# LISA CosWG Perspective on Tests of $\Lambda \text{CDM}$

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10/08/2023

### Outline

LISA CosWG governing rules
Past CosWG collaborative projects
Future/ongoing collaborative projects
LISA Cosmology white paper

## LISA CosWG Organisation

### LSC CONSORTIUM COSMOLOGY Working Group (CosWG)

Access: Full and Associate members

Contact: cos-wg-chairs[at]lisamission.org

Governance:

- co-chair: Germano Nardini
- co-chair: Nicola Tamanini
- co-chair: Marco Peloso
- co-chair: Mauro Pieroni

~ Monthly CosWG telecons

- Inform the group and collect feedback
- Share relevant news and information
- Present recent interesting works

Currently 440 members

- 10th LISA CosWG Workshop, Stavanger (Norway), 5-9 June 2023
   <u>Workshop website</u>
- New rules to regulate CosWG collaborative projects
  - Link to rules online

## LISA CosWG Workshop

## 10th LISA Cosmology Working Group Workshop

| CONSORTIUM                              |                        |
|---|------------------------|
| 5–9 Jun 2023<br>University of Stavanger | Enter your search term |

5-9 June 2023, Stavanger, Norway

First in-person workshop after Covid

78 participants

Plenty of time for discussion of new collaborative projects

Finalisation of new CosWG rules

### Overview

Europe/Oslo timezone

- Call for Abstracts
- Timetable
- Contribution List
- Registration
- Participant List
- Accommodations
- Leisure and touristic activities
- Arrival Information from the airport
- Organizers and Sponsors

### Organizers

- ChairscoswgWITHOUTT...
- micol.pezzottaWITHOU...



The 10th LISA Cosmology Working Group Workshop will take place at the University of Stavanger on June 5th-9th, 2023.

The workshop aims at gathering the LISA CosWG community after the break due to the Covid pandemic. The goal is to review the recent progress in cosmology relevant to LISA and initiate collaborative projects to investigate new directions and tackle open problems in LISA cosmology.

The discussed topics include:

- Predictions for SGWBs from the early universe
- Detection of stochastic backgrounds and foregrounds
- Characterization of isotropic and anisotropic SGWB components
- Standard sirens and cosmological tests of the late universe
- Cosmological probes of general relativity and non-standard paradigms
- Primordial black holes and dark matter
- Gravitational-wave lensing
- Structure formation

## LISA CosWG White Paper



Cosmology with the Laser Interferometer Space Antenna

- 1. Introduction
- 2. Tests of cosmic expansion and acceleration with standard sirens
- 3. Gravitational lensing of gravitational wave signals
- 4. Constraints on modified gravity theories
- 5. Stochastic gravitational wave background as a probe of the early universe
- 6. First order phase transitions
- 7. Cosmic Strings
- 8. Inflation

9. Tests of non-standard pre-Big-Bang nucleosynthesis cosmology via the SGWB 10. Primordial black holes

- 11.Tools/pipelines for the analysis of transient signal data in cosmology
- 12. Tools/pipelines for the analysis of stochastic gravitational wave background data

### LISA CosWG White Paper

- White paper has been <u>accepted by Liv. Rev. Rel.</u> and is already on the arXiv: <u>arXiv:2204.05434</u>
- Huge community effort and coordination
- Some data:
  - <u>180 authors</u>: 107 directly contributing (1st tier) + 73 endorsers (2nd tier)
  - <u>176 pages in total</u> (~30 pages of bibliography)
  - <u>1346 references</u> mainly from last few years (young and expanding field)



## LISA CosWG Rules

- The CosWG rules mainly regulate the collaborative projects
  - Link to complete rules online

### • In a nutshell

- Any CosWG member can propose a new collaborative projects
- Preliminary discussions define the scope, timeline and needed person power
- CosWG chairs (in consultation with LSG WP coordinators) approve if the project is expected to advance the investigation of one or more of LISA's science objectives
- A contributing team is then formed from CosWG members volunteers + solicited LISA members if specific expertise/knowledge is needed
- Two coordinators are nominated with the task of managing the project and the team, and of giving regular update at the monthly CosWG calls
- Each collaborative project is followed by (at least) one CosWG chair
- All publications produced by CosWG collaborative projects receive a LISA CosWG preprint number and digital watermark (after LISA internal PnP review)
- Short-author papers written by CosWG members may ask for a CosWG preprint number
  - Papers must undergo LISA internal PnP review
  - Results must advance the investigation of at least one of LISA's science objectives

## LISA CosWG Rules

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### In practice:

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Coordinator(s):

CosWG chair(s):

**Target timeline** 

Milstone 1

Milestone 2

Project title:

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• A blue form to propose a new CollPorject

В

This is the title of the project

Coordinator 1, Coordinator 2

Calendar

- A green form to offer own personal mei Nar contribution to a proposed CollProject
- A standardised weekly logbook to keep track of individual contributions

С

Contributor 1

email address

Weekly contribution

I worked on sec. 2 of the draft.

Coordinators email(s):

Useful links:

Chairs email:

Week 1 I did this and this.

Week 4 On holidays

Week 3

Week 5

Week 6

Week 7

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Week 13

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Week 15

Week 16

Week 2 I didn't have time this week.

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Weekly

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chairscoswg@gmail.com

|  | LISA CosWG to offer a personal contribution  | ion to a proposed collaborative project  |  |
|--|--|--|--|
|  | This form must be sent in response to a proposed CosWG collaborative project to both the CosWG chairs and the coordinators of the proposed project.                  |  |  |
|  | Name of the collaborative project (to be the same as the one proposed)   |  |  |
|  |  |  |  |
| LISA CosWG Form to Start a Collaborative Pr  | Name of the person proposing the contrib   | ution  |  |
| This form must be sent to the CosWG chairs for<br>been already circulated within the CosWG and a<br>members has already taken place.   | Proposed contributed expertise (if applica   | ble)   |  |
| Name and emails of project coordinators  | Please provide the expertise you would like to contribute to the project. This expertise must be among the ones identified in the project proposal form (blue form). |  |  |
| Tentative title of the project   |  |  |  |
| <b>Executive summary of proposed work</b><br><i>Please provide one short paragraph to explain th</i>   | <b>Proposed contributed work (if applicable)</b><br>Please provide the work you would like to con<br>the working packages and tasks identified in t                  | ntribute to the project. This must be aligned with<br>the project proposal form (blue form). |  |
| Proposed timeline<br>Please provide a rough preliminary timeline f   |  |  |  |
| working packages and specific intermediary mile  | Estimated time commitment (in average w  | eekly hours):  |  |
|  | I agree to follow the CosWG rules (link) for<br>By checking this box you agree to follow the<br>CosWG on [ADD DATE].   | r collaborative projects<br>rules outlined at this link and approved by the full             |  |
| <b>Needed expertise and personpower</b><br>Please provide a list of expertise and a rough<br>needed to complete the project, preferably as<br>tasks. Editorial tasks should not be included here | Additional information<br>Please add anything relevant not included above.   |  |  |
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| Additional information<br>Please add anything relevant not included above.   |  |  |  |

## LISA CosWG Rules

### In practice:

Α

Coordinator(s):

CosWG chair(s):

**Target timeline** 

Milstone 1

Milestone 2

Project title:

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 A blue form to propose a new CollPorject

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- A green form to offer own personal contribution to a proposed CollProject
- A standardised **weekly logbook** to keep track of individual contributions

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email address

Weekly contribution

Coordinators email(s):

Useful links:

Chairs email:

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chairscoswg@gmail.con

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|---|---|---|--|
|   | This form must be sent in response to a propo<br>CosWG chairs and the coordinators of the pro   | osed CosWG collaborative project to both the<br>oposed project.                           |  |
|   | Name of the collaborative project (to be the  | e same as the one proposed)   |  |
|   |   |   |  |
| LISA CosWG Form to Start a Collaborative Pr   | Name of the person proposing the contribution   | ution   |  |
| This form must be sent to the CosWG chairs for been already circulated within the CosWG and a       | Proposed contributed expertise (if applicat   |   |  |
| members has already taken place.  | Please provide the expertise you would like to<br>be among the ones identified in the project pa  | b) commute to the project. This expertise must  |  |
|   |   |   |  |
| Tentative title of the project  |   |   |  |
|   | 207 st  | 16.   |  |
| Executive summary of proposed work<br>Please provide one short paragraph to ax, an th               | Proposed contributed for a <b>(if toplicable)</b><br>Please provide the work of u toplic-like to con<br>the working particles and tasks identified in t | ntribute to the project. This must be aligned with the project proposal form (blue form). |  |
| inst De te  | d   |   |  |
| Proposed timeline   |   |   |  |
| Please provide a rorgy profin, my timeline for<br>working pack, es and sp cific intermediary mile   | Estimated time commitment (in average weekly hours):  |   |  |
| Jer -   | I agree to follow the CosWG rules (link) for collaborative projects   |   |  |
| <b>)</b>  | By checking this box you agree to follow the rules outlined at this link and approved by the full CosWG on [ADD DATE].                                  |   |  |
| Needed expertise and personpower  | Additional information  | ove   |  |
| needed to complete the project, preferably as<br>tasks. Editorial tasks should not be included here |   |   |  |
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|   |   |   |  |
| Additional information<br>Please add anything relevant not included above.                          |   |   |  |

## CosWG Past CollProjects

### List of completed CosWG Collaborative Projects

| CosWG id.<br>number  | ArXiv number     | Title  | Atrium link         | Keywords  |
|----------------------|------------------|--|---------------------|---|
| LISA-CosWG-19-<br>01 | ArXiv:1906.07204 | Testing modified gravity                         | ATRIUM-<br>357187   | Modified GR, standard sirens, cosmol.<br>parameters |
| LISA-CosWG-19-<br>02 | ArXiv:1906.09244 | Reconstructing the spectral                      | ATRIUM-<br>358359   | Stochastic background reconstruction, data analysis |
| LISA-CosWG-19-<br>03 | ArXiv:1909.00819 | Probing cosmic strings with LISA                 | ATRIUM-<br>369107   | Cosmic strings                                      |
| LISA-CosWG-19-<br>04 | ArXiv:1910.13125 | GWs from phase transitions with LISA             | ATRIUM-<br>374234   | Phase transitions                                   |
| LISA-CosWG-20-<br>01 | ArXiv:2006.03313 | Maximum likelihood map-making with<br>LISA       | ATRIUM-<br>423792   | Anisotropy detection, data analysis                 |
| LISA-CosWG-20-<br>02 | ArXiv:2009.11845 | Improved reconstruction of a SGWB with<br>LISA   | ATRIUM-<br>428815   | Stochastic background reconstruction, data analysis |
| LISA-CosWG-21-<br>01 | ArXiv:2201.08782 | Probing anisotropies of SGWB with LISA           | [ATRIUM-<br>4288xx] | Stochastic background reconstruction, anisotropies  |
| LISA-CosWG-21-<br>02 | ArXiv:2203.00566 | Measuring the propagation speed of gravitational | [ATRIUM-<br>4288xx] | Modified GR, GW propagation                         |
| LISA-CosWG-21-<br>03 | ArXiv:2204.05434 | Cosmology with the Laser Interferometer Space    | [ATRIUM-<br>4288xx] | White paper   |

## CosWG Past CollProjects

### Probing modified GW propagation with LISA bright sirens

The GW luminosity distance differ from the EM luminosity distance if GR is modified at cosmological scales:

$$\frac{d_L^{\rm GW}}{d_L^{\rm EM}} = \Xi_0 + \frac{1 - \Xi_0}{(1 + z)^n}$$

| Model   | $\Xi_0 - 1$   | n  | Refs.    |
|---|---|--|----------|
| HS $f(R)$ gravity   | $rac{1}{2}f_{R0}$  | $rac{3(	ilde{n}+1)\Omega_m}{4-3\Omega_m}$       | [68]     |
| Designer $f(R)$ gravity                                   | $-0.24 \Omega_m^{0.76} B_0$                                       | $3.1\Omega_m^{0.24}$                             | [69]     |
| Jordan-Brans-Dicke  | $rac{1}{2}\delta\phi_0$  | $rac{3(	ilde{n}+1)\Omega_m}{4-3\Omega_m}$       | [70]     |
| Galileon cosmology  | $rac{eta \phi_0}{2 M_{ m Pl}}$                                   | $rac{\dot{\phi}_0}{H_0\phi}$                    | [71]     |
| $lpha_M=lpha_{M0}a^{	ilde n}$                             | $rac{lpha_{M0}}{2	ilde{n}}$                                      | $	ilde{n}$                                       | [67]     |
| $lpha_M=lpha_{M0}rac{\Omega_\Lambda(a)}{\Omega_\Lambda}$ | $-rac{lpha_{M0}}{6\Omega_\Lambda}\ln\Omega_m$                    | $-rac{3\Omega_\Lambda}{\ln\Omega_m}$            | [67, 72] |
| $\Omega = 1 + \Omega_+ a^{\tilde{n}}$                     | $rac{1}{2}\Omega_+$  | $	ilde{n}$                                       | [6]      |
| Minimal self-acceleration                                 | $\lambda \left( \ln a_{ m acc} + rac{C}{2} \chi_{ m acc}  ight)$ | $rac{C/H_0-2}{\ln a_{ m acc}^2-C\chi_{ m acc}}$ | [66]     |

Forecast with LISA MBHBs as bright sirens -

[Belgacem+ (LISA CosWG), JCAP (2019)]



## CosWG Past CollProjects

Slide by T. Baker & G. Tasinato

### Measuring the propagation speed of gravitational waves with LISA

T. Baker, G. Calcagni, A. Chen, M. Fasiello, L. Lombriser, K. Martinovic, M. Pieroni, M. Sakellariadou, G. Tasinato, D. Bertacca, and I. D. Saltas for the LISA Cosmology Working Group

> arXiv 2203.00566 JCAP 08 (2022) 031







## **CosWG Ongoing CollProjects**

Slide by S. Clesse & J. Garcia-Bellido

### LISA team of Living-review on primordial PrimBHoles black holes (PBHs) **PBH** experts A modular code/toolbox 1. **GWB** from Sebastien Clesse (coord), GWB from GWB from Mergers of 2nd order Juan Garcia-Bellido (coord), **Poisson fluct** early binaries early binaries 2. for end-to-end computations pert. Eleni Bagui, of PBH GW signatures Valerio De Luca, Asteroid-Mergers in Gabriele Franciolini. mass PBHs in 3. developed by a team of 20 **PBH clusters** Cristian Joana. solar system **PBH** experts, Rajeev Kumar Jain, Sachiko Kuroyanagi, 4. based on PBH living review GWB from LSS-GW Ilia Musco. **PBH clusters** correlations Theodoros Papanikolaou, with pre-implemented 5. Marco Peloso, models and scripts GWB from Continuous Alvise Raccanelli, High-z hyperbolic GW from hyperbolic Sebastien Renaux-Petel, binaries encounters subsolar BH encounters 6. well documented and up-to-Antonio Riotto, date Ester Ruiz Morales. From the latest theoretical models Marco Scalisi, to the GW signatures of PBHs 7. public Olga Sergijenko, Caner Unal. and perspectives for LISA Vincent Vennin. 8. easy to install, to use and to modify **David Wands Coming very soon!**

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(internal review almost completed)

### **Preliminary** coordinators:

Macarena Lagos (Columbia) Alberto Mangiagli (APC)

[Ezquiaga, Zumalacarregui 2019]

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**TESTING GW POLARISATIONS** 

Six possible polarisations in a general theory of gravity

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## **CosWG Future CollProjects**

## **CosWG Future CollProjects**

### -----TESTING GW POLARISATIONS

### LISA target sources:

<u>MBBHs</u>

- Typically high SNR: help detect small deviations from GR
- "Short"-lived: limited LISA orbital motion leverage
- Higher-order modes: dependence on waveform assumptions

### <u>SOBBHs</u>

- Typically low SNR
- Long-lived: LISA orbital motion leverage for angular parameters
- Monochromatic: no frequency-evolution assumption involved

### EMRIs?

- Long-lived: LISA orbital motion leverage for angular parameters
- Difficult to model: disentangling alternative polarisations may be challenging

Preliminary coordinators: Macarena Lagos (Columbia) Alberto Mangiagli

(APC)

## **CosWG Future CollProjects**

-----TESTING GW POLARISATIONS

Collaboration with the LISA Fundamental Physics WG will be welcome! Preliminary coordinators:

Macarena Lagos (Columbia) Alberto Mangiagli (APC)

Get in touch with CosWG chairs or one of the project coordinators if you are interested in contributing to this project!

### Conclusions

New rules governing the LISA CosWG are in place
CosWG collaborative projects
8 completed
5 ongoing
~10 new proposals under discussion
LISA Cosmology white paper
Currently in editorial production
Huge effort from CosWG members

### **BACKUP SLIDES**

### Early universe SGWB ( $z \rightarrow \infty$ )

LISA can detect <u>stochastic backgrounds of GW</u> of both astrophysical and cosmological origin



[LISA (2017), arXiv:1702.00786]

[Caprini & Figueroa, CQG (2018)]

### Early universe SGWB ( $z \rightarrow \infty$ )

LISA can detect <u>stochastic backgrounds of GW</u> of both astrophysical and cosmological origin



### LISA CosWG White Paper



Cosmology with the Laser Interferometer Space Antenna

- 1. Introduction
- 2. Tests of cosmic expansion and acceleration with standard sirens
- 3. Gravitational lensing of gravitational wave signals



High redshift events (MBHBs) have high probability of being lensed

Wave effects for lenses of mass  $10^6 \lesssim M_L \lesssim 10^9$ 

### Massive BBHs ( $z \leq 10$ )

### LISA MBHB data will be very useful to probe $\underline{\Lambda CDM}$ at high-redshift



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LISA MBHB data will be very useful to probe  $\underline{\Lambda CDM}$  at high-redshift

