Understanding Dust Obscured Activity in High Redshift Galaxies

Alexandra Pope (UMass Amherst)

FIR Surveyor Workshop - June 3, 2015

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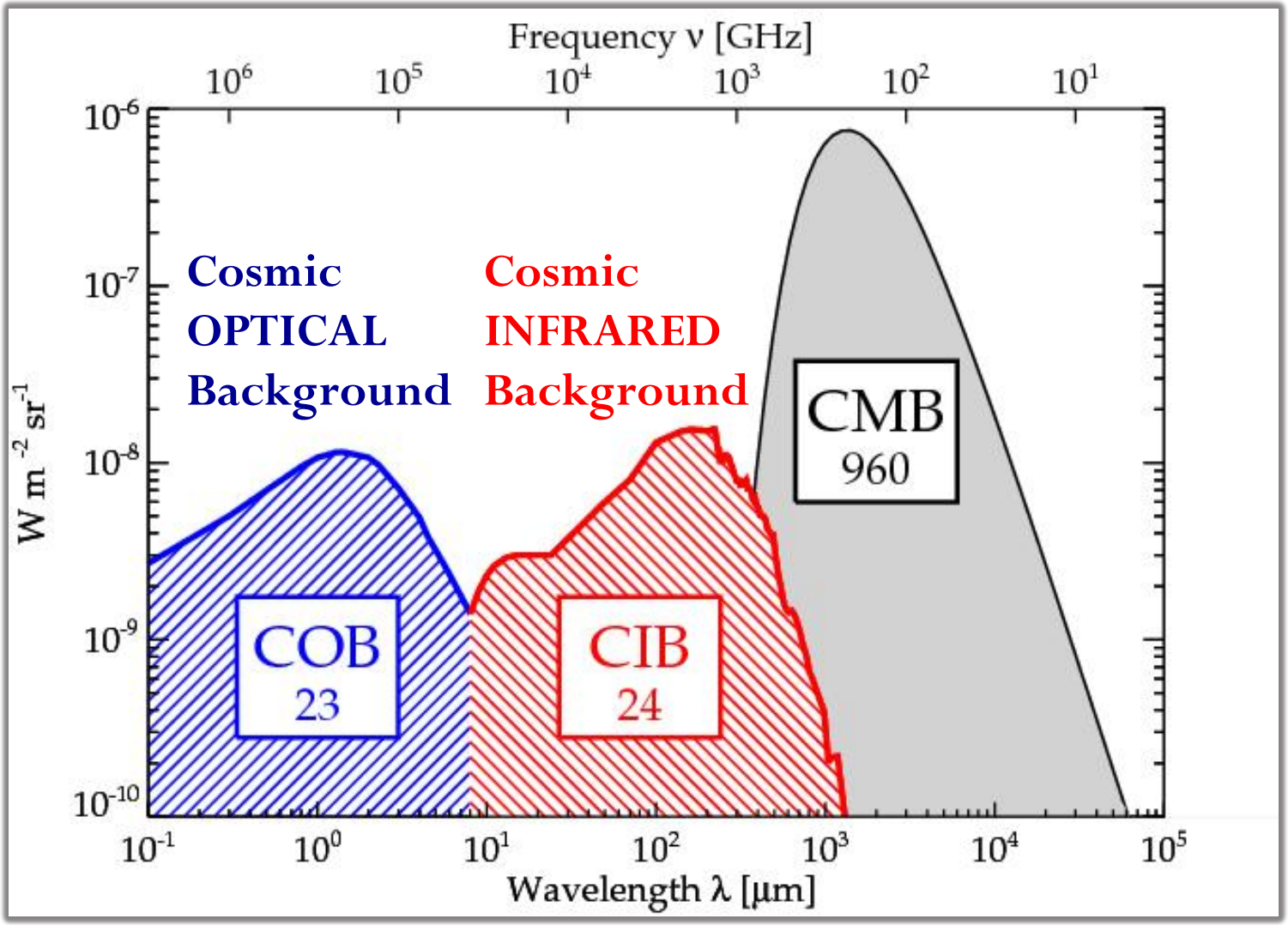
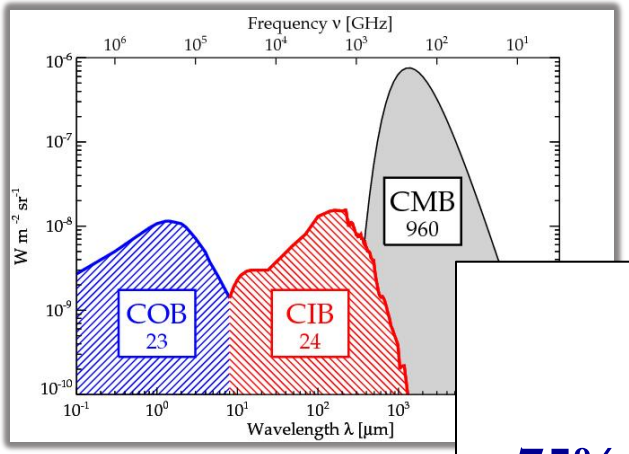
Much of galaxy formation and evolution occurs behind dust



Dole et al. 2006

Much of galaxy formation and evolution occurs behind dust



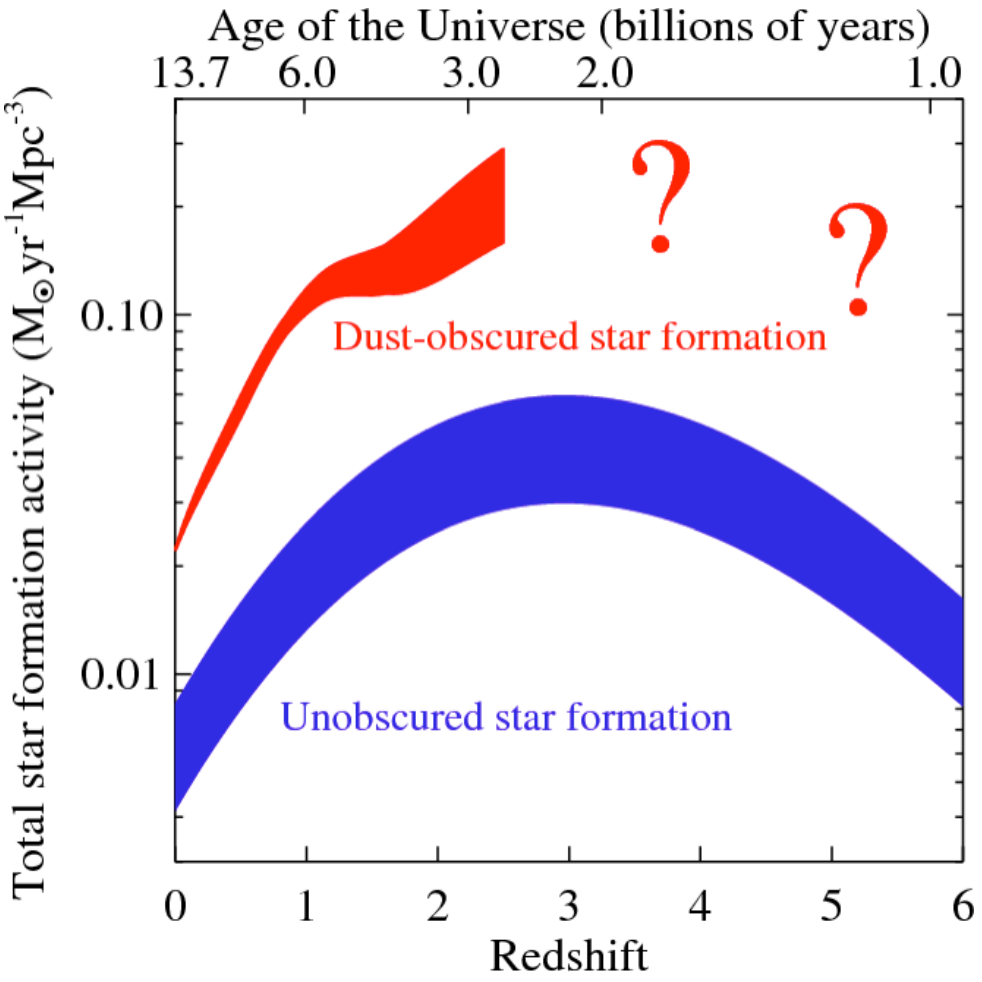
Herschel Space Observatory:

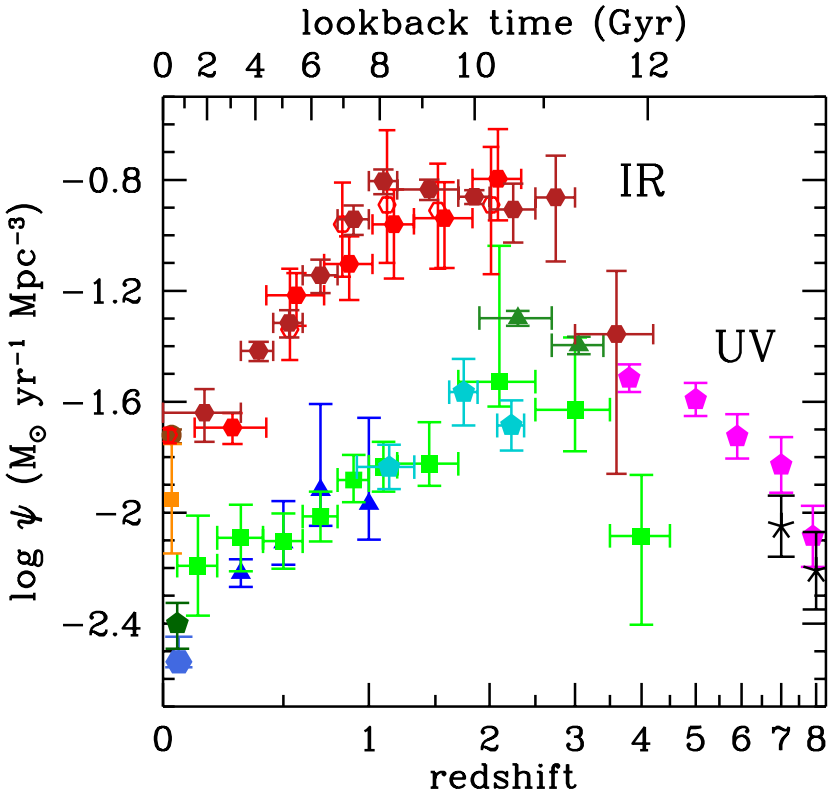
~75% of the CIB at 100 μ m and 160 μ m is resolved by individually detected sources (Magnelli+2013)

80-100% of CIB at 250 μ m is resolved from stacking 24 μ m and *K*-band selected galaxies (Bethermin+2013; Viero+2013)

RESOLVING THE CIB IS NO LONGER THE MOST PRESSING QUESTION

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





Madau & Dickinson 2014

Using data from **Bouwens+2009** and **Murphy+2011**

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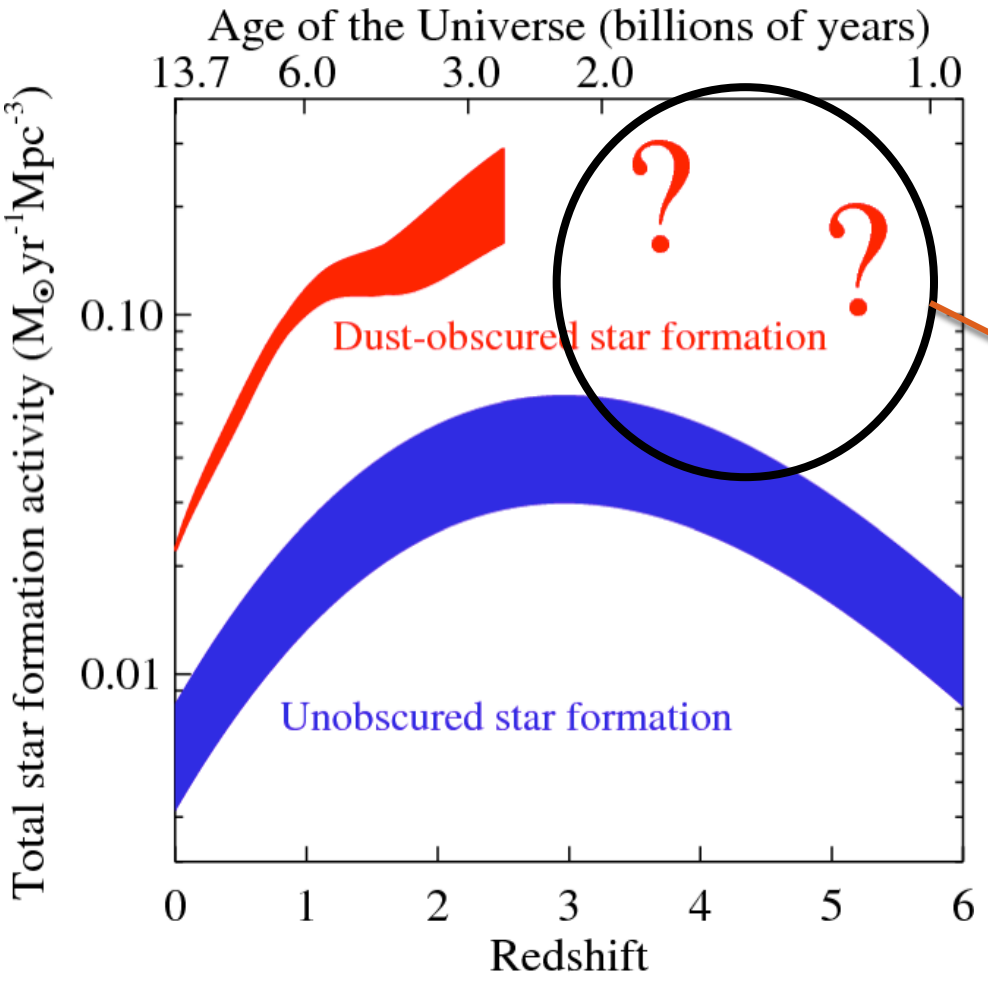
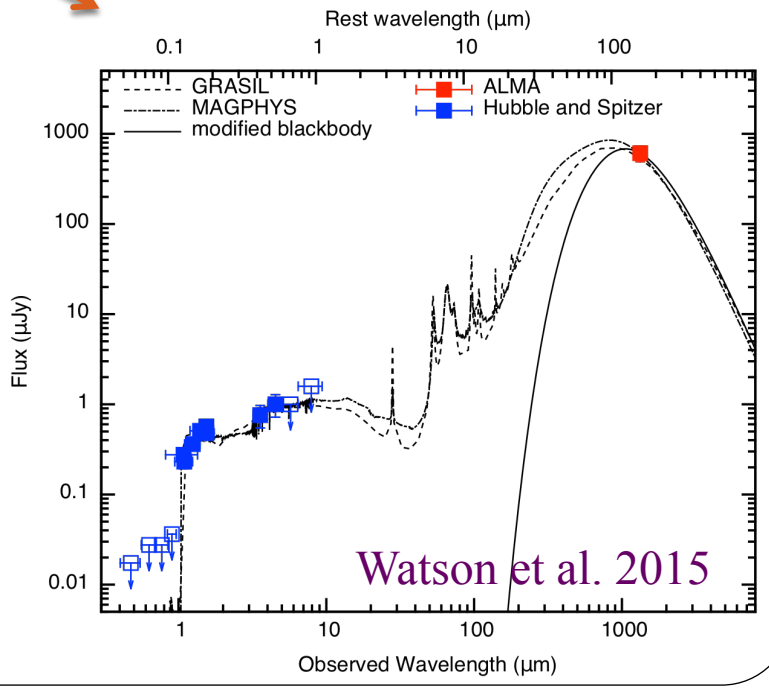
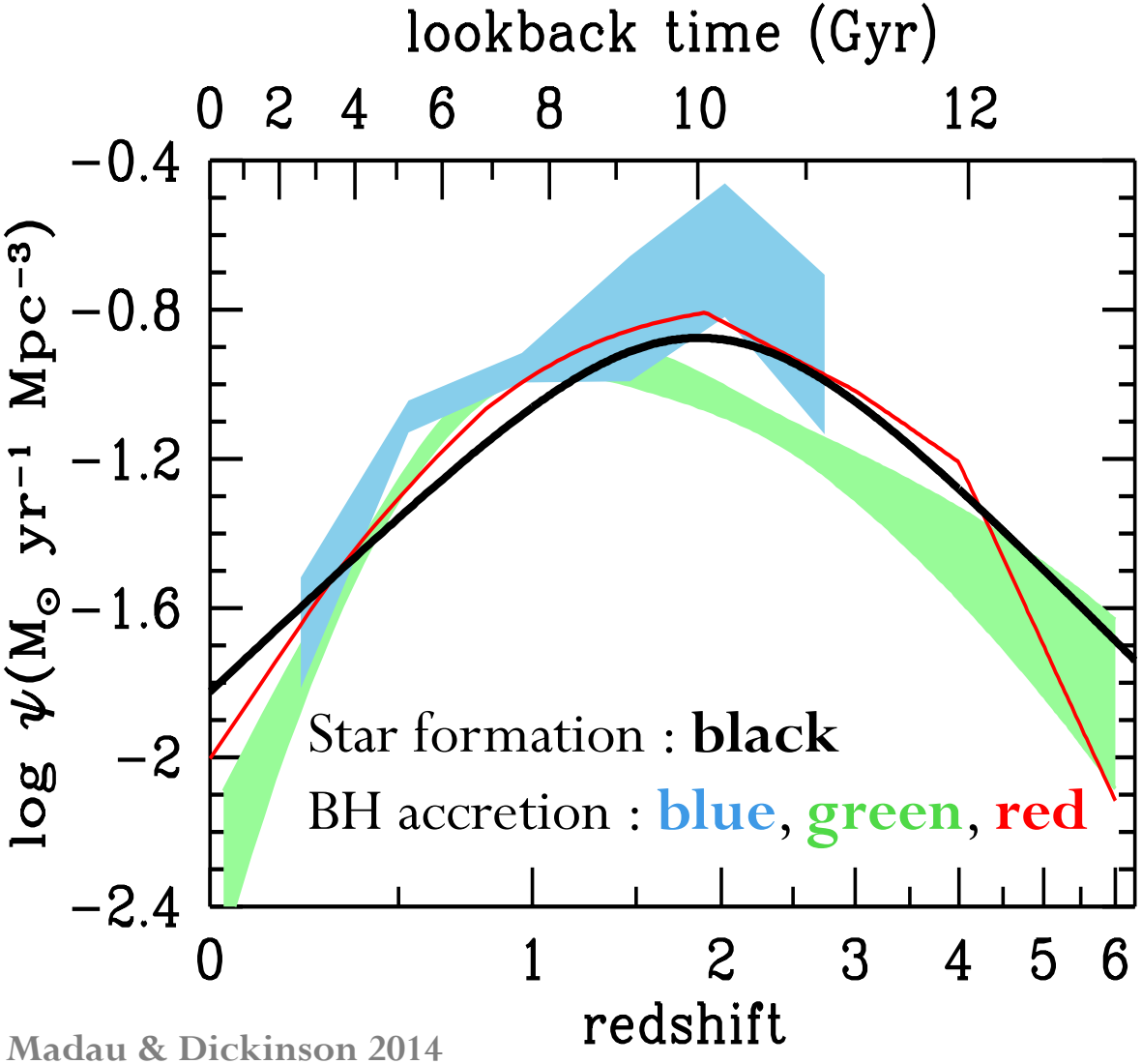


Using data from **Bouwens+2009** and **Murphy+2011**

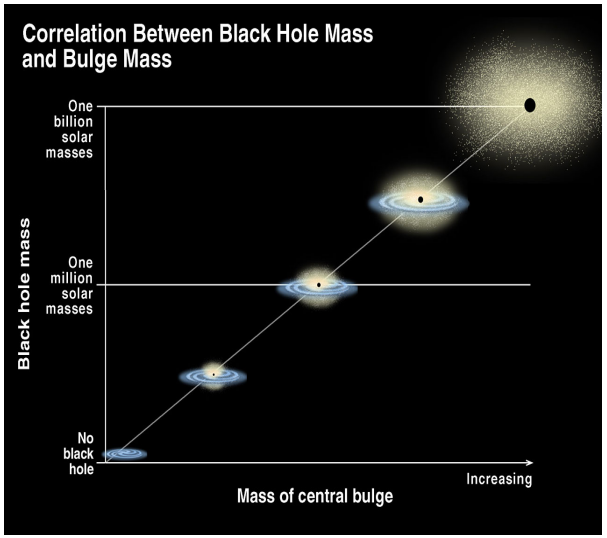
A dusty galaxy at z~7.5!
SFR~10Msun/yr



Dust-obscured activity dominates the build-up of stars **and black holes** in galaxies



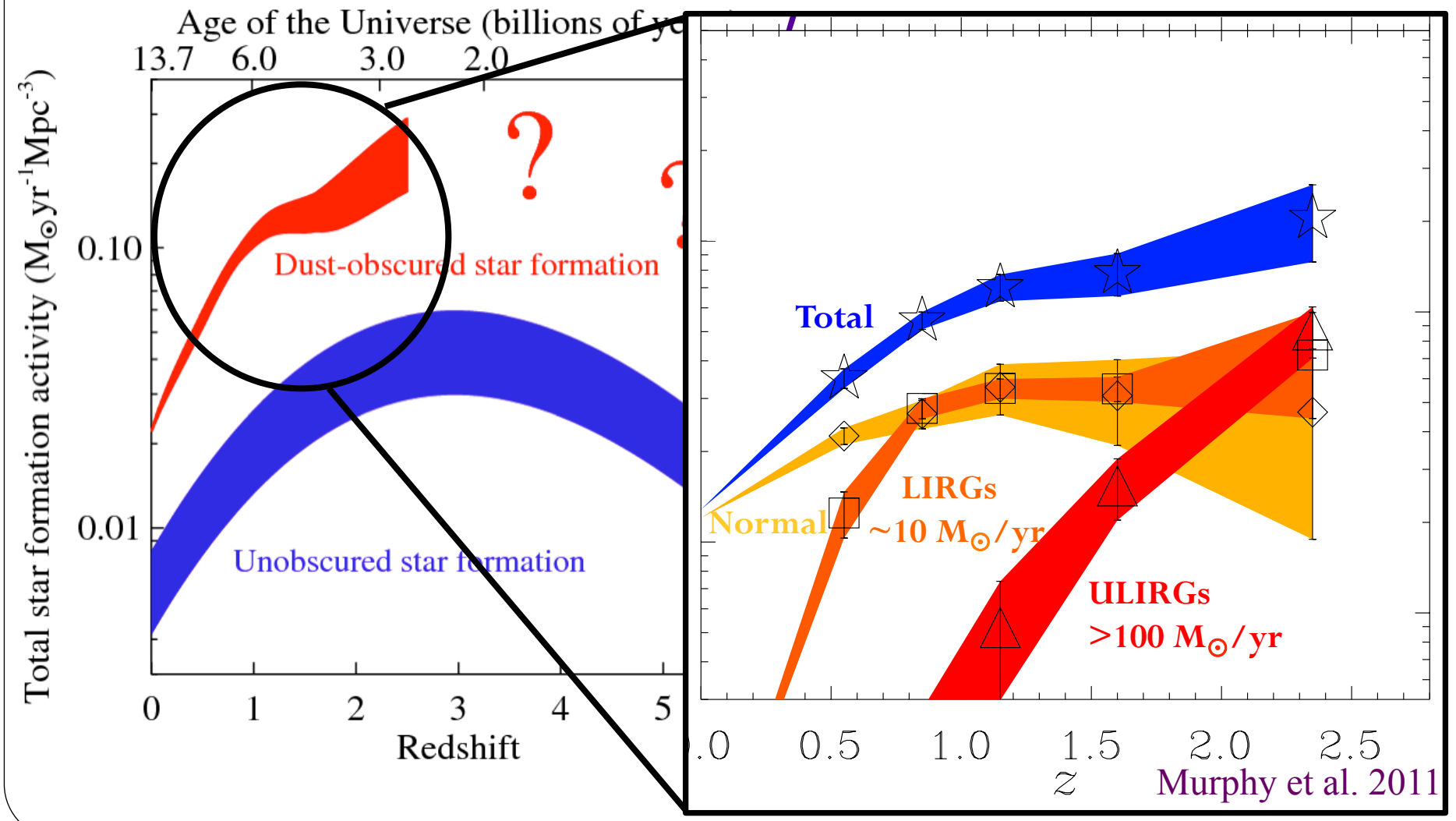
Madau & Dickinson 2014



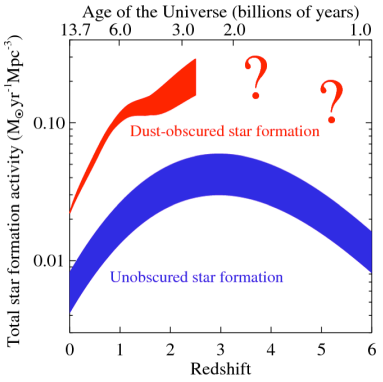
Credit: K. Cordes, S. Brown (STScI)

Most of the z~1-3 peak stellar mass growth occurs in dusty galaxies:

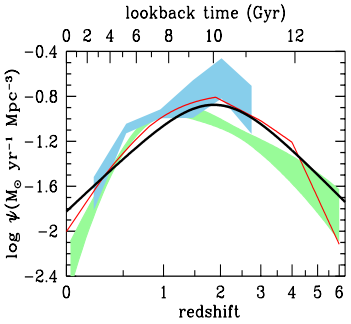
(Ultra) Luminous Infrared Galaxies (LIRGs/ULIRGs)



Dust-Obscured Activity Dominates Galaxy Evolution over Cosmic Time



Outstanding Questions:



- **What drives the cosmic history of star formation?**

  Why is there a peak period at z~2? How is the process/mode of star formation evolving? How is the rise of metals/dust linked to SF? We need to probe the ISM where stars are forming.

- **How is the star formation linked to the black hole growth?**

  We need to identify and separate the emission from each in our observations.

Key science questions that are likely to be relevant in the 2020's which are uniquely addressable with a FIR mission:

- **What drives the cosmic history of star formation?**

  Why is there a peak period at z~2? How is the process/mode of star formation evolving? How is the rise of metals/dust linked to SF? We need to probe the ISM where stars are forming.

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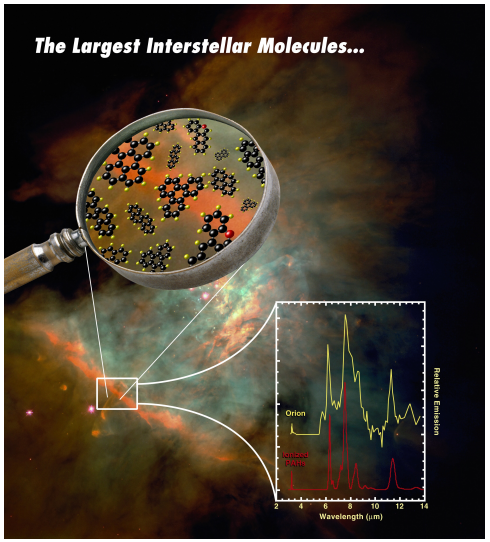
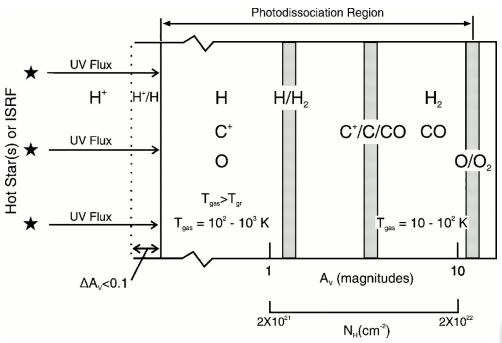
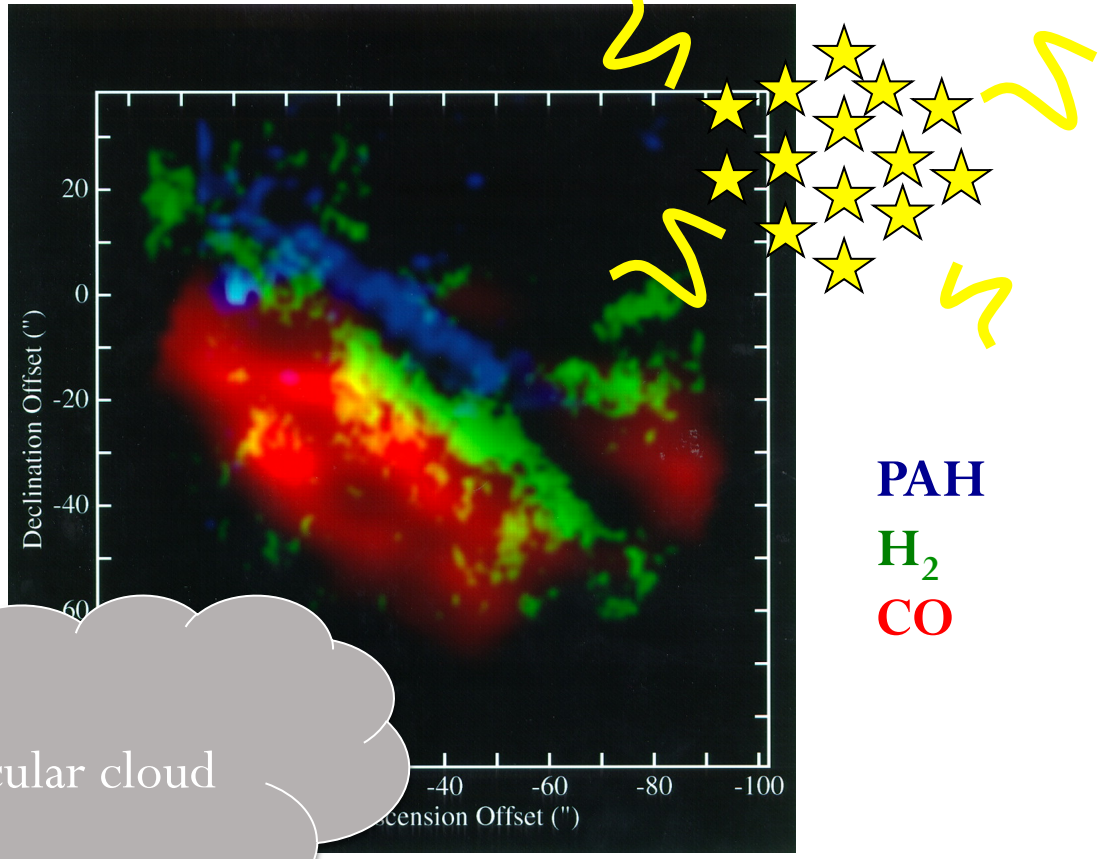
How do we probe the interstellar medium (gas and dust where stars are forming) in high redshift galaxies?







PAH
H_2
CO

Molecular cloud

Hollenbach &Tielens 1997

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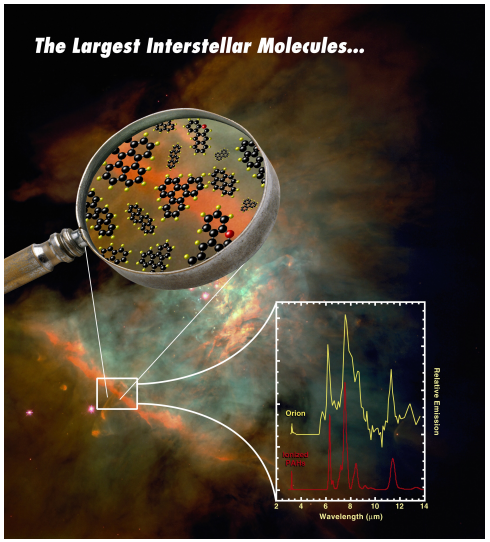
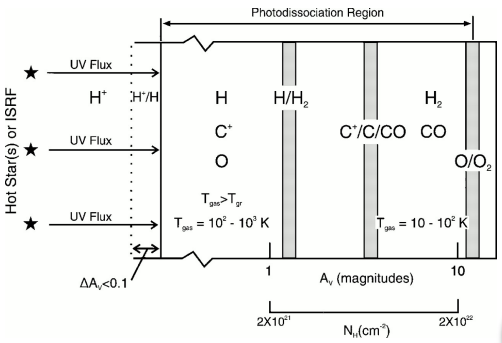
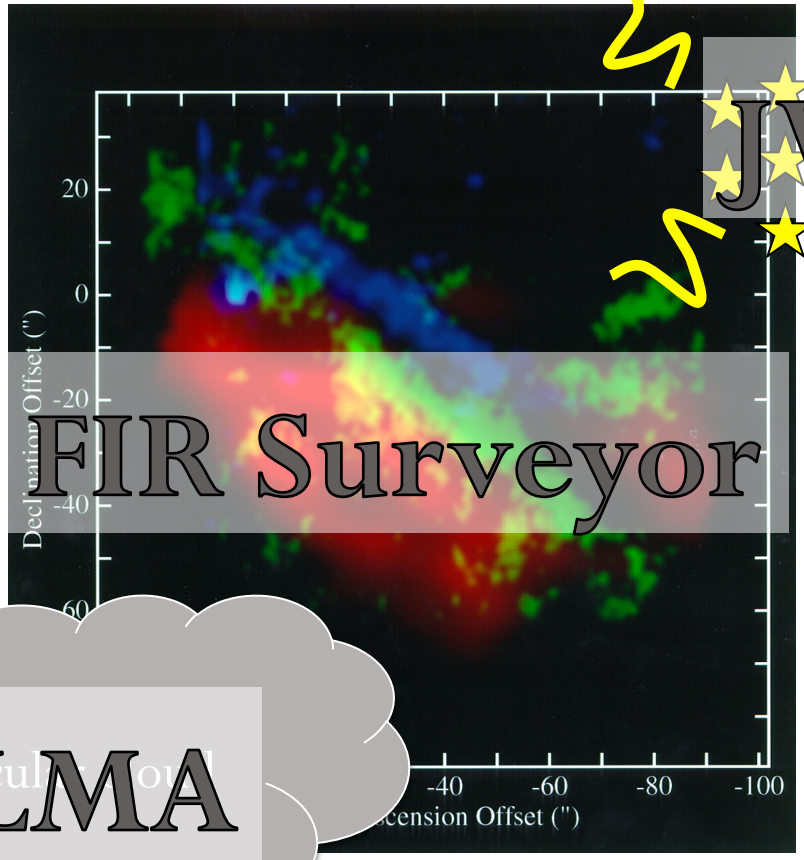






JWST

FIR Surveyor

ALMA

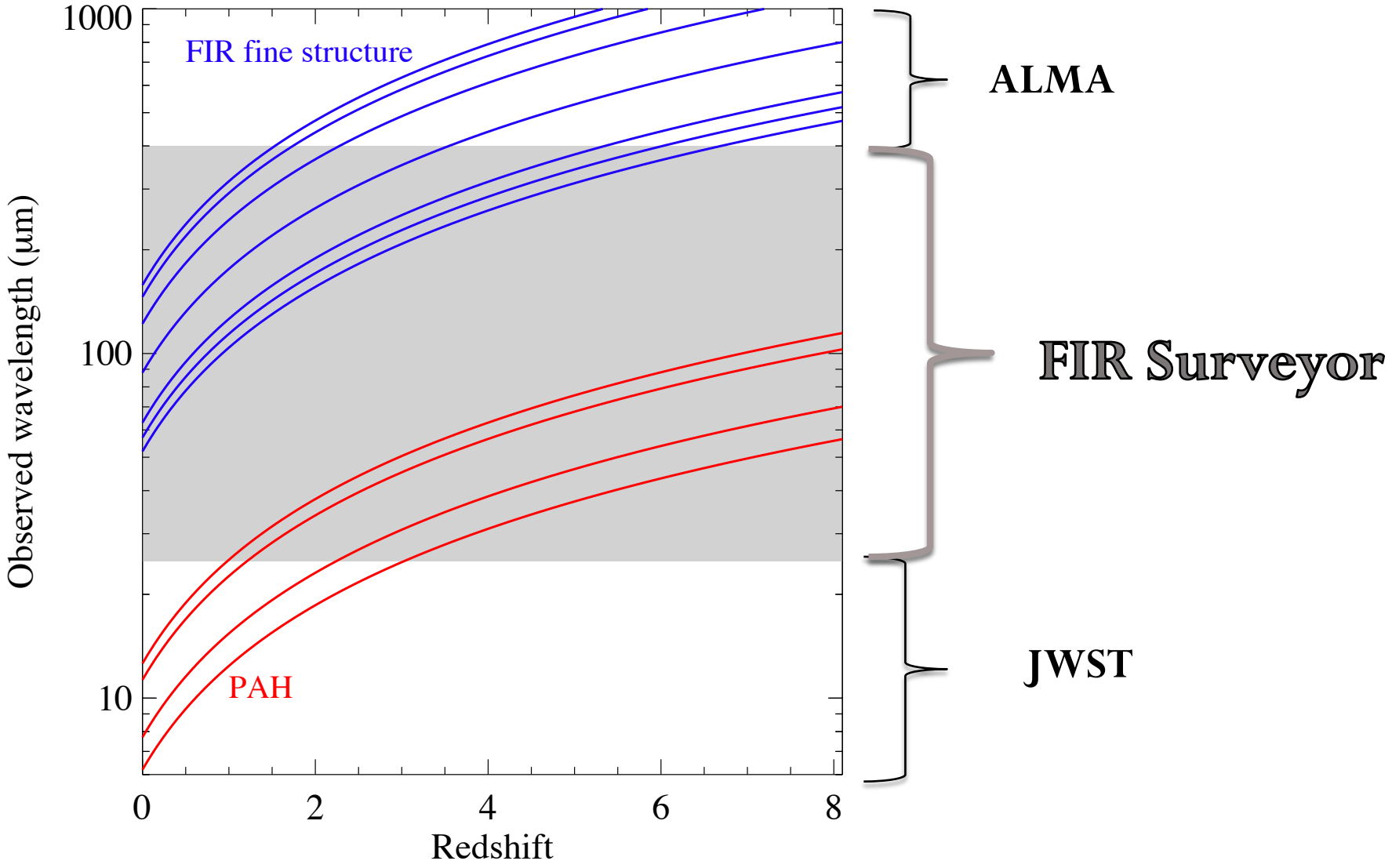
PAH

H_2

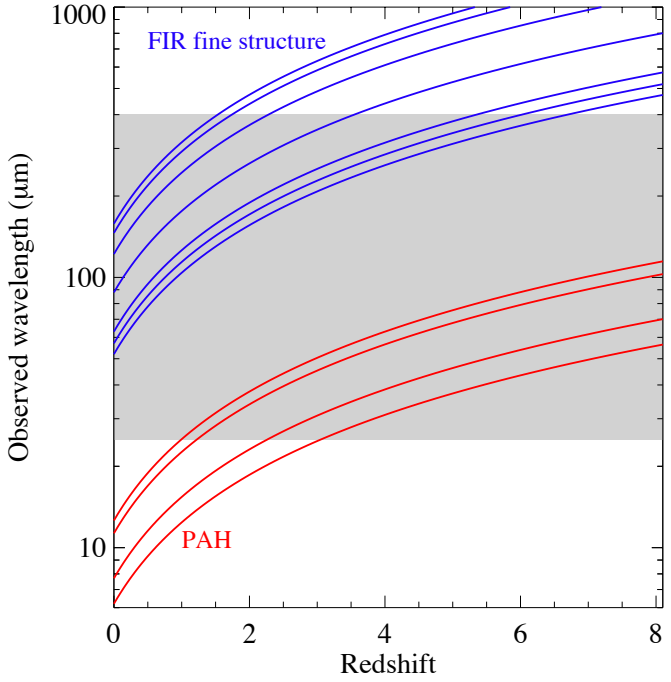
CO

Hollenbach &Tielens 1997

Infrared lines at high redshift



Galaxy Evolution: IR Diagnostics



1. **Far-IR spectrum**
   - Fine structure lines probe PDR chemistry and strength of incident radiation field

2. **Mid-IR spectrum**
   - ID and quantify AGN emission
   - Fine structure lines identify high ionization gas
   - PAHs probe ISM conditions (=>SF)
   - Warm H_2 -> see P. Appleton talk
   - Metallicity indicators

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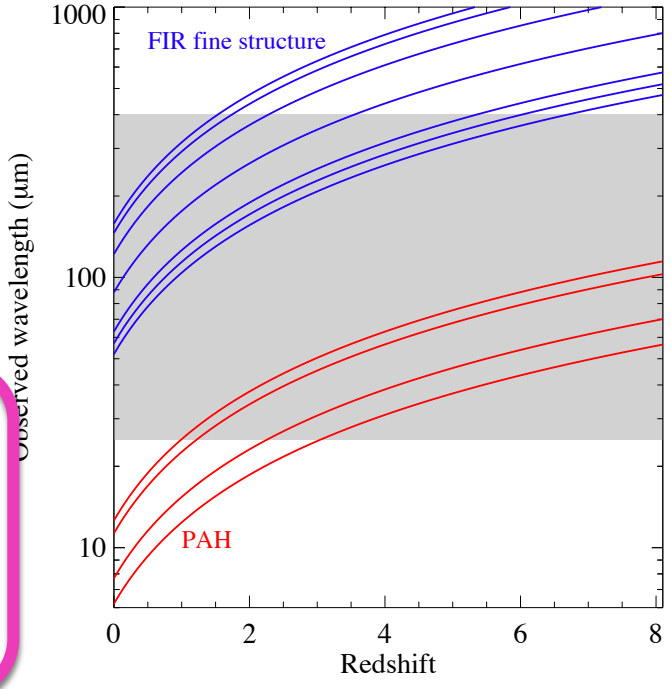

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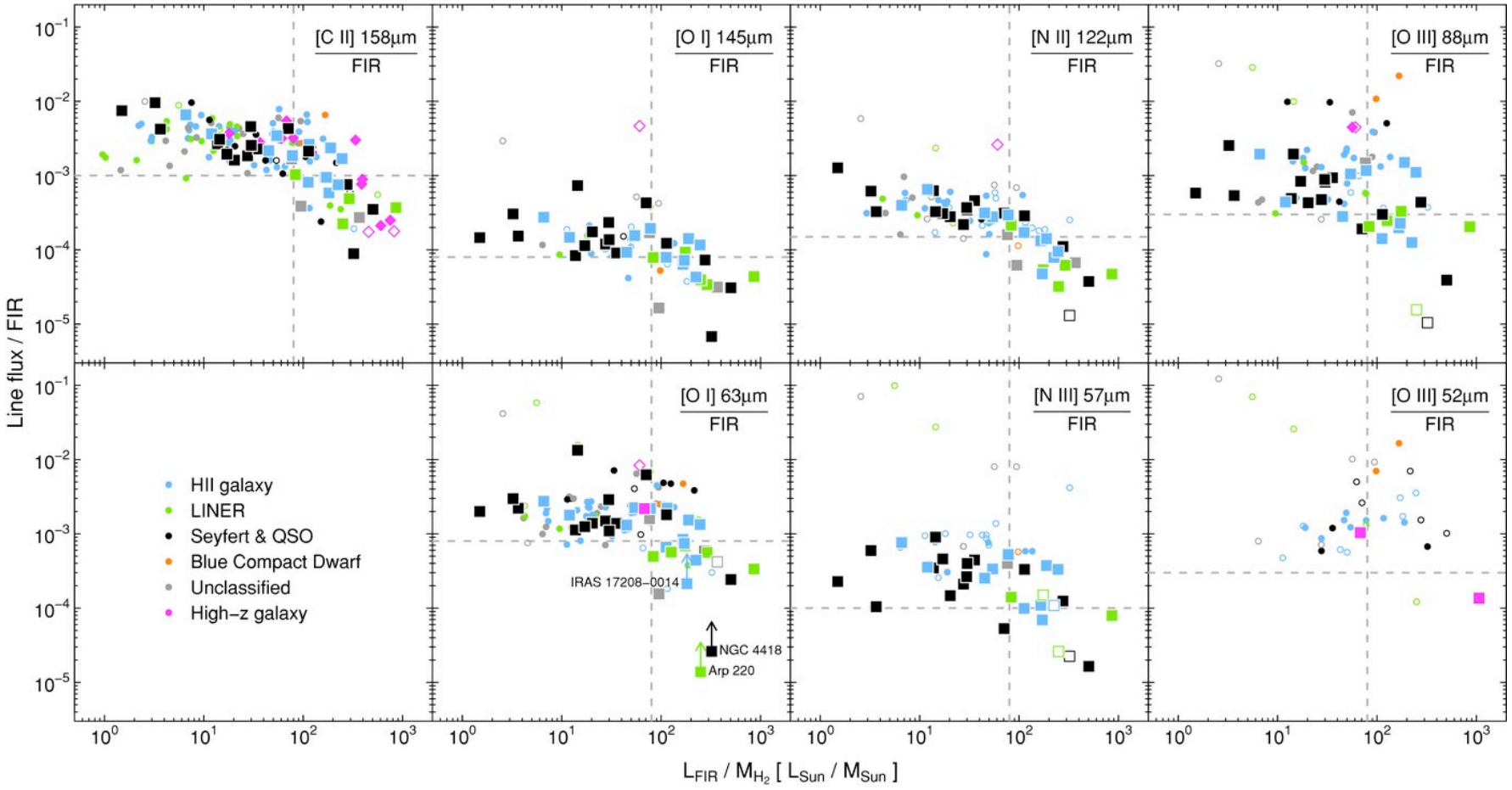
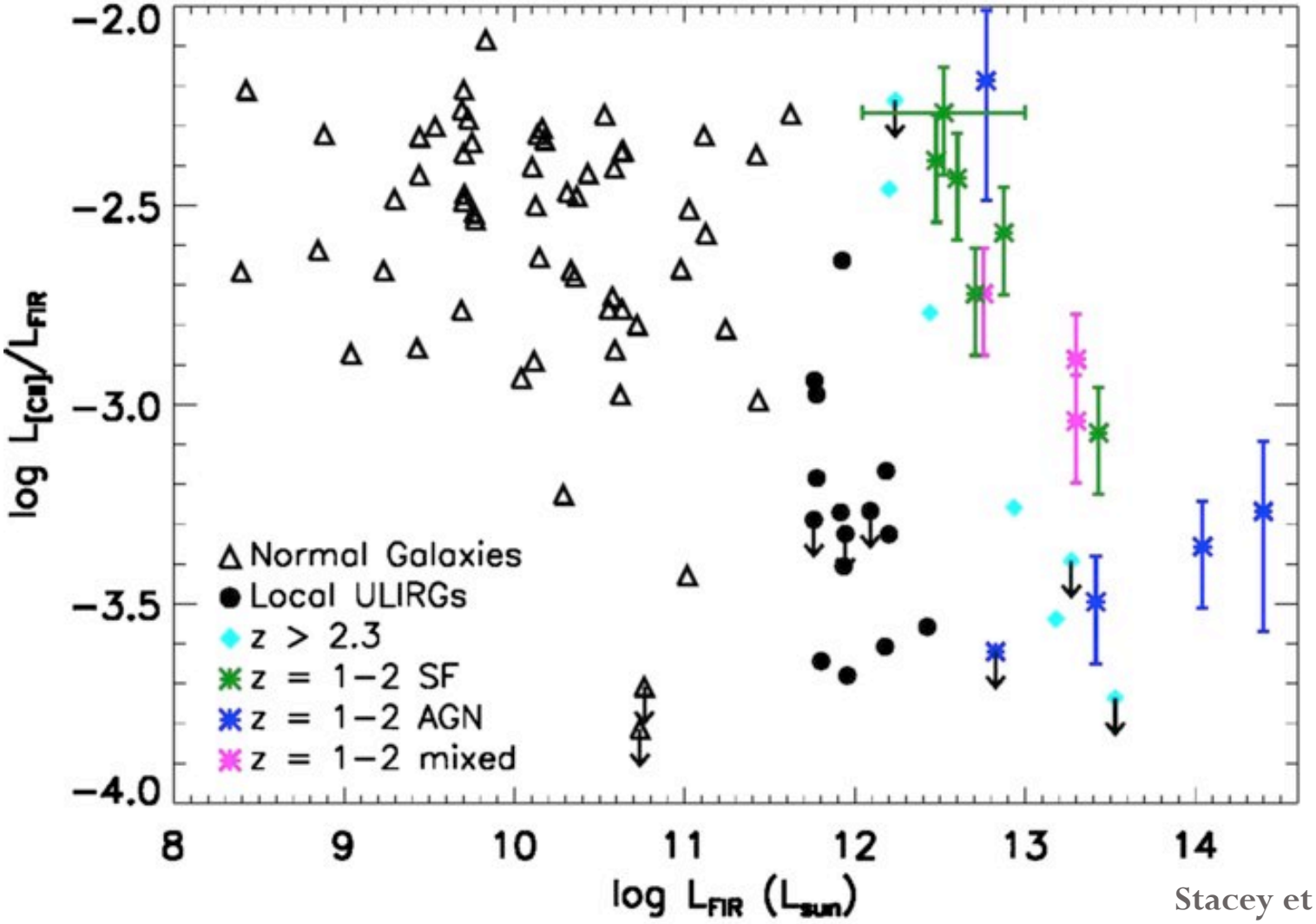
Far- IR fine structure lines (C, O, N) in the local Universe : Universal deficit at high L_{IR} or L_{IR}/M_{H2}



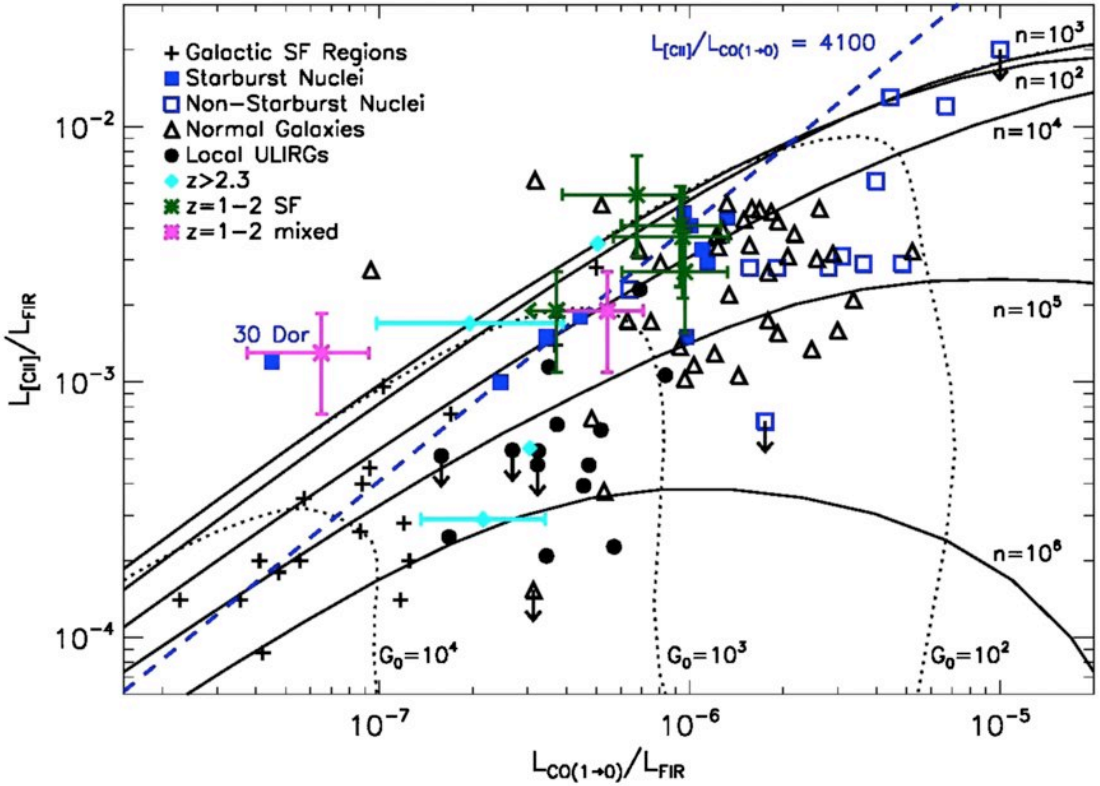
Gracia-Carpio et al. 2011, see also Farrah et al. 2013

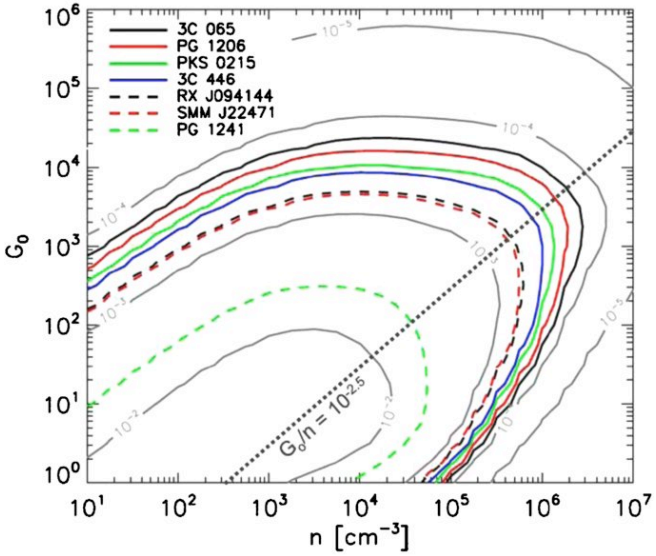
Far- IR [CII]158 at high redshift: Deficit at higher L_{IR} than local galaxies



Stacey et al. 2010

Far- IR [CII]158 at high redshift: PDR modeling to estimate G_0 and n

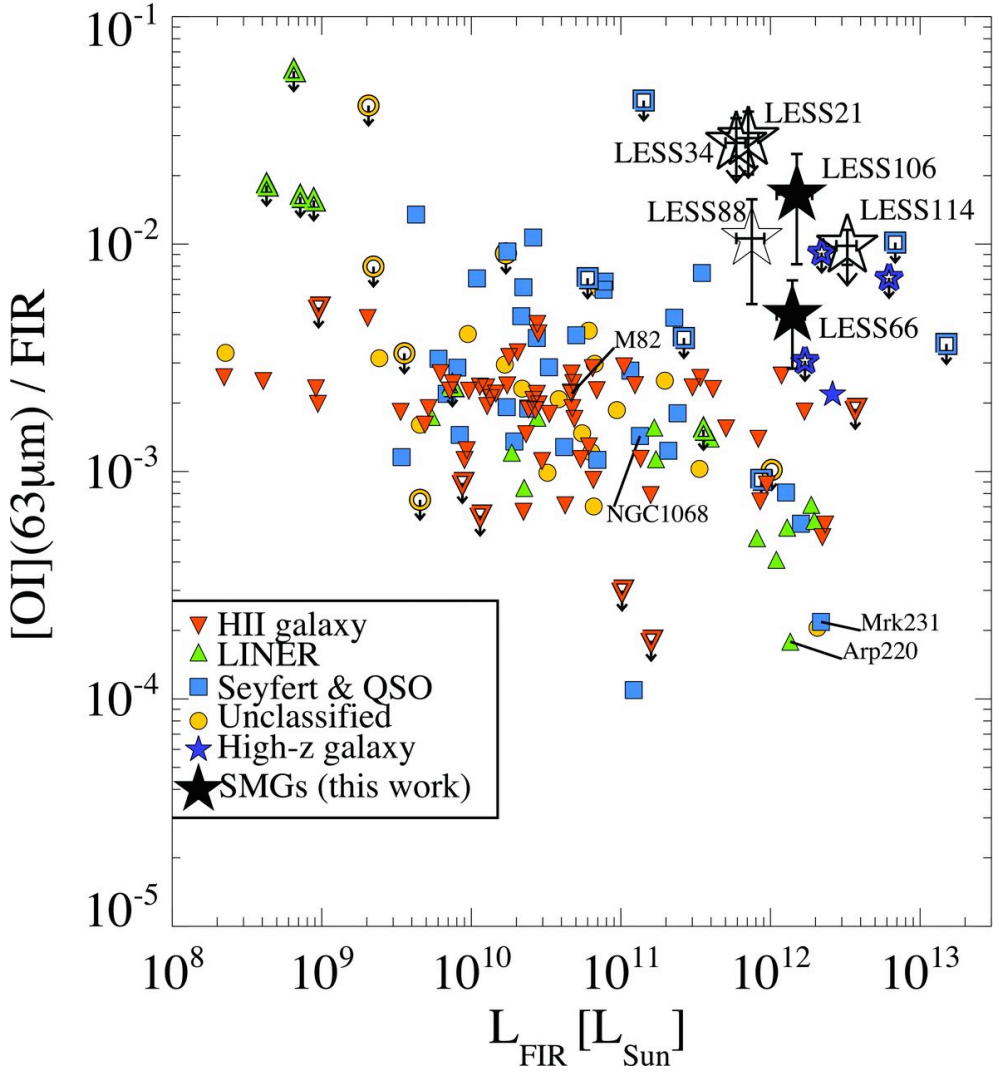


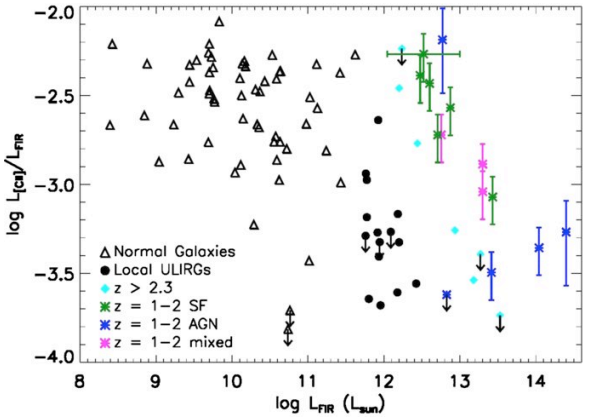


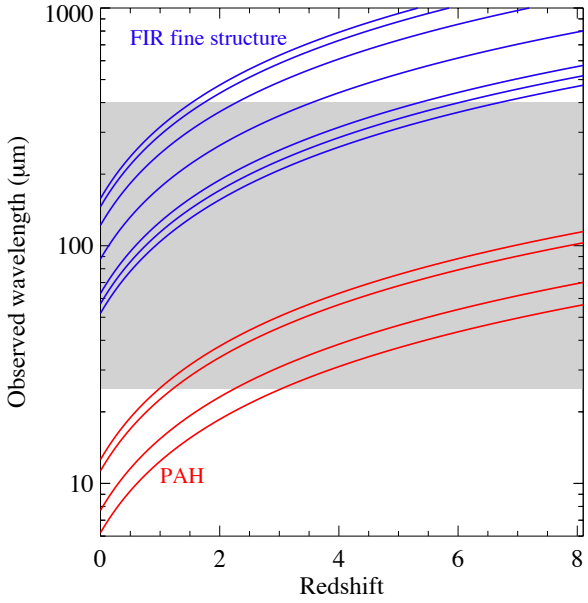
High redshift galaxies are scaled up version of local starburst galaxies but with intense activity occurring over kpc scales

Stacey et al. 2010

Far- IR [OI]63 at high redshift: Also enhanced in high redshift galaxies







Coppin et al. 2012

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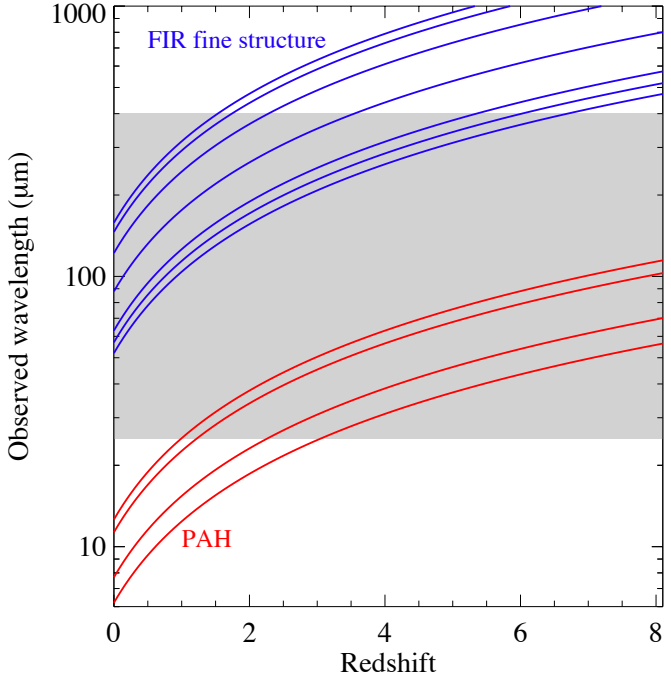

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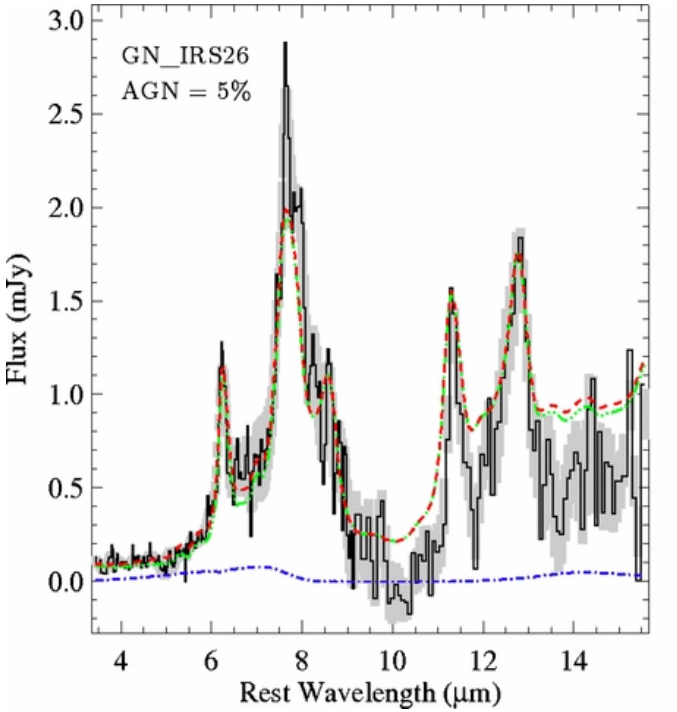
Quantifying AGN and SF activity in high redshift galaxies: mid-IR spectral decomposition

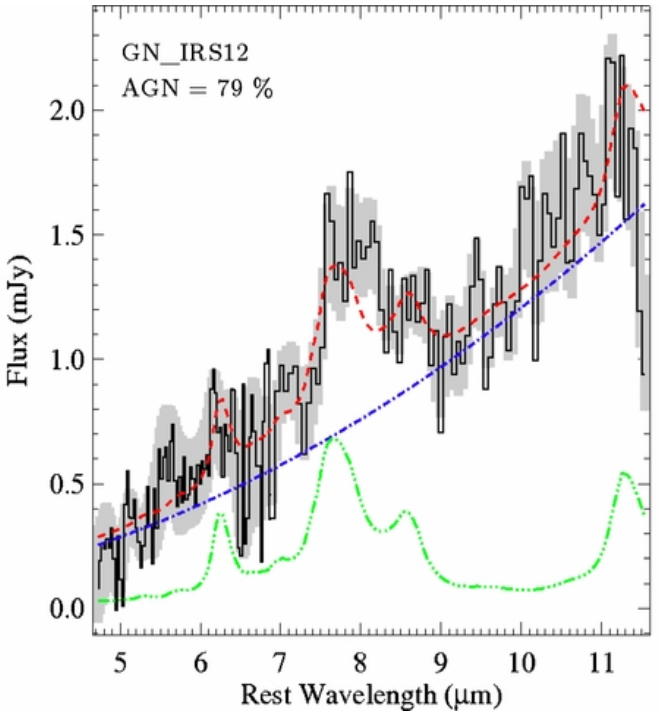
1. Star formation:

Polycyclic aromatic hydrocarbons (PAH) emission lines + extinction

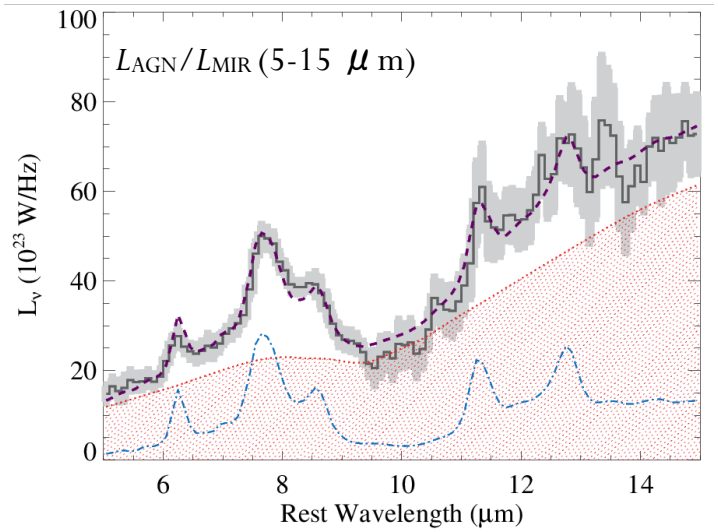


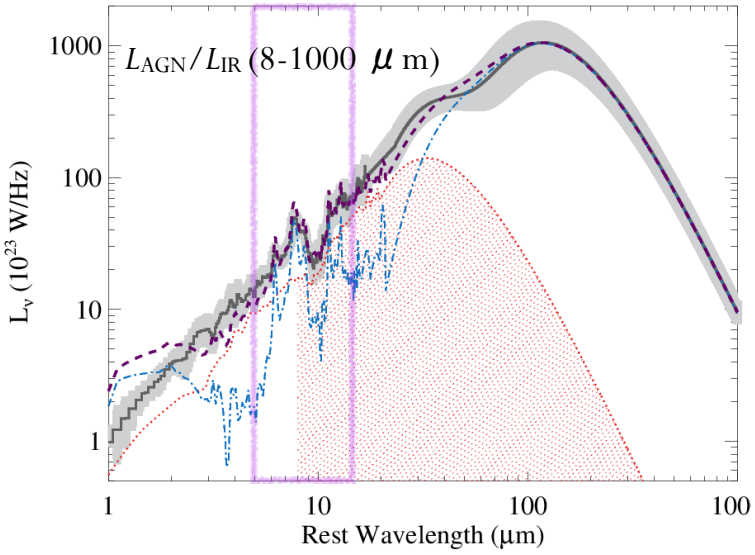
2. Active Galactic Nuclei:

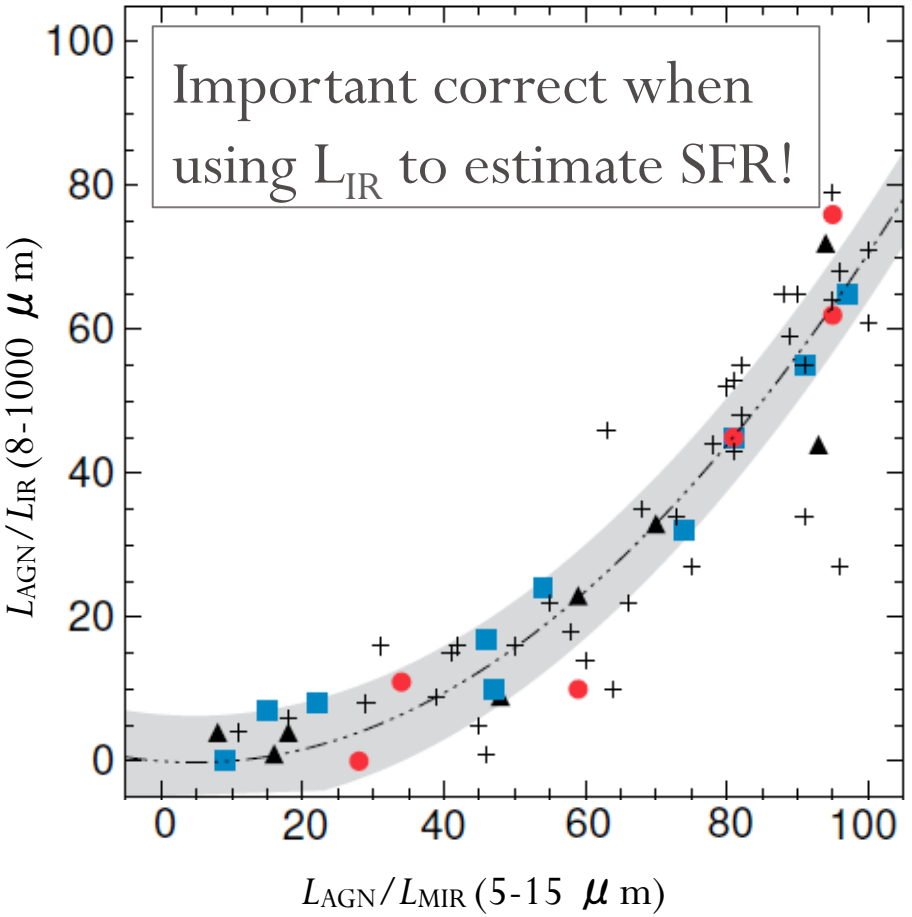
Power-law + extinction



Mid-IR AGN fraction -> Total IR AGN fraction





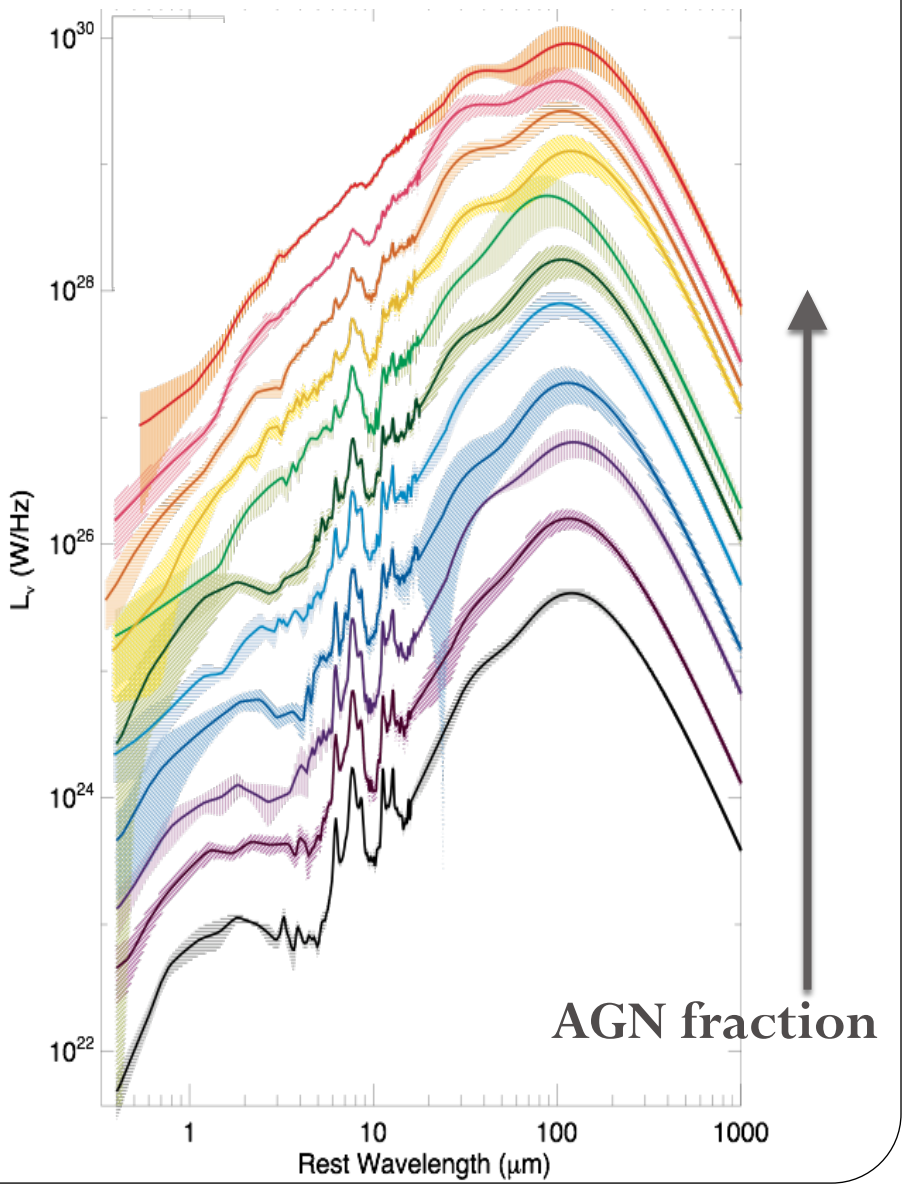


Pope et al. 2008; Kirkpatrick, Pope, et al. in prep

Galaxy SEDs as a function of AGN fraction

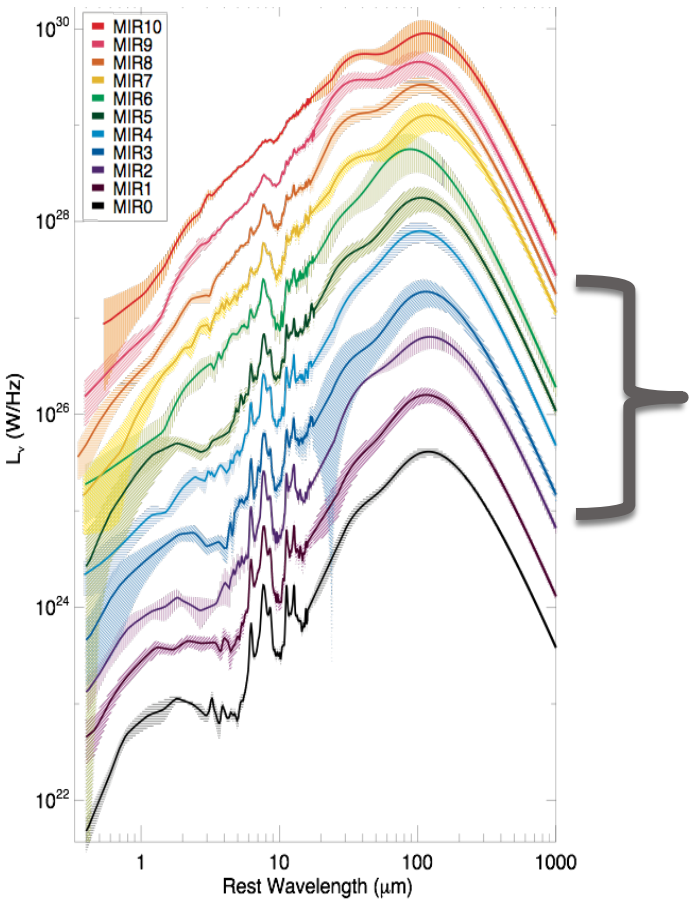
Empirical SED templates based on *Spitzer* and *Herschel* observations of >300 galaxies from z=0.5-4

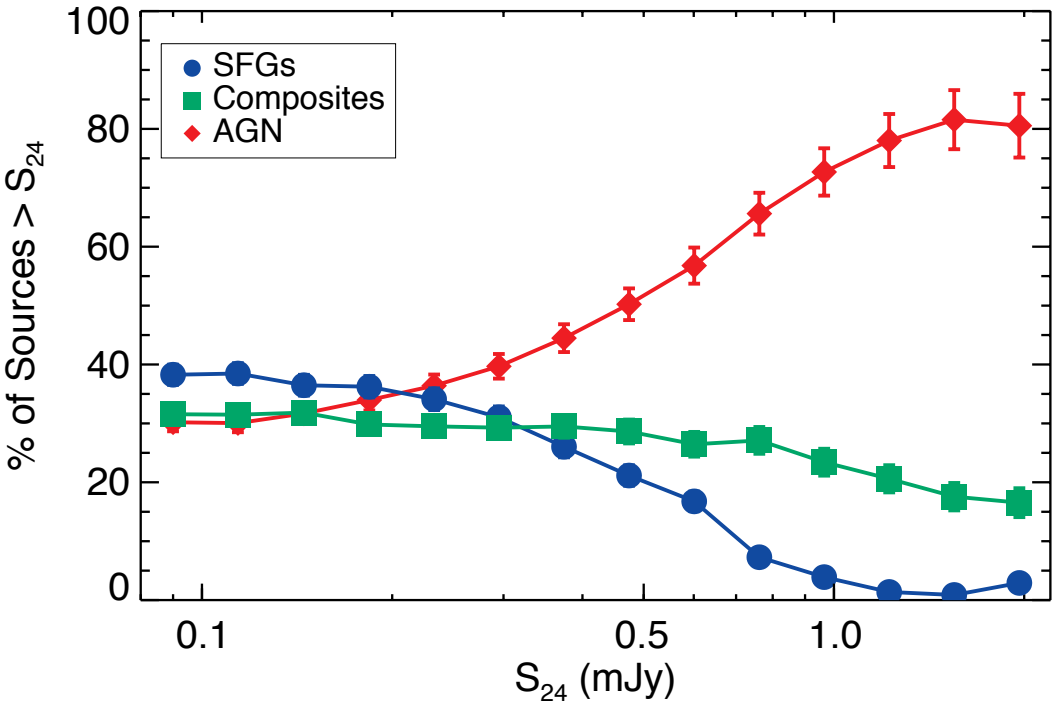
Many high redshift galaxies contain significant AGN emission and are missed in X-ray and mid-IR color selection techniques



Kirkpatrick, Pope, et al. in prep

Composites sources are a significant fraction of high redshift galaxy samples

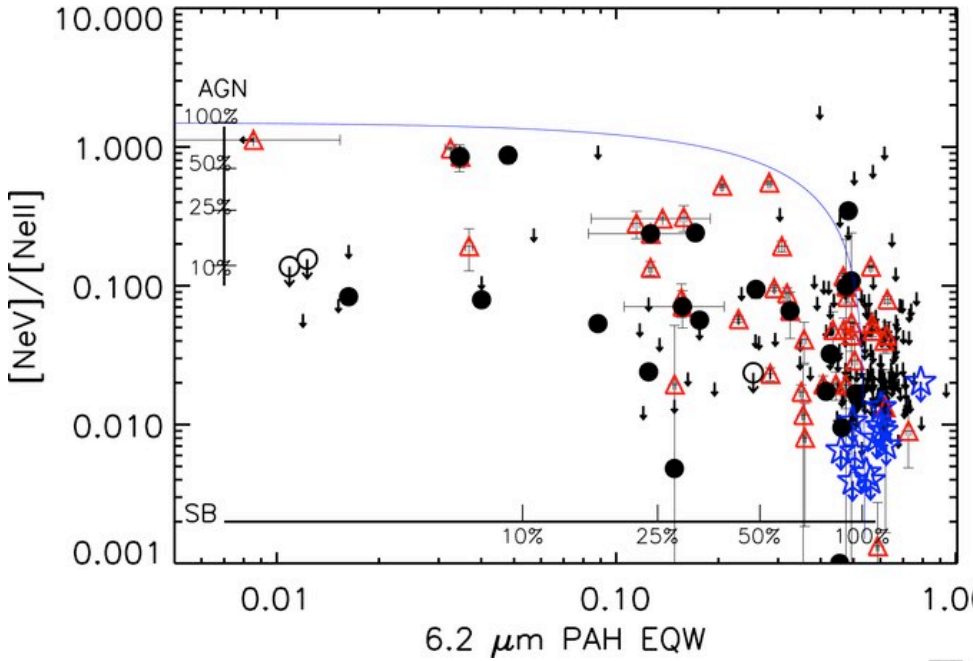


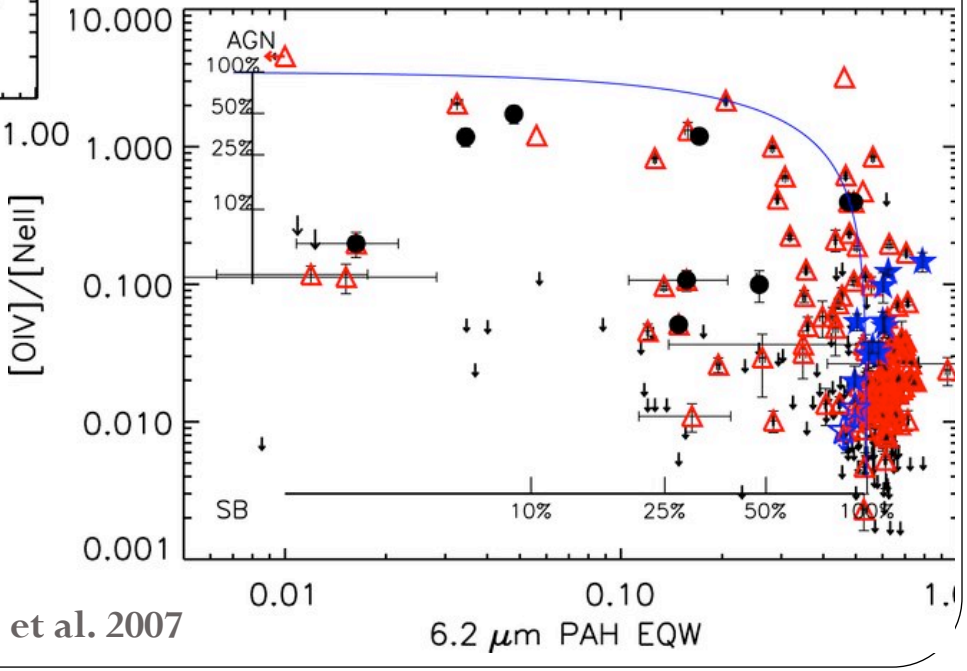


Need mid-IR spectra to reliably identify and quantify the AGN emission in high redshift galaxies.

Kirkpatrick, Pope, et al. in prep

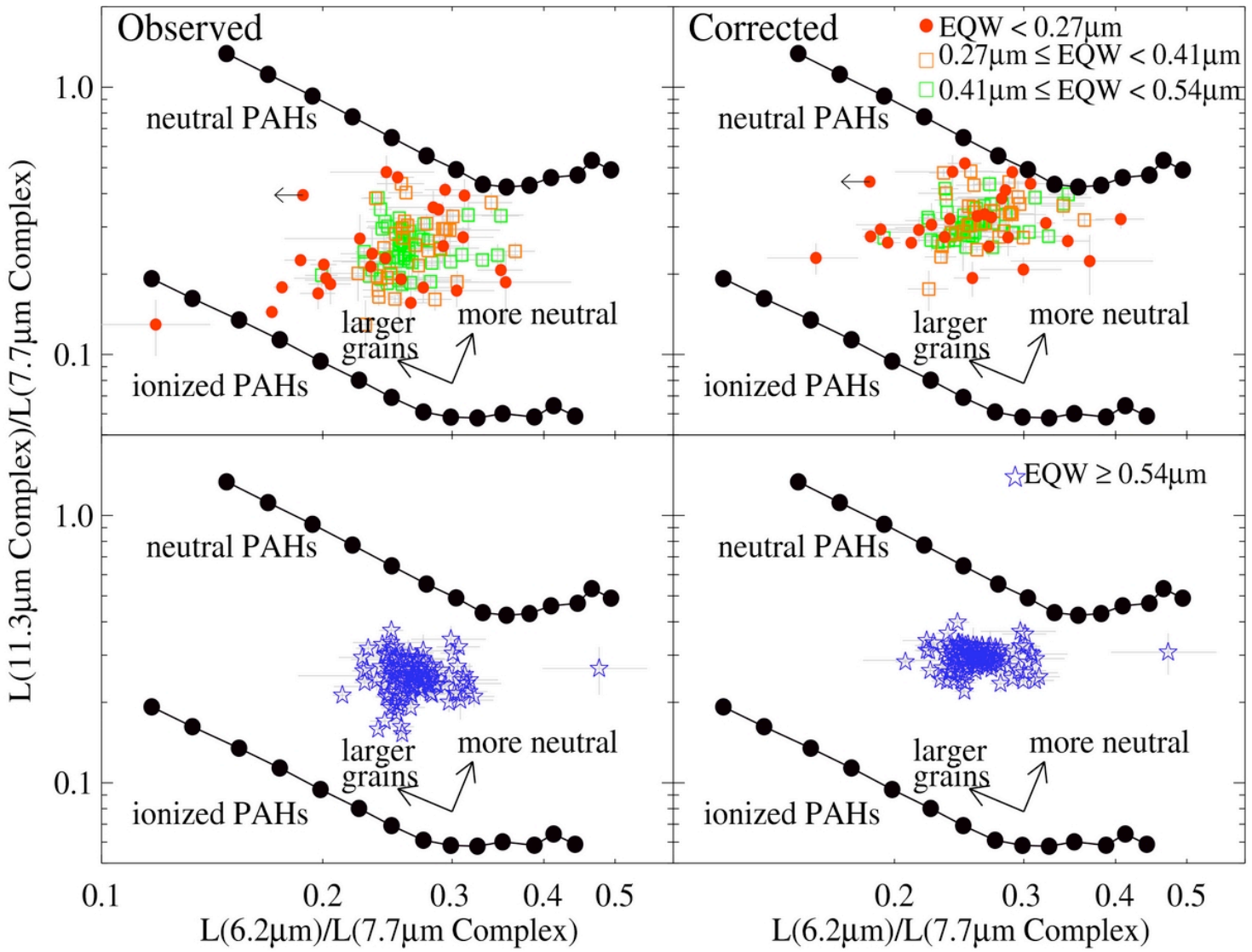
Quantifying AGN and SF activity in high redshift galaxies: high ionization lines





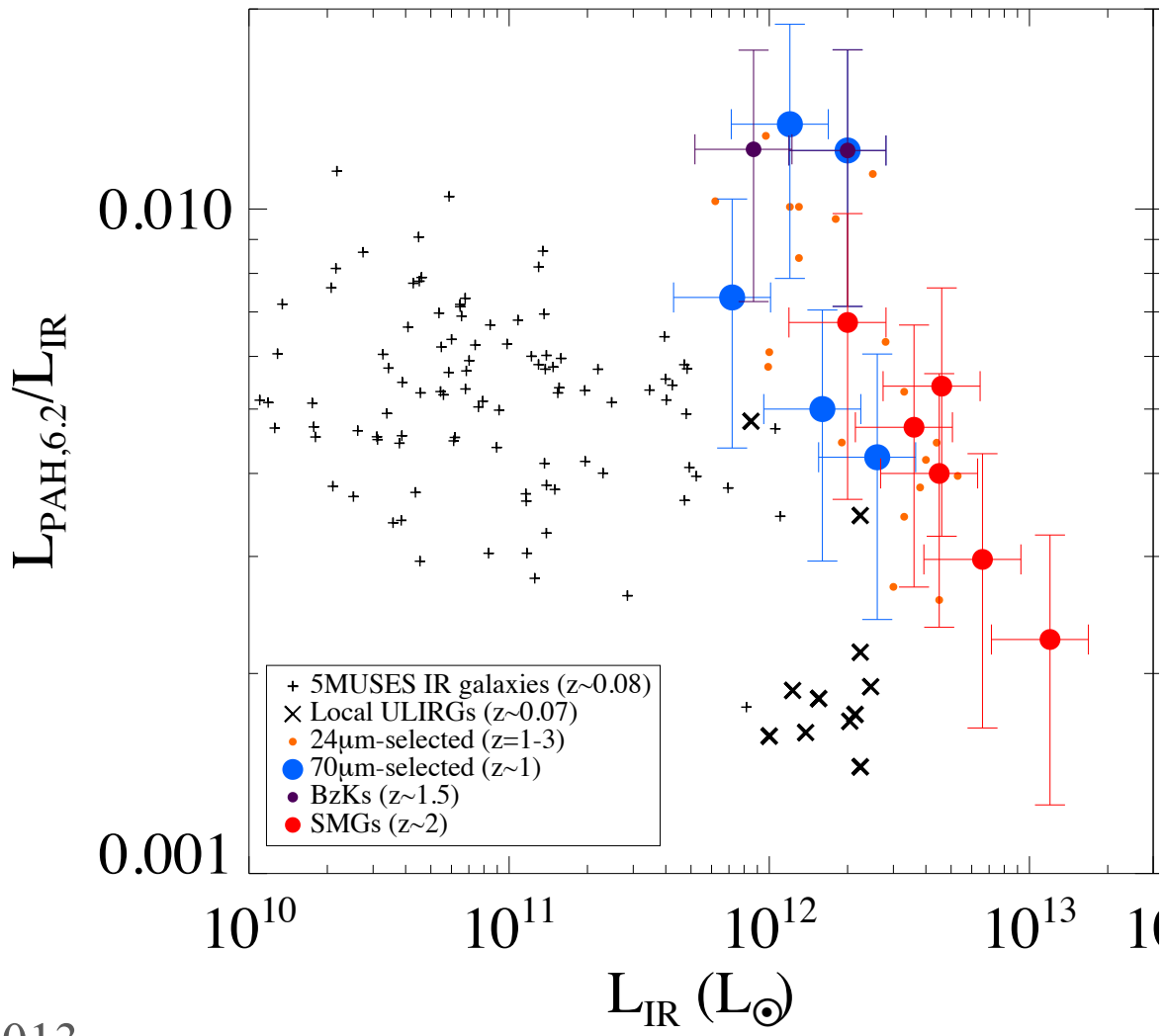
Petric et al. 2011; see also Armus et al. 2007, Farrah et al. 2007

Probing ISM conditions: PAH line ratios



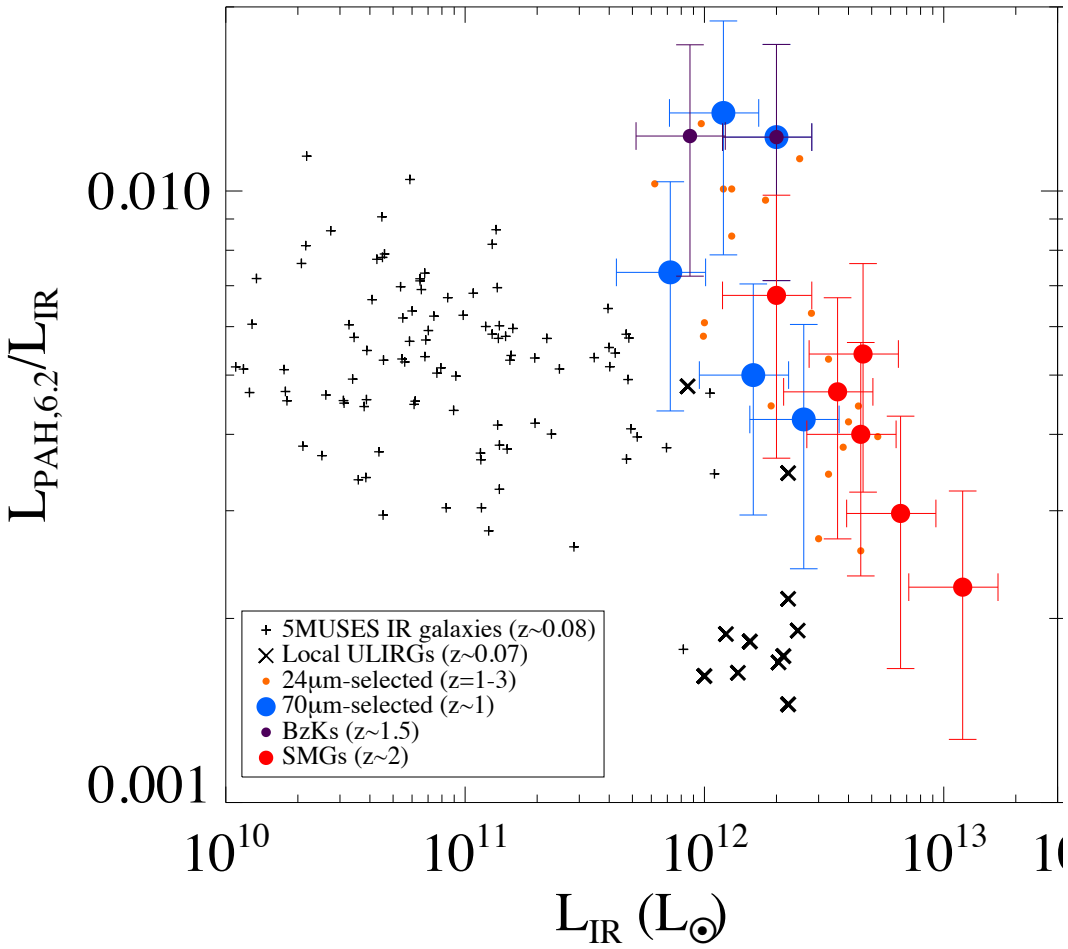
Stierwalt et al. 2014

Enhanced PAH emission at high redshift

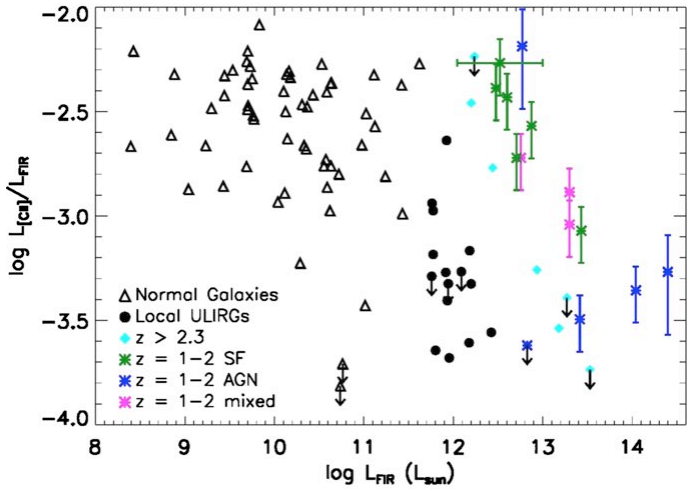


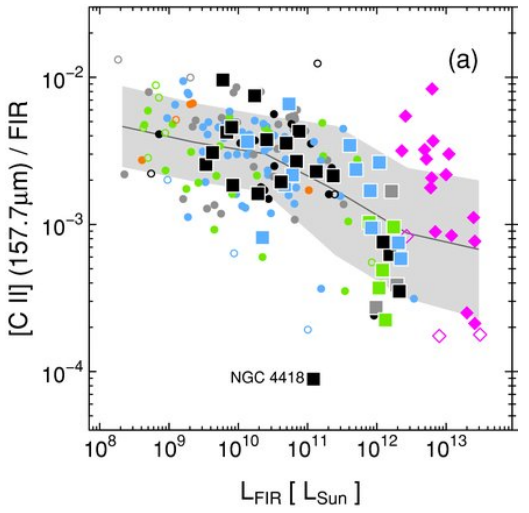
Pope et al. 2013

Enhanced PAH emission at high redshift … similar to enhanced [CII] emission?



Pope et al. 2013





Stacey et al. 2010, Graciá-Carpio et al. 2011

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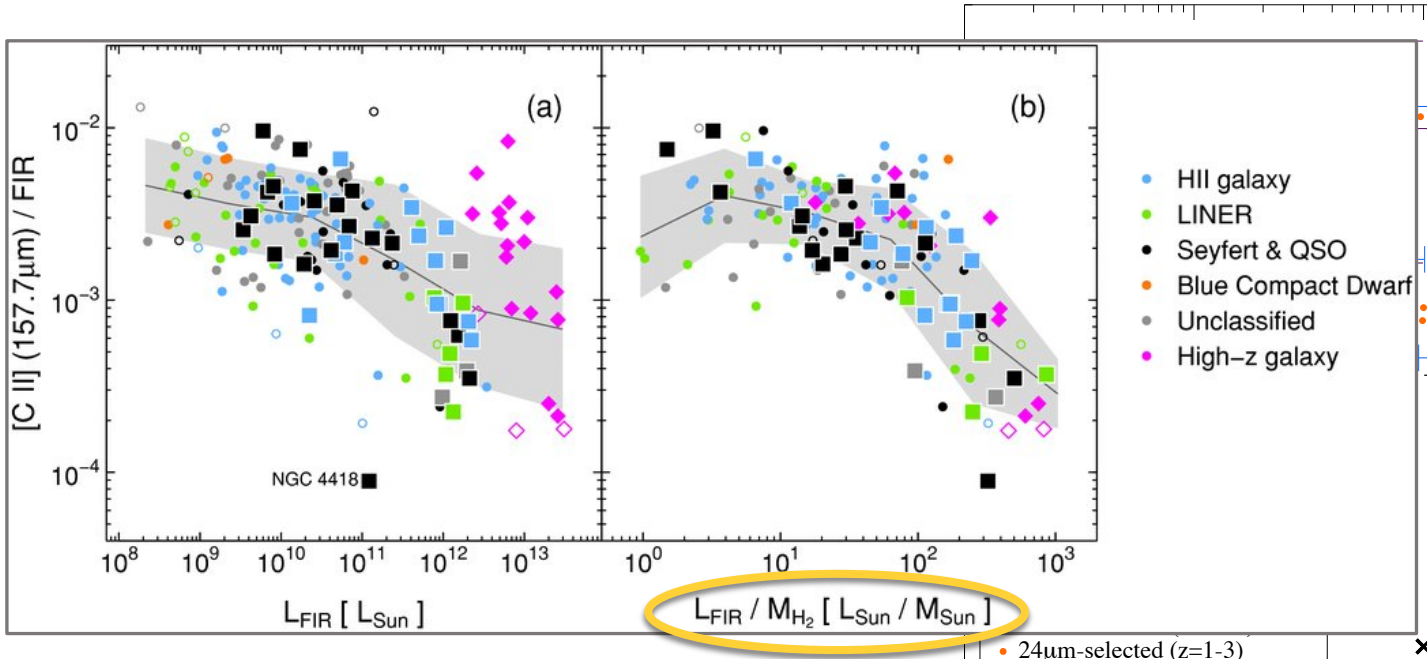
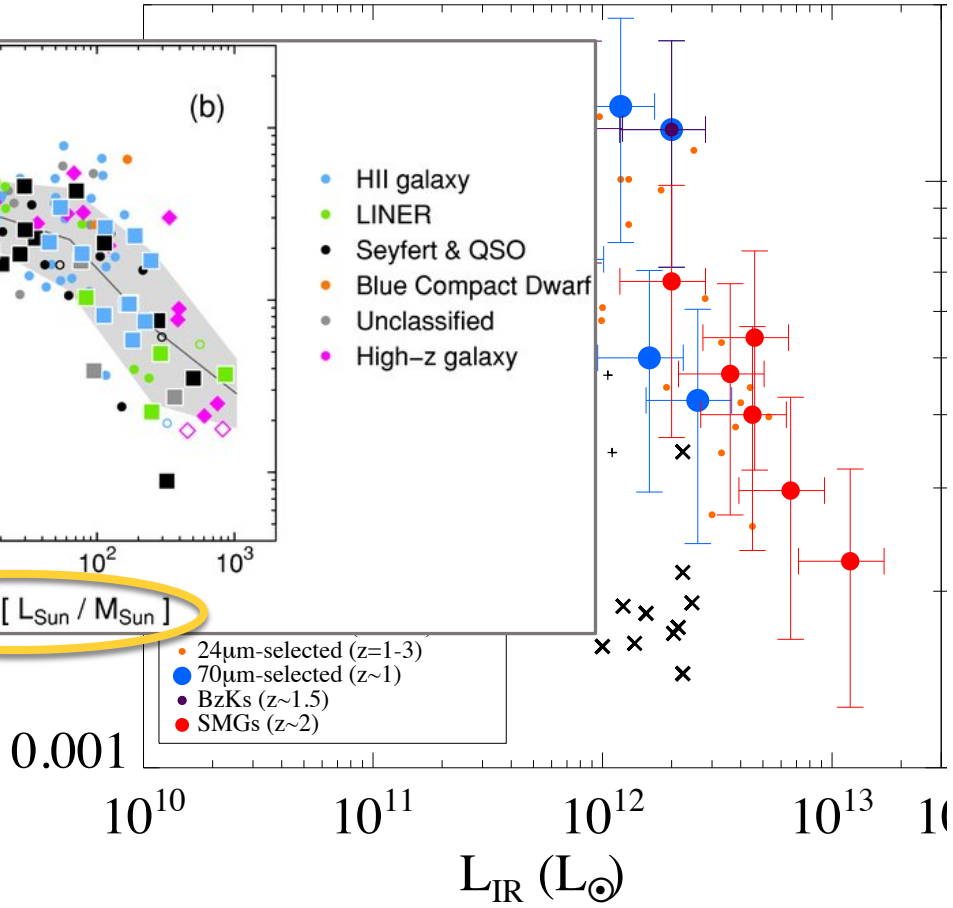
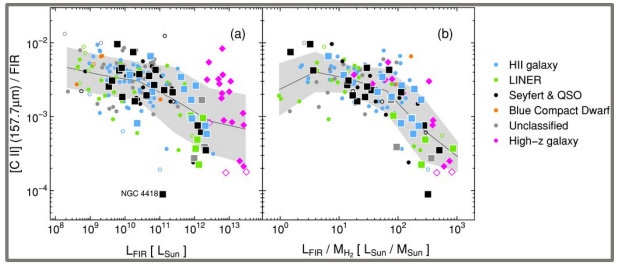


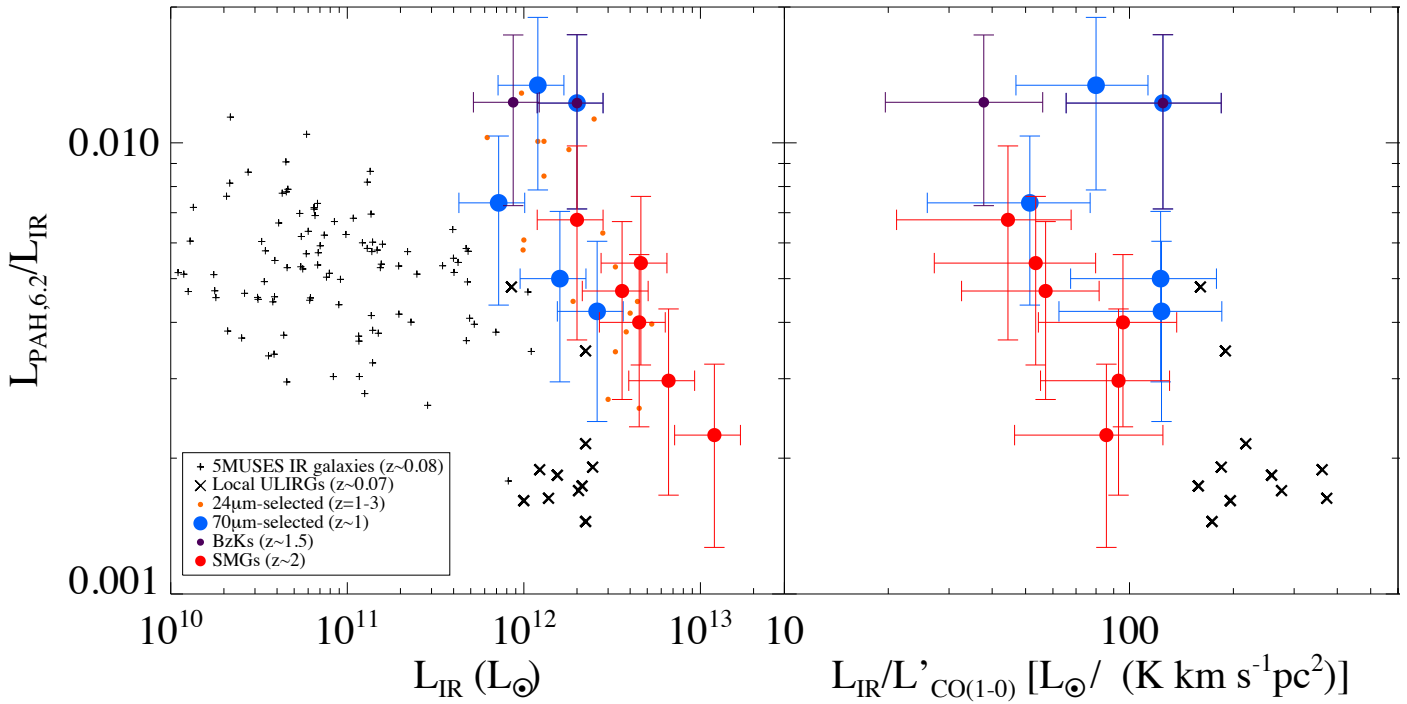
Graciá-Carpio et al. 2011



Pope et al. 2013

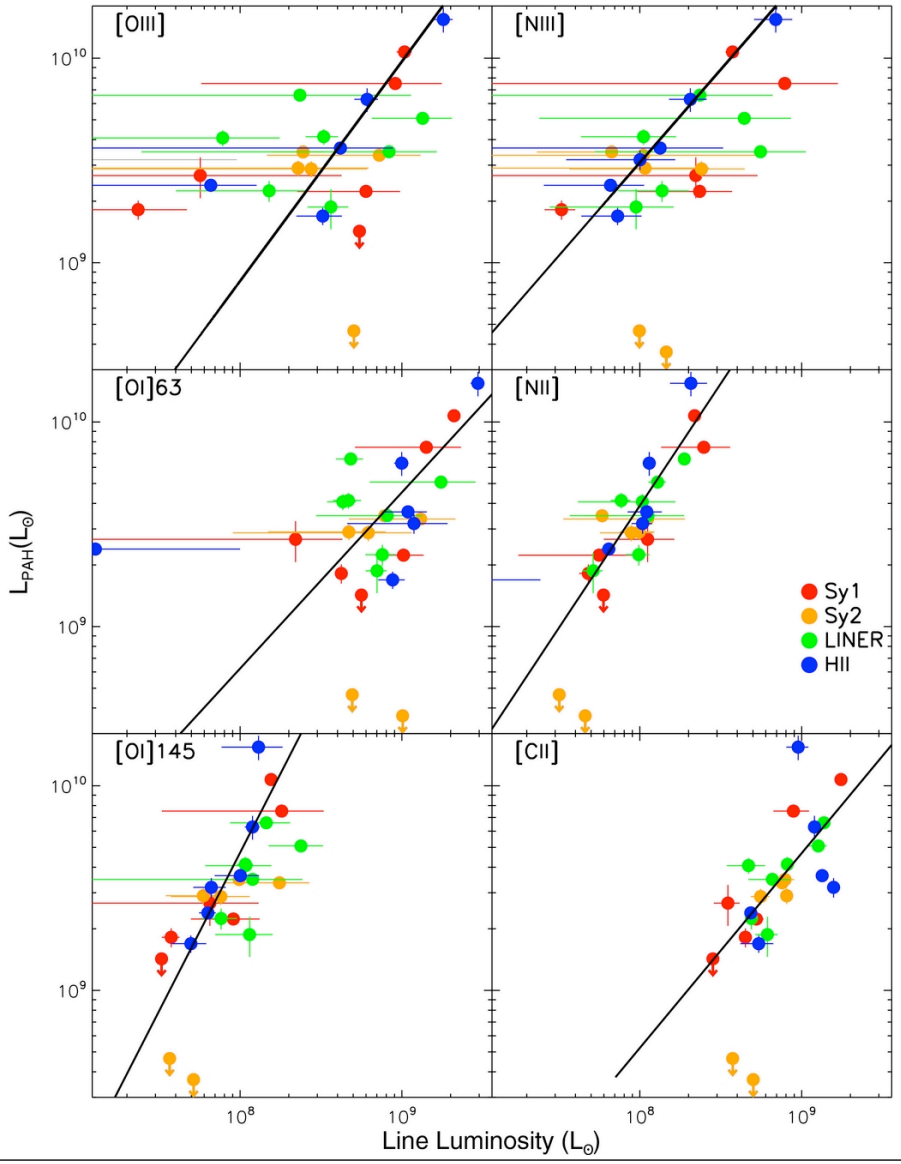
Link between **enhanced PAH emission** at high redshift and **more molecular gas**





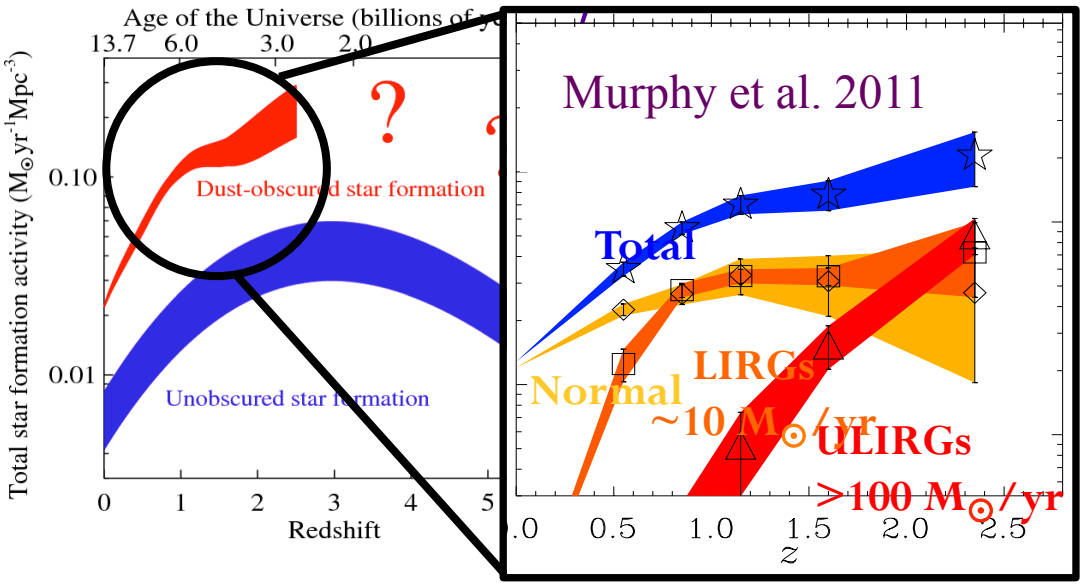
Pope et al. 2013

Combining mid-IR and far-IR line diagnostics: Powerful probe of the ISM at high redshift



Farrah et al. 2013

How faint do we need to go?



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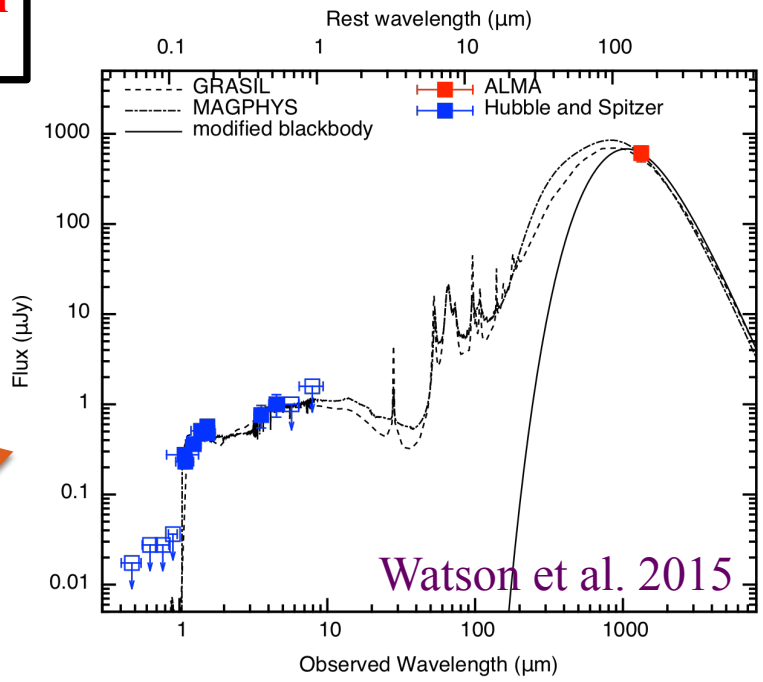
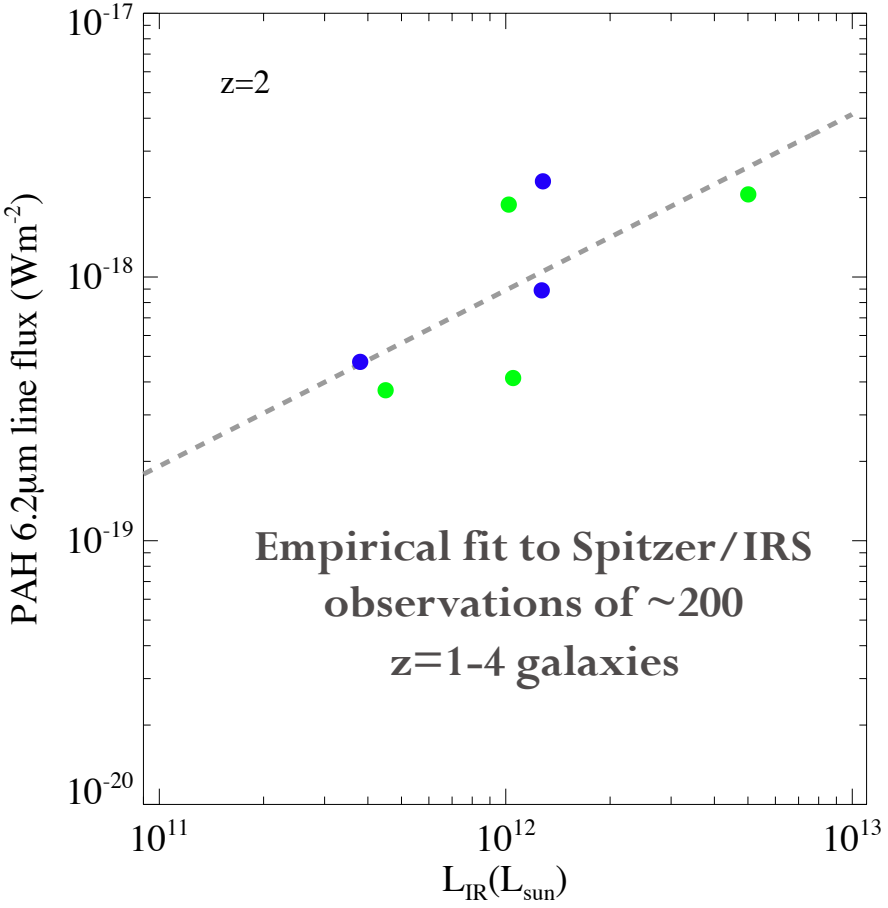
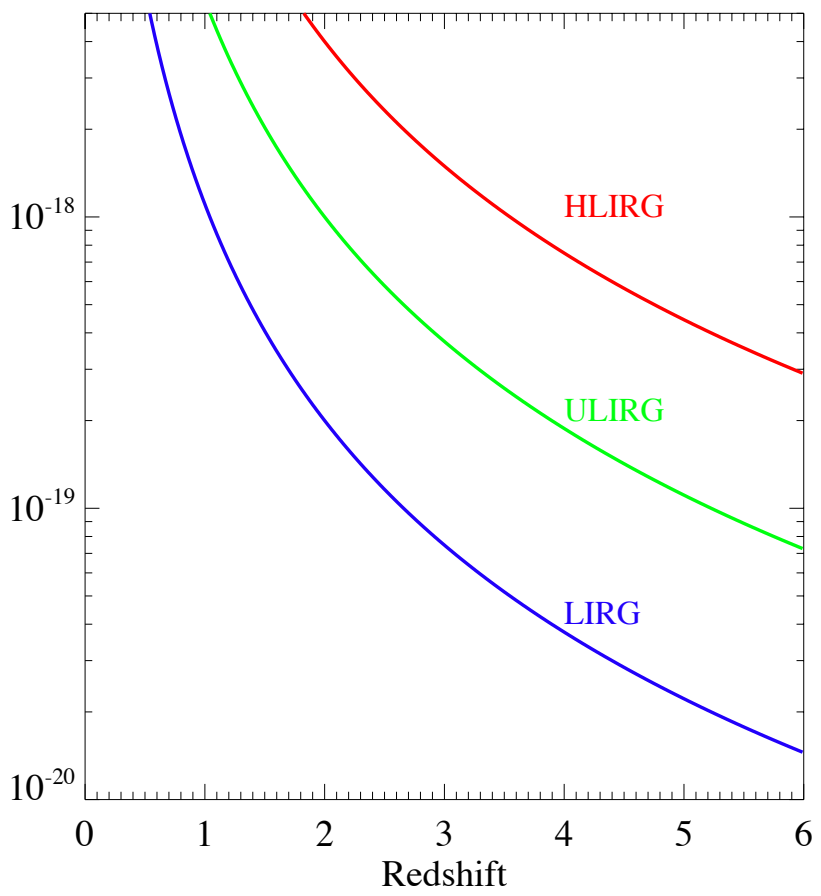


How faint do we need to go?



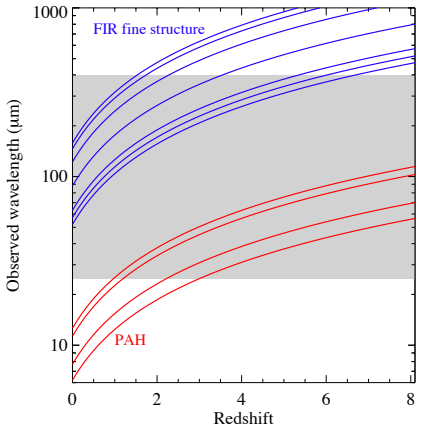


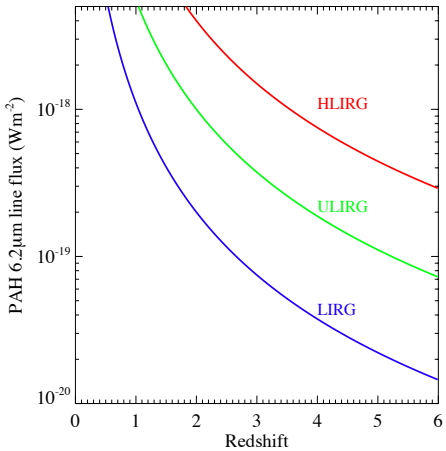
To detect PAHs and far-IR fine-structure lines (e.g. [OI]63) in <u>every LIRG out to z~6</u> we need ~10^{-20} Wm^{-2}

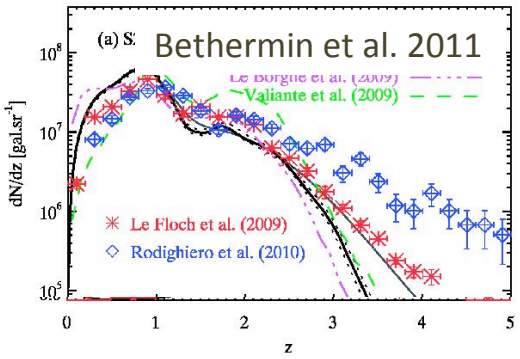
Desired Measurement Capabilities:
High redshift galaxies

Parameter	Units	Value or Range
Wavelength range	μm	25-400
Angular resolution	arcsec	6
Spectral resolution, (λ/Δλ)	dimensionless	100
Continuum sensitivity	μJy	
Spectral line sensitivity	10^{-19} W m^{-2}	0.1
Instantaneous FoV	arcmin	
Number of target fields	dimensionless	
Field of Regard	sr	~all sky

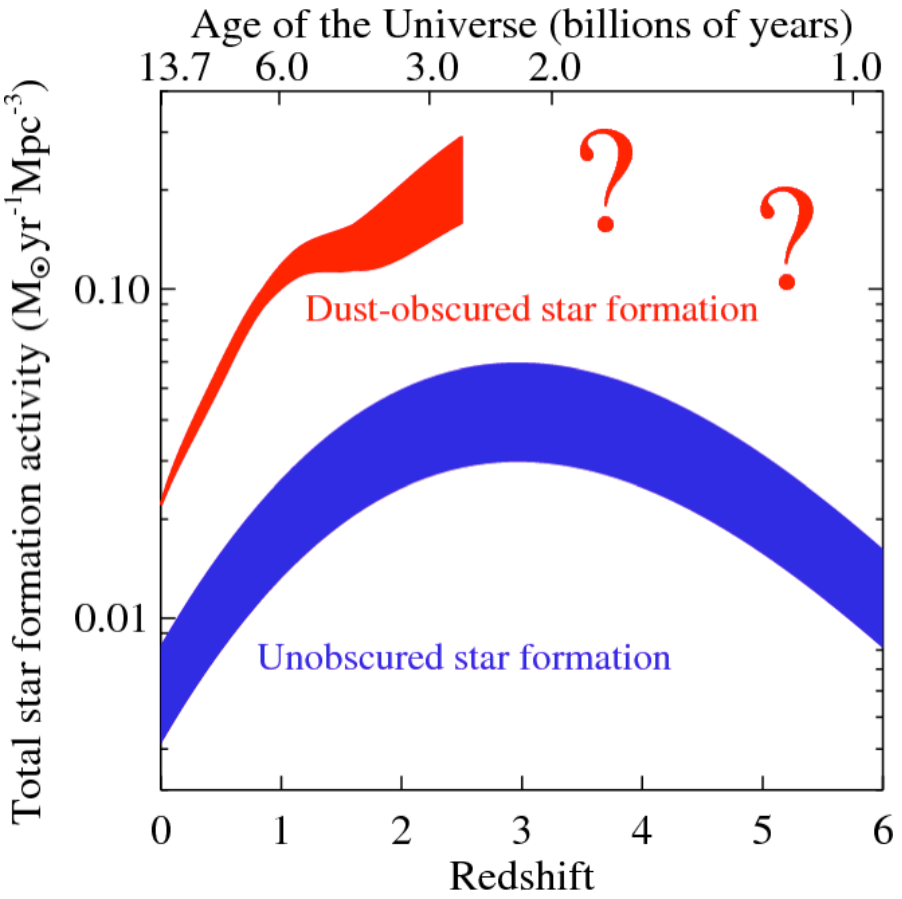
similar to *Spitzer*

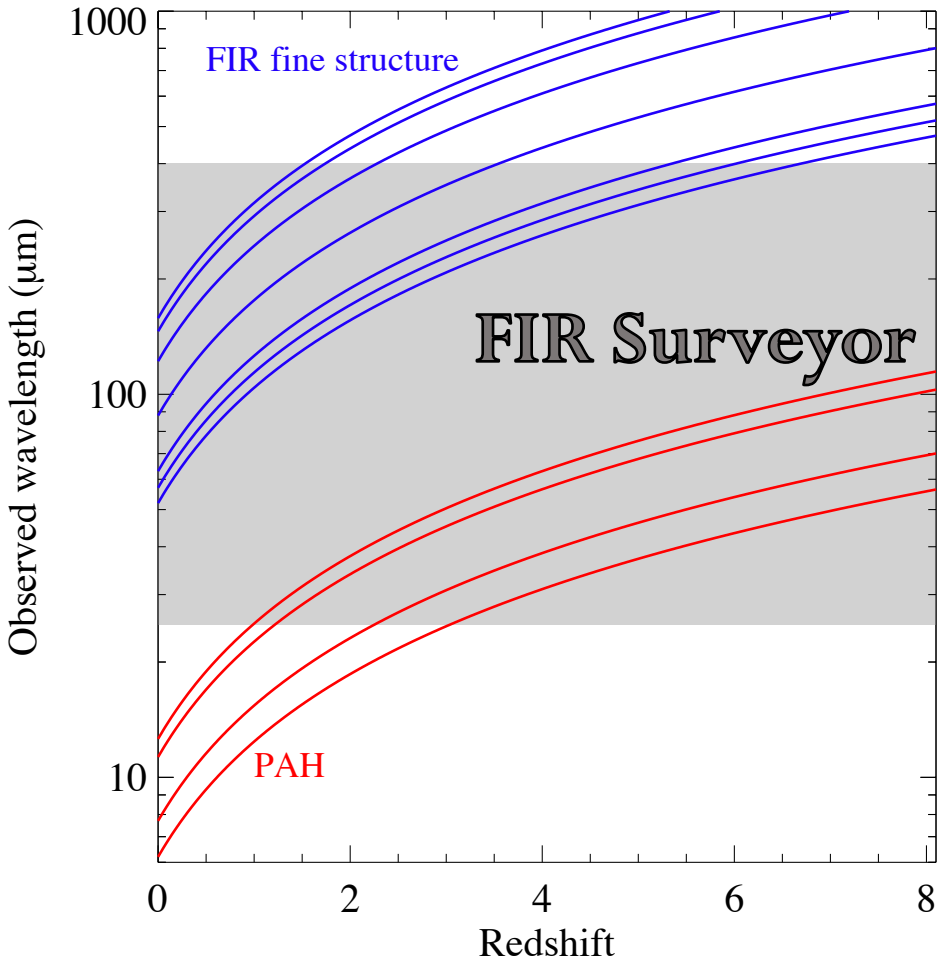






Summary: Understanding the cosmic history of star formation and BH growth with a FIR Surveyor





Key science questions that are likely to be relevant in the 2020's which are uniquely addressable with a FIR mission:

- **What drives the cosmic history of star formation?**

  Why is there a peak period at z~2? How is the process/mode of star formation evolving? How is the rise of metals/dust linked to SF? We need to probe the ISM where stars are forming.

- **How is the star formation linked to the black hole growth?**

  We need to identify and separate the emission from each in our observations.