CHANDRA AGN OBSERVATIONS OF X-RAY REFLECTION ON GALAXY-SCALES?

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INTRODUCTION

Observations and theoretical models suggest that more than half of the AGN population is obscured, and there remain interesting questions about how much of the obscuration may be due to gas and dust on the scales of the host galaxy. In this work, we use the *Chandra* Deep Field South (CDFS) 7 Ms catalog (Luo et al. 2017) to derive the relation between SFR of the host galaxies and BH obscuration.

Figure 1: The central region of the 7 Ms CDF-S.

X-RAY SPECTRA STACKING

CDFS 7 MS CATALOG

EXTENDED FE Kα EMISSION

CONCLUSION

Tracking the Growth of … in the Progenitors …

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[1]NASA MSFC/USRA, [2]Pennsylvania …

Abstract

To constrain different formation paths of intermediate-mass (10,000-1,000,000 solar mass) black hol… galaxies over the past 9 Gyr using deep Chandra observations in the CANDELS fields and in COSM… downsizing phenomenon, our results can be used to derive most of the BH mass accumulated via a… $10^{9.5}$ solar mass in the present day Universe can harbor IMBHs of $10^{5.5}$ solar mass grown through acc…

How were the present-day SMBHs seeded?

Direct observational constraints on how the supermassive black holes were seeded in the very early Universe are extremely challenging, if not impossible, with current instruments. Therefore, numerous efforts have been made to study the more tractable observable – the massive black hole occupation fraction in low-redshift dwarf galaxies. In the hierarchical galaxy evolution scenario, dwarf galaxies have gone through fewer mergers and therefore can serve as the ``fossil record'' of the early galaxies. Simulations and theories have predicted that different BH seeding mechanisms would result in different BH occupation fractions in present-day dwarf galaxies. The searches for mBHs in the centers of the local dwarf galaxies have started to set limits on the fraction of galaxies hosting active black holes (e. g., Miller et al. 2015), but the true BH occupation fraction remains challenging for observers due to various observational limits on identifying mBHs in dwarf galaxies.

Results

Conclusion

Measuring SMBH Spin in the Chandra-COSMOS Legacy Survey

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[1]Center for Astrophysics | Harvard & Smithsonian, [2]INAF OAS Bologna

Spin measurements provide crucial constraints on the accretion processes that power AGN

Black hole spin measurements are limited to a few dozen nearby sources with high quality, high signal spectra.

Figure: (a) robust measurements of black hole spins and masses for 22 black holes. (b) distribution of these black hole spins with an estimate for the expected spin population.

Chandra-COSMOS Legacy Survey

- We stack ~2000 *Chandra*-COSMOS Legacy sources to recover the average broad Fe Kα line emission, thereby improving the S/N of faint sources.
- Fitting the Fe Kα line with a relativistic line provides a measurement of the spin magnitude and direction.
- The Legacy catalog provides a unique environment to investigate the average spin as a function of observables.
- This work will provide insights into the physical mechanisms governing AGN growth and feedback.

Stacking Chandra-COSMOS Legacy sources to measure the average black hole spin

1 RE-BIN SPECTRA
2 FIT SPECTRA
3 CALCULATE RATIOS
4 AVERAGE RATIOS
5 FIT AVG RATIO

How does the black hole spin change with observed AGN ch…

ATH…

INAF OAS BOLOGNA

The WFI survey … and growth of …

G. Lanzuisi, A. Co… R. Gilli…

Athena (Advanced Telescope for High ENergy Astrophysics) is the next **ESA** X-ray observatory, selected in the Cosmic Vision program to address the Hot and Energetic Universe scientific theme. It has passed Mission Formulation Review in November 2019 and is due for adoption in 2021 and launch in early **2030s**. Will carry the X-ray Integral Field Unit (**X-IFU**) for high spectral resolution, and the imaging instrument **WFI**.

The **Wide Fi…** Athena. The l… across most … improvement… respect to cur…

Athena will spend ~**25Ms** during its first four years, p… two-tiers WFI survey, to detect tens of early group… z>2, thousands of heavily obscured AGN at cosmic … 3), ionized absorbers and disk winds in QSOs up … **hundreds of z>6 AGN**.

… number of AGN and galaxies comparable to those collected so far by Chandra and XMM-Newton with 10s of Ms in several fields.

The sources at z>6 detected in the simulated fields will allow us to test **SMBH seed** models, that now provide widely different predictions at these redshifts. On the right, the reconstructed LF at 7<z<8 compared with predictions from one SMBH seed model (Ricarte et al. 2018) with two different seeding mechanisms (heavy for direct collapse BH and light for PopIII remnants).

Opening Up a New Deep Field for Chandra's Third Decade

W. Peter Maksym[1,2], …

…at is JWST-NEP-TDF?

JWST-NEP-TDF/Chandra The First 300 ks

X-Ray Synergy with Chandra

A Bright X-ray Transient!

Jet Emission from an Iron-Loud NLSy1/FSRQ

P83

Wei Yan: X-ray reflection on galaxy scales

Chien-Ting Chen: AGN in dwarf progenitors

Mackenzie Jones: BH spin in COSMOS

Andrea Comastri: *Athena*

Peter Maksym: The *Chandra* NEP survey

1960s: Discovery of the X-ray background

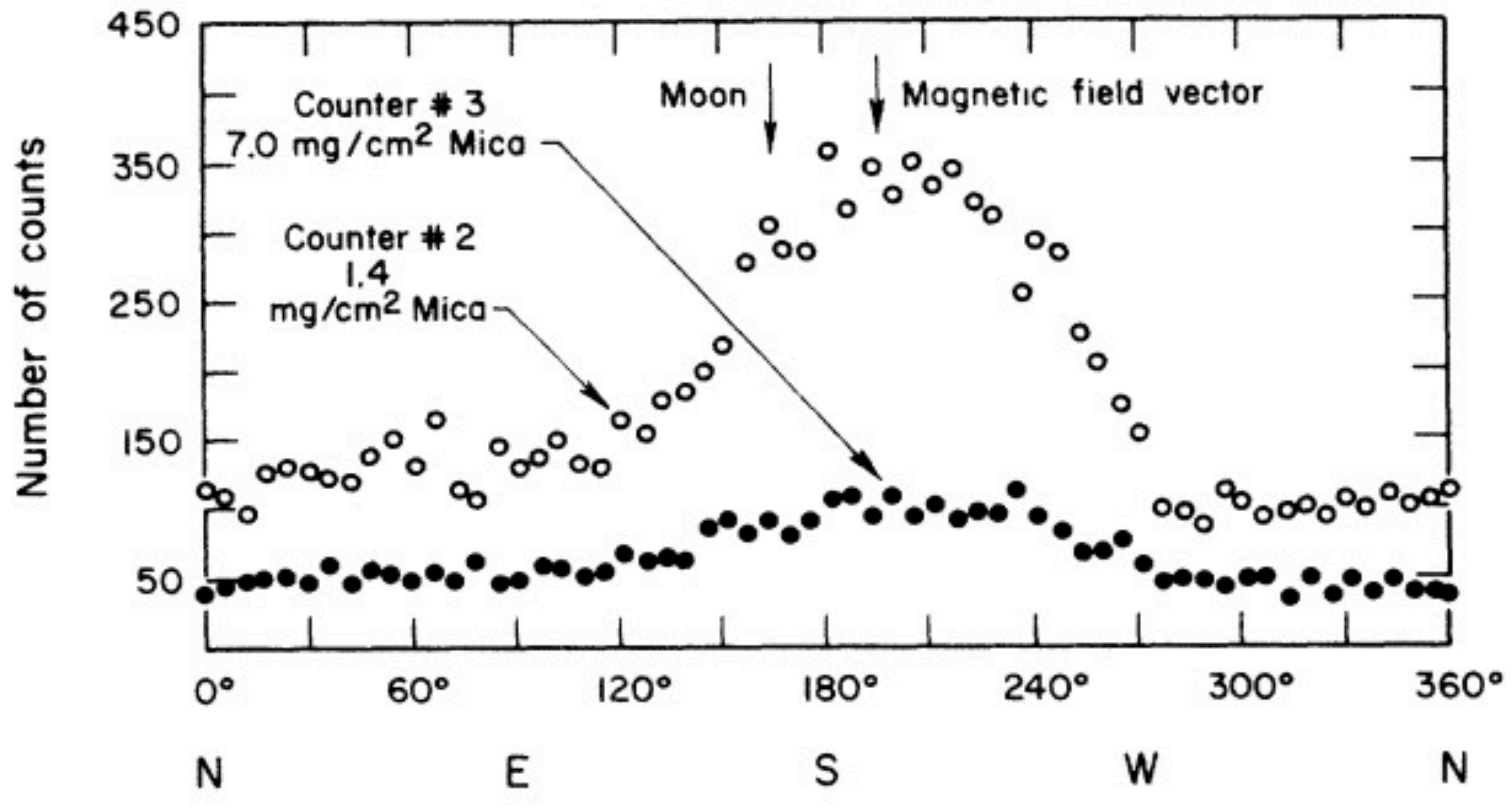
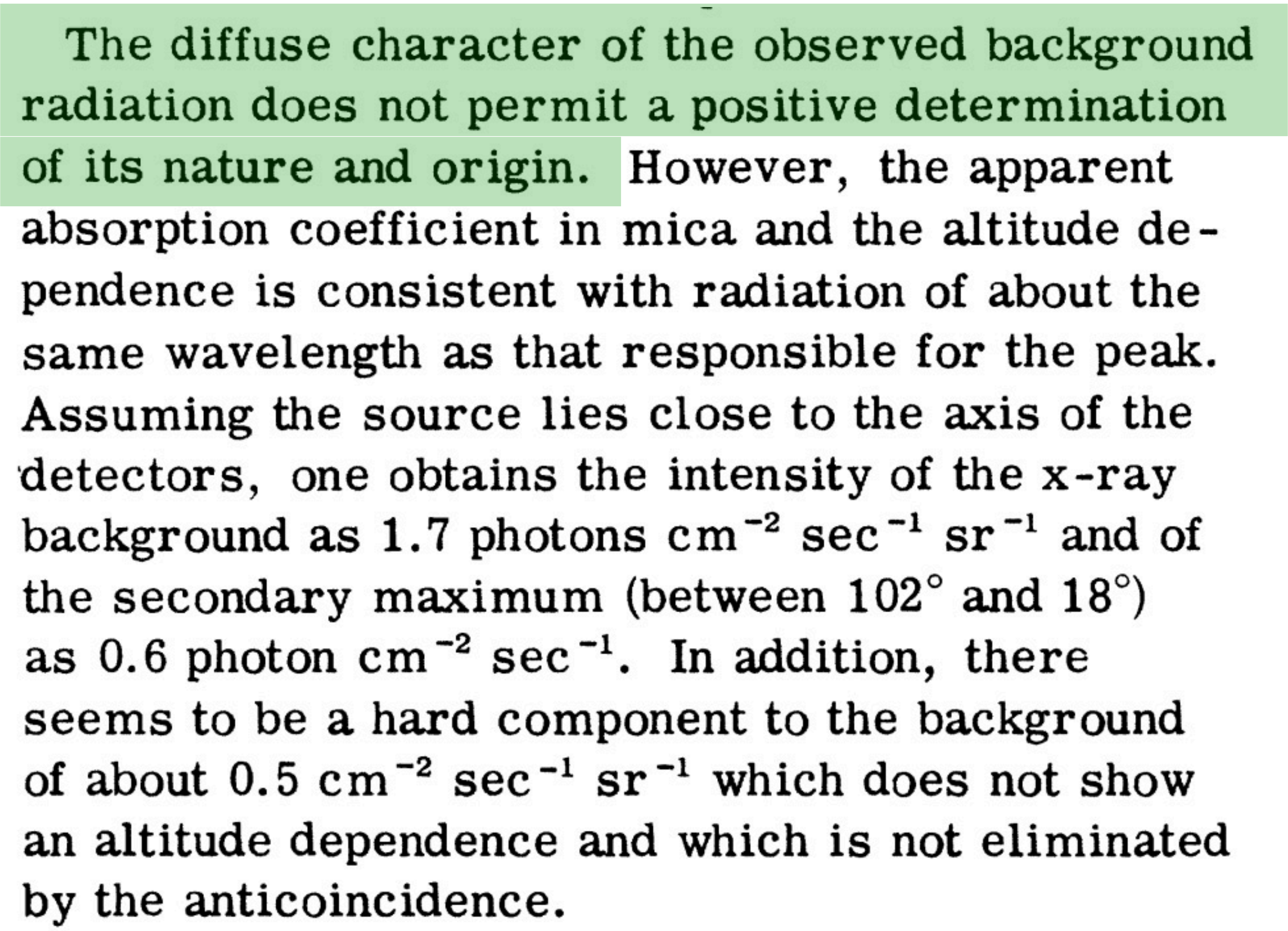


FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.



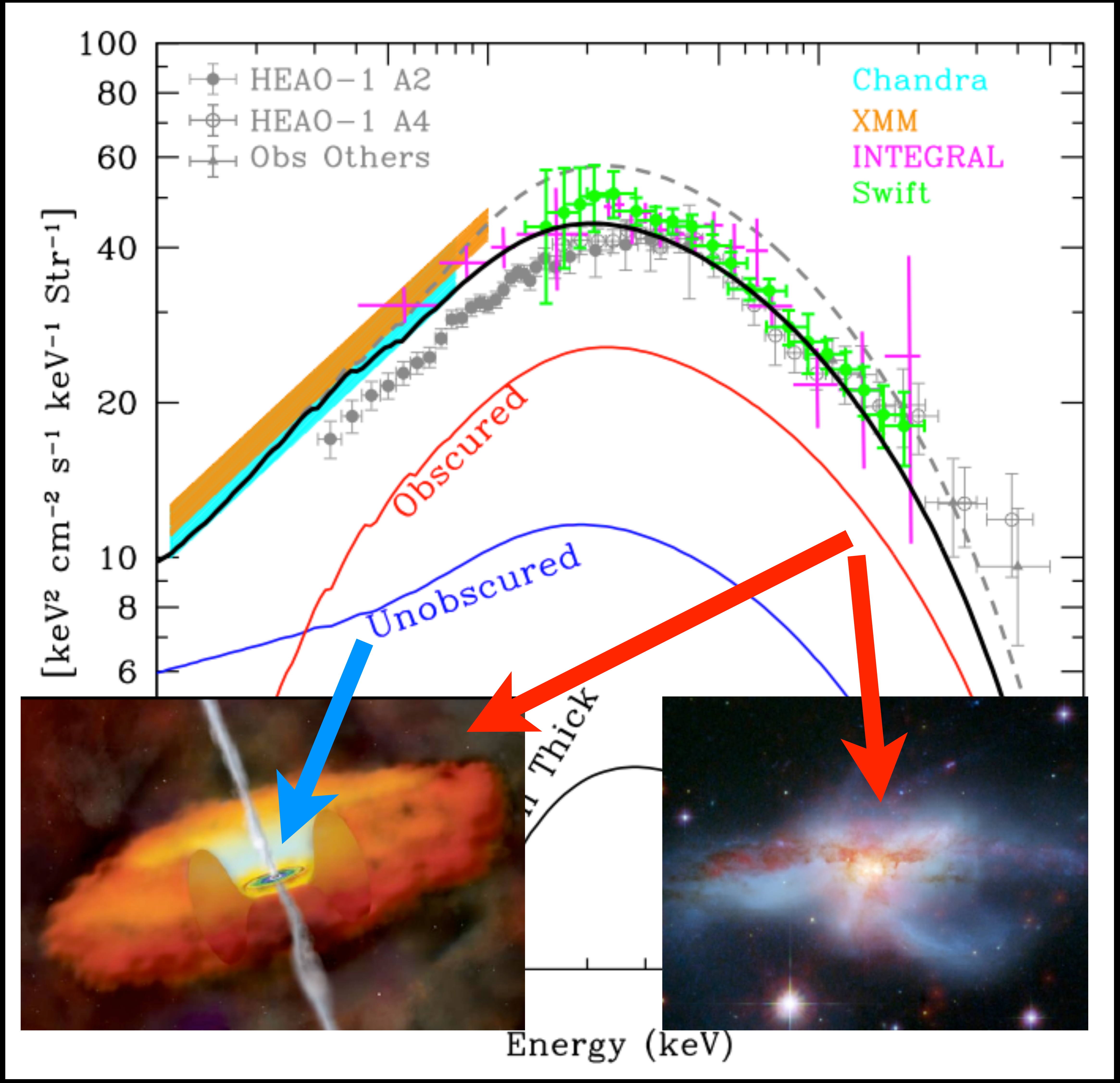
The diffuse character of the observed background radiation does not permit a positive determination of its nature and origin. However, the apparent absorption coefficient in mica and the altitude dependence is consistent with radiation of about the same wavelength as that responsible for the peak. Assuming the source lies close to the axis of the detectors, one obtains the intensity of the x-ray background as 1.7 photons cm^{-2} sec^{-1} sr^{-1} and of the secondary maximum (between 102° and 18°) as 0.6 photon cm^{-2} sec^{-1}. In addition, there seems to be a hard component to the background of about 0.5 cm^{-2} sec^{-1} sr^{-1} which does not show an altitude dependence and which is not eliminated by the anticoincidence.

Giacconi et al. (1962)

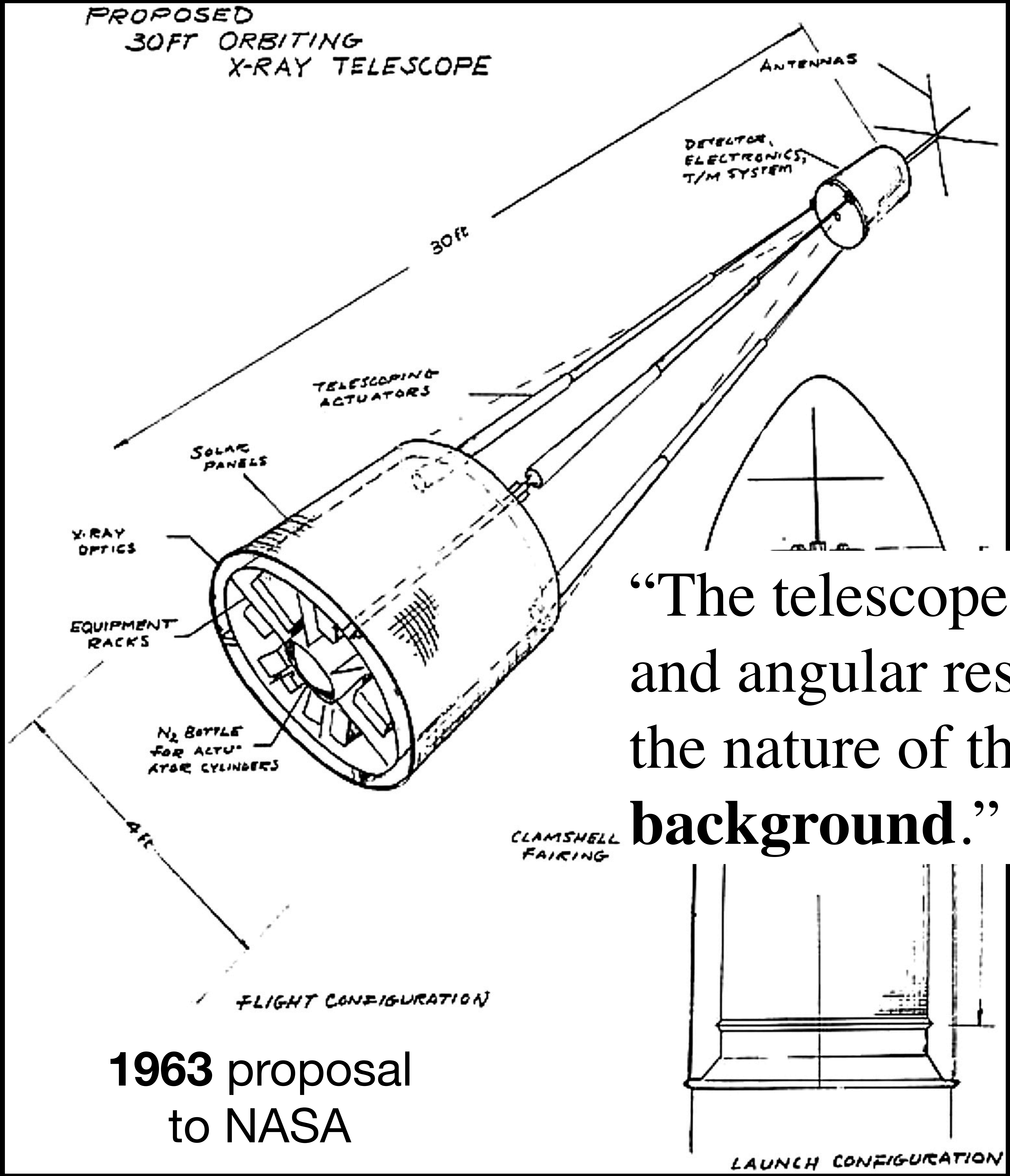
Origin of the cosmic X-ray background

The answer:
The CXB is produced by **growing black holes**

Hard spectrum of the CXB, with peak at ~30 keV, requires a combination of **unobscured** and **obscured** AGN
(e.g., Gilli, Comastri & Hasinger 2007; Treister et al. 2009; Ballantyne et al. 2011; Ueda et al. 2014, Ananna et al. 2019)



Treister et al. (2009)



1963 proposal
to NASA

“The telescope was of sufficient area and angular resolution to determine the nature of the **unresolved X-ray background**.” (Weisskopf 2010)

QUIZ TIME!

Go to pollev.com/blackhole

OR

text BLACKHOLE to 37607

What was the first X-ray telescope you used in your career?

Sounding rockets

Uhuru

Einstein

ROSAT

ASCA

Chandra

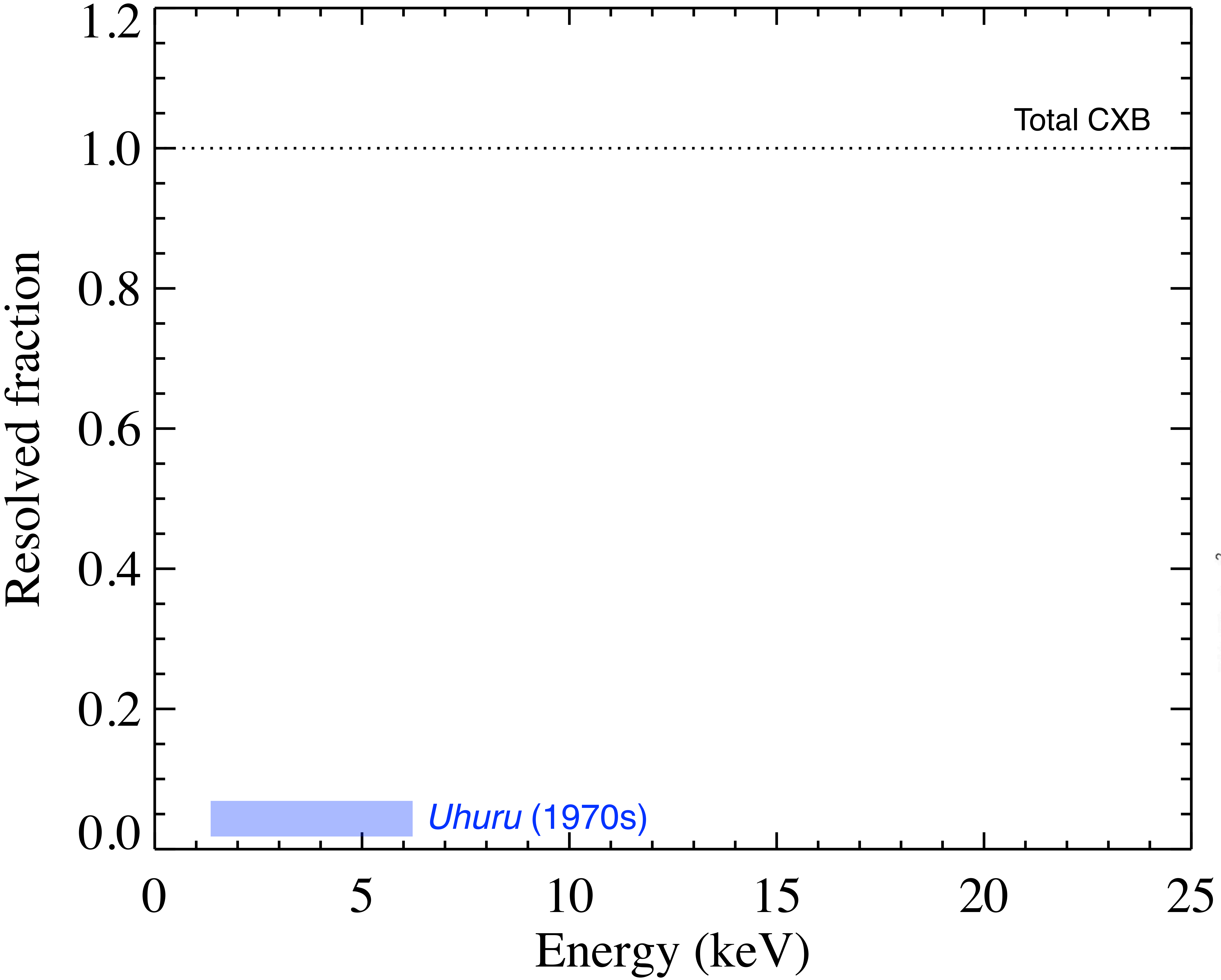
XMM-Newton

NuSTAR

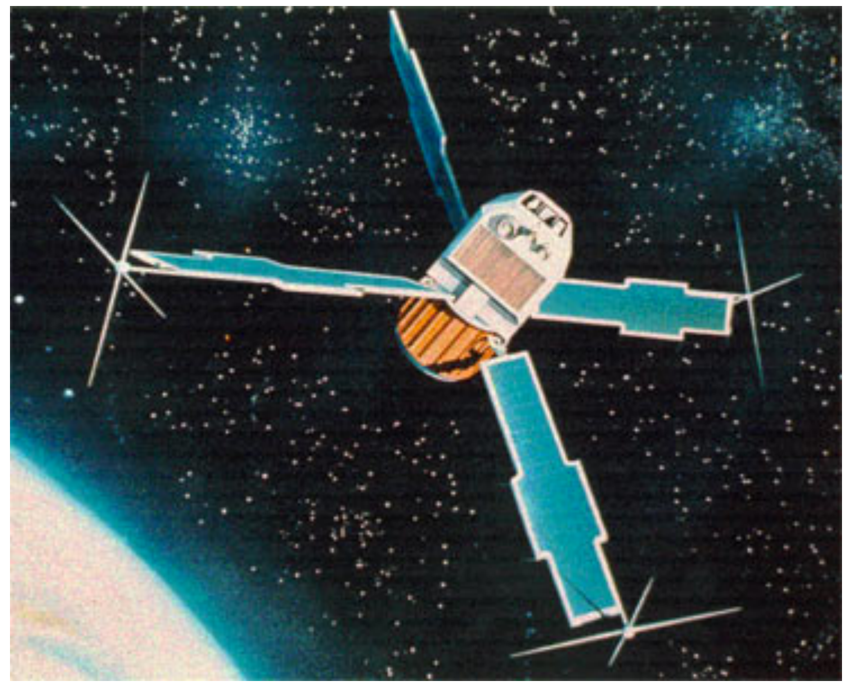
Other

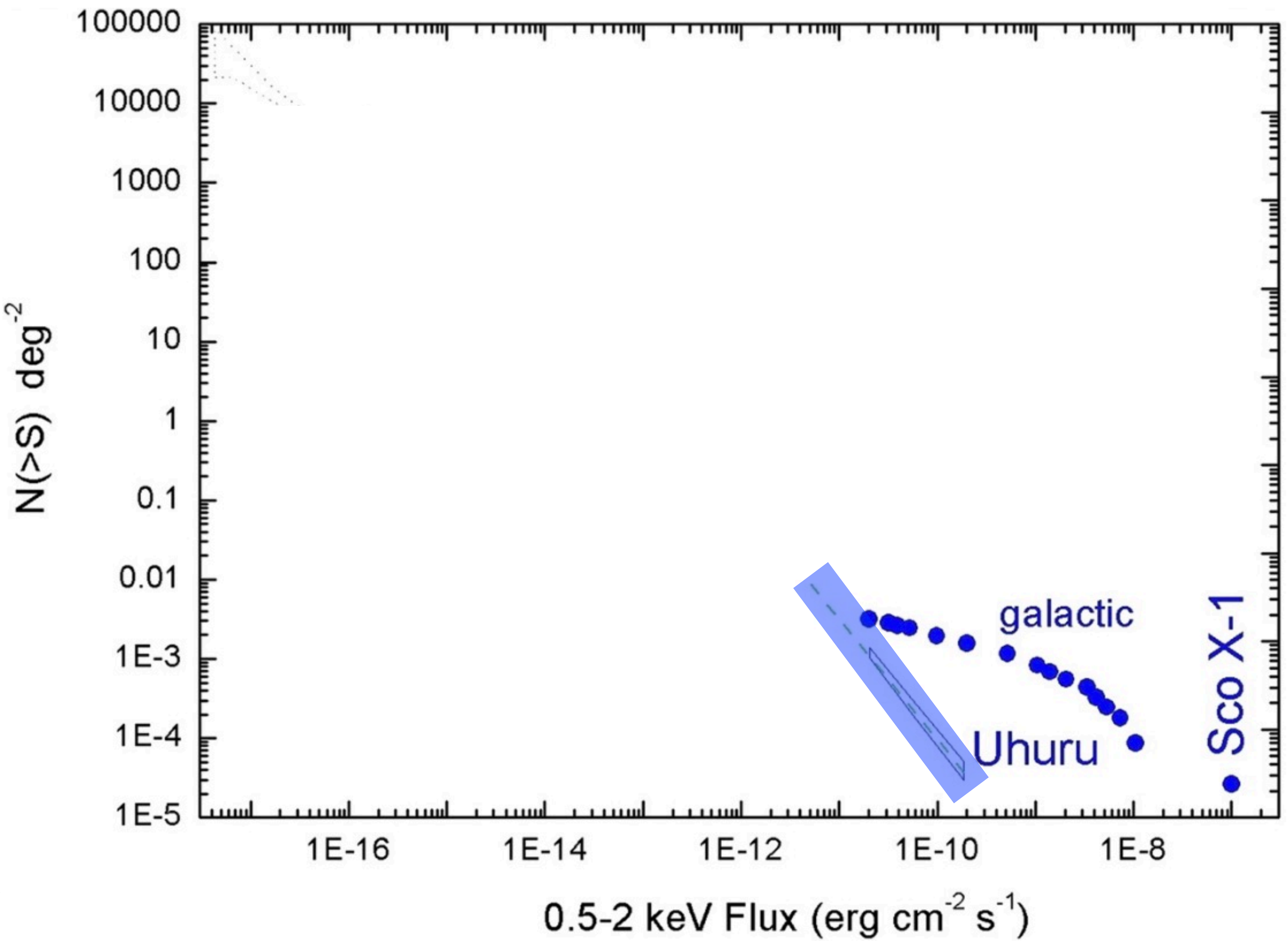
None, I’m a theorist

The **resolved fraction** of the CXB vs. energy



Uhuru

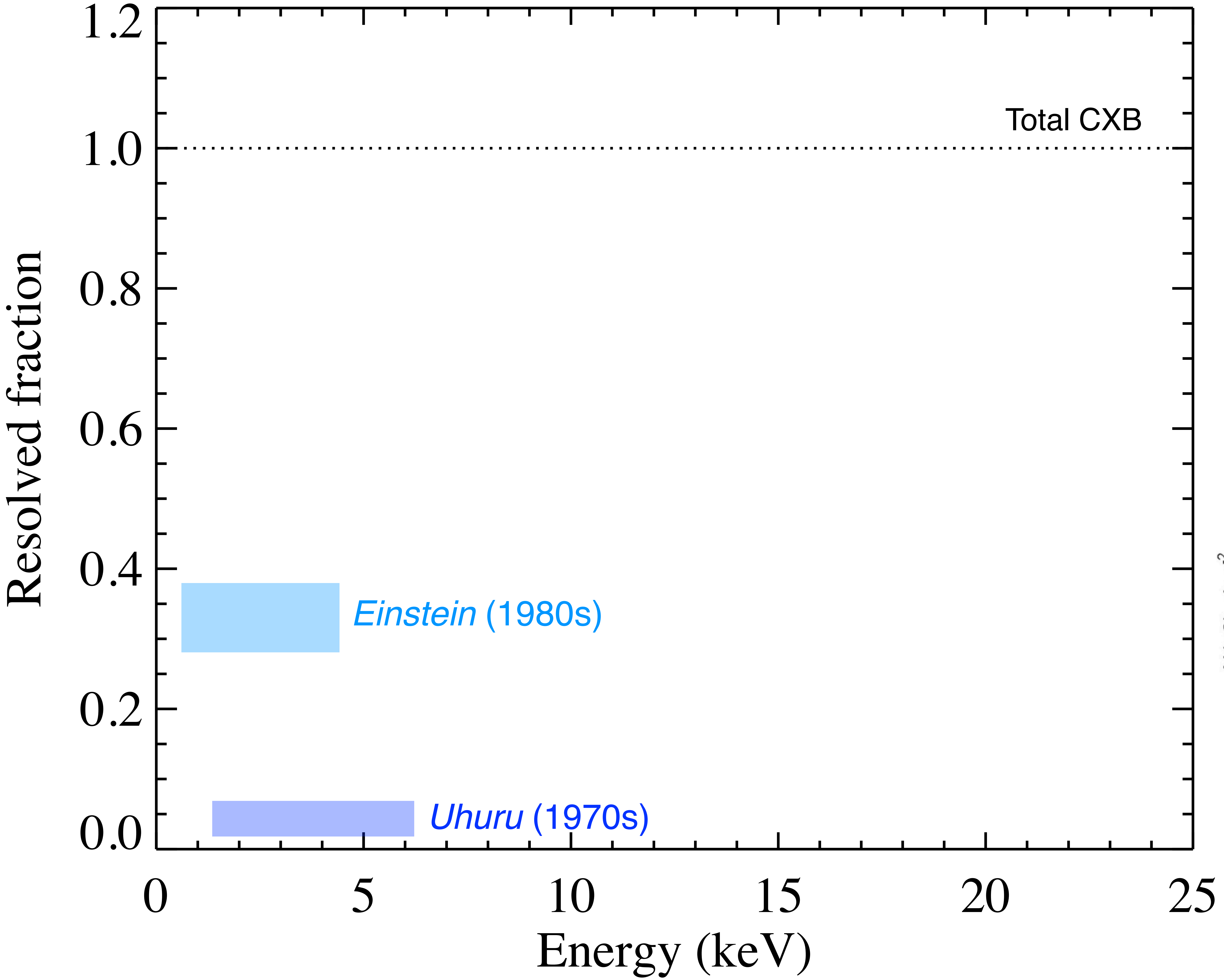


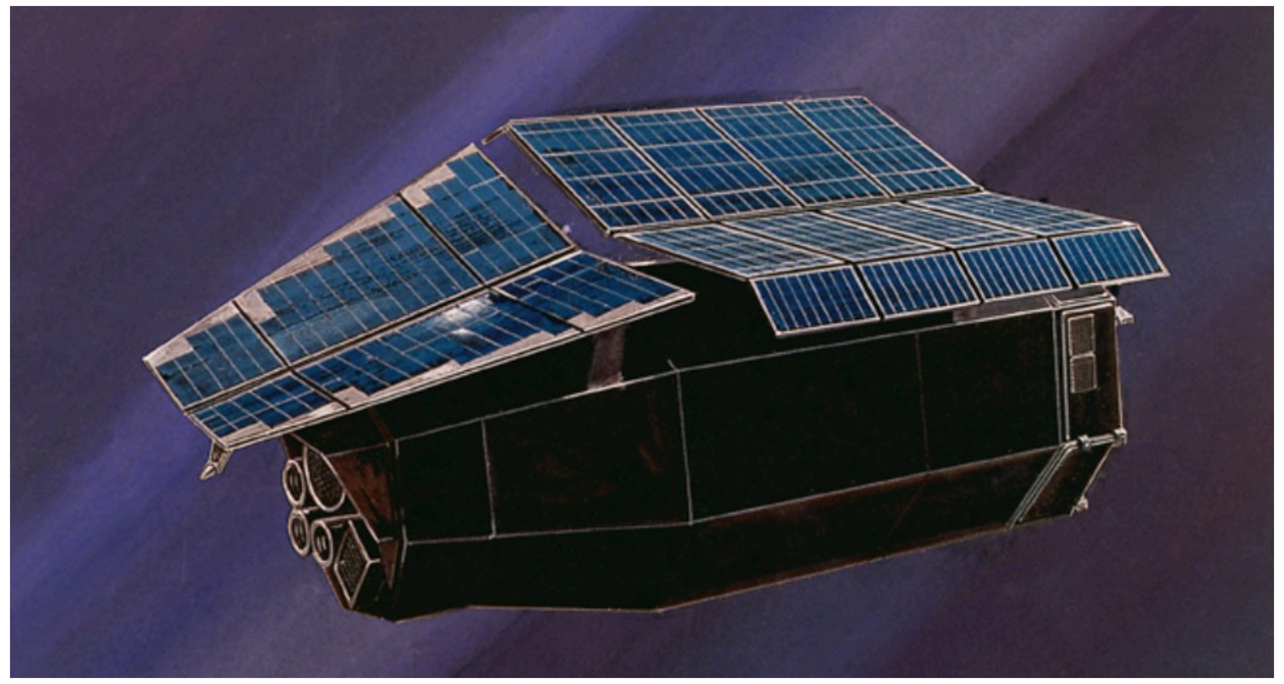


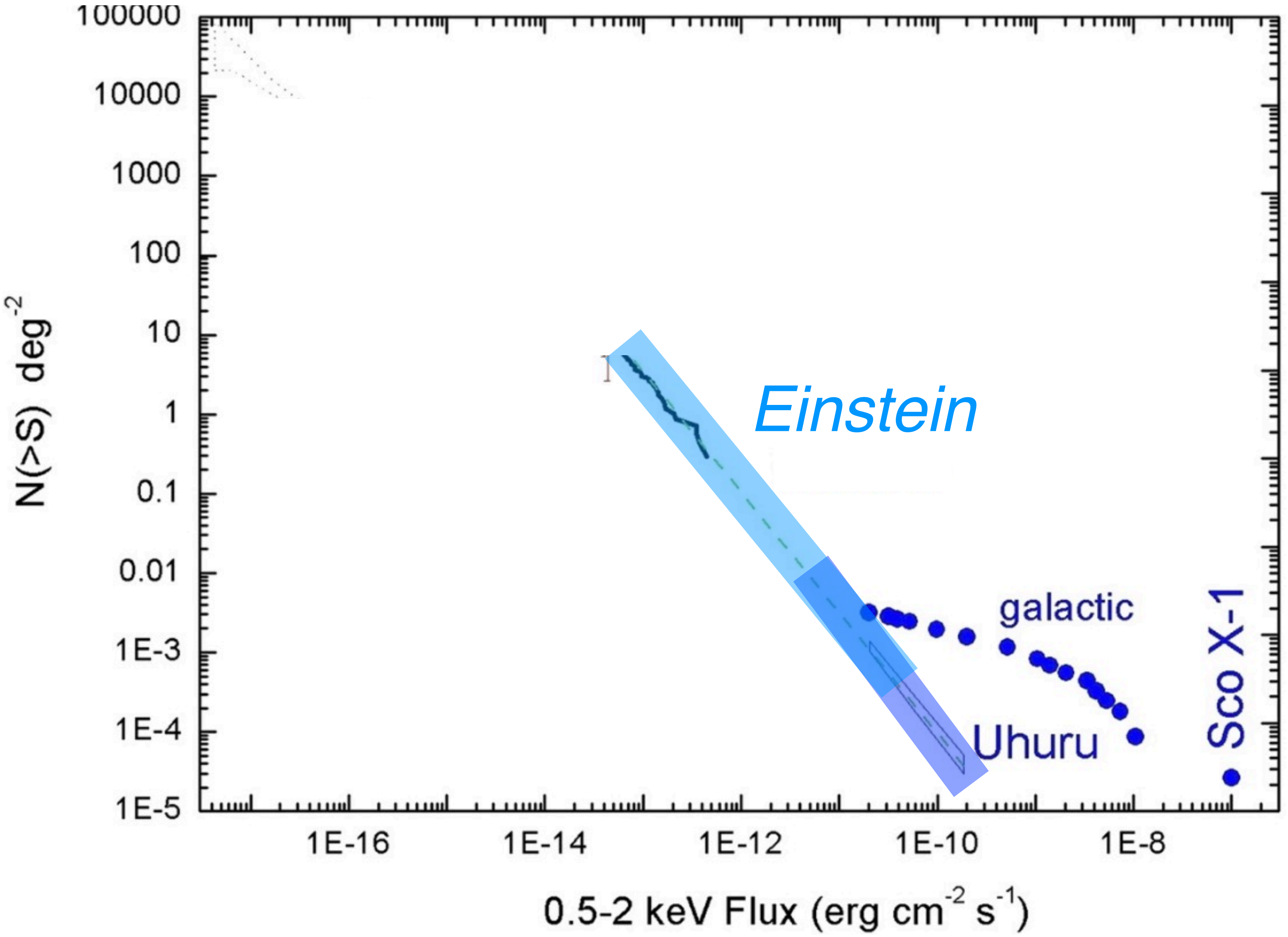
Giacconi & Rosati (2008)

The **resolved fraction** of the CXB vs. energy

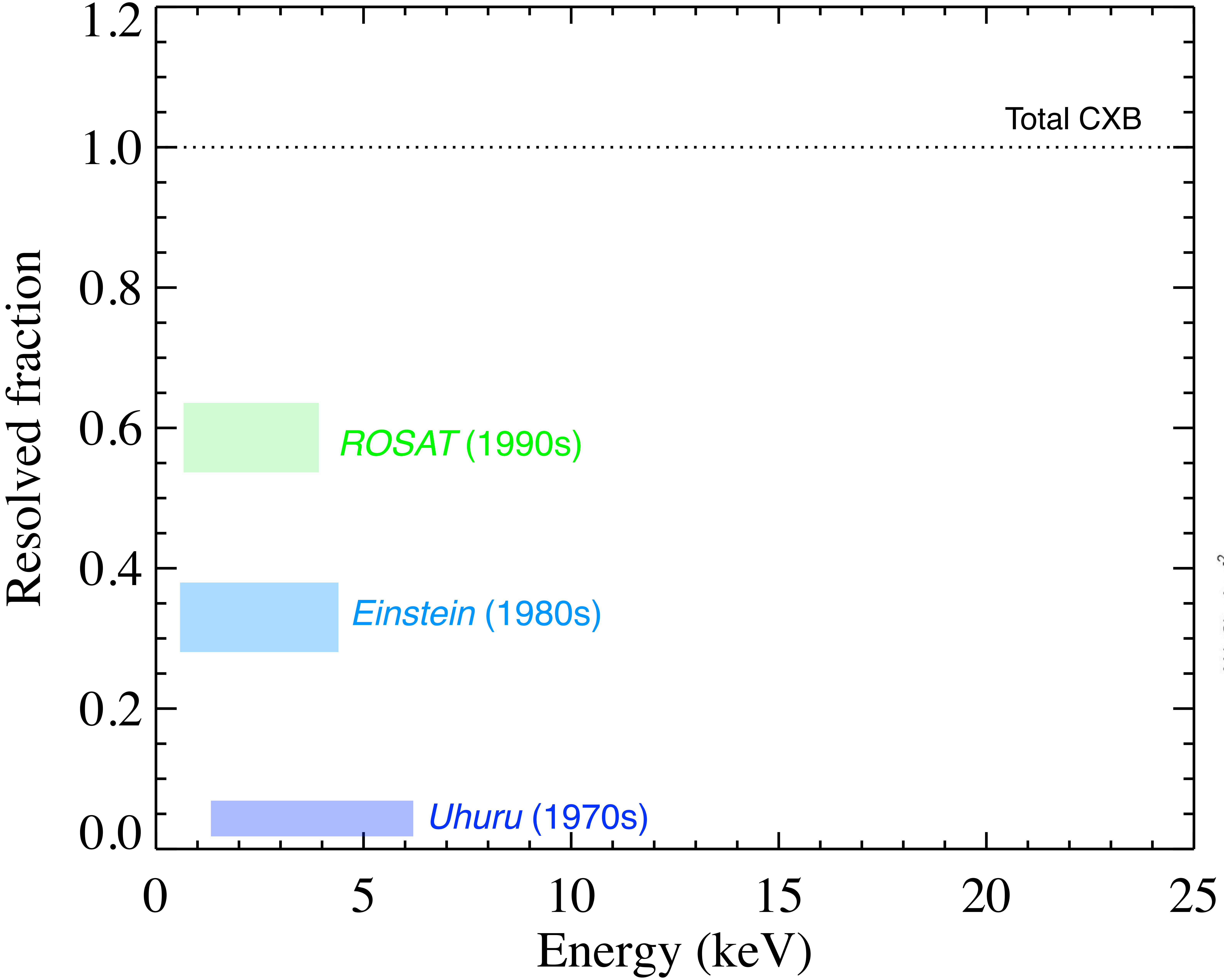
Einstein



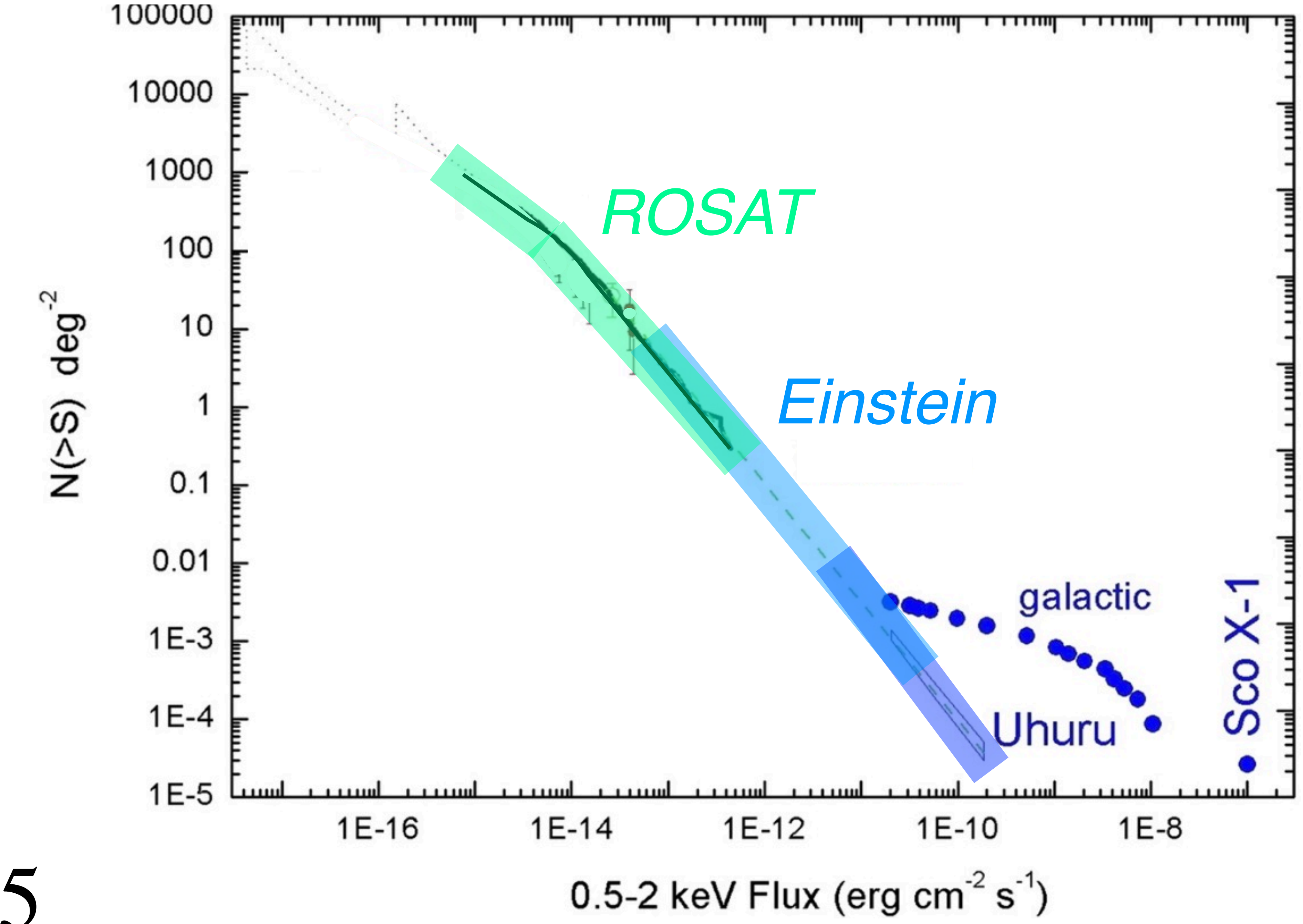


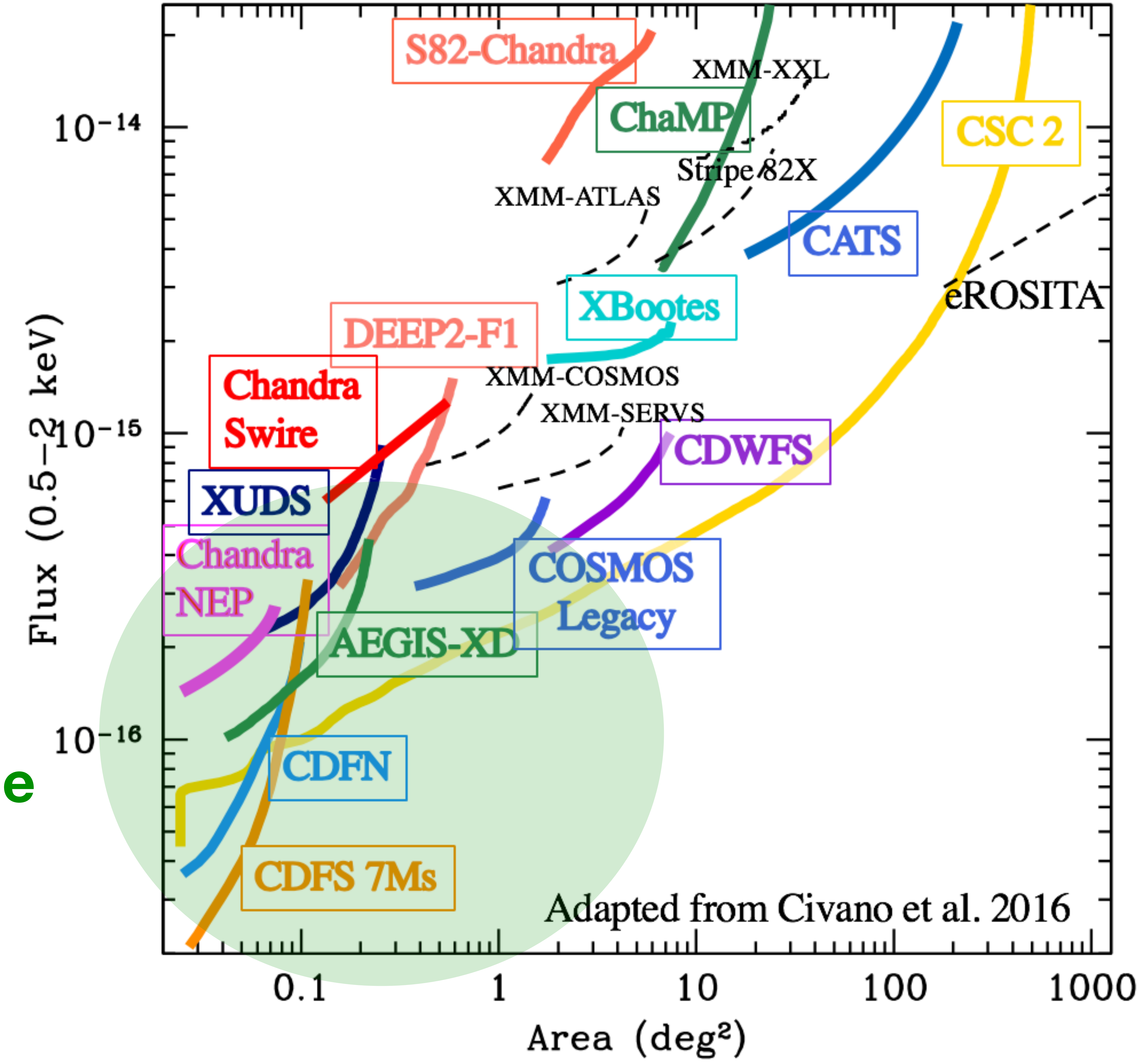


The **resolved fraction** of the CXB vs. energy



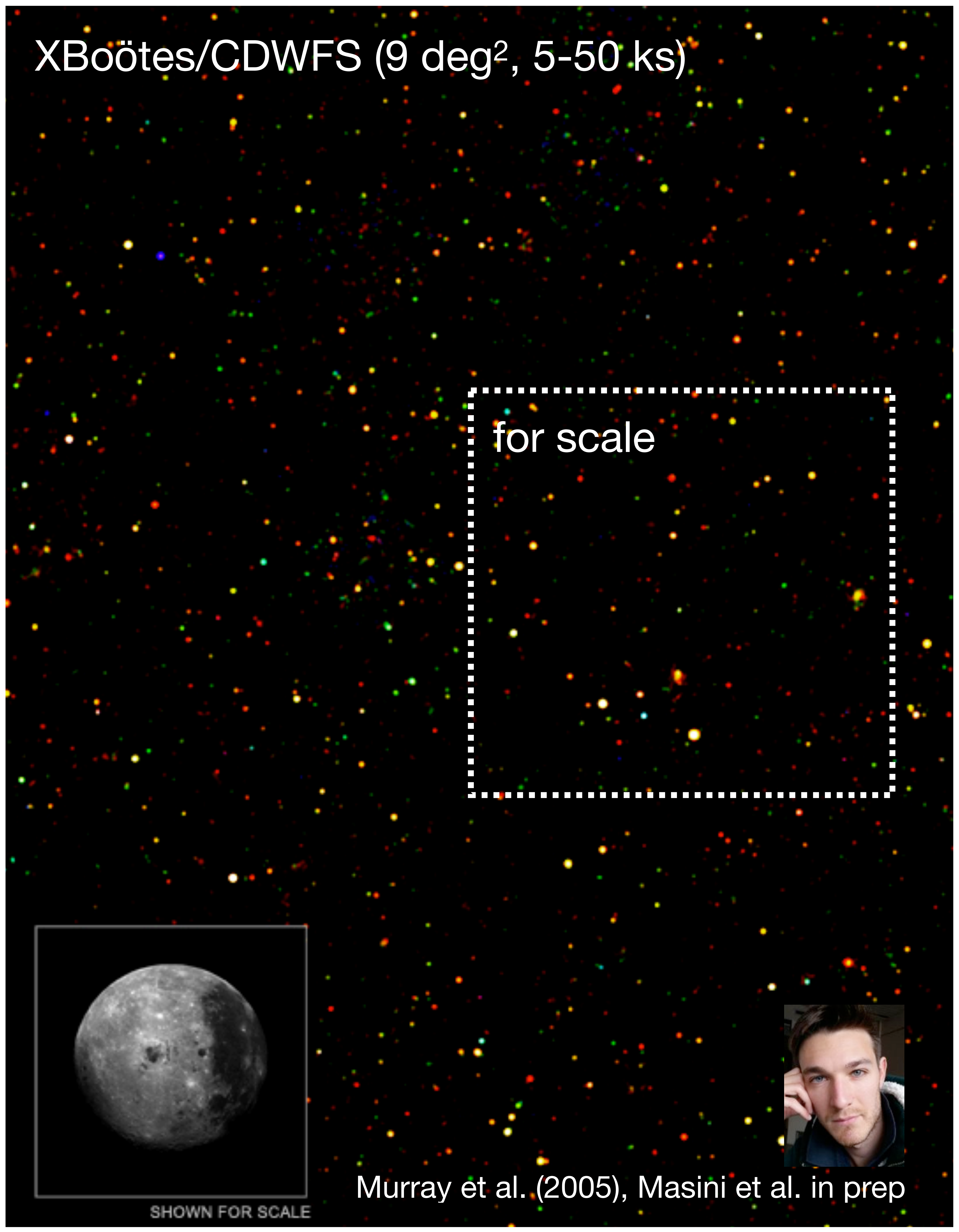
ROSAT



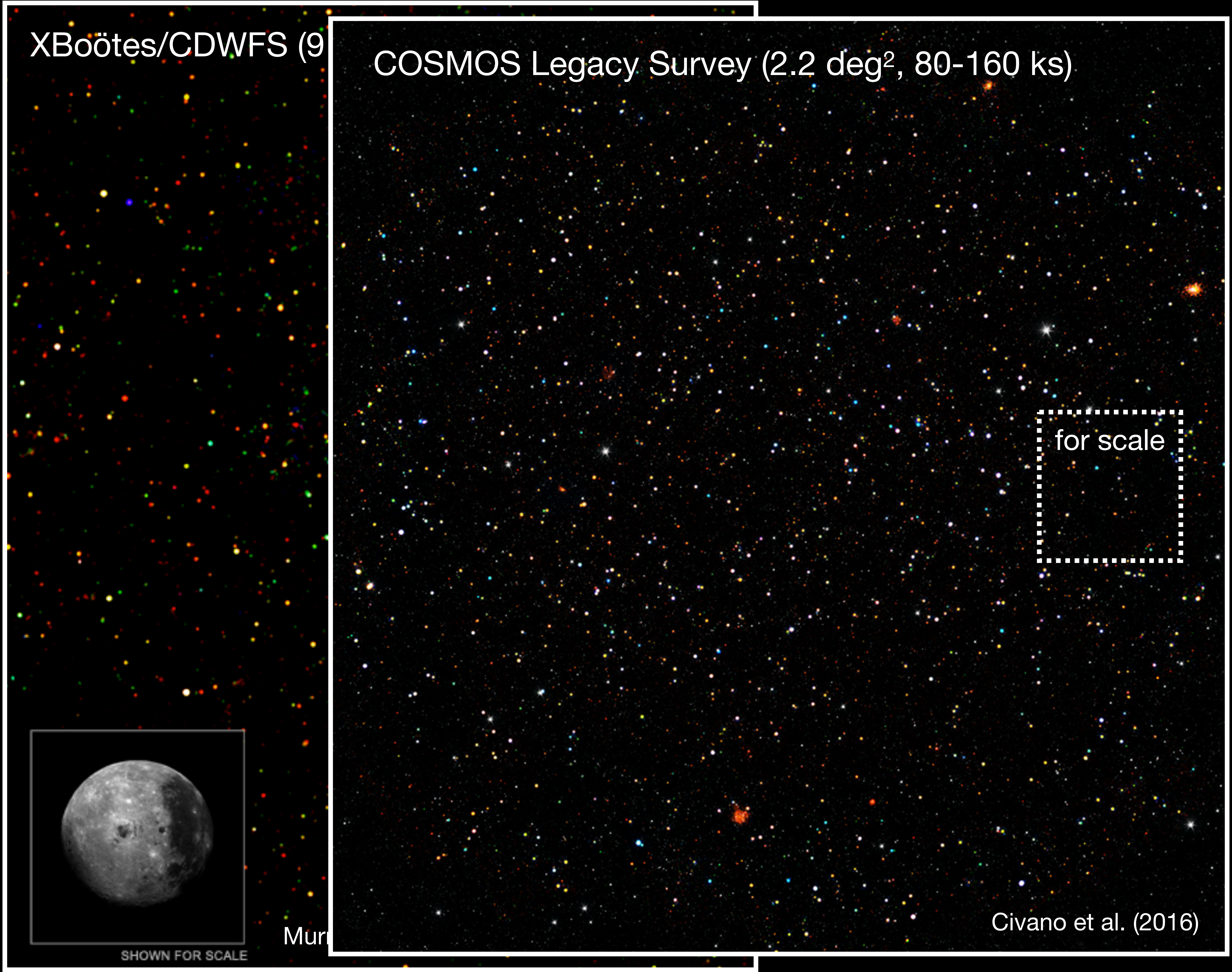


Focus on the deepest *Chandra* surveys

XBoötes/CDWFS (9 deg^2, 5-50 ks)



Murray et al. (2005), Masini et al. in prep

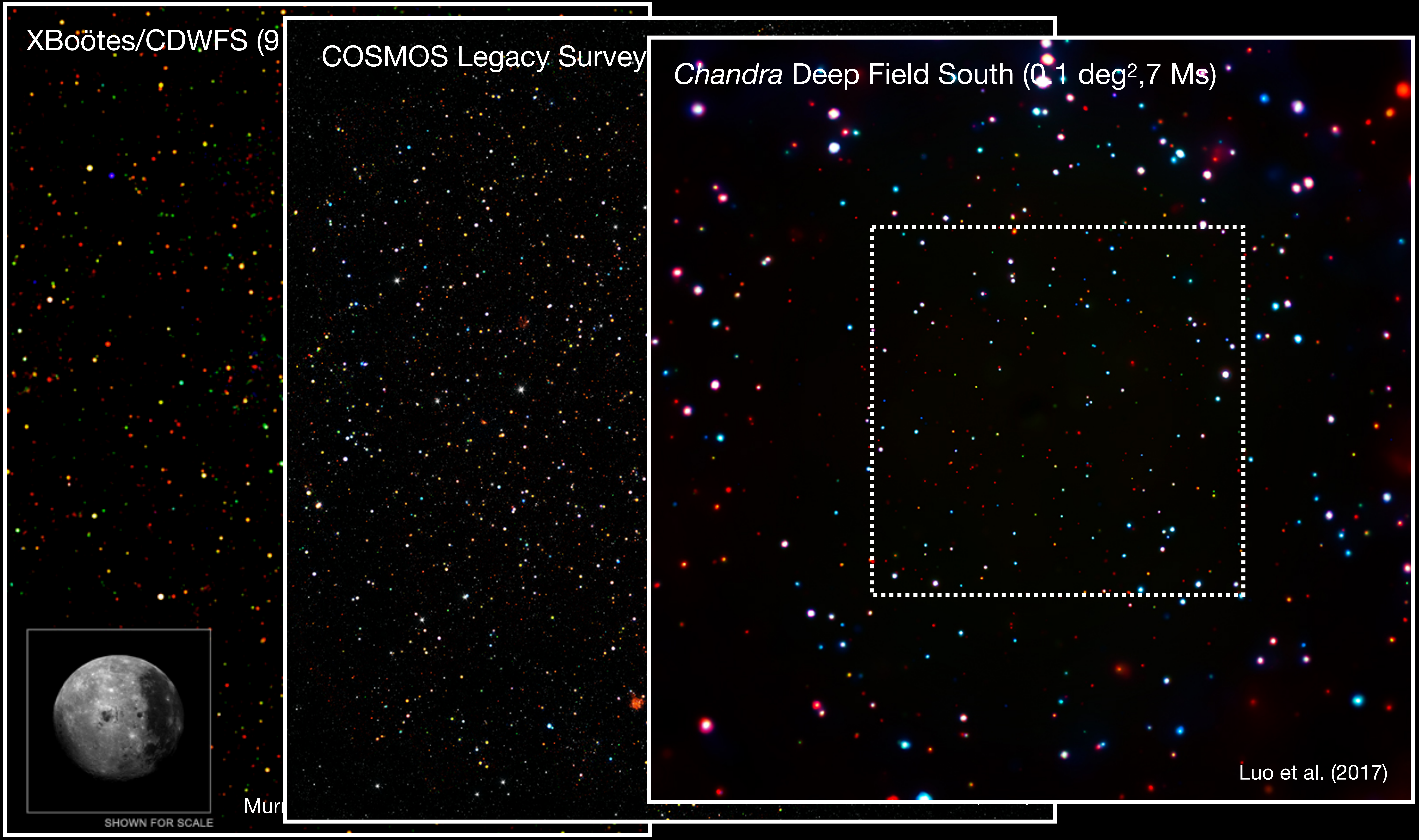


XBoötes/CDWFS (9

COSMOS Legacy Survey (2.2 deg^2, 80-160 ks)

Murr

Civano et al. (2016)



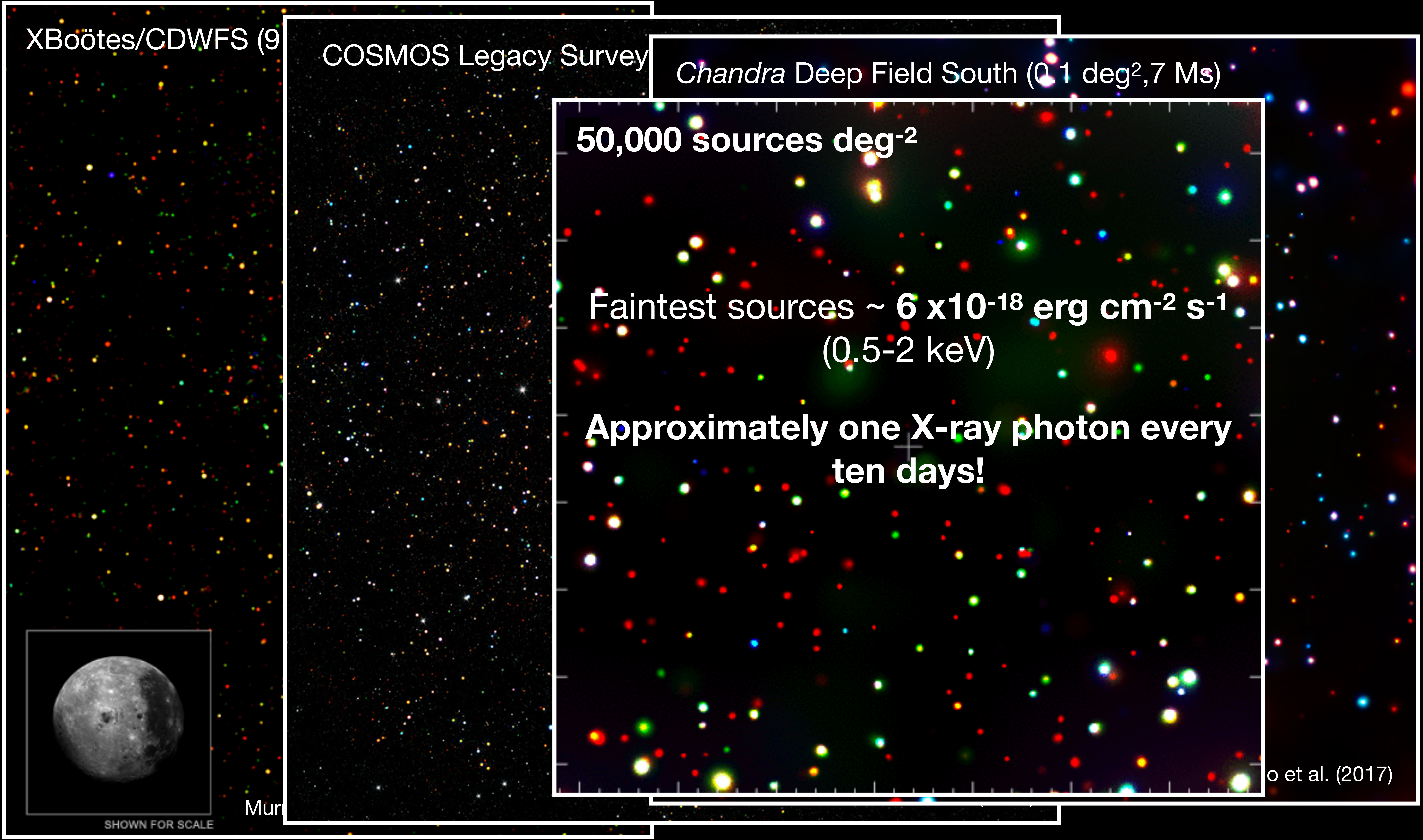
XBoötes/CDWFS (9

COSMOS Legacy Survey

Chandra Deep Field South (0.1 deg^2,7 Ms)

Murr

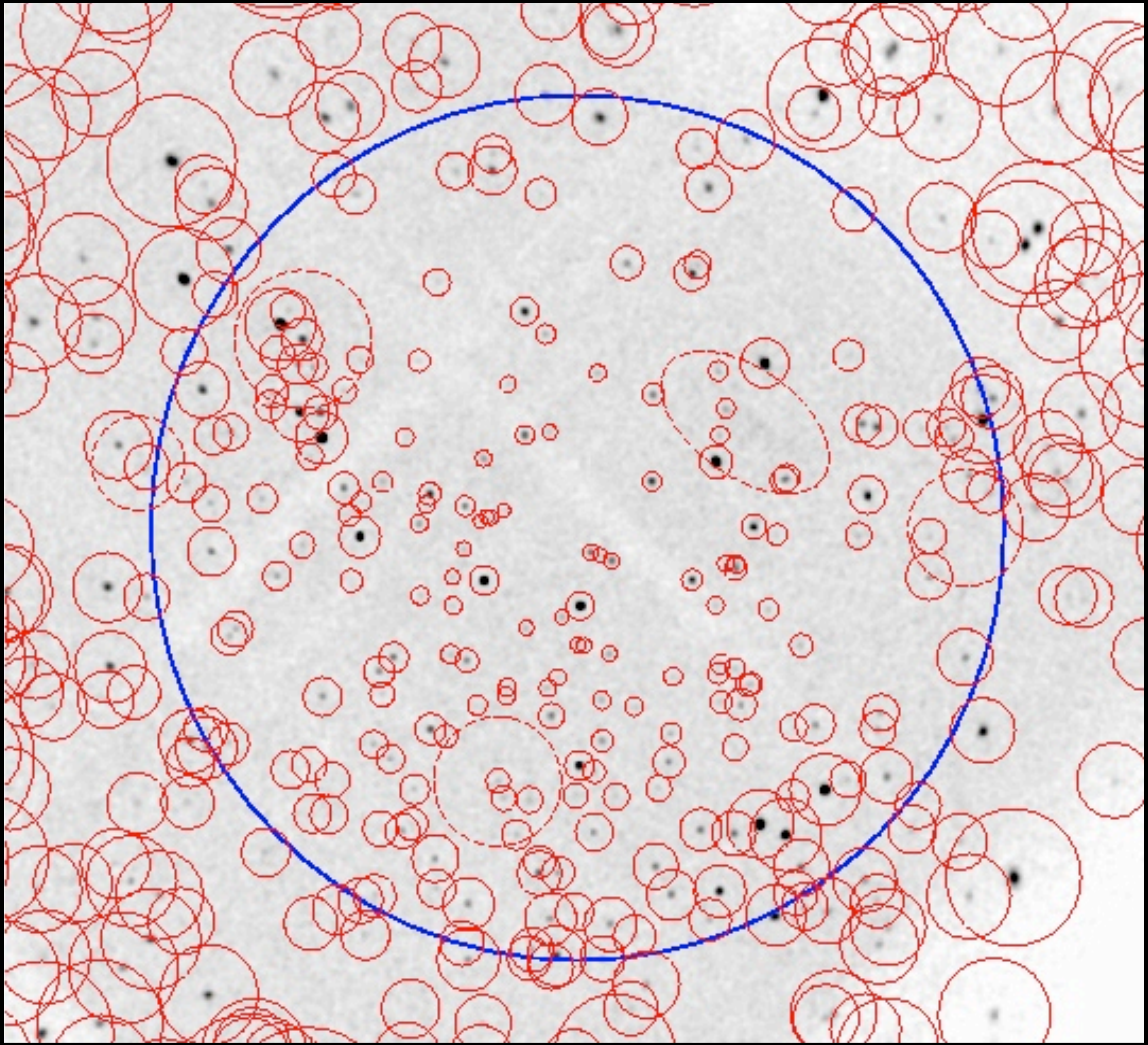
Luo et al. (2017)



50,000 sources deg^{-2}

Faintest sources ~ **6 x10^{-18} erg cm^{-2} s^{-1}**
(0.5-2 keV)

Approximately one X-ray photon every ten days!



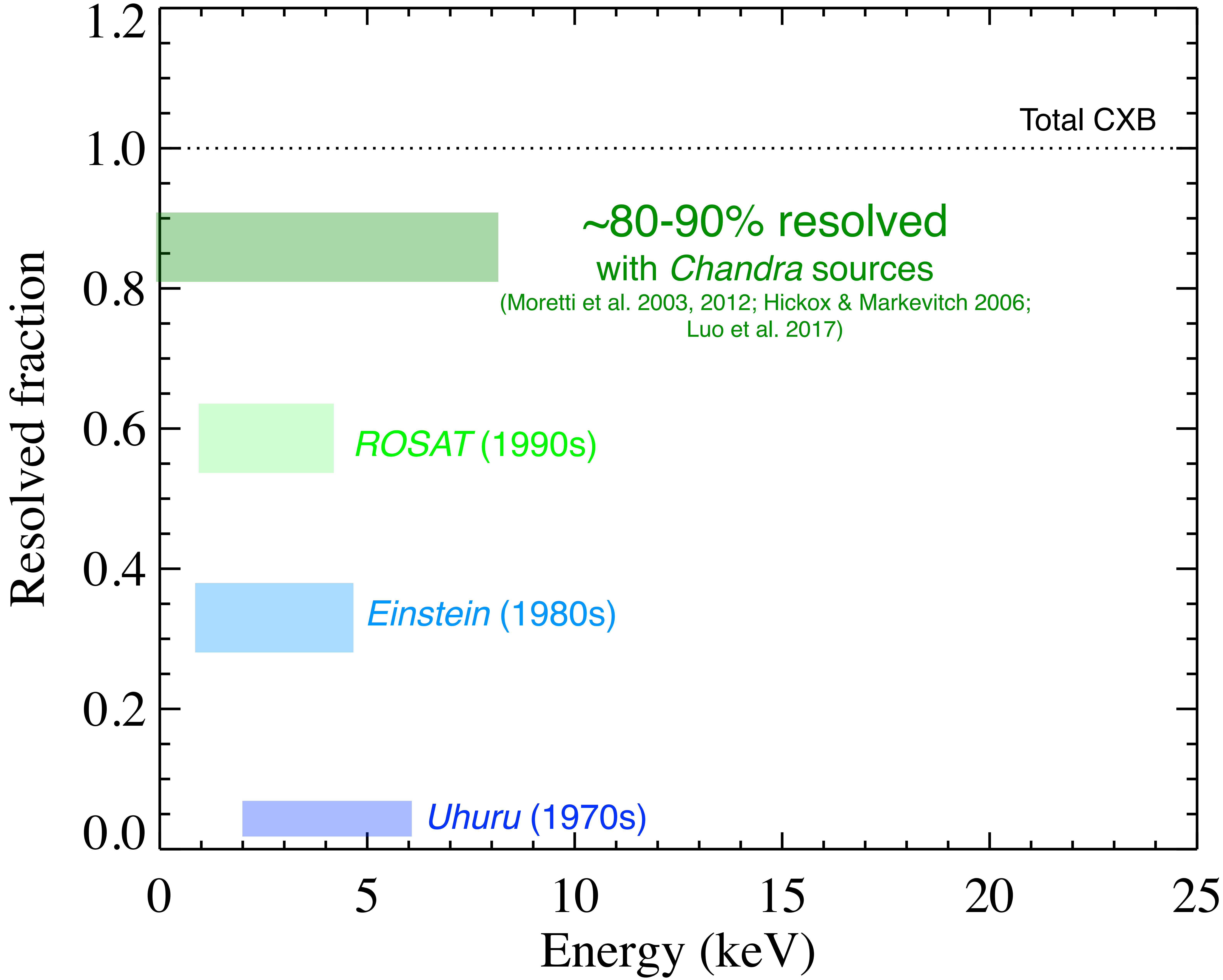
Hickox & Markevitch (2006)

What is the **absolute unresolved background**?

Requires careful subtraction of instrumental background

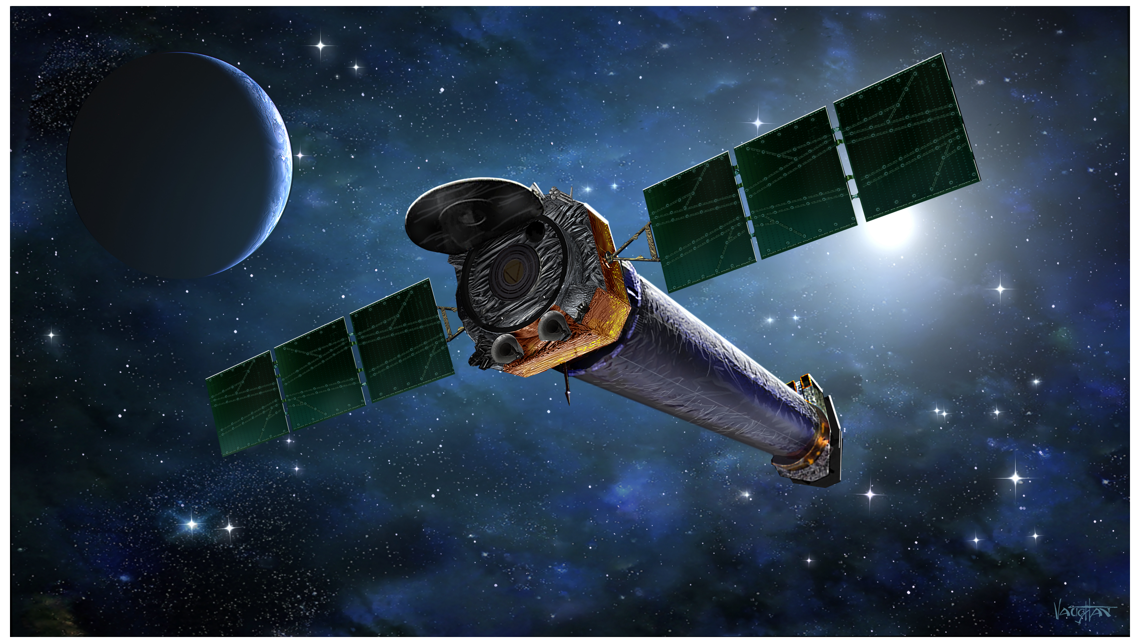
~80-90% of 0.5-8 keV background is resolved by *Chandra*

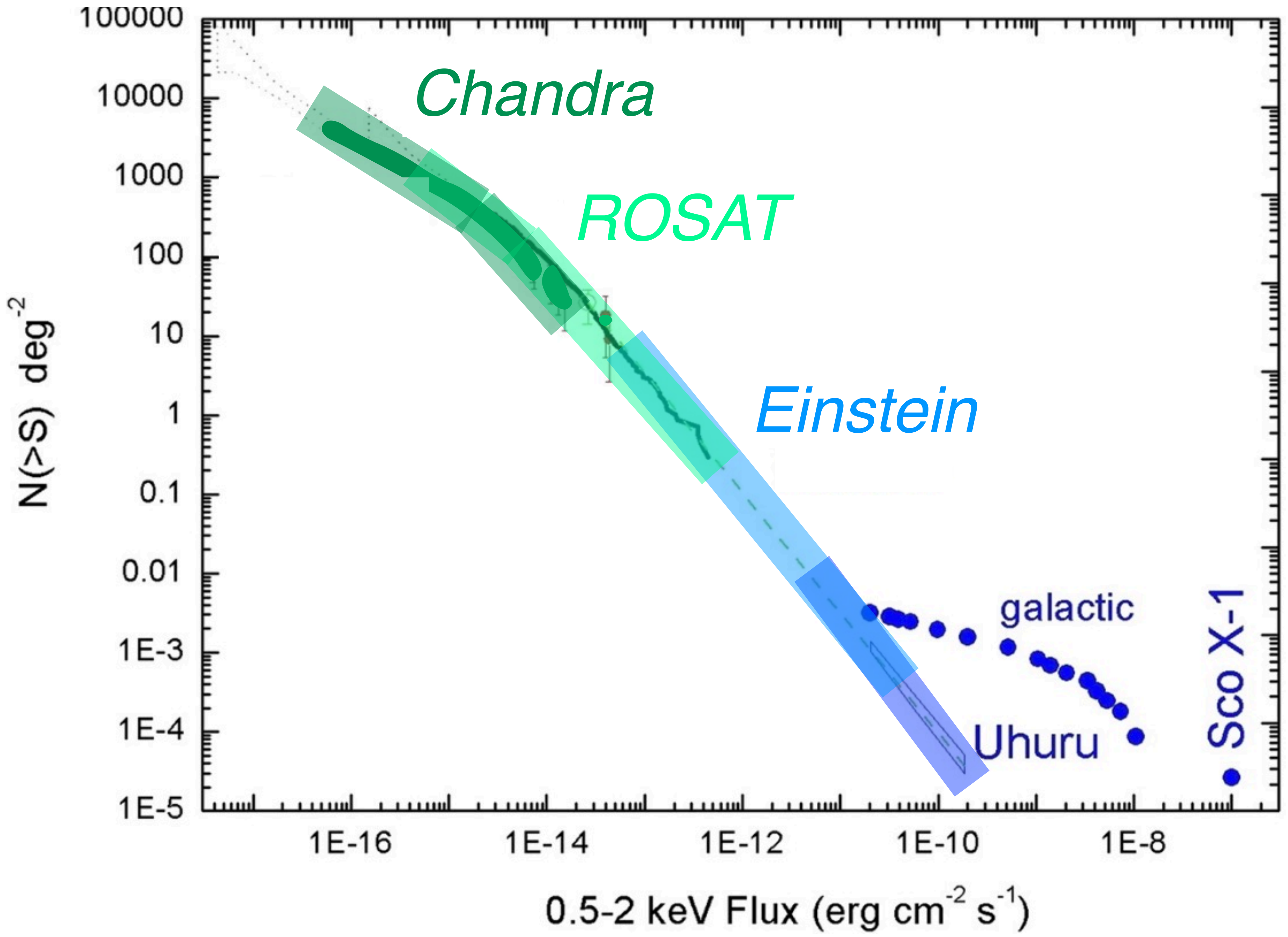
The **resolved fraction** of the CXB vs. energy



~80-90% resolved
with *Chandra* sources
(Moretti et al. 2003, 2012; Hickox & Markevitch 2006; Luo et al. 2017)

Chandra





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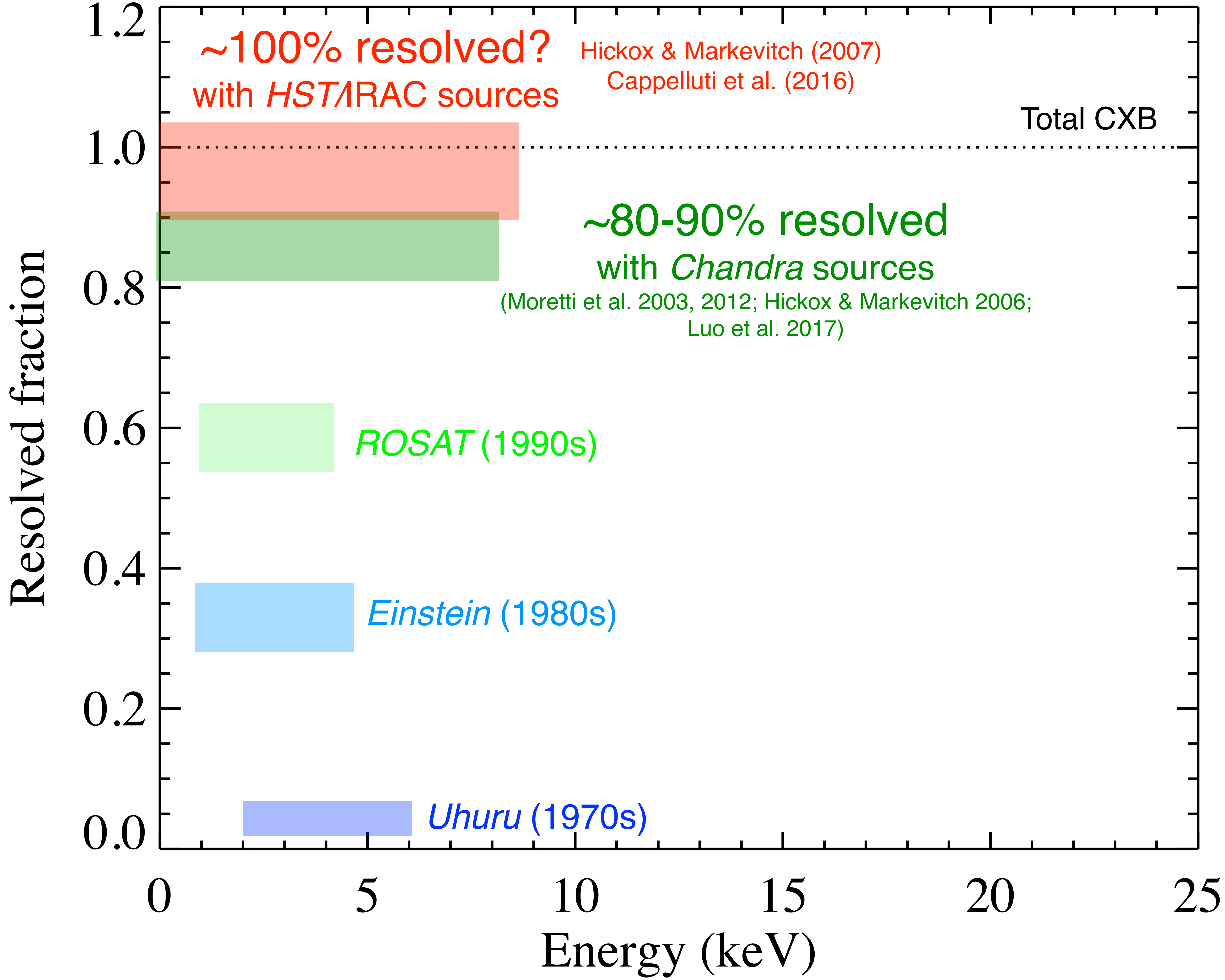
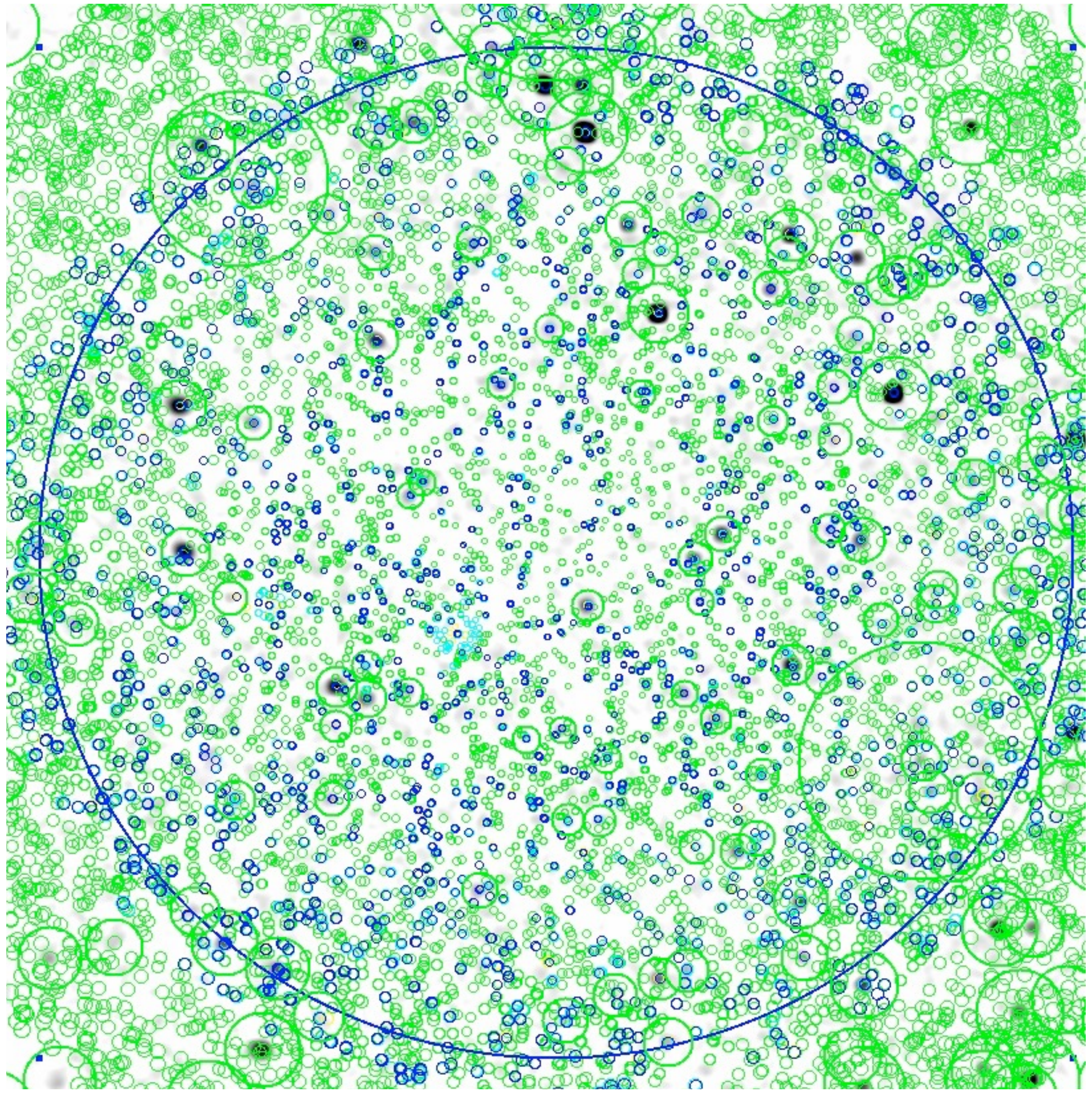




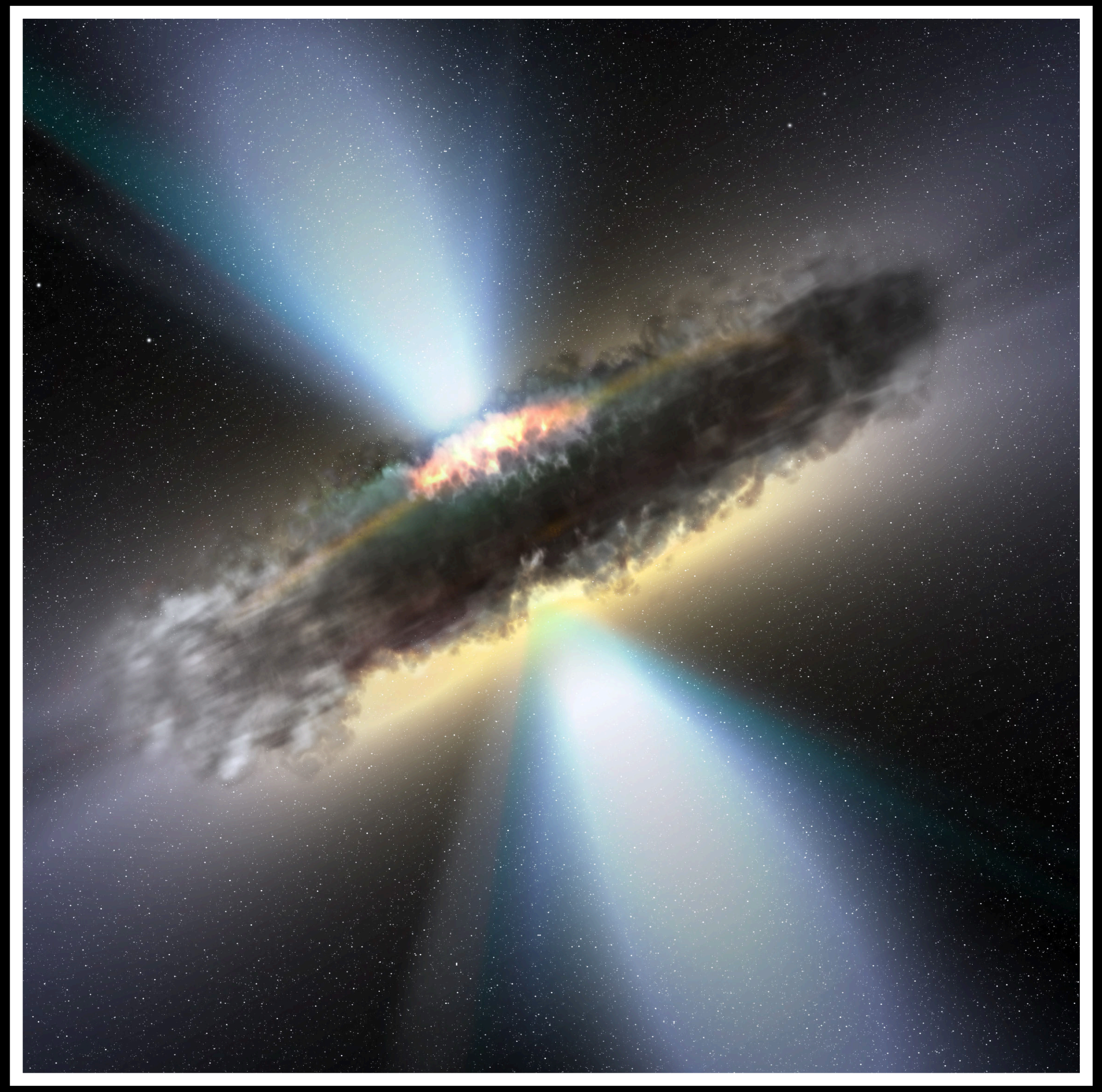
Hickox & Markevitch (2007)

brighter

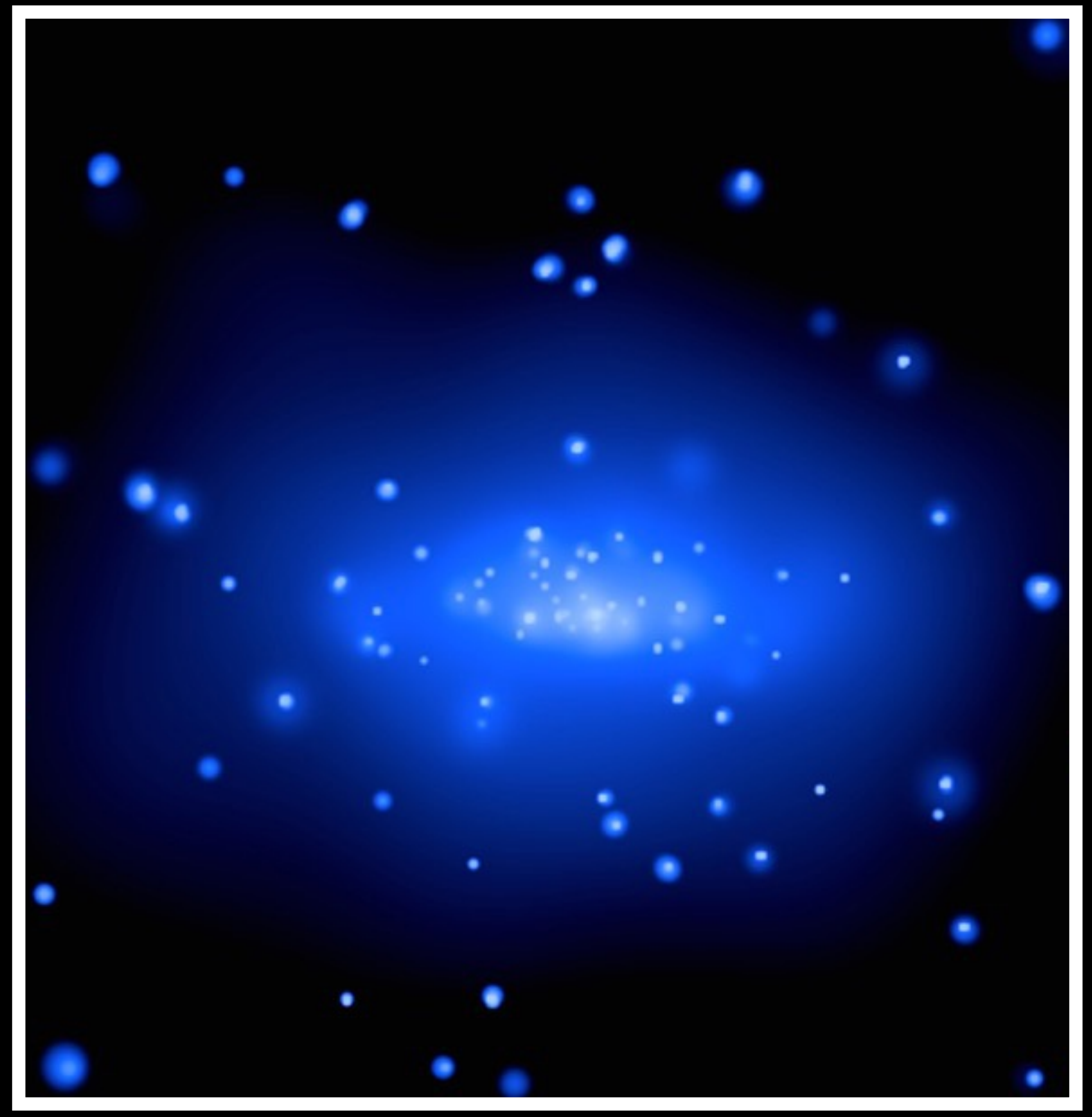
fainter

Evolution of black holes and galaxies

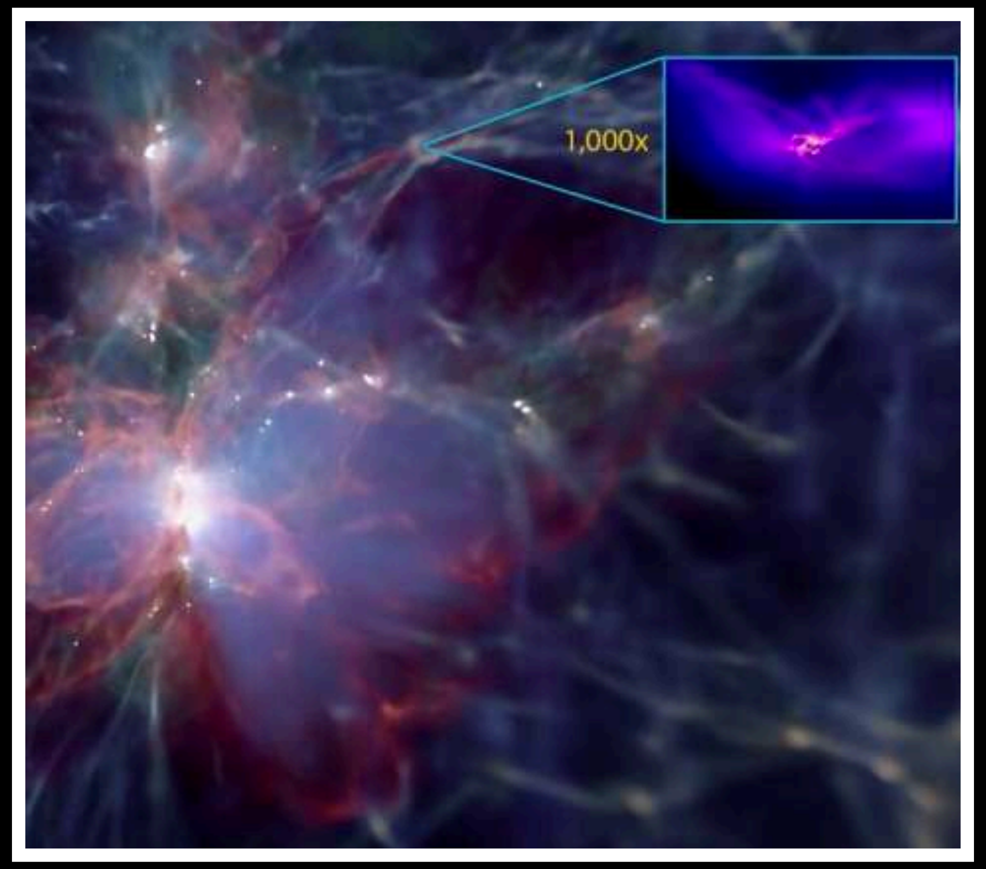
Unveiling hidden black holes



The realm of “normal” galaxies



Black holes in the early Universe



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Evolution of black holes and galaxies

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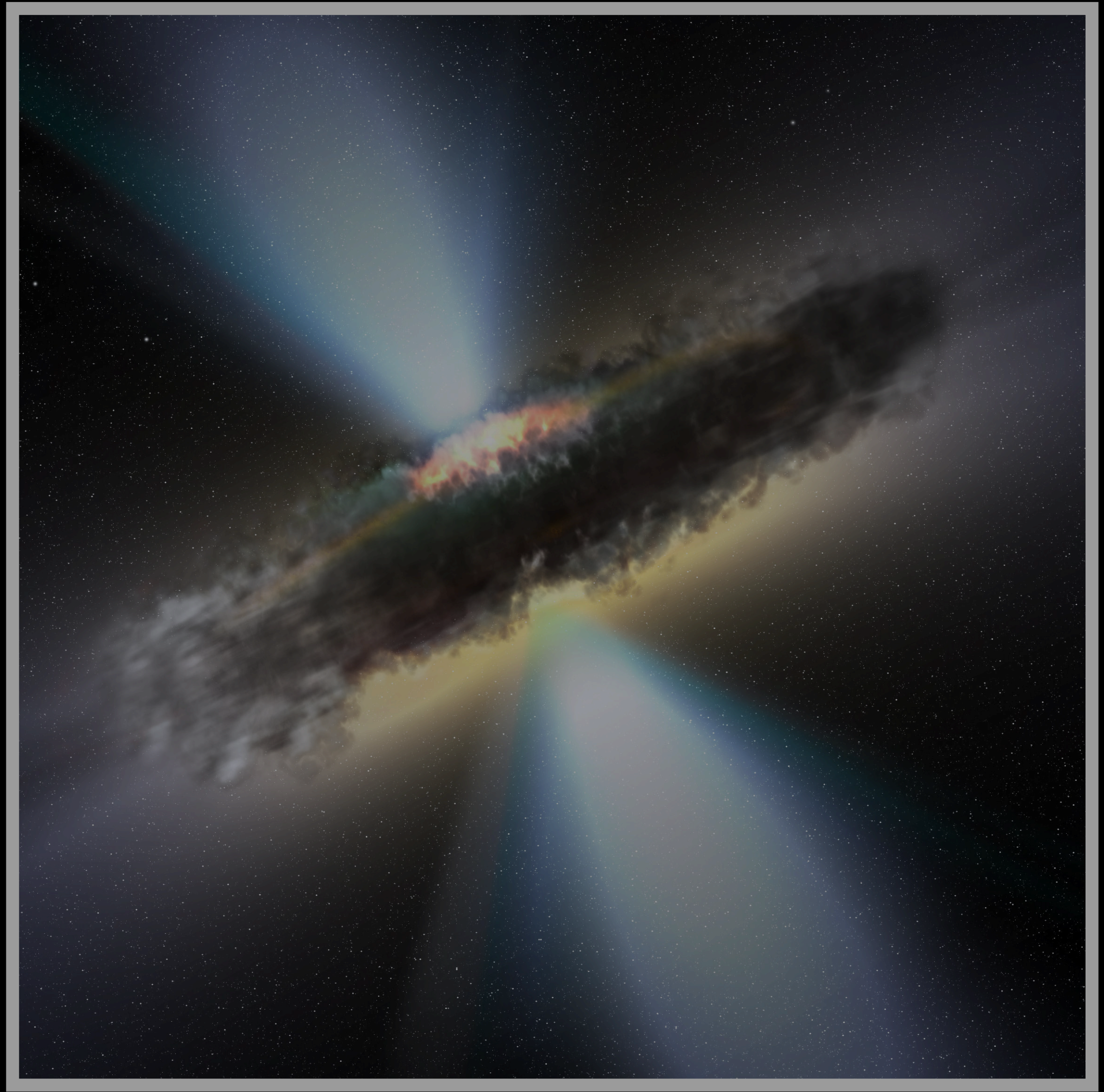

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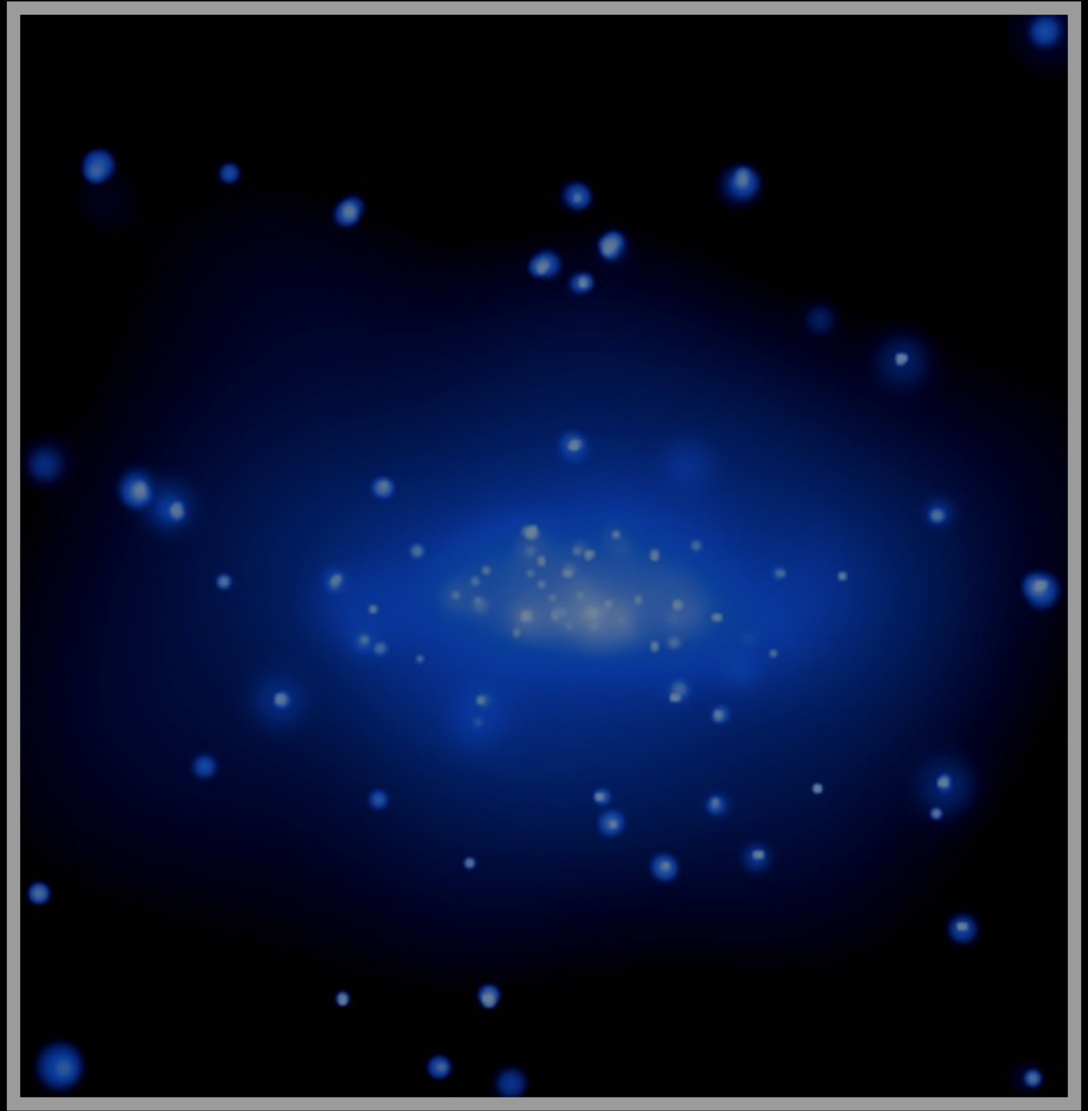
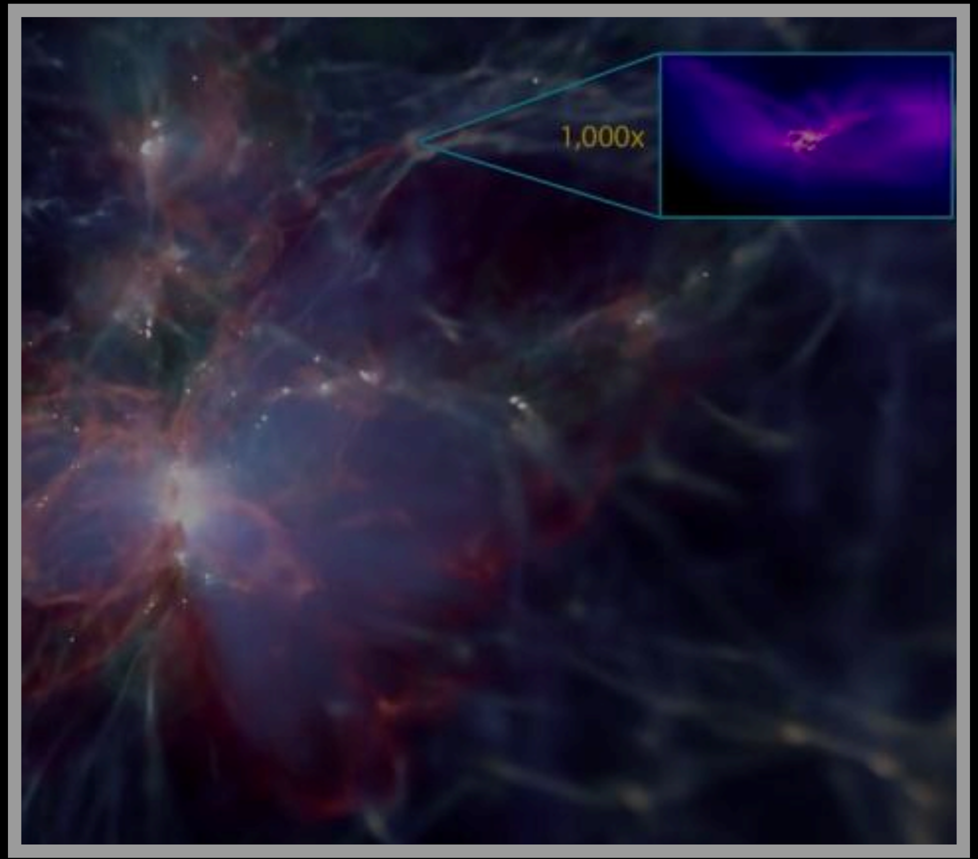
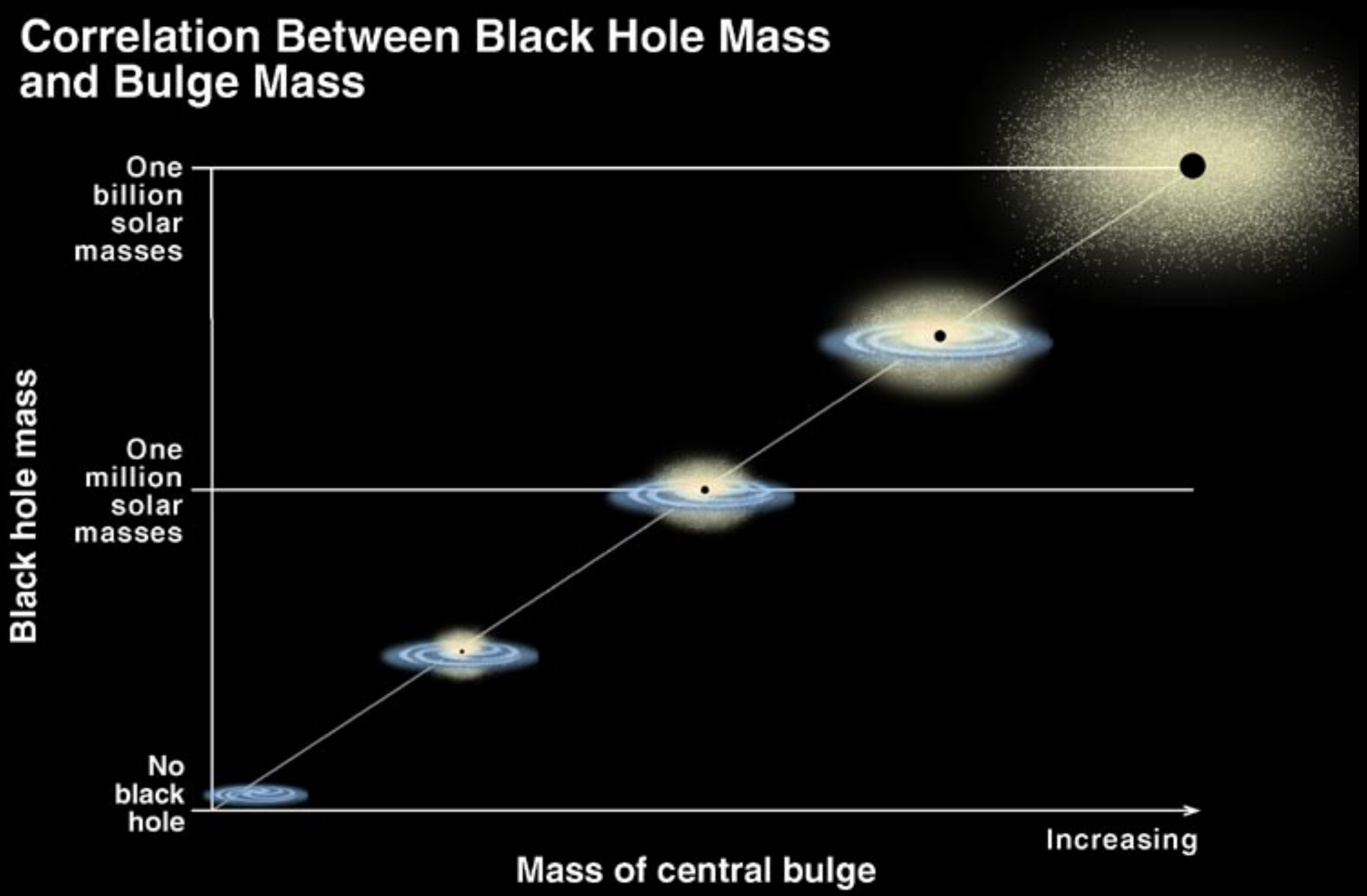
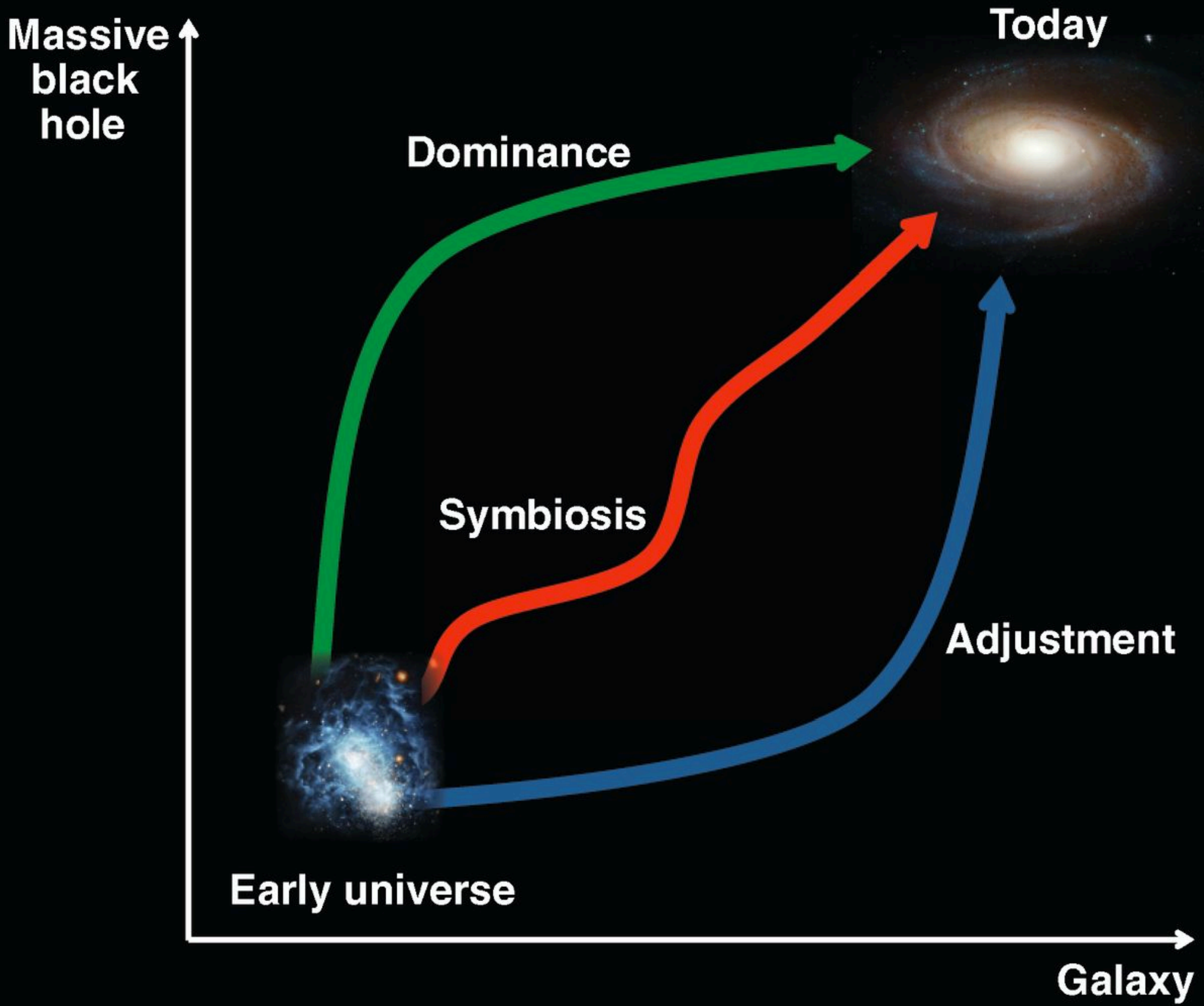


Black holes in the early Universe



Correlation Between Black Hole Mass and Bulge Mass




Massive black hole
Today
Dominance
Symbiosis
Adjustment
Early universe
Galaxy

What came first, the galaxy or the black hole?

The black hole (“Dominance”) **A**

The galaxy (“Adjustment”) **B**

They grew together (“Symbiosis”) **C**

It depends widely on the system (“It’s complicated”) **D**

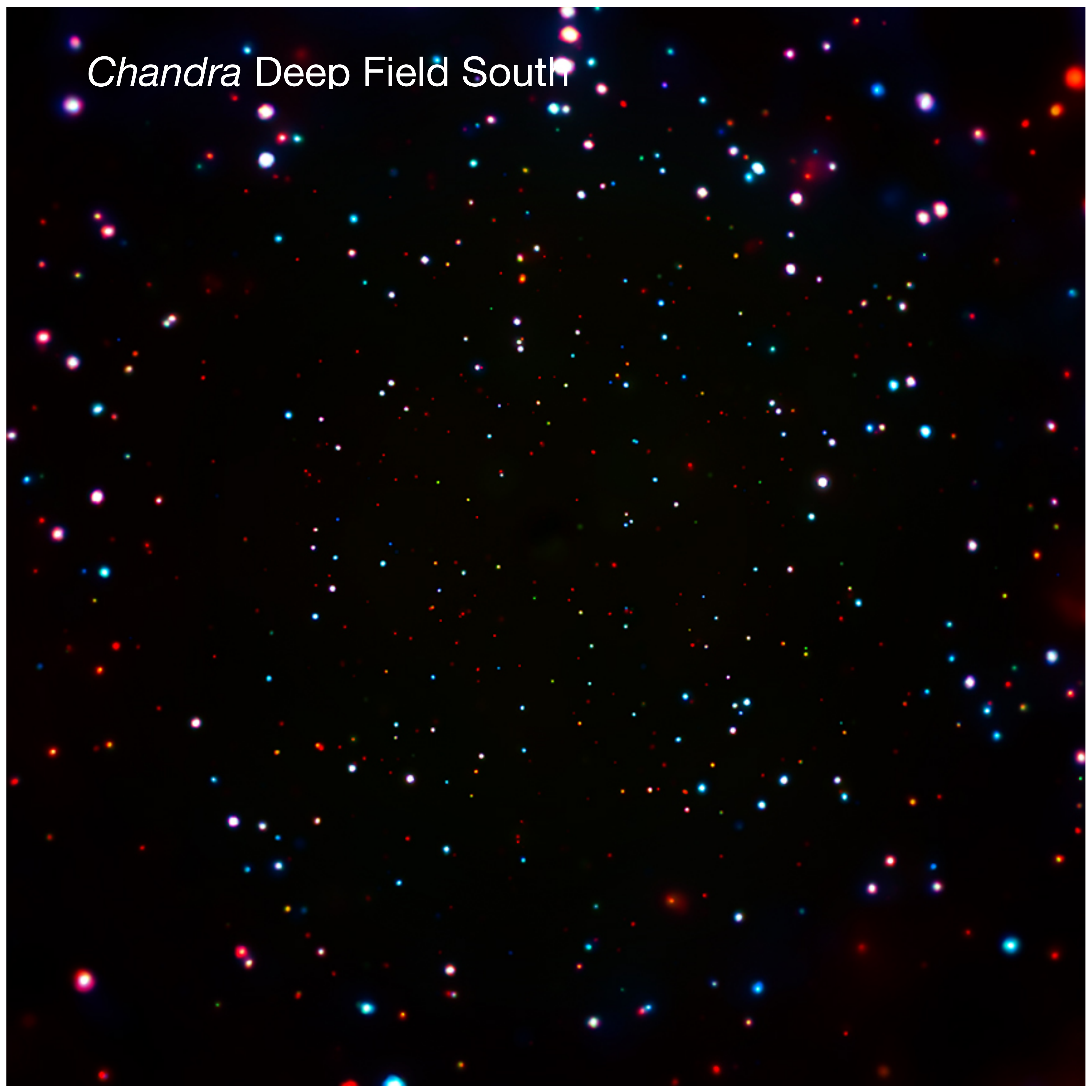
We have absolutely no idea **E**

Hubble Ultra Deep Field

Hubble Ultra Deep Field

Where are the growing **black holes**?

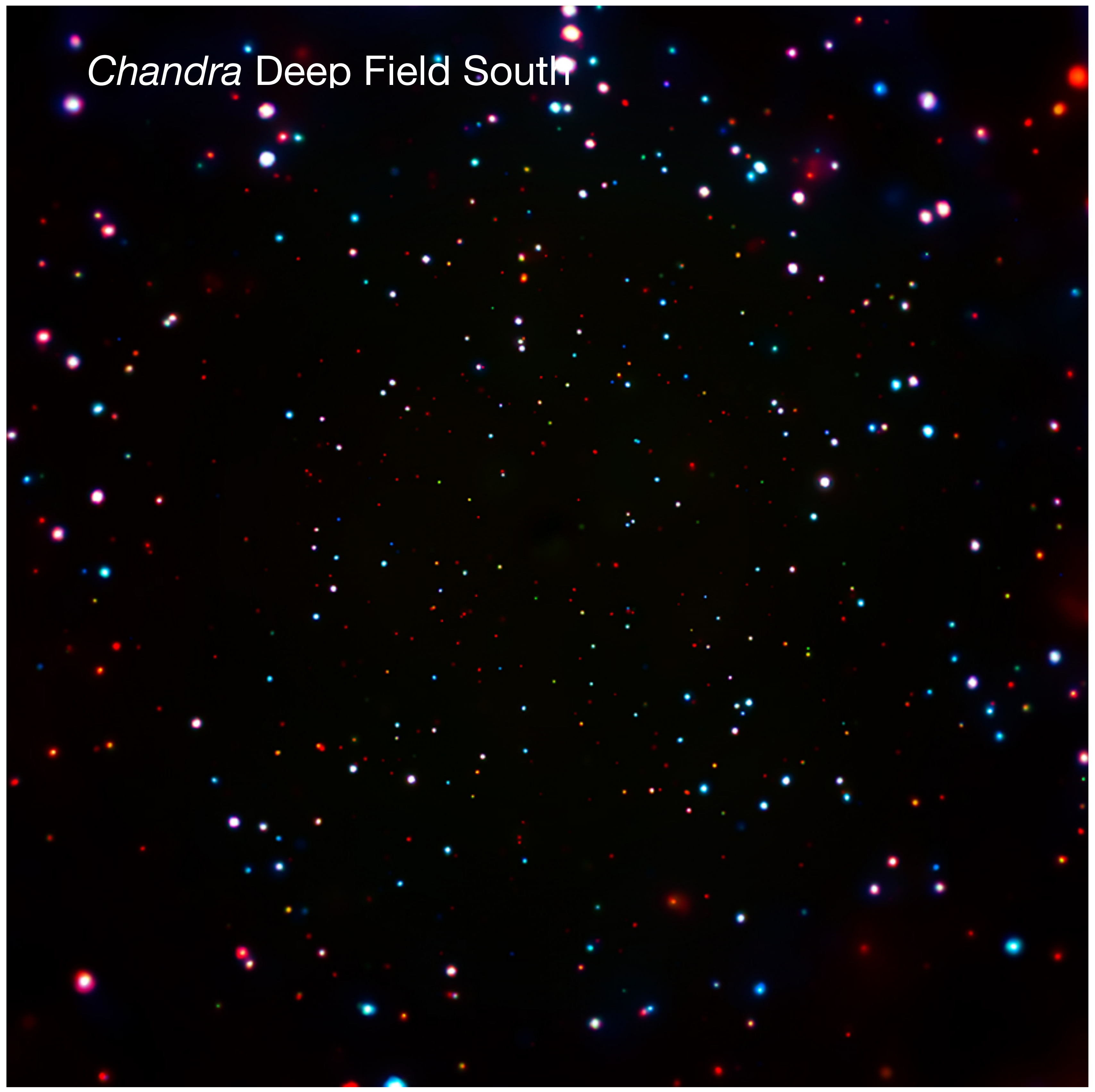
X-rays identify weak or obscured AGN that are not detectable in the UV/optical/IR



optical

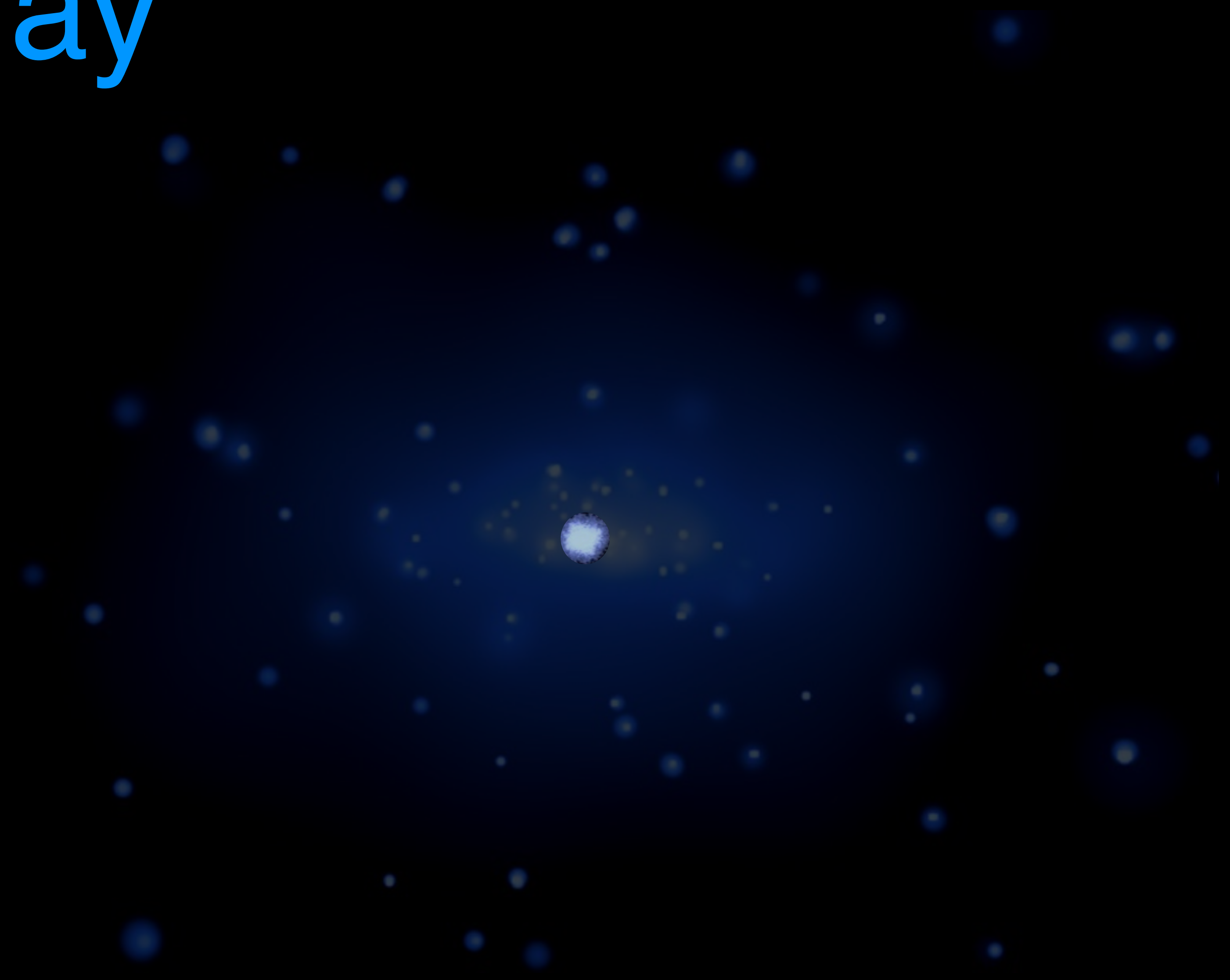
X-ray

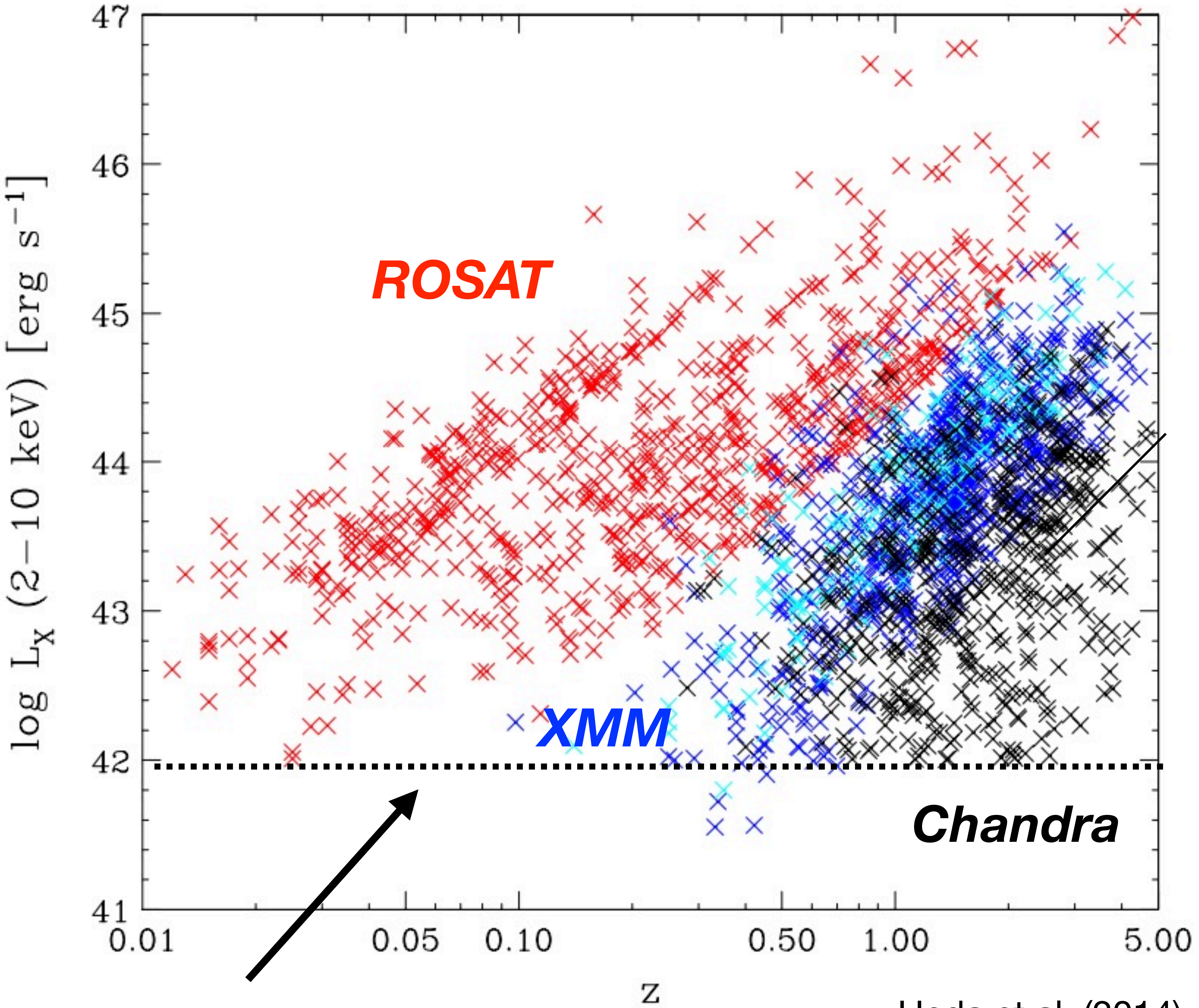
X-rays identify weak or obscured AGN that are not detectable in the UV/optical/IR



optical

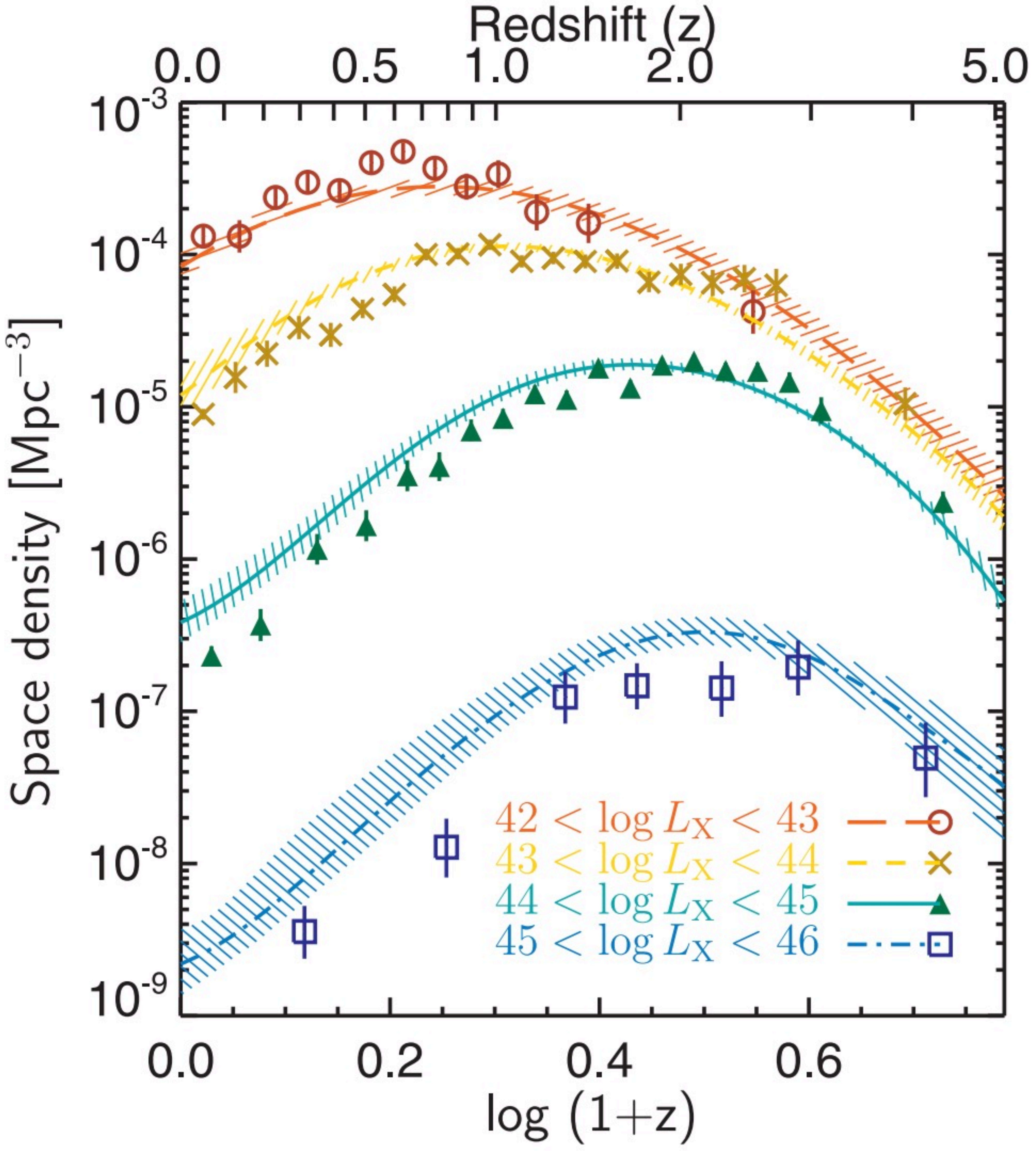
X-ray





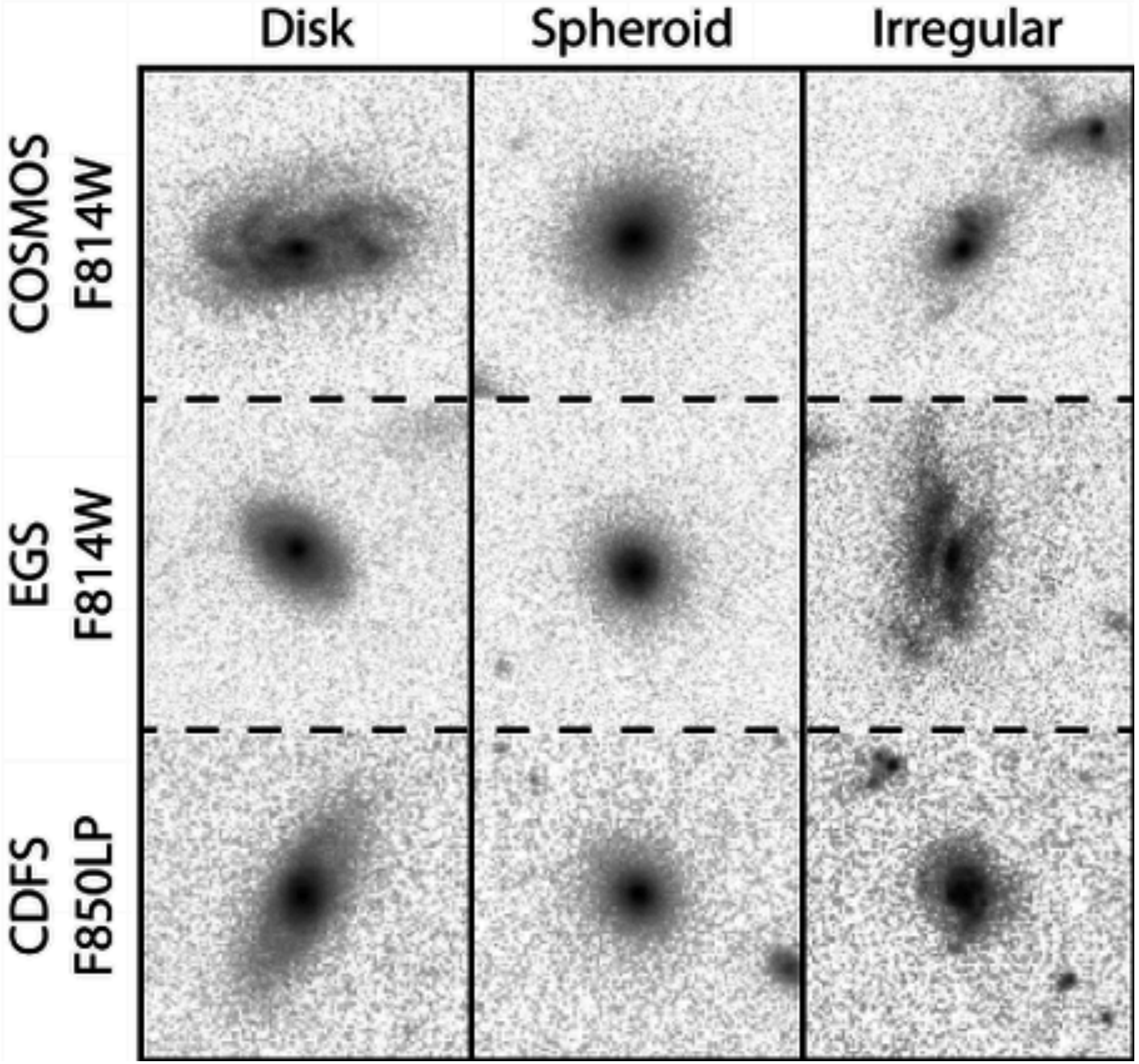
Ueda et al. (2014)

Eddington limit for ~10^6 $M_\odot$ black hole



Aird et al. (2015)

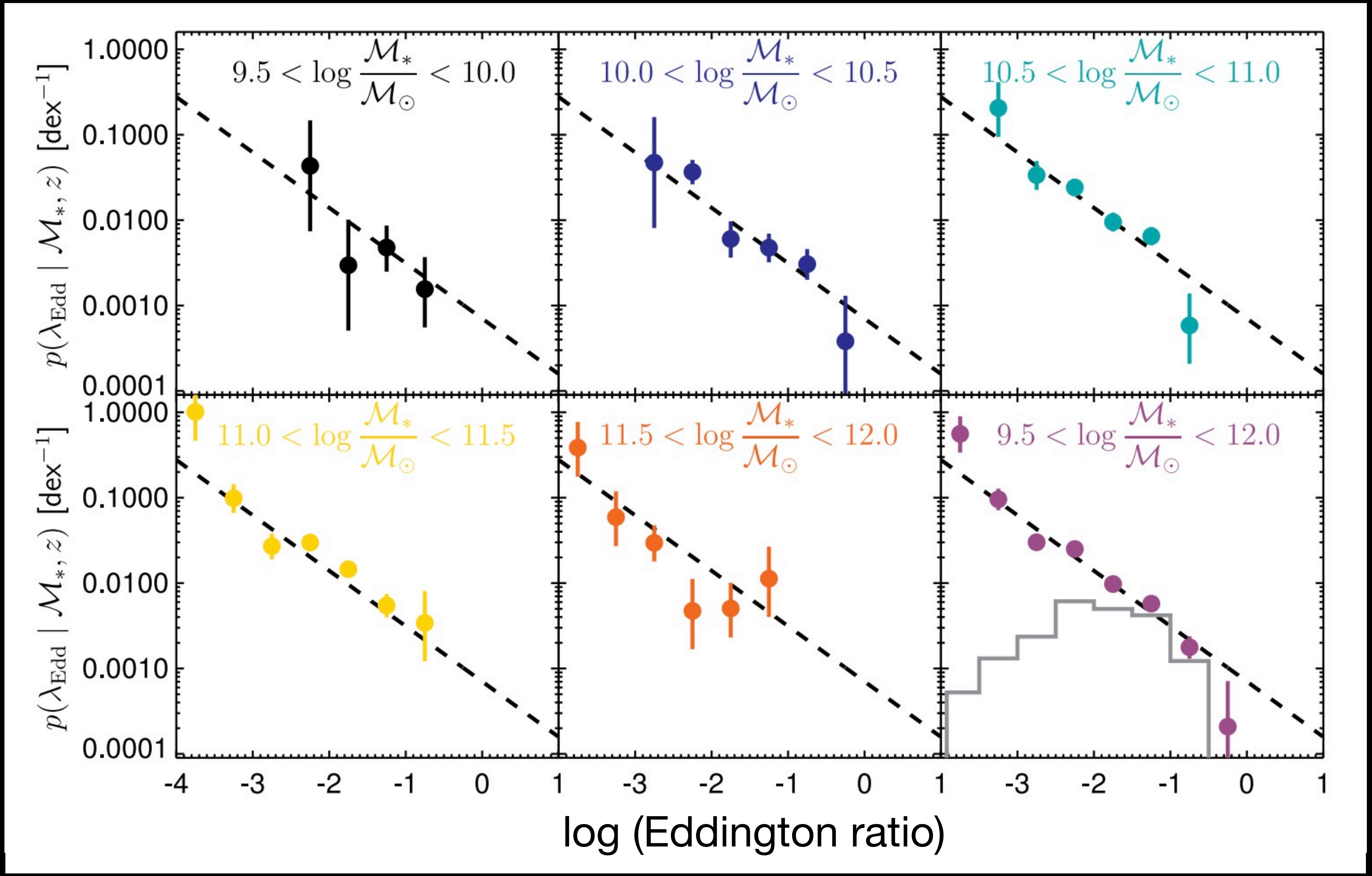
HST images of *Chandra* X-ray AGN hosts



Kocevski et al. (2012)

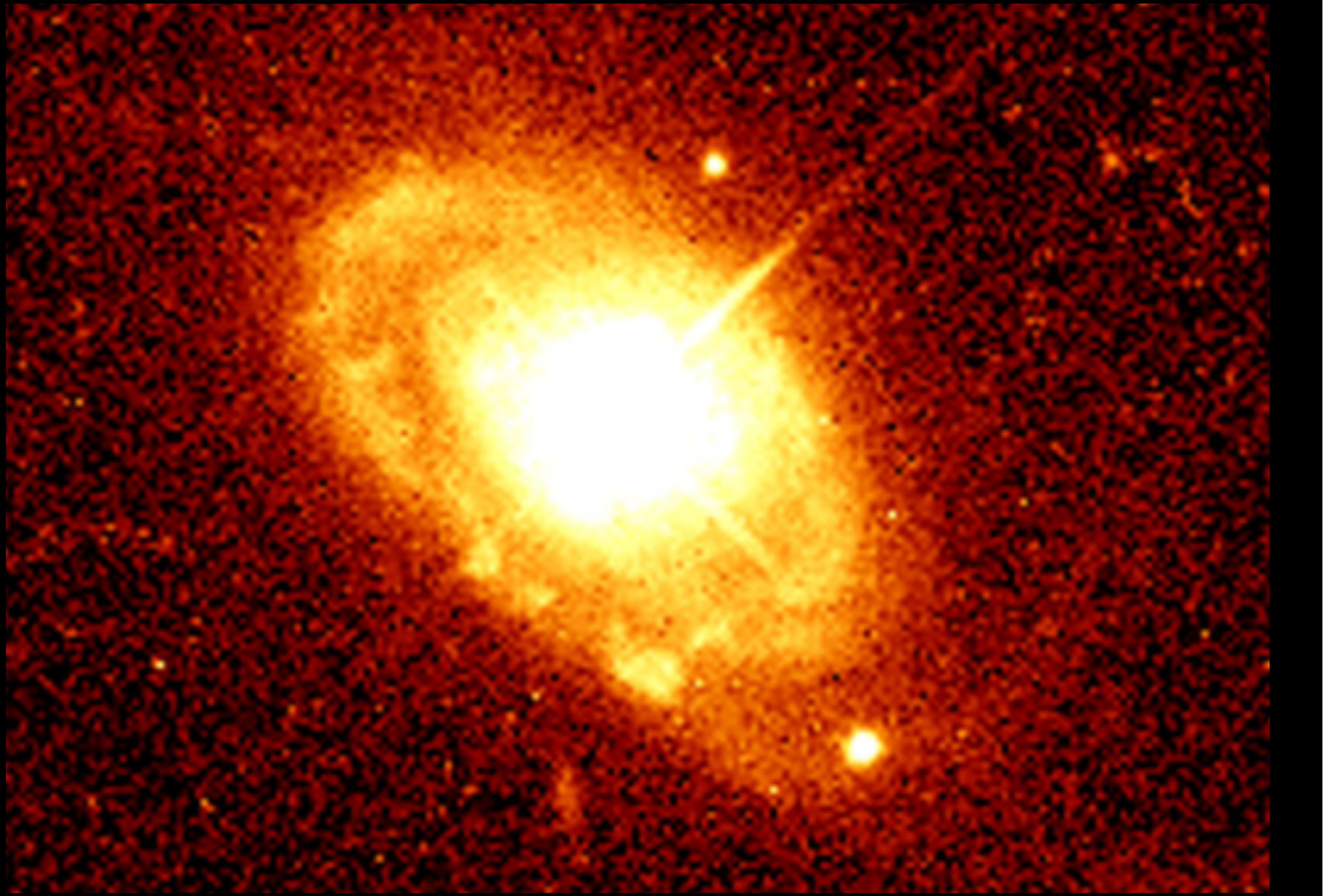
X-ray selected AGN are found in **all kinds of galaxies**

Hickox et al. (2014), Schawinski et al. (2015), Jones et al. (2016, 2018, 2019)

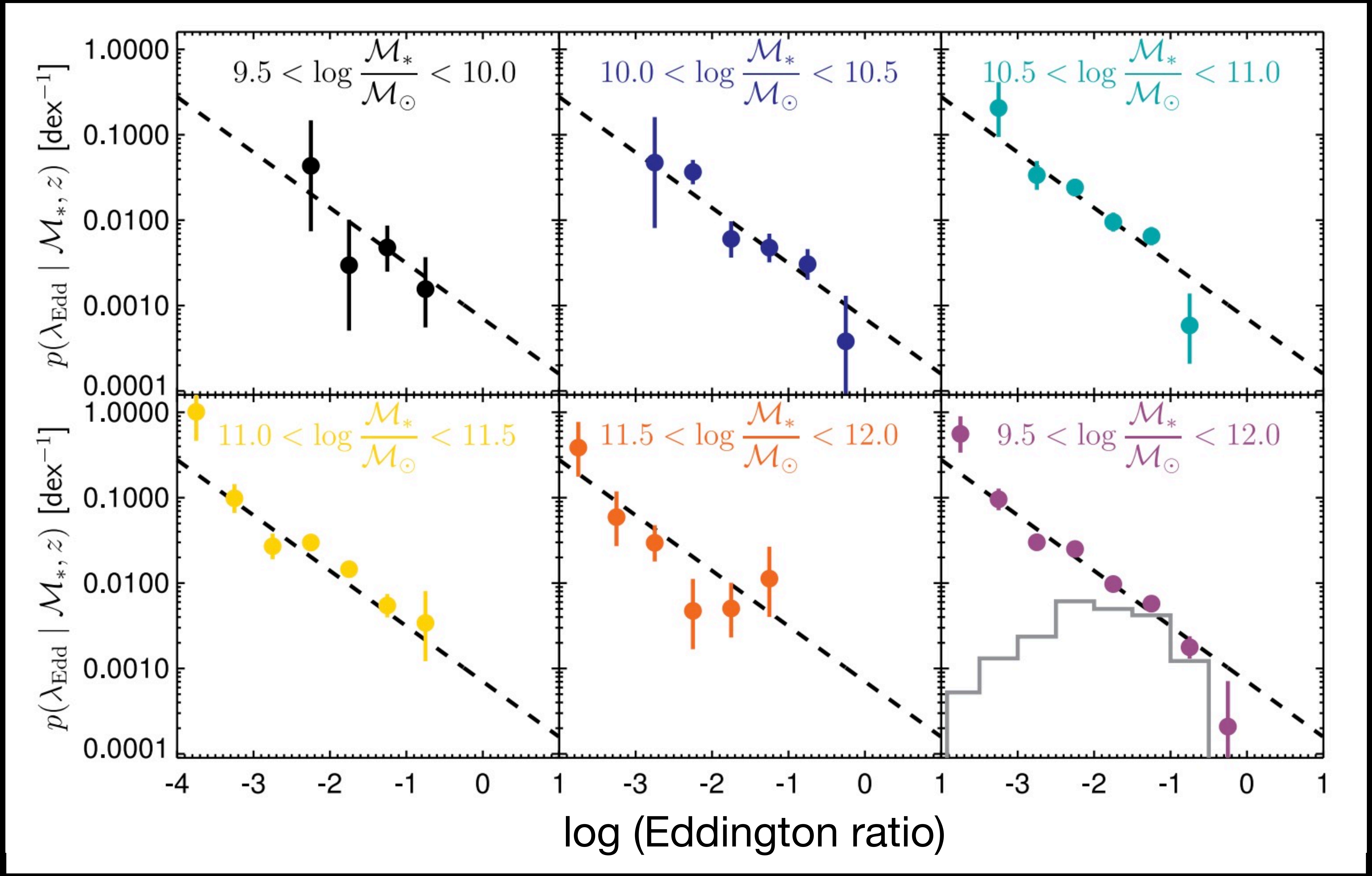


Aird et al. (2012)

AGN “flicker” over a wide dynamic range in Eddington ratio



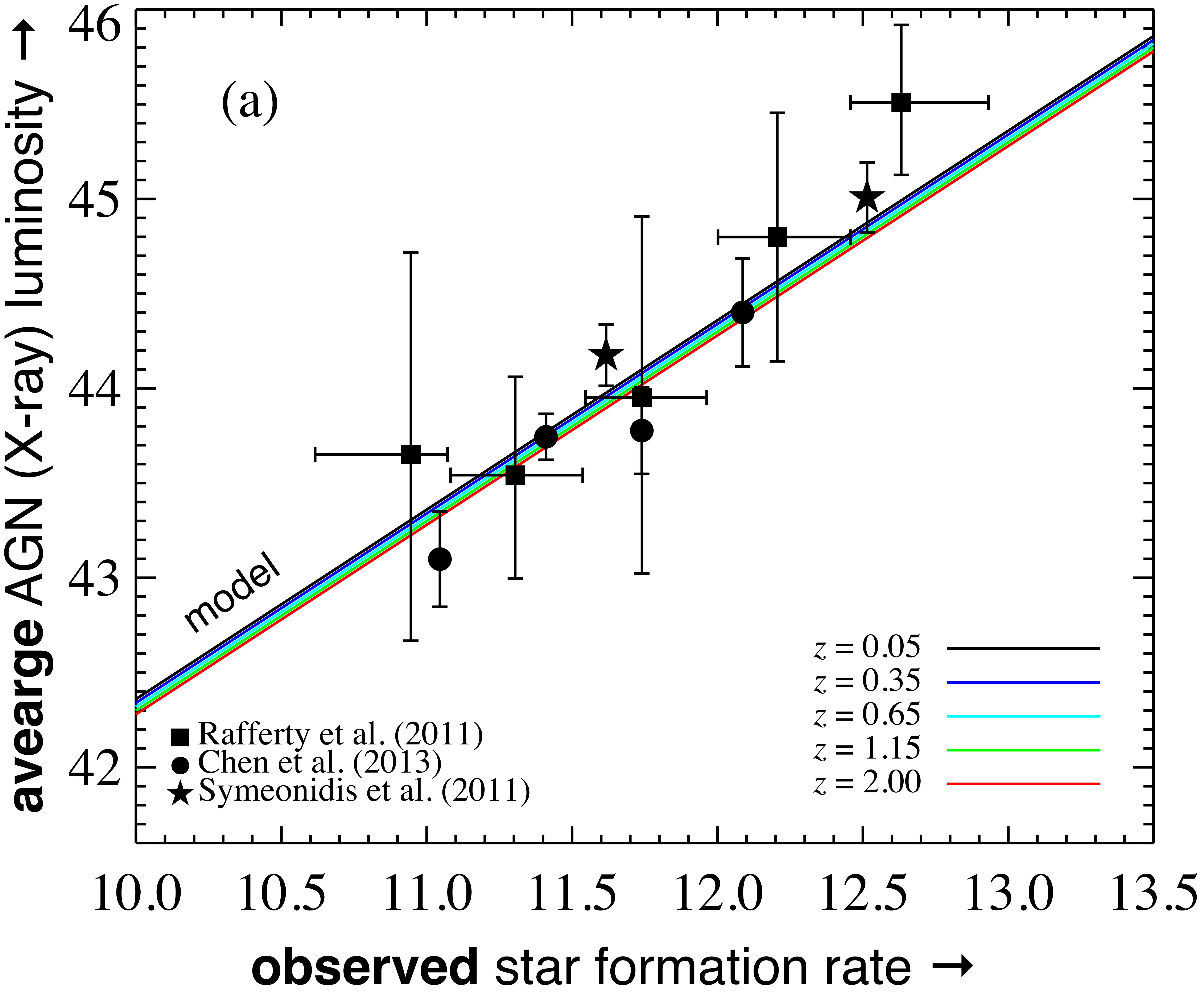
Hickox et al. (2014), Schawinski et al. (2015), Jones et al. (2016, 2018, 2019)



Aird et al. (2012)

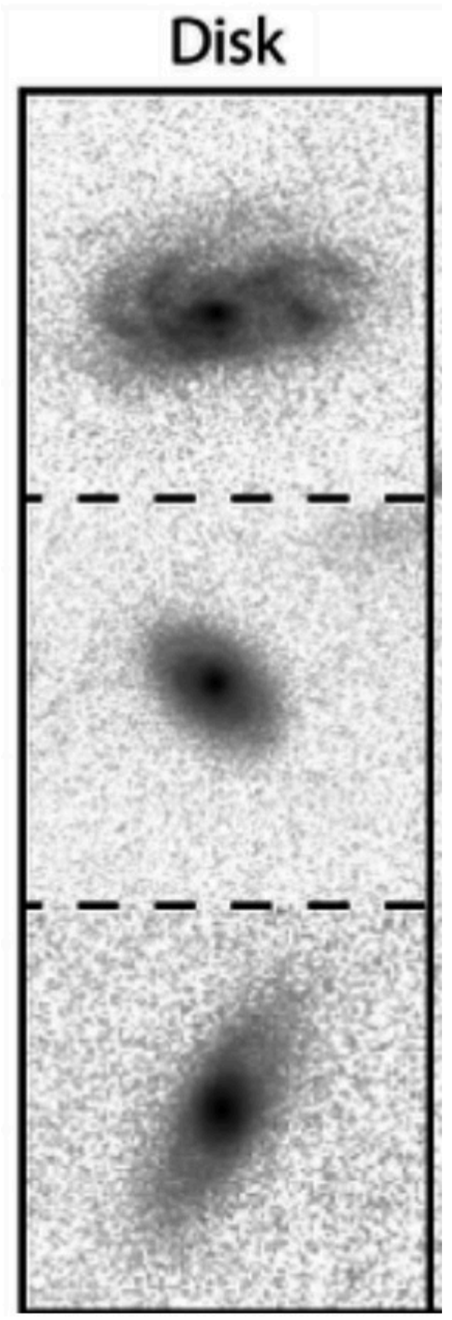
AGN “flicker” over a wide dynamic range in Eddington ratio

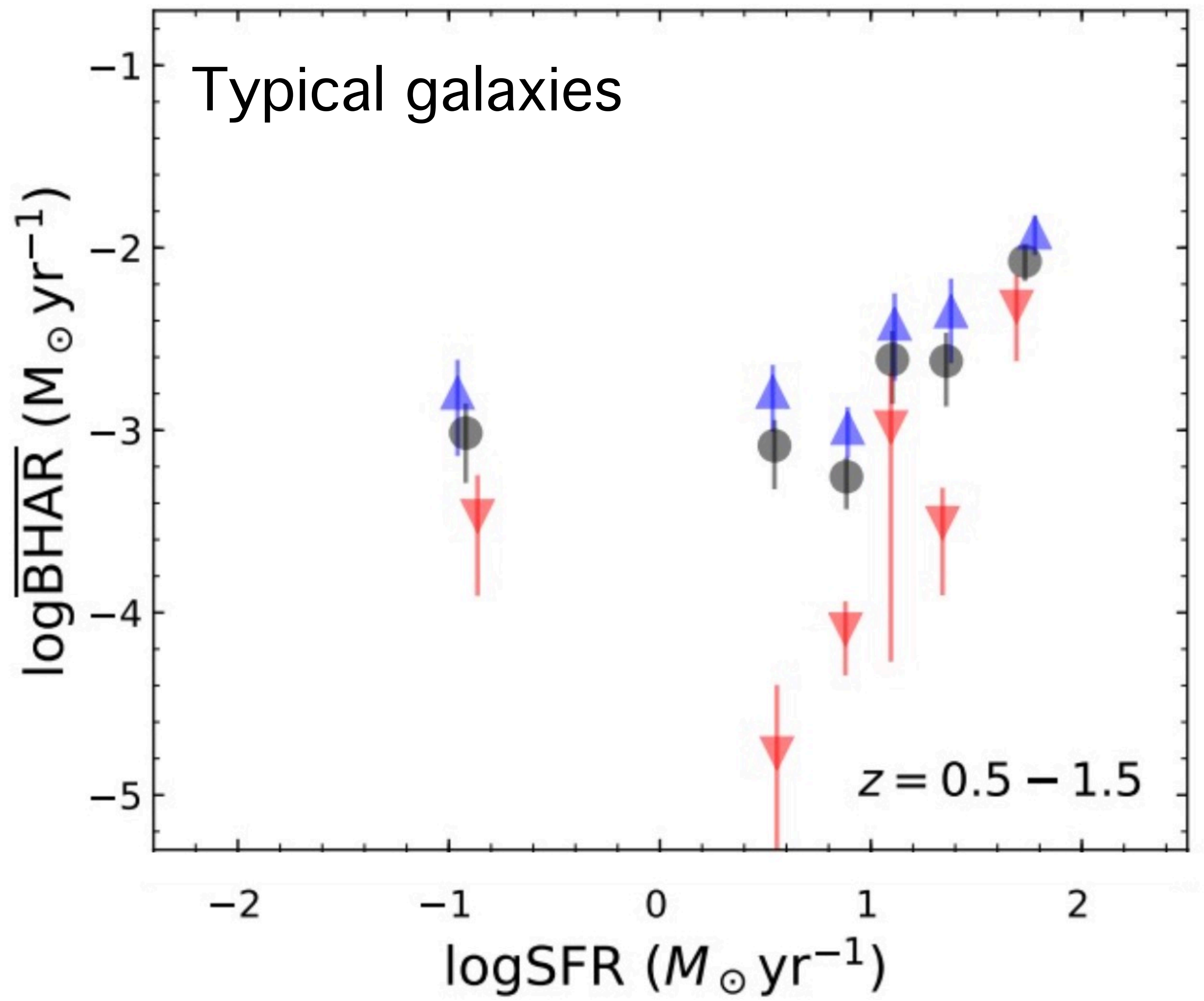
On average, **black hole growth follows star formation** in galaxies

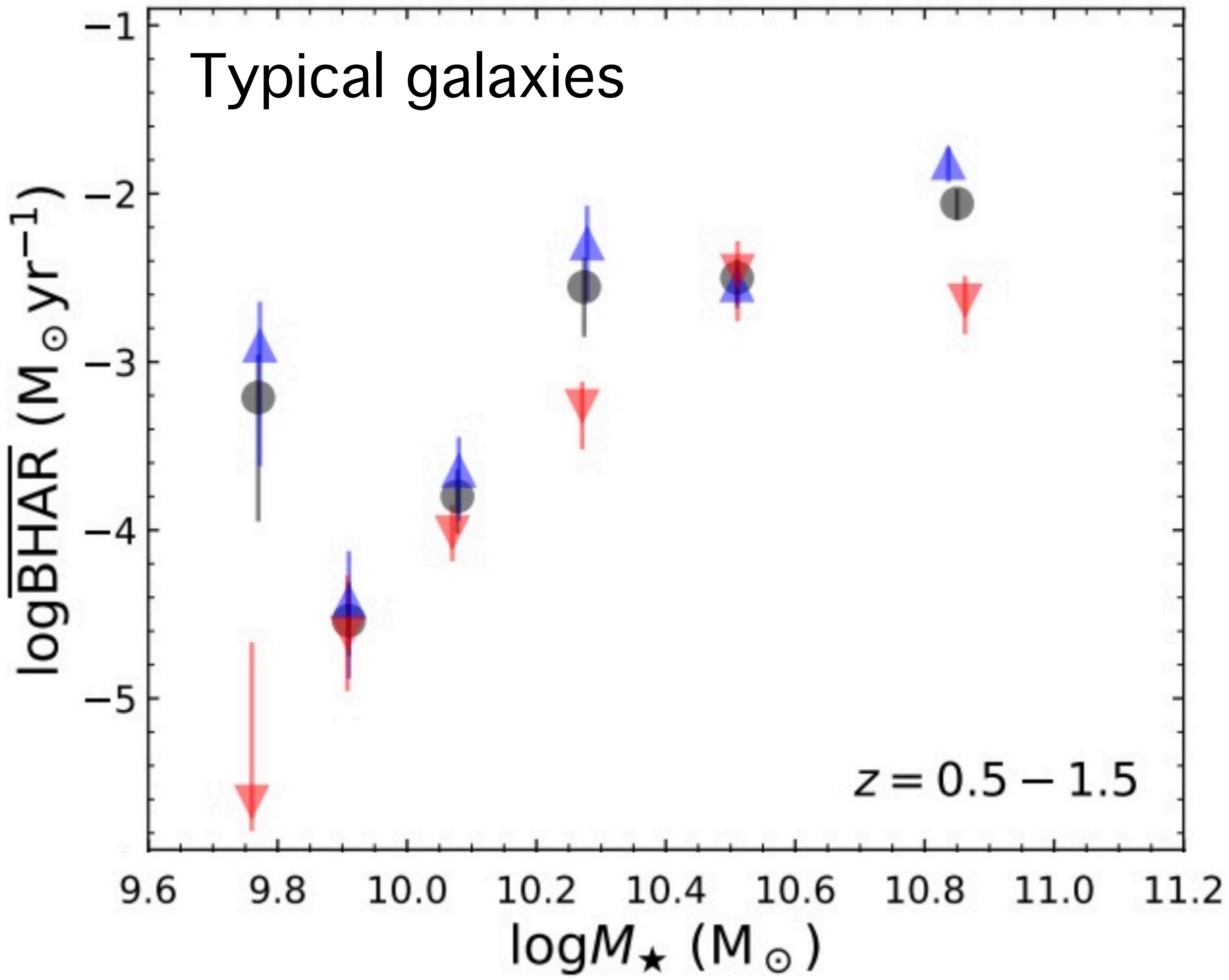


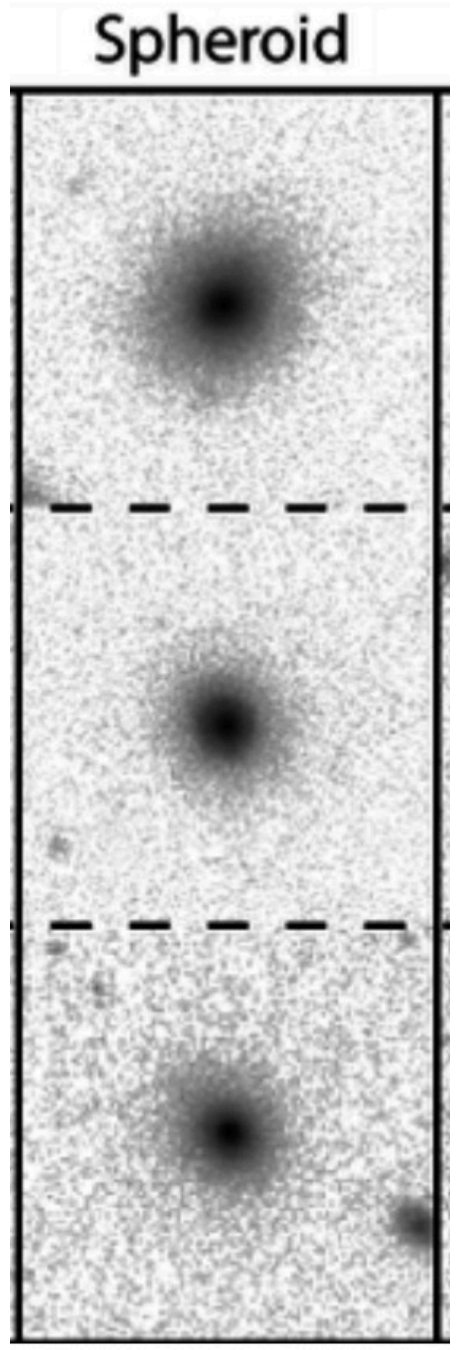
Chen et al. (2013)

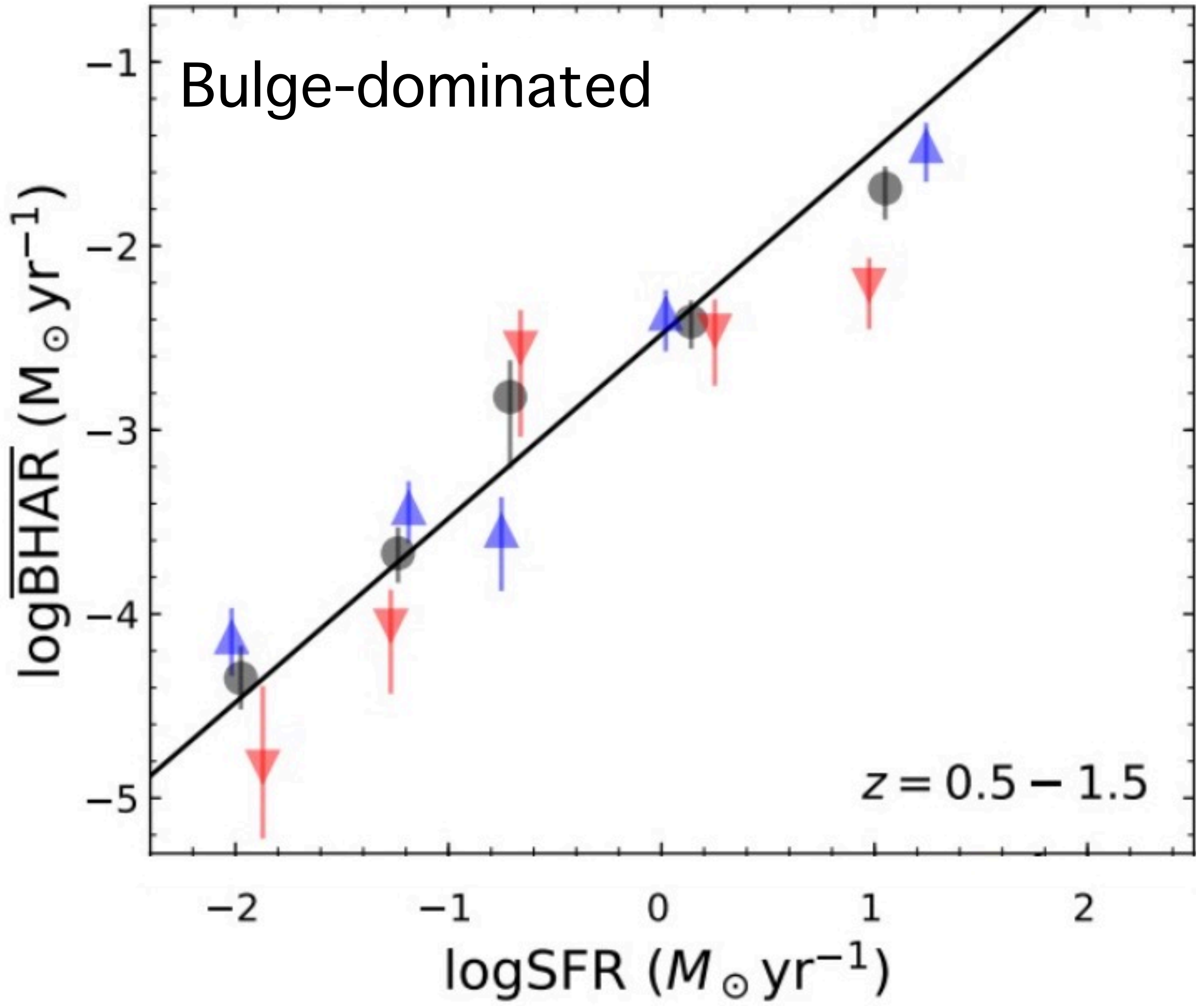
Hickox et al. (2014)

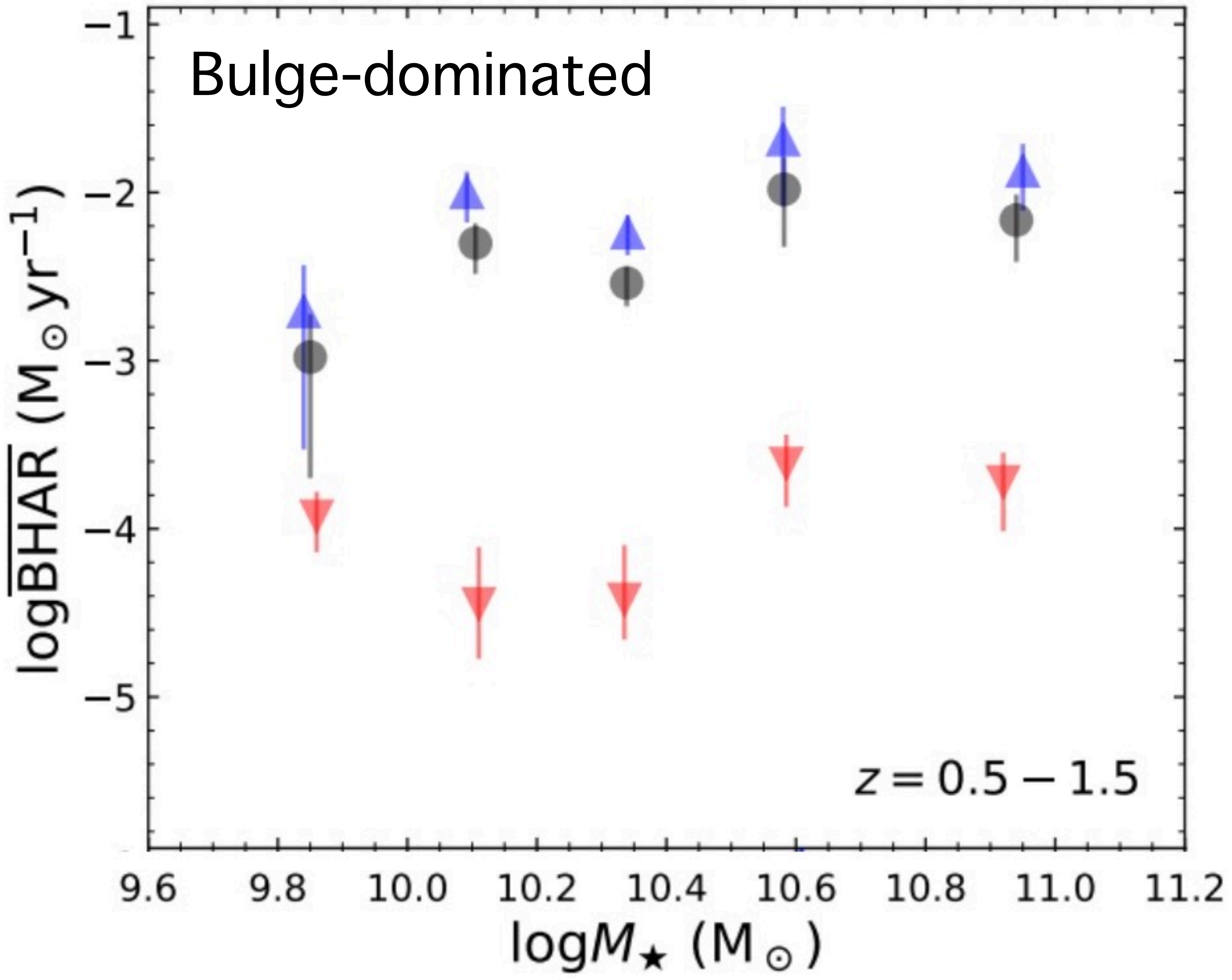






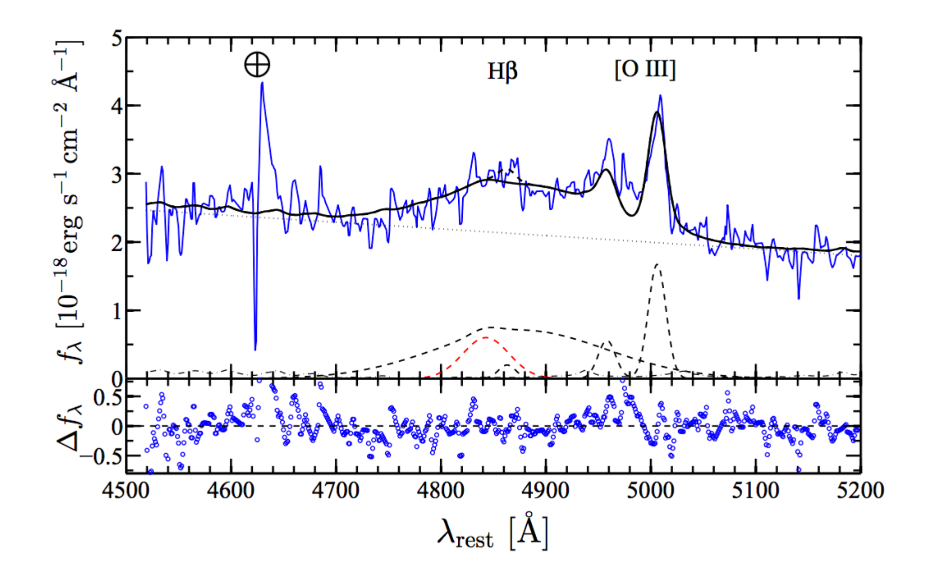




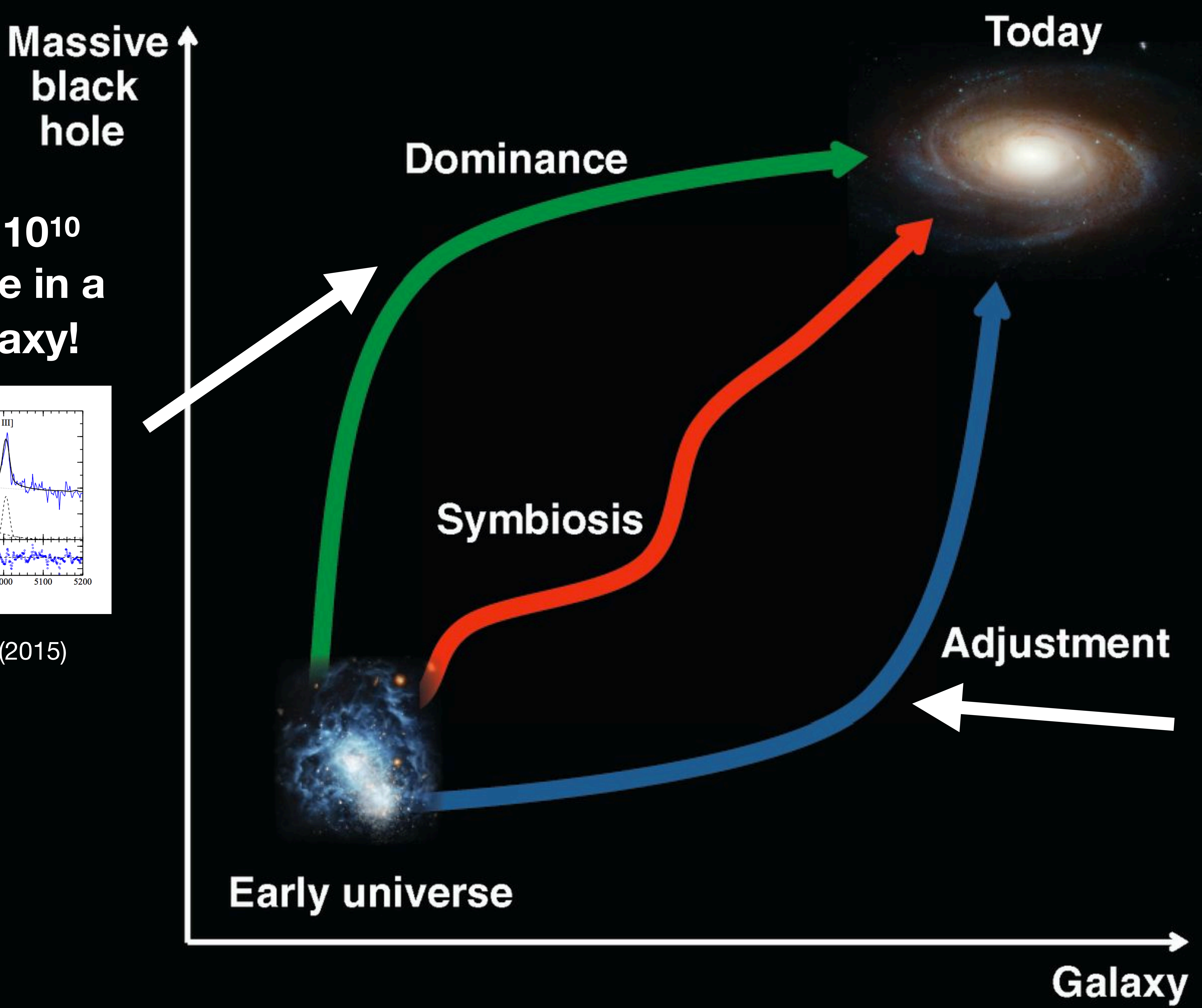


Yang et al.
(2019)

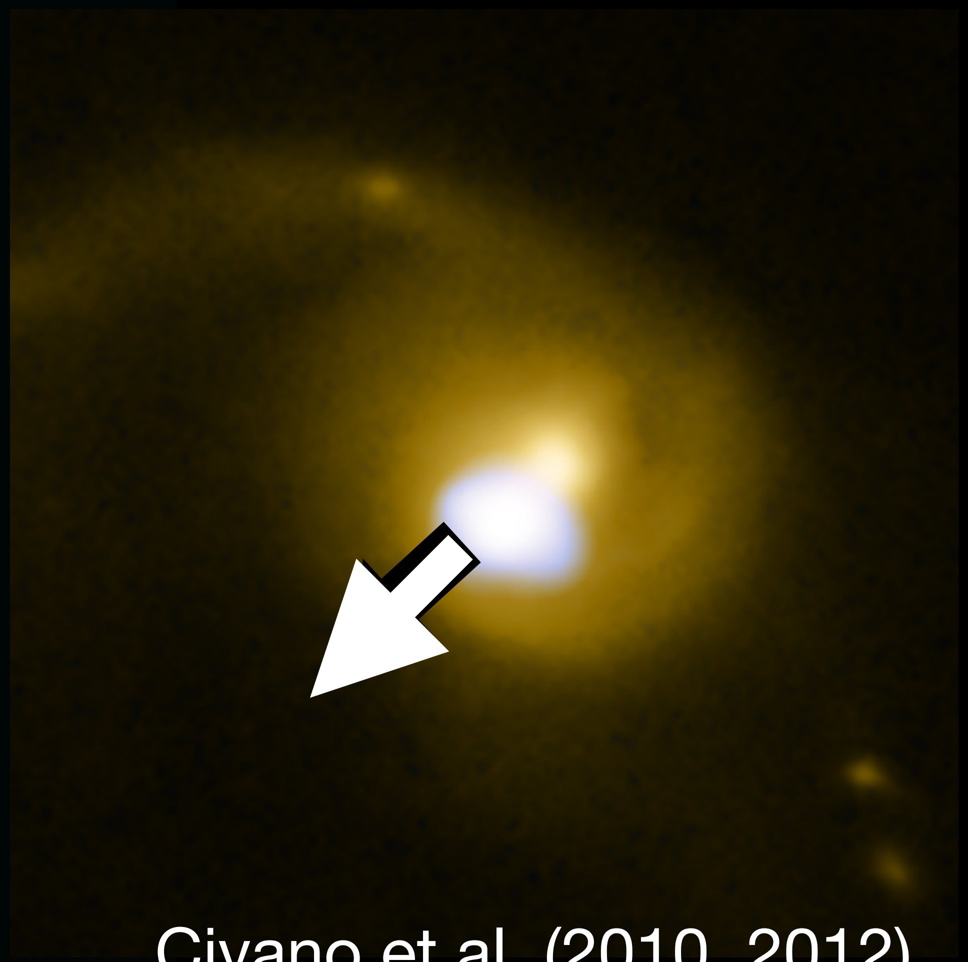
CID-947: A 10^{10} $M_\odot$ black hole in a 10^{11} $M_\odot$ galaxy!



Trakthenbrot et al. (2015)



CID-42: A black hole that has left its galaxy?



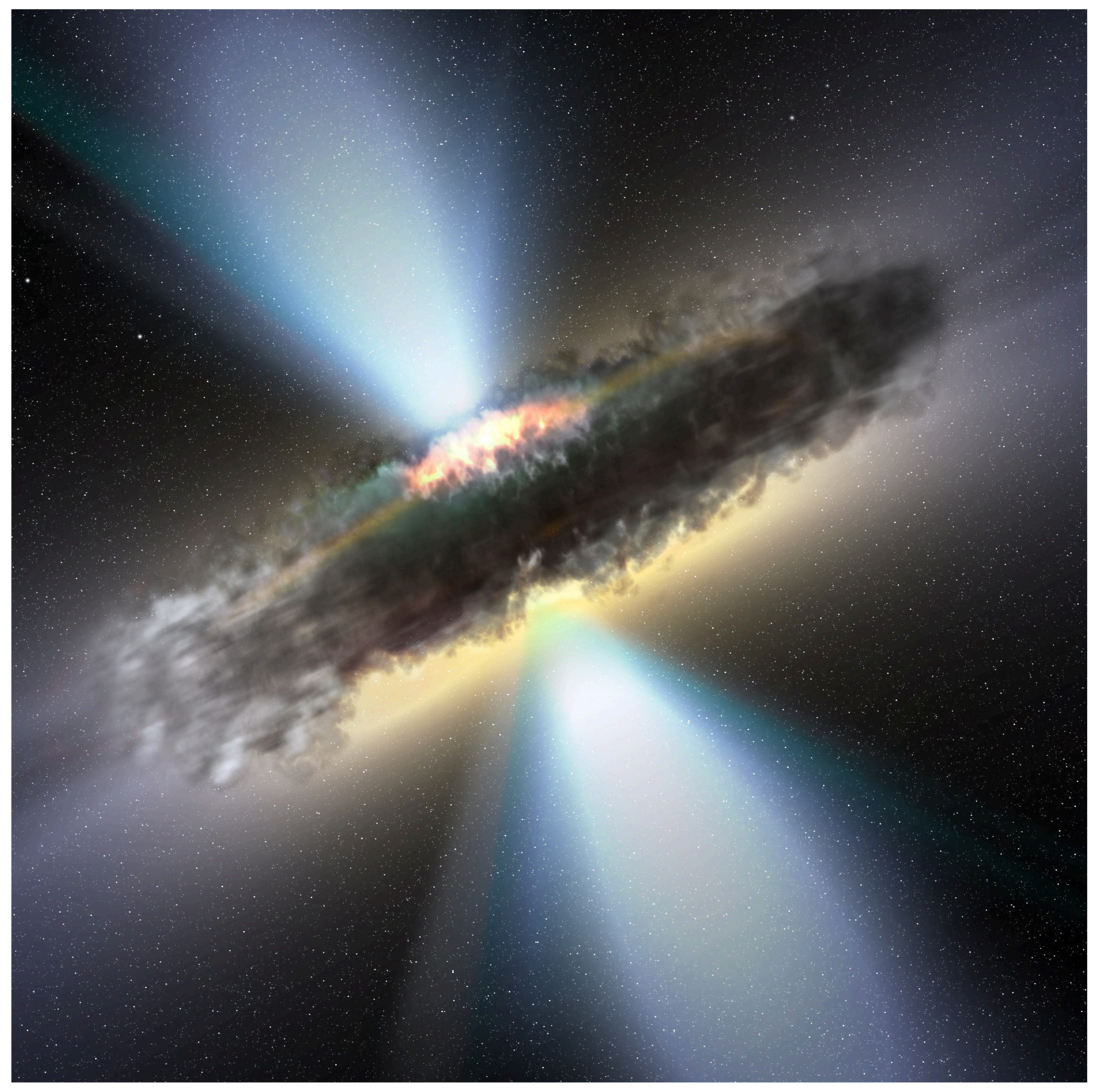
Civano et al. (2010, 2012)

brighter

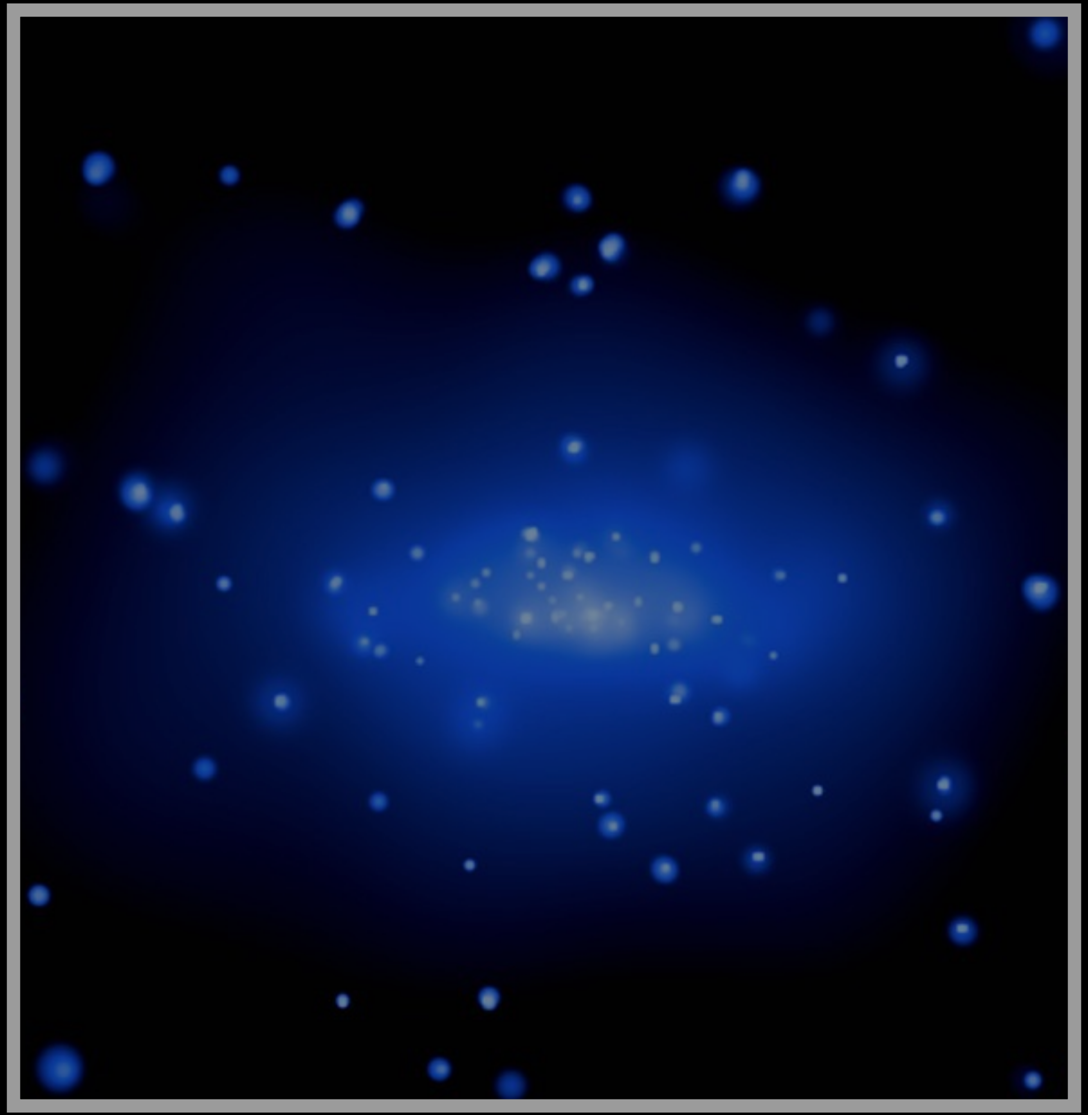
fainter

Evolution of black holes and galaxies

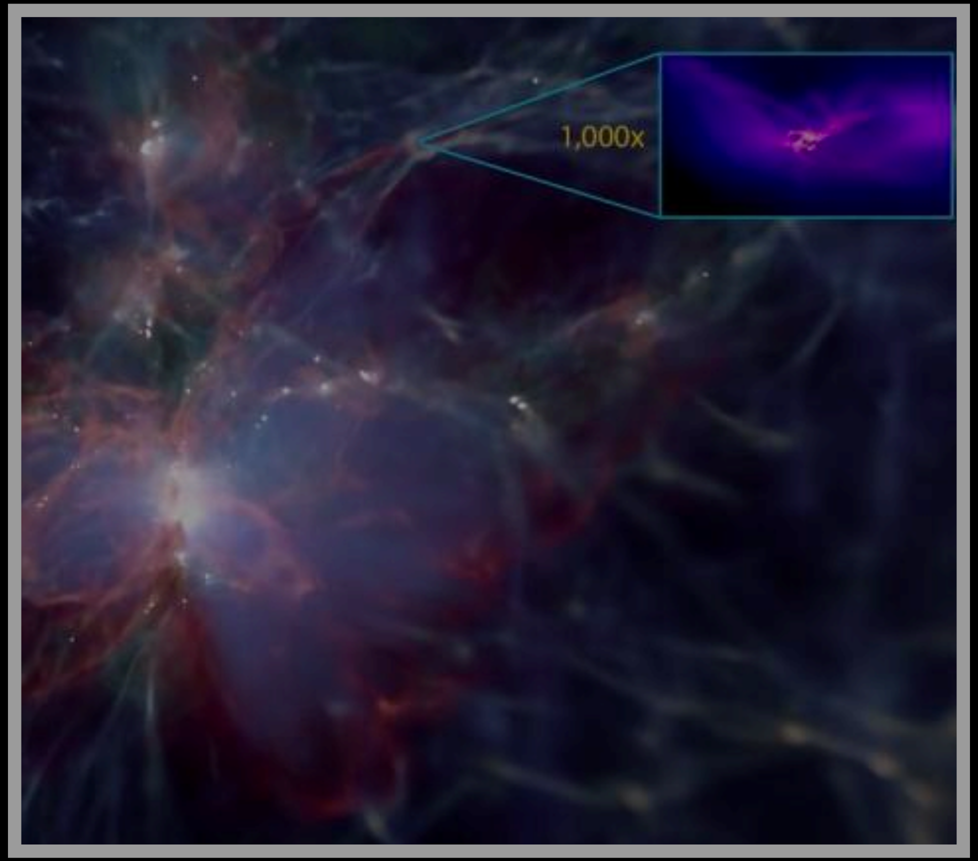
Unveiling hidden black holes



The realm of “normal” galaxies

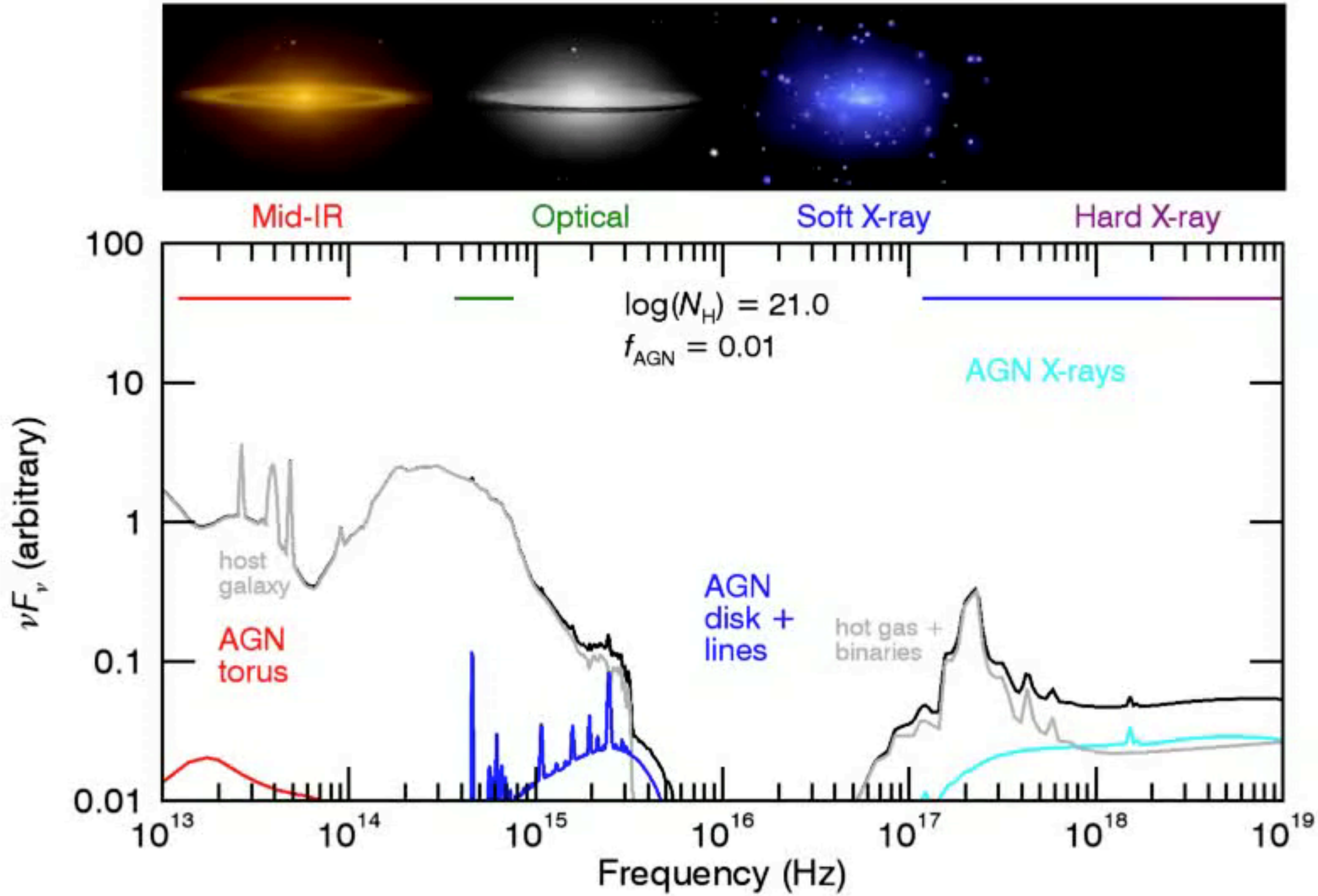


Black holes in the early Universe



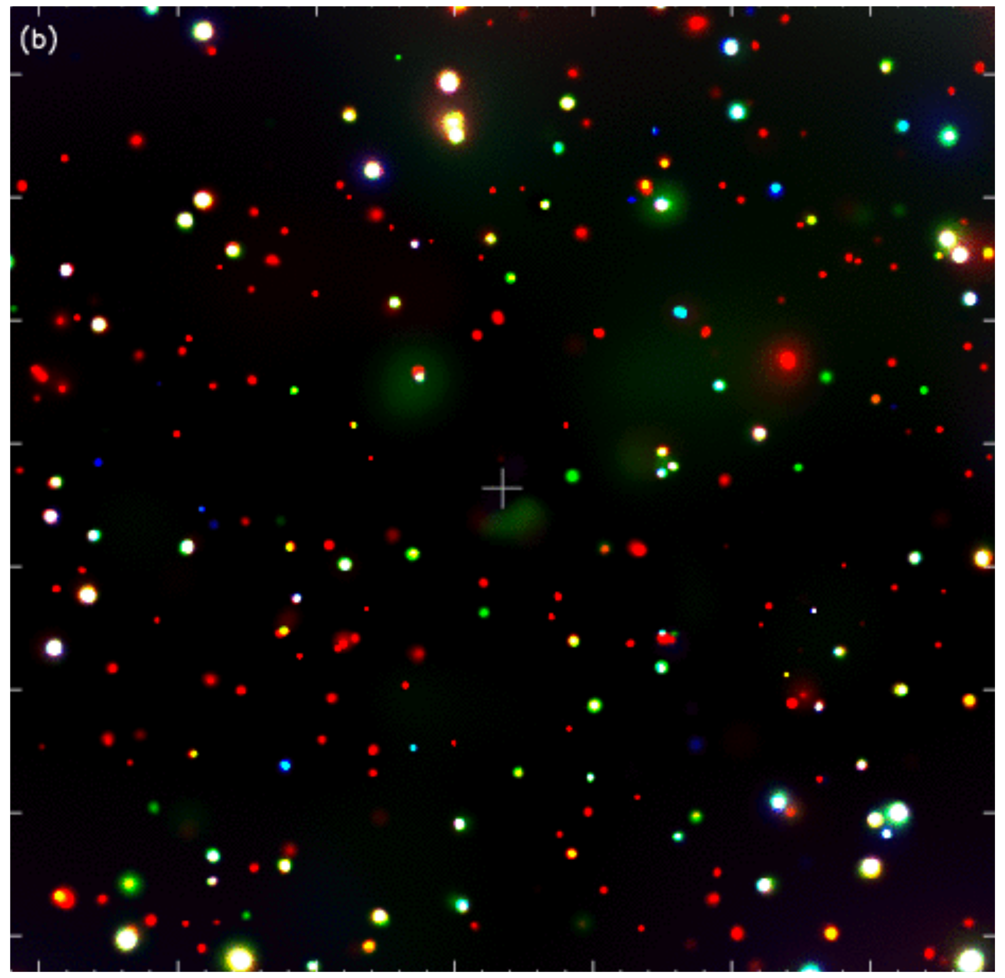
Composite AGN and galaxy SEDs and images
for varying AGN dominance and obscuration

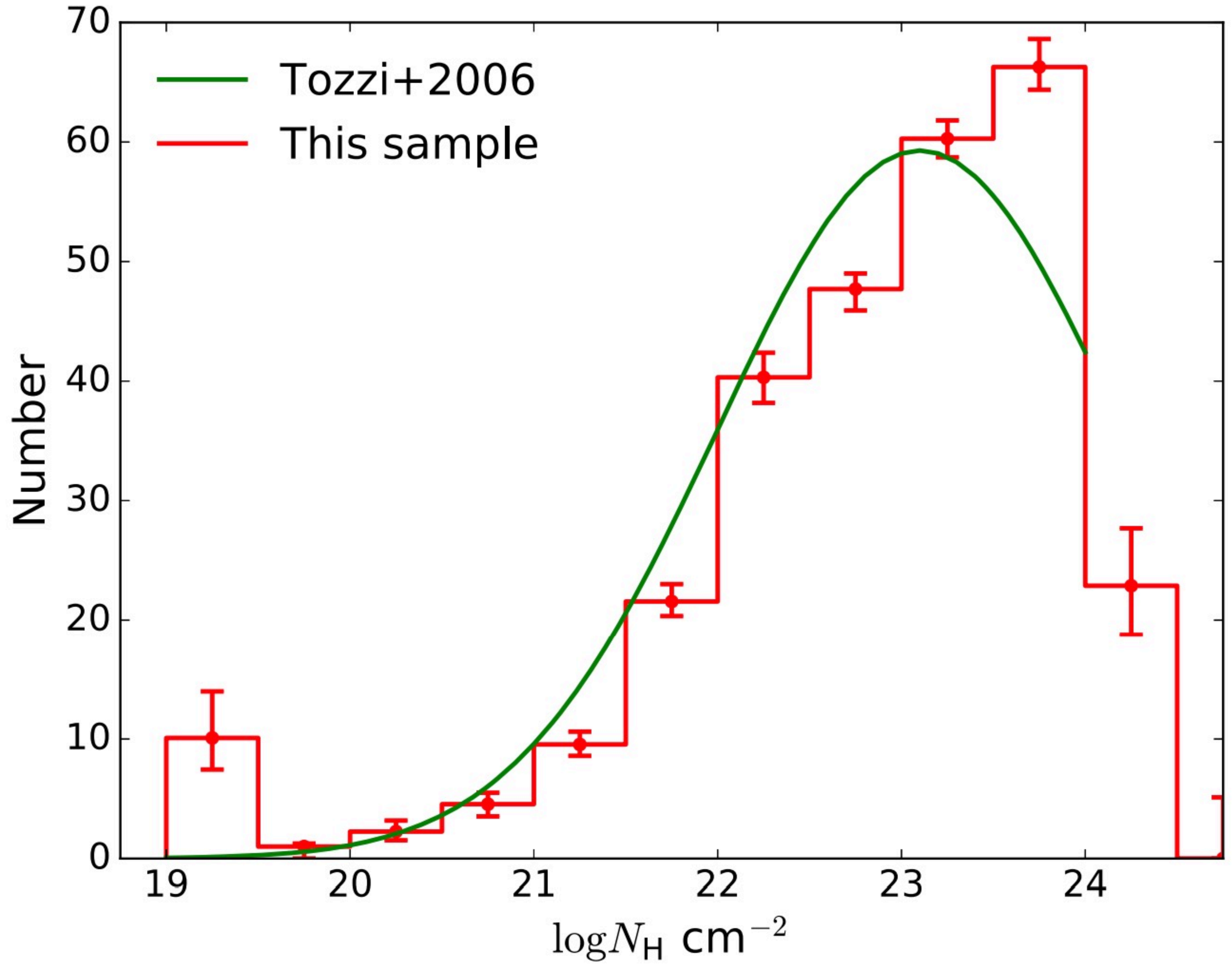
Hickox & Alexander (2018)
"Obscured Active Galactic Nuclei"
ARA&A, Volume 56

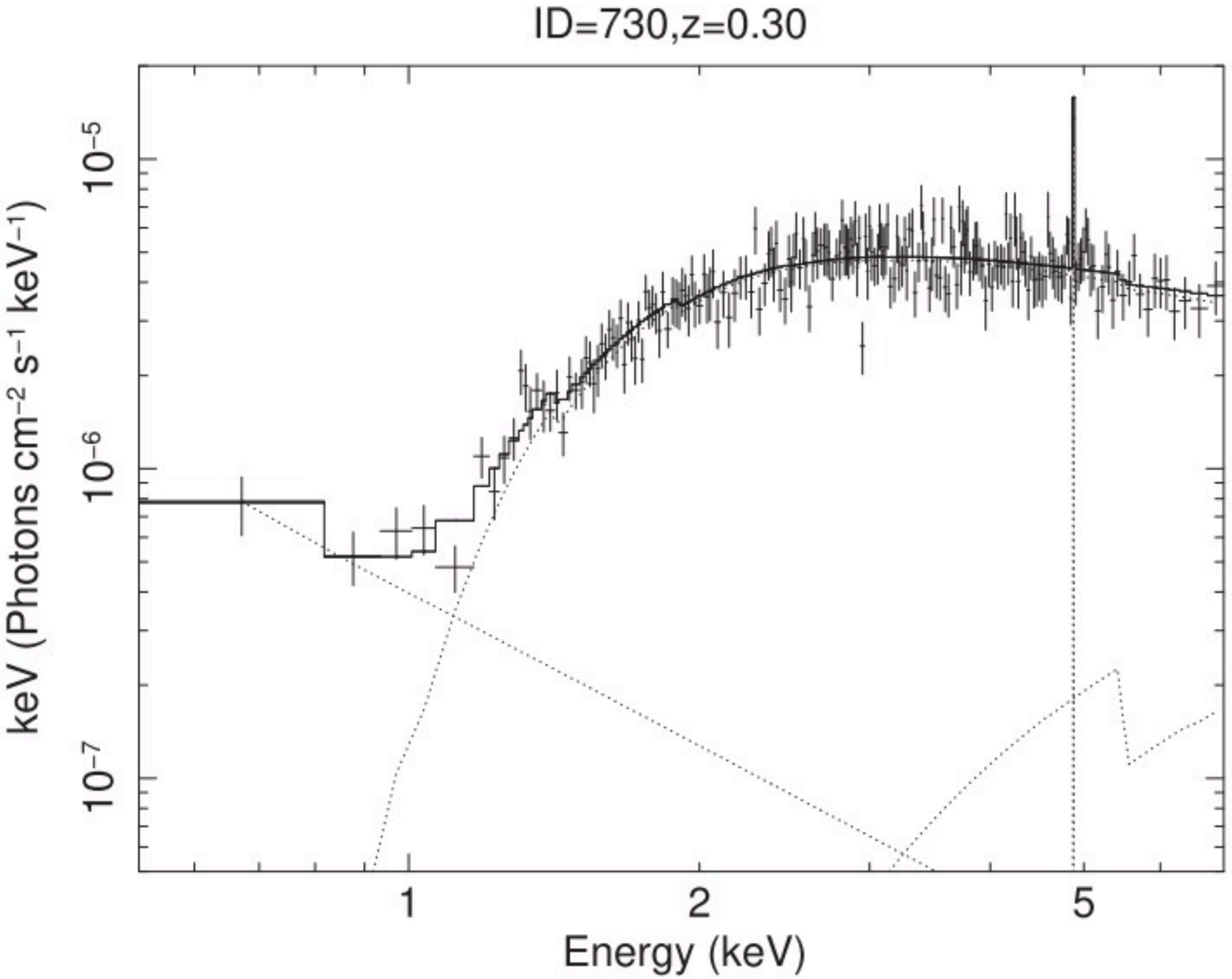


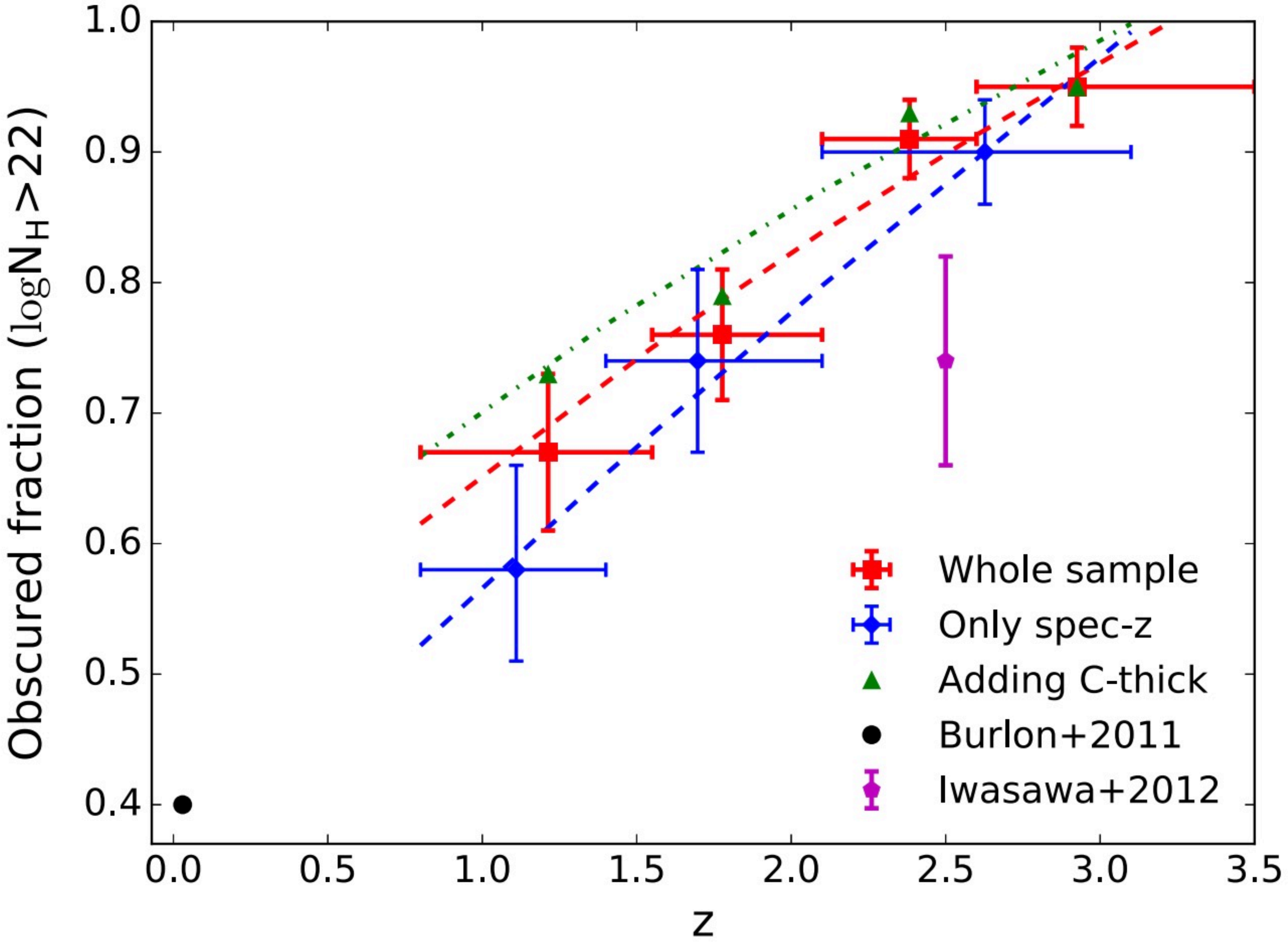
Direct constraints on obscuration from deep *Chandra* spectra

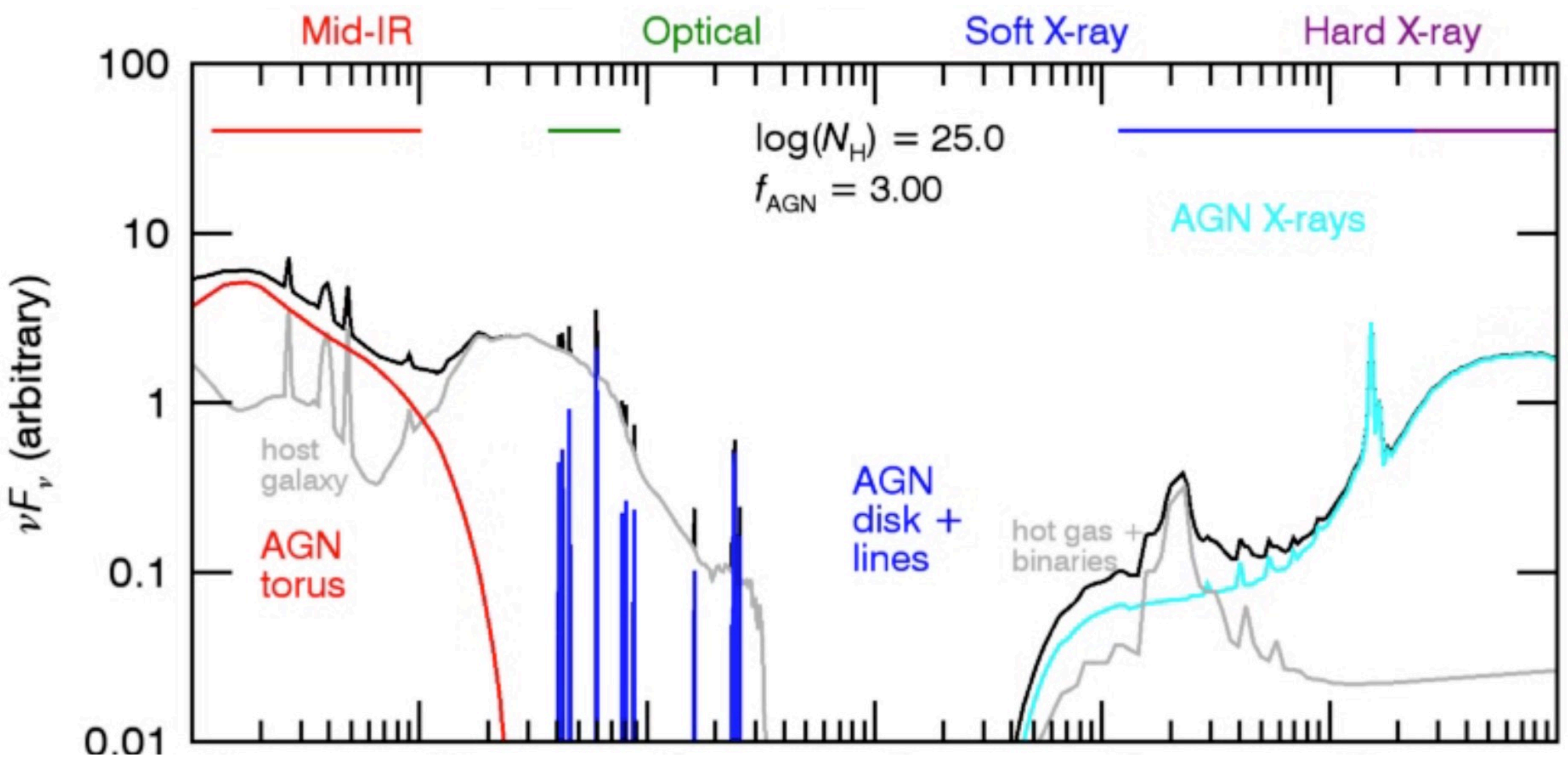
(Liu et al. 2017)

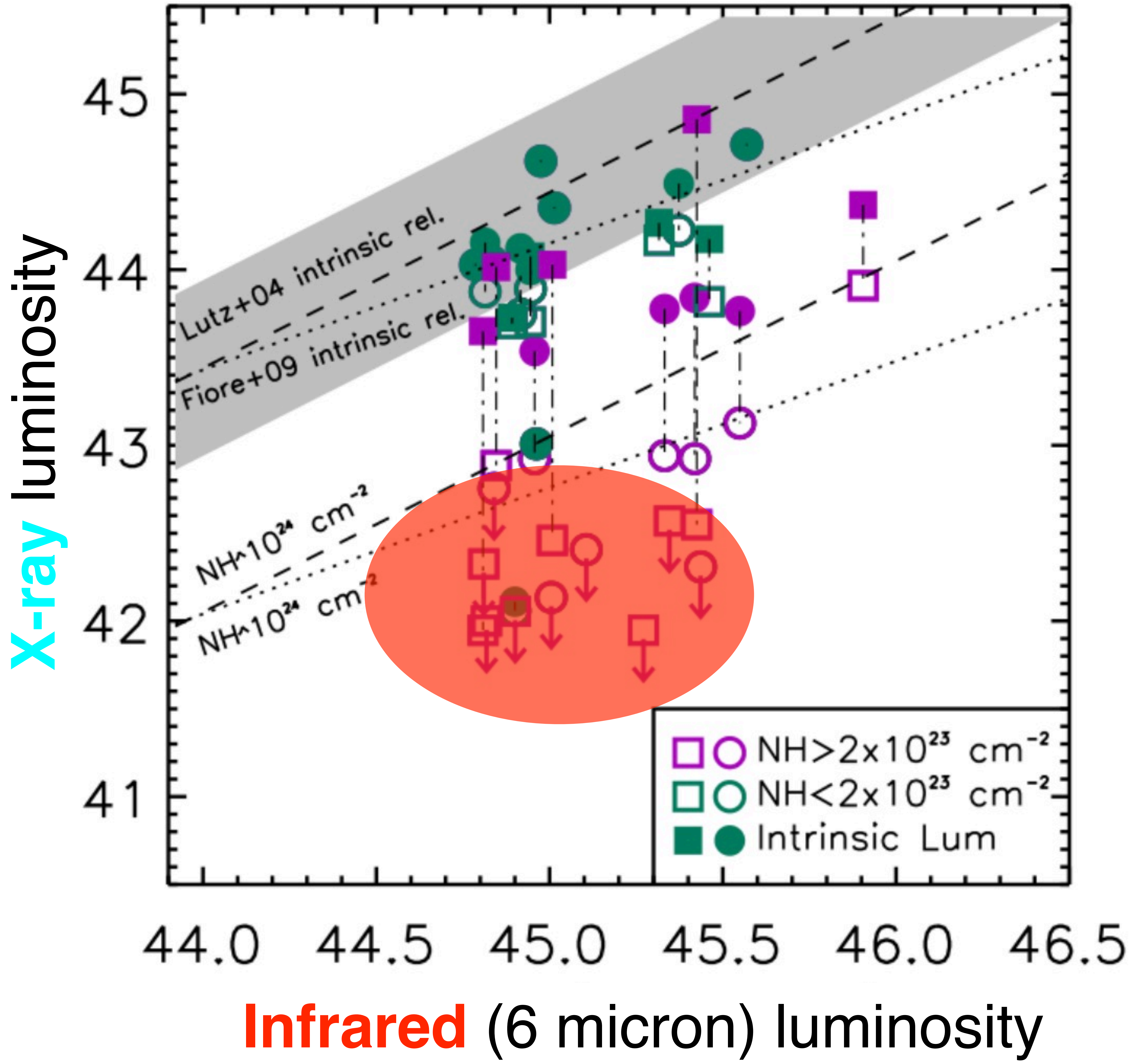








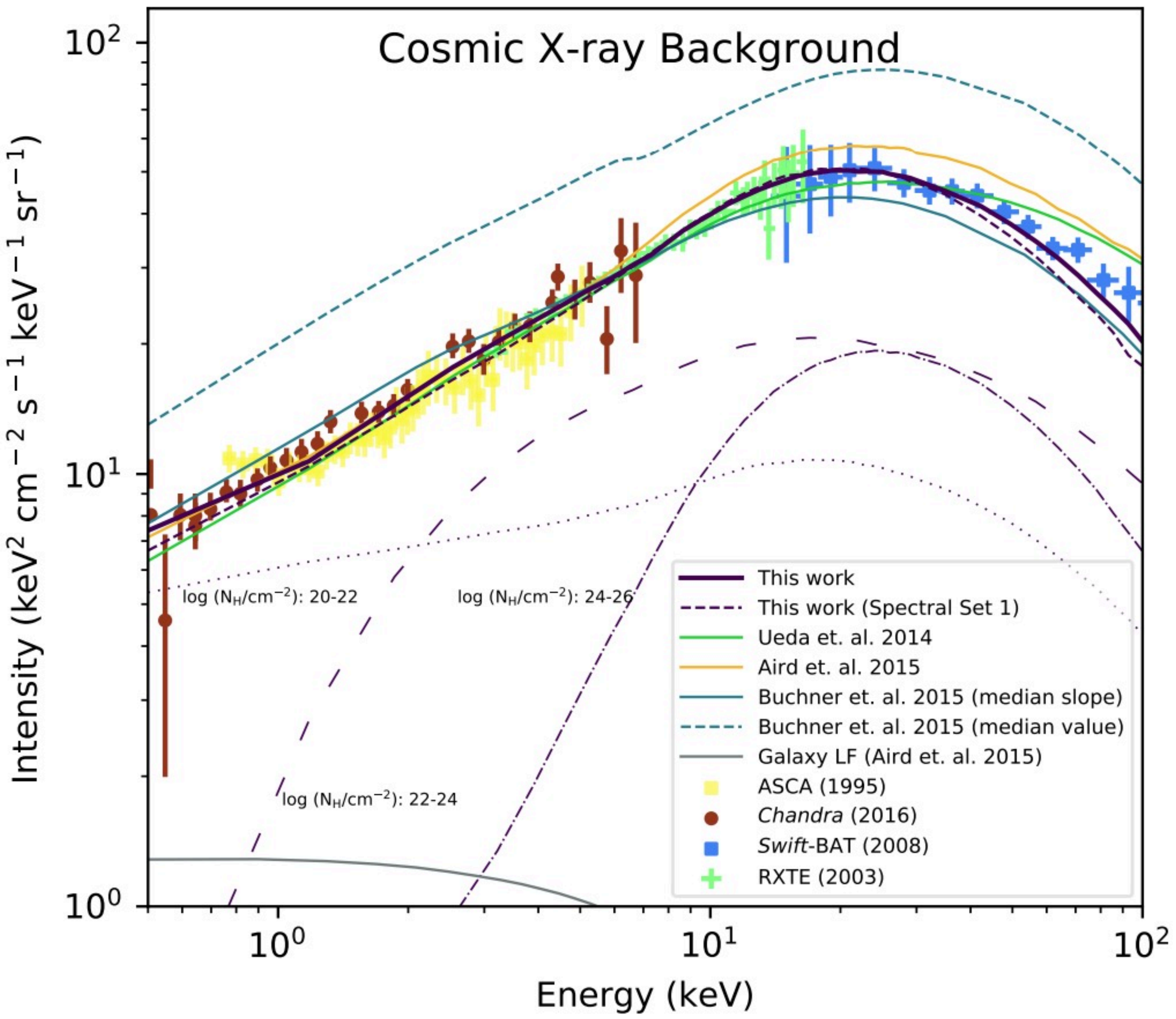




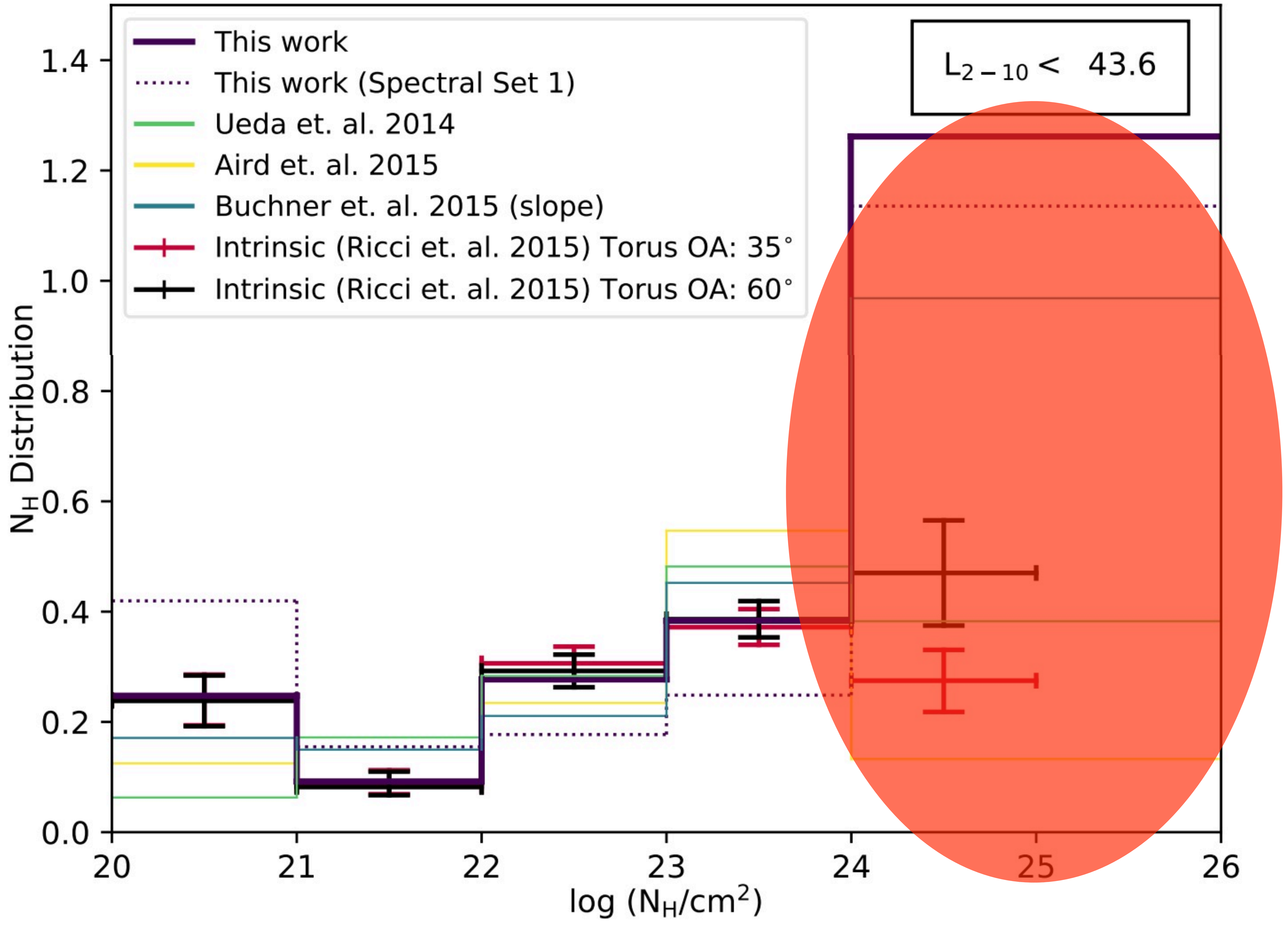
Powerful **Compton-thick AGN**
not detected in even the deepest *Chandra* surveys

del Moro et al. (2016)

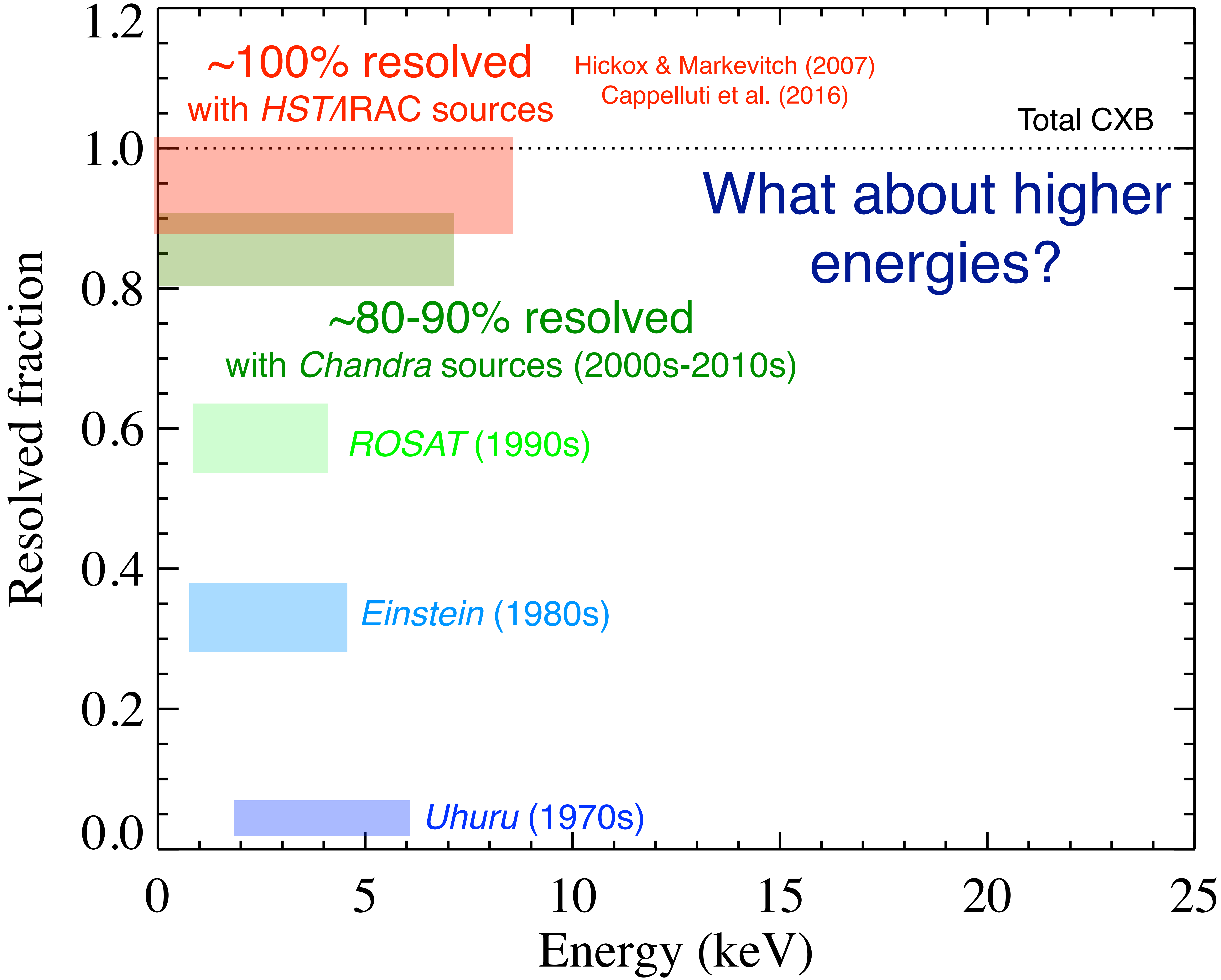
Updated modeling of the cosmic X-ray background



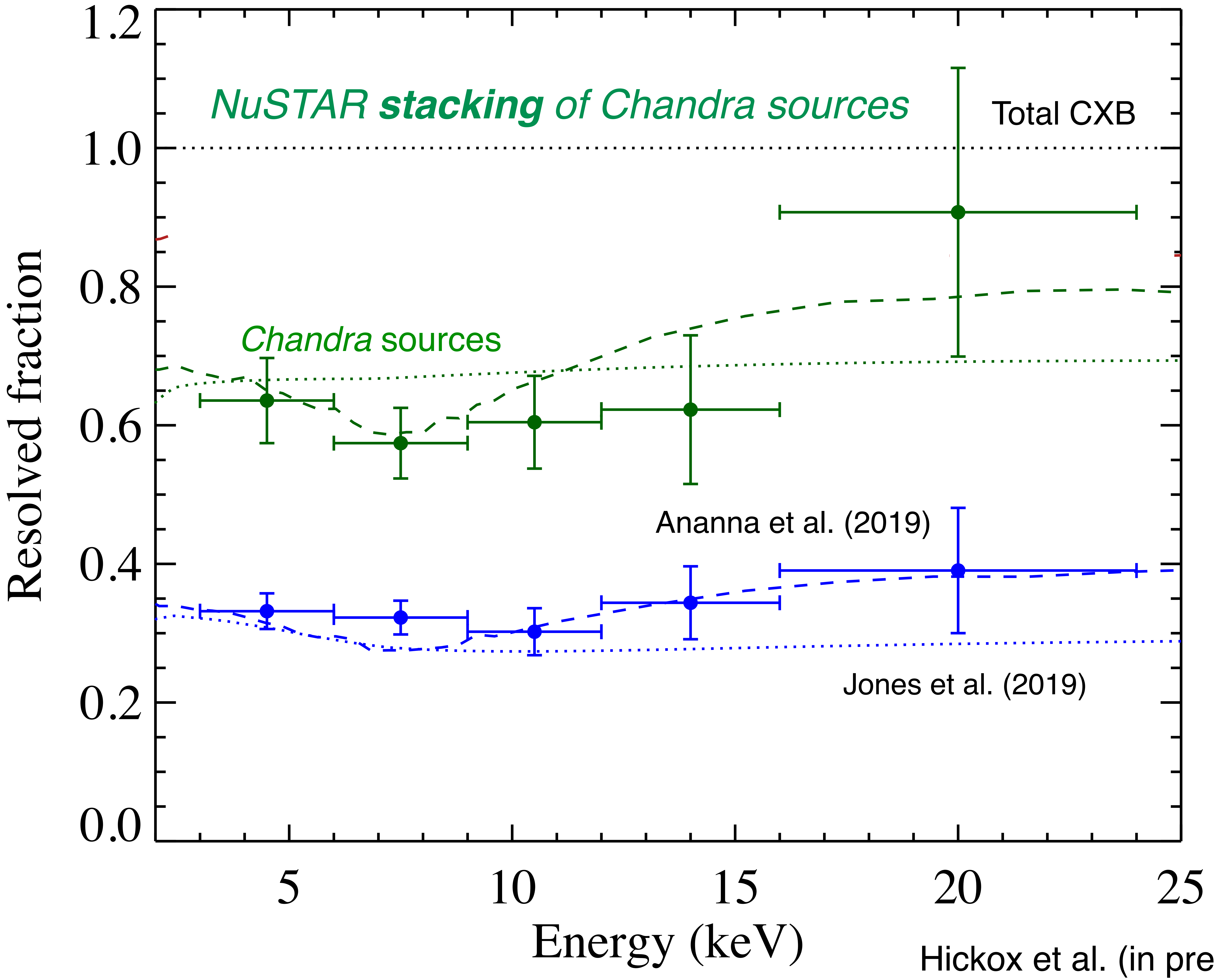
Ananna et al. (2019)



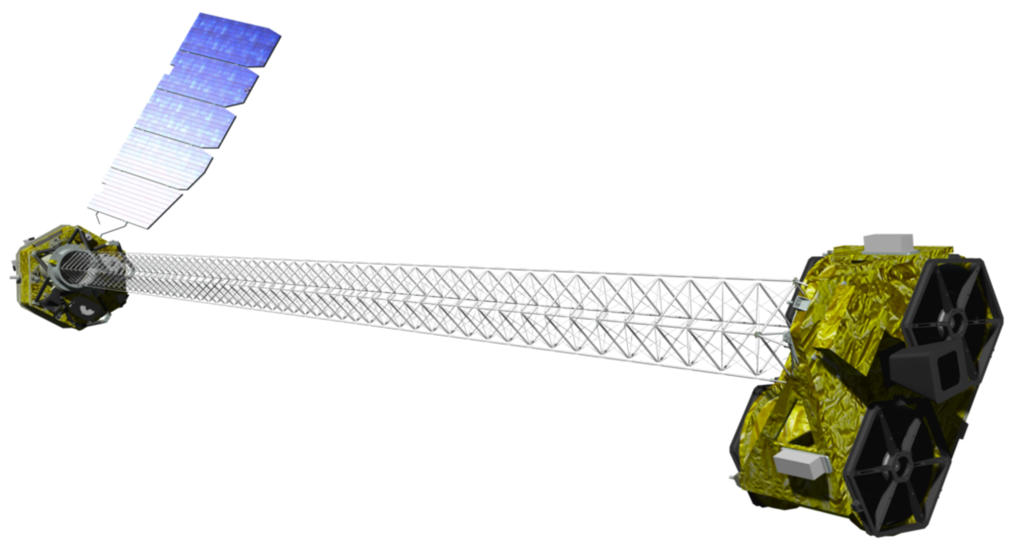
~50% of AGN are **Compton-thick**?

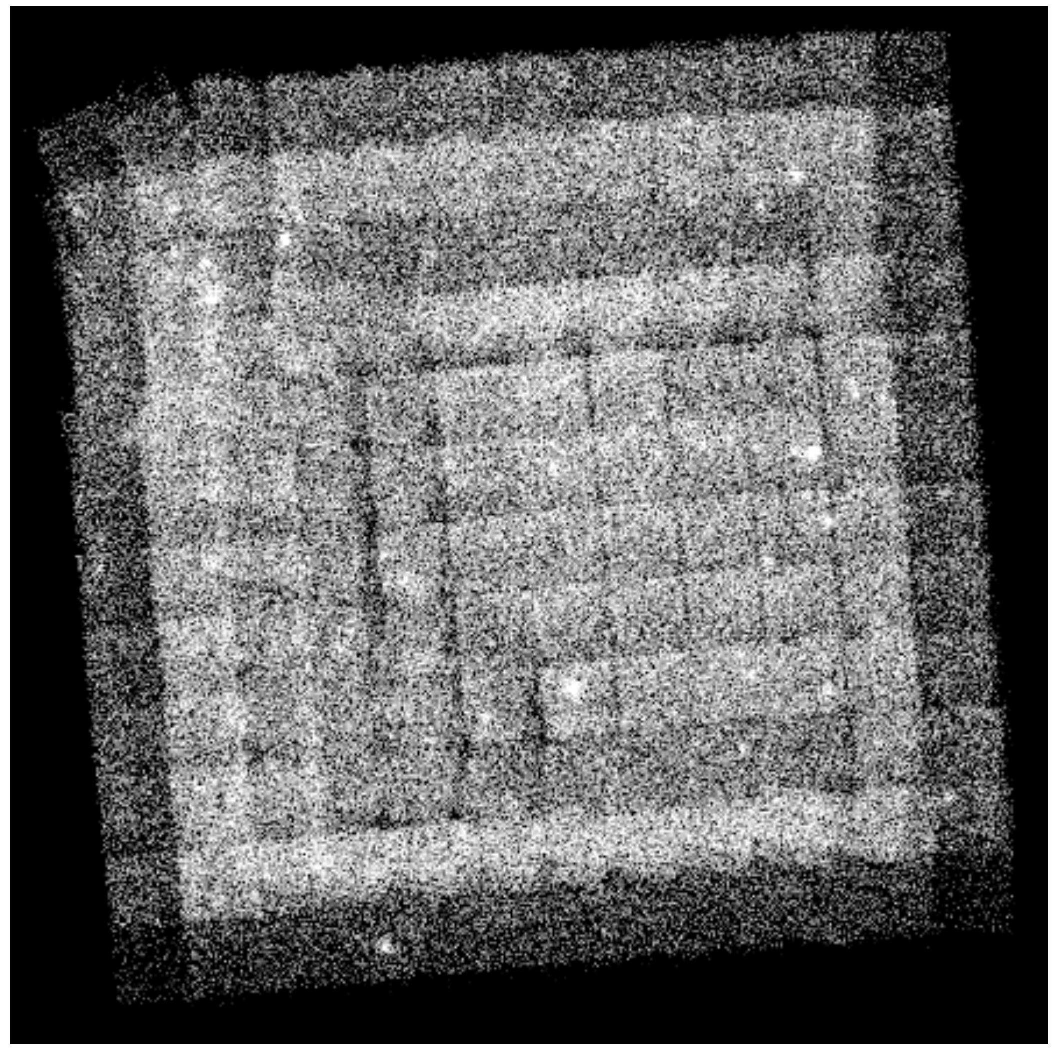


What about higher energies?



Hickox et al. (in prep)





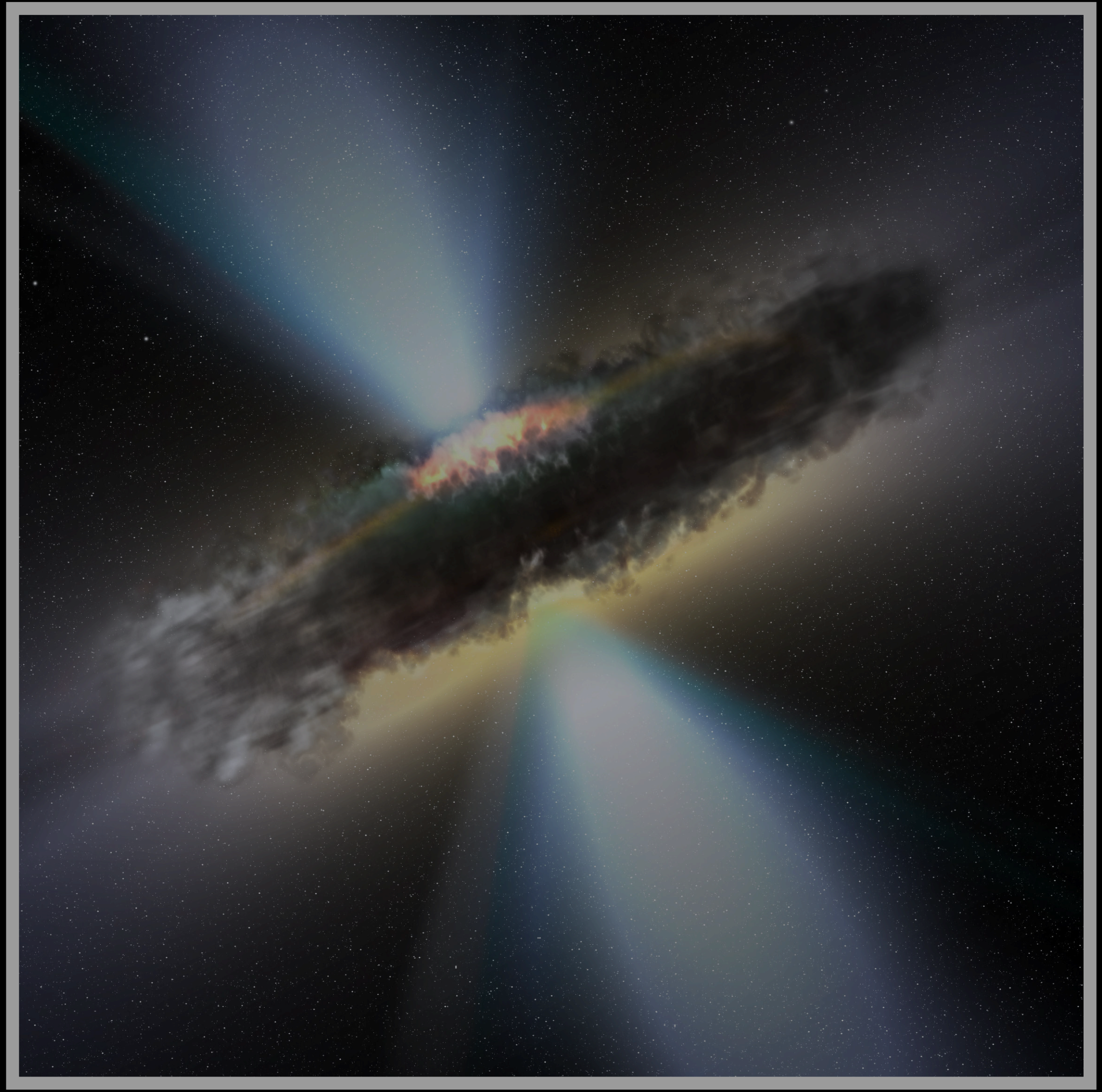
NuSTAR/COSMOS
(Civano et al. 2015)

brighter

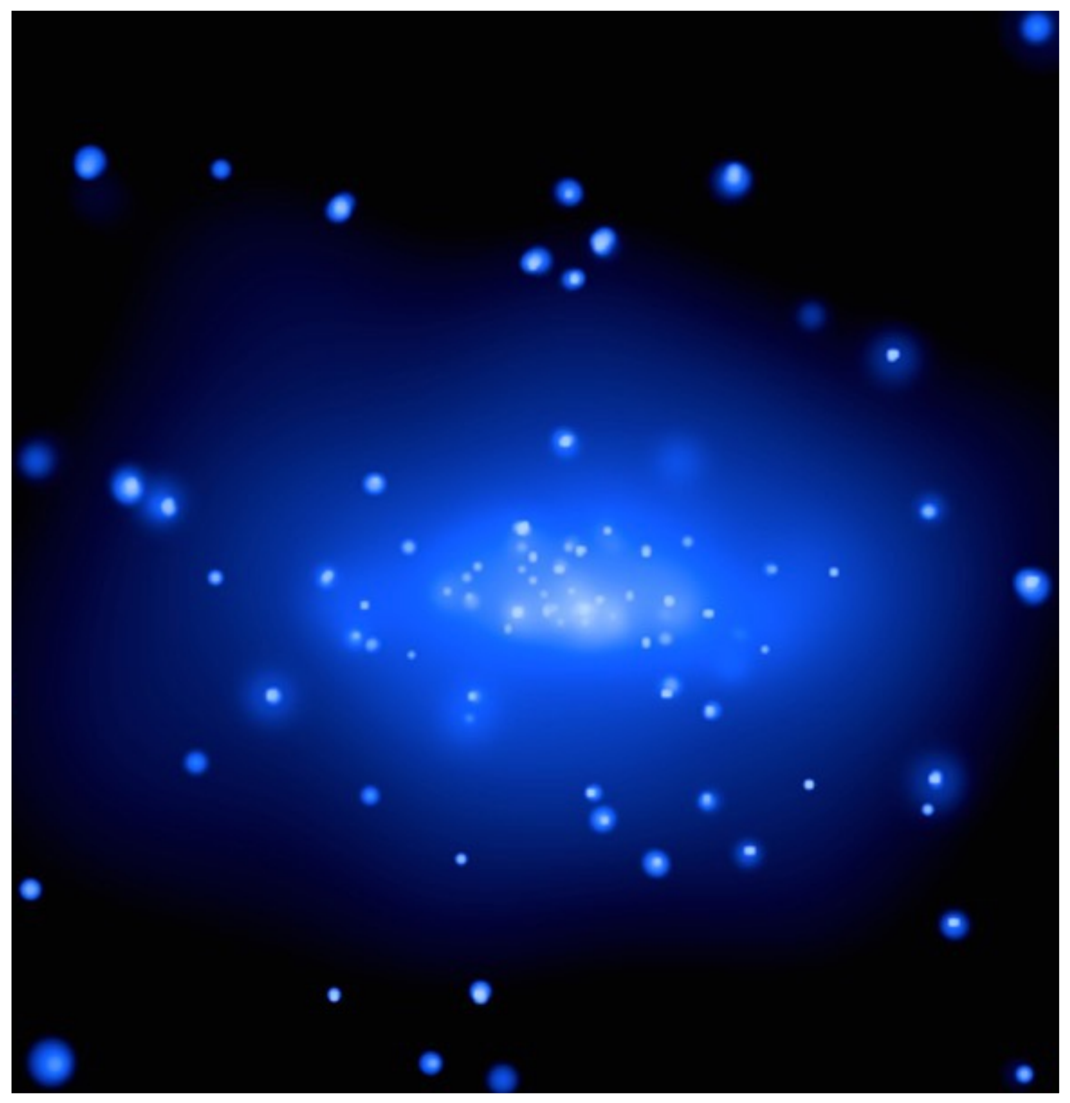
fainter

Evolution of black holes and galaxies

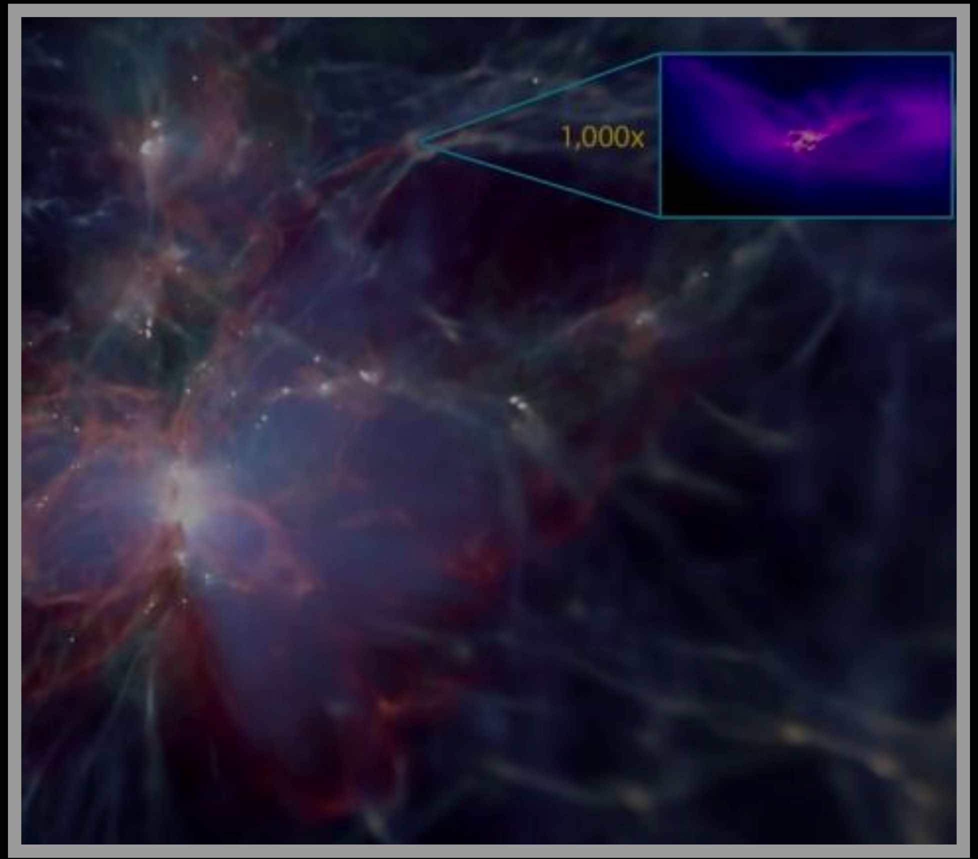
Unveiling hidden black holes

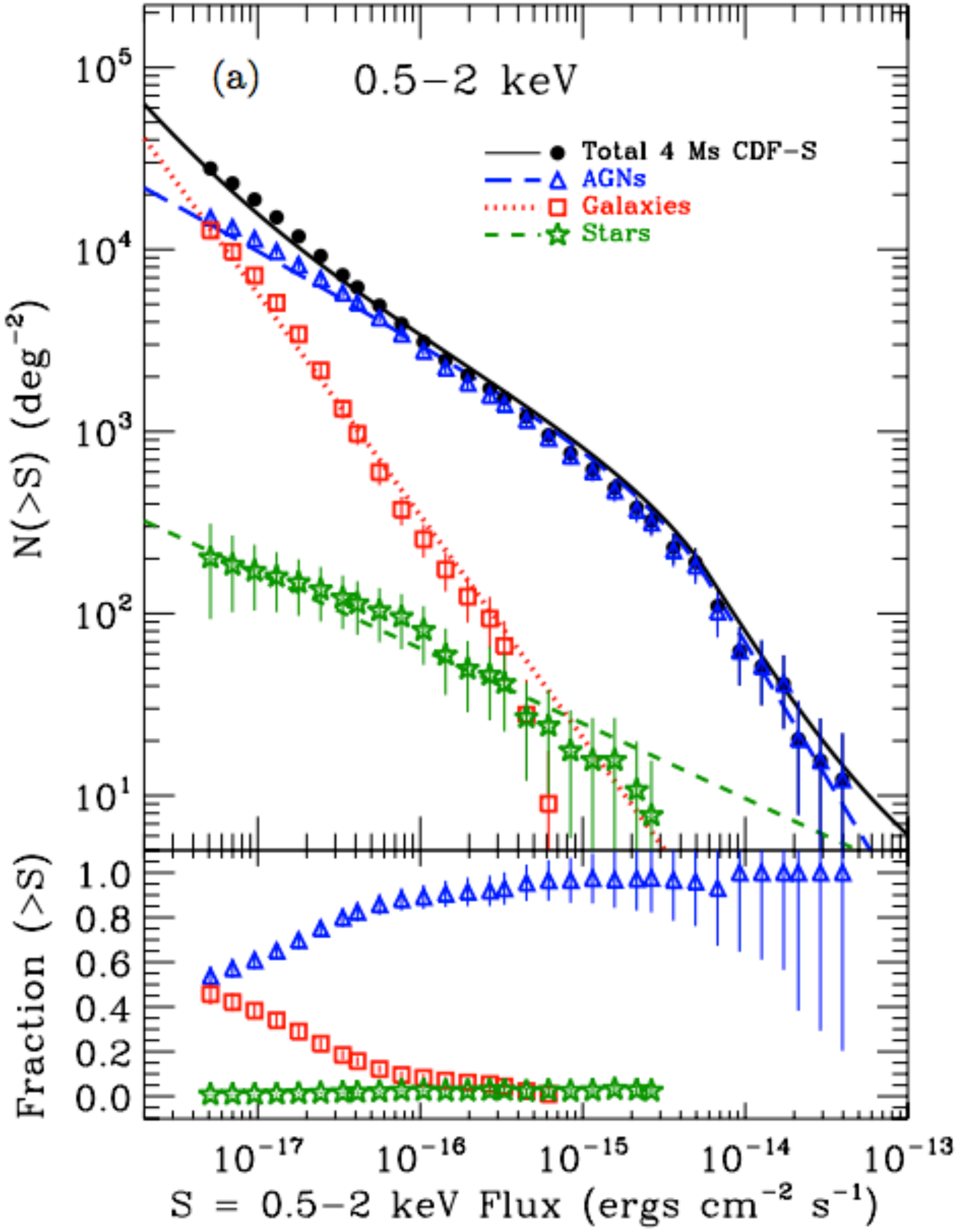


The realm of “normal” galaxies

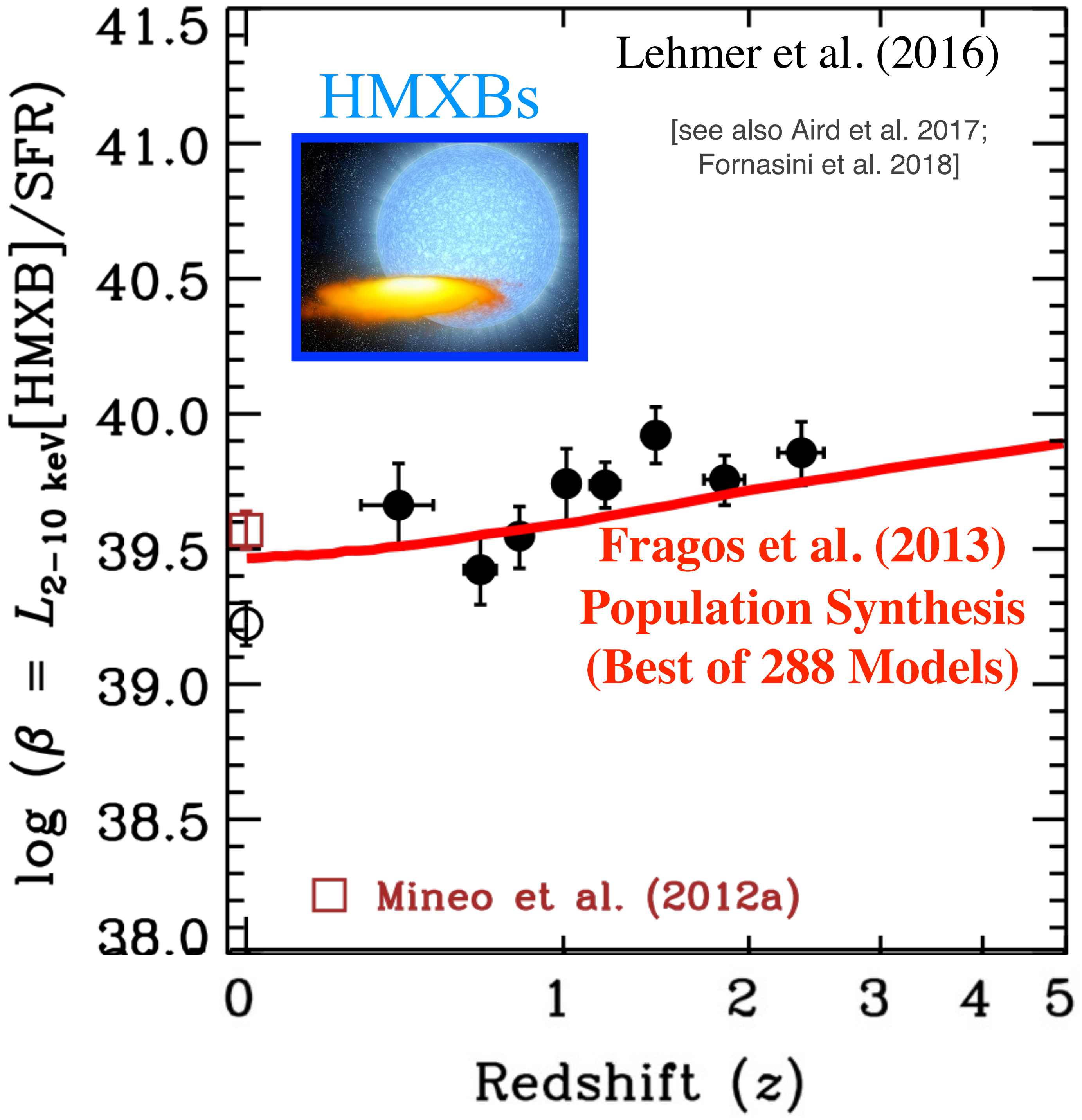


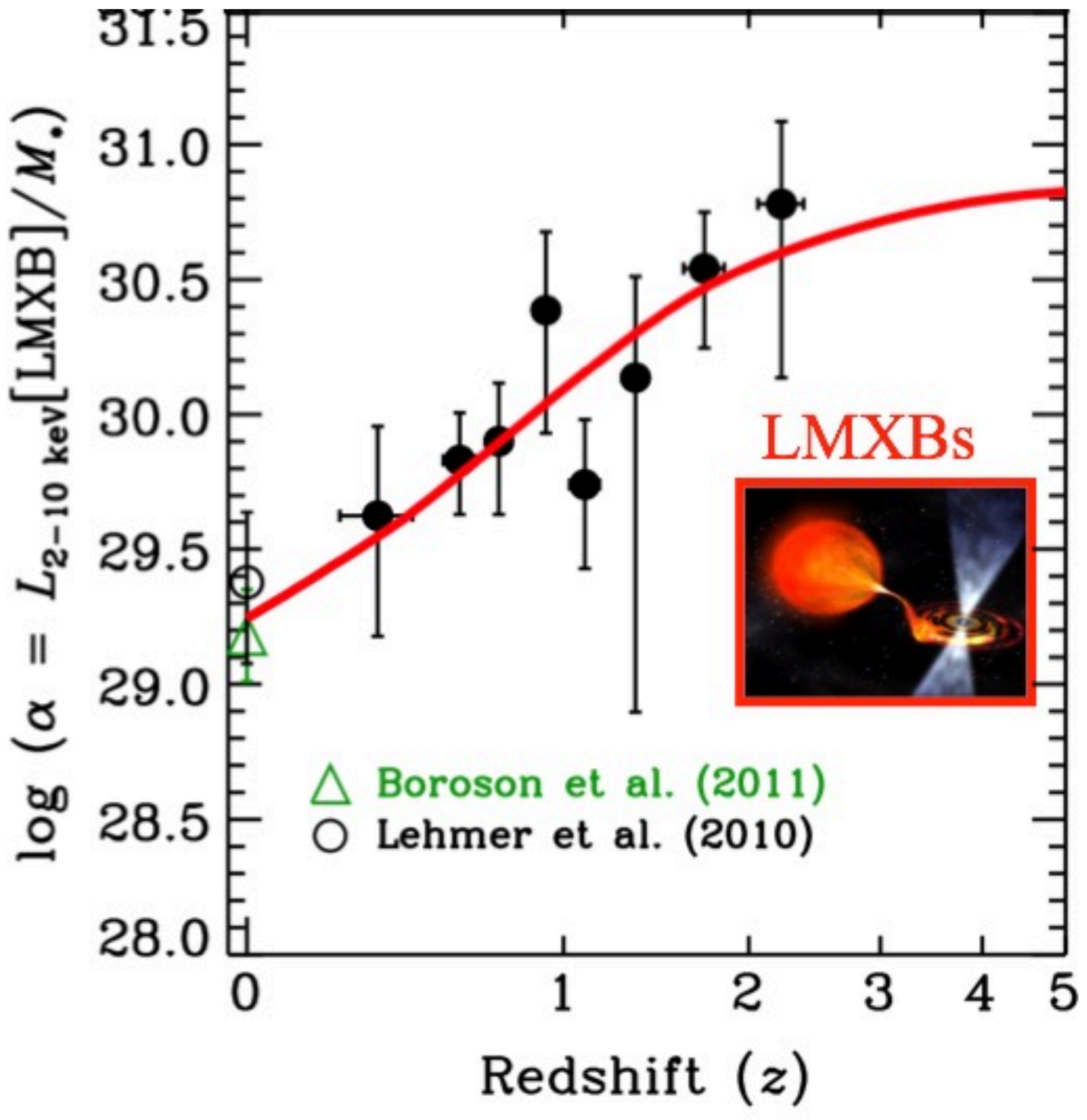
Black holes in the early Universe

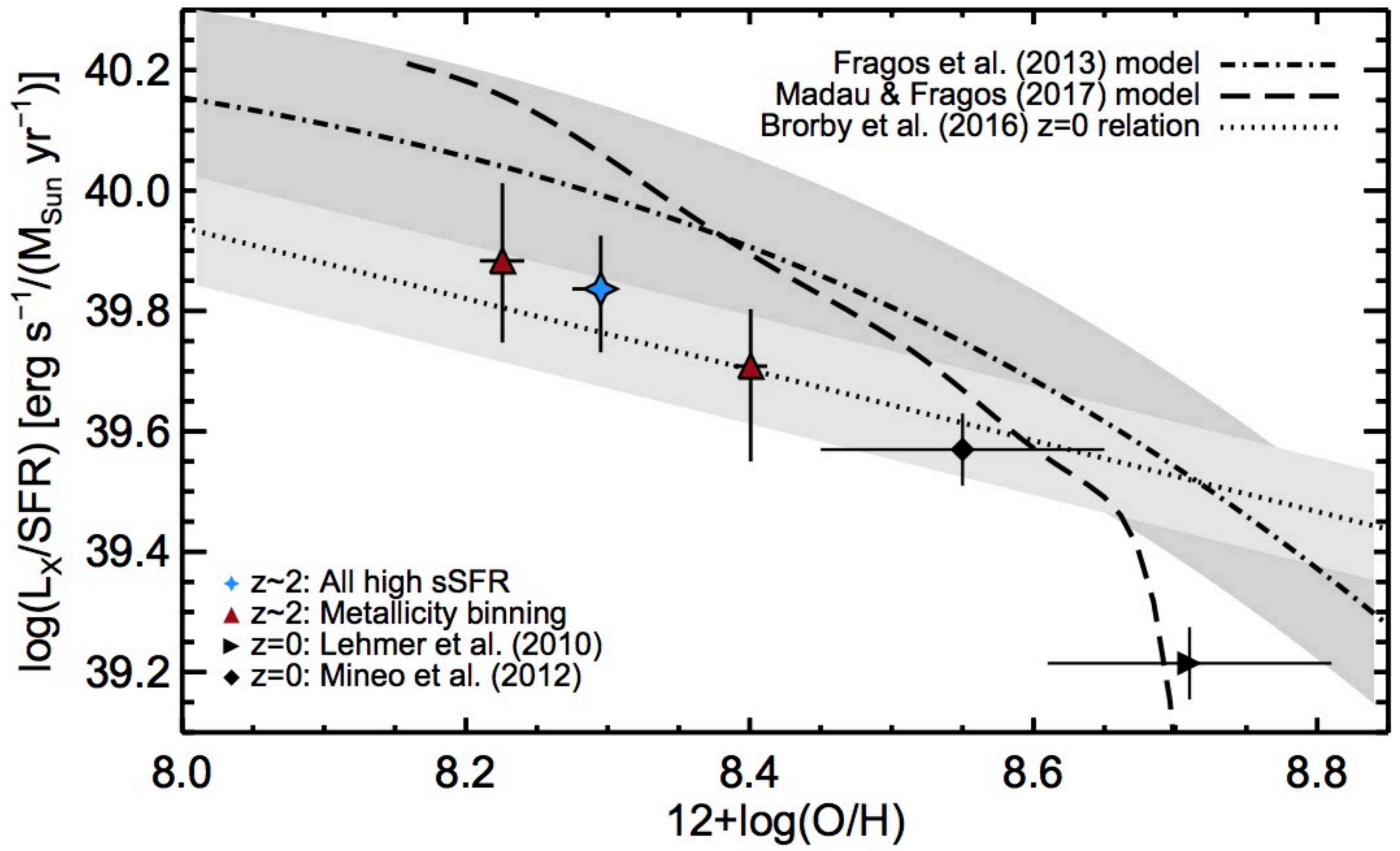




Lehmer et al. (2012)





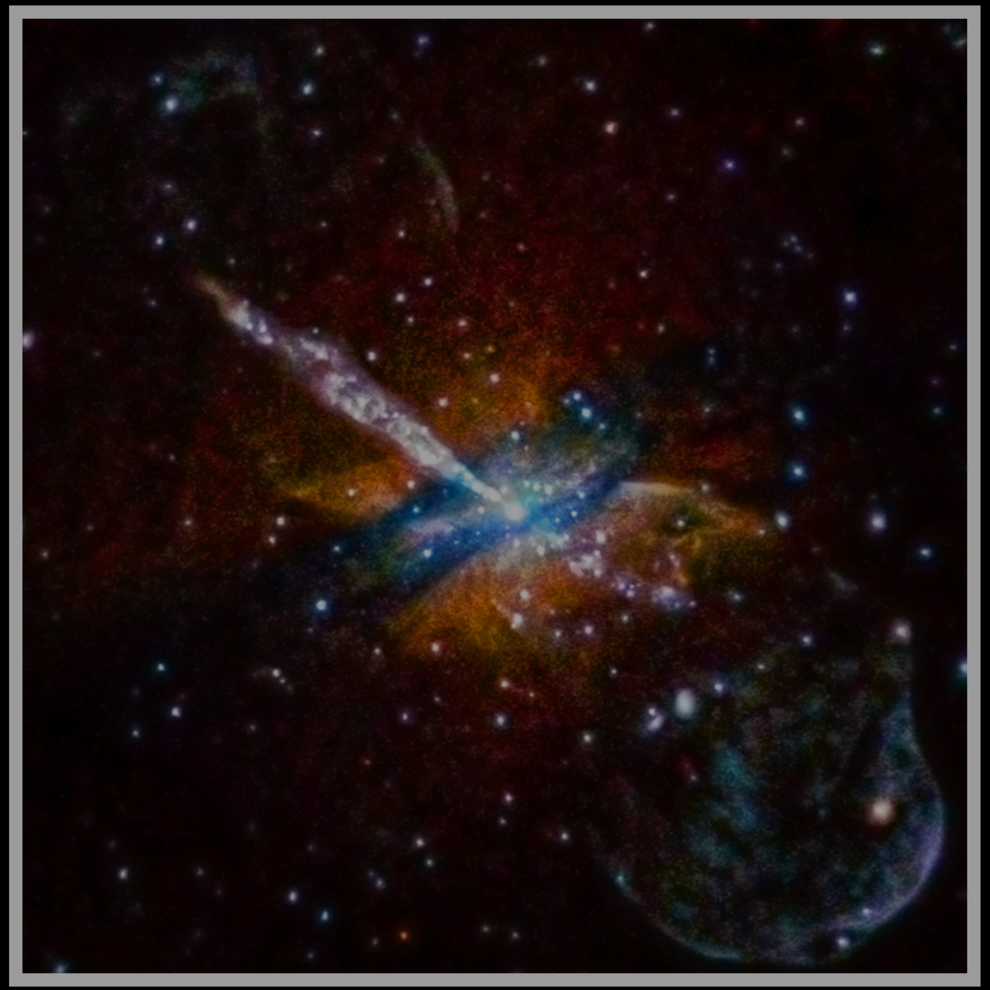


Evidence for **metallicity dependence** on HMXB luminosity? (Fornasini et al. 2019)

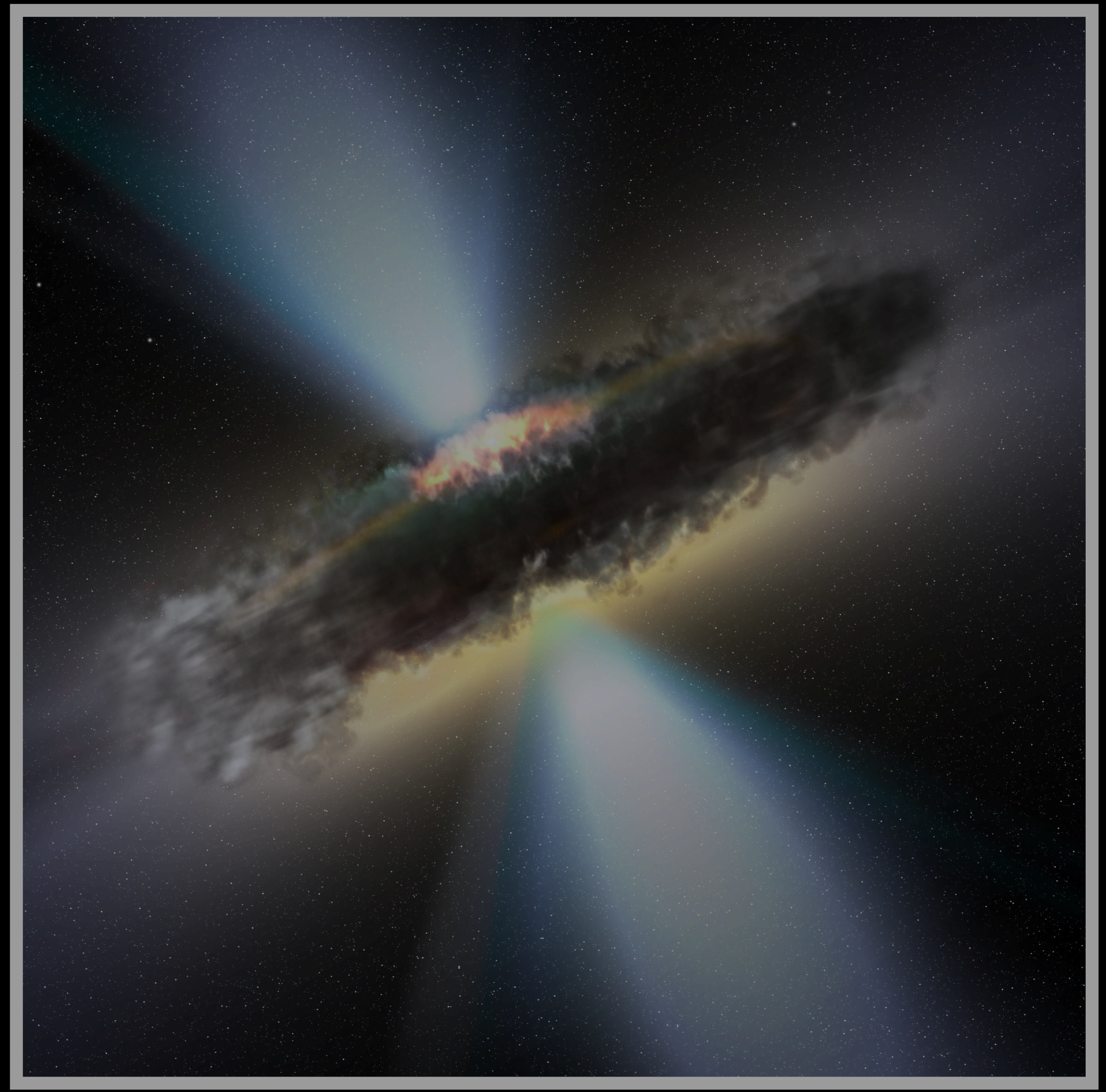
brighter

fainter

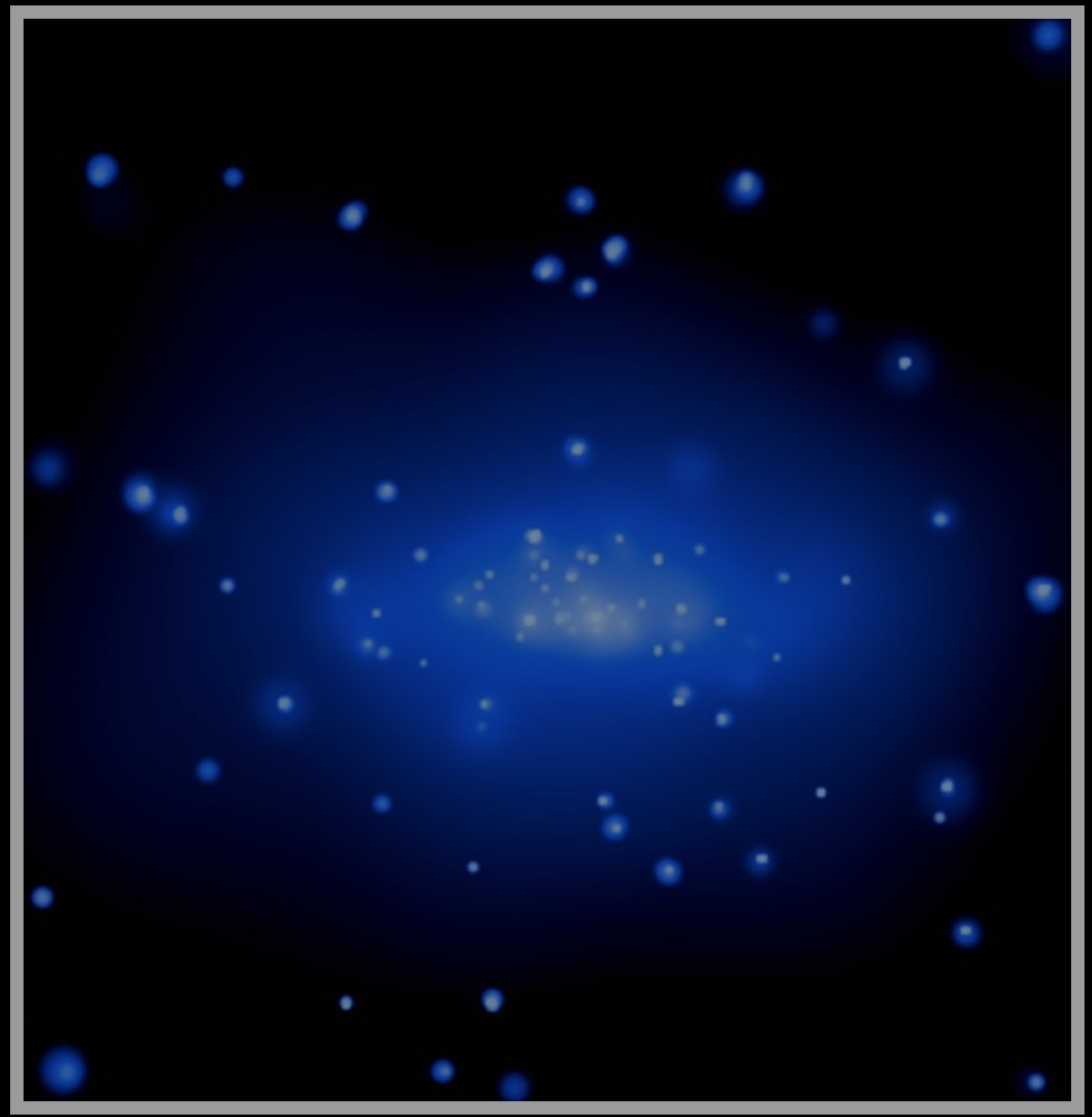
Evolution of black holes and galaxies



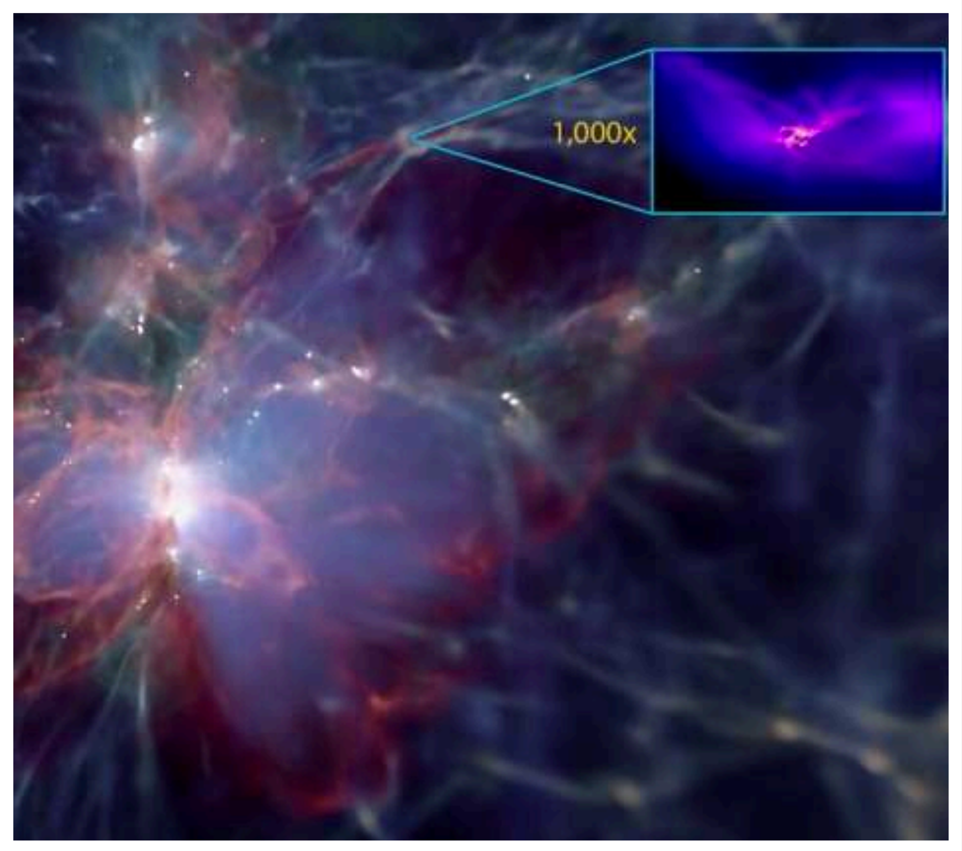
Unveiling hidden black holes

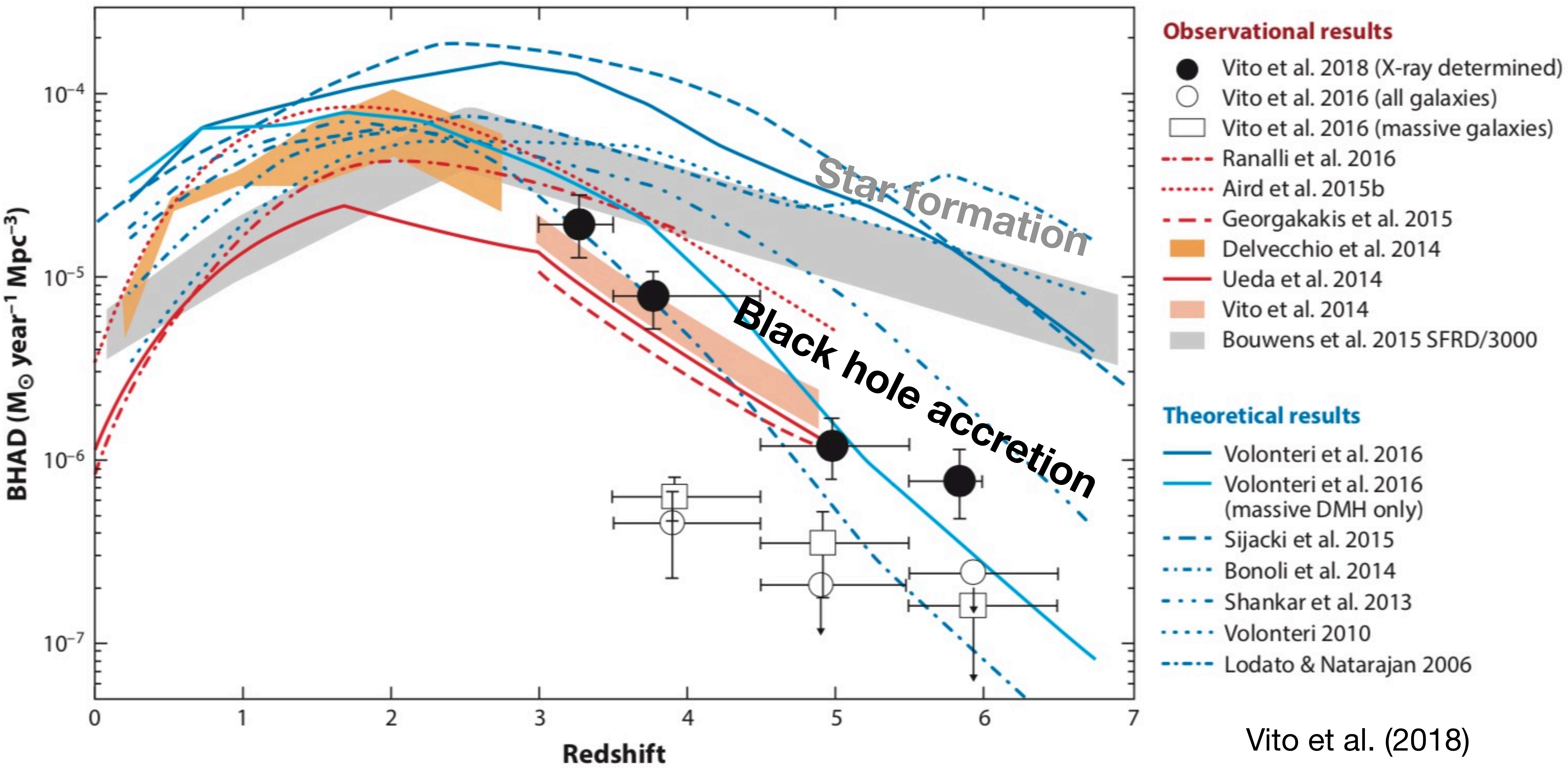


The realm of “normal” galaxies



Black holes in the early Universe





Vito et al. (2018)

Black hole growth **lags star formation** at high *z* or is **heavily obscured?**

What capabilities would you most like to see improved on a new X-ray observatory?

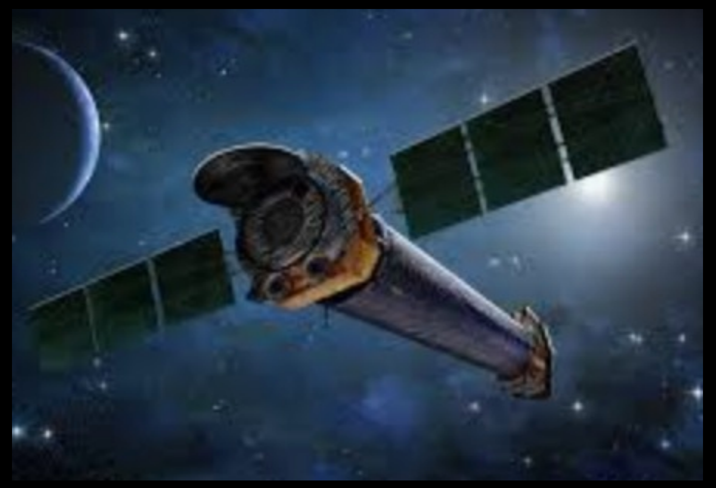
- Effective area
- Angular resolution
- Spectral resolution
- Energy coverage
- None - we have nothing left to learn
- Why do I have to choose? I want them ALL

Start the presentation to see live content. Still no live content? Install the app or get help at **PollEv.com/app**

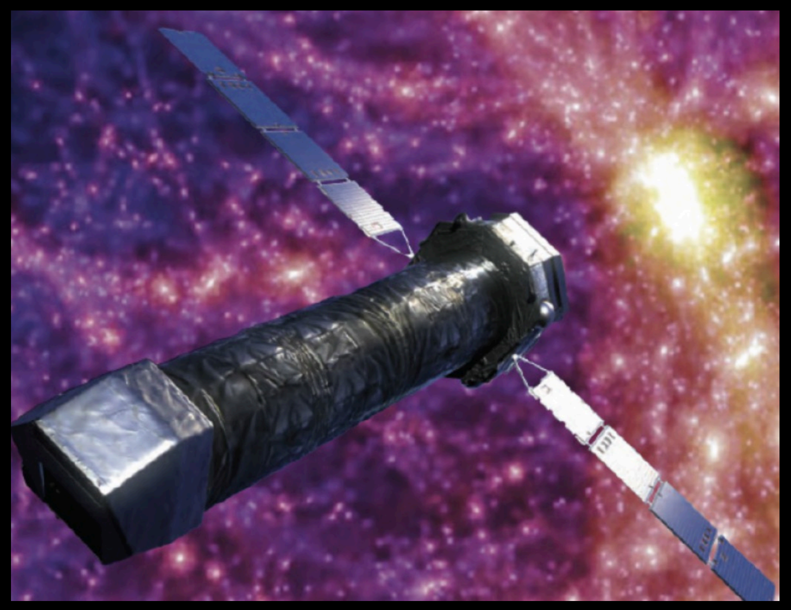
The Future

XMM

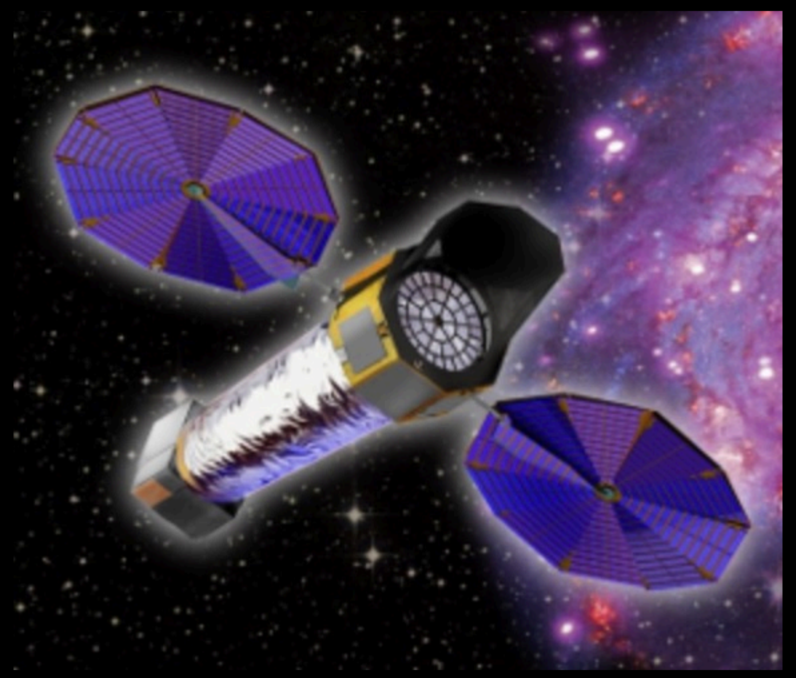
Chandra

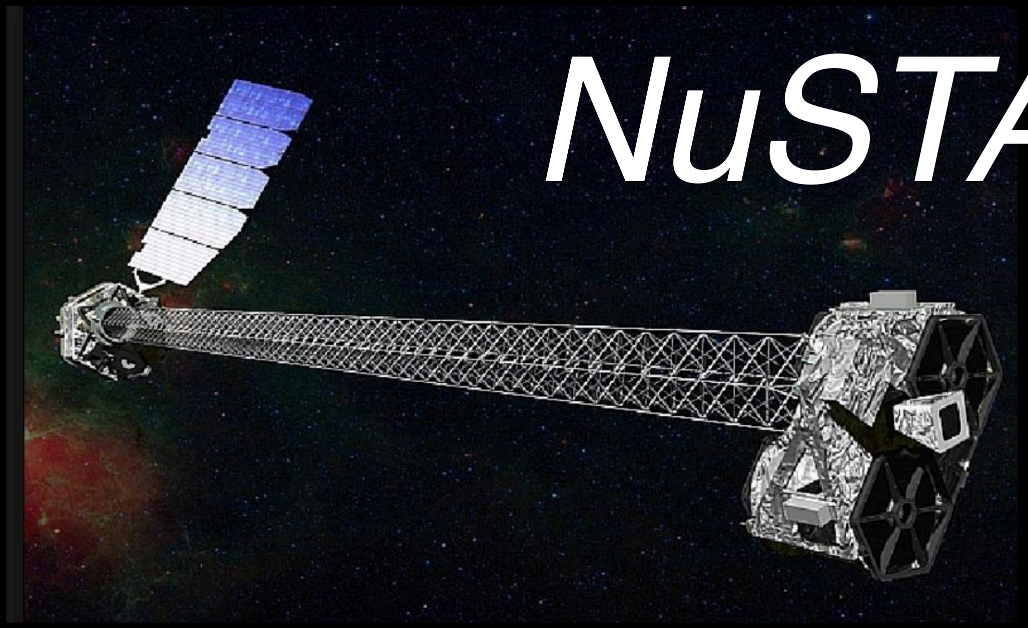


ATHENA



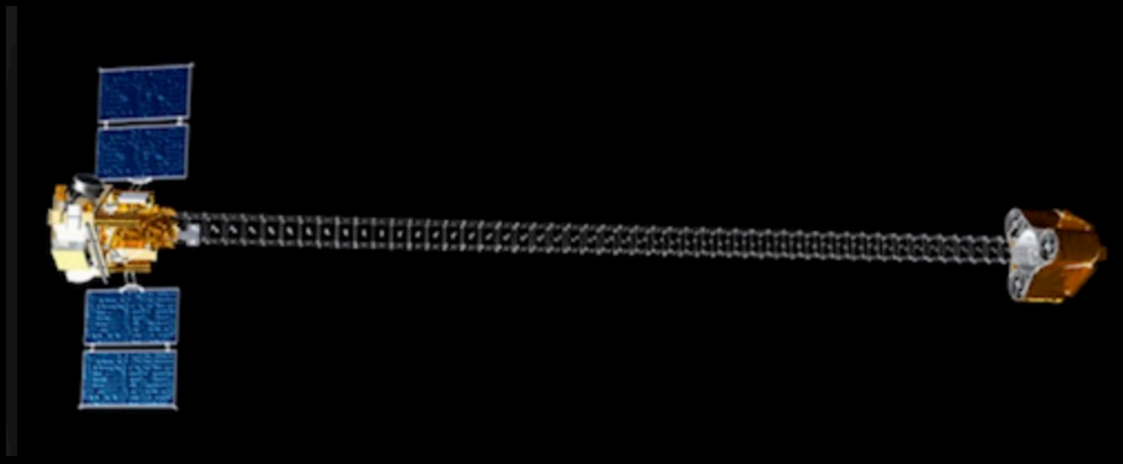
X-RAY OBSERVATORY
LYNX



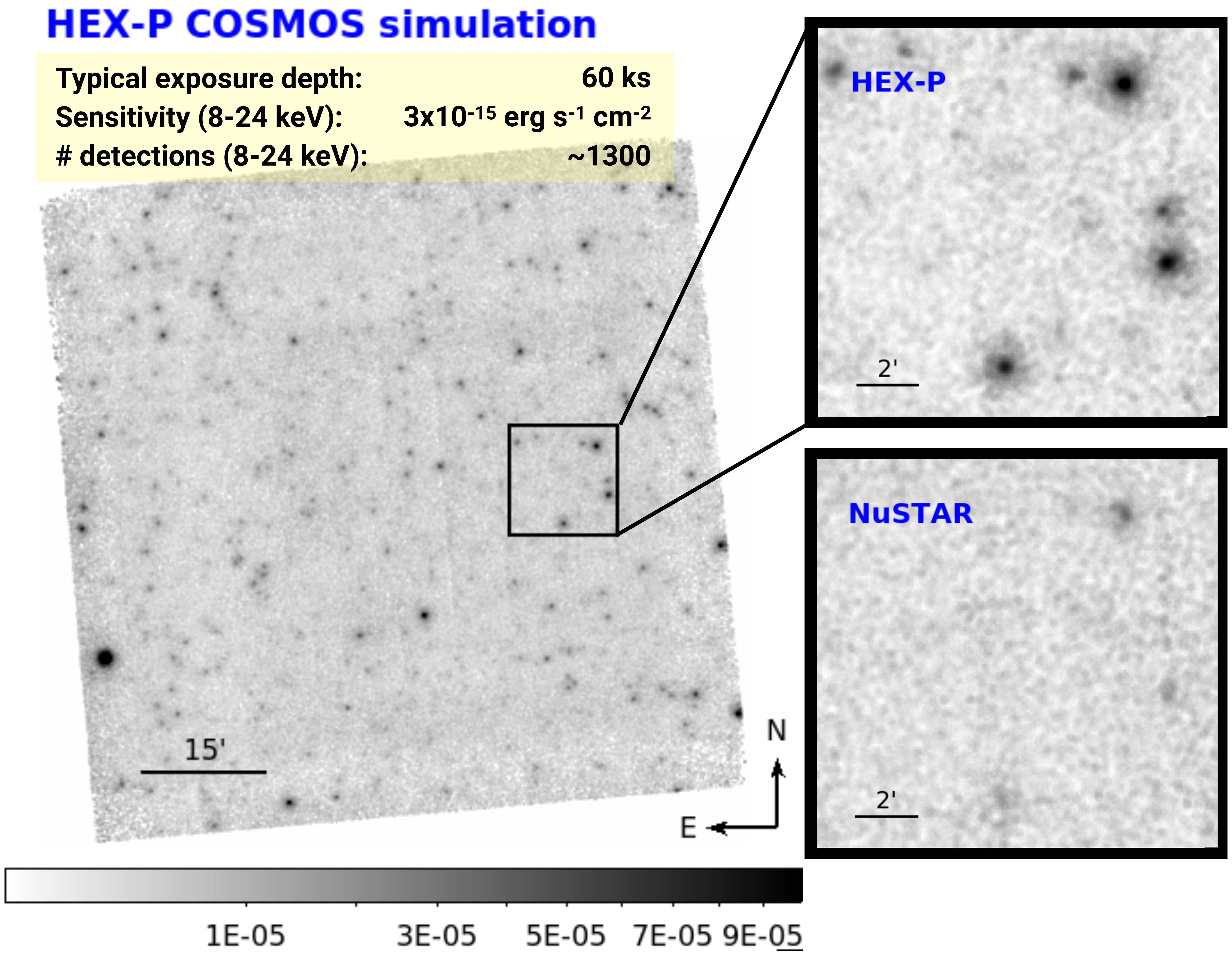


NuSTAR

HEX-P



HEX-P

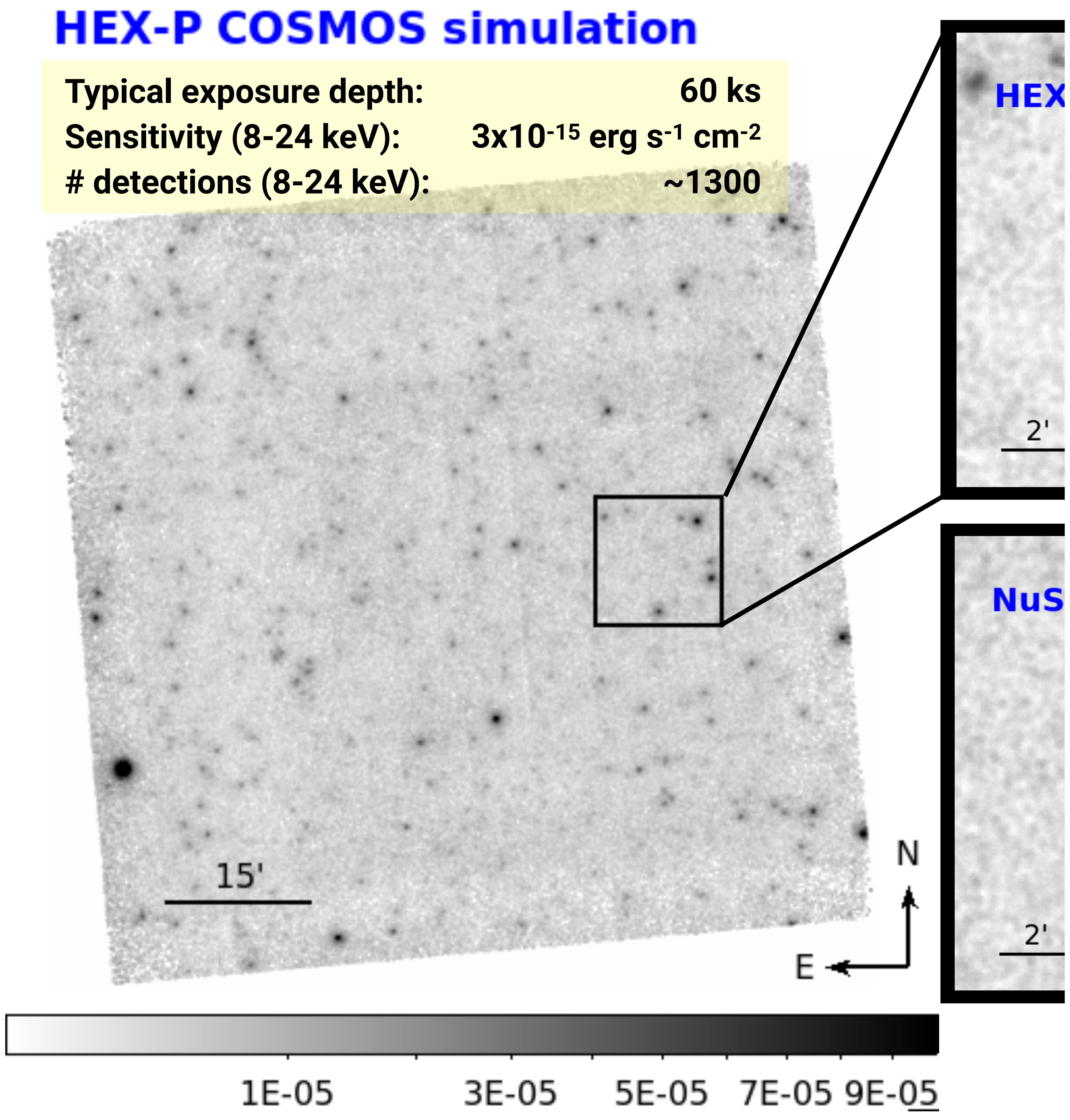


HEX-P COSMOS simulation

Typical exposure depth:	60 ks
Sensitivity (8-24 keV):	3×10^{-15} erg s^{-1} cm^{-2}
# detections (8-24 keV):	~1300

Hickox et al. (2019) Astro2020 White Paper

HEX-P



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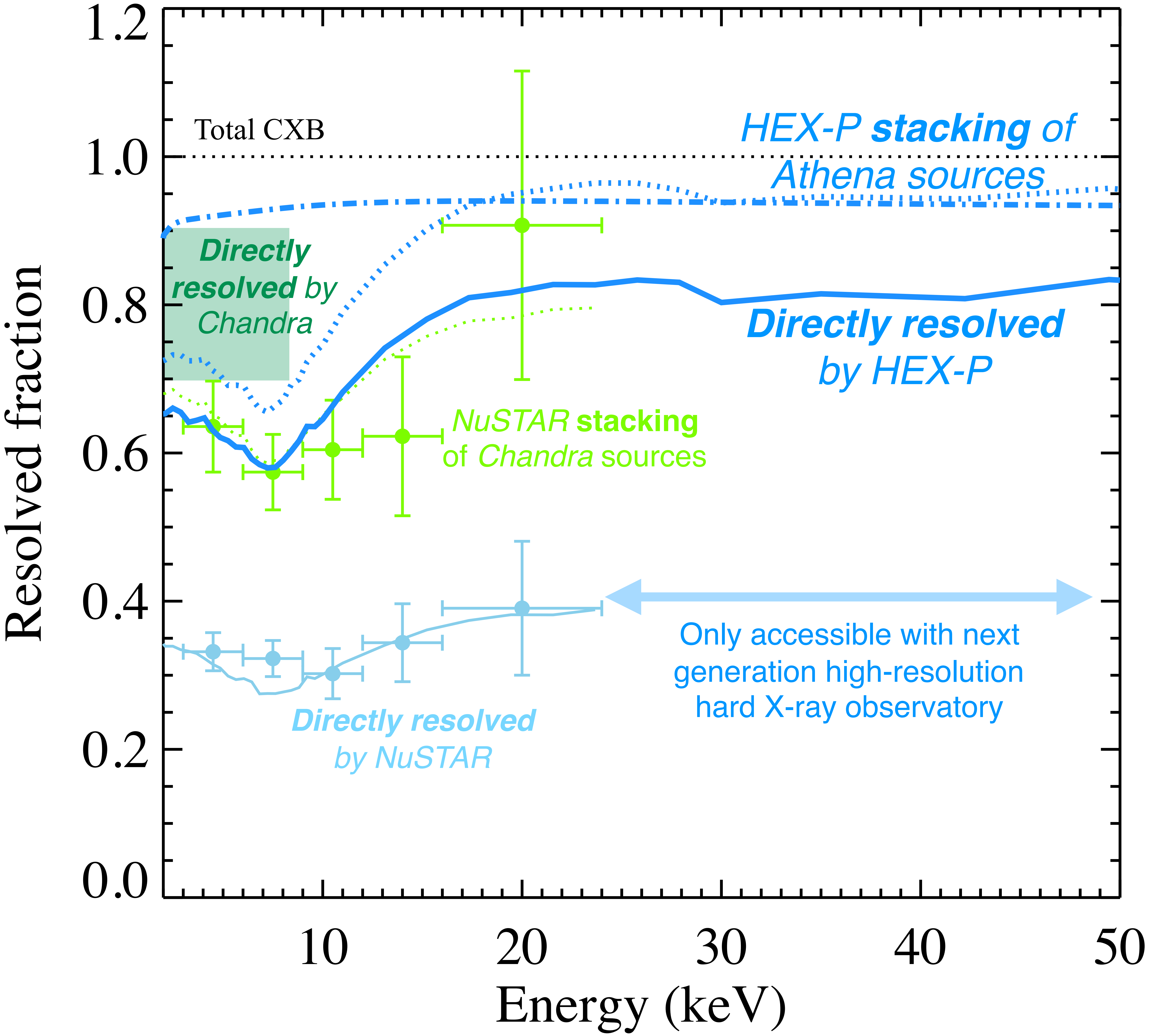
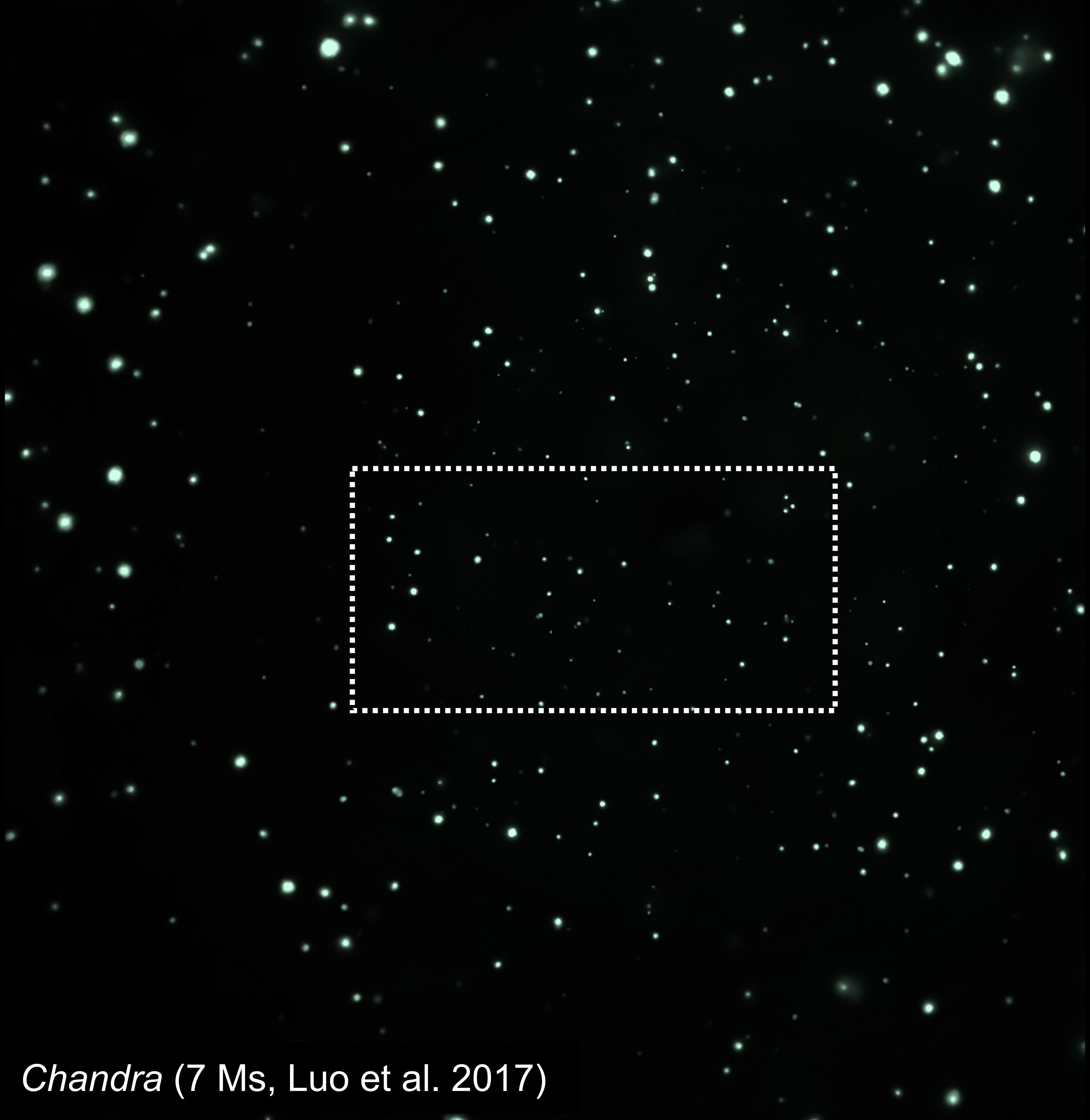
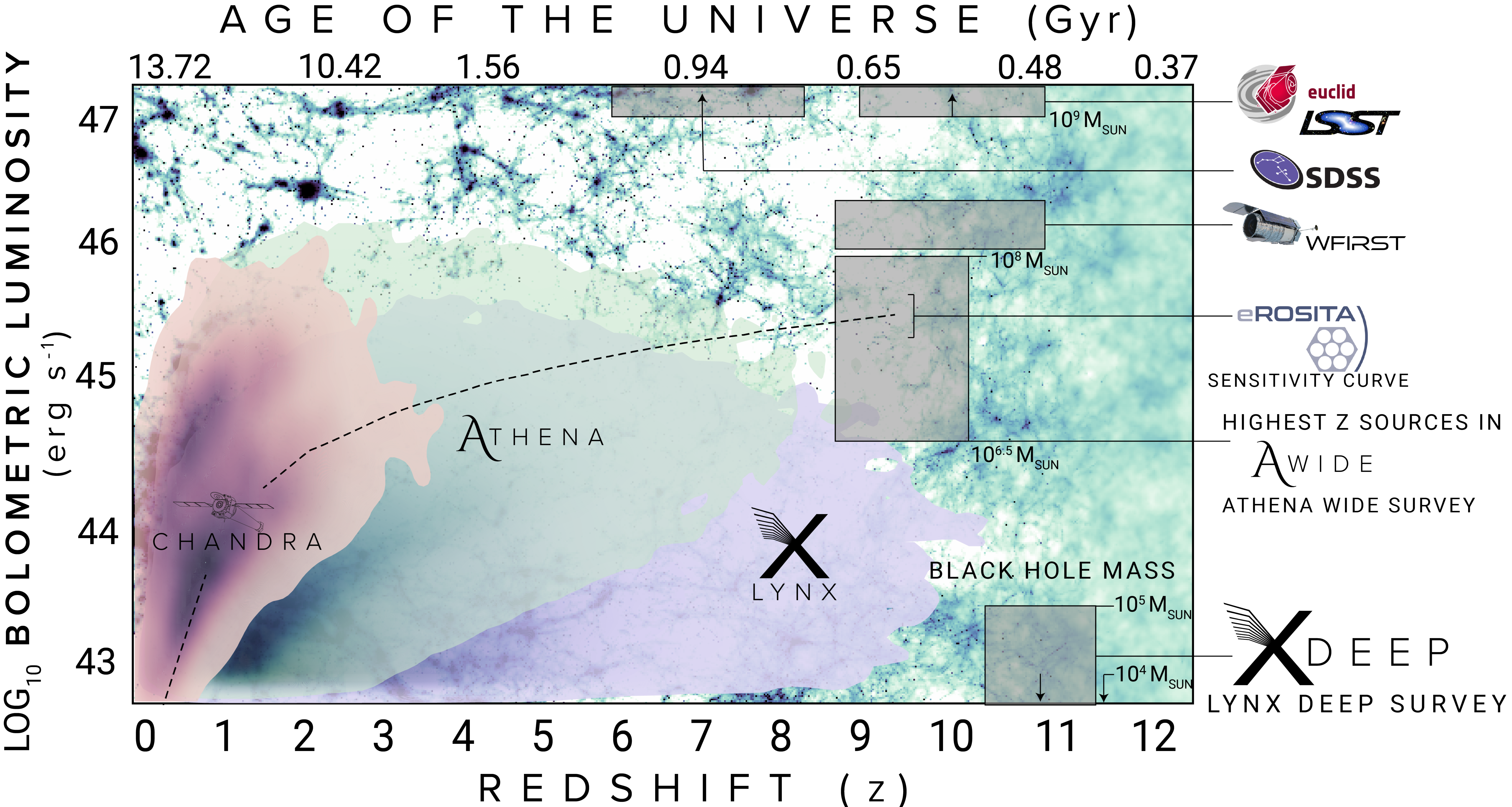


Hickox et al. (2019) Astro2020 White Paper

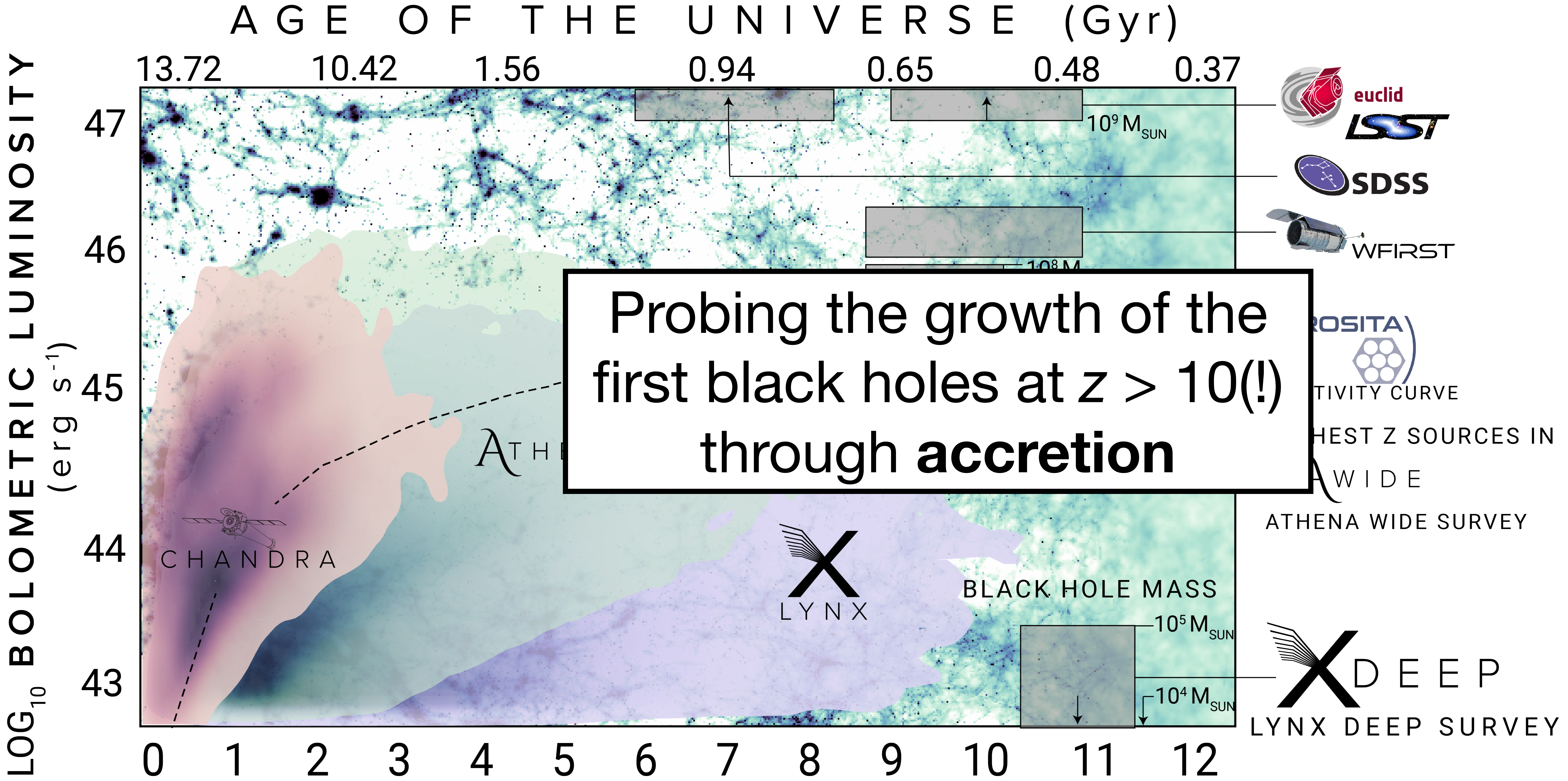


Chandra (7 Ms, Luo et al. 2017)


Lynx HDXI (~1 Ms)
Chandra (7 Ms, Luo et al. 2017)



Civano et al. (2019) Astro2020 White Paper



Probing the growth of the first black holes at *z* > 10(!) through **accretion**

Civano et al. (2019) Astro2020 White Paper

Summary

The deepest *Chandra* surveys have resolved the **X-ray background**, uncovered the **co-evolution** of galaxies and black holes, unveiled **heavily obscured AGN**, traced X-ray emission from **normal galaxies** across cosmic time, and tracked the **growth of black holes at high redshift**

The future is bright!

Thanks to everyone involved with the *Chandra* mission, as well as NASA, the NSF, and ultimately the U.S. taxpayers for enabling these remarkable discoveries. Work by the author was supported by NASA through grants NNX15AP24G, NNX15AU32H, and NNX16AN48G, *Chandra* program GO7-18130X, and the NSF through CAREER award 1554584.