ESA UNCLASSIFIED – For Official Use

estec

European Space Research - and Technology Centre - Keplerlaan 1 - 2201 AZ Noordwijk - The Netherlands
T +31 (0)71 565 6565 - F +31 (0)71 565 6040 - www.esa.int

DOCUMENT

LOFT Mission Requirements Document

Prepared by	**LOFT Study Team**
Reference	**SRE-F/2012-076/RQ/MA**
Issue	**3**
Revision	**6**
Date of Issue	**11/02/2013**
Status	**Approved/Applicable**
Document Type	**RQ**
Distribution	**Open**

European Space Agency
Agence spatiale européenne

APPROVAL

Title LOFT Mission Requirements Document	
Issue 3	**Revision** 6
Author LOFT Study Team	**Date** 11/02/2013
Approved by	**Date**

CHANGE LOG

Reason for change	Issue	Revision	Date
New SciRD (Issue 1 Rev. 3), PDD (Issue 1, Rev. 2) and multiple clarifications/corrections on requirements	2	1	03/02/2012
New SciRD (Issue 1 Rev. 4), PDD (Issue 1, Rev. 3) and multiple clarifications/corrections on requirements	3	1	29/06/2012
Multiple clarifications/corrections on requirements after consultation with industry	3	2	04/07/2012
Corrections mainly on pointing and GS requirements after further clarification and consultation with payload team and industry; main change is introduction of degraded field of regard in response to SCI-LAD-R-22 in the SciRD.	3	3	09/09/2012
Revision following internal review in preparation for instrument AO. Updated LAD temperature requirements based on clarification exercise with the payload consortium.	3	4	19/09/2012
Revision to establish baseline for the remainder of the Assessment Phase, and also to establish better links to the SciRD. Updated payload information and requirements. Also included NGRM as additional PL, and made various changes throughout (listed in CL.)	3	5	08/02/2013
Slight update to tidy annexes and include goal requirements in MRD which were previously not represented – NO CHANGES TO CONTROLLING REQUIREMENTS MADE, except reinstatement of applicability of RPE requirement to LAD Reference Boresight.	3	6	11/02/2013

CHANGE RECORD

Issue 3	**Revision** 6		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

Transfer of updated SciRD into MRD and multiple clarification on requirements - Slight changes to section order to improve readability. Minor changes to wording throughout. Provided issue numbers for several references. Added description of the platform/payload split of responsibilities for the PLM. Inclusion of parent SciRD requirements where appropriate throughout. Removed references to Vega launch vehicle throughout (now only Soyuz is applicable launch vehicle) Changed space debris AD from European Code of Conduct to ESA/ADMIN/IPOL Annex 1. Slight change to definition of LAD solar aspect angle. Specification of epoch for GC location definition. Change to documentation issue schedule to include “3” issues during industrial assessment study, Update to Soyuz user manual reference. Inclusion of LOFT Mission Analysis Guidelines document as applicable document. Added requirement on GC occupancy 35% R-PERF-014. Added R-PERF-011 to specify BoL FoR. Added description of agreed availability budget line-items below R-PERF-040. Removed R-PERF-042 relating to observations outside the South Atlantic Anomaly (superseded by guidelines to R-PERF-040). Turned section 4.2 (instrument requirements) into information only – was repetition of SciRD requirements. Added R-PERF-106 on LAD FoV obscuration. Changed R-PERF-120 to specify alignment of WFM Z-axis and LAD FoV. Added G-PERF-152 related to broadcast of triggered alerts. Altered R-PERF-100, R-PERF-130, R-THRM-030, R-THRM-070 to allow evolution of required temperatures on detectors throughout the mission lifetime. Also altered to specify detector energy resolutions until end of EOL Change R-Sys-060 to specify 5.25 mission lifetime. Deleted R-MECH-020, superseded by global mechanical alignment specification R-MECH-030 and R-MECH-032. Added R-MECH-030 and R-MECH-032 specifying maximum misalignment of LAD modules. Added R-THRM-040 as global requirement specifying LAD payload temperature limits. Changed R-THRM-050 and R-THRM-060 to link to PDD temperature requirements.	29/06/2012	throughout	throughout

Changed R-THRM-080 to link to PDD temperature requirements. Reinstated R-AOCS-060 to specify jitter requirements on LAD boresight. Moved R-AOCS-080 to AOCS section. Created new section 'Pointing Requirements'. Deleted R-PWR-030. Changed R-TTC-025. Added R-TTC-089 to specify uplink requirements. Added R-SEM-050 to specify compatibility with in-flight mechanical environment. Added R-SEC-015 to specify PDD contamination requirements. Removed data-limit from R-OGS-020. Removed G-OGS-130 (superfluous to R-OGS-120 which contains reference which contains Malindi GS information). Introduced concept of LAD Module and LAD Reference Boresights – this establishes the limit of spacecraft responsibility in alignment and pointing; above this is the LAD-payload responsibility. Slight rewording of G-MIS-150. Replaced 'should' with 'shall' in R-PERF-014 and R-PERF-160. Included specific reference to WFM FoV specification in PDD (R-PERF-110). [R-SYS-050]Included note to specify that when the SC is in eclipse, +X_sc specification can be relaxed. [R-MECH-030] re-expressed using LAD Module Reference Boresight. [R-MECH-032] re-expressed using LAD Module Reference Boresight. [R-MECH-040] re-expressed using LAD Reference Boresight. [R-MECH-050] re-expressed alignment requirement between WFM/SC I/F and AOCS reference frame. [R-AOCS-060] re-expressed using LAD Reference Boresight, and changed wording in explanatory text. [R-TTC-025] changed to 99% CD on weather effects. Corrected hyperlink reference in R-SYS-030. **Issue 3.3/4 changes:** Split R-AOCS-070 into two (separated AKE requirement and sampling speed). Moved pointing section out of AOCS requirements. Turned R-PERF-011 into a goal not a requirement. Inserted LBAS into LOFT system product tree. Clarified R-PERF-045: requirement applies to 5% of the net observing time (i.e. 2% of the total time assuming observation availability is 40%).			

Cleaned up to remove separate AOCS and mechanical apportionments for pointing performance of the instrument boresights – there was a problem in that there was decomposition into AOCS and mechanical alignment (which is design specification). There was also double-accounting such that the actual APE requirement on the LAD was 2 arcminutes (1 arcmin satellite APE and 1 arcmin co-alignment) when the real requirement from the SciRD is 1 arcminute. Similar for the WFM. Adopted Reference Boresight also for WFM Camera (as already done for LAD) to clearly specify that part which is under platform responsibility. R-AOCS-060 retired and new requirement identifier given (R-POIN-030) – requirement is exactly the same, but now in Pointing Section, and with PSD-graphical representation of requirement included. R-MECH-040 and R-AOCS-050 both deleted and their combined effect replaced by R-POIN-010 which specifies the LAD Reference Boresight APE directly. R-MECH-050 and R-AOCS-050 both deleted and their combined effect replaced by R-POIN-020 which specifies the WFM Camera Reference Boresight APE directly. Note that it is now APE, because there is no capability from the WFM to provide a STR-like capability to determine its own attitude, and because the LBAS needs instantaneous knowledge, the requirement has become APE. R-AOCS-070 and 080 retired and given new identifiers in pointing section (R-POIN-040/050). Various changes to GS section to reflect the latest developments in GS-definition. New section on Science Data Centre and Instrument Team Centre. Updated I/F description to clear up responsibility for LBAS components. Removed 'arbitrary' in R-PERF-014, G-PERF-018 to make clear that requirement applies to a single point. Added G-PERF-050 to reflect SCI-SYS-G-14 in SciRD (within 8 hour observation). Corrected reference to SciRD in R-PERF-080 (was SCI-SYS-R-14, now SCI-LAD-R-14). Inserted TBC into R-PERF-150 to reflect that 30s is total allocation to LBAS speed, whereas the requirement here is placed only on the broadcast of the packet (i.e. could expect time to be allocated in this requirement to become something less than 30s). Added TBC to R-POIN-040 as it is under discussion with PI whether this requirement is truly needed Corrected missing "C" in requirement R-OGS-040. Added adoption ECSS-U-AS-10C adoption notice for ISO24113 on Space Debris Mitigation.			

Modified R-MIS-180 to include modified applicability of space debris mitigation reference according to the space sustainability ECSS. Added R-PERF-041 to specify that the availability should be produced against the LOFT observation plan document, which becomes an AD Struckthrough (proposed for removal) R-PERF-070, - ToO shall be specified in the observation plan, and then that is made applicable in R-PERF-041. Removed R-PERF-105 – FoV of the LAD is determined by the instrument design and is not under prime control. Changed shall to should in G-PERF-152. Specified J2000 in R-POIN-020. Added J2000 specification in R-POIN-040. Added figure to coordinate system specification. R-MECH-030 changed to specify mis-alignment with respect to the LAD reference boresight, because a global bias would be acceptable, i.e. what is important is the dispersion of the individual module boresights around the integrated instrument boresight. Introduced degraded FoR and BoL/EoL requirements on nominal and degraded FoR in order to allow profiling of the FoR evolution over the mission lifetime, in support of resolution of difficulties in satisfying LAD temperature requirements. Changed R-PERF-020 slightly to state upon eclipse egress rather than prior, to allow for a short thermal transient if this can be tolerated. Changed galactic centre requirements to apply to nominal FoR (i.e. requirements are effectively unchanged, but needed to account for the introduction of the degraded FoR). Changed note to R-SYS-060 to harmonise with only nominal mission performance to end of NOP. Changed R-MECH-030 to state module boresight relative to LAD reference boresight (LAD reference boresight can be off-set from AOCS reference frame by some angular distance, but after commissioning this is dealt with, and then only Module to reference is important. Changed R-THRM-070 to specify only applicable during WFM operation. Reinstated energy resolution requirements on instruments, and introduced R-PERF-101 for LAD, to provide definition of degraded energy resolution applicable during the degraded FoR operation. Removed 'if necessary' from R-PROP-020, because it has now been established that a controlled de-orbit and re-entry will be need for LOFT.			

Struckthrough R-IFG-010 as it was not specific. Struckthrough R-SEM-020 as it was not specific. Struckthrough R-SEC-010 because cleanliness and contamination requirements are TBD. Struckthrough R-SEMC-010 as it was not specific. Included note under R-MIS-010 to indicate that the launcher performance is defined in [AD11] – this is necessary because the Soyuz User Manual does not provide equatorial LEO performance information. Changed R-PERF-120 to specify the WFM global reference frame. Changed R-PROG-040 to remove 'as far as practicable' which is not measurable. Struckthrough R-PROG-030 as this is really non-specific and in any case is covered by R-PROG-020 which is specific. Removed mention of GNSS in note to R-PERF-080 (superfluous, design specification). Specified Soyuz-Fregat 2-1b in R-MIS-010. Replaced 'total' by 'overall' in R-PERF-045. Struckthrough G-STR-010 (specifies design implementation). Added 'and execution of the mission' to R-AOCS-010. Removed R-PWR-010 (design specification, not a requirement). Changed 'interface' to 'be compatible with' in R-TTC-030. Added LOFT Environmental Specification as an AD. Corrected MOC to SOC in R-OGS-040. Listed LBAS Ground Segment in descriptive text at start of Ground Segment section. R-OPS-150 added to specify compatibility with LBAS ground segment. Changed mission goals (2.2) to make more descriptive of the science objectives of the LOFT mission. Retired R-SYS-060 and replicated requirement as R-MIS-181 in section 3.4. R-STR-020 retired and placed in AIV section, with new identifier of AIV-020. R-PWR-010 removed (was implementation). R-TTC-120 added to specify that SC must be compatible with LBAS Ground Segment. Changed to R-PERF-150 and G-PERF-150 to 10s and 5s respectively, based on clarification in SciRD that 30s /20s requirement/goal refers to end-user receipt. Struckthrough R-PERF-041. Included LAD and WFMM SDD temperature requirements as table taken from PDD. Corrected R-OPS-140 and R-OPS-150 to R-OGS-140 and R-OGS-150. Added list of requirement identifier categories in section 1.3.1.			

Added R-MIS-182 for 2-year ground storage requirement (TBC). R-PERF-092 and 095 previously struckthrough, now removed. All previously struckthrough requirements now removed. Added ‘to the LBAS Ground Segment’ in R-PERF-150 and G-PERF-152. Deleted R-AIV-010 (not an MRD requirement). R-AIV-020 changed ‘instrument’ to ‘any unit’. Moves 2% of total time sentence from R-PERF-045 to supporting information text below. Struckthrough R-THRM-010. Deleted AOCS 050, 060, 070, 080. All previously struckthrough requirements have been removed, with their identifier remaining in the document with ‘deleted’ next to it. Requirement identifier for R-AOCS-080 was a previously retired requirement, so R-AOCS-080 becomes R-AOCS-090 and R-AOCS-080 now marked as deleted. R-MIS-050, 060 deleted (implementation). Inserted clarification note under R-MIS-020 on launch date dependence upon JUICE programme. Updated FoR values to 35% requirement, 50% goal (nominal energy resolution) and 50% requirement, 75% goal (degraded energy resolution). This is to bring the MRD into line with the updated SciRD which has changed as a consequence of an agreed change to the science requirements. Changed R-PERF-014 and G-PERF-018 (Galactic Centre visibility requirements) to specify Degraded Field of Regard instead of Nominal (this is to make them consistent with the updated sky visibility requirements. Removed ‘Extended’ from R-PERF-045 (40% requirement R-PERF-040 only applies to the Nominal Operations Phase. Included tables for temperature requirements of detectors at beginning and end of Nominal Operations Phase as a function of candidate orbit altitude and inclination. Issue 3.5 changes Add section in explanatory text explaining reference to SciRD annexes for translated requirements. Revised acronym list. Replaced AD7 ESSB-HB with ECSS control standard. ESSB-HB now a RD. Added casualty-risk expectation TN to RD list. Updated explanatory notes throughout the document,			

particularly with regards to referencing the Annexes in for translated (derived) engineering requirements. Updated RPE requirement R-POIN-030 to make applicable to each LAD Module Reference Boresight; this is a conservative specification and avoids the complexity of accounting for non-coherence of Modules. In any case previous formulation was not correct, as effective area cannot be constrained by the global LAD Reference Boresight Vector. Corrected confidence for AKE from 3-sigma to 99.7% in R-POIN-040. Some corrections to figure/table captions. Included graphical representation of detector operating temperature requirements. Added: WFM sunshield requirement added CFDP protocol [G-TTC-078] Revised TT&C section to reflect recommended approach by ESOC. Included accommodation of NGRM (standard radiation environment monitor) requirement. Included Annex explaining derivation of key MRD derived system requirements from Science (SciRD) requirements. Also included additional RDs to support the Annex. Rearrangement of requirements to clearly split mission and SC requirements in a more transparent way. Detector temperature requirements changes to apply factor 20 proton flux to AP8 results to account for discrepancy with AP9 model. [R-PERF-109/110/120] deleted and reproduced in payload accommodation section as [R-SYS-080,090,100]. R-PERF-106 deleted and reproduced in payload accommodation section as R-SYS=073. R-POIN-010 removed (covered by lower un-bound response stability requirement) Relaxed LAD Module boresight requirement R-MECH-030 from 2.5' to 3'. Added G-PERF-153 and G-POIN-022 for WFM goal localisation of 30arcseconds. 3.6 changes Annexes rationalised. LAD reference boresight rein-stated as being applicable for the RPE requirement. Some goals from SciRD reflected in MRD. SciRD reinstated as RD not AD.			

Table of contents:

1 INTRODUCTION

1.1 Background

LOFT is an M-class mission candidate for the M3 slot within the Cosmic Vision programme, for a planned launch between 2022 and 2024. LOFT, with 3 other science missions, was recommended by the Space Science Advisory Committee (SSAC) to enter an assessment study (Phase 0), starting by an ESA internal study followed by parallel industrial study activities.

Within the M3 boundary conditions, the readiness for launch by end 2022/2024 is a severe requirement which in practice requires designing the space segment without major technology developments and with minimum developments risks. Therefore, only technologies with estimated Technology Readiness Levels (TRL) of at least 5 by the end of the Phase A (estimated at the end of 2014) may be used.

1.2 Scope of Document

This document aims at providing a complete and comprehensive list of all high level mission requirements (including S/C and payload, launcher, ground segment and operations) necessary to achieve the science goals detailed in [RD 1]. Accordingly it is an applicable document that shall be complied with for all mission design activities. The MRD will be further reviewed matching the results of future study phases (e.g. definition phase) to finally evolve into the System Requirements Document at the start of the implementation phase.

1.3 Requirements Identification

1.3.1 Requirement Identification

All requirements in this specification that require verification are marked with a unique reference, which is given as follows:

X-YYYY-nnn

where:

- *X* is the requirement type: "**R**" for a requirement or "**G**" for a goal
- *YYYY* is the requirement category consisting of 3 to 4 letters:
  - MIS: Mission Analysis Requirements
  - PERF: Science Performance Requirements
  - POIN: Pointing Requirements
  - SYS: System Requirements
  - STR: Structure & Configuration Requirements
  - MECH: Mechanism & Alignment Requirements
  - THRM: Thermal Requirements
  - AOCS: Attitude & Orbit Control Requirements

- PWR: Power Requirements
- TTC: Telecommunication Requirements
- CDMS: Command & Data Handling Requirements
- SFTW: Software Requirements
- IFL: Launcher Interface Requirements
- IFP: Payload Interface Requirements
- IFG: Ground Segment Interface Requirements
- SEM: Mechanical Environment Requirements
- TEM: Thermal Environment Requirements
- SEC: Cleanliness & Contamination Requirements
- SER: Radiation Environment Requirements
- SEMI: Micrometeoroid Environment Requirements
- SEMC: Electromagnetic Compatibility Requirements
- AIV: Assembly, Integration & Test Requirements
- OGS: Operations & Ground Segment Requirements
- PROG: Programmatic Requirements.

- *nnn* is the requirement identifier (sequential number of 3 digits).

1.3.2 Requirements and Goals

Requirements are mandatory and must be complied with. They shall be verified by the Contractor using a verification method approved by ESA.

Goals are desirable in order to maximise the science return while keeping the impact on the cost and complexity to a minimum. They are to be the subject of system trade-offs and analysis, and are to be fulfilled under restricted conditions which are to be defined and quantified.

1.3.3 Explanatory Text

Supplementary text added to explain the source or reasoning behind a requirement is written after the requirement in *italics*. Where appropriate, the parent requirement from the SciRD [RD 1] is declared in supporting text to the MRD requirement to aid comprehension. This can also include reference to annexes in the case where the MRD requirement represents the translation of a scientific requirement into an engineering requirement.

1.4 Definitions

For the Large Area Detector (LAD) and Wide Field Monitor (WFM) the following definitions are made.

LAD Nominal Field of Regard: The region of the sky where the LAD can be pointed to continuously for at least 1 orbit (disregarding a potential temporal occultation of the target by the Earth) guaranteeing the LAD nominal energy resolution [R-PERF-100] and nominal response stability at any time during the mission.

LAD Degraded Field of Regard: The region of the sky where the LAD can be pointed to continuously for at least 1 orbit (disregarding a potential temporal occultation of the target by the Earth) guaranteeing the LAD degraded energy resolution [R-PERF-101] and nominal response stability at any time during the mission.

Note: The LOFT convention when discussing the LAD Field of Regard is to work from the reference position of the SC when the boresight of the LAD is orthogonal to the Sun-line (i.e. LAD SAA=90°). The Field of Regard is then expressed as a ± deviation from this position, e.g. the Nominal Field of Regard of 50% of the sky is written as 90°±30°.

LAD Solar Aspect Angle (SAA): The angle between the direction to the Sun and the viewing direction of the LAD (i.e. normal to the plane formed by the LAD detectors).

Galactic Centre: The 20×20 degree area of the sky centred around the equatorial coordinates Right Ascension: 17:45:40; Declination: -29:00:28, J2000 Epoch.

LAD Module Reference Boresight: This is a unit pointing vector normal to the LAD Module mounting I/F plane on the Detector Panel (i.e. nominally aligned with the LAD Module peak response) in satellite coordinates.

LAD Reference Boresight: This is computed as:

$$\overrightarrow{BS}_{LAD} = \frac{\sum_{m=1}^{M} \sum_{n=1}^{N_m} \overrightarrow{BS}_{[m,n]}}{\left|\sum_{m=1}^{M} \sum_{n=1}^{N_m} \overrightarrow{BS}_{[m,n]}\right|}$$

The alignment performance has to be evaluated statistically over all Modules (M and N_m) and is computed as:

$$\phi_{[m,n]} = \operatorname{acos}\left(\overrightarrow{BS}_{[m,n]} \cdot \overrightarrow{BS}_{LAD}\right)$$

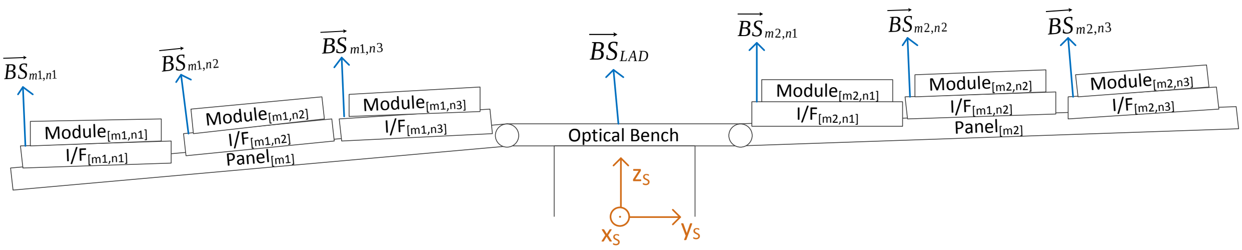


Figure: LAD Module and LAD Reference Boresight definition

WFM Camera Reference Boresight: The vector normal to the WFM Camera mounting I/F plane (i.e. nominally aligned with the WFM camera boresight.)

LAD Effective Detector Operating Temperature: The effective temperature of the entire LAD instrument detector, obtained by applying the energy resolution requirement to the spectra of all events from all detectors rather than on the spectrum from a single detector.

For the purposes of the Assessment Phase, the calculation of the LAD Effective Detector Operating Temperature can occur at Module-level, under the assumption that the temperature of the detectors across one Module is constant. In this case the following equation can be used:

$$T_{equ} = \Delta T . log_2 \left(\frac{1}{M} \sum_{i=1}^{M} \frac{T_i}{2\Delta T} \right)$$

Where:

$\Delta T = 7°\mathrm{C}$ *(the delta temperature which causes a factor 2 change in leakage current)*
M *is the number of LAD Modules on the spacecraft*
T_i *is the detector temperature of the ith LAD Module (assumed constant over Module).*

1.5 Acronyms

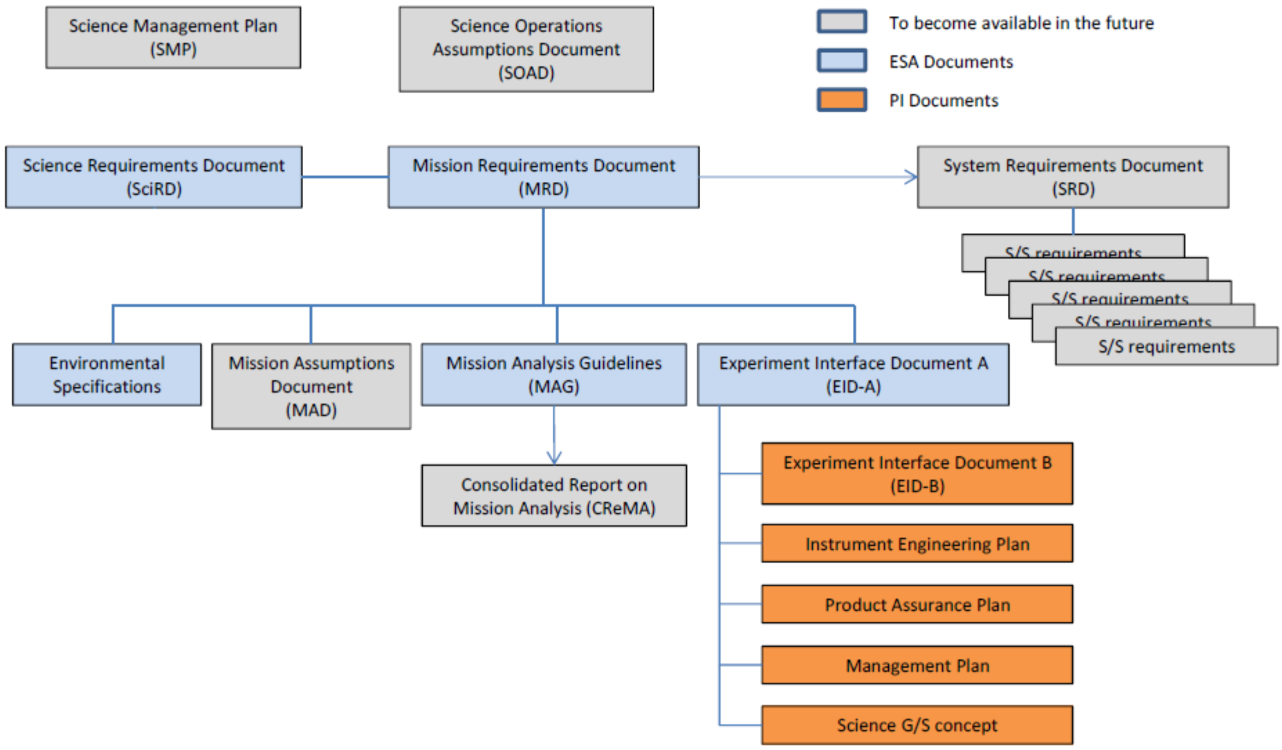
AD	Applicable Document
AGN	Active Galactic Nucleus
AIT	Assembly, Integration and Test
AIV	Assembly, Integration and Verification
AOCS	Attitude and Orbit Control System
AKE	Absolute Knowledge Error
APE	Absolute Performance Error
BH	Black Hole
CCSDS	Consultative Committee for Space Data Systems
CDMS	Control and Data Management System
CDF	Concurrent Design Facility
CFDP	CCSDS File Delivery Protocol
CPU	Central Processing Unit
CReMA	Consolidated Report on Mission Analysis
DPU	Data Processing Unit
ECSS	European Cooperation for Space Standardisation
EGSE	Electrical Ground Support Equipment
EMC	Electromagnetic Compatibility
ENC	Equivalent Noise Charge
EMI	Electromagnetic Interference
EOL	End of Life
EOS	Equation of State
EPS	Electric Power System
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
FAR	Flight Acceptance Review
FEC	Forward Error Correction
FDIR	Failure Detection, Isolation and Recovery
FEE	Front-End Electronics
FMECA	Failure Mode, Effects, and Criticality Analysis
FWHM	Full Width at Half Maximum
FoR	Field of Regard
FoV	Field of View
GR	General Relativity
GSE	Ground Support Equipment
H/W	Hardware
HGA	High Gain Antenna
HK	Housekeeping
ITC	Instrument Team Centre
LAD	Large Area Detector
LBAS	LOFT Burst Alert System
LEO	Low Earth Orbit
LEOP	Launch and Early Orbit Phase
LGA	Low Gain Antenna

LOS	Line of Sight
LOFT	Large Observatory For X-ray Timing
MGSE	Mechanical Ground Support Equipment
MOC	Mission Operations Centre
MRD	Mission Requirements Document
NS	Neutron Star
OTS	Off-The-Shelf
P/L	Payload
PA	Product Assurance
PDR	Preliminary Design Review
PLM	Payload Module
PSD	Power Spectral Density
QPO	Quasi-Periodic Oscillation
RD	Reference Document
RPE	Relative Pointing Error (pointing stability)
SAA	South Atlantic Anomaly
S/C	Spacecraft
S/W	Software
SciRD	Science Requirements Document
SDC	Science Data Centre
SDD	Silicon Drift Detector
SI	International System of Units
SOC	Science Operations Centre
SPF	Single Point Failure
SSAC	Space Science Advisory Committee
SVM	Service Module
SVOM	Space-based multi-band astronomical Variable Objects Monitor
SVT	System Verification Test
TBC	To Be Confirmed
TBD	To Be Determined
TC	Telecommand
TM	Telemetry
ToO	Target of Opportunity
TRL	Technology Readiness Level
WFM	Wide Field Monitor

1.6 Documentation

1.6.1 *Documentation Architecture*

The Mission Requirements Document is one of the documents that constitute the complete documentation set for the LOFT study; the top-level LOFT document architecture is presented in the following figure.



LOFT top-level architecture

1.6.2 *Applicable Documents*

[AD 1] LOFT – Experiment Interface Document Part A, LOFT/SRE-F/2012.095, Issue 1.1.

[AD 2] LOFT – Experiment Interface Document Part B [LAD], Issue 1.1.

[AD 3] LOFT – Experiment Interface Document Part B [WFM], Issue 1.1.

[AD 4] Margin Policy for SRE-PA Studies, SCI-PA/2007-022, Issue 1, Rev. 3, 15/06/20012.

[AD 5] ESA Tracking Stations Facilities Manual, DOPS-ESTR-OPS-MAN-1001-OPS-ONN, Issue 1, Rev. 1, 19/09/2008.

[AD 6] Soyuz-Fregat2-1b from the Guiana Space Centre User's Manual, Issue 2, Revision 0, March 2012.

[AD 7] List of ESA Approved Standards ESSB-AS, I3.2, Dec 2010.

[AD 8] Space Debris Mitigation for Agency Projects. ESA/ADMIN/IPOL (2008), 1st April 2008, Annex 1 and 2.

[AD 9] Space Engineering: Control Performance. ECSS-E-ST-10C, Issue 1.0, 15/11/2008.

[AD 10] LOFT Mission Analysis Guidelines, Issue 1, Revision 0, 27 April 2012. MAS WP-575.

[AD 11] LOFT Observation Plan Document (TBW)

~~[AD 12] ECSS-U-AS-10C Space Sustainability: Adoption Notice of ISO 24113, 10 February 2012.~~

[AD 13] LOFT Environmental Specification, Issue 1, Rev.0, JS-20-12.

[AD 14] LBAS Ground Segment I/F specification, TBW.

[AD 15] NGRM Specification for Assessment Phase. SRE-F/2013.009, Issue 1.0, 08/02/2013.

1.6.3 Reference Documents

[RD 1] LOFT Science Requirements Document (SciRD), SRE-SA/LOFT/2011-001, Issue 1, Rev. 7.

[RD 2] Technology Readiness Levels handbook, TEC-SHS/5551/MG/ap, v1.6.

[RD 3] ECSS System - Description, implementation and general requirements ECSS-S-ST-00C.

[RD 4] ECSS Set of Space Engineering Standards, ECSS-E-Series.

[RD 5] ECSS Set of Space Product Assurance Standards, ECSS-Q-Series.

[RD 6] ESSB-HB-E-003, ESA pointing error engineering handbook, Issue 1, Rev. 0, 19/06/2011.

[RD 7] Re-entry casualty expectation assessment for LOFT. Technical Note, LFT-REN-TN-00088-HSO-GR. B. Bastida Virgili, H. Krag, 10/05/2012.

[RD 8] LOFT Large Area Detector Response Stability, M. van der Klis et al. LOFT-LAD-RespStab-20120322. 22/03/2012, Issue 1.0

[RD 9] LOFT Observing Plan Document (TBW).

[RD 10] LOFT Large Area Detector Background Models, R. Campana. LOFT Technical Note, LOFT-LAD-BkgMdl-20111130. 30/11/2011, Issue 1.0.

[RD 11] 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 12] 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 13] LOFT Large Area Detector: Telemetry Estimate, J. Wilms & C. Tenzer. LAD Technical Note, LOFT-LAD-TMest-20120518. 18/05/2012, Issue 2.0.

[RD 14] 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.

2 MISSION OVERVIEW

2.1 Mission Description

LOFT (Large Observatory For X-ray Timing) is one of the four candidate missions (together with EchO, Marco Polo R, and STE-QUEST) selected for the next medium class mission (M3) in ESA's Cosmic Vision programme, with a launch planned in the period 2020-22.

LOFT is intended to answer fundamental questions about the motion of matter orbiting close to the event horizon of a black hole, and the state of matter in neutron stars, by detecting their very rapid X-ray flux and spectral variability. LOFT would carry two instruments: a Large Area Detector (LAD) with an effective area (around 10 m^2) far larger than current space-borne X-ray detectors, and a Wide Field Monitor (WFM) that would monitor a large portion of the sky to provide interesting targets for follow-up observations with the LAD, and also to provide a rapid burst-alert function (via the LOFT Burst Alert System – LBAS) to the broader x-ray astronomy community.

2.2 Science Goals

High-time-resolution X-ray observations of compact objects provide direct access to strong-field gravity, black hole masses and spins, and the equation of state of ultra-dense matter. A 10 m^2 class instrument in combination with good spectral resolution is required to exploit the relevant diagnostics and answer two fundamental questions of ESA's Cosmic Vision Theme "Matter under extreme conditions", namely:

- does matter orbiting close to the event horizon follow the predictions of general relativity?
- What is the equation of state of matter in neutron stars?

Due to an innovative design and the development of large monolithic silicon drift detectors, the Large Area Detector (LAD) on board LOFT will achieve an effective area of ~10 m^2 (more than an order of magnitude larger than current space-borne X-ray detectors) in the 2-30 keV range (up to 80 keV in expanded mode). With this large area and a nominal spectral resolution of <260 eV over the entire band, LOFT will revolutionise the study of collapsed objects in our galaxy and of the brightest supermassive black holes in active galactic nuclei, yielding unprecedented information on strongly curved space-times and matter under extreme conditions of pressure and magnetic field strength.

In addition to these core science goals, LOFT will provide a 50% allocation of the observing time to observatory science. This, combined with the burst-alert function, means that LOFT will provide an extremely valuable resource to the x-ray astronomy community.

2.3 Measurement Principle

The scientific objectives are be achieved through the measurement of the X-ray photometric light curves and spectra of a range of different astrophysical target classes.

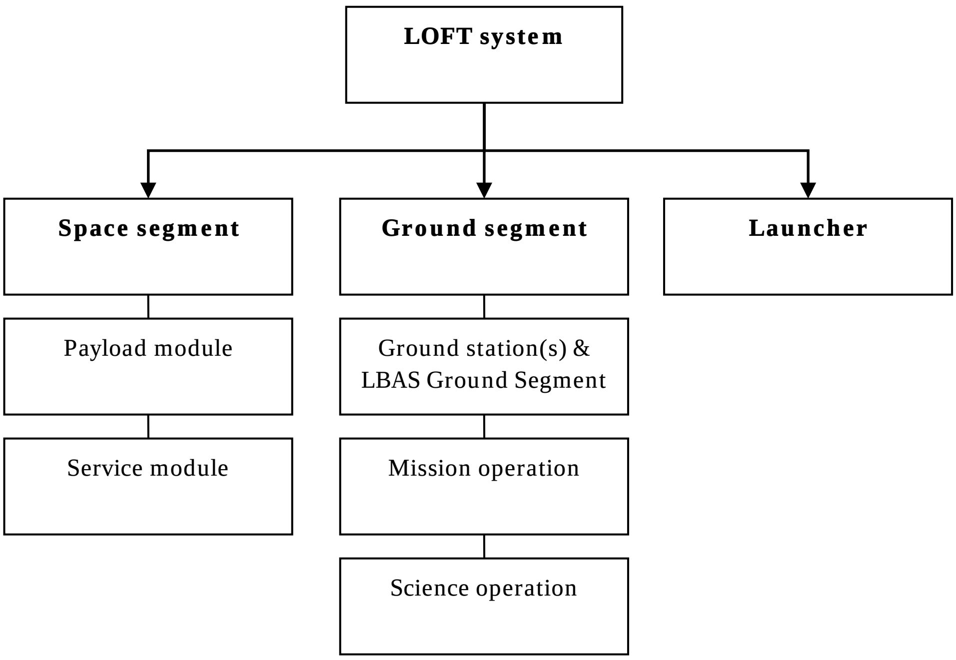
The targets are all compact objects (neutron stars, black holes and AGN) therefore the measurement requires no imaging capability. Targets will be selected by a pointing a collimating structure that discriminates the required source from the background of diffuse or nearby X-ray emitting sources. The 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 (200eV 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 data will be transmitted to ground in the form of photon event lists (time and energy of each photon).

A complementary measurement will take place to monitor a large fraction of the instantaneously visible sky for transients and outbursts that allows for Targets of Opportunity, as well as long term source monitoring. This measurement 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 busts and transients.

2.4 System Description

The LOFT system consists of the complete end-to-end system (LV, space and ground segment), which fulfils the mission requirements according to the product tree below:



LOFT system product tree

The LOFT space segment consists of the Payload module (PLM) and the Service Module (SVM). The PLM mainly consists of the two scientific instruments of the mission, namely:

- The LAD (Large Area Detector) instrument

- The WFM (Wide Field Monitor) instrument.

as well as the structure and mechanisms that support them, together with additional sensors (e.g. star trackers). The space segment will be launched in to a broadly equatorial LEO by the Soyuz-Fregat launch vehicle from Kourou – this orbit is chosen in order to limit as much as is practicable the radiation damage to the detectors of the LAD and WFM instruments throughout the mission lifetime (balanced primarily against the propellant requirements to maintain the low altitude orbit against atmospheric drag.)

The ESA ground segment (Kourou and Malindi) provides the means and resources to manage and control the mission via telecommands, to receive and process the telemetry from the satellite, and to disseminate and archive the generated products. This is complemented by the payload-provided LOFT Burst Alert System (LBAS) Ground Segment, a distributed network of VHF ground stations, which provides near real-time alerts of x-ray events. The platform-provider will provide the TM-function on-board the SC to allow the WFM to transmit the LBAS packet to ground.

The mission operation centre (MOC) is responsible for the operations of the spacecraft and instruments, for ensuring the spacecraft safety and health, for provision of flight dynamics support including determination and control of the satellite's orbit and attitude and for provision of auxiliary data to the Science Operation Centre (SOC). The MOC performs all communications with the satellite through the ground stations*.

**Note that this does not include the WFM burst-alert transmissions, which are communicated to the SVOM VHF network and then distributed via the SOC to interested parties.*

The Science Operation Centre (SOC) depends on the scientific organisation of the mission, and the responsibilities for each instrument and the partnerships to be put in place are still TBD.

The launcher refers here not only to the launch vehicle, but also to the means and facilities made available on site for the spacecraft preparation, fuelling (if any), encapsulation and launch operations. It is considered as a component of the system until the end of the launcher mission.

3 MISSION PERFORMANCE REQUIREMENTS

Note: The following section presents the top-level mission performance requirements from [RD 1] which drive the mission and spacecraft design. These can be categorised as falling into two types:

- *Requirements for which an allocation between the payload and platform is yet to take place; these requirements do not have directly derived requirements in the spacecraft requirements section 5.*
- *Requirements for which an allocation between the payload and platform, or a derived mission analysis requirement, has been produced; these form the basis of explicitly derived spacecraft or mission analysis requirements which are placed in chapters 4 and 5.*

3.1 Observation Requirements

R-PERF-010 The LAD Nominal Field of Regard (FoR) shall be at least 35% of the sky at the end of the Nominal Operations Phase.

Note: The LAD nominal Field of Regard (FoR) is defined in section 1.4. A FoR of 35% of the sky can be achieved, for example, if the LAD solar aspect angle can be varied between 90±~20°.

Note: See [SCI-SYS-R-19] in [RD 1].

G-PERF-011 The LAD Nominal Field of Regard (FoR) should be at least 75% of the sky at the beginning of the Nominal Operations Phase.

Note: see [SCI-SYS-G-05] in [RD 1].

G-PERF-012 The LAD Nominal Field of Regard (FoR) should be at least 50% of the sky at the end of the Nominal Operations Phase.

Note: see [SCI-SYS-G-19] in [RD 1].

R-PERF-011 The LAD Degraded Field of Regard (FoR) shall be at least 50% of the sky at the end of the Nominal Operations Phase.

Note: The LAD Degraded Field of Regard (FoR) is defined in section 1.4. A FoR of 50% of the sky can be achieved, for example, if the LAD solar aspect angle can be varied between 90±30.

Note: see [SCI-SYS-R-05] in [RD 1].

G-PERF-013 The LAD Degraded Field of Regard (FoR) should be at least 75% of the sky at the beginning of the Nominal Operations Phase.

G-PERF-014 The LAD Degraded Field of Regard (FoR) should be at least 75% of the sky at the end of the Nominal Operations Phase.

Note: see [SCI-SYS-G-05] in [RD 1].

R-PERF-014 The LAD Degraded Field of Regard shall contain a single point located within the Galactic Centre area for at least 35% of the nominal mission duration.

Note: see [SCI-SYS-R-06] in [RD 1]. The Galactic Centre area is defined in section 1.4.

G-PERF-018 The LAD Degraded Field of Regard should contain a single point located within the Galactic Centre area for at least 65% of nominal mission duration.

Note: see [SCI-SYS-G-06] in [RD 1].

G-PERF-020 ~~During the Nominal and Extended Operations Phases, for each Solar eclipse period, it shall be possible to perform a slew manoeuvre to point the LAD to any source in the sky not occulted by the Earth, observe it for at least 10 minutes (TBC), and slew back to the previous source upon eclipse egress.~~

Once per orbit during the Nominal and Extended Operations Phase it shall be possible to observe a target located outside of the Degraded Field of Regard in the anti-sun direction for 10 minutes (TBC), at the degraded energy resolution of 295eV.

Note: see [SCI-SYS-R-04] in [RD 1]. LAD Detector Effective Temperature requirements to fulfil the degraded energy resolution requirement are provided in [R-THRM-031].

R-PERF-030 The maximum slew angle for the slew manoeuvres defined in [G-PERF-020] shall be 60° (TBC).

R-PERF-040 The overall observation availability of the LAD instrument (taking into account [AD 11]) during the Nominal Operation Phase shall be at least 40%.

Note: This observation availability provides a total net observing time which covers both the net observing time requirements for core science *and net guest observer allocations – see [SCI-SYS-R-01, 02], [SCI-SYS-G-01, 02] in [RD 1] and Annex A.1.*

Note: the observation availability of the LAD shall be demonstrated against the observing plan specified in [AD 11]. When calculating the observation availability, the following line-items should be taken into account as a minimum:

- *Earth occultation of the target*
- *Slew & associated settle-times*
- *South Atlantic Anomaly occupancy*
- *Orbit maintenance manoeuvres*
- *Safe Mode*
- *STR-reference loss (if any)*
- *GNSS-reference loss (if any)*
- *Other attitude transients which suspend science performance.*

Note: For the purpose of calculating the observation availability, the following guidelines shall apply:

- *For the purposes of FoV blockages, The Sun, Earth system only shall be considered*
- *An Earth atmospheric limb height of 145 km (TBC) is to be considered as preventing LAD observations*
- *Observations with the LAD shall be considered as suspended during the period of the orbit when the background integral flux of protons with energy greater than 50keV is greater than 0.5/cm2/s (TBC).*

~~R-PERF-041 deleted.~~

~~R-PERF-042 deleted.~~

R-PERF-045 5% of the net observing time during the Nominal Operations Phase shall be considered for the calibration of the instruments when calculating the overall observation availability of LOFT (TBC).

Note: for example this equates to 2% of the total time assuming observation availability of 40%. See [SCI-SYS-R-03] in [RD 1].

R-PERF-050 During normal working hours LOFT shall be able to observe with the LAD any target of opportunity located within the accessible sky within 12 hours after notification to the SOC.

Note: see [SCI-SYS-R-14] in [RD 1].

G-PERF-050 During normal working hours LOFT shall be able to observe with the LAD any target of opportunity located within the accessible sky within 8 hours after notification to the SOC.

Note: see [SCI-SYS-G-14] in [RD 1].

R-PERF-060 Outside working hours LOFT shall be able to observe with the LAD any target of opportunity located within the accessible sky within 24 hours after notification to the SOC.

Note: see [SCI-SYS-R-14] in [RD 1].

~~R-PERF-070 deleted.~~

R-PERF-080 The accuracy of absolute time of the measurements reconstructed on-ground shall be better than 1 μs.

Note: see [SCI-LAD-R-14] in [RD 1].

~~R-PERF-092 deleted.~~

~~R-PERF-095 deleted.~~

3.2 Instrument Requirements

3.2.1 LAD Requirements

~~R-PERF-105 deleted.~~

~~R-PERF-106 deleted (moved to payload accommodation section).~~

R-PERF-090 The LAD instrument shall have an effective area of 9.5m^2 at 8 keV.

*Note: To show compliance to this goal at least the number of modules as specified in [R-SYS-072] has to be accommodated on the S/C and the alignment requirements [*R-MECH-028*] and [*R-MECH-030*]. See [SCI-LAD-R-01] in [RD 1].*

G-PERF-092 The LAD instrument should have an effective area of 10.0m^2 at 8 keV.

*Note: To show compliance to this goal at least the number of modules as specified in [G-SYS-072] has to be accommodated on the S/C and the alignment requirements [*R-MECH-028*] and [*R-MECH-030*]. See [SCI-LAD-R-01] in [RD 1].*

R-PERF-100 During science operations within the Nominal FoR, the energy resolution of the LAD detectors throughout the mission to the end of the Nominal Operations Phase for 2 anode events, shall be better than 260 eV (FWHM) at 6 keV.

Note: 2 anode events at 260eV are equivalent to 1 anode events at 200eV.

Note: See [SCI-LAD-R-08] in [RD 1].

Note: For the purposes of evaluating compliance to this requirement, the LAD Detector Effective Operating Temperatures at the beginning and end of the Nominal Operations Phase specified in [R-THRM-030] are applicable. See Annex A.3.

R-PERF-101 During science operations within the Degraded FoR, the energy resolution of the LAD detectors throughout the mission to the end of the Nominal Operations Phase for 2 anode events, shall be better than 400 eV (FWHM) at 6 keV.

Note: 2 anode events at 400eV are equivalent to 1 anode events at 295eV.

Note: See [SCI-LAD-R-22] in [RD 1].

Note: For the purposes of evaluating compliance to this requirement, the LAD Detector Effective Operating Temperatures at the beginning and end of the Nominal Operations Phase specified in [R-THRM-031] are applicable. See Annex A.3.

R-PERF-102 The response (effective area) stability of the LAD shall be constrained according to the requirements in the following table.

Note: see [SCI-LAD-R-23, 24, 25, 26] in [RD 1], and Annex A.4.

G-PERF-102 The response (effective area) stability of the LAD should be constrained according to the goals in the following table.

Note: see [SCI-LAD-G-23,24,25,26] in [RD 1] and Annex A.4.

Stability	**Value (%)**	**Condition**
requirement	<2	<0.01 Hz and max unusable bandwidth <1 octave per decade
goal	<1	
requirement	<0.2 (per decade)	0.01-1 Hz and max unusable bandwidth <1 octave per decade
goal	<0.05 (per decade)	
requirement	<0.02 (per octave)	1-1200 Hz and max unusable bandwidth

		<1 % per decade
goal	<0.005 (per octave)	

LAD response stability requirements

3.2.2 WFM Requirements

~~R-PERF-109 deleted (moved to payload accommodation section)~~

~~R-PERF-110 deleted (moved to payload accommodation section)~~

~~R-PERF-120 deleted (moved to payload accommodation section)~~

R-PERF-130 The energy resolution of the WFM detectors throughout the mission to the end of the Nominal Operations Phase, for 6-anode events, shall be better than 500eV (FWHM) at 6 keV (ENC=12e-).

Note: for the purposes of evaluating compliance to this requirement, the WFM detector operating temperatures specified at the end of the Nominal Operations Phase in [R-THRM-070] are applicable. See [SCI-WFM-R-07] in [RD 1] and Annex A.3.

R-PERF-140 It shall be possible to downlink the science data generated by the WFM with a maximum delay of 2 orbits in duration with a probability of 99% (TBC).

Note: The WFM instrument data will include information on transients which must be down-linked in a timely manner in order to be input into the observation planning for the LAD instrument - see [SCI-WFM-R-14] in [RD 1].

R-PERF-150 The time and position of triggered events detected by the WFM shall be broadcast to end users within 30s for 65% of events.

Note: see [SCI-WFM-R-17] in [RD 1].

G-PERF-152 The time and position of triggered events detected by the WFM should be broadcast to end users within 20s for 75% of events.

Note: see [SCI-WFM-G-17] in [RD 1].

R-PERF-152 The WFM shall be able to localise x-ray sources down to 1 arcminute accuracy.

Note: This requirement supports sufficient source position accuracy to enable observations by the LAD and also to provide the required localisation accuracy to the LBAS. See [SCI-WFM-R-01] in [RD 1].

G-PERF-153 The WFM should be able to localise x-ray sources down to 30 arcseconds accuracy.

Note: see [SCI-WFM-G-01] in [RD 1].

4 MISSION ANALYSIS REQUIREMENTS

4.1 Launch Vehicle, Site and Date

R-MIS-010 The spacecraft shall be compatible with a launch on Soyuz-Fregat 2-1b from Kourou.

Note: for the purposes of evaluating compatibility with the launcher capacity to the selected orbit, refer to [AD 10] for a specification of Soyuz performance to the candidate orbit range defined in [R-MIS-030]. Table 1 from [AD 10] is reproduced here. The values presented include the launch vehicle adaptor.

Inclination	*Perf. to 500x500km [kg]*	*Perf. to 600x600km [kg]*
0	*6100*	*5800*
2.5	*6750*	*6450*
3	*6850*	*6550*
5.2	*7140*	*6800*

Simulated Soyuz-Fregat performance from Kourou: taken from [AD 10]

R-MIS-020 The mission shall be compatible with a launch date in 2022 (study baseline), with a launch in 2024 as study back-up.

Note: The M3 mission is intended as a backup candidate for the 2022 launch slot, depending on JUICE schedule. Although in the science programme the baseline launch slot for M3 is 2024, all current study planning should remain compatible with a 2022 launch. The final decision on the nominal launch date will be made following JUICE mission adoption.

4.2 Injection, Transfer and Operational Orbits

R-MIS-030 The orbit for nominal science operations shall be a circular LEO with the following characteristics:

- Altitude <= 600 km
- Eccentricity <= 0.002
- Inclination <= 5.24°

Note: This requirement limits the instrument background and the radiation dose to the detectors, which in-turn limits the growth in radiation-induced leakage current, thereby allowing reasonable temperature limits to be defined to achieve the required energy resolution specified in [R-PERF-100], [R-PERF-101] and [R-PERF-130]. See Annex A.2.

4.3 Mission Phases

R-MIS-040 The mission phases shall be defined as follows, chronologically following each other unless specified otherwise:

0	Pre-launch Phase (Launch Campaign)
1	Launch and Early Operations Phase (LEOP)
2	Commissioning Phase (CP)
3	Nominal Operations Phase (NOP)
4	Extended Operations Phase (EOP)
5	Decommissioning Phase (DP)

LOFT mission phases

4.3.1 Pre-Launch Phase

Specific Pre-Launch Phase requirements are TBD.

~~R-MIS-050 deleted.~~

~~R-MIS-060 deleted.~~

4.3.2 LEOP

R-MIS-070 The S/C shall autonomously detect separation from the launcher.

R-MIS-080 After separation from the launcher, the S/C shall autonomously activate its TT&C system with at least one Tx and Rx channel active to enable ground to establish contact.

R-MIS-090 After separation from the launcher, the S/C shall command the deployment of the solar arrays, and acquire a safe attitude, defined as:

- with solar arrays pointed such that power generation is possible and sufficient for operation and battery charging
- such that the temperature of the P/L is within its non-operating temperature range.

4.3.3 Commissioning

R-MIS-110 During the Commissioning Phase, the payload instruments on-board shall be deployed, calibrated and tested.

R-MIS-120 The Commissioning Phase shall last no longer than 3 months.

Note: This limit is required in order to constrain the radiation dose seen by the detectors in support of achievement of the required energy resolution, and also to constrain the overall mission operations costs.

4.3.4 Nominal Operations

R-MIS-130 The Nominal Operations Phase (NOP) shall last 4 years.

Note: this requirement is driven by the net core and guest observing durations, and the probability to observe rare x-ray transient events. See [SCI-SYS-R-01, 01, 07] in [RD 1] and Annex A.1.

R-MIS-140 During the Nominal Operations Phase, all science performance requirements shall be fully met and include all specified margins.

4.3.5 Extended Operations

G-MIS-150 The Extended Operations Phase (EOP) beginning after the end of the Nominal Operations Phase should have a duration of 1 year.

Note: see [SCI-SYS-G-01, 02] in [RD 1] and Annex A.1.

G-MIS-160 During the Extended Operations Phase, all science performance requirements should be fully met and include all specified margins.

4.3.6 Decommissioning

R-MIS-170 The Decommissioning Phase (DP) shall not last longer than 2 months.

R-MIS-180 Design and operations of the space segment shall comply with the rules and procedures put forth in [AD 8].

Note: In the case of LOFT, this necessitates a controlled re-entry capability, due to the need to comply with casualty-risk regulations specified in [AD 8]. See [RD 7] for a preliminary prediction of the casualty risk for an uncontrolled re-entry of the LOFT SC.

4.4 Mission Lifetime

R-MIS-181 The spacecraft shall be dimensioned for a 5.25-year lifetime (corresponding to 5 years in the operational orbit *after* the Commissioning Phase lasting up to three months).

Note: This corresponds to a design for the nominal plus extended science operations, as defined in [R-MIS-130] and [G-MIS-150], and the commissioning phase [R-MIS-130]. In the EOP degradation in mission performances are allowable.

R-MIS-182 The Space Segment shall be compatible with a ground storage duration of 2 years (TBC).

R-MIS-190 All S/C consumables and radiation sensitive units shall be sized to last from launch till the end of the Extended Operations Phase.

5 SPACECRAFT REQUIREMENTS

5.1 Design Requirements

5.1.1 Standards

R-SYS-010 The SI international system of units shall be used. Radians, degrees, arcminutes and arcseconds are acceptable as angle units. All (sub)-multiples by factors of 10 of any of the above mentioned units are also acceptable.

R-SYS-020 For the initial phases of the study, the margin policy described in [AD 4] shall be applied.

Note: the margin philosophy and margin depletion scheme will be defined at a later stage.

R-SYS-025 A launcher performance margin of 5% shall be considered.

Note: this additional margin is to account for uncertainties in the simulated performance of Soyuz-Fregat from Kourou to the target orbits (for which no information exists in [AD 6].)

R-SYS-030 The published list of ESA approved standards [AD 7], including approved ECSS standards, shall apply throughout the LOFT assessment study, and are available at:
http://ecss.nl/

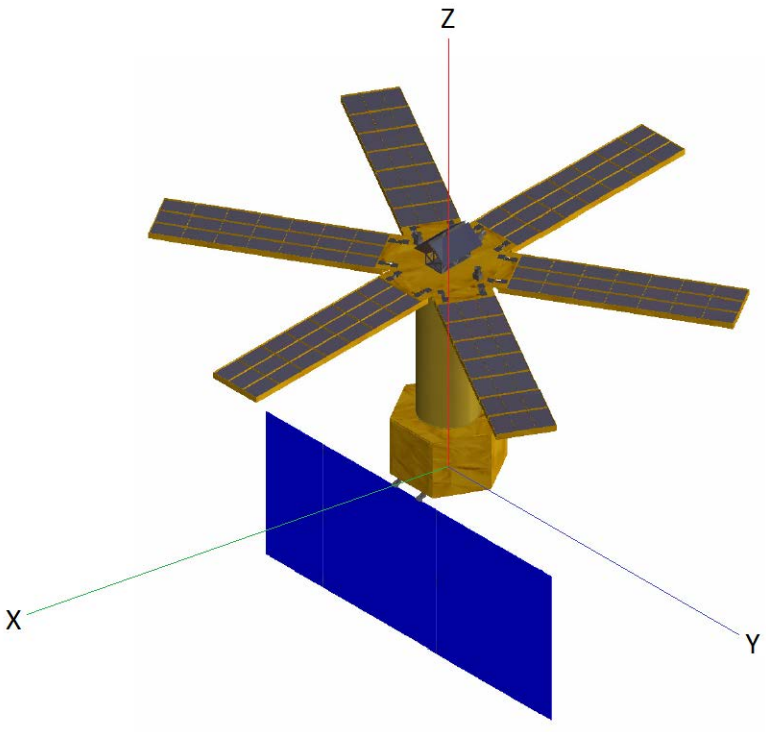
5.1.2 Coordinate Systems

R-SYS-040 All reference frames shall be right-handed orthonormal triads.

R-SYS-050 The LOFT spacecraft reference frame shall be defined with:

- The origin in the geometrical centre of the separation plane between the launch adapter and the spacecraft
- $+Z_{SC}$ (roll axis) coincident with the launcher symmetry axis and skywards
- $+X_{SC}$ in the separation plane between the launcher adapter and the S/C, oriented so that during science operations the Sun lies in the XZ plane, positive towards the Sun.
- $+Y_{SC}$ completing the system.

Note: when the SC is in eclipse and thermal constraints due to the Sun no longer apply, the constraint on $+X_{SC}$ *can be ignored.*



The LOFT SC reference frame applied to the LOFT P/L consortium reference SC design

5.2 System Requirements

5.2.1 Spacecraft Mass

~~R-SYS-060 deleted.~~

R-SYS-070 The spacecraft wet total mass including all applicable margins shall not exceed the launcher performance derived for the operational orbit from [AD 10], and considering the performance margin defined in [R-SYS-025].

5.2.2 Payload Accommodation

R-SYS-071 The spacecraft shall accommodate the LAD and WFM payloads as described in the LAD EID-B [AD 2] and WFM EID-B [AD 3].

R-SYS-072 The spacecraft shall accommodate at least 121 LAD Modules.

Note: this will provide 9.5m^2 of effective area in combination with [R-MECH-028, R-MECH-030]. This requirement does not preclude the possibility to relax/tighten the Module alignment requirements in combination with a larger/smaller number of Modules to achieve the same effective area.

G-SYS-072 The spacecraft should accommodate at least 128 LAD Modules.

Note: this will provide 10m^2 of effective area in combination with [R-MECH-028, R-MECH-030]. This requirement does not preclude the possibility to relax/tighten the Module alignment requirements in combination with a larger/smaller number of Modules to achieve the same effective area.

R-SYS-073 The FWHM FoV of the LAD (1.1°) shall be un-obscured by other spacecraft or WFM structures.

R-SYS-075 The spacecraft shall accommodate the Next Generation Radiation Monitor as specified in [AD 15].

R-SYS-080 At all times during operation, the WFM shall be shielded from direct solar flux by a sunshield.

Note: this requirement is driven by the thermo-mechanical stability requirements of the WFM coded-mask relative to the detector plane, with a required temperature stability of the WFM camera of TBD °C.

R-SYS-090 The FoV of the WFM at zero-response, as defined in the following table, shall not be obscured by other spacecraft structures by more than 10% (TBC).

Field of View at Zero Response	90° x 90°	90° x 90°	180°x90°+90°x90°

Note: Because the WFM FoV is very large, partial obstructions of the FoV by other S/C structures are likely, and may be acceptable to the instrument – if the obscuration is more than 10%, this is to be agreed on a case-by-case basis.

R-SYS-100 The reference axis of the WFM global reference frame, shall be aligned with the FoV of the LAD to within an accuracy of 1° (TBC).

Note: This is not a strict co-alignment requirement, but is intended to specify the expected relative orientations between the LAD and WFM instruments, and ensure that the LAD boresight is within the most sensitive region of the WFM FoV.

5.2.3 Reliability and Fault Management

R-SYS-080 The overall reliability of the spacecraft (inc. payload) shall be ≥ 85% from launcher separation to the end of the Nominal Operations Phase.

Note: for the purposes of this calculation, the assumed reliability of the payload until the end of the Nominal Operations Phase shall be expressed as a single factor of 0.95 (TBC); note that the LAD deployment is under

SC responsibility and is not contained within the payload reliability figure.

R-SYS-090 The spacecraft design shall eliminate or prevent single-point failures with a severity of catastrophic or critical as per [RD 4].

R-SYS-095 Non-compliance to [R-SYS-090] above shall be subjected to formal approval by ESA and an issued waiver.

R-SYS-100 No failure of any single component at unit level shall lead to failure of or damage to another component or subsystem.

R-SYS-110 No failure of any instrument shall lead to failure of or damage to other instruments or subsystems.

R-SYS-120 Individual or multiple failures of instruments and/or instrument subsystems shall not lead to a transition into safe-mode on spacecraft level.

R-SYS-130 Degradation or delayed loss of the spacecraft caused by failures of either instruments or spacecraft subsystems on any level shall be prevented or protected against by design.

R-SYS-140 The spacecraft shall have a safe-mode which assures spacecraft and payload survival.

R-SYS-150 The spacecraft shall enter safe-mode in case of anomalies or failures from which it cannot recover autonomously.

R-SYS-160 For design and analysis purposes, an average of 2 safe modes events of 4 days each per year shall be considered.

R-SYS-170 The design of the S/C failure detection, isolation and recovery (FDIR) function shall be such that all anticipated on-board failures can be overcome either by autonomous on-board action or by clear, unambiguous and timely notification of the problem to the ground segment.

R-SYS-180 The FDIR design shall ensure that the S/C is safe and satisfies [R-OGS-210] in the presence of a single failure.

5.3 Platform Pointing Requirements

Note: The pointing requirements expressed here are the portion of the Instrument pointing performance requirements from section 3 that are under the responsibility of the spacecraft platform (i.e. up to the payload I/F.)

Note: A temporal statistical interpretation is to be used for the evaluation of the pointing requirements (TBC). Pointing requirements must be evaluated in accordance with the updated ESA pointing error engineering handbook and ECSS standard [RD 6].

~~R-POIN-010 The LAD Reference Boresight LoS Absolute Performance Error (APE) shall be better than 1 arcminute (TBC) at all times during observation to a confidence of 99.7%.~~

~~*Note: This requirement applies to the LAD Reference Boresight which is defined in section 1.4. This requirement ensures that the LAD commanded pointing direction brings the source to within the flattened central region of the LAD response (where stability and effective area are maximised) - see [SCI-SYS-R-08] in [RD 1].*~~

~~*Note: the degree to which initial commissioning and periodic calibration activities can support this requirement is TBC.*~~

R-POIN-020 Each WFM Camera Reference Boresight LoS Absolute Performance Error (APE) shall be better than 50 arcseconds (TBC) at all times during observation to a confidence of 99.7% with respect to the J2000 reference frame.

G-POIN-022 Each WFM Camera Reference Boresight LoS Absolute Performance Error (APE) should be better than 20 arcseconds (TBC) at all times during observation to a confidence of 99.7% with respect to the J2000 reference frame.

Note: These requirements apply to the WFM Camera Reference Boresight which is defined in section 1.4. The quantity given in this requirement is the portion of [R-PERF-152, G-PERF-153] under the responsibility of the SC (i.e. up to the WFM Camera I/F); the remainder (misalignments internal to the WFM Camera) is the responsibility of the payload. See Annex A.6.

R-POIN-030 During LAD instrument operations, the LoS RPE (pointing jitter) of the LAD Reference Boresight and each LAD Module Reference Boresight shall not exceed the requirement limits specified in the following table.

G-POIN-030 During LAD instrument operations, the LoS RPE (pointing jitter) of the LAD Reference Boresight and each LAD Module Reference Boresight should not exceed the goal limits specified in the following table.

Frequency Range	Timescale	Requirement (rms)	Goal (rms)	Unusable bandwidth
<0.01 Hz	>100s	<93 arcseconds per frequency	46 arcseconds per decade	<1 octave per decade

		decade (*)		
0.01 - 1 Hz	100s – 1s	<13 arcseconds per frequency decade(*)	3 arcseconds per decade	<1 octave per decade
1 – 1200 Hz	1s – 0.8ms	<1.4 arcseconds per frequency octave (**)	0.4 arcseconds per octave	<1% per decade
>2000 Hz	<0.5 ms	TBD	TBD	<1% per decade

LAD Reference and Module Reference Boresight RPE requirements

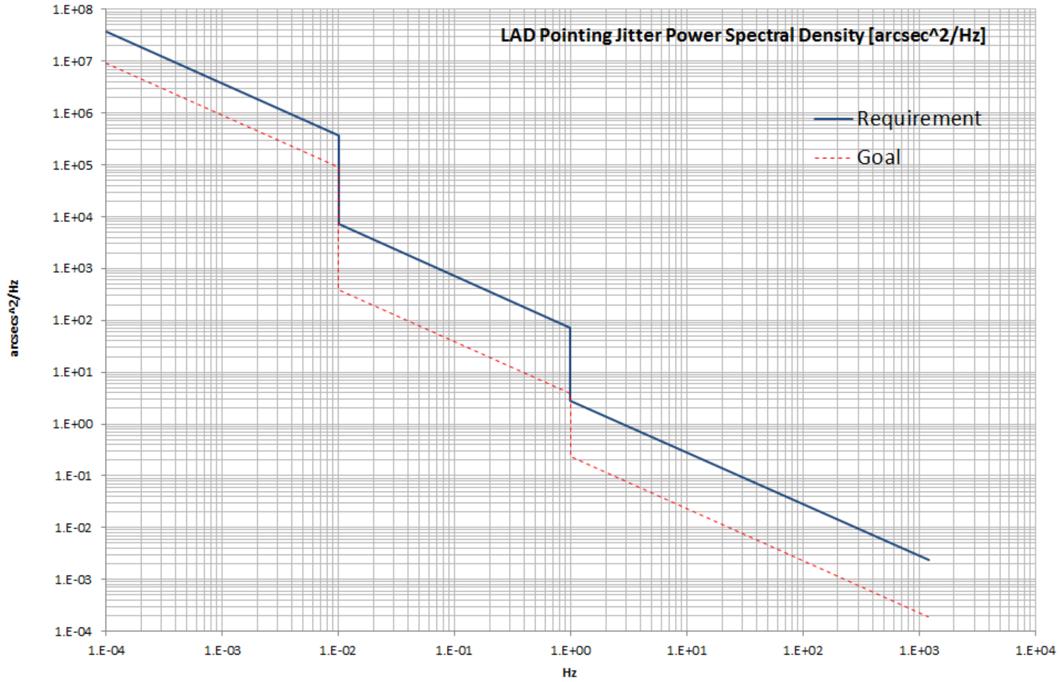
*the requirement will need to be satisfied over individual frequency decades (range covering factor 10 in frequency)
**the requirement will need to be satisfied over individual frequency octaves (range covering factor 2 in frequency)

In other words:

- For frequencies < 1Hz: The Power Spectral Density of RPE integrated over each frequency decade shall be lower than the PSD, specified in the following figure, integrated over the same frequency decade.

- For frequencies > 1Hz: The Power Spectral Density of RPE integrated over each frequency octave shall be lower than the PSD, specified in the following figure, integrated over the same frequency octave.

Note: A suggested conservative approach will be to ensure that Power Spectral Density of RPE is always lower than the PSD specified in the following figure.



Note: this requirement is the platform contribution (i.e. up to the I/F with the LAD Module) to meeting the response stability requirement of the LAD instrument [R-PERF-102] – the remainder is the responsibility of the payload.

R-POIN-040 The absolute knowledge error (AKE) during instrument operation of the AOCS reference frame shall be better than 20 arcseconds (TBC) for each spacecraft axis to a confidence of 99.7%, with respect to the J2000 reference frame.

Note: This requirement refers to an AOCS reference frame linked to the Optical Head of the star trackers. The Absolute Knowledge Error (AKE) is equivalent to the previously used Absolute Measurement Error. See [SCI-SYS-R-10] in [RD 1].

Timescale: The information should be made available on ground.

R-POIN-050 The absolute knowledge error (AKE) specified in [R-POIN-040] shall be made available at a sampling rate of at least 10Hz.

5.4 Structures and Configuration

~~G-STR-010 deleted.~~

~~R-STR-020 deleted.~~

R-STR-030 The spacecraft shall be compatible with the payload allocated volume of the launcher as specified in [AD 6].

R-STR-040 The spacecraft shall be compatible with the launcher environment as specified in [AD 6] at any stage before and during LEOP.

5.5 Mechanisms & Alignment

R-MECH-010 The use of mechanisms shall be avoided as far as possible. Use of mechanisms shall be subject to ESA approval.

~~R-MECH-020 deleted.~~

R-MECH-028 The mechanical misalignment at any time between the LAD Reference Boresight and any LAD Module Reference Boresight during instrument operation shall be less than 1 arcminute (TBC) to a confidence of 68.3% when evaluated over all LAD Modules.

Note: This requirement applies to the LAD Module Reference Boresight which is defined in section 1.4. This requirement supports the restriction of the loss in A_eff due to misalignment of the LAD Modules. The quantity *expressed in the requirement above is the mechanical misalignment under the responsibility of the SC; the remainder (mis-alignments internal to the LAD Module) is the responsibility of the payload.*

R-MECH-030 The mechanical misalignment at any time between the LAD Reference Boresight and any LAD Module Reference Boresight during instrument operation shall be less than 3 arcminutes (TBC) to a confidence of 99.7% when evaluated over all LAD Modules.

Note: See note to [R-MECH-028].

~~R-MECH-032 deleted~~

~~R-MECH-040 deleted.~~

~~R-MECH-050 deleted.~~

5.6 Thermal Control

~~R-THRM-010 deleted.~~

G-THRM-020 Thermal control should be achieved passively.

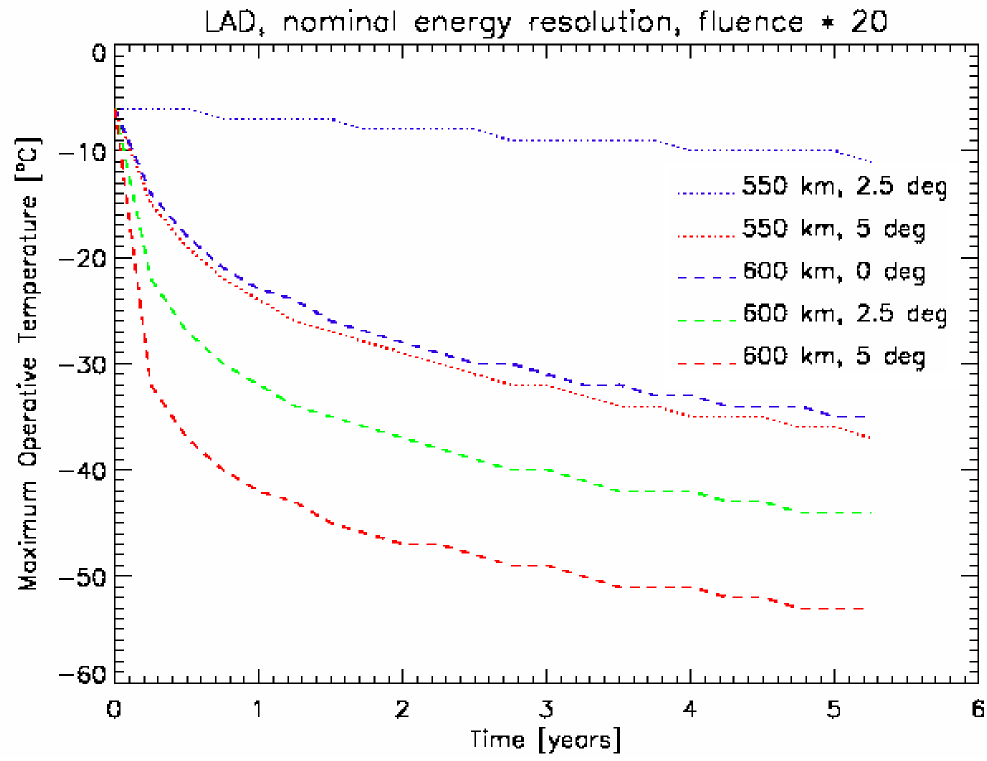
R-THRM-030 During science operations within the Nominal FoR, the LAD Effective Detector Operating Temperature shall be always kept below the maximum temperatures specified in the following table that ensure the fulfilment of the energy resolution requirement [R-PERF-100] throughout the mission until the end of the Nominal Operations Phase.

Note: See Annex A.3. For the purposes of evaluating compliance to this requirement, the formula for LAD Effective Detector Temperature provided in section 1.4 is applicable.

Note: to cover uncertainties between AP8/9 models, the applicable temperatures are those in the last row for each orbit (green cells), that have been derived by applying a factor 20 to the proton flux predicted by the AP8 model; temperatures corresponding to nominal and factor 10 flux are provided for information only.

Altitude [km]	Inclination [°]	Fluence Case	B_NoP Temp [°C]	M_NoP Temp [°C]	E_NoP Temp [°C]
550	0.0	AP8	-6	-6	-6
		AP8*10	-6	-7	-8
		AP8*20	-6	-8	-10
550	2.5	AP8	-6	-6	-6
		AP8*10	-6	-7	-8
		AP8*20	-6	-8	-10
550	5.0	AP8	-7	-11	-14
		AP8*10	-12	-25	-30
		AP8*20	-15	-30	-35
600	0.0	AP8	-6	-10	-13
		AP8*10	-11	-24	-28
		AP8*20	-14	-29	-34
600	2.5	AP8	-8	-17	-21
		AP8*10	-17	-33	-38
		AP8*20	-22	-38	-43
600	5.0	AP8	-12	-26	-30
		AP8*10	-26	-43	-47
		AP8*20	-32	-47	-52

LAD Effective Detector Operating Temperature requirements at the beginning, middle and end of the Nominal Operations Phase within the Nominal Field of Regard, for the candidate range of orbits



Required maximum LAD Effective Operating Temperature over the course of the mission within the Nominal Field of Regard, for the candidate range of orbits

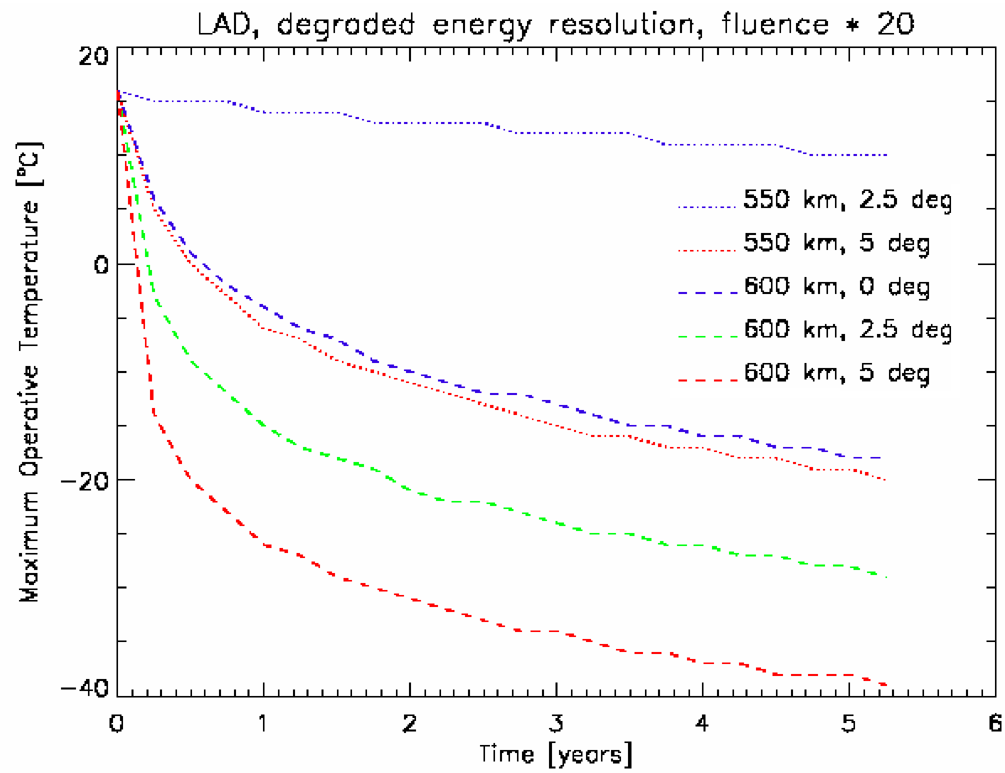
R-THRM-031 During science operations within the Degraded FoR, the LAD Effective Detector Operating Temperature shall be always kept below the maximum temperatures specified in the following table that ensure the fulfilment of the energy resolution requirement [R-PERF-101] throughout the mission until the end of the Nominal Operations Phase.

Note: See Annex A.3. For the purposes of evaluating compliance to this requirement, the formula for LAD Effective Detector Temperature provided in section 1.4 is applicable.

Note: to cover uncertainties between AP8/9 models, the applicable temperatures are those in the last row for each orbit (green cells), that have been derived by applying a factor 20 to the proton flux predicted by the AP8 model; temperatures corresponding to nominal and factor 10 flux are provided for information only.

Altitude [km]	Inclination [°]	Fluence Case	B_NoP Temp [°C]	M_NoP Temp [°C]	E_NoP Temp [°C]
550	0.0	AP8	16	15	15
		AP8*10	15	14	13
		AP8*20	15	13	11
550	2.5	AP8	16	15	15
		AP8*10	15	14	13
		AP8*20	15	13	11
550	5.0	AP8	15	9	6
		AP8*10	9	-7	-12
		AP8*20	5	-12	-18
600	0.0	AP8	15	10	7
		AP8*10	10	-5	-10
		AP8*20	6	-11	-16
600	2.5	AP8	13	3	-2
		AP8*10	2	-16	-21
		AP8*20	-3	-22	-27
600	5.0	AP8	9	-7	-12
		AP8*10	-8	-27	-32
		AP8*20	-14	-32	-37

LAD Effective Detector Operating Temperature requirements at the beginning, middle and end of the Nominal Operations Phase within the Degraded Field of Regard, for the candidate range of orbits



Required maximum LAD Effective Operating Temperature over the course of the mission within the Degraded Field of Regard, for the candidate range of orbits

R-THRM-070 During science operations, the operating temperature of the WFM detectors shall be always kept below the maximum temperature that ensures the fulfilment of the energy resolution requirement [R-PERF-130] throughout the mission until the end of the Nominal Operations Phase.

Note: for the purposes of evaluating compliance to this requirement, the WFM detector operating temperatures specified in the following figure and table are applicable.

Note: to cover uncertainties between AP8/9 models, the applicable temperatures are those in the last row for each orbit (green cells), that have been derived by applying a factor 20 to the proton flux predicted by the AP8 model; temperatures corresponding to nominal and factor 10 flux are provided for information only.

Altitude [km]	Inclination [°]	Fluence Case	B_NoP Temp [°C]	M_NoP Temp [°C]	E_NoP Temp [°C]
550	0.0	AP8	0	0	-1
		AP8*10	0	0	-2
		AP8*20	0	0	-3
550	2.5	AP8	0	0	-1
		AP8*10	0	0	-2
		AP8*20	0	0	-3
550	5.0	AP8	0	-1	-5
		AP8*10	0	-13	-18
		AP8*20	-2	-18	-23
600	0.0	AP8	0	-1	-4
		AP8*10	0	-12	-17
		AP8*20	-2	-17	-22
600	2.5	AP8	0	-5	-9
		AP8*10	-4	-20	-25
		AP8*20	-9	-26	-31
600	5.0	AP8	0	-14	-19
		AP8*10	-14	-32	-37
		AP8*20	-20	-37	-42

WFM detector operating temperature requirements at the beginning, middle and end of the Nominal Operations Phase for the candidate range of orbits

R-THRM-040 The LAD payload components shall be maintained to within their operating, non-operating and start-up temperature limits as defined in the following table.

Component	NonOp Min [C]	NonOp Max [C]	OpMin [C]	OpMax [C]	StartUp [C]
SDD/FEE	-60	+60	-50	As given by R-THRM-030, 031	TBD
MBEE	-60	+40	-60	+40	TBD
PBEE	-60	+40	-60	+40	TBD
DHU	-60	+40	-60	+40	TBD

Table: LAD operating, non-operating and start-up temperature limits (all TBC)

~~R-THRM-050 deleted.~~

R-THRM-032 The temperature of each individual LAD detector shall be maintained to a stability of ±10°C, over the full LAD over one orbit.

R-THRM-033 The temperature of each individual LAD detector shall be maintained to a stability of ±15°C, over the full LAD during a single observation.

R-THRM-060 The temperature of each WFM camera shall be maintained to a stability of ±TBD°C during observations.

R-THRM-080 The WFM payload components shall be maintained to within their operating, non-operating and start-up temperatures as defined in the following table.

Component	NonOp Min [C]	NonOp Max [C]	OpMin [C]	OpMax [C]	StartUp [C]
SDD/FEE	-60	+60 (TBC)	-50	As given by R-THRM-070	TBD
BEE/PSU	-60	+40	-60	+40	TBD
DHU	-60	+40	-60	+40	TBD

Table: WFM operating, non-operating and start-up temperature limits (all TBC)

R-THRM-090 The temperature of the LAD and WFM detectors shall be monitored by the platform in support of maintaining the requirements [R-THRM-040, R-THRM-080].

Note: this is in addition to temperature-monitoring internal to the payload.

5.7 AOCS

R-AOCS-010 During all mission phases, the AOCS shall acquire and control the S/C attitude and orbit within ranges allowing for nominal operation of all S/C systems and payload, and execution of the mission.

R-AOCS-020 After separation from the launch vehicle, AOCS shall:

- Damp-out any residual rates within the specifications of [AD 6].
- Bring the spacecraft into a safe attitude for power generation and payload thermal control within a time compatible with internal power resources
- Maintain an attitude in which communications with ground are possible.

R-AOCS-030 During all mission phases, AOCS shall avoid attitudes with:

- Insufficient power generation
- Compromised thermal control
- Loss of communication possibilities.

R-AOCS-035 After a major on-board failure the AOCS shall acquire and maintain a "safe mode" attitude that:

- Allows a continuous and sufficient supply of power for S/C survival
- Allows communication with Earth
- Ensures a survivable thermal environment
- Prevents damage to the instruments.

R-AOCS-040 The S/C shall be 3-axis controlled to assure proper orientation of science payload instruments.

~~R-AOCS-050 deleted.~~

~~R-AOCS-060 deleted.~~

~~R-AOCS-070 deleted.~~

~~R-AOCS-080 deleted.~~

~~R-AOCS-090 The design and performance of the AOCS shall be demonstrated against the observing plan specified in [AD 11].~~

5.8 Propulsion

R-PROP-010 The propulsion subsystem shall guarantee that the spacecraft can maintain an operational orbital altitude for the mission lifetime as defined in [R-MIS-181].

R-PROP-020 The propulsion subsystem shall support end-of-life measures according to [AD 8].

5.9 Power

~~R-PWR-010 deleted.~~

R-PWR-020 The Power subsystem shall provide sufficient power for the spacecraft systems and payload instruments during all operational modes and mission phases.

~~R-PWR-030 deleted.~~

5.10 Telemetry, Tracking & Command

R-TTC-010 The spacecraft shall comply with the ESA telecom standards within [RD 4].

R-TTC-020 The spacecraft shall be able to simultaneously perform the following actions throughout all the mission phases and spacecraft modes following launch and regardless of spacecraft attitude:

- Receive and demodulate the uplink signal from the ground segment and transmit the telecommands to the data handling system.
- Receive a telemetry data stream from the data handling system and transmit these data to the ground segment
- Transpose the ranging signal.

Note: because the SC should nominally use GPS for ranging during routine operations, ranging is only envisaged for LEOP.

R-TTC-025 The downlink capability shall be demonstrated on the basis of the following assumptions:

- Instantaneous reliability of the link due to the weather conditions of at least 95% CD for worst month and 98% for average (whichever is more stringent)
- 5 degrees or greater local elevation at the ground station
- The average contact duration with the ground segment.

R-TTC-030 The TTC subsystem shall be compatible with Kourou and Malindi ground stations, as defined in the ESA Tracking Stations Facilities Manual [AD 5].

R-TTC-040 The TTC-link shall support range and range-rate measurements.

Note: because the SC should nominally use GPS for tracking during routine operations, ranging is only envisaged for LEOP. If a cost advantage could be realised by omitting this capability, this can be considered.

R-TTC-050 The receive function of the TTC subsystem shall be hot-redundant, the transmission function shall be cold redundant.

R-TTC-070 The TTC subsystem shall enable spacecraft mode-changes through ground commands.

R-TTC-080 The uplink and downlink data rates shall be compatible with the data transmission requirements during all mission phases.

R-TTC-087 The LOFT spacecraft shall support the use of CFDP.

Note: The implementation of CFDP shall enable the automatic retransmission of data, when the respective link was lost due to adverse weather conditions. The feedback loop shall be closed via the MOC. The retransmission of the data shall be attempted not later than the next pass. The use of CFDP shall support the timeliness requirements of priority data (e.g. WFM data) and maximise the overall data downlink volume. (This may require an on board downlink re-planning capability.)

R-TTC-088 LOFT shall be able to downlink, on average, 6.7 Gbit of science and housekeeping data from the payload per orbit.

Note: The requirement refers to raw science data at the output of the payload, prior to encoding (FEC), the addition of telemetry frames, or additional overhead for CFDP. See Annex A.7.

R-TTC-089 The spacecraft shall be able to uplink with an average TC-rate of 64 kbps (TBC) during ground contact periods.

Note: This requirement ensures the LOFT uplink capability shall be sufficient to upload the required calibration data for the LAD instrument within reasonable timescales.

R-TTC-090 Link budget calculations for uplink shall be based on a maximum BER of 1E-5 at decoder input.

R-TTC-100 Link budget calculation for downlink shall be based on a maximum FER of 1E-7 at decoder output.

R-TTC-110 Link budgets shall have a nominal margin of 3dB.

R-TTC-120 The LBAS subsystem shall be compatible with the LBAS Ground Segment, as defined in [AD 14].

R-TTC-130 The time and position of triggered events detected by the WFM shall be broadcast to the LBAS Ground Segment, in less than 10s (TBC) since detection.

Note: The data content to be broadcast is less than 1 kbit/event. The implementation for this capability is use of a low-rate VHF telemetry transmitter on-board to the SVOM ground network. This is the allocation to the SC of the overall requirement to end user [R-PERF-150], i.e. from *detection to transmission (accordingly it must be decomposed between WFM instrument and platform.)*

R-TTC-140 The time and position of triggered events detected by the WFM should be broadcast to the LBAS Ground Segment, in less than 5s since detection for at least 75% of the triggered events.

Note: This is the allocation to the SC of the overall requirement to end user [G-PERF-152], i.e. from detection to transmission (accordingly it must be decomposed between WFM instrument and platform.)

5.11 Control and Data Management System

R-CDMS-010 The Control and Data Management System (CDMS) shall perform the following general functions:

- Telemetry acquisition, encoding, and formatting
- Telecommand acquisition, decoding validation, and distribution
- Data storage
- Time distribution and time tagging
- Autonomy supervision and management
- On Board Control Procedure management (OBCP) functions.

R-CDMS-020 The CDMS shall collect and prepare for transmission to ground all scientific and housekeeping data from the instruments and spacecraft.

5.12 On-Board Software

R-SFTW-010 The on-board software shall be able, in conjunction with hardware, to execute all the tasks identified for the CDMS.

R-SFTW-020 The S/C shall support replacement of the on-board software, either partially or totally, with software up-linked from the ground.

6 INTERFACES

6.1 Launcher Interfaces

R-IFL-010 The spacecraft shall be compatible with Soyuz-Fregat I/F requirements as specified by [AD 6].

6.2 Payload Interfaces

R-IFP-010 The spacecraft shall provide the interfaces required by the LAD and WFM payloads, as described in [AD 2], [AD 3].

6.3 Ground Facility Interfaces

~~R-IFG-010 deleted.~~

Note: Specific ground facility requirements are TBD.

7 SPACECRAFT ENVIRONMENT

7.1 Mechanical Environment

Note: specific ground handling requirements are TBD.

R-SEM-010 The spacecraft shall be compatible with the launcher environment specified in [AD 6].

~~R-SEM-020 deleted.~~

R-SEM-050 The spacecraft shall be compatible with all mechanical environments encountered during flight.

7.2 Thermal Environment

R-TEM-010 The spacecraft shall be compatible with the thermal-vacuum environment expected during all mission phases.

7.3 Cleanliness and Contamination

~~R-SEC-010 deleted.~~

R-SEC-015 ISO 8 standard cleanroom facilities must be used for activities involving the LAD collimators (TBC).

Note: other ground-handling cleanliness and contamination requirements are TBD. In-flight cleanliness and contamination requirements are currently TBD.

7.4 Radiation Environment

R-SER-010 The spacecraft shall be compatible with the radiation environment for all mission phases, as specified in [AD 13].

7.5 Meteoroids

R-SEMI-010 The spacecraft shall be compatible with the micrometeoroid & orbital debris environment predicted for all mission phases.

7.6 Electromagnetic Compatibility

~~R-SEMC-010 deleted.~~

Note: other specific EMC requirements are TBD.

R-SEMC-020 The magnetic field strength at the WFM location shall be lower than 4 Gauss.

8 ASSEMBLY, INTEGRATION AND VERIFICATION

Note: Applicability of ESA approved ECSS standards related to AIV is required in [R-SYS-030].

~~R-AIV-010 deleted.~~

R-AIV-020 The S/C design shall allow simple mounting and dismounting procedures so that any unit can be individually installed or uninstalled and tested throughout the integration process.

R-AIV-030 The SC shall provide the AIVT environment described in the EID-B [AD 2] for the LAD.

R-AIV-040 The SC shall provide the AIVT environment described in the EID-B [AD 3] for the WFM.

9 OPERATIONS AND GROUND SEGMENT

Note: Applicability of ESA approved ECSS standards related to operations and ground segment is required in [R-SYS-030].

9.1 Operations

R-OGS-010 The S/C design shall enable the operational control by the ground segment during all mission phases and modes in both nominal and contingency situations.

9.2 Ground Segment

The ground segment consists of the following:

- *Mission Operations Centre (MOC)*
- *Science Operation Centre (SOC)*
- *Science Data Centre (SDC)*
- *Instrument Team Centre (ITC)*
- *Ground Stations.*
- *LBAS Ground Segment (under PI-responsibility).*

R-OGS-020 The LOFT ground segment shall provide sufficient RF communications coverage with the spacecraft to downlink all recorded telemetry data.

9.2.1 Mission Operations Centre

R-OGS-030 The MOC shall be responsible for spacecraft operations after launch, including mission planning, spacecraft monitoring and control, and orbit and attitude determination and control.

R-OGS-050 The MOC shall perform all communications with the spacecraft through the ground stations.

R-OGS-060 The MOC shall provide all telemetry to the SOC.

Exception: this requirement applies only to the nominal TM downlinked by the nominal TT&C subsystem; it does not apply to the WFM burst-alert data transmitted by VHF transmitter to the SVOM ground network, which is under the responsibility of the payload consortium.

Note: LBAS I/F requirements are TBD.

R-OGS-070 The MOC shall provide telecommand history and other auxiliary data including attitude history to the SOC within TBD days.

9.2.2 Science Operations Centre

R-OGS-80 The SOC shall be responsible for instrument characterisation and calibration.

R-OGS-040 SOC shall be responsible for LOFT instrument operations, including instrument control, collection of science data and transmission to the SOC, and intervention in case of anomalies.

R-OGS-90 The SOC shall be responsible for analysing the science data received from the spacecraft via the MOC, as well as data reduction and production of the final scientific products.

R-OGS-100 The SOC shall prepare the Science Operation Plan and provide detailed operational requests to the MOC.

R-OGS-110 The SOC shall be responsible for the science data archive, which will contain raw telemetry, processed science products and relevant auxiliary data.

9.2.3 Science Data Centre

R-OGS-111 The Science Data Centre (SDC) shall be responsible for implementing and operating a Quick Look Analysis for checking the scientific progress of observations

R-OGS-112 The SDC shall be responsible for providing interactive and pipeline data analysis software

R-OGS-113 The SDC shall perform pipeline processing of Science Data and deliver products to the SOC.

9.2.4 Instrument Team Centre

R-OGS-114 The Instrument Team Centre (ITC) shall be responsible for characterising and calibrating the instrument responses.

R-OGS-125 The ITC shall be responsible for monitoring the science performance health of the instruments.

9.2.5 Ground Stations

R-OGS-120 The mission shall be compatible with the network of ESA ground stations [AD 5].

~~G-OGS-130 deleted.~~

R-OGS-140 During LEOP and critical mission phases, the 15-m ESA station at Kourou shall be used.

R-OGS-150 The spacecraft shall be compatible with the LBAS Ground Segment as defined in [AD 14].

9.3 Spacecraft Autonomy

R-OGS-150 The S/C shall support autonomous (without ground contact) operations according to a mission timeline uploaded from ground.

R-OGS-160 The S/C shall support re-scheduling of planned events in the mission timeline by ground.

R-OGS-170 The S/C shall support interruption of the mission timeline execution by ground command.

R-OGS-180 During LEOP, the S/C shall be able to operate nominally without ground contact for at least 12 hours.

R-OGS-190 In all mission phases after LEOP, the S/C shall be able to continue to operate nominally without ground support for at least 1 day (TBC).

Note: nominal operation in this context does not include storage of all the generated science telemetry.

~~R-OGS-200 deleted.~~

R-OGS-210 In all mission phases after LEOP, the S/C shall be able to survive without ground contact for at least 7 days (TBC).

10 PRODUCT ASSURANCE

Note: Applicability of ESA approved ECSS standards related to PA is required in [R-SYS-030].

11 PROGRAMMATIC

11.1 Technology Readiness and Availability

R-PROG-010 The TRL definitions shall be as from [RD 1].

R-PROG-020 All spacecraft components and payload items shall reach TRL 5 by the end of the definition phase (Phase A/B1).

Note: End of Phase A/B1 is expected in the end of 2014.

~~R-PROG-030 deleted.~~

R-PROG-040 European equipment shall be used.

Note: European equipment shall be preferred to non-European equipment with an equivalent performance. If a European equipment does not meet the requirements, a non-European alternative can be used.

11.2 Schedule

R-PROG-050 The schedule shall be compatible with the launch date defined in [R-MIS-020].

R-PROG-060 The flight units of the payload instruments shall be delivered at least 24 months (TBC) before launch.

ANNEX A: DERIVED MISSION REQUIREMENTS

This appendix provides traceability for those science requirements which have been transformed or allocated into spacecraft requirements. In each of these cases, the format declares the relevant MRD requirement, the parent SciRD requirement(s), and a brief justification text for the MRD requirement, with references to supporting documentation as appropriate.

Note: this Annex will be developed during the course of the industrial assessment study extension, but should not have any impact on the requirements contained in the main body of the MRD.

A.1 Mission Duration

MRD Requirement(s)	
R-MIS-130	Nominal Operations Phase requirement
G-MIS-150	Extended Operations Phase requirement
Parent SciRD Requirement(s)	
SCI-SYS-R-01	Net core science observing time requirement
SCI-SYS-G-01	Net core science observing time goal
SCI-SYS-R-02	Net observatory guest observing time requirement
SCI-SYS-G-02	Net observatory guest observing time goal
SCI-SYS-R-07	BHCT/AMXP detection requirement
Justification	

There are 2 separate science requirements that impact on required science mission lifetime.

To observe a Black Hole Transient or an Anomalous Millisecond X-ray Pulsar outburst during the mission with a high degree of confidence: These are unpredictable and rare events, with frequency of occurrence within an observable field of regard that can only be roughly estimated from previous experience (e.g. RXTE). Likewise the acceptable probability one should specify for observing such an event is hard to justify (e.g. 3 sigma / 5 sigma?) - However based on RXTE rates AND expected LOFT baseline characteristics simulations show that ~4 years is needed to have 98-99.5% chance to observe such events.

This is then comparable and consistent with the estimation of time needed for an overall observing programme. For example for the range of object classes, and targets per class, to be observed in order to fulfil the top level science goals, a total of ~20Ms observing time is required. However these observations must be spread over extended “campaigns” to observe objects in appropriate emission states, and furthermore some objects in nearby regions of sky cannot be observed simultaneously. Hence, given some baseline estimate of observing efficiency the 20Ms observing time must be spread out, with an estimate of +/- 4 years again resulting from initial simulation work.

Extended operations [G-MIS-150] naturally follows from providing margins on the above arguments for greater security in completing the core science observing aims.

Estimate of probability of observing Black hole transients:

In 5400 days (15 yrs) RXTE observed 17 big or major (very big) outbursts of 11 BH transient sources. We have taken those outbursts where the accretion state occurs during which the high-frequency quasi-periodic oscillation was detected with RXTE/PCA. Factoring in the LOFT sky visibility, from a Sun angle constraint of +-30 degrees, when comparing with the RXTE/PCA observations, by Poisson statistics in 4 years we expect >=1 at 98% probability, >=2 at 89% in different sources.

In 4 years you have a probability of covering at least one of these outbursts of 98%. In 4 years the probability to get 2 major outbursts is 90%, to get 3 is 74%.

Estimate of probability of observing accreting millisecond X-ray pulsars:

The RXTE rate of new AMXP discoveries is 13/15=0.87/yr. These outbursts are brief so RXTE misses 10% of them, and LOFT will see less due to the reduced accessible sky fraction when compare with RXTE. Nevertheless, in 4 years LOFT discovers >=1 with 99.7% probability (>=2 w/ 98%).

Note: It is important to understand that prob=f(FoR, duration), so failure to meet FoR or mission duration requirements will necessitate re-evaluation of the satisfaction of these requirements.

A.2 Orbit Selection

MRD Requirement(s)	
R-MIS-030	Orbit range requirement
Parent SciRD Requirement(s)	
SCI-LAD-R-08	LAD nominal spectral resolution requirement (2-anode events)
SCI-LAD-G-08	LAD nominal spectral resolution goal (2-anode events)
SCI-LAD-R-09	LAD nominal spectral resolution requirement (1-anode events)
SCI-LAD-G-09	LAD nominal spectral resolution goal (1-anode events)
SCI-LAD-R-22	LAD degraded spectral resolution requirement (2-anode events)
SCI-LAD-G-22	LAD degraded spectral resolution goal (2-anode events)
SCI-LAD-R-17	LAD background rate requirement
SCI-LAD-G-17	LAD background rate goal
SCI-LAD-R-18	LAD background knowledge requirement
SCI-LAD-G-18	LAD background knowledge goal

Justification

Background suppression

The choice of orbit for LOFT is strongly influenced by the requirement to minimise the instrument background - furthermore for reasons of reducing systematic effects due an unstable background (contributing to background knowledge error) the orbit must be chosen to avoid regions intersecting known enhancements of charged particles. These two considerations favour a LEO with low inclination (i.e. avoiding SAA and polar horns.)

See [RD 10] which demonstrates that for the specified range of orbits, the LAD background and background knowledge are suppressed to acceptable levels.

Background stability

In addition to the mean background rate, it should remain as much as possible *stable*. While the background will be periodically monitored by pointing to selected fields containing no bright sources, the variation between an observation and a reference field must be minimised. Effects such as geomagnetic shielding of the primary cosmic rays, and the solid angle for accepting atmospheric albedo neutrons may be compounded by the variability in orbital charged particle populations. Therefore maintaining a circular orbit will minimise the variability of such components.

Detector damage suppression (see also §A.3)

The energy resolution of the SDD is a function of the bulk leakage current – this is influenced primarily by (i) accumulated radiation damage and (ii) temperature. It is critically important to minimise as far as practical the radiation dose seen by the

LAD/WFM SDD detectors in support of their energy resolution requirements.

Two types of radiation damage are generally encountered by silicon devices: bulk damage and surface damage. The surface damage is related to the increase of the fixed oxide charge, and the production of trapping holes in the Si-SiO2 interface and is quantified by the Total Ionizing Dose (TID). The bulk damage, i.e. the displacement of the Si atoms from their lattice sites that creates additional energy levels within the band gap, producing a variation of the effective bulk doping and increasing the leakage current, is quantified by the Non Ionizing Energy Losses (NIEL).

Because active thermal control (cooling) of the LAD array is not feasible (because of its very large area), it is necessary to target a LEO orbit at low inclination, to minimise the radiation dose seen by the detectors, and accordingly to relax the detector temperature requirements to achievable values.

See [RD 11] for a full description of the modelling of the detector damage for the candidate range of orbits for LOFT – this document provides the resulting maximum allowable detector temperatures which provide the required energy resolution. Also see [RD 12] for initial test results on radiation damage tests to the SDDs which supports the assumptions made in [RD 11].

Given the other important system-level factors to consider when selecting the baseline orbit (launcher performance, orbit maintenance dV requirements, GS contact times...), the MRD requirement has been expressed as a range, within which the baseline can be freely selected by the System Prime (to first-order the T/O is between required detector temperature and fuel required for orbit maintenance).

A.3 Detector Maximum Temperatures

MRD Requirement(s)	
R-PERF-100, R-THRM-030	LAD nominal spectral resolution and temperature requirements
R-PERF-101, R-THRM-031	LAD degraded spectral resolution and temperature requirements
R-PERF-130, R-THRM-070	WFM spectral resolution and temperature requirements
Parent SciRD Requirement(s)	
SCI-LAD-R-08	LAD nominal spectral resolution requirement (2-anode events)
SCI-LAD-G-08	LAD nominal spectral resolution goal (2-anode events)
SCI-LAD-R-09	LAD nominal spectral resolution requirement (1-anode events)
SCI-LAD-G-09	LAD nominal spectral resolution goal (1-anode events)
SCI-LAD-R-22	LAD degraded spectral resolution requirement (2-anode events)
SCI-LAD-G-22	LAD degraded spectral resolution goal (2-anode events)
Justification	
The temperatures specified in the MRD requirements on energy resolution are derived from [RD 11] which describes the modelling of the SDD radiation damage, and resulting increase in leakage current, for the candidate range of orbits for LOFT – this document provides the resulting maximum allowable detector temperatures which provide the required energy resolution, for the range of candidate orbits. Also see [RD 12] for initial test results on radiation damage tests to the SDDs which supports the assumptions made in [RD 11]. Given the other important system-level factors to consider at LEO (launcher performance, orbit maintenance dV requirements, GS contact times etc...), the MRD requirements have been expressed as a range, within which the baseline can be freely selected by the System Prime (to first-order the trade-off is between required detector temperature and fuel required for orbit maintenance).	

A.4 LAD Response Stability

MRD Requirement(s)	
G-PERF-102, G-POIN-030	LAD response stability and I/F RPE goals
R-PERF-102, R-POIN-030	LAD response stability and I/F RPE requirements
Parent SciRD Requirement(s)	
SCI-LAD-R-23	LAD effective area stability (<0.01 Hz) requirement
SCI-LAD-G-23	LAD effective area stability (<0.01 Hz) goal
SCI-LAD-R-24	LAD effective area stability (0.01 - 1 Hz) requirement
SCI-LAD-G-24	LAD effective area stability (0.01 - 1 Hz) goal
SCI-LAD-R-25	LAD effective area stability (1 – 1200 Hz) requirement
SCI-LAD-G-25	LAD effective area stability (1 – 1200 Hz) goal
SCI-LAD-R-26	LAD effective area stability (>2000 Hz) requirement
SCI-LAD-G-26	LAD effective area stability (>2000 Hz) goal
Justification	
The variation of the LAD effective area will modulate the count-rate seen by the instrument – this must be limited to ensure that distortion of the core astrophysical signals of interest is kept down to levels that are acceptable in the view of the statistical quality with which they will be measured. See [RD 8], which translates the effective area stability requirements into an equivalent RPE requirement on the SC platform, applicable to the LAD Module reference boresight (at the mechanical I/F to the LAD Module.)	

A.5 LAD Mechanical Alignment

MRD Requirement(s)	
R-MECH-028	Module I/F alignment requirement (68.3%)
R-MECH-030	Module I/F alignment requirement (99.7%)
Parent SciRD Requirement(s)	
SCI-LAD-R-01	LAD effective area @ 8keV requirement
SCI-LAD-G-01	LAD effective area @ 8keV goal
SCI-LAD-R-02	LAD effective area @ 2keV requirement
SCI-LAD-G-02	LAD effective area @ 2keV goal
SCI-LAD-R-03	LAD effective area @ 5keV requirement
SCI-LAD-G-03	LAD effective area @ 5keV goal
SCI-LAD-R-04	LAD effective area @ 30keV requirement
SCI-LAD-G-04	LAD effective area @ 30keV goal
SCI-LAD-R-05	LAD effective area knowledge requirement
SCI-LAD-G-05	LAD effective area knowledge goal
Justification	
To be updated.	

A.6 WFM Pointing

MRD Requirement(s)	
R-PERF-152	WFM source localisation requirement
G-PERF-153	WFM source localisation goal
R-POIN-020	WFM Camera Reference Boresight APE requirement
G-POIN-022	WFM Camera Reference Boresight APE goal
Parent SciRD Requirement(s)	
SCI-SYS-R-08	Source localisation accuracy requirement
SCI-SYS-G-08	Source localisation accuracy requirement
Justification	
A statement has been received from the LOFT consortium that, after calibration, the residual error in the WFM camera is of the order of ~arcseconds. Accordingly an initial allocation has been made of 10'' to the WFM instrument, with the remaining 50'' allocated to the SC, up until the mechanical I/F with each WFM camera. *Note: The LOFT consortium is in the process of developing a WFM source-localisation budget, within which the platform contribution shall be placed.*	

A.7 Telemetry Rate

MRD Requirement(s)	
R-TTC-088	LOFT P/L telemetry requirement
Parent SciRD Requirement(s)	
SCI-LAD-R-19	LAD source intensity requirement (500 mCrab)
SCI-LAD-G-19	LAD source intensity goal (1 Crab)
SCI-SYS-R-15	Typical data-rate requirement
SCI-SYS-G-15	Typical data-rate goal
SCI-SYS-R-16	Sustained data-rate requirement
SCI-SYS-G-16	Sustained data-rate goal

Justification

The LAD scientific telemetry budget is estimated assuming default event-by-event data transmission, 24-bit per event. We conservatively assume a source with intensity 500 mCrab in the field of view at any time (this flux threshold includes >95% of the known X-ray sources with flux above 1 mCrab). The expected count rate under the assumption is ~117 000 cts/s, in addition to the expected ~3000 cts s^{-1} from the background.

Taking into account the typical net source exposure in LEO (4000 s) and the full-orbit background counts, a total of ~11.5 Gbit are created over one orbit, corresponding to 1.9 Mbps orbit-average. This will be compressed to ~960 kbps through a lossless algorithm in the DHU. Preliminary simulations have been carried out using simulated LAD data streams and standard compression algorithms (gzip, bzip2, 7Z(PMMd), ZPAQ, PAQ8l), providing compression factors up to ~2.1. Therefore, adopting lossless algorithms for space applications (e.g., Rice compression) we assume that a 2 compression factor is affordable. The required computational resources are being evaluated as well. A 64 GB mass memory on the DHU will allow the temporary storage of excess telemetry.

Some of the key science targets (~10 persistent sources and some bright X-ray transients) will have average LAD count rate above 1.2x105 cts s^{-1}. In these cases we will employ a flexible set of data modes, as was done with the Event Data System (EDS) on RossiXTE. These modes allow the time and energy binning to be optimized for the science goals within the available telemetry budget. The observing plan will be optimized by alternating bright and weak sources to allow for a gradual download of the excess telemetry, a strategy already successfully adopted by the RossiXTE/PCA. The strategy envisaged in the previous paragraphs is based on the assumption that telemetry down-link with a maximum net science data rate of 6.68 Gbit/orbit is available (6 Gbit of which is allocated to the LAD – the remainder being allocated to the WFM.)

See [RD 13] for a simulation of LAD telemetry generation and downlink.

See [RD 14] for an analysis of the WFM instrument TM generation within the ~100kbps allocation.

A.9 LAD Temperature Stability Requirements

MRD Requirement(s)	
R-THRM-032	LAD detector temperature stability (orbit)
R-THRM-033	LAD detector temperature stability (observation)
Parent SciRD Requirement(s)	
SCI-LAD-R-08	LAD nominal spectral resolution requirement (2-anode events)
SCI-LAD-G-08	LAD nominal spectral resolution goal (2-anode events)
SCI-LAD-R-09	LAD nominal spectral resolution requirement (1-anode events)
SCI-LAD-G-09	LAD nominal spectral resolution goal (1-anode events)
SCI-LAD-R-22	LAD degraded spectral resolution requirement (2-anode events)
SCI-LAD-G-22	LAD degraded spectral resolution goal (2-anode events)
Justification	

The LAD observations require co-addition of data taken by the >28,000 detector channels composing the detector, reaching the required energy resolution. This implies that any differences in the response of the ASICs is known with sufficient accuracy so as not to introduce worsening of the energy resolution due to different gains of the circuitry. As this is known to depend on the temperature, we initially fixed a cautionary requirement on the maximum temperature variation across the instrument (5C) and during an observation (stability). In addition there is planned a linear on-board correction to the event amplitude, based on a set of pre-loaded look-up tables providing the linear coefficients of the off-set and gain of the ASICs as a function of temperatures, within the operative range. The tables will be built during the thermal tests on the ground, by using the fast and effective electrical calibration procedure, allowing to inject know charges into all pre-amp channels and get the response with high statistical accuracy (the test capacitor will be in turn calibrated against X-rays on the ground with the required statistical accuracy, as planned). The electrical calibration can also be repeated and benchmarked in orbit. Of course, the concept of temperature correction implies that for every detected photon an equilibrium temperature can be defined and used for correction (i.e., T variations should not be "too fast").

On January 2013 the first LAD ASIC prototype was made available at IRAP and temperature tests were carried out. These tests show a much better thermal stability of the gain under this design than the one used as early reference. The analysis, reported in *LAD_TempReq_v2 (22.01.2013) by F. Muleri et al.*, shows that with the LAD ASIC the energy resolution is affected by less than the required 1% over the full temperature range even without the application of the linear gain correction. Based on this result, the temperature stability requirements of the LAD can be much relaxed in comparison to the previous specification. We maintain the on-board linear gain correction approach for robustness.

Note: These requirements are not related to the management of thermo-elastic effects *on the Detector Panel in pursuit of achievement of the mechanical alignment stability of the LAD in order to prevent loss of effective area.*

Note: The above requirements concern only gradients and stability, under the assumption that the absolute T value is in-spec, guaranteeing the required energy resolution.