Resolving the Cosmic X-ray Background

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to Honor
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Chandra (7 Ms, Luo et al. 2017)
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 $1.7 \text{ photons cm}^{-2} \text{ sec}^{-1} \text{ sr}^{-1}$ and of the secondary maximum (between $102^\circ$ and $18^\circ$) as $0.6 \text{ photon cm}^{-2} \text{ sec}^{-1}$. In addition, there seems to be a hard component to the background of about $0.5 \text{ cm}^{-2} \text{ sec}^{-1} \text{ sr}^{-1}$ which does not show an altitude dependence and which is not eliminated by the anticoincidence.

Giacconi et al. (1962)
1963 proposal to NASA

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

1976: Proposal to NASA (w/ Harvey Tananbaum) for X-ray observatory that would become Chandra
1970s: Uhuru

Extragalactic

Galactic

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

Quasar Number Counts and the X-ray Background

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Received April 6, 1979
The **resolved fraction** of the CXB vs. energy

Giacconi & Rosati (2008)
1980s: *Einstein*

![Image of Einstein satellite](image)

**EINSTEIN EXTENDED MEDIUM-SENSITIVITY SURVEY**

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

![Graph showing the distribution of photon counts](graph)

Gioia et al. (1990)
1990s: ROSAT

Figure 1. Close-scale image of the inner 20-arcmin radius of the Deep Survey field (0.4–2.3 keV), smoothed with a two-dimensional Gaussian of 30 arcsec FWHM.

Hasinger et al. (1990)
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*
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
What is the absolute unresolved background?

Requires careful subtraction of instrumental background

~80% of 0.5-8 keV background is resolved

Hickox & Markevitch (2006)
\textbf{Resolved fraction} 
~80-90\% resolved with \textit{Chandra} sources 
(Moretti et al. 2003, 2012; Hickox & Markevitch 2006; Luo et al. 2017)
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 $7\% \pm 3\%$ of the 1-2 keV CXB remains.

Hickox & Markevitch (2007a)
See also Worsley et al. (2006); Xue et al. (2012)
Worsley et al. (2005)

- Total CXB
- Energy (keV)
- Resolved fraction

- ~80-90% resolved with Chandra sources (2000s-2010s)
- ~100% resolved with HST/IRAC sources

- Hickox & Markevitch (2007)
- Cappelluti et al. (2016)

- Einstein (1980s)
- ROSAT (1990s)
- Uhuru (1970s)
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)

logN-logS for AGN does not produce the unresolved CXB
Unresolved soft sources consistent with star-forming galaxies

Hickox & Markevitch (2007b)
What about higher energies?

Total CXB

Resolved fraction

~80-90% resolved
with Chandra sources (2000s-2010s)

~100% resolved?
with HST/IRAC sources

Einstein (1980s)

ROSAT (1990s)

Uhuru (1970s)
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)
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What about higher energies?

- Total CXB

- ~100% resolved with HST/IRAC sources (2000s-2010s)
- ~80-90% resolved with Chandra sources (2000s-2010s)
- ROSAT (1990s)
- Einstein (1980s)
- Uhuru (1970s)

Hickox & Markevitch (2007)
Cappelluti et al. (2016)
What about higher energies?

Resolved fraction

~80-90% resolved with *Chandra* sources

~100% resolved with *HST/IRAC* sources

Total CXB

Swift/BAT sources

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

8-24 keV
(all surveys)

Harrison et al. (2016)

NuSTAR/COSMOS (Civano et al. 2015)
Worsley et al. (2005)

![Graph showing resolved fraction vs. energy (keV) for different sources: Chandra sources, NuSTAR sources, Swift/BAT sources, and Total CXB. The graph indicates the contribution of each source at various energy levels.]
NuSTAR stacking of Chandra sources

- Ueda et al. (2014)
- Ananna et al. (2019)
- Jones et al. (2019)

Chandra detected sources

NuSTAR detected sources

NuSTAR sources

Total CXB

Resolved fraction vs. Energy (keV)
The Future

Uhuru → Chandra

HST → JWST

VLT → ELT
The Future

XMM  Chandra

ATHENA  LYNX

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

HEX-P COSMOS simulation

Directly resolved by HEX-P
Directly resolved by NuSTAR
Directly resolved by Chandra

Total CXB
HEX-P stacking of Athena sources
HEX-P stacking of Chandra sources

Only accessible with next generation high-resolution hard X-ray observatory

Hickox et al. (2019) Astro2020 White Paper
Chandra (7 Ms, Luo et al. 2017)
Chandra (7 Ms, Luo et al. 2017)
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?
Probing the growth of the first black holes at \( z > 10(!) \) through \textit{accretion}
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

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