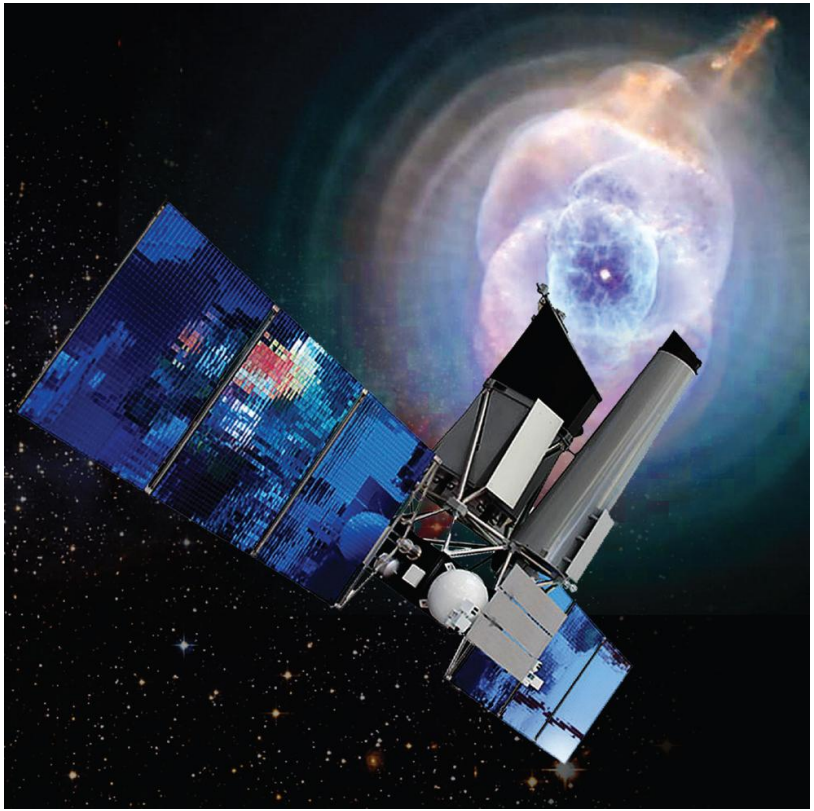
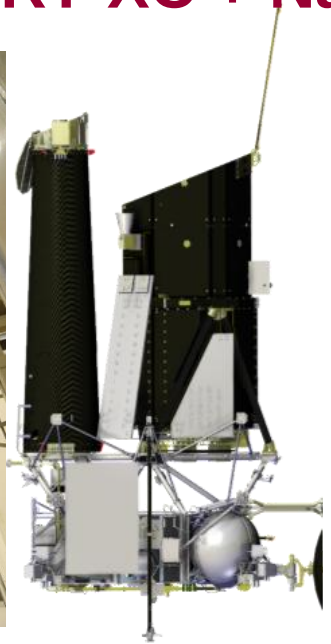
Телескоп СРГ/ART-XC: пять лет на орбите

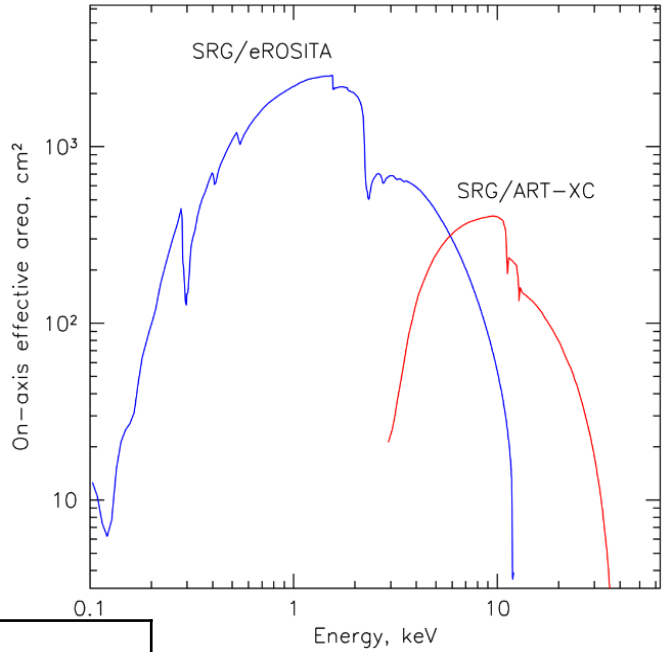
Александр Лутовинов
ART-XC Team
(ИКИ РАН, РФЯЦ-ВНИИЭФ, MSFC)



ФТИ им. А.Ф.Иоффе, 19.11.2024

СРГ (eRosita + ART-XC + Navigator)





	Energy Band	FoV	Angular resolution	Area
eRosita	0.3-10 keV	1°	15”	2400 cm^2 @ 1 keV
ART-XC	4-30 keV	36’	45”	~400 cm^2 @ 8 keV

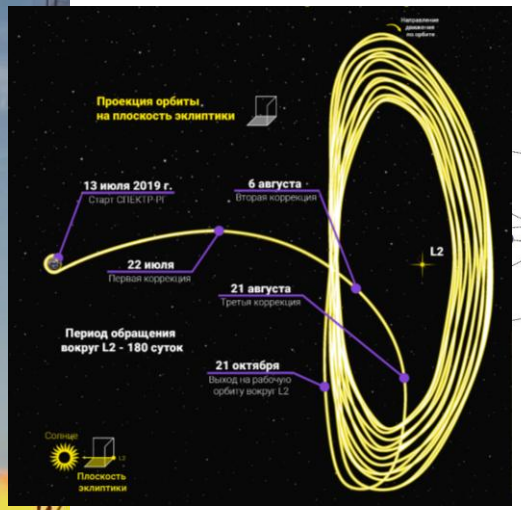
Key property:

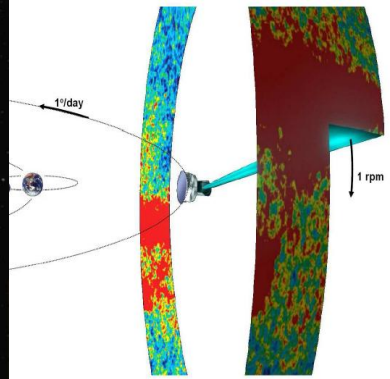
Large area x Large FoV

Observational Program

Combination of the large FoV and effective area
=>
probing record volume of the Universe

All-sky Survey – 4 years
+2.5 years of pointed observations





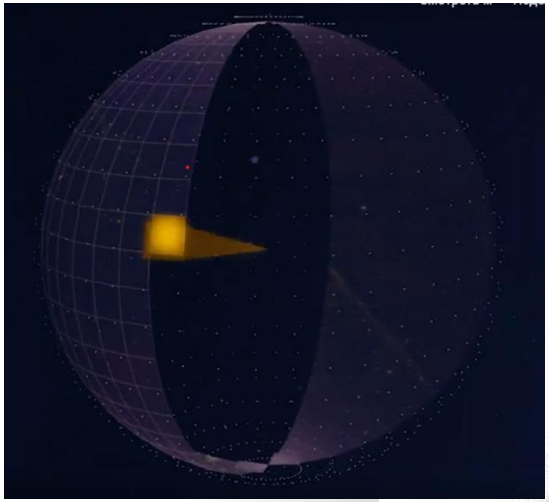
Proton-M Buster DM-3

ART-XC:
Hard X-ray survey, catalog, heavily absorbed AGNs, galactic sources, transients

eRosita
(see M.Gilfanov talk)

Period 4 hours
Full sky in 6 months,
8 surveys in 4 years

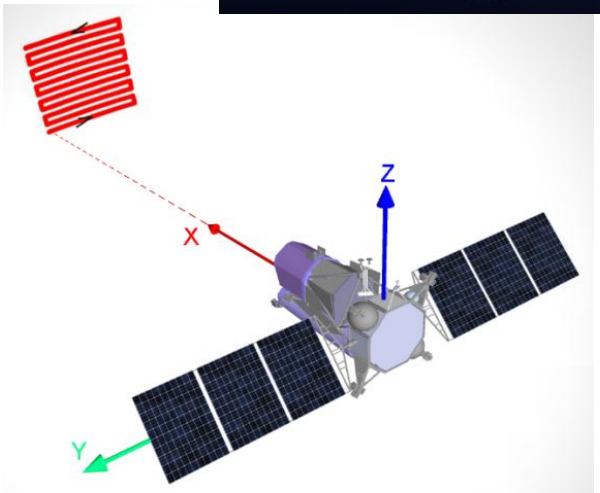
SRG (modes of observations)

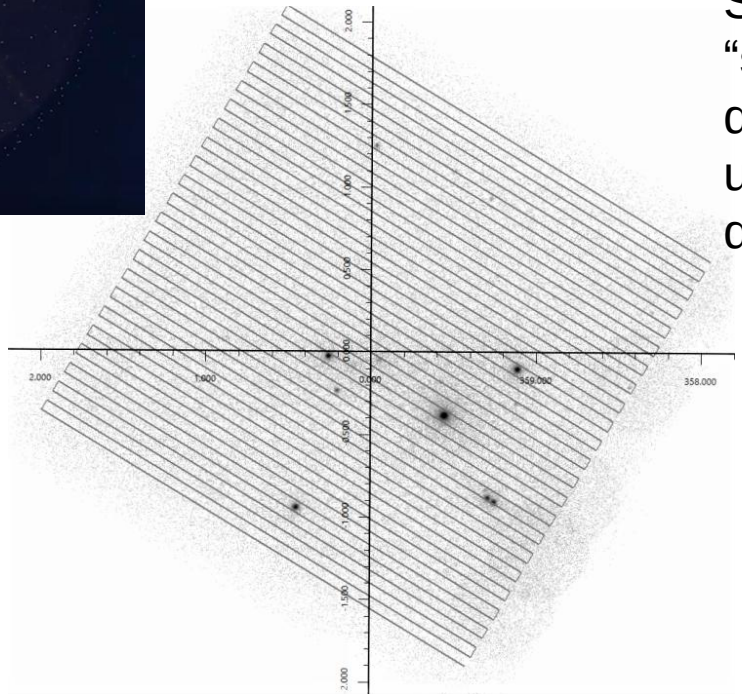


Survey mode

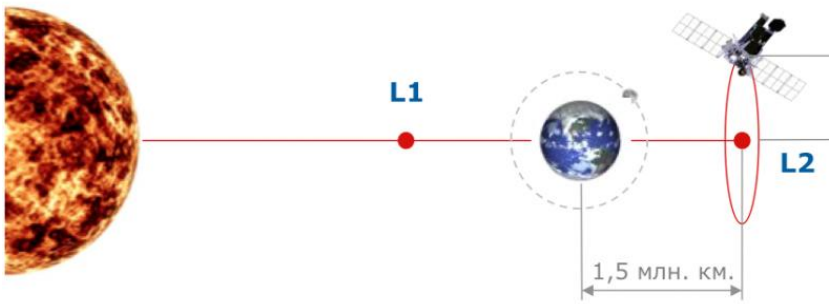
Pointing observations

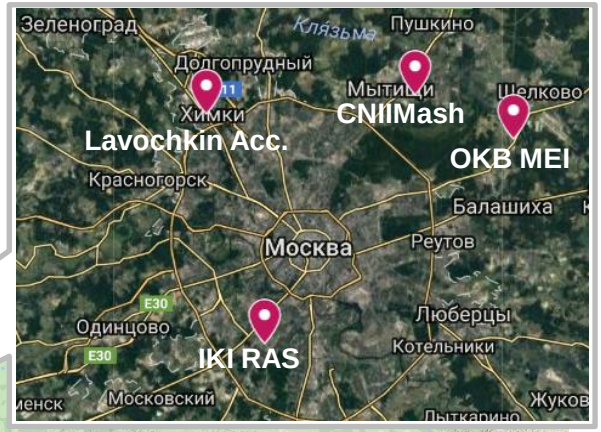
Scanning mode:
“snake scan”
different templates
up to 12x12 deg per
day

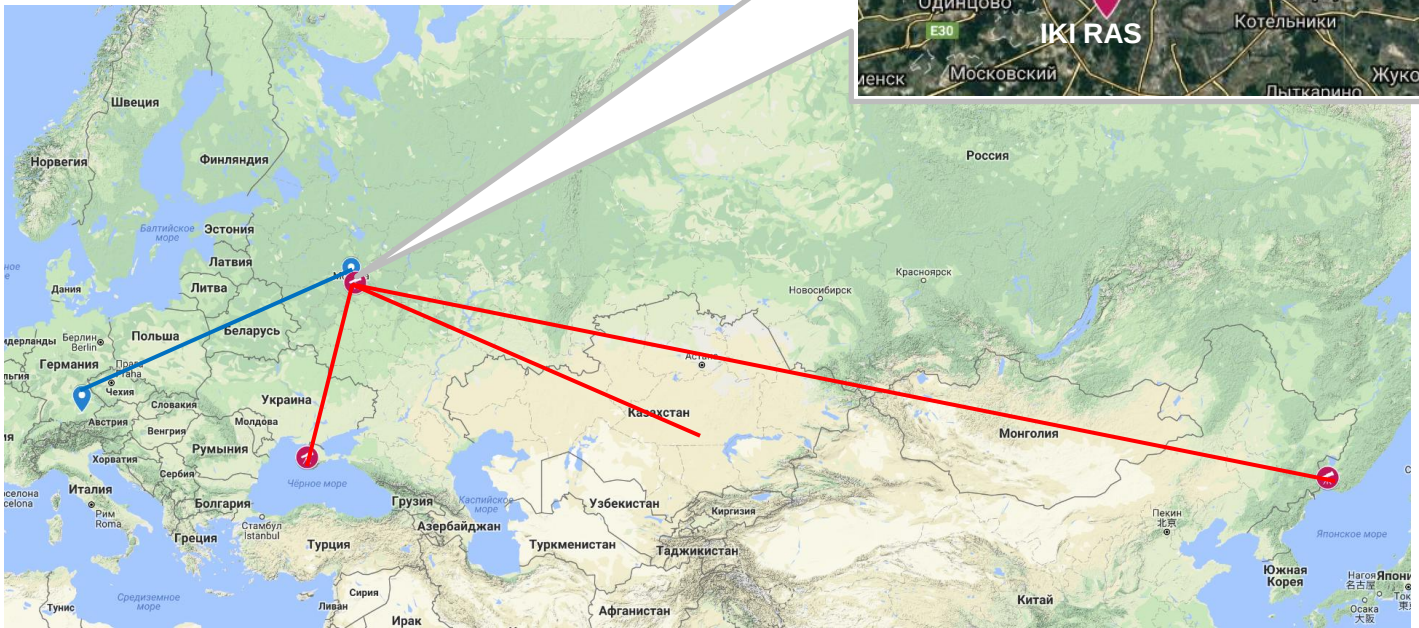




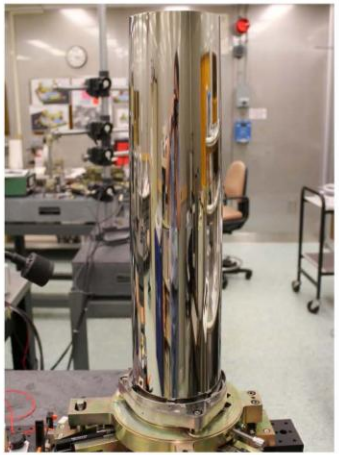
Орбита и наземный сегмент

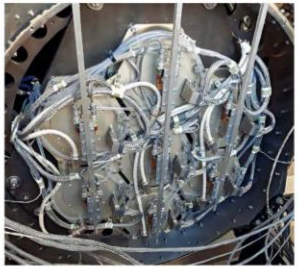


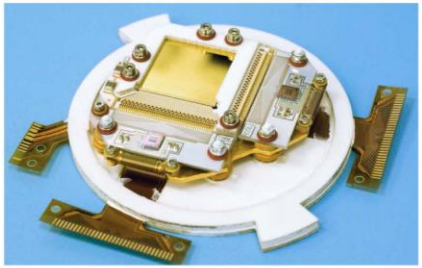


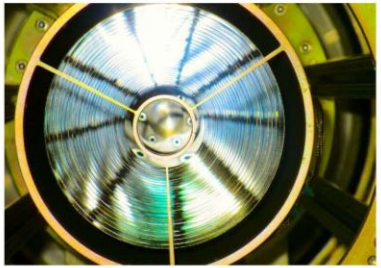


The *Mikhail Pavlinsky* ART-XC telescope









7 modules
(MS+Det)

28 mirror shells

2.7 m focal length

CdTe detectors

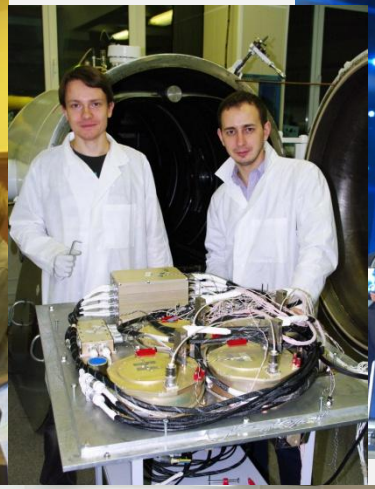
Energy range
4-120 keV

Timing resolution
23 microsec

Pavlinsky et al. 2022

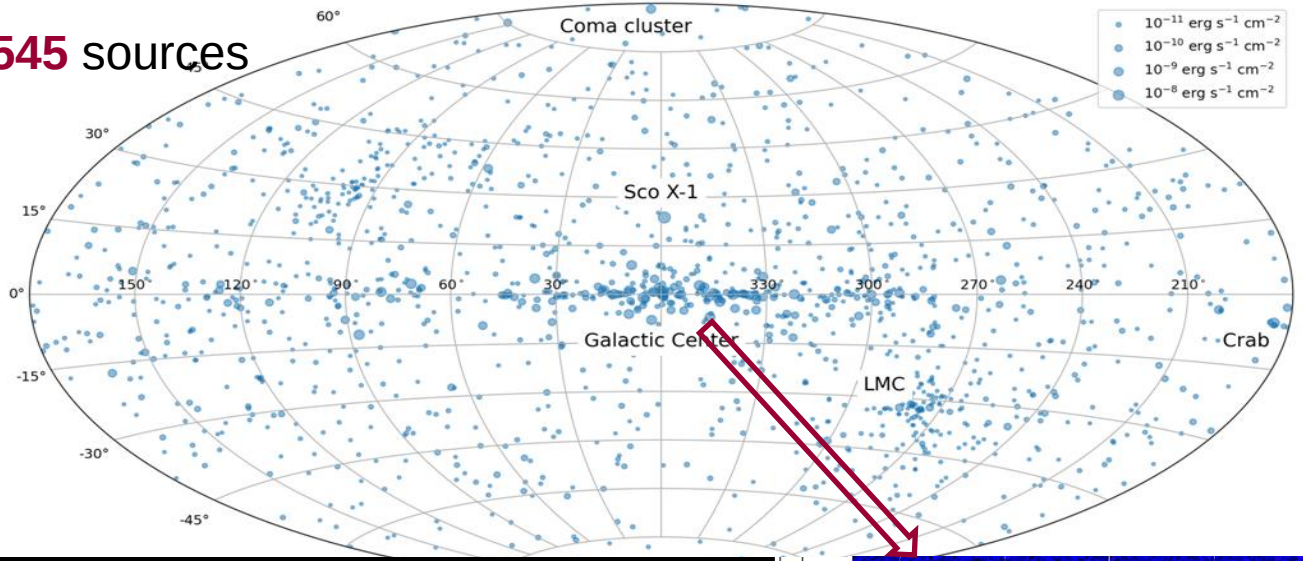
Команда телескопа ART-XC им. М.Н.Павлинского

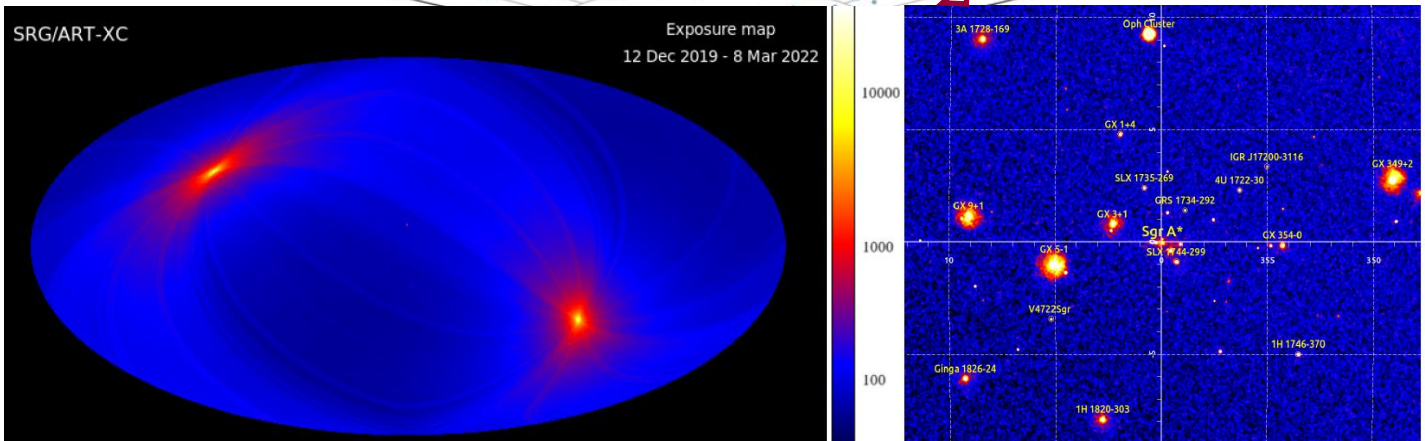
Первый свет ART-XC (30.07.2019)



Two (+0.4) years all sky survey with ART-XC (ARTSS1-5)

1545 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

Sazonov et al. (2024)

Optical identification of ART-XC sources (CV)

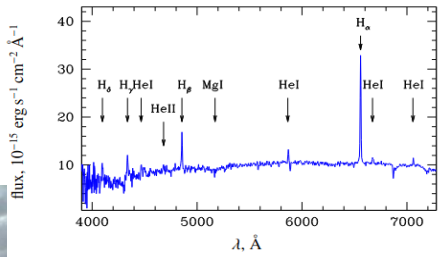
RTT150

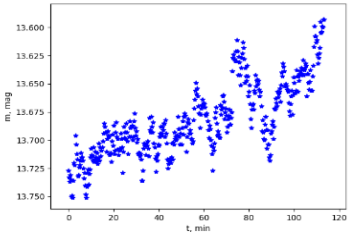
AZT-33IK

CMO SAI MSU

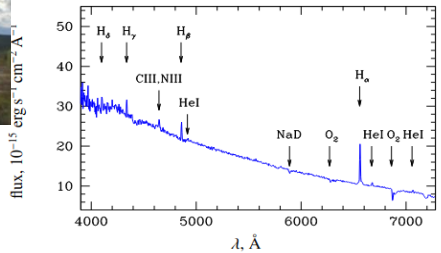
BTA SAO

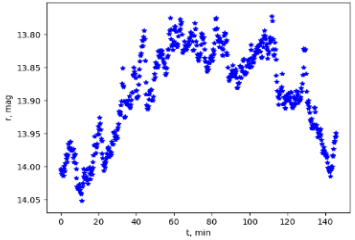
SRGA J194638.9+704552



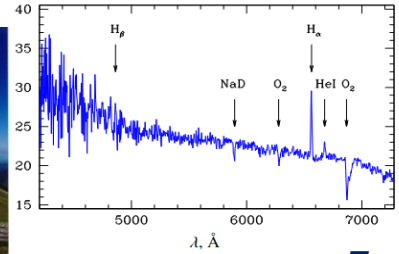


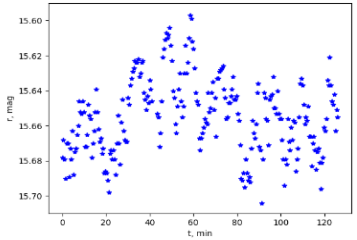
SRGA J204547.8+672642

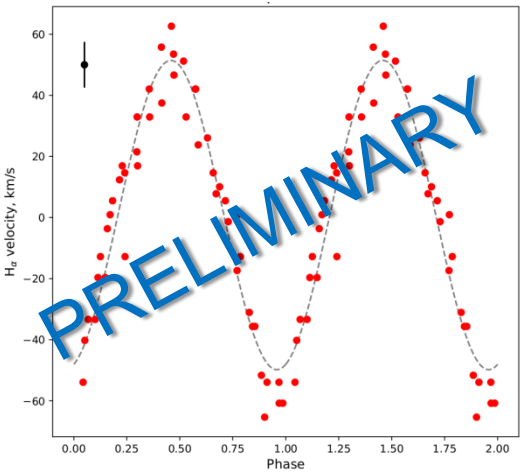




SRGA J225412.8+690658

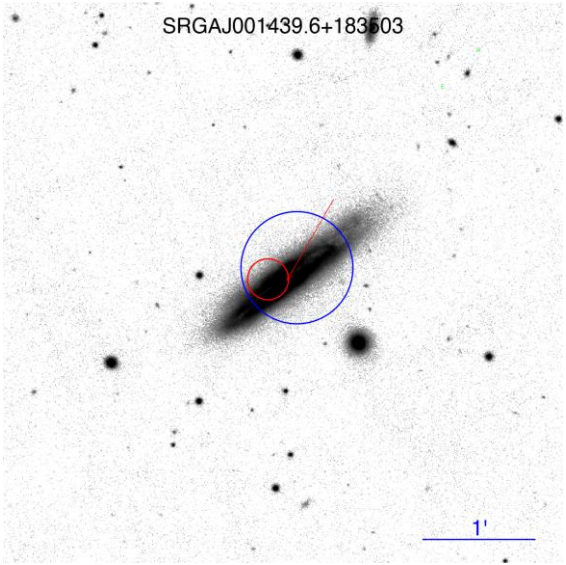


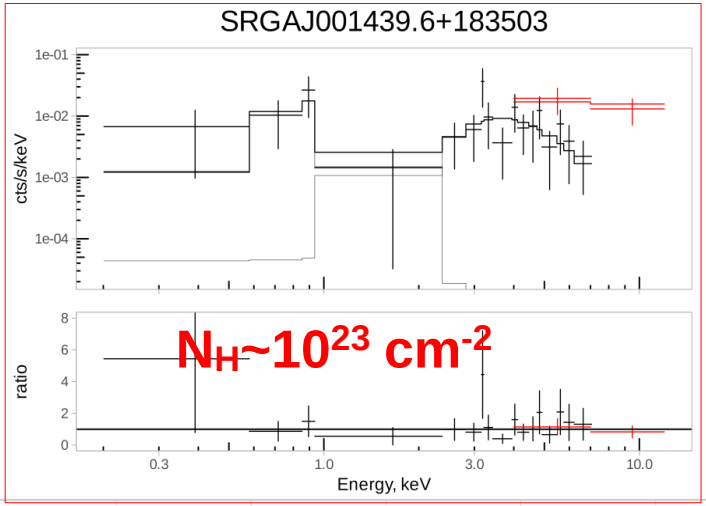




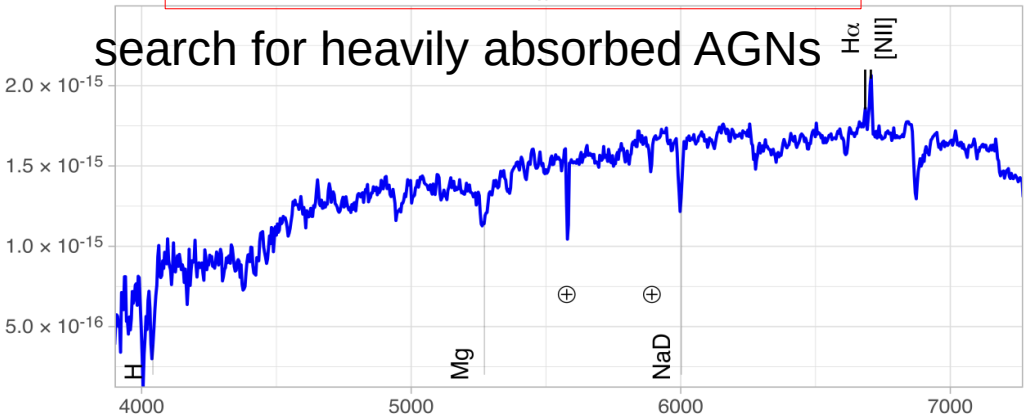
Zaznobin et al. 2022

Optical identification of ART-XC sources (AGNs)





search for heavily absorbed AGNs

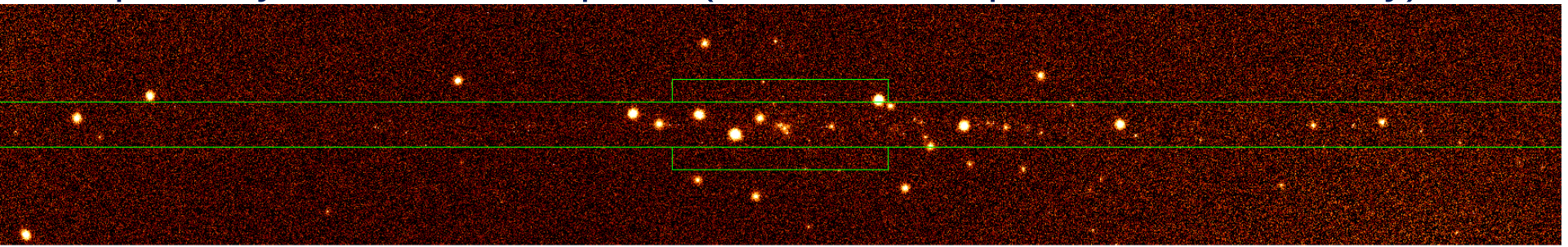


AZT-33IK

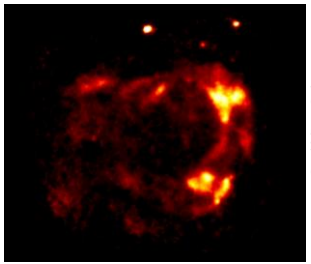
Uskov et al. 2023

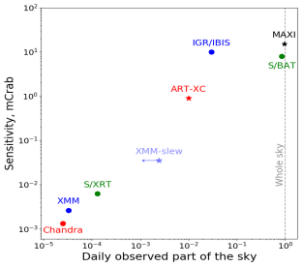
SRG/ART-XC Observational Program

Deep survey of the Galactic plane (~15 times deeper than in the survey)



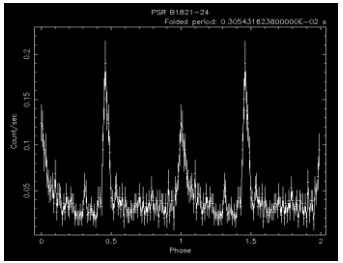
Most interesting sky regions and objects revealed by ART-XC (Legacy Survey of the ART-XC Objects)





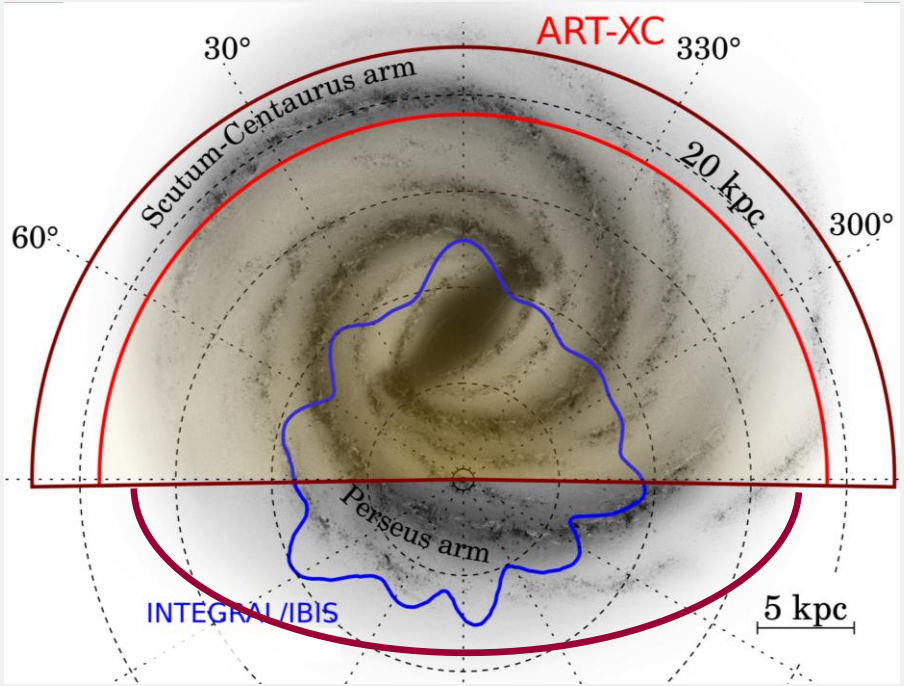
Transient sources

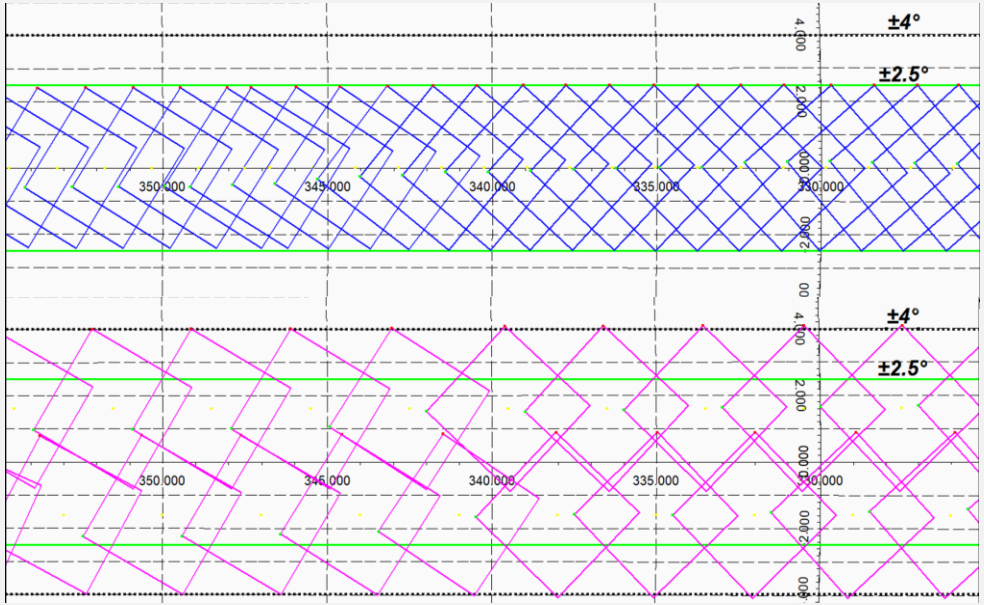
Joint observations (large program with IXPE, NuSTAR, ground based telescopes)



Millisecond pulsars

Deep survey of the Galactic plane





A.Tkachenko, NPOL

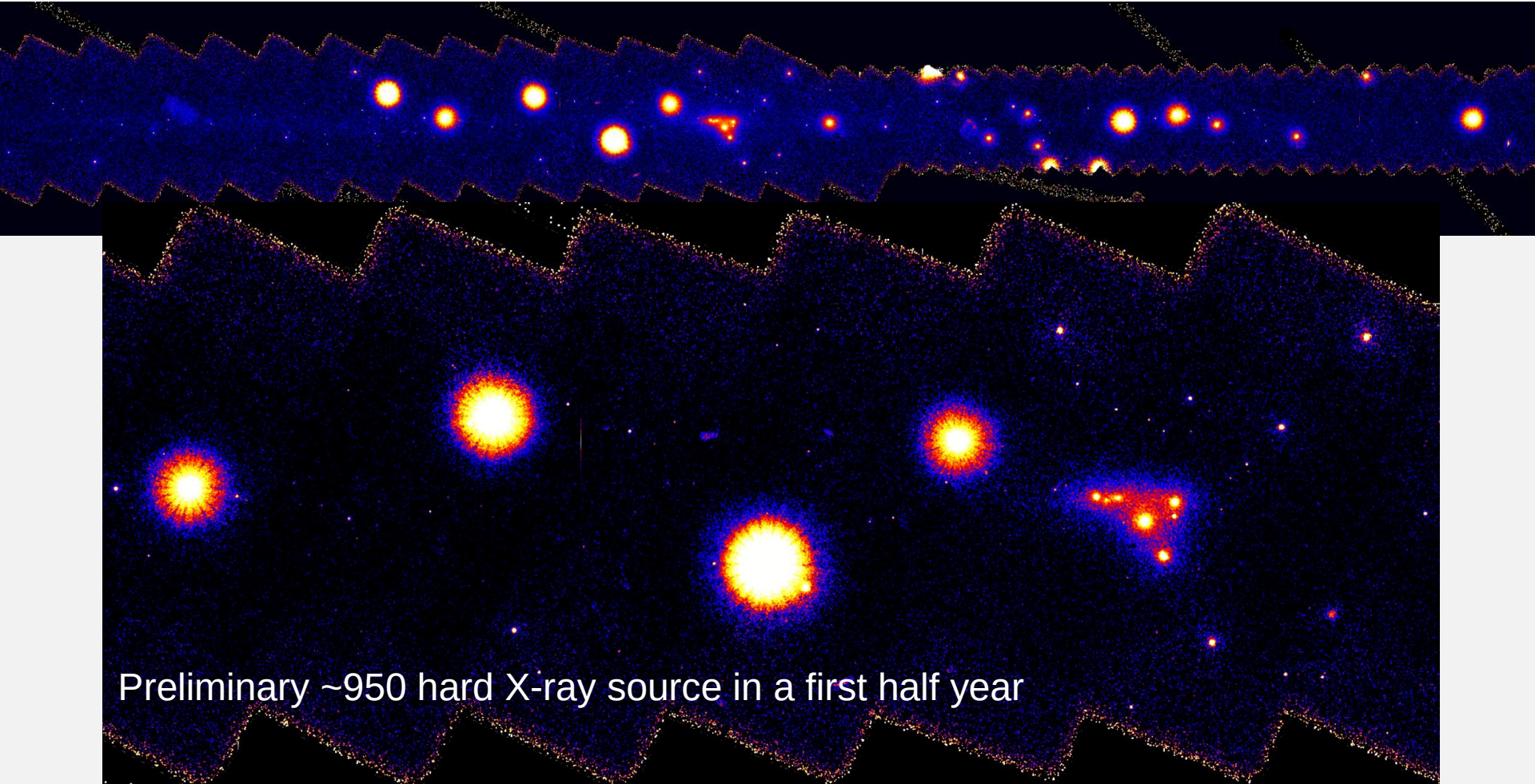
Median luminosity 3×10^{34} erg/s at 20 kpc

Inside b+/- 1 deg down to ~10^{34} erg/s

We scanned the Galaxy **from March 2022 till October 2023** with some interruptions in two ways: 1) along b=0; 2) along b=+/-1.6

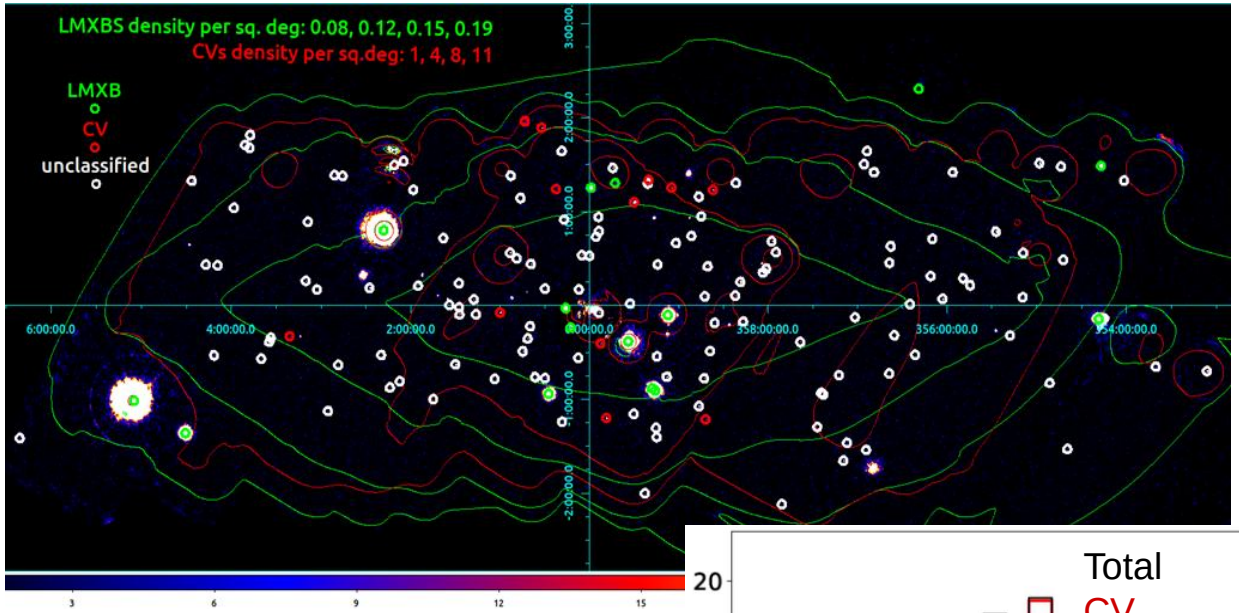
Add ~15% mass of the Galaxy

Deep survey of the Galactic plane

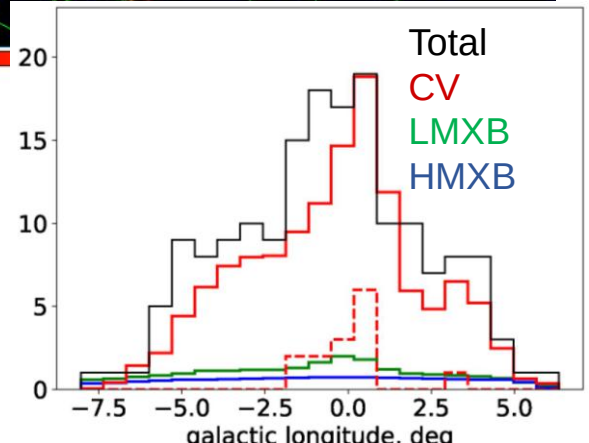


Galactic Bulge survey with ART-XC

Population study of weak galactic sources



Central zone of our Galaxy, sources in the Galactic bulge can have a luminosity not exceeding 5×10^{33} erg/sec



~60 sq.deg

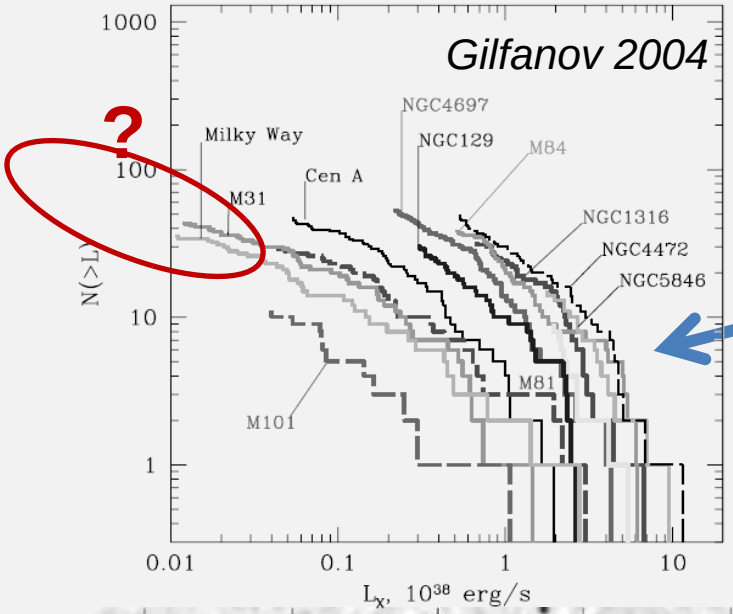
172 sources:
43 of known nature

LMXB	18
CV	14
HMXB	8
CWB	1
AGN	2

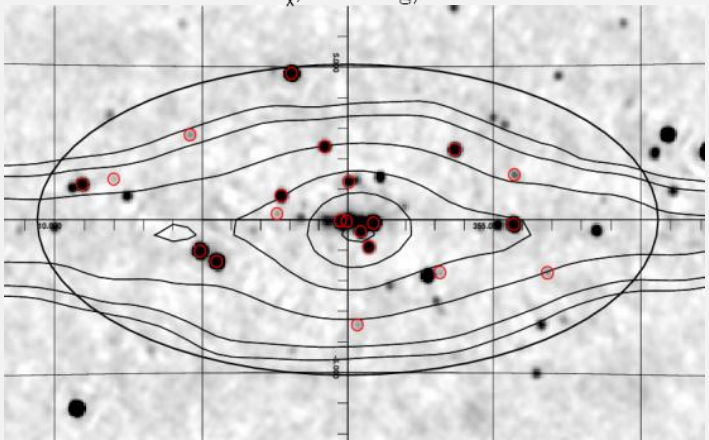
89 from other catalogues (XMM-Newton,Chandra, Swift)
50 new ones (5 at > 7 keV)

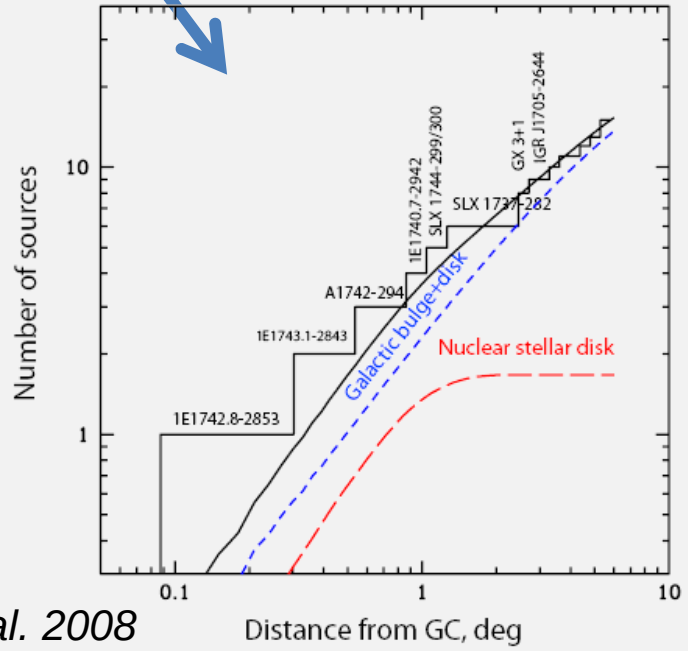
Semena et al. 2024a,b

LMXBs in galaxies



LF normalization
«follow»
stellar mass

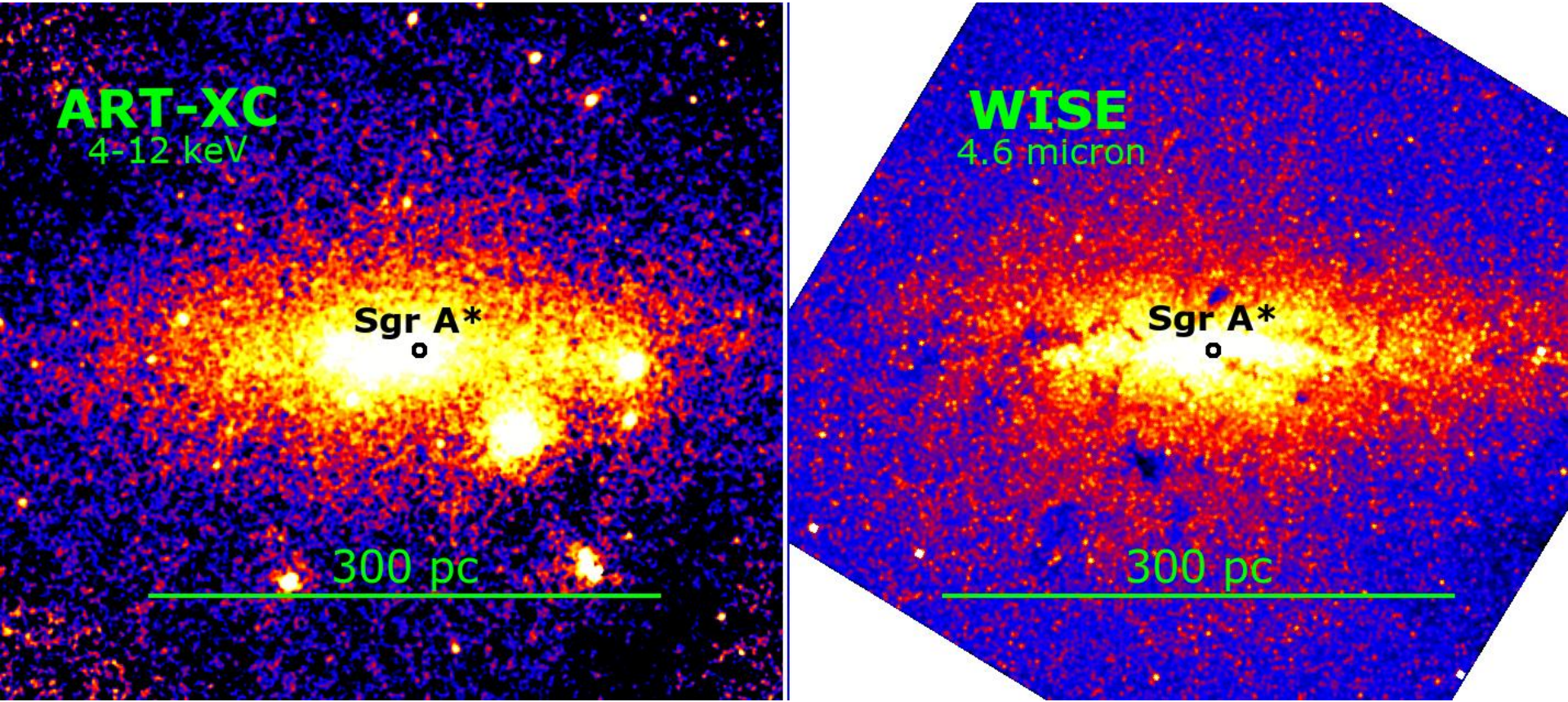




Revnivtsev et al. 2008

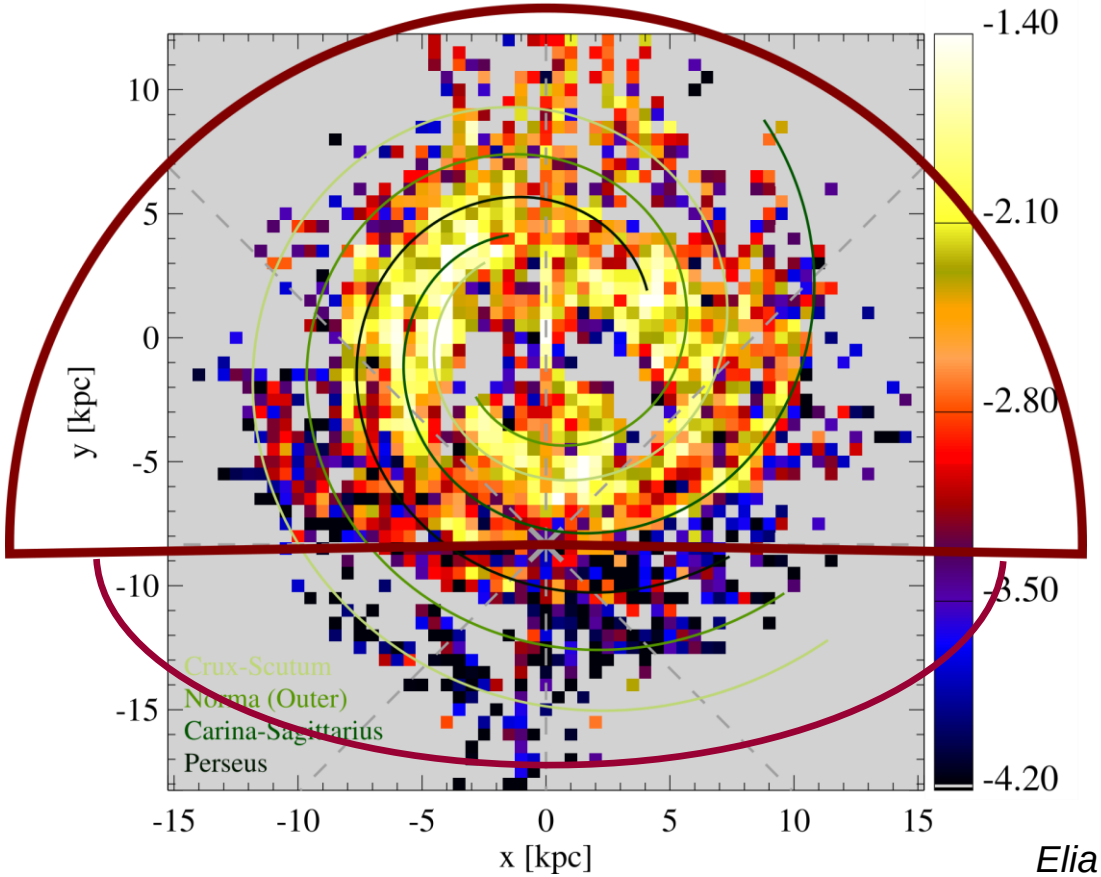
Nuclear Stellar Disk

First wide-field X-ray image of NSD



Credit: Krivonos&Nezabudkin

Not only reaching out to outers parts of disk

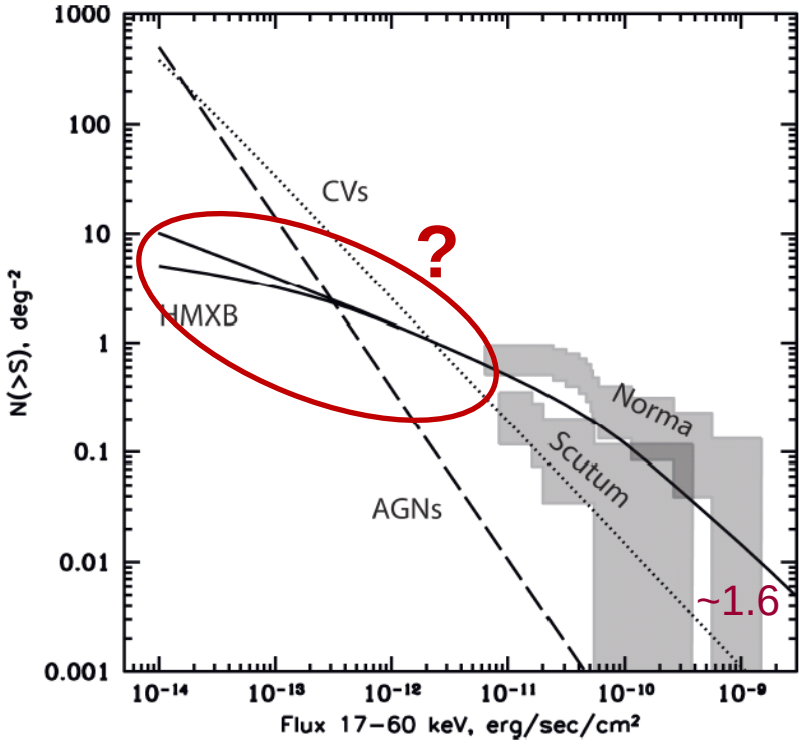


BUT
Also covering major part of Galactic SF

Elia et al 2022

Luminosity function of high mass X-ray binary systems

LF follows the SFR. How many such systems in the Galaxy?



Lutovinov et al. 2013

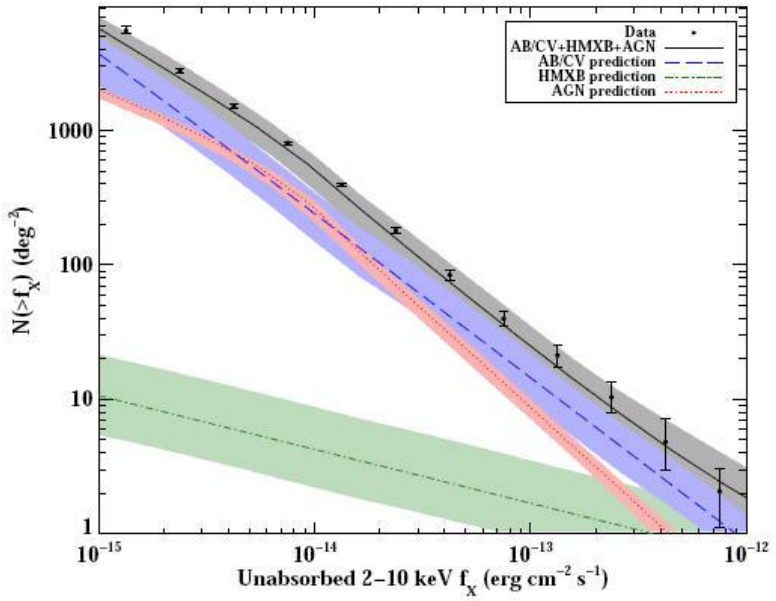
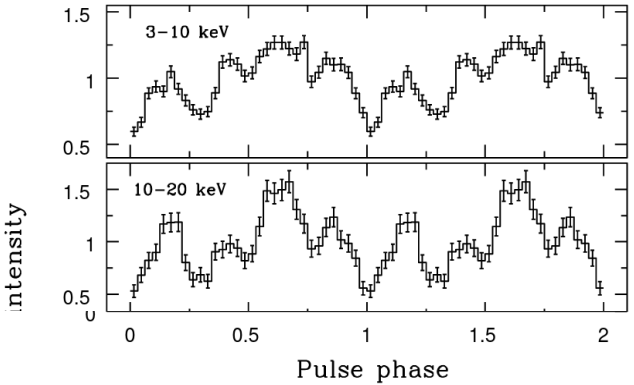
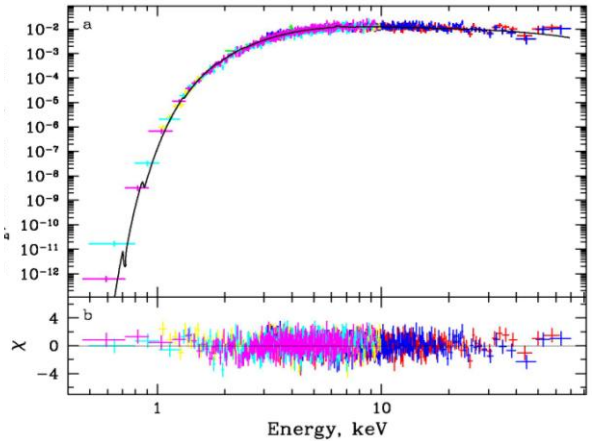


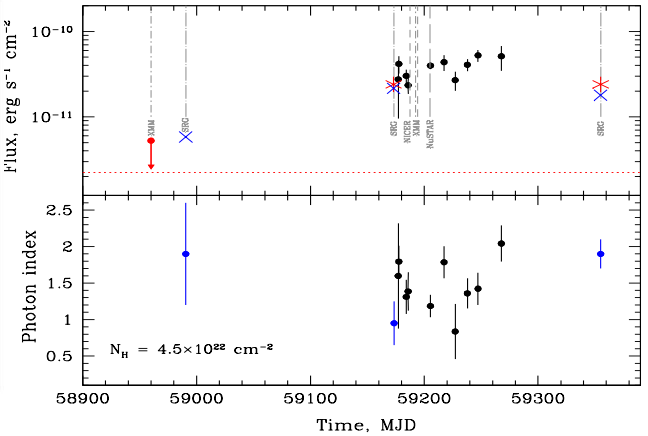
Figure 19. The observed number-flux distribution compared to the combined estimates of the expected AB/CV, HMXB, and AGN flux distributions based on the luminosity functions of these populations from other surveys. Estimated uncertainties for the predictions are shown as shaded regions. The

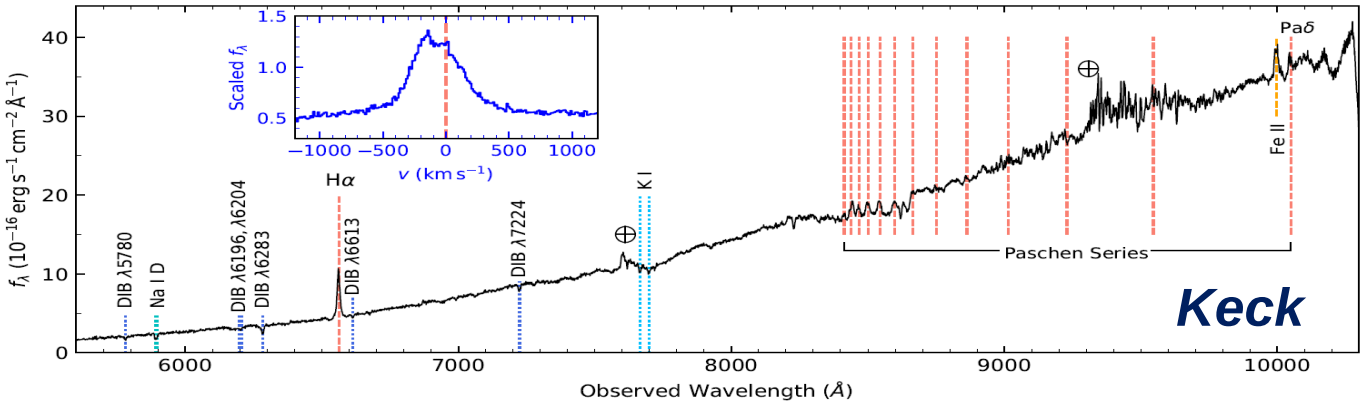
Fornasini et al. 2014

Discovery of slowly rotating neutron stars in HMXBs
«towards the complete population of faint X-ray pulsars»







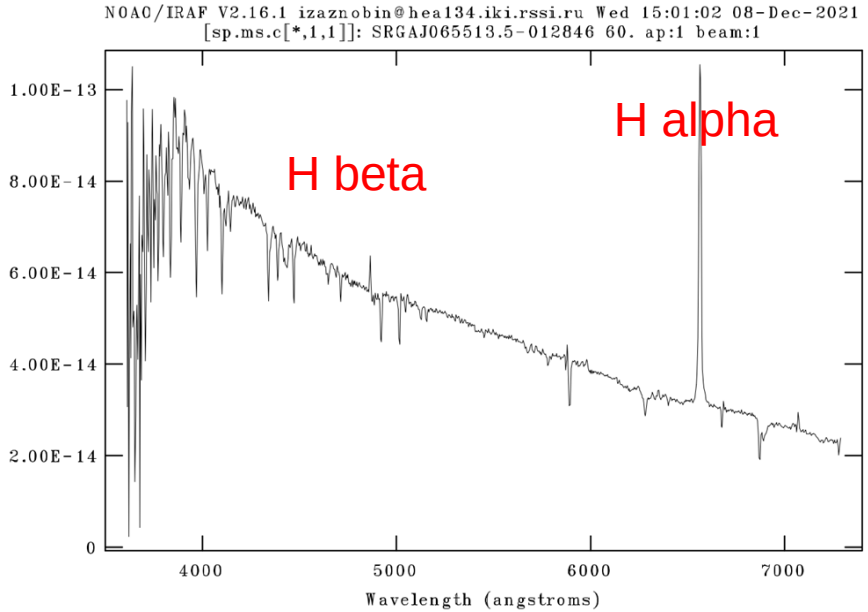


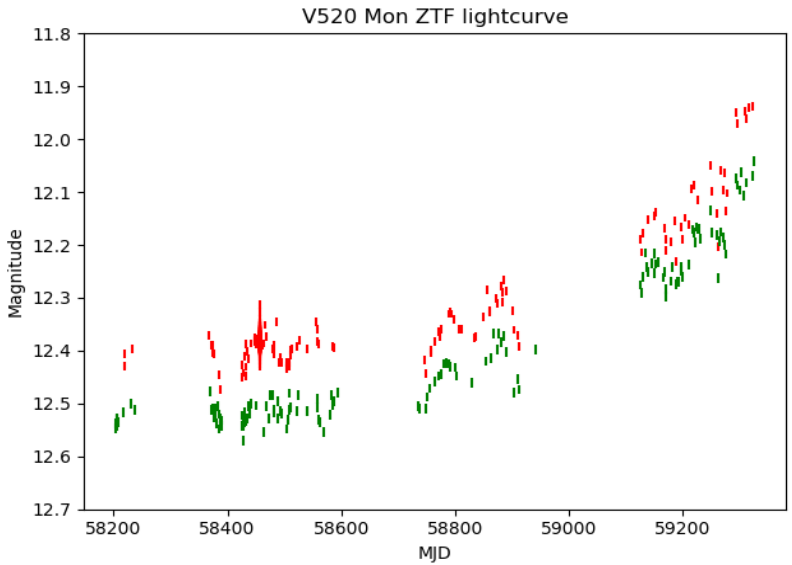
SRGA J204318.2+443815
~740 s
Lutovinov et al. 2022

SRGA J124404.1-632232
~540 c
Doroshenko et al. 2022

Discovery of slowly rotating neutron stars in Be/HMXBs

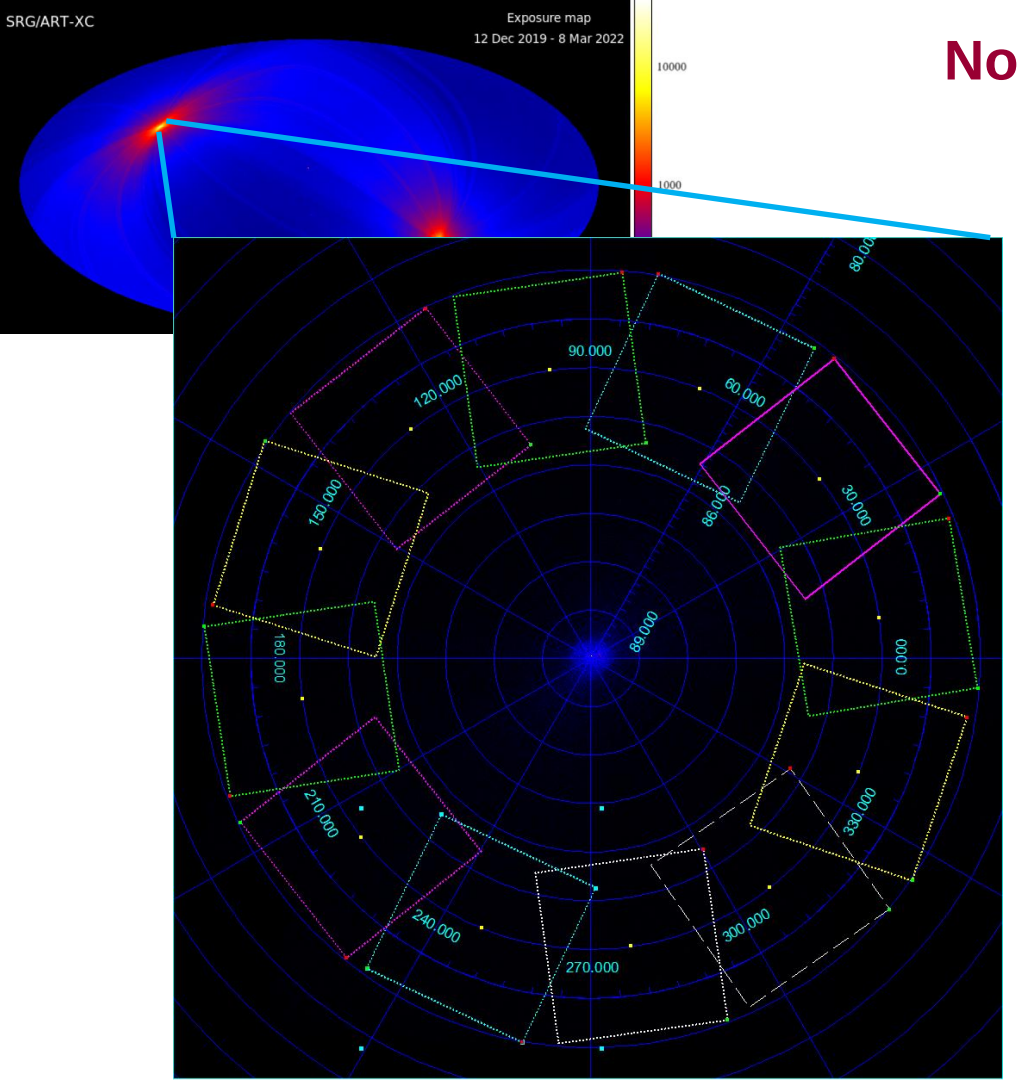
Be X-ray binary SRGAJ0655/V520 Mon





Discovered in the SRG all-sky survey, the source was identified as Be X-ray binary with optical spectrometry performed on AZT-33IK Sayan telescope (*Pavlinsky et al. 2021*) and extensive optical variability observed by ZTF. Later revealed as X-ray transient by MAXIJ0655 (*Serino et al. 2022*), pulsations at ~1130 s (*Shidatsu et al. 2022*)

North ecliptic pole



Joint IKI – NASA (MSFC) program
~200 sq. deg around NEP

In 2022 we modified the observational program to have approx. same exposure in a year for this region

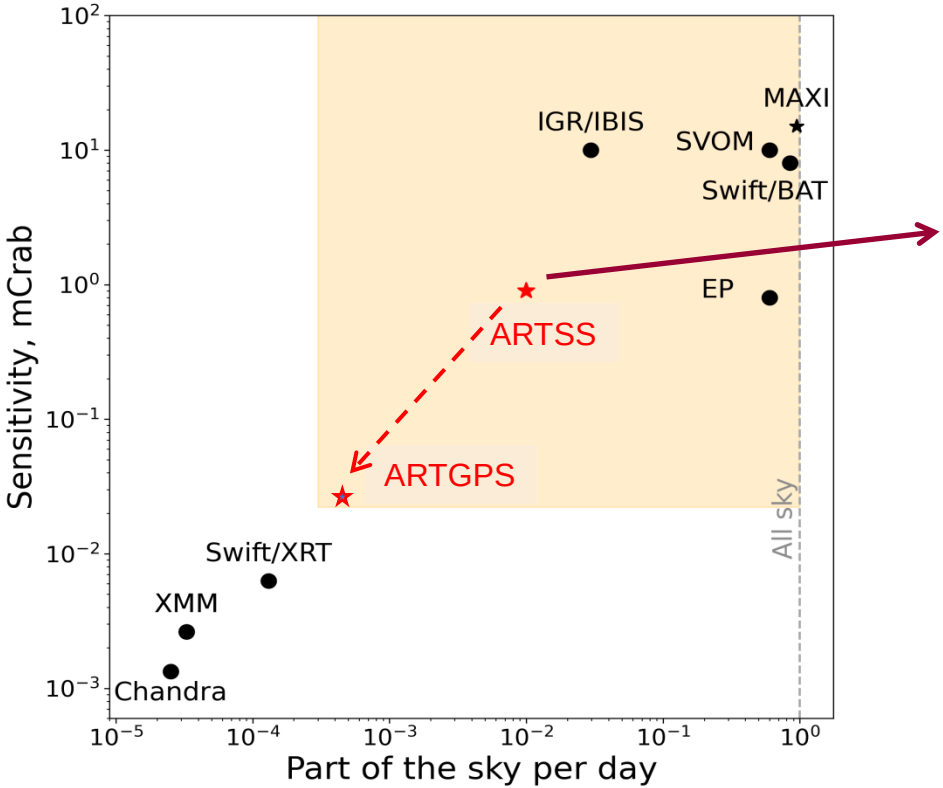
~100 objects detected

Follow-up observations with NuSTAR in 2023-2024
Follow-up observations at the Palomar observatory in 2023-2024

Work in progress


ART-XC/M31

ART-XC: search for transients, discoveries and studies



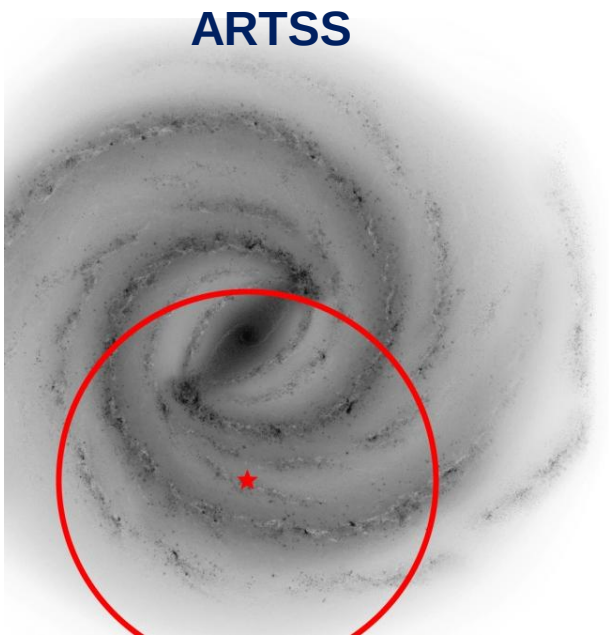
In all-sky survey ~1% of sky daily reaching down to ≈ 10^{-11} erg/cm/s

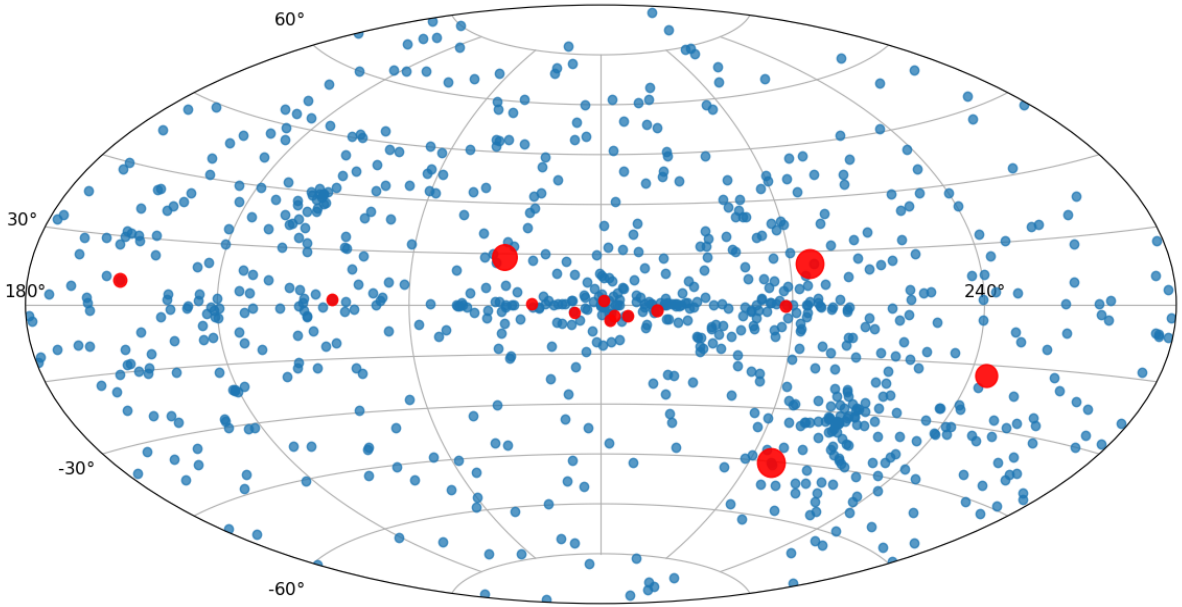
LMXBs/HMXBs in bulge:
10^{35} erg s^{-1} @ **10 kpc**
CVs, stellar superflares:
10^{33} erg s^{-1} @ **1 kpc**
FBOTs (AT2018cow-like):
10^{43} erg s^{-1} @ **100 Mpc** (first days)

Localization accuracy <15″
Fast responce — 1-2 hours after downlink

Dozens new sources discovered and studied: microquasars, X-ray pulsars, accreting millisecond X-ray pulsars (AMXP), etc.

ART-XC: search for transients, discoveries and studies



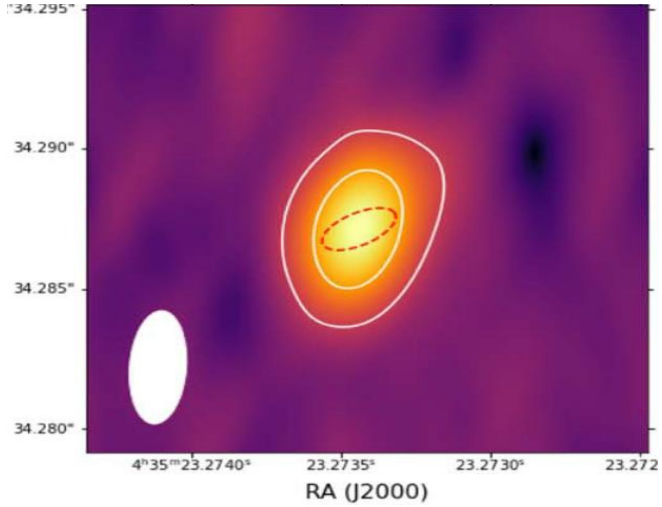


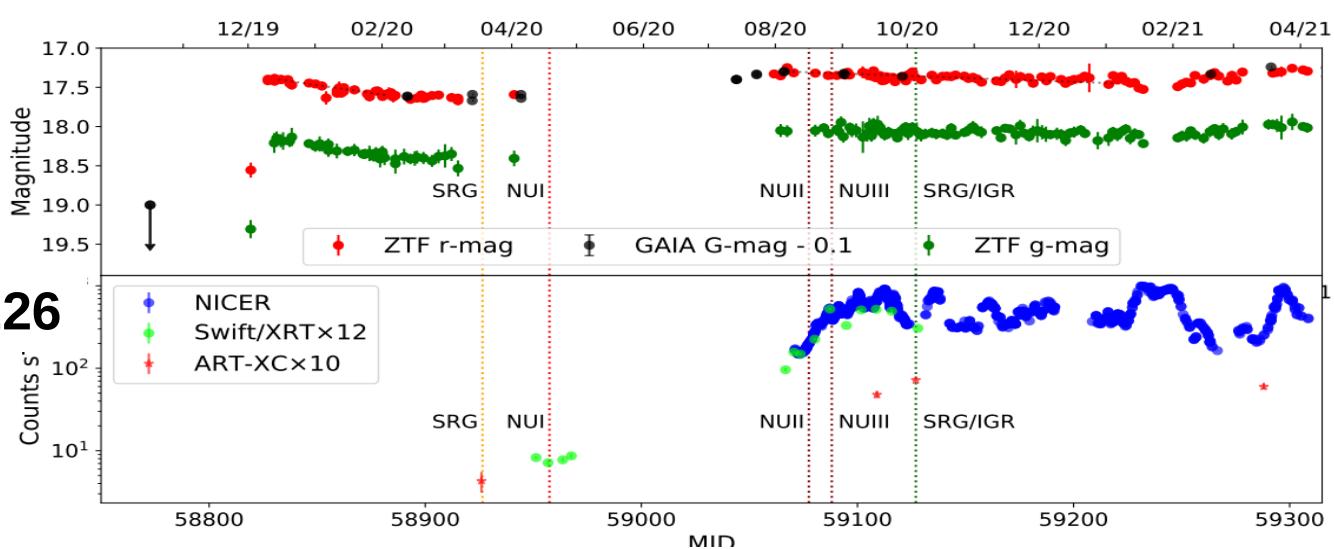
New Galactic sources are white dwarfs, neutron stars in massive and low-mass systems, black holes, and so on.

New microquasar in Galaxy

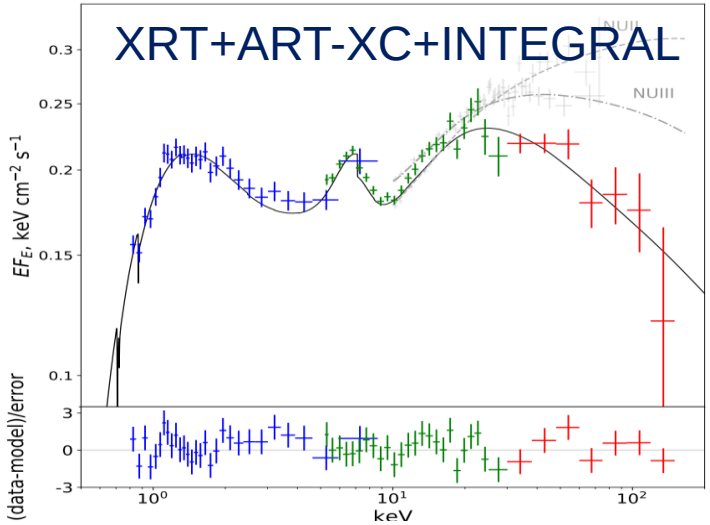
SRGAJ043520.9+552226

Yao+20a,b
Yadlapalli+21

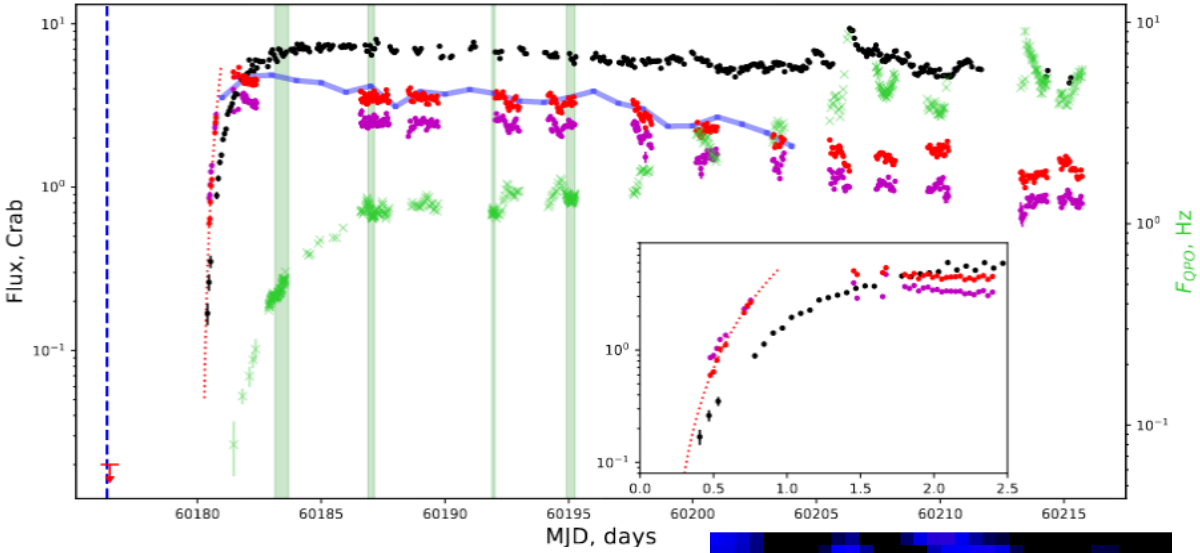




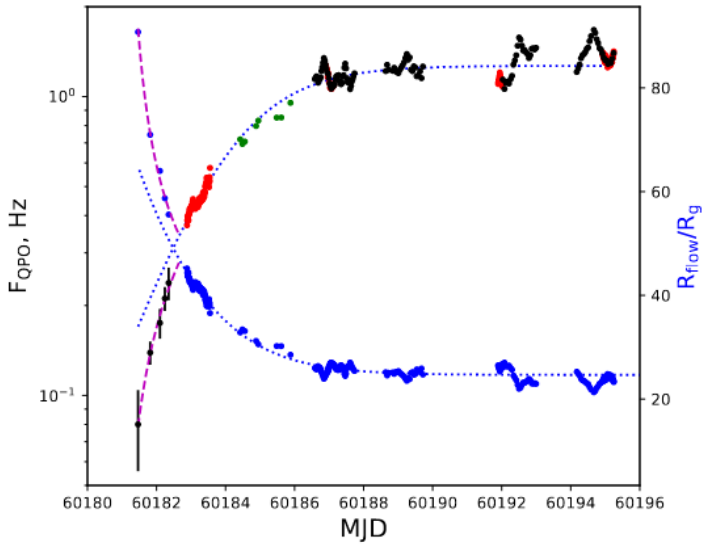
Mereminsky et al. 2022



Hard X-rays and QPO in SwiftJ1727.8-1613 – most bright X(γ)-ray source in 2023



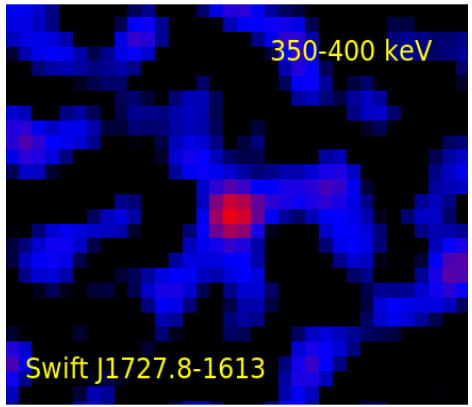
Aug-Sept 2023



ART-XC+INTEGRAL+MAXI

ART-XC started observations just 3 days after discovery, obtained 4 long observations through rise and peak

Mereminsky et al. 2024a

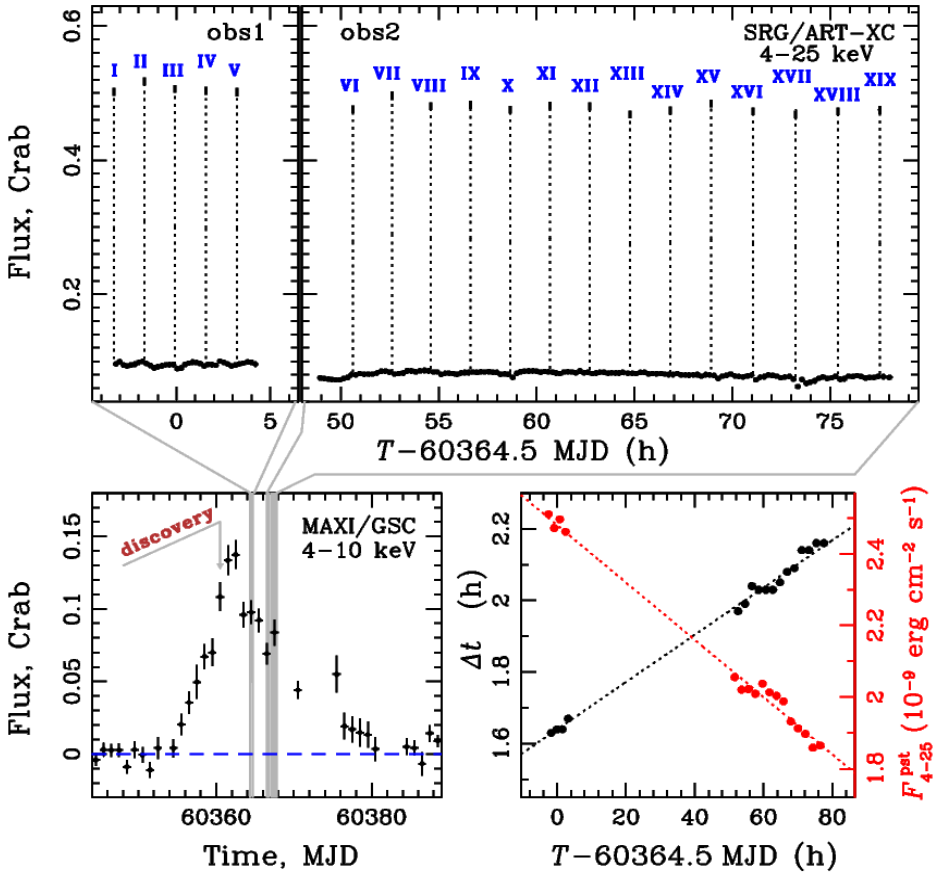


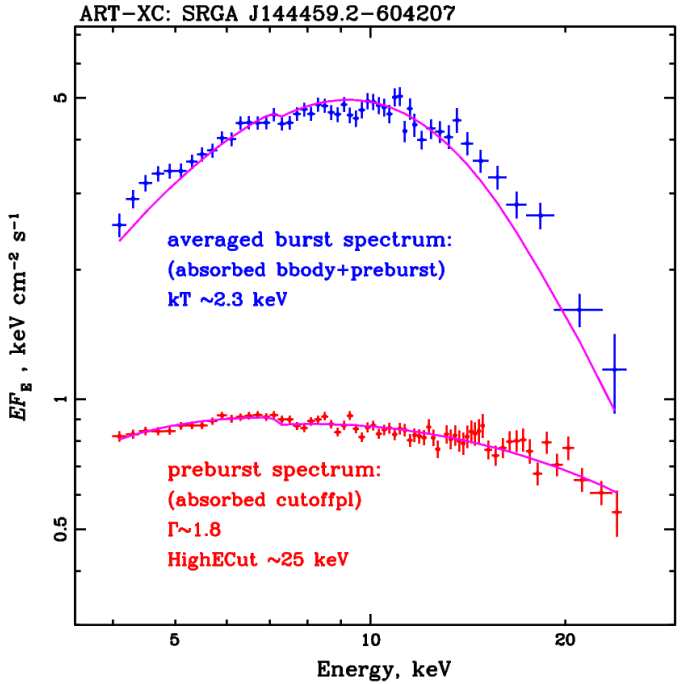
Model of *Ingram et al. (2009)*
M_{BH}~10 M_{sun} a=0

Inner disk boundary contracts rapidly during fast rise (~40 $R_G\,d^{-1}$), then show slow (~15 $R_G\,d^{-1}$) random-walk variations during plateau stage

Discovery of SRGA J144459.2-604207

Mereminsky et al. (2024b) Atel16464 on 21.02.2024

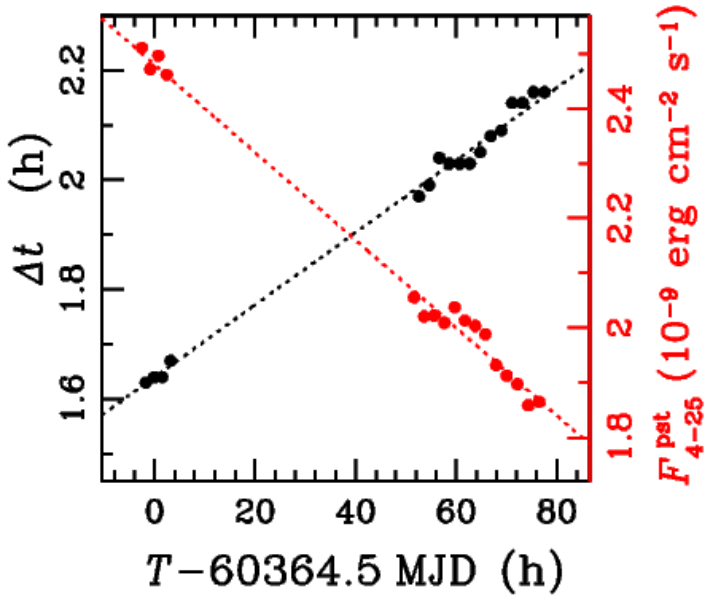


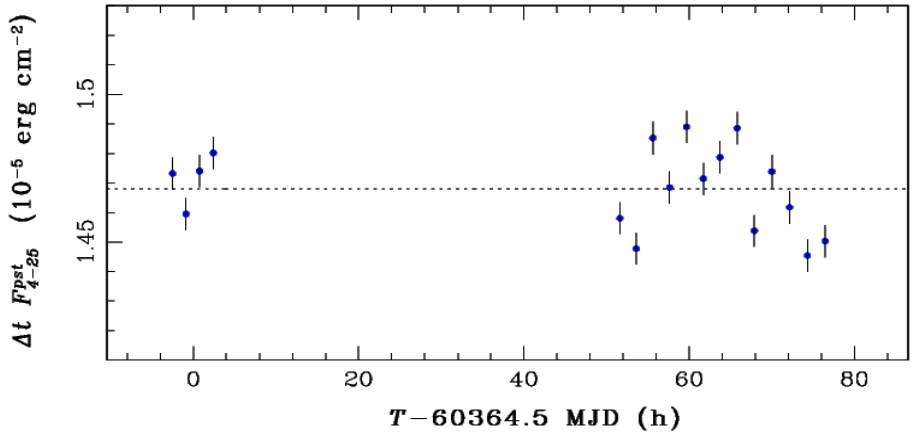


Average energy spectrum of all type-I X-ray bursts observed by ART-XC during first observation (blue crosses) and the spectrum of the persistent emission

Molkov et al. (2024)

SRGA J144459.2-604207





$$\alpha = \frac{\Delta t\, F^{\rm pst}_{4-25} C_{\rm bol}}{E_{\rm b}}$$

$$E_{\rm b} = 4.18 \times 10^{-7}\ {\rm erg\ cm^{-2}}$$

α~105

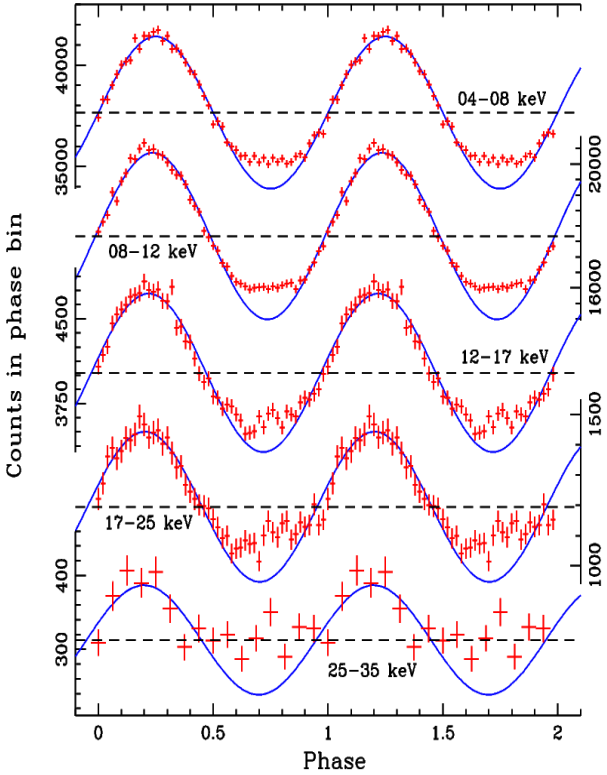
mean hydrogen fraction at ignition

$$\overline{X} = z\frac{155}{\alpha}\frac{\xi_b}{\xi_p} - 0.223$$ *(Galloway et al. 2022)*

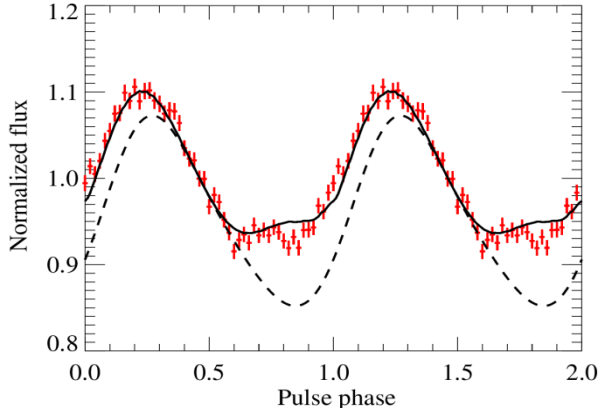
X~0.16 (H at the ignition layer)

Molkov et al. (2024)

Pulsations ~447.8 Hz SRGA J144459.2-604207 Orbital period ~5.2 hrs



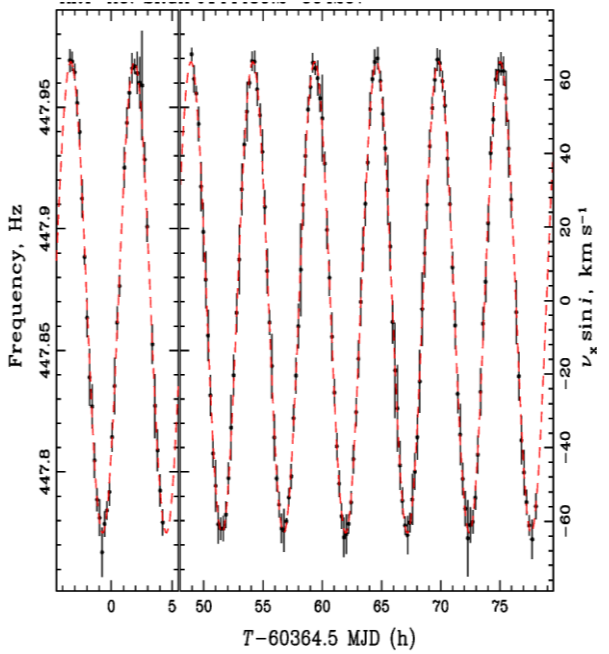
Pulse profiles of the persistent emission. Blue lines a sine wave in the phase interval 0.0–0.5



Simplest model *(Beloborodov 2002, BP06)* two hot spots visible together due to the NS large compactness can produce a plateau. **BUT!** Spectrum is not BB!

Alternative model (*Poutanen et al. 2009*) partial eclipse of the secondary hotspot by the accretion disk with:

- pulsar inclination i = 58°,
- co-latitude of the spot center of 14°
- its angular radius of 33°,
- the inner disk radius of 24.6 km.



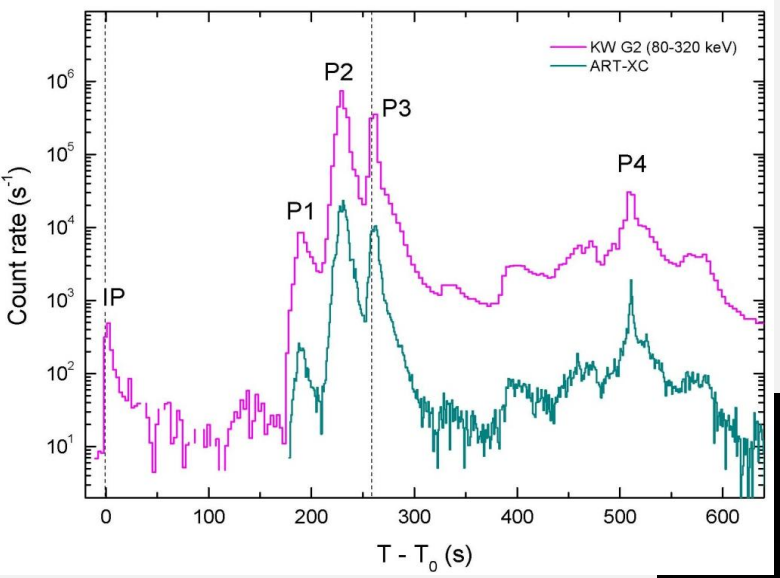
Variations of the measured NS spin-frequency due to an orbital motion with

Porb = 0.217649(5) d

$a_x \sin i$ = 0.6513(2

Molkov et al. (2024)

GRB221009A

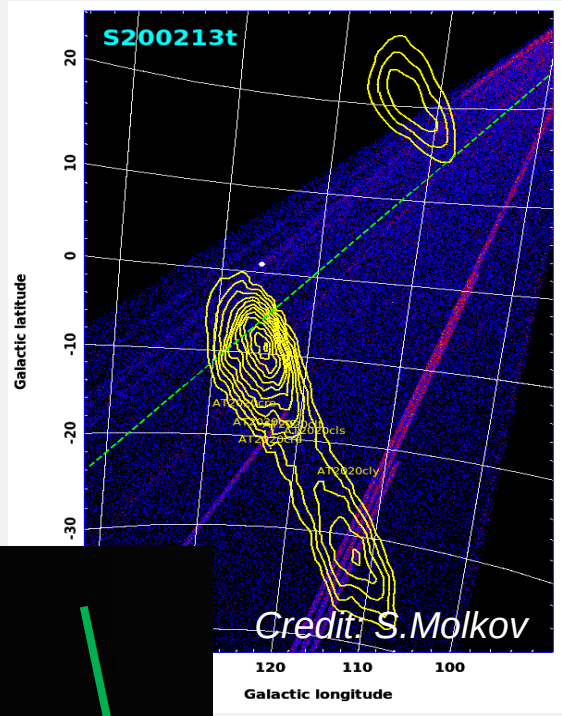


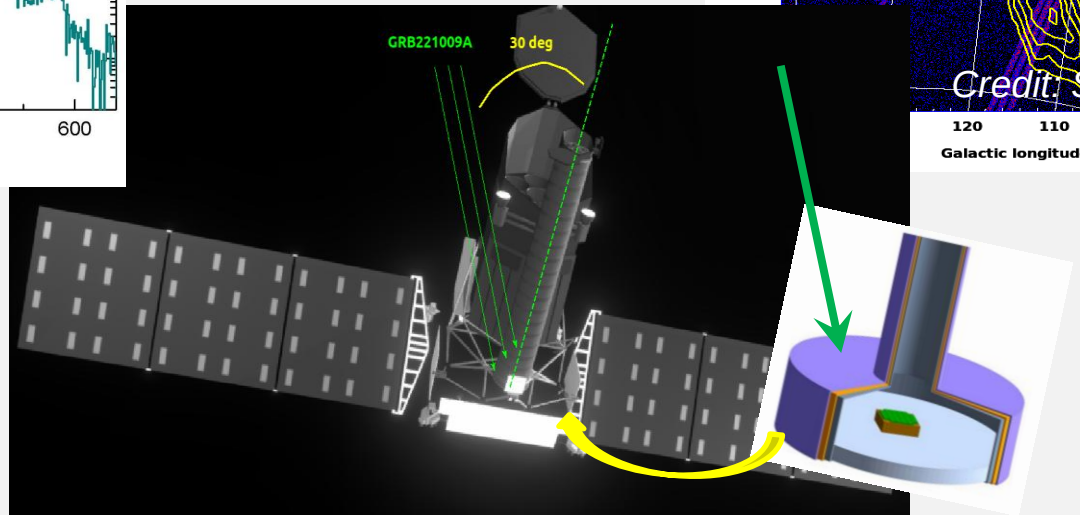
KW + ART-XC =
Record energy ~10^{55} erg
Luminosity ~3.5×10^{54} erg/s

Fredericks et al. (2023)

Bright GRBs, GW events, neutrino sources

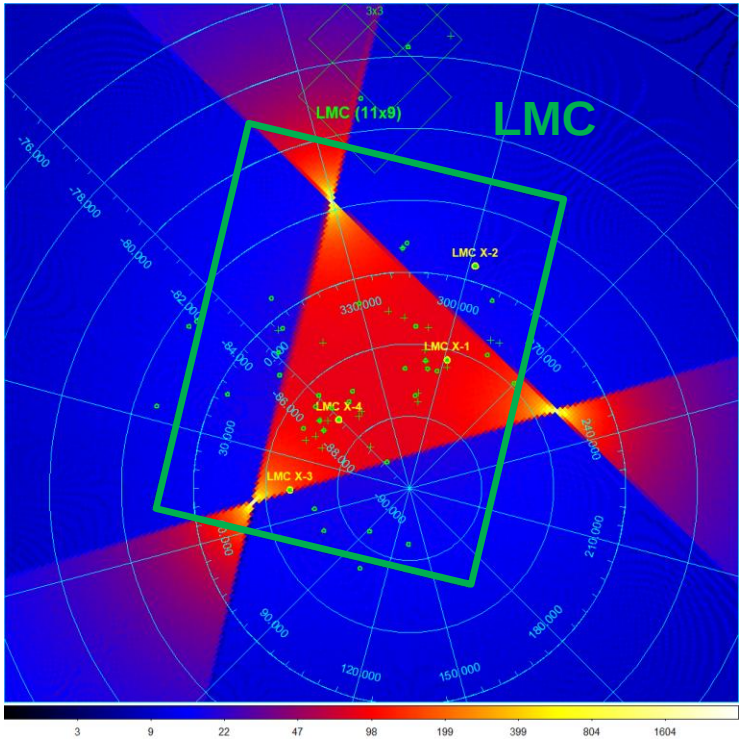
ART-XC detections up to ~120 keV, no pile-up, other problems

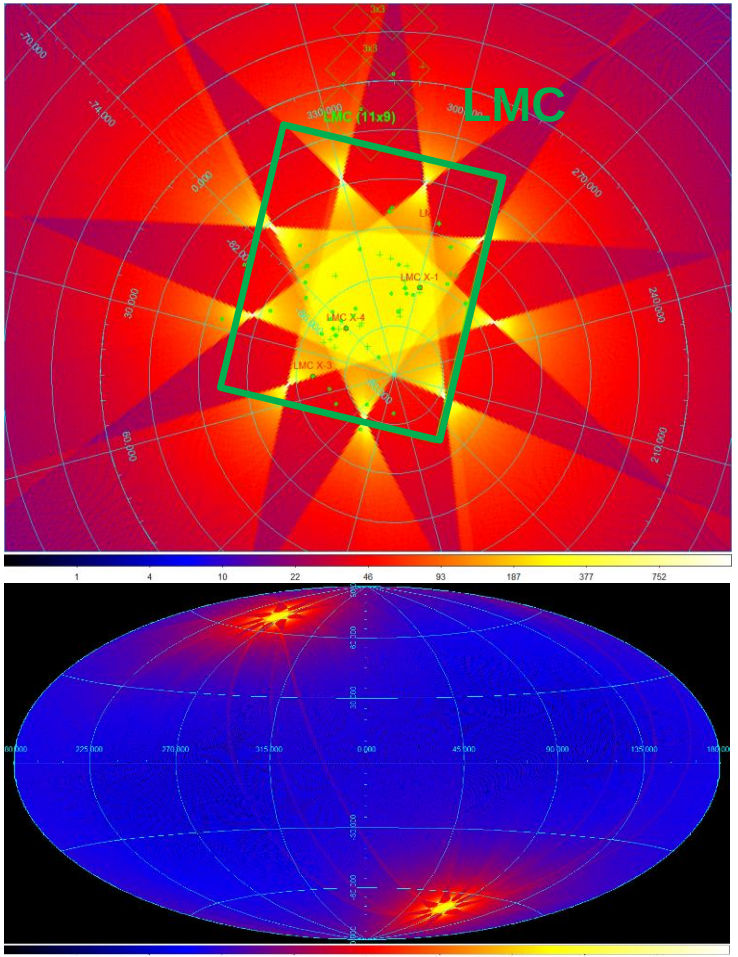




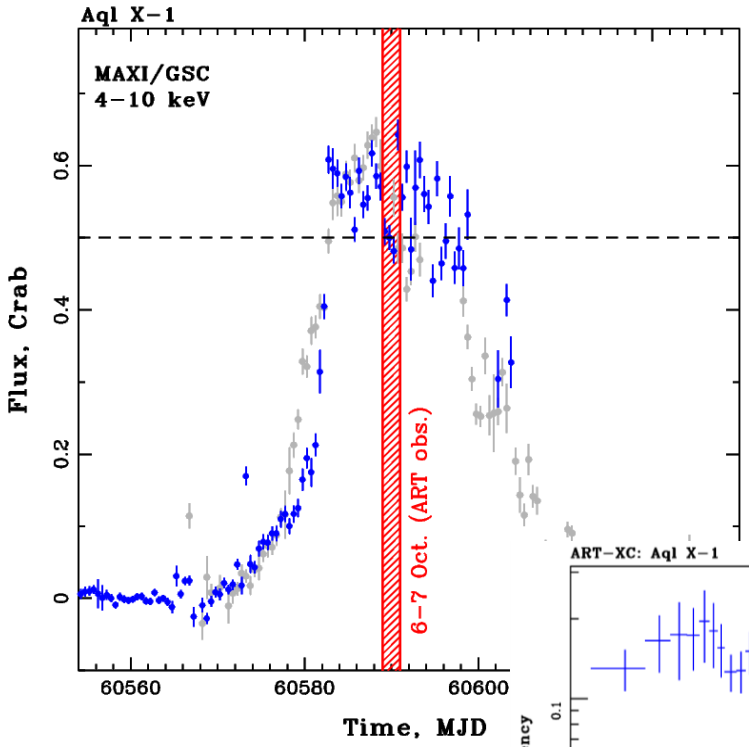
All-sky survey 2023-2025 (with new strategy)

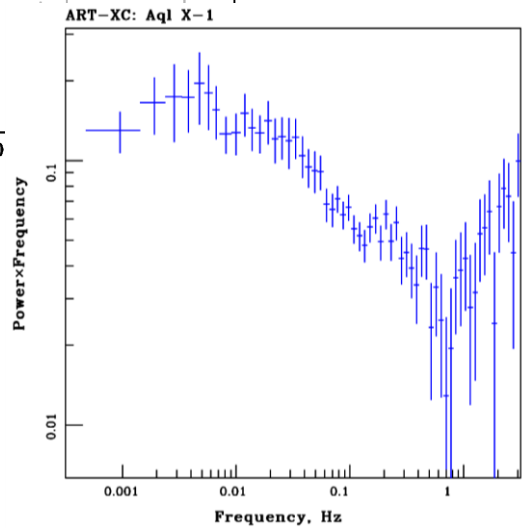
Change the poles every 2 months
Survey of the LMC field
Possibility to interrupt the survey to observe interesting targets

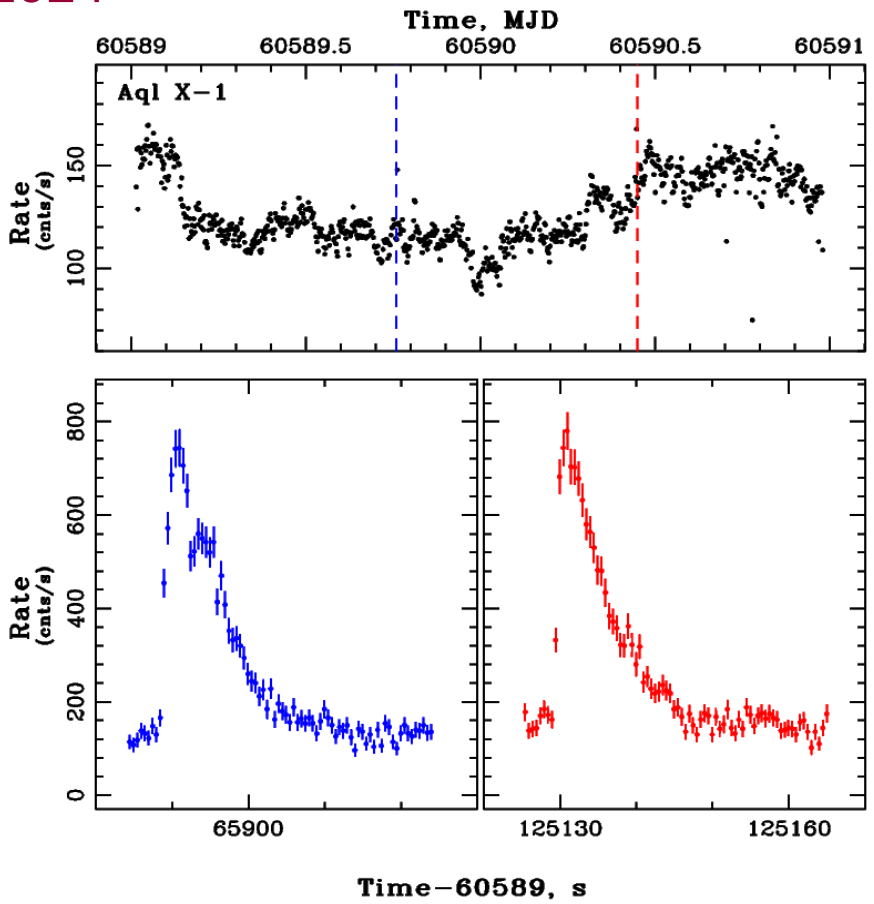




Aql X-1 ART-XC/HXMT joint observations in Oct 2024

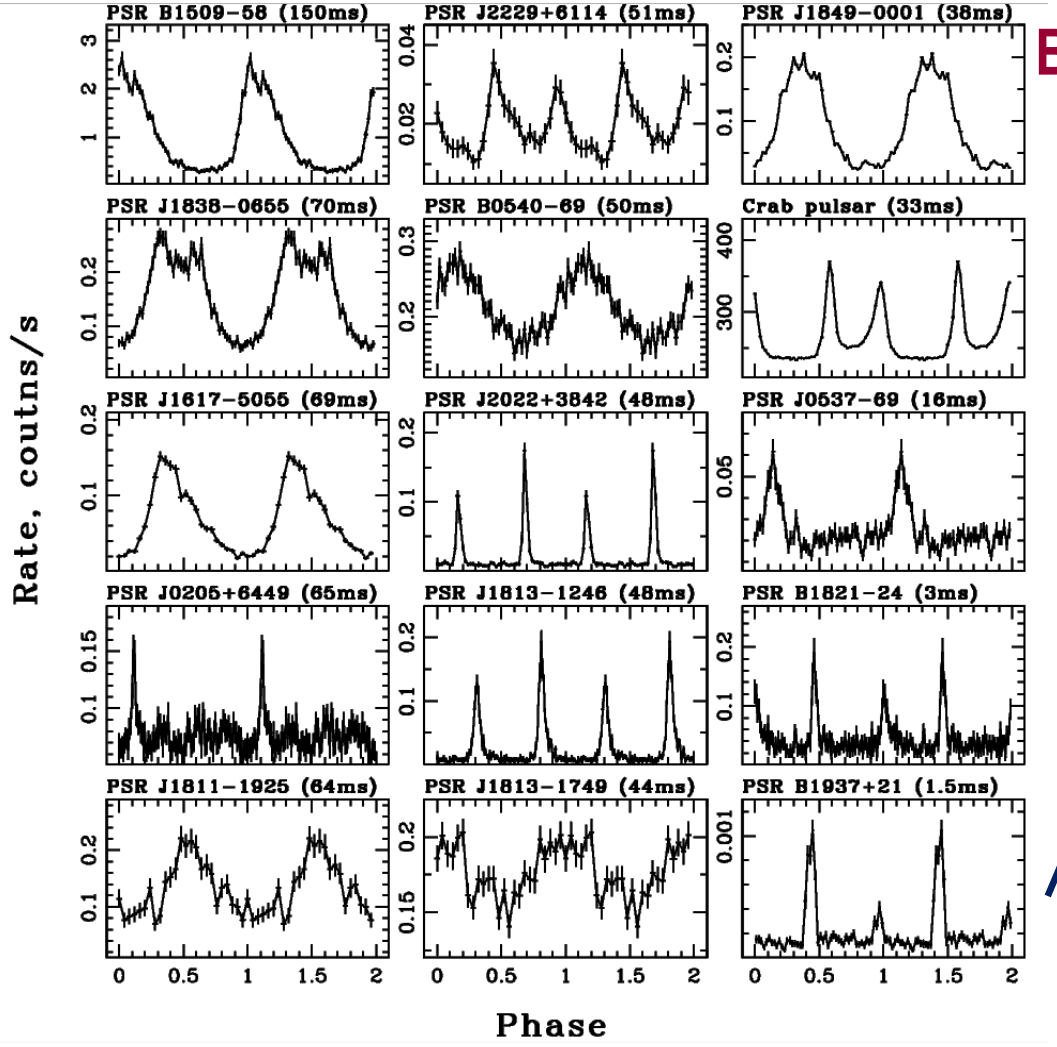


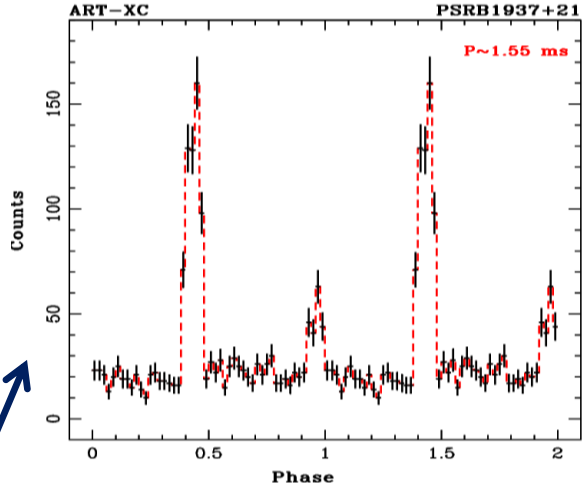




Credit: Sergey Molkov

Высокоточный тайминг с ART-XC





Программа совместных наблюдений с наземными радиотелескопами ИПА РАН 14-17 ноября 2024 г.

Credit: Sergey Molkov

СРГ/ART-XC работает – 24 часа в сутки, 7 дней в неделю

- Научная программа богата и разнообразна, может быть оперативно изменена
- Глубокий обзор Галактики закончен в октябре 2023 г
- С октября 2023 г. возобновлен обзор всего неба с новой стратегией, предполагается что он продолжится до конца 2025 г
- Совместные наблюдения с другими обсерваториями (IXPE, HXMT, EP)
- Наблюдения и исследования транзиентных событий (открытие, отождествление новых источников, GRBs, солнечные вспышки)

Спасибо за внимание!