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XMM-Newton: 25 years and looking into the future

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Abstract

XMM-Newton stands as the European Space Agency (ESA)'s flagship mission for X-ray astronomy and a cornerstone in space science. Equipped with three X-ray telescopes and an optical-ultraviolet telescope, it is recognized as the most sensitive mission to cosmic X-rays. Celebrating 25 years of operation in December 2024, XMM-Newton has been pivotal, and is expected to continue being pivotal for many more years, in revolutionizing our understanding of dynamic and high-energy phenomena in the universe. This article explores selected scientific highlights showcasing how the Spanish community has contributed to groundbreaking results, from the early stages to present and future plans.

1 Introduction

XMM-Newton is the European Space Agency (ESA) space observatory for studying cosmic X-ray sources. Launched on 10th December 1999, at the time of writing this article, in October 2024, it continues producing first-class science. The spacecraft contains three X-ray and one optical telescope. The scientific instrumentation comprises three X-ray cameras, the European Photon Imaging Camera (EPIC), two X-ray spectrographs, the Reflection Grating Spectrometer (RGS), and the Optical Monitor (OM). Together, they provide long simultaneous observations of celestial sources from optical and ultraviolet wavelengths to X-rays in the 0.2 – 12 keV range. Observing time is made available to scientists around the world. Once per year, the call for observing proposals is open, and those submitted by the worldwide astronomical community are subject to peer review to select the best possible science.

X-ray emission can only occur under very extreme conditions not accessible from Earth, such as strong gravity, very high temperatures, or magnetic fields or a combination of these. Observing cosmic X-rays, therefore, provides unique tools for better understanding fundamental questions about the universe, including the physical laws that govern it. Do the same laws apply under conditions so considerably different from those on Earth? How does matter behave under such extremes? How did matter combine to form the great range of structures we observe today, from planets to galaxy clusters? How have these structures evolved from the Big Bang to the present day? And ultimately, what is our place in the universe?

With almost 25 years of X-ray astronomy with XMM-Newton, and its complementary NASA mission Chandra, the field of astronomy has experienced a revolution and prepared for many more years of discoveries. The aim of this paper is not to review the many discoveries already made. Nor is it intended to anticipate those expected in the future. This job is done by two Nature Review papers published after the first and second decades of XMM-Newton and Chandra science, [21] and [25] respectively. This paper summarizes a presentation to the Spanish Astronomical Society, SEA, in the year of the 25th launch anniversary of XMM-Newton and therefore intends to complement these two reviews with a brief look at the contributions of teams located in Spain working with XMM-Newton to better understand our universe.

2 XMM-Newton Science from Spain

2.1 Scope and Disclaimer

This section must necessarily begin with a disclaimer. As of mid-2024, the list of refereed publications that make direct use of XMM-Newton data or its main catalogues includes more than 200 papers with the first author's primary affiliation in Spain and more than 90 different scientists across 22 different institutions involved. This set of papers misses Spain-based co-authors who may have made significant contributions to the science presented. It may also miss first authors whose second or subsequent affiliation is a Spanish institute and, by definition, misses Spanish scientists who, at the time of writing their paper, had a main affiliation not based in Spain. Therefore, it is certain that important scientific contributions are unrepresented, and I apologize in advance for that. Feedback from readers will always be appreciated, and every effort will be made to correct mistakes.

To appreciate the revolution in astronomy brought about by XMM-Newton and Chandra, we examine how these two observatories – especially XMM-Newton – have collected X-rays from cosmic structures across the universe, spanning the nearest to the most distant, and from the smallest to the largest scales.

2.2 Tracking Stellar Evolution and their End Points

XMM-Newton observations have enabled the detection of powerful outflows from protostars, young stellar objects, or runaway stars. For instance, Javier López Santiago and collaborators detected non-thermal X-ray emission in HH 80 [10] and from a bow shock produced by a runaway star in AE Aurigae [11].

Massive stars are the primary drivers of the evolution not only of star clusters, but also of galaxies and of the universe itself. This is because they are responsible for re-ionization in the early universe through their intense UV radiation, star formation triggering, and interstellar enrichment through their powerful winds. Silvia Martínez-Núñez and her collaborators wrote an excellent review paper about stellar winds in isolated giant stars and supergiant high-mass X-ray binaries ([14]). Together with collaborators, she also successfully modeled the wind accretion onto the neutron star in the complex Vela X-1 system [13]. Graciela Sanjurjo-Ferrín and her collaborators identified inhomogeneous accretion flows in another High Mass X-ray Binary, HMXB, Cen X-3 [20].

The endpoints of stellar evolution have also been studied in X-rays. Margarita Herranz and Gloria Sala have made significant contributions to the study of Novae. In the early days of XMM-Newton, they observed V2487 Oph, which exploded in 1998, and found that the system had returned to its normal accretion regime only 2.7 years after the explosion. Jesús Toalá, Martín Guerrero, and their colleagues captured spectacular images of X-rays from gas heated by shocks produced by the Wolf-Rayet wind in the Thor's Helmet Nebula [23].

End points of more massive stars are neutron stars or black holes. Nanda Rea and her team have investigated the composition of neutron stars and demonstrated that the study of the X-ray emission of neutron stars is inherently multidisciplinary, ranging from general relativity (which describes the effects of gravity over large scales) to quantum mechanics (which describes particle-level phenomena) and spanning particle physics to the study of gravitational waves ([12]). Rea and her collaborators have also yielded intriguing results when studying magnetars, neutron stars powered by extremely high magnetic fields, and uncovering magnetar-like behaviors without a strong magnetic field ([19]).

2.3 Beyond our Galaxy

Deep and medium-deep surveys, combined with dedicated Active Galactic Nuclei, AGN, observations, have proven essential for identifying active supermassive black holes, SMBH, at galaxy centres thanks to their X-ray emission (for instance, see the work by Silvia Mateos and collaborators [15]), helping answer open questions in astrophysics and cosmology: What is the nature of sources like LINERs ([7])? What constitutes the cosmic X-ray background, is it composed of obscured AGN? How does matter behave in the extreme gravitational field around SMBHs, and how does this environment evolve over cosmic time ([3], [5])?

2.4 Expect the Unexpected

XMM-Newton was proposed and approved by ESA before the discovery of the first planet orbiting a Sun-like star. However, once in orbit, it has proven useful for assessing the habitability of exoplanets. A team at the Centro de Astrobiología publicly released a database of X-ray observations of stars with exoplanets, [22]; the UV photometry from the OM telescope on-board XMM-Newton has supported the characterization of exoplanet atmospheres [18], and the X-ray luminosity is used to further characterize some planets discovered by the CARMENES instrument in Calar Alto, [9].

One of the most spectacular and unexpected discoveries, published in 2019, revealed nine-hour X-ray quasi-periodic eruptions, QPE, from a low-mass black hole galactic nucleus [17]. Only a few months earlier, another team working in a Spanish institute had reported, for the first time, the observation "live" of a jet formation from within a galactic nucleus [16]. Both events are thought to be related to a star passing near enough to be disrupted by the strong gravity of a black hole at the center of a galaxy.

3 The Science Operations Centre

The discovery of quasi-periodic eruptions was announced at the decadal X-ray Astronomy conference in Bologna in 2019. One of the attendees was a young PhD student, R. Arcodia, who recognized the exceptional discovery and was then inspired to explore new methods for identifying similar events. A few years later, in 2021, he published a new discovery and wrote a "Behind the Paper article [1]. The process described by Arcodia beautifully illustrates the work done "behind the scenes" by the XMM-Newton Science Operations Centre (SOC), located at the ESA's European Space Astronomy Centre, near Madrid. Since the center's location is in Spain, this paper, which is about Spain's contribution to XMM-Newton discoveries, deserves a brief description of the SOC team and their work. The SOC organizes scientific conferences, provides public access to data via the XMM-Newton Science Archive (which helped Margherita Giustini confirm QPE from another source [6]), supports observing proposals, helps review panels in identifying the best to-be-done science, supports joint programmes (such as the follow-up of eROSITA that R. Arcodia proposed), implements target-of-opportunity observations, such as the one initiated following an eROSITA detection, and assists astronomers in analyzing XMM-Newton data, providing instrument performance monitoring, calibration, analysis software, and science products.

The science products generated at the SOC form the basis of the source catalogues produced by the Survey Science Centre [24], a consortium that includes the Instituto de Física de Cantabria. These catalogues are essential for data mining and "treasure hunting".

At the heart of the XMM-Newton ground segment, near Madrid, scientists and engineers work together to serve the community world wide.

4 Future

Currently, based on on-board consumables and projections of payload and spacecraft performance, XMM-Newton is estimated to be capable of continuing its science operations well into the 2030s. Funding is reviewed every three years; at present, it is fully approved through December 2026, with provisional support extending to the end of 2029.

We anticipate exciting new discoveries, many of which are likely to arise from observations complementing those of recently launched or soon-to-be-commissioned astronomical facilities. Multi-messenger astronomy is already driving compelling scientific insights, and XMM-Newton will continue to contribute significantly to these developments. We also foresee unexpected findings, just as groundbreaking discoveries have continued to emerge even 20 years after the mission's launch. The hope is that XMM-Newton will remain operational until the launch of ESAs future flagship X-ray observatory, newAthena, ensuring the continuation of the strong and active research community in the interim and a bright X-ray astronomy future.

Acknowledgments

I want to thank all those who have worked over the years at the XMM-Newton Science Operations Centre, forming an outstanding team. Their dedication and commitment beyond formal responsibilities have been essential to the missions success. I am also deeply grateful to the Project Scientists who have led the mission over the years; to the scientists who have served on time allocation committees or as members of the Users' Group; to the entire X-ray astronomical community who has made the best possible use of this facility; and to the team at the Mission Operations Centre in Darmstadt, Germany. It is often said that people are the greatest asset of any project, and though common, this sentiment remains deeply true. I am firmly convinced that, without the SOC team's dedication and engagement, the mission would have been very different. Finally, I would also like to thank the organizers of the 16th Scientific Meeting of the SEA and of the symposium about "Spanish participation on X-ray observatories" for their efforts and for their invitation to give a talk about XMM-Newton.

At the time of writing the final details of this document, we are learning of the dramatic consequences of the DANA in Valencia and other affected areas of Spain. Our thoughts are with all those impacted.

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