X-ray Probes of Star Formation Outside the Local Universe

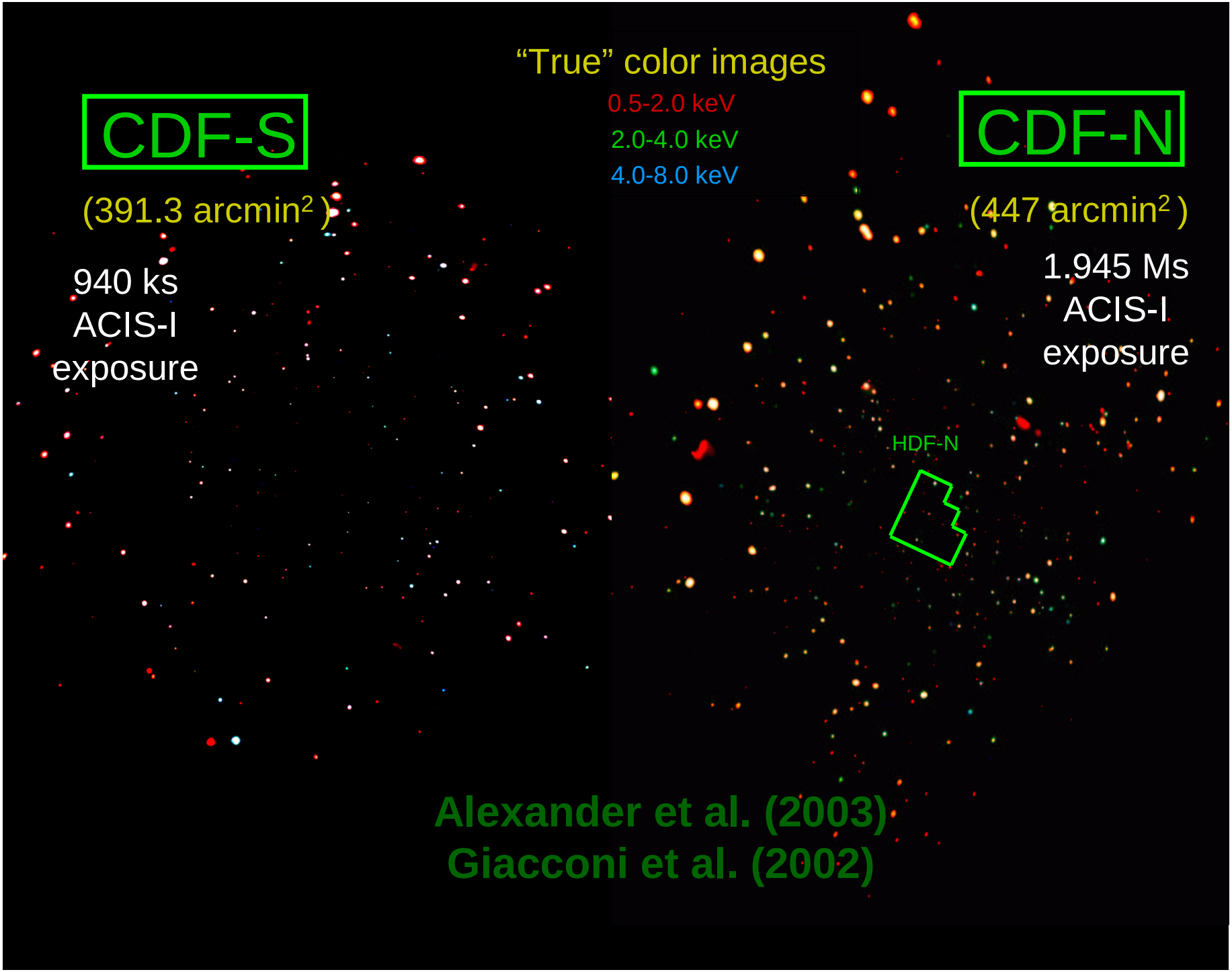
Ann Hornschemeier
Johns Hopkins University

See http://www.pha.jhu.edu/~annh

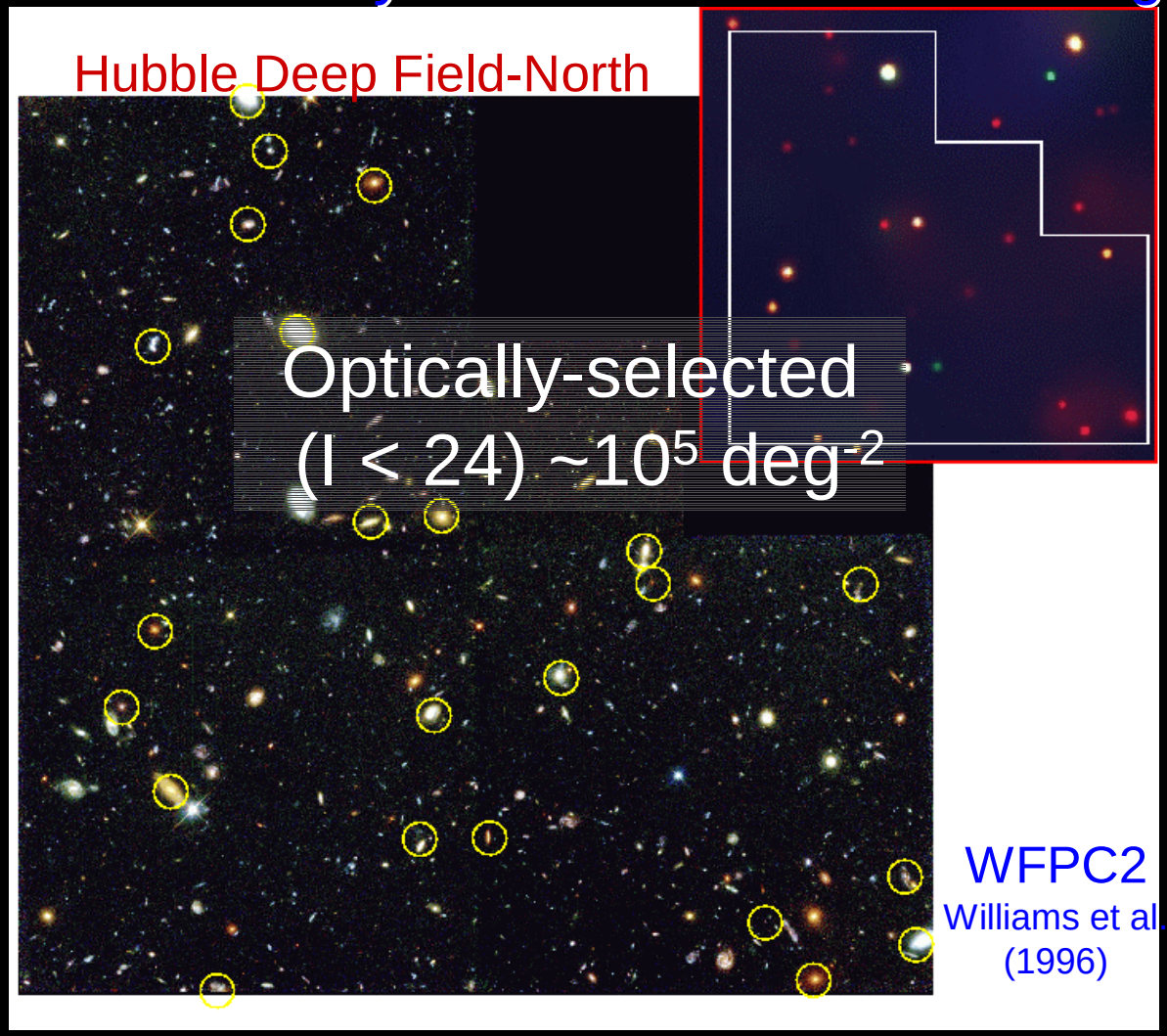
Star Formation/Galaxy Formation

- Deep Chandra Survey Results
- X-ray Galaxy Redshift Gap ($0.05 < z < 0.30$)
- Effect of Galaxy Environment: Coma Cluster
- Future of Deep X-ray Imaging Surveys

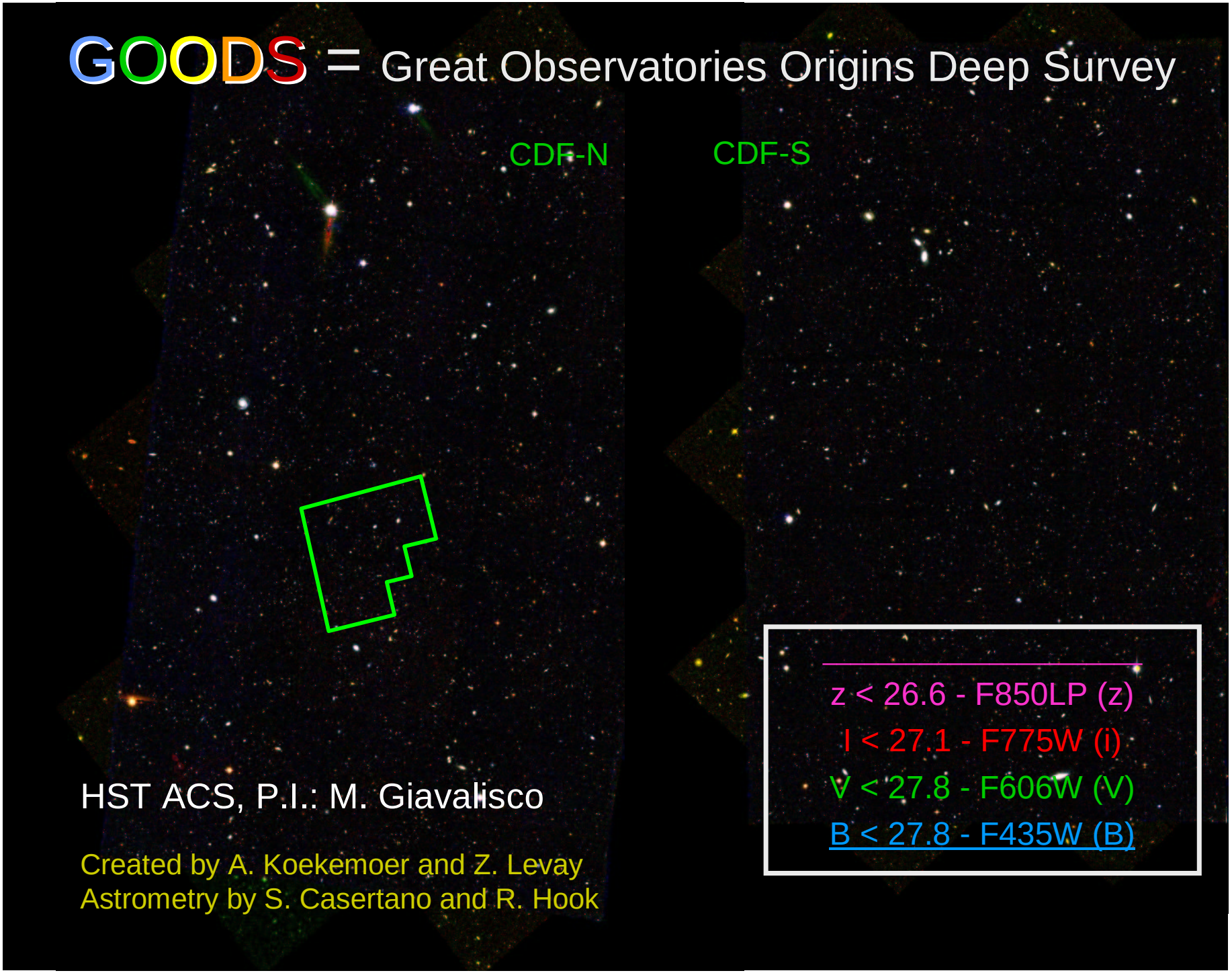
Deep Chandra Survey Results:
Introduction/Review


"True" color images
0.5-2.0 keV
2.0-4.0 keV
4.0-8.0 keV
CDF-S
(391.3 arcmin^2)
940 ks
ACIS-I
exposure
CDF-N
(447 arcmin^2)
1.945 Ms
ACIS-I
exposure
HDF-N
Alexander et al. (2003)
Giacconi et al. (2002)

Source density: 13600 ±3400 sources deg^{-2}



Alexander et al. (2003)


GOODS = Great Observatories Origins Deep Survey
CDF-N
CDF-S
z < 26.6 - F850LP (z)
I < 27.1 - F775W (i)
V < 27.8 - F606W (V)
B < 27.8 - F435W (B)
HST ACS, P.I.: M. Giavalisco
Created by A. Koekemoer and Z. Levay
Astrometry by S. Casertano and R. Hook

Deep Chandra Survey Results:
X-ray-SFR Connection

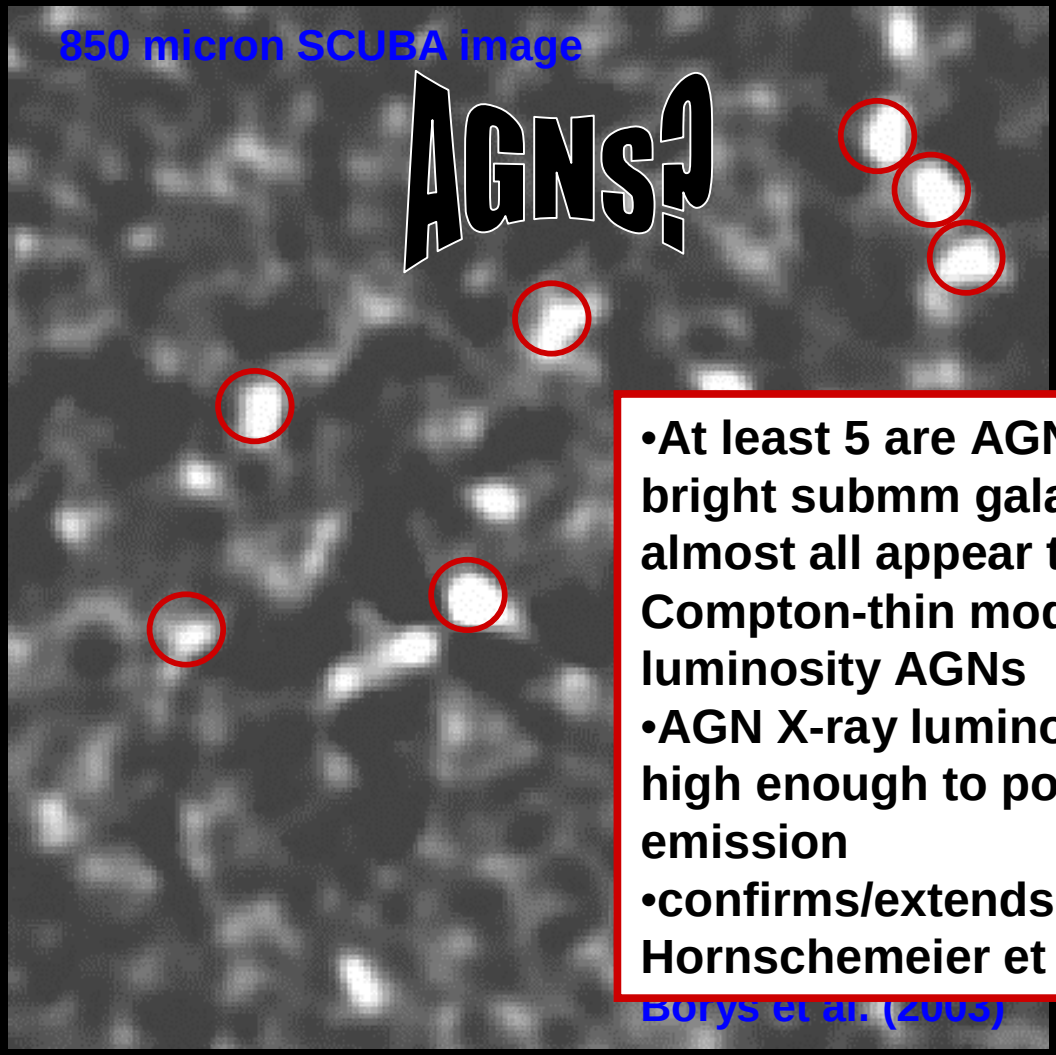
X-ray/SFR Connection at high *z:* Submillimeter (850 μm) sources

Dusty high-redshift starburst galaxies?

< 250 ks Chandra surveys à
little overlap with 850 μm (submm) source population

(e.g., Fabian et al. 2000; Severgnini et al. 2000;
Hornschemeier et al. 2000, 2001;
Bautz et al. 2001; Barger et al. 2001)…

SFR-AGN Connection at high *z* : Submillimeter sources

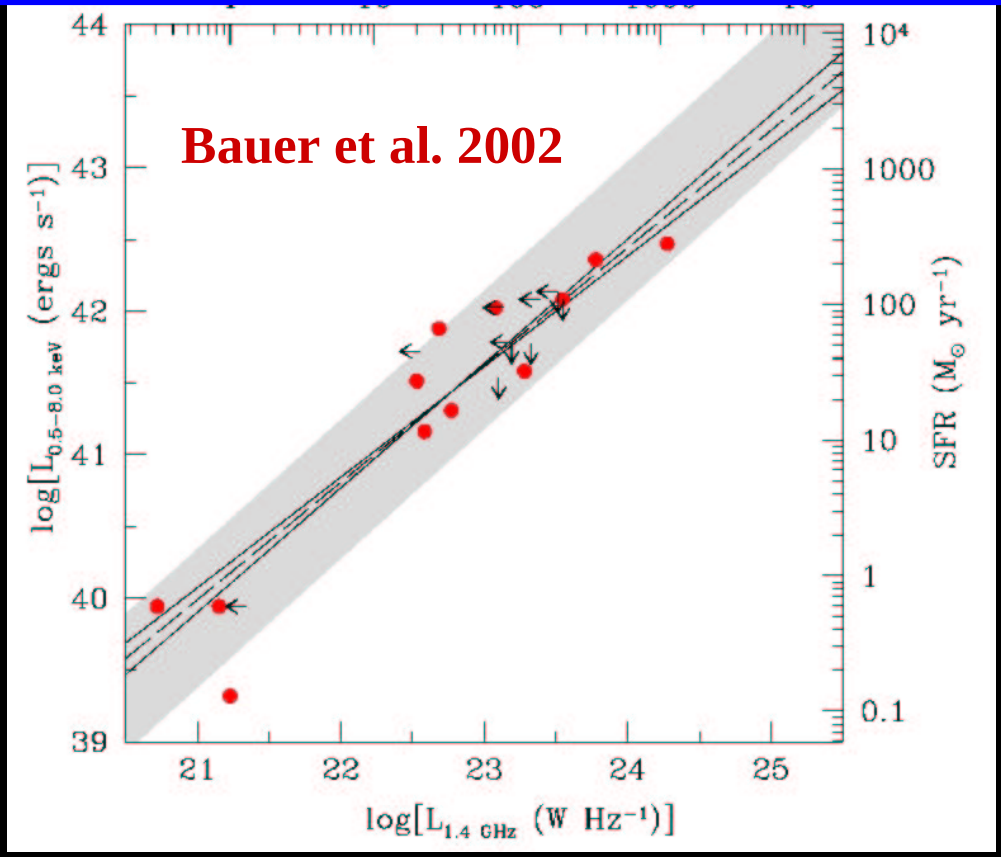


- At least 5 are AGNs (38% of bright submm galaxies) à almost all appear to be Compton-thin moderate-luminosity AGNs
- AGN X-ray luminosity not high enough to power submm emission
- confirms/extends results of Hornschemeier et al. (2000)

Borys et al. (2003)

7 (54%) of the sources are X-ray detected (Alexander et al. 2003)

X-ray-SFR Connection: Radio/FIR – X-ray Correlations

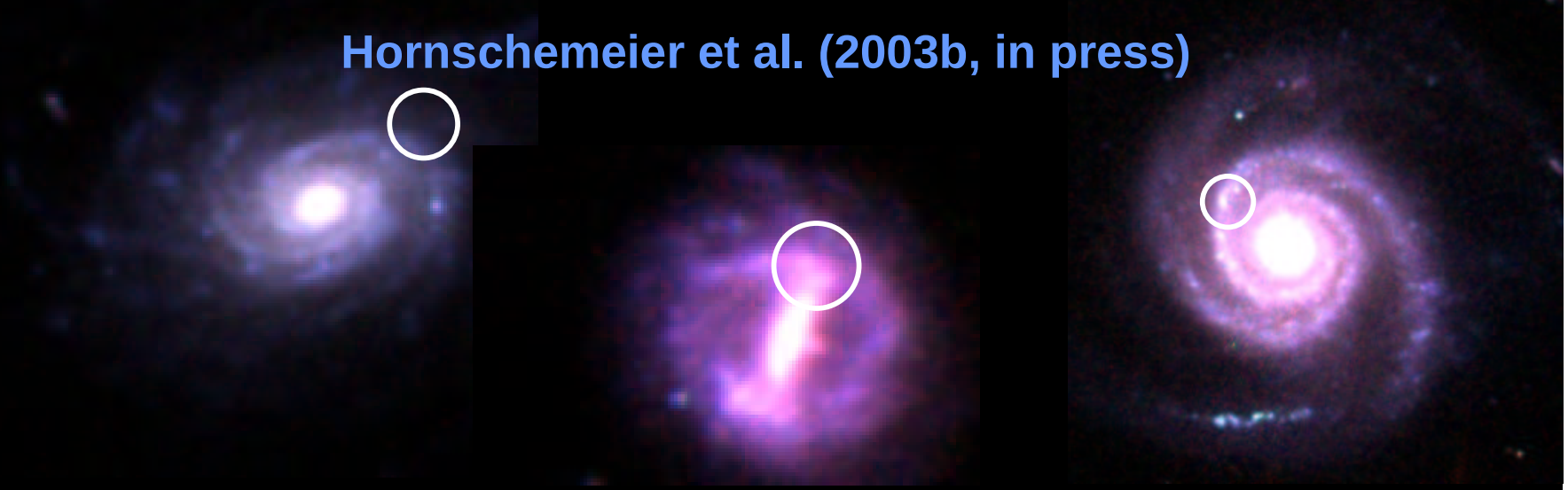


0.5-8 keV luminosity may be an SFR indicator

(Bauer et al. 2002, Seibert et al. 2002, Ranalli et al. 2002, Nandra et al. 2002, Grimm et al. 2002, Cohen et al. 2003)

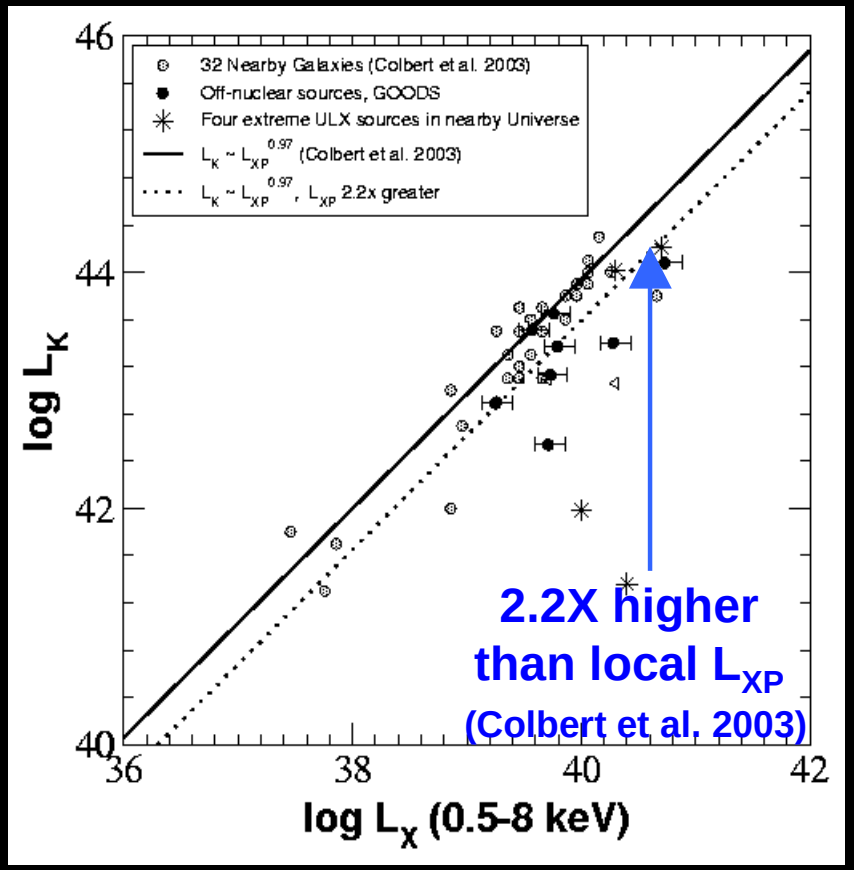
X-ray-SFR Connection: ULX Population at z=0.1

Hornschemeier et al. (2003b, in press)



- 12 confident off-nuclear (ULX) sources in GOODS fields
- ACS BVIz à SFR history
- Since ULXs dominate L_{XP} at high SFR, constraint on X-ray point source luminosity
- Complementary to intensive studies of e.g., the Antennae (Fabbiano & Zezas 2001-2003)

X-ray-SFR Connection: ULX Population at z=0.1 (GOODS)



- **36%** of galaxies at *z*=0.1 have a ULX with >2 x 10^{39} erg s^{-1}
- compare with **8%** in a nearby galaxy sample (Sipior, PhD thesis, Ho et al. 2001 LLAGN sample)
- GOODS galaxies have higher SFR than local samples
- Consistent with bright-end XLF slope $\alpha = 0.4$
- Compare with Antennae XLF, $\alpha = 0.47$ (Zezas et al. 2002)
- SIRTF data will more accurately characterize SFR

Hornschemeier et al. (2003b)

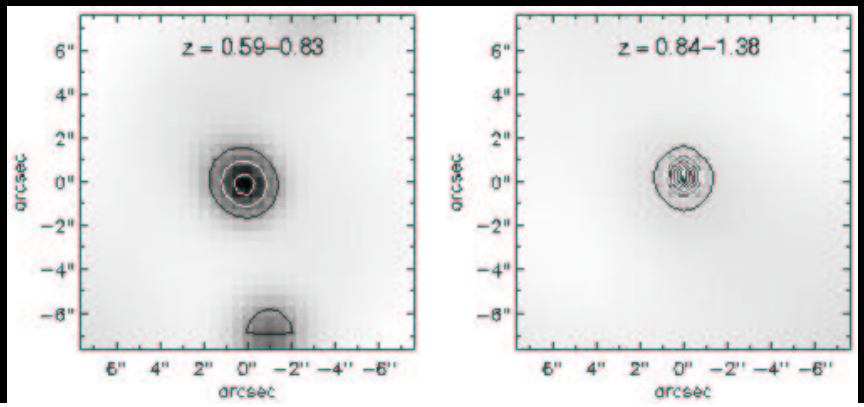
Deep Chandra Survey Results: Evolution of Galaxy X-ray Emission

...a little higher in redshift (0.3 < z < 1.0)...

Evolution of Galaxy X-ray Emission: Spiral & Elliptical Galaxies

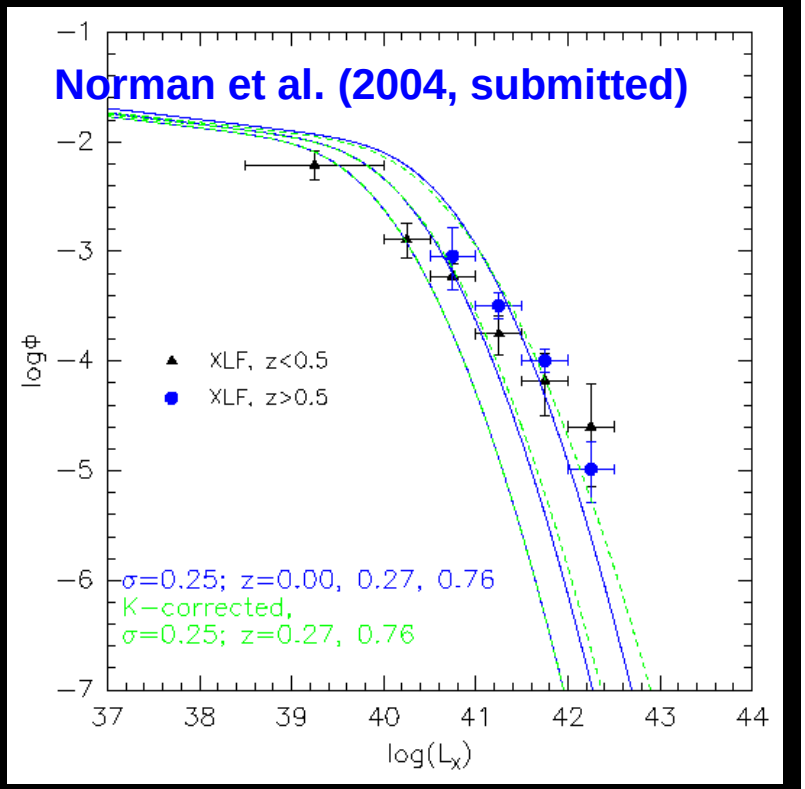
- Probe X-ray binaries over timescales much longer than achievable in nearby Universe (e.g., White & Ghosh 1998)
- Hornschemeier et al. (2002) placed constraints on the X-ray evolution of spirals, increase by at most factor of 2 by z=1.0
- Recently more accurately calibrated in the wider-field *XMM*/2dF survey (z=0.1, Georgakakis et al. 2003)
- X-ray components of ellipticals largely in place by *z*=1 (Immler et al. 2003)

120 galaxies; Immler et al. 2003



Evolution of Galaxy X-ray Emission: "Normal Galaxy" XLF at z>0.3

- Little evolution of normal galaxy XLF up to z~1
- Bayesian selection technique à L_X/HR alone effective at selecting normal galaxies
- XLF/IRLF Differences:
  - Likely AGN contamination at bright end
  - Poor statistics at faint end: small volume sampled
  - At z>0.5,XLF and IRLF match, X-ray/SFR relations "confirmed" (e.g., Ranalli et al. 2002)

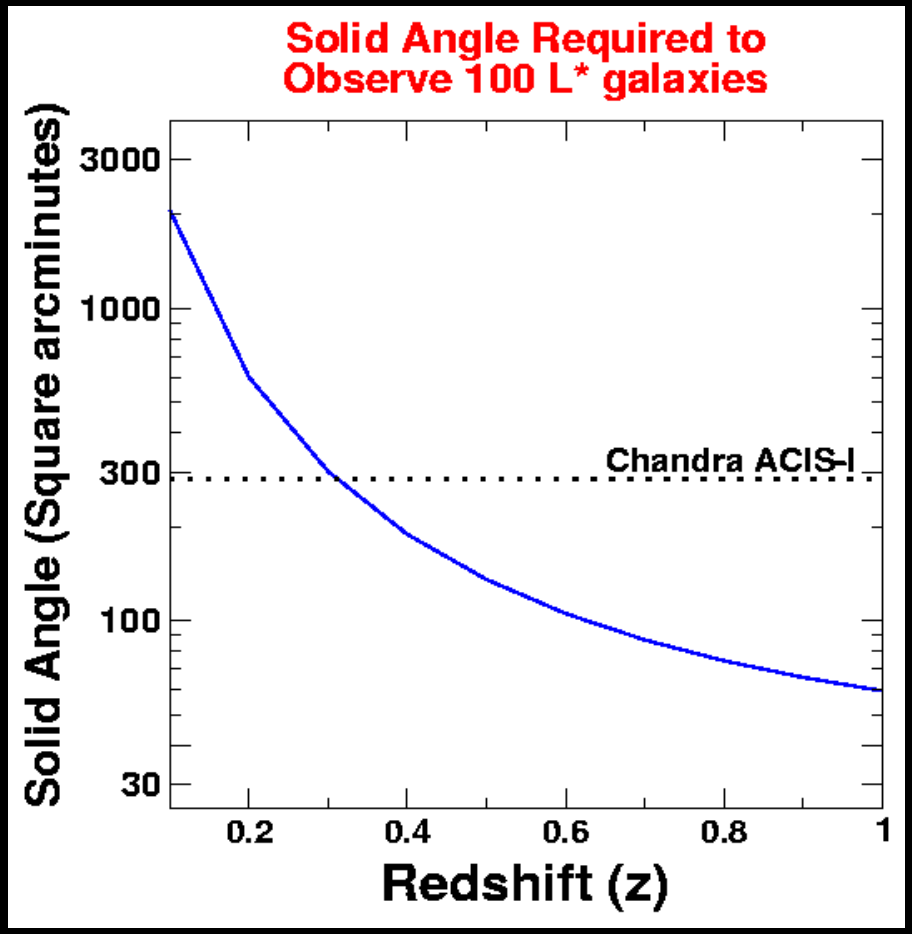


Deep Chandra Survey Results:
X-ray Galaxy Redshift Gap

The X-ray Galaxy Redshift Gap (0.05 < z < 0.30)

COSMIC VOLUME PROBLEM

Based on SDSS source density in g-band (Blanton et al. 2003)

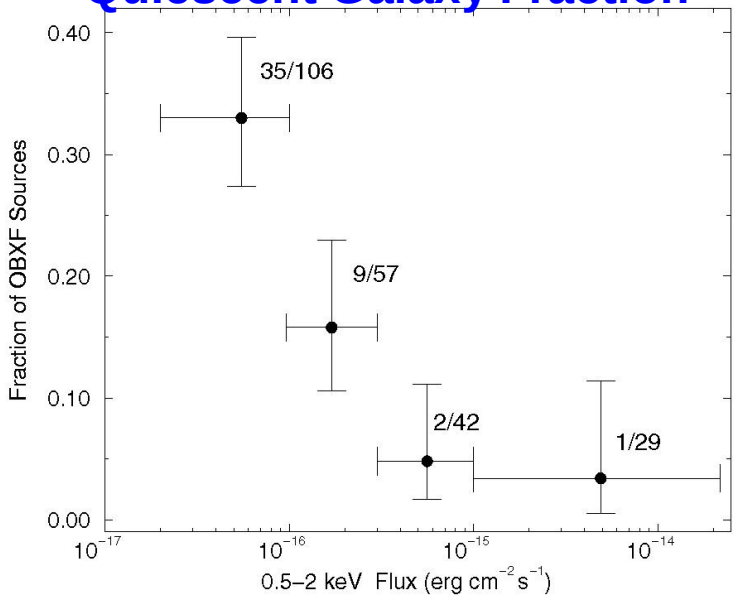


Ω_M=0.3,Ω_Λ=0.7, H_0=70 km s^{-1}Mpc^{-1}

Future of Deep X-ray Imaging Surveys

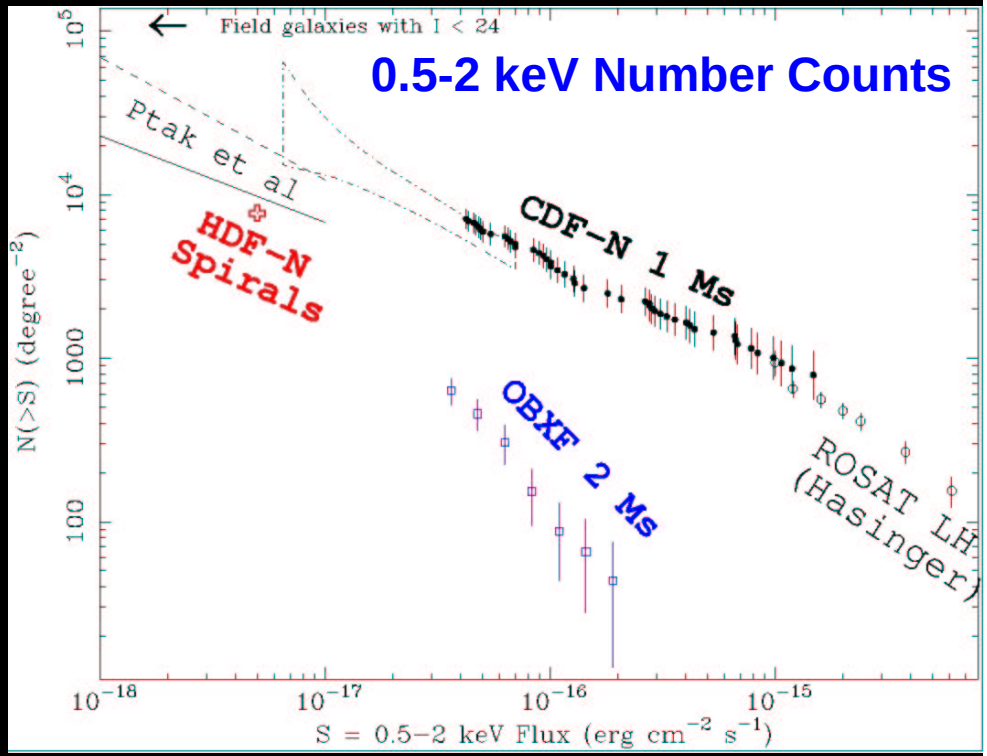
X-ray Emissivity of Galaxies :
Steeply Rising Normal Galaxy Number Counts

Quiescent Galaxy Fraction



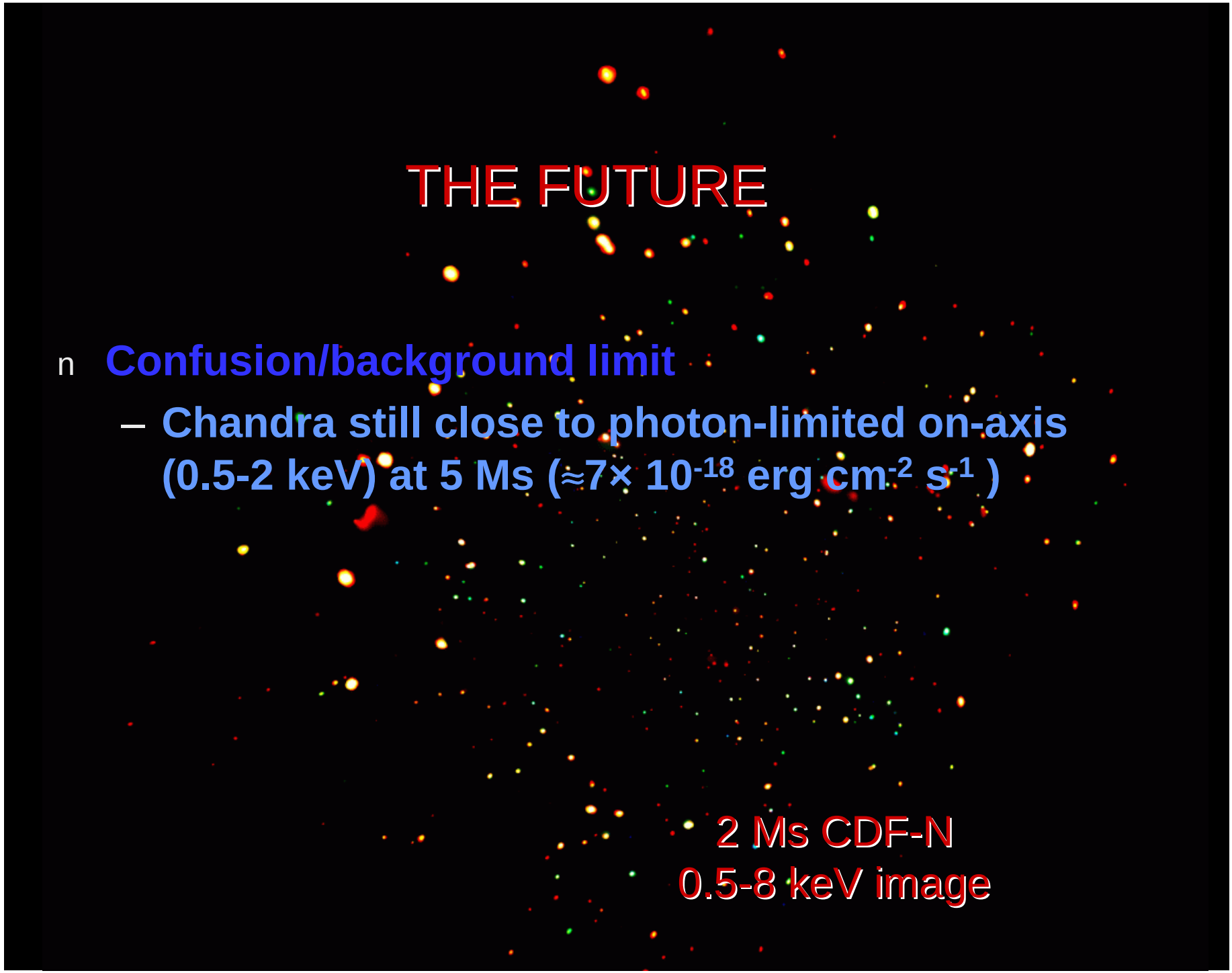
- Below 3 x 10^{-16} erg cm^{-2} s^{-1}, ~30% of X-ray sources are galaxies

Hornschemeier et al. (2003a)



THE FUTURE

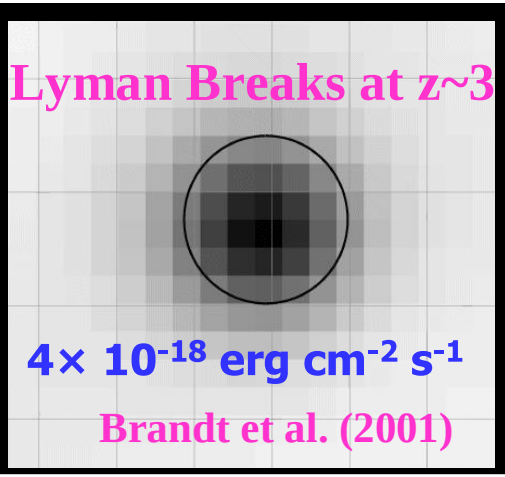
- **Confusion/background limit**
  - **Chandra still close to photon-limited on-axis (0.5-2 keV) at 5 Ms (≈7× 10^{-18} erg cm^{-2} s^{-1})**



2 Ms CDF-N
0.5-8 keV image

5-10 Ms: What will we see?

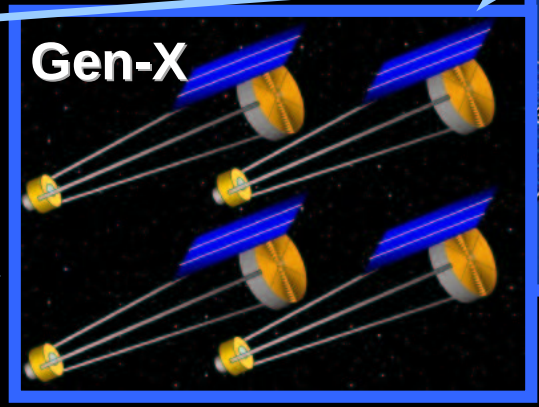
- Starburst galaxies up to z~3
  - Directly probe SFR evolution

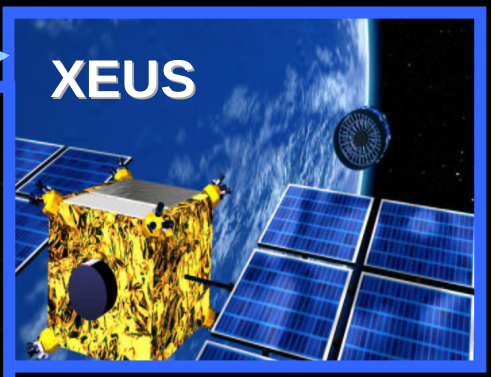


- In HDF-N
  - 50-100 galaxies
- Within GOODs area
  - 400+ galaxies

- Through stacking:
  - probe at least 5-10× deeper
  - 10,000 galaxies
- Stellar-mass black holes
  - Plausibly expect 20—30

•Confusion at ≈2× 10^{-18} erg cm^{-2} s^{-1} for 2.0" spatial resolution
•5-10 Ms Chandra survey is the most direct way to evaluate before





Collaborators

Coma project:

Bahram Mobasher, Bianca Poggianti

Mark Bautz

SDSS-Chandra work:

T. Heckman (JHU), A. Ptak (JHU), E. Colbert (JHU)

CDF-N Team:

D. Alexander, F. Bauer (IoA),

W. Brandt, G. Garmire (PSU)

CDF-S Team:

C. Norman, A.Ptak (JHU), G. Hasinger (MPE)

GOODS Team:

S. Ravindranath, M. Paolillo (STScI),

C. Conselice (Caltech), N. Grogin (JHU),

A. Koekemoer (STScI)