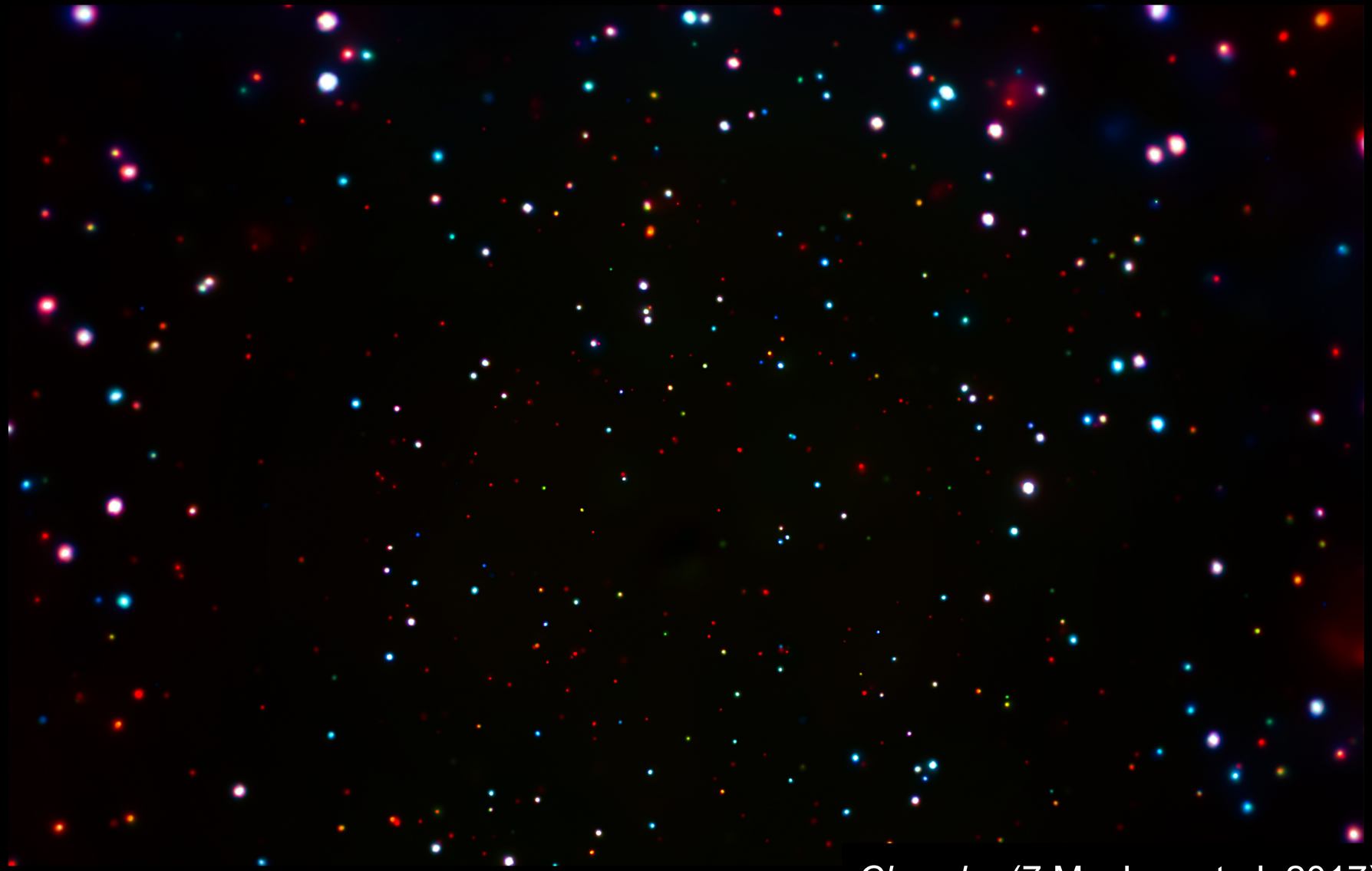
Resolving the Cosmic X-ray Background

Ryan C. Hickox

DARTMOUTH

Memorial Symposium
to Honor
Riccardo Giacconi
National Academy of
Sciences
Washington DC
29-30 May 2019



Chandra (7 Ms, Luo et al. 2017)

1960s: Aerobee rocket flights

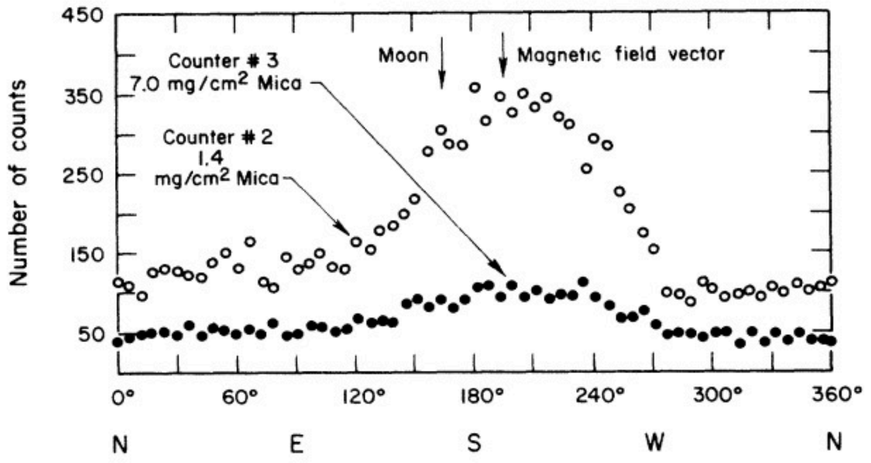
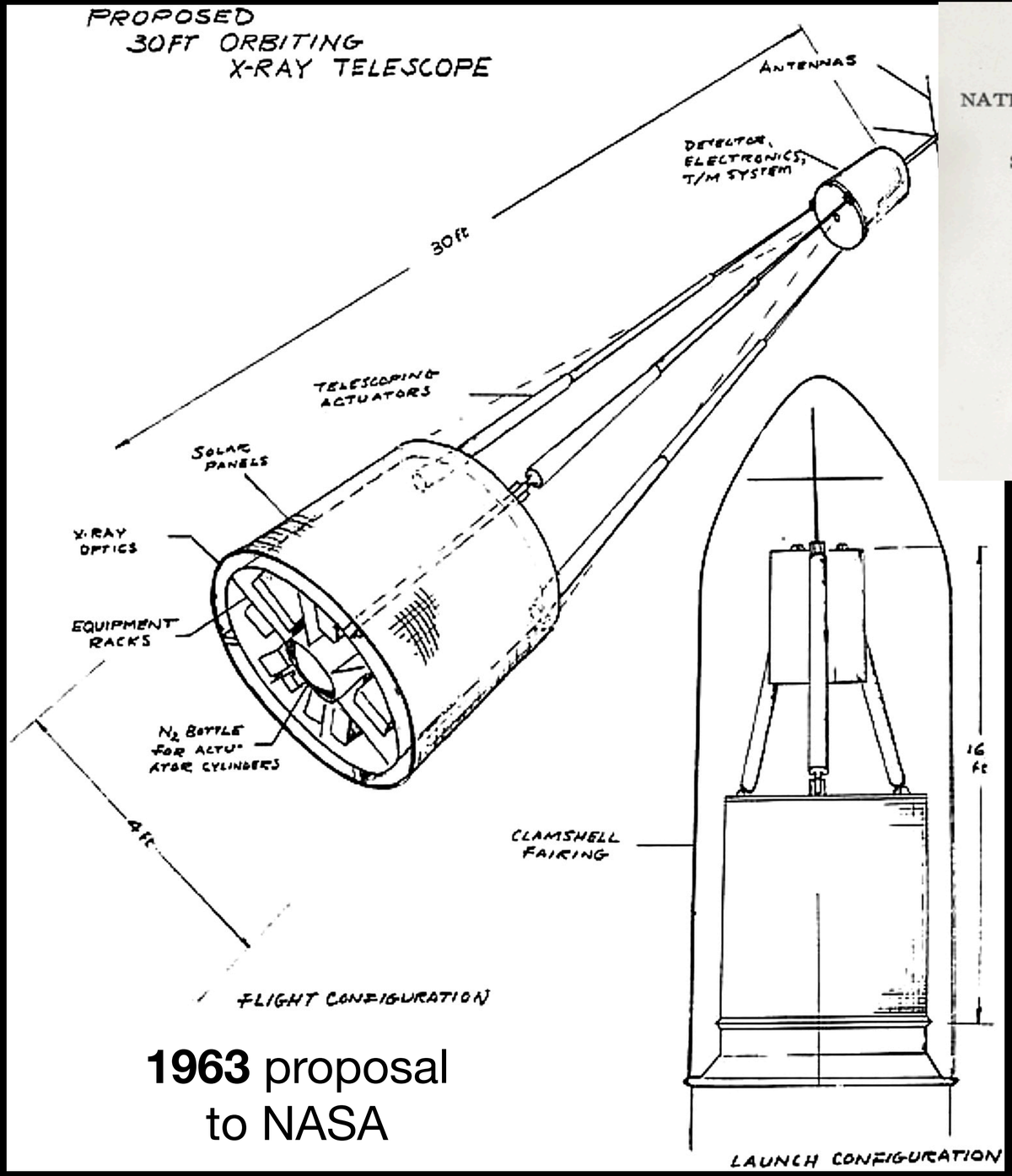


FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.

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)



1963 proposal to NASA

PROPOSAL TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOR THE

STUDY OF THE 1.2 METER X-RAY TELESCOPE

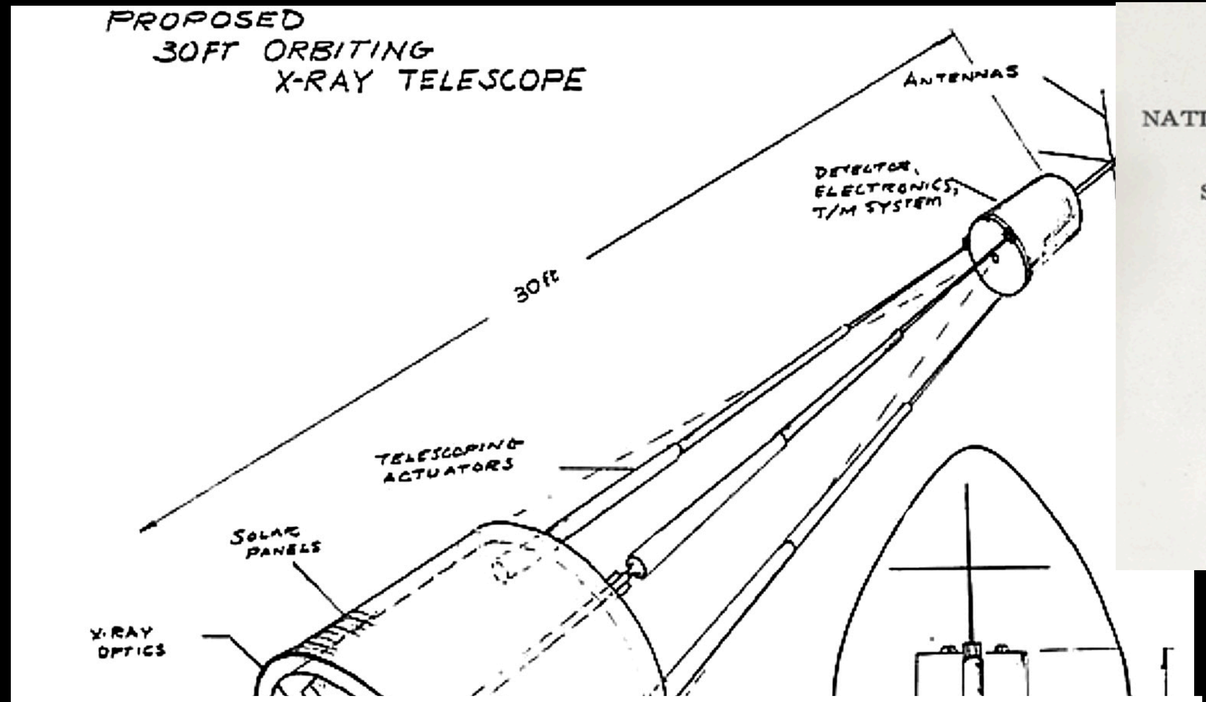
NATIONAL SPACE OBSERVATORY

P605-4-76

For the period 1 July 1976 to 30 September 1978

April 1976

1976: Proposal to NASA (w/ Harvey Tananbaum) for X-ray observatory that would become *Chandra*



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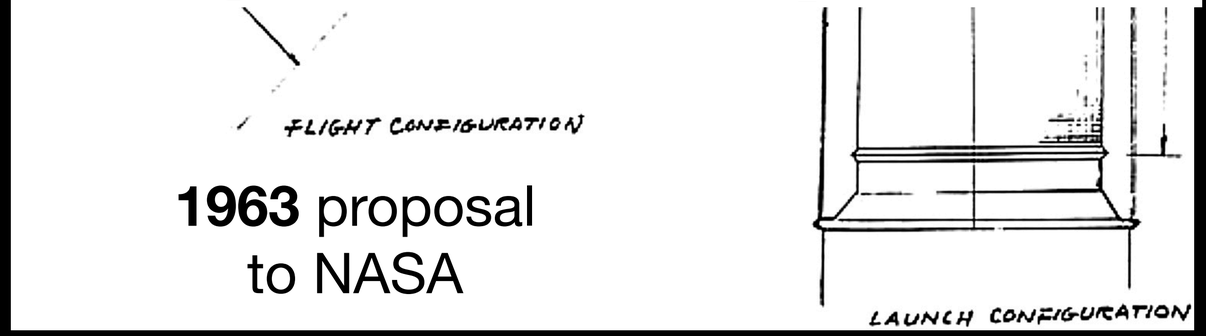
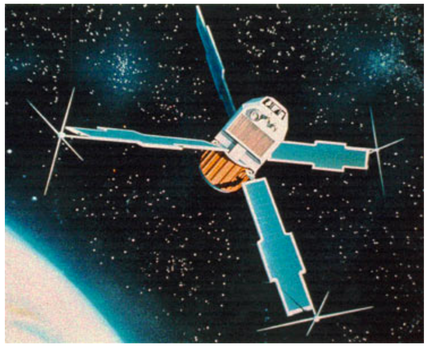
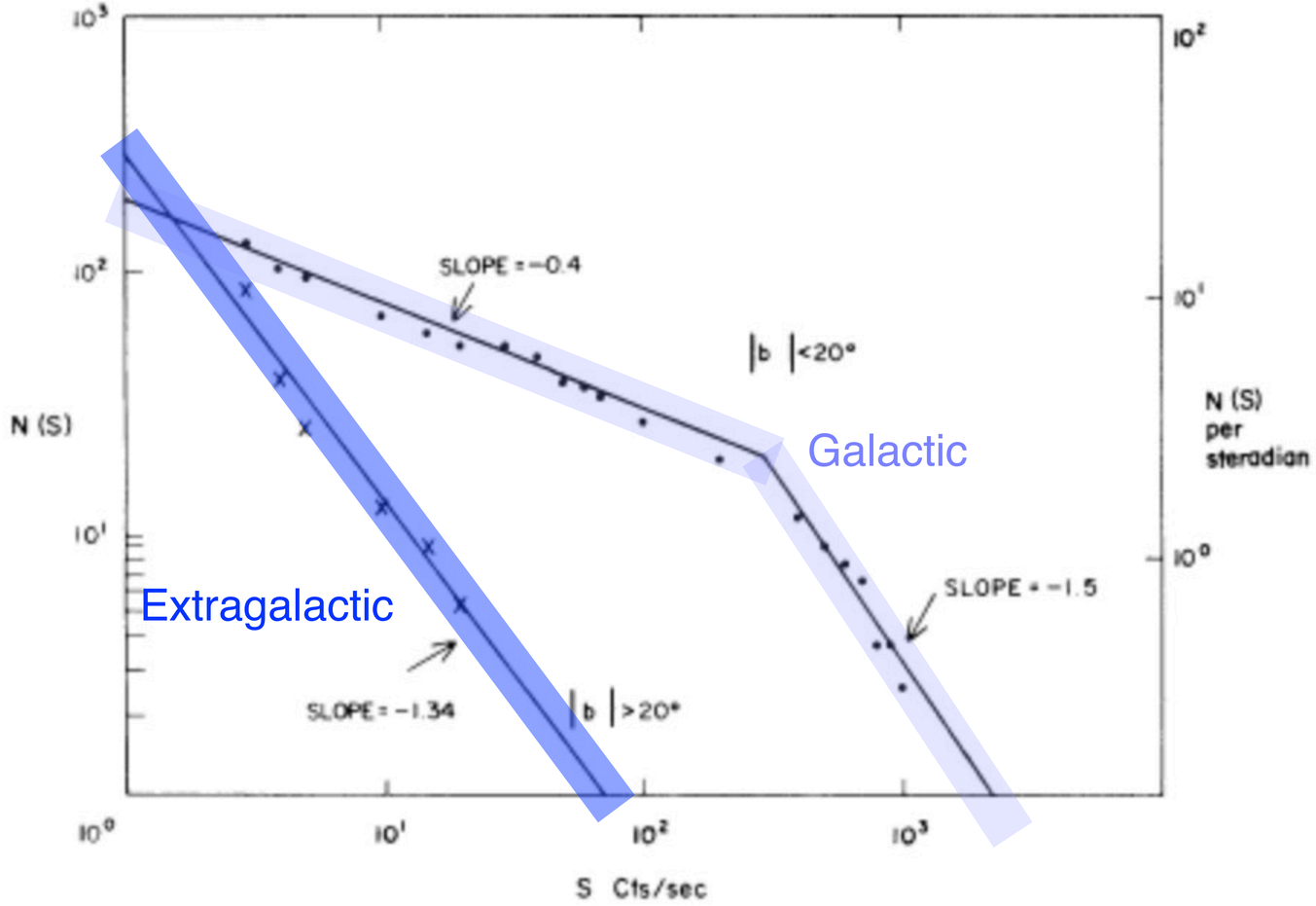
"The telescope was of sufficient area and angular resolution to determine the nature of the **unresolved X-ray background**." (Weisskopf 2010)



1963 proposal to NASA

1970s: *Uhuru*





Matilsky, Gursky, Kellogg, Tananbaum, Murray & Giacconi (1973)

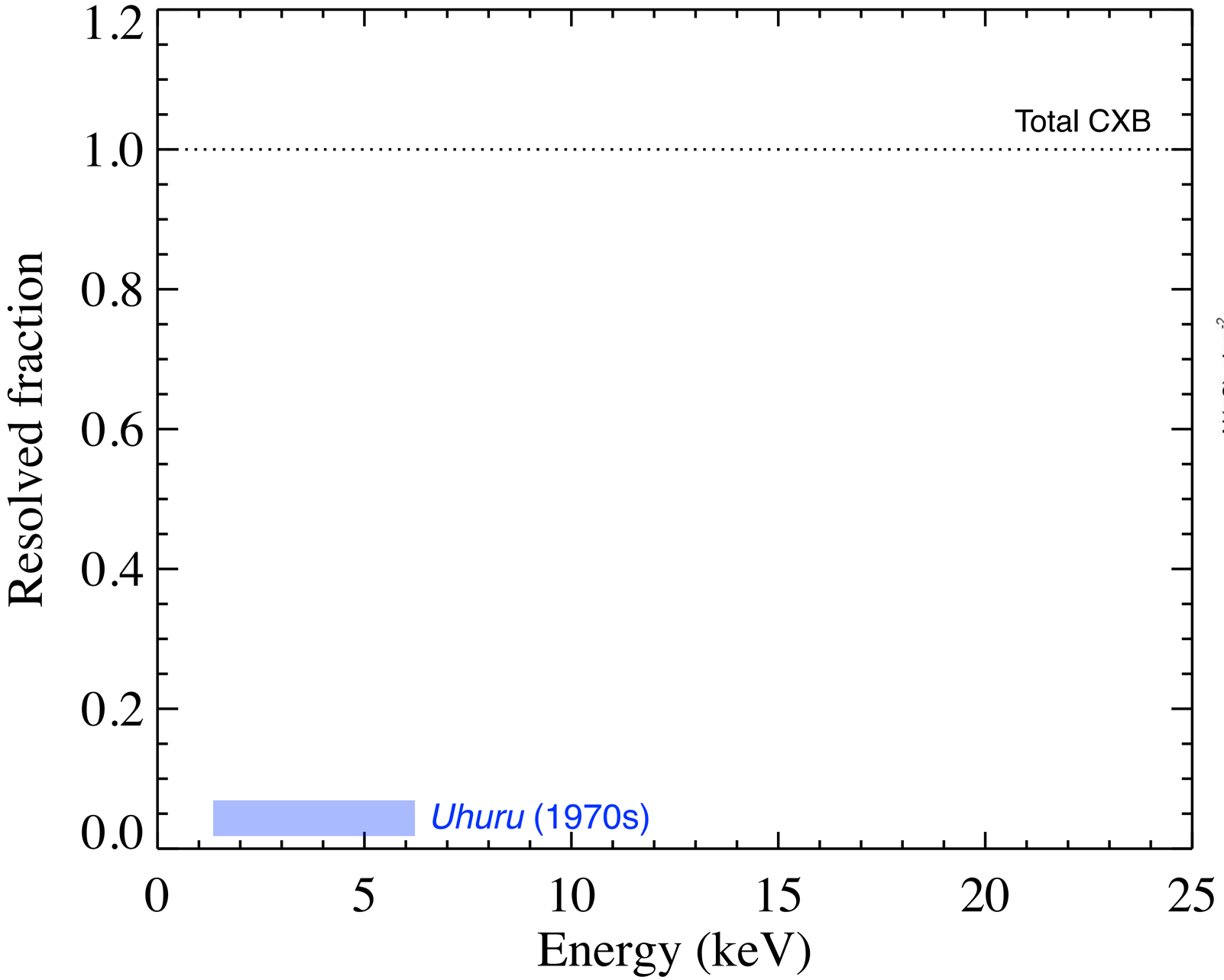
Quasar Number Counts and the X-ray Background

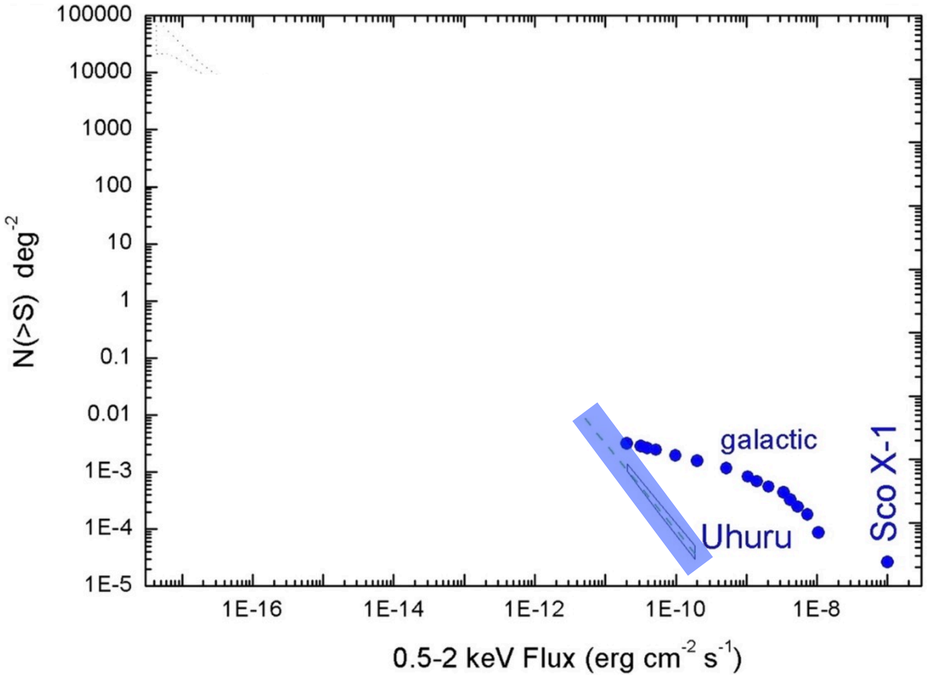
G. Setti[1] and L. Woltjer[2]

[1] Università di Bologna, Laboratorio di Radioastronomia C.N.R. Via Irnerio, 46, 40126 Bologna, Italy
[2] European Southern Observatory, c/o CERN, 1211 Geneve 23, Switzerland

Received April 6, 1979

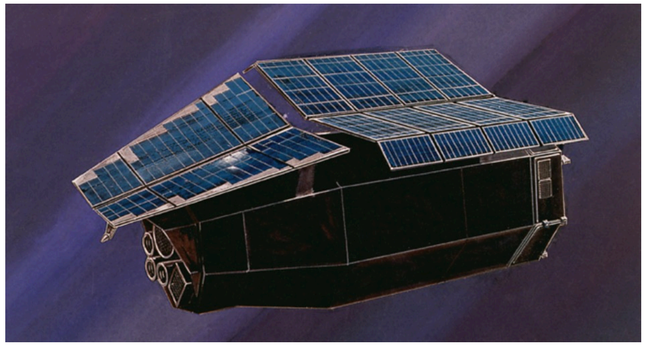
The **resolved fraction** of the CXB vs. energy





Giacconi & Rosati (2008)

1980s: *Einstein*



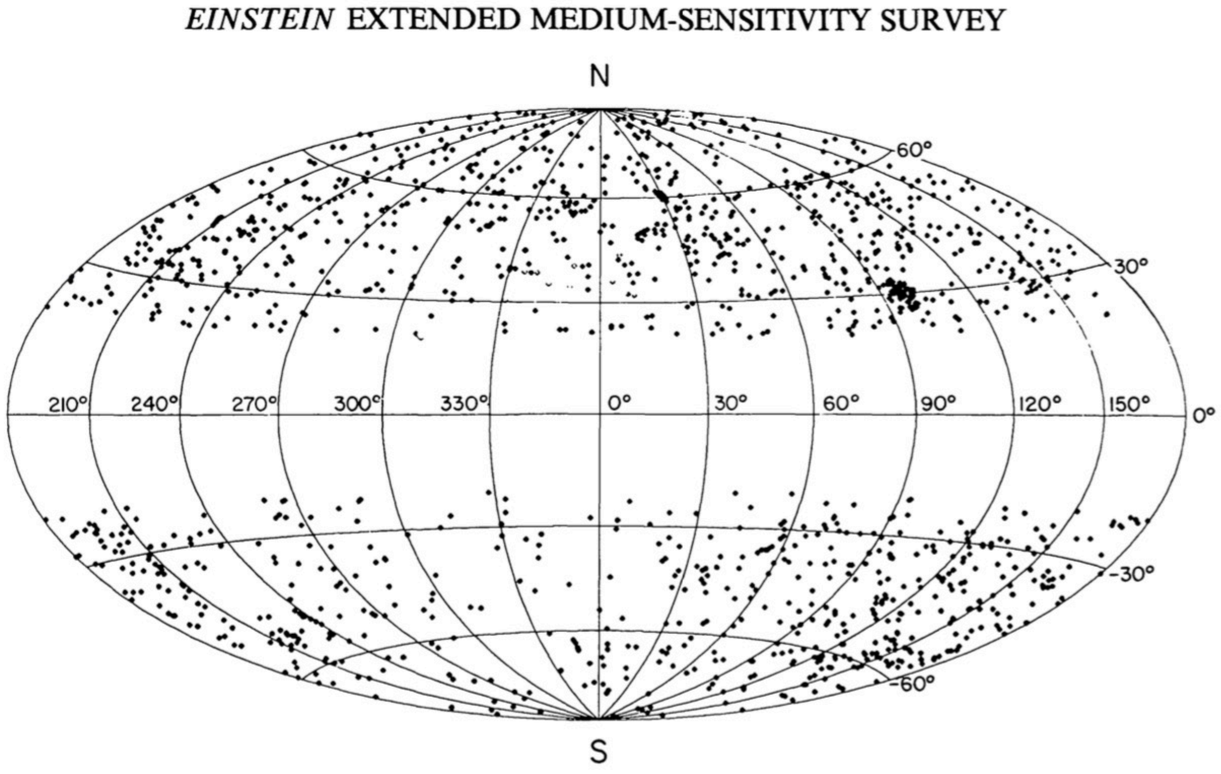
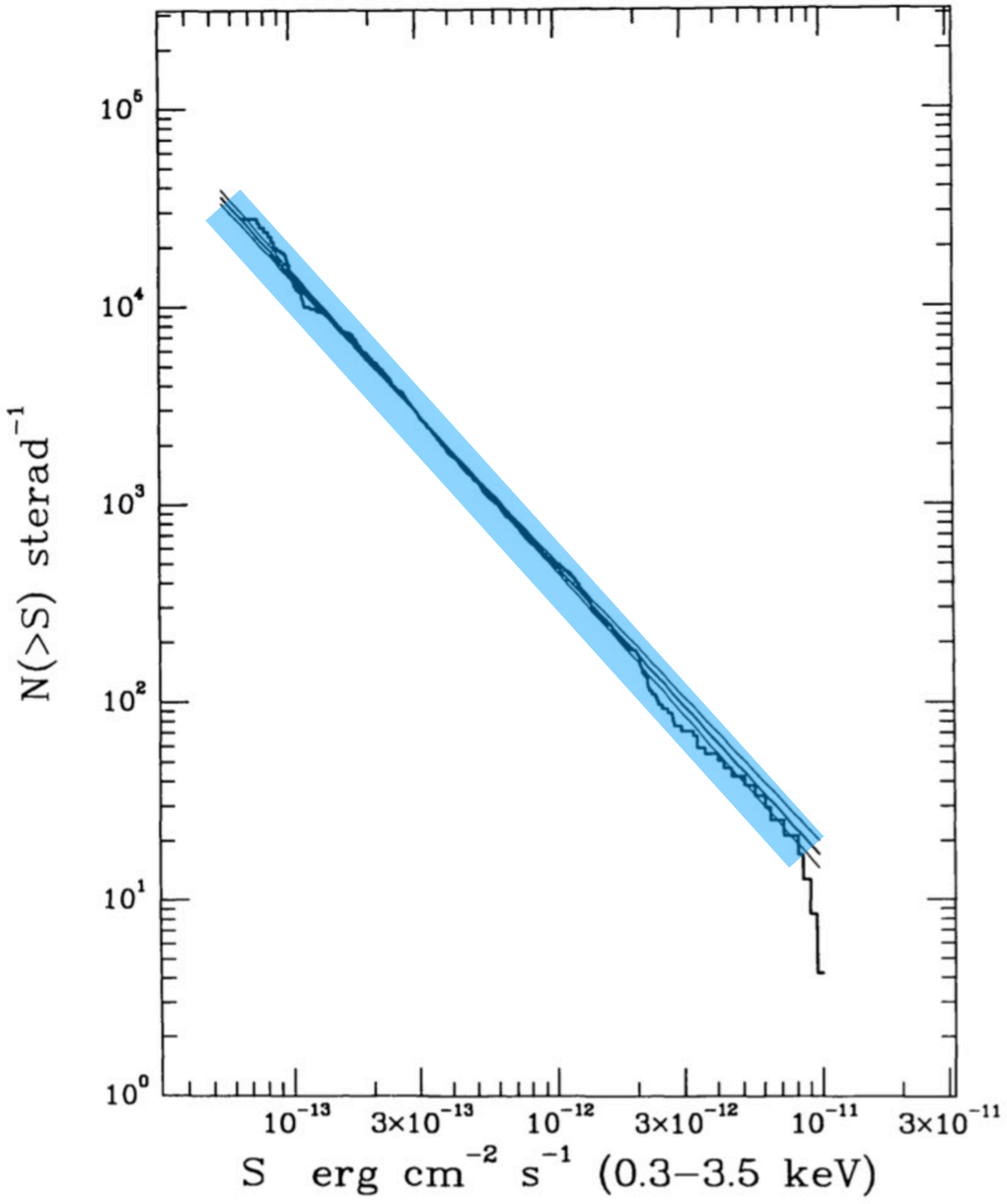
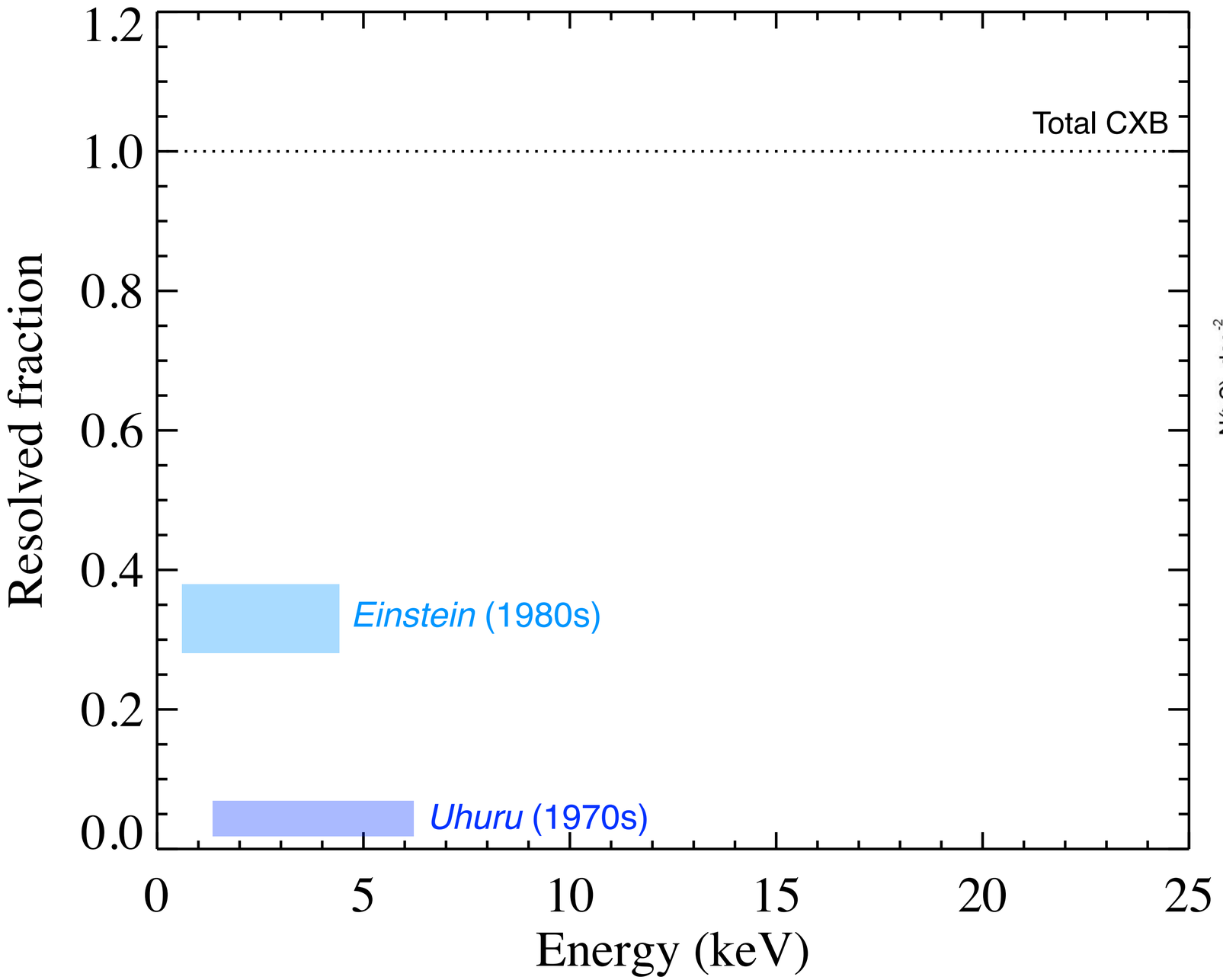
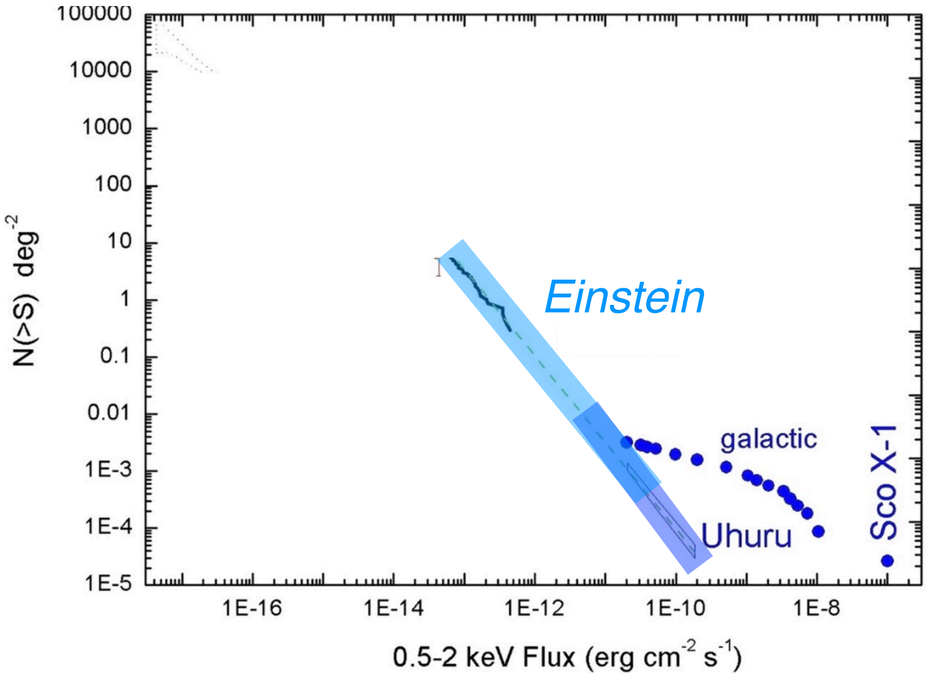


FIG. 2.—Distribution of IPC images used in the EMSS in Galactic coordinates



Gioia et al. (1990)


Resolved fraction
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Total CXB
Einstein (1980s)
Uhuru (1970s)
0
5
10
15
20
25
Energy (keV)


N(>S) deg-2
100000
10000
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
Einstein
galactic
Uhuru
Sco X-1
1E-16
1E-14
1E-12
1E-10
1E-8
0.5-2 keV Flux (erg cm-2 s-1)

1990s: *ROSAT*

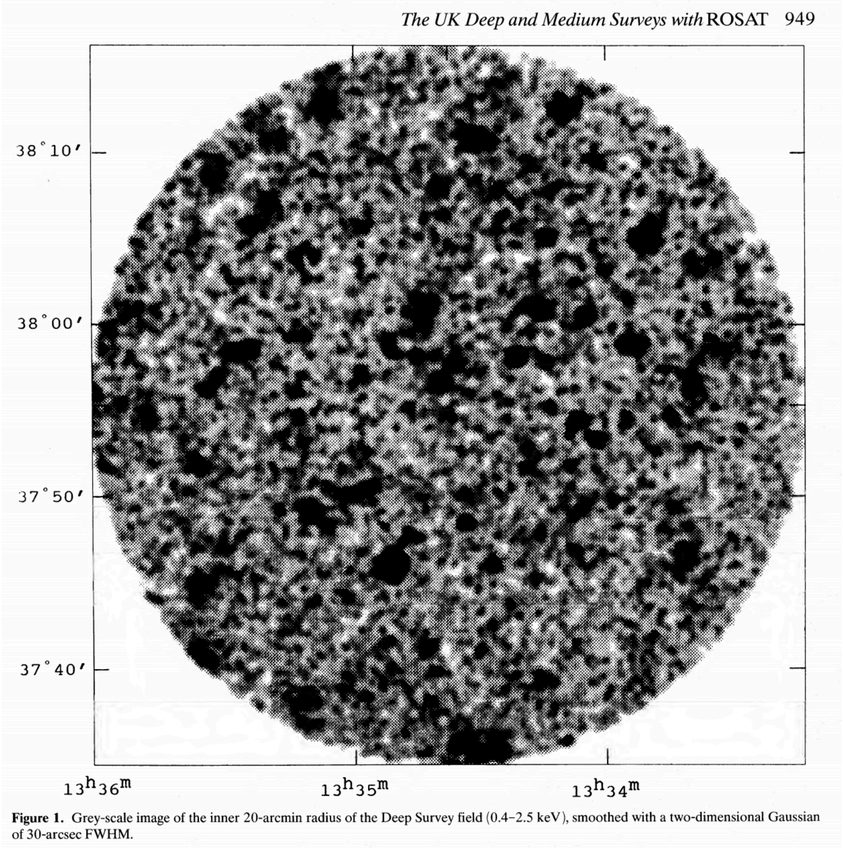
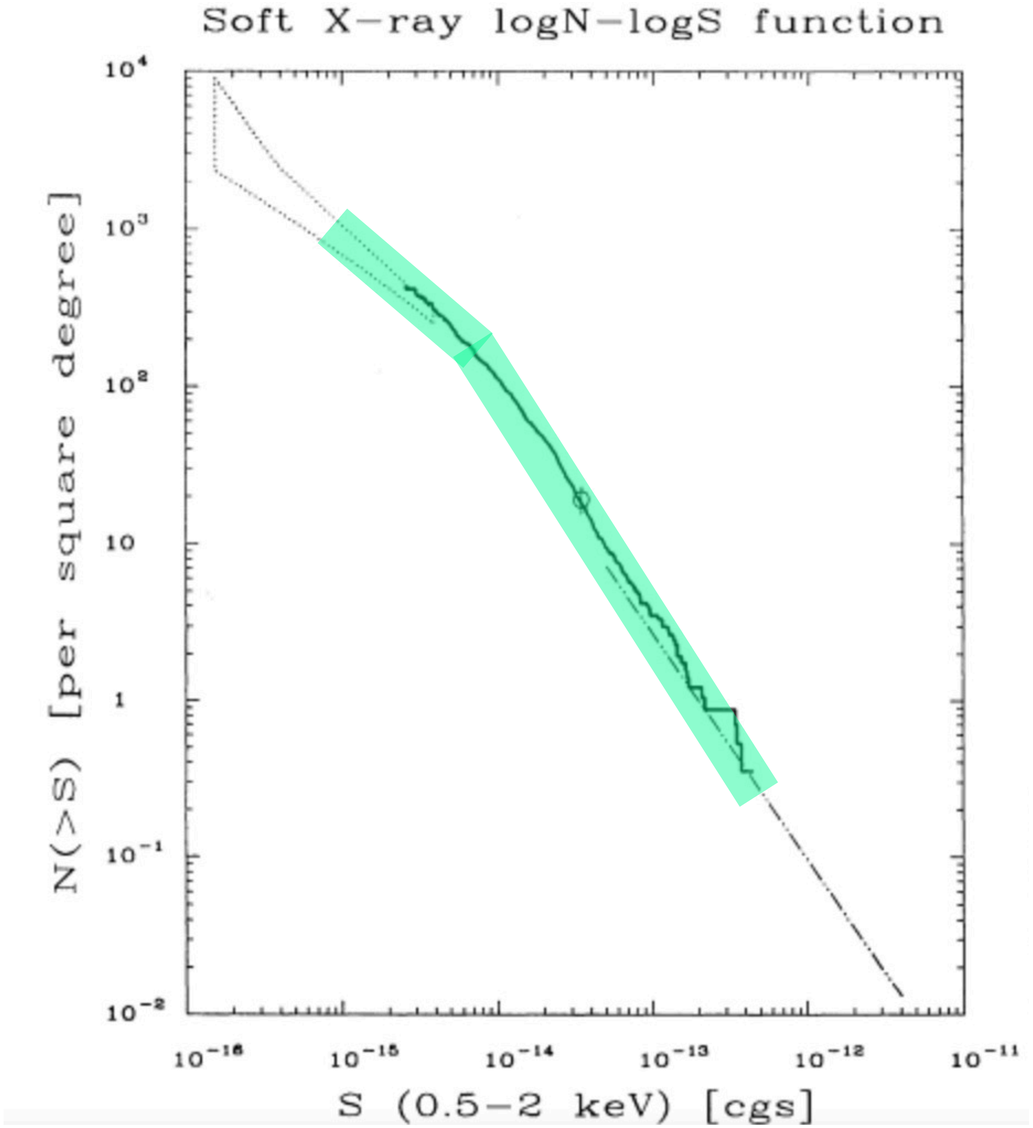
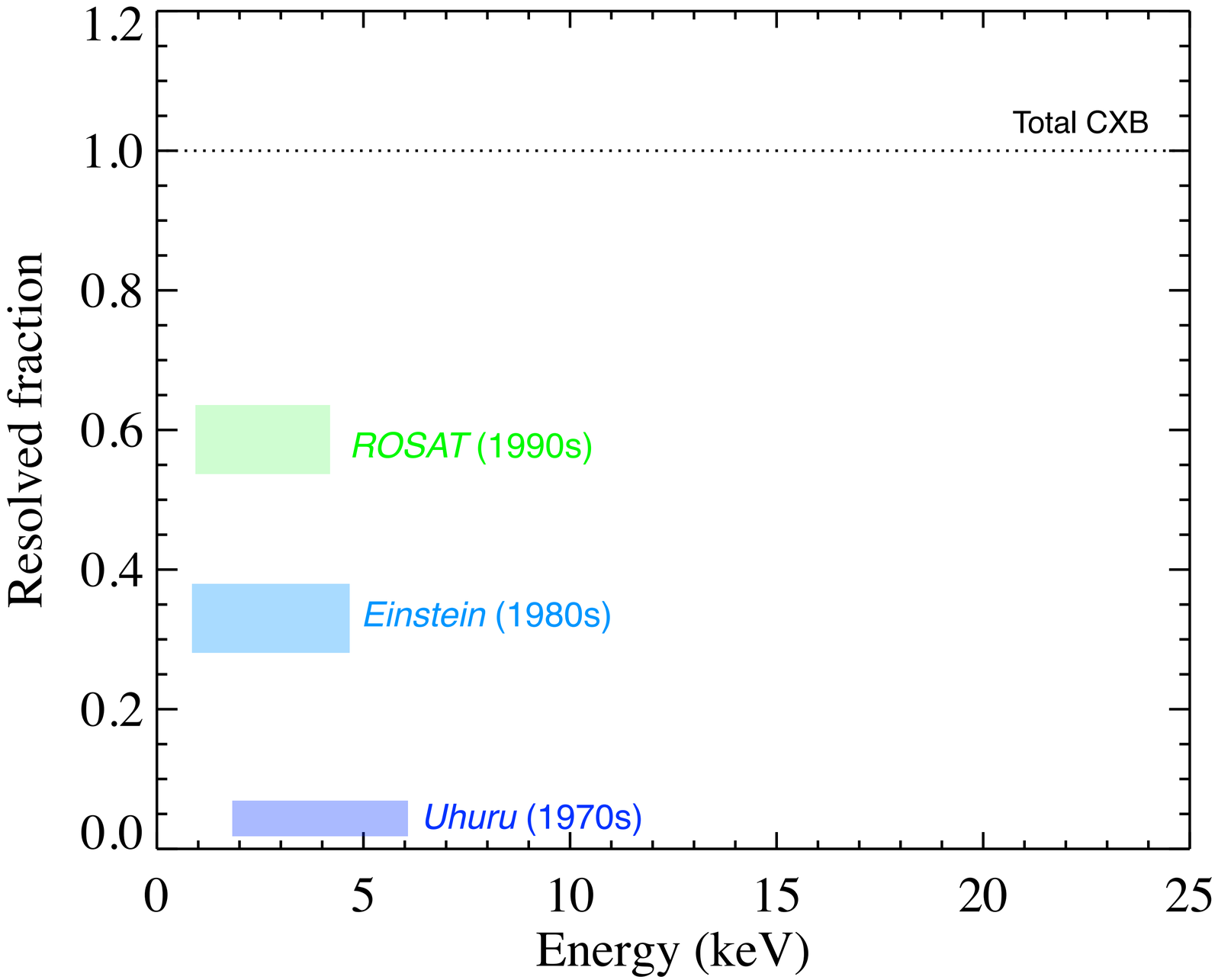
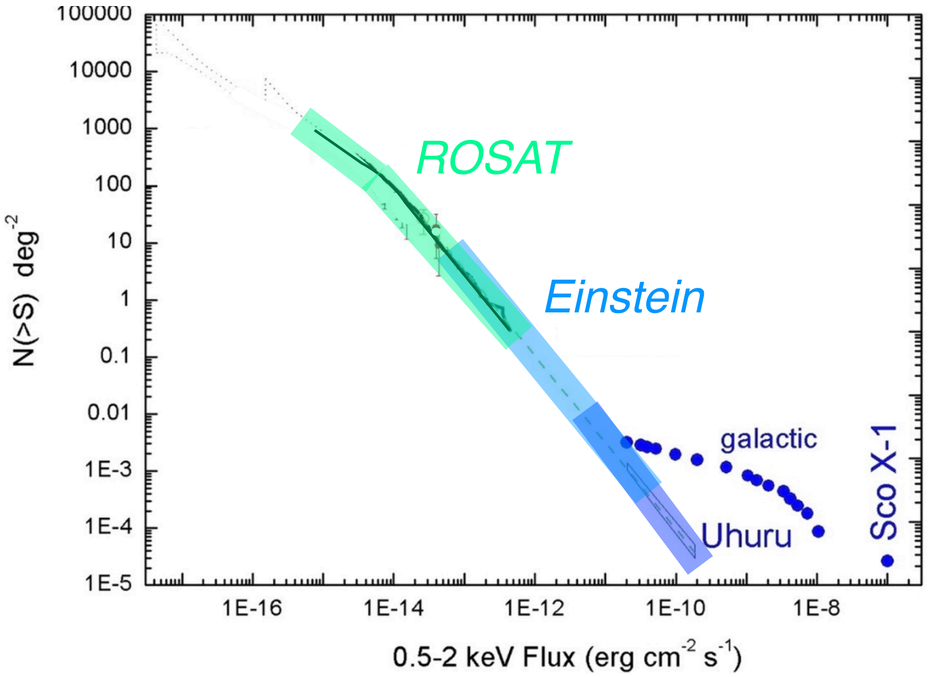


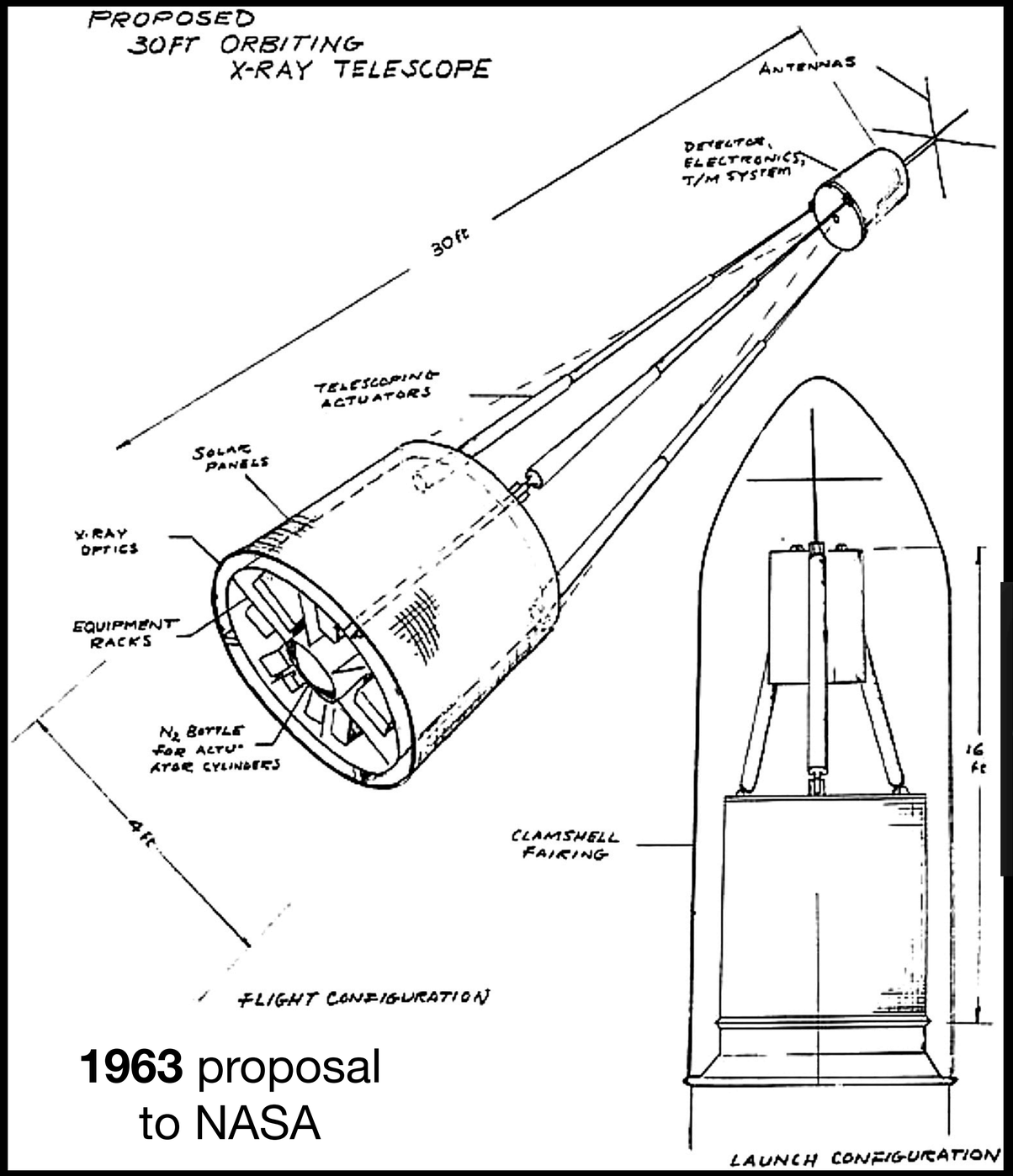
Figure 1. Grey-scale image of the inner 20-arcmin radius of the Deep Survey field (0.4–2.5 keV), smoothed with a two-dimensional Gaussian of 30-arcsec FWHM.



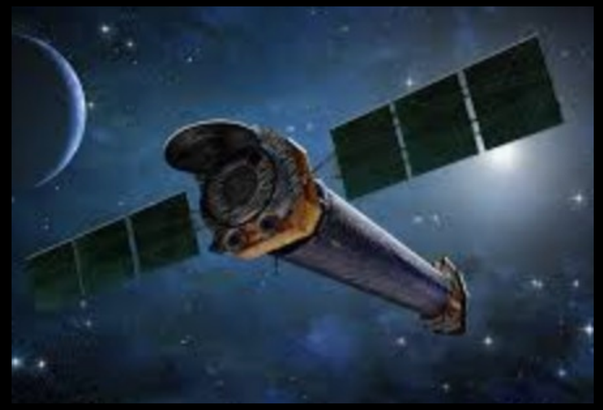
Hasinger et al. (1990)


Resolved fraction
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
Energy (keV)
Total CXB
ROSAT (1990s)
Einstein (1980s)
Uhuru (1970s)


N(>S) deg^{-2}
100000
10000
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-16
1E-14
1E-12
1E-10
1E-8
0.5-2 keV Flux (erg cm^{-2} s^{-1})
ROSAT
Einstein
galactic
Uhuru
Sco X-1

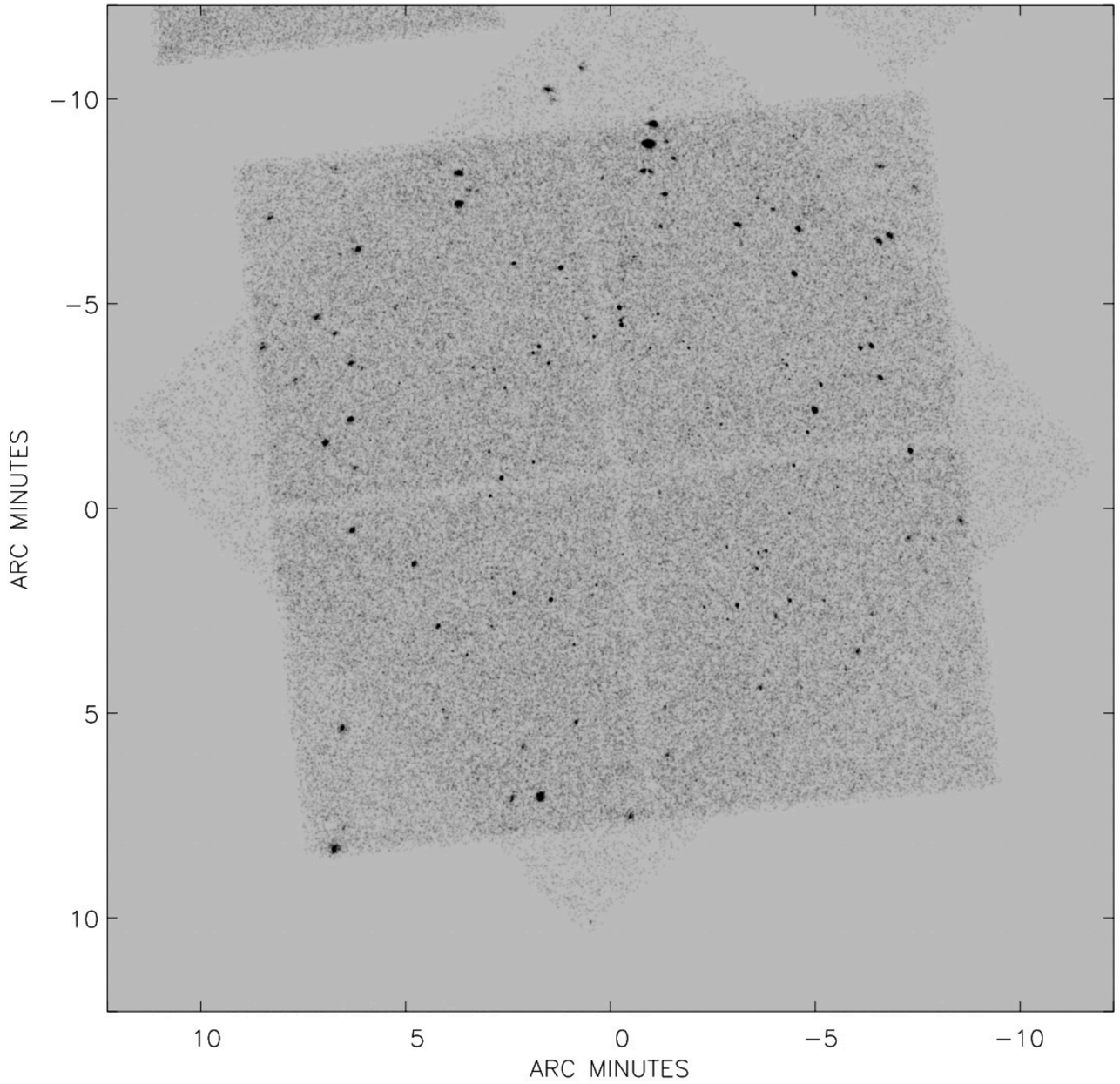


1963 proposal to NASA

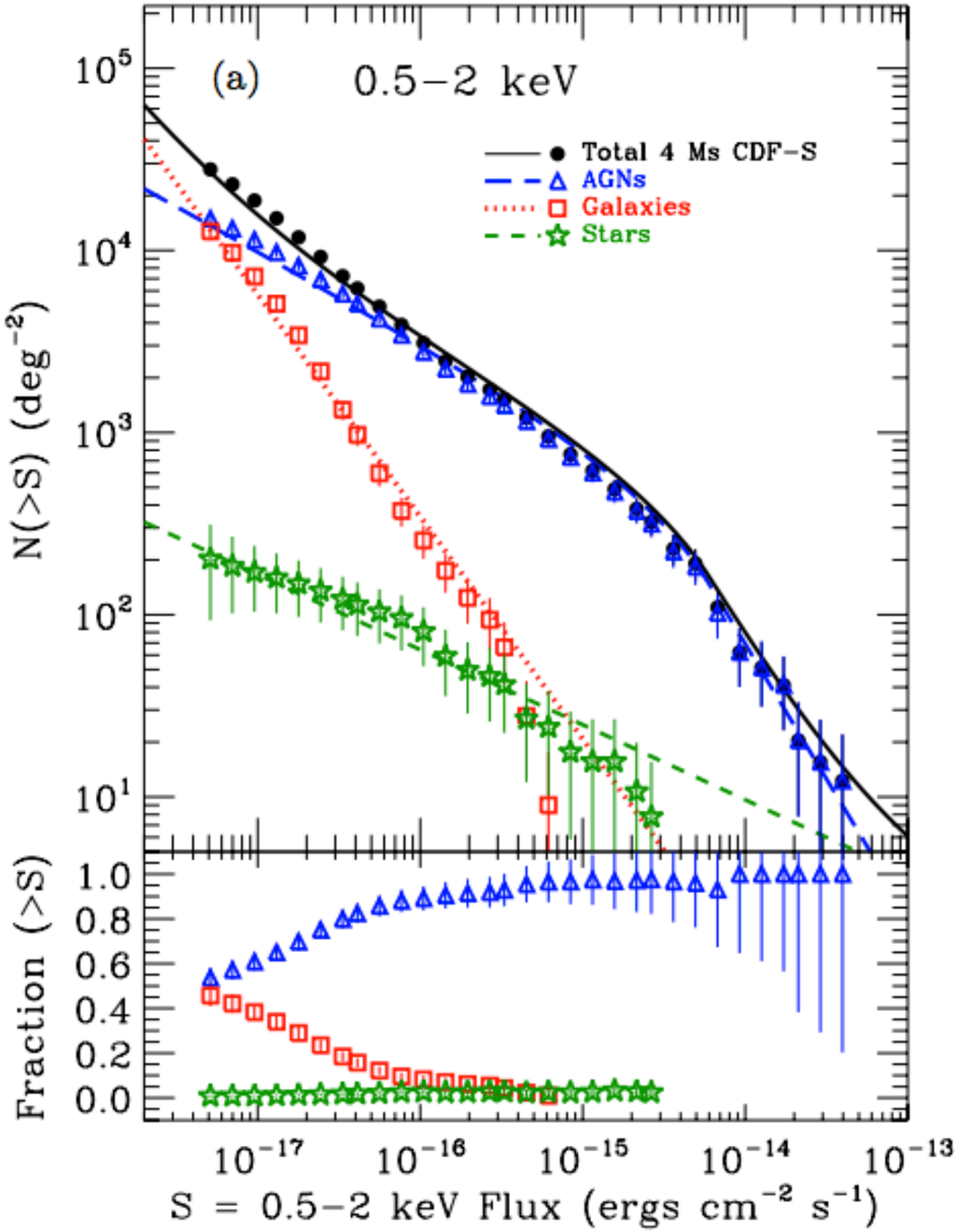


Chandra

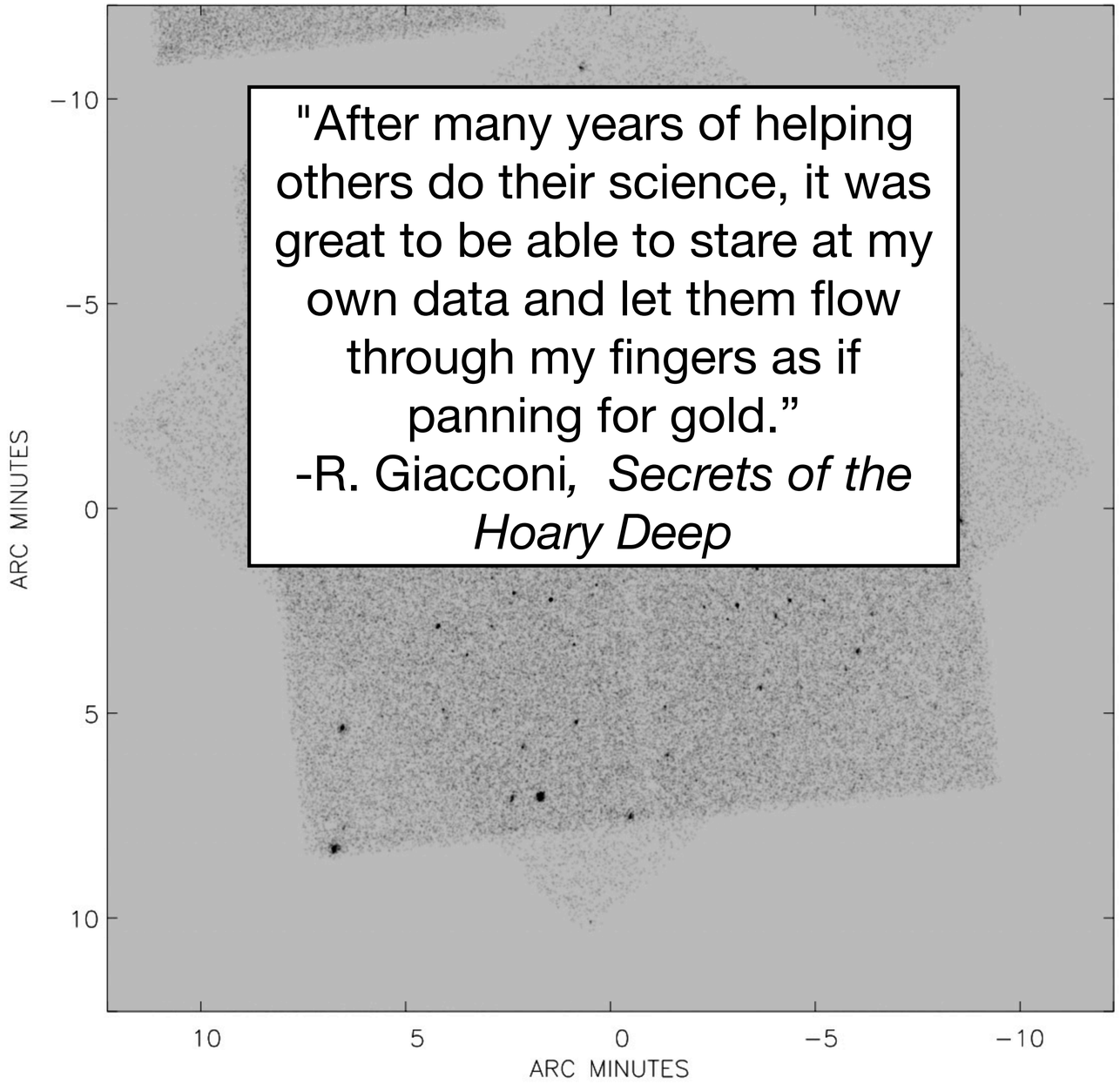
XMM-Newton



150 ks: Giacconi et al. (2001)

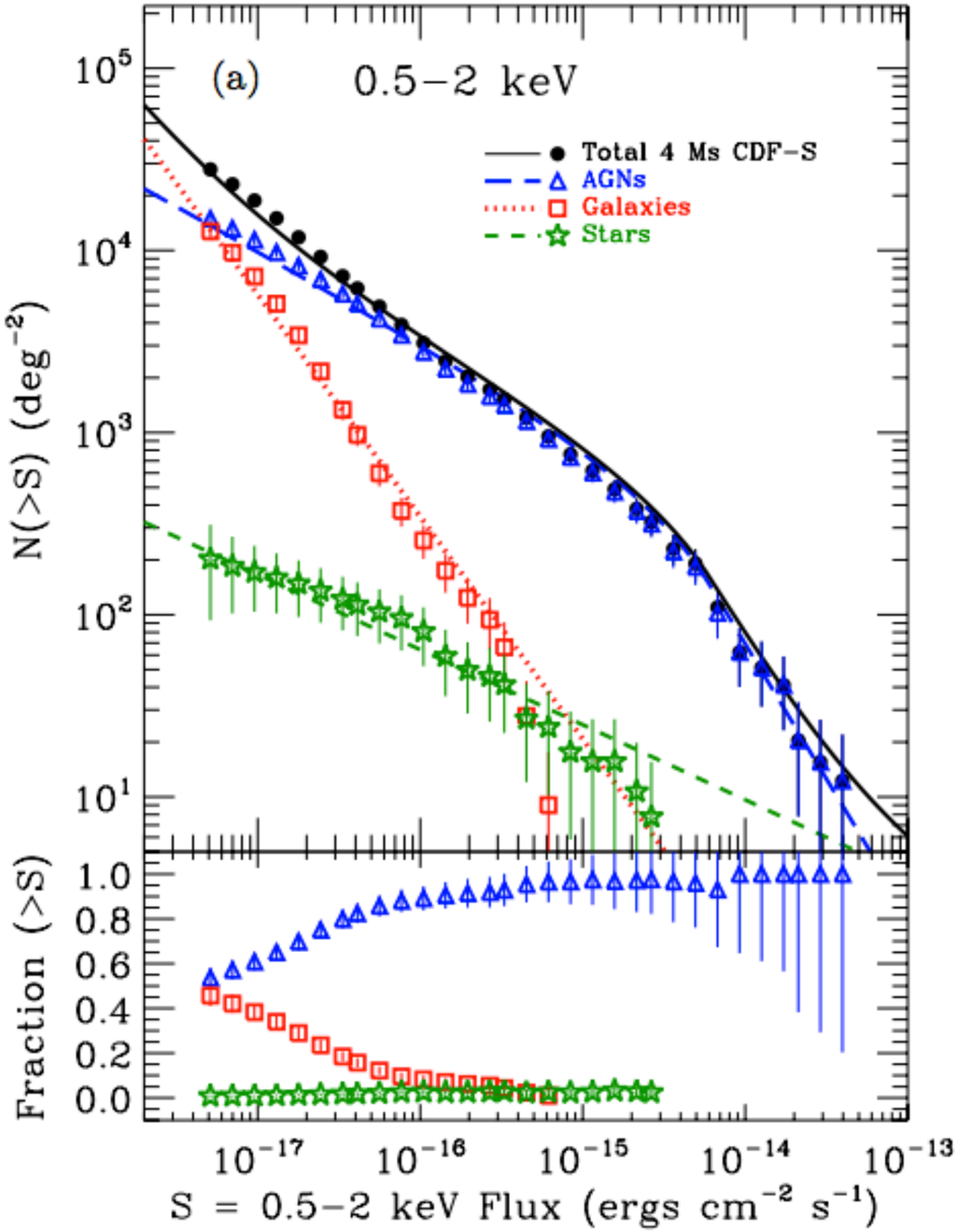


Lehmer et al. (2012)



"After many years of helping others do their science, it was great to be able to stare at my own data and let them flow through my fingers as if panning for gold."
-R. Giacconi, *Secrets of the Hoary Deep*

150 ks: Giacconi et al. (2001)



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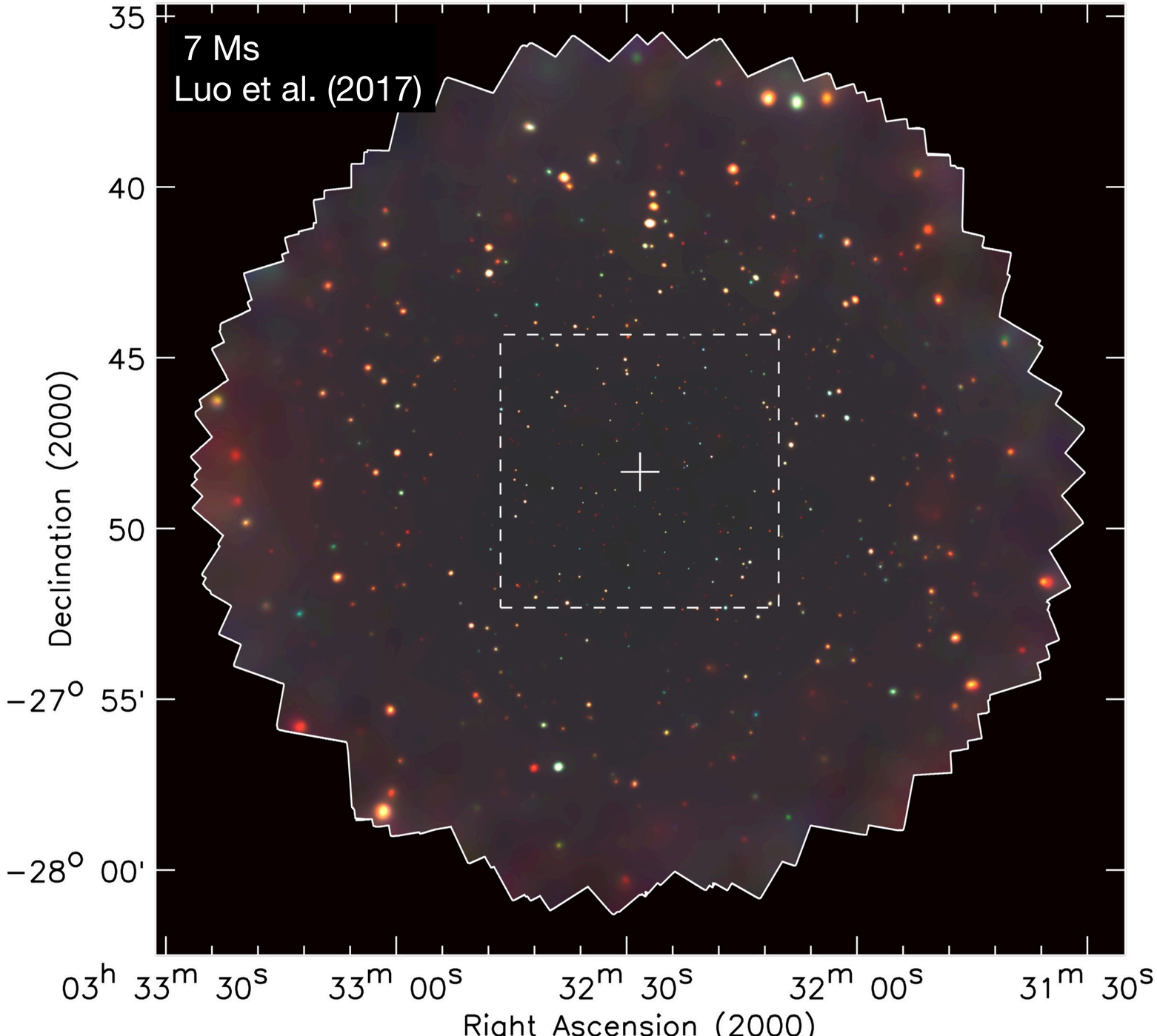
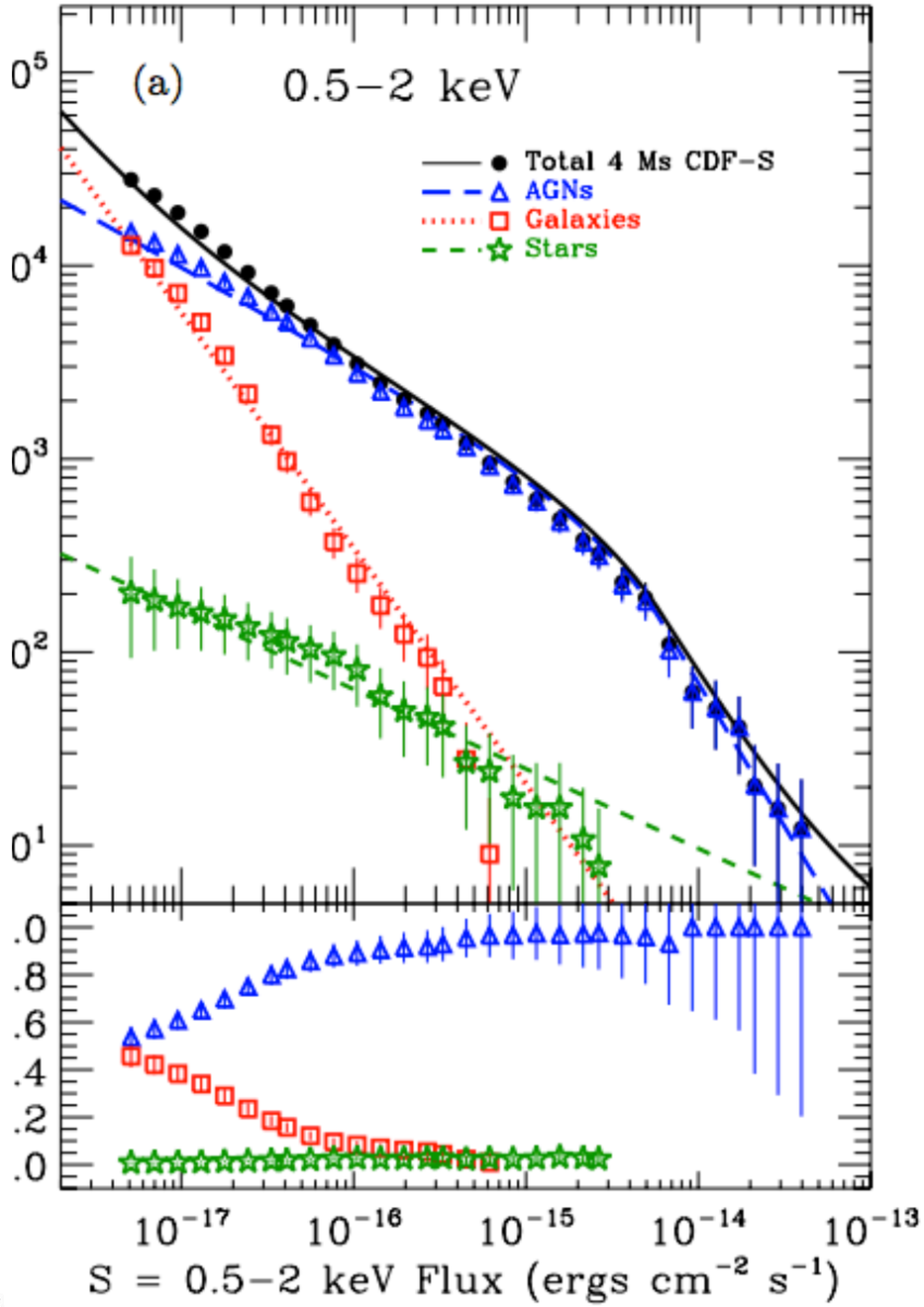


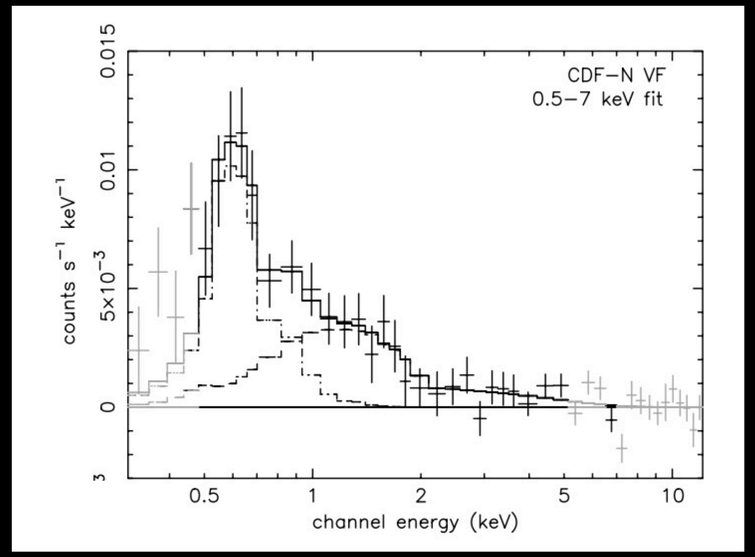


Lehmer et al. (2012)

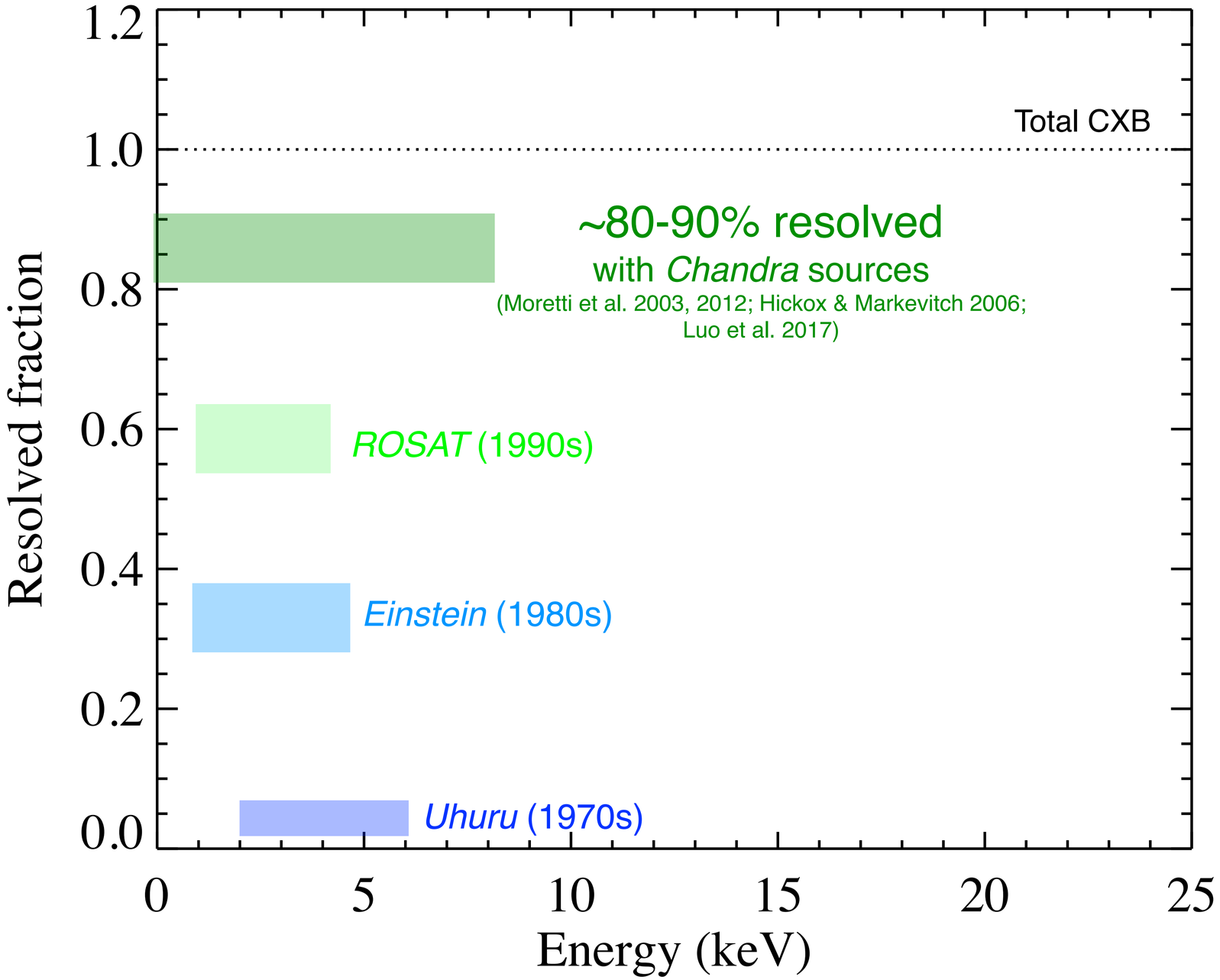
What is the **absolute unresolved background**?

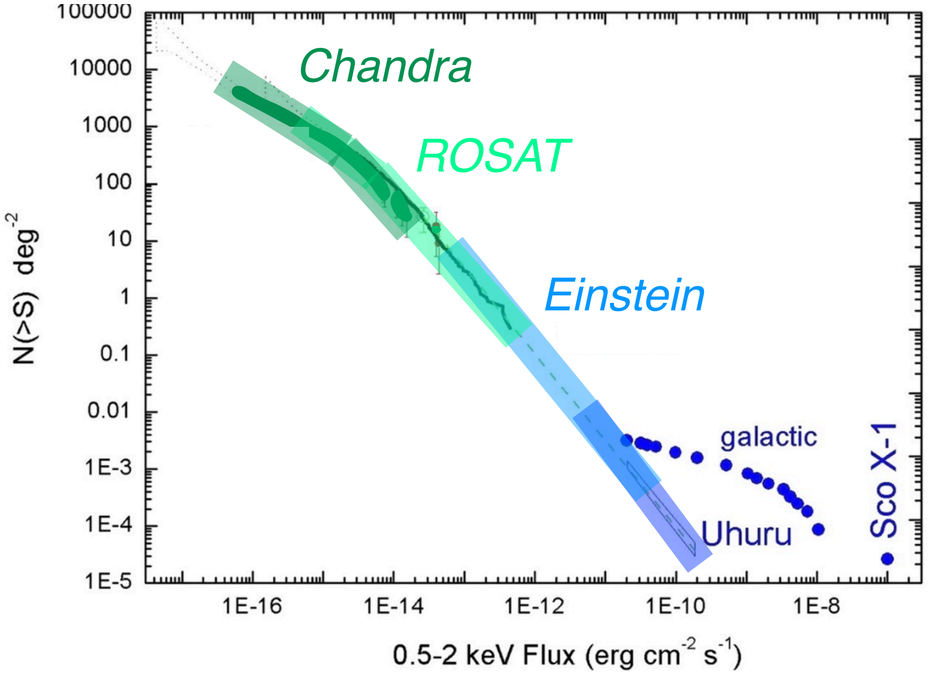
Requires careful subtraction of instrumental background

~80% of 0.5-8 keV background is resolved



Hickox & Markevitch (2006)


Resolved fraction
Energy (keV)
Total CXB
~80-90% resolved
with *Chandra* sources
(Moretti et al. 2003, 2012; Hickox & Markevitch 2006;
Luo et al. 2017)
ROSAT (1990s)
Einstein (1980s)
Uhuru (1970s)


N(>S) deg^{-2}
0.5-2 keV Flux (erg cm^{-2} s^{-1})
Chandra
ROSAT
Einstein
galactic
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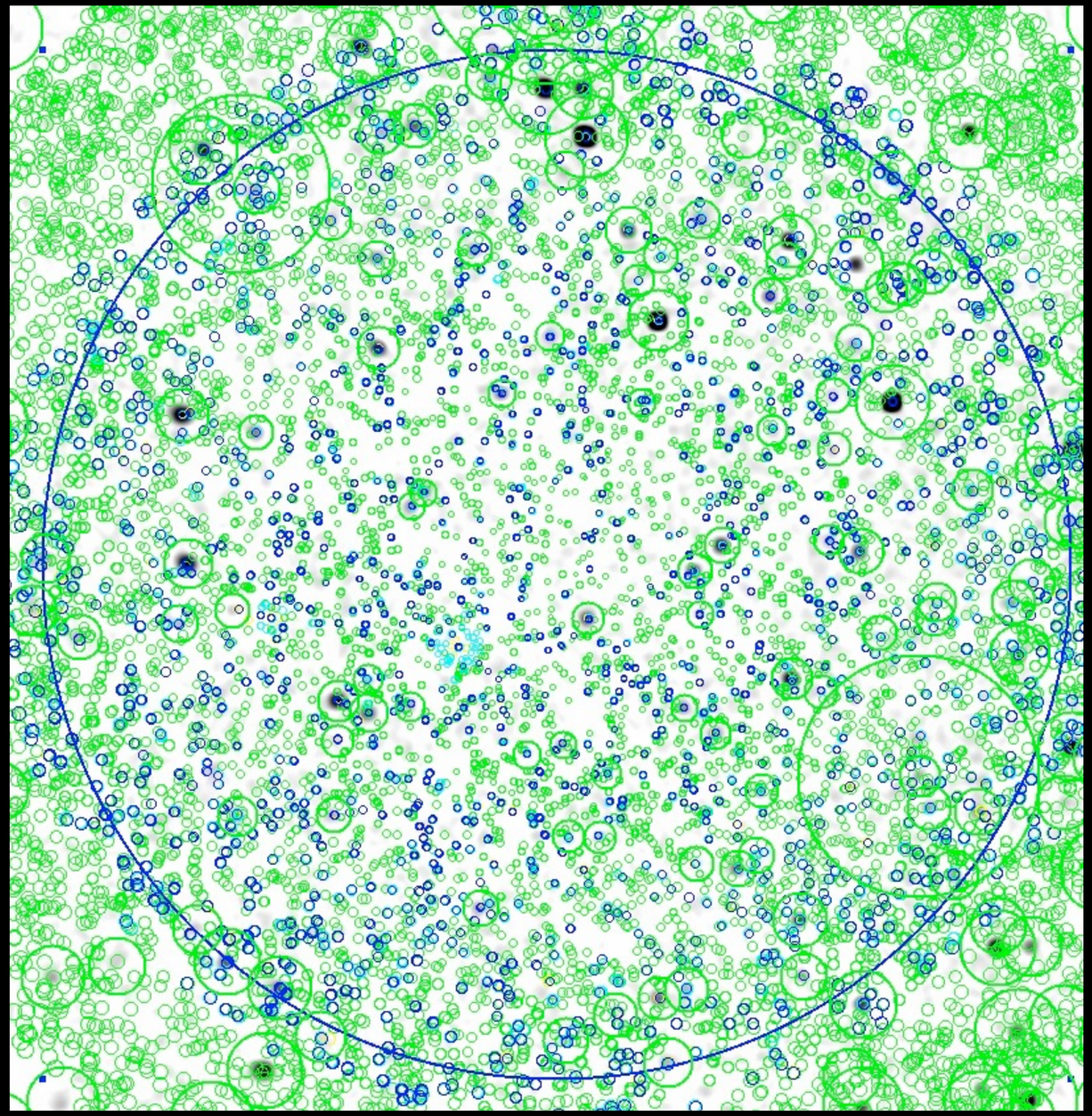
Sco X-1

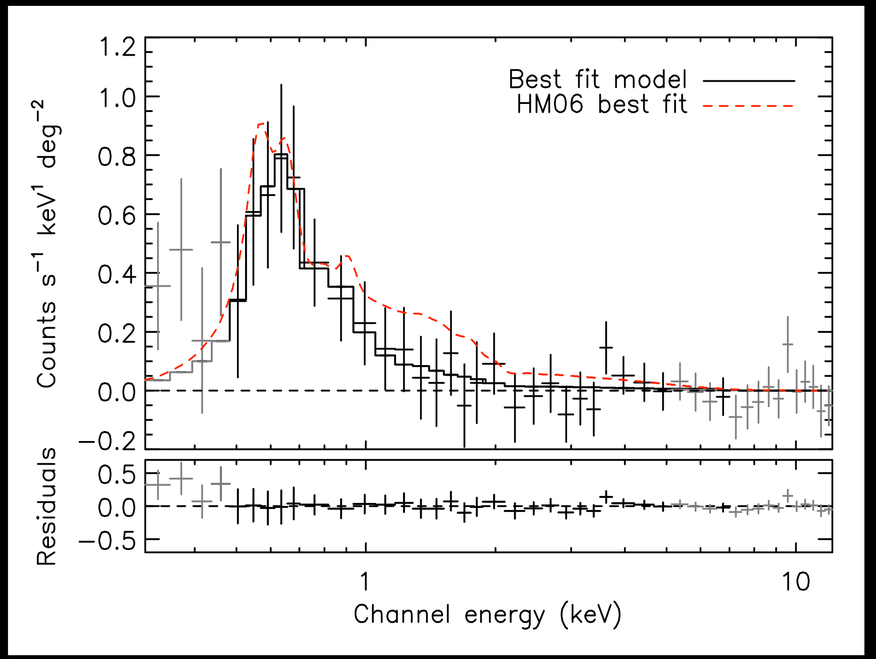


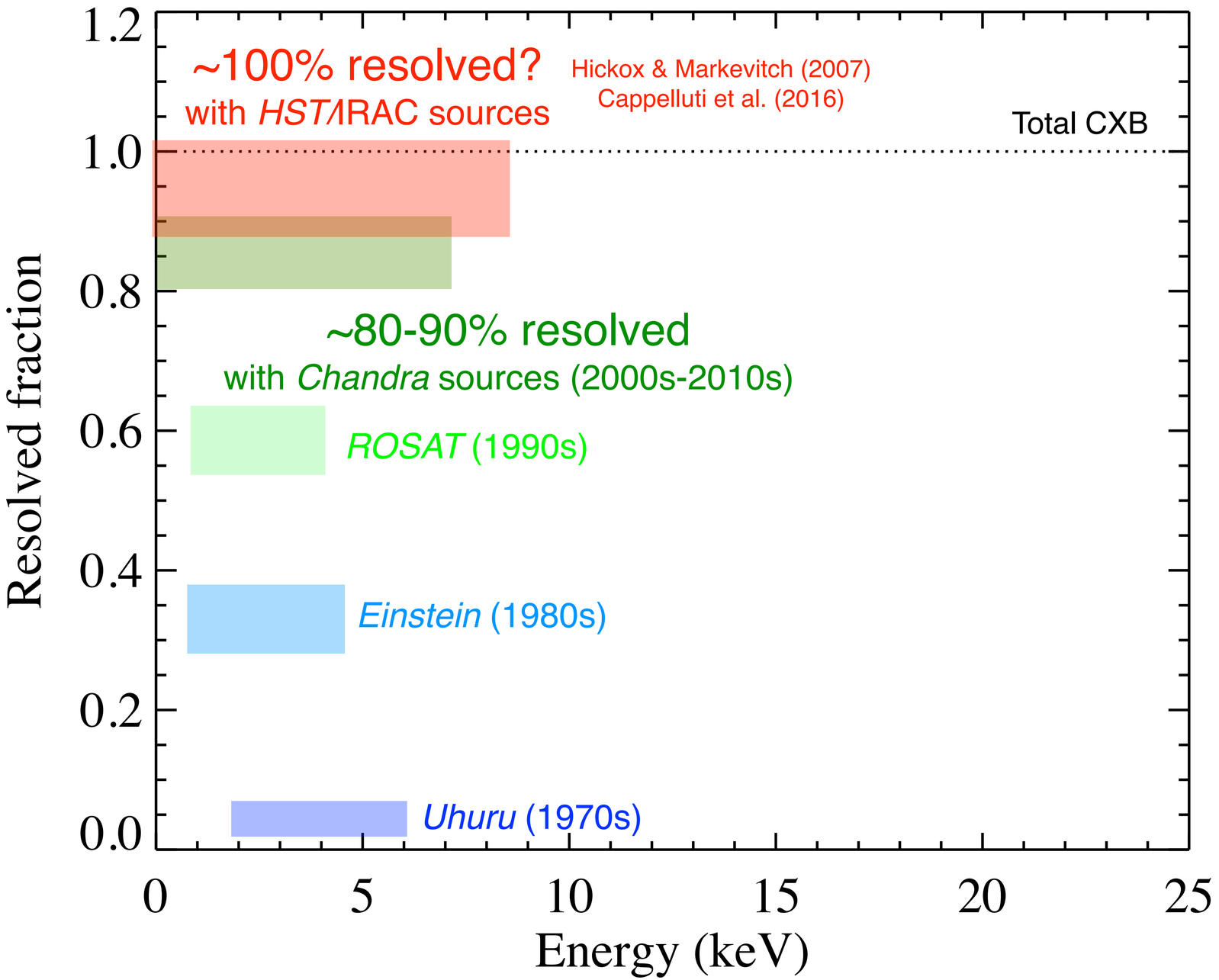
Hickox & Markevitch (2007a)
See also Worsley et al. (2006); Xue et al. (2012)

Exclude even optical/IR sources and **directly measure** the residual unresolved signal

Exclusion of *HST* z band
and IRAC sources

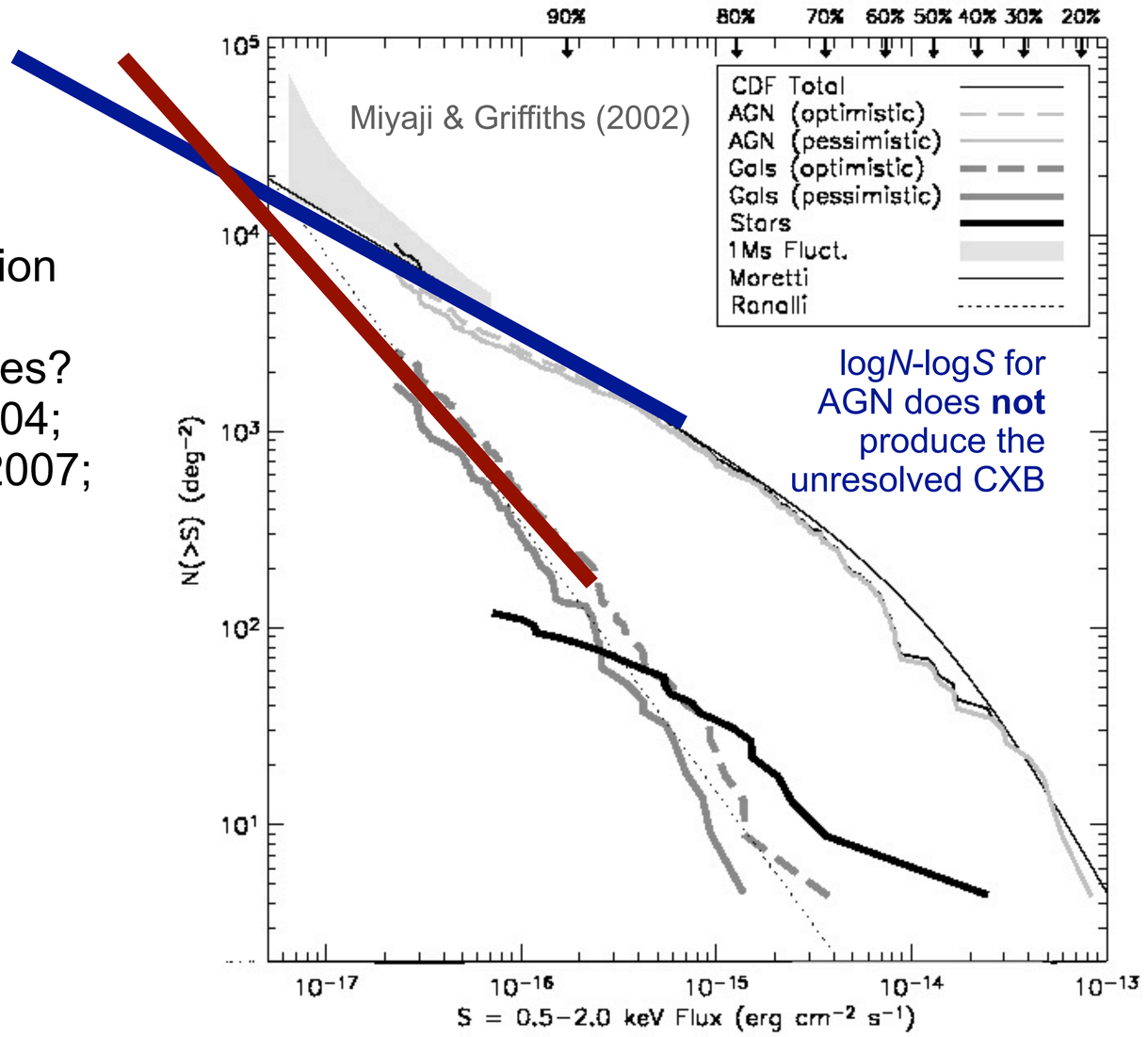
After exclusion of these sources, only **7%±3%** of the 1-2 keV CXB remains.




~100% resolved?
with HST/IRAC sources
Hickox & Markevitch (2007)
Cappelluti et al. (2016)
Total CXB
~80-90% resolved
with Chandra sources (2000s-2010s)
ROSAT (1990s)
Einstein (1980s)
Uhuru (1970s)
Resolved fraction
Energy (keV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
5
10
15
20
25

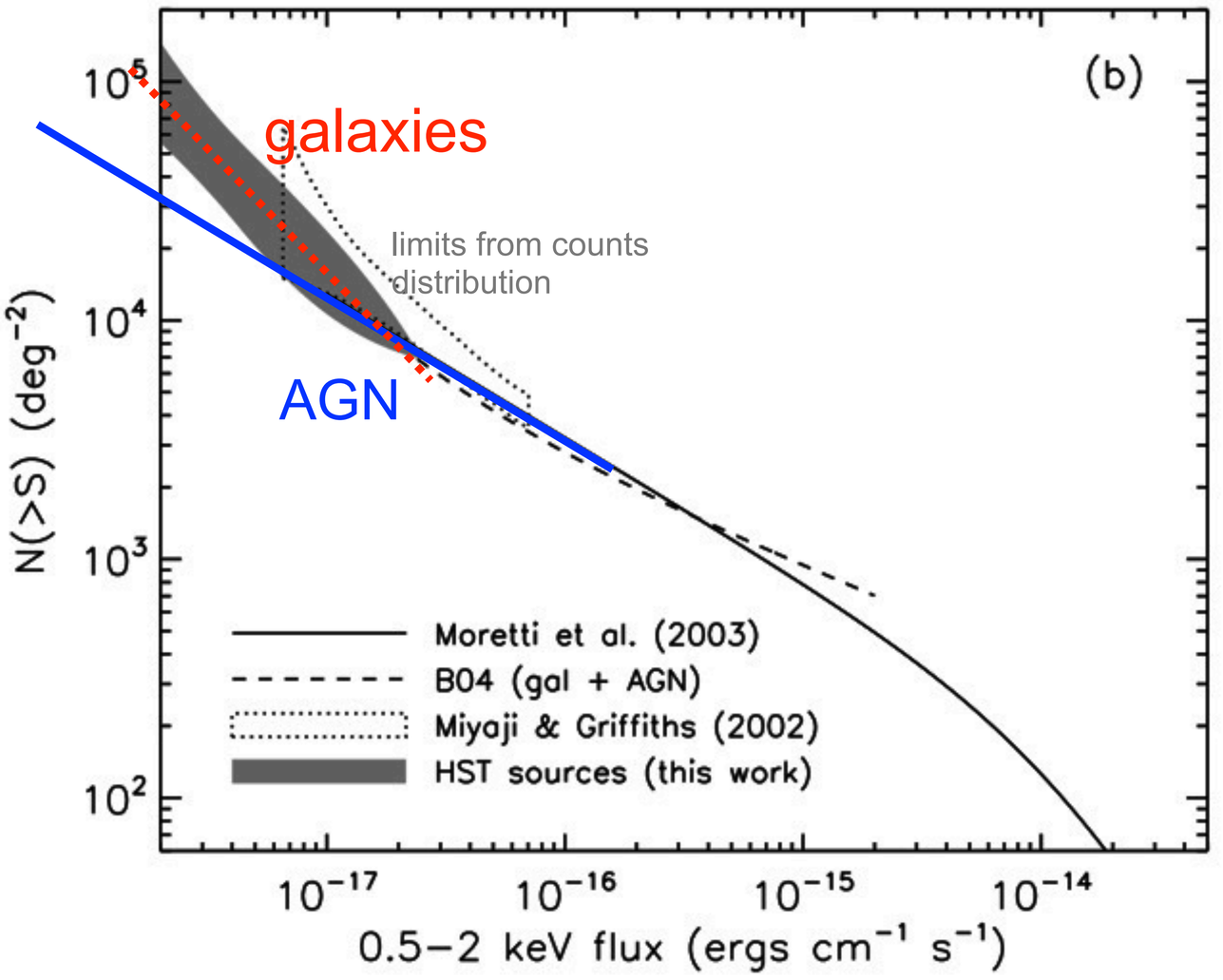
What are the faint, unresolved sources?

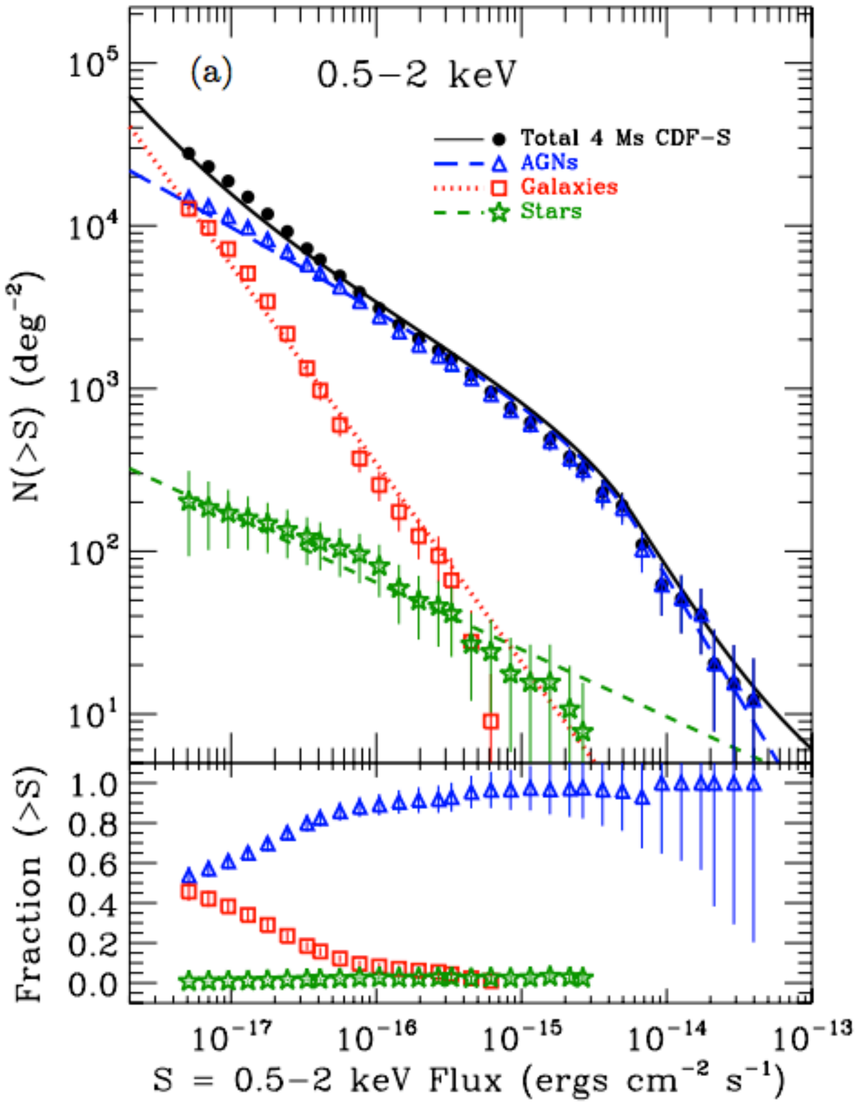
Significant contribution from star-forming galaxies at faint fluxes? (e.g. Bauer et al. 2004; Georgakakis et al. 2007; Lehmer et al. 2012)



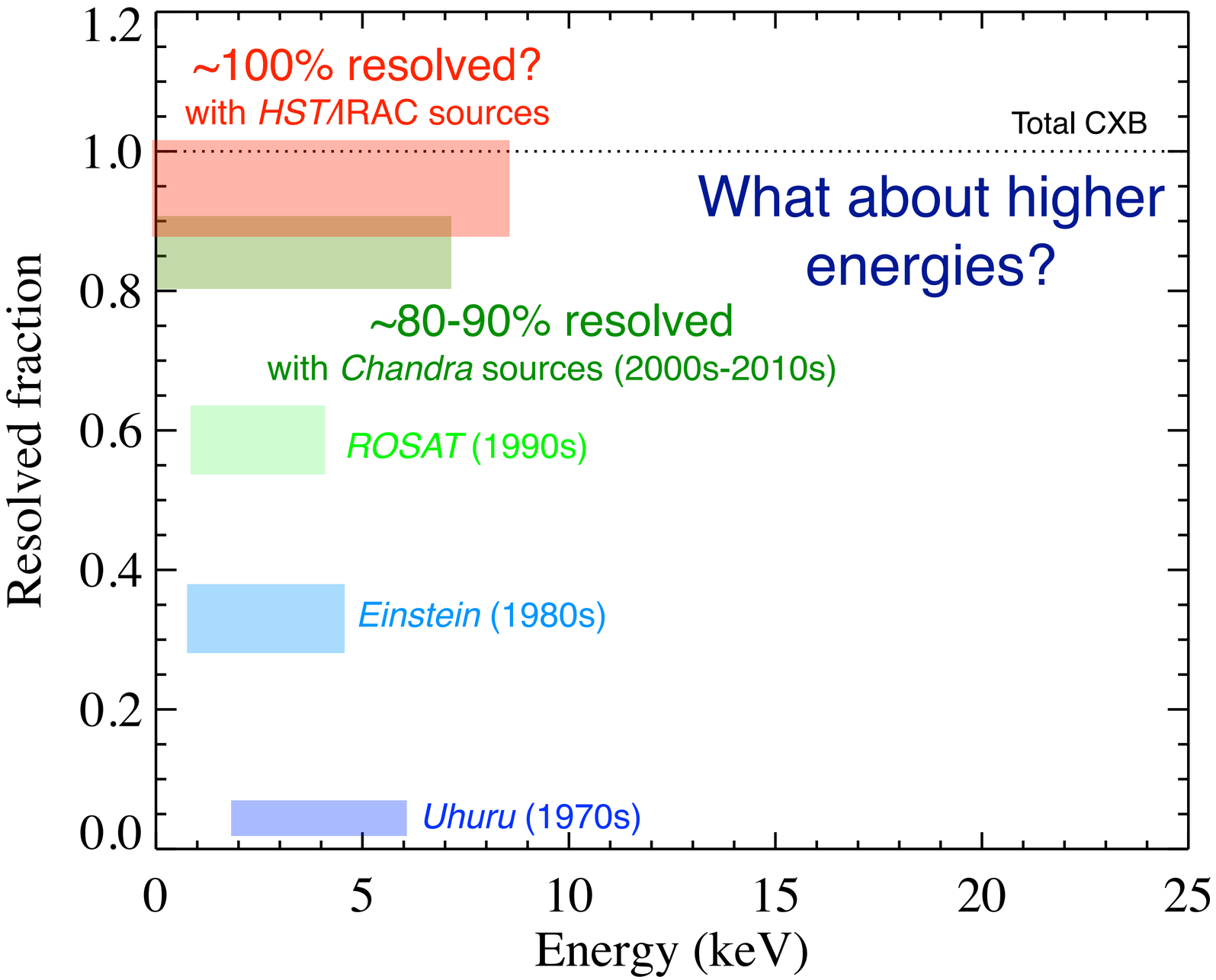
Bauer et al. (2004)

Unresolved soft sources consistent with star-forming galaxies



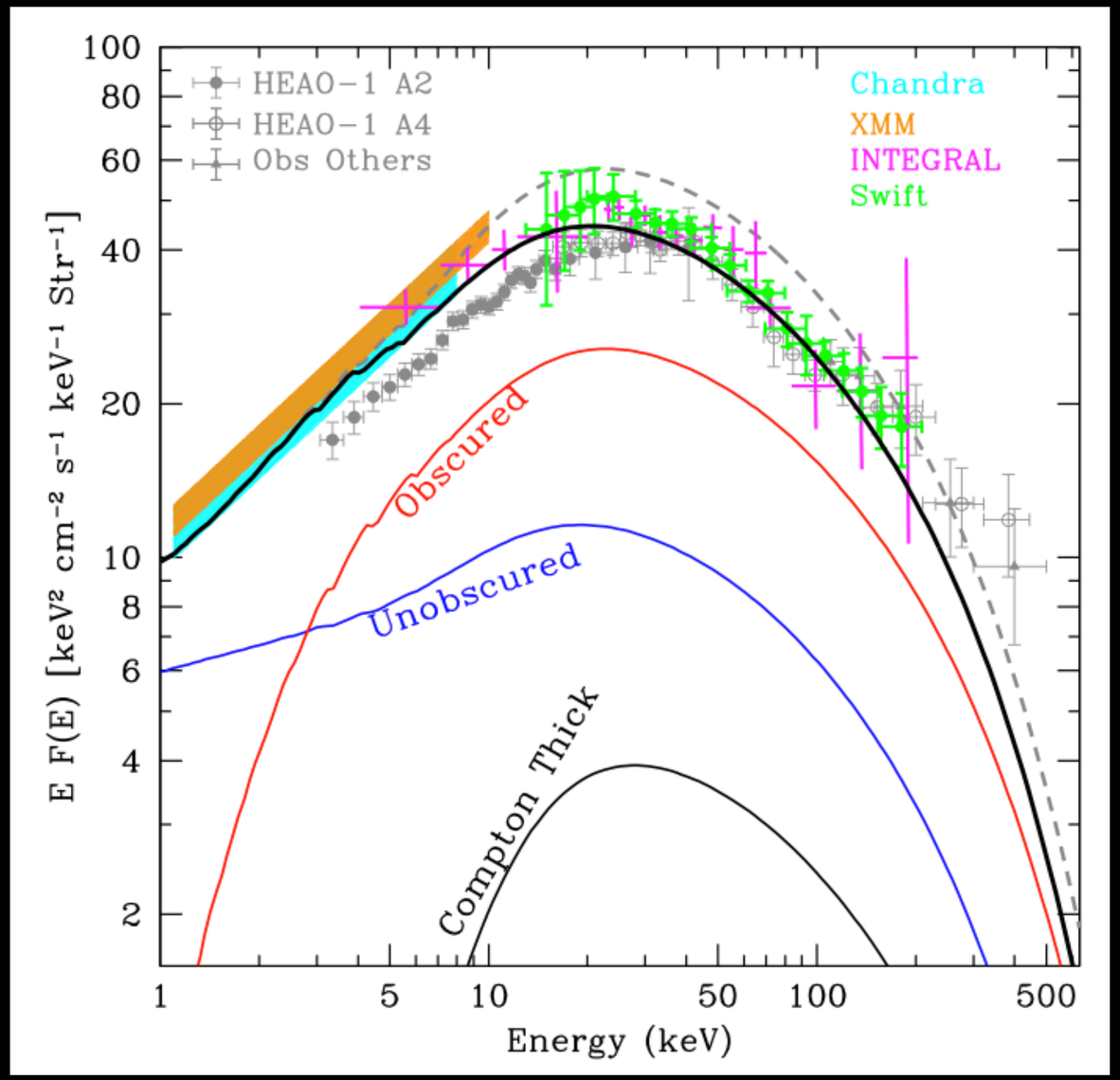


Hickox & Markevitch (2007b)


~100% resolved?
with HST/IRAC sources
Total CXB
What about higher energies?
~80-90% resolved
with Chandra sources (2000s-2010s)
ROSAT (1990s)
Einstein (1980s)
Uhuru (1970s)
Resolved fraction
Energy (keV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
5
10
15
20
25

Origin of the cosmic X-ray background

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. 2018)



Treister et al. (2009)

Origin of the cosmic X-ray background

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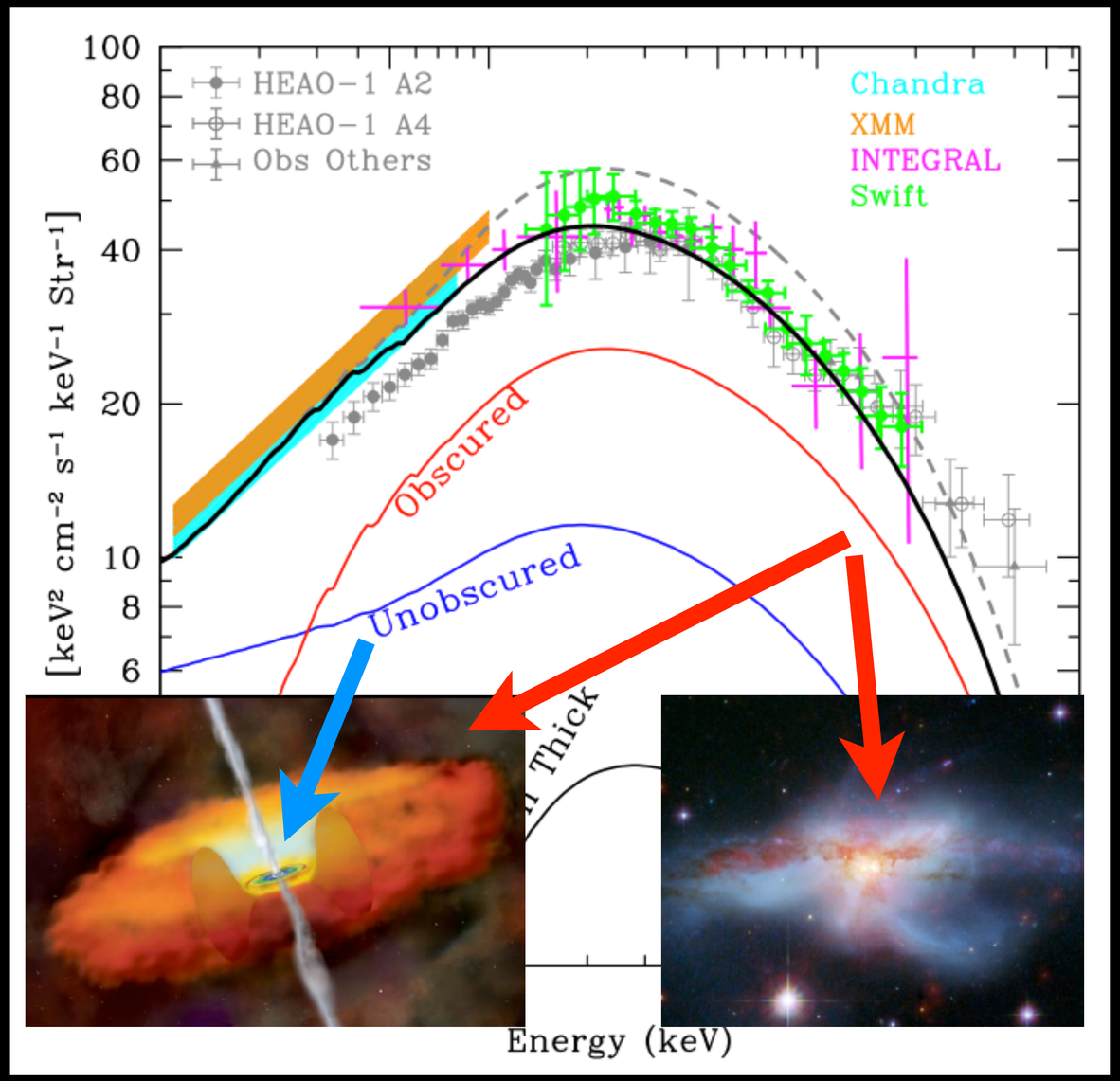
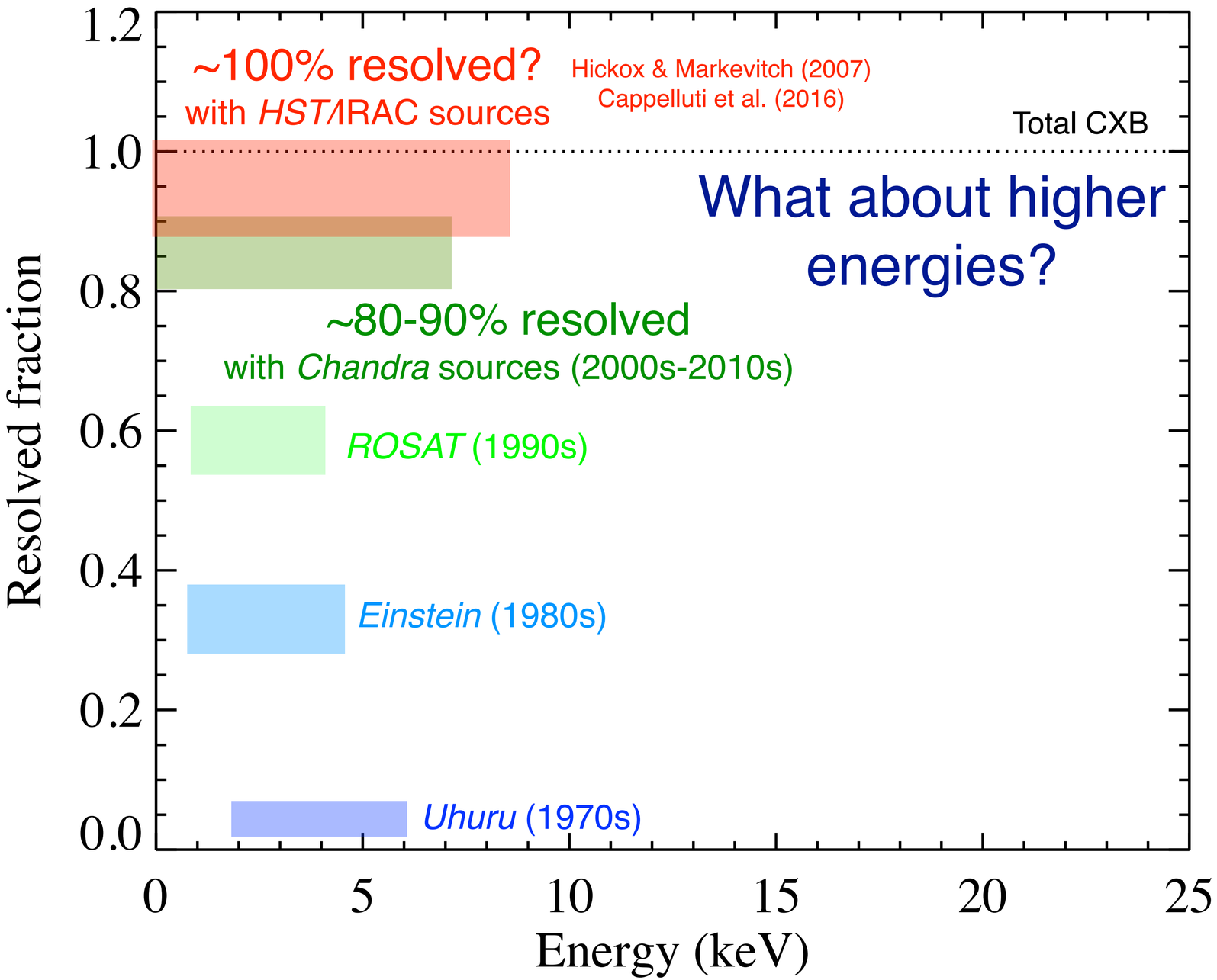


Treister et al. (2009)


~100% resolved?
with HST/IRAC sources
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Cappelluti et al. (2016)
Total CXB
What about higher energies?
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Resolved fraction
Energy (keV)
0.0
0.2
0.4
0.6
0.8
1.0
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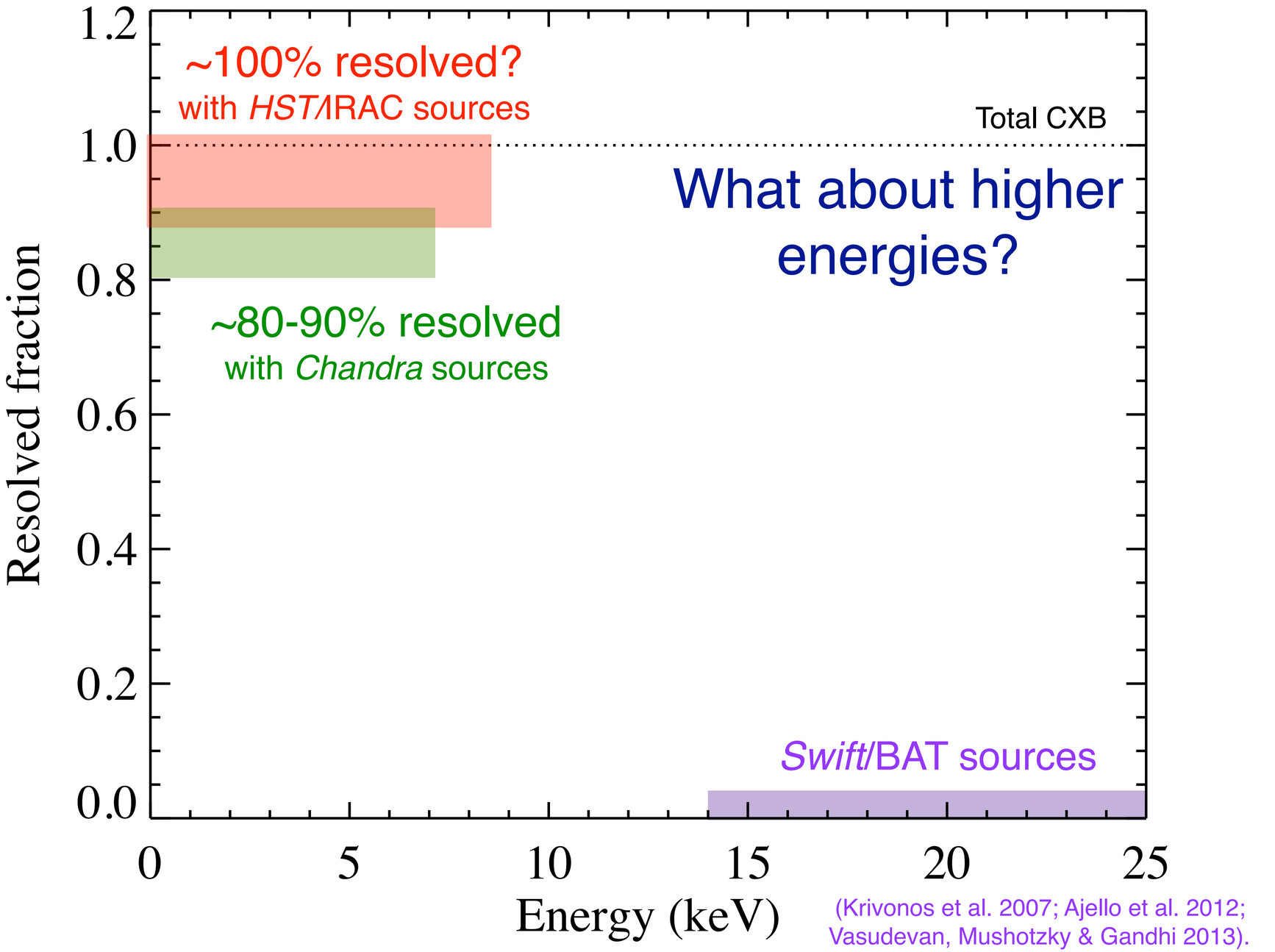
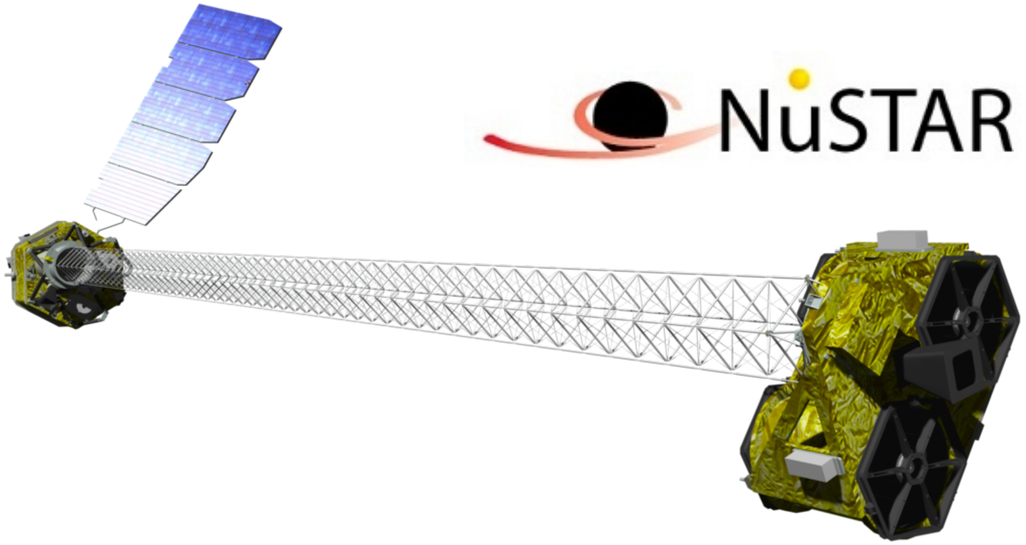
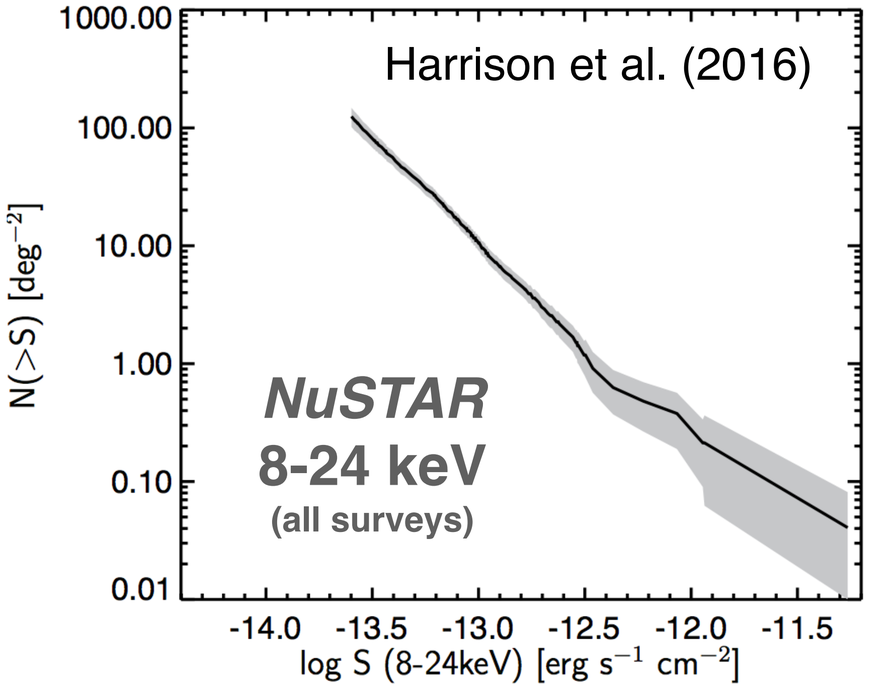
0
5
10
15
20
25

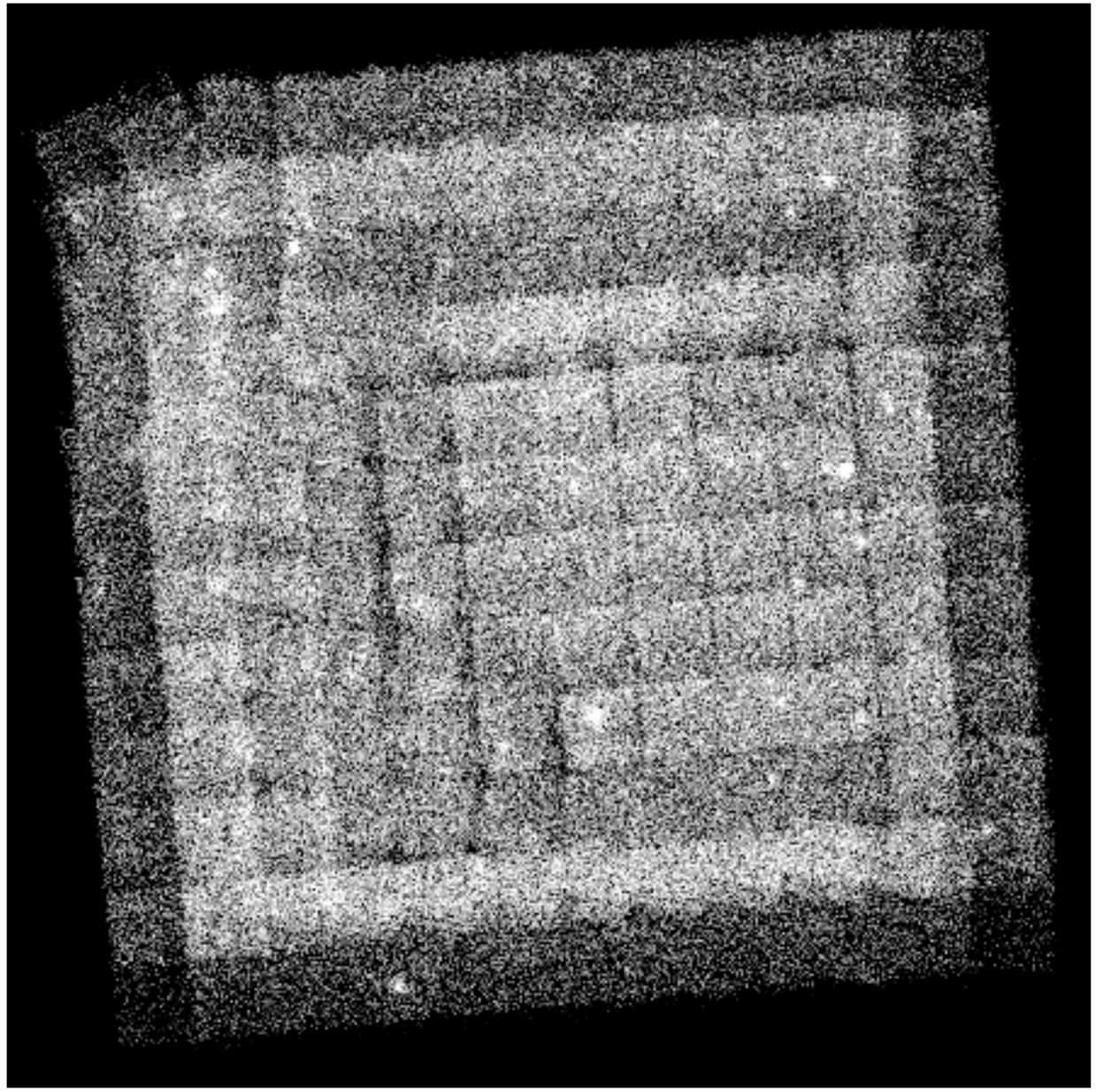


(Krivonos et al. 2007; Ajello et al. 2012; Vasudevan, Mushotzky & Gandhi 2013).

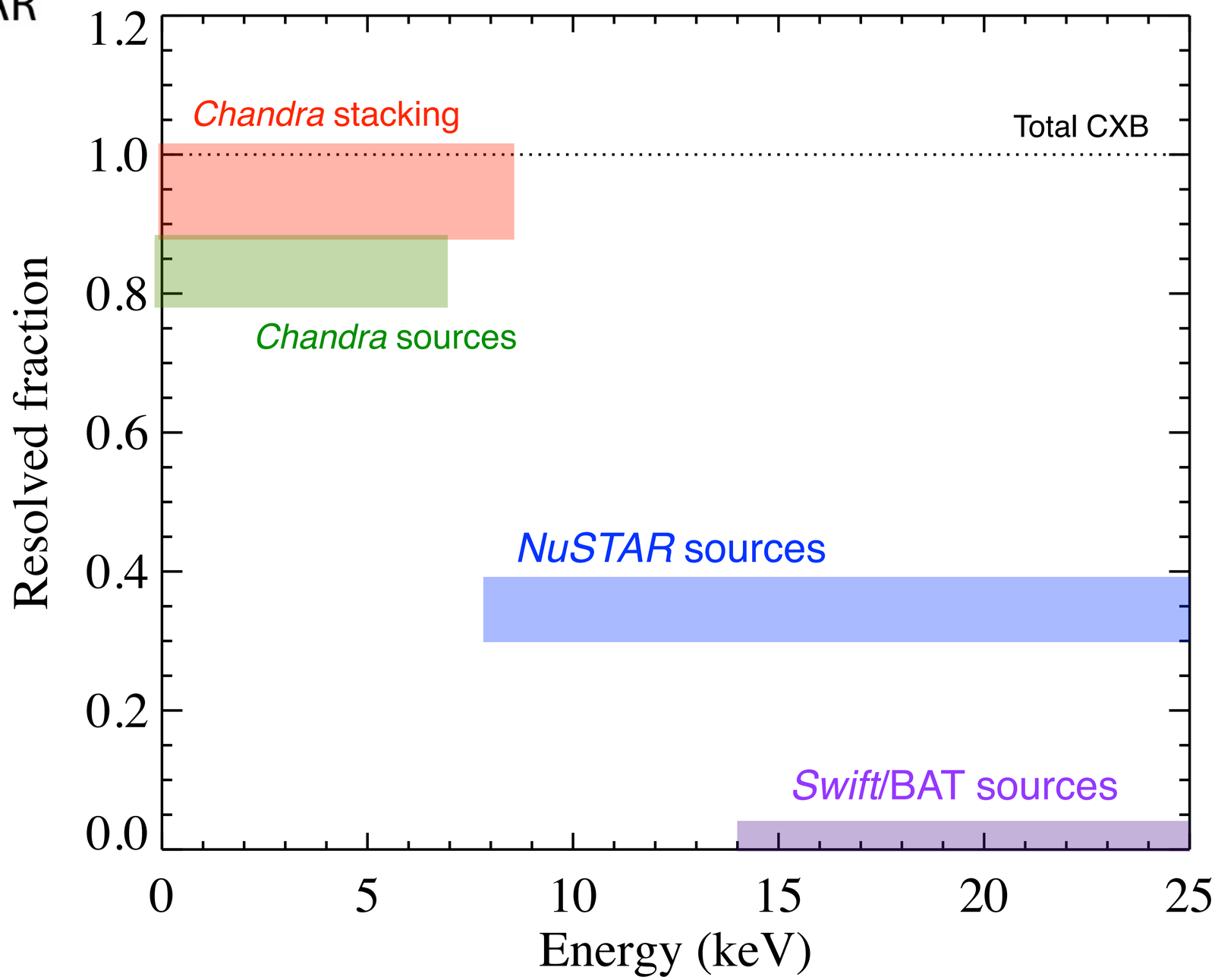


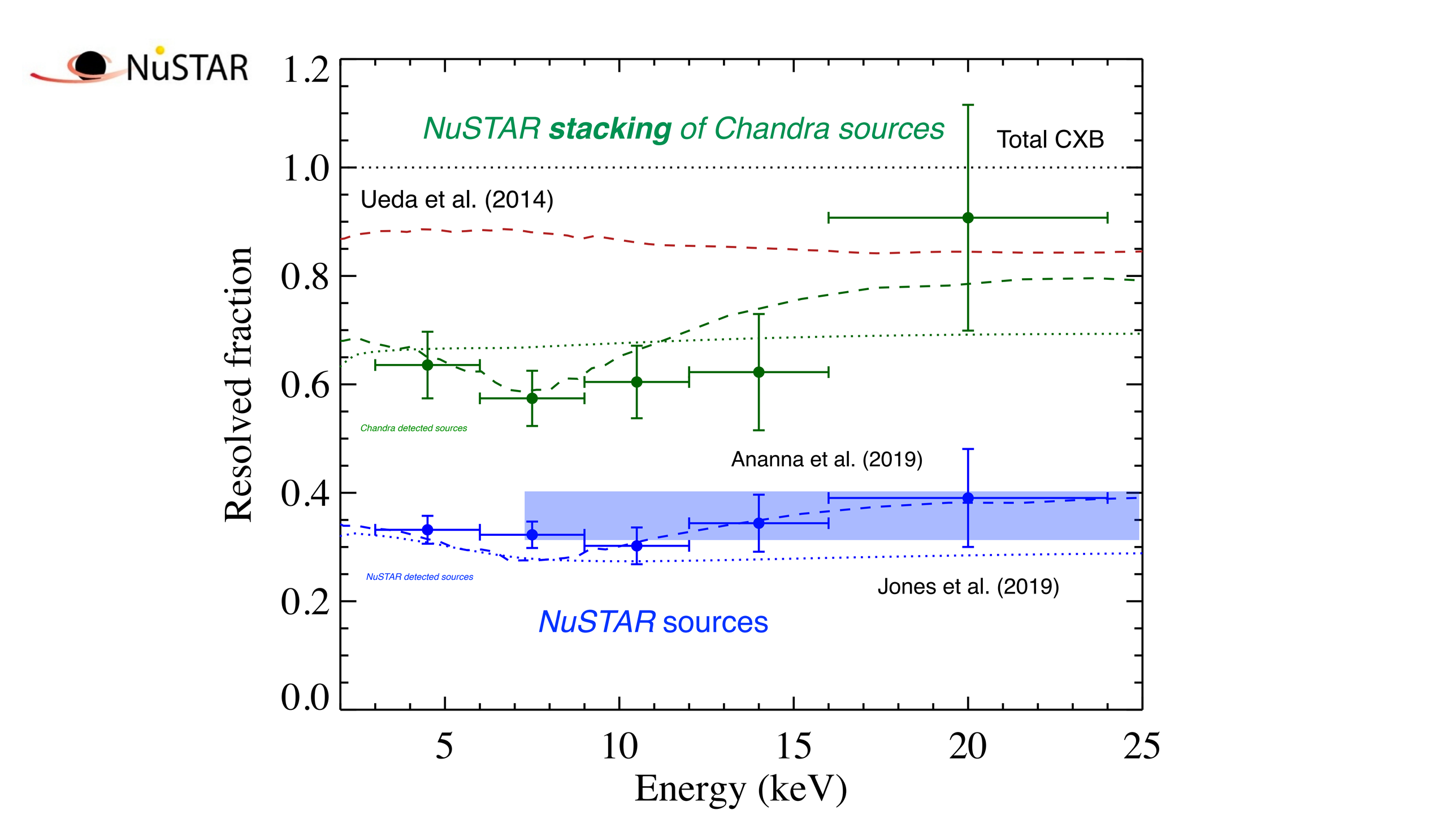
NuSTAR





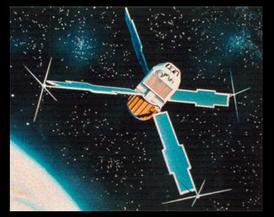
NuSTAR/COSMOS (Civano et al. 2015)


Chandra stacking
Total CXB
Chandra sources
NuSTAR sources
Swift/BAT sources
Resolved fraction
Energy (keV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
5
10
15
20
25


NuSTAR
NuSTAR stacking of Chandra sources
Total CXB
Ueda et al. (2014)
Chandra detected sources
Ananna et al. (2019)
NuSTAR detected sources
Jones et al. (2019)
NuSTAR sources
Resolved fraction
Energy (keV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
5
10
15
20
25

The Future

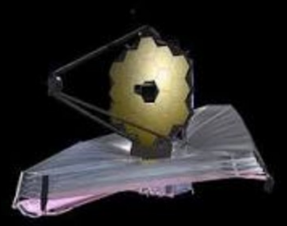
Uhuru



Chandra

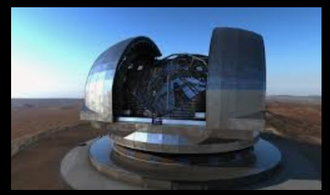
HST

JWST



VLT

ELT

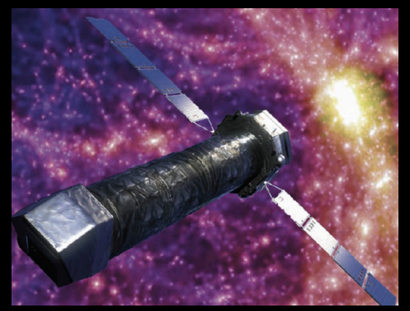


The Future

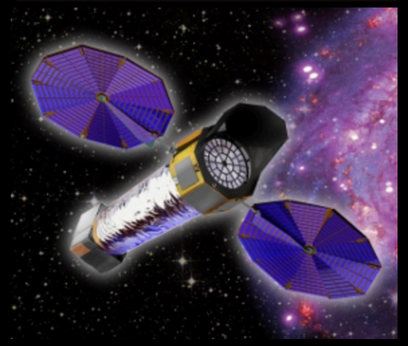
XMM

Chandra

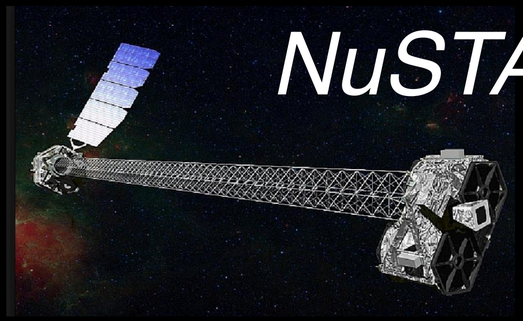
ATHENA:



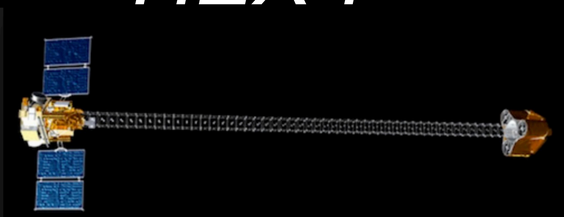
X-RAY OBSERVATORY LYNX



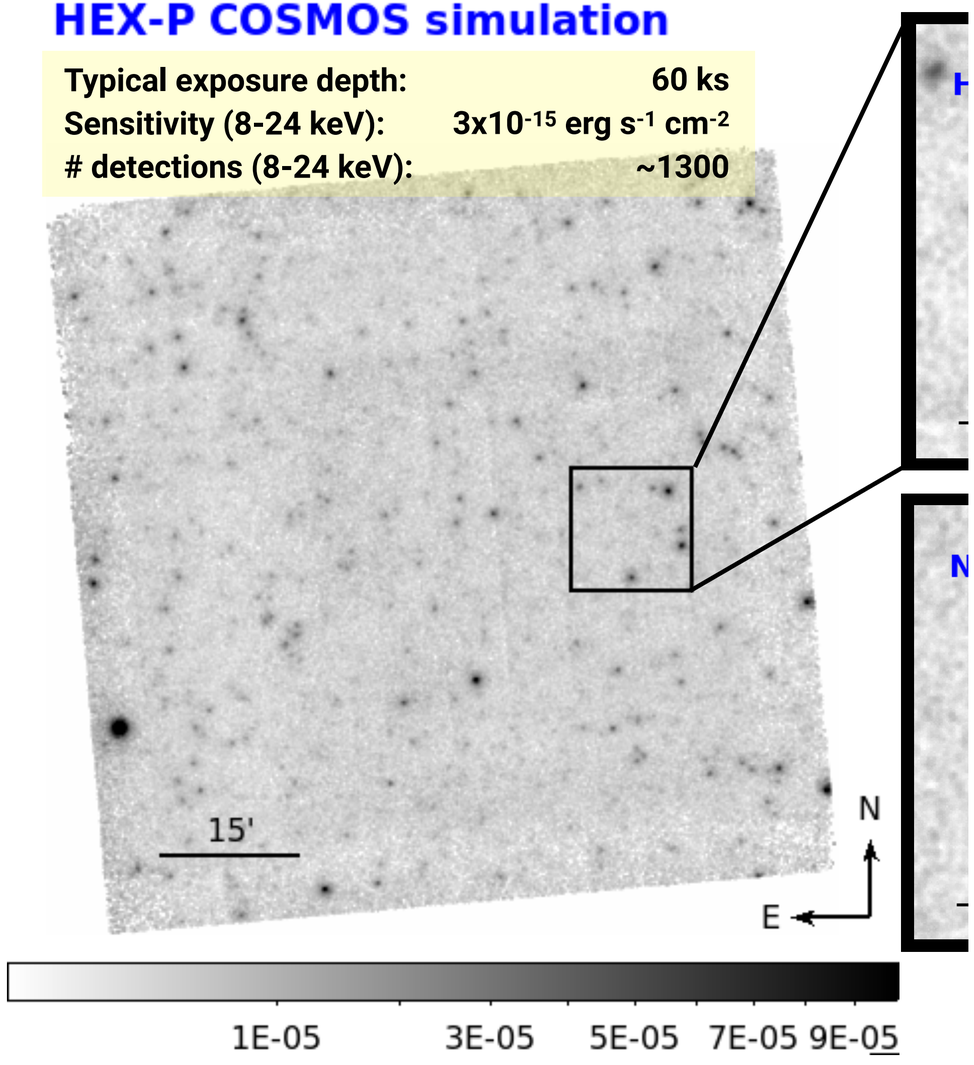
NuSTAR

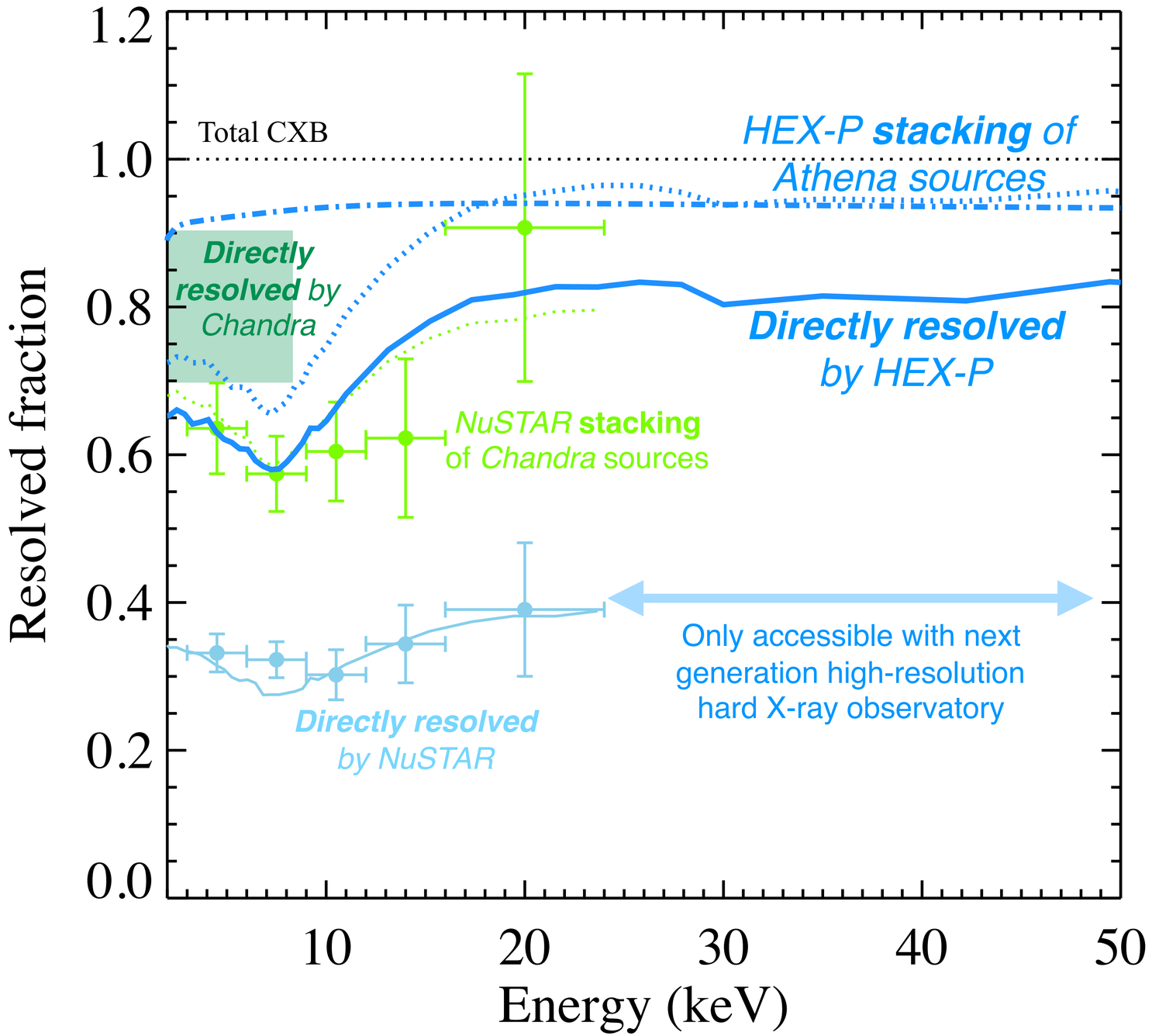


HEX-P

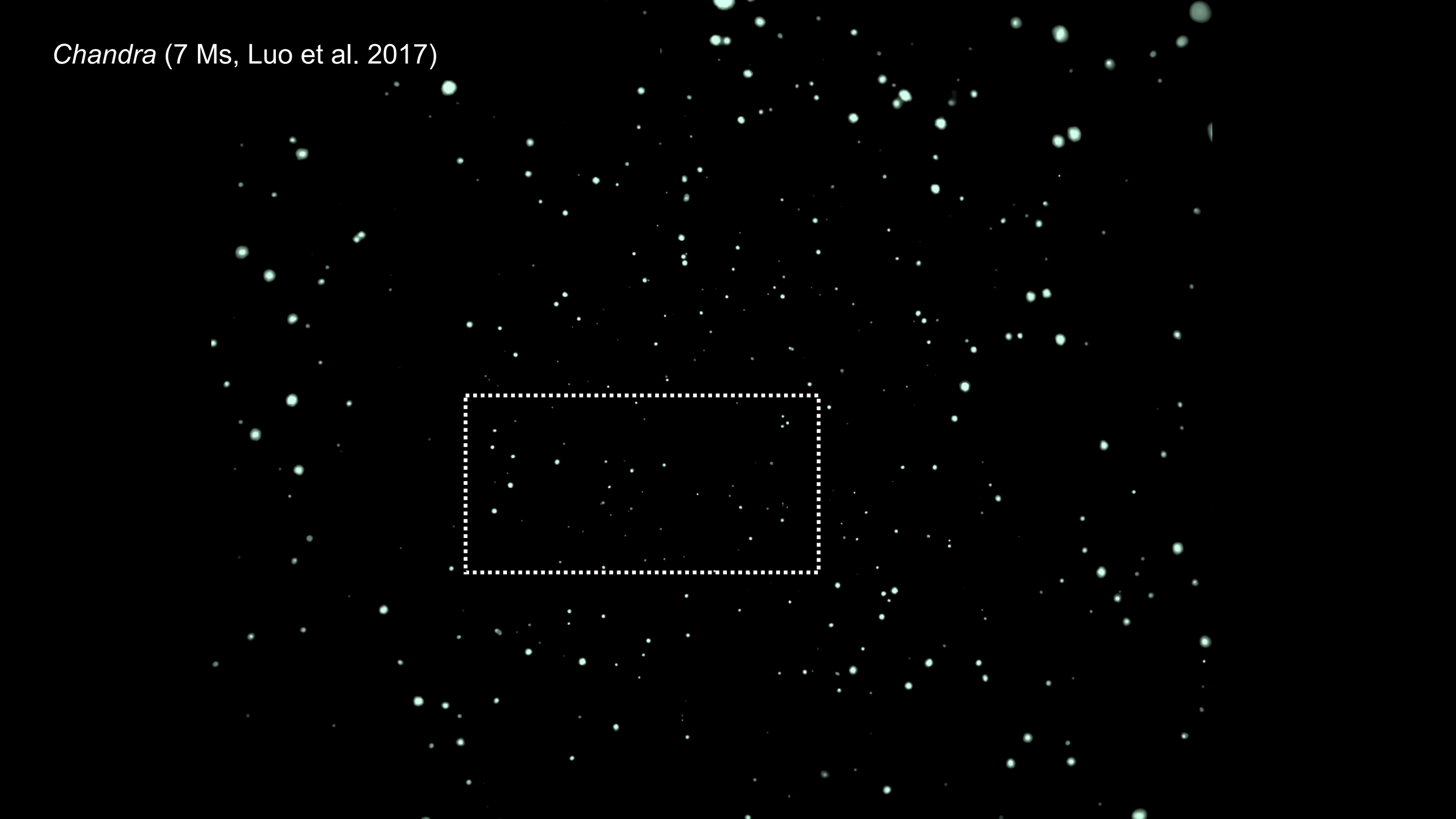


HEX-P

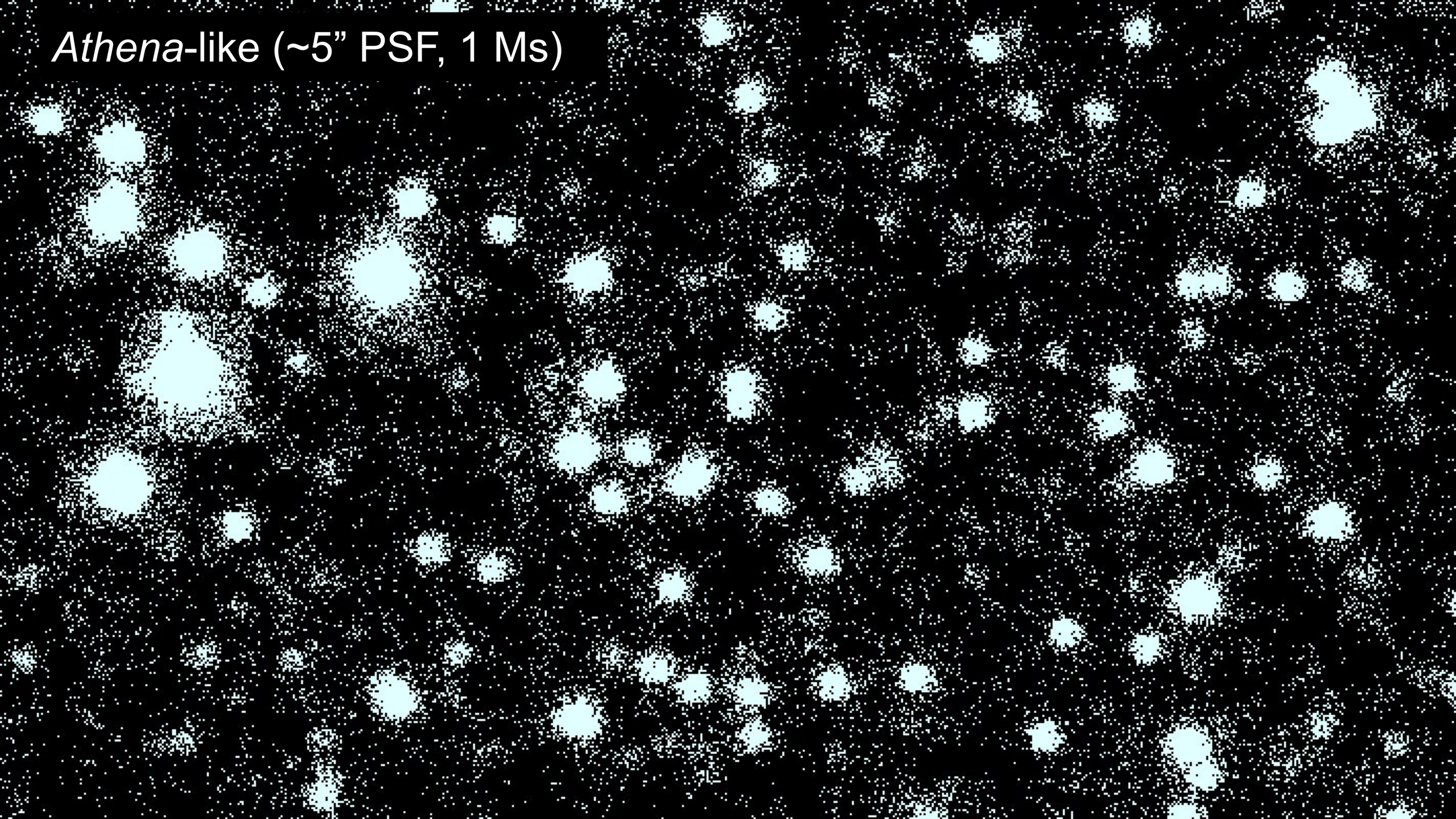


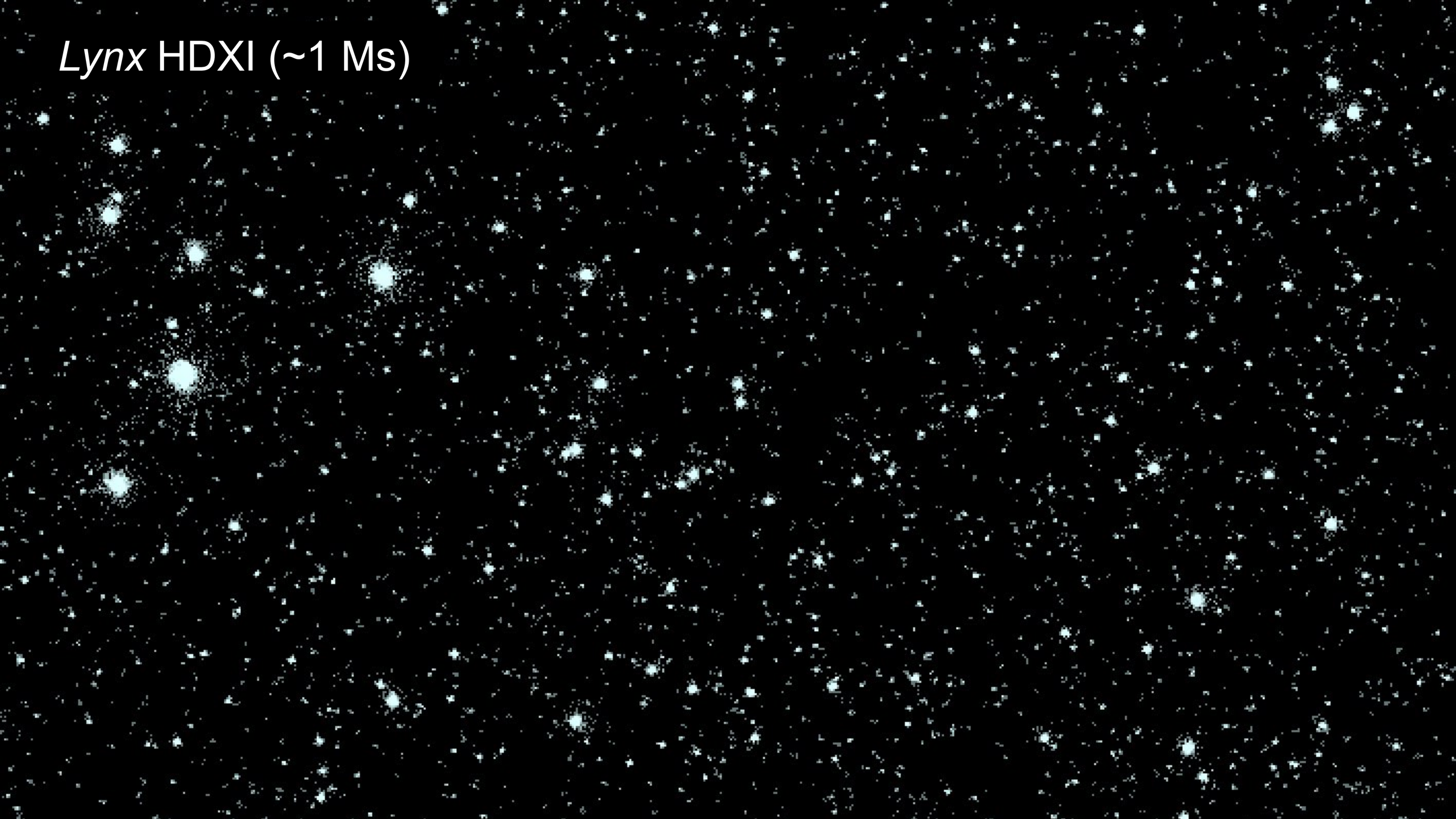


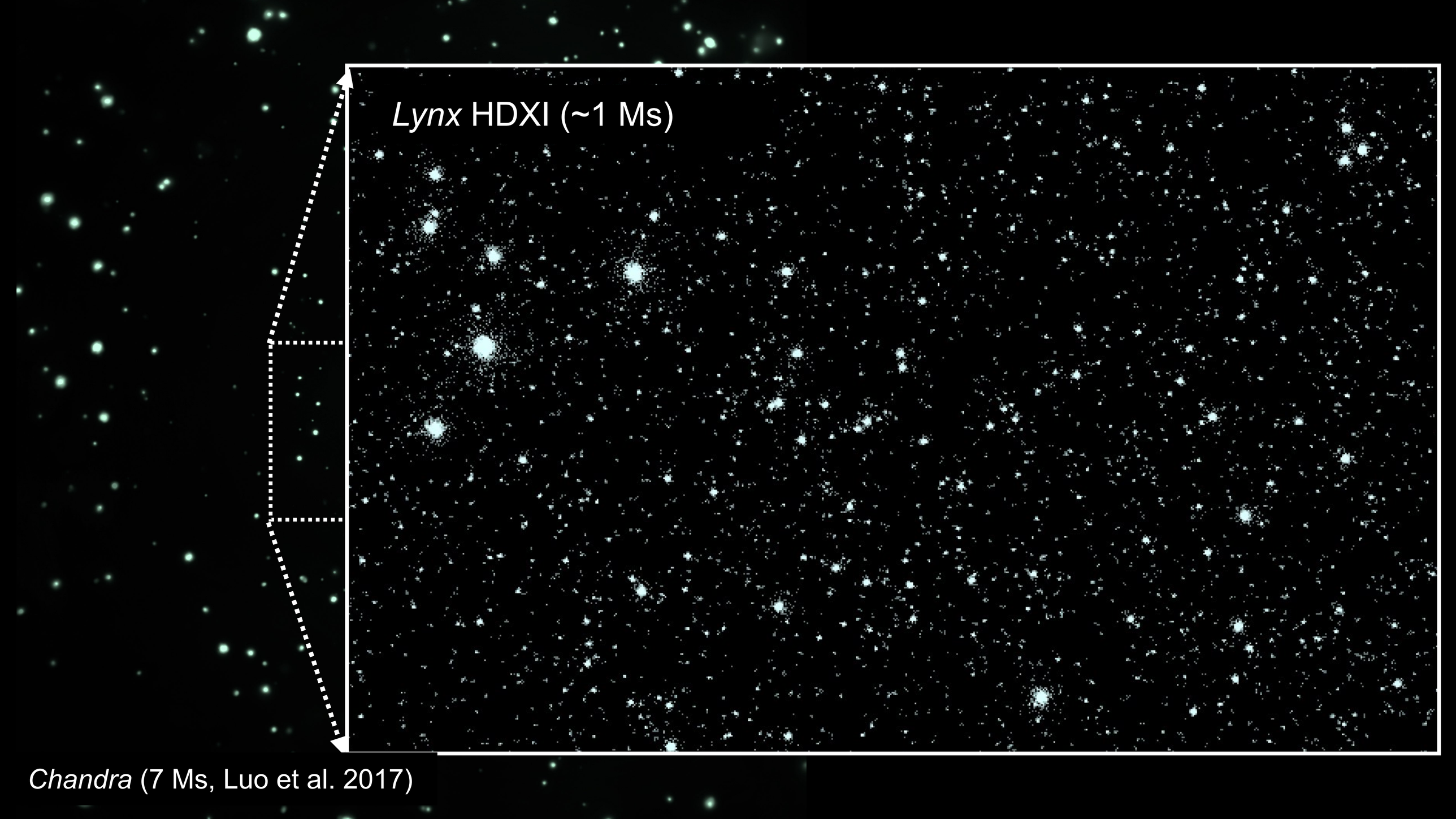
Hickox et al. (2019) Astro2020 White Pape

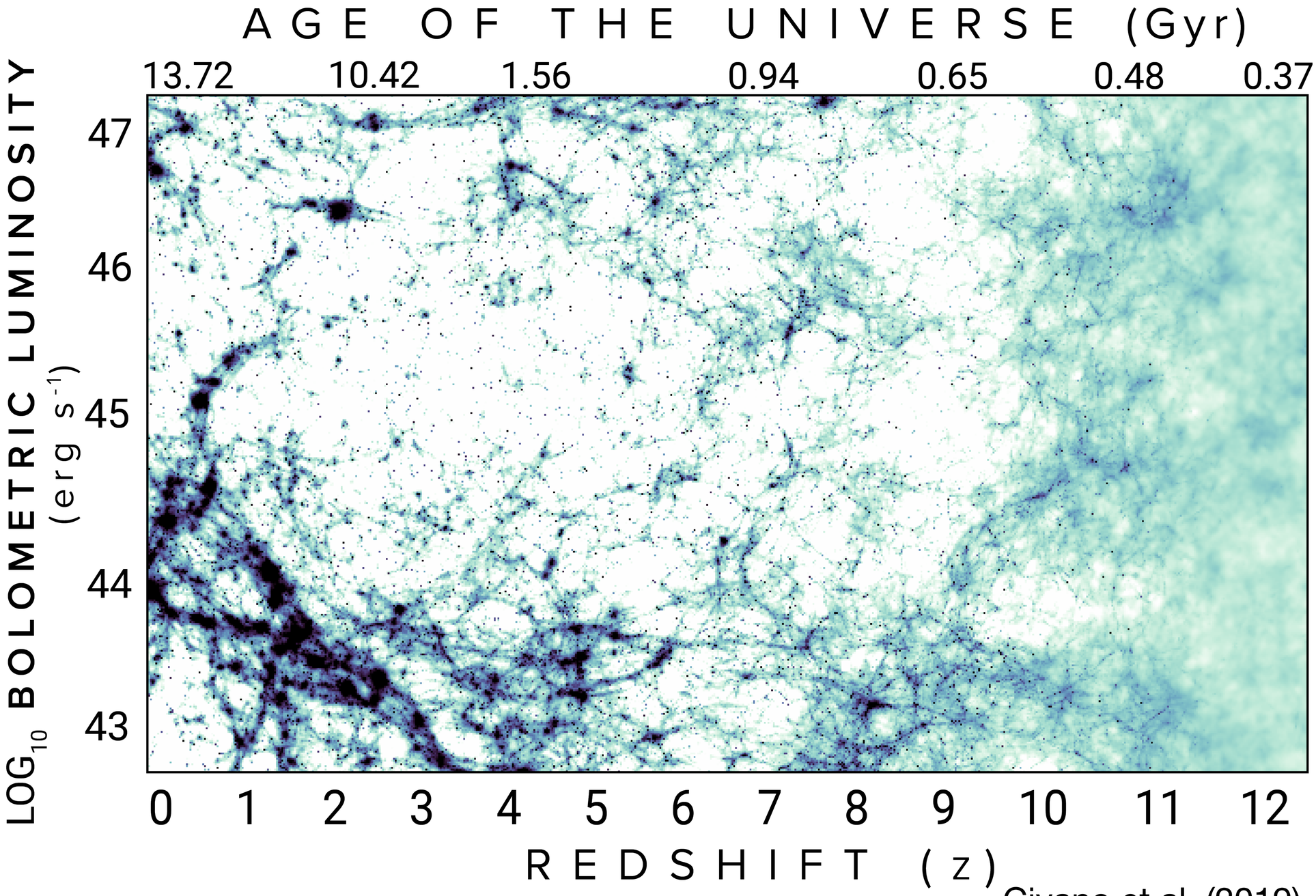

Chandra (7 Ms, Luo et al. 2017)


Chandra (7 Ms, Luo et al. 2017)


Athena-like (~5” PSF, 1 Ms)

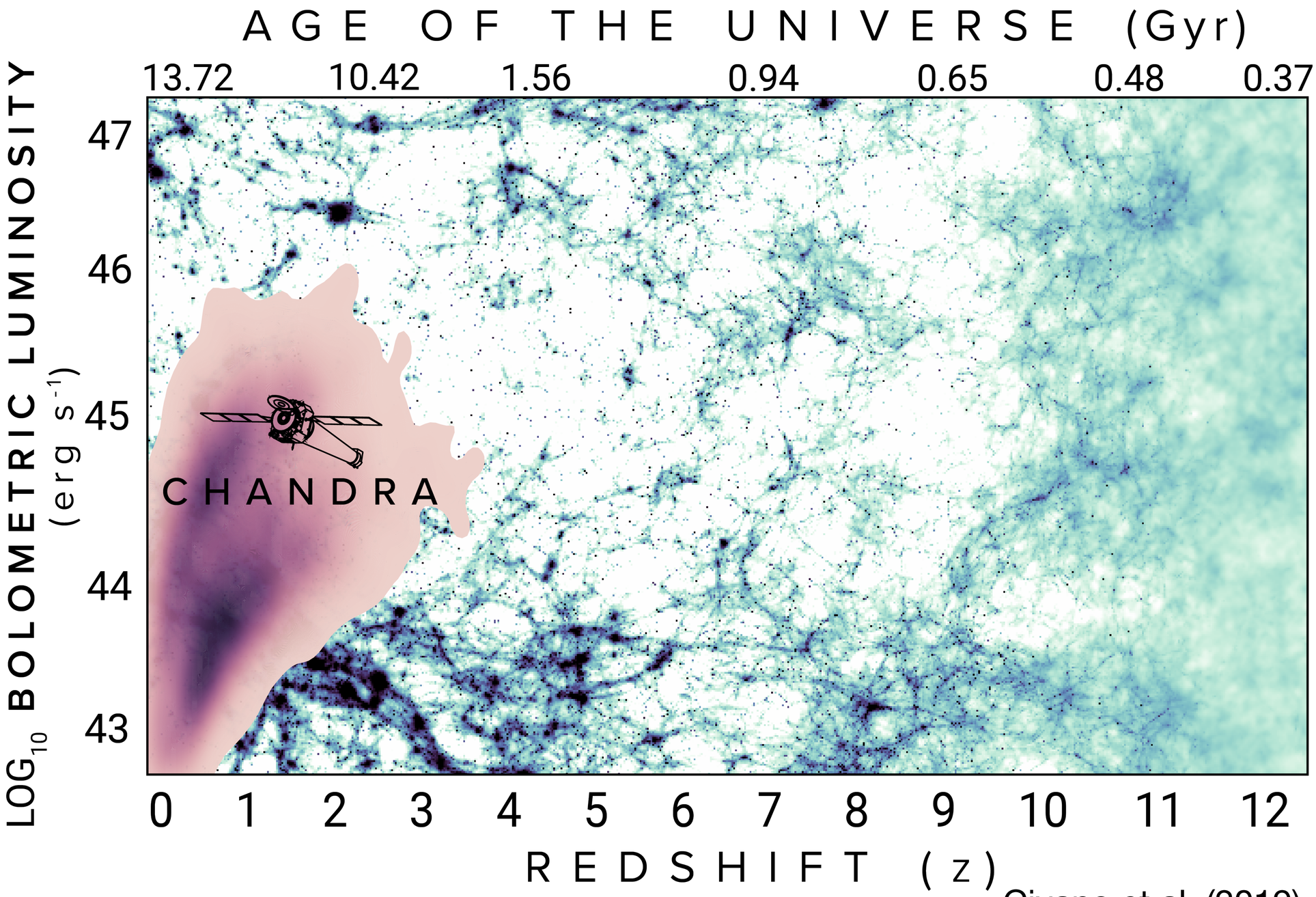

Lynx HDXI (~1 Ms)


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

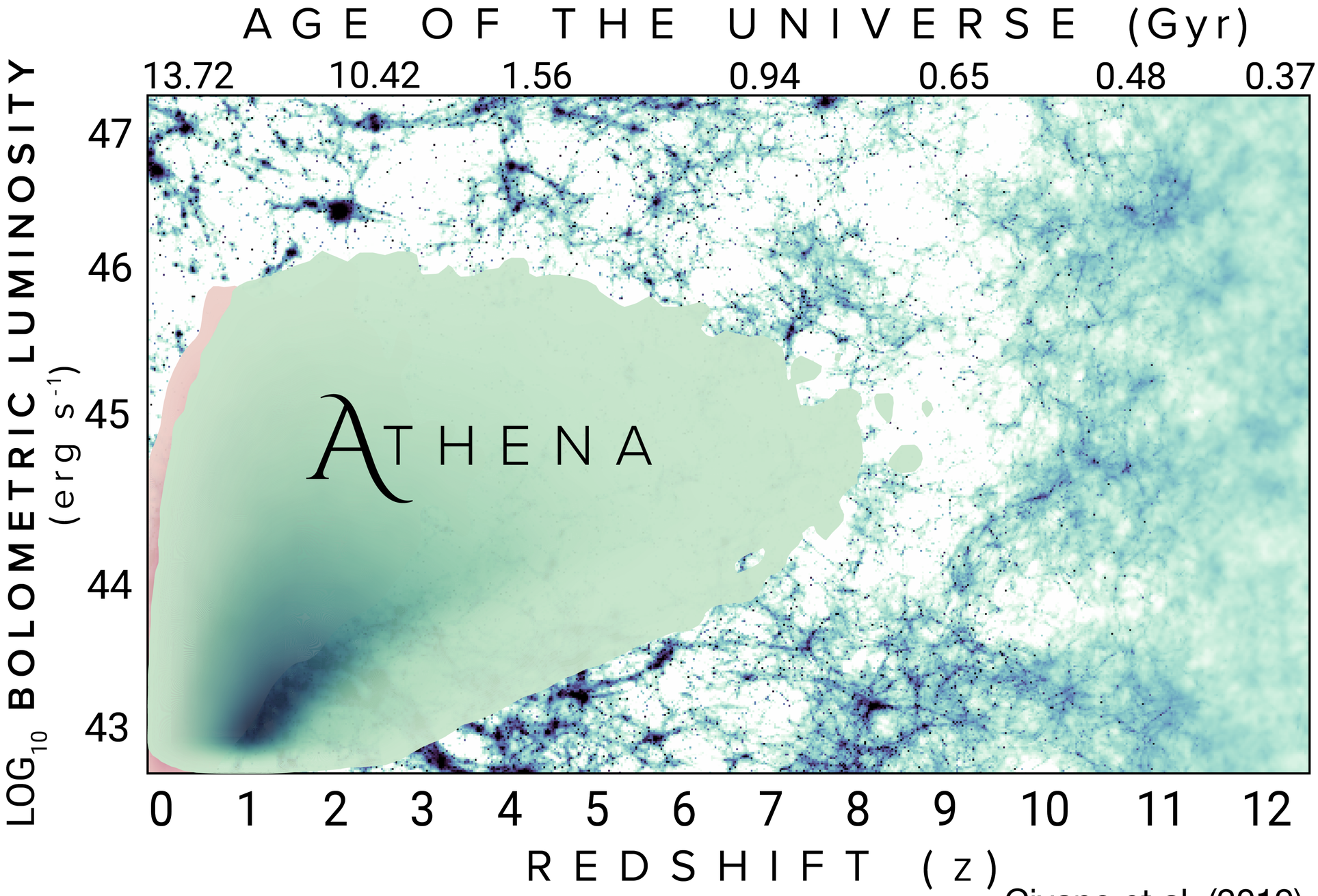


How did the **first black holes** form and grow over cosmic time?

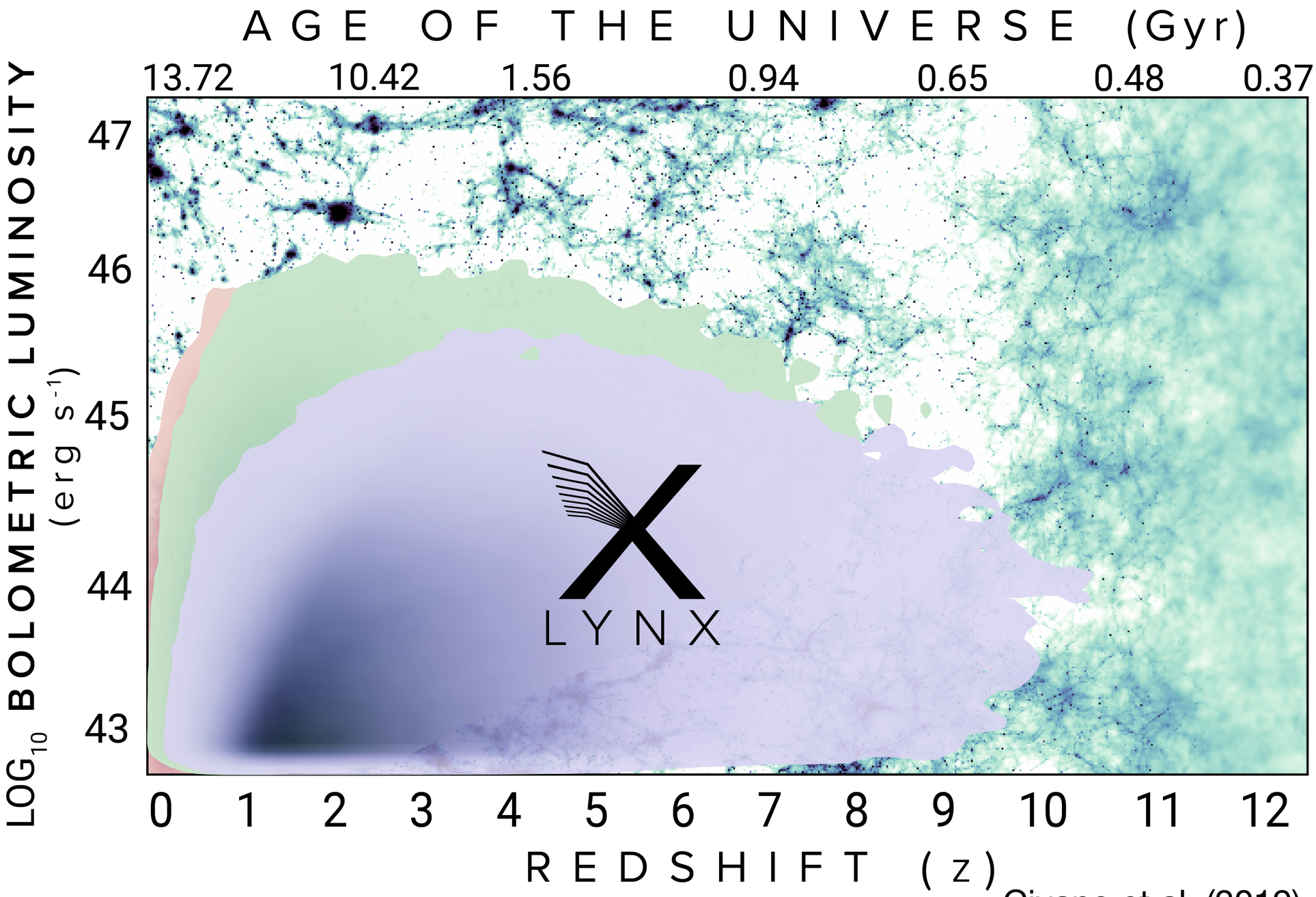
Civano et al. (2019) Astro2020 White Paper



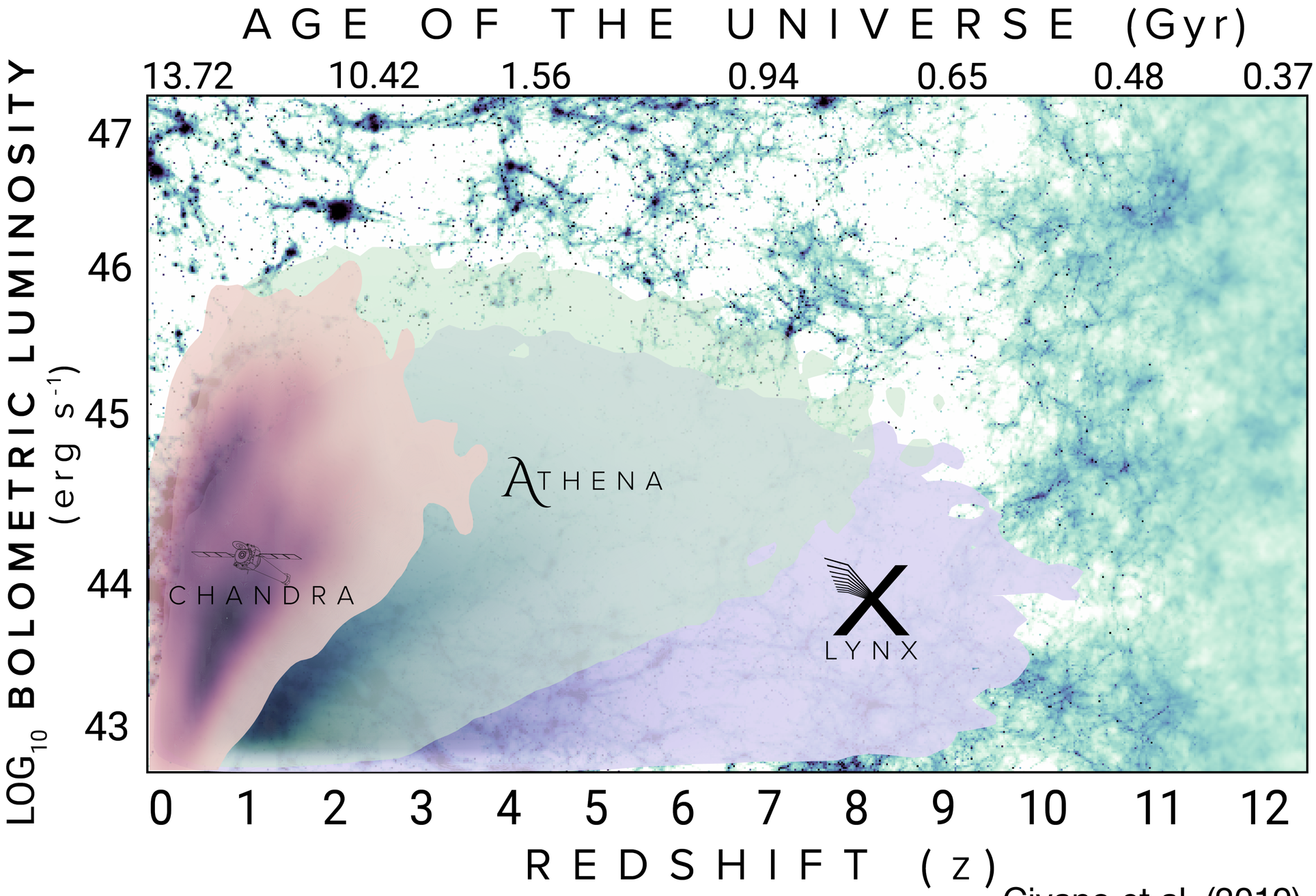
Civano et al. (2019) Astro2020 White Paper



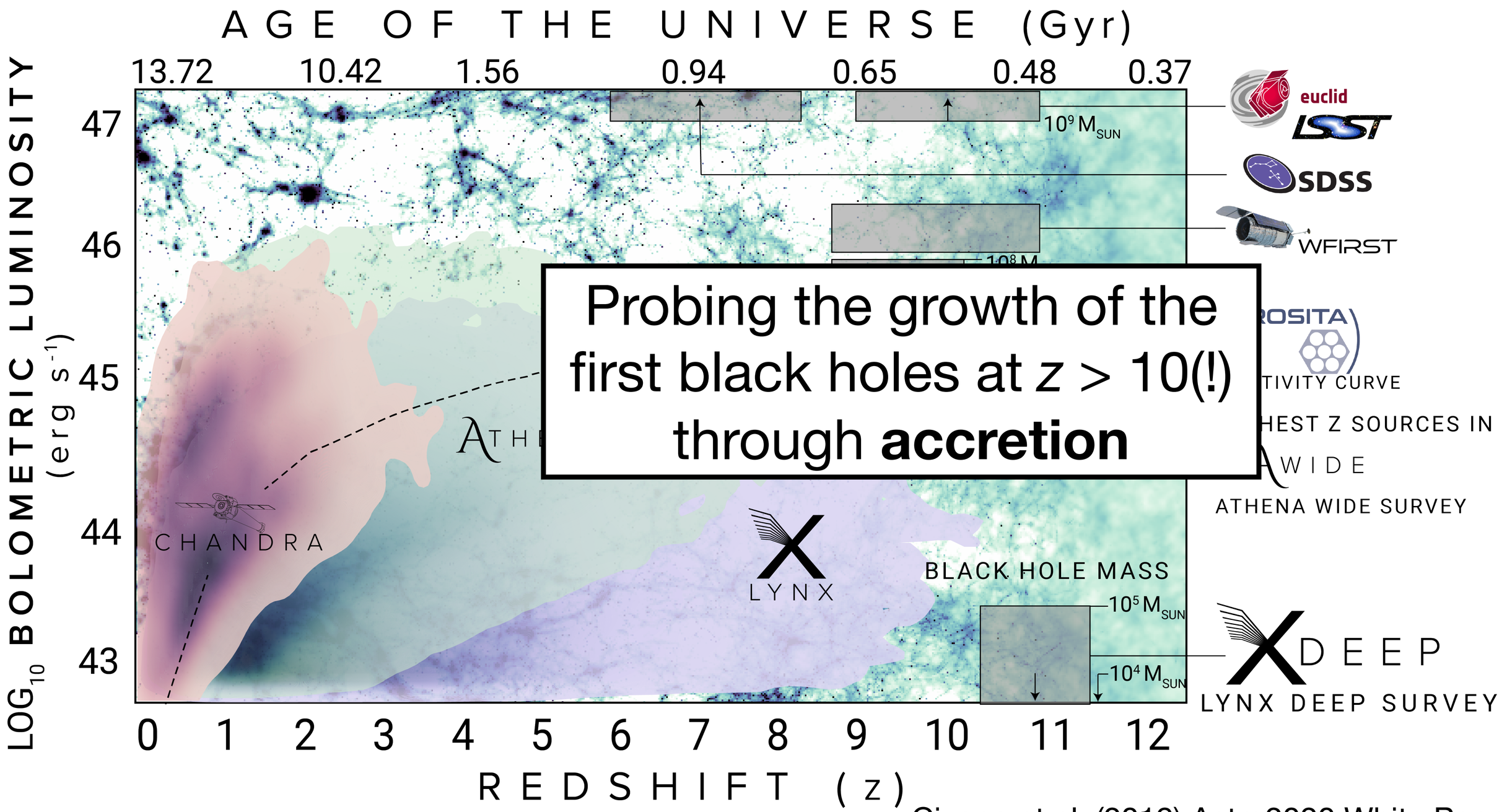
Civano et al. (2019) Astro2020 White Paper



Civano et al. (2019) Astro2020 White Paper



Civano et al. (2019) Astro2020 White Paper



Civano et al. (2019) Astro2020 White Paper

In conclusion

We've just about achieved Riccardo's vision of resolving the **cosmic X-ray background**

In the faint unresolved components, some of the most exciting secrets are still hiding

One last thought on Riccardo's legacy

Thanks to 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, and the NSF through CAREER award 1554584.