Highlights from XMM-Newton
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Abstract
The launch of the Chandra (NASA) and XMM-Newton (ESA) X-ray observatories in 1999 has revolutionized our view of the Universe, by providing astrophysical information about many classes of sources with unprecedented detail. The high throughput of XMM-Newton makes it the ideal instrument to provide low to moderate resolution spectroscopy of faint and extended sources. After 3 years of operations, XMM-Newton has observed all types of astronomical sources and delivered very interesting results in many areas. In this review, we highlight a few points where the contribution of XMM-Newton has significantly furthered our knowledge of the energetic Universe.

1 Introduction
X-ray Astronomy is at the very heart of the enormous progress that our astrophysical knowledge of the Universe has undergone over the last decades. X-rays are emitted in a wide range of physical situations in the Universe, invariably linked to the presence of hot gas and strong gravitational fields. These phenomena, largely unsuspected in the early days of X-ray astronomy, are nowadays seen to be ubiquitous in a variety of astronomical objects. X-ray observations of previously known objects have often revealed phenomena (e.g., the presence of an accreting black hole) just not seen at other wavelengths. In addition, new sources serendipitously discovered in X-ray surveys have uncovered new classes of objects, totally inconspicuous at optical wavelengths. One datum that illustrates the impact of X-ray observations in Astronomy is that 20% of the papers published by the 3 main Astrophysics journals in 2002 (Astrophysical Journal, Monthly Notices of the Royal Astronomical Society and Astronomy & Astrophysics) contain the “X-ray” keyword in the abstract. The 2002 Nobel Prize in Physics given to Riccardo Giacconi (father and leader of X-ray Astronomy), is also a sign of the good health reached by this discipline, as it is one of the very few granted to astronomers.

1.1 Some history
X-ray Astronomy began in 1962, when a rocket flown to detect the Moon in scattered X-rays from the Sun, discovered instead the first extra-solar X-ray source (Sco X-1) and the cosmic X-ray background (Giacconi et al. 1962). This already showed that the Universe out there could be radically more energetic than what was known before, as Sco X-1 had a much larger X-ray to optical flux ratio than the Sun. More rockets followed this pioneering discovery, but there was a basic limitation in the amount of observing time available in a single flight.

UHURU (which means freedom in swahili) was the first orbiting X-ray observatory. It was launched from Italy’s San Marco station in Kenya on the 12th of December of 1970, coinciding with the independence day of this country (thence the name). The UHURU payload weighed less than 60 kg. It scanned the sky for over 2 years and produced the first all-sky catalogue of X-ray sources, containing a few hundred of them. Subsequent work demonstrated that outside the galactic plane, most of the sources were Active Galactic Nuclei (AGN) and clusters of galaxies. In the Galactic plane, UHURU found X-ray binaries, supernova remnants and other diffuse structures. This rough picture (but with varying fractions of objects) still describes to zero-th order the present knowledge of the X-ray Universe.

This early generation of X-ray orbiting observatories (which also included HEAO-1 and more recently Ginga, Japanese word for Milky Way) were equipped with a mechanical collimator as the only means to
limit the field of view covered by the (usually gas-filled proportional counter) detectors, without any further optics. This provided a very rough angular resolution, of the order of several degrees, which ultimately limited the sensitivity of the observatory because of confusion of fainter sources.

Proper imaging X-ray optics was featured for soft X-rays (below 4.5 keV) with the Einstein Observatory first. With an angular resolution of a couple of arc minutes, Einstein discovered many new X-ray sources (including many at cosmological distances), showing that the word experiment was in the way of being replaced by observatory in X-ray missions. Einstein made it possible to discover new classes of sources by their X-ray emission, resolved the spatial structure of the intracluster gas in galaxy clusters and produced large catalogues of X-ray sources that were subsequently used to conduct detailed astrophysical studies. It also showed, for the first time, that a significant fraction of stars are X-ray emitters. ROSAT, in some sense a successor to Einstein, deepened our knowledge of the X-ray Universe, by conducting first an all-sky survey (this yielded the, so far, largest catalogue of X-ray sources, exceeding 50000), and for almost a decade, targeted observations of a full range of astronomical objects, from comets to distant QSOs.

Focusing X-ray photons is not an easy task. In a standard reflecting optical telescope, photons are directed almost normally to the reflector’s surface and collected in the focal plane. If the same setup is used for X-rays, they end up either transmitted or absorbed, but never reflected. Grazing incidence is needed to achieve total reflection for X-rays, the maximum angle with respect to the surface being of a few degrees for a photon of ~ 1 keV. Reflection becomes more difficult at higher photon energies, as the angle for total reflection becomes smaller and the mirrors need to be placed almost parallel to the optical axis. It is easy to see that the effective area that a photon sees is very small with a mirror placed in grazing incidence, and therefore several (or many) mirrors are nested one inside each other to increase the collecting area. It is also clear that an X-ray focusing telescope of higher energy photons will have less effective area and longer focal length than a similar one focusing soft X-ray photons.

The start of the nineties brought X-ray observatories able to produce images with photons of up to 10 keV, such as the Japanese ASCA were launched. ASCA also opened the door to a more modern type of X-ray detector (the Charge Coupled Device or CCD) that ended up burying the proportional counters. CCD-based detectors deliver an order of magnitude better spectral resolution for single photons than proportional counters. At the energy of the Fe Kα line (6.4-6.7 keV), the resolution of ~ 50 achieved by these detectors enables a detailed study of the physical environment where it is produced.

Other X-ray observatories have been launched during the 1990’s, including BeppoSAX (which also featured higher energy detectors sensitive to many tens of keV) and Rossi X-ray Timing Explorer (RXTE) which is tailored to timing analysis of bright sources. However, at the turn of the new millenium, both NASA and ESA decided to launch their respective large X-ray observatories: Chandra (launched July 1999) and XMM-Newton (launched December 1999). The coincidence of operations between both missions (being just by chance, as Chandra was over-delayed for several years) has brought what can be called the golden age of X-ray Astronomy. By virtue of their respective designs Chandra is mostly an imaging observatory, while XMM-Newton has its major capabilities at spectroscopy. Having both of them operating at the same time has opened a huge window to X-ray astrophysics, whose dimensions are just beginning to be realized after the first few years of operations.

## 2 XMM-Newton

**XMM-Newton** is an X-ray observatory launched and operated by the European Space Agency (ESA), with instruments contributed and funded by ESA member states and NASA (USA). XMM-Newton was successfully launched by an Ariane 5 on the 10th of December of 1999. Its orbit is highly eccentric with a period of ~ 2 days. Although the original XMM-Newton project was approved for 2 years of scientific operations, all systems and payloads are designed to last for ~ 10 years. Specifically, fuel (hydrazine) is currently thought to last for more than that. In fact, an extension of the XMM-Newton operations has already been approved to 2006 with a further 2 year period being revised by mid 2003. For comparison with early missions, the full XMM-Newton satellite weighs more than 3000 kg. Currently, the XMM-Newton spacecraft is operated by ESOC at Darmstadt (Germany), but the instruments and science operations in general are managed from VILSPA (Villacfranca del Castillo, Spain).

**XMM-Newton** consists of 3 co-aligned grazing incidence X-ray telescopes (Jansen et al. 2001), with angular resolution of 4-6 arcsec (FWHM) and 13-15 arcsec (Half Energy Width). Each X-ray telescope nests 58 grazing incidence mirror pairs, with a total collecting area of ~ 4000 cm$^{-2}$ (see Fig 2 for a schematic of the X-ray optics in the XMM-Newton.
X-ray telescopes. One of these telescopes focuses all X-rays into a single spectroscopic imaging detector (EPIC-pn, Strüder et al. 2001), which has a pixel size of 4 arcsec and covers a field of view of about 30 arcmin in diameter. About half of the X-rays focused by the other two telescopes go undispersed to similar imaging spectrographs called EPIC-MOS (Turner et al. 2001). The EPIC instruments can measure the energy of individual photons with a resolution of $\sim 20 - 50$. EPIC is sensitive to photons from 0.2 to 12 keV and can detect X-ray sources as faint as $\sim 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ in the 0.5-2 keV band in a few tens of kiloseconds (ks). Its main limiting sensitivity in soft X-rays is caused by confusion, due to the modest angular resolution of the X-ray telescopes. At higher photon energies the main limiting factor is photon counting, with an expected confusion limit in the 2-10 keV band reached in a several Ms exposure only.

The two X-ray telescopes that focus the X-rays into the EPIC-MOS detectors are equipped with diffractive gratings working by reflection. These disperse the remaining X-rays according to their wavelength and these are recorded in a further chain of CCD detectors. This wavelength-dispersive instrument is called the Reflection Grating Spectrometer (RGS) and delivers a spectral resolution $\sim 200$ in first order dispersion (i.e., $\sim 0.06 \AA$) in the soft X-ray domain (5-35 A, or 0.3-2.4 keV). The sensitivity of the RGS can be viewed in terms of a source with 0.5-2 keV flux of $\sim 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ producing peak $S/N \sim 10$ per spectral resolution element in 100 ks. It is therefore an instrument designed to observe bright sources with relatively high spectral resolution. The moderate angular resolution of the XMM-Newton mirrors makes it possible to obtain integrated moderate resolution of extended sources, a capability that is producing extremely interesting results (see later).

Besides that, XMM-Newton has a co-aligned optical/UV telescope (the Optical Monitor - OM) which operates in the range from 1600 to 6600 A. At its focal plane the OM has a photon counting device (Mason et al. 2001), which delivers time-resolved information for the detected photons. The field of view of the OM is 17 arcmin, with a point-spread-function of FWHM between 1.3 and 2.5 arcsec, with a limiting sensitivity of $23.5^{\text{mag}}$ for 1000 sec integration. The OM is equipped with a number of UV and optical filters, plus low resolution UV and optical grisms, whose calibration is being conducted at the time of writing this report. All three XMM-Newton instruments (EPIC, RGS and OM) are simultaneously operated.

The ground segment operations of XMM-Newton are conducted by the SOC at Villafranca del Castillo (Spain) with the assistance of an ESA member-state funded consortium called Survey Science Centre (SSC). The SSC tasks include the development of Science Analysis Software tasks in collaboration with the SOC; the pipeline processing of all XMM-Newton data and the identification of the serendipitous sources discovered by XMM-Newton. This last task is specially demanding, as it is likely that XMM-Newton will find about 50000 new X-ray sources per year. Identifying and cataloguing these data will constitute a major legacy of XMM-Newton (see Watson et al. 2001).

ESA has already released the first version of the XMM-Newton catalogue provided by the SSC, which contains over 30000 good-quality X-ray sources. Some of these sources are identified thanks to the extensive archival search conducted by the SSC. At the time of writing this report the SSC has imaged in various optical filters a large fraction of fields that contain the catalogued sources. Besides that, well over 500 of these X-ray sources have been spectroscopically identified. All this optical imaging and spectroscopic information will be included in future versions of the XMM-Newton catalogue, delivering an extremely powerful tool to investigate the X-ray sky.

### 3 Normal stars

One of the areas where the impact of XMM-Newton has been strongest is the study of X-ray emission from “normal” stars. The possibility that stars without compact companions could be X-ray emitters had not been initially foreseen. Though some nor-
normal stars had been detected by previous experiments (e.g., Topka et al. 1978), only after the observations by Einstein was it fully realised that many solar-type stars emitted soft X-rays (Vaiana et al. 1981). Equally surprising was the discovery that hot OB stars also appeared to be substantial soft X-ray sources.

The X-ray emission from low-mass stars was quickly interpreted in terms of coronal activity, similar to that observed in the Sun, but on a much larger scale. Many M-type stars were found to display relatively strong X-ray emission, which correlated with other indicators of activity, such as emission in H$_\alpha$ or the Ca II doublet (Noyes et al. 1984; Vilhu 1984, Fleming et al. 1989).

It was also found that there was a strong correlation between age and X-ray activity. In this sense, the all-sky survey by ROSAT greatly changed the previous view on the evolution of low-mass stars towards the main sequence. It was seen that many stars not displaying the typical characteristics of T Tauri stars could be identified as very young objects because of their X-ray emission (e.g., Neuhäuser 1997). This lead to the discovery of whole new associations of young stars. As previous missions lacked spectral resolution in the soft X-ray range, XMM-Newton and Chandra offer the possibility of obtaining, for the first time, information about the physical causes of this emission.

### 3.1 Coronal activity

Coronal activity in chromospherically active low-mass stars is thought to result in X-ray emission through mechanisms similar to those observed in the Sun. Observations with XMM-Newton provide spectra showing lines from a large variety of elements (O, Ne, Mg, Fe, N, etc), many of them in at least two different ionisation states. From them, coronal abundances, which are in many cases very different from the stellar atmospheric abundances, are derived. In the Sun, elements with low first ionisation potential are overabundant with respect to their photospheric abundances, while elements with high first ionisation potential are not. In a survey of RS CVn binaries (tidally locked binaries containing a highly active slightly evolved G-K star), Audard et al. (2003) find that the most active stars display a behaviour opposite to that seen in the Sun, suggesting that fractionation mechanisms should be revised. They indicate that this opposite effect is seen in all stars with high coronal activity, while stars with lower activity seem to present an effect similar to the Sun.

Simultaneous observations of σ Gem, an RS CVn binary with a K1III primary, with XMM-Newton and the VLA have allowed the discovery of a correlation between the radio luminosity of a large flare and the time derivative of the X-ray luminosity (Güdel et al. 2002). This relationship is observed in solar flares, where it is known as the Neupert effect, and supports flare mechanisms causing chromospheric evaporation.

The presence of X-ray emission from young (pre-main-sequence) stars is now recognised as a widespread phenomenon (Feigelson & Montmerle 1999). It is assumed to be a consequence of the same magnetohydrodynamical processes that drive the outflows and winds associated with classical T Tauri stars (e.g., Shu et al. 1994). Large-scale surveys with XMM-Newton will allow an understanding of these phenomena. As a first example, Favata et al. (2003) have observed the L1551 star forming complex. They find that the characteristics (both temporal evolution and spectrum) of classical T Tauri stars and weak-lined T Tauri stars are very different, suggesting that while weak-lined T Tauri stars show an enhanced version of the coronal activity seen at older ages, classical T Tauri stars have a different X-ray emission mechanism, related to their accretion disks.

### 3.2 Massive stars

Although emission from low mass stars can be understood in terms of coronal activity, the existence of relatively soft X-ray emission from massive stars came as a bit of a surprise (Harnden et al. 1979). Models trying to explain it invoke hydrodynamic shocks resulting from intrinsic instabilities in their radiatively driven winds (see Feldmeier et al. 1997). XMM-Newton RGS spectra have allowed the exploration of physical conditions in the regions where the emission is produced. Observations of the O4If star ζ Puppis have provided confirmation that the X-ray emission consists mostly of broad emission lines from H-like and He-like charge states of N, O, Mg and Si, as well as Ne-like ions of Fe (Kahn et al. 2001). In this object with a very strong radiative wind, X-ray emission reaching us seems to be produced at large distances from the star.

Conversely, the X-ray spectrum of the B0.2V MK standard τ Scorpii is not very consistent with standard models. Emission lines in its XMM-Newton RGS spectrum are as narrow as the instrumental profile, suggesting that they are produced much closer to the star (Mewe et al. 2003). X-ray emission shows a hot component corresponding to a temperature in excess of 20 × 10$^6$ K. This is supported by a Chandra observation of the same star by Cohen et al. (2003), who suggest that the spectrum of τ Scorpii is intermediate.
between those of O-type stars and coronal emitters. As there is rather strong evidence against the possibility of a cool companion for τ Scorpii, a model in which dense clumps in the wind stall and decelerate, perhaps falling back onto the stellar surface, such as that presented by Howk et al. (2000), is preferred. The hard X-rays would then originate in bow shocks around those clumps.

In some cases, emission from relatively hot stars seems to be due to late-type companions. Simultaneous observations of Castor with XMM-Newton and Chandra allow the resolution of its three components, all of which are close binaries. Castor C is a pair of M1V stars, both of which appear to be moderately active (Stelzer et al. 2002). Both Castor A and Castor B contain an A-type star and a low-mass companion, but their emission appears typical of coronal activity in the low mass stars (Stelzer & Burwitz 2003).

Another interesting result obtained with XMM-Newton is the lack of X-ray emission from C-rich Wolf-Rayet stars. Oskinova et al. (2003) failed to detect WR 114 with XMM-Newton, implying a lower limit on its X-ray luminosity \( L_x/L_{bol} \leq 4 \times 10^{-9} \). Until now, no single WC star has been detected in X-rays, while several WN star have. An example is WR 110, detected with XMM-Newton by Skinner et al. (2002). Surprisingly, the X-ray spectrum of this very hot star also shows a hard component which cannot be explained with current models.

In some cases, a relatively hard X-ray spectrum is produced when the winds of two massive stars forming a close binary collide. This is the case of HD 93403 (O5.5I + O7V), where clear orbital modulation has been detected with XMM-Newton (Rauw et al. 2002).

4 Accreting binaries

X-ray binaries (XRBs) are systems in which high energy radiation is emitted as a consequence of the accretion of material from a donor star (in most cases, a hydrogen-burning “normal” star) onto the surface of a compact object (see Lewin et al. 1995, for extended reviews). Binary systems in which the accreting compact object is a white dwarf are generally considered as a separate subclass, known as Cataclysmic Variables, though there are no strong physical reasons for this separation.

XRBs emit most of the X-ray flux detected from normal galaxies, including the Milky Way. They have been discovered in large numbers by previous satellites and now a sufficiently large sample exists for population studies to be statistically significant (e.g., Helfand & Moran 2001). XMM-Newton offers several potentialities for their study. On the one hand, it opens up the opportunity of obtaining spectra of Galactic sources with moderate resolution and high signal-to-noise ratio. On the other hand, because of its large collecting area and moderately high spatial resolution, it provides an excellent opportunity for studying the populations of nearby galaxies. Last but not least, XMM-Newton offers the possibility of obtaining X-ray spectra of faint Galactic sources, opening the door to studies of low-luminosity accreting binaries.

XRBs are generally divided into two main subclasses, high mass (HMXBs) and low mass (LMXBs), depending on the nature of the donor star (either an OB star or G−M spectral type). Additionally, depending on the temporal behaviour, they can be divided in persistent and transient sources. LMXBs containing an accreting neutron star can be either persistent or transient, but systems with black holes are generally transient.

4.1 Low mass X-ray binaries

Classical low mass X-ray binaries (LMXBs) consist of a neutron star with a moderately strong magnetic field (\( \sim 10^8 \) G) accreting from a low-mass star. The light-curves of these objects are rather complex (dis-
playing temporal features such as eclipses and dips). There is a large variety of behaviours among LMXBs, likely due to the complexity of their accretion geometries, which has prevented the creation of a unified model. As a matter of fact, while all LMXBs observed with ASCA could be well fit with a two component model, a blackbody representing the accretion disk and an extended Comptonising region (Church & Balucinska-Church 2001), this model failed to fit observations of several LMXBs with BeppoSAX (e.g., Oosterbroek et al. 2001).

Many LMXBs also display bursts, very rapid increases in the X-ray flux followed by exponential declines (typically lasting seconds to minutes). The bursts are interpreted as thermonuclear explosions on the stellar surface, after material has accumulated due to accretion (Lewin et al. 1993). During this bursts, X-ray emission from the vicinity of the neutron star dominates that coming from the disk.

**XMM-Newton** has allowed the study of the accretion environments of low mass X-ray binaries, with the discovery of complex narrow absorption features in their X-ray spectra, corresponding to H-like and He-like ions of O and Fe, and likely other elements (Cottam et al. 2001; Sidoli et al. 2001; Parmar et al. 2002). For example, comparing the number of absorbed photons at the O vii and O viii edges with the number of photons emitted in the O viii Lyα and O vii He-like complexes, Cottam et al. (2001) argue that absorbing material must be aligned with the accretion disk and extend along our line-of-sight.

Jimenez-Garate et al. (2002) are able to derive elemental abundance ratios from recombination emission lines seen in the spectrum of the LMXB Her X-1. They derive very high N/O ratios, which they interpret as proof of strong interactions during the formation history of this binary.

### 4.2 Soft X-ray transients

LMXBs containing a black hole (and a few transient sources containing neutron stars) are generally termed Soft X-ray transients (SXTs) or X-ray novae. This is because they display very strong X-ray and optical outbursts (generally also accompanied by radio emission) separated by long periods of quiescence (see Tanaka & Shibazaki 1996). They are “soft” in the sense that their outburst spectra are dominated by a soft blackbody component at ∼ 1 keV. The X-ray spectra of SXTs are very variable and characteristic low/hard and high/soft states have been identified. The geometry of the accretion flow and the source of soft photons during the outbursts is currently debated. In order to explain their long quiescent states optically thin advection-dominated accretion flows (ADAFs) have been invoked (Narayan et al. 1996; Esin et al. 1998). Some authors have argued that the very low X-ray fluxes during quiescence could be due simply to coronal activity from the donor.

The large collecting area of XMM-Newton allows the observation of very faint sources in quiescence. The SXT GU Mus was observed in quiescence as a very faint source. The X-ray flux was characterised by a power law, ruling out coronal activity and apparently supporting ADAF models (Sutaria et al. 2002). Similar conclusions were drawn from an observation of the SXT GRO J1655−40 (Hameury et al. 2003). However, observations of the black hole candidate and micro quasar GRS 1758−258 found a very soft spectrum in the off state, against the predictions of simple ADAF models (Miller et al. 2002).

Another source, XTE J1650−500, was observed in the very high state by Miller et al. (2003a). Its spectrum displayed broad Fe Kα lines, whose shape suggests that rotational energy is being extracted from a spinning black hole.

### 4.3 Cataclysmic variables

Cataclysmic variables (CVs) are systems containing a white dwarf accreting from a low-mass hydrogen-burning star (e.g., Sion 1999). As such, CVs may manifest themselves under the guise of classical novae, dwarf novae, recurrent novae, nova-likes and similar objects (Patterson 1984). X-ray emission is generally detected from those CVs in which the white dwarf exhibits a strong magnetic field, the polars or AM Her stars, or a moderate magnetic field, the intermediate polars or DQ Her stars (Paterson 1994). The interest of CVs stems from the fact that they allow a detailed study of accretion processes, with wide applications in several astrophysical contexts.

As the X-ray spectra of CVs are not as hard as those of accreting neutron stars and their luminosities are also not very high, sensitive instruments are needed to detect their emission. ROSAT surveys resulted in the discovery of large numbers of new faint CVs and it is expected that XMM-Newton will provide spectral information for a large number of sources, making statistical studies possible. Such work is already in progress, with large numbers of CVs having been observed (e.g., Ramsay & Cropper 2002; Ramsay & Cropper 2003), allowing determination of their basic parameters, such as white dwarf mass and mass transfer rate.

Of particular interest is the observation of the recent nova V2487 Oph 1998. This classical nova was detected with signatures of an accreting white dwarf.
less than three years after its nova outbursts (Hernanz & Sala 2002). This detection suggests that the system was back to its standard configuration after the phenomenal thermonuclear explosion which originated the nova outburst.

4.4 Supersoft sources

Discovered originally in the LMC, supersoft X-ray sources (SSSs) display X-ray spectra peaking at energies much lower than traditional X-ray binaries ($\sim 40$ eV). Because of this, they are heavily affected by interstellar absorption and unlikely to be detected in the Milky Way, unless they are very close. They are generally interpreted as white dwarfs accreting from a more massive hydrogen-burning donor. The mass transfer is therefore unstable and proceeds on the thermal timescale (van den Heuvel et al. 1992). Because of their soft spectra, they have only been studied in any detail with ROSAT. XMM-Newton provides now the opportunity to observe their spectra.

The first RGS spectrum of an SSS, CAL 83 in the LMC, proved that the X-ray emission originated from the photosphere of a very hot white dwarf by showing a rich spectrum of absorption complexes due to several elements (Paerels et al. 2001b). Even though this spectrum is qualitatively similar to expectations from white dwarf atmosphere models, RGS observations of the Galactic SSS MR Vel reveal a wealth of emission lines displaying P-Cygni profiles, indicative of a strong wind from the white dwarf’s surface, which cannot be reproduced with current models (Motch et al. 2002). Also interesting is the likely detection of Doppler shifts due to orbital motion in the X-ray emission lines of MR Vel, probably the first detection of orbital motion at high energies (Motch et al. 2002).

In XMM-Newton pointings, Osborne et al. (2001) have found a transient SSS close to the nucleus of M31 displaying an 865-s periodicity. King et al. (2002) interpret this as the spin period of a white dwarf and hence argue (see also Schenker et al. 2002) that CVs are descendants from SSSs.

5 Supernova Remnants

Supernova explosions have a very profound impact on the Interstellar Medium (ISM), both as sources of mechanical energy and heavy elements. Supernova Remnants (SNRs) provide information about these issues and can be observed as high-energy sources. The interaction of high velocity ejecta with the ISM generates very high temperatures, giving rise to line emission from heavy elements. By studying the spatial distribution of elements, we can gain insight into nucleosynthesis in the progenitor and the geometry of the explosions. SNRs are also possible sites of cosmic ray acceleration.

The characteristics of the RGS make it possible to obtain spectral information from relatively extended sources. RGS spectra of SNRs allow the study of physical conditions all over the remnant (e.g., Rasmussen et al. 2001). By measuring the mass, temperature and bulk velocity of material, it is possible to obtain information about the supernova explosion. Using XMM-Newton observations of the young SNR Cas A, Willingale et al. (2002) have derived kinematic information and abundance ratios for the supernova ejecta. From analysis of those data, they find evidence for beaming in the supernova explosion, suggesting that most of the material was ejected in two jets (Willingale et al. 2003). They also suggest that the progenitor was a very massive Wolf-Rayet star.

The compact object born in the Cas A supernova explosion has been identified with a point-like Chandra source, CXO J232327.8+584842. A long pointing with XMM-Newton, however, has failed to detect the X-ray pulsations that would be expected from a neutron star (Mereghetti et al. 2002a). The spectral properties of this source are also difficult to interpret in terms of a rapidly spinning neutron star.

No pulsations have been detected either from the SNR G21.5–0.9, which in many aspects resembles the Crab SNR, where a central pulsar is injecting high energy electrons (La Palombara & Mereghetti 2002). In this SNR, the X-ray spectrum of the nebula softens as one moves out from the centre, reflecting the energy losses of the electrons due to synchrotron radiation, as they diffuse out (Warwick et al. 2001). Similar conclusions are reached for the SNRs G0.9+0.1 (Porquet et al. 2003) and 3C 58 (Bocchino et al. 2001). While the central compact object of G0.9+0.1 has been detected with Chandra (CXOU J174722.8–280915), no obvious emission from a central object is seen in 3C 58.

The SNR IC 443 is specially interesting, because it is interacting with a dense molecular cloud rather than with the low density ISM. XMM-Newton has resolved several discrete hard X-ray sources, which could be fragments of the SNR interacting with the dense cloud (Bocchino & Bykov 2003).
6 Neutron stars

6.1 Young neutron stars in supernova remnants

The previous generation of imaging X-ray satellites (mainly ROSAT and ASCA) have detected a large population of young neutron stars which appear as rotation powered X-ray pulsars. X-ray emission in these systems may arise from a variety of physical processes. In many of them, non-thermal emission from relativistic particles accelerated in the pulsar magnetic field shows a power law spectrum over a broad energy range.

The large collecting area of XMM-Newton has provided for the first time spectral information for many of these weak X-ray sources. Its spatial resolution has also been necessary to separate them from their surrounding supernova remnants (SNRs). Preliminary results have been advanced by Becker & Aschenbach (2002), and the publication of many interesting results is expected in the near future.

6.2 Millisecond pulsars

Millisecond pulsars were first detected as radio sources (see Lorimer 2001) and only detected as X-ray pulsars with ROSAT (Becker & Trümper 1993). It is generally believed that millisecond pulsars are “recycled” pulsars, which have been spun up to their present high rotational velocities by accretion in a low mass X-ray binary and therefore objects of the highest interest for our understanding of binary evolution (Bhattacharya & van den Heuvel 1991).

Because of this, the recent detections of millisecond pulsars in accreting binaries (Wijnands & Van der Klis 1998) has sparked enormous interest. XMM-Newton observations of two of the currently four known accreting millisecond pulsars have been reported. The first accreting millisecond pulsar SAX J1808.4−365 has been detected in quiescence (Campana et al. 2002) and at a slightly higher luminosity (Wijnands 2003). In both cases, its spectrum was dominated by a power law, incompatible with thermal emission from the cooling surface of the neutron star (heated by accretion). A much better spectrum was obtained for the 2.3-ms accreting millisecond pulsar XTE J1751-305 (Miller et al. 2003b). However, no spectral features were detected.

The apparently isolated 4.86-ms pulsar PSR J0030+0451 was detected by XMM-Newton, which was able to measure its pulsed fraction. Its spectrum could be fitted by a two component model (either blackbody plus power law or two blackbodies) or a broken power law (Becker & Aschenbach 2002). Current models accounting for the spectra of millisecond pulsars predict that PSR J0030+0451 should be detectable at optical wavelengths. However, a very deep search in its XMM-Newton error circle conducted with the VLT has failed to detect any source down to $B=27.3$, casting into doubt such models (Koptsevich et al. 2003).

6.3 Thermal emission from neutron star atmospheres

Observations of isolated neutron stars (or neutron stars in quiescent X-ray binaries) are extremely important in fundamental physics, as thermal emission from the surface of a neutron star carries signatures of its gravitational field, which may be used to infer its mass and radius. Detection of absorption lines corresponding to elements on the neutron star atmosphere and measurement of their gravitational redshift would provide rather accurate data (e.g., Özel & Psaltis 2003). From the gravitational redshift at the surface of the neutron star, the ratio between its mass and radius may be measured, providing a very strong constraint on neutron star models. Such models give Physics an experimentally testable handle on properties of matter at (supra-)nuclear densities.

Unfortunately, observations so far have not been very successful at detecting these atmospheric features. The first XMM-Newton observation of an isolated neutron star (RX J0720.4-3125) yielded no spectral features on top of the black body continuum in a 62.5 ks exposure (Paerels et al. 2001a). Also, the isolated neutron star RX J1856.5−3754 was observed for 57 ks with XMM-Newton without revealing any spectral feature. An extremely long (505 ks) exposure was then performed with Chandra, also failing to detect any feature (Burwitz et al. 2003). This result is against predictions by most current model atmospheres for neutron stars.

The spectrum of RBS 1223 shows a very broad absorption line, but this is interpreted as a cyclotron feature caused by electrons moving in its very large magnetic field of $2 - 6 \times 10^{13}$ Gauss (Haberl et al. 2003). No lines have been seen in the spectra of several other isolated neutron stars observed with Chandra or the anomalous X-ray pulsar 1E1048.1−5937 observed with XMM-Newton (Tiengo et al. 2002). The only secure detection is that of two absorption features, discovered with Chandra, in the isolated neutron star 1E 1207−5209. XMM-Newton observations have shown a phase dependence in at least one of these features (Mereghetti et al. 2002b), but their identification is still not clear.
Absorption features from the surface of a neutron star have likely been identified during a burst from the LMXB EXO 0748–676 (Cottam et al. 2002). If the identification of the observed features with Fe XXVI and XXV and O VIII lines is correct, they imply a $z = 0.35$ gravitational redshift.

7 Normal galaxies

As indicated above, X-ray emission from normal galaxies arises from their populations of X-ray binaries. By comparing the populations of different galaxies, we are able to obtain information about their star forming histories (e.g., Grim et al. 2003). In order to resolve the populations, imaging capabilities are necessary. Because of this, thorough exploration of the most nearby galaxies, the Magellanic Clouds, started only with *Einstein* and flourished with *ROSAT* (e.g., Sasaki et al. 2000; Haberl et al. 2000). *ROSAT* also allowed the study of other nearby galaxies such as M31 (Supper et al. 2001) or M33 (Haberl & Pietsch 2001).

The potentialities of *XMM-Newton* for this sort of study are enormous. Deep pointings of the Magellanic Clouds result in the detection of a wealth of X-ray sources, many of which are accreting binaries. The sensitivity of *XMM-Newton* permits the detection of effectively any active XRB. A pointing at the North of the LMC resulted in the detection of 150 discrete sources, among which a newly discovered HMXB, a new likely SSS and several new SNRs (Haberl et al. 2003). A pointing to the SMC resulted in the detection of the pulse periods of two previous candidates to HMXBs and the discovery of two new candidates (Sasaki et al. 2003). The wide field allows a large number of sources to be observed at the same time, considerably improving our knowledge of HMXB populations.

*XMM-Newton* can also extend this sort of work to more distant galaxies. Pointings to M 31 have allowed the detection of sources down to a luminosity of $L_x = 6 \times 10^{35}$ erg s$^{-1}$ (Osborne et al. 2001), resulting in the characterisation of the whole XRB population. As expected, the bulge population is dominated by bright LMXBs, while the disk population appears to be composed mostly of young HMXBs (Trudolyubov et al. 2002a). The temporal evolution of some bright transients has been studied with both *XMM-Newton* and *Chandra* (Trudolyubov et al. 2001). Among them, a bright LMXB has been detected in a globular cluster of the M 31 system (Trudolyubov et al. 2002b). All this work suggests an overall galactic XRB population similar to that of...
the Milky Way.

Even further, XMM-Newton has identified the first eclipsing X-ray binary outside the Local Group (Pietsch et al. 2003). This is RX J004717.4−251811 in the nearby starburst galaxy NGC 253.

7.1 Ultraluminous X-ray sources

One of the most interesting problems in extragalactic X-ray Astrophysics is the existence of Ultraluminous X-ray sources (ULXs). These sources are variable on short timescales, but their luminosities are typically much higher than those observed in Galactic and Magellanic Cloud XRBs, approaching in many cases \( L_x \approx 10^{40} \text{erg s}^{-1} \). As this luminosity is much higher than the Eddington limit for a neutron star or a low-mass black hole, it seems to require massive black holes with masses of the order of \( \sim 100 M_\odot \) (generally called intermediate-mass black holes, as their masses are between those of stellar-mass black holes and the supermassive objects at the heart of galaxies). Severe problems are found when trying to understand the formation mechanism of such black holes, leading to the thought that perhaps ULXs can be explained as normal XRBs in which the X-ray emission is beamed towards the observer, requiring thus much lower fluxes (King et al. 2001).

A very important result obtained with XMM-Newton has been the discovery of quasi-periodic modulation in the flux from an ULX in M82 (Strohmayer & Mushotzky 2003). Such modulation must arise in the immediate vicinity of the compact object and represents evidence against beaming. Unfortunately, because of the relatively low spatial resolution, the identification of the ULX is not completely certain and a simultaneous observation with Chandra seems desirable.

Further evidence supporting intermediate-mass black holes has been collected from analysis of the spectra of two ULXs in the nearby spiral galaxy NGC 1313. The blackbody temperatures inferred from the fits are a factor of ten lower than those of typical SXTs, suggesting rather more massive black holes (Miller et al. 2003c).

8 Clusters of galaxies

One of the very first discoveries of X-ray astronomy was that clusters of galaxies are strong X-ray emitters (see Sarazin 1986 for an early review and Mushotzky 2001 for a much more up-to-date compilation). Their X-ray spectrum is well fitted by plasma emission at a temperature of \( 10^7 – 10^8 \text{K}, \) which includes thermal bremsstrahlung and line emission, most notably the Fe K emission line at \( \sim 6.7 \text{keV} \). The inferred Fe abundance is about \( \sim 0.3 – 0.5 \) solar, with possible gradients across the cluster, but remarkable homogeneity across the cluster population. Clusters (and groups) of galaxies are therefore filled with enriched gas (likely deposited by the mass loss of the member galaxies), which appears to be trapped in the cluster potential well.

The intracluster medium appears to be close to hydrostatic equilibrium Except for the core (with a few \( \times 100 \text{kpc} \)), cluster gas is isothermal (or perhaps with a slowly decaying temperature) out to the distances where X-ray emission can be detected (less than the virial radius). Relaxed clusters often exhibit a cooling flow phenomenon, whereby the gas in the central part of the cluster is significantly cooler and the density higher possibly due to a highly subsonic inflow amounting typically to \( \sim 100 M_\odot \text{yr}^{-1} \) (see Fabian 1994 for an extensive review).

8.1 The physical structure of the intracluster medium

One of the best studied clusters with XMM-Newton is A1795 (\( z = 0.063 \)). This cluster shows a smooth gas density profile along the lines of the \( \beta \) profile adopted for many clusters (Arnaud et al. 2001). The temperature of the gas is seen to be constant from 0.1 to 0.4 virial radii, but dropping significantly at smaller distances from the cluster centre. This is now seen as a common feature in many clusters, like A496 (Tamura et al. 2001), A1413 (Pratt & Arnaud 2002).

The possibility of mapping the intracluster gas structure with unprecedented detail is now also opening big questions on its physical state. In their detailed analysis of the \( z = 0.143 \) A1413 cluster, Pratt & Arnaud (2002) argue that the gas departs from hydrostatic equilibrium when approaching the virial radius, as expected from the very long timescales involved. They also find evidence for a cuspy central density profile (at variance of the usually assumed \( \beta \)-profile). The mass profile of the cluster, as derived under the assumption of hydrostatic equilibrium, is not far from the predictions of standard Cold Dark Matter computations.

Another important contribution of XMM-Newton to cluster science has been illustrated with the observations of the \( z = 0.54 \) cluster CL0016+16, a working horse for the use of the Sunyaev-Zel’dovich effect to determine accurate values of the Hubble constant. Worrall & Birkinshaw (2003) have been able to derive accurate values for the gas temperature (to within 2.5%) and of the emission measure (electron
density integrated along the line of sight) to within a similar accuracy. The subsequent revised value of $H_0 = 68 \pm 8$ km s$^{-1}$ is now in agreement with the latest determinations using the Hubble Space Telescope and the Cosmic Microwave Background power spectrum obtained by WMAP.

### 8.2 Building up clusters

For many years it has been thought that clusters build up from smaller structures, as predicted by popular cosmological scenarios. For instance, evidence for hierarchical merging in the Coma cluster was provided by ROSAT observations of X-ray emission of a merging sub-structure (White, Briel & Henry 1993).

With its much improved sensitivity, XMM-Newton is able to map intracluster gas down to very low surface brightness limits and therefore to strengthen or disprove the merging hypothesis. Indeed, the very first EPIC images of the Coma cluster (Briel et al. 2001) confirm the presence of the probably infalling lump from the SW (around NGC 4839) already detected by ROSAT, but they also find a further lump probably ahead of this one on its infall into the Coma cluster. N-body simulations do predict indeed that the infall into large clusters of galaxies proceeds along filamentary structures! The structure of the gas around NGC 4839 does show clear traces of being into its first infall into Coma (Neumann et al. 2001). The tail of the X-ray emission is very hot ($\sim 4.5$ keV) and indeed hotter than the temperature of the galaxy itself. Together with a displacement of the X-ray emission with respect to the galaxy NGC 4839 (well placed at the centre of the optical group) this provides confirmation of the subgroup gas being ram pressure stripped in its infall into the Coma cluster.

Evidence for filamentary structures infalling onto clusters is also seen in XMM-Newton observations of the cluster A 85 (Durret et al 2003). Early ROSAT reports on a large $\sim 4$ Mpc filamentary structure towards the south of the central cD galaxy of A 85 are confirmed, together with a determination of the gas temperature of around $\sim 2$ keV. This suggests that the filamentary structure is made of a chain of several galaxy groups.

Further evidence in favour of clusters being built by merging blocks comes from observations of distant clusters. De Filippis et al. (2003) observed the cluster CL 0939+4713 at $z = 0.47$ and showed that it exhibits significant gas structure, with the gas in between the two dominant galaxies being the hottest. This implies a largely non-relaxed state with a likely collision between the two merging blocks within a few million years. Hashimoto et al. (2002) observed the very distant cluster RX J1053.7+5735 at $z = 1.26$ and also detected a double structure suggestive of a merger.

Therefore, XMM-Newton has brought evidence for merging activity in clusters of galaxies, particularly at significant redshifts. Assessing the incidence of mergers in the building up of galaxy clusters (there are examples of dynamically relaxed clusters at high redshift, see Arnaud et al. 2002, for observations of RX J1120.1+4318 at $z = 0.6$) has just started but will ultimately provide the most direct evidence on how large-scale structure forms in the Universe.

### 8.3 Challenging cooling flows

Perhaps one of the most unexpected discoveries by XMM-Newton has been the challenge to the standard picture of the cooling flow phenomenon. The cooling time in the centres of galaxy clusters is significantly smaller than the age of the Universe, and therefore that gas will cool if no other phenomena prevent it (see, e.g., Fabian 1994 for a comprehensive review). Maintaining hydrostatic equilibrium with the hotter outer gas implies that gas should be steadily flowing inwards, increasing the density towards the cluster centre. Mass deposition rates are of the order of $\sim 100 - 1000 M_\odot$ yr$^{-1}$, which integrated over a Hubble time result in a substantial contribution to the mass of a large galaxy. Cooling flows manifest themselves as a peaked surface emissivity at the centre of the cluster, where the X-ray spectrum shows cooler gas. They occur almost invariably in cD clusters (i.e., those dominated by a large central-dominant early type galaxy), but very rarely happen in more non-relaxed structures, possibly due to the disruption of cooling flows by mergers.

Previous to the operation of Chandra and XMM-Newton there were doubts about the physics governing cooling flows. Conduction need to be suppressed to prevent the gas from thermalising in the hotter cluster environment, but lower temperature gas was unambiguously seen. The most intriguing question was (and still is) where does all this gas go. cD galaxies present at the centres of cooling flow clusters are red and, although they do form some stars (see the extensive work by Cardiel 1999 on star formation in cooling flow clusters), they certainly do not form $\sim 100 - 1000 M_\odot$ normal stars every year. A high pressure ambient as that present in cooling flows could favour the formation of low-mass stars.

A major XMM-Newton result has been to show that the gas in cooling flow clusters does not cool below a temperature which is 1/2 to 1/3 of the outer...
Figure 4: *XMM-Newton* RGS spectrum of the core of the Virgo cluster around the M87 galaxy (from Sakelliou et al. 2002). The discrepancy between the standard cooling flow model prediction (top green line) and the data (bottom lines) is most evident by the lack of Fe L lines around 12-17 Å.

The reasons for that are still unclear. Both conduction and heating by the central source (usually a powerful AGN) have been revived. Conduction should probably be decreased by the presence of magnetic fields, as a temperature gradient is indeed seen. Heating is also non-trivial, as it should deposit heat uniformly over a large volume, but on the contrary *Chandra* images show lots of structure in cluster cores.

A further complicating point is that, despite the fact that the amount of gas seen at temperatures of millions of degrees is much smaller than predicted by the simplest cooling flow models, *FUSE* observations reveal in some cooling flow clusters large OVI emission lines (Oegerle et al. 2001, Bregman 2003, priv comm). The amount of gas cooling at a few $10^5$ K is paradoxically in agreement with the *cooling flow* models, but the few million degree gas is missing. There is clearly much to learn in the coming years from this phenomenon.

9 Active Galactic Nuclei

Active Galactic Nuclei (AGN) are the most populous class of X-ray sources in the Universe, particularly at high galactic latitude. The large variety of AGN manifestations results in distinctive X-ray emission properties. Radio-loud AGNs were early claimed to have flatter X-ray spectra than radio-quiet ones (Wilkes & Elvis 1987), with flat spectrum radio sources having an even flatter X-ray spectrum (Canizares & White 1989). This is now understood in terms of radio-loud AGNs being absorbed by cold gas (Sambruna et al. 1999), plus relativistic beaming affecting the X-ray emission in core-dominated radio sources.

Radio-quiet type 1 AGN (Seyfert 1 galaxies and QSOs) where optical broad emission lines are seen and type 2 AGN (Seyfert 2s) where these broad components are not seen in unpolarized light, should have different X-ray properties. Indeed, the simplest version of the AGN unified scheme (Antonucci 1993), where the type 1/type 2 dichotomy results from different viewing directions of the same (or very similar) central engine, predicts that X-rays emerging from the nucleus would be directly seen in type 1 AGNs but absorbed/scattered in type 2 AGNs.

The standard AGN model, i.e., that of a supermassive black hole fed by a geometrically thin accretion disk and collimated jets along the rotation axis, has found some of its best support in the X-ray observations. Hard X-ray photons at a rate of $10^{44}$ erg s$^{-1}$ are very difficult to produce by other means in a galactic centre. Additionally, some spectral features, as a broad relativistic Fe K$\alpha$ emission discussed below, are distinctive tracers of accretion onto massive compact objects.

X-ray emission from AGN is characterised by an underlying power law with photon index $\Gamma \sim 1.5 - 2$ (on the steep side for radio-quiet AGN), which probably rolls over at energies $\sim 100$ keV (see the review by Mushotzky et al. 1993 summarizing the situation pre-*XMM-Newton*). For radio-quiet objects and those which are radio-loud but the beaming towards the observer is not important, this power law is interpreted as the Compton up-scattering of the UV photons produced in the accretion disk by the disk’s relativistic electron atmosphere.

An Fe K$\alpha$ emission line at 6.4-6.7 keV is the most prominent emission feature, along with a high-energy ‘bump’ at $> 20$ keV (Pounds et al. 1990), both of them probably arising from reflection of the X-rays in some thick material. For Seyfert 1 galaxies the equivalent width of the Fe line lies in the range 100-300 eV, while for Seyfert 2 galaxies the emission line is much stronger (up to 1 keV of equivalent width),
in particular in Compton-thick Seyfert 2s. The most striking feature of the Fe line is that it is very broad (inferred Doppler velocities up to $\sim c/3$). In the best studied case of the Seyfert 1 galaxy MCG-6-30-15 it exhibits a relativistically broadened shape interpreted in terms of Doppler shifts produced by the disk rotation, aberration and gravitational redshift in the red horn due to the proximity to the black hole's event horizon (Tanaka et al. 1995). Similar shapes were observed in other Seyfert 1 galaxies, suggesting that this is a relatively general feature of type 1 AGNs. In the best studied Seyfert 2 galaxies (e.g. NGC 1068), ASCA showed a more complex emission line structure (Iwasawa et al. 1997).

AGN often exhibit photoelectric absorption features in excess of those produced by cold gas in our Galaxy. Radio-loud AGNs at high redshifts, often exhibit large cold (neutral) absorbing gas columns (Cappi et al. 1997) but in radio-quiet AGN the situation is more complex. In this case, type 1 AGN appear to have little neutral absorbing gas (Nandra & Pounds 1994), but they often exhibit signs of ionised gas along the line of sight in the form of absorption edges, most notably OVII K at 0.74 keV and OVIII K at 0.87 keV (Reynolds 1997, George et al. 1998). On the contrary Seyfert 2 AGN usually display large absorbing columns of neutral gas (Smith & Done 1996), which is attributed to the “dusty torus” that the unified AGN scheme predicts to hide the broad line region. The average good correlation between optical spectral properties of radio quiet AGN and the amount of neutral absorbing gas along the line of sight has been clearly shown in Risaliti et al. (1999) on the basis of an [OIII]-selected sample of AGN (the [OIII] emissivity is believed to originate further away than any obscuring material in AGN, and therefore is regarded as an isotropic measure of the true intrinsic AGN luminosity).

9.1 The complex Fe line

Chandra and to a larger extent XMM-Newton have provided a qualitative leap forward in the study of Fe K lines, due to the large increase (in particular for XMM-Newton) of effective area at $\sim 6$ keV with respect to previous missions while preserving or improving the spectral resolution.

The best-studied Seyfert 1 galaxy MCG–6-30-15 has indeed been the subject of several long XMM-Newton observations. Fabian et al. (2002) discuss a 300 ks observation, where they confirm the existence of a very broad Fe line feature. A careful physical modeling of this feature shows that the line emissivity comes in two parts: the blue part of the line arises from the outer accretion disk (radius $> 6r_g$, where $r_g = GM/c^2$ is the gravitational radius of the black hole with mass $M$), but to account for the very extended red tail displayed by the line (extending down to 4 keV) a very concentrated emission at much lower radii is required. This unambiguously confirms early claims based on ASCA that reflection features arise from radii as close as $\sim 2r_g$ from the black hole, requiring a rapidly rotating (Kerr) hole. In fact Wilms (2001) caught the same source in the “low” state where the red wing of the Fe line dominates, suggesting extraction of energy from the spinning black hole through magnetic fields. In any case it is clear that the Fe line diagnostic of MCG–6-30-15 can only be understood in the context of reflection in an accretion disk around a Kerr black hole.

Observations of many other Seyfert galaxies have shown that the profile of the Fe line varies very much from source to source. In general, the reflection Fe line arises either in the inner part of the accretion disk, where it is likely to be highly ionised and broad, and/or at much more distant regions (perhaps the “dusty torus”) where it betrays mostly neutral Fe with a narrow line. Prototypical cases showing both a narrow component at 6.4 keV and a broad component centered at 6.7 keV are Mkn 205 (Reeves et al. 2001) and NGC 5506 (Matt et al. 2001).

Interestingly, one of the cases claimed to have a broad Fe line with ASCA data, NGC 5548, does only show a neutral narrow line in XMM-Newton observations (Pounds et al. 2003). Although the Fe line appears to vary less than the continuum in some of the best-studied Seyferts (such as MCG–6-30-15), there are reports of varying Fe lines. Guainazzi (2003) stud-
ies non-simultaneous ASCA, XMM-Newton and BeppoSAX observations of ESO198-G24, and he reports a broad component appearing and then fading away along with a narrow component.

It must also be stressed that the “holy grail” of using reverberation mapping (i.e., the response of reflected components, such as the Fe line, to continuum variations) to measure the mass of the black holes involved in AGN, has turned out to be rather complex. The Fe line intensity does not trivially follow the continuum variations and therefore much work is needed before this technique can be applied.

9.2 Soft X-ray broad lines?

A very lively debate has arisen since the launch of XMM-Newton on whether or not there are weak, relativistically broadened emission lines corresponding to C, N and O at soft X-ray energies. This stems from the use of the grating spectrographs both in XMM-Newton and Chandra, which provide spectral resolutions of the order of 200-500. Branduardi-Raymont et al. (2001) were the first to suggest the presence of these features in the RGS spectra of MCG-6-30-15 and Mkn 766, as an alternative to a standard warm absorber picture. Using a Chandra observation of MCG-6-30-15, Lee et al. (2001) identified a number of spectral features that were expected from a warm absorber, and even some of them only expected in Fe atoms trapped in dust grains, supporting the dusty warm absorber picture and no evidence for broad emission lines. Mason et al. (2003) have recently reported an analysis of RGS data on Mkn 766, where it is shown that broad relativistic emission lines of C, N and O give a better fit to the data than a dusty warm absorber. As of today, higher signal to noise XMM-Newton data over a larger bandpass appear to favour the presence of relativistic soft X-ray emission lines, and higher spectral resolution Chandra data appear to favour the dusty warm absorber interpretation. But the story continues . . .

9.3 The complexity of the ionized absorbers

The higher spectral resolution provided by RGS has enabled the possibility of studying the ionized absorbers in AGN with much more detail. Sako et al. (2001) conducted the first of such detailed analyses on the QSO IRAS 13349+2438, which was already suspected from the combined ROSAT, ASCA and optical data to have a complex absorption structure along the line of sight. The RGS spectrum shows a large number of absorption lines of C,N,O,Ne with one and two electrons, as well as a number of Fe lines in various ionisation states. Most remarkably, an Unresolved Transition Array (UTA) of inner-shell lines of Fe M is detected for the first time at X-ray wavelengths, which might be confused, at the lower resolution of non-dispersive CCD imaging spectrographs, with an absorption edge. Absorption lines of Fe are detected in Fe VII - Fe XII and in Fe XVII - Fe XX, but not in the intermediate ionisation states Fe XIII - Fe XVI. This suggests the existence of two distinct absorbers, a low ionisation one, which happens to be outflowing with a velocity $\sim 400 \text{ km s}^{-1}$ and a high ionisation absorber basically at rest with the QSO. The low ionization outflowing absorber implies (for normal dust to gas ratio) a reddening coincident with the optical one, but the high ionisation absorber, with a much larger column density, does not appear to have any dust.

Similar deep studies have been conducted on other targets (e.g., Blustin et al. 2002), revealing almost invariably the presence of UTAs, and a complex (at least two-phase) ionisation structure for the absorbers. It must be stressed that we are likely prob-
ing the gas in between the broad-line region and the “obscuring torus” in a manner that no other observational strategy could do.

10 Surveys and the X-ray background

The existence of a cosmic X-ray background (CXRB) was among the very first discoveries of X-ray Astronomy (Giacconi et al. 1962). Its spectrum was well measured by the HEAO-1 mission (Marshall et al. 1980, Gruber 1992) and fits remarkably well a thermal bremsstrahlung model at a temperature of 0.1 (Barcons et al. 1991) and fits remarkably well a temperature measured by the HEAO-1 mission (Marshall et al. 1980, Gruber 1992) and fits remarkably well a thermal bremsstrahlung model at a temperature of \( T \approx 30 \text{ keV} \). At galactic latitudes > 20° the CXRB is remarkably isotropic claiming for a true cosmological origin (see Fabian & Barcons 1992 for a review). Most of the energy density in the CXRB resides at \( \sim 30 \text{ keV} \), an energy which is not accessible to sensitive enough instrumentation in the current era. Below 1 keV the Galaxy (and probably a local hot bubble) dominates the X-ray intensity, and the extragalactic component is shielded by the interstellar medium, making it difficult to measure. In spite of this, deep ROSAT observations resolved \( \sim 70\% \) of the CXRB in the 1-2 keV (Hasinger et al. 1998) while Chandra has resolved practically 90% of this and \( \sim 70\% \) of the 2-7 keV CXRB (Mushotzky et al. 2000).

The lack of spectral distortions of the Cosmic Microwave Background ruled out the presence of substantial amounts of intergalactic gas at the very high temperatures needed to produce the CXRB through thermal bremsstrahlung (Barcons et al. 1991). Finding the sources that produce the CXRB, their astrophysical nature, their cosmic evolution, spatial clustering and so on has been since then the main objective of CXRB studies.

The most popular models for the CXRB make use of the unified model for AGN, and assume a mixture of unabsorbed (presumably type 1) and absorbed (presumably type 2) objects as a function of redshift \( z \) (Comastri et al. 1995, Gilli et al. 2001).

Medium sensitivity (Mason et al. 2000) and deep (Lehmann et al. 2002) surveys carried out with ROSAT revealed that at soft X-ray energies the X-ray sky is dominated by AGNs, most of which are type 1 Seyferts and QSOs. A small fraction of the AGN were type 2 and other narrow emission line galaxies (e.g., starburst galaxies). However, due to its bandpass limited to soft X-ray photons ROSAT missed most of the sources absorbed by \( \text{H} \) columns in excess to \( 10^{21} \text{ cm}^{-2} \).

The large field of view of the EPIC cameras (0.5° in diameter) makes XMM-Newton a very powerful tool to conduct X-ray surveys. The Survey Science Centre (SSC) is carrying out a series of serendipitous surveys in order to characterise the content of the X-ray sky at different depths. At high Galactic latitudes, 3 samples of \( \sim 1000 \) sources each, selected at 0.5-4.5 keV fluxes of \( \sim 10^{-13}, \sim 10^{-14} \) and \( \sim 10^{-15} \text{ erg cm}^{-2} \text{s}^{-1} \) will provide a major handle on this task. A number of surveys are being conducted besides the SSC ones, most of which are discussed in the proceedings of the workshop X-ray Surveys, in the light of the new observatories held in Santander during 4-6 September 2002 (Astronomische Nachrichten, vol 324, issues 1 and 2).

The AXIS programme\(^1\) is providing a substantial leap forward in the XMM-Newton SSC medium sensitivity survey. This is a flux limited survey at \( 2 \times 10^{-14} \text{ erg cm}^{-2} \text{s}^{-1} \), in the 0.5-4.5 keV band, with a source density of \( \sim 100 \text{ deg}^{-2} \), which has the goal of covering \( \sim 5 \text{ deg}^{-2} \) both in the North and in the South. Preliminary results were presented in Barcons et al. (2002) and an update can be found in Barcons et al. (2003a).

The deepest X-ray survey conducted by XMM-Newton so far is in the Lockman Hole area, with a total exposure approaching 1000 ks (adding the payload verification, AO-1 and AO-2 data). The scope of this survey is not only to detect the faintest sources, particularly at hard X-ray energies where confusion is still unimportant and XMM-Newton is 5-10 times more efficient than Chandra, but more importantly to obtain X-ray spectra of the faintest sources. A preliminary account, based on 100 ks data, is presented in Hasinger et al. (2001).

10.1 Challenging the AGN unified scheme

XMM-Newton is also providing evidence that the one to one association of type 1 AGNs with unabsorbed sources and type 2 AGNs with absorbed sources fails clearly in some cases. For example Barcons et al. (2003b) have shown that the H1320+551 \( z=0.068 \) Seyfert 1.9 galaxy (and therefore with a broad line region putatively obscured) does not show any signs of neutral or ionised gas along the line of sight. This is in direct contradiction to the unified AGN model.

\(^1\) AXIS is an International Time Programme at the Observatorio del Roque de Los Muchachos in La Palma, which was granted 85 observing nights spread on the INT, NOT, TNG and WHT telescopes from April 2000 through April 2002. See \text{http://venus.ifca.unican.es/~xray/AXIS}
On the opposite side, type 1 QSOs are found which display large absorbing columns of neutral gas (e.g., Georgantopoulos et al. 2003), while none or very little was expected. A possible explanation to this is that X-ray absorption occurs very close to the central engine where dust just sublimates and therefore the optical spectrum is unaffected by the surrounding material. This might be a non-isolated situation, as explained by Mateos et al. (2003) in an analysis of the X-ray spectra of XMS sources, where a fraction of type 1 AGNs do require absorbing columns along the line of sight.

10.2 Faint and absorbed sources

If anything, the deep observation of Hasinger et al. (2001) demonstrates that the basic picture for the origin of the CXRB, based on absorbed sources, is roughly correct. Indeed, some $\sim 40\%$ of the faint sources detected show some hint of absorption in their X-ray colours, in agreement with the general expectations. Quantitatively, however, the situation is still far from clear.

One of the most striking results obtained from the optical identification of Chandra deep surveys is that the redshift distribution of type 2 AGN is peaked at significantly lower redshifts ($z \sim 0.8$) than that of type 1 AGN ($z \sim 1.7$) (Hasinger 2002). Similarly, in the XMS all type 2 AGNs are concentrated at low redshifts, while the type 1s reach $z \sim 3$.

This probably means that the models for CXRB need some revision. Following this, Franceschini, Braito & Fadda (2002) have suggested that type 1 AGN arise in the rare highest peaks of the density field in the Universe, but that type 2 AGN result from the evolution and merging of the very massive galaxies, a process that occurs later in the cosmic history.

10.3 Optically dull X-ray bright galaxies and obscured accretion

A still intriguing issue raised by the new observations and studied in detail by XMM-Newton is the existence of optically inactive but X-ray luminous galaxies. Such objects were first highlighted in a Chandra deep survey by Mushotzky et al. (2000), as early type galaxies with a large X-ray to optical ratio. Comastri et al. (2002) conducted a multi-wavelength study of one of these objects discovered in their HEL-LAS2XMM survey, which shows no optical or infrared emission lines, but does show a rather hard X-ray spectrum. They concluded that the counterpart galaxy at $z = 0.159$ hosts a completely obscured
active nucleus.

Severgnini et al. (2003) have recently reported on the study of 3 of these objects discovered in the SSC bright source survey. Their X-ray properties are varied, but in all cases reflecting clearly the presence of an X-ray luminous AGN. In that work it is shown that the emission lines related to the more or less obscured AGN are diluted with the galaxy light and therefore very weak and inconspicuous in some cases.

All this appears to support previous suspicions that most, if not all, galaxies host a black hole in their center, many of them active but obscured. Obscured accretion is probably 3 times more frequent in the Universe than unobscured accretion, if the CXRB models are roughly correct. A detailed accounting on the black hole density can then be inferred by assuming a radiative efficiency of the black holes (typically 10%) and compared to other independent estimates of the local black hole density. Fabian (2003) concludes that the estimate based on the CXRB and with what is known from the redshift distribution of obscured sources, converges towards \( \sim 4 \times 10^5 \text{M}_\odot \text{Mpc}^{-3} \), a value which is consistent with local estimates. Obscured accretion onto black holes is therefore important, although the “hidden” black hole mass is of the same order than that seen in unobscured AGN.

11 Gamma-ray burst afterglows

*XMM-Newton* is making a big effort in observing Gamma Ray Bursts (GRB) following alerts provided by other higher-energy observatories. The absolute minimum reaction time reached is 6-8 hours after the alert. In all observations (conducted as Target Of Opportunity observations, and therefore immediately public) the GRB afterglow has been detected and much has been learnt on this phenomenon from the X-ray data.

Perhaps the most interesting case is that of GRB011211 (identified to occur in a galaxy of \( \sim 25\text{mag} \) at \( z = 2.141 \)) observed by *XMM-Newton* for 27 ks, 11 hours after its detection by *BeppoSAX*. During the first 10 ks of that observation, the EPIC X-ray spectrum showed emission lines which Reeves et al. (2002) identified as Mg XI, Si XIV, SXVI, Ar XVIII and Ca XX but at a significantly blueshifted velocity \( \sim 0.1c \) (the detection confidence of these lines has been challenged by Rutledge & Sako 2003 though). If the Reeves et al. (2002) interpretation is correct, then this would provide direct evidence for outflowing material, favouring the model of the collapse of a massive star for GRBs.

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