Towards Testing Sterile Neutrino Dark Matter with Spectrum-Roentgen-Gamma Mission

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Motivations

- The recently launched Spectrum-Roentgen-Gamma space observatory (SRG), carrying two X-ray telescopes on board, ART-XC and eROSITA, is expected to contribute considerably to cosmology by investigating cosmic large scale structure properties associated with galaxy clusters, providing a major improvement in cosmological constraints as compared to the results from earlier X-ray, Sunyaev-Zeldovich and optical galaxy cluster surveys.

- These studies can further refine the parameters of Standard Cosmological Model (ΛCDM), the SRG has also high potential in testing specific particle physics models of dark energy and dark matter.

Decaying Sterile Neutrinos

We concentrate on a particular candidate of dark matter—sterile neutrinos—unstable because of mixing with active neutrinos and consequently exhibiting a two-body radiative decay into active neutrino and photon

$$\boldsymbol{\nu_s = \nu_{e,\mu,\tau} + \gamma}$$

Decay Rate:

$$\boldsymbol{\Gamma = \frac{9}{1024}\frac{\alpha}{\pi^4} G_F^2 m_s^5 \sin^2(2\theta) = 1.36 \times 10^{-22} \left(\frac{m_s}{1\ keV}\right)^5 \sin^2(2\theta)\ [s^{-1}]}$$

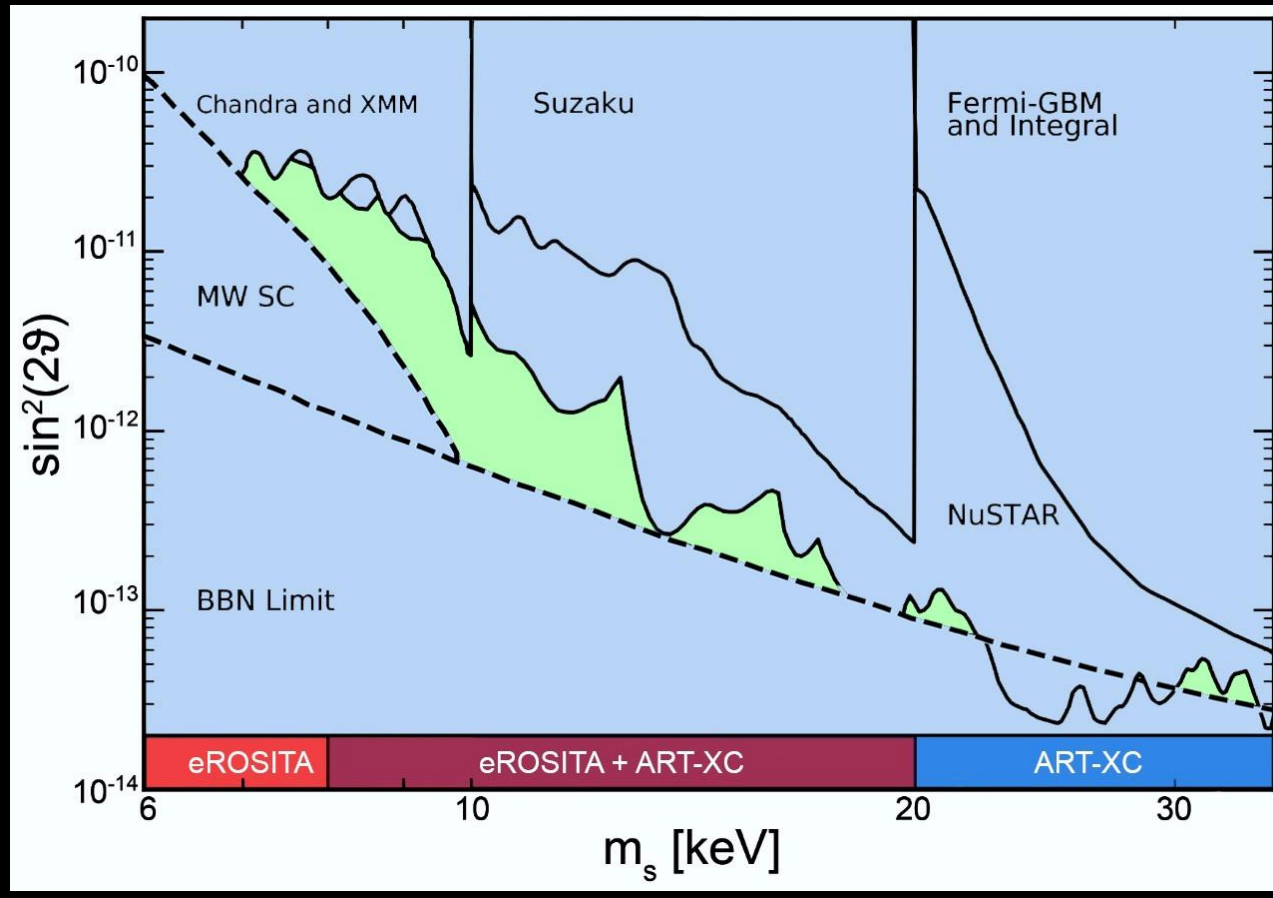
The outgoing photon energy is

$$\boldsymbol{E_\gamma = m_s/2}$$

Modern Constraints

Constraints on the parameters of sterile neutrinos.

The green color indicates the allowed region of sterile neutrino parameter space consistent with X-ray searches (solid lines indicate the upper limits), cosmological limits from Big Bang Nucleosynthesis (dashed line refers to the lower bounds) and cosmological constraints from MW satellite galaxy counts (dashed line).



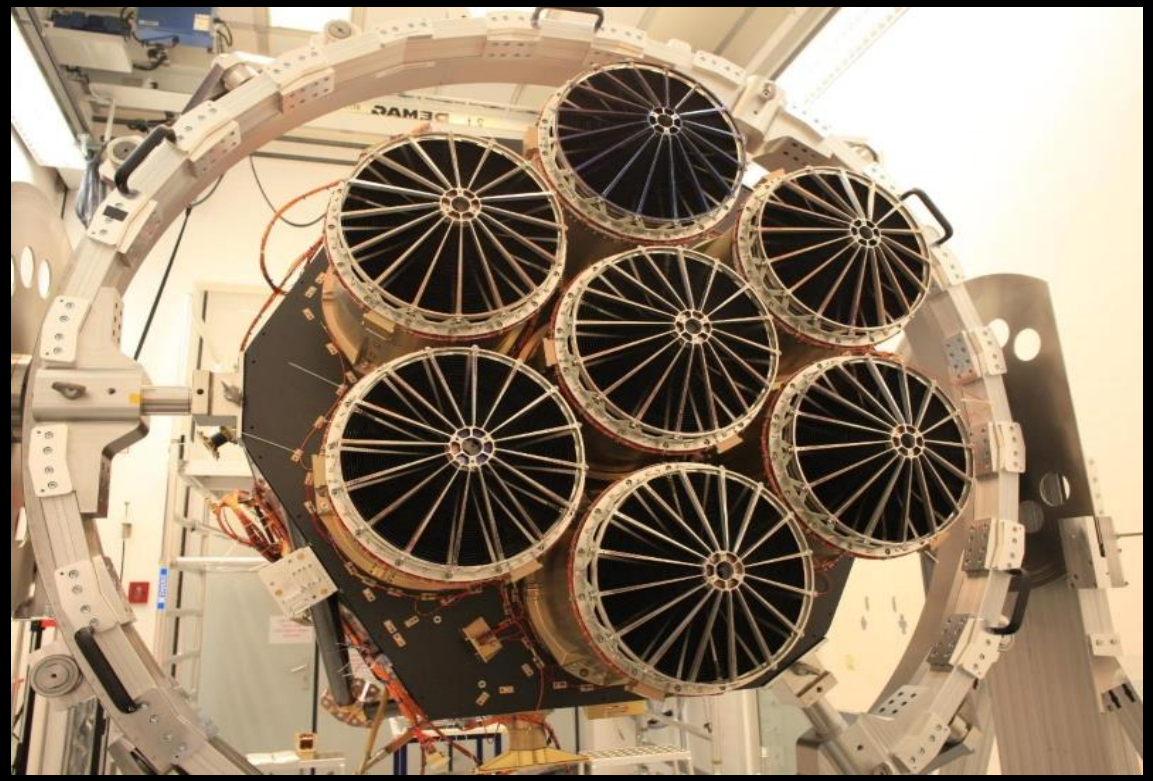
SRG Scheme

eROSITA

ART-XC

Credit: http://srg.iki.rssi.ru/

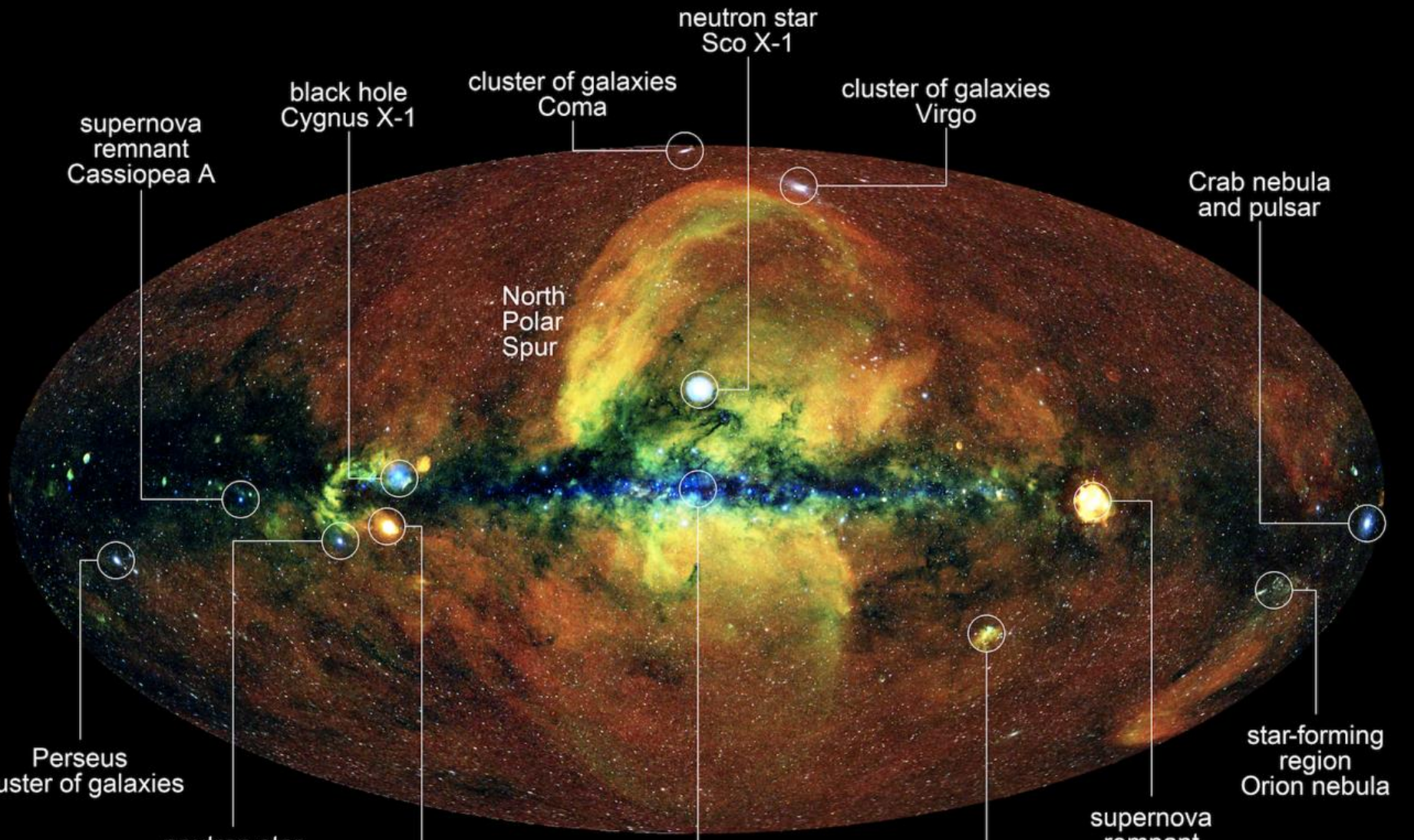
SRG Scheme



The eROSITA X-Ray Mirrors

First SRG/eROSITA all-sky survey: A million of X-ray sources and the Milky Way.

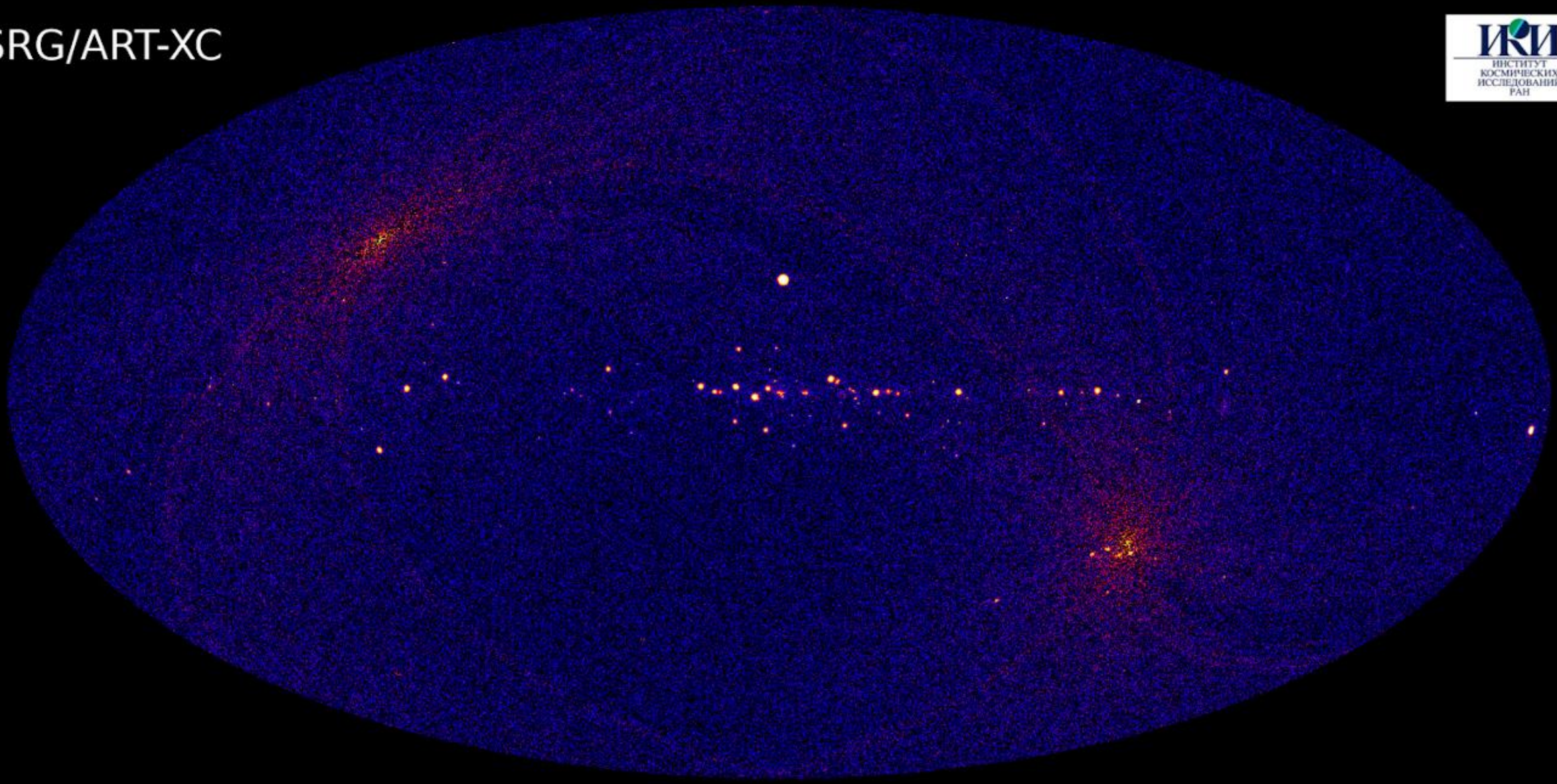
Credit: arXiv:2104.13267v2



IKI

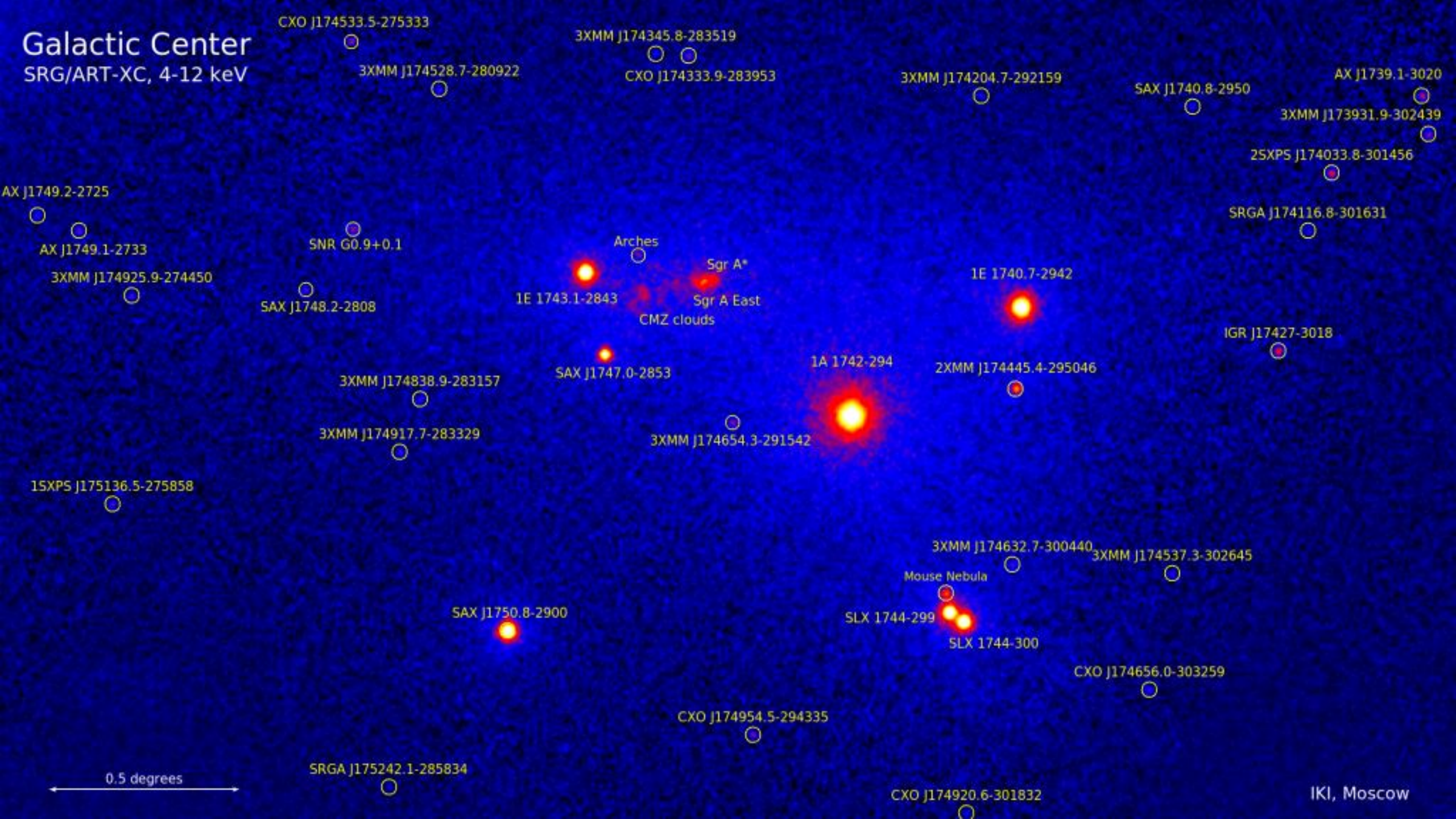
MPE

SRG/ART-XC



ИКИ
ИНСТИТУТ КОСМИЧЕСКИХ ИССЛЕДОВАНИЙ РАН

Credit: http://srg.iki.rssi.ru/


Galactic Center
SRG/ART-XC, 4-12 keV
CXO J174533.5-275333
3XMM J174345.8-283519
3XMM J174528.7-280922
CXO J174333.9-283953
3XMM J174204.7-292159
SAX J1740.8-2950
AX J1739.1-3020
3XMM J173931.9-302439
2SXPS J174033.8-301456
AX J1749.2-2725
AX J1749.1-2733
SNR G0.9+0.1
SRGA J174116.8-301631
Arches
Sgr A*
1E 1740.7-2942
3XMM J174925.9-274450
1E 1743.1-2843
Sgr A East
SAX J1748.2-2808
CMZ clouds
IGR J17427-3018
SAX J1747.0-2853
1A 1742-294
2XMM J174445.4-295046
3XMM J174838.9-283157
3XMM J174654.3-291542
3XMM J174917.7-283329
1SXPS J175136.5-275858
3XMM J174632.7-300440
3XMM J174537.3-302645
Mouse Nebula
SAX J1750.8-2900
SLX 1744-299
SLX 1744-300
CXO J174656.0-303259
CXO J174954.5-294335
SRGA J175242.1-285834
0.5 degrees
CXO J174920.6-301832
IKI, Moscow

SRG Technical performance

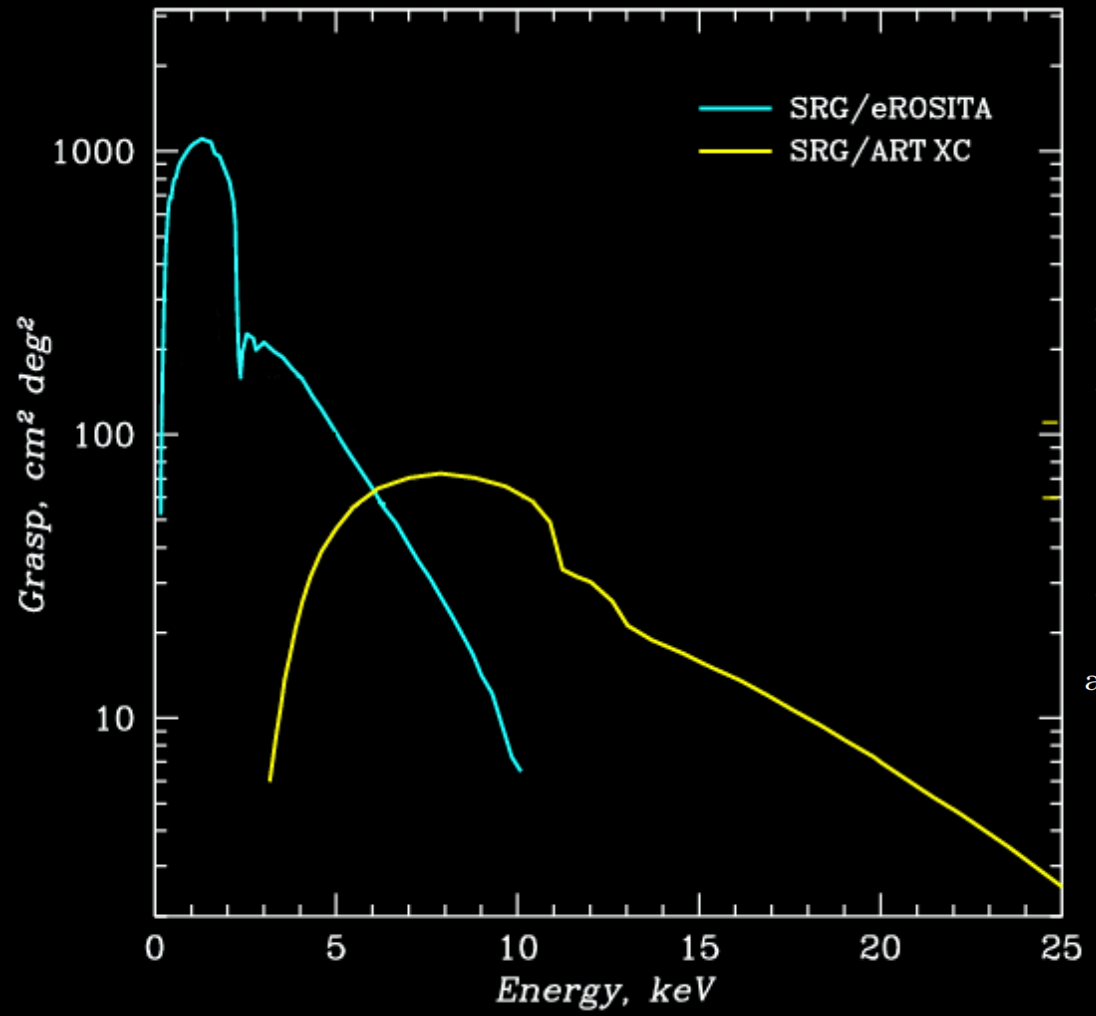
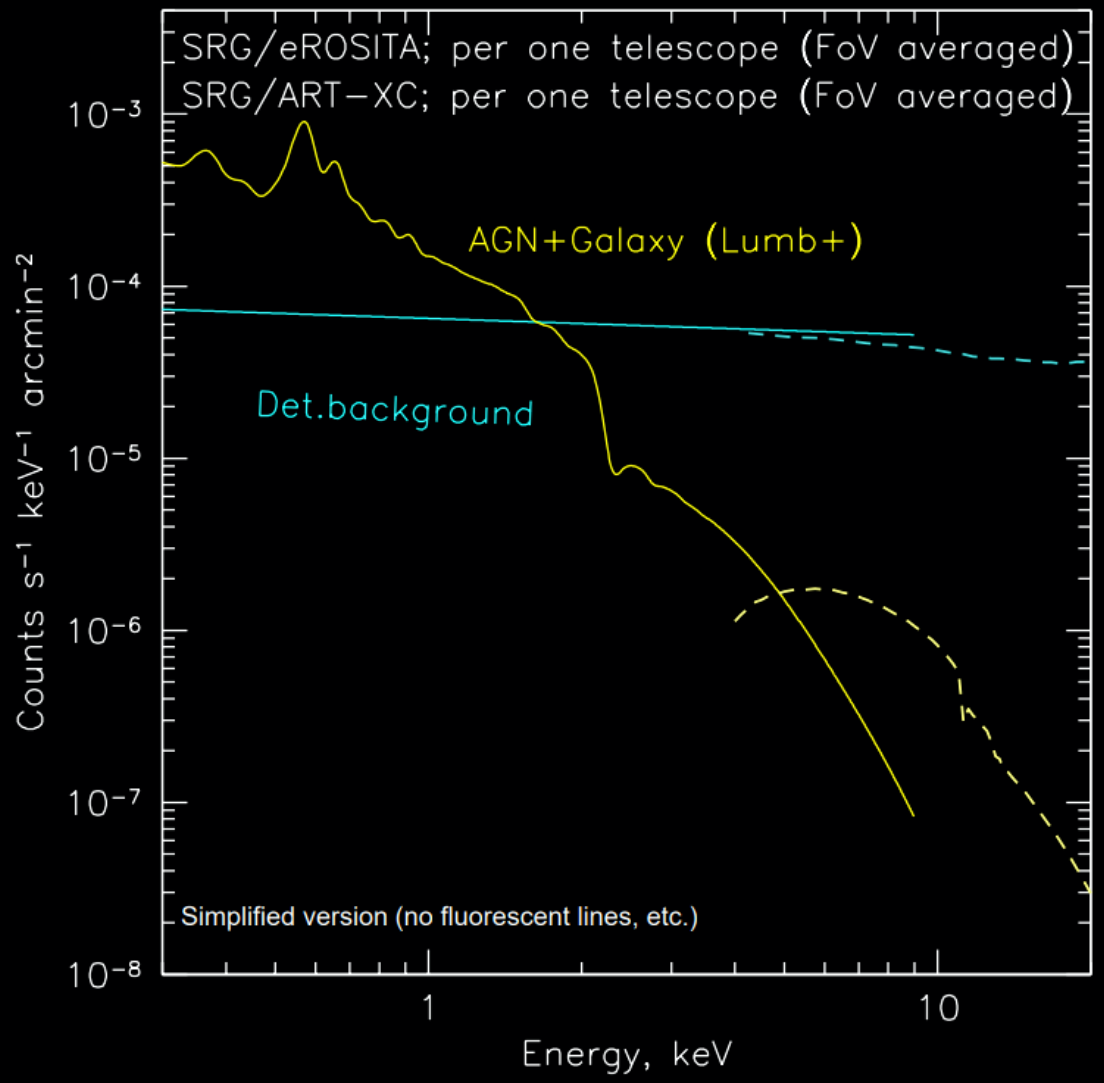


TABLE I. Telescopes technical performance.

	eROSITA	*ART-XC*
energy range [keV]	0.2 – 10	4 – 30
energy resolution, FWHM	138 eV at 6 keV	10% at 14 keV
field of view (FOV) [deg^2]	0.833	0.3 – 2.0 [a]

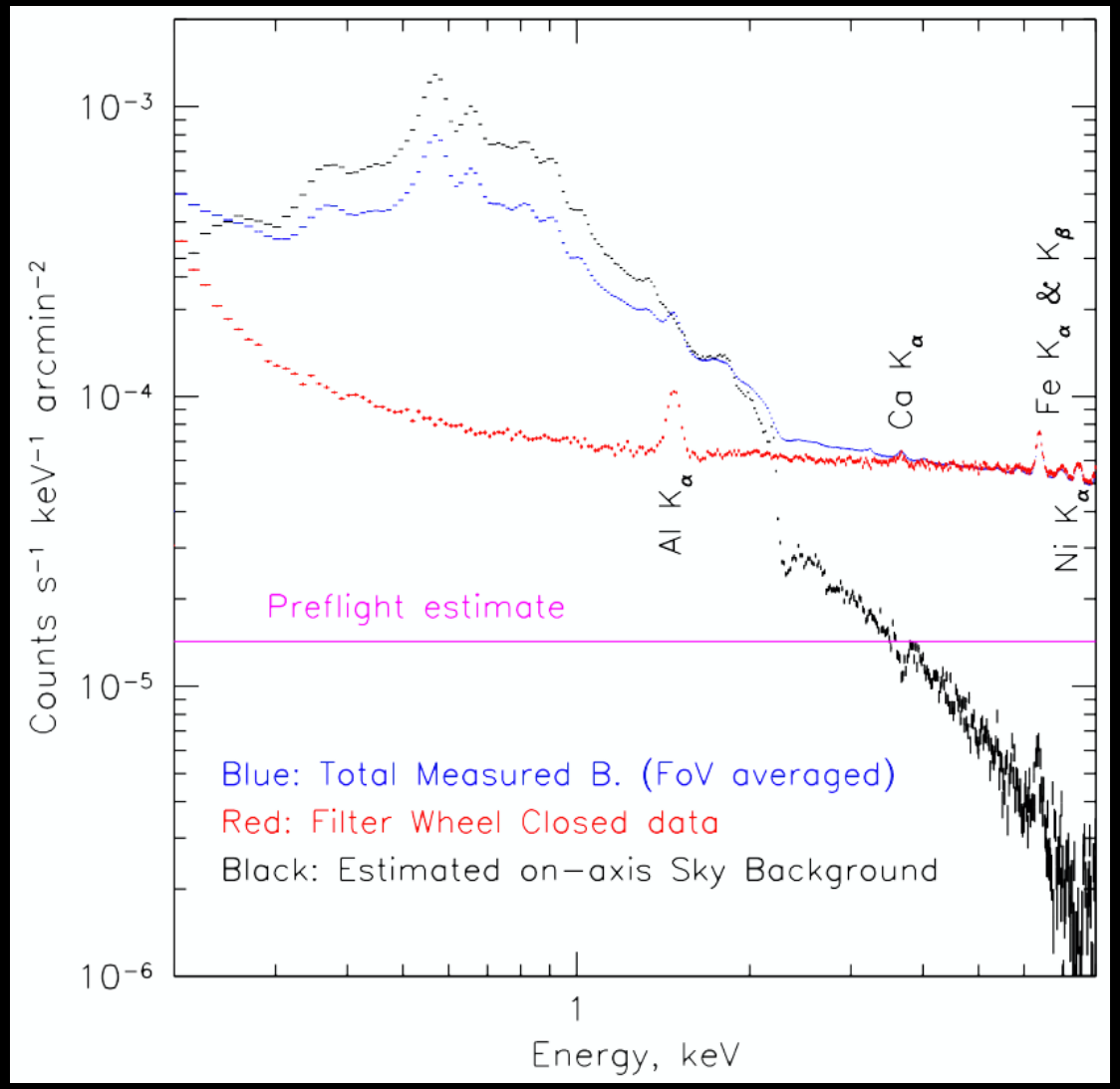
[a] FOV [deg^2]: Telescope 0.31, Concentrator 1.7, Full 2.0 [3–5].

SRG Background



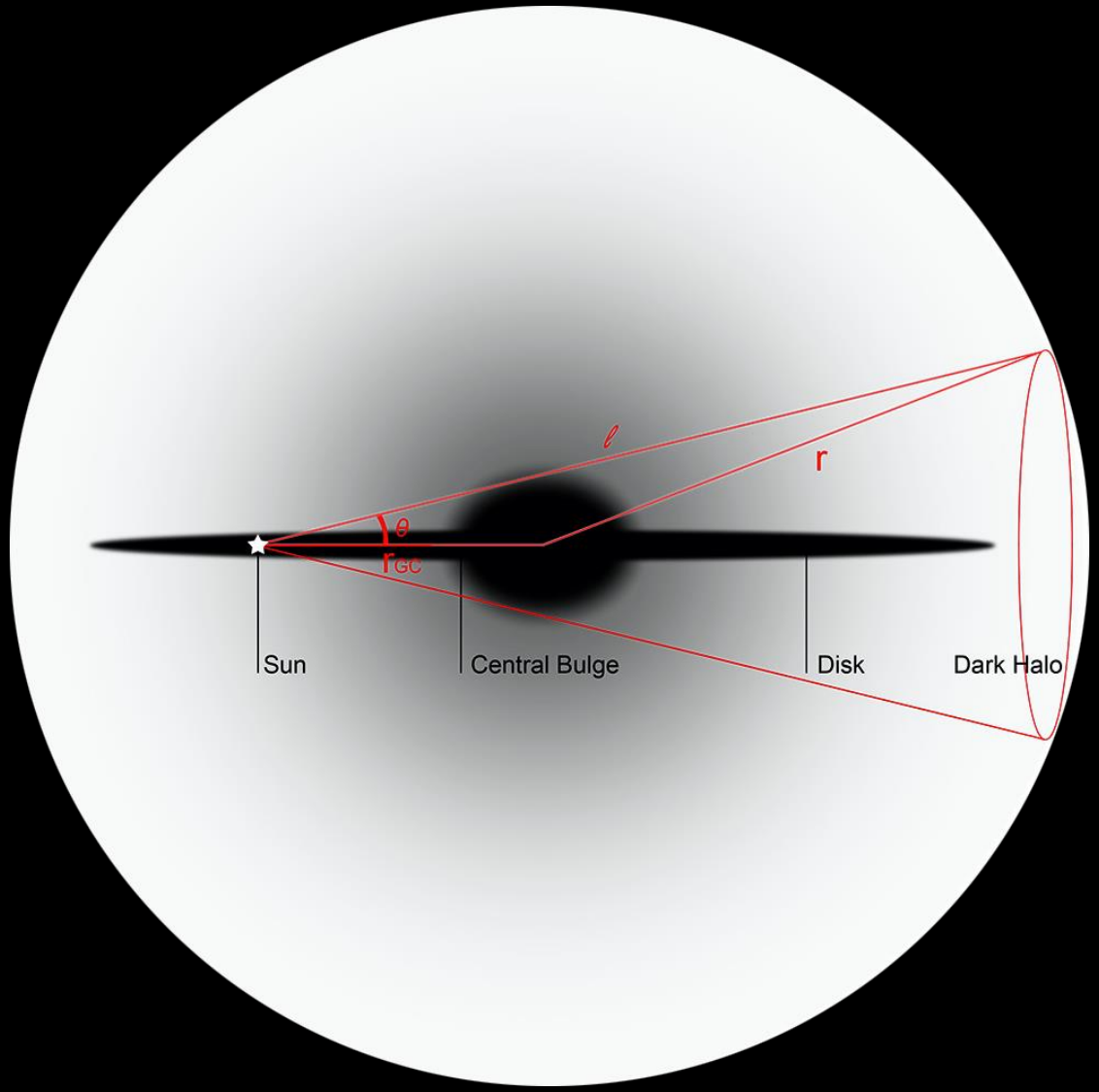
Sketch of ART-XC (dashed lines) and eROSITA (solid lines) astrophysical and internal detector backgrounds. The yellow lines show the estimated sky background using the models of Lumb et al. (2002) and Gruber et al. (1999), convolved with the telescopes' responses averaged over the FoV. The blue lines show the level of the detector internal background (fluorescent lines are not shown). For eROSITA, the astrophysical background dominates below ~ 2 keV, while at higher energies, the detector background exceeds the sky background by an order of magnitude. (arXiv:2104.13267v2)

SRG Background



Stacked eROSITA all-sky survey background spectrum (per individual telescope). The blue points are the total measured background. The red points show the background measured during filter wheel closed observations (see Fig. 12). The indicated spectral lines are of instrumental origin (see text). The black points mark the reconstructed (i.e., corrected for vignetting) on-axis photon background spectrum. The horizontal magenta line is the approximate expected particle background level estimated pre-launch (Tenzer et al. 2010). (arXiv:2010.03477)

Expected Signal



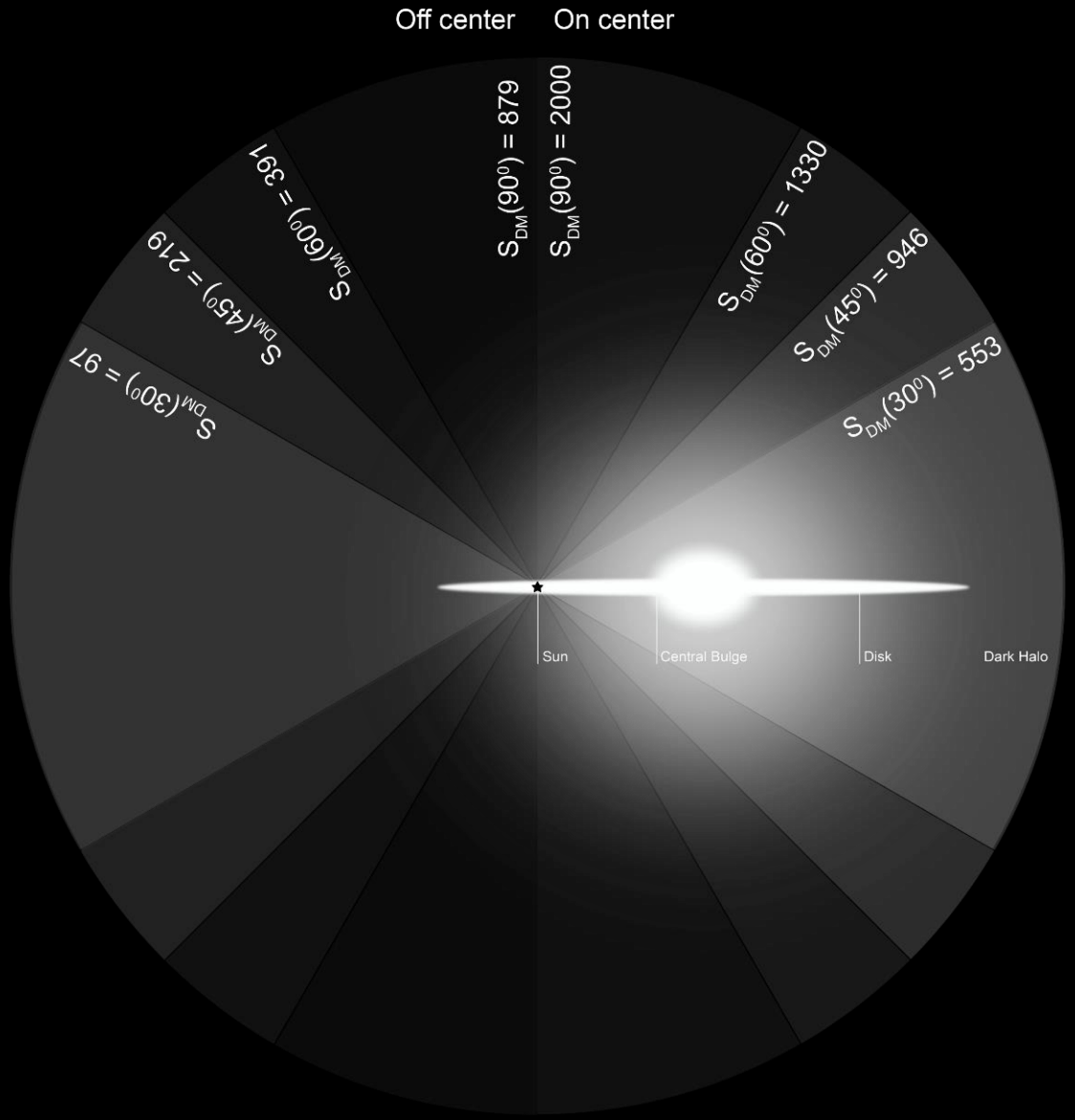
$$F_{DM} = \frac{1}{4\pi}\frac{\Gamma}{m_s}S_{DM}$$

$$S_{DM} = \int_0^{2\pi}\int_0^{\omega_r}\int_0^{\infty}\frac{\rho_{DM}(r(l,\theta))}{l^2}l^2\sin(\theta)d\psi d\phi dl$$

$$r(l,\psi) = \sqrt{R^2 + l^2 - 2Rlcos(\theta)}$$

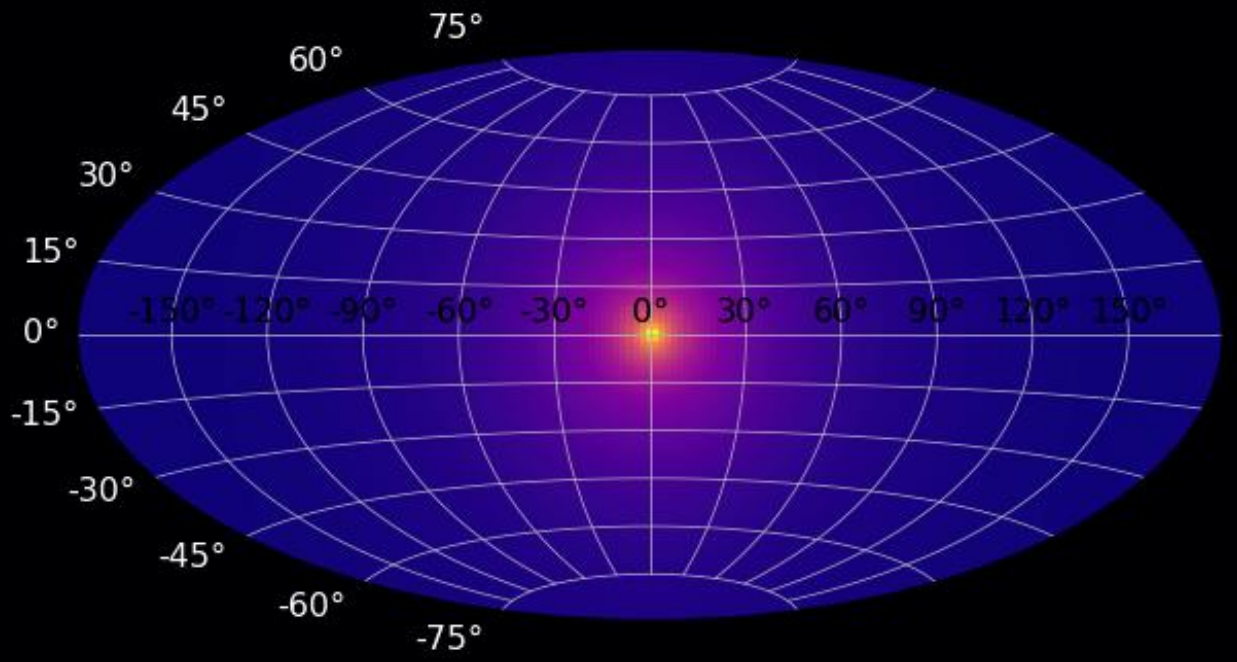
$$F_{DM} = \frac{1}{7.88\times10^{-4}}\left(\frac{S_{DM}}{M_{sun}pc^{-2}}\right)\left(\frac{2E_\gamma}{1\ keV}\right)^4\sin^2(2\theta)$$

Dark Matter Profile

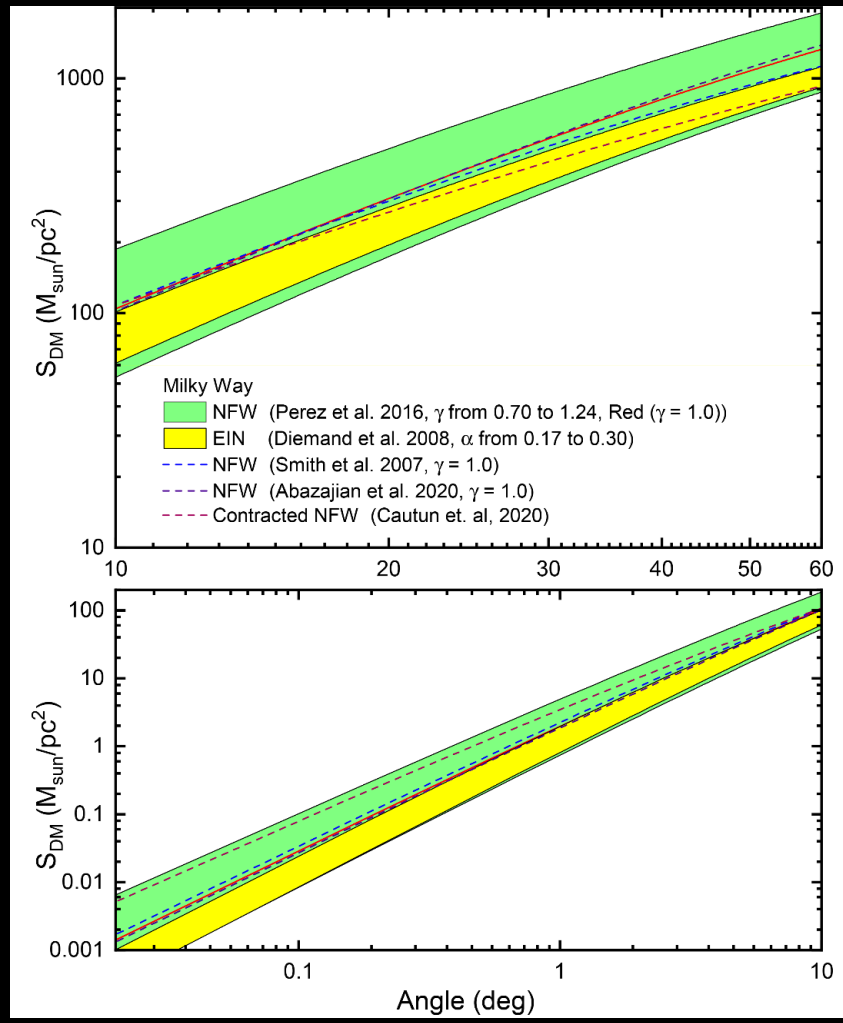


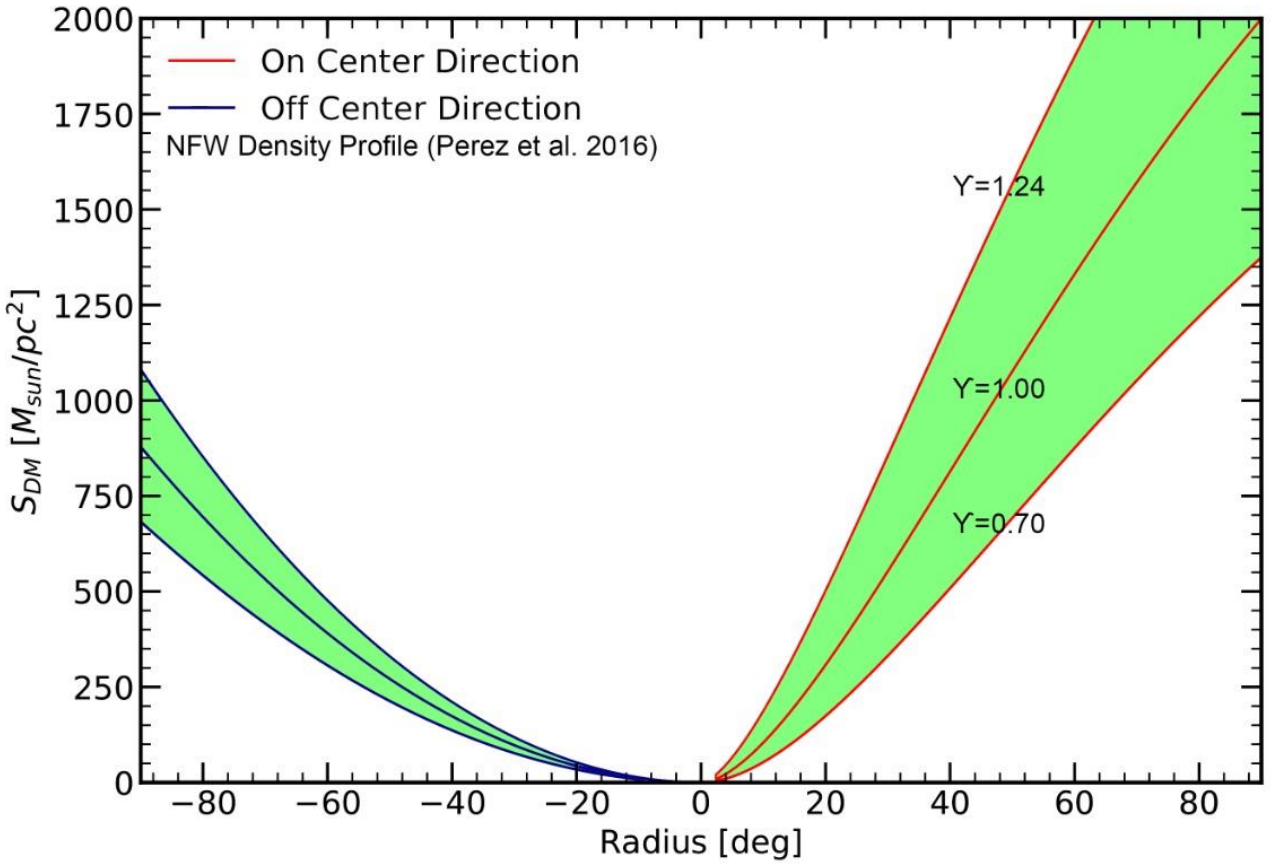
$$S_{DM} = 2\pi \int_0^{\omega_r} \int_0^{\infty} \rho_{DM}(r(l,\theta))\sin(\theta) d\psi dl$$

NFW profile: $\rho_{DM}(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$



Uncertainties of Profiles

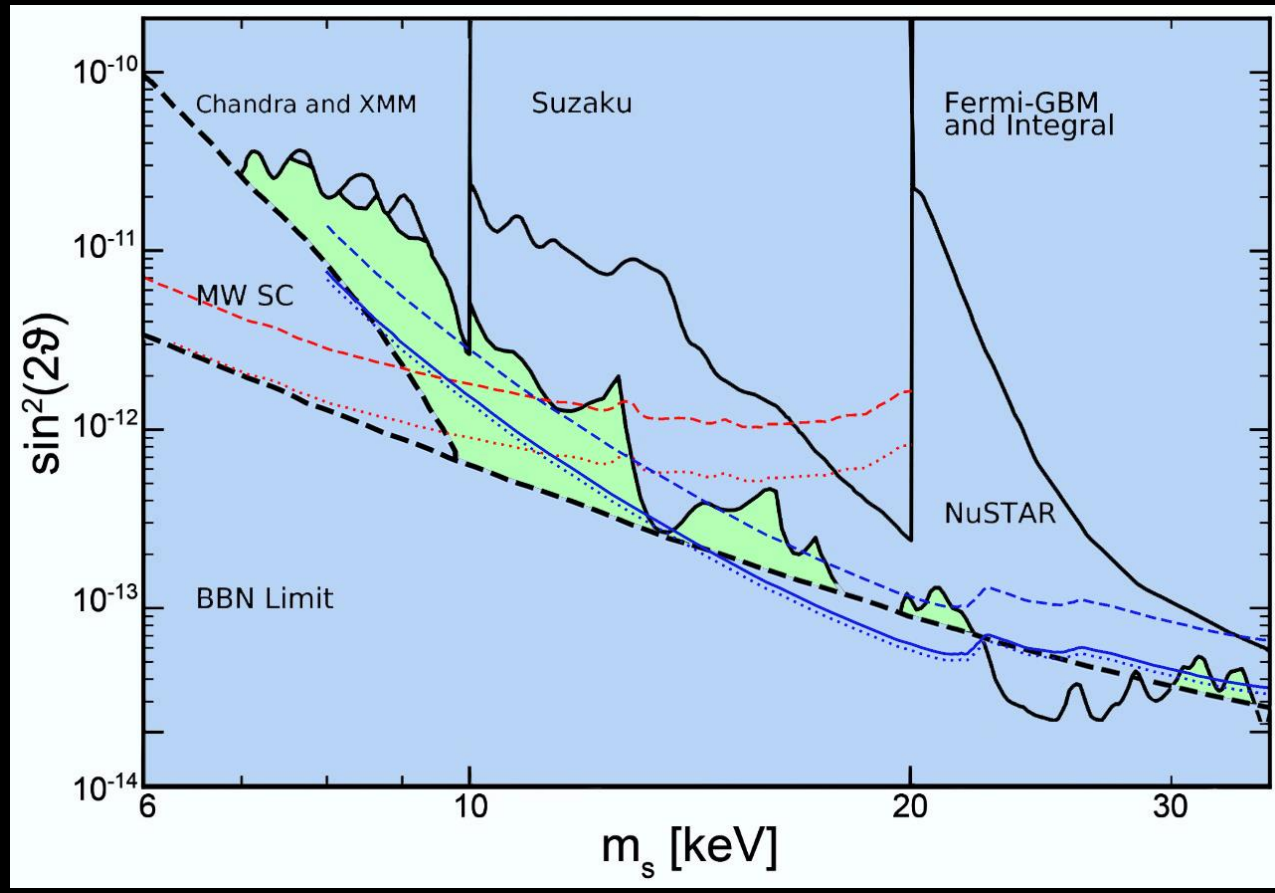




Expected SRG Constraints

$$\frac{F_{DM}\left(\frac{G(E)}{\Omega}\right)T_{obs}}{\sqrt{F_{DM}\left(\frac{G(E)}{\Omega}\right)T_{obs} + C_{BG}T_{obs}}} = \sigma, d.o.f. = 1$$

The expected limits on the sterile neutrino model parameter space to be obtained (assuming no signal) with already collected data towards the GC (solid line) and with data to be collected after 1-year (dashed line) and 4-year (dotted line) operation in the all-sky survey mode and used to analyze the signal from 60◦ -region around the GC. Red (blue) lines refer to eROSITA (ART-XC) instruments; black solid and dashed lines indicate existing constraints.



Summary and Outlooks

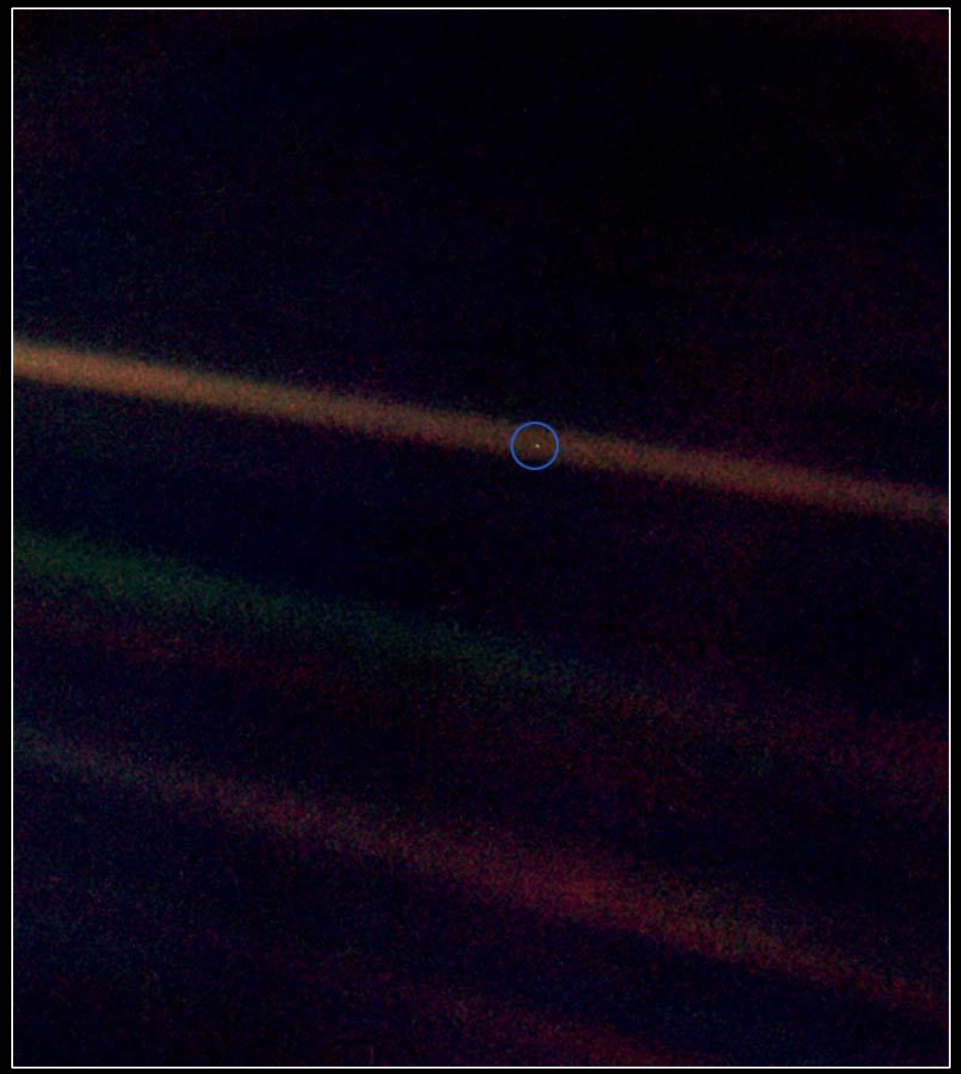
- The SRG telescope has a high potential for testing the hypothesis of the presence of decaying dark matter. During this mission, it becomes possible to further limit the allowed range of parameters.

- The distribution of dark matter in a galaxies has significant uncertainties, which requires refinement of the parameters of the distribution of dark matter.

- As part of the SRG mission, it becomes possible to conduct a joint correlation analysis of galaxies, galaxy clusters, and traces of the decay of dark matter in the analysis of the large-scale structure of the Universe.

- The cosmic X-ray background detected by the SRG observatory is very stable. Covering the entire sky will allow us to study not only the dependence of the background on energy, but also on direction.

- We are currently developing our analysis for new observations and data.



Pale Blue Dot: Earth is a bright pixel when photographed from Voyager 1, 6 billion kilometers (3.7 billion miles) away.

“The Cosmos is all that is or was or ever will be. Our feeblest contemplations of the Cosmos stir us - there is a tingling in the spine, a catch in the voice, a faint sensation, as if a distant memory, of falling from a height. We know we are approaching the greatest of mysteries.”
— Carl Sagan, Cosmos

Thank you for your attention!