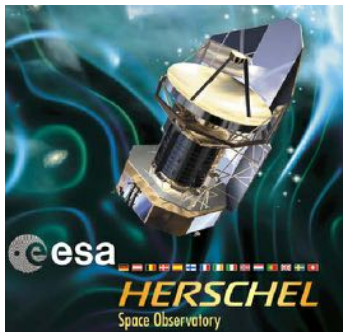
Observational signatures of an evolving interstellar medium in high redshift galaxies

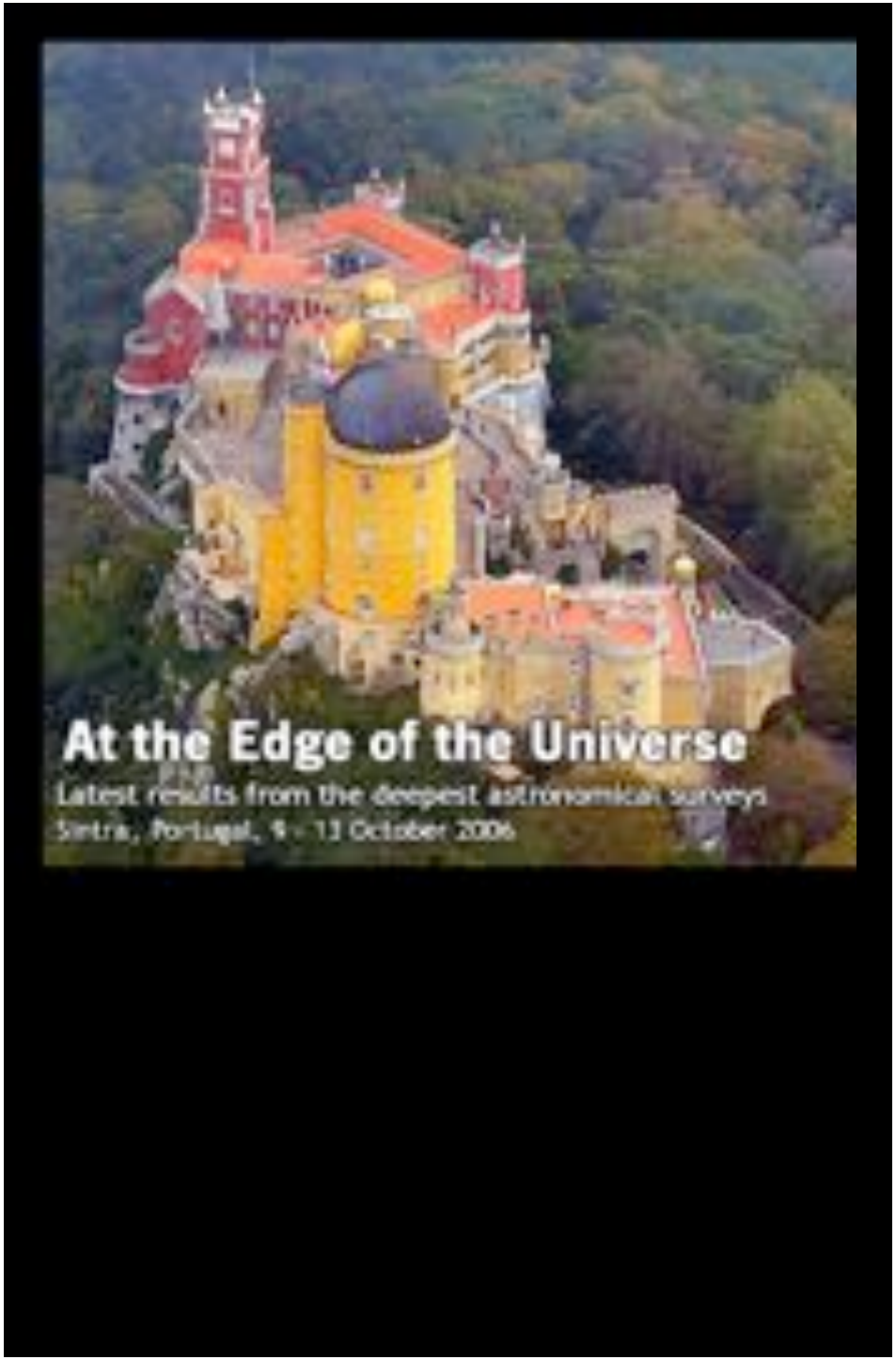
Alexandra Pope (UMass Amherst)

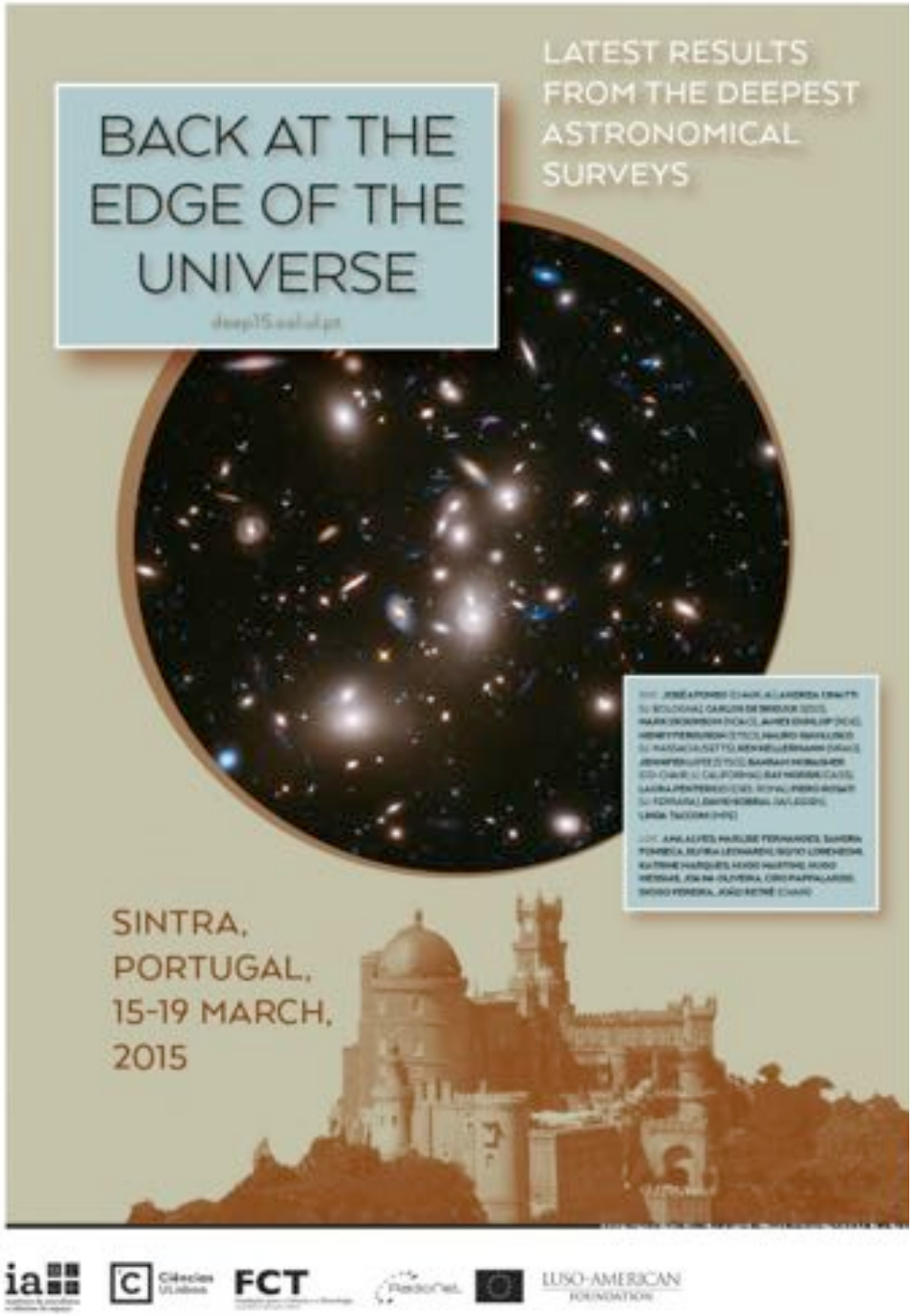
Back at the Edge of the Universe:

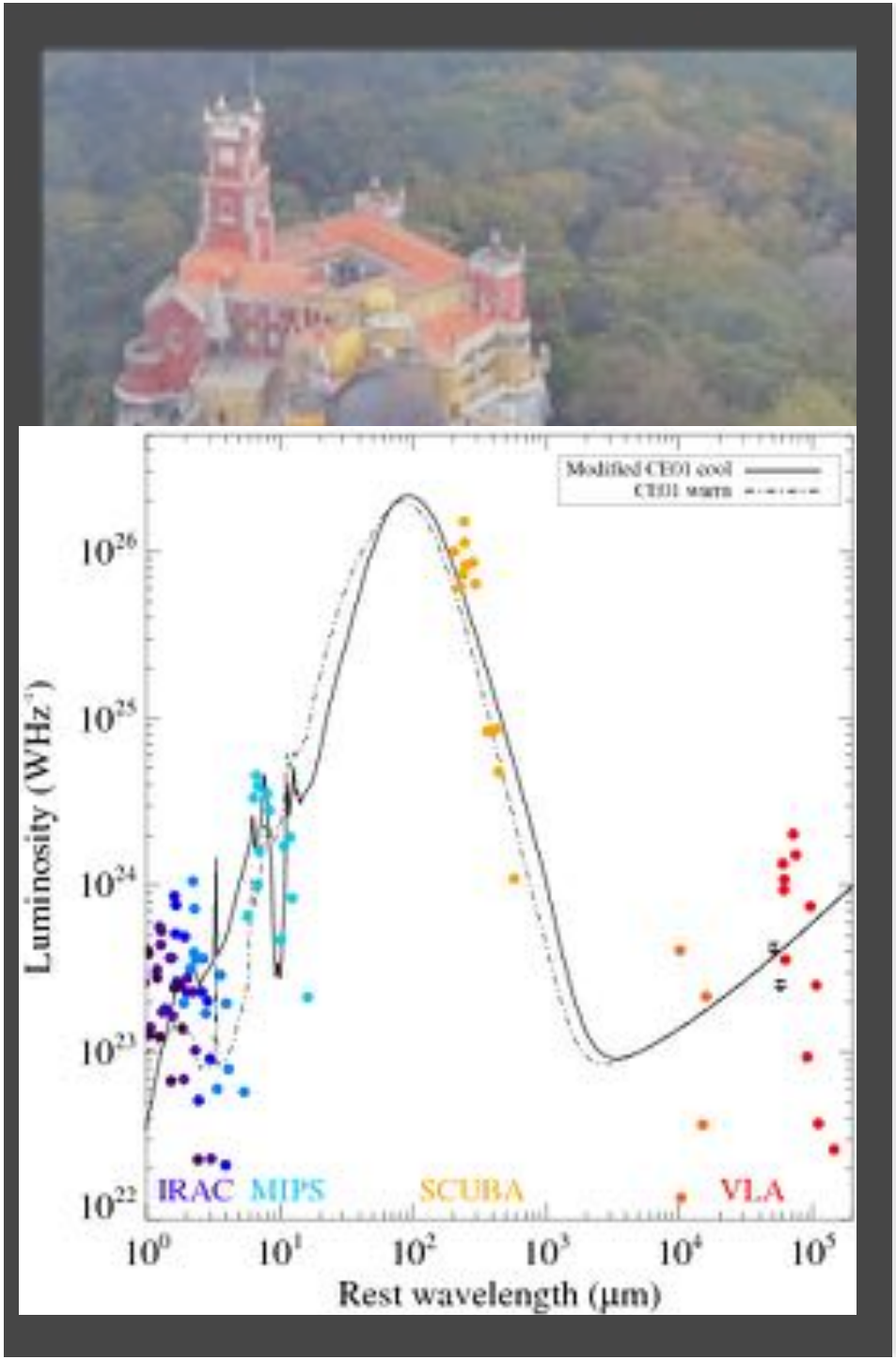
Latest results from the deepest astronomical surveys

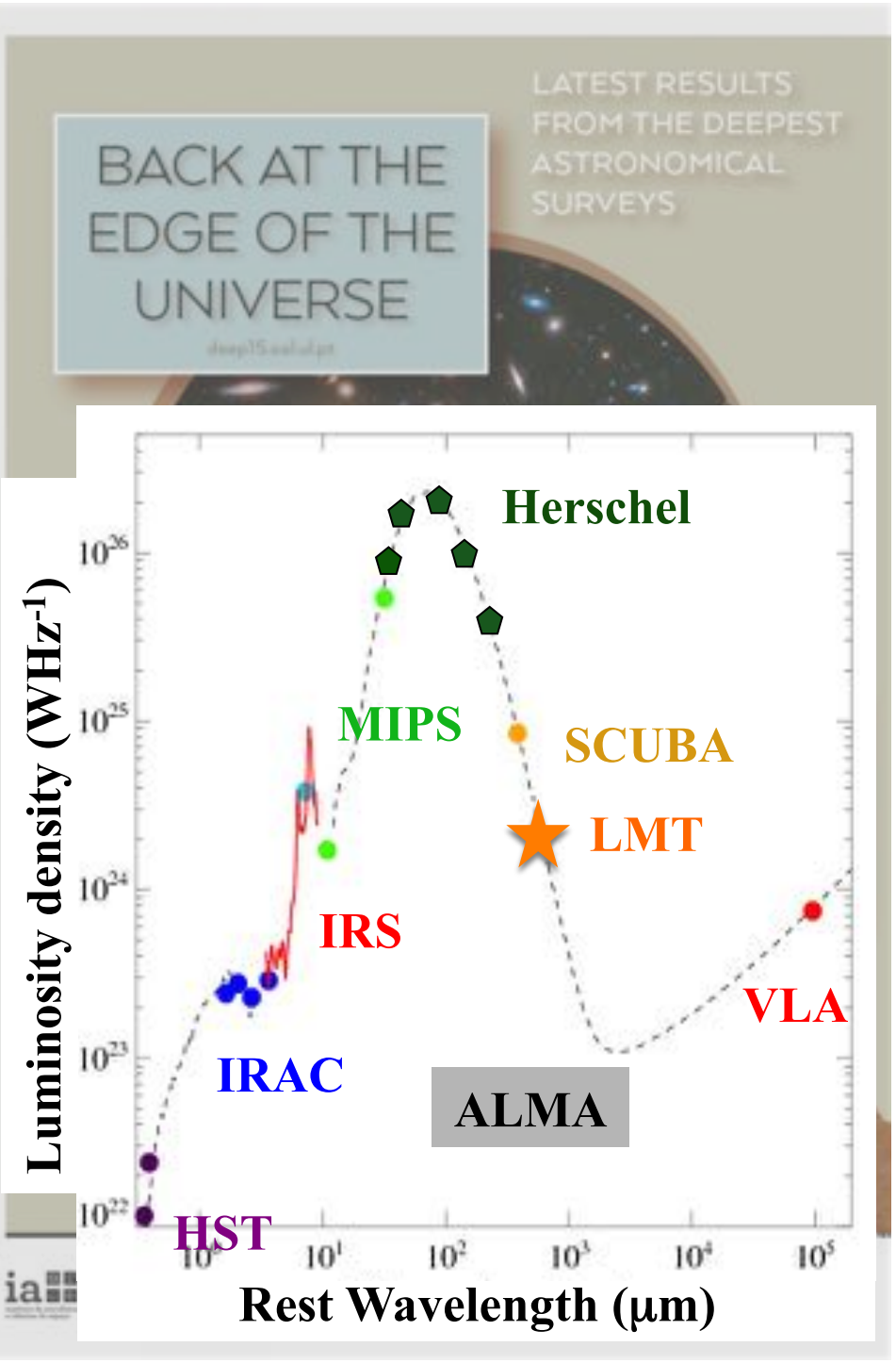
Sintra, Portugal – March 18, 2015



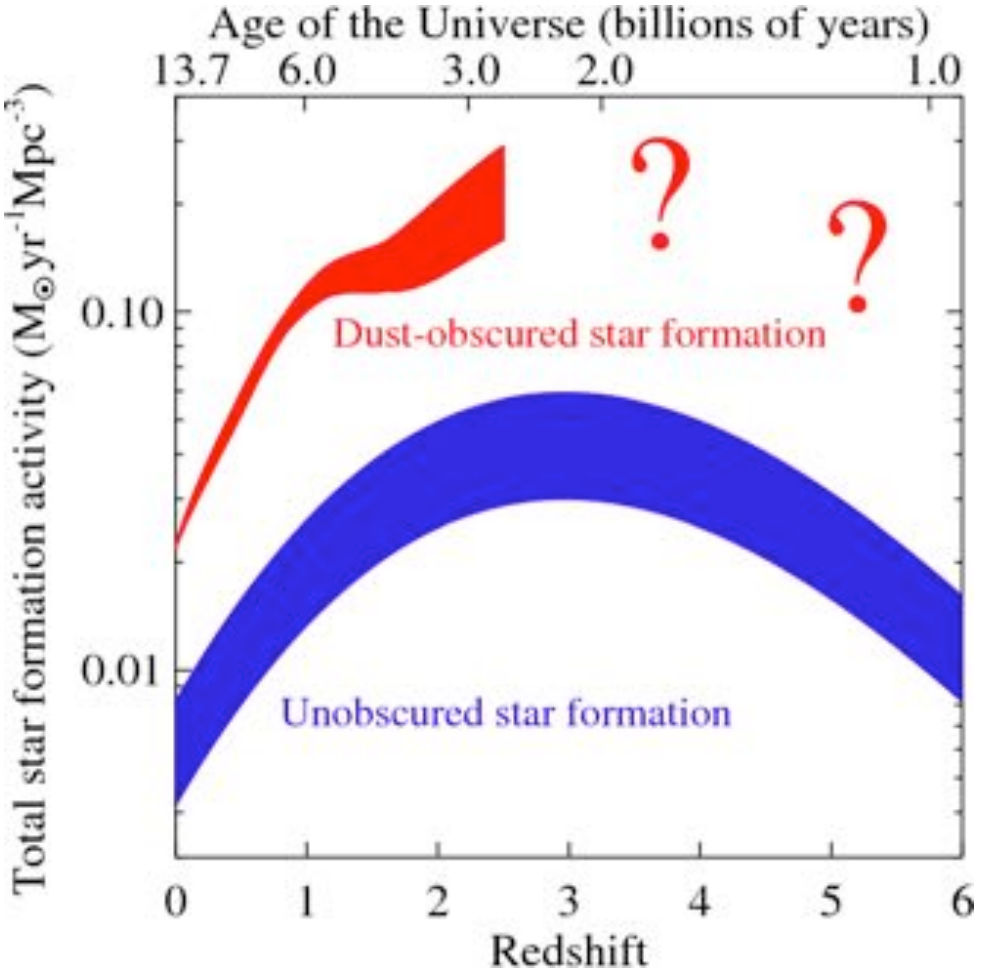

At the Edge of the Universe
Latest results from the deepest astronomical surveys
Sintra, Portugal, 9 - 13 October 2006


LATEST RESULTS FROM THE DEEPEST ASTRONOMICAL SURVEYS
BACK AT THE EDGE OF THE UNIVERSE
SINTRA, PORTUGAL, 15-19 MARCH, 2015
FCT
LUSO-AMERICAN FOUNDATION


Modified CE01 cool
CE01 warm
Luminosity (WHz⁻¹)
IRAC
MIPS
SCUBA
VLA
Rest wavelength (μm)

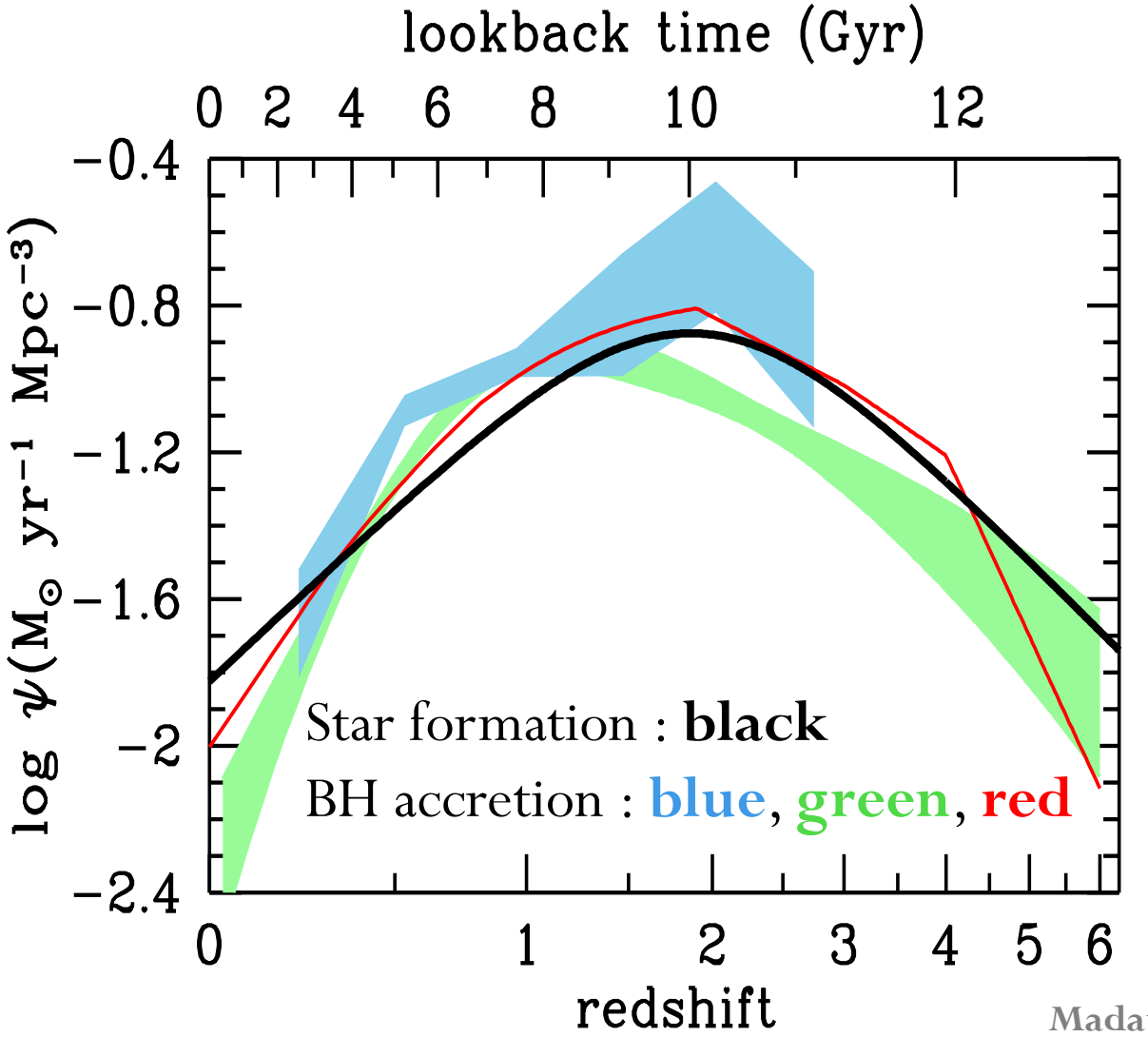

LATEST RESULTS FROM THE DEEPEST ASTRONOMICAL SURVEYS
BACK AT THE EDGE OF THE UNIVERSE
Herschel
MIPS
SCUBA
LMT
IRS
VLA
IRAC
ALMA
HST
Luminosity density (WHz⁻¹)
Rest Wavelength (μm)

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



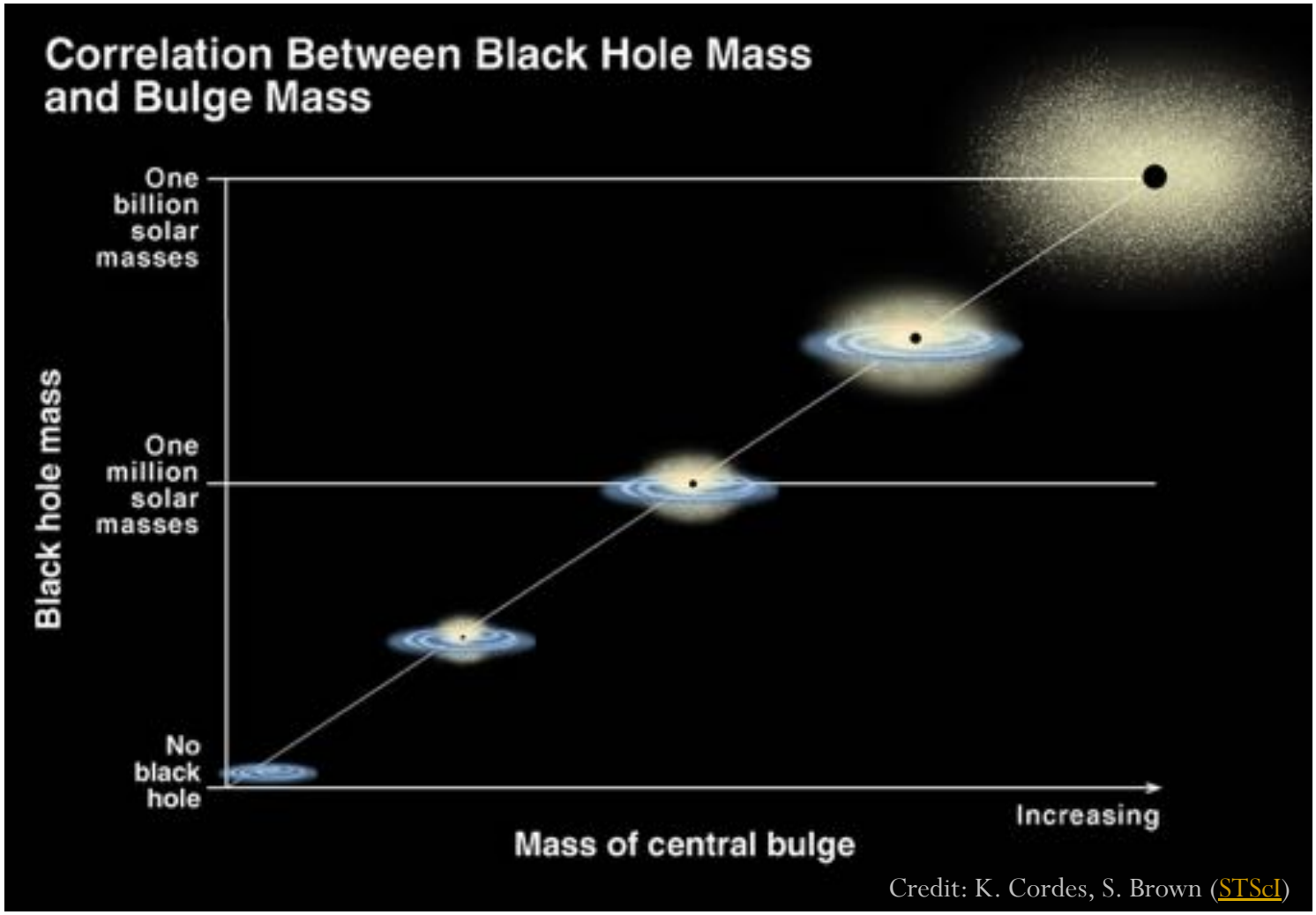
Using data from **Bouwens+2009** and **Murphy+2011**

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

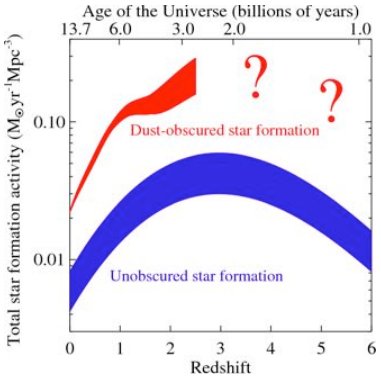


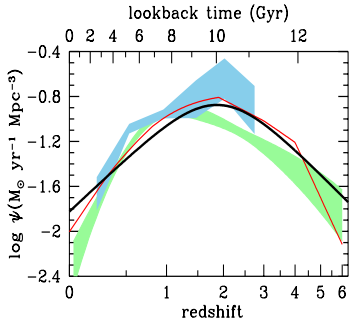
Madau & Dickinson 2014

Stars and black holes grow together in galaxies



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





Outstanding Questions:

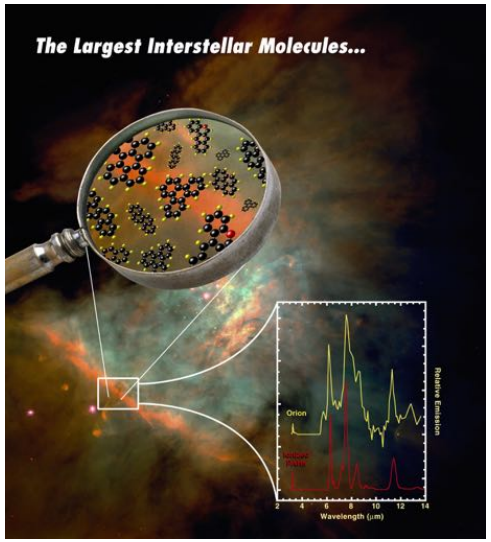
- **How is the star formation linked to the black hole growth?**

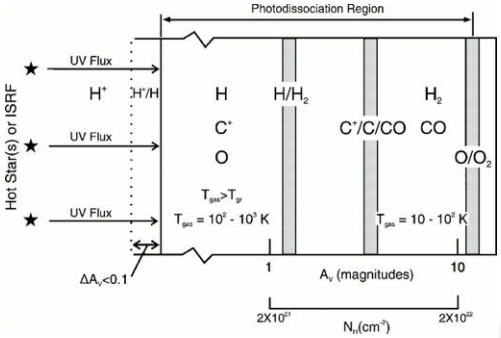
  Can we separate emission from each in our observations?

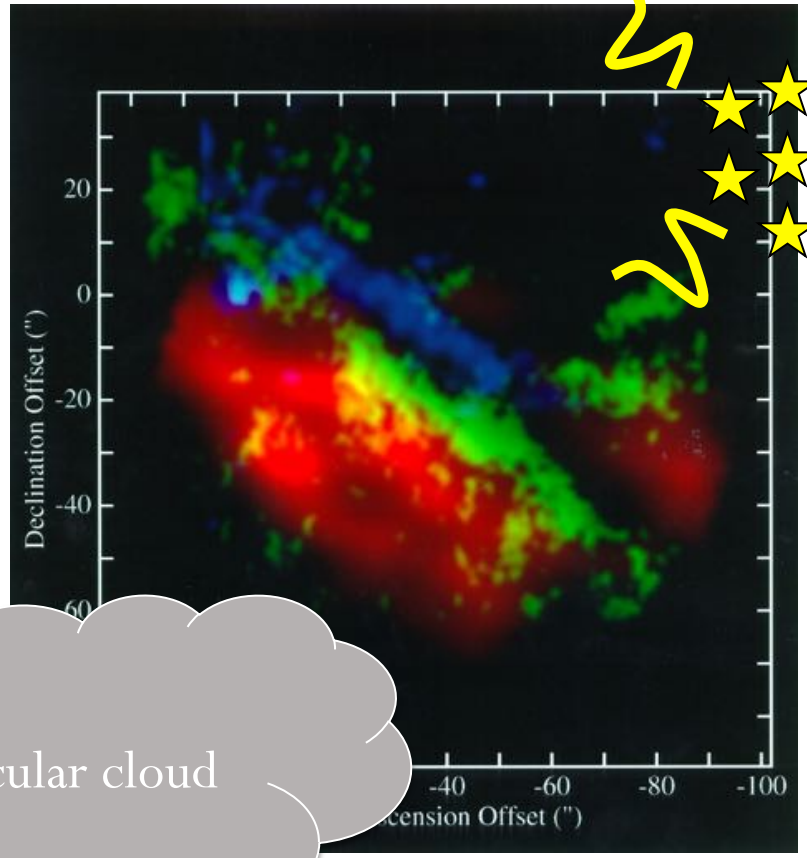
- **Are the mechanisms of triggering and fueling star formation during the peak period of z=1-3 different from those in the local Universe?**

  How do the interstellar medium conditions differ during the peak period of z=1-3 from those in local galaxies?

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







Molecular cloud

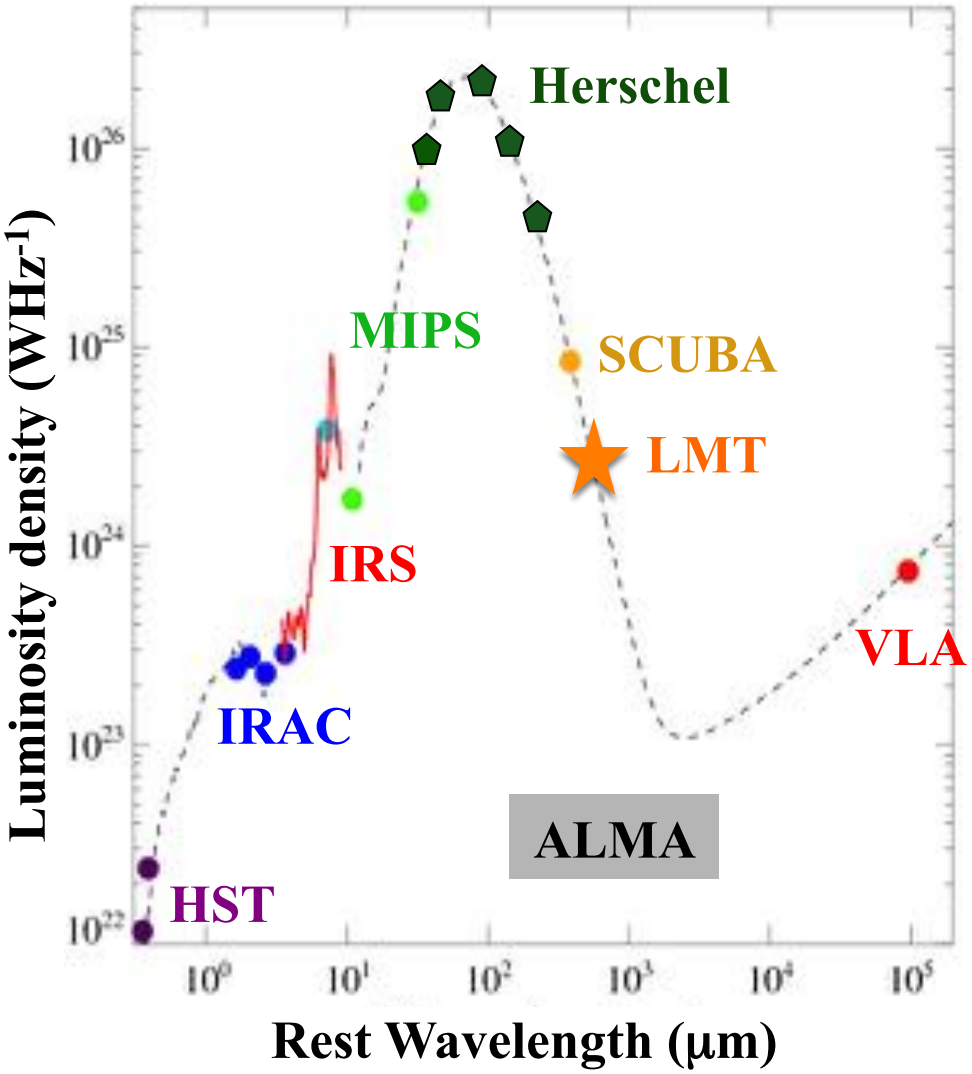
PAH

H_2

CO

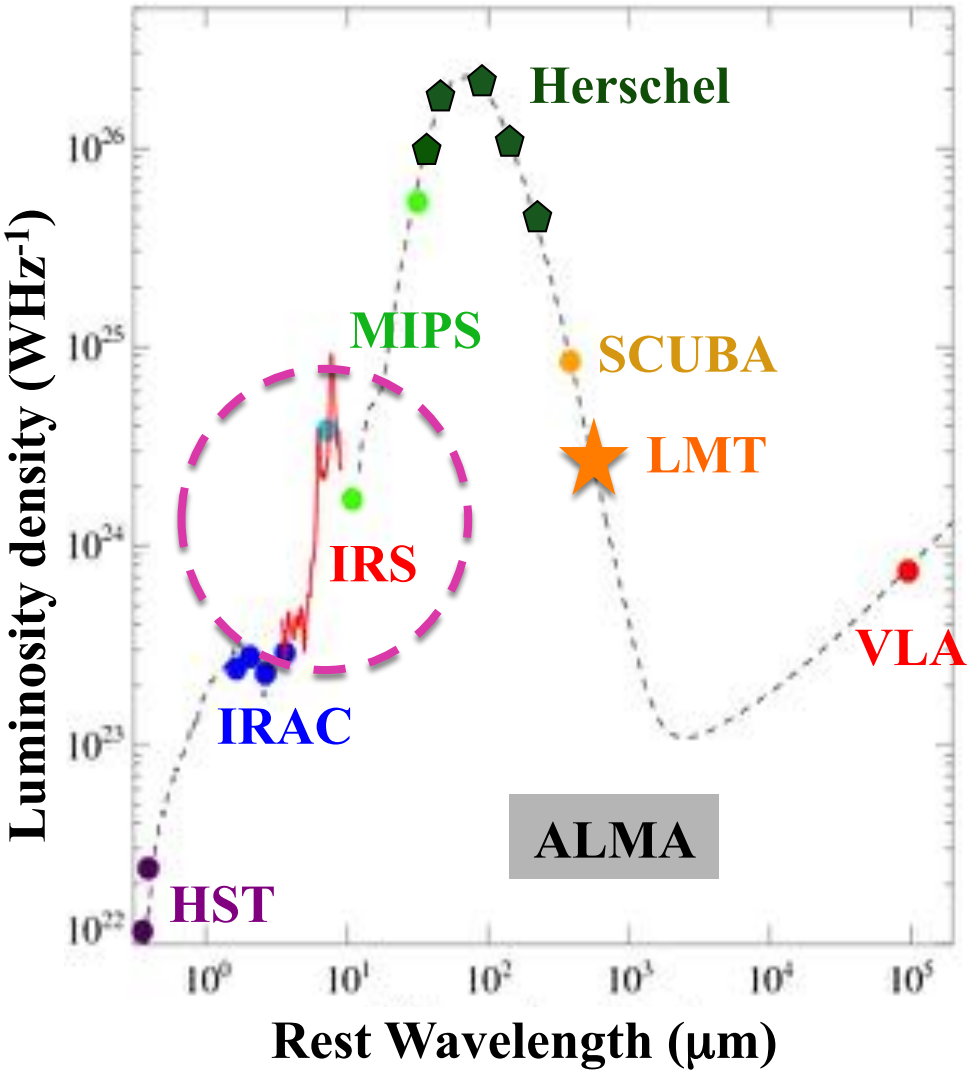
Hollenbach &Tielens 1997

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



Circa 2015: Well sampled spectral energy distribution (SED) for high redshift dusty galaxies

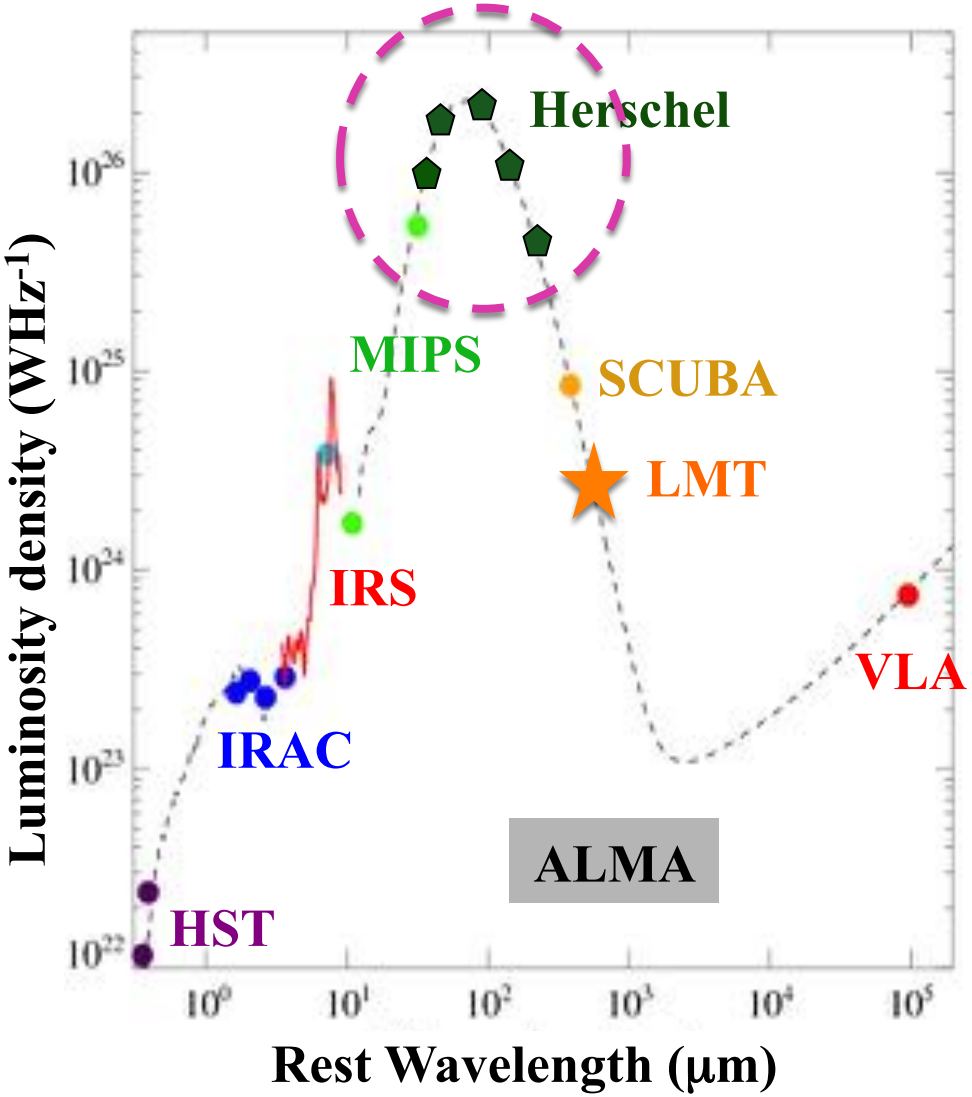
How do we probe the interstellar medium (gas and dust) in high redshift galaxies?



***Spitzer* mid-IR spectroscopy is sensitive to:**

1) **radiation heating the dust : star formation (SF) or AGN**
2) **PAHs tell you about dust composition**

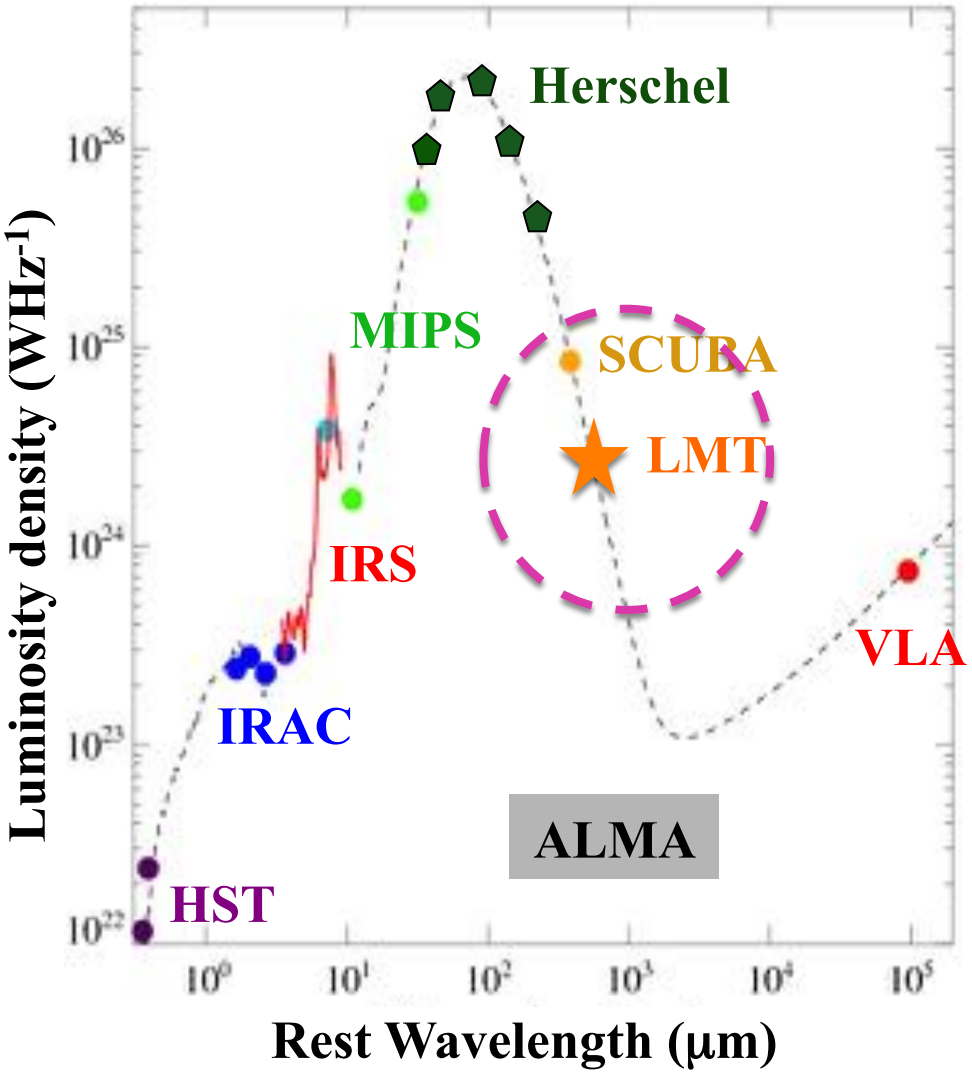
How do we probe the interstellar medium (gas and dust) in high redshift galaxies?



Herschel **imaging samples the peak of the dust emission:**

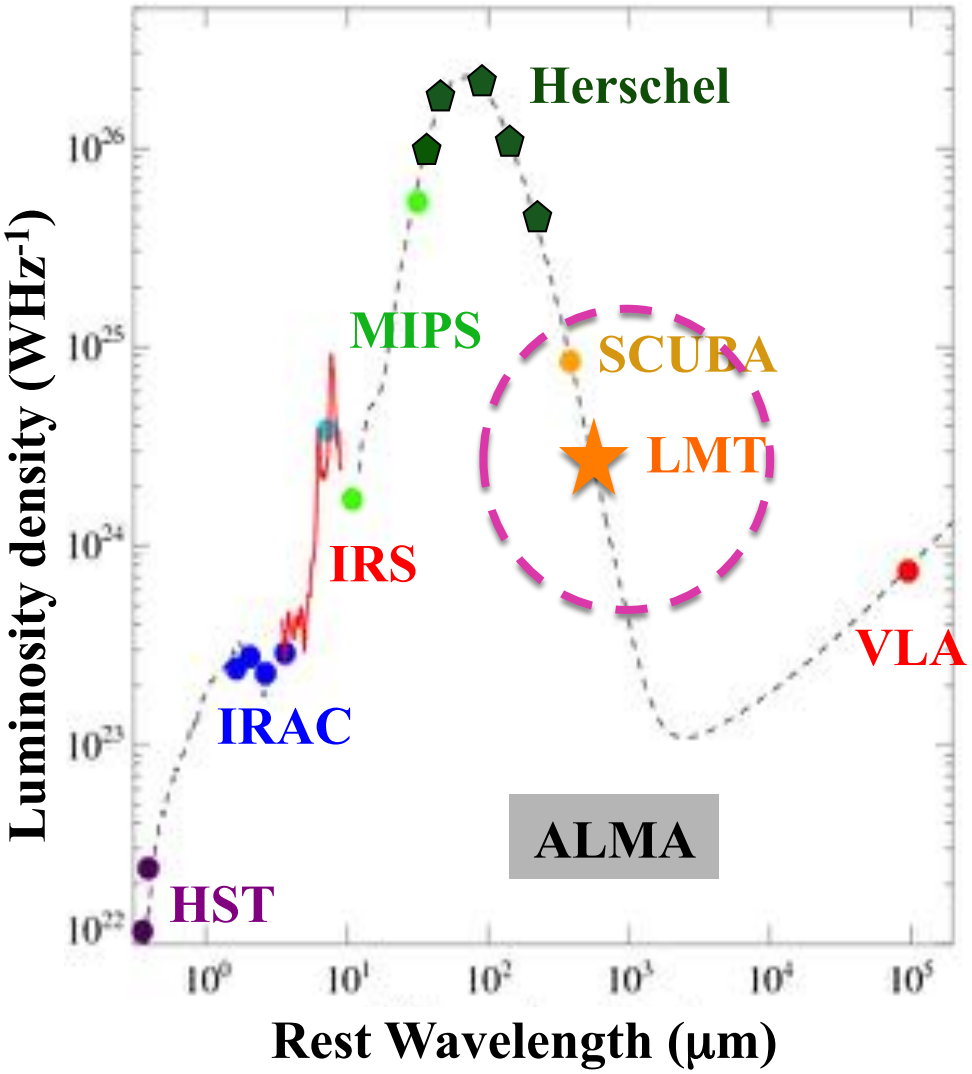
1) **dust temperatures**
2) **total IR luminosity (proxy for SFR)**

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



Millimeter spectroscopy probes the molecular gas reservoir (observations of CO)

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



Millimeter <u>continuum</u> is sensitive to the dust mass (proxy for the total ISM mass)

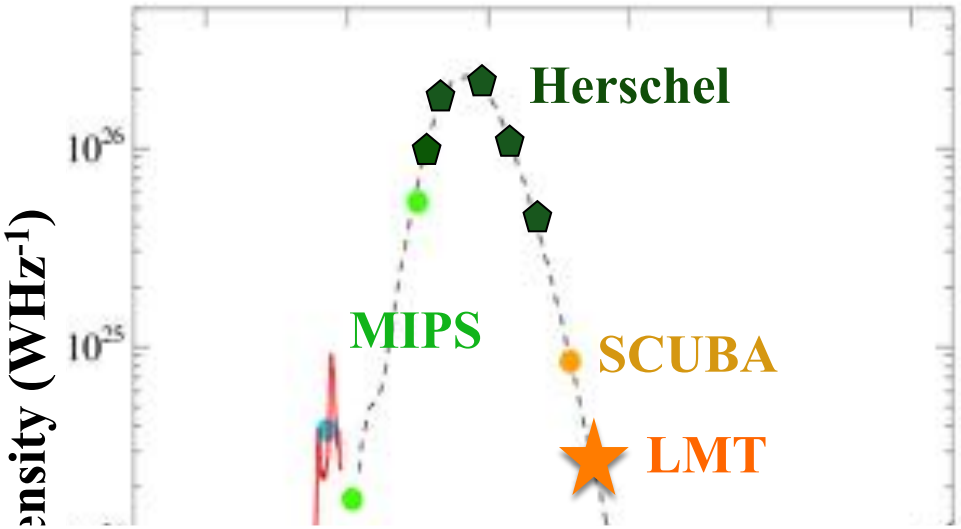
Large Millimeter Telescope (LMT)

- 50m millimeter telescope in Mexico
- 15,000 ft: Excellent mm site
- Owned by UMass and Mexico

- Currently operating in *Early Science* mode as a 32.5m telescope
- Early science instrumentation:
  - AzTEC 1.1mm camera (FWHM=8 arcsec)
  - Redshift Search Receiver (RSR) 3mm
- 50 m LMT [~2016] = 1/3 the collecting area of ALMA

Time lapse video from June 2013, courtesy of James Lowenthal

How can we probe the interstellar medium (gas and dust) in high redshift galaxies?



- ***Spitzer*** **mid-IR spectroscopy is sensitive to the radiation heating the dust : SF or AGN**
- ***Herschel*** **imaging samples the peak of the dust**

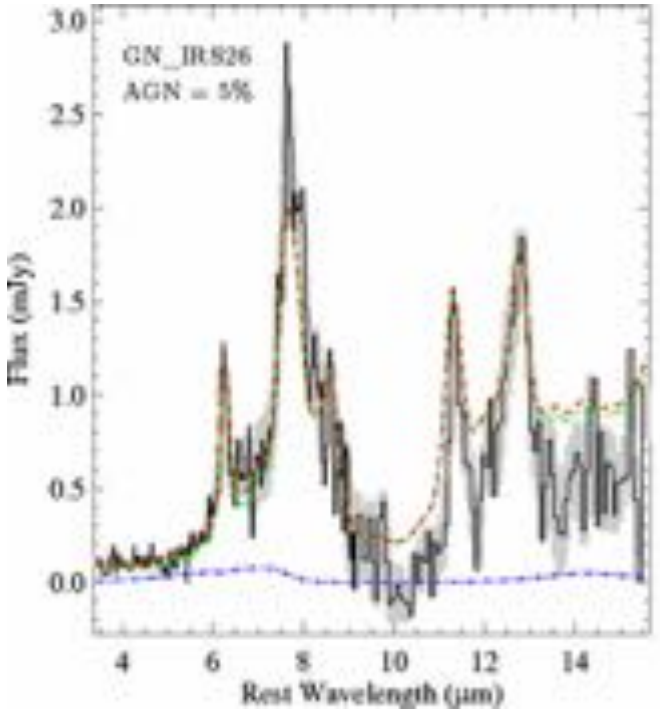
<u>Goal:</u> Understand how dusty star formation and black hole growth proceeds during the peak epoch

<u>Approach:</u> Link multi-wavelength diagnostics of the ISM in high redshift dusty galaxies

Decomposing *Spitzer* mid-IR spectra into two main components:

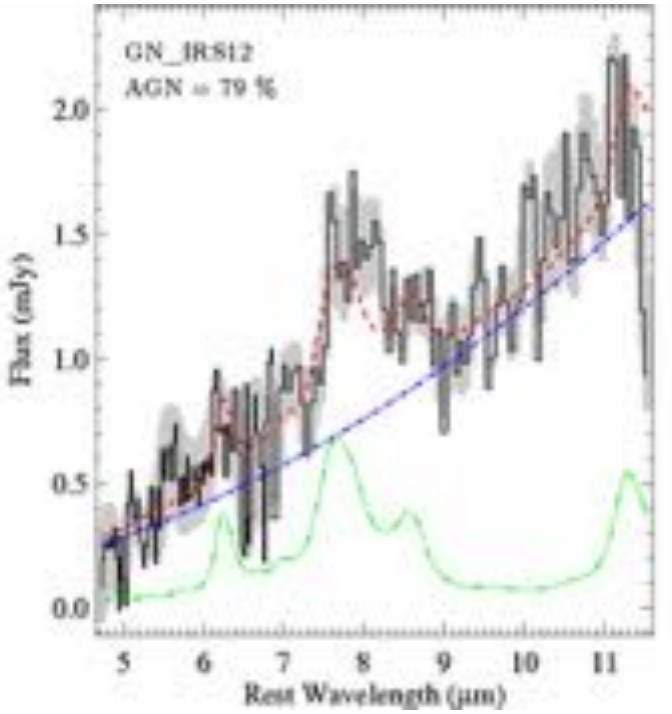
1. Star formation:

Polycyclic aromatic hydrocarbons (PAH) emission lines + extinction

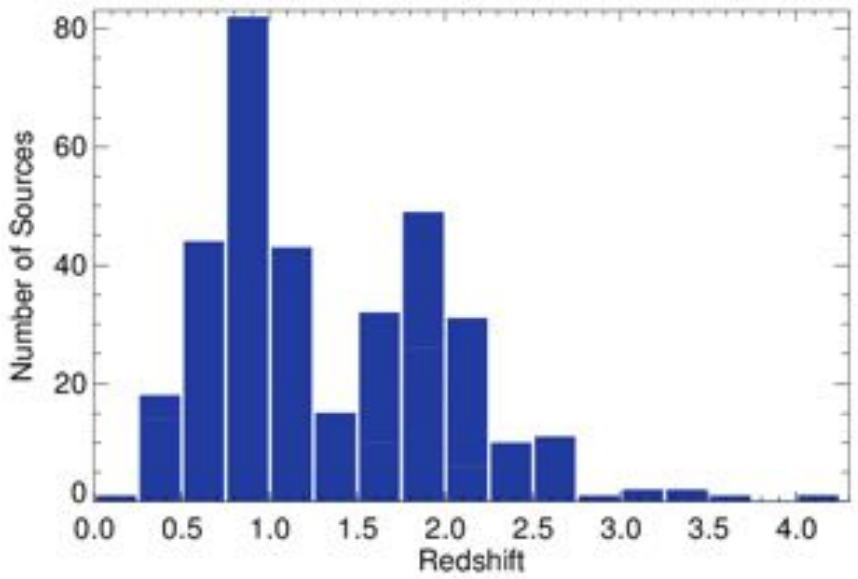


2. Active Galactic Nuclei:

Power-law + extinction



High redshift mid-IR spectra supersample



343 galaxies from *Spitzer* FLS and GOODS

Selected at 24 μ m:

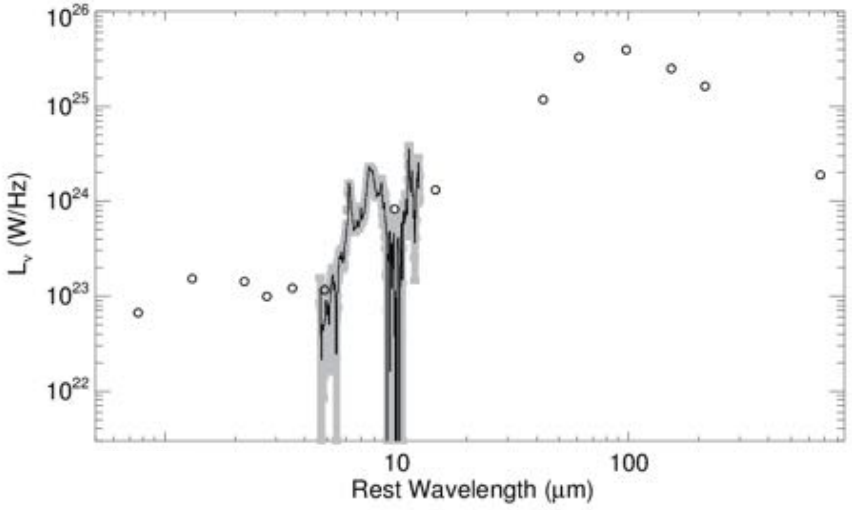
S_{24} > 0.9 mJy (xFLS)

S_{24} > 0.2 mJy (GOODS)

Redshift range: 0.2-4

All sources have mid-IR spectroscopy

Photometry from *Herschel*, *Spitzer*, and ground-based telescopes



Kirkpatrick, Pope, et al. in prep

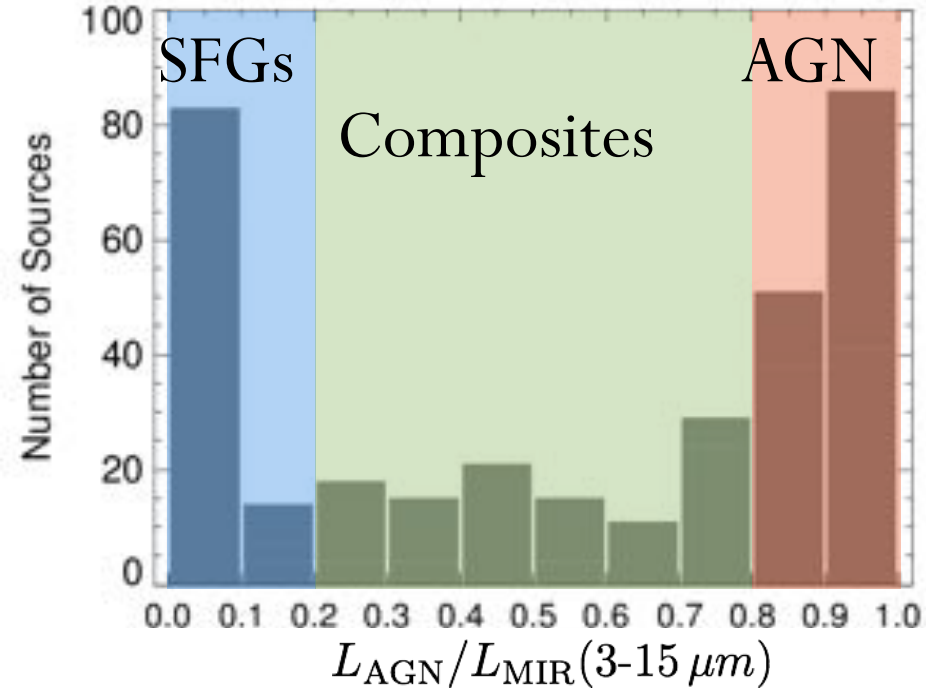
Galaxies as a function of mid-IR AGN fraction (based on spectral decomposition)

Split 343 galaxies into 3 categories:

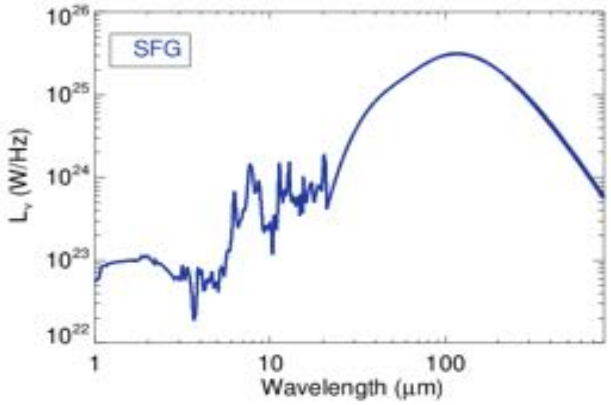
Star Forming Galaxies – 30%

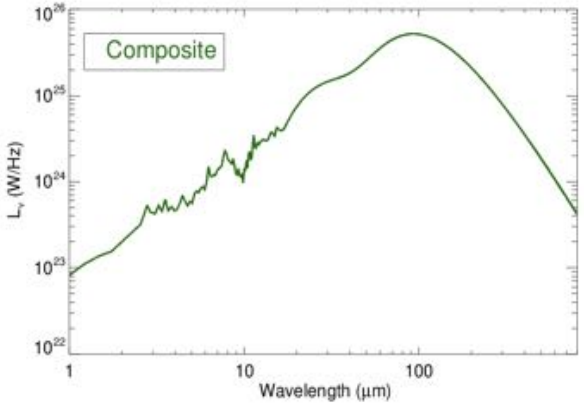
Composites – 34%

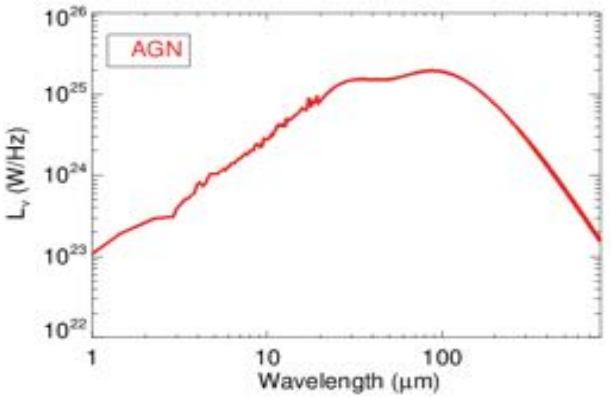
AGN – 36%



Average SEDs:





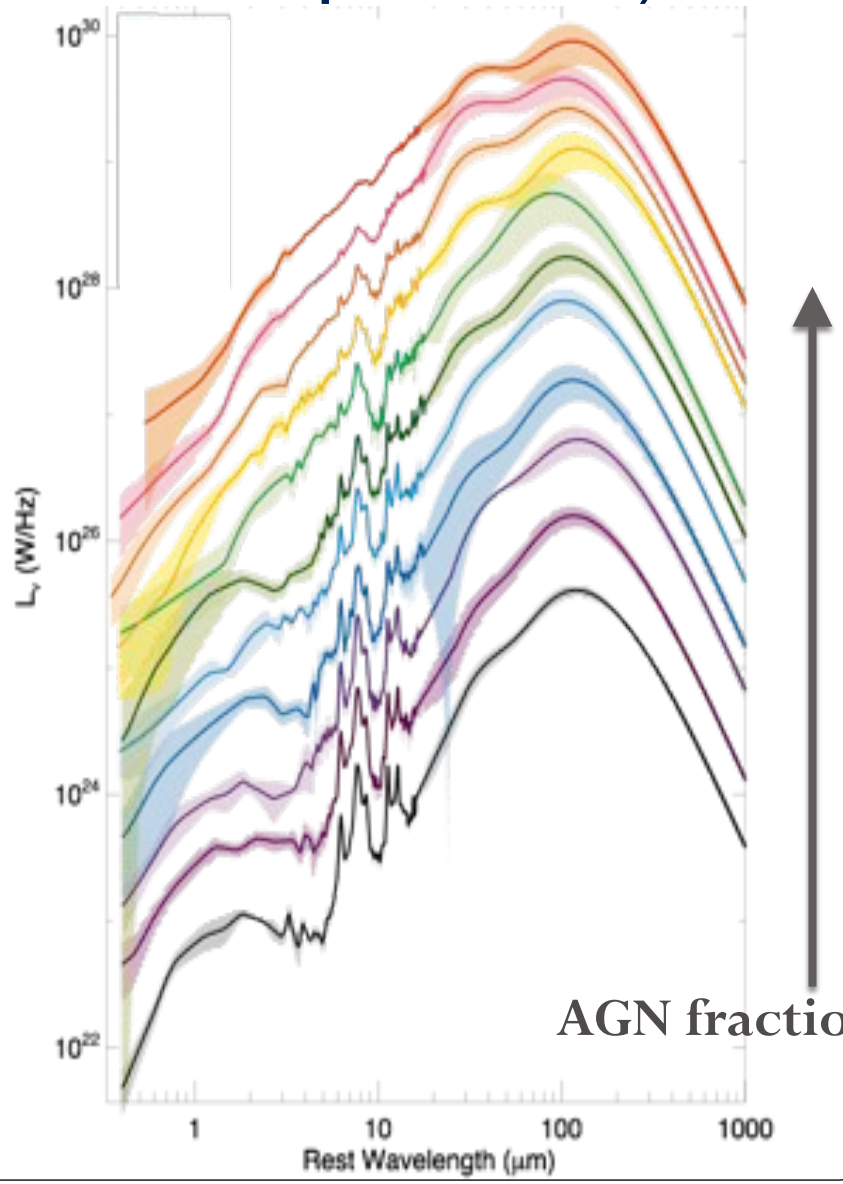


Kirkpatrick, Pope, et al. in prep; see also Kirkpatrick, Pope, et al. 2012

SEDs as a function of mid-IR AGN fraction (based on spectral decomposition)

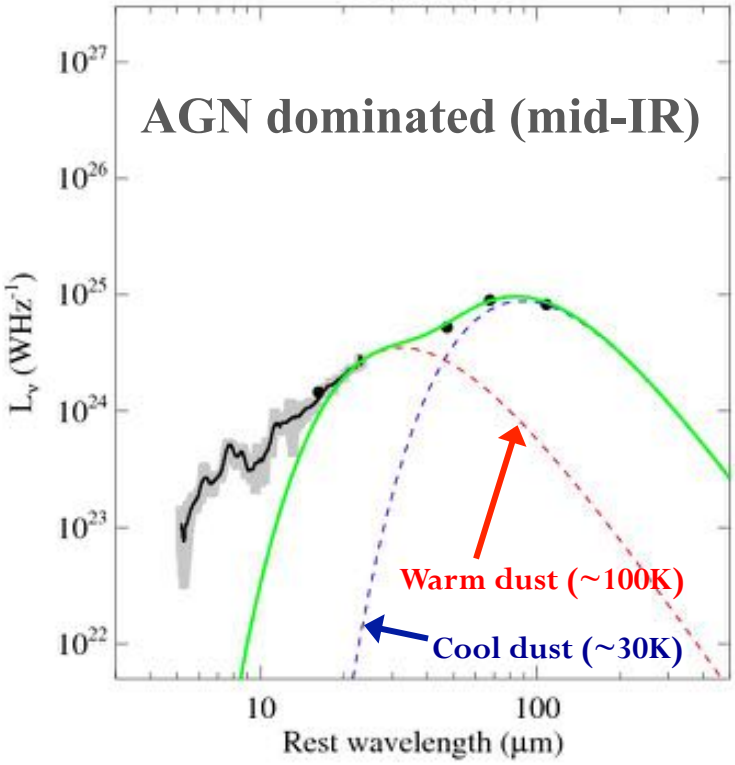
Want to look for **evolution** in SED properties with redshift, L_{IR} and AGN fraction

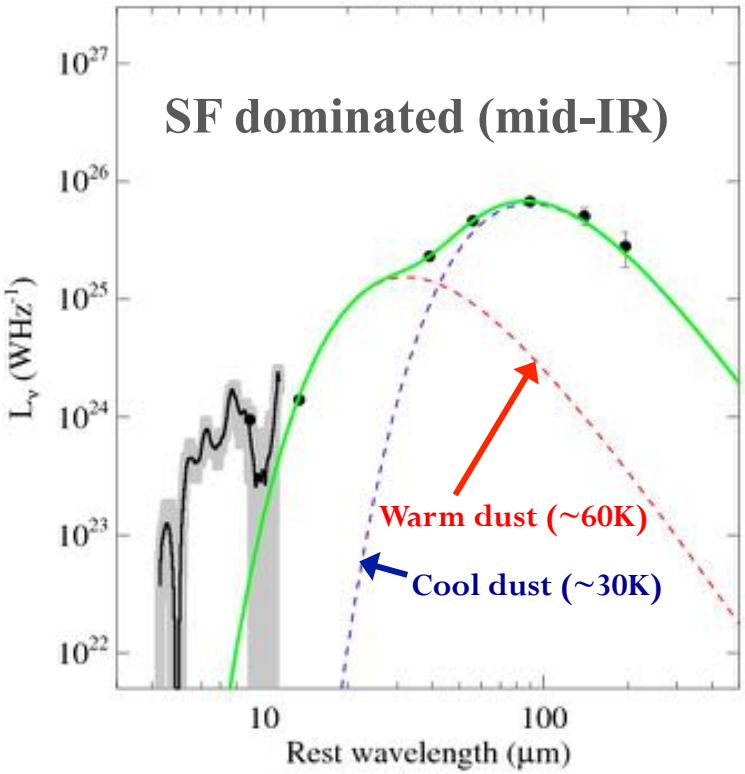
Create SED template libraries by stacking sources to control for these parameters



Kirkpatrick, Pope, et al. in prep

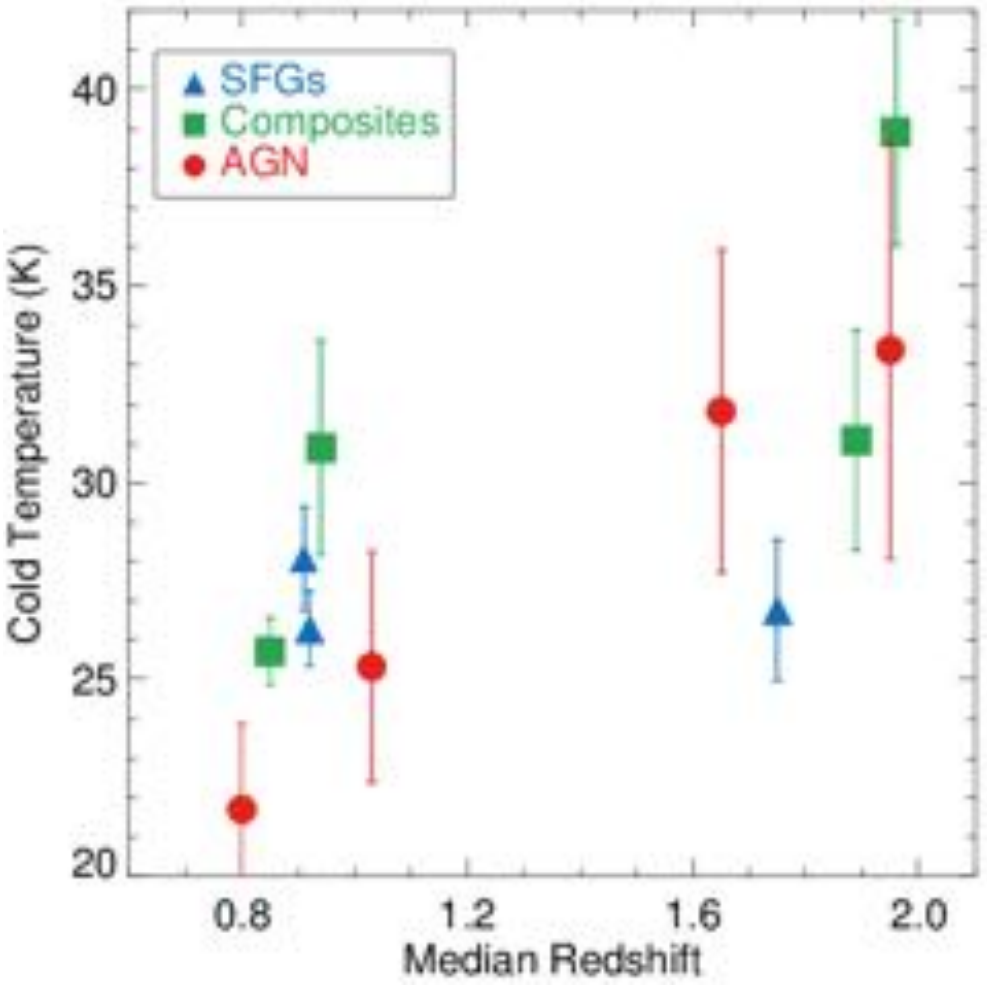
SED fitting with *Spitzer*/IRS + *Herschel*

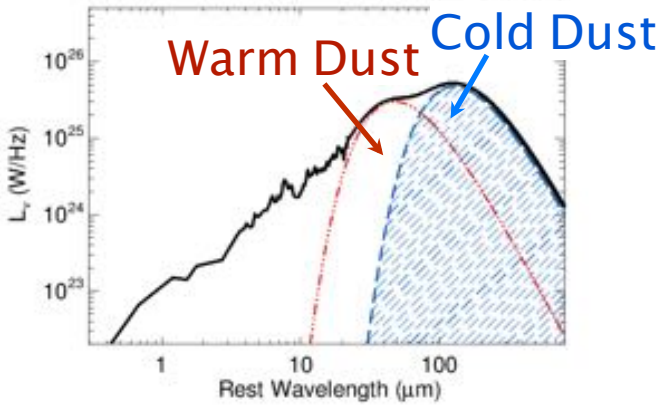




Kirkpatrick, Pope, et al. 2012

Evolution in cold dust component





Kirkpatrick, Pope, et al. in prep

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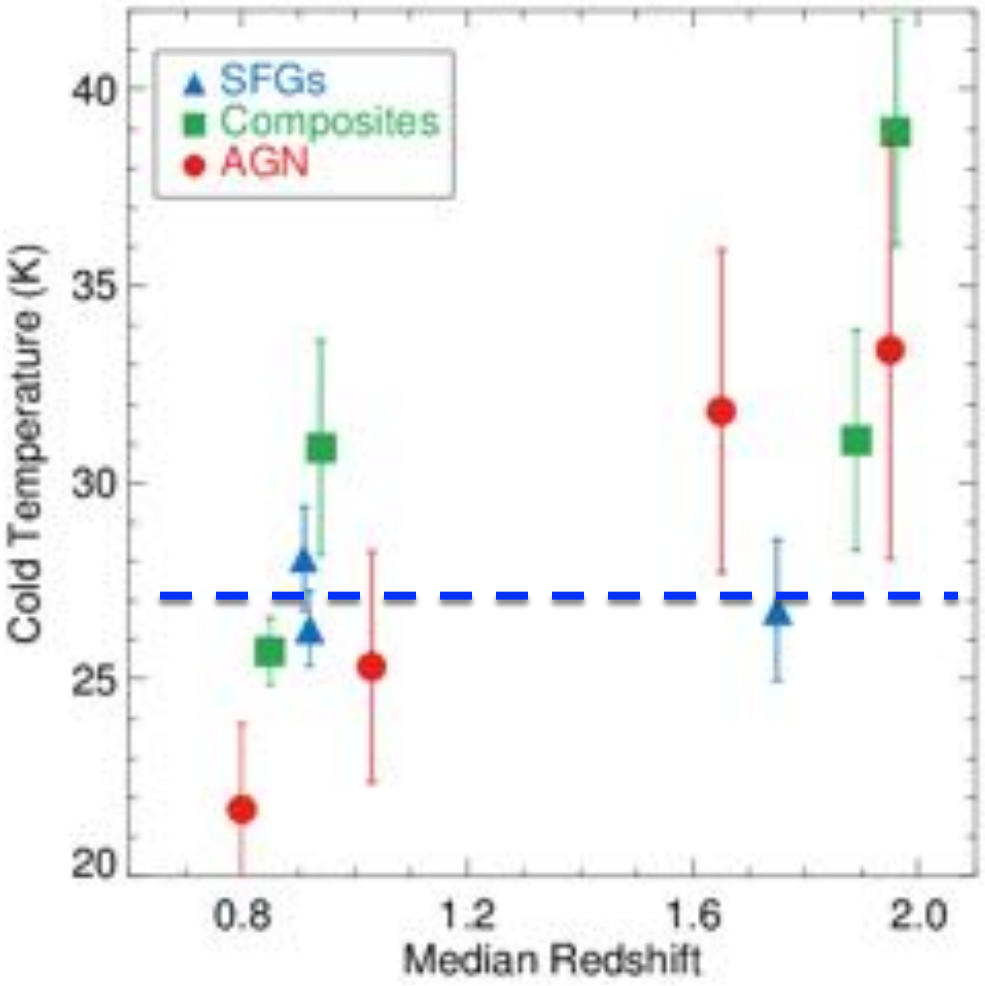
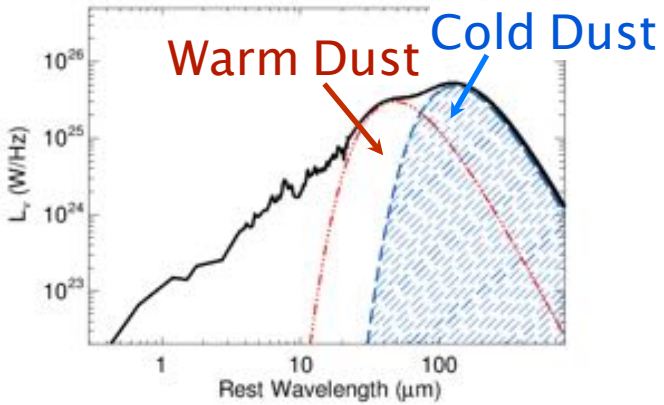
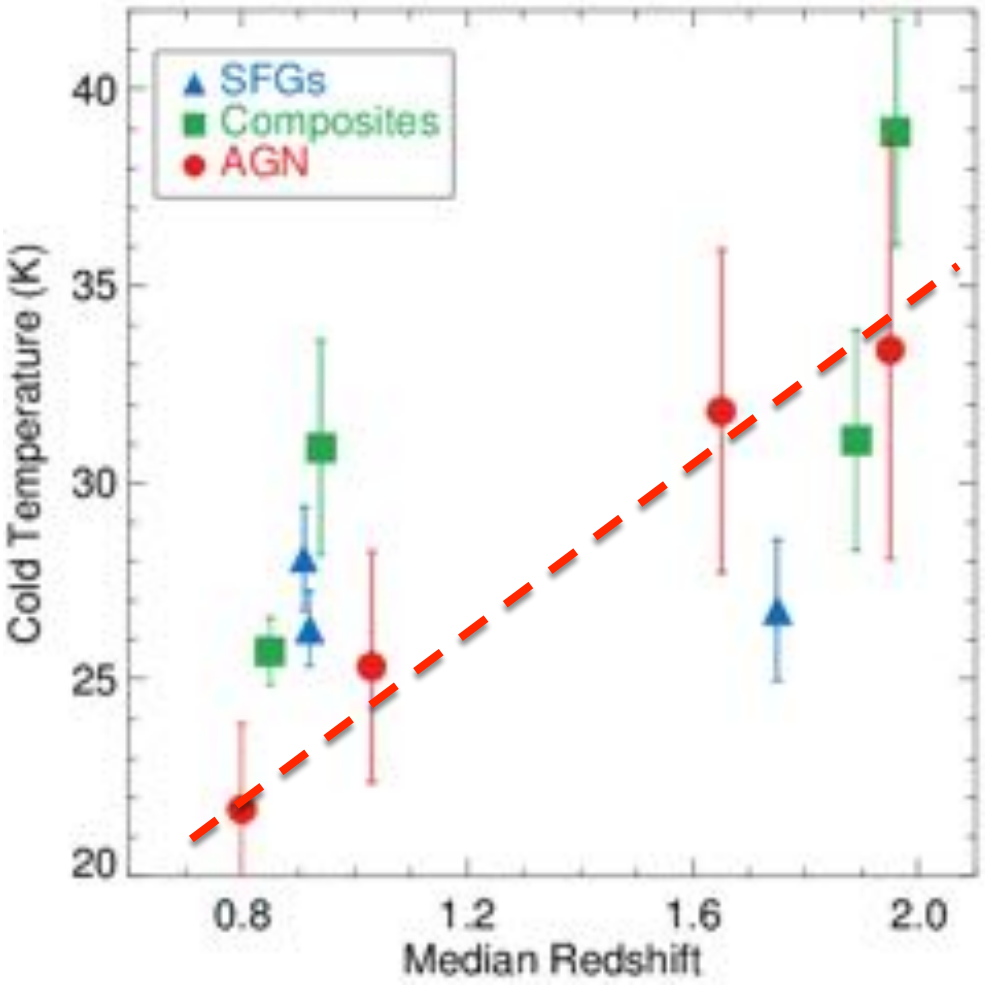


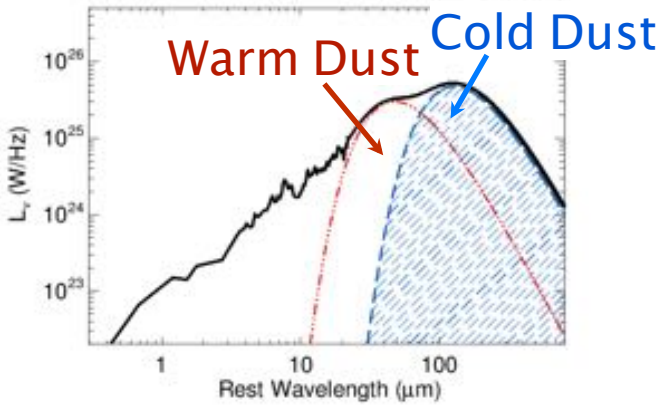


Star Forming Galaxies show no change in cold dust temperature from z~1-2

Kirkpatrick, Pope, et al. in prep

Evolution in cold dust component

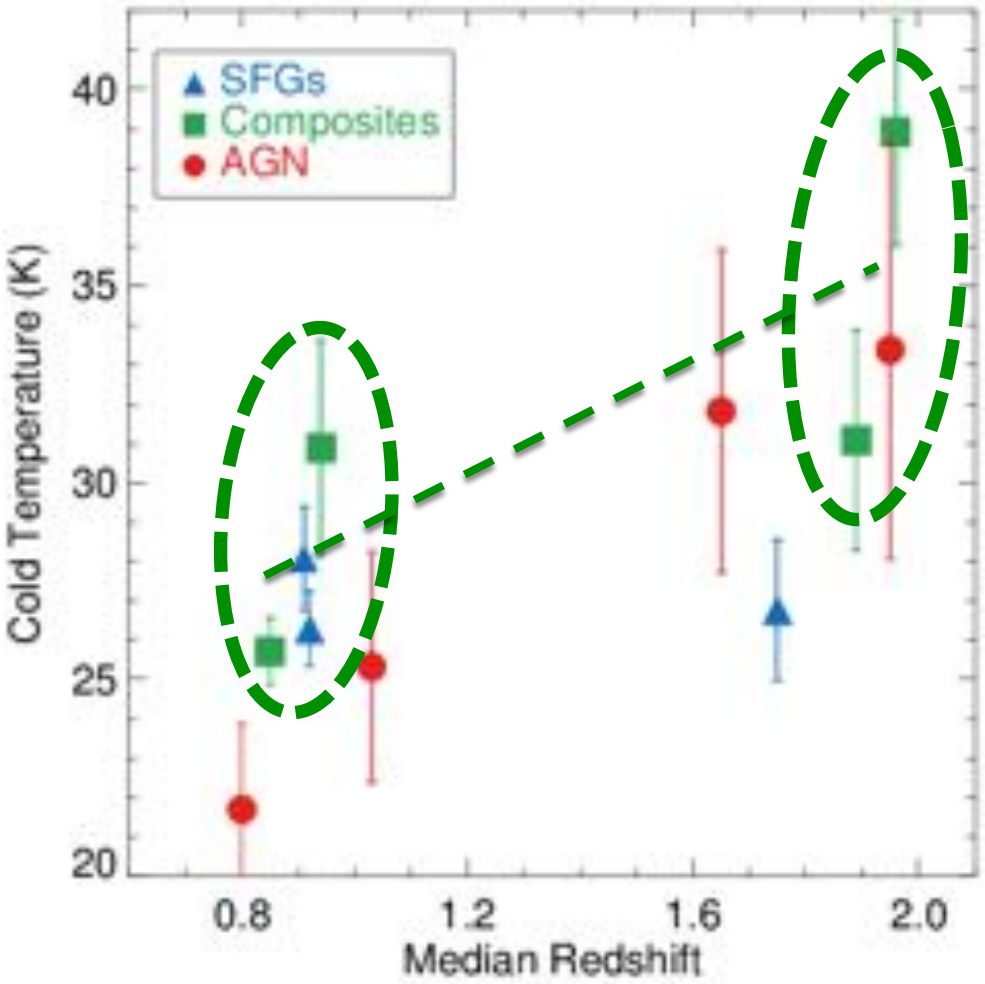


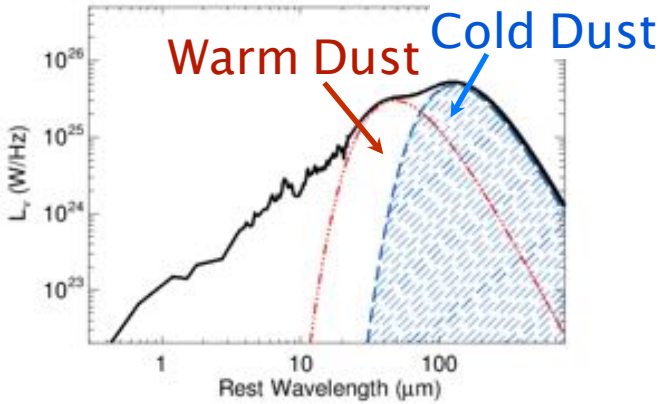


Mild evolution in cold dust temperature for AGN

Kirkpatrick, Pope, et al. in prep

Evolution in cold dust component

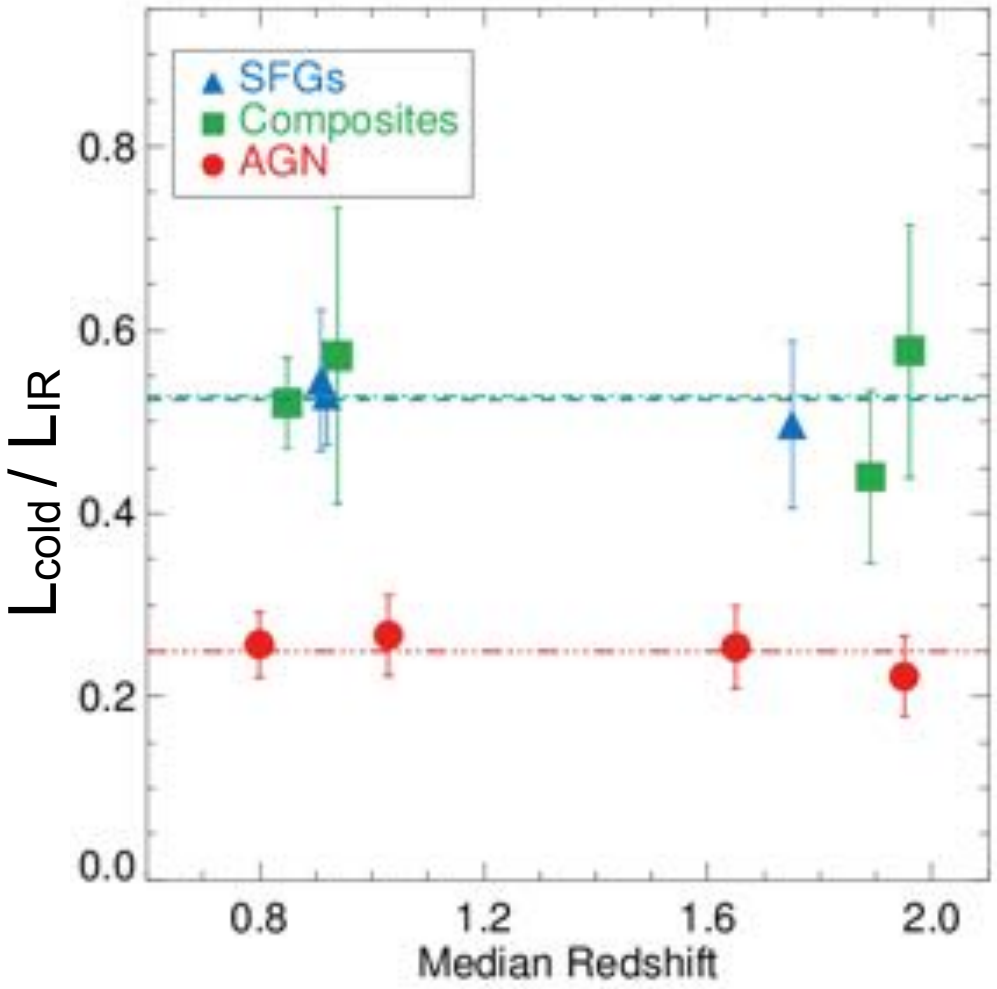


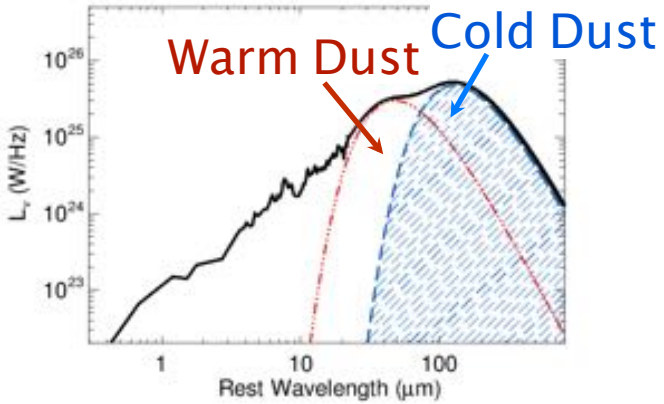


Composite sources show mild increase in cold dust temperature with redshift and L_{IR}

Kirkpatrick, Pope, et al. in prep

Evolution in cold dust component

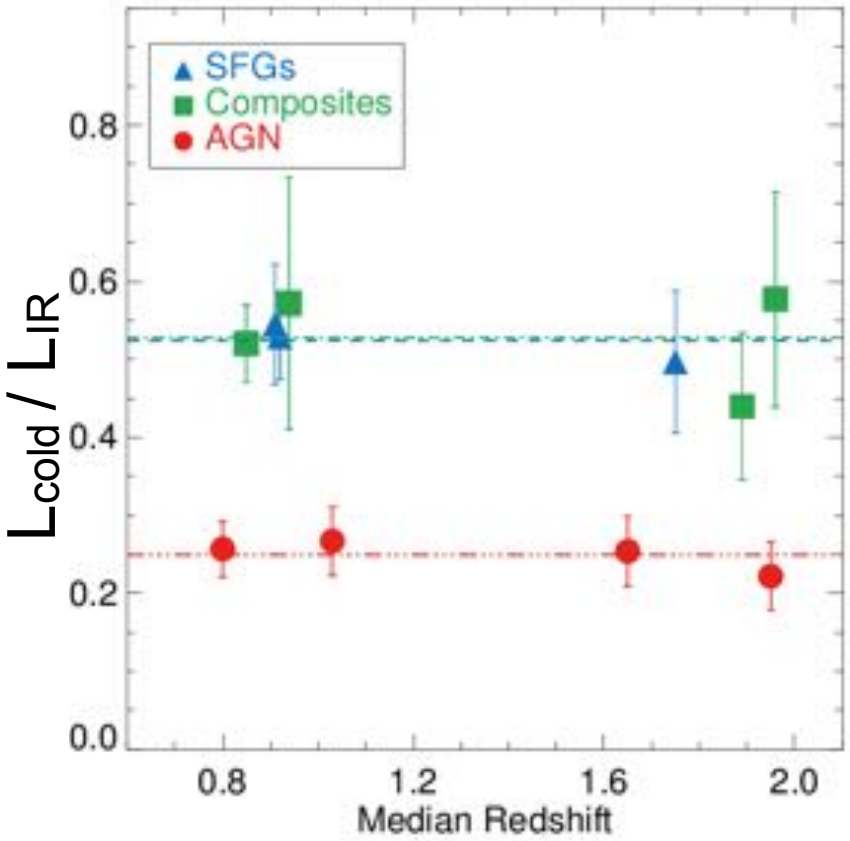


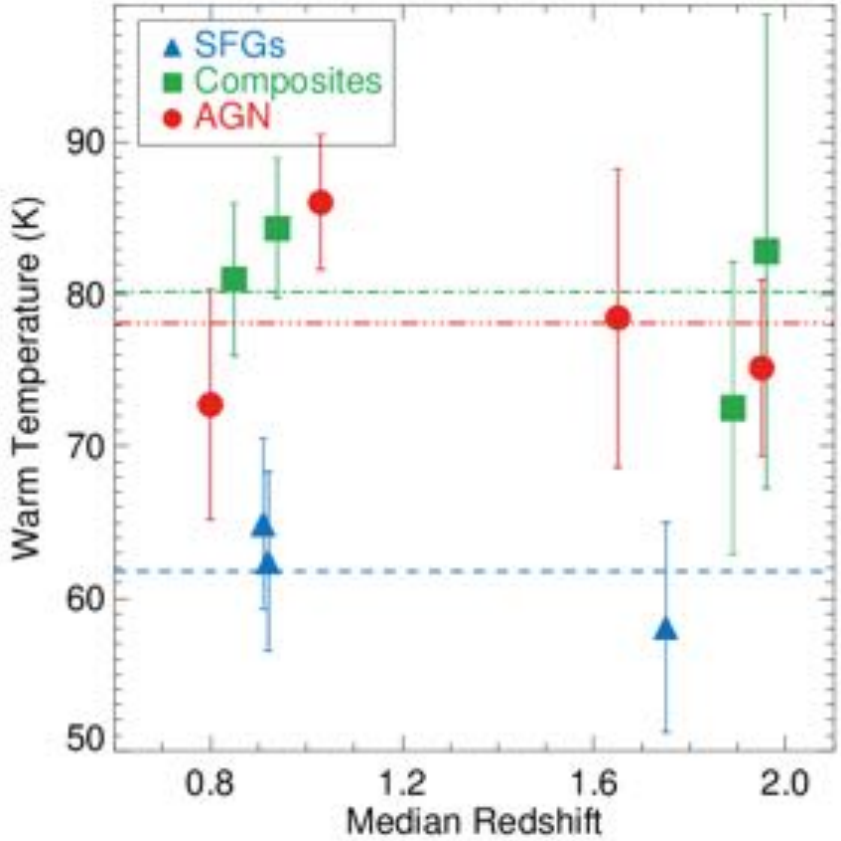


Fraction of L_{IR} from the cold dust component is 50% for **SFGs** and **composite galaxies** but only 25% for **AGN**

Kirkpatrick, Pope, et al. in prep

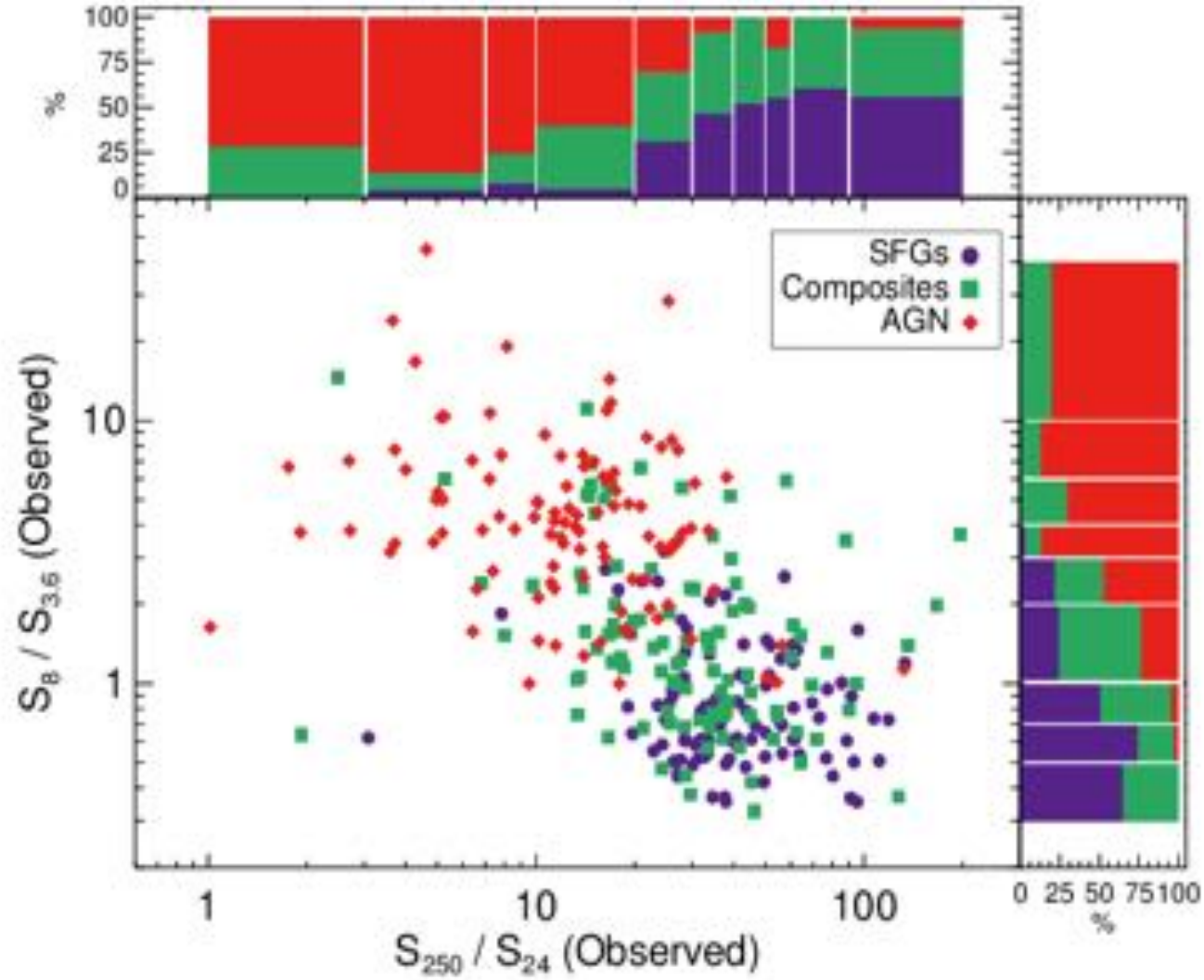
Composites sources: same amount of cold dust as **SFGs** but same warm dust temperature as **AGN**





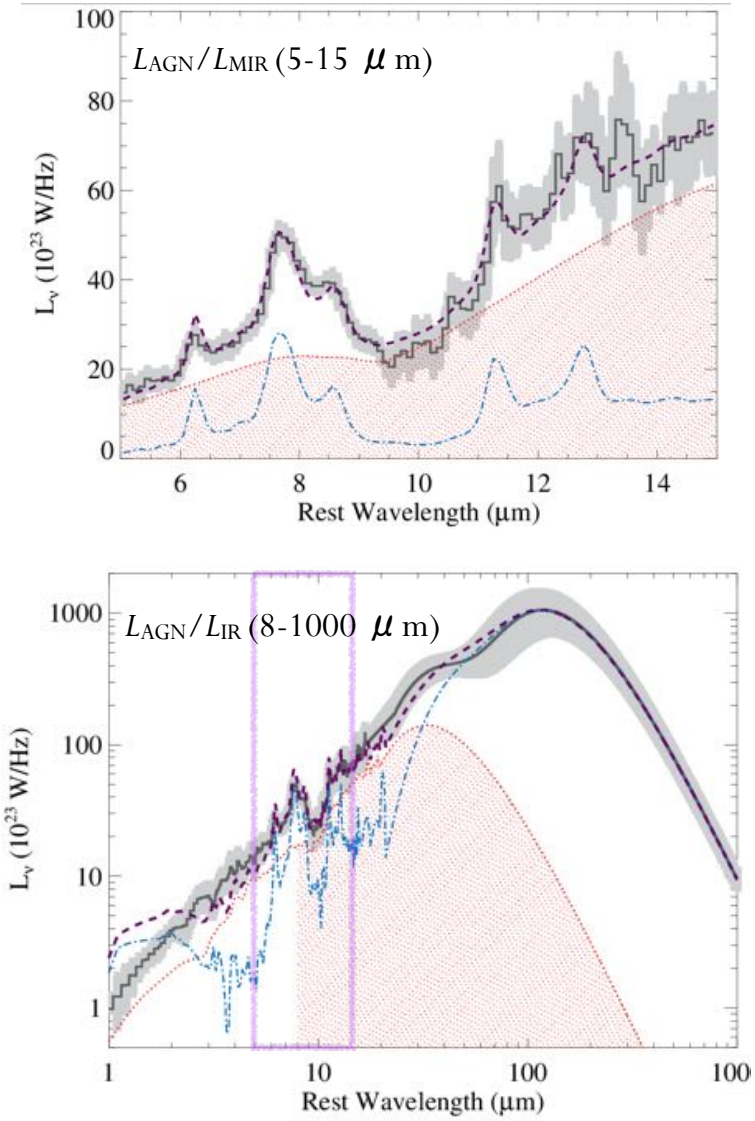
Kirkpatrick, Pope, et al. in prep

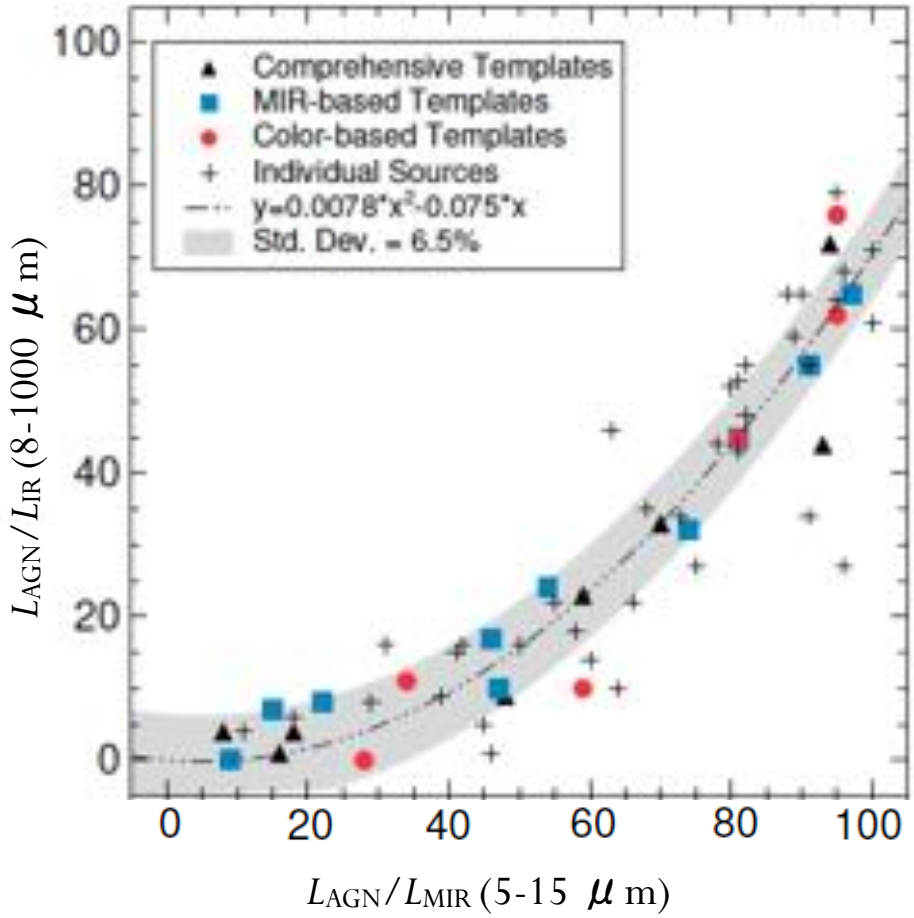
Composites sources are important



Kirkpatrick, Pope, et al. in prep

Total L_{IR} AGN fractions





Kirkpatrick, Pope, et al. in prep

Take away points

1. Composite sources really do show a mix of AGN and SF activity across the SED (MIR and FIR)

2. Composite sources can be significant contaminants to samples of "star forming galaxies"

3. The AGN component of the total IR SED can be significant – need to account for this when calculating SFR from L_{IR}

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2. Composite sources can be significant contaminants to samples of "star forming galaxies"

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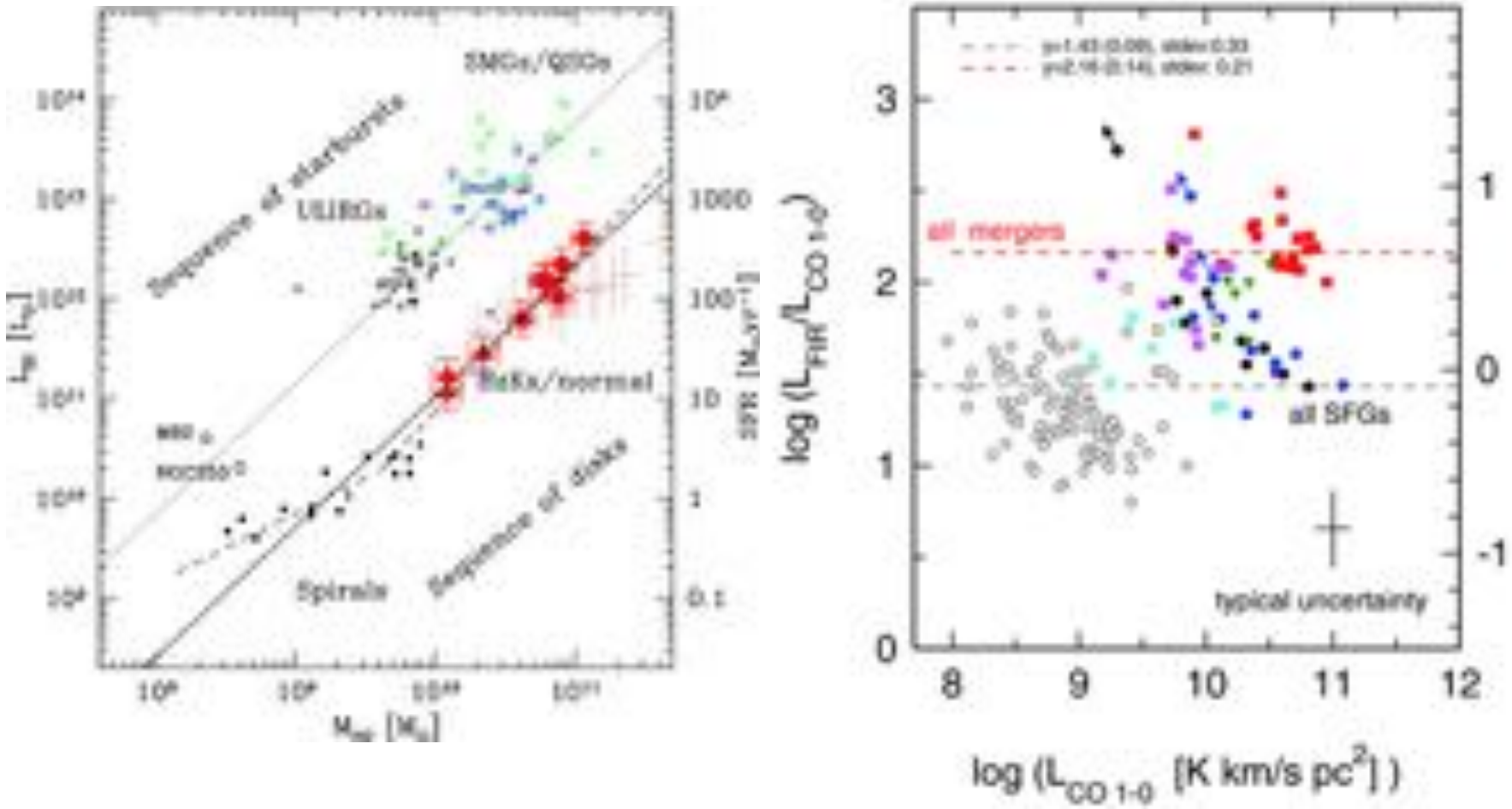
Linking molecular gas and star formation at high redshift: Integrated Schmidt-Kennicutt relation



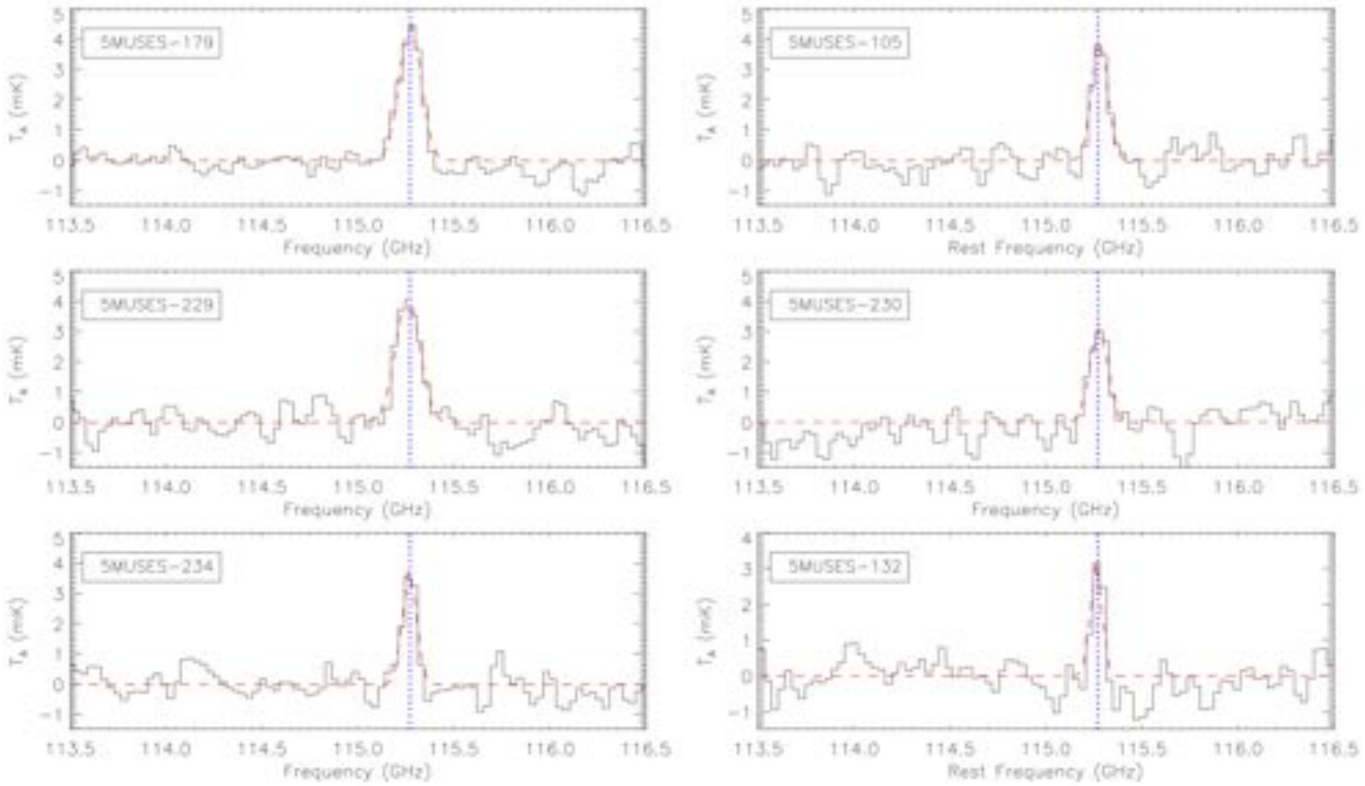
Daddi et al. 2010; Genzel et al. 2010

EARLY SCIENCE WITH THE LARGE MILLIMETER TELESCOPE: EXPLORING THE EFFECT OF AGN ACTIVITY ON THE RELATIONSHIPS BETWEEN MOLECULAR GAS, DUST, AND STAR FORMATION

Allison Kirkpatrick[1], Alexandra Pope[1], Itziar Aretxaga[2], Lee Armus[3], Daniela Calzetti[1], George Helou[4], Alfredo Montaña[2], Gopal Narayanan[1], F. Peter Schloerb[1], Yong Shi[5], Olga Vega[2], Min Yun[1]

2014, ApJ, 796, 135

Observations: LMT/RSR CO(1-0) detections for AGN and SF galaxies

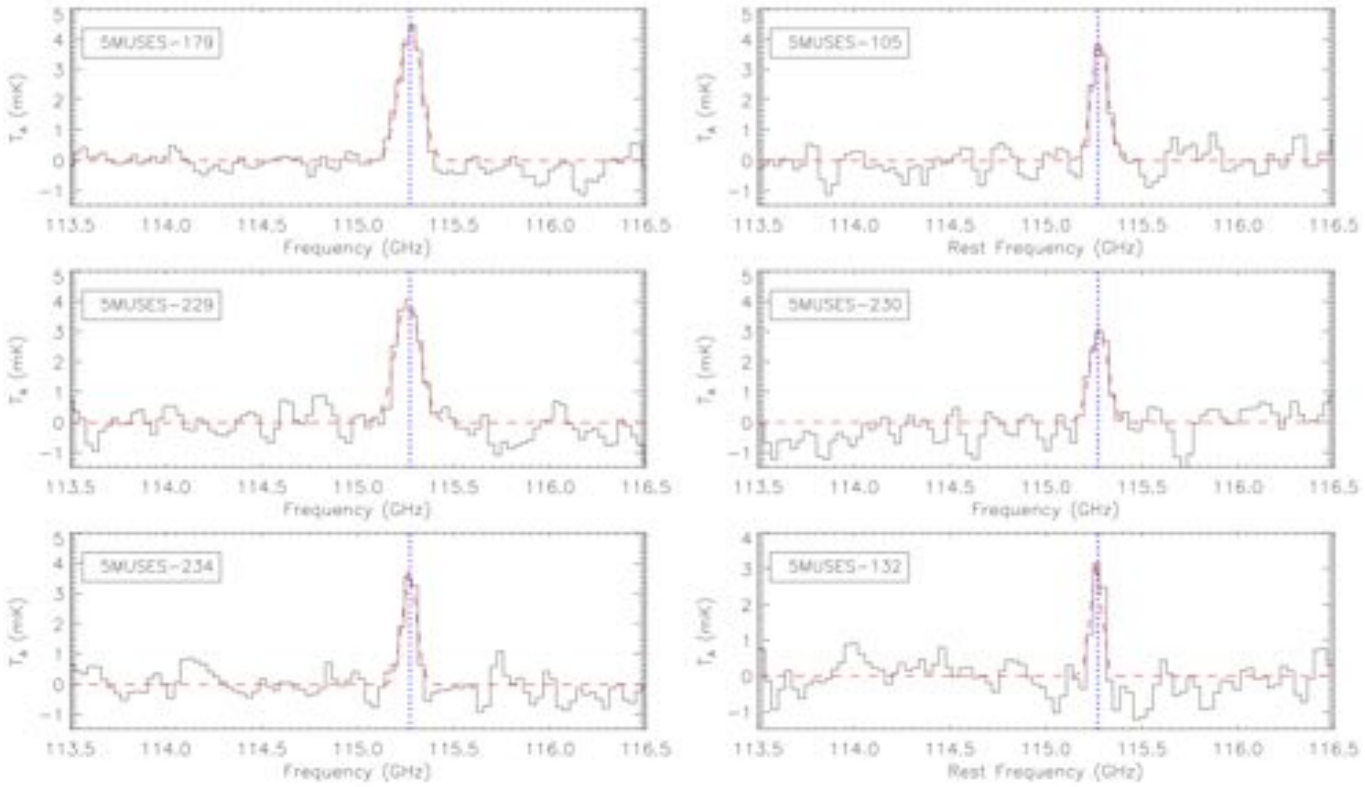


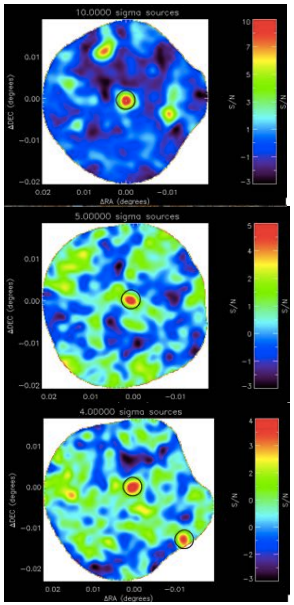
EARLY SCIENCE WITH THE LARGE MILLIMETER TELESCOPE: EXPLORING THE EFFECT OF AGN ACTIVITY ON THE RELATIONSHIPS BETWEEN MOLECULAR GAS, DUST, AND STAR FORMATION

Allison Kirkpatrick[1], Alexandra Pope[1], Itziar Aretxaga[2], Lee Armus[3], Daniela Calzetti[1], George Helou[4], Alfredo Montaña[2], Gopal Narayanan[1], F. Peter Schloerb[1], Yong Shi[5], Olga Vega[2], Min Yun[1]

2014, ApJ, 796, 135

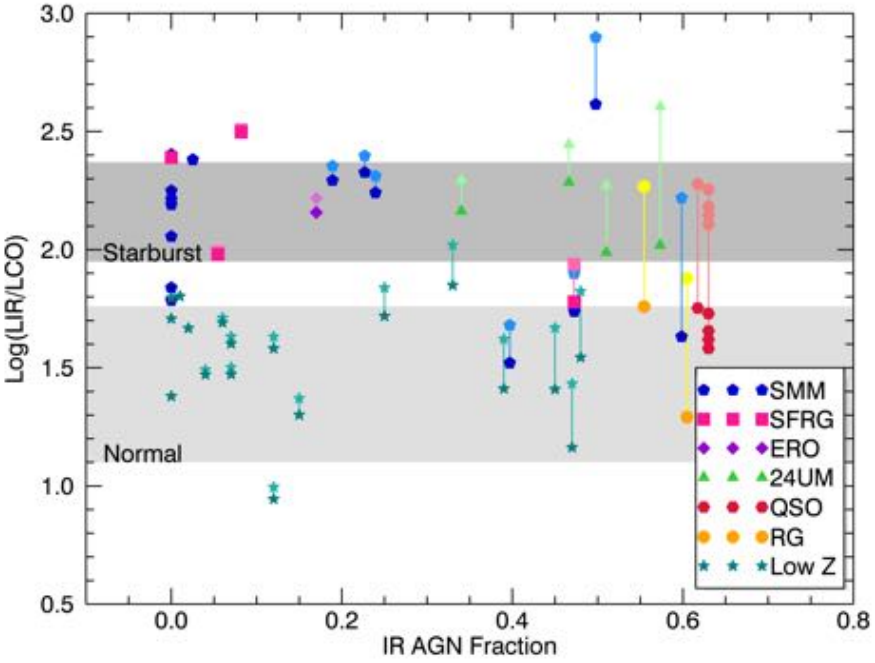
Observations: LMT/RSR CO(1-0) detections for AGN and SF galaxies

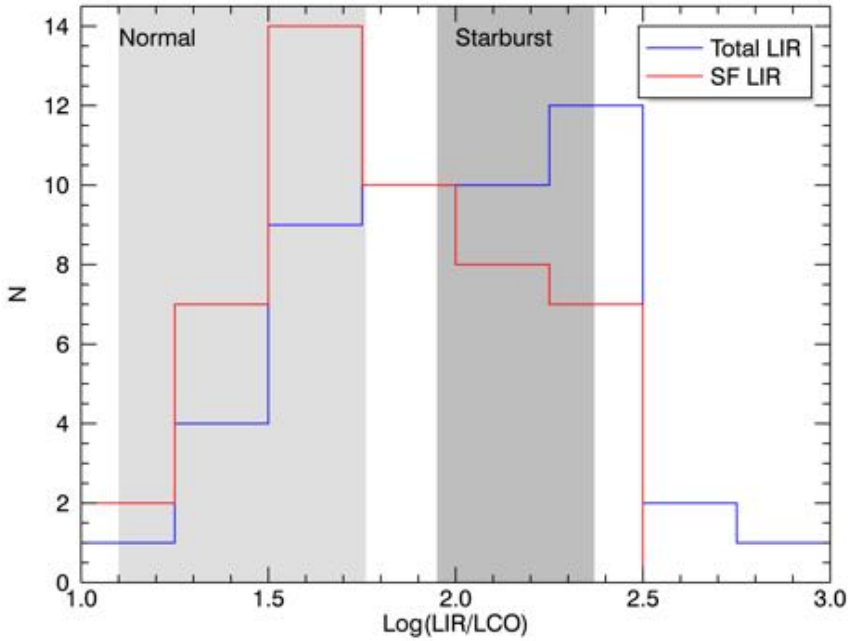




NEW: AzTEC 1.1mm imaging 8" beam

“AGN-corrected” integrated S-K relation





Need to account for AGN emission when using these diagnostics

Kirkpatrick, Pope, et al., 2014; Keller, Pope, et al., in prep.

Outstanding Questions

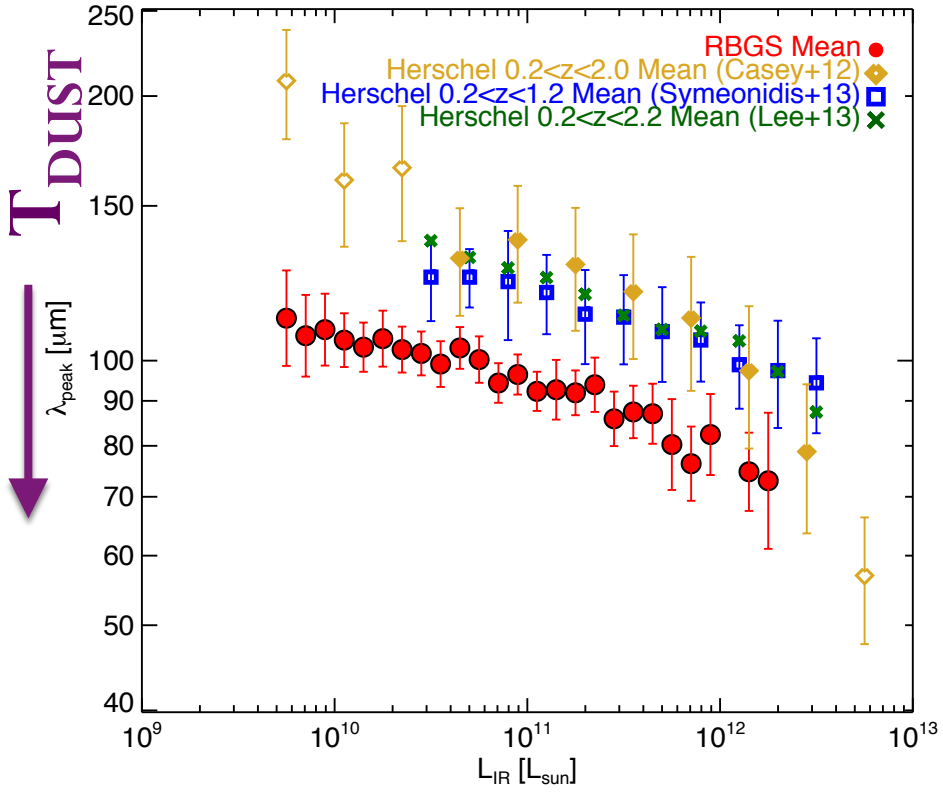
- **How is the star formation linked to the black hole growth?**

  Can we separate emission from each in our observations?

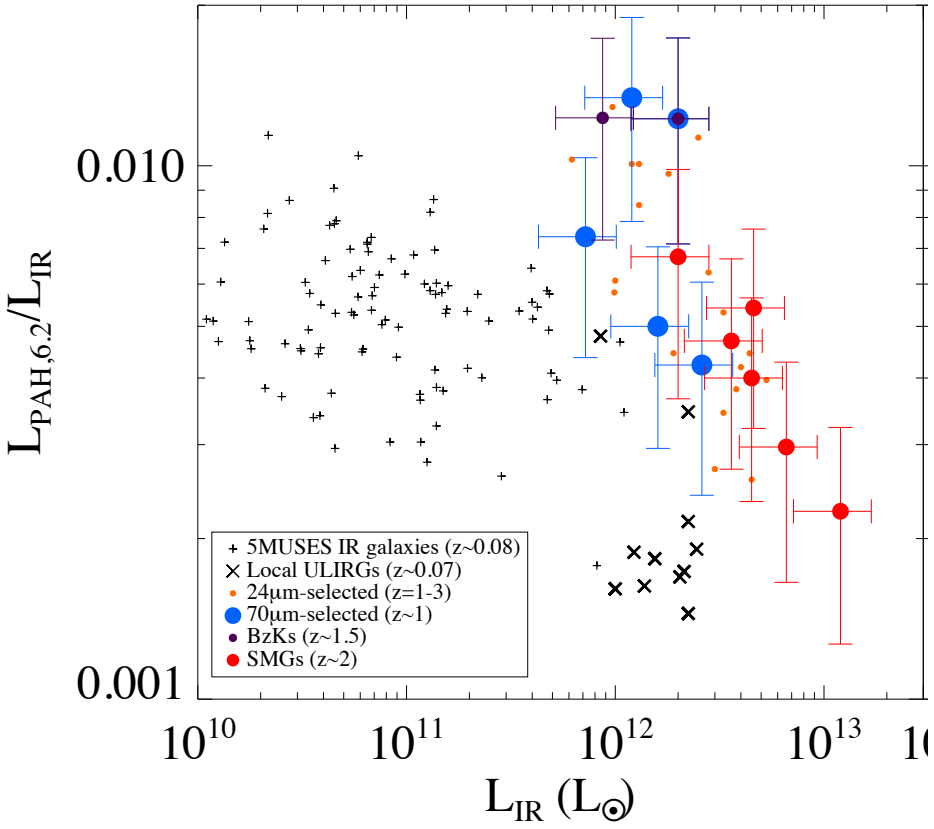
- **Are the mechanisms of triggering and fueling star formation during the peak period of z=1-3 different from those in the local Universe?**

  How do the interstellar medium conditions differ during the peak period of z=1-3 from those in local galaxies?

More cold dust and enhanced PAH emission at high redshift

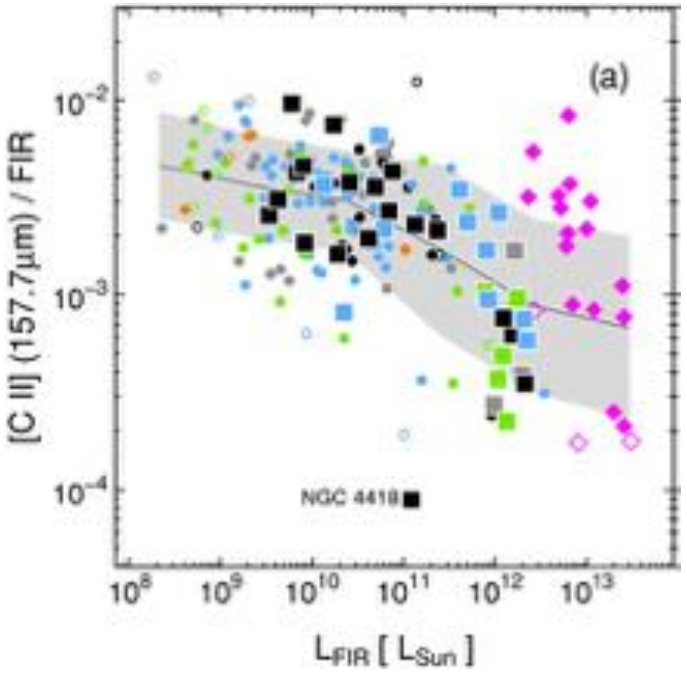


Casey et al. 2014
see also Chapman et al. 2005, Pope et al. 2006

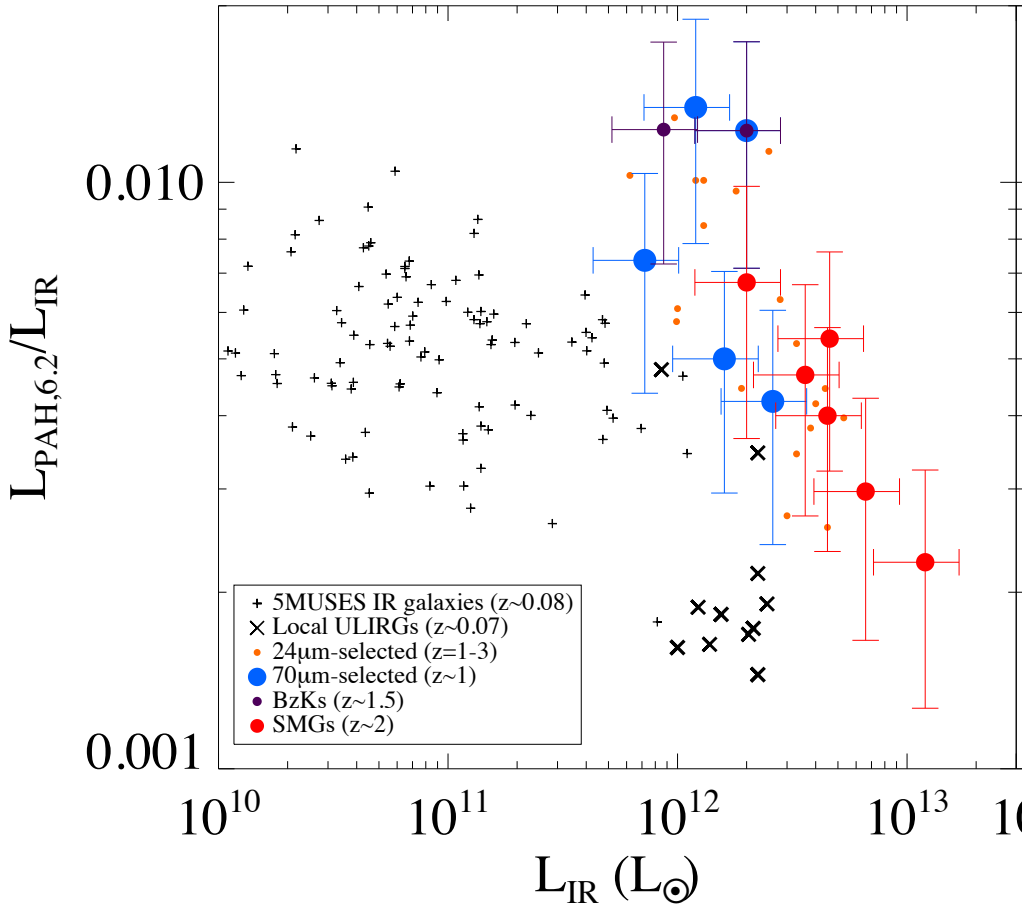


Pope et al. 2008, 2013

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



Graciá-Carpio et al. 2011



Pope et al. 2013

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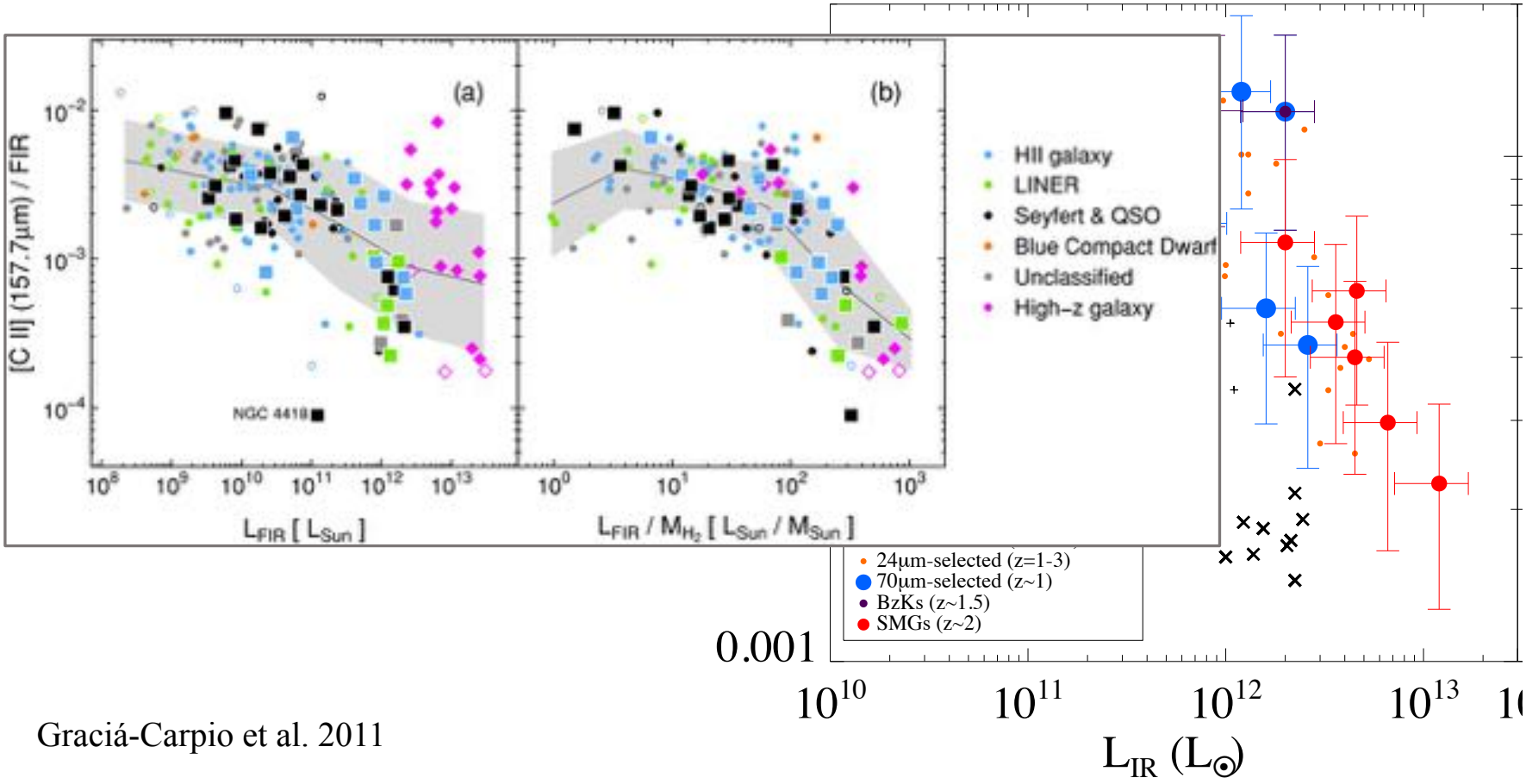
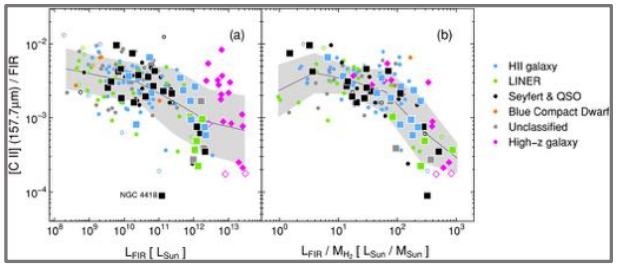
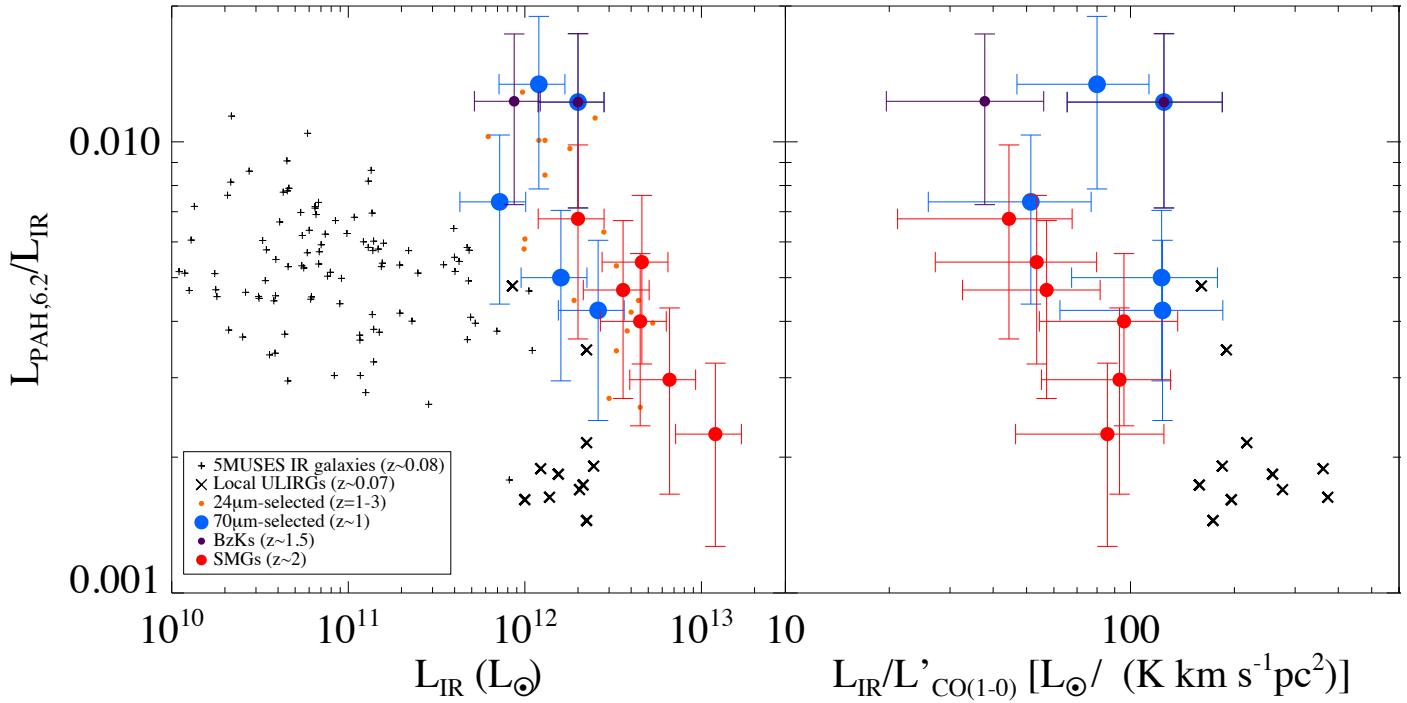


Graciá-Carpio et al. 2011

Pope et al. 2013

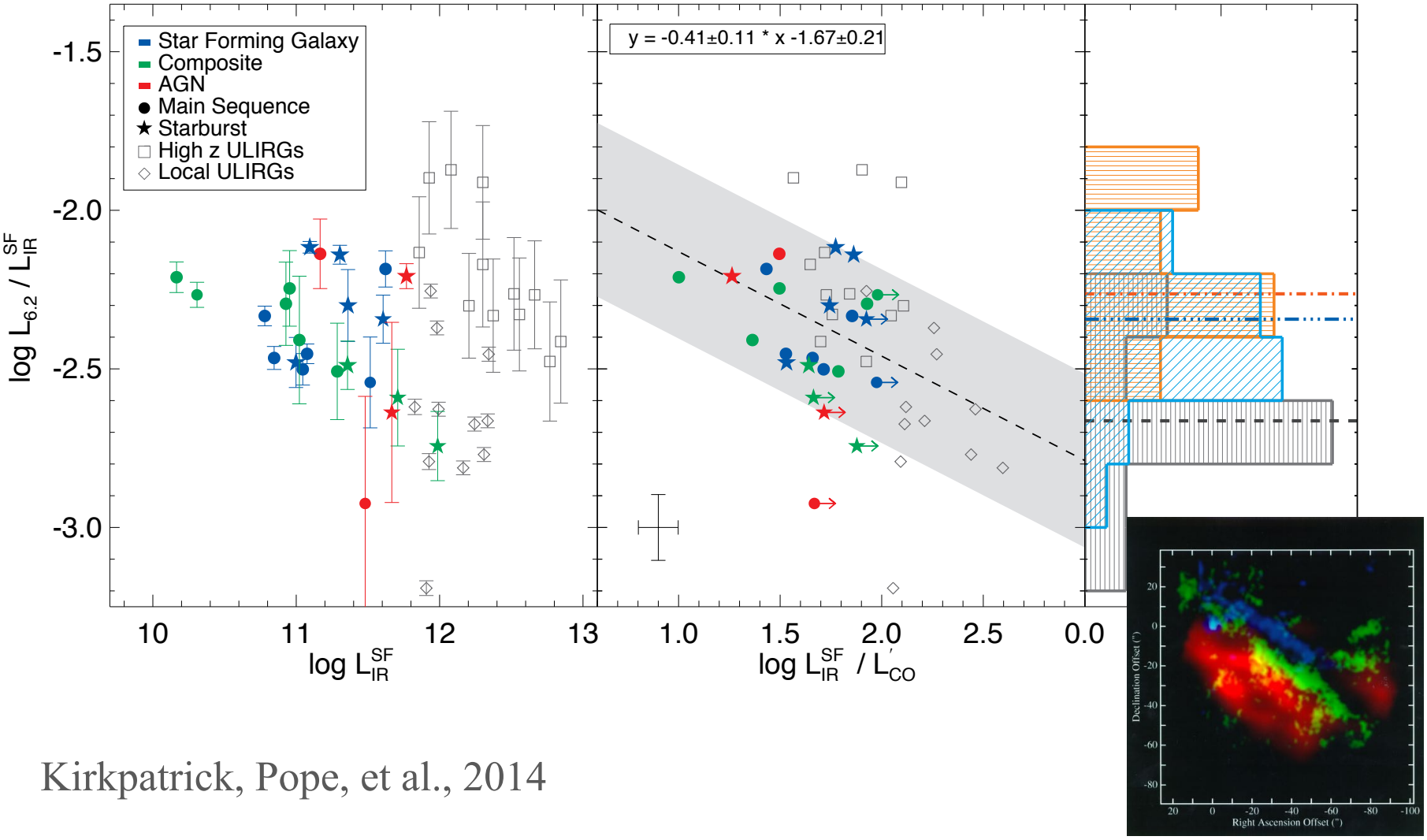
Link between **enhanced PAH emission** at high redshift and **more molecular gas**





Pope et al. 2013

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



Kirkpatrick, Pope, et al., 2014

SUMMARY

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

  Can we separate emission from each in our observations?

  - Yes: decompose IR SED into SF and AGN components. Many galaxies show significant emission from both: "composite galaxies"

  - We observe differences in the cool and warm dust temperatures between the AGN, composite and SF galaxies => AGN heat the dust to higher temperatures and can account for up to 80% of L_{IR}

  - AGN emission must be subtracted when calculating SFRs (e.g S-K)

SUMMARY

- **Are the mechanisms of triggering and fueling star formation during the peak period of z=1-3 different from those in the local Universe?**

  How do the interstellar medium conditions differ during the peak period of z=1-3 from those in local galaxies?

  - Enhanced PAH emission is linked to the increased molecular gas in high redshift galaxies -> star formation in scaled up PDRs?

  ALMA+large single dish (sub)mm telescopes (e.g. LMT) are allowing us to push studies of the ISM down to typical L* galaxies that are dominating the SFRD

Work in progress

LMT Frontier Fields Program

PIs: A. Pope, A. Montana

Deep AzTEC 1.1mm imaging

8 arcsec beam FWHM

Observed depth~100Msun/yr

Intrinsic depth<50Msun/yr