Results from the Chandra Deep Field–North

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

Chandra Deep Field–North

ACIS–I
1.95 Ms over 2.3 yr

Red: 0.5–2 keV
Green: 2–4 keV
Blue: 4–8 keV

448 arcmin$^2$
(~ 60% Moon)

~ 582 point sources
~ 6–7 extended sources
Posns. good to 0.5–1.0 arcsec

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

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)

Giavalisco et al. (2003)
Other Deep Chandra and XMM–Newton Surveys

**Chandra**
- **ACIS–I**
  - 0.94 Ms

**CDF–S**

**XMM-Newton**
- **EPIC pn**
  - 100 ks + More

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

**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**
Summary of Detected Sources

Full source catalogs delivered to public.

<table>
<thead>
<tr>
<th>Band (keV)</th>
<th>Number of Sources</th>
<th>Detected Counts per Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
</tr>
<tr>
<td>Full (0.5–8.0)</td>
<td>479</td>
<td>20,994.8</td>
</tr>
<tr>
<td>Soft (0.5–2.0)</td>
<td>451</td>
<td>15,233.9</td>
</tr>
<tr>
<td>Hard (2–8)</td>
<td>332</td>
<td>5793.7</td>
</tr>
<tr>
<td>SB1 (0.5–1.0)</td>
<td>249</td>
<td>4696.3</td>
</tr>
<tr>
<td>SB2 (1–2)</td>
<td>413</td>
<td>10,517.2</td>
</tr>
<tr>
<td>HB1 (2–4)</td>
<td>310</td>
<td>3933.0</td>
</tr>
<tr>
<td>HB2 (4–8)</td>
<td>183</td>
<td>1851.1</td>
</tr>
</tbody>
</table>

Note.—There are 503 independent X-ray sources detected in total with a false-positive probability threshold of $1 \times 10^{-7}$. We have included cross-band counterparts from the WAVDETECT runs with a false-positive probability threshold of $1 \times 10^{-5}$ (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)
At faint X-ray fluxes, optical fluxes span a 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

87% complete to R = 24

284 sources with spectroscopic IDs
219 sources without

Barger et al. (2003)
Most identified AGN have $z < 1.5$, although a significant minority have $z = 1.5−5.2$ (some incompleteness bias).

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

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 ($z \sim 0–1$).
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.

HST

Chandra
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

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

(Bauer et al. 2003)

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.
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).

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.


Constrain sky density with follow–up and Lyman break.

No more than $\sim 8$ 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 $z \sim 6$ reionization small.

Better source statistics needed.
X–ray Spectral Energy Distributions and Spectra

Accretion processes and environments

X–ray vs. optical flux for z > 4 AGN

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

Adapted from Hasinger et al. (2003); also see Cowie et al. (2003)

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.
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).

Luminous mid−IR and radio emission − part of the strongly evolving starburst pop. making bulk of IR background.  

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)

Source densities of ~ 100,000+ deg−2

Brandt et al. (2001); Hornschemeier et al. (2002); Miyaji & Griffiths (2002); Nandra et al. (2002)
Future Prospects for Deep X–ray Surveys

Chandra 2.0 Ms
- High-redshift AGN XLF
- AGN clustering
- Groups and low-lum. clusters to z ~ 1

Starbursts, normal galaxies, LLAGN
- Very first SMBH search
- Compton–thick AGN at high redshift

Chandra can go significantly deeper with best posns. for ~ 20 yr

Also deeper surveys at > 10 keV
Allocated 1 Ms for Chandra Cycle 5

Extended Chandra Deep Field–South

Cosmic accretion history for obscured and Compton–thick

Moderate–luminosity, typical AGN at $z > 4$

Clustering of X–ray selected AGN to $z \sim 2.5$

Groups and low–luminosity clusters to $z \sim 1$

GEMS, GOODS, ACS UDF

734+ HST orbits

VLT/Keck spectroscopy

6000+ VLT redshifts

SIRTF coverage coming