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OBSCURED AND UNOBSCURED GROWTH OF SUPERMASSIVE BLACK HOLES

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RESUMEN

La acreción es el mecanismo dominante en el crecimiento de los agujeros negros presentes en los centros galácticos. Los rastreos del cielo a longitudes de onda de rayos X trazan la historia de esta acreción en el Universo y muestran que la mayor parte de ella ocurre en objetos oscurecidos. En este artículo presentamos algunos resultados obtenidos con el *XMM-Newton* Medium Sensitivity survey (XMS), que investiga la población de fuentes que produce aproximadamente la mitad más brillante del fondo de rayos X por debajo de 10 keV. Hacemos énfasis en el papel que juegan los telescopios de gran apertura, como GTC, en poner al descubierto el crecimiento de agujeros negros en objetos oscurecidos

ABSTRACT

Accretion is the dominant mechanism governing the growth of massive black holes in galaxy centers. Surveys at X-ray wavelengths trace the accretion history in the Universe and reveal that most of it occurs in obscured objects. In this paper we present some results from the *XMM-Newton* Medium Sensitivity survey (XMS), which investigates the source population that produces about the brightest half of the X-ray background below 10 keV. We emphasize the role of large aperture telescopes, such as GTC, in unveiling the black hole growth in obscured objects.

Key Words: **GALAXIES: ACTIVE — X-RAYS: DIFFUSE BACKGROUND — X-RAYS: GALAXIES**

1. INTRODUCTION

Supermassive black holes (SMBHs, i.e., with masses $\sim 10^6 - 10^9\,\mathrm{M}_\odot$) have been detected in the centers of virtually all nearby galaxies (Merrit & Ferrarese 2001). In many of these galaxies -including our own- the SMBH is largely dormant, i.e., the luminosity is many orders of magnitude below the Eddington limit. Only a limited $\sim 10\%$ of today's galaxies (at most) host active nuclei, and a very large fraction of them are in fact inconspicuous at most wavelengths because of obscuration (Fabian & Iwasawa 1999). SMBH masses correlate well with host galaxy properties (stellar or gas central velocity dispersion, bulge luminosity), and are estimated to contain around 0.4-0.6% of the bulge masses (Magorrian et al. 1998).

It is generally believed that the seeds of these SMBHs were the remnants of the first generations of massive stars in the history of the Universe. These early black holes had masses of tens of $\mathrm{M}_\odot$ at most. The growth of these relic black holes to their current sizes is very likely dominated by accretion, with additional contributions by other phenomena like black hole mergers and tidal capture (Marconi et al. 2004). Accretion leaves a trail, the X-ray emission, that can be used to pin-point the epochs and places where SMBHs grew. According to current synthesis models, the integrated X-ray emission produced by the growth of SMBHs by accretion along cosmic history is the X-ray background (XRB).

Matching the local SMBH mass density function to the XRB spectrum and intensity (as first proposed by Soltan 1982), is intimately linked to two main unknowns: the fraction of accretion that occurs in *obscured* objects and the mass to radiation efficiency of accretion. Obscured accretion is believed to be dominant because the XRB spectrum calls for a large fraction of absorbed AGN (Comastri et al. 1995), and indeed local type 2 AGN (obscured AGN in the unified scheme) outnumber by a factor of several type 1 (unobscured) AGN (Risaliti, Maiolino, & Salvati 1999). Whether this is true at high redshift where most of the XRB is generated is a subject of active investigation. In the standard optically thick geometrically thin accretion disk paradigm, the efficiency of accretion is dictated by the inner disk accretion radius, and therefore heavily linked to the

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SMBH spin. It has been argued that an accretion efficiency of 10% or more is required (Elvis, Risaliti, & Zamorani 2002), which would in turn require rapidly spinning black holes in the population of distant AGN (as reported by Streblyanska et al. 2005).

Quantitative results on many of these issues are often hampered by the lack of large samples of X-ray emitting objects at various depths. Wide-angle, shallow X-ray surveys such as the *XMM-Newton* Bright Source Survey (BSS, Della Ceca et al. 2004) map the low redshift population of accreting SMBHs. The most distant sources are studied by deep pencil-beam X-ray surveys, which resolve virtually all the XRB at energies below 7 keV (Tozzi et al. 2005; Hasinger et al. 2001). As an intermediate step, the *XMM-Newton* Medium Sensitivity survey (XMS) - among others- offers the opportunity of characterizing the population of accreting SMBHs responsible for about the brightest half of the XRB, and over a reasonably large area.

2. THE *XMM-NEWTON* MEDIUM SENSITIVITY SURVEY (XMS)

The XMS is a collection of serendipitous X-ray sources at intermediate flux levels, drawn from 25 high-galactic latitude *XMM-Newton* target fields with good quality X-ray data. The area covered exceeds 3 $\deg^2$, and a very careful source screening process has been conducted on all the data in order to exclude unwanted artifacts. The XMS has been built as part of the *XMM-Newton* Survey Science Centre activities to characterize the X-ray source populations (Watson et al. 2001).

The XMS contains a total of 318 X-ray sources that were selected for optical identification. Out of this collection, we built three truly flux-limited samples: the XMS-S soft sample selected in the 0.5-2 keV band, the XMS-H hard sample selected in the 2-10 keV band and the XMS-X sample selected in the 0.5-4.5 keV band to optimize the *XMM-Newton* throughput. An additional ultrahard sample (XMS-U) was built with all the sources detected in the 4.5-7.5 keV band without any flux cutoff. Table 1 shows the main features of these largely overlapping samples.

Extensive optical multi-band imaging was conducted, and (often unique) candidate optical counterparts to all sources were targeted. Optical spectroscopy on these candidate counterparts has resulted in the identification of $\sim$ 90% of the XMS sources (see again Table 1). Optical observations entailed the use of a number of telescopes at the Observatorio del Roque de Los Muchachos in La Palma (INT, WHT, TNG and NOT), the Centro Astronómico Hispano Alemán (2.2-m and 3.5-m telescopes), and the ESO's Paranal Observatory (VLT).

TABLE 1

CURRENT STATUS OF THE XMS

Sample	Band	Flux lim.	Srcs[a]	Ident.[b]
XMS-S	0.5-2.0 keV	1.5	210	202 (96%)
XMS-H	2-10 keV	3.3	159	134 (85%)
XMS-X	0.5-4.5 keV	2.0	284	261 (92%)
XMS-U	4.5-7.5 keV		70	60 (76%)

[a]In units of 10^{-14} erg cm^{-2} s^{-1} in the given energy band.

[b]Number of sources that have been identified through optical spectroscopy and the fraction of the total sample.

A detailed discussion of the contents of the XMS is presented in Barcons et al. (2007, in preparation), while a preliminary account was given in Barcons et al. (2002). Here we only report on the most significant issues. Figure 1 gives some insight into the overall properties of our sample, where we plot the X-ray 2-10 keV to optical r (SDSS) flux ratio versus the X-ray hardness ratio. We can see that various parts of this diagram are populated primarily by different classes of sources.

The first point to note is that the content of all samples is dominated by AGN of various classes.

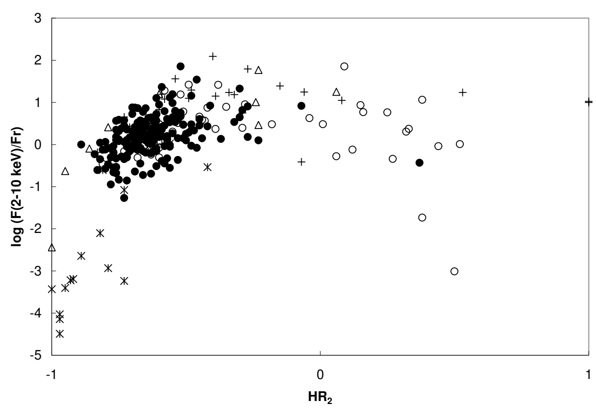

Fig. 1. Log of the flux ratio between 2-10 keV X-ray flux and r' SDSS optical flux versus *XMM-Newton* hardness ratio $HR_2 = (C(2-4.5)-C(0.5-2))/C(0.5-4.5)$, where $C(0.5-2)$ and $C(2-4.5)$ are exposure map-corrected count-rates. Filled circles represent type-1 AGN, hollow circles are narrow-line emission galaxies (including type-2 AGN and star forming galaxies), triangles are absorption-line galaxies, asterisks are stars and crosses unidentified sources.

In the XMS-S soft X-ray flux-limited sample, unobscured type-1 AGN constitute 74% of all sources, while type-2 obscured AGN represent less than 18% of the total. When the XMS-H hard X-ray flux-limited sample is used, the fraction of type-1 AGN among the list of identified sources is significantly smaller (62%), while obscured AGN could represent as much as 34%. These numbers highlight the importance of using hard X-ray surveys to unveil accretion in obscured objects.

In all samples, the population of type-1 AGN (i.e., those AGN displaying broad permitted lines) is well sampled out to high redshifts ($z > 2$) and peaks at around $z \sim 1.5$. The population of type-2 AGN (i.e., those AGN without broad components in their optical spectrum) is concentrated at significantly lower redshifts, with the peak at $z \sim 0.5$, consistent with the results from deeper X-ray surveys. We find among the XMS-H sample a total of 6 type-2 QSOs, i.e., objects with 2-10 keV luminosity exceeding $10^{44}\,\mathrm{erg\,s^{-1}}$ and without broad emission lines. The most distant of these type-2 QSOs lies at $z = 2.2$.

3. OBSCURED AND UNOBSCURED AGN

Obscured accretion can manifest itself in different ways, not fully equivalent among themselves: lack of optical/UV broad emission lines, presence of significant ($N_H > 10^{22}\,\mathrm{cm^{-2}}$) photoelectric absorption in the X-ray spectrum, a large X-ray to optical ratio, etc. We now discuss the relation between these observables in the XMS samples.

The link between optical AGN classification and photoelectric absorption in the X-ray band is on average seen to work as expected in the unified AGN model, i.e., type-1 AGN do not display absorption and type-2 are heavily absorbed in X-rays. Mateos et al. (2005a,b) show, however, that around 10% of type-1 AGN do show photoelectric absorption (although at moderate levels), and 15% of type-2 AGN do not exhibit absorption at any noticeable level. The former can possibly be due to weak ionized winds or host galaxy intervening material, while the latter probably indicates that the absorbing material is clumpy so that it obscures the extended BLR but not the nucleus around the SMBH itself.

The X-ray to optical flux ratio F_X/F_r for a normal QSO or type-1 AGN is typically measured to be of order ~ 1 within an order of magnitude. Indeed, in the XMS-S soft sample, only 5% of the sources have $F_X/F_R > 10$, and only 30% of these are obscured AGN (in terms of their optical spectrum). On the contrary, the XMS-H has 15% of its sources in the $F_X/F_r > 10$ regime, and 70% of these are obscured AGN. This demonstrates that the $F_X/F_r = 10$ barrier is indeed a good (but not perfect) discriminator between obscured and unobscured accretion in the 2-10 keV band.

Optical colours have also been inspected vis a vis optical spectral characterization. While $g-r$ (SDSS colors) is generally a good discriminator between unobscured (blue) and obscured (red) AGN, it turns out that a significant amount ($\sim 10\%$) of XMS-H type-1 AGN are red.

Reddening is a general trend of the whole X-ray source population towards fainter fluxes, a fact that has been also noted in deep surveys. The $r-i$ (SDSS filters) color increases towards the faint flux end of the XMS-H sources, and this effect is more pronounced if the $i-Z$ color is used instead.

4. CONCLUSIONS

The X-ray sky at intermediate fluxes, where somewhere between one third and one half of the XRB is produced, is dominated by unobscured accreting SMBHs. The obscured component, however, starts to dominate at faint fluxes. There are a number of indicators of obscured accretion (optical colours, optical spectroscopic classification, X-ray colours, X-ray to optical flux ratios) which agree among themselves on average, but leave 10-25% outliers. The optical counterparts of faint X-ray sources are optically faint and red, which calls for large aperture telescopes equipped with efficient optical and near infrared spectrometers for their identification.

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