The first results from the XMM-Newton satellite

The Universe seen in X-rays

The XMM-Newton satellite, the second corner stone of the ESA Horizon 2000 program (Jansen et al 2001), has been launched in December 1999. High throughput X-ray telescopes and the provision of a co-aligned optical telescope, allowing multi-wavelength observations, are the key distinguishing features of XMM. Designed for high-throughout spectroscopy it provides simultaneously non-dispersive spectroscopic imaging (EPIC instrument) and high-resolution dispersive spectroscopy (RGS instrument). The EPIC instrument (Turner et al 2000, Struder et al 2000) combines a high sensitivity with good spatial resolution (FWHM = 8", better than ROSAT/PSPC) and spectral resolution (?E=60-140 eV, better than ASCA), on a wide energy range (0.1 to 12 keV). The RGS experiment (den Herder et al 2001) allows high-resolution spectroscopy (?E/E=0.1-0.3%) in the range of 0.3-2 keV.

The SAp was in charge of making part of the electronics of the two EPIC/MOS cameras and actively participated on the on-ground and in flight calibration and verification phases for the EPIC instrument. The SAp is also part of the SSC consortium, which, in collaboration with ESA, develops the scientific processing software, performs the routine pipeline processing of all the observations and generates the XMM Serendipitous Source Catalog.

The first scientific results from XMM-Newton, based on the observations made during the verification phase, were published in a special issue of Astronomy & Astrophysics. This series of articles provide a first look at the exciting capabilities of XMM in all X-ray astronomy fields. The SAp researchers largely contribute to this work, particularly in the study of galaxy clusters, supernova remnants (SNR) and stars, the traditional area of expertise of SAp in X-rays. In parallel, a combined analysis of the XMM and ISOCAM sources detected in the Lockman Hole region was conducted by SAp (Fadda et al, 2001), shedding new light on the respective contribution of starburst galaxies and AGNs to the deep field galaxy population (see Section Cosmology).

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- Compacts sources
- Stellar coronae

Galaxy clusters and cosmology

Clues for missing mass

In hierarchical formation models, such as the Cold Dark Matter model, clusters are formed from mergers of smaller units that have previously collapsed. Clusters are thought to form preferentially at the crossing of filaments and to grow by anisotropic matter infall/sub cluster mergers along them.

The Coma cluster belongs to a large scale filamentary structure that defines the Coma-A1367 supercluster. There is a striking alignment between the distribution of sub-clusters within Coma (in particular the NGC 4839 group-main cluster orientation along the south-west direction) and this large scale filamentary structure.

The analysis of the XMM Mosaic observation (Briel et al 2001; Arnaud et al 2001b; Neumann et al 2001) demonstrates that Coma is currently accreting matter along this preferred direction, giving direct support to the standard formation scenario. In particular, as shown by Neumann et al (2001), the complex temperature structure around the galaxy NGC 4839 is consistent with simulations of galaxies falling into a cluster environment, with indications of a bow shock and of ram pressure stripping around the galaxy.

The XMM data also reveal a displacement between NGC4839 and the center of the hot gas in the group.

This displacement can be explained by the ram-pressure force originating from the infall, which acts much stronger on the group gas than on the galaxies.

Furthermore, the XMM temperature map of the central part (r < 20') of Coma (Arnaud et al 2001) revealed for the first time a hot front in the South-West, perpendicular to the direction connecting the center of Coma and NGC4839.

This feature is likely to be due to adiabatic compression, caused by the infall of matter along that direction. On the other hand, the temperature distribution around the two central galaxies is remarkably homogeneous within r<10', suggesting that the core of Coma is actually in a relaxed state.

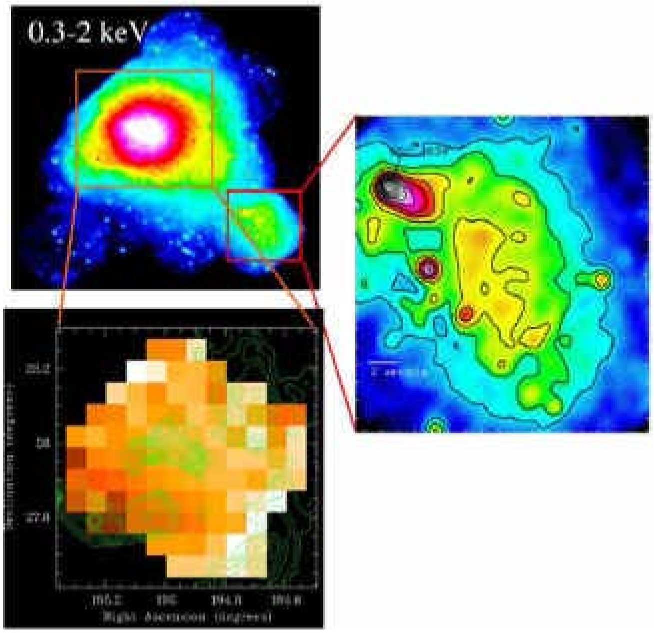

Fig. 1. The Mosaic EPIC-pn image of Coma in the 0.3-2 keV energy band is shown on the top left panel (update of the image published in Briel et al (2001), including new observations, provided by U.Briel). The excess of emission in the south-west direction, towards NGC 4839, already seen by ROSAT, is detected with a high signal to noise. The right panel shows a zoom on the NGC 4839 group (Neumann et al, 2001). One notes the displacement between the galaxy and the center of the group intra-cluster medium and the tail-like structure around the galaxy, pointing away from the Coma cluster center. The bottom panel shows a color coded temperature map of the central (r < 20') region of Coma (Arnaud et al 2001a from EPIC/MOS data). The iso-contours overlaid are the excess emission over a beta--model fitted to the EPIC/MOS image. Note the hot front in the South-West, perpendicular to the direction connecting the center of Coma and NGC4839, likely to be due to adiabatic compression. These data are interpreted as indication of matter infall along the South-West direction.

The total mass profile and mass content of clusters are key information for cosmology studies of structure formation, based on the properties of the galaxy cluster population. They can be derived from X-ray observations of the gas density and temperature profiles, through the hydrostatic equilibrium equation. The shape of the temperature profiles, as measured by ASCA and Beppo-Sax, was a matter of debate. As a result total mass estimates were typically uncertain by a factor of two and no real constrains on the shape of the dark matter profiles could be inferred.

Significant progress was expected with XMM-Newton/EPIC, which has a much better sensitivity and a much smaller PSF than ASCA and Beppo-Sax. The capability of XMM-Newton to measure cluster temperature profiles was illustrated by Arnaud et al (2001), using the PV observation of A1795, a bright cluster at z=0.063. A methodology to derive temperature profiles, adapted to XMM vignetting and background characteristics, was presented in this article. Beyond the cooling flow region, where a clear resolved drop in temperature is observed, the temperature profile is remarkably flat, up to 0.4 virial radius. Obviously no definitive statement on cluster temperature profiles can be drawn from this single observation. On going GT and open time programs will extend this type of results to a significant sample of clusters and to larger radii (using mosaic observations for specific objects).

The physics in the core of clusters is particularly complex. The cooling time can be less than the Hubble time and radiative cooling has to be taken into account, as well as the impact of the nuclear activity of the central galaxy.

A major discovery with XMM, concerning the physics of gas cooling, is the lack of emission lines from gas below ~ 2 keV in the RGS spectra of cooling flow clusters like A1835 (Peterson et al 2001). These data, inconsistent with standard cooling flow models, represent a serious theoretical challenge. The interaction of the thermal and radio emitting plasma was studied in detail in the central region of the Virgo cluster, around the giant elliptical galaxy M87 (Belsole et al 2001). XMM/EPIC establishes unambiguously the thermal nature of the X-ray emission from the eastern and south western extensions previously seen by ROSAT around M87, which are related to the radio lobes. The extensions have a significantly lower temperature than the surrounding ambient medium. Buoyant radio emitting bubbles powered by the central AGN and dragging cooler material from the center, as proposed by Churazov et al.(2000), seems to qualitatively explain the XMM results but fails to describe the misalignment between X-ray and radio lobes.

The supernova remnants

The explosions that produce the atom nuclei

The Tycho SNR is considered as the prototype of Type I SNR. This young SNR (the explosion occurred in 1572) was poorly resolved by instruments with ASCA, due its small extent (8' in diameter). Detailed mapping of the emission lines and high energy continuum (Decourchelle et al 2001) became possible with XMM/EPIC, allowing to probe the physics of the explosion (in particular the mixing of the nucleosynthesis products) and of the dynamical interaction between the ejecta and the ambient ISM. In such young SNR, bright emission lines originate from shocked material in the ejecta, whereas the high-energy continuum emission is attributed to the shocked ambient medium.

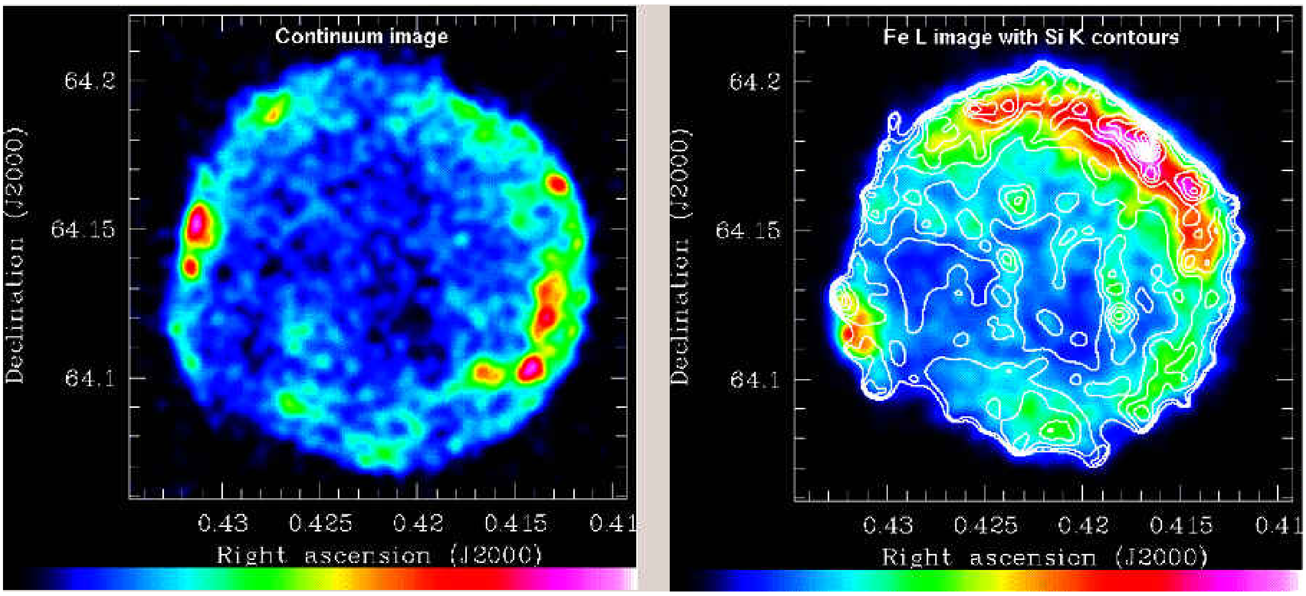

Fig. 2. XMM-Newton images of the Tycho supernova remnant. Left: The smooth and symmetric emission in the continuum (4.5-5.8 keV) implies that Tycho is evolving in a homogeneous interstellar medium. On the eastern and western edges, bright and hard continuum knots are observed, which may correspond to sites of particle acceleration at the shock front. Right: In contrast, the line emission (Fe XVII MOS image overlaid with Si XIII contours) is much brighter in the northern rim and is related to azimuthal variations, in the ejecta, of the heavy element distribution or/and the temperature. Note the good correlation between the Fe and Si maps which indicate that mixing occurs between the different ejecta layers.

Decourchelle et al (2001) showed that the profile of the continuum emission peaks indeed further out that the line emission profile, and that its extent corresponds well with the extent of the radio profile, which gives the position of the outer blast wave. Furthermore, the continuum map has a regular spherical morphology, suggesting that the SNR expands in a uniform medium. Some inhomegeneities in the periphery of the Silicon line emission image, coincident with similar structures in the radio maps, suggest that Rayleigh-Taylor instabilities are developing at the contact discontinuity between the ejecta and the ambient medium. The variation with radius of the temperature and ionization time scale in the ejecta, as indicated by the FeK/FeL line ratio, is in qualitative agreement with hydrodynamic models of a reverse shock propagating in the inner ejecta plateau. Finally, the good correlation between the Fe and Si maps indicates that the Iron layer in the ejecta has been well mixed with the Silicon layer, although the mixing is not perfect as indicated by small scale inhomogeneities. (See also the "High Energy phenomena" chapter)

The compact sources

A hyperdense star surrounded by a disk

The X-ray binary EXO 0748-676 is unique in showing all type of variability commonly seen in different low-mass X-ray binaries. The XMM observation (Bonnet-Bidaud et al 2001) allowed for the first time to study its spectral variability with enough precision to identify the various emitting regions and to build a consistent picture of the system. In particular XMM revealed that during the eclipses only the hard X-ray emission disappears, whereas the soft component is essentially un-eclipsed. This sets strong constrains on the size of the corresponding emitting regions. The source is found to be the superposition of a central (~2 108 cm) Comptonized emission, most probably a corona surrounding the inner edge of the accretion disk, associated with a more extended (~3 1010 cm) thermal halo. The estimated density and dimension of the halo suggests that it may be a hot atmosphere at the surface of an irradiated accretion disc.

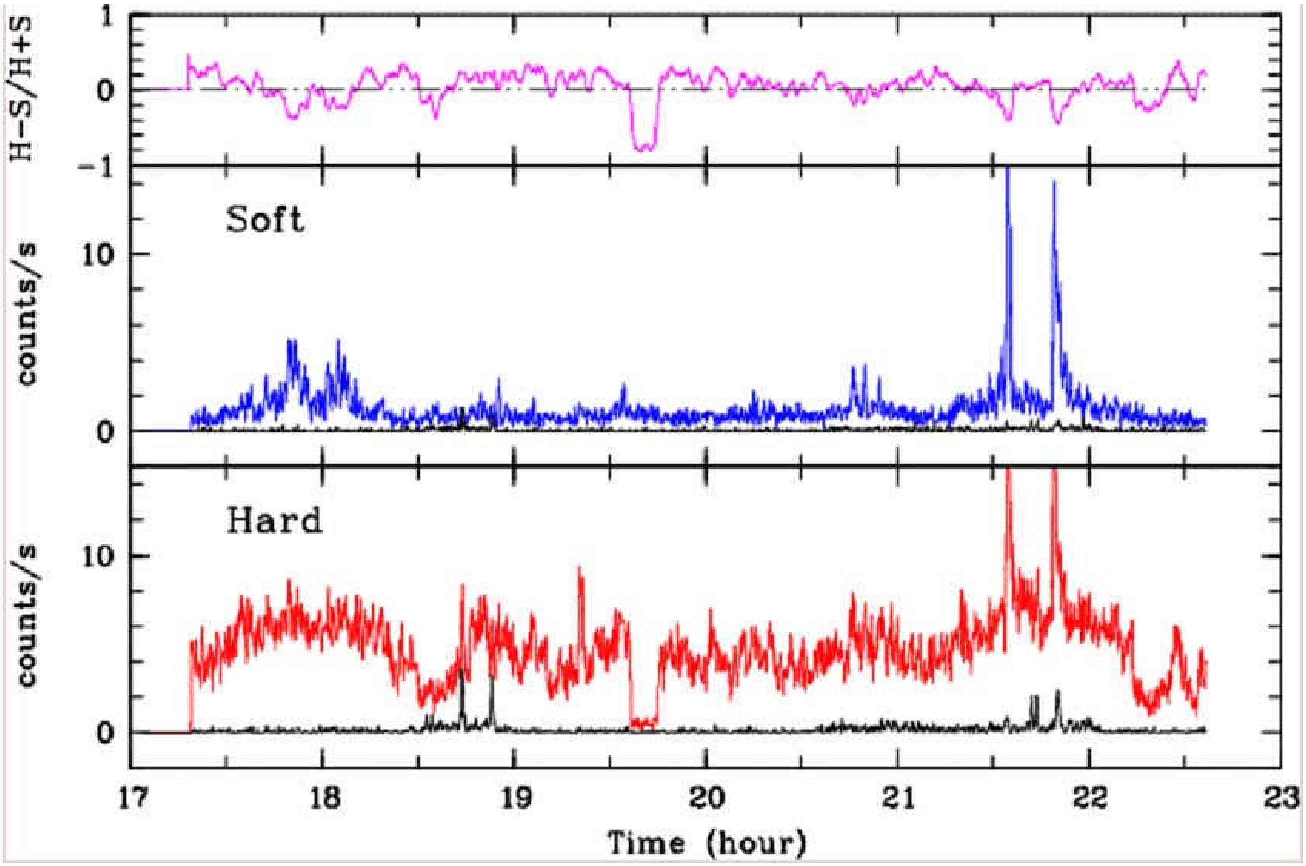

Fig 3. The EPIC/MOS hard (2-10 keV) (bottom) and soft (0.5-2 keV) (middle) light curves of EXO 0748-676 as observed by XMM-Newton on 2000, April 4 (Bonnet-Bidaud et al, 2001). The underlying curve, in each case, is the background rate. The hardness ration computed as (H-S)/(H+S) is shown on the top. Note the near total eclipse at 19.40 UT, where only the hard X-ray emission disappears whereas the soft component is essentially un-eclipsed . These data set constrains on the size of the corresponding emitting regions.

The stellar coronae

A hot gas halo around stars

The XMM/RGS instrument offers unprecedented spectroscopic power for the study of stellar corona plasma. Such high-resolution spectroscopy is essential to understand the connection between solar and stellar coronae and their respective heating mechanisms. D. Porquet collaborated to the analysis of the XMM spectrum of the high X-ray flux binary star Capella (Audard et al, 2001). Using in particular the plasma diagnostics developed by D. Porquet and collaborators, this study shows that the coronae is probably bimodal: a cool low density plasma coexists with a higher density hotter plasma. This suggests the simultaneous presence of low-lying, compact hot loops with larger, cooler loops in the stellar coronal atmosphere.