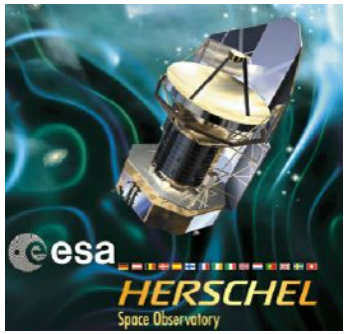
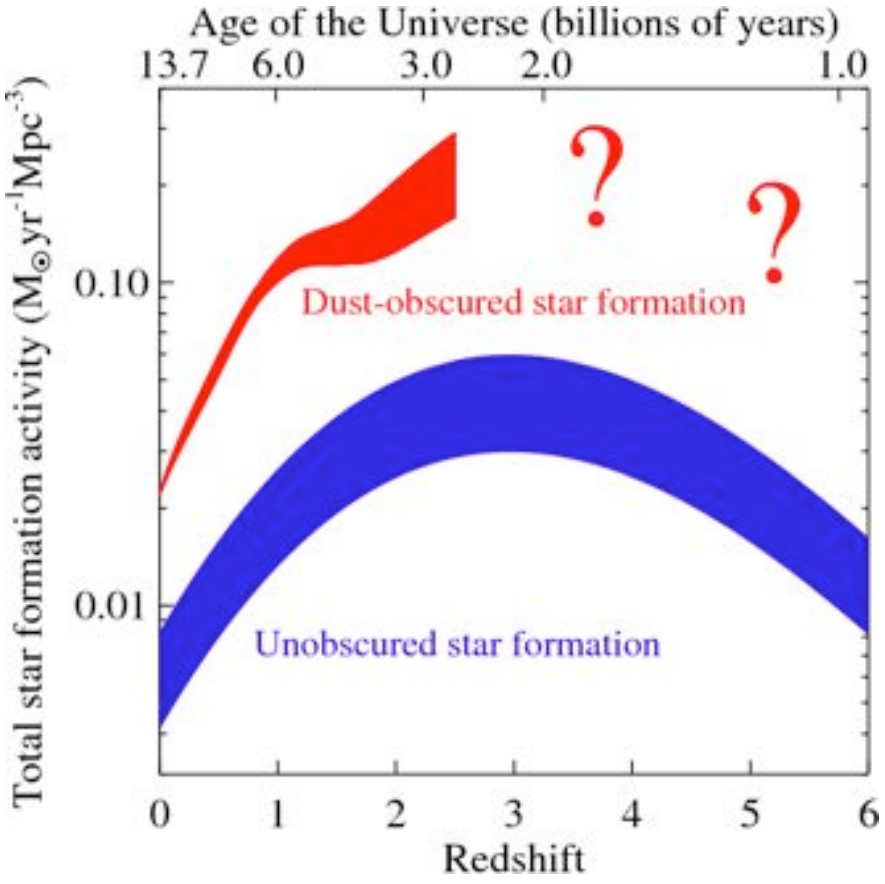
Multi-wavelength ISM diagnostics in high redshift galaxies

Alexandra Pope (UMass Amherst)

Transformational Science in the ALMA Era:
Multi-Wavelength Studies of Galaxy Evolution Conference
Charlottesville, VA – August 5, 2014

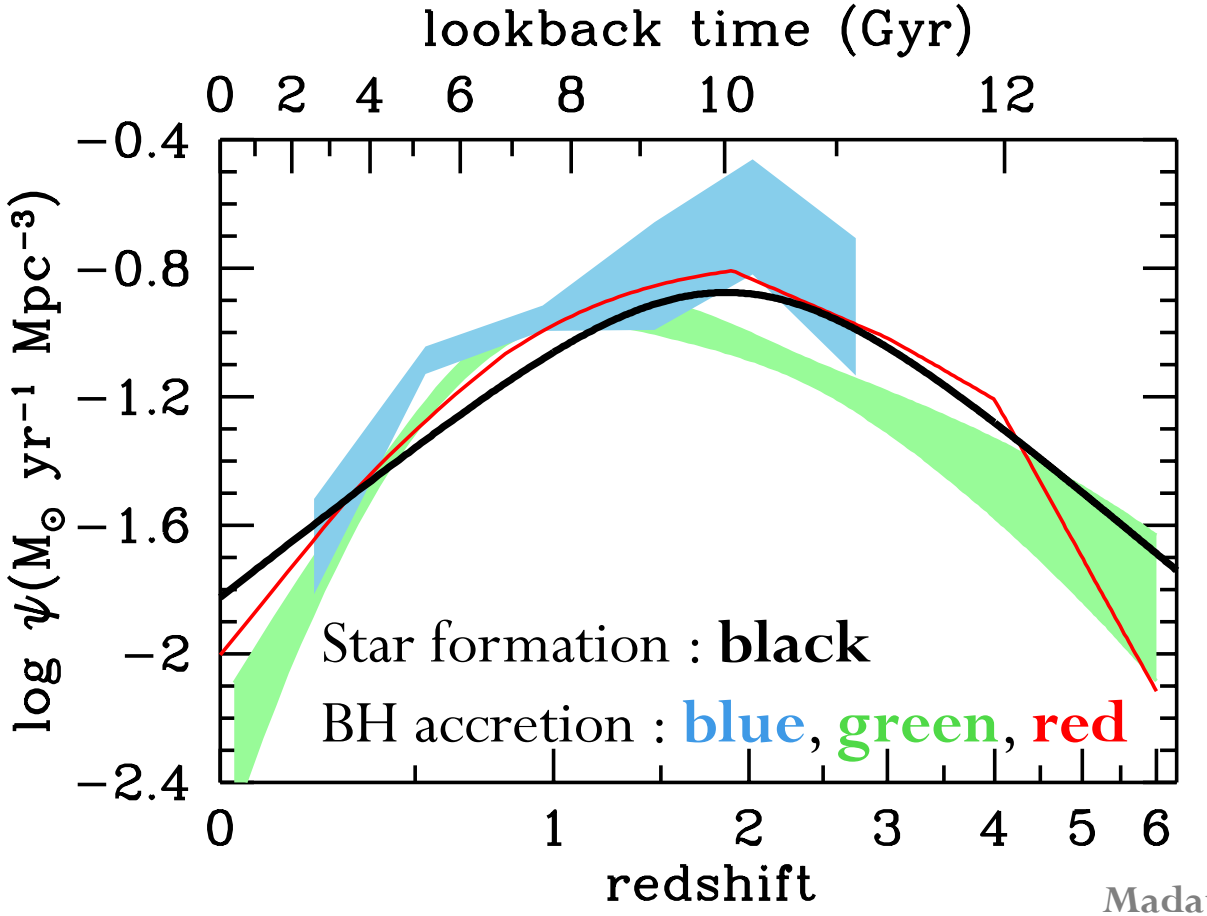


Dust-obscured activity dominates the build-up of stars and black holes in galaxies



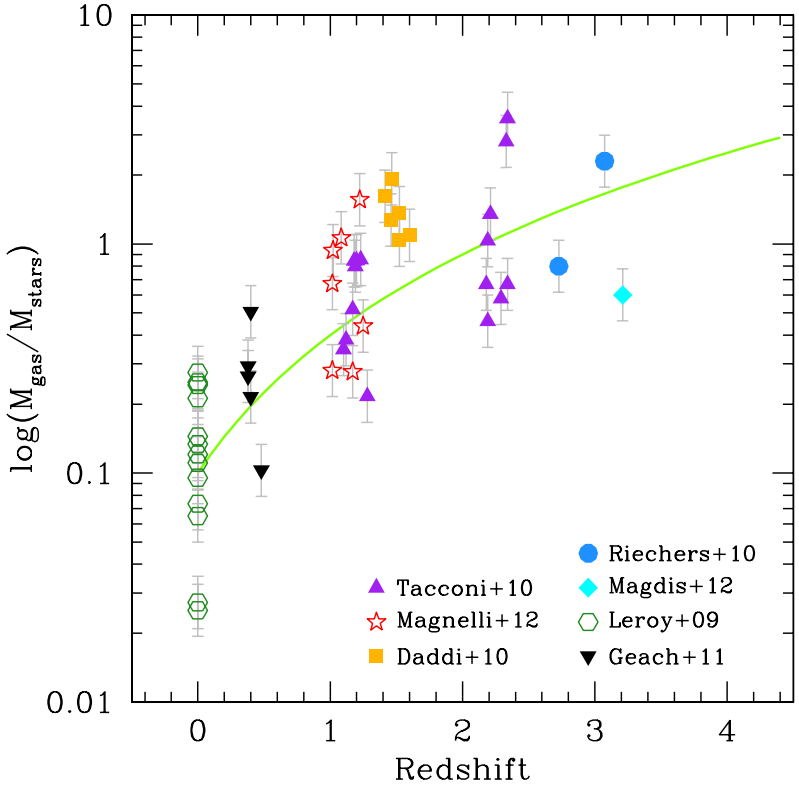
Using data from **Bouwens+2009** and **Murphy+2011**

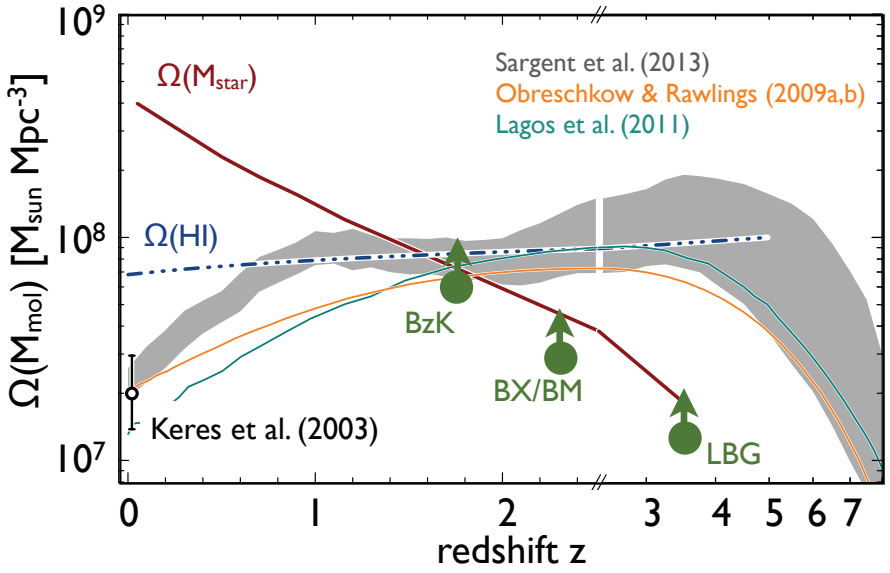
Dust-obscured activity dominates the build-up of stars **and black holes** in galaxies



Madau & Dickinson 2014

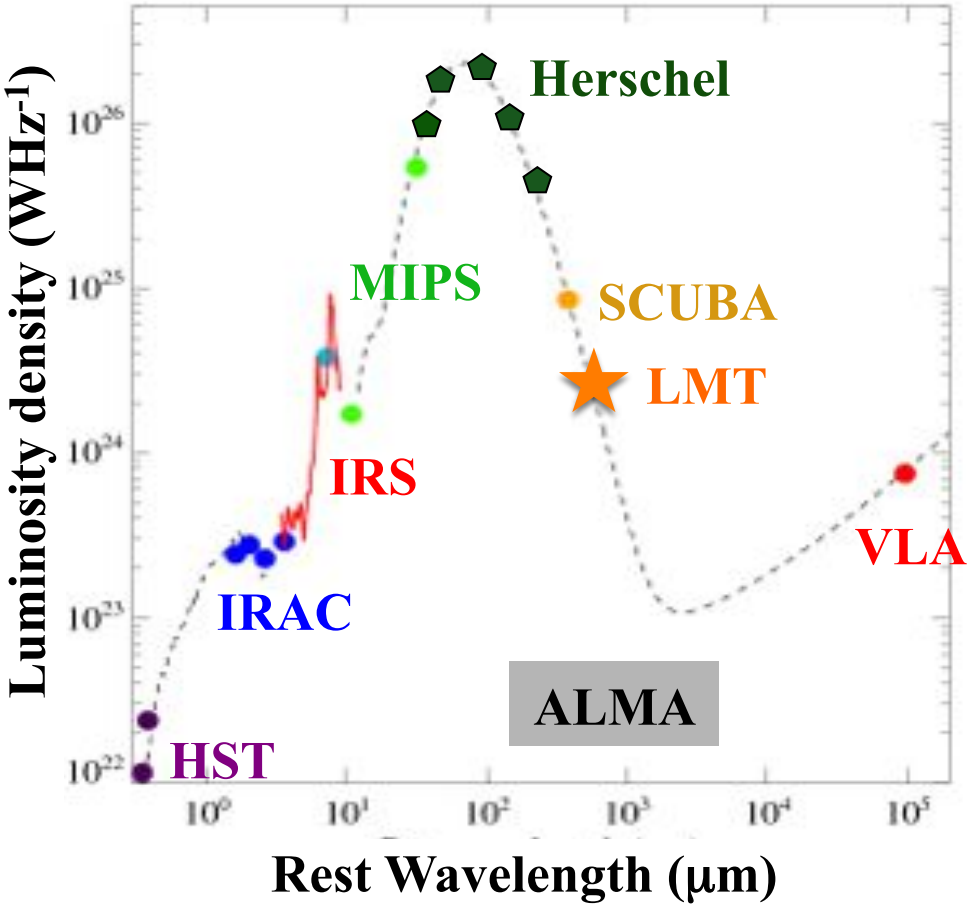
More molecular gas available during the peak epoch of dusty star formation and black hole growth





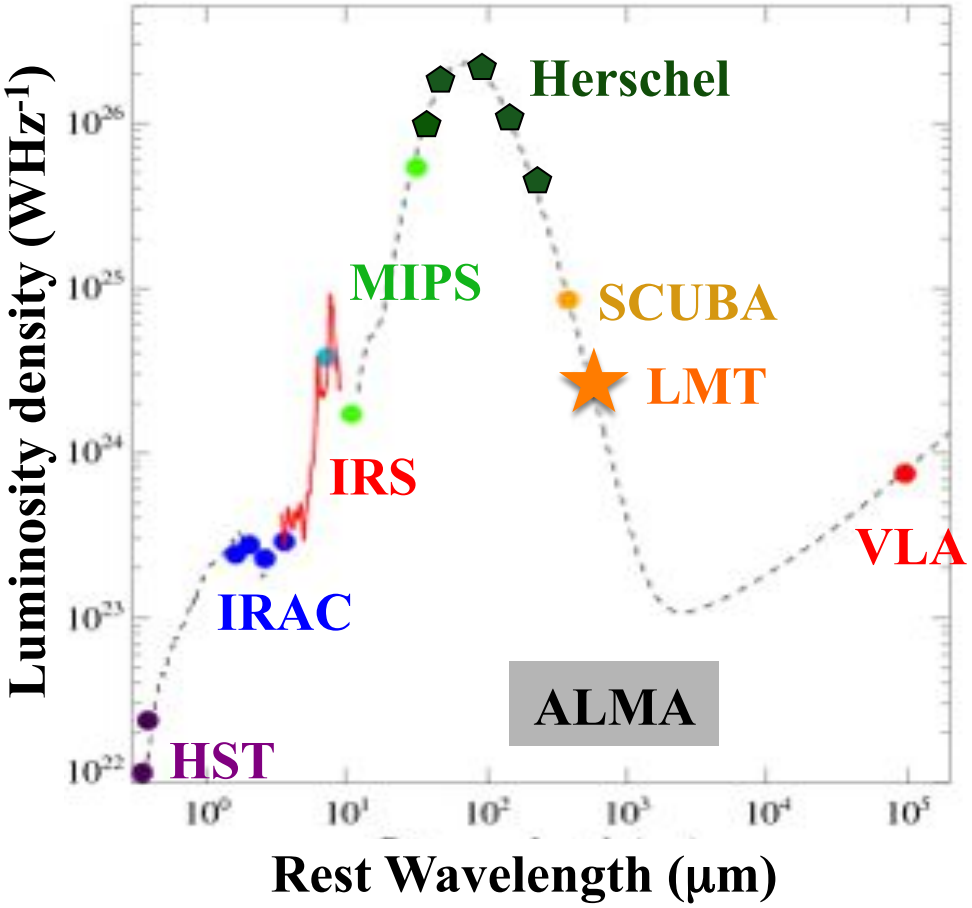
Carilli & Walter 2013

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



Circa 2014: Well sampled spectral energy distribution (SED) for high redshift Ultra Luminous Infrared Galaxies (ULIRGs, SFR ≥ ~100 M_{sun}/yr)

How do 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 emission: dust temperatures**
- **Millimeter spectroscopy (e.g. ALMA, LMT) probes the molecular gas reservoir**

Large Millimeter Telescope (LMT)

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

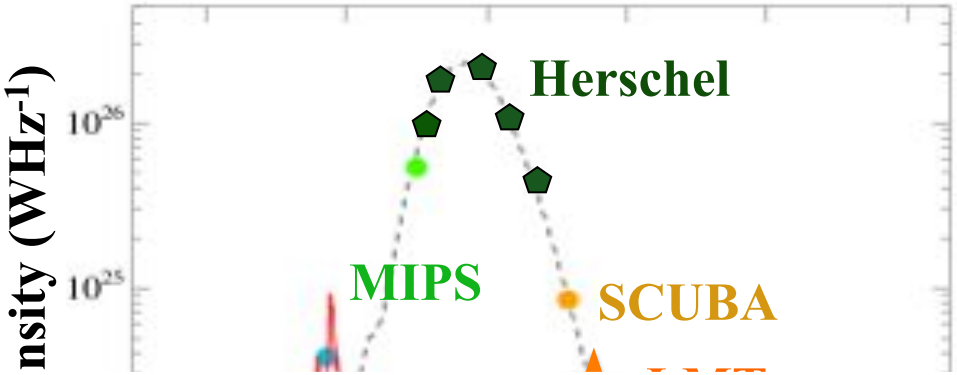
- Currently operating in *Early Science* mode as a 32.5m telescope
- Early science instrumentation:

  - AzTEC 1.1mm camera
  - 3mm Redshift Search Receiver (RSR)

- 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**

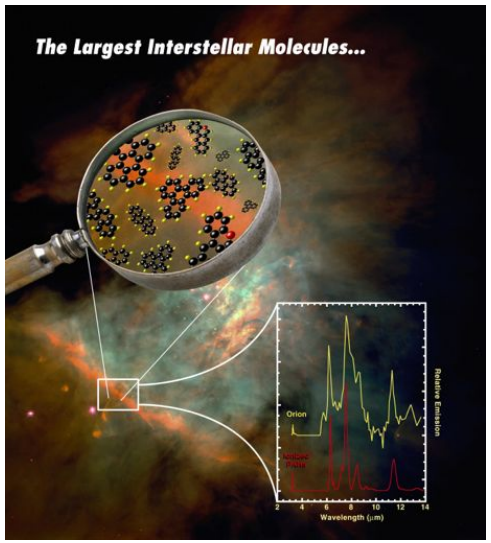
<u>Goal:</u> Understand how dusty star formation and black hole growth proceeds during the peak epoch

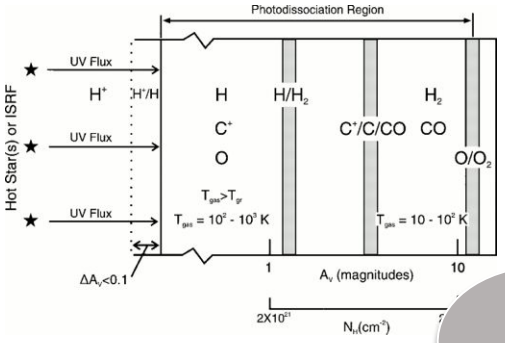
<u>Approach:</u> Link multi-wavelength diagnostics of the ISM in high redshift dusty galaxies

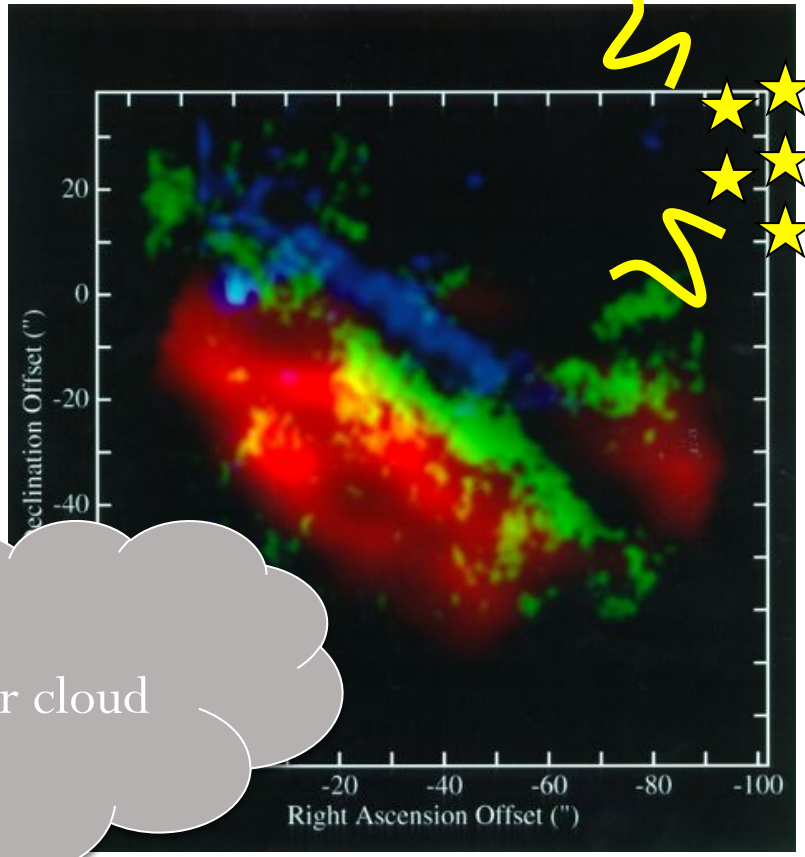
Session: Star Formation and Assembly of Galaxies

- How is the S-K law "law" affected by different measurement limitations or conversion factors (from tracer molecules or emission / absorption lines to amounts of gas and SFR)?
- Are the measurements from different tracers of ISM and SF consistent?
- How do galaxies grow (*evolve*) over cosmic time?

Tracers of the ISM and star formation







Molecular cloud

PAH

H_2

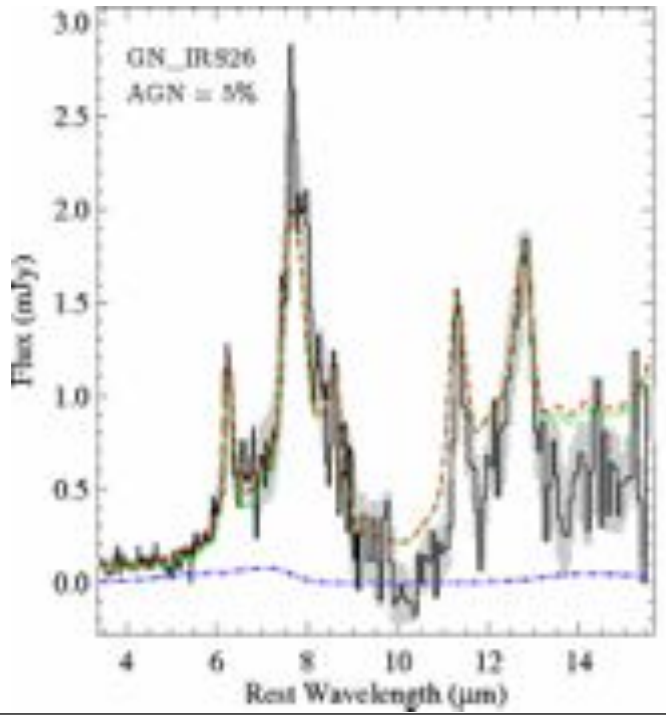
CO

Hollenbach &Tielens 1997

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

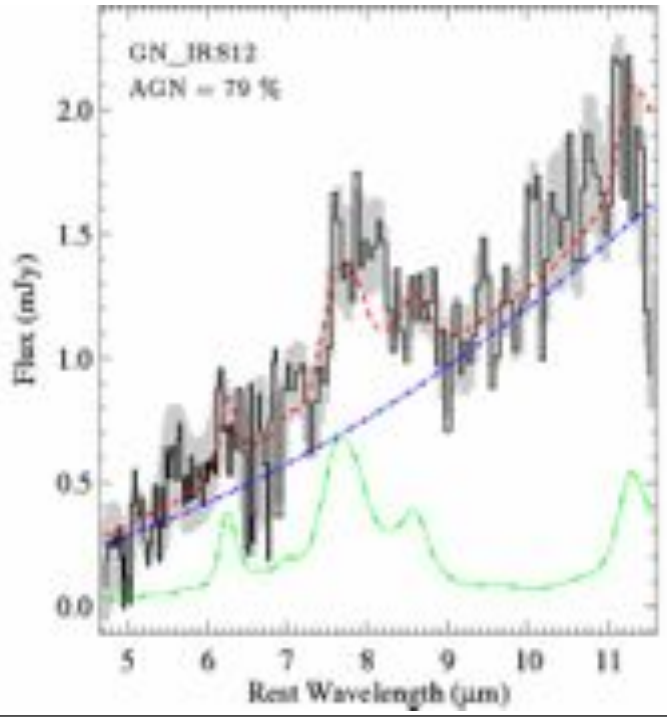
1. Star formation:

Polycyclic aromatic hydrocarbons (PAH) emission lines + extinction

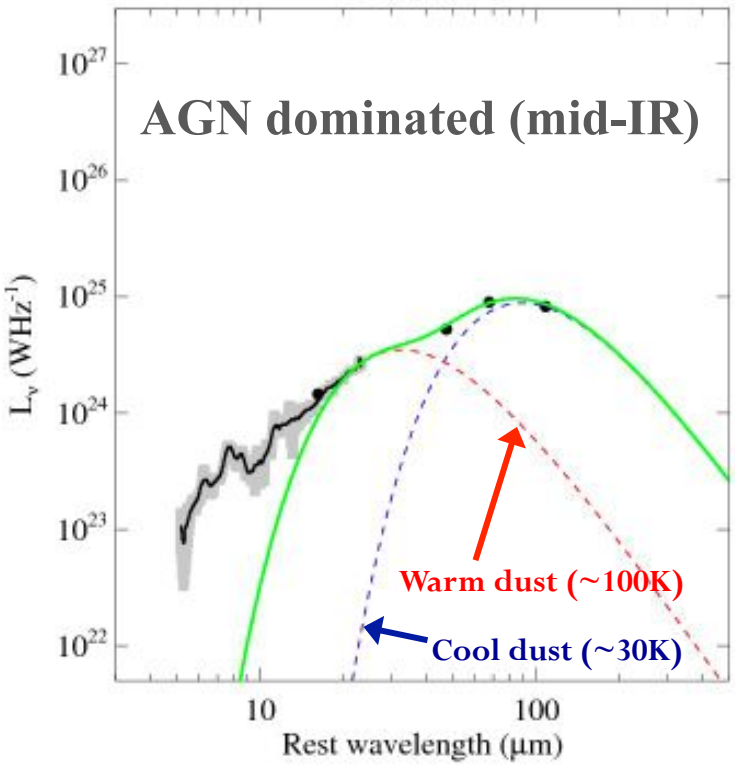


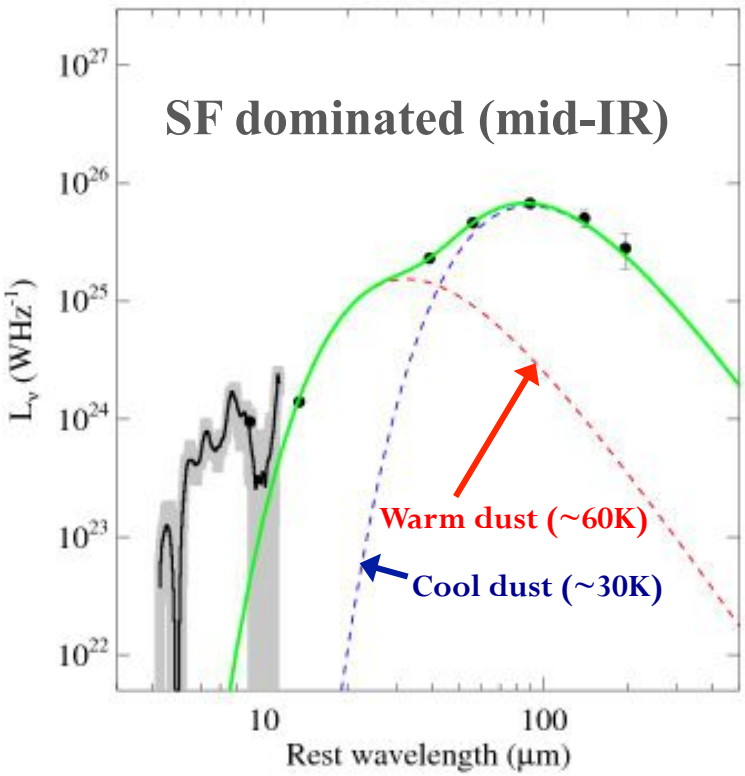
2. Active Galactic Nuclei:

Power-law + extinction



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





Kirkpatrick, Pope, et al. 2012

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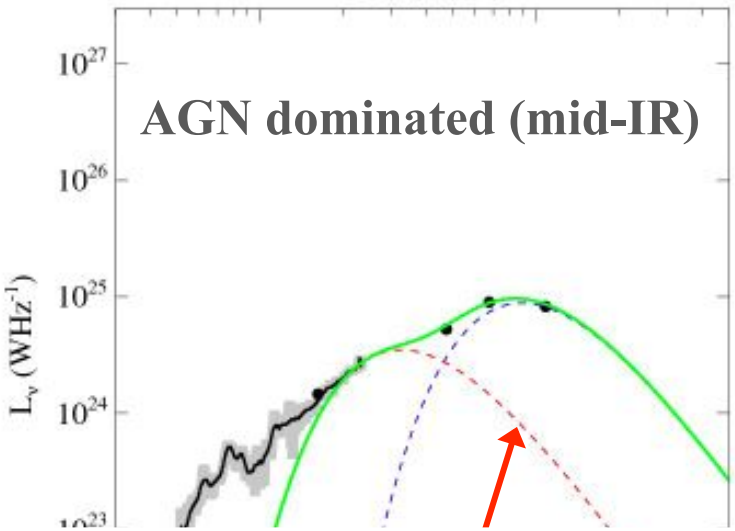


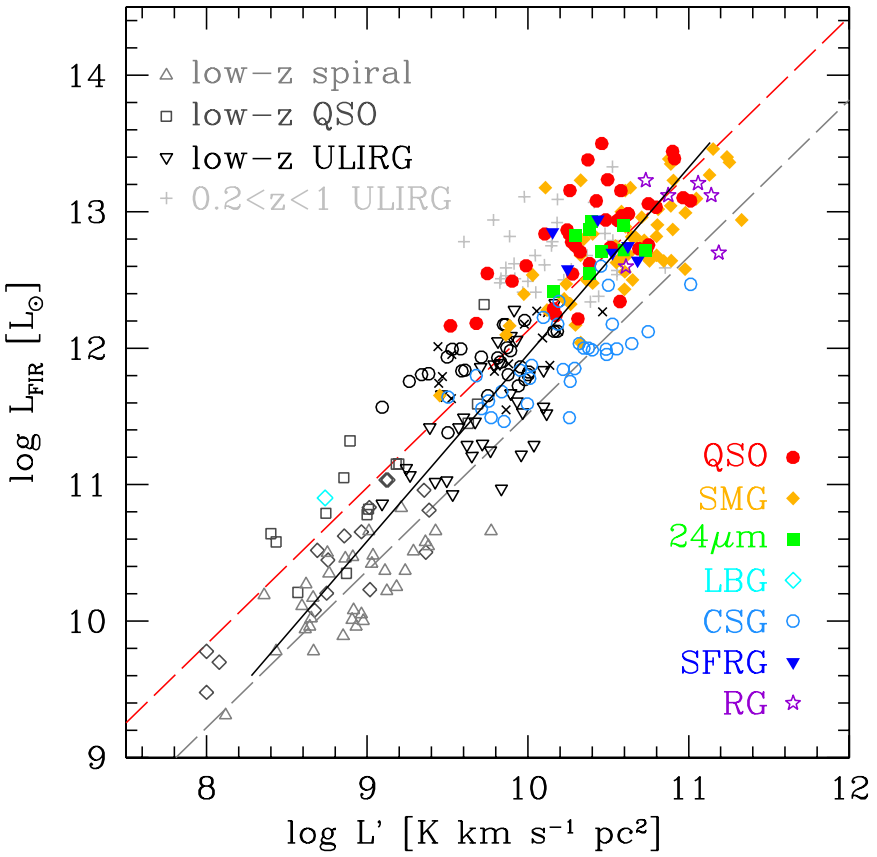
$L_{IR,cold}/L_{IR,total} = 0.2\text{-}0.5$

$SFR = (0.2\text{-}0.5) * 1.5e\text{-}10 * L_{IR,total}$

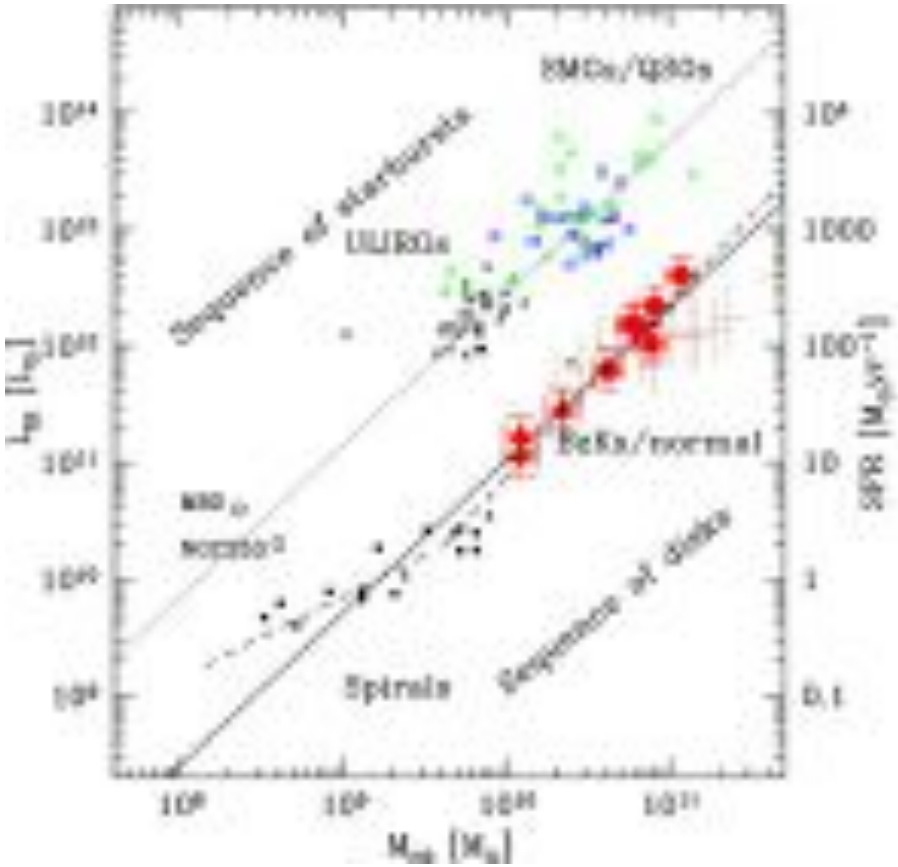
How does this affect the Schmidt-Kennicutt relation?

Kirkpatrick, Pope, et al. 2012

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

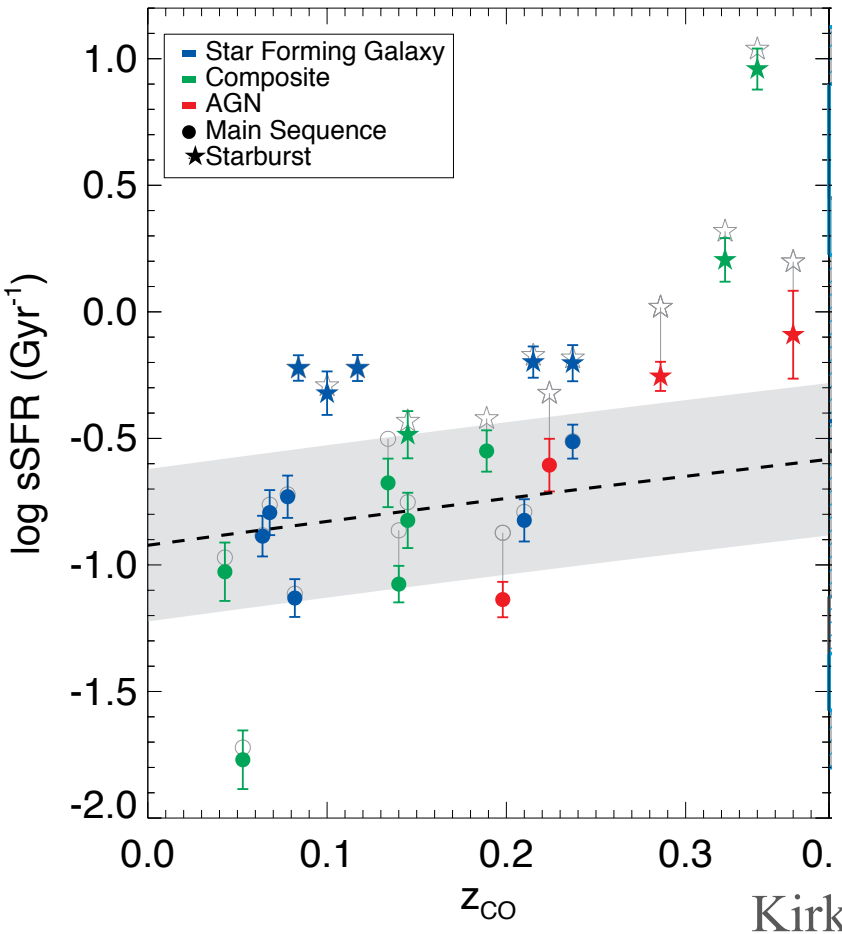


Carilli & Walter 2013



Daddi et al. 2010; see also Genzel et al. 2010

Sample: Intermediate redshift AGN and SF galaxies

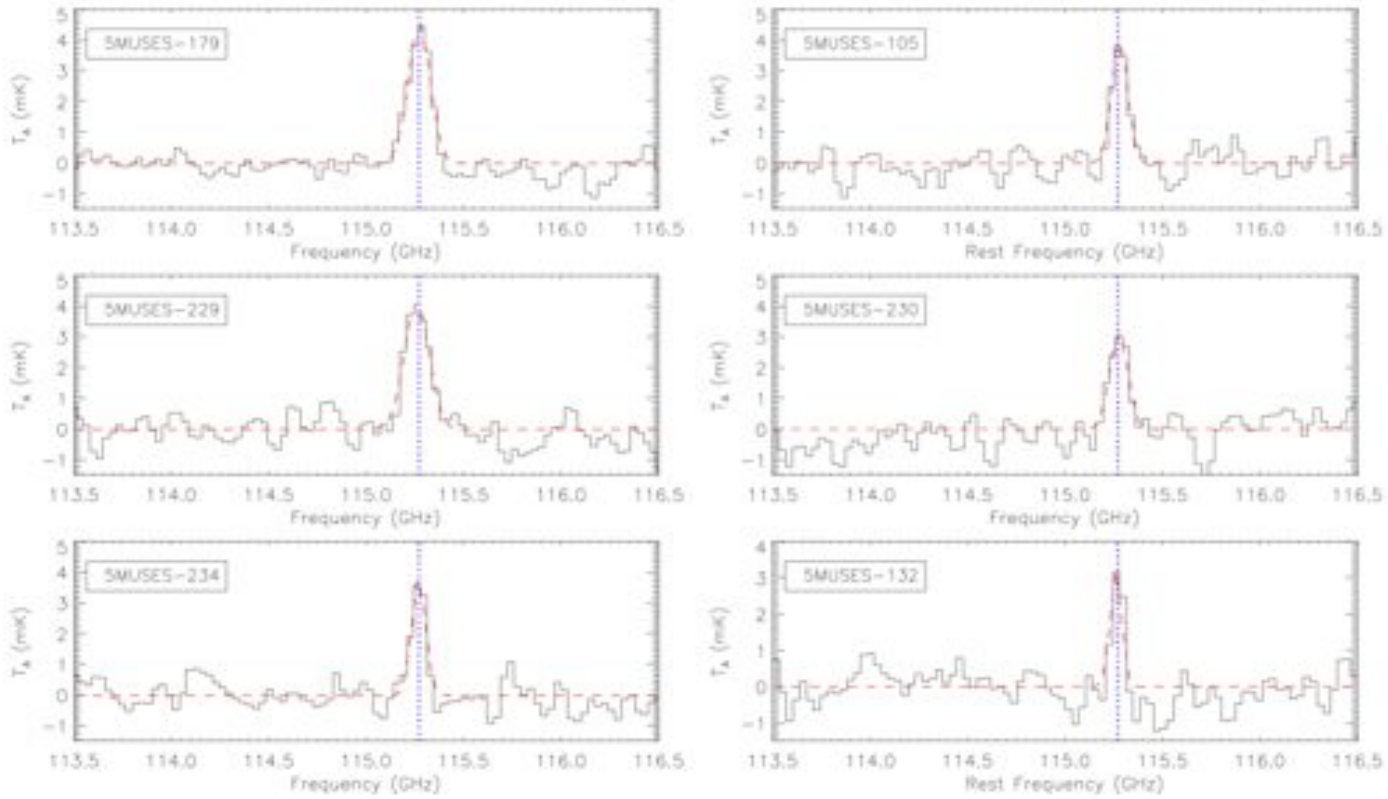


5MUSES survey

- z~0.2
- *Spitzer*/IRS spectra + *Herschel* imaging = decompose IR SED into SF and AGN components
  => SFR($L_{IR,SF}$)
- From SSFR:
  14 Main Sequence
  10 Starbursts

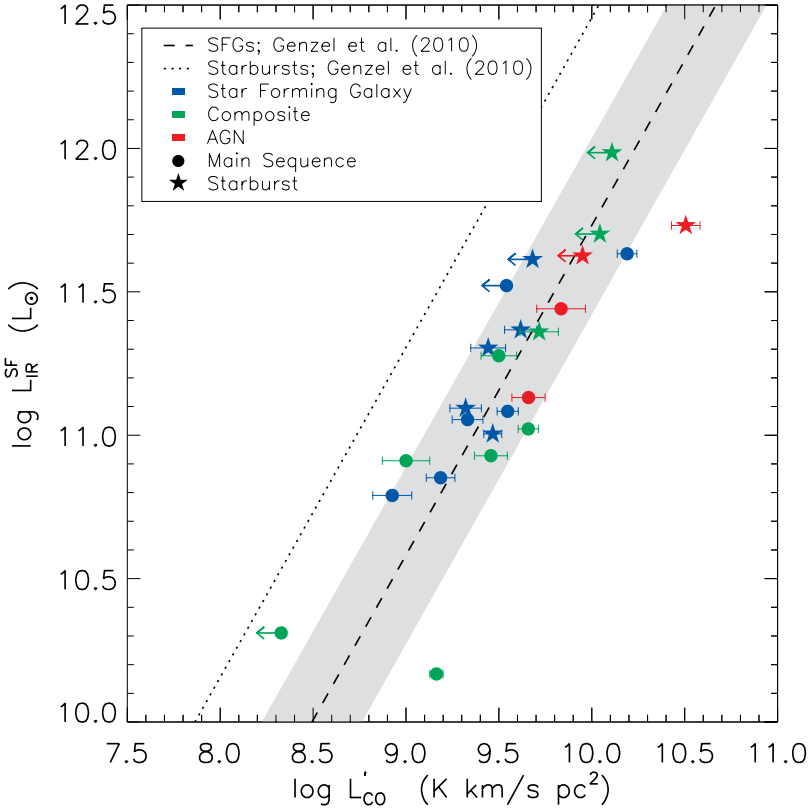
Kirkpatrick, Pope, et al., 2014, ApJ submitted

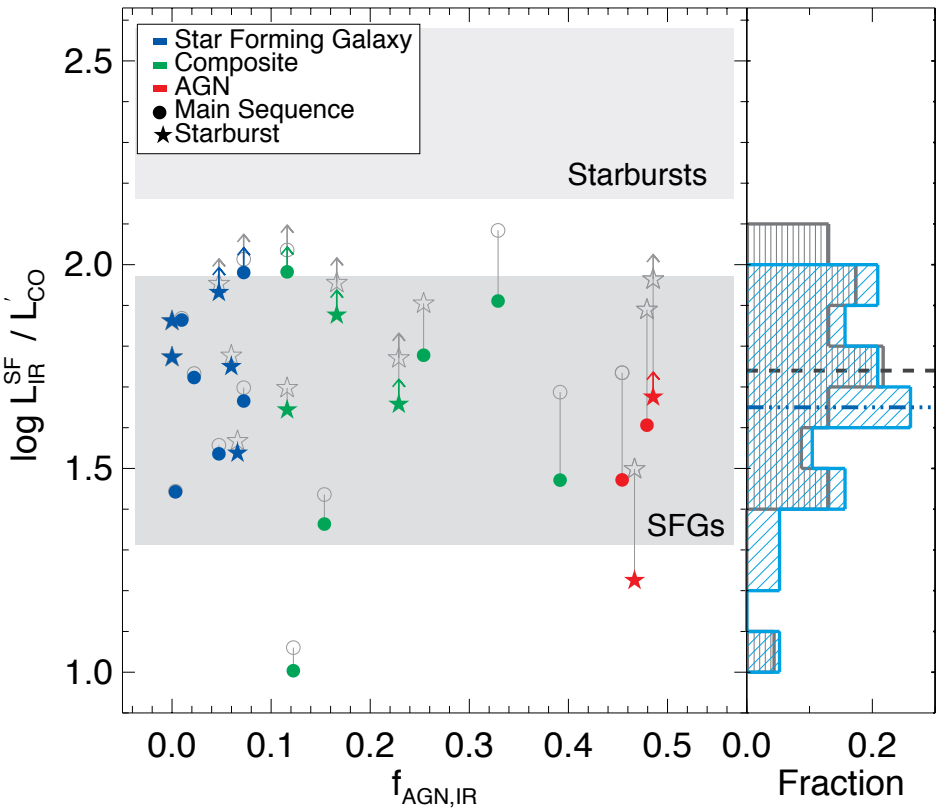
Observations: New LMT/RSR CO(1-0) data for AGN and SF galaxies



Kirkpatrick, Pope, et al., 2014, ApJ submitted

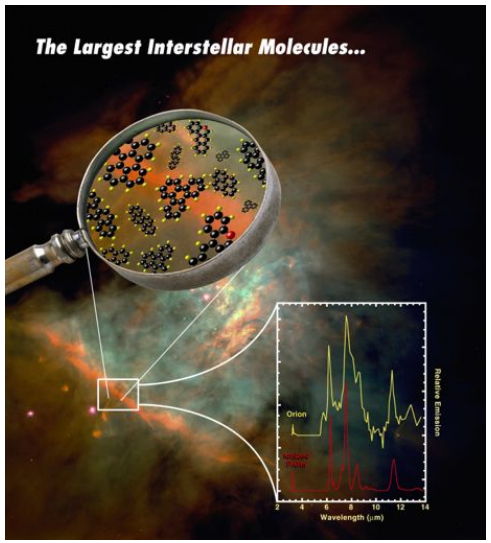
“AGN-corrected” integrated S-K relation

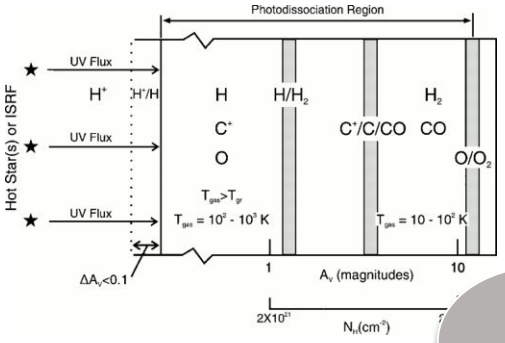


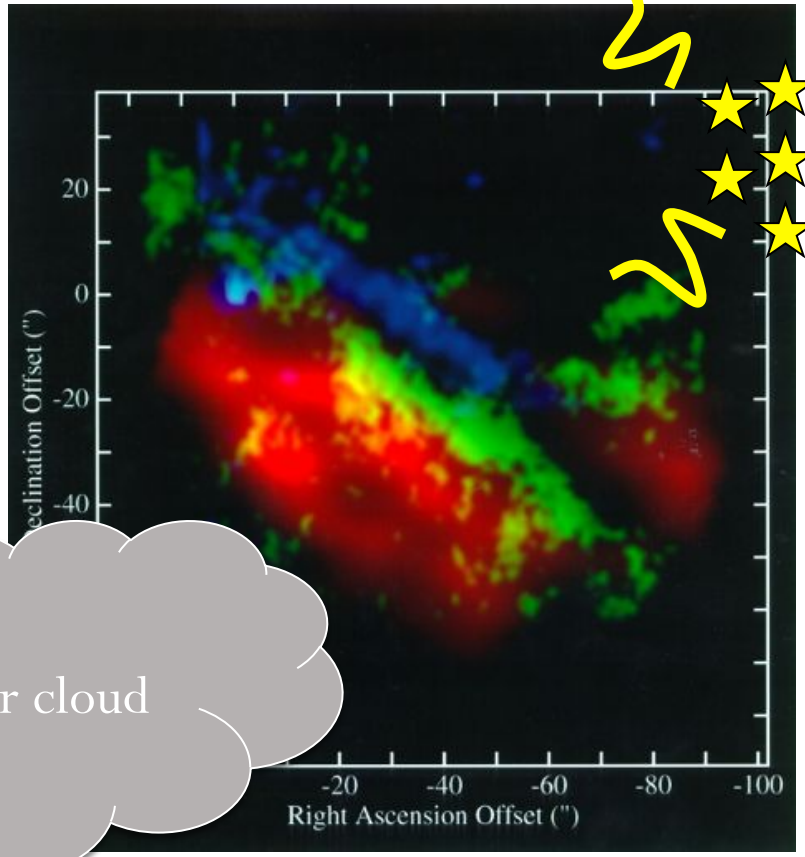


Kirkpatrick, Pope, et al., 2014, ApJ submitted

Polycyclic Aromatic Hydrocarbon (PAH) emission as a tracer of star formation







Molecular cloud

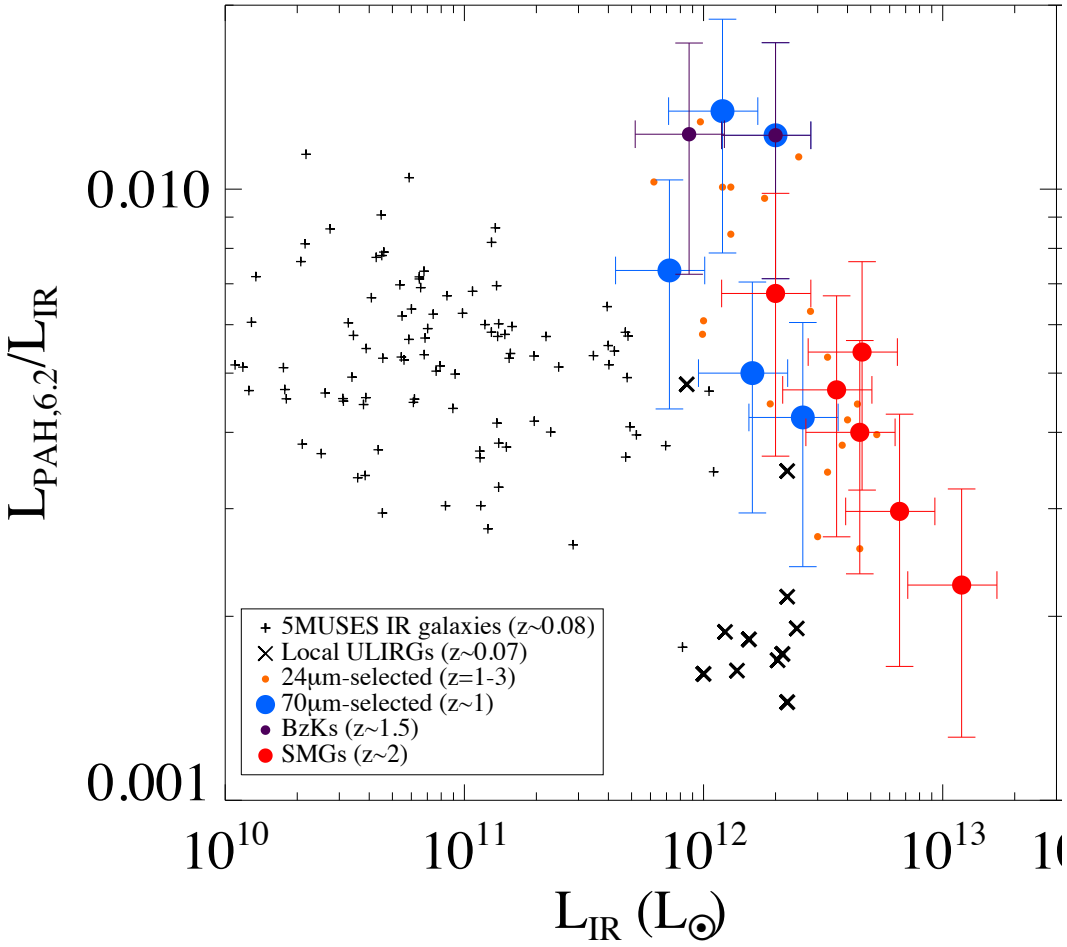
PAH

H_2

CO

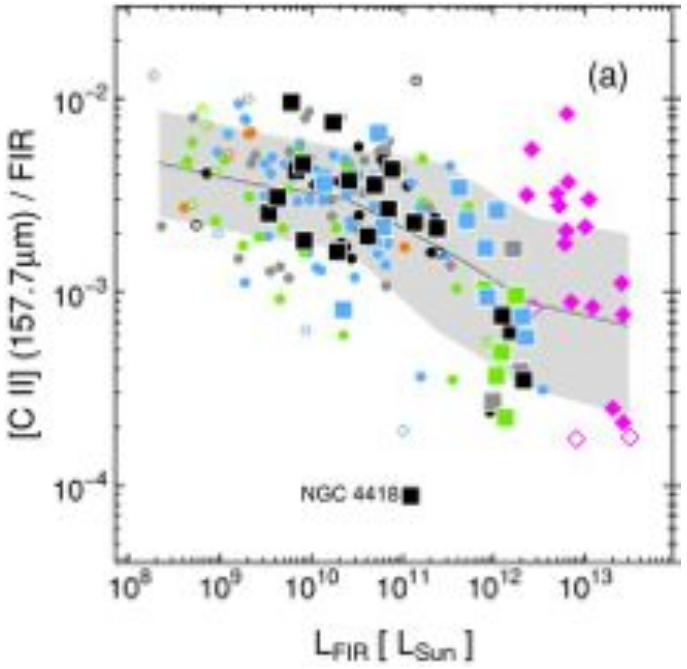
Hollenbach &Tielens 1997

Enhanced PAH emission at high redshift

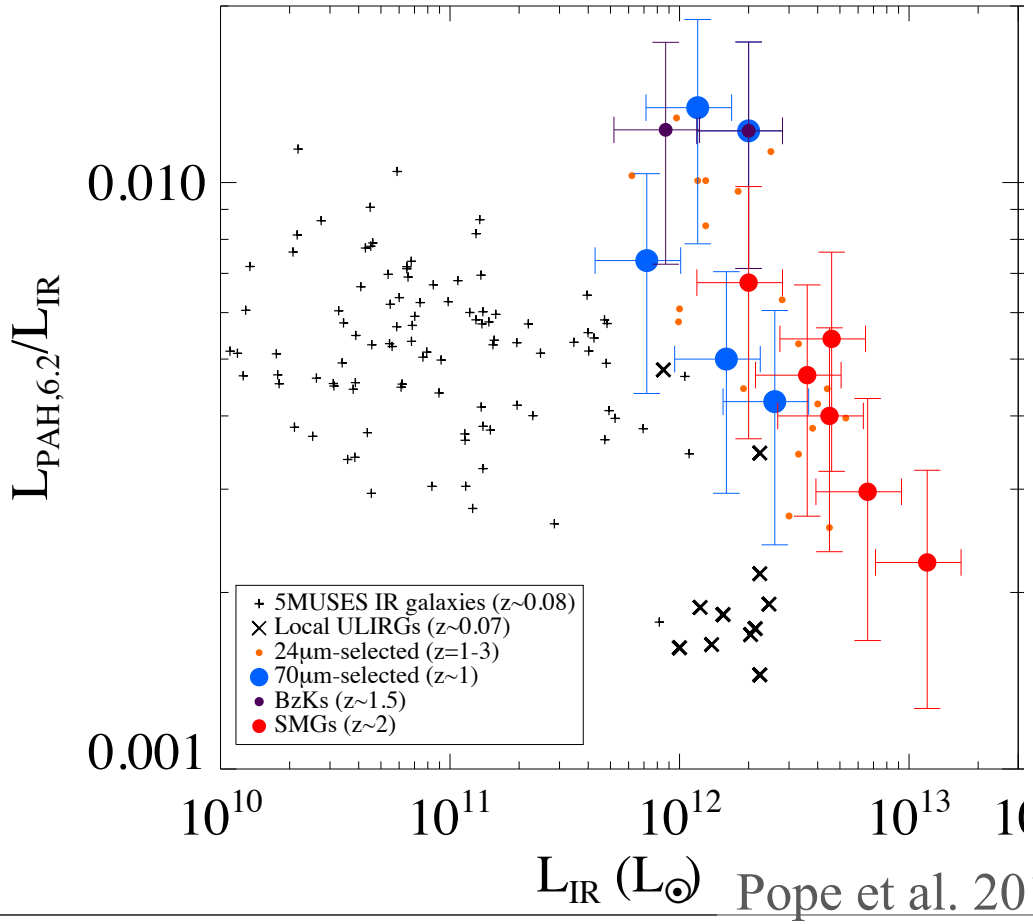


Pope et al. 2013

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



Graciá-Carpio et al. 2011



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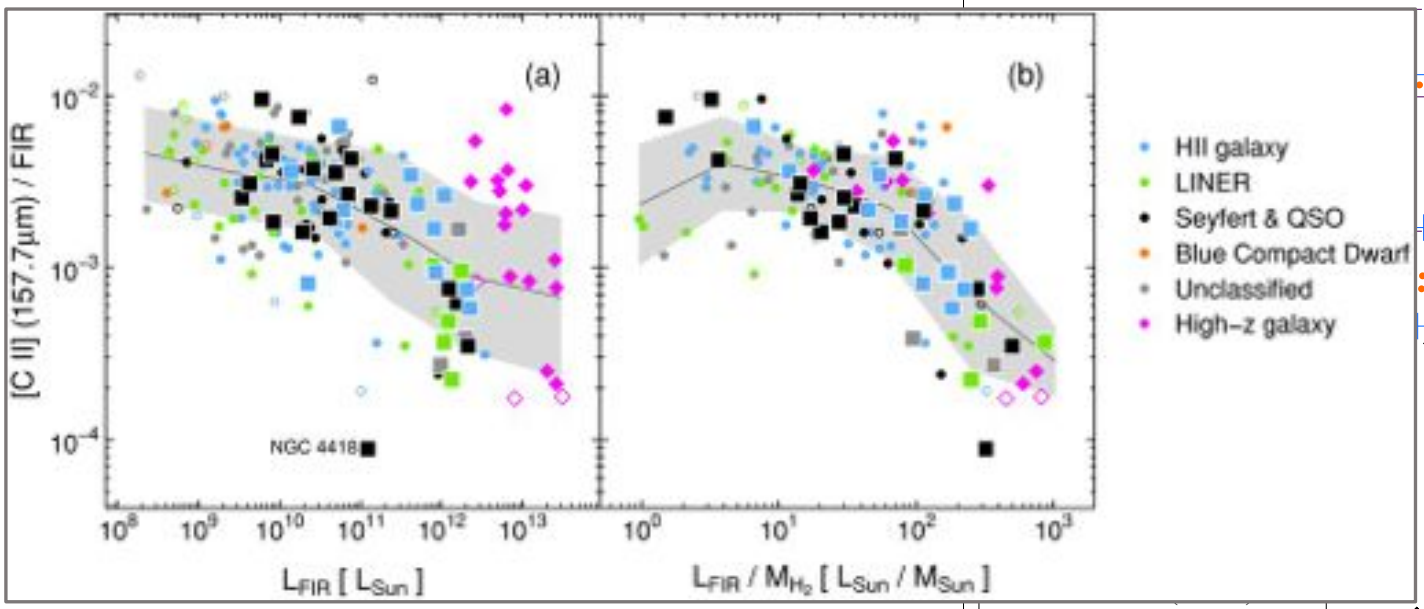

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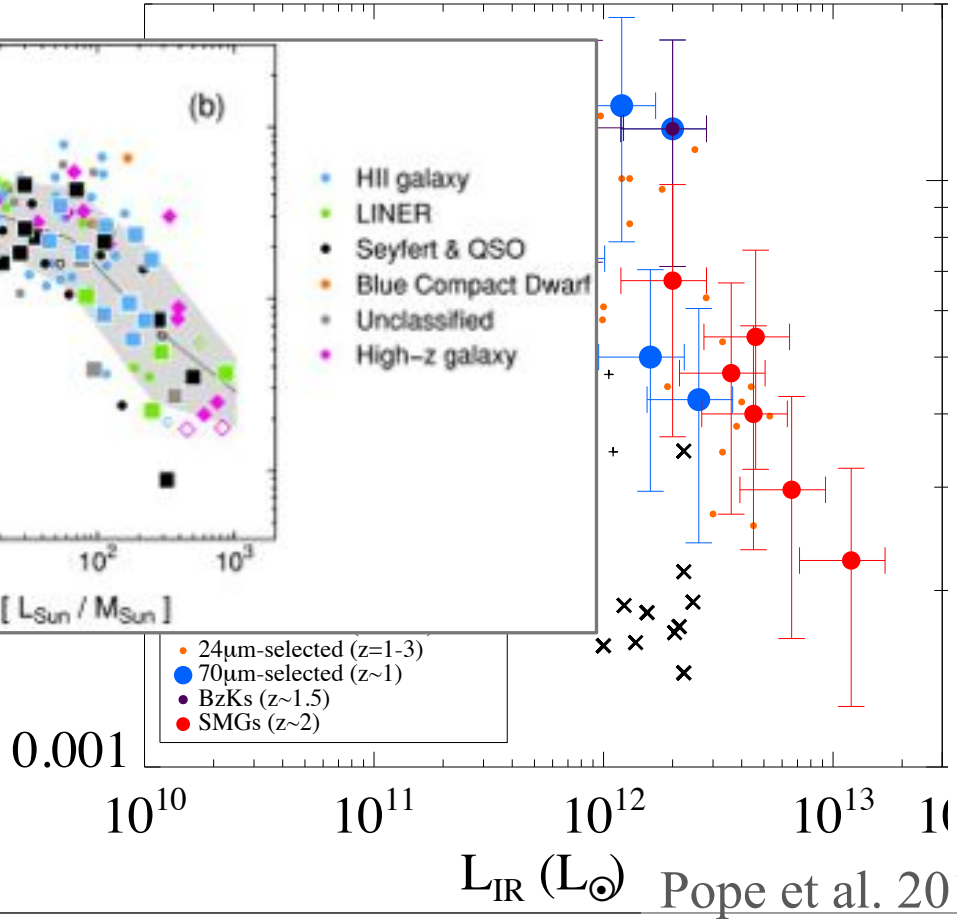
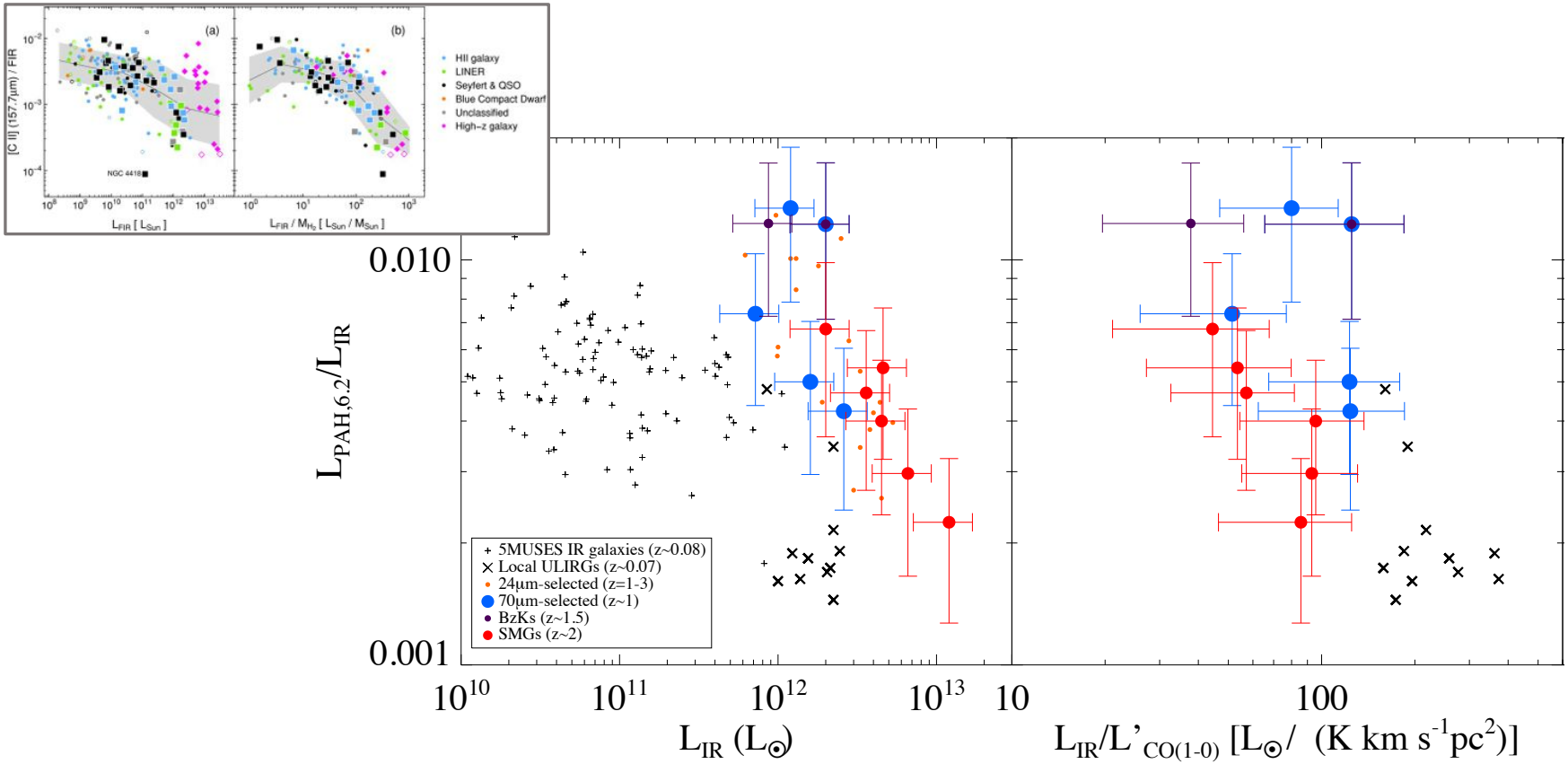


Pope et al. 2013

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



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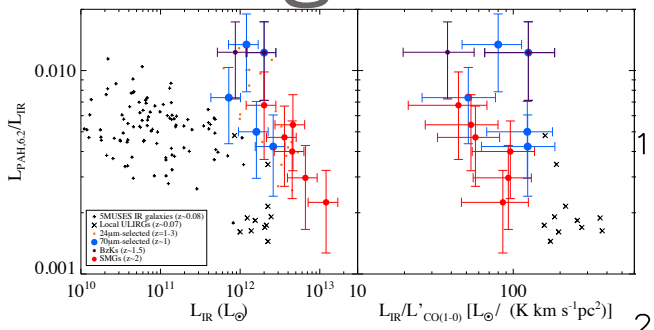

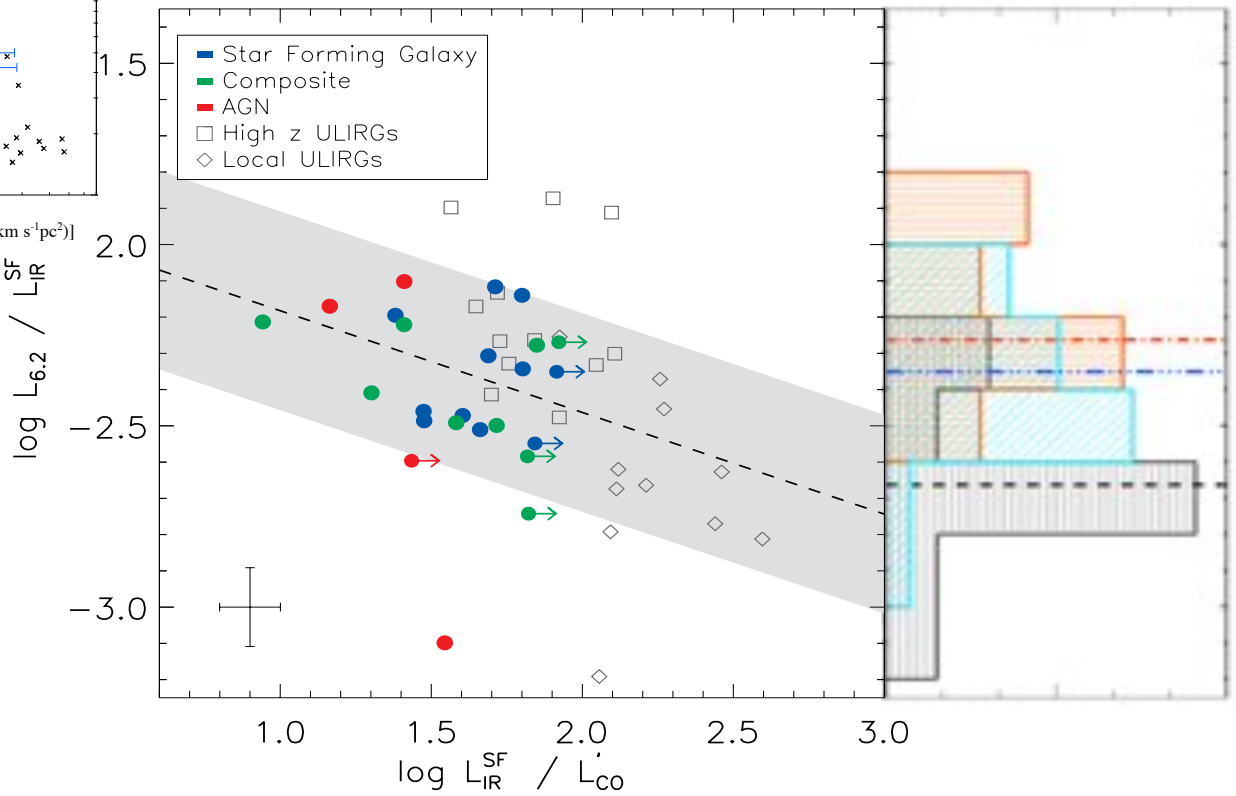

Pope et al. 2013; Kirkpatrick, Pope, et al., 2014, ApJ submitted

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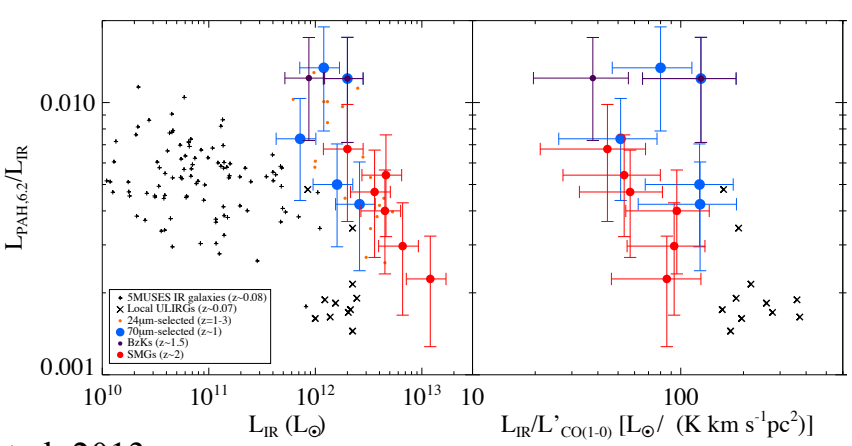
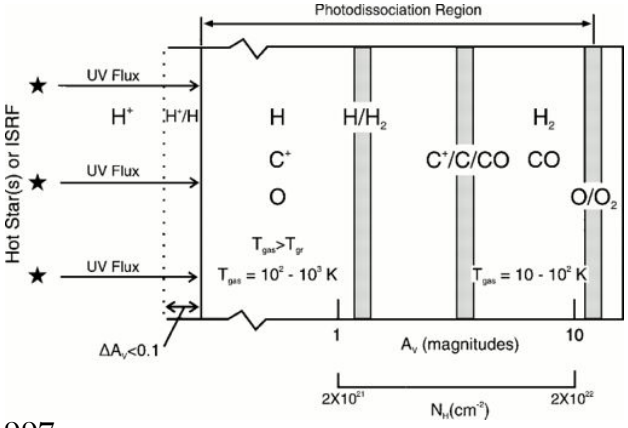


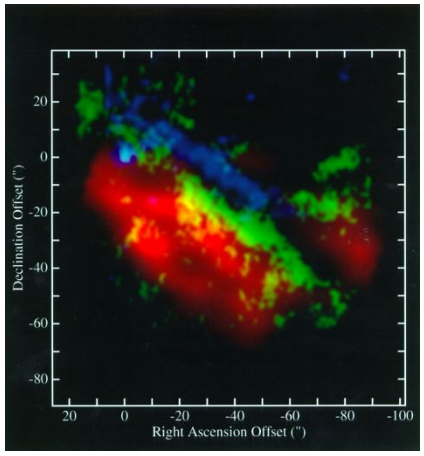
Pope et al. 2013

Add [CII] to the mix

ALMA!



Hollenbach & Tielens 1997



Session: Star Formation and Assembly of Galaxies

- How is the S-K law "law" affected by different measurement limitations or conversion factors (from tracer molecules or emission / absorption lines to amounts of gas and SFR)?
- Are the measurements from different tracers of ISM and SF consistent?
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- How is the S-K law "law" affected by different measurement limitations or conversion factors (from tracer molecules or emission / absorption lines to amounts of gas and SFR)?

Many LIRGs/ULIRGs show concurrent black hole growth (50-80% of L_{IR}).

Decompose IR SED to get the only the $L_{IR,SF}$ heated by SF.

LMT pilot study:

- Reduces the scatter in S-K
- Brings more galaxies down onto the normal galaxy sequence

Session: Star Formation and Assembly of Galaxies

- Are the measurements from different tracers of ISM and SF consistent? How do galaxies grow (*evolve*) over cosmic time?

  - Strong PAH emission is much more prevalent at high redshift compared to locally

  - Enhanced PAH emission is linked to the increased molecular gas in high redshift galaxies

  - Future: add links to [CII] and other ISM tracers using ALMA

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 Narayan[1], [illegible]ong Shi[5], Olga Vega[2], Min Yun[1]

Submitted to ApJ July 12, 2014

Synergy between ALMA and LMT

50 m LMT [~2016] = 1/3 the collecting area of ALMA

- Wide field mm mapping
- Wide bandwidth CO redshift surveys