GALACTIC PLANE SURVEYS

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ABSTRACT

We review the main results obtained from recent Galactic Plane X-ray surveys carried out by XMM-Newton and Chandra, limiting our discussion to the faint discrete sources. The wide X-ray band-pass, high sensitivity and good spectral resolution of these new instrumentations offer for the first time the opportunity to explore the X-ray source populations of our own Galaxy in the medium to low X-ray luminosity regime ($L_X < 10^{35}$erg s^{-1}). At very low latitudes ($b \sim 0°$) the vast majority of the soft (0.5-2.0 keV) sources are identified with active stars whereas at galactic latitudes above a few degrees the background of AGN dominates log N(>S)-log S curves down to a few 10^{-15}erg cm^{-2} s^{-1} at all energies. The large number of stellar identifications allows to study with unprecedented depth the distribution of young stars up to about 1 kpc. XMM-Newton and Chandra measurements are not strongly biased by interstellar extinction, as were earlier studies based on ROSAT observations restricted to the softer 0.1-2.4 keV band. Current surveys are thus particularly well suited for the study of the hard X-ray emitting low luminosity population which has mostly escaped ROSAT scrutiny. Chandra and XMM-Newton observations indeed reveal the presence of a population of low X-ray luminosity hard galactic sources exhibiting a marked concentration in the central parts of the Galaxy. Several source types such as cataclysmic variables, Be/X-ray binaries, RS CVn's or low luminosity stages of classical X-ray binaries predicted by theories of evolution could contribute to this population. Follow-up optical observations provide constraints on the nature of these sources and even positive identifications in a number of cases. The numerous sources detected close to the center could be associated with the nuclear bulge and the nuclear cluster. Their nature remains so far uncertain.

Key words: X-ray; Surveys; Accreting sources.

1. INTRODUCTION

In the early 70's the Uhuru satellite (Forman et al. 1978) discovered a concentration of bright X-ray sources along the galactic plane, the most prominent of them being Sco X-1. A number of other satellites completed the bright source mapping, such as Ariel V (Warwick et al. 1981) and HEAO-1 (Wood et al. 1984). These experiments have lead to the discovery of the first accreting neutron stars and black holes and opened a rich and exciting new field of astrophysics. However, the collimator design of these instruments limited their detection efficiency and only the brightest X-ray sources with X-ray luminosities above $\sim 10^{36}$erg s^{-1} at the distance of the galactic center could be detected. At present, XTE and INTEGRAL are continuously detecting new luminous transient galactic sources and very significantly extend our understanding of the various kinds of accreting neutron star and black hole binaries.

From 1978 till 1981, the *Einstein* satellite was the first to fly a relatively large X-ray imaging telescope equipped with detectors sensitive to the soft X-rays (0.5-4.5 keV). *Einstein* discovered the high energy emission of many galactic sources such as cataclysmic variables (CVs) (Hertz & Grindlay 1984) and revealed the unexpected X-ray emission from many young stars all along the HR diagram. In the first years of the 90's, ROSAT conducted the first all-sky soft (0.1-2.4 keV) X-ray map ever made followed by a large number of pointed observations. Among the many galactic discoveries which can be attributed to ROSAT are the super soft sources, already suspected by *Einstein*, and the thermal emission of radio-quiet isolated neutron stars. Although many faint accreting binaries (CVs, Be/X-ray systems) were found in the galactic plane, the number source count remained dominated by active stars (Motch et al. 1997). With its hard X-ray (0.7-10 keV) sensitive imaging instrument, ASCA provided the first detailed view on the population of faint hard X-ray sources in the Galaxy (Sugizaki et al. 2001).

The new generation of imaging X-ray satellites, Chandra and XMM-Newton offer a much improved spatial resolution and collecting area compared to previous experiments. In the hard X-rays, the sensitivity of XMM-Newton and Chandra are roughly a factor 10 and 100 better than that of ASCA respectively. A similar situation is encountered in the soft band where XMM-Newton and Chandra do better than the deepest ROSAT pointings by similar factors. Apart from the improved sensitivity, Chandra also provides the excellent positions required to identify galactic sources in the crowded fields prevailing at low latitude. As for XMM-Newton it delivers good spectra and light curves for many sources.

The excellent hard X-rays capabilities of Chandra and XMM-Newton offer the unique opportunity to unveil low luminosity sources ($L_X \sim 10^{31}$erg s^{-1}) shinning through large amounts of interstellar material up to the distance of the galactic center and to explore to much larger distances the population of soft sources (CVs, active coronae, etc.) discovered by *Einstein* and ROSAT. Galactic plane X-ray surveys are a vast topic and the present review concentrates on the discussion of the properties of the faint sources, typically F_X(0.5-12 keV) $< 10^{-12}$ erg cm^{-2} s^{-1} which make the vast majority of the new sources discovered in Chandra and XMM-Newton observations at low galactic latitudes. We furthermore restrict our presentation to the ”classical” E < 12 keV X-ray range and to discrete sources. A review on the various components contributing to the diffuse galactic emission in presented by R. Warwick in this volume.

2. SCIENCE DRIVERS

The study of the nature of the X-ray source population of our own Galaxy in the medium to low luminosity regime ($L_X \sim 10^{29}$ - 10^{35} erg s^{-1}) brings essential information on accretion power, star formation and end points of stellar evolution throughout the Galaxy. Their distribution in the Galaxy and their connection to different galactic structures such as the disc, the bulge and the central regions yield important information on their evolutionary status. In addition, the knowledge of the log N(>S)-log S curves down to faint fluxes is prerequisite to separate truly diffuse from unresolved emission, a very debated issue in the framework of the Galactic Ridge (Warwick 2005).

Because of the steep decay of X-ray luminosity with age, soft X-ray surveys unveil the young (age $\leq$ 2 Gyr) stellar population much more efficiently than at optical wavelength and allows to study the evolution of the scale height with age and the mechanism leading to the ”heating” of the disc stars. Number counts and distribution in distances give access to the recent stellar formation rate. Clustering structures, such as the Gould Belt enhancement revealed by ROSAT (Guillout et al. 1998) can also be discovered. Current estimates are that our Galaxy could harbour about 10^6 to 10^7 CVs. However, CV demography is based on local estimates and their scale height and distribution at large distances in the disc and bulge of the Galaxy are essentially unknown. This problem has impact on our knowledge of the actual novae rate and connects with the origin of low-mass X-ray binaries (LMXBs) and SN1a supernovae.

The binary evolution scenarios leading to the low and high mass X-ray luminous accreting binaries predict the existence of a number of low X-ray luminosity stages, which in most cases have no yet been observed. Before entering their high mass transfer states, LMXBs should go through a long lived, close, detached neutron star - red dwarf phase during which accretion of the stellar wind onto the neutron star may produce a detectable X-ray luminosity excess above the coronal stellar activity (Bleach 2002). Willems and Kolb (2003) predict that between 10^4 and 10^5 such pre-LMXBs could exist in the Galaxy among which a large fraction will emit X-ray luminosities of the order of 10^{31}erg s^{-1}. All Be/X-ray binaries known so far display direct evidences (pulsations) or indirect evidences (X-ray spectrum) of an accreting neutron star (Negueruela 1998). In high mass binaries, the large mass transfer which may occur during the evolution of the primary star can lead to the creation of a white dwarf (WD) remnant instead of a neutron star in a large number of cases. Averaging over all spectral types, the number of Be + WD should be 7 to 10 times that of Be + neutron stars (Raguzova 2001). Although a number of candidate systems, the γ-Cas analogs, exist (Lopes de Oliveira et al. 2005), the presence of an accreting white dwarf has not yet been confirmed in any of these candidates. Neutron stars accreting from the wind of a relatively unevolved companion could also account for a large number of low luminosity sources ($L_X < 10^{35}$erg s^{-1}; Pfahl et al. 2002). Their expected number may be of the order of 10^5 and should be dominated by intermediate mass primaries (M = 3-8 $M_\odot$). Although some neutron stars accreting from the wind of massive supergiant stars are known, no neutron star has yet been seen accreting from the wind of a main sequence star. The absence of X-ray detection of any of these low L_X states could be partly due to observational biases. It remains however somewhat puzzling and could cast some doubts on binary evolution theories or may indicate that the efficiency with which X-rays are produced considerably drops at low mass accretion rates. Finally, the detection of thermal emission from isolated compact neutron stars either cooling, similar to those discovered by ROSAT or accreting from the interstellar medium could give valuable information on the past or recent massive star formation and end points. The detection of isolated accreting black holes may also be within the reach of the current instruments provided the efficiency with which accretion from the interstellar medium produces X-rays is large enough.

3. A TYPICAL GALACTIC LANDSCAPE

At the level of sensitivity of the Chandra and XMM-Newton instruments (F_X(0.5-12 keV) $\sim 10^{-15}$ erg cm^{-2} s^{-1}) various populations contribute to the source content of low galactic latitude fields. The total galactic photoelectric absorption is often large enough to absorb completely the soft X-rays emission from background AGNs and many soft sources are relatively nearby active coronae. At higher energies, the galaxy becomes transparent to X-rays and the dense background of AGNs sources becomes progressively dominant. The detectability of a genuine population of hard X-ray galactic sources over the extragalactic contribution depends considerably on the galactic direction, total galactic absorption and flux range.

Chandra and XMM-Newton are currently conducting several surveys of various regions of the galactic plane. In this section we focus on the discrete source content of a typical region of the galaxy, i.e. away from the central regions and void of any known structure such as local absorbing clouds, star clusters or star forming regions.

Probably the most ambitious galactic plane survey carried out by Chandra is the Champlane program (Grindlay et al. 2005) which aims at surveying about 8 deg^2 spread over 154 fields distributed over the entire galactic plane. More than 8000 sources are detected above a sensitivity of $\mathrm{F_X} \geq 5\ 10^{-16}$ erg cm^{-2} s^{-1} in the 0.5 to 2.0 keV band and $\mathrm{F_X} \geq 3\ 10^{-15}$ erg cm^{-2} s^{-1} in the 2 to 10 keV band. Champlane includes a large wide-field optical and IR imaging program as well as spectroscopy. First analysis of the source content in 14 fields located in the anti-center direction (Grindlay et al. 2005) shows that $\sim$ 40% of them have optical counterparts fainter than R = 24.5. The statistics of identification hint at a CV density of $n \sim 10^{-5}$ pc^{-3}, about one third of that estimated locally (Schwope et al. 2002).

Ebisawa et al. (2005) have conducted a somewhat deeper survey concentrated on a small field (0.07 deg^2) located in a region void of bright sources at l = 28.5°and b = 0.0°. Sources detected in the soft (0.5-2.0 keV) and hard (2-10 keV) bands have little overlap. Follow-up near infrared photometry allows to classify them on the basis of their X-ray and IR properties. Almost all soft sources have counterparts with near-infrared (NIR) colours consistent with those of late type star counterparts and only 22% of the hard sources have NIR counterparts. Soft sources with NIR counterparts have stellar-like X-ray spectra, hard sources with NIR counterparts have CV like X-ray spectra and hard sources without NIR counterparts have AGN compatible X-ray spectra. The authors conclude that there are evidences for a genuine hard X-ray galactic population, but that the vast majority of the hard sources are extragalactic and that consequently, the diffuse X-ray galactic ridge emission detected in this field cannot be due to the unresolved contribution of discrete galactic sources.

Hands et al. (2004) report results from the XGPS survey which consist of $\sim$ 400 sources detected in relatively shallow dedicated pointings covering 3 deg^2 at l = 19°-22° and b = ±0.6°. The 2-10 keV sensitivity is $\sim 2\ 10^{-14}$ erg cm^{-2} s^{-1}, roughly 10 times brighter than that of Chandra. Again, there is little overlap between sources detected in soft (0.4-2 keV) and hard (2-6 keV) X-rays. Soft sources are best fitted by 0.25 keV + 1.5 keV thin thermal spectra (active coronae like) while hard sources have spectra consistent with a power law (Γ = 1.6) with varying $\mathrm{N_H}$= 0.6 - 4 $10^{22}\mathrm{cm}^{-2}$. Fig 1 shows that the log N(>S)-log S curves observed by ASCA and Chandra nicely merge with that derived from the XGPS. An inflection occurs in the log N(>S)-log S curve at $\mathrm{F_X}\sim 10^{-12}$ erg cm^{-2} s^{-1} which reflects the transition between a high and low $\mathrm{L_X}$ population dominance. The observed hard X-ray log N(>S)-log S is significantly above the expected extragalactic curve, clearly revealing the presence of a galactic population of hard X-ray sources in the XGPS flux regime ($\mathrm{F_X}\sim$ 2 - 100 10^{-14} erg cm^{-2} s^{-1}; 2-10 keV). Extragalactic sources account for the majority of sources below $\sim 10^{-13}$ erg cm^{-2} s^{-1} (2-10 keV) with a predominant galactic component above this threshold.

Table 1. Optical identifications of bright XGPS sources

Class	Nbr	mean HR
INS candidate	1	–0.82
Late type stars	19	–0.68
Early type stars	4	–0.68
CVs	3	+0.19
Unidentified	14	+0.61
Be/X-ray	3	+0.85
WR star	1	+1.00

As part of its galactic plane survey (see below), the Survey Science Center (SSC) of the XMM-Newton satellite undertook the optical identification of the 45 brightest XGPS sources in the broad (0.4-6 keV) band. Table 1 summarizes the statistics of optical identifications as function of the mean hardness ratio. Negative HR values indicate soft spectra. Most soft sources are indeed positively associated with active coronae or shocked wind emission from early type stars. Cataclysmic variables exhibit significantly medium hard spectra and are among the sources detected in both soft and hard bands. Their appearance in the soft band probably reflects the fact that they were optically bright enough and therefore close enough to be identified, although one of them was as faint as V = 23.3. Be/X-ray systems are intrinsically much brighter in the optical and can thus be identified at larger distances than CVs with a comparatively higher interstellar absorption and therefore harder spectrum. It is worth noting, however, that the identification essentially relies on the presence of a Balmer Hα line which can also be heavily absorbed. Near infrared spectroscopy in the region of the Paschen series could allow the identification of several more such massive X-ray binaries. The extremely hard spectrum of the WR star is probably partly intrinsic to the source. Unidentified sources have hardness ratio mostly consistent with those expected from background AGNs but could also be consistent with accreting galactic sources. In the $\mathrm{F_X}$ range between 10^{-12} and 10^{-13} erg cm^{-2} s^{-1} (2-10 keV), among 20 XGPS sources investigated, 8 have galactic counterparts and 12 are possibly extragalactic with no optical identification brighter than R$\sim$ 23. These numbers ($\sim$ 40% of galactic sources) are in good agreement with the log N(>S)-log S curves shown in Fig. 1.

Thanks to its wide field of view (30′ dia) and good spatial resolution maintained over the whole field, the XMM-

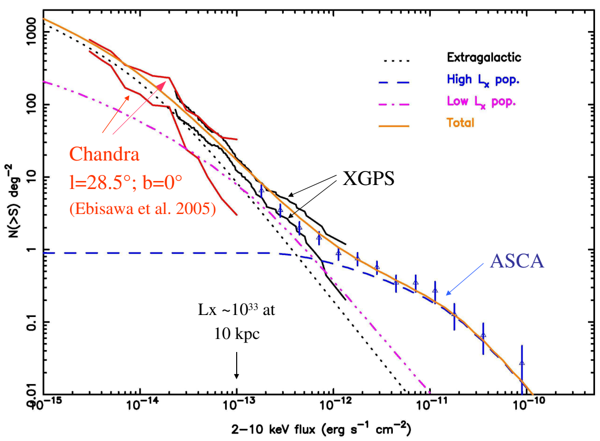

Figure 1. Combined ASCA, XMM-Newton and Chandra hard X-ray log N(>S)-log S curves at l = 19-28.5° and b $\sim$ 0°.

Newton telescope optics provide an excellent opportunity to conduct a large and sensitive X-ray survey. The potential of XMM-Newton surveys was recognised by ESA in setting up a dedicated XMM-Newton Survey Science Center to facilitate the exploitation of the XMM-Newton Serendipitous Sky Survey by providing a public archive of data products and carrying out a carefully coordinated follow-up programme to characterise the overall X-ray source population (Watson et al. 2001). One of the most demanding mission devoted to the SSC is the "statistical" identification of all serendipitous EPIC sources. To achieve this goal, the SSC is conducting optical identification campaigns on samples of $\sim$ 1000 sources at various galactic latitudes and flux limits which will be later used as "calibration" for the statistical identification. Optical identification of the low galactic latitude sample constitutes the core of the XMM/SSC galactic plane survey ($|b|$ $\leq$ 20°; Motch et al. 2003; Motch et al. 2005). The program uses wide field optical and IR imaging and optical spectroscopy at 2 to 8m class telescopes. At present, the SSC has searched for the optical counterparts of more than 400 sources located in 1.8 deg^2 with $F_X > 3\ 10^{-15}$ erg cm^{-2} s^{-1} (0.5-2 keV) and $F_X >$ 3 10^{-14} erg cm^{-2} s^{-1} (2-12 keV), in addition to $\sim$ 80 sources selected on the basis of their X-ray and optical properties. The identification statistics (see Tab. 2) reveal the strong dependency of the source content on galactic latitude. At the limiting R magnitude of 19-22 reached for spectroscopic identification, only few accreting binaries can be positively identified. Clearly, deeper optical and near infrared spectroscopy are needed to identify the faint CVs at large distances and high-mass X-ray binaries in the most absorbed directions. At very low galactic latitudes, background AGNs are in most cases too absorbed to be within the reach of the current optical and near infrared instrumentation.

The nature of the accreting binaries, CVs and Be/X-ray binaries, identified in the XMM/SSC survey is not different from what is already known. In particular, no neutron star accreting from the wind of an unevolved companion has been discovered yet. A small number of relatively bright optical objects fall in the 90% confidence error circle of hard sources (typically 3-4″ radius). So far optical observations of these candidates have failed to detect any spectral signature such as Balmer or He II λ4686 line emission or radial velocity variations which could reveal the presence of an accreting compact object. A small group of hard and low X-ray luminosity Be stars is however emerging in XMM-Newton surveys and is now also recognized in HEAO-A1 and ROSAT surveys (Lopes de Oliveira et al. 2005). The common characteristics of these Be stars are: a narrow range of B0.5-1 V-IIIe spectral types, Hα EW of $\sim$ -30 Å, relatively stable Balmer line profiles, hard X-ray spectra (thin thermal kT $>$ 8 keV or power law with Γ = 1.5-2.0 + possible presence of a softer component), relatively strong H-like, He-like and low-ionization Fe-K line emission, stable X-ray luminosity over years time scales, soft X-ray luminosities slightly above the mean $L_X \sim 10^{-7}\ L_{bol}$ relation for normal OB stars, hard (0.5-12 keV) X-ray luminosities of a few 10^{32}erg s^{-1}, hour time scale modulations + rapid X-ray variability on short time scales ($\tau <$ 10-100 s), but absence of stable periodicity (Motch et al. 2006). These properties are essentially those of the so far unique and puzzling X-ray emitting Be star γ-Cas. Their X-ray spectra, luminosity and also time behaviour in some cases appear amazingly similar to those of some dwarf novae cataclysmic variables. This has been long considered as the main argument for the Be + WD model and has caught even more attention because of the expected frequency of such systems predicted by evolutionary scenarios. However, a number of correlated X-ray, UV and optical behaviours can hardly be explained in this model and find a better interpretation if one assumes that the flaring X-ray emission arises close to the surface of the Be star in magnetically confined regions and are partially absorbed and reprocessed in colder material located in the circumstellar disc (Smith et al. 1998). This latter model, is however, not free of problems and the origin of the hard X-ray emission of this particular group of Be stars still remains elusive.

Table 2. Statistics of optical identifications in the XMM/SSC galactic plane survey

Fields	Nbr of sources	Stars	EG	Accre-ting	Unid
$b \sim 0^o$	233	40%	$\sim$ 1%	$\sim$ 1%	58%
$b \sim$ 3-12^o	125	27%	14%	$\sim$ 1%	58%

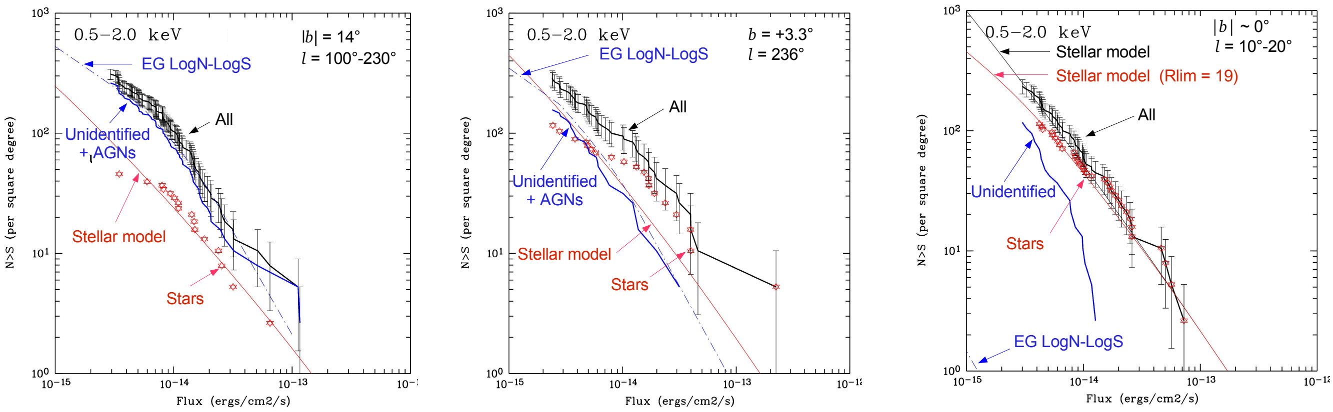

Figure 2. Variation of the stellar and extragalactic + unidentified log N(>S)-log S curves as a function of galactic latitude. Data are extracted from the XMM/SSC galactic plane survey.

4. THE X-RAY STELLAR POPULATION

Active stars constitute the bulk of the identification of soft X-ray sources. At low latitudes, X-ray emitting stars are dominated by the young population (age $\leq$ 750 Myr). XMM-Newton can detect them up to $\sim$ 1 kpc in a typical exposure. As mentioned in section 2, the distribution of the properties of active stars can provide extremely valuable information on some essential galactic parameters such as the variation of the scale height with age for instance. Comparing various observable quantities (log N(>S)-log S curves, distributions in distance, spectral types, colours, etc..) with model predictions is the best suited method to constrain these parameters. The X-ray stellar population model used in the framework of the XMM/SSC survey of the galactic plane is that of Guillout et al. (2005) and Herent et al. (2005) which includes the latest luminosity functions and a description of the dependency of the X-ray energy distribution on age and spectral type. These models also allow to take into account the limiting magnitude of the optical identifications and the presence of enhanced and uneven absorption on the line of sight. Model predictions are in excellent agreement with the observations over six orders of magnitude at high galactic latitude (Herent et al. 2005). At low galactic latitudes, the agreement between model and observations is generally good, except in some regions having pathological distributions of the absorption in distance (Guillout et al. 2005). This overall agreement suggests that the galactic structure parameters of young stars assumed in the model are probably close to their true values.

5. GALACTIC AND EXTRAGALACTIC CONTRIBUTIONS

In a typical low galactic field and at a given flux level, the relative number of galactic and extragalactic sources depends on the energy band considered and on the latitude, longitude and total galactic absorption on the line of sight. The source identification records of the XMM/SSC galactic plane survey can be used to quantify these effects in the range of flux F_X = 3 - 100 10^{-15} erg cm^{-2} s^{-1} (0.5-2 keV) and F_X = 3 - 50 10^{-14} erg cm^{-2} s^{-1} (2-12 keV) covered by this survey. Fig. 2 shows the evolution of the galactic and extragalactic soft X-ray populations as the line of sight plunges toward low galactic latitudes. At $|b|$ = 14° and l = 100°-230°, the number of active stars amounts to roughly a quarter of the total number of soft sources. The log N(>S)-log S curve made from the sum of the identified extragalactic sources and of the unidentified sources (which have too faint counterparts) matches well that expected for the extragalactic component, taking into account the total galactic N_H. At b = 3.3° and l = 236°, the number of stars rises significantly, reaching on average about half of the total number of sources. Again, the expected extragalactic log N(>S)-log S curve fits well the distribution of identified extragalactic sources plus unidentified sources. Finally, at $|b| \sim 0°$ and l = 10°-20°, stars account for the totality of the identifications and the background of AGN is completely shielded. In general, the identified stellar log N(>S)-log S curves are in good agreement within the error bars with the predictions of the stellar population model. This gives confidence in the source identification process at the telescope and indicates that no strong bias for or against a particular population was introduced at this stage. Because of the absorption and of the higher F_X/F_{opt} of the young stars which concentrate in the deep plane (Herent et al. 2005), at $b \sim 0°$, it is necessary to consider the limiting magnitude (R $\sim$ 19) at which it is possible to identify positively an active corona at the telescope. Taking this bias into account allows to fit properly the log N(>S)-log S curve of the identified stellar component while the stellar model without magnitude limit represents well the log N(>S)-log S curve of the total source sample. This is a strong indication that most of the unidentified soft sources are probably optically faint active coronae. Amazingly, in spite of the drastic change in composition of the soft source content, the increase of the number of stellar sources when moving down in

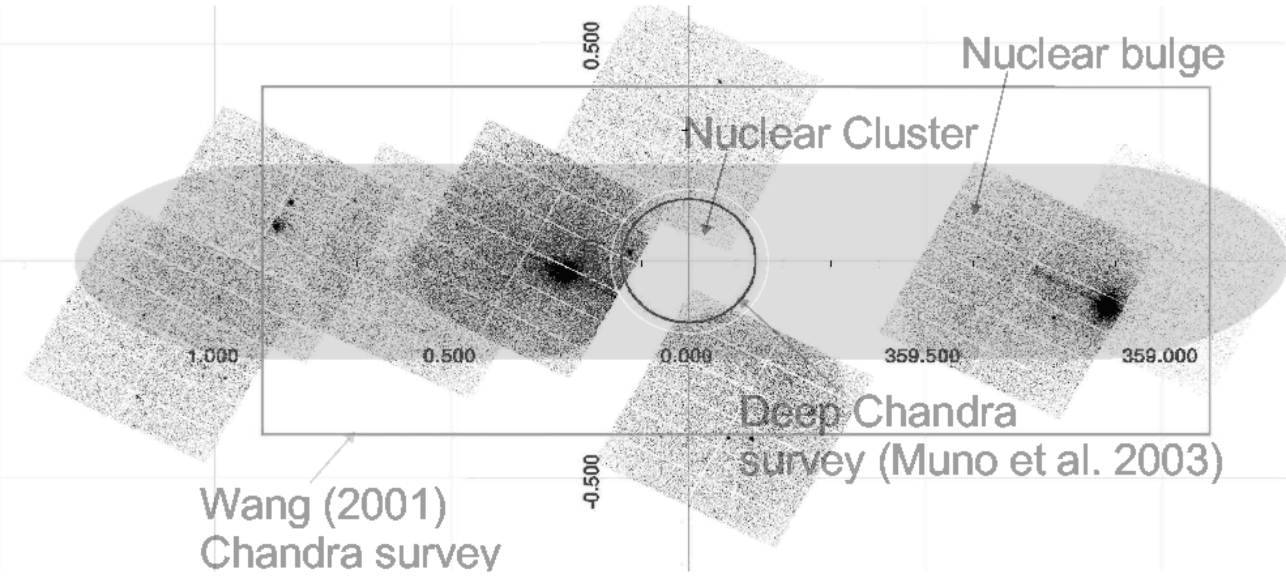

Figure 3. A map showing the location of the main observations carried out by XMM-Newton and Chandra in the region of the galactic center. The size of the nuclear bulge and cluster are not exactly to scale.

the deep plane is almost counterbalanced by the simultaneous decrease of the number of extragalactic sources bright enough to shine through the increasing interstellar absorption.

In the hard X-rays (2-12 keV), AGN completely dominate source counts at $|b|$ = 14° and b = 3.3° in the XMM/SSC galactic plane survey. In the $|b| \sim 0°$ field (l = 10°-20°), there is a clear excess of hard sources above the expected extragalactic background, similar to that found in the XGPS by Hands et al. (2004).

6. THE GALACTIC CENTER REGION

The galactic center region has been the target of all major X-ray telescopes such as, *Einstein*, GRANAT, ROSAT, BeppoSAX and ASCA. XMM-Newton and Chandra are now collecting deep observations of this important region. Fig. 3 shows the XMM-Newton images of the deepest public observations around the galactic center (Wijnands et al. 2005). The XMM-Newton pointings on the center itself are not shown for clarity reasons. The positions of the large scale Chandra survey conducted by Wang et al.(2002) and of the extremely deep pointing of Muno et al. (2003) are also shown. Also sketched on this figure are the positions of the ”nuclear bulge” and of the ”nuclear cluster”. The nuclear bulge, not to be confused with the galactic bulge, is a flat disc-like structure of radius $\sim$ 230 pc, scale height $\sim$ 45 pc with a high stellar density and ongoing stellar formation. Its total mass is $\sim$ 1.4 $10^9 M_\odot$ (Launhardt et al. 2002). The nuclear cluster is a central concentration of stars with a R^{-2} distribution.

Chandra has intensively observed the inner parts of the Galaxy. The first survey published is that of Wang et al. (2002) which covers about 0.8° in latitude, 2° in longitude approximately centered on Sgr A*. About 800 new X-ray sources are detected in this area above a minimum flux of $\sim 10^{-14}$ erg cm^{-2} s^{-1}(2 - 8 keV) corresponding to a detection limit of 8 10^{31}erg s^{-1} at 8 kpc. The He-like Fe Kα line mainly arises from the discrete sources. The number and the hard spectra of the discrete sources indicate the presence of numerous accreting white dwarfs, neutron stars or black holes in that region. Most of the X-ray flux is in the diffuse component which is apparently following known interstellar structures and may be related to regions of recent star formation.

Muno et al. (2003) have obtained a very long 590 ksec Chandra exposure centered on Sgr A*. The 17 by 17 arcminute ACIS-I field corresponds to a 40 pc$\times$ 40 pc area at the distance of the galactic center and therefore essentially covers the nuclear cluster. The survey completeness limit is $L_X \sim 10^{31}$erg s^{-1} at the distance of the galactic center. A total of 2357 sources were detected, mostly above 1.5 keV. Their radial distribution drops as θ^{-1} when moving away from Sgr A* and thus follows the infrared distribution of stars in the nuclear cluster. The density of faint hard sources is extremely high, being more than one order of magnitude above the expected extragalactic background of sources. Their spectra are very hard with power law photon index below 1.0 and exhibit strong lines from low ionization, He-like and H-like iron. Some of these sources display variability on day or month time scales (Muno et al. 2004). Both spectral and timing properties are compatible with magnetically accreting white dwarfs and wind accreting neutron stars. On the other hand, soft sources are uniformly distributed on the sky as expected from a local stellar population.

XMM-Newton has repeatedly observed the galactic center area, focusing on Sgr A* and on the very faint transients located within $\sim$ 1° of the galactic center (Wij-

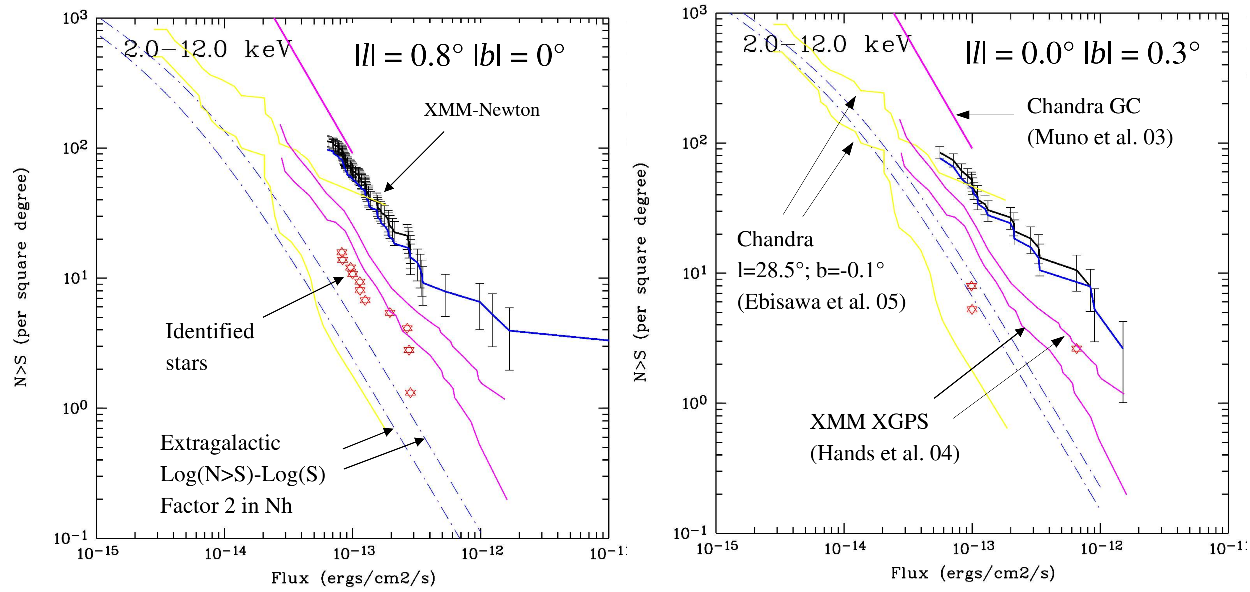

Figure 4. log N(>S)-log S curves observed by XMM-Newton in the central regions of the Galaxy.

nands et al. 2005). We have used the series of 'GC' fields shown in Fig. 3 to study the spatial distribution of the hard sources in the central regions. Fig. 4 (left panel) displays the log N(>S)-log S curves derived from XMM-Newton fields GC2, GC3, GC4 and G8 which are clear of strong diffuse emission. The sources were extracted from the 1XMM catalogue and are therefore in principle free of spurious sources if one imposes a maximum likelihood larger than 8 and a sum flag greater than 0. The log N(>S)-log S curve of the XGPS survey, that derived from the deep Chandra pointing at l =28.5°, b∼0°and the log N(>S)-log S curve computed by Muno et al. (2003) at the center of the deep Sgr A* fields are also shown for comparison. At a 2-12 keV flux of $\sim 7\ 10^{-14}$ erg cm^{-2} s^{-1}, corresponding to $L_X \geq 5\ 10^{32}$erg s^{-1}at 8 kpc, the source density $\sim$ 0.8° away from the galactic center is about 3 times that observed in the XGPS at l = 20° and an order of magnitude above the estimated extragalactic contribution. Since a sizable fraction of the hard XGPS sources are extragalactic, the density increase of galactic sources from $|l|$ = 20° to $|l|$ = 0.8° is even larger. There is however no clear evidence of variation of the source density with longitude in these pointings. The direction of the nuclear bulge is thus very rich in hard X-ray sources and its source density is only surpassed by that measured at the center of the nuclear cluster by Muno et al. (2003). Fig. 4 (right panel) also shows the log N(>S)-log S curve derived from the two XMM-Newton pointings north and south of Sgr A*, GRO J1744 and GC10, which have a mean galactic latitude of $|b|$ = 0.33°(corresponding to 46 pc at 8 kpc). At $|b|$ = 0.33°, the density of galactic sources is about half of that at $|b|$ = 0.0 for $F_X = 7\ 10^{-14}$ erg cm^{-2} s^{-1}. If confirmed, this steep density drop with galactic latitude may indicate that the majority of the hard sources have an origin in the nuclear bulge which has a scale height of $\sim$ 45 pc.

Optical identifications are severely hampered by the huge interstellar absorption toward the central regions. The GC2 field l=+0.8, b=+0.07 was selected for the XMM/SSC galactic plane survey. Unfortunately, the optical wavelength and the medium size (4-m) of the telescope used for this project did not allow to identify any of the hard sources. A majority of the soft sources were identified with F-K + Me stars. This picture is consistent with the idea that all sources detected in this direction at F_X(0.5-2.0 keV) $\geq 5\ 10^{-15}$erg cm^{-2} s^{-1} are nearby active coronae. Interestingly, their source densities are similar to those seen at other galactic longitudes, reinforcing the idea that soft sources represent a local population. Clearly, only an infrared instrumentation on a large telescope can obtain discriminating information on the nature of the hard sources. Bandyopadhyay et al. (2005) find K band counterparts for $\sim$ 75% of a sample of sources in the nuclear bulge region surveyed by Wang et al. (2002) ($F_X \geq 4\ 10^{-14}$ erg cm^{-2} s^{-1}) suggesting a galactic population. The near-infrared magnitudes and colours of the candidate objects are consistent with highly reddened stars. Laycock et al. (2005) have obtained deep infrared imaging showing that there is no significant excess of bright counterparts in the nuclear stellar cluster (5′ away from Sgr A*). They conclude that high mass X-ray binaries cannot account for more than 18% of the identifications.

The nature of the low X-ray luminosity sources encountered in large number very close to the galactic center remains weakly constrained. Massive X-ray binaries are unlikely to be the dominant population and CVs, in particular the magnetic ones, appear as the best candidate population, although a large population of wind accreting neutron stars could still be present.

7. CONCLUSIONS

Background AGNs and active stars account for a majority of the 0.5-12 keV sources detected in the Galactic Plane at mid galactic latitudes. AGN dominate source counts in both soft and hard bands down to relatively low latitudes ($|b| \sim 3°$, depending on galactic longitude). Stellar population models match so far remarkably well the properties of identified stars. The decrease of the stellar density with increasing galactic latitude should provide a sensitive test of the evolution of scale height with age. At very low galactic latitudes stellar coronae (very young stars) dominate in the soft X-rays and their spatial density which mainly depends on relatively local absorption does not vary much with longitude. A population of hard galactic sources appears above $F_X \sim 5\ 10^{-14}$erg cm^{-2} s^{-1} (2-10 keV) at $l \leq 30°$and $b \sim 0°$. Optical follow-up observations confirm their galactic nature since a sizable fraction of these hard sources are identified with accreting binaries (Be/X-ray and CVs). Chandra and XMM-Newton have unveiled a dense population of low X-ray luminosity hard galactic sources peaking in the central $\pm 1°$ region of the Galaxy. Two components associated with the nuclear cluster and the nuclear bulge may be present. The nature of these sources, cataclysmic variable or wind accreting neutron stars, remains uncertain.

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