SRG/eROSITA results in the Eastern Galactic hemisphere

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Spektrum-Roentgen-Gamma (SRG)

Long and turbulent history

1987-2002

Ambitious mission with 5 telescope from UV to hard X-rays, including Bragg spectrometer and X-ray polarimeter.
Broad cooperation: Denmark, the UK, Italy, Germany, USA, Switzerland, Israel and Turkey.
Terminated in 2002

2007-2019-…

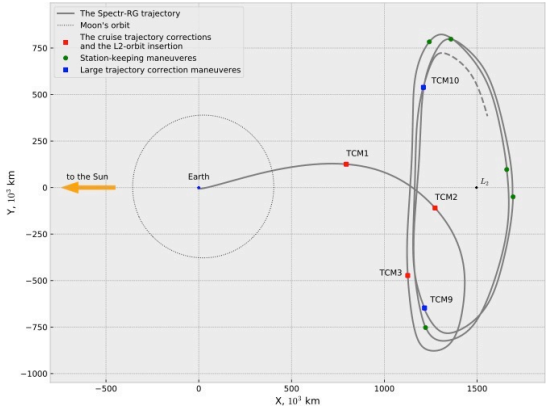
Successor of the ”old SRG”
Designed to detect all massive clusters of galaxies in the observable Universe

Science leader of SRG: Rashid Sunyaev

Spectrum-Roentgen-Gamma

2019, July 13	Launch
2019, Oct. 22	official “arrival” at L2
2019, Dec. 12	start of the all-sky survey
2022, Feb. 26	switched to safe mode by request of MPE eROSITA team. SRG continues to operate in the interests of ART-XC telescope

halo orbit around L2 point

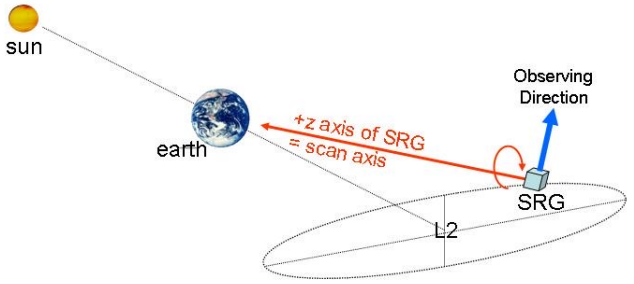


All-sky survey – main component of SRG science program

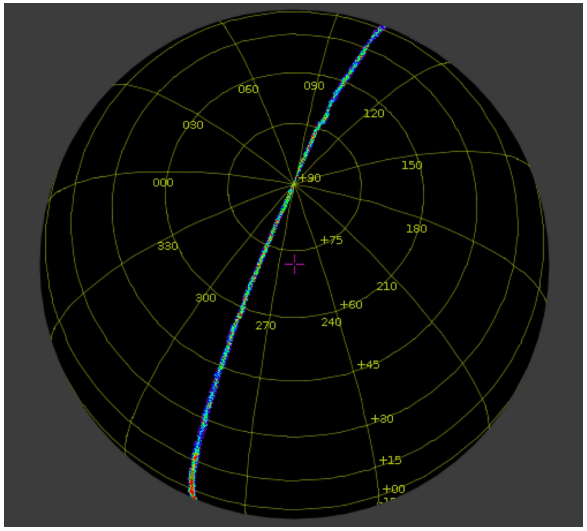
- initial plan: 4 years, 8 all-sky surveys
- big circle on the sky every 4 hrs
  rotation axis to the Sun/Earth
- shift 1 degree per day
- full sky coverage every 6 months
- average exposure ~2 ksec
- ~150 ksec in ecliptic poles

✧ the survey was designed to be 25 times more sensitive than previous all-sky X-ray survey by ROSAT (1991)

○ to Feb 26, 2022 completed 4.38 surveys



24 hours of scanning
1 degree wide stripe on the sky



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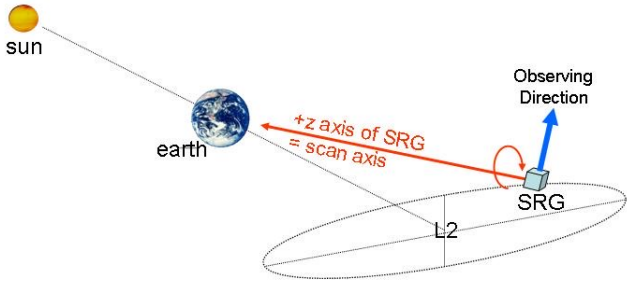
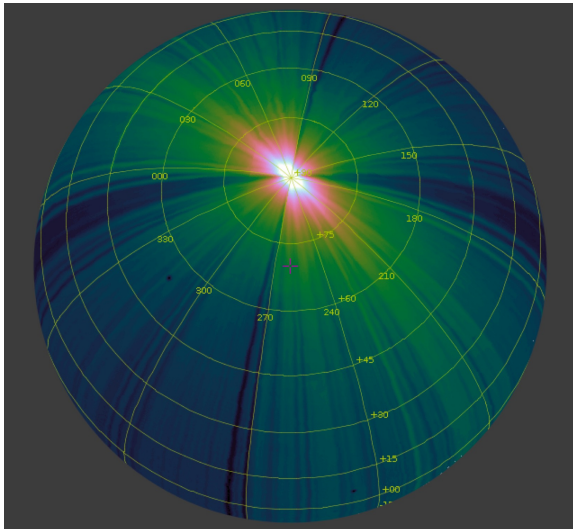
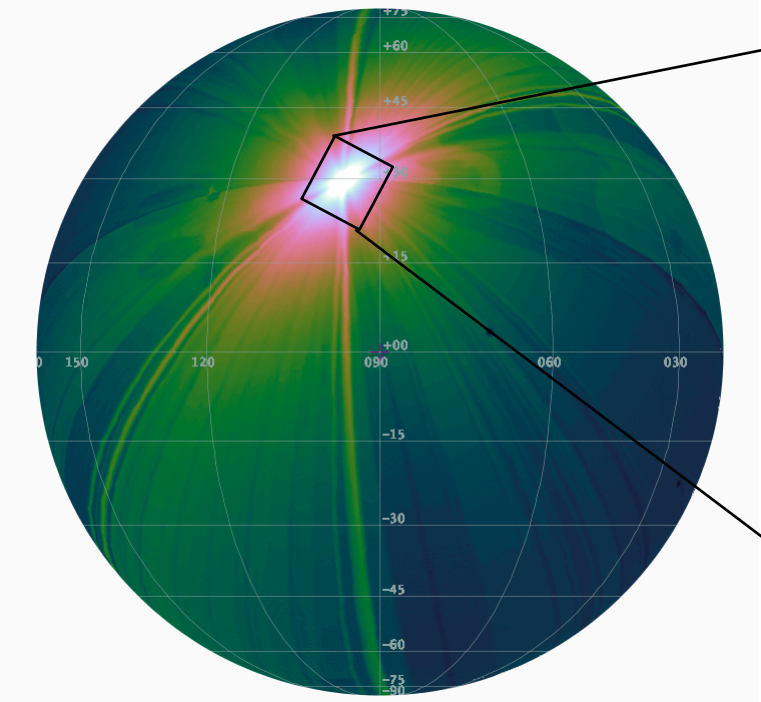


exposure map

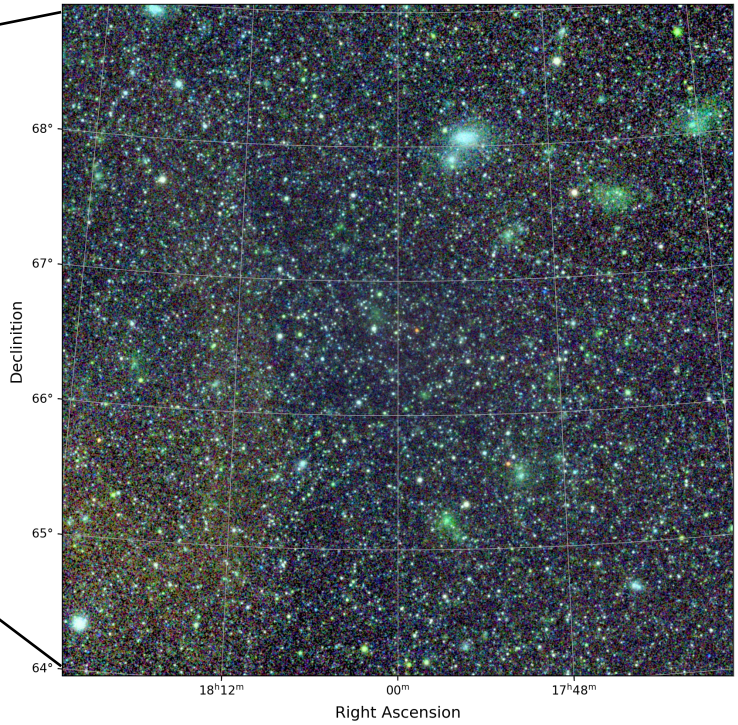


The North ecliptic pole region

exposure map



0.3-2.3 keV image



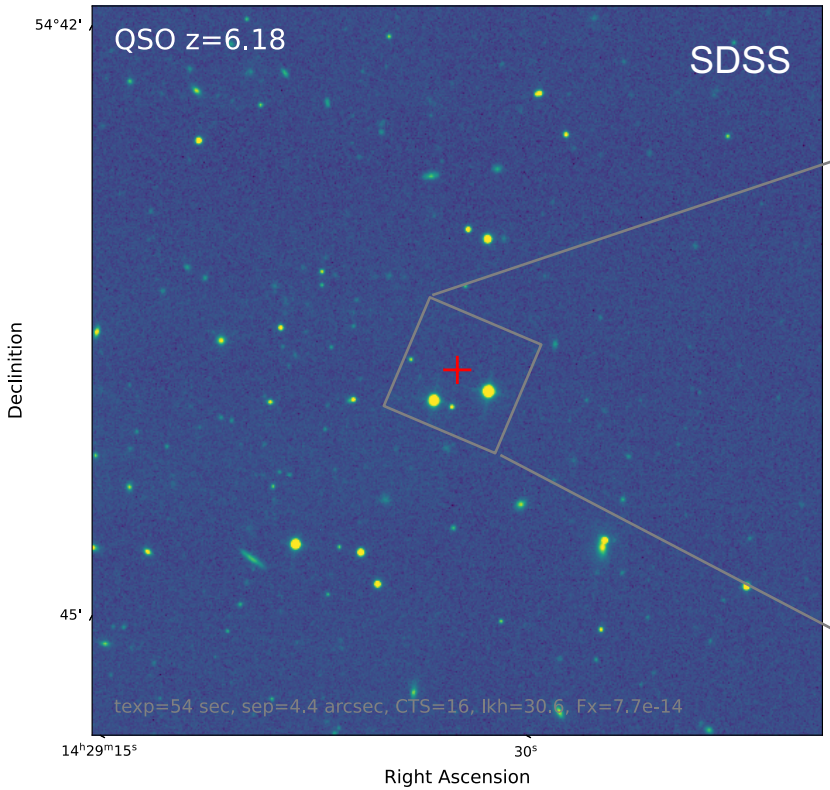
~700 sources per sq.degree, confusion limited

Why an all-sky survey in X-ray band may be interesting?

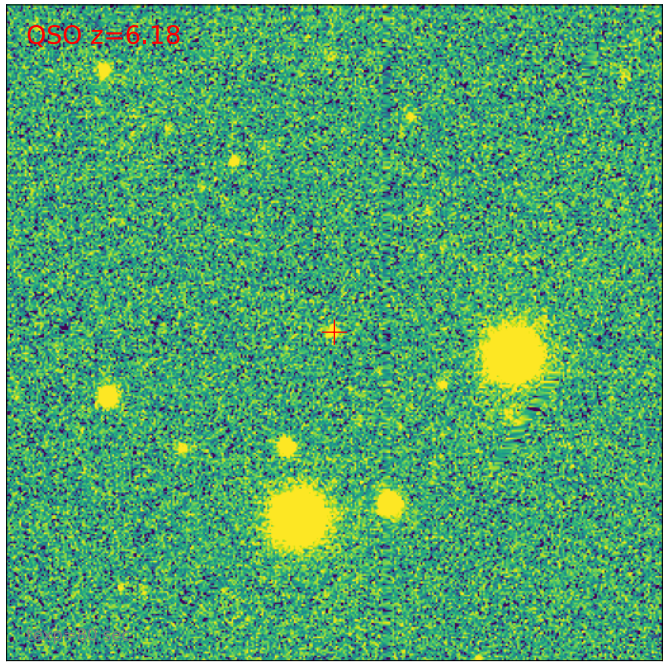
- an “easy” way to find clusters of galaxies and accreting supermassive black holes in the “sea” of much more numerous stars and nearby galaxies
- detailed X-ray map of the sky
- astrophysics of many types of objects
  - previous all-sky X-ray survey was performed 30 years ago (ROSAT satellite)

Quasars

optical image

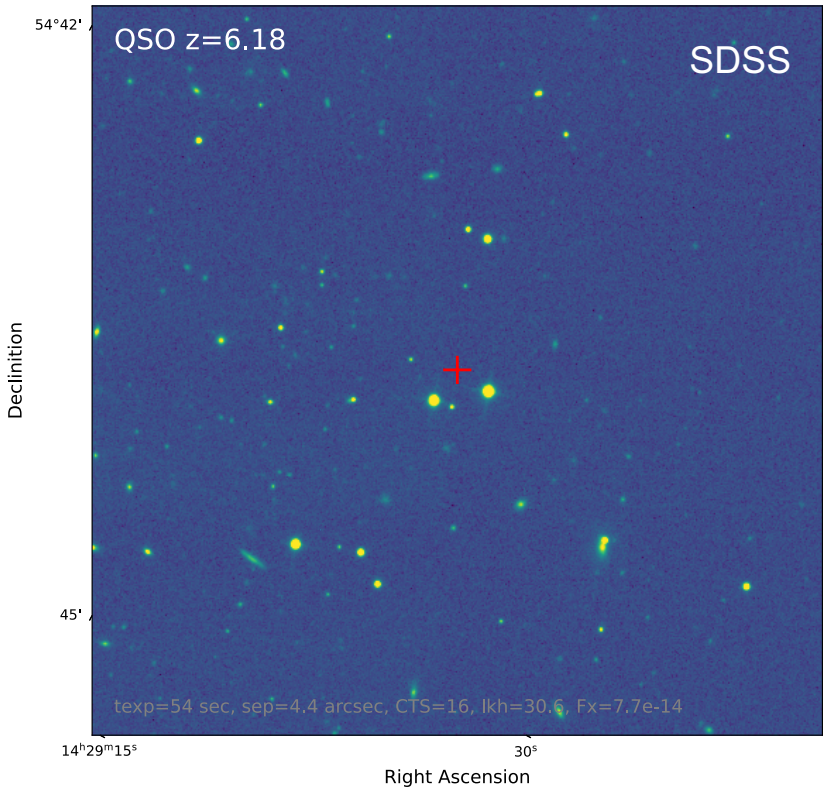


deep optical image (DESI LIS)



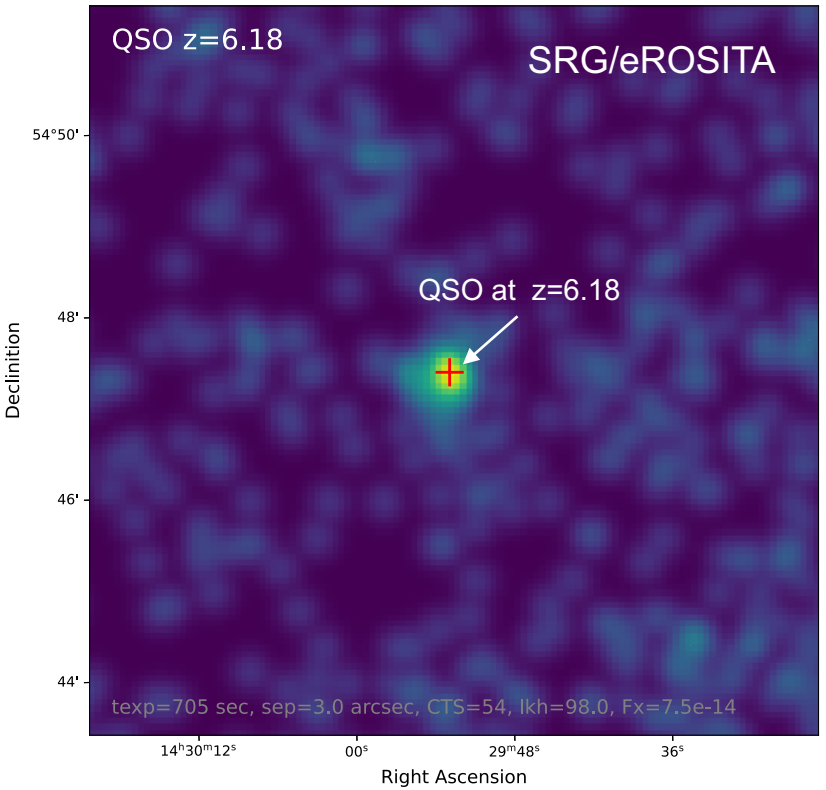
Квазары

optical image



~10^3-10^4 src/deg^2
mostly stars and galaxies
quasars ~ few%

X-ray image of same size

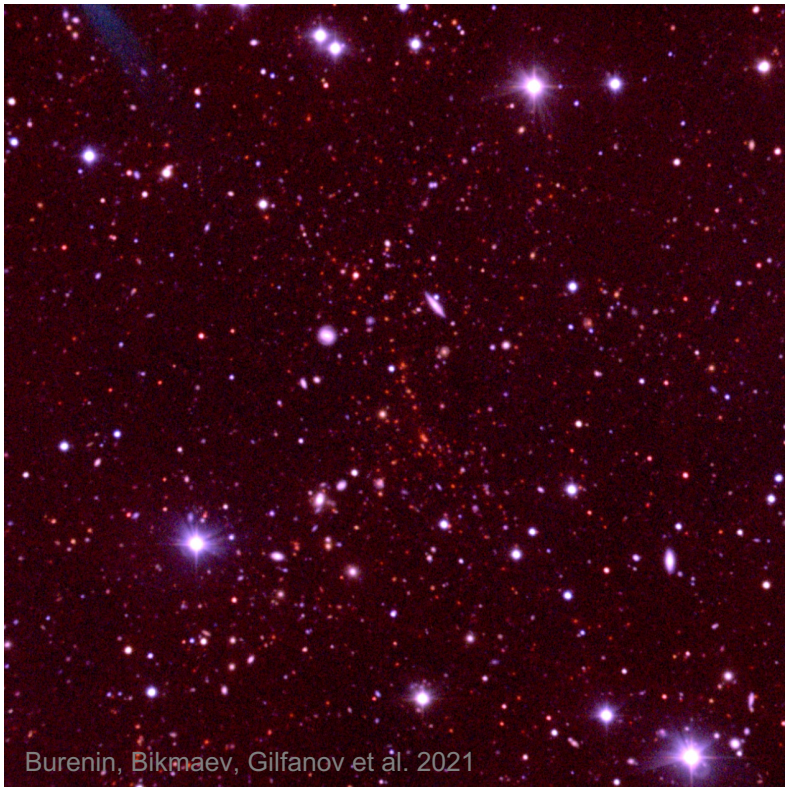


~10^2 src/deg^2
quasars dominate
galaxies ~ few %
contribution of stars ~10%

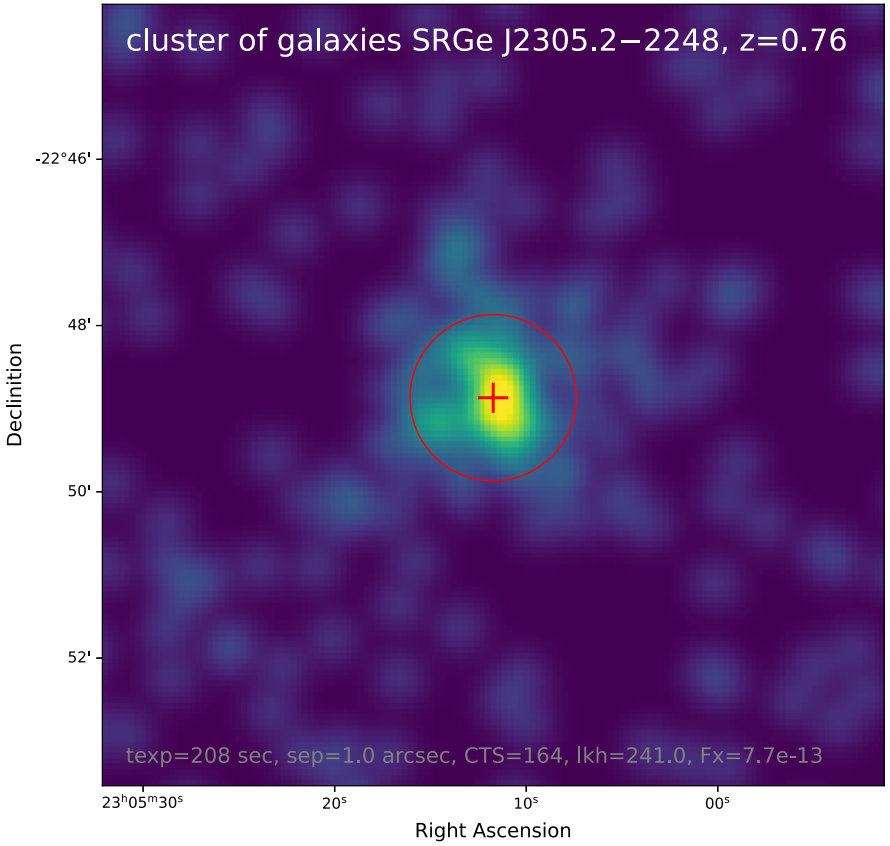
Massive cluster of galaxies

$$z = 0.76,\ M = 9 \cdot 10^{14} M_{\odot}$$

optical image



X-ray image of same size



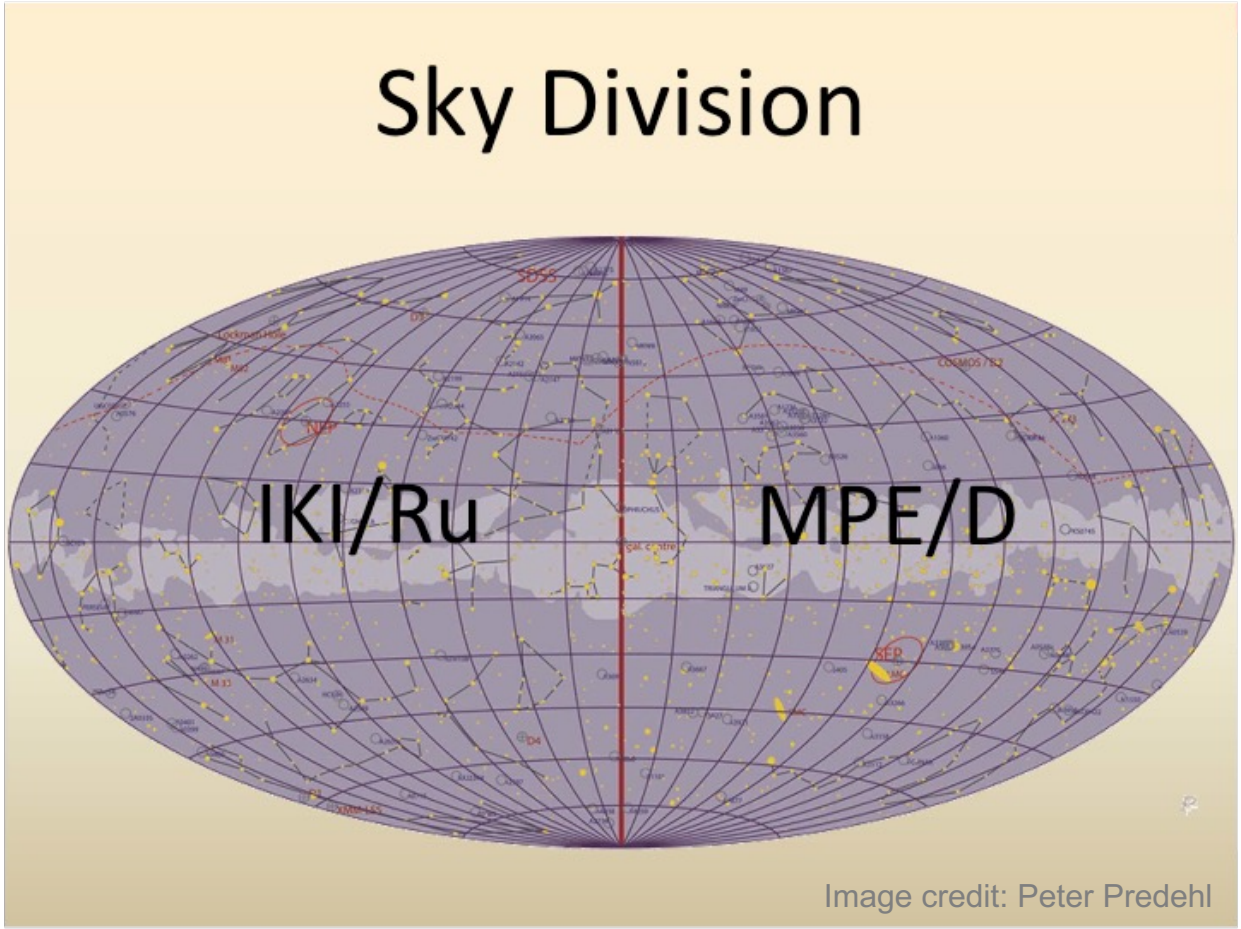
Goals of SRG/eROSITA all-sky survey

Obtain record large and uniform samples of quasars and clusters of galaxies (~10^4-10^6 объектов)

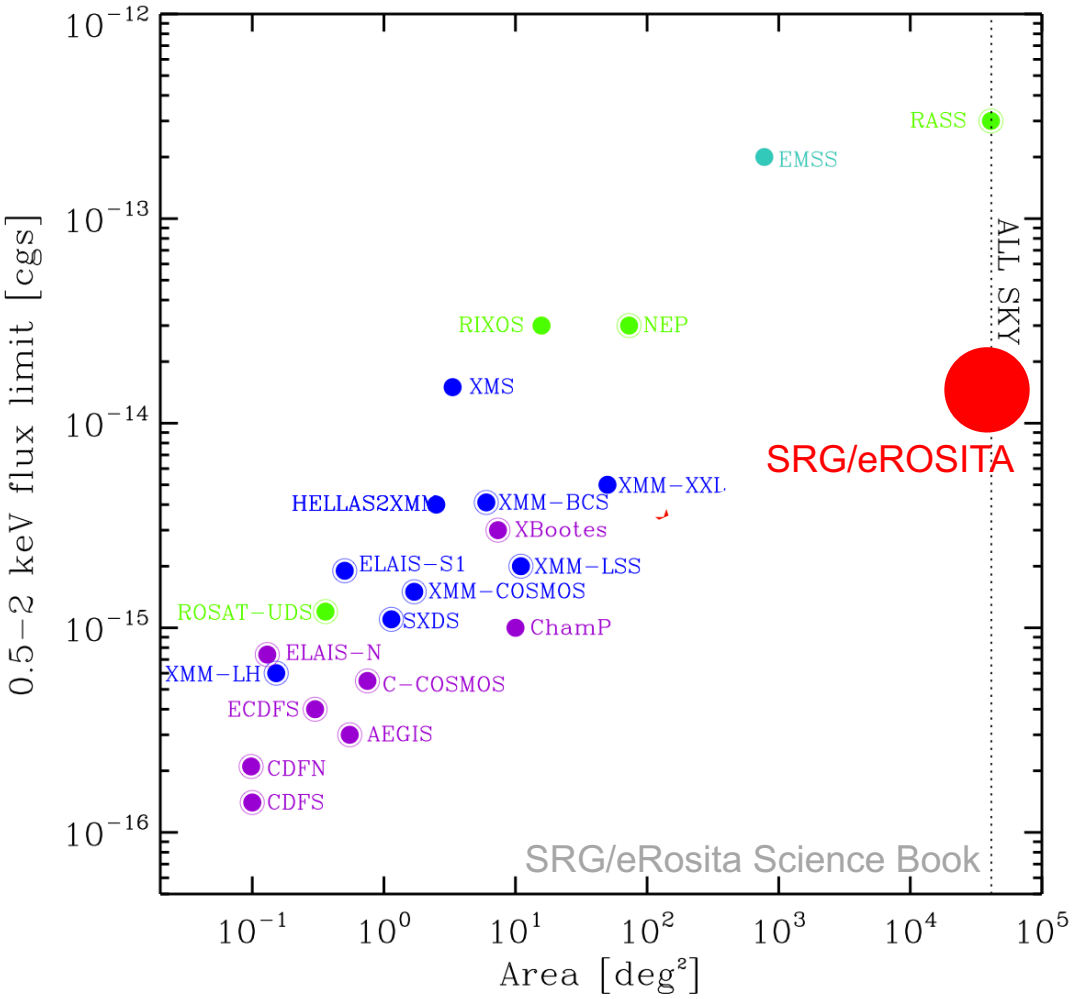
- ✧ cosmology with clusters of galaxies and quasars
- ✧ large scale structure of the Universe at z~1
- ✧ growth of supermassive black holes
- ✧ non-stationary processes in the vicinity of supermassive black holes
- ✧ astrophysics of a broad class of objects

planned 8 independent sky surveys, 4.4 surveys completed

eROSITA data rights



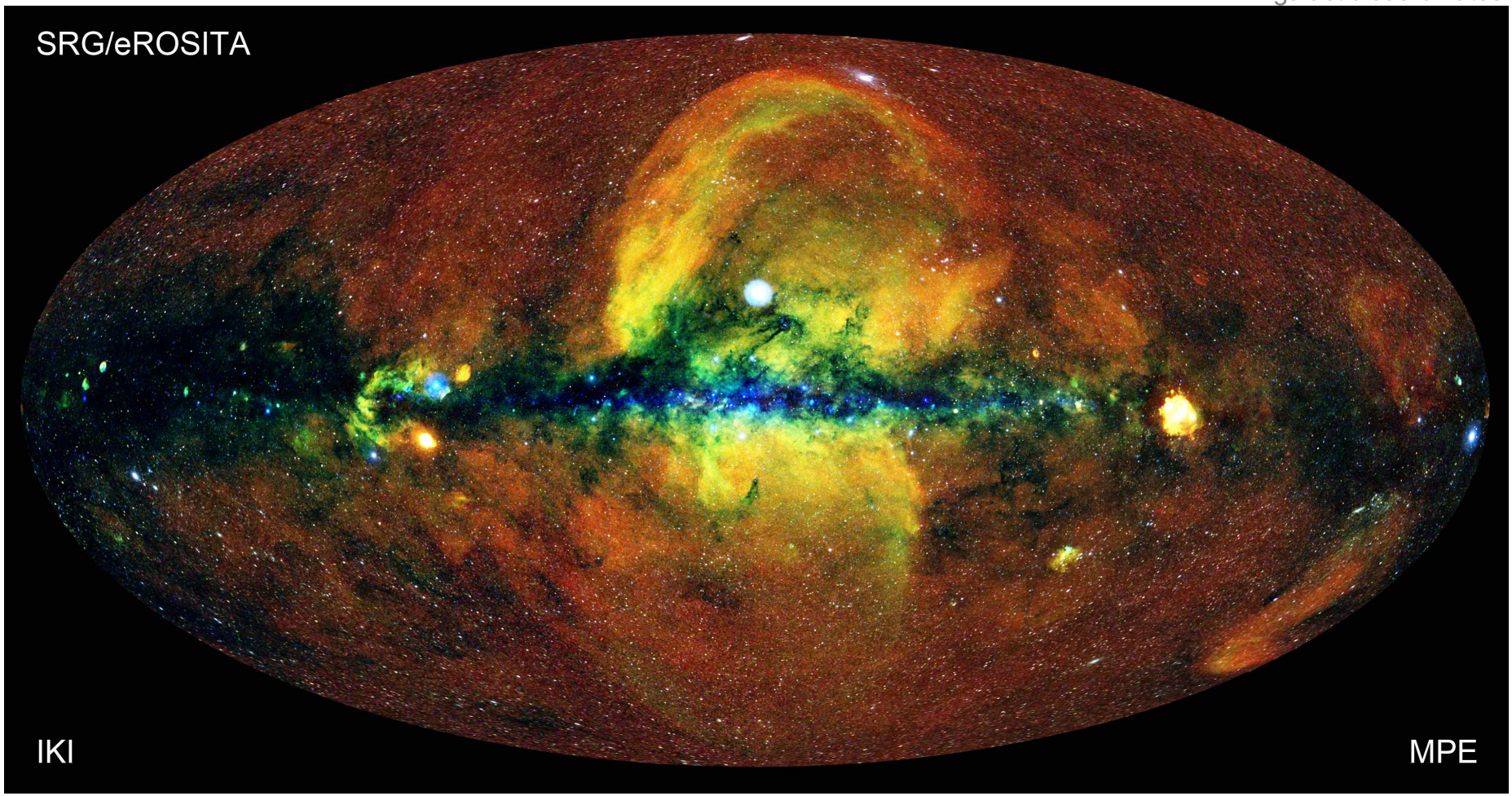
X-ray surveys: wide and narrow, deep and shallow



currently achieved sensitivity of eROSITA all-sky survey exceeds by **15 times** the sensitivity of the previous (and the only) all-sky X-ray survey by ROSAT observatory

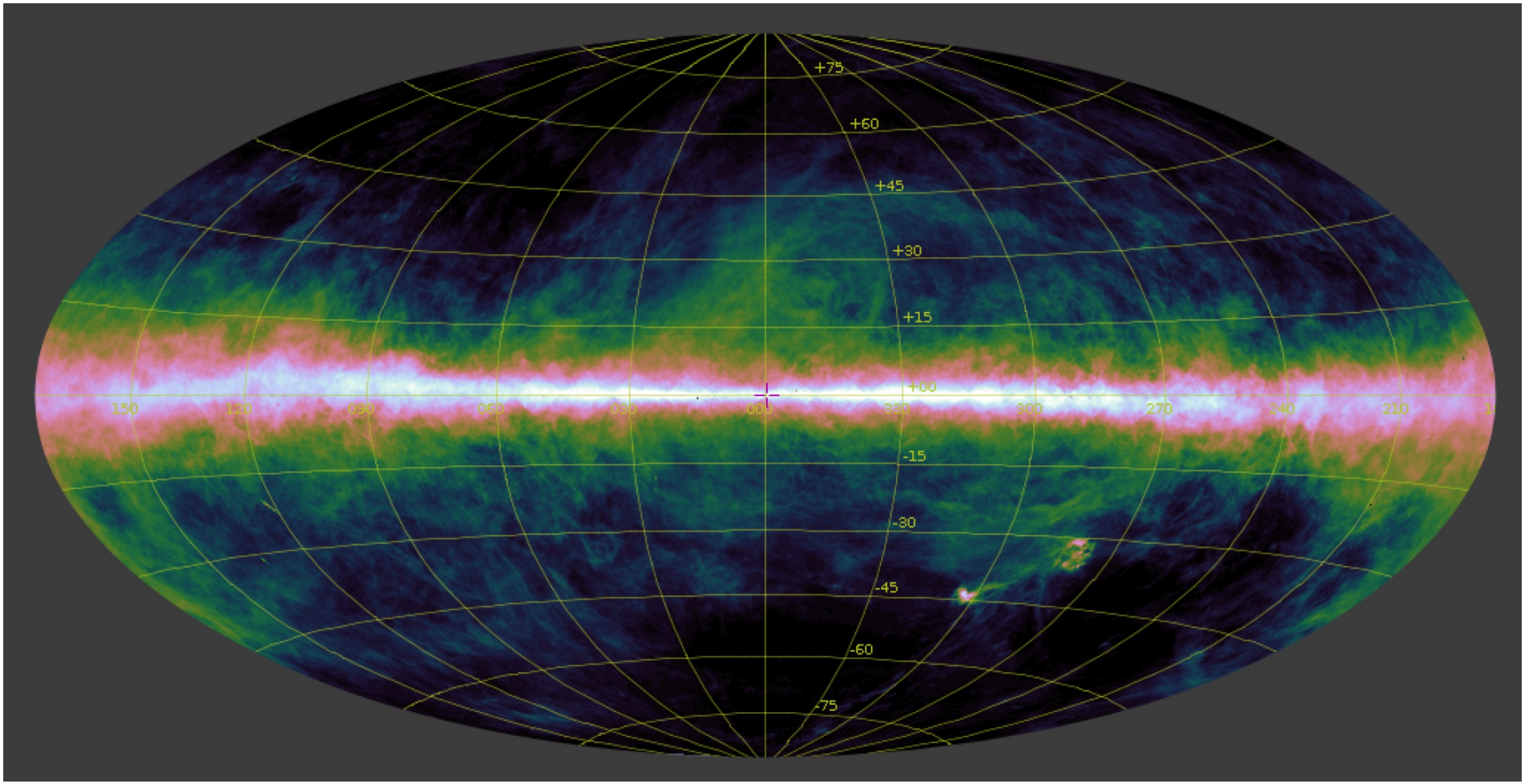
X-ray RGB map of the sky

galactic coordinates



Churazov, Gilfanov, Sunyaev, Brunner, Merloni, Sanders

HI in the Milky Way (HI4PI)



X-ray RGB map of the sky

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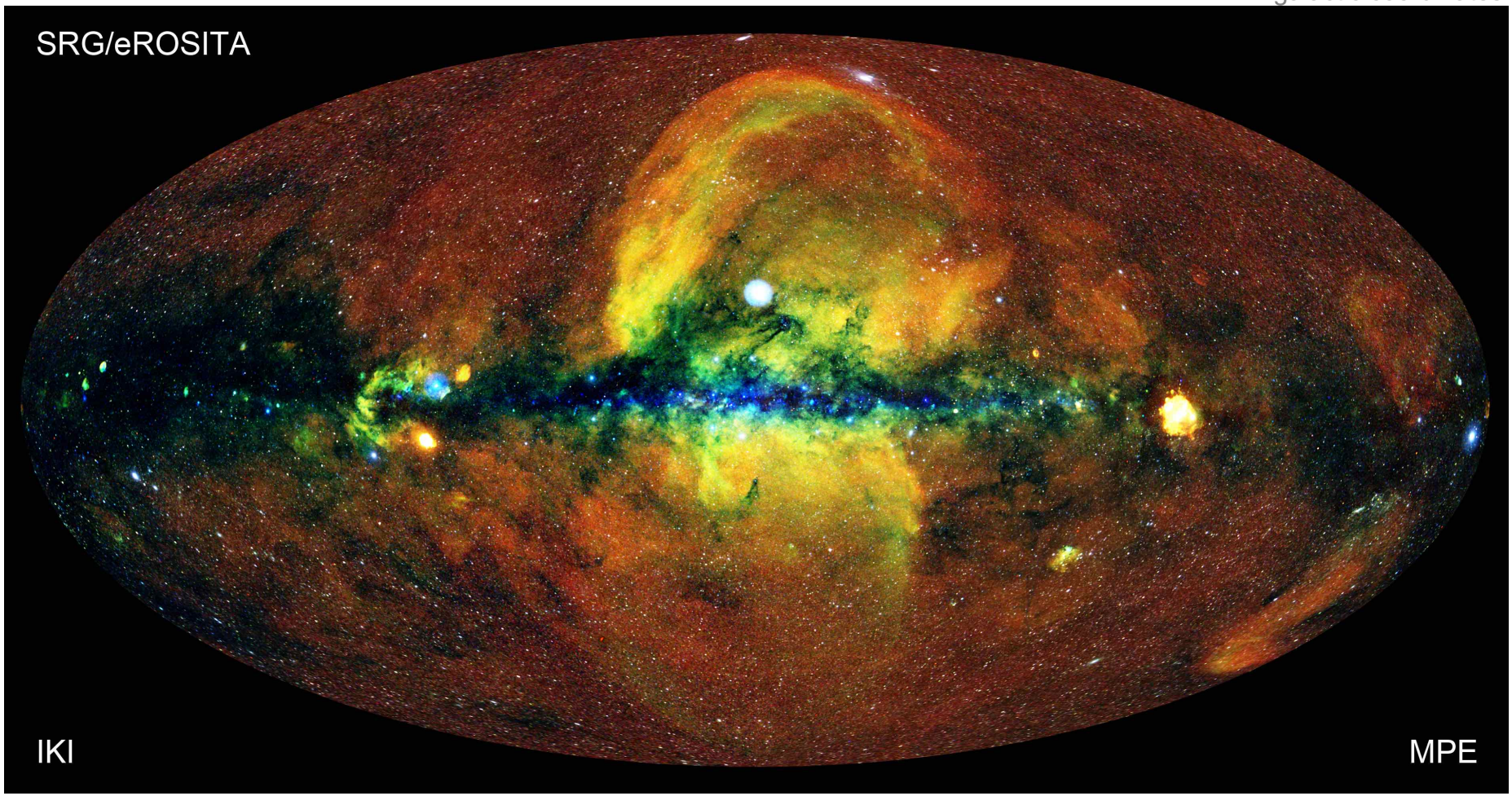


Churazov, Gilfanov, Sunyaev, Brunner, Merloni, Sanders

eROSITA bubbles

X-ray luminosity

$$L_X \approx 10^{39}\ \mathrm{erg/s}$$

Temperature jump

$$0.2 \rightarrow 0.3\ \mathrm{keV}$$

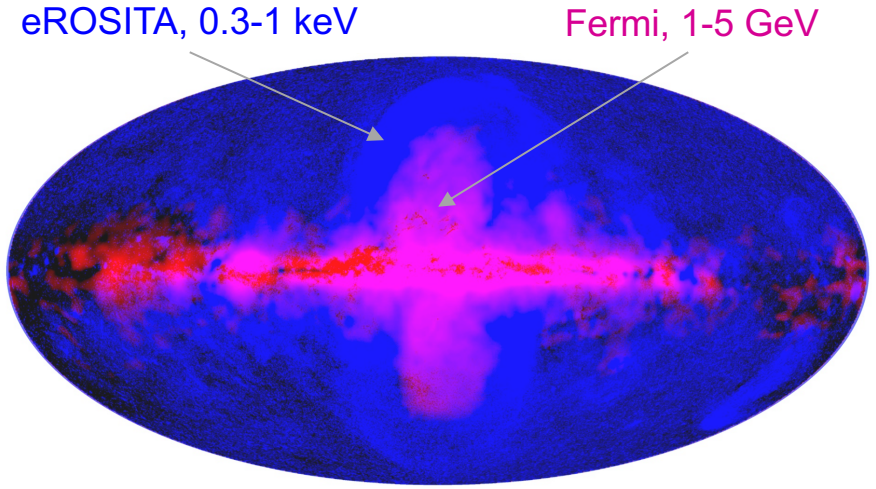
Shock

$$\mathrm{M} \approx 1.5$$

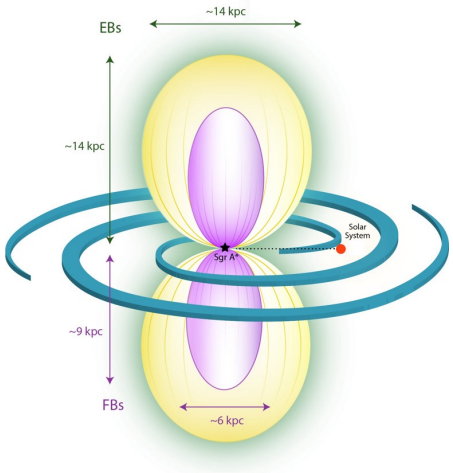
Total energy of eROSITA bubbles

$$\mathrm{E} \sim 10^{56}\ \mathrm{erg}$$

envelope Fermi bubbles



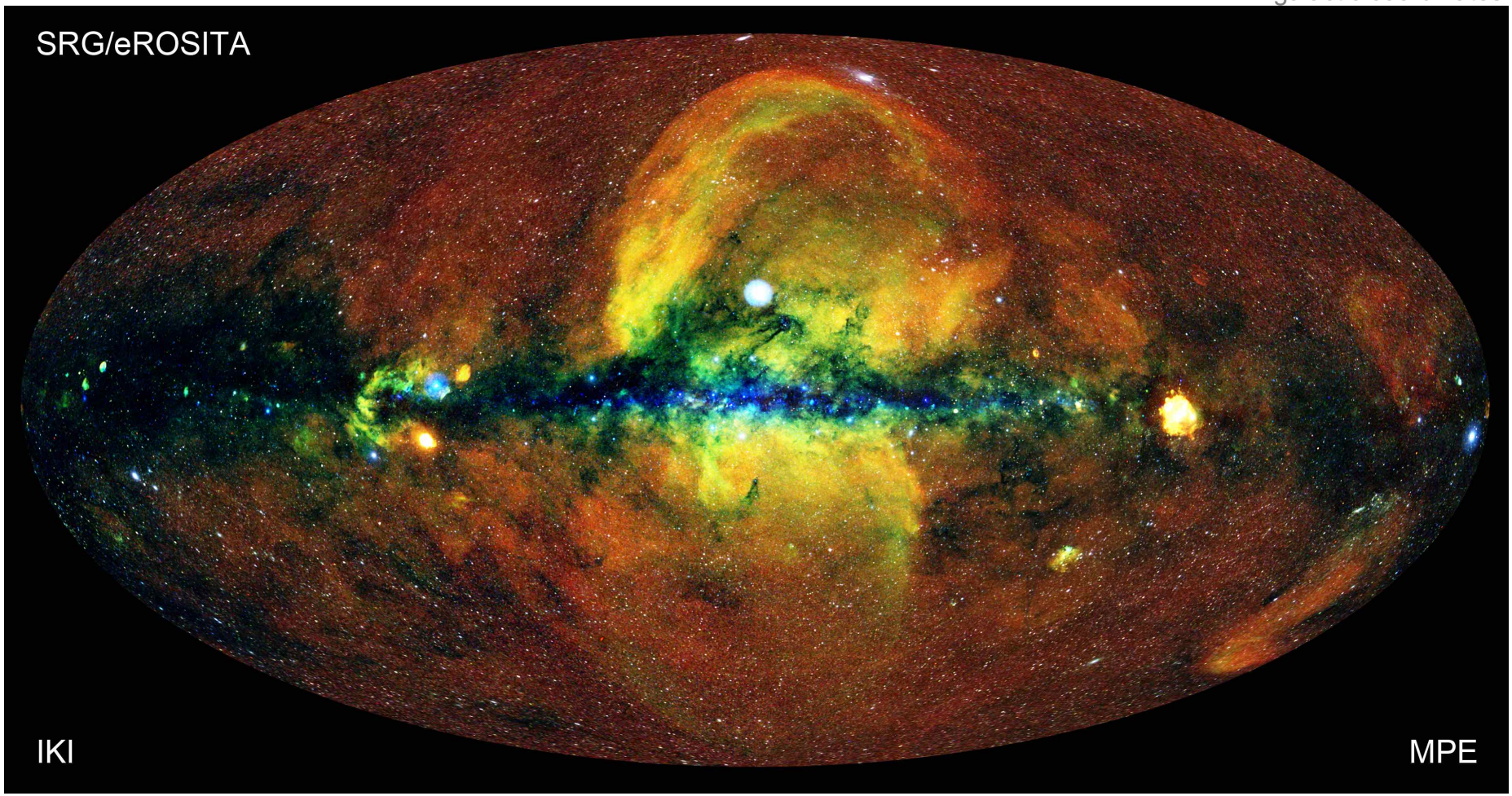
Supermassive black hole activity
at the level of
$L_X \sim 10^{43}$ erg/s timescale of ~ 2 mln years
or star − formation event ~ 10 mln years



Predehl, Sunyaev et al, Nature, 2020

X-ray RGB map of the sky

galactic coordinates



Churazov, Gilfanov, Sunyaev, Brunner, Merloni, Sanders

X-ray catalog and QSO/TDE science working groups


Sergey Sazonov


Rashid Sunyaev


Pavel Medvedev


Alexei Starobinsky

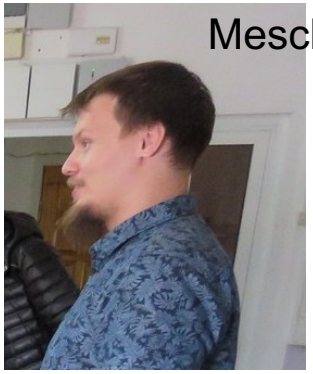

Alexander Mescheryakov


Sergey Bykov


Georgii Khorunzhev


Rodion Burenin


Ilfan Bikmaev


Igor Zaznobin

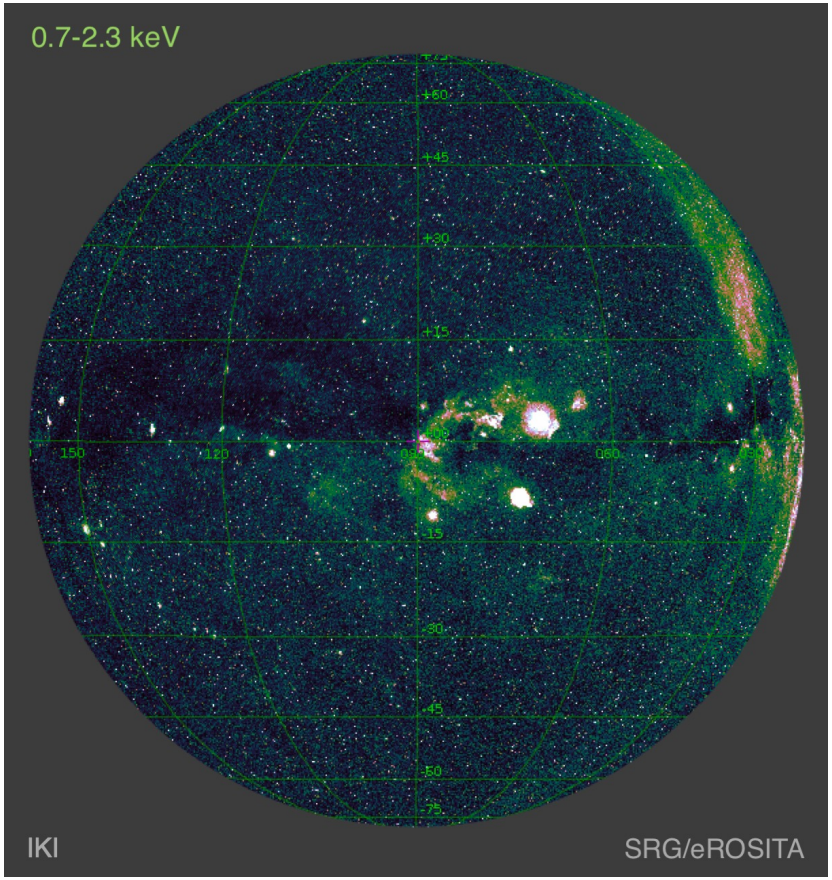
Students and postdocs:

Mikhali Belvedersky, Viktor Borisov, Ilkham Galiullin, Nadezhda Malysheva, Allisa Nemeshaeva, Sergey Prokhorenko, Grigorii Uskov

SRG/eROSITA source catalog

4 sky surveys
Dec. 2019 – Dec. 2021

- 1.5 mln. X-ray sources (L>8)
- 240,000 stars (Gaia)
- >1 mln. AGN and QSO
- 31,500 clusters of galaxies with extent sign. > 4 sigma
  talk of Rashid Sunyaev
- ~5,000 sources in the hard X-ray band 4-9 keV



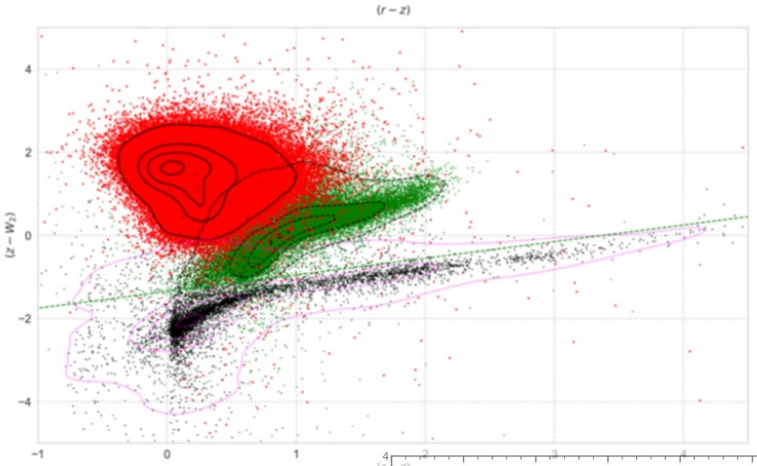
Making sence out of 1.5 million of X-ray sources

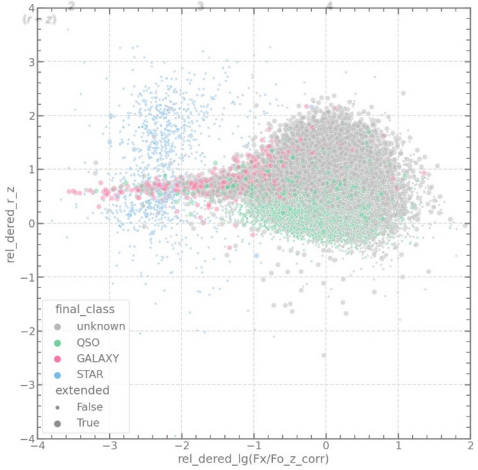
- ✧ identification
  finding optical counterpart (problem of multiple matches)
- ✧ classification – star/galaxy/quasar etc
- ✧ measuring distances/redshifts

- ✓ machine learning algoritms (random forest), neural networks – SRGz system, Mescheryakov+ 2023
- ✓ more astrophysically motivated approaches Bykov+, Belvedersky+ 2022

Making sence out of 1.5 million of X-ray sources

classification

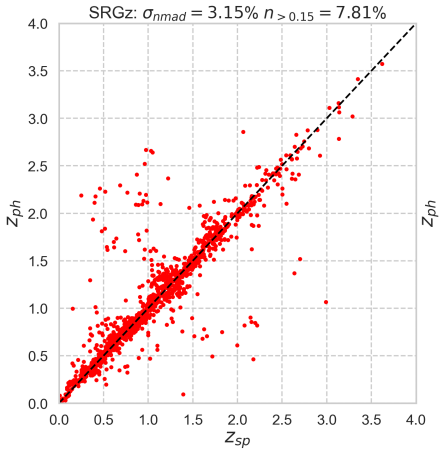




Bykov, Belvedersky, MG, 2022

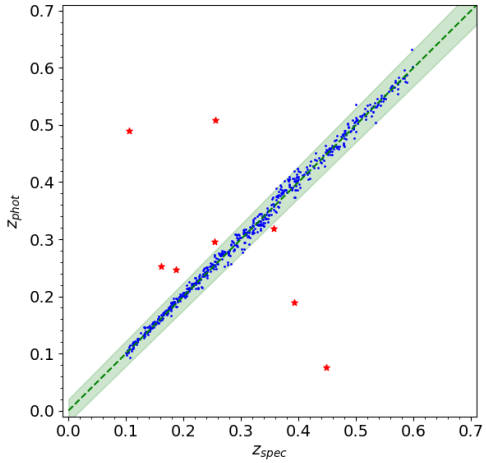
photometric redshifts

quasars



machine learning approaches Mescheryakov et al., 2023

clusters of galaxies

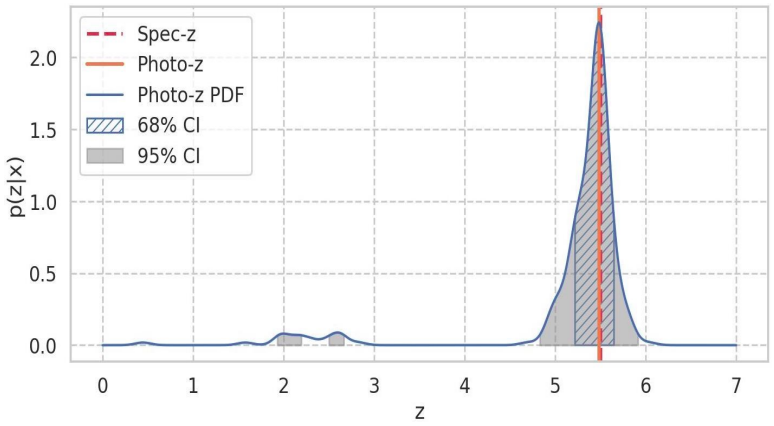


Zaznobin, Burenin et al. 2023

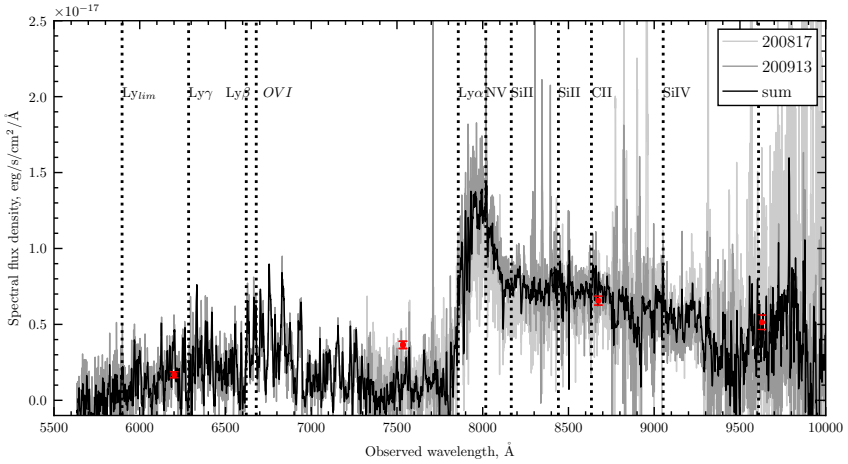
SRGe J170245.3+130104
QSO at z=5.5

The most distant QSO discovered by eROSITA in the blind search. It is found by SRGz and confirmed by optical spectroscopy at BTA 6m

SRGz prediction



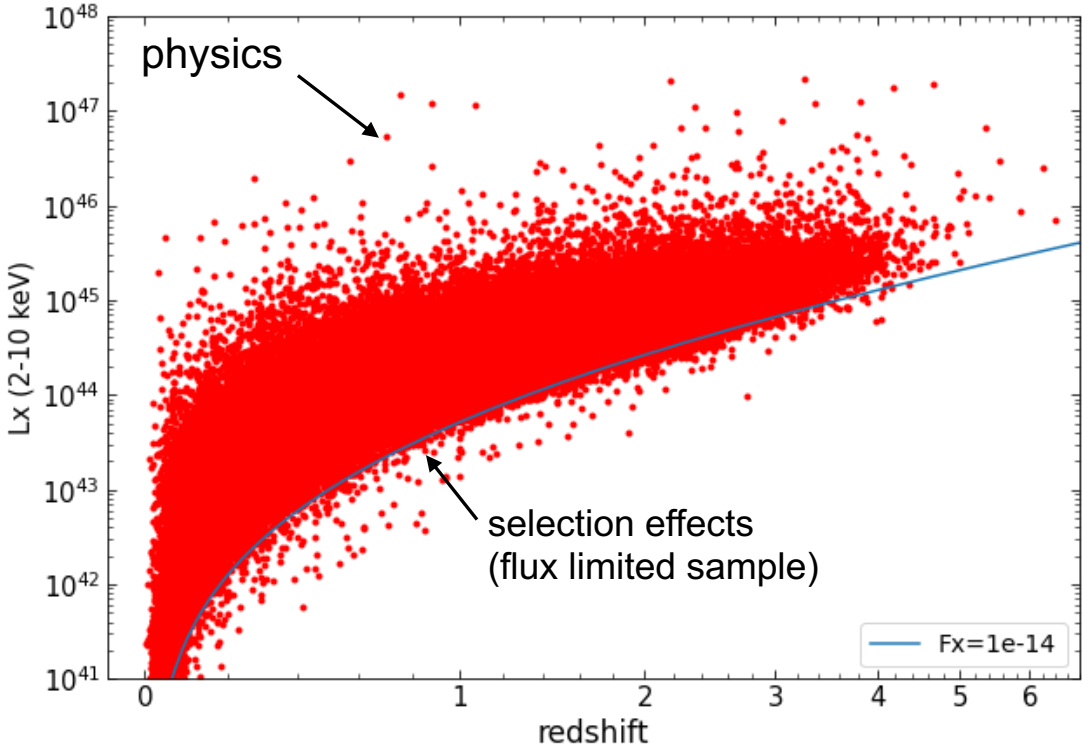
BTA spectrum



Khorunzhev et al. 2021

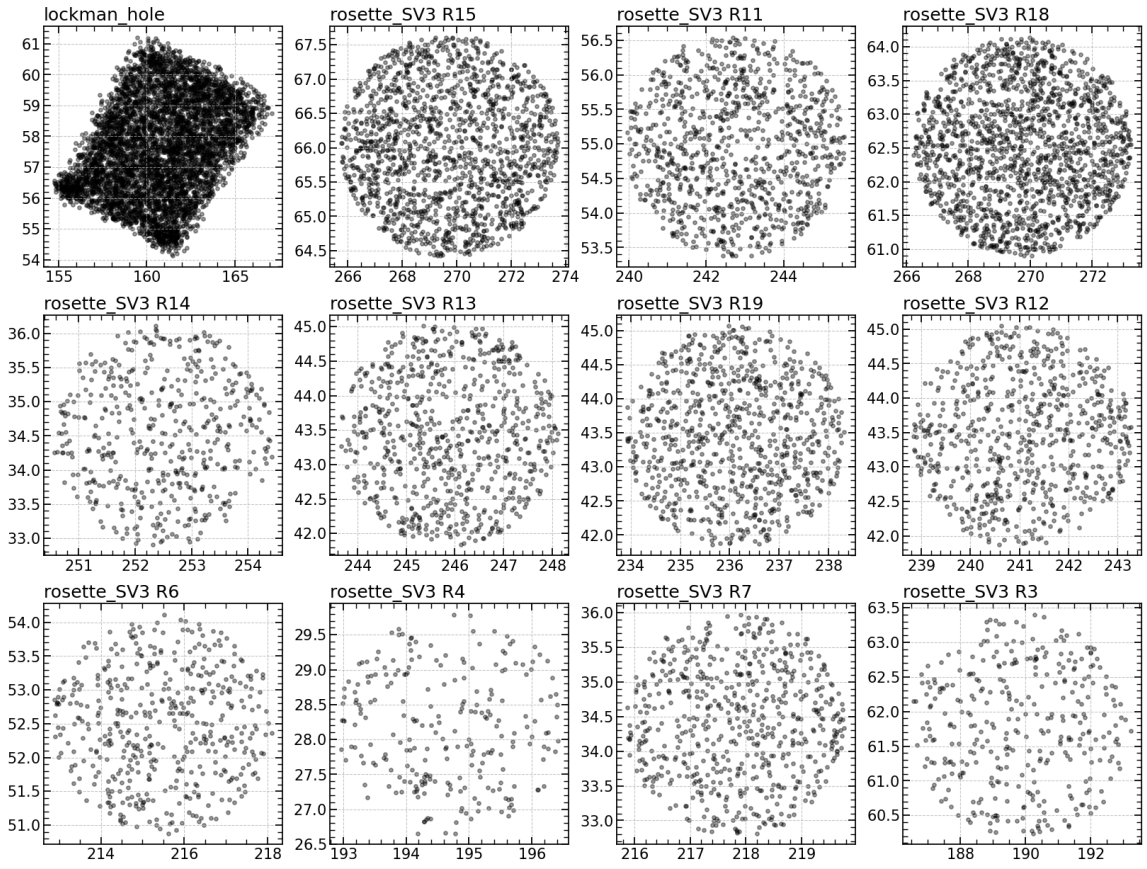
SRGz: Mescheryakov et al. 2023

eROSITA AGN sample spectroscopically confirmed



- quasars at lower redshifts are less luminous (cosmic downsizing)
- population of $\log L_X > 46 - 46.5$ is dominated by blazars
- SRG/eROSITA detects objects out to $z \geq 6$
- in total over 1 mln X-ray bright AGN and quasars

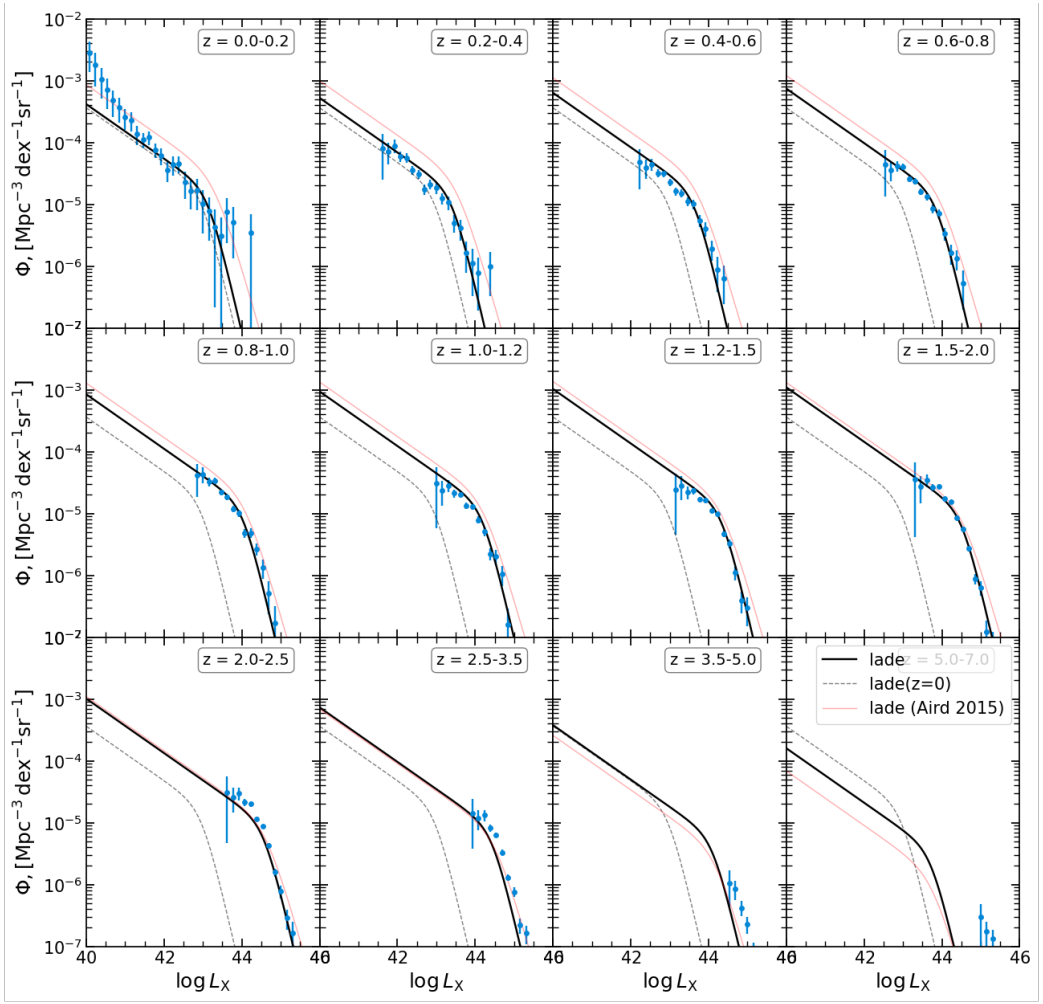
X-ray luminosity function of quasars



Lockman Hole region and Early Data Release of DESI spectroscopic survey

Bykov, MG, Mescheryakov, Khorunzhev+

X-ray luminosity function of quasars



Lockman Hole region and Early Data Release of DESI spectroscopic survey

~1% of eROSITA data

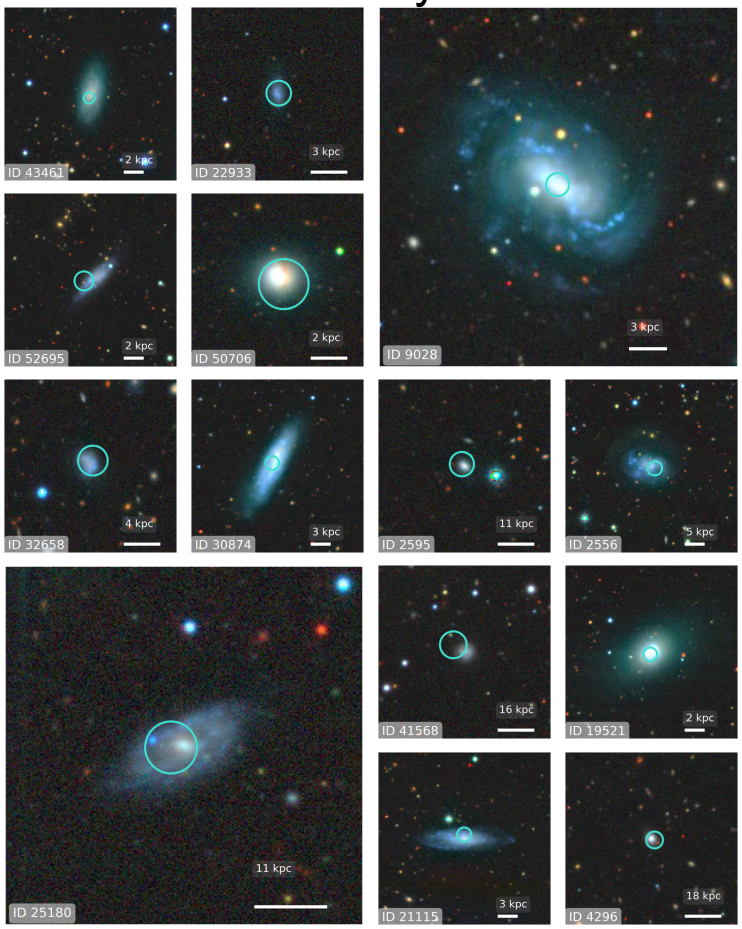
Redshifts:

- spectroscopic
- photometric(SRGz) + PDF(z)

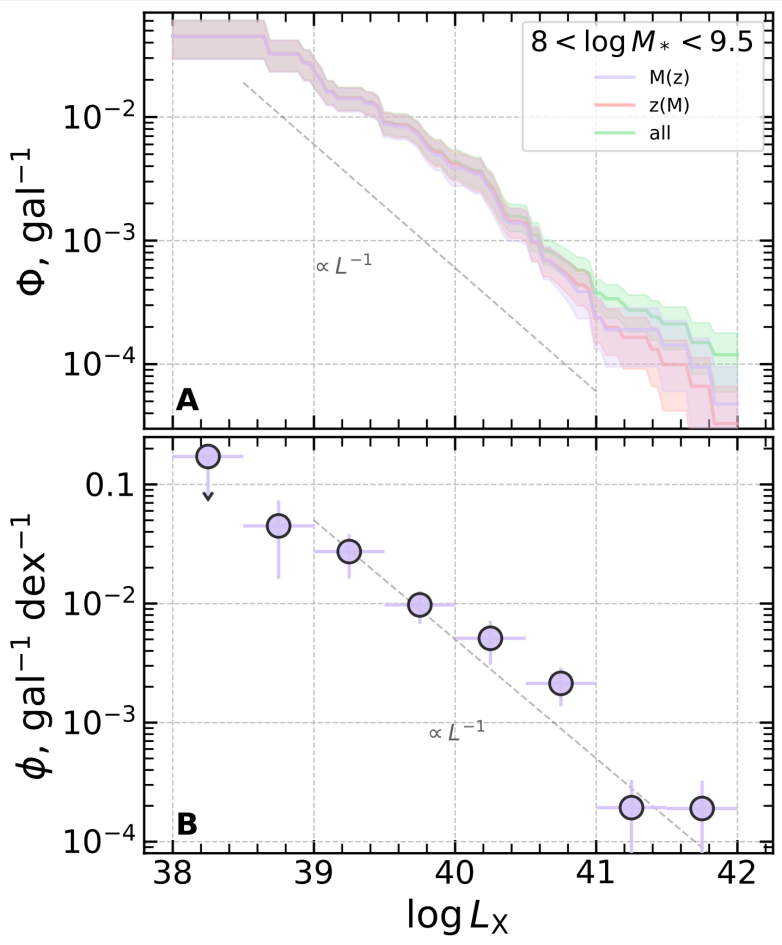
Bykov, MG, Mescheryakov, Khorunzhev+

AGN in dwarf galaxies

DESI LIS & X-ray error circle

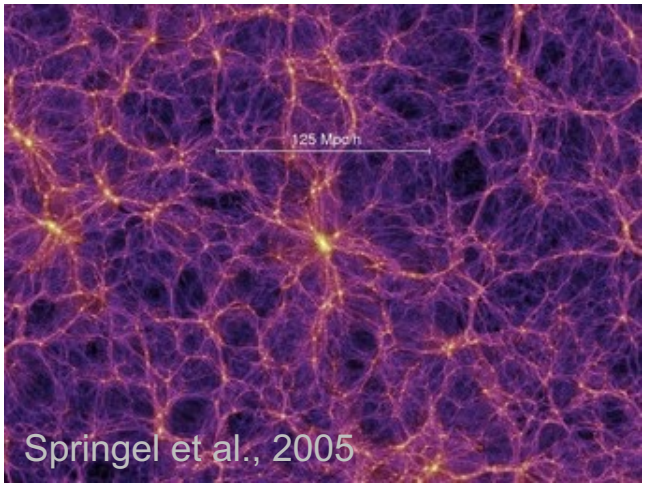


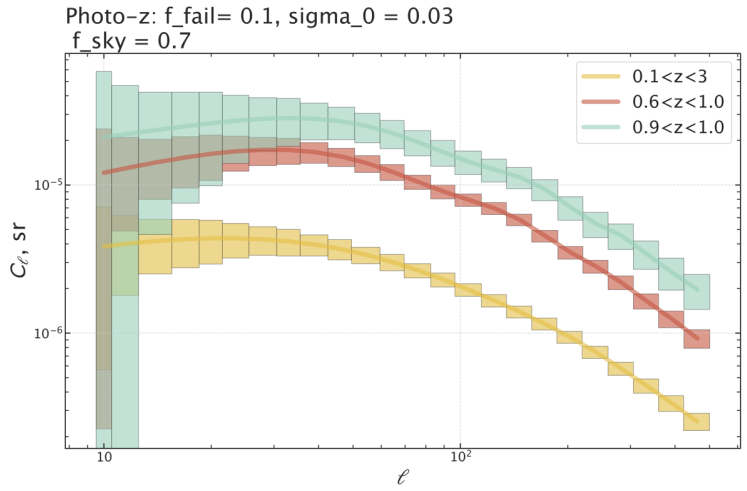
AGN occupation fraction
in MPA-JHU SDSS catalog



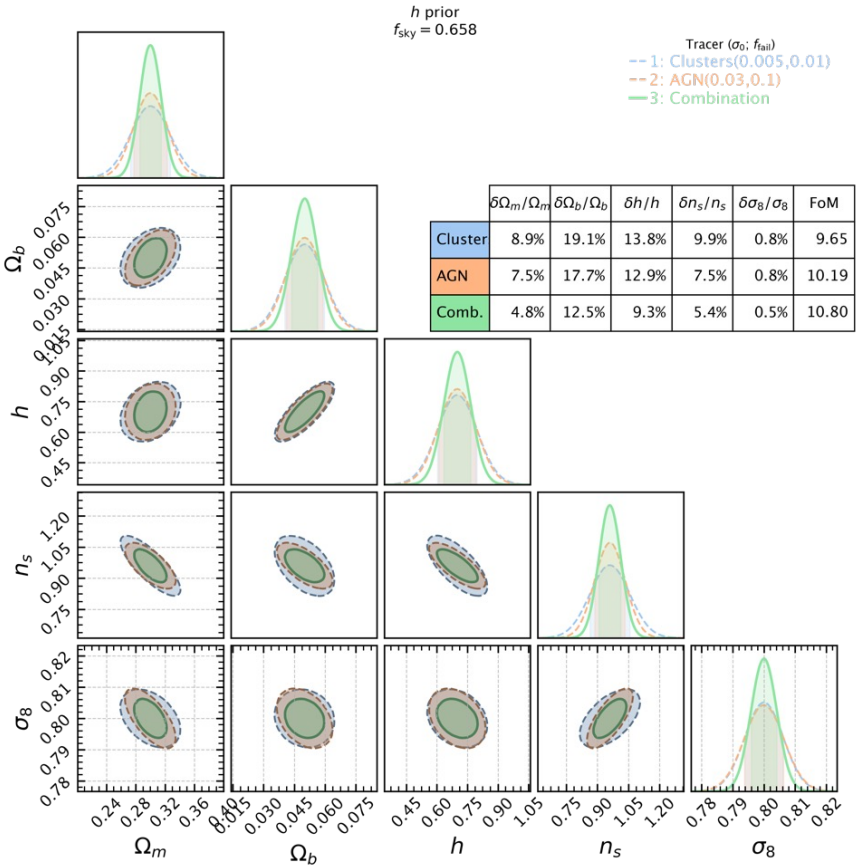
Cosmological measurements using angular distribution of quasars and clusters of galaxies

Millenium simulations





Simulations for eROSITA QSO sample using **realistic accuracy of SRGz redshifts**



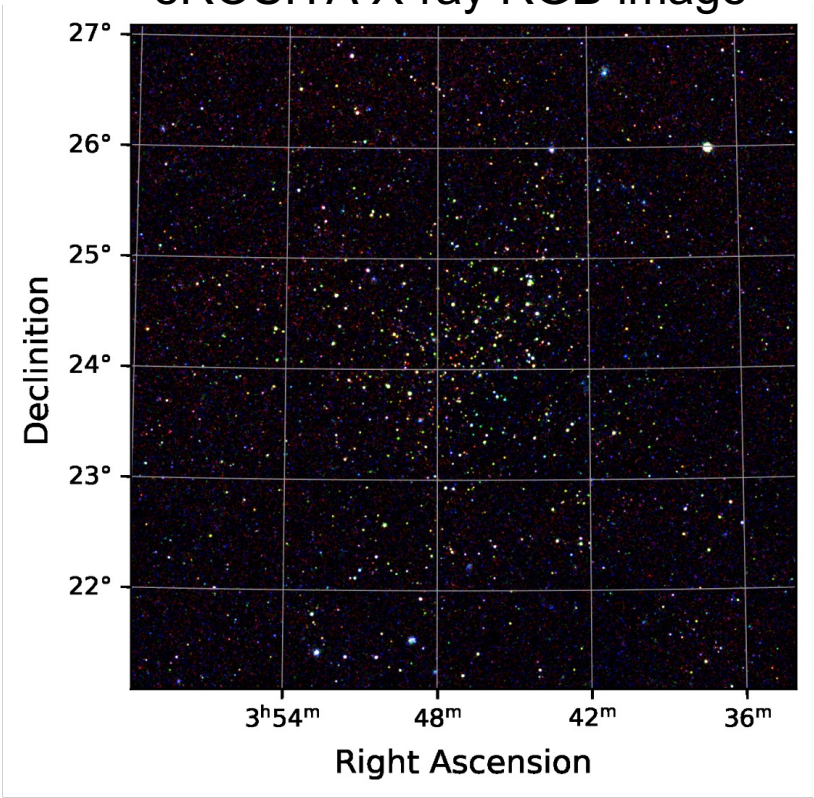
	$\delta\Omega_m/\Omega_m$	$\delta\Omega_b/\Omega_b$	$\delta h/h$	$\delta n_s/n_s$	$\delta\sigma_8/\sigma_8$	FoM
Cluster	8.9%	19.1%	13.8%	9.9%	0.8%	9.65
AGN	7.5%	17.7%	12.9%	7.5%	0.8%	10.19
Comb.	4.8%	12.5%	9.3%	5.4%	0.5%	10.80

Bykov, MG, Sunyaev, A&A, 2022

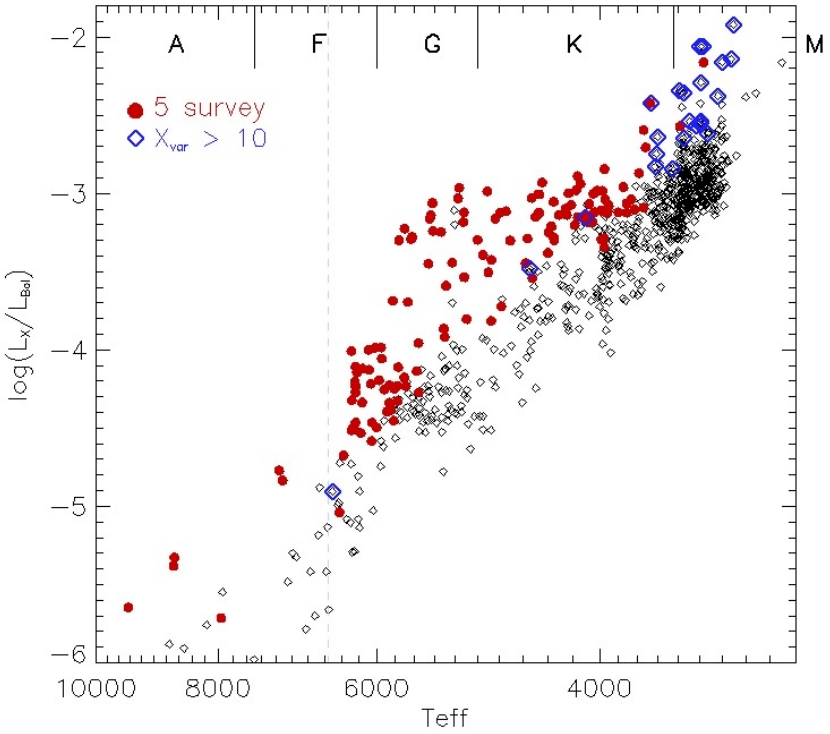
X-rays from stars: Pleiades

827 X-ray bright stars out of 1355 stars within 3 tidal radii

eROSITA X-ray RGB image



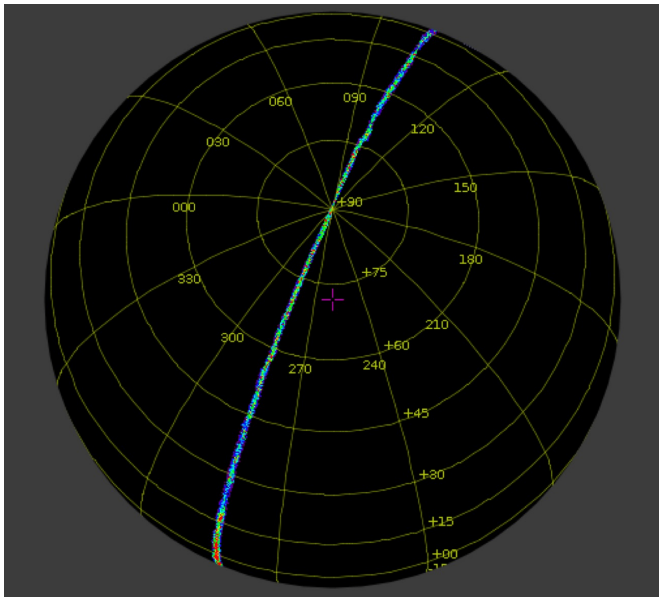
Lx/Lopt vs spectral type



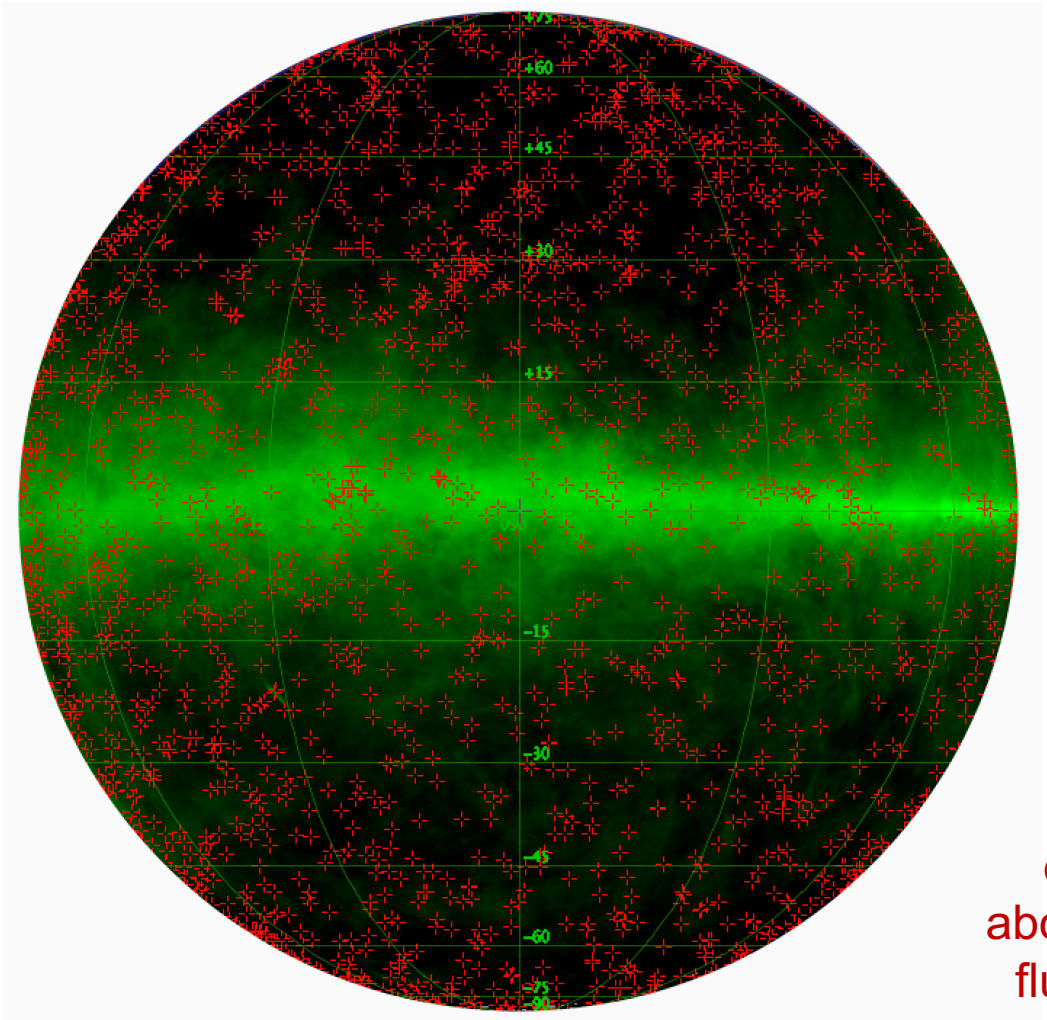
Khamitov, Bikmaev, MG, Sunyaev et al., 2024

Non-stationary and transient phenomena

- every 24 hours SRG/eROSITA scans a ~360 deg^2 stripe on the sky
- full sky survey in 6 months
- (quasi-) contiguous coverage at the ecliptic poles
- accessible time scales:
  30 sec … 4 hours …. 6 months



Distribution of strongly variable (>10x) sources on the sky



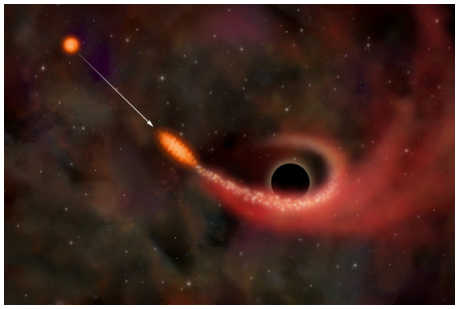
green – neutral hydrogen in the Galaxy

- stellar flares
- variable AGN
- tidal disruptions of stars by SMBH
- gamma-ray bursts
- “hostless” transients
- X-ray binaries

every 24 hours we used to find about ~3-5 objects changing their flux by >10x as compared to the previous survey

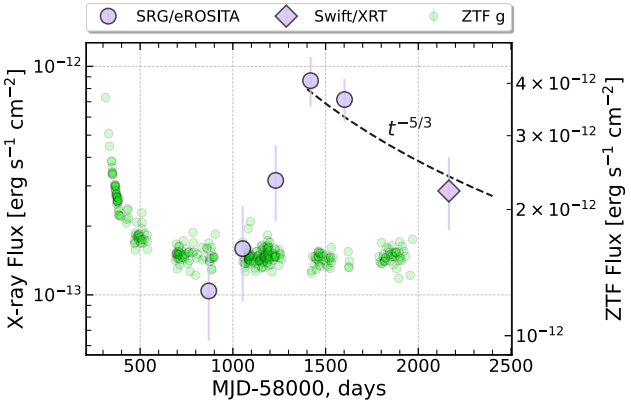
Tidal disruption events

disruption of a normal star by tidal forces in the gravitational field of a supermassive black hole

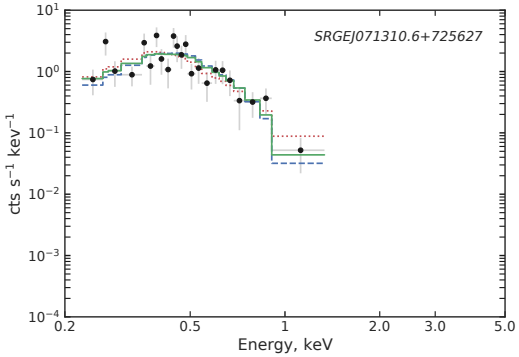


- eROSITA detected about 70+ TDEs
- first eROSITA TDE catalog published
- mean rate: one event in 100,000 years per galaxy
- dichotomy between optically and X-ray bright
- associations with three IceCube neutrino events discovered

Optical and X-ray lightcurves



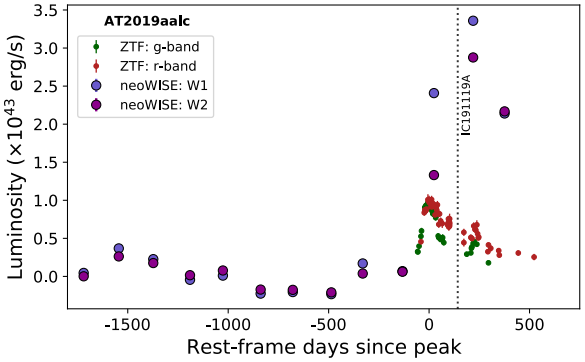
X-ray spectrum (SRG/eROSITA)

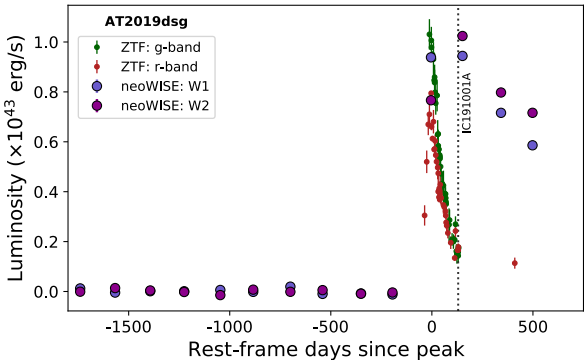


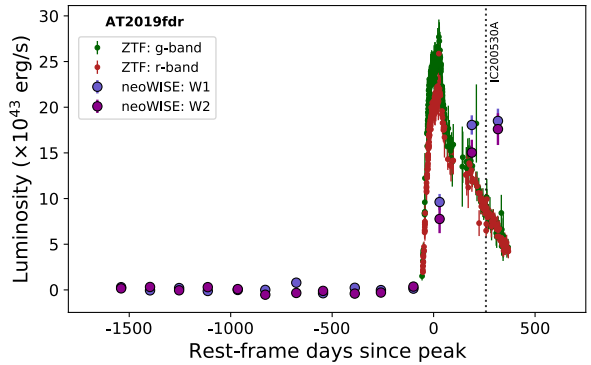
Sazonov, Gilfanov, Khorunzhev et al., 2021
Gilfanov, Sazonov, Medvedev et al., 2021, 2023
van Velzen, Stein, Gilfanov et al. 2024

Thank you!

Association of TDEs with IceCube neutrinos







- 3 ZTF+WISE TDEs have spatial and temporal matches with IceCube neutrinos
- 2 of these TDEs are detected by SRG/eROSITA
  super-soft spectra кT~71 и 170 эВ,
- $\frac{L_{bol}}{L_{Edd}} \sim 0.5$
- found in correlating 36 neutrino events with 63 ZTF+WISE flares
- probability of chance coincidence

$$p = 1.5 \cdot 10^{-6} \div 1.9 \cdot 10^{-4}$$

van Velzen, Stein, Gilfanov, … RS, PM, et al. 2023