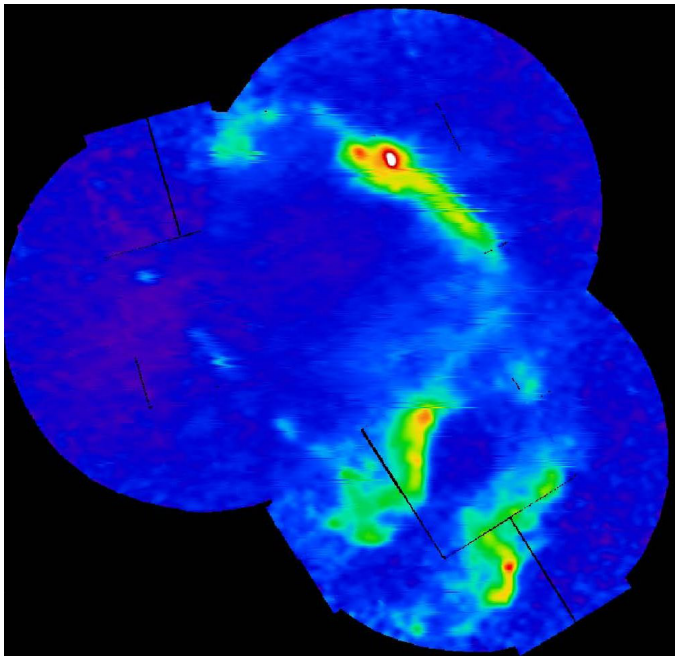
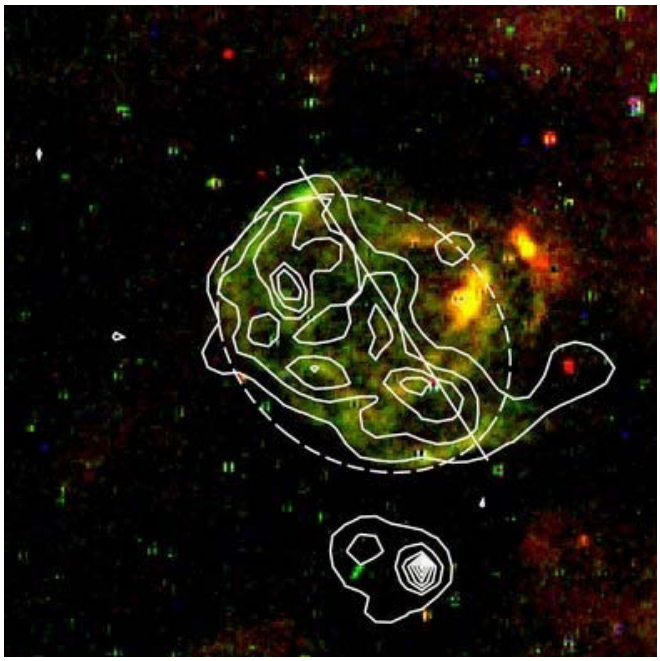


EPIC MOS image of G296.1-0.5 in the 0.3–3.0 keV band (Castro et al. 2011)



Three-color image of SNR0537-6628 with X-ray contours overlaid (Klimek et al. 2010)

XMM-Newton Guest Observer Facility, Guest Observer Funding, US RGS Team, and *XMM-Newton* Education and Public Outreach

2012 Senior Review

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January 2012

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On behalf of the US *Newton X-ray Multi-Mirror Observatory* (*XMM-Newton* or *XMM*) user community, the NASA Goddard Space Flight Center (GSFC) Guest Observer Facility (GOF), the US Reflection Grating Spectrometer (RGS) Team, and the *XMM* Education and Public Outreach (E/PO) program, we request funding for the continued support of US participation in the European Space Agency (ESA) *XMM* mission. *XMM*'s instruments provide a unique resource enabling US astronomers to continue to produce high-quality and significant results, at particularly low cost to NASA relative to other Great Observatory-class missions.

XMM is the second cornerstone of the ESA Horizon 2000 program. Launched on 1999 December 10, *XMM* remains in full operation and in excellent health. ESA mission support is confirmed through 2012, with funding allocated through 2014.

1.1 XMM Mission Attributes

Relevance to NASA Goals: The science goals and achievements of *XMM* are directly responsive to the 2011 NASA Strategic Plan[1] Strategic Goal 2: "Expand scientific understanding of the Earth and the universe in which we live," and through our E/PO effort Strategic Goal 6: "Share NASA with the public, educators, and students to provide opportunities to participate in our Mission, foster innovation, and contribute to a strong national economy." In addition, the *XMM* program is responsive to the Science Mission Directorate (SMD) 2010 Science Plan[2] providing important advances primarily towards the Astrophysics goal to "Discover how the universe works, explore how the universe began and developed into its present form, and search for Earth-like planets."

Science Applications: *XMM* provides crucial data for studies of fundamental and relativistic processes from neutron stars (NS) and quasars (e.g., constraining the spin of black holes in active galactic nuclei, AGN), the creation of the elements in supernovae (SNe) and their dispersal in supernova remnants (SNR) and starburst galaxies, the evolution of the elements on the largest scales in groups and clusters of galaxies, and the distribution of dark matter in clusters, groups, and elliptical galaxies. *XMM* observations of young active stars provide important constraints on models of the early solar system and star forming regions, furthering understanding of the origin and evolution of the Sun and stars. While the science areas of *XMM*, *Chandra*, and *Suzaku* do overlap, *XMM* has unique capabilities which strongly enhance its utility to observers.

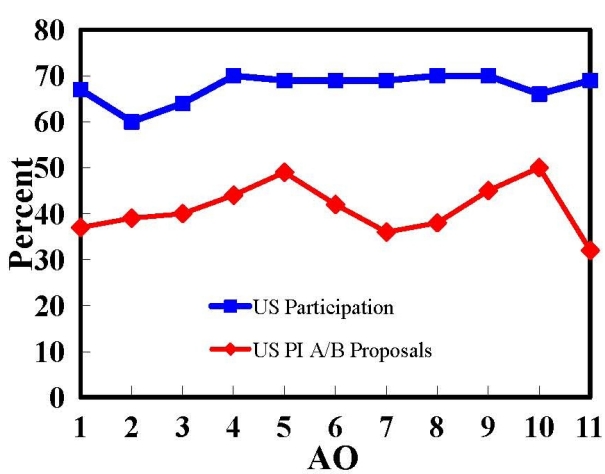

Figure 1. US participation rates (accepted) by AO. The total rate includes A, B, and C (filler) proposals with US PIs or Co-Is.

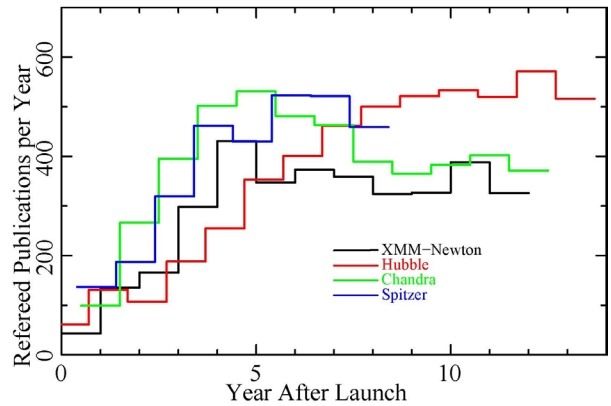

Figure 2. Comparison of XMM and other major observatory refereed publication rates versus year since launch. Publication numbers were taken from Astrophysics Data System (ADS) searches requiring the observatory's name to be in the paper's abstract or title. Note that XMM is comparable to the other major observatories, yet it has a much smaller cost to NASA.

Observatory Usage: *XMM* operates in a Guest Observer (GO) mode and the program is fully open to US participation, including US representation in peer reviews and on the ESA Users Group. Announcements of Opportunity (AOs) are on an annual cycle with proposals due in October. There are ~500 proposals submitted annually with ~180 approved. US scientists have been major participants in the GO process through all AOs (**Fig. 1**). For AO-10 and AO-11, an average of 41% of the accepted proposals for A or B time (guaranteed observations) had US Principal Investigators (PIs). An additional 39% of the accepted A/B proposals had US Co-investigators (Co-Is). There are ~300 targets chosen for guaranteed observation and ~250 targets chosen as "filler" observations with a ~30% chance of being observed. The interest in *XMM* by the world-wide community remains high with a relatively constant time oversubscription (6.7 × in AO-11). The project also accepts Target of Opportunity (ToO) requests with ~340 observed to date. As demonstrated by the large oversubscription factor, there is no obsolescence (perceived or actual) of the instruments.

Science Accomplishments: Among the major scientific achievements of *XMM* so far are: the solution of the 20-year-old "cooling flow" problem in clusters of galaxies; the unexpected detection of X-ray emission from brown dwarfs; the discovery of previously unknown types of novae and supernovae; the observation of relativistic iron lines from neutron stars; the discovery of an ultra-luminous X-ray source (ULX, a probable intermediate mass black hole) in a globular cluster; the detection of the first quasi-periodic oscillation (QPO) in an AGN, connecting accretion by stel-

1 http://www.nasa.gov/pdf/516579main_NASA2011StrategicPlan.pdf
2 http://science.nasa.gov/media/medialibrary/2010/08/30/2010SciencePlan_TAGGED.pdf

lar mass and supermassive black holes; and the detection of a filament of intergalactic gas between two clusters of galaxies, which may be evidence for the warm-hot intercluster medium (WHIM) containing most of the baryons in the present day Universe.

Scientific Productivity: The scientific output from *XMM* remains very strong with over 830 refereed papers in the last two years (27% have US lead authors and an additional 29% have US co-authors), and a grand total of 3,692 through 2011 December (see **Fig. 2** and the publication list[3]). These papers are cited four times more often than the average refereed paper in the astronomical literature. Indeed, 38% of *XMM* papers published a year ago belong to the top 10% of the most cited articles published in the same time span, while 8% belong to the top 1%, a spectacular record of high-quality papers.

NASA Support: NASA funds a GOF and a GO grant program to support the usage of *XMM* by the US scientific community. This includes the provision of proposal support, data analysis support, software development, calibration, and E/PO activities. ESA bears the entire burden of mission operations allowing US expenditures to be relatively minor for access to data from a Great Observatory class mission.

Summary: *XMM*'s status as one of the world's preeminent astronomical observatories is established by the high proposal oversubscription, high publication rate, and the frequent citation of refereed papers. Note that US scientists' impressive publication record for *XMM* comes with only limited GO funding support and without contributions from mission funded archive, theory, and fellowship opportunities that are available through the *Chandra*, *Hubble*, and *Spitzer* programs. Given the quality and the health of the instruments and the satellite, the high oversubscription rate, the high fraction of the time going to US guest observers, the large archive, the rich scientific future, and the low cost to NASA, we believe that continued funding of the US *XMM* program is well justified.

Data Availability

XMM's observation data sets are made public after the expiration of a proprietary period, typically one year after data delivery. The *XMM* archive had ~7400 scientific observations (with a further ~2470 slew-survey and ~1170 calibration observations) publicly available as of 2012 January.

1.2 Mission Overview

XMM observes in the 0.2–12 keV and optical/UV bands in a sky swath ±20 degrees from the perpendicular to the Earth/Sun line. The observatory has three co-aligned high throughput 7.5 m focal length X-ray telescopes with 6" full width at half maximum (FWHM) angular resolution. Three European Photon Imaging Camera (EPIC) charge-coupled device (CCD) detectors (PN, MOS1, and MOS2) provide X-ray images over a 30' field of view (FOV) with moderate energy resolution. Higher resolution spectra ($E/\Delta E \sim$ 200–800) are provided by two RGSs where their Reflection Grating Arrays (RGAs) deflect half of the beam from two of the X-ray telescopes. These high spectral resolution instruments are capable of observing extended sources up to 2' in angular extent. The sixth instrument, the Optical Monitor (OM), is a co-aligned 30 cm optical/UV telescope sensitive in the 1600–6500 Å band with a 16' FOV and a wide variety of modes and filters. *XMM*'s two-day orbital period allows long, uninterrupted observations with contiguous coverage up to ~135 ks. This ability is critical for many timing studies of compact objects. For example, reverberation mapping in the X-ray band for AGN (i.e., the determination of the time lag of one X-ray spectral component relative to another) requires long, contiguous observations.

Exceptional Instrumental Versatility

All of *XMM*'s scientific instruments are co-aligned and operate simultaneously, providing exceptionally rich data sets. All instruments can be run in a variety of modes, allowing them to be tuned for the scientific needs of a specific observation/scientific investigation.

1.3 The Case for XMM

XMM excels in providing high throughput X-ray and optical/UV imaging, timing, and spectroscopy for an extremely wide variety of astrophysical sources, from comets and planets to quasars and clusters of galaxies. *XMM* provides this broad range of exceptional data to a large number of US GOs at a low cost to NASA.

There is no current mission, or any mission planned for launch in the next decade, which has *XMM*'s combination of simultaneous high throughput X-ray imaging and spectroscopy, broad band (X-ray, optical, and UV) capabilities, and ability to make long observations. The only relevant new mission is *Astro-H*, a Japanese-US mission that will have a spectroscopic capability superior to *XMM*'s RGS above ~0.9 keV, but will not have the angular resolution or collecting area of *XMM*, or the long contiguous observations.

Because ESA and its member nations carry the brunt of the costs for *XMM* operations, software development, and data processing, the US community has access to "Great Observatory" science at a small fraction of the cost to NASA of similar US-operated missions. The US community has received immediate access (either as PIs or Co-Is of accepted proposals) to data from a steady ~70% of the total *XMM* programs (**Fig. 1**). While removing US *XMM* funding would not reduce the access of the US community to *XMM*'s new observations (AOs are open to the entire world), the lack of GO funding for data analysis and interpretation and the elimination of the US GOF science and technical support would likely have a major impact on the productivity of the mission by reducing the participation of the US community. Continued funding will allow US scientists to maintain their leadership role in many of *XMM*'s important discoveries in the coming years. GO funding support, which comprises half of our requested "In-Guidelines" budget, combined with access to Astrophysics Data Analysis Program (ADAP) funding, is vital to achieve the continued science output.

XMM is a general observation facility not closely linked to any specific field of astrophysical study, and is able to

3 http://xmm.gsfc.nasa.gov/docs/xmm/xmmbib.html

XMM's Future is Bright Because of its Unique Properties

1) The large effective area supports studies requiring many counts (but not necessarily high count rates) such as determining the abundance profiles of high-z clusters, or the structure of AGN Fe K lines, allowing the determination of black hole spin.

2) The ability to make long contiguous observations allows studies requiring long-looks (i.e., variability studies), such as AGN timing or detailed studies of isolated neutron stars.

3) The combination of X-ray and Optical/UV bandpasses support studies requiring multiwavelength observations, such as detailed studies of star forming regions.

4) The high "speed" of *XMM*'s response supports projects needing large samples of objects (e.g., legacy programs), such as studies of groups of galaxies.

5) The ability to obtain good signal-to-noise (S/N) spectra for weak sources supports studies such as the origin of the X-ray background and binary populations in nearby galaxies.

6) The wide FOV and project software allows studies of extended sources requiring the mosaicking of pointings such as the diffuse X-ray background, SNRs, nearby galaxies, and clusters of galaxies.

XMM has a rich scientific future and US astrophysicists, with continued scientific funding and technical/analysis support from the GOF, can be expected to remain outstanding participants in the program.

make observations supporting an extremely wide range of investigations. With its great flexibility and attributes, new ideas can be tested, and, with the ToO program, *XMM* can be rapidly retasked (as fast as 5 hours but typically within 8 hours) to observe new phenomena. To increase the usefulness of *XMM* for ToOs from *Fermi* and *Swift*, a new policy was introduced which allows GOs to propose observations of targets whose coordinates are not known at the time of submission (e.g., a new SN).

XMM is the mission of choice for spectroscopic and timing follow-ups to new ground and space-based surveys, such as the *Planck* cluster survey. *XMM*'s capabilities in the X-ray and optical/UV bands coupled with *NuSTAR*'s 6–79 keV bandpass (which overlaps the *XMM* X-ray band), sensitivity, and imaging ability will make possible exceptionally detailed studies of faint black holes, mapping the galactic center region in hard X-rays, imaging supernova remnants, mapping their radioactive elements, and monitoring blazars.

ESA has modified the AO to introduce proposals for very large programs (VLPs) allowing requests for 1–3 Ms of time and increasing the time dedicated to large programs (LPs) and VLPs to about 30% of the total. This has allowed investigations which, because of their required exposures, were not approved in early AOs but are now feasible. Examples include the deep surveys of the Large and Small Magellanic Clouds (LMC, SMC), M31, and M33 that will allow very sensitive studies of their X-ray source populations and diffuse emission. *XMM* is also open to cutting-edge high risk/high reward observations.

1.4 XMM Science

Exciting new discoveries by *XMM* are indicated by the recently (2011 December) approved LPs in AO-11. These include two joint *XMM*/*NuStar* proposals: the first will observe ULXs to provide unprecedented spectral coverage from optical to hard X-rays yielding a unique look at these complex objects and the second will study black-hole spin in AGN. Together the two joint LPs were granted 10% of the AO-11 A/B time. Two other large projects will observe *Planck*-identified clusters to confirm their identification and in many cases determine their physical properties. Observations of mirrored X-ray emission from molecular clouds near the Galactic center will be used to determine the history of the Sgr A* region. There will be a 2 Ms VLP wide-field survey of the LMC which will provide data for a very wide variety of studies from SNRs, to compact objects, to the interstellar medium (ISM). In addition, there is an LP to do AGN tomography.

The future science of *XMM* is considerably enhanced by the availability of the well-calibrated and extensive EPIC Serendipitous Source Catalog and associated data products (2XMMi), EPIC Slew Survey Source Catalog (SSSC), and OM Catalog (OMCat, produced by the US GOF). These databases are vast resources for archival research and in addition provide finding charts for future proposals. Continual improvements in calibration and the advent of new software allow measurements, for example, of the soft X-ray background, Galactic plane emission, and measurement of the mass profiles of clusters. The continued development of the *XMM* Science Analysis System (SAS) has made analysis easier and more robust as well as providing new automatic data products, easing the analysis of the large and complex data sets. The following is just a taste of what has been accomplished in the last couple years, and suggests what the future holds.

US Scientists LP/VLP Participation

Two of these successful AO-11 LP/VLP proposals have US PIs, and all have US Co-Is. In AO-10 there were 14 accepted LPs/VLPs of which 11 had US participation. These projects will provide US astronomers with immediate access to a wealth of astrophysical data.

1.4.1 Active Galactic Nuclei (AGN)

XMM has provided a detailed view of AGN over the last decade. *XMM*'s superior effective area enables it to collect spectra with a higher S/N ratio in a given time than any other X-ray observatory currently in orbit, and its orbit allows for long, continuous observations. Combined, these two properties make *XMM* the ideal choice for deep exposures of AGN, which can vary in flux by up to an order of magnitude in a matter of hours. Further, the simultaneous data collected by the EPIC, RGS, and OM instruments allow astronomers to examine the properties of the absorbing gas/outflowing wind, continuum, distant and inner disk reflection and soft excess. Simultaneous, broad-band data such as these paint a more complete picture of the correlations between spectral components, enabling a more accurate assessment of their origins and physical properties.

Relativistically Broadened Fe K Emission Lines: The search for, and characterization of, relativistic Fe K lines has been a strong aspect of *XMM* science. Among the three AGN-themed LPs selected in AO9, the observation of the Narrow Line Seyfert 1 (NLS1) 1H0707-495 has yielded the most striking result: a relativistically broadened Fe L emission line seen in tandem with the more commonly found broad Fe K line (Fabian et al. 2009). These lines have the same spectral shape (see **Fig. 3**), indicative of a reflection origin from the inner accretion disk extending down to a radius of < 1.8 r_g. Such a small inner radius is consistent with a black hole that is nearly maximally rotating ($\alpha > 0.97$). The accretion disk surrounding the black hole must also have an iron abundance ≥ 9 × solar in order to produce the Fe L line (Zoghbi et al. 2010).

Absorption in the Central Engines of Active Galaxies: Long *XMM* observations of the heavily obscured AGN NGC 1365 have shown evidence for rapid Compton-thin/thick transitions that periodically reveal/obscure a relativistic Fe K line and reflection continuum. These "eclipses" of the inner accretion disk occur on typical timescales of ~10 hours, indicating that the cold absorber has a distance from the black hole consistent with the Broad Line Region (Risaliti et al. 2009). The coveted observation of a high-contrast (ΔN_H resulting in a factor ~ 10 × flux change) eclipse from beginning to end is still being sought, and would enable time-resolved spectroscopy (effectively tomography) of the inner accretion disk. Such an observation would provide conclusive evidence of the relativistic origin of the broad Fe K emission line (Risaliti et al. 2011). The long RGS observations of NGC 1365 also highlight the AGN/starburst connection.

Ionized absorption by outflowing gas is also a common feature of AGN, and has been noted in both radio-quiet and radio-loud galaxies. This gas can be multi-phase, spanning a range of column densities and ionizations. In radio-quiet AGN these outflows have been observed with speeds of up to 0.4c, as noted by Tombesi et al. (2010). Such ultra-fast outflows (UFOs) have been noted in 35% of a sample of 42 radio-quiet AGN and show variations on timescales of days, indicating that they are compact. UFOs can have ionizations high enough to show absorption lines of Fe XXV and Fe XXVI. Ionized absorption signatures have also been reported in 75% of broad line radio galaxies observed with the RGS.

Multi-Wavelength Observations: *XMM*'s simultaneous multi-wavelength capabilities have revolutionized our understanding of the overall energy budget of AGN. Observations of 29 reverberation-mapped AGN with the EPIC and OM instruments enabled the spectral energy distributions (SEDs) of these sources to be measured with unprecedented detail, allowing robust estimates of their bolometric luminosities and Eddington ratios. Interestingly, the bolometric correction for these sources increases with increasing Eddington ratio for the sample (Vasudevan & Fabian 2009), demonstrating the importance of reprocessing in AGN.

Finally, *XMM* follow-up observations of three supposedly Compton-thick AGN detected by *Swift* Burst Alert Telescope (BAT) have demonstrated that these are not reflection-dominated sources, as hypothesized by their flat spectra, but instead show soft excesses and power-law emission obscured by Compton-thin gas. Five out of the six flat-spectrum BAT AGN are now known not to be Compton-thick sources, and in fact have optical spectra that vary in appearance from Seyfert 1s to normal galaxies. This indicates that the BAT survey is perhaps not as robust an identifier of Compton-thick AGN as has previously been thought (Winter et al. 2009; Trippe et al. 2011).

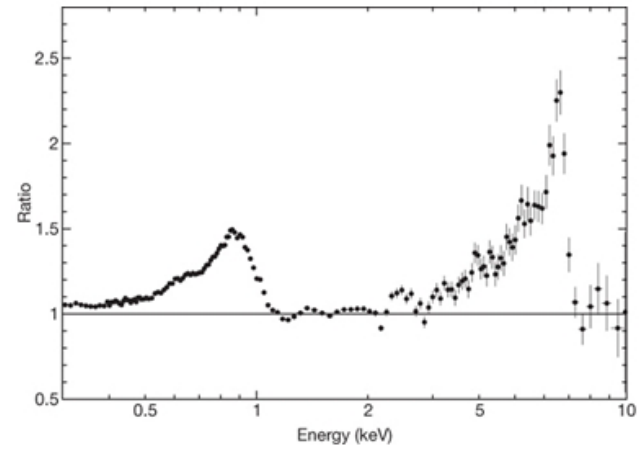

Figure 3. Ratio of the XMM spectrum of 1H0707-495 to a continuum power-law, showing the residual broad emission structure in their Fe K and Fe L lines (Fabian et al. 2009).

Future AGN research

XMM's future research on AGN will likely feature extensive work in the following areas of study. High S/N spectra will be used to determine black hole spin and the origin of variable Fe K lines. Simultaneous *NuSTAR* observations will provide a vital high-energy complement to *XMM* in the 6–79 keV range. They will enable the most accurate and precise constraints yet on black hole spin by firmly establishing the X-ray continuum and breaking the degeneracy between reflection and absorption models that has plagued past observations. Deep exposures of a sizable sample of AGN with the RGS will aid in the characterization of AGN outflows. Reverberation studies will require three or four well-sampled sources, each with ~1 Ms exposure. Also, detailed follow-up studies of "new" highly obscured AGN discovered by *Spitzer*, *SDSS*, *Integral*, *Fermi*, and perhaps *Swift*-BAT will be an important legacy of *XMM*. These areas of study are well-represented in the LPs selected for AO-10 and AO-11.

1.4.2 Clusters of Galaxies and the Dark Universe

Early Clusters: The epoch of galaxy cluster formation was pushed back significantly with the discovery of a mature, fully-formed cluster at a redshift of z = 2.07, when the Universe was only three billion years old. This surprising find by Gobat et al. (2011) used *XMM* to detect X-ray emission from the intracluster medium of CL J1449+0856, a collection of old, red–sequence elliptical galaxies imaged with *Spitzer*, *Subaru*, and Very Large Telescope (VLT). Unlike other galaxy structures at similar redshifts that were found to

be young and still in the process of forming, CL J1449+0856 appears to be old enough to have accumulated an appreciable amount of hot intracluster medium (ICM). Finding a mature galaxy cluster at such a large look-back time challenges our assumptions about the timescales on which clusters formed in the early Universe.

Nearby Clusters: *XMM* has also been vital in investigating the nature of the nearest cluster of galaxies, the Virgo Cluster. Urban et al. (2011) used *XMM* data to determine the temperature, density, entropy, and metallicity profiles of the hot gas beyond the virial radius of Virgo, a first for a moderate-mass dynamically young cluster. An abrupt temperature and metallicity drop at large radii, coupled with a flattening entropy profile was argued to result from clumping of the ICM. If confirmed, this result has important ramifications for our understanding of the physics at the outskirts of clusters. A non-zero measurement of iron at > 0.5 r_{virial} indicates that ram pressure stripping of the metal-enriched ISM of the constituent galaxies by the ICM might be more effective at larger radii than is generally assumed. In addition, Simionescu et al. (2011) compared the metal abundance of the ICM in front of and behind a cold front in Virgo and demonstrated that "sloshing" of the ICM may be a more important mechanism for distributing metals to the outer regions of clusters than AGN activity.

***Planck* Clusters**: *XMM* has proved invaluable in confirming Sunyaev-Zel'dovich (SZ) *Planck* cluster candidates. The *Planck* Collaboration (2011a) used *XMM* snapshot observations of 25 cluster candidates to confirm that 21 of the candidates harbored extended X-ray emission indicative of single or multiple clusters, a majority of which exhibited highly irregular and disturbed morphologies. The *XMM* follow-up will allow improvement in the use of the SZ Compton parameter as a tool to identify bona fide clusters with *Planck* and to measure their masses. Another *Planck*-detected cluster candidate validated by *XMM* is PLCK G266.6-27.3 at z = 0.94 (**Fig. 4**; *Planck* Collaboration 2011b), whose mass of 8×10^{14} $M_{\odot}$ makes it one of the most massive and X-ray luminous galaxy clusters in the z~1 Universe.

ICM Turbulence: Sanders et al. (2010) utilized the velocity broadening of emission lines in deep, high resolution RGS spectra to place the first constraints on turbulence in the ICM of Abell 1835. Turbulence within the inner 30 kpc of the cluster was no greater than 270 km s^{-1}, indicating that any AGN-feedback in the cluster is not generating significant turbulent motions. Sanders et al. (2011) followed up this result with a larger sample of clusters observed with the RGS, and found comparable upper limits as Abell 1835.

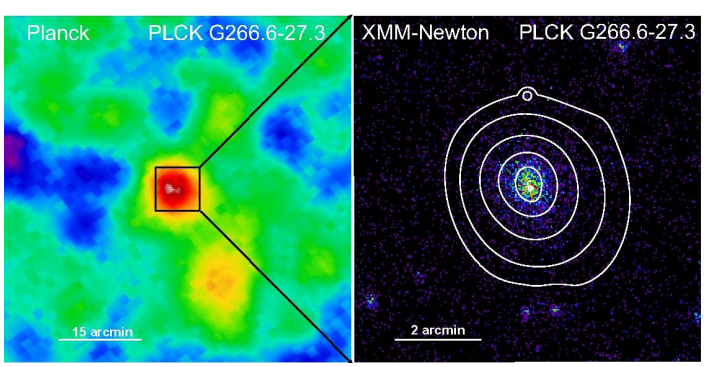

Figure 4. Planck (left) and XMM (right) images of the z ~ 1 galaxy cluster PLCK G266.6-27.3 (Planck Collaboration 2011b)

OM Observations of Bright Cluster Galaxies (BCGs): Donahue et al. (2010) used the OM in conjunction with GALEX to determine ultraviolet fluxes from a sample of 32 BCGs. The seven UV-brightest clusters all had short central cooling times for the hot gas, strongly linking cooling gas in the cores of clusters to recent episodes of star formation in the BCG.

Future Cluster Research

The detection of high-z clusters and the validation of *Planck*-detected cluster candidates are two key areas for which *XMM* will significantly advance cluster research, not only in terms of understanding cluster physics but also using clusters as precise cosmological tools. While *Planck* is expected to detect over 2000 bona fide clusters, it will also identify an unknown number of false detections due to fluctuations in the complex microwave sky. Detecting the X-ray emission from a mature cluster is therefore crucial for constructing an unbiased cluster sample. With its large collecting area, even a snapshot *XMM* observation can detect any *Planck*-identified cluster to a redshift of z~1.5 (*Planck* Collaboration 2011a). The leverage provided by having a complete cluster sample out to that redshift will give unprecedented constraints on not only the dark energy equation of state but also the evolution of cluster properties with redshift.

1.4.3 Solar System and Diffuse Emission

XMM's strong soft X-ray response, large FOV, and large effective area make it the best current instrument for the study of extended diffuse emission both in the Milky Way and in nearby galaxies. *XMM* remains at the forefront of determining the amount and sources of the hot gas in galaxies. In nearby galaxies, the problem is distinguishing the different possible sources for this emission. Studies of M33 (Owen & Warwick 2010) and M31 (Bogdan & Gilfanov 2010) have used multi-wavelength correlations to begin to separate the contributions to the diffuse emission by hot gas produced by star-formation, hot gas that may be due to a halo, and emission due to active stars. Both studies were strongly photon limited, but a new study of M33 (AO9) will produce far more secure results.

Solar Wind Charge Exchange (SWCX) Emission: Because the diffuse hot gas in the Milky Way and its halo always fills the complete FOV, studies are complicated by SWCX emission, a time-variable foreground component with a spectrum similar to thermal emission. Since the SWCX emission is generated throughout the heliosphere, and particularly strongly in the earth's exosphere, this emission is present in all observations of all X-ray missions, but only *XMM* has the grasp (effective-area solid-angle product) to study it in detail (e.g., Henley & Shelton 2010). Starting with *ROSAT* and continuing with *XMM*, the ISM and halo have been mapped using shadows in the X-ray background

produced by molecular clouds (e.g., Anderson et al. 2010). Shadow observations require multiple pointings to reduce the sensitivity to the variable SWCX emission. Repeated observations of key shadows, such as that cast by MBM12 (Koutroumpa et al. 2011) are clarifying both the structure of the ISM and the nature of the SWCX emission. Observations of the sub-solar point of the magnetosheath (Snowden et al. 2009) and of the He focusing cone (Koutroumpa et al. 2009) are directly determining the SWCX emissivity which will allow its removal from sensitive observations, and are laying the foundation for several proposed magnetosheath observing missions. Similar observations during the upcoming solar maximum will be key to understanding SWCX.

Charge-exchange emission has also become important for extragalactic astronomy; RGS observations of M82 (Liu et al. 2011) and the nuclei of M51 and M83 (Liu et al. submitted) suggest charge-exchange emission, rather than thermal emission, is the dominant emission mechanism in these objects, and may be important for all galactic emission. These results could have far-reaching implications for the energy budgets of the ISM.

Future Diffuse Emission Research

Using *XMM*'s uniquely large area-solid angle product, the role of SWCX emission from the heliosphere to SNRs and beyond will continue to be examined. Observing Earth's magnetosheath and the interplanetary emission at different geometries and at different times in the solar cycle will provide further constraints on SWCX emission models. Shadowing measurements of Galactic objects will further refine our understanding of the distribution of hot gas in the Milky Way. The wide-field surveys of nearby galaxies will produce exceptional views of their dynamic and energetic ISMs leading to a better understanding of their energy balance and evolution.

1.4.4 Stars and Star Formation

The study of stars and star formation in the Milky Way continues to exploit three of *XMM*'s main capabilities: imaging spectroscopy of star-forming regions and OB associations (large field of view and good spatial resolution of EPIC), imaging spectroscopy of individual X-ray sources (large effective area of EPIC), and grating spectroscopy of very bright sources (large effective area of the RGS from 6–40 Å).

Star-Forming Regions: Star-forming regions are ideal targets for the EPIC instruments on *XMM* because they contain hundreds to thousands of coeval young stars spanning the entire initial mass function. The brightest X-ray sources are the massive luminous blue variables (LBVs), Wolf-Rayet stars and OB stars, and the flaring low- and intermediate-mass pre–main-sequence (PMS) stars. In the Survey of Orion A in X-rays (SOX), Pillitteri et al. (2010a) discovered over 1,000 sources in a dozen EPIC fields, over 700 of which are low-mass PMS stars including a new cluster around the B0 supergiant κ Ori. Over half the cluster members are newly discovered Class III sources (naked T-Tauri stars). The Class I protostars and Class II T-Tauri stars are clustered into several small groups while Class III candidates are more dispersed. The SOX survey suggests that nearly 2,000 stars formed in the Orion A cloud, about the same number as in the younger, adjoining Orion Nebula Cluster.

T-Tauri Stars: The PMS T Tauri stars have X-ray activity levels that are 10^3 to 10^4 times higher than older late-type stars like the Sun. Some of this activity may be scaled up dynamo-driven coronal activity, but X-ray spectroscopy of the classical T Tauri star (CTTS) TW Hya showing enhanced Ne abundance and weak forbidden-line emission of He-like ions suggests the X-rays are produced in high-density accretion shocks. A recent multi-wavelength campaign to observe the accreting CTTS V1118 Orionis (Audard et al. 2010) showed variations in the *XMM* light curve that were well-correlated with optical and infrared variability during the outburst, further strengthening the case for accretion-driven X-ray emission. Curran et al. (2011) compared the accretion rates derived from optical emission lines, with accretion rates derived from *XMM* EPIC and *Chandra* CCD spectra of eight well-studied CTTSs. While the optical accretion rates varied by nearly three orders of magnitude, the X-ray accretion rates were all comparable, suggesting that only a small portion of the accretion column is seen in X-rays, possibly because of absorption. The *XMM* and *Chandra* results prompted Brickhouse (2011) to propose an accretion-fed corona model wherein the accretion shock not only produces X-rays, but also heats the surrounding magnetized atmosphere, producing soft coronal X-rays.

Planet Hosting Stars (PHSs): The explosion in the number and variety of exoplanets detected in recent years has prompted a variety of studies on the viability of exoplanet atmospheres around stars spanning a wide range of masses and activity levels, from very low mass dMe stars to intermediate-mass T-Tauri stars. *XMM* observations of a flare around the PHS HD 189733 (Pillitteri et al. 2011) share the same orbital phase and characteristics as the flare ob-

Future Stellar Research

Future stellar observations with *XMM* will include more solar- and lower-mass stars hosting planets to search for activity (e.g., flares due to star-planet magnetic field interactions) as well as to provide detailed information on the X-ray radiation fields around these stars (to allow more refined simulation of the processes affecting the atmospheres of these planets). Observations of stellar clusters and star formation regions will continue, making good use of *XMM's* large FOV and good sensitivity to diffuse emission in order both to widen the range of parameter space (e.g., ages, masses, metallicity) by observing new clusters and to study stellar variability on time-scales from minutes to years by re-observing previously studied ones. X-ray emission from massive stars, including both isolated stars and those in associations, will continue to be studied, driven by the fact that the production of X-ray emission from such stars is still an unresolved problem after nearly three decades of study. *XMM* will continue to play a key role in advancing our understanding of the subclass of X-ray bright colliding wind massive binaries through further studies of the time-variable X-ray emission (e.g., from Eta Carinae and WR 140) as well as newly discovered systems.

served in 2009 (Pillitteri et al. 2010b). They suggest that the flares may be triggered by reconnection between the magnetospheres of the host star and a nearby hot Jupiter.

Poppenhaeger et al. (2010) used *XMM* and *ROSAT* data to examine the stellar X-ray luminosity of all PHSs within 30 pc of the Sun and found no significant correlations of the activity indicator L_X/L_{bol} with planetary mass or semimajor axis. Poppenhaeger & Schmitt (2011) used *XMM* and *ROSAT* data to examine the X-ray luminosity of planet-hosting stars. They found that there is no detectable influence of planets on their host stars; however, star-planet interactions may provide valuable information on stellar and planetary magnetic fields.

1.4.5 Supernova Remnants

Supernova Remnants in the Milky Way: X-ray emission sources in SNRs can include both shocked supernova material and shocked ambient material, as well as non thermal emission and a compact central object. *XMM's* RGS has the unique ability to obtain detailed, high-resolution spectra of moderate sized SNRs (< 2') with only modest smearing. Its measurements can be used to derive the chemical abundances and age of the SNR, shock velocities and explosion energetics, and properties of the circumstellar environment.

Supernova products continue to be the most common identification for the growing population (>70) of Galactic TeV sources discovered by *HESS* and *VERITAS*, with pulsar wind nebulae (PWNe) the most numerous class. *XMM* has discovered and imaged many of the new SNRs and PWNe that are responsible for these high-energy sources, most recently HESS J1731−347/SNRG353.6−0.7 (Tian et al. 2010), IGR J18490−0000/HESS J1849−000 (Gotthelf et al. 2011), HESS J1832−084/PSR J1833−0827 (Esposito et al. 2011), and SNR G327.1−1.1 with a pulsar candidate (**Fig. 5**; Temim et al. 2009, Acero et al. 2011a). A new PWN associated with the 65 ms, energetic pulsar PSR J0855−4644 has been imaged by *XMM* near the rim of the SNR RXJ0852.0−4622 (Vela Jr.) by Acero et al. (2011b). It appears to be associated with an enhancement in TeV emission. With a distance estimated as ~900 pc, PSR J0855−4644 at $E = 1.1 \times 10^{36}$ erg s^{-1} is the second most energetic nearby pulsar (after the Vela pulsar), and could contribute to the cosmic-ray e−/e+ spectrum received at Earth.

The large EPIC FOV also enables detailed studies of large SNRs that can reveal their evolutionary state and the nature of the progenitor star. In a mosaic of three pointings covering the bright SNR G296.1−0.5, Castro et al. (2011) used both the MOS and the RGS to make a complete spatial and spectral map. (See the left hand figure on the proposal cover page.) They found that the shell is characterized by enhanced N abundance and low O abundance, characteristics of CNO-processed material that is often observed in winds of red supergiants and the nitrogen sequence (WN subclass) of Wolf-Rayet stars. Thus, the shell may be largely swept-up stellar wind material. While previous observations of this remnant with *ROSAT* left its parameters poorly constrained, the *XMM* data can be interpreted, assuming that all the X-ray emission is from a shocked stellar wind, as indicating an age of ~2800 yr. The measured $N_H = (2-4) \times 10^{20}$ cm^{-2} indicates

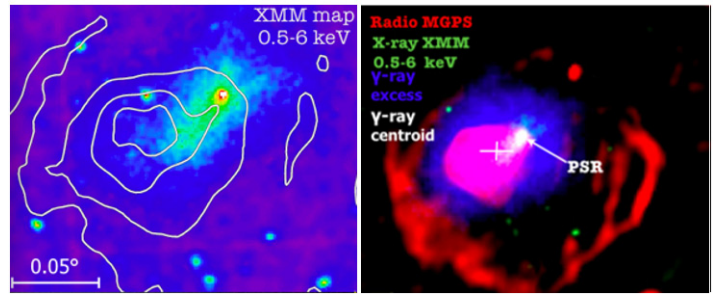

Figure 5. ***Left****: XMM X-ray image of the PWN in the SNR G327.1−1.1, from Temim et al. (2009). Radio contours are shown in white.* ***Right****: Superimposed radio (red), X-ray (green) and H.E.S.S. TeV (blue) images of G327.1−1.1. From HESS Source of the Month (2011 November).*

that it is relatively nearby, at a distance of ~2 kpc, which is in accord with the wind interaction model of its size and age.

Supernova Remnants in Other Galaxies: The high sensitivity of *XMM* makes it extremely useful for studies of extragalactic SNRs. In the Magellanic Clouds, *XMM* has the spatial resolution to provide structural information about SNRs in the X-ray band, along with the unsurpasssed soft band sensitivity. The right hand figure on the proposal cover page is a three-color image of SNR0537-6628 with X-ray contours overlaid (Klimek et al. 2010). Red is Hα, green is [S II], and blue is [O III]. It is an example of some of the SNRs which show quite different morphologies in the X-ray and the radio or optical. The difference in morphologies is difficult to understand (see Crawford et al. 2010), as is the fact that some remnants are radio bright while X-ray faint, or vice versa. Observing such remnants in nearby galaxies provides a much broader sample from which to understand these morphological differences. Outside of the Galactic satellites, even though *XMM* is not capable of resolving the SNR structures, it can measure colors and low S/N spectra with reasonable observing times, allowing one to distinguish SNRs from HII regions, and to determine the basic physical state (energetics).

Future SNR Research

Knowledge of the population of SNRs emitting at GeV and TeV energies is growing quickly as exposure in the Galactic plane by *Fermi*, *HESS*, and *VERITAS* accumulates. *XMM* will image these unidentified sources and identify them as SNRs or PWNe. Together with the *Fermi* GeV data, multi-wavelength spectra will discriminate between hadronic or leptonic models. As a result, we will learn if the gamma-rays are due to the SNR shock interacting with dense molecular clouds, or relic electrons from an earlier phase of an aging PWN. Surveys of nearby galaxies will provide a better understanding of SNR evolutionary states and progenitor stars.

1.4.6 Neutron Stars (NSs)

NSs are laboratories for the study of matter at densities at or higher than nuclear, while their populations are a tracer of massive star formation and a window into the physics of supernova explosions. The imaging and timing capabilities

simultaneously available with EPIC are needed to study the majority of isolated pulsars that are radiatively inefficient at all wavelengths, and often only detected in X-rays.

Magnetars: *XMM* continues to contribute to the spectral and timing studies of new magnetars (NSs with extremely strong magnetic fields), especially those that are faint in quiescence (**Fig. 6**). The anomalous X-ray pulsar (AXP) discovered in 2010 in the SNR CTB 37B is possibly the youngest known magnetar (Sato et al. 2010), with a timing age of < 1000 yr that agrees with the inferred age of the SNR. CTB 37B also contains a bright *HESS* TeV source of uncertain origin. The recently discovered soft gamma ray repeater SGR J1833−0832 is so faint that it was not detected in a previous *XMM* observation of the field (Kargaltsev et al. 2011). Neither was the SGR Swift J1834.9−0846 detected in a previous *XMM* observation of its possible host SNR W41 (Halpern 2011b). The implication is that many young magnetars are transients, and so distant and/or faint in quiescence that repeated deep exposures with *XMM* will be required to follow their evolution.

Antimagnetars: The antimagnetar (NSs born with very weak magnetic fields) nature of the central compact objects (CCOs) in SNRs has also been confirmed largely through coherent timing campaigns with *XMM* that are measuring very small spin-down rates for the three of these thermally emitting NSs for which pulsations are detected (**Fig. 6**). The 0.112 s pulsar in Puppis A is seen to have a very small dipole field $B_s \leq 3 \times 10^{10}$ G (J. Halpern, private communication), which is less than that of any other young NS, but similar to the 0.105 s pulsar in Kes 79. The prototype 1E 1207.4−5209 probably has $B_s = 9.9 \times 10^{10}$ G (Halpern & Gotthelf 2011), which is the right value to explain the unique presence of cyclotron absorption lines in its soft X-ray spectrum.

XMM continues to discover new CCO candidates, which now number at least 11, and are evidently a major new class of young NSs. Theorists are investigating their possible magnetic field structure and evolution. Their internal magnetic fields must be stronger and more complex than their external dipoles. The absence (as yet) of their required numerous descendants among the radio or X-ray pulsar populations hints that some new process is being observed.

The *XMM* detection by Zane et al. (2011) of 59 ms pulsations from the nearby, isolated neutron star candidate 1RXS J141256.0+792204 ("Calvera"), may be the first indication of an "orphaned CCO," a weakly magnetized neutron star that has outlived its SNR. This would be an important clue to the aging process of CCOs, whose descendants must be common but have so far not been detected. Because Calvera is not seen at any other wavelength including gamma-rays (Halpern 2011a), its spin-down rate and magnetic field can only be measured in X-rays, which can be accomplished by *XMM* in the coming years.

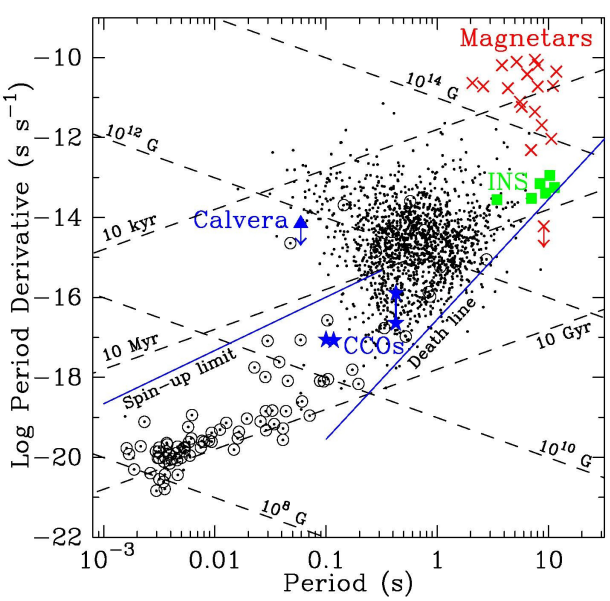

Figure 6. $P-\dot{P}$ digram of isolated pulsars (dots), binary radio pulsars (circled dots) and various types of X-ray pulsars (colors). Figure courtesy J. Halpern.

Future Neutron Star Research

The *XMM* EPIC PN is the most capable instrument for millisecond timing as well as the most sensitive for the detection of faint X-ray pulsars in general. It will be used in timing campaigns that require dense and long baselines to measure weak dipole fields of anti-magnetars, orphaned CCOs, and in studies of the new black-widow millisecond pulsars discovered by *Fermi*. It will also be used to reveal the pulsar powerhouses of TeV sources previously thought of as "dark accelerators." New pulsars that are very energetic but radio quiet and radiatively inefficient will be discovered, and the faint, quiescent counterparts of newly discovered SGRs will be studied. Some of the latter will have weaker magnetic fields that overlap the normal pulsar population, and will require years to measure. *XMM* will be at the forefront of efforts to establish a unification of the diverse pulsar population.

1.4.7 X-ray Binaries (XRBs) and Cataclysmic Variables (CVs)

X-ray Binaries in the Milky Way: While Fe K line spectroscopy is the principal tool for studying the structure and dynamics of the accretion disks around stellar mass and supermassive black holes. Disk-line studies of neutron-star low mass X-ray binaries (LMXBs) in recent years are also yielding important information about neutron star radii and the structure of the accretion flow. In a comprehensive study of ten neutron star LMXBs with Fe K lines from *XMM* and *Suzaku*, Cackett et al. (2010) showed that the disk lines indicate a narrow range of inner radii, (6–10) GM/c^2 consistent with the disk extending to the neutron star surface. In addition, spectral modeling reveals a hot blackbody component that is likely coming from the boundary layer between the rapidly rotating accretion disk and the slower neutron star surface. It is this component that probably photoionizes the disk and produces the Fe K emission.

Both radii and masses of NSs need to be known in order to determine the fundamental NS equation of state, still a hot topic after all these years. The primary technique is to use measurements of Eddington-limited X-ray bursts from

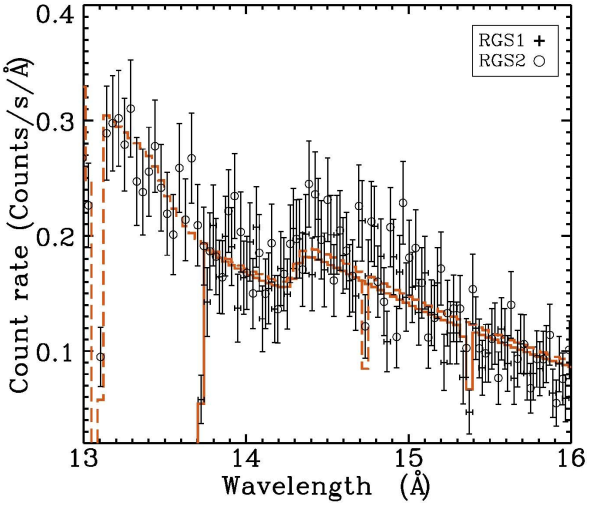

Figure 7. RGS1 and RGS2 spectra of 4U 1608–52 together with the best-fit models (solid line for RGS1 and dashed line for RGS2) used to determine the foreground column density of Ne (Gűver et al. 2010).

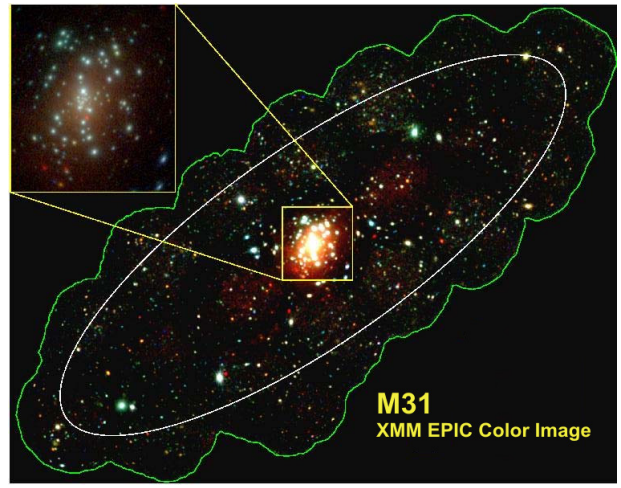

Figure 8. Three-band X-ray color image of M31, rendered from the M31 Deep XMM Legacy Survey (Stiele et al. 2011).

RXTE, but the accuracy is limited by the uncertain distance of the source. Gűver et al. (2010) used the RGS spectra of the LMXB 4U 1608−52 to measure the interstellar absorption edges of Ne (**Fig. 7**) and Mg, which they compared with optical extinction to red-clump stars to determine a distance. This led to a well-constrained mass of 1.74 ± 0.14 $M_\odot$ and a radius of 9.3 ± 1.0 km.

X-ray Sources in Other Galaxies: *XMM* has been crucial to the study of the X-ray source populations of nearby galaxies. Despite its medium spatial resolution, its large field of view and high sensitivity allow it to cover in full galaxies such as the SMC, M31, and M33 that have not been fully surveyed by *Chandra*. *XMM* surveys of these local galaxies have recently produced exciting results, shedding new light on the properties of X-ray binaries and other accreting compact objects.

The *XMM* Survey of the SMC (e.g., Coe et al. 2011; Sturm et al. 2011a,b) has produced many interesting results over the past few years. Recently a US-led effort resulted in the discovery of a link between the X-ray source population in the SMC and its stellar population. The richness in Be-XRBs (X-ray binaries consisting of a Be star and a neutron star) in the SMC appears linked to a burst of star formation there 25–60 Myr ago, consistent with the most likely age of Be-XRBs of 40 Myr. This result is strengthened by observation that areas with more recent bursts do not appear to show such an overdensity of Be-XRBs. This discovery provides some of the tightest constraints available on the formation and evolution of these objects, including formation rates, supernova kick velocities, and the role of circumstellar "decretion" disks (Antoniou et al. 2010).

The *XMM* surveys of M31 and M33 stand alone in their full coverage and depth. The large M31 survey has produced a homogeneous catalog of all X-ray sources within the M31 D_{25} isophote down to 10^{35} erg s^{-1} (Stiele et al. 2011). While the majority of these sources remain unclassified, this survey has clearly provided a rich resource of interesting multiwavelength sources (**Fig. 8**). Using the ongoing monitoring program, Pietsch et al. (2011) have discovered a supersoft X-ray counterpart to an optical nova, providing improved constraints of the physical parameters of the system. The US-led deep *XMM* survey of M33 is only partially complete, so that only preliminary findings have thus far been released (e.g., Pietsch et al. 2010; Plucinsky et al. 2011). These include a very early detection of a nova outburst with the OM. When the data are fully analyzed, they will provide another resource comparable to the richness that is now available for M31.

Ultraluminous X-ray Sources (ULXs): Whether or not ULXs represent accretion onto intermediate-mass black holes (IMBHs) remains a contentious question. With apparent X-ray luminosities that can far exceed the Eddington luminosity of a 10 $M_\odot$ stellar-mass black hole, one natural interpretation for the excessive luminosity is that the accreting object has a mass of hundreds to thousands of solar masses in the most extreme cases. Alternatively, beaming or violations of the Eddington limit might explain most if not all ULXs. Much less is known about their properties than Galactic black-hole binaries, which radiate X-rays in a variety of spectral states. The thermal dominant (TD) state is the most useful as it can be fitted with a standard Shakura-Sunyaev accretion disk model allowing estimates of black hole mass and spin. While ULXs are thought to host stellar-mass or intermediate-mass black holes, until recently they have not been identified in the TD state, so it is difficult to infer their masses. In joint *Chandra* and *XMM* observations, Feng & Kaaret (2010) found that one of the most luminous ULXs, X41.4+60 in the galaxy M82, was in a TD state according to its spectral variability behavior, with $L_{disk} \propto T^4_{in}$. From the data, they deduced a black hole mass of at least 200 $M_\odot$ and spin parameter near maximum, a* = 0.93, confirming it is an IMBH.

With a maximum luminosity of 10^{42} erg s^{-1}, HLX-1 in the galaxy ESO 2349−49 is apparently the most luminous known ULX, and presents another strong case for the existence of intermediate mass black holes. Its large distance means that its X-ray count rate is low when it is in its low/hard state. The large collecting area of *XMM* allowed a spectrum of HLX-1 to be obtained when the luminosity of the

source declined by two orders of magnitude from its peak, and found that the spectrum exhibited the same power-law spectral shape that stellar-mass black holes exhibit when in their low state. This finding in conjunction with *Swift* and *Chandra* data revealing a thermal disk-dominant spectral shape when the source was at its peak provides the first evidence of a ULX that clearly follows the stellar-mass black-hole state paradigm, and argues strongly that HLX-1 does indeed harbor a black hole of at least 9000 $M_\odot$ (Servillat et al. 2011).

Future X-ray Binary Research

A large *XMM* program will observe energy-dependent time lags in Cygnus X-1, for the first time mapping the emission region of Fe Kα with sub-millisecond time resolution. At the same time, the RGS will be used to study the stellar wind that feeds the black hole. *XMM* will perform ToO observations to obtain high-resolution spectra of transient X-ray binaries discovered by *MAXI*, *Swift* BAT, and *INTEGRAL*. Many of these will show disk-like emission lines, and some will have unusual abundances indicating the evolved state of the donor star in ultracompact systems. The long, continuous observations that are possible with *XMM* are ideal for discovering their spin and orbital periods, and distinguishing among the types of compact objects. Surveys covering the full extent of nearby galaxies (LMC, SMC, M31, and M33) will be crucial archives for all future multiwavelength studies of nearby galaxies. Since the sources native to such nearby galaxies are typically soft (X-ray emitting gas, SNRs, and LMXBs), and the galaxies cover large areas on the sky, *XMM* is poised to make many more significant contributions to this field.

1.4.8 Cosmology, Surveys, and Serendipitous Science

Because of it large field of view and collecting area, *XMM* is the ideal X-ray survey instrument. Recent surveys have fallen into three broad classes:

The All-Sky X-ray Slew Survey: This will be the deepest and largest solid angle 2–8 keV survey ever performed (Read et al. 2011). At present it covers ½ of the sky to a flux depth of 4×10^{-12} erg cm^{-2} s^{-1}, five times deeper than the best previous survey. It has over 1450 sources in the 2–12 keV band and 10,000 sources in the 0.2–2 keV band with a sensitivity similar to the *ROSAT* All Sky Survey. Over 70% of the sources have been identified from catalogs and follow-up work. *Swift* observations are showing the existence of many highly variable objects. This all sky capability has resulted in the discovery of: two tidal disruption events from stars falling into super massive black holes; the first measurement of AGN X-ray variability on long time scales showing that 5% of them vary by a factor of over 10 (one spectacular object, GSN069, varied by a factor of over 300); and the extension of the hard X-ray log N-log S relation reducing the gap between the all sky and serendipitous source surveys (**Fig. 9**). The data are all available publicly on line.

The Serendipitous Source Survey (2XMMi): This involves the processing of all of the *XMM* public data (Watson et al. 2009) and has produced the largest X-ray catalog to date. The 3XMM catalog (expected at the end of 2012) will have ~450,000 detections of ~330,000 unique sources, roughly double the number in the 2XMMi catalog. All the data are publicly available. The size and uniformity of the data base enabled a giant leap in the understanding of the properties of a large sample of objects, particularly AGN. One highlight concerns the relationship between [O III] 5007Å equivalent width and obscuration in AGN. Caccianiga & Severgnini (2011) show that a significant part of the very large dispersion in the ratio of two measures of the AGN bolometric luminosity, $L_{O[III]}$ and L_X, is due to the effects of obscuration of the optical line emitting regions and a large spread in the intrinsic relationship. Since both of these measures have been used to determine the bolometric luminosity of AGN, the wide scatter had caused a lot of confusion in previous surveys.

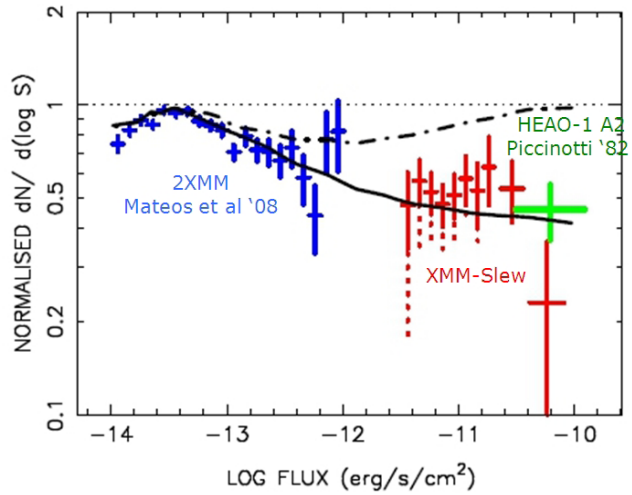

Figure 9. XMM Slew Survey hard band (red) is filling the gap in the AGN number vs. flux relation between other shallower all-sky surveys (green) and the XMM Serendipitous Source Survey. The solid curve represents the AGN model curve from Gilli et al. (2007) and the dot-dashed curve shows AGN plus clusters (Read et al.2011).

Dedicated Surveys of the Milky Way and Nearby Galaxies: A large program first approved in AO-8 is surveying a ~10 square degree area of the SMC down to a limiting point source luminosity of 2×10^{33} erg s^{-1}, detecting over 3000 sources. This will allow a complete inventory of SNRs, X-ray binaries and Super-Soft Sources, and the study of the diffuse emission of the hot ISM. The high throughput of *XMM* enables detailed spectral and temporal analyses of a large fraction of these sources. Together with the existing EPIC data, these observations will create a unique data set to study the star-formation history and its implications on the morphology of the ISM in the SMC. Similar surveys of the LMC (AO-11 LP) and M31 are in progress.

Appendix B. Acronyms

2dF	Two Degree Galaxy and Quasar Survey
2XMMi	EPIC Serendipitous Source Archive
AAVSO	American Association of Variable Star Observers
AAS	American Astronomical Society
ACS	Advanced Camera for Surveys
ADAP	Astrophysics Data Analysis Program
ADS	Astrophysics Data Service
AGN	Active Galactic Nuclei
AO	Announcement of Opportunity
ARK	RPS software system
ASCA	Advanced Satellite for Cosmology and Astrophysics
AXP	Anomalous X-ray Pulsar
BAL	Broad Absorption Line
BAT	Burst Alert Telescope
BGC	Bright Cluster Galaxies
BROWSE	HEASARC mission data and parameter search tool
CCD	Charge-Coupled Device
CCF	Current Calibration Files
CCO	Compact Central Object
CDM	Cold Dark Matter
CLEA	Contemporary Laboratory Experiences in Astronomy
Co-I	Co-Investigator
COTR	Contracting Officer's Technical Representative
COUP	*Chandra* Orion Ultradeep Project
CSM	Circumstellar Matter
CTI	Charge Transfer Inefficiency
CTTS	Classical T-Tauri Stars
CU	Columbia University
CV	Cataclysmic Variable
CWB	Colliding Wind Binaries
CXO	*Chandra* X-ray Observarory
DDT	Delayed Detonation
DPU	Digital Processing Unit
DROXO	Deep ρ Ophiuchi *XMM* Observation
EA	Educator Ambassadors
EPIC	European Photon Imaging Camera
EON	Extended Orion Nebula
E/PO	Education and Public Outreach
ESA	European Space Agency
ESAC	European Space Astronomy Center
ESAS	Extended Source Analysis Software
ESOC	European Space Operations Center
Fermi	*Fermi* Gamma-ray Space Telescope
FOV	Field of View
FTE	Full Time Equivalent
Ftools	HEASARC multi-mission data analysis software package
FWHM	Full Width at Half Maximum
FY	Fiscal Year
GALEX	Galaxy Evolution Explorer
GBH	Galactic Black Hole
GLAST	Gamma-ray Large Area Space Telescope
GO	Guest Observer
GOF	NASA/GSFC Guest Observer Facility
GPG	Public domain version of Pretty Good Privacy
GRB	Gamma-Ray Burst
GSFC	Goddard Space Flight Center
GT	Guaranteed Time
GTN	Global Telescope Network
HEASARC	High Energy Astrophysics Science Archive Research Center
HEASoft	HEASARC data reduction and analysis software package
HESS	High Energy Stereoscopic System
HERA	HEASARC multi-mission interactive data analysis facility
HETG	High Energy Transmission Grating
HPD	Half Power Diameter
HST	*Hubble* Space Telescope
ICM	Intracluster Medium
IGM	Intergalactic Medium
IMBH	Intermediate Mass Black Hole
INS	Isolated Neutron Stars
INTEGRAL	International Gamma-Ray Astrophysics Laboratory
IR	Infra Red
IRAS	Infra Red Astronomical Satellite
ISM	Interstellar Medium
ITEA	International Technology Education Association
IYA	International Year of Astronomy
JPL	Jet Propulsion Laboratory
LANL	Los Alamos National Laboratory
LBV	Luminous Blue Variables
LETG	Low Energy Transmission Grating
LMC	Large Magellanic Cloud
LMXB	Low Mass X-ray Binary
LP	Large Programs
LTI	Learning Technologies, Inc.
LTSA	Long Term Support in Astrophysics
MAST	Multimission Archive at Space Telescope
MESA	Math, Engineering, Science, Achievement
MOO	Mission of Opportunity
MOS	MOS style EPIC CCD detector
MSSL	Mullard Space Science Laboratory
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NLS1	Narrow Line Seyfert~1
NPS	North Polar Spur
NRC	National Research Council
NS	Neutron Star
NSF	National Science Foundation
NuSTAR	Nuclear Spectroscopic Telescope Array
NVO	National Virtual Observatory
OM	Optical Monitor
OMCat	Optical Monitor Source Catalog
OSS	Office of Space Science
PDS	Power Density Spectrum
PGP	Pretty Good Privacy
PHS	Planet Hosting Star
PI	Principal Investigator
PIMMS	Portable, Interactive Multi-Mission Simulator
Planck	An ESA microwave space observatory
PMS	Pre Main Sequence

PN	PN style EPIC CCD detector
PNe	Planetary Nebulae
PSD	Power Spectral Density
PSF	Point Spread Function
PV	Pointing Verification
PWN	Pulsar Wind Nebula
QPO	Quasi-Periodic Oscillation
QSO	Quasi-Stellar Object
RASS	*ROSAT* All-Sky Survey
RCS	Resonant Cyclotron Scattering
REXCESS	Representative *XMM*-Newton Cluster Structure Survey
RGA	Reflection Grating Array
RGS	Reflection Grating Spectrometer
RMS	Root Mean Square
ROSAT	Rontgen Satellite
RPS	Remote Proposal System
RXTE	Rossi X-ray Time Explorer
SAS	Science Analysis System
SDSS	Sloan Digital Sky Survey
SED	Spectral Energy Distribution
SEU	Structure and Evolution of the Universe
SGR	Soft Gamma-ray Repeater
SMD	Science Mission Directorate
SMC	Small Magellanic Cloud
SMEX	Small Explorer
SN	Supernova
SNe	Supernovae
S/N	Signal to Noise
SNR	Supernova Remnant
SOC	Science Operations Center
SOX	Survey of Orion A in X-rays
SPI	Star-Planet Interactions
Spitzer	*Spitzer* Space Telescope
SRON	Netherlands Institute for Space Research
SSB	Space Studies Board (of the NRC)
SSC	Survey Science Centre
SSSC	Slew Survey Source Catalog
SSU	Sonoma State University
STEM2	Science, Technology, Engineering and Math
STScI	Space Telescope Science Institute
SWCX	Solar Wind Charge Exchange
Swift	*Swift* Gamma-Ray Burst Mission
SWIRE	*Spitzer* Wide-area Infrared Extragalactic Survey
SZ	Sunyaev-Zel'dovich
TAX	Two-Absorber X-ray
TAXP	Transient Anomalous X-ray Pulsar
TD	Thermal Dominant
ToO	Target of Opportunity
UFO	Ultra Fast Outflow
UK	United Kingdom
ULX	Ultra-Luminous X-ray source
UMCP	University of Maryland-College Park
US	United States
USNO	US Naval Observatory
UV	Ultra Violet
VERITAS	Very Energetic Radiation Imaging Telescope Array System
VLP	Very Large Program
VLT	Very Large Telescope
WHIM	Warm Hot Intercluster Medium
WN	Nitrogen sequence subclass of Wolf-Rayet stars
WR	Wolf-Rayet
XCS	X-ray Cluster Survey
XDINS	X-ray Dim Isolated Neutron Stars
XEST	*XMM*-Newton Extended Survey of Taurus
XID	X-ray source IDenfication program
XMM	*XMM*-Newton
XMM-Newton	Newton X-ray Multi-Mirror Observatory
XMM-ESAS	*XMM* Extended Source Analysis Software
XRB	X-ray Binary
XSA	*XMM* Science Archive
YSO	Young Stellar Object

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