SEARCHING FOR NEUTRON STARS BY CROSS CORRELATION OF X-RAY AND OPTICAL CATALOGS

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Abstract

Identification of neutron stars is usually done either in the radio domain, in X-rays or in the Υ-Rays. X-ray catalogues contain many unidentified sources. Among them are probably many neutron stars that are difficult to identify based on their X-ray properties alone. The optical counterpart of these unidentified X-ray sources may help obtain the information necessary for their classification, and therefore discover previously unknown neutron stars.

I therefore performed a cross-correlation of catalogues in the X-rays (XMM-DR7 [2]) and the visible domain (GAIA DR1 & DR2 [4,5]) using the algorithm NWAY [6] which uses a Bayesian approach to identify the most likely matches. A careful selection of the numerous matched pairs can then be done using various properties (X-ray spectral hardness, X-ray to visible flux ratio, etc.) in order to extract the most interesting candidates.

Background – Motivation

- Neutron stars are very interesting compact objects where an extremely high density occurs. Understanding the nature of the material in their interiors is essential for the comprehension of the nature of cold and dense matter.
- Identifying new neutron stars can help our understanding of cold dense matter and help to constrain models of stellar evolution and the initial mass functions of galaxies

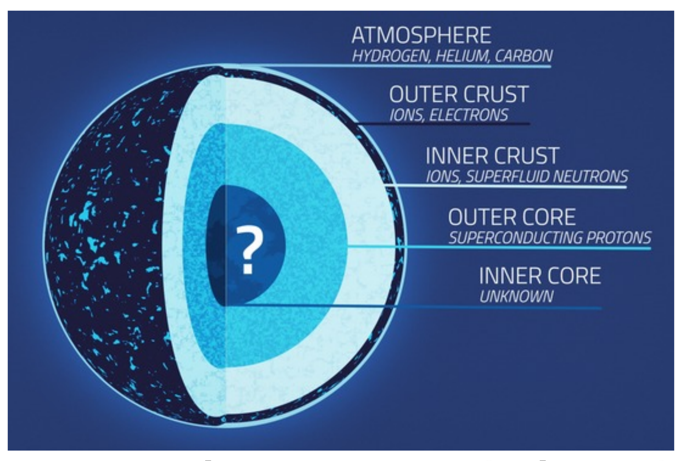


Figure 1: Inside a neutron star. Credits: NASA

But…
- Neutron stars are difficult to identify and study using X-rays alone

So…
- We decided to cross-correlate X-Ray catalogue with an Optical one in order to also have information on the parallaxes, magnitudes or proper motion for the counterparts found.

XMM-Newton

Launched in 1999, XMM-Newton [1] is a telescope developed by ESA for soft X-ray (0.2-12 kev) observations.

- The DR7 [2]: more than 727,000 detections (500,000 are unique sources).
- Models of spectral-fitting from the XMMFITCAT catalogue [8]

→ Blackbody spectral models (sometimes with the addition of a power law) can give a good description of (accreting) neutron stars

GAIA

Launched in 2013, the GAIA telescope [3] was also developed by ESA, for the optical wavelengths (0.33-1.05µm).

- DR1 [4] in 2016 – DR2 [5] in April 2018
- More than 10^9 stars detected
- Provides Positions, parallaxes, magnitudes and proper motion

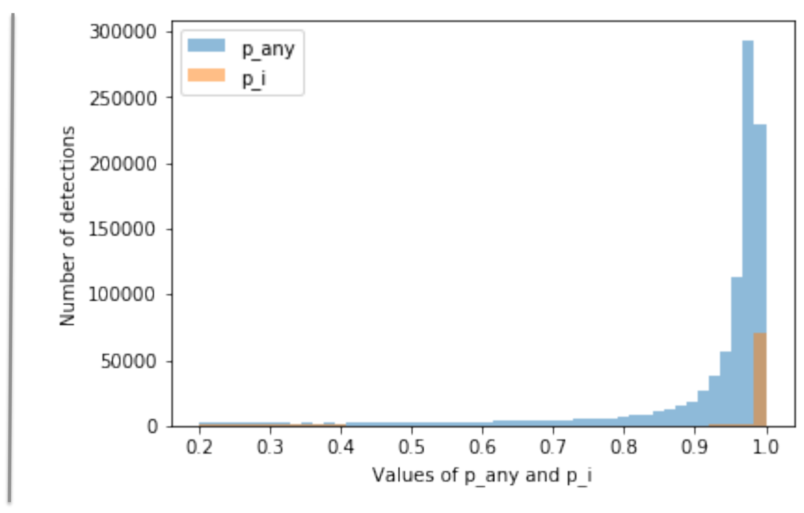
NWAY [6]: Source cross-matching tool for astronomical catalogues

NWAY is a powerful tool developed for identifying the multi-wavelength counterparts of multiple catalogues. It is a python code based on the original work of [7].

- Inputs/constraints

→ The use of catalogues as fits files
→ Adding a total coverage header (area in square degrees)
→ Specific column names
→ Columns RA and DEC in degrees

We then obtain a new table with all the matches and probabilities



$$p_{any} = 1 - P(H_0|D) / \Sigma (H_i|D)$$

$$p_i = P(H_i|D) / \Sigma (P(H_i|D)$$

Figure 2: probabilities from NWAY on 1.5 million of matches.
p_{any} representing the probability that the source as any counterpart in the other catalogue and p_i representing the probability that this association is the good one.
H_1 and H_0 are hypothesis of association: if the sources belong to the same object (H_1) or if they are coincidently aligned (H_0)

Results - Future

Currently I obtain almost 1,700 candidates with GAIA DR1 (over more than 5 million matches) and the selection of the data from the cross-correlation with DR2 is in progress. The selection is mainly based on these criteria:

- Probabilities given by NWAY (p_{any} and p_i explained above on Fig.2) which allowed to reduce to nearly 10,000 possibilities
- Point-like sources well fitted with blackbody (+power law) models are good neutron star candidates

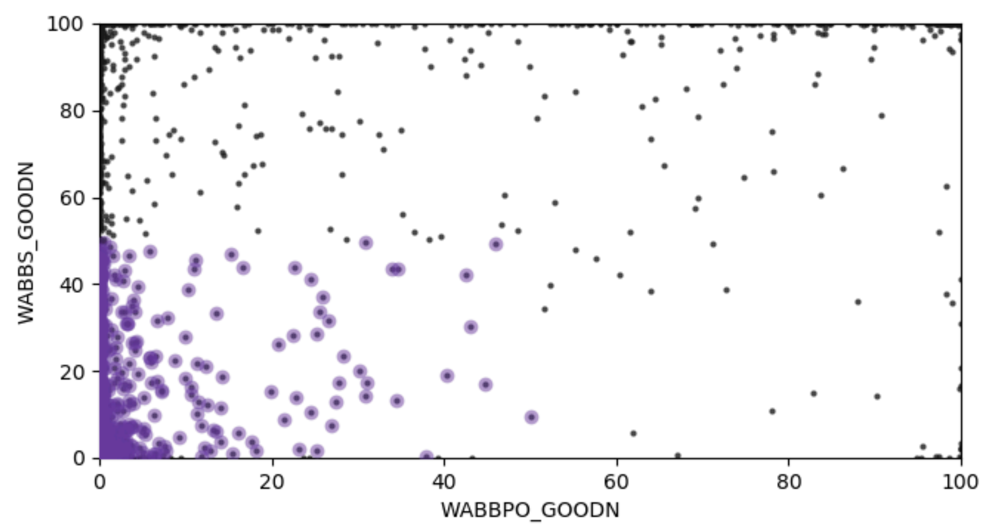


Figure 3: Goodness of the blackbody (WABBS) and the black body plus power law (WABBPO) spectral models.
It represents the degree of rejection confidence. Selection was based on a criterion of less than 50%.

Using the X-ray to optical flux ratio we will estimate the emission region of the neutron stars. Using the distances from Gaia we will deduce the radius for the neutron star, essential for constraining the neutron star equation of state.

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