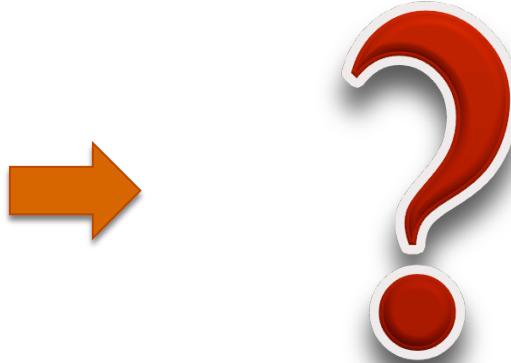


# Understanding Dust Obscured Activity in High Redshift Galaxies

Alexandra Pope (UMass Amherst)



FIR Surveyor Workshop - June 3, 2015

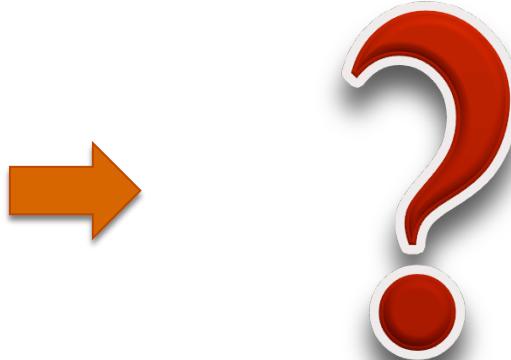
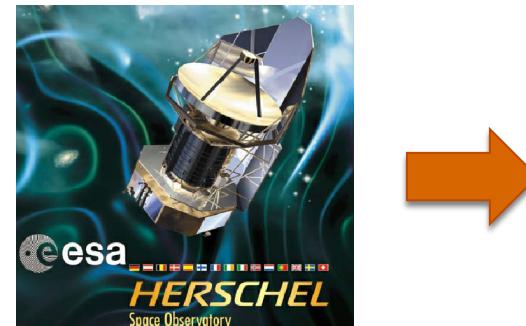


# Understanding Dust Obscured Activity in High Redshift Galaxies

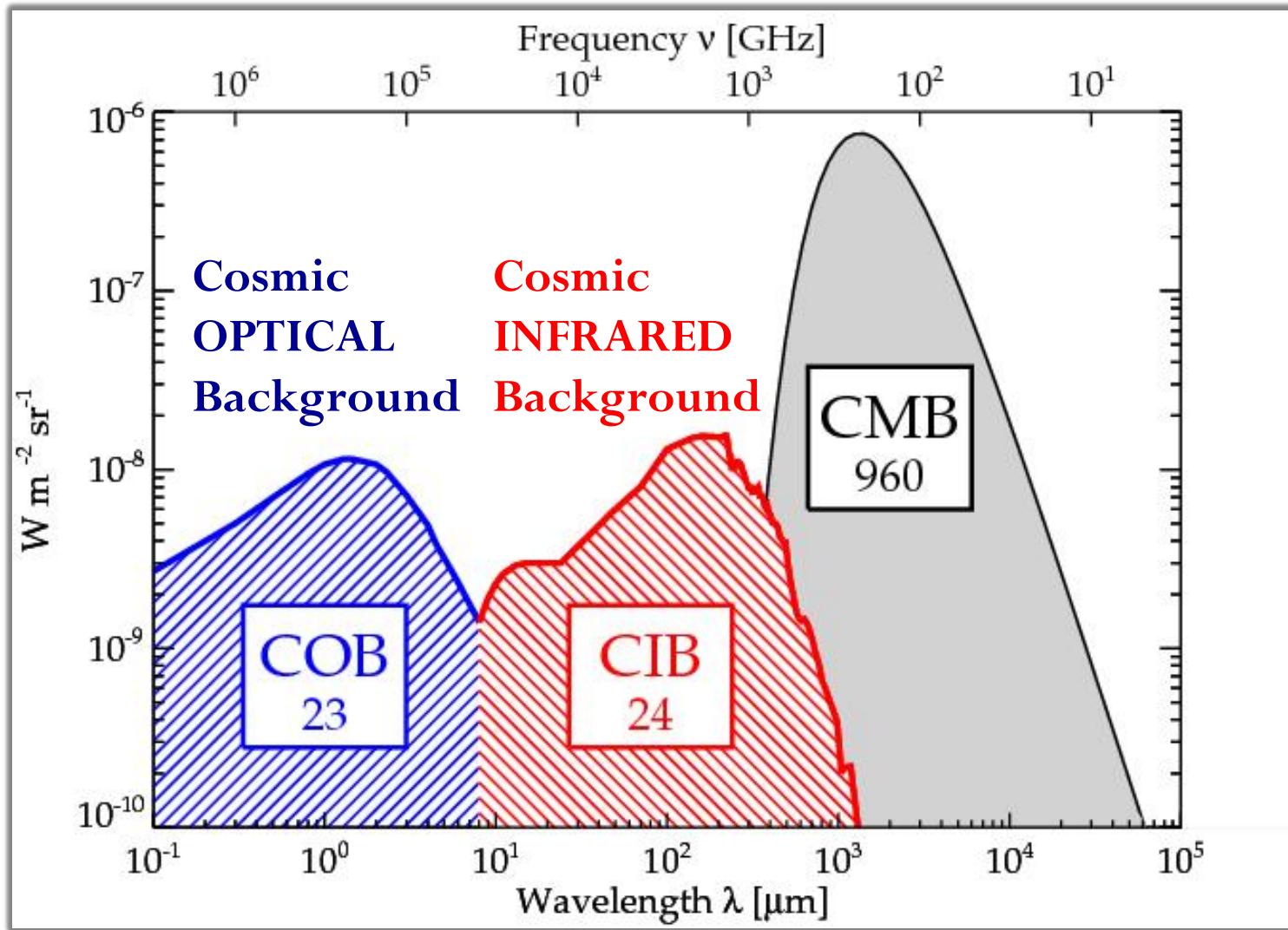
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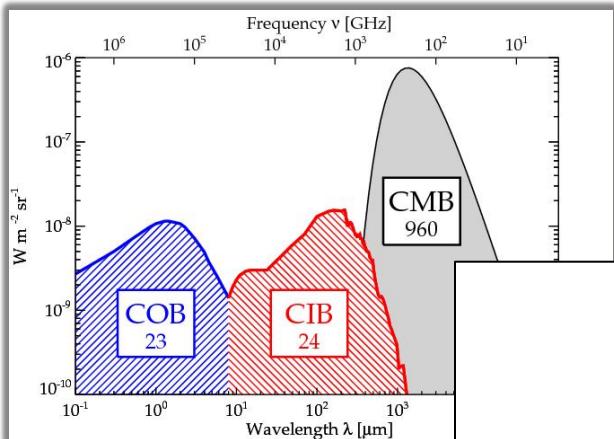
FIR Surveyor Workshop - June 3, 2015



# Much of galaxy formation and evolution occurs behind dust



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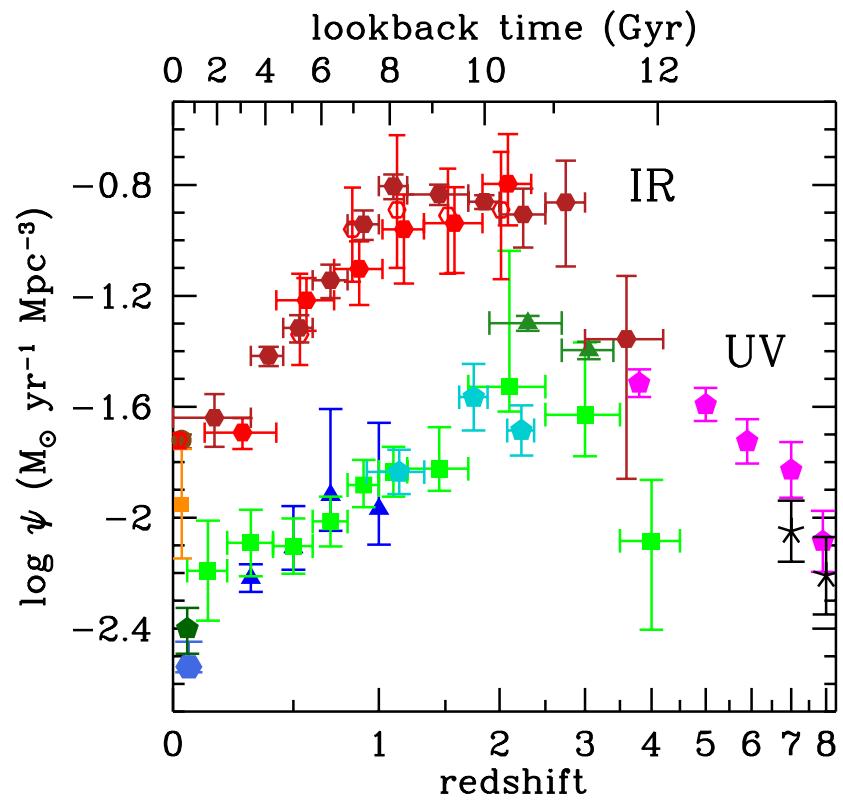
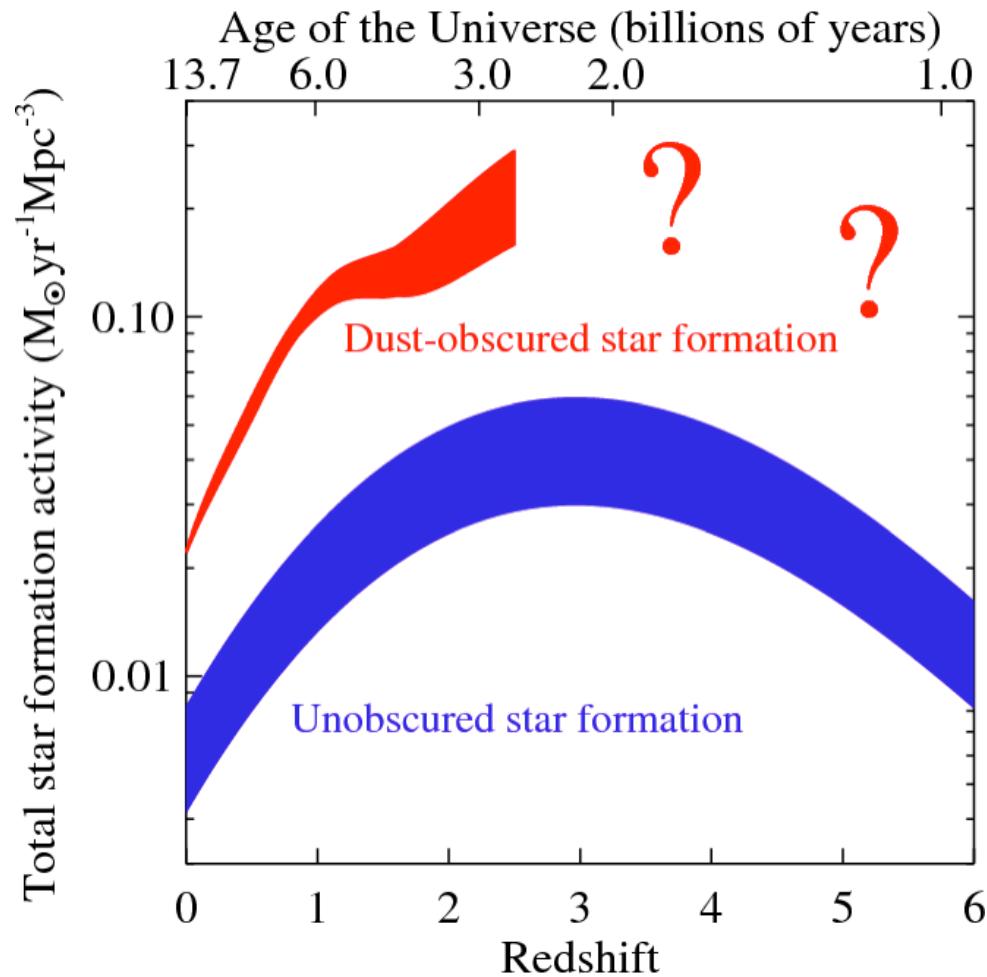
*Herschel Space Observatory:*

~75% of the CIB at  $100 \mu\text{m}$  and  $160 \mu\text{m}$  is resolved by individually detected sources (Magnelli+2013)

80-100% of CIB at  $250 \mu\text{m}$  is resolved from stacking  $24 \mu\text{m}$  and  $K$ -band selected galaxies (Bethermin+2013; Viero+2013)

**RESOLVING THE CIB IS NO LONGER THE MOST PRESSING QUESTION**

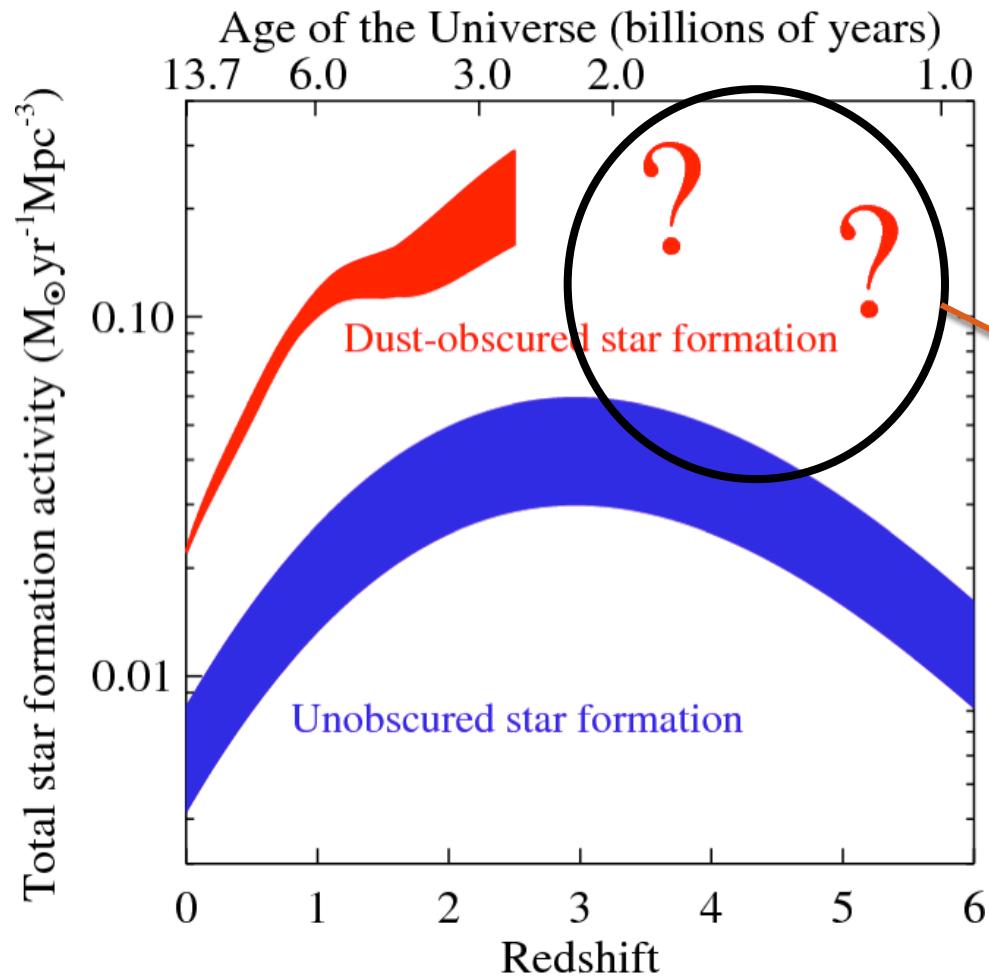
# Dust-obscured activity dominates the build-up of stars and black holes in galaxies



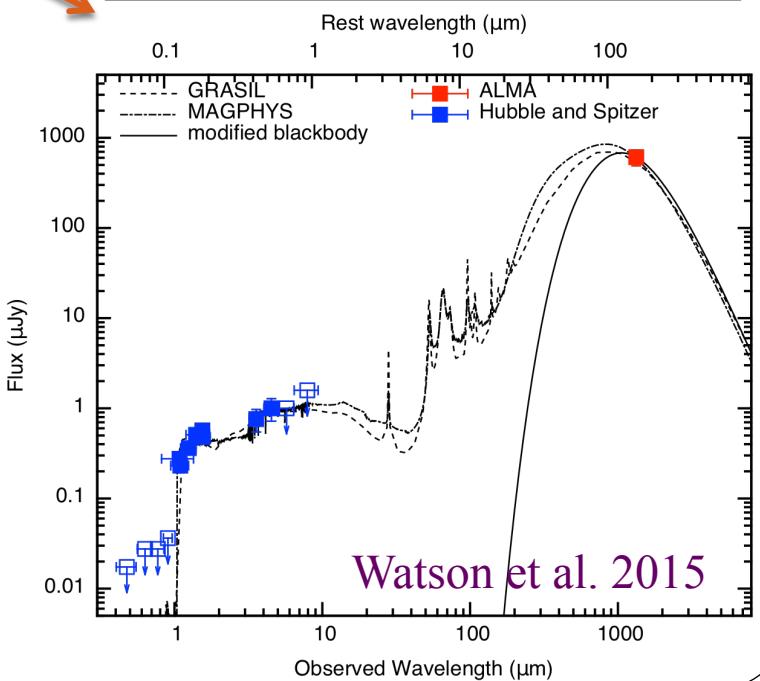
Madau & Dickinson 2014

Using data from Bouwens+2009 and Murphy+2011

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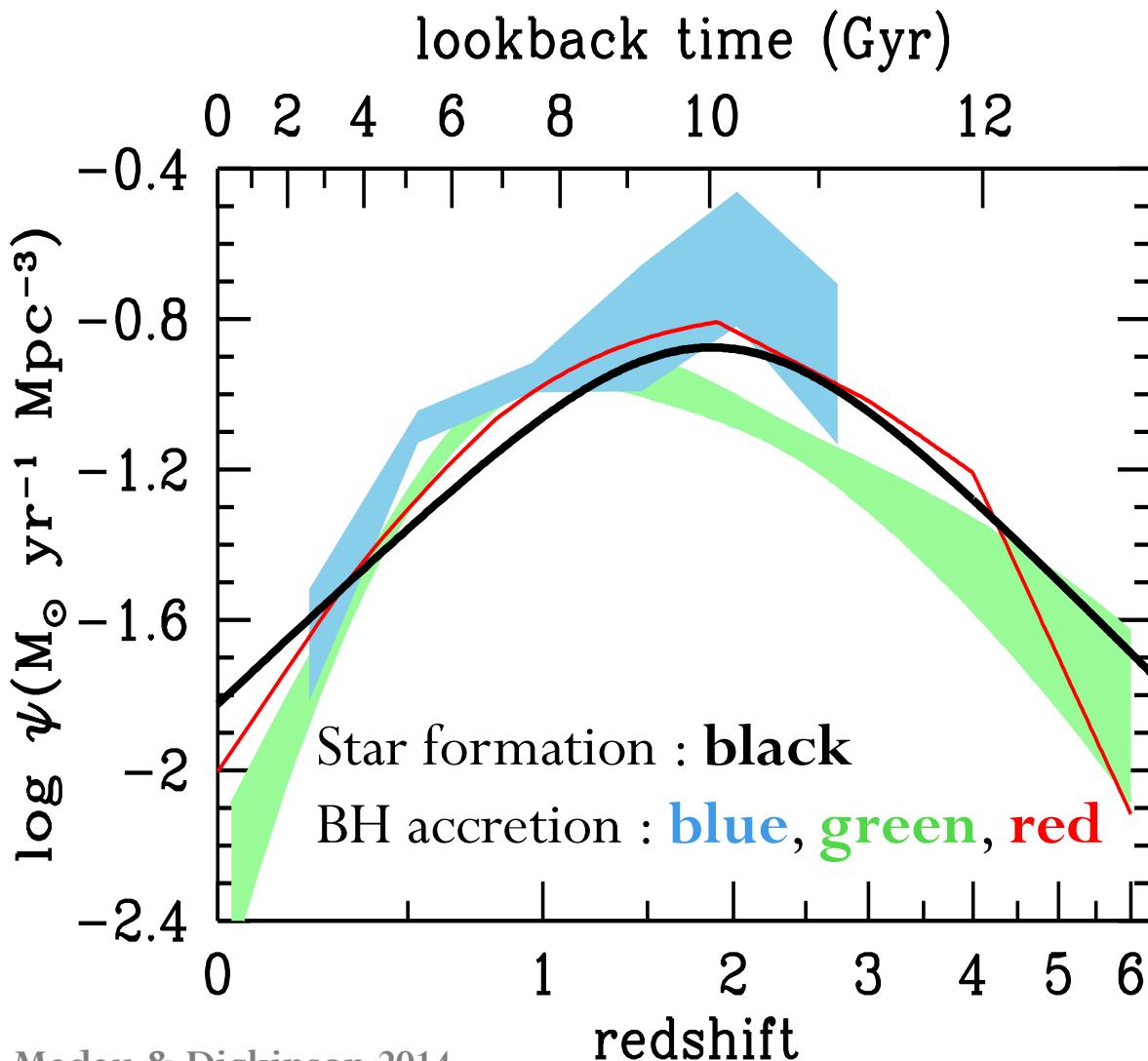


A dusty galaxy at  $z \sim 7.5!$   
SFR  $\sim 10 \text{Msun/yr}$

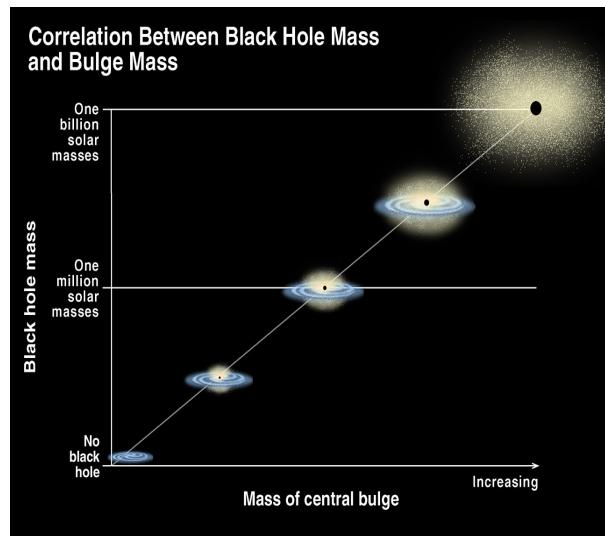


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# Dust-obscured activity dominates the build-up of stars **and black holes** in galaxies



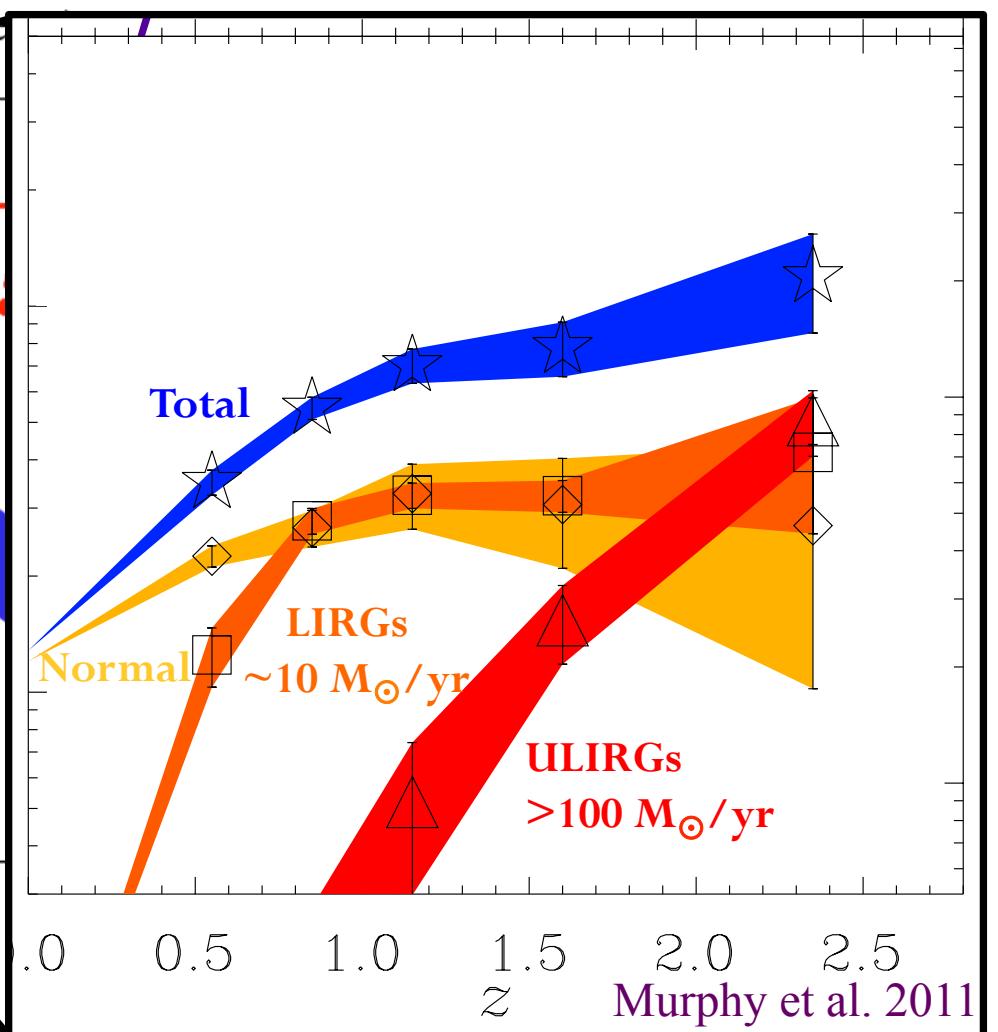
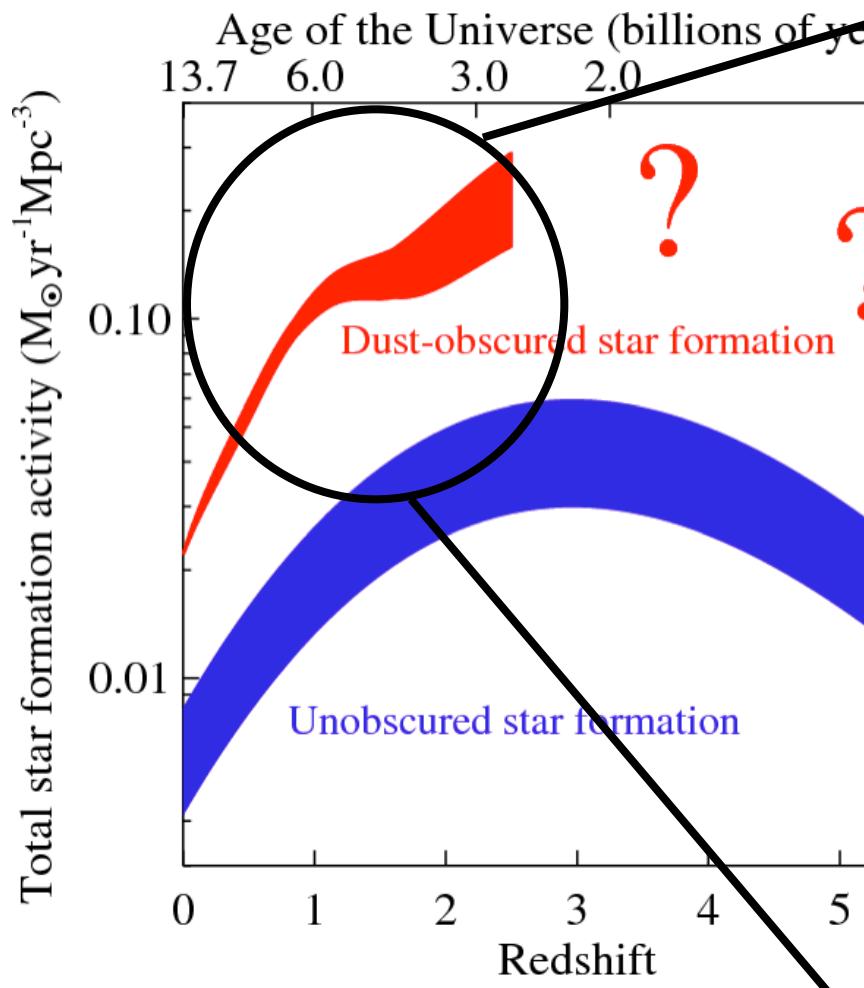
Madau & Dickinson 2014



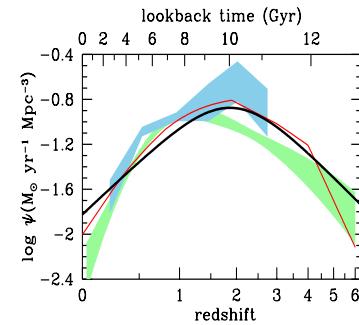
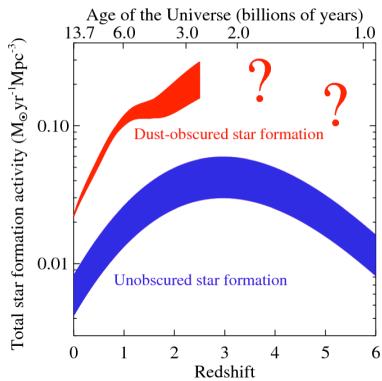
Credit: K. Cordes, S. Brown ([STScI](#))

# Most of the $z \sim 1$ -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  $z \sim 2$ ? 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:

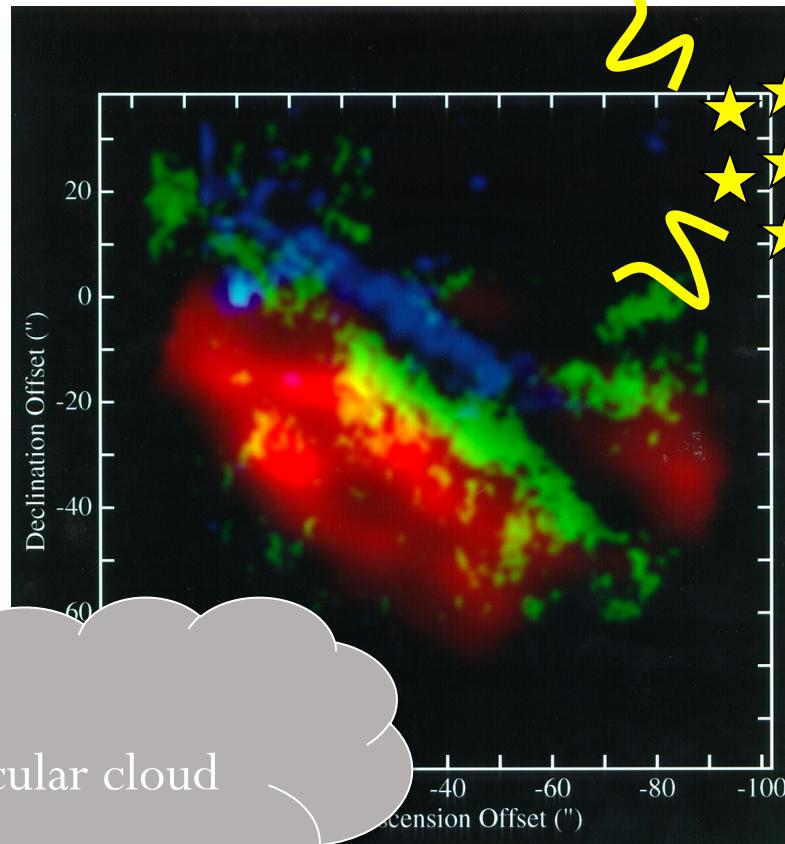
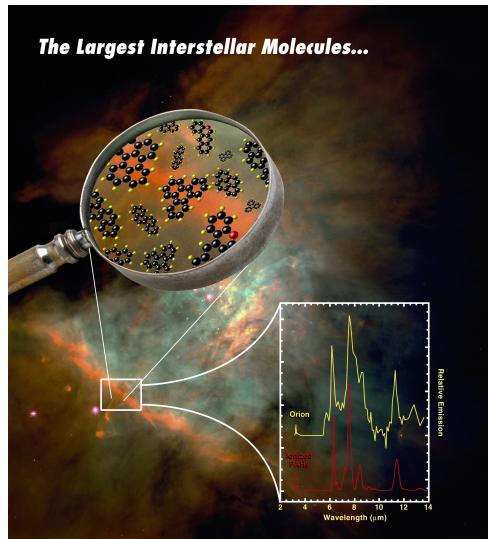
- **What drives the cosmic history of star formation?**

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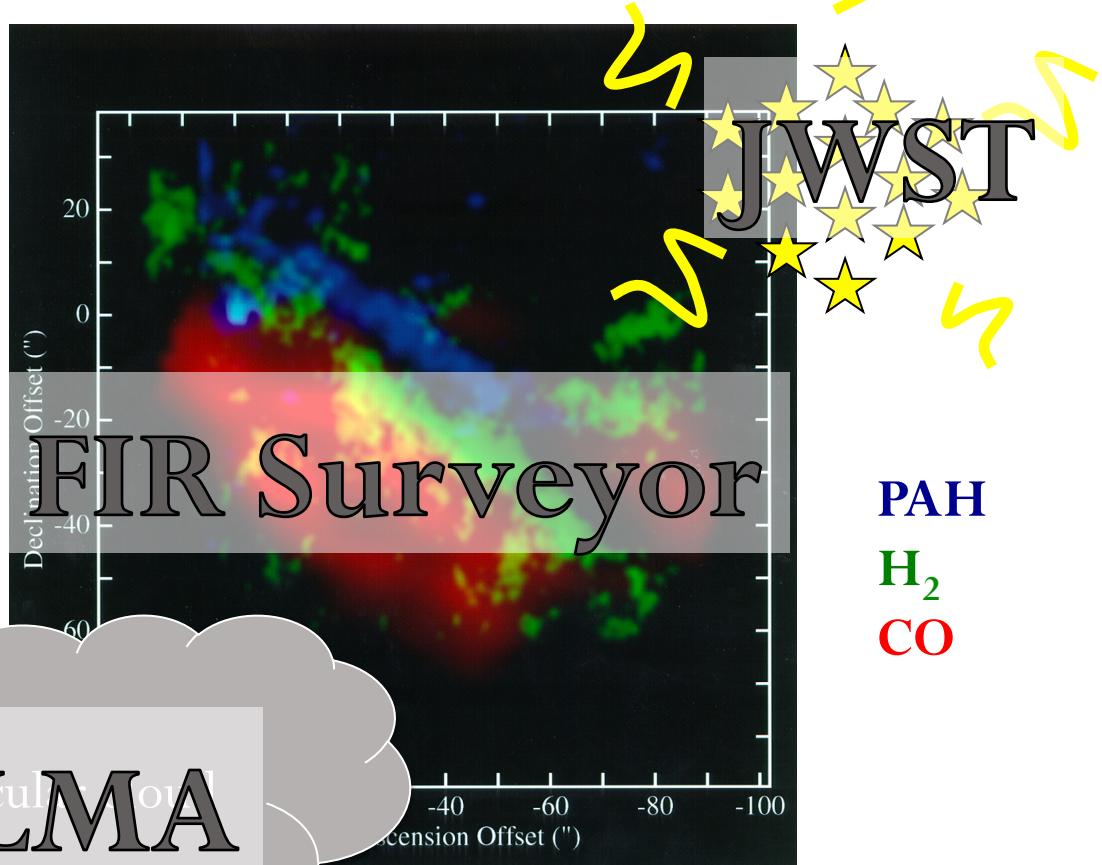
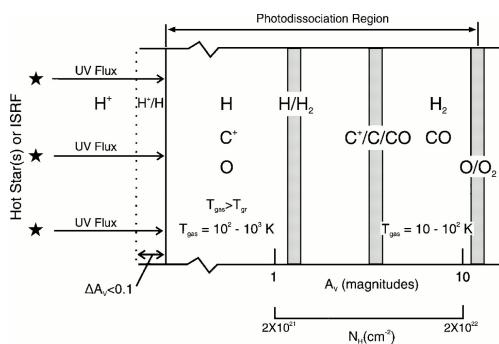
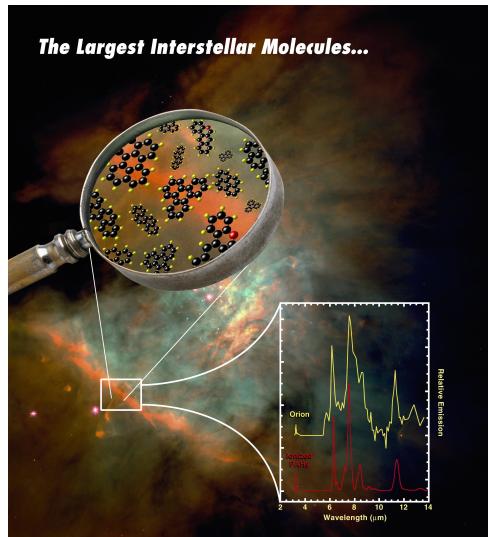
We need to identify and separate the emission from each in our observations.

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



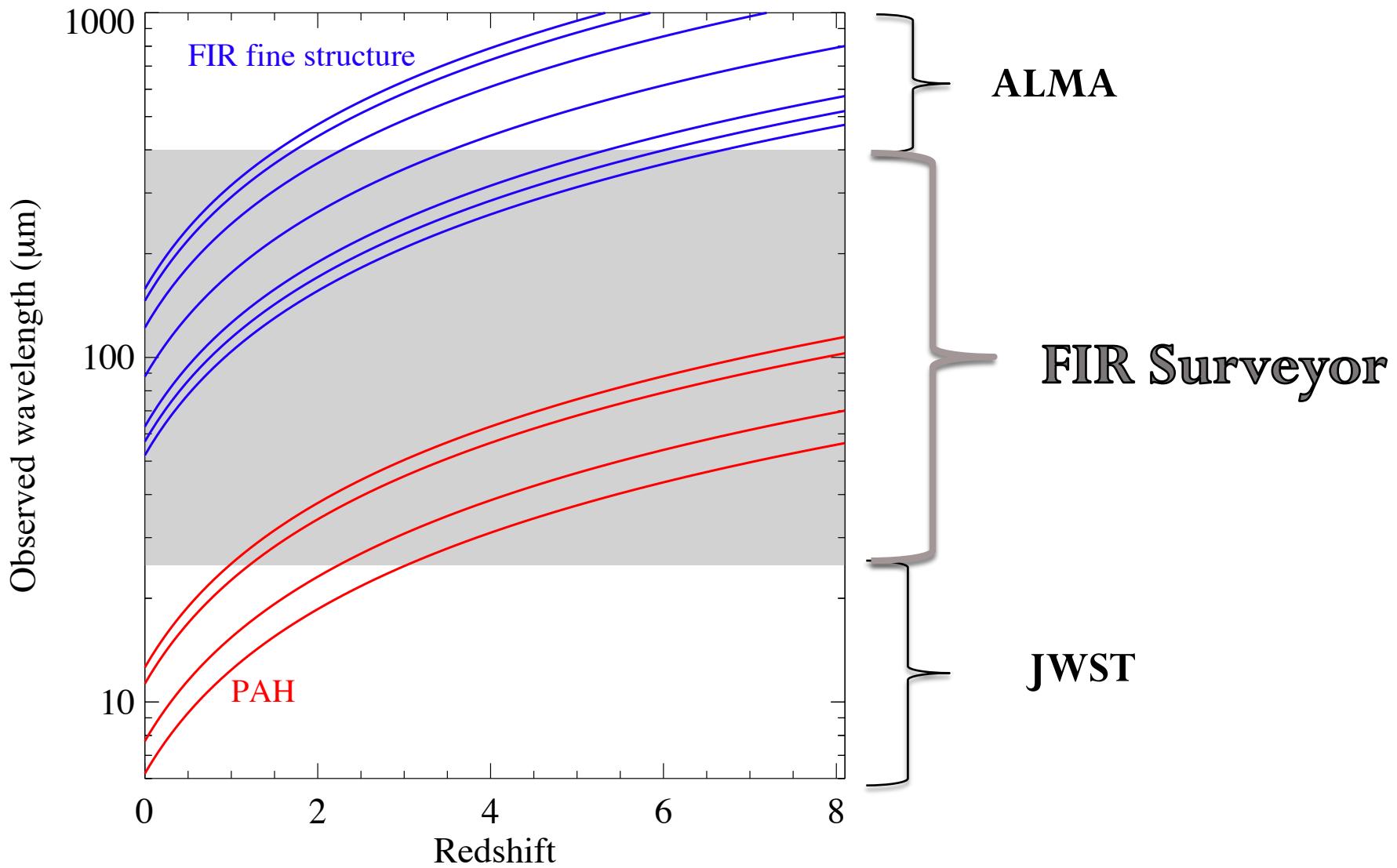
Hollenbach & Tielens 1997

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Hollenbach & Tielens 1997

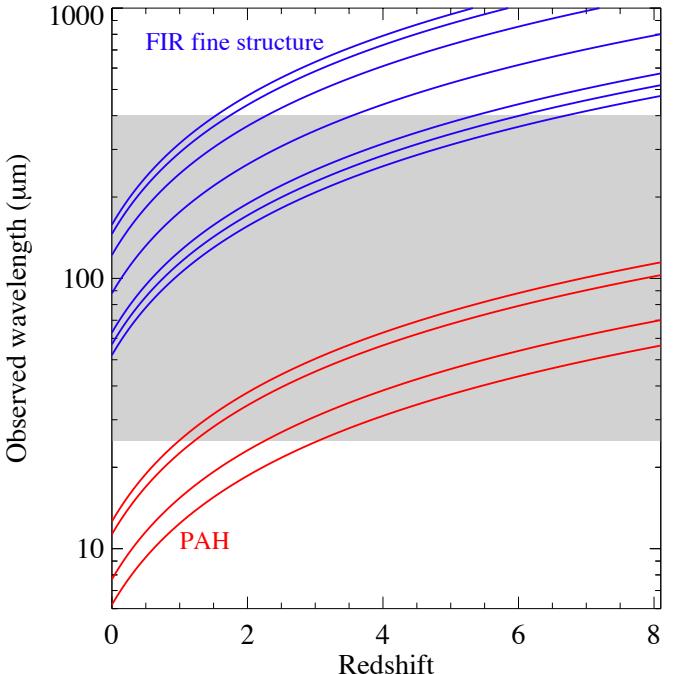
# Infrared lines at high redshift



# Galaxy Evolution: IR Diagnostics

## 1. Far-IR spectrum

- Fine structure lines probe PDR chemistry and strength of incident radiation field



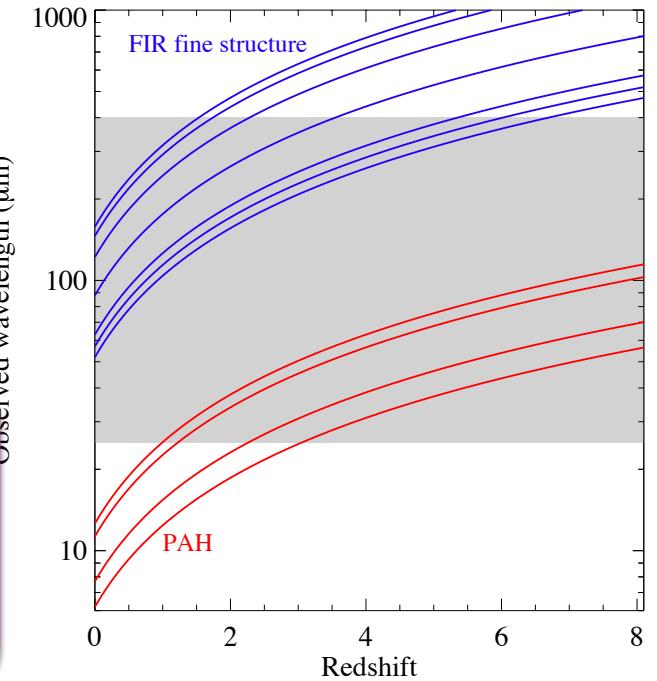
## 2. Mid-IR spectrum

- ID and quantify AGN emission
- Fine structure lines identify high ionization gas
- PAHs probe ISM conditions ( $\Rightarrow$ SF)
- Warm H<sub>2</sub> -> see P. Appleton talk
- Metallicity indicators

# Galaxy Evolution: IR Diagnostics

## 1. Far-IR spectrum

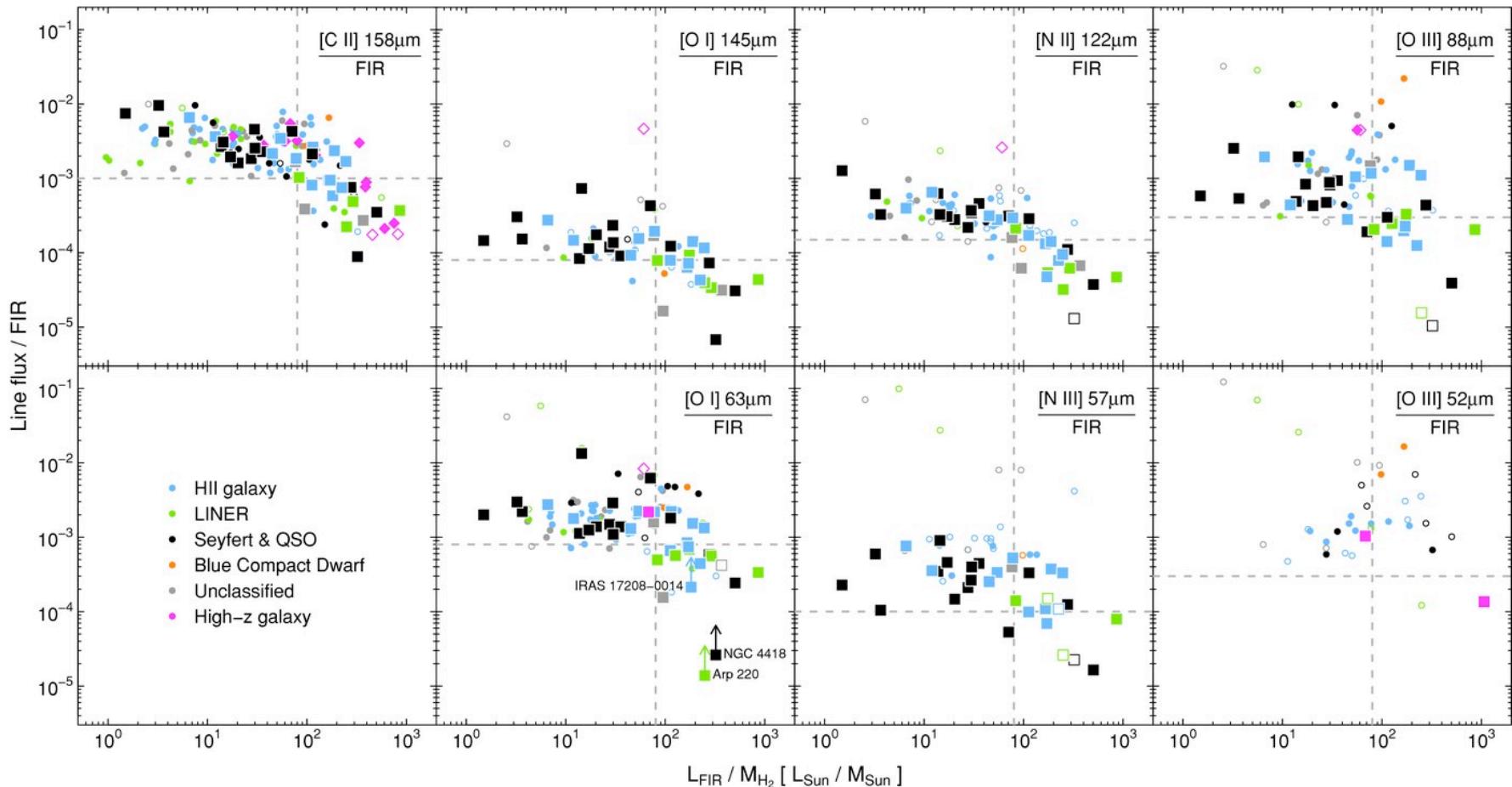
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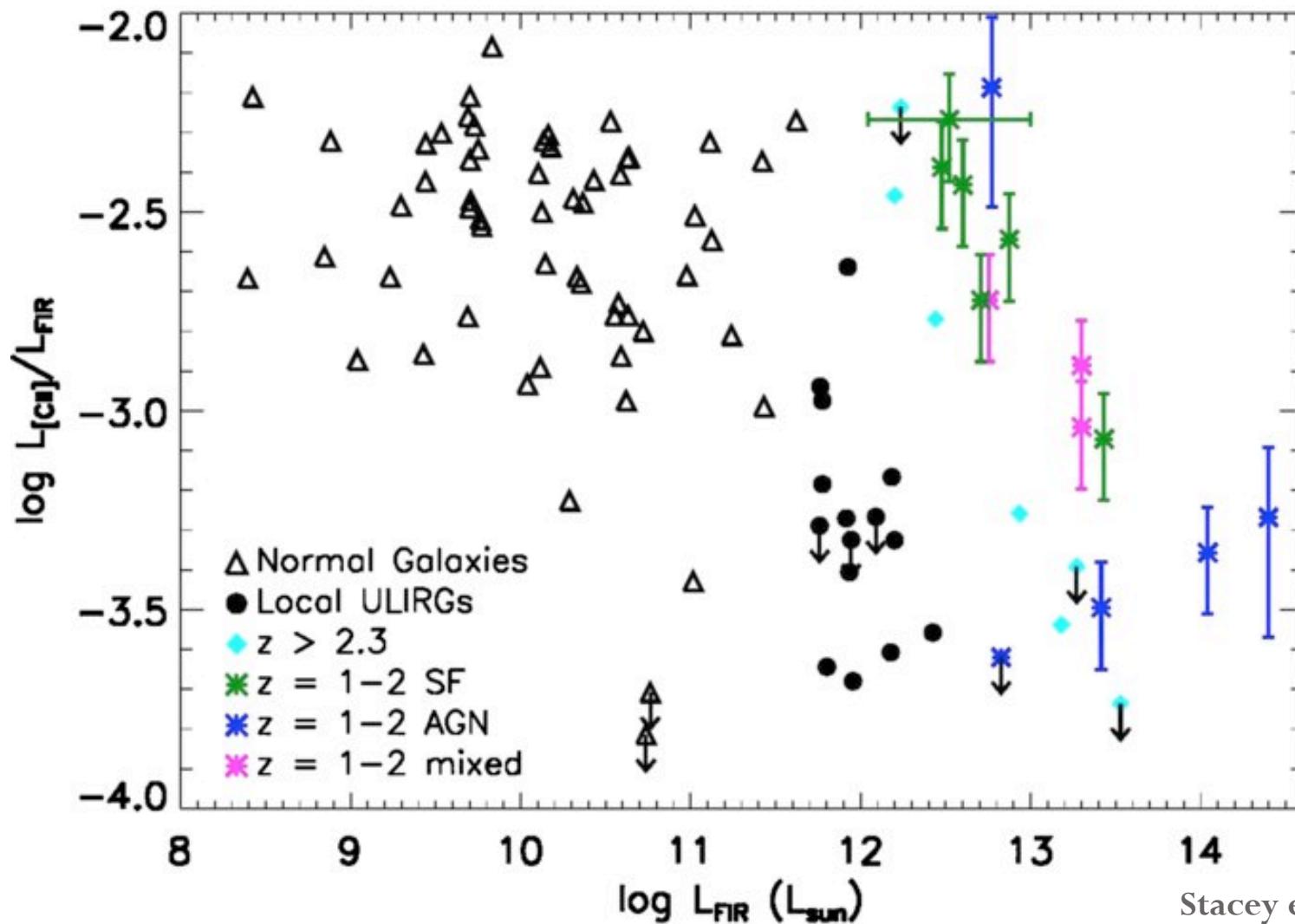
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# Far-IR fine structure lines (C, O, N) in the local Universe : Universal deficit at high $L_{\text{IR}}$ or $L_{\text{IR}}/M_{\text{H}_2}$

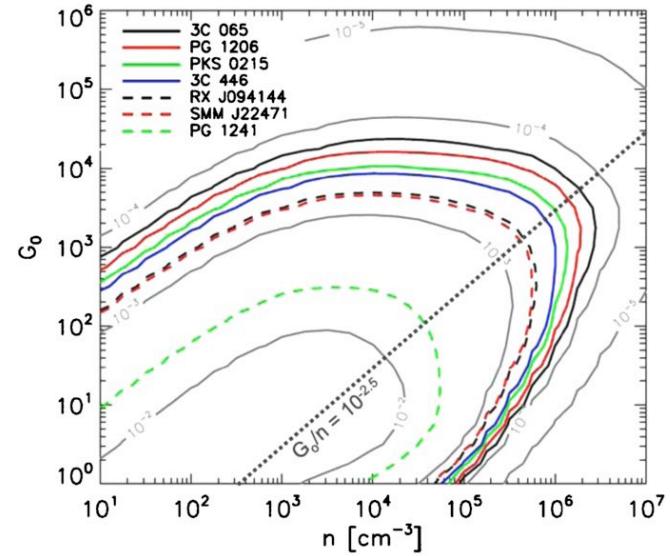
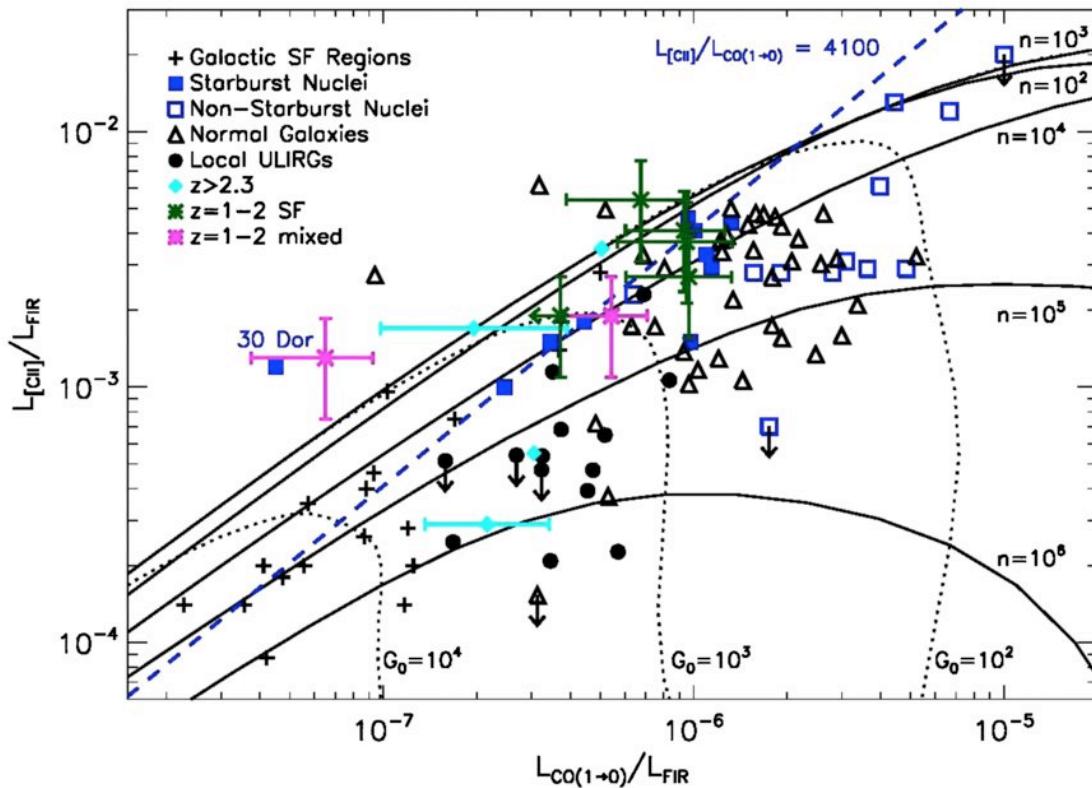


Gracia-Carpio et al. 2011, see also Farrah et al. 2013

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

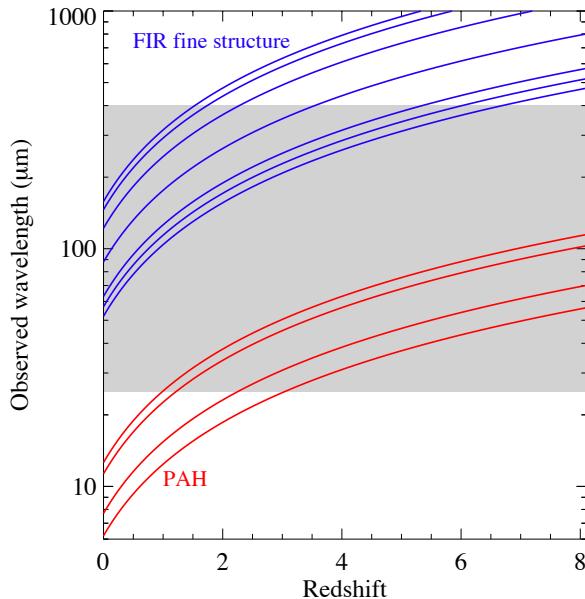
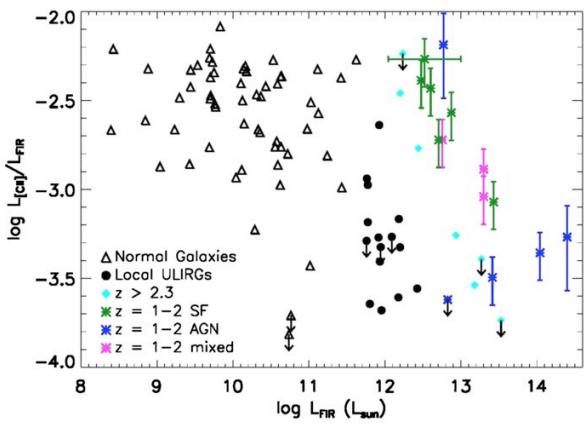
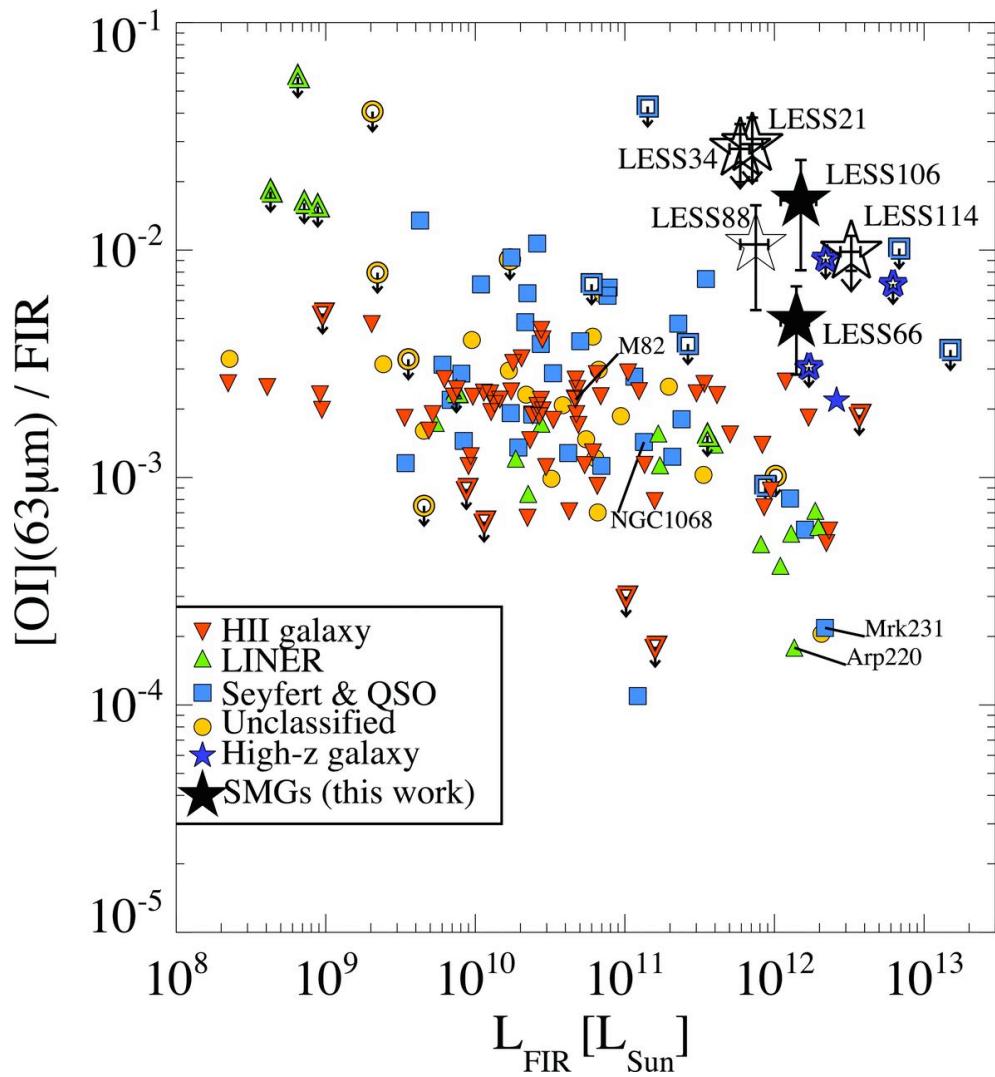


# Far-IR [CII]158 at high redshift: PDR modeling to estimate $G_0$ and $n$



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

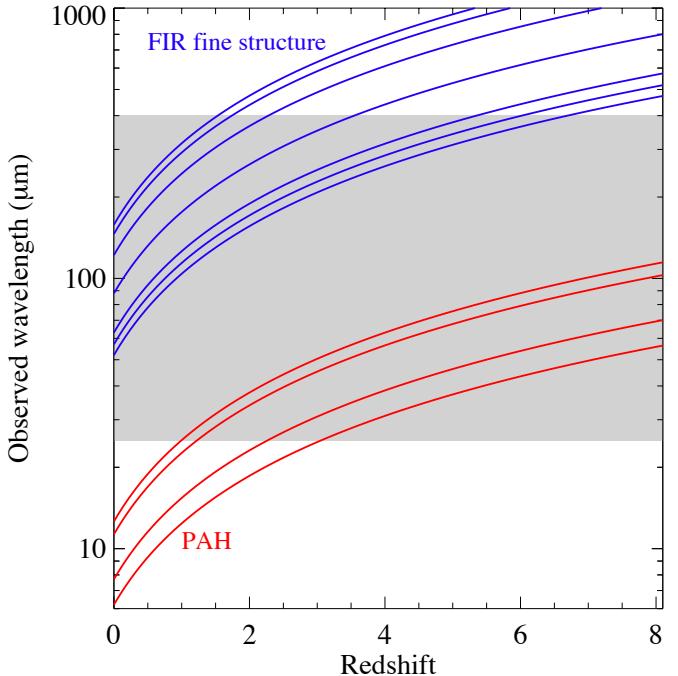
# Far-IR [OI]63 at high redshift: Also enhanced in high redshift galaxies



# Galaxy Evolution: IR Diagnostics

## 1. Far-IR spectrum

- Fine structure lines probe PDR chemistry and strength of incident radiation field



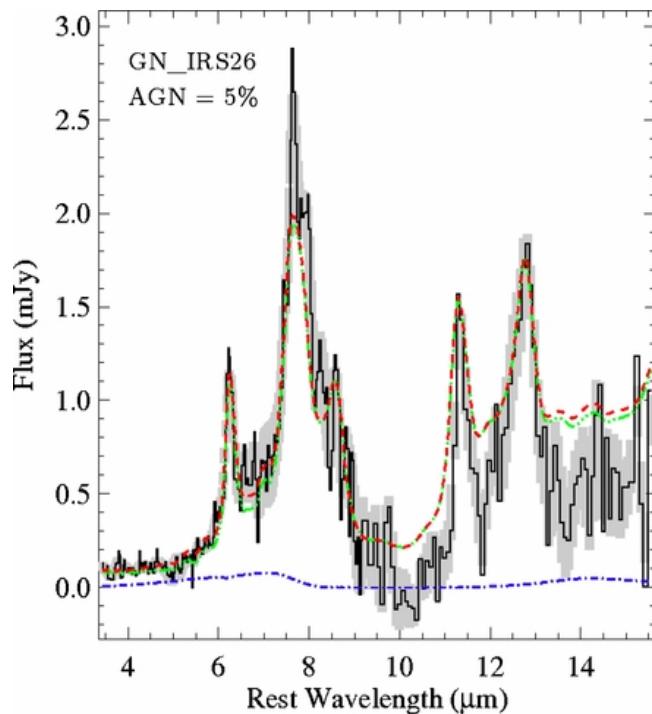
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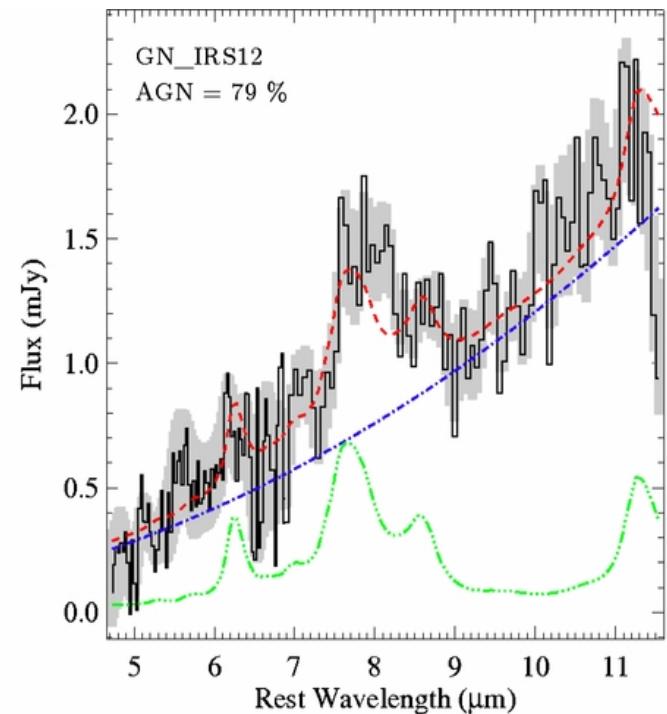
# Quantifying AGN and SF activity in high redshift galaxies: mid-IR spectral decomposition



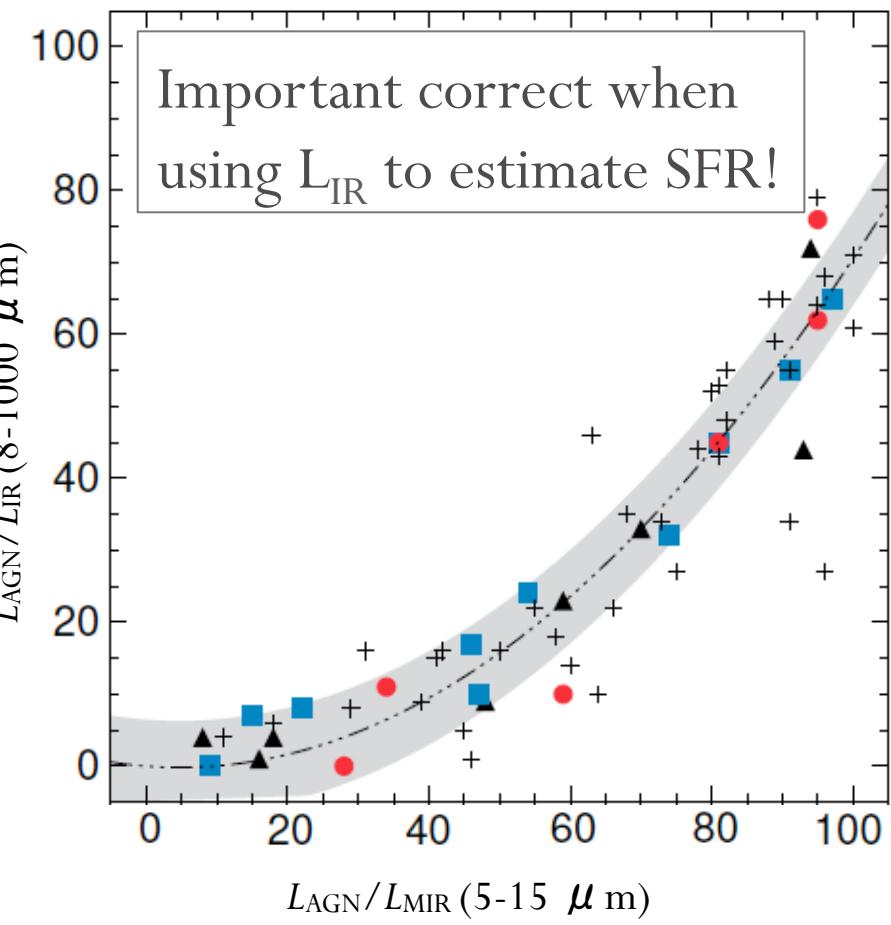
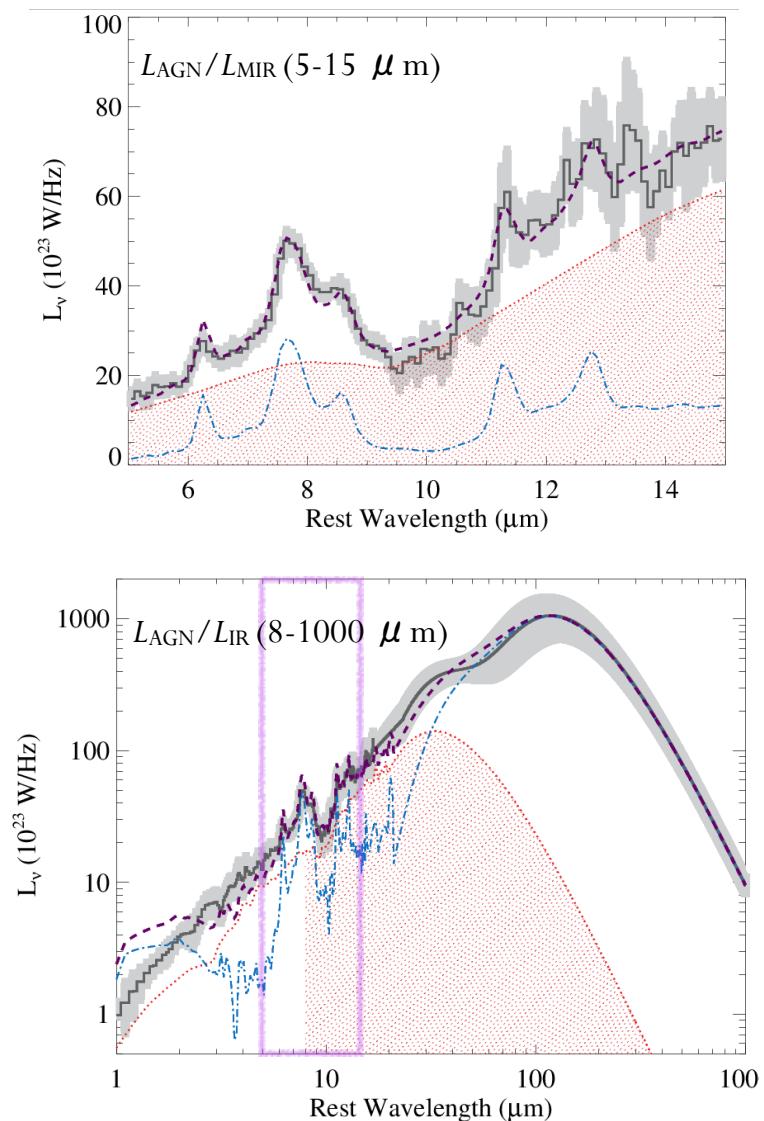
## 1. Star formation: Polycyclic aromatic hydrocarbons (PAH) emission lines + extinction



## 2. Active Galactic Nuclei: Power-law + extinction



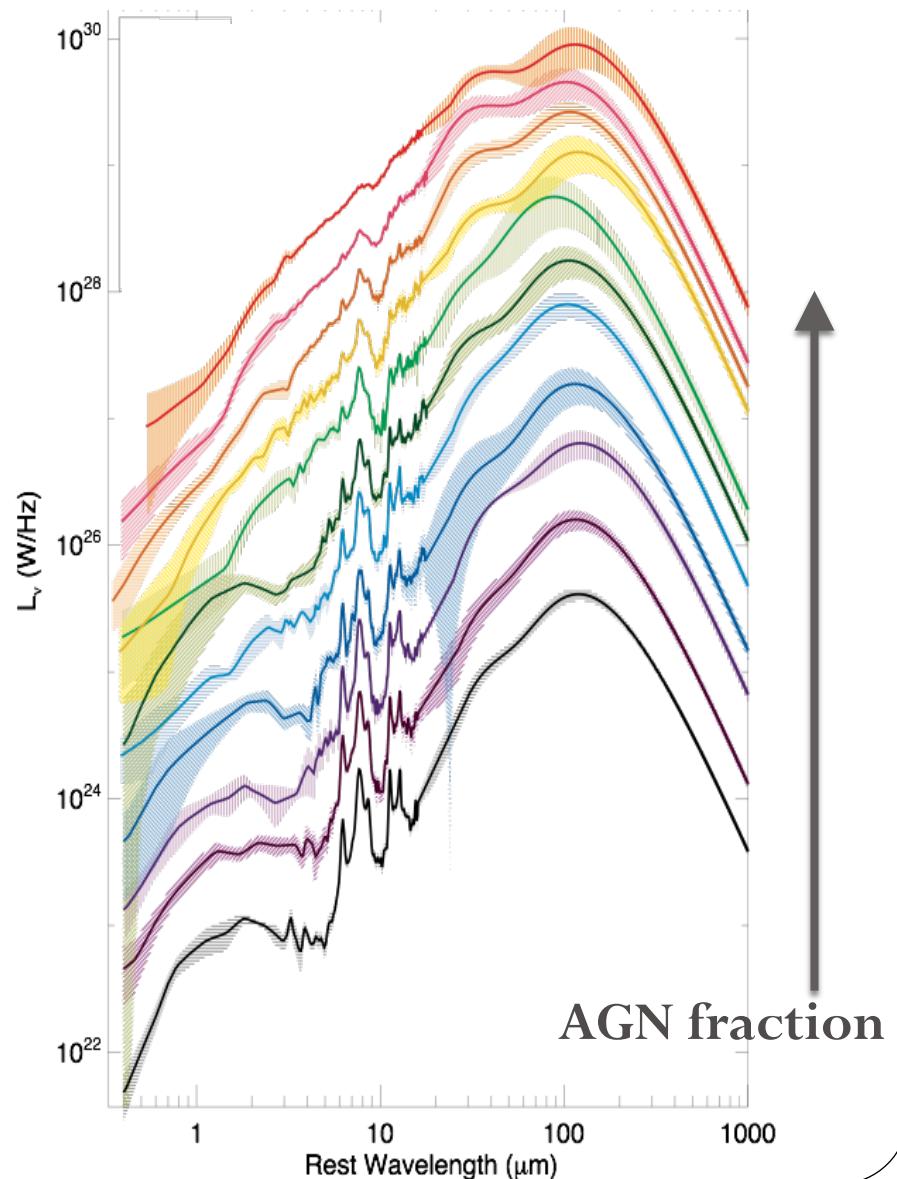
# Mid-IR AGN fraction $\rightarrow$ Total IR AGN fraction



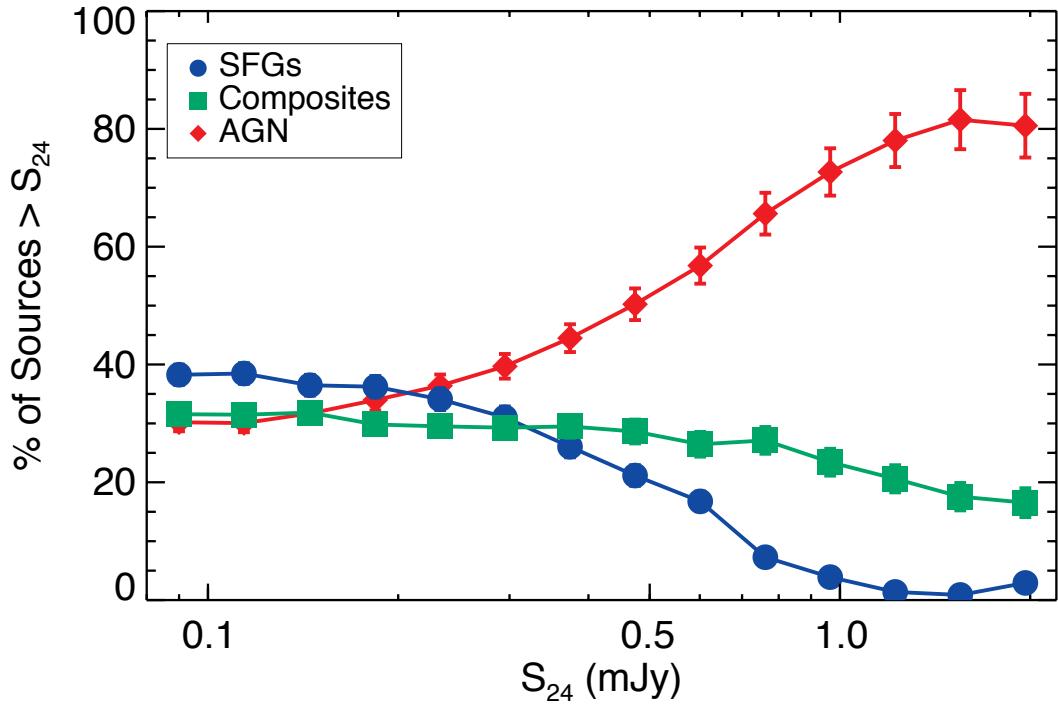
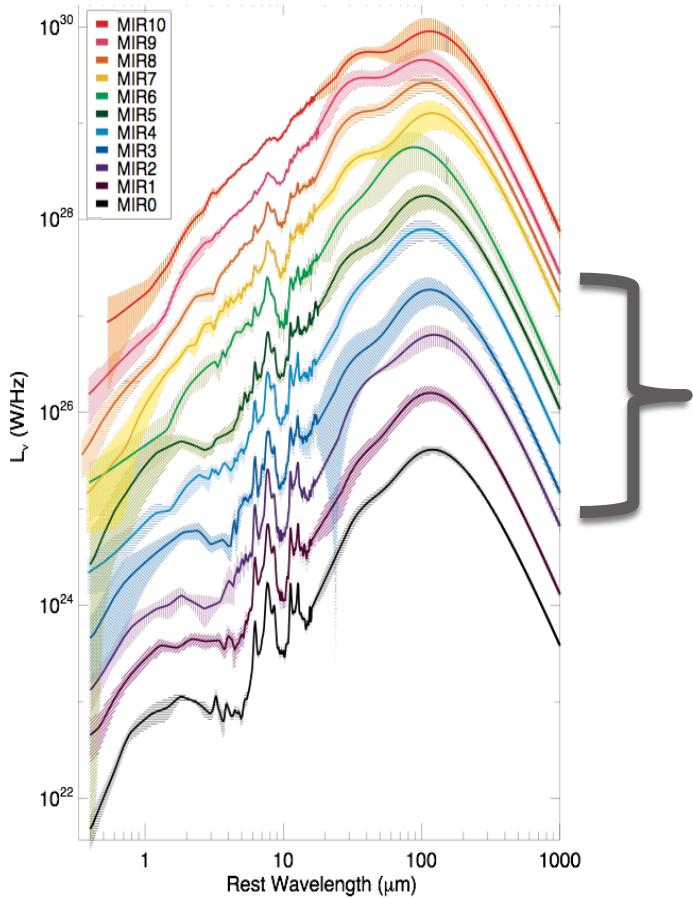
# Galaxy SEDs as a function of AGN fraction

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

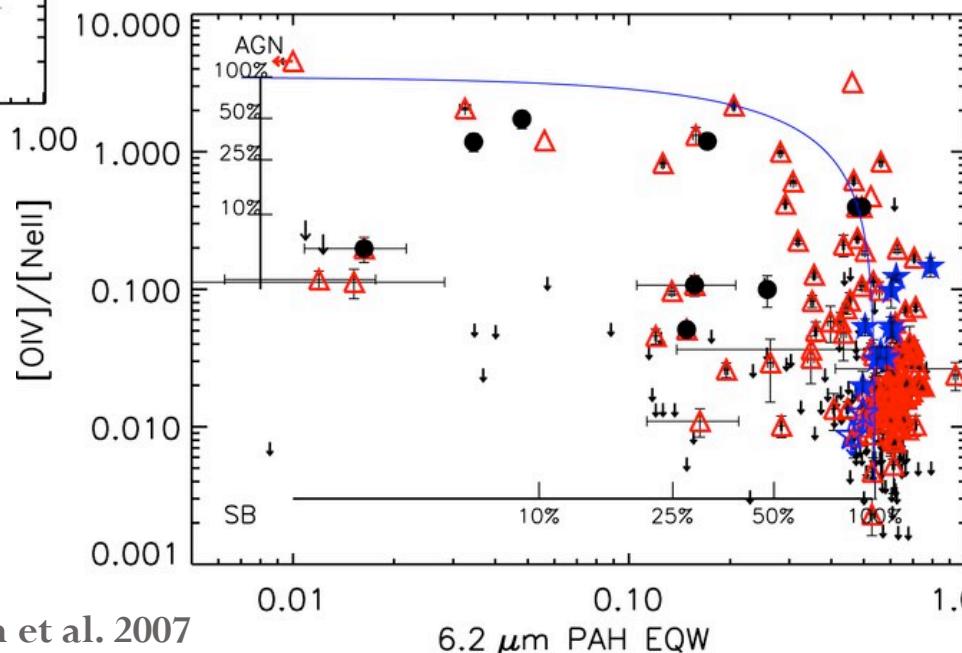
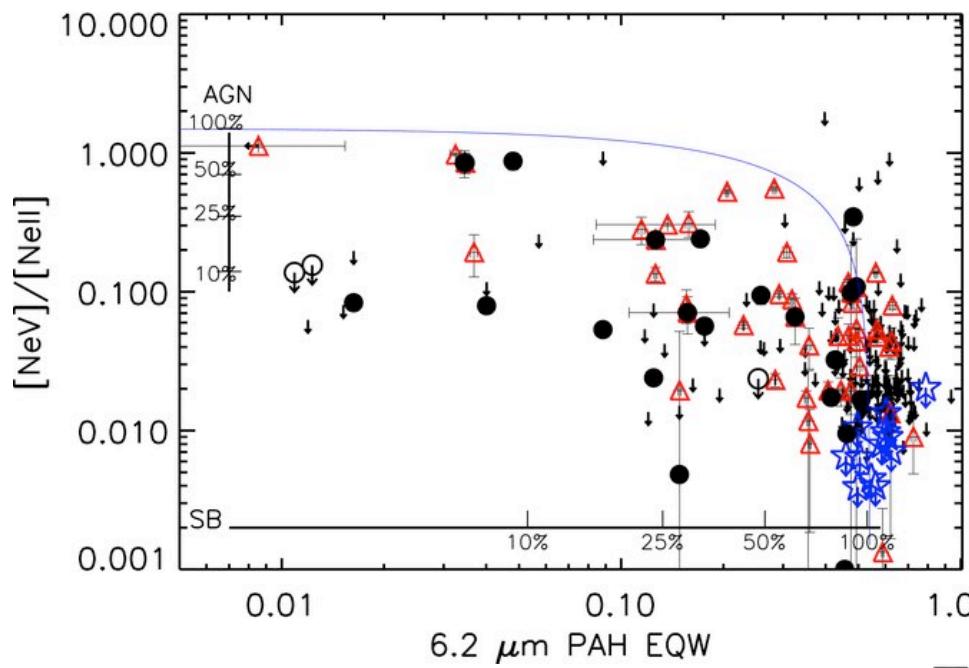


# Composites sources are a significant fraction of high redshift galaxy samples

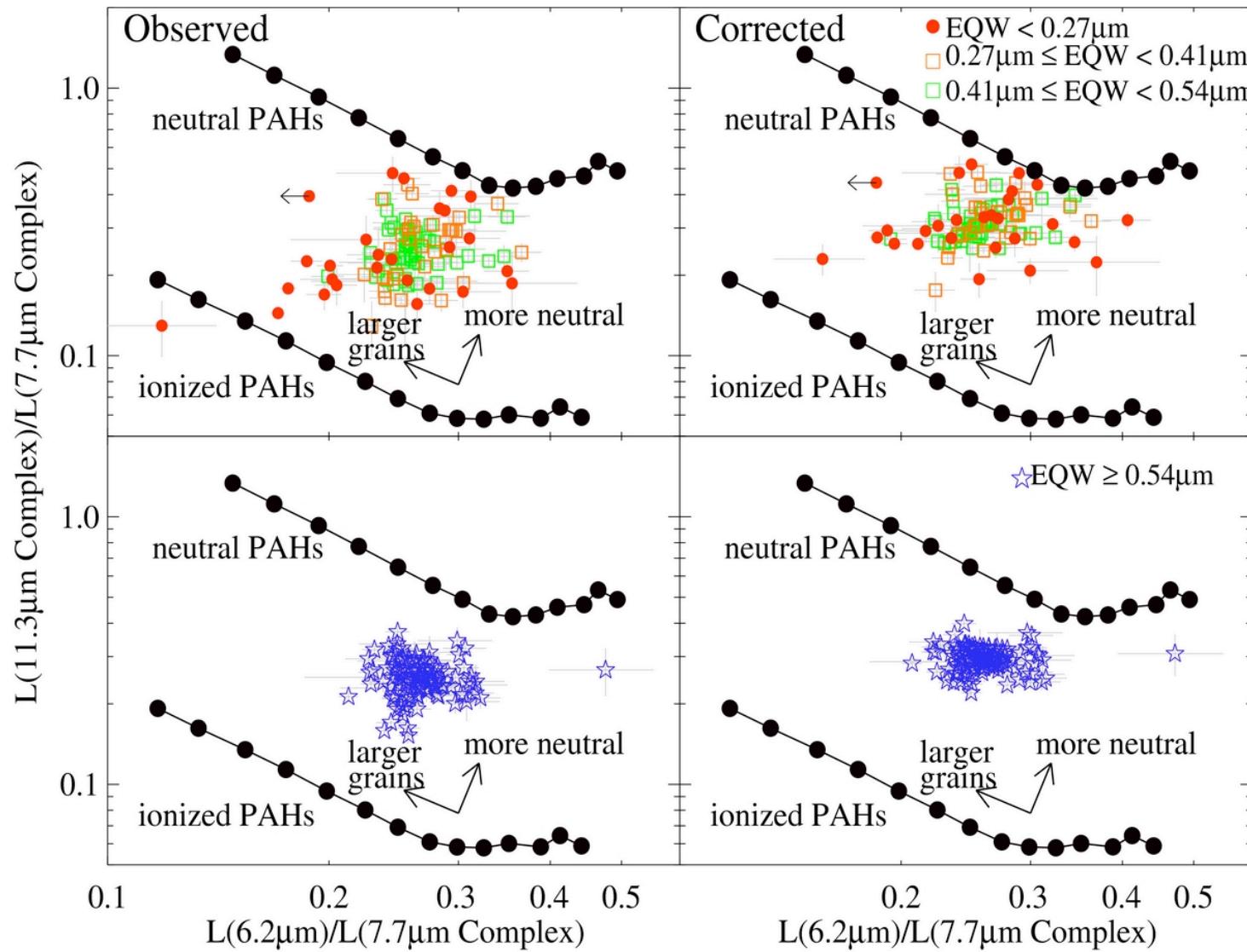


Need mid-IR spectra to reliably identify and quantify the AGN emission in high redshift galaxies.

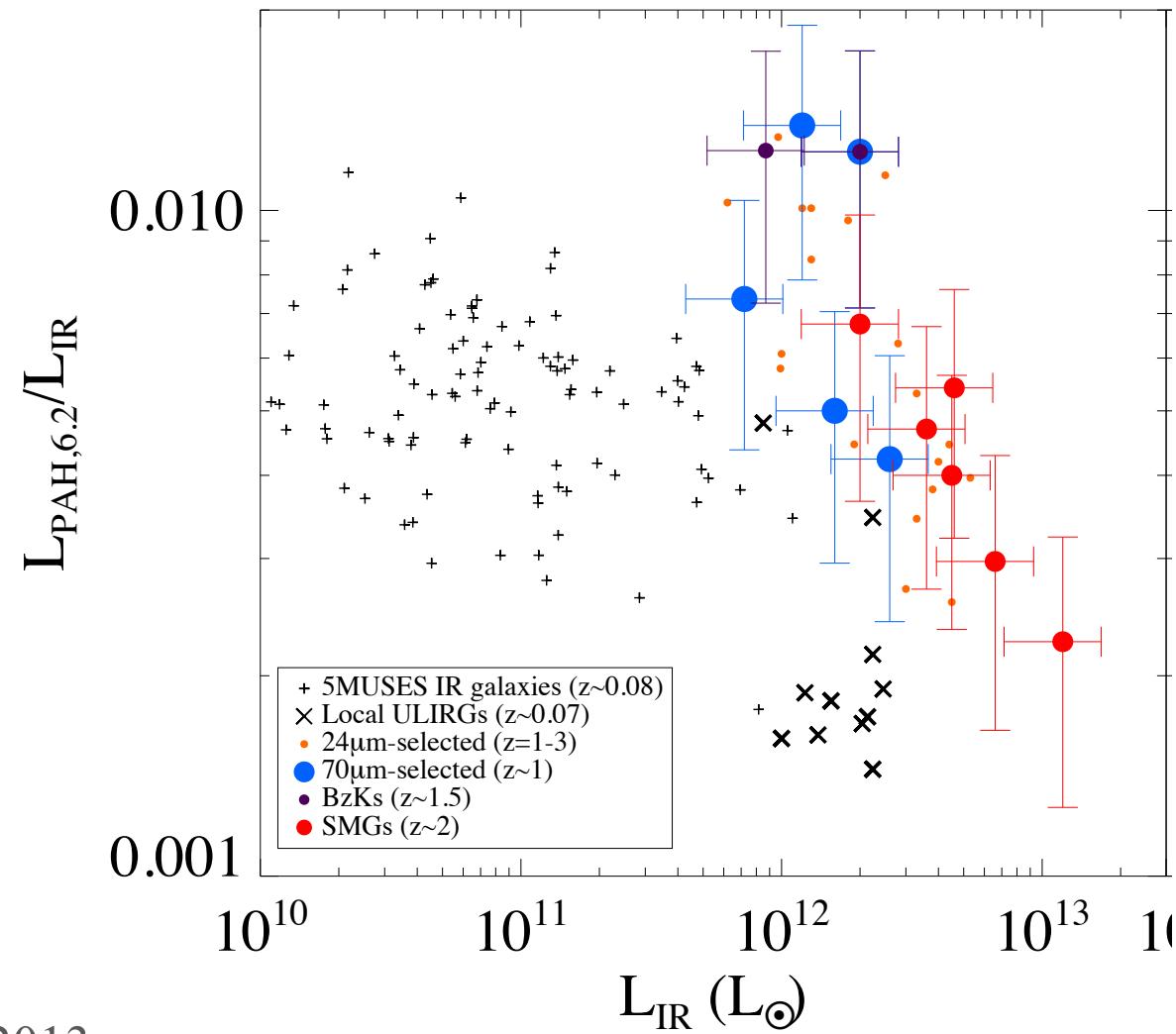
# Quantifying AGN and SF activity in high redshift galaxies: high ionization lines



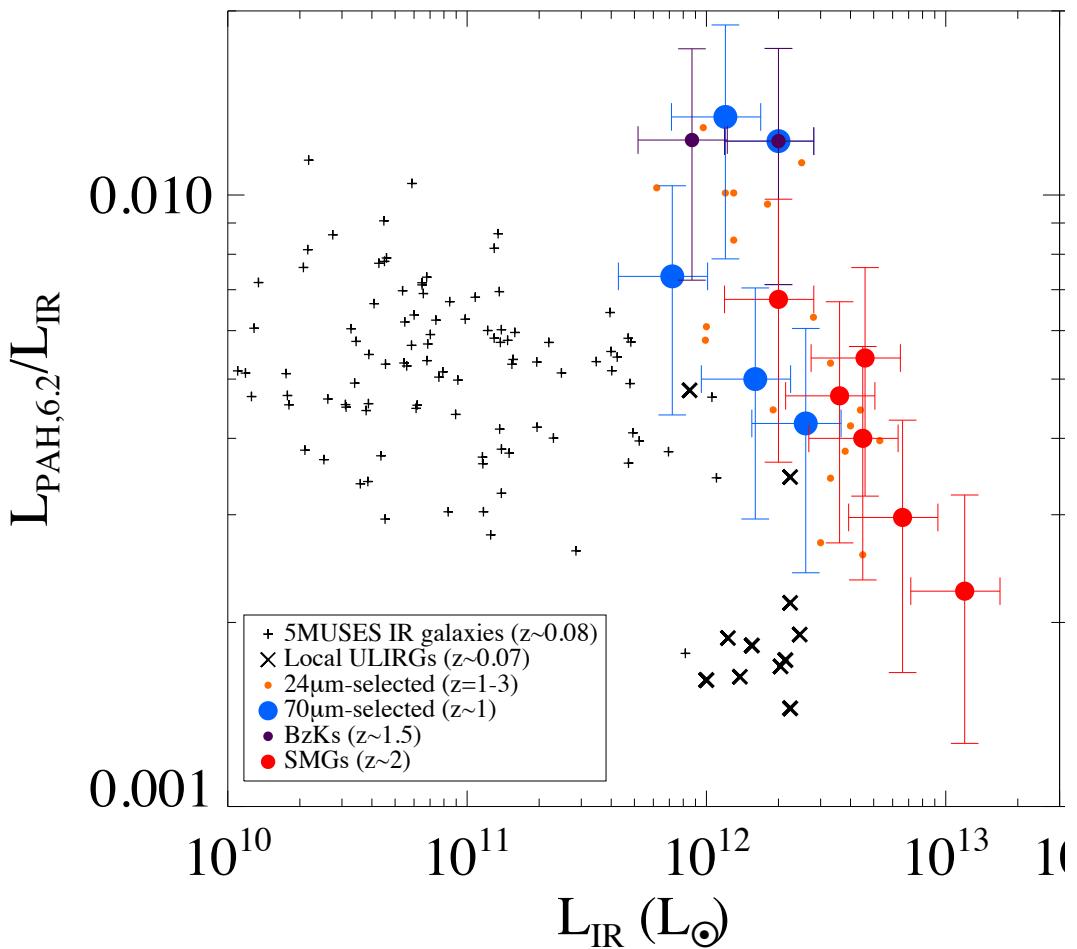
# Probing ISM conditions: PAH line ratios



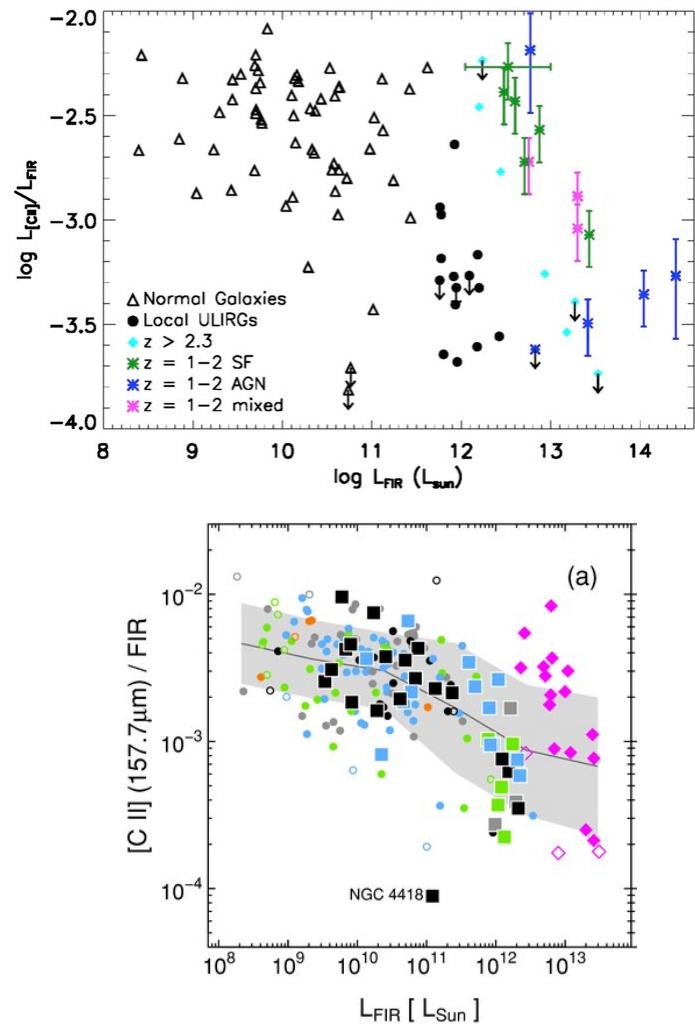
# Enhanced PAH emission at high redshift



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

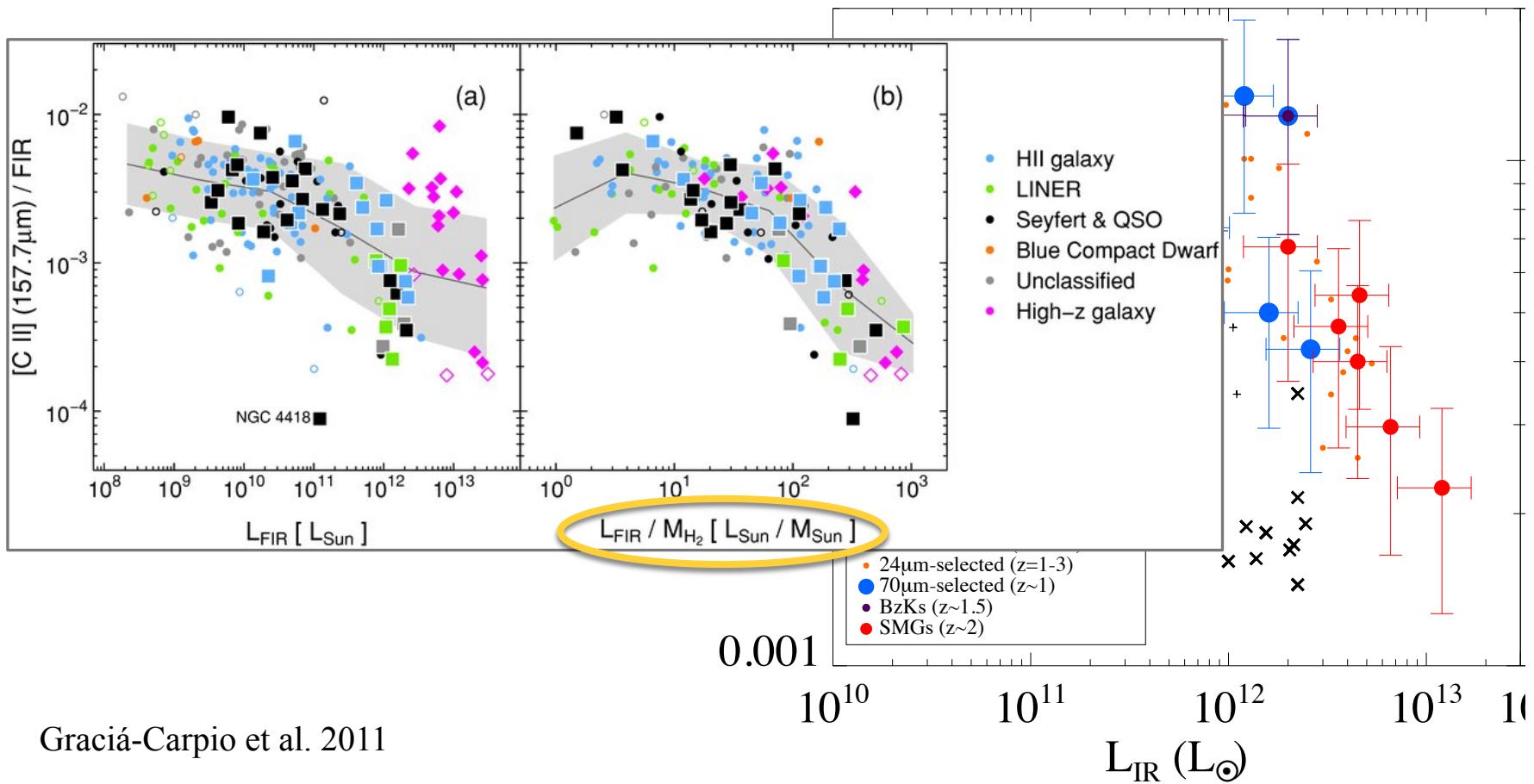


Pope et al. 2013



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

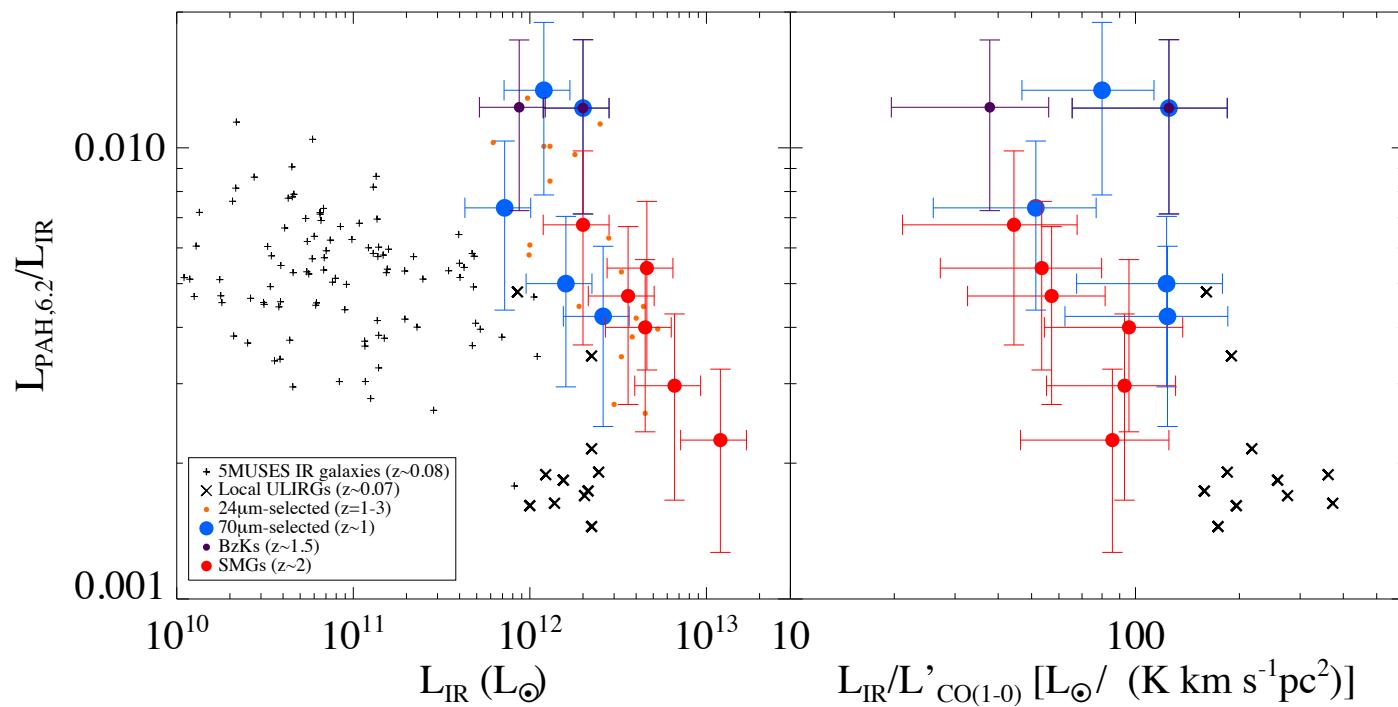
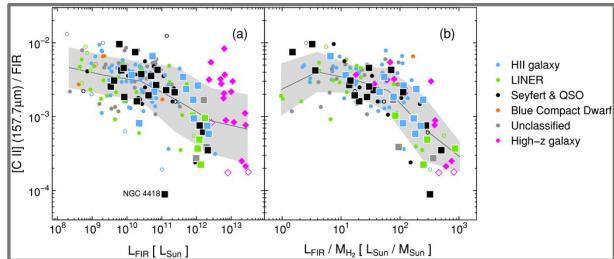
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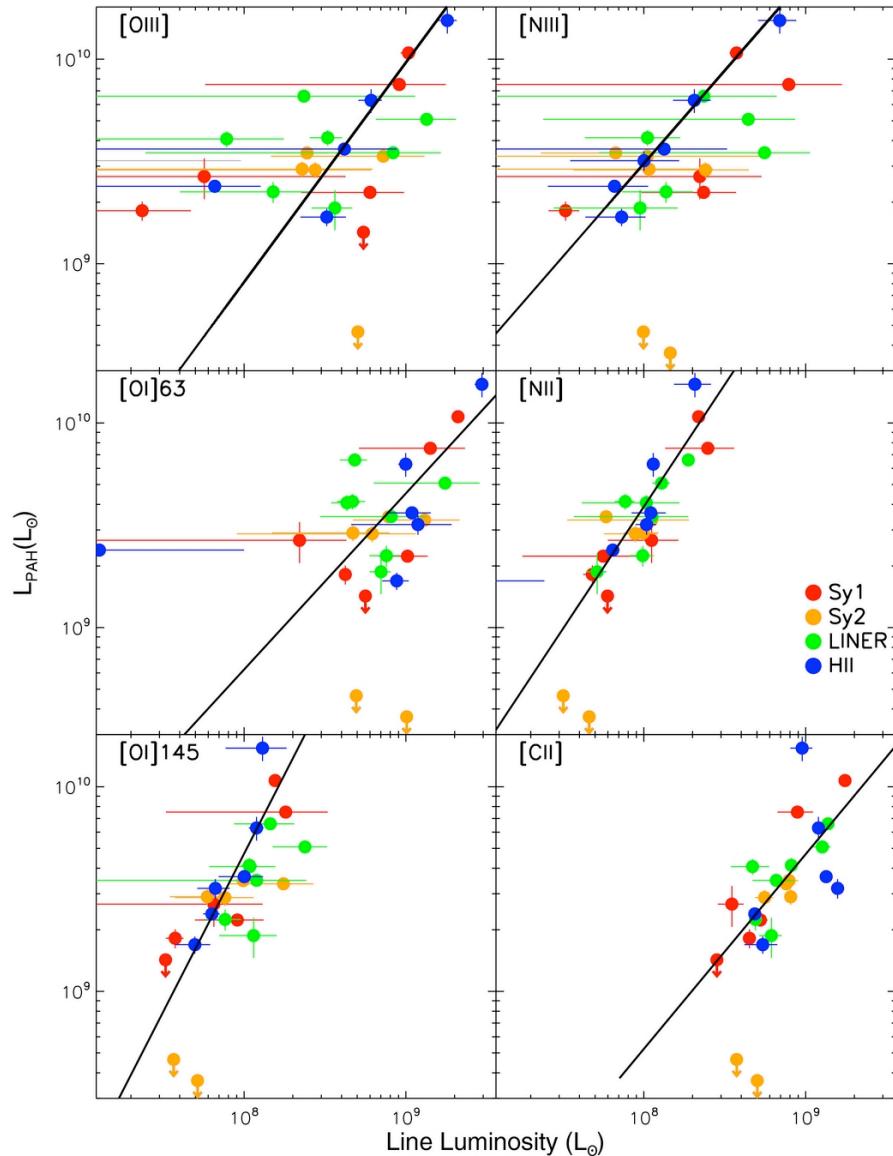
Pope et al. 2013

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

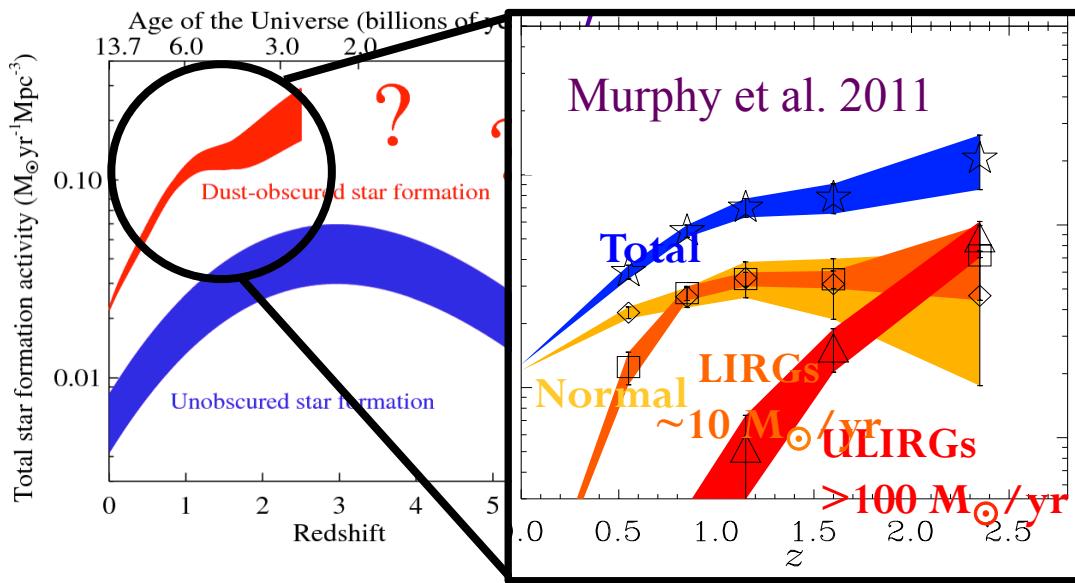


Pope et al. 2013

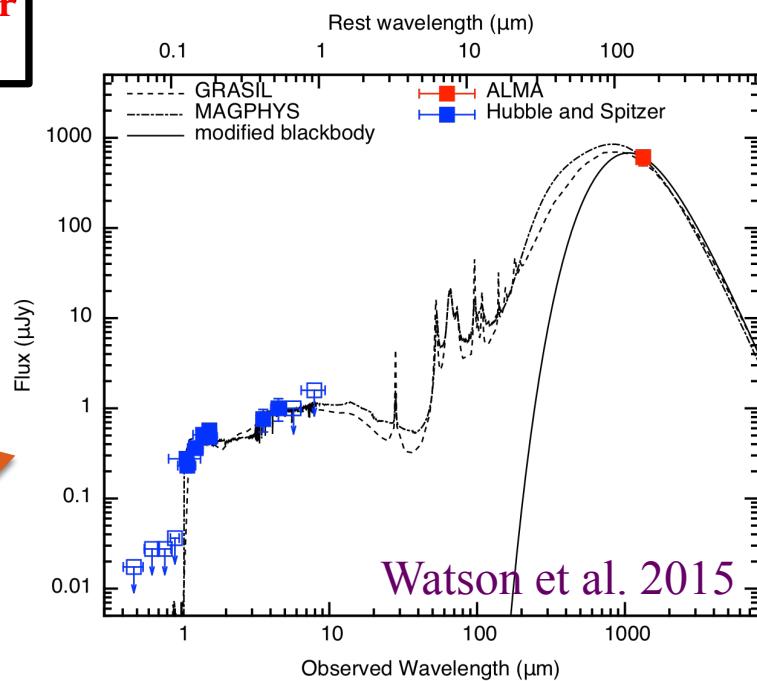
# Combining mid-IR and far-IR line diagnostics: Powerful probe of the ISM at high redshift



# How faint do we need to go?

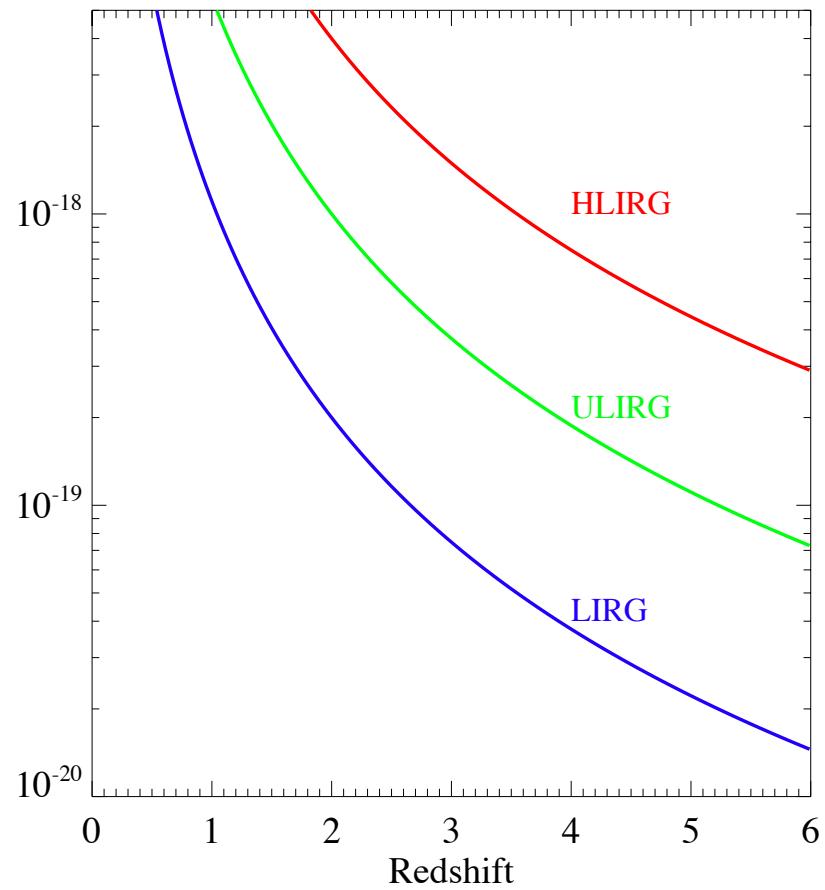
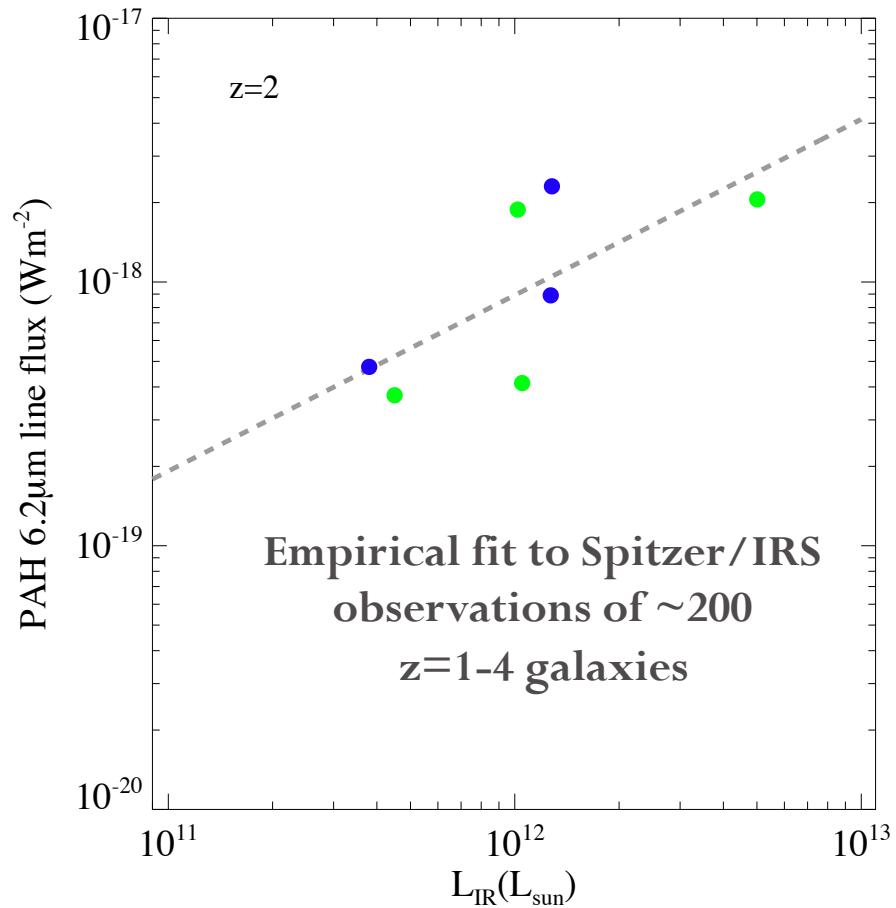


A dusty galaxy at  $z \sim 7.5!$   
SFR  $\sim 10 M_{\odot}/\text{yr}$



Watson et al. 2015

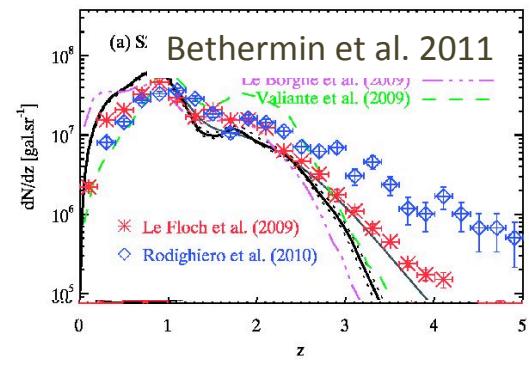
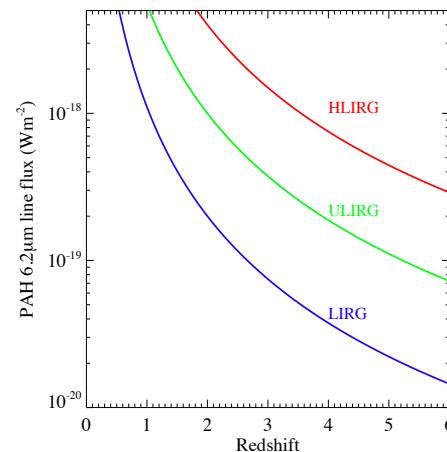
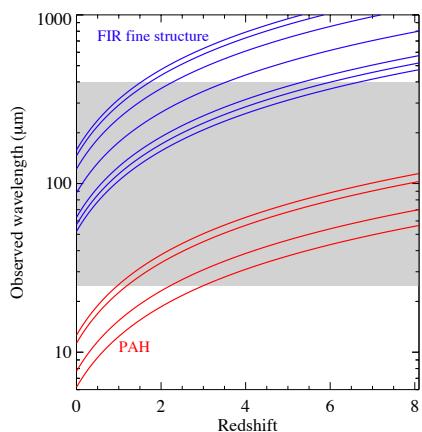
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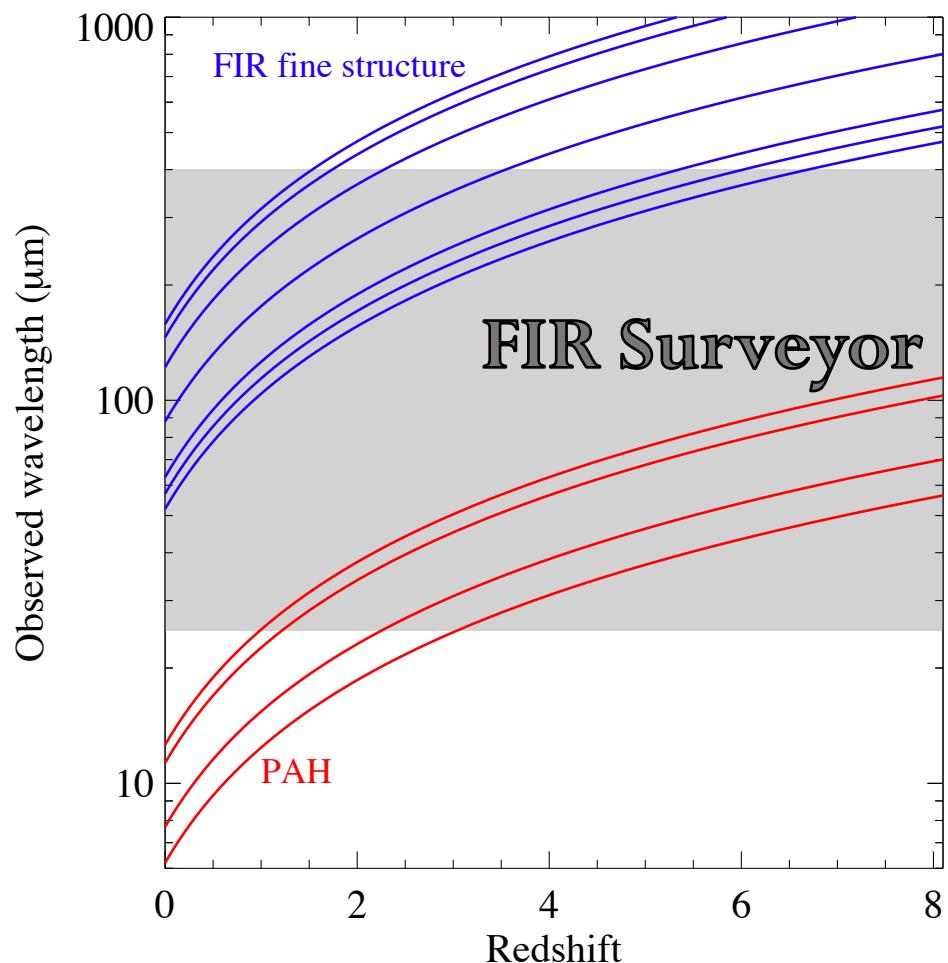
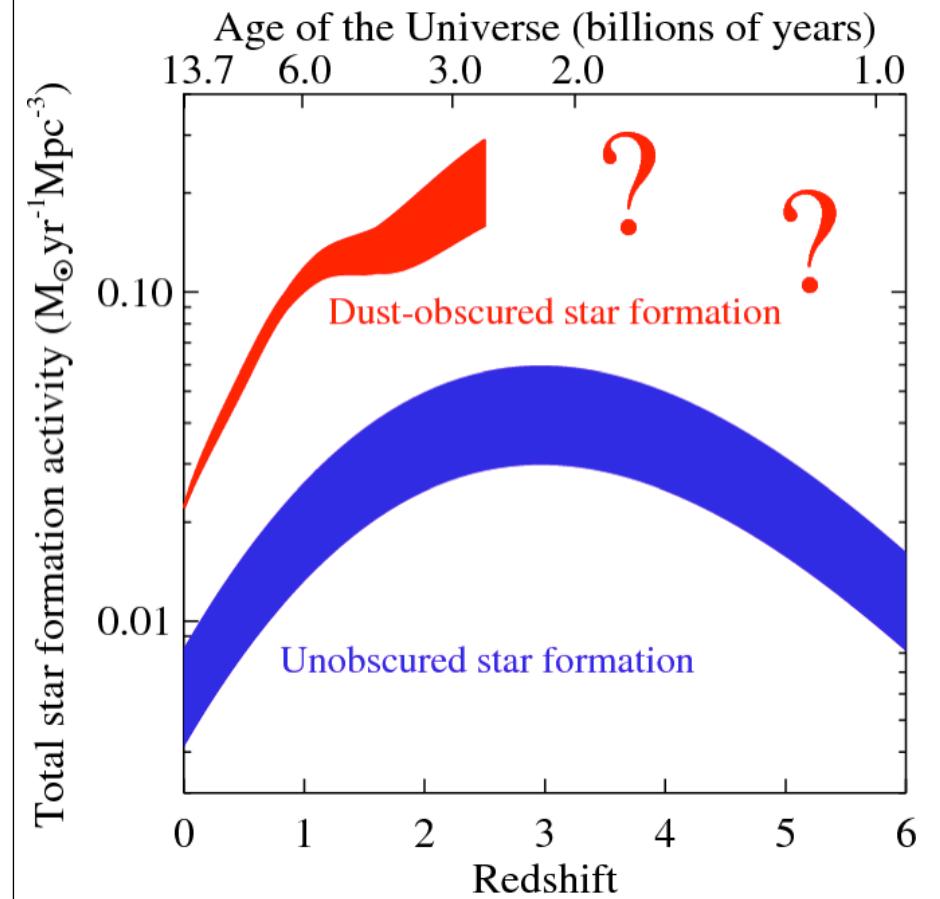
To detect PAHs and far-IR fine-structure lines (e.g. [OI]63)  
in every LIRG out to  $z \sim 6$  we need  $\sim 10^{-20} \text{ W m}^{-2}$

# Desired Measurement Capabilities: High redshift galaxies

| Parameter                                      | Units                       | Value or Range |
|--|-----------------------------|----------------|
| Wavelength range                               | $\mu\text{m}$               | 25-400         |
| Angular resolution                             | arcsec                      | 6              |
| Spectral resolution, $(\lambda/\Delta\lambda)$ | dimensionless               | 100            |
| Continuum sensitivity                          | $\mu\text{Jy}$              |                |
| Spectral line sensitivity                      | $10^{-19} \text{ W m}^{-2}$ | 0.1            |
| Instantaneous FoV                              | arcmin                      |                |
| Number of target fields                        | dimensionless               |                |
| Field of Regard                                | sr                          | ~all sky       |



# 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  $z \sim 2$ ? 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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