LISA Consortium Work Plan

N/Ref :	LISA-LCST-WorkPlan-001
Title	**LISA Consortium Work Plan**
Abstract	LISA Consortium Work Plan

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Document Change Record

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Ver.	Date	Author	Description	Pages
0.1	2025/03/04	CCC (LISA)	Initial version	all
1.0	2025/04/03	CCC (LISA)	Current Version	

Distribution list

Recipient	Restricted	Not restricted
CCC		✗
LISA Consortium		✗

Contents

List of acronyms

DDPC	Distributed Data Processing Centre
ESA	European Space Agency
GW	Gravitational Wave
LISA	Laser Interferometer Space Antenna
LST	LISA Science Team
MLA	Multilateral Agreement
MoU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NSGS	NASA Science Ground Segment
P&O	Performance and Operations
R&D	Research and Development
WG	Working Group

1 Introduction

This document outlines on a rather high level what activities we consider as Consortium work, i.e., work that counts to fulfil the commitment to the Consortium to be a core member rather than a Community member. The definition, rights and duties of core member and Community Members are developed elsewhere. The work will be subject to service tracking in a way that is also being discussed elsewhere. Finally, the organisation of the work within the Consortium is also discussed elsewhere. The main aim for this document is to help the transition of the current membership to the new Consortium, i.e., to make sure people know what work is considered Consortium work and what not.

Work that is done for the *LISA project* [1], is not described here. However, for membership purposes this is treated in the same way as Consortium work. This allows people that work on the project to be core members and bring in their expertise, but also to acknowledge that in some cases the boundary between project work and Consortium work is not yet completely clear and, at present, we do not make our lives unnecessarily complicated.

The Consortium work described below will be subject to changes in the near future, when the new Consortium develops its work plan further.

Consortium work should logically follow from the newly formulated Consortium vision: *The LISA Consortium is a scientific collaboration working together to maximize the scientific return of LISA, in particular using the LISA data. The Consortium will support all aspects of the LISA mission throughout the mission lifecycle.*

The LISA Consortium is committed to promoting the long-term growth and development of the LISA scientific Community, by providing a supportive and inclusive environment that offers training, mentoring and opportunities for scientists at all stages of their careers, in particular, early career scientists. The Consortium will also engage with the wider scientific community to foster interest in and support applications of the LISA data.

2 Consortium work areas

We have structured the Consortium work in the following categories. Below, we give a brief description and the current consortium activities that will be carried over to the new consortium. At application core members have to sign up for these activities.

2.1 Working group projects

We expect the work of the Consortium to be done in projects of the working groups. The exact number and division of working groups is not yet decided (e.g. work on multi-messenger science and on simulations), but we list the current consortium projects below in several subsections. They can later be combined or split depending on the final structure of the consortium working groups.

2.1.1 Waveform Working Group

One of the important activities of the Consortium should be to form a central interface between waveform development and the LISA mission. We expect that the DDPC and NSGS will provide fast, efficient and faithful waveform generators for all the LISA sources that are part of the science objectives reflected in the Red Book. However, development of the waveform models themselves

[1] Defined here as all work that is done by European Space Agency (ESA) or under agreements with ESA, either in member states via the Multilateral Agreement (MLA) or in the US via the Memorandum of Understanding (MoU) between ESA and National Aeronautics and Space Administration (NASA). This includes, e.g., hardware, Performance and Operations (P&O), Distributed Data Processing Centre (DDPC), NASA Science Ground Segment (NSGS), and so on.

will take place in the community outside the DDPC/NSGS. The Waveform Working Group will identify modeling needs and help organize activities to ensure waveform models meet the requirements of the DDPC/NSGS and benefit the broader science activities of the Consortium.

Future projects might include

- Explore the impact of DDPC and NSGS conventions (e.g., definitions of eccentricity, spin directions at reference time/frequency) on the physical interpretation of waveform parameters. Ensure waveforms are in the same asymptotic (BMS) frame for meaningful comparisons.
- Create common verified data sets for use in LISA waveform models:
  - 0PA and 1PA input data for self-force/FEW models
  - Repositories of post-Newtonian/post-Minkowskian series
  - Tools to perform cross-code comparisons of Numerical Relativity waveforms and verification of waveform models
- Assess the impact of waveform systematics on each of the LISA Science Objectives (SO1 to SO8), with reference to the Figures of Merit and for both intrinsic and extrinsic parameters. Translate this into accuracy requirements and necessary waveform improvements. Examples of likely needed improvements which need to be assessed include the following:
  - Extend the number of higher harmonics in MBHB waveform models
  - Include different types of gravitational wave memory in models and study their relevance for MBHs detectable by LISA
  - Improve the description of eccentricity & spin precession
- Jointly with the Astrophysics, Fundamental Physics, and Cosmology Working Groups, identify environmental and beyond-GR effects that are needed in waveform models based on the Figures of Merit for LISA Science Objectives (SO1 to SO8). Work to incorporate these effects into waveform models in either a physical or parameterized way. Examples include the following:
  - Investigate the interplay of environmental effects and eccentricity in waveform models
  - Study potential degeneracies between environmental and beyond-GR effects.
  - Identify needs and develop waveform models to probe black holes on horizon scales
  - Identify needs and develop inspiral-merger-ringdown waveform models to perform ringdown tests
  - Assess waveform modelling requirements for cosmic string sources

2.1.2 Astrophysics Working Group

The Consortium aims to maximise the science return of the LISA mission. In order to do so, several science investigations will need to be developed, and there is a very large number of consortium members interested in Astrophysics. The LISA Astrophysics white paper is an important resource of the Astrophysics GW.

Current Astrophysics Working Group (WG) consortium projects are

- **MBHcatalogs**: (i) compare the results in order to quantify the spread in predictions, i.e., the global astrophysical uncertainties, and (ii) identify what are the robust model-independent predictions. Could evolve to include development of a website where users can visualize, select and download data from the project and a longer-term plan to update catalogues resulting from the projects.

- **UCBcatalogs**: assess (i) Uncertainties from numerical implementation and (ii) Uncertainties from our knowledge in DWD codes and catalogues
- **DiscIMRI**: code comparison of torques on massive black hole binaries in the intermediate-mass ratio regime
- Updating the whitepaper/Living Review in Relativity

Ideas/plans for new projects include

- **Dual/binary AGN**: comparison between simulated and observed samples. This would decrease the astrophysical uncertainties in MBH merger rates
- **Environment**: Explore the galactic and large-scale environments fostering MBH mergers (e.g., galaxy morphologies?, filaments or clusters?) and evolution with redshift. This would help understand if we can ?supplement? the sky localization from LISA with informed astrophysical ?priors?.
- **Task force** between astroWG and waveformWG to **define the parameter space** needed to be explored by waveforms for MBH mergers.
- **EMRIcatalogs**: EMRI events and properties are largely uncertain. This project aims at providing the DDPC and the Consortium with catalogs exploring the astrophysical parameter space.
- **Develop a data standard for catalogs**, as the **UCBcatalogs** has already done for their codes.
- **DDPC-friendly MBHcatalogs**: convert raw data from models into x-years of data for ease of use in the DDPC and Consortium.

2.1.3 Cosmology Working Group

The Cosmology Working Group has a significant history of joint consortium projects and the LISA Cosmology white paper is an important resource. Current Cosmology WG projects are

- **SIGWB reconstruction with LISA observations**: The project aims to assess the prospect of detecting and characterizing Scalar Induced GWs (SIGWs) with LISA. Among the deliverables of the project, there's a new code for fast evaluation of SIGWs given the scalar power spectrum.
- **Constraining additional polarisation degrees of freedom with LISA observations**: Additional polarizations beyond the two tensor modes of General Relativity might be generated in modified theories of gravity. The project aims to assess LISA's capability of measuring such signatures using signals emitted by mergers of compact objects.
- **Standard sirens with cosmoLISA**: The project aims to assess the prospect of measuring cosmological parameters using standard sirens LISA will detect. Possible future ancillary projects:
  - Assess the implications of LISA cosmological measurements with respect to other GW observations and EM probes, especially at high redshift
  - Explore new ways to conduct cosmological measurements (e.g. lensing, cross-correlation with LSS, MBHBs as dark sirens and other connections with AGN hosts?, ...)
- **PBH tools**: The goal of the project is to develop a public numerical toolbox to compute the GW signatures of PBHs, starting from theoretical models. The methods have been investigated in the PBH review project.

- **Cosmic strings beyond minimally-coupled models**: This project will look at LISA's ability to detect and discriminate between models for GWB sourced by metastable strings, superstrings, global strings, and potentially other scenarios, such as superconducting strings or a detailed follow-up to non-standard cosmologies.
- **Characterisation of stochastic backgrounds**:
  - Construct accurate predictions of the SGWB
    - Cosmological
    - astrophysical
  - Produce data analysis pipelines performing the reconstruction of the SGWB signal:
    - reconstruction of the SGWB spectral shape
    - reconstruction of the noise
    - account for residuals from global fit subtraction
    - Forecasts on the SGWB generation processes: assess how the (non-)detection of the SGWB constrains/confirms the production processes and the underlying physics

2.1.4 Fundamental physics Working Group

Also the Fundamental physics Working group has experience with joint projects and the white papers. Current FP projects are

- Detecting black-hole ringdown with LISA:
  - **Extend pyRing for LISA use**: extend the python package pyRing to allow it to be used for black-hole ringdown analysis in LISA
  - **Ringdown tests with pSEOBNR**: Conduct study to assess measurement of ringdown frequencies with LISA using the pSEOBNR waveform (SEOB waveform with generic deviations in the ringdown frequencies).
  - **Beyond GR ringdown**: Look into agnostic deviations that can be mapped to dimensionless couplings and get constraints on these.
  - **Multimode memory detectability**: look into memory detectability with CCE waveforms in the right BMS frame using the LISA response
- Systematic errors in parameterized Inspiral-Merger-Ringdown tests:
  - Implementation of pSEOBNR/TIGER/FTI in the LISA tools
  - Impact of waveform modeling errors in tests of GR
  - Effects of eccentricity in tests of GR
  - Effects of spin-precession in tests of GR
  - Injection studies with beyond-GR and beyond-Standard-Model waveforms
- Jointly with the Waveform Working Group, identify environmental and beyond-GR effects that are needed in waveform models based on the Figures of LISA for LISA Science Objectives (SO1 to SO8). Develop tools to investigate the potential to detect these effects with LISA. Examples include the following:
  - Investigate the ability of LISA to identify signatures from non-vacuum environments and beyond-GR
  - Study potential degeneracies between environmental and beyond-GR effects
  - Investigate the ability to probe black holes on horizon scales and exotic compact objects

2.1.5 Multimessenger Work

A separate category is reserved for multimessenger work, because several multi-messenger investigations need significant preparation, either in terms of ensuring the instrumentation needed will be available, or in terms of setting up the way the consortium will work with or include parts of the EM community. Again we have to decide on what EM work is Consortium work and what is not, as a wide definition may lead to a consortium with a very large scope (and membership). Current projects are:

MMA.1 Exploration of multi-messenger and multi-band science with LISA

- 1.1 Multiband and multimessenger science opportunities with LISA
- 1.2 Astronomical signatures of LISA sources

MMA.2 Joint multi-messenger and multi-band analyses

- 2.1 Mock Data Challenges
- 2.2 Electromagnetic and particle data analysis
- 2.3 Multi-band gravitational wave analyses

MMA.3 Preparations needed for LISA to make use of external data

- 3.1 Gathering astrophysical information on galactic binaries
- 3.2 Processing astrophysical data on galactic binaries for LISA
- 3.3 EM/particle/multi-band data on massive binaries for LISA
- 3.4 Other sources of astrophysical information

MMA.4 Communications, logistics and procedures

- 4.1 Data sharing
- 4.2 Develop and plan interfaces with target communities outside LISA

2.1.6 Instrument Working Group

The consortium is also a good place to link instrument activities related to LISA and future GW space missions. Even though the consortium is not providing hardware to ESA, there still is room for the Consortium to play a role in connecting particular Research and Development (R&D) activities in the area of the instrument, including performance work (but see also next section). For these activities, one can think of work that (ultimately) can support the ESA project work on instrument and P&O, or work that is aimed at the longer-term future of GW missions in space. These activities are mainly focussed on R&D and can be coordinated by an instrument working group. Current projects are:

- Future GW (space) instrument development

2.1.7 Data analysis research and development

We expect that people in the consortium will continue to develop data processing methods for space Gravitational Wave (GW) missions and the Consortium is an excellent place to bring those activities together. This platform gives a lot of freedom to investigate the bleeding edge data analysis techniques (for example based on machine learning) and improve the methods which are planned by the Laser Interferometer Space Antenna (LISA) ground segment. We can benefit from the usual scientific interactions in the consortium, but can also be coordinated with the DDPC and NSGS project work. There can be several WGs on sub-aspects of these

activities. All are perfect entry points for new people interested in data analysis. In addition, the Consortium can play a role in keeping the connection between all international participants to the LISA mission project. Current projects are

- Figure of Merit project
- LDC: LISA Data Analysis Living Reviews
- Analysis of LISA data challenges

2.1.8 Outreach/Communications Working Group

Vision and mandate

The Communications Implementations Working Group will coordinate and implement all consortium communications activities together with the Communications Committee. We will organise in task-focused teams. This will allow WG members to productively contribute within varying personal time budgets, and maintain flexibility as the mission and the wider environment evolves. We also aim to support communications initiatives and outreach projects from other consortium groups, and the wider community.

The Working Group goals are focused on several key pillars:

- Internal Communications
- Public engagement & Outreach
- Media Relations
- Education

Core Projects (based on current activities)

The WG will focus on the following regular tasks:

- Social Media - maintain & develop social media channels and content
- LISA Consortium website - maintain & develop the content
- Press releases - support media activities such as creation of press kits
- Conference Outreach - support & initiate outreach at events eg AAS, LISA Symposia
- Monday Calls - Host and organise regular community & consortium calls
- Creation of Outreach materials - develop & support production of outreach materials
- Network within LISA and the wider GW and scientific community

The list of core projects represents tasks the working group will seek to fulfill or engage with at all times to the best of its abilities.

Ideas and plans for future Projects

In addition to the already ongoing tasks, the WG will work on new formats, support additional areas, consortium infrastructure and last but not least, explore the potential of exciting, novel content types. These new tasks may include

- Newsletter - a regular community newsletter

- LISA Magazine publication - similar to the LIGO Magazine
- Collated repository of all outreach materials, including educational materials
- Explore new content mediums - textured materials, sonification, or VR
- Support advocacy & educational activities
- Support onboarding, training & mentorship programs

As more members join the WG, these additional projects will become achievable. Both core and future projects will require close collaboration with other WGs and Committees, external partners, and space agencies.

2.2 Liaison with LISA project work

We have agreed that there need to be close connections/liaisons with several entities that are doing ESA/NASA/member state project work, such as the DDPC, NSGS, P&O team, hardware consortia. Activities that are aimed at these liaisons count towards Consortium work. Examples include work done as LISA Science Team (LST) member, or organising meetings with people from e.g., DDPC and NSGS or membership of advisory committee that these groups may form.

2.3 Consortium management and support

In addition to the above "science" activities, the new Consortium needs significant work for its own organisation. These tasks count as Consortium work. A discussion is if it should be possible to only do management work or not. Examples include:

- Taking on leadership roles in the Consortium as member or chair of one of the following organisms, as described in the bylaws:
  - Consortium Council;
  - Consortium Management Team;
  - Chair of an internal committee (see below);
  - Chair of a Working Group;
  - Chair of a temporary management sub-committee.
- Participation in internal management through membership of permanent committees such as diversity-equality-inclusion (current DEI), membership management (current MMT), bylaws, Ombuds office, and any other permanent or temporary internal committee established by the Council in the course of time (e.g. mentoring?);
- Coordination of one or more Consortium science projects/Working Group projects.