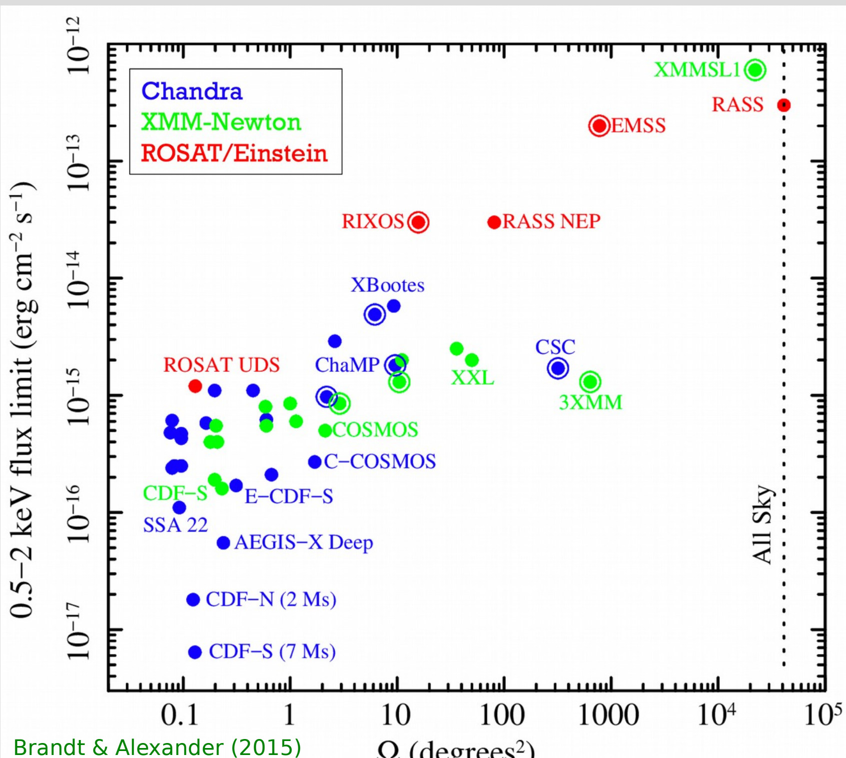
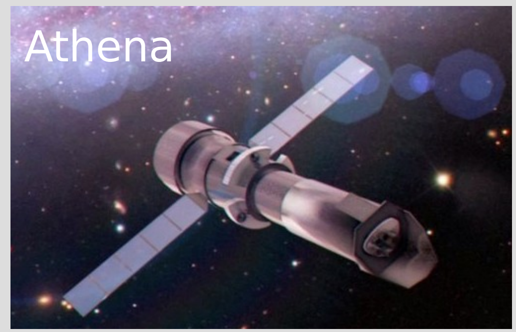
rom the Chandra Deep Fields to Lyn

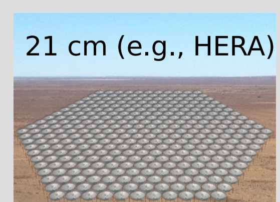
Niel Brandt, Fabio Vito, the Chandra Deep Fields Team,
and the Lynx “First Accretion Light” Working Group

Demographic and Spectral Results at High Redshift from Current X-ray Surveys



Some Prospects for the 2020’s





SMBH Seeds and Lynx

Current Observational Overview

Over the past ~ 18 yr, Chandra and XMM-Newton have allowed a large expansion in the number of X-ray detected AGNs at z = 4-7.

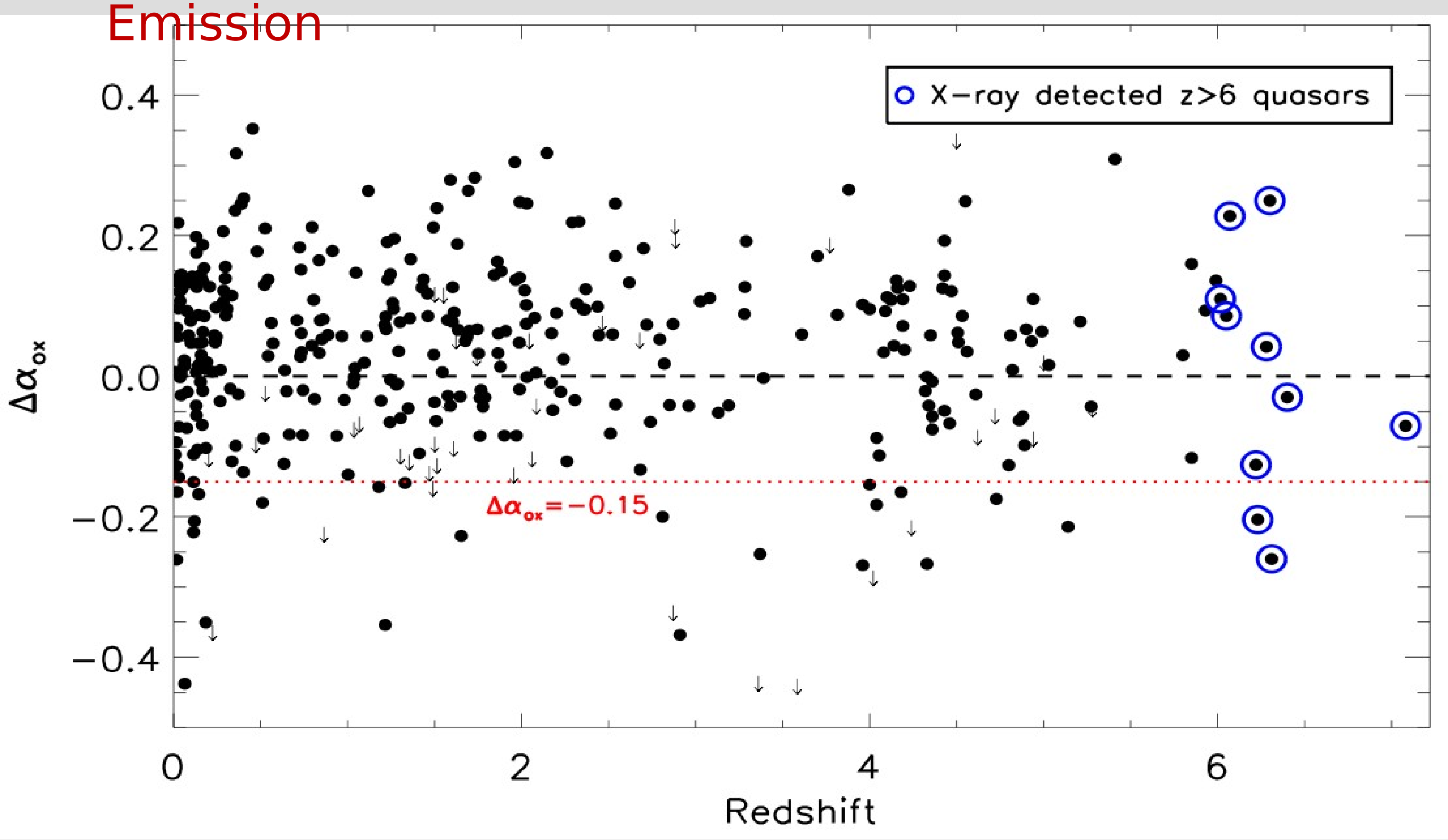
Now have ~ 153 X-ray detections at z = 4-7, allowing X-ray population studies out to the reionization era.

X-ray follow-up of high-redshift AGNs first found in other multiwavelength surveys; e.g., SDSS, PSS, FIRST.

<u>X-ray selected</u> high-redshift AGNs in <u>X-ray surveys</u>.

X-ray Emission from AGNs Remains Strong to the Highest Redshifts

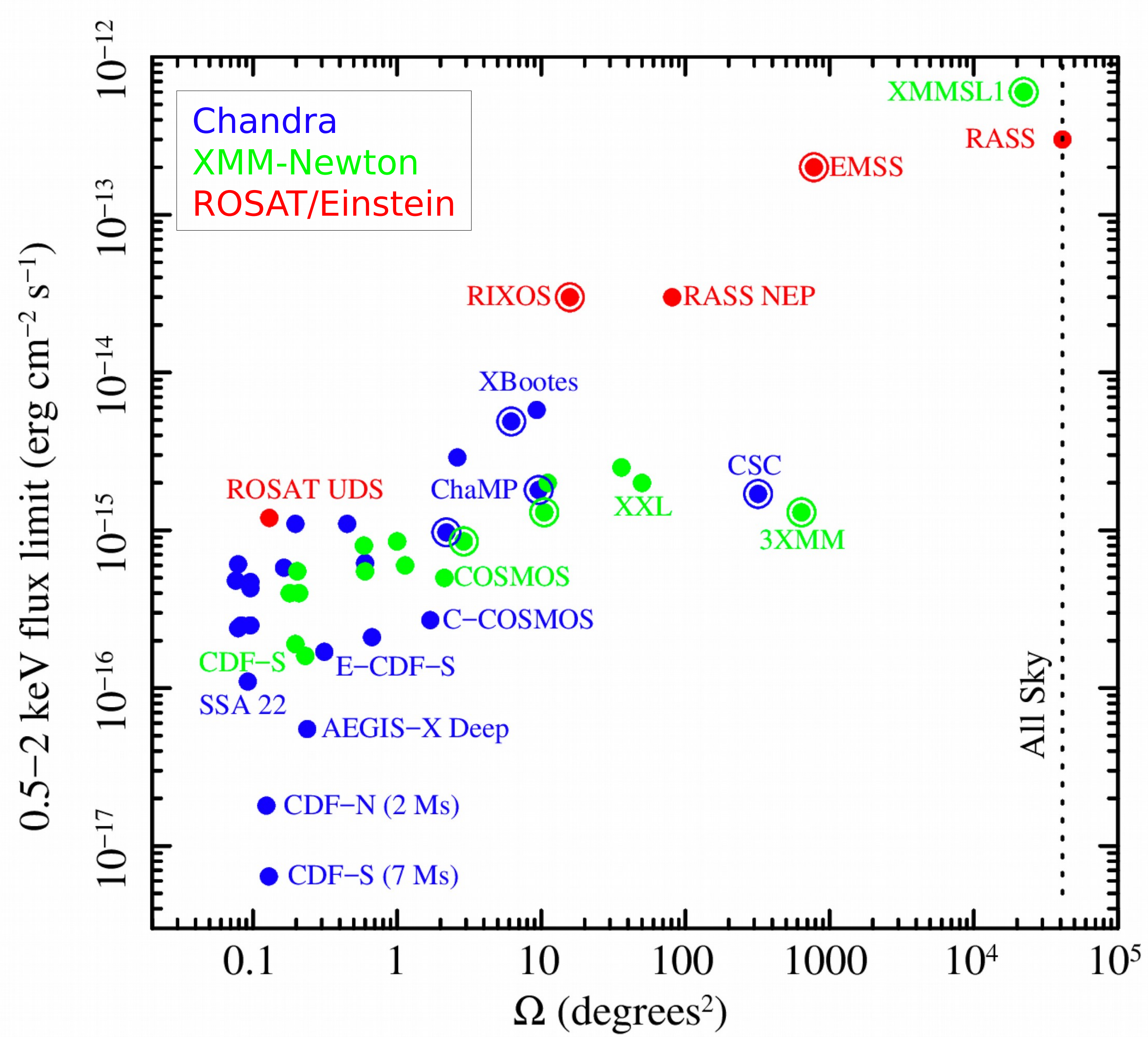
Level of X-ray Emission Relative to Optical/UV Emission



Constraints at *z* = 6-7 will be significantly improved by large Chandra Cycle 19 project.

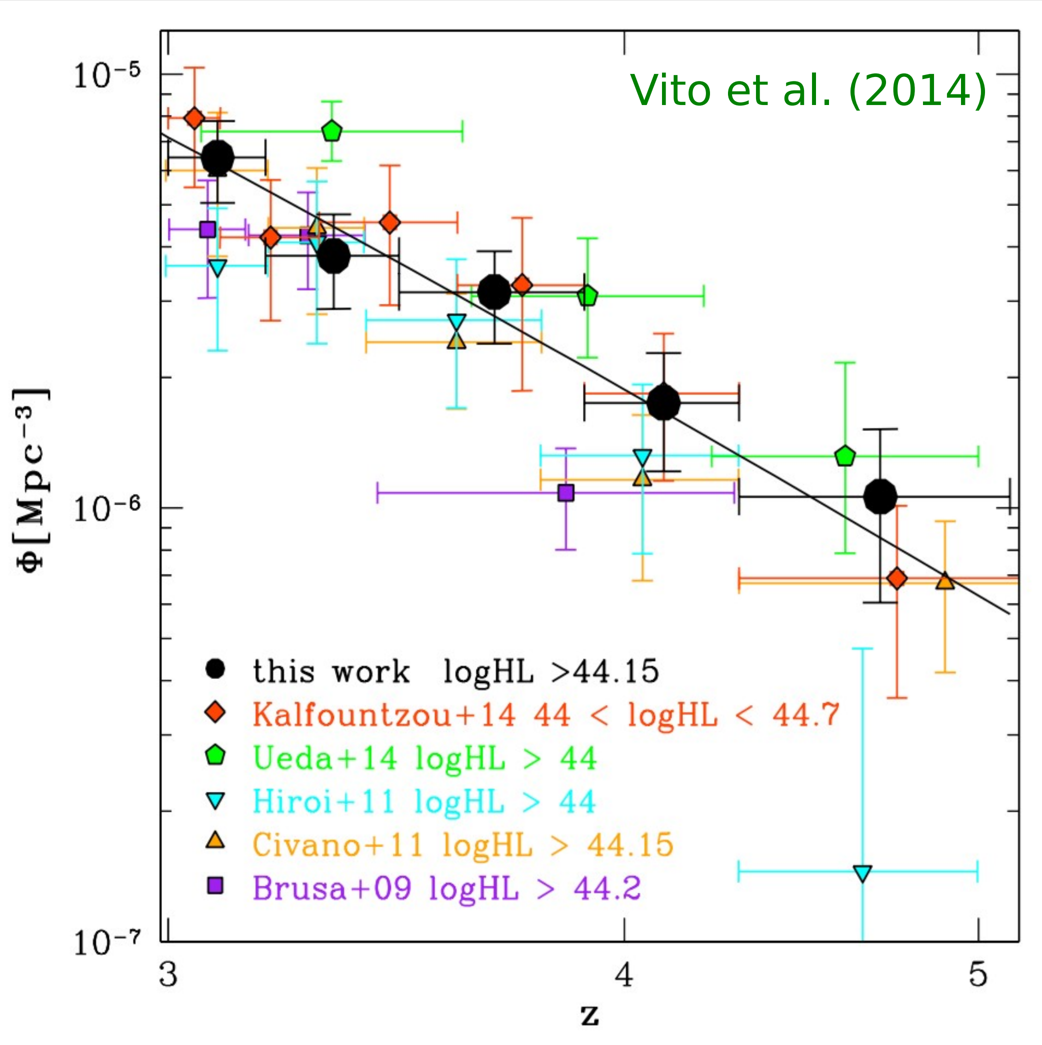
Demographic and Spectral Results at High Redshift from Current X-ray Surveys

(Focusing on the Deepest)



Brandt & Alexander (2015)

Space Density Declines for High-Luminosity X-ray AGNs



In contrast to early suggestions from ROSAT, clearly see ~ exponential
decline for luminous X-ray selected AGNs at $z > 3$.

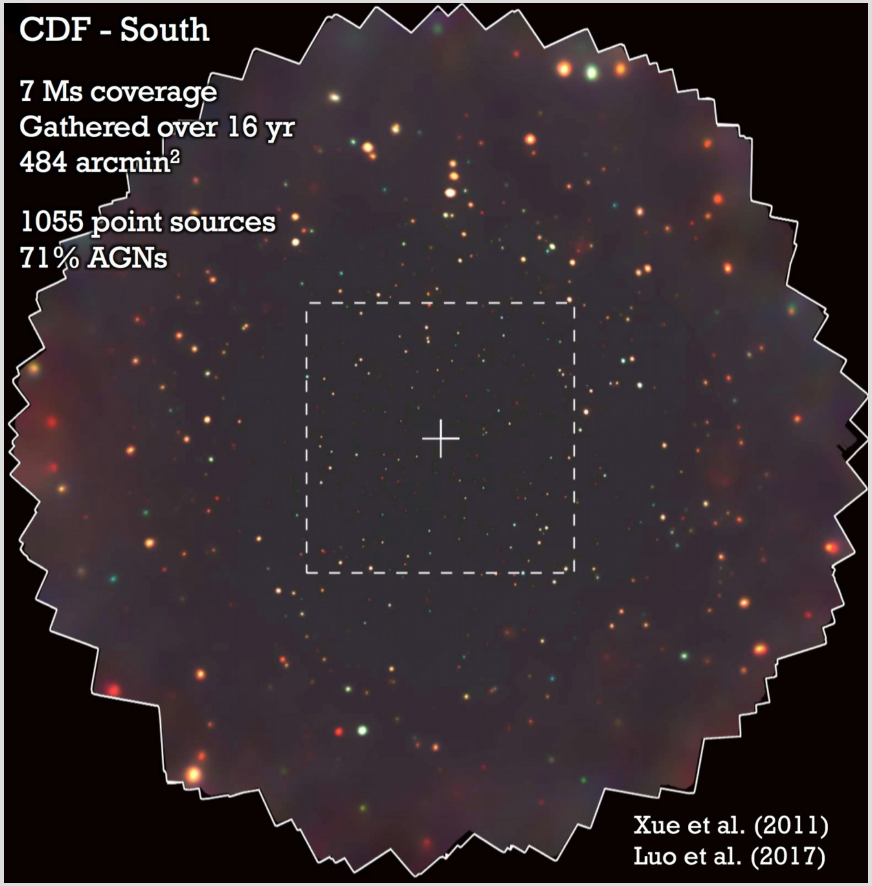
$\Phi \propto (1 + z)^p$ with p = -6.0 +/- 0.8

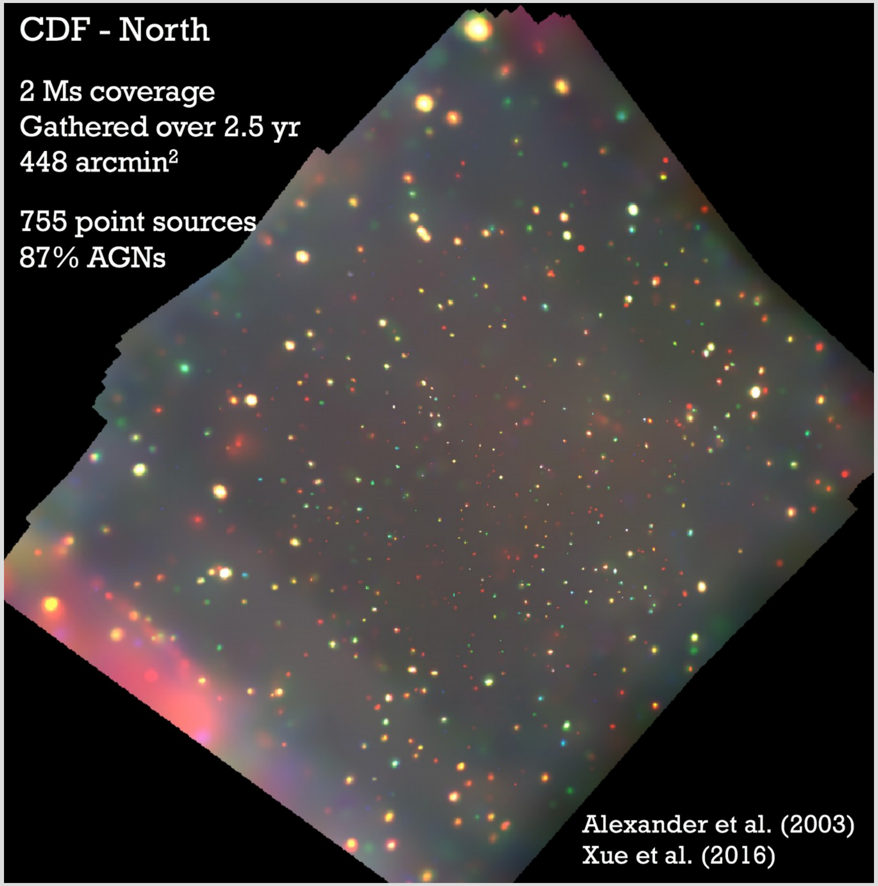
Space-density comparisons with optically selected quasars indicate
agreement to within factors ~ 2-3.

Decline is similar to that of massive

Space Density at z ~ 3-5 for Moderate-Luminosity X-ray AGNs

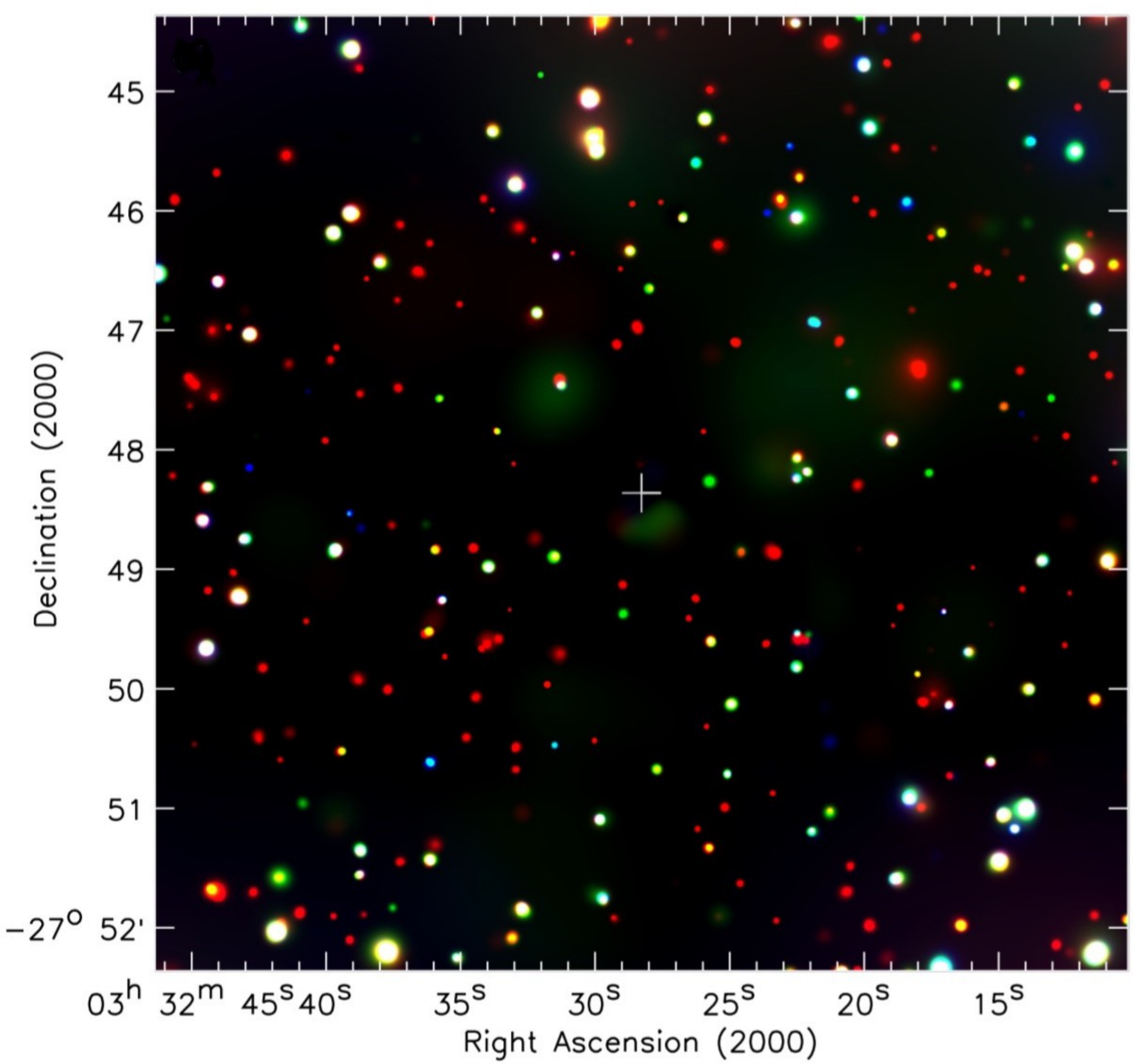
Ultradeep X-ray Surveys Required – The Chandra Deep Fields





Center of the CDF-S

Faintest sources have 1 count per 10.0 days!



0.5-2 keV
2-4 keV
4-7 keV

Luo et al. (2017)

Counterparts and Redshifts for 7 Ms CDF-S

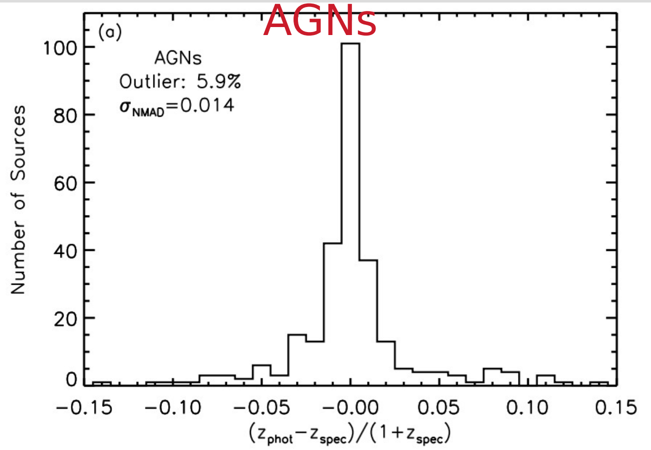
98.4% of X-ray sources have counterparts

97.8% have redshifts

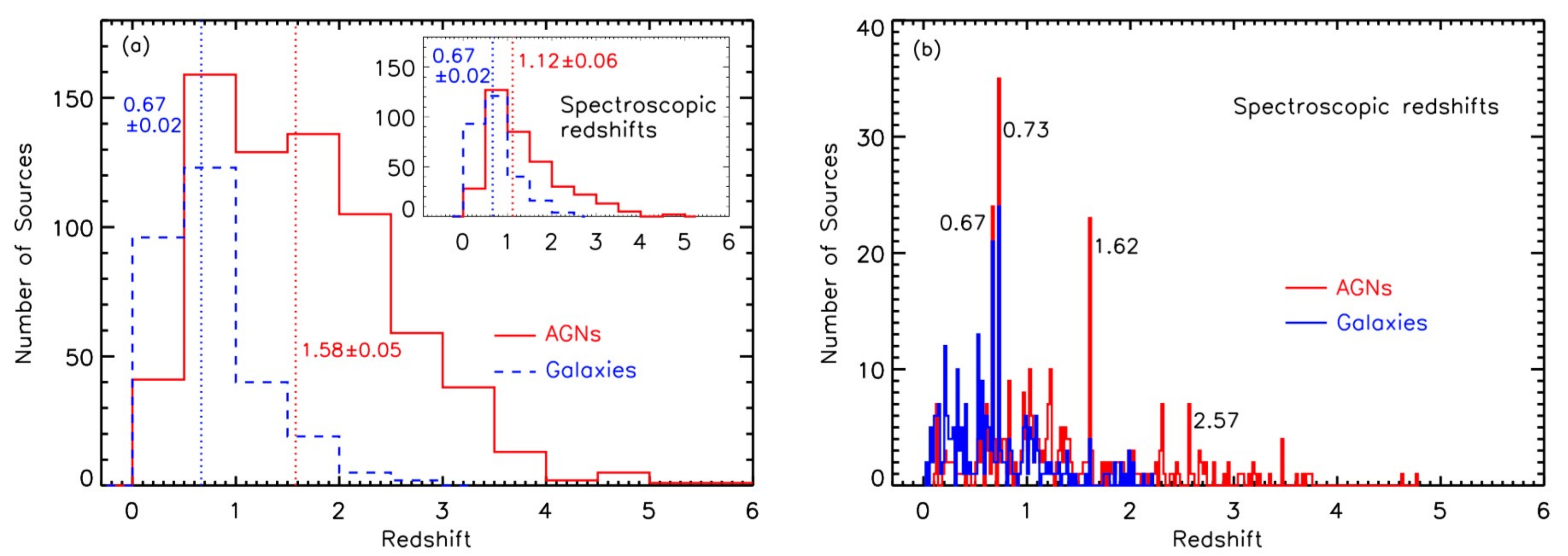
- 64.8% are spectroscopic redshifts
- 33.0% are photometric redshifts

Luo et al. (2017)

Photometric Redshifts for AGNs

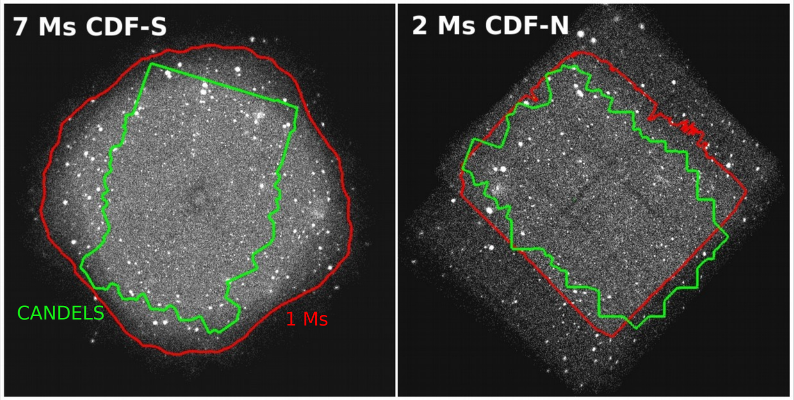


Redshift Distributions - AGNs and Galaxies



Space Density at $z \sim 3$-5 for Moderate-Luminosity X-ray AGNs

Utilized Regions of CDFs



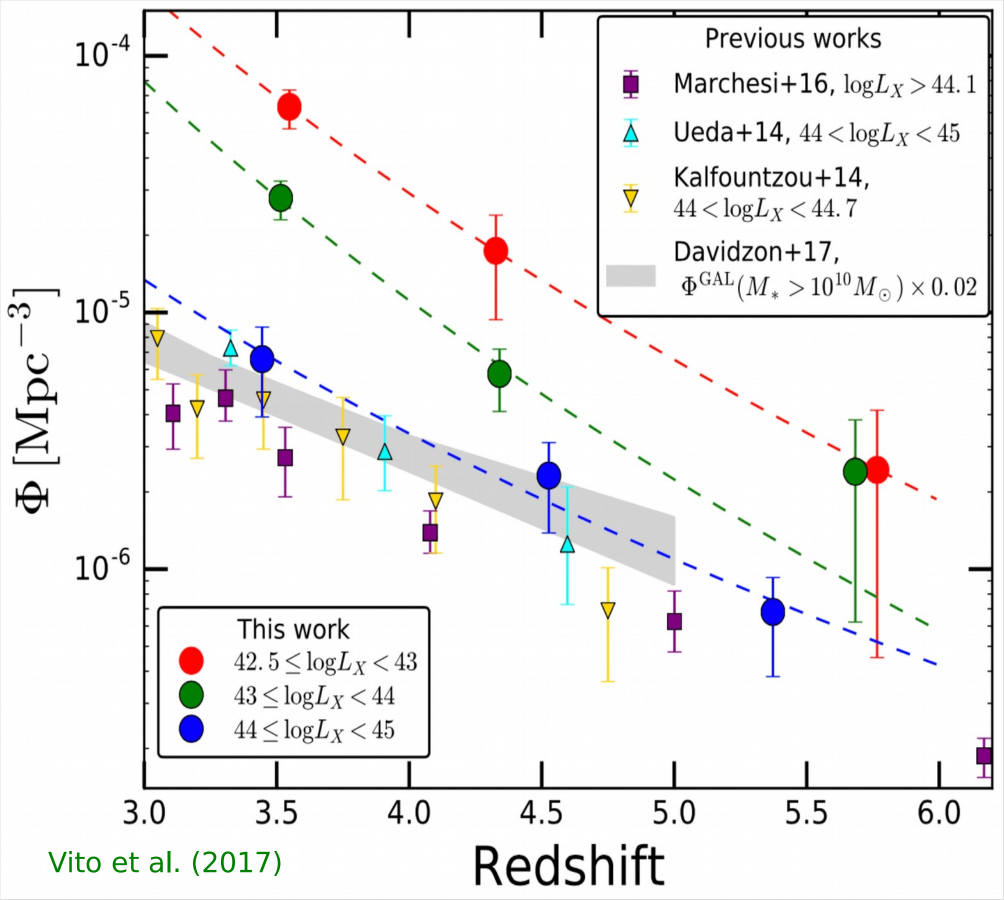
Tough work – small samples, follow-up hard, incompleteness corrections.

Decline at low-to-moderate L_X slightly steeper than at high luminosities.

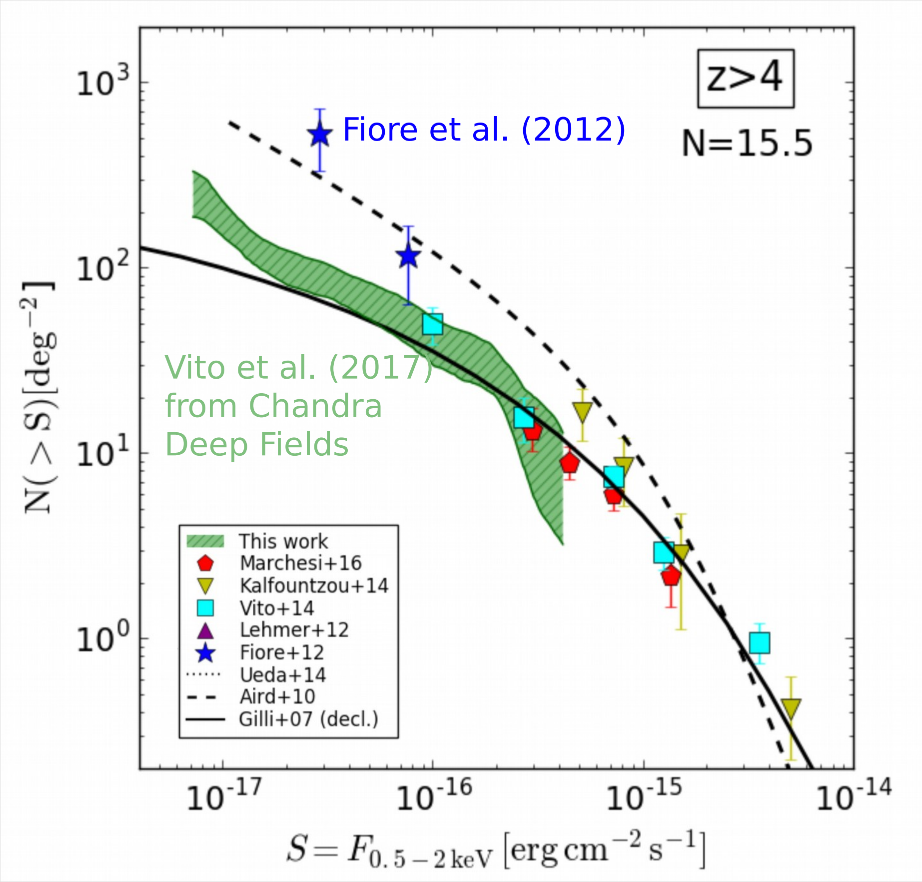
Similar to but weaker than trend in Georgakakis et al. (2015).

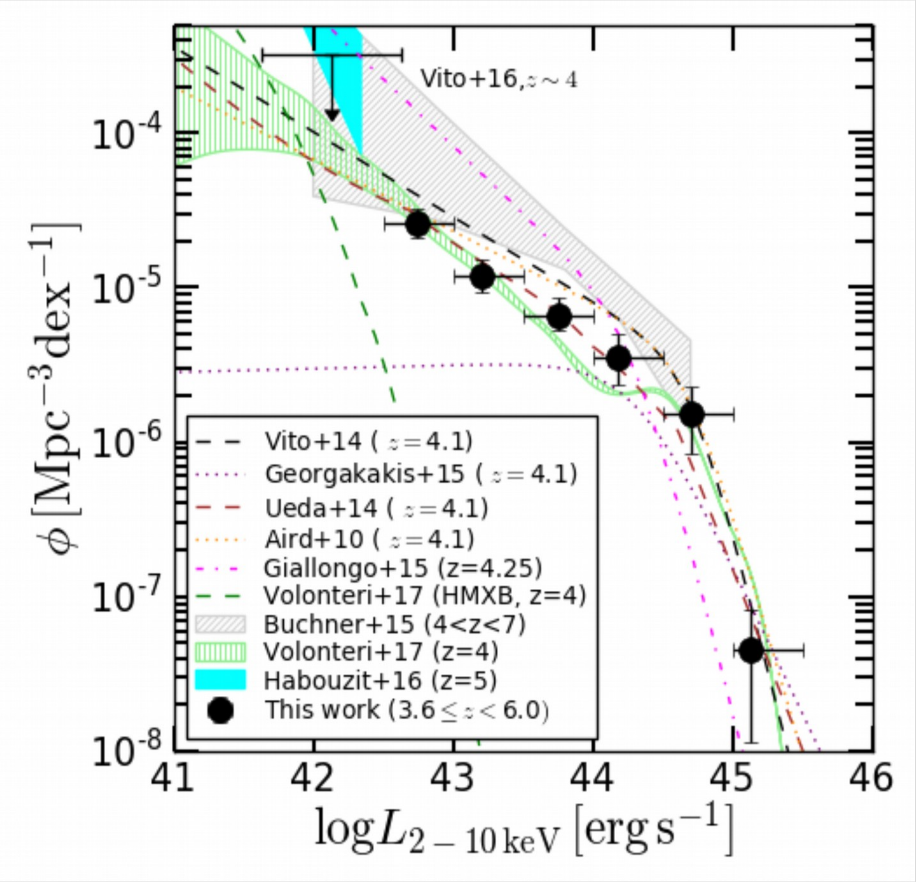
Decline at moderate L_X also steeper than for massive galaxies at high redshifts.

High-Redshift Decline at Low, Moderate, and High Luminosities



log$N$ – log$S$ and X-ray Luminosity Function



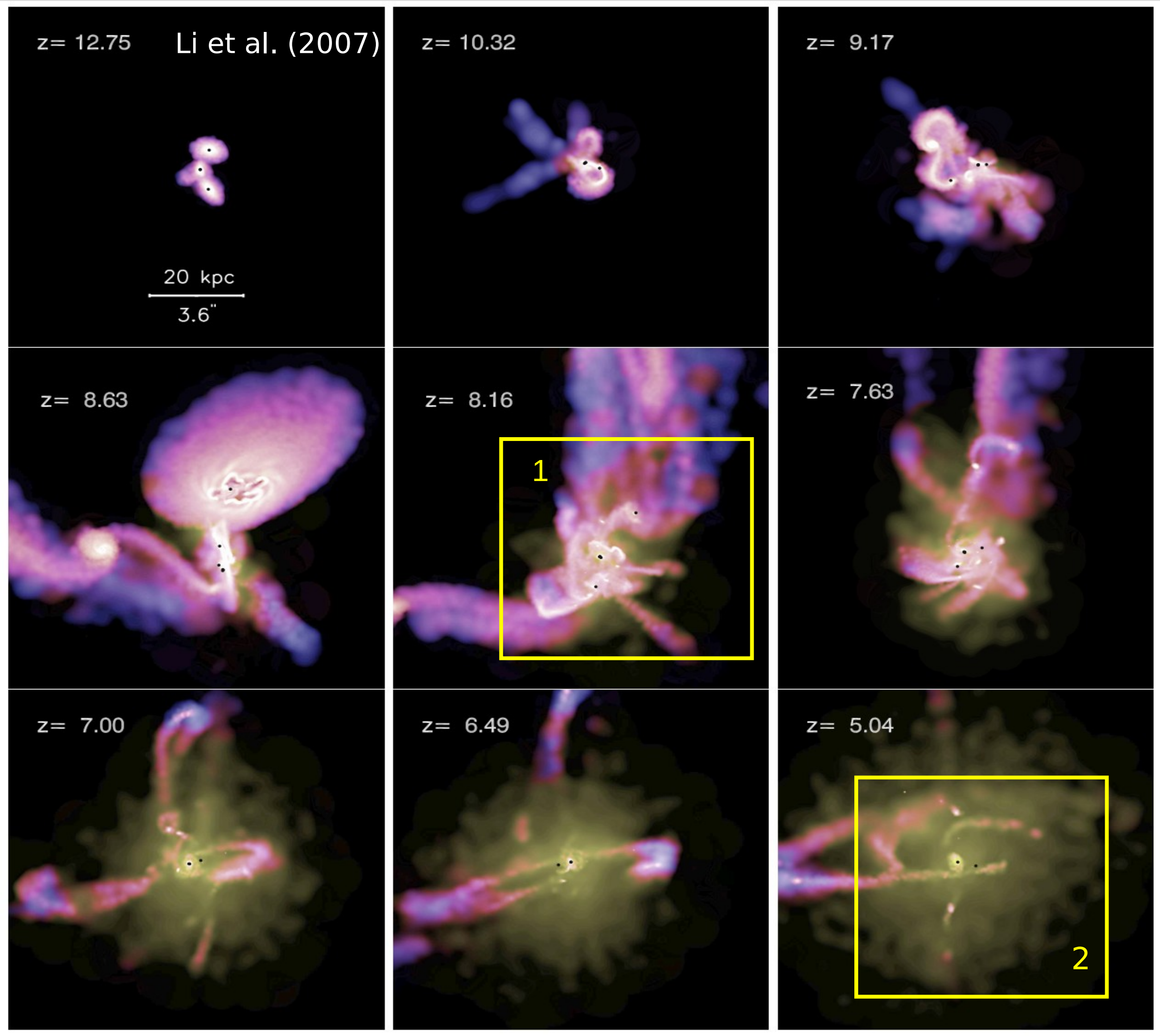


Agree with earlier work at the bright end, and lower than some past claims at the faint end.

Space density is lower than many theoretical model predictions from 2010-2015.

AGNs are unlikely to drive z ~ 6 cosmic reionization.

Simulation of the Formation of a $z \sim 6$ Quasar from Hierarchical Galaxy Mergers



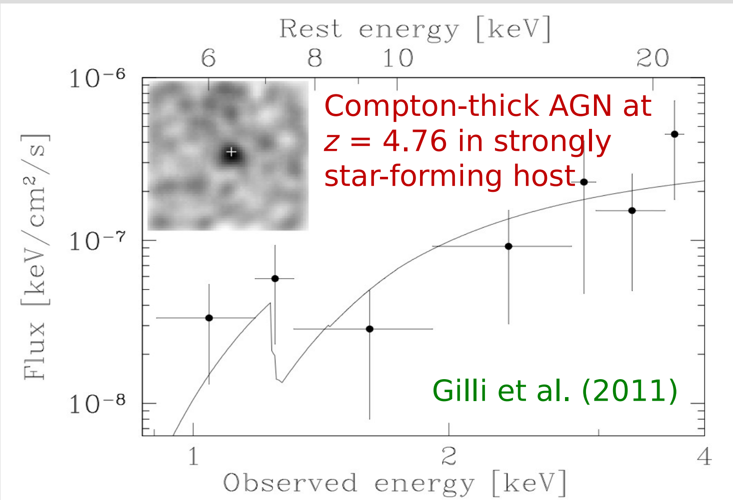
Gas density and temperature for high-redshift quasar host

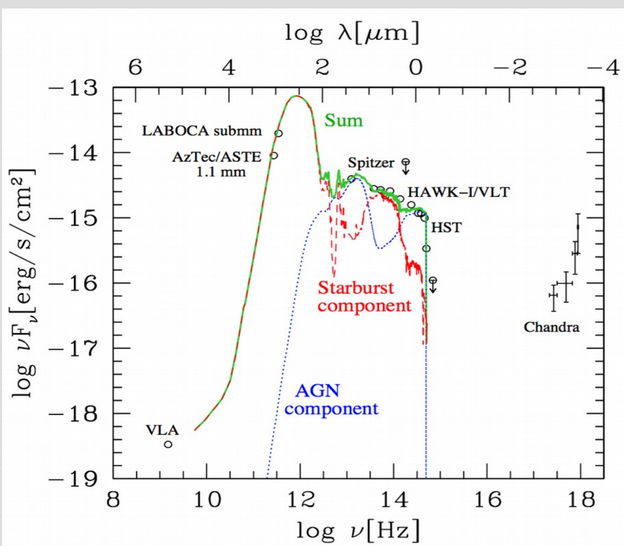
Albeit at somewhat lower redshifts, we observe similar phenomena at $z \sim$ 4-5 via X-ray spectroscopy:

(1) X-ray obscured protoquasars of moderate luminosity.

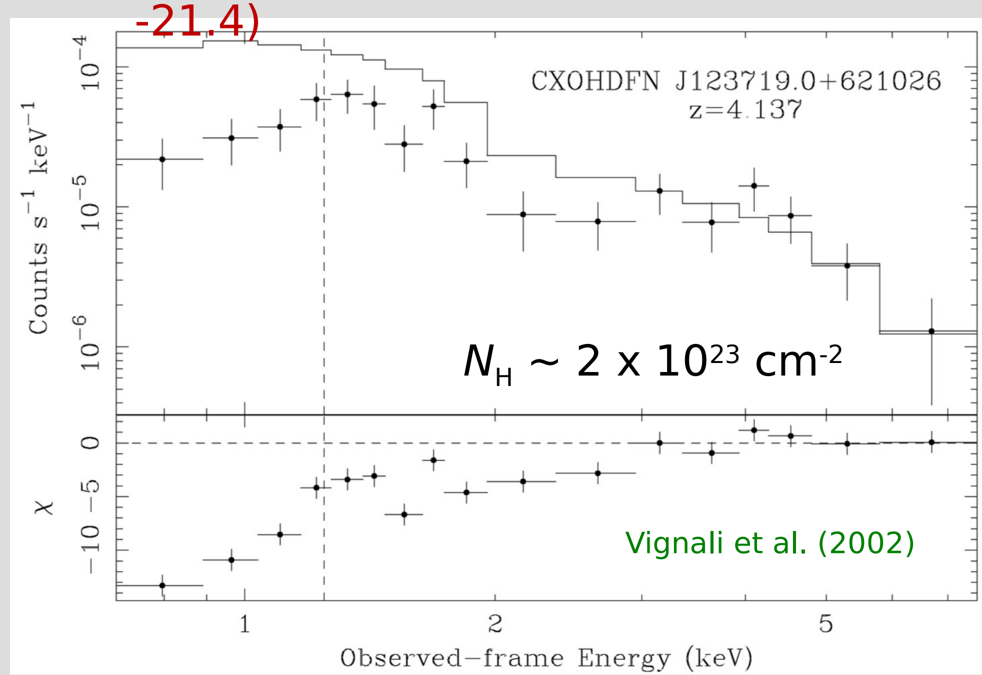
(2) powerful winds from luminous quasars, likely capable of host feedback.

X-ray Obscured Protoquasars of Moderate Luminosity at z ~ 4-5



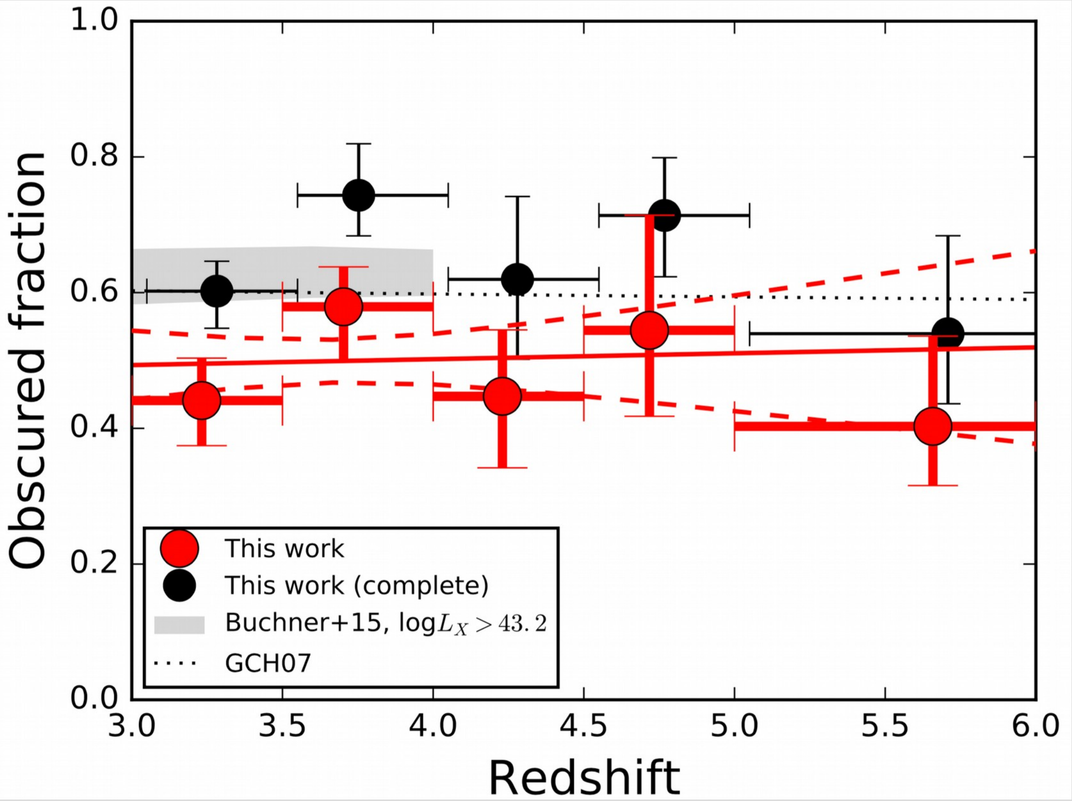


Obscured CDF-N AGN (M_B = -21.4)

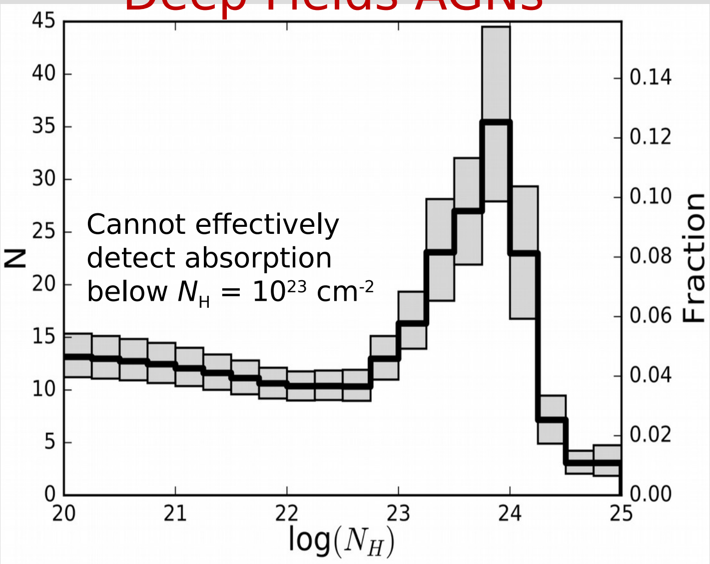


X-ray Obscured Protoquasars of Moderate Luminosity at z ~ 4-5

High Obscured Fraction ($N_H > 10^{23}$ cm^{-2}) of Chandra Deep Fields AGNs

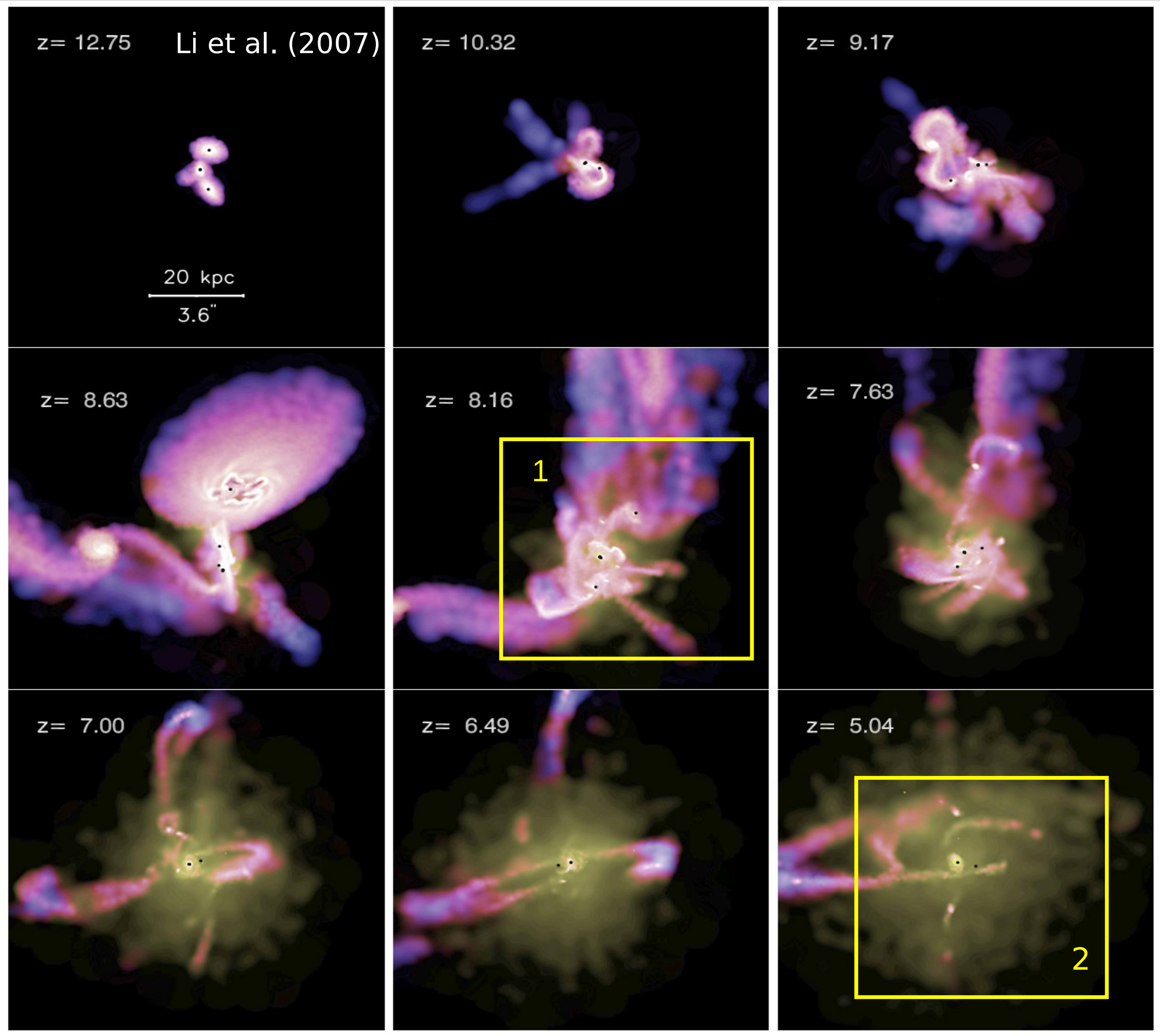


Column Density Distribution of Chandra Deep Fields AGNs



Vito et al. (2017)

Simulation of the Formation of a $z \sim 6$ Quasar from Hierarchical Galaxy Mergers



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Albeit at somewhat lower redshifts, we observe similar phenomena at $z \sim$ 4-5 via X-ray spectroscopy:

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(2) powerful winds from luminous quasars, likely capable of host feedback.

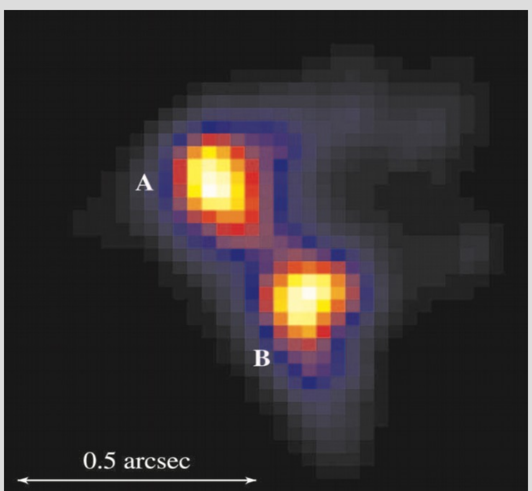
Powerful Winds from Luminous High-Redshift Quasars

Implied X-ray velocity is $v \sim 0.2\text{-}0.4c$.

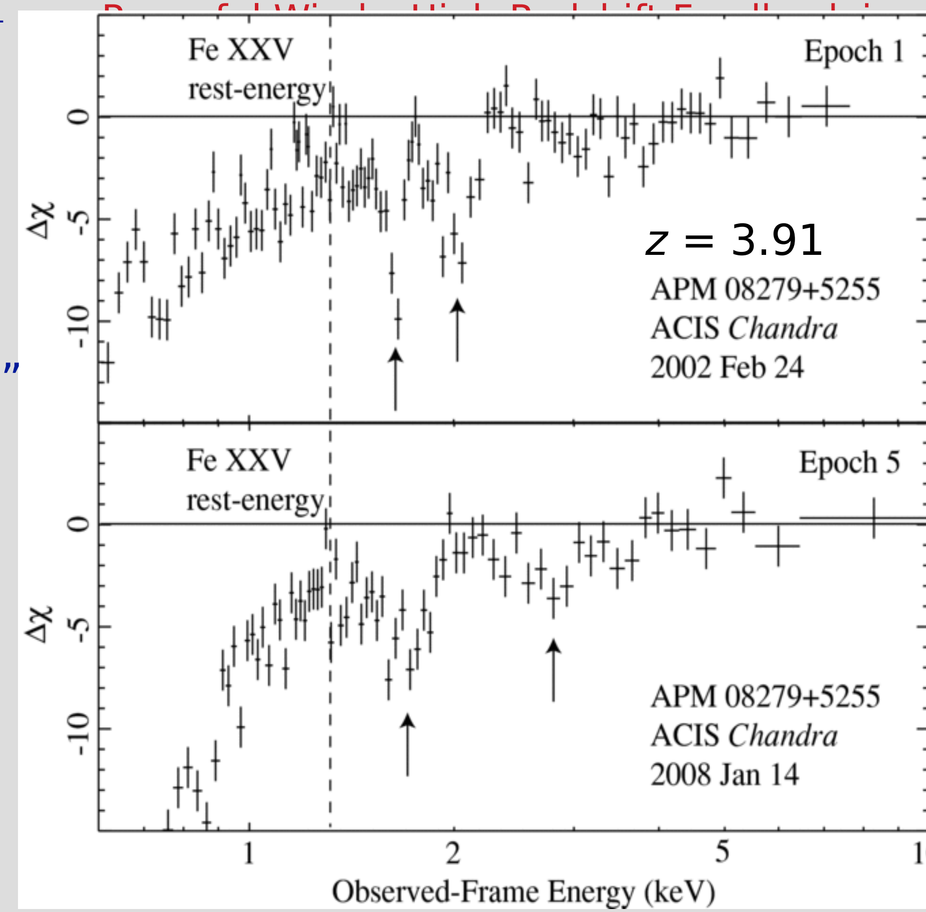
Implied mass-outflow rate is ~ 10-30 $M_{\odot}$ yr^{-1} and kinetic luminosity is ~ $10^{46\text{-}47}$ erg s^{-1}.

Could be present but undetected in many other high-redshift quasars (had boost from gravitational lensing).

First example of a "Ultra Fast Outflow (UFO)"



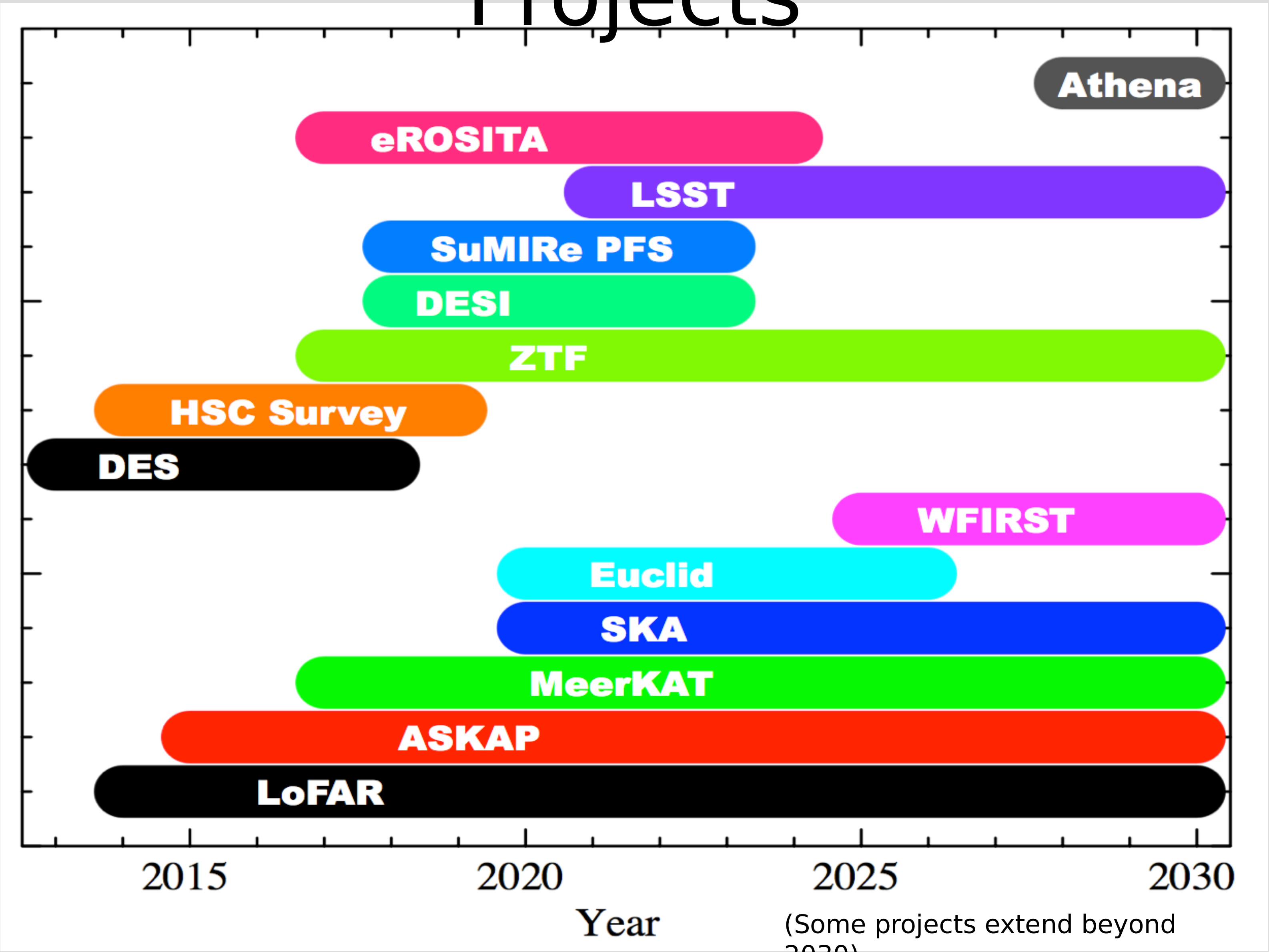
X-ray Broad Absorption Lines from Iron K Indicating



Chartas et al. (2002, 2009)

Some Prospects for the 2020’s

Some Future Large Survey Projects



(Some projects extend beyond 2030)

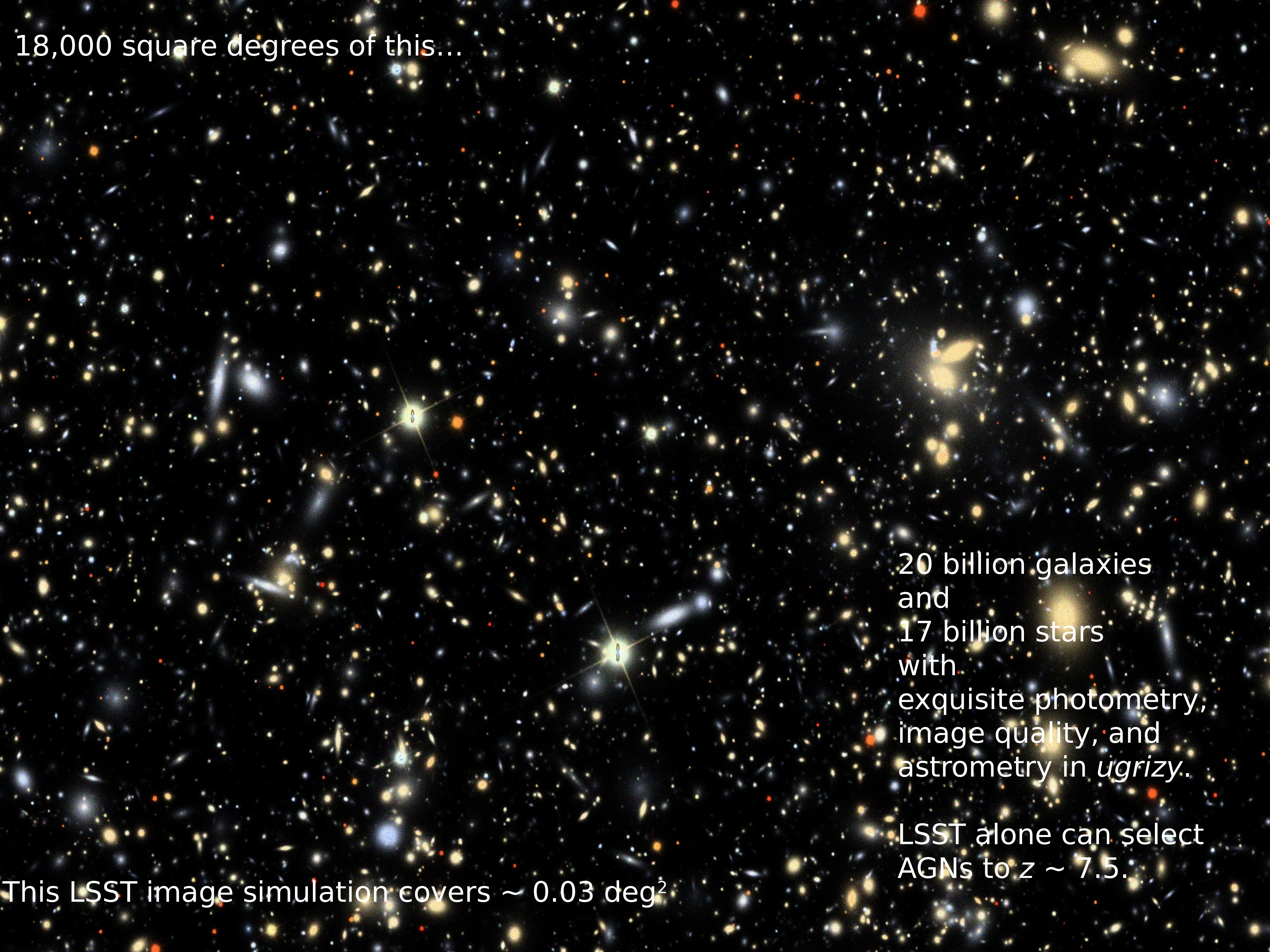
LSST Becoming Real!

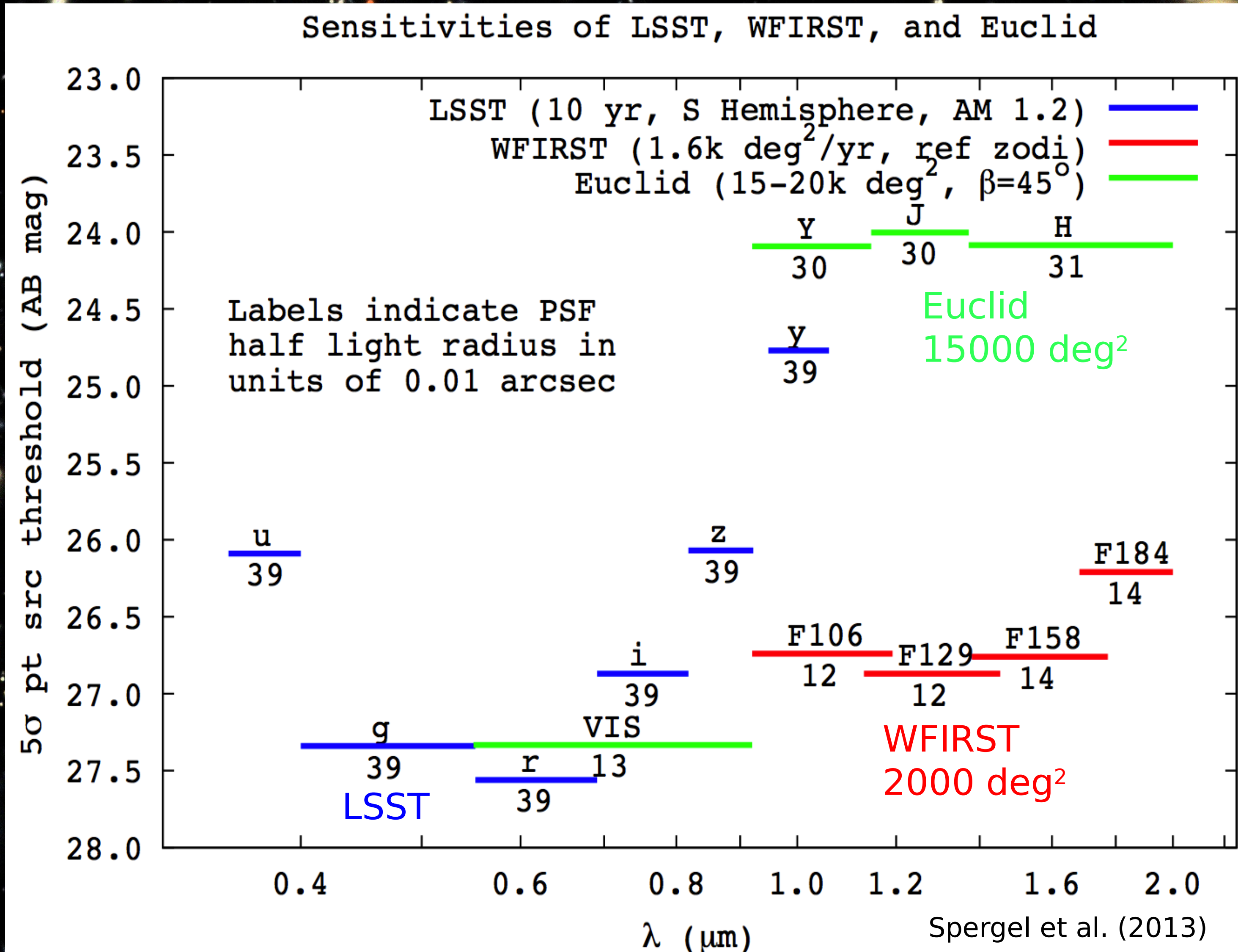
Joint Technical Meeting – 2017 March

M1M3 after polishing (Tucson)

LSST Summit Facility – 2017 June

Actively under construction


18,000 square degrees of this…
20 billion galaxies
and
17 billion stars
with
exquisite photometry,
image quality, and
astrometry in *ugrizy*.
LSST alone can select
AGNs to z ~ 7.5.
This LSST image simulation covers ~ 0.03 deg^2



LSST + WFIRST/Euclid should discover ~ 1500 AGNs at $z > 7$, and ~ 30 at $z > 10$

Excellent targets for X-ray follow-up studies with Chandra, XMM-Newton, Athena.

Massive Mining of Chandra and XMM-Newton Archives

Combine Chandra and XMM-Newton source
catalogs, especially for deeper observations,
with DES, HSC, LSST, Euclid, WFIRST, etc.

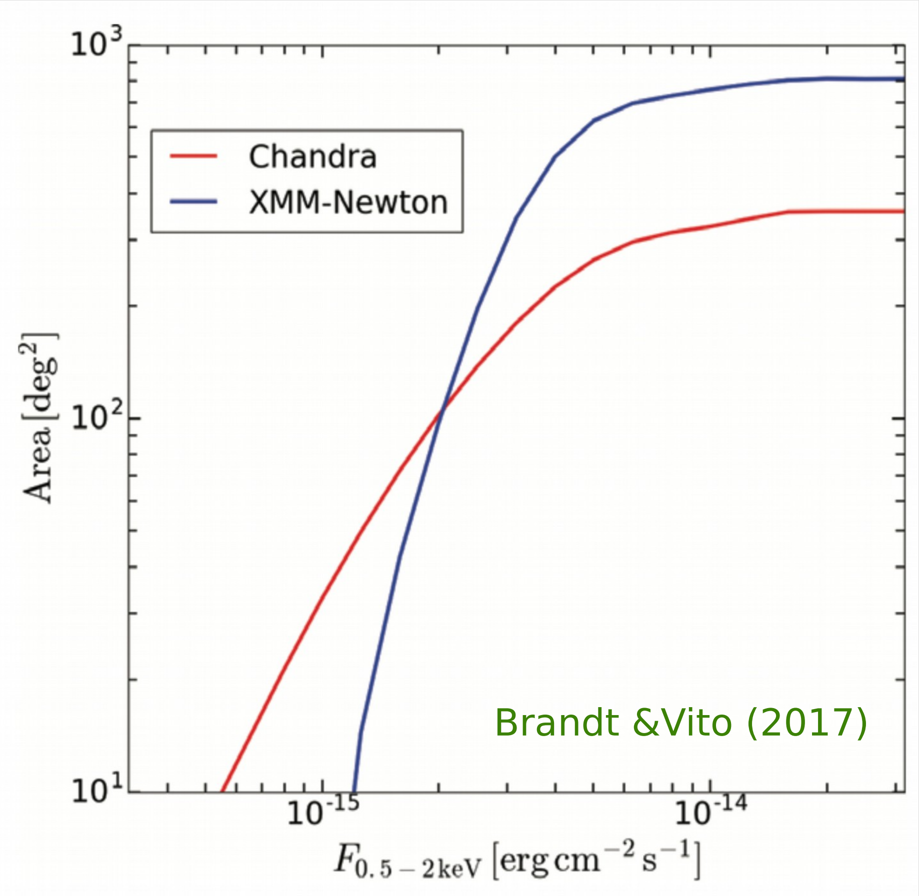
Can aim for an effective *z* ~ 4 - 8 AGN survey,
including obscured AGNs, over ~ 1100 deg^2.

Identify X-ray sources with optical / NIR colors
indicating high redshifts.

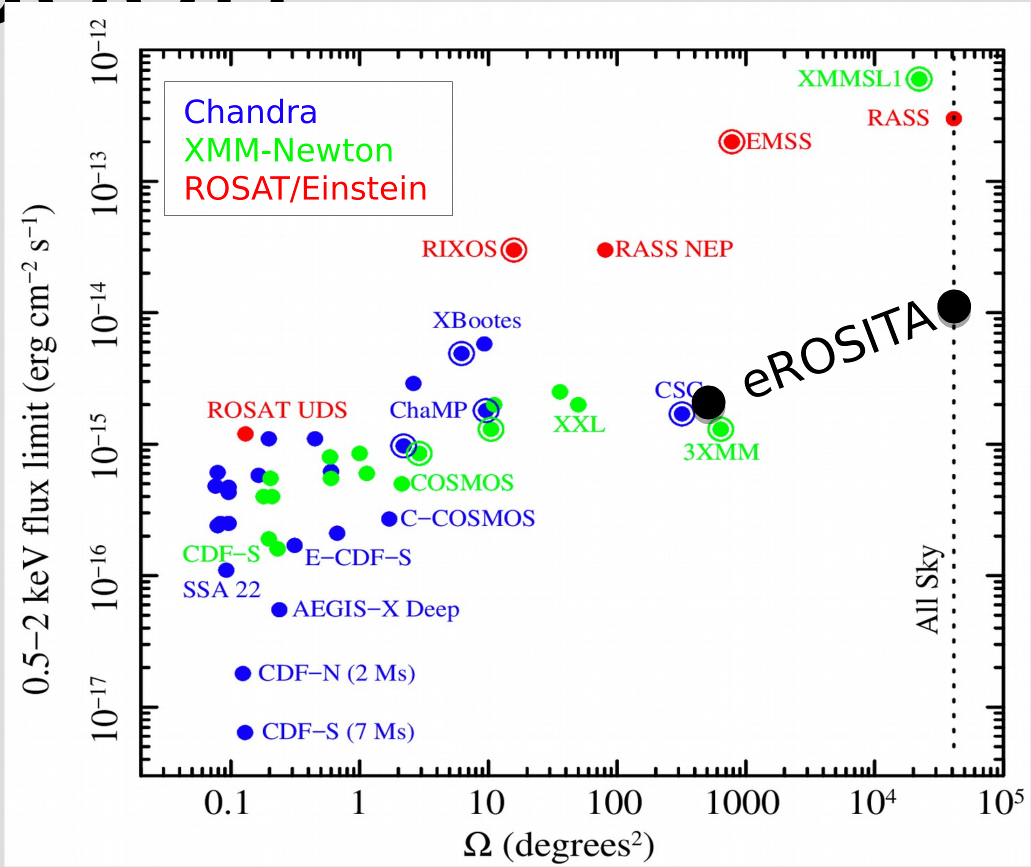
Only new cost is follow-up spectroscopy,
which could use DESI, PFS, 4MOST.

Measure XLF bright end and *f* with

Solid Angle vs. Depth for a 25 yr Chandra + XMM-Newton Survey



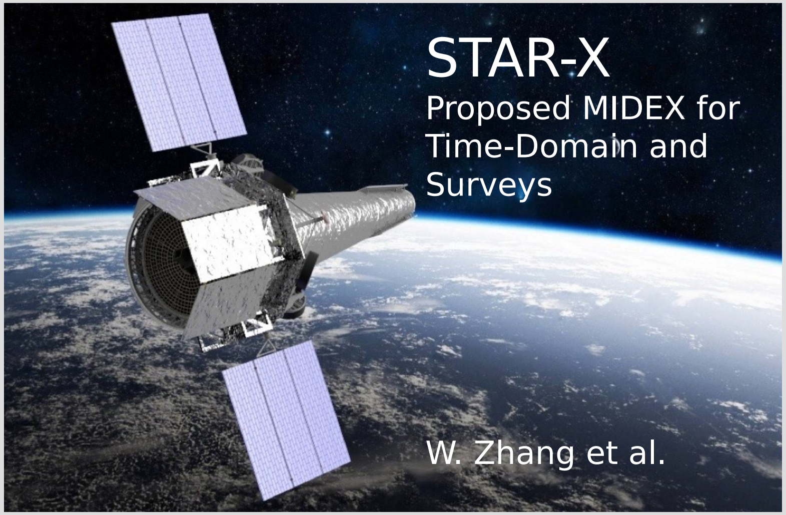
eROSITA Launching Soon

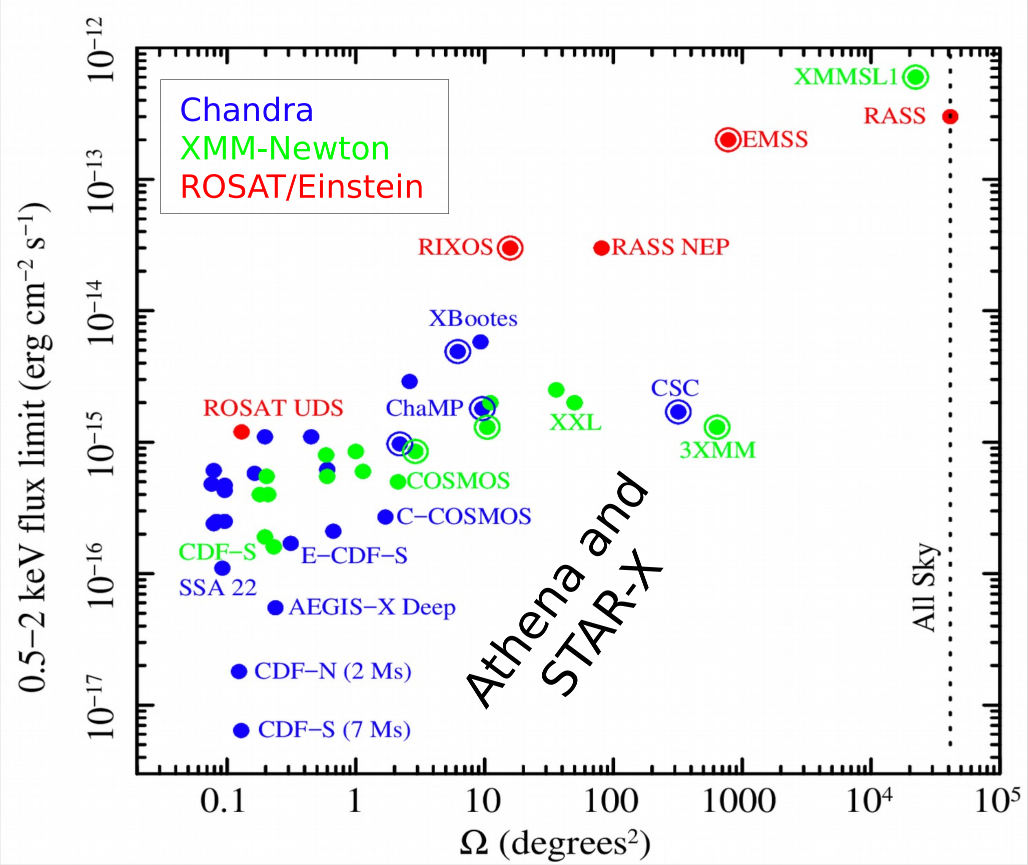


About 20 times more sensitive than ROSAT RASS, and will discover about 3 million AGNs.

Helpful for pinning down high-redshift XLF bright end.

Need More ~ Chandra Deep Fields

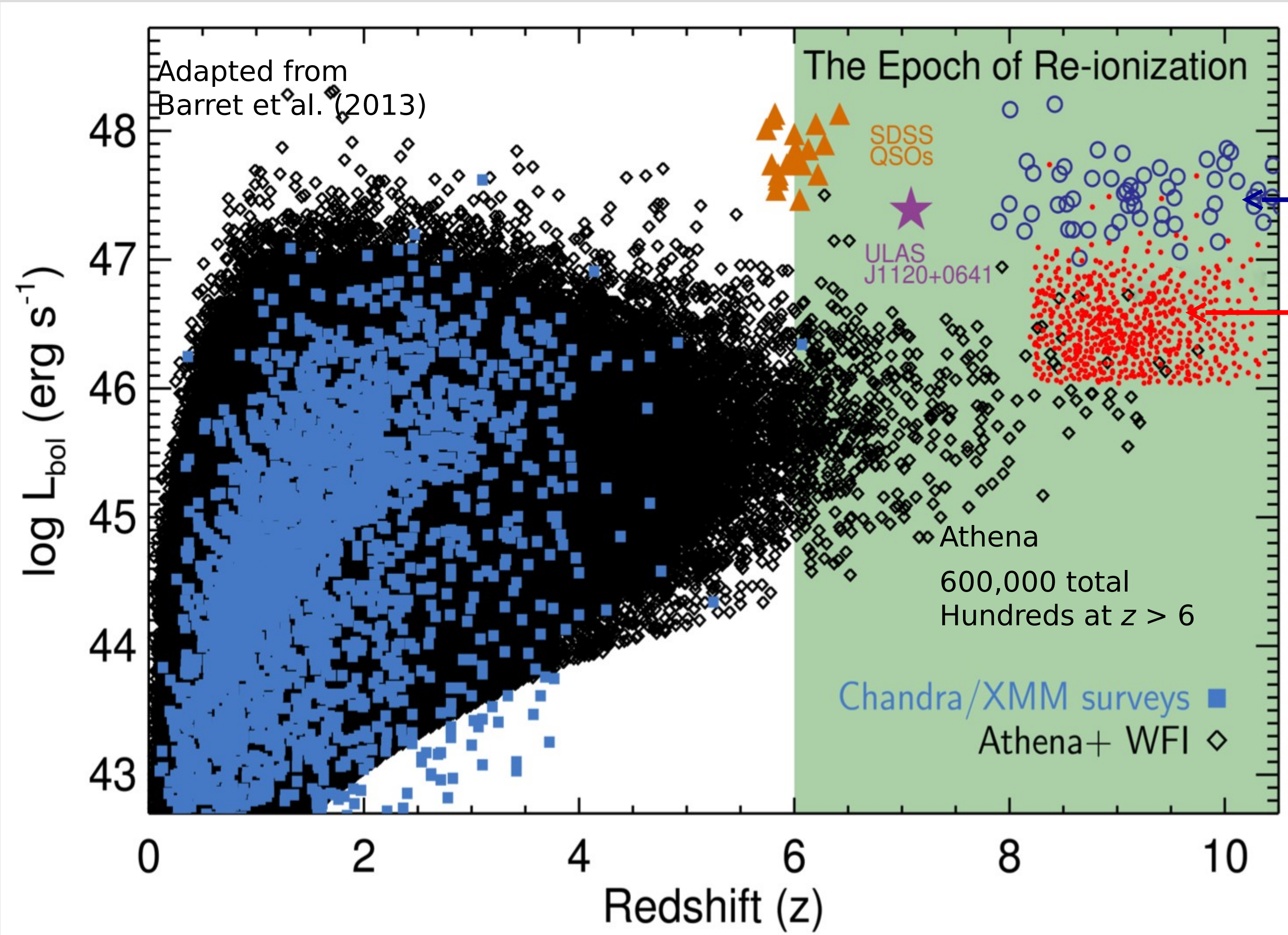




More Ω needed for *z* = 5-10 obscured and faint AGN populations.

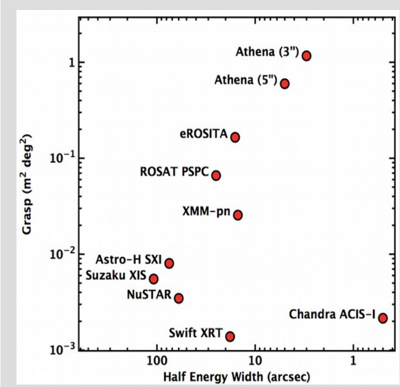
Also better photon statistics for characterization.

High-Redshift AGNs from a 25 Ms Multi-Tier Athena Survey Program

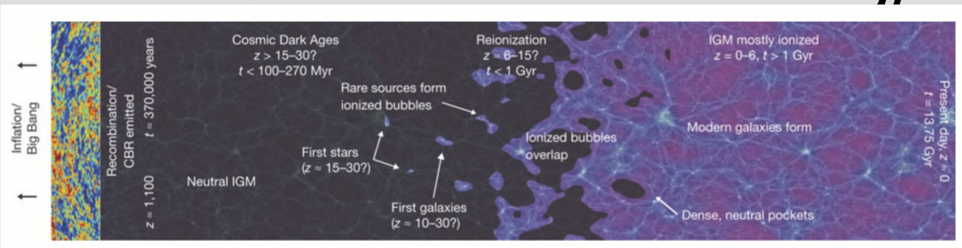


Euclid

WFIRST+LSST
at $z > 8$

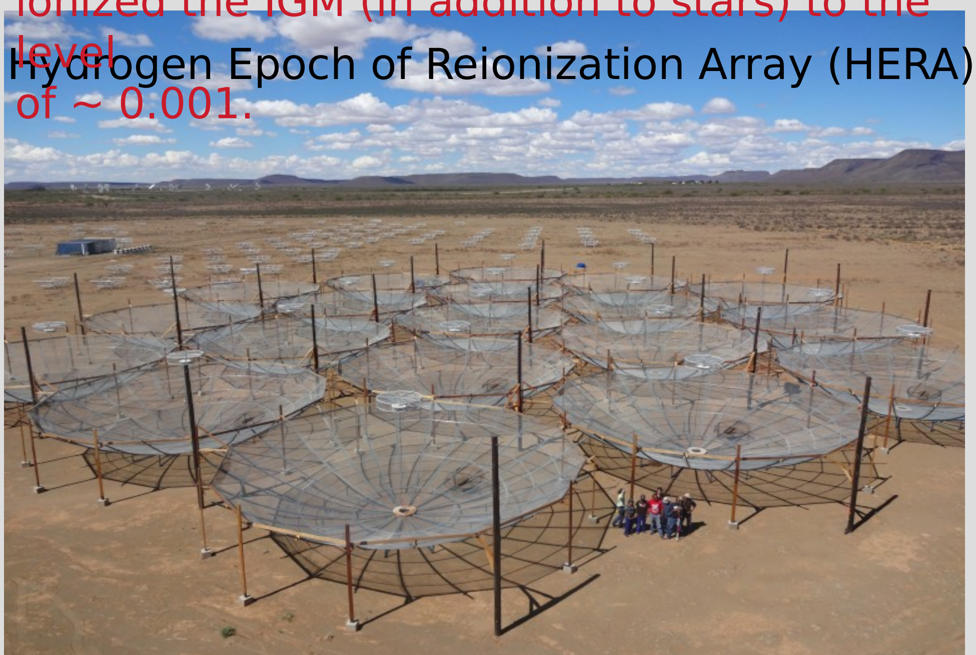


21 cm Measurements of X-ray IGM Heating/Ionization

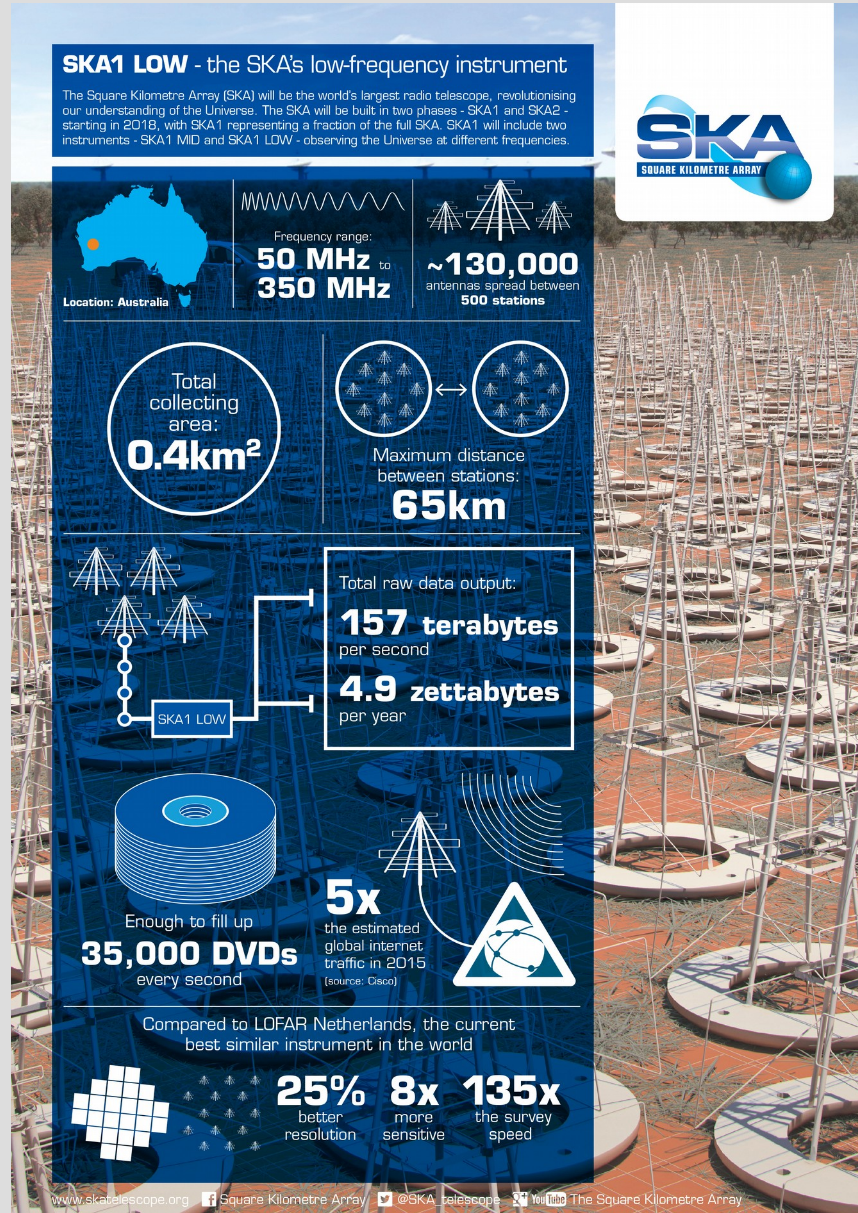


First X-ray sources heated the IGM at *z* ~ 10-20
from *T* ~ few K to *T* > 10000 K. They also mildly
ionized the IGM (in addition to stars) to the level
of ~ 0.001.

Hydrogen Epoch of Reionization Array (HERA)



Many more such experiments ongoing!



SMBH Seeds and Lynx

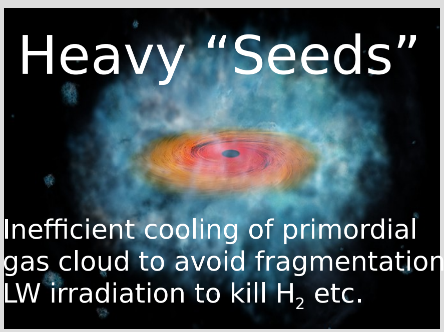
Possible Seeds of First SMBHs

Possible Black Hole "Seeds"
Formed in a Protogalaxy

Early AGN

Early Pop III Remnants - Isolated and Binaries

Direct Collapse Black Holes (10^4-10^5 $M_\odot$)

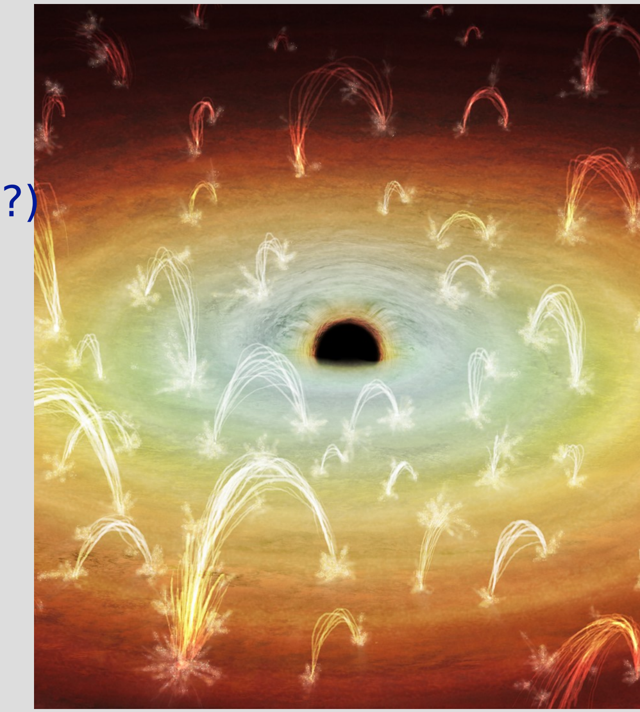


Eddington-Limited or Super-Eddington Growth (Sustainable?)

Likely obscured

Episodic Growth

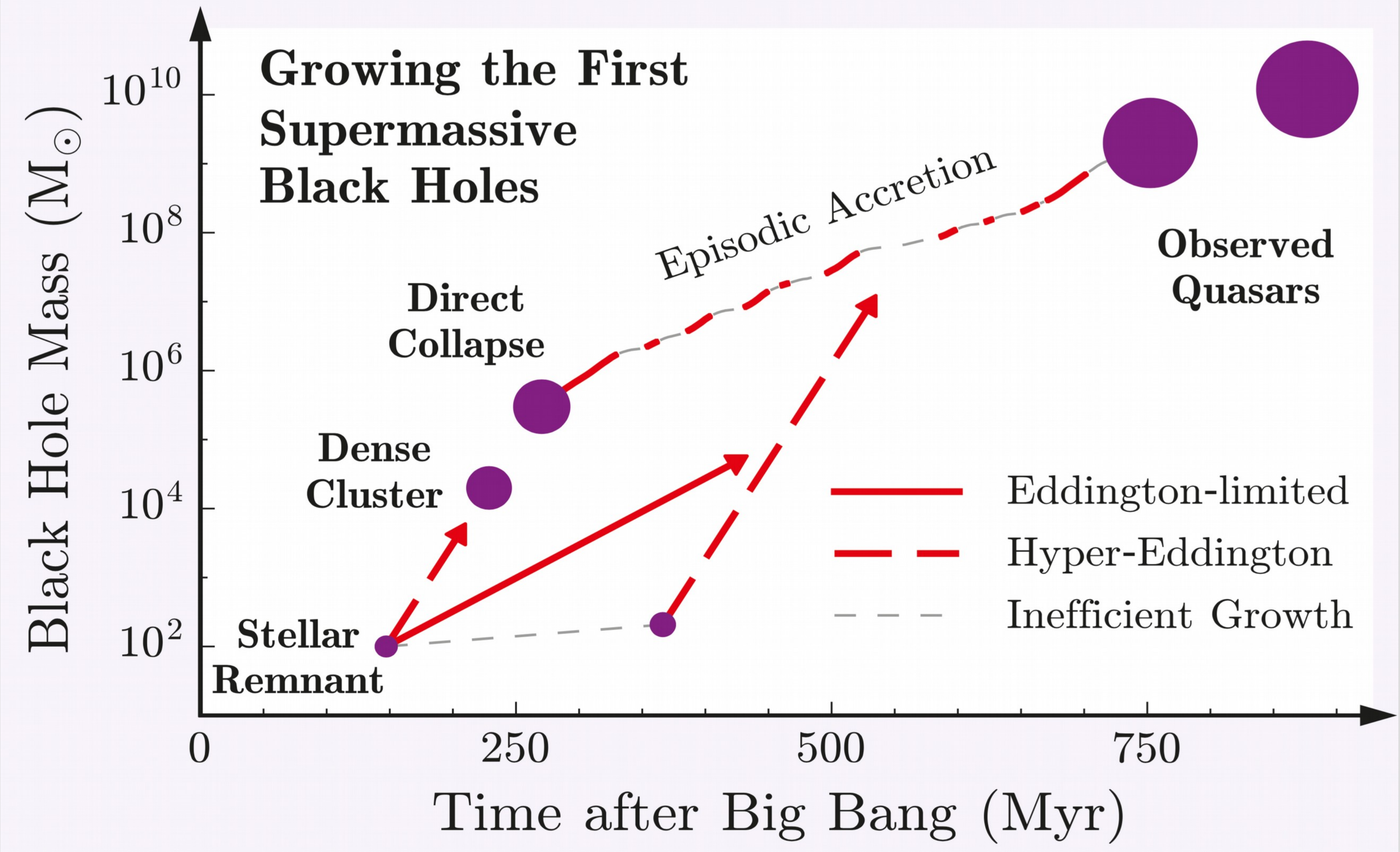
Likely obscured



What is the nature of the seeds? Light or heavy?

Extremely sensitive X-ray measurements needed.

Possible Seeds of First SMBHs



Smith et al. (2017)

Stacking: A Romantic Example


30 candles - Courtesy of Bret Lehmer

3 / 100 second exposure

1 / 1000 second exposure

Stacked image

30 candles with 1/1000 sec exposure = 3/100 sec

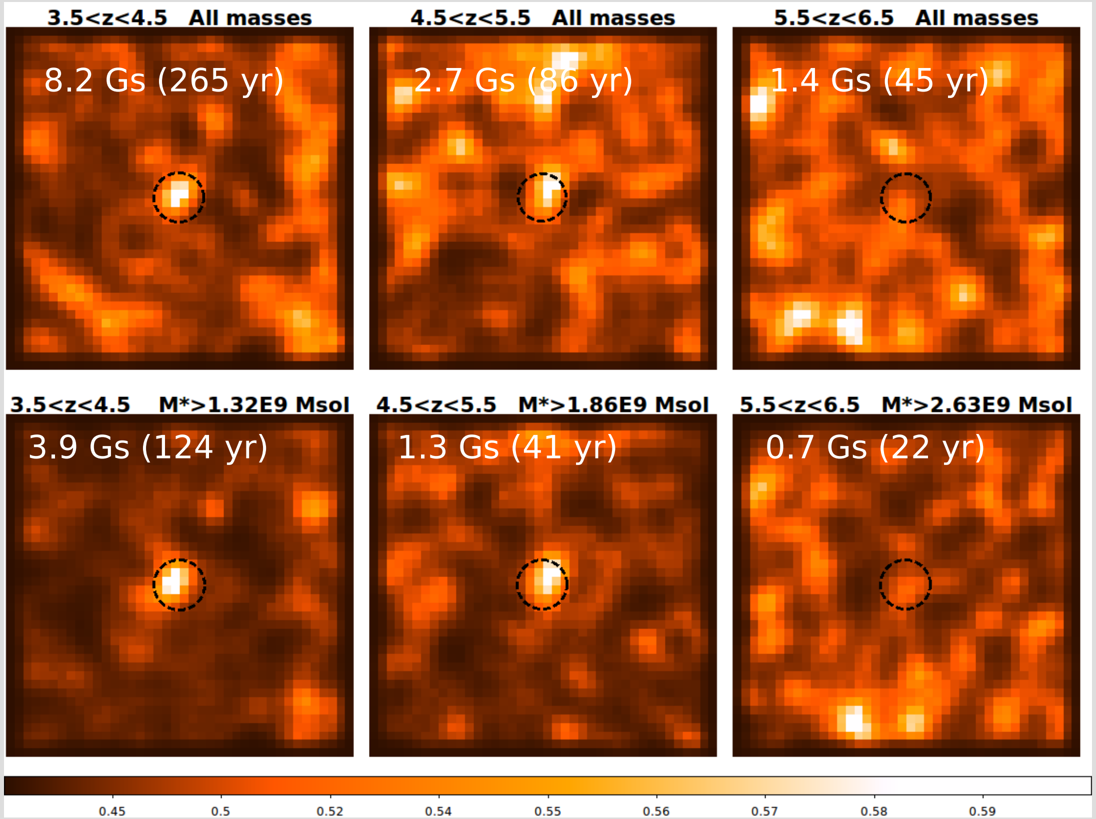
Seeds of First SMBHs – 7 Ms Stacking

Pushing as faint as possible to constrain first SMBH seeds with Chandra.

X-ray stacking of individually undetected galaxies (100-1400 per bin) can provide average X-ray detections to z = 4.5-5.5, and useful upper limits at higher redshifts.

Signal appears to be mostly from high-mass X-ray binaries in massive galaxies.

Most high-redshift SMBH accretion occurs in short AGN phase – continuous low-rate accretion contribution appears small.



Note the Gigasecond stacked exposures!

Vito et al. (2016)

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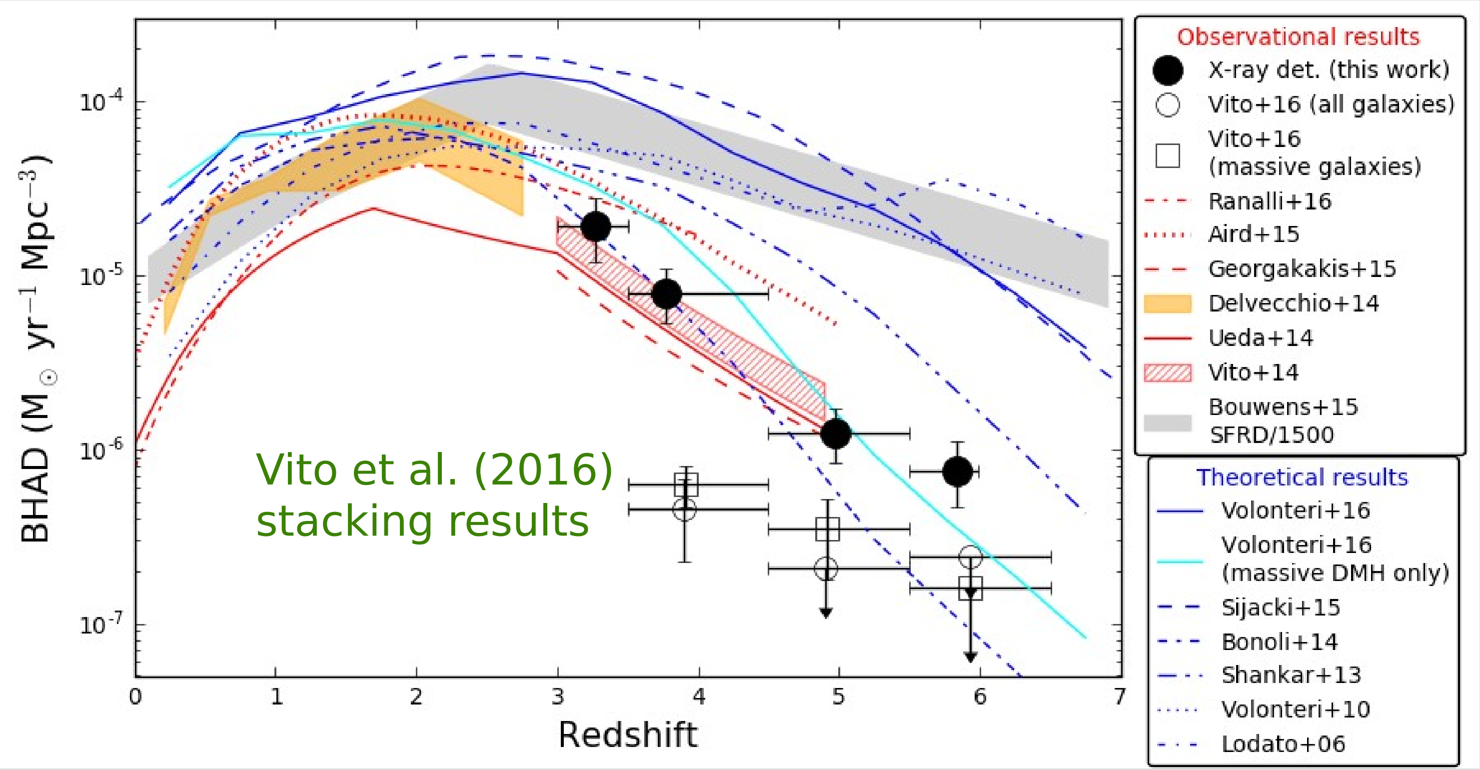
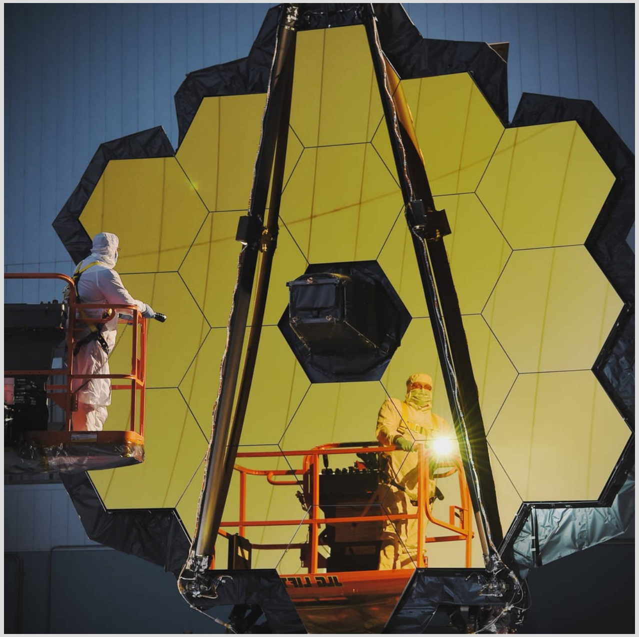


Pushing to the Highest Redshifts with Stacking

Stacking of Lyman Break Galaxy Samples with 7 Ms CDF-S

z	N	$\langle H \rangle$ mag	Exp. (10^9 s)	CR^{w}_{TOT} (10^{-5}cts s^{-1})	$F^{w,obs,TOT}_{0.5-2keV}$ (10^{-16}erg cm^{-2} s^{-1})	SNR_{boot} σ
(1)	(2)	(3)	(4)	(5)	(6)	(7)
∼4	2444	26.4	14.33	11.30 ± 5.12	7.06 ± 3.20	2.26
∼5	673	26.7	3.95	< 2.63	< 1.64	0.48
∼6	259	26.8	1.52	< 1.58	< 0.99	−1.89
∼7	107	27.1	0.62	< 1.03	< 0.64	0.60
∼8	36	27.1	0.21	< 0.32	< 0.20	−1.65

Vito et al. (2016)

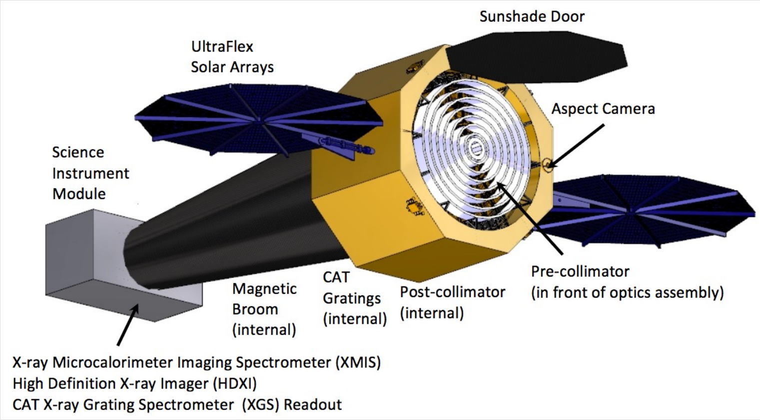


JWST will provide large samples at higher redshifts, better redshift identifications, and better removal of low-redshift interlopers.

Aim to push Chandra stacking analyses to $z \sim$ 10-15 with the samples of high-redshift galaxies from JWST in the
7 Ms CDF-S (and other fields).

Also could stack 21-cm selected regions, or perform cross-correlation analyses.

Lynx Basic Parameters



Chandra-like angular resolution

30-50 x effective area of Chandra

15 x FOV of Chandra

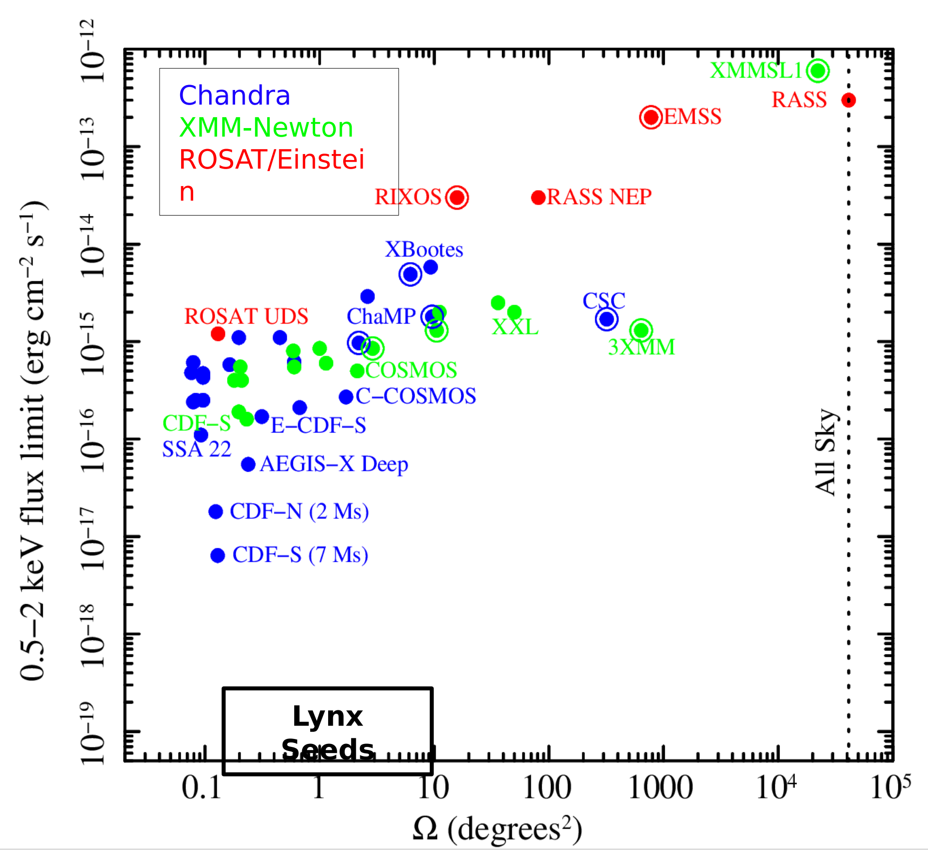
20 x sensitivity of Chandra

	Chandra	X-Ray Surveyor
Relative effective area (0.5 – 2 keV)	1 (HRMA + ACIS)	50
Angular resolution (50% power diam.)	0.5”	0.5”
4 Ms point source sensitivity (erg/s/cm^2)	5×10^{-18}	3×10^{-19}
Field of View with < 1” HPD (arcmin^2)	20	315
Spectral resolving power, R, for point sources	1000 (1 keV) 160 (6 keV)	5000 (0.2-1.2 keV) 1200 (6 keV)
Spatial scale for R>1000 of extended sources	N/A	1”
Wide FOV Imaging	16’ x 16’ (ACIS) 30’ x 30’ (HRC)	22’ x 22’

	3x10
Detection threshold @ 4Msec (0.5-2 keV) (for known locations)	3.0×10^{-19} erg/s/cm^2 (1.1×10^{-19})
2–10 keV luminosity at z=10 assuming Γ=1.7	3.7×10^{41} erg/s (1.35×10^{41})
Bolometric luminosity at z=10, assuming 10% correction	3.7×10^{42} erg/s (1.35×10^{42})
Black Hole Mass assuming Eddington rate	29,000 Msun (11,000 Msun)
For X-rays from star forming galaxies, assuming x10 higher Lx/SFR ratio at z=10 relative to local normalization	SFR=7.4 Msun/yr (2.7 Msun/yr)

Vikhlinin, Gaskin, et al.

Lynx Survey of SMBH Seeds



A Lynx survey of 1 deg^2 to 0.5-2 keV fluxes
of 1.1 x 10^{-19} cgs can plausibly detect ~ 1000
SMBH seeds at *z* ~ 8-10 to ~ 3 x 10^4 $M_{\odot}$.

Sampling hard 5-20 keV rest-frame
X-rays to overcome obscuration effects.

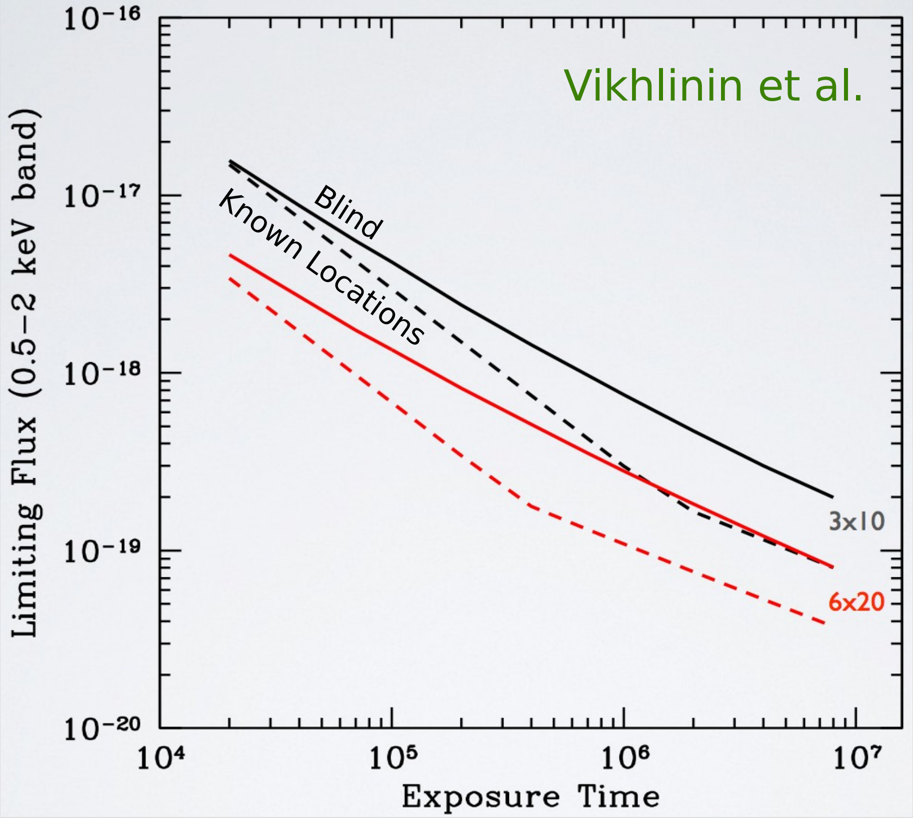
The precise yield is uncertain by factors
of at least several (e.g., Volonteri et al. 2017).

Need ~ 1000 such seeds to derive an
X-ray luminosity function (XLF) for them.

Survey needs 8.2 Lynx fields of ~ 4 Ms each.

Details given in Brandt, Haiman, & Vito
report on behalf of the Lynx "First
Accretion Light" working group.

Lynx Survey of SMBH Seeds



A Lynx survey of 1 deg^2 to 0.5-2 keV fluxes
of 1.1 x 10^{-19} cgs can plausibly detect ~ 1000
SMBH seeds at z ~ 8-10 to ~ 3 x 10^4 $M_{\odot}$.

Sampling hard 5-20 keV rest-frame
X-rays to overcome obscuration effects.

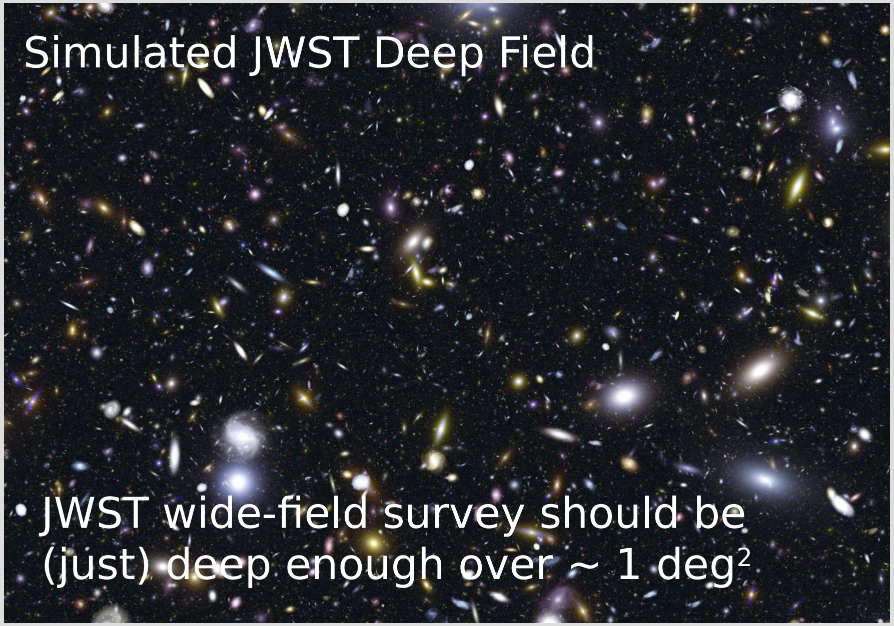
The precise yield is uncertain by factors of at least several (e.g., Volonteri et al. 2017).

Need ~ 1000 such seeds to derive an
X-ray luminosity function (XLF) for them.

Survey needs 8.2 Lynx fields of ~ 4 Ms each.

Details given in Brandt, Haiman, & Vito report on behalf of the Lynx "First Accretion Light" working group.

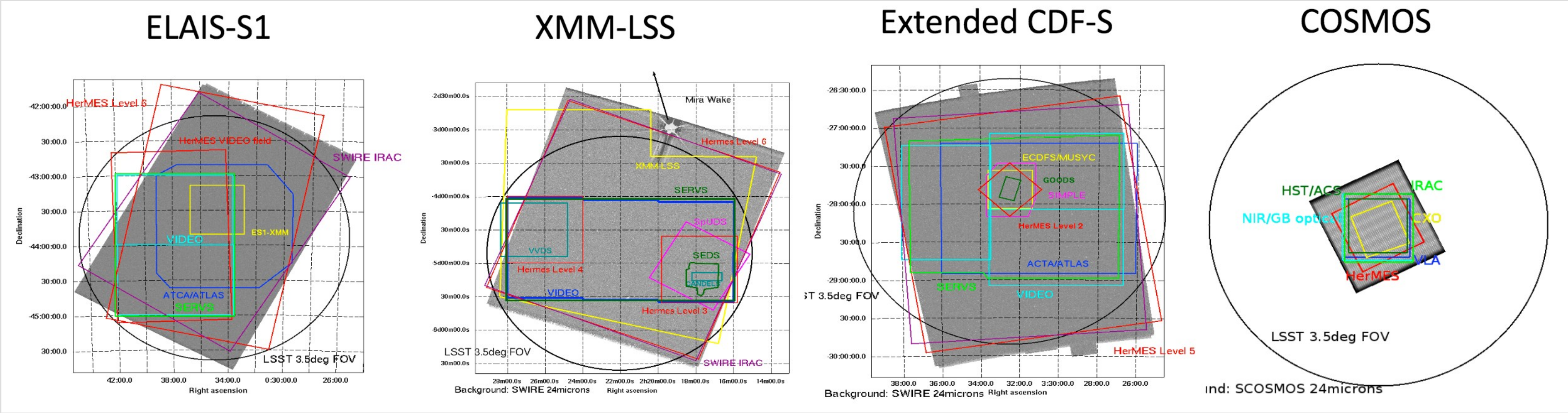
Sites for the Lynx Survey



This survey must be sited in regions with ultradeep MIR/NIR/optical data from JWST,
WFIRST, LSST, GSMTs, 21 cm, etc.

Needed to aid the X-ray source searching,
to identify $z \sim 7\text{-}10$ counterparts, and to measure host stellar masses.

Some Good Potential Sites: The Central LSST Deep Drilling Fields



XLF for Light Seeds and Heavy Seeds

The behavior of the high-redshift X-ray luminosity function (XLF) at the very faint end will be key for insights into seed-growth models.

Light Seeds:

Growth should lead to a large number of faint high-redshift AGN fueled by accretion onto low-mass BH – steep XLF.

Heavy Seeds:

AGNs can more easily reach luminosities close to L_*, producing a flatter faint end of XLF.

But seed mass, Eddington-ratio distribution, and occupation
fraction can be traded-off against each other to give similar
XLFs (e.g., Volonteri et al. 2017).

Using XLF + Hosts to Study Seeds

The Lynx XLF alone cannot not determine seed masses - utilize additional information such as their host stellar masses.

Light seeds:

The ~ 3 x 10^4 $M_{\odot}$ black hole was assembled from many stellar-mass black holes, and a larger stellar cluster (M_* ~ 2 x 10^7 $M_{\odot}$) is needed to make them (cf. gas blow out, black-hole ejections, etc.).

Heavy seeds:

The black hole can consume most of the gas in its halo, so it will have only a small stellar cluster around it ($M_* < 10^6$ $M_{\odot}$). This cluster's light will be subdominant compared to black-hole emission.

The hope is that both XLF + host information *together* can discriminate light seeds vs. heavy seeds.

The End

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