Thermally emitting isolated neutron stars in the eROSITA sky

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The bulk of the neutron star population

Two main groups, discovered from radio surveys:

Standard (rotation-powered) pulsars
- slow down due to magnetic dipole radiation and particle acceleration
- young objects emit across the entire electromagnetic spectrum
- $P \sim 0.1\text{–}1 \text{ s}; B \sim 10^{12} \text{ G}$

Millisecond (recycled) pulsars
- fast spin and low magnetic fields
- high energy (X-rays, $\gamma$-rays) and radio
- old neutron stars “recycled” by accretion in a binary system
Unknown from radio surveys!

1. Magnetars show complex phenomenology, dominated by manifestations of a super strong magnetic field.

2. XINS aka the “M7” rotate more slowly and have higher thermal luminosity than pulsars of similar age.

3. CCOs aka “anti-magnetars” are young, seemingly weakly magnetised neutron stars.

Properties challenge understanding of NS emissivity and evolution.
Radio pulsars do not tell the whole story

The magnetar-M7 connection

Strong fields at birth produce hot and long-period NSs due to field decay

(models by Viganò, Rea, Pons, Aguilera et al.)

CCOs: different outcome of NS evolution

If the NS accretes lots of fallback debris:
  ➤ its magnetic field may be buried
  ➤ it won’t spin down (no radio)
  ➤ its cooling rate is affected

(Chevalier, Muslimov & Page, Geppert, Ho, Bernal, Viganò, . . .)
We need more sources!

These channels are not probed by radio and $\gamma$-ray pulsars.

Despite the theoretical development seen in recent years:

- state-of-the-art models built over uncertain assumptions (e.g. initial field configuration, level of impurity of the crust)
- known pulsars not sufficient to constrain models of field decay (Gullòn et al. 2015)
- formation and fate of CCOs:
  - how common is such an episode in the Galaxy?
  - timescale of field re-emergence?
- ... plus transients and the unknown! (faint AXPs/SGRs, old accreting neutron stars?)
eROSITA on board Spectrum-RG

- orbit around L2
- 4 years all-sky survey
- 3 years pointed observations
- large collecting area and FoV
- seven identical mirror modules
- data split MPE/IKI
  (West/East of the galactic centre)
- launch: September 25, 2017
  (shipment to Russia: October 2016)

Unique potential (for decades to come!) to unveil faint radio-quiet neutron stars and probe the population as a whole
Tracking neutron stars from birth up to present time

- progenitor stars in spiral arms
- interstellar medium (H layers), abundances, cross-section
- birth properties: spatial velocity, isotropical kick, constant birthrate
- motion integrated in the galactic potential
- thermal evolution: standard cooling (*to be included*: effects of fallback and field decay)
- isotropic blackbody emission
- eROSITA effective area and filters, averaged over FoV, survey exposure
- detection limit of 30 counts (0.2–2 keV)
- Monte Carlo simulations for average population properties
85 to 100 thermal sources in the survey after 4 yr

average distances within 300 pc and 8 kpc (median 2 kpc)

minimum flux $\sim 10^{-14}$ erg/s/cm$^2$

median flux
$\sim 3.5 \times 10^{-14}$ erg/s/cm$^2$

20% of the sources at intermediate flux
($\sim 10^{-13}$ erg/s/cm$^2$)

Potential for discoveries

Sources at intermediate flux can be targeted for follow-up in the optical (VLT, LBT) and in X-rays (XMM-Newton, Chandra)
Pinpointing candidates
Cross-correlation, selection in hardness ratio, visual screening, optical follow-up

What’s the limiting magnitude to rule out ordinary X-ray emitters (AGN/CV/stars)?

Discovery of a NS in Carina

2XMMp: 30 out of 72,000
\( f_X > 10^{-14} \text{ ergs}^{-1} \text{ cm}^{-2} \)

\( m_V > 27 \ (2\sigma) \)

log(\( F_X / F_V \)) > 3.5

\( m_V > 27 \ (2\sigma) \)
Follow-up expectations

Based on our past work with the 2XMMp and the NS in Carina:


- efficient selection of 600 candidates with \( m_R > 21 - 23 \)
- 5 min/target (8 m class) to rule out CVs/AGN \( (m_V > 27) \)

Assuming 20 neutron stars within the sample of candidates:

- 100 ks (5 ks/target) with Chandra for sub-arcsecond precision
- 2 Msec (100 ks/target) with XMM-Newton to:
  - constrain pulsations down to 15%
  - determine spectral parameters \( (5\% \ kT, \ 15\% \ N_H) \)
  - detect spectral features/deviations
Summary

- Peculiar neutron stars: few in number, but very important!
- eROSITA all-sky survey: ten-fold increase on known sources
- Population synthesis: knowledge beyond the Solar vicinity
  (spatial density, birthrate, alternative evolutionary channels)
- Follow-up studies: evolutionary state
  identifying missing links in the NS zoo

Thank you!