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

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Purpose

The main purpose of my short term scientific mission (STSM) at the Anton Pannekoek Institute for Astronomy of the University of Amsterdam (from 2014 September 1st to November 30th) was the prosecution of my PhD project on X-ray observations of ultra-magnetized isolated neutron stars. Dr. Nanda Rea at the University of Amsterdam is an external supervisor of my PhD thesis at the University of Insubria (in Como, Italy). Her group comprises a PhD student (Alice Borghese) working on radio and X-ray timing of highly magnetic neutron stars, and a post-doctoral researcher (Dr. Justin Elfritz) dedicated to 3D MHD simulations of neutron star cooling. The group is young and lively, and well balanced in terms of theoretical and observational studies.

During my stay in Amsterdam I could greatly benefit from a close 3-month day-by-day interaction with Dr. Rea's group, as well as other scientists with experience relevant to isolated and accreting neutron stars (among others, Prof. Michiel van der Klis, Dr. Rudy Wijnands and Dr. Jason Hessels). Moreover, I had the opportunity to attend the weekly "X-ray timing group" meetings and the colloquia organized by the institute. The former allowed me to take my first steps in the timing analysis techniques, whereas the latter gave me the possibility to discuss on topics closely related to my project with experts in the field, in particular Dr. Chryssa Kouveliotou (from the NASA's Marshall Space Flight Center) and Prof. Geoffrey Bower (from the University of California).

Description of the work and of the main results obtained

During my STSM in Amsterdam, I worked mainly on the data analysis of the long-term X-ray monitoring campaign of the magnetar SGR 1745-2900. This source was discovered as it underwent an X-ray outburst in 2013 April at only 2.4 arcsec from the supermassive black hole at the Centre of the Milky Way. It has a spin-down magnetic field of $\sim 2 \times 10^{14}$ Gauss and it is the neutron star closest to a black hole observed to date. It was detected both in the X-ray and radio bands, with a peak luminosity $L_X \sim 5 \times 10^{35}$ erg s^{-1}. We analysed 25 observations performed with the *Chandra X-ray Observatory* and 3 more with the *XMM–Newton* satellite spanning a time interval of $\sim$ 500 days, from the onset of the outburst in 2013 April until 2014 August. This unprecedented dataset allowed us to refine the timing properties of this pulsar, as well as to study the outburst spectral evolution as a function of time and rotational phase. The observed flux decay is very slow compared to other magnetars' outbursts and it challenges most of the crustal cooling models. Instead, it is likely that a large contribution to the emission arises from Ohmic heating of the star surface from currents flowing in a twisted bundle of magnetic field lines.

More recently, inspired by the discovery of a phase-dependent absorption feature in a magnetar (Tiengo et al., 2013, Nature), we started a systematic search for similar features in the class of X-ray dim isolated neutron stars. These are relatively close-by (less than a few hundred parsecs), middle-age (several hundred thousand years) isolated neutron stars emitting soft X-rays due to cooling and seven such sources are known to date (the so called "Magnificent Seven"). This investigation led to a clear detection of a phase-dependent absorption feature in the X-ray spectrum of RX J0720.4$-$3125, during the longest available *XMM–Newton* observation of this star. We are currently performing a detailed phase-resolved spectral analysis of all 20 *XMM–Newton* observations of this source in order to characterize the variability of such feature as a function of time and neutron star rotation (resulting in the analysis of more than 100 X-ray spectra). This feature, if interpreted as due to proton resonant cyclotron scattering, provides the first compelling evidence for the existence of non-purely-dipolar magnetic field configurations near the surface of these neutron stars.

I was also involved as co-investigator in the preparation of some observing proposals with the *XMM–Newton* satellite. Among others, we asked to observe the possible new transitional binary millisecond pulsar candidate 1RXS J0838−2827 (PI: Dr. Rea). To date, three systems have been observed to swing between an accretion powered (X-ray pulsar) and a rotation powered (radio pulsar) state. To enlarge the number of systems caught in this transitional phase is crucial to test binary evolution theories, and study the disk-field interaction over a large range of mass accretion rates. Another proposal was focused on the latest discovered magnetar, SGR 1935+2154, which is of particular interest due to a diffuse emission component clearly detected around the source (PI: Dr. Israel). Further X-ray observations will allow us to infer the main pulsar parameters, monitor its decay and carry out a detailed study of the extended emission, possibly unveiling its real nature (it might be either the signature of the elusive magnetar wind nebula or a dust-scattering halo). We also asked for new observations of the Galactic Centre magnetar to refine its spin period evolution and monitor its flux and spectral decay on a longer temporal baseline (PI: Dr. Ponti).

Foreseen publications resulting from the STSM

The interaction with Dr Rea's group during the STSM led to the preparation of two articles which will be submitted for publication in two refereed journals: one concerning the X-ray long-term monitoring campaign of the Galactic Centre magnetar (to be submitted to "Monthly Notices of the Royal Astronomical Society") and one related to the discovery of a phase-dependent absorption feature in an X-ray dim isolated neutron star (in preparation). Further X-ray observations of the magnetar at the Galactic Centre and related analysis will be included in future works.

Future collaboration with the host institution

I am going to continue a close collaboration with Dr Rea's group at the University of Amsterdam until the end of my PhD (for about half a year every year). My project envisages also a systematic study of magnetars' outbursts, from the very first active phases throughout the decay. I will re-analyze all available X-ray observations of all magnetars' outbursts (about 15 outbursts were monitored with hundreds of observations by *Swift*, *RXTE*, *Chandra* and *XMM–Newton*) in a coherent way, with a particular attention on modeling their spectra using physically-motivated resonant cyclotron scattering codes. Further I plan to model these decays with a recent crustal cooling model developed by Pons & Rea (2012, The Astrophysical Journal Letters), and compare the outburst decay characteristics over all available sources. A close interaction with Dr. Rea and her group will give me the great opportunity to pursue these studies in a very stimulating research environment and at the same time 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.