

# Probing the submm-luminous phase of galaxy evolution with Spitzer IRS

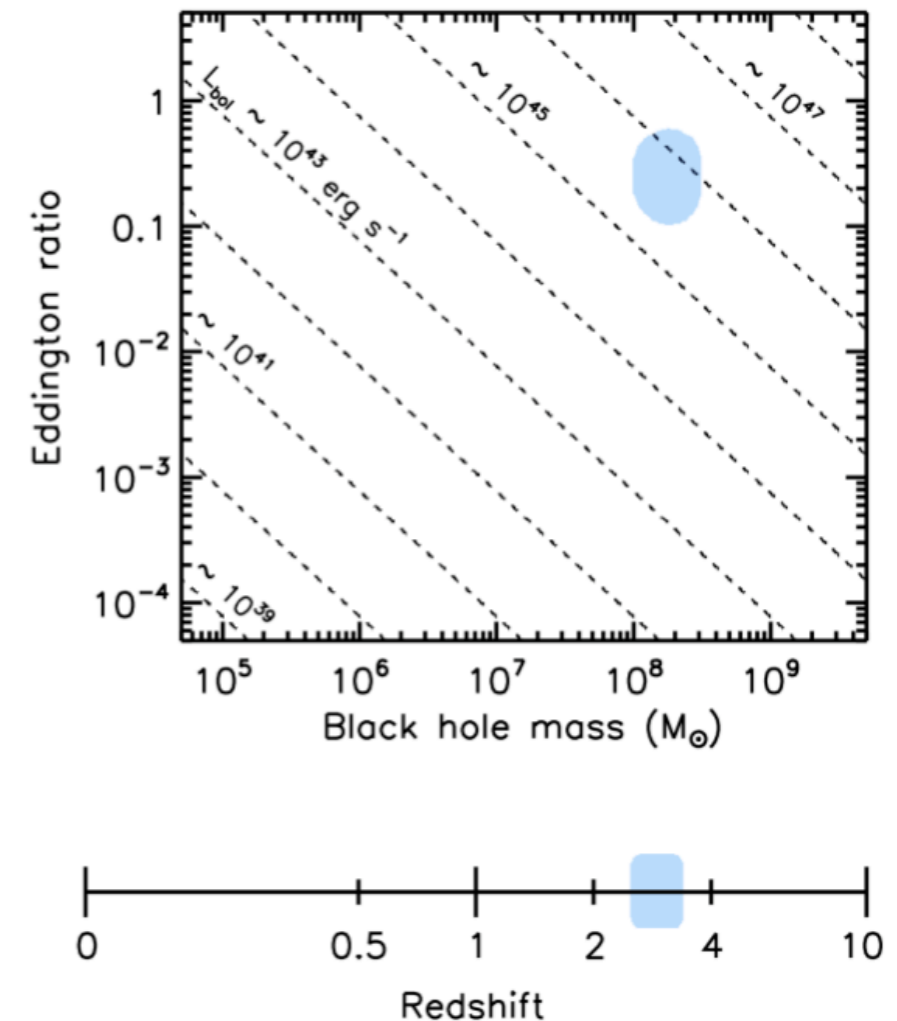


Kristen Coppin  
STFC fellow, Durham

Collaborators: Alex Pope, Karin Menendez-Delmestre, Dave Alexander, Jim Dunlop, Ian Smail et al.

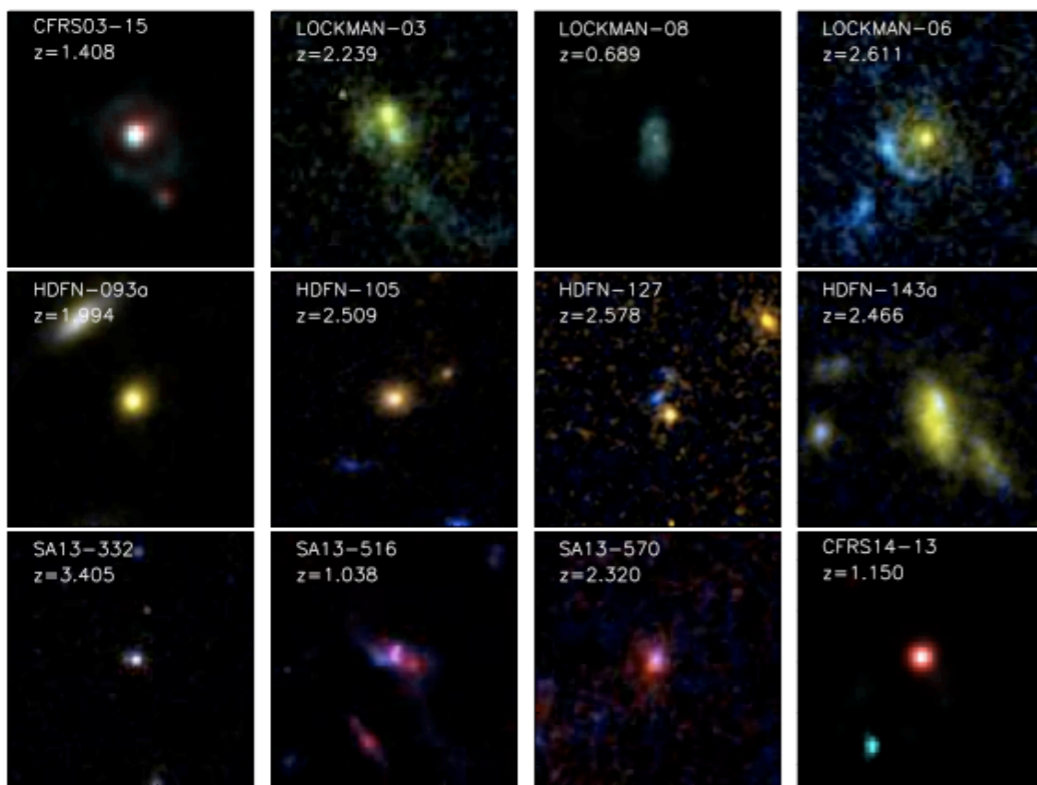
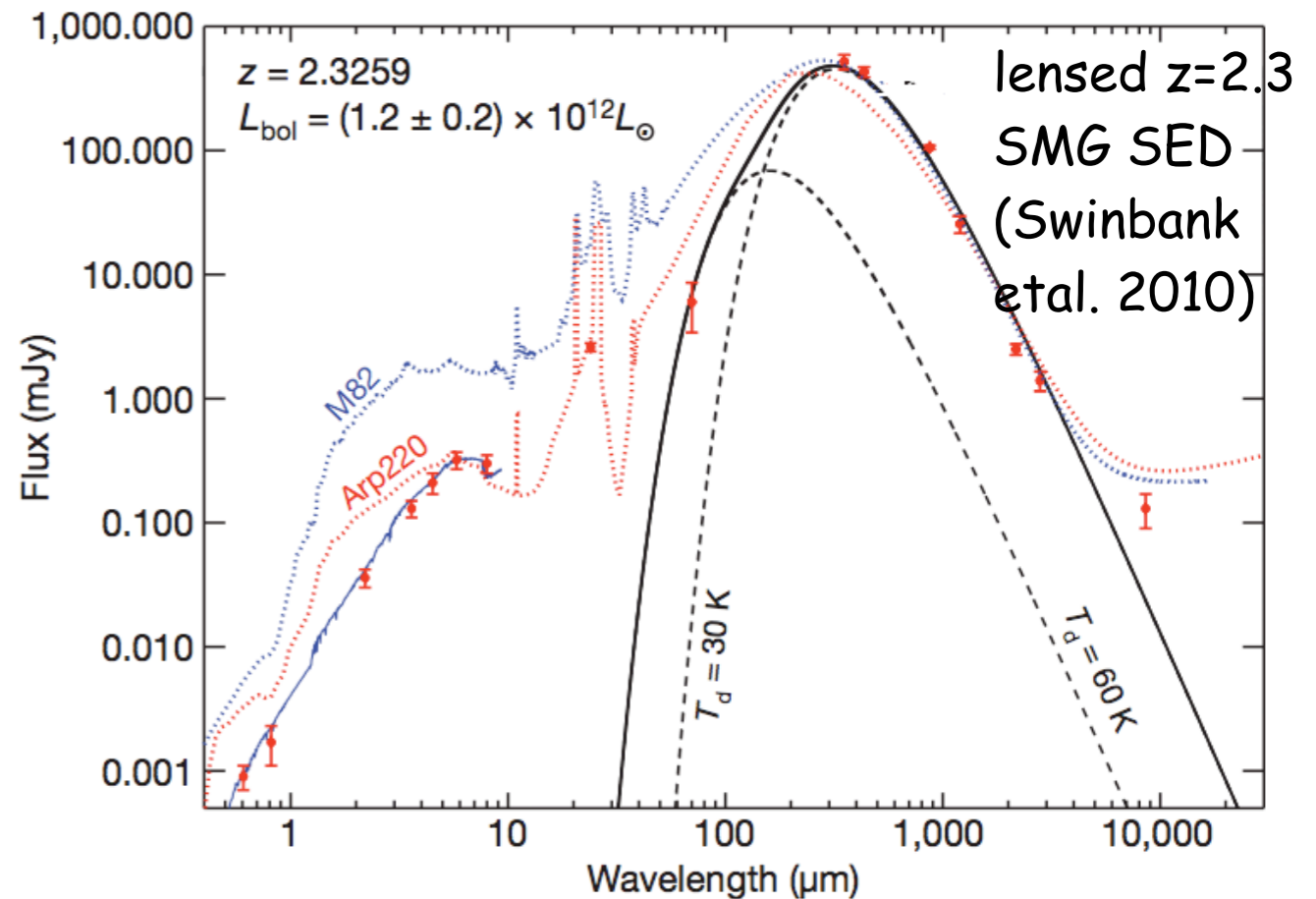
# Talk Outline

- Background:
  - Primer on Submillimetre Galaxies (SMGs)
  - Why am I giving an SMG talk at the growth of black holes workshop?
- Experiment & Results
  - Probing the Sanders et al. evolutionary sequence at high-redshift by honing in on "transition sources"
  - Disentangling relative SF and AGN activity using the Spitzer-IR Spectrograph
  - What did we learn?
- Brief Summary
  - KEY take home point



# What are Submillimetre Galaxies (SMGs)?

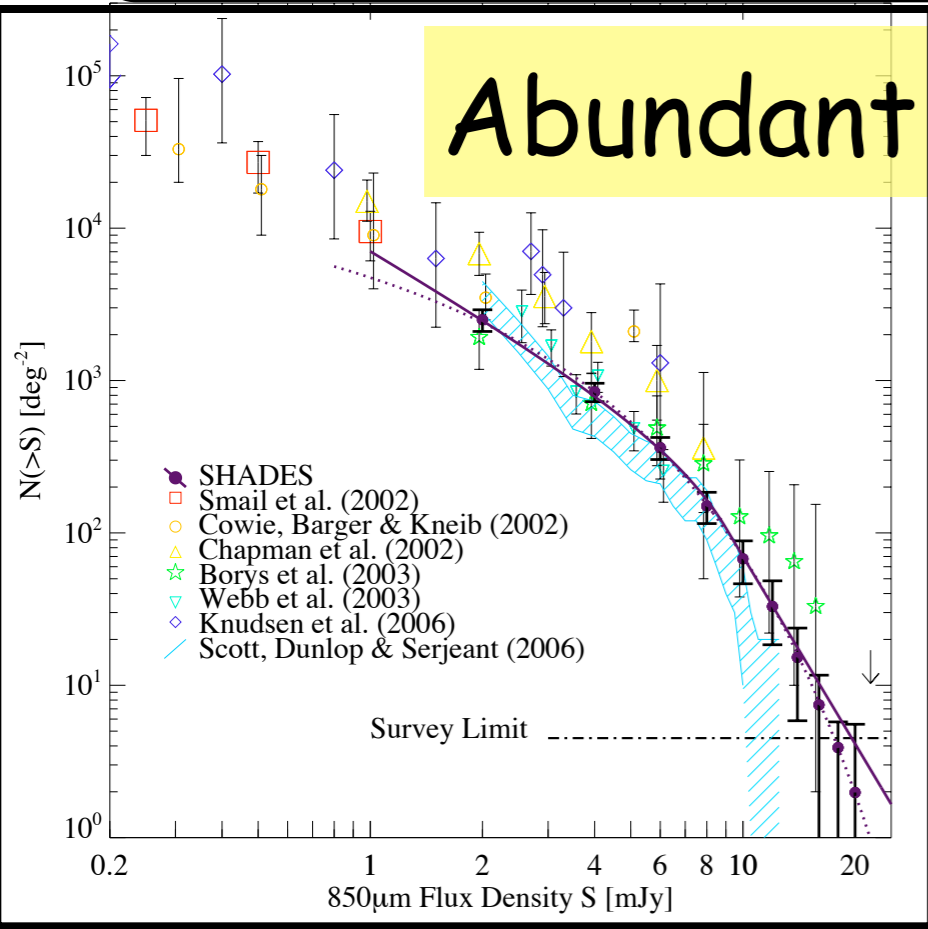
- Dusty star-forming galaxies at  $z \sim 2-3$
- $SFR \sim 100-1000 M_{\text{sun}}/\text{yr}$   
(100-1000x that of Milky Way!)



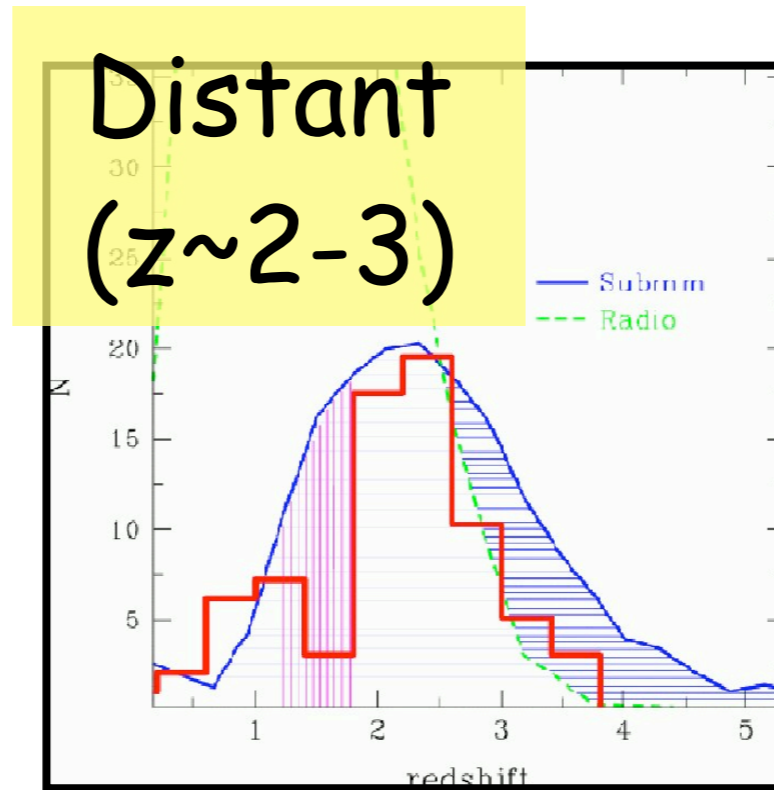
HST IH-band images of SMGs (Swinbank et al. 2010) show a mix of morphologies - mergers? Cousins of local ULIRGs?



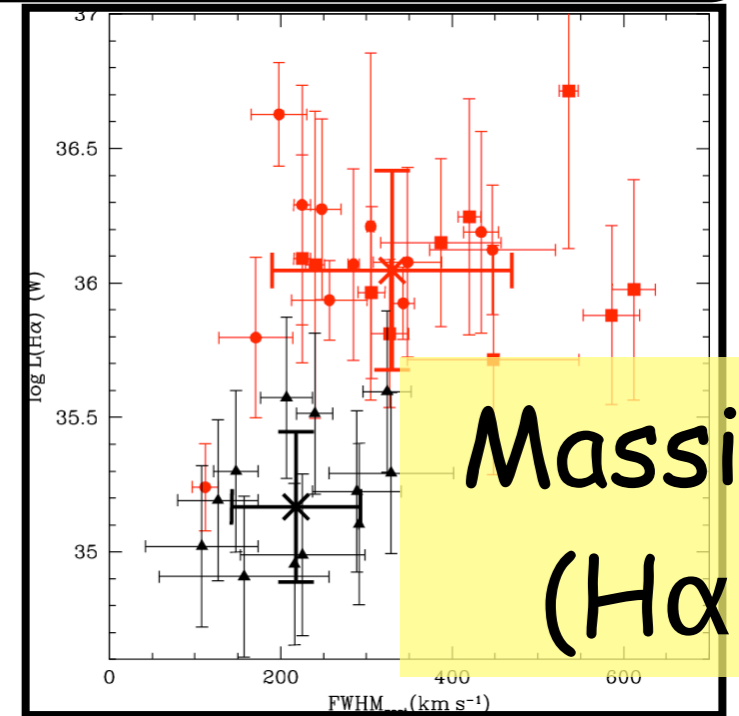
# SMGs: ancestors of massive ellipticals?



Coppin et al. (2006)

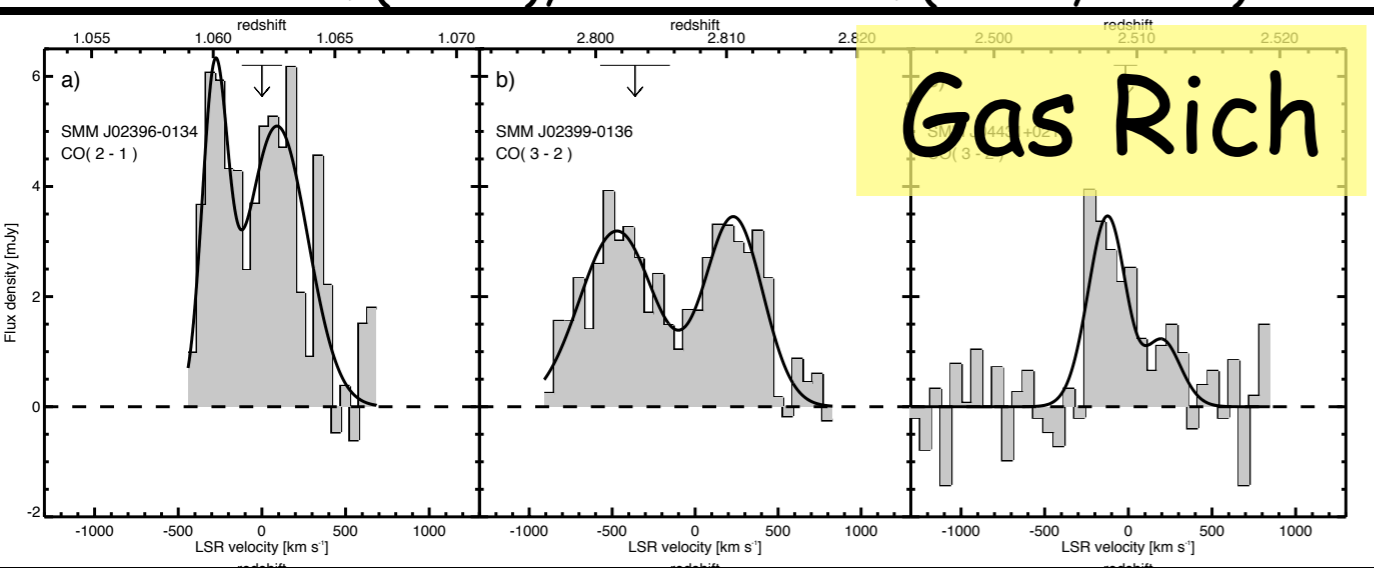


Chapman et al. (2003, 2005)



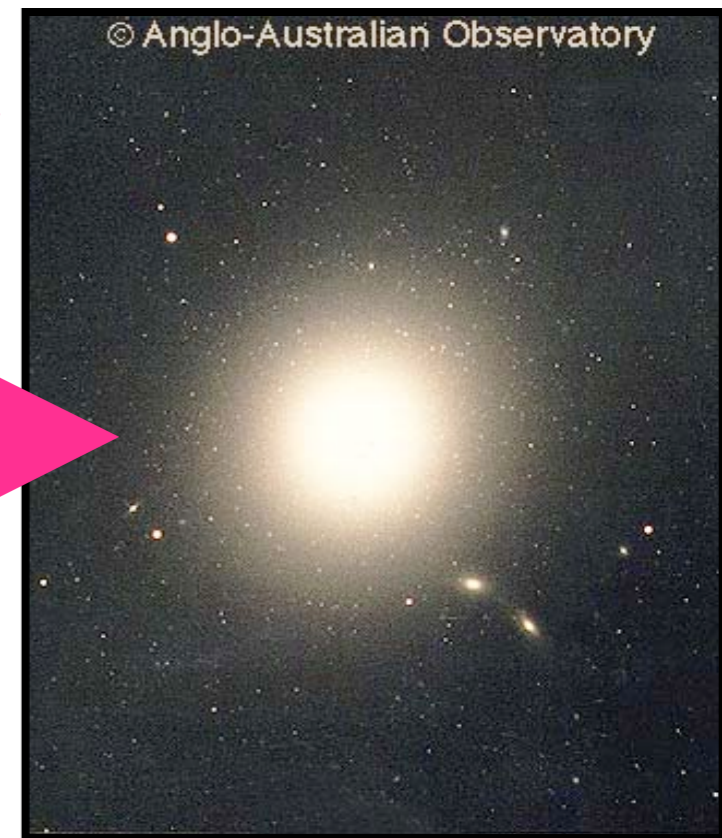
Swinbank et al. (2004)

Greve et al. (2005), Tacconi et al. (2006, 2008)



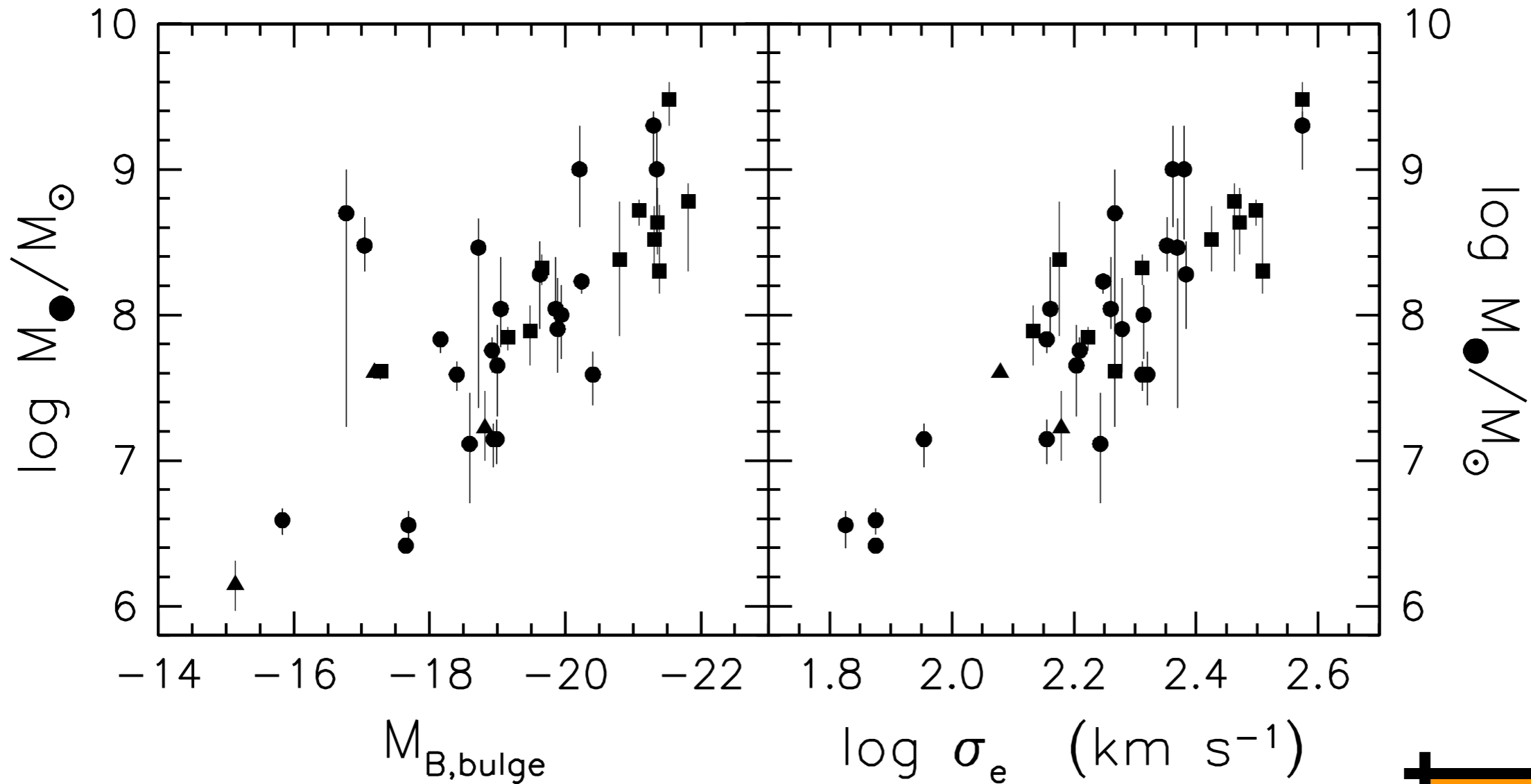
Progenitors of today's

massive galaxies?



# BH growth & galaxy formation are related

Action: AGN activity



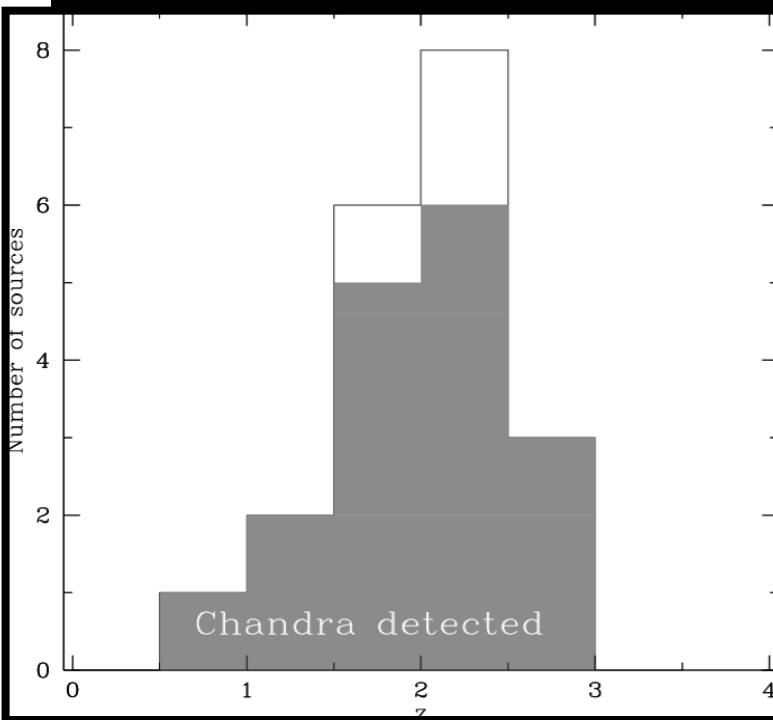
Action: Star formation

Magorrian relation

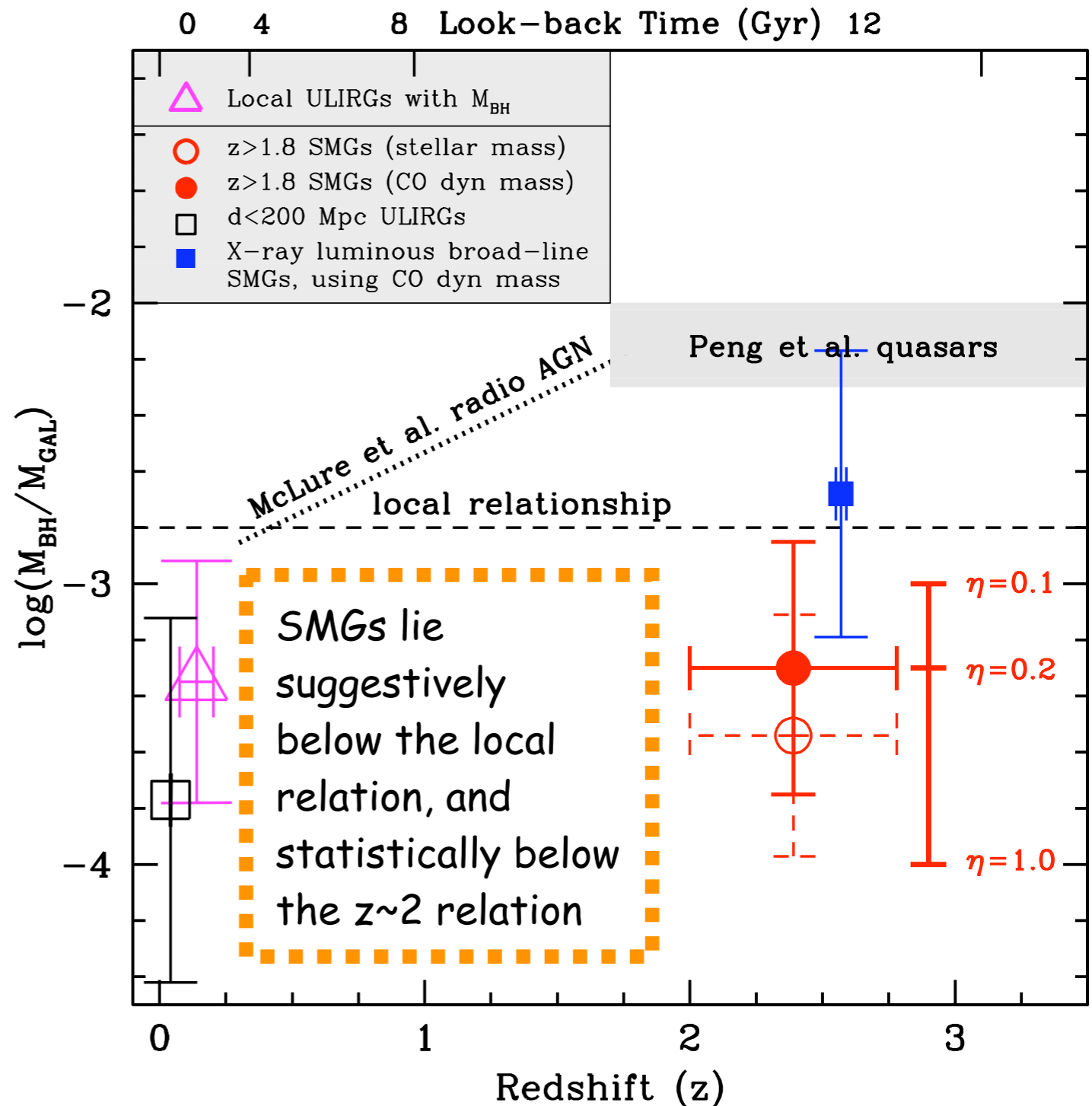
# SMGs: evidence for BH growth?

• ~30-50% of SMGs host AGNs --> indicates a long (almost continuous) BH growth during an intense SF episode (Niel Brandt's talk yesterday)

2Ms Chandra (CDF-N/GOODS-N)



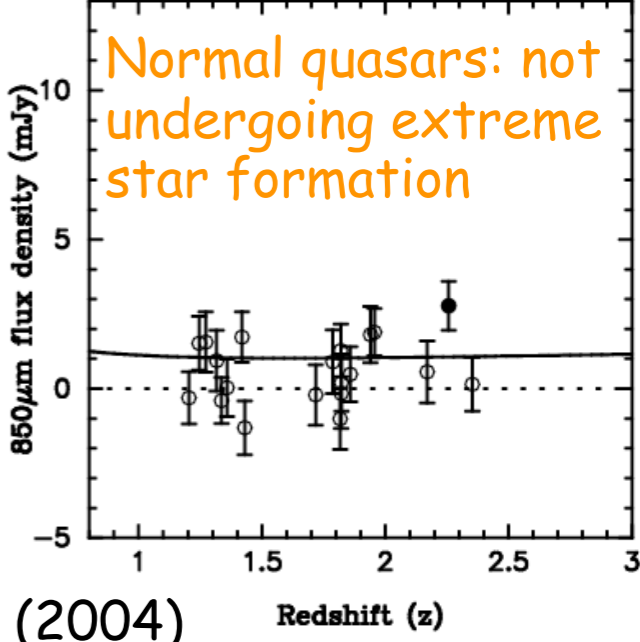
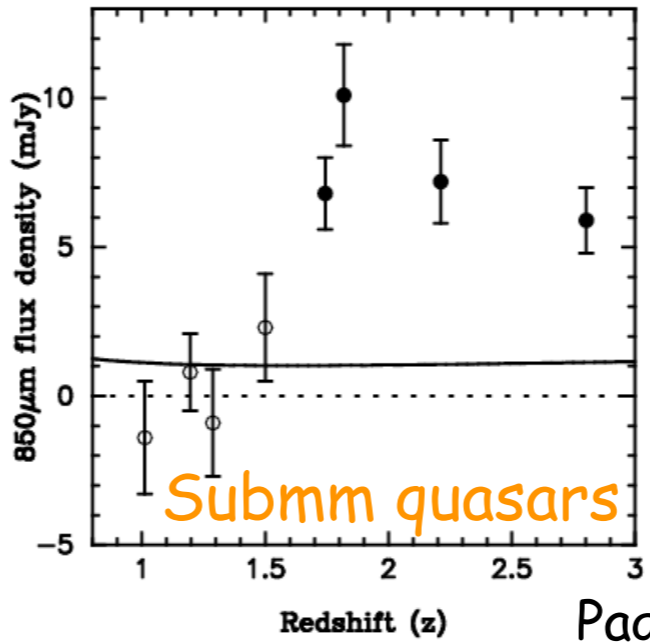
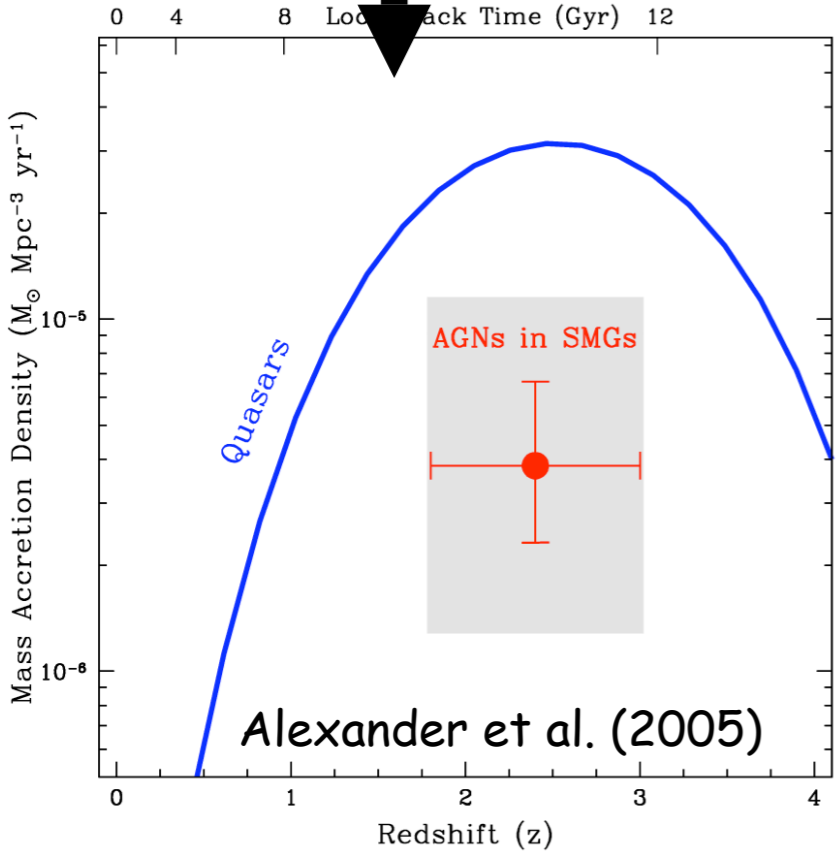
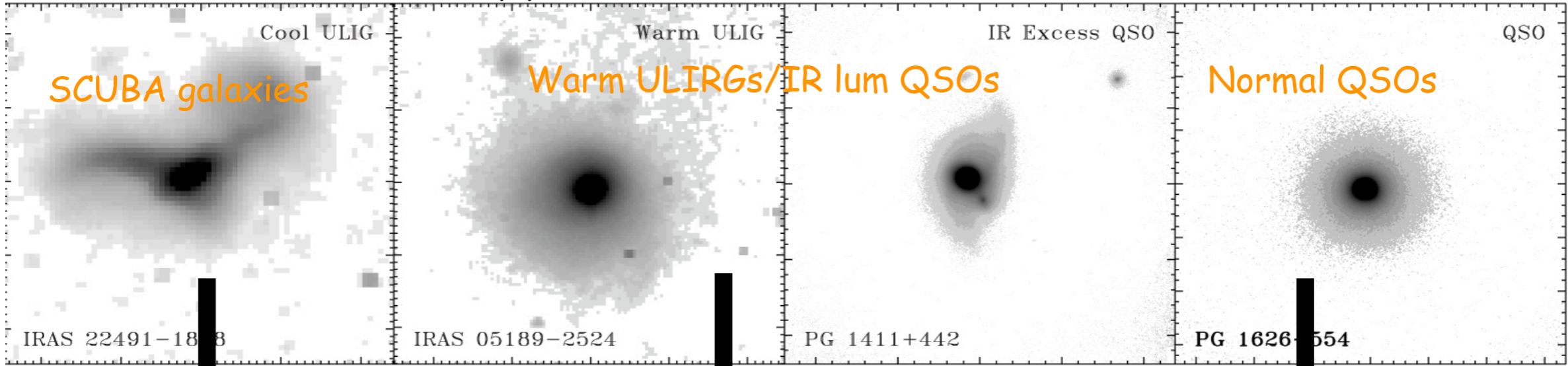
Alexander et al. (2005)



Alexander et al. (2008)

# Potential evolutionary sequence?

The Sanders et al. evolutionary picture



Black Holes getting bigger



# Potential evolutionary sequence?

The Sanders et al. evolutionary picture



We will focus on "missing link" sources to probe this evolutionary sequence: SCUBA galaxies (SMGs) which show extreme star formation **AND** evidence of AGN heating the dust torus



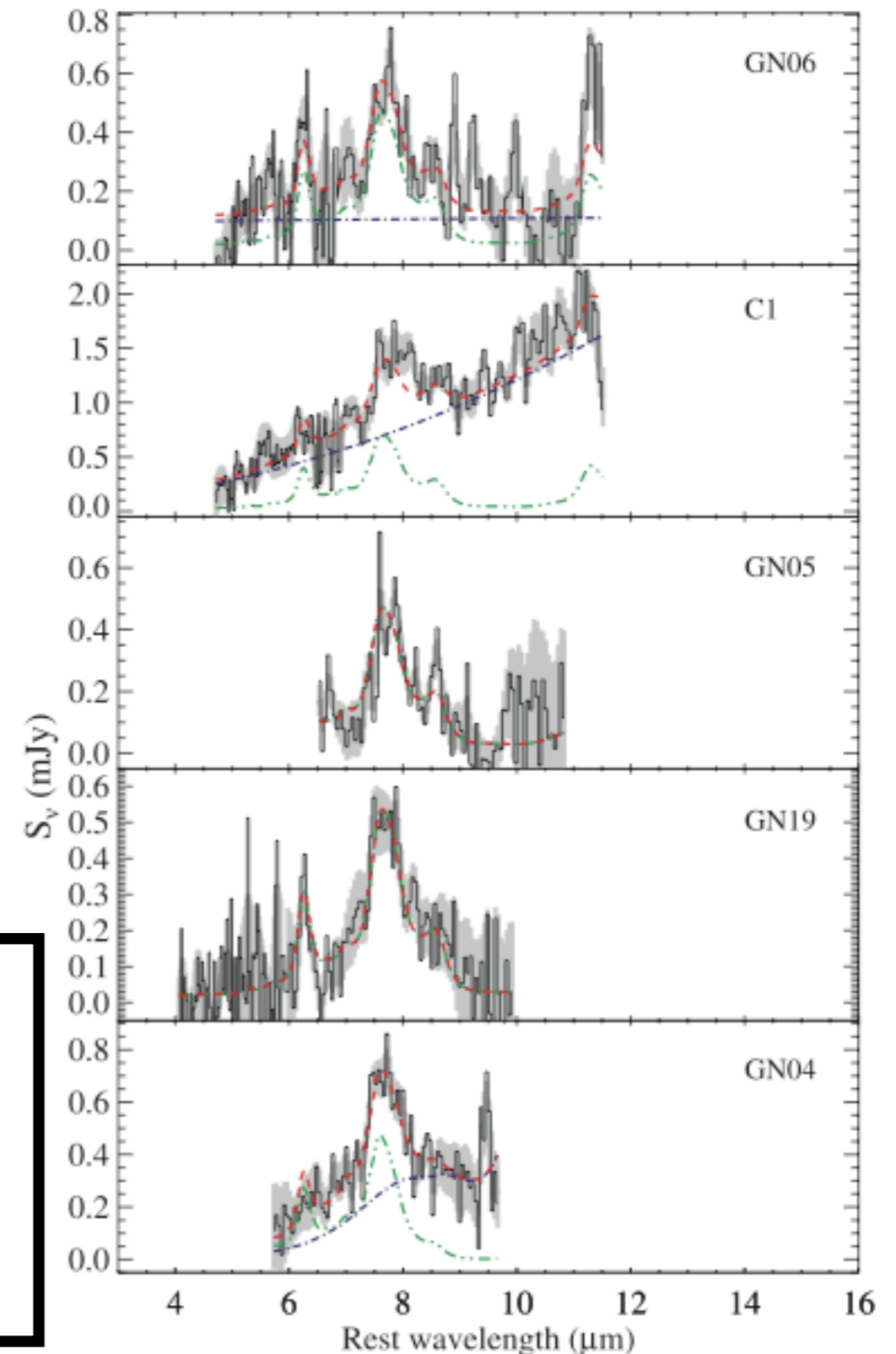
# SMGs - energetics dominated by AGN or SF?

~80% of SMGs are dominated by star-formation in the mid-IR (Pope et al. 2008; Menendez-Delmestre et al. 2009)

A few SMGs show signs in their IR spectra for AGN dominance in the mid-IR --> are these 'transition' objects in the evolutionary sequence?



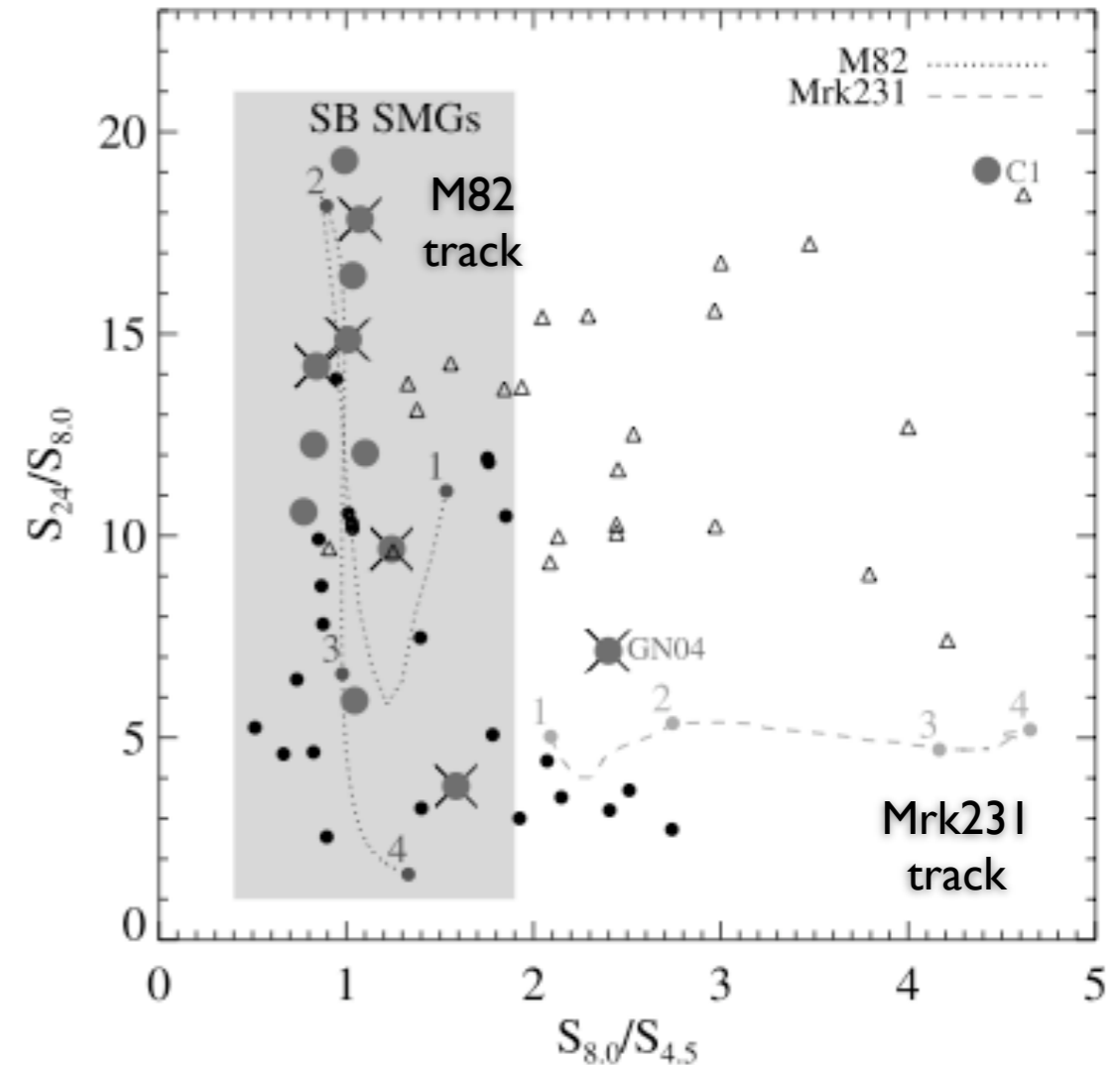
--- continuum/AGN (power-law)  
--- StarBurst (M82 template)  
--- TOTAL fit



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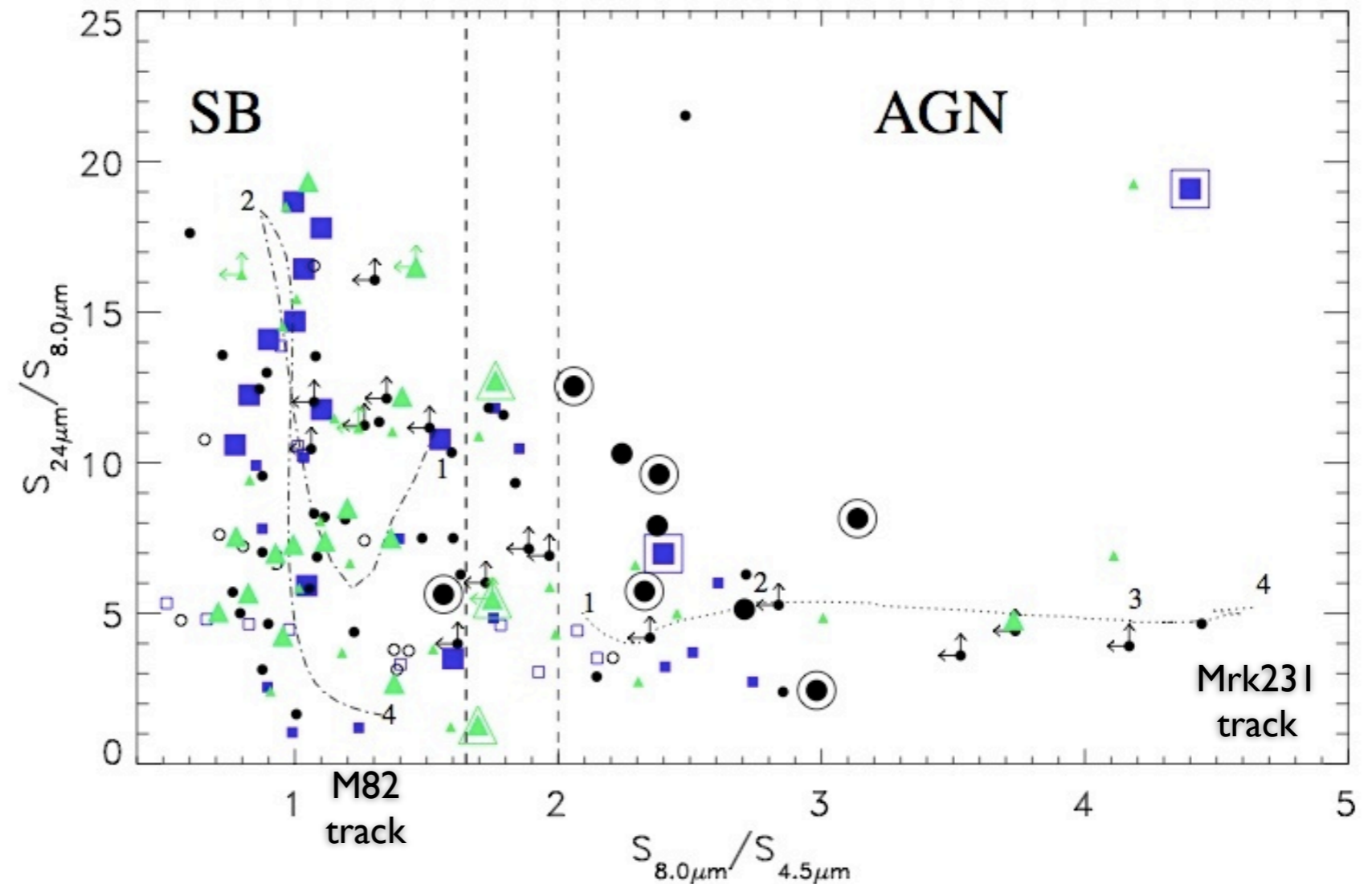
Spitzer colour-colour diagram showing that the majority of SMGs are SF-dominated in the mid-IR Pope et al. (2008)

# Target selection for mid-IR spectroscopy

-Parent submm sample:  
the largest SCUBA  
850 $\mu$ m survey (SHADES;  
Mortier et al. 2005;  
Coppin et al. 2006)

-AGN-candidates:  
24 $\mu$ m > 200 $\mu$ m &

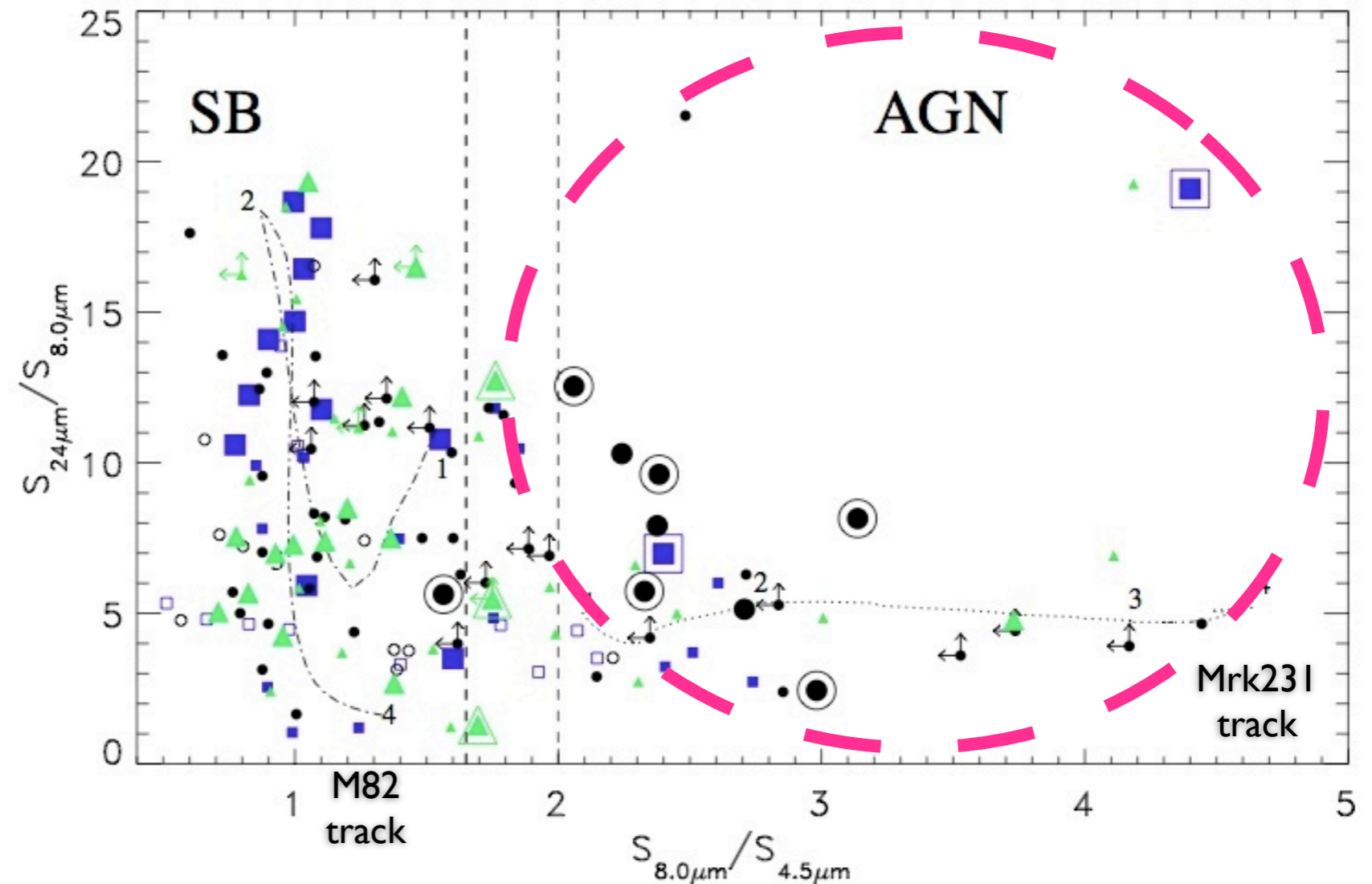
$S_{8\mu\text{m}}/S_{4.5\mu\text{m}} > 2$  (Ivison et  
al. 2007; Dye et al.  
2008; Clements et al.  
2008)



Pope et al. (2008) GOODS-N SMGs  
Menendez-Delmestre et al. (2009) SMGs  
Coppin et al. (2006, 2010) SHADES SMGs

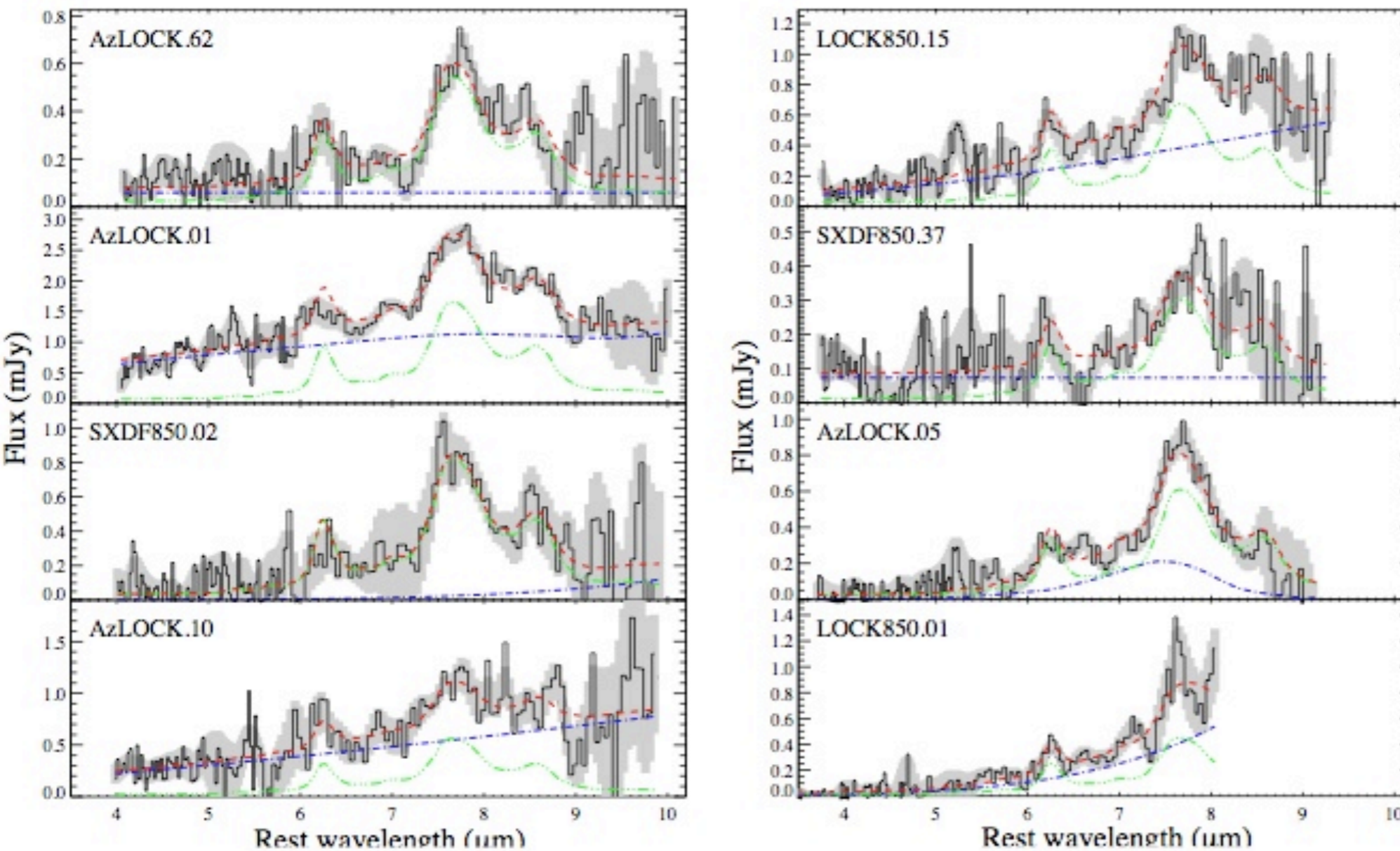
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Pope et al. (2008) GOODS-N SMGs  
Menendez-Delmestre et al. (2009) SMGs  
Coppin et al. (2006, 2010) SHADES SMGs

# Spitzer-IRS spectra of candidate AGN-dominated SMGs

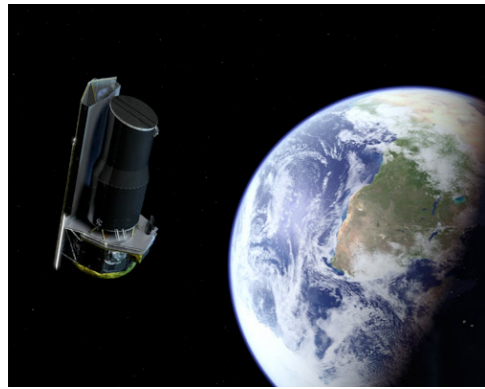


Coppin et al. (2010)

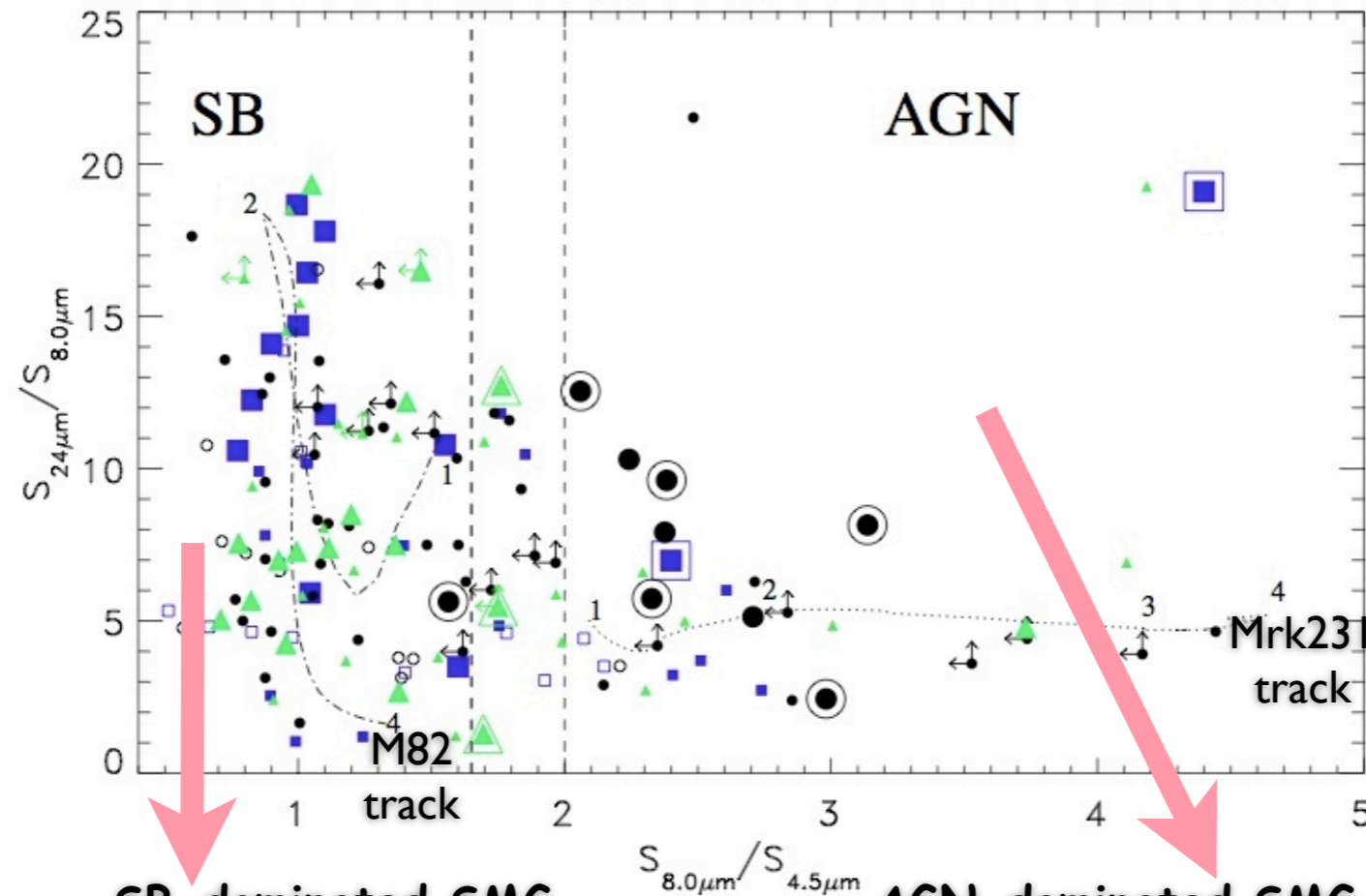
--- continuum/AGN (power-law)  
 --- StarBurst (M82 template)  
 --- TOTAL fit

- presence of PAHs --> star formation
- PAHs give redshifts  $2.5 < z < 3.4$
- show a mix of SB/AGN properties
- some have steep continuum slopes --> dusty torus heated by an AGN?

Key result: ~15% of SMGs are AGN-dominated in the mid-infrared



Probing the mid-infrared with the Spitzer-IR Spectrograph (IRS)



85% of SMGs are PAH- (SB-) dominated

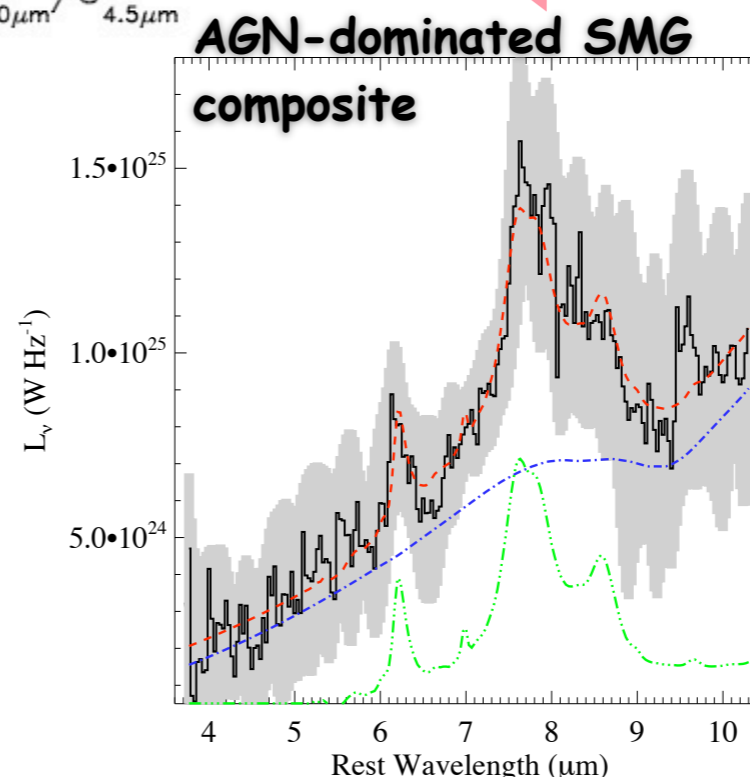
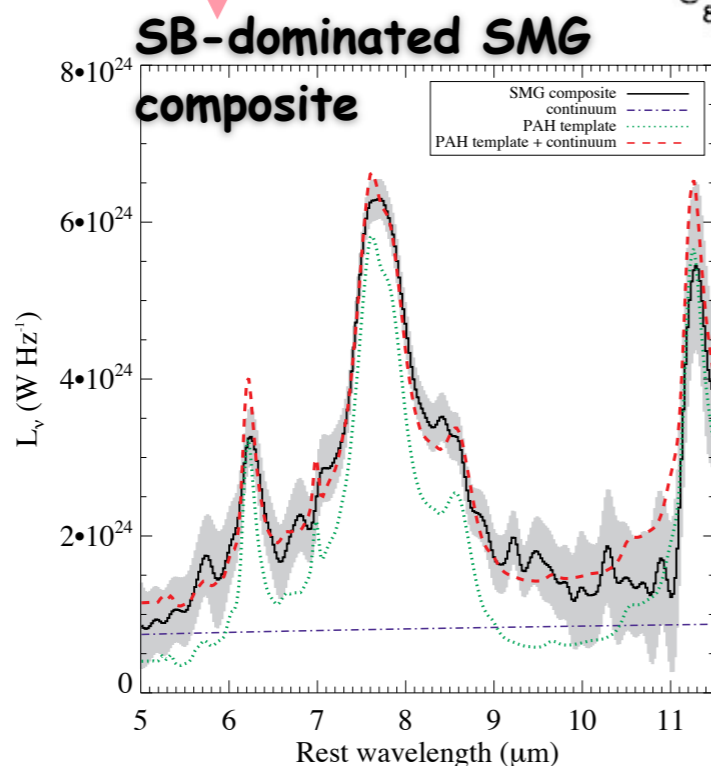
Median AGN content < 30%

Pope et al. (2008),  
Menendez-Delmestre et al. (2009)

62% of our sample is continuum- (AGN-) dominated (~15% of SMG pop)

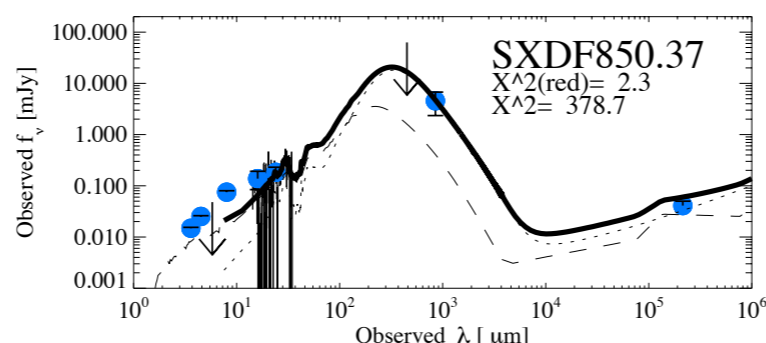
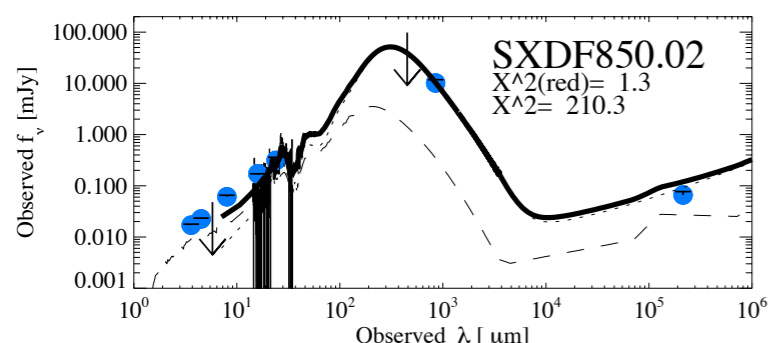
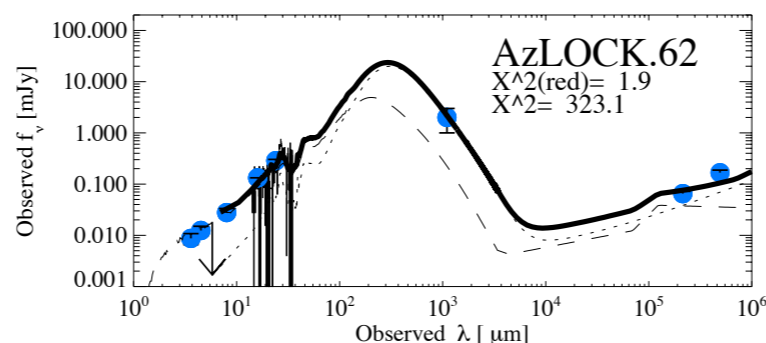
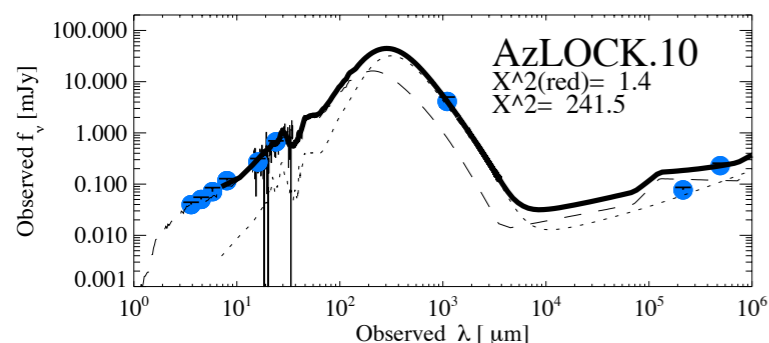
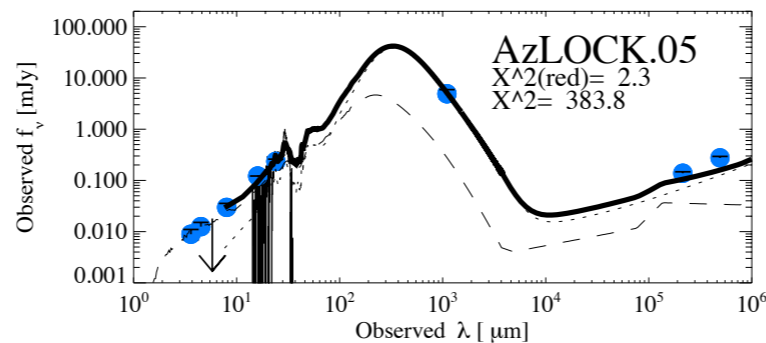
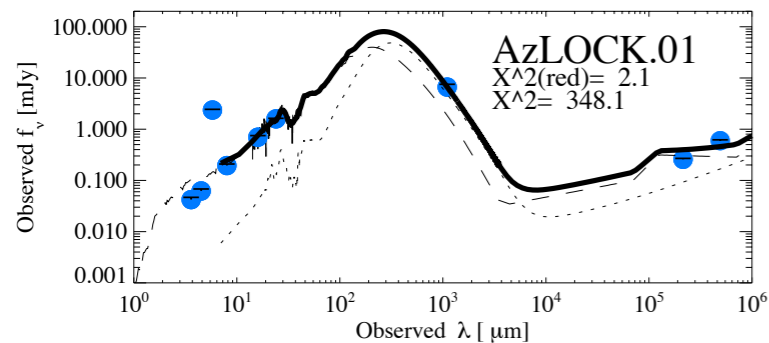
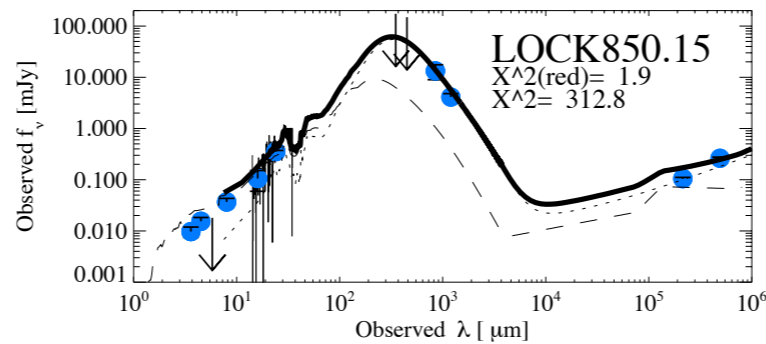
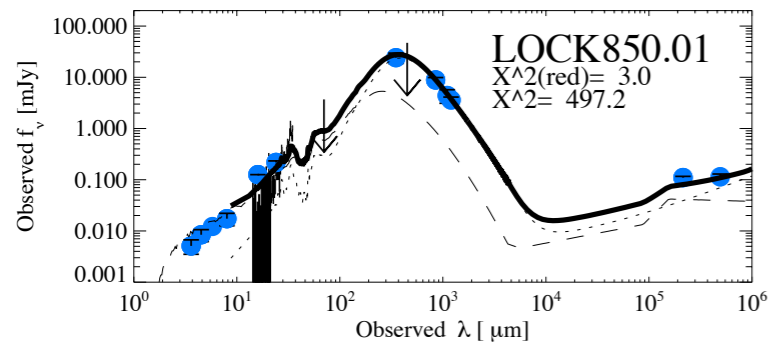
Median AGN content: 56%

Coppin et al. (2010)



--- continuum/  
AGN (power-law)  
--- StarBurst  
(M82 template)  
--- TOTAL fit

# 15% of SMGs are AGN-dominated in the mid-infrared, but the AGN are unimportant bolometrically

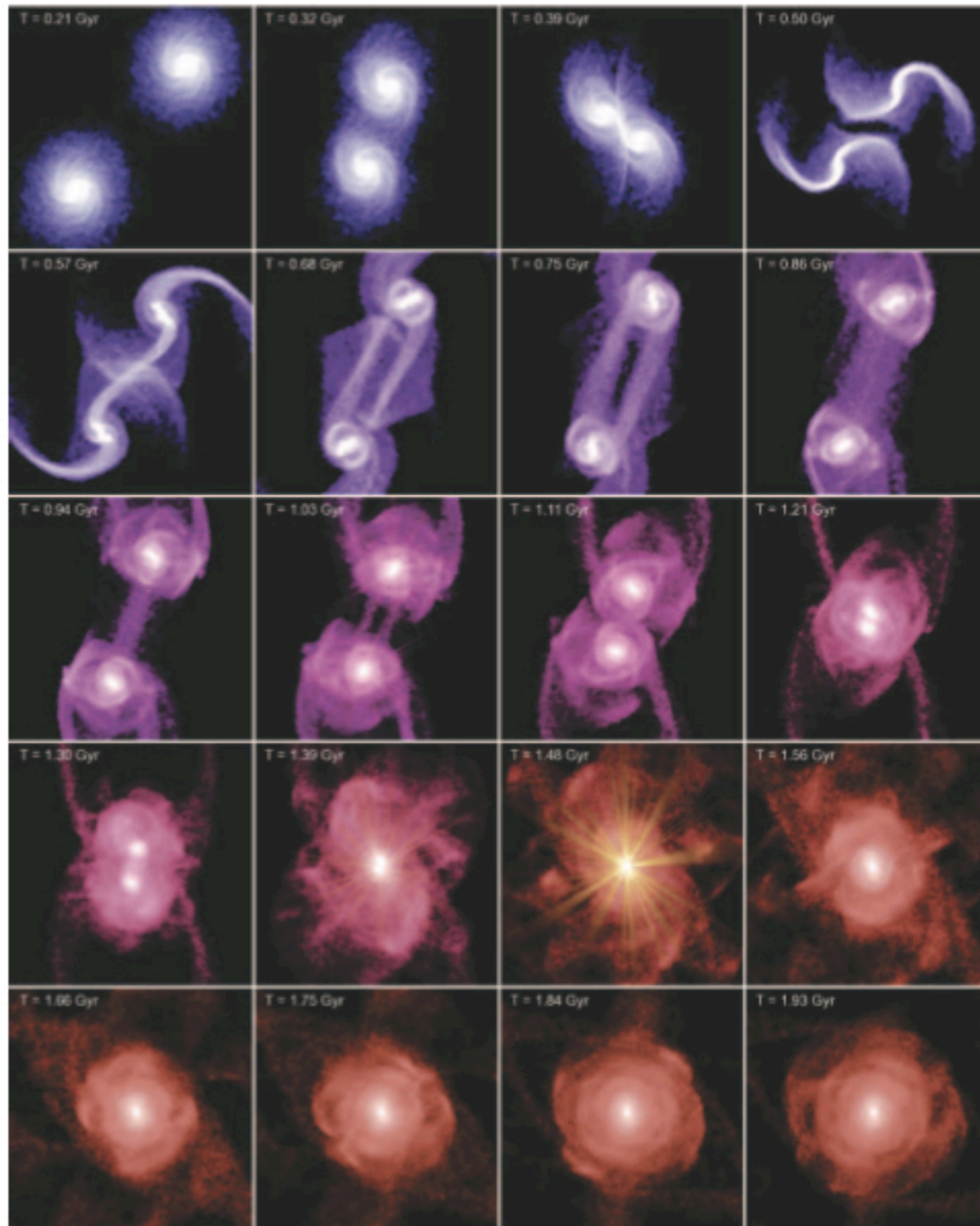


..... SB-SMG template  
 --- Mrk231 template  
 \_\_ TOTAL

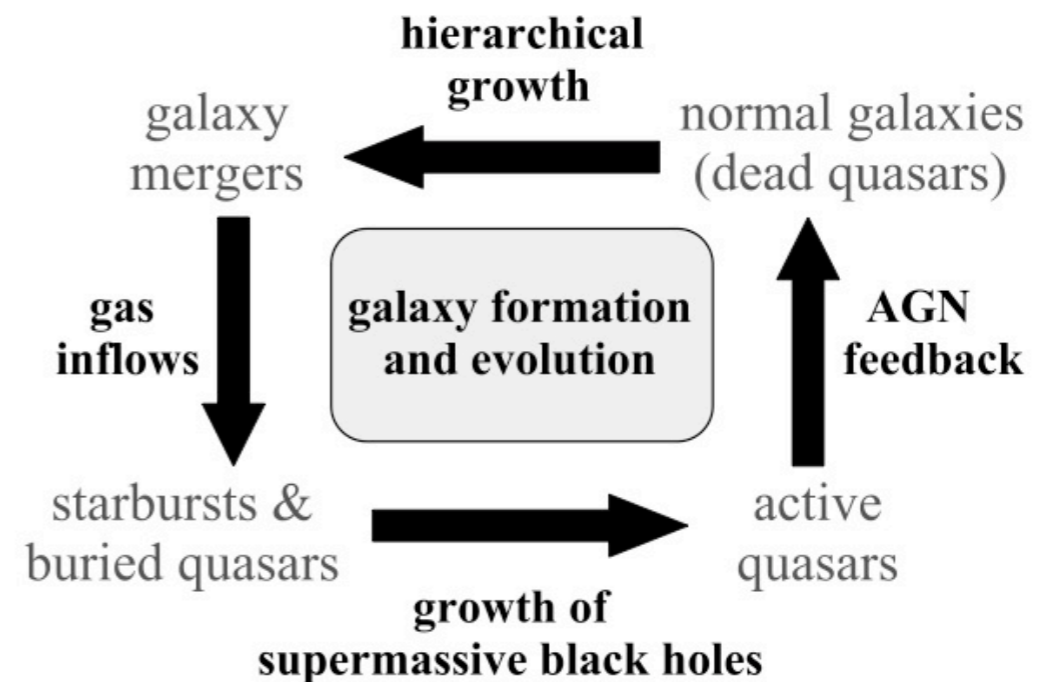
When extrapolated to longer wavelengths, <5% of SMGs contain a bolometrically important AGN

SB-SMG template alone is a poor fit to the photometry - need an additional AGN component

# Mid-IR AGN-dominated SMGs are consistent with the Evolutionary Sequence



- --> these are consistent with being in a 'transition phase' in the evolutionary sequence of the formation of massive galaxies proposed by Sanders et al. (1988)
- implies 15% duty cycle in this phase if all SMGs go through a subsequent AGN phase



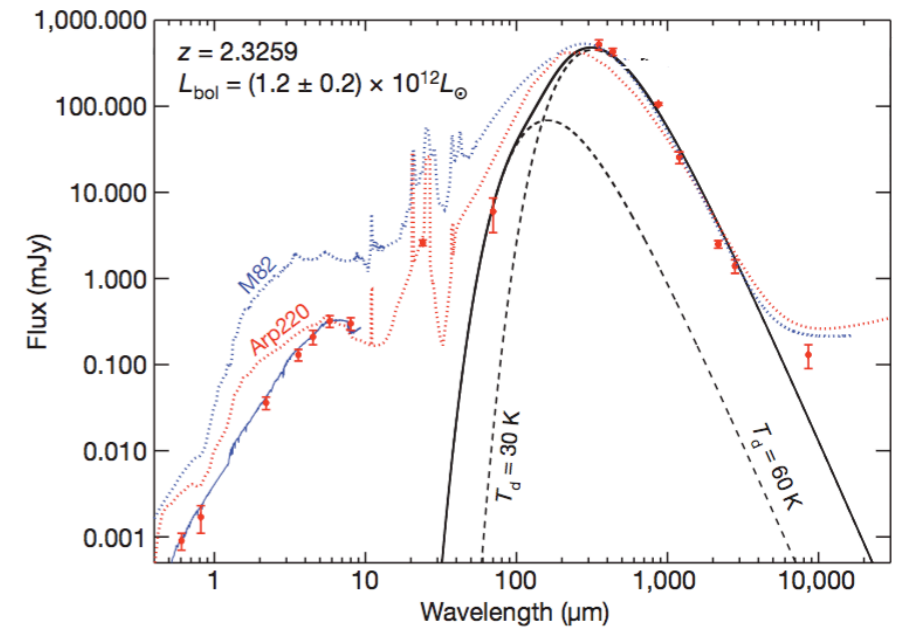
Hopkins et al. (2006); Springel et al. (2005)



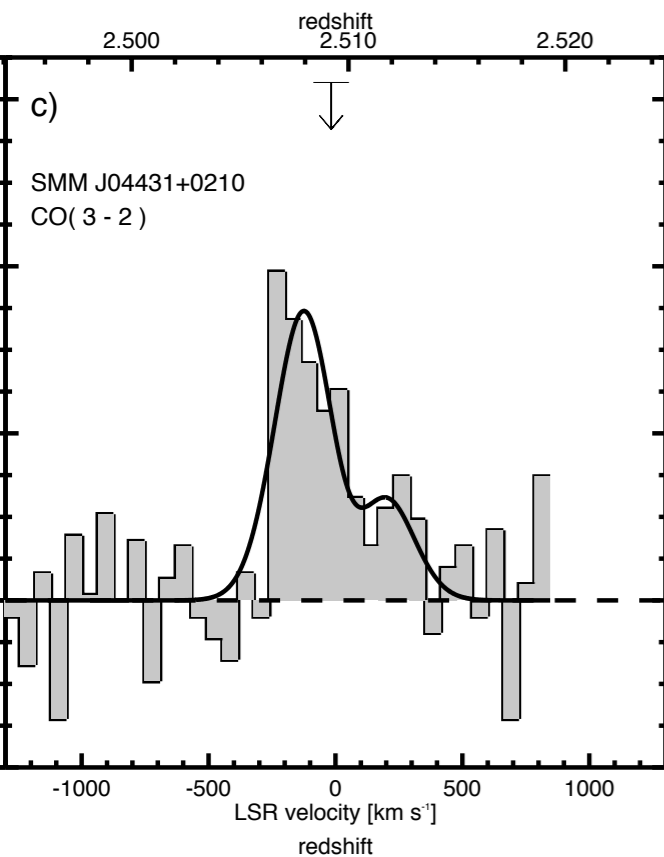
# What's next?

Probe the CO emission with PdBI/ALMA: are they more evolved than typical SMGs in terms of their gas masses?

Herschel photometry: measure far-IR SEDs to better constrain  $L_{\text{fir}}$  and  $T_d$

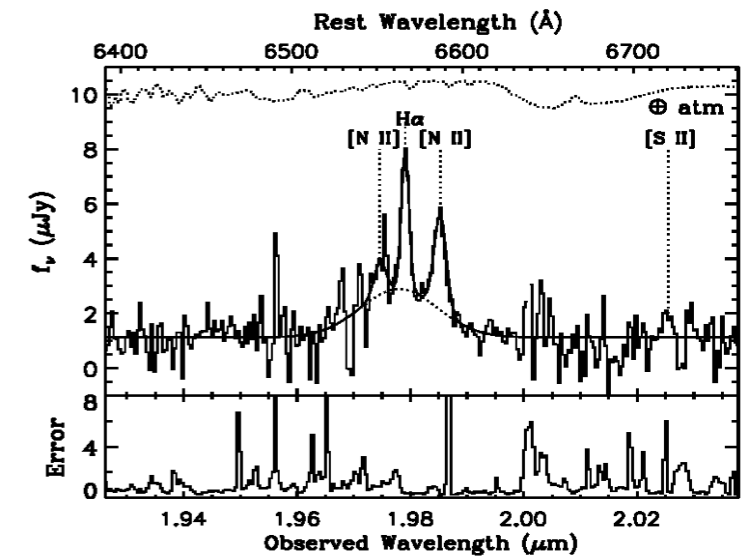


(Swinbank et al. 2010)



CO line emission --> measure of the total cold gas mass

near-IR spectroscopy (JWST?): measure BH masses to help gauge their evolutionary state compared to typical SMGs

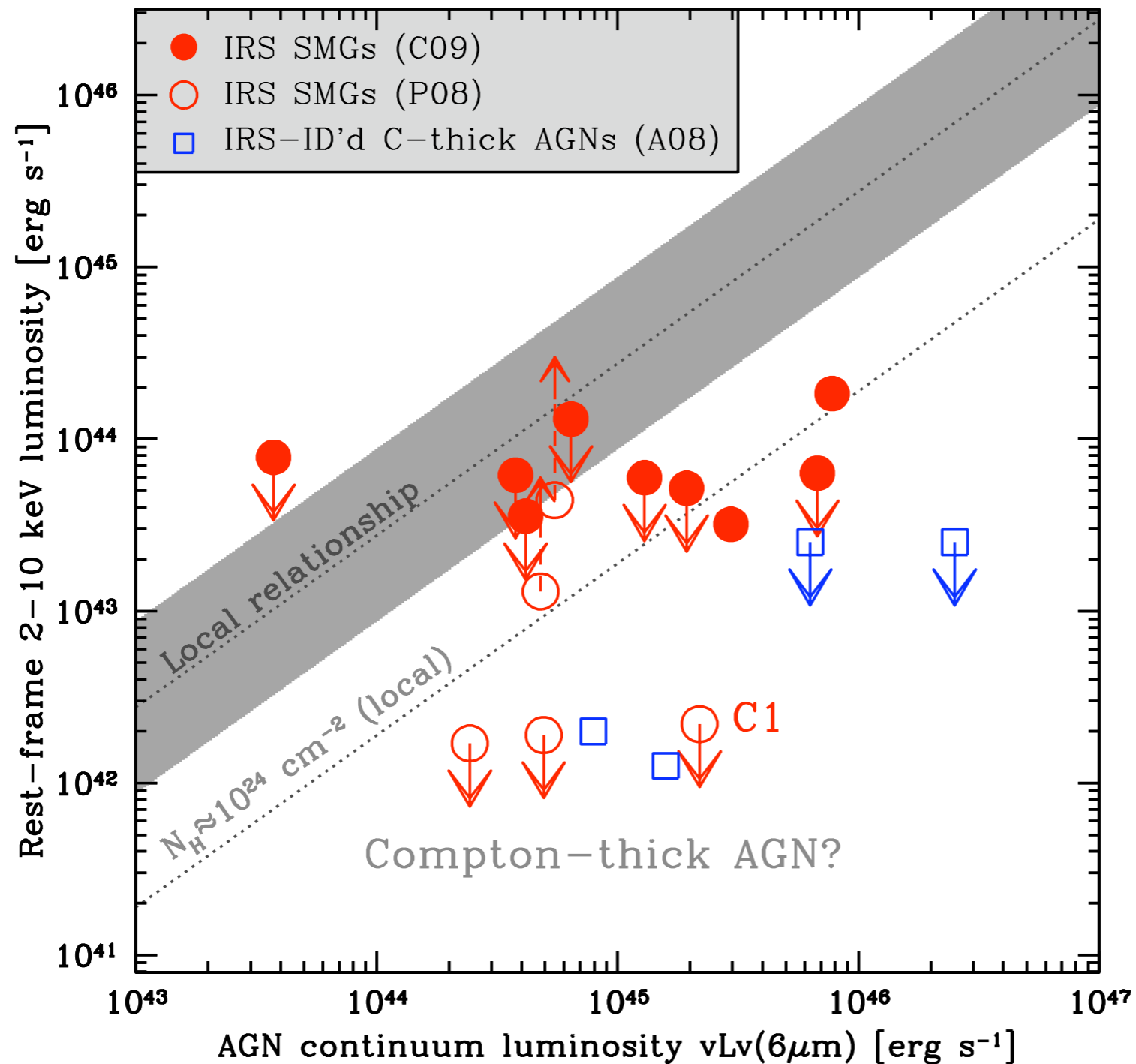


Broad component of H-alpha emission line --> BH mass

## Summary

- Studying the relative SF and AGN activity in these 'transition' or 'missing link' sources can thus provide important insight on the validity of an evolutionary sequence
  - ~15% of SMGs are AGN dominated in mid-IR (IRAC colours  $S_{8\mu\text{m}}/S_{4.5\mu\text{m}} > 1.65$ )
  - BUT bolometrically, these mid-IR AGN-dominated systems are unimportant in majority of SMGs
  - If all SMGs go through a later AGN-dominated phase, the 15% detection fraction of mid-IR dominant AGN in SMGs is consistent with them being 'transition objects' in the Sanders et al. (1988) evolutionary sequence

# Comparing mid-IR fits with the X-ray constraints



- can tell us about intrinsic lum of the AGN & see if any are Compton-thick by comparing to other SMGs and local AGN

