Suppressed Star Formation in X-ray Luminous AGNs

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Outline

- What is the maximum star formation rate (SFR) in high-redshift galaxies?

- Are the SF contributions from the rest-frame UV population distinct from the SF contributions from the faint submm galaxy population?

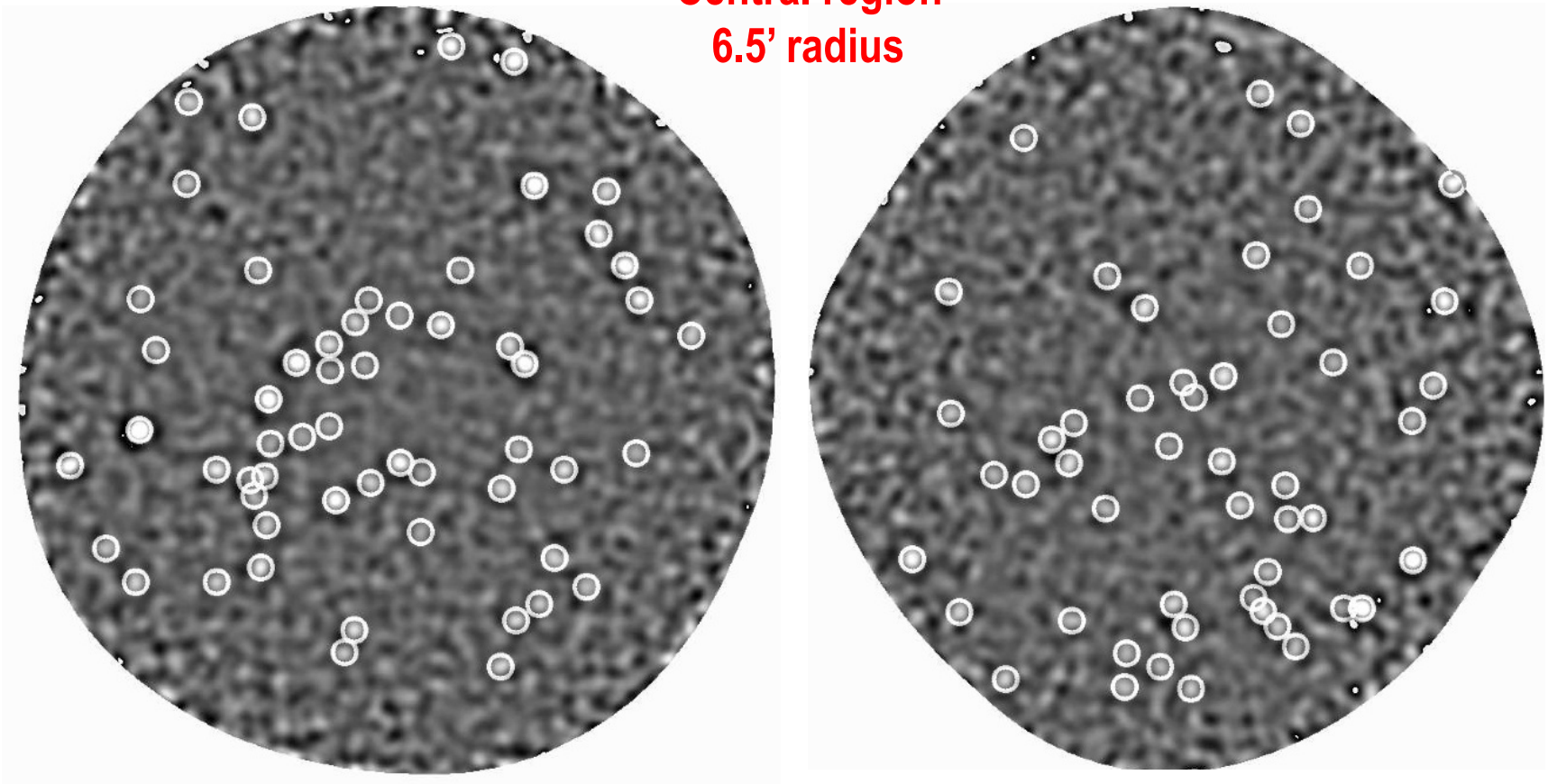
- How is the X-ray AGN population drawn from the star-forming galaxy population?

SCUBA-2 images provide large distant, dusty, star-forming galaxy samples

CDF-N

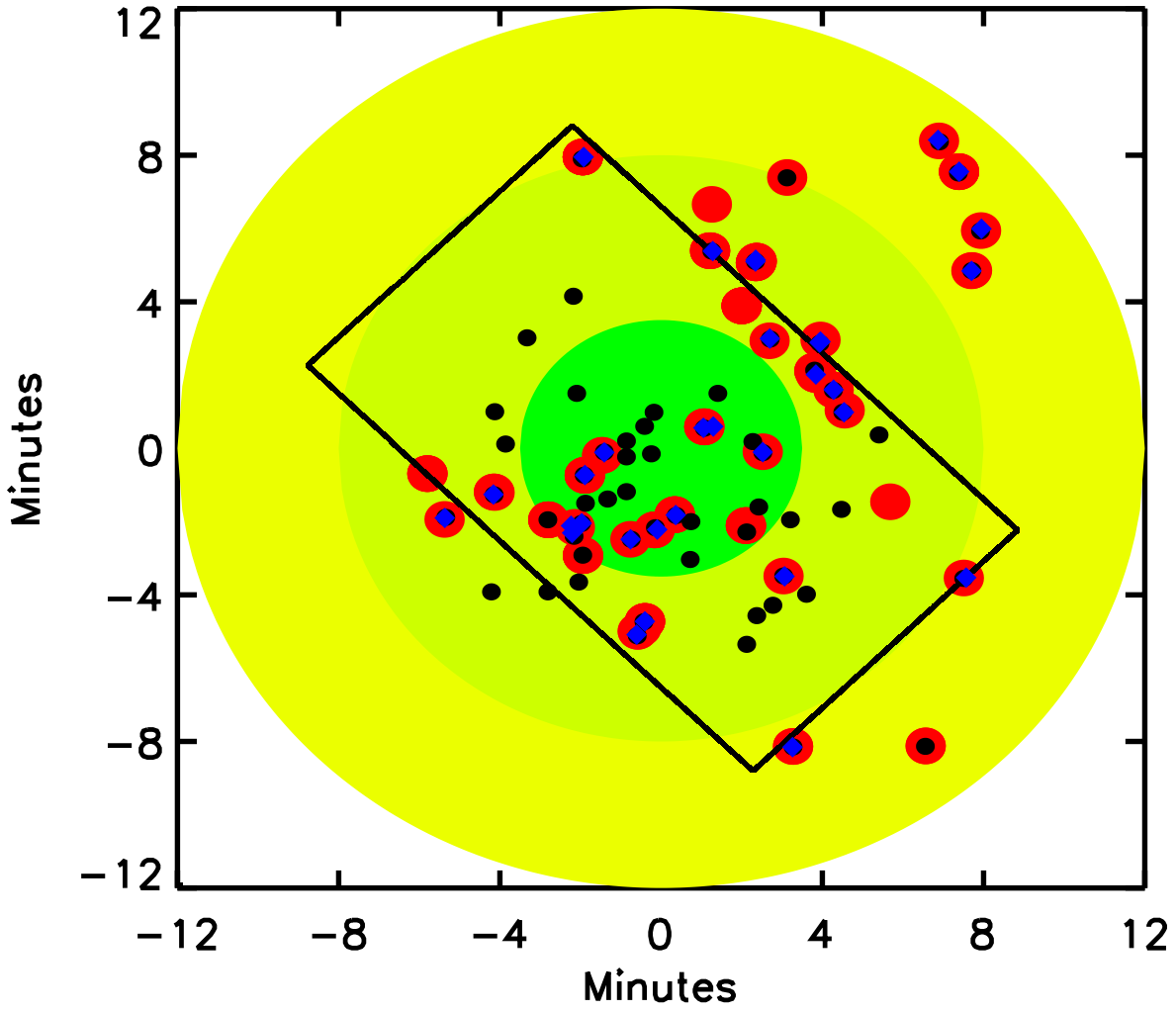
CDF-S

Central region
6.5' radius



40 hr 850μm SCUBA-2 exposures on each field (1σ=0.37 mJy)

SMA Follow-up in CDF-N for Accurate Positions



(Darkest green: 850 μm rms noise less than 0.55 mJy)

Red: 24" radius

Rectangle: GOODS-N HST

SCUBA-2 4σ (66 sources)

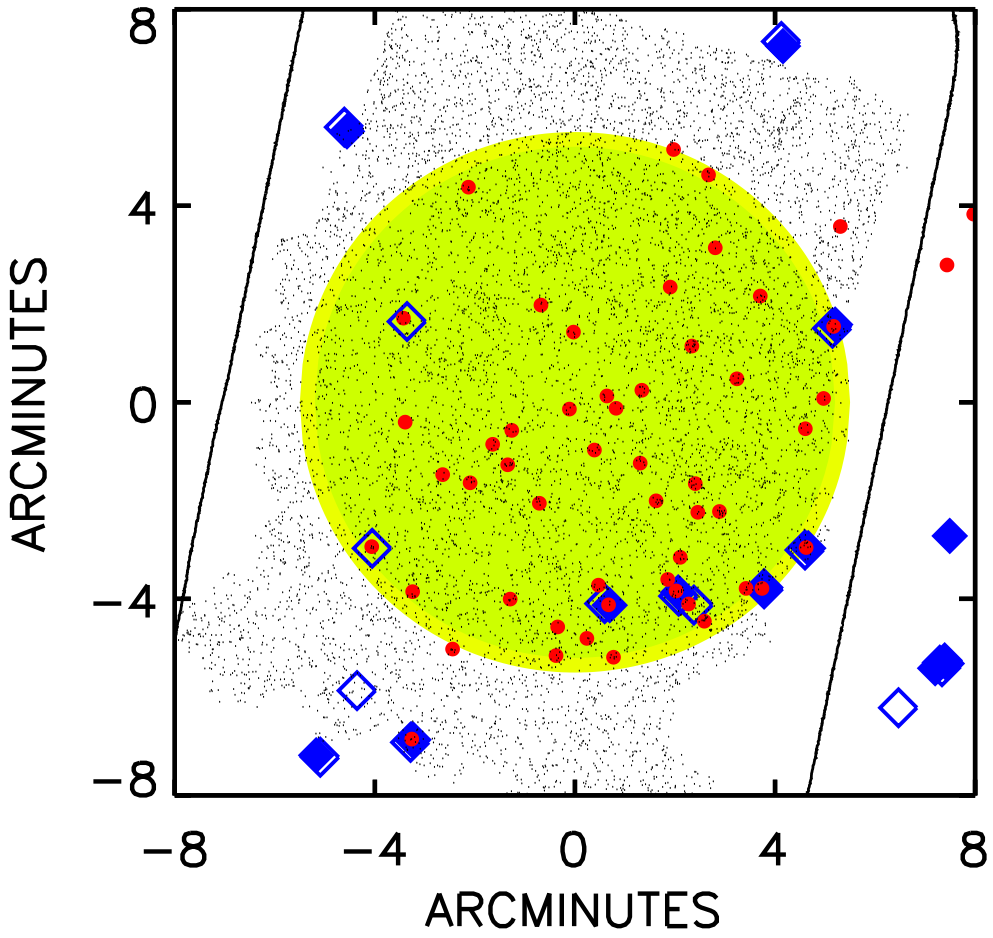
All SMA observed areas, including non-SCUBA-2 targets

32 SMA detections (includes all >5 mJy SCUBA-2 sources)

ALMA ALESS Survey in CDF-S

The SCUBA-2 images are much deeper than the CDF-S LABOCA (LESS) (Weiss et al. 2009) survey, on which the ALMA sample is based (ALESS) (Hodge et al. 2013)

Deep areas (<twice the central noise) in X-ray (green) and SCUBA-2 (yellow) for CDF-S



Blue open = LESS; solid = ALESS

Red = 4σ SCUBA-2

Multiplicity
(First found by Wang et al. 2011 using SCUBA/SMA)

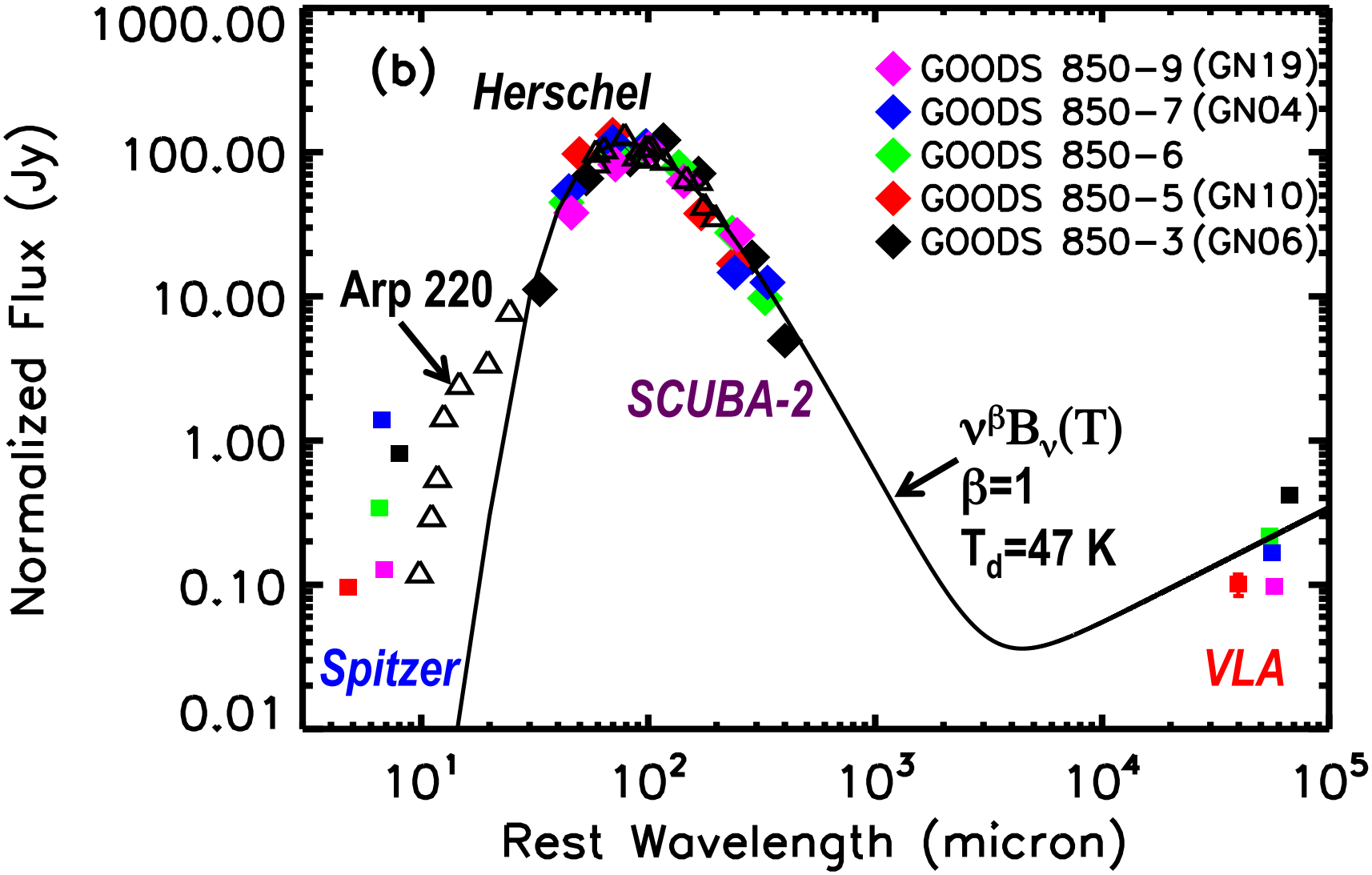
- All of the brightest ALESS sources ($S_{870\mu m}$>12 mJy) were composed of emission from multiple fainter SMGs, each with $S_{870\mu m}$<9 mJy; no ALMA source was >9 mJy (Karim et al. 2013)

- Karim et al. therefore proposed a natural limit of <1000 M_{Sun} yr^{-1} on the SFR of SMGs

- In the GOODS-N, we have 6 SMA detections of SCUBA -2 sources with $S_{860\mu m}$>11 mJy, all of which are singles. The brightest has a flux of 23.9 mJy

- [LABOCA (19.2”) has a larger beam size than SCUBA-2 (14”), so multiplicity or non-detections may be more common in LABOCA/ ALMA observations than in SCUBA-2/SMA observations]

SMG spectral energy distributions (SEDs) are similar to Arp 220



Here the SMGs are normalized to Arp 220 at rest-frame 100 μm

Star Formation Rates

Submm flux based at z>1.5:

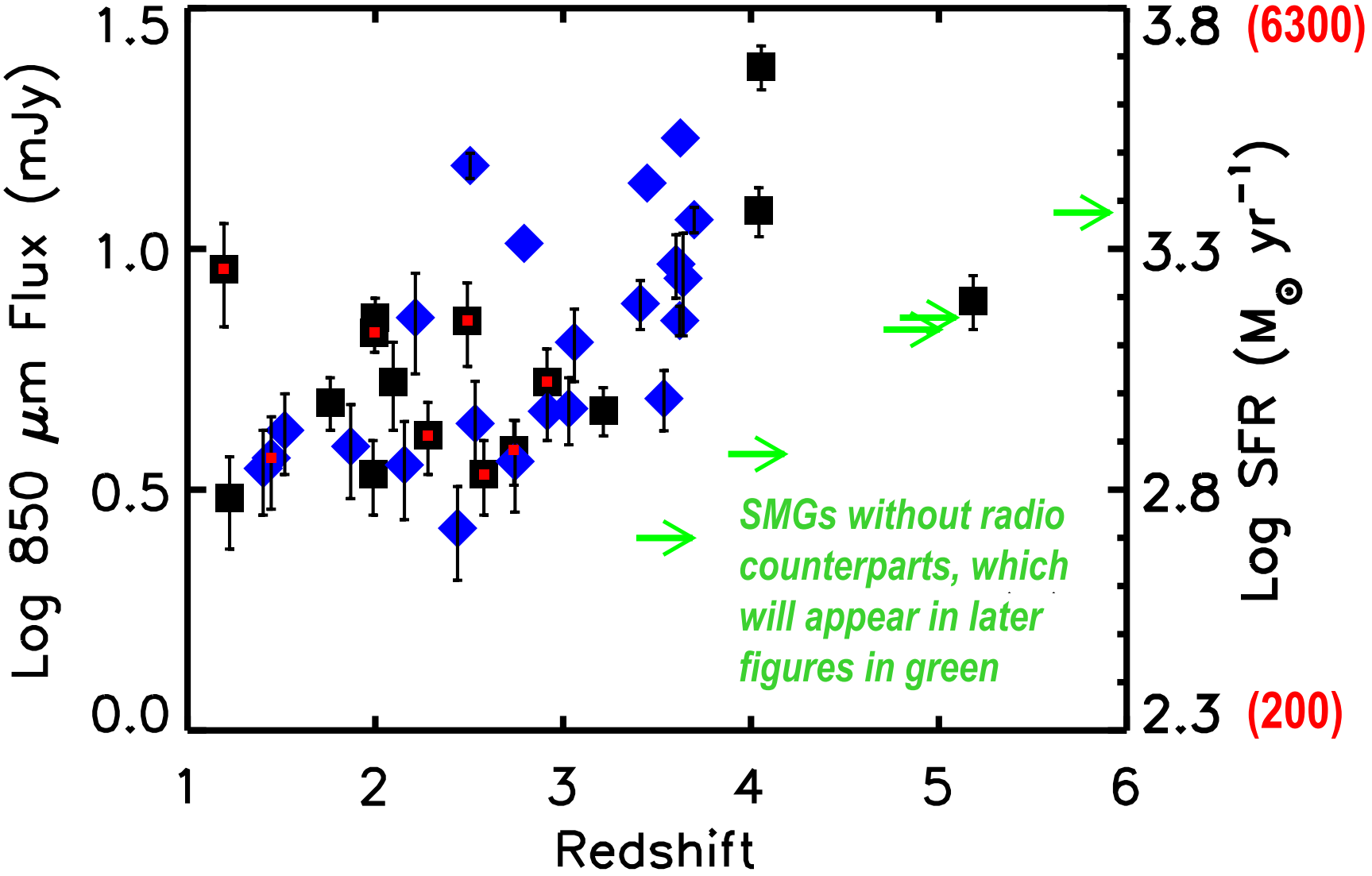
- Integrate SED fits to get $L_{FIR(8\text{-}1000\mu m)}$, then convert to SFR with Kennicutt 1998

$$SFR(M_{Sun}yr^{-1}) = 200 \times S_{850\,\mu m}$$

- **The mean conversion value of 200 is close to that obtained from integrating the Arp 220 SED, while the individual values vary by ~x2 relative to the mean**

- **Emphasizes the redshift-independent nature of the SFRs from the submm**

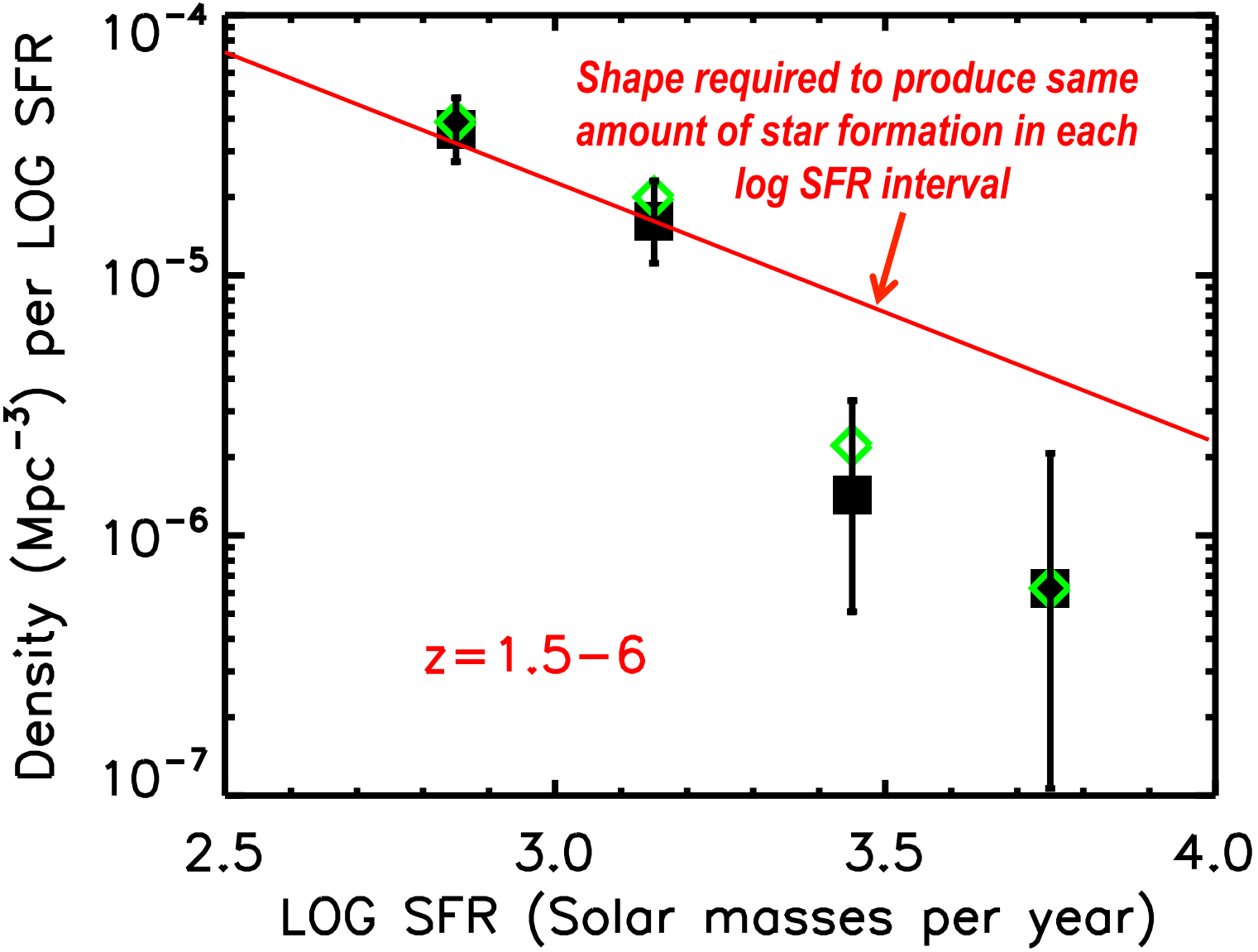
The SFRs of the SMGs range from 400 to 6000 M_{Sun} yr^{-1}



What is the maximum SFR in high-redshift galaxies?

SFR Distribution Function

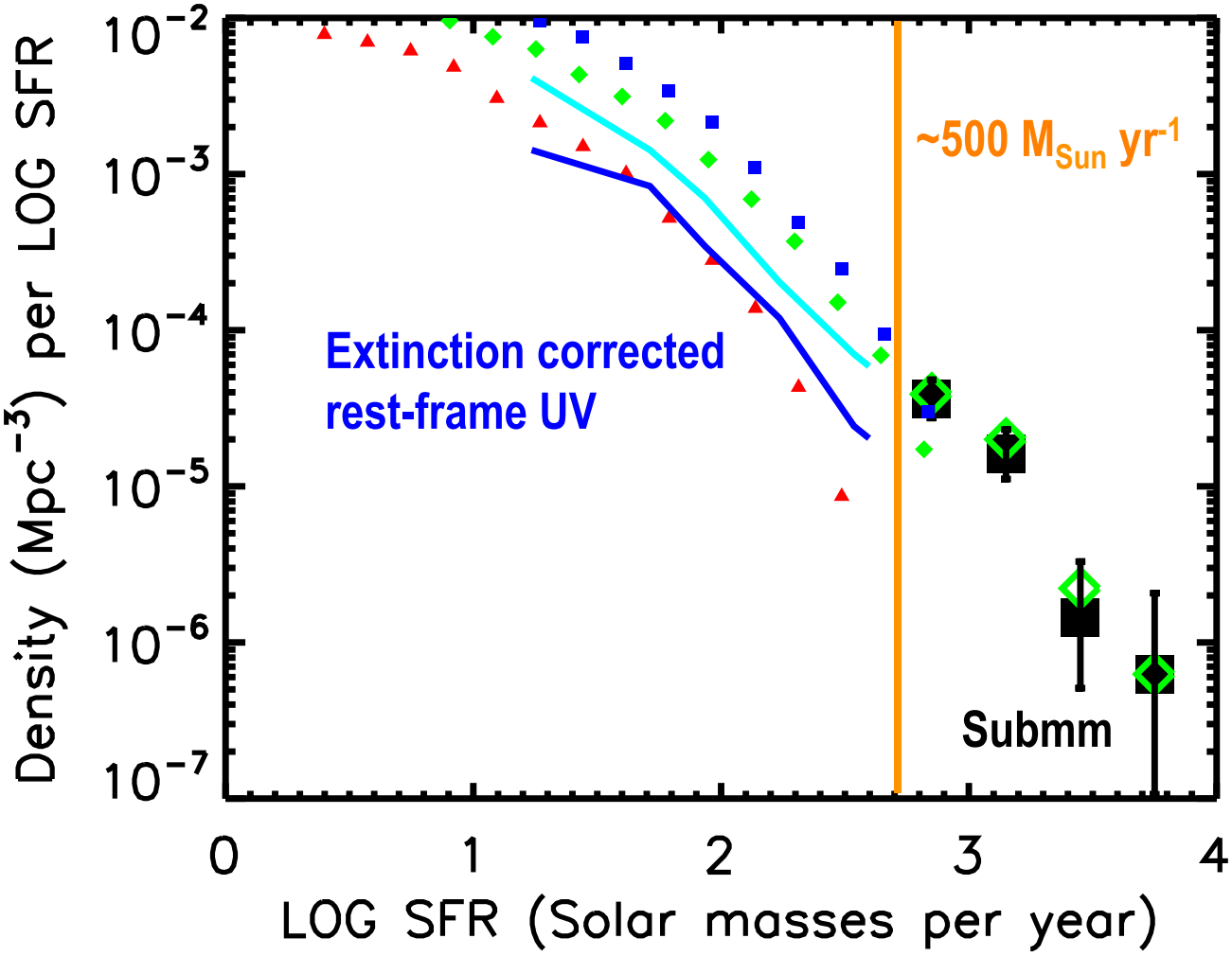
contributions to the SFR density begin to drop above 2000 M_{Sun} yr^{-1}



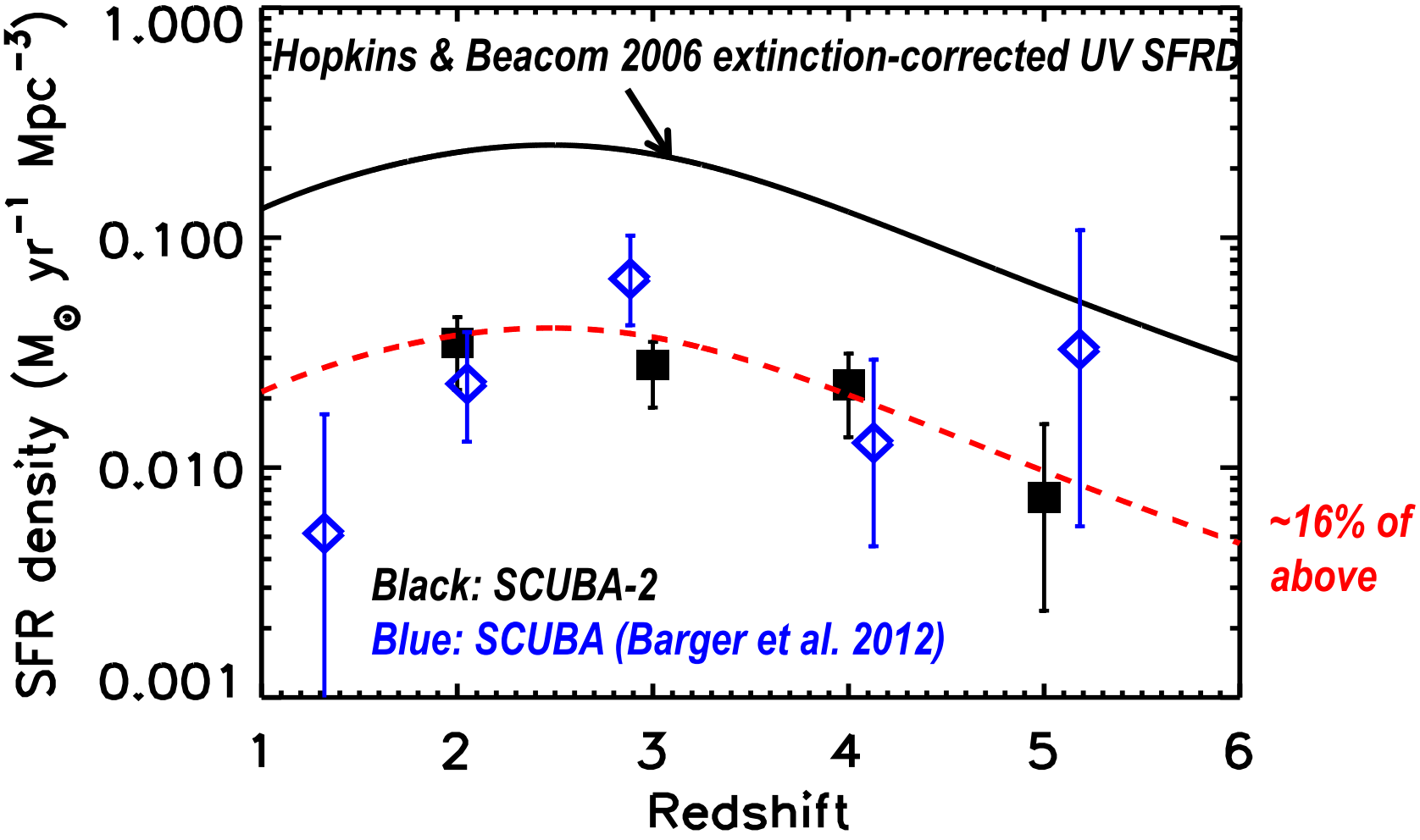
In fact, the submm is a unique probe of the highest SFR galaxies --- the rest-frame UV selected samples max out at ~500 M_{Sun} yr^{-1}, even after extinction correction

Symbols at z=4.8, 3.8, and 3.1 from van der Burg et al. 2010

Curves at z=3 and z~2 from Reddy & Steidel 2009

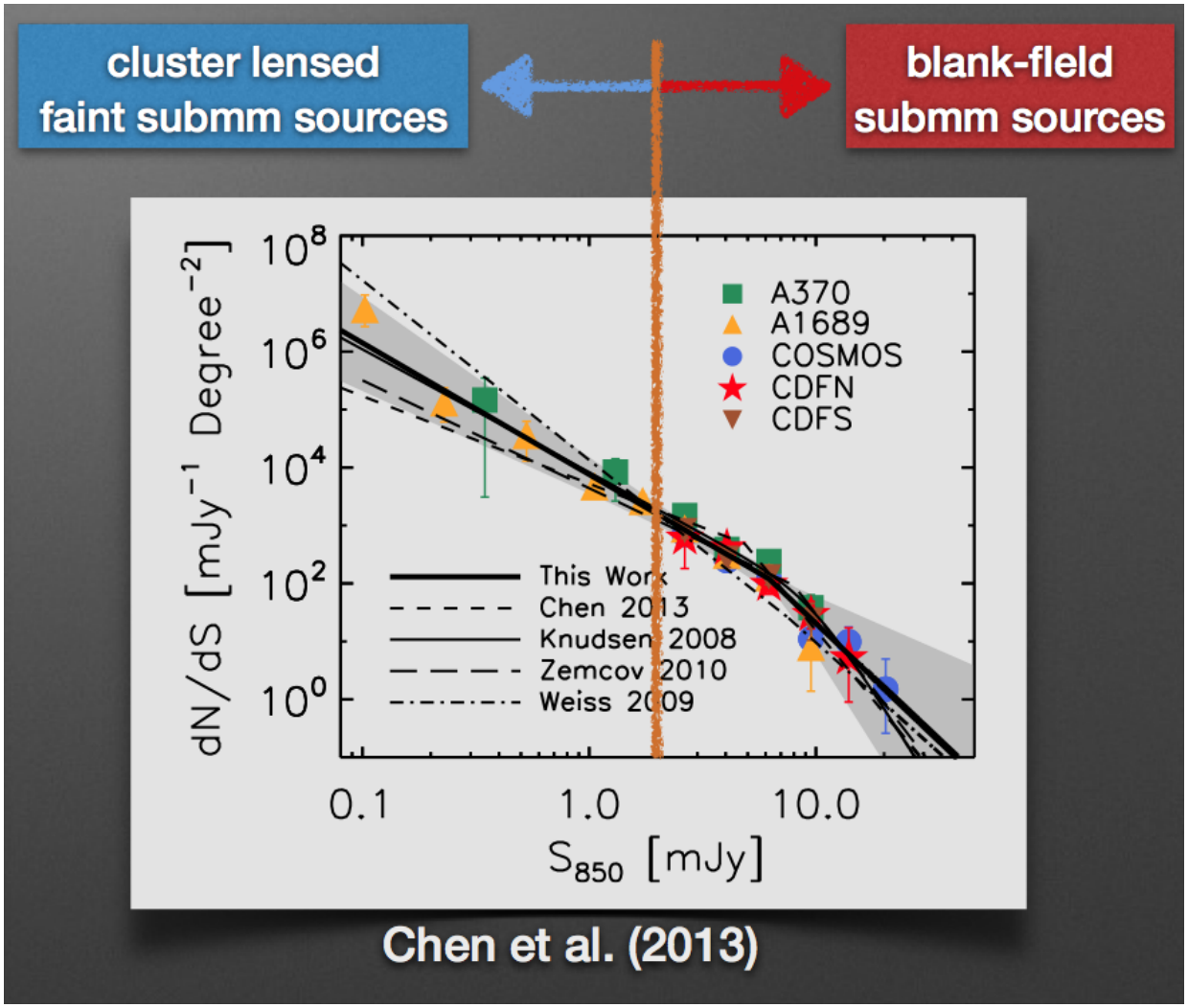


Moreover, a large and relatively invariant fraction of the overall SFR density is contained in these massively star-forming galaxies, and this is true at all redshifts to beyond z=5



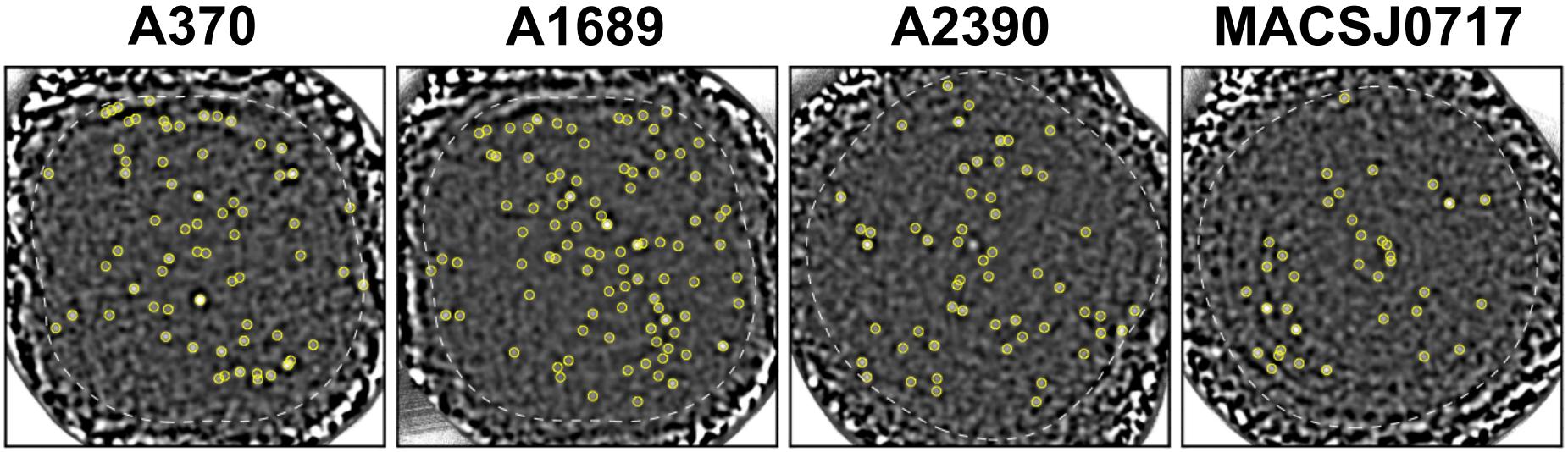
Since the samples are disjoint, the two contributions need to be added!

However, only 20-30% of the submm light is contained in bright SMGs!
Need lensing to probe the faint SMGs



Key question: how overlapped are the rest-frame UV and faint SMG populations? Look for optical/NIR counterparts to the faint SMGs

SCUBA-2 Lensing Cluster Survey

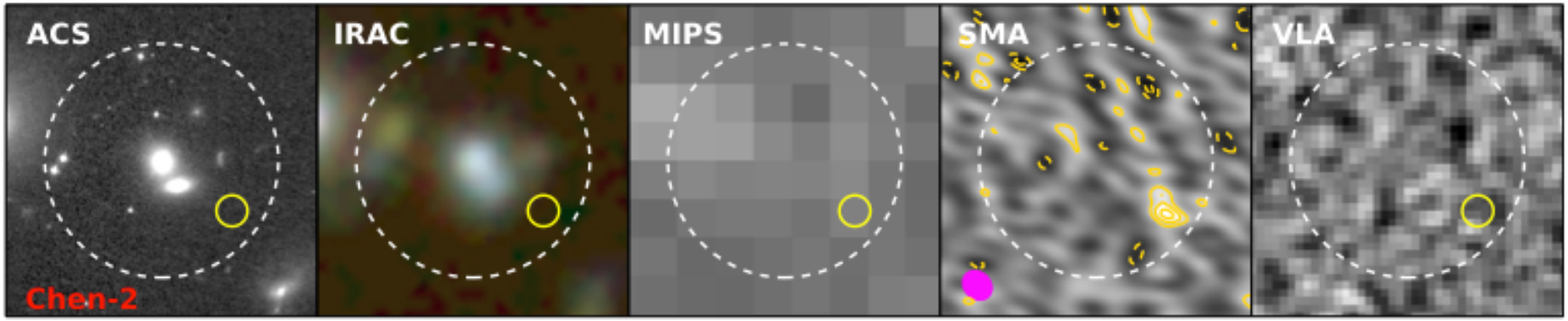


Images: 14' x 14'

All 5 SMGs detected in Chen et al. (2014) with the SMA have intrinsic fluxes ~0.1-0.8 mJy (SFR~20-160 $M_{\odot}$/yr)

SCUBA-2 Lensing Cluster Surveys

However, 3/5 do not have optical/NIR counterparts

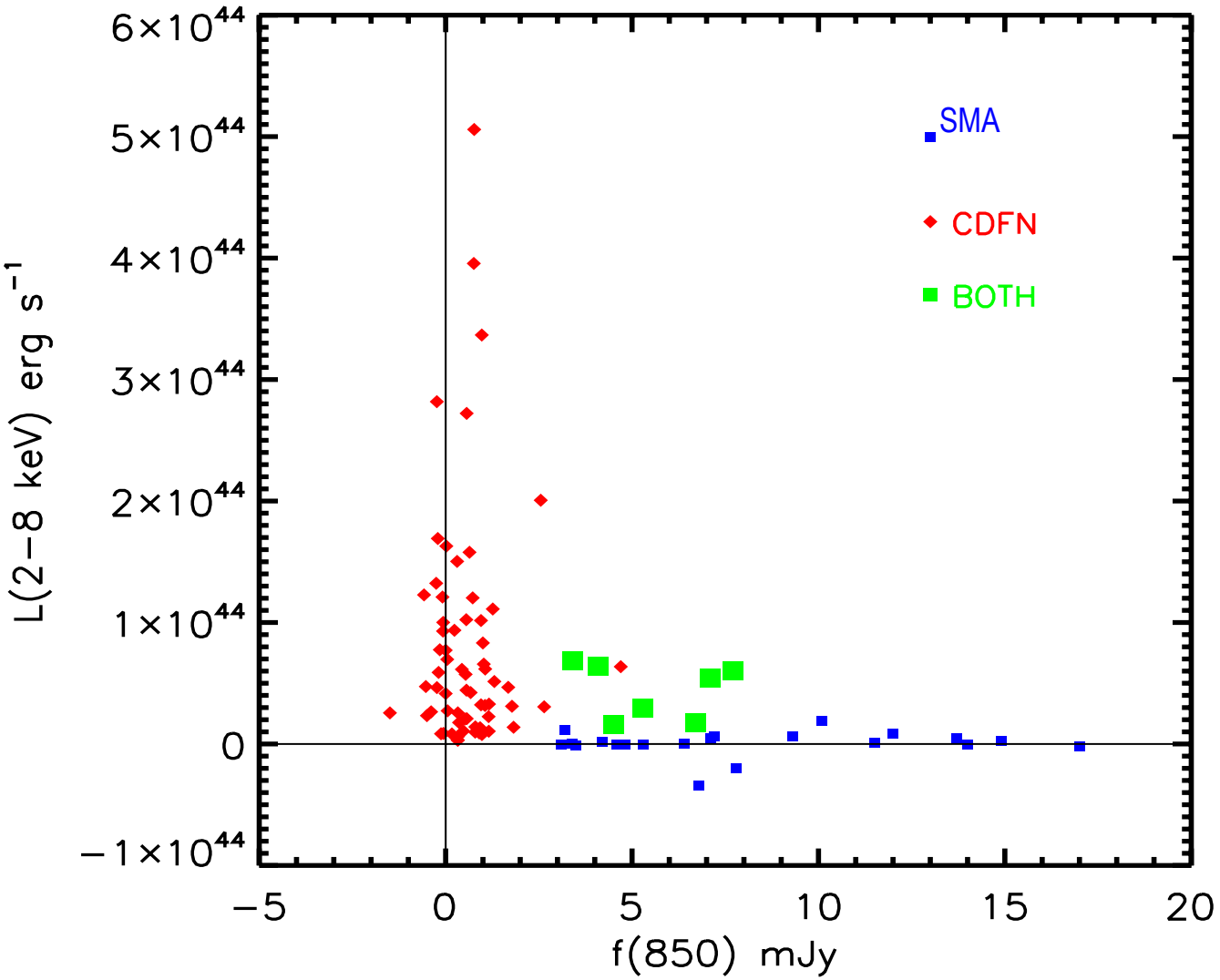


Images: 20" x 20"
White circle: 7.5" radius SCUBA beam
Yellow circle: 1" radius SMA beam

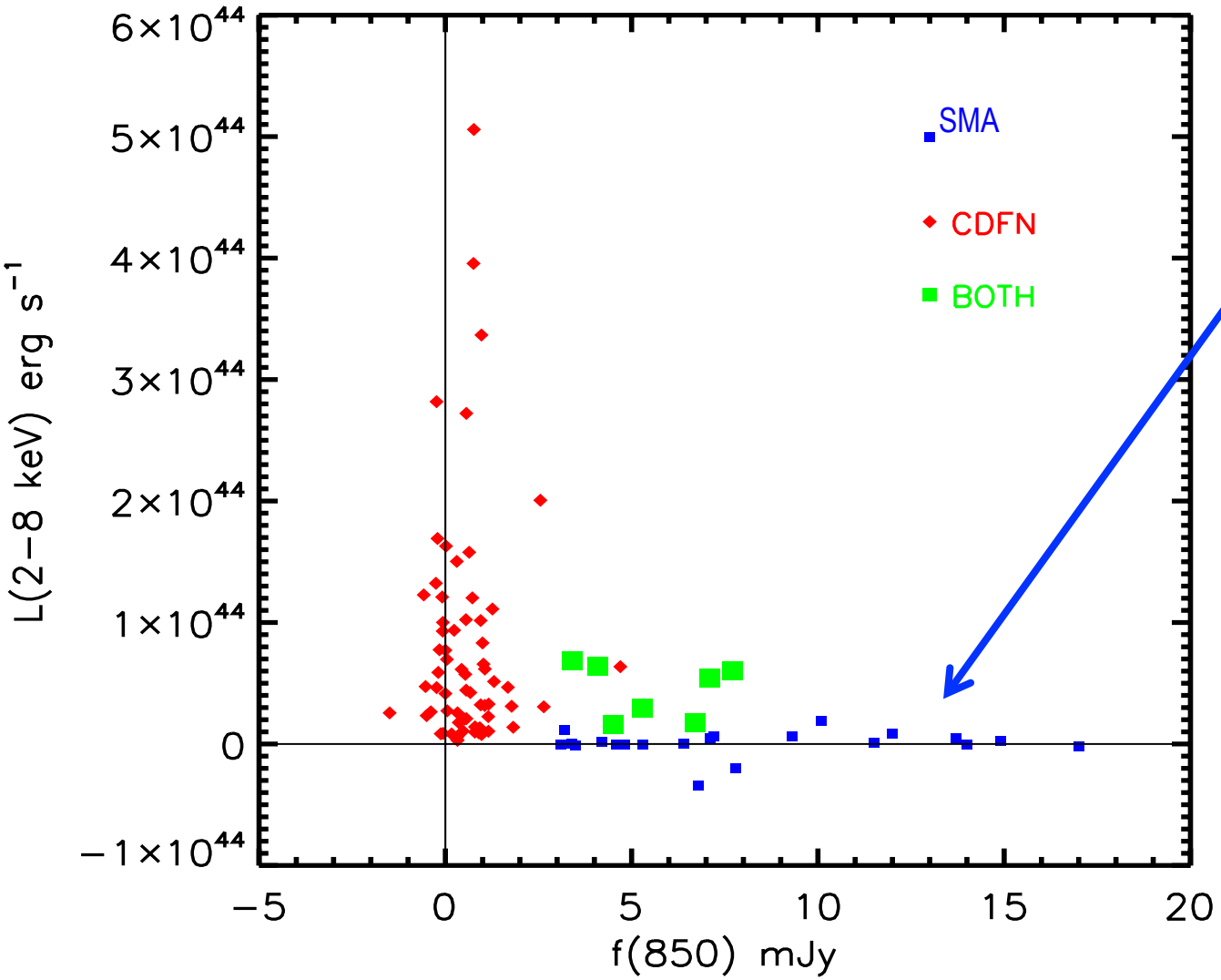
Thus, many low-luminosity, obscured star-forming galaxies at high z also might not be included in the measured optical star formation history!

Possible the SMGs are major mergers, while the UV selected are smooth star formers

How are strongly star-forming galaxies related to AGN?

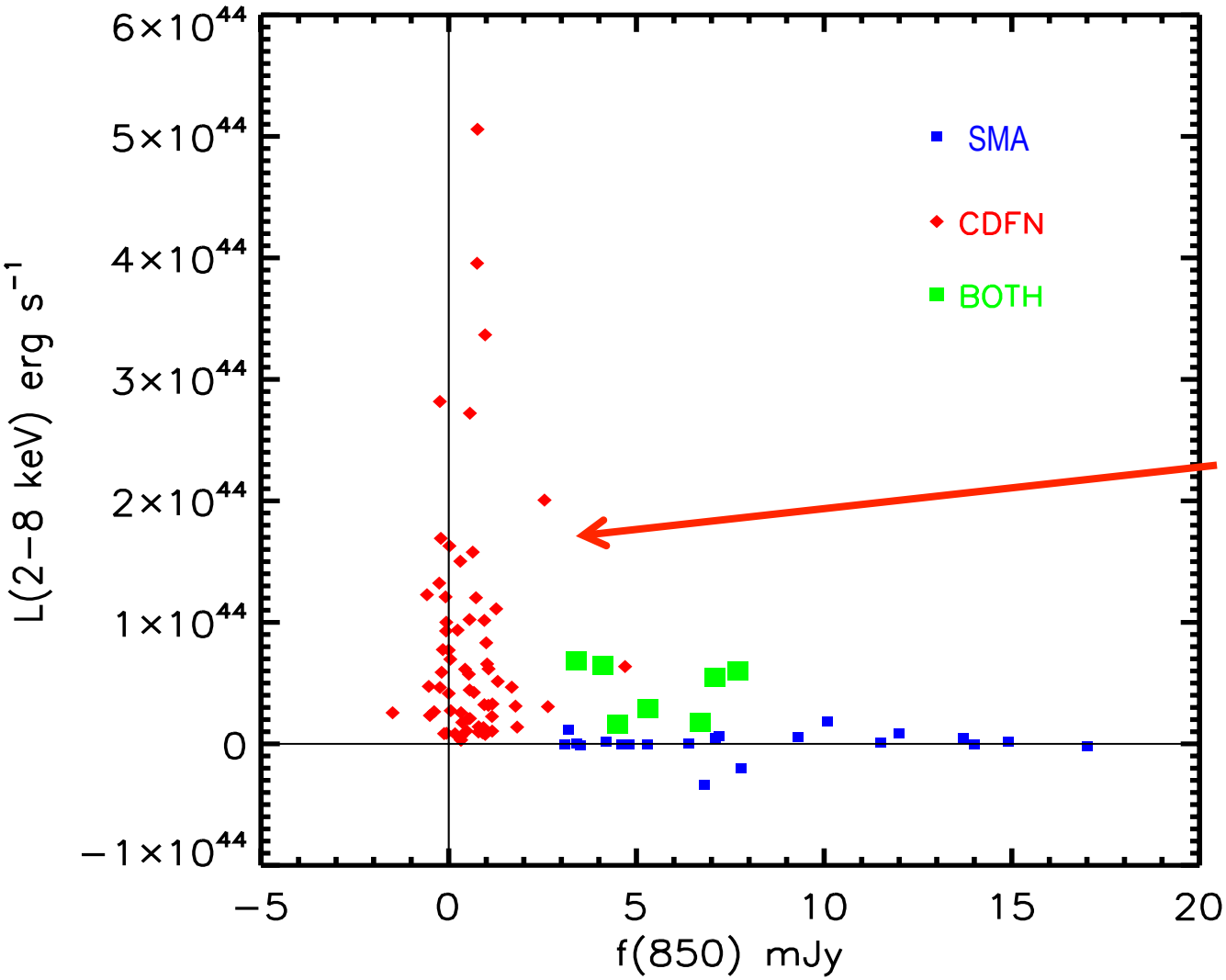


We can look for X-ray detections of the interferometrically-confirmed submm selected samples

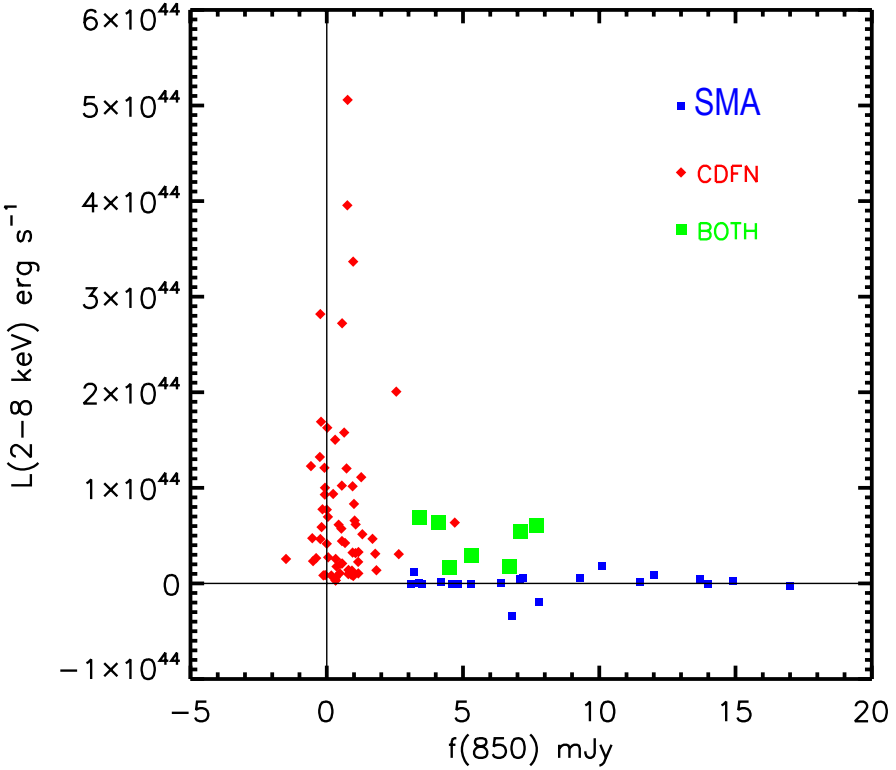


The most luminous star formers do not contain X-ray AGN

Conversely, we can look at the submm properties of the X-ray samples using the SCUBA-2 images



The X-ray luminous AGN are drawn from lower star-forming galaxies



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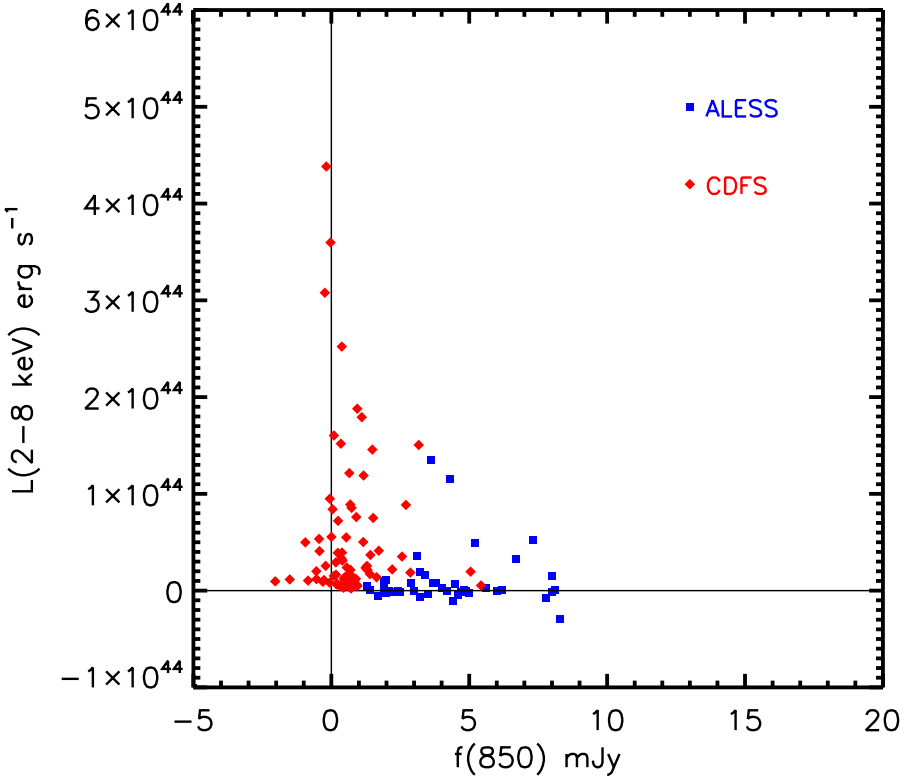
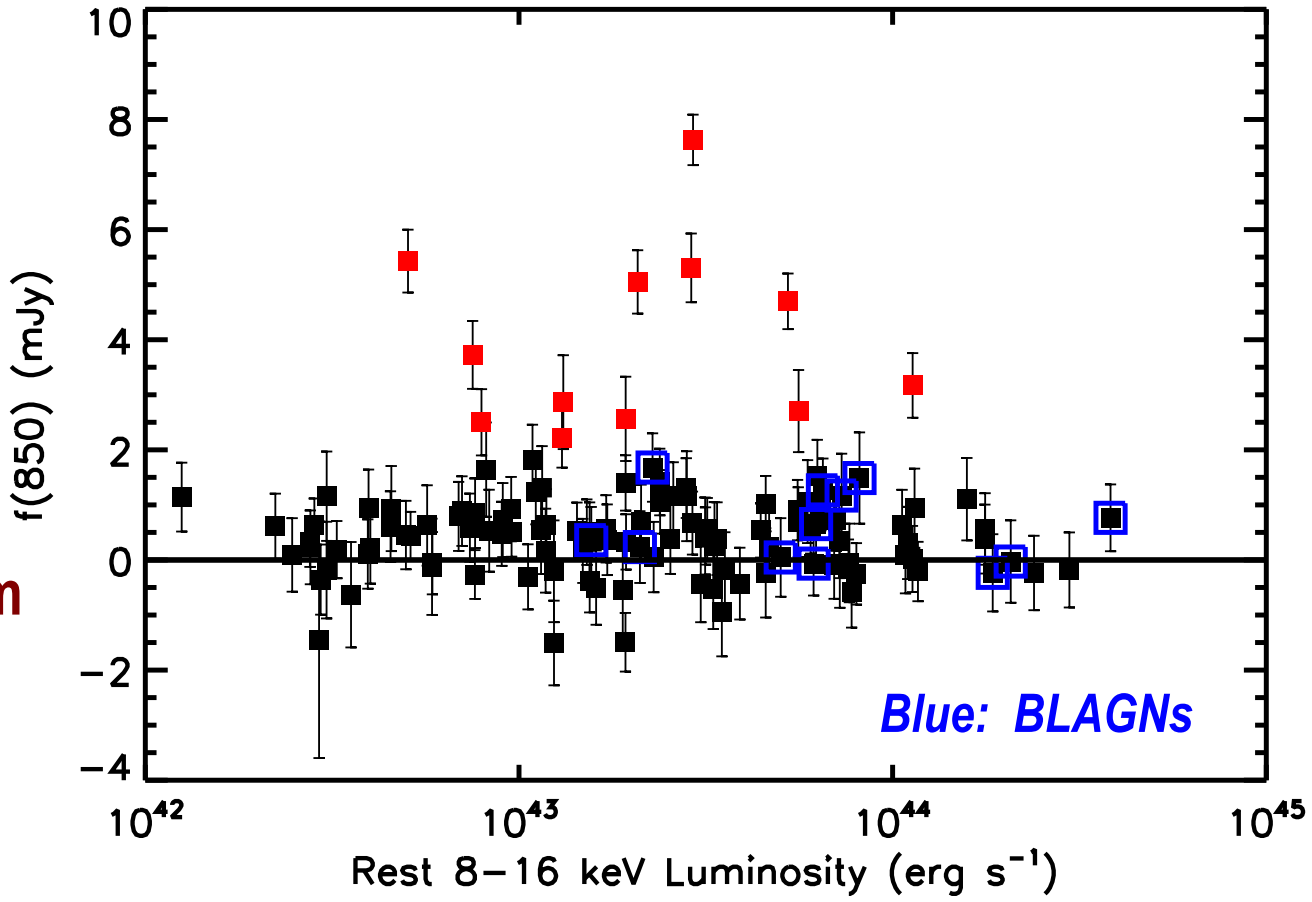


To minimize opacity effects, use hardest *Chandra* X-ray band available, 4-8 keV (Alexander et al. 2003 for CDF-N; Lehmer et al. 2012 for CDF-S)

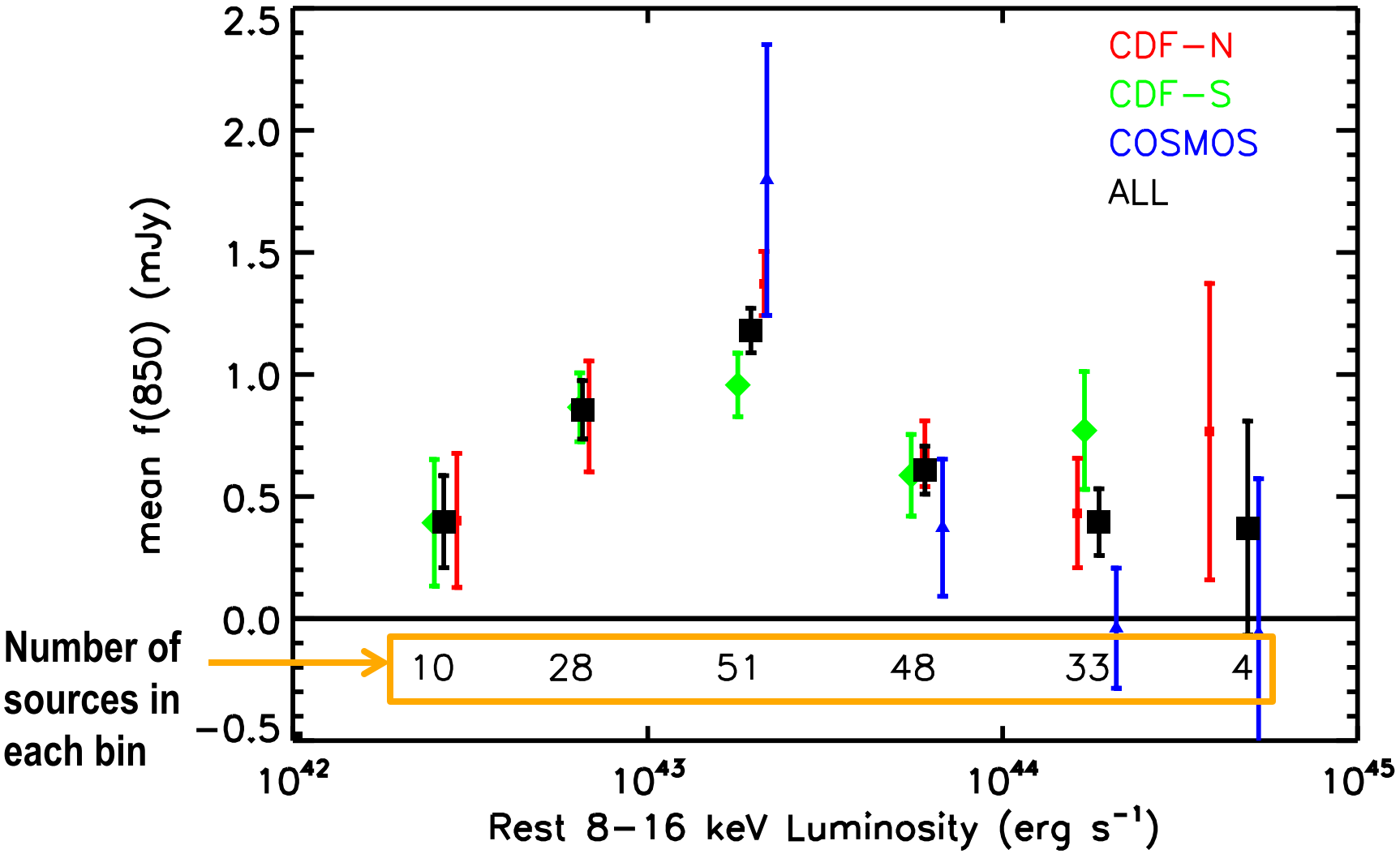
The bulk of the submm detected X-ray sources (>3σ) in the CDF-N and CDF-S are X-ray less luminous AGN

We see little submm light in the X-ray luminous AGN



The error-weighted means show a peak at ~$10^{43.5}$ erg s^{-1} before dropping at higher X-ray luminosities

Evident in the 2 CDF fields and in the COSMOS field (Casey et al. 2013)



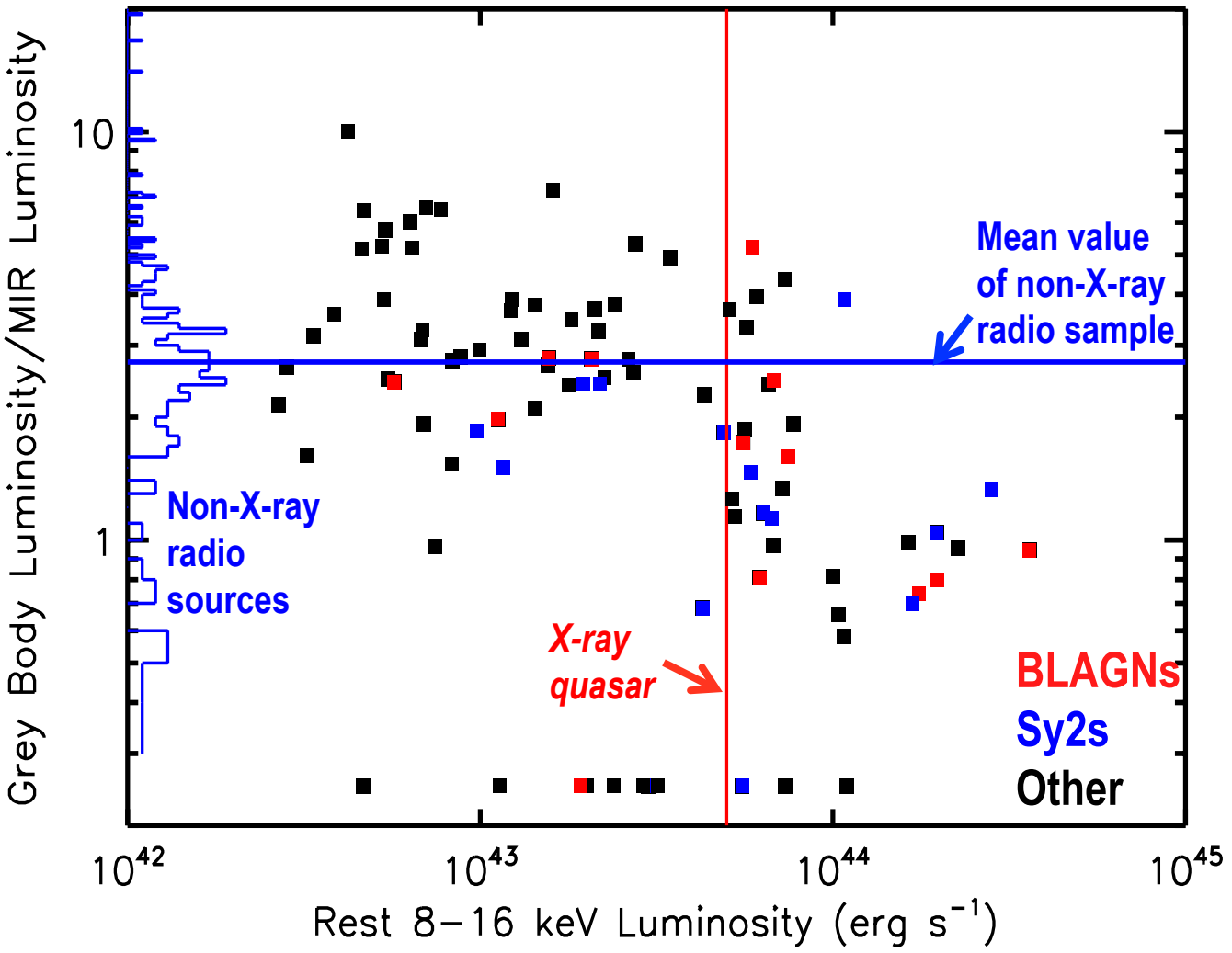
Finally, we can combine the submm/mm data with the Herschel FIR data and fit the individual source SEDs with a FIR grey body + a truncated MIR power law

Comparison of the relative strengths of the FIR and MIR components

Confirm existence of a FIR-MIR correlation in SF dominated galaxies

Most of the *X-ray less luminous* AGN follow this correlation, suggesting significant FIR emission due to SF

However, most of the *X-ray luminous AGN* are low relative to the correlation, as would be expected if SF is suppressed



Summary

- SMGs have SFRs up to 6000 M_{Sun} yr^{-1} over z=1.5-6 (rest-frame UV-selected galaxies only reach ~500 M_{Sun} yr^{-1}), but evidence for a turn-down in the SFR distribution function > 2000 M_{Sun} yr^{-1}
- Bright SMGs contribute an additional ~16% of the optical star formation history at all z>1 (to be added to the UV contribution)
- The star formation history is still missing *additional* contributions from faint SMGs, which do not appear to be highly overlapped with the rest-frame UV-selected galaxies
- High SFR galaxies do not contain X-ray luminous AGN
- Conversely, X-ray luminous AGN do not lie in high SFR galaxies; the SF in their host galaxies appears to be suppressed

The End