

The Missing Neutron Stars: Insights from X-ray Surveys

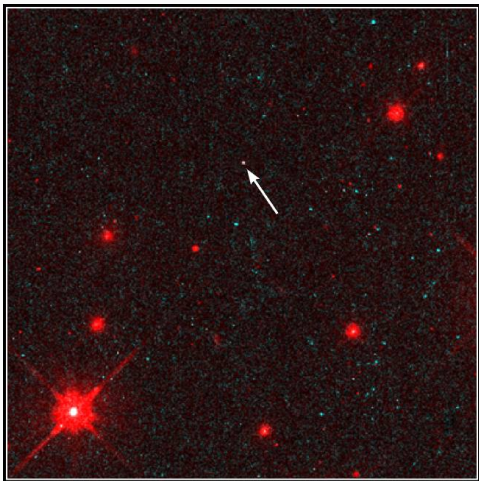
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FAST Future Pulsar Symposium, 5th July 2026

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In collaboration with: OA Strasbourg, Guizhou University, NAOC, PMO, SHAO, eROSITA_DE, XMM2ATHENA

Radio-quiet neutron stars vs. active pulsars



Isolated Neutron Star RX J185635-3754 HST • WFPC2

PRC97-32 • ST ScI OPO • September 25, 1997
F. Walter (State University of New York at Stony Brook) and NASA

ROSAT expectations

➡ Old slow isolated ISM accretors

- $\gtrsim 10^3$ predicted
- 7 discovered; “*magnificent*”
- no accretors ...but coolers

Rare! Only two found after the M7
(Rutledge+08, Pires+09)

⚠ CCSN ↔ NS birthrate

Diehl+06, Keane & Kramer 2008

The Magnificent Seven

- a legacy of ROSAT
- X-ray bright, soft, $\sim$ purely thermal
- nearby, low absorbed (within 0.2–1 kpc)
- faint optical/UV counterparts
- no accretion, no hard tails, “constant”



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MPE

Relevance

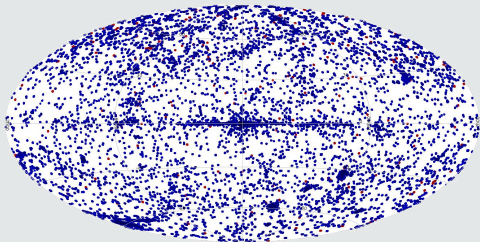
- Distance, luminosity, age, undisturbed emission from the stellar surface
- Cooling theory and atmosphere $\rightarrow$ equation of state
- Long P , high $L_X/\dot{E}$, high B -field: M7 as waning magnetars
- Do canonical (spin-powered) pulsars tell us the whole story?

Are there more distant XINS* hidden in X-ray catalogues?

(*) X-ray-selected INSs dominated by thermal emission, irrespective of class



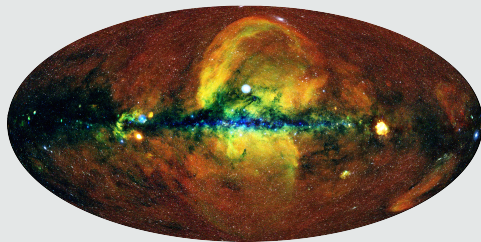
ESA XMM-Newton



- pointed observations
- legacy: XMM2ATHENA ($> 10^{-14}$ cgs)

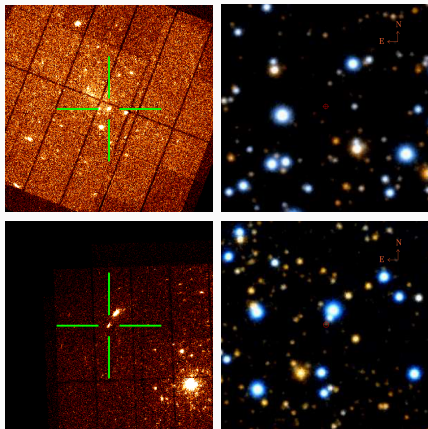


DLR/IKI SRG/eROSITA



- all-sky survey (eRASS_DE data rights)
- flux-limited: population ($> 10^{-13}$ cgs)

Selection method and identification campaigns



- soft spectral slope in the 0.5-2 keV band
- range of absorption by ISM
- probabilistic cross-match (optical, nIR, UV)
- <http://www.arches-fp7.eu>
- visual screening (high proper motion stars)
- possible IDs in astronomical databases
- ✓ efficient: 0.05% of $> 10^5$ X-ray emitters
- ➡ deep follow-up to confirm XINS nature

Pires+22 arXiv:2208.07637 ; Kurpas+24 arXiv:2405.12846 ; Pires+17 arXiv:1611.07723
see also: Rigoselli+22 arXiv:2110.06234 ; Demasi+24 ApJ 961 36D

The new kids on the block

4XMM J0221

Very soft and constant

XMM, eROSITA, LS-DR10 (Pires+ arXiv:2208.07637)

eRASS J0657 $\equiv$ PSR J0657+2604

Middle-aged, radio+ γ -ray quiet

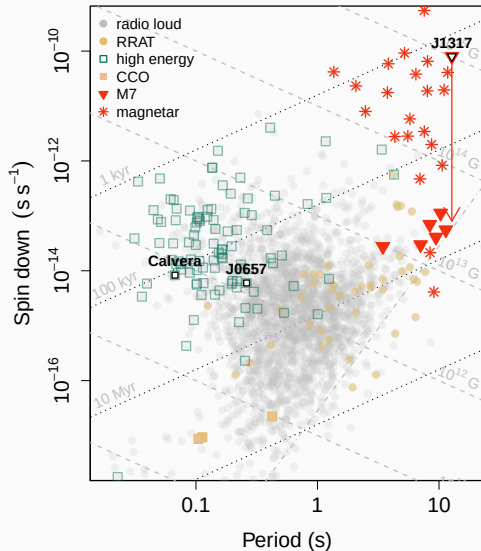
XMM+VLT, NICER, FAST, Fermi (Kurpas+2501.07347)

eRASS J1317 $\equiv$ PSR J1317-4026

A long pulsator (M7-like)

XMM+VLT, NICER (Kurpas+arXiv:2401.17290, 2606.11291)

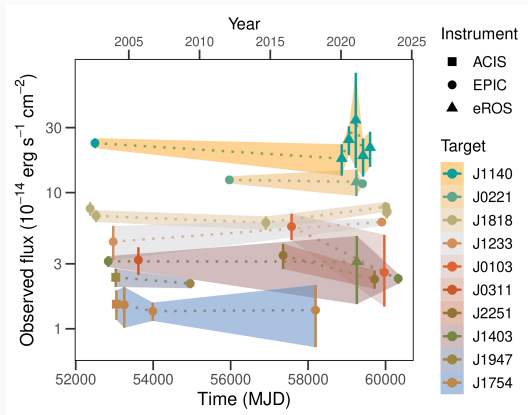
✓ plus several XINSs with $p_f < 10 - 15\%$



Follow-up of ten selected XINS candidates from 4XMM-DR12

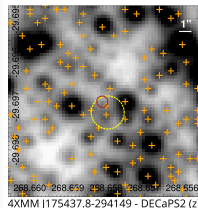
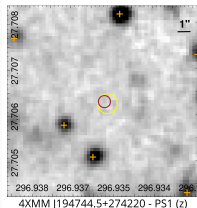
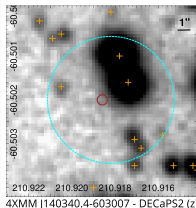
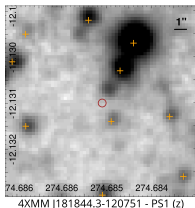
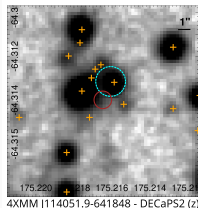
Genuine XINSs vs. contaminants

- ➡ XMM-Newton Fulfil, FAST
- ➡ eRASS, XMM2ATHENA validation
- ➡ population synthesis
- ✓ Spectra, stacked detections, astrometry, variability, flux ratios
- ✓ Results vs. model predictions
- ✓ Sample completeness, detectability, overall properties



Pires+26 A&A arXiv:2606.08023

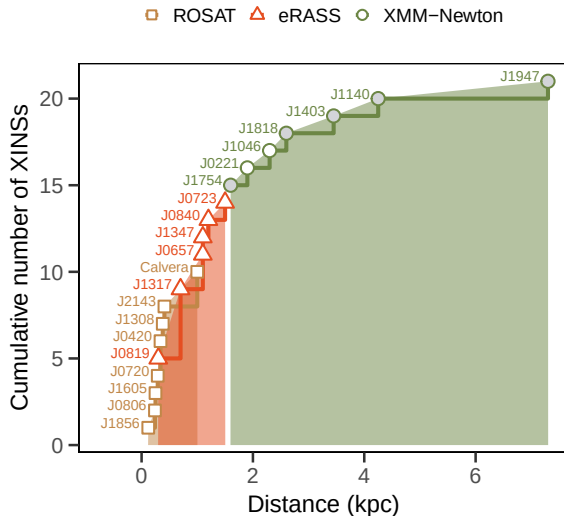
Identifying XINS in crowded regions of the Galactic plane



Optical limits and secured follow-up

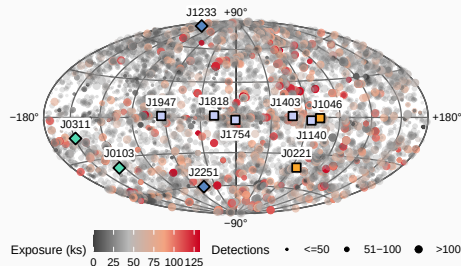
- Possible associations: open cluster (1.8 kpc); SNR/PWN system (6 kpc)
- Current limits (DECaPS, Legacy Survey, PAN-STARRS): $g > 22.8\text{--}25.4$
- ➡ Gemini (FT; 26A, 26B) + LBT: deep imaging to rule out counterparts
- ⚠ In progress: Einstein Probe, Chandra, and FAST follow-up

Expanding the population of distant neutron stars



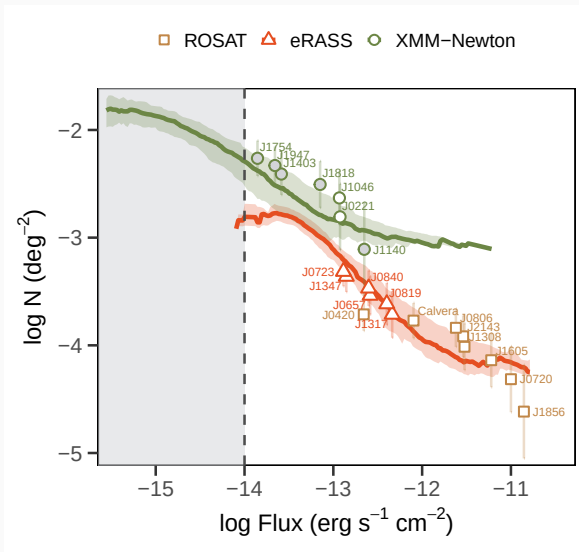
Distances of new 4XMM XINs

- Estimates from best-fit N_H and extinction maps
- Vertical distance $|h_z| \leq 200$ pc



XINS surface density and survey observability from population synthesis

- Neutron stars formed at fixed rate in Galactic spiral arms
- Isotropic natal kicks; evolved in Galactic potential
- Identical cooling curves; isotropic emission assumed
- ISM absorption included via analytic model and standard cross-sections
- Selection functions specific to eRASS (western Galactic) and 4XMM-DR12 footprint



Median properties of the synthetic population

		4XMM-DR12	Sought	Remaining
N_{XINS}		20 ± 5	6^{+2}_{-3}	13^{+6}_{-4}
N_{eRASS}		2 ± 2	2 ± 2	0
C_{min}		$10.7^{+1.4}_{-0.4}$	52^{+90}_{-25}	$10.7^{+1.5}_{-0.4}$
C/C_{eROS}		14^{+4}_{-3}	11^{+6}_{-5}	16^{+6}_{-4}
f_X	10^{-14} cgs	$0.41^{+0.3}_{-0.14}$	$2.8^{+2.3}_{-1.3}$	$0.23^{+0.11}_{-0.07}$
kT	eV	97^{+6}_{-7}	103^{+15}_{-17}	97^{+6}_{-7}
d	kpc	$2.7^{+0.4}_{-0.7}$	$1.7^{+1.1}_{-0.4}$	$3.2^{+0.5}_{-0.6}$
N_{H}	10^{21} cm $^{-2}$	$6.8^{+1.1}_{-1.2}$	$5.9^{+1.4}_{-1.8}$	$7.4^{+1.6}_{-1.4}$
t_{coo}	kyr	80^{+50}_{-30}	50^{+110}_{-40}	110 ± 40
t_{EPIC}	ks	29 ± 6	24 ± 10	31 ± 9

4XMM-DR12 20 ± 5 XINS

2 century $^{-1}$

(Gill+Heyl'07)

Sought $\sim$ Consistent

eRASS Up to four

Hidden Most (70%)
remain below
flux cut, but
still detected

Check Pires+26 A&A arXiv:2606.08023 for details!

Summary: Aftermath of X-ray survey searches

- ✓ **Candidate sample from 20+ years of XMM observations likely identified**
- ⇒ Evidence for distant Galactic XINS population
- ⇒ Deeper follow-up needed for confirmation and characterisation
- ⚠ Catalogue and follow-up limitations become dominant

Outlook

- ⇒ eRASS/XMM/NewAthena next-generation searches and surveys

Implications

Neutron star birthrate: towards a more complete census

Channels of neutron star evolution and links between classes

Observability of missed (off-beamed) spin-powered neutron stars

Thank you!