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X-RAY SURVEYS WITH *XMM–NEWTON* AND *CHANDRA*

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RESUMEN

Los rayos X permiten investigar las regiones más internas de los Núcleos Galácticos Activos (AGN) y puedan escapar casi sin absorción de regiones donde la emisión óptica y ultravioleta está fuertemente enrojecida. Los muestreos en rayos X son los más eficientes detectando fuentes que emiten por acreción (por ejemplo los AGN), y pueden detectar también cúmulos de galaxias sin ambigüedad. El espectro "duro" del fondo extragaláctico de rayos X (producido por la superposición de la emisión de muchos AGN) indica que hasta el 85% de la emisión procedente de acreción en el Universo es absorbida. Los muestreos extragalácticos de fuentes de rayos X con *XMM-Newton* and *Chandra* permiten investigar la historia de la acreción en el Universo. El fondo extragaláctico de rayos X ha sido resuelto con esos observatorios, constatando que proviene de la emisión de tres diferentes tipos de objetos, con fracciones parecidas de cada uno de ellos: objetos con características de AGN en sus espectros ópticos, objetos sin esas características (galaxias tempranas luminosas, algunas de ellas probablemente AGN absorbidos), y objetos sin identificación espectroscópica con $I > 23.5$ y colores compatibles con galaxias tempranas evolucionadas. La identificación de estas fuentes requiere telescopios de la clase de 10 m. Las densidades superficiales de este tipo de muestreos son las ideales para espectrógrafos multiobjetos (como OSIRIS). Cámaras y espectrógrafos en el infrarrojo cercano (como EMIR) también son necesarios, especialmente para aquellos objetos con contrapartidas ópticas débiles o inexistentes.

ABSTRACT

X-rays probe the inner regions of active galactic nuclei (AGN) and can escape almost unimpeded from regions where the optical–ultraviolet emission is heavily reddened. Surveys in X-rays are the most efficient in detecting accretion-powered sources (e.g., AGN) and also detect clusters of galaxies unambiguously. The hard spectrum of the extragalactic X-ray background (produced by the superposition of emission from many AGN) indicates that up to 85% of the accretion power in the Universe is absorbed. Extragalactic surveys with *XMM-Newton* and *Chandra* probe the history of accretion in the Universe. The extragalactic X-ray background has been resolved with these observatories into three different types of objects in approximately equal numbers: objects with AGN signatures in their optical spectra, sources without them (luminous early galaxies, some of them probably hidden AGN), and $I > 23.5$ spectroscopically unidentified objects with colors compatible with evolved early galaxies. These identifications require 10 m class telescopes. The source densities of these surveys are ideal for multiobject optical spectrographs (such as OSIRIS). Near-IR cameras and spectrographs (such as EMIR) are also required, especially for those X-ray souces with optically faint or nonexistent counterparts.

Key Words: **X-RAYS: GENERAL, GALAXIES, STARS — GALAXIES: ACTIVE**

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1. INTRODUCTION

The high Galactic latitude X-ray background (XRB) is made up through the superposition of individual extragalactic sources. The best candidates for this role are active galactic nuclei (AGN) because of their high luminosities and number densities. However, the spectrum of the XRB in the 2–20 keV band is well approximated by a power law with slope $\alpha = 0.4$, while the average spectrum of the AGN in that interval is much steeper ($\alpha \sim 0.7$–1). One possible way of reconciling these facts is to assume that a substantial fraction of the AGN making up the XRB are absorbed, because absorption by neutral hydrogen preferentially absorbs the lower X-ray energies, thereby hardening the spectrum.

Popular models for the origin of the XRB (based on the unified model for the AGN) thus propose that most AGN are viewed through the putative molecular torus, so that the X-ray emission is highly absorbed. It is then possible to get a flat slope combining orientations (Setti & Woltjer 1989). A good spectral fit to the XRB spectrum is obtained assuming an absorbed-to-unabsorbed ratio of about 3 (constant with z) and the luminosity function and evolution of soft X-ray (0.1–2 keV) selected AGN (Comastri et al. 1995; Gilli et al. 2001). An immediate deduction from these models is that many absorbed

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AGN should be found in X-ray surveys performed at higher energies (> 2 keV), most of which would have been missed at lower X-ray energies (and at optical–UV wavelengths).

Despite the general agreement of the observations with the above models, other models involving roughly spherical coverage of the absorber by turbulent star forming gas might be needed (Fabian et al. 1998), implying a relationship between star formation and AGN accretion activity. The mass density in black holes required by this model agrees with local estimates at $\sim 6 \times 10^5\ M_\odot$ Mpc-3 (Magorrian et al. 1998).

Another consequence of interpreting the flat X-ray spectrum of the XRB as resulting from absorption of intrinsically steeper spectra of AGN, is that up to 85% of the energy generated by accretion in those objects is absorbed (Fabian & Iwasawa 1999).

X-ray surveys are thus very important for uncovering the dominant population of AGN in the Universe, which could outnumber those selected in soft X-rays and in the optical–UV by a factor of 3 to 4 (Gilli et al. 2001). These absorbed AGN and their evolution could have a direct bearing on the similar evolution observed in the star formation rate and the X-ray volume emissivity (Franceschini et al. 1999), which indicates that the galaxy growth via star formation and black hole growth via accretion could be intimately related (Fabian et al. 1998).

Another task in which X-ray surveys excel is the unambiguous detection of clusters of galaxies (Ebeling 2001). The hot gas trapped in the potential well of these objects emits X-rays via thermal bremsstrahlung. This gas is not present in physically unrelated galaxy groups and its detection in X-rays is thus free of projection effects.

The general characteristics of X-ray surveys will be discussed in Section 2. In Subsection 2.1 we present the main results from deep surveys, while those from a medium depth survey will be presented in Subsection 2.2. The main conclusions and some pointers to possible contributions of the GTC to this field will be discussed in Section 3.

2. X-RAY SURVEYS

X-ray astronomy is at present experiencing a revolution with the combination of the launch in 1999 of *Chandra* (Weisskopf et al. 2000) and *XMM-Newton* (Jansen et al. 2001). Both are imaging X-ray observatories sensitive to X-rays between ~ 0.2 and 10 keV. *Chandra* has unprecedented imaging capabilities, with an angular resolution of the order of 1 arcsec, while the effective area of *XMM-Newton* is about an order of magnitude larger than that of any previous X-ray observatory. In the particular field of X-ray surveys, the pinpoint accuracy on the X-ray source positions provided by *Chandra* is complemented by the large number of photons collected by *XMM-Newton* that allows a study of their X-ray spectral properties.

There are at present many X-ray surveys making use of these two observatories. The surveys looking for serendipitous sources (i.e., those not previously known) can be subdivided into low galactic latitude (to study sources from our Galaxy) and high galactic latitude ones (to study extragalactic sources). These also come in many flavors; some are directed to specific types of sources, such as galaxy clusters; some look for sources related to others already known (such us stars and supernova remnants in M31); and others just try to identify all the sources in some particular region(s) of the sky. We will concentrate on this last type of survey.

One ready way of classifying high galactic latitude surveys looking for serendipitous sources is their depth. Deep surveys are performed by pointing to the same position of the sky for long times (typically hundreds of kiloseconds). With such observations (necessarily specifically designed to this end) it is possible to detect very faint sources—at the cost of covering only very limited regions. The alternative approach is to look for serendipitous sources in the field of view of "normal" observations, covering much larger areas at shallower depths (typical exposure times of kiloseconds or tens of kiloseconds).

These different types of surveys are complementary: the deep pencil-beam surveys probe fainter fluxes, both reaching higher redshifts and low luminosity nearby objects, medium depth wide area surveys allow the study of brighter populations at medium redshift, while shallow surveys provide anchor points for luminosity function studies detecting nearby bright objects.

2.1. *Deep surveys*

Most (80–90%) of the extragalactic XRB has been resolved in the deepest surveys down to 0.5–2 keV and 2–10 keV fluxes of 2×10^{-17} and 1.4×10^{-15} erg cm^{-2} s^{-1} respectively (Brandt et al. 2002; Barger et al. 2001; Hasinger et al. 2001) into three different types of objects in approximately equal numbers: those with AGN signatures in their optical spectra, those without them (luminous early galaxies, some of them probably hidden AGN), and $I > 23.5$ spectroscopically unidentified objects. The fainter X-ray sources have harder X-ray spectra

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(Mushotzky et al. 2001; Hasinger et al. 2001; Brandt et al. 2002; Giacconi et al. 2001), as expected if absorbed AGN make up most of the XRB.

Most of the identified objects have $z < 1.3$. Even after allowing for selection effects, this suggests that more power originates at $z < 1.3$ than predicted by some X-ray background synthesis models, which will require revision (Brandt et al. 2002).

Many of the optically faint X-ray sources have red optical-to-near-IR colors, and a significant fraction have $I - K > 4$. They also have harder X-ray spectra than the brighter optical sources. About half of the optically faint sources for which X-ray variability could be detected show it. Together, these facts are compatible with the faint sources being luminous obscured AGN (Brandt et al. 2002).

Therefore, while the main contributors to the XRB seem to be obscured AGN, important facts such us their cosmic evolution, the distribution of obscuration and its evolution with redshift are far from determined. The identification of most of the faint sources that hold the clues to solve the XRB riddle definitively and probably dominate the AGN population is out of reach of present-day instrumentation even in 10 m class telescopes.

2.2. *The Survey Science Centre and the AXIS survey*

During most science observations *XMM-Newton* discovers ∼30–150 new X-ray sources, which add to the *XMM-Newton* serendipitous survey at an expected rate of ∼50 000 new sources per year. The *XMM-Newton* Survey Science Centre (SSC) was appointed by ESA to exploit the *XMM-Newton* serendipitous survey for the benefit of the scientific community and as a major legacy of *XMM-Newton* for future generations. This is being implemented by the SSC consortium in terms of a mostly ground-based optical follow-up and identification (XID) program.

The XID program has been described in detail in Watson et al. (2001). Briefly, it has been divided into two parts: a *core program*, which will identify spectroscopically significant samples of sources at 0.5–4.5 keV flux limits of around $\sim 10^{-13}$ erg cm^{-2} s^{-1} (bright sample), $\sim 2 \times 10^{-14}$ erg cm^{-2} s^{-1} (medium sample), $\sim 10^{-15}$ erg cm^{-2} s^{-1} (faint sample), covering a range of galactic latitudes, and an *imaging program* aiming at providing deep optical/infrared images of a large number of *XMM-Newton* fields in several colors, to aid statistical identification of the serendipitous sources. See Della Ceca et al. (2002), Barcons et al. (2002a), and Motch et al. (2002) for updates on the status of the bright sample, medium sample, and galactic sample, respectively.

AXIS (An *XMM-Newton* International Survey, Barcons et al. 2002a,b) forms the backbone of the XID program. It has been awarded a total of 85 observing nights spread over the period 2000 April–2002 April on the four largest telescopes of the Observatorio del Roque de los Muchachos.

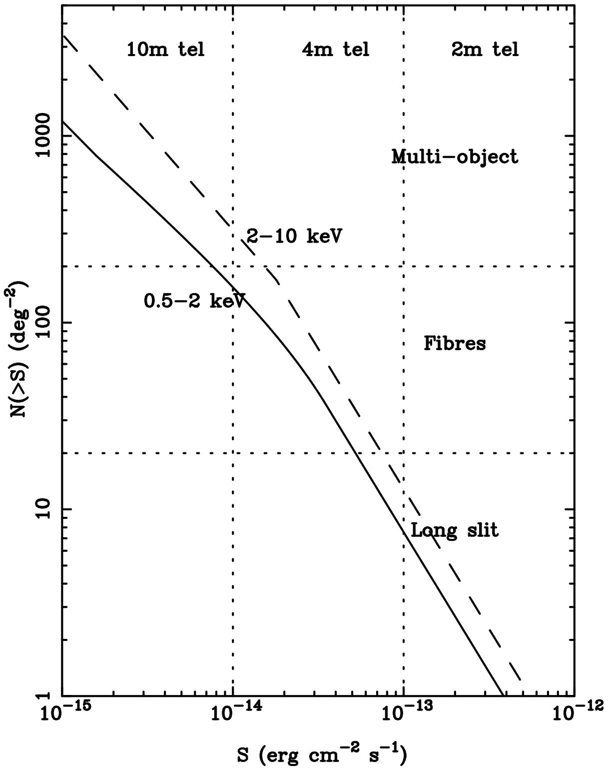

Fig. 1. Cumulative number density of X-ray sources in the 0.5–2 and 2–10 keV ranges, showing the approximate number density ranges for which each type of spectrograph is required, as well as the approximate flux ranges for which different size class of telescopes are needed.

We will concentrate here on the high galactic latitude medium sample, preliminary resuls for which have already been published by (Barcons et al. 2002). At the time of writing (beginning of 2002 March) we have identified 174 sources out of 397 X-ray sources (44%) over 29 *XMM-Newton* fields. We have a subsample of fifteen fields with 173 X-ray sources, of which ∼72% are identified.

Most of our identifications are AGN (89), followed by narrow emission line galaxies (seventeen, most of which turn out to be AGN), non-emission line galaxies (seven), galaxy clusters (one), and stars with active coronae (ten). There is marginal evidence for narrow line galaxies being harder than broad line AGN. The X-ray spectra of our AGN seem to change their effective spectral slope from ∼2 at 0.5–4.5 keV region to ∼1.6 at 4.5–10 keV, perhaps revealing the onset of new spectral components at $z \sim 1$–2.

Even at the relatively high X-ray flux of the medium sample, up to 14% of the X-ray sources do not show optical counterparts down to r or $i \sim 22.5$. These sources have large X-ray-to-optical ratios and are probably brighter examples of the absorbed AGN population that makes up the bulk of the XRB.

3. CONCLUSIONS AND POSSIBLE CONTRIBUTION FROM THE GTC

Medium and deep X-ray surveys are finding mostly AGN, many of which are obscured. They are also uncovering $I < 24$ sources with red colors ($I - K > 4$). The identifications of these sources are already making use of the best existing instruments on the currently largest telescopes. Some of the X-ray sources have no counterpart even down to $R, I \sim 25$. The source densities at the lowest fluxes require multiobject spectroscopy for optimum efficiency (see Figure 1).

The GTC will represent a significant improvement over present-day capabilities. OSIRIS will provide good MOS to $R \sim 24$, opening the way to the identification of many of the optically faint objects beyond the grasp of present hardware. EMIR will be able to perform MOS to $K \sim 21$, allowing the IR-brighter optical-to-IR redder objects to be identified.

Most of those will be obscured AGN, which dominate the XRB and the AGN population. The study of these AGN could have significant bearings on the formation and evolution of galaxies, and on the history of accretion in the Universe.

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