What Lies Beneath:

Probing Dust Obscured Star Formation and Black Hole Growth through Spectral Energy Distributions

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Sesto Workshop

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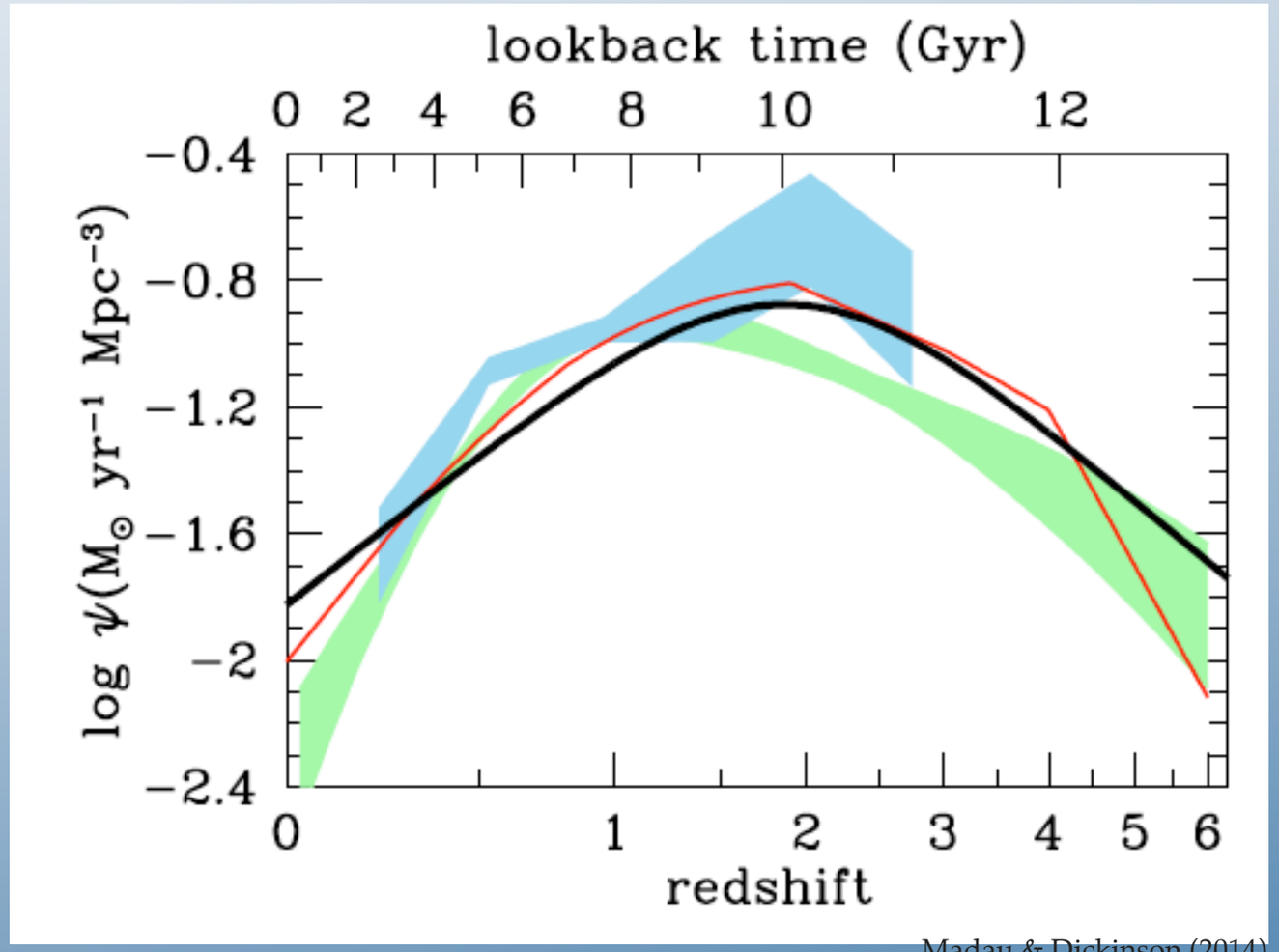
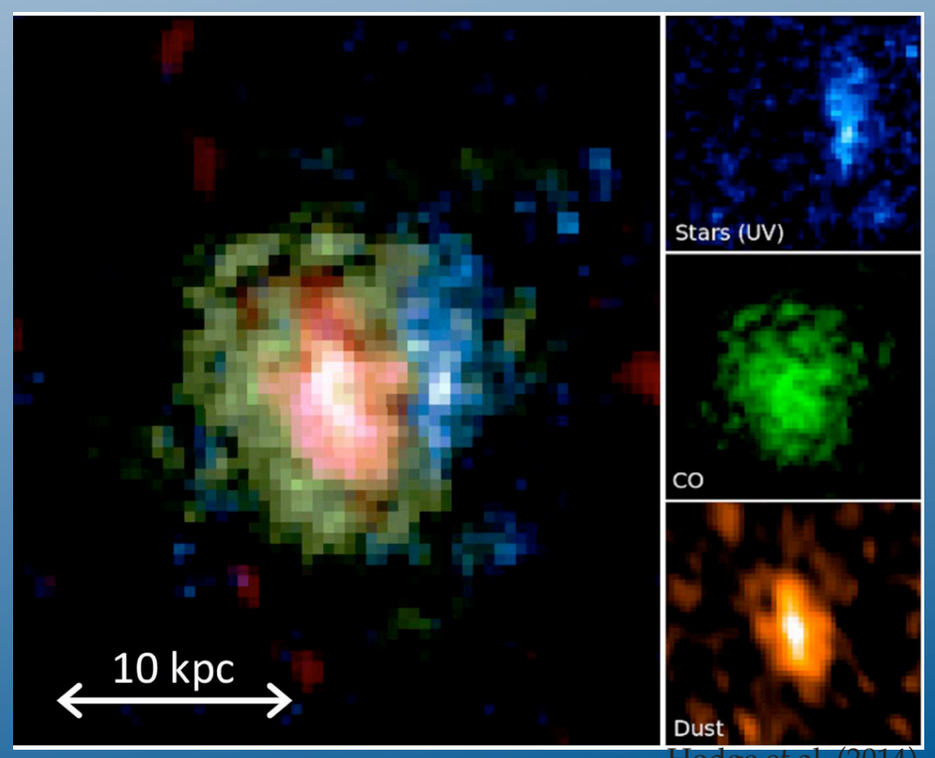
In The Beginning...



Madau & Dickinson (2014)

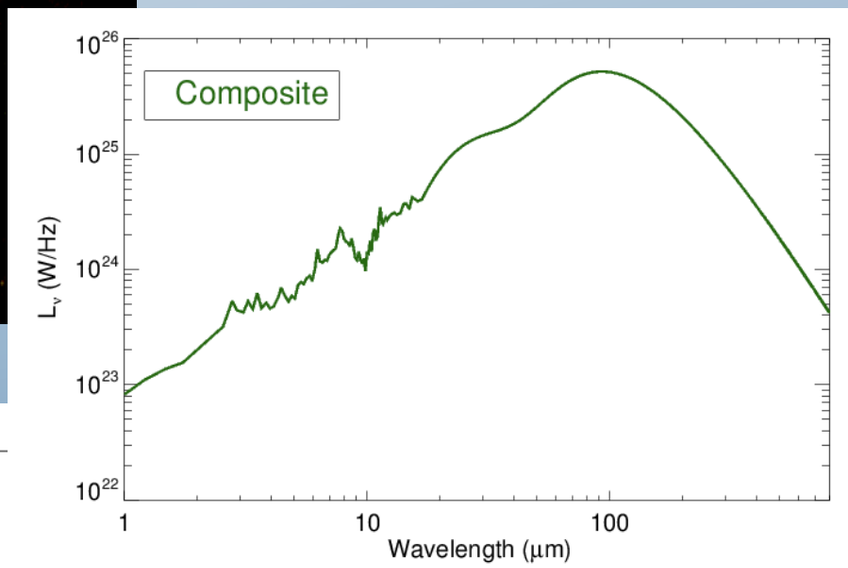
Star formation and **black hole growth** peak at z=1-3

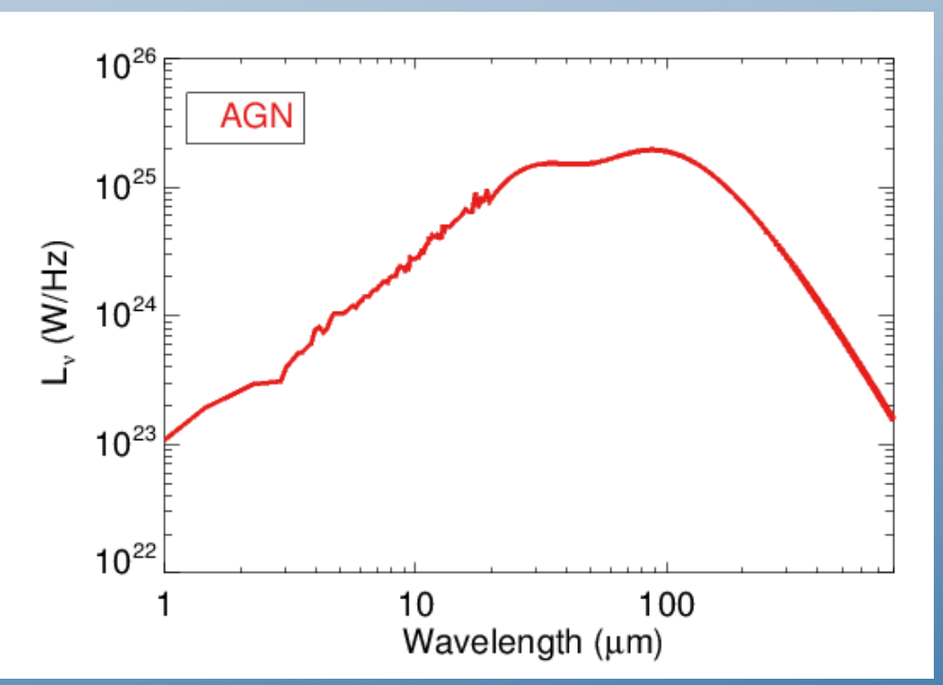
Most of this growth occurs in LIRGs and ULIRGs

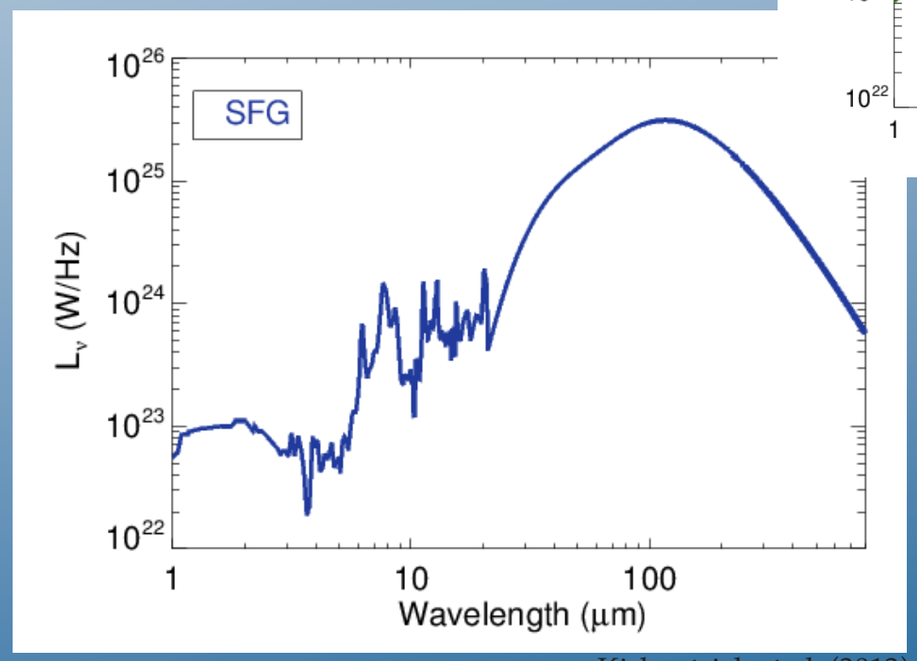


Hodge et al. (2014)

Black Holes Change Dust Emission

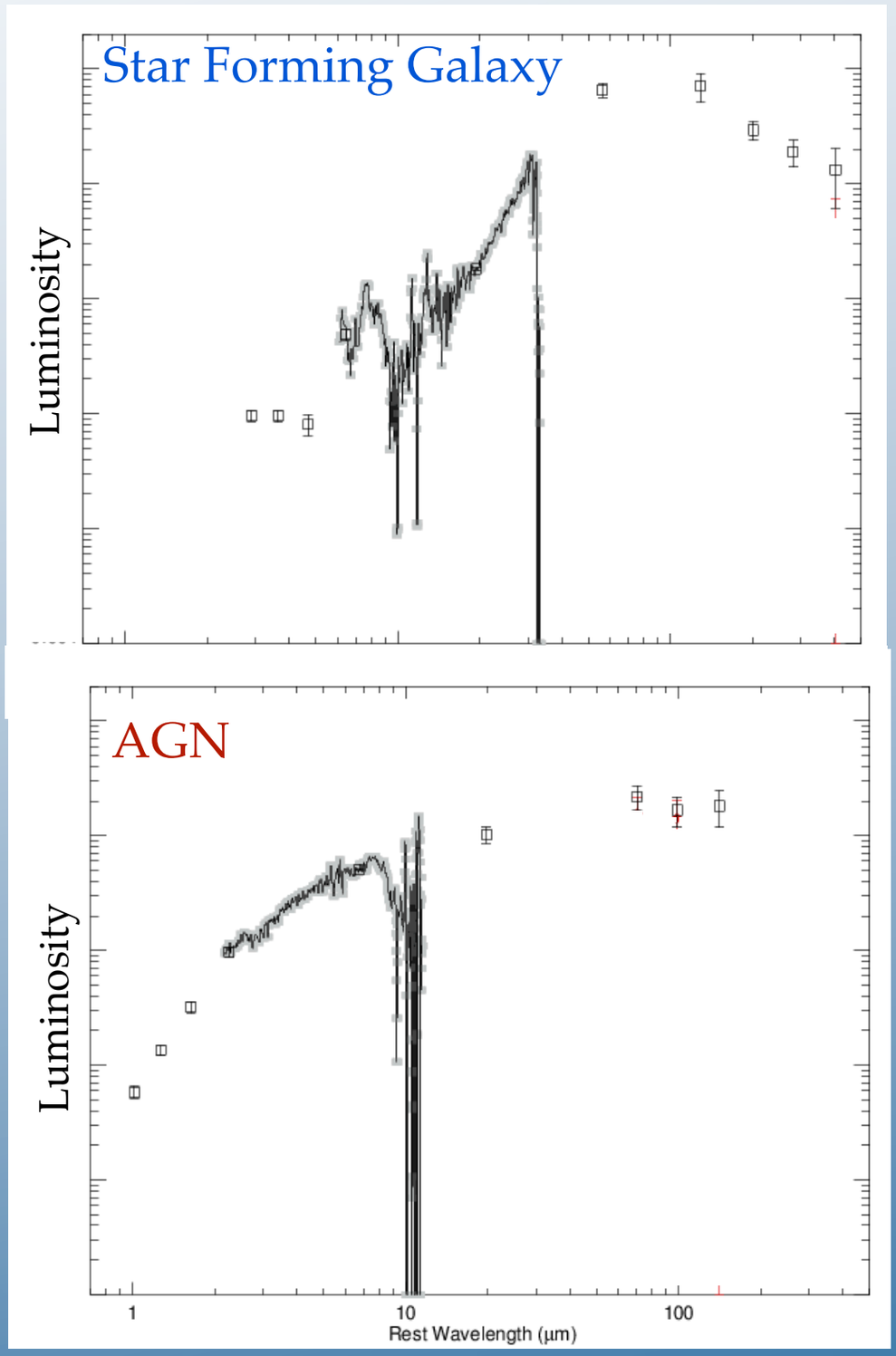






Kirkpatrick et al. (2012)

Empirical Templates



GOAL: Create templates to represent a range of high redshift LIRGs and ULIRGs

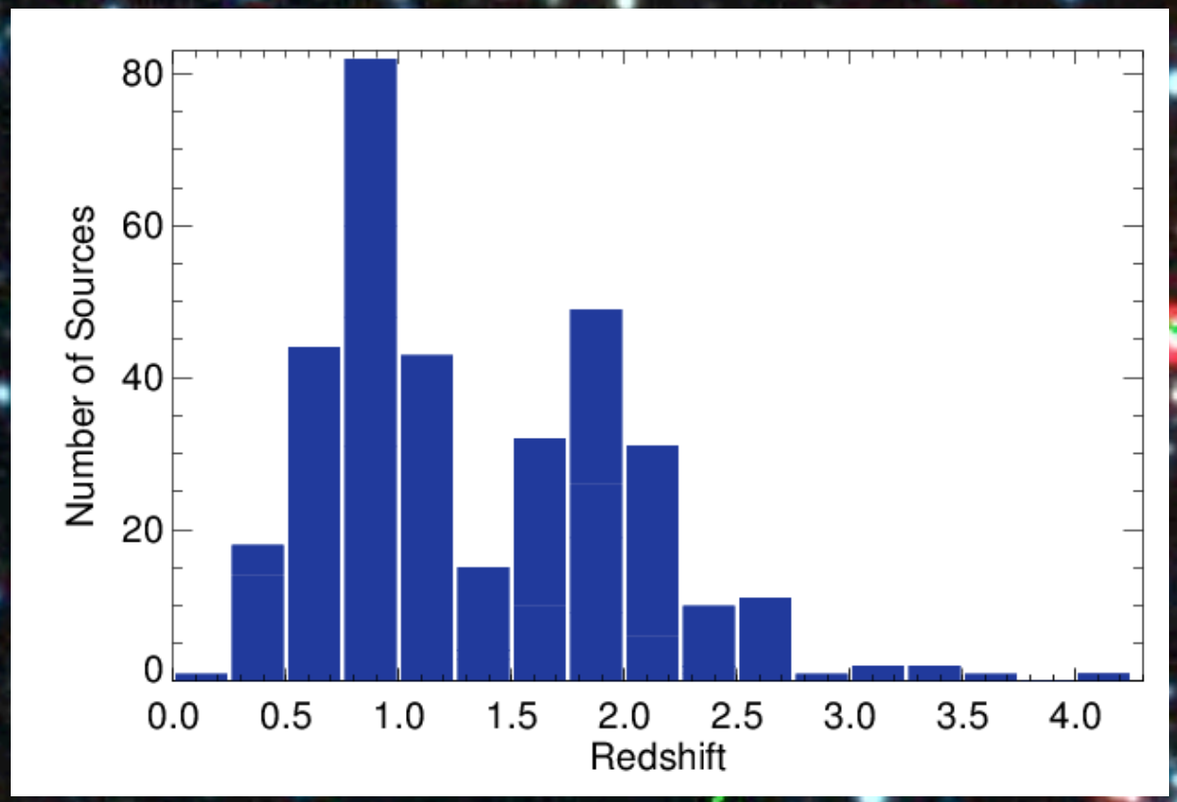
Large sample size: > 300 galaxies

ALL galaxies have MIR spectroscopy

ALL galaxies have Herschel imaging

Create large library of publicly available templates

High Redshift Sample



350 galaxies from *Spitzer* First Look Survey (xFLS) and Great Observatories Origins Deep Survey (GOODS)

Sources are selected at 24 μm:

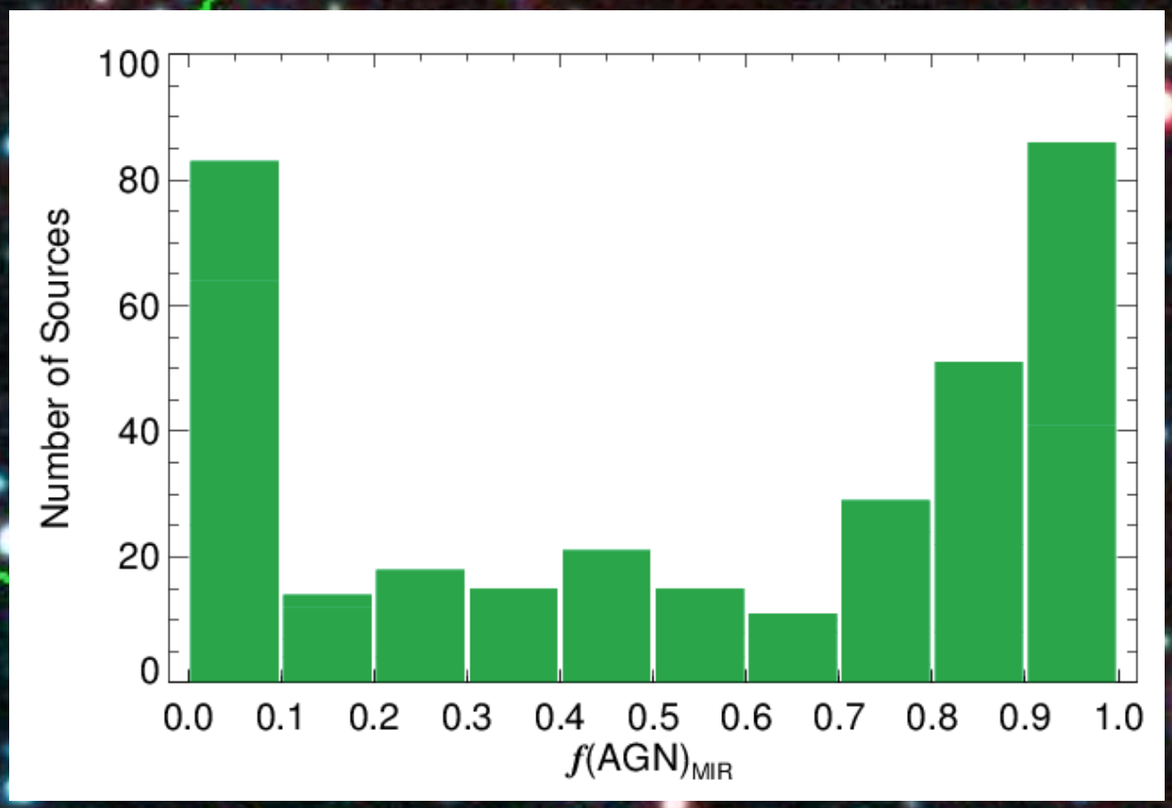
S_{24} > 0.9 mJy (xFLS)

S_{24} > 0.2 mJy (GOODS)

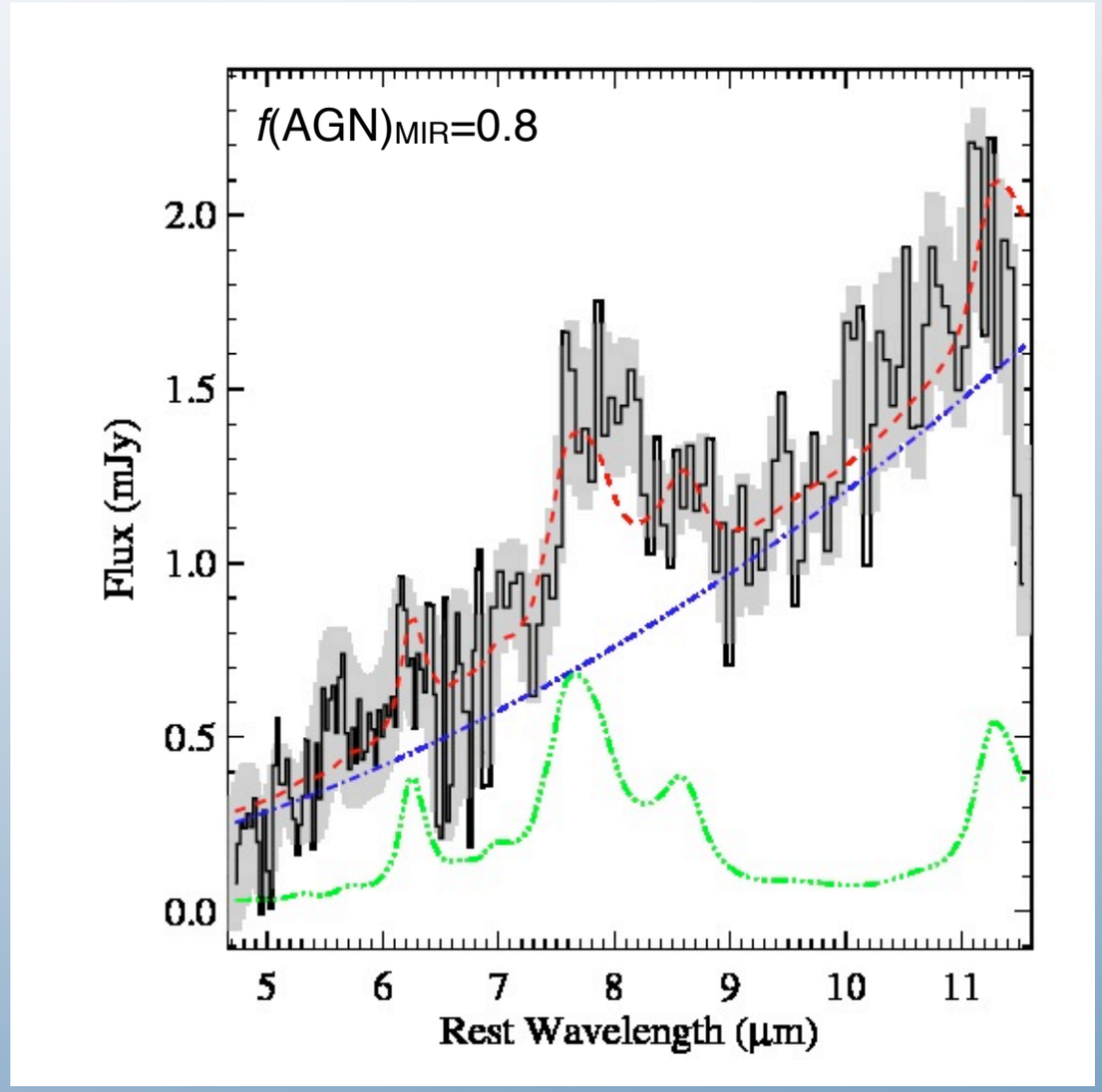
Redshift range: 0.2-4

All sources have mid-IR spectroscopy

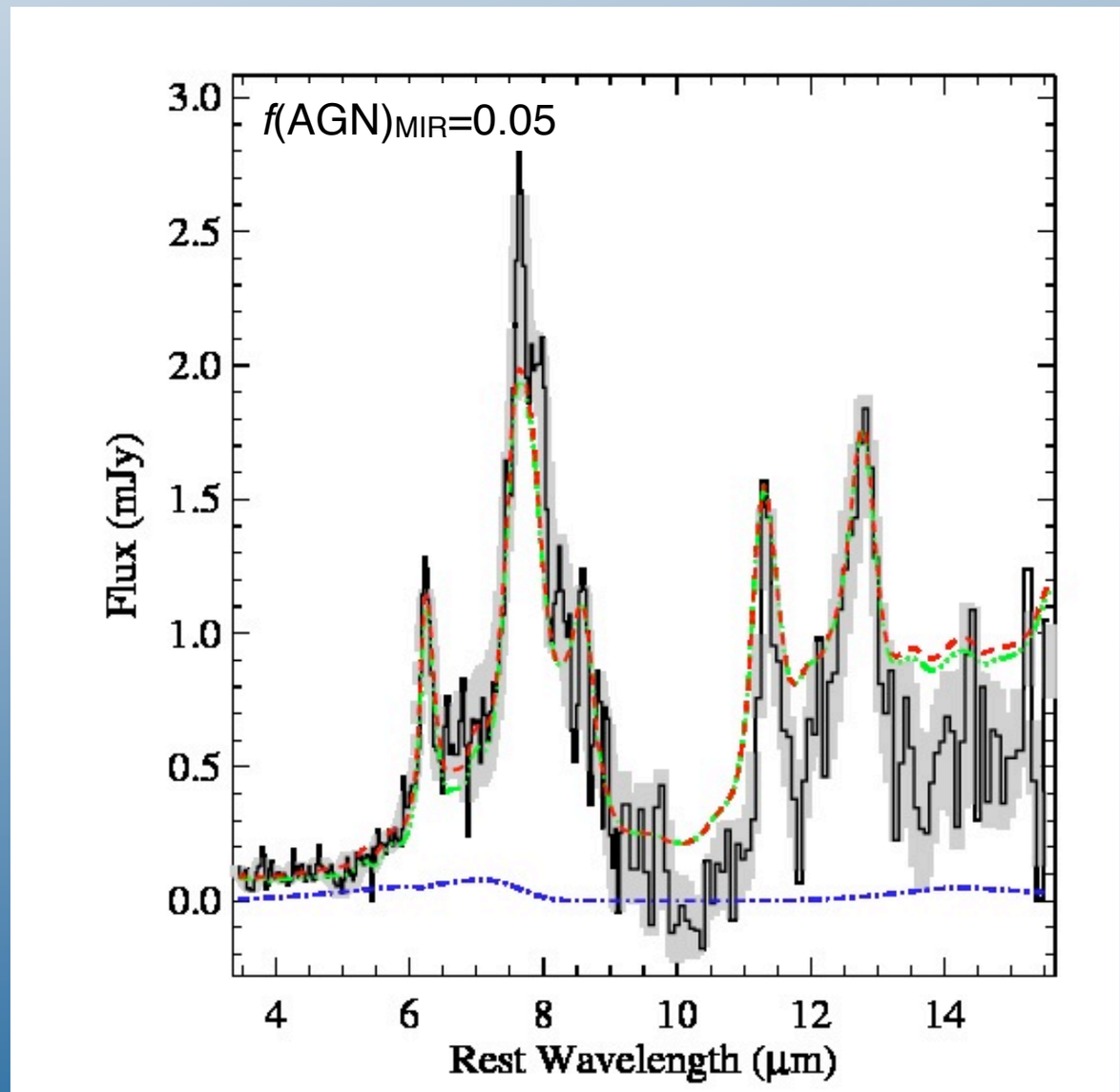
Photometry from *Herschel, Spitzer,* and ground-based telescopes



AGN or Star Formation?



Relative contributions of PAH features and power law continuum determine mid-IR classification.

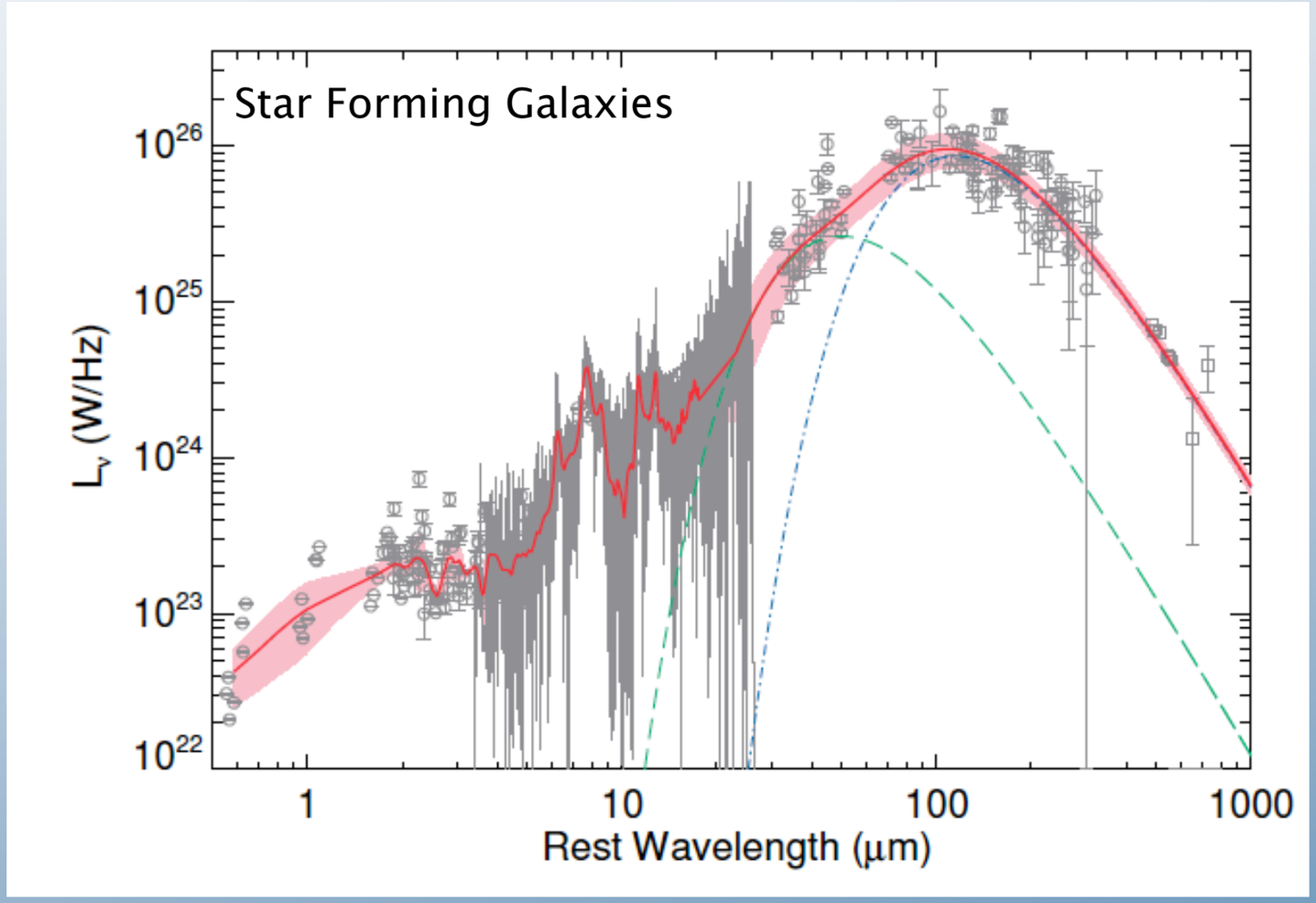


Fit 4 components simultaneously:

- PAH template (M 82)
- Power law
- Extinction curve (Draine 2003)

$$\mathrm{model} = N_{\mathrm{AGN}}\,\lambda^{\alpha}\,e^{-\tau_{\mathrm{AGN}}} + N_{\mathrm{SB}}\,S_{\mathrm{M82}}\,e^{-\tau_{\mathrm{SB}}}$$

Composite Spectra



- Group galaxies by AGN strength, redshift, and luminosity
- Normalize each group by the mid-IR (3-15μm) luminosity
- Calculated median luminosity in wavelength bins using resampling with replacement
- Fit a two temperature modified blackbody model to the far-IR:

$$\mathrm{BB} = N_W \times B_\nu(T_W) \times \nu^{1.5} + N_C \times B_\nu(T_C) \times \nu^{1.5}$$

- Three Libraries of templates

Comprehensive Template Library

Separate sources by $f(\mathrm{AGN})_{\mathrm{MIR}}$

SFG:

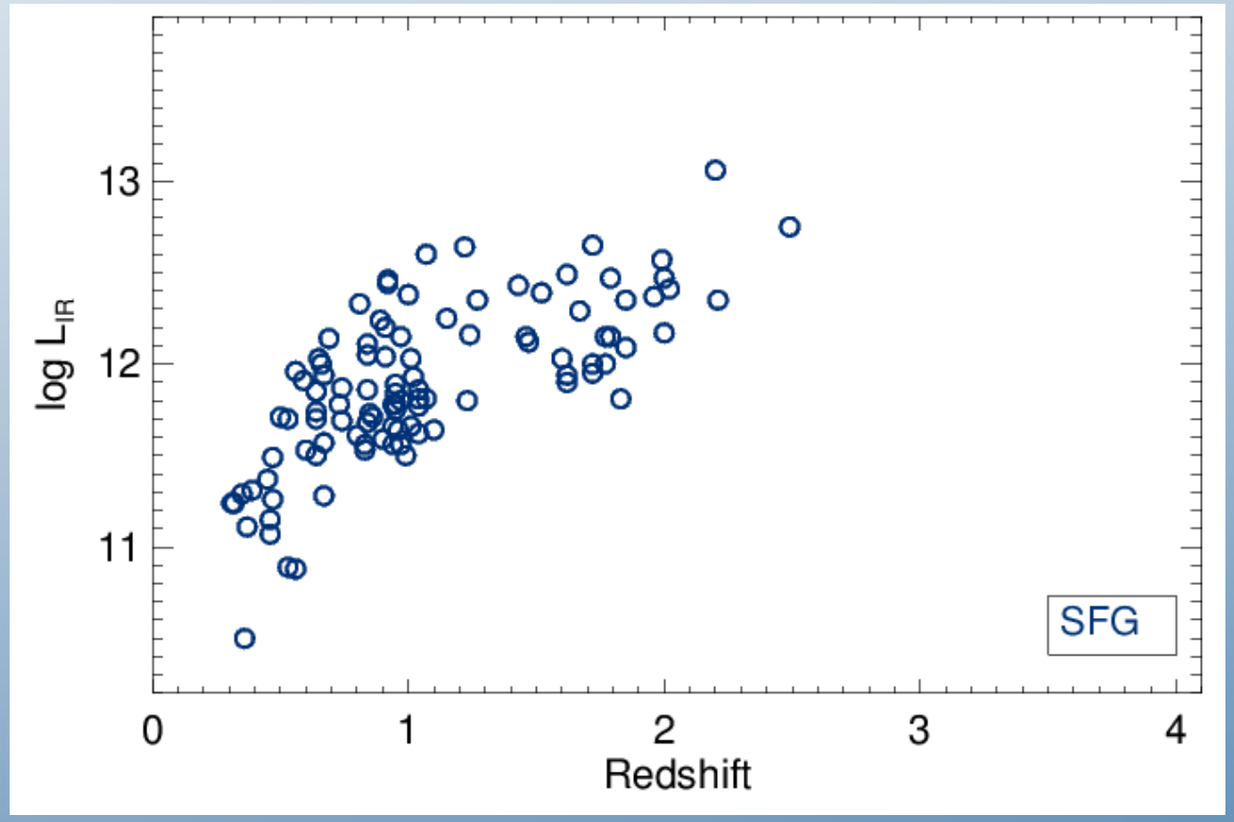
$f(\mathrm{AGN})_{\mathrm{MIR}} < 0.2$

Composite:

$f(\mathrm{AGN})_{\mathrm{MIR}} = 0.2\text{-}0.8$

AGN:

$f(\mathrm{AGN})_{\mathrm{MIR}} > 0.8$



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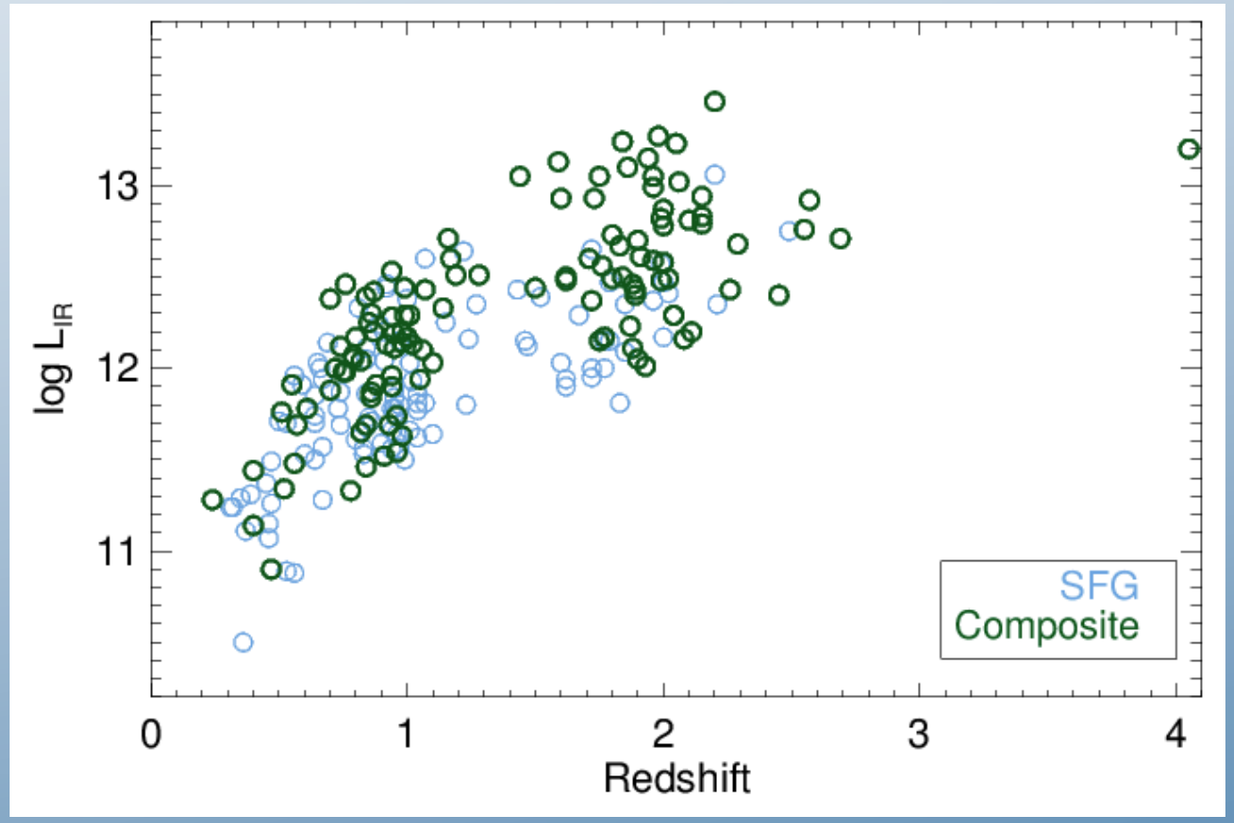

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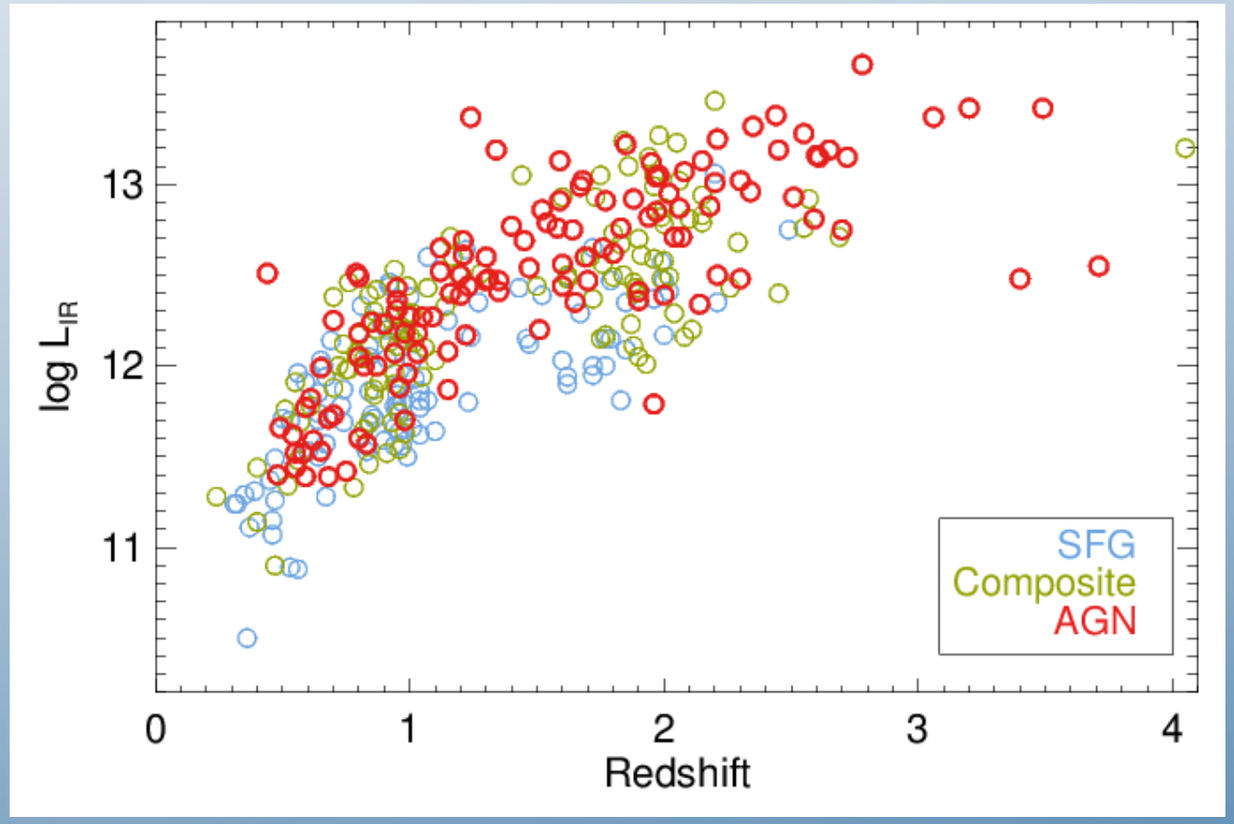

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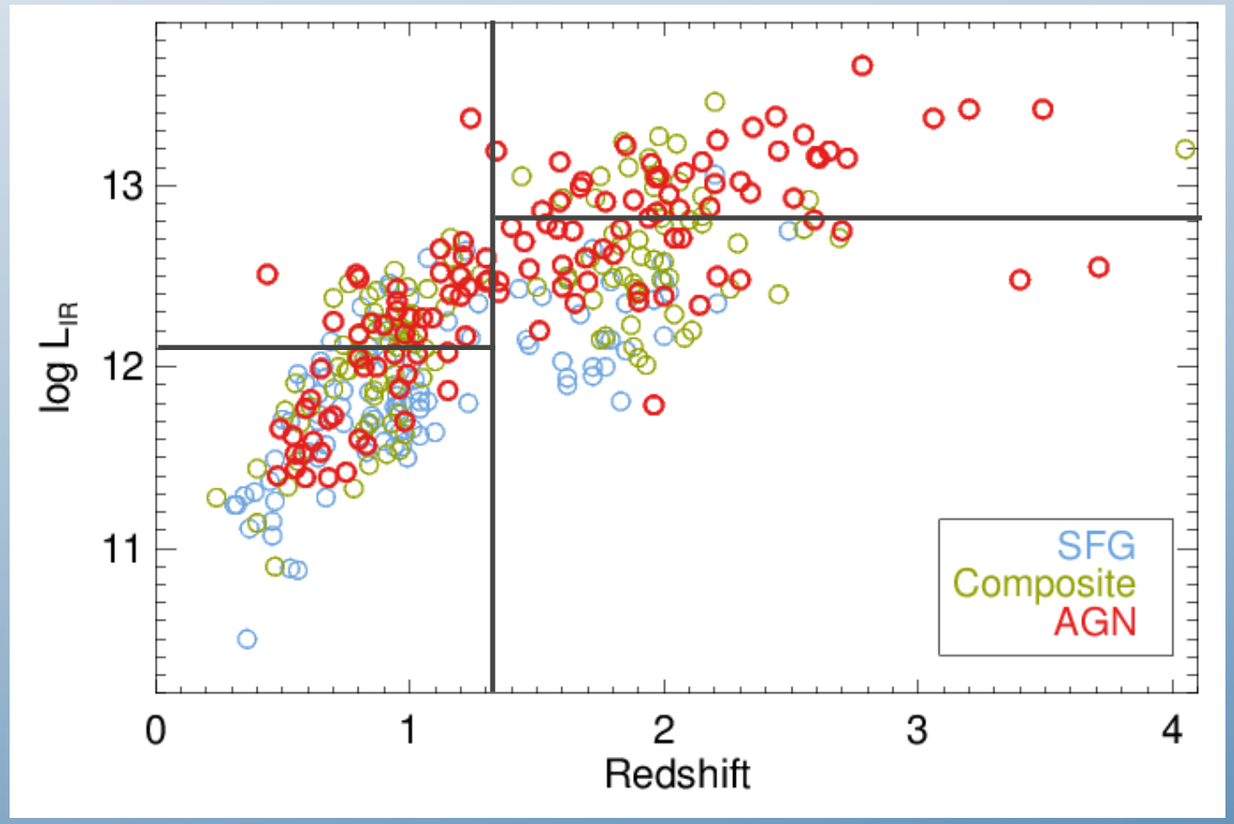
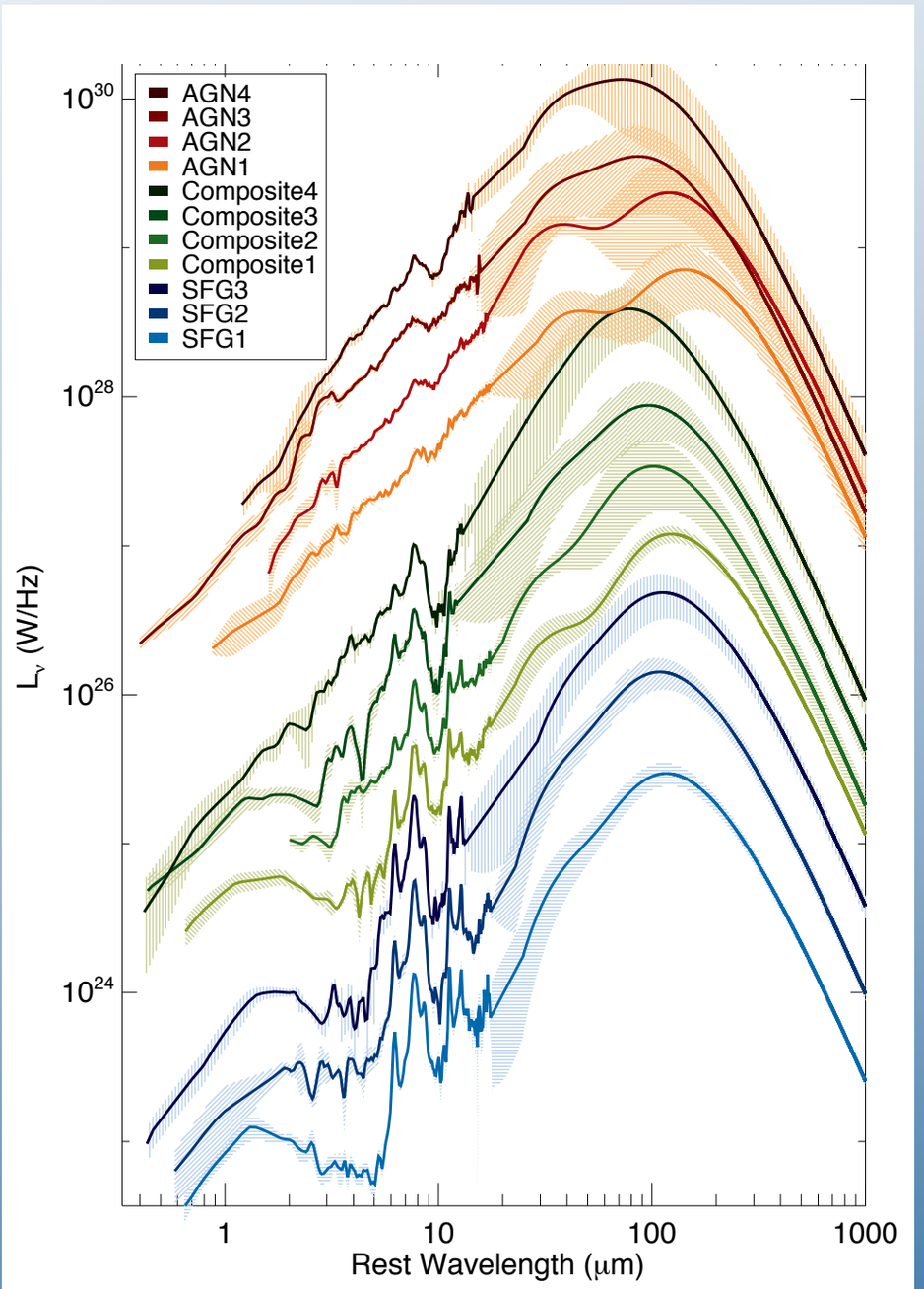


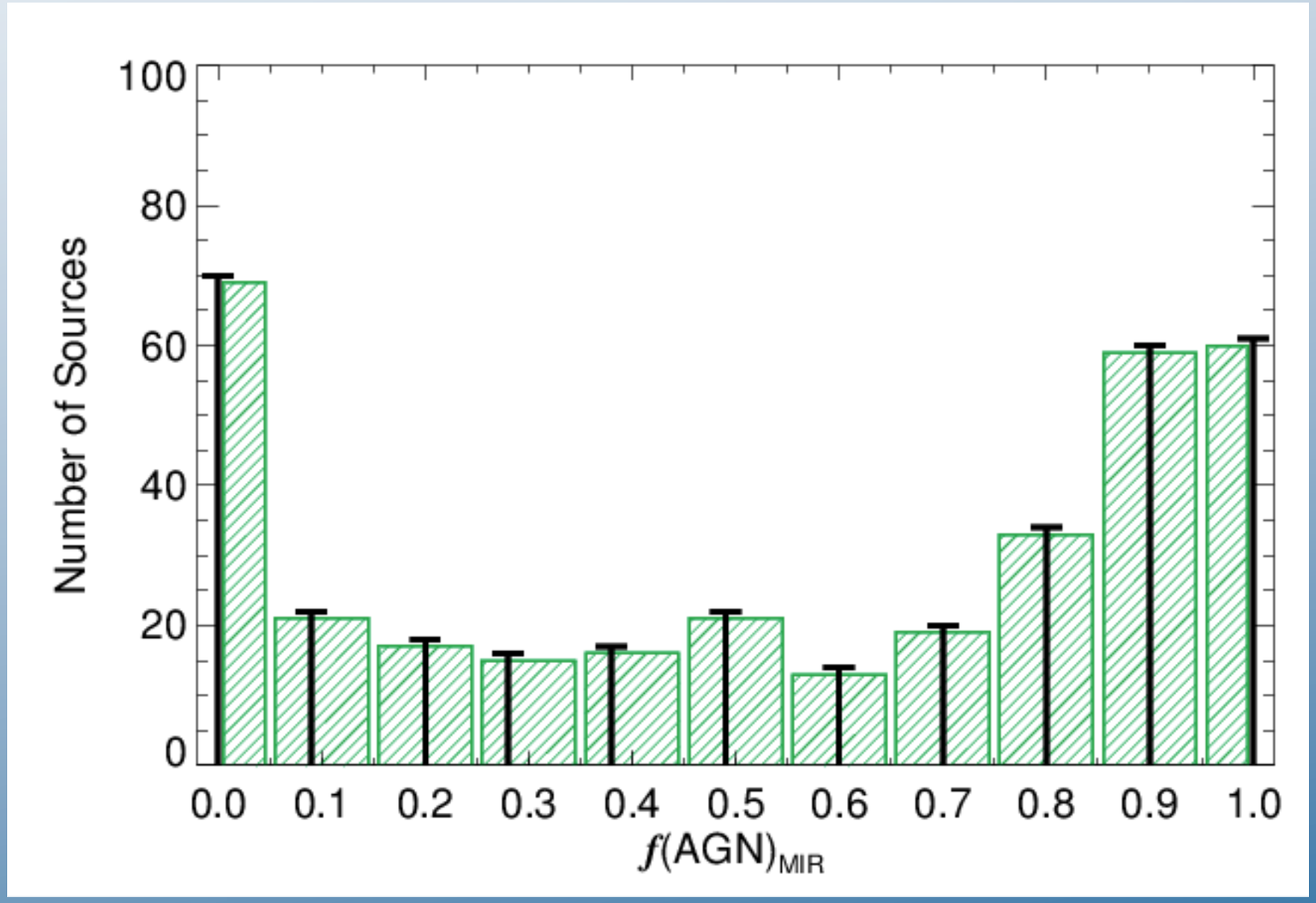
Further separate by luminosity and redshift

Three Template Libraries

Comprehensive Templates



MIR-Based Library



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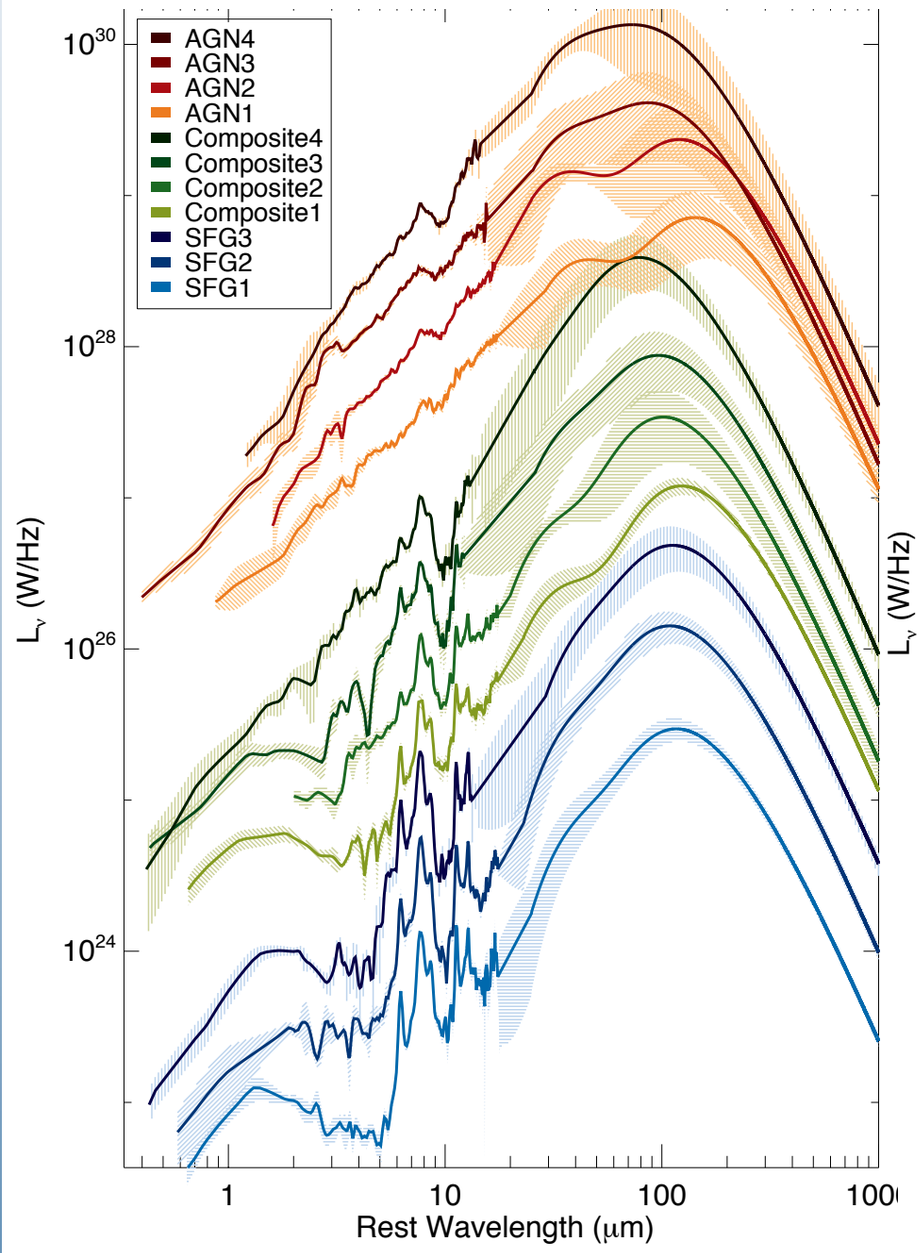
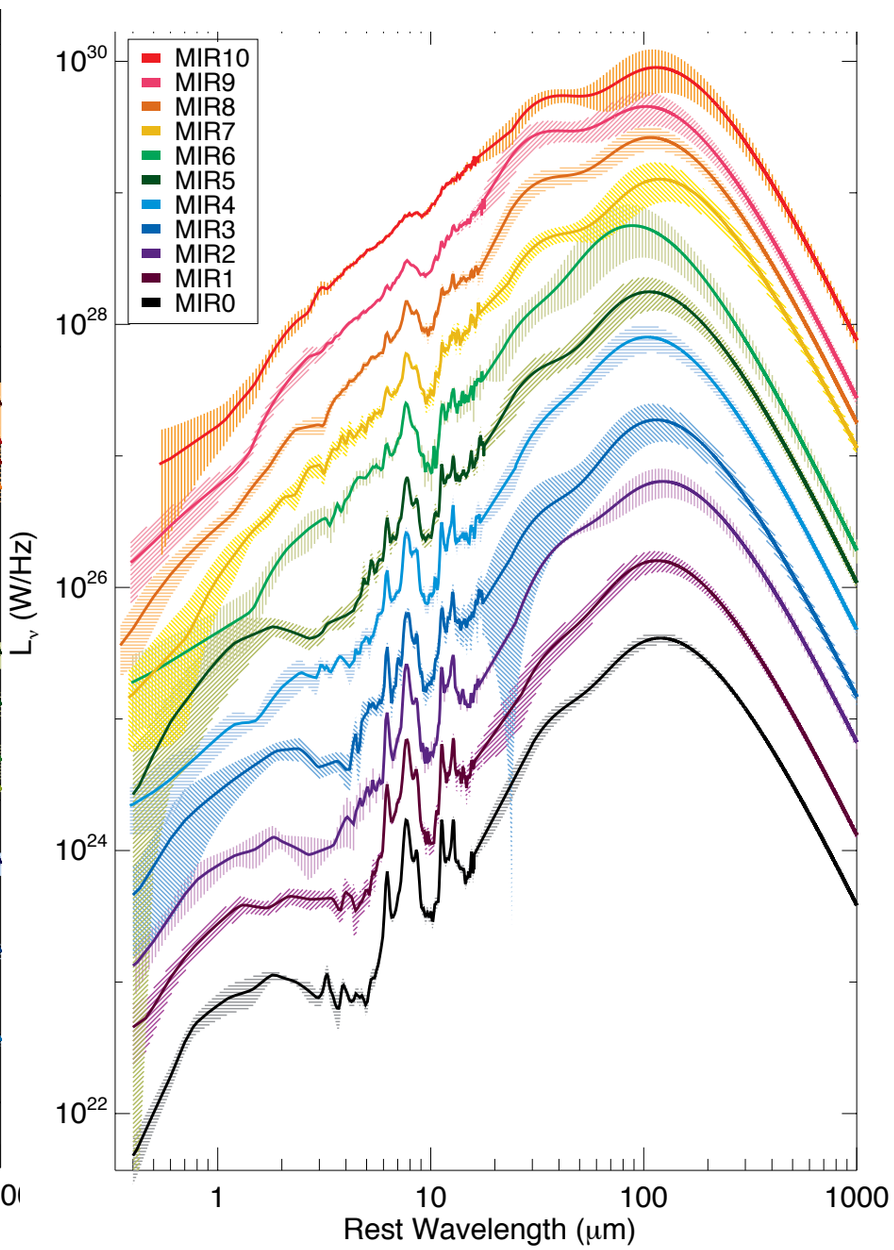
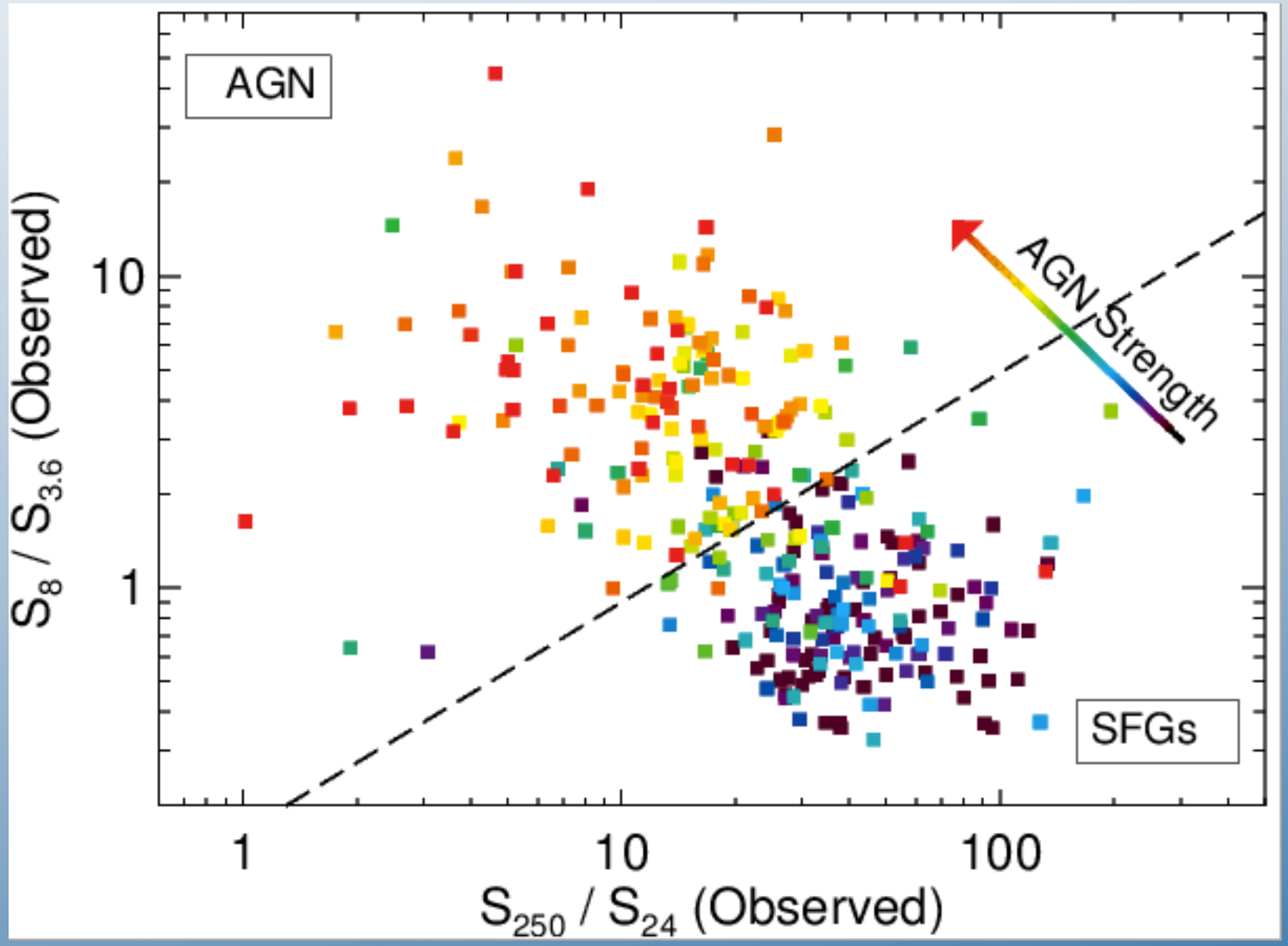


MIR-Based Templates



Color-Based Library



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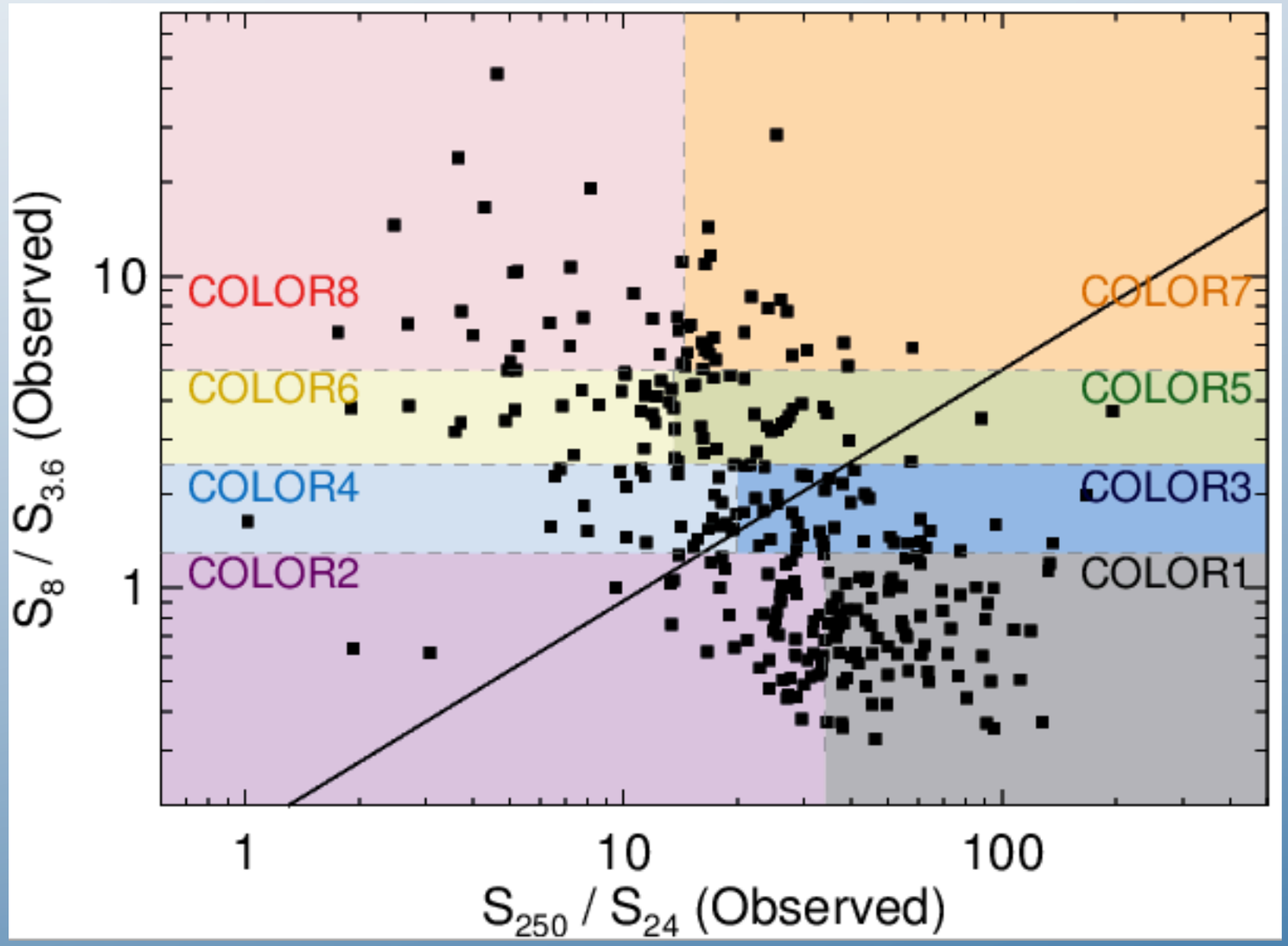

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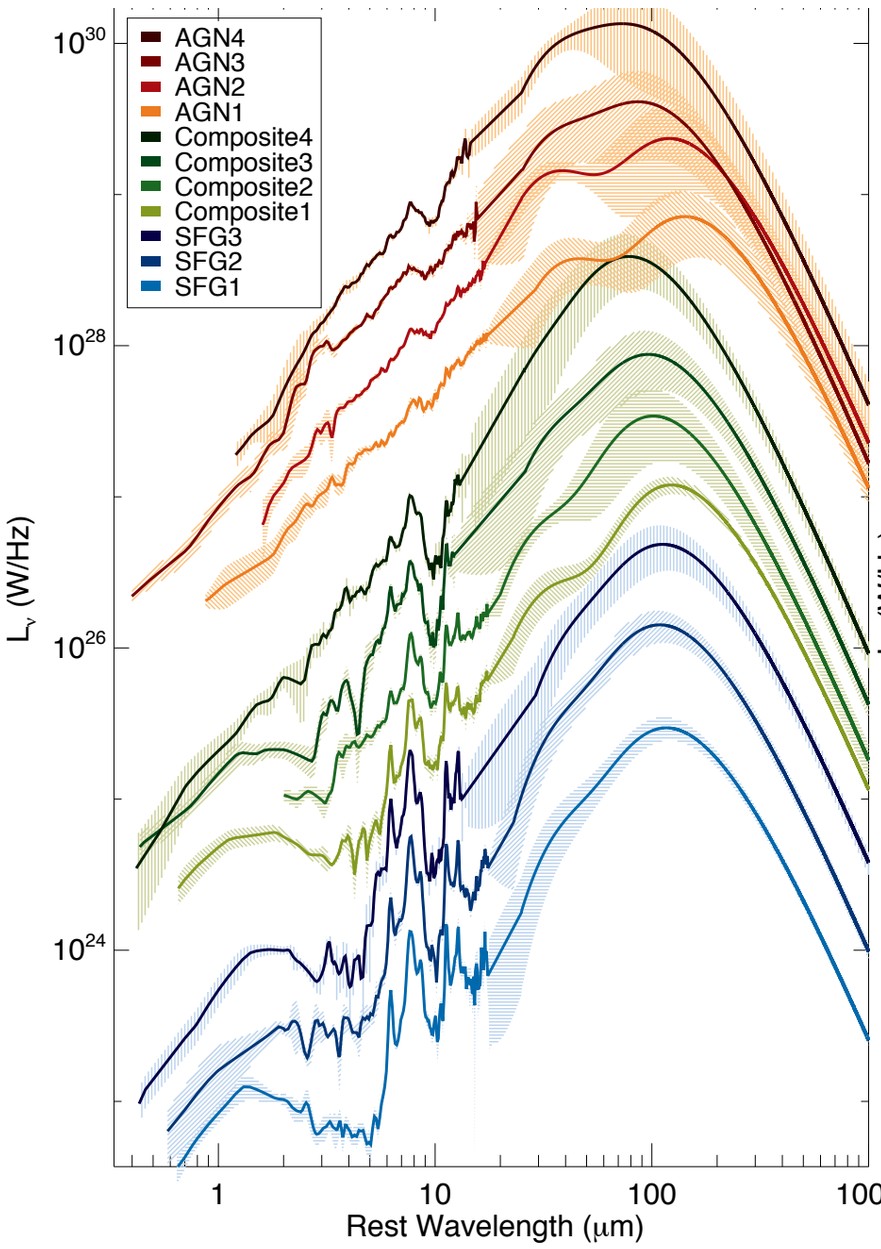

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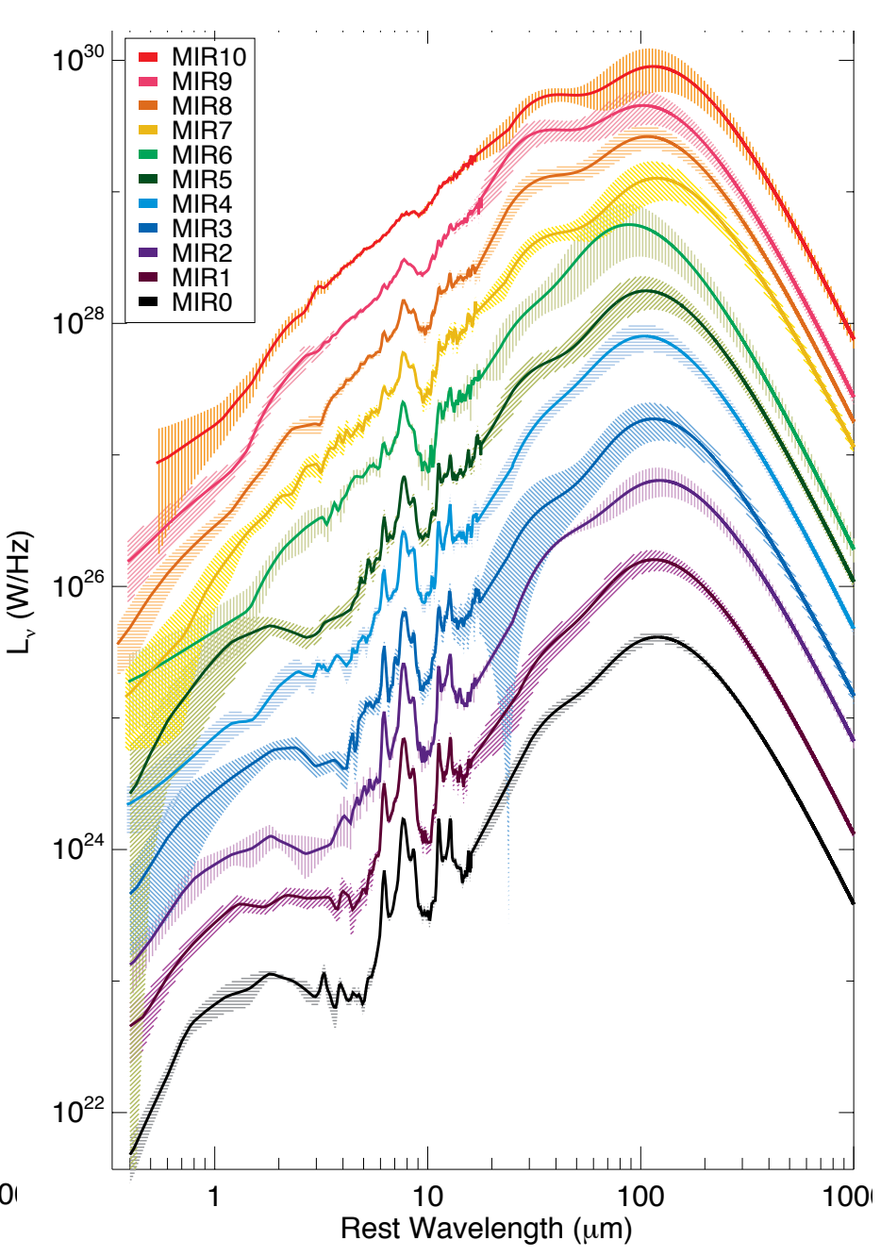

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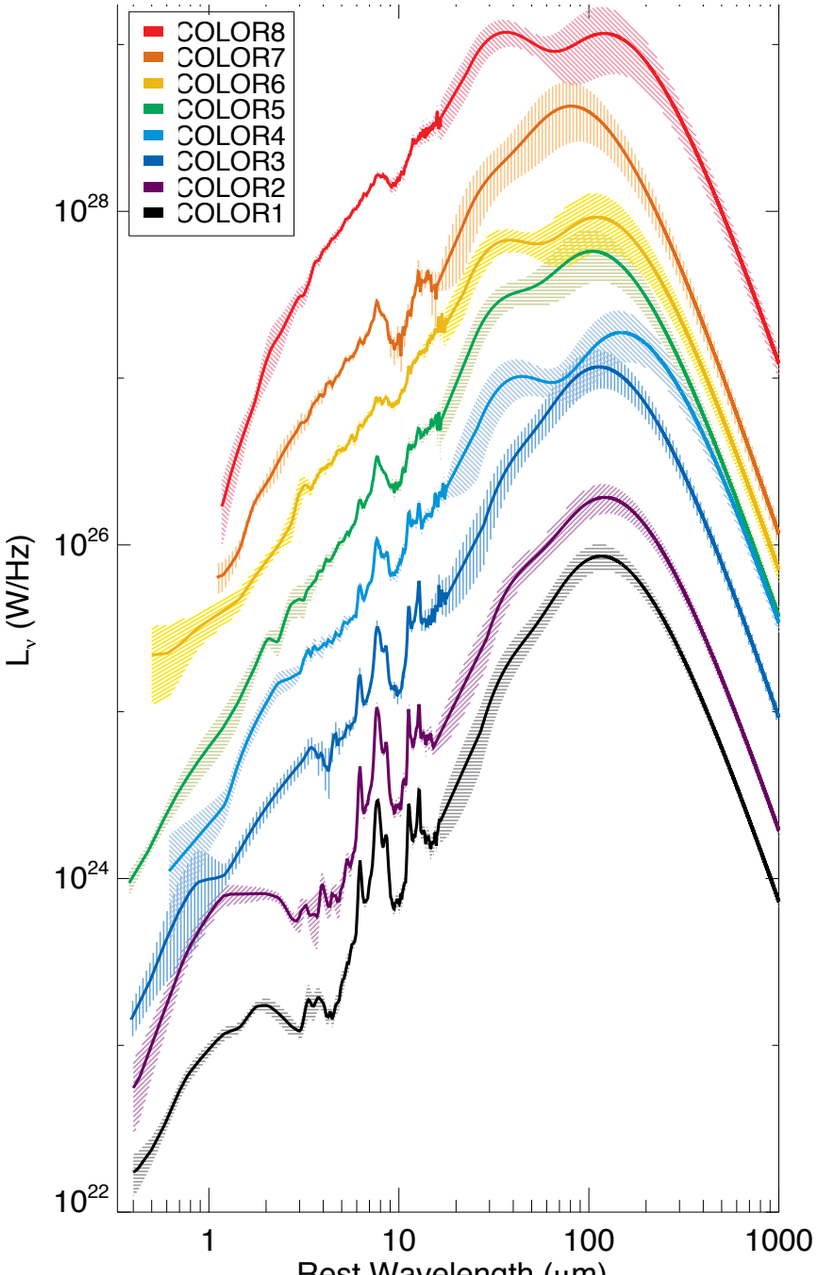
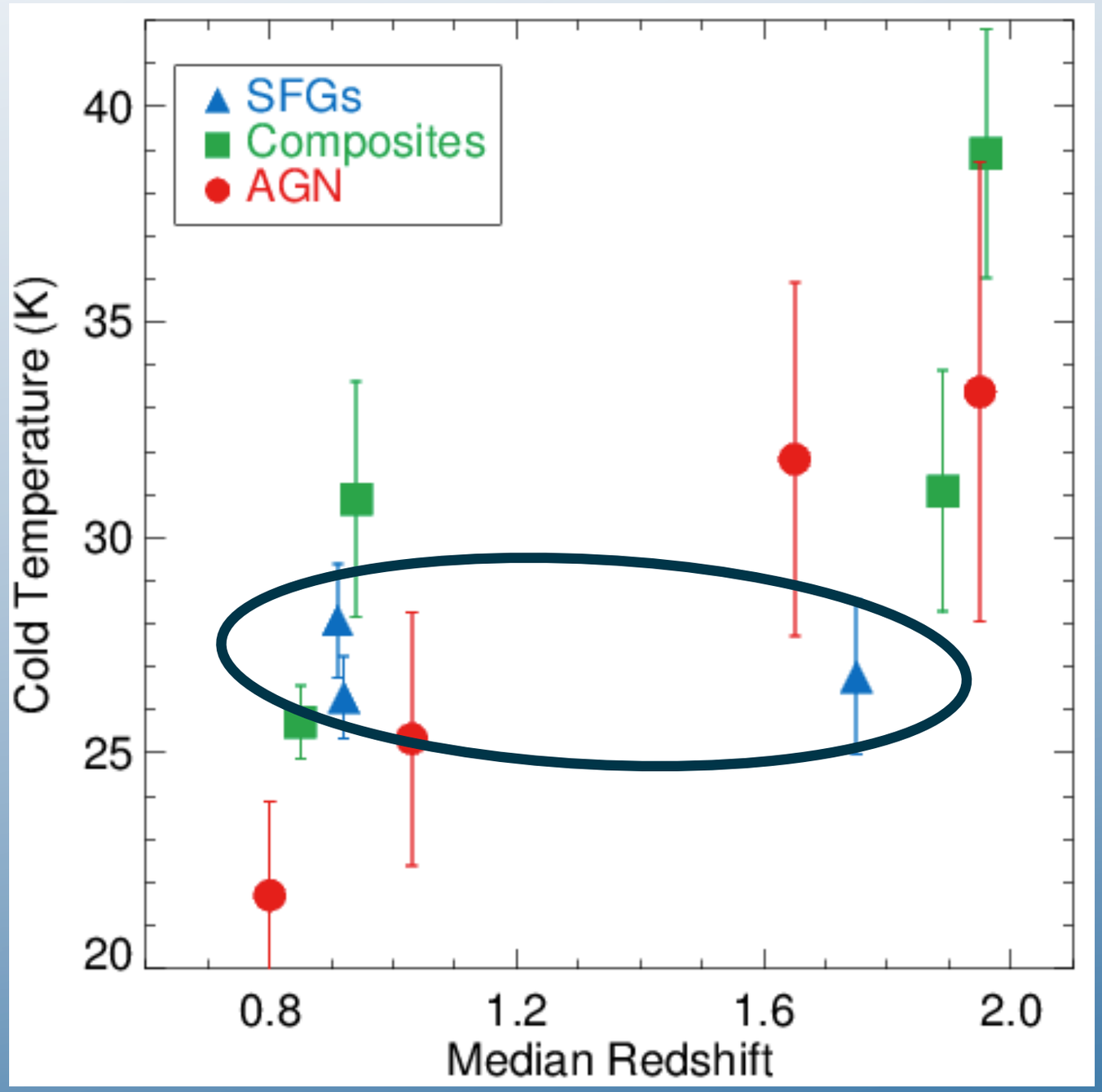
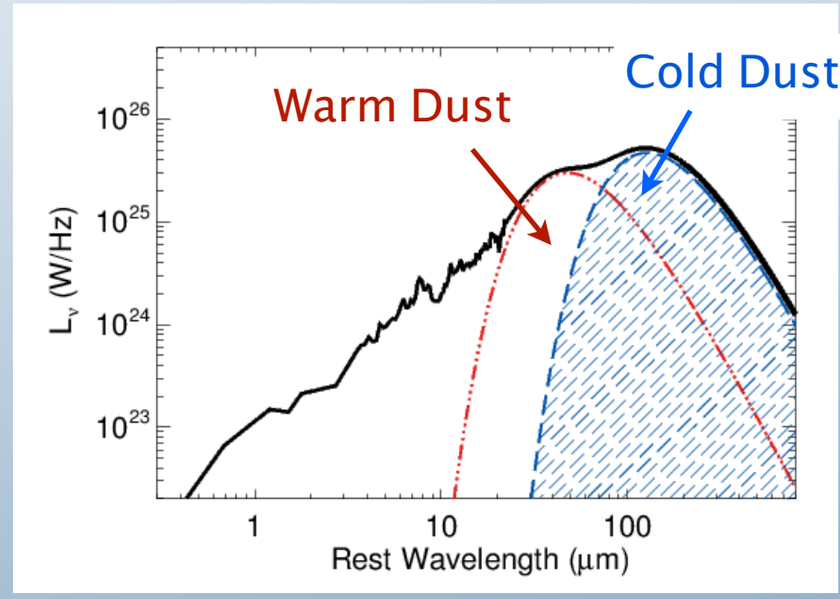


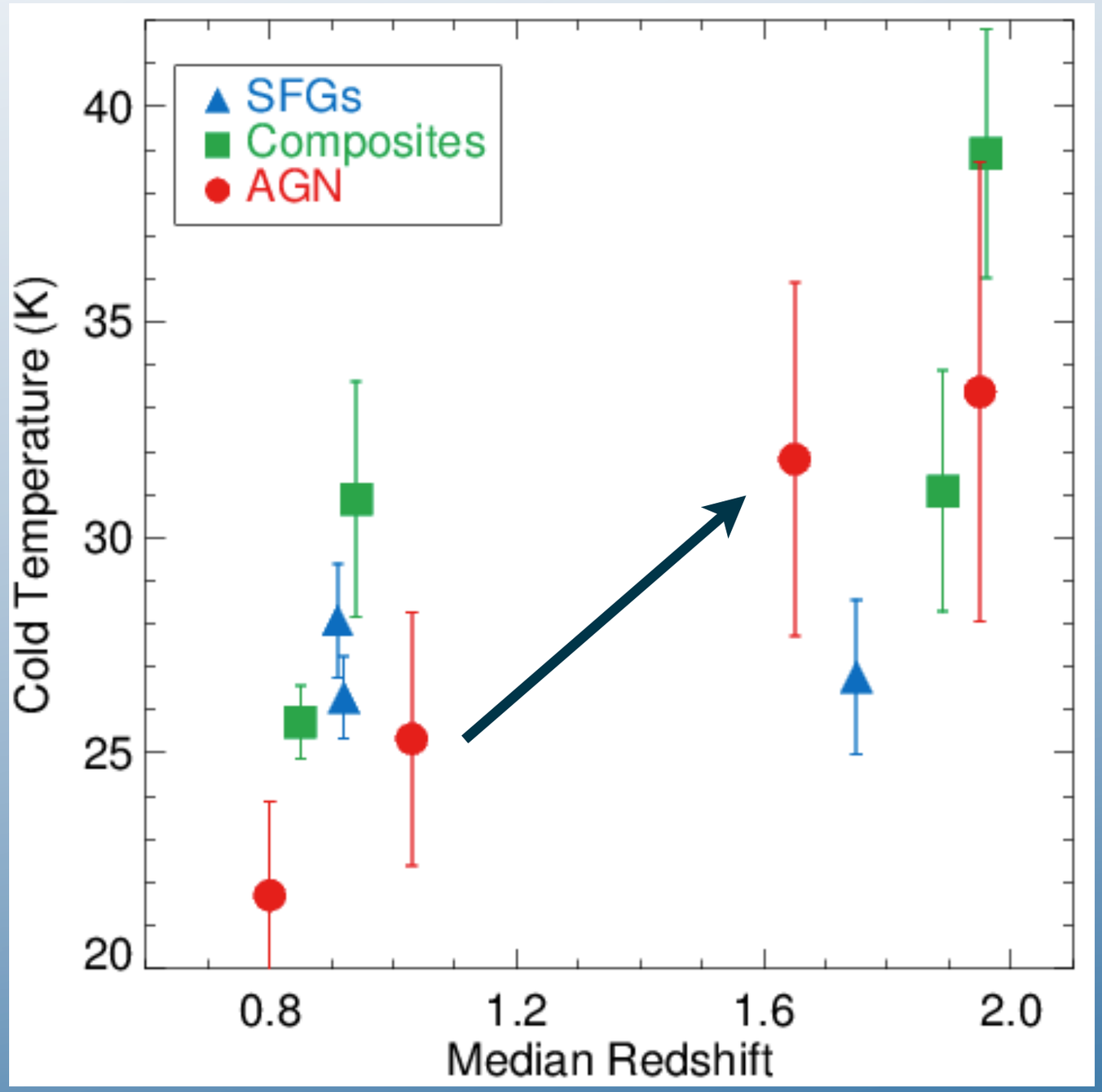
Dust Temperature

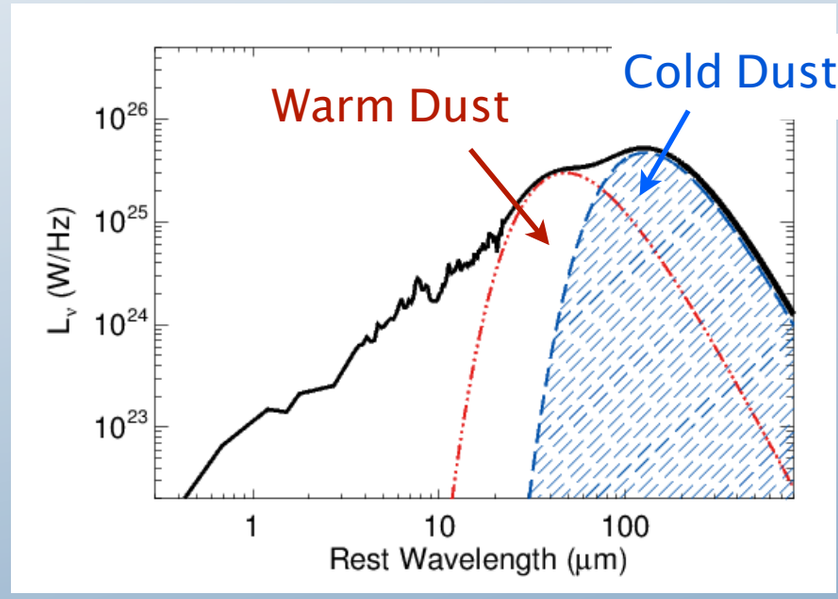




SFGs are remarkably consistent

Dust Temperature

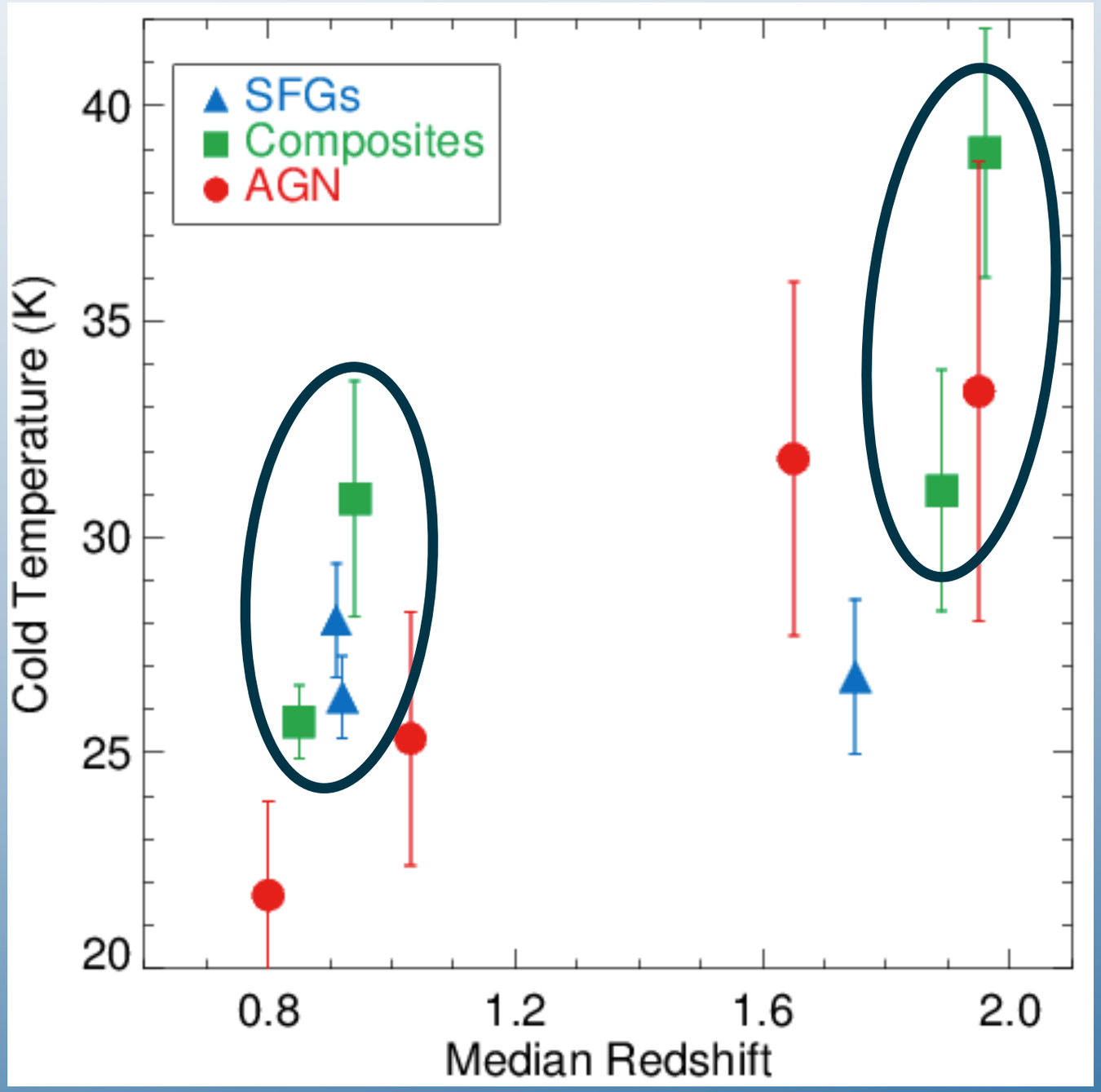


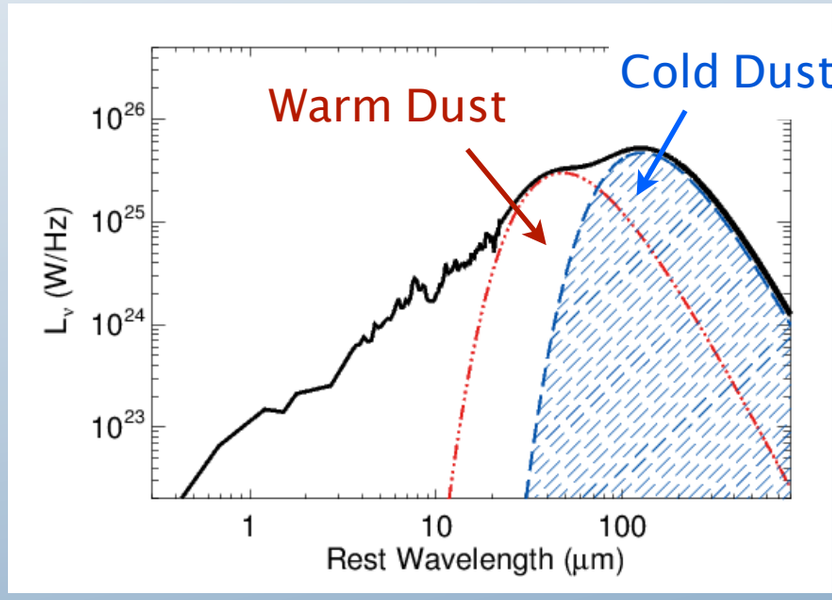


SFGs are remarkably consistent

Mild evolution in AGN with redshift

Dust Temperature



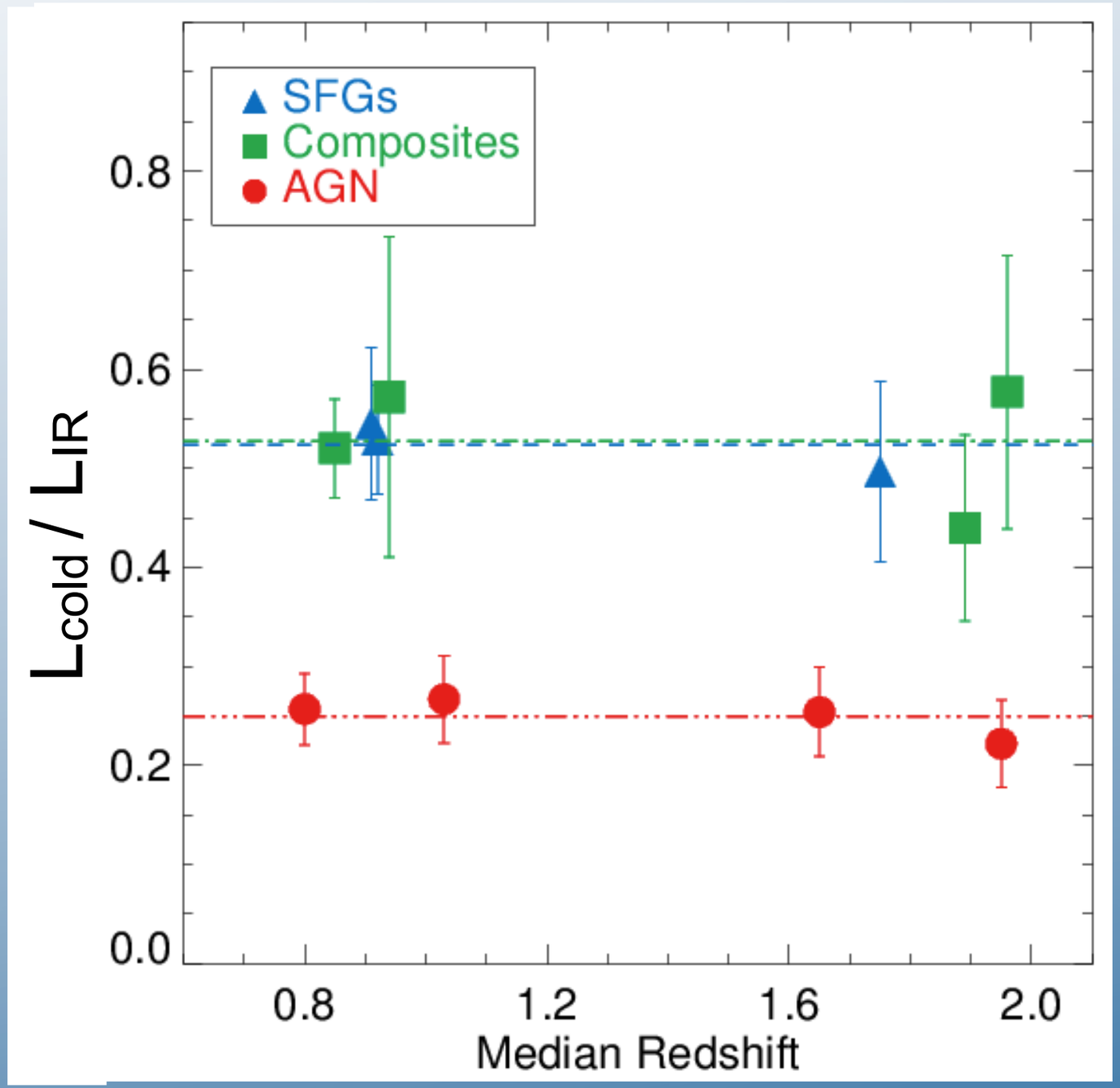


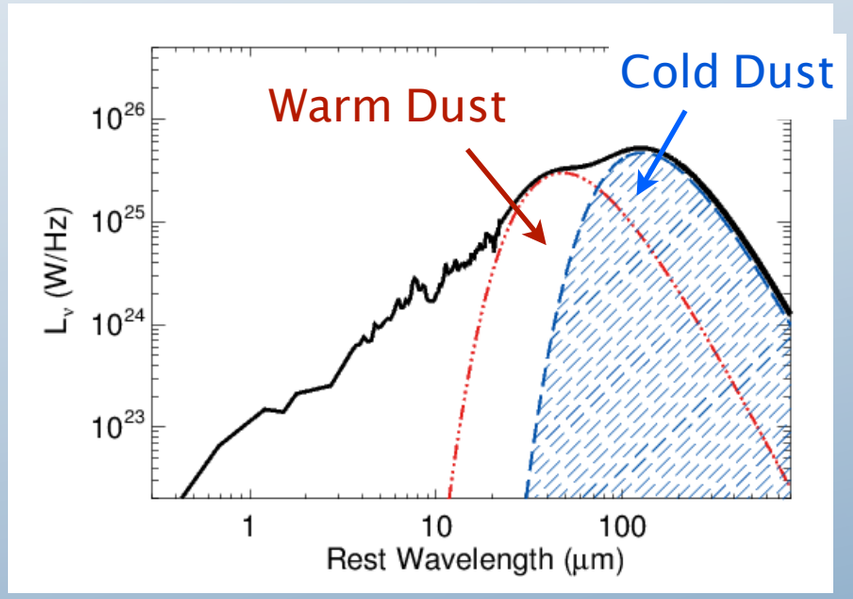
SFGs are remarkably consistent

Mild evolution in AGN with redshift

Composite dust emission changes with luminosity

Host Emission

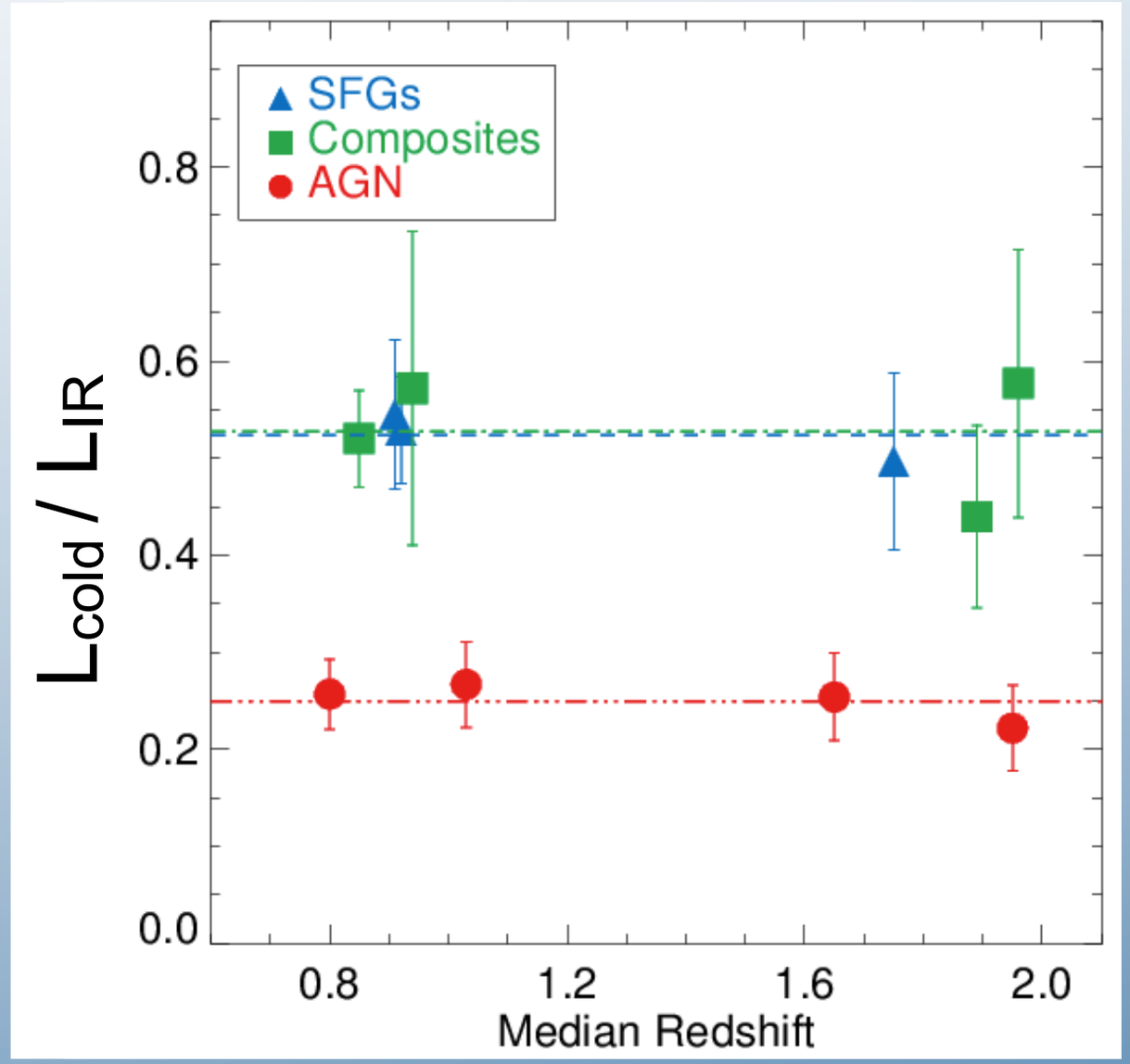


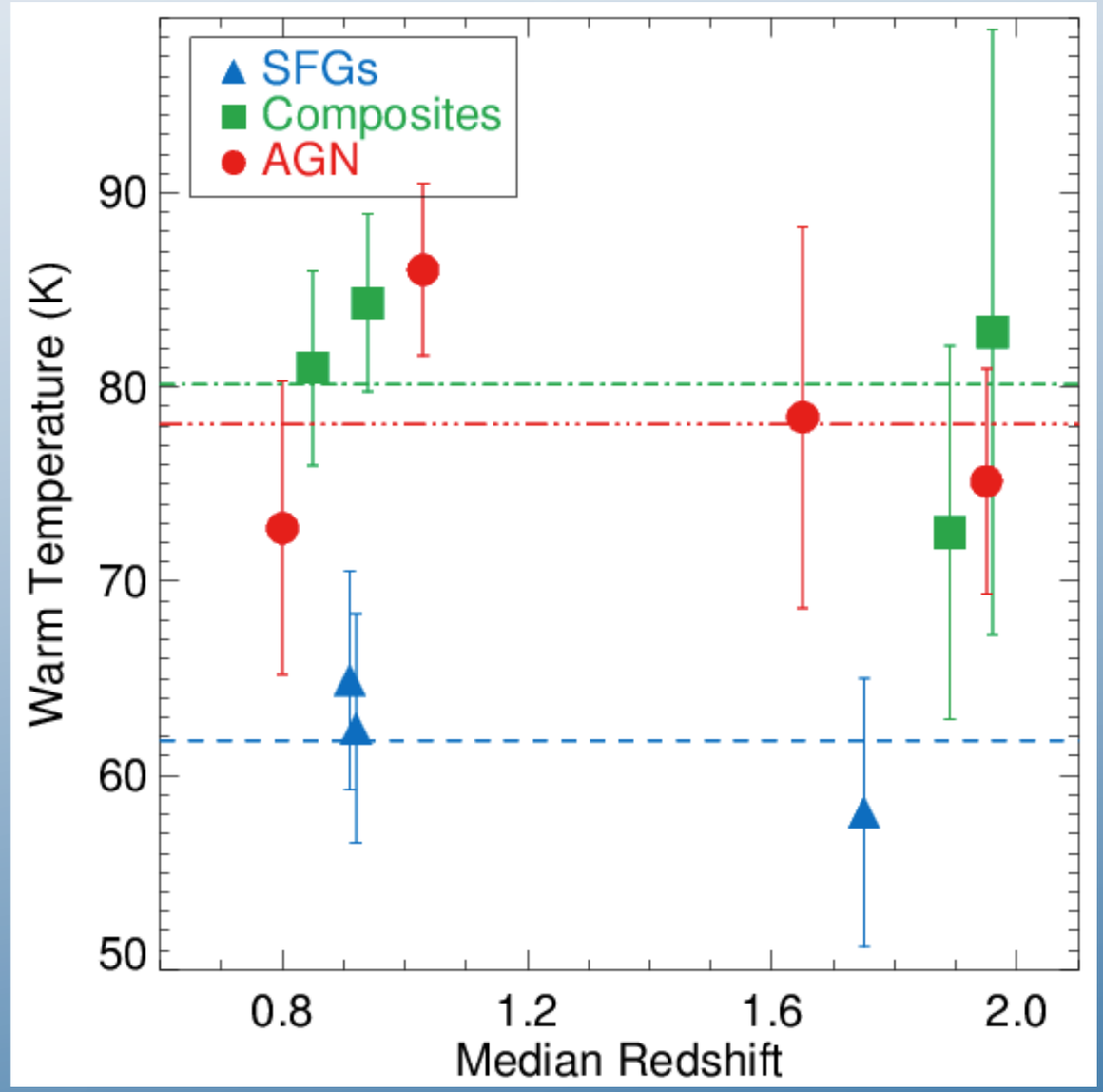


IR emission of SFGs and Composites is dominated by the host galaxy

In AGN, more of the L_{IR} comes from warmer dust heated by the AGN

Dust Heating

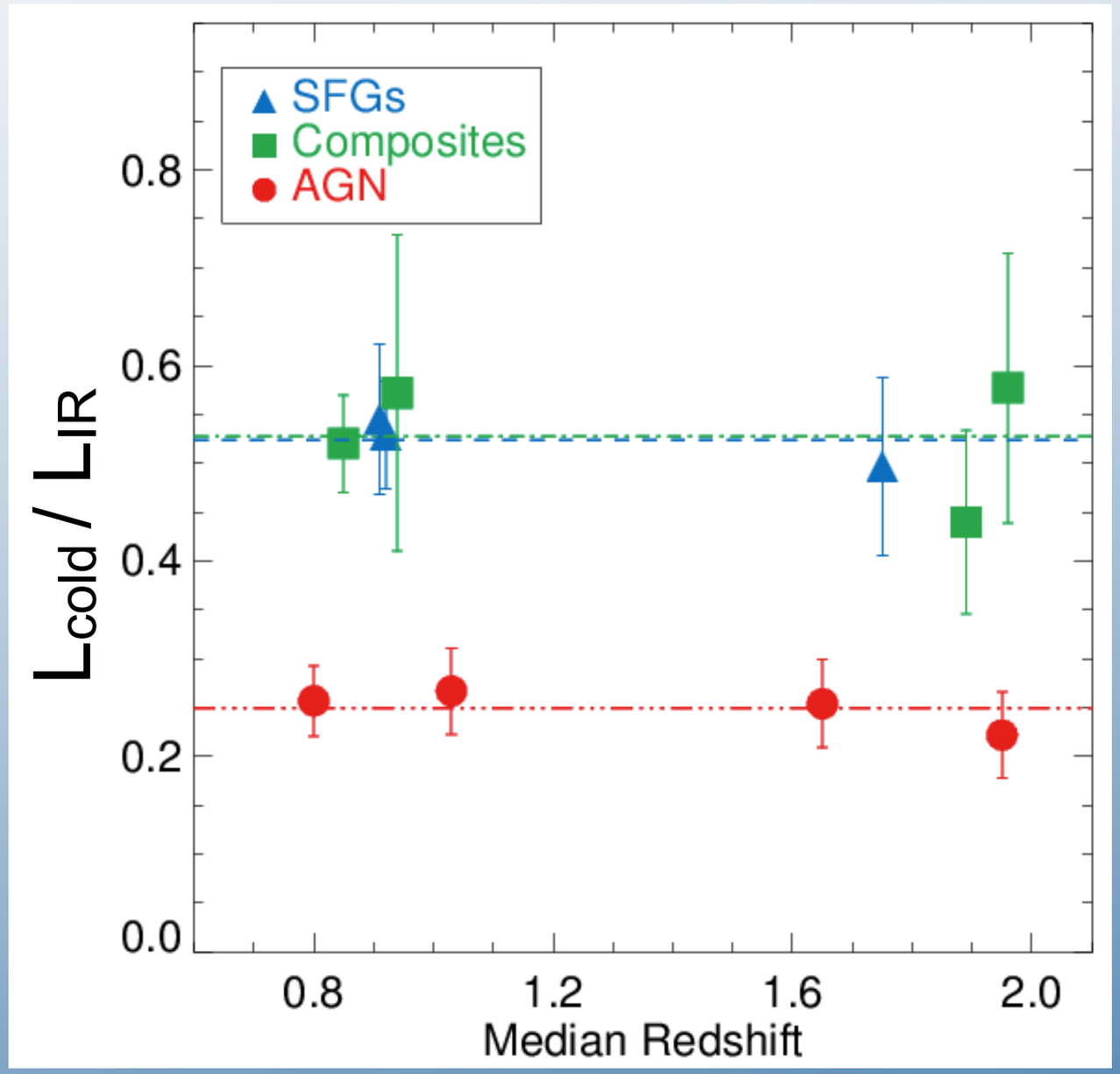


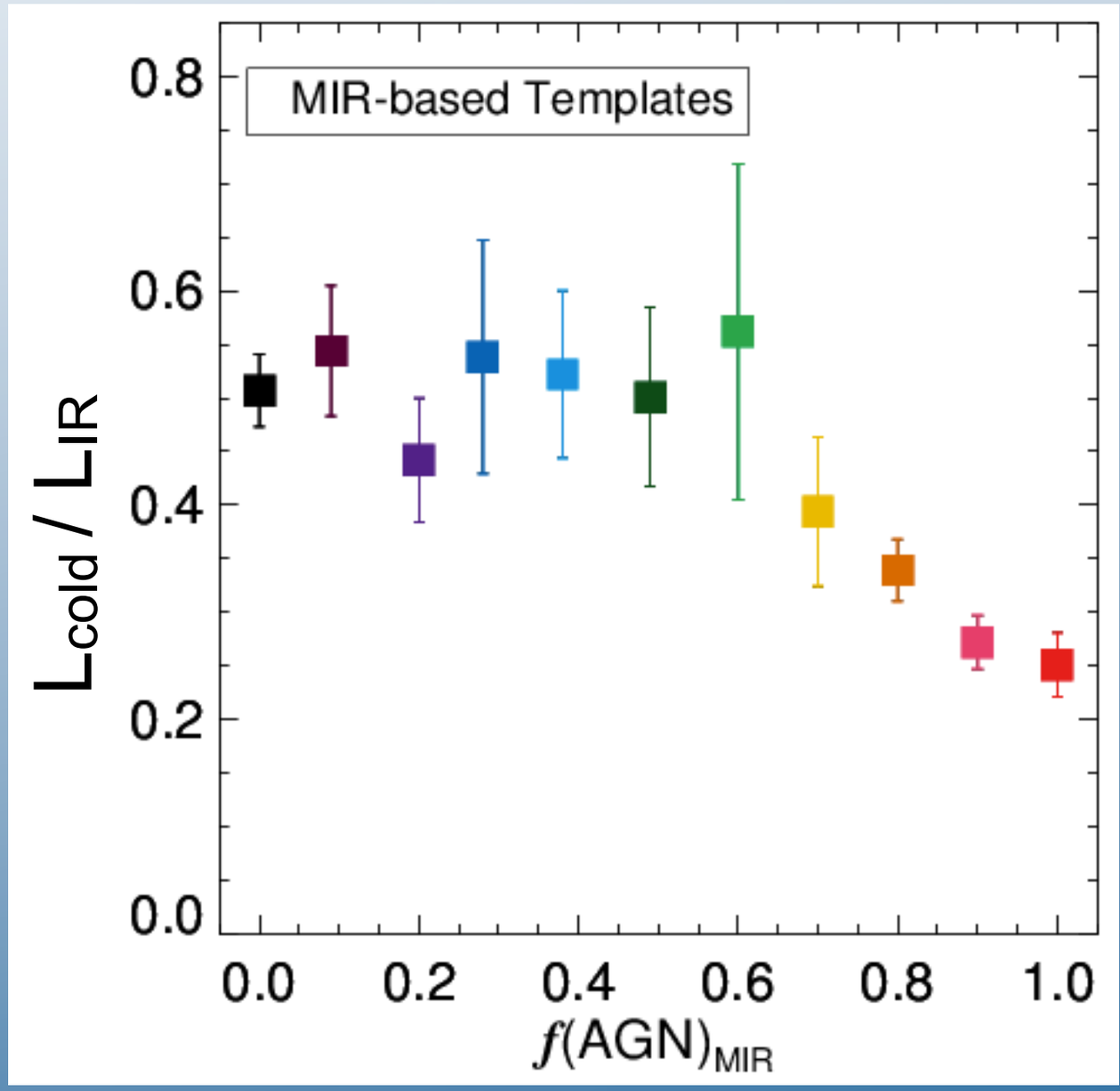


SFGs & Composites:
same amount of extended dust

AGN & Composites:
same dust heating source

AGN Effect on Host

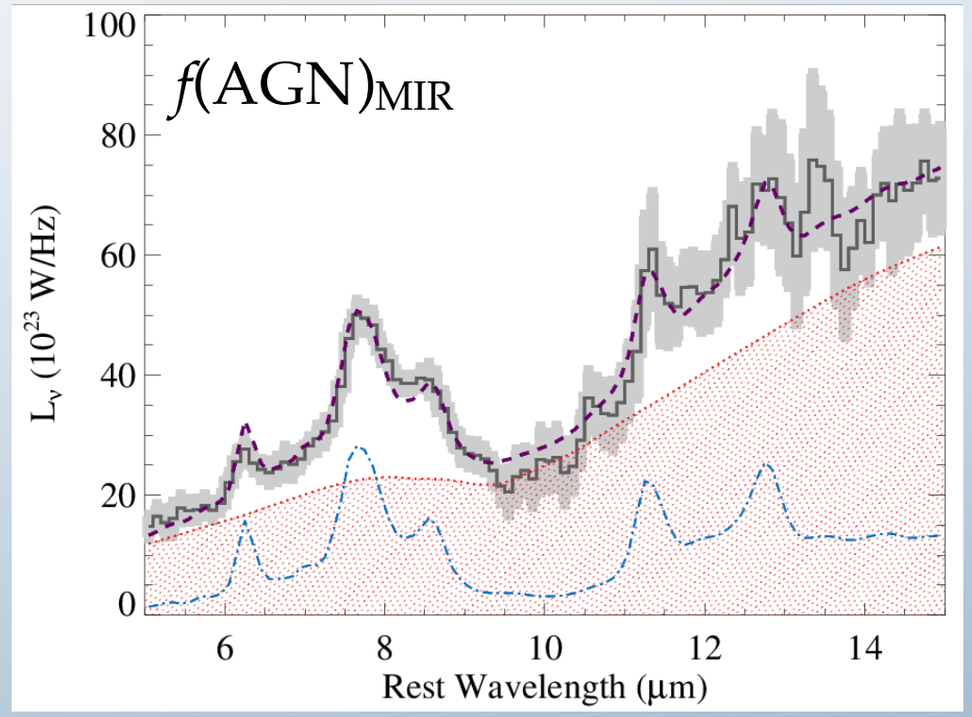


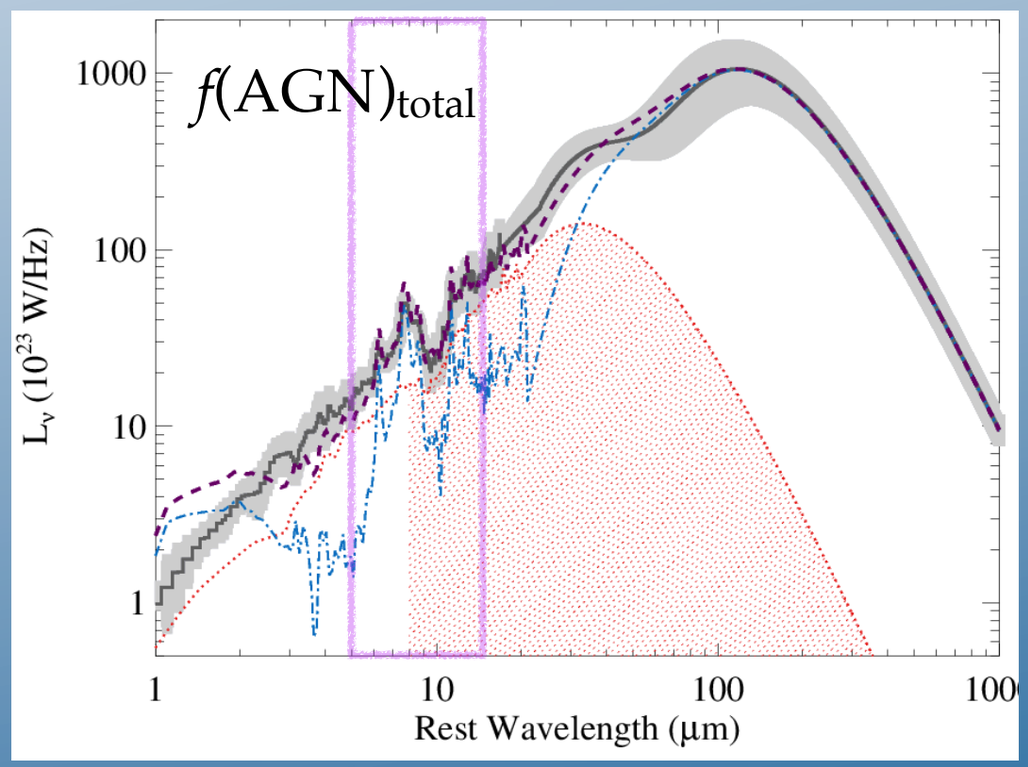


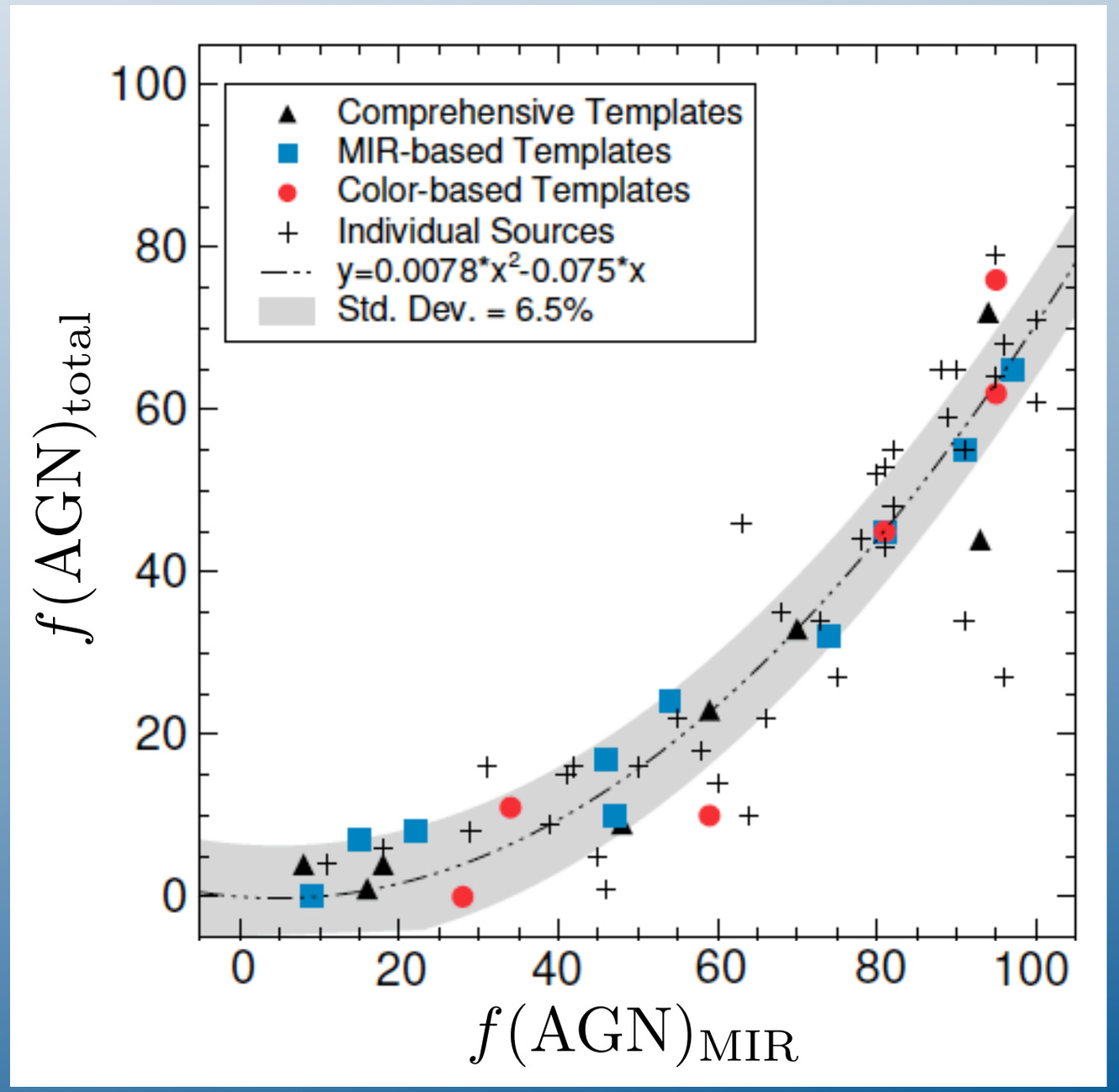
Warm dust does not outshine cold dust until

$f(\mathrm{AGN})_{\mathrm{MIR}} > 0.5$

MIR v. Total AGN







Summary

Technique

Classify high redshift (z = 0.2 - 4) galaxies as AGN by decomposing mid-IR spectra

Create empirical templates spanning λ=0.5-1000 μm

1) Comprehensive Library: $f(\mathrm{AGN})_{\mathrm{MIR}}$, L_{IR}, and redshift
2) MIR-based Library: $f(\mathrm{AGN})_{\mathrm{MIR}}$
3) Color-based Library: S_{250}/S_{24} v. $S_8/S_{3.6}$

Conclusions

SFGs in the early Universe are remarkably consistent

SFGs and Composites have the same relative amount of cold dust emission visible

AGN and Composites have the same heating source for the warm dust

Relationship between MIR and total AGN contribution is non-linear

Templates will be made publicly available later this year.

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