Short term scientific mission within COST Action MP1304: "Exploring fundamental physics with compact stars" – Scientific report

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1 Purpose

The main purpose of my short term scientific mission (STSM) at the Anton Pannekoek Institute for Astronomy of the University of Amsterdam (from 2016 November 1st to December 31st; reference: ECOST-STSM-MP1304-011116-080064) was to pursue my PhD project on X-ray observations of ultra-magnetized isolated neutron stars and accreting binary systems in a close 2-month day-by-day interaction with Dr. Rea's group.

Dr. Nanda Rea at the Anton Pannekoek Institute of the University of Amsterdam is an external advisor of my thesis. Her group has been created one year and a half ago, and comprises a PhD student, Alice Borghese, working on radio and X-ray timing of highly magnetic neutron stars and population synthesis simulations, a post-doctoral researcher, Dr. Justin Elfritz, dedicated to 2D/3D numerical simulations of neutron star magneto-thermal cooling, and a senior post-doctoral researcher, Dr. Paolo Esposito, focused on multi-band observations of Galactic compact objects. The group is young and lively, and well balanced in terms of theoretical and observational studies.

2 Description of the work and main results obtained

• I performed analysis of a large data sets as part of a multiwavelength monitoring campaign of RX J0838−2827, an X-ray source spatially compatible with the gamma-ray source 3FGL J0838.8−2829 in the Fermi catalogue which we have tentatively identified as an asynchronous polar: a strongly magnetized white dwarf in a binary system with a low mass main sequence star. In particular, I carried out all the analysis (both spectral and temporal) of the *XMM-Newton* (EPIC, OM and RGS instruments), *Swift* (XRT and UVOT instruments) and infrared data of this object as well as the other X-ray sources compatible with the gamma-ray source. RX J0838−2827 is extremely variable in the X-ray and optical wavelengths, and timing analysis reveals the presence of several prominent peaks in the X-ray power spectrum. We ascribed the most significant periodcities to the orbital period of the binary system (~ 5.9 ks) and the spin period of the white dwarf (~ 5.3 ks). Furthermore, we observed a strong modulation of the flux at ~ 54.7 ks at all energy bands, consistent with the beat periodicity between the spin and orbital periods. Interestingly, optical spectra show prominent Hβ, HeI and HeII lines doppler modulated at the binary orbital period and at the long 15.2hr beat period. We concluded that RX J0838−2827 accretes through a disc-less configuration and could be either a strongly asynchronous Polar or a rare example of a pre-polar system in its way to reach synchronism. A poster describing these results was presented at the EXTraS Workshop in Pavia (November 21–23, 2016).

• In search for new isolated compact objects in the Galaxy, I started working on the data analysis of a unique X-ray point source (which we dubbed CXO J0717+3746) with no associated optical counterpart at high Galactic latitude ($b = +21^{\circ}$) in the field of the galaxy cluster MACS J0717.5+3745. I analysed observations with the *Chandra* satellite and found no significant variations of the X-ray properties of the source between 2003 and 2013. Modeling of the average X-ray spectrum revealed a negligible absorption by the interstellar medium and a flux $\sim 1 \times 10^{-14}$ erg cm^{-2} s^{-1} (0.3–10 keV). The upper limits for the optical brightness derived from exposures of the field with the *Hubble Space Telescope* imply an unabsorbed X-ray-to-optical flux ratio $F_X/F_I > 1600$ (at 3σ confidence level). All these properties nail down this object as an isolated neutron star in our Galaxy. Interpretation of our results started during my visit, and is still ongoing.

• I was involved in the preparation of the revision of a paper on the results of a detailed phase-resolved spectroscopy of archival *XMM-Newton* observations of X-ray Dim Isolated Neutron Stars (XDINSs). Our analysis revealed a narrow and strongly phase-variable absorption feature in the X-ray spectrum of RXJ1308.6+2127 during the entire timespan covered by the observations (2001 December - 2007 June). The strong dependence on the pulsar rotation and the narrow width suggest that the feature is likely due to resonant cyclotron absorption/scattering in a confined structure with a high magnetic field close to the stellar surface. Assuming a proton cyclotron line, the magnetic field strength in the loop is about a factor of ∼5 higher than the surface dipolar magnetic field, and shows (as expected by theoretical simulations) that small scale magnetic loops close to the surface might be common to many highly magnetic neutron stars. We also investigated the available *XMM-Newton* data of all XDINSs in search for similar narrow phase-dependent features, but could derive only upper limits for all other sources.

• I led the preparation of an observing proposal with *XMM-Newton* (proposal number 080438, PI: Coti Zelati, "First *XMM-Newton* observation of the unique eclipsing transitional millisecond pulsar candidate 3FGL J0427.9−6704"). The proposal was focused on 3FGL J0427.9−6704, a recently proposed transitional millisecond pulsar candidate (i.e., a binary system hosting a neutron star that is observed to swing between an accretion and a rotation powered state). The system is a neutron star low-mass X-ray binary spatially compatible with an uncatalogued γ-ray source, and shows H and He double-peaked lines in its optical spectrum and short-term X-ray variability (detected with *NuSTAR*), similarly to the known transitional millisecond pulsars. Moreover, the high inclination of the system makes it one of the few eclipsing low-mass X-ray binaries and a unique test-bed among transitional pulsars. The proposal aimed at studying simultaneously its soft X-ray and optical emission, and in particular at characterizing its short-term soft X-ray variability, studying the profile shape, duration and spectrum of the eclipse, and searching for X-ray pulsations at lower energies. I was also involved as co-investigator in the preparation of other observing proposals with the *XMM-Newton* (two of them were allocated time) and *Kepler2* satellites.

3 Foreseen publications resulting from the STSM

The interaction with Dr Rea's group during the STSM led to the preparation of two papers. A paper entitled "Multi-band study of a new asynchronous magnetic cataclysmic variable and a flaring X-ray source" by N. Rea, F. Coti Zelati et al. was submitted to

"Monthly Notices of the Royal Astronomical Society" (MNRAS). The other one on the source CXO J0717+3746 is currently in preparation and will be submitted to the same journal after finalization of the interpretation of the results (within the end of January). The paper "Narrow phase-dependent features in X-ray Dim Isolated Neutron Stars: a new detection and upper limits" by A. Borghese, N. Rea, F. Coti Zelati et al. on the phase-resolved spectroscopy of X-ray dim isolated neutron stars was submitted to the same journal a few months ago and a favorable review was received. The answer to the reviewer has already been discussed and edited, and the revised version of the paper will be submitted within the next month.

Copies of the papers written during the STSM (either submitted or in preparation) can be produced upon request. In any publication resulted from this short stay, the NewCompStar action was acknowledged by including the following sentence: "FCZ is supported by the European COST Action MP1304 (NewCOMPSTAR)".

4 Future collaboration with the host institution

I am going to continue a close collaboration with Dr Rea's group at the University of Amsterdam for the upcoming years. An ongoing project within our group concerns a systematic study of outbursts from magnetars (i.e. isolated ultra-magnetized neutron stars), from the very first active phases throughout the decay. After one year and a half of systematic analyses of more than 800 X-ray observations of magnetar outbursts in a coherent way (with a particular attention on modeling their spectra using physically-motivated resonant cyclotron scattering codes), I now plan to compare the characteristics of the outburst decays over a vast sample of sources (18 in total), and search for correlations among different physical parameters (magnetic field, energetics, peak luminosity). Moreover, I will reproduce the outburst decays with state-of-the-art crustal cooling models, a unique and profitable tool to investigate the interior properties of NSs, such as the crustal structure and composition, as well as the role of neutrino emission processes in the outburst evolution. A close interaction with Dr. Rea and her group will give me the opportunity to enlarge my theoretical background on ultra-magnetized isolated neutron stars, which is definitely needed to get a comprehensive picture of the physics underlying these very peculiar compact stars.