# LISA Definition Study Report

Colpi, Danzmann, Hewiston et al. 2024 arXiv: 2402.07571



European Space Agency





University of Milano Bicocca, Italy

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# LISA passed adoption !

# Monica Colpi





## LISA ADOPTION ON THE 25TH OF JANUARY 2024

# THE WAY TO LISA





### 1989

ANTENNA FOR LASER GRAVITATIONAL WAVE OBSERVATIONS IN SPACE

FALLER, BENDER, HALL, HILS, STEBBINS, VINCENT

...millions of km sized antenna

LISA PROPOSED TO ESA AS FLAGSHIP L3 MISSION

LISA CONSORTIUM

2017

LISA Laser Interferometer Space Antenna Lead Proposer Prof. Dr. Karsten

2015 LAUNCH OF LISA PATHFINDER

VITALE ET AL.





**DISCOVERY OF** GW150914









**Mission Adopted** 25/01/24 28/03/24 Invitation to Tender published 02/08/24 late Prime proposals evaluation Selection of Prime Contractor October ふ Negotiation with Prime Contractor Dec/Jan 25 Industrial Contract Kick Off January 25 **KICK OFF OF THE DDPC JUNE 2024** 

Courtesy of Bill Weber

→ THE EUROPEAN SPACE AGENCY



#### Courtesy of Bill Weber

### SCIENCE MANAGMENT PLAN (SMP)





#### **SCHEME DURING MPLEMENTATION PHASE**

### SCIENCE MANAGMENT PLAN (SMP)





### **SCIENCE OPERATIONS PHASE**

 LISA is a constellation of three drag-free spacecraft at the corners of an equilateral triangle, each side 2.5 million km long



2AU

s-hours-minutes

• Lifetime - 4.5 years mission at  $\sim 82\%$  availability - extendable to 10 years



# LISA

- railing heliocentric orbit between 50 and 65 million km from
  - 0.1 Hz : best sensitivity at 0.01 Hz corresponding to ~ 0.1 AU
- emporal change in the proper distance of free-falling test masses protected by the spacecraft from non gravitational disturbances







# UNIVERSE







### TRACE THE ORIGINS, GROWTH AND MERGER HISTORIES OF MASSIVE BLACK HOLES-THE TRANSIENT UNIVERSE





# TRACE THE ORIGINS, GROWTH AND MERGER HISTORIES OF MASSIVE BLACK HOLES

# LISA HORIZON FOR MASSIVE BLACK HOLE BINARIES IS THE UNIVERSE



 LISA. Signal dominated sources

 Discover the population of massive black hole binaries

 Mass-Spin: shaped by accretion and mergers measured with high accuracy

Rate: ten(s) of mergers per year



# TRACE THE ORIGINS, GROWTH AND MERGER HISTORIES OF MASSIVE BLACK HOLES

# LISA DISCOVERY SPACE AGAINST OBSERVATIONS OF AGN



High-z quasars JWST AGN accretion  $10^9$   $10^{10}$ 

 LISA, exploring the low-mass tail of the MBH mass function, extends knowledge on the way supermassive black holes outshining as quasars and AGN formed and grew



# LINKING STELLAR BLACK HOLES TO THE GIANT THROUGH THE FORMATION OF SEEDS BLACK HOLE UNIVERSALITY OVER 10 ORDERS OF MAGNITUDE IN MASS?



REDSHIFTS, AND GROWING THROUGH MERGERS AND ACCRETION EPISODES

# SUPERMASSIVE BLACK HOLES CAME INTO BEING FROM "<u>SEEDS</u>" FORMING AT HIGH

# **MULTI MESSENGER WITH LISA**

- HOW DOES ACCRETION PROCEED IN THE VIOLENTLY CHANGING SPACETIME OF A MERGER?

# **Precursor emission**

Only binaries of  $10^5 M_{\odot}$  at z~0.5 can be localised within 10 deg<sup>2</sup> for EM alerts





# EM PERIODIC SIGNATURES IN THE PRECURSOR - JETTED-AGN EMISSION POST-MERGER EMISSION?

# Afterglow emission

At merger localisation within ~0.1 deg<sup>2</sup> or better is possible for the LISA binaries out to  $z \sim 3$ 





## SCIENCE OBSERVATIONS: LOW LATENCY ALERTS FOR A MULTIMESSENGER OBSERVATION



- 3 months

Realtime in 8/24 h of data exchange

Protected periods

Multi-messenger will be done "online" with alerts but also "offline" for long lived sources (Galactic binaries, Stellar BH)

### EXPLORE THE FUNDAMENTAL NATURE OF GRAVITY AND BLACK HOLES

# USE THE RINGDOWN SIGNAL TO TEST THE KERR NATURE OF BLACK HOLES

- ARE THE MASSIVE OBJECTS THAT MERGE AND THEIR REMNANTS KERR BLACK HOLES?
- DO HORIZONLESS ULTRACOMPACT OBJECTS EXIST IN NATURE?  $\bigcirc$



- Black hole "spectroscopy": quasi-normal modes and damping times - function of M and spin only - "no hair conjecture"
- GR deviations measured with precision of 10% to 1%
- EXOTIC COMPACT OBJECTS?



# **EXTREME MASS RATIO INSPIRALS**



## EXPLORE THE FUNDAMENTAL NATURE OF GRAVITY AND BLACK HOLES

# EMRIS TO EXPLORE THE MULTIPOLAR STRUCTURE OF MBHS AND SEARCH FOR NEW FIELDS



- Redshifted mass of the primary with accuracy ~ 0.001%
- Spin of the primary with absolute error~10<sup>-5</sup>
- Quadrupole Moment (M, spin) - fractional accuracy of 10<sup>-5</sup>



#### UNDERSTAND STOCHASTIC GW BACKGROUNDS AND THEIR IMPLICATIONS FOR THE EARLY UNIVERSE AND TEV SCALE PARTICLE PHYSICS

# FIRST ORDER PHASE TRANSITION AT THE ELECTROWEAK SCALE BEYOND THE STANDARD MODEL

- WHAT IS THE AMPLITUDE AND SPECTRAL SLOPE OF ASTROPHYSICAL BACKGROUNDS?
- IS THERE A COSMOLOGICAL SGWB?



- sBHB (DWDs) astrophysical background
  - Amplitude determined with error ~%
- **Cosmological background** encompassing the TeV energy scale
- **First Order Phase Transition:** benchmark signal
  - Fractional error on  $\log \Omega$ ~0.45%

### LISA - LASER INTERFEROMETER SPACE ANTENNA



**DATA PROCESSING** Global Fit

Waveforms

MMMMMWW 

