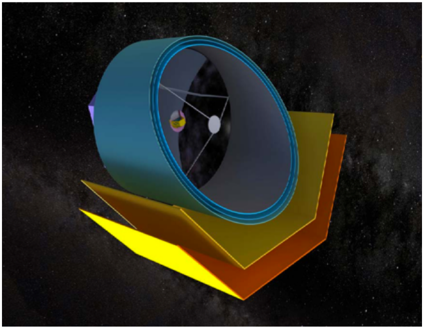
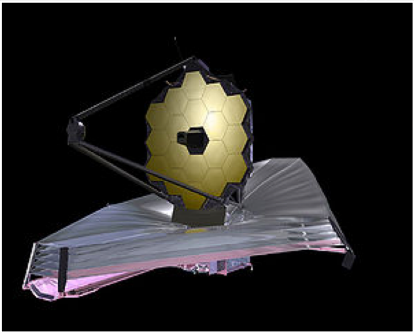
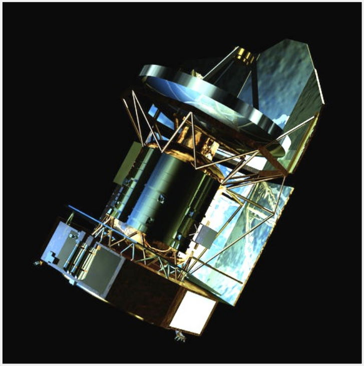


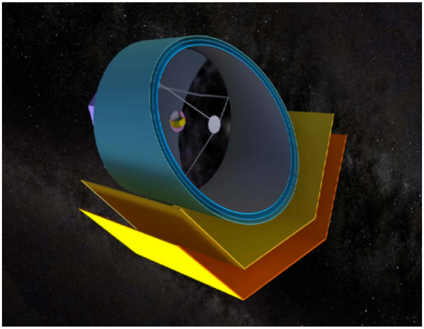


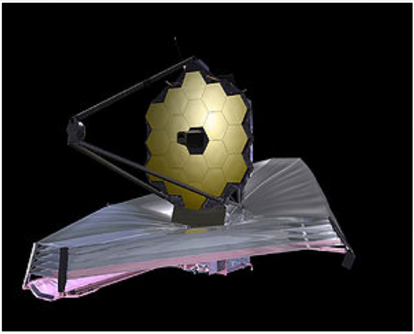
Dust, PAHs, and Star Formation

with future outlook for current and upcoming NASA missions

Irene Shivaei
Hubble fellow, University of Arizona

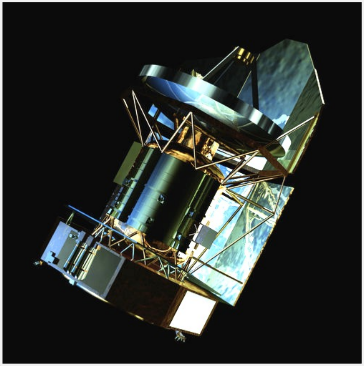


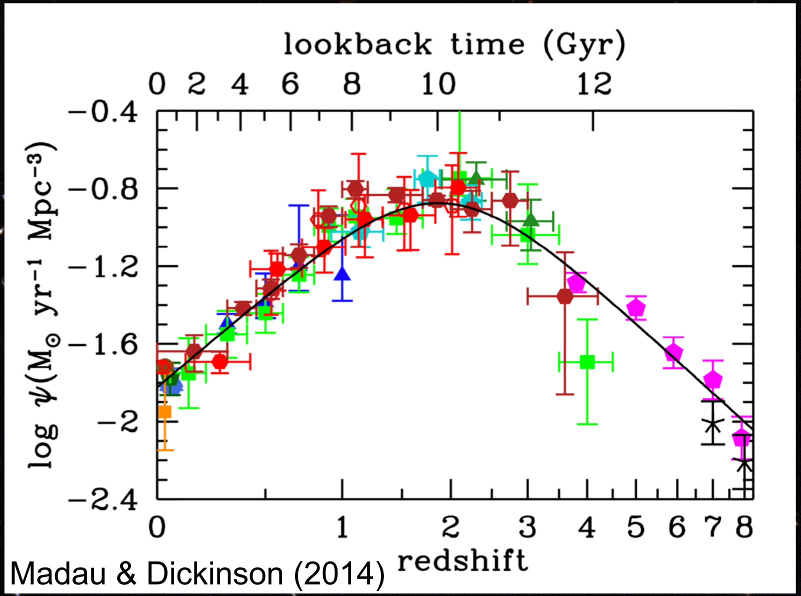




Determining the evolution of the infrared universe

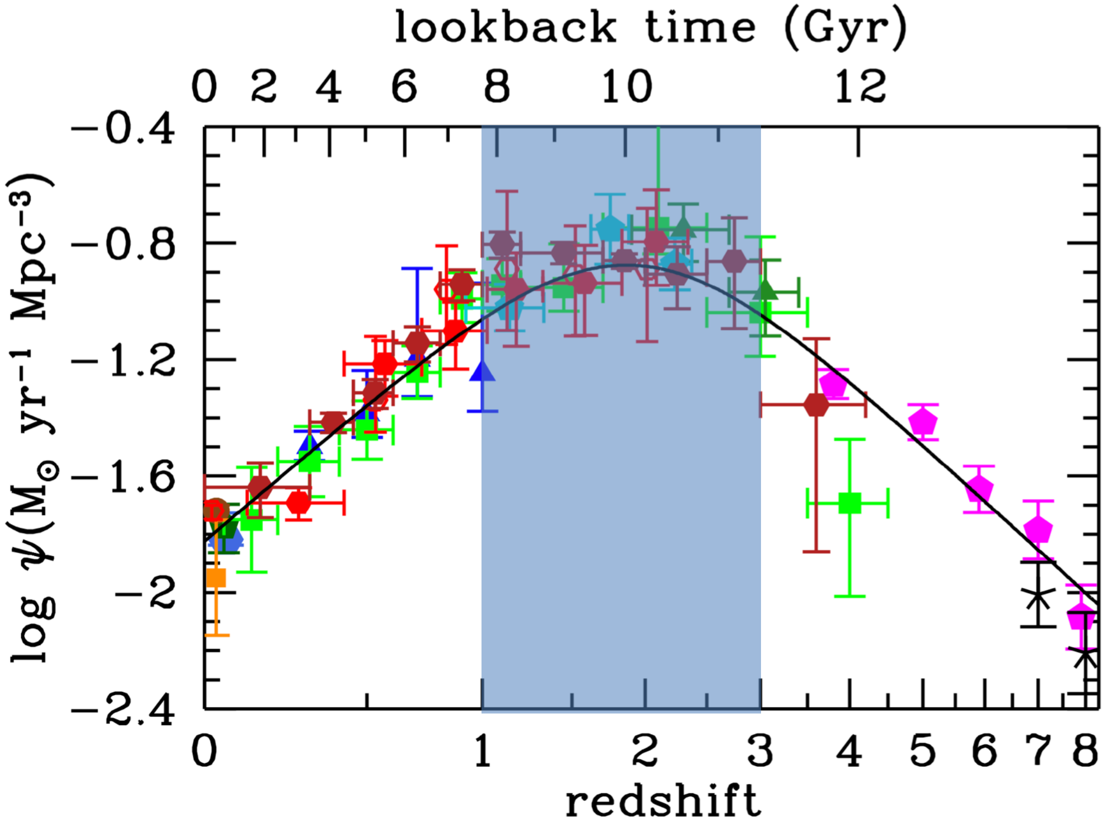
- Obscured Star Formation
- Dust and ISM
- AGN

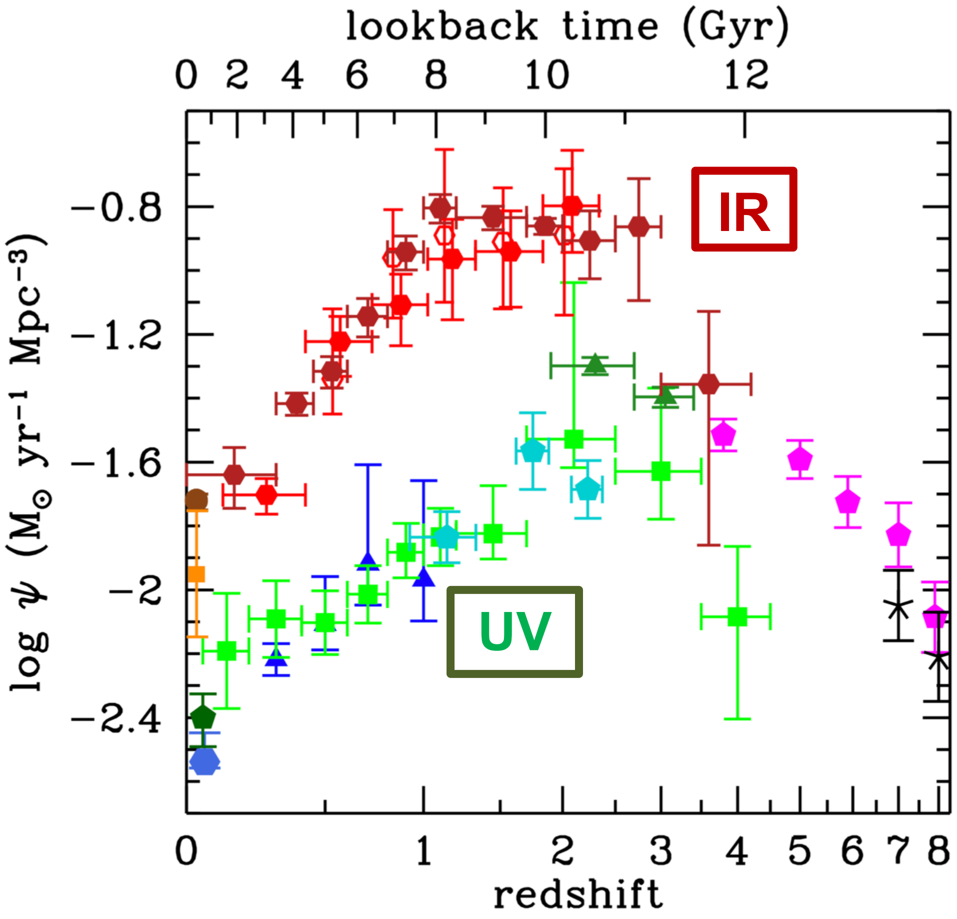




Madau & Dickinson (2014)

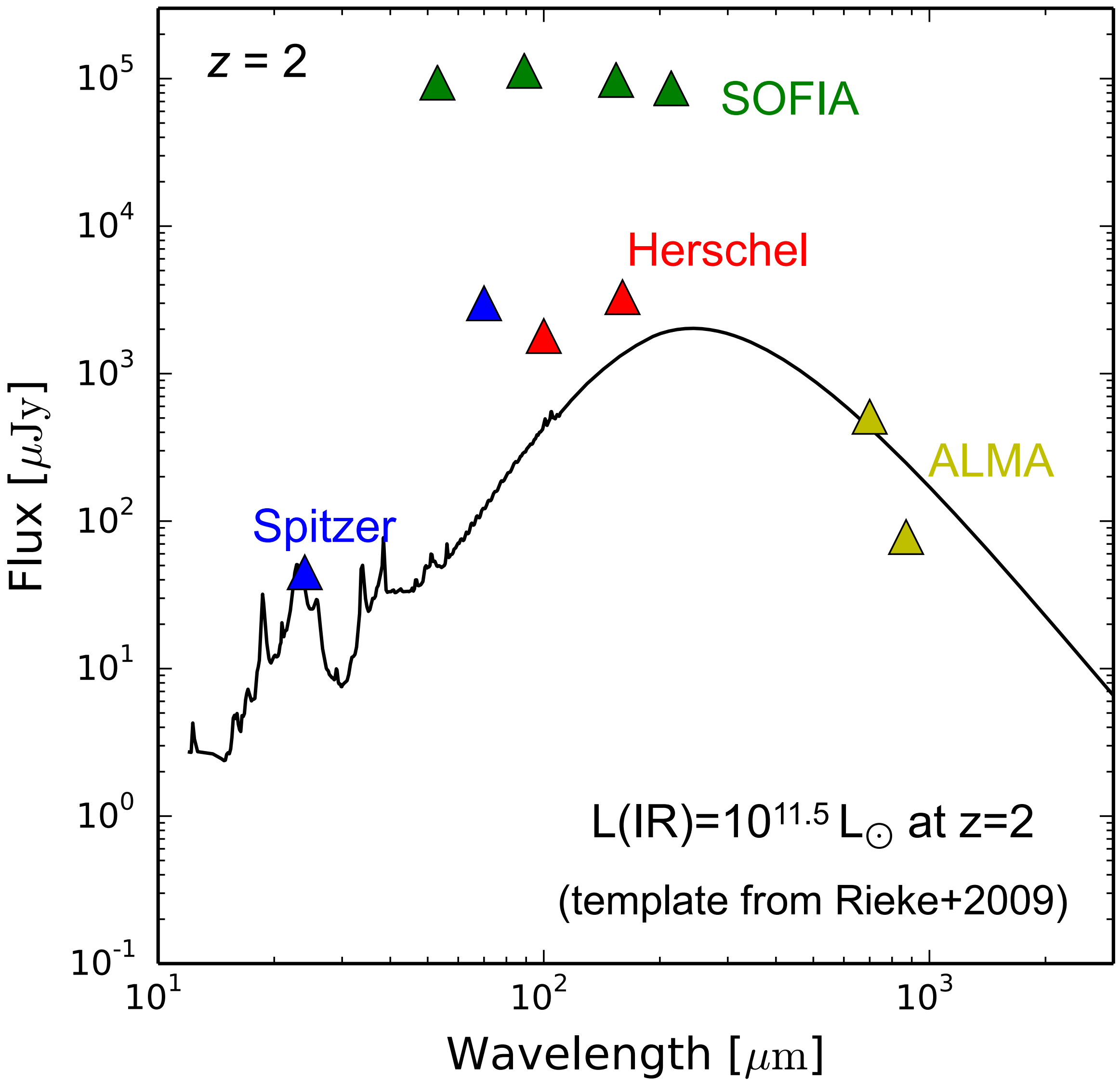
A significant fraction of our universe at all epochs is dominated by infrared emission

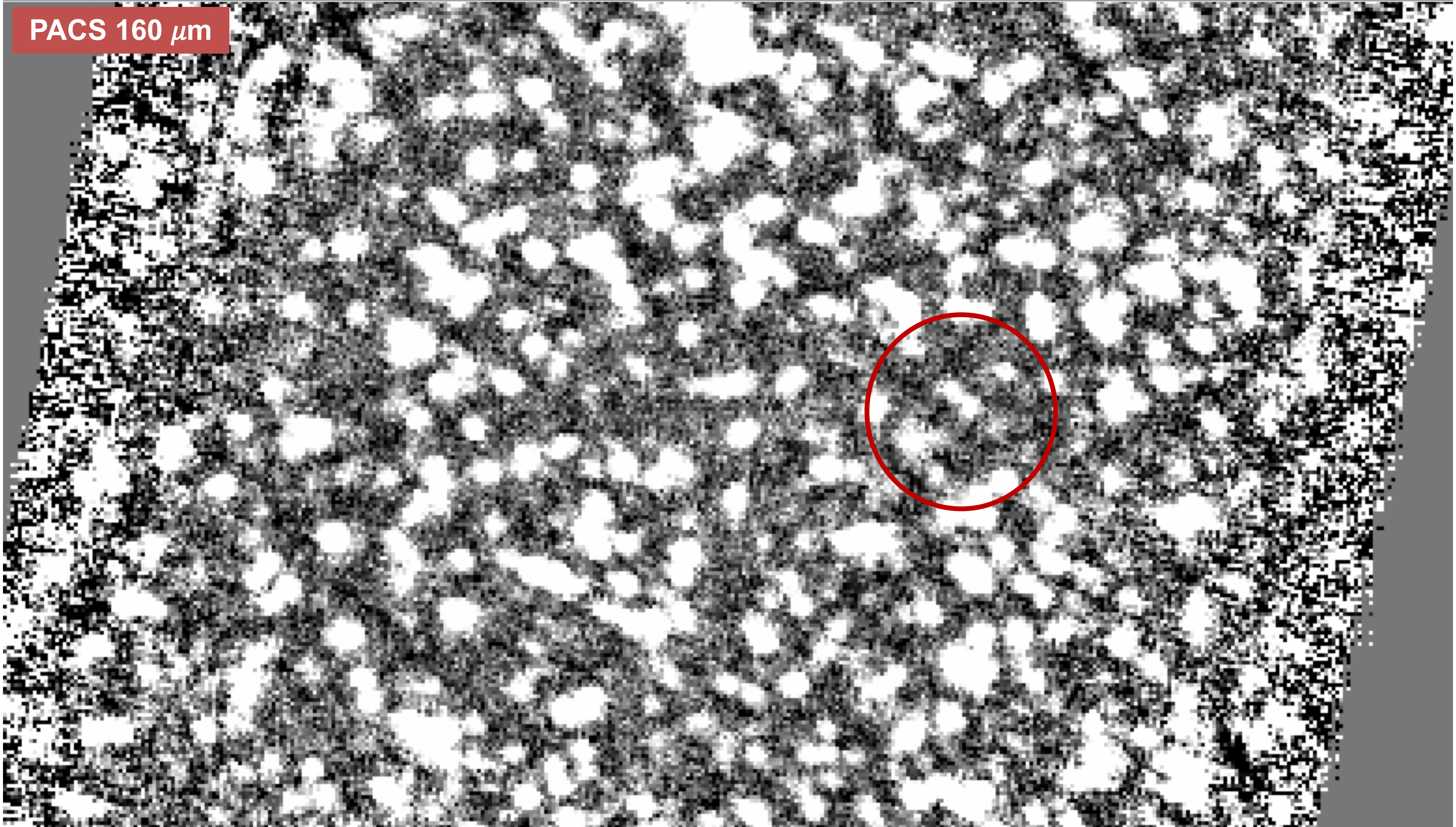




Madau & Dickinson (2014)

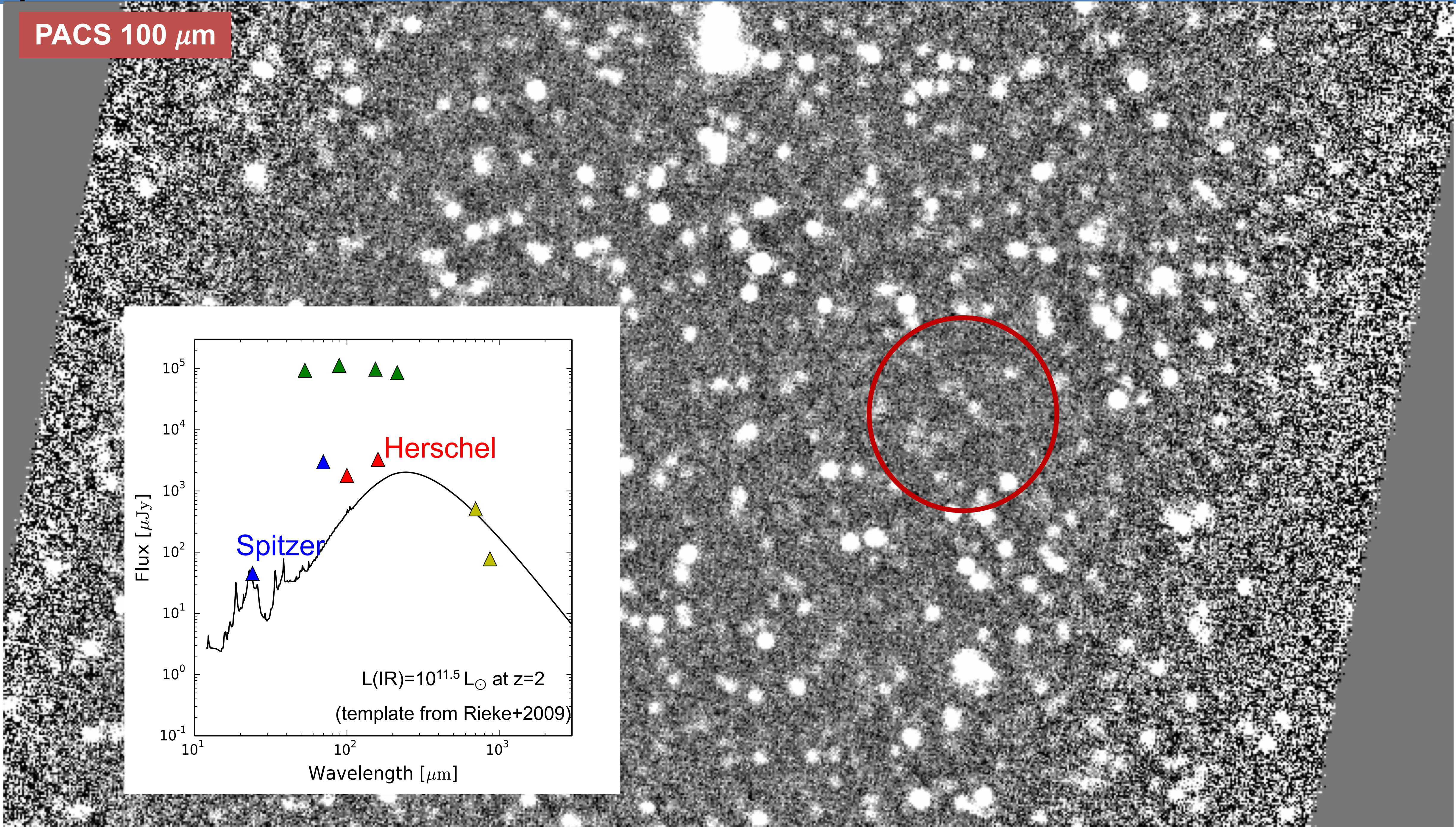
How can we capture infrared light at intermediate redshifts?





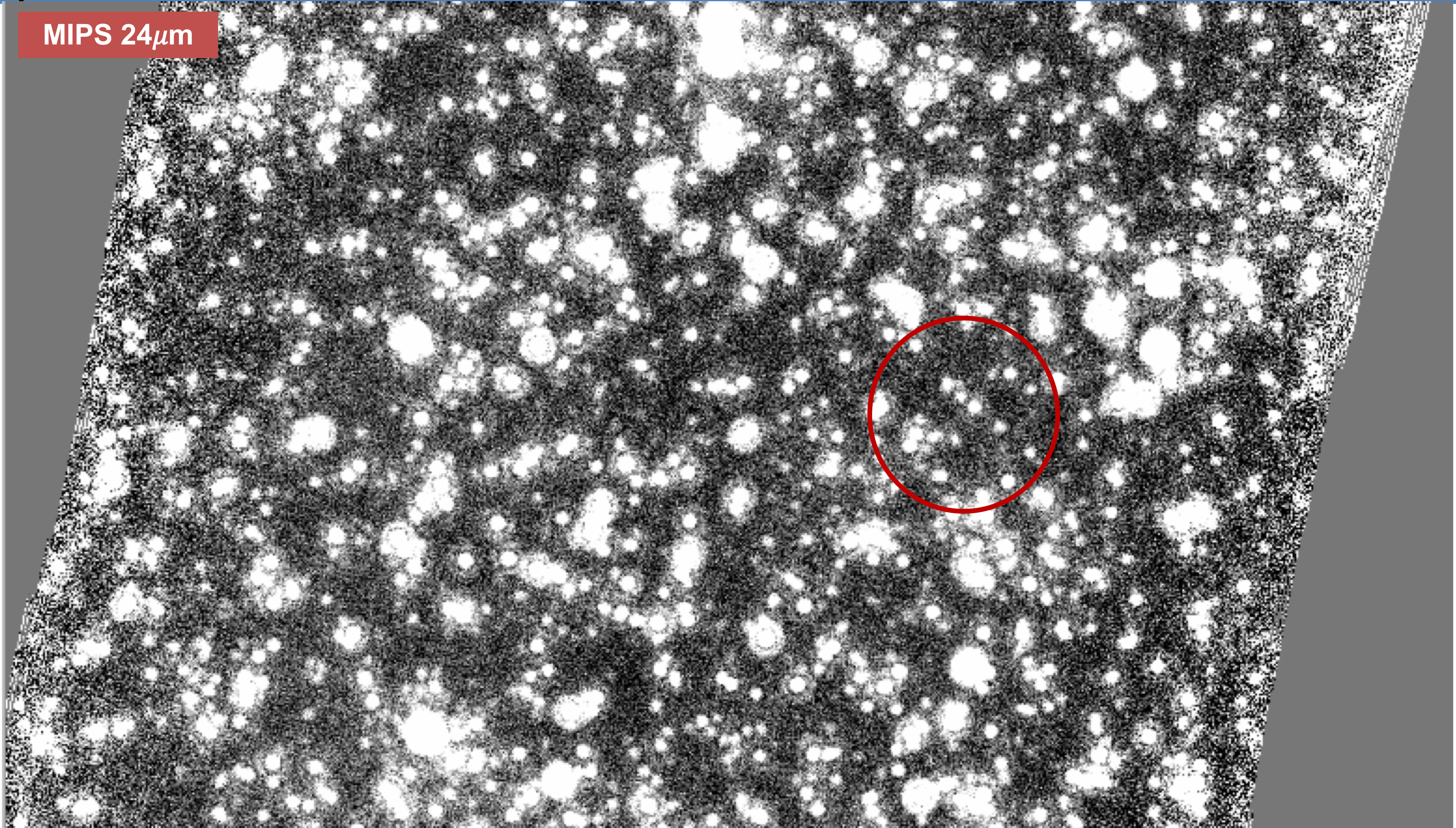
PACS 160 μm

PACS 100 μm



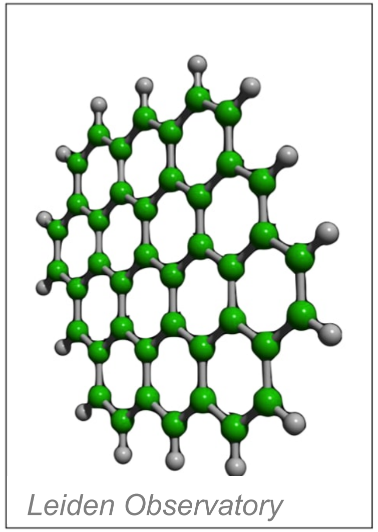
L(IR)=$10^{11.5}$ $L_\odot$ at z=2

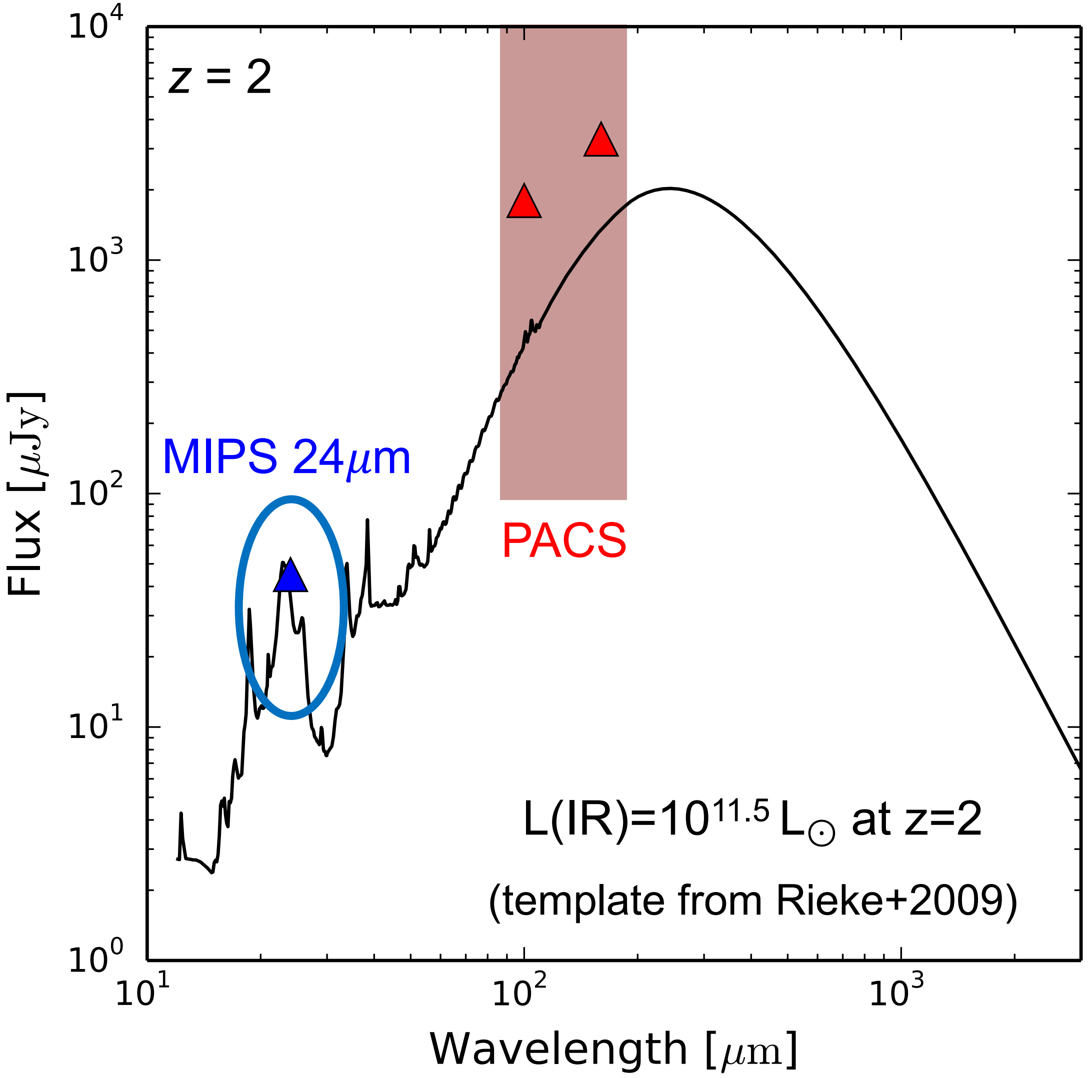
(template from Rieke+2009)


MIPS 24μm

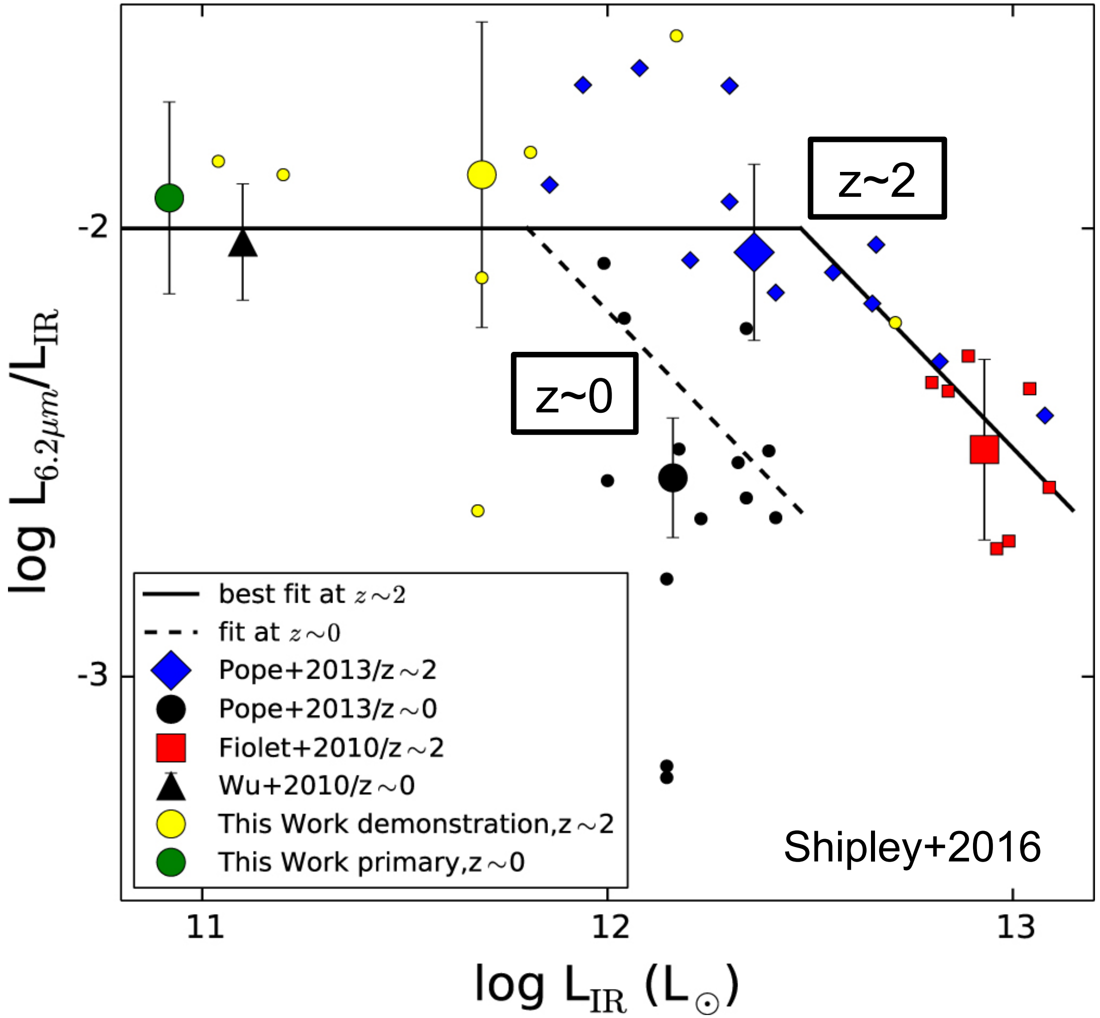
PACS bands trace the thermal IR emission, while MIPS 24μm traces the PAH emission

PAH molecule



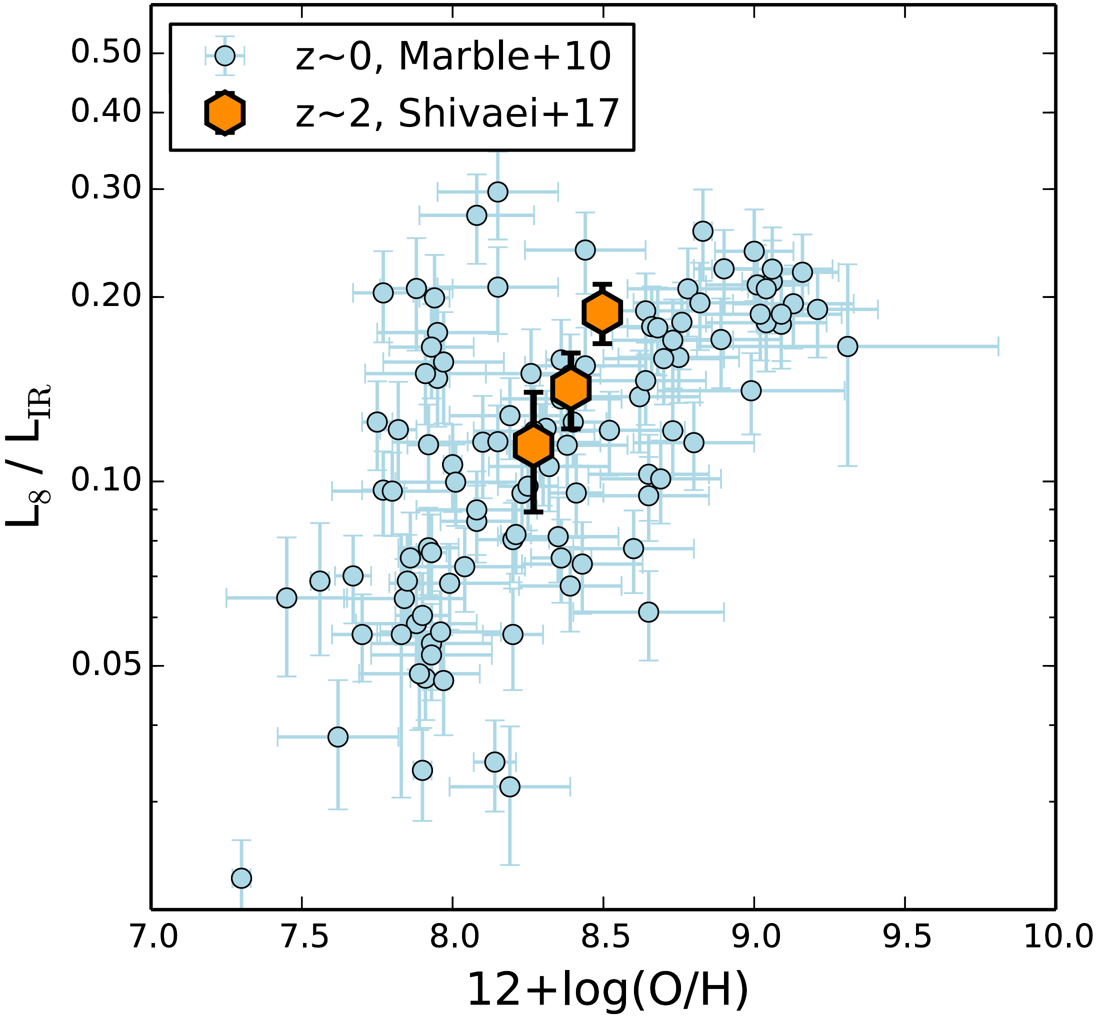


The PAH luminosity suppression at high luminosities is redshift dependent



See also: Rujopakarn et al. 2013, Fiolet et al. 2010, Papovich et al. 2009; Muzzin et al. 2010; Finkelstein et al. 2011; Rujopakarn et al. 2011

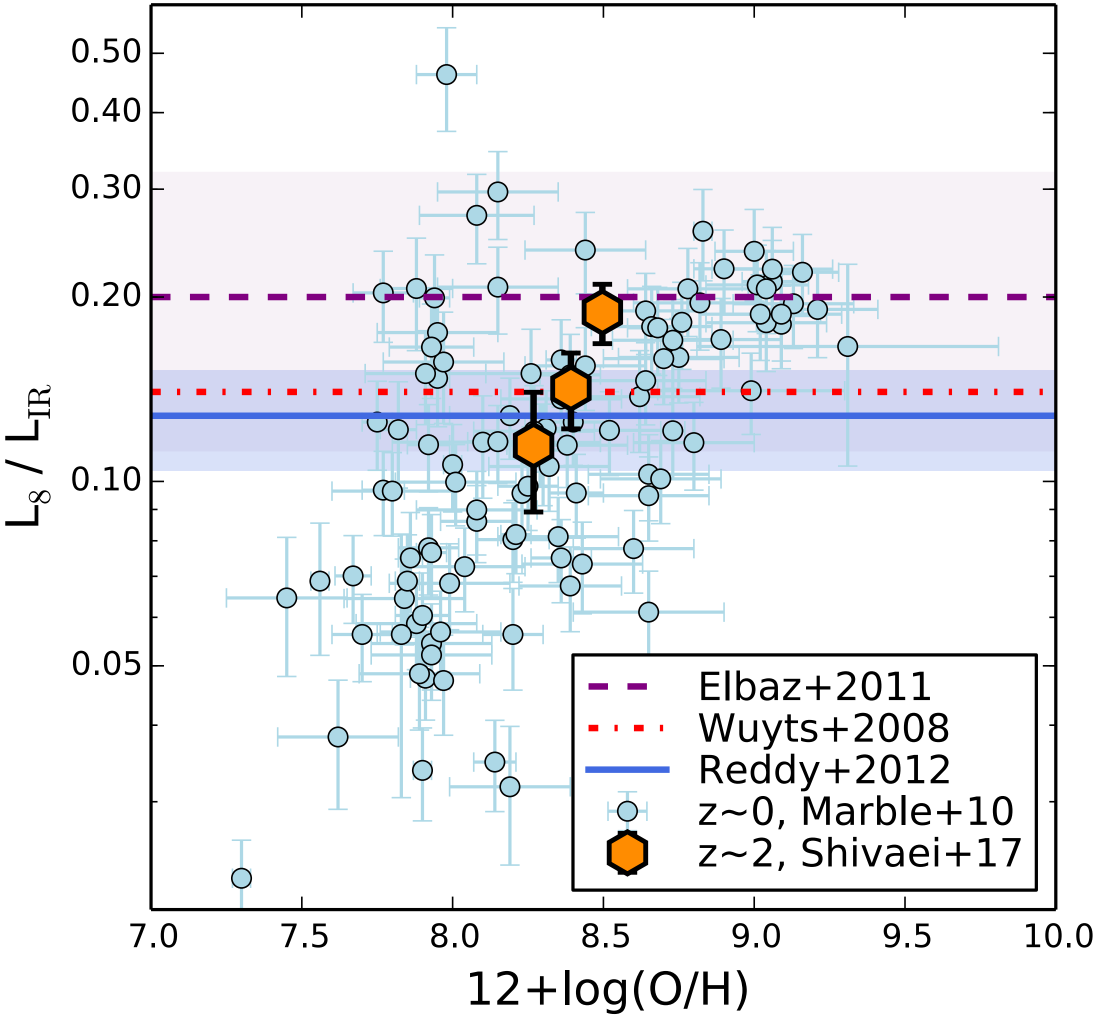
PAH intensity scales with metallicity

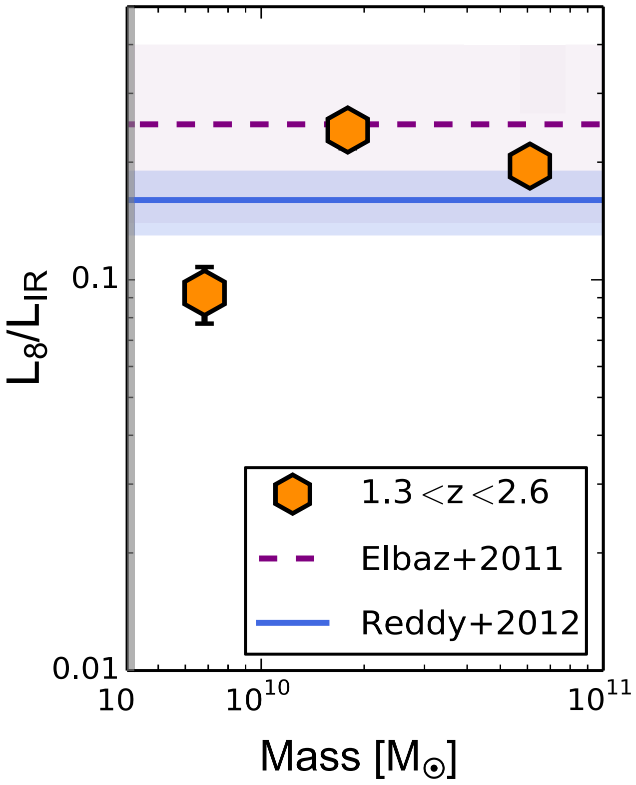


- Paucity of PAH molecules in low-metallicity environments
- Preferential destruction of PAH molecules in environments with hard and intense radiation

See also: Normand et al. 1995; Engelbracht et al. 2005; Calzetti et al. 2007; Draine et al. 2007; Smith et al. 2007; Hunt et al. 2010; Cook et al. 2014

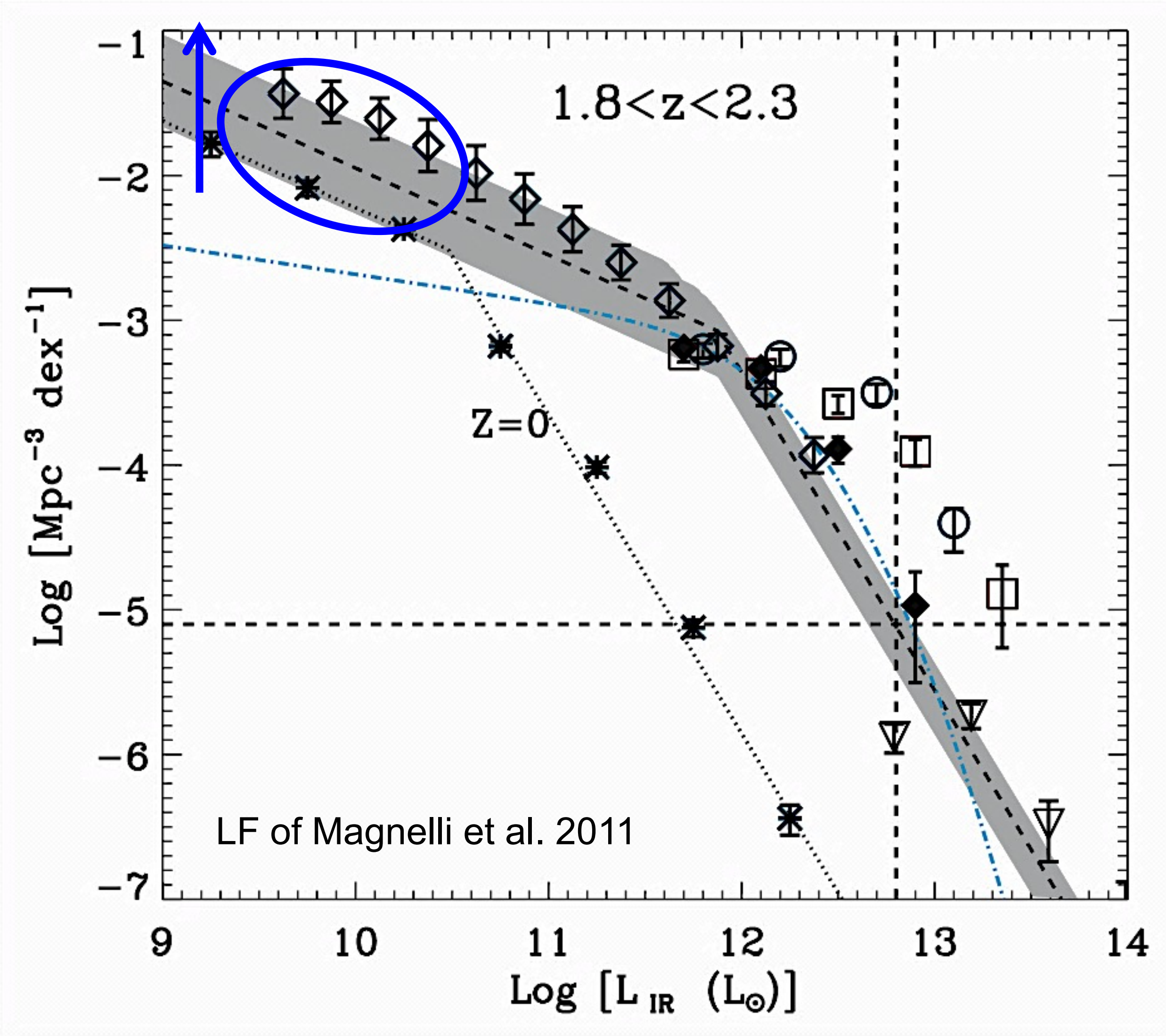
At low mass and low metallicities, single conversions of 7.7um to L(IR) underestimate the L(IR) and SFR(IR) by a factor of ~ 2





The IR luminosity density at z~2

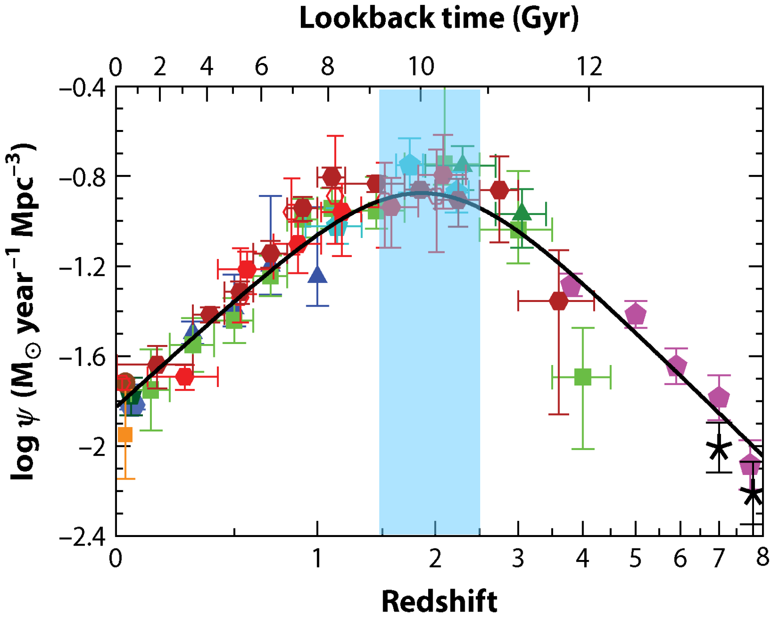
30% increase in the IR luminosity density at z~2

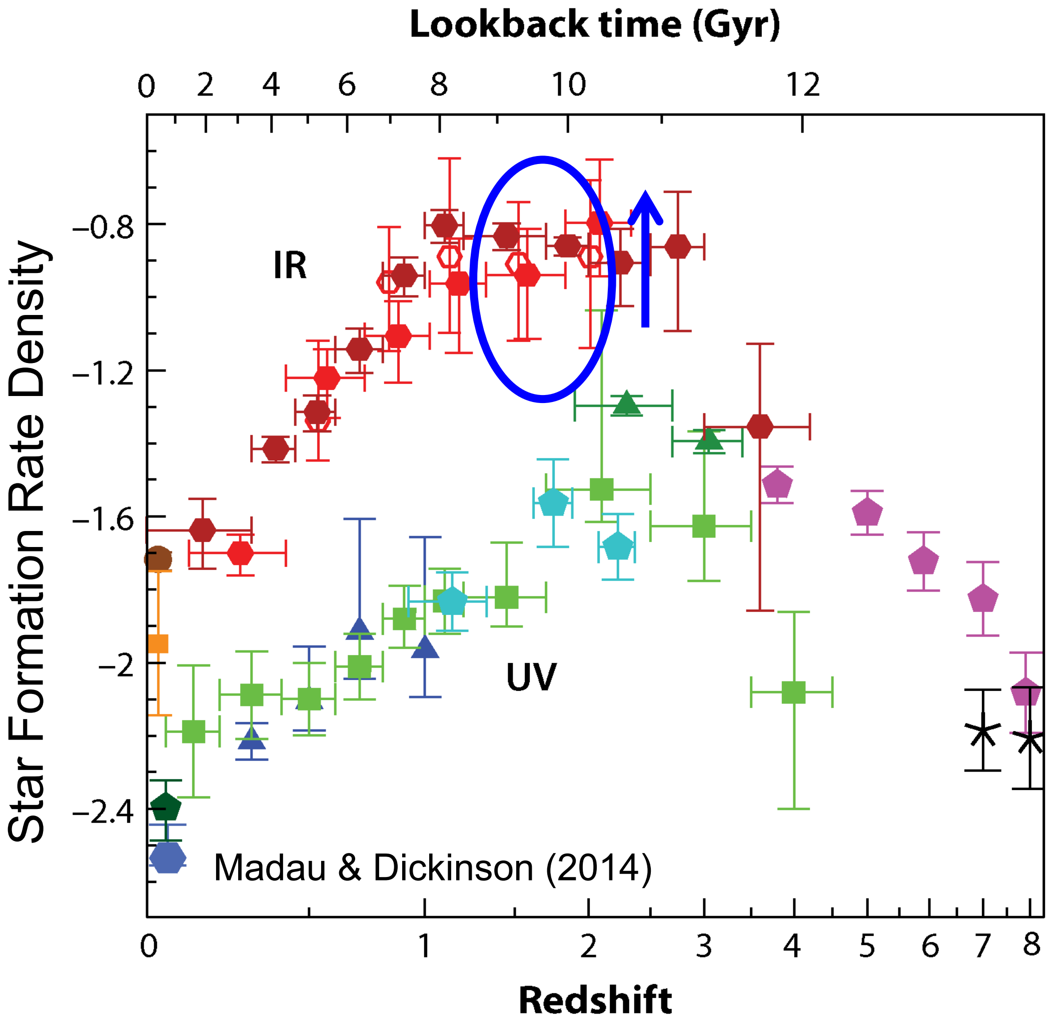


Shivaei et al. (2017)

The SFR Density at z~2

30% increase in the SFR density at z~2

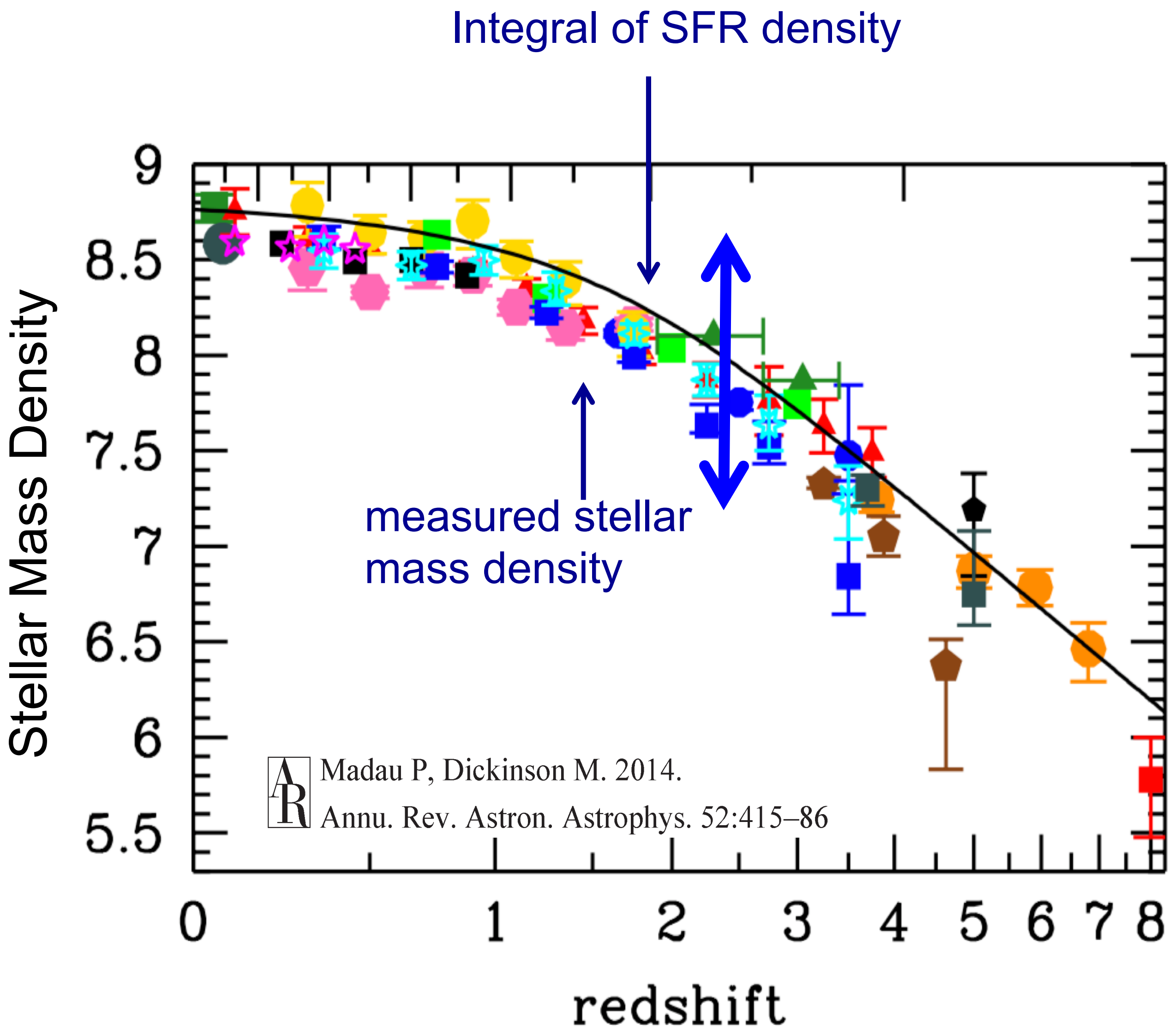




Shivaei et al. (2017)

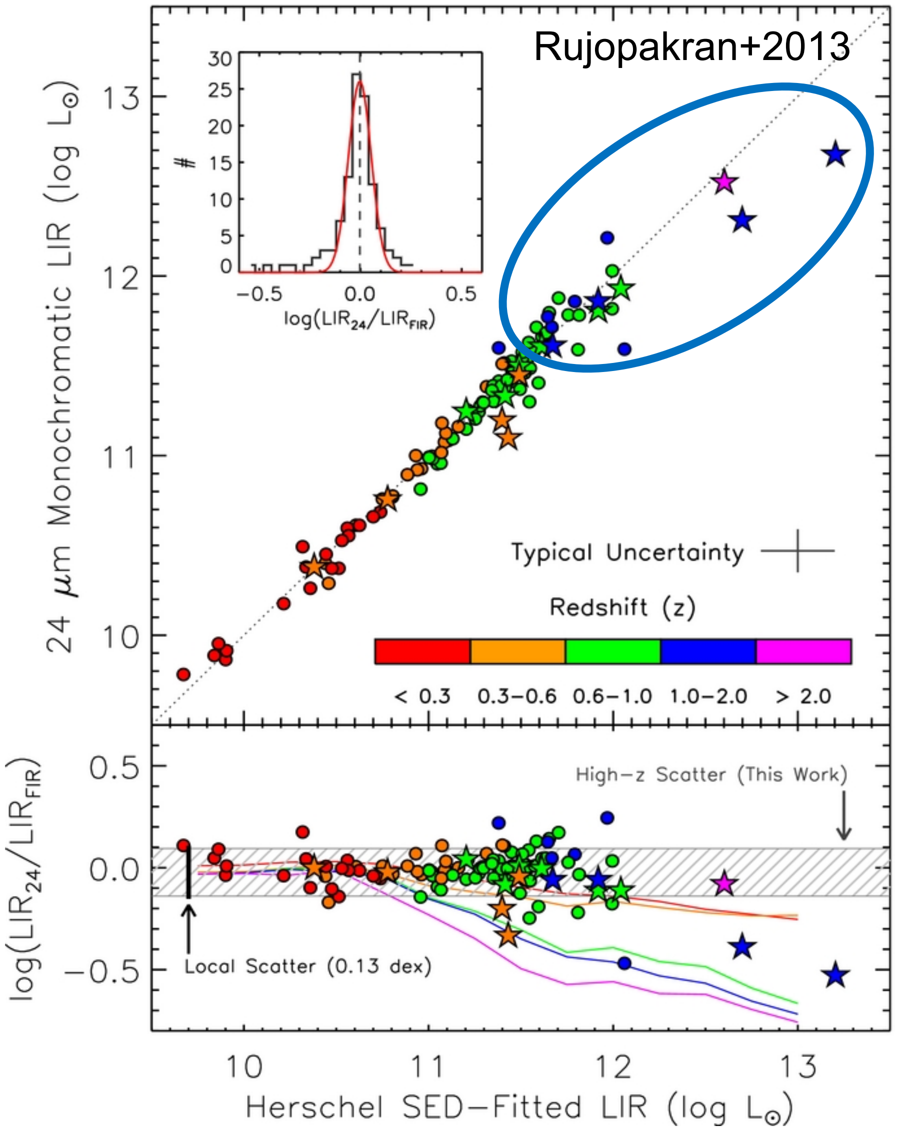
Stellar Mass Density at z~2

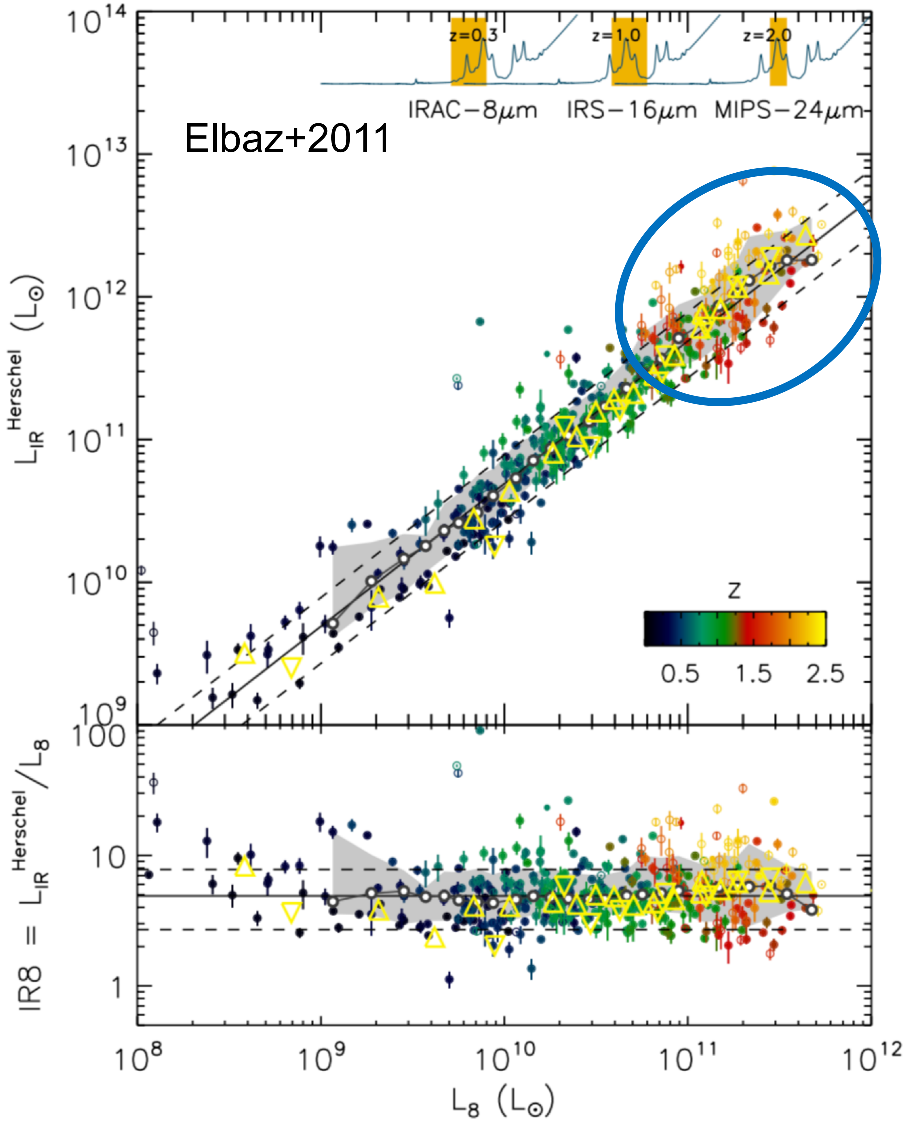
- Reinstates the discrepancy between the measured stellar mass density and the integral of SFR density over time



Shivaei et al. (2017)

PAH conversion to IR luminosity



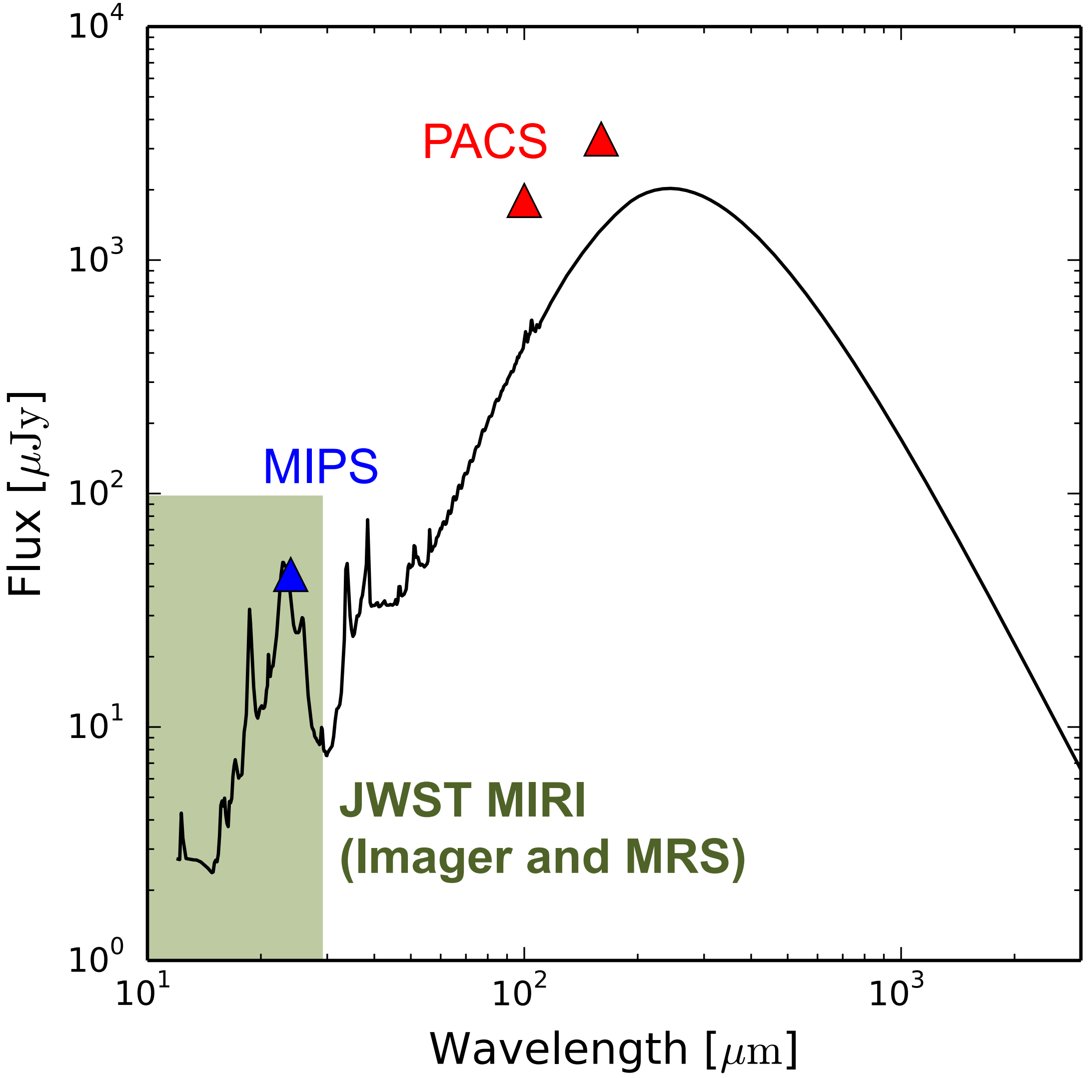


See also: Kennicutt & Evans (2012), Reddy et al. (2012), Wuyts et al. (2008), Bavouzet et al. (2008), Rigby et al. (2008), Caputi et al. (2007)

JWST Mid-Infrared Instrument (MIRI)

Imaging and spectroscopy at λ = 4.9 – 28.8 µm

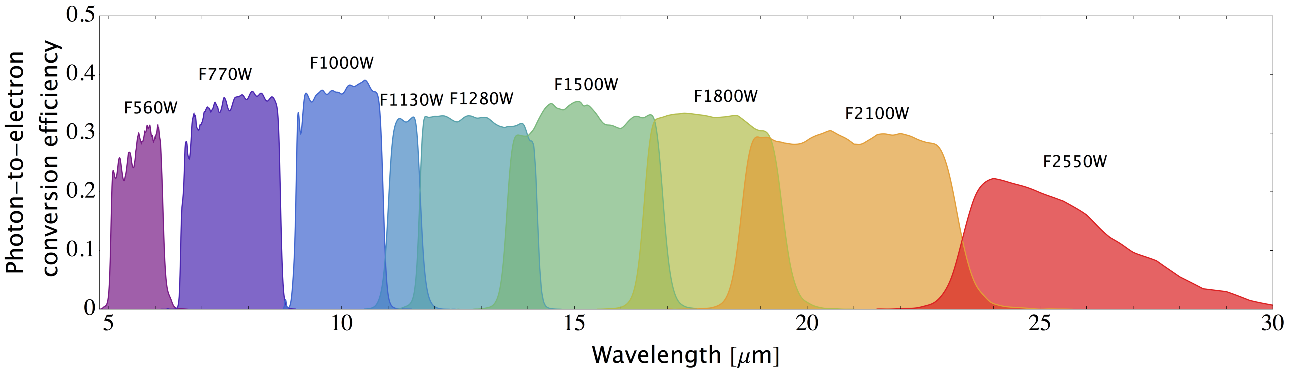
- **Imager**
- **LRS**: low-resolution spectroscopy (R~100)
- **MRS**: medium-resolution integral field unit (IFU) spectroscopy (R~1550–3250)
- **Coronagraphy**

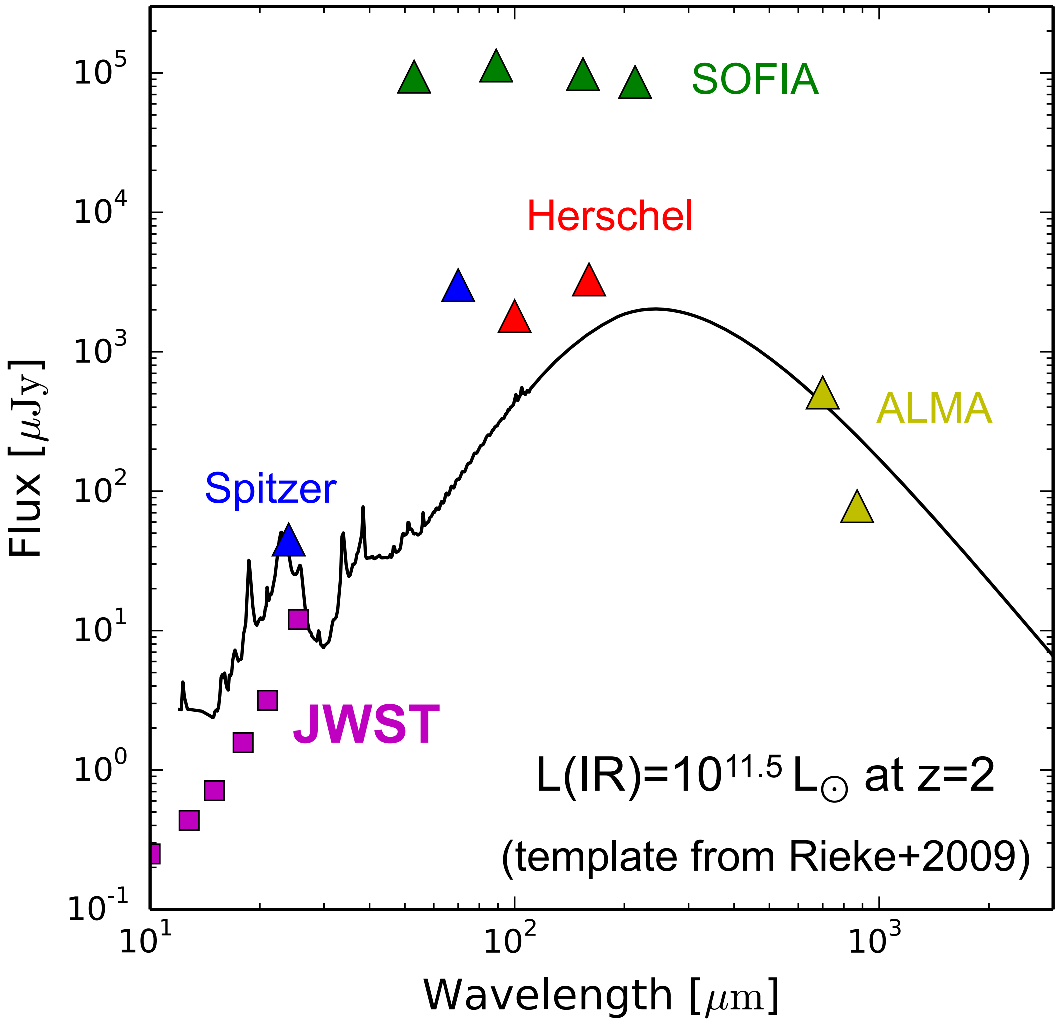


See: Wright et al. 2015, Rieke et al. 2015

JWST MIRI Imager

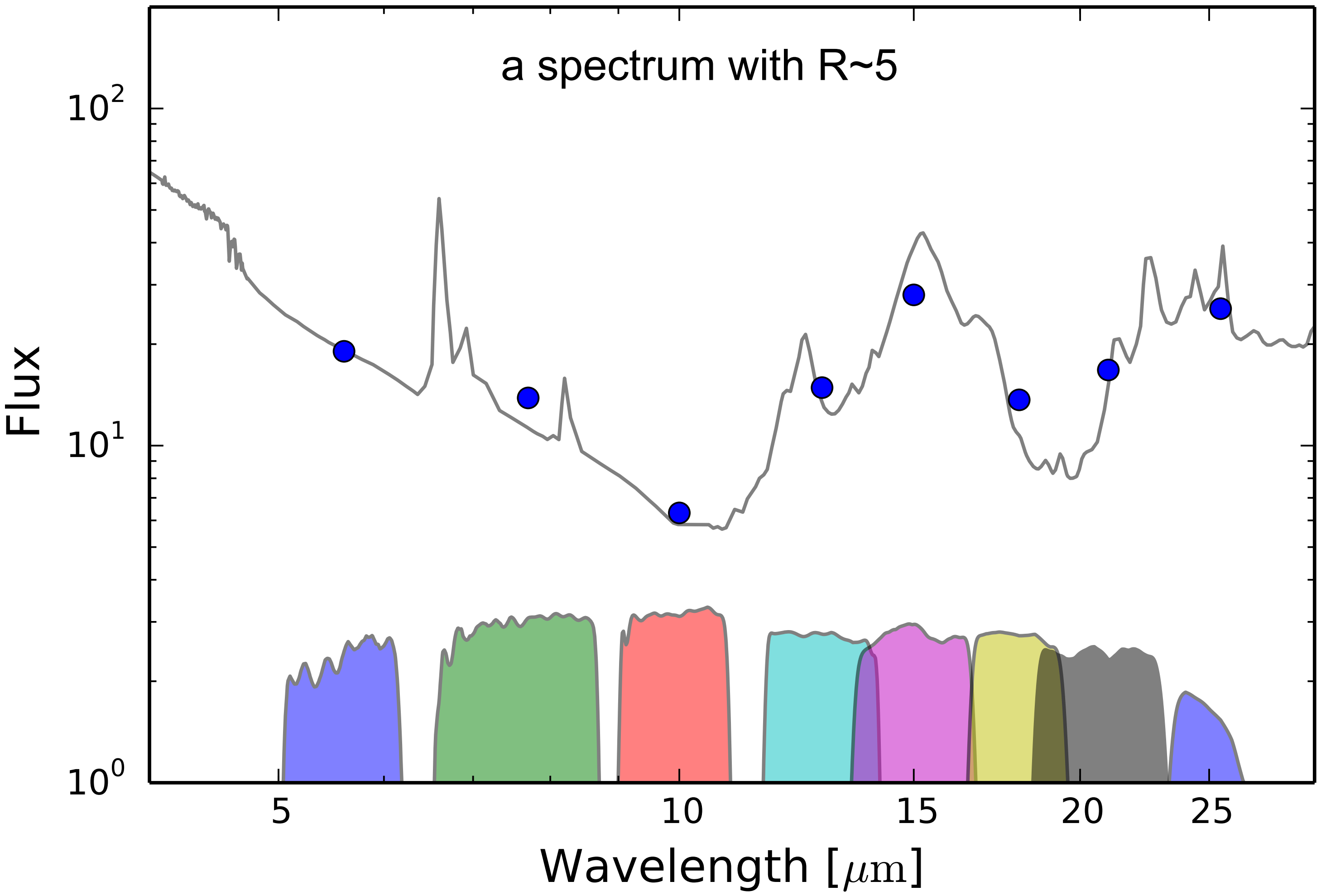
- 9 filters at 4.9 – 28.8 μm
- Pixel scale: 0.11 arcsec/pix
  - At 25 μm: FWHM of 0.82 arcsec
- Field of view: 74 × 113 arcsec





Tracing multiple PAH components:

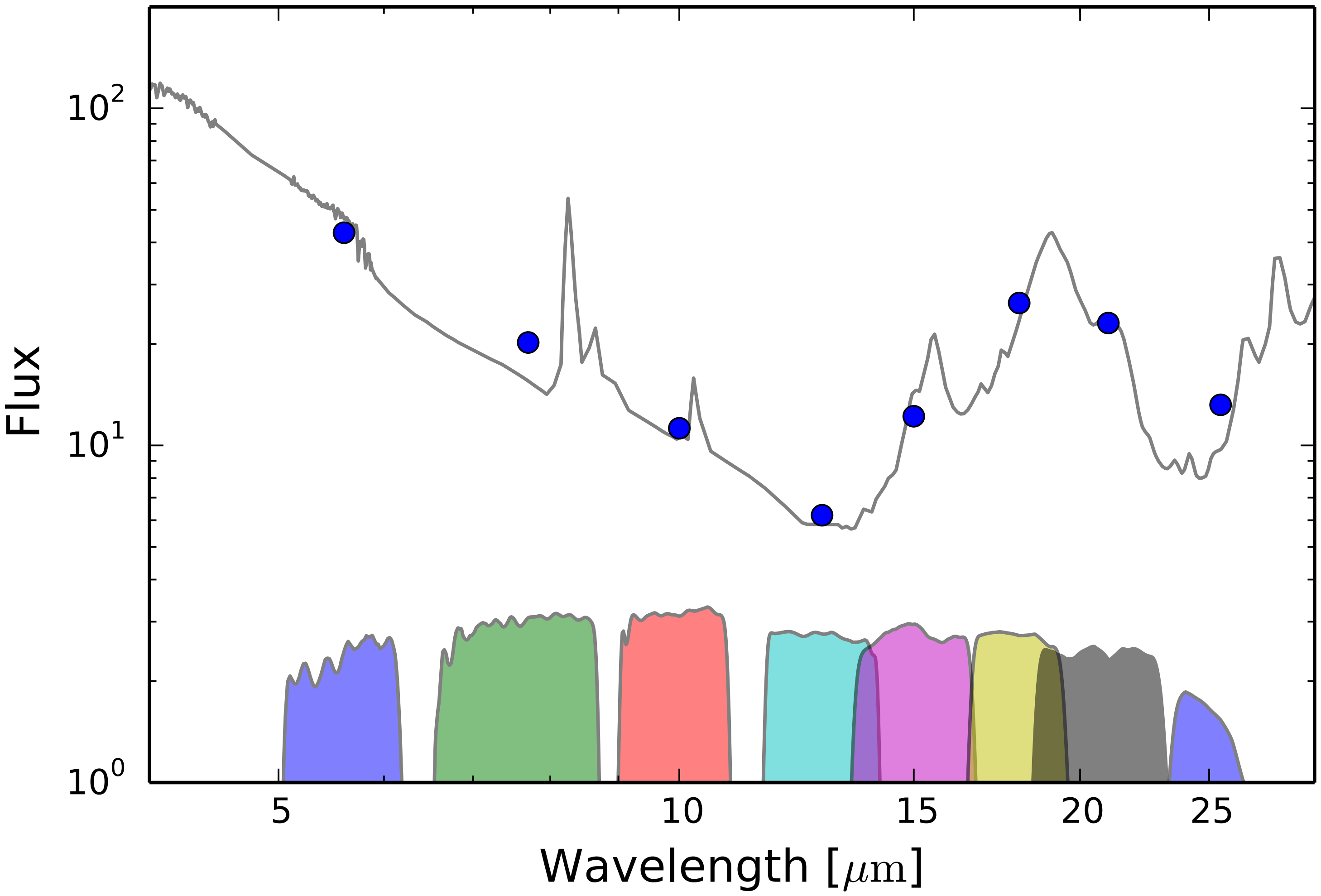
z = 1.0



Also see: JWST/MIRI US extragalactic GTO program (PI: G. Rieke, Co-Is: S. Alberts, J. Lyu, J. Morrison, I. Shivaei)

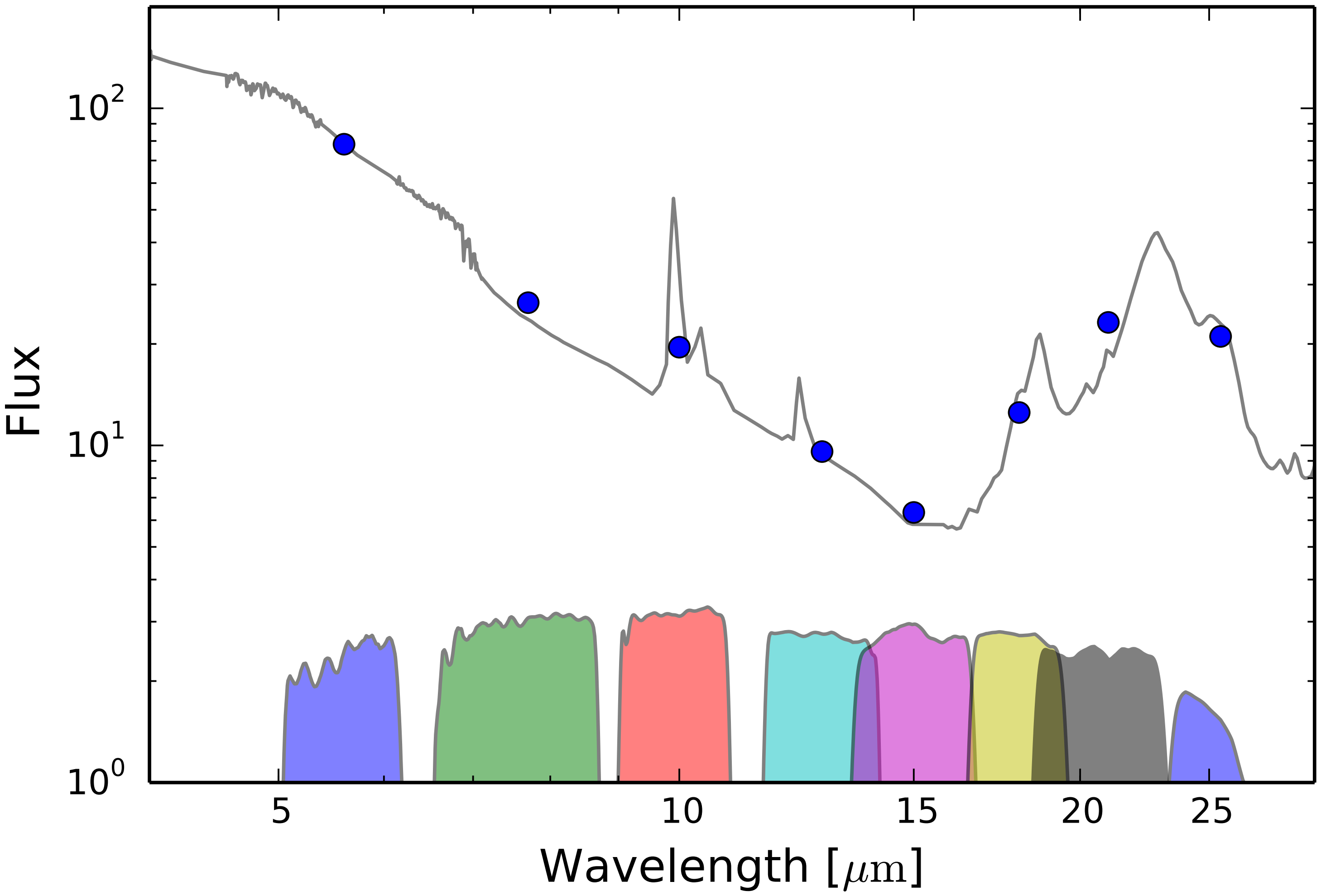
Tracing multiple PAH components:

z = 1.5



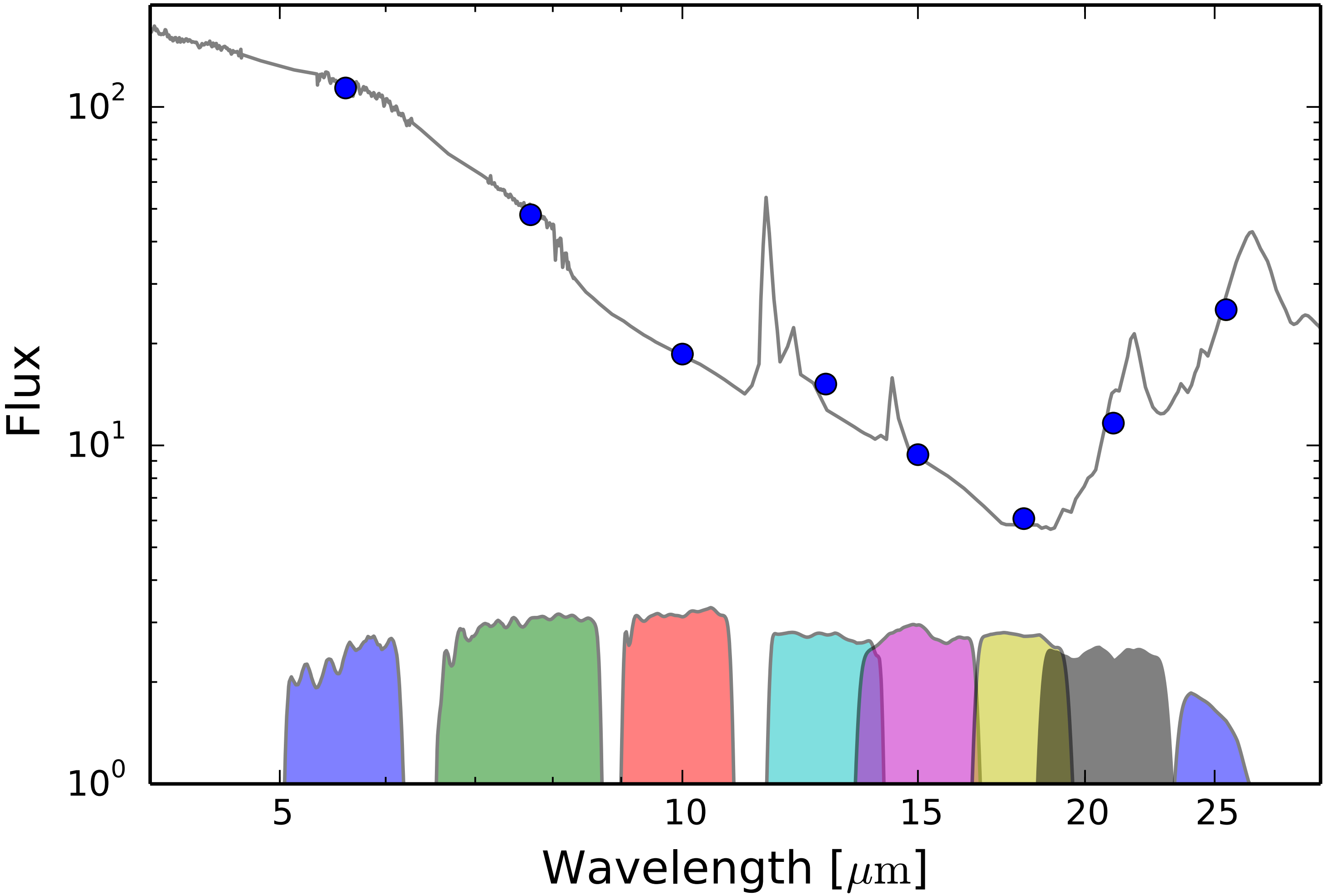
Tracing multiple PAH components:

z = 2.0



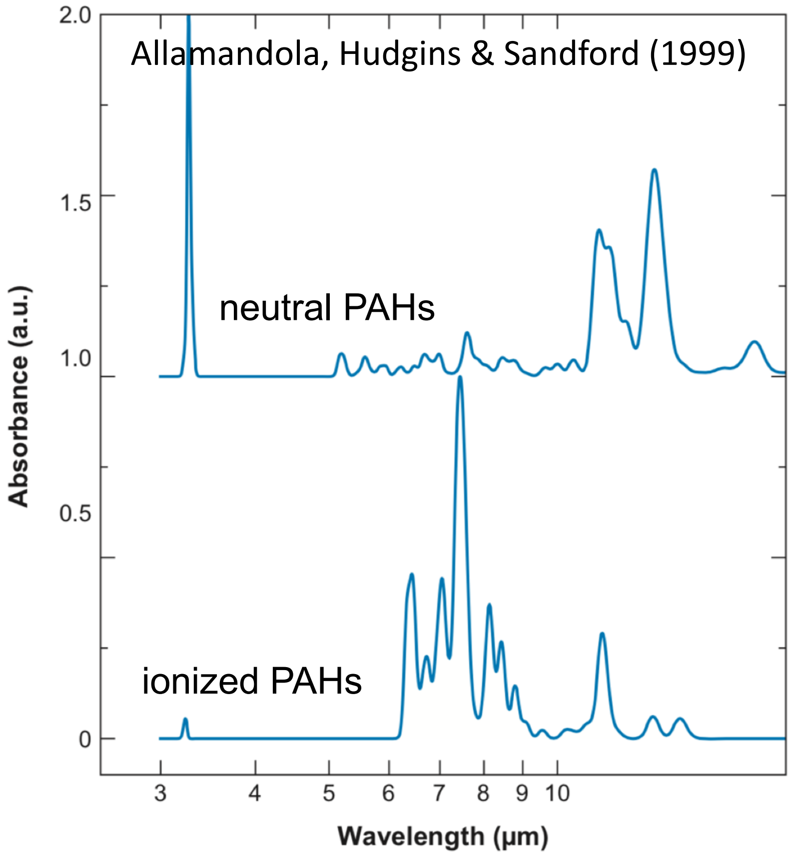
Tracing multiple PAH components:

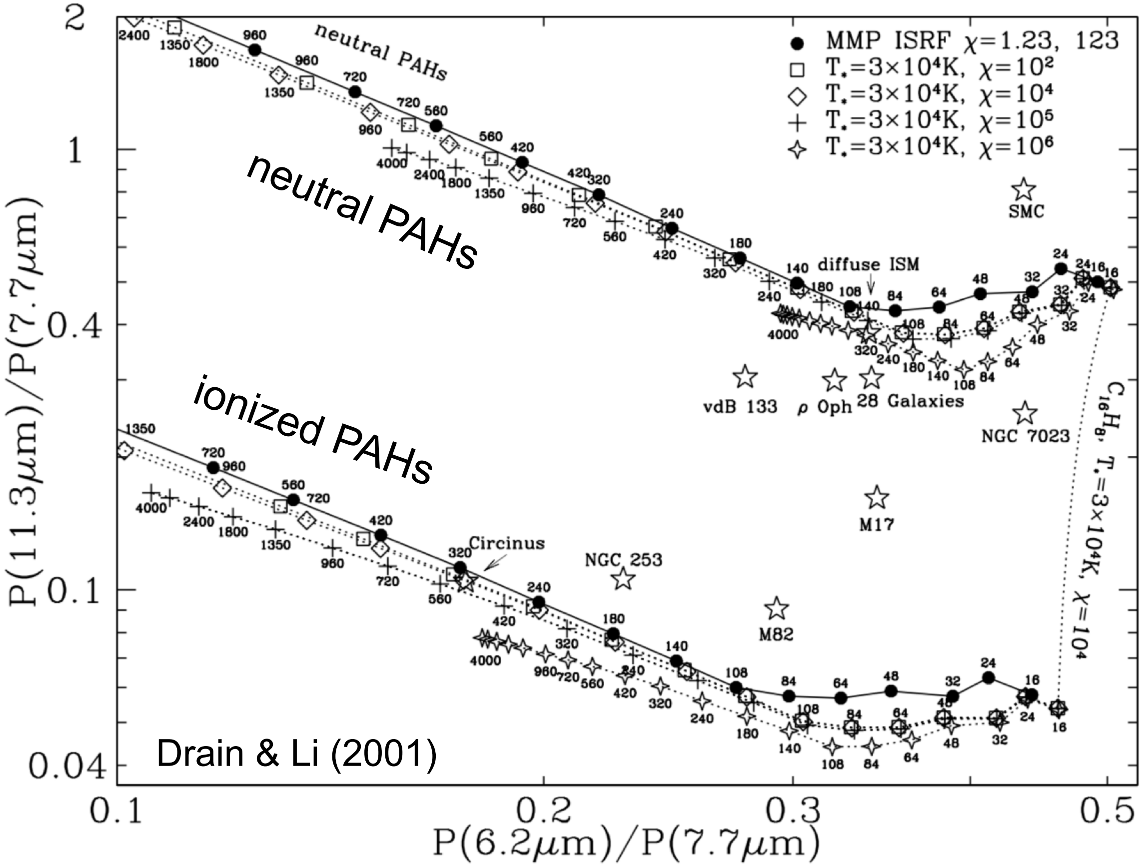
$z = 2.5$



What can we learn from the relative intensities of aromatic features?

- PAH charge, size, and molecular structure

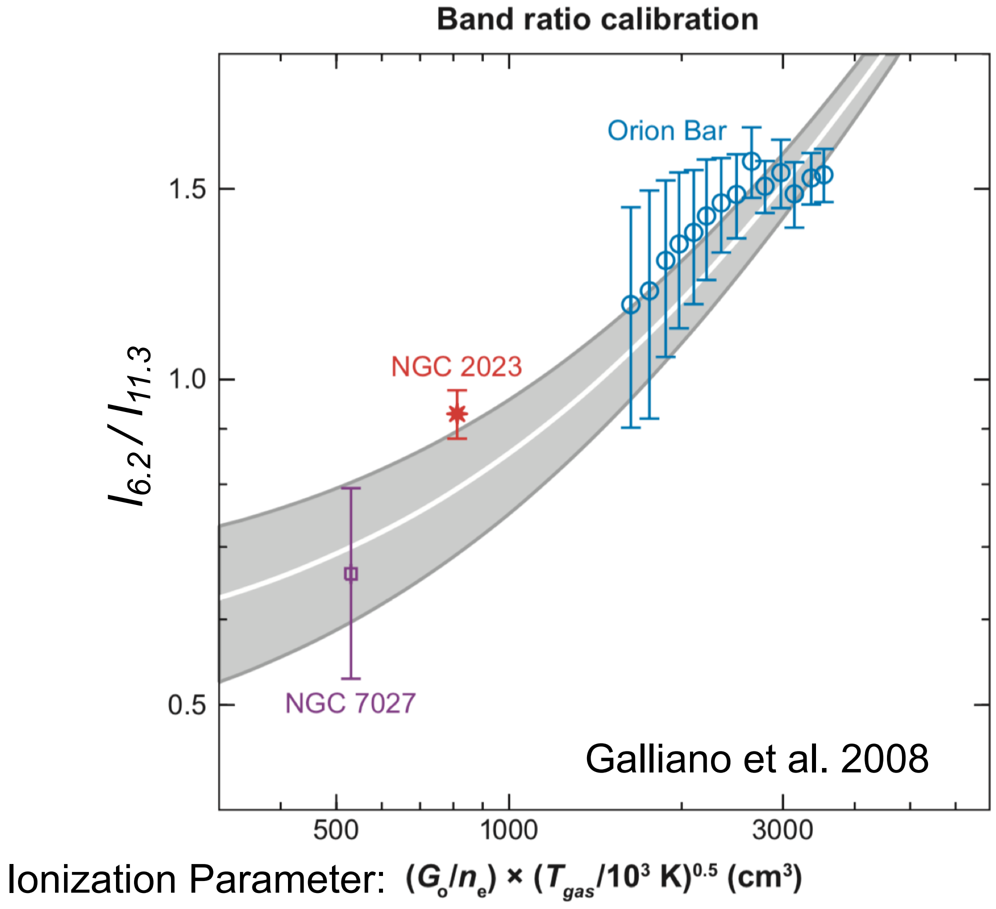




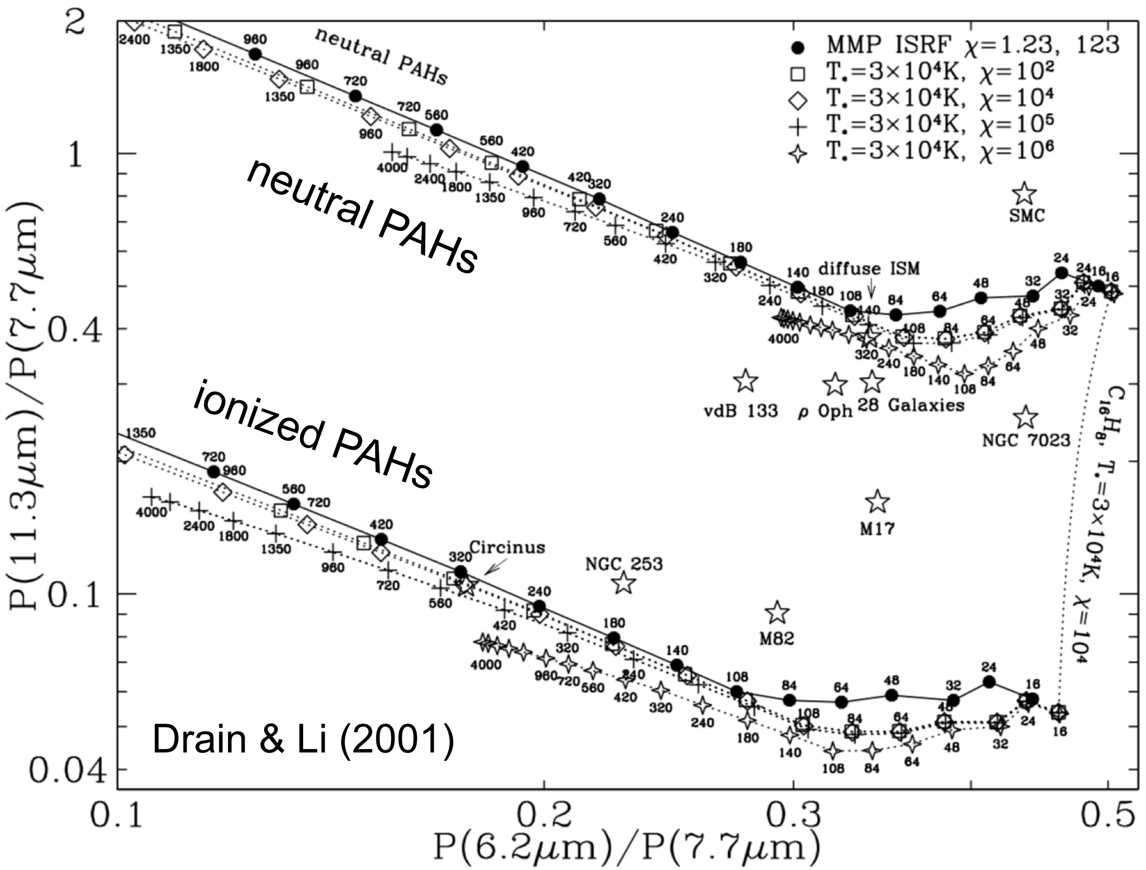
See also: Tielens 2008, Smith et al. 2007, Draine & Li 2007, Peeters et al. 2002, Hony et al. 2001

What can we learn from the relative intensities of aromatic features?

- PAH charge, size, and molecular structure
- Conditions of ISM and properties of the emitting sources



Galliano et al. 2008



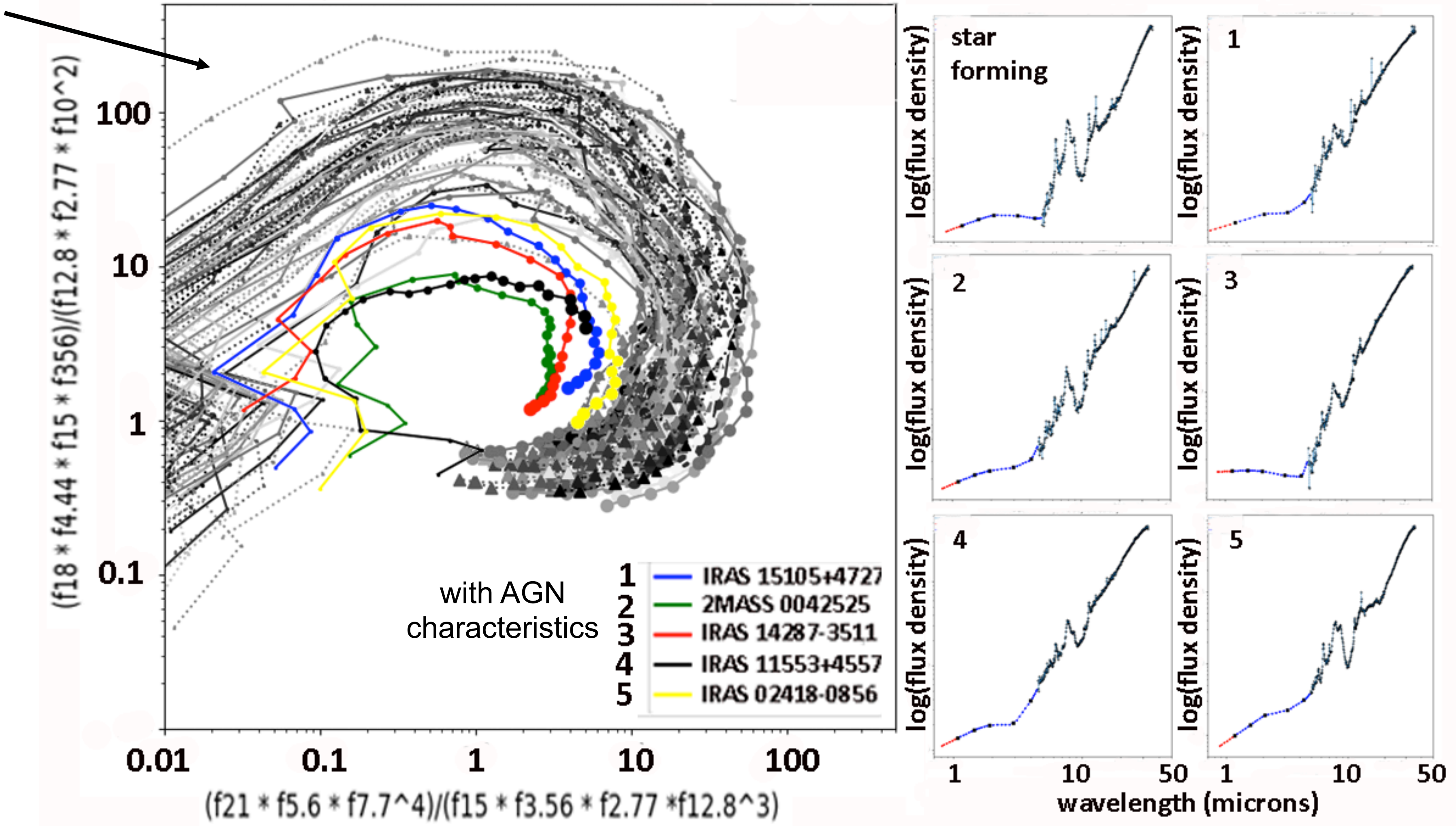
Drain & Li (2001)

See also: Tielens 2008, Smith et al. 2007, Draine & Li 2007, Peeters et al. 2002, Hony et al. 2001

MIRI and NIRCam multi-color diagrams to identify sources with embedded AGN

Star-forming
galaxies at
z = 0.5 – 2.4

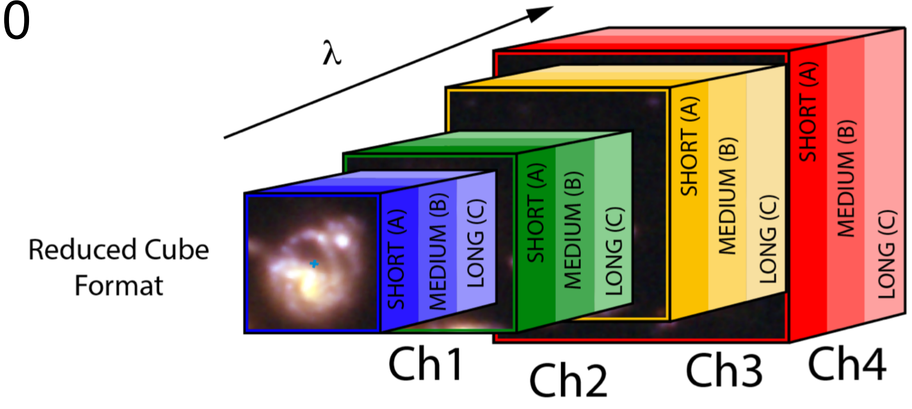
Image Credit: G. Rieke, J. Lyu, J. Morrison; JWST/MIRI GTO program



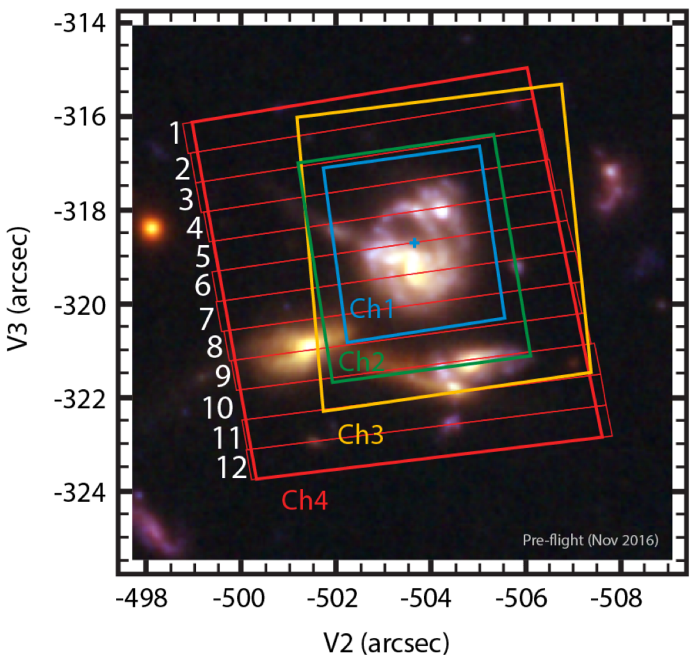
AGN identification multi-color methods: Kirkpatrick et al. (2017), Lacy et al. (2004), Stern et al. (2005), Donley et al. (2012), Stern et al. (2012), Del Moro et al. (2016)

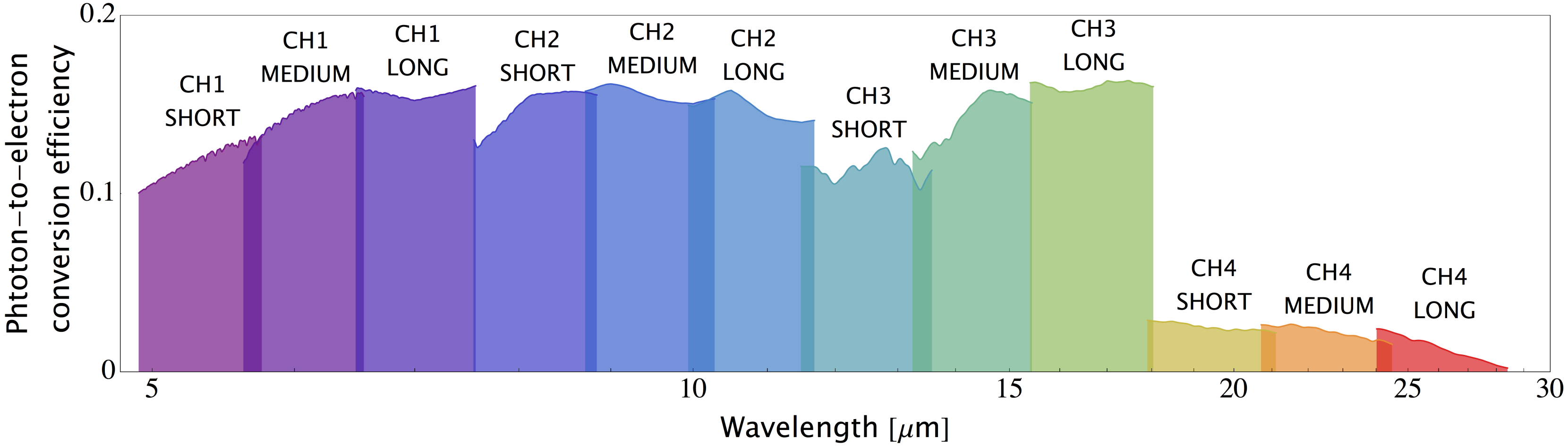
JWST MRS: Medium Resolution Spectroscopy

- Four separate IFUs, called channels 1, 2, 3 and 4
- 5 to 28.5 μm
- R ~ 1550–3250



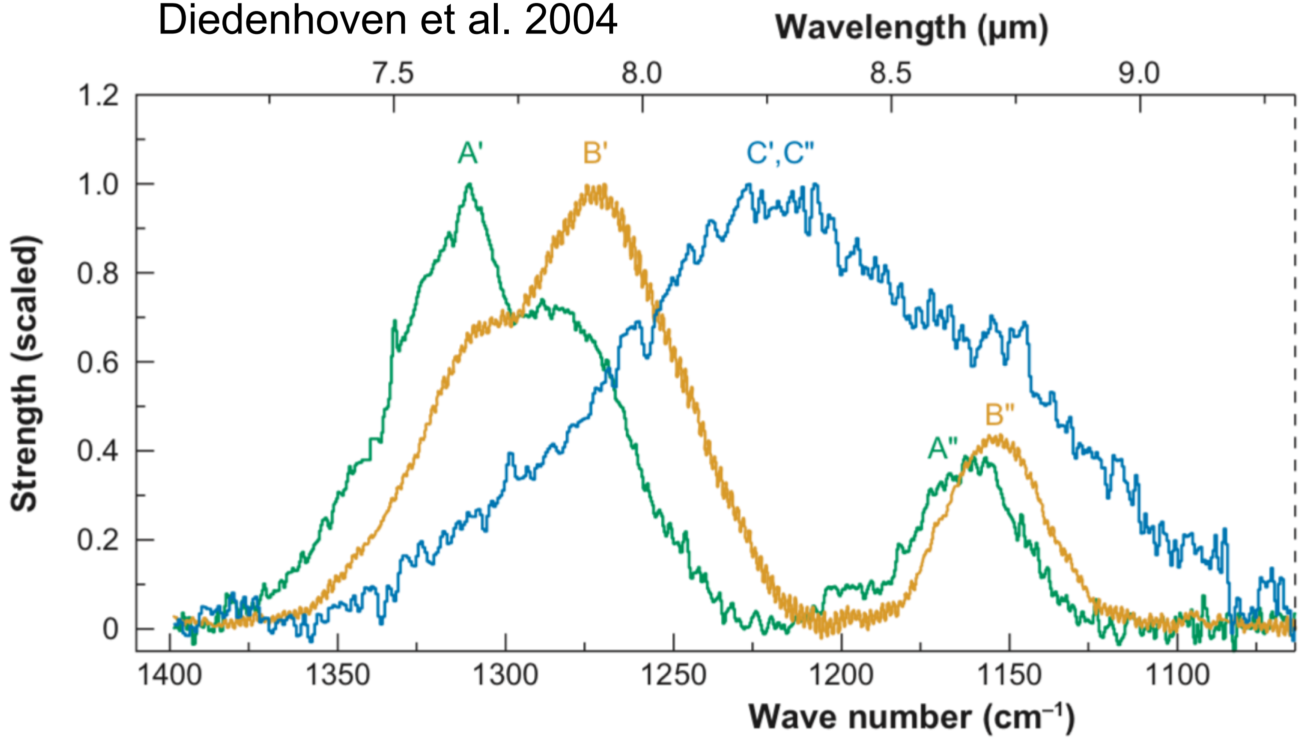
IFU Footprint on Sky

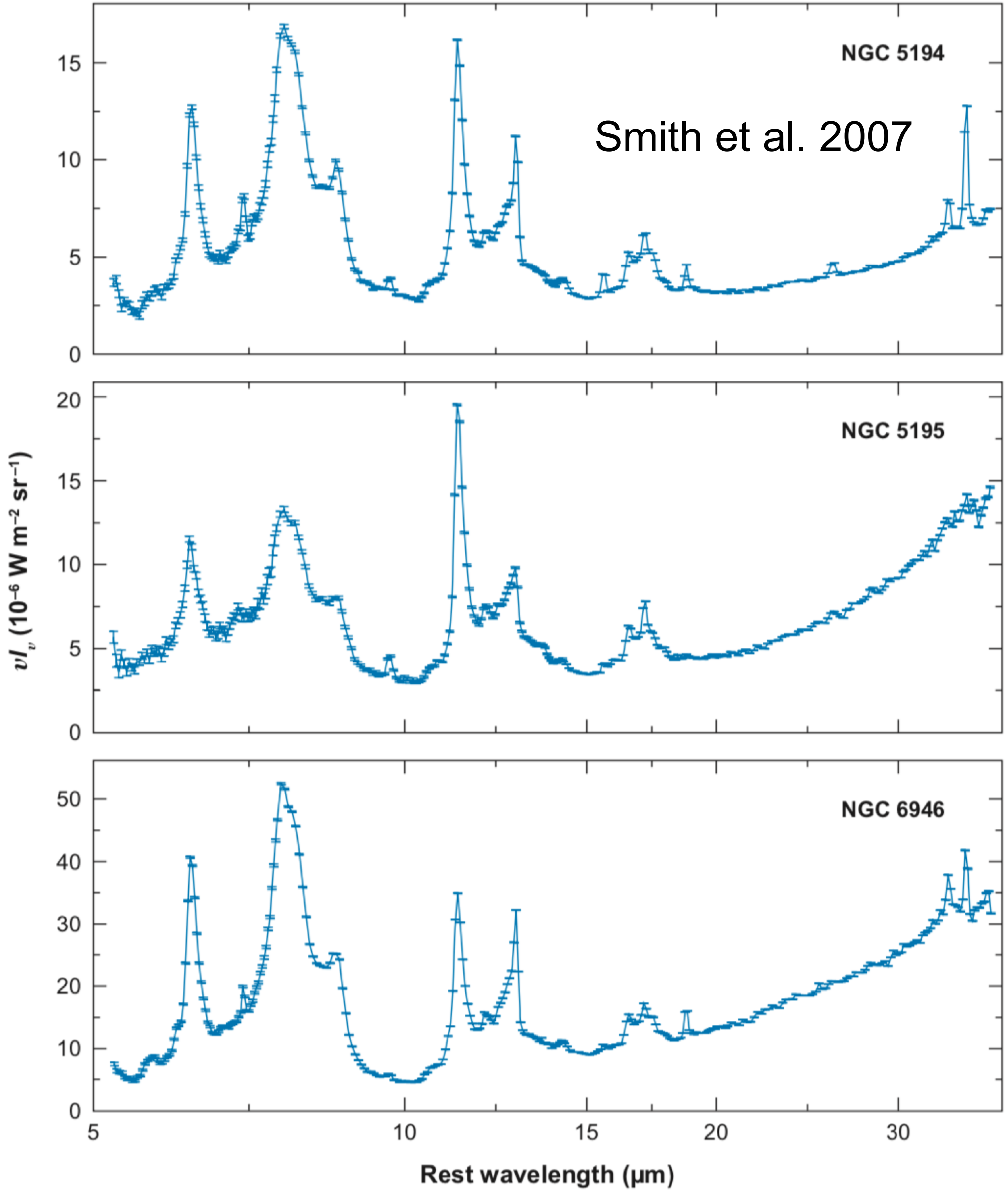




Aromatic bands spectra: variations in the profile and peak position

Diedenhoven et al. 2004

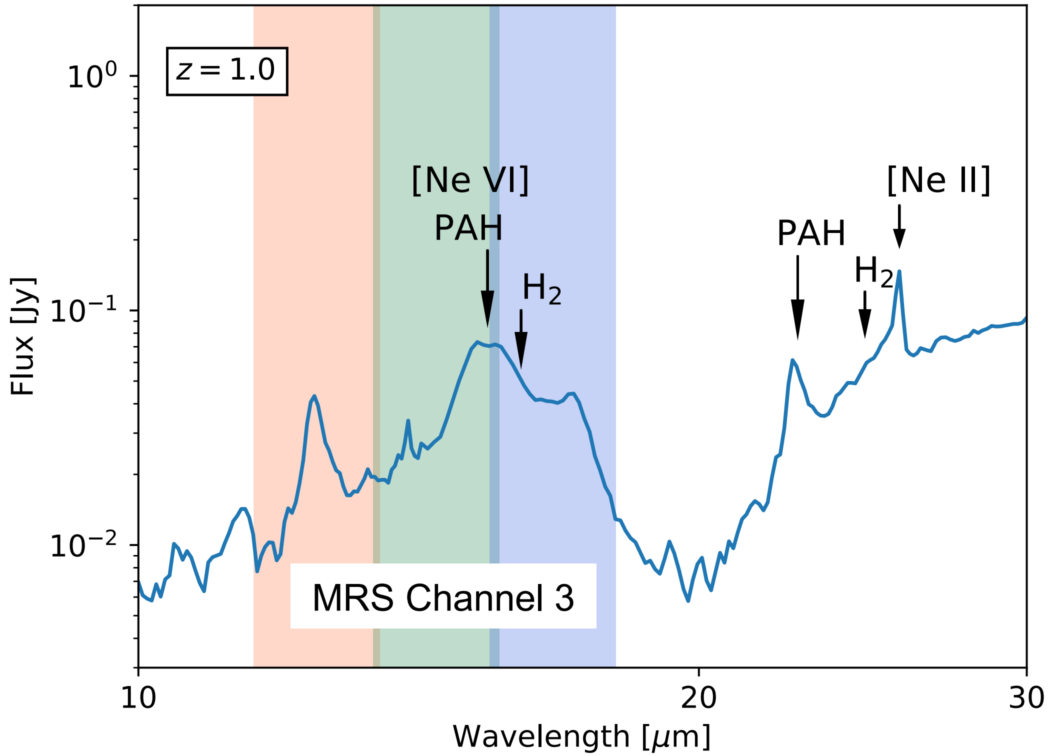


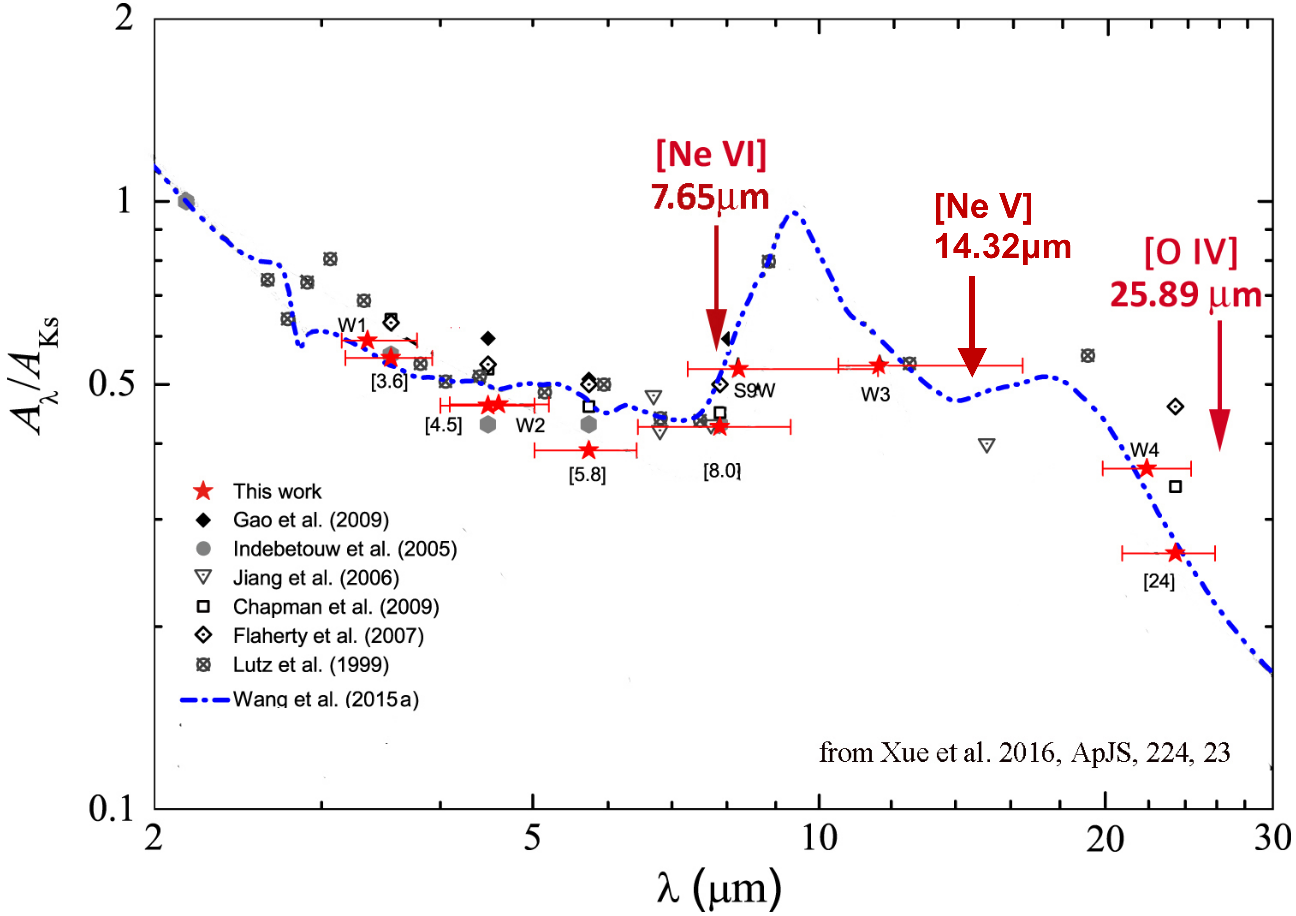


Smith et al. 2007

See also: Peeters et al. (2002); Sloan et al. (2007), Tielens (2008)

Pulling the AGN needle out of the star formation haystack:
Using [N VI] 7.65μm fine structure line (ionization potential of 158 eV)

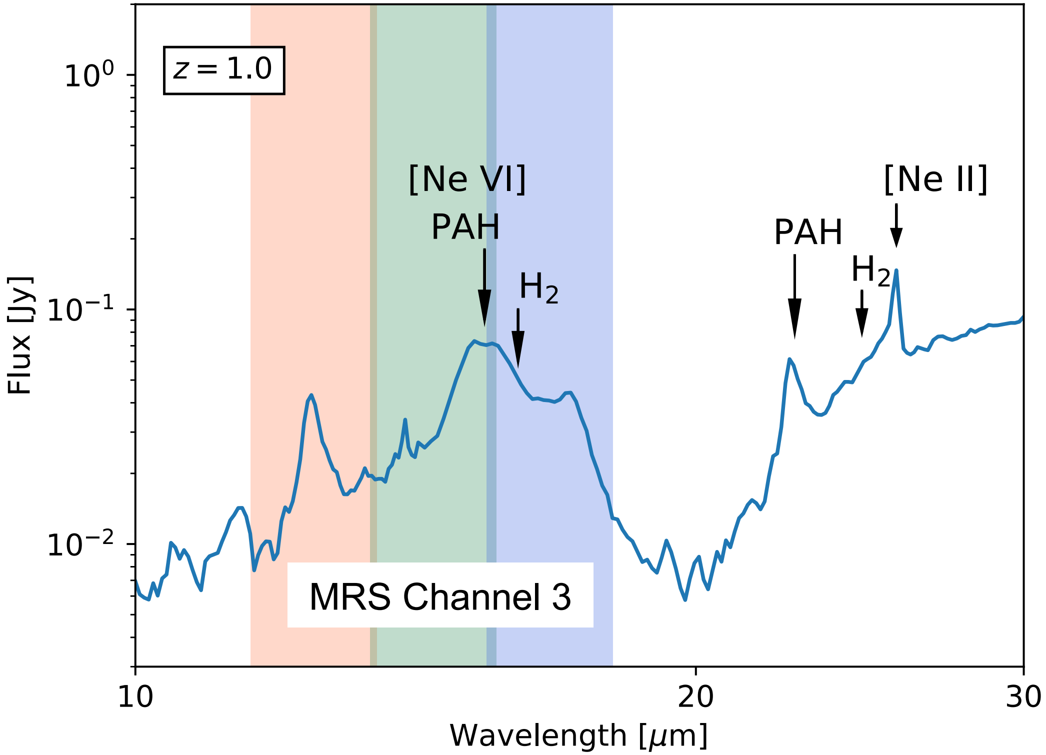


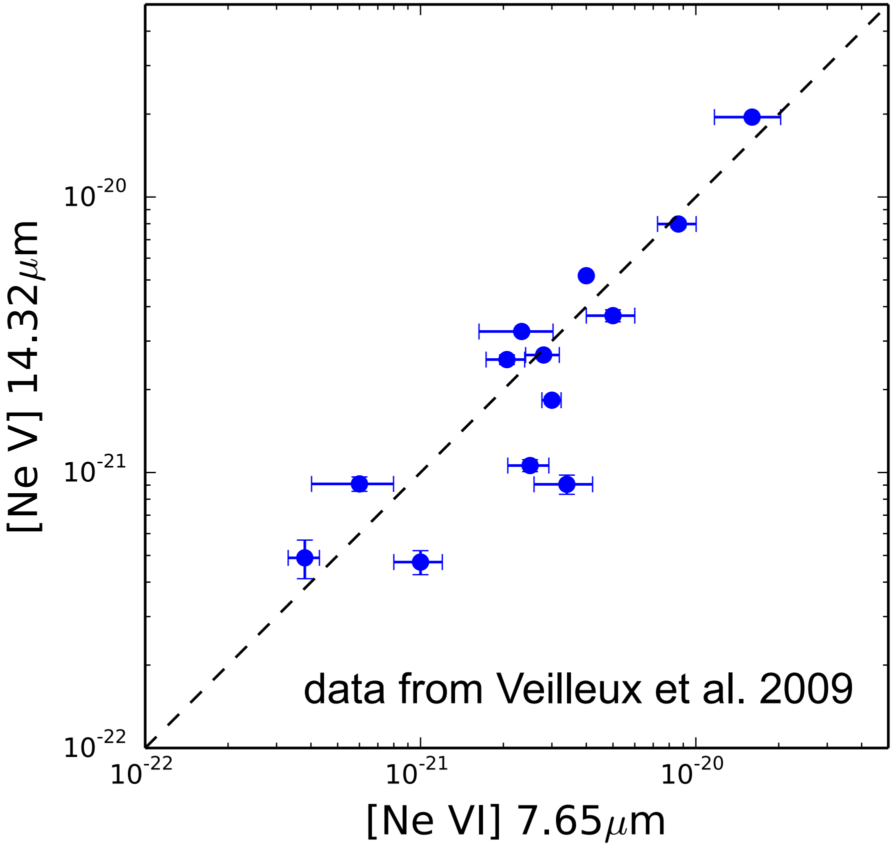


from Xue et al. 2016, ApJS, 224, 23

Also see: JWST/MIRI US extragalactic GTO program (PI: G. Rieke, Co-Is: S. Alberts, J. Lyu, J. Morrison, I. Shivaei)

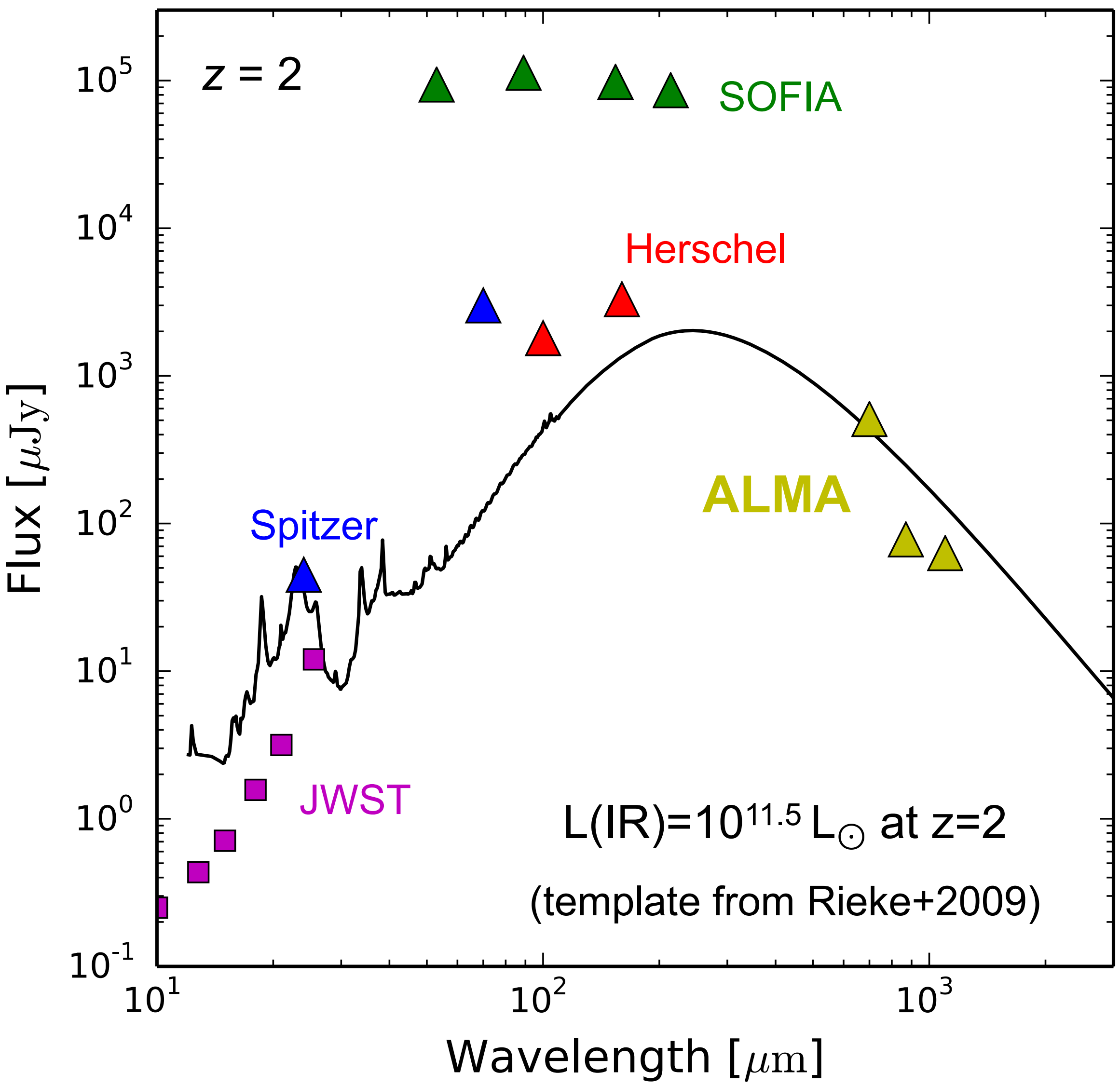
Pulling the AGN needle out of the star formation haystack: Using [N VI] 7.65µm fine structure line (ionization potential of 158 eV)





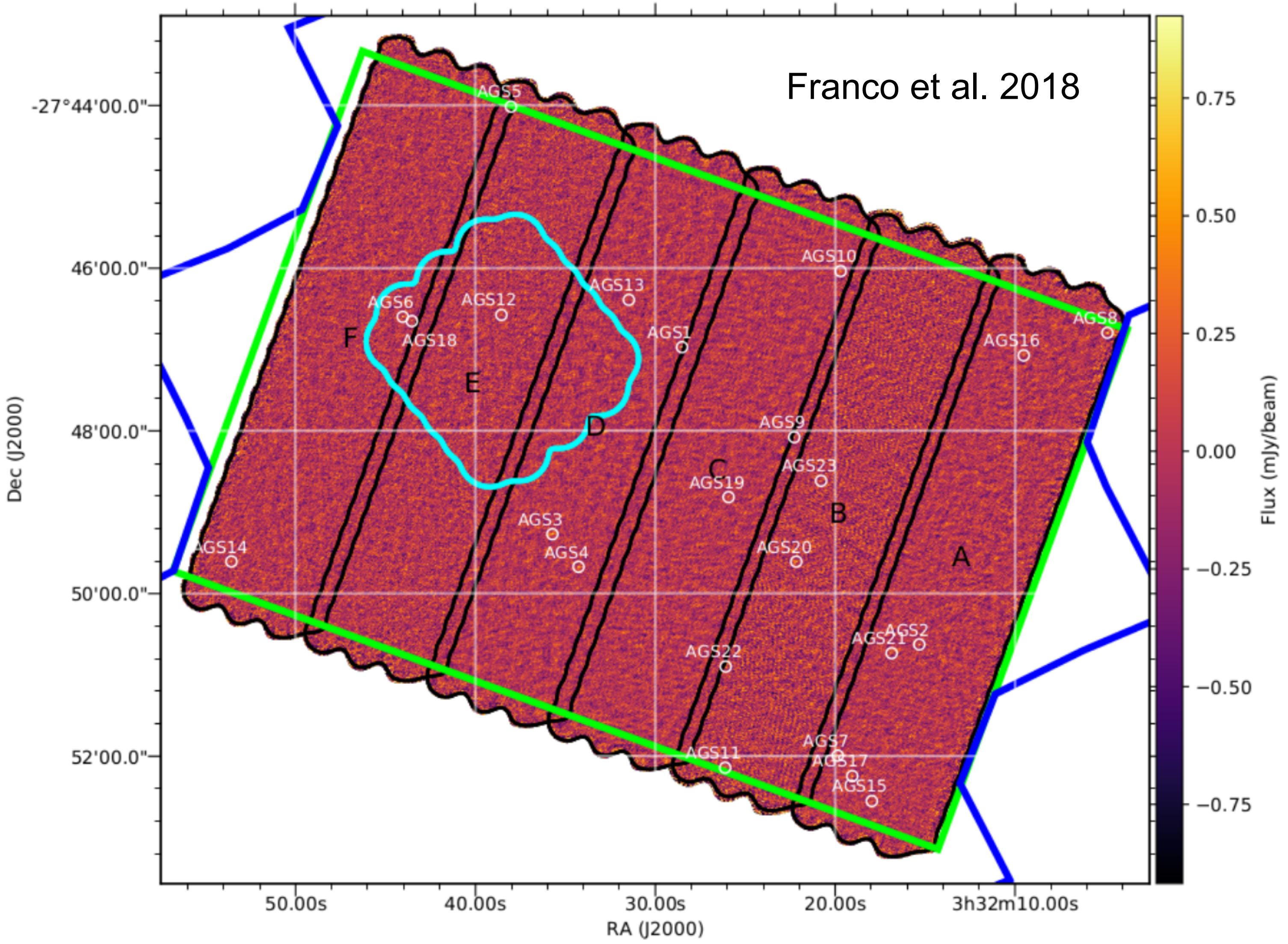
Also see: JWST/MIRI US extragalactic GTO program (PI: G. Rieke, Co-Is: S. Alberts, J. Lyu, J. Morrison, I. Shivaei)

Moving to longer wavelengths to calculate total IR luminosity…



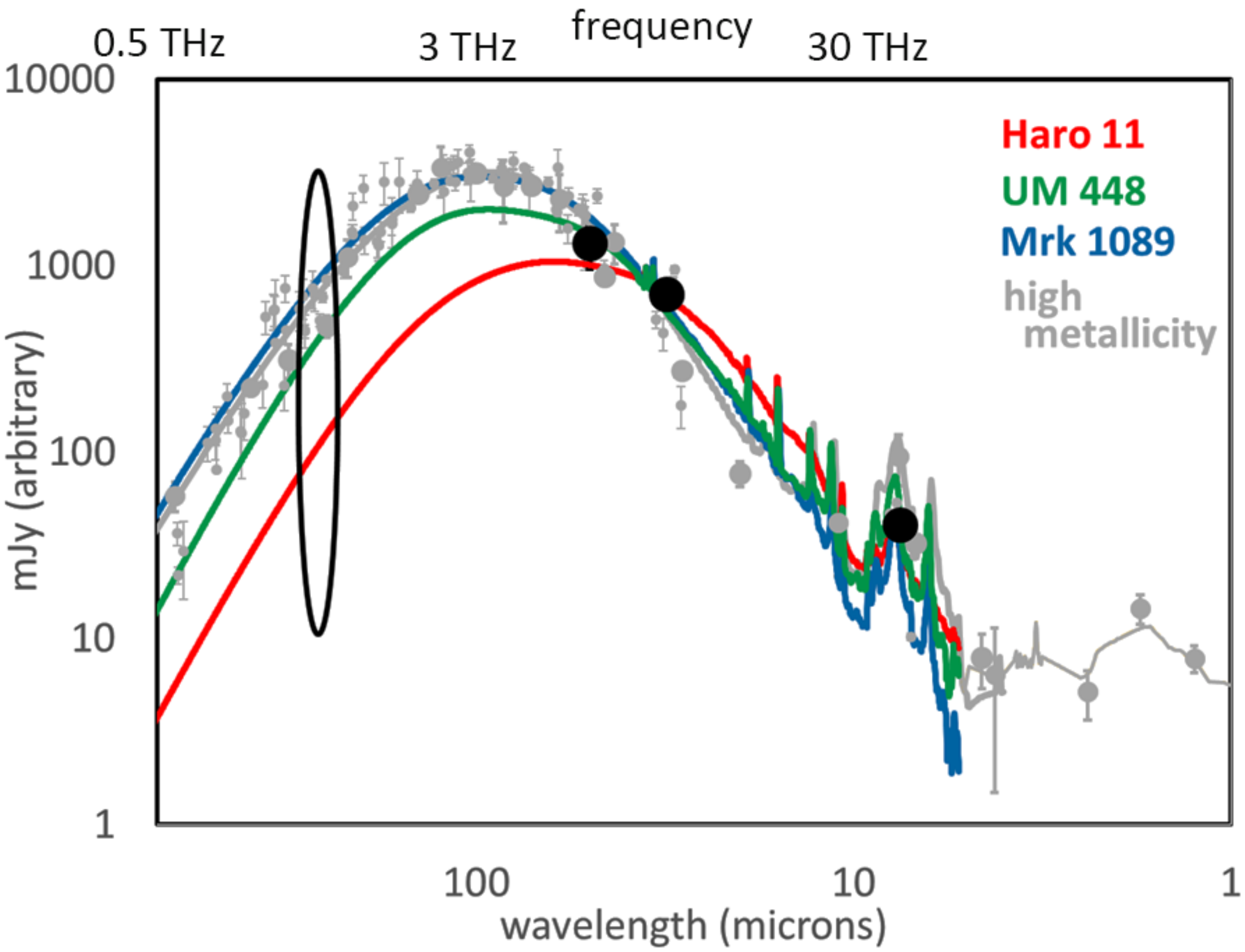
GOODS-S ALMA 1.1 mm image

846-pointing mosaic
~60 seconds per pointing



See also: Aravena et al. 2016, Scoville et al. 2016, Dunlop et al. 2017, Elbaz et al. 2018, Rujopakarn et al. 2016

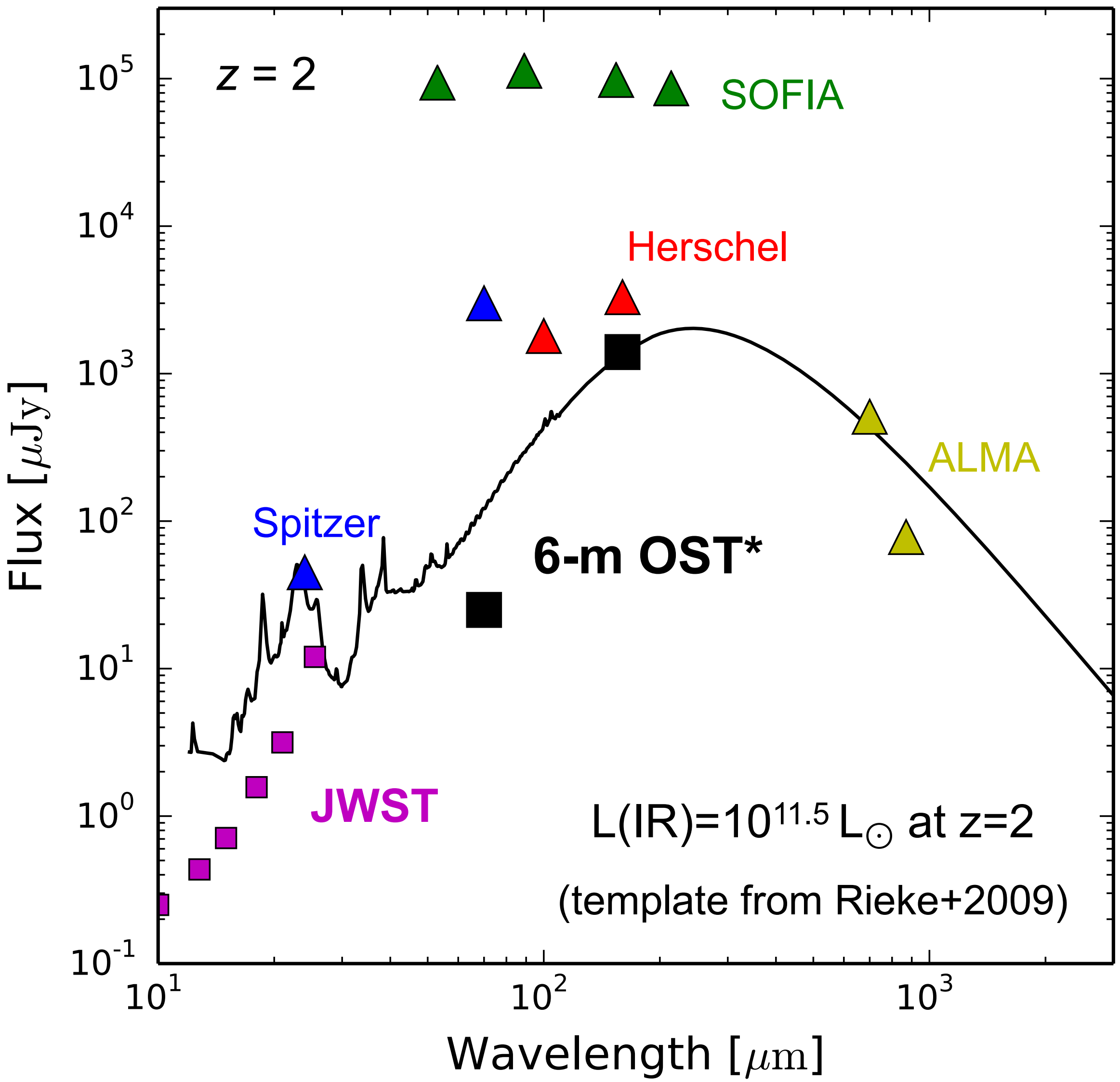
The large range of behavior in the far-IR emission of z~2 galaxies

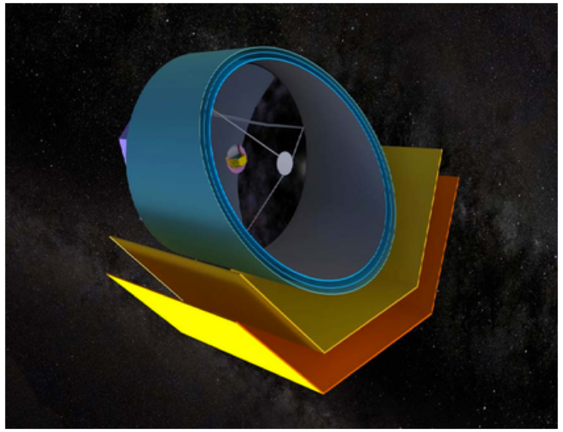


~ 0.8 dex variation in the observed 870 μm

See: De Rossi, Rieke, Shivaei+2018

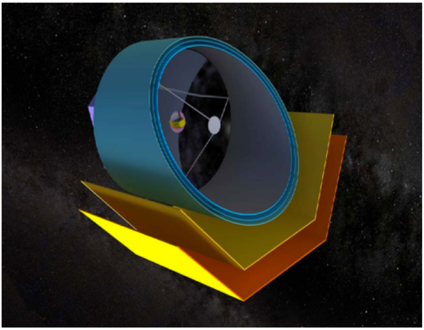
6-m Origins Space Telescope Imager at 70 and 160 μm

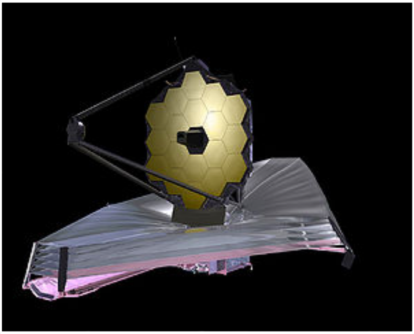




* Confusion-limited sensitivity calculations using SDC method; Dole+2003, 2004

Summary





- For the foreseeable future, mid-IR aromatic bands will be the main indicators of the dust emission and obscured star forming regions at intermediate redshifts (z~1-3)
  - PAH intensity is strongly dependent on metallicity, which suggests a higher sSFR at $M_* < 10^{10} M_\odot$ and higher bolometric luminosity density and SFR density at z ~ 2
- Future with ***JWST*/MIRI**:
  - MIRI imager: tracing PAH band ratios to characterize the PAH molecules characteristics and physical conditions of the emitting source, identifying embedded AGN
  - MIRI MRS: spectra of the aromatic bands, looking for [N VI] as a tracer of obscured AGN
- A 6-m ***OST*** can get accurate SFRs at z~2 (based on rest 24 μm) down to $10^{11}\ L_\odot$. Accompanied with *JWST*, it will be a powerful way to measure the aromatic bands on the same galaxies.