

An Overview of the XMM Observatory System

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The XMM system

XMM is a powerful end-to-end space observatory system that will enable astronomers around the world to obtain directly processed and calibrated scientific results based on their own observation proposals. This means that the XMM system has been designed to:

- process the observation requests, proposals and targets of opportunity
- plan and schedule the sequence of observations in an optimal manner, taking into account their duration, the orbital position and the satellite control and maintenance

- the Ariane-5 launcher system, the most powerful European launch vehicle, needed to inject the XMM satellite into a dedicated highly elliptical orbit (HEO) perfectly suited to the space observatory
- the ground segment, comprising all components necessary to control and communicate in real time with the XMM satellite, i.e. ground stations and associated communication systems, control centres and ground facilities.

Figure 1 shows the overall XMM mission architecture.

XMM is the largest scientific observatory developed by ESA and dedicated to exploring the Universe in the soft-X-ray portion of the electromagnetic spectrum. This article presents XMM as a complete system, composed by the space segment (the satellite and its launch vehicle) and the ground segment (all of ground-based infrastructure needed to control the satellite and gather the scientific data). The definition of the XMM orbit, which is also described, is a key element in meeting the primary mission objectives and satisfying the project programmatic requirements and constraints.

- carry out the observations by pointing the satellite precisely in the right direction
- gather, evaluate, process and calibrate the scientific data in a format suitable for the end user
- archive all mission products for the complete mission lifetime.

In order to serve those functions, the XMM observatory is composed of:

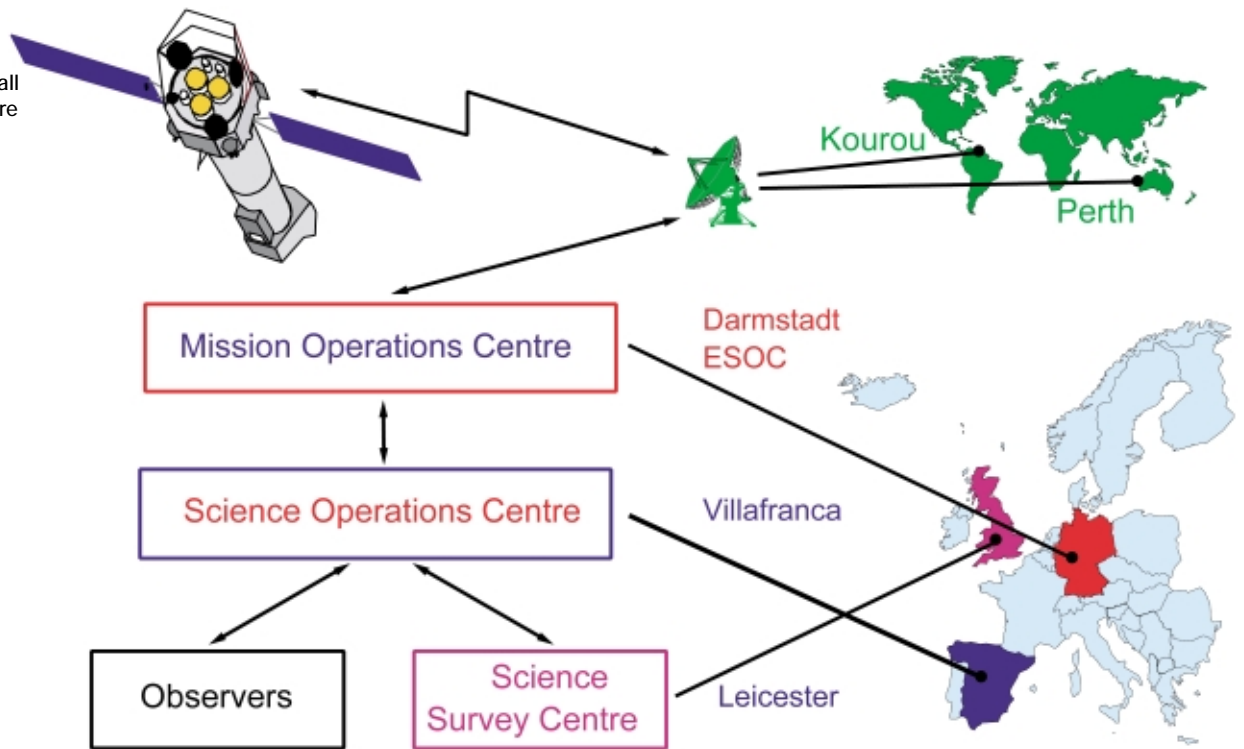
- the XMM satellite, a very powerful X-ray space telescope mainly characterised by its three mirror modules focusing the X-ray radiation towards the five scientific cameras located at the other extremity of the satellite at a focal distance of 7.50 m

The XMM satellite

Designed around the X-ray telescope system, the XMM satellite is configured modularly and is composed of four main elements:

- The Focal-Plane Assembly (FPA), consisting of the Focal-Plane Platform (FPP) carrying the focal-plane instruments, the European Photon and Imaging Camera (EPIC) and the Reflection Grating Spectrometer (RGS), and the data-handling and power distribution units for the cameras. The EPIC and RGS instruments are fitted with radiators, which cool the CCD detectors via cold fingers.
- The Telescope Tube (TT), maintaining the relative position between the FPA and the MSP. Due to its length of 6.80 m, the Telescope Tube is physically composed of two halves: the upper and lower tubes. The upper tube includes two reversible venting and outgassing doors (VOD), and supports the outgassing baffle (OGB).
- The Mirror Support Platform (MSP), consisting of the platform itself and carrying the three mirrors assemblies (Mirror Modules + entrance and exit baffles + doors + two RGS grating boxes), the Optical Monitor (OM) and the two star-trackers.

Figure 1. The overall mission architecture



- The Service Module (SVM), which carries the spacecraft subsystems and associated units providing the necessary resources to the satellite. Also attached to the SVM are the two solar-array wings, the Telescope Sun Shield (TSS) and the two S-band antennas mounted on their booms.

Figure 2 presents an exploded view of XMM, highlighting the spacecraft's modular configuration. Figure 3 indicates the physical implementation of the XMM telescopes, showing the X-ray mirror assemblies and the focal-plane cameras at the two ends of the Telescope Tube.

The Focal-Plane Assembly and the Service Module are designed as self-contained modules, so that they can be fully integrated and tested independently from each other. During the qualification and acceptance programmes, most environmental tests (vibration, thermal vacuum) have been conducted at satellite assembly level:

- the Lower Assembly, comprising the SVM, MSP and lower Telescope Tube
- the Upper Assembly, comprising the FPA and upper Telescope Tube.

The Service Module consists of a closed box, shaped around a hollow central cone, and comprises the lower and upper platforms as well as four side panels, on which all satellite bus units are installed.

The functions provided by the Service Module are:

- the primary and secondary structures to interface with the launcher adapter, to support the subsystem units, and to interface with and support the Mirror Support Platform and the Telescope Tube
- the thermal control to maintain the SVM units and equipment within specified temperature limits, and to provide a very strictly controlled thermal environment for the mirror assemblies via the Mirror Thermal Control Unit (MTCU)
- the Attitude and Orbit Control System (AOCS) for precise pointing/slewing in all operational modes, and for the performance of orbit acquisition/maintenance via the RCS propulsion system (Reaction Control System)
- the On-Board Data Handling (OBDH) for the decoding of ground telecommands, the distribution of ground or on-board commands, the sampling and formatting of telemetry data, and central on-board time distribution
- the Radio Frequency System (RFS), operating in S-band, ensuring communications (uplinking of telecommands, downlinking of telemetry) with the ground stations and providing a ranging mode for orbit determination
- the Electrical Power Subsystem (EPSS) for the generation and distribution of regulated power to all equipment via a 28 V main bus.

Figure 4 is an exploded view of the XMM Service Module, with its side panels open. Thanks to its particular shape, with a large central hole of 2.10 m diameter, the XMM bus can be used to accommodate a large variety of

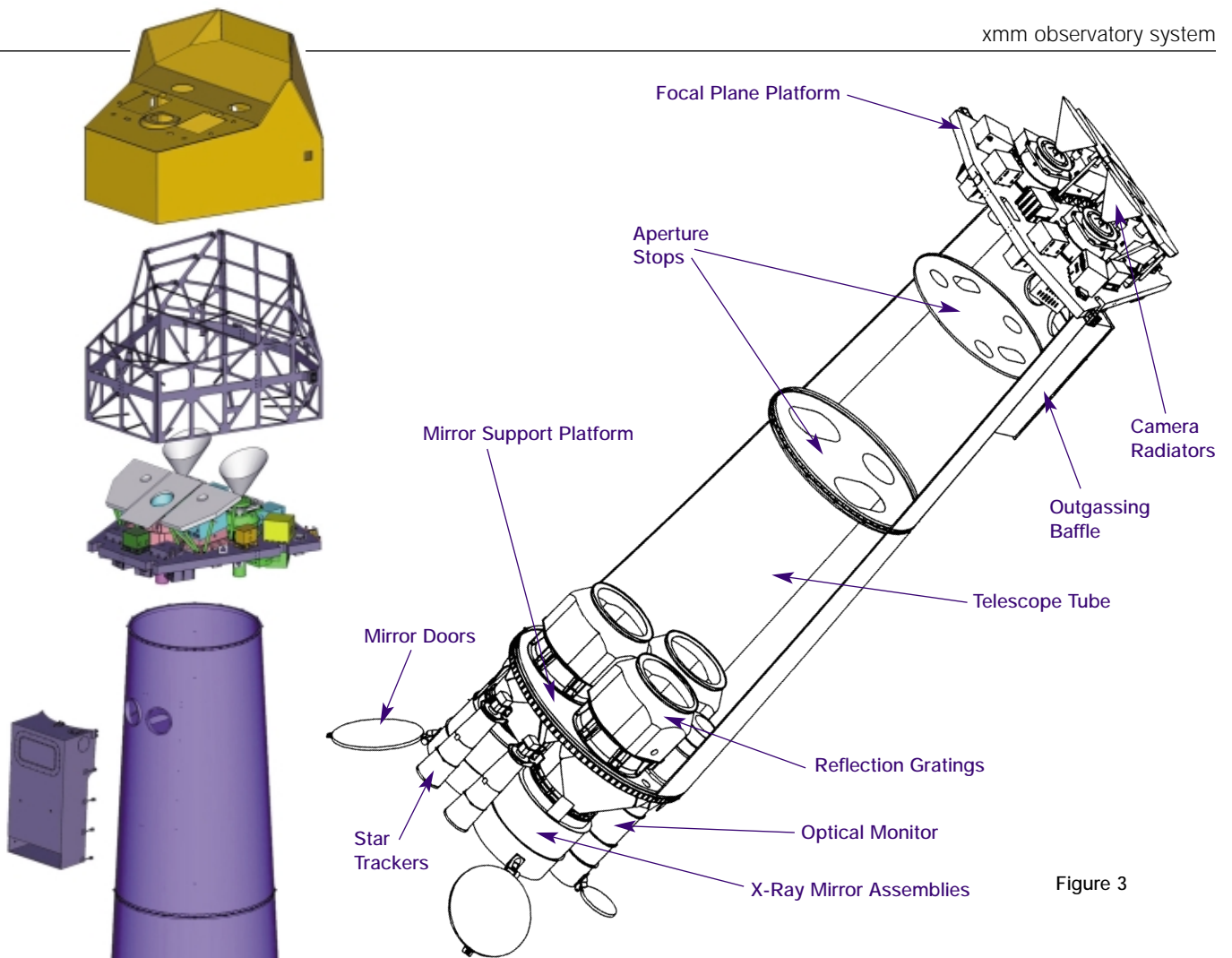


Figure 3

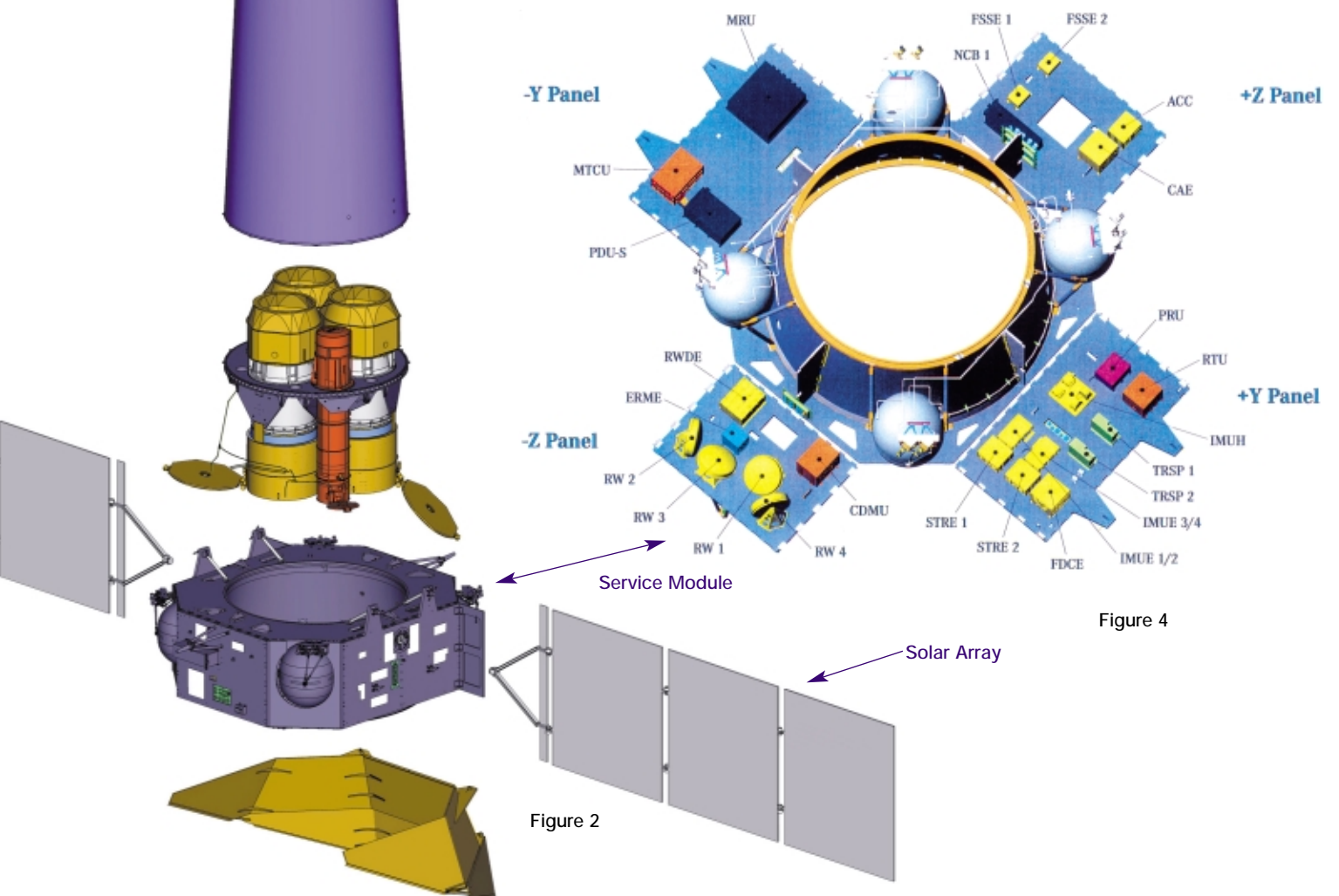


Figure 4

Figure 2

payloads. ESA's Integral satellite is reusing the complete XMM Service Module and the majority of its equipment.

Complete descriptions of the XMM subsystems are to be found in the articles dedicated to them in this ESA Bulletin.

The Ariane-5 launcher system

Throughout the XMM development phases, the launch vehicle has permanently been taken into account as a major component in the definition of the XMM system. The launch-vehicle capabilities have had a direct influence on all elements of the mission, such as:

- The achievable orbit, which in turn has an impact on the scientific return (percentage of the mission time dedicated to scientific observations), as well as the infrastructure needed on the ground (number and location of ground stations, communications networks).
- The performance (payload dimensions and mass) and features (ballistic phase; delayed injection) that drive the satellite design mainly in terms of: loads and structure; orbit-acquisition and reaction-control systems; and mass, propellant and power budgets.

Figure 5. Ariane-5



Initially – during the Phase-A studies – it was planned to launch XMM on an Ariane-44L vehicle. XMM has evolved rapidly since Phase-B, the design phase, to take advantage of the benefits of a launch by Europe's most powerful launcher, Ariane-5.

During Phase-C/D, the main development phase, the detailed designs for the satellite, the orbit and the ground segment have been traded-off and adjusted to take optimal advantage of Ariane-5's capabilities in terms of performance, trajectory, and qualification features. By now, therefore, the XMM satellite and its launcher form a truly tailored pair, characterised by:

- Full usage of the available volume under the Ariane-5 short fairing (the upper corners of the satellite have been 'tailored' to fit inside the conical part of the fairing).
- Full usage of the launcher's performance in terms of launch mass and target orbit.
- Optimised launch trajectory and injection orbit and sequence.

In December 1999, XMM will be injected by Ariane-5 into a Highly Elliptical Orbit (HEO) defined by the following orbital parameters:

- Perigee altitude 850 km
- Apogee altitude 114 000 km
- Inclination 40 deg
- Argument of perigee 55 deg
- Longitude of ascending node (measured from Kourou meridian) - 5.513 deg.

The injection of XMM will take place some 1610 sec (almost 27 min) after lift-off from ESA's launch base in Kourou, French Guiana, at a true anomaly angle of 42.25 deg. Figure 5 shows an earlier Ariane-5 launch.

The XMM orbit

As a major engineering activity, the selection of XMM's orbit has been the subject of numerous system studies and trade-offs to optimise the top-level XMM mission objectives, whilst taking into account all other components of the system. The following requirements were thereby derived:

- to maximise scientific observation time in an undisturbed environment
- to ensure an orbital lifetime of at least 10.25 years (3 months commissioning + 2 years nominal + 8 years extended lifetime)
- to maximise ground coverage during scientific observations (real-time mission, no on-board data storage)
- to make optimal use of the available launcher
- to respect the requirements applied to the satellite and its design limitations and constraints such as: maximum eclipse duration compatible with the satellite power

autonomy (battery capacity); separation and first orbit (satellite activation/checkout) in sunlight; solar aspect angles during perigee-raising manoeuvres at subsequent apogees.

The analysis of those requirements led to the selection of an orbit that is:

- highly elliptical, allowing maximum time above the radiation belts, i.e. higher than 40 000 km
- geosynchronous, with a period that is multiple of 24 hours, giving optimal coverage from dedicated ESA ground stations.

Further trade-offs between eclipse duration, visibility from ground stations and launch-window size led to the optimal definition of the remaining orbital parameters (inclination, argument of perigee, minimum altitude of perigee) and allowed the calculation of the complete launch-window scenario by combining the derived constraints. As an example, the perigee altitude will remain higher than 6000 km throughout the 10.25 year mission lifetime.

The resulting XMM launch window has the following specific characteristics:

- There are two seasonal windows per year: a summer and a winter window, each with a typical length of about 70 days.
- Each seasonal window is bounded by the orbital stability requirement at the opening (lower limit), and by the eclipse duration at the closing (upper limit).
- The daily window has a duration of between 30 and 60 minutes.

The operational XMM orbit (Fig. 6), reached about 8 days after lift-off, has the following initial parameters:

- Perigee altitude 7000 km
- Apogee altitude 114 000 km
- Inclination 40 deg
- Argument of perigee 55 deg
- RA of ascending node 240 deg
- Period 47.86 h.

These parameters will evolve as the mission progresses. As an example, the perigee altitude will vary between 7000 km and 22 000 km, while the apogee altitude will vary between 115 000 km and 100 000 km.

Such an orbit gives more than 44 hours of direct contact with the ground stations, of which some 40 hours will be dedicated to scientific observations above 40 000 km.

Another significant system-engineering activity has been to adequately use the system margins to increase flexibility at project-management level and to find optimal solutions in terms of technical performance, cost and schedule.

By continuous and rigorous control of the XMM satellite mass budget, it has been possible to preserve positive mass margins, which have mainly been exploited on two occasions:

- Installation of bigger batteries (24 Ah, instead of 18 Ah). This was induced by the non-availability of the delayed injection capability of the launcher, which in turn led to the selection of an orbit with an apogee in the

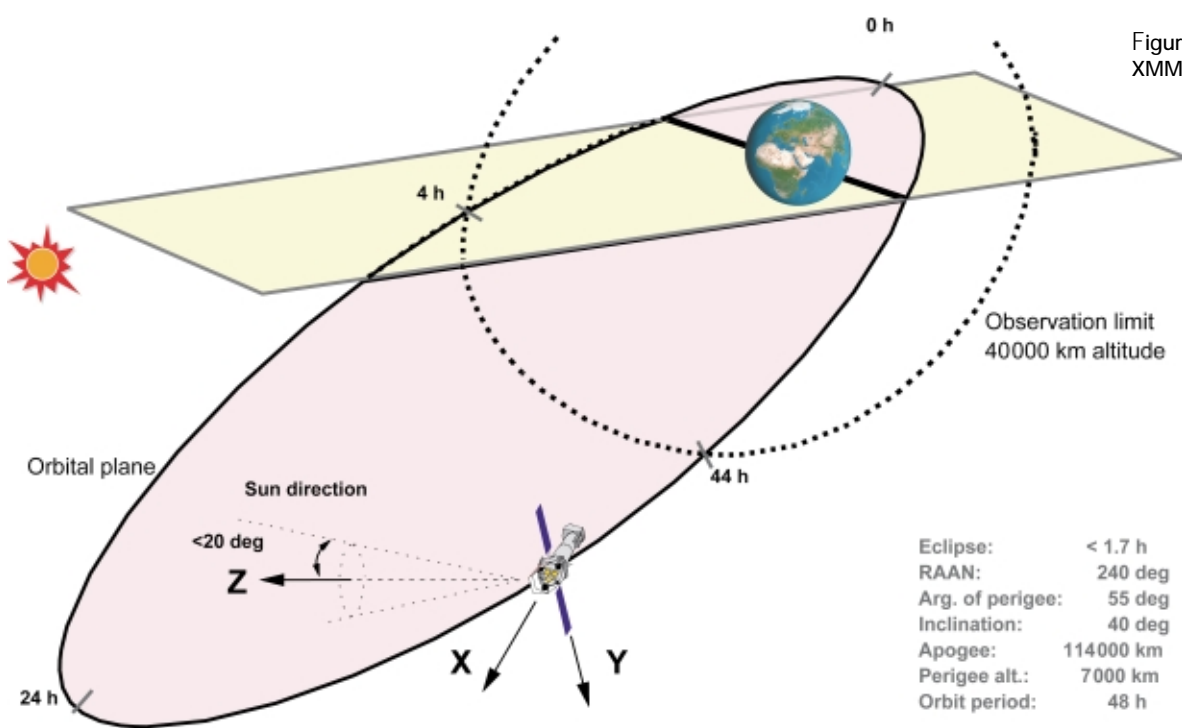


Figure 6. The operational XMM orbit

Southern Hemisphere, rather than in the Northern Hemisphere.

- Loading of additional propellant (some 52 kg) into the spacecraft's four tanks. Part of this extra fuel allowed the launch date for XMM to be advanced by about 1.5 months (from 21 January 2000, to 8 December 1999).

Dedicated manoeuvres have been defined in order to relax the above constraints for XMM orbit definition, namely:

- Sub-optimal attitude during the three Perigee Raising Manoeuvres (PRMs), thus relaxing the Solar Aspect Angle (SAA) requirements
- Raising of the initial altitude of the perigee above 7000 km, thereby getting around the orbital stability limit.
- Final acquisition of the operational orbit via an Apogee Correction Manoeuvre (ACM), to maintain the mandatory period of 48 h.

As a result of this interactive engineering process, four XMM reference orbits were baselined throughout the project development cycle.

The XMM ground segment

The ground segment consists of all of the infrastructure and systems needed on Earth to communicate with, monitor and control the XMM satellite in real time, as well as to gather, process and archive the scientific data harvested by the X-ray cameras on board.

The major components of the XMM ground segment are:

- The ground stations to track the satellite and communicate at S-band with the on-board transponders. During the operational scientific part of the mission, two ESA ground stations are used: Perth in Australia and Kourou (the 'Diane' station) in French Guiana. These stations were selected as offering near-complete coverage of the XMM orbit, with its apogee in the Southern-Hemisphere. During XMM's first 10 days in space – the so-called Launch and Early Orbit Phase (LEOP) – a third ESA station will be used in addition, namely Villafranca in Spain.
- The Mission Operations Centre (MOC) located at ESOC in Darmstadt (D). The MOC is responsible for monitoring and controlling the satellite: all telecommands will be sent from the MOC, and all telemetry will be received at the MOC.

The main elements of the Mission Operations Centre are:

- The XMM Mission Control System (XMCS), in charge of receiving, decoding and processing the telemetry, as well as assembling the telecommands to the satellite.
- The XMM Simulator (called the MOC-SIM), a software model of the satellite platform, used for pre-validation of commands and procedures.
- The Flight Dynamics System, in charge of orbit determination and attitude re-constitution. The FDS also defines all of the attitude and orbit control manoeuvres in an optimal way to maximise the duration of the scientific observations, whilst still respecting the XMM-imposed in-orbit constraints, such as avoidance of bright celestial bodies in the telescope field of view.

- The Science Operations Centre (SOC), located at Vilsba (Villafranca) in Spain. The SOC is responsible for preparing all scientific observations, and analysing and processing the corresponding scientific data. The main elements of the SOC are:

- The XMM Science Control System (XSCS) in charge of defining the planning of the scientific observations and monitoring their execution
- The XMM Simulator (called the SOC-SIM), a software model of the satellite experiments, used for validation of ground procedures, as well as validation of instrument on-board software
- The XMM Archive Management System (AMS), which stores and allows retrieval of all XMM data and associated products.

- The Science Survey Centre (SSC), located in Leicester (UK), in charge of pipeline processing the XMM observations data, as well as performing serendipitous sky surveys.

Conclusion

Besides the technical achievements realised during the complete project development cycle, XMM as a true system results from the synergy of a huge amount of expertise, knowledge, competence, motivation and sheer hard work. In total, more than 50 institutes or companies in some 15 countries have been involved in XMM.

