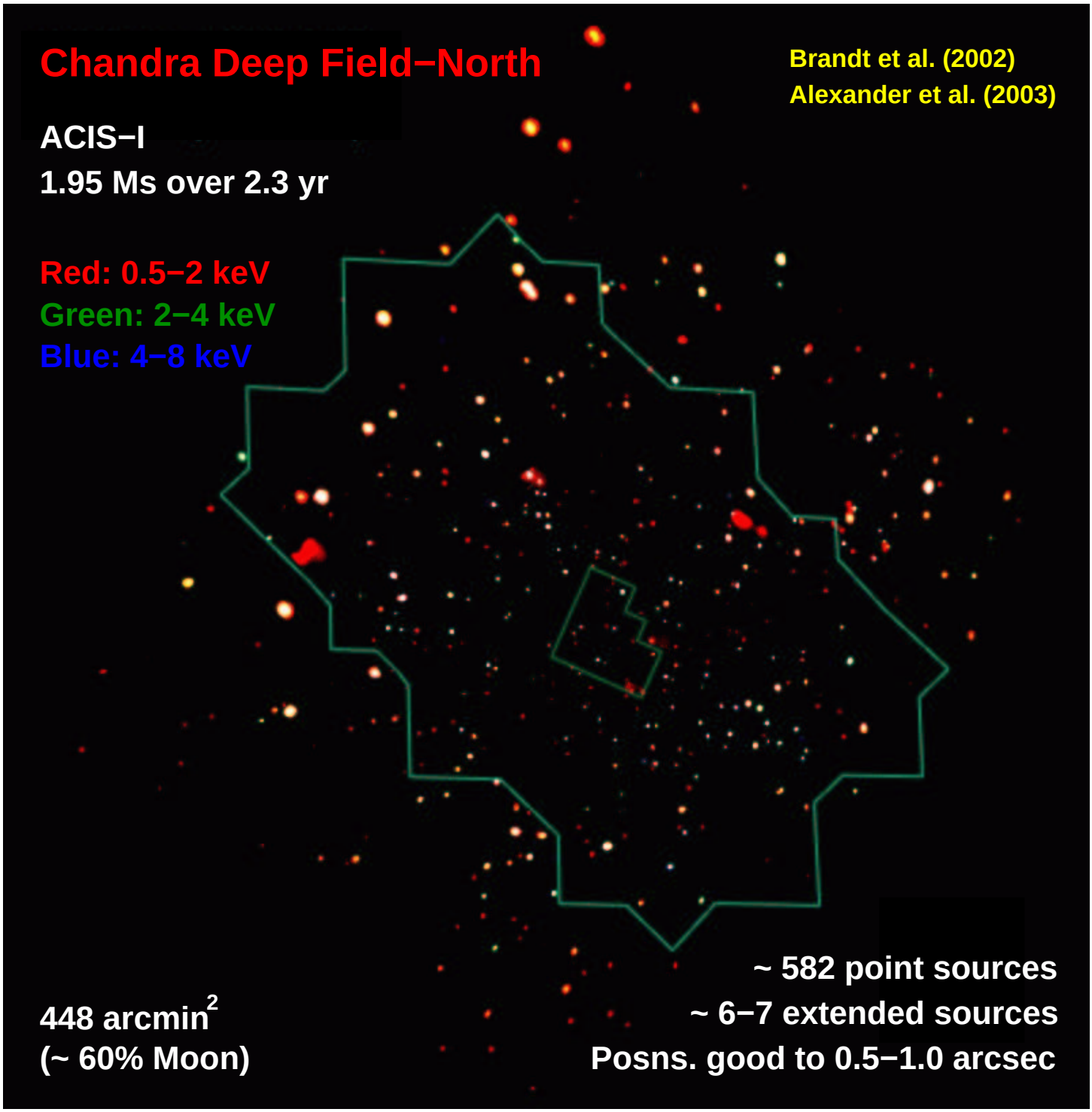
Results from the Chandra Deep Field−North

Brandt, Alexander, Bauer, Garmire, Hornschemeier, Immler, Lehmer, Schneider, Vignali, Wu, Barger, Cowie, Bautz, Nousek, Sargent, Townsley



50−250 times the sensitivity of pre−Chandra surveys and still photon limited near the aim point.

HST ACS imaging of deepest 1/3 of CDF−N
BViz to 27−28
0.125" resolution

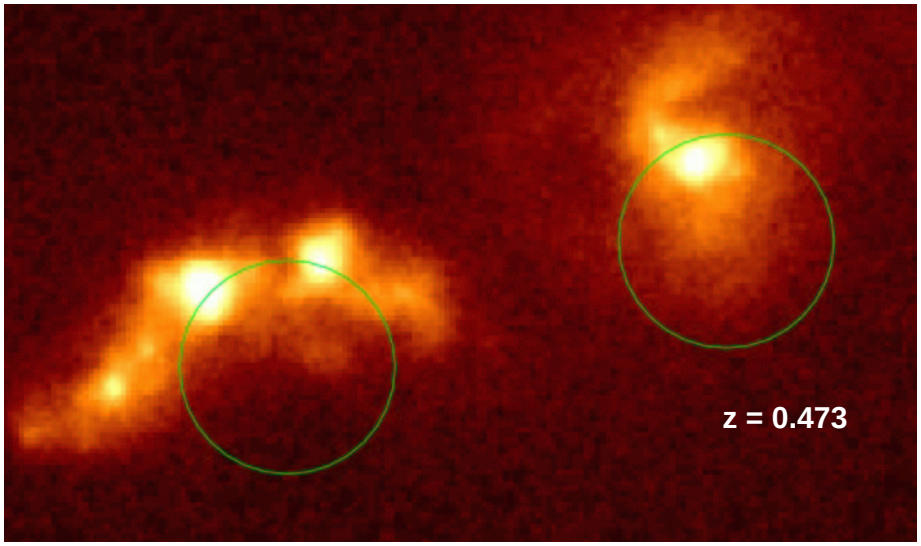
~ billion pixels

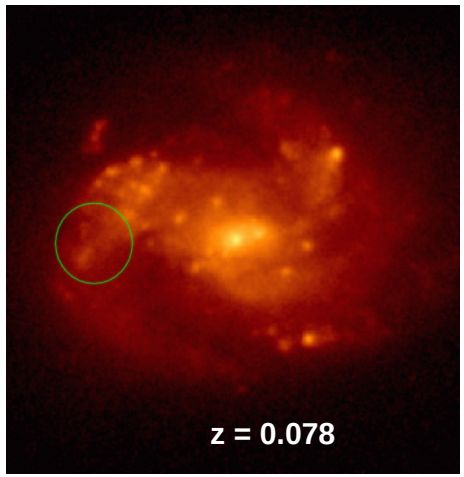
Giavalisco et al. (2003)

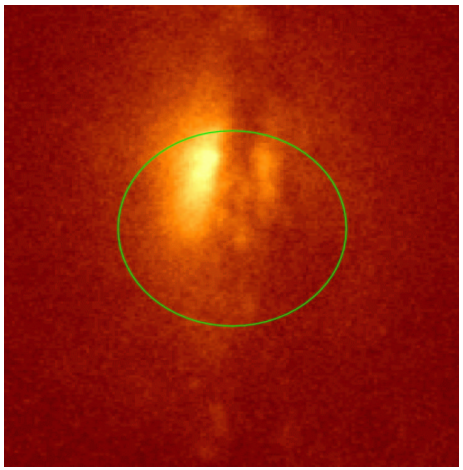
Great Observatories Origins Deep Survey (GOODS)

160 sq. arcmin (30 times HDF−N) − also CDF−S

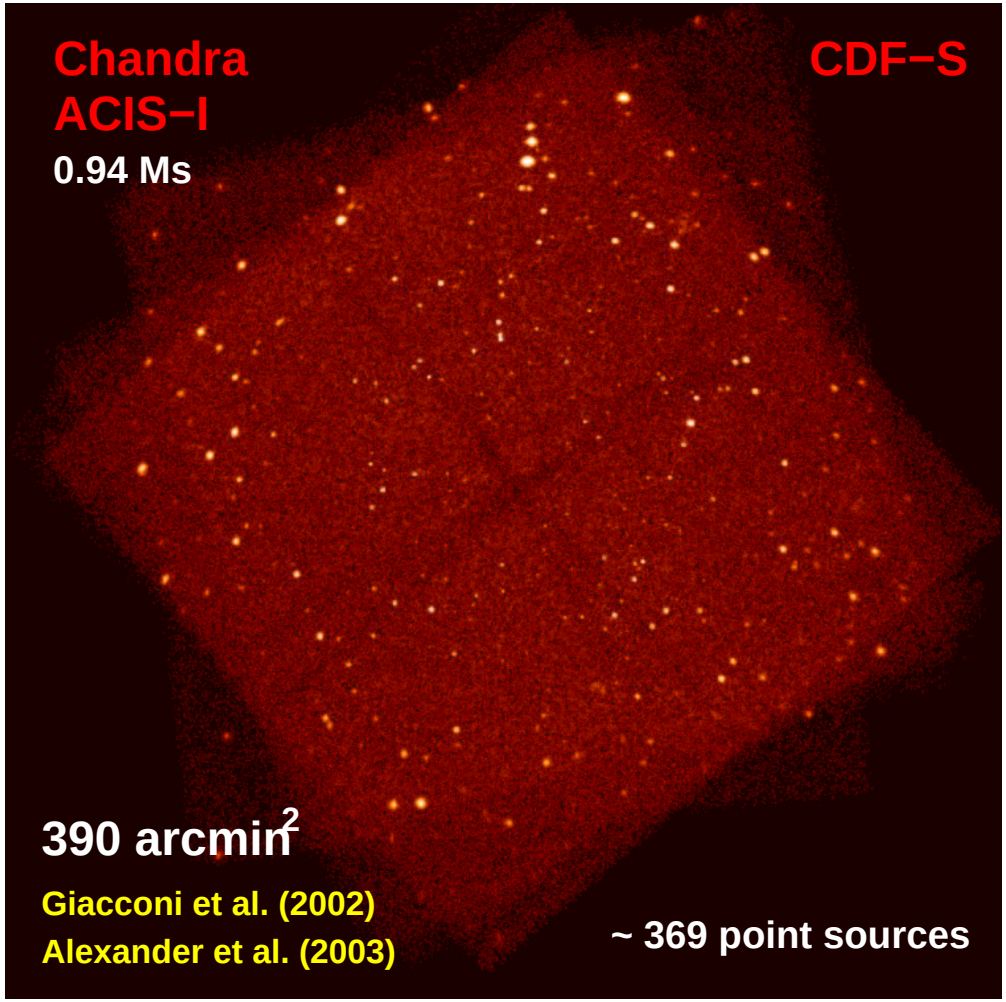
HST ACS images of Chandra sources
(X−ray error circles are ~ 1" in radius)

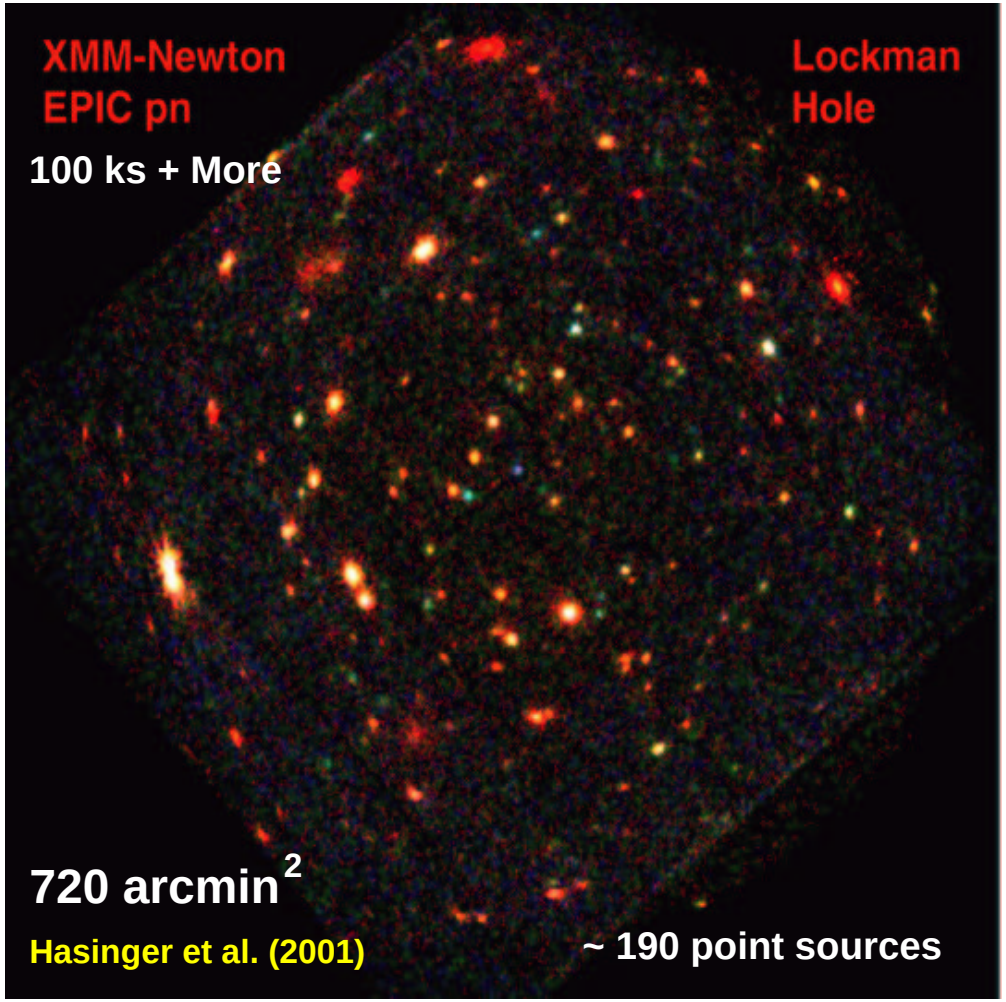






Other Deep Chandra and XMM−Newton Surveys

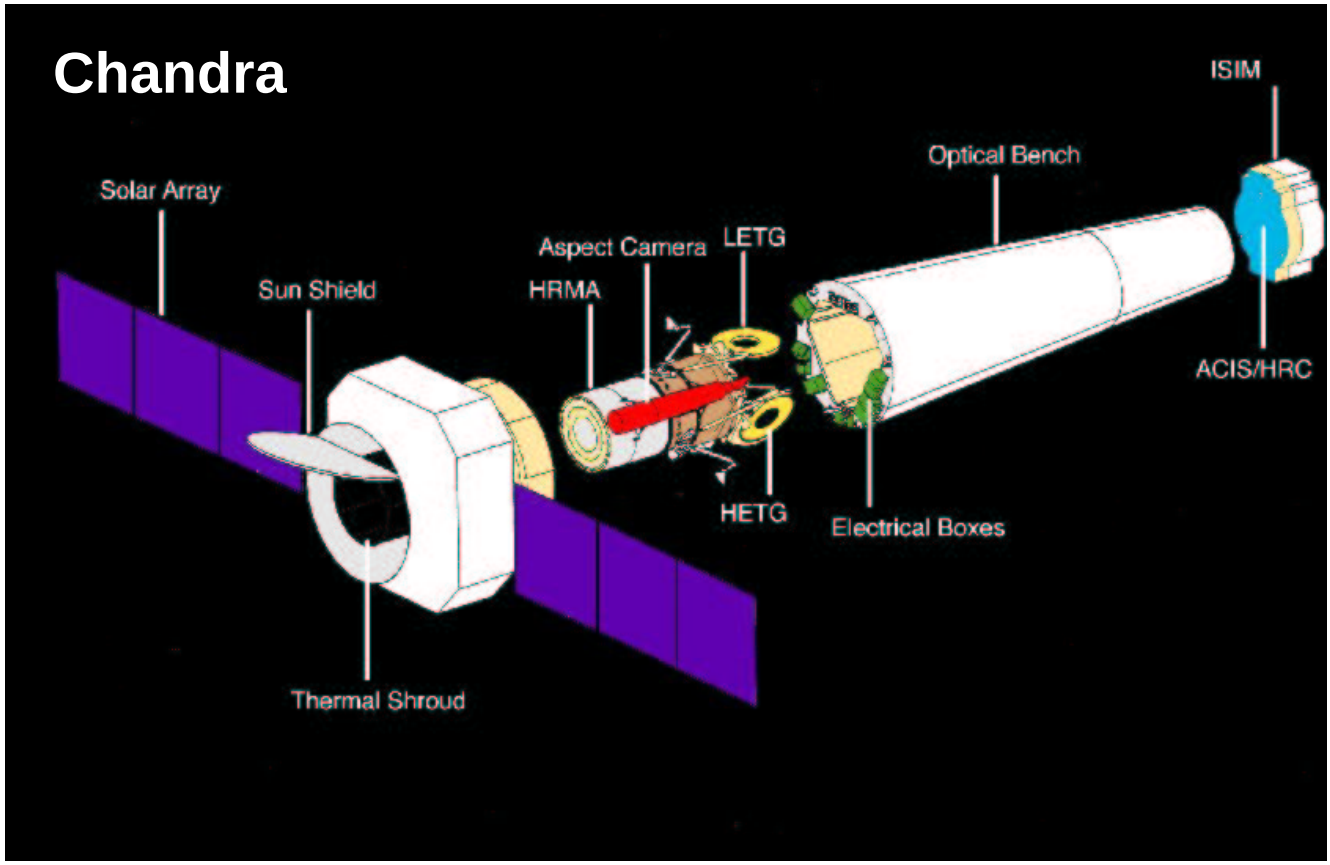


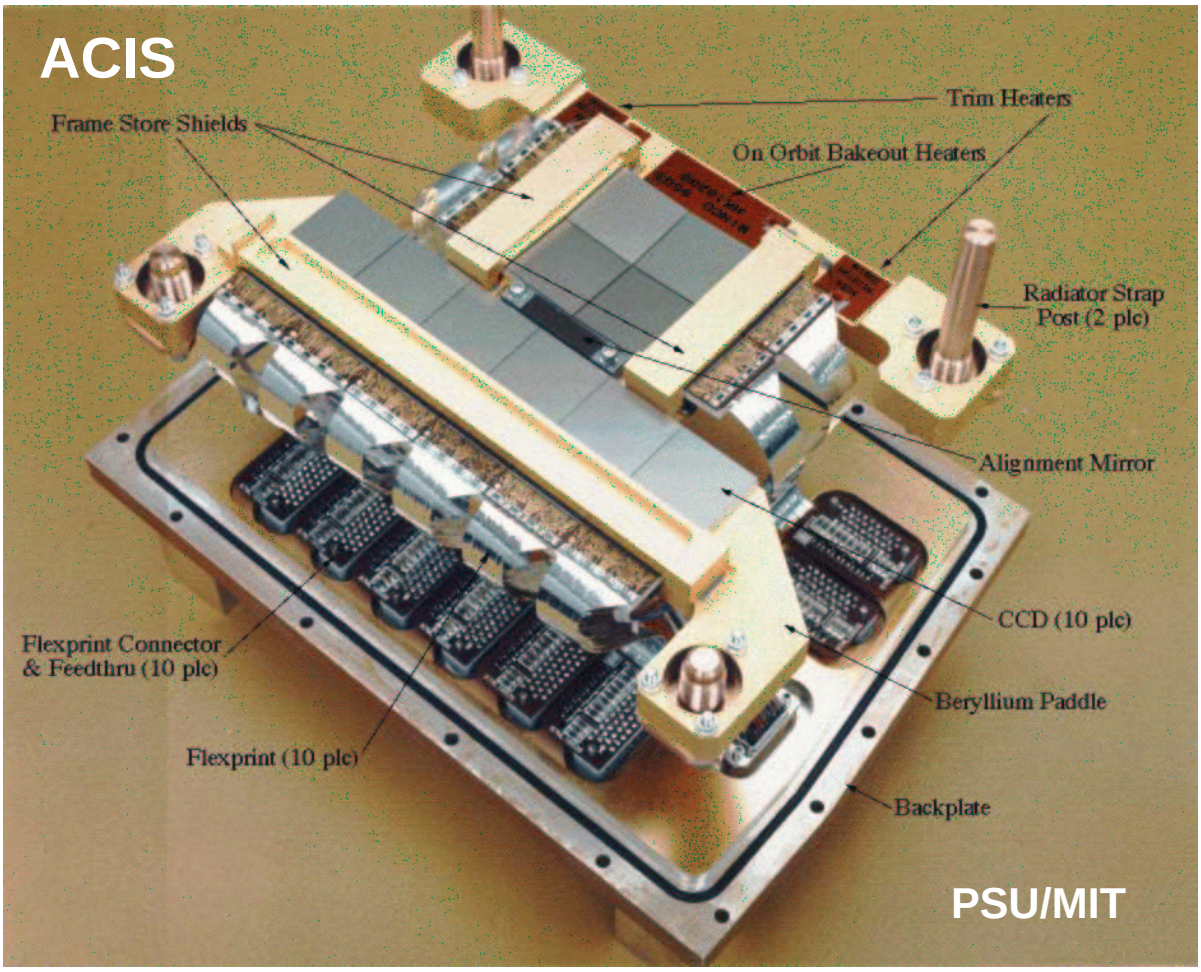


Also

13 hr (e.g., McHardy et al. 2003)
ELAIS (e.g., Manners et al. 2003)
Groth−Westphal
LALA (e.g., Wang et al. 2003)

Lynx (e.g., Stern et al. 2002)
SSA13 (e.g., Mushotzky et al. 2000)
Subaru Deep


Chandra
ISIM
Optical Bench
Solar Array
Aspect Camera
LETG
Sun Shield
HRMA
ACIS/HRC
HETG
Electrical Boxes
Thermal Shroud


ACIS
Trim Heaters
Frame Store Shields
On Orbit Bakeout Heaters
Radiator Strap
Post (2 plc)
Alignment Mirror
CCD (10 plc)
Flexprint Connector
& Feedthru (10 plc)
Beryllium Paddle
Flexprint (10 plc)
Backplate
PSU/MIT

Summary of Detected Sources

Full source catalogs delivered to public.

Band (keV)	Number of Sources	Detected Counts per Source			
		Maximum	Minimum	Median	Mean
Full (0.5–8.0).....	479	20,994.8	11.4	99.3	438.7
Soft (0.5–2.0).....	451	15,233.9	4.3	54.3	307.8
Hard (2–8)	332	5793.7	6.6	76.7	209.2
SB1 (0.5–1.0).....	249	4696.3	4.1	33.8	161.3
SB2 (1–2)	413	10,517.2	4.8	48.6	234.5
HB1 (2–4)	310	3933.0	4.1	49.1	146.7
HB2 (4–8)	183	1851.1	6.7	53.3	114.8

Note.—There are 503 independent X-ray sources detected in total with a false-positive probability threshold of 1×10^{-7}. We have included cross-band counterparts from the WAVDETECT runs with a false-positive probability threshold of 1×10^{-5} (see § 3.4.1).

503 primary X−ray sources

79 supplementary X−ray sources (optically bright)

6−7 extended X−ray sources

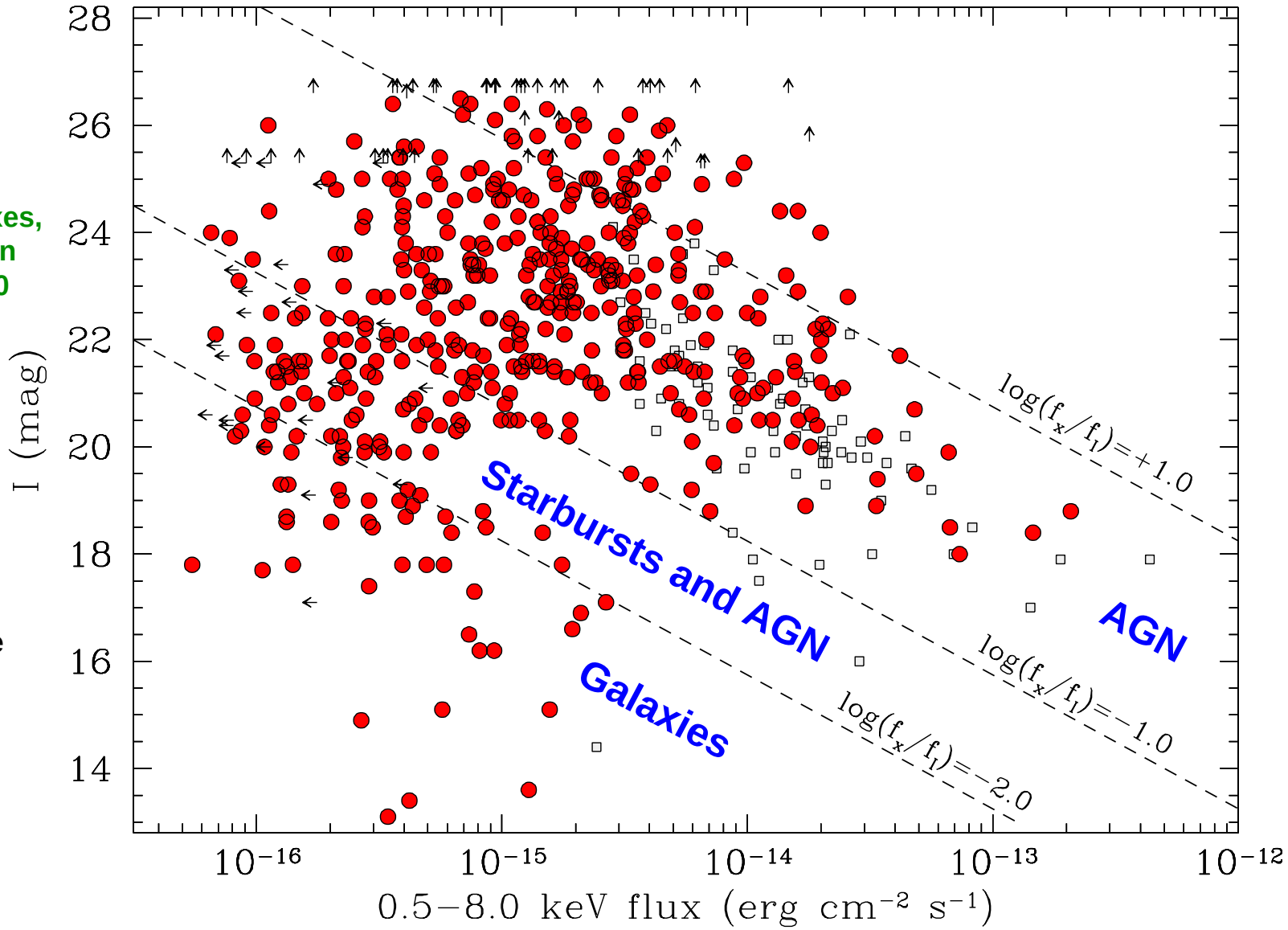
Alexander et al. (2003)
Bauer et al. (2002)
Brandt et al. (2001)

Optical vs. X−ray Fluxes − Diversity of X−ray Sources

At faint X−ray fluxes, optical fluxes span factor of ~ 100,000

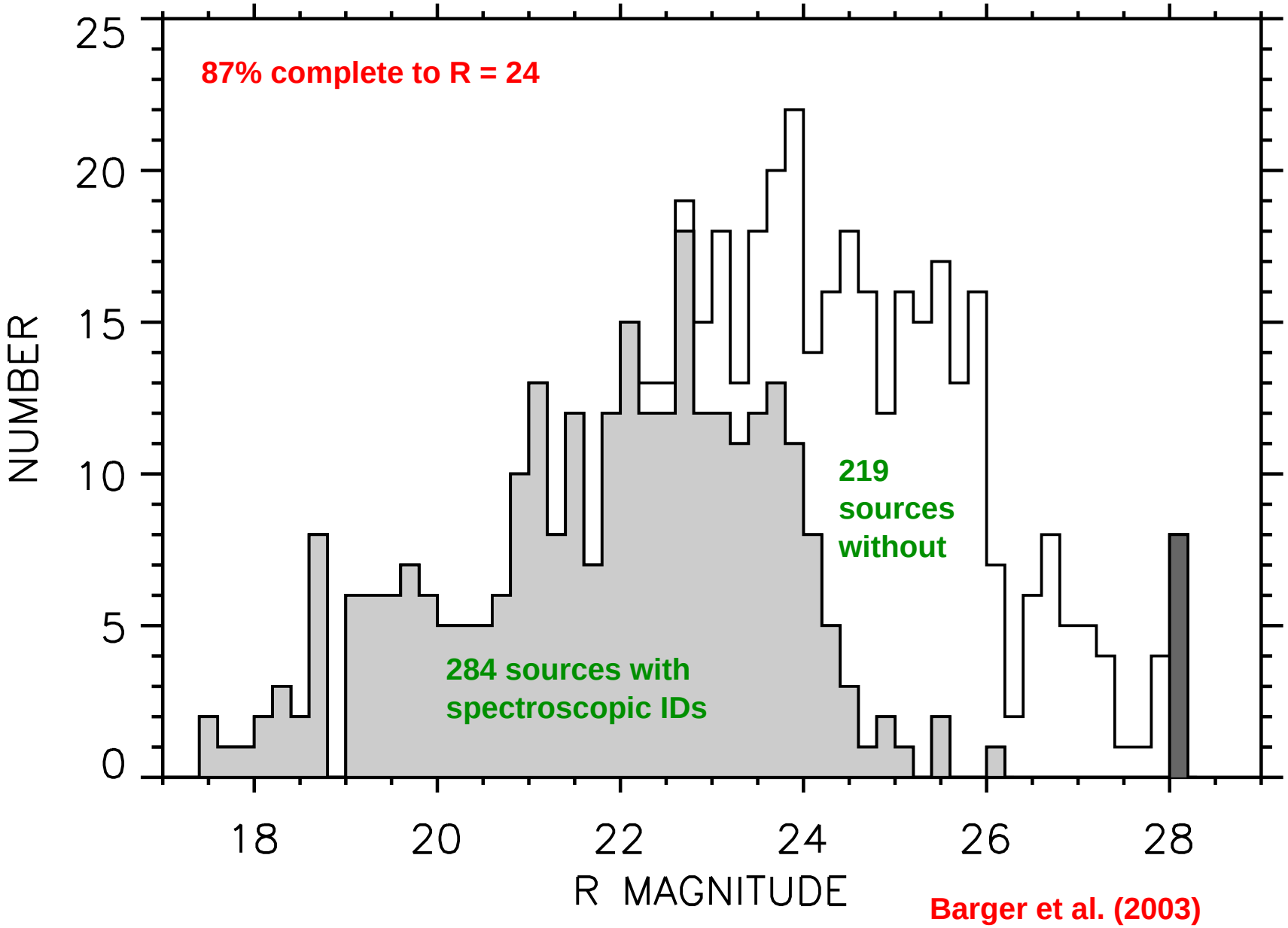
Red circles are CDF−N sources

Black squares are Lockman Hole sources



Optical Spectroscopic Follow–Up

Done with Keck DEIMOS, Keck LRIS, HET LRS, WIYN HYDRA

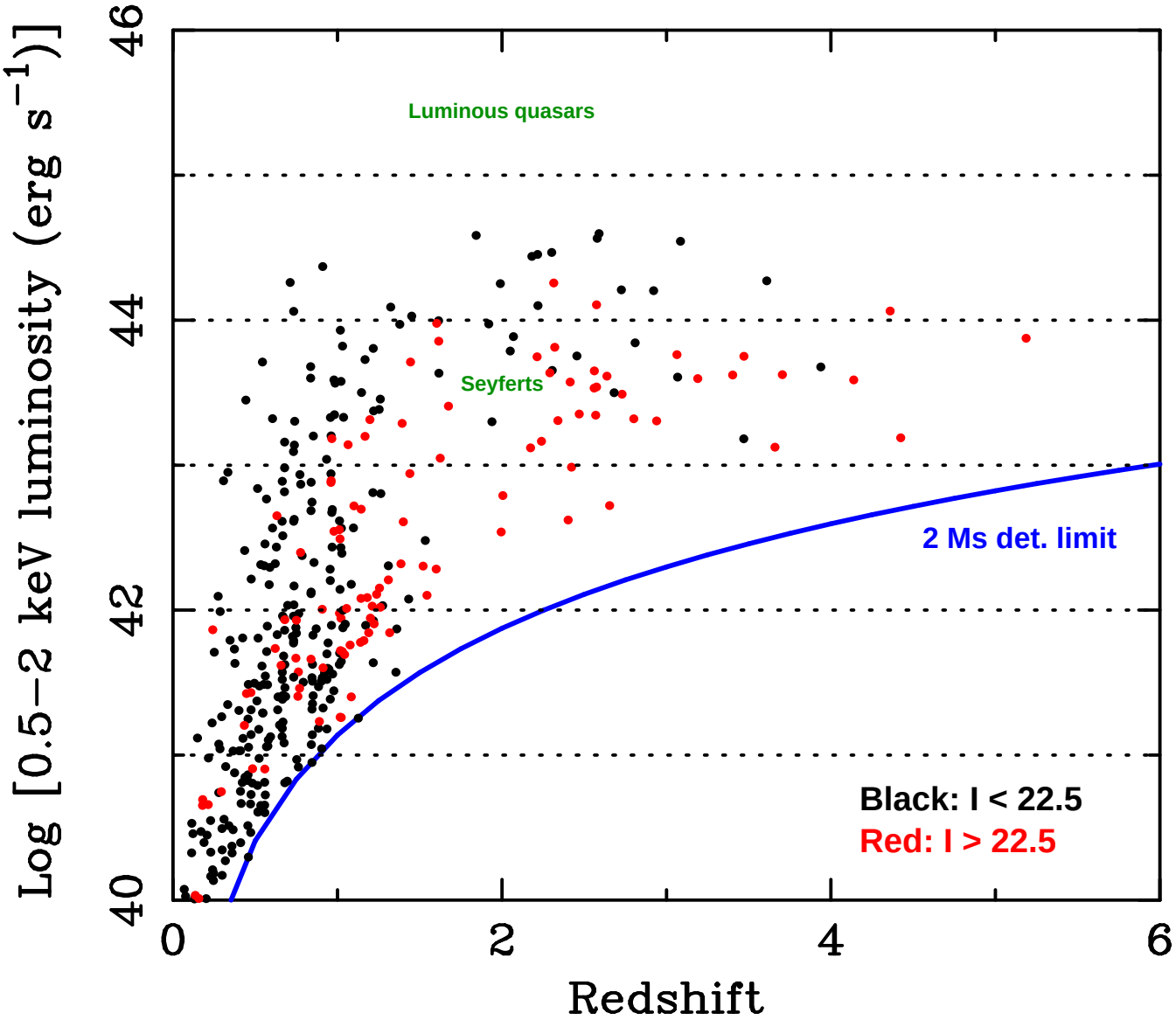


Barger et al. (2003)

Sky Density, X−ray Luminosity, Redshift

AGN density exceeds 6000 deg $^{-2}$ Highest known!

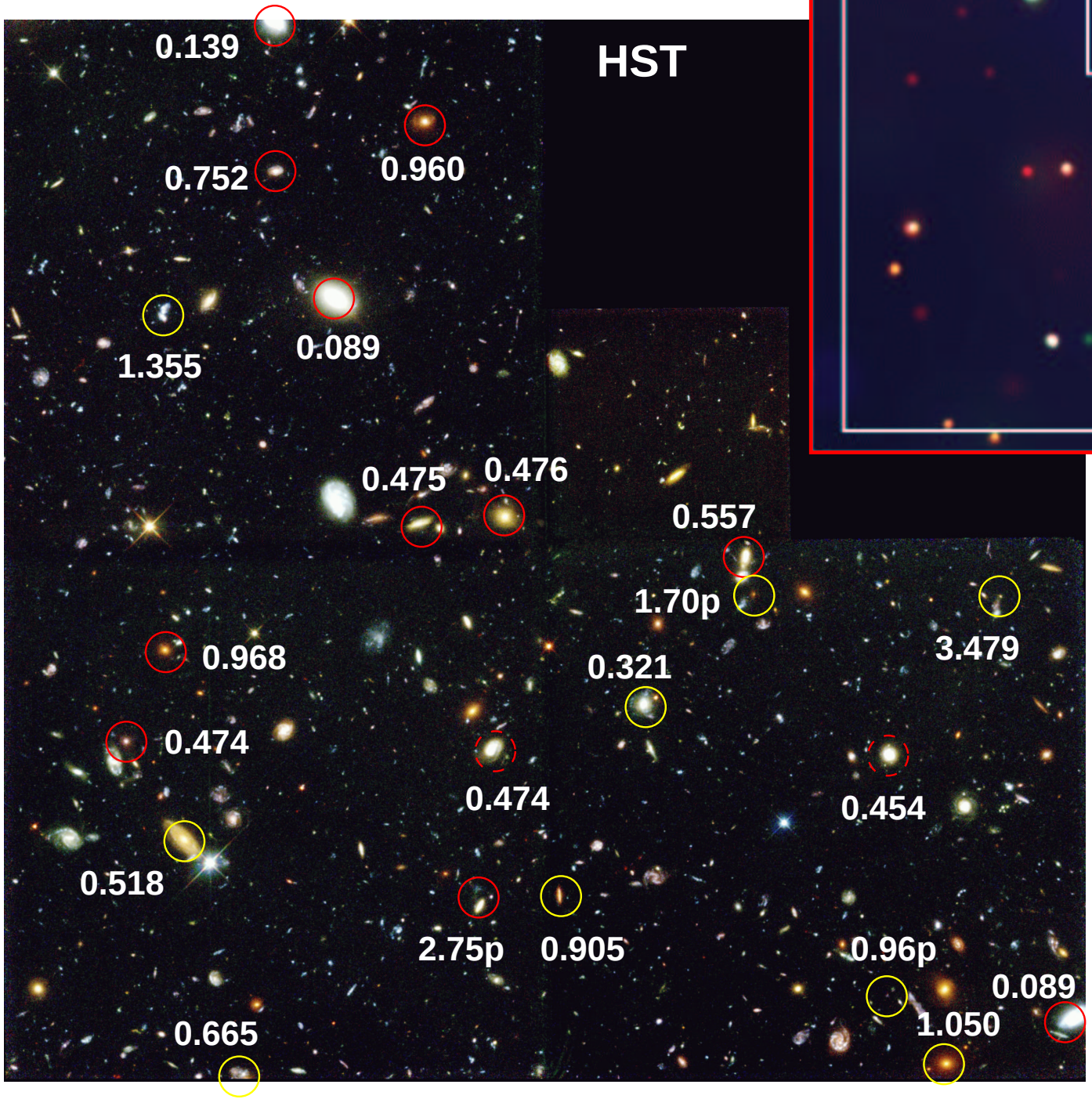
Most identified AGN have z < 1.5, although a significant minority have z = 1.5−5.2 (some incompleteness bias).

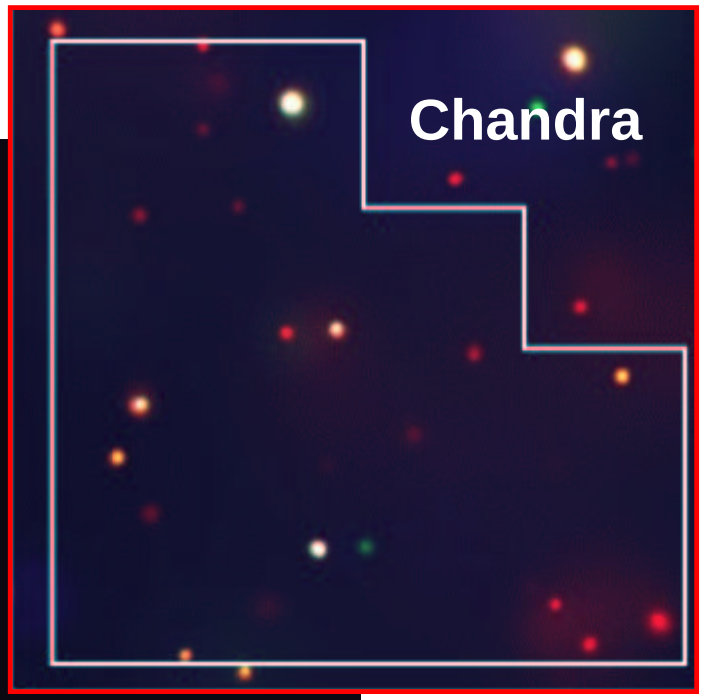


Most of XRB made by moderate−luminosity objects; Type 2 quasars etc. only make small contributions.

At faintest X−ray fluxes a numerically significant pop. of starburst + normal galaxies emerges (z ~ 0−1).

Hubble Deep Field–North





Circles show 2 Ms Chandra sources (error circles are much smaller)

Numbers show redshifts

Solid = Highly signif.

Broken = Signif.

Red = ISOCAM src.

Yellow = Not ISOCAM src.

Heavy and Complex X−ray Obscuration

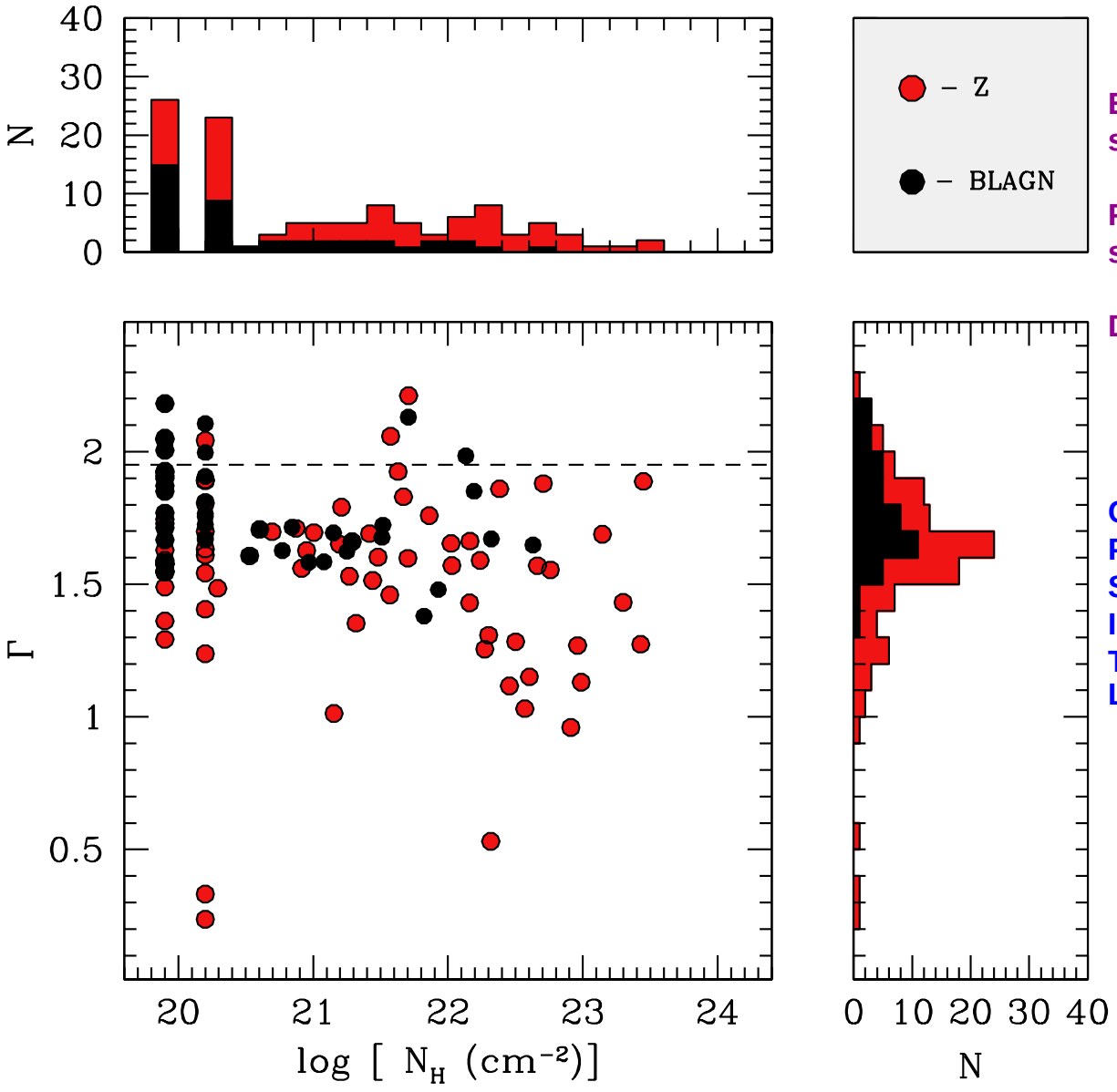
Evidence for X−ray obscuration seen in > 70% of sources.

Variety of opt. types: Type 1, Type 2, XBONGS

Complete obscuration?
Host galaxy dilution?

CDF−N+CDF−S − Fitting of > 200 ct. Sources with Redshifts

(Bauer et al. 2003)



Evidence for spectral complexity

Fit quality and systematic resid.

Derived fit param.

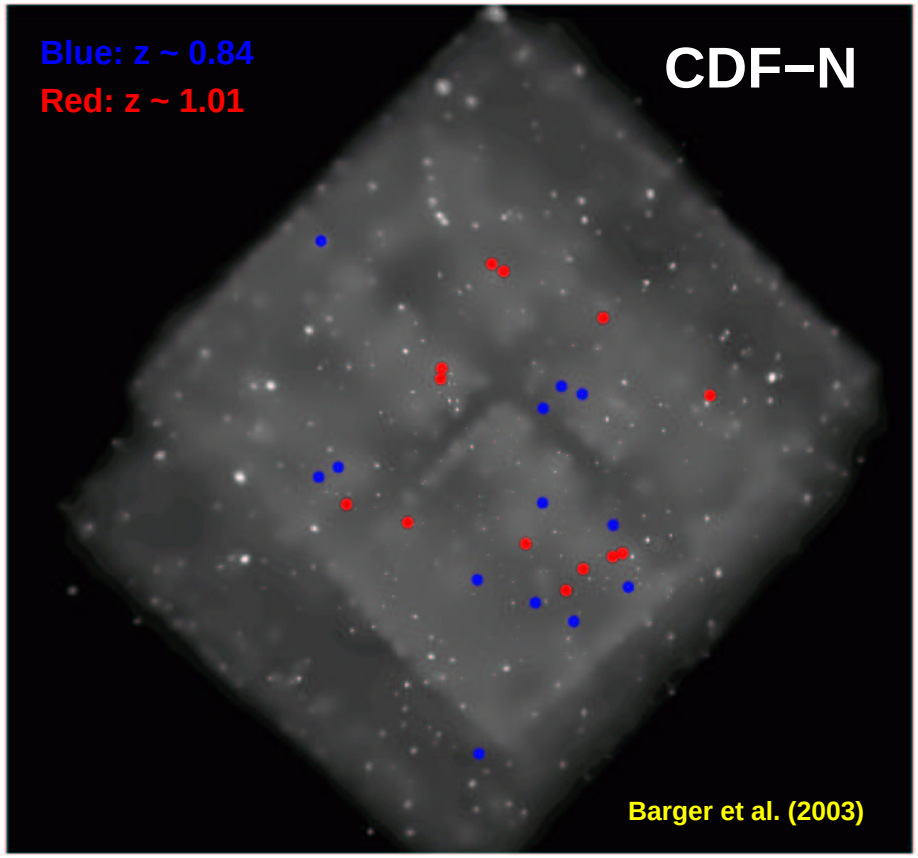
Compton reflection
Partial covering
Scattered X−rays
Ionized absorption
Time−variable absn.
Line emission

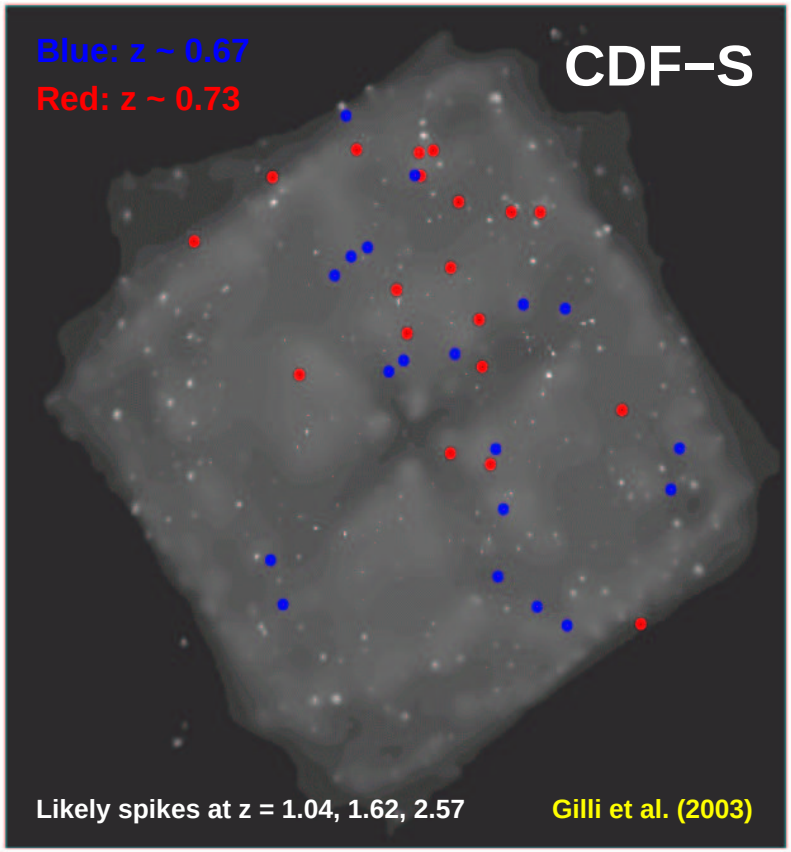
Few objects have very heavy absn. Surprising since ~ 40% of local AGN are Compton thick.

Mis−fitting of spectral complexity can lead to N_H underestimates. Also some selection bias.

Large−Scale Structure Traced by X−ray AGN

The ~ 30% ‘cosmic variance’ between the CDF−N and CDF−S suggests the presence of large−scale structures. (e.g., Brandt et al. 2001; Cowie et al. 2002; Giacconi et al. 2002; Rosati et al. 2002)





Physical size is at least ~ 7 Mpc. Large−scale ‘sheet−like’ structures.

Preferential AGN clustering would indicate an AGN fueling/environment connection.

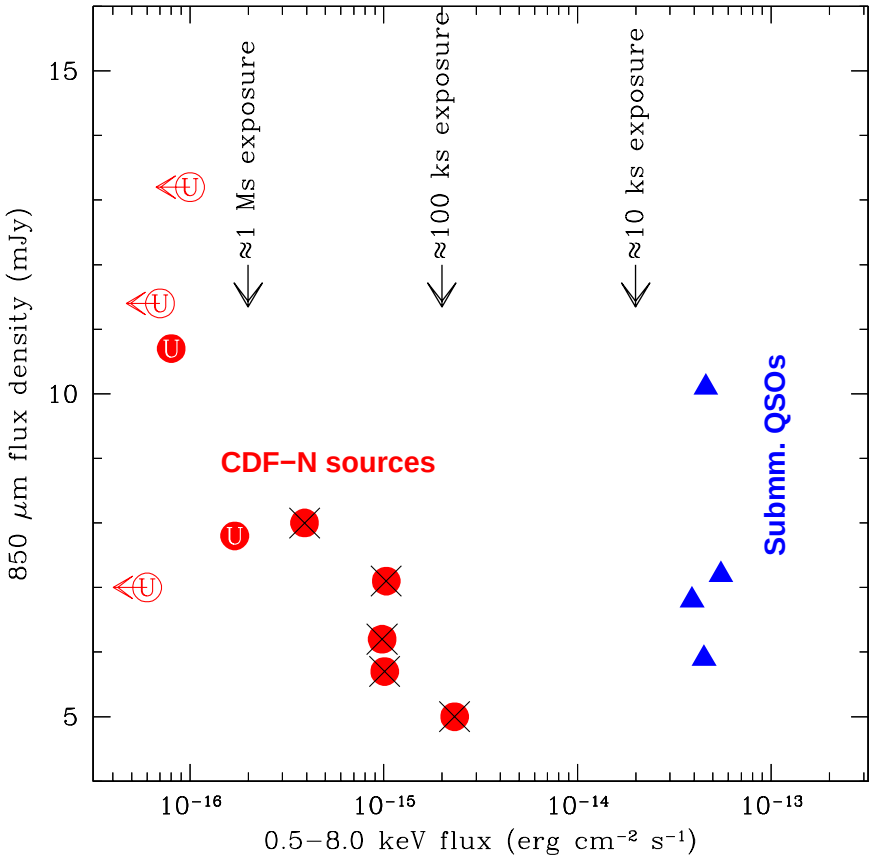
Gilli et al. (2003) find suggestive (~ 2 sigma) evidence for this.

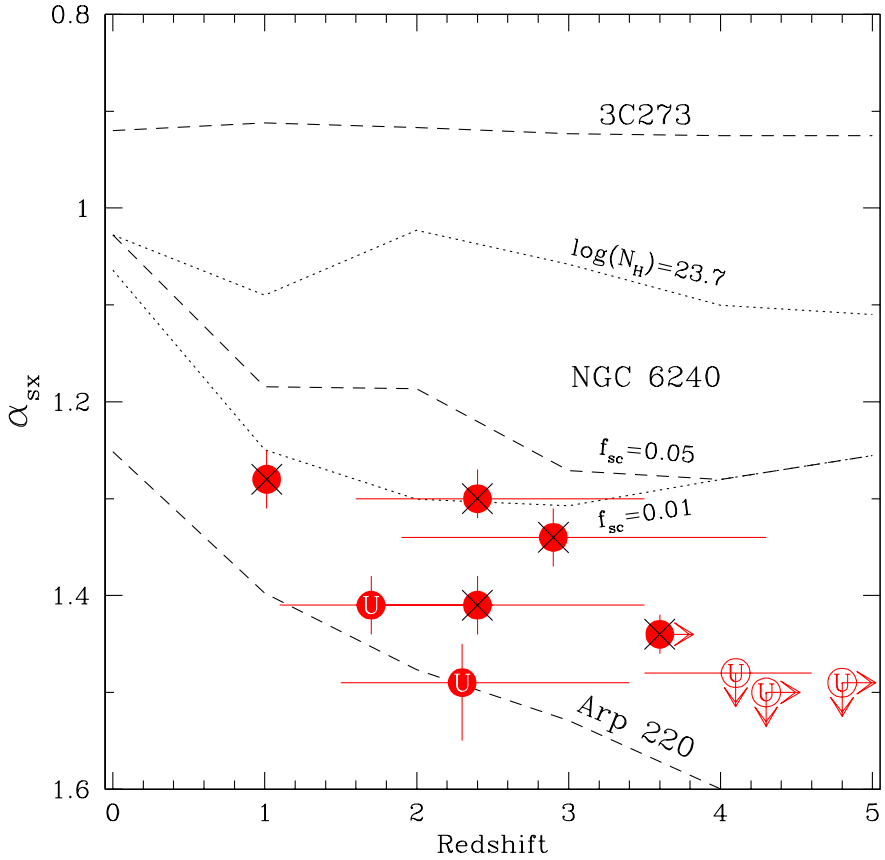
X−ray/Submillimeter Connection at the 2 Ms Level

Early comparisons between SCUBA surveys and moderately deep Chandra surveys yielded little source overlap.

But at the 2 Ms level, 7/10 bright SCUBA sources in the central CDF−N have X−ray detections (filled circles).

Alexander et al. (2003)





Five appear to be Seyfert−lum. AGN from X−ray spectra and luminosities (crosses).

(3 Compton thin, 1 Compton thick, 1 poorly constrained)

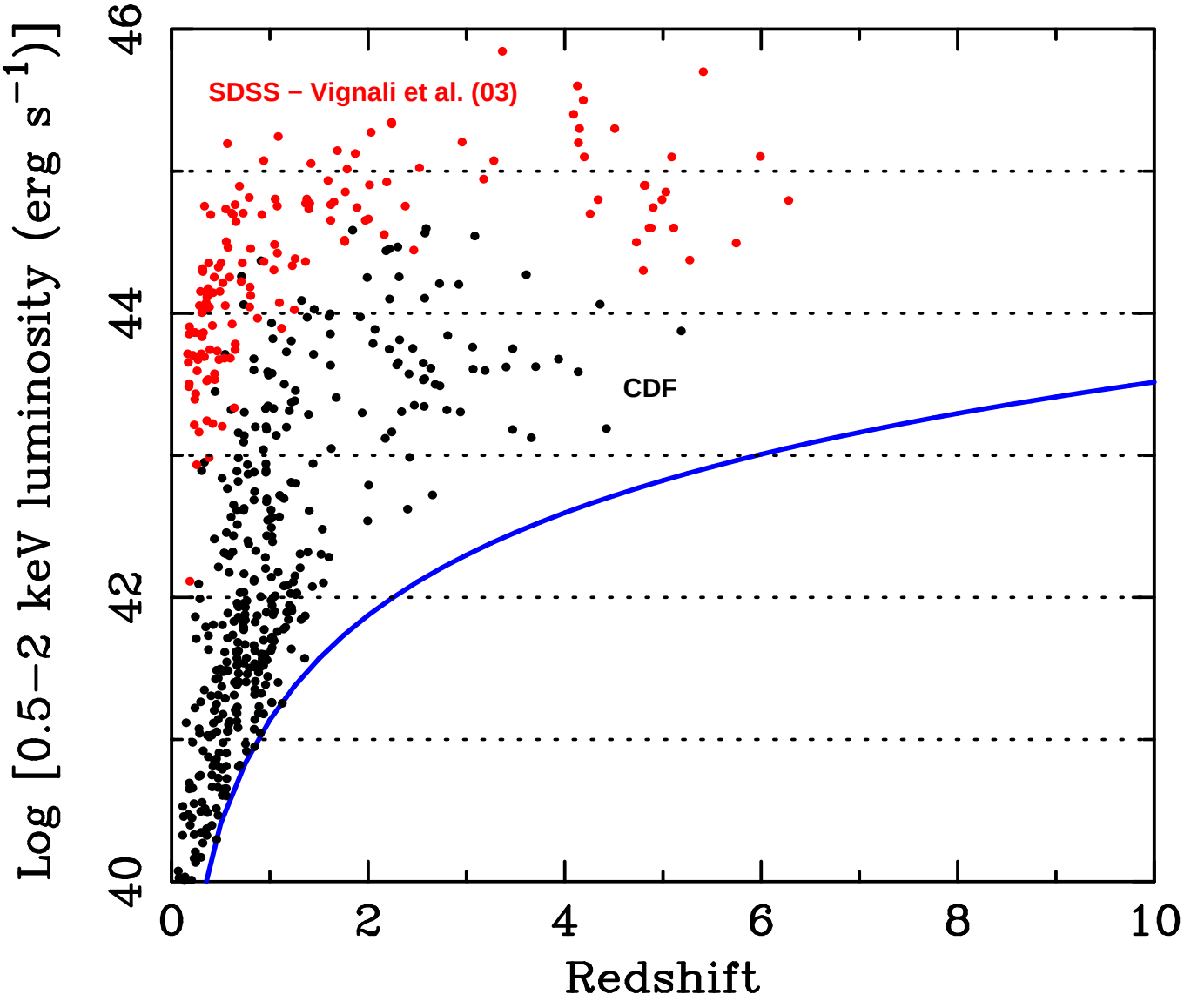
Two consistent with luminous star formation.

High−Redshift AGN Demography

Deep X−ray surveys probe z > 4 AGN that are 10−30 times less luminous than SDSS quasars.

More numerous and representative than rare SDSS quasars.

Minimal absorption bias − sample 2−40 keV rest−frame X−rays.



Constrain sky density with follow−up and Lyman break.

No more than ~ 8 detectable AGN at z > 4 per field.

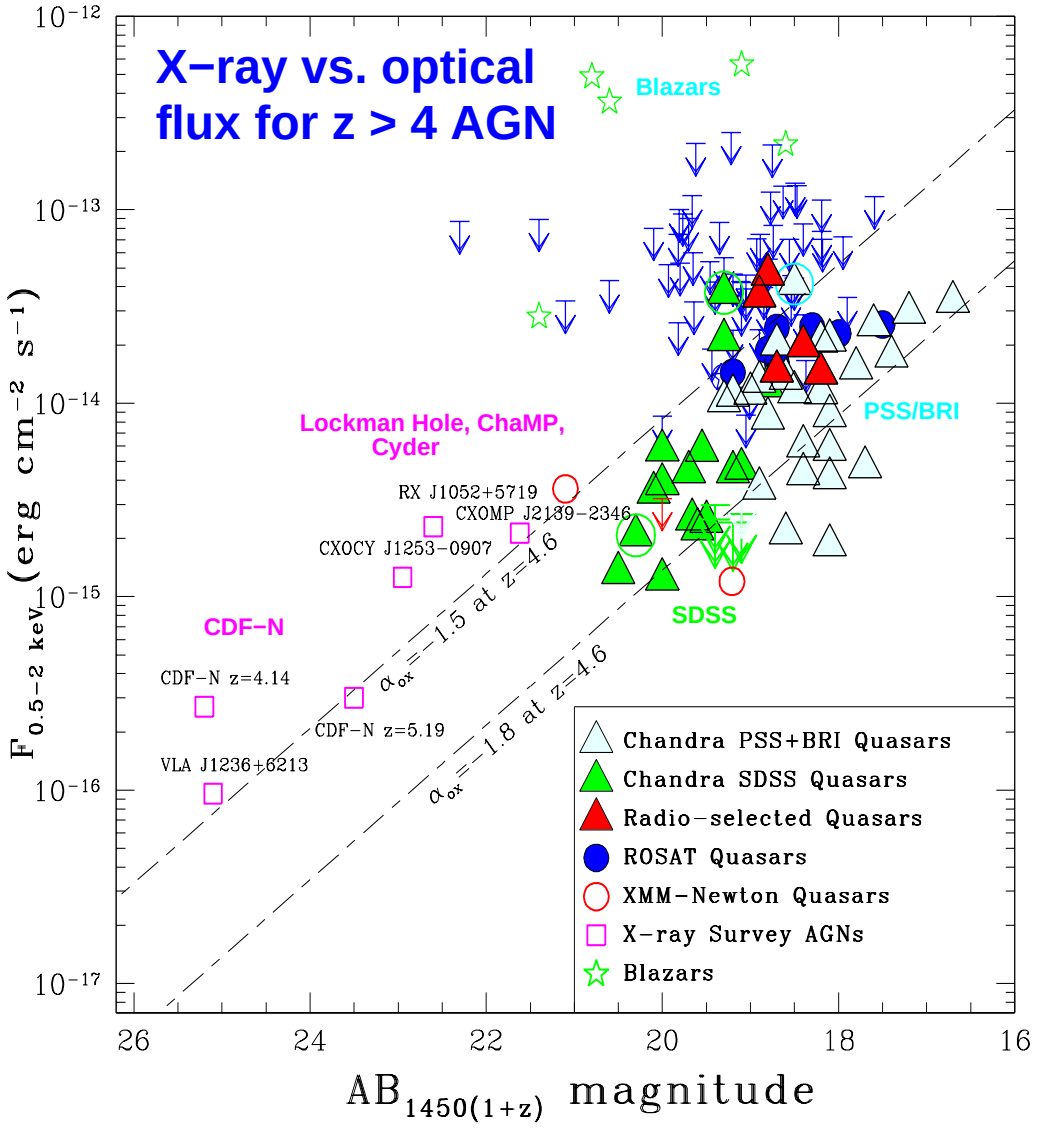
Alexander et al. (01), Barger et al. (03), Cristiani et al. (03), Koekemoer et al. (03)

Contribution to z ~ 6 reionization small.

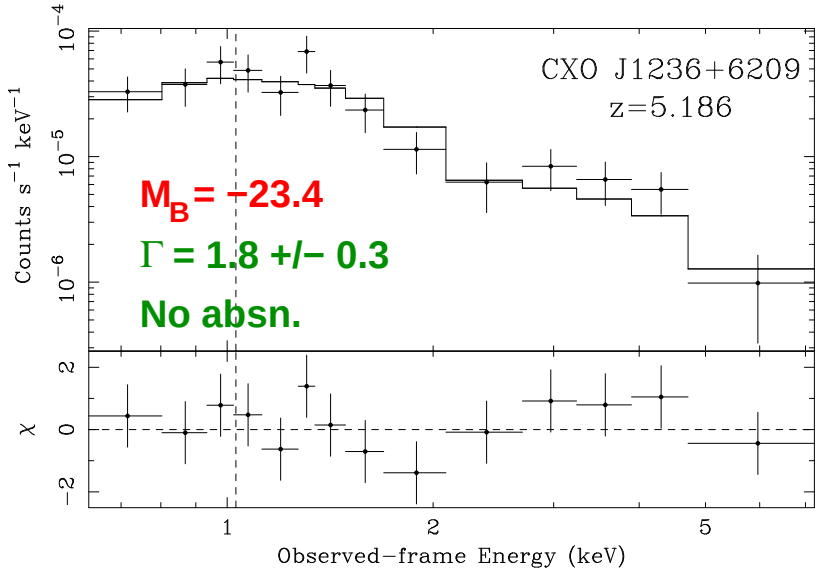
Better source statistics needed.

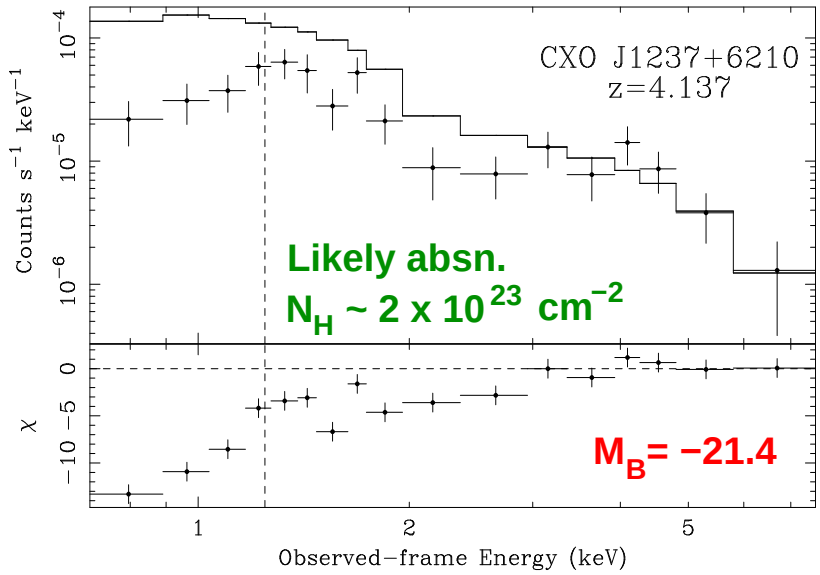
X−ray Spectral Energy Distributions and Spectra

Accretion processes and environments



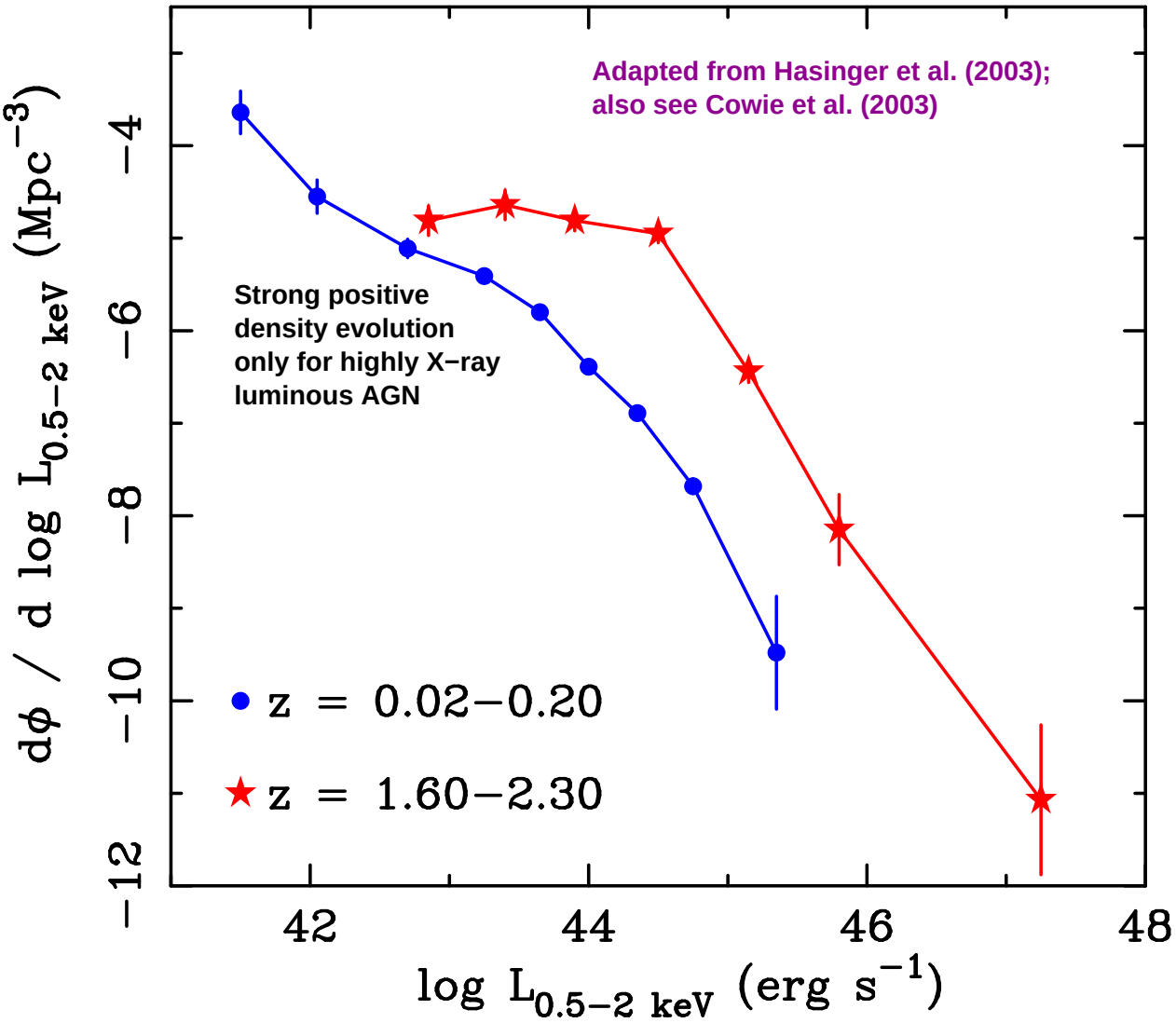
Vignali et al. (2002, 2003)





Different Evolution for High and Moderate X−ray Luminosity Active Galaxies?

Type 1 AGN from CDF−N + CDF−S + ROSAT



Incompleteness of optical follow−up at high redshift.

Significant source of error, but appears unlikely to change main trend.

Absorbed vs. unabsorbed AGN evolution.

Need to understand the X−ray absorption better.

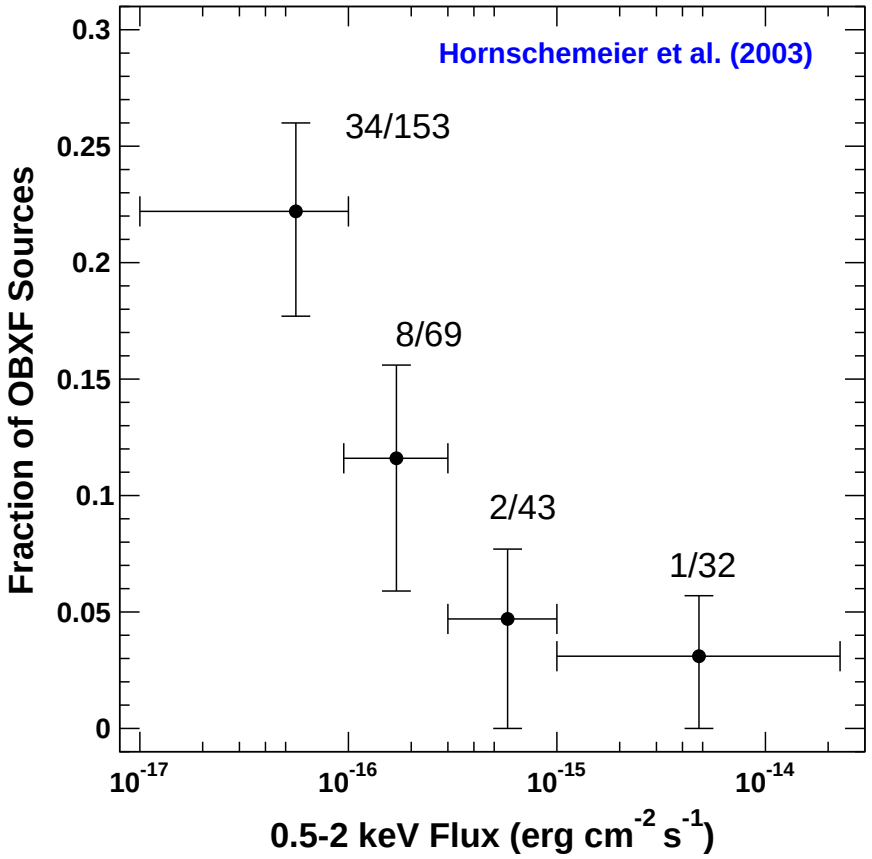
Compton−thick AGN at high−redshift could be missed.

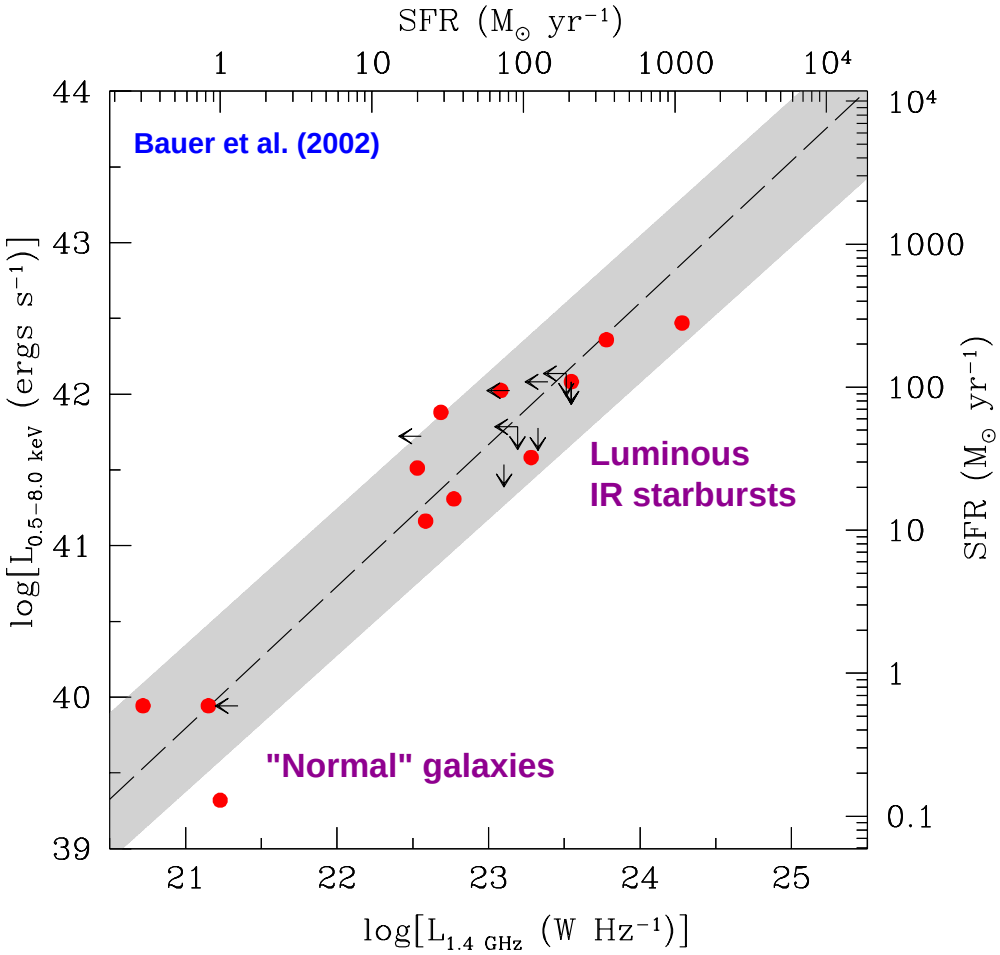
Confusion with luminosity effects.

Luminosity−redshift plane now well sampled at z < 1.5. Need to fill with moderate−lum. AGN at z = 1.5−4.

Need more ~ 1/4 Ms+ exposures.

Starburst and Normal Galaxies in Deep X−ray Surveys





Increasing fraction of X−ray srcs. at low fluxes are z ~ 0−1.5 starburst and normal galaxies.

Number doubled from 1 to 2 Ms in CDF−N.

Stacking and fluctuation analyses show that this will continue and detect galaxies out to z ~ 4 (on average).

Brandt et al. (2001); Hornschemeier et al. (2002); Miyaji & Griffiths (2002); Nandra et al. (2002)

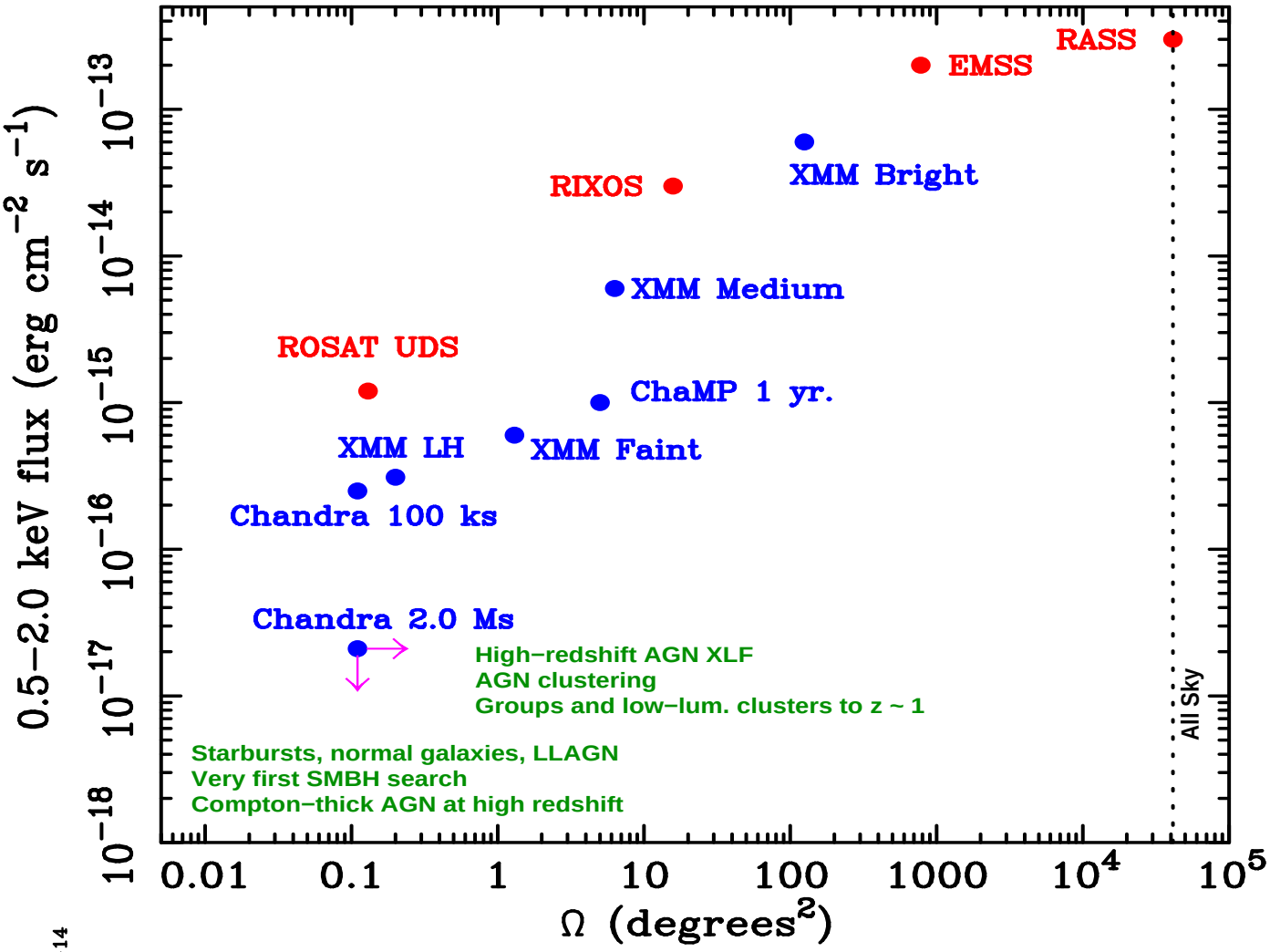
Source densities of ~ 100,000+ deg^{-2}

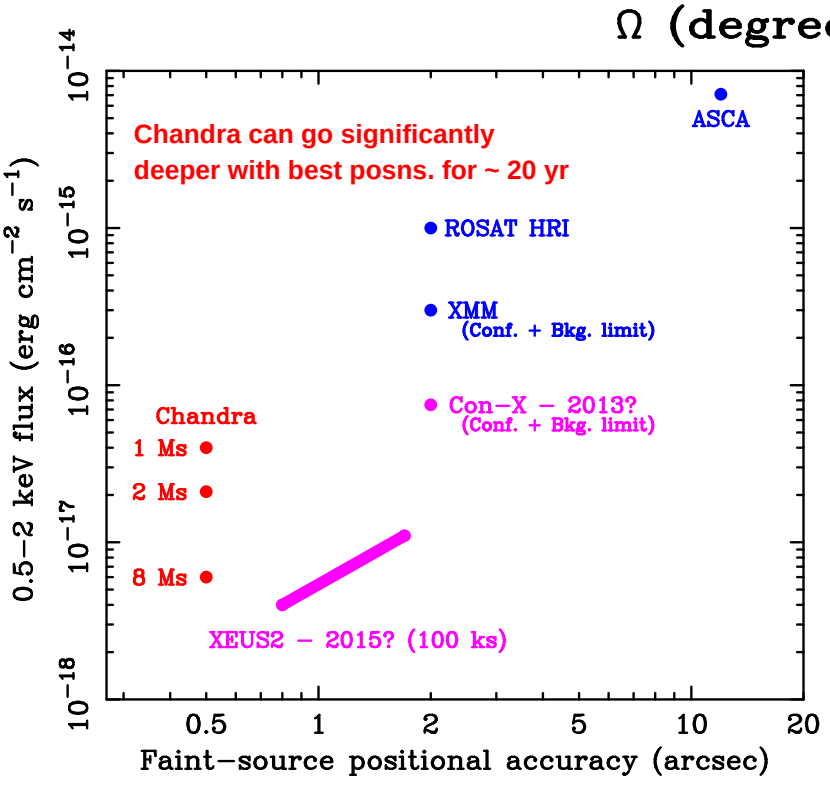
Luminous mid−IR and radio emission − part of the strongly evolving starburst pop. making bulk of IR background. Alexander et al. (2002)

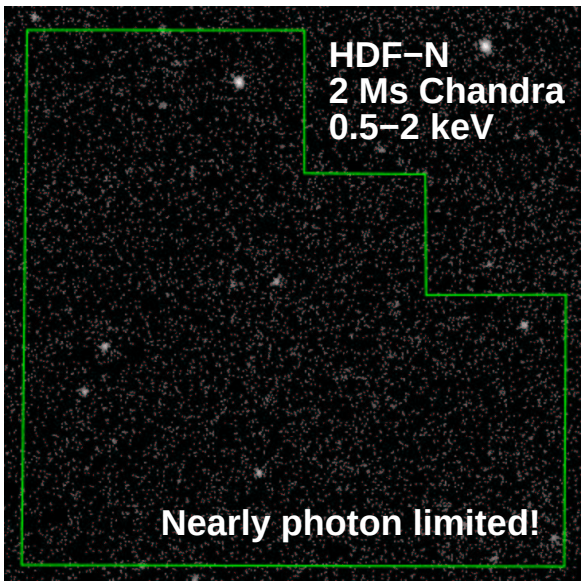
Link X−rays into radio−FIR correln. for starburst galaxies. Unabsorbed SFR indicator.

Bauer et al. (2002); Grimm et al. (2002); Nandra et al. (2002); Ranalli et al. (2002)

Future Prospects for Deep X−ray Surveys



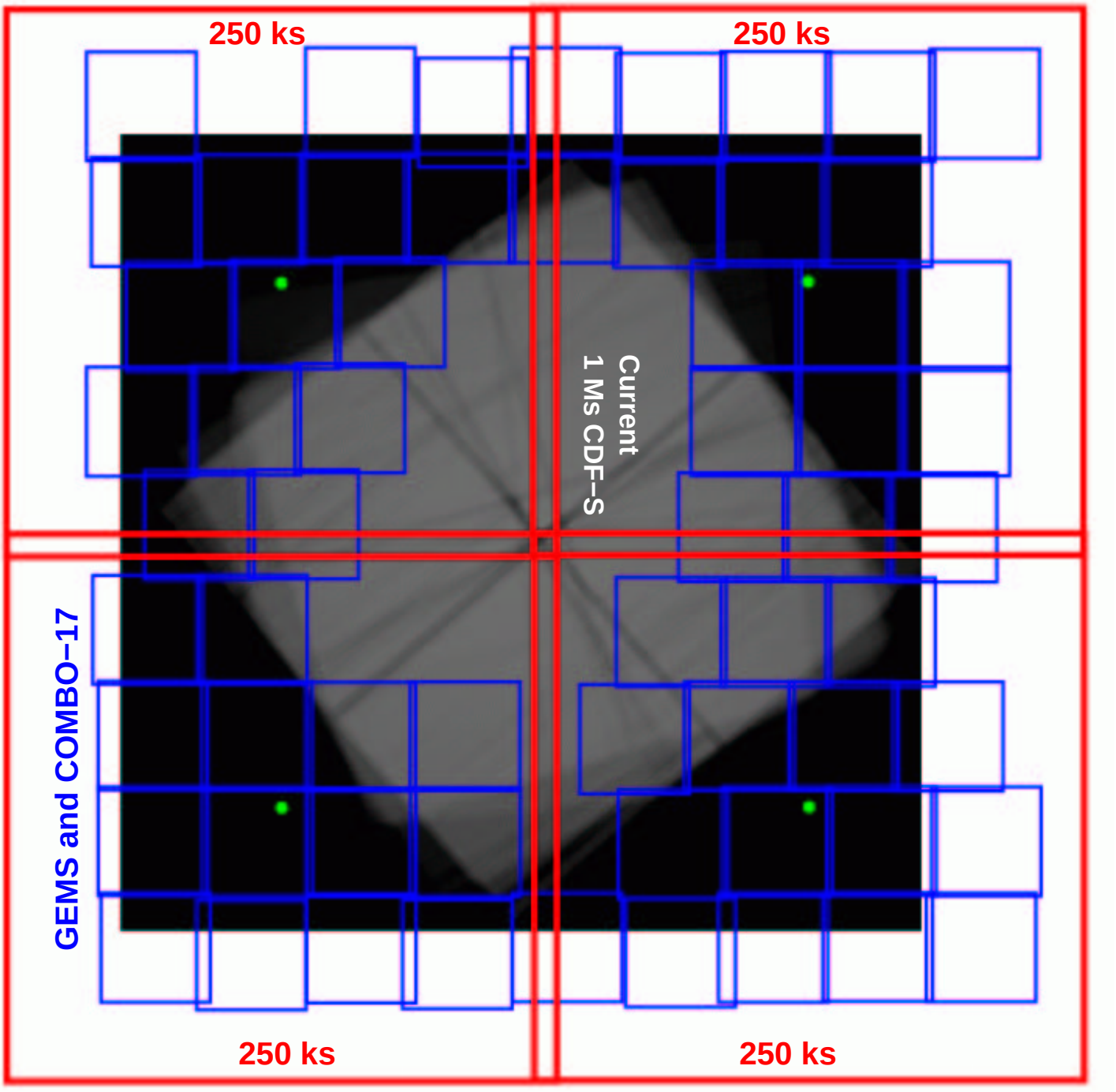




Also deeper surveys at > 10 keV

Extended Chandra Deep Field−South

Allocated 1 Ms for Chandra Cycle 5



Cosmic accretion history for obscured and Compton−thick

Moderate−luminosity, typical AGN at z > 4

Clustering of X−ray selected AGN to z ~ 2.5

Groups and low−luminosity clusters to z ~ 1

GEMS, GOODS, ACS UDF
734+ HST orbits

VLT/Keck spectroscopy
6000+ VLT redshifts

SIRTF coverage coming