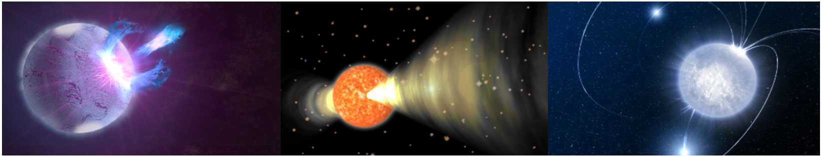


The missing links of neutron star evolution in the eROSITA sky

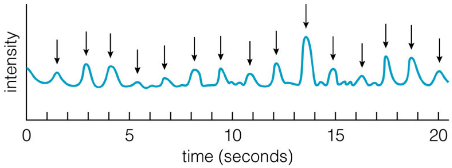
Adriana Mancini Pires

Axel Schwope, Christian Motch, Frank Haberl, eROSITA_DE

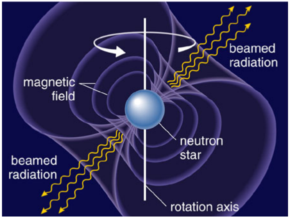
Leibniz Institute for Astrophysics Potsdam (AIP)

Physics of Neutron Stars 2017, St. Petersburg

The neutron star census today



"PULSAting source of Radio" (Bell, 1967)

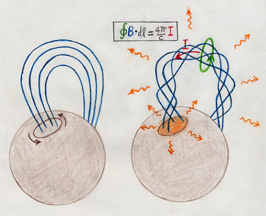


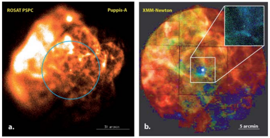
Hewish et al., *Nature* 1968

Today: over 2600 catalogued pulsars, most seen in radio

- rotation powered pulsars
- millisecond recycled pulsars (mostly binary)
- radio transients (RRATs)
- 2% 'peculiar' X-ray emitting

Peculiar groups of neutron stars





© Duncan, UA/MPE, Hui & Becker

Unknown from radio surveys!

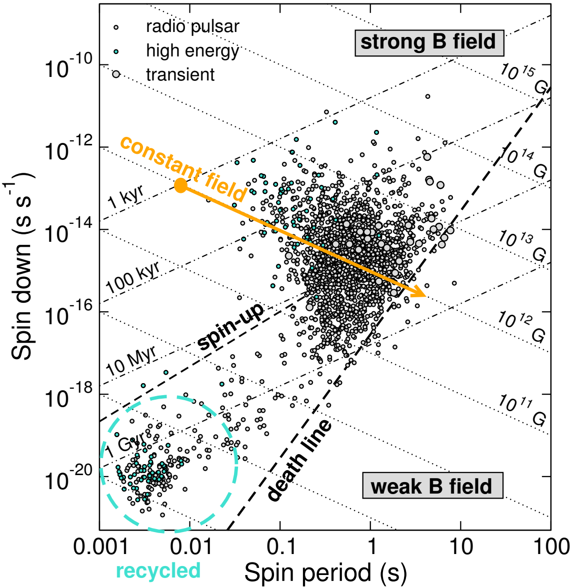
- magnetars
- XINS (M7)
- CCOs (anti-magnetars)

Challenge understanding of emissivity and evolution

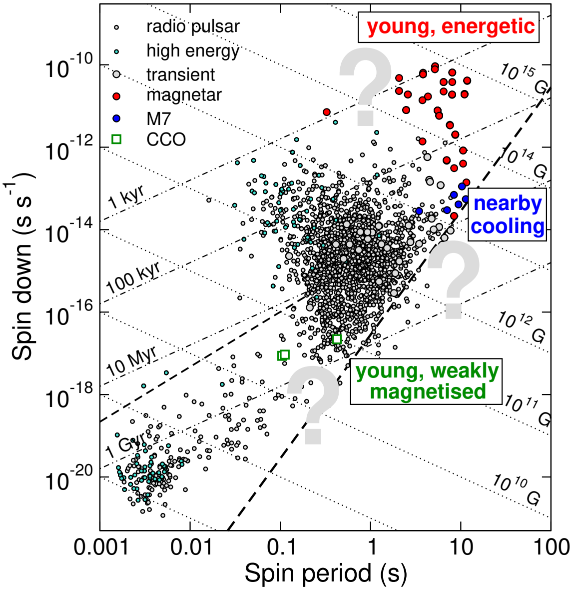
⟶ *Samar Safi-Harb's talk*

Do radio pulsars tell the whole story?

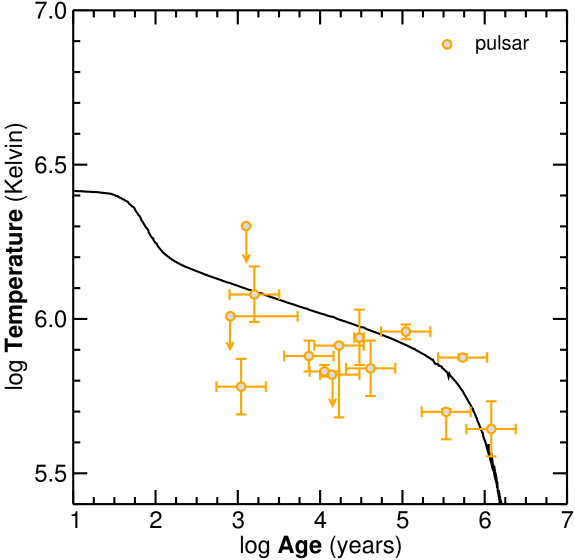
Evolution in the $P - \dot{P}$ diagram



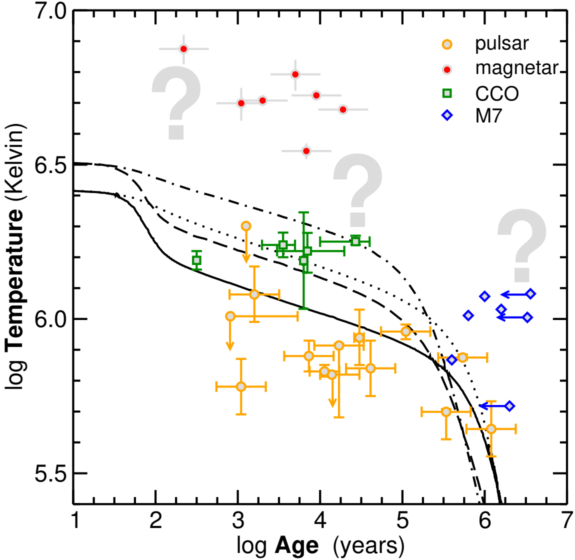
Evolution in the $P - \dot{P}$ diagram



How fast does a neutron star cool down?



How fast does a neutron star cool down?



Alternative evolutionary channels

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

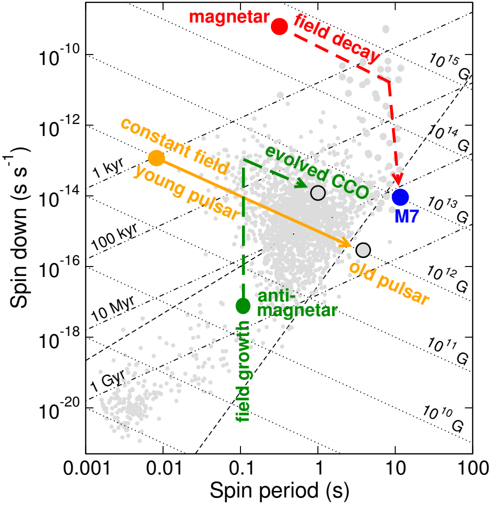
c.f. Pons, Viganò, Popov, Rea, Aguilera et al.

If there's lots of fallback accretion after supernova:

- B-field may be buried
- no $\dot{P}$, no radio
- cooling rate is affected
- re-emergence $\gtrsim 10^4$ yr

evidence: Halpern & Gotthelf, Bogdanov, Luo

models: Chevalier, Geppert, Ho...



The many faces of the same 'monster'

© *La chimère*, Louis Jean Desprez (c. 1780)

B-field governs phenomenology

$\longrightarrow$ *Alternative scenarios!*

- strength at birth
- decay/growth during lifetime
- effect on *P*, *kT* development

...thus visibility across the spectrum

Evolution and emissivity not probed by the bulk of the population and unpredicted by theory

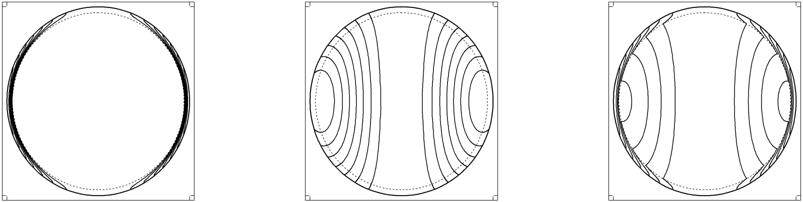
Big issues (1)

State-of-the-art models built over uncertain assumptions

- initial field configuration

from Viganò et al. (2013)

(A) crust-confined (B) core-extended (C) hybrid



- field dissipation controled by 'impurity' of the crust

Observed population (radio + X-rays) insufficient
to constrain models of field decay (Gullòn et al. 2015)

Big issues (2)

CCOs: lively debate over their formation and fate

- fraction of neutron stars undergoing fallback?
- will evolved CCOs join the rest of the population?

Amount of accreted material

level of submergence + timescale of re-emergence

Conditions determining / preventing fallback

Are alternative scenarios rather ordinary?

how numerous are peculiar sources in the Galaxy?

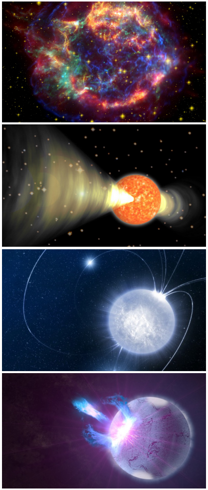
consequence to the NS/SNII rate

explain transitional and transient behaviour

From the state-of-the-art, how to progress?

Groups should be unified in a 'grand scheme' of evolution

(c.f. Popov, Kaspi)



© CXC/ASTRON/ESO/NASA

- only X-ray bright neutron stars are known (or when in outburst)

  from the ROSAT X-ray survey and Swift Telescope

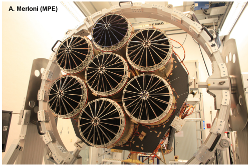
We need to:

- obtain a better sampling of radio and gamma-ray quiet sources
- discover and characterise evolutionary missing links
- evaluate the impact of alternative scenarios on evolution and observability

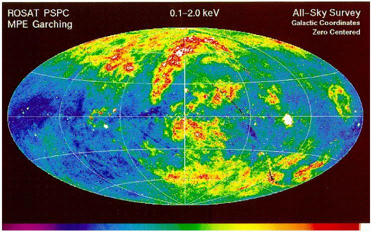
Timely: eROSITA is coming soon!

“Mapping the Structure of the Energetic Universe”; ROSAT’s successor

New all-sky X-ray survey
mission on-board Spectrum-RG
(RU/DE collab.; launch: 09/2018)



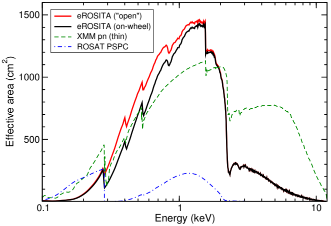
- unprecedented sensitivity, angular/energy resolution
- millions of X-ray sources
- synergy with multi-λ surveys and facilities
  (E-ELT, LSST, Athena, SKA. . .)

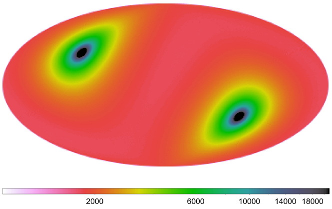


Unique potential (for decades to come) to unveil faint radio-quiet neutron stars and probe the whole population

A model of thermal INSs in the eRASS

Effective area and sky exposure



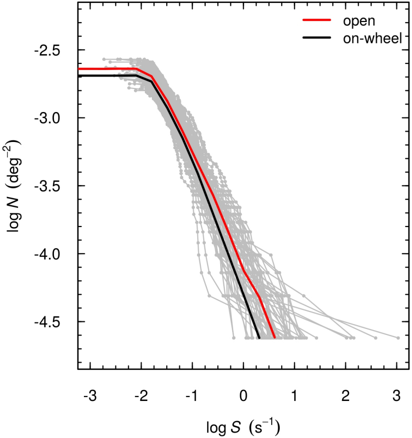


Credit: K. Dennerl, J. Robrade (eROSITA_DE)

- progenitor stars in spiral arms
- interstellar medium (H layers), abundances, cross-section
- birth properties: spatial velocity, isotropical kick, constant birthrate
- integrated motion GP
- thermal evolution: standard cooling
- isotropic blackbody emission
- eROSITA effective area and filters, averaged over FoV, survey exposure
- detection: 30 counts (0.2–2 keV)
- Monte Carlo simulations for average population properties

eROSITA forecast

Pires, Schwope, & Motch (2017)

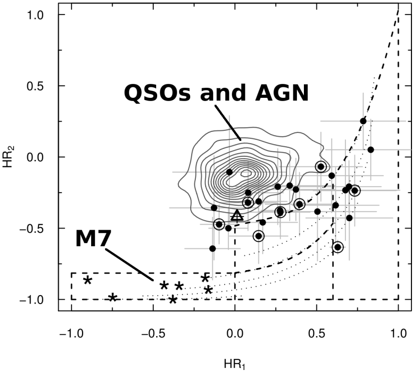


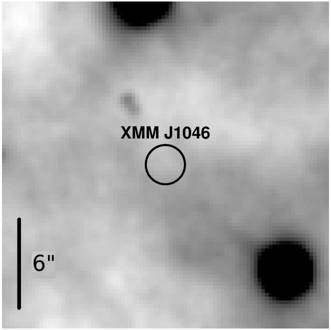
- 85 to 95 (filter-dependent) thermal INSs after 4 yr
- Distances 400 pc – 8 kpc (median 2 kpc)
- Exposures: 1.6 ks – 8 ks
- Faintest INSs: $\sim 10^{-14}$ erg s^{-1} cm^{-2}
- Median flux: $\sim 5 \times 10^{-14}$ erg s^{-1} cm^{-2}

- eRASS 50 times more sensitive to INSs than ROSAT BSC
- 28% of the sources brighter than 10^{-13} erg s^{-1} cm^{-2}

Pinpointing candidates

Cross-correlation, cuts in X-ray colour, visual screening, optical/IR follow-up

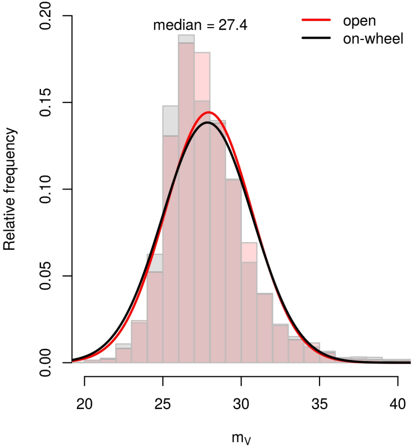




- past work with 2XMMp catalogue:
  30 out of 72,000; flux-limited (Pires et al. 2009a,b)
- discovery of ∼120 eV purely thermal INS in Carina
  (Pires et al. 2012, 2015)

Follow-up expectations

Immediate aftermath of the survey



What's the limiting magnitude to rule out AGN/CVs/stars?

- $F_X / F_V \geq 10^{3.5}$
- $m_V = 27.44(6)$

Sources at intermediate flux: VLT, LBT, Chandra, XMM

- spectra, timing
- diffuse emission, counterparts
- evolutionary state

Outlook and perspectives

$\sim$ 100 NSs in the eRASS (50$\times$ more sensitive than ROSAT)

30% at intermediate flux level

- 4 m and 8 m-class imaging to rule out AGN/CVs
- XMM/eROSITA to search for pulsations, spectral lines
- Chandra for sub-arcsec precision, diffuse emission, PWN
- search for γ-ray and radio counterparts (Fermi, MeerKAT)

Tackle the evolutionary state of individual sources

Effects on cooling, alternative evolutionary scenarios

In the long term: E-ELT, LSST, Athena, SKA

Some quick Neutron Star Accounting

- Number of Neutron stars produced in SNe in our galaxy: 10^9
- Number observationally discovered as radio pulsars: ~2000
- Number observationally discovered as X-ray binaries: ~500
- Number observationally discovered as INSs: ~10
- Number remaining to be observationally discovered: 10^9-2000-500-10 =

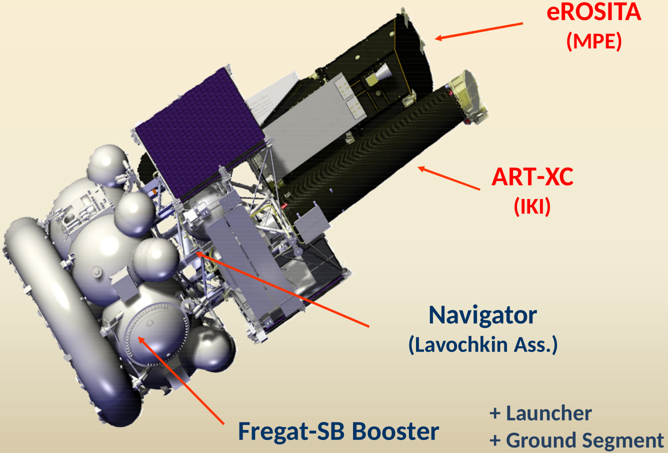
$$10^9$$

Friday, November 18, 2011

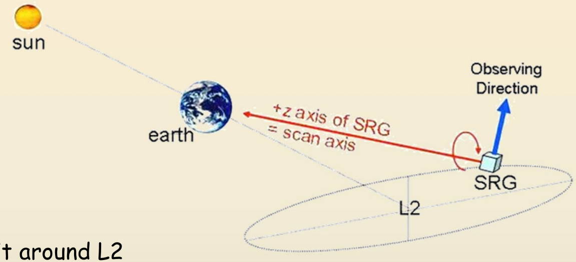
Thank you!

Extra slides

Spectrum-Roentgen-Gamma



Mission-Profile

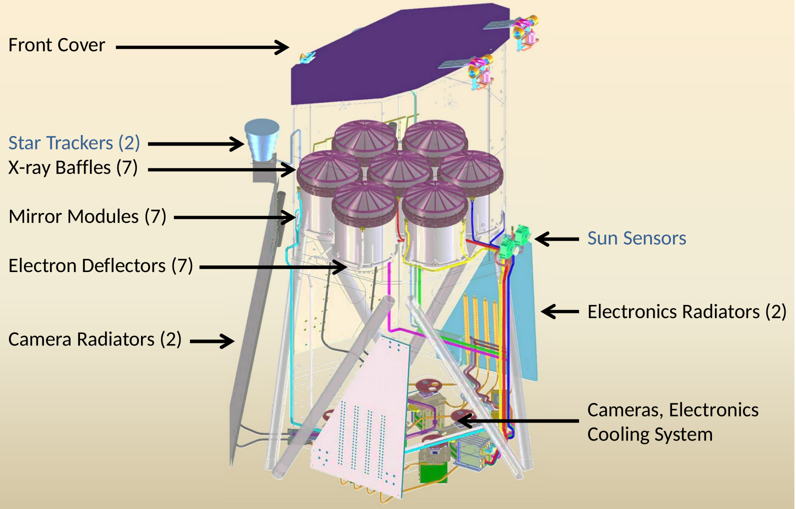


Orbit around L2

Permanent Rotation des S/C, ~ 4 hours / revolution

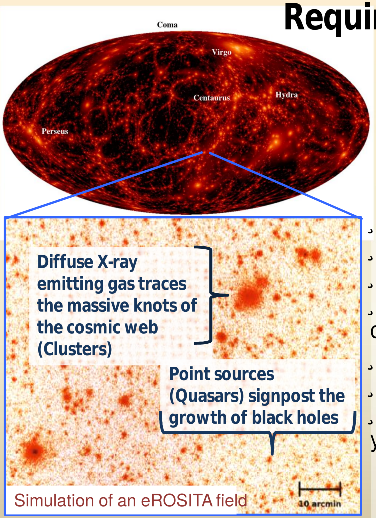
4 years all-sky survey
3 years pointed observations

eROSITA: Scheme



© P. Predehl

Mapping the structure of the hot Universe: Requirements



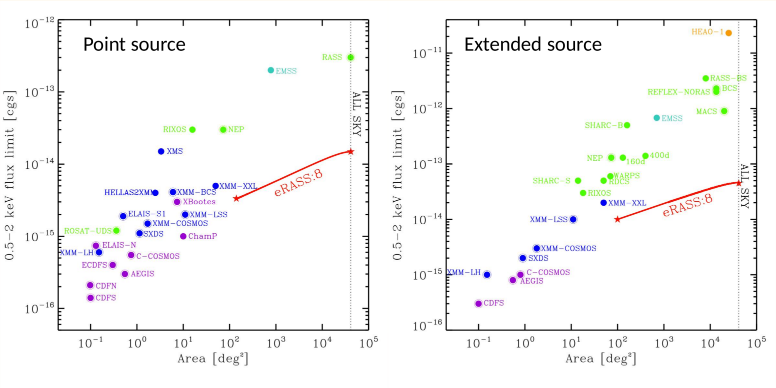
Images coutesy of K. Dolag (LMU), M. Mühlegger (MPE), O. Hahn (ETH)

Detect 100.000 Clusters of Galaxies

- All-sky survey sensitivity 6×10^{-14} erg/cm^2/s
- Deep survey field(s) (~100 deg^2) to 1×10^{-14}
- Individual pointed observations
- Moderate angular resolution (<30'' aver. over FoV)
- Large collecting area (>2000 cm^2 @ 1keV)
- Large FoV (1° Ø)
- Long duration survey: 4 years fl ‡ 1/2 year (ROSAT)

© P. Predehl

eROSITA Performance



Point source sensitivity:

~30 times better than ROSAT (soft band 0.5-2 keV)

~100 times better than HEAO/RXTE (hard band 2-10 keV)