The deepest X-ray view of high-redshift galaxies: constraints on low-rate black-hole accretion

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Techical details in

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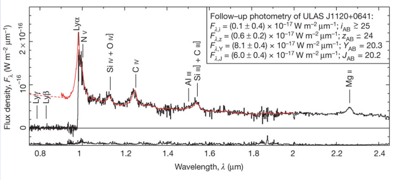
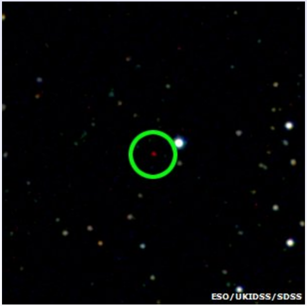
Massive BH at high redshift are very massive!

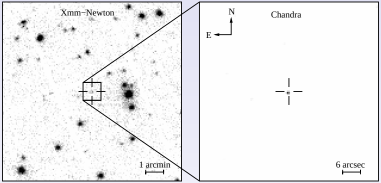


Mortlock+11



ULASJ1120+0641 is the highest redshift ($z = 7.1$) QSO ever discovered and has $M_{BH} \gtrsim 10^9\, M_\odot$

$z = 7.1 \Rightarrow < 1$ Gyr after Big Bang



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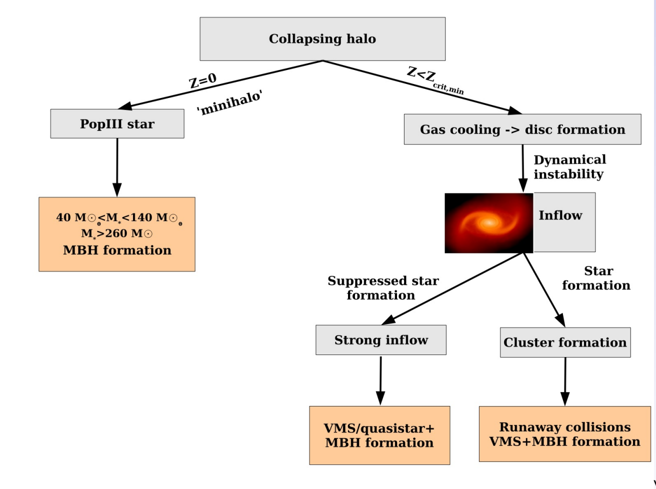
Other SMBH at $z > 6$ discovered

(e.g. Willott+03,+09, Fan+06a,+06b, Venemans+13, Banados+14, Wu+15)

SMBH seed formation models



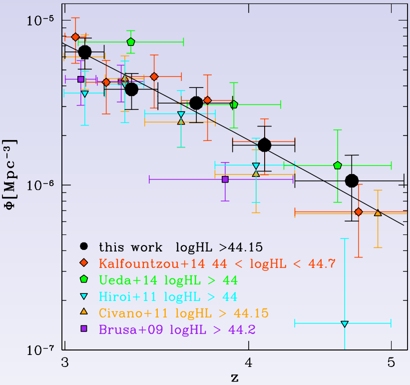
Volonteri+10

LIGHT SEEDS
$(\mathrm{M_{BH}} \sim 100\,\mathrm{M_\odot})$

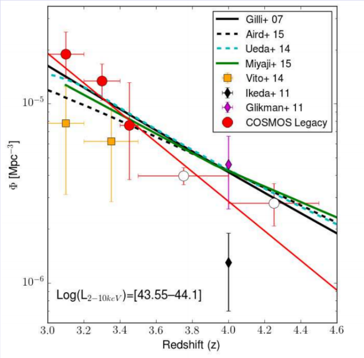
HEAVY SEEDS
$(\mathrm{M_{BH}} \sim 10^4 - 10^6\,\mathrm{M_\odot})$

High-Redshift AGN Population Evolution

Vito+14



Marchesi+16



$\log L_X \gtrsim 44$

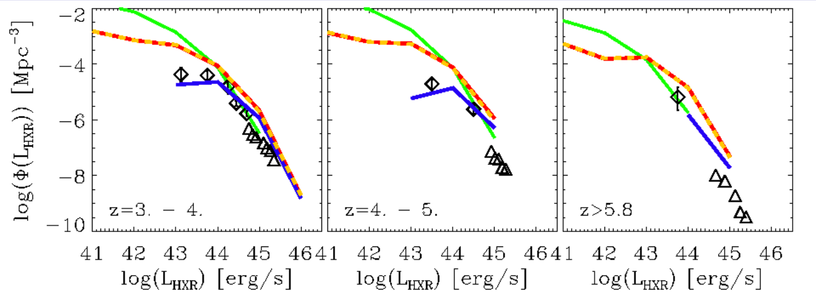
Decline at $z > 3$ (e.g. Brusa+09, Civano+11, Hiroi+12, Kalfountzou+14)

$\Phi \propto (1+z)^p$
$p = -6.0 \pm 0.9 \Rightarrow$ Factor ~ 10 from z=3 to 5

$\log L_X \lesssim 44$

???

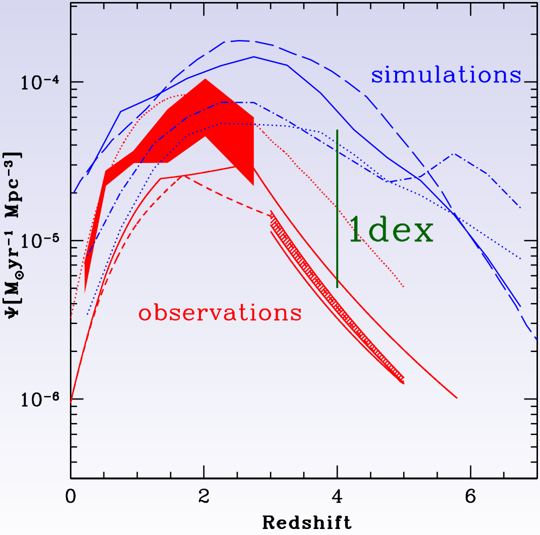
Faint end of high-z LF can help in discriminating the models



Examples of high-z HXLF predicted from models of light and heavy seeds (Hirschmann+12)

Need to sample the faint end of the LF at high-z!

BHAD: observations vs. simulations



Simulations from Lodato+06, Volonteri+10,+16, Sjiacki+15

Observations from Delvecchio+14, Ueda+14, Vito+14, Aird+15, Georgakakis+15, Miyaji+15

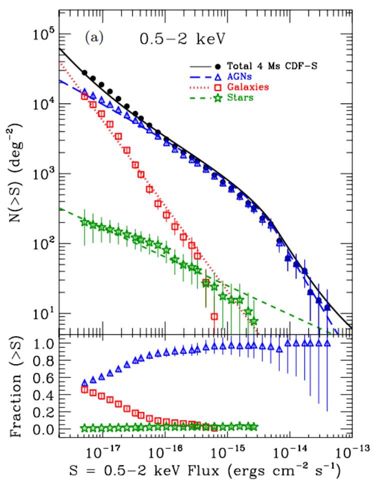
Low-rate (i.e. undetected in X-ray) accretion in "normal" galaxies?

Goals of the work

Stacking X-ray emission from $z > 4$ CANDELS galaxies (undetected in X-rays) to look for signatures of accretion onto SMBH.

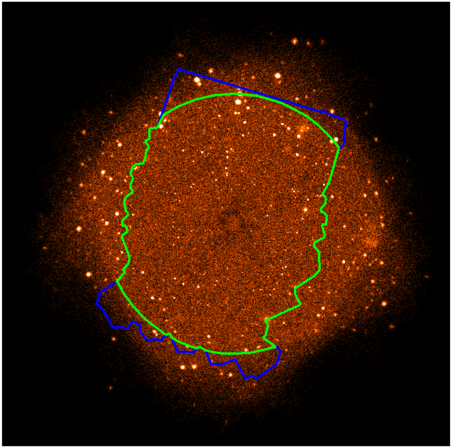
Trying to give estimates of:

- Black Hole Accretion Rate Density (BHAD)
- Star Formation Rate Density (SFRD)
- Faint end of the AGN LF



Lehmer+12

Exploiting the best X-ray and optical/NIR data: 7 Ms CDFS + CANDELS



$\sim$ 7 Ms CDFS ($\sim$ 480 arcmin^2)

PI: W.N. Brandt, Luo et al. in prep.

Deepest X-ray survey ever!
(and great spatial resolution!)

+

Deep HST catalogs in GOODS-S
(CANDELS + ERS + HUDF; Guo+13, Santini+15)
Limit mag F160w $\lesssim$ 30

+

Multiwavelength data,
high quality spec. and phot. z,
dedicated SED-fitting campaigns
(M_*, SFR, etc.)

Stacking techique

Stacking: A Romantic Example

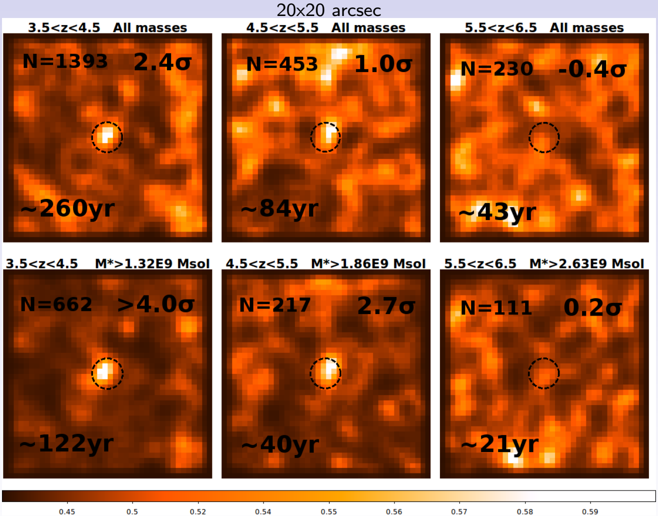
3 / 100 second exposure

1 / 1000 second exposure

Stacked image of 30 candles with 1 / 1000 sec exposure.

Effective stacked exposure of $(30 \times 1/1000$ sec$) = 3/100$ sec.

Stacked images



Normalized to (min,max)=(0,1); smoothed (Gaussian function with $\sigma = 3\text{pix}$), power-law scale

Black Hole Accretion Rate Density (BHAD)

$$\Psi_{bhar}(z) = \frac{(1-\varepsilon)K_{bol}}{(\varepsilon c^2)} \frac{L_{AGN}^{TOT}}{V_c^{CANDELS}}$$

Black points: all galaxies

Red Points: massive galaxies

Grey points: individually X-ray detected sources (i.e. AGN)

Observational results from:

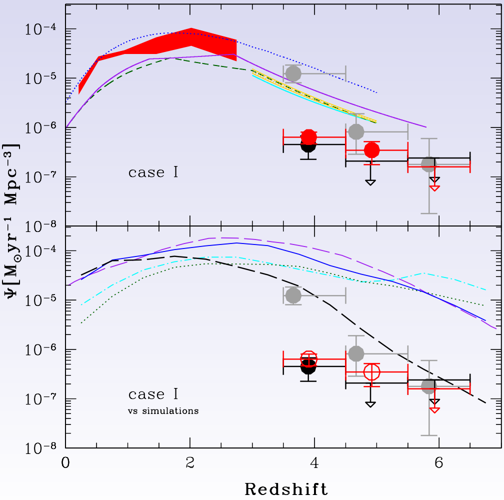
Delvecchio+14, Ueda+14, Vito+14,

Aird+15, Georgakakis+15, Miyaji+15

Predictions from simulations from:

Lodato&Natarajan 2006,

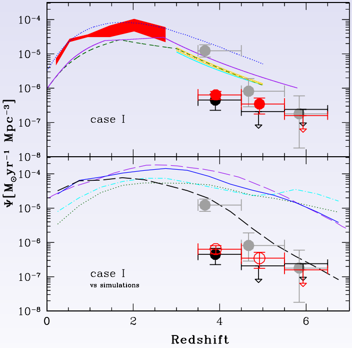
Volonteri+10, +16, Sijacki+15.



Result I:

X-ray detected AGN dominate the BHAD at high redshift. Continuous low-rate accretion in "normal" (i.e. undetected in the 7 Ms CDF-S) provides a negligible contribution to the total BH mass growth.

(see also Volonteri+16).

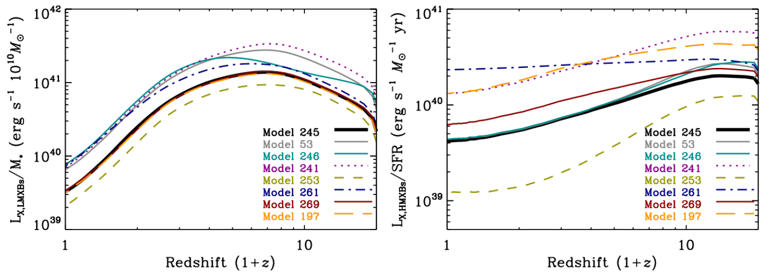


Similar to what found at low redshift via the Soltan argument and direct measurements (see Brandt&Alexander 2015).

Star Formation Rate Density (SFRD)

$$\rho_{sfrd}(z) = \frac{N \times \langle SFR \rangle}{V}$$

$$\langle SFR \rangle = SFR(L_X^{stack}, M_*)$$



Fragos+13

Star Formation Rate Density (SFRD)

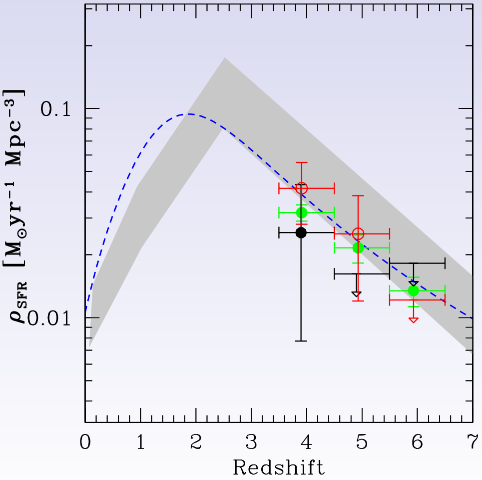
$$\rho_{sfrd}(z) = \frac{N \times \langle SFR \rangle}{V}$$

Black points: all galaxies

Red Points: massive galaxies

Green points: SFRD from CANDELS SFR and M_*

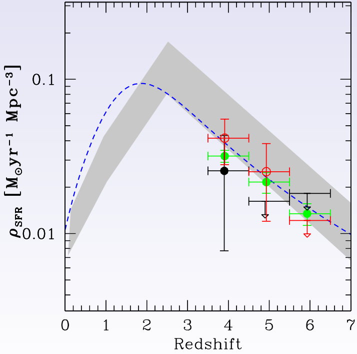
Observational results from: Bouwens+15, Madau&Dickinson 2014



Result II:

Stacked X-ray emission in high-z galaxies plausibly entirely due to XRB (i.e. star formation) (see also Cowie+12)

or, in other words, we need the stacked X-ray emission in high-z galaxies to be due entirely to XRB in order to match the SFRD found in previous works and the SFRD derived by CANDELS SFRs for the same galaxies.

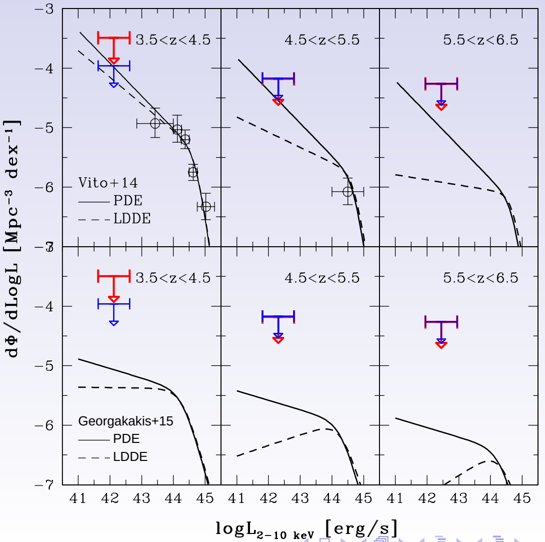


This strengthens result I. Caveat: SFR-L_X relations not constrained observationally at high-z.

Faint end of AGN XLF

$$N^{AGN}(L) \le \frac{L^{stack}_{AGN}}{L} \implies \phi = \frac{dN^{AGN}}{dVdlogL}$$

Blue upper limits: all galaxies
Red upper limits: massive galaxies



Result III:

The faint end of the AGN XLF at high-z is fairly flat. First constraints on the XLF at such low luminosities at $z > 3.5$.

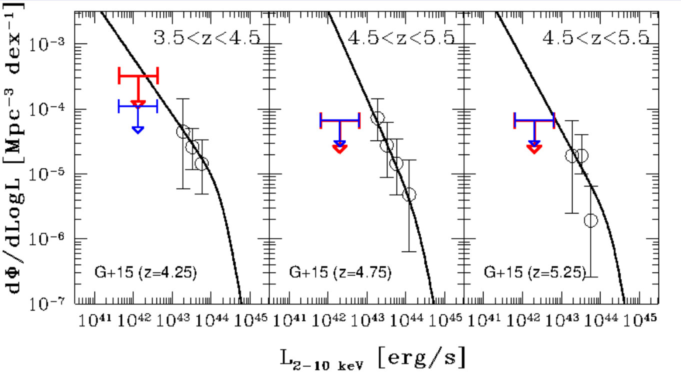
This qualitatively (and naively) supports massive seeds.

Faint end of AGN XLF

Testing the AGN contribution to the Cosmic Reionization (Giallongo+15 found a high number of faint X-ray AGN (i.e. steep XLF faint end), Madau&Dickinson2016 used that result to predict a high AGN contribution to the Reionization).

Blue upper limits: all galaxies
Red upper limits: massive galaxies

Curves and empty circles: Giallongo+15



Evidence for flatter AGN XLF faint end! Different analysis, photometric redshift uncertainties, ...

Need to directly probe the AGN XLF faint end!

Conclusions

Stacking X-ray data from 7 Ms CDF-S $\Longrightarrow \sim 10^9$s effective exposure.

X-ray detected AGN dominate the BHAD at high redshift. Continuous low-rate accretion in "normal" (i.e. undetected in the 7 Ms CDF-S) provides a negligible contribution to the total BH mass growth.

(see also Volonteri+16).

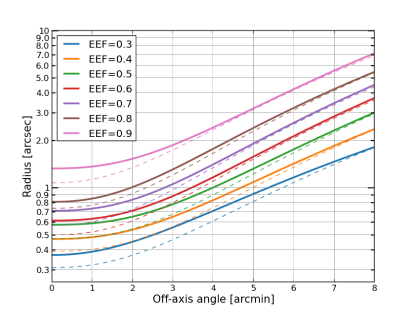
Stacked X-ray emission in high-z galaxies plausibly entirely due to XRB (i.e. star formation) (see also Cowie+12)

The faint end of the AGN XLF at high-z is fairly flat. First constraints on the XLF at such low luminosities at $z > 3.5$.

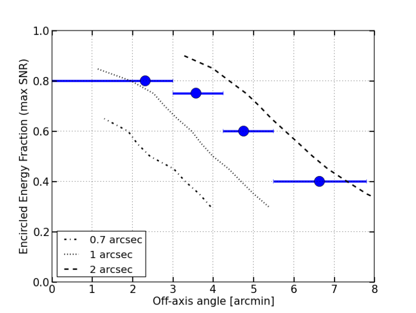
Athena, *WFXT* and *X-Ray Surveyor* will directly sample the faint end of the AGN XLF at $z > 4$.

Techical notes

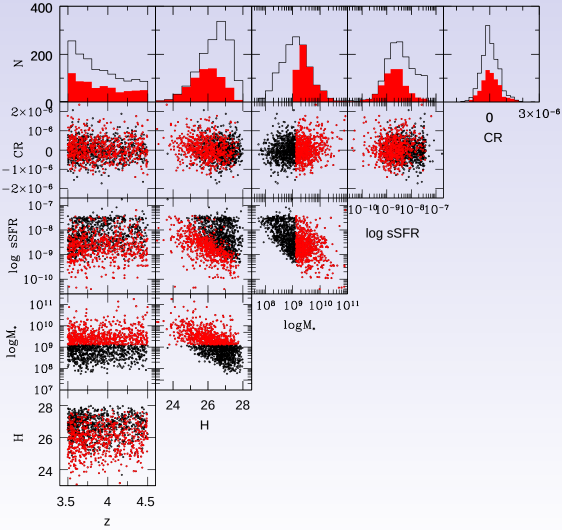
Simulating *Chandra* PSF:



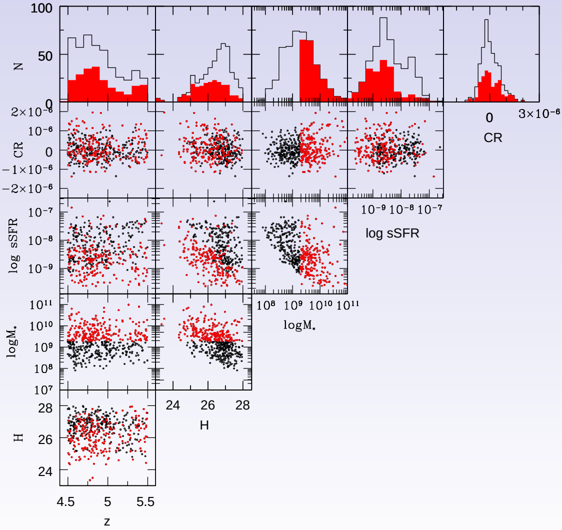
Best choice for the aperture-photometry region size:



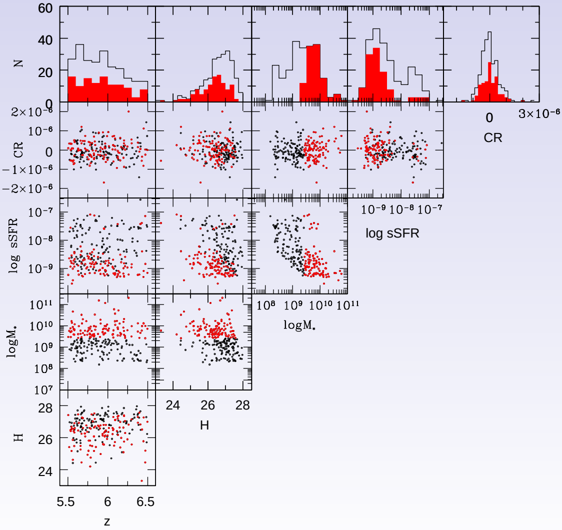
The sample


N
400
200
0
CR
log sSFR
logM*
H
z
3.5
4
4.5
24
26
28
10⁸ 10⁹ 10¹⁰ 10¹¹
10⁻¹⁰ 10⁻⁹ 10⁻⁸ 10⁻⁷
0
3×10⁻⁶

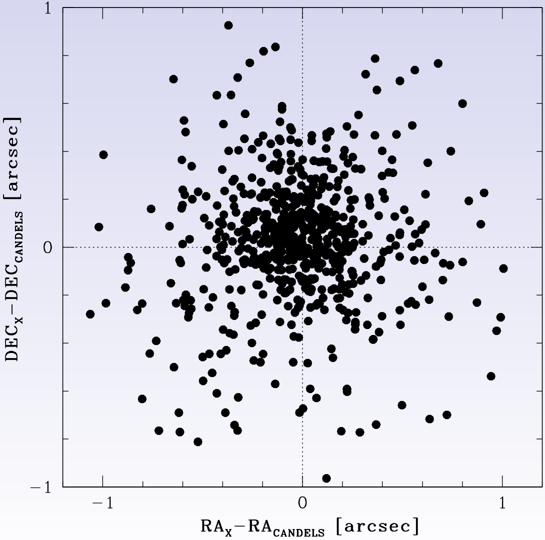
The sample


100
50
0
N
2×10⁻⁶
10⁻⁶
0
−1×10⁻⁶
−2×10⁻⁶
CR
0
3×10⁻⁶
CR
10⁻⁷
10⁻⁸
10⁻⁹
log sSFR
10⁻⁹ 10⁻⁸ 10⁻⁷
log sSFR
10¹¹
10¹⁰
10⁹
10⁸
10⁷
logM*
10⁸ 10⁹ 10¹⁰ 10¹¹
logM*
28
26
24
H
24 26 28
H
4.5 5 5.5
z

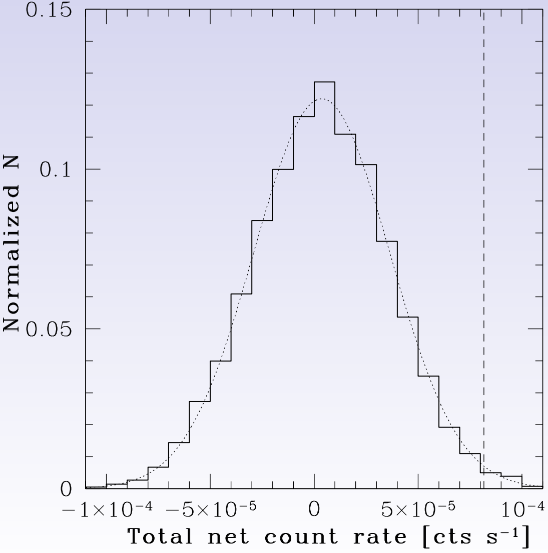
The sample


N
60
40
20
0
CR
2×10^{-6}
10^{-6}
0
-1×10^{-6}
-2×10^{-6}
log sSFR
10^{-7}
10^{-8}
10^{-9}
logM*
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
H
28
26
24
5.5
6
6.5
z
24
26
28
H
10^{8} 10^{9} 10^{10} 10^{11}
logM*
10^{-9} 10^{-8} 10^{-7}
log sSFR
0
3×10^{-6}
CR

X-ray/optical offset



Stacking random positions



Effect of photometric redshift uncertainties