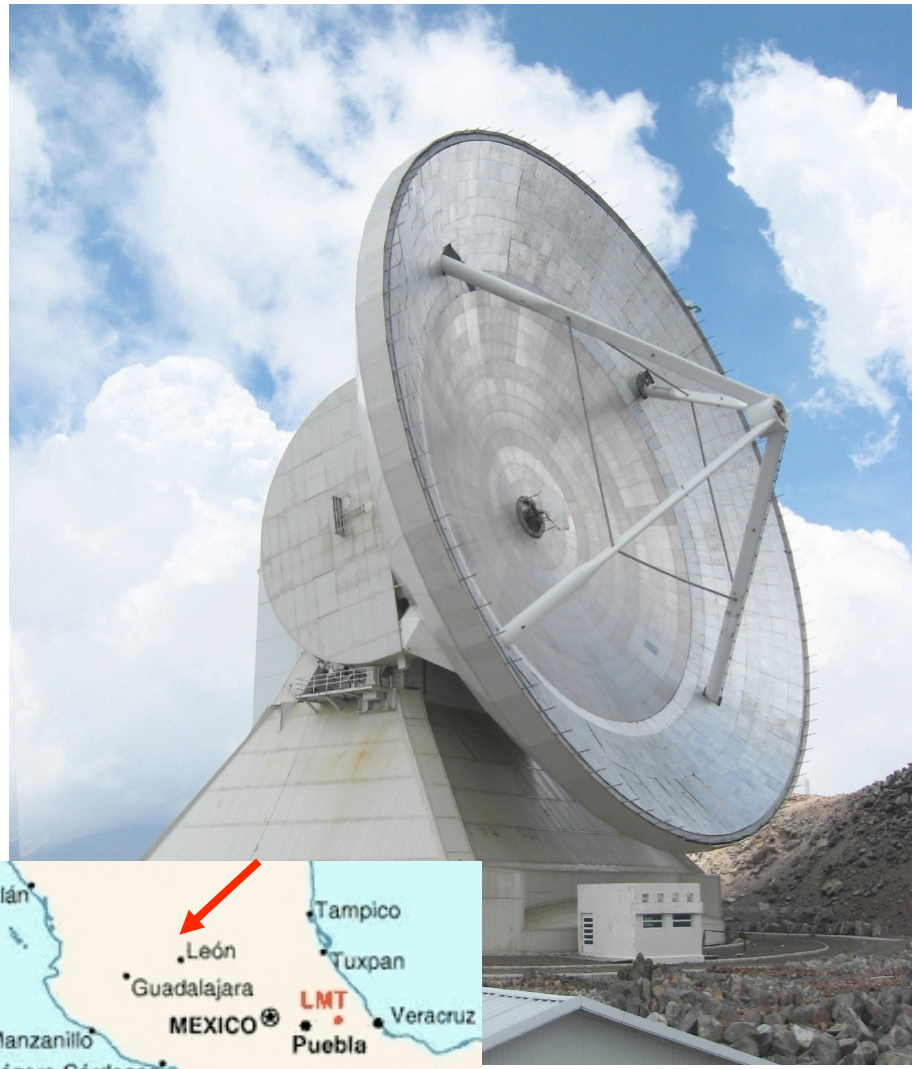
Large Millimeter Telescope (LMT)

- 50m Antenna
  - Operation: 4mm-0.85mm
  - Active Primary Surface

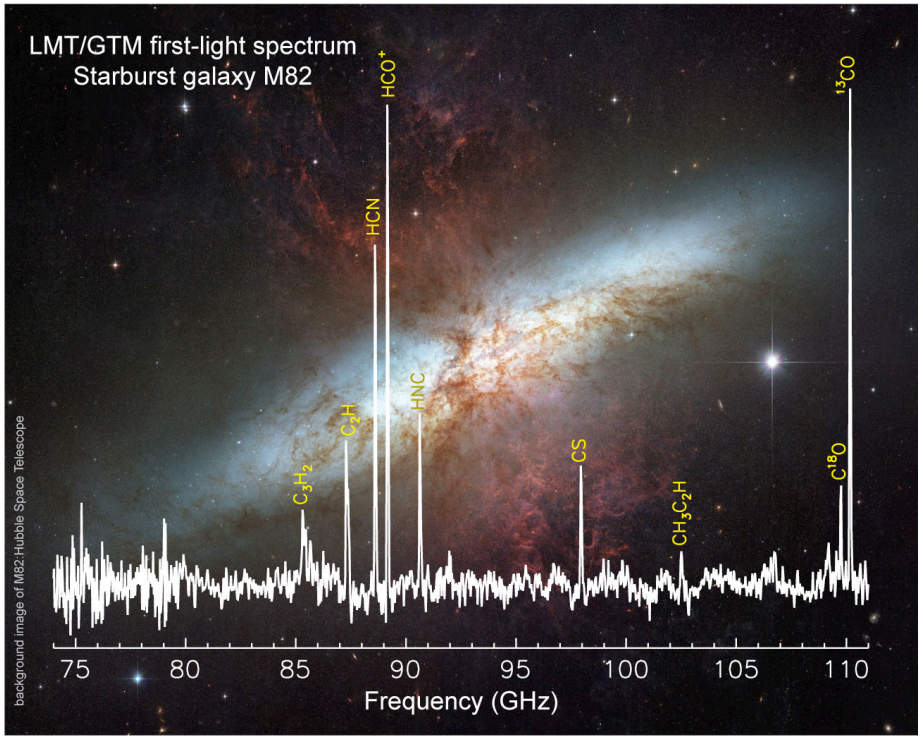
    75 microns rms.
- Located in Mexico
  - Excellent mm-wave site
  - High Altitude (15,000 ft)
  - +19 deg. Latitude
- State-of-the-art instrumentation:

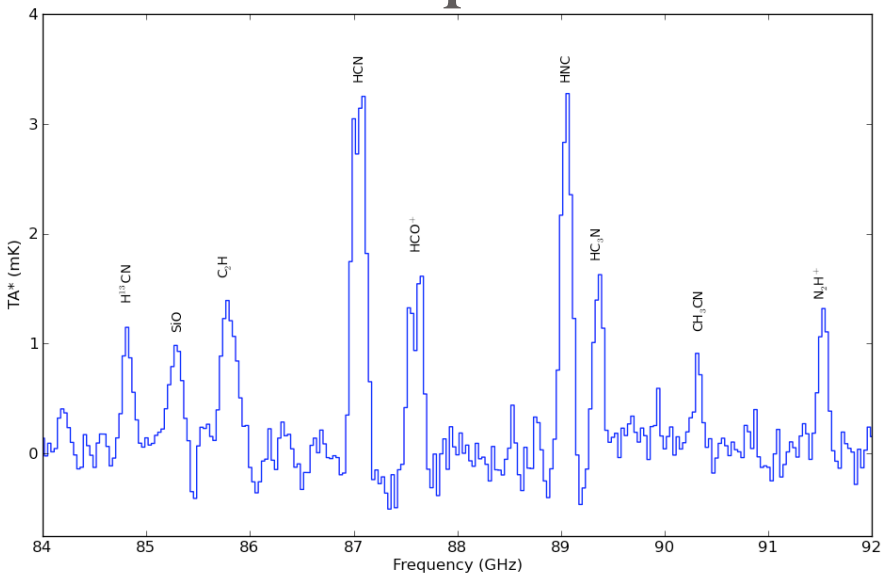
  AzTEC 1.1mm camera

  Redshift Search Receiver (RSR)

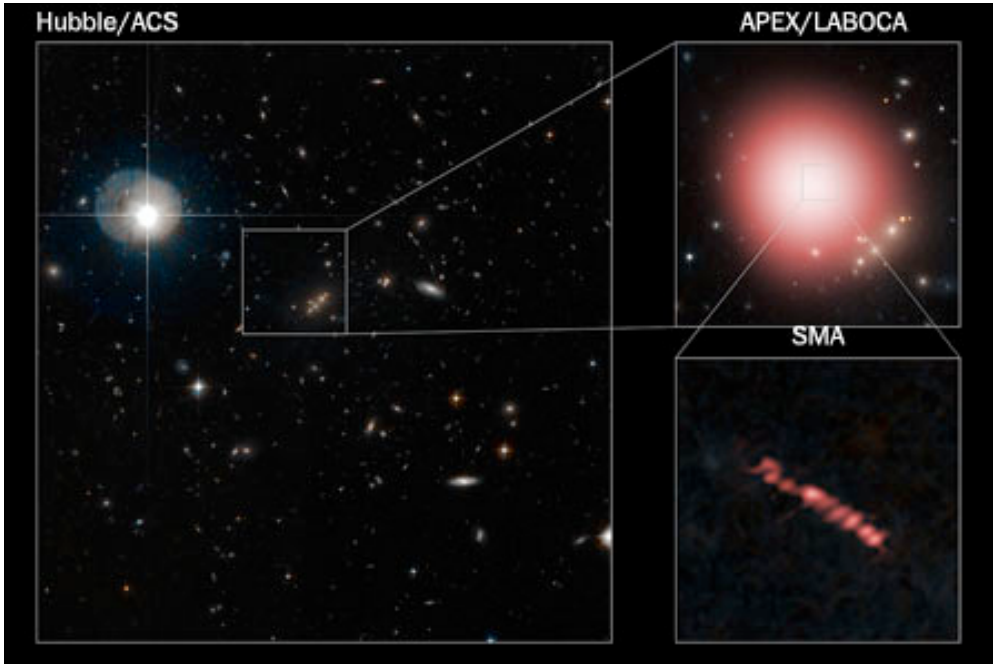


LMT First Light with RSR!

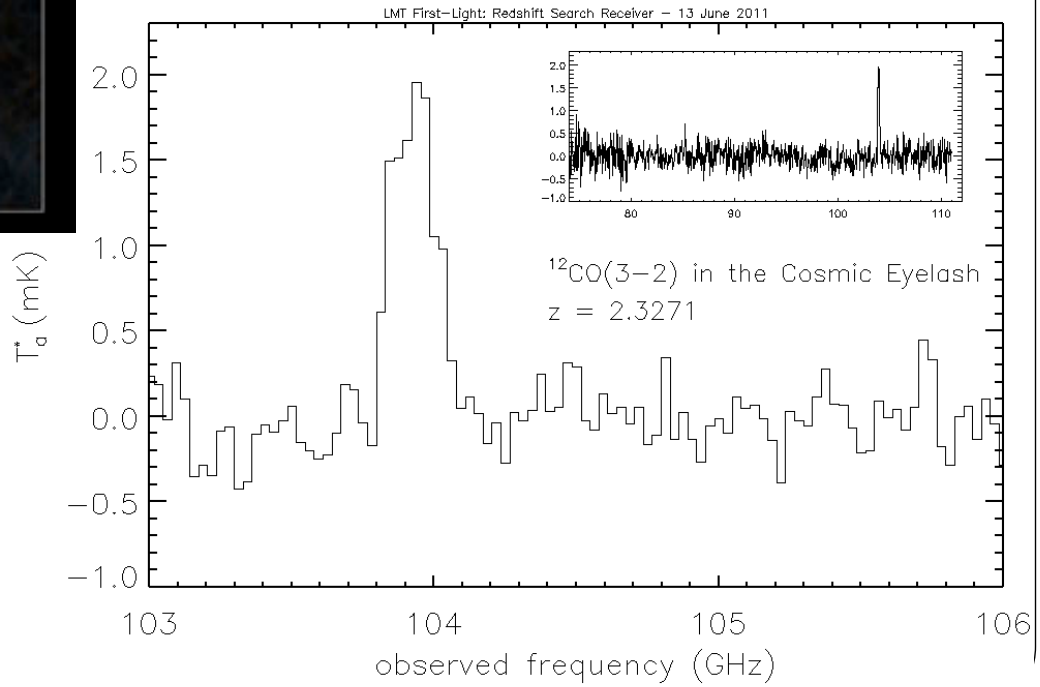




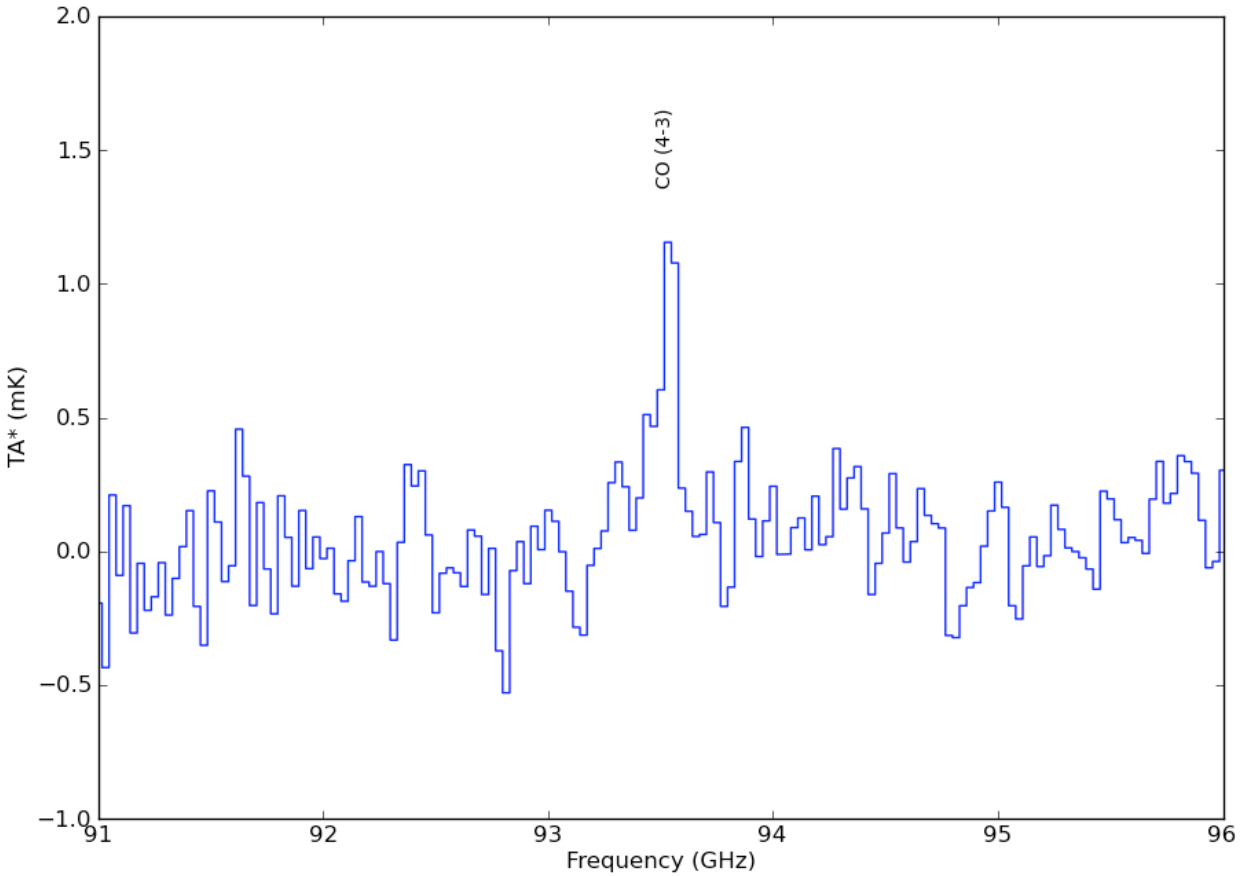
LMT First Light with RSR!



Swinbank+2010



LMT First Light with RSR!



z=3.930 SMG MMJ18423+5938

AzTEC in the LMT Receiver Cabin

Summary

- Strong PAH emission is much more prevalent at high redshift compared to locally – different physical conditions/mechanisms for star formation
- We see a PAH deficit similar to [CII] (also tracing PDRs) – high and low redshift galaxies are unified in this trend when we consider the molecular gas supply
- Uniformity in SEDs at z=1-2 in that AGN fraction does not appear to strongly affect the average dust temperature – Host galaxy dominates the submm light or more extended dust
- ALMA+large single dish submm telescopes will allow us to push studies of dust down to typical L^* galaxies that are dominating the SFRD