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INTEGRAL IBIS EXTRAGALACTIC SURVEY: ACTIVE GALACTIC NUCLEI SELECTED AT 20–100 keV[1]

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ABSTRACT

Analysis of *International Gamma-Ray Astrophysics Laboratory* (*INTEGRAL*) Core Programme and public open-time observations performed up to 2005 April provides a sample of 62 active galactic nuclei in the 20–100 keV band above a flux limit of $\sim 1.5 \times 10^{-11}$ ergs cm^{-2} s^{-1}. Most (42) of the sources in the sample are Seyfert galaxies, almost equally divided between type 1 and type 2 objects; six are blazars, and 14 are still unclassified. Excluding the blazars, the average redshift of our sample is 0.021, while the mean luminosity is $\log L = 43.45$. We find that absorption is present in 65% of the objects, with 14% of the total sample due to Compton-thick active galaxies. In agreement with both *Swift* BAT team results and 2–10 keV studies, the fraction of absorbed objects decreases with the 20–100 keV luminosity. All Seyfert 2's in our sample are absorbed, as are 33% of Seyfert 1's. The present data highlight the capability of *INTEGRAL* to probe the extragalactic gamma-ray sky and to find new and/or absorbed active galaxies.

Subject headings: galaxies: active — gamma rays: observations — surveys

1. INTRODUCTION

The extragalactic gamma-ray sky is still poorly explored, with only a few surveys having been performed so far above 10 keV: the all-sky survey conducted in the 1980s by the *HEAO* A-4 instrument in the 13–80 keV band (Levine et al. 1984) and, more recently, those of the *Rossi X-Ray Timing Explorer* (*RXTE*) Proportional Counter Array and *Swift* Burst Alert Telescope (BAT), in the 8–20 and 14–195 keV bands, respectively (Revnivtsev et al. 2004; Markwardt et al. 2005). The latter, characterized by a positional uncertainty of $\leq 3'$ and a flux detection limit of $\sim 10^{-11}$ ergs cm^{-2} s^{-1}, is the most accurate and sensitive survey to date at high energies. It covers the high-latitude sky, providing a sample of 44 active galactic nuclei (AGNs), most of which were previously known from X-ray studies.

Despite being so rare, gamma-ray surveys are an efficient way to find AGNs, as they probe heavily obscured regions and objects, that is, those that could be missed in optical, UV, and even X-ray surveys. Indeed, 64% of the nonblazar sources found by the *Swift* BAT have absorption in excess of 10^{22} atoms cm^{-2}, and the overall column density distribution is bimodal. While none of the sources brighter than 3×10^{43} ergs s^{-1} show high column densities, almost all weaker objects are absorbed. Quantifying the fraction of AGNs missed by low-energy surveys is necessary if we want to provide input parameters for synthesis models of the X-ray background and to understand the accretion history of the universe.

A further step in this field is provided by IBIS, the Imager on Board the *INTEGRAL* Satellite, which, like BAT, is surveying a large fraction of the sky above 20 keV with similar sensitivity and positional accuracy. Analysis of the first year of *INTEGRAL* observations, largely covering the Galactic plane and center, has provided a first sample of 10 gamma-ray–selected AGNs (Bassani et al. 2004); more recently, the second IBIS survey has listed 32 such objects (Bird et al. 2006). Detailed analysis of *INTEGRAL* observations also suggests that AGNs are becoming a major constituent of the IBIS source population (Revnivtsev et al. 2006; Beckmann et al. 2006); at least 15% of the objects in the second IBIS catalog are active galaxies. Here we present a further step in our all-sky survey project, limiting the search to extragalactic objects. We have analyzed ~11,300 *INTEGRAL* pointings and detected 62 AGNs in the 20–100 keV energy range.

2. DATA ANALYSIS

Data reported here belong to the Core Programme and public open-time observations and span from revolution 46 (2003 February) to revolution 309 (2005 April) inclusive; this represents a significant extension in both exposure time and sky coverage with respect to the second IBIS catalog (Bird et al. 2006), with more than 4000 extra pointings being analyzed. A detailed description of the data analysis and source extraction criteria can be found in the above reference, the only difference being the use of an updated version (4.2) of the standard OSA software.

To search for AGNs, we have used the 20–100 keV flux map, which provides a good balance between significance of detection and overall background level over the mosaic image: most AGNs have power-law spectra with $\Gamma = 1.9$ and a break around 100 keV (Malizia et al. 2003), and the energy band was selected to match these spectral characteristics. The threshold significance level used for the source extraction was 5 σ.

Staring data (which tend to be much noisier than dithering observations), as well as early exposures performed while the instrument setup was still being finalized, were not included in the present mosaic; also, sources detected only occasionally, for example, in one or two revolutions only, are not considered in the present sample although they may be associated with

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flaring AGNs such as blazars. Because of the different database used, our catalog results may not include some sources already reported in the literature (e.g., Beckmann et al. 2006).

For each excess, the flux extracted from the 20–100 keV light curve was then used to estimate the source strength (up to 6% in flux can be lost in the mosaicking process) and independently confirm the image detection. Once a list of reliable excesses was produced, we proceeded to identify them by cross-checking the IBIS error boxes (assumed to be 3′ as default) with the SIMBAD, NED, and HEASARC databases.

3. SOFT GAMMA-RAY–SELECTED AGNs

Of all the excesses found in this survey, we report in Table 1 only those that can be confidently associated with AGNs. While some of the other detections may also be active galaxies, because of their location near the Galactic plane it is difficult to discriminate them from Galactic objects without further observations.

The 62 sources listed in the table are divided into two sections: (1) 32 objects already reported as confirmed or candidate active galaxies in the second IBIS catalog (all but one of the candidates have subsequently been confirmed as AGNs through follow-up optical spectroscopy; Masetti et al. 2006a, 2006b) and (2) 30 new objects, including four that were classified as unidentified in the second IBIS survey but which we now consider to be AGN candidates. Between both sets there are 14 sources that do not yet have any optical classification, but their extragalactic nature is strongly indicated either by follow-up *Chandra* observations (IGR J07565−4139, J12026−5349, and J17204−3554), by their high-latitude location (IGR J13000+2529, J13057+2036, J16194−2810, and J18249−3243), or by multi–wave-band analysis using archival radio, infrared, and X-ray data whereby their optical counterpart has been found to be associated with a galaxy (IGR J07597−3842, J14552−5133, J14492−5535, J16558−5203, J20187+4041, J20286+2544, and J21178+5139).

In the table, we list the relevant IBIS parameters (position, exposure, and flux in millicrabs) together with (where available) the optical classification and redshift obtained from NED or from more recent publications, as detailed in the table. Between 20 and 100 keV, 1 mcrab corresponds, for a Crab-like spectrum, to 1.6×10^{-11} ergs cm^{-2} s^{-1}, which is a value close to our detection limit. For objects with known distances, fluxes have been converted to gamma-ray luminosities assuming $H_0 = 71$ km s^{-1} Mpc^{-1} and $q_0 = 0$ (Spergel et al. 2003). Available column densities are also listed and were obtained from X-ray data in the literature or in public databases. Unfortunately, a significant fraction (about 30%) of our objects do not have archival X-ray spectra, so that an estimate of the column density must await follow-up X-ray observations. The quoted column densities are intrinsic to the source, except for those cases where N_H is comparable to the Galactic absorption, in which case the quoted values are upper limits.

About 40% of the objects listed in Table 1 are well-known gamma-ray emitters and have been studied in the IBIS energy range by previous missions such as *BeppoSAX*, the Oriented Scintillation Spectrometer Experiment (OSSE), and *RXTE*; comparison of our data with past observations indicates overall agreement (within a factor of a few) on the flux (Soldi et al. 2005). The remaining objects are detected above 10 keV for the first time; many of these were not even known to be active or to be X-ray sources before their *INTEGRAL* discovery (Sazonov et al. 2005). This is largely due to their location in the Galactic plane, which has prevented an in-depth study of these objects up to now.

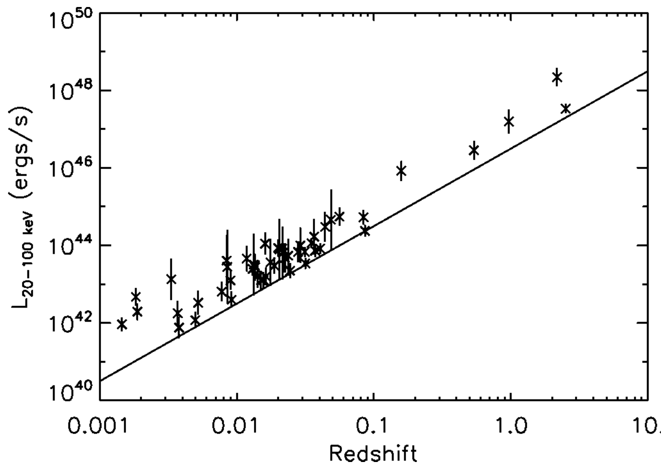

FIG. 1.—The 20–100 keV luminosity vs. redshift for optically classified AGNs in the present survey; the straight line corresponds to the IBIS survey limit.

A comparison of the IBIS catalog with the *Swift* sample indicates that the intersection is very small (only nine sources), as a consequence of BAT's observing mostly the high Galactic latitude sky while IBIS preferentially maps the Galactic plane. It is likely that, together, these two surveys will provide complete and deep sky coverage and, thus, the best-yet sample of gamma-ray–selected AGNs for some time to come.

4. RESULTS AND CONCLUSIONS

It must be remembered that the present survey is highly inhomogeneous in sky exposure and coverage, and thus the sample is far from being complete. Nevertheless, a few interesting considerations can be drawn by a simple statistical analysis. For objects with known distances, we plot in Figure 1 the gamma-ray luminosity against redshift, to show the large range in these parameters sampled by the present survey. From this figure it is also evident that our sensitivity limit is around 1.5×10^{-11} ergs cm^{-2} s^{-1} (*straight line*).

Within the overall sample, 42 objects are classified as Seyfert galaxies, six are blazars, and 14 are still unclassified. Within the sample of Seyfert galaxies, 23 objects are of type 1–1.5 while 19 are of type 2, thus illustrating the power of gamma-ray surveys to find narrow-line AGNs. Excluding the blazars, the average redshift of our sample is 0.021 ± 0.017 ($1\,\sigma$), while the mean logarithmic luminosity is 43.45 ± 0.71. Assuming 10^{22} atoms cm^{-2} to be the dividing line between absorbed and unabsorbed sources, we find that absorption is present in 65% ± 17% of the sample. This result is in line with the *Swift* findings (Markwardt et al. 2005) and above that found in X-ray surveys for bright objects (Comastri 2004; La Franca et al. 2005). It is also interesting to note that 14% ± 7% of the total sample is due to Compton-thick objects, which is about 3 times the frequency found by *Swift*.

In Figure 2, we show the column density of the sources as a function of IBIS luminosity. Although from this figure there is little evidence of any strong correlation, the few high-luminosity objects in the survey all have low absorption. We can further investigate the relationship between N_H and $\log L$ by forming the ratio between the fraction of absorbed sources above a given luminosity and that below this value. It can be seen from Figure 3 that below $\log L \sim 43.5$ the ratio is prac-

TABLE 1
Sample of Soft Gamma-Ray–selected AGNs

Source	R.A. (J2000) (deg)	Decl. (J2000) (deg)	Exp. (ks)	F[a]	Type[b]	z[b]	N_H[c]	Reference	log L[a]	Note
AGNs in the Second IBIS Catalog										
QSO B0241+62	41.210	+62.481	159.9	4.3 ± 0.4	S1	0.044	1.5 ± 0.3	1	44.48	
MCG +8-11-11	88.718	+46.447	33.8	5.4 ± 0.8	S1.5	0.020	<0.02	1	43.90	
IGR J07597−3842	119.948	−38.723	892.0	2.2 ± 0.2	…	…	…		…	1
ESO 209-12	120.490	−49.757	1062.0	1.4 ± 0.1	S1.5	0.040	…		43.92	
Fairall 1146	129.649	−36.023	992.0	1.0 ± 0.2	S1.5	0.031	…		43.54	
MCG −5-23-016	146.895	−30.932	333.6	11.2 ± 1.0	S2	0.008	1.6 ± 0.2	2	43.45	
IGR J10404−4625	160.105	−46.400	182.8	2.8 ± 0.4	S2[d]	0.024[d]	>1	3	43.74	
NGC 4151	182.637	+39.400	56.2	35.4 ± 0.5	S1.5	0.003	3 ± 0.4	1	43.13	
4C 04.42	185.615	+4.253	208.0	2.2 ± 0.3	Bl	0.965	…		47.20	
NGC 4388	186.449	+12.652	62.3	16.5 ± 0.7	S2	0.008	43 ± 10	1	43.61	
3C 273	187.285	+2.036	270.0	8.3 ± 0.3	Bl	0.158	<0.03	4	45.92	
NGC 4507	188.904	−39.904	216.0	9.4 ± 0.3	S2	0.012	29 ± 2	1	43.66	
LEDA 170194	189.807	−16.202	110.2	3.5 ± 0.5	S2[e]	0.037[e]	1.9 ± 0.3	5	44.23	
NGC 4593	189.917	−5.349	342.0	4.4 ± 0.2	S1	0.009	<0.02	1	43.10	
3C 279	194.037	−5.777	318.0	1.8 ± 0.2	Bl	0.536	<0.02	4	46.46	
NGC 4945	196.358	−49.469	470.0	16.1 ± 0.2	S2	0.002	400 ± 80	1	42.29	
Cen A	201.363	−43.021	406.0	40.8 ± 0.2	S2	0.002	23 ± 13	2	42.67	
4U 1344−60	206.882	−60.619	732.0	4.2 ± 0.2	S1[d]	0.013[d]	…		43.39	
IC 4329A	207.332	−30.314	236.0	12.5 ± 0.3	S1.2	0.016	0.42 ± 0.02	1	44.05	
Circinus	213.282	−65.347	644.0	12.7 ± 0.2	S2	0.001	360 ± 70	1	41.97	
IGR J16482−3036	252.050	−30.590	1644.0	2.0 ± 0.1	S1[d]	0.031[d]	…		43.83	
ESO 138-G01	253.029	−59.218	572.0	1.4 ± 0.2	S2	0.009	>150	6	42.60	2
NGC 6300	259.234	−62.816	256.0	3.8 ± 0.3	S2	0.004	29 ± 2	7	42.25	
GRS 1734−292	264.369	−29.140	4040.0	5.1 ± 0.1	S1	0.021	<0.5	8	43.92	
2E 1739.1−1210	265.466	−12.199	906.0	1.5 ± 0.2	S1[f]	0.037[f]	…		43.87	
IGR J18027−1455	270.690	−14.917	1476.0	2.6 ± 0.1	S1	0.035	…		44.06	
PKS 1830−211	278.413	−21.057	1950.0	3.1 ± 0.1	Bl	2.507	<0.26	9	48.53	3
ESO 103-G35	279.695	−65.408	41.7	5.3 ± 0.8	S2	0.013	15.1 ± 0.5	4	43.51	
2E 1853.7+1534	283.984	+15.610	664.0	2.0 ± 0.2	S1[e]	0.084[e]	…		44.73	
NGC 6814	295.666	−10.329	252.0	3.6 ± 0.3	S1.5	0.005	<0.05	4	42.52	
Cygnus A	299.869	+40.733	426.0	4.9 ± 0.2	S2	0.056	38 ± 8	2	44.75	
IGR J21247+5058	321.156	+50.970	438.0	6.1 ± 0.2	S1	0.020	…		43.93	
New AGNs										
1ES 0033+595	9.004	+59.833	776.0	0.9 ± 0.2	Bl	0.086	0.36 ± 0.08	10	44.38	
NGC 788	30.264	−6.814	134.8	4.2 ± 0.4	S2	0.014	21 ± 0.5	4	43.43	
NGC 1068	40.704	−0.007	218.0	1.5 ± 0.3	S2	0.004	>1000	1	41.88	
NGC 1275	49.878	+41.566	78.8	3.4 ± 0.6	S2	0.018	1.5 ± 0.7	2	43.57	4
3C 111	64.611	+37.998	42.4	5.5 ± 0.8	S1	0.049	<0.9	4	44.67	
UGC 3142	70.988	+28.960	71.7	3.9 ± 0.7	S1	0.022	…		43.81	
LEDA 168563	73.054	+49.530	115.3	3.4 ± 0.5	S1	0.029	…		44.00	
Mrk 3	93.854	+71.044	468.0	4.8 ± 0.2	S2	0.014	110 ± 16	1	43.49	
Mrk 6	103.040	+74.450	500.0	2.5 ± 0.2	S1.5	0.019	10 ± 0.6	1	43.48	
IGR J07565−4139	119.080	−41.613	1078.0	1.0 ± 0.1	…	…	1.1 ± 0.2	5	…	5
QSO 0836+710	130.320	+70.920	412.0	3.1 ± 0.2	Bl	2.172	<0.03	4	48.34	
IGR J12026−5349	180.709	−53.820	334.0	2.5 ± 0.3	…	0.028	2.2 ± 0.3	5	43.83	6
IGR J12415−5750	190.368	−57.851	576.0	1.1 ± 0.2	S2	0.024	…		43.35	7
IGR J13000+2529	195.022	+25.490	232.0	1.3 ± 0.3	…	…	…		…	8
IGR J13057+2036	196.422	+20.595	174.1	1.8 ± 0.3	…	…	…		…	9
ESO 323-G077	196.611	−40.445	336.0	1.6 ± 0.2	S1.2	0.015	55 ± 33	11	43.11	
MCG −6-30-15	203.976	−34.297	324.0	3.1 ± 0.3	S1.2	0.008	<0.02	12	42.81	
ESO 511-G030	214.849	−26.659	178.5	2.7 ± 0.4	S1	0.022	<0.05	11	43.68	
IGR J14492−5535	222.318	−55.587	814.0	1.2 ± 0.2	…	…	…		…	10
IGR J14552−5133	223.811	−51.583	860.0	1.0 ± 0.2	…	…	…		…	11
IGR J16119−6036	242.981	−60.597	600.0	1.5 ± 0.2	S1	0.016	…		43.11	12
IC 4518A	224.410	−43.129	770.0	1.7 ± 0.2	S2	0.016	…		43.20	13
IGR J16194−2810	244.874	−28.110	526.0	1.7 ± 0.2	…	…	…		…	14
NGC 6221	253.029	−59.218	572.0	1.4 ± 0.2	S2	0.005	1.1 ± 0.1	13	42.07	2
IGR J16558−5203	254.014	−52.052	894.0	1.8 ± 0.2	…	…	…		…	15
IGR J17204−3554	260.090	−35.909	3100.0	1.3 ± 0.1	…	…	14 ± 1	14	…	16
IGR J18249−3243	276.245	−32.715	2600.0	1.2 ± 0.1	…	…	…		…	17
IGR J20187+4041	304.693	+40.697	576.0	1.4 ± 0.2	…	…	…		…	18
IGR J20286+2544	307.156	+25.765	202.0	2.3 ± 0.4	…	0.014	…		43.21	19
IGR J21178+5139	319.429	+51.671	408.0	1.6 ± 0.3	…	…	…		…	20

Notes.—(1) IRAS 07579−3835; (2) analysis of various energy band mosaics indicates detection of both ESO 138-G01 and NGC 6221, which are 11′ apart; (3) lensed galaxy with magnification factor of ∼10; (4) possibly contaminated by the Perseus Cluster; (5) 2MASX J07561963−4137420 (Sazonov et al. 2005); (6) WKK 560 (Sazonov et al. 2005); (7) WKK 1263; (8) possibly MAPS-NGP O-379-0073388; (9) possibly NGP9 F379-1241685; (10) possibly 2MASX J14491283−5536194; (11) WKK 4438; (12) WKK 6092, but contamination by the nearby galaxy WKK 6103 is possible; (13) one of a pair of strongly interacting galaxies, in which the companion has so far not been classified as an active galaxy; (14) 1RXS J161933.6−280736; (15) possibly 1RXS J165605.6−520345 = IRAS 16520−5158; (16) NGC 6334B (Bassani et al. 2005); (17) possibly PKS 1821−327; (18) 2MASX J20183871+4041003; (19) MCG +4-48-002, possibly interacting with NGC 6921; (20) 2MASX J21174741+5138523.

[a] Fluxes (in units of millicrabs, with associated 90% errors) and luminosities (in units of ergs s^{-1}) in the 20–100 keV band.

[b] Type (S1–S1.5 = Seyfert 1–1.5; S2 = Seyfert 2; Bl = blazar) and redshift according to NED or to noted reference.

[c] In units of 10^{22} atoms cm^{-2}.

[d] Masetti et al. 2006b.

[e] Masetti et al. 2006a.

[f] Torres et al. 2004.

References.—N_H taken from (1) Lutz et al. 2004; (2) Bassani et al. 1999; (3) Masetti et al. 2006b; (4) Tartarus database; (5) Sazonov et al. 2005; (6) Collinge & Brandt 2000; (7) Guainazzi 2002; (8) Sazonov et al. 2004; (9) De Rosa et al. 2005 (ionized intrinsic absorption also possible); (10) Donato et al. 2005; (11) Sazonov & Revnivtsev 2004; (12) Reynolds et al. 1997; (13) Panessa & Bassani 2002; (14) Bassani et al. 2005.

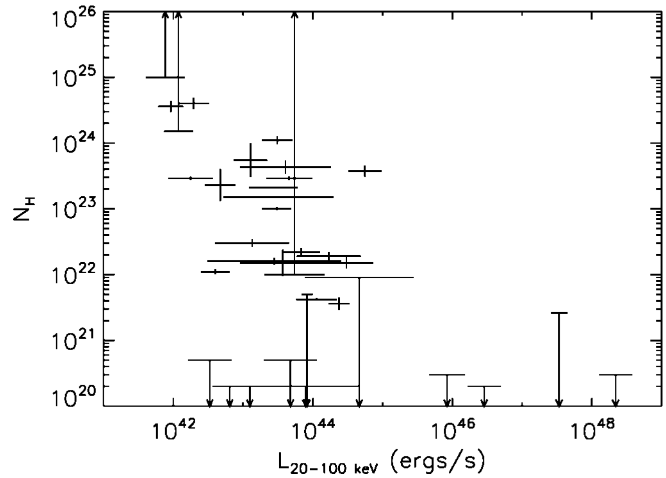

FIG. 2.—Column density vs. 20–100 keV luminosity for AGNs in the present survey with known intrinsic absorption.

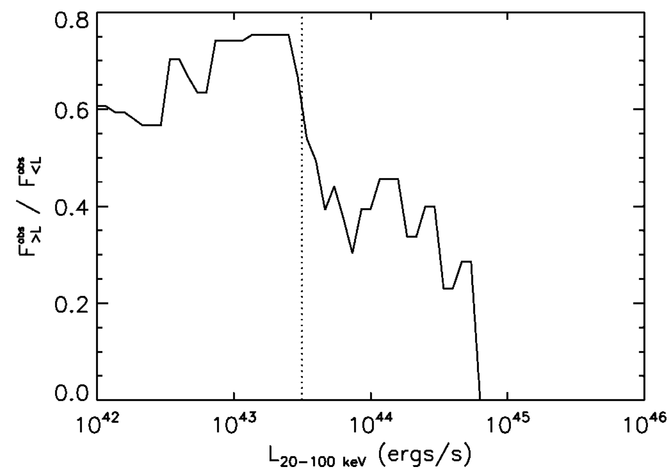

FIG. 3.—Ratio between the fraction of absorbed sources above a given luminosity and that below this value as a function of 20–100 keV luminosity.

tically constant, while above this luminosity it decreases sharply, implying that at high IBIS luminosities there are very few absorbed sources. Please note that our data are in agreement the *Swift* results obtained in the 15–200 keV band and also with results obtained in the 2–10 keV band.

Within the subsample of 17 Seyfert 2's with known N_H, we find that all are absorbed and almost 30% are Compton-thick; this is in line with previous estimates of the column density distribution of type 2 objects based on X-ray data (Risaliti et al. 1999; Bassani et al. 1999). Interestingly, we also find that 33% of type 1 objects are absorbed.

More in-depth studies of the present sample require optical classification of all objects and a detailed analysis of their broadband behavior (particularly in the X-ray–to–gamma-ray band) in order to understand the role of absorption and the relation of extragalactic gamma-ray surveys to those in other wave bands. In the meantime, this catalog testifies to the power of *INTEGRAL* and IBIS to probe the extragalactic gamma-ray sky, discover new active galaxies, and find absorbed objects.

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