SPECTRUM-RG/eROSITA/LOBSTER

MISSION DEFINITION DOCUMENT

Roscosmos
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Max-Planck-Institute for extraterrestrial Physics, MPE, Munich, Germany
University of Leicester, Space Research Center, LU, Leicester, United Kingdom

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1. MISSION OVERVIEW

The baseline configuration of the new SRG mission was defined to be as following:

- Soyus-2 launch in the 2009-2010 timeframe from Kourou into a 600 km equatorial (<4^o) orbit, with a launch from Baikonur into a 29^o orbit as a fallback;
- Medium class spacecraft would be perfectly suitable for the mission, such as Yamal, which has been extensively operated in space, or Navigator;
- Wolter-telescopes **eROSITA** (**e**xtended **RO**entgen **S**urvey with an **I**maging **T**elescope **A**rray, MPE, Germany), wide field X-ray monitor **Lobster** (LU, UK), and coded-mask telescopes **ART** (IKI, Russia) were defined as core instruments to be mounted on the SRG platform.

The mission will conduct the first all-sky survey with an imaging telescope in the 2-12 keV band to discover the hidden population of several hundred thousand obscured supermassive black holes and the first all-sky imaging X-ray time variability survey. In addition to the all-sky surveys it is foreseen to observe dedicated sky regions with high sensitivity to detect ten thousands of clusters of galaxies and thereafter to do follow-up pointed observations of selected sources, in order to investigate the nature of Dark Matter and Dark Energy. The proposed orbit provides an order of magnitude lower particle background than those of Chandra and XMM-Newton, which will allow the detailed study of low-surface-brightness diffuse objects.

Both eROSITA and Lobster were previously studied and endorsed by ESA for the International Space Station. Their accommodation on a dedicated free flyer would provide significantly improved scientific output.

The eROSITA telescopes are based on the existing design launched on the (unfortunately failed) ABRIXAS mission and flight-ready detectors have been fabricated, which guarantees the high sensitivity required for the broad band all-sky survey. In order to optimise eROSITA for the additional science goal of the Dark Energy study, it is highly desirable to increase the grasp and improve the angular resolution of the X-ray telescopes. The group asked MPE to undertake feasibility studies for such improvements. The improved capabilities would respond to scientific developments of the last years; they e.g. match well the goals set out in the recent call for ideas on Dark Energy observations.

For Lobster, for which a detailed ESA Phase-A study has been successfully completed, it may be possible to increase the focal length of the micropore optics, thus improving the high-energy response.

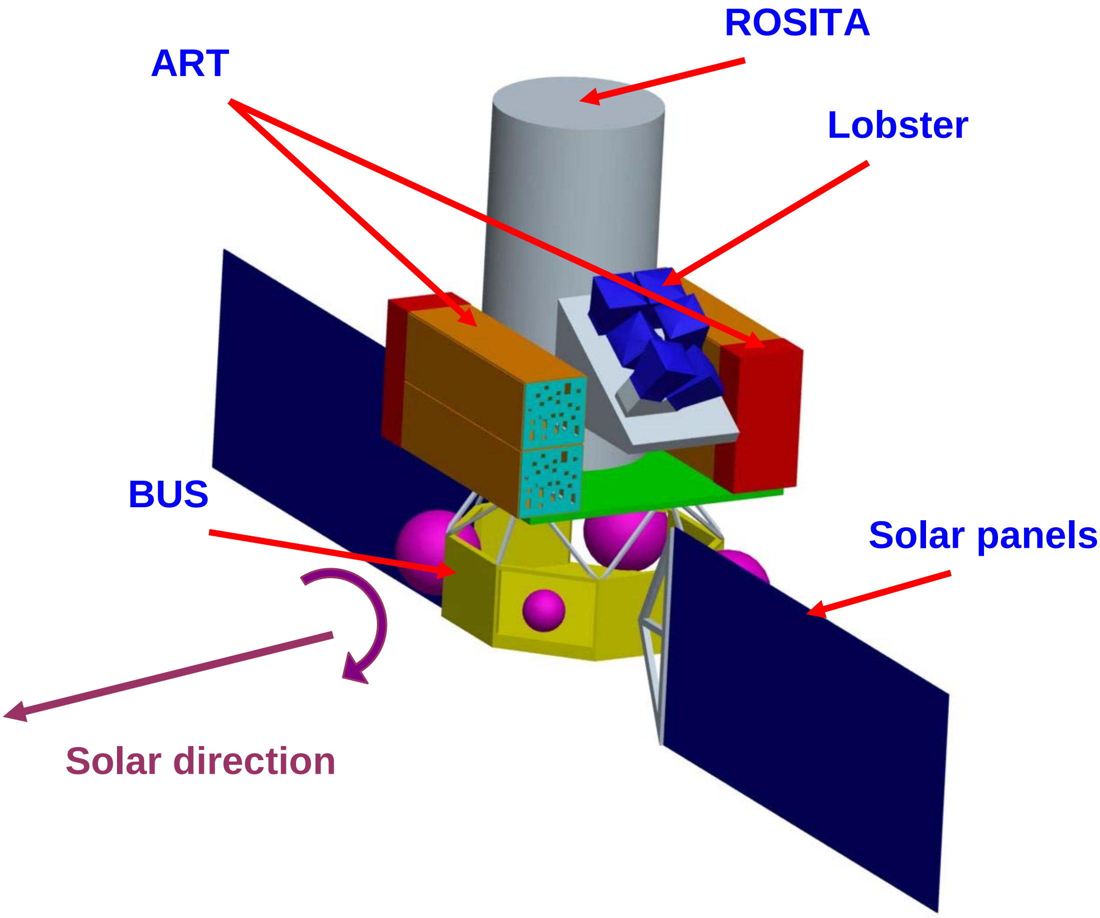
The new SRG mission would thus be a highly significant scientific and technological step beyond Chandra/XMM-Newton and would provide important and timely inputs for the next generation of giant X-ray observatories like XEUS/Con-X planned for the 2015-2025 horizon. A timely launch of SRG in the 2009-2010 period will help to sustain the high levels of technological and scientific expertise in European and Russian astronomy, and supply both communities with large bodies of high-quality data.

The following contributions by the different partners will be sought:

- Provision of the Soyus-2/Fregat launch vehicle by Roscosmos;
- Provision of a space tested platform by Roscosmos;
- Provision of the eROSITA instrument by the German-led consortium;

- Provision of the Lobster instrument by the UK-led consortium;
- Provision of the ART instrument and Gamma-Ray Burst detector by Roscosmos (IKI-led consortium);
- Contribution by ESA to the Kourou launch operations;
- Contribution by ESA to the telemetry system;
- Contribution by ESA to the ground station support.

2. SCIENTIFIC PAYLOAD



Scientific payload:

- eROSITA (MPE, Germany), Wolter-telescopes, 7 mirror systems, size of individual ROSITA-Telescopes – 35 cm diameter, energy range 0.2 - 12.0 keV, PSF ~20″ (FOV averaged) and ~15″ on axis, energy resolution 130 eV at 6 keV, effective area 2500 cm^2, a grasp of ~700 cm^2 deg^2 at 1 keV, mass 600 kg, power consumption 95 W, dimensions ∅1.3×2.6 meter;
- Lobster (LU, UK), wide field x-ray monitor, 6 modules, energy range 0.1 - 4.0 keV (TBD), angular resolution 4′ (FWHM), energy resolution ΔE/E ~20%, a grasp of ~10^4 cm^2 deg^2 at 1 keV, ~0.15 mCrab daily sensitivity, FOV 22.5°×162°, mass 120 kg, power consumption – 144 W, dimensions 1223×1168×845 mm;

- ART – Astronomical Roentgen Telescopes (IKI, Russia), imaging coded mask telescopes, consist of 2 telescopes (ART-X) for 3-30 keV energy range and 2 telescopes (ART-HX) for 20-120 keV energy range, FOV of each telescope 10°×10° (TBD), angular resolution ≤3′ (TBD) (ART-X) and ≤9′ (TBD) (ART-HX), detector effective area ~10^3 cm^2 (each), energy resolution 1.2 keV at 6 keV (ART-X), 3 keV at 60 keV (ART-HX). Two units with mass – 150 kg (each) and dimensions – 2.0×0.5×1.0 meter (each), power consumption – 160 W (TBD);
- GRB – Gamma-Ray Burst detector (IKI, Russia), TBD, mass 50 kg, power consumption – 50 W;
- BIUS – on-board computer (IKI, Russia), mass 10 kg, power consumption 10 W, dimension (TBD).

PL mass – 1250 kg (130 kg margin).

PL power consumption – 600 W (100 W margin).

3. SCIENTIFIC OBJECTIVES

3.1 eROSITA

3.1.1 Science

X-rays are a powerful diagnostic tool to study the physical universe, because the strongest gravitational potentials (clusters, black holes) heat up matter to X-ray temperature and a significant fraction of the baryons in the Universe is in the form of hot gas which can only be observed in X-rays. X-rays can penetrate gas and dust which obscure significant portions of galaxies. Relativistic effects and the extreme physics of the nucleonic equation of state can be diagnosed in the X-ray regime. The K-shell transitions of almost all chemical elements occur in the X-ray regime, which thus allows the study of the creation of the elements over cosmic time. Wide field deep X-ray surveys are dominated by active galactic nuclei, diffuse emission in clusters of galaxies with some contribution from galactic stars.

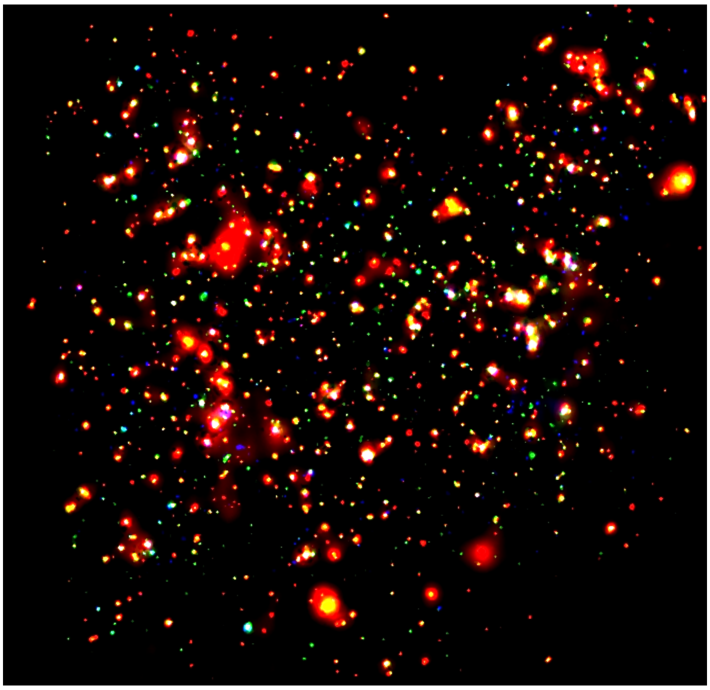


Figure 3.1.1: XMM-Newton Survey of the COSMOS field. The solid angle of 2°×2° and sensitivity make this the deepest wide field X-ray survey ever performed. Point sources (AGN) and extended emission (clusters of galaxies) can be readily distinguished. The surveys planned with eROSITA are expected to yield a similar composition over huge solid angles on the sky.

3.1.1.1 The quest for Dark Energy

The nature of the mysterious Dark Energy that is driving the Universe apart is one of the most exciting questions facing astronomy and physics today. It may be the vacuum energy providing the Cosmological Constant in Einstein's theory of General Relativity, or it may be a time-varying energy field. The solution could require a fundamental revolution in physics. The discovery of Dark Energy has come from three complementary techniques: observations of distant supernovae, the microwave background, and clusters of galaxies. Together these leave no doubt that only 4% of the Universe is made up of baryons, and the majority is Dark Energy

(73%) and Dark Matter (23%), which govern the structure and evolution of the Universe on the largest scales. Clusters of Galaxies are the largest collapsed objects in the Universe. Their formation and evolution is dominated by gravity, i.e. Dark Matter, while their large scale distribution and number density depends on the geometry of the Universe, i.e. Dark Energy. In addition to the constraints on the structure and mass content of the Universe, X-ray observations of clusters provide information on the rate of expansion of the Universe, the fraction of mass in visible matter and the amplitude of primordial fluctuations. The amount and nature of dark energy (DE) can be tightly constrained by measuring the spatial correlation features and evolution of a sample of about 50000 galaxy clusters over the redshift range $0<z<1.5$. Such an X-ray survey will discover all collapsed structures with mass above $3.5\times10^{14}\ h^{-1}M_{\odot}$ at redshifts $z<2$. Above this mass threshold the tight correlations between X-ray observables and mass allow direct interpretation of the data. DE affects both the abundance and the spatial distribution of galaxy clusters. Measurements of the number density $d^2N/dMdz$ and the three–dimensional power spectrum P(k) of clusters are complementary (have different parameter degeneracies) to other DE probes, such as Type Ia SNe or CMB anisotropies, and precisely constrain cosmological parameters. In particular, a survey of 50000 clusters of galaxies will allow to measure the «baryonic wiggles» imprinted on the power spectrum of primordial fluctuations, which gives an independent measurement rod for precision cosmology.

3.1.1.2 The quest for Obscured Accretion

Most of the light created after the «dark ages» in the Universe comes from active centres of galaxies, emitted either by vigorous star formation processes or by prodigious supermassive black holes residing in the centre of almost every galaxy, swallowing stars and gas. It was only realized in recent years, that most of this energy output must be obscured in the galaxies behind thick veils of gas and dust. Only in ranges of the electromagnetic spectrum, where the light can penetrate these cocoons, i.e. at hard X-rays and in the Infrared, can these phenomena be studied. Deep surveys in the hard X-ray range with Chandra and XMM-Newton, in the mid-infrared with ISO and in the sub-mm with the SCUBA and MAMBO bolometers, together with population synthesis models, have shown that both the cosmic star forming rate and the black hole feeding rate were about two orders of magnitude higher in the early universe than today. The decline of this activity occurred at a surprisingly recent stage in cosmic history and is as yet not understood. In particular, deep X-ray surveys have shown, that lower-luminosity AGN (Seyfert galaxies) show a maximum in space density much later in cosmic time, compared to the powerful quasars. Also, there are indications that the fraction of obscured sources increases strongly with decreasing X-ray luminosity. The X-ray background has almost completely been resolved below 2 keV, but only about 50% have been resolved above 5 keV, even in the deepest Chandra and XMM-Newton surveys. Many hidden, but still very active black holes should therefore be lurking in rather nearby galaxies, waiting to be detected by a hard X-ray survey. A survey in the hard X-ray band was defined as one of the future priorities in the last «Decadal Survey» of the American National Academy of Sciences. This was also the goal of the ABRIXAS mission which unfortunately failed in 1999 due to a design error in the spacecraft power system. An imaging hard X-ray survey is still of high scientific interest and not yet planned by any other project.

The mission eROSITA will perform the first imaging all-sky survey in the medium energy X-ray range up to 10 keV with an unprecedented spectral and angular resolution. The main scientific goals are:

1) to detect systematically all obscured accreting Black Holes in nearby galaxies and many (>170000) new, distant active galactic nuclei in the hard band;

2) to detect the hot intergalactic medium of 50-100 thousand galaxy clusters and groups and hot gas in filaments between clusters to map out the large scale structure in the Universe and to find in particular the rare massive distant clusters of galaxies for the study of Dark Energy; and
3) to study in detail the physics of galactic X-ray source populations, like pre-main sequence stars, supernova remnants, and X-ray binaries.

Starting from the existing ABRIXAS mandrels, but adding another set of 27 shells on the outside, we can achieve a large factor (~6) increase of the effective area at 1 keV, while still maintaining the ABRIXAS effective area at 1 keV. Figure 3.1.2 shows the on-axis effective area of 7 eROSITA telescopes. The effective area at 1 keV of 7 eROSITA telescopes is about twice the effective area of one XMM-Newton telescope.

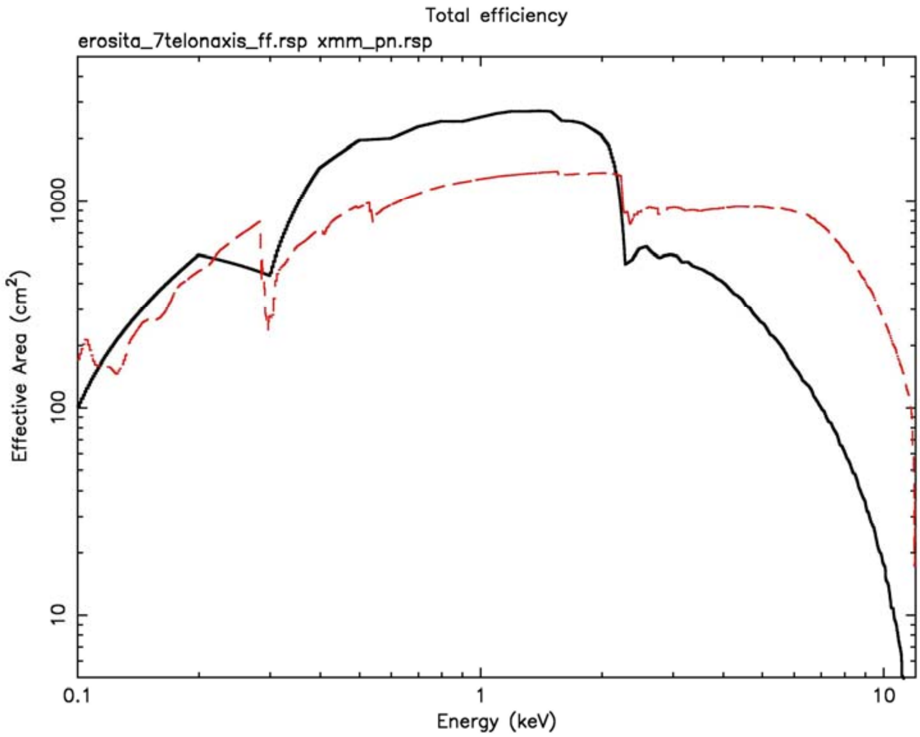


Figure 3.1.2: On-Axis effective area of 7 (thick black line) eROSITA telescopes with filter and CCD quantum efficiency included. The effective area is compared with that of the XMM-Newton pn-CCD camera (dashed red curve).

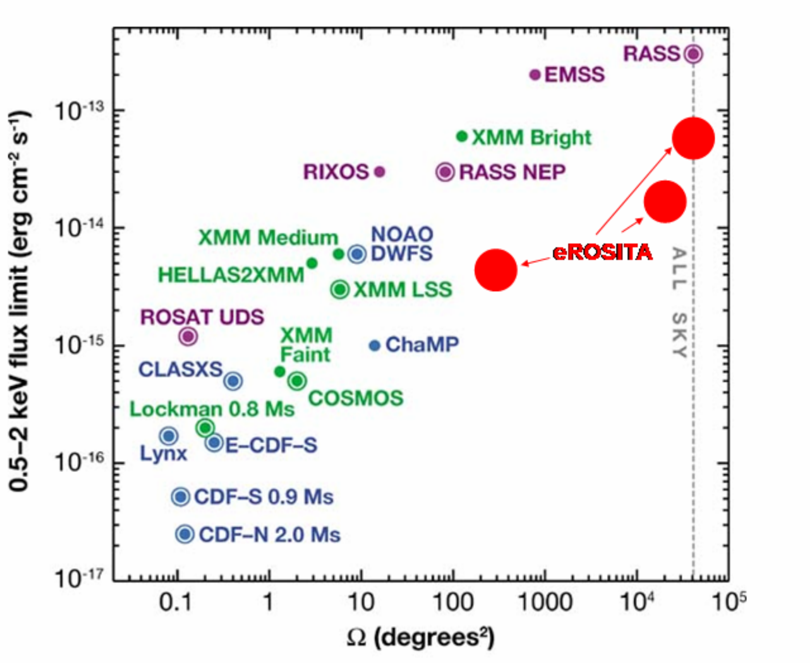
3.1.1.3 eROSITA Surveys

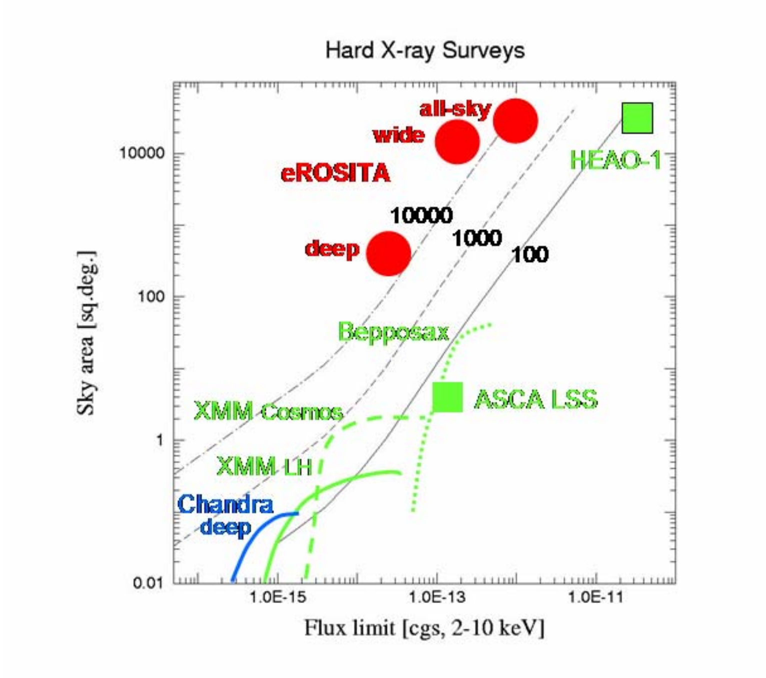
We envisage the following surveys for eROSITA: An all-sky survey with about 1 year integration time to discover obscured black holes and galactic sources, a deeper, high galactic latitude survey to discover 50-100 thousand clusters of galaxies and about 1 million AGN, covering 20000 deg^2 in 3 years observation time and a 200-300 deg^2 deep survey close to the south Galactic pole. Using the effective area curve and assuming an observation efficiency of 60%, we estimate the following survey sensitivities:

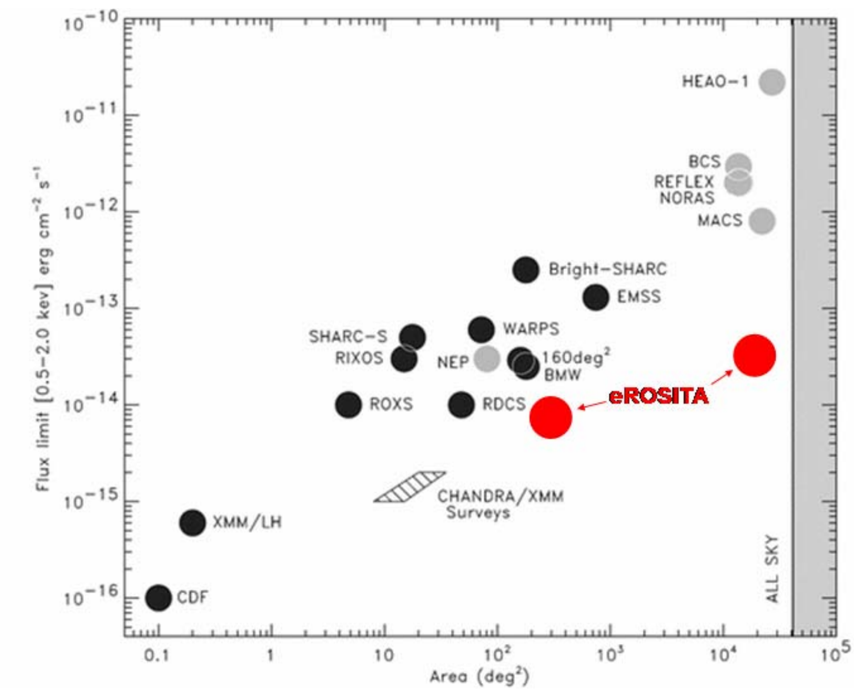
Summary of ROSITA Surveys:

Survey	All-Sky Survey	Wide Survey	Deep Survey
Solid Angle	42000	20000	200
Exposure time	1 yr	2.5 yrs	0.5 yrs
0.5-2 keV $S_{min\ AGN}$	5.7×10^{-14}	1.5×10^{-14}	4×10^{-15}
2-10 keV $S_{min\ AGN}$	1.0×10^{-12}	2.1×10^{-13}	2.4×10^{-14}
0.5-5 keV S_{min} Clusters	1.6×10^{-13}	3.3×10^{-14}	8×10^{-15}
0.5-2 keV AGN	240000	800000	740000
2-10 keV AGN	12600	84000	44000
Clusters	32000	72000	6500

The following figures compare these planned surveys with existing surveys.




Hard X-ray Surveys
Sky area [sq.deg.]
Flux limit [cgs, 2-10 keV]
eROSITA
all-sky
wide
deep
10000
1000
100
HEAO-1
Beppesax
ASCA LSS
XMM Cosmos
XMM LH
Chandra deep


Flux limit [0.5–2.0 kev] erg cm^{-2} s^{-1}
Area (deg^2)
HEAO−1
BCS
REFLEX
NORAS
MACS
Bright−SHARC
EMSS
WARPS
SHARC−S
RIXOS
NEP
160deg^2
BMW
eROSITA
ROXS
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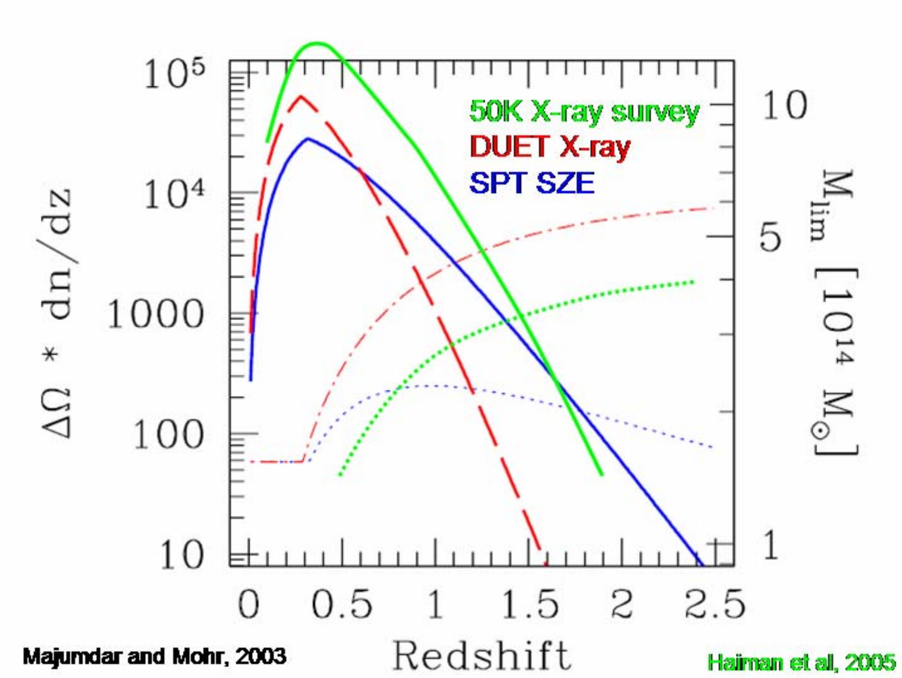
CHANDRA/XMM Surveys
XMM/LH
CDF
ALL SKY



3.1.2 Instrument

The eROSITA X-ray telescope consists of seven mirror modules (Wolter-I optics) each having its own CCD-detector in the focus. The basic structure of eROSITA is the optical bench, a tube which carries at its front the seven mirror modules and at its rear end the seven cameras. This concept was developed for the ABRIXAS mission, which failed shortly after launch in 1999. On ABRIXAS, the seven telescopes shared one large CCD camera; therefore the telescopes were tilted by about 7° with respect to each other. The eROSITA mirrors will have larger apertures, and their optical axes will be in parallel. Therefore the cameras are separated into individual housings, giving the instrument a seven fold redundancy (Fig. 3.1.3). The basic parameters of the instrument are given in table 3.1.1.

Table 3.1.1

number of mirror systems	7
number of nested mirror shells	54
angular resolution	<15″ (1 KeV)
energy range	0.5 – 10 keV
diameter of 1 mirror system	358 mm
focal length	1600 mm
material of mirror shells	nickel
mirror coating	gold
weight of 1 mirror system	<50 kg
detector principle	pn-CCD
size	19.2×19.2 mm^2
Pixel size	75 µm × 75 µm
read out speed	50 msec
energy resolution	130 eV at 6 keV
weight of each detector	~14 kg
Total weight of instrument	~600 kg
Size (diameter / length)	1.3 m / 2.6 m

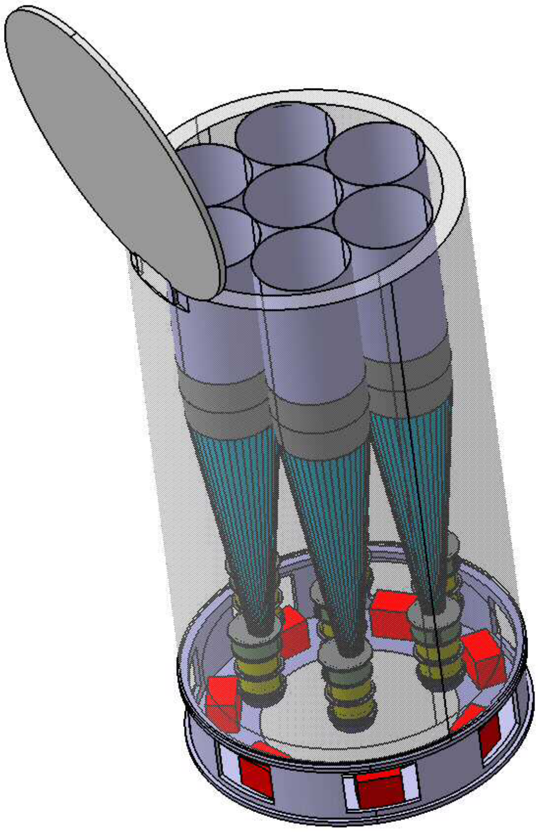


Fig. 3.1.3: schematic view of the eROSITA telescopes with Wolter-I optics + baffles (grey) and the 7 CCD-cameras including their (red) electronics boxes.

3.1.3 X-ray Optics

Although there are many possible configurations, only Wolter-I optics (paraboloid + hyperboloid) have got real importance in X-ray astronomy. The ABRIXAS mirrors also had this geometry. We will copy them for eROSITA with reducing the risk of a new development. In order to enhance the effective area at low energies, we will add 27 outer shells thereby doubling the diameter of the mirrors. We note that the (smaller) ABRIXAS mirrors are already qualified. Each of the mirror systems contains 54 nested shells. The focal length is 1600 mm. The on-axis resolution is 15" (half energy width, HEW). The geometry of the mirror systems is optimized in order to achieve maximum sensitivity between 0.5 and 10 keV.

The optical design of the mirror modules requires shells with a wall thickness between 0.2 and 0.4 mm and diameters between 76 and 358 mm. The length of the paraboloid-hyperboloid pairs is 300 mm. Such mirrors are fabricated using a nickel-galvanoplating process similar to the one used for XMM-Newton. In order to enhance the reflectivity, all mirrors are coated with gold.

Figure 3.1.4: The entrance apertures of the seven telescopes (ABRIXAS flight model).

Like on ABRIXAS the mirror systems still have the hexagonal geometry but are no longer tilted with respect to each other.

Baffl*e*: The baffles are tubes in front of each mirror system in order to suppress any direct stray light into the mirror system. They do not have any influence on the X-ray performance of the telescope. Their length is 600 mm.

Camera(s): eROSITA will carry seven individual CCD-detectors, each mounted in its own housing and equipped with its own electronics (in a separate box). The CCD size of 19.2×19.2 mm^2 corresponds to a field of view of 41.2′×41.2′. The CCDs have to be cooled down to -60°C for optimum operation and energy resolution.

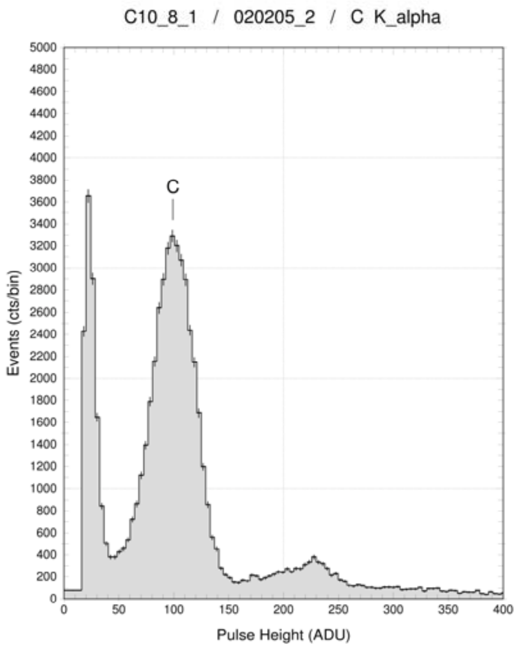


Figure 3.1.5: Clearly resolved C K_α peak, measured with the novel eROSITA CCD.

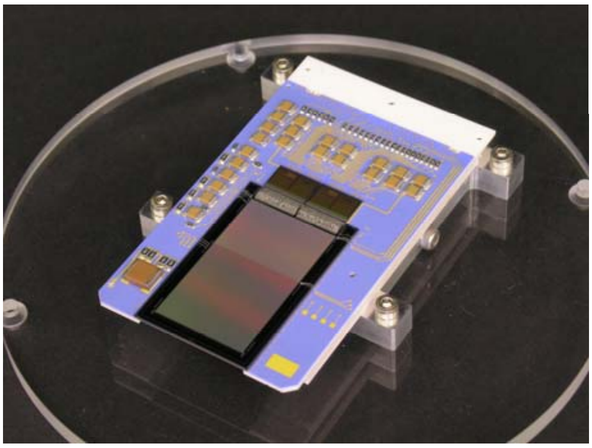


Figure 3.1.6: CCD module with a frame store pn-CCD, connected to 2 CAMEX-chips. Everything is mounted onto a ceramic carrier which, in turn, will be mounted to the cold plate (adapter seen).

Detector: During the last 18 years MPE has developed in the semiconductor laboratory the cameras for XMM-Newton and ABRIXAS based on the pn-CCD principle. The camera on XMM-Newton has been operated successfully since early 2000. The eROSITA CCD are already fabricated; they are an advanced version of the pn-CCD with smaller pixel sizes (75×75 µm^2

instead of 150×150 μm^2) and faster readout. The latter is achieved by combining the proven technology with a frame store area.

First tests with these novel devices show quite promising results: both the response at low energies and the CTE (charge transfer efficiency) could be dramatically improved with respect to the XMM-Newton camera (Figure 3.1.5). In order to suppress the internal background generated by fluorescent X-rays, the detectors will be equipped with graded shields, whose design is currently being developed. Events generated by minimum ionizing particles (MIPS) can be removed by the high energy response of the CCDs according to the mechanism developed for the XMM-Newton camera.

Cooling: We aim for passive cooling (by means of heat pipes and a radiator), temperature control is performed by means of heaters. The radiator concept has still to be worked out because it critically depends both on the configuration of all instruments as well as the mission scenario.

eROSITA Electronics: Figure 3.1.7 illustrates the internal system architecture of the electronics. Each of the seven detector modules has its own front-end electronics which comprises the processing of the primary event data and the control of the CCD. The latter («Sequencer») includes the proper timing for the parallel read out of the CCD via the multiplexer-chips («CAMEX») and the adjustment of all necessary voltages. The «Camera Electronics» provides the signal-filtering, the rejection of events induced by minimum ionizing particles (MIPS) and the recognition of «real» events, also when split among a group of adjacent pixels. A variety of tables (offset-map, noise-map etc. are calculated by the event processor and kept in memory. The CPU will be a signal processor (type: SMJ320C6203).

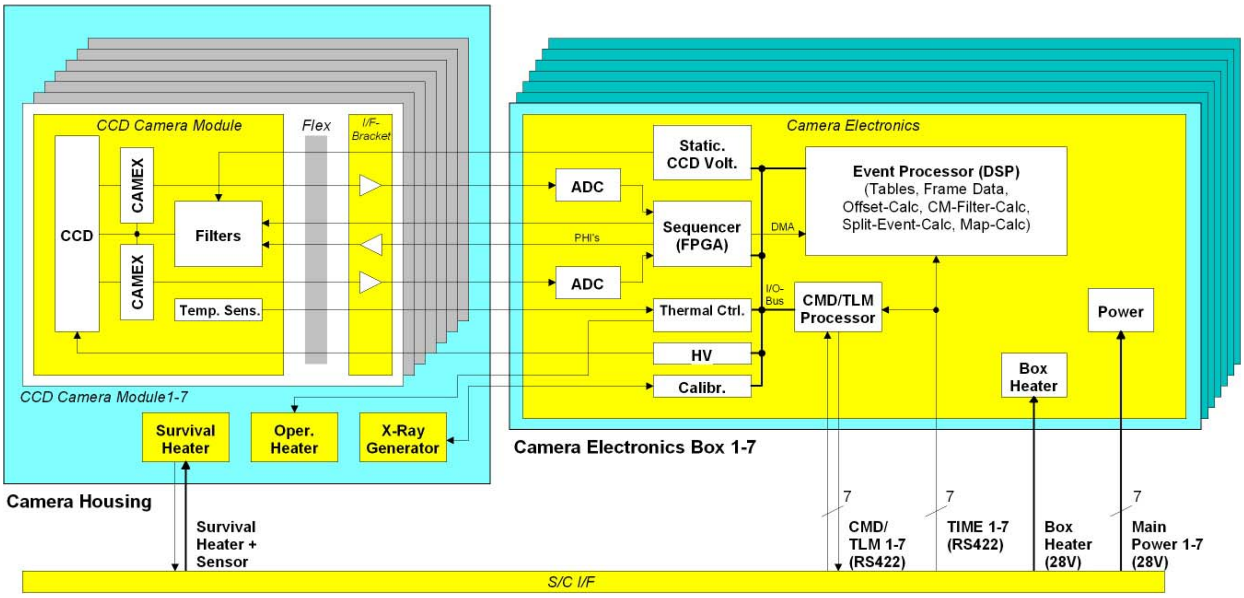


Figure 3.1.7: Architecture of the electronics

The «Control Unit» is the central unit providing all interfaces to the camera head electronics, collecting all information from the other units (HK, event data) as well as the commanding of these units. eROSITA interfaces to the spacecraft via 7 individual lines (data and power).

Star Sensor: eROSITA needs star-trackers information (for post-facto analysis only).

Frontdoor: A front cover door is probably needed for contamination reasons on ground and during launch. During the mission it will serve as sunshield.

3.2 Lobster

3.2.1 Science

The goal of Lobster, as for any ASM, is to approach the limit of «all the sky, all the time». The instrument consists of six «lobster eye» MCP telescopes, collectively providing wide angle (22.5°×162°) X-ray imaging in the 0.1-3.5 keV energy band, covering almost the entire X-ray sky once per 90 minute ISS orbit. For comparison, the instantaneous fields-of-view of XMM-Newton and Chandra are less than 1 degree diameter. All-sky coverage is provided in a straightforward way by the motion of the spacecraft, whose orbital period is synchronous with the period of rotation about its alpha axis. The goal of the mission is address the variability of the X-ray sky with order-of-magnitude better sensitivity (~0.15 mCrab in one day, 5σ) and angular resolution than any previous (or indeed feasible) non-imaging ASM. The scientific impact of Lobster-ISS spans all of astronomy - from studies of the X-ray emission of comets to stars and quasars, from regular X-ray binaries to erratic stellar transients (~4 000 per year at a flux level of 10^{-10} erg cm^{-2} s^{-1} and ~36 000 at 10^{-11} erg cm^{-2} s^{-1}), from the energetically gentle fluctuations in the hot outer regions of stars to the catastrophic events of supernovæ and the enigmatic gamma-ray bursts (GRBs - more than 1000 GRBs per year out to z ~4). Most importantly, about 400 bright AGN will be monitored at the 20% level on a daily basis for the duration of the mission, providing the first true census of X-ray time variability in active galaxies, and providing a definitive answer as to whether characteristic timescales exist in such sources. About 30 AGN are bright enough at any given time to allow daily monitoring with Lobster to ~5% accuracy, forming a «core sample» which is ideal for multi-wavelength monitoring campaigns. An important secondary function of Lobster data analysis, as with any X-ray ASM, will be to alert contemporary narrow-field-of-view X-ray observatories. The final Lobster catalogue will contain some ~250 000 sources. Fig. 3.2.1 shows the simulated Lobster images of a 10 × 10 sq.degree field at high galactic latitude, after elapsed times (clockwise from top left) of 1, 5, 25 and 125 days.

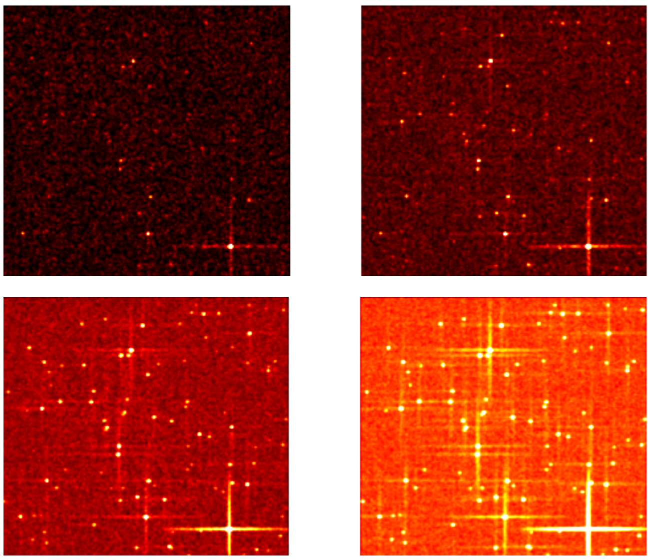


Figure 3.2.1. simulated Lobster images of a 10°×10° field at high galactic latitude, after elapsed times (clockwise from top left) of 1, 5, 25 and 125 days, based on data from the ROSAT all-sky catalogue.

3.2.2 Instrument

Lobster is an all-sky X-ray monitor comprising of six telescope modules, each consisting of approximately 60 Microchannel Plate (MCP) optics, tiled to produce the required field of view and geometrical area. Each telescope module has a Microwell array proportional counter detector in the focal plane.

The basic structure of Lobster is shown in figure 3.2.2. The basic parameters of the instrument are given in table 3.2.1. Note that both figure and table describe the original configuration of Lobster, which was a design for deployment on the International Space Station. In particular, no Gamma Ray Burst Monitor (GRBM) will be required in the SRG configuration since a GRBM is already specified in the overall mission design. The six telescope modules are aligned to produce a single, contiguous field of view of 165°×22°; the motion of the spacecraft platform sweeps this FOV around the sky once per orbit to build up the all-sky map. *Note that the 165° field width is a result of volume constraints in the ISS configuration and may be increased to 180° in the SRG design.* A number of smaller subsystems are provided to support the core instruments (star trackers, sun sensor and particle monitor). Mass and power requirements are provided in tables 3.2.2 and 3.2.3.

Table 3.2.1. Instrument characteristics in the original ISS configuration

number of telescope modules	6
number of MCP optic tiles	~60 per module
angular resolution (FWHM)	4′
Field of view (1 module)	27.5°×22°
energy range	0.1 – 4.0 keV
focal length	375 mm
Reflectivity coating	Gold or Iridium
detector principle	Microwell array
Size	20×20 cm^2
Pixelsize	200 μm diameter
read out speed	0.1 sec
energy resolution	~1.2 keV
Instrument mass	120 kg
Data volume	~5.6 Gbit/day

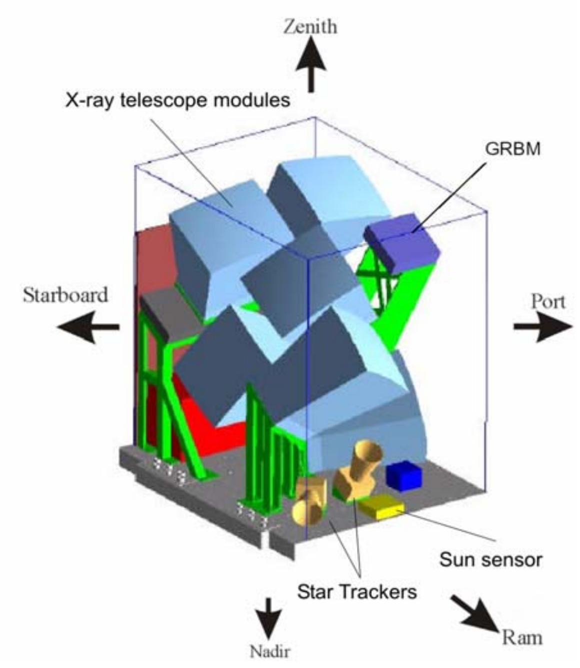


Fig. 3.2.2: Schematic view of the Lobster instrument in the original configuration designed for the ISS. GRBM will be omitted for the SRG mission, which carries its own monitor.

MCP X-ray optics: Lead-glass plates containing a square array of square cross-section holes or channels. The square sides are 40 mm long and the plate thickness is 1 mm. X-rays may be reflected at grazing incidence, from the inside surfaces of these channels; the reflectivity of these channel walls will be enhanced by the deposition of a nickel, gold or iridium coating. The plates, initially flat, are curved or «slumped» to a 0.75 m radius spherical figure. In this way X-rays from a distant object can be focused to a point. Each optic module is a 6×8 square array of MCP tiles and forms the top surface of a telescope module. Each MCP optic is aligned by (visible-light) optical means and fixed to a beryllium alloy optic module support structure using a quasi-isostatic design. This support structure is also spherical, with radius 0.75 m. The anticipated bonding method is UV curing epoxy adhesive. An MCP-to-MCP alignment variation of 1′ (RMS) is tolerable for the overall 4′ resolution goal of the instrument. The structure shall be constructed from materials which minimize thermal gradients (i.e. a quasi-isothermal structure) to minimize thermally induced bending of the structure.

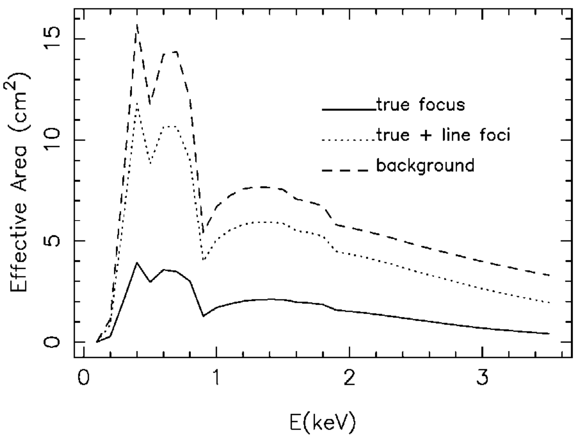


Figure 3.2.3: Effective area for Lobster, with Nickel reflectivity coating.

Microwell array detectors. These are a very robust and stable type of gas-filled proportional counter X-ray detector. Their history can be traced back to the very first Geiger counters used to detect ionizing radiation. The detector is a gas cell with an electric field applied across it. The cell has a thin window through which X-rays may enter. The well array is manufactured by laser-drilling holes in a flexible kapton substrate. There are three electrodes in the system, one on the detector window and one on either side of the kapton. X-ray photons cause ionization of the gas and the electric field causes the electrons produced to drift down towards the array. Within the wells there is a region of much higher field strength and acceleration sufficient to cause an electron avalanche by repeated, multiple ionizations. The result is a detectable signal collected on the electrodes at the top and bottom of the well. The electrodes are connected to pre-amps in such a way that the well in which the avalanche falls can be identified and, hence, the entry position of the detected photon localized. The voltages on the electrodes are set so that the output signal is proportional to the number of electron-ion pairs produced in the initial interaction between the X-ray photon and the gas. In this way an energy resolution of $\Delta E/E \sim 20\%$ is achieved. The detector works in the same way as a conventional multi-wire proportional counter except that the avalanches are localized in the wells. The advantage of electrodes deposited by printed circuit technology on the kapton is relative simplicity, stability and scalability.

Although they operate using the same principles as traditional wired proportional counters, the architecture of the microwell arrays is less susceptible to heavy ion damage. Since the high field region is very small (i.e. limited to the well depth, approx. 0.25 mm) the spark is contained within a limited area of the detector and, in the worst case, a damaged region will be limited to a single microwell.

The focal surface of each optic array is a 20×20 cm^2 section of a sphere. However, as the required angular resolution of the instrument is only 4′, some position error in the detectors is allowable. We can, therefore, approximate the focal surface by tiling it with four 10×10 cm^2 detectors, with planar well arrays, arranged in a pyramid. Each of these detectors has a window (and hence drift electrode) with four panes, also arranged in a pyramid. Hence, the spherical focal surface of each module is approximated, with sufficient accuracy, by sixteen flat window panes. The total window surface area per detector is 400 cm^2, or 2400 cm^2 for the complete instrument. The gas in the detectors will be pure Xe, or a Xe/CO_2 mixture, at a pressure of 1.5 bar with a conversion/drift depth of 3 mm. The detectors are protected from solar ingress into the field of view by: (a) an aluminum film across the MCP optic arrays, which rejects much of the sunlight, yet is thin enough to allow transmission of X-rays and (b) a single solar monitor coupled to each telescope which automatically cuts the detector HV just before solar ingress. The detailed nature of the solar disc, imaged by the MCPs onto the entrance windows of the detectors is unknown.

Lobster Electronics: Fig. 3.2.4 illustrates a possible configuration for the internal system architecture, defined for the original ISS configuration. All control of the six microwell detectors is via the Detector Interface Unit (DIU). Data from the environmental sensors (sun and particle detectors) is processed by dedicated electronics (which, in the case of the particle detector and sun sensor, are incorporated into the sensor unit), and passed to the DIU, which can shut down detector power selectively (i.e. a single detector at a time for solar avoidance) or globally (to protect against high particle backgrounds during ISS passages through the SAA). Signals from the GRB monitor (GRBM) and star trackers are not required as input to the telescope modules, but are processed in the DPU. High priority events are flagged for telemetry during the next available «telescience» downlink. Due to the need for rapid burst source localization, on-the-fly aspect reconstruction of images from the Lobster-ISS telescopes is required. Data from the star trackers are therefore passed to the DPU and used to deconvolve the motion of the ISS platform from the X-ray telescope images.

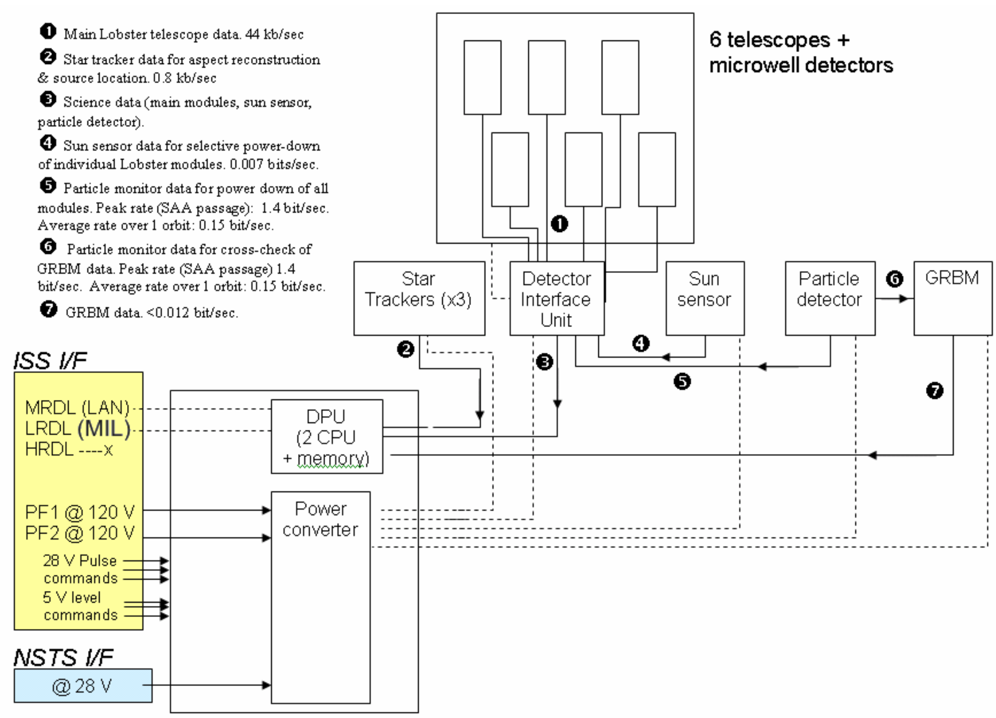


Figure 3.2.4: Internal system architecture

Star Tracker: Lobster uses star trackers to provide data for aspect reconstruction of X-ray telescope images. On-board aspect reconstruction of X-ray telescope data will be required when an event designated as «high priority» is detected, such that the location of the source can be rapidly identified and transmitted to ground via the continuously available «telescience» link.

Sun Sensor: Owing to the ISS orbit and Lobster-ISS configuration there will be periods of time when the sun shines into one, or more, of the Lobster telescope modules. At these times, there is a requirement to cut the detector HT to the appropriate detector(s). Failure to do so may result in detector breakdown and possible loss of (part of) a telescope module. ISS attitude at any one time is somewhat uncertain, so programming solar ingress times in advance will be imprecise. As a result a sun position sensor is necessary. The sensor must be positioned such that its field of sensitivity leads the Lobster telescope field of view to allow adequate warning of solar ingress into the field of view of the MCP optics.

Space qualified sun sensors are available, commercially, within Europe from Jena-Optronik GmbH in Germany and TNO/TPD in the Netherlands. Note that in addition to the Sun Sensor, a simple photodiode may be fitted to each module as a backup precaution.

Particle Monitor: A particle monitor is included as a precaution against the high particle flux the instrument will experience during transits of the SAA, at which time the detectors are protected by lowering the HT to zero as prolonged operation at high rates of particle events will cause deterioration of the detectors. Various off-the-shelf models are available, and the Lobster consortium also has the capability to build a custom made, low-cost proton counter (based, for example, on Channel Electron Multiplier technology). Timing information can also be used to initiate power-down procedures for SAA passages.

Digital Processor Unit: The DPU provides Lobster with the computational capability required to perform on-board aspect reconstruction and source location in the event that a «high priority» event is detected. It incorporates a mass storage device to store normal science data during the periods between downlinks.

Thermal Control Hardware: Thermal control is self standing (no thermal control from equipment external to the payload is required. Electrical heaters situated in the MCP optic arrays between the corners of adjacent MCPs provide heat while the arrays are in shadow, to reduce the thermal gradient across the optics. 40 W of heating power is reserved for this purpose. In addition, an estimated 10 W of additional power is included for thermal control of electronics subsystems. Current estimates suggest that radiators are not required in the thermal control subsystem.

Support Structure: The support structure holds the optics in the correct position, relative to the local zenith. This structure includes a wedge-shaped base and the six skeletal telescope modules. The focal plane detectors and MCP optics are mounted onto this structural element. The structure consists of a CFRP «carapace», with a wall thickness of 1.5 mm. The CFRP is a filament wound, 5/95 degrees symmetrical lay-up with T300 adhesive and epoxy resin. Invar bars maintain the correct optic-to-focal plane distance; these bars have 8 mm outside diameter square tube, 0.8 mm wall thickness, brazed to solid end fittings suitable for good thermal and structural connection (bonded at optics frame, bolted at focal plane). Note that although a 0/90 CFRP lay-up would be used in an ideal situation, this requires the use of very broad fabric, making it difficult to apply the resin); adopting 5/95 configuration allows use of a narrower strip which can be wound around the structure in a «spiral» form, and which is less challenging in terms of resin application.

Table 3.2.2. Lobster mass budget, based on the original ISS configuration of the instrument.

Item	Mass (kg)	Contin. (%)	Mass (inc. contin.)
Support Structure	45	10	49.5
Lobster eye optics	5	10	5.5
Focal plane detectors	19.5	10	21.4
Detector interface unit	1	30	1.3
DPU-PDU	16	35	21.6
Instrument harness	2	40	2.8
Instrument thermal control subsystem	6	35	8.1
Sun sensor	0.25	10	0.275
Particle detector	1	10	1.1
Star trackers	7.4	0	7.4
Total Instrument Mass			**119.0**

Table 3.2.3. Lobster power budget, based on the original ISS configuration of the instrument.

Unit	Power (W)	Contin. (%)	Power (inc. contin.)
Support Structure	0	10	0
Lobster eye optics	0	10	0
Focal plane detectors	14	10	15.4
Detector interface unit	1	30	1.3
DPU-PDU	36	35	48.6
Instrument harness	0	40	0
Instrument thermal control subsystem	50	35	67.5
Sun sensor	1	10	1.1
Particle detector	1.5	10	1.65
Star trackers[1]	9	0	9
Total Instrument Power			**144.55**

[1]*Only one star tracker will be powered at any given time.*

3.3 ART

3.3.1 Science

ART instrument is designed for the following tasks:

- Extend the energy coverage of the SRG observatory up to 120 keV;
- Search for heavily absorbed / Compton thick sources (both extragalactic and Galactic);
- Provide a necessary high energy extension of AGN spectra to allow detailed modeling of their spectra, including reflection component;
- Provide the information on the hard tails in the spectra of galaxy clusters to constrain the strength of the magnetic fields in the inter cluster medium;
- Study broad band spectra of Galactic objects (including binary systems, anomalous pulsars, supernova remnants);
- Study non-thermal component in the Galaxy diffuse emission.

3.3.2 Instrument

A set of four coded mask telescopes with two of them operating in 20-120 keV (ART-HX) and the other two in 3-30 keV energy range (ART-X). Field of view of each telescope is $10°\times10°$. Angular resolution is $\leq 3'$ for ART-X and $\leq 9'$ for ART-HX. Telescopes are binned in two pairs, each pair constituting a module of $1\times0.5\times2$ meter size and 150 kg weight. Each pair (module) includes one ART-X telescope and one ART-HX telescope with co-aligned axes. One pair is pointed along +Y axis, the other one at –Y, i.e. fields of view is perpendicular to the ROSITA field of view. This scheme will allow to:

- carry out all-sky surveys in 3-120 keV energy range synchronous to ROSITA telescope and Lobster wide-field monitor;
- perform observations of various sources in the Galactic plane during the deep surveys of the sky areas near galactic poles by ROSITA telescope.

It is planned to make use of the detector based on pixel array based on semiconductor CdZnTe crystals in ART-HX telescope (prototypes are ISRGI/Integral and BAT/SWIFT) and gas filled position sensitive counter in ART-X telescope (prototypes are ART-P/Granat, WFC/BeppoSAX, TTM/Mir-Kvant).

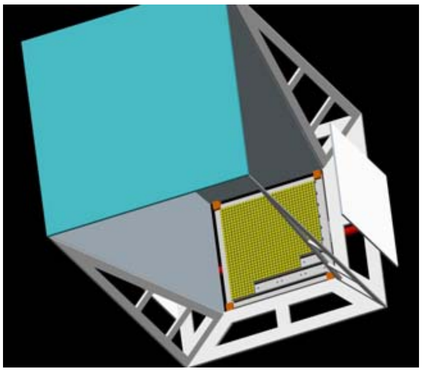
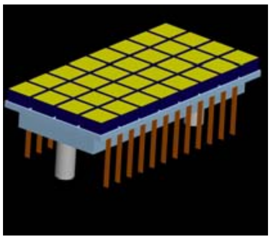
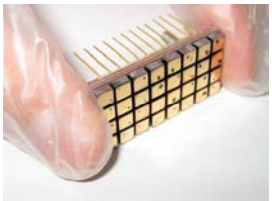


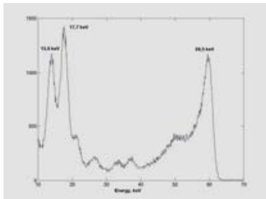
Fig. 3.3.2: ART-HX, CZT detector plane based on 128 MXDM (4096 CZT crystals) 300×300 mm



Layout of Multielement X-Ray Detection Module (MXDM)



Laboratory model of MXDM



Am^{241} spectrum with MXDM

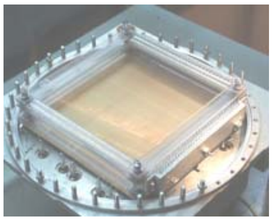
Energy range 20-120 keV

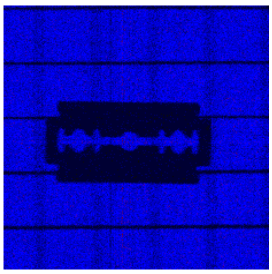
FOV 10°×10°

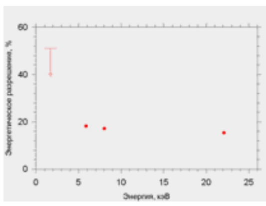
Angular resolution ≤9′

Energy resolution ≤3 keV at 60 keV

Fig. 3.3.1: ART-P/Granat







Energy range 3-30 keV

FOV 10°×10°

Angular resolution ≤3′

Energy resolution ≤1.2 keV at 6 keV

The area of each detector is about 10^3 cm^2.

3.4 GRB detector

The Gamma Ray Burst Monitor (GRBM) will provide timing, spectral and (rough) localization of GRB (and other classes of hard X-ray transients, such as Soft Gamma-Ray Repeaters) by covering the range 5-300 keV (TBC) and a field of view overlapping the LOBSTER FOV with the goal of:

- identify classical GRBs from other fast transients detected with LOBSTER, through timing coincidence and rough position localization (a few degrees TBD);
- provide wide band spectra of GRB to determine the peak energy, and low energy absorption column density. Study the broad band spectral evolution with time.

4. LAUNCH VEHICLE

Soyuz launch vehicle is proposed for the delivery of SRG project. For the launch from Kourou that will be Soyuz-ST, in case of launch from Baikonur – Soyuz-FG or Soyuz-2a/b.

Soyuz-FG rockets are the primary launch vehicles among Russian family of launchers. They are delivering into orbit the lion's share of spacecrafts in frameworks of Federal Space Program of RF and the program of international collaboration in space.

Russia is developing Soyuz-2 rocket intended for the delivery of autonomous spacecrafts into low, middle, high, sun-synchronous, geo-transfer and geostationary orbits, as well as for manned and cargo spacecrafts within the International Space Station program.

Development of Soyuz-2 launch vehicle is carried out in two steps: phase 1a and 1b. During the modification phase 1a new control and telemetry systems, as well as modified first and second stage engines will be used. At the phase 1b a new engine with increased total impulse will be installed on the third stage.

Nose-cones of the following diameters can be used with Soyuz-2 rocket: 2.7, 3.0, 3.3, 3.7 and 4.11 m. The 11.4 m long nose-cone of 4.11 m diameter is under construction.

In order to provide launches from Kourou cosmodrome the modified Soyuz-ST rocket adapted for use at Kourou is under development based on Soyuz-2a/b.

4.1 Soyuz LV main characteristics

Parameters	SOYUZ-FG	SOYUZ-2	
		phase A	phase B
Length (m)	42.5	44.3	44.3
Diameter (m)	10.3	10.3	10.3
Lift-off mass (t)	302	305	305
Number of stages	3		
Propellant	O_2+Kerosene		
1st stage engine	RD-107	RD-107	
2nd stage engine	RD-108	RD-108	
3rd stage engine	RD-0110	RD-0110	RD-0124
Avionics	analogue type on 2nd and 3rd stages	unified digital avionics on the 3rd stage	
Status	in operation	under development	
Performance from Baikonur* (kg)	7130**	7020***	8250***

* LEO, 200 km, 51.6°, ** Diameter of fairing 3.3 m, *** Diameter of fairing 3.7 m

4.2 FREGAT payload assist module

For final insertion of SRG SC into operational orbit Fregat Payload Assist Module will be used. It can be also used for insertion of commercial payload.

Characteristics:

Height (m)	1.5
Diameter (m)	3.35
Dry mass (kg)	970
Total mass with propellant (kg)	6635
Propellant	UDMH/N_2O_4
Main engine thrust (kN)	19.6
Re-ignition capability	up to 20
Lifetime (hours)	up to 48

5. SATELLITE BUS

Medium class spacecraft would be suitable for the mission, such as Yamal (RSC Energia), which has been operated in space, or Navigator (Lavochkin Association). Both platforms are three-axis stabilization.

5.1 *Yamal (RSC Energia)*

5.1.1 Status

In operation, Yamal-100 since 1999, Yamal-200 since 2003.

5.1.2 Main characteristics

Mass	Up to 2110 kg
Payload mass	Up to 1340 kg
Payload power consumption (including payload thermal system)	Up to 1200 W
Orientation accuracy	1.5′
Stabilization accuracy:	
Angular	30″
angular rate	10^{-4} °/s
Retargeting rate, °/min	
Nominal	0.05…0.1
maximum	0.4
Life time	Up to 10 years

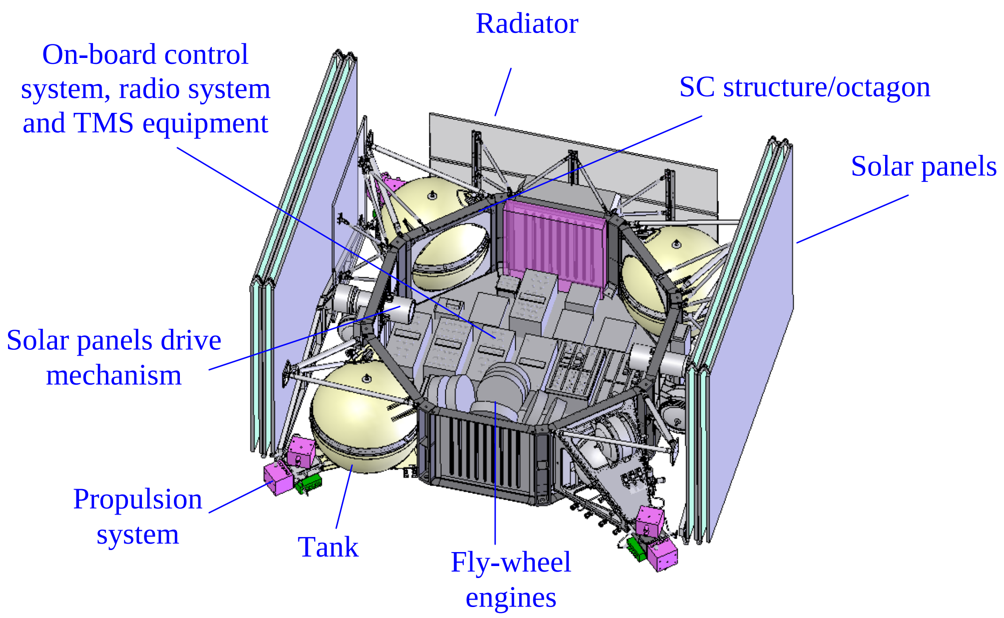
Generic Yamal - 100 Satellites Bus. Launch and operation since September 6, 1999.

5.2 Navigator (Lavochkin Association)

5.2.1 Status

Under development, first flight test is planned for 2007.

5.2.2 Main characteristics



SC dry mass	757 kg
Propellant (hydrazine, helium)	175 kg
Navigation and stabilization parameters:	
Pointing	2′
Stabilization	±2.5″
stabilization average velocity	0.36″/sec
maximal re-orientation velocity	0.25°/sec
Power supply system parameters:	
supply voltage	27 ± 1.35 V
Science equipment unit power	500 W
Lifetime	5 years

5.3 On-board radio complex

It is considered to install European on-board radio system similar in characteristics to the radio complex manufactured by SystemTechnik Taubenreuther STT, Germany, delivered to RSC Energia by Kayser Threde Company for accommodation at the Russian segment of International Space Station.

Transmitter:

Frequency range	2200 .. 2290 MHz
Antenna output transmitting power	+36 dBm (+2 dBm / - 0 dBm)
Transmitter modulation	BPSK 4 Mbps
Power consumption	≤ 30 W

Receiver:

Frequency range	2025 .. 2110 MHz
Frequency	2058 MHz
holding range	±100 kHz
Error bit rate	Less than 10^{-6} @ –105 dBm
Receiver demodulation	BPSK 256 kbps
Power consumption	≤ 3 W
Receiver sensitivity	-105 dBm min @ error bit rate = 10^{-6}

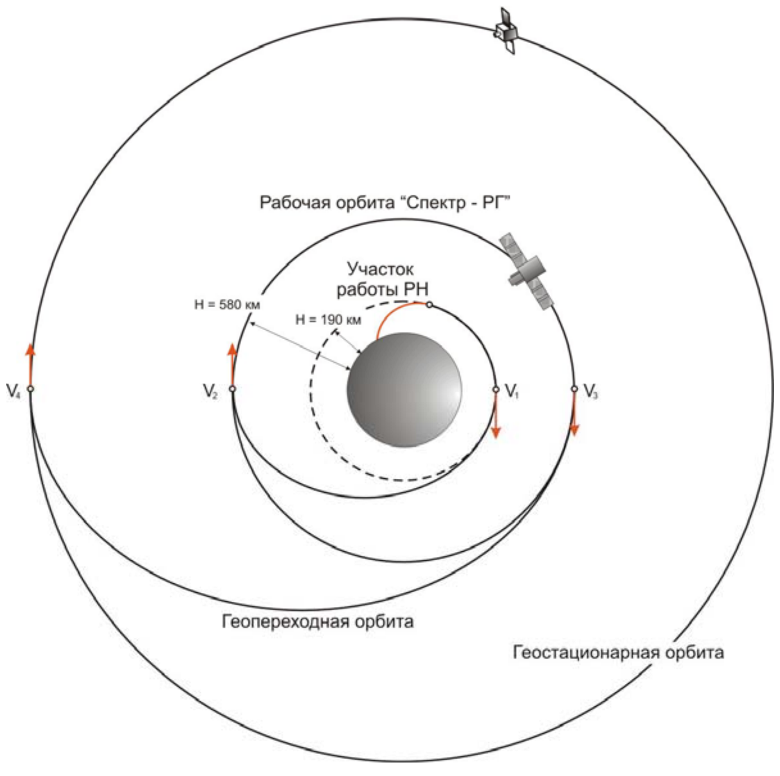
Antenna:

Polarization	circular / RHC
Covering	Hemispherical
Power	max. 40dBm CW
Impedance	50 Ω
Operational temperature	-40° … +120°C
Uplink frequency range	2025 … 2110 MHz
Downlink frequency range	2200 … 2290 MHz

6. MISSION MAIN PHASES

6.1 From Kourou

- SC insertion by Soyuz-2 LV from Kourou launch into 200 km circle orbit with 5 deg inclination;
- Space head module (SHM) separation from LV;
- Fregat PAM 1st ignition, characteristic velocity (V_1 = 110 m/sec) performance and insertion of SRG SC and additional PL into parking orbit;
- Fregat PAM 2nd ignition, characteristic velocity (V_2 = 107 m/sec) performance and insertion of SRG SC and additional PL into operational orbit;
- SRG SC separation from Fregat PAM;
- Additional PL two impulse insertion (V_3 = 2363 m/sec, V_4 = 1434 m/sec) by means of Fregat PAM into geostationary or high elliptical orbits, additional PL separation.



6.1.1 <u>Orbital parameters</u>

- height - 580 km;
- inclination ≤5°;
- orbital period 96 min;
- maximal shadow duration 35 min.

6.2 From Baikonur

- SC insertion by Soyuz-2 LV from Baikonur launch into 200 km circle orbit with 51.5 deg inclination;
- Space head module (SHM) separation from LV;
- Fregat PAM 1st and 2nd ignition, insertion of SRG SC into operational orbit;
- SRG SC separation from Fregat PAM;

6.2.1 Orbital parameters

- height - 600 km;
- inclination 29°;
- orbital period 96 min;
- maximal shadow duration 35 min.

SRG SC mass ≤2180 kg with inclination 29° (+130 kg with inclination 30°).

7. GROUND SEGMENT

Structure:

- SC Flight Control Center in Moscow (RSC Energia, Korolev or Lavochkin Association, Khimki, Russia);
- ESA Ground Station (15 m antenna), Kourou, French Guiana, 5.1° North latitude, 52.64° West longitude;
- Italian Ground Station (10 m antenna), Malindi, Kenya, 2.93° South latitude, 40.2° East longitude (subject of discussion with Italian Space Agency ASI).

Visibility intervals from Kourou or Malindi ground station 8 – 11 min.

There are other possibilities concerned to ground stations in the case of launching from Baikonur.

8. ADDITIONAL PL MASS

In the preferred case of the Kourou launch, a second satellite launch, including the possibility of a geostationary orbit, could be offered to supplement funding for the launch.

<table>
<tr><th>Orbit parameters</th><th>Additional PL mass, kg</th><th>Maximum dimension</th><th>Satellite applications</th></tr>
<tr><td>Circular orbit:
H = 580 km,
Inclination ≤5°</td><td>5600 (with Fregat PAM)</td><td rowspan="3">H = 1000 mm,
diameter = 1800 mm</td><td>Telecommunication, for Earth remote sensing, Technological experiments</td></tr>
<tr><td>Geostationary orbit</td><td>800</td><td>Telecommunication, Meteorological</td></tr>
<tr><td>Elliptical orbit:
H_π = 580 km,
H_α = 300000 km,
Inclination ≤5°</td><td>1200</td><td>Scientific</td></tr>
</table>