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DOCUMENT

LOFT Science Requirements Document

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Issue 2	**Revision** 6
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CHANGE LOG

Reason for change	Issue	Revision	Date
Clarifications to release to the industry study	1	3	2/2/2012
Updates during Mission Requirements review by LOFT Science Team	1	4	25 May 2012
Update provided to industry for CCN	1	5	08/09/2012
Update for payload consortium AO	1	6	19/09/2012
Update for Industry second phase activity and following the Payload AO Review cycle	1	7	7/2/2013
Requirements flow down and descope trade-offs were requested to be added after ICR	2	Draft	15/05/2013
Consolidated review prior to PRR	2	1	09/09/2013
Minor editorial changes	2	2	11/09/2013

CHANGE RECORD

Issue 1	**Revision** 2 and 3		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
First formal issue, compared to the draft version (0.8) there are many minor textual changes but the main substantial changes include: LAD • drop of collimator off-axis transparency as top level requirement (not a requirement but a trade-off between the instrument background and the sensitivity off-axis) • collimated FoV of LAD is now defined as less than instead of 1 and 0.5 (goal) degree • added a requirement for the response stability which, in combination with the flat top requirement, will avoid unintended (time dependent) modulations in the response • moved the calibration knowledge to the goal (essentially affects the time needed for calibration on module level) • some justifications of the requirements updated and reference to the top level goals added for the LAD requirements WFM	24 Jan 2012		

• defined FoV of WFM in steradian • defined broadcast requirement for trigger (and position) information (TBC) System • defined the visibility of the galactic centre (as the goal for increasing it had top priority) • defined times for core and observatory science with an accuracy of 100 ks • updated the ToO time to be consistent with the MRD			
Effective Area stability is the driving requirement, therefore suggest to ignore requirement SCI-LAD-R-11	2/2/2012	16	Table 5.1 and Section 5.1.4
"Full data" is replaced by " nominal binning" to emphasise the fact that in nominal binning the is already some compression of energy scale data	2/2/2012	19	5.1.7
Clarified that the broadcast triggers should occur with 30 seconds for the event time and within 2 minutes for an event position. For any reasons, 75% of trigger events should be broadcast within these time limits.	2/2/2012	25	5.2.5
Modify the LAD data rates	2/2/2012	26	5.3 - table of system requirements
Modified the definition of Galactic Centre visibility for range and equatorial coordinates, as well as defining better the constraint	2/2/2012	28	5.3.1
The energy resolution is allowed to degrade for some science goals, and this relaxes constraint on SAA and thermal performance (Note this requirement needs further justifying vs. the list of Science Top Level Goals to be relaxed)	25-05-2012	15	5.1.3
Update the background knowledge requirement. It is believed to be achievable with the use of a low fraction (1%) of the LAD effective area being blocked off.	25-05-2012	18	5.1.7
Added position information to the burst trigger data	25-05-2012	25	5.2.5
Added WFM relative sensitivity calibration requirement	25-05-2012	25	5.2.6
Provide justification for number of triggers to be downlinked	25-05-2012	26	5.2.7
Added explanatory note re. redundancy	25-05-2012	11, 19	5.1, 5.2
Modified summary of LAD requirements.	25-05-2012	12	Table 5.1
Upper energy range of detection set to 80keV	25-05-2012	14,22	5.1.2, 5.2.4
LAD Field of View - changed the requirement to a small range around 1 degree, whilst dropping the goal for a small field that otherwise complicates the stability requirement	25-05-2012	15	5.1.4
Added explicit requirement of response stability of LAD as function of frequency	25-05-2012	15	5.1.5
Added comment to the observing plan table accounting for background observations.	25-05-2012	32	6
Rev. 5/6 Changes			
Updated reference to MRD. Minor formatting throughout.	08/09/2012	Throughout	throughout
SCI-LAD-R-18 update to justification.	08/09/2012	20	5.1.8
Changed LBAS broadcast requirement from 65 to 75% of events in Table 5.2	08/09/2012	23	5.2
Justification included for SCI-WFM-G-19.	08/09/2012	28	5.2.8
Removed 1' RPE requirement in system requirements table 5.1, and included table caption for this table. Justification included for SCI-SYS-G-04.	08/09/2012	31	5.3.2

Deleted SCI-SYS-R-09 which is old RPE requirement.			
Updated reference to MRD and M3 proposal.	08/09/2012	8	3
Removed caption at top of LAD requirements table. Updated LAD requirements table (5-1) to reflect latest evolution of payload design.	08/09/2012	13	5.1
Included frequency-dependent TN in table 5-1 and included in references list.	08/09/2012	13	5.1
Changed SCI-LAD-R-06 to split between primary and extended energy ranges.	08/09/2012	16	5.1.3
Updated justification for SCI-LAD-G-08.	08/09/2012	17	5.1.4
Updated SCI-LAD-R-10 to include goal FoV.	08/09/2012	17	5.1.4
Added section 5.1.1 System requirements and SCI-LAD-R/G-23, which specify tolerable loss in effective area.	08/09/2012	14	5.1.1
Updated WFM requirements table 5-2.	08/09/2012	23	5.2
Updated SCI-WFM-R-06 to correct to primary and extended energy ranges.	08/09/2012	25	5.2.5
Added WFM system requirements section and redundancy requirement.	08/09/2012	24	5.2.1
Updated system requirements table and added caption	08/09/2012	29	5.3
Completed SCI-SYS-G-04.	08/09/2012	30	5.3.1
Updated justification for SCI-SYS-G-13.	08/09/2012	32	5.3.3
Added note to specify that mock observation plan has been made applicable to the MRD.	08/09/2012	34	6
Added preliminary Table 6-7 of observing time spent in different viewing directions.	08/09/2012	38	6
Modified "GOALS" to "OBJECTIVES"	10/09/2012	9	4
Added sub-section on measurement principles	10/09/2012	10	4.2
SCI-WFM-R-22 justification changed to make more readable	12/09/2012	23	5.2.1
Clarify requirement justifications WFM-R 18 and 19	12/09/2012	26	5.2.7
Removed requirement WFM-R-15. Poorly written and offers nothing additional to associated requirements #14 and #16	12/09/2012	25	5.2.6
Requirement added, SCI-SYS-R-18. Noting that QLA should support the decision making process to change observing plans as a result of TOOs or source properties not meeting observing criteria. Implied performance criteria is really driven by the planning and decision process and not the QLA per se.	12/09/2012	32	5.3.4
Redundancy requirement for LAD is not formally a science requirement and is explains in Appendix B	17/09/2012	14	5.1.1
Orbit requirement is not strictly a science requirement. It is driven by required minimisation and stability of background, and therefore recalled in Appendix B for traceability	17/09/2012	31	5.3.3
DATA rates are to be seen as an instrument/spacecraft design requirement. Only the minimum source flux to be telemetered without data loss should be the requirement from science. Requirements modified and/or moved to appendix	17/09	33	5.3.5
Modified FoR with energy resolution requirements. Based on telecon with consortium team, only some science objectives need the 260eV resolution and they are predictable targets where the greatest FoR is not thought to be required. Also made clear the GC visibility requirements are applicable to the extended FoR.	19/09/2012	17 31	5.1.4 5.3.1

Removed derived engineering requirements to appendices. These requirements are now held in the MRD	7/2/20013	Throughout	Throughout
Modification of effective area requirement to consider possible directions for relaxation (explanatory text)	7/2/2013	15	5.1.2
Issue 2 of the document has a large number of changes. Most of these are related to the report of the IPR in which a number of clarifications are requested. The most important one include: (not yet complete!) - updated introduction introducing also level 0, level 1 and level 2 requirements - updated objectives where the observatory science is one of the level 0 requirements (effectively this does not change the missions) - some reformulation of the level 1 requirements to clarify ambiguities (no substantial change) - addition of the level 2a, 2b and 2c requirements in the section on instruments and mission, and a clarification of the requirements'definition - clarified that the energy resolution requirements of the LAD correspond to 260 eV for 60% of the events and 200 eV for 40% of the events corresponding to 240 eV with no event selection - change in the requirement on the absolute time accuracy to 2 microsec for the LAD and the WFM - clarification that the required 10 m^2 area is a rounded number. In engineering terms the requirement is thus strictly > 9.5 m^2 (at other energies this is the same) and has now been clarified. The goal of 12 m^2 turned out to be not realistic can has therefore been reduced to 10.5 m^2. The area at low energy and high energy is given at a specified energy +/- 0.5 keV (the slope in the effective area curve is steep at the low energy) - updated the off-axis energy response for the LAD - specified the required deadtime knowledge of the LAD to be 2.8% - set the requirement of the background knowledge to 0.25% to enable the science goals for the Fe-line - slightly updated the WFM description (bullet wise) as this gives the reader some idea before getting into the detailed requirements - clarified text of net observatory time: all observing time including for the core science will be allocated through a peer review process and is open to the community - clarified the ToO requirement as this should not drive the ground segment - corrected SCI-SYS-R-06 indicating the GC visibility as being 3 ks. The original number was elapsed time - extended the observing plan showing also the required energy resolution per science goal and number of observed sources - added the magnetar to the target list (does not change the observing plan as this will be observed through collimator - Revised and clarified the Observing plan - added the probability to detect BHCT and AMXPs as function of mission duration and sky visibility - added an appendix with the main dependencies of	10/7/2013	all	2

the key requirements (area, mission duration, sky visibility) - added another appendix (B) specifying the dependencies in the instrument and mission requirements - added appendix C justifying the drop of some requirements - added appendix D justifying the require spectral resolution in some more detail - Provided a narrative definition for most of the requirements, particularly the 2a level			
Iss 2 Rev 2			
Goal increase 10% not 20% - consistent with evolution potential of spacecraft envelope	11/09/2013	18	SCI-LAD-G-01 -04
For consistency with MRD definitions, we need to specify not specifically performance for 2 anode events, but the overall AVERAGE performance. FWHM~$\sqrt{(40\%*(200eV)^2 + 60\%*(260eV)^2)}$= 240eV The 60%/40% split between events is a consequence of the instrument design and not an element of the science requirements. This leads to internal consistency with the case for 'degraded energy resolution' (SCI-LAD-R-22) which has been specified for an average over all detected events	11/09/2013	20	SCI-LAD-R-08
Field of view should be defined as a limit and not a range. Update the justification to explain the rationale	11/09/2013	21	SCI-LAD-R-10
Editorial explanation	11/09/2013	30	SCI-WFM-R-19
Editorial - 400eV is consistent with requirements and had not been copied across from the correctly Tech Note.	11/09/2013	52	A.3.2

Table of contents:

1 ACRONYMS

AGN	Active Galactic Nucleus
AMXP	Accreting millisecond X-ray pulsar
BH	Black Hole
BHCT	Black Hole Candidate Transient
EOS	Equation of State
FWHM	Full Width at Half Maximum
GR	General Relativity
HEW	Half Energy Width
ISM	Inter Stellar Medium
LAD	Large Area Detector
LMXB	Low Mass X-ray Binary
NS	Neutron Star
QCD	Quantum Chromodynamics
QPO	Quasi-Periodic Oscillation
SMBH	Super Massive Black Hole
TOO	Target of Opportunity
WFM	Wide Field Monitor

2 INTRODUCTION

This document records the scientific requirements for the Large Observatory for X-ray Timing (LOFT). These are the reference requirements through which the Mission Requirements Document will be derived and also the instrument specifications are deduced.

The document starts with the mission statement (also called level 0 requirements) and the minimum scientific success criteria. Next these goals are quantified in a number of sub-goals (level 1 requirements). These level 1 requirements translate into requirements for the two instruments, the mission and the observation plan (level 2 requirements). These requirements are split into different groupings: level 2a, 2b and 2c requirements:

Level 0: top level goals
Level 1: breakdown of top level goals in quantified sub-goals
Level 2a: instrument, mission and observation plan requirements needed to fulfil the top level goals
Level 2b: subsystem requirements which are directly inferred from the Level 2a requirements
Level 2c: instrument, mission and observation plan requirements that will not drive the mission design but will enhance the scientific return of the mission considerably

Although the level 2b and 2c could be omitted we have included them as they define rather well the type of mission needed to optimize the science (and, for example, level 2c requirements follow a science judgement and cannot be derived from the top level requirements).

The structure of the document is as follows: first the top level objectives and science requirements are given (levels 0 and 1, see section 4). Next the requirements for the two instruments are presented, including a detailed justification and specification of the requirements. In section 6 we provide system level requirements. These are, for a significant fraction, based on the observation plan given in section 7. Detailed description of dependencies in the requirements is presented in appendix A, showing that there is a safe margin in the key requirements with respect to achieving the science goals. In appendix B we provide an overview of the requirement flow down, in appendix C we provide some information about requirements which have been dropped and in appendix D we provide a detailed justification for the required energy resolution.

This version 2 of the science requirements document has relatively few substantial changes in the numbered requirements compared with the issue 1.6. It has however been restructured to meet the request from ESA to provide a more rigorous flow down of the requirements. Only the substantial changes are listed in the change log.

3 REFERENCES

[RD 1] LOFT: Large Observatory For X-ray Timing, M3 proposal.

[RD 2] Calibration accuracy of the dead-time, M. vd Klis. LOFT-LAD-TimePerf-20121126LOFT

[RD 3] LOFT Large Area Detector Response Stability, M. van der Klis et al. LOFT-LAD-RespStab-20120322. 22/03/2012, Issue 1.0

[RD 4] LOFT Observing Plan Document , LOFT_ObservingPlan_TN2_MA

[RD 5] LOFT Large Area Detector Background Models, R. Campana. LOFT Technical Note, LOFT-LAD-BkgMdl-20111130. 30/11/2011, Issue 1.0.

[RD 6] Radiation damage of the LOFT SDDs and its effects on the energy resolution, E. Del Monte et al. LOFT System Note, LOFT-SysN-NIEL-20121105. 05/11/2012, Issue 3.0.

[RD 7] LOFT System Note: Measurement of the Radiation Damage from soft protons on the Silicon Drift Detectors, E. Del Monte et al., LOFT System Note, LOFT_SysN-IrradSoftProtons_20121112.. 12/11/2012, Issue 1.0.

[RD 8] LOFT Large Area Detector: Telemetry Estimate, J. Wilms & C. Tenzer. LAD Technical Note, LOFT-LAD-TMest-20120518. 18/05/2012, Issue 2.0.

[RD 9] LOFT Wide Field Monitor Data modes, compression and telemetry, S. Brandt, LOFT WFM Technical Note, LOFT-WFM-DTC-20120524. 24/05/2012, Issue 2.1.

[RD 10] The Large Observatory For X-ray Timing (LOFT), M Feroci et al, Experimental Astronomy, Volume 34, Issue 2, pp.415-444

[RD 11] LAD data compression assessment, B. Artigues, LOFT-LAD-DCA-20130116

[RD 12] LOFT Wide Field Monitor Preliminary Simulations, J in't Zand, LOFT-WFM-Simul-20120515

[RD 13] LOFT Background Working Group Report LOFT-LAD xxx 2013nnnn TBC

4 OBJECTIVES

Mission statement:

LOFT is designed to study the equation of state of ultra-dense matter and to explore the conditions of strong-field gravity.

The statement is elaborated below in narrative form that explains how our Level 0 requirements are defined:

EOS of ultra-dense matter and neutron star structure. Understanding the properties of ultra-dense matter and determining its equation of state (EOS) is one of the most challenging problems in contemporary physics. At densities exceeding that of atomic nuclei, exotic states of matter such as Bose condensates or hyperons may appear; a phase transition to strange quark matter may take place at higher densities. Only neutron stars probe these densities in the 'zero' temperature regime relevant to these transitions.

Very "soft" EOSs give a maximum neutron star mass in the 1.4-1.5 solar mass (Mo) range, whereas "stiff" EOSs can reach up to 2.4 -2.5 Mo before collapse to a black hole becomes unavoidable. Apart from maximum mass, the relation between the neutron star mass and radius (M-R) is a powerful probe of the EOS. With the exception of redshifts of any narrow atmospheric lines (feasible for slowly rotating stars only), all tools devised to constraint mass-radius are based primarily on accurate time-resolved and high-throughput broadband spectral measurements. In ~25 neutron stars, spins are now observed in burst oscillations and/or coherent pulsations at frequencies of up to 620 Hz, proving that millisecond spins and dynamically relevant magnetic fields are common among neutron stars in low-mass X-ray binaries.

LOFT will measure the masses and radii of thermonuclear powered millisecond pulsars to an instrumental accuracy of of 4% in mass and 3% in radius by modelling their pulse profiles: their fast spin and strong gravity affect the radiation from the surface hot spots producing the pulsations through relativistic beaming, time dilation, red/blue-shifts, light bending and frame dragging (hence they provide an alternative probe of strong field gravity effects as well). LOFT will be able to cross-validate these results by flux and spectral modelling at photospheric touch-down of radius-expansion thermonuclear X-ray bursts. Since the maximum rotation a neutron star can sustain depends on its mass and structure, fastest spin periods also constraint the neutron star EOS. LOFT will detect periodic signals (and QPOs as well) with unprecedented sensitivity. Models indicate that the pulsation amplitude in fast spinning neutron stars in X-ray binaries could be as low as 0.1%, so the effective area of the LAD is needed to detect these pulsations in a typical 10^4 s observation of a 100 mCrab source. The recent discoveries of a few intermittent X-ray pulsars, with small pulse amplitudes over short periods of time, indicate that it should be possible to build up a much better spin period distribution for accreting neutron stars than has been possible with RXTE. These intermittent pulsations were also very hard, underscoring the need for a timing mission with a good hard X-ray response. LAD can search for them with an unprecedented sensitivity (0.4 % amplitude in 100s for 100mCrab source).

A different approach has recently emerged from the discovery of global seismic oscillations GSOs) in the tens of Hz to kHz range from magnetars during the rare and extremely luminous giant flares emitted by these sources. The lower frequency GSOs likely arise from torsional shear oscillations of the crust and their frequency, in combination with the magnetic field inferred from the magnetar spin-down, tightly constrains the EOS. LOFT has the capability detect and study GSOs for the first time in 'intermediate' flares, which are tens of times more frequent than giant ones, down to amplitudes of 0.7%, an order of magnitude lower than seen up to now. This will open a new window in the study of neutron star structure through astero-seismology.

In summary these different measurements all address the same top level requirement:

TOP1 The equation of state of ultra-dense matter will be quantified using neutron star mass and radius measurements and measurements tailored to neutron star crust properties.

Strong gravitational fields. About 40 compact objects accreting matter in binaries are now known to display variability arising in, and occurring at the (millisecond) dynamical timescale of their inner accretion flows: black holes and neutron stars, respectively, show QPOs of up to 450 and 1250 Hz. These QPOs require an explanation that involves the fundamental frequencies of the motion of matter in the inner, strong-field gravity-dominated disk regions. In the absence of sufficient guidance from observations, modelling has so far been to a large extent phenomenological, and different interpretations are still viable.

For example, competing models variously identify observed QPOs with the relativistic radial and vertical epicyclic frequencies or relativistic nodal and periastron precession. Very high-signal-to-noise LOFT/LAD measurements of the QPOs will unambiguously discriminate between such interpretations and in the process tease out as yet untested general relativistic effects such as frame dragging, strong-field periastron precession, and the presence of an innermost stable orbit. Crucially, LOFT will provide access for the first time to types of information in these signals that are qualitatively new due to the capability to measure dynamical timescale phenomena within their coherence time, where so far only statistical averages of signals were accessible. This will allow studies that directly witness QPO formation and propagation and tie in with phenomena that state-of-the-art numerical work is just beginning to address.

LOFT will allow direct measurements of the black hole mass and spin through timing measurements, to compare with other estimates such as mass from optical studies or spin from the thermal X-ray continuum or the Fe K-line profile. The spectral capabilities of LOFT will allow use of the energy dependence of amplitudes and phase delays in the QPOs together with the Fe-K line profiles to measure the compact object’s mass and spin, the disk inclination and to study massive black holes in the brightest active galactic nuclei (AGNs) by measuring with unprecedented accuracy the profiles and variability of their Fe K-lines. Additionally, LOFT's good response to higher-energy X-rays is crucial for most of this work; the discoveries of the highest-frequency quasi-periodic oscillations from black holes – the ones which can be used to probe the mass and spins of the black holes – were made only above 13 keV, despite the much higher count rates at lower energies. Similarly, reliable measurements of Fe lines can only be made when both the Fe spectral edges around 8-9 keV and the continuum at energies significantly higher than these edge energies can be well measured.

In summary this leads to the second top level requirement:

TOP2 The conditions of strong-field gravity will be quantified by measuring the mass and spin of black holes (BH) and by verifying predictions of general relativity (GR), such as precession and epicyclic motion. To these aims study of Quasi-Periodic-Oscillations (QPOs) in the time domain, Fe line reverberation and tomography in bright Active Galactic Nucleus (AGNs) and Galactic Black Hole Candidates (BHCs) will be exploited.

Additional Science Themes. LOFT will additionally be a powerful observatory for studying the X-ray variability and spectra of a wide range of objects, from accreting pulsars and bursters, to magnetar candidates (Anomalous X-ray Pulsars and Soft Gamma Repeaters), cataclysmic variables, bright AGNs, X-ray transients and the early afterglows of Gamma Ray Bursts. Due to its high sensitivity it will also enable the study of disk-jet interaction. Through these studies it will be possible to address a variety of problems in the physics of these objects. Coordinated optical/NIR and radio campaigns on specific themes, as well as spin measurements which can aid the Advanced Virgo/LIGO searches for gravitational wave signals from fast rotating neutron stars will add great value to the LOFT program. Although not part of the core science we have identified the following third top level requirement:

TOP3 Enable observational science of a wide variety of X-ray sources during the mission life time, these topics will be complementary with the core science.

Although it is expected that a reasonable fraction of the mission lifetime can be allocated to observatory science (25 Ms) it has not been quantified and therefore it does not drive the mission design

4.1 Minimum success criteria

The minimum scientific success criteria for the mission are reached if the two core science objectives (TOP1 and TOP2) are achieved. It has been indicated in the description of these top level science objectives that supplementary observation strategies are followed to achieve this. For the minimum success criteria this is not required and a constraint from a single method is sufficient:

- The EoS and the QCD phase diagram is constrained by measuring neutron star masses with 4% accuracy and radii with an accuracy of 3% for 3 NSs.

- Strong-field general relativistic effects close to BHs and NSs are detected and BH masses and spins measured through time variability and spectroscopic measurements pf 3 BHs and 6 NSs.

4.2 Core science requirements (level 1)

For each of the level 0 objectives we have identified above a number of complementary methods to achieve these, these are specified quantitatively as our level 1 requirements. The Level 1 requirements for the LOFT mission are to:

Determine Equation of State by different approaches:

EOS1 Constrain the equation of state of supranuclear-density matter by the measurement, using three complementary types of pulsations, of mass and radius of at least 4 neutron stars with an instrumental accuracy of 4% in mass and 3% in radius[1].

EOS2 Provide an independent constraint on the equation of state by filling out the accreting neutron star spin distribution through discovering coherent pulsations down to an amplitude of about 0.4% (2%) rms for a 100 mCrab (10 mCrab) source in a time interval of 100 s, and oscillations during type I bursts down to typical amplitudes of 1% (2.5%) rms in the burst tail (rise) among 35 neutron stars covering a range of luminosities and inclinations.

EOS3 Probe the interior structure of isolated neutron stars by observing seismic oscillations in Soft Gamma-ray Repeater intermediate flares when they occur with flux ~1000 Crab through high energy photons (> 20 keV).

Study Strong-field GR by different approaches:

SFG1 Detect strong-field GR effects by measuring epicyclic motions in high frequency QPOs from at least 3 black hole X-ray binaries and perform comparative studies in neutron stars.

SFG2 Detect disk precession due to relativistic frame dragging with the Fe line variations in low frequency QPOs for 10 neutron stars and 5 black holes.

SFG3 Detect kHz QPOs at their coherence time, measure the waveforms and quantify the distortions due to strong-field GR for 10 neutron stars covering different inclinations and luminosities.

SFG4 constrain fundamental properties of stellar mass black holes and of accretion flows in strong field gravity by (a) measuring the Fe-line profile and (b) carrying out reverberation mapping and (c) tomography of 5 black holes in binaries providing spins to an accuracy of 5% of the maximum spin (a/M=1) and do comparative studies in 10 neutron stars

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[1] Unless specified differently 1 σ errors are given

SFG5 constrain fundamental properties of supermassive black holes and of accretion flows in strong field gravity by (a) measuring the Fe-line profiles of 20 AGNs and for 6 AGNs (b) carry out reverberation mapping and (c) tomography, providing BH spins to an accuracy of 20% of the maximum spin (10% for fast spins) and measuring their masses with 30% accuracy,

The scientific objectives may be achieved through the measurement of the X-ray photometric light curves and spectra of a range of different astrophysical target classes. The targets are all compact objects (neutron stars, stellar-mass as well as supermassive black holes) therefore the measurement requires no imaging capability. Targets will be selected by pointing a collimating structure that discriminates the required source from the diffuse background and nearby X-ray emitting sources. The photons from the selected target will be registered by an array of semiconductor detectors that will measure the X-ray photon energy and arrival time to high precision (~250eV FWHM and 10µs respectively).

A large effective collecting area ensures that sufficient photons can be collected to accumulate spectra and precision photometry over the variability time scales of interest for the different target classes. The energy resolution of the detector in combination with an energy range of 2 to 50 keV will enable the measurement of the Fe-line profile, needed for the Strong Field Gravity goals. This instrument is called the Large Area Detector. The data will be transmitted to ground in the form of photon event lists (time and energy of each photon).

To catch the relevant sources in outburst it is required to monitor a large fraction of the visible sky on a daily basis. If a change in state of a source for the core program is observed, LOFT may be pointed to this source and repeated observations are feasible till the source state is no longer of interest. This monitoring is enabled by a coded mask imaging technique, providing time- and energy sliced images of the available field of view, as well as spectra and light curves of bursts and transients. For the core science objectives processing of these data on the basis of a few days is sufficient to adjust the observation schedule if a source state changes.

4.3 Observatory science

As indicated in the section about science objectives, it is required that LOFT will allow 'observatory type' of science during the periods which are not required for the core science objectives. This will be a significant fraction of the observing time (>25%) and will be allocated on the basis of peer reviewed proposals. In this section we include a few of the most interesting topics.

The LOFT LAD and WFM will be very important for the study of thermo-nuclear explosions on the surface of neutron stars, so called Type I X-ray bursts. Current instruments have revealed residuals in the spectra of a sub-set of these bursts (extreme radius-expansion bursts) suggesting the presence of absorption edges, perhaps arising from nuclear burning ashes mixed into the radiation-driven ejecta powered by the burst flux. Such features have been predicted theoretically, and can provide information on the neutron star compactness. However, as the occurrence of such extreme Type I bursts is unpredictable and as they occur infrequently, high-quality spectra have proved difficult to obtain. The LOFT WFM should allow for the detection of these bursts with sufficient spectral resolution to investigate if the neutron star compactness can be constrained.

The LOFT mission will be capable to advance the field of Gamma Ray Bursts (GRBs) significantly. The LOFT WFM energy band, sensitivity, field of view, source location accuracy and energy resolution are well suited for the investigation of some of the open issues in the study of GRBs. Some of the issues include: the models for the physics of prompt emission, the existence and properties of spectral absorption features by circum-burst material (and hence the nature of the progenitors), the detection and rate of high-z GRBs (which is important for the investigation of the early universe).

Another area where in particular the WFM will contribute is that of X-ray flashes. WFM studies of the population and properties of X-ray flashes found to accompany supernova shock break-out and the disruption of stars and planetary objects by supermassive black holes should provide important results.

A last example in this (incomplete) report on the LOFT Observatory Science involves the study of the magnetic accretion in, for instance, high-mass X-ray binaries. The LOFT/LAD is ideally suited to study the X-ray time variability on timescales of a fraction of the neutron star spin period. The variability is also reflected in the observed spectral properties such as the centroid energy of the cyclotron lines.

5 INSTRUMENT PERFORMANCE REQUIREMENTS

5.1 Large Area Detector

The prime instrument of the mission is the large Area Detector (LAD). This is a non-focusing but collimated X-ray detector with a very large collecting area. This allows for very-high count rates and combined with its spectral resolution, allows researchers also to carry out spectral analysis of bright objects. It will have the following characteristics:

- A large area detector with a collimated field of view (~1 degree).

- Good spectral resolution using Silicon Drift Detectors (~ 240eV). It should be noted that not all events can be reconstructed with the same resolution, depending on the number of anodes to reconstruct the energy. In practice around 40% of the events will be read-out by a single anode and 60% by two anodes. Where required by different science investigations, these datasets can be reduced separately

- A high level of modularity (the different detector segments operate independently) increasing the level of redundancy. The loss of a whole panel and subsequent reduction in effective area may compromise some capability (e.g. EOS2), however many science goals could be completed albeit with longer observation times.

- The capability to monitor available data rates in the LAD instrument and onboard storage to enable switching modes in case the data rates get too high (e.g. to re-binned mode).

The instrument requirements are summarized in Table 5-1 and more details are given for each requirement later. Also the level (cf. Section 2) of the requirements is given. Part of the justification of the requirements is given in the subsequent paragraphs but especially the flow down is discussed in Appendix A where also the relations between the different requirements are explained.

Table 5-1 Overview LAD requirements, all fluxes in Crab units are defined in 2-10 keV in nominal conditions. This table was provided as an initial set of scientific requirements at the time of the proposal and retained for reasons of continuity.

Item	Requirement	Goal	Level
Effective area (given energy is E ± 0.5 keV)	3.8 m² @ 2 keV 7.6 m² @ 5 keV 9.5 m² @ 8 keV 0.95 m² @ 30 keV	4.2 m² @ 2 keV 8.4m² @ 5 keV 10.5 m² @ 8 keV 1.05 m² @ 30 keV	2a
Effective area knowledge	15%	10%	2b
Energy range	2 – 30 keV primary 30-80 keV extended	1.5 – 80 keV	2a
Energy knowledge	1%	0.8%	2b
Spectral resolution @6keV (end of life)	260 eV (doubles, 60%) 200 eV (singles, 40%)	200 eV (doubles, 60%) 160 eV (singles, 40%)	2a
Degraded spectral resolution outside the nominal Field of Regard**	400 eV @ 6 keV	300 eV @ 6 keV	2a
Field of View (FWHM)	0.9 – 1.1 degree	0.45 - 0.55 (*) degree	2b
Off-axis response (45°)	0.02% - 0.2% at 30 keV	0.02 – 0.2 % at 30 keV	2b
Response stability (frequency-dependent, see [RD 3])	<0.01 Hz: <2% per decade 0.01 -1 Hz: <0.2% per decade 1-1200 Hz: <0.02% per octave >2000 Hz: Lower is better 10-2000 Hz: <0.0002% nearly periodic	1% per decade 0.05% per decade 0.005% per octave Lower is better <0.00005% nearly periodic	2a
Time resolution	10 μs	7 μs	2c
Absolute time accuracy	2 μs	1 μs	2c
Dead time	< 1% @ 1 Crab	< 0.5% @ 1 Crab	2b
Dead time knowledge	2.8%	Less than the statistical precision of power spectrum for 1 day at 15 Crab up to F_{Ny} = 10 kHz (see [RD 2])	2b
Background	< 10 mCrab	< 5 mCrab	2a
Background knowledge	0.25% at 5-10 keV	0.20% at 5-10 keV	2b
Maximum flux (sustained, nominal binning)	> 500 mCrab	> 750 mCrab	2a
Maximum flux (sustained, re-binned)	15 Crab	30 Crab	2a
Onboard memory (transmit ted over more orbits)	15 Crab, 300 minutes	30 Crab, 300 minutes	2b
Modularity (loss of area due to loss of single point failure)	< 25%	< 10%	2c

*(*) note that the smaller FoV, which is a design parameter, improves the background towards the 5mCrab goal but can only be realised if the pointing goal is reached (as they are dependent upon one another). ** not all science (EOS1, EOS2, EOS3, SFG1, SFG3) requires the best energy resolution. By having the nominal energy resolution in the Field of Regard and the energy resolution outside the Field of Regard the observing plan can be optimized taking the need for a good energy resolution into account, see also SCI-SYS-R-19 and SCI-SYS-R-05)*

5.1.1 *Effective area*

The effective area requirement is given at 4 energies (maximum of the distribution, a high energy cut-off and at two lower energies). The effective area is directly related to the stopping power in the detector and the transmission of the thermal blanket and any inactive layer on top of the detector. Especially at the low cut-off the effective area is a steep function of energy and the given energy should be interpreted as energy ± 0.5 keV.

Effective Area	Value (m^2)	ID	Condition	Level
Definition	The projected collecting area for photons (a function of photon energy) determined as the product of geometric area and detectors' quantum efficiency, transmission factors of collimators, and associated thermal/optical shields. Value achieved after in-orbit calibration			
Requirement	**9.5**	**SCI-LAD-R-01**	At 8 keV	2a
	Justification Effective area provides the translation from a source flux to detected count rate. This requirement is the minimum detector effective area, near the peak of source photon and variability distribution in energy, that is required to ensure the most driving science case can be fulfilled (determine masses and radii of neutron stars , investigate gravity in the strong field regime). This area is required to reduce the statistical errors on the mass and radius to < 4% and < 3% respectively. [GOAL EOS1, EOS2, SFG1, SFG2, SFG3, SFG4]			
Goal	**10.5**	**SCI-LAD-G-01**	At 8 keV	
	Justification An increase by 10% allows several science goals to tackle signals 20% fainter as in several cases the S/N ratio is proportional to the number of detected photons which is proportional to the effective area. [e.g. GOALS EOS1 (in part), EOS2, and EOS3, SFG1, SFG3]			
Requirement	**3.8**	**SCI-LAD-R-02**	At 2 keV	2a
	Justification: The soft part of the spectrum is important for strong red wings in very broad Fe lines, see also SCI-LAD-R-03 [GOALS SFG2, SFG4, SFG5]. A factor ~40% of the peak area is necessary to guarantee adequate modelling of the source spectral shape			
Goal	**4.2**	**SCI-LAD-G-02**	At 2 keV	
	Justification See requirement but the goal is 10% more ambitious.			
Requirement	**7.6**	**SCI-LAD-R-03**	At 5 keV	2a
	Justification: To ensure that the LAD effective area does not change by more than ~20% over the energy interval (5-8 keV) in which the broad Fe-K lines are detected and studied.GOALS: SFG2, SFG4 and SFG5.			
Goal	**8.4**	**SCI-LAD-G-03**	At 5 keV	
	Justification See requirement but the goal is 10% more ambitious.			
Requirement	**0.95**	**SCI-LAD-R-04**	At 30 keV	2a
	Justification To detect QPOs during intermediate flares of SGR/AXP; to detect the continuum emission of bright AGN (>1 mCrab) with a S/N of 200 to measure the Compton reflection component with a 15% accuray [GOAL EOS3, SFG4]			
Goal	**1.05**	**SCI-LAD-G-04**	At 30 keV	
	Justification See requirement but the goal is 10% more ambitious.			

*: *Small deviations (less than 5%) with respect to the original 10 m^2 requirement can be accommodated without significant impact on achieving the LOFT science objectives. To allow for unambiguous interpretation the lowest number (9.5m^2) in this range has been specified as requirement. However, this requirement is inter-related to several other requirements including the spectral resolution, the field of regard and the redundancy requirement. Deviations in the effective area can, for a significant part of the science, be compensated by a suitable combination of sky visibility and longer mission duration (see also appendix A). With the tuning of these other requirements the impact of the reduced area on the science can be made small. In addition the 25% redundancy requirement may need to be adjusted in order to maintain a 7.5 m^2 effective area in case of a single point failure.*

*** An increase in number of modules is not realistic but an increase in the effective area can, potentially, be achieved by a larger open area fraction of the collimator or by a slightly different design of the silicon drift detector where the HV divider is optimized.*

Related to the effective area itself is also the knowledge about the effective area:

Effective area knowledge	**Value**	**ID**	**Condition**	**Level**
Definition	After in-orbit calibration, the measured flux in a standard (e.g. 2-10keV) energy band for selected astronomical "standard candle" sources should be verified against International Astronomical Consortium for High Energy Calibration recommendation			
Requirement	**15%**	**SCI-LAD-R-05**	near the maximum of the area	2b
	Justification to limit the impact of systematics in studies that require knowledge of absolute flux, e.g. accurate measurements of the Eddington luminosity during Type I bursts, translating into a (minimum) uncertainty of 7-8% in the determination of the radius of neutron stars through this technique.			
Goal	**10%**	**SCI-LAD-G-05**		
	Justification see requirement but uncertainties will be further reduced.			

5.1.2 Energy Range

Energy range	**Value (keV)**	**ID**	**Condition**	**Level**
Definition	The lower and upper energies measured for detected photons after reconstruction. For primary range the nominal binning appropriate to detector energy resolution shall apply. For extended range a binning factor in energy may be applied.			
Requirement	**2 – 30 primary, 30-80 extended**	**SCI-LAD-R-06**		2a
	Justification: 2 keV: to be able to study photoelectric absorption and soft components of a variety of sources; 30 keV: to determine the AGN and X-ray binary continuum spectra in order to study the reflection/absorption effects and allow for an accurate determination of the Fe-K line profile. 30- 80 keV is essential to detect fast high-energy phenomena such as SGR/AXP flares, GRBs etc. [EOS3, SFG2, SFG4, SFG5]			
Goal	**1.5 – 30 primary, 30 – 80 extended**	**SCI-LAD-G-06**		
	Justification: a 1.5 keV lower threshold will yield more accurate measurements of the properties of the absorber in AGNs [GOAL SFG5].			

Energy knowledge	**Value ($\Delta E/E$)**	**ID**	**Condition**	**Level**
Definition	After applying all known calibration factors, the linearity and offset of the energy scale applying to a measured spectrum shall allow a photon energy to be determined to within a small fraction.			
Requirement	**10^{-2}**	**SCI-LAD-R-07**	3 - 15 keV range	2b
	Justification: to combine data from different epochs the energy scale should be known with a fraction (1/4) of the energy resolution (reference point is 6 keV). [GOAL SFG2, SFG4, SFG5]			
Goal	**$0.8\ 10^{-2}$**	**SCI-LAD-G-07**	3 - 15 keV range	
	Justification: absolute knowledge scales with the difference in resolution (goal is 200 eV).			

5.1.3 *Spectral Resolution*

The resolution is specified at 6 keV. The requirements are split between all events and the events that will be collected on a single anode of the detector (40% of the events).

Nominal spectral resolution	Value (ΔE)	ID	Condition	Level
Definition	FWHM of a Gaussian distribution response to a monoenergetic stimulus of the detector, under nominal operating conditions			
Requirement	**240 eV @ 6 keV**	**SCI-LAD-R-08**	Average that assumes 60% of the events which are read-out by more than a single anode in addition to 40% read by single anode. See SCI-LAD-R-09 for the specification of the single anode	2a
	Justification: End-of-mission spectral resolution integrated over the full detector but after channel to channel corrections (e.g. gain); Using both single and double anode events this resolution allows for gravitationally broadened Fe Kα line-width studies, removal of narrow lines and edges, line/edge studies in PRE type I X-ray bursts. [GOAL SFG2, SFG4, SFG5]. This number includes all not-correctable contributions to the spectral resolution. The available margin on top of the Fano limit of Si will be distributed over different components (calibration, sensor uniformity, gain knowledge etc). See also appendix D and Tech Note on defined contributions to energy resolution.			
Goal	**<200 eV @ 6 keV (60%)**	**SCI-LAD-G-08**		
	Justification: For bright AGN (> 1 mCrab) and black hole X-ray binaries selection of the better resolution will improve all science objectives especially in SFG4 and SFG5.			
Requirement	**<200 eV @ 6 keV (40% of selected events)**	**SCI-LAD-R-09**	2 – 10 keV	2b
	Justification: For bright AGN (> 1 mCrab) and black hole X-ray binaries selection of the single events will improve all science objectives given in SFG4 and SFG5. Selected events are only those that correspond to the read-out of a single anode (explaining the 40% of the selected events). [GOAL SFG2, SFG4, SFG5].			
Goal	**<160 eV @ 6 keV (40% of selected events)**	**SCI-LAD-G-09**	2 – 10 keV	
	Justification: For bright AGN (> 1 mCrab) and black hole X-ray binaries selection of the single events will improve all science objectives given in SFG4 and SFG5.			

Degraded spectral resolution	Value (ΔE)	ID	Condition	Level
Definition	FWHM of a Gaussian distribution response to a monoenergetic stimulus of the detector, under degraded thermal operating conditions			
Requirement	**<400 eV @ 6 keV**	**SCI-LAD-R-22**	When nominal Solar Aspect Angle (SAA) cannot be maintained, and an increased SAA is adopted to meet sky visibility constraints. Field of regard to be achieved 50% (required) 75% (goal).	2b
	Justification: Not all science goals require optimal energy resolution. In order to avoid unnecessary limitations to the accessible sky at any time, a 50% worse than optimal resolution is acceptable over an extended sky region and this allows the Solar Aspect Angle and thermal constraints to be relaxed. See section 7 (observation plan) and appendix A for more information			
Goal	**< 300 eV @ 6 keV**	**SCI-LAD-G-22**	See above	
	Justification: a degraded energy resolution similar to the requirement "standard" energy resolution effectively means a larger FoR.			

5.1.4 *Field of view*

Field of view	Value (FWHM)	ID	Condition	Level
Definition	The FWHM of distribution in transparency of the instrument (i.e. collimator) at the peak energy for the effective area. A triangular distribution is assumed.			
requirement	**FoV <1 degree**	**SCI-LAD-R-10**		2b
	Justification: Limiting confusion in crowded fields. [GOAL EOS1, EOS2]. Assuming that science data degrade if an observation includes more than 5% photons from other sources, for on-axis observations ~20% of all bright sources in the sky are affected by source confusion. Thist source confusion can be mitigated using offset-pointings			
Goal	**FoV <0.55 degree**	**SCI-LAD-G-10**		
	Justification: improved background, affecting fewer sources and reducing the need for offset pointings. However this is related to the response stability, it can only be considered if the response stability goals are within reach.			

Off-axis response	Transmission through the collimator	ID	Condition	Level
Definition	The fraction of photons, at specified energy, that reach the detector plane following transmission through the collimator from a large off-axis angle (for reference purposes 45°).			
Requirement	**0.02% - 0.2% at 30 keV**	**SCI-LAD-R-11**	Assuming off-axis angle of 45 degree and integrated over full detector area	2a
	Justification: some response is required at off-axis angles to be able to observe seismic oscillations in SGR (EOS3), the value is not critical as long as it is in this range (0.02 – 0.2 %). This can be achieved by either a transparent collimator at higher energies or by a fraction of the LAD area which has no collimator at all.			
Goal	**TBD**	**SCI-LAD-G-11**		
	Justification: same.			

5.1.5 *Response Stability*

The key science requirement is to avoid any spurious (e.g., induced by a variable instrument response) modulation in the measured source count rate, down to a level of the astrophysical signal of interest. As the latter highly depends on the type of source/signal and its characteristic frequencies, it is hard to specify the requirement with a single number. The derivation of these requirements is explained in [RD 3].

Stability	Value (%)	ID	Condition	Level
Definition	Response stability is the broad-band (e.g. 2-30keV) effective area as a function of frequency. In practice this is derived from a Fourier transform of the effective area as a function of time.			
Requirement	**<2**	**SCI-LAD-R-23**	<0.01 Hz and max unusable bandwidth <1 octave per decade	2a
Goal	**<1**	**SCI-LAD-G-23**		
	Justification: SFG5: AGN, see also RD 3. On timescales of light crossing time of a few gravitational radii (10's seconds) the signature of reflection lags must robustly be determined. 1mCrab in 100 seconds gives <1% statistical fluctuations			
Requirement	**<0.2 (per decade)**	**SCI-LAD-R-24**	0.01-1 Hz and max unusable bandwidth <1 octave per decade	2a
Goal	**<0.05 (per decade)**	**SCI-LAD-G-24**		
	Justification: SFG2, 4: NS&BH LF noise, BH LF QPO. Low frequency QPOs seem correlated with broad band noise phenomena. Unstable response leads to apparent noise in constant flux sources and also to QPO broadening or sidebands. Statistical fluctuations for typical 100mCrab source in 1s are ~0.5%			
Requirement	**<0.02 (per octave)**	**SCI-LAD-R-25**	1-1200 Hz and max unusable bandwidth <1 % per decade	2a
Goal	**<0.005 (per octave)**	**SCI-LAD-G-25**		
	Justification: SFG1, 2, 3: BH & NS LF, HF & kHz QPO, EOS1: Burst oscillations			
Requirement	**Lower is better**	**SCI-LAD-R-26**	>2000 Hz and max unusable bandwidth <1 % per decade	2a
Goal	**Lower is better**	**SCI-LAD-G-26**		
	Justification: Discovery space			
Requirement	**<0.0002 (nearly periodic)**	**SCI-LAD-R-27**	10-2000 Hz and max unusable bandwidth <1 % per decade	2a
Goal	**<0.00005 (nearly periodic)**	**SCI-LAD-G-27**		
	Justification: EOS1: BO EOS2: AMXP, EOS3: seismic oscillations			

5.1.6 *Time information*

Intrinsic to the detector is that the arrival time of an event is not known much better than 10(7) μsec as the drift time through the detector depends on the position of the event with respect to the anode. However, as this distribution is stable and uniform, the absolute time knowledge should be better (2 μsec).

Time resolution	**Value**	**ID**	**Condition**	**Level**
Definition	The 3σ uncertainty in assigning the time datum of an event to its actual arrival time on the LAD			
Requirement	**10 μs**	**SCI-LAD-R-13**		2c
	Justification: Behaviour of matter under extreme conditions and ultra-dense matter – modelling waveforms of periodic signals, X-ray burst oscillations and QPOs. Moreover searches for very short impulsive phenomena. [GOAL EOS1, EOS2, EOS3, SFG1, SFG3, SFG4]			
Goal	**7 μs**	**SCI-LAD-G-13**		
	Justification: As above but now limited to optimal drift times in each detector. i.e. the pk-pk spread in assigned arrival times associated with “next-to-anode” versus “centre-of-detetcor” events			

Absolute time accuracy	**Value**	**ID**	**Condition**	**Level**
Definition	The accuracy with which the LAD time datum can be assiged to UTC, after ground calibration			
Requirement	**2 μs**	**SCI-LAD-R-14**	After correction on the ground	2c
	Justification: The absolute time accuracy requirement is higher than the detector time resolution. For pulsars, knowing the detection time with an accuracy of 2 microsecond allows comparison with other wavebands (e.g. radio). [GOAL EOS 1, EOS2, EOS3, SFG1, SFG3, SFG4].			
Goal	**1 μs**	**SCI-LAD-G-14**		
	Justification: Giant pulses from Crab and msec radio pulsars are very brief (some as short as 0.5 us, observed in radio at 0.125 us resolution and rising within that time (Knight et al. ApJ 640, 941) and extremely energetic, so if one is looking for X-ray counterparts to giant pulses 1 us or even better would certainly be very interesting			

Dead Time	**Value**	**ID**	**Condition**	**Level**
Definition	The fraction of available time during which a LAD detector channel is not able to record an event following the processing of a previous event in the same channel			
Requirement	**< 1% @ 1 Crab**	**SCI-LAD-R-15**		2b
	Justification: The critical parameter is the dead time knowledge but with a too large dead time it will be hard to reduce the error. [GOAL EOS 1, EOS2, EOS3, SFG1, SFG3, SFG4]			
Goal	**< 0.5% @ 1 Crab**	**SCI-LAD-G-15**		
	Justification: lower is better but the effect is small (when the deadtime is known accurately)			

Dead time knowledge	**Value**	**ID**	**Condition**	**Level**
Definition	The accuracy to which the loss of effective area due to dead time is known			
Requirement	2.8%	**SCI-LAD-R-16**		2b
	Justification: assuming the dead time is given per half detector and the deadtime is statisticlly independent from the other the error scales with: 2.8% * $(M/4000)^{3/2}$ * $(t_{dead}/50\ \mu s)^2$ * $f_{Nyq}/10kHz$ with M the total number of independent detection elements (half of a single SDD), t_{dead} the dead time for such element and $f_{Nyquist}$ the Nyquist frequency chosen			
Goal	Less than the statistical precision of power spectrum for 1 day at 15 Crab up to FNy=10 kHz	**SCI-LAD-G-16**		
	Justification: Dead time is relevant to all sources where we want to do accurate characterization of aperiodic phenomena, particularly at high frequency ($1/t_{\_dead}$). We need to be able to calibrate the dead-time process to an accuracy better than the precision afforded by the count rates. That is, if you can measure the Fourier transform to a certain precision given the count rate, then the uncertainty in the distortions induced by dead time to the Fourier transform should be less than that precision. [GOAL EOS 1, EOS2, EOS3, SFG1, SFG2, SFG3, SFG4, SFG5]			

5.1.7 Background

Back ground rate	**Value**	**ID**	**Condition**	**Level**
Definition	Equivalent flux of all cosmic diffuse, external particle and internally generated events that cannot be distinguished from true X-ray events from the target in the LAD field of view			
Requirement	10 mCrab	**SCI-LAD-R-17**	2 – 30 keV	2a
	Justification: Some of the science goals are related to low flux sources (1-10 mCrab) such as AGNs and some accretion powered X-ray pulsar and black hole transients. [GOAL EOS1, EOS2, SFG5]			
goal	5 mCrab	**SCI-LAD-G-17**	2 – 30 keV	
	Justification: The lower goal increases the number of (AGNs) sources accessible to the LAD.			

Background knowledge	**Value**	**ID**	**Condition**	**Level**
Definition	The accuracy with which the equivalent background flux is known after ground based application of calibration and modelling of environmental factors			
Requirement	0.25%[2] of the flux	**SCI-LAD-R-18**	5-10 keV	2b
	Justification: Some of the science goals are related to low flux sources (1-10 mCrab) such as AGNs and some accretion powered X-ray pulsars. The spectral analysis of these sources is sensitive to residual systematics after background subtraction. [GOAL EOS1, EOS2, SFG5]. See Technical Note			
goal	0.20%	**SCI-LAD-G-18**	5 - 10 keV	
	Justification: Same as requirement.			

[2] Studies by the Background Working Group reported in technical Note [RD-13] suggest this is feasible especially where one or more modules have a blocked collimator unit in part of the array.

5.1.8 *Source flux*

Maximum flux (nominal binning)	Value	ID	Condition	Level
Definition	The maximum equivalent target flux for which the nominal LAD event data binning scheme can be sustained			
Requirement	> 500 mCrab	**SCI-LAD-R-19**	Stable source with no loss of event information	2a
	Justification: only sources brighter than 0.5 Crab require temporal re-binning. Bright transient sources can be stored on-board and the full information can be transferred during subsequent ground contacts. [GOAL EOS1, EOS3, SFG1, SFG2, SFG3, SFG4]. Around 30 sources in the observation plan have intensities > 250 mCrab and around 20 sources > 500 mCrab. These sources will in general be observed during their bright state and require then the sustained data rate.			
goal	> 1 Crab	**SCI-LAD-G-19**	No loss of event information	
	Justification: improved performance, typical 10 sources will be above this level.			

Note: whereas the source flux is specified for a source within the FoV the science goal EOS3 requires to be able to detect high-energy photons from a 1000 Crab source from outside the field of view (i.e., through the collimator). This does not drive the design in view of the spectral slope and the stopping power of the collimator for photons < 20 keV where the bulk of the photons are for these 1000 Crab sources.

Maximum flux re-binned	Value	ID	Condition	Level
Definition	Utilising user-defined rebinning in time and/or energy the higher flux that can be accommodated within the available telemetry rates			
Requirement	15 Crab	**SCI-LAD-R-20**	loss of information is acceptable (user defined re-binning of the data)	2a
	Justification: Behaviour of matter under extreme conditions – modelling lines and waveforms of X-ray burst oscillations for instance during type I X-ray bursts. Spin and relativistic effects around BH and NS. SGR/AXP flares shining at offset angles. [GOAL EOS1, EOS3, SFG1, SFG2, SFG3, SFG4]			
Goal	30 Crab	**SCI-LAD-G-20**	Data compression with loss of information acceptable (user defined)	
	Justification: Behaviour of matter under extreme conditions. Spin and relativistic effects around BH and NS. SGR/AXPs in flaring states. Brightest state of Sco-X-1 and very bright transients.			

Onboard memory	Value	ID	Condition	Level
Definition	The amount of data storage to be provided in the LAD sub-system for extended downlink, commensurate with the data generated by a bright target for specified duration			
Requirement	15 Crab, 300 min	**SCI-LAD-R-21**	No loss of event information	2b
	Justification: Being able to retrieve all data over a number of ground contacts for bright and unexpected transients, taking advantage from long observation of weak sources (e.g., AGNs). [GOAL EOS1, EOS3, SFG1, SFG2, SFG3, SFG4]			
Goal	30 Crab, 300 min	**SCI-LAD-G-21**		
	Justification: Same as above but more ambitious.			

5.1.9 Modularity

LAD Modularity	**Value**	**ID**	**Condition**	**Level**
Requirement	Corresponding to a loss of effective area of < 25%	**SCI-LAD-R-23**	Loss due to a single point failure	2c
	Justification: In case of a major failure 75% of the area will still allow to achieve the minimum success criteria. This is explained in appendix A where it can be seen that with 70% of the area and increased observing time a significant fraction of the science can be achieved (although for fewer sources or with somewhat reduced sensitivity)			
Goal	< 10%	**SCI-LAD-G-23**		
	Justification: with a 10% loss of area the science is still affected significantly less			

5.2 Wide Field Monitor

The main goal of the WFM is to provide good triggers of active sources for the LAD. The instrument requirements will therefore have the following characteristics:

- Desirable trigger levels for bright transients is 100 mCrab for part of the sky accessible to LAD as 90% of these transients in this part of the sky should be identified, weaker transients (about 2 mCrab, duration few days) are more frequent and about 50% should be found. This can be achieved by a FoV that is a compromise between the accessible sky and the dimensions of the Galactic Centre region (~60 degree). A detailed trade-off has been determined (see RD 12).

- Sensitivity (5 σ detection) over 50 ks must be < 5 mCrab over energy range of 2 - 50 keV for a field where there is no source confusion (outside the Galactic Centre).

- Location accuracy < 1 arcmin for a 10 σ source. This defines the error budget for pointing and reconstruction of the pointing.

- The total allocation for the WFM data (in normal operations) is 10% of the total telemetry band width with a maximum of 100 kbits/s. If the LAD data rate is <80%, the WFM should be able to use up the available bandwidth.

- The allocation of the bandwidth should be under control of the user (e.g. the user may select to reserve a larger part of the bandwidth for one of the instruments).

- Energy range and telemetry bandwidth should allow at least 8 spectral bands for the detection of spectral state changes in transient sources and be sensitive to thermal (e.g. disk) spectral components.

- Enable storage of full data on board for at least 1 trigger per orbit for short (300 sec) transients (GRBs, XRFs, type I bursts, ...)

- Find rate triggers for transient events on board and use this to switch modes (e.g. different data compressions).

- Low energy threshold provides largest discovery space and should match the threshold of the LAD.

- A WFM redundancy scheme should avoid loss of FoV (at the cost of degradation of imaging)

Table 5-2: Overview of Wide Field Monitor requirements

Item	Requirement	Goal	level
Location accuracy (confidence level 90%)	<1 arcmin	<0.5 arcmin	2a
Angular resolution	<5 arcmin	<3 arcmin	2b
Peak sensitivity in LAD pointing direction (5 σ source detection)	1 Crab (1 s) 5 mCrab (50 ks)	0.2 Crab (1s) 2 mCrab (50 ks)	2a
Absolute flux calibration accuracy	20 %	15 %	2b
Relative flux calibration precision	5 %	2.5%	2b
Sensitivity variations knowledge	10 %	5 %	2b
Duration for rate triggers	0.1 sec - 100 sec	1 msec - 100 sec	2b
Rate meter data	16 msec	8 msec	2b
Field of view	1 pi steradian around the LAD pointing	1.5 pi steradian for large Sun angles part of the LAD accessible sky would otherwise not be monitored	2a
Energy range	2 – 50 keV primary 50-80 keV extended	1.5 – 50 keV primary 50-80 keV extended	2b
Energy resolution	500 eV	300 eV	2c
Energy scale calibration accuracy	4%	1%	2c
Number of energy bands for compressed images	>=8	>=16	2c
Time resolution	300 sec for images 10 μsec for event data	150 sec for images 5 μsec for event data	2b
Absolute time calibration accuracy	2 μsec	1 μsec	2b
Event/image data downlink maximum delay	3 hours	1.5 hours	2a
Onboard storage of triggered date	3 hours	2 hours	2c
Broadcast of trigger time and position to end user	< 30 sec after on board detection of the event for 65% of the events	< 20 sec	2c
Number of triggers for WFM	>> 1 per day	>> 1 per orbit	2b
Modularity	No full loss of FoV due to single point failure		2b
On-board memory	5 min @ 100 Crab	10 min @ 100 Crab	2a

5.2.1 Angular resolution and source localization accuracy

The angular resolution and source localization accuracy are related and the source localization depends also in the signal to noise ratio.

Localization accuracy	**Value**	**ID**	**Condition**	**Level**
Definition	The ability to determine the position of a source on the celestial sphere			
Requirement	< 1 arcmin	**SCI-WFM-R-01**	For an isolated source > 10 mCrab (2-10 keV) in 50 ks observation and an isolated source > 100 mCrab in 1 ks. Position accuracy refers to 90% confidence radius and a source in the fully illuminated field of view of a WFM camera. This requirement is with respect to J2000 reference frame	2a
	Justification: A 1 arcmin localization accuracy allows for follow up measurements of the LAD or ground observatories in case a new and unknown source is found (e.g. a BH X-ray binary) Note: localization refers to position derived on ground			
Goal	< 0.5 arcmin	**SCI-WFM-G-01**		
	Justification: Reduce crowding effects, and allow for better multi-wavelength follow-up.			

Angular resolution	**Value (FWHM)**	**ID**	**Condition**	**Level**
Definition	For each WFM camera, the FWHM angular distribution for a point source.			
Requirement	< 5 arcmin	**SCI-WFM-R-02**		2b
	Justification: For sources of the specified brightness the driving requirement is the localization accuracy. The localization depends on the angular resolution and the signal to noise ratio.			
Goal	< 3 arcmin	**SCI-WFM-G-02**		
	Justification: Reduce crowding effects, and allow for better multi-wavelength follow-up.			

5.2.2 Sensitivity

Peak sensitivity	**Value**	**ID**	**Condition**	**Level**
Definition	The equivalent flux that can be detected in the centre of the WFM field, for a point source and for a given observation time.			
Requirement	1 Crab in 1 second 5 mCrab in 50 ks	**SCI-WFM-R-03**	2 – 30 keV, 5 σ detection. Spectrum is assumed to be Crab-like and presence of the Cosmic Diffuse X-ray Background. Source position in LAD pointing direction.	2a
	Justification: 1s: Fast events of all kinds: SGRs, AXPs bursts/flares, X-ray flashes and bursts. 50 ks: Weak transients; accreting ms pulsars; AGN and weak source monitoring. Source detection sensitivity scales with the signal to noise ratio.			
Goal	0.2 Crab in 1 second 1 mCrab in 50 ks	**SCI-WFM-G-03**	2 – 30 keV, 5 σ detection. Spectrum is assumed to be Crab-like	
	Justification: Improved performance, especially opening up new parameter space (e.g. very fast transient events).			

Absolute flux calibration accuracy	**Value**	**ID**	**Condition**	**Level**
Definition	Following the application of calibration data, the accuracy with which the equivalent flux of a high S:N detected source can be specified. The reference shall be targets recommended by International Astronomical Consortium for High Energy Calibration.			
Requirement	20%	**SCI-WFM-R-04**	5 – 12 keV, in the LAD pointing direction	2b
	Justification: Cross calibrations with observations performed with other X-ray instruments.			
Goal	15 %	**SCI-WFM-G-04**	5 - 12 keV	
	Justification: Somewhat improved knowledge which is still achievable			

Relative flux calibration precision	**Value**	**ID**	**Condition**	**Level**
Definition	After applying all calibration knowledge, the relative change in flux sensitivity with off-axis angle must be known to a small fraction and within radii corresponding with an area at least 20% of peak on-axis area.			
Requirement	**5%**	**SCI-WFM-R-18**	5-12 keV, relative flux determination over time scale of ~ 1 month	2b
	Justification Relative calibration of the flux determination precision of the WFM at varying off-axis angles down to 20% of the peak effective area. This provides an upper limit on the systematic errors in source light curves as they are derived from different pointings placing the sources in different cameras and at different off-axis angles.			
Goal	**2.5%**	**SCI-WFM-G-18**	5-12 keV	
	Justification further lowering the systematics in source light curves.			

Sensitivity variation knowledge	**Value**	**ID**	**Condition**	**Level**
Definition	After applying all ground based calibration knowledge, the accuracy of determining the flux of any given target, and the also minimum flux sensitivity, from one pointing period to another.			
Requirement	**10%**	**SCI-WFM-R-19**	5-12 keV, time scale of nominal mission duration	2b
	Justification Relative knowledge of variations in the sensitivity of the WFM over the mission duration. Needed to cross check with other observations made of similar sky locations at different observing times and to maintain absolute flux calibration. Compared with R-18, this prioritises the relative change in sensitivity with time.			
Goal	**5%**	**SCI-WFM-G-19**	5-12 keV	
	Justification Further reducing the systematic errors in long term variations of sources.			

Duration for rate triggers	Value	ID	Condition	Level
Definition	A selectable duration over which counts are integrated to detect a count rate increase for triggering burst mode.			
Requirement	0.1 - 100 sec	**SCI-WFM-R-12**	Time scales of significant rate increase.	2b
	Justification: The time scales are typical for the transient events to be studied in detail with the full resolution data to rise significantly above the background level. Full resolution data for validated triggers will be stored for nominally 300 s around the burst trigger time, including a pre-burst interval. Transients with longer time scales can be studied with the normal image data with 300 s integration time.			
Goal	0.001 - 100 sec	**SCI-WFM-G-12**	User selectable set of integration periods.	
	Justification: Triggering sensitivity to very short events (e.g., TGFs: Terrestrial Gamma-ray Flashes).			

5.2.3 Field of view

Field of View	Value	ID	Condition	Level
Definition	The coverage of the celestial sphere provided by the ensemble of WFM units.			
Requirement	1 pi steradian around the LAD pointing	**SCI-WFM-R-05**	By rotating the spacecraft over 180 degrees the other 50% of the sky accessible to the LAD can be observed in one orbit.	2a
	Justification: Need to match as closely as possible the sky that is accessible to the LAD at any one time, but limited to 180 degrees centred around the LAD pointing. Allow study of the long term variability of AGNs, type I X-ray burst history, provide triggers for e.g. state changes and the occurrence of super-bursts. For a typical pointing, 50% of the accessible part of the sky of the LAD should match with 20% of the WFM peak effective area.			
Goal	1.5 pi steradian, including coverage for the anti-Sun direction	**SCI-WFM-G-05**	The total sky accessible to the LAD can be observed by the WFM by two suitable pointings of the spacecraft	
	Justification: Part of the LAD accessible sky would otherwise not be monitored.			

5.2.4 Energy range and resolutions

Energy range	Value	ID	Condition	Level
Definition	The lower and upper energies measured for detected photons in spectral accumulation mode. For primary range the nominal binning of 100eV shall apply. For extended range a further binning factor in energy may be applied.			
Requirement	2 – 50 keV primary 50-80 keV extended	**SCI-WFM-R-06**		2b
	Justification: Soft response, below 5 keV important for high redshift GRBs, study of type I X-ray bursts, supernova-shock break out: Science products in the primary energy range: Extended dynamic range up to 80 keV intended for monitoring of very bright sources (>1 Crab) as part of LAD background monitoring strategy.			
Goal	1.5 – 50 keV primary 50-80 keV extended	**SCI-WFM-G-06**		
	Justification: Allows better signal to noise ratio for the same geometrical detector area.			

Energy resolution	Value	ID	Condition	Level
Definition	FWHM of a Gaussian distribution response to a monoenergetic stimulus of the detector			
Requirement	500 eV	**SCI-WFM-R-07**	At 6 keV	2c
	Justification: Allows scientific products from WFM such as spectra for bight sources but it is not driving the design as the number of sources with sufficient countrates and spectral features is not part of the core sciene			
Goal	300 eV	**SCI-WFM-G-07**	At 6 keV	
	Justification: Improved energy resolution could eventually help.			

Energy scale calibration accuracy	Value	ID	Condition	Level
Definition	After applying all known calibration factors, the linearity and offset of the energy scale applying to a measured spectrum shall allow a photon energy to be determined to within a small fraction.			
Requirement	4%	**SCI-WFM-R-08**	At 6 keV	2c
	Justification: The energy resolution (and hence the scale) is not a main driver for the WFM. This allows scientific products from WFM such as edges from type I bursts.			
Goal	1%	**SCI-WFM-G-08**	At 6 keV	
	Justification: Even though not a main driver several Observatory Science cases would benefit.			

Energy bands compressed images	Value	ID	Condition	Level
Requirement	>=8	**SCI-WFM-R-09**	User selectable bands	2c
	Justification: Allows the downlink of limited data in a number of energy bands that match interesting regions in the energy spectrum. 8 allow for some finer ranges around the Fe-line and still coverage of the full range			
Goal	>=16	**SCI-WFM-G-09**	User selectable bands	
	Justification: Increase in number of energy bands and better use of the intrinsic energy resolution capability.			

5.2.5 *Time information*

Time resolution	Value	ID	Condition	Level
Definition	The cadence of the time datum of different WFM mode data			
Requirement	300 s normal, 10 μs triggered	**SCI-WFM-R-10**		2b
	Justification: Typical integration time for images is 300 s (yet programmable). The time scale corresponds to the resolution needed to monitor the intensity of non-bursting sources. The time resolution of triggered data will, however, be more accurate (10 μs) in the event by event mode. This number matches the time information of the LAD.			
Goal	150 s normal, 5 μs triggered.	**SCI-WFM-G-10**		
	Justification: Higher performance for brighter sources.			

Absolute time calibration	Value	ID	Condition	Level
Definition	The accuracy with which the WFM time datum can be assiged to UTC after ground calibration.			
Requirement	2 μs	**SCI-WFM-R-11**	Applies to photon-by-photon data	2b
	Justification: Pulsar studies and correlation of timing results with other missions and observations and equal to the LAD			
Goal	1 μ	**SCI-WFM-G-11**		

	Justification: Same as requirement.

Rate meter data	Value	ID	Condition	Level
Definition	The cadence of total count rate data per camera in 8 TBD energy bands.			
Requirement	16 msec	**SCI-WFM-R-13**		2b
	Justification: Provide the ability to study time coherent or non-coherent time variability on shorter time scales than the normal 300 s integration for imaging data and in cases where imaging is not required to identify the source. The primary use will be the monitoring of X-ray pulsars (coherent sources) over longer time scales.			
Goal	8 msec	**SCI-WFM-G-13**		
	Justification: Improved performance.			

5.2.6 Transient sources

Data downlink	Value	ID	Condition	Level
Definition	Once the WFM has identified a transient event and stored this in a priority queue it must be down linked within a maximum period of time			
Requirement	3 hours following data storage	**SCI-WFM-R-14**	Assumes one ground contact each orbit of which one can be missed (e.g. weather conditions)	2a
	Justification: WFM will be used to identify transient events and state changes in X-ray sources. The presence of transients or state changes could result in follow up (ToO) with the LAD (prime mission science) or with measurements by other (ground based/space based) instruments. The transients may be detected both in triggered data and in normal data if the transient rise time is >100s or a spectral state change has occurred.			
Goal	1.5 hr	**SCI-WFM-G-14**		
	Justification: Factor 2 faster, it is not expected that this will drive the design and is acceptable if this is not reached for 100% of the cases.			

Storage of triggered data	Value	ID	Condition	Level
Definition	Event-by-event data generated in burst mode, triggered by a transient source will be stored, for submision at the next available ground contact			
Requirement	3 hours	**SCI-WFM-R-15**	Assumes one ground contact each orbit of which one can be missed (e.g. weather conditions)	2c
	Justification Onboard memory will store up to 3 hours of data (although depending on the event rate some binning is foreseen for bright events/episodes/areas). This allows transmission of all relevant information if a transient has been identified by the instrument			
Goal	3 hours	**SCI-WFM-G-15**		
	Justification: Longer storage is not needed considering the transient down link requirement			

Broadcast of trigger time and position	**Value**	**ID**	**Condition**	**Level**
Definition	After a trigger into burst mode, the WFM will attempt to localise the source on the sky and determine the time of trigger. These data will be broadcast in a Burst Alert message.			
Requirement	Within 30 sec of generation of a valid event packet the event time and localisation (to ~1 arcminute accuracy) by the WFM, this shall be broadcast and reach the end user.	**SCI-WFM-R-17**	High galactic latitude, isolated sources > 2 Crab (2-30 keV) in a 10 sec observation. Position accuracy refers to 90% confidence radius and a source in the fully illuminated field of view of a WFM camera pair. Accuracy to be achieved after inflight calibration of systematic position offsets. 65% of the triggered events should be broadcast within the 30 sec cap. The data content <1kbit/event at a typical rate of once per orbit.	2c
	Justification: If broadcasted, a set of ground receivers can see the trigger times and positions for follow up measurements. A 30 sec latency is a reasonable number based on the chain of data transmission to the end-user.			
Goal	For the same triggered events, the goal of reaction time should be 75% in <20s.	**SCI-WFM-G-17**	Some ground based observatories need rapid response to utilise the LOFT alerts.	
	Justification: Enhanced performance of the full system handling burst alerts.			

Note: this requirement calls for an additional system with a set of ground stations to receive the broadcasted trigger time and position and disseminate this to the community

Number of triggers	**Value**	**ID**	**Condition**	**Level**
Requirement	**Up to 5 GRB triggers per day**	**SCI-WFM-R-20**		2b
	Justification Estimates suggest there should be at least 150 GRB per year detected by WFM, therefore statistically several per day should be accommodated.			
Goal	**>>1 per orbit**	**SCI-WFM-G-20**		
	Justification: Other triggers such as Type 1 X-ray bursts, as well as potential false triggers imply the need for relatively frequent downloading of burst triggers.			

5.2.7 System Requirements

Modularity	Value	ID	Condition	Level
Requirement	No loss of FoV	**SCI-WFM-R-22**	One single point failure in the WFM.	2b
	Justification: The design and geometric arrangement of the WFM shall be such that in the case of a single point failure still the full FoV should be covered although it is accepted that the effective area as well as the angular resolution for a certain part of the sky is reduced.			

On-board memory	Value	ID	Condition	Level
Requirement	5 min @ 100 Crab	**SCI-WFM-R-16**		2a
	Justification: storage of all event data for very bright transients in a continuous fashion without gaps (or less bright transients over longer periods). This allows for transmission of these data to the ground after the transient event happened without loss of information.			
Goal	10 min @ 100 Crab	**SCI-WFM-G-16**		
	Justification: the same but with increased capability.			

6 MISSION PERFORMANCE REQUIREMENTS

In this section science requirements for the system are given. This is clearly related to the instrument requirements but also to the strawman observing plan (see section 7). In addition to these requirements the natural functions of the satellite such as the control of the instruments (start/stop of observations, attitude keeping etc.) are, of course also required but these are not listed in the science requirements document.

Table 6-1 Overview of system requirements

Item	Requirement	Goal	level
Net observing time core science	24.7 Msec	24.7+6Msec	2a
Additional observing time observatory science	25 Msec	25+6 Msec	2a
Calibration time	5%	2%	2b
Minimum science observing times	1 minute (1 source during 2 weeks per year) 10 minutes (10 sources during 2 weeks per year)		2b
Accessible sky fraction (nominal energy resolution)	>35 %	50%	2a
Accessible sky fraction (degraded energy resolution)	>50 %	75%	2b
Galactic centre visibility (at degraded energy resolution)	> 35%	> 65%	2a
Probability to detect 2 BHCT and 2 AMXP (each)	> 98%	> 99%	2a
Mission duration	4 year	5 year	2b
Source pointing LAD (3σ)	1 arcmin	0.5 arcmin	2b
Pointing knowledge for each axis over the full orbit (AKE, 3 sigma, 10 Hz)	<20 arcsec	<5 arcsec	2c
Orbit	LEO with low inclination	LEO with low inclination	2b
Slews per orbit (average) Slews per orbit (at least)	from observing plan 2	from observing plan 2	2b
Change in observing plan following alert of SOC (ToO)	<12 SOC working hours	< 8 SOC working hours	2b
Quick look analysis	< 7 days	< 3 days	2b
Instrument data rate (typical)1)	LAD: 350 kbps (~ 150 mCrab) + WFM: 100 kbps	WFM in event mode	2b
Instrument data rate (sustained)	LAD: 1000 kbps (~ 500 mCrab) + WFM 100 kbps2)	LAD: ~1 Crab	2b
Data transfer per orbit	6.7 Gbit/orbit	14 Gbit/orbit	2b

1) The WFM is less than 10% of the total bandwidth unless a Guest Observer requests this to be higher. For a total of 6.7 Gbit/orbit 10% corresponds to 100 kbps (~100 minute orbit).
2) This indicates that during typical observations it will be possible to downlink data which were collected during periods with strong sources provided this data is stored on-board.

6.1.1 Observing Time for LAD

The core science time is related to the top-level goals (see section 4.1) and the observatory science is related to the third top level goal.

Net core science observing time	Value	Id	Condition	Level
Definition	The amount of observing time required to execute the nominal core science topics.			
Requirement	24.7 Ms	**SCI-SYS-R-01**		2a
	Justification: See observation plan (section 7). One year with a 40% observing efficiency corresponds to 12 Ms and at 50% observing efficiency it corresponds to 15 Ms.			
Goal	24.7 Ms + 6 Ms	**SCI-SYS-G-01**		
	Justification: The goal is to have the mission extended by one year 50% of that time is reserved for core-science and 50% for observatory science.			

Net observatory science observing time	Value	Id	Condition	Level
Definition	Amount of observing time that can be devoted to non-core science topics			
Requirement	25 Ms	**SCI-SYS-R-02**		2a
	Justification: In addition to the core science about 50% of the net observing time is proposed for observatory science. All time will be allocated through a peer review process			
Goal	same + 6 Ms	**SCI-SYS-G-02**		
	Justification: In case of an extended mission life time (to 5 year) it is expected to increase the guest observing time as well.			

Calibration time	Value	Id	Condition	Level
Definition	The fraction of usable observing time reserved for celestial calibration observations			
Requirement	5%	**SCI-SYS-R-03**		2b
	Justification: The calibration time is specified as a fraction of the total net observing time. Sufficient time should be allocated for periodic calibrations, both internal (electrical) and external (astrophysics sources). This number is based on past experience and not on a detailed calibration plan. 5% refers to total net observing time (corresponds to 2.6 weeks per year at the typical observing efficiency).			
Goal	2%	**SCI-SYS-G-03**		
	Justification: Maintain the same quality but over the mission lifetime its performance can be predicted and less calibration time is required.			

Minimum observing time	Value	Id	Condition	Level
Definition	Capability of the spacecraft to slew to a target, acquire stable pointing and obtain LAD data for a minimum duration irrespective of earth and solar aspect angle constraints			
Requirement	1 minute per orbit for 1 source / year during 2 weeks 10 minutes per orbit for 10 sources during 2 weeks per year	**SCI-SYS-R-04**		2b
	Justification: There is no theoretical limit on the shortest observation time and hence, during night time there will be additional observing time if the satellite slews to a given position. Considering the slew rate we do not expect this will be very efficient. Nevertheless, from a science perspective some sources only accessible from the night side will be very interesting and this is estimated to be one strong source (1 Crab) and 10 weak sources (150 mCrab) per year. Considering typical decay times it would be required to observe these sources over as many orbit that the source is visible (up to two weeks).			
Goal	Factor 2 longer times	**SCI-SYS-G-04**		
	Justification: Increases observing efficiency for sources outside FoR.			

Sky visibility- nominal Field of Regard	**Value**	**ID**	**Condition**	**Level**
Definition	Fraction of 4π steradians celestial sphere that can be instantaneously visible to the LAD			
Requirement	35%	**SCI-SYS-R-19**	nominal energy resolution[1]	2a
	Justification: The energy resolution should be < 260 eV for SFG2, SFG4 and SFG5. but as these are mostly predictable targets, the observation schedule can be tuned to observe these sources when they are in the FoR (for the nominal energy resolution), see also appendix A..			
Goal	50%	**SCI-SYS-G-19**		
	Justification: This increases the probability to execute the observing programme within 4 years, given the added pointing freedom.			

1) The corresponding sky fraction is also called the Nominal Field of Regard

Sky visibility – extended Field of Regard	**Value**	**ID**	**Condition**	**Level**
Requirement	50%	**SCI-SYS-R-05**	Degraded energy resolution	2b
	Justification: Combined with the mission duration (4 years) this gives a 98% probability to detect two BHCT and 98% to detect two AMXPs. For various science goals (see section 7) the energy resolution is not critical.			
Goal	75%	**SCI-SYS-G-05**	Will require adjustable solar panels (TBC)	
	Justification: This increases the probability to detect 2 BHCT and AMXPs to 99% for a 4 year mission and would still be 98% for a 3 year mission. Furthermore, it allows Observatory science to be done in the Galactic Centre area on the sky. Otherwise (50% sky visibility) the observation time when the bulge is visible to LOFT is used for a significant fraction by observing the core-science targets.			

1) The corresponding sky fraction is also called the **Extended** Field of Regard

Galactic centre visibility	**Value**	**ID**	**Condition**	**Level**
Definition	The fraction of yearly coverage of the Galactic Centre location that is within the LAD Extended Field of Regard.			
Requirement	The GC location (equatorial coordinates 17 45 40; -29 00 28) must be visible in 35% of orbits	**SCI-SYS-R-06**	Coupled to the extended Field of Regard (400eV energy resolution).	2a
	Justification: 35% corresponds to the Extended Field of Regard requirement of 50% of the sky [SCI-SYS-R-05] and allows for sufficiently long net observing time of the Galactic Centre to meet the top level goals.			
Goal	65%	**SCI-SYS-G-06**	Will require adjustable solar panels.	
	Justification: This number corresponds to the Extended Field of Regard goal of 75% of the sky [SCI-SYS-G-05] and will optimize the science return as it enables longer viewing of the Galactic Centre which is important for the observatory science.			

BHCT/AMXP Detection	**Value**	**ID**	**Condition**	**Level**
Requirement	>98% probability to detect two major or big outburst of a BHCT showing the high-frequency quasi-periodic oscillation and > 98% probability to detect two AMXP	**SCI-SYS-R-07**	Coupled to sky visibility	2a
	Justification: See the observation plan (section 7)			
Goal	> 99% probabilities for AMXP and for BHCT with HF QPO	**SCI-SYS-G-07**		
	Justification: Increased probability			

Mission duration	**Value**	**ID**	**Condition**	**Level**
Definition	The elapsed time for science observing programme after completion of in-orbit commissioning but not including TBC months performance verification/calibration phase.			
Requirement	4 years	**SCI-SYS-R-09**		2b
	Justification: With a 4 year mission all requirements in terms of observing time, probability to catch rare events and energy resolution are achieved with margin. Details are given in appendix A.			
Goal	5 years	**SCI-SYS-G-09**		
	Justification: A longer mission duration allows for a larger science return.			

6.1.2 Pointing

Source pointing LAD	**Value**	**Id**	**Condition**	**Level**
Definition	The accuracy of pointing the LAD boresight towards a catalogued target. This shall be a 3σ radius value, and applies once the LAD boresight to star tracker offset is calibrated in orbit.			
Requirement	1 arcmin	**SCI-SYS-R-08**	Pointing of LAD, 3σ	2b
	Justification: This is well within the field of view of the LAD. It also corresponds to the accuracy with which the WFM can determine a source position. This requirement is coupled to the stability requirement of the LAD pointing. (Note there should be an equivalent value to be maintained during periods when the LAD is not observing, to enable the WFM localization of transient sources, with an initial boresight estimate. However this is TBD and not driving science.)			
Goal	0.5 arcmin	**SCI-SYS-G-08**		
	Justification: Reduces gradient of response vs. pointing in LAD to provide more margin in response stability.			

Absolute Knowledge Error	**Value**	**ID**	**Condition**	**Level**
Definition	The instantaneous reported star tracker reference axis location .			
Requirement	20 arcsec	**SCI-SYS-R-10**	3 σ, 10 Hz	2c
	Justification: Any pointing jitter can be corrected on the ground if we have good knowledge about the pointing. This provides additional margin, especially in the case of finite frequencies that exceed the SCI-LAD-G-26 specification. The AMA should be small compared to the FoV, but the actual number (20 arcsec) is an engineering estimate and not strictly deduced from the science requirements. Hence it is a level 2c requirement. Any distortions in the relative alignment in the LAD is included in the pointing error and not in this AMA.			
goal	5 arcsec	**SCI-SYS-G-10**		
	Justification: As many star trackers provide few arcseconds pointing knowledge it would be nice to have this but it is not really required.			

6.1.3 Orbit

Requirements on orbit are derived from a requirement on instrument background rates, stability and radiation damage due to charged particles. At this level we only give a top level requirement and more details are given in the MRD.

Orbit altitude	**Value**	**ID**	**Condition**	**Level**
Requirement	LEO, low inclination	**SCI-SYS-R-11**		2b
	Justification: Only a LEO orbit provides a low enough background. In combination with a low inclination the radiation damage to the detectors will be low enough to have them passively cooled and still reach the end-of-life temperature requirements. Details are given in the MRD.			
goal	LEO, lower inclination	**SCI-SYS-G-11**		
	Justification: A lower inclination will reduce the effects of the SAA.			

Slews per orbit	**Value**	**ID**	**Condition**	**Level**
Requirement	From observing plan	**SCI-SYS-R-13**		2b
	Justification: This allows for slewing of the satellite during monitoring campaigns and is directly related to SCI-SYS-R-04, this is NOT equal to the average number of slews per orbit which depend on the observation plan (see RD4).			
Goal	4	**SCI-SYS-G-13**		
	Justification: This increases the number of potential observations of otherwise inaccessible targets (at a given time) by a factor 2.			

6.1.4 *Target of Opportunity*

Although not the prime science it is clear that fast response times will enable additional science. The provided requirements are supposed not to drive the design but are nevertheless ambitious in the sense that the ToO response time should be optimized within the planned ground system.

Change in observing plan (ToO)	Value	ID	Condition	Level
Requirement	<12 working hours after the reception of ToO trigger at SOC	**SCI-SYS-R-14**		2b
	Justification: LOFT is not a mission dedicated to **fast** transients (like SWIFT). However, it is important to be able to respond to state changes in sources at a reasonable rate (called ToOs). Therefore the ToO response time should not drive the design of the ground system. The provided specification corresponds to a reaction time <12 SOC working hours following the notification of a ToO trigger submitted by a user to the SOC during their normal working hours. Clearly, this requirement should not inhibit faster response times in case a ToO is identified at the beginning of a working day. Although many targets will be triggered by a change in state, the number of ToOs is limited as subsequent observations of a target which changed state, will be pre-planned at the time of the first observation and do not need re-planning of the observation schedule. Following the change of a source state, the relevant sources will be on between something like a week to very long periods (campaigns up to one year after the transient trigger may be expected). This makes a response of < 12 hours for the core science not mandatory. Clearly a faster response will improve the science in general (see the goal).			
Goal	< 8 working hours after reception of trigger at SOC	**SCI-SYS-G-14**		
	Justification: During day time a response within 8 hours is feasible based on XMM/Integral experience			

Note: We expect between 12 and 24 ToOs per year.

QLA and utilisation for observation planning	Value	ID	Condition	Level
Definition	A Quick Look data analysis subsystem should be provided at SOC (and SDC) in order to determine the properties of triggering sources and LAD target object in order to provide an alert for observation plan changes, and verify LOFT Burst Alert messages.			
Requirement	<7 days	**SCI-SYS-R-18**		2b
	Justification: The analysis using a QLA system should be powerful enough to be able to identify source spectral and brightness changes that allow an alert for new ToOs to be generated, or identify failure to meet observing proposal criteria. The planning cycle to update the observing plan shall be <7days and therefore QLA should be able to generate the required data for Duty Scientist decision on a much shorter timescale. Observation campaigns can last weeks.			
Goal	< 3 days	**SCI-SYS-G-18**		
	Justification: The re-planning timescales should be faster to avoid loss of useful observing time.			

6.1.5 Data rates

Typical data rate	**Value**	**ID**	**Condition**	**Level**
Definition	The science data rate generated by the instruments, after nominal binning and lossless compression ratios, when observing a source at the typical LAD brightness for event mode data.			
Requirement	350 kbps (LAD) + 100 kbps (WFM)	**SCI-SYS-R-15**		2b
	Justification: For a 150 mCrab source, observed with an efficiency of 60% the data rates must support the full LAD event mode data. Simultaneously data for nominal event modes for the WFM should be transmitted (100 kbps).			
Goal	TBD kbps	**SCI-SYS-G-15**		
	Justification: Increase in the data rate for the WFM to exploit fully the available transmission rate.			

Sustained data rate	**Value**	**ID**	**Condition**	**Level**
Definition	The science data rate generated by the instruments, after nominal binning and lossless compression ratios, when observing a source at the maximum LAD brightness for event mode data.			
Requirement	1000 kbps (LAD) + 100 kbps (WFM)	**SCI-SYS-R-16**		2b
	Justification: For a 500 mCrab source, observed with an efficiency of 60% the data rates must support all LAD event mode data. Simultaneously all data for nominal event modes for the WFM plus the transmission of data stored on board for previous measurements.			
Goal	>1500 kpbs	**SCI-SYS-G-16**		
	Justification: Increase of the LAD source to >1 Crab without loss of information.			

Downlink rate	**Value**	**ID**	**Condition**	**Level**
Requirement	6.7 Gbit/orbit	**SCI-SYS-R-17**		2b
	Justification: This is linked to the previous science requirement SCI-SYS-R16 (500 mCrab) , and SCI-LAD-R19 and the minimal telemetry of the WFM, under the assumption of no loss of LAD information within the above limits.			
Goal	14 Gbit/orbit	**SCI-SYS-G-17**		
	Justification: Enables the higher sustained rate required by the goal SCI-SYS-R-16 in the previous requirement.			

7 OBSERVING PLAN

In *Table 7-1* the total observing time per core science requirement is given split over the different source categories. Also the number of required sources per category is given as well as the number of observed sources. This number of observed sources is larger than the number of required sources as it is not always known a priori if a source is in a given state, We also specify whether the spectral resolution is important for the science goal (Fe-line characterization). For the Neutron Stars, both transient outburst NS and the transient weak NS will be observed. From these we expect that 3 will have the properties of an AMXP which are then observed for a longer period.

Table 7-2 lists more details per source type: the number of sources, the number of pointings per source, the campaign duration (= time over which pointings should be distributed, for transients this is how long the outburst lasts, for persistent sources the minimum time over which we need to sample their behavior), the total exposure time for that class of sources, the top level science goals addressed, and examples of sources in this class (for transients of course these are really examples, as usually other ones like these will occur and be observed with LOFT). Most classes of sources serve to address >1 science goal as is already indicated in *Table 7.1.*

Table 7-3 lists the archetypal sources per class. *A* mock observation plan defined in [RD-4] has been produced based on this table, and for the purposes of deriving the impact of the observing plan on the system, has been made applicable to the mission in the MRD. It should be recognized that a ToO for LOFT is of a different nature than 'usual' observatory ToOs. When the source state changes, a change in the observing program can be triggered but then, for this source, a campaign of weeks to longer periods is started. Only when, during this campaign, the source fades away, the campaign can be stopped to save observing time. So, effectively we expect about 60 ToOs over the mission life time. Despite this difference with the more usual use of ToOs (changes in the observation plan by external triggers) we have kept the name as it would result in a re-planning of the observation schedule.

Table 7-1 Overview of sources and total observation time per core science requirement. Also the total time on the Galactic Centre is given. Note that observation of the same source can be used for different science goals. This explains that the total time is not the sum but the maximum of the entries

	#	EOS1	EOS2	EOS3	SFG1	SFG2	SFG3	SFG4	SFG5	total	time on bulge
BH transient outburst	4				2400	2400		2400		2400	1920
BH quasi persistent	2				400	1600		1600		1600	800
AGN1 (reveberation)	6								4800	4800	0
AGN2	14								2400	2400	0
milisec pulsar outbursts[1)]	3	1000	1000			1000	1000			1000	850
NS persistent bright	13	2900	800		4800	4800	2800	4800		4800	3600
NS transient bright outbursts	3	1200	600		1800	1800	1800	1800		1800	900
bursters	10		1000							1000	750
NS persistent weak	14		280							280	210
NS transient weak[2)]	7	500	120							500	375
magnetars (seismic)	1			100						100	
Follow up sources EOS[3)]	2	4000								4000	3000
total	85	9600	3800	100	9400	11600	5600	10600	7200	24680	12405
number required NS		4	35		8	10	10	10			
number required BH					3	5		5			
number observed NS		20	48		15	18	18	15			
number observed BH					6	6		6			
Other				1 SGR					14+6 AGN		
spectral resolution		no	no	no	no	yes	no	yes	yes		

1) *The NS transient outburst NS and the transient weak NS will be observed. From these we expect that 3 will have the properties of an AMXP which are then observed for a longer period*

2) *we have allocated 500 ks for the long term transient NS KS1731-260 for the EOS1 goal*

3) *We have allocated 4 Ms additional time for EOS1 to reduce the errors on the mass/radius relation for the two most favourable/interesting sources. These cannot be identified before the measurements are done*

Table 7-2: Detailed overview of observations to meet the core science requirements

Source type	# of sources	Total pointings [1]	Campaign length [days]	Total time [ks]	TOO	Number of TOOs	Fraction in bulge [%]	Science goals	Example objects
BH transient outbursts	4	800	100-350	2400	Yes	16	80	SFG1,2, 4	XTEJ1550-564, GROJ1655-40, XTEJ1118+480, GX339-4
BH quasi persistent	2	400	1000	1600	No	0	50	SFG1,2, 4	GRS1915+105, Cyg X-1
AGN1	6	24	700	4800	No	0	0	SFG5	See list AGN1 (reverberation)
AGN2	14	14	5	2400	No	0	0	SFG5	See list AGN2 (profiles)
Millisec pulsar outbursts	3	250	10-30	1000	Yes	6	85	EOS1, SFG1,2, 3,4	SAXJ1808.4-3658,XTEJ1814-338,HETEJ1900.1-2455
NS persistent bright	13	50	10-200	4800	No	0	75	EOS1,2 SFG1,2, 3, 4	See bright persistent NS
NS transient bright outbursts	3	250	6 - 60	1800	Yes	6	50	EOS1,2 SFG1,2, 3,4	CirX-1, AqlX-1, 4U1608-52
Bursters	10	40	15 - 30	1000	Yes	20	75	EOS2	See list bursters
NS persistent weak	14	14	1	280	No	0	75	EOS2	See list weak persistent NS
NS transient weak	7	6	1	500	Yes	12	75	EOS1, EOS2	See list weak transient NS
Magnetar	1	1	1	100	No	No		EOS3	Shines through collmator

1) Average time per pointing is total time/total pointings. If the total number of pointings is a concern, pointings of less than 10 ks can be added up to make pointings of at least 10 ksec in length.

2) For some ~10 of AGN2 sources additional offset background fields are needed (~700ks total). There should be several "standard" background fields that must be quasi-periodically revisited to monitor the evolution of background. This should be ~3% of net observing time.

Table 7-3: Potential sources per class (not exhaustive)

Source class	Sources
Brightest AGN1 (8 candidates)	MCG-5-23-16, MCG-6-30-15, NGC4051, NGC3516, NGC3783, NGC3227, MRK509, MRK766
AGN2 (22 candidates)	H0557-385, HE1143-1810, MCG-2-58-22, MCG+8-11-11,MRK110 MRK279, NGC4593, NGC5548, NGC7213, NGC7314, IC4329A, NGC7469, Q2251-178, ESO511-G030, IRAS05078+1626, NGC526A NGC2110, NGC2992, HE 1143-182, NGC4593, NGC4151, ARK120
BH Transients	4U 1543-47, 4U 1630-47, GRO J1655-40, GRS 1739-278, GX 339-4, H1743-322, IGR J17091-3624, MAXI J1543-564, MAXI J1659-152, MAXI J1836-194, SAX J1711.6-3808, SLX 1746-311, Swift J1753.5-0127, V4641 Sgr, GS1354-64, XTE J1118+480, XTE J1550-564, XTE J1650-500, XTE J1652-453, XTE J1720-318, XTE J1748-288, XTE J1752-223, XTE J1817-330, XTE J1818-245, XTE J1859+226, XTE J1908+094, XTE J2012+381, GRS 1915+105, (persistent; Cyg X-1)
Bright transient NS (3 sources)	AQL X-1, CIR X-1, 4U 1608-52
Bright persistent NS (13 sources)	Sco X-1, GX 5-1, GX 17+2, 4U 1636-53, 4U 1728-34 4U 1820-30, 4U 0614+091, 2S 0918-549, Ser X-1, 4U 1705-44 GX 349+2, Cyg X-2, 4U1702-429
Bursters (10 sources)	EXO 1745-248, 1M 0836-425, 4U 1323-62, 4U 1705-44, XTE J1710-281 XTE J1723-376, 4U 1746-37, GS 1826-24, XTE J2123-058, XTE J1739-285
Weak persistent NS (14 sources)	4U 1850-087, 4U 1915-05, XB 1832-330, 4U 0513-40 , 1A 1246-588 4U 1812-12 , 1RXS J170854.4-321857 , SAX J1712.6-3739 , 4U 1722-30 SLX 1735-269, SLX 1737-282, SLX 1744-299/300, 1A 1742-294, XTE J1701-407
Weak transient NS (7 sources)	XTE J1759-220, SAX J1806.5-2215 , GRS 1741.9-2853, KS 1741-293 SAX J1753.5-2349, 2E 1742.9-2929, KS 1731-260
Millisec pulsar outburst	SAX J1808.4-3658, XTE J1751-305, XTE J0929-314, XTE J1807-294, XTE J1814-338, IGR J00291+5934, HETE J1900.1-2455, S wift J1756.9-2508, SAX J1748.9-2021, NGC 6440 X-2, IGR J17511-3057

Observing times and schedules in the overwhelming majority of cases are set by intrinsic source state variations rather than by S/N considerations. Sources have different spectral/timing states, and we need to sample each state over a range of luminosities in order to understand the processes we are detecting with LOFT, or in order to catch a source in the right state to see the process in the first place. Transients are named that will likely not be on, these serve as placeholders for similar transients that will be discovered by LOFT WFM and perhaps other means.

The total observing time required for the **top level science requirement is 24.7 Ms**, which corresponds with a realistic but conservative observing efficiency of 50% to 1.6 years elapsed time of which ToO targets are 6.7 Ms v and non-ToO 18.0. For the bright AGNs we could save observing time by doing 50% as ToOs (need to cover several flux levels in each source). However, it should be recognized that we need a longer mission duration to ensure a good probability to observe the rare transient events needed for some of the science goals. There are no SGRs in the table as we only have the serendipitous offset observations as a top level goal – we DO plan to have TOO triggers in place for when an SGR becomes active, to point at them to see if intermediate flares happen – this is not guaranteed to succeed, hence not a top level goal.

A preliminary breakdown (based on reasonable assumptions on the targets for Observatory science) of observing time spent at different viewing directions is given in [RD 4].

Table 7-4: Expected observing time spent at different viewing directions (note that a mission duration of 4 years corresponds to 50 Ms with a 50% observing efficiency)

Viewing Direction	Primary Science	Observatory Science	Total (Ms, %)
Galactic Centre	12.4	4.6	17.0 (35%)
Galactic Plane	2.5	5.2	7.7 (15%)
Rest	9.8	15.2	25.0 (50%)
Total	24.7	25	49.7

A final consideration for the observation plan is the mission life time to have a good probability to catch rare events: BHCT in the intermediate state with HF QPOs, and AMXPs. The number of transients is relatively low (few). We have selected realistic assumptions in the sense that we do not take into account that the number can be larger due to the huge improvement in the sensitivity of LOFT compared to RXTE. Still we assume that some of the known, persistent, sources will be active in the LOFT era. This includes GRS1915+105 (BH transient outburst) and NGC 6440X-2 (AMXP). This probability has to be folded with the field of regard of the mission (as it is of no use if LOFT cannot observe the source when it becomes active due to viewing constraints.

Table 7-5: Probability for the occurrence of transient events as function of life time and sky visibility given as constraints on the Solar Aspect Angle (note that we always expect 1 source based on current data)

Sky visibility	± 30		+30/-50		+30/-70		+30/-90	
BH transient outburst								
number sources	2	3	2	3	2	3	2	3
5 years	0.993	0.95	0.999	0.99	1	0.997	1	0.998
4 years	0.98	0.90	0.995	0.96	0.999	0.99	0.999	0.99
3 years	0.95	0.79	0.98	0.9	0.994	0.95	0.996	0.97
Accreting millisecond X-ray pulsars								
number sources	2	3	2	3	2	3	2	3
5 years	0.993	0.95	0.998	0.98	1	0.995	1	0.997
4 years	0.98	0.87	0.994	0.95	0.998	0.98	0.999	0.99
3 years	0.95	0.77	0.98	0.87	0.992	0.94	0.995	0.96

Based on these expectations it is concluded that the minimum life time of the mission should be 4 years for a sky visibility of +30/-50 degree and 3 years for +30/-70 degree. Under these conditions the expectation for 3 BH transient outbursts and AMXPs is around 95% and the probability of detecting two in each group is larger than 99%. Also, with a conservative estimate of 50% observing efficiency the full program can be performed.

Appendix A Additional science requirement dependencies

Some of the instrument and mission requirements are highly coupled and we have selected a reasonable balance between the key parameters which include effective area, sky visibility (field of regard and extended field of regard and mission duration). For example

- a reduction in effective area of the LAD can, to a significant degree, be compensated by a longer mission duration or a larger field of regard. There is only a limited effect on attaining the core objectives. It will, of course, affect the overall science return of the mission as it reduces the discovery space.
- a smaller field of regard can be compensated by a longer mission duration;
- although all science goals benefit from it, not all core science requirements (L1 level) need a good spectral resolution. Hence the nominal Field of Regard with nominal spectral resolution is driven by those core science objectives which need good spectral resolution (SFG2, SFG4, SFG5) and for the other science goals the extended field of regard can be used. If good spectral resolution is available also for the observations aimed at the other core science objectives, it will enable a desirable additional scientific return;
- a larger field of regard or extended field of regard allow for a shorter mission duration provided we can execute the observations for the core science (e.g. sky visibility of the Galactic Centre is sufficient).

Although the number of combinations is large, two issues are driving part of the instrument and mission design: the effective area and the sky visibility with good or degraded energy resolution. We can demonstrate that the current instrument and mission requirements have a safe margin for these parameters.

A.1 Effective area

In Table A-1 we provide an overview of the science impact of a reduced effective area. For this we provide first the basic effects of a reduced area, followed by the potential mitigation. As is indicated some of the L1 core requirements can be fully compensated but in other cases some loss of science (less sensitivity, fewer sources) can also be the consequence. In the last columns of this table we quantify the effect of a reduction to 70%, 80% and 90% of the effective area, on increase in observing time, source flux constraints or number of sources.

	Type	Compensation	Aeff reduction		
Science			70%	80%	90%
EOS1	coherent analysis, errors scale as $Aeff^{-1/2}$	**Yes**: observe longer to collect same number of photons: $T_{new} = T_{old} * A_{old}/A_{new}$	1.43	1.25	1.11
EOS2	coherent blind search, attainable amplitudes scale as $Aeff^{-1/2}$	**Mostly**: observe longer $T_{new}=T_{old}*(A_{old}/A_{new})$ *small correction; this means more acceleration smearing so one loses the tightest orbits	1.43	1.25	1.11
EOS3	incoherent blind search, attainable amplitudes scale as $Aeff^{-1/2}$, S/N drops as Aeff	**Mostly**: longer mission to catch brighter SGRs. For the same signal the source needs to be brighter (see next columns)	>1430 mCrab	1250 mCrab	1110 mCrab
SFG1	incoherent detections and analyses. attainable amplitudes scale as $Aeff^{-1/2}$, S/N drops as Aeff, centroid errors increase as $Aeff^{-1}$, number of detections drops as Aeff	**Mostly**: longer mission and better sky access to observe more BHTs --- average more data as $T_{new}=T_{old}*(A_{old}/A_{new})^2$ but this increases smearing	2.04	1.56	1.23
SFG2	coherent analysis, errors scale as $Aeff^{-1/2}$	**Yes**: observe longer as $T_{new} = T_{old} * A_{old}/A_{new}$	1.43	1.25	1.11
SFG3	detect signal within coherence time (~0.1 s) attainable amplitudes scale as $Aeff^{-1/2}$	**Fewer sources**: no compensation possible, this will be done for fewer sources, need proportionally brighter sources, assuming a galactic disk distribution the number drops as Aeff. Nominal sources is 10	7 NS	8 NS	9 NS
SFG4	incoherent analysis	**Yes**: observe longer $T_{new} = T_{old} * (A_{old}/A_{new})^2$ and assume process is stationary for this longer time	2.04	1.56	1.23
SFG5	coherent analysis dominated by background systematics	**Fewer sources**: for average line profiles observe longer $T_{new}=T_{old}*A_{old}/A_{new}$. for tomography fewer sources are accessible as time is fixed, need proportionally brighter sources, so cover smaller volume, number scales as $Aeff^{3/2}$. Nominal sources is 6 + 14 AGN	1.43 4+14 AGN	1.25 5+14 AGN	1.11 6+14 AGN

Table A-1 *Impact of reduced effective area*

In summary this analysis shows that the core science goals are not at stake if the effective area reduces by the order of 10%. However, some of the science goals will be less ambitious (e.g. a slight reduction in the number of AGNs on which LOFT can perform highly significant Fe line tomography) whereas others can be still achieved but require (significantly) longer observation times (and hence mission duration). However, we cannot claim that the accuracy in the predictions is such that it is mission critical to change one of the other mission constraints (Field of Regard, mission life time) when the effective area reduces by 10%. When larger reductions in the effective area are needed it is strongly recommended to optimize some of these other design parameters.

A.2 (Extended) Field of Regard

The Nominal Field of Regard is the part of the sky which can be observed with the nominal energy resolution and the extended field of regard has been introduced to allow for observations of sources where the energy resolution is not required. The required field of regard is 35% of the sky (corresponding to the FoV in the M3 proposal) and the extended field of regard is 50%. In practice this implies that for the extended field of regard the thermal requirements on the LAD instrument will be less stringent.

A second factor which needs to be folded in is that a fraction of the relevant sources for LOFT is in the Galactic Centre, which implies that we need to consider the fraction of observing time for the Galactic Centre separately from the total observing time. In *Table A-2* we summarize the required observing times for the core program (top half) and the available observing time on the Galactic Centre for different assumptions. As can be seen there is a considerable margin between the needed observing time with good spectral resolution and the available observing time (needed 8.1, available 17.8 for a 4 year mission). Also with a shorter mission the margin is significant.

Table A-2 Available observing time on the Galactic Centre

Type	Time [Ms]	Comment
Core observing plan		
Total on Galactic Centre	12.4	
with spectral resolution on Galactic Centre	8.1	
Total core science	24.7	
Total core science with nominal spectral resolution	18.8	
Available observing time for nominal mission duration		
Total observing time	63.1	(50% observing efficiency)[1)]
Total observing time Galactic Centre for Sun constraint ± 10° (20% of sky visible)	8.8	
Total observing time Galactic Centre for Sun constraint ±20 ° (35% of sky visible)	17.8	nominal spectral resolution requirement and thus the baseline
Total observing time Galactic Centre for Sun constraint ±30 ° (50% of sky visible)	26.4	Degraded spectral resolution requirement

1) Note that both the industrial studies give an observing efficiency in excess of 50% hence the calculated number is conservative.

The last factor to be considered is the observing time available for the BHCT and AMXPs. In total we require for these very bright sources 3.4 Ms which is not predictable in time (and may happen at a part of the year when the Galactic Centre is poorly visible). Of these sources the BHCT require a campaign length of 100 – 300 days, only a few weeks of which can be expected to exhibit the HF QPOs required for SFG1 and the AMXPs require observing campaigns of typical 20 days (total required time is 300 ks per AMXP). This potential risk is mitigated by the allowance of regular out of field of regard observations (due to the few hour thermal intertia of the system). As can be seen from Table A-2 the visibility with a very small solar constraint (± 10°) gives still a total of 8.7 Ms for a 4 year mission, well in excess over the needed observing time.

A.3 Energy resolution and bandwidth

LOFT will provide a unique combination of effective area, energy bandwidth and spectral resolution. The area, also in connection with the field of regard, has been discussed above and here we will discuss the justification and trade-offs for the energy resolution and bandwidth.

A3.1 Bandwidth

The energy resolution and bandwidth are driven primarily by the Strong Field Gravity science goals. It is very important to have the broadband energy coverage to model the reflection properties measuring both Fe line profile and Compton reflection continuum above 10 keV. The good leverage on the continuum in a broad energy band will allow us to disentangle all spectral components and, in turn, to correctly model the residuals of the Fe line. The power of the broad energy range in determining model parameters has been recently demonstrated by XMM and NuStar analysis of NGC1365 (Risaliti et al. 2013). In this respect the high energy response of LOFT is unique, covering simultaneously the 2-30 keV band with a great improvement in effective area in both low and high energy ranges, a factor >60 higher with respect to XMM in the Fe K domain and a factor of ~30 with respect to NuStar or Astro-H at 30 keV. The 2 keV low end of the bandwidth has been set to enable the study of photo electric absorption and soft components, the 30 keV allows one to determine the AGN and X-ray binary continuum spectra in order to study reflection or absorption effects and allow for the accurate determination of the continuum underneath the Fe-K line profile. With an upper range of 80 keV (no specific resolution is required) fast high-energy phenomena such as SGR/AXP flares can be studied. In practice these bandwidth limits are not absolute limits but the science will degrade gradually (an effect of about 10% in the energy thresholds has a small effect on the science but it depends somewhat on details of the science case). It should be noted that the energy range is unique for the WFM and will, for the first time enable the monitoring of the sky below 5 keV with CCD-class spectral resolution.

A3.2 Energy resolution

The energy resolution of the LAD is driven by three of the five goals (level 1) of the Strong Field Gravity science and these have been used to define the energy resolution requirement. The 3 relevant science goals are:

SFG2 Detect disk precession due to relativistic frame dragging with the Fe line variations in low frequency QPOs for 10 neutron stars and 5 black holes.

SFG4 constrain fundamental properties of stellar mass black holes and of accretion flows in strong field gravity by measuring (a) the Fe-line profile and (b) carrying out reverberation mapping and (c) tomography of 5 black holes in binaries providing spins to an accuracy of 5% of the maximum spin (a/M=1) and do comparative studies in 10 neutron stars

SFG5 constrain fundamental properties of supermassive black holes and of accretion flows in strong field gravity by measuring (a) the Fe-line profiles of 20 AGNs and, for 6 AGNs: (b) carry out reverberation mapping and (c) tomography, providing BH spins to an accuracy of 20% of the maximum spin (10% for fast spins) and measuring their masses with 30% accuracy,

However, whereas these science goals drive the energy resolution, the combination of spectral resolution with timing resolution (large effective area) will open up a new discovery space and the results of this new discovery space cannot be predicted at this time. Hence, we have aimed at a design with an ambitious but feasible , but ambitious energy resolution. As we will show, with CCD-class spectral resolution and passively cooled detectors we can achieve these three science goals.

As specified in this requirement document, in practice the instrument will have different classes of events:

single anode events and double anode events. They will have different resolution but for simplicity we will analyze the data for the full detector and refer to this as ~ 240 eV resolution ("nominal" energy resolution) and study the science impact in the event of a degradation, taking 270 eV and 300 eV as case study (it is useful to note here that this is not the degradation in energy resolution associated with the extended field of regard, which is 400 eV). The two main components to the resolution are the intrinsic limiting resolution of Silicon detectors (called Fano noise) and the electronic noise (read-out pre-amplifier and detector leakage current). A number of other components - including uncertainties in the knowledge of DC noise, gain and offset (see LOFT-IAPS-PLC-MD-0001 for details) - contribute to the resolution but they are of less importance.

A.3.2.1 Reverberation mapping and tomography of BHs and NS (SFG4 and SFG5)

A degraded spectral resolution will increase the uncertainty on the determination of the centroid (typically by the inverse of the degraded resolution) for a given model. The extra uncertainty here is statistical (depending also on photons per phase or time-delay bin), rather than systematic (i.e. not being able to distinguish distinct variable spectral components, which are all broad in this case and variable in much longer time scale with respect to the orbital period of the disc). Thus the increase of the uncertainty can be mitigated by longer observations, with the exposure time scaling roughly with the square of the relative degradation in energy. This has been verified by detailed simulations for an orbiting hot spot and for the reverberation mapping. The fact that the Fe-line is relatively broad and we also fit the broad reflection component confirms this also qualitatively.

This argument is only correct if the hot spot lasts long enough to compensate a loss in spectral resolution by longer observations. However, in case of a hot spot the prime science comes from the variability of the spectra. In this case the complexity and correctness of the model for the emission without hot spot is therefore of less importance.

A.3.2.2 Fe-line variations in low frequency QPOs (SFG2)

Essentially the same correction can be applied as for the reverberation mapping and tomography case.

A.3.2.3 Fe-line profile in 20 AGNs and determination of spin and masses (SFG5)

The driving requirement is to be able to disentangle all different emission line contributions in the Fe K band (3-8 keV), namely: narrow neutral and ionized lines (Fe Kα, Fe Kβ, Ni Kα) plus broad Fe K line with the goal of determining accurately the broad line parameters to recover the BH's spin. These components are illustrated in Figure A-1. We worked with AGN, since they will represent the weak, i.e. worst, case scenario. The requirement 240 eV (the expected resolution of single anode events with 200 eV resolution for 40% and 260 eV for the other 60%) is necessary to measure the BHs spin in AGNs with the 20% accuracy. This is shown in the left panel of Fig. A-2 where the 68, 90 and 99% (black, red and green respectively) confidence levels of the disc inclination vs BH's spin are given We also mention that all narrow emission line components in the X-ray spectra of AGNs are produced in reprocessing media distant from ~0.1pc to a few pc from the central BH (BLR and molecular torus) and then likely constant over years timescales. Since we are targeting here bright AGNs, Chandra and XMM already observed all of them allowing characterization of the narrow emission lines. It is also worth noting that Astro-H will observe the AGN LAD sample long enough to characterize with its unprecedented eV precision all narrow components in the Fe K energy range.

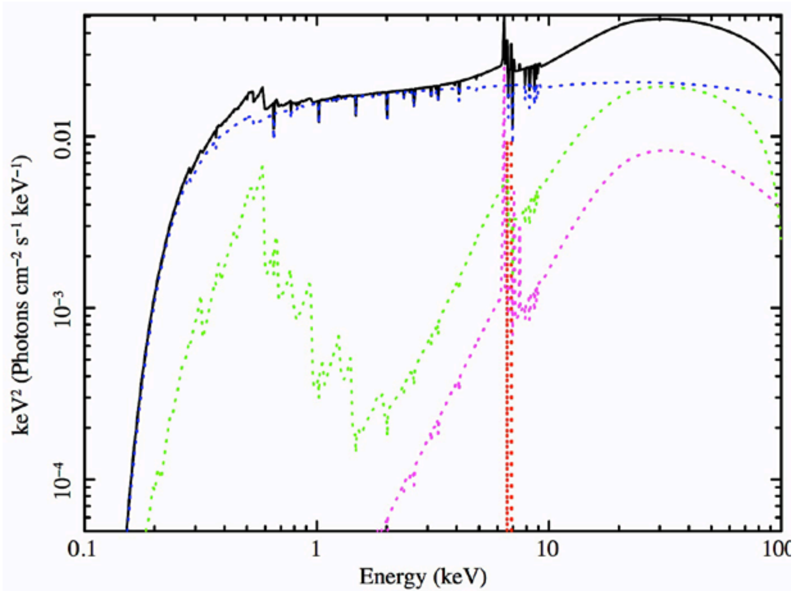

Figure A-1: different components of a AGN spectrum including the continuum and ionized absorber (blue), the cold reflection and narrow Fe line Kα, Fe-Kβand Ni-Kα (magenta), the ionized lines FeXXV and Fe XXVI (red) and the blurred ionized reflection component (green). The total emission is given in black.

With the nominal energy response of 240 eV we are able to disentangle all the different line components in the Fe region and get good measurements of the blurred reflection components (continuum and lines). As an example, starting with BH spin a=0.7, we were able to recover the BH spin at the ~20% level of accuracy, despite the presence of narrow Fe Kα, Fe Kβ, Ni Kα and ionized lines due to a "hot gas" emitter with ionization parameter log(xi)~3.5 (see left panel in Fig. A-2). Assuming instead 300 eV FWHM energy resolution for the total of events, we detect some ambiguity in disentangling the different line contributions. In particular, the ionized lines (Fe XXV/XXVI with equivalent width ~ 40 eV) are blurred together and with the broad line blue wing that prevents the determination of the disc inclination and emissivity with the requested accuracy. This also prevents an accurate spin determination and the error rises to > 50 % (see right panel in Fig. A-2). We also check the effect of an intermediately degraded energy resolution (270 eV FWHM). In this case the scientific objective is still reached, although with a larger uncertainties on the spin determination (typical 99% confidence level at ~40%, see middle panel in Fig. A-2).

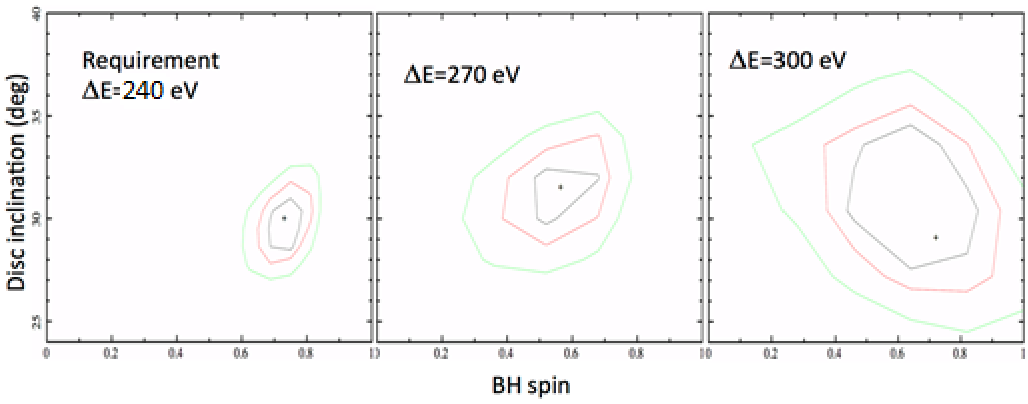

Figure A-2. Confidence contours (68, 90 and 99% in black, red and green respectively) of disc inclination vs BH's spin for different value of the LAD energy resolution: the requirement value (240 eV), degraded (270 eV) and worst case (300 eV). The model is that presented in Fig. A-1 including warm absorption, cold reflection and narrow ionized Fe line.

Conclusion

We performed a sensitivity analysis of the risks associated with a potential non-compliance of the LAD energy resolution parameter with the requirement. It has been illustrated that even in the event of an energy resolution not meeting the requirement, consequences for the science objectives can be mitigated by longer observations, with the exception of the Fe-line profile fitting where a 10% spectral resolution degradation is still within the science requirements but a 20% degradation will not meet the requirements. This is summarized in Table A-3. Of course, this conclusion depends on the assumption that we have a correct understanding and description of the spectra of these sources (and with a better energy resolution this will be verified more easily).

Science goal	Type and effect	~270 eV resolution	~300 eV resolution
Relativistic frame dragging in LF QPOs	Coherent, change of observing time	Observing time x 1.1	x 1.2
Reverberation mapping	Incoherent, change in observing time	x 1.2	x 1.4
Tomography	Incoherent, change in observing time assuming the hot spot lasts sufficiently long	x 1.2	x 1.4
Fe-line profile fitting	increase of errors in spin/mass	Increased uncertainty but close to requirement	Increased uncertainty by about a factor 2 above the requirement

Table A-3

Appendix B Science requirements flow down

In this appendix we give the logic of the requirements flow down. We have taken a number of reasonable assumptions for the balance between the various requirements (which need to be confirmed by the mission design). Below we first present the flow down of the requirements (level 1 to level 2a> This is given in Table B-1 for the LAD and in Table B-2 for the WFM. The flow-down from level 2a to level 2b is given in Table B-4 and finally we list the additional requirements (level 2c) that should not drive the mission design but are nevertheless important to optimize the science output of the mission. The flow down from level 0 to level 1 is omitted for brevity.

Table B-1 LOFT science requirement flow down (only driving science goals are given and the others are left empty).

	Level 2a								**Other**
Level 1	LAD 1,2,3,4	LAD-23,24, 25,26,27	LAD-6	LAD-8	LAD-11	LAD-17	LAD-19		WFM
	Aeff [m² @ keV]	Response stability[3] [for range]	E- range [keV]	ΔE@6 keV [eV]	Off-axis @30 keV for 45°	Back-ground (2-30 keV) [mCrab]	Flux [mCrab]	Max flux sustained	Camera[2]
EOS1	10 @ 8	10-2000 Hz				10	>500	15 Crab	Yes
EOS2	10 @ 8	10-2000 Hz				10		15 Crab	Yes
EOS3	1 @ 30	10-2000 Hz	Upper limit of 80 keV		1%[1]		>500		
SFG1	10 @ 8	1-1200 Hz					>500	15 Crab	Yes
SFG2	4 @ 2 10 @ 8 8 @ 5	0.01 – 1 Hz 1-1200 Hz	2 - 30	260			>500	15 Crab	Yes
SFG3	10 @ 8	1-1200 Hz					>500	15 Crab	Yes
SFG4	4 @ 2 10 @ 8 8 @ 5 1 @ 30	0.01 – 1 Hz	2 - 30	260			>500	15 Crab	Yes
SFG5	4 @ 2 10 @ 8 8 @ 5	< 0.01Hz	2 - 30	260		10			

1) the EOS3 can be met by either a part of the detector without collimator (at the expense of area) or by a transparency in the collimator (SCI-LAD-R-28)
2) A wide field monitor is required to detect transient events or state changes in known sources for all Level 1 science requirements with the exception of EOS3 and SFG2
3) For the response stability not the requirements are given but the frequency range for which they apply, the absolute numbers can be found in the requirement itself (SCI-LAD-R23,24,25,26,27)

Table B-2 LOFT science requirement flow down (second part for WFM). Note that the need to have a WFM is given in the first part of the table

	Level 2a				
Level 1	WFM-01[1)]	WFM-03	WFM-05	WFM-14	WFM-16
	Location accuracy [arcmin]	Sensitivity	Field of view	Transient down link	Onboard memory
EOS1		1 Crab/s	π sr	3 hr	
EOS2		1 Crab/s	π sr	3 hr	
EOS3					
SFG1	1		π sr	3hr	5 min 100 Crab
SFG2	1	1 Crab/s	π sr	3h	5 min 100 Crab
SFG3		1 Crab/s	π sr	3h	
SFG4	1	1 Crab/s			5 min 100 Crab
SFG5		5 mCrab/50 ks	π sr		

1) Localization accuracy is given for a source > 10 mCrab (2-10 keV) in 50 ks (typical S/N around 20)

In addition a number of level 2a requirements follow from the top level goals and the observing plan. These are listed in Table B-3.

Table B-3 Level 2 system requirements including their parent requirement

Level 2a requirement	Parent requirement	background to the requirement (details are given in section 5.2)
Net core science observing time (SYS-01)	TOP1, 2	See table in section 7, needed to accomplish the two core science goals
Net observatory observing time (SYS-02)	TOP3	Allocated time for the observatory science
Accessible sky fraction nominal resolution (SYS-19)	Observing plan	See table 7.1 in section 7 and appendix A
Galactic center visibility (SYS-06)	Observing plan	A large fraction of the events will take place in the Galactic Centre
BHCT/AMXP probability (SYS-07)	Observing plan	See observation plan. These are key observable targets and the probability to observe two should be large

Table B-4 LOFT derived science requirement flow down (from level 2a to level 2b)

Level 2a parameter	Level 2b parameter	Level 2b number	justification
LAD effective area (LAD 1,2,3,4)	LAD effective area knowledge	LAD-05	Allows to cross correlate with data of other missions
	LAD deadtime	LAD-15	A large deadtime, even if accurately known, corresponds to a reduction in effective area. This also indicates that, in principle, it can be compensated by larger area detectors
	Typical data rate	SYS-15	The observation plan in combination with area (and event decoding) defines the typical observing data rate
	Sustained data rate	SYS-16	The same is true for the sustained data rate
LAD response stability, (LAD-23,24,25,26,27)	LAD deadtime knowledge	LAD-16	A unknown deadtime corresponds to countrate dependent variations in the response which may result in false detections
LAD energy range (LAD-06)	WFM Energy range	WFM-06	Matches the LAD energy range
LAD energy resolution (LAD-08)	LAD ΔE=200 eV @ 6 keV for 40% of events	LAD-09	For the data analysis we can combine the nominal resolution together with the improved resolution for events read-out in a single anode. Hence the final spectral resolution is a combination of the two resolutions
	LAD degraded resolution	LAD-22	Not all science requires a good spectral resolution. As the required spectral resolution drives the temperatures (and hence the SAA) it is useful to define a degraded energy resolution as well (outside the field of regard). The actual value is set at 400 eV but could be also somewhat larger (100 eV) before affecting the science significantly.
	LAD energy knowledge	LAD-07	Combination of data for different epochs should not affect the energy resolution significantly (contribution is set at 1/4 of the energy resolution at 6 keV)
	Orbit	SYS-11	Radiation damage due to the selected orbit should allow for the resolution to stay within the requirements at the end-of-life.
LAD background (LAD-17)	Collimated field of view	LAD-10	A smaller field of view results in a lower CXRB but this needs to be balanced with the pointing accuracy and stability as well as with feasibility to make a collimator with a 70% open area fraction
	Background knowledge	LAD-18	With the proper knowledge on the background (including variations over an orbit) a larger background is acceptable. The required level is feasible and is in agreement with the 10 mCrab background requirement
	Orbit	SYS-11	The orbit should be such that the background is achieved (and also the resolution degradation over the mission life time)
Max flux (nominal) LAD-19	Max flux rebinned	LAD-20	For brighter sources it is acceptable to lose some information (rebinning needed) but some upper limit had to be set. The proposed upper limit will only affect a limited number of sources over the mission lifetime (about 30) and, in these cases, the number of counts is high and data compression is required
	Onboard data	LAD-21	To cope without critical science loss in case ground contact is

	memory		lost for 4 orbits
	Telemetry rate		
Location accuracy WFM-01	Angular resolution	WFM-02	The localization depends on the angular resolution and the S/N ratio. With 5 arcmin a position accuracy of 1 arcmin is feasible for sources with a S/N of about 20 (few mCrab/day)
Peak sensitivity in LAD direction WFM-03	Sensitivity knowledge	WFM-04	Cross calibration with other X-ray instruments
	Time resolution	WFM-10	Time resolution matches the typical integration time
	Duration of rate triggers	WFM-12	Combined with the sensitivity this sets the trigger level for transient events
	Rate meter data	WFM-13	Study time variability on short time scales when no position information is needed
	Relative sensitivity	WFM-18	Allows determination of peak fluxes irrespective of camera and orientation
	Sensitivity variations	WFM-19	Allows to compare results of different epochs
	Number of triggers	WFM-20	Corresponds to the expected sensitivity
Field of view WFM-05	Redundancy	WFM-22	Need to cover field of view even with failure of single camera
Collimated LAD field of view LAD-10	Pointing accuracy	SYS-08	Satellite pointing accuracy should match the field of view of the LAD and thus also match the WFM position accuracy
	Pointing knowledge	SYS-10	On top of the accuracy we need also to have the knowledge as, together with the LAD field of view this defines the background
Net observing time (SYS-01)	Calibration time	SYS-03	a reasonable fraction for the calibration time defines, together with the observing time the mission duration. With 5% the required calibration levels are feasible
	Slews per orbit	SYS-13	Together with the observing plan this number is required to reach the required observing efficiency
Probability to detect AMXP/BHCT SYS-R07	Minimum observing time	SYS-04	A minimum observing time improves the probability to observe rare events in case they are only visible in the night part of the orbit
	Mission duration	SYS-09	In combination with the observing plan and the sky visibility the probability to detect AMXP/BHCT defines the mission duration
	TOO alert	SYS-14	In order to respond in reasonable times to transient events (needed to detect some sources such as AMXP/BHCT) a response time is needed
	Quick Look analysis	SYS-18	To catch the transient events that data should be inspected. No fast response is required (as sources will, in general, be on for periods of weeks to months)
Pointing accuracy (SYS-08)	Absolute measurement accuracy	SYS-10	The absolute measurement accuracy of the AOCS system should be a relatively minor contribution
Sky visibility nominal energy (SYS-19)	Extended Field of Regard with degraded energy resolution	SYS-05	Allowing for a degraded energy resolution increases the total observing time available. This is advantageous as not all science requires the good spectral resolution
Typical data rate SYS-15	Downlink rate	SYS-17	The downlink rate follows from the amount of data collected over an orbit (sized for 500mCrab source, but assuming WFM data and/or telemetry "catch-up" will fill up to this

rate).

Table B-5 Level 2c requirements on the LAD, WFM and system. Note that some WFM requirements are derived from the LAD requirements (to match the LAD performance) but are intrinsically not driving the design

Level 2c requirement	number	background to the requirement (details are given in section 5.2)
LAD Time resolution	LAD-13	Time resolution is determined by the drift time in the detector but the system should not add a significant additional component
LAD Absolute time accuracy	LAD-14	Comparison with other wavelength bands is facilitated by a good timing accuracy (but again this is not driving the design)
LAD redundancy	LAD-23	This requirement follows from the minimum success criteria for the mission
WFM energy resolution	WFM-07	In principle the resolution is similar as for the LAD but given the number of counts a somewhat degraded resolution is for almost all cases equivalent
WFM energy scale knowledge	WFM-08	Allows to combine data from different epochs. The accuracy of 4% corresponds to 240 eV at 6 keV (where the intrinsic resolution requirement is 500 eV)
WFM energy bands	WFM-08	See justification in section 5.2
Energy bands compressed images	WFM-09	Defines the energy ranges which can be limited (considering count rates and spectral resolution in the WFM)
WFM absolute time accuracy	WFM-11	Matches the LAD absolute time accuracy (LAD-14)
Onboard availability of triggered data	WFM-15	Not a driving requirement but will ensure that important data for the WFM is stored to enable secure transmission to the ground
Broadcast trigger information	WFM-17	Not a driving requirement but will enhance the mission science return for a large community and other observatories

Appendix C Obsolete requirements

Compared to the version 1.6 of the SciRD various requirements have been refined (in substance they were not changed but their definition has been sharpened to avoid misunderstandings). At the same time a few requirements have been dropped as they were obsolete or better captured in a more general formulation. The relevant requirements are given below for traceability.

Flat top	LAD-12	Concept of flat top was dropped and replaced by pointing stability requirement
Orbit altitude	SYS-R11	Replaced by a more top level orbit with low background and low radiation dose
Orbit inclination	SYS-R11	Dropped in favor of the more generic requirement. The actual orbit requirements are given in the MRD

Likewise there were requirements on redundancy that were defined, but which are not classified as science requirements. Accordingly it was decided that the data rate and other technical issues should be captured in this appendix in order to trace the scientific arguments behind design issues that should instead be reflected in the Experiment Interface Document Annex A.