# The High Redshift ($z > 3$) AGN Population In The 4 Ms Chandra Deep Field South

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# Outline

# High-redshift AGN issues



- physical properties (obscuration)
- evolution (space density, obscured AGN fraction)
- Observables: spectral properties, number counts, etc.
- Need for large (high-redshift) samples

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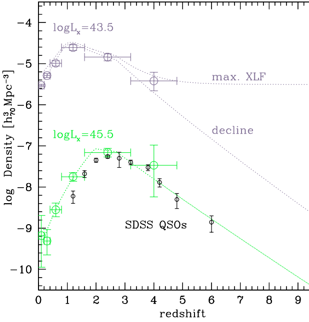
  (X-ray) surveys

  COSMOS (Brusa et al. 2009, Civano et al. 2011)

  4 Ms CDF-S (Fiore et al. 2012, Lehmer et al. 2012)




(Gilli et al., 2011)

# Catalogues



740 X-ray sources in the 4 Ms CDF-S main catalogue (Xue et al. 2011)

Spectroscopic redshifts:
Szokoly et al. (2004); Vanzella et al. (2008); Popesso et al. (2009); Silverman et al. (2010); Wuyts et al. (2008); Vanzella et al. (2010).

Photometric redshifts:
Luo et al. (2010), Cardamone et al. (2010); Rafferty et al. (2011); Santini et al. (2009); Wuyts et al. (2008); Taylor et al. (2009); Dahlen et al. (2010).

# Selection criteria

65 sources have zadopt $> 3$ in Xue et al. (2011)

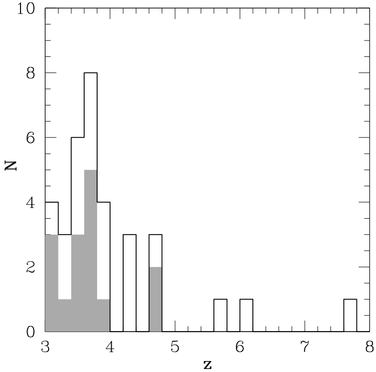
96 sources have $z > 3$ in at least 1 of the considered catalogues

1. "Secure" spectroscopic $z > 3$ **(12 sources)**
2. "Insecure" spectroscopic $z > 3$, upgraded to "secure" through visual inspection **(3 sources)**
3. When more than 2 phot-z are available, $N_{z_{phot}>3} - N_{z_{phot}<3} \geq 3$ **(7 sources)**
4. When only 2 phot-z are available, both are at $z > 3$ **(8 sources)**
5. When only one phot-z is available, its $1\sigma$ lower limit is at $z > 3$ **(4 sources)**

TOTAL: 34 SOURCES

# Redshift distribution

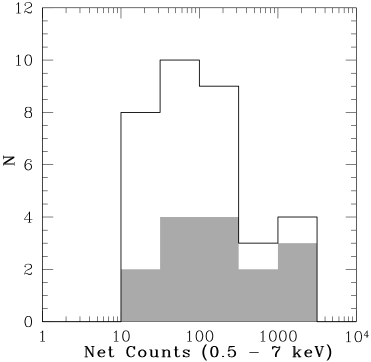
Following Xue et al. (2011), in order of preference: spec-z, phot-z from Luo et al. (2010), phot-z from Cardamone et al. (2010), phot-z from Dahlen et al. (2010)




Median redshift: $z = 3.7$

# 0.5 – 7 keV Net-counts distribution






Median net counts: 80

Low statistics

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simple spectral model

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Absorbed power-law ($\Gamma = 1.8$)

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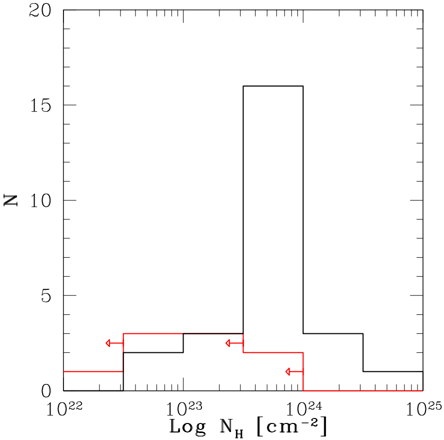
Focus on the column density

# $N_H$ distribution



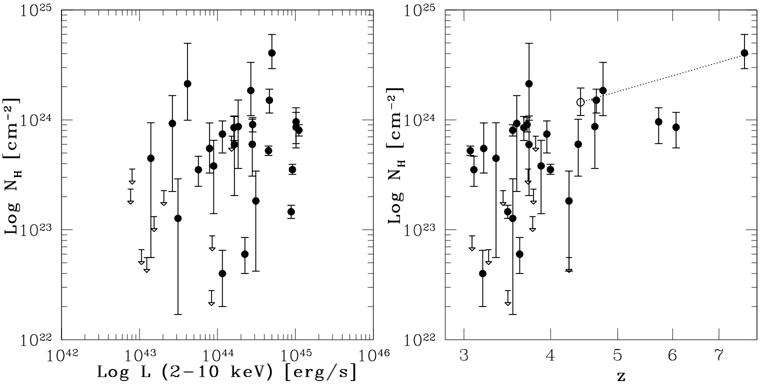



$\sim$ 67% strongly obscured ($N_H > 10^{23}\,\mathrm{cm}^{-2}$) sources

Possible bias due to low statistics and high-z (overestimate of the column density)

# $N_H$ distribution






Median $L_{2-10 \text{ keV}} = 1.52 \times 10^{44} \text{ erg s}^{-1}$

# Correction factors for the $N_H$ distribution



Problem: possible $N_H$ overestimation due to low statistics and high-z

$\downarrow$

How many times a X-ray spectrum intrinsically absorbed by a column density $N_{H_j}$ is best-fitted by a different column density $N_{H_i}$?

$\downarrow$

Spectral simulations!

$\downarrow$

Correction factors $P_{ij}$

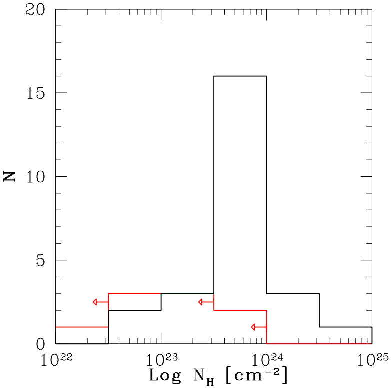
(probability to derive $N_{H_i}$ given an intrinsic $N_{H_j}$)

# Correction factors for the $N_H$ distribution



Sample divided into 3 $N_H$ range (only sources with constrained best-fitting $N_H$):

- **A:** $log(\frac{N_H}{\mathrm{cm}^{-2}}) < 23$ **(2 sources)**
- **B:** $23 < logN_H < 24$ **(19 sources)**
- **C:** $logN_H > 24$ **(4 sources)**



# Correction factors for the $N_H$ distribution



$$N_A = \sum_{j=A}^{C} X_j P_{Aj}$$

$$N_B = \sum_{j=A}^{C} X_j P_{Bj}$$

$$N_C = \sum_{j=A}^{C} X_j P_{Cj}$$

where $\mathbf{N_i}$ is the number of sources with (observed) best-fitting $N_H$ in the $i$-th bin; $\mathbf{X_j}$ is the number of sources with intrinsic $N_H$ in the $j$-th bin; $\mathbf{P_{ij}}$ is the probability to derive a best-fitting $N_H$ in the $i$-th bin, given an intrinsic $N_H$ in the $j$-th bin.

$i, j =$ A, B, C

# Correction factors for the $N_H$ distribution: (basic) procedure



For $i, j$ = A, B, C:

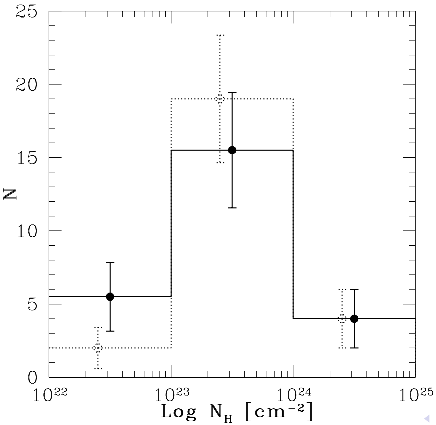
1. 1000 simulations of a X-ray spectrum with $\Gamma = 1.8$, $N_H$ in the $j$-th bin, 100 net counts at $z = 4$ ($\approx$ median values of the sample)
2. Fit of the 1000 simulated spectra to derive the best-fitting $N_H$
3. Counting how many times the best-fitting $N_H$ lies in the $i$-th bin $\rightarrow P_{ij}$

# Corrected $N_H$ distribution



| $\Gamma = 1.8$ | | | |
|---|---|---|---|
| $P_{ij}$ | $j$=A | $j$=B | $j$=C |
| $i$=A | 0.361 | 0.0 | 0.0 |
| $i$=B | 0.639 | 1.0 | 0.0 |
| $i$=C | 0.0 | 0.0 | 1.0 |

- $N_A = 2 \rightarrow X_A = 5.5$
- $N_B = 19 \rightarrow X_B = 15.5$
- $N_C = 4 \rightarrow X_C = 4$

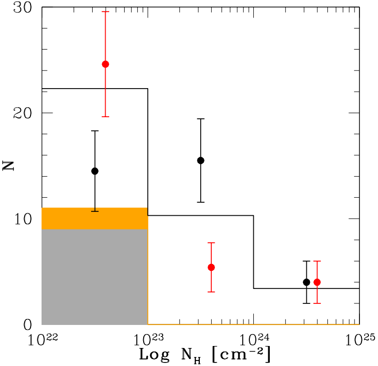



Dashed line: observed distribution

Solid line: corrected (intrinsic) distribution

# Corrected $N_H$ distribution






Black points: intrinsic $N_H$ distribution ($\Gamma = 1.8$)

Red points: intrinsic $N_H$ distribution ($\Gamma = 1.6$)

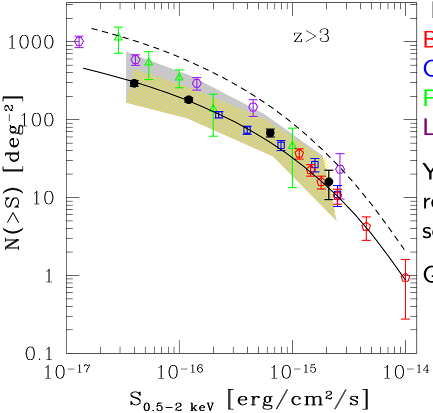
| $\Gamma = 1.6$ | | | |
|---|---|---|---|
| $P_{ij}$ | $j$=A | $j$=B | $j$=C |
| $i$=A | 0.147 | 0.0 | 0.0 |
| $i$=B | 0.853 | 1.0 | 0.0 |
| $i$=C | 0.0 | 0.0 | 1.0 |

Shaded areas: upper limits

Histogram: Gilli et al. (2007) XRB synthesis model with high-z decline (no evolution with redshift at the $2\sigma$ c.l.)

# $z > 3$ LogN-LogS






Black: this work
Brusa et al. (2009)
Civano et al. (2011)
Fiore et al. (2012)
Lehmer et al. (2012)

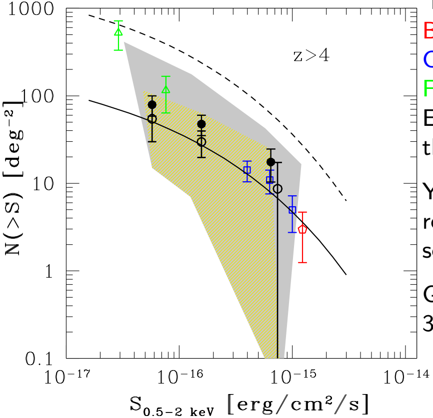
Yellow shaded area: relaxing/tightening the selection criteria

Grey shaded area: adding 39 sources without redshift in any catalogue

Model from Gilli et al. (2007) assuming (solid line) or not assuming (dashed line) a high-z decline in the AGN space density

# $z > 4$ LogN-LogS






Black: this work

Brusa et al. (2009)

Civano et al. (2011)

Fiore et al. (2012)

Empty circles: excluding the 3 sources at $z > 5$

Yellow shaded area: relaxing/tightening the selection criteria

Grey shaded area: adding 39 sources without redshift in any catalogue

Model from Gilli et al. (2007) assuming (solid line) or not assuming (dashed line) a high-z decline in the AGN space density

# Conclusions



- 34 X-ray selected AGN at $z > 3$ in the 4 Ms CDF-S
- Spectral analysis assuming a simple spectral model ($\Gamma = 1.8$)
- Large fraction ($\sim 70\%$) of obscured sources (but possible biases). Typical luminosity $L_{2-10\ \mathrm{keV}} \approx 10^{44}\,\mathrm{erg\ s^{-1}}$
- Spectral simulations to derive correction factors
- Corrected $N_H$ distribution consistent (within $2\sigma$) with no evolution of obscuration with redshift
- LogN-LogS in agreement with a decline in the high-z AGN space density