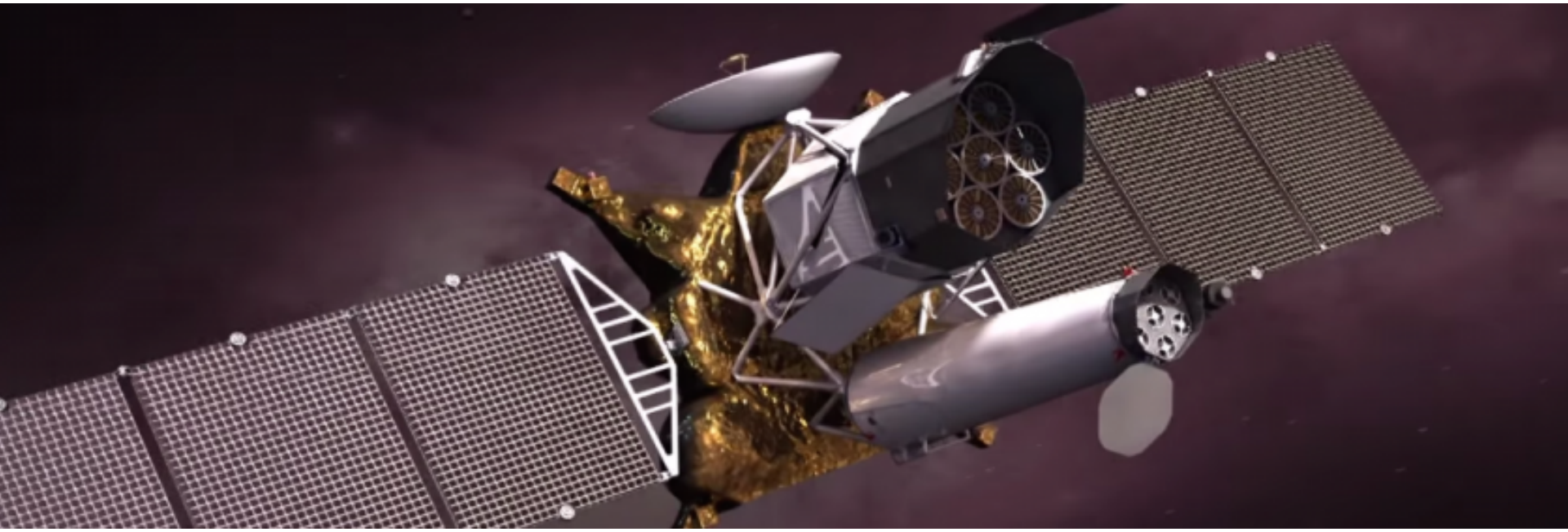
SRG/ART-XC all-sky X-ray survey:
Catalog of sources detected during the first five surveys



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Astronomy & Astrophysics

SRG/ART-XC all-sky X-ray survey: Catalog of sources detected during the first five surveys★

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ABSTRACT

We present an updated catalog of sources detected by the *Mikhail Pavlinsky* ART-XC telescope aboard the Spektrum-Roentgen-Gamma (SRG) observatory during its all-sky survey. It is based on the data of the first four and the partially completed fifth scans of the sky (ARTSS1-5). The catalog comprises 1545 sources detected in the 4–12 keV energy band. The achieved sensitivity ranges between $\sim 4 \times 10^{-12}$ erg s^{-1} cm^{-2} near the ecliptic plane and $\sim 7 \times 10^{-13}$ erg s^{-1} cm^{-2} near the ecliptic poles, which is a ∼30–50% improvement over the previous version of the catalog based on the first two all-sky scans (ARTSS12). There are ∼130 objects, excluding the expected contribution of spurious detections, that were not known as X-ray sources before the SRG/ART-XC all-sky survey. We provide information, partly based on our ongoing follow-up optical spectroscopy program, on the identification and classification of the majority of the ARTSS1-5 sources (1463), of which 173 are tentative at the moment. The majority of the classified objects (964) are extragalactic, a small fraction (30) are located in the Local Group of galaxies, and 469 are Galactic. The dominant classes of objects in the catalog are active galactic nuclei (911) and cataclysmic variables (192).

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Astronomy & Astrophysics

The Early Data Release of eROSITA and Mikhail Pavlinsky ART-XC on the SRG mission

Special issue

SRG/ART-XC all-sky X-ray survey: Catalog of sources detected during the first year★

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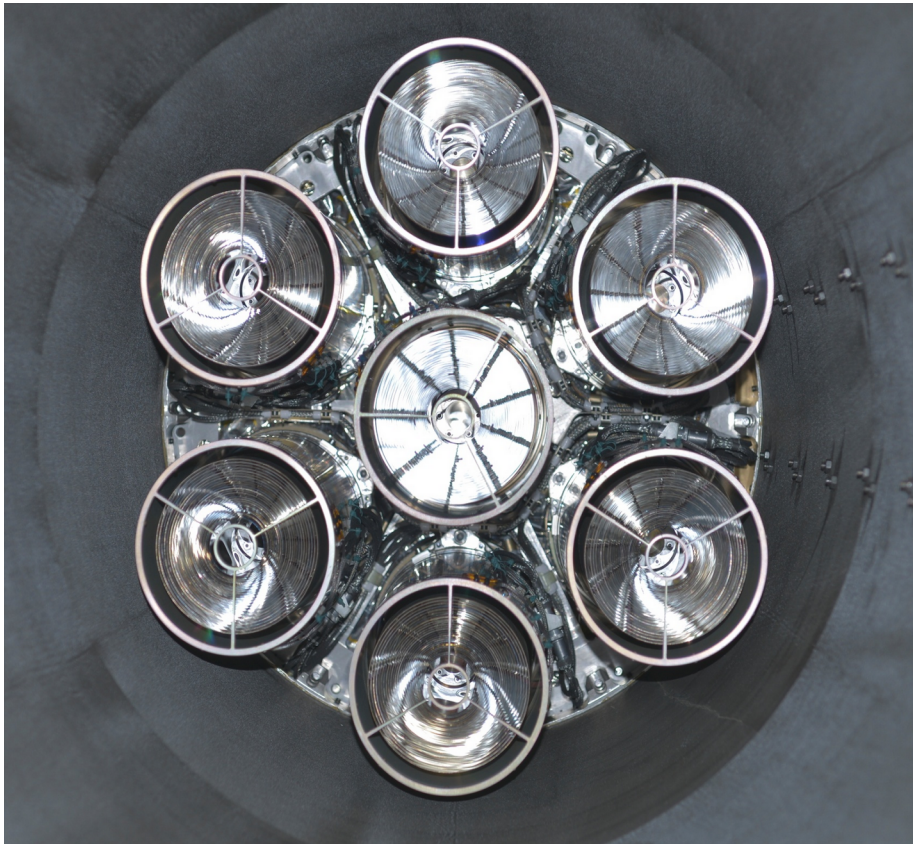
ABSTRACT

We present a first catalog of sources detected by the *Mikhail Pavlinsky* ART-XC telescope on board the SRG observatory in the 4–12 keV energy band during its ongoing all-sky survey. The catalog comprises 867 sources detected on the combined map of the first two 6-month scans of the sky (December 2019–December 2020), ART-XC sky surveys 1 and 2, or ARTSS12. The achieved sensitivity to point sources varies between $\sim 4 \times 10^{-12}$ erg s^{-1} cm^{-2} near the ecliptic plane and $\sim 8 \times 10^{-13}$ erg s^{-1} cm^{-2} (4–12 keV) near the ecliptic poles, and the typical localization accuracy is $\sim 15''$. Of the 750 sources of known or suspected origin in the catalog, 56% are extragalactic (mostly active galactic nuclei, AGN; and clusters of galaxies) and the rest are Galactic (mostly cataclysmic variables, CVs; and low- and high-mass X-ray binaries). For 114 sources, ART-XC has detected X-rays for the first time. Although the majority of these (~80) are expected to be spurious (given the adopted detection threshold), there can be a significant number of newly discovered astrophysical objects. We have started a program of optical follow-up observations of the new and previously unidentified X-ray sources, which has already led to the identification of several AGN and CVs. With the SRG all-sky survey planned to continue for a total of four years, we can expect the ART-XC survey in the 4–12 keV band to significantly surpass previous surveys that were carried out in similar (medium X-ray) energy bands in terms of the combination of angular resolution, sensitivity, and sky coverage.

Spectrum-Roentgen-Gamma (SRG) Observatory

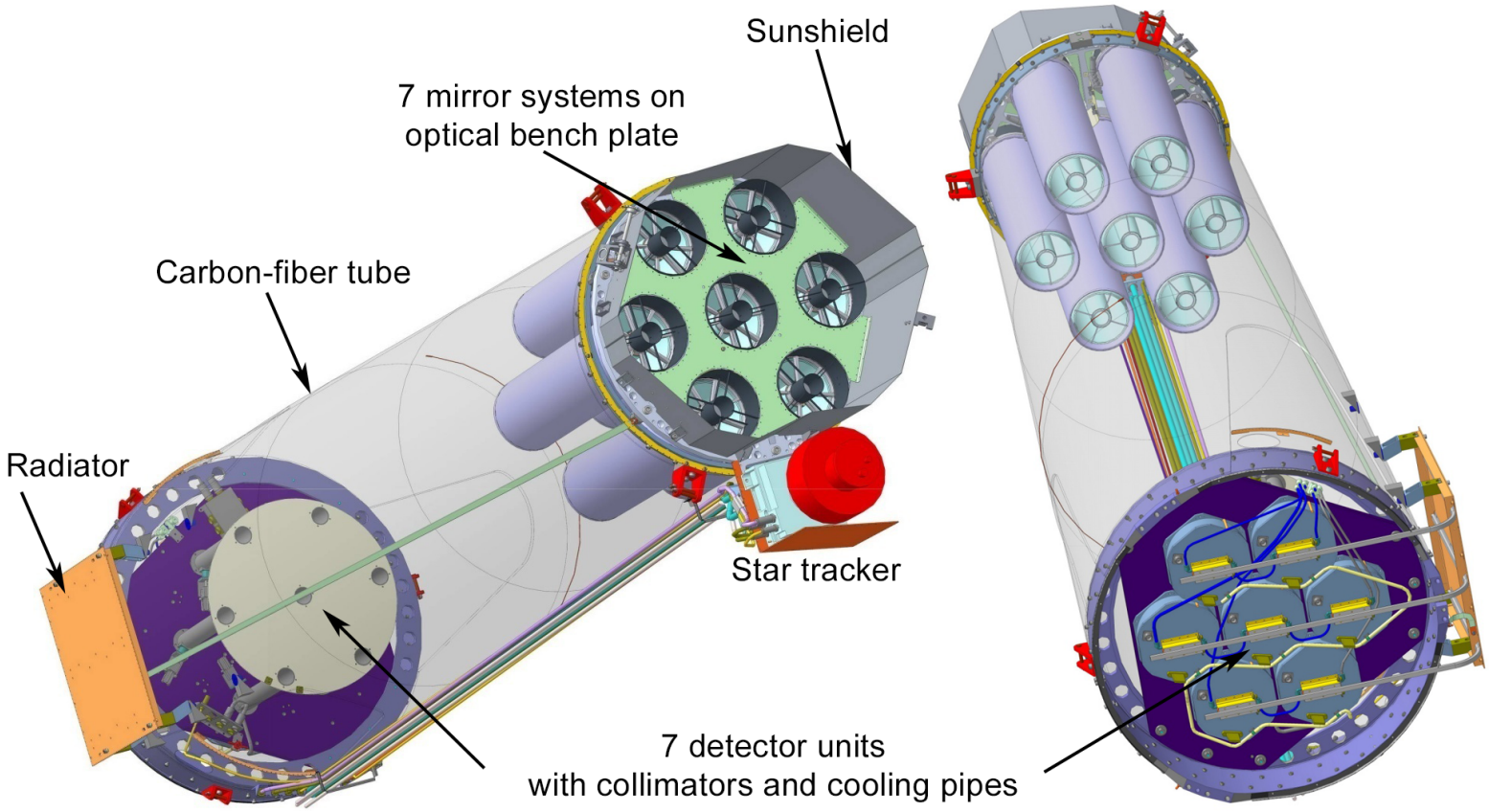
Mikhail Pavlinsky ART-XC Telescope

1959-2020



IKI (Moscow), VNIIEF (Sarov), NASA MSFC

ART-XC

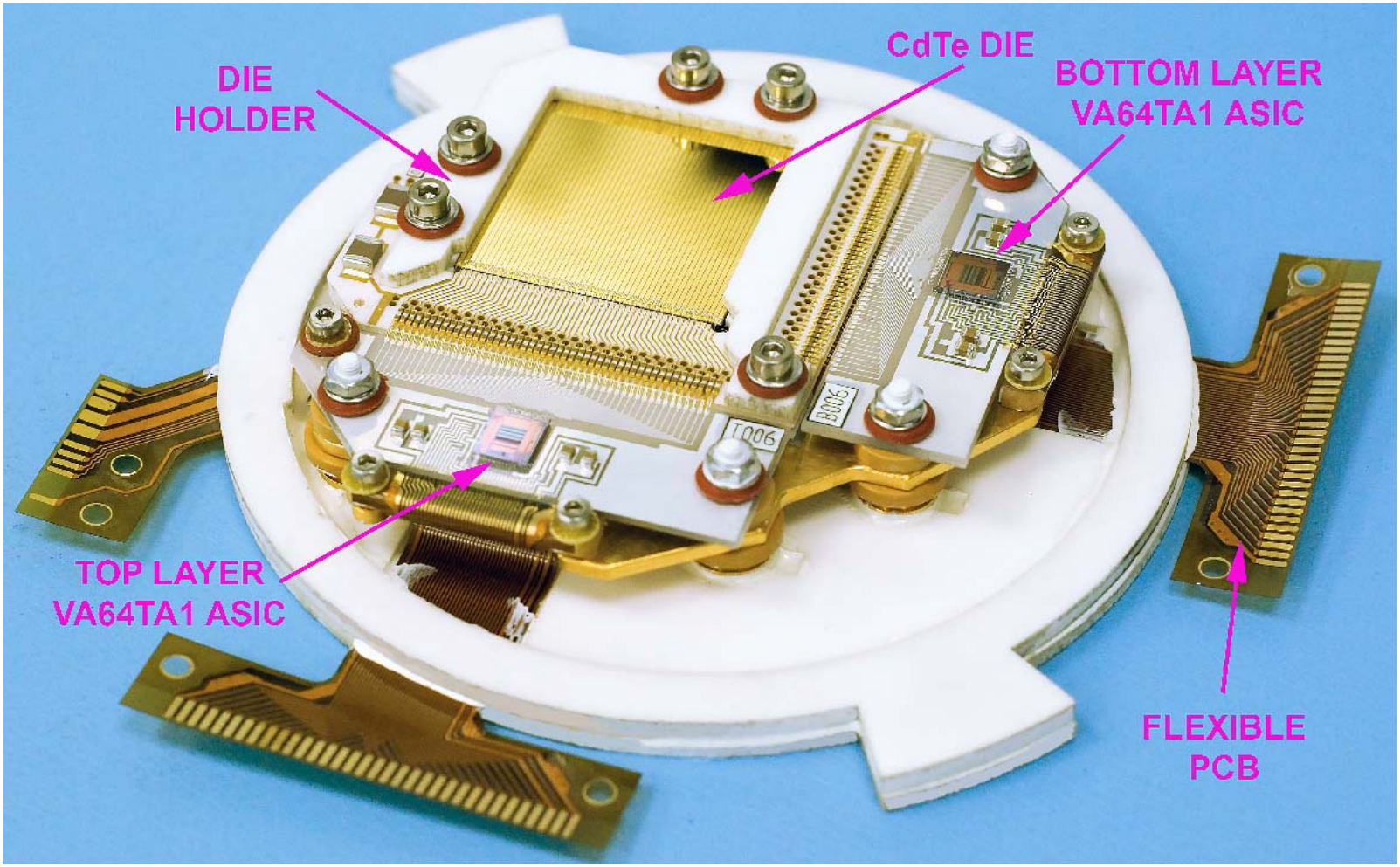


Grazing incidence X-ray optics (paraboloid + hyperboloid)

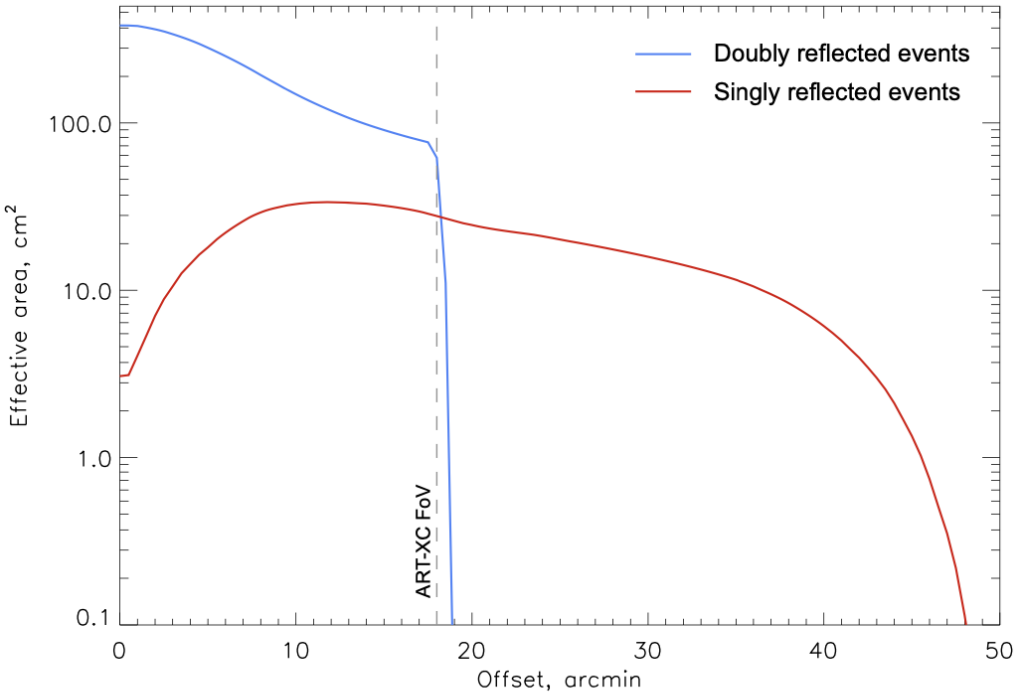
Focal length 2.7 m

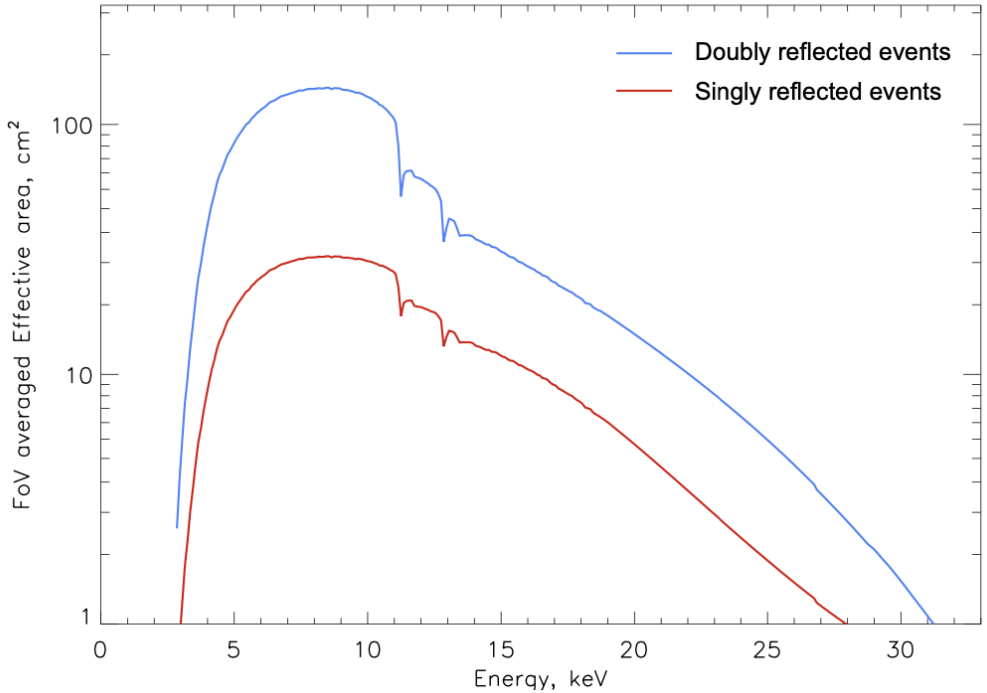
7 mirror systems, each consisting of 28 shells covered by iridium

ART-XC



CdTe detectors





Effective area:

36 arcmin diameter

Energy band:

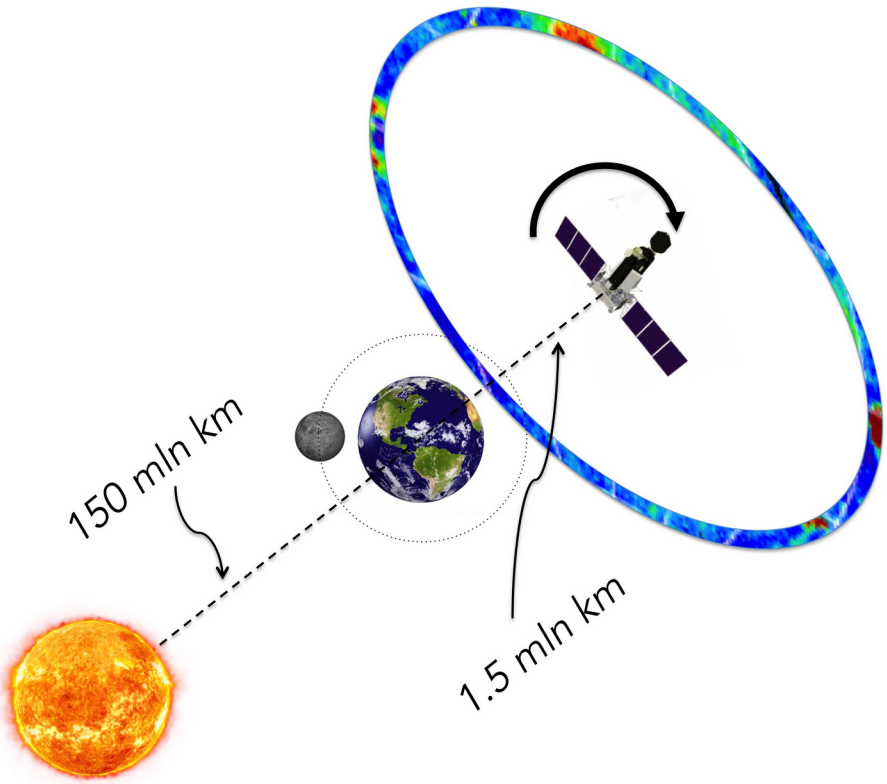
4–30 keV in pointing observations

4-12 keV in survey

Angular resolution in survey:

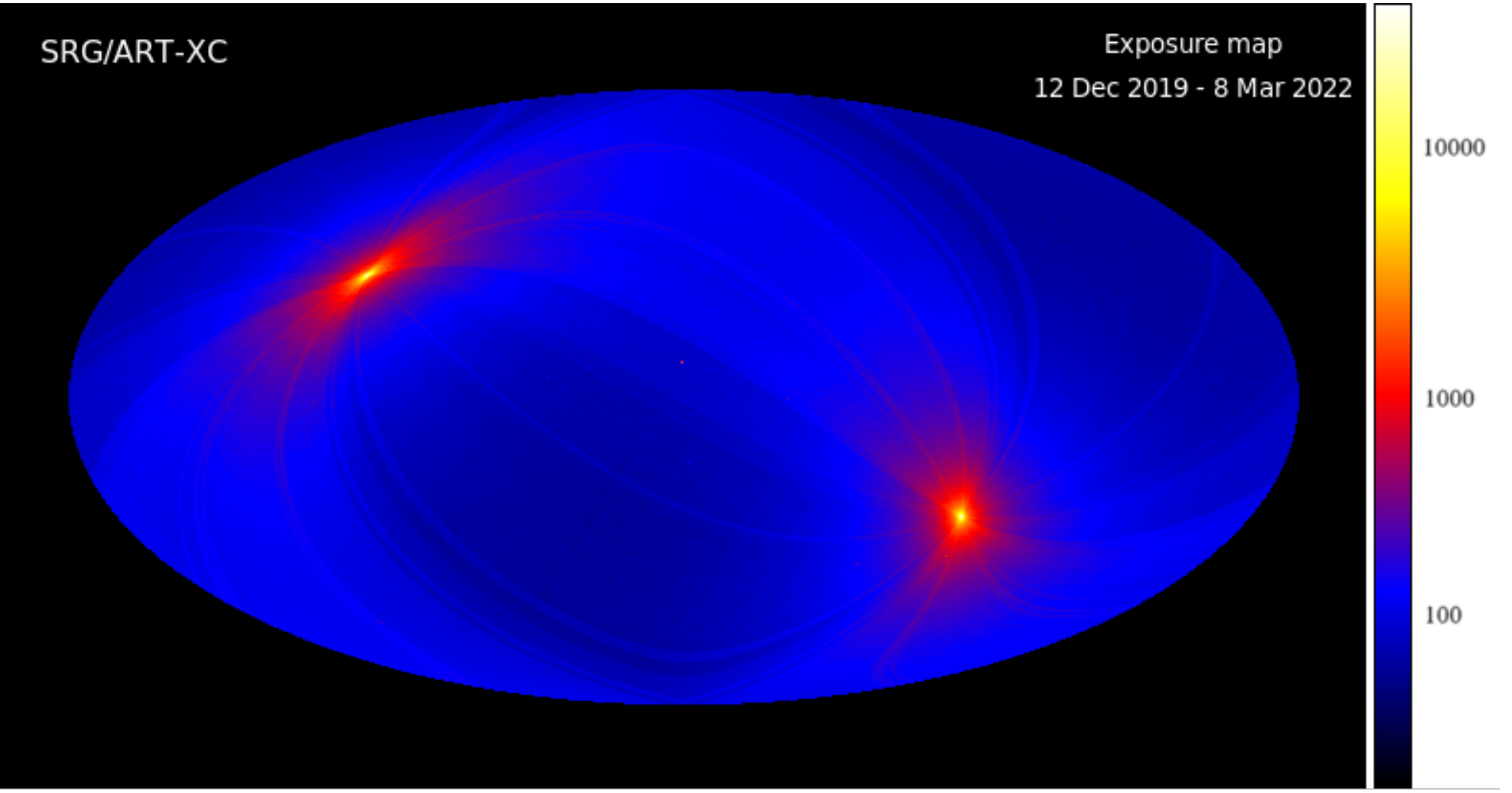
53 arcsec

SRG all-sky survey



- Conducted from a halo orbit around the Sun-Earth L2 point.
- The satellite spins around its axis with a period of 4 hours. The axis is pointed at the Sun.
- A typical source is visited by ART-XC once every 6 months: 4 times for 20 sec every 4 hours.
- The sky is fully scanned every 6 months.
- **The all-sky survey started in Dec. 2019 and by March 2022, four full scans and 40% of the 5th one were completed.**
- In October 2023, ART-XC resumed the all-sky survey.

ARTSS1-5 exposure map in Galactic coordinates
12 December 2019 — 7 March 2022



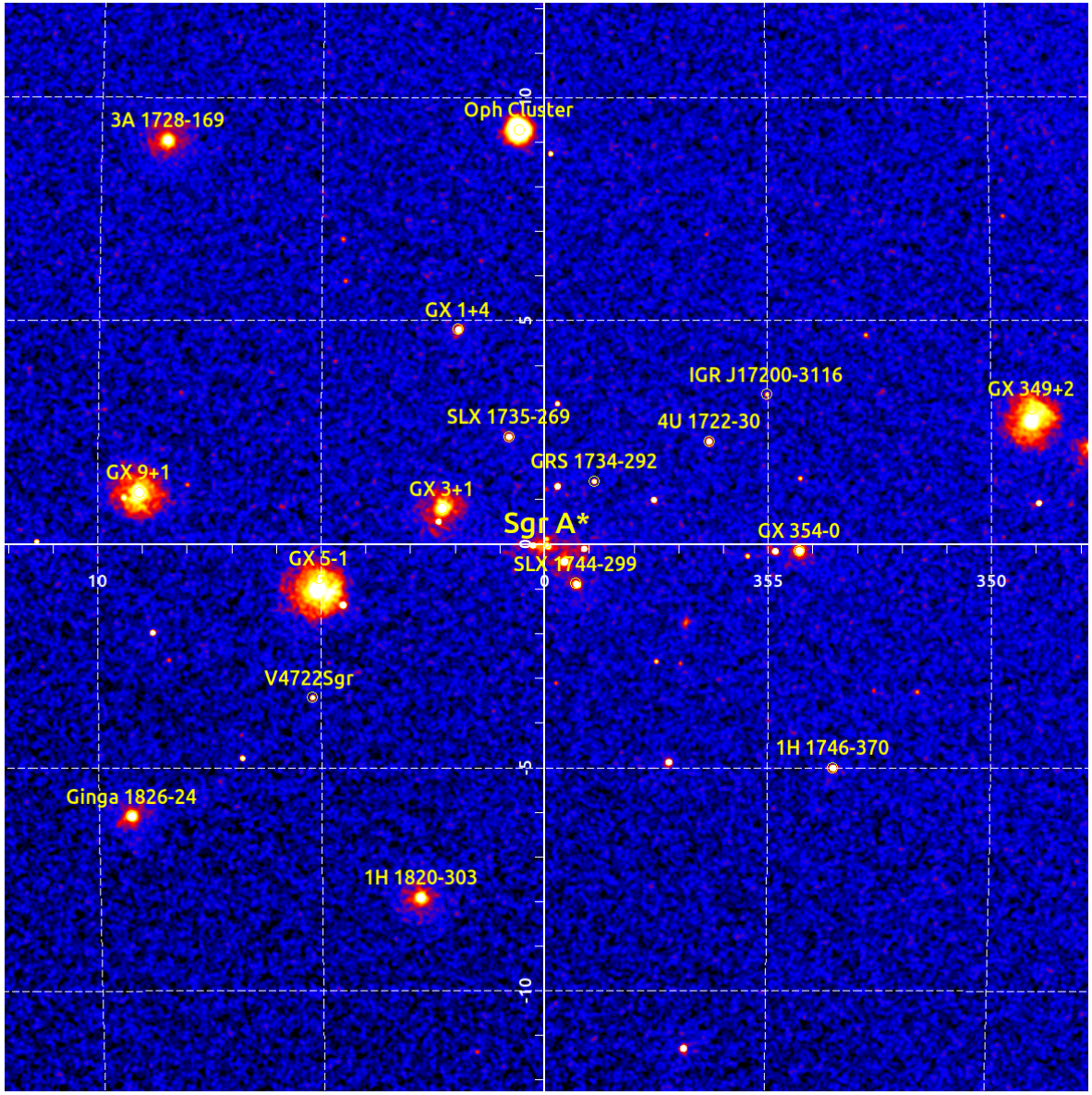
Vignetting corrected exposure varies between ~100-300 sec in the ecliptic plane and ~40 ксec in the Ecliptic poles

Sky map and source catalog of the first 4.4 SRG/ART-XC all-sky surveys (ARTSS1-5)

Previously, we issued the source catalog of the first two surveys (ARTSS12, Pavlinsky et al. 2022).

As before, the main (detection) energy band is 4-12 keV, additional bands: 4-7, 7-12, 12-20, and 20-30 keV. Novelties:

- account of detection of source photons and background events depending on energy and detector grades,
- determination of source position uncertainties,
- improved determination of source fluxes,
- allowance for events with energies of 3-4 keV.

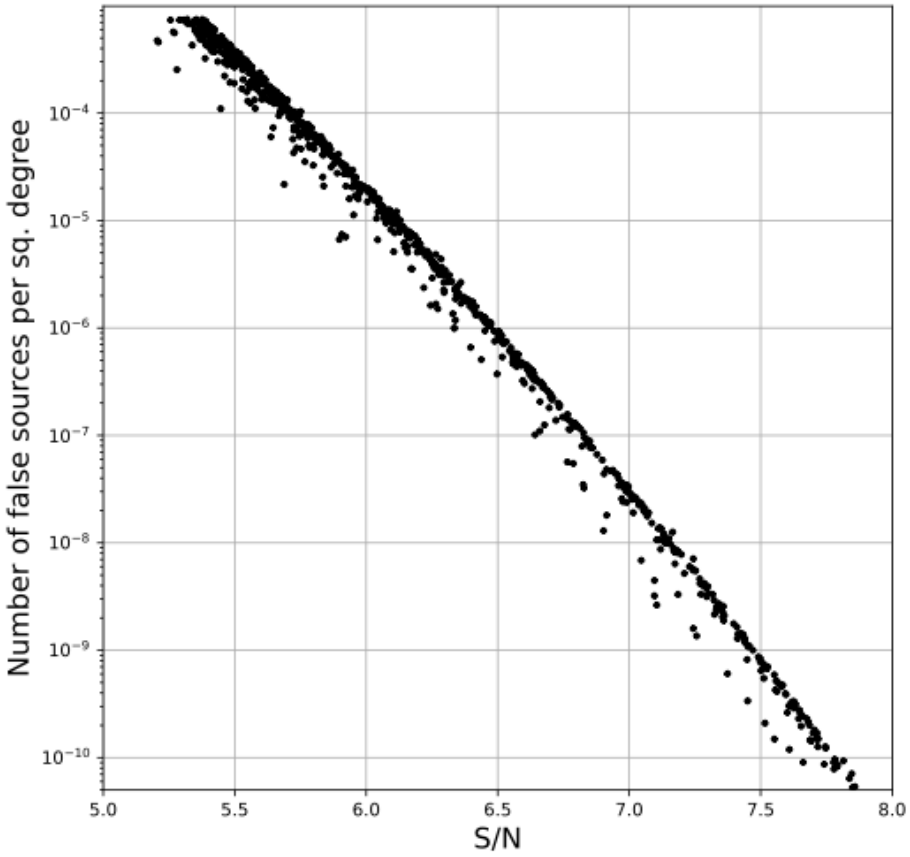


ART-XC Image of a 25 x 25 deg region near the Galactic Center

4-12 keV band

Only bright sources are marked

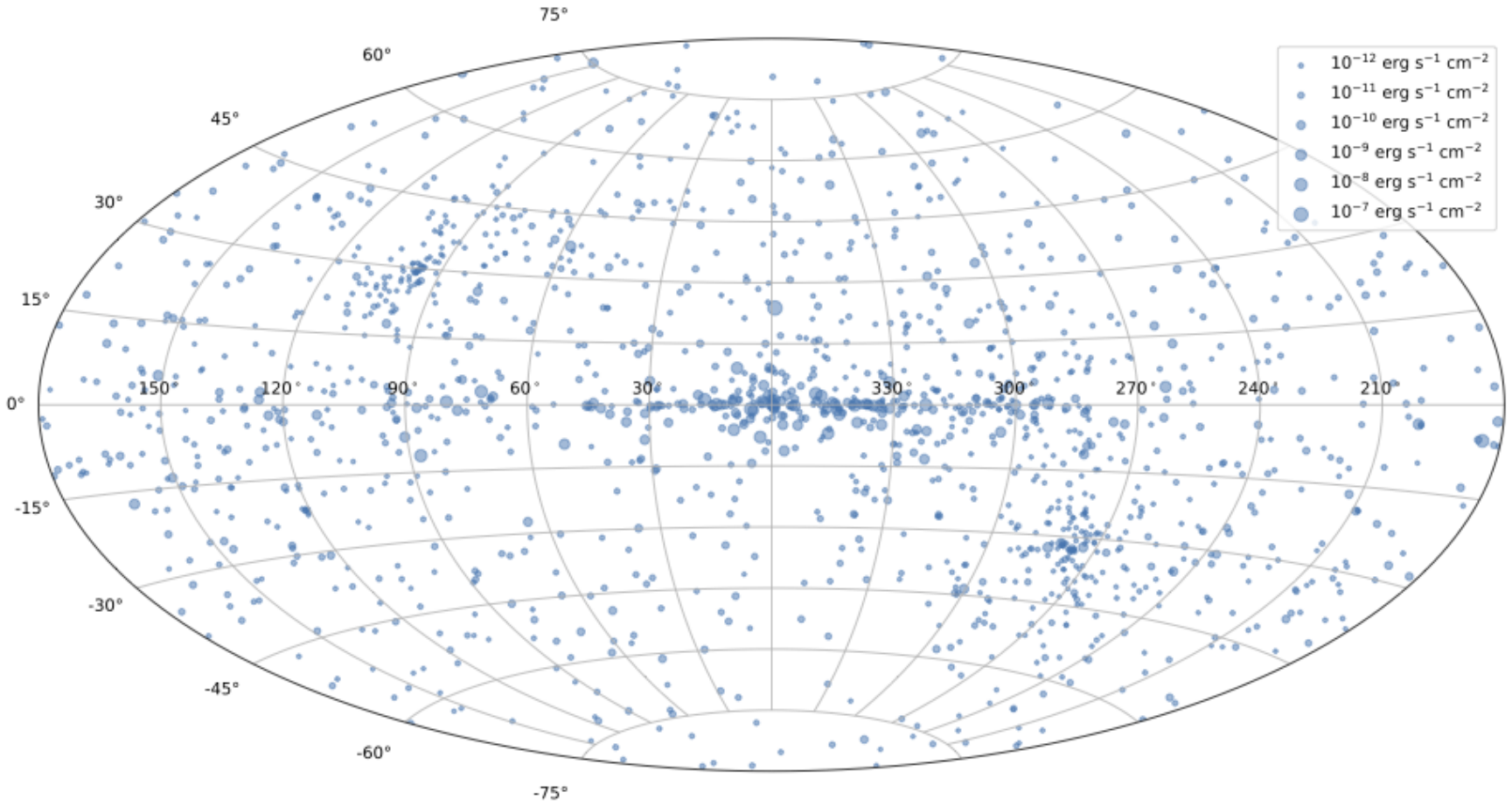
Choosing a detection limit



Using simulations of emtpy fields, we established a relationship between the expected number of spurious sources, background level and source detection signifcance (S/N).

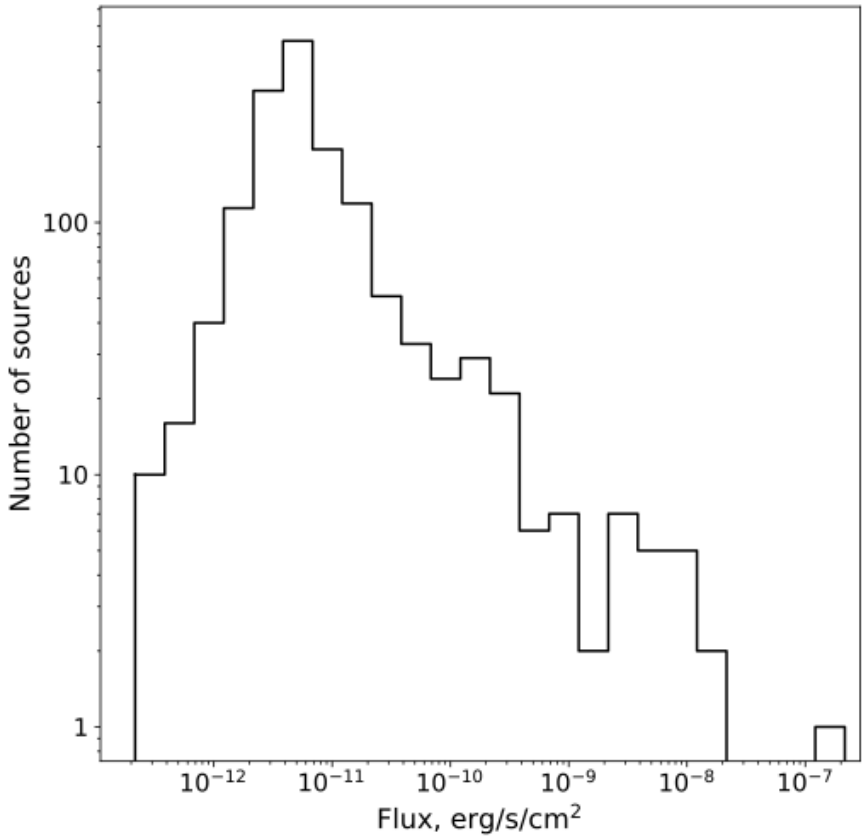
For publication, we adopted a level of 7.475 10^{-4} spurious sources per sq. deg (S/N~5.3), which corresponds to 2% of spurious sources in the ARTSS1-5 catalog.

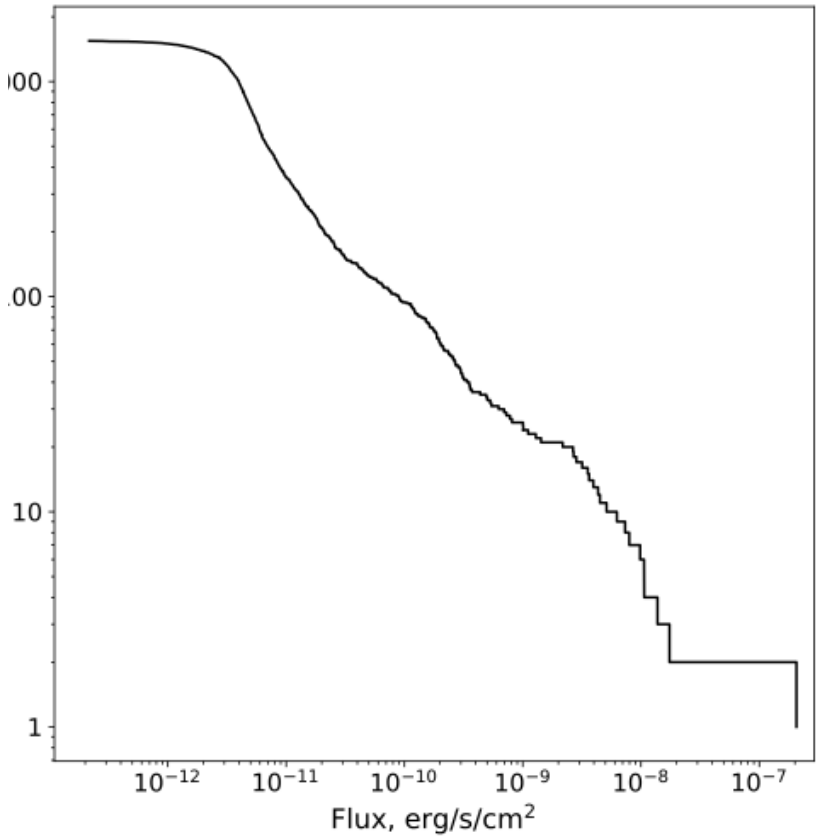
The ARTSS1-5 catalog (1545 sources)



Positions in Galactic coordinates of the ARTSS1-5 sources. The symbol size reflects the source flux in the 4-12 keV energy band.

Flux distribution of ARTSS1-5 sources

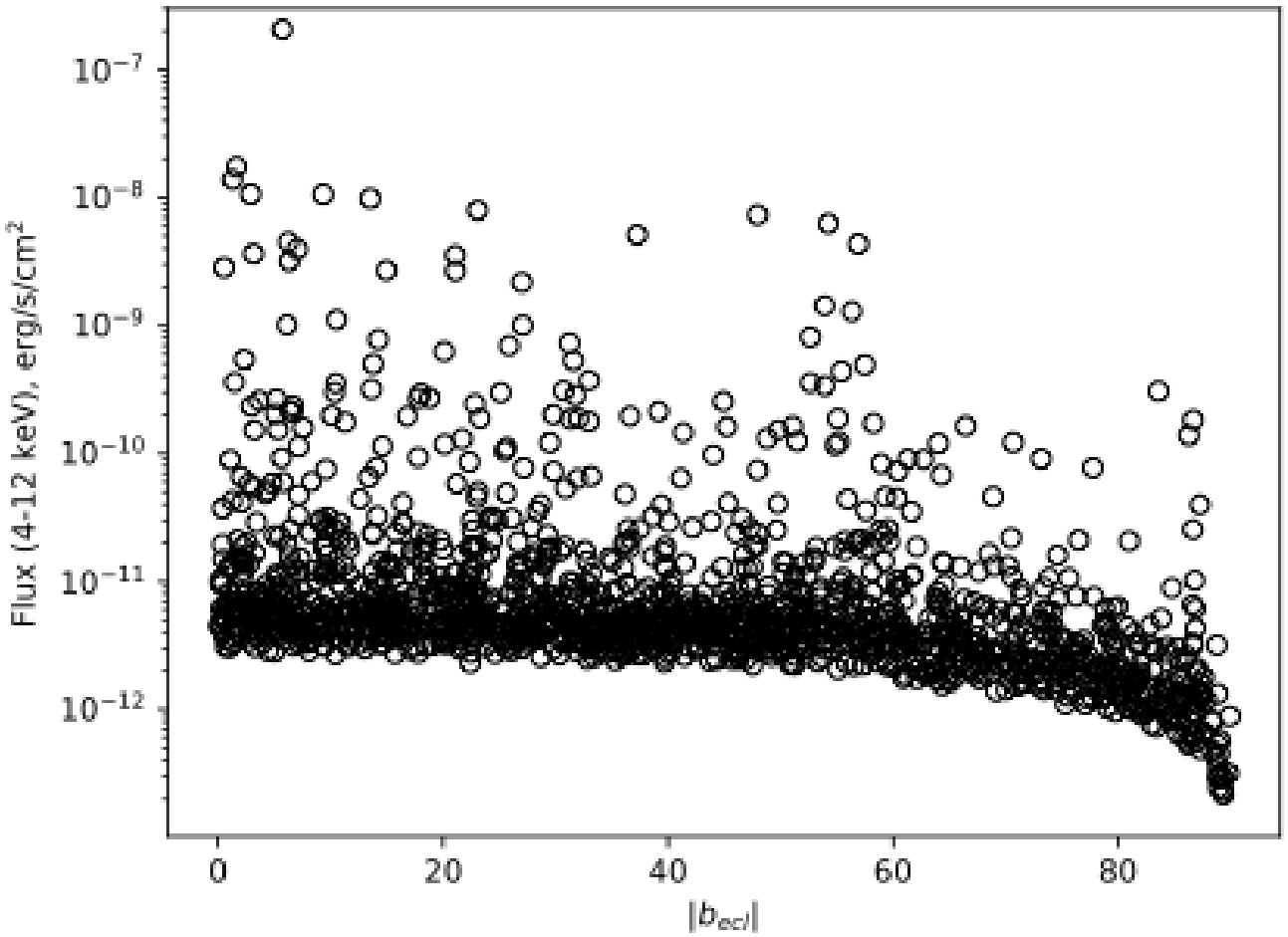




Median flux:

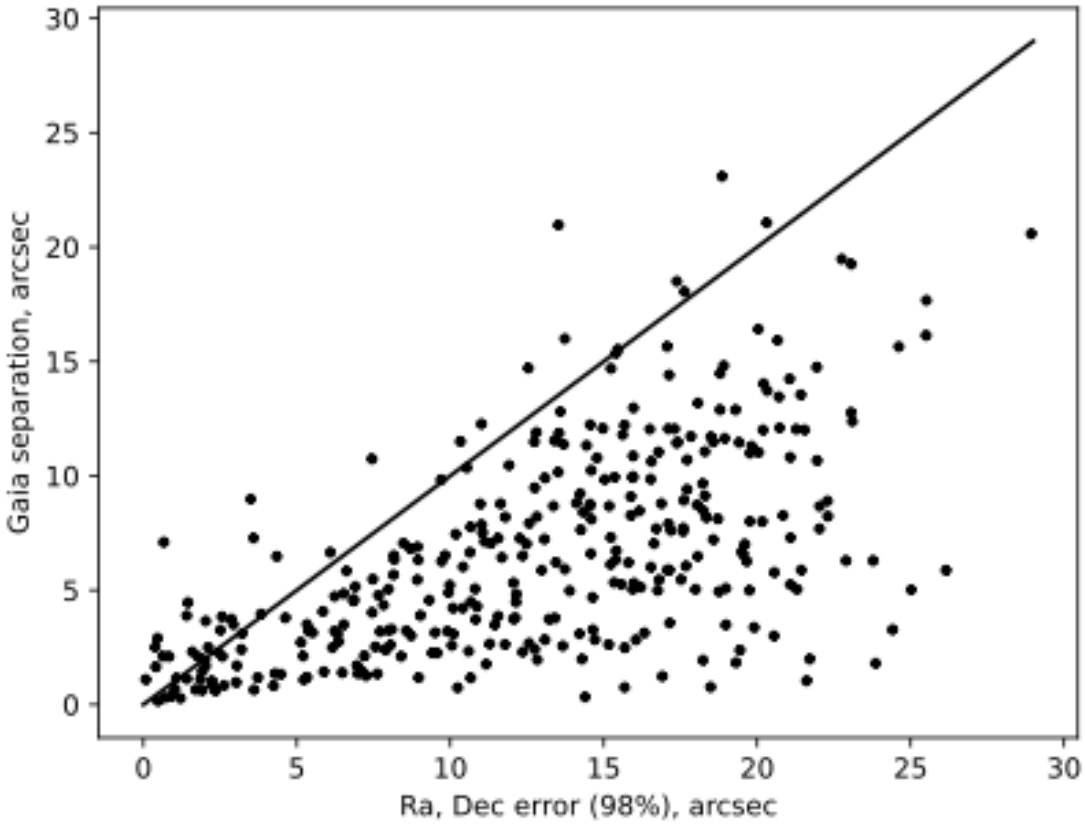
4.9 10^{-12} erg/s/cm^2 (=0.36 mCrab) in 4-12 keV

Sensitivity of the survey



~4 10^{-12} erg/s/cm^2 (=0.3 mCrab) at $|b_{ecl}| < 30^{\circ}$
~7 10^{-13} erg/s/cm^2 (=0.05 mCrab) at $|b_{ecl}| > 82^{\circ}$

Localization precision



Offsets between the positions of ARTSS1-5 sources and their Gaia DR3 counterparts (346 Galactic objects).

- **The 98% uncertainty does no exceed 30¨ for weak sources**
- **The systematic astrometry error is ~7¨**

ARTSS1-5 catalog's database
(srg.cosmos.ru)

Name	Survey	CName	H	G	W	R	RA	Dec	Lon	Lat	Cnts	Expo	ML Sign.	log_ML_nFalse	ML DL	ML Flux	Class
SRGA J000048.1-070914 M8	S1-5v12345.14W	SWIFT J0001.0-0708	3	5	0	0	0.2005	-7.1539	89.5984	-66.6904	17.6	105	6.36	-5.70	39.12	5.69e-12	[extra] SEYFERT …
SRGA J000132.9+240237 M12	S1-5v12345.14W	NEW X-RAY SOURCE	0	4	0	2	0.3869	24.0435	108.5503	-37.4311	16.4	129	5.57	-3.66	29.73	3.96e-12	[extra] SEYFERT …
SRGA J000148.6-765739 M12	S1-5v12345.14W	SWIFT J0001.6-7701	2	8	0	1	0.4526	-76.9607	306.5503	-39.8168	16.6	153	5.57	-3.60	29.67	3.85e-12	[extra] SEYFERT …
SRGA J000310.3+215744 M7	S1-5v12345.14W	Mrk 334	3	10	0	2	0.7931	21.9622	108.3713	-39.5410	9.1	132	5.81	-4.24	32.46	3.58e-12	[extra] SEYFERT
SRGA J000359.1+701922 M8	S1-5v12345.14W	IGR J00040+7020	2	30	0	2	0.9962	70.3227	118.9253	7.8210	25.4	358	6.21	-5.22	37.21	2.19e-12	[extra] SEYFERT …
SRGA J000549.7+102227 M6	S1-5v12345.14W	RX J0005.8+1022	1	7	0	0	1.4571	10.3742	104.9722	-50.9002	9.8	116	5.62	-3.79	30.32	4.38e-12	[extra] SEYFERT …
SRGA J000632.6-690026 M13	S1-5v12345.14W	CTCV J0006-6900	2	6	0	0	1.6357	-69.0071	308.8676	-47.6004	17.7	137	8.17	-11.37	65.39	5.63e-12	[gal] CV DWARF…
SRGA J000636.0+434219 M8	S1-5v12345.14W	2RXS J000637.0+434223	1	13	0	0	1.6499	43.7052	114.4137	-18.4237	24.9	217	6.67	-6.53	43.24	3.61e-12	[extra] SEYFERT
SRGA J001030.5+105836 M8	S1-5v12345.14W	Mrk 1501	3	4	0	7	2.6269	10.9767	106.9767	-50.6227	19.7	121	7.79	-10.08	59.40	6.20e-12	[extra] BLAZAR
SRGA J001123.9-112850 M14	S1-5v12345.14W	WW Cet	2	2	0	0	2.8496	-11.4805	89.9935	-71.7432	41.6	114	10.55	-21.03	110.02	1.12e-11	[gal] CV DWARF…
SRGA J001439.6+183500 M10	S1-5v12345.14W	XMMSL2 J001439.6+183450	1	3	0	2	3.6649	18.5833	110.8947	-43.4272	18.2	129	7.01	-7.56	47.78	4.99e-12	[extra] SEYFERT …
SRGA J001706.1+813458 M14	S1-5v12345.14W	6C 001403+811827	2	8	0	3	4.2754	81.5828	121.6094	18.7994	31.1	319	8.73	-13.43	74.89	3.69e-12	[extra] BLAZAR
SRGA J002052.7+554212 M9	S1-5v12345.14W	V592 Cas	2	81	0	0	5.2197	55.7034	118.6043	-6.9114	16.2	222	6.03	-4.76	35.06	3.62e-12	[gal] CV NOVA …
SRGA J002107.1-191005 M7	S1-5v12345.14W	2RXS J002108.2-190950	2	6	0	3	5.2797	-19.1681	80.1683	-79.4261	11.5	91	5.38	-3.25	27.60	4.94e-12	[extra] SEYFERT …
SRGA J002203.6+254017 M10	S1-5v12345.14W	XMMSL1 J002202.9+254004	1	2	0	1	5.5150	25.6713	114.6667	-36.7286	24.4	134	7.89	-10.40	60.90	5.57e-12	[extra] SEYFERT …
SRGA J002241.4+804348 M9	S1-5v12345.14W	2RXS J002247.6+804418	2	11	0	0	5.6723	80.7299	121.7182	17.9260	29.9	337	6.83	-6.97	45.29	2.97e-12	[extra] SEYFERT …
SRGA J002256.9+614101 M15	S1-5v12345.14W	V1033 Cas	3	21	0	0	5.7372	61.6837	119.5598	-1.0013	51.9	246	10.91	-22.63	117.73	6.30e-12	[gal] CV INTER…
SRGA J002314.4-152032 M5	S1-5v12345.14W	NEW X-RAY SOURCE	0	5	0	0	5.8100	-15.3422	92.4332	-76.5145	13.6	116	5.44	-3.35	28.28	3.55e-12	Follow-up UNIDENTI.
SRGA J002848.1+591719 M22	S1-5v12345.14W	V709 Cas	6	25	0	0	7.2004	59.2885	120.0400	-3.4561	246.1	233	36.56	-100.00	1335.21	4.04e-11	[gal] CV INTER…
SRGA J002913.8+131610 M7	S1-5v12345.14W	PG 0026+129	2	7	0	2	7.3074	13.2695	114.6384	-49.2443	16.7	126	5.52	-3.54	29.21	4.23e-12	[extra] SEYFERT …

We actively use this system to cross-match the ARTSS1-5 catalog with astronomical databases and select objects for optical follow-up (input for the TRITON system).

X-ray source census

- In total, 1545 sources, including ~30 (2%) spurious detections.
- For comparison, in ARTSS12, there were 867 sources, including ~90 (10%) spurious.
- For 1463 sources, a counterpart/class is established (for 174, tentatively).
- Some 130 sources (excluding the expected number of spurious detections) are new X-ray sources.

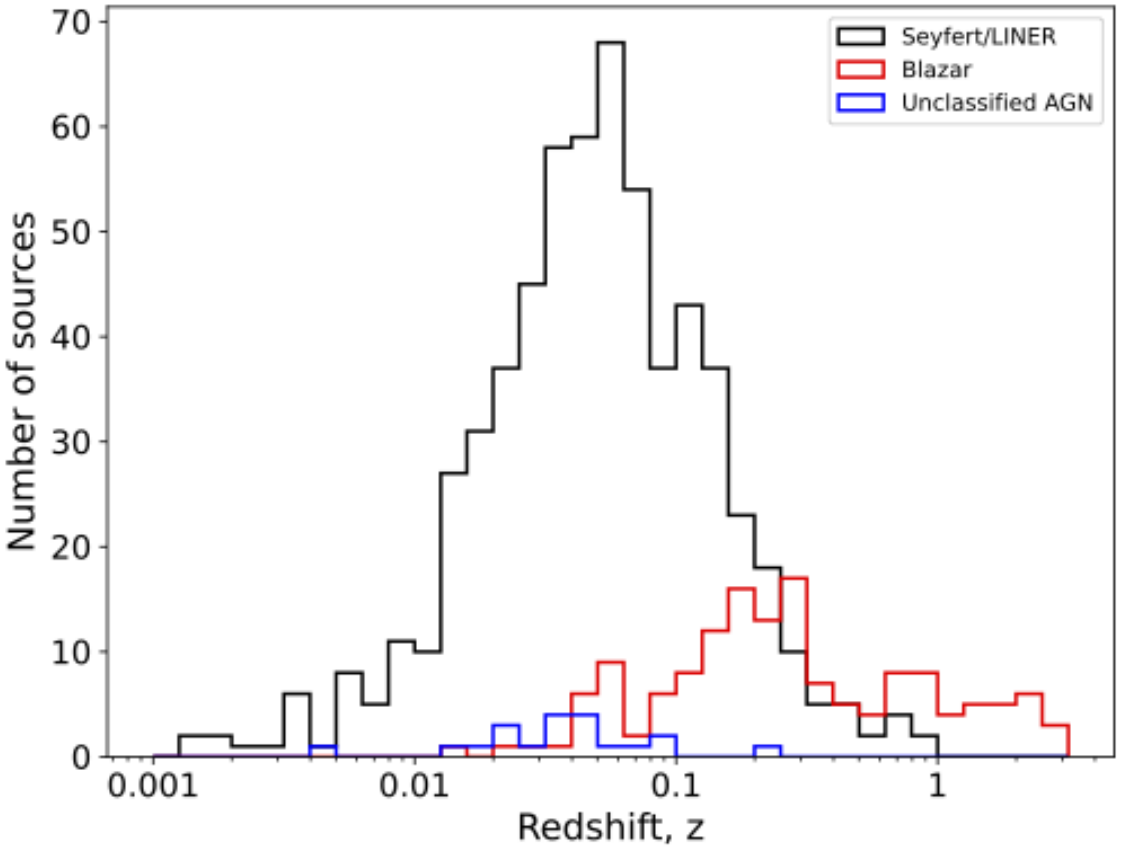
Category and type	Count
Galactic	470
LMXB	97
HMXB	84
X-ray binary	2
CV	193
magnetar	7
star	66
SNR, SNR/Pulsar	17
star-forming region	2
unclassified	2
The Local Group	30
galaxy	1
LMXB	3
HMXB	19
X-ray binary	1
ULX	1
SNR and SNR/Pulsar	5
Extragalactic	963
galaxy cluster	47
Seyfert or LINER	619
blazar	196
unclassified AGN	96
galaxy	1
ULX	4
unidentified	82

Cross-match of the ARTSS1-5 sources with selected X-ray and gamma-ray source catalogs

X-ray survey	Energy band	Reference	Cross-matches	Spurious matches[a)]
ROSAT (2RXS) 1 year	0.1–2.4 keV	Boller et al. (2016)	960	4.5 (2–7)
XMM-Newton slew	0.2–12 keV	Saxton et al. (2008)	874	1.8 (< 4)
MAXI/GSC 7 years	4–10 keV	Kawamuro et al. (2018); Hori et al. (2018)	286	5.6 (3–9)
Swift/BAT 105 months	14–195 keV	Oh et al. (2018a)	785	5.8 (3–8)
INTEGRAL 17 years	17–60 keV	Krivonos et al. (2022)	504	4.5 (2–7)
Fermi/LAT 14 years	50 MeV–1 TeV	Abdollahi et al. (2022)	222	23.8 (18–30)

194 ARTSS1-5 sources are not present in any of these catalogs (this includes ~30 spurious detections).

Active galactic nuclei
(911, including 196 blazars)

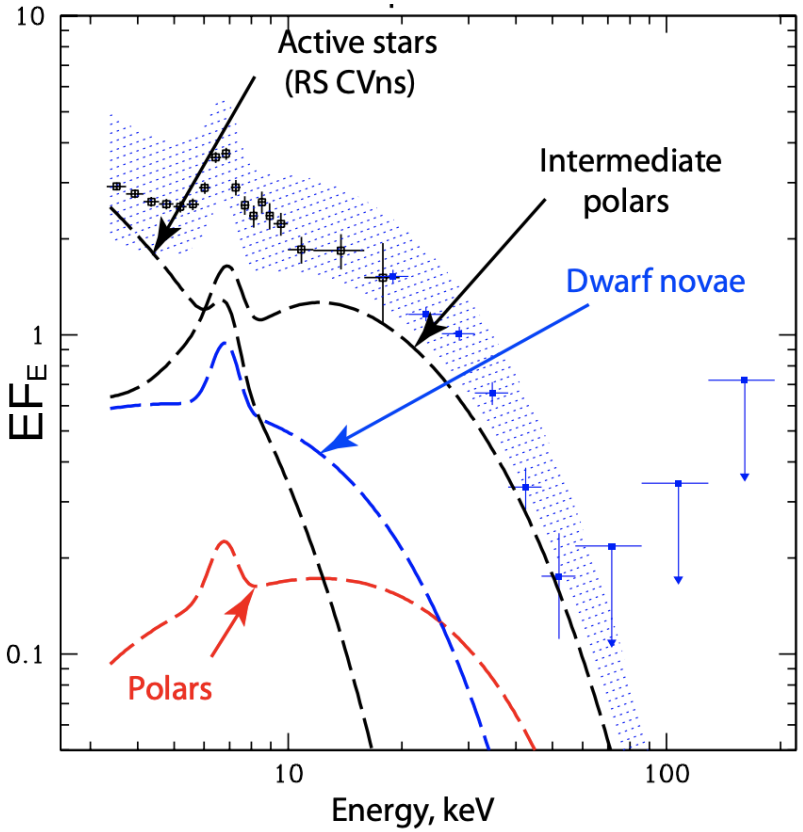


Redshift distribution (782 AGN)

- Median:
  z=0.05 — Seyferts
  z=0.25 — blazars
- Near the Ecliptic poles, these values are larger
- The redshifts are not yet measured for 129 AGN and AGN candidates

For comparison, in the 105-month Swift/BAT catalog (14-195 keV, Oh+18), there are 1105 AGN, including 158 blazars.

Cataclysmic variables (192)

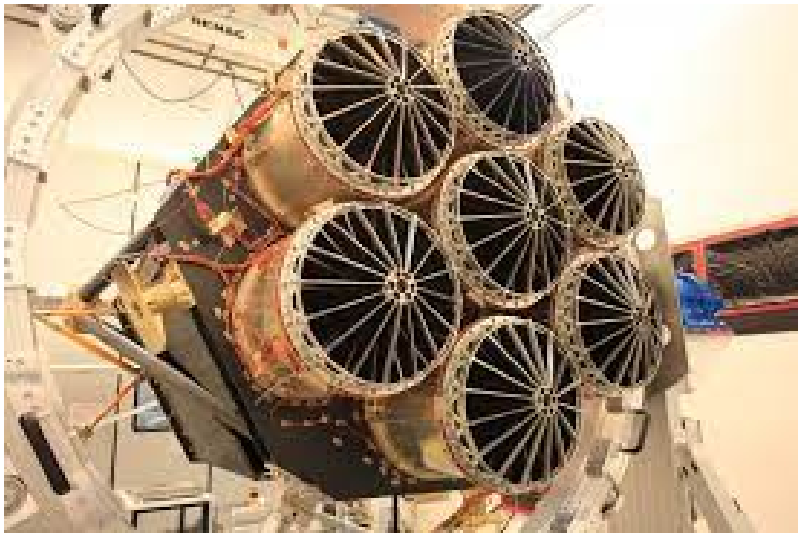


Revnivstev, SS & Sunyaev 2007

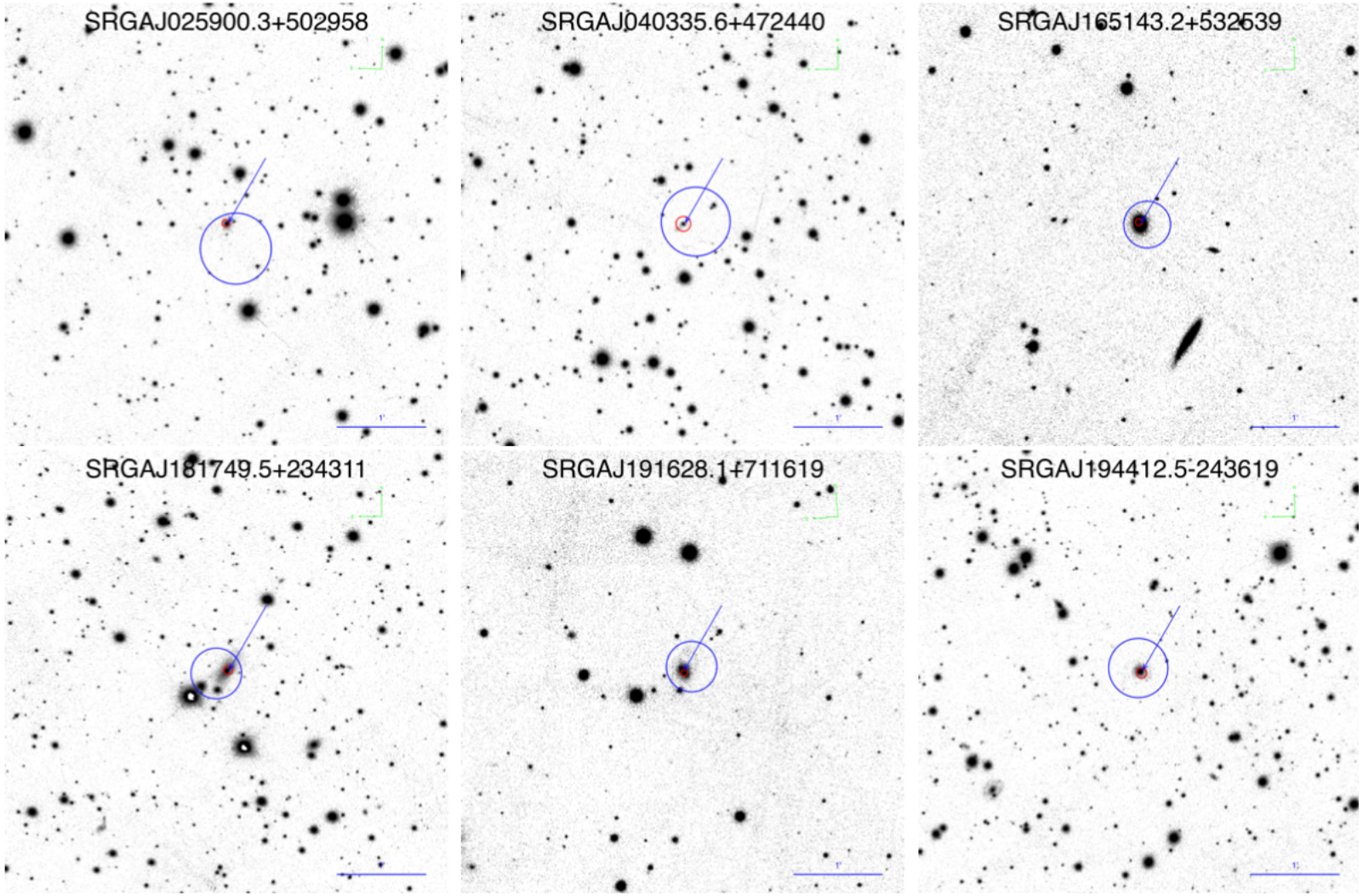
The 4-12 keV range is optimal for CV selection, since soft X-rays are subject to internal absorption, and there is a spectral cutoff above 20 keV.

For comparison, there are only 79 CVs in the 105-month каталоге Swift/BAT catalgo (14-195 кэВ, Oh+18).

Identification and multi-wavelength exploration of ARTSS1-5 sources



СРГ/eROSITA



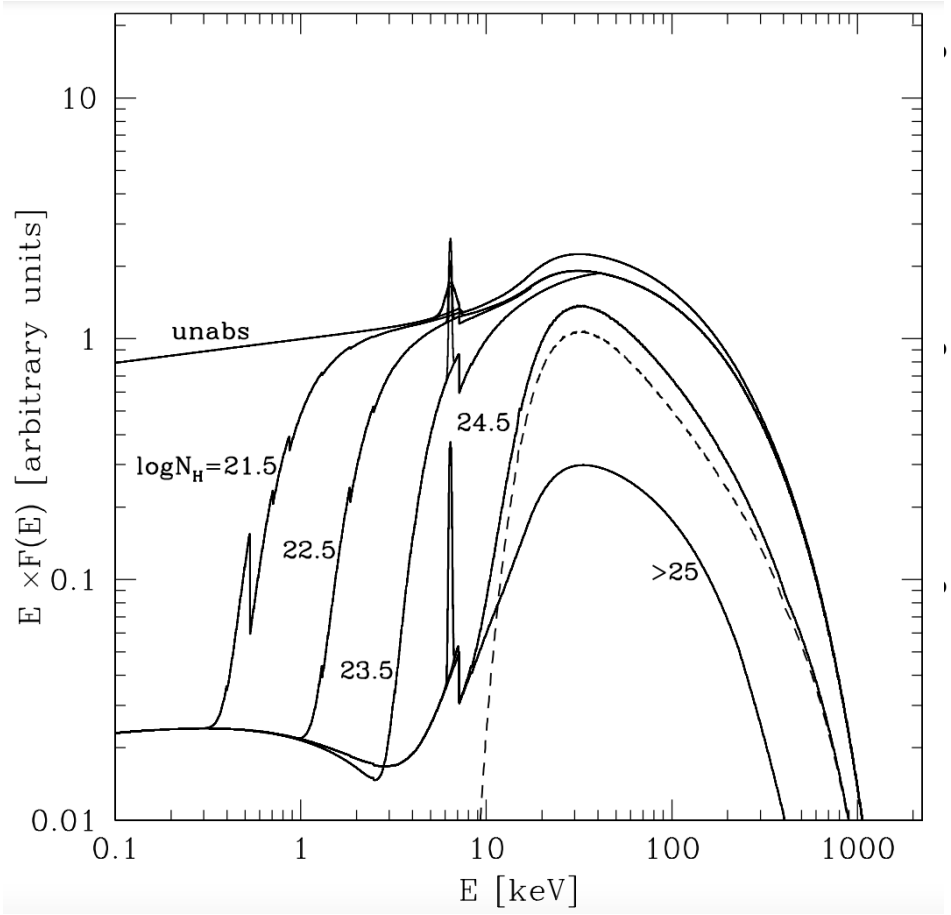
Pan-STARRS1 (r-фильтр)
кружки — области локализации ART-XC и eROSITA

Uskov et al. 2024

We have already identified more than 60 AGN and 10 CVs among the SRG/ART-XC sources.

Our main goal is to reach nearly 100% identification and classification completeness for the ARTSS1-5 catalog.

- *Зазнобин и др. «Оптическое отождествление кандидатов в активные ядра галактик, обнаруженных телескопом ART-XC им. М.Н. Павлинского обсерватории СРГ в ходе рентгеновского обзора всего неба», ПАЖ, 47, 89 (2021)*
- *Усков и др. «Новые активные ядра галактик, обнаруженные телескопами ART-XC и eРОЗИТА обсерватории СРГ в ходе рентгеновского обзора всего неба», ПАЖ, 48, 95 (2022)*
- *Zaznobin et al. «Identification of three cataclysmic variables detected by the ART-XC and eROSITA telescopes on board the SRG during the all-sky X-ray survey», A&A 661, id. A39 (2022)*
- *Усков и др. «Новые активные ядра галактик, обнаруженные телескопами ART-XC и eРОЗИТА в ходе первых пяти рентгеновских обзоров всего неба обсерватории СРГ», ПАЖ, 49, 97 (2023)*
- *Усков и др. «Новые активные ядра галактик, обнаруженные телескопами ART-XC и eРОЗИТА в ходе первых пяти рентгеновских обзоров всего неба обсерватории СРГ. Часть 2», ПАЖ (2024).*
- *Publication on transient sources.*



Gilli et al. 2007

- AGN discovered by SRG/ART-XC are typically characterized by moderate absorption column densities (N_H~10^{21} - 10^{23} см$^{-2}$).
- Unabsorbed AGN are usually known from the ROSAT all-sky survey and other soft X-ray surveys.
- Many strongly absorbed (N_H >10^{23} см$^{-2}$) AGN are already present in the catalogs of the hard X-ray all-sky surveys by ИНТЕГРАЛ/IBIS and Swift/BAT.

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INTEGRAL/IBIS 17-yr hard X-ray all-sky survey

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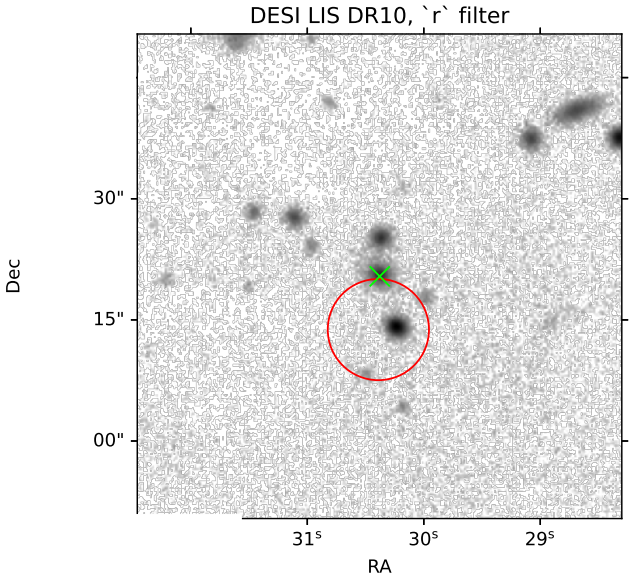
ABSTRACT

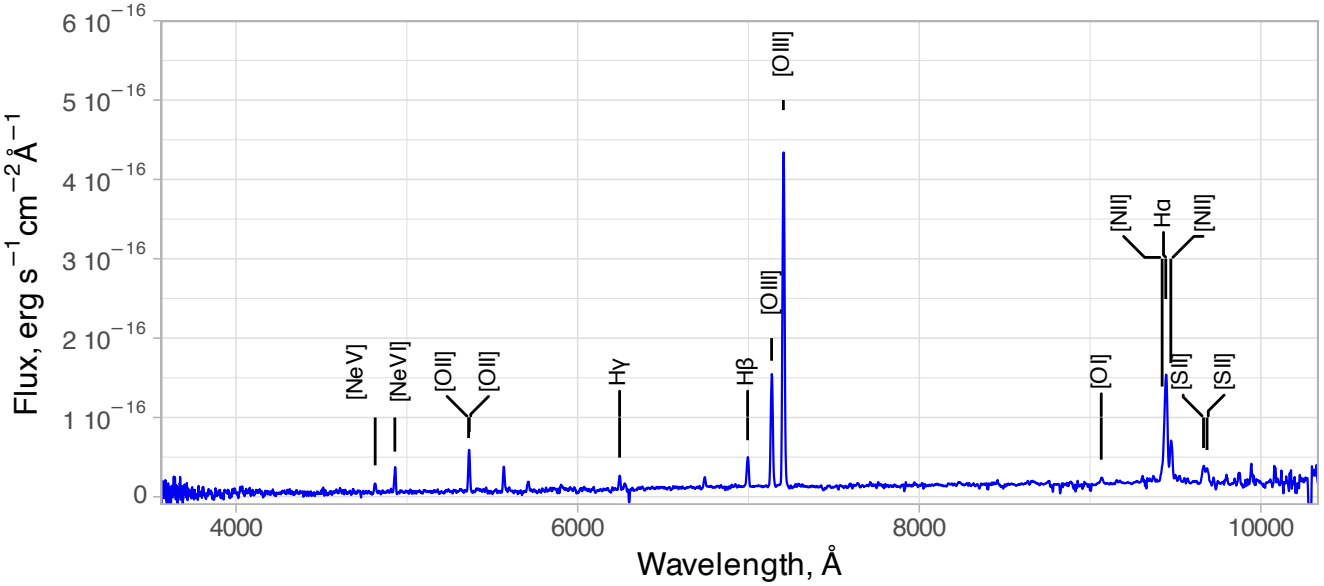
The International Gamma-Ray Astrophysics Laboratory (*INTEGRAL*), launched in 2002, continues its successful work in observing the sky at energies $E > 20$ keV. The legacy of the mission already includes a large number of discovered or previously poorly studied hard X-ray sources. The growing *INTEGRAL* archive allows one to conduct an all-sky survey including a number of deep extragalactic fields and the deepest ever hard X-ray survey of the Galaxy. Taking advantage of the data gathered over 17 yr with the IBIS coded-mask telescope of *INTEGRAL*, we conducted survey of hard X-ray sources, providing flux information from 17 to 290 keV. The catalogue includes 929 objects, 890 of which exceed a detection threshold of 4.5σ and the rest are detected at 4.0σ–4.5σ and belong to known catalogued hard X-ray sources. Among the identified sources of known or suspected nature, 376 are associated with the Galaxy and Magellanic clouds, including 145 low-mass and 115 high-mass X-ray binaries, 79 cataclysmic variables, and 37 of other types; and 440 are extragalactic, including 429 active galactic nuclei (AGNs), 2 ultra-luminous sources, 1 supernova (AT2018cow), and 8 galaxy clusters. 113 sources remain unclassified. 46 objects are detected in the hard X-ray band for the first time. The Log$N$-Log$S$ distribution of 356 non-blazar AGNs is measured down to a flux of 2×10^{-12} erg s^{-1} cm^{-2} and can be described by a power law with a slope of 1.44 ± 0.09 and normalization 8×10^{-3} deg^{-2} at 10^{-11} erg s^{-1} cm^{-2}. The Log$N$-Log$S$ distribution of unclassified sources indicates that the majority of them are of extragalactic origin.

Heavily obscured quasars

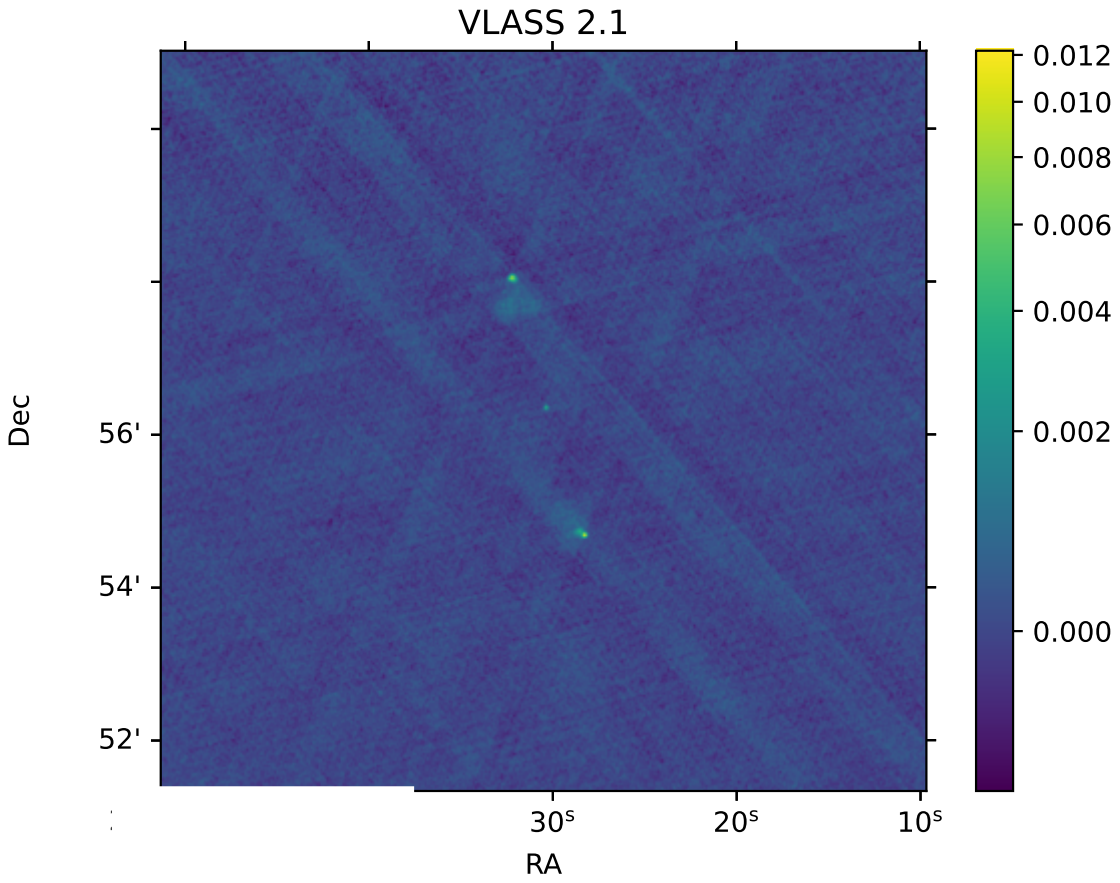
SRGA ...

- Discovered by ART-XC during the all-sky survey.
- Undetected by eROSITA (Gilfanov, private comm.)
- In the X-ray error circle, there is an optical object with an SDSS spectrum, which allowed us to classify it as Seyfert 2 at z=0.44.



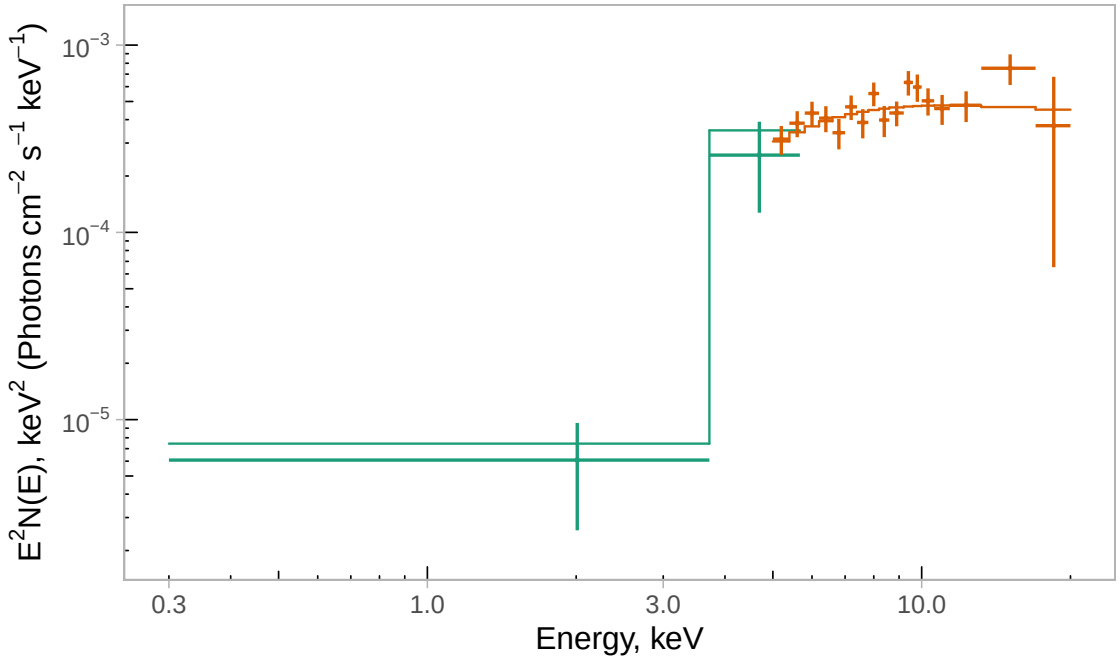


Also a radio source!
Two lobes and a core?



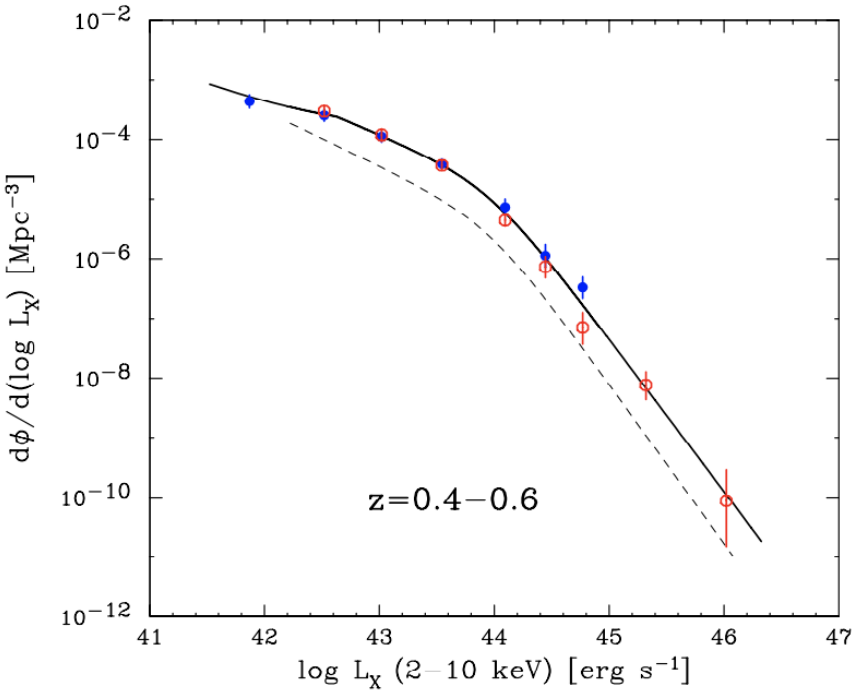
The Very Large Array Sky Survey, 2-4 GHz, Gordon et al. (2021)

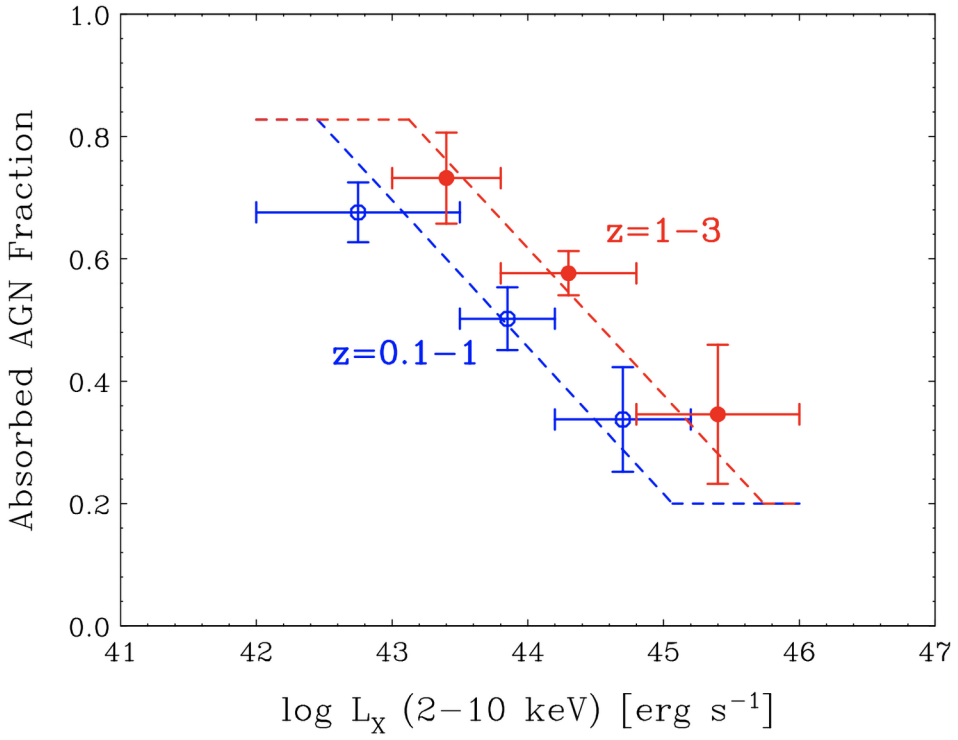
We carried a pointed observation by SRG/ART-XC with an exposure of 21 hours and a nearly simultaneous observation by Swift/XRT for 2 hours



- **~1000 photons detected by ART-XC and just a few by Swift/XRT.**
- **Inferred column density N_H ~ 3 10^{23} cm^{-2}.**
- **X-ray luminosity ~ several x 10^{45} erg/s !**

Such obscured quasars are extremely rare!





Ueda et al. 2014

Summary

- A new X-ray source catalog, ARTSS1-5, based on the SRG/ART-XC data of the first 4.4 all-sky surveys (Dec. 2019 — March 2022), is available. It comprises 1545 sources detected in the «medium» X-ray band of 4-12 keV.
- The SRG/ART-XC survey has filled the niche between the soft X-ray and hard X-ray all-sky surveys.
- Among the ARTSS1-5 sources, the most interesting (for population studies) are the samples of AGN and CVs.
- Optical follow-up work is underway. The goals are to: 1) reach ~100% identificantion/classification completeness for ARTSS1-5, 2) unveil unique objects, such as heavily obscured quasars.
- The next official catalog release will presumably take place upon completion of the 8th SRG/ART-XC all-sky survey at the end of 2025. We expect to have ~3000 sources, including ~2000 AGN.