Which X-ray Sources Have Associated Star Formation?

Are the highest-z X-ray sources unusual?

Amy Barger

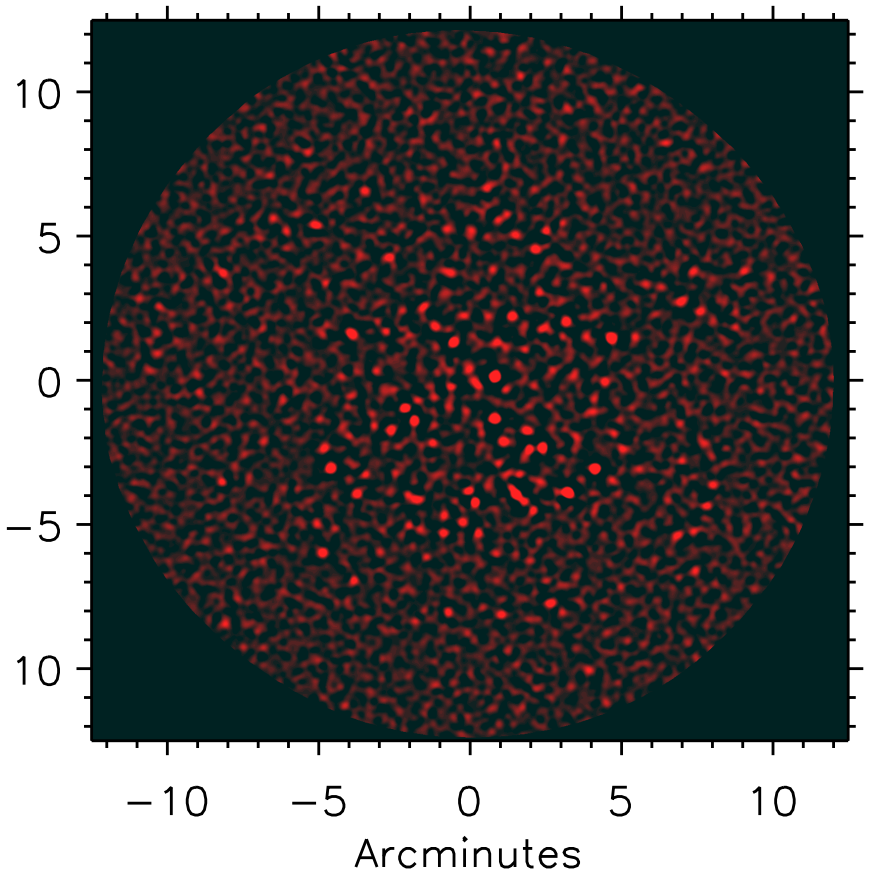
- To address these questions, we start with 850 micron SCUBA-2 observations of the Chandra Deep Fields

- We want such long-wavelength observations, because the light at these wavelengths is star formation rather than AGN dominated for most sources; the 850 micron fluxes are a crude measure of star formation rate (SFR) independent of redshift

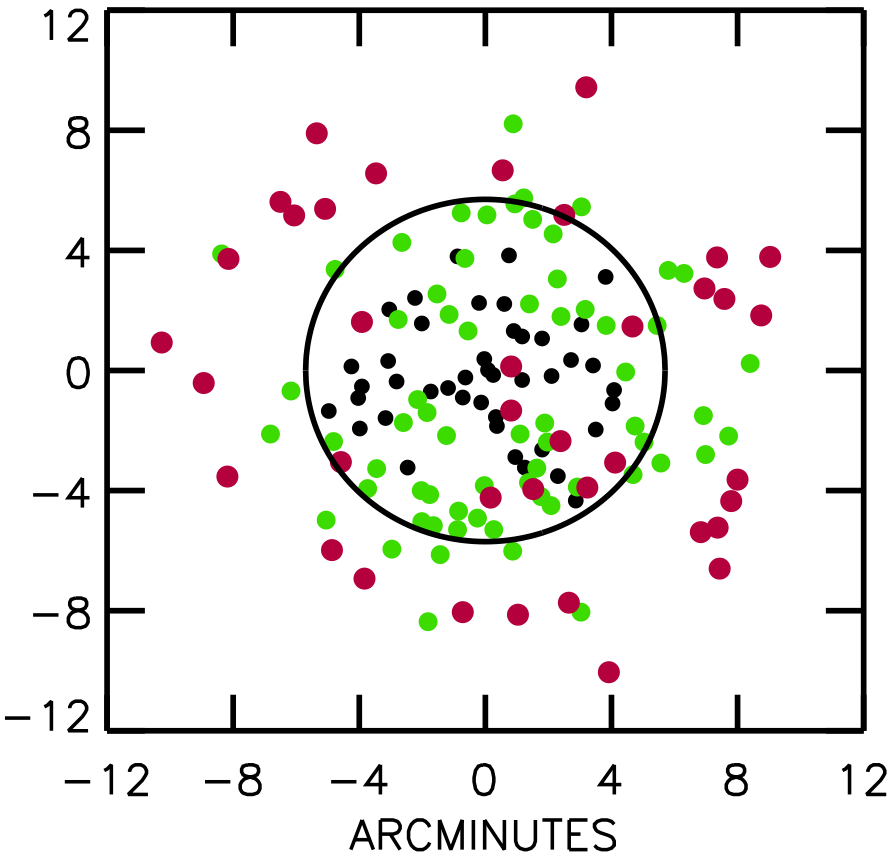
- Herschel observations are short enough in wavelength that they are contaminated by AGN at $z>>2$

Ultradeep SCUBA-2 850 micron images

CDF-S 146 > 4σ sources
(CDF-N 209 > 4σ sources)



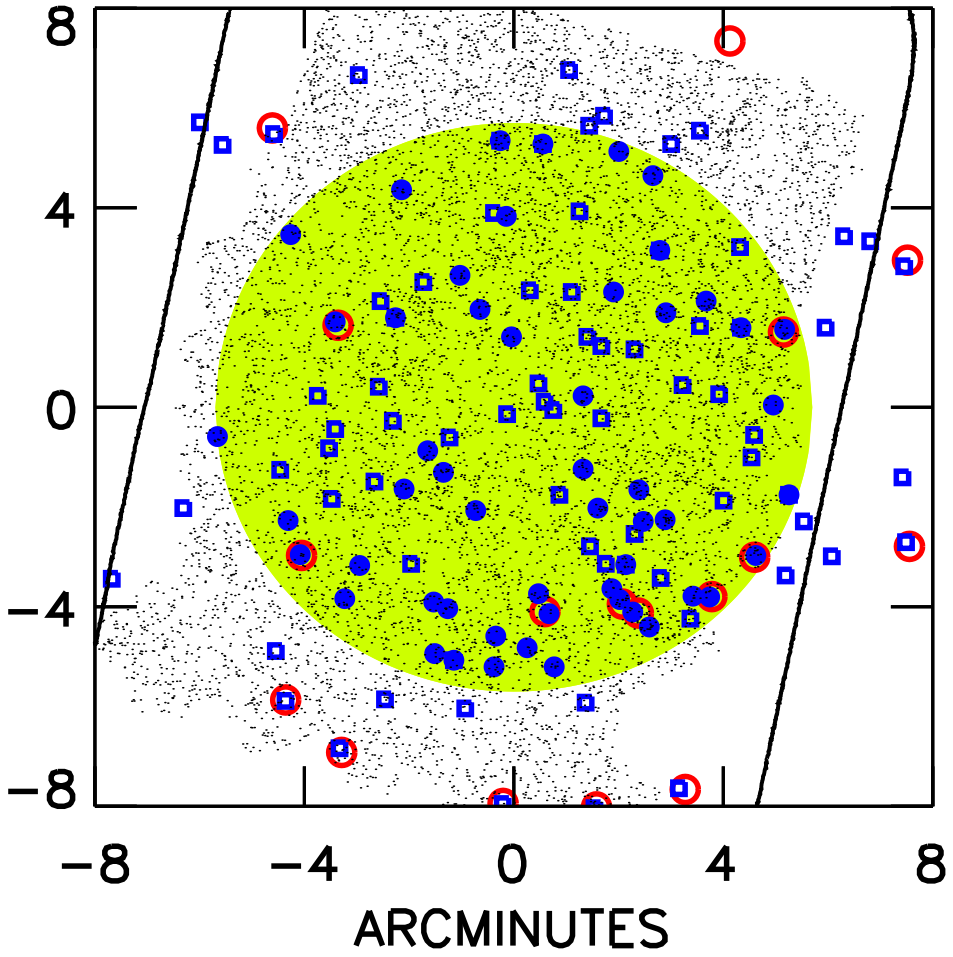
Focus on deep central CDF-S:
5.6’ radius (circle)



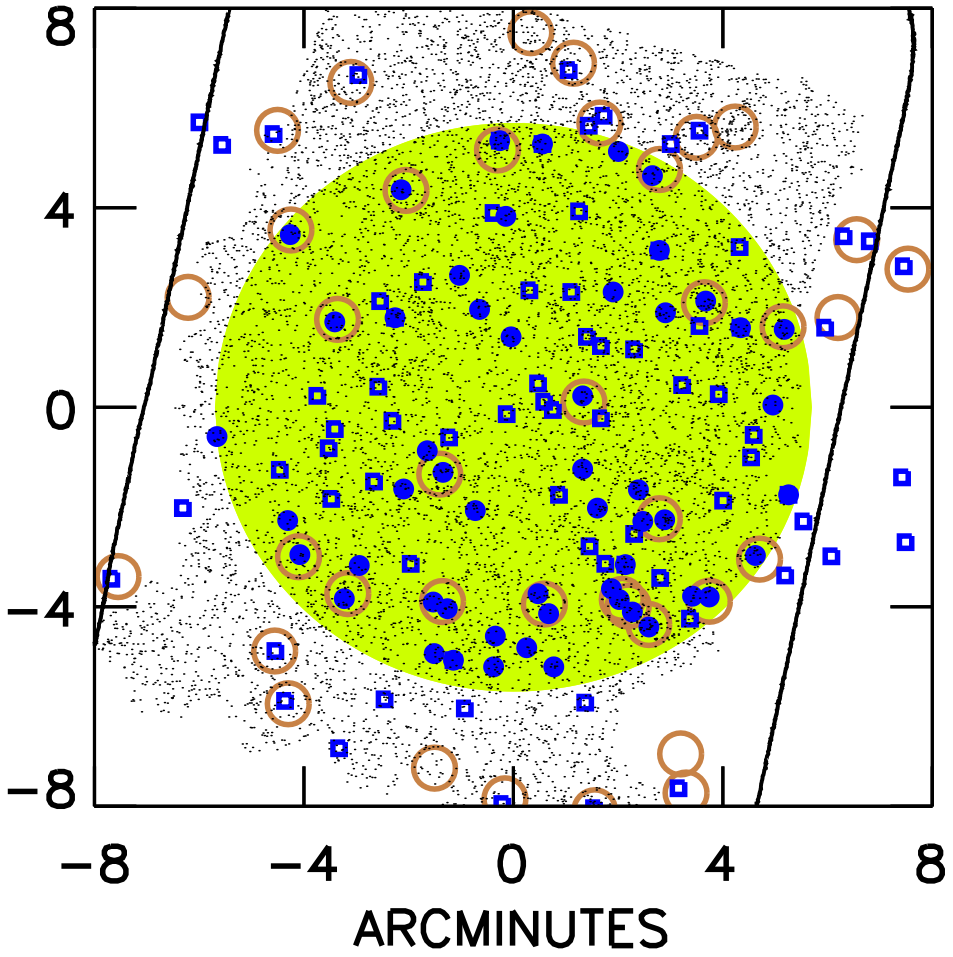
Red is >5 mJy
Green is 2.25-5 mJy
Black is <2.25 mJy

Cowie+17

Much deeper than previous single-dish surveys



LABOCA 870 micron: red circles
Weiss et al. 2009 (ALESS based on this)



AzTEC 1.1mm: gold circles
Scott et al. 2010

Green = deep Chandra, black shading = CANDELS, black rectangle = GOODS-Herschel

Followup with ALMA (SMA for CDF-N) for precise positions

BASIC Survey (Band 7, 870 micron)

- We targeted SCUBA-2 sample (obtained rms on peak fluxes of ~0.13 mJy, total area ~ 5 arcmin^2, only considered sources within 8.7" radius, which is half-power radius of the ALMA primary beam in band 7)

- Natural resolution 0.23", but generally worked with 0.5" tapered images for better integrated fluxes

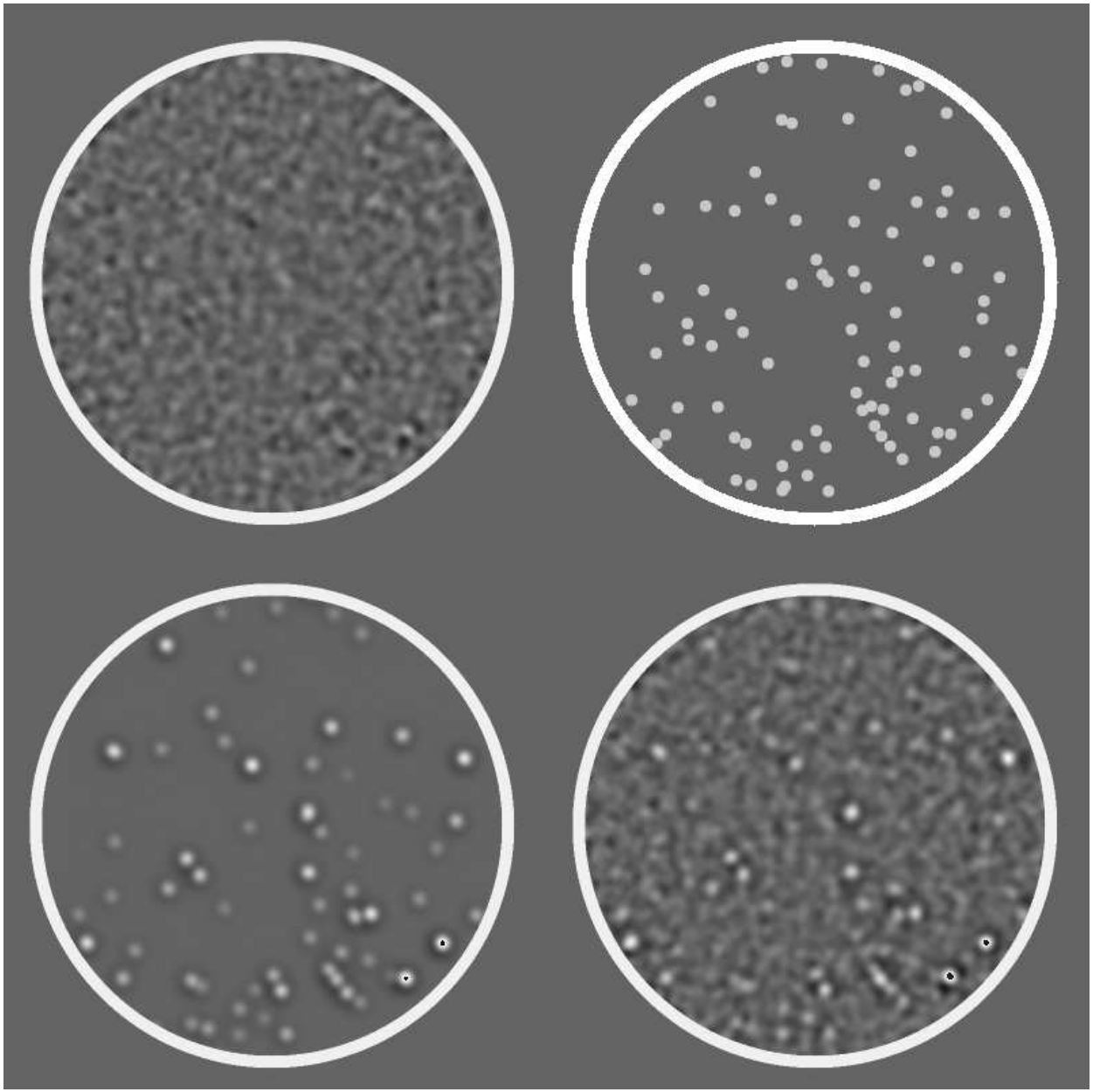
- Fluxes used are corrected to total using aperture corrections

- We took 15 additional sources from archive

- **Total sample of 68 >4.5σ ALMA detections in central 5.6' region** (simulations show significant number of spurious sources at lower S/N, but we do not expect more than 1 contaminating source at this level)

How does SCUBA-2 do in finding the submm sources?

SCUBA-2 minus ALMA; nothing extra! – *SCUBA-2 finds all the submm sources at >2.5 mJy*



ALMA pointings

ALMA-based image (ALMA smoothed through SCUBA-2 PSF)

SCUBA-2 image

Cowie+18

Mapping large areas with ALMA directly is less efficient

(Observational status prior to our BASIC ALMA program)

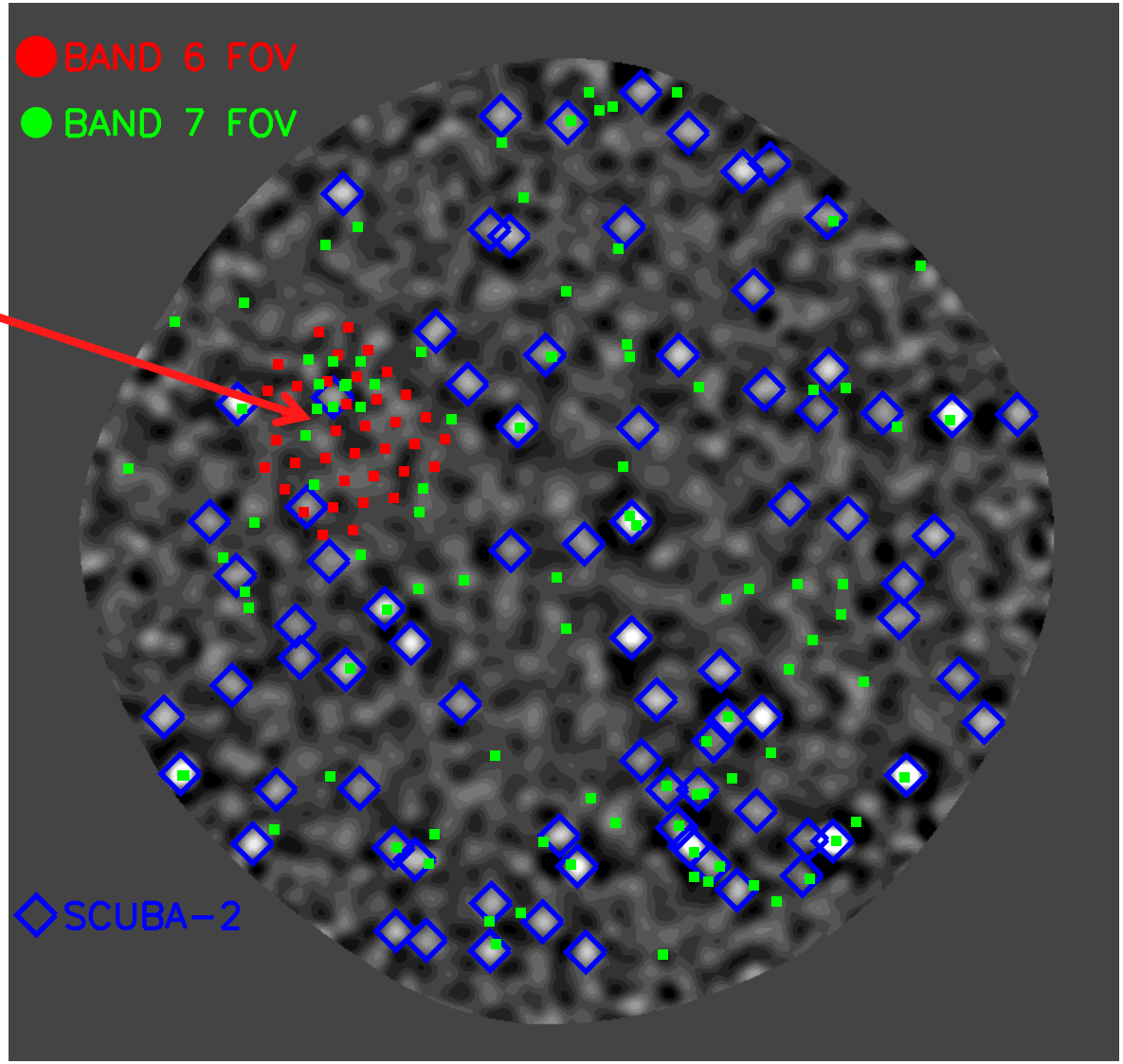
DIRECT ALMA SEARCHES (ALL BAND 6 OR 1.2mm/1.3mm):

Dunlop+17 (3; 4.5 arcmin^2)

Ueda+18 (12; 26 arcmin^2)

Franco+18 (16 + 4 that are likely false; 69 arcmin^2)

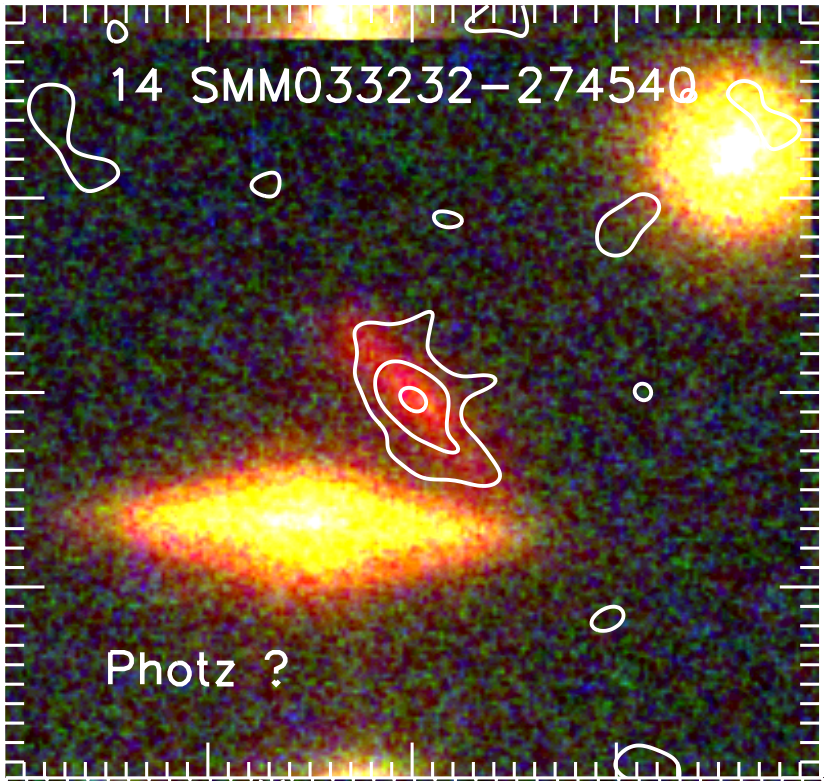
Combined (excluding overlaps): 22 sources, of which we detected 18. Remaining 4 from Ueda+18, but 2 that are likely false

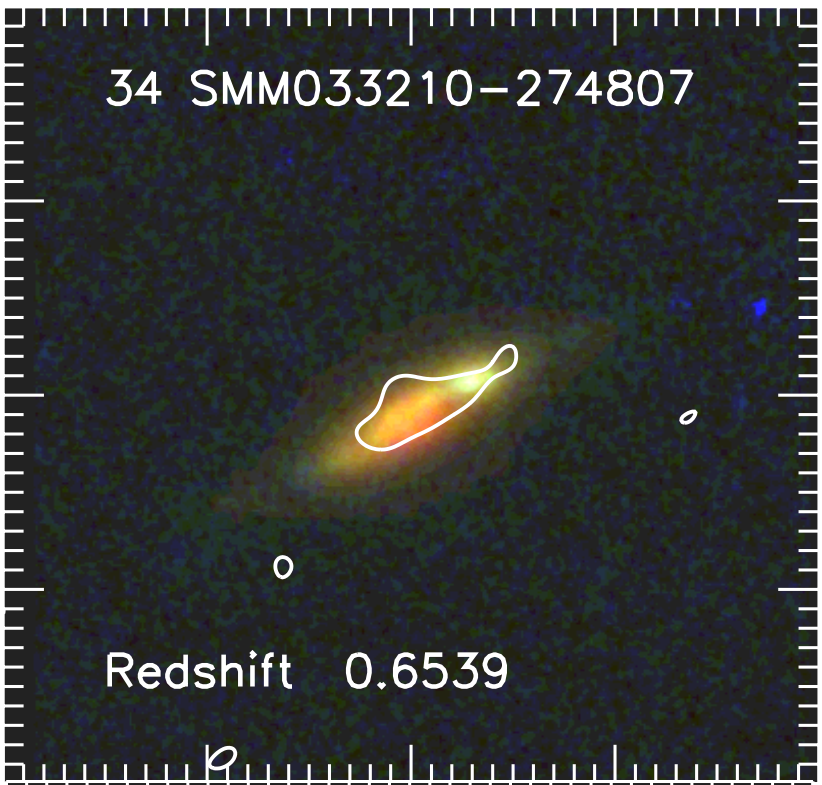


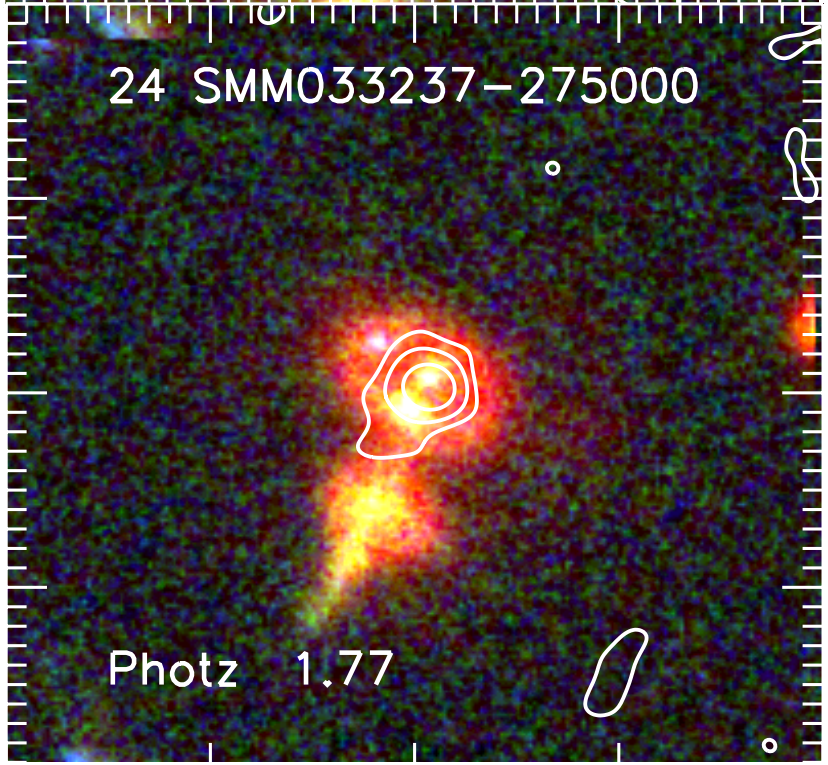
GREAT ADVANTAGE

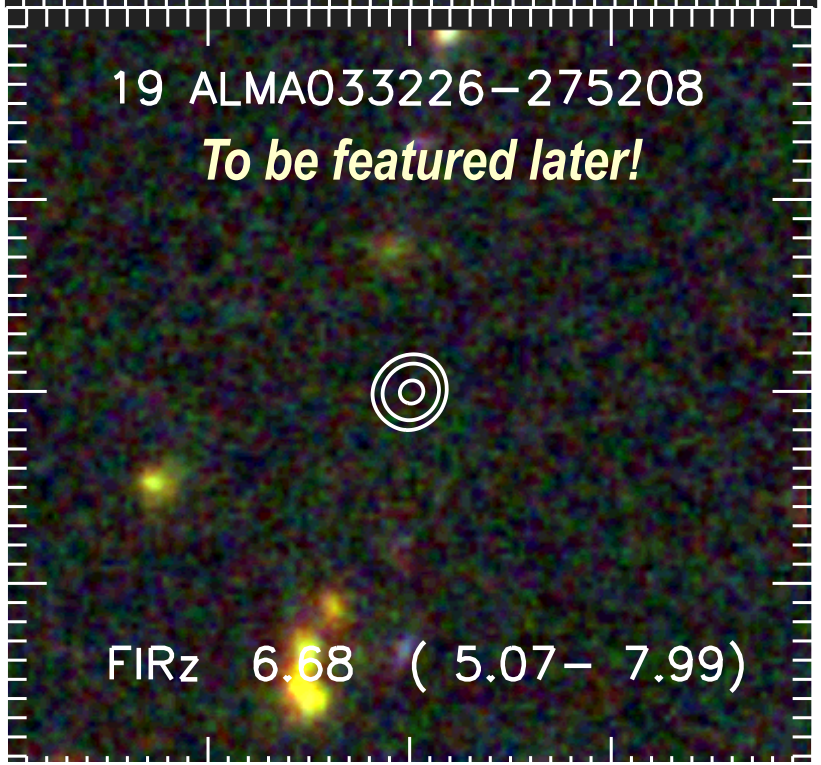
Ultradeep HST - B, Z, H (4" x 4")

ALMA shown by white contours

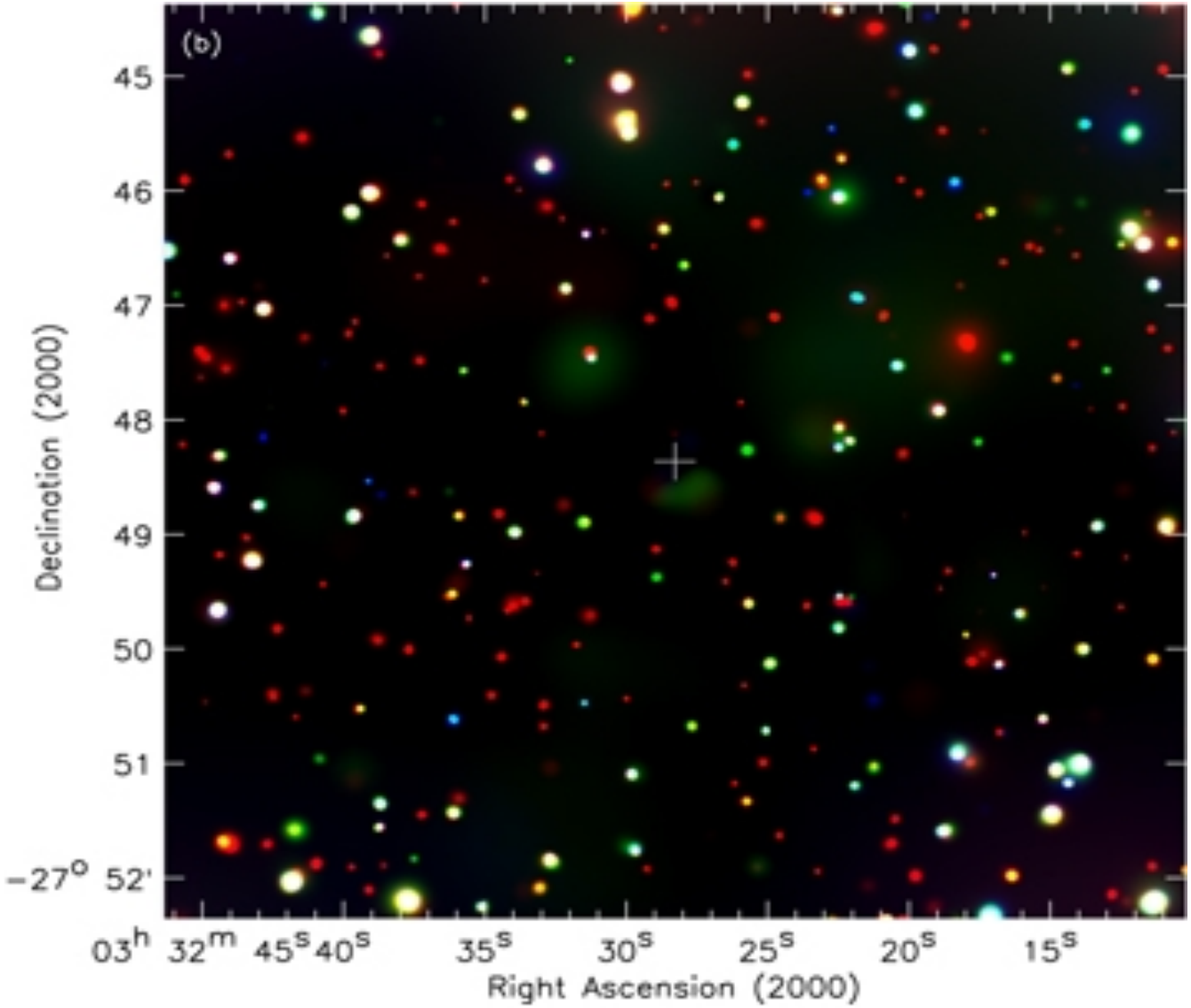








Now consider the CDF-S 7 Ms X-ray image



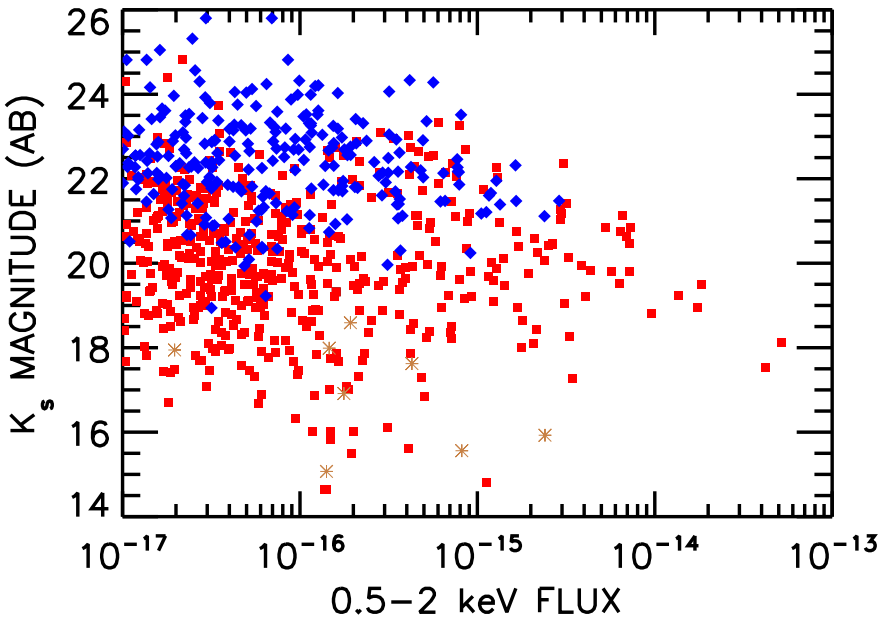
central 8’ x 8’

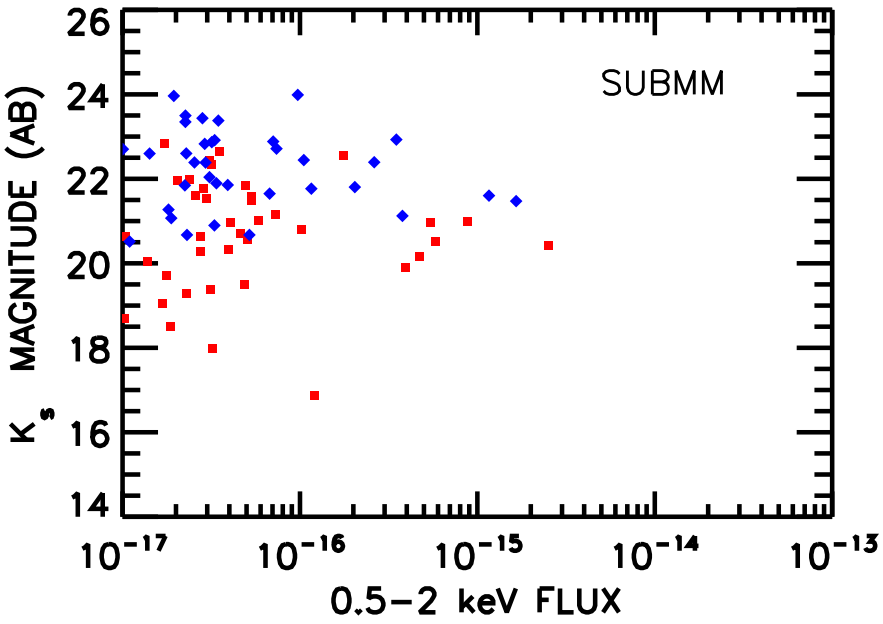
0.5-2 keV (red), 2-4 (green), 4-7 (blue)

Luo+17

X-ray sources in CDF-S intensively observed spectroscopically

576 of 983 sources in 10' radius have spectroscopic redshifts, and we have assigned them optical spectral types (red)





Barger+18

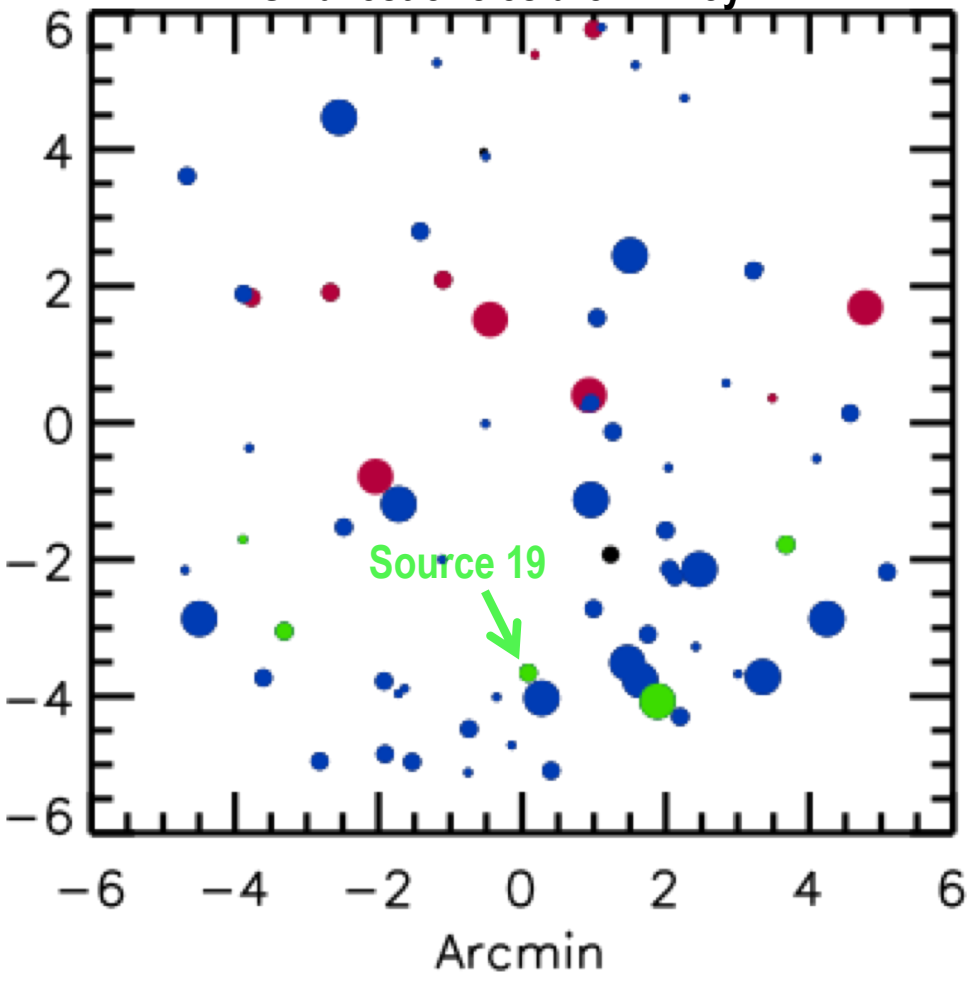
ALMA Sample:

Red = specz

Blue = photz (from Hsu+14)

Green = NIR blank

Largest circles are >4 mJy
Medium circles are >2 mJy
Smallest circles are >1 mJy



Open squares: > 2mJy ALMA

Chandra AGN Sample: (>10^43 erg/s)

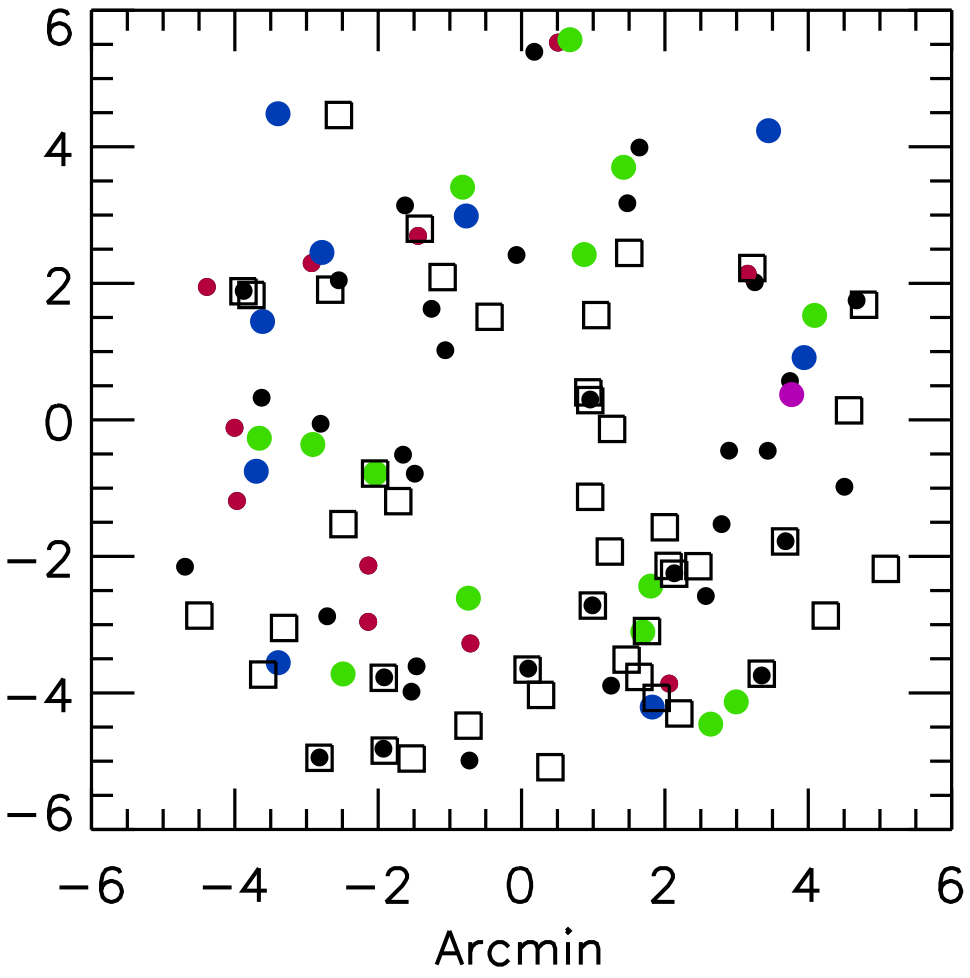
Purple = BALQSO

Blue = BLAGN

Green = Type 2

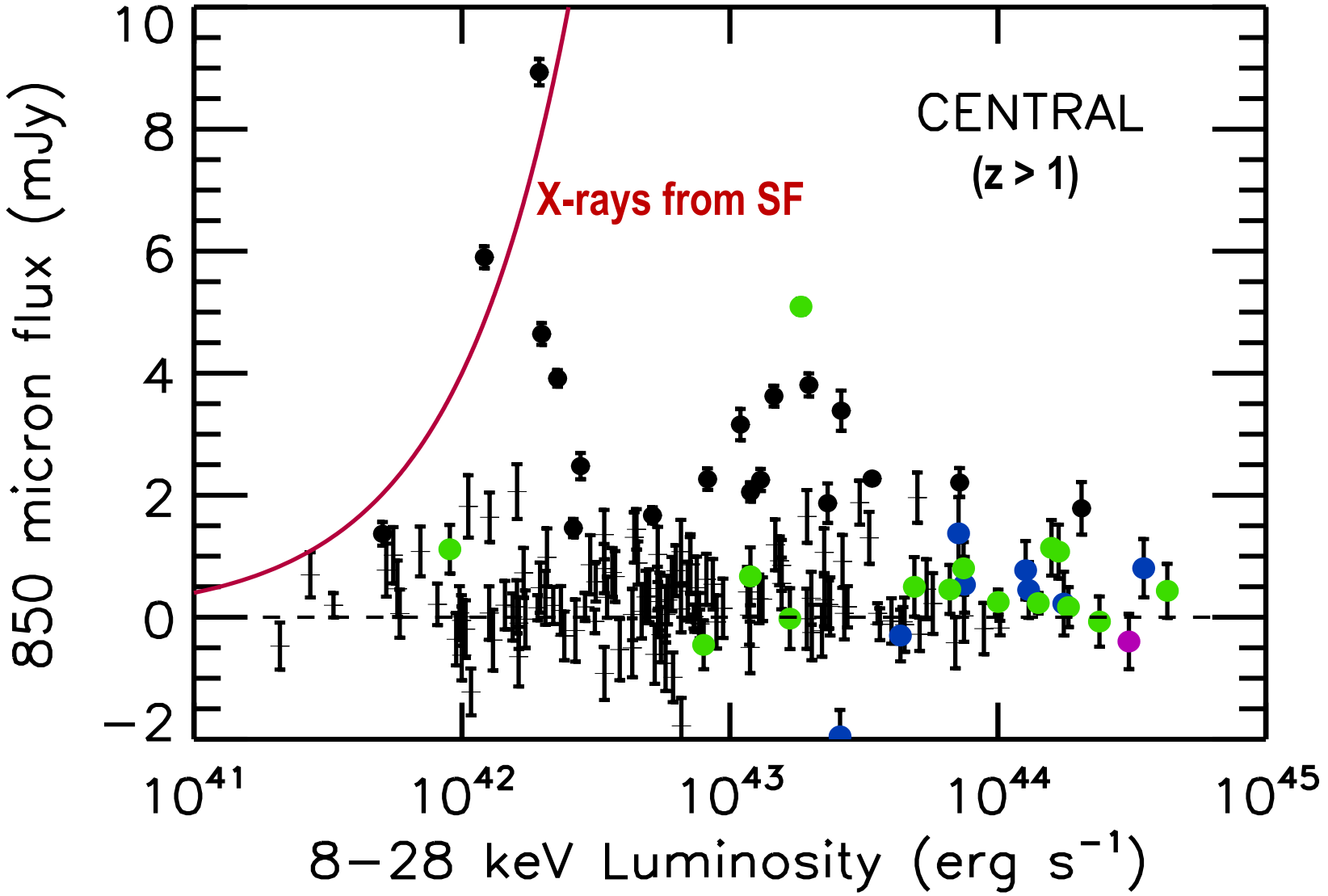
Red = other specz

Black = photz (from Hsu+14)



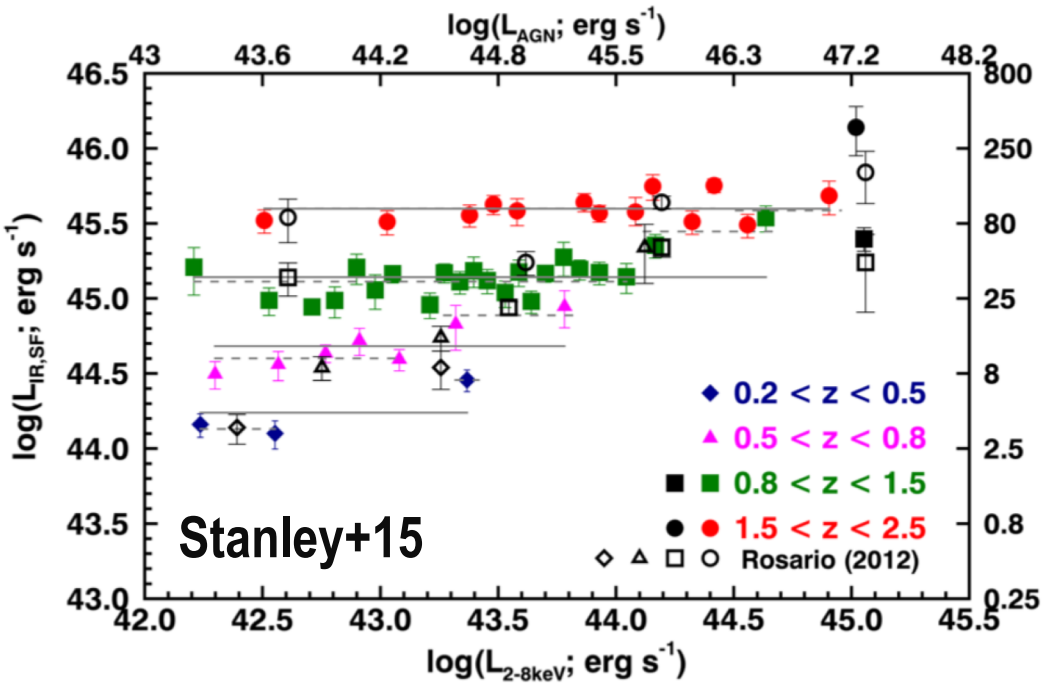
850 micron flux versus X-ray luminosity

Blue = BLAGN, Green = type 2, Purple = BALQSO



(Note: circles show ALMA measurements, crosses show SCUBA-2 measurements)

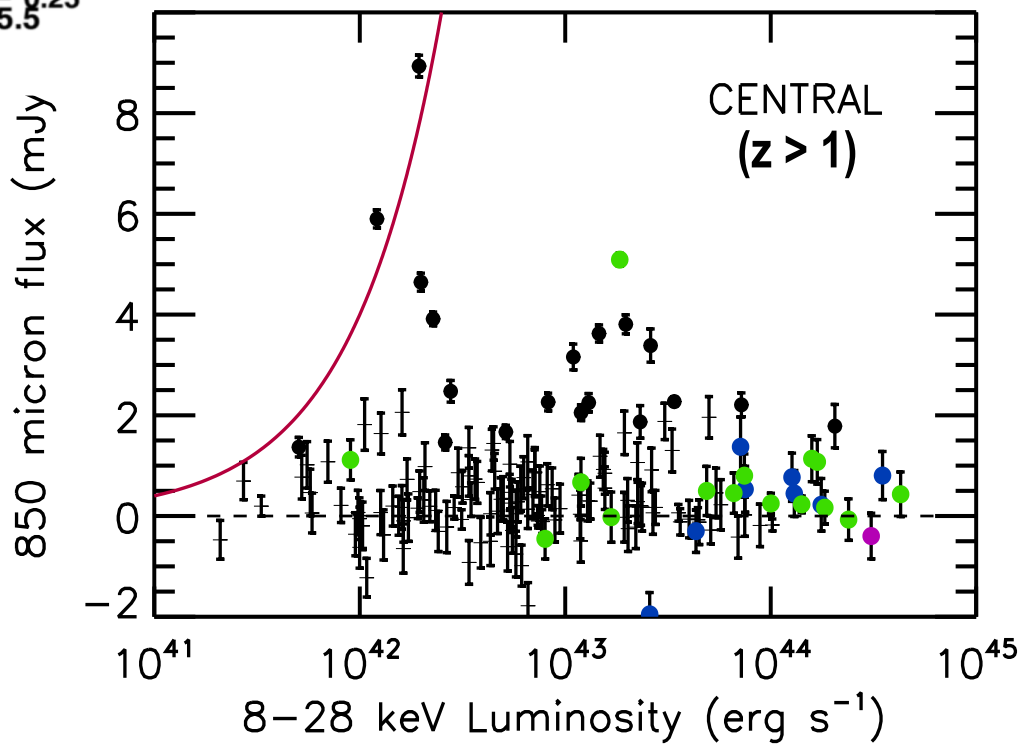
A flat relation between mean SFR and X-ray luminosity



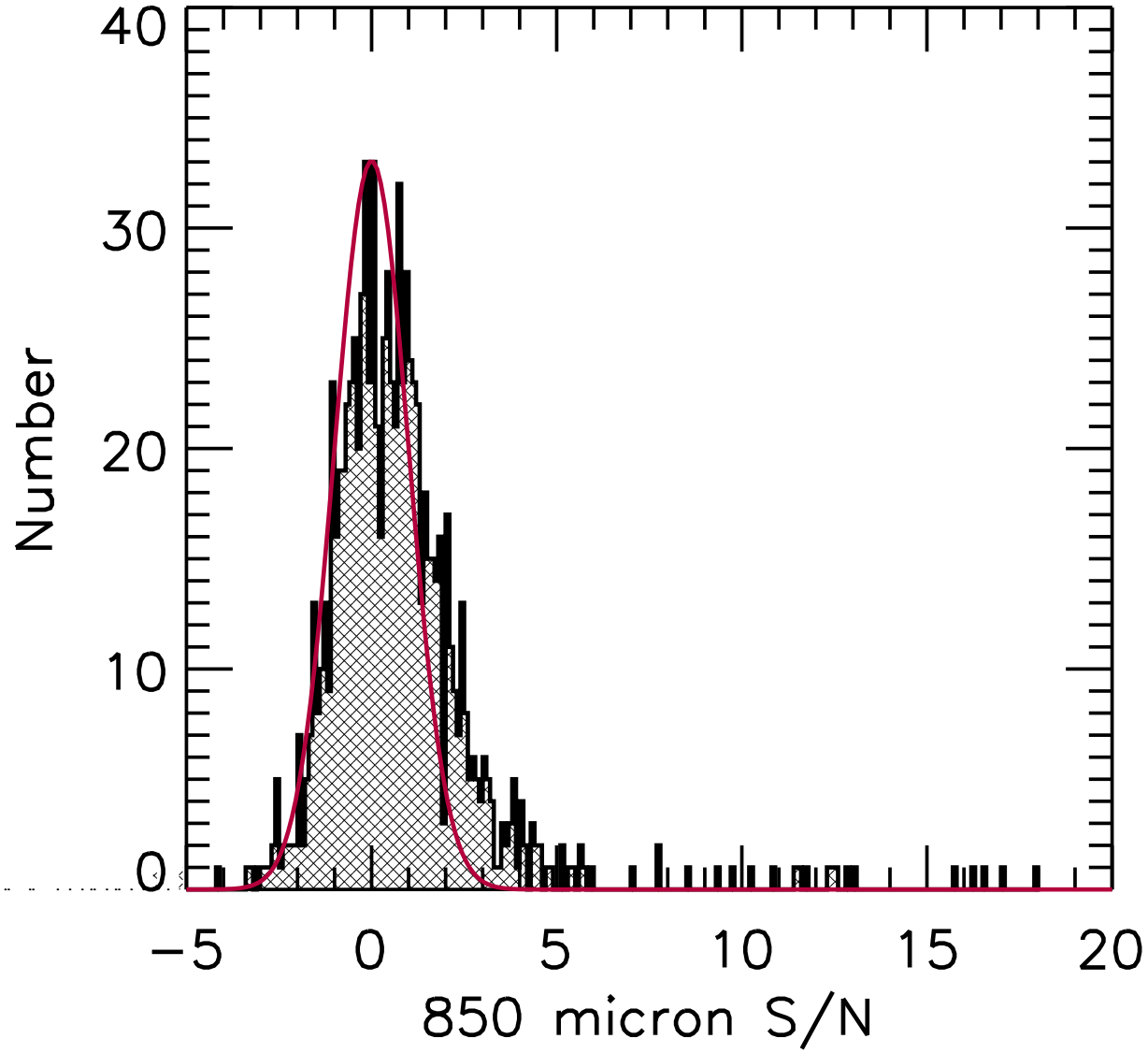
Is this misleading?

The ultradeep Chandra and ALMA images let us see the problem based on the properties of individual sources:

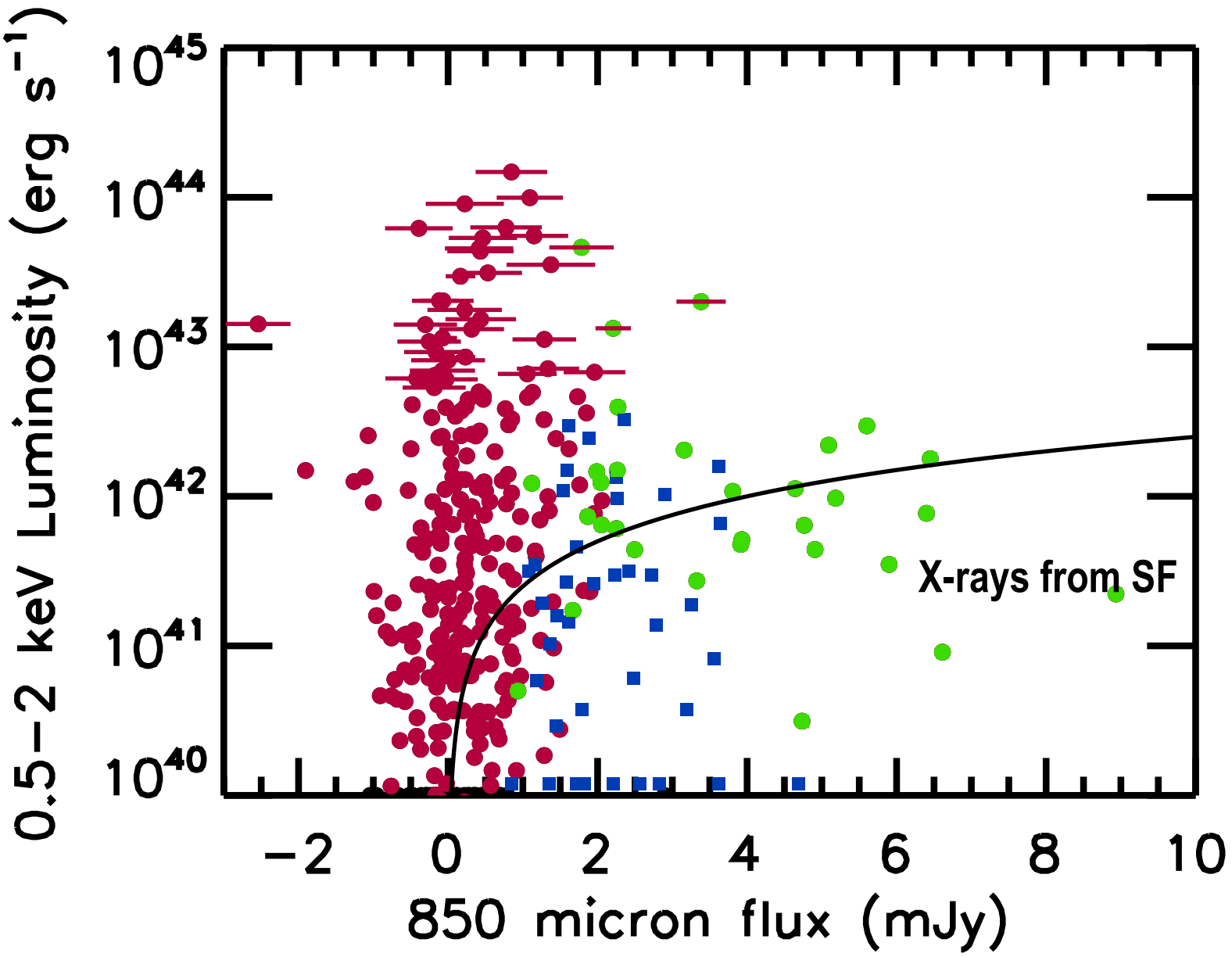
Odd distribution of submm fluxes at any given X-ray luminosity



Indeed, the distribution of submm flux from X-ray sources is highly skewed – the extended tail dominates the mean SFR



Barger+18



X-ray luminous AGN are mostly not strong submm sources, and submm sources are mostly not X-ray luminous AGN

How many high-z X-ray AGN are there, and what are their properties?

Open squares > 2mJy ALMA

Chandra AGN Sample: (>10^43 erg/s)

Purple =BALQSO

Blue = BLAGN

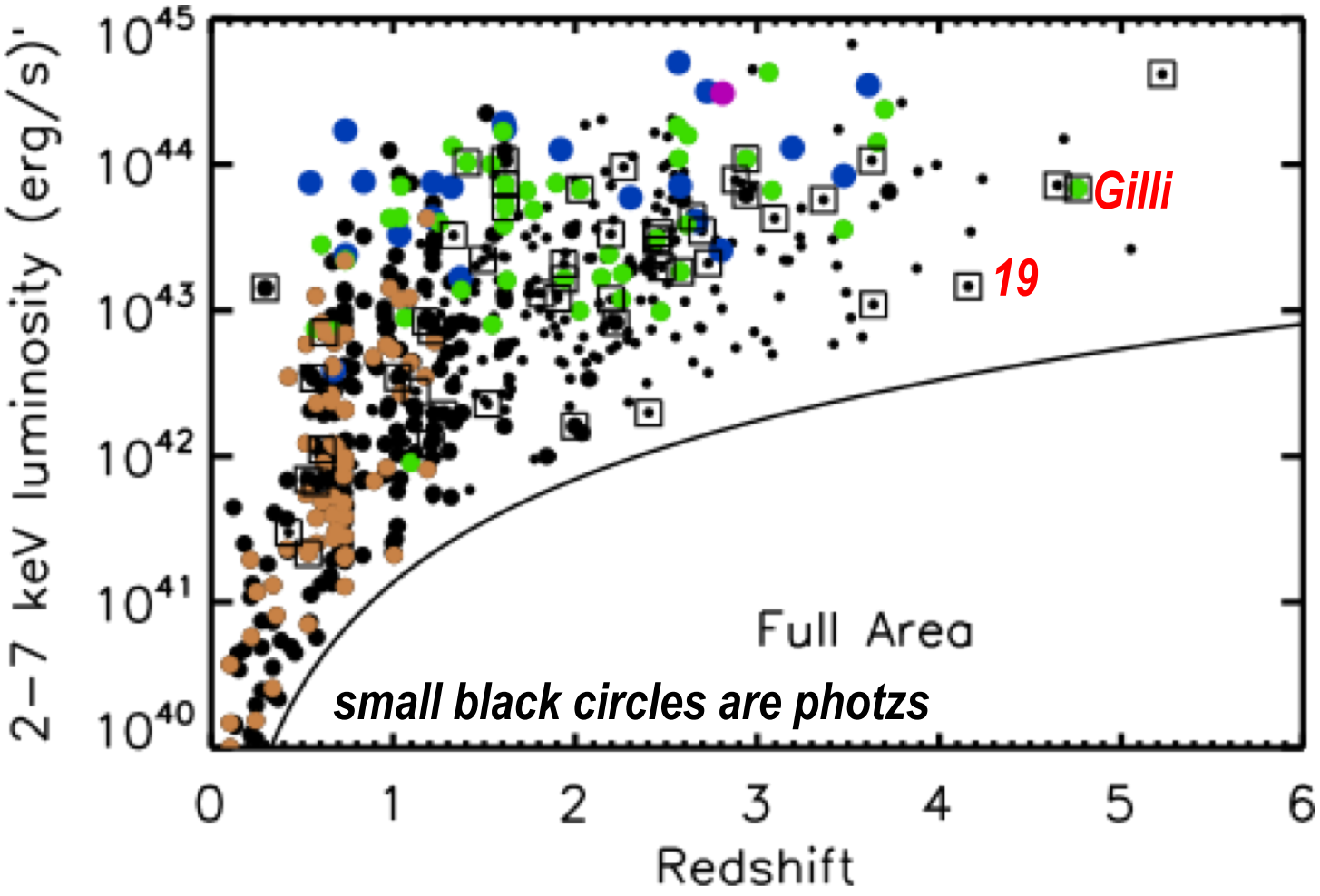
Green = Type 2

gold = absorber

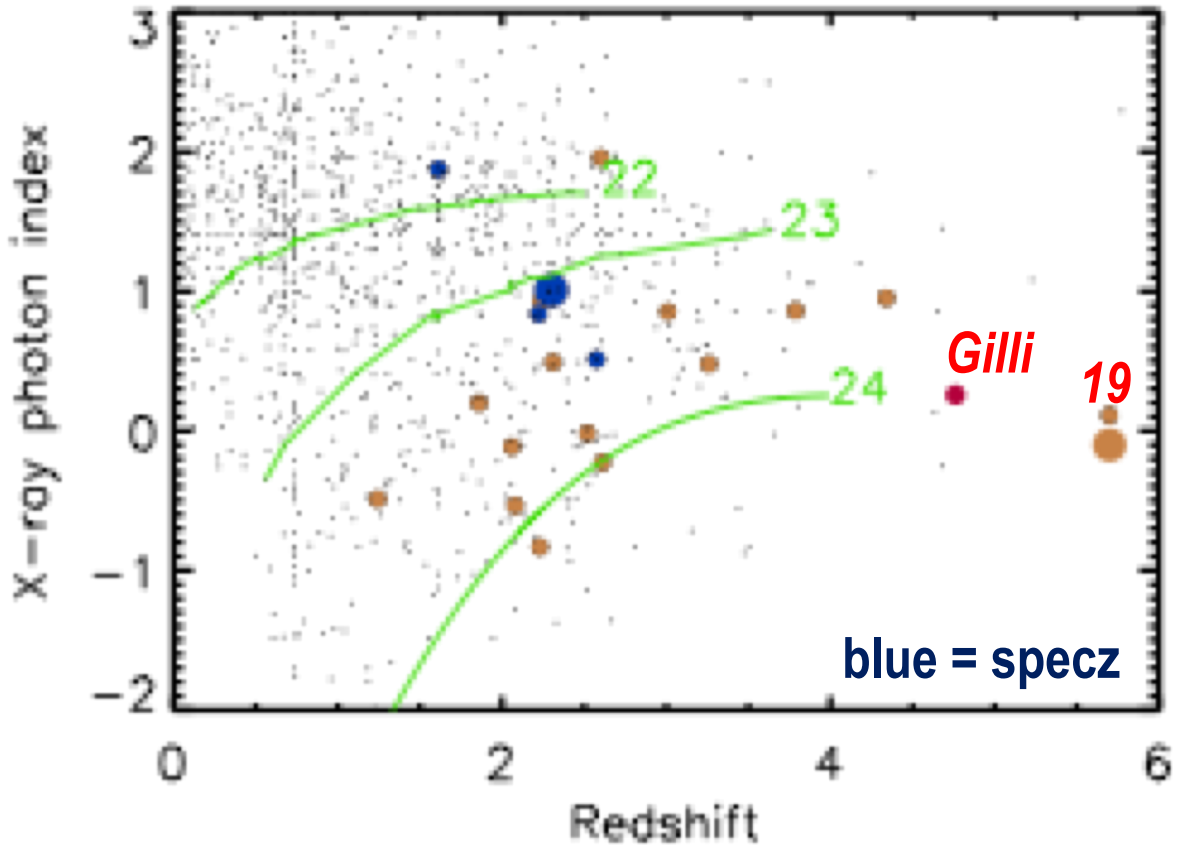
large black = SFer

Only 10 z>4 AGN

- 1 is a known z = 4.76 Compton thick AGN (Gilli+11)
- A fairly large fraction (4/10) are submm sources, including the Gilli+11 AGN



What about the obscuration in the submm AGN?



At lower redshifts, most have higher absorption than the general X-ray population (dots). They are not Compton thick, but they do have high hydrogen column densities (different from general pop)

High-z sources are near to or Compton thick

Summary

- There is a wide distribution of SFRs at any given X-ray luminosity. The mean SFR is dominated by a relatively small number of sources. Stacking may not be a good approach, since it is always weighted towards the strong sources

- The most luminous X-ray AGN are generally not the strongest star formers

- z>4 X-ray AGN are not common (caution: still some sources too faint even for photzs that might be at high z), but at these redshifts we do see sources exhibiting obscured AGN activity and extreme star formation indicating co-eval evolution