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Neutron star observations with WFXT

S. Campana

Istituto Nazionale di Astrofisica – Osservatorio astronomico di Brera, Via E. Bianchi, I-23807, Merate (LC), Italy e-mail: `sergio.campana@brera.inaf.it`

Abstract. The Wide-Field X-ray Telescope (WFXT, see Rosati et al. in this volume) is a proposed NASA mission dedicated to performing surveys of the sky in the soft X-ray band (0.3 – 6 keV). The key characteristics of this missions are a constant point spead function with Half Energy Width of ∼ 5 arcsec over ∼ 1 degree fielf of view as well as an effective area ∼ 10 times larger than the one of Chandra. Despite the fact tjat the mission is tailored for extragalactic purposes, we show here that extremely inetersting results can also be obtained on the study of neutron stars.

Key words. Neutron: stars – X-rays

1. Introduction: status

Neutron stars are formed in supernova explosions and live their early life as rotationally powered emitters, shining mainly in the high energy band. A small fraction of the neutron star spin-down power goes in the radio band in the form of pulsed emission, making their discovery possible. As newborn objects, neutron stars are also very hot (millions of degrees) and emit in the soft X–ray band thanks to the cooling of the compact object. As the neutron star ages its spin-down power and internal heat decreases and it becomes readily unobservable. Only for compact objects in close binary systems there is an additional way to power their emission thanks to the exchange of mass from the companion to the neutron star. Accretion of matter onto a compact object naturally leads to emission in the X–ray band, powering the so-called X–ray binaries.

Stable mass transfer onto compact objects produces the brightest objects in the X–ray sky. For this reason our knowledge of the population of X–ray binaries in the Galaxy started with the first all-sky hard-band survey from the Uhuru satellite. Monitoring instruments such as the RossiXTE ASM and now INTEGRAL, Swift BAT and MAXI provide a nearly real-time census of the population of bright X–ray binaries in our Galaxy and in our closeby neighboorhood. With these instruments we have access, however, only to the brightest tip of the population. It was clear from the first X–ray missions that, together with persistent sources, there is a large population of transient X–ray binaries which spend most of their time (90 – 99%) in quiescence and show signs of X–ray activity only for very limited periods of time (during which they share the same properties of persistently bright sources). With the coming of new facilities such as XMM-Newton and Chandra it became clear that intermediate luminosity X–ray binaries are also present, but difficult to discover and, in turn, difficult to study.

Send offprint requests to: S. Campana

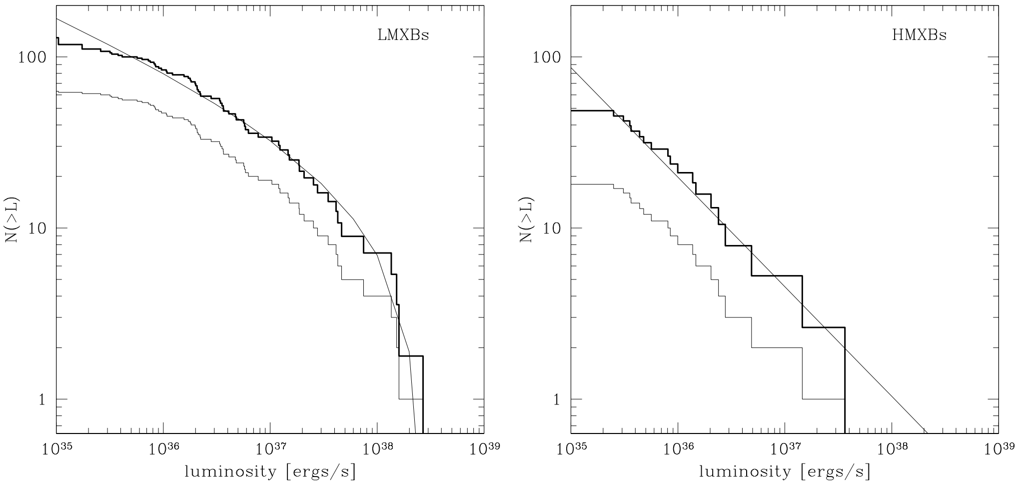

Fig. 1. The apparent (thin histogram) and volume corrected (thick histogram) cumulative luminosity function for Low Mass X–ray Binaries and High Mass X–ray Binaries. The solid lines are the best fits to the data (from (Grimm et al. 2002)). Credit: Grimm et al., A&A, 391, 923, 2002, reproduced with permission © ESO.

Our present view on quiescent and intermediate luminosity X–ray binaries comes from the ROSAT All Sky Survey (RASS) in the soft band only and from partial or limited serendipitous surveys carried out with imaging satellites like XMM-Newton and Chandra.

2. A WFXT survey of the Galactic plane: neutron stars

Actually our knowledge of X–ray binaries as a population relies only on studies with the RossiXTE ASM, providing luminosity function of high-mass and low-mass X–ray binaries (depending on the mass of the companion) down to luminosities of the order of $10^{35}-10^{36}$ erg s^{-1} (Grimm et al. 2002, see also Fig. 1). This clearly provides only a biased view of the population missing the great majority of faint objects. In addition, below this limiting luminosity level accretion onto neutron stars in high mass (magnetic field $B\sim10^{12}$ G and spin periods in the few seconds range for the fastest pulsators) and low mass (magnetic field $B\sim10^{8-9}$ G and spin periods of a few milliseconds) X–ray binary transients might enter in accretion regimes different from the direct fall of matter onto the neutron star surface (e.g. Campana et al. 1998). These regimes (e.g. propeller, reactivation of a radio pulsar) are basically unexplored as a population. In quiescence X–ray binary transients are observationally in the $\sim 5\times10^{31}-10^{33}$ erg s^{-1} range (e.g. Campana 2004).

A WFXT survey of the Galactic plane comparable in depth with the 'wide' survey (i.e. reaching a flux limit of $\sim\,3\times10^{-15}$ erg cm^{-2} s^{-1} will reach a luminosity limit of $\sim10^{32}$ erg s^{-1} throughout the Galaxy, providing a complete census of the X–ray binary population. A complete census of the X–ray binary population will help constraining the formation and evolutionary models.

A similar mapping can be achieved on the Magellanic Clouds with a survey comparable in depth to the 'medium' survey. Studying the properties of X–ray binary sources in the Magellanic Clouds rather than in our own Galaxy presents several advantages: *i*) the distance of all sources are well known; *ii*) the much lower column density allows us to investigate a much wider spectral range than it is possible in the Galactic plane. The importance of this low column density is highlighted by

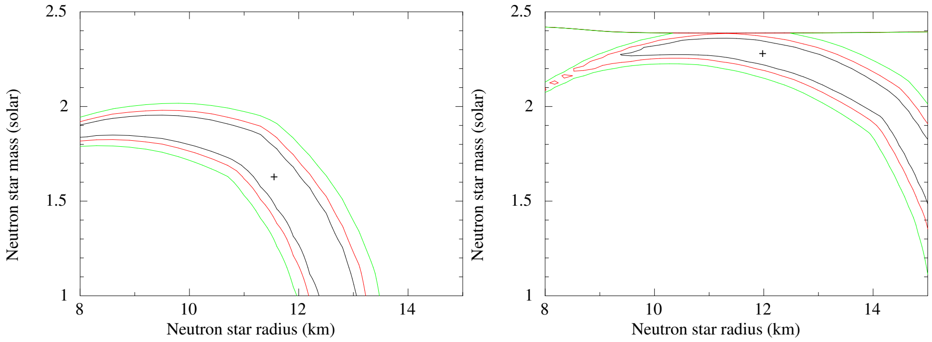

Fig. 2. Typical mass-radius relation that can be obtained with WFXT observing for 100 ks a neutron star low mass transient in quiescence. Simulations were carried out taking the quiescent transient in Omega Cen as a template. In the left panel a mass and radius of 1.66 $M_{\odot}$ and 11.6 km were selected, respectively; in the right panel 2.25 $M_{\odot}$ and 12 km.

e.g. the large number of supersoft sources discovered in the Magellanic Clouds; *iii*) since the metallicities of the Magellanic Clouds differ from that of our Galaxy, a comparison of their X–ray population will help us understanding the role of abundances in their properties.

2.1. Globular Clusters

Globular clusters contain a large number of X–ray binaries, that are formed thanks to close encounters (Heinke et al. 2003) and the large majority of them are quiescent. The X–ray spectrum of a transient low mass X-ray binary in quiescence comprises two spectral components: one hard usually modelled with a power law (with variable importance of a source-by-source basis, from $\lesssim 3\%$ to $\sim 50\%$) and the other soft modelled with a black body emission. The soft component is also consistent with emission coming from the cooling of the entire neutron star surface that has been heated during (transient) accretion episodes (Brown et al. 1998). This emission is well understood and, if data of very good quality are gathered, in principle, it can provide a tool to disentangle the small spectral differences induced by different neutron star masses and radii. Given the large area of WFXT, 100 ks observation will allow to set strong constraints on the neutron star equation of state through observations of transient low mass X-ray binaries in quiescence (see Fig. 2).

In addition, globular clusters contain also a large number of recycled millisecond pulsars (Bogdanov et al. 2006). A statistical study of millisecond radio pulsars can provide insight on the energy conversion mechanism of spin down power into high energy photons.

2.2. Galactic Center

Thanks to the Chandra observatory the Galactic center region has been mapped in exquisite details (Wang et al. 2002; Muno et al. 2009). A scan of two degree across the Galactic center has been carried out (with 2 Ms exposure) reaching a completeness 0.5–8 keV flux limit of 4×10^{32} erg s^{-1} and up to an order of magnitude more sensitive in the deepest exposure around Sgr A (see Fig. 3). 9017 X–ray sources were detected. The majority of the absorbed sources ($N_H > 4 \times 10^{22}$ cm^{-2}) are made by cataclysmic variables, even if a number of transients have been discovered. WFXT can cover the same area more deeply by an order of magnitude in in 200 ks. This opens the possibility of variability studies either temporal and spectral. Monitoring programs can be very effective in discovery faint or very faint transients ($L \sim 10^{34} - 10^{36}$ erg s^{-1}) that cannot be detected and followed by all-sky monitor instruments. Explorative campaigns have

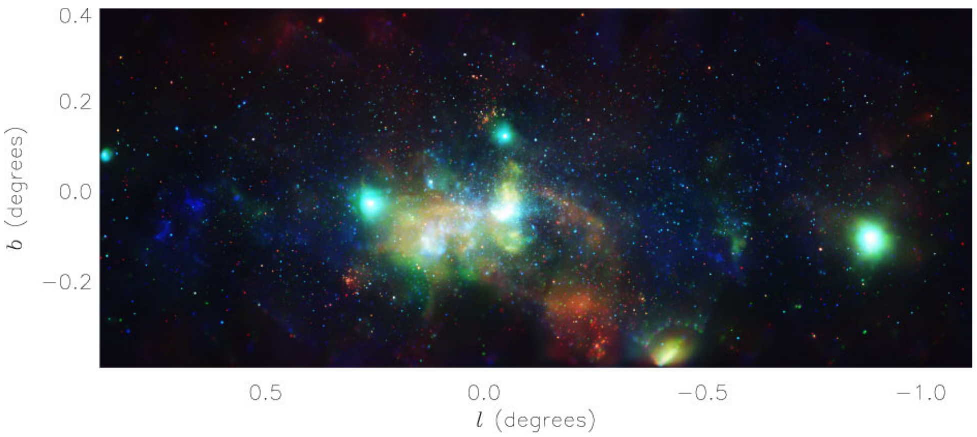

Fig. 3. Three-color image of the Galactic center region. Red is 1–3 keV, green is 3–5 keV, and blue is 5–8 keV, from Muno et al. (2009). Reproduced by permission of the AAS.

been carried out in the Galactic center region with Chandra and XMM-Newton (Wijnands et al. 2006). These systems are poorly studied and only focussing telescope surveys can reveal and study their population (Campana 2009).

2.3. Old neutron stars

About 10^9 neutron stars are thought to populate our Galaxy, but only $\sim 2 \times 10^3$ are directly observed as radio pulsars or as accretion-powered X–ray binaries (see Fig. 4). In principle also the accretion of the interstellar medium material may make isolated neutron stars shine, and their weak luminosity could be detected in soft X–rays. Recent ROSAT observations have convincingly shown that neutron stars accreting from the interstellar medium are extremely rare, if observed at all, in contrast with earlier theoretical predictions. In addition, accreting objects can be confused with much younger, cooling neutron stars. However, a combination of observations and theoretical modeling may help in discriminating between the two classes (Treves et al. 2000).

Clearly also isolated cooling neutron stars are extremely important targets since they can shed light on the supernova explosion rate in the Galaxy and chemical evolution. The ROSAT All-Sky-Survey is the only available survey for this kind of studies. Turner et al. (2010), using new and archival observations made with the Swift satellite and other facilities, examined 147 X–ray sources selected from the RASS Bright Source Catalog (BSC) searching for isolated neutron stars (INS). Independent of X–ray spectrum and variability, the number of INSs is $\lesssim 48$ (90% confidence). Restricting attention to soft ($T < 200$ eV), non-variable X–ray sources they put an all-sky limit of $\lesssim 31$ INSs. Five new objects were also detected. A future (nearly) all-sky X–ray survey with WFXT can be expected to increase the detected population of X–ray-discovered INSs from the 8 to 50 in the BSC, to (for a disk population) 240 to 1500, which will enable a more detailed study of neutron star population models.

3. Conclusions

The Wide Field X-Ray Telescope (WFXT) is a medium-class mission designed to be 2-orders-of-magnitude more sensitive than any previous or planned X–ray mission for large area surveys and to match in sensitivity the next generation of wide-area optical, IR, and radio surveys. The WFXT mission is scientifically broad. The main focus of the mission is on extragalactic science but, as shown above, many important topics can be covered by WFXT concerning neutron stars.

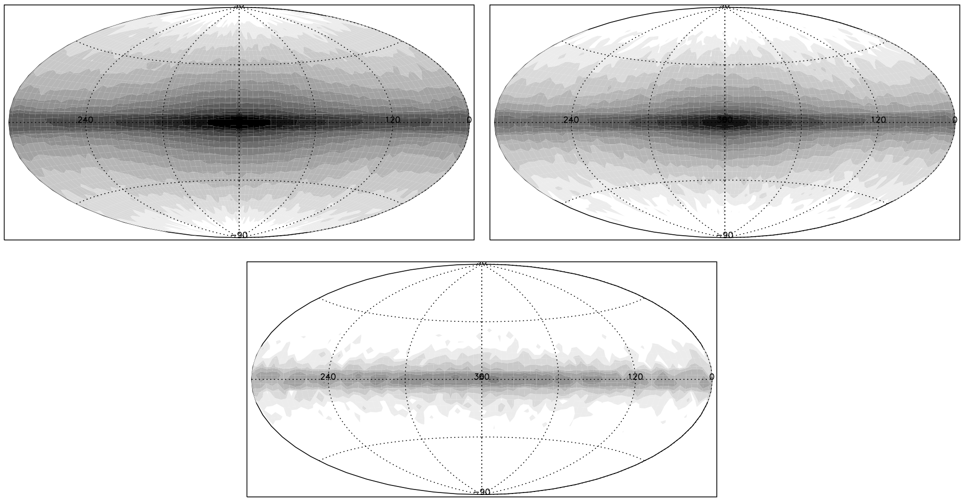

Fig. 4. Sky maps of the projected density of neutron star (N_{star} = 10^9) - The cut-off distances are 30 kpc (upper panel), 10 kpc (central panel) and 3 kpc (lower panel) respectively. The density scale is normalized to the maximum density at 30 kpc, from (Sartone et al. 2010). Credit: Sartone et al., A&A, 510, A23, 2010, reproduced with permission © ESO.

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