# LISA

# The Laser Interferometer Space Antenna

# Science Management Plan

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# 1 INTRODUCTION AND SCOPE

The Laser Interferometer Space Antenna (LISA) is an ESA-led mission in partnership with NASA. It aims to study the Gravitational Universe through the observation of low frequency gravitational waves. LISA is the first space mission designed to observe the Universe via gravitational waves.

The Science Management Plan (SMP) describes the approach that will be implemented to ensure the fulfilment of the scientific objectives of the LISA mission and to optimise its scientific return, with special emphasis on science operations and data generation and management. It identifies and outlines the roles and responsibilities of all parties involved in the LISA mission.

The SMP provides a mission overview (Section 2), followed by a summary of the mission management scheme (Section 3), a description of the mission products and data rights (Section 4), publication policy (Section 5) and of the opportunities for participation in the mission (Section 6). The SMP then describes the ground segment and operations (Section 7), concluding with public outreach plans (Section 8).

The SMP is approved by the Science Programme Committee following a recommendation by the scientific advisory structure to the Science Programme and may be subject to revisions and updates at a later stage through the same approval loop if needed.

# 2 MISSION OVERVIEW

## *2.1 Scientific objectives*

LISA is a space mission designed to measure gravitational radiation over a broad band at low frequencies, from 0.1 mHz to 1 Hz; a band where the universe is richly populated by strong sources of gravitational waves. It will measure signals from a wide range of different sources that are of high relevance to the astrophysics of black hole and galaxy formation, to tests of general relativity and to cosmology, including: massive black holes mergers at all redshifts; extreme mass ratio inspirals; the inspiral of stellar-origin black hole binaries; known compact binary stars and stellar remnants; and probably other sources, possibly including relics of the extremely early Universe, which are as yet unknown.

A major objective of the mission is to determine how and when the massive black holes, present in most galactic nuclei today, have formed and grown over cosmic time. LISA will explore almost the entire mass-redshift parameter space relevant for reconstructing their evolution. The gravitational wave signal from coalescing black holes reveals their spin and redshifted mass, and the distribution of masses and spins will be studied to differentiate between different formation scenarios.

The mission will also study in detail the signals from thousands of stellar-mass close binaries in the Galaxy and give information on the extreme endpoints of stellar evolution. It will provide distances and detailed orbital and mass parameters for hundreds of the most compact binaries, a rich trove of information for detailed mapping and reconstruction of the history of stars in our Galaxy, and a source of information about tidal and non-gravitational influences on orbits associated with the internal physics of the compact remnants themselves.

By observing highly relativistic black hole-black hole coalescences, LISA will provide exceptionally strong tests of the predictions of General Relativity. The signal from merging binary black holes, where maximally warped vacuum spacetimes travel at near the speed of

light interacting strongly with each other, allow the study of the full nonlinear dynamics of the theory of gravity. By observing the signal of stellar black holes skimming the horizon of a large massive black hole at the centre of a galaxy, LISA will measure the mass, spin and quadrupole moment of the central object, testing its level of Kerrness; thus testing for the first time the black hole hypothesis and the no-hair conjecture.

Finally, a space-based gravitational wave detector will probe new physics and cosmology, and will search for unforeseen sources of gravitational waves. The LISA frequency band in the relativistic early Universe corresponds to horizon scales where phase transitions of new forces of nature or extra dimensions of space may have caused catastrophic, explosive bubble growth and gravitational wave generation.

### *2.2 Mission description*

The LISA observatory consists of three spacecraft forming an equilateral triangular constellation of 2.5 million km on a side. The passage of a gravitational wave results in a modulation of the proper distance between the satellites; by monitoring the length of one arm with respect to another using laser interferometry, the effect of the passage of the gravitational wave can be measured.

The orbits of each satellite are independent, however they are chosen such that the constellation of the three satellites remains stable over the course of the nominal science mission, without the need for orbit maintenance. The constellation rotates as it orbits the sun, performing one full rotation over the course of a year. This rotation sweeps the constellation response function over the sky, and, along with the motion of the constellation around its orbit, allows the sky position of permanent gravitational wave sources to be estimated.

Each spacecraft in LISA is notionally identical, with the constellation of the three spacecraft forming the science instrument. Each spacecraft houses two optical terminals capable of transmitting and receiving laser light to/from the other satellite at the end of the arm, as well as two drag-free gravitational reference sensors which constitute the fiducial points at the end of the arms. These terminals are referred to as the Moving Optical Subsystem Assemblies (MOSA). The spacecraft platform also provides all necessary infrastructure enabling space operations, including notably for LISA the micro-Newton propulsion system and the drag-free and attitude control systems (DFACS).

## 3 OVERVIEW OF THE MISSION MANAGEMENT SCHEME

The overall LISA mission management scheme and the responsibilities of key contributors to the LISA mission are introduced in this section and their relations sketched in Figure 1 (Implementation), and Figure 2 (Operations).

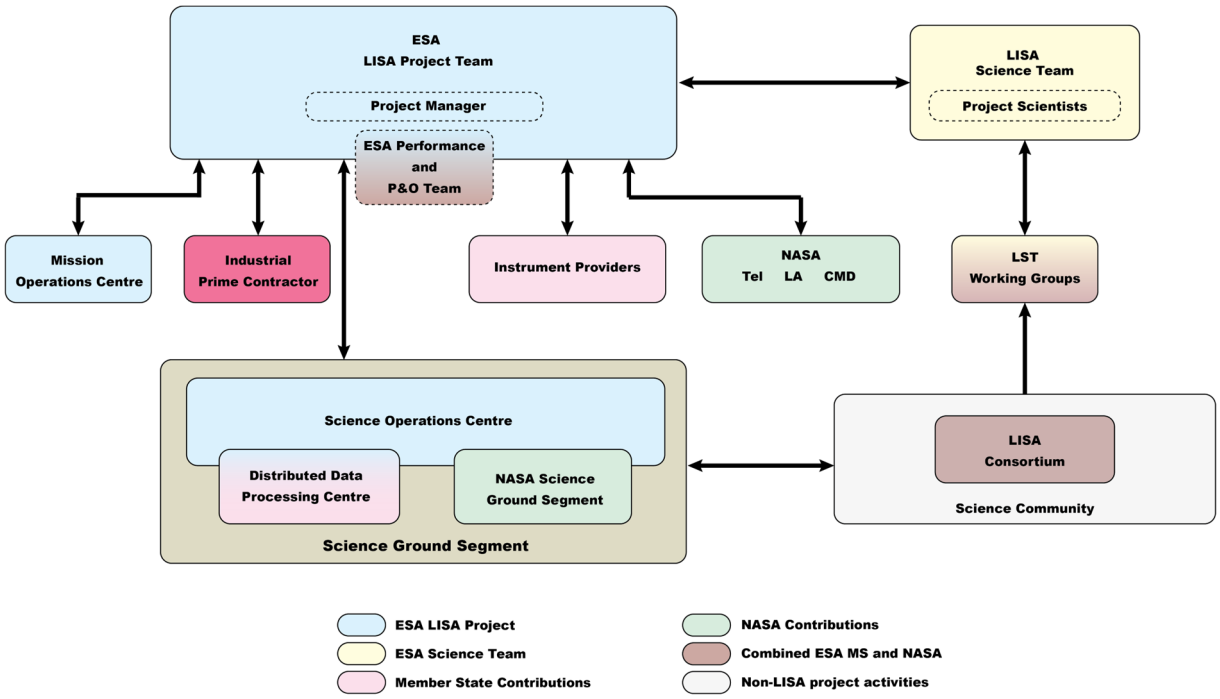


**Figure 1: Overview of the LISA management scheme during the Implementation phase.**

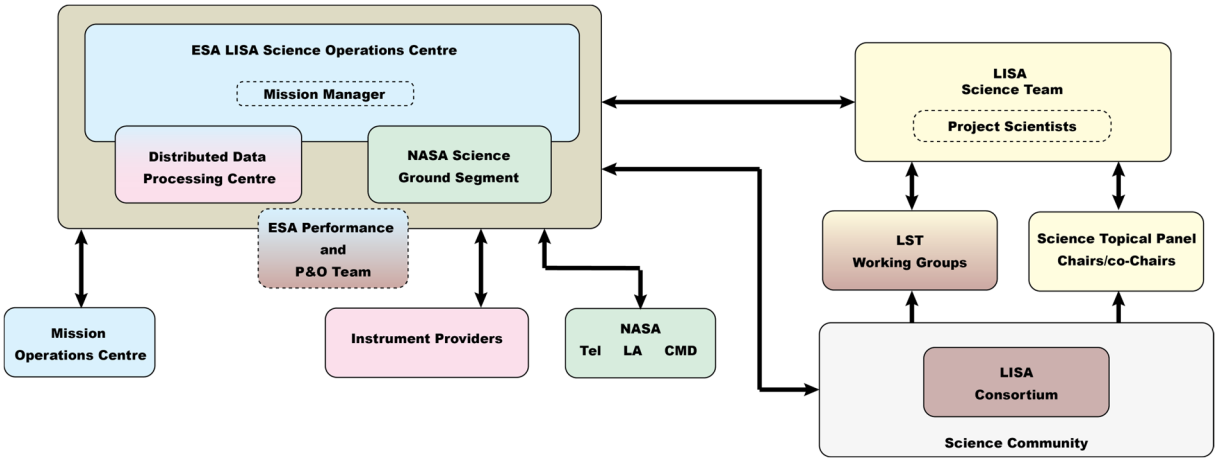


**Figure 2: Overview of the LISA management scheme during the science operations phase.**

Note: the Science Topical Panels' tenure ends at Data Release 1.

The overarching responsibility for all aspects of the LISA mission rests with ESA's Directorate of Science and its director.

ESA is responsible for the LISA mission, and in particular for:

- The development of the space segment, consisting of three nearly identical spacecraft to be provided by ESA, housing the LISA payload subsystems, to be provided by ESA, Member States and International Partner Agencies.
- The development of the ground segment, in particular the Mission Operations Centre (MOC), and the Science Operation Centre (SOC, part of the SGS), as detailed in Section 7;
- The launch services procurement;
- The mission and science operations covering early operations, commissioning and all subsequent in-orbit operation phases, including the de-commissioning and disposal of the spacecraft.

During the development and commissioning phases, an ESA-appointed Project Manager will be responsible for implementing and managing ESA's activities. After a successful near-Earth commissioning review, a Mission Manager will take over the responsibility for the mission throughout the transfer, commissioning, nominal science operations phase, and any extended phases.

Pursuant to the relevant Memorandum of Understanding (MOU[1]) between ESA and NASA, NASA is responsible for the following:

- Provision of hardware elements of the LISA payload, in particular the telescopes, laser assemblies, and the UV LEDs for the test mass discharge system;
- Contributing to the activities of the ESA Project Team;
- Providing contributions to ESA's Performance Management Team, through the Performance and Operations (P&O) team, as detailed in Section 7.3;
- Contributing to the science ground segment through the NASA Science Ground Segment (NSGS) activities;
- Providing scientific expertise to the LISA Science Team (LST) and the Science Ground Segment (SGS).

Funded by national Funding Agencies (FA), within the remit of a Multi-Lateral Agreement (MLA[1]), including ESA and the national FAs, the Member States are responsible for:

- Provision of hardware elements of the LISA payload;
- Providing contributions to ESA's Performance Management Team, through the Performance and Operations (P&O) team, as detailed in Section 7.3;
- Providing contributions to the SGS, through the Distributed Data Processing Centre (DDPC), as detailed in Section 7.2.2;
- Providing scientific expertise to the LST and the SGS.

Day-to-day contacts between the instrument providers, DDPC and ESA will be via designated personnel with responsibility for the particular areas of work and the appropriate ESA project team member. Selected members of the instrument providers and the DDPC will form a

[1] In case of conflicting provisions, precedence will be given to the MLA and MOU, over the present SMP.

Performance and Operations Team (P&O), a subset of which will function as part of the ESA Project Team, and will be managed by the ESA Project Manager.

Each provider of instrument hardware will establish a Project Office to manage the day-to-day activities of their responsible system.

The LISA Consortium is an organisation which represents the knowledge, capabilities and interests of the larger scientific community. The LISA Consortium internal structure and participation mechanisms are not regulated by ESA.

The LISA Consortium provides an organizational forum beyond the working groups and Science Topical Panels set up by the LST. It will set up science interest groups which focus on scientific topics which are either not represented in one of the working groups of the LST or will require integrated data sets well beyond the first data release. In addition, it will provide a pool of scientific expertise that can be drawn on as needed to support the implementation of the SGS and the P&O activities. Depending on the number, type and size of the LST working groups, the LISA Consortium might also set up larger science interest groups outside the LST WGs to provide pathways for early career scientists to later join the LST WGs. The LISA Consortium will also publicise LISA science to the public.

The LISA Consortium will nominate a representative to serve as an ex-officio member of the LST, whose role will be to represent the interests of the scientific community working on preparation for LISA science exploitation.

ESA's European Space Operations Centre (ESOC) implements the Mission Operations Centre (MOC), operates the spacecraft, and delivers telemetry and attitude data to the Science Ground Segment via the ESA Science Operations Centre (SOC).

ESA's European Space Astronomy Centre (ESAC) implements the SOC, which acts as the central node for the SGS, including the science mission planning, and is the single interface to the MOC. The SOC performs an initial quality check of the Level-0 data, and runs the Level-0 to Level-0.5 and Level-0.5 to Level-1 data processing pipelines developed in conjunction with the DDPC and NSGS. The SOC is also responsible for the development and operations of the Mission Data Repository (MDR) and the LISA Public Archive (LPA), and for issuing and updating alerts to the scientific community.

The LISA Science Team will be asked to review and endorse top-level requirements (in all areas of the mission) that impact science return, and to monitor all aspects of the subsequent implementation. Details of the LST composition and responsibilities are reported in Section 3.2.

### *3.1 Project Scientist*

The LISA Project Scientists (PSs) are the Project's interface with the LISA Consortium and the general scientific community for all scientific matters.

The ESA and NASA PSs co-chair the LST and coordinate its activities.

During the development phase, the ESA PS, with the help of the LST, advises the Project Manager on all issues that affect the scientific performance of LISA. They monitor the development of the space and ground segment to ensure that the scientific objectives of the mission can be achieved and to maximise its scientific output within programmatic constraints. They are a member of formal review boards that convene throughout the project development cycle to examine the status and progress of the mission implementation. The PS pays special attention to those aspects that are directly related to the scientific performances of the mission, in particular the payload and the SGS.

During operations, the ESA and NASA PSs, with the help of the LST, advise the Mission Manager on all issues that affect the scientific output of LISA.

The ESA and NASA PSs, with the help of the LST, will monitor the production of the Level-2 data products by the DDPC and NSGS to ensure their timely delivery to allow the production of the Level-3 data products. The PSs will also lead the teams responsible for the production of the Level-3 source catalogue, including the archival and distribution to the scientific community.

### *3.2 LISA Science Team*

The LISA Science Team monitors the correct implementation of the scientific objectives of the mission and maximises its scientific return. The LST acts as a focus for the interest of the scientific community in LISA. Its recommendations to the PSs are geared toward:

- maximising the scientific return of LISA within programmatic constraints, while ensuring that the development and operations of the mission remain compatible with its main scientific objectives;
- optimising the scientific performance of the instrument and spacecraft;
- formulating, optimising, and maintaining the gravitational wave calibration strategy;
- optimising access to the data via the mission archive(s);
- optimising the analysis and utilisation of LISA data;
- overseeing the generation of the Level-3 source catalogue from Level-2 data products;
- authorising the release of scientific data products to the community;
- establishing, when necessary, Working Groups to provide expertise to support the LST in providing scientific advice to the Project and Mission Managers;
- establishing and managing the Science Topical Panels (STPs) of the Early Release Science Time;
- promoting public awareness and appreciation of the LISA mission, and supporting ESA and its partners in their outreach efforts.

In general, members of the LST are expected to monitor the development and operations of the mission and give advice on all aspects that affect its scientific performance. They perform specific scientific tasks as required to discharge their responsibilities during development and operation.

The LST is formed after the adoption of the mission and remains in place until the end of the post-operations phase. In addition to the ESA Project Scientist who chairs it, and the NASA Project Scientist who co-Chairs it, the LST comprises the following members:

- A representative nominated by the LISA Consortium
- Up to 17 members covering the instrumentation, performance and operations, data processing and scientific objectives of the mission. These members will be selected through a coordinated open call issued by ESA and NASA;
- Up to two “Complementary Scientists”, who are experts in fields relevant for complementary science (e.g., Multi-messenger astronomy), selected through an open call issued by ESA.

A commensurate number of members of the LST will be selected from U.S. institutions.

With the exception of members from U.S. institutions, all LST members are appointed by the ESA Director of Science. All LST members will be appointed for a period of three years, renewable. In the event that an LST member is to be replaced, his/her successor is selected through a similar call issued at the appropriate time, or if the LISA Consortium representative is to be replaced, their replacement will be nominated by the appropriate body.

The ESA Project Manager, NASA Project Manager and the ESA Mission Manager (after commissioning) have a standing invitation to attend LST meetings.

To discharge its responsibilities, the LST relies mainly on technical information provided by the ESA Project. However, if deemed necessary, the co-Chairs may request external scientific consultant(s) to conduct an independent review of any of the activities which fall under the responsibility of the LST.

### *3.3 Steering Committee*

A Multi-Lateral Agreement (MLA) is established between ESA and the LISA instrument and ground segment funding agencies to formalise the commitments and deliverables of all parties. In case of conflicting provisions, the MLA will prevail over the present SMP. A LISA Steering Committee with representatives from the national funding agencies and ESA will be set up to oversee the activities and the timely fulfilment of the obligations of all parties to the MLA and address any issues that may arise in that context.

## 4 DATA PRODUCTS AND DATA RIGHTS

### *4.1 Data products*

LISA data products are summarised as follows:

Level 0: Raw data.

- Telemetry data processed in the following way:
  - De-multiplexed and annotated with time correlation, quality flags and positioning data;
  - Anomalous, corrupted items corrected or removed;

  - All measurements time-ordered and uniquely tagged.
- Level 0 data are not releasable to the public, as it may allow to reverse-engineer proprietary algorithms.

Level 0.5:

- Level 0 data which have been further processed and reformatted by ESAC in the following way:
  - De-packetized, de-compressed (if applicable);
  - Reformatted to the data exchange format of the Science Ground System;
  - Clock data synchronised and converted to a common, non-Earth-bound astronomical timescale;
  - Binary units (ADC counts), where applicable, converted to physical values.
- Level 0.5 data are fully releasable, i.e. do not contain data that allows to reverse-engineer proprietary algorithms.

Level 1:

- Calibrated and noise corrected Time-Delay Interferometry (TDI) data streams.
- This is “analysable data” and the main input to the core downstream processing to isolate individual GW signals., i. e. major noise sources removed and constitutes the minimum viable science data.
- Level 1 data, and the algorithms used to produce the data product, will be released via the LISA Public Archive.

Level 2:

- Output from a global fit pipelines, providing Probability Density Functions (PDFs) for identified sources.
- They include the reconstructed waveforms and detector signals for identified sources as well as regular updates on the critical parameters of transient sources, such as coalescence times and sky location.
- These are “analysed data”. Several Level 2 products will be produced that vary depending on prior probabilities for source parameters and numbers of sources, on the methods used, and on the volume of the data engaged.

Level 3:

- Catalogue of GW source candidates with detection confidence, estimated astrophysical parameters and their strain time series, *h(t)*. This is “consolidated data”.
- Level 3 data also include the “residual” data stream, i.e., the L1 data stream with the contribution of identified sources removed, as well as tools for data visualization, preliminary analysis and to cross match with outside data.
- Level 3 data constitute the mission end products.

Alerts:

- The alerts shall contain the information needed by the scientific community to decide upon, and to conduct, co-observations. Such information shall include at a minimum: sky location of the source as a probability density function, the expected timeline of the event, the source model, prediction for the evolution of the parameter probability density

function of the source parameters, and the schedule of the expected updates of the alerts.

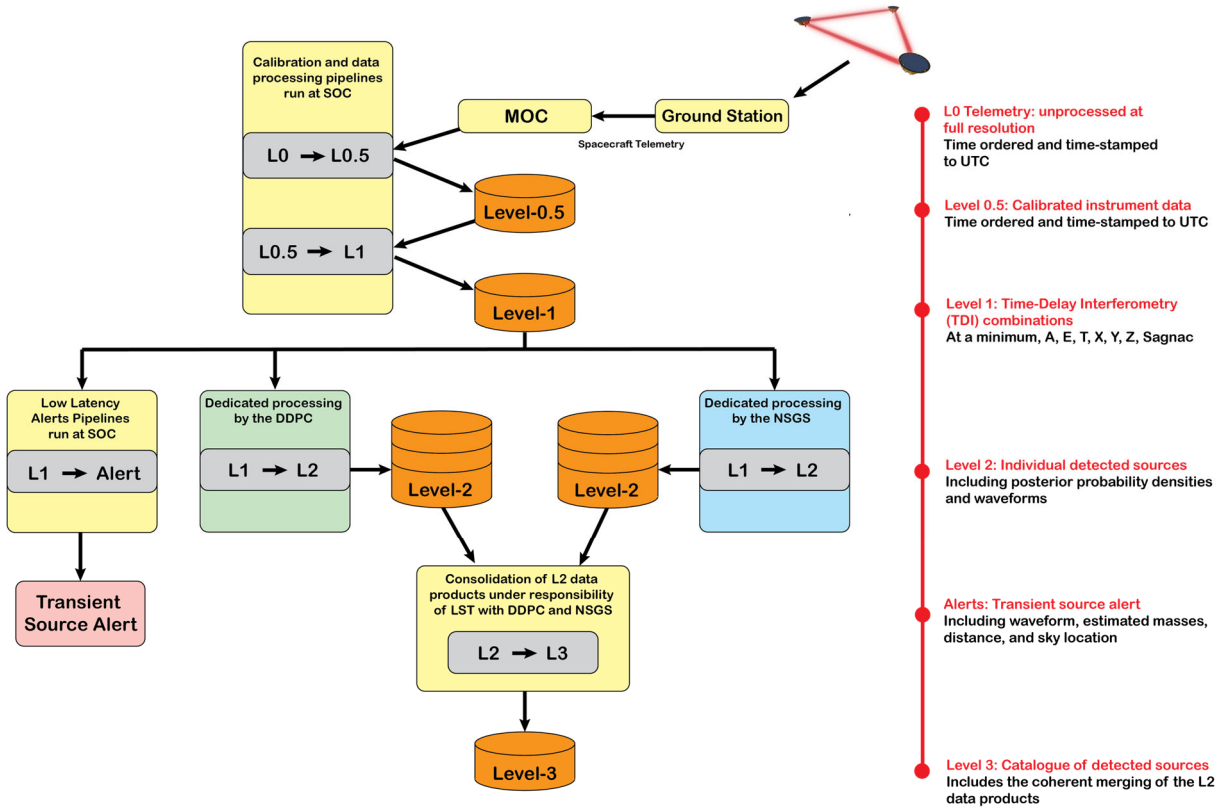


**Figure 3: Schematic of the LISA science data processing and data flow.**

Level 0.5 to Level 3 data are made available to the SGS through the MDR.

The consolidated Raw data (Level 0) are provided by the MOC to the SOC. The SOC calibrates the Level 0 data and converts the data to engineering values (Level 0.5). The individual phase readouts, along with auxiliary data, are then combined to form the Time Delay Interferometry (TDI) combinations. This is achieved using the Level 0.5 to Level 1 data processing pipeline developed by the DDPC and NSGS in conjunction with the SOC, and is run on a daily basis in the SOC. The Level 1 data products are the lowest level of *analysable* LISA data. Level 0.5 to Level 1 data products are made available to the DDPC and the NSGS immediately through the Mission Data Repository (MDR) located at the SOC, and to the wider scientific community at the time of a LISA data release (see Section 4.3), via the LISA Public Archive. New TDI combinations forming L1 data products produced external to the SOC, will be evaluated by the LST and SOC; if deemed to be an enhancement of the existing L1 products, they will subsequently be produced by the SOC and made available as before. Multiple sets of Level-2 data are generated by the DDPC and the NSGS before being consolidated to produce a single Level 3 source catalogue under the responsibility of the Project Scientists and LST.

The Level 3 catalogue will be made publicly available through the LISA Public Archive, and will be accompanied by processing software and documentation sufficient to allow the product to be reproduced from the previous level data products.

The SOC will also run the Low Latency Alert Pipeline (LLAP), developed by the DDPC and NSGS. The LLAP output is used to raise and update scientific alerts for transient sources.

### *4.2 Early Release Science Time*

After the 3 months of in-orbit commissioning, a period, estimated to be 12 months (called the Early Release Science Time, ERST), will be required to validate the instrument performance, data processing pipelines and to verify mission and science data products. The period includes: engineering activities to characterise the instrument; data taking of sufficient duration to allow verification binaries to be uniquely identified; pre-processing of the Level 0 data; data processing phase where the DDPC and NSGS will perform the first global fit of LISA data to extract individual GW sources. It is expected that, given LISA is the first mission of its kind, the pipelines will have to be modified to deal with uniqueness of the data, e.g. glitches, gaps in the data, non-uniformity between the three satellites, etc.; and, consolidation of the Level 2 data into a single Level 3 source catalogue.

Before the launch of the mission, the LST will establish a number of Science Topical Panels (STPs) which will focus on one specific science question. The STPs will be selected by canvassing the scientific community via the submission of whitepapers. The final list of STPs will be under the responsibility of the LST. STP members will be encouraged to publish science interpretation[2] papers related directly to their STP science theme using *only* data acquired during the ERST period.

Each STP will be led by a Chair and up to two co-Chairs, selected through a coordinated call issued by ESA and NASA, and will a constitute a Working Group of the LST. A commensurate number of chairs and co-chairs will be selected from scientists from US institutions.

Membership of the STPs is open to the scientific community, and will selected through a coordinated call issued by ESA and NASA . Interested scientists can apply to be a member of up to two STPs.

### *4.3 Data release and data rights*

Data processing of the Level 0 to Level 0.5 and Level 0.5 to Level 1 takes place continuously at the SOC throughout the mission, with the Level 0.5 and Level 1 data products made available to the DDPC and NSGS via the LISA Mission Data Repository. To guarantee homogeneous, consistent and scientifically validated data product deliveries to the community, periodic data releases are planned throughout the mission (See Figure 3).

The first data release will occur not later than 12 months after the end of the commissioning; data will be made public via the LISA Public Archive. In addition to the data, a set of instrument performance and science validation papers will be published by the instrument teams, DDPC, NSGS, and SOC.

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[2] “Science Interpretation” refers to papers with use the LISA Level 2 and Level 3 data products to produce scientific publications. These papers differ from “instrument/science validation” papers which are factual, with no interpretation of the results.

Due to the limited data taking period, the source catalogue will contain sources with signal-to-noise ratio above a certain threshold, to be defined by the LST.

After the first data release, subsequent data releases will be classified as major releases, which require accompanying documentation, and minor releases, which are data updates with minimal documentation. Major releases will occur at least once per 12 months, while minor release will have a six months cadence. All data releases (major and minor) contain the complete set of data from L0.5 up to L3 data with equal level of quality. In exceptional cases, the LISA Science Team may choose to publish scientific papers to communicate high-impact discoveries out of the nominal data release schedule. These papers will be accompanied by a LISA data release.

Data products obtained from the Low Latency Alert Pipeline (transient sources) are made publicly available immediately through alerts to enable rapid follow-up observations.

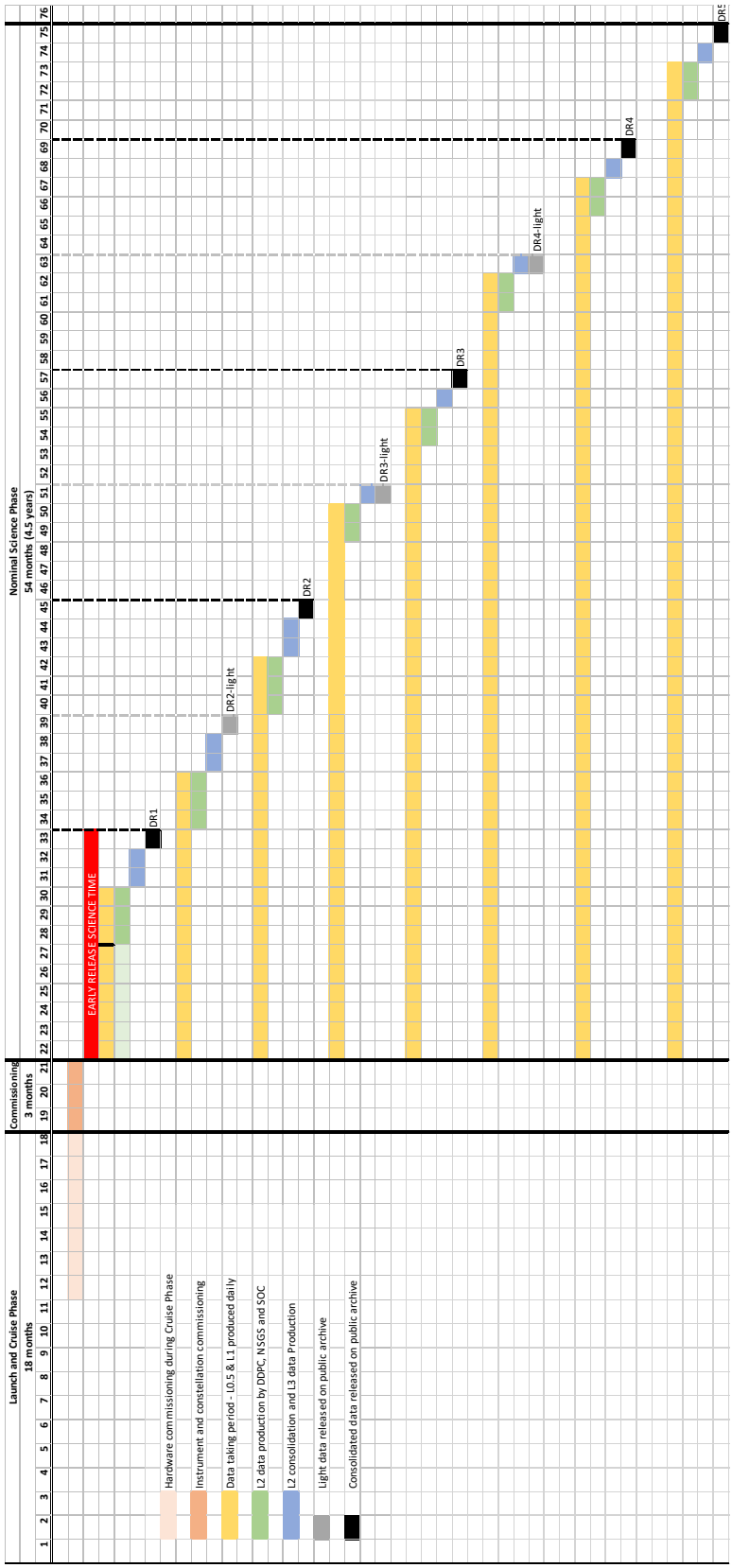


**Figure 4: Timeline of data product releases**

# 5 PUBLICATION POLICY

With each formal data release, a set of pre-defined instrument/science verification papers will be approved by the LST and released with the data. For these, the LST will maintain a list of authors ("LISA Collaboration") who should appear on these papers. This list will include:

- A LISA heritage author list comprising the names of members of the community who have made a significant contribution to the mission. This list does not have an expiration date;
- A LISA member author list comprising scientists and engineers working on the mission at the time of the science operations. This list has a roll-off period of 2 years after the person has left the mission. Following the roll-off period LISA members can be included in the LISA heritage list, if deemed appropriate by the LST.

The above author lists will also be used for the first few high impact discovery papers (e.g., the first massive black hole merger). These papers will be approved by the LST and accompanied with an extraordinary data release.

During the ERST, science interpretation papers will be published by the STPs on their specific science theme. These papers will contain all STP members and the LISA heritage and member list as authors. Papers should acknowledge ESA in the acknowledgement section.

The above policy does not apply to scientific papers published after the ERST.

# 6 PROGRAMME PARTICIPATION

There are four ways for members of the scientific community to participate in the LISA mission:

- Become a member of the LISA Consortium (see Section 3)
- Become a member of the ESA appointed LISA Science Team (see Section 3.2)
- Become a member of the Science Topical Panels during the Early Release Science Time (see Section 4.2)
- Participate in LISA Masterclasses, organised by the LISA Science Team (See Section 6.1).

## *6.1 LISA Masterclasses*

In order to prepare the scientific community to use LISA data, a series of "Masterclass" workshops will be planned. These workshops will function within the "train the trainer" concept, where scientists from ESA member states can apply to being trained in a workshop on LISA data and data processing tools and then to return to their home countries to train their own community with support from ESA. This concept was successfully applied in the JWST mission and will maximize the scientific turnout for all member states interested in participating in LISA science.

# 7 GROUND SEGMENT AND OPERATIONS

As indicated in Section 3, ESA will be responsible for the launch, early operations, transfer to the final science orbits, platform and instrument commissioning and operations of the three satellites, forming a single gravitational wave observatory.

ESA will establish a LISA Mission Operations Centre (MOC) and a Science Operations Centre (SOC). ESA-provided ground station(s) will ensure the necessary telecommanding and telemetry capabilities.

## *7.1 Mission Operations Centre*

The MOC is responsible for the operation of the three spacecraft, and in particular for the following tasks, related to the Science Ground Segment:

- Performing uplink of the platform and payload telecommands and receiving telemetry through the ground stations and communications network;
- Monitoring the health and safety of the three spacecraft;
- Monitoring the instrument safety and reacting to contingencies and anomalies according to procedures provided by the instrument providers;
- Generation and uplink of the master schedule using inputs from the SOC (Payload Operations Requests) and adding the necessary platform commanding;
- Alerting the SOC to all significant anomalies or deviations from nominal behaviour of the satellites and instrument for onward transmission to the instrument providers, DDPC, and NSGS as relevant;
- Performing maintenance of the three satellites' on-board software;
- Performing uplinks of payload on-board software updates as generated, validated and delivered by the instrument providers via the SOC;
- Handling provision of the science and housekeeping telemetry to the SOC;
- Producing and providing ancillary data to the SOC (orbit files, time correlations, etc.);
- Supporting the SGS on all aspects concerning spacecraft operations.

## *7.2 Science Ground Segment*

The Science Ground Segment (SGS) consists of the ESA SOC (including the P&O), the DDPC provided by the ESA Member States, and the NSGS provided by NASA.

### 7.2.1 Science Operations Centre

The SOC is the single point of contact to the MOC during routine operations and is responsible for the following tasks:

- Lead the overall validation of the SGS;

- Design, development, procurement, integration, validation and maintenance of the software and computational resources under the SOC responsibility;
- Design, development, and maintenance of the LISA Parameter database;
- Design, development, operations, and maintenance of the LISA Public Archive;
- Perform the long term planning and scheduling of the science operations of the observatory;
- Storage of all levels of data products (Level 0 to Level 3) and all auxiliary mission data and their dissemination within the SGS;
- Maintenance and updating of the instrument calibration data;
- Reception of the raw telemetry from the MOC;
- Processing of the Raw telemetry to Level-0 data products in a near-real-time;
- Design, development (with support by the DDPC and NSGS), and operations of a near-real-time pipeline to produce validated Level-0.5 data products from the Level-0 data;
- Design, development (with support by the DDPC and NSGS), and operations of a near-real-time pipeline to produce validated Level-1 data products from the Level-0.5 data;
- Development (with support by the DDPC and NSGS) of the capacity to produce Level-2 data products from the Level-1 data;
- Management, through the Project Scientists and the LST, the generation of the Level-3 source catalogue;
- Management of periodic data releases of the Level-1 to Level-3 data products via the LISA Public Archive;
- Design, development (with support by the DDPC), and operations of the Quick-look data processing systems;
- Integration and operations of the Low Latency Alert Pipeline (LLAP) provided by the DDPC;
- Issue and update alerts for transient signals.

The SOC will take the lead in the overall design and systems engineering of the SGS with the understanding that the purely DDPC and NSGS-specific elements will fall under the responsibility of the Member States and NASA, respectively. The SOC will organise and manage the end-to-end tests that are needed to validate the SGS uplink and downlink systems, interfaces, and operational processes prior to the start of the Nominal Science Operations Phase.

#### 7.2.2 Distributed Data Processing Centre

The DDPC receives the Level 0, and Level 1 data from SOC during routine operations and is responsible for the following tasks:

- Development, procurement, integration, validation and maintenance of the software and hardware under the DDPC responsibility:

  - software: at least two Global Fit pipelines, Level-3 data generation pipeline, simulated data generation pipeline, instrument simulator, waveform generator, external data, source population generation and the system engineering software;
  - hardware: the primary Data Computing Center and multiple satellite Data Computing Centers ;
- Provision of a prototype, and validation of at least one instance of the pipeline producing Level-1 data products from the Level-0 data, to be developed, integrated and maintained by the SOC;
- Provision of a prototype and validation of at least one instance of the Low Latency Alert Pipeline (LLAP) for the detection of alerts and parameter estimation of sources to be monitored, to be integrated, maintained by the SOC;
- Performing investigation on each alerts provided by SOC and providing feedback to the SOC;
- Operating the Global Fit pipelines (Level 1 to level 2) to extract GW sources;
- Providing to the SOC alerts (from Global Fit pipelines) and input for protected periods;
- Providing to the SOC the list of sources to be monitored in near real-time by the LLAP Parameter Estimation;
- Providing to the SOC Level-2 data products;
- Performing noise characterization while searching for GW sources and providing feedback to the SOC;
- Contributing to the generation of the Level-3 data product;
- Operating the simulation pipelines to generate simulated data of different data levels.

The DDPC is responsible for its own overall design and engineering.

### *7.3 Performance and Operations Team*

The Performance and Operations Team contributes to the ESA Project's Performance Management Team. The P&O team consists of members from the Member State and International Partner instrument and data processing teams and will be managed by the P&O lead scientist. Each institute/agency involved in the mission development and/or operations will be asked to nominate a P&O point-of-contact. The points-of-contact will select a subset of members to be included in the ESA project team structure, under the responsibility of the ESA Performance Manager.

The primary objectives of the P&O team are to:

- Support ESA in analysing and optimising the performance of LISA, by;
  - Developing a Constellation level performance model;
  - Providing a framework to track and report performance risk;
- Support ESA in simulating and modelling the LISA system, by;

  - Developing a LISA system model to track the system architecture, the functional breakdown and high-level requirements;
  - Developing and operating LISA simulations to support performance verification and operations analysis;
- Support ESA in designing, preparing and executing the mission operations, by;
  - Support the development of commissioning plans;
  - Support the development of early science phase characterisation and optimisation experiments;
  - Support the development of routine maintenance operations.
- Support ESA in observatory commissioning (including L0-L1 pipeline commissioning)
- Support ESA in operating, characterising, optimising and monitoring the constellation during science operations.

## 8 PUBLIC OUTREACH

ESA will have overall responsibility for the science communications, educational and outreach activities related to LISA. Agreements regarding public outreach activities will be established between ESA, NASA, relevant funding authorities, and other institutions involved in the mission. ESA and the involved partners will have the right to use any data acquired by LISA for outreach purposes, in coordination with the holders of the data rights as applicable, as covered by the ESA Rules on Information, Data and intellectual Property (ESA/REG/008).

The public outreach activity will be established and led by ESA in close collaboration with NASA, the relevant bodies funding the provision of the scientific payload in the Member States, and other institutions involved in the mission. Such outreach activity will be based on a regular flow of science results from the mission presented in a manner suitable for communication and public outreach purposes. Such outreach activity necessitates the timely availability of suitably processed data and the full involvement of the various scientific teams engaged.

Formal dedicated agreements regarding public outreach activities will be established between ESA, the relevant funding authorities, and other institutions involved in the mission. The terms and conditions contained in these agreements will be applicable on the relationships between the funding authorities and the various scientific investigators. These agreements will take account of any necessary project-specific science-to-public-outreach balance. The implementation of such agreements will be tracked by the Steering Committee defined in Section 3.3 and as part of the standard project reviews.

The authorities funding the provision of the payload in the Member States (Funding Bodies) and other institutions involved in the mission will prepare a public outreach agreement involving ESA, the relevant Funding Bodies, the LISA Consortium, and any other relevant organisations.

Interactions between these parties will have to guarantee consistency between all applicable documents and policies.

## Acronyms

| | |
|---|---|
| AO | Announcement of Opportunity |
| CMD | Charge Management Device |
| DCC | Distributed Computing Centre |
| DDPC | Distributed Data Processing Centre |
| DFACS | Drag-Free and Attitude Control System |
| DR | Data Release |
| ERST | Early Release Science Time |
| ESA | European Space Agency |
| ESAC | European Space Astronomy Centre |
| ESOC | European Space Operations Centre |
| FA | Funding Agency |
| GW | Gravitational Wave |
| GRS | Gravitational Reference Sensor |
| IDS | Interferometer Detection System |
| JWST | James Webb Space Telescope |
| LA | Laser Assembly |
| LED | Light Emitting Diode |
| LISA | Laser Interferometer Space Antenna |
| LLAP | Low Latency Alert Pipeline |
| LPA | LISA Public Archive |
| LST | LISA Science Team |
| MDR | Mission Data Repository |
| MLA | Multi-Lateral Agreement |
| MOC | Mission Operations Centre |
| MOSA | Moving Optical Sub-Assembly |
| MS | Member State |
| NASA | National Aeronautic and Space Administration |
| NSGS | NASA Science Ground Segment |
| OTS | Optical Test System |
| PDF | Probability Density Function |
| P&O | Performance and Operations |
| PS | Project Scientists |
| SDS | Science Diagnostic System |
| SGS | Science Ground Segment |
| SMP | Science Management Plan |
| SOC | Science Operations Centre |
| SPC | Science Programme Committee |
| STP | Science Topical Panel |
| TDI | Time Delay Interferometry |
| TEL | Telescope assembly |
| UTC | Universal Time Coordinated |
| UV | Ultra-Violet |
| WG | Working Group |