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Black Hole Results from XMM-Newton

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Abstract

XMM-Newton is one of the most successful science missions of the European Space Agency. Since 2003 every year about 300 articles are published in refereed journals making directly use of XMM-Newton data. All XMM-Newton calls for observing proposals are highly oversubscribed by factors of six and more. In the following some scientific highlights of XMM-Newton observations of black holes are summarized.

Keywords: X-ray - AGN - black hole.

1 Introduction

XMM-Newton ([1]) is the second cornerstone of European Space Agency's (ESA) Horizon 2000 Science Programme, providing an observatory-class X-ray facility. The spacecraft was launched by an Ariane 5 on 10 December 1999. The observatory provides simultaneous non-dispersive spectroscopic imaging and timing (European Photon Imaging Camera; EPIC, [2] and [3]), medium resolution dispersive spectroscopy (Reflection Grating Spectrometer; RGS, [4]) and optical/UV imaging, spectroscopy and timing from a co-aligned telescope (Optical Monitor; OM, [5]). The three X-ray mirrors ([6]) in combination with the cameras of EPIC offer a large effective area over the energy range from 300 eV to 12 keV, up to 2500 cm^2 at 1.5 keV and $\sim$1800 cm^2 at 5 keV. The scientific potential of the effective area may be illustrated by the first observation of an evolving dust-scattered X-ray halo around a gamma ray burst ([7]). Each of the two modules of the RGS cover the energy range from $\sim$0.4 keV to 2.2 keV with an effective area of 60 cm^2 at 15 Å.

2 Scientific Highlights

Scientific highlights resulting from the first decade of XMM-Newton and Chandra observations can be found in [8]. In the following I list a number of highlights from XMM-Newton observations of black holes. In this paper I have focused on some of the most exciting discoveries in this field, which also received wide publicity in public relations announcements by ESA.

2.1 Galactic black holes and ultraluminous X-ray sources

Globular clusters (GC), containing thousands of stars packed within tens of light years, were considered as a possible breeding ground for black holes. A rival hypothesis suggests that black holes are ejected through close star encounters and consequently GCs are devoid of black holes. XMM-Newton observations of NGC 4472 allowed the first detection of a black hole in a GC ([9]) excluding the latter hypothesis. Ultraluminous X-ray sources (ULX) were proposed to harbour intermediate-mass black holes, which provides the link between stellar mass black holes and supermassive black holes (SMBH) in the centres of galaxies. XMM-Newton and Chandra observations of CXOM31 J004253.1+411422 in Andromeda allowed to connect this ULX to Low Mass X-ray Binaries ([10], implying accretion onto a stellar-mass black hole in the Eddington regime. A second ULX found in Andromeda, XMMU J004243.6+412519, allowed to observe the emission of the accretion disk in X-rays together with the emission form its jets in radio ([11]). The experimental key for both observations was the low absorbing column density towards Andromeda whereas absorption is a major obstacle of ULX observations in our own Galaxy. [12] found an intermediate-mass black hole in NGC 1313. The X-ray spectra of the ULX can be described with a power law plus an accretion disk ($kT \cong$ 150 eV) implying a mass of $\cong 10^3 M_\odot$. A intermediate-mass black hole with $m > 500$ M$_\odot$ could be associated with an ULX in ESO 243-49 based on luminosity variations observed by XMM-Newton ([13]).

2.2 The strong gravitational field

Currently, X-ray observations are the only way to observe the strong gravitational field in the direct vicinity of black holes and neutron stars ([14]). Special and general relativistic effects distort the spectra of particles orbiting black holes depending on the orbital parameters and the black hole's spin. Theoretical discussion can be found in [15], [16], [17] [18] or more recently in [19] and [20]. Experimentally the iron Kα line is most studied as there are no lines of abundant elements nearby. Early examples are the XMM-Newton observations of the Galactic black hole XTE J1650-500 in outburst ([21]) and the Active Galactic Nuclei (AGN) MGC-6-30-15 in low state ([22]). Both spectra are explained by a fast spinning black hole and the extraction and dissipation of rotational energy from it. The simultaneous XMM-Newton and NuSTAR observation of NGC 1365 revealed that reflection from an ionized disk readily explains the spectra taken by both satellites ([23]). The XMM-Newton spectra of the Galactic black hole, GX 339-4 in outburst ([24]) is an example of a black holes with almost maximum spin. The observation of 1H 0706-495 is unique as it shows not only the iron Kα, but also the iron Lα line ([25]). In addition the light cure shows the expected characteristic variability of reflection from an ionized disk (compare also [26], [27], [28], [29]).

2.3 Active Galactic Nuclei (AGN) in low states

Following [30] X-ray spectra of AGNs are composed of a power-law continuum emitted above a black hole plus reflection from an ionized disk. During the low state the continuum emission region moves nearer to the black hole and gravitational bending affects its light path. Observationally, during low states the continuum emission appears suppressed whereas the reflected emission appears constant or even enhanced, compare also [31]. The most intensive studied AGN in low state with XMM-Newton is PG 2112+059, where an additional layer of ionized material was used to favour the reflection interpretation versus alternative scenarios ([32], [33] and [34]). [35] used variability considerations to discriminate the reflection interpretation versus an absorption scenario for PG 0844+349 in an X-ray weak state. And [36] could demonstrate for the low state observation of 1H0707-495 reflected emission within one gravitational radius of the event horizon of the black hole.

2.4 Aspects of variability near Supermassive Black Holes (SMBHs)

Whereas quasi-periodic-oscillations (QPO) are well established in X-ray binaries for almost 30 years, QPOs remained elusive in AGNs. XMM-Newton measured a $\sim$1 hour QPO for RE J1034+396 ([37]). [38] found evidence for orbital motion of material close to the central black hole of Mrk 766. A XMM-Newton observation allowed [39] to observe a co-rotating flare at a distance of only 3.5 to 8 Schwarzschild radii to the SMBH of NGC 3516.

2.5 Energy budget, winds and outflows

[40] established for the fist time simultaneous spectral energy distributions for the majority of the [41] reverberation mapped sample of AGN based on XMM-Newton EPIC and OM measurements. [42] used XMM-Newton observations to show that radio-galaxies produce sufficient mechanical energy to unbind a significant fraction of the intra-group medium, an effect which is negligible in massive clusters of galaxies. Combining high resolution RGS spectra with sensitive light-curves of EPIC, [43] demonstrated an accretion-disk origin for the two warm absorber winds in NGC 4051. 1H 0707-495 shows a mildly relativistic, highly ionized outflow which changed its velocity from about 0.11c to 0.17c between 2008 January and 2010 September ([44]). Ultrafast outflows are present in >35% of radio-quiet AGN observed with XMM-Newton, providing a significant contribution to the AGN cosmological feedback ([45], [46], [47]).

2.6 Flares and tidal disruption events

[48] observed several peaks in the power density spectrum of the X-ray light curve of the SMBH in the Galactic Centre during which period a bright X-ray flare was detected ([49]). Theoretical studies revealed a previously unknown topological structure inherent to black holes with high spin: in a small region near the event horizon of the spinning black hole the orbital velocity decreases for decreasing orbital radius ([50]). This effect is now rightfully known as the Aschenbach effect ([51]). [52] could identify a tidal disruption event based on ROSAT, Chandra and XMM-Newton observations. Suzaku and XMM-Newton observations taken shortly after the occurrence of the tidal disruption event Swift J164449.3+573451 reveal a 200-second X-ray quasi-periodicity ([53]). This QPO might be explained with the forming of an accretion disc or precession of the jet.

2.7 Deep fields and cosmology

A total of 1000 AGN detections from a variety of ROSAT, XMM-Newton and Chandra surveys allowed [54] to obtain for the first time reliable space densities for low-luminosity (Seyfert-type) X-ray sources at high cosmological redshifts. Their evolutionary behaviour shows strong dependency on the X-ray luminosity and differs from the dependency found for high luminosity AGNs and quasars. XMM-Newton allows the detection of quasars at highest redshift, e.g. SDSS J104433-012502 at z=5.80 ([55]). The spacecraft could even establish an X-ray spectrum of SDSS J1030+0524 at z=6.30 ([56]). An ionized iron Kα absorption edge in the X-ray spectrum of APM 08279+5255 allowed to obtain an, at the time of publication, highly interesting constrain on the age of the universe ([57]).

3 Discussion and Conclusions

Since 2003 every year about 300 articles are published in refereed journals making directly use of XMM-Newton data. All XMM-Newton calls for observing proposals are highly oversubscribed by factors of six and more. Within ESA's mission extension scheme all missions are evaluated every 2 years and possibly extended by 4 years subjected to midterm confirmation. XMM-Newton is funded up to end of 2016 subject to midterm confirmation and further extension discussion in 2014. Currently, the XMM-Newton mission is implementing four-reaction-wheel operation schemata, which will reduce fuel consumption significantly. The envisaged operation mode will allow technically operating the mission up to 2026.

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