

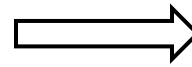
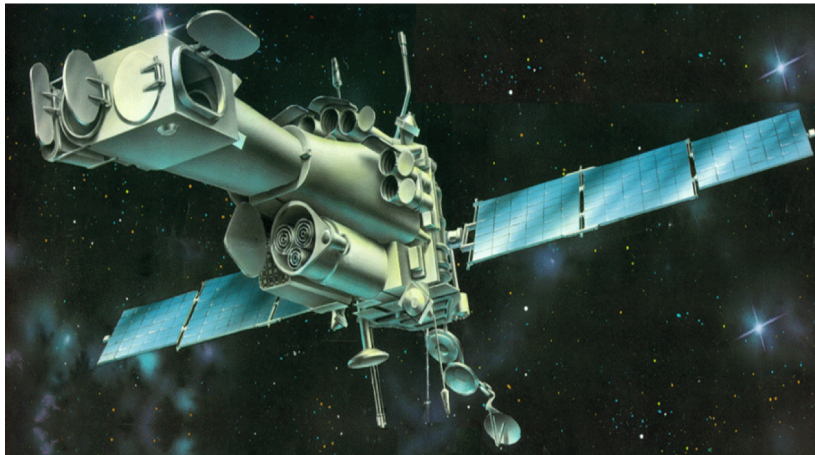
SRG/eROSITA all-sky survey

Marat Gilfanov
MPA, IKI

Spektrum-Roentgen-Gamma (SRG)

Long and turbulent history

1987-2001

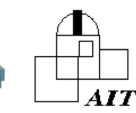


2007-2019-...

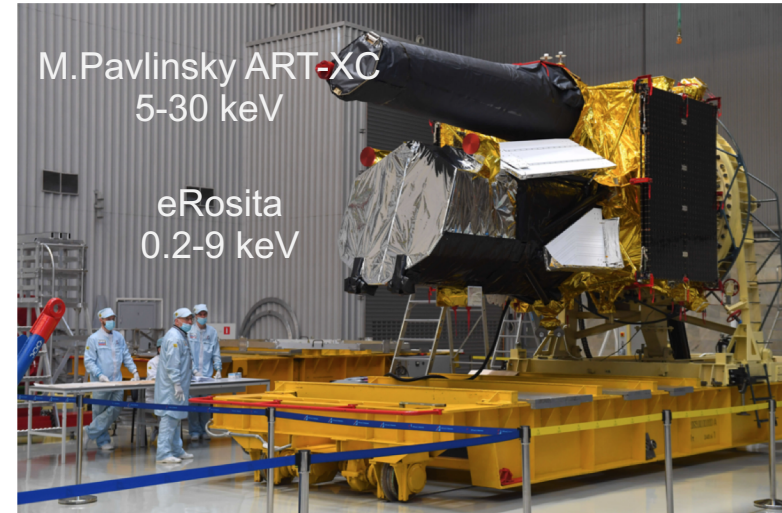


Designed to detect all massive clusters of galaxies in the observable Universe

Science leader of SRG: Rashid Sunyaev

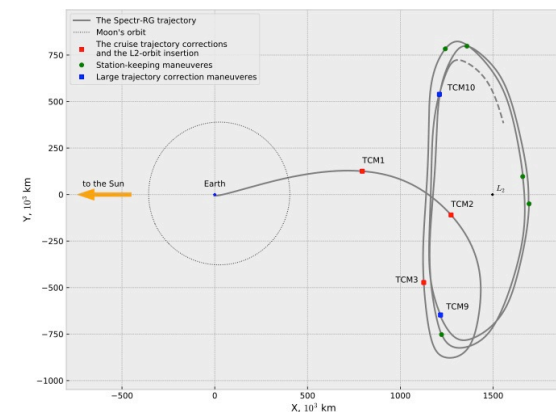


Spectrum-Roentgen-Gamma



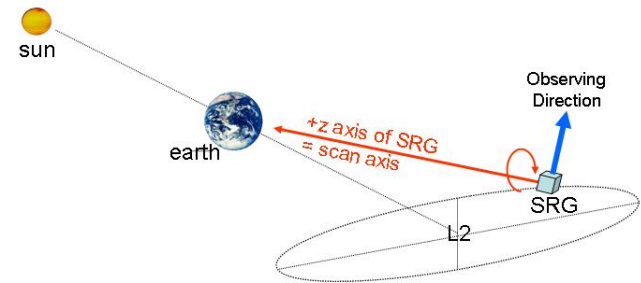
- 2019, July 13 Launch
- 2019, Oct. 22 official “arrival” at L2
- 2019, Dec. 12 start of the all-sky survey
- 2022, Feb. 26 by the request of MPE eROSITA
switched to safe mode. SRG
operates in the interests of ART-
XC telescope

halo orbit around L2 point

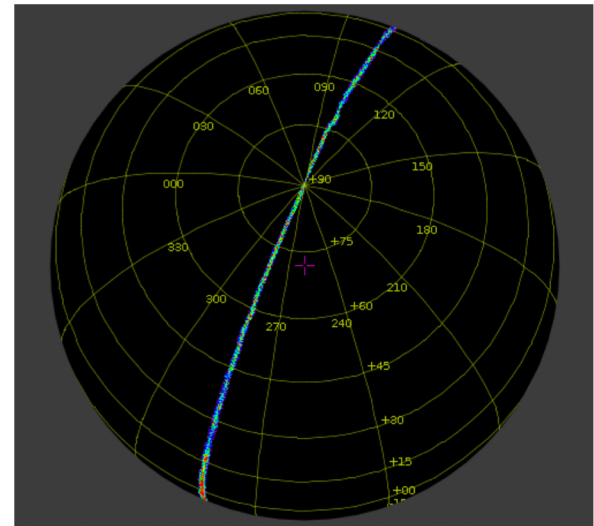


All-sky survey – main component of SRG science program

- 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
- ✧ designed to be 25 times more sensitive than previous all-sky X-ray survey by ROSAT (1991)
- completed 4.38 surveys

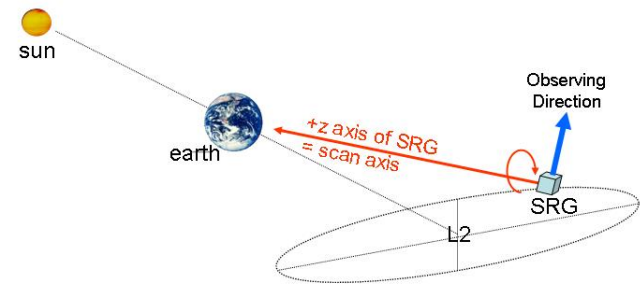


24 hours of scanning
1 degree wide stripe on the sky

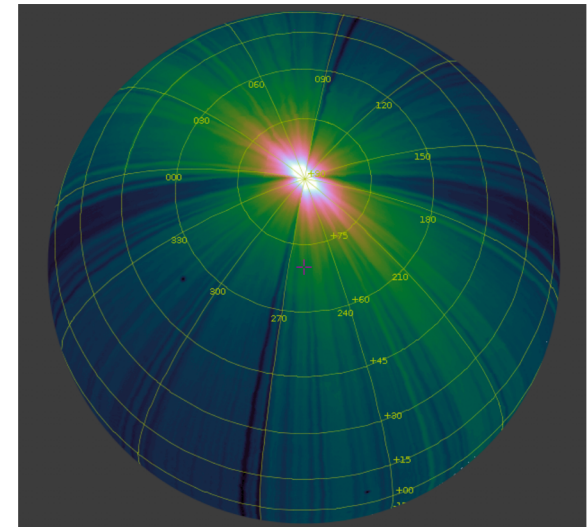


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exposure map

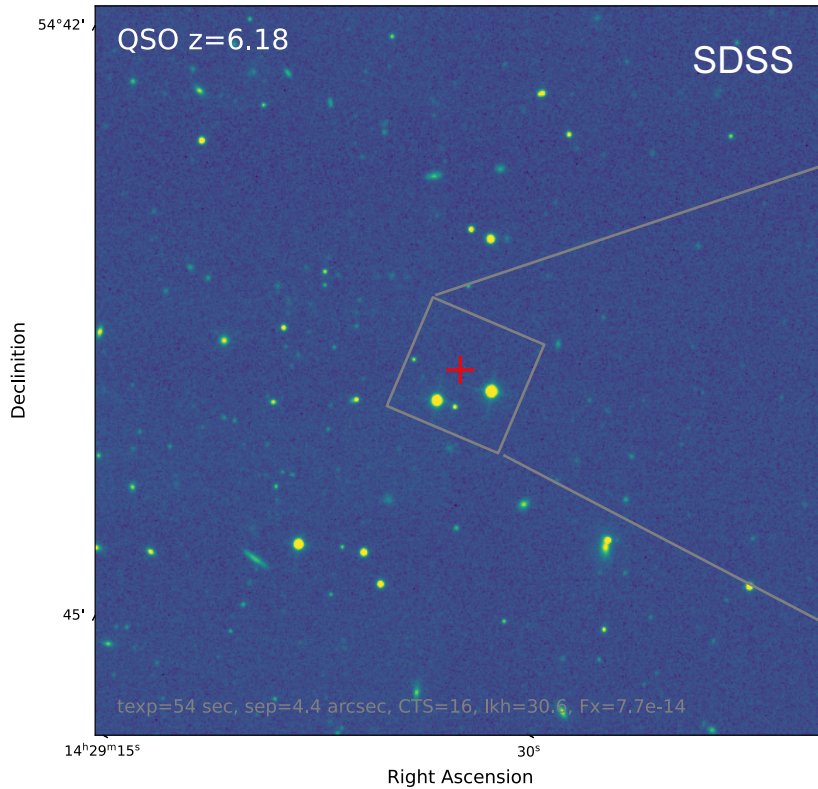


Why an all-sky survey in X-ray band may be interesting?

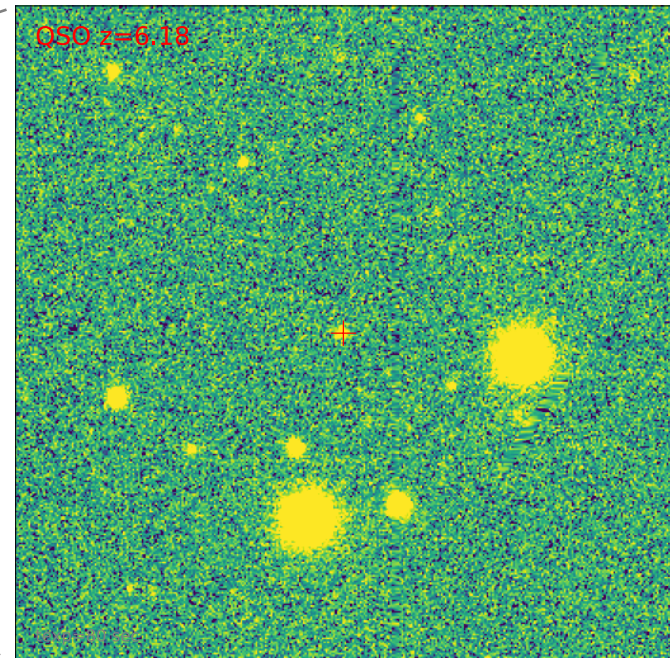
- ✧ an “easy” way to find clusters of galaxies and accreting supermassive black holes in the “sea” of much more numerous stars and nearby galaxies
- ✧ detailed X-ray map of the sky
- ✧ astrophysics of many types of objects
- previous all-sky X-ray survey was performed 30 years ago (ROSAT satellite)

Quasars

optical image

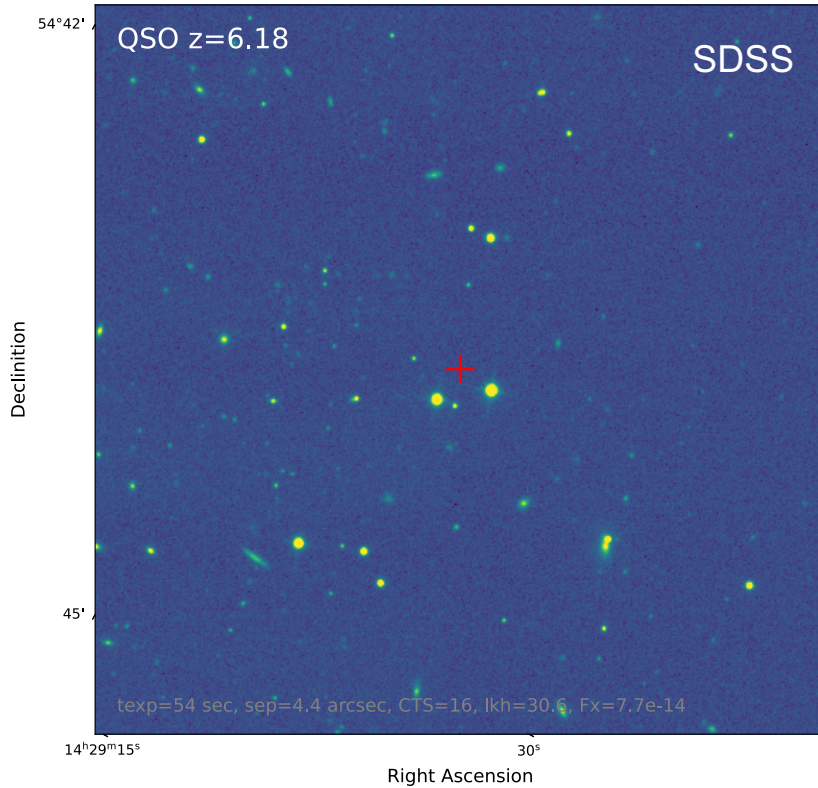


deep optical image (DESI LIS)



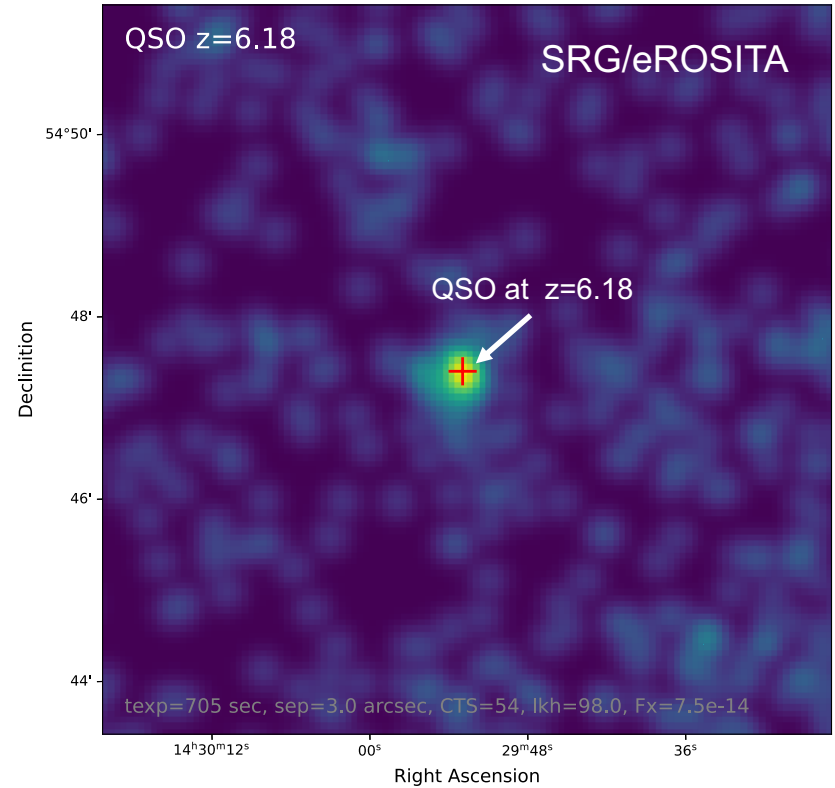
Квазары

optical image



$\sim 10^3 - 10^4$ src/deg²
mostly stars and galaxies
quasars ~ few%

X-ray image of same size

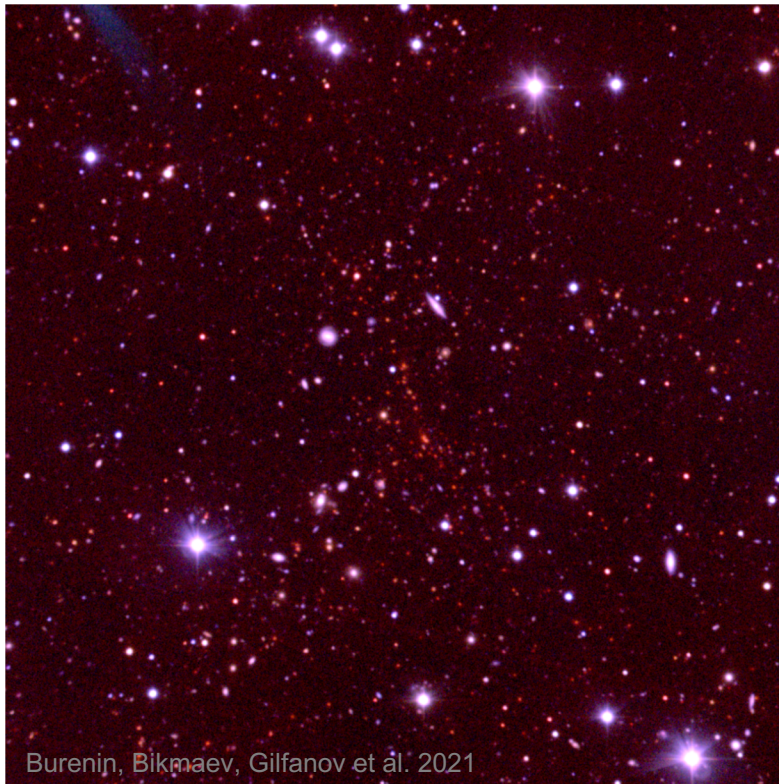


$\sim 10^2$ src/deg²
quasars dominate
galaxies ~ few %
contribution of stars ~ 10%

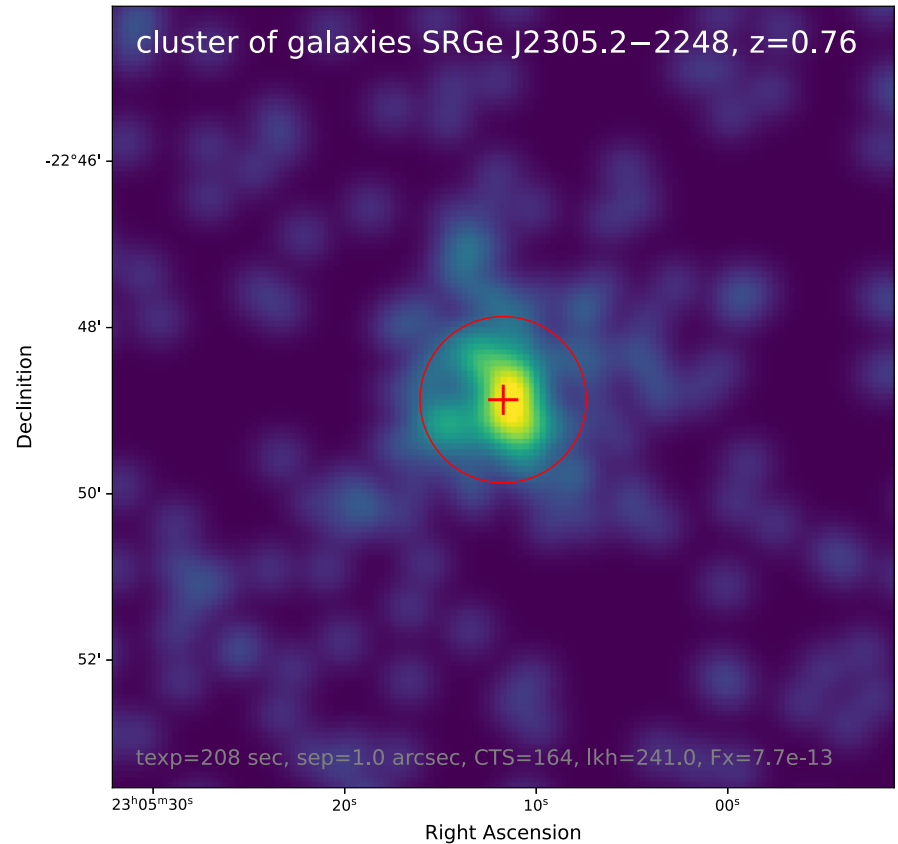
Massive cluster of galaxies

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

optical image



X-ray image of same size



Goals of SRG/eROSITA all-sky survey

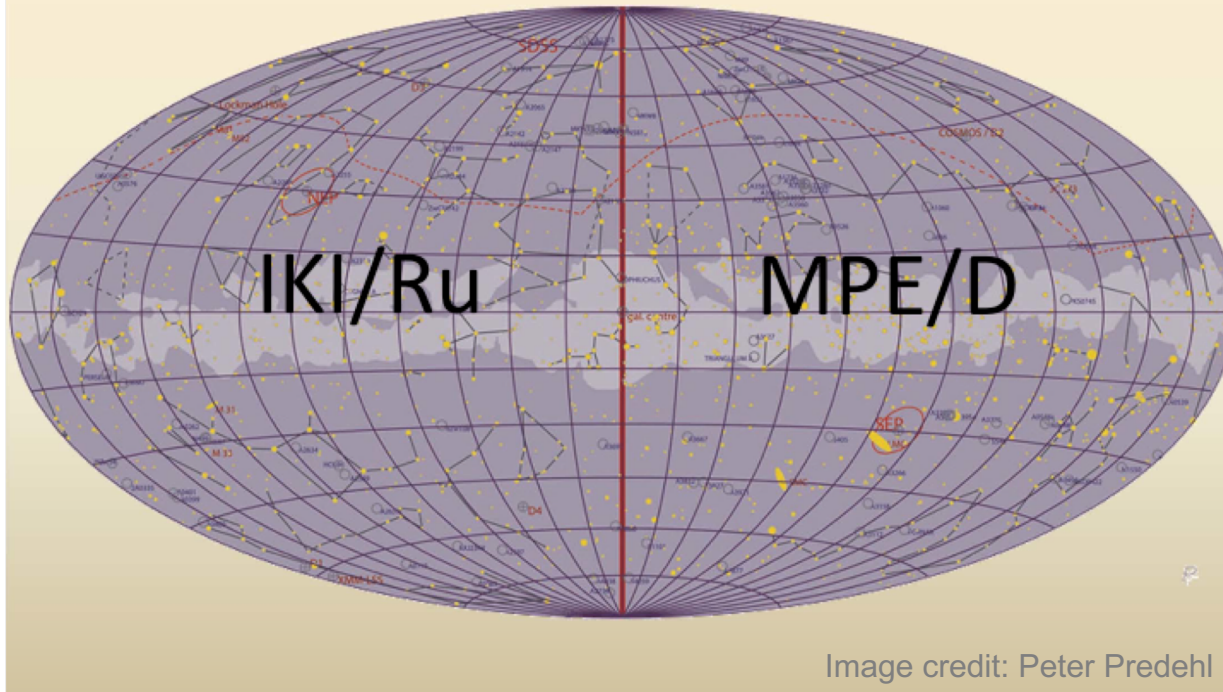
Obtain record large and uniform samples of quasars and clusters of galaxies ($\sim 10^4$ - 10^6 объектов)

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

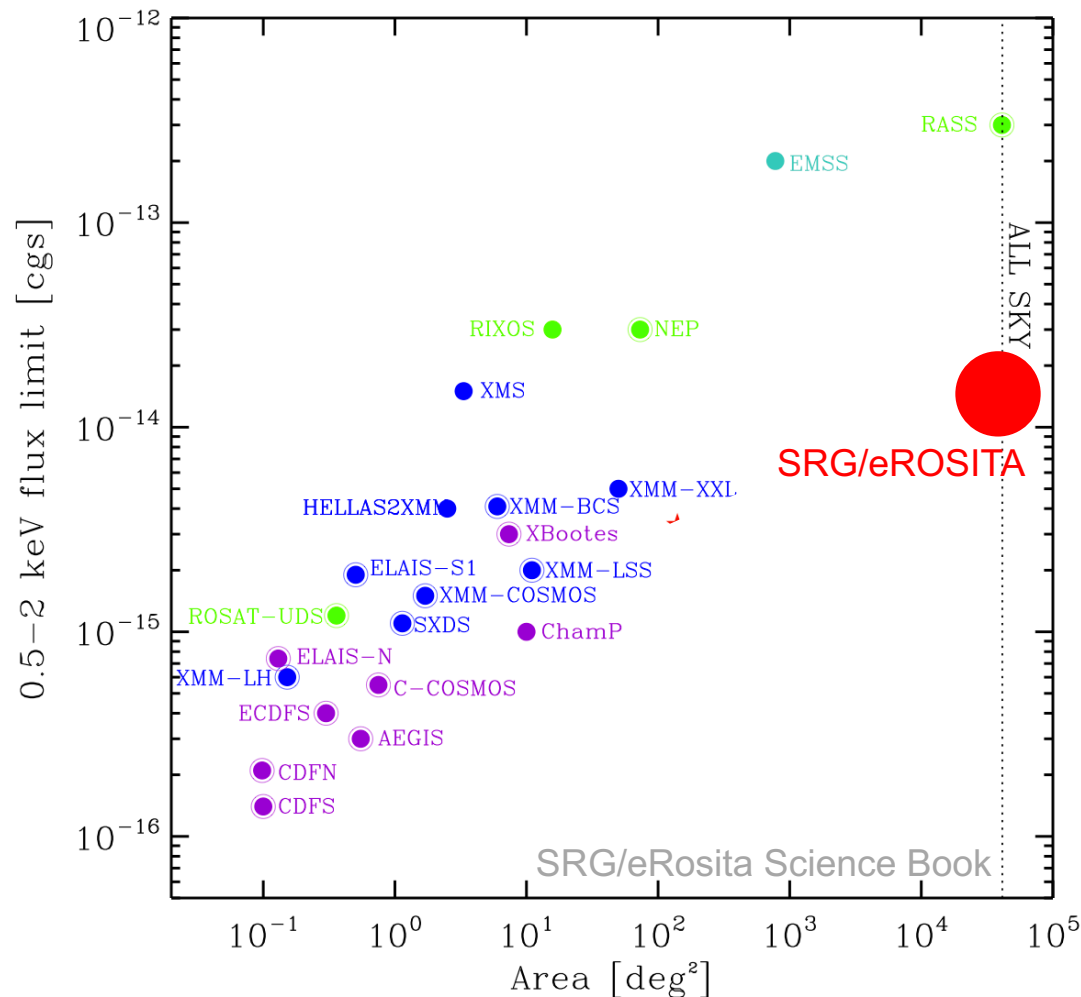
It is planned to perform 8 independent sky surveys
4.4 surveys completed

eROSITA data rights

Sky Division



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

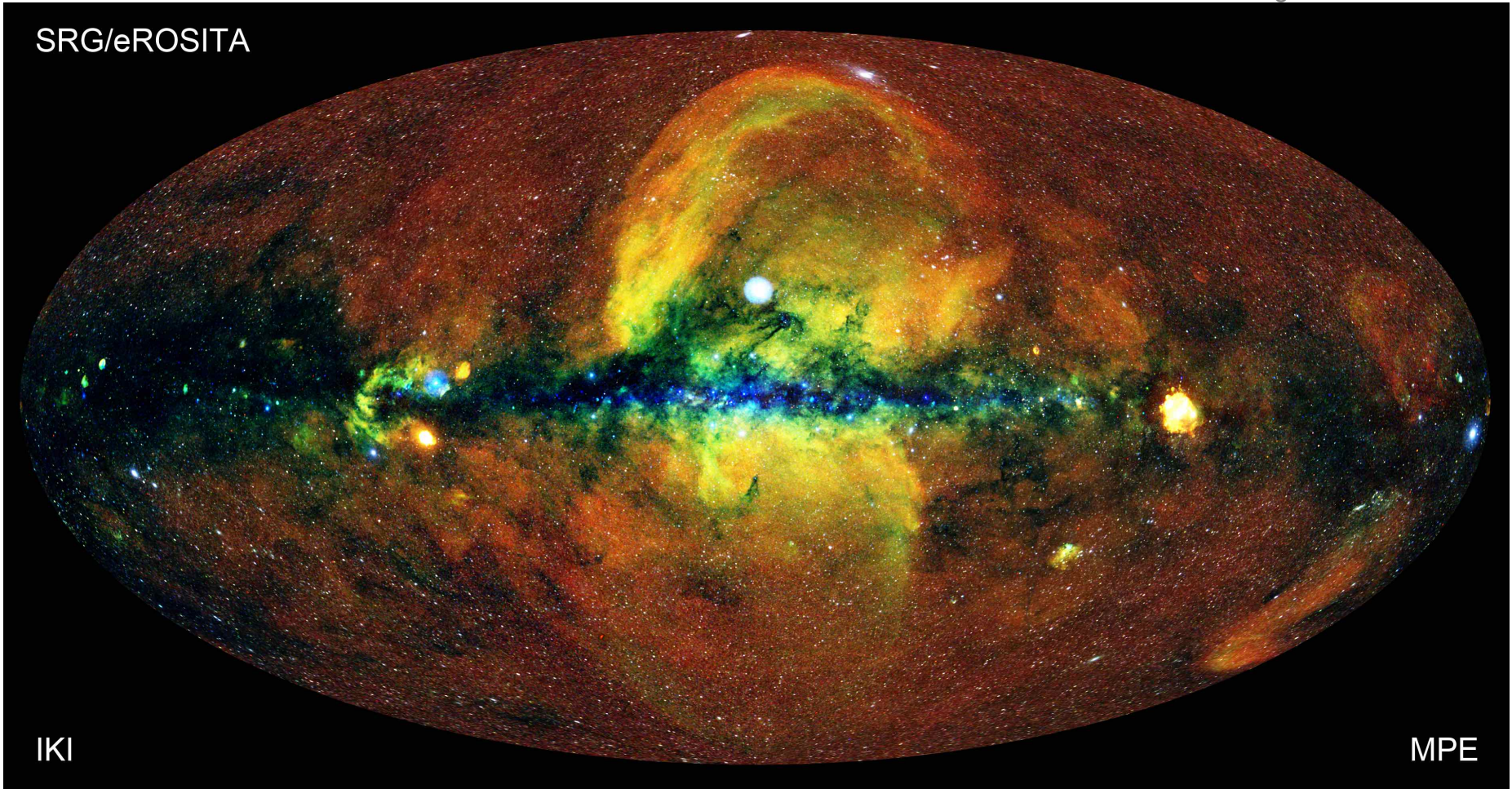
SRG/eROSITA

SRG/eRosita Science Book

X-ray RGB map of the sky

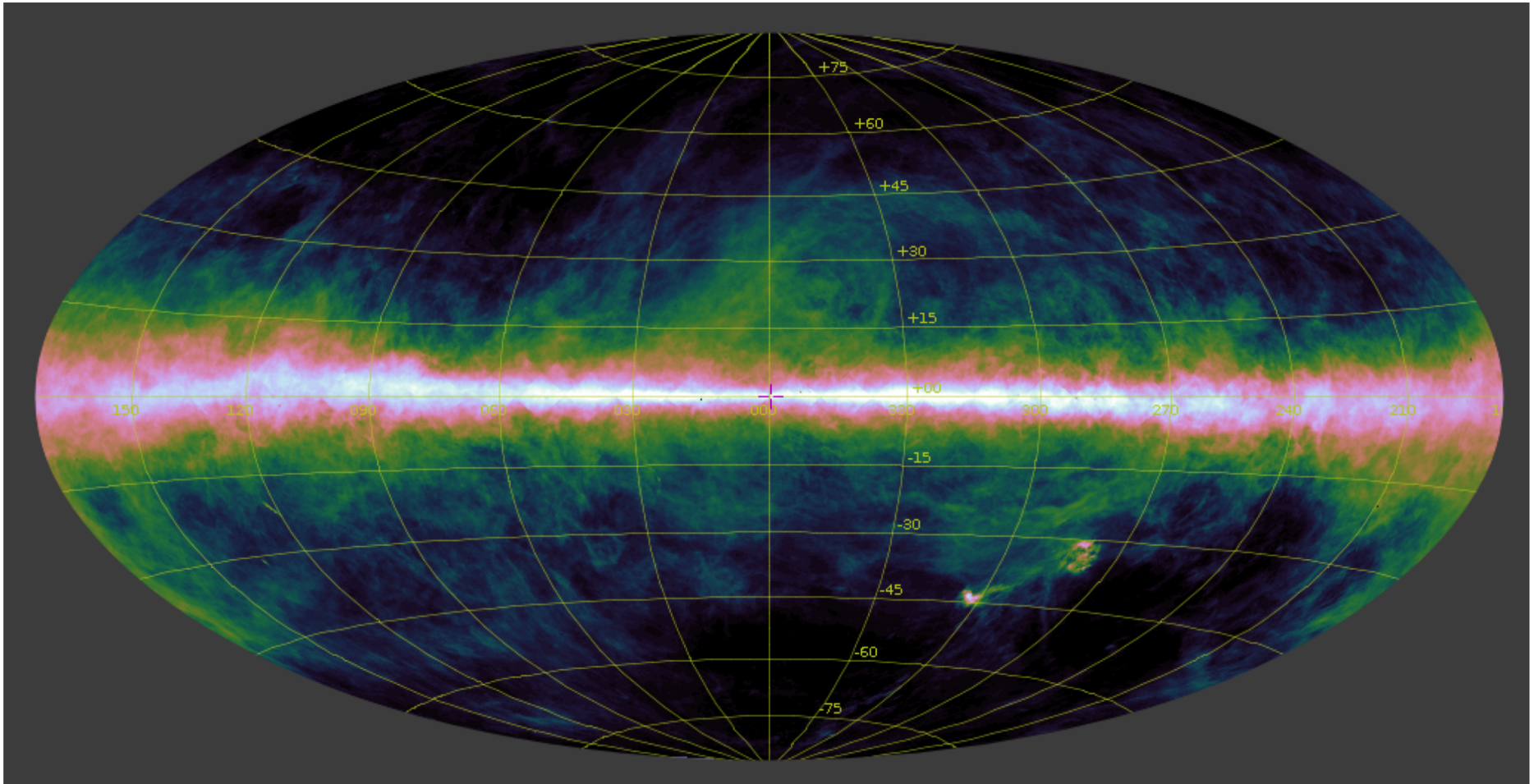
galactic coordinates

SRG/eROSITA



Churazov, Gilfanov, Sunyaev, Brunner, Merloni, Sanders

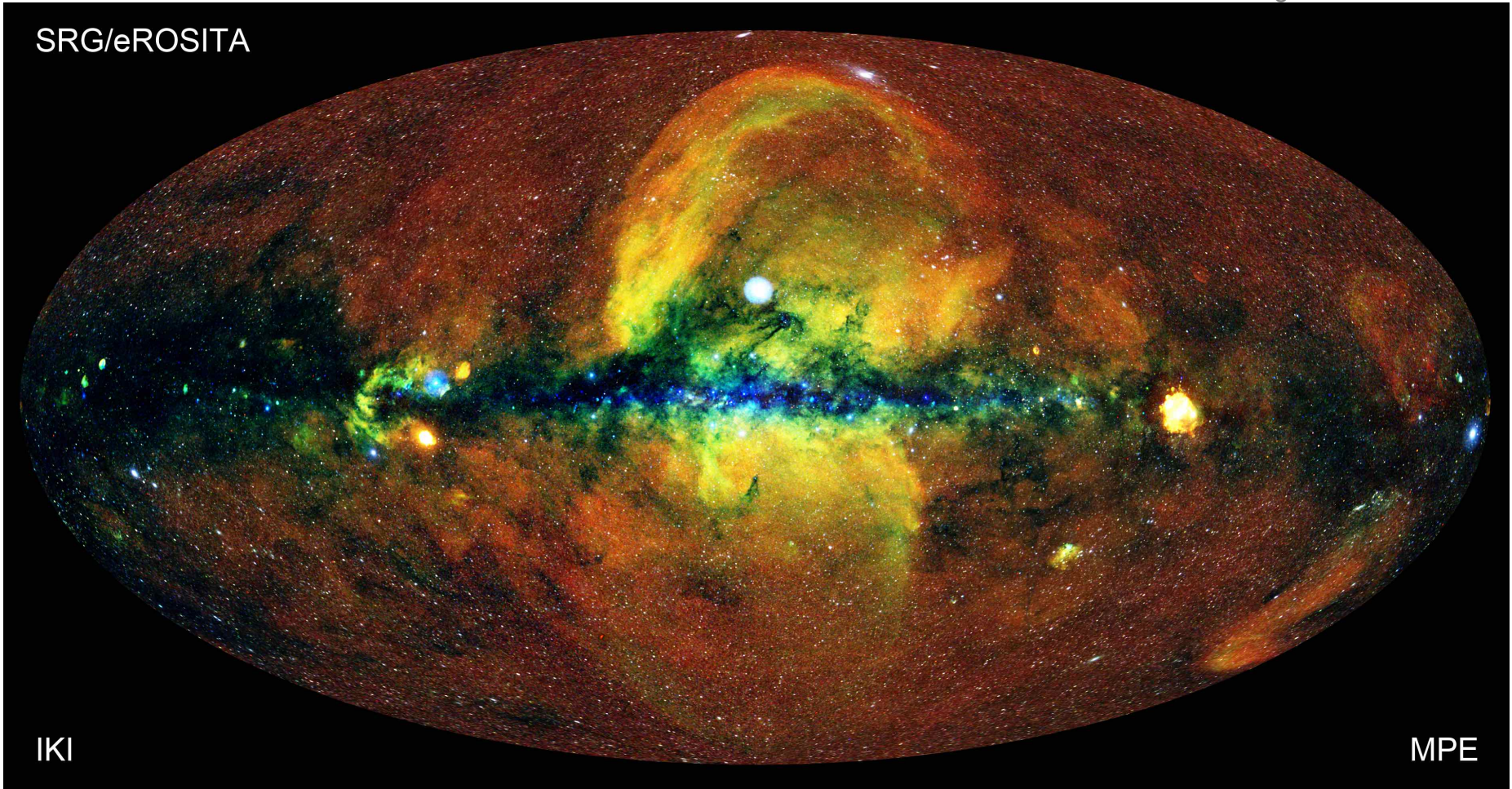
HI in the Milky Way (HI4PI)



X-ray RGB map of the sky

galactic coordinates

SRG/eROSITA



IKI

MPE

Churazov, Gilfanov, Sunyaev, Brunner, Merloni, Sanders

eROSITA bubbles

X-ray luminosity

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

Temperature jump

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

Shock

$$M \approx 1.5$$

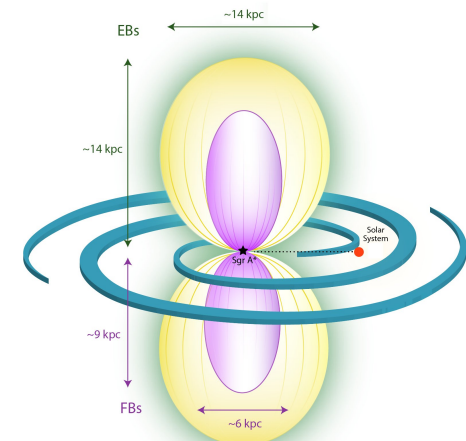
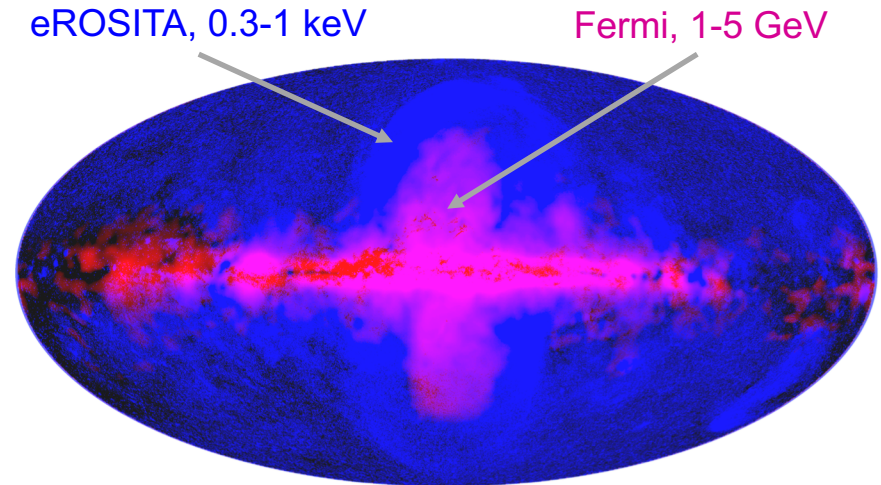
Total energy of eROSITA bubbles

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

Supermassive black hole activity
at the level of

$L_X \sim 10^{43} \text{ erg/s}$ timescale of $\sim 2 \text{ mln years}$
or star – formation event $\sim 10 \text{ mln years}$

envelope Fermi bubbles

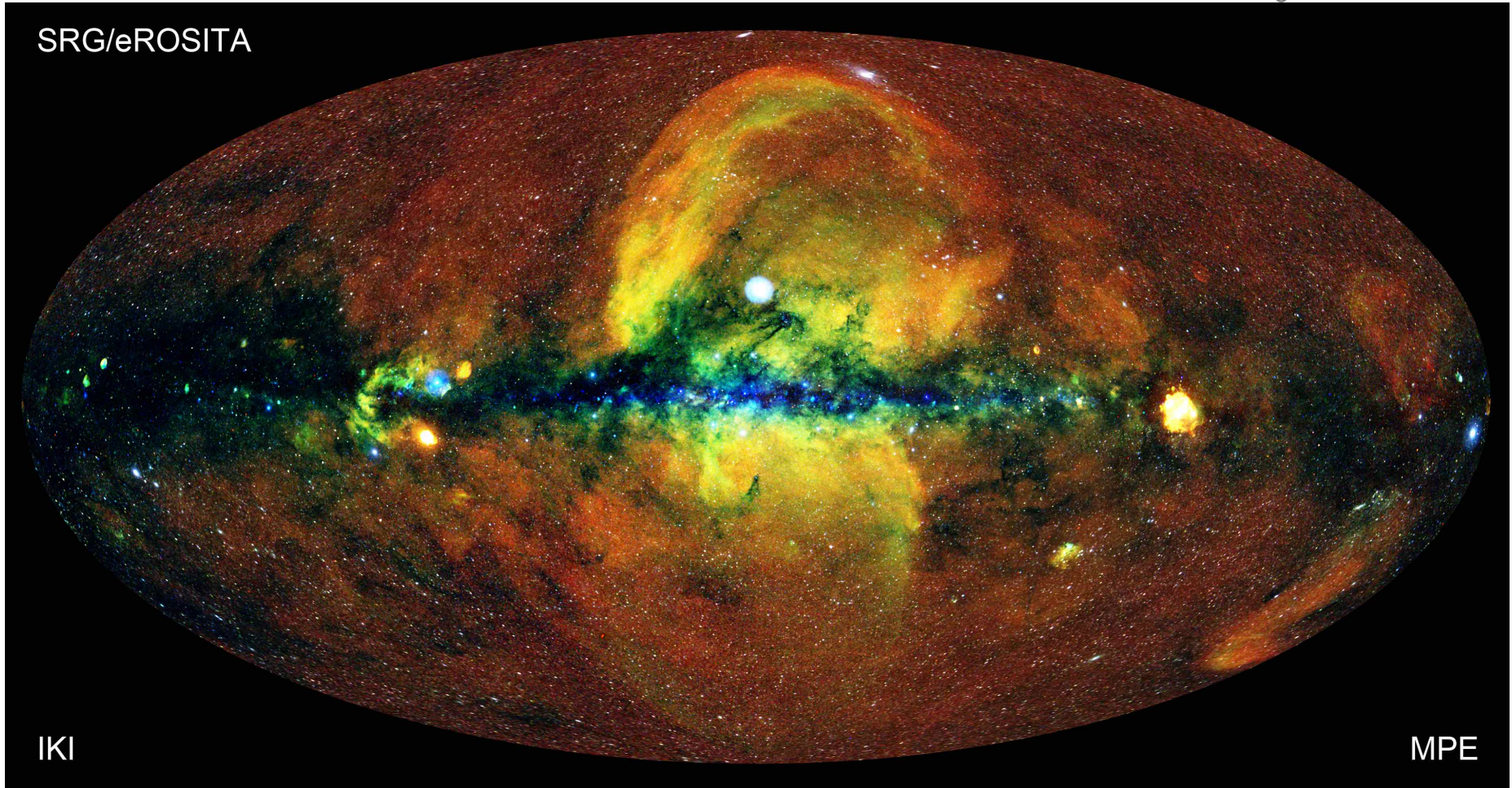


Predehl, Sunyaev et al, Nature, 2020

X-ray RGB map of the sky

galactic coordinates

SRG/eROSITA



IKI

MPE

Churazov, Gilfanov, Sunyaev, Brunner, Merloni, Sanders

X-ray catalog and QSO/TDE science working groups



Sergey Sazonov



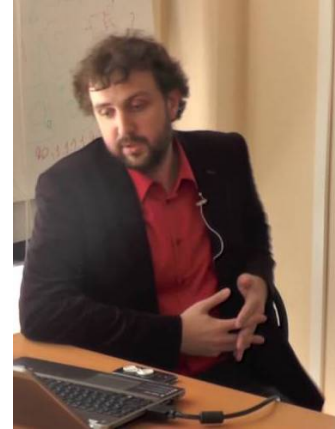
Rashid Sunyaev



Pavel Medvedev



Alexei Starobinsky



Alexander
Mescheryakov



Georgii
Khorunzhev



Rodion Burenin



Ilfan Bikmaev



Igor Zaznobin

working groups on clusters of galaxies and stars

Students:

Mikhali Belvedersky

Viktor Borisov

Sergei Bykov

Ilkham Galiullin

Nadezhda Malysheva

Allisa Nemeshaeva

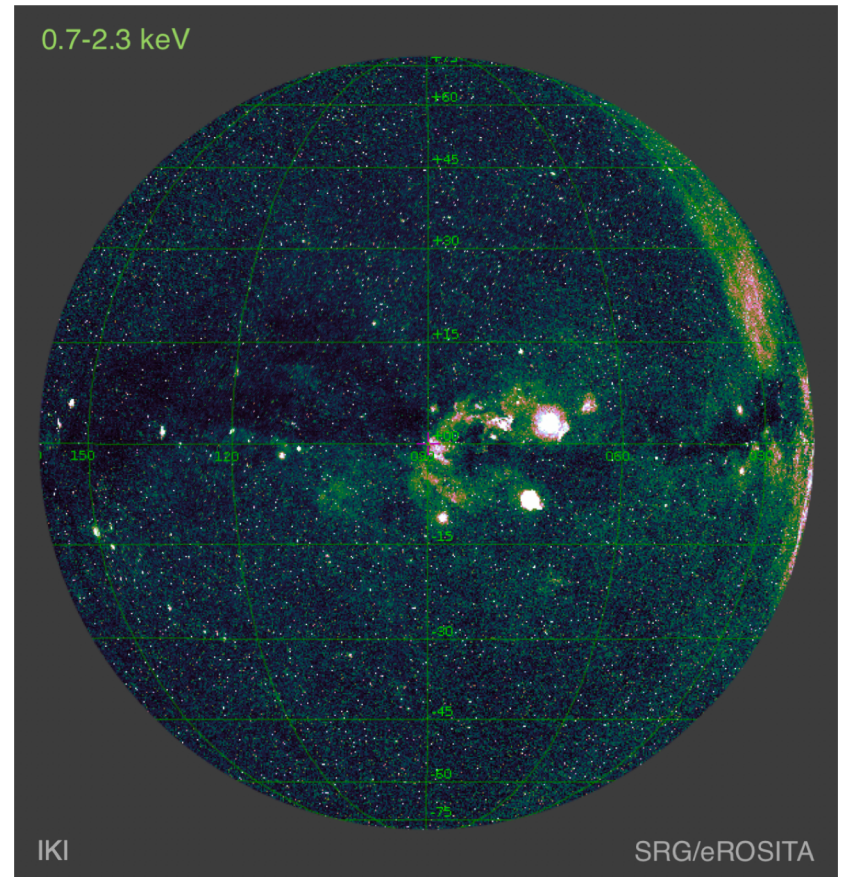
Sergey Prokhorenko

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
- ✧ 23,000 clusters of galaxies
- ✧ ~5,000 sources in the hard X-ray band 4-9 keV



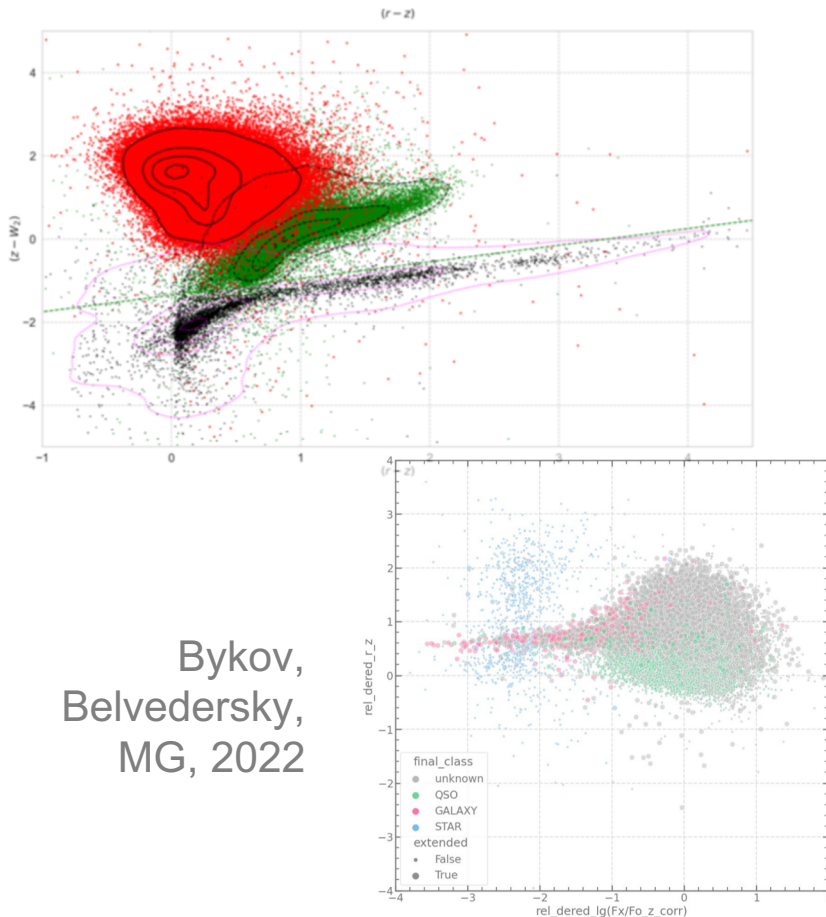
Making sense out of 1.5 million of X-ray sources

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

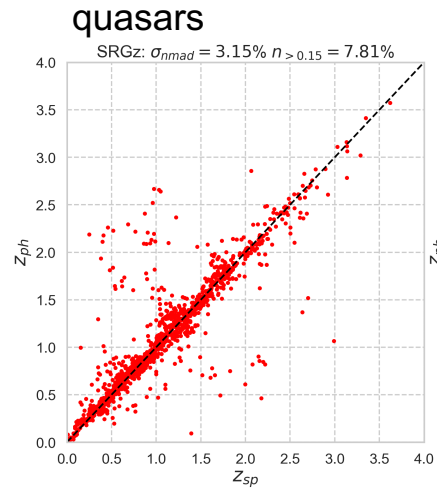
- ✓ machine learning algorithms (random forest), neural networks – SRGz system, Mescheryakov+ 2023
- ✓ more astrophysically motivated approaches
 - Bykov+, Belvedersky+ 2022

Making sense out of 1.5 million of X-ray sources

classification

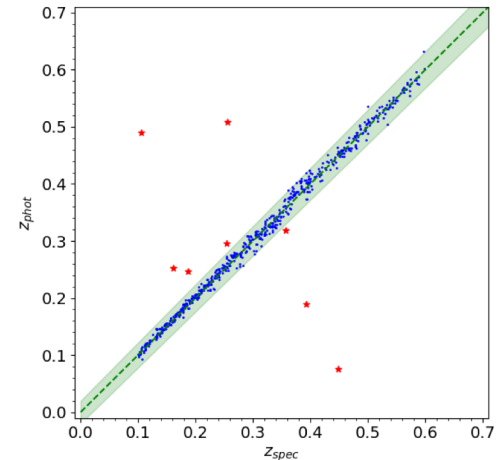


photometric redshifts



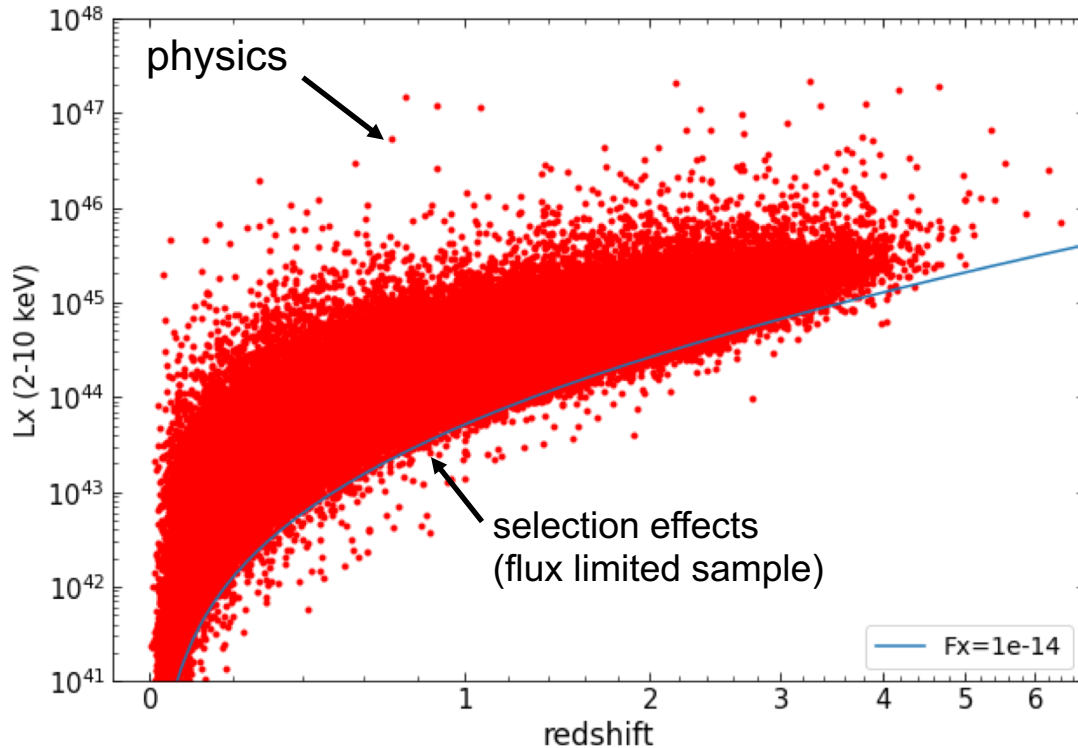
machine learning approaches
Mescheryakov et al., 2023

clusters of galaxies



Zaznobin, Burenin et al. 2023

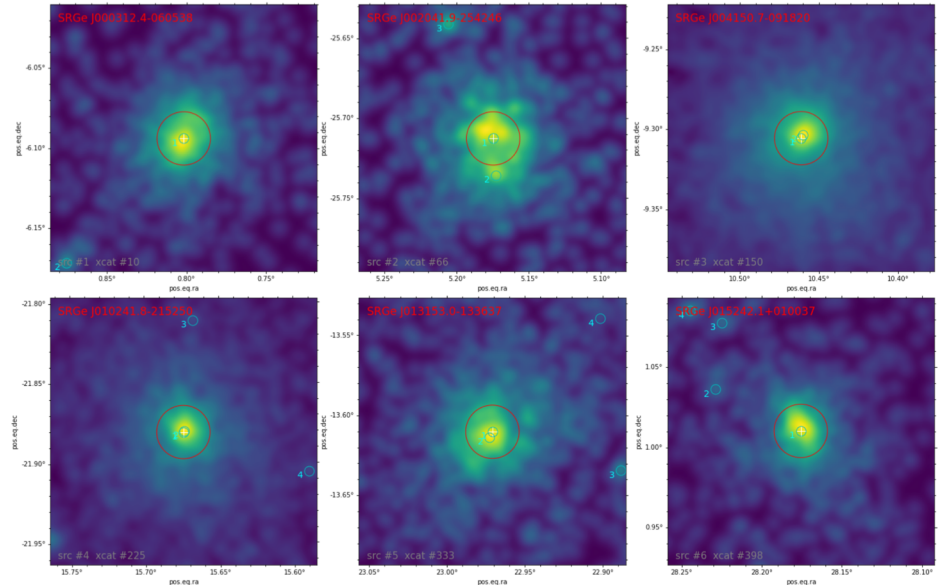
eROSITA AGN sample spectroscopically confirmed



- ✧ 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

Clusters of galaxies

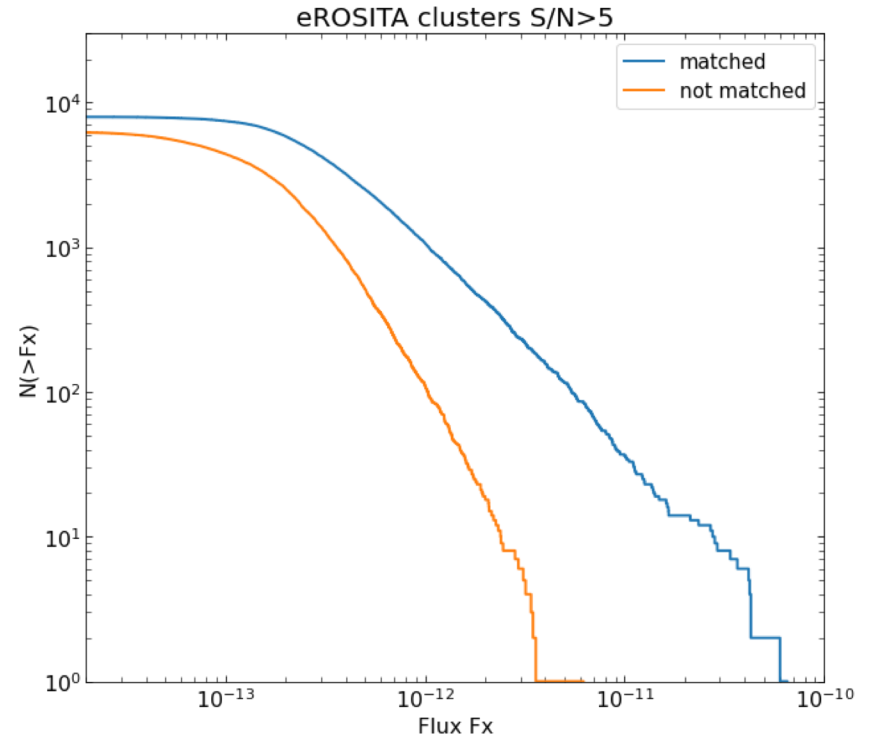
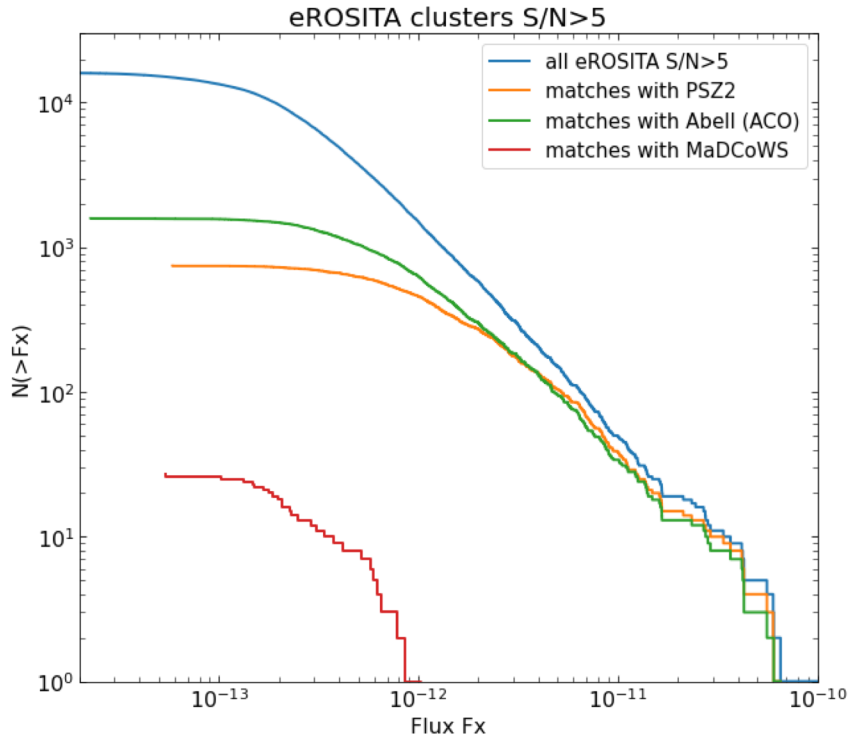
eRosita was designed to detect **all massive clusters of galaxies in the observable part of the Universe**: 50,000 clusters with virial mass $M > 2 \cdot 10^{14} M_{\odot}$ ($\sim 100,000$ clusters and groups of galaxies in total)



Number of detected clusters ($0 < l < 180$):

	$> 5\sigma$	$> 4\sigma$
survey 1	7,500	10,500
survey 1+2	14,000	19,500
survey 1+2+3	18,800	25,500
survey 1+2+3+4	23,200	31,500

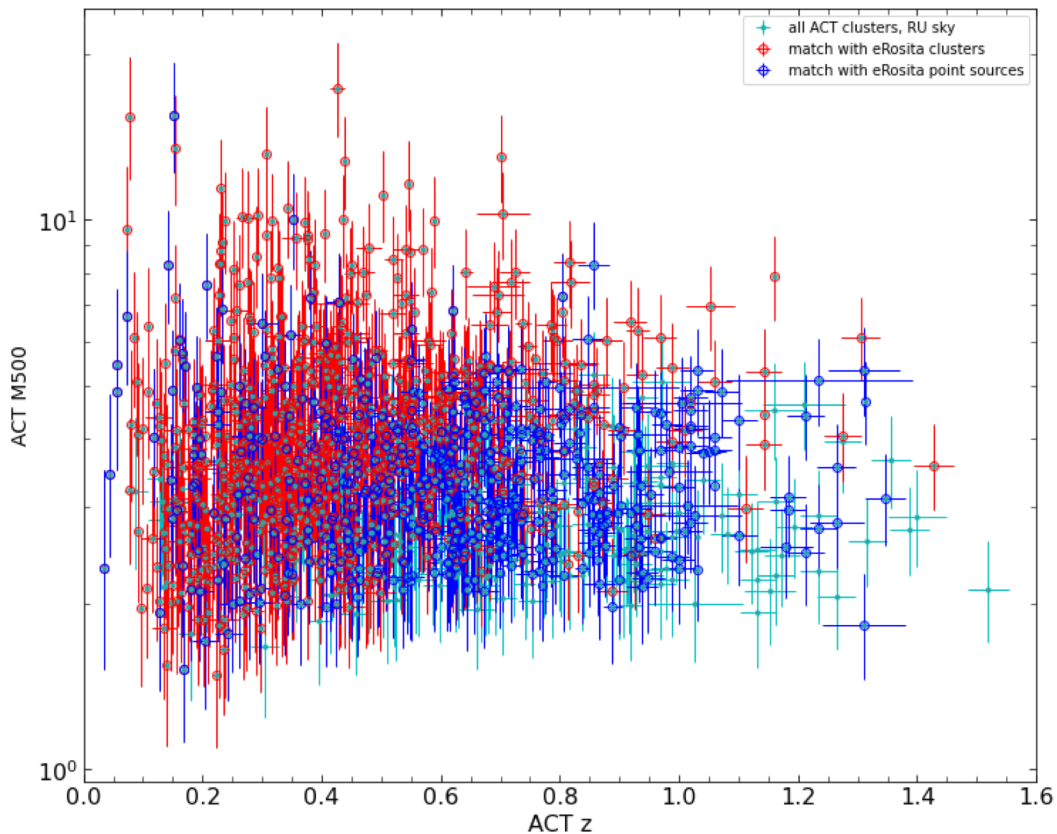
eROSITA clusters (3 surveys)



MG, Medvedev and SRG/eROSITA X-ray catalog working group, IKI

Synergy and competition with SZ-effect

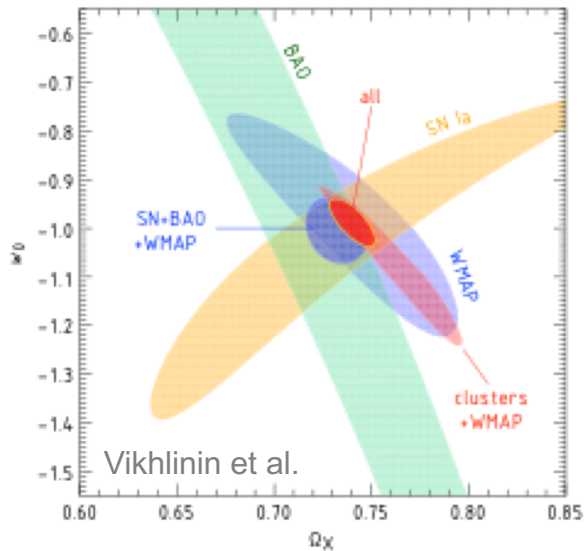
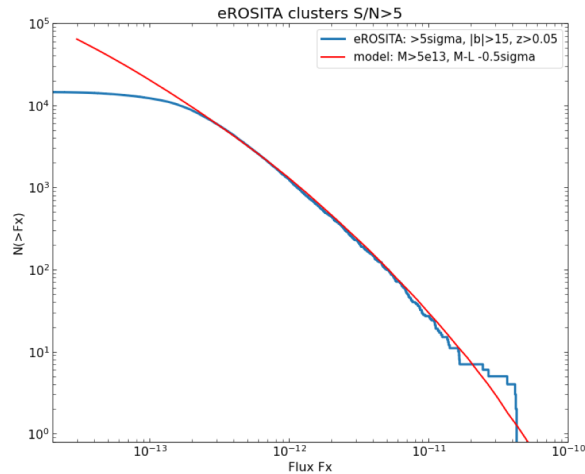
Atacama Cosmology Telescope (SZ-effect) and SRG/eROSITA



- 1591 ACT clusters
- 3975 eROSITA clusters ($>5\sigma$) in the ACT footprint
- 1367 ACT-eROSITA matches:
 - 1052 eROSITA clusters
 - 315 eROSITA point sources

Gilfanov, Sunyaev, Medvedev et al. 2023 (in preparation)

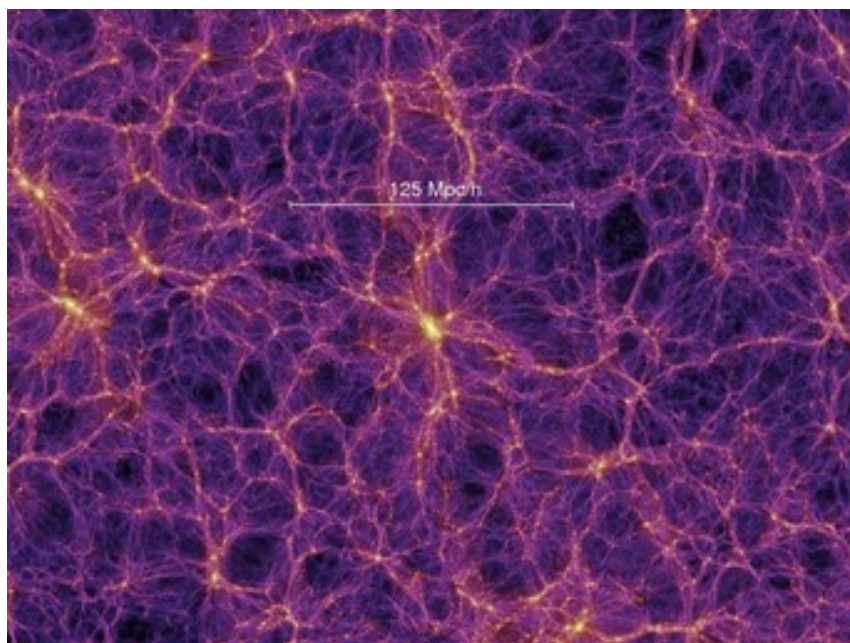
Measuring parameters of the Universe via mass function of clusters of galaxies



- ✧ **mass functions of dark matter haloes** is described by relatively well understood physics and is determined by the cosmological parameters
- ✧ **X-ray luminosity is a proxy** to the dark matter halo mass
- ✧ given the size of the sample (~50,000) cosmological studies with eROSITA clusters will be **dominated by systematics**
- ✧ work in progress...

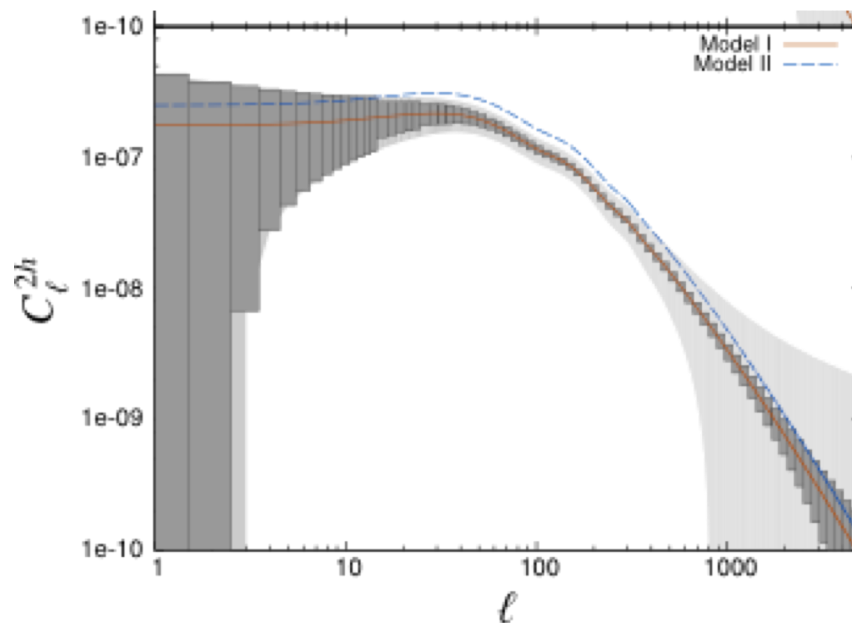
Large scale structure – yet another method of measuring parameters of the Universe

Millenium simulations



Springel et al., 2005

Simulated angular power spectrum of eROSITA quasars

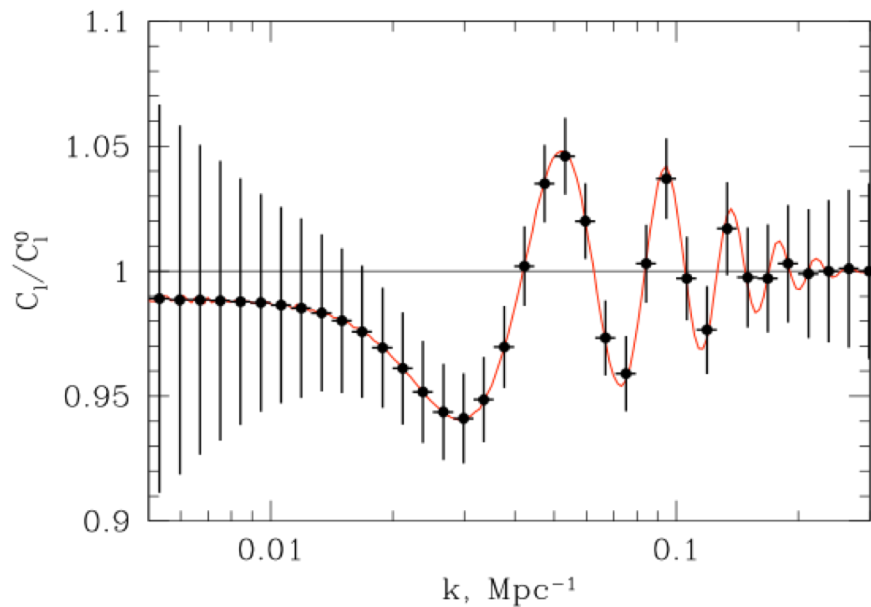


Huetsi, MG, Sunyaev 2013. 2014

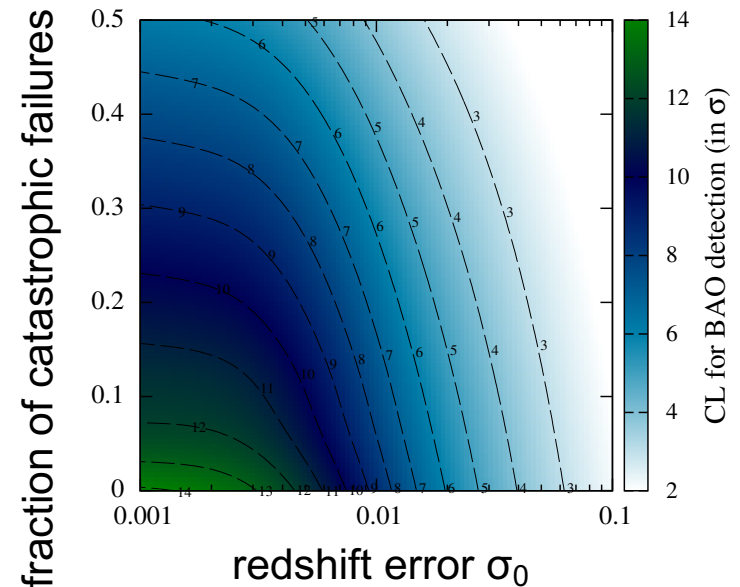
Barionic acoustic oscillations

eROSITA simulations

BAO in the simulated angular power spectrum of eROSITA AGN



requirements to the accuracy of redshift measurements



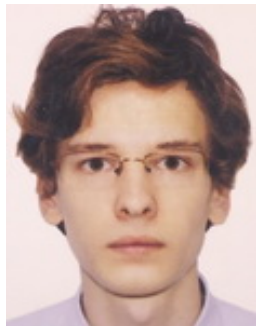
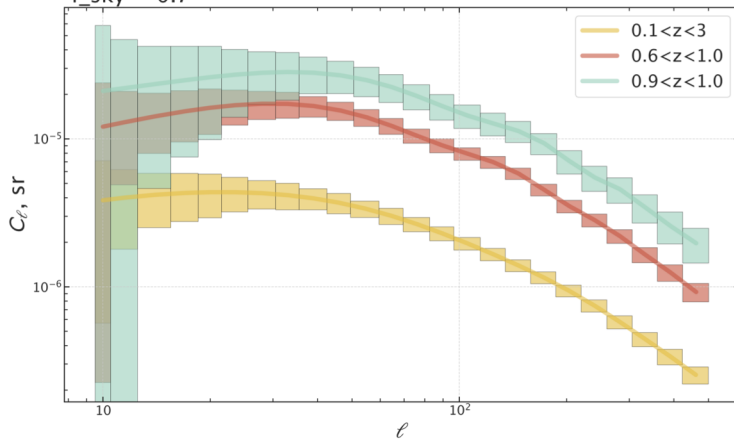
For direct BAO detection high quality redshift measurements are required for a large number of objects

Huetsi, MG, Sunyaev 2013. 2014
Bykov, MG, Sunyaev, 2022

Cosmological measurements using angular distribution of quasars and clusters of galaxies

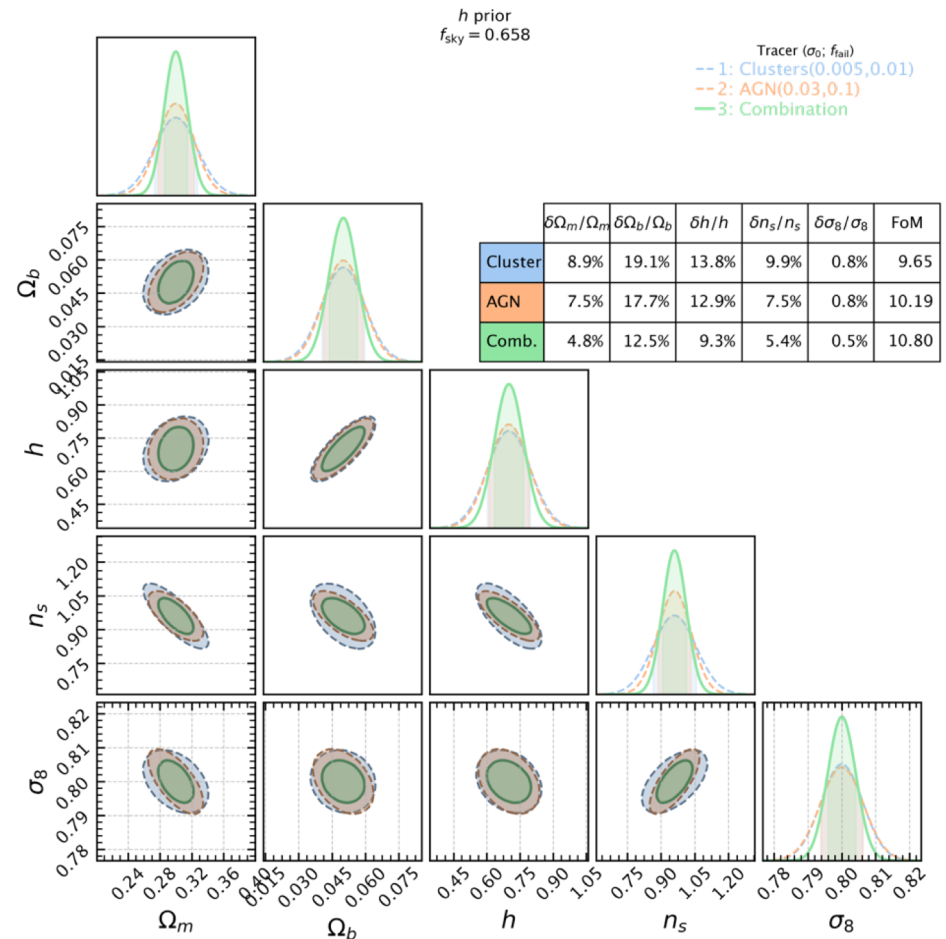
Simulations for eROSITA QSO sample using realistic accuracy of SRGz redshifts

Photo-z: $f_{\text{fail}} = 0.1$, $\sigma_0 = 0.03$
 $f_{\text{sky}} = 0.7$



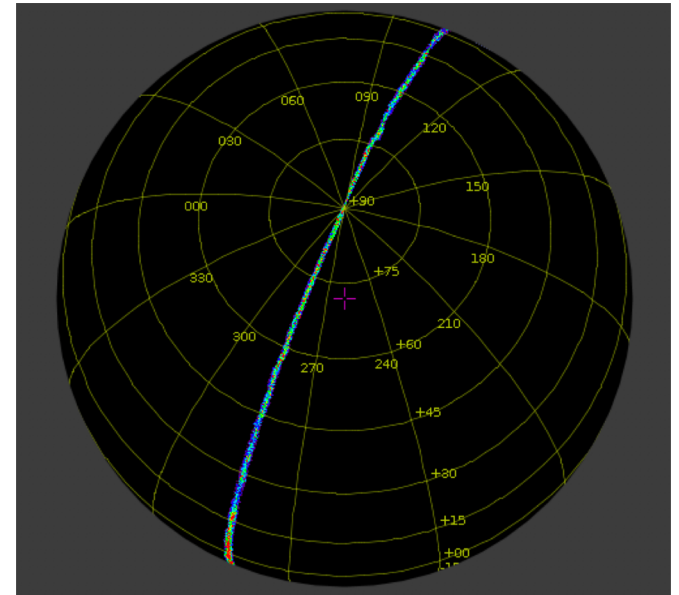
Marat Gilfanov

Bykov, MG, Sunyaev, A&A, 2022



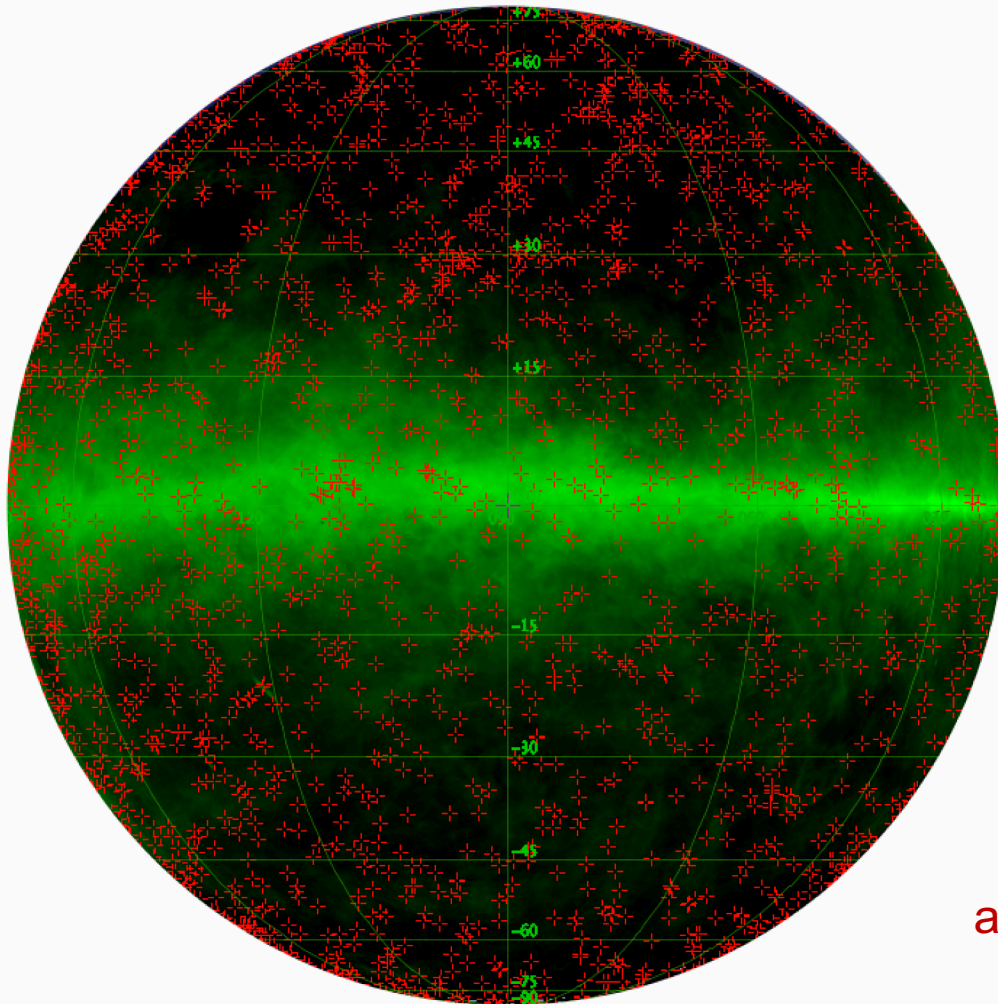
Non-stationary and transient phenomena

- ✧ every 24 hours SRG/eROSITA scans a ~ 360 deg² 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

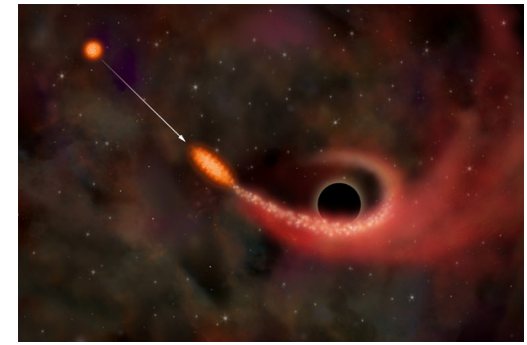
every 24 hours we used to find about ~3-5 objects changing their flux by $>10x$ as compared to the previous survey

Tidal disruption events

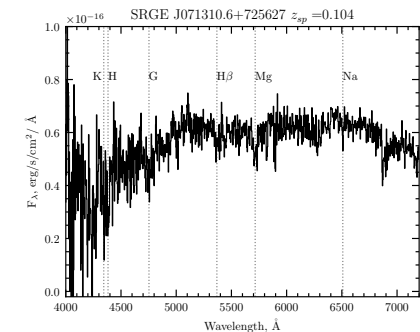
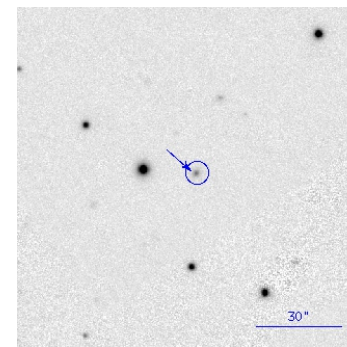
disruption of a normal star by tidal forces in the gravitational field of a supermassive black hole

- ✧ eROSITA detected about 70+ TDEs
- ✧ first eROSITA TDE catalog published
- ✧ mean rate: one event in 100,000 years per galaxy
- ✧ associations with IceCube neutrino events discovered

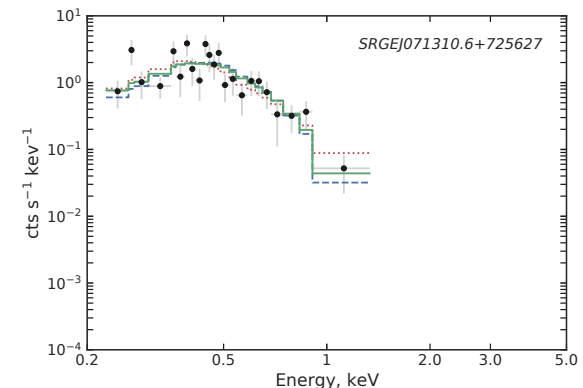
Sazonov, Gilfanov, Khorunzhev et al., 2021
Gilfanov, Sazonov, Medvedev et al., 2021, 2023



Optical spectrum (AZT-33IK)

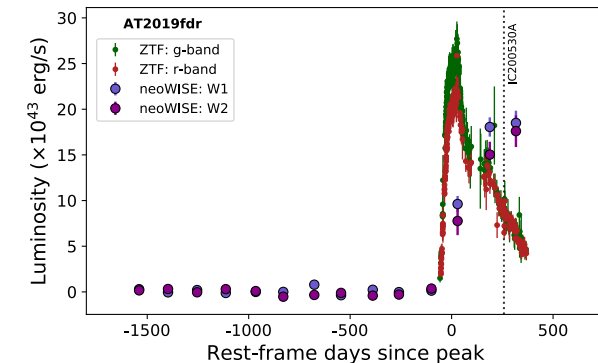
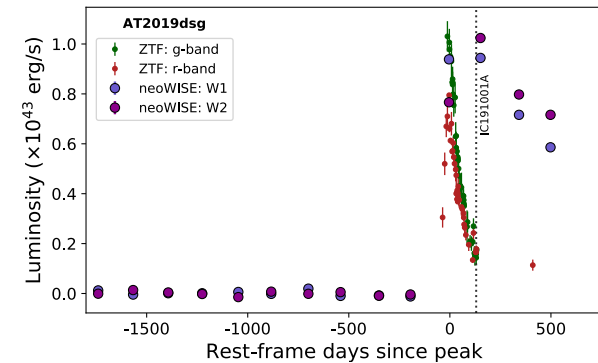
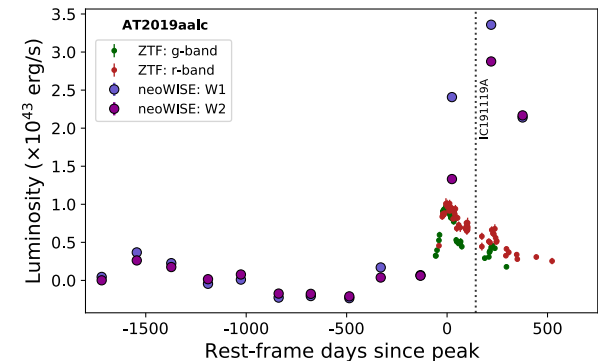


X-ray spectrum (SRG/eROSITA)



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 $\kappa T \sim 71$ 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 $p = 1.5 \cdot 10^{-6} \div 1.9 \cdot 10^{-4}$



Science goals of SRG/eROSITA

- ✓ cosmological measurements with clusters of galaxies and AGN
- ✓ growth of supermassive black holes
- ✓ large scale structure of the Universe at $z \sim 1$
- ✓ astrophysics of clusters of galaxies, AGN and quasars; synergy with observations at other wavelength
- ✓ detailed studies of nearby galaxies
- ✓ extragalactic and galactic transients, tidal disruption events
- ✓ astrophysics of all types of galactic X-ray sources
- ✓ interstellar medium in the Milky Way

image credi: V.Burwitz (MPE)

8 all-sky surveys planned, 4.38 completed

Thank you!