Statistics of local hard X-ray selected AGN: a link to the cosmic history of black holes

Sergey Sazonov

E. Churazov, R. Krivonos, M. Revnivtsev, R. Sunyaev et al.
(MPA, Garching, IKI, Moscow)
The bulk of the cosmic X-ray background below 10 keV has been resolved:

- 0.5–2 keV: 94±7%, 2–10 keV: 89±7% (Moretti et al. 2003)
- 1–2 keV: 77±3%, 2–8 keV: 80±8% (Hickox & Markevitch 2006)
History of MBH growth: first the big, then the small

AGN–1, 0.5–2 keV  Hasinger et al.
Deep X-ray surveys have taught us a lot, but we need complementary surveys of two kinds:

1) Large area shallow surveys to have a census of AGN at low redshift and of most luminous quasars at all redshifts

2) Hard X-ray (>15 keV) surveys to discover heavily obscured AGN
INTErnational Gamma-Ray Laboratory

- Launched October 17, 2002 from Baikonur by Russia’s Proton rocket
- In a high 72-hour orbit
- ESA payload
- Extended till December 31, 2012

Coded mask imager IBIS with the ISGRI detector

- Effective energy band: 15–300 keV
- Detector area: 2,600 cm²
- Field of view: 28°x28°, 9°x9° fully coded
- Angular resolution: 12 arcmin
- Localization accuracy: 2–3 arcmin for weak sources, <1 arcmin for bright ones
INTEGRAL All-Sky Survey (Dec 2002 – June 2006)

Mostly serendipitous + a program of “empty field” observations

12% sky – 1 mCrab, 80% – 5 mCrab in 17–60 keV
All-sky map

IBIS/ISGRI

17–60 keV

403 sources, including 131 confirmed AGN
(as of mid-2006)

Krivonos et al. 2007
RXTE 3–20 keV Slew Survey

294 sources at $|b|>10^\circ$, including 103 confirmed AGN

Revnivtsev et al. 2004
Sazonov, Revnivtsev 2004
>80% of the CXB below few keV is resolved into distant AGN

1–2% of the CXB at 17–60 keV is resolved into nearby AGN
log N – log S of extragalactic sources (AGN)
AGN space density (D<70 Mpc) reveals local LSS

40 AGNs

\[ n = 1.4 \times 10^{-3} / \text{Mpc}^3, \quad L > 10^{41} \text{ erg/s} \]
All sky:
94 AGN (86 Seyferts, 8 blazars)
+37 AGN temporarily detected
+40 unidentified sources

|$b| > 5^\circ$:
76 AGN (68 Seyferts, 8 blazars)
+7 unidentified sources
Identification program: discovery of obscured AGN

R = 3'

NGC 4992
Sa galaxy at 
z = 0.0251

$N_H = (9 \pm 1) \times 10^{23} \text{ cm}^{-2}$ (Sazonov et al. 2005)

$\Rightarrow$ nearly Compton thick AGN

No optical emission lines (Masetti et al. 2007)

$\Rightarrow$ nearest X-ray bright, optically normal galaxy!
Identification and classification usually straightforward with a 1.5-m class telescope (e.g. Russian–Turkish Telescope, Antalya), once the localization is improved with Chandra or Swift/XRT but often even without that.

Bikmaev et al. 2005
Hard X-ray luminosity function

\[ \log(L^*) = 43.4 \pm 0.3 \]
\[ \gamma_1 = 0.76 \pm 0.19 \]
\[ \gamma_2 = 2.28 \pm 0.25 \]

AGN number density:
\[ n(L > 10^{41}) = (1.4 \pm 0.6) \times 10^{-3} \text{ Mpc}^{-3} \]

AGN luminosity density:
\[ \varepsilon_{17-60 \text{ keV}}(L > 10^{41}) = (12.4 \pm 1.5) \times 10^{38} \text{ erg/s/Mpc}^3 \]

In good agreement with:
- Beckmann et al. 2006 (smaller INTEGRAL sample)
- RXTE Slew Survey 3–20 keV LF (Sazonov & Revnivtsev 2004)
- HEAO-1 2–10 keV LF (Shinozaki et al. 2006)
- Swift (Tueller et al. 2007)

Sazonov et al. 2007
AGN downsizing continues at $z \sim 0$

$L^* \sim (1+z)^3$ ($z < 1$)

Barger et al. 2005
Obscured vs. unobscured AGN

- Fraction of obscured AGN decreases from 65–70% at low L to 20–30% at high L.
- Only 10–15% of AGN are Compton thick – all at low L.

Same luminosity trend was seen by RXTE (Sazonov & Revnivtsev 2004) and is being observed by Swift (Tueller et al. 2007).

Simplest AGN unification doesn’t work!
Similar trends are seen at higher redshifts
Average hard X-ray SED of local AGN

Simple stacking:

$$S = \sum f_i$$
Space density weighted sum: \( S = \sum \frac{L_i}{V_{\text{max},i}} \)

\( L < 10^{43.5} \text{ erg/s} \)

Model: \( \Sigma f(N_H) E^{-\Gamma} e^{-E/E_{\text{cut}}} \)
Space density weighted sum: $S = \sum \frac{L_i}{V_{\text{max},i}}$

$L > 10^{43.5} \text{ erg/s}$

Model: $\Sigma f(N_H) E^{-\Gamma} e^{-E/E_{\text{cut}}}$

Sazonov et al., submitted to A&A
Let’s convolve average local AGN SED with $z$-dependence

$\epsilon \sim 1/z$ at $z>1$
Let’s convolve average local AGN SED with $z$-dependence

$\epsilon = \text{const at } z > 1$

Consistent with the CXB spectrum! (within large uncertainties)
Main results from the INTEGRAL survey so far

Ø Local ratio of obscured to unabscured AGN drops from 2:1 at low luminosities to 1:3 at high luminosities. The same trend is seen in deep surveys at higher redshifts. Does this mean that AGN feedback on the dusty torus is important or something else?

Ø Observed fraction of Compton–thick AGN is significant (~15%), but not as large as some early expectations. But we do not know yet the space density of extremely thick objects ($N_H > 10^{24.5} \text{ cm}^{-2}$) – infrared surveys could help.

Ø Average properties of local AGN – hard X–ray luminosity density, column density distribution, and high–energy cutoff – are all consistent (within large uncertainties) with the CXB spectral shape and flux if the local AGN population is just a downsized version of that at $z=1–2$. 
Future work

Ø Complete identification of INTEGRAL sources near the Galactic plane and around the Galactic Center – unique possibility of studying LSS in the Zone of avoidance. In combination with Swift at high Gal. latitudes, <1 mCrab hard X-ray coverage of the whole sky will soon be achieved.

Ø Using the increased INTEGRAL AGN sample, re-derive the hard X-ray luminosity function, absorption column distribution and improve the average 3–300 keV AGN SED – better constraints on the high-energy spectral cutoff.

Ø Observe the whole local AGN sample in the infrared with Spitzer (proposal submitted). Study IR – hard X-ray correlations – use for diagnostics of weak sources detected in deep surveys. Construct a representative infrared to hard X-ray SED of local AGN.