6.3 Stellar mass compact objects

6.3.1 Galactic sources

Galactic compact X-ray sources contain a white dwarf star, a neutron star or a stellar mass black hole. They form a heterogeneous class of X-ray emitters, that may be powered by accretion, eruption, magnetic field decay, stellar spin-down, collapse, remnant heat and other less common mechanisms. Galactic compact X-ray emitters hold the key to understand evolutionary channels both of single and binary stars. As individuals they offer incredible diagnostic power via timing and spectroscopy; as a class, they provide key information on population synthesis models and are essential to unveil the nature of the diffuse galactic ridge X-ray emission observed in the Milky Way and in other galaxies.

The scientific impact of the eRosita survey in the field of compact objects in our (and nearby galaxies) is governed by two factors: (1) its discovery potential and (2) its monitoring capability potential. The discovery power lies in the eRosita ability to detect many new point-like X-ray source identifying galactic compact candidates (or compact objects in the MCs) among them. The latter is a very challenging task which will in most cases require follow-up X-ray or MWL observations (see Chapter 7). However, a number of identifications will already be possible on the basis of the eRosita data alone thanks to the instrument's spectral (up to several keV) and timing resolution which were very limited in the previous surveys.

The monitoring potential of eRosita is related to the observational strategy during the survey which allows multiple observations of a considerable portion of the sky around ecliptic poles. Many X-ray sources located in those regions will therefore be repeatedly observed with an "XMM-class"instrument for the first time, which will allow an unprecedented study of their long-term flux-, spectral and timing variability.

The following paragraphs describe the objectives of the eROSITA mission per source class, beginning with the single compact objects followed by the more abundant accreting binaries; within those main classes ordering is done according to gravity.

6.3.2 Isolated systems

Isolated WDs

The final phase of evolution of low and intermediate mass stars begins with their departure from the AGB. They evolve at almost constant luminosity towards extremely high effective temperatures (T_{eff} > 100 000 K) while they are burning H or He in shells. When their nuclear burning finally ceases, the stars begin to fade and cool and enter the hot end of the white dwarf cooling sequence. Thermal soft X-ray emission is detected from many hot hydrogen-rich white dwarfs (spectral type DA) with an effective temperature in excess of $T_{eff} \sim$ 20 000 K. The actual X-ray spectral shape of pre-white dwarfs and white dwarfs is very much dependent on the chemical composition of their atmospheres, which is enriched by radiative levitation of trace metals. All those objects have a relatively soft X-ray spectrum which can be modeled in great detail (e.g. Werner et al. 2004). They are thus invaluable for the calibration of spectrally resolving X-ray instruments. The hydrogen-rich DA-type white dwarfs HZ 43 A (Teff = 51 100 K) and Sirius B (Teff = 24 900 K) in particular were used to establish soft X-ray standards allowing intercalibration between X-ray observatories (Beuermann et al. 2006) and will be used as ideal calibration targets for eROSITA as well.

Isolated Neutron stars

The observed population of neutron stars is dominated by radio pulsars. In recent years, however, different subclasses of isolated neutron stars (INSs), characterized by peculiar properties and not yet understood physics, have been discovered: magnetars, thermally emitting INSs (a.k.a. the ``Magnificent Seven'' or XDINS), central compact objects in supernova remnants and rotating radio transients. While currently fewer in number, they might represent a considerable fraction of the neutron stars in the Galaxy. The few sources known are impacting already on our understanding of the physics of matter at extreme conditions of gravity and magnetic field. Understanding evolutionary relations between different subgroups and extablishing a comprehensive picture of neutron star birth and evolution in the Milky Way requires larger sample than known today. Highly sensitive optical surveys (such as SDSS, VISTA etc.) coupled to the 30 fold increase eRosita sensitivity, with respect to ROSAT, will enable the mission to discover and identify many new members in the classes of INS. While MWL follow up of several candidates will still be crucial, as a matter of fact magnetars (AXPs, SGRs), CCOs, M7-like and young X-ray bright pulsars all have very faint optical companions which are difficult to identify: the timing and spectral capabilities of eRosita come as a valuable addition in the identification process.

In particular, XDINS constitute a homogeneous group of seven nearby, cooling, middle-aged INSs discovered by ROSAT, which display unique properties. Their proximity and the combination of strong thermal radiation and absence of significant magnetospheric activity make them ideal targets for testing atmosphere models, deriving radii and constraining the equation of state of neutron star interior. It is remarkable that a group of very similar sources, displaying at the same time unique properties that are so different from ordinary radio pulsars, are all detected in the very local Solar vicinity. Is this fact an anomaly caused by the Sun's current location near regions of active star formation of the Gould Belt or is it really meaning that radio surveys do miss a large population of INSs, at least as large as that of standard radio pulsars? Answering these questions will be possible with the unprecedented survey efficiency of eROSITA. Based on a population synthesis model (Pires 2009), it will allow the detection of an estimated number of 60 to 100 new X-ray thermally emitting INSs with more than 100 photons thus increasing the population by an order of magnitude. A major statistical and observational challenge will be the identification of the new XDINS in suitably taylored optical follow-up programs.

Before ROSAT, predictions were made to discover thousands of isolated neutron stars reheated by accretion from the interstellar medium (e.g. Treves & Colpi 1991; Blaes & Madau 1993) but none were found. The much larger sensitivity of eROSITA will shed new light on the Bondi accretion efficiency and the NS velocity distribution.

Isolated BHs

TBW

6.3.3 Binary systems

Most of the X-ray compact objects are found in accreting binaries, in which a compact companion (a white dwarf, a neutron star or a BH) accretes matter from a primary star. In High mass X-ray binaries (HMXRBs), the primary star is a massive (M > 10 solar masses) Be or Oe star characterized by a variable disk-like envelope along its rotational equatorial plane. In Low Mass X-ray Binaries (LMXRBs) plasma from a later than type A star (M < 1 Solar Mass) or a white dwarf, is accreted onto a compact companion. In all these systems the compact companion accretes matter from the primary star, either via an accretion disk or an accretion stream/curtain fed by Roche-lobe overflow, via a stellar wind or via rapid thermal-timescale mass transfer.

Cataclysmic variables

Cataclysmic variables are binary systems containing either magnetic or non-magnetic white dwarfs (CVs and MCVs). Some subclass is expected to contain the long-sought progenitor of the Supernova type Ia explosions, candidates being the double degenerates (DD), the Recurrent Novae, and the Supersoft X-ray Sources (SSS). In addition, DDs will serve as calibration targets for gravitational wave antennae. CVs in general hold the key to explain the mysterious Galactic Ridge X-ray Emission (GRXE), and they are crucial to quantify our understanding of close-binary evolution.

Although several hundred CVs are known we are far from establishing a coherent picture about their evolutionary role and their contribution to the X-ray active Milky Way. Main reasons are the highly biased sample composition and the uncertainties un the distances for complete samples. Cataclysmic binaries were detected in various ways, due to their strong variability, their blue color or due to pronounced soft X-ray emission, and each method left largely unknown imprint on the observed population. Complete sample that were used to determine space density comprise typically one or two handful of objects and estimated space densities vary by up to two orders of magnitude (Hertz et al. 1994, Schwope et al. 2002, Pretorius et al. 2007).

The situation will substantially change since the eROSITA survey will unravel the zoo of compact binaries for the first time within ~1kpc radius down to a luminosity of 10^{30} erg s^{-1}, the minimum luminosity of CVs in the ROSAT Bright Survey (RBS, Schwope et al. 2002) and the ROSAT NEP (North Ecliptic Pole survey, Pretorius et al. 2007). Assuming the current best estimates of the population parameters, a galactic scale height of 150 pc and a mid-plane space density of ρ_0 = $1.1x10^{-5}$ pc^{-3}, the eROSITA All Sky Survey is expected to detect more than 4000 non-magnetic CVs in a flux-limited sample with radius 900 pc. Predictions were made that the mid-plane space density of CVs might be as high as $2x10^{-4}$ pc^{-3} (Kolb 1993). Should such a population exist, it would have luminosities below $2x10^{-29}$ erg s^{-1} (Pretorius et al. 2007) and about 5000 of those low luminosity sources would populate the eROSITA X-ray sky.

Most CVs will be discovered in the soft band between 0.5 and 2 keV. Recent surveys at higher energies with Swift, INTEGRAL, and RXTE have revealed a significant number of magnetic CVs (Intermediate Polars and asynchonous Polars) that might be sufficiently abundant to synthesize the GRXE. Adopting a minimum IP luminosity in the 2-10 keV band of 10^{32} erg s^{-1} and a 10% IP fraction among the CVs, eROSITA will yield a flux-limited IP sample with radius 1.7 kpc that contains 9000 IPs. While one has to admit that these numbers are highly uncertain there is little doubt that the eROSITA sky will contain a few thousand cataclysmic binaries of all flavours.

Distance determination with Gaia and optical identification with spectroscopic facilities are essential to further proceed. With this unique data set we will

- Uncover the parent population of CVs free of selection and detection bias from flux-limited samples comprising about 10^3 objects. For the first time the true composition of the CV population with magnetic and non-magnetic systems will be uncovered to constrain the effect of magnetic fields on close binary evolution.
- Probe the existence of the putative large population of low-luminosity CVs with $L_X=10^{29}$ erg s^{-1}, predicted by binary population synthesis, and determine their local CV space density with 10% accuracy or better. This number will have profound impacts on theoretical models of close binary evolution (strength of angular momentum loss) and on CV birth rates.
- Measure the galactic scale height and luminosity functions of both magnetic and non-magnetic CVs. The population parameters will be determined in a local volume to synthesize the galactic ridge X-ray emission with high fidelity. We will finally solve the decades lasting debate about the true nature and composition of the GRXE by extrapolating from the local sample into the Milky Way.

The CV surveys will definitely uncover rare objects of great importance for astronomy and fundamental physics. Examples are the hard X-ray emitting Symbiotic Binaries, the Double Degenerates and the Galactic SuperSoft X-ray sources, all of them being regarded as SNIa progenitor candidates.

Double Degenerates (or AM CVn stars) exist in ultra-compact configurations with orbital periods ranging from 65 min down to 5.4 min (see Solheim 2010 for a recent review). They are important laboratories for binary stellar evolution theory, in particular to elucidate the elusive common-envelope phase, and can potentially produce rare, sub-luminous, SNIa-like explosions (e.g. Bildsten et al. 2007, Nelemans et al 2001, Podsiadlowski et al. 2003). They are the strongest known sources predicted to emit gravitational-wave below the detection threshold of the Laser Interferometer Space Antenna (LISA; see Nelemans et al. 2004, Stroeer et al 2005, Roelofs et al . 2007). Althouh 10^3 and 10^4 systems are predicted to be in the Milky Way (Nelemans et al. 2004, Roelofs et al. 2007), only 27 have been discovered so far. Of those, nine have been detected as soft X-ray emitters with unabsorbed fluxes of $\sim 10^{-13..-14}$ erg cm^{-2} s^{-1} corresponding to luminosities of $\sim 10^{30..33}$ erg s^{-1}. In this case and assuming the recent estimated density of about 1-3 x 10^{-6} pc^{-3}, eROSITA is expected to uncover roughly 1300 Double Degenerates.

Supersoft X-ray sources (SSS) are featuring steady hydrogen shell burning on the surface of a massive white dwarf. Together with the recurrent novae they are promising candidate progenitors for Type Ia supernovae via the single degenerate channel. The small population of currently known SSS is very inhomogeneous and heavily biased towards unabsorbed, high luminosity sources, which do not undergo temporal variations. This is partially reflected in the disjunct SSS samples found in the Milky Way, the Magellanic Clouds and M31 (4, 15 and 90 sources respectively, Orio et al. 2010), with the M31 census strongly contaminated by classical novae undergoing a supersoft phase after the thermo-nuclear runaway. Assuming that the known sources are representative of the entire population, it appears that the initial theoretical expectations of ~1000 sources per galaxy (di Stefano & Rappaport 1994) are highly overestimated, a finding which is partially confirmed by the deficiency of integrated soft X-ray flux from several elliptical galaxies (Gilfanov & Bogdan 2010). There is however the possibility that a large fraction of SSS is predominantly in a state where the high energy flux is shifted into the unobservable UV (as observed in the transient sources CAL 83 or RXJ0513.9-695), or hidden by absorbing interstellar material. eROSITA has the great potential of uncovering such hidden population in our galaxy by detecting X-rays not from the shell burning white dwarf, but from the accretion process itself.

Galactic novae in the eROSITA All Sky Survey

The outbursts of classical novae (CNe) are caused by the explosive hydrogen burning on the WDs hosted in CVs. After sufficient H-rich material is transferred to the WD, ignition in degenerate conditions takes place in the accreted envelope and a thermonuclear runaway is initiated. As a consequence, the envelope expands and causes the brightness of the star to increase to maximum luminosities up to 10^5 L_{solar}. A fraction of the envelope is ejected, while a part of it remains in steady nuclear burning on the WD surface. This powers a bright supersoft X-ray source (SSS) radiating at about the Eddington limit which can be observed as soon as the expanding ejected envelope becomes optically thin to soft X-rays (Gallagher and Starrfield 1978, ARAA, 16, 171). The duration of the SSS phase is inversely related to the WD mass while the turn-on of the SSS is determined by the mass ejected in the outburst. The SSS phase can last from less than a month to more than ten years (Pietsch et al. 2007, A&A 465, 375). In addition shocks may form in the ejecta giving rise to a lower luminosity hard X-ray source (V382 Vel, Orio et al. 2001, MNRAS, 326, L13). Henze et al. 2011, A&A, in press (arXiv1010.1461) derived correlations between several optical, X-ray and physical parameters of a sample of novae in M 31.

In the Galaxy, to date about eight novae are detected every year (Pietsch 2010, AN, 331, 187). Most of these novae have been followed up in X-rays with the help of monitoring campaigns with the Swift satellite (Ness et al. 2007, ApJ, 663, 505) and also with Chandra and XMM-Newton observations. They showed a diversity of time variability patterns and partly complicated variable spectra with emission and absorption lines.

During its four year all sky survey, eROSITA will allow us to get a homogeneous census of the X-ray behavior of all Galactic (and also Magellanic Cloud) novae with snapshots every half a year. While we may miss novae with a short SSS phase, we will efficiently follow the development of novae with long SSS phases. We will be able to investigate X-ray spectra and light curves and also trigger follow-up X-ray monitoring campaigns with shorter observation intervals and/or observations with X-ray instruments providing higher spectral resolution. During the survey we also may detect SSS from novae where the outburst has been missed in optical observations. This was the case for XMMU J115113.3-623730, which was detected during an XMM-Newton slew manoeuver and later identified as a nova (see Greiner et al. 2010, ATel #2746). Detailed modeling will allow us to constrain the number of novae showing a SSS phase and to extend correlations between nova parameters and compare them to those derived for M 31.

X-ray binaries in the Milky way

Over 300 Galactic XRBs are known (114 HMXBs and 187 LMXBs, over 100 of them are X-ray pulsars; Liu et al. 2006, 2007), and yet this may be just tip of the iceberg. They exhibit amazing diversity of properties, often variable on timescales ranging from ms to years. Many of XRBs are heavily absorbed which makes it difficult to detect and identify them in existing soft X-ray surveys. As a matter of fact the Galactic XRB luminosity function in the 2-10 keV energy range is therefore poorly constrained for fluxes below 10^{-10} erg/s, while the majority of sources are expected to be fainter (Grimm et al, 2002). On the other hand, many objects are dim/soft enough to escape existing hard X-ray surveys. The eRosita survey with its improved sensitivity in the 2-10 keV energy range by factor of $\sim 10^3$, is expected by far to exceed the sensitivity of existing hard X-ray all sky surveys (about 4 x 10^{-12} erg/s for INTEGRAL, Krivonos et al, 2010).

From the observed luminosity function and current population synthesis studies one might expect about 3000 new XRBs (mostly LMXBs) to emerge from the eRosita survey (Grimm et al, 2002, Belczynski et al, 2004). And in fact this population already started to emerge in pointed observations (Muno et al, 2006). eRosita will provide a complete census of the Galactic population of the accretion powered X-Ray binaries down to luminosities of about $10^{33...34}$ erg/s. Many fainter sources as well as new transient sources will be discovered not only in the Galaxy but also in the LMC and SMC. The eRosita survey will provide a robust estimate of the galactic XRB X-ray luminosity function and provide constraints for population synthesis models. This will help to understand the origin and evolution of X-ray binaries in the Galaxy.

In addition, properties of known nearby transients in quiescence will be probed. eRosita will monitor state transitions in known LMXBs and observe many thermonuclear bursts with high time resolution (several per each of the almost 50 known bursters). These observations, as discussed Poutanen et al (2010) and Duncan et al. (2008) will most likely provide new constraints on the EOS of neutron stars.

New high-quality data taken with RXTE, INTEGRAL, and Suzaku on a number of transient and persistent X-ray pulsars allowed a detailed study of their spectral properties as a function of luminosity, i.e. of the mass accretion rate. The data reveal the existence of at least two different modes of spectral-flux dependencies, which are most probably due to different accretion regimes realized in different sources depending on the averaged accretion rate (Klochkov et al. 2011). The emerging diversity of the accretion modes, which is of key importance for understanding of the physics and configuration of the accretion flow close to the neutron star surface is currently studied on a relatively small sample of X-ray pulsars. The monitoring capability of eRosita will allow to extend this analysis to a larger sample of sources by measuring the slope of the X-ray continuum at different luminosity states of transient sources. The Liu et al., (2006) catalog of XRB contains 28 transient accreting pulsars which will be included in the sample using eRosita data.

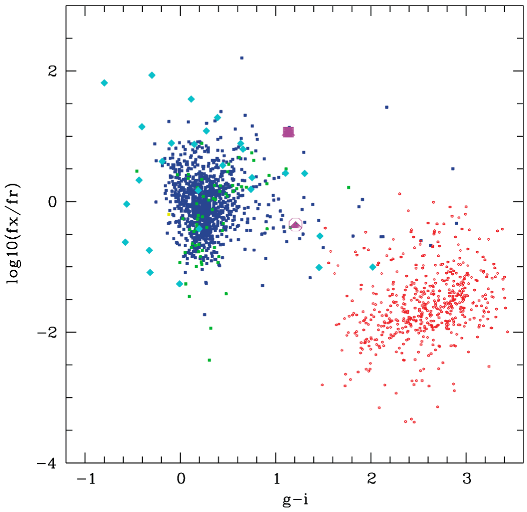
X-ray binaries in the LMC

As LMC is located close to the south ecliptic pole, a lot of exposure spread over multiple observations will be accumulated on many XRBs in LMC. This will allow one to study the spectral and timing properties of the XRBs over a longer time (months to years).

Many XRBs, with LMC X-4 being one of the best-known examples, exhibit variability not related to their orbital or pulsation (in case of an X-ray pulsar) periodicity, namely super-orbital variations and sporadic flaring activity. The former is often attributed to a precessing inclined and/or warped accretion disk (Lang et al., 1981) while the latter in case of accreting pulsars is believed to be related to instabilities of the accretion flow close to the NS surface (e.g. Moon et al. 2003). Despite of these general ideas, a detailed physical picture of the two phenomena directly related to the configuration of the accretion flow in XRBs is still missing. Both phenomena are difficult to address with targeted observations: the time scale of the superorbital variability is usually longer than a typical observation duration, while the flaring activity episodes are difficult (or impossible) to predict. The monitoring power of eRosita can, therefore, naturally be utilized for this purpose.

BHCs (TBW)

7. eROSITA in the context of multi-wavelength large-area surveys



Cataclysmic variables and related objects are minorities in the X-ray sky. Their X-ray morphology, X-ray color, and X-ray to optical flux ratio makes them almost indistinguishable from the much more abundant AGN population. The figure to the right indicates the location of interacting binaries (cyan) in an optical color-color and X-ray/optical color diagram composed of more than 1500 correlated XMM-Newton/SDSS X-ray pointlike sources (Pineau et al 2011). While coronally active stars (red) and AGN (blue) appear well separated will very little overlap, interacting binaries appear similar to AGN. Their identification is feasible through large-scale specroscopic identification programs with e.g. SDSS/BOSS and ESO/4MOST targeting X-ray unresolved sources. CV surveys can be successfully performed at galactic latitudes larger than 15 degrees to avoid optical source confusion and low identification rates due to strong galactic absorption. To counteract the loss of objects in the galactic plane, a spectroscopic identification rate as high as possible is of utmost importance to reach the scientific aims. Once Gaia data are available, the distances to individual objects can be used to separate galactic and extragalactic sources and settle any issue regarding luminosities of galactic sources.

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