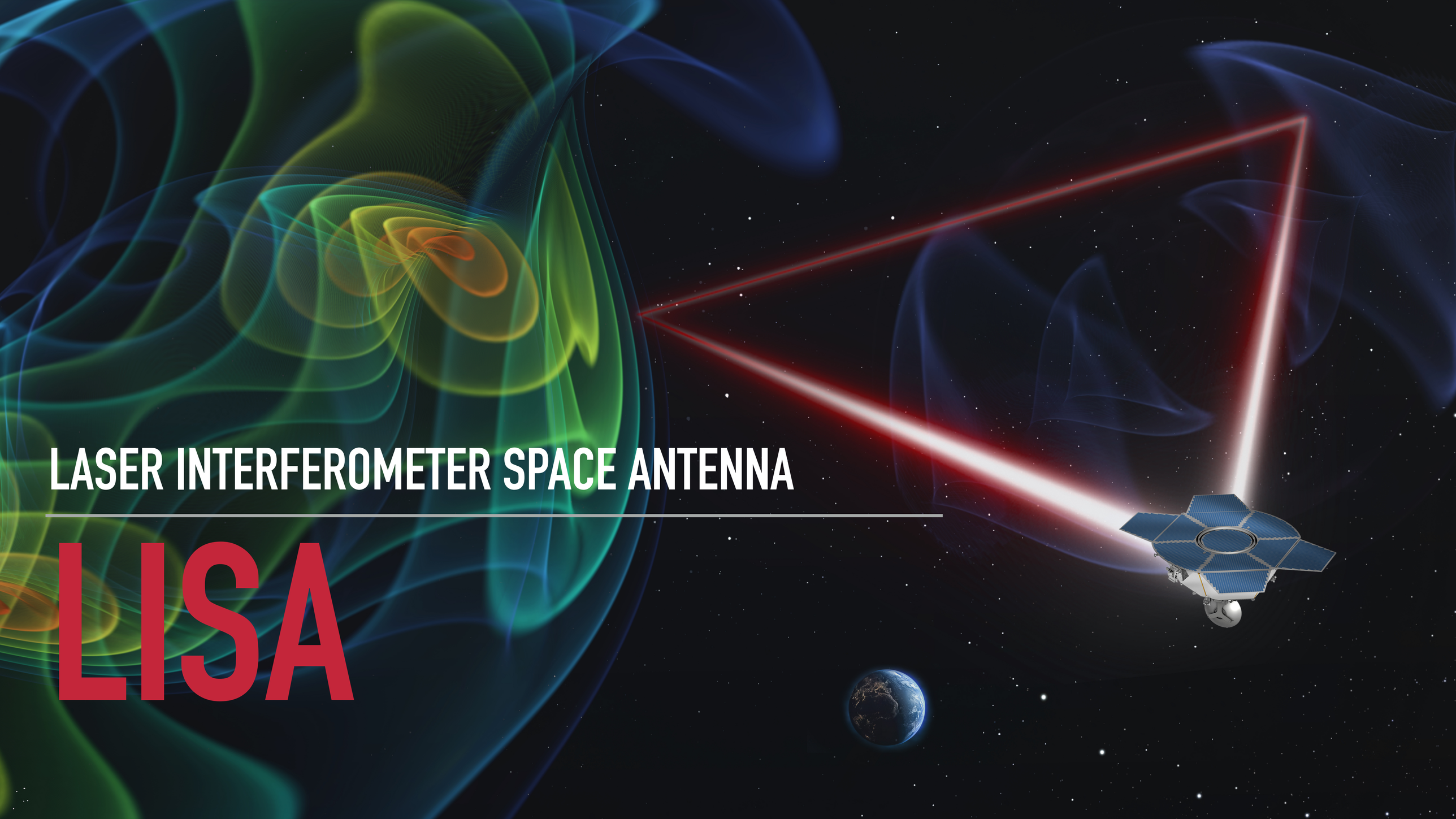

LASER INTERFEROMETER SPACE ANTENNA
LISA

JOB OPPORTUNITIES AT ESA

ESA SPACE-SCIENCE RESEARCH FELLOWSHIP

OPENING LATE SUMMER



ESA SCI NEWSLETTER

🚀 WHAT?

- Postdoctoral fellowship for ESA State nationals
- Your own research in space science
- Duration: 2 + 1 years (with extension proposal)

🌍 WHERE?

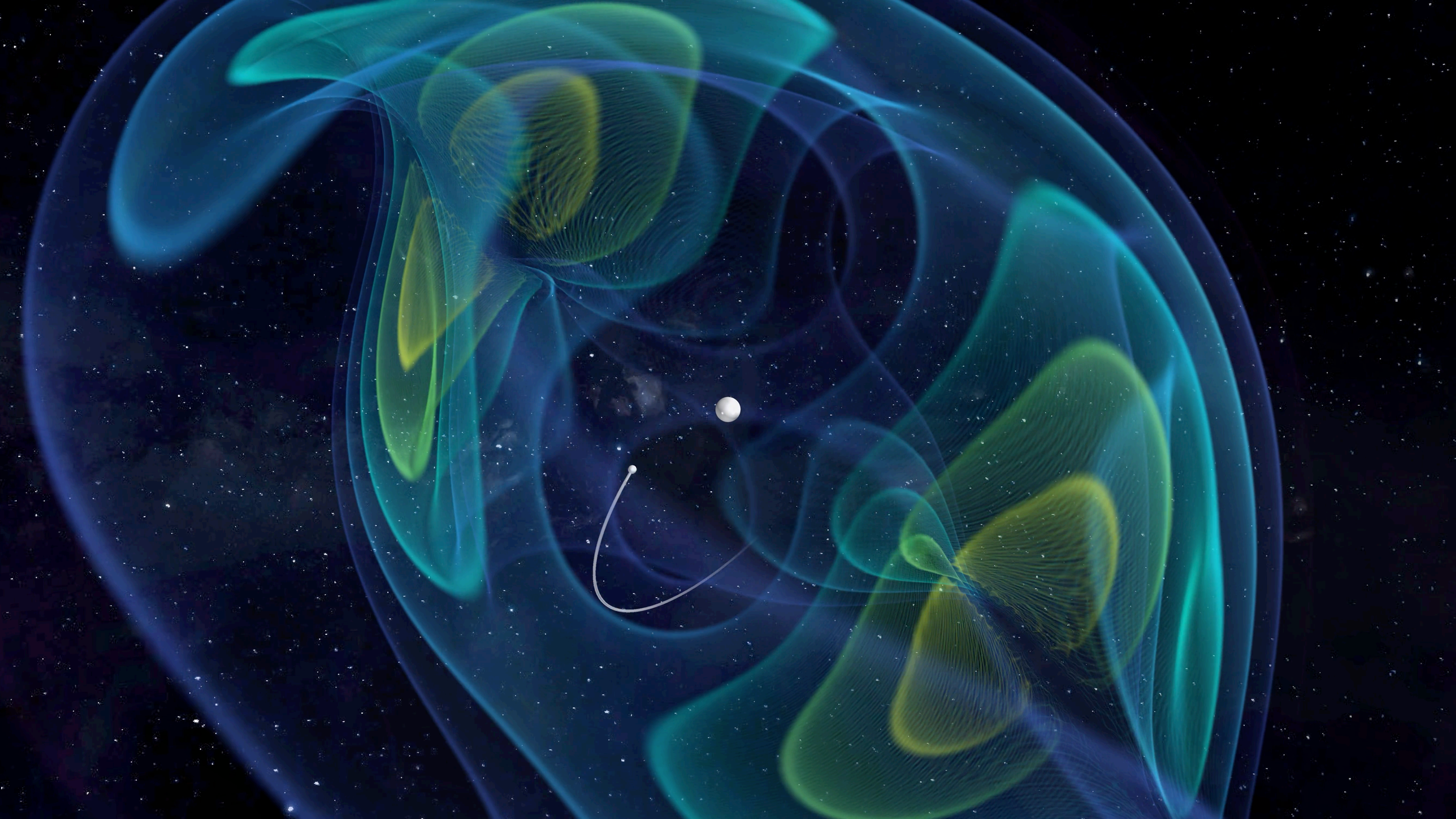
- ESTEC (Netherlands), ESAC (Spain) or STScI (USA)

🎯 WHY?

- 100% research time (optional <20% functional work)
- Access to ESA missions & environment
- Mentoring from senior ESA Faculty
- Monthly salary: €3000–€4600 (based on location & experience)

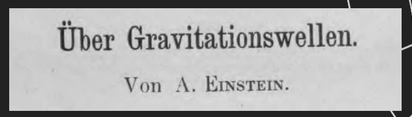
Contact: fellowship@cosmos.esa.int

esa

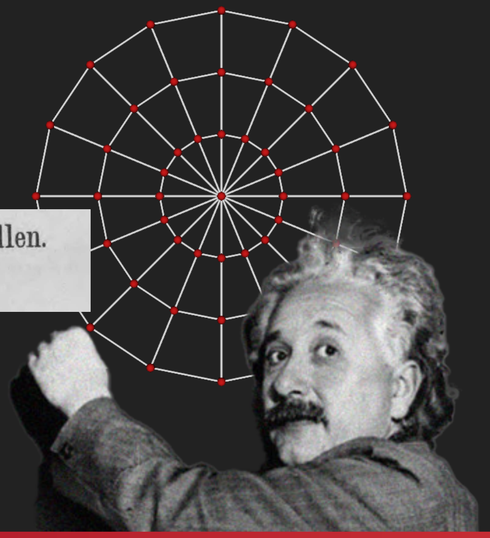


GRAVITATIONAL WAVES ARE REAL!

Very small effects: ~10^{-21}


Über Gravitationswellen.

Von A. Einstein.



1918

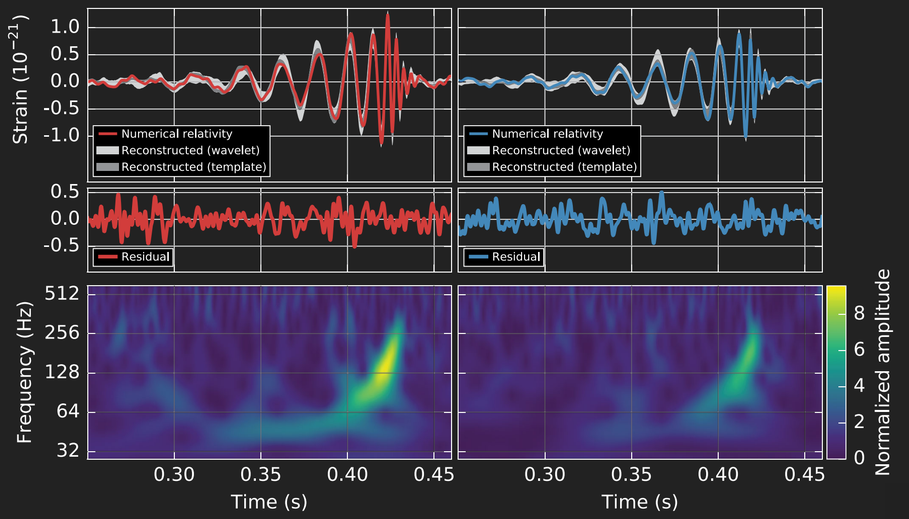
1957

Chapel Hill workshop – Bondi, Pirani, Robinson

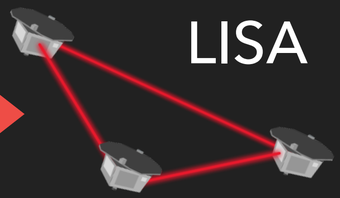
"... when gravitational radiation is present, the gravitational energy-flux cannot be removed by a local Lorentz transformation"

2016

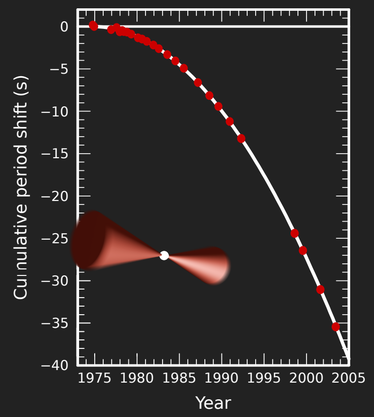
LIGO/VIRGO: GW Discovery



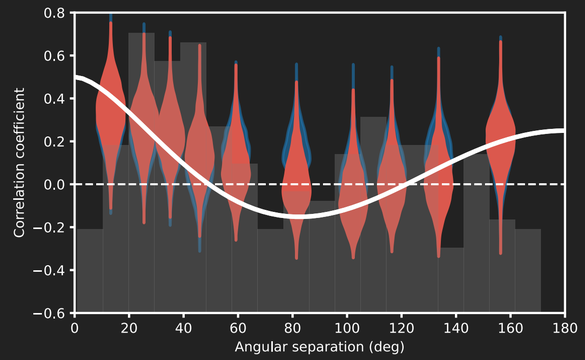
LISA



1974 Hulse-Taylor



2023 Evidence of PTA GW Background

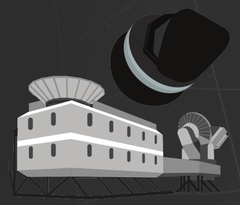




esa

WHY INTO SPACE?

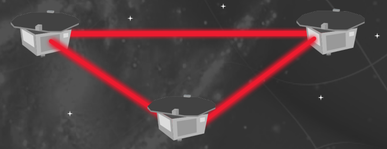
Cosmic microwave background polarisation



Pulsar timing array



Space-based observatory



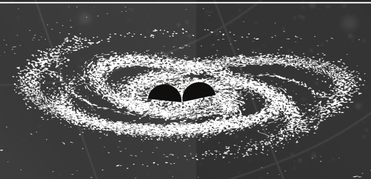
Ground-based experiments



Timescales — billions of years — years — hours — seconds — milliseconds

Frequency [Hz] — 10^{-16} — 10^{-8} — 10^{-6} — 10^{-4} — 10^{-2} — 1 — 100

Cosmic fluctuations in the early Universe



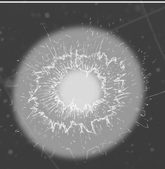
Merging supermassive black holes



Compact object and supermassive black hole systems



Pulsar



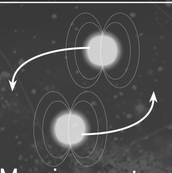
Supernova



Galactic Binaries



Merging stellar-mass black holes



Merging neutron stars

esa

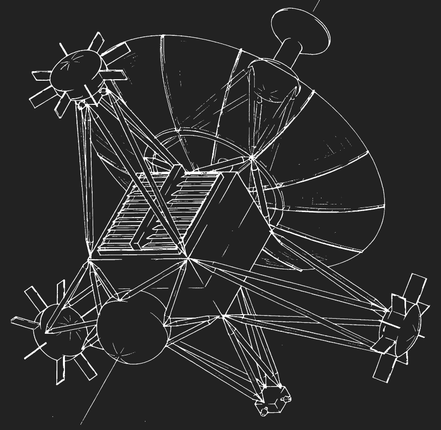
THE WAY TO LISA

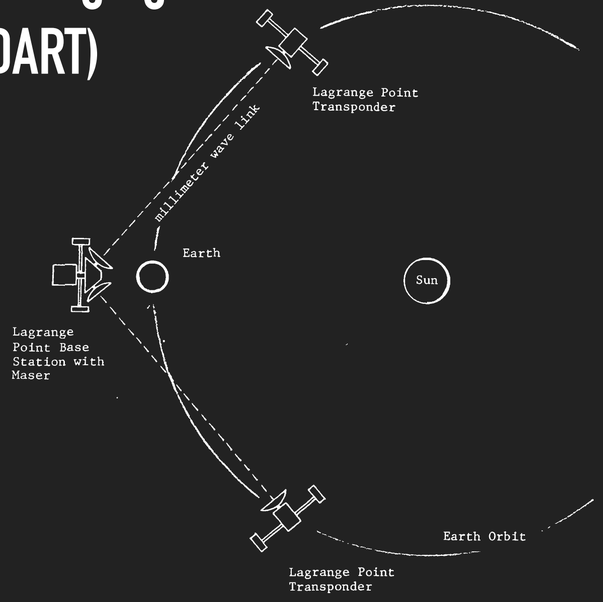
FIRST IDEAS TO MEASURE GW IN SPACE

BENDER

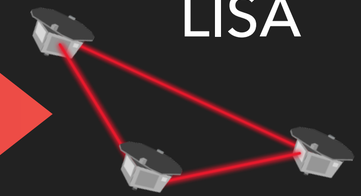
1974

1) Dopper and Ranging Transponder (DART)





LISA

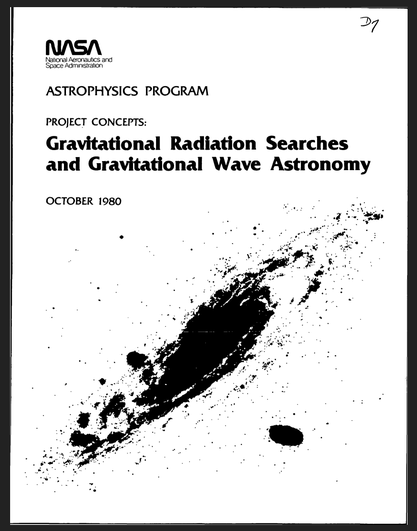


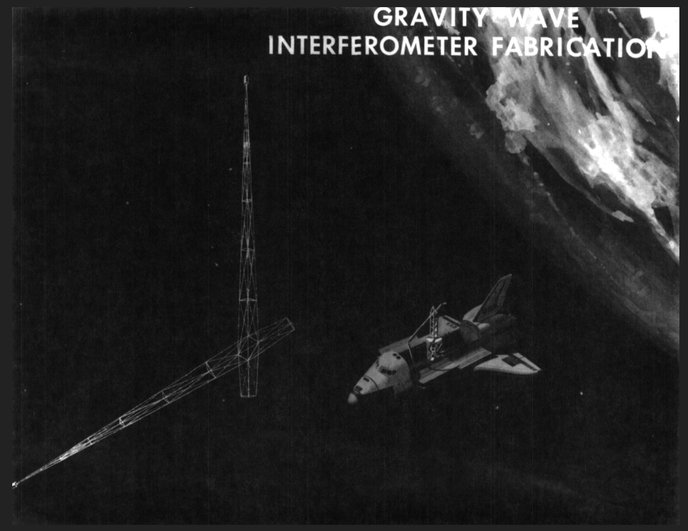


1980

SOME COOL IDEAS...







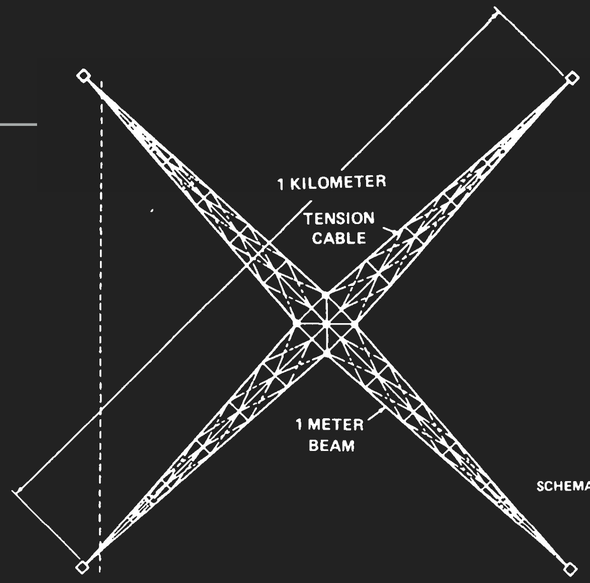


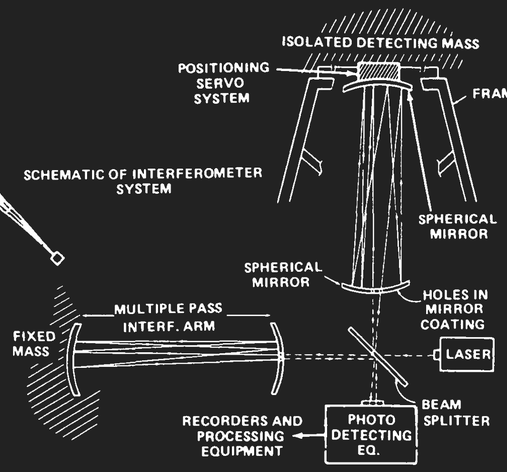
THE WAY TO LISA

FIRST IDEAS TO MEASURE GW IN SPACE

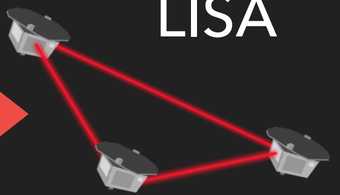
BENDER

1974





2) Laser Interferometer Gravitational Wave Mission



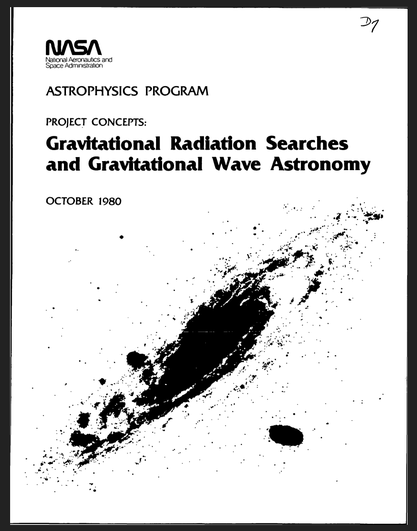
LISA



1980

SOME COOL IDEAS...





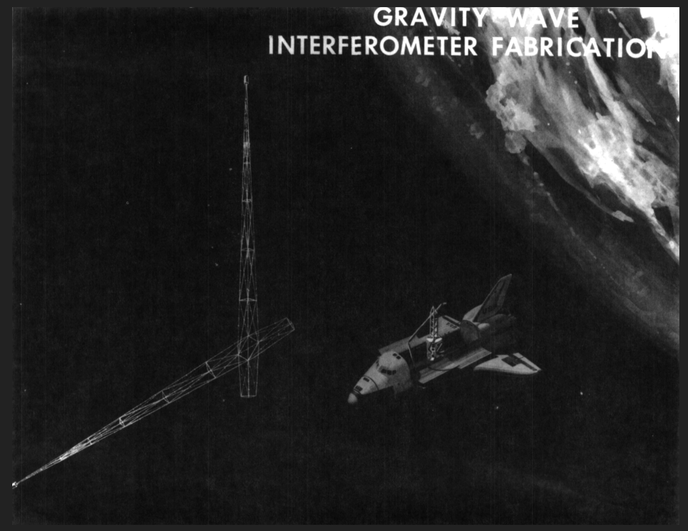
NASA
National Aeronautics and Space Administration

ASTROPHYSICS PROGRAM

PROJECT CONCEPTS:

Gravitational Radiation Searches and Gravitational Wave Astronomy

OCTOBER 1980





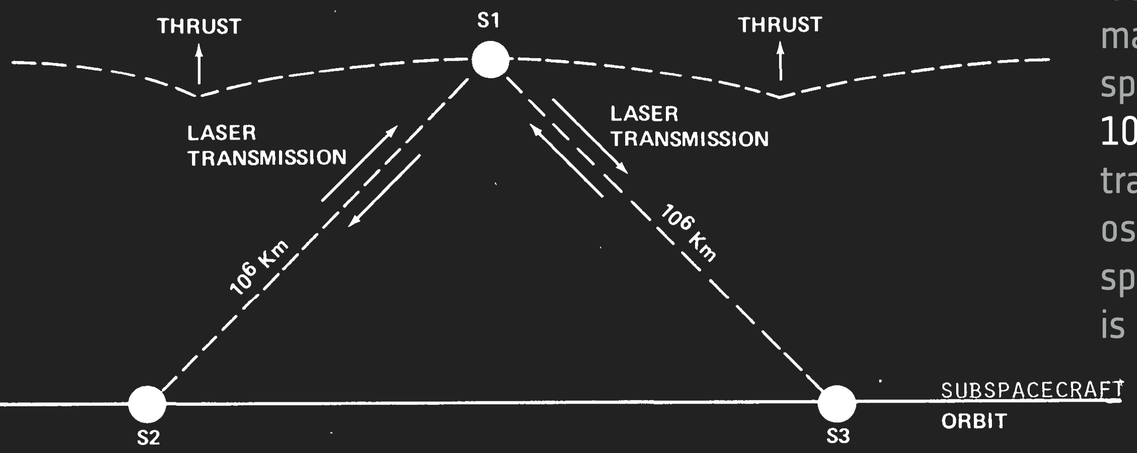
THE WAY TO LISA

FIRST IDEAS TO MEASURE GW IN SPACE

BENDER

1974

3) Laser Heterodyne Gravitational Wave Mission



"It consists of three spacecraft (S_1, S_2, S_3) in circular orbits around the Sun with periods close to 1 Earth year. [...] Two-way laser signals are transmitted between the main spacecraft (S_i) and each of the sub-spacecraft, which are separated from S_i by 10^6 km. Each spacecraft contains a laser transmitter that serves also as local oscillator. A distance change between the spacecraft caused by gravitational waves is detected by a heterodyne technique."



LISA

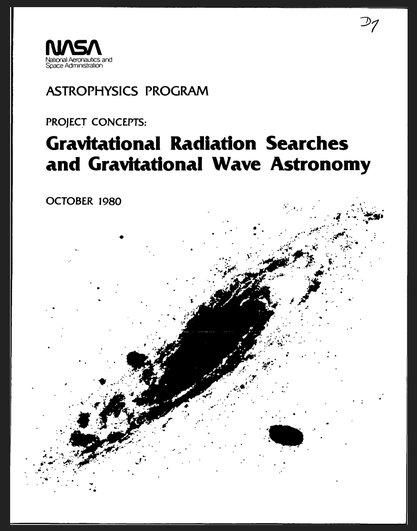


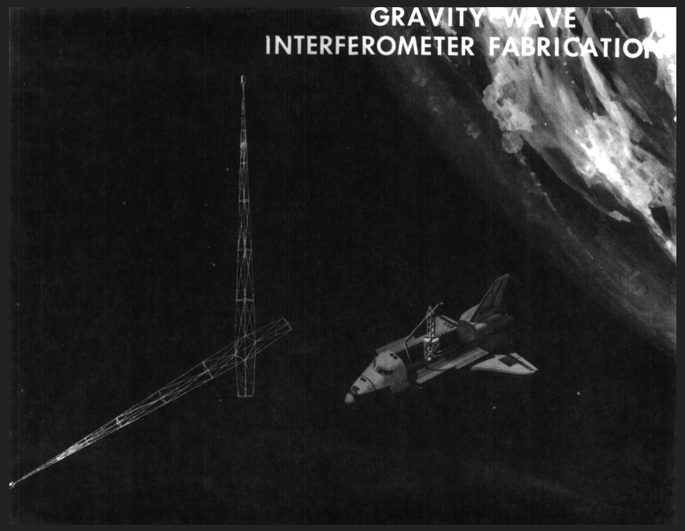


1980

SOME COOL IDEAS...









THE WAY TO LISA

FIRST IDEAS TO MEASURE GW IN SPACE

BENDER

1974



LISA PROPOSED TO ESA AS M3 MISSION TO DETECT GWs AND OBSERVE THE UNIVERSE

DANZMANN ET AL.

1993

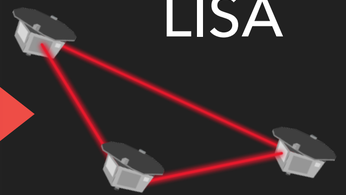
LISA PROPOSED TO ESA AS FLAGSHIP L3 MISSION

LISA CONSORTIUM

2017



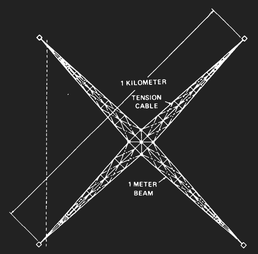
LISA

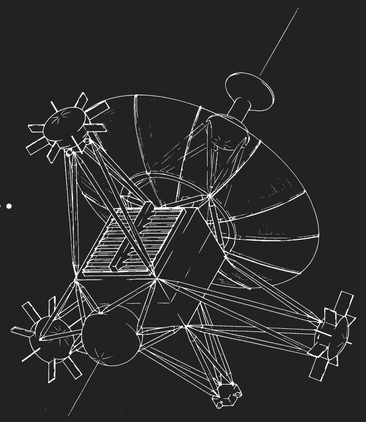




1980

SOME COOL IDEAS...



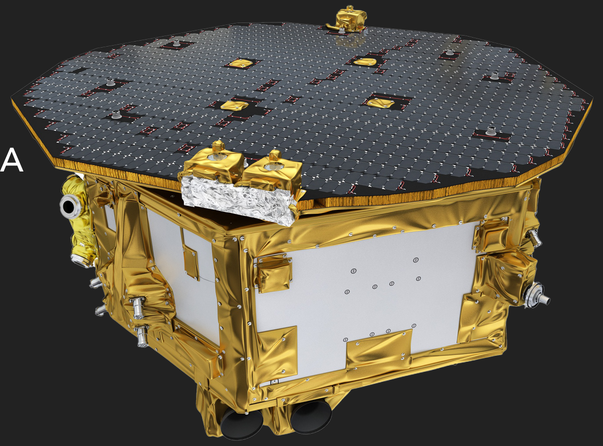




2015

LAUNCH OF LISA PATHFINDER

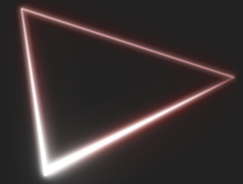
VITALE ET AL.

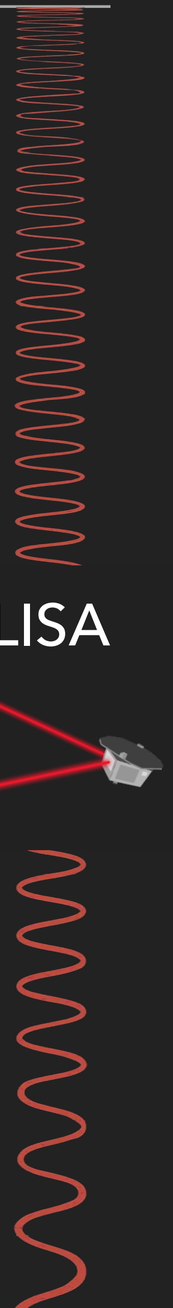


2024

LISA ADOPTION

COLPI ET AL.



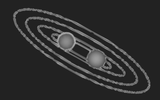



LISA
SCIENCE

Redbook: https://www.cosmos.esa.int/web/lisa/lisa-redbook

LISA SCIENCE OBJECTIVES

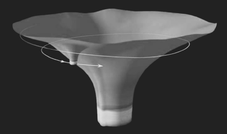
1. Galactic Binaries



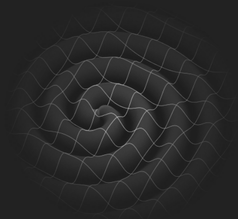
2. Massive Black Holes



3. Extreme and Intermediate mass-ratio Inspirals



4. Stellar Mass Black Holes



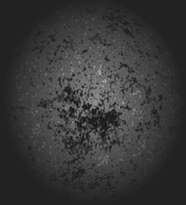
5. Fundamental nature of gravity



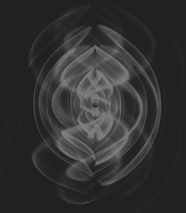
6. Expansion of the Universe



7. Stochastic gravitational wave backgrounds

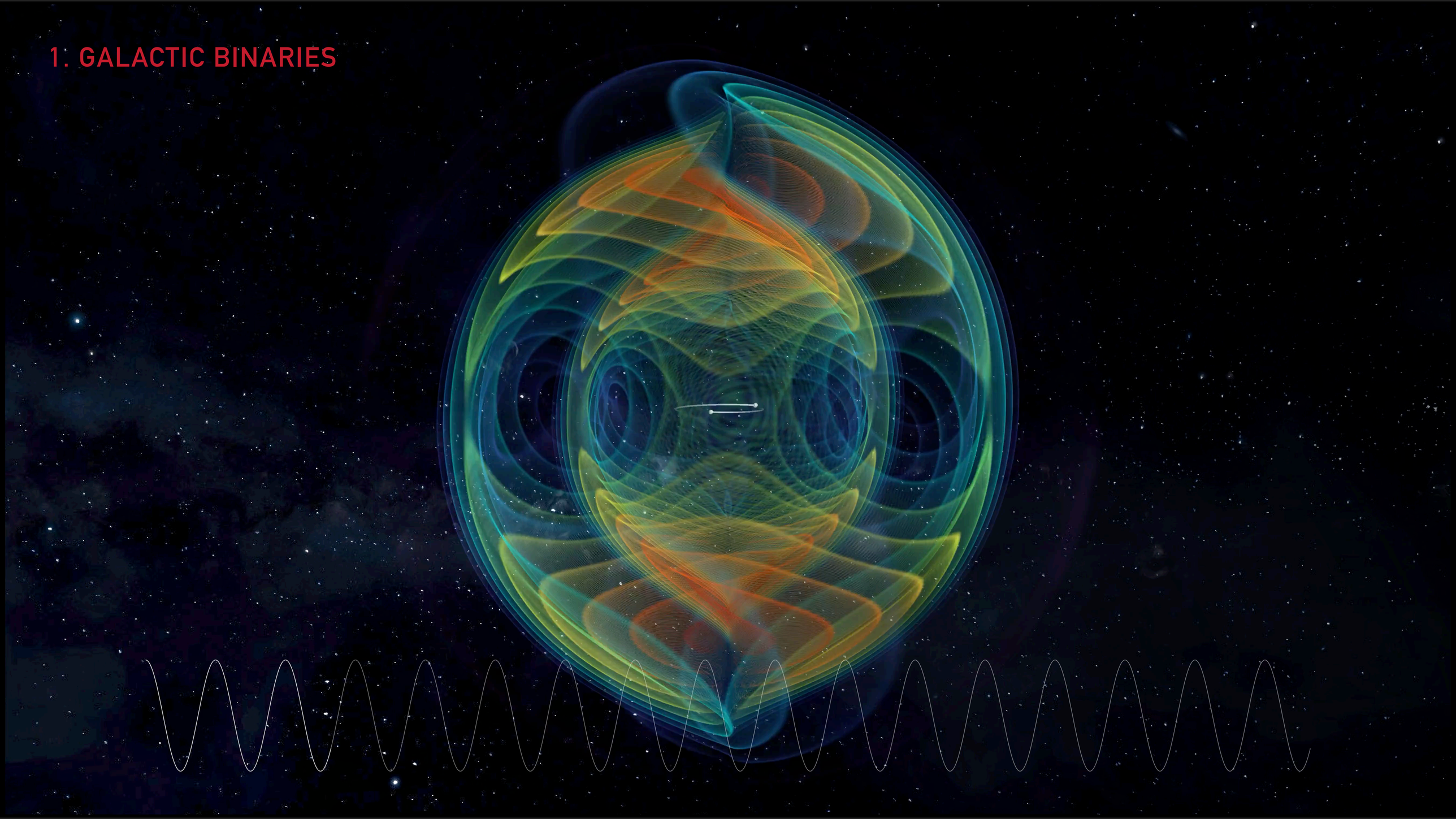


8. Unforeseen sources



esa

1. GALACTIC BINARIES



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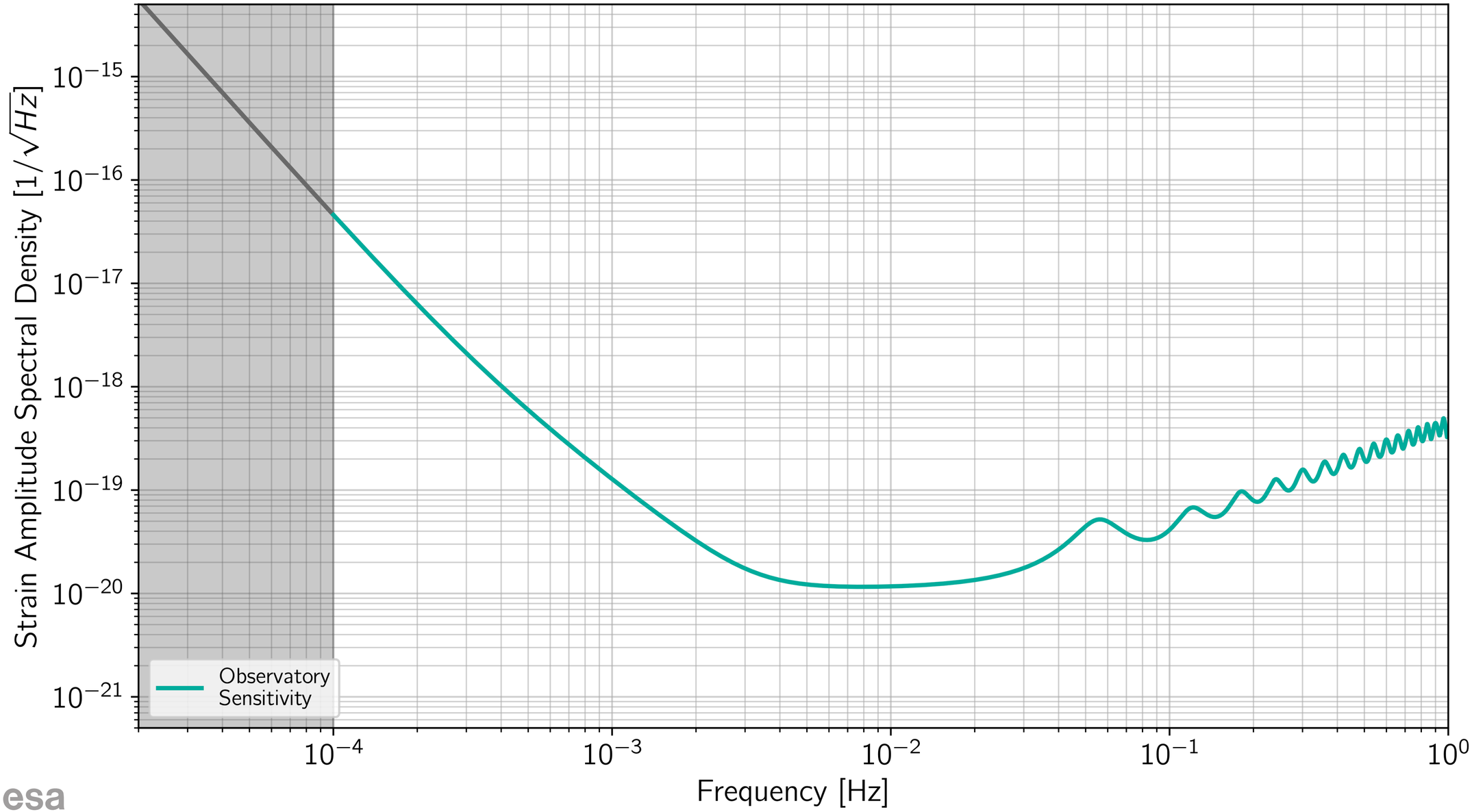

esa

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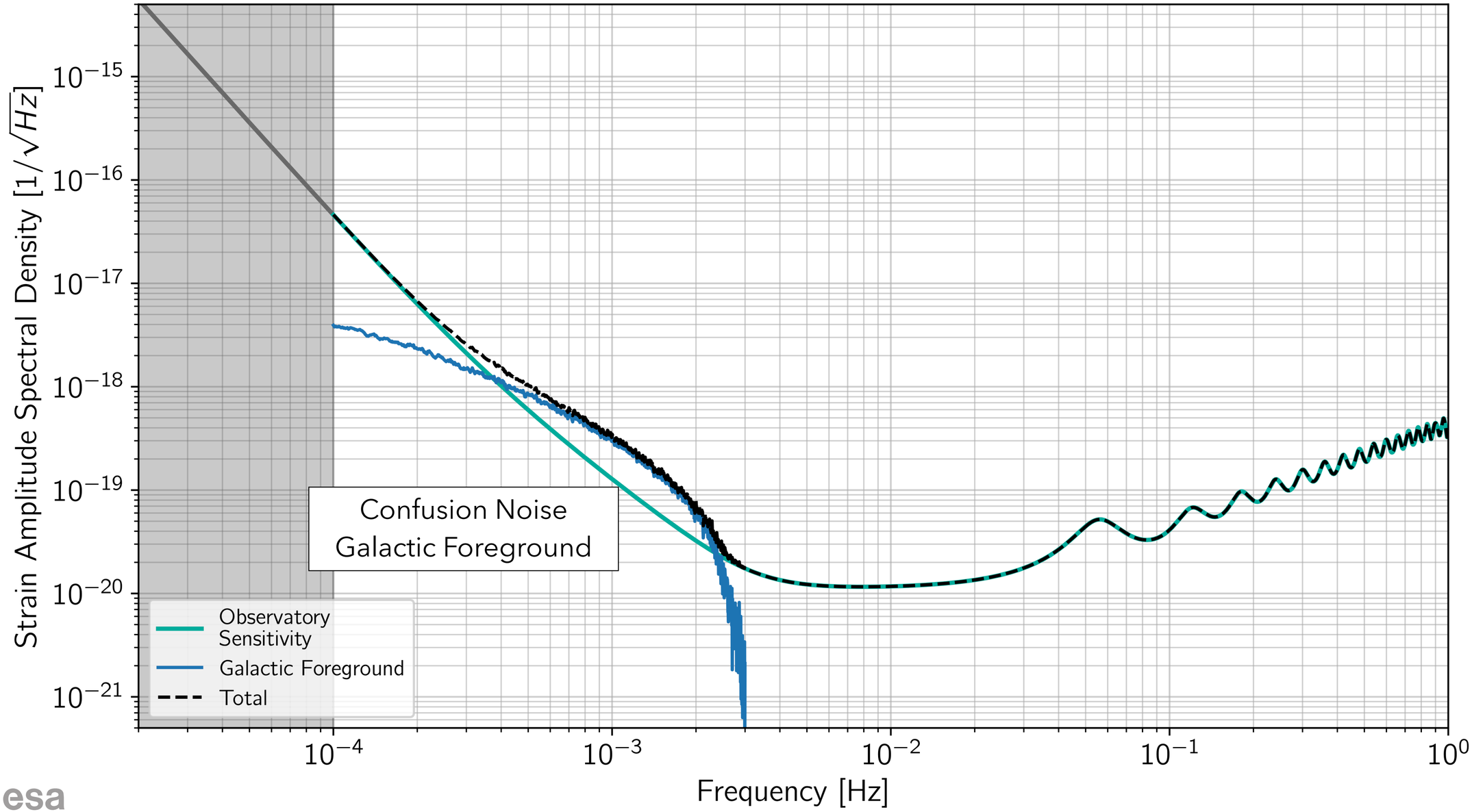

esa

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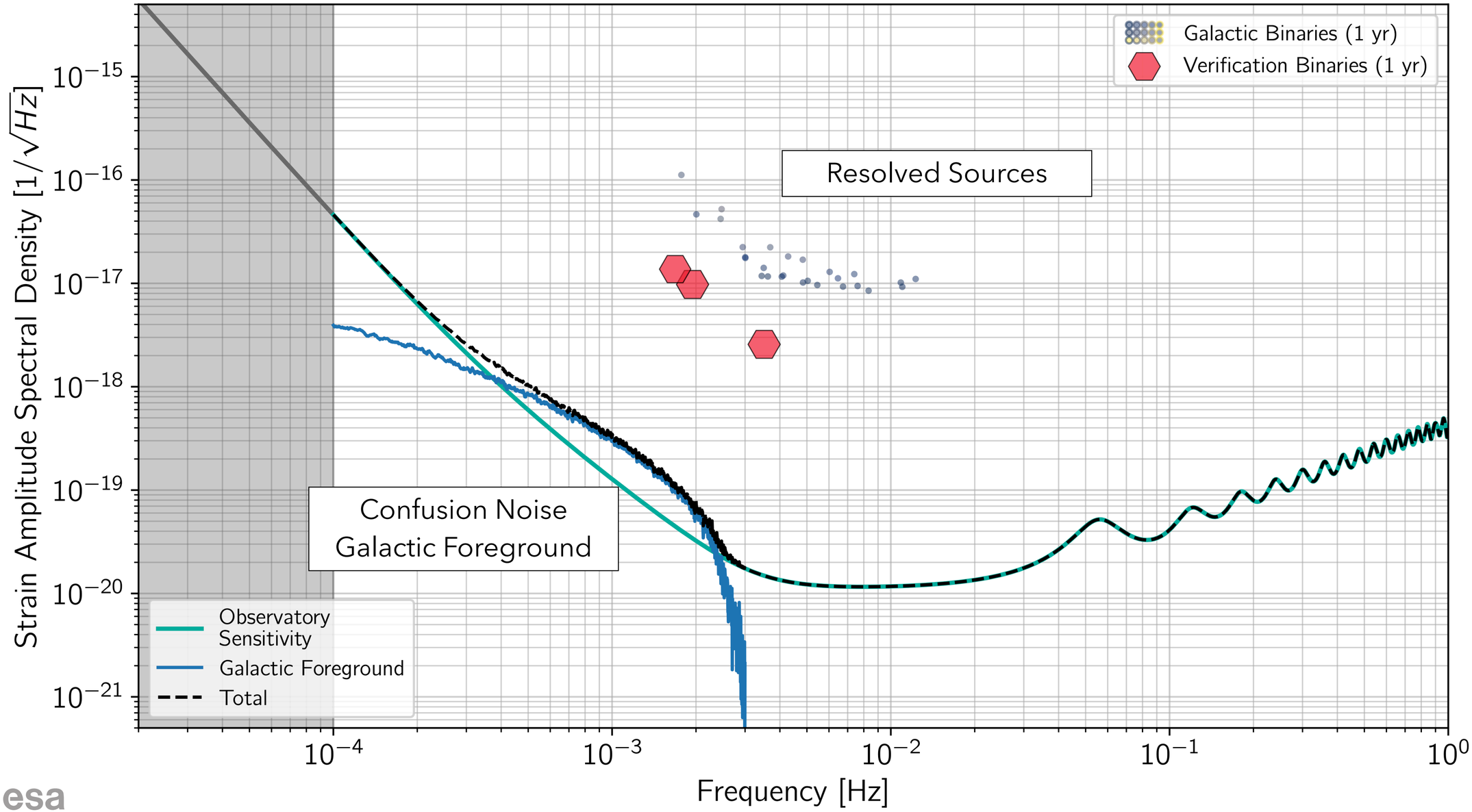

esa

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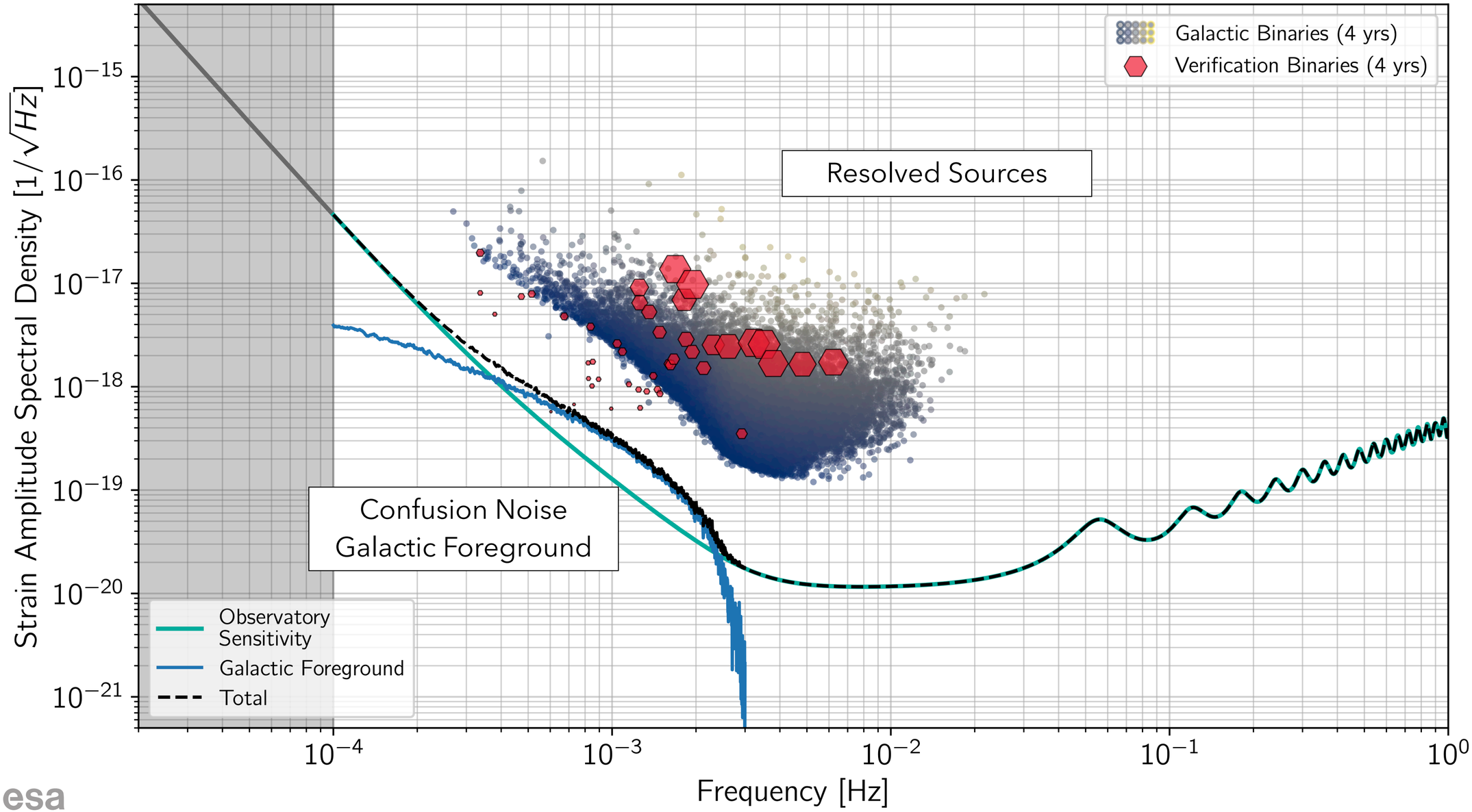

esa

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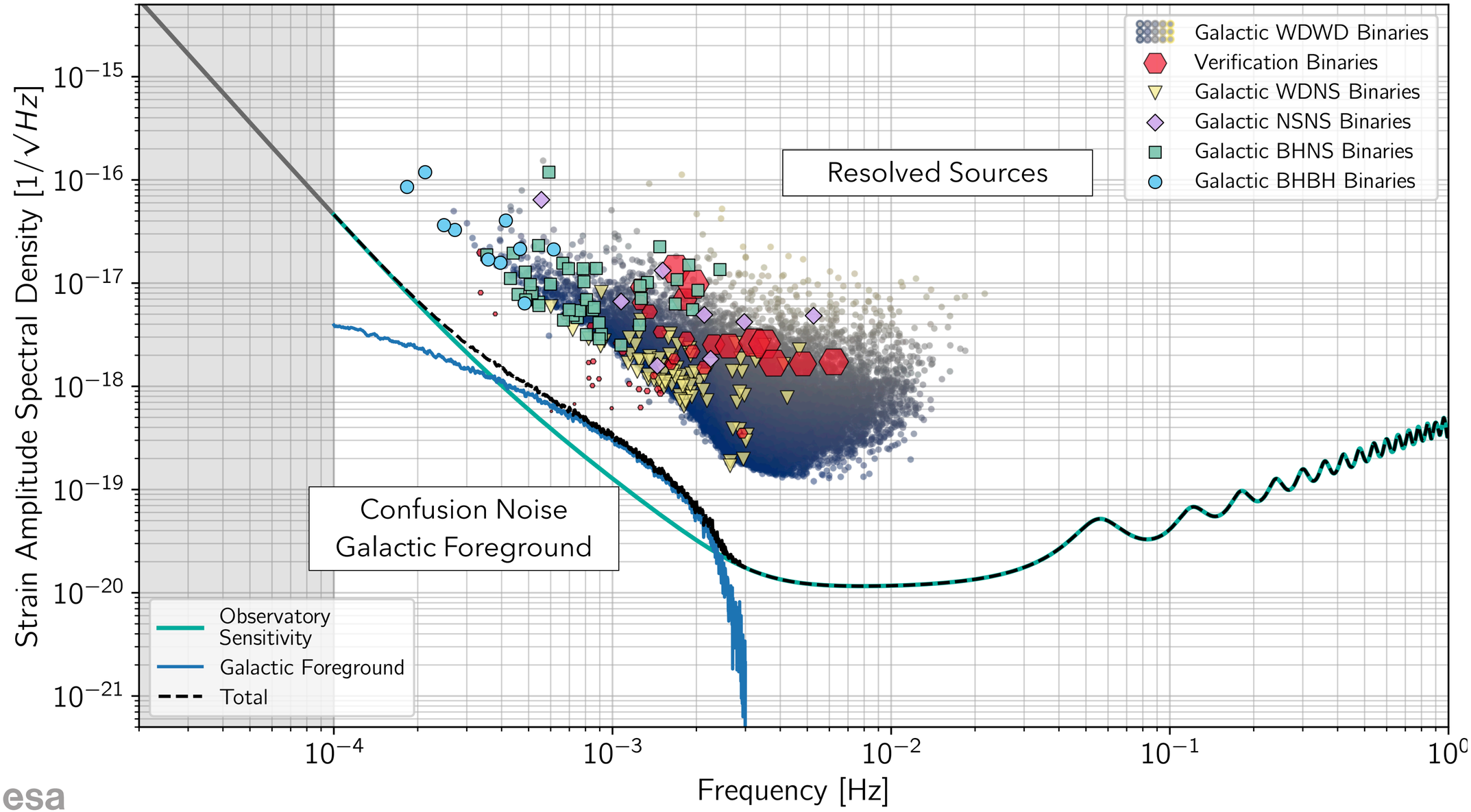
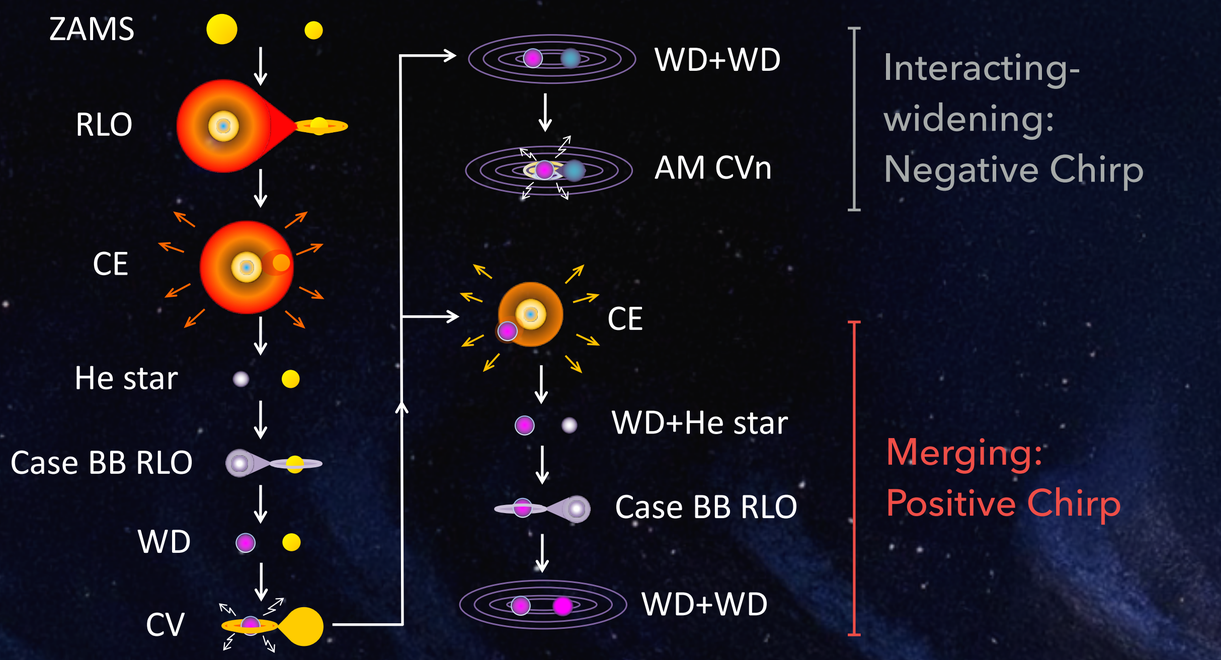
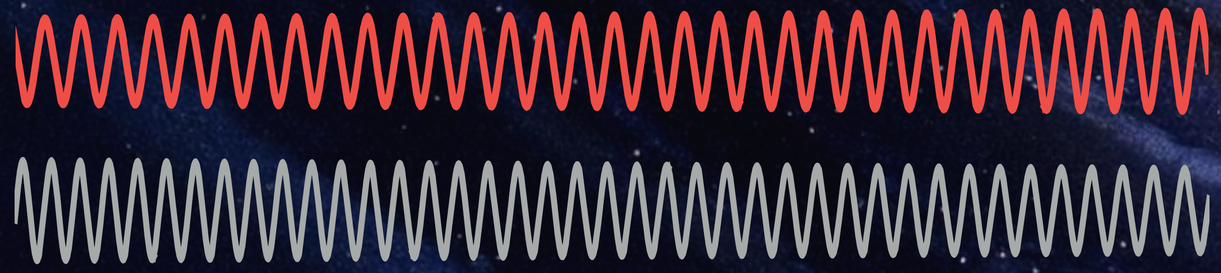
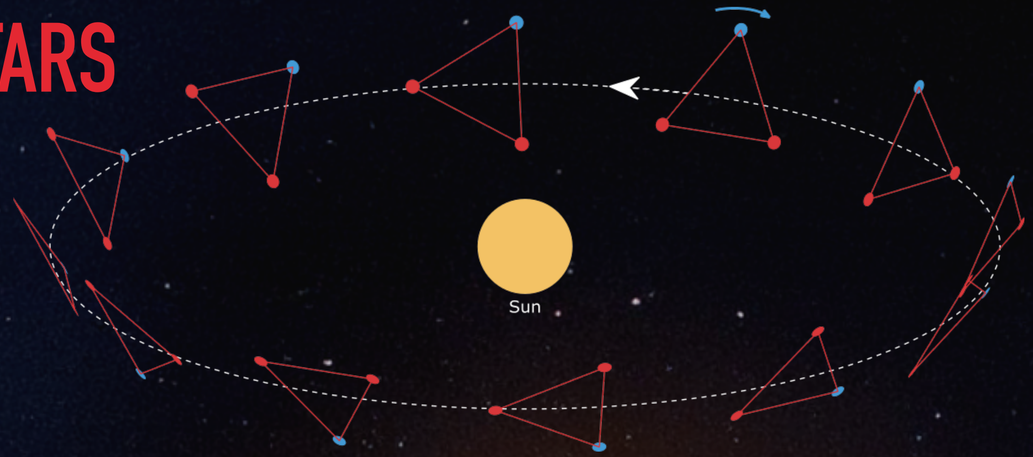


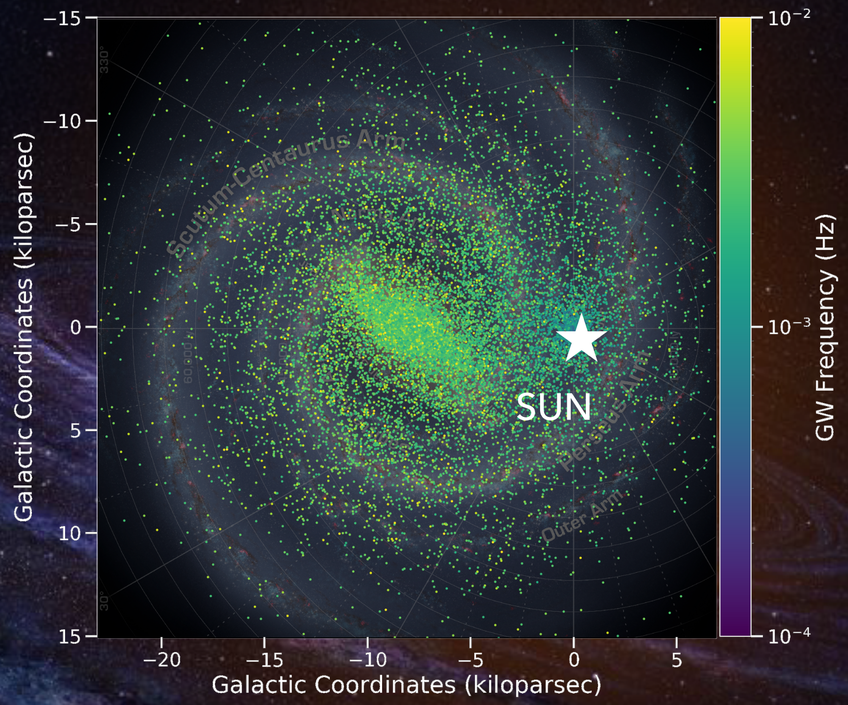
esa

FORMATION PATHWAYS OF COMPACT BINARY STARS



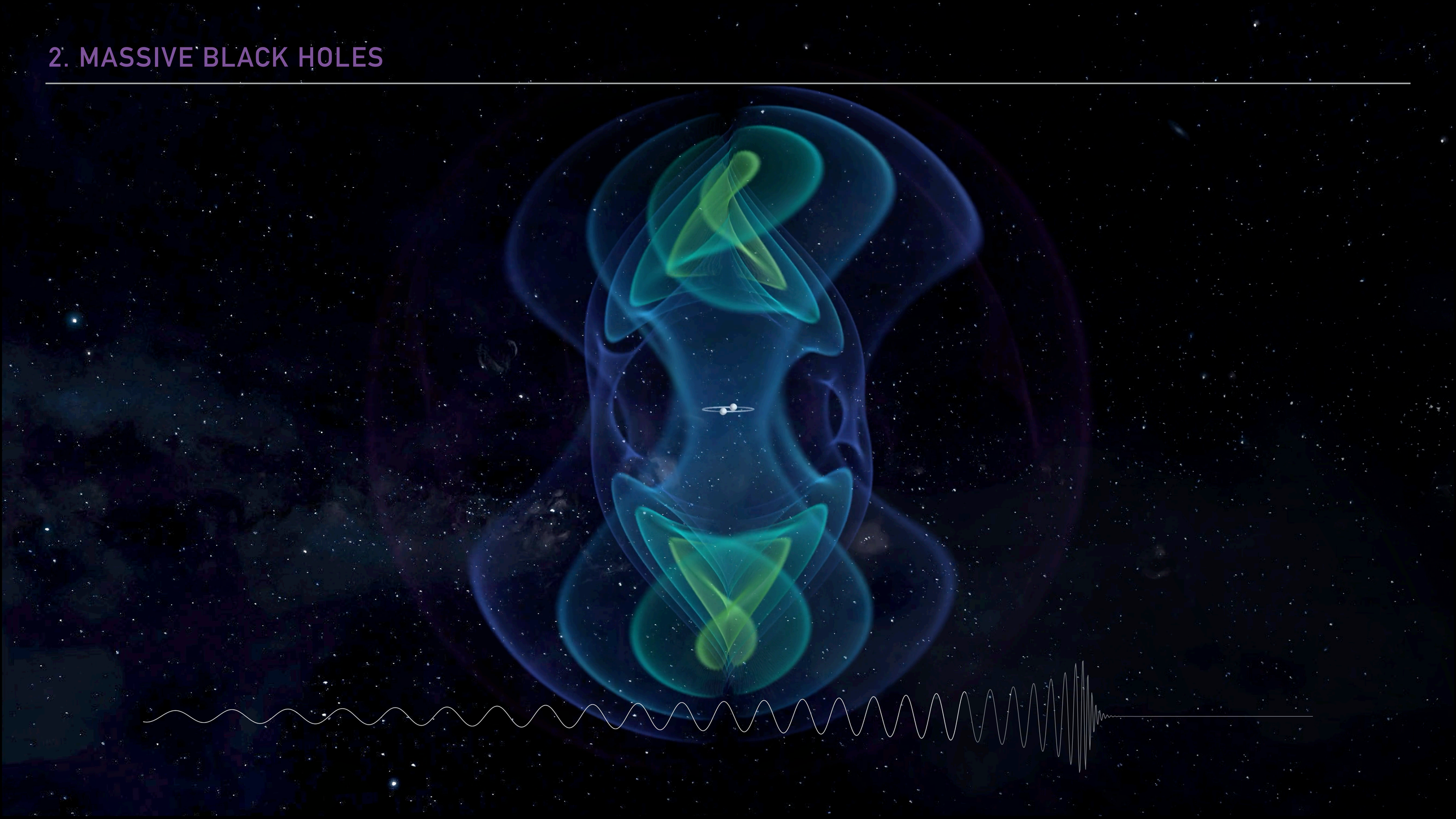


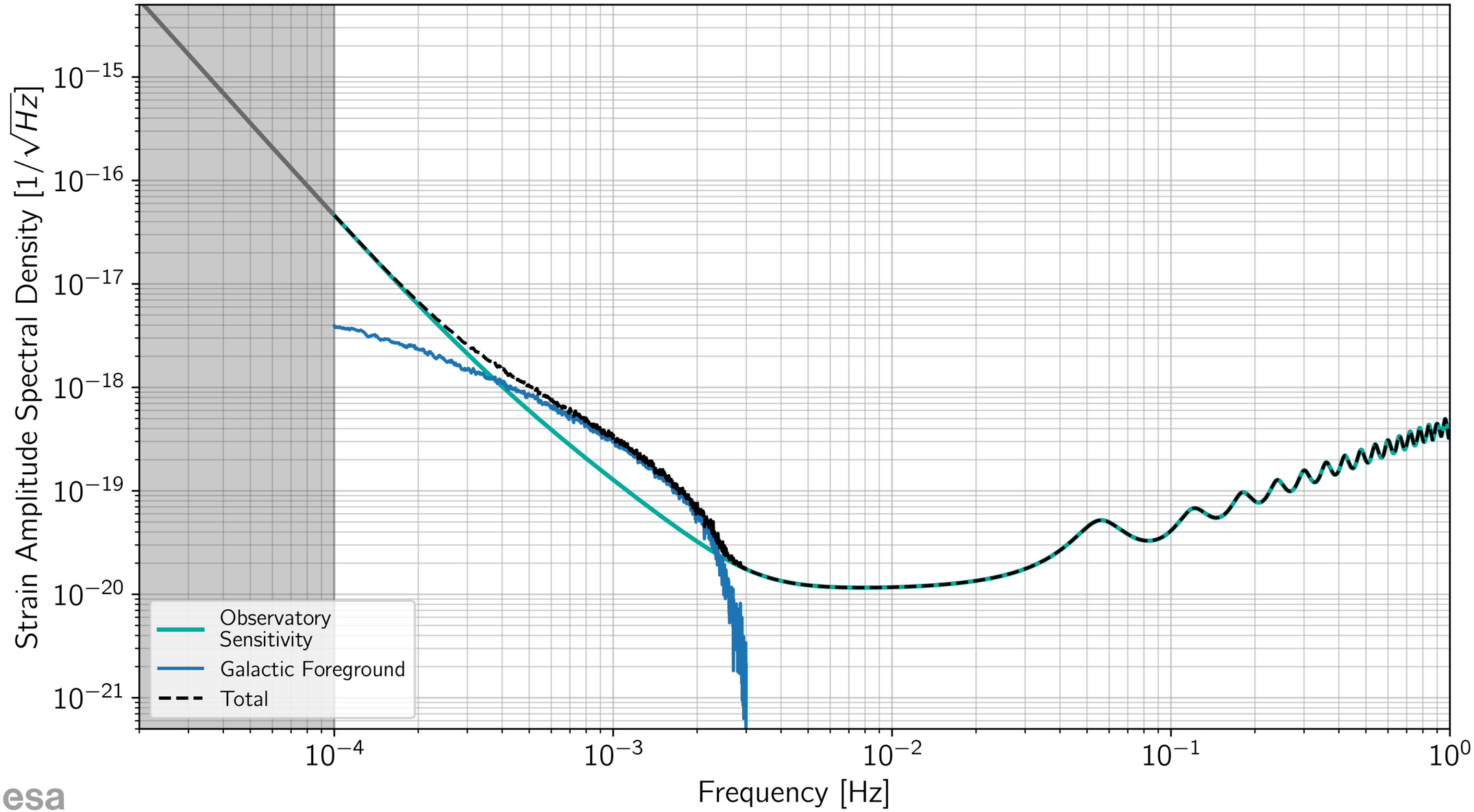


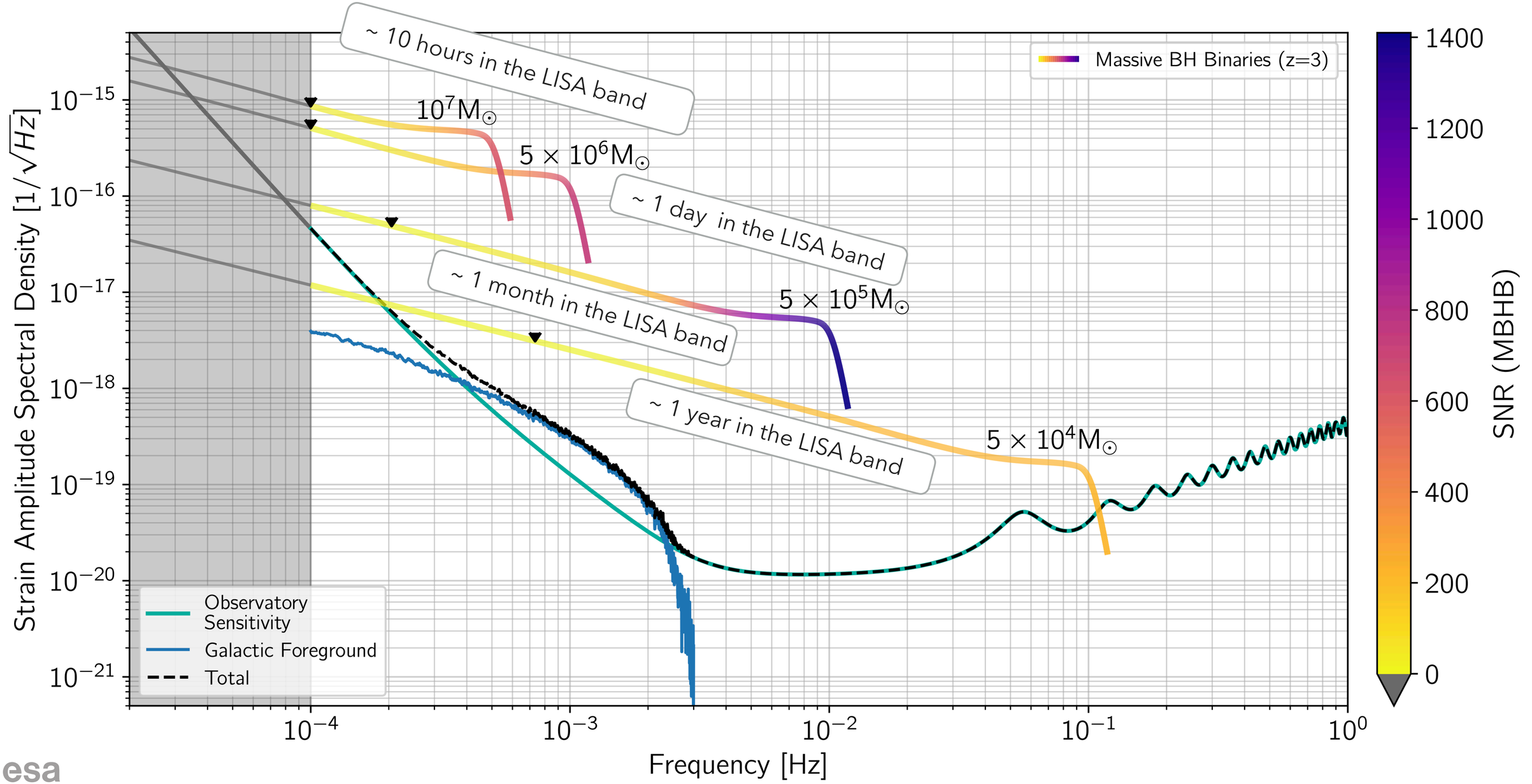


esa

2. MASSIVE BLACK HOLES




Strain Amplitude Spectral Density $[1/\sqrt{Hz}]$
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Frequency [Hz]
Observatory Sensitivity
Galactic Foreground
Total

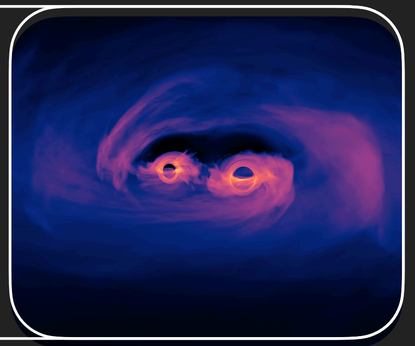

~ 10 hours in the LISA band
~ 1 day in the LISA band
~ 1 month in the LISA band
~ 1 year in the LISA band
$10^7 M_\odot$
$5 \times 10^6 M_\odot$
$5 \times 10^5 M_\odot$
$5 \times 10^4 M_\odot$
Massive BH Binaries (z=3)
Observatory Sensitivity
Galactic Foreground
Total
Strain Amplitude Spectral Density $[1/\sqrt{Hz}]$
Frequency [Hz]
SNR (MBHB)
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
1400
1200
1000
800
600
400
200
0

MULTI-MESSENGER ASTRONOMY

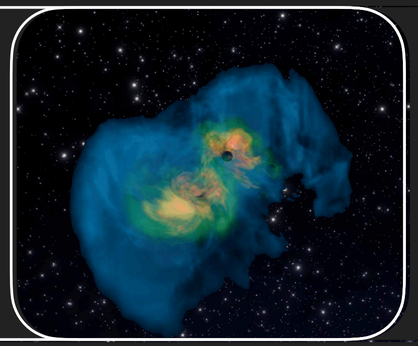
- ELECTROMAGNETIC SIGNALS BEFORE, DURING AND AFTER MERGER
- HOW DOES ACCRETION FLOW DURING A MERGER?

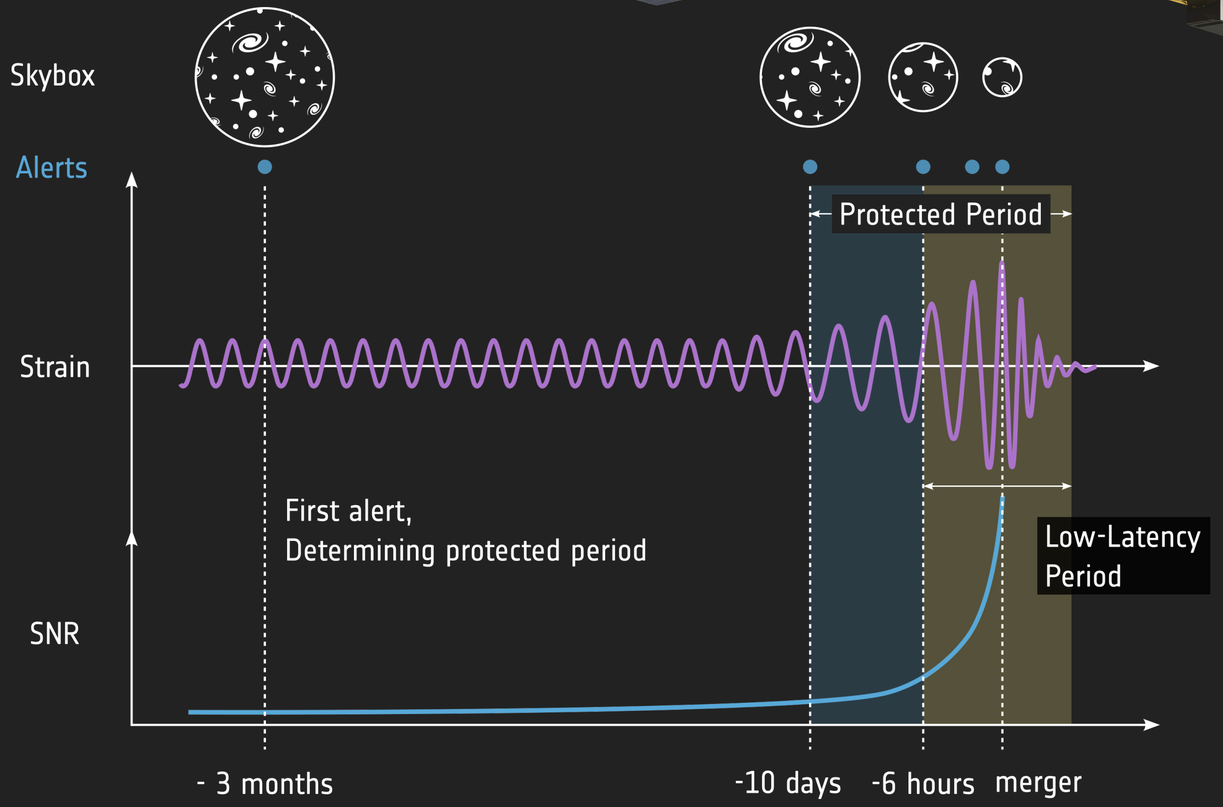


Precursor emission



Afterglow emission





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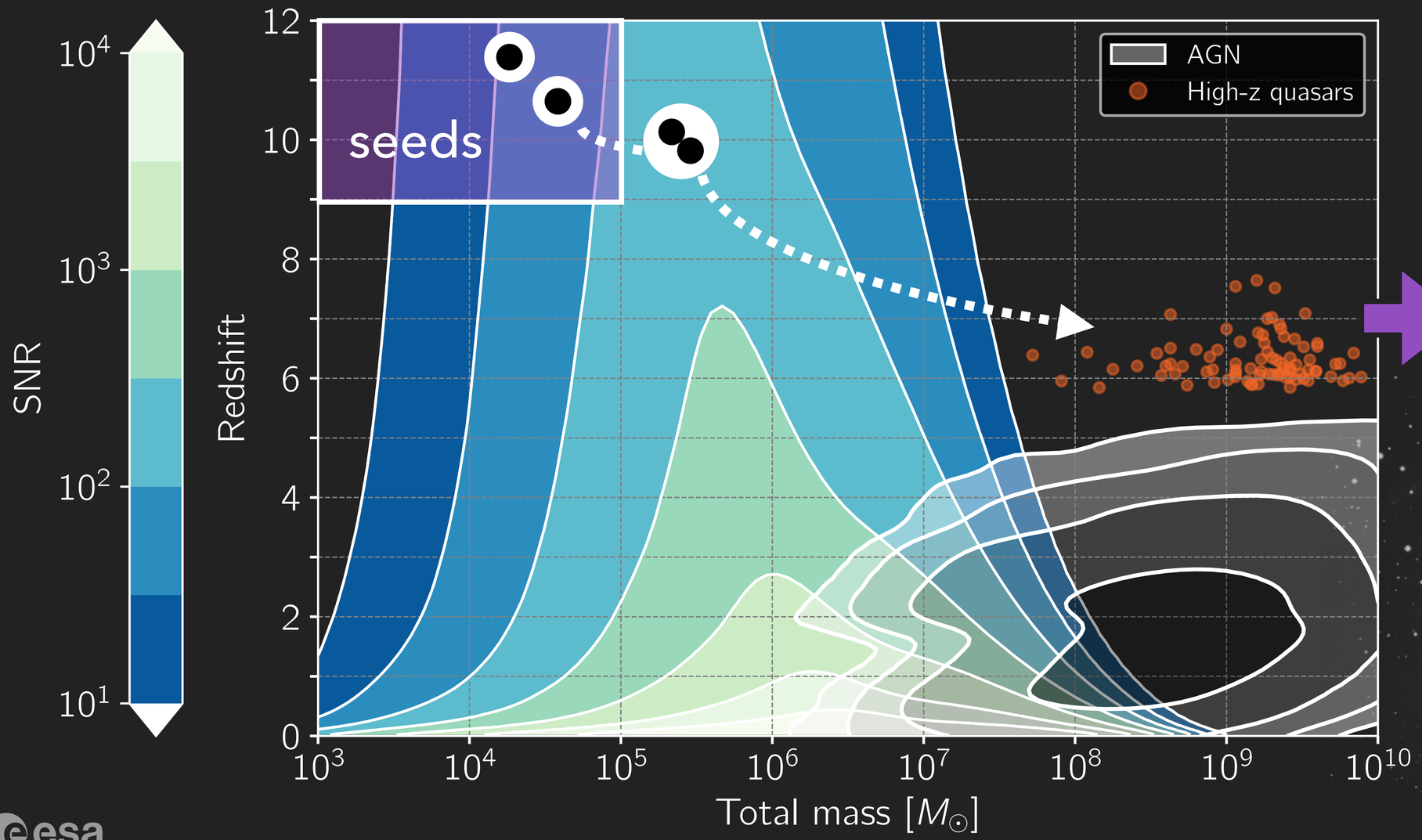
DISCOVER SEED BLACK HOLES AT COSMIC REIONISATION



Not enough time to form from stellar-mass BHs!

"Seed" black holes $(10^2 - 10^5)$ are needed

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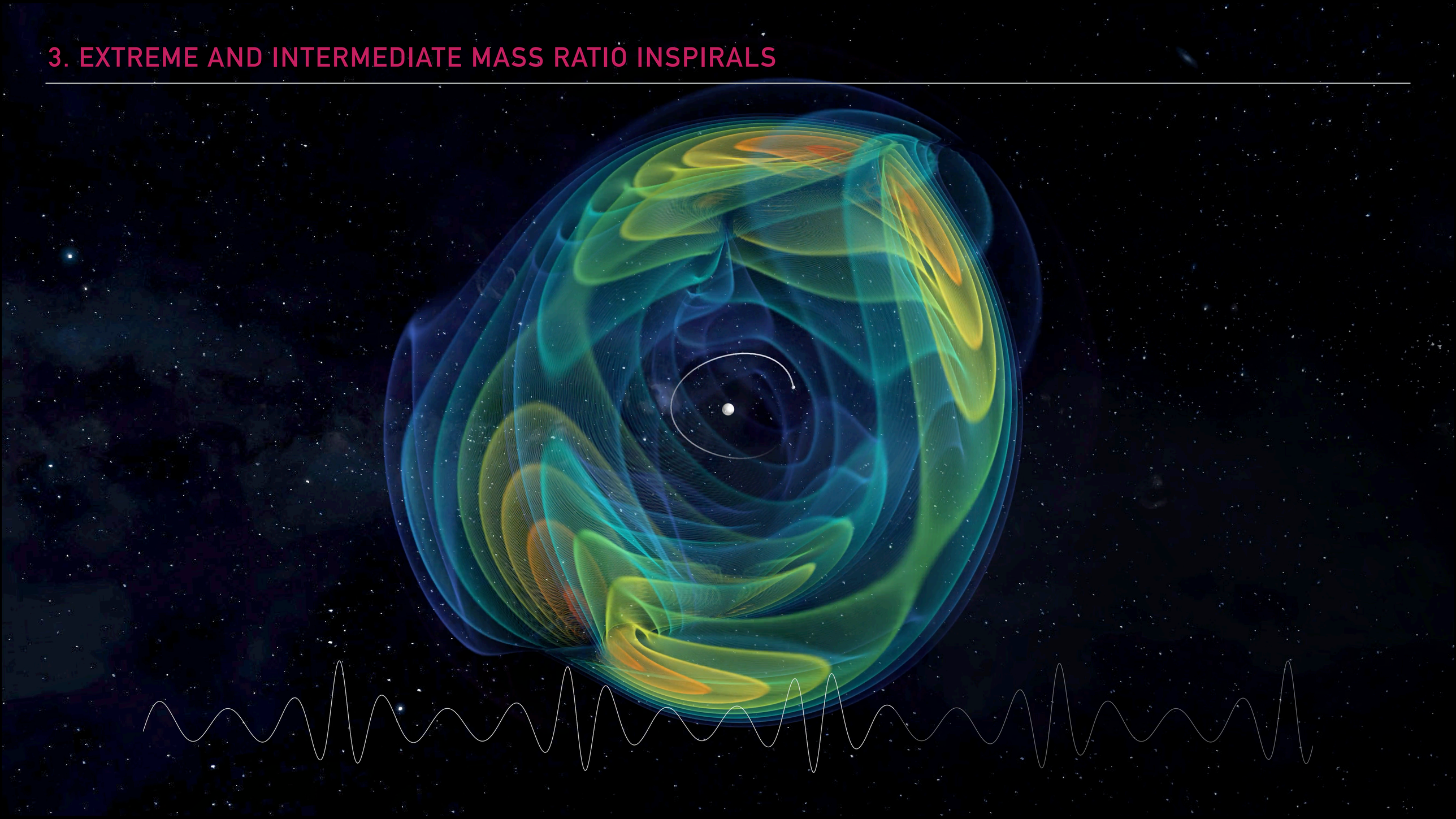
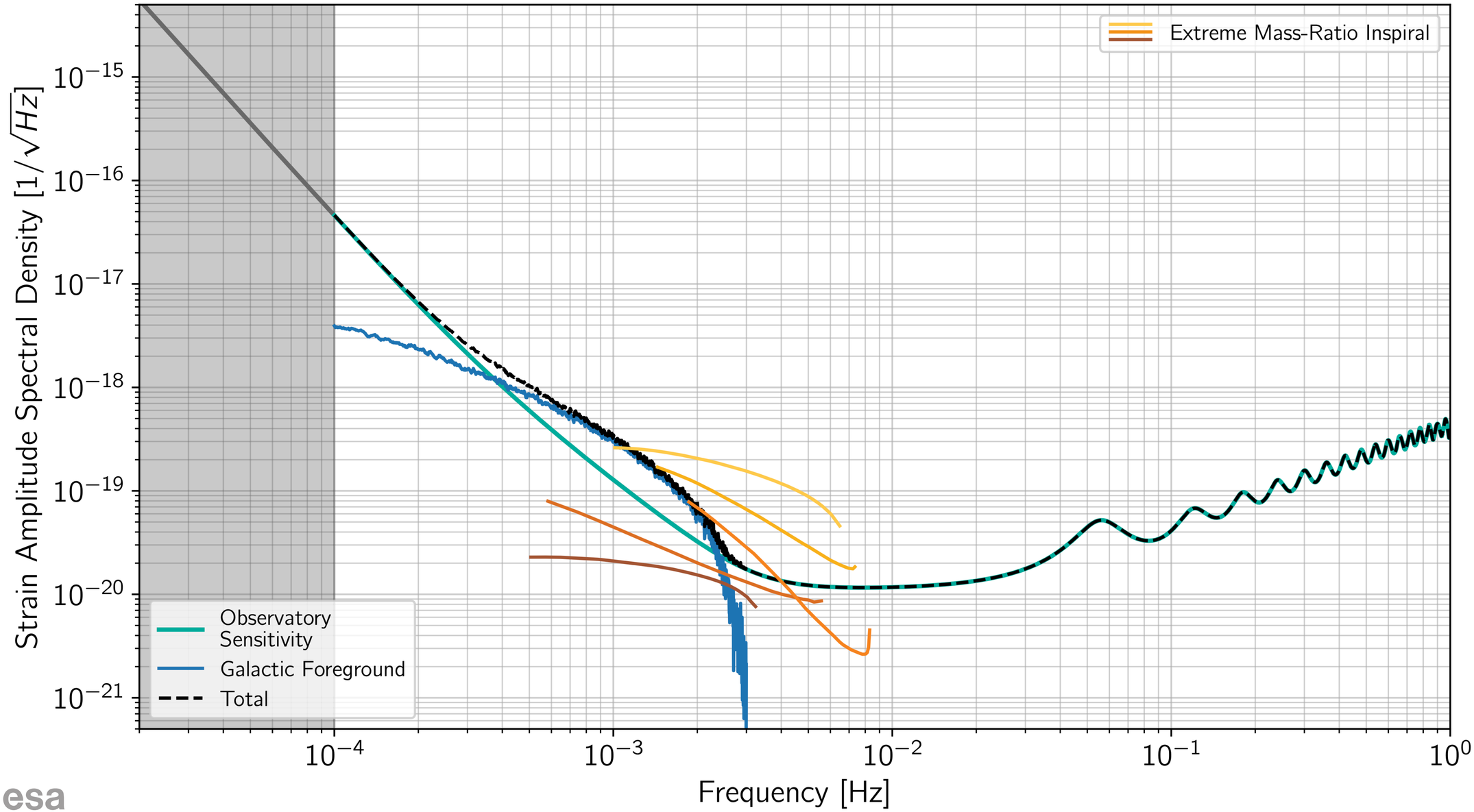
3. EXTREME AND INTERMEDIATE MASS RATIO INSPIRALS



3. EXTREME AND INTERMEDIATE MASS RATIO INSPIRALS



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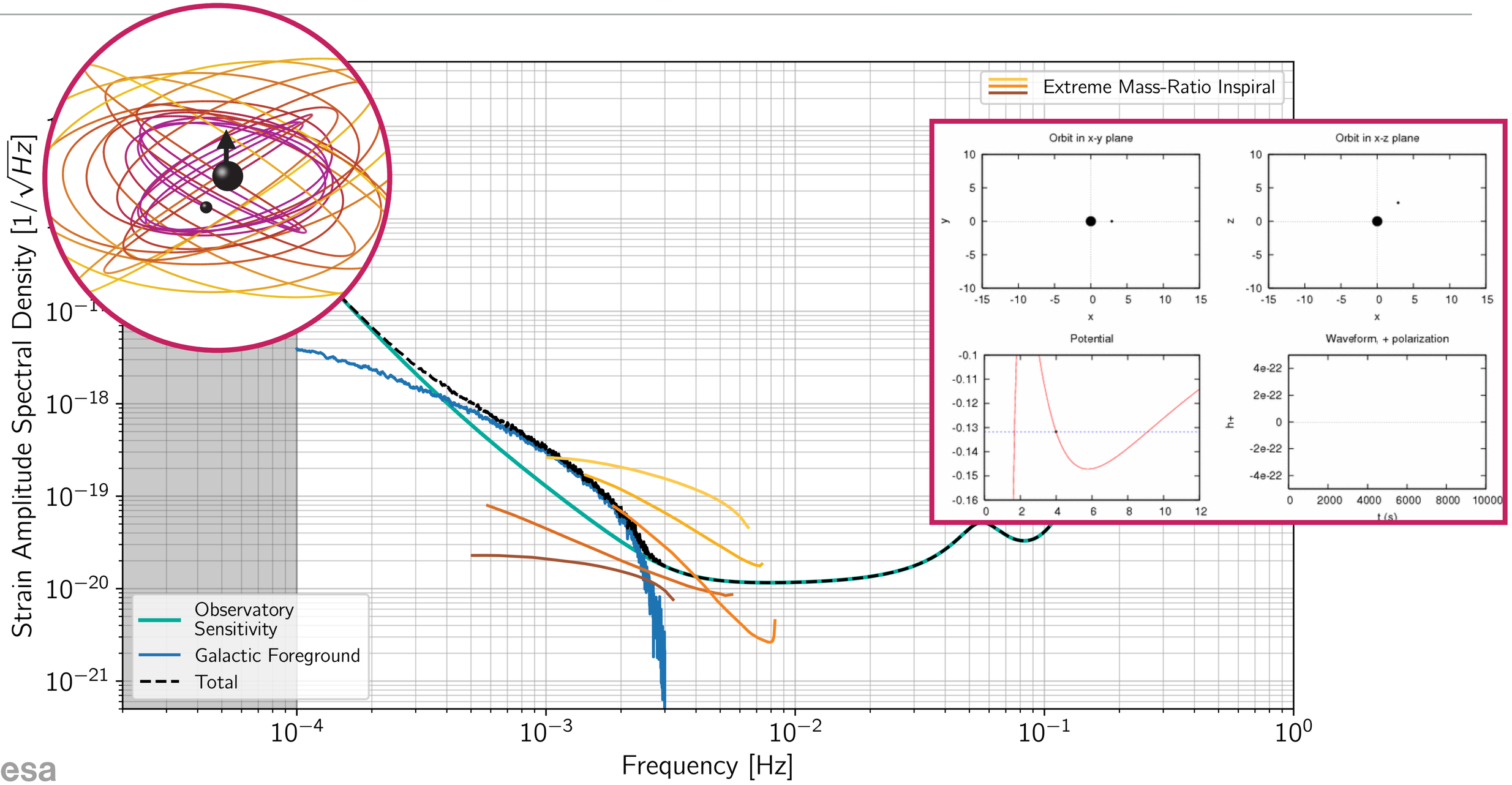
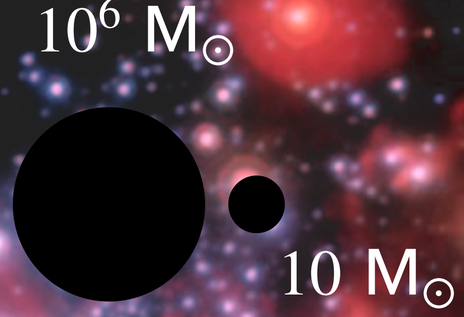
3. EXTREME AND INTERMEDIATE MASS RATIO INSPIRALS

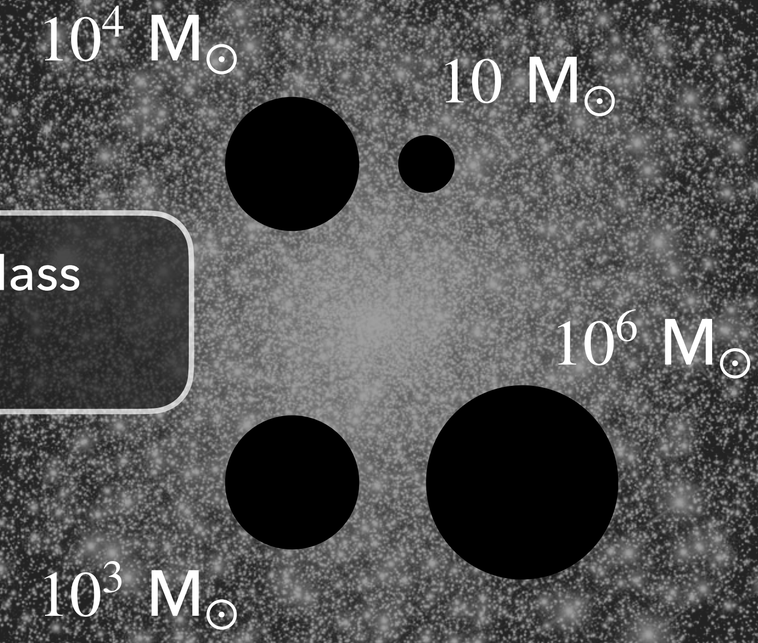


FINDING THE HIDDEN BLACK HOLES

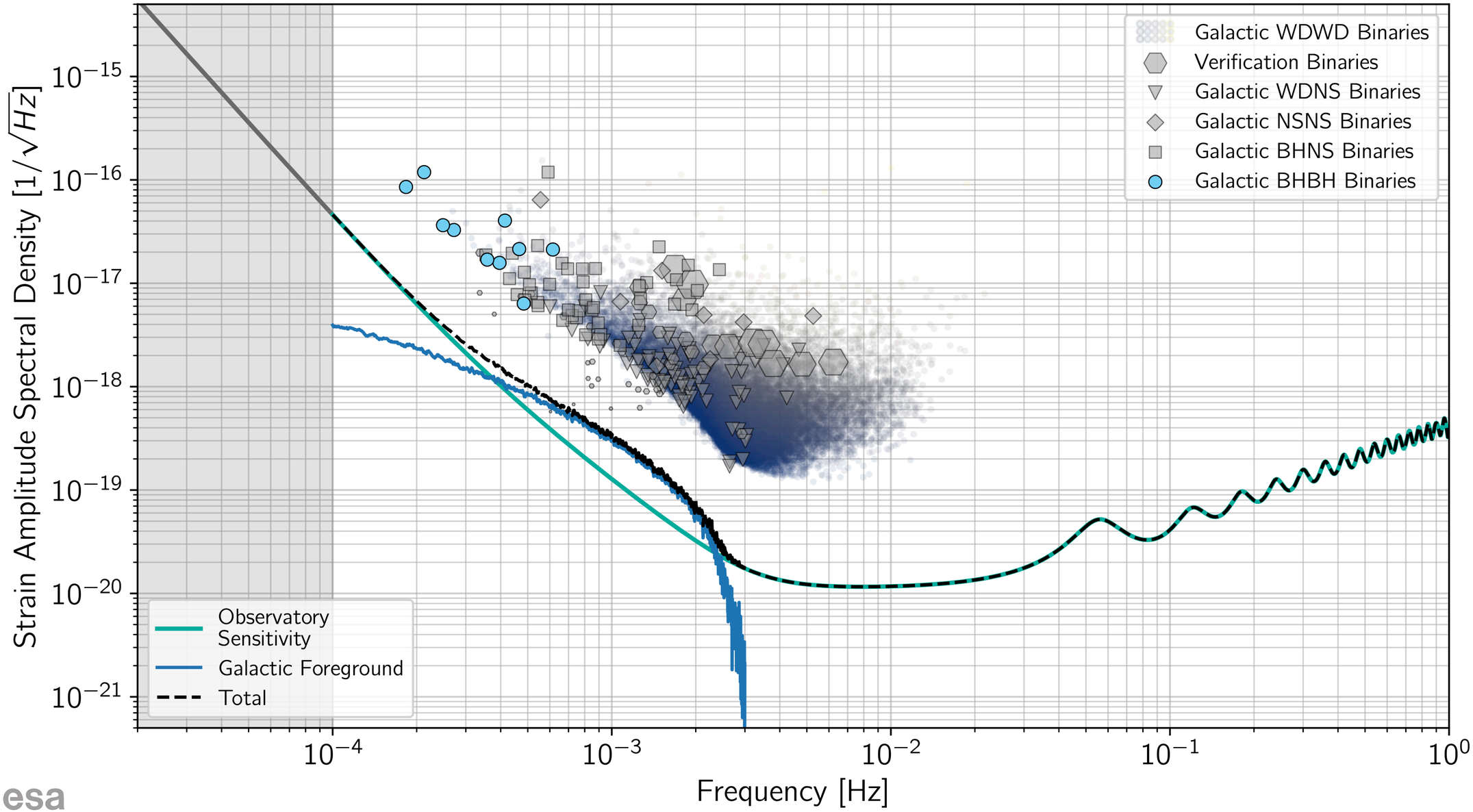
- Quiesent Massive Black Holes



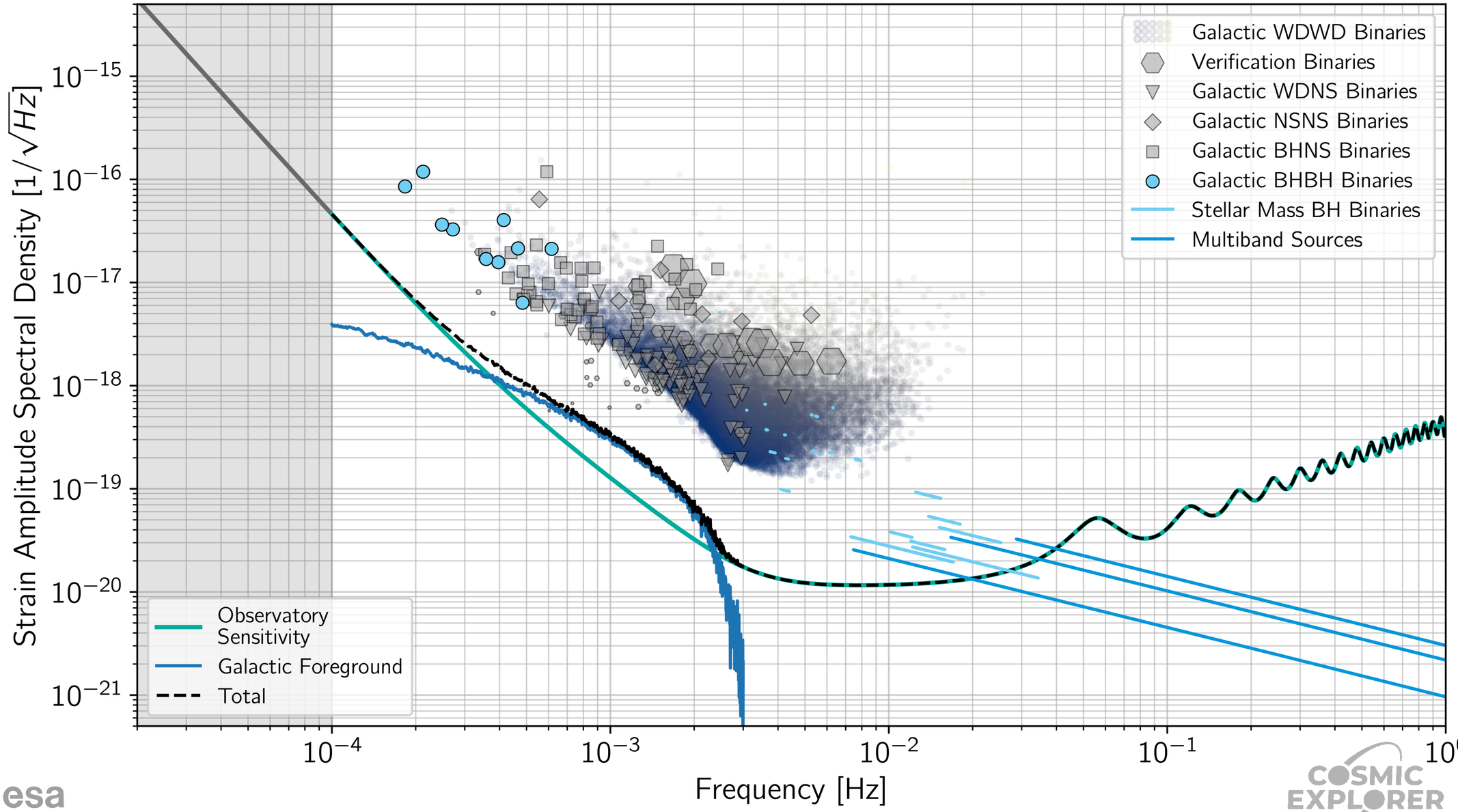
- Intermediate Mass Black Holes



4. STELLAR MASS BLACK HOLES



4. STELLAR MASS BLACK HOLES



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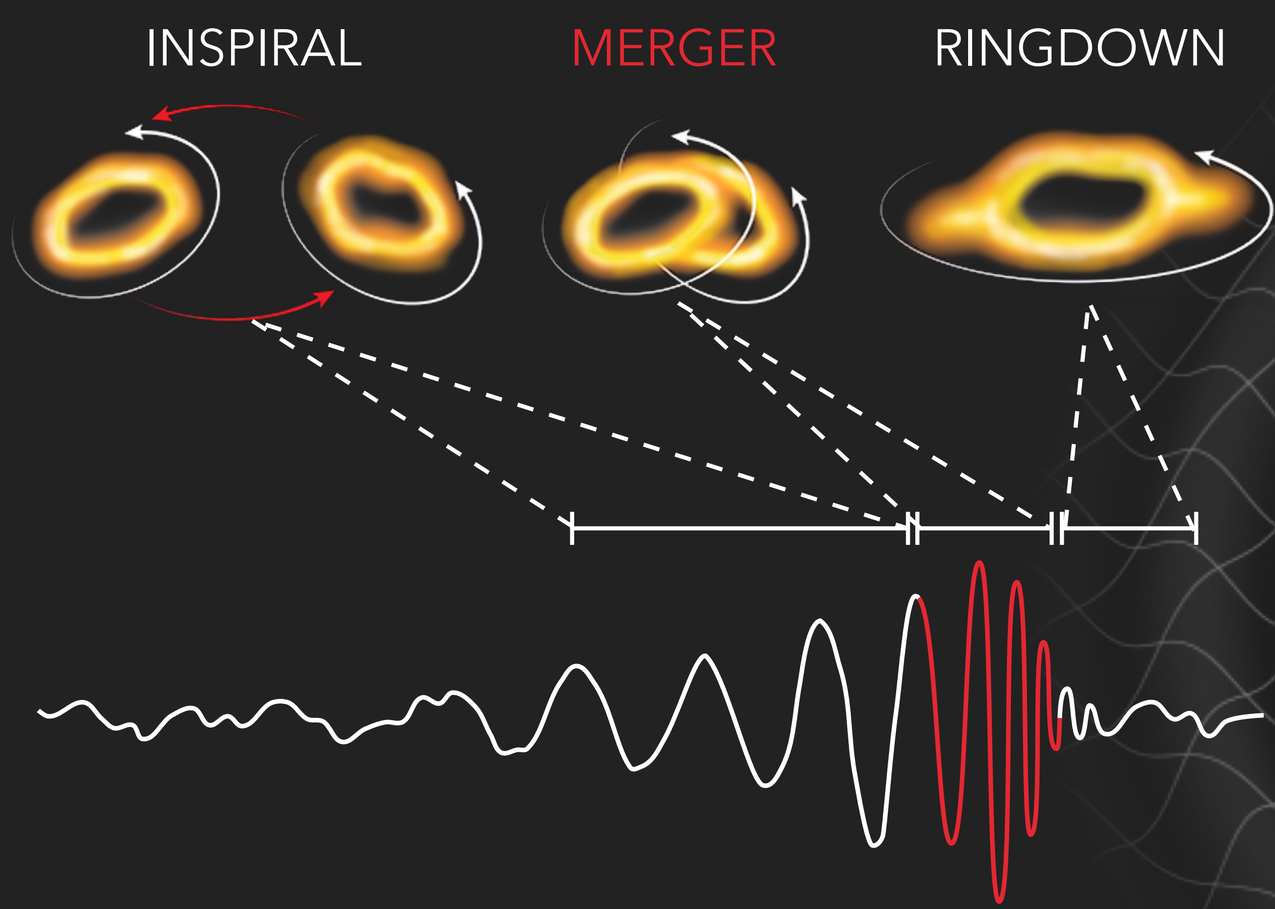
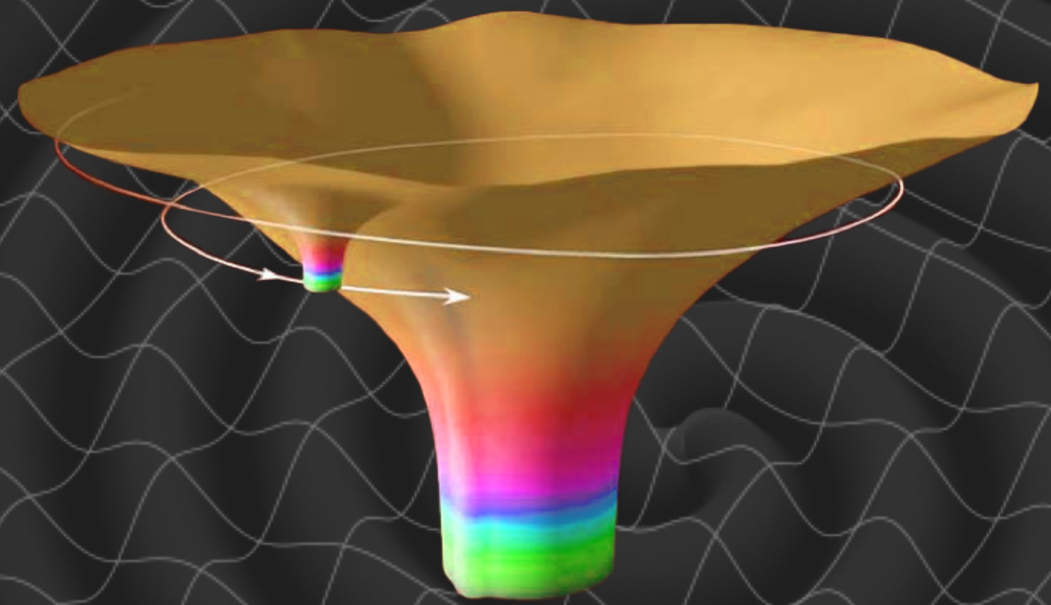
Einstein Telescope

COSMIC EXPLORER

LIGO VIRGO KAGRA

TEST KERR-NESS, NO HAIR THEOREM, GENERAL RELATIVITY





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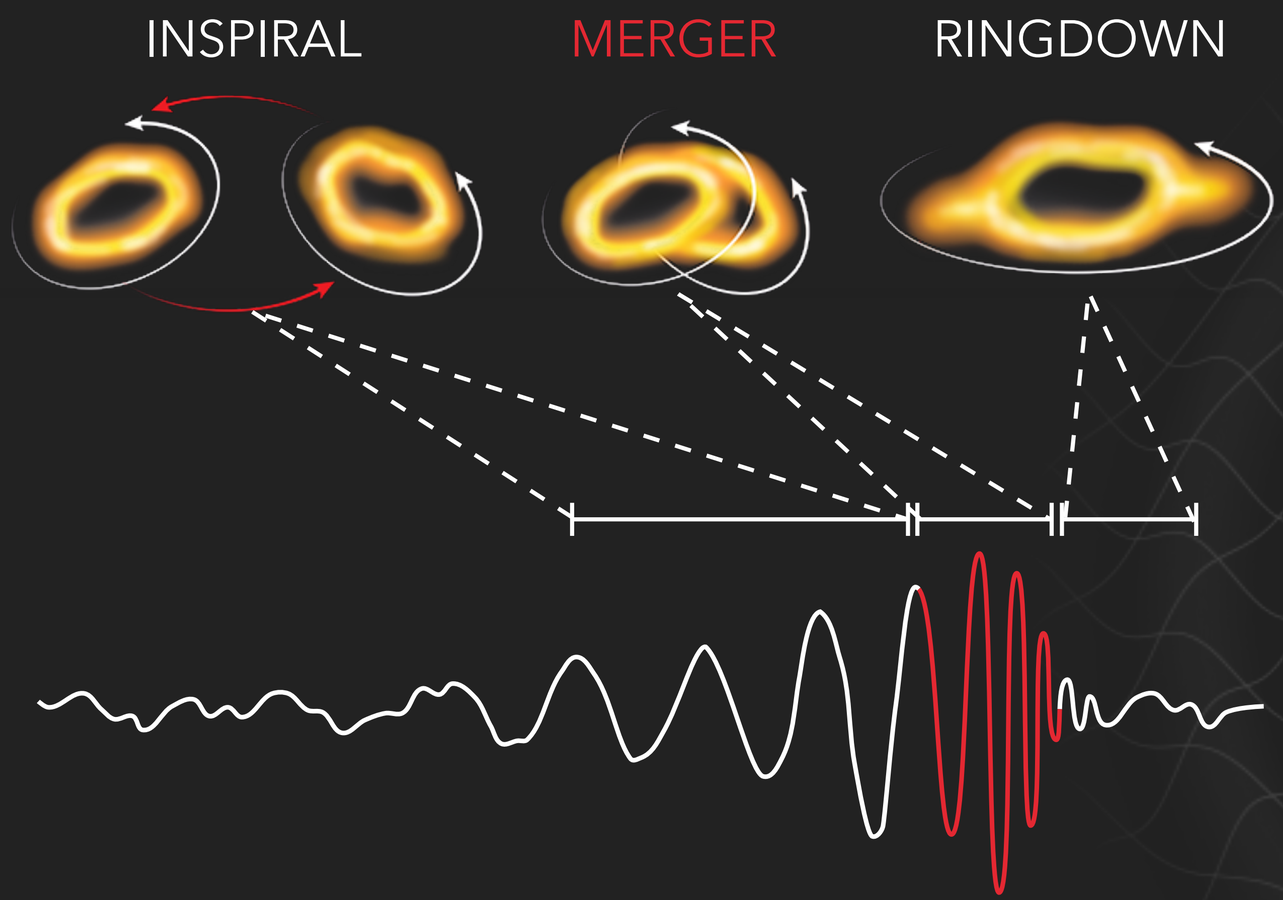
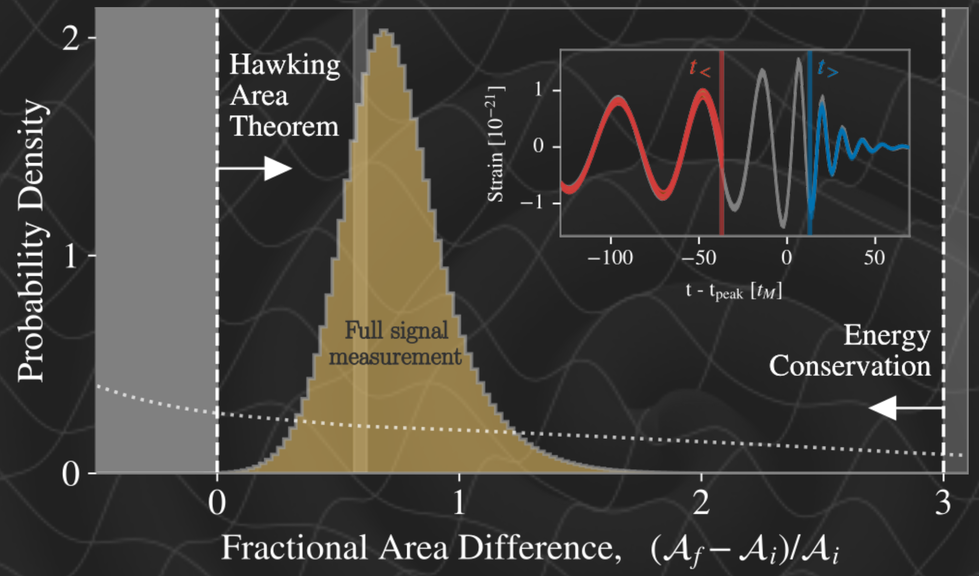
TEST KERR-NESS, NO HAIR THEOREM, GENERAL RELATIVITY

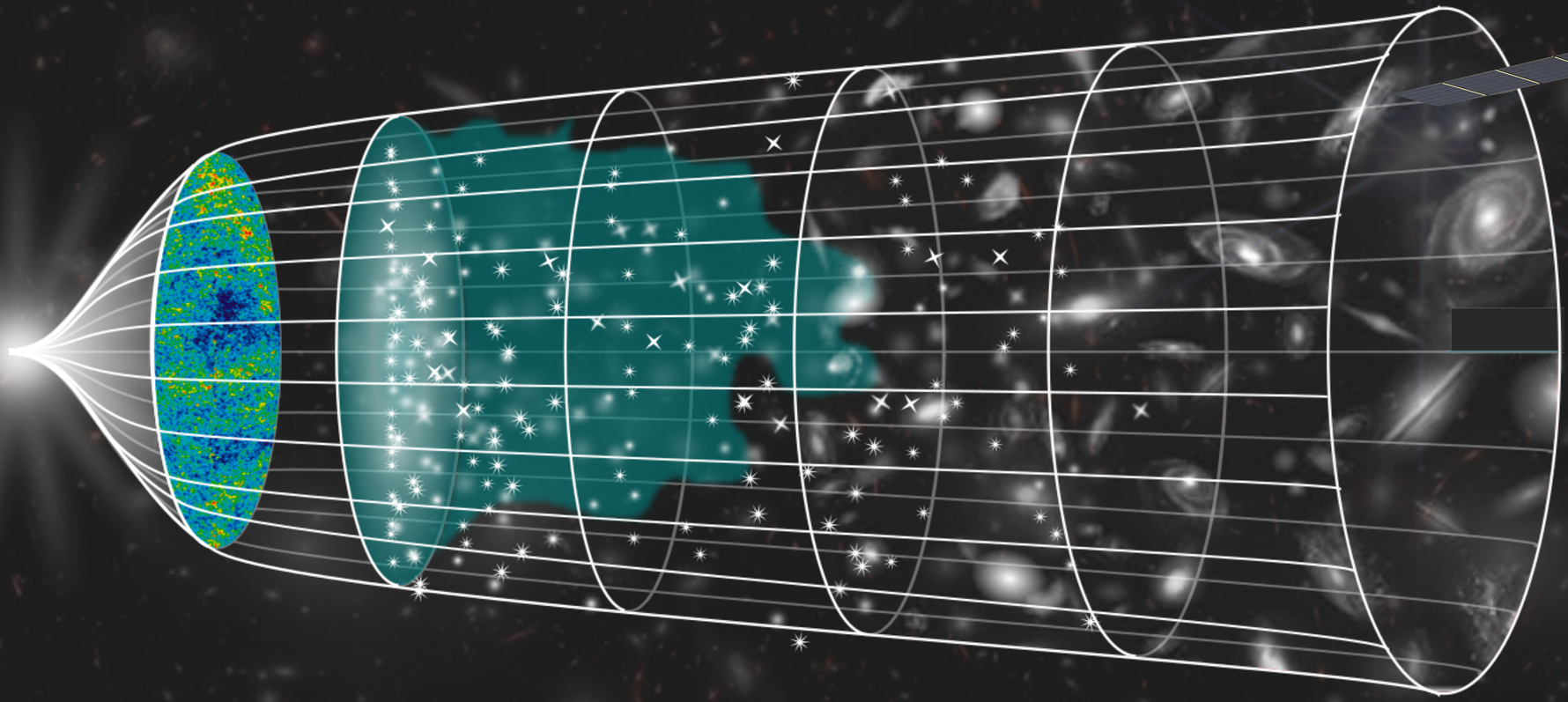


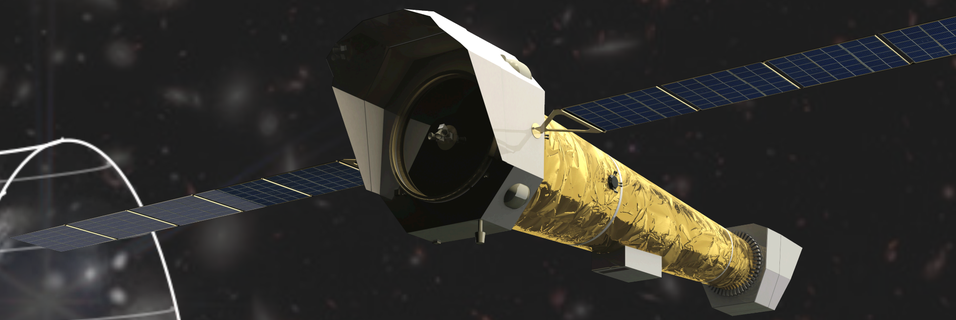
Abac et al. GW250114: Testing Hawking's Area Law and the Kerr Nature of Black Holes, PRL 135, 111403 (2025)



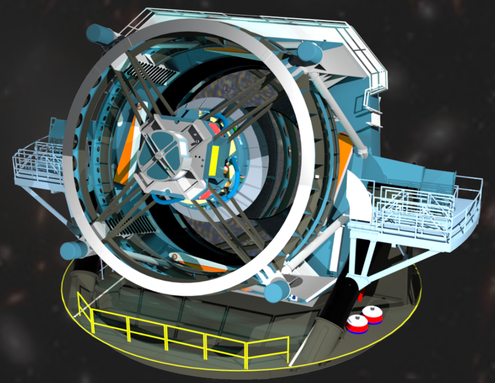
esa

COSMOLOGY WITH DARK AND BRIGHT SIRENS



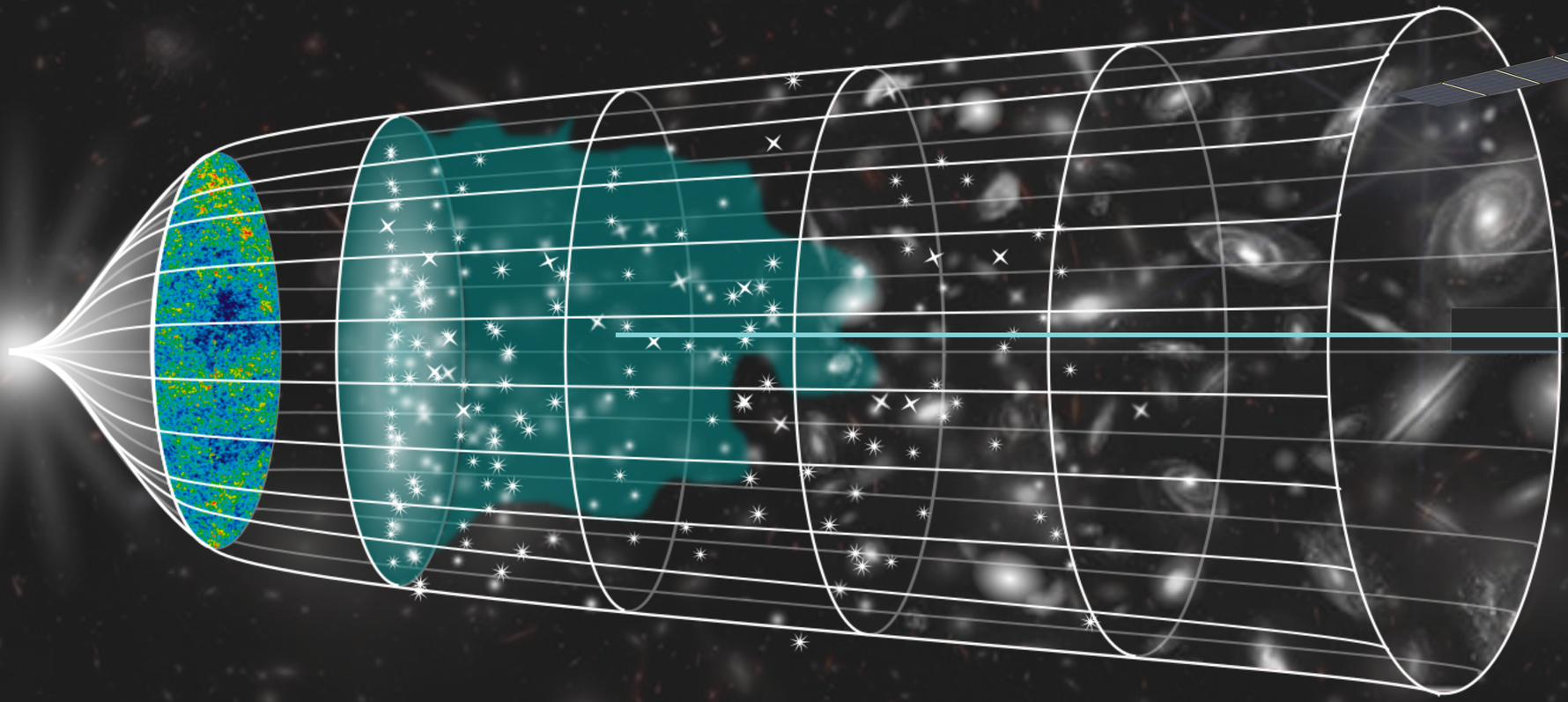




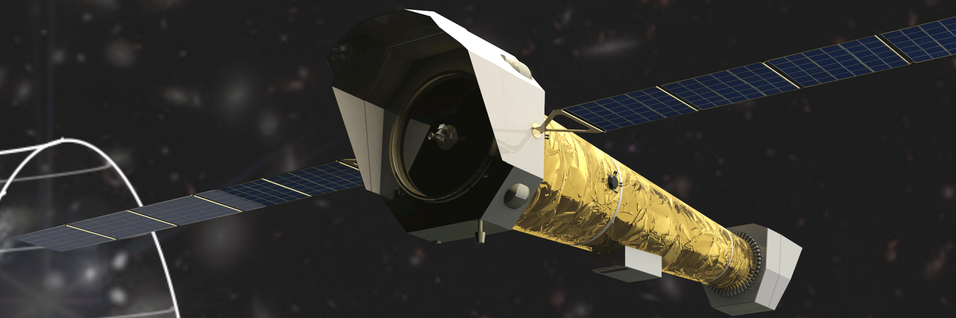


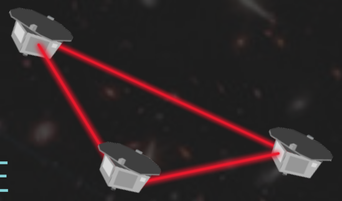
Electromagnetic Follow-ups

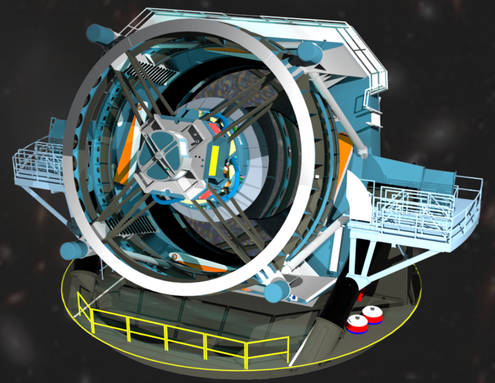
COSMOLOGY WITH DARK AND BRIGHT SIRENS



DISTANCE







Electromagnetic Follow-ups

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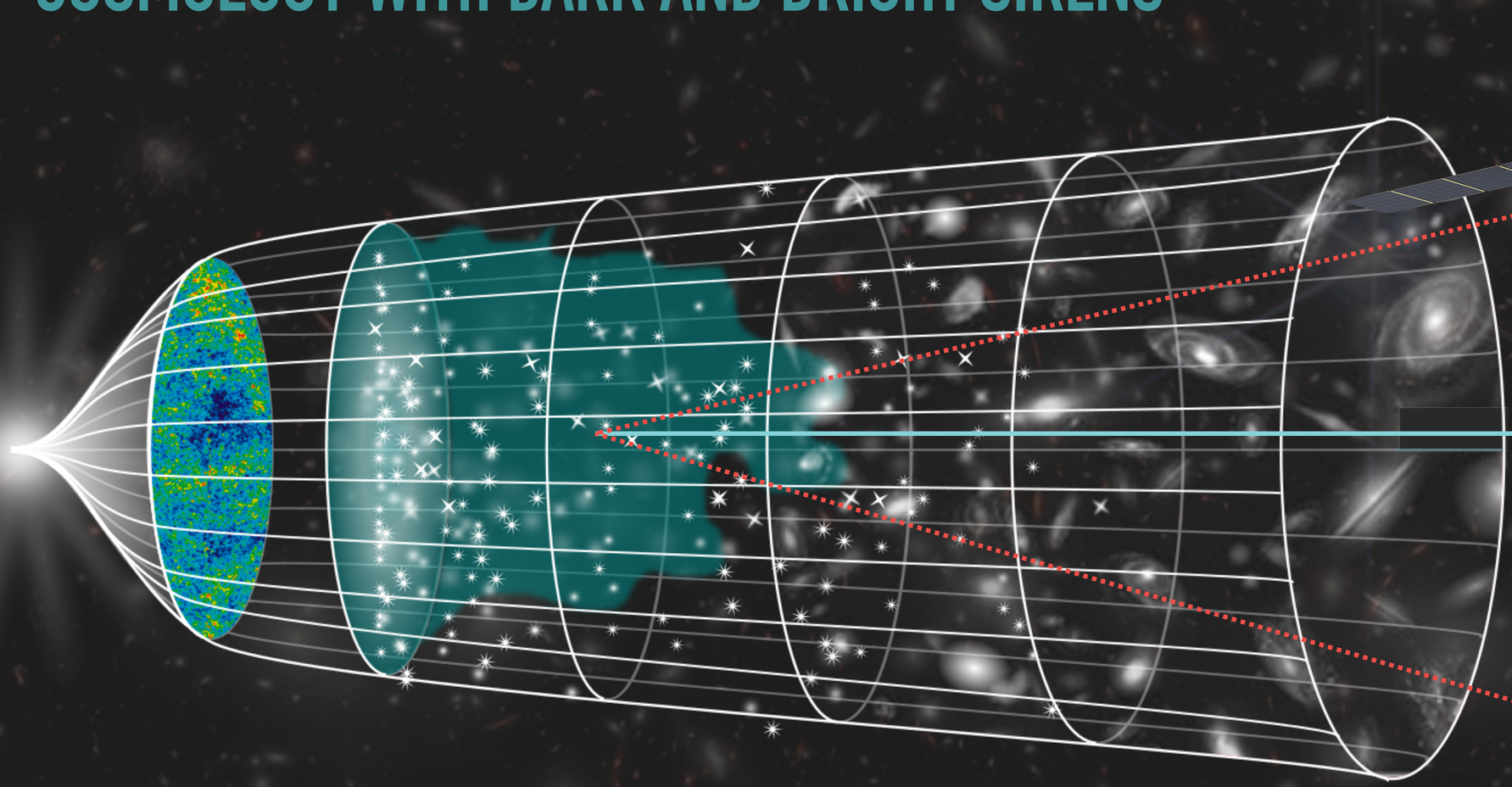
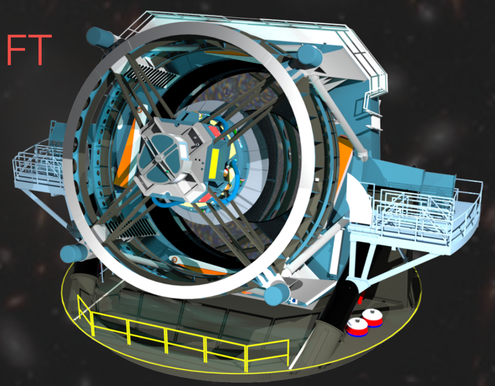


REDSHIFT

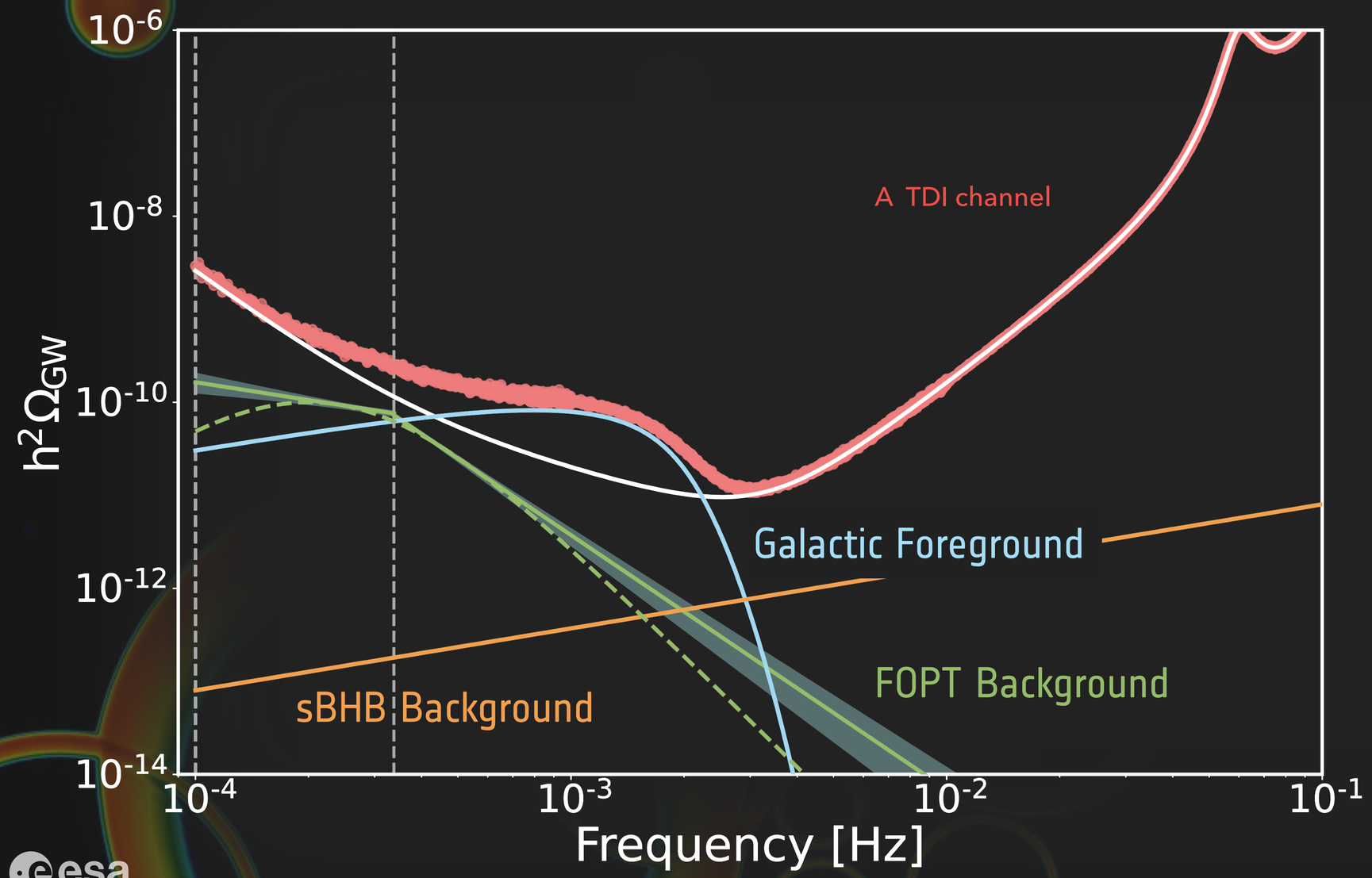
DISTANCE

REDSHIFT



Electromagnetic Follow-ups

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



esa

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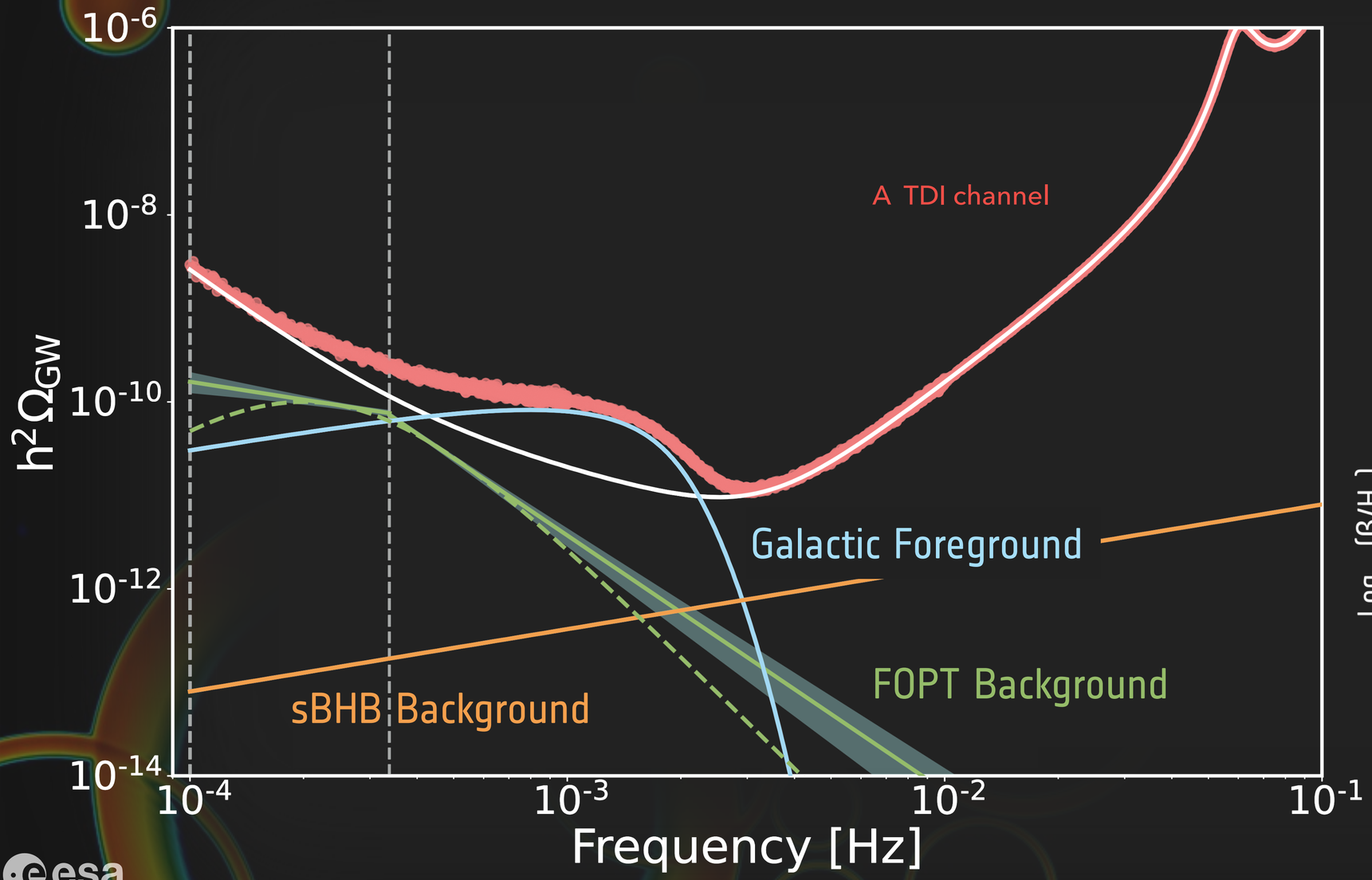
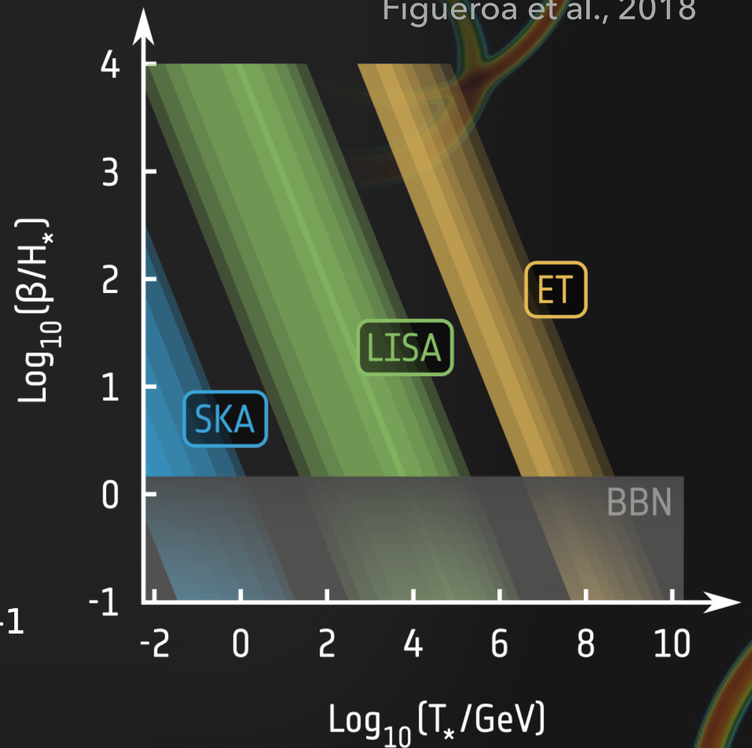


PROCEEDINGS OF SCIENCE

LISA as a probe for particle physics: electroweak scale tests in synergy with ground-based experiments

D. G. Figueroa[1], E. Megías[2,3], G. Nardini[*4,5], M. Pieroni[6], M. Quiros[7], A. Ricciardone[8], G. Tasinato[9]

Figueroa et al., 2018



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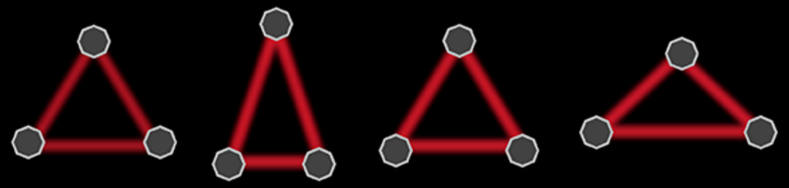
LISA
MISSION

LISA - LASER INTERFEROMETER SPACE ANTENNA

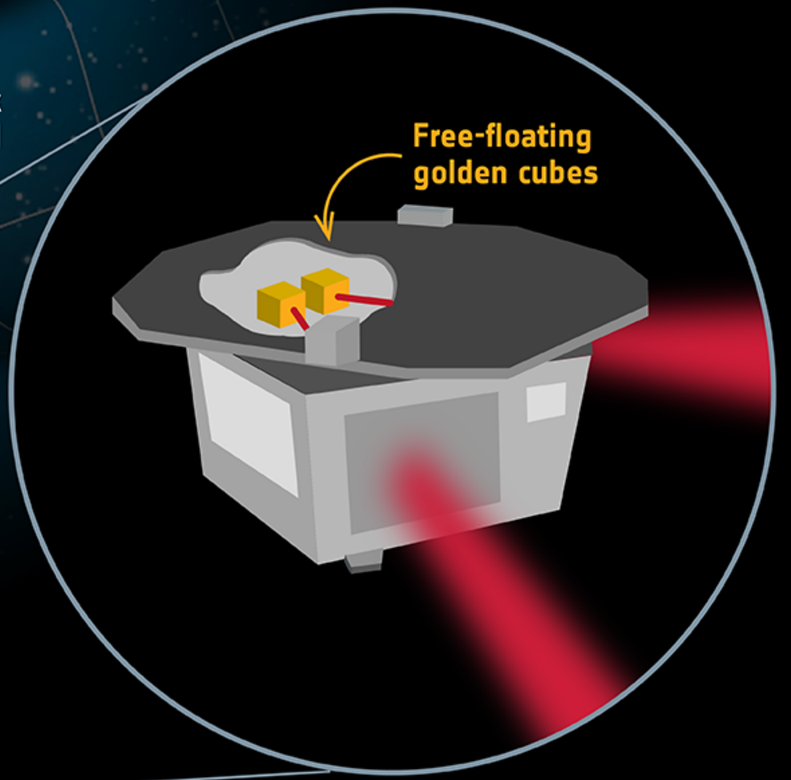
Gravitational waves are ripples in spacetime that alter the distances between objects. LISA will detect them by measuring subtle changes in the distances between **free-floating cubes** nestled within its three spacecraft.

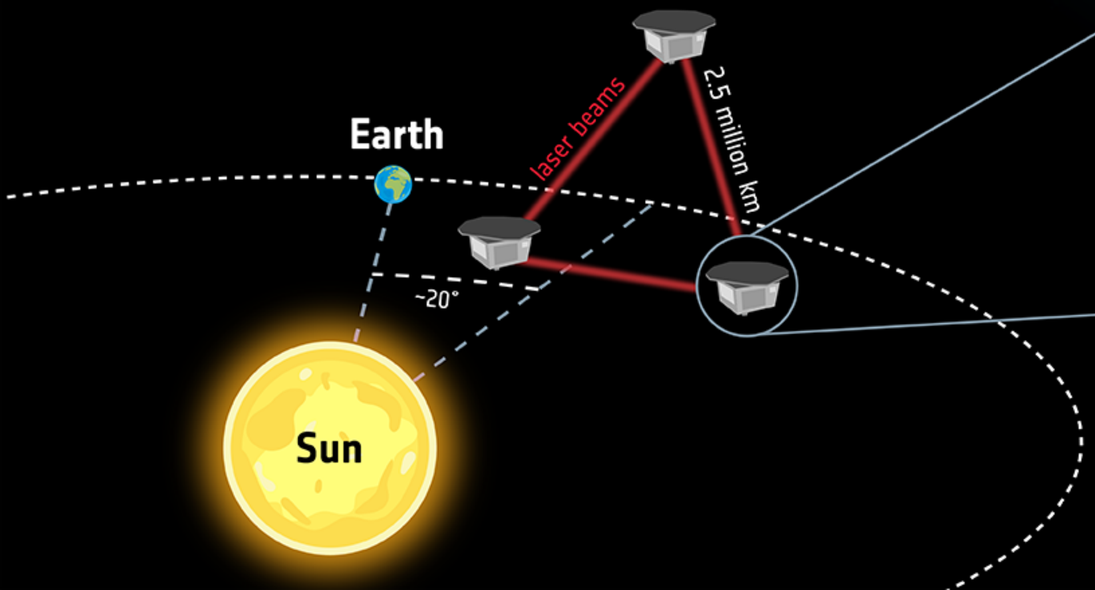
3 identical spacecraft exchange **laser beams**. Gravitational waves change the distance between the **free-floating cubes** in the different spacecraft. This tiny change will be measured by the laser beams.



* *Changes in distances travelled by the laser beams are not to scale and extremely exaggerated*

Powerful events such as **colliding black holes** shake the fabric of spacetime and cause gravitational waves





ESA | NASA
lisa

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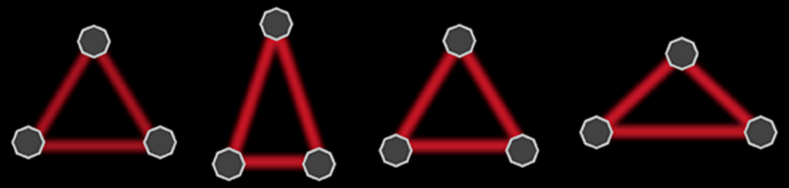

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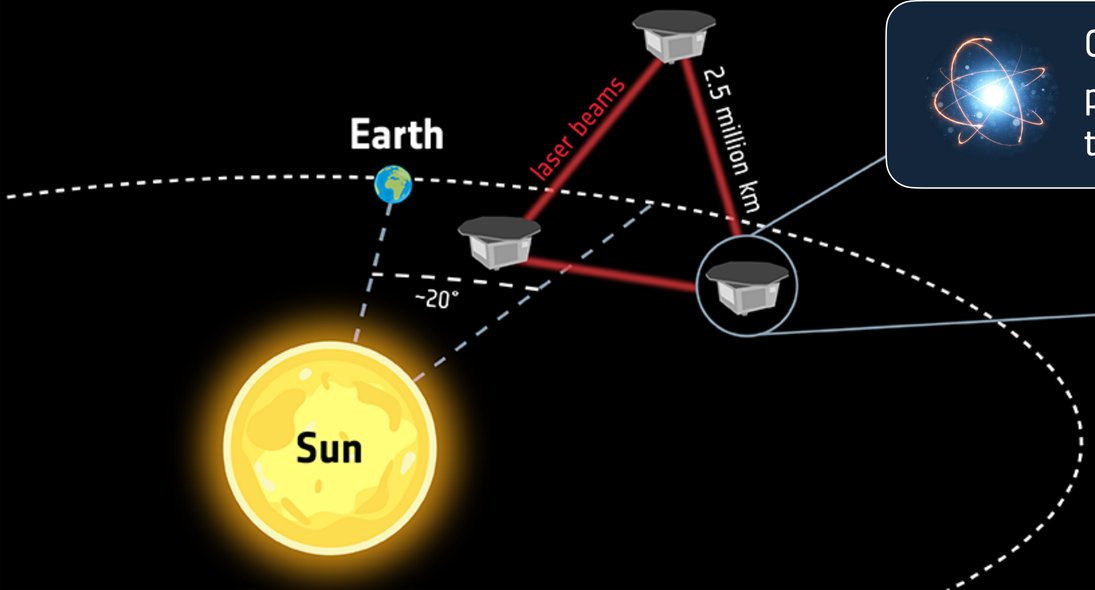

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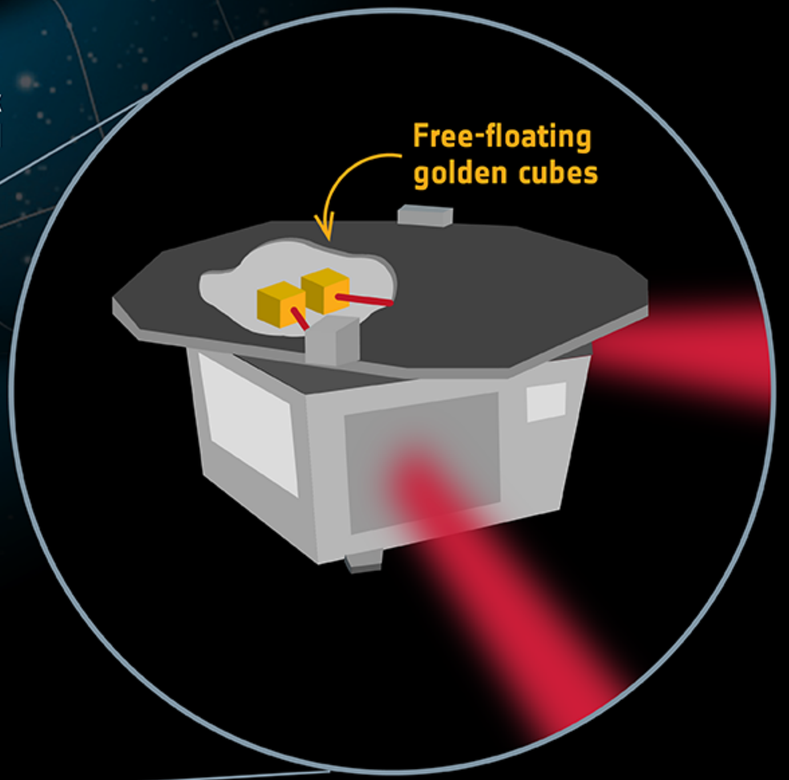
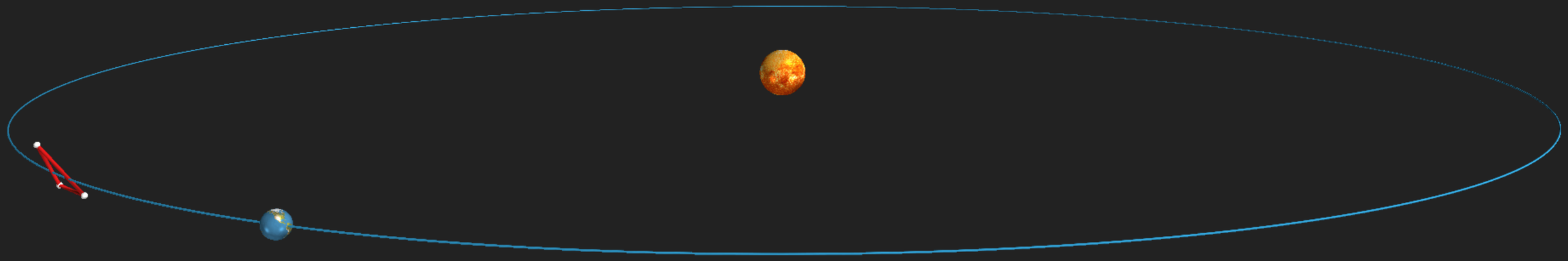


Changes in distance of the order of picometres (10^{-12}) — about the size of the **core of an atom**!

ESA | NASA
lisa

LISA MISSION CONCEPT



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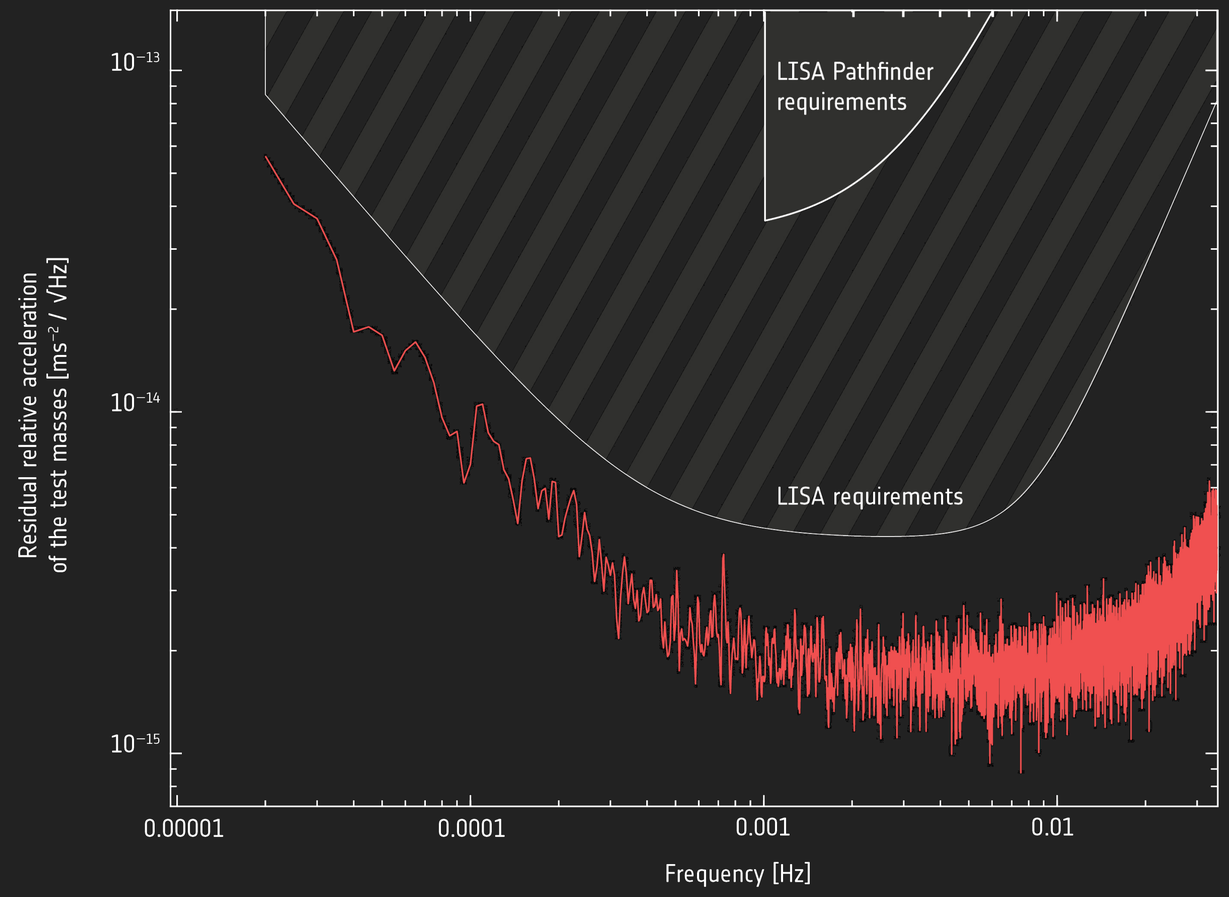
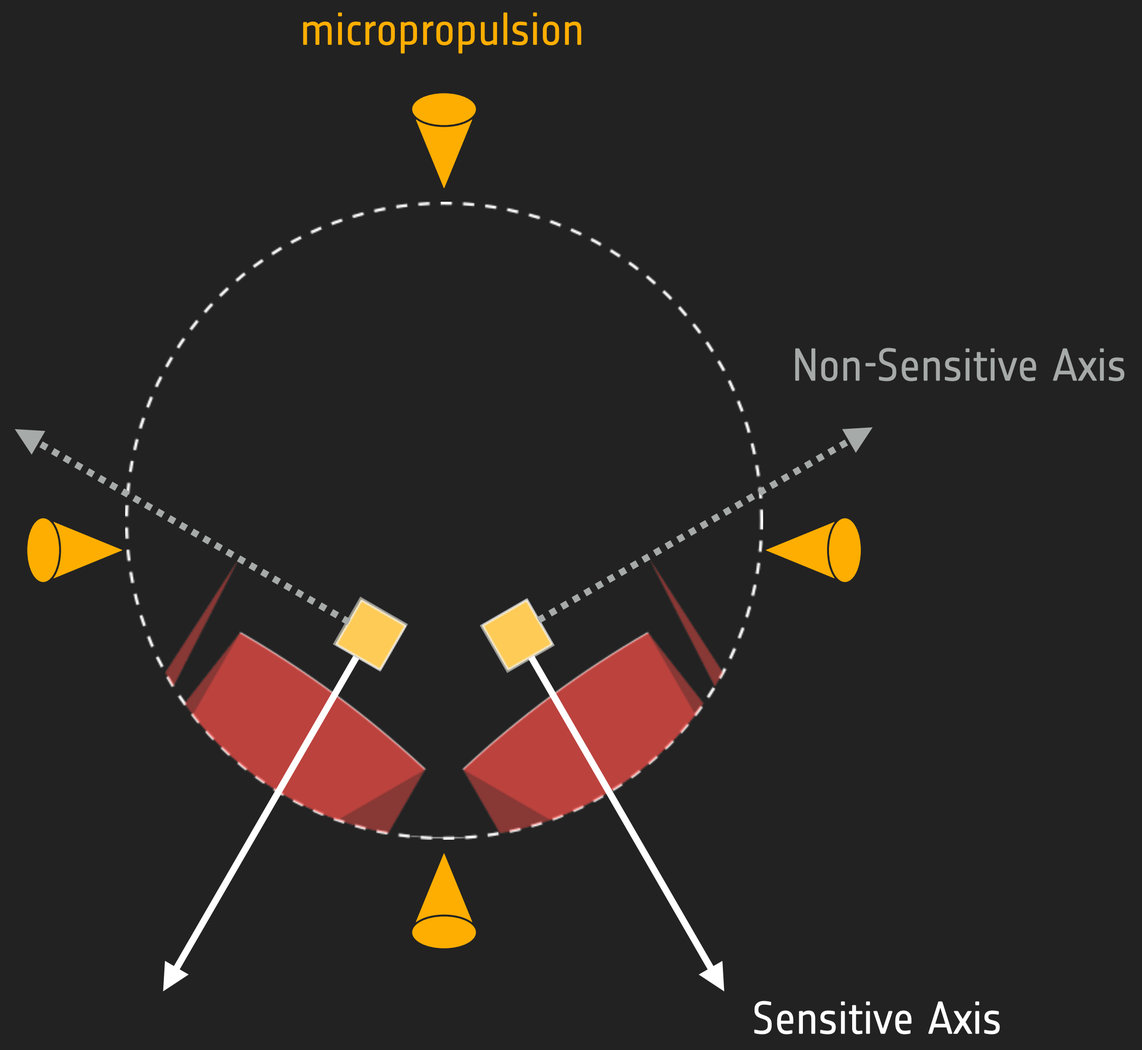
FREE-FALLING TEST MASSES

Drag-Free Attitude Control System (DFACS)





FREE-FALLING TEST MASSES

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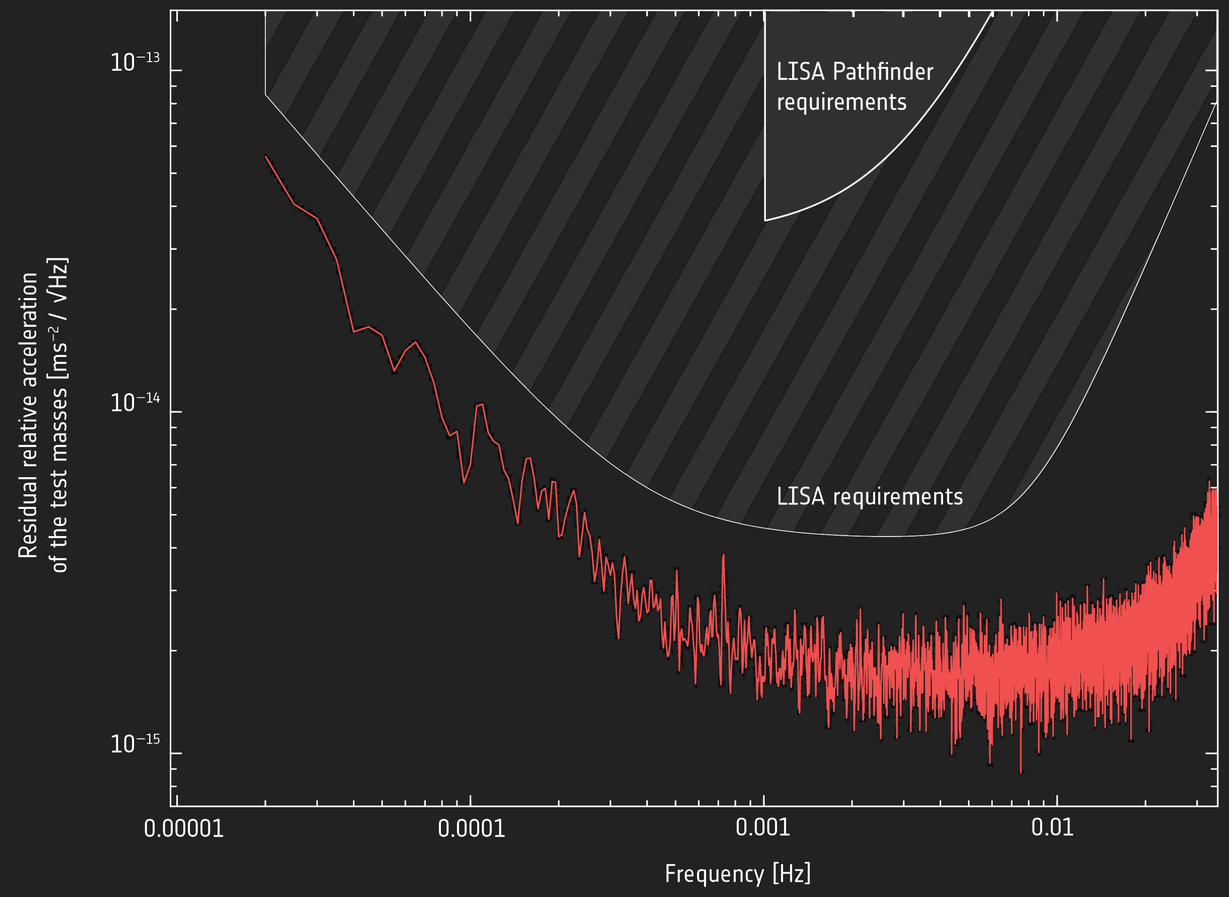

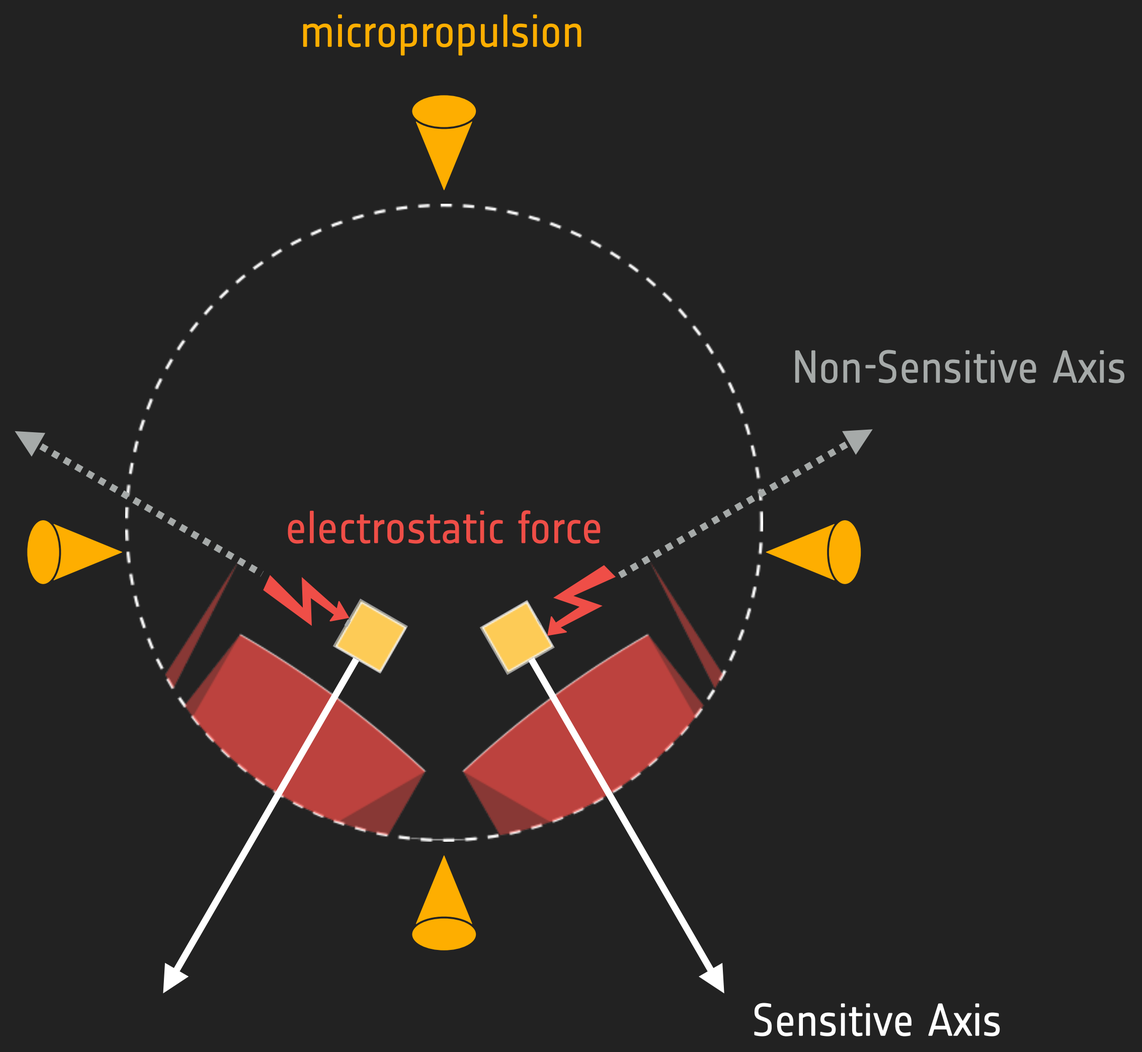

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FREE-FALLING TEST MASSES

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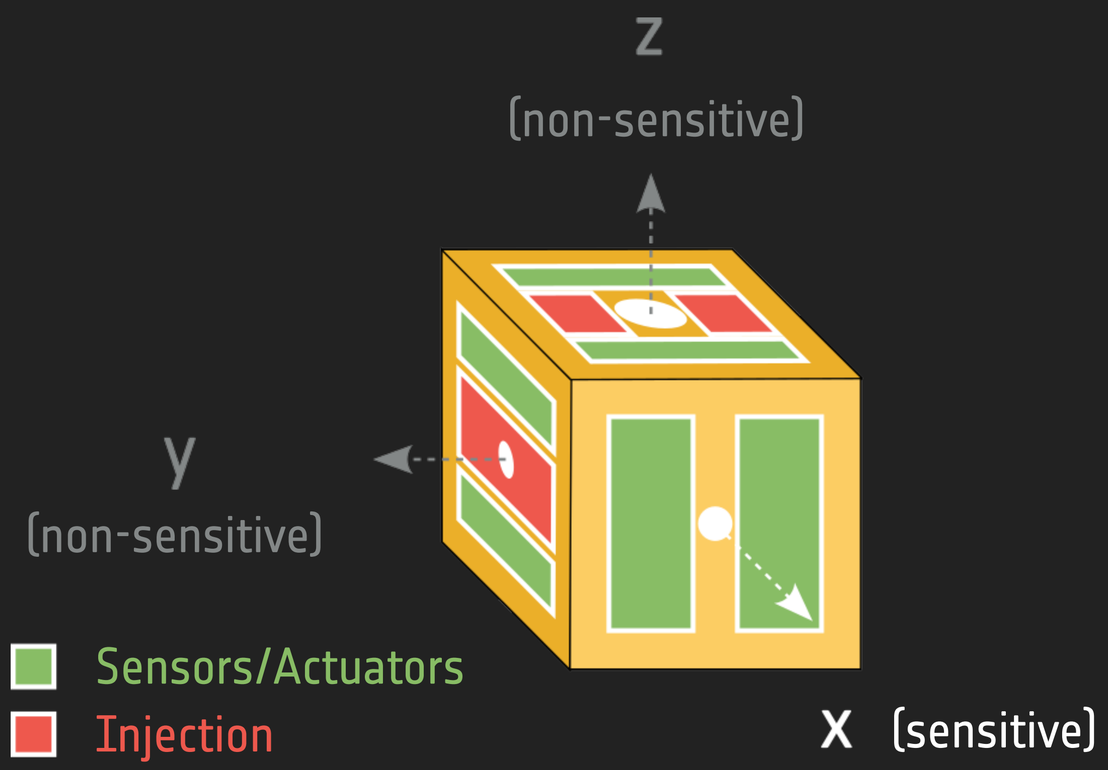
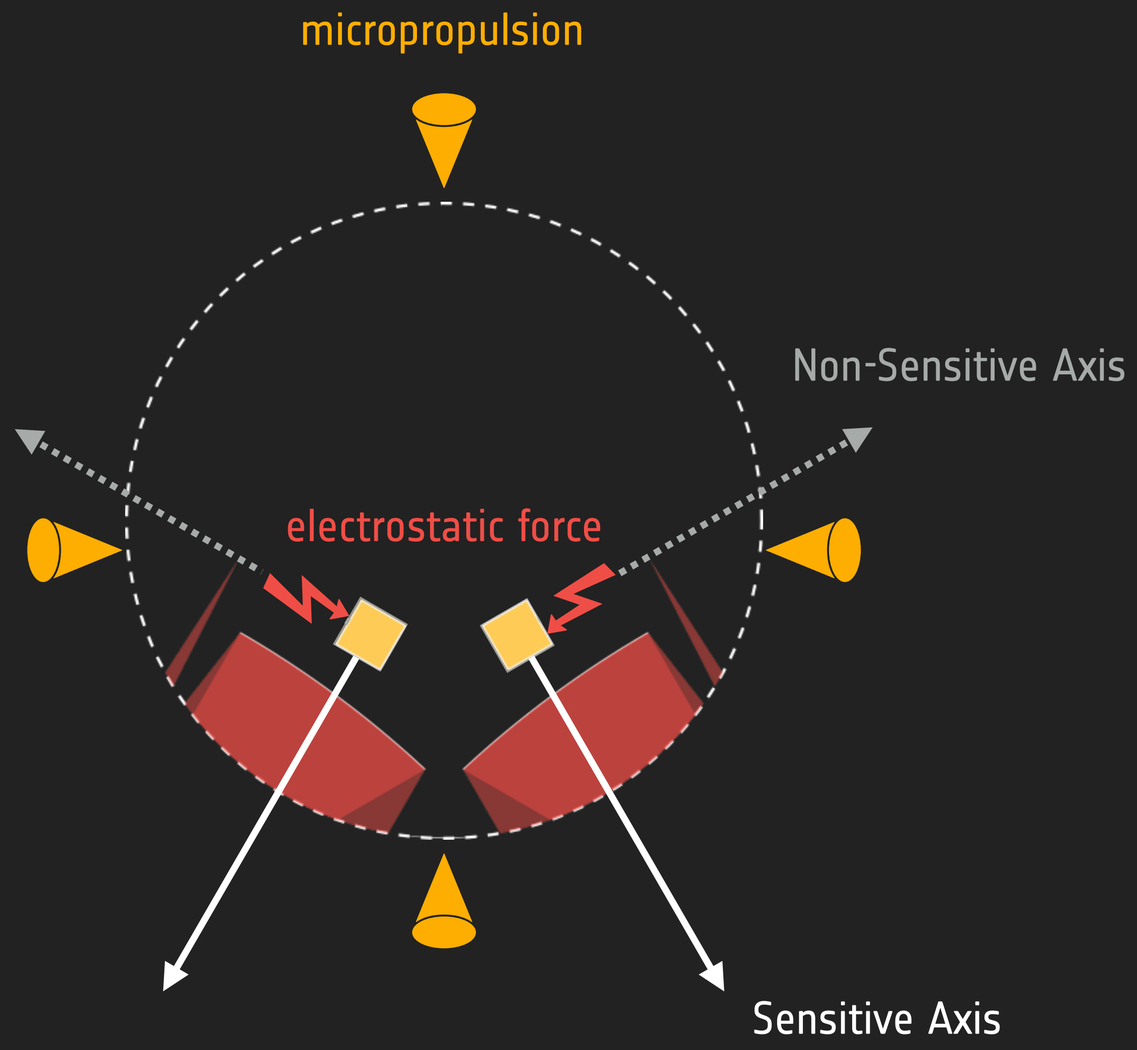
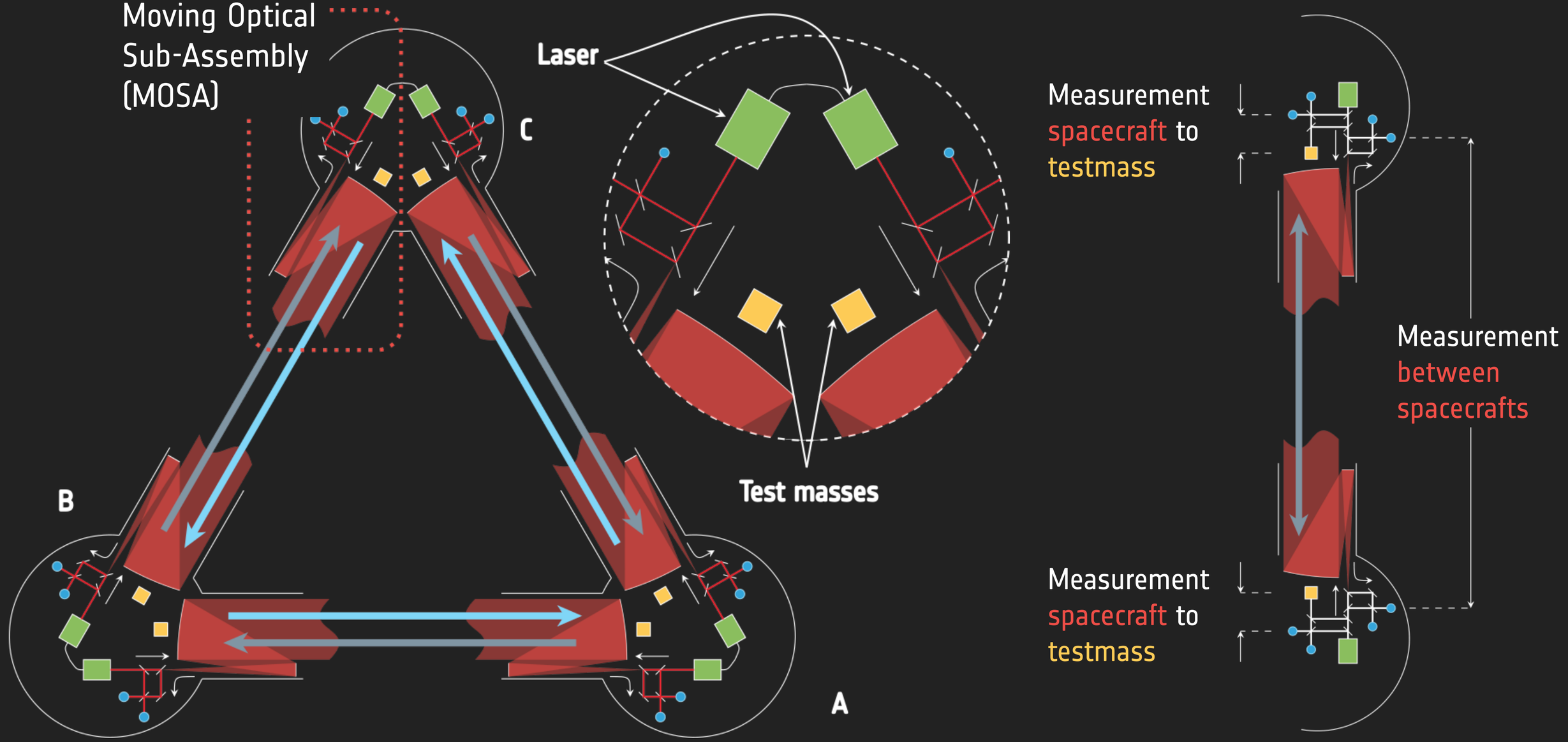


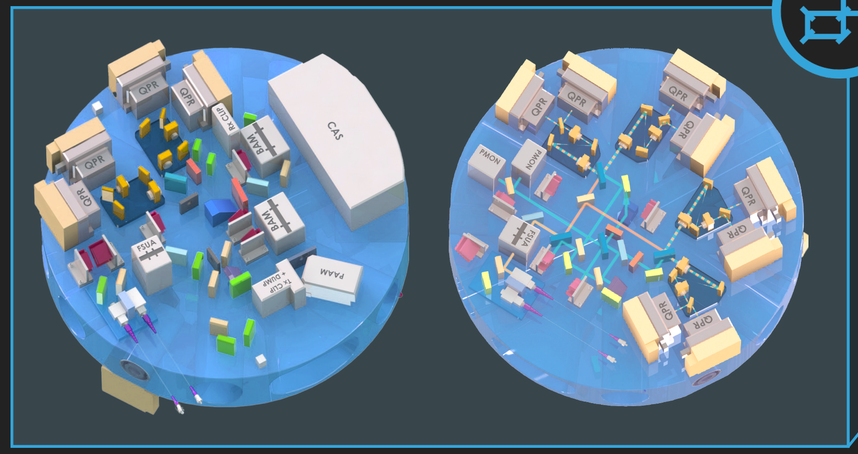





Moving Optical
Sub-Assembly
(MOSA)
Laser
C
B
A
Test masses
Measurement
spacecraft to
testmass
Measurement
between
spacecrafts
Measurement
spacecraft to
testmass

esa

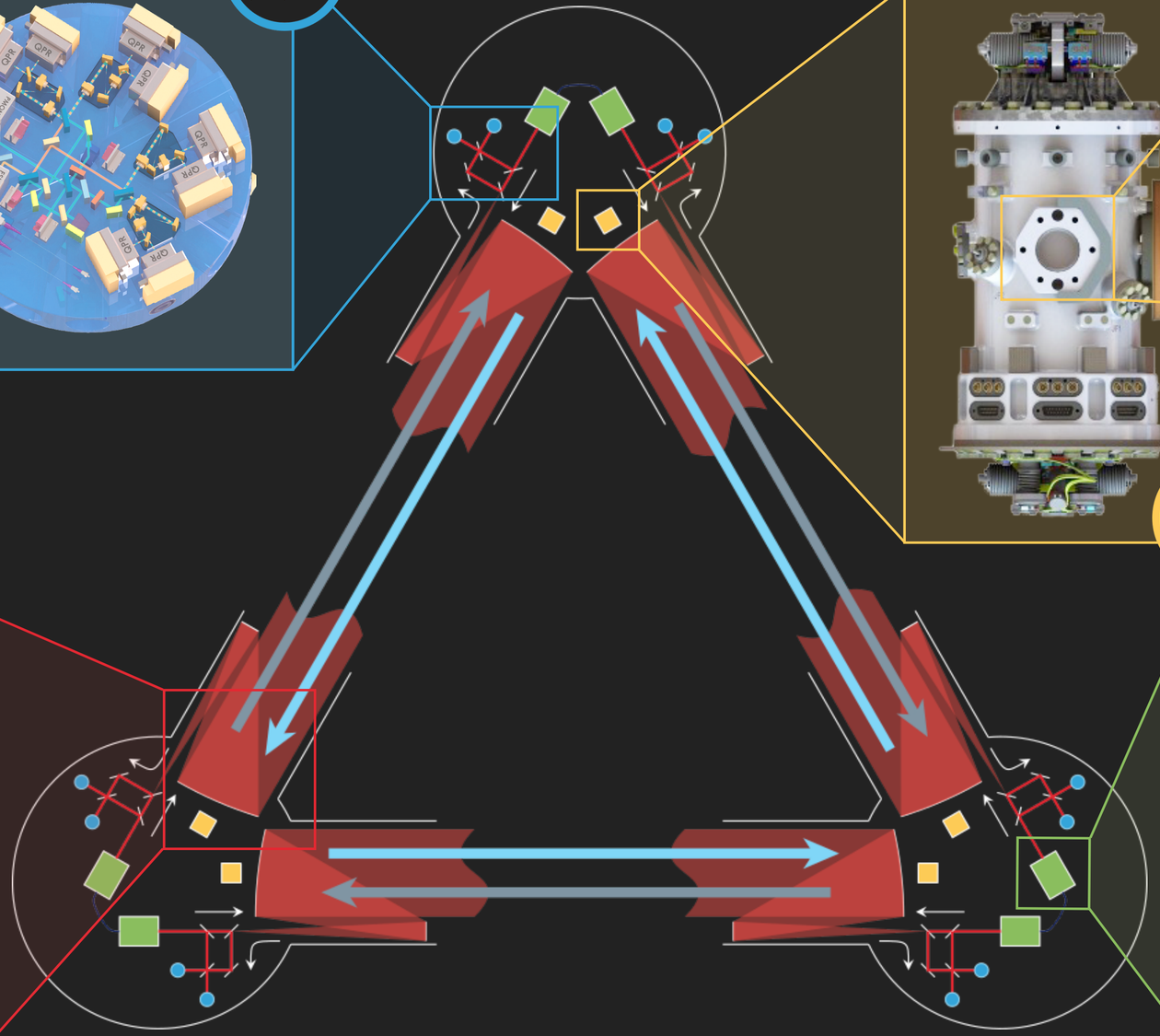
MISSION - INSTRUMENT

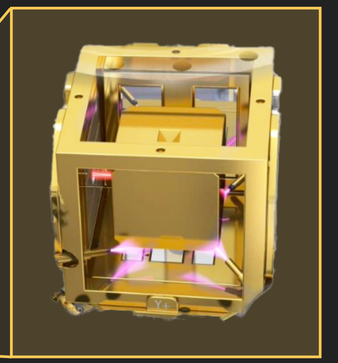


Interferometers

Telescope



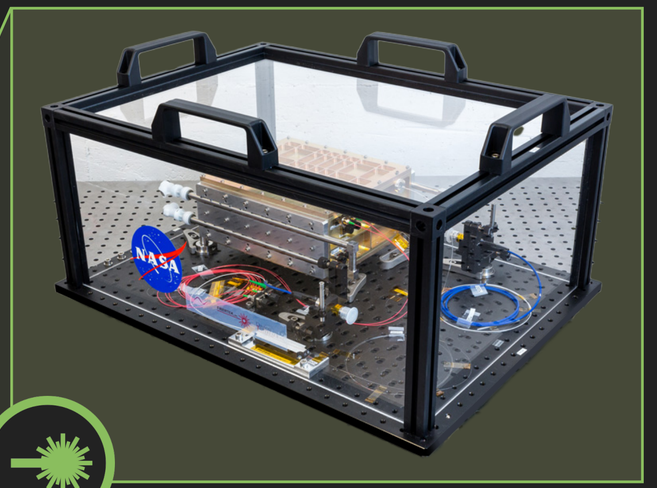


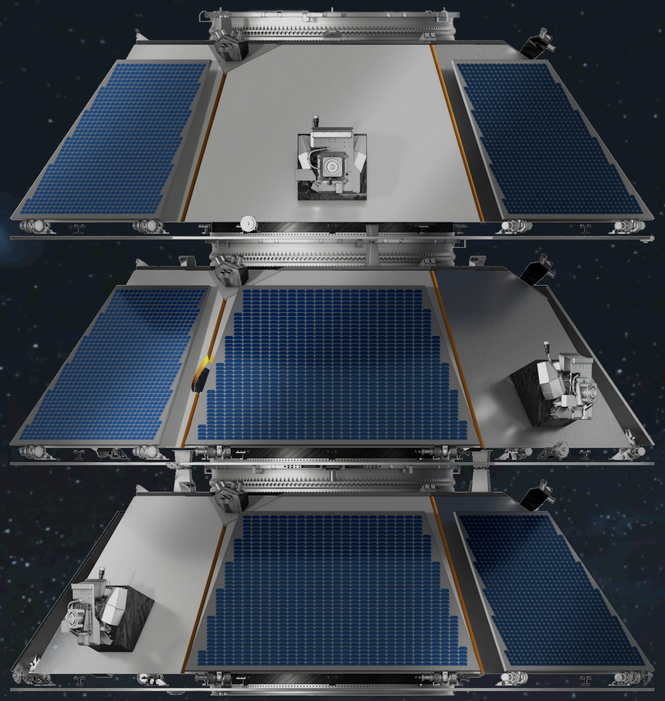


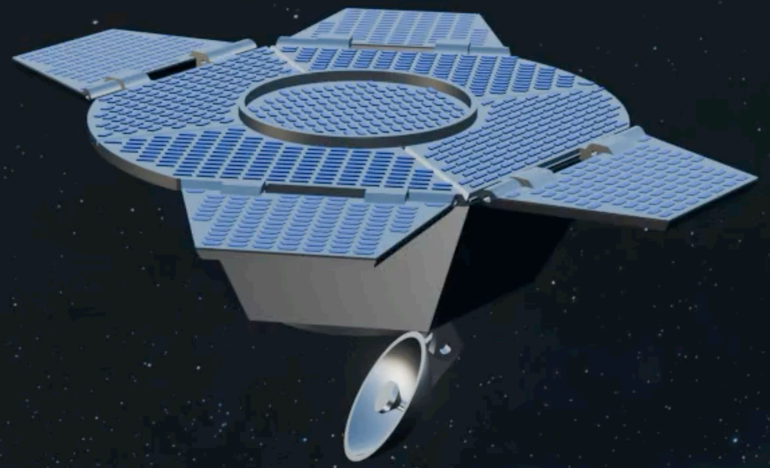
Test Masses

Gravitational Reference System (GRS)

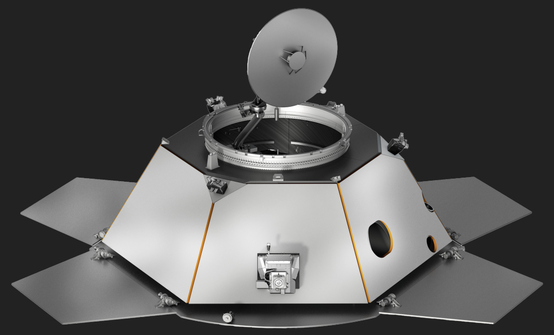
Laser







TIMELINE



We are here

Adoption
2024

Mission **P**reliminary
Design **R**eview
2027

Payload
PDRs

Payload
Delivery

Here we build it!

Flight
Acceptance
Review
2035



B1 | B2 | C | D | E1

Preliminary Definition

Detailed Definition

Qualification & Production

Invitation to
Tender

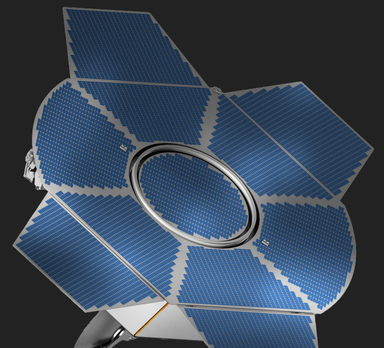
2025
Prime
Contractor
Kickoff

Payload CDRs

2031
Mission **C**ritical
Design **R**eview

S/C
Delivery

Launch
AUG 2035



esa

OHB



LISA

DATA ANALYSIS

TIME DELAY INTERFEROMETRY

Why?

- Laser Noise: 10^{-13}
- Gravitational Waves: 10^{-20}

TIME DELAY INTERFEROMETRY

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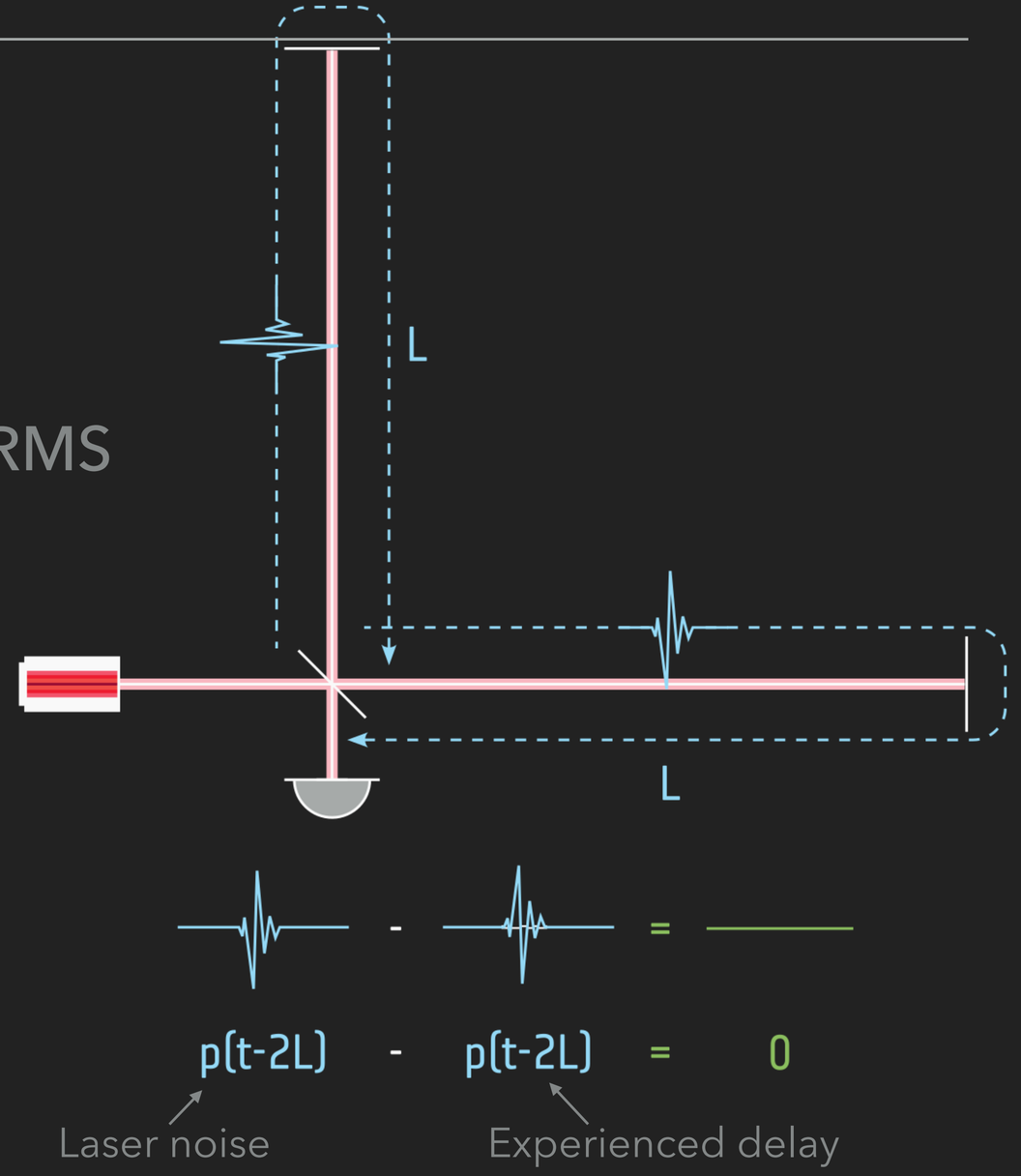
EQUAL ARMS



TIME DELAY INTERFEROMETRY

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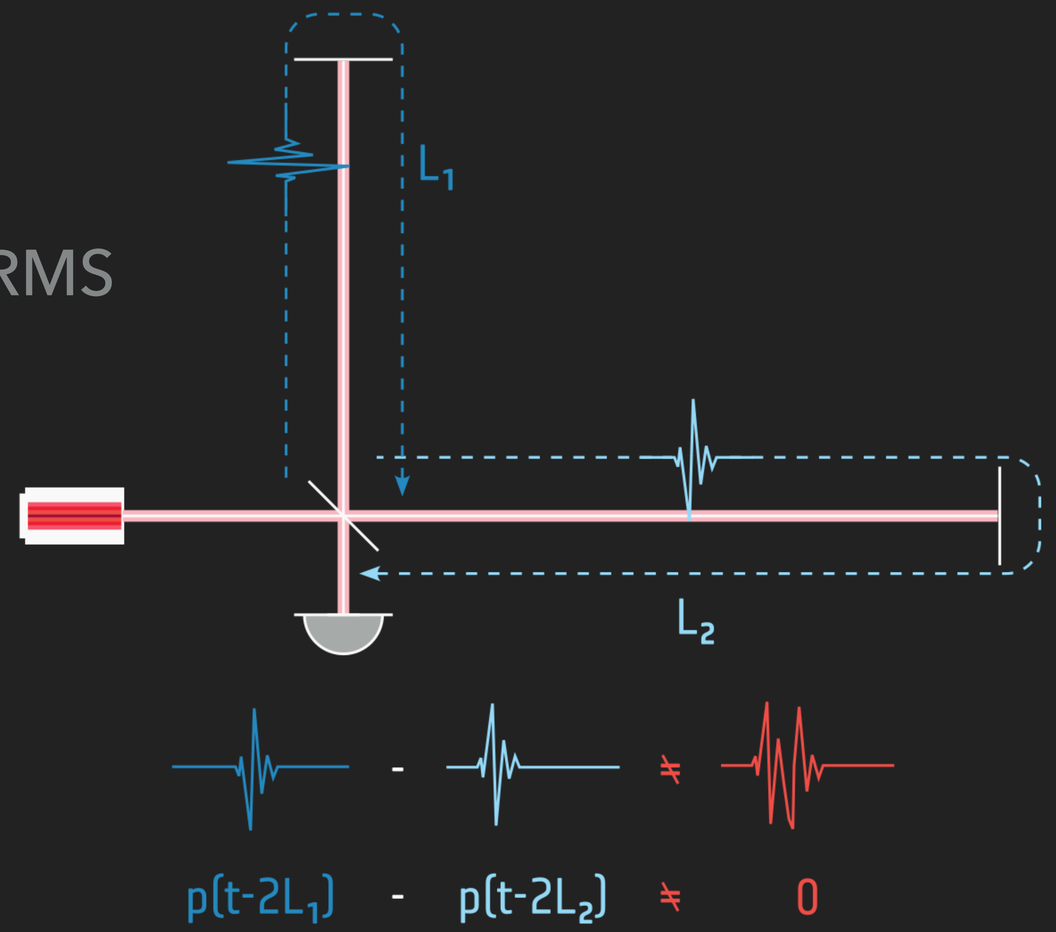
UNEQUAL ARMS



TIME DELAY INTERFEROMETRY

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- Laser Noise: 10^{-13}
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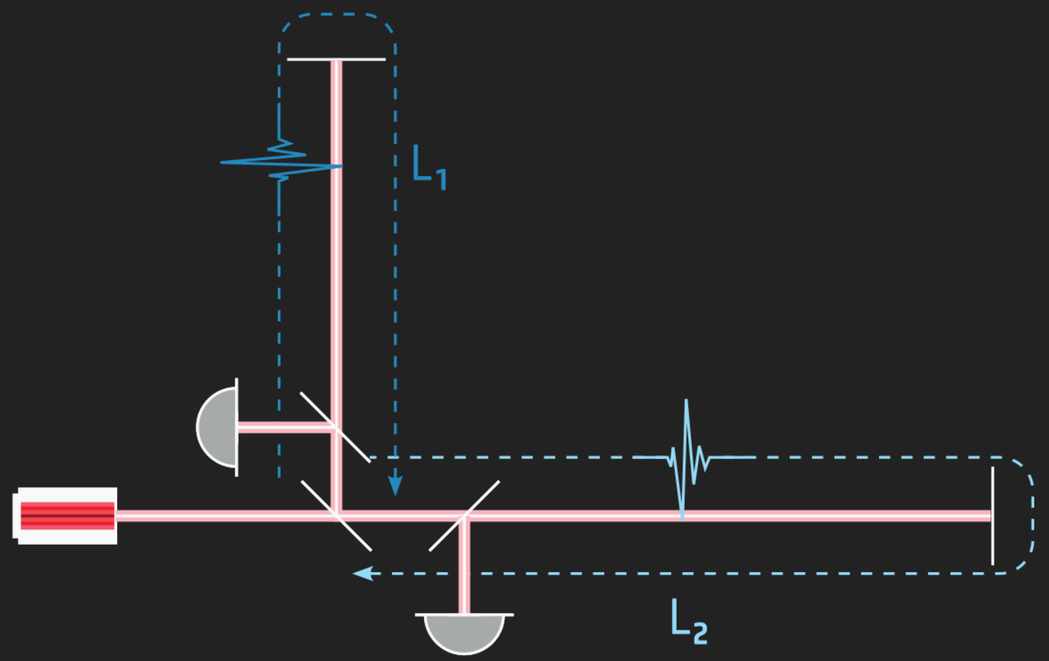
Solution:

- Record data for each arm individually



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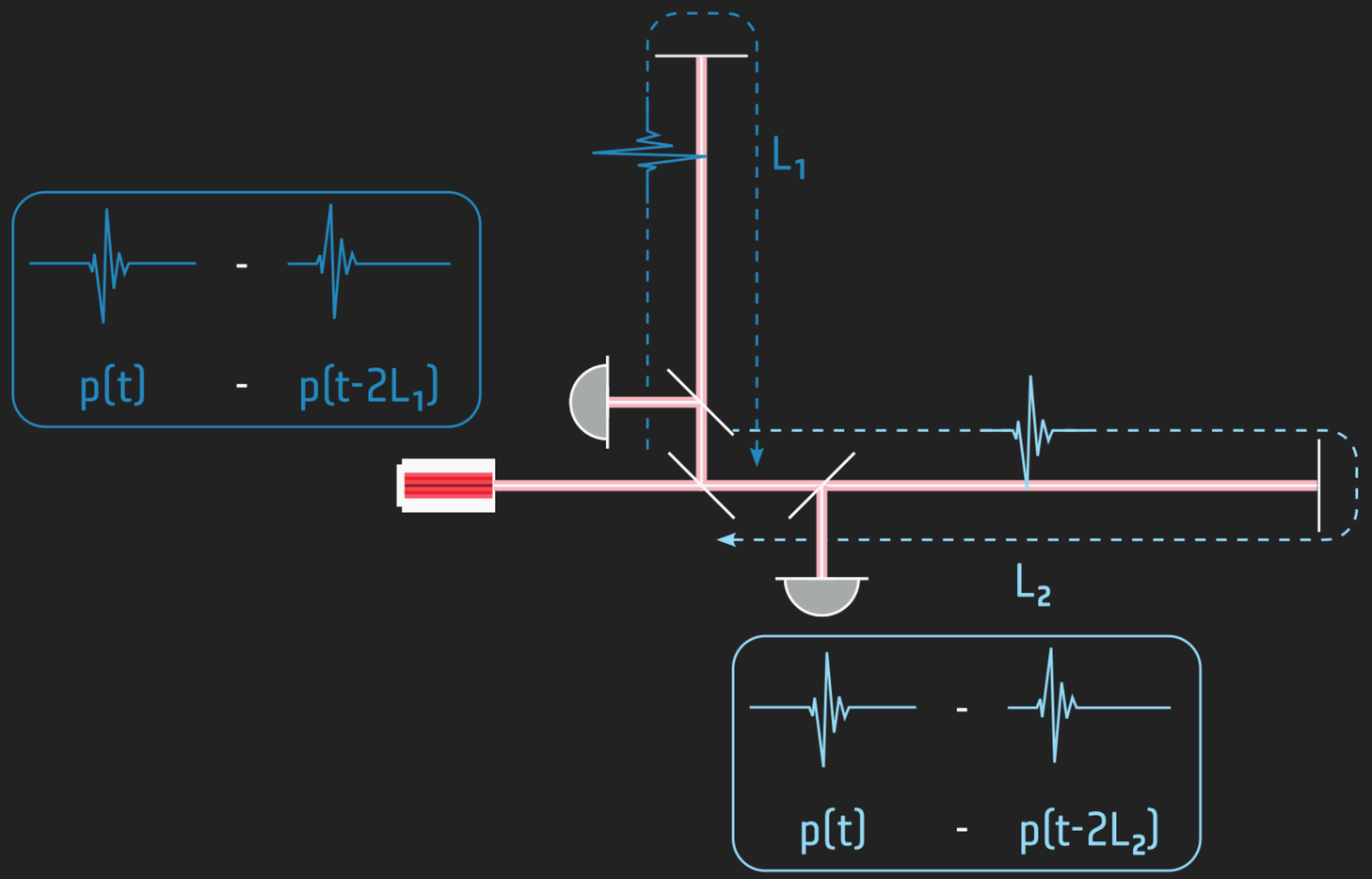

TIME DELAY INTERFEROMETRY

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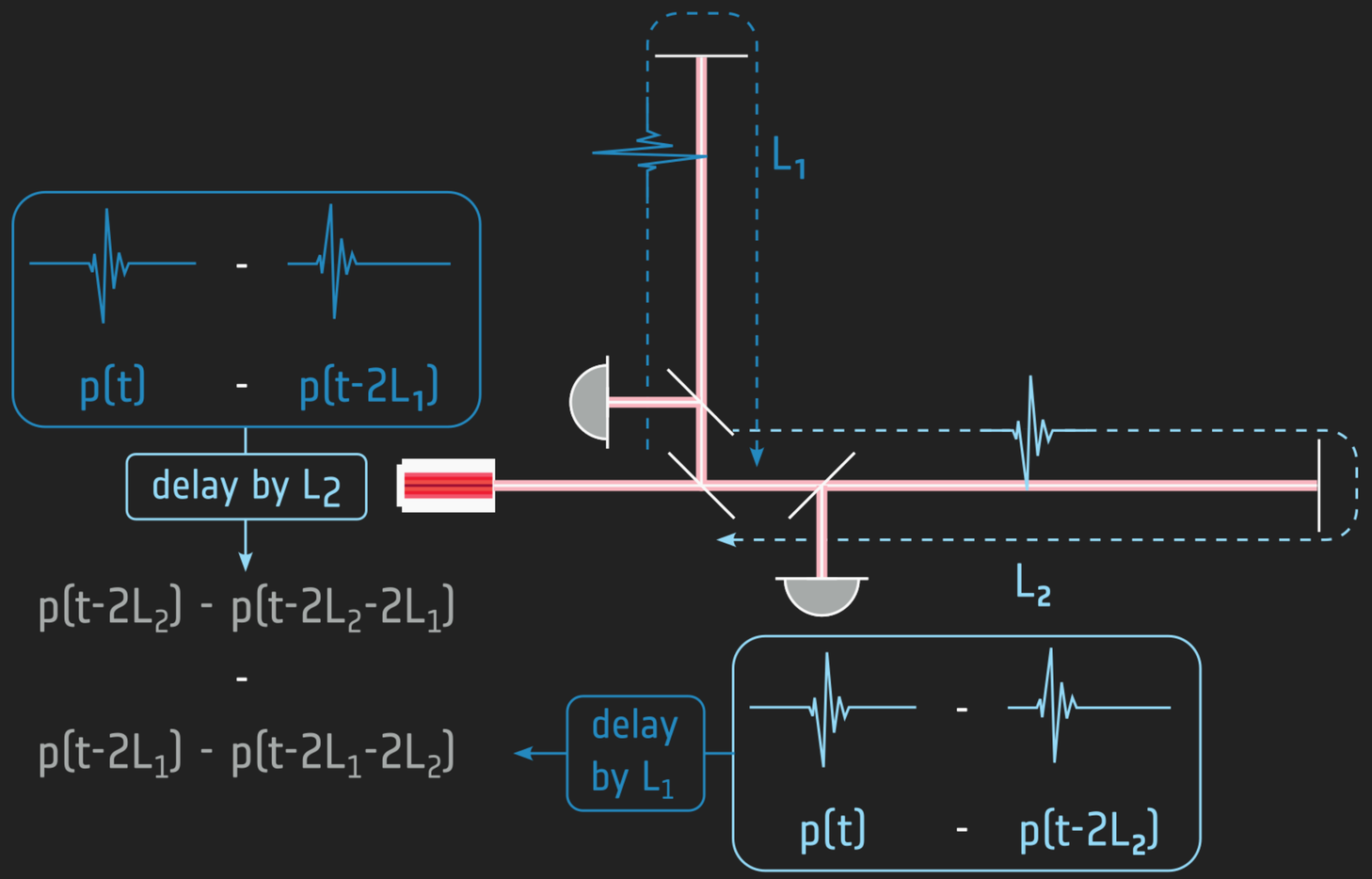
- Delay and combine in post-processing



TIME DELAY INTERFEROMETRY

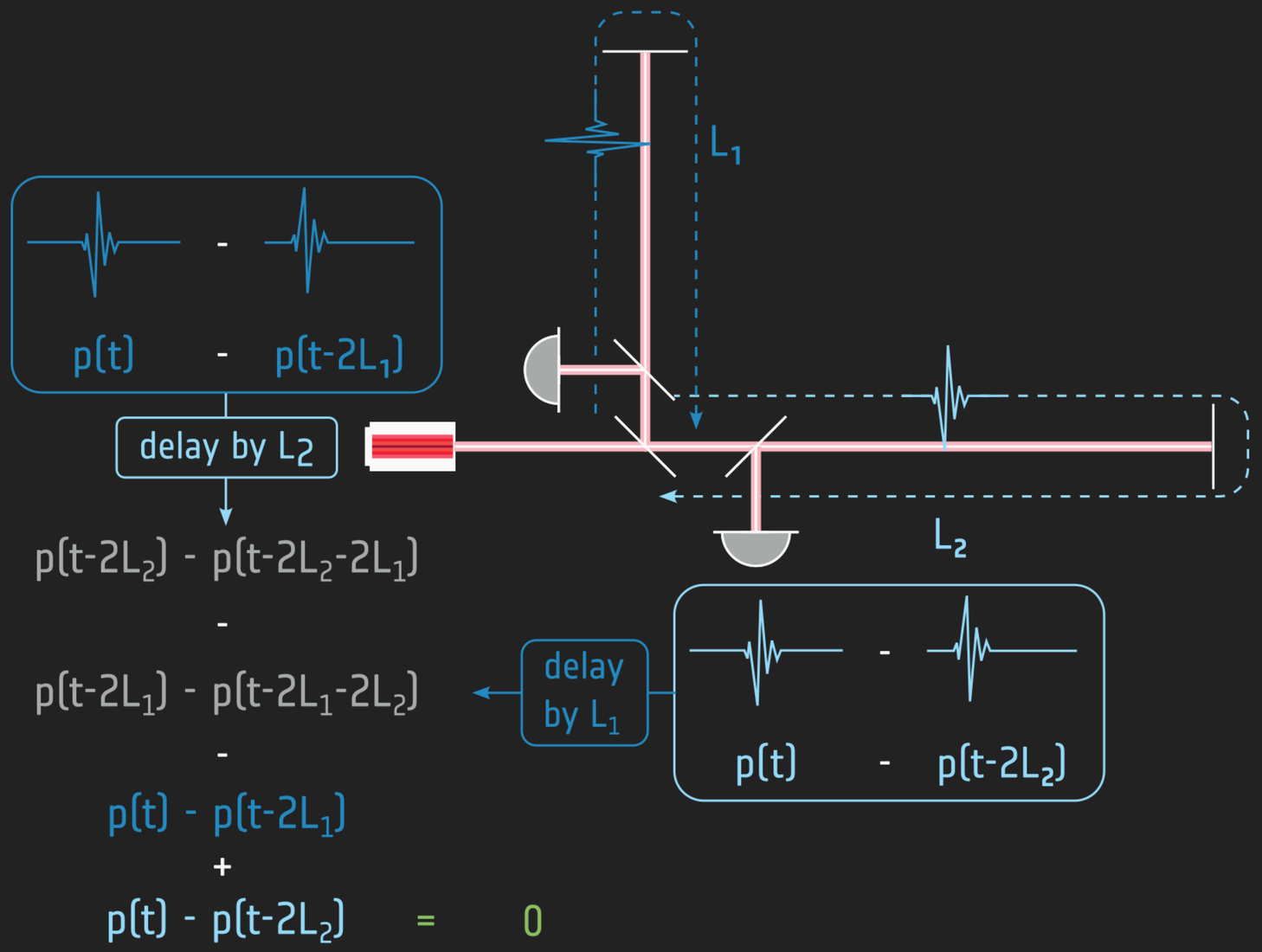
Why?

- Laser Noise: 10^{-13}
- Gravitational Waves: 10^{-20}

Solution:

- Record data for each arm individually
- Delay and combine in post-processing

➡ Laser noise cancels out

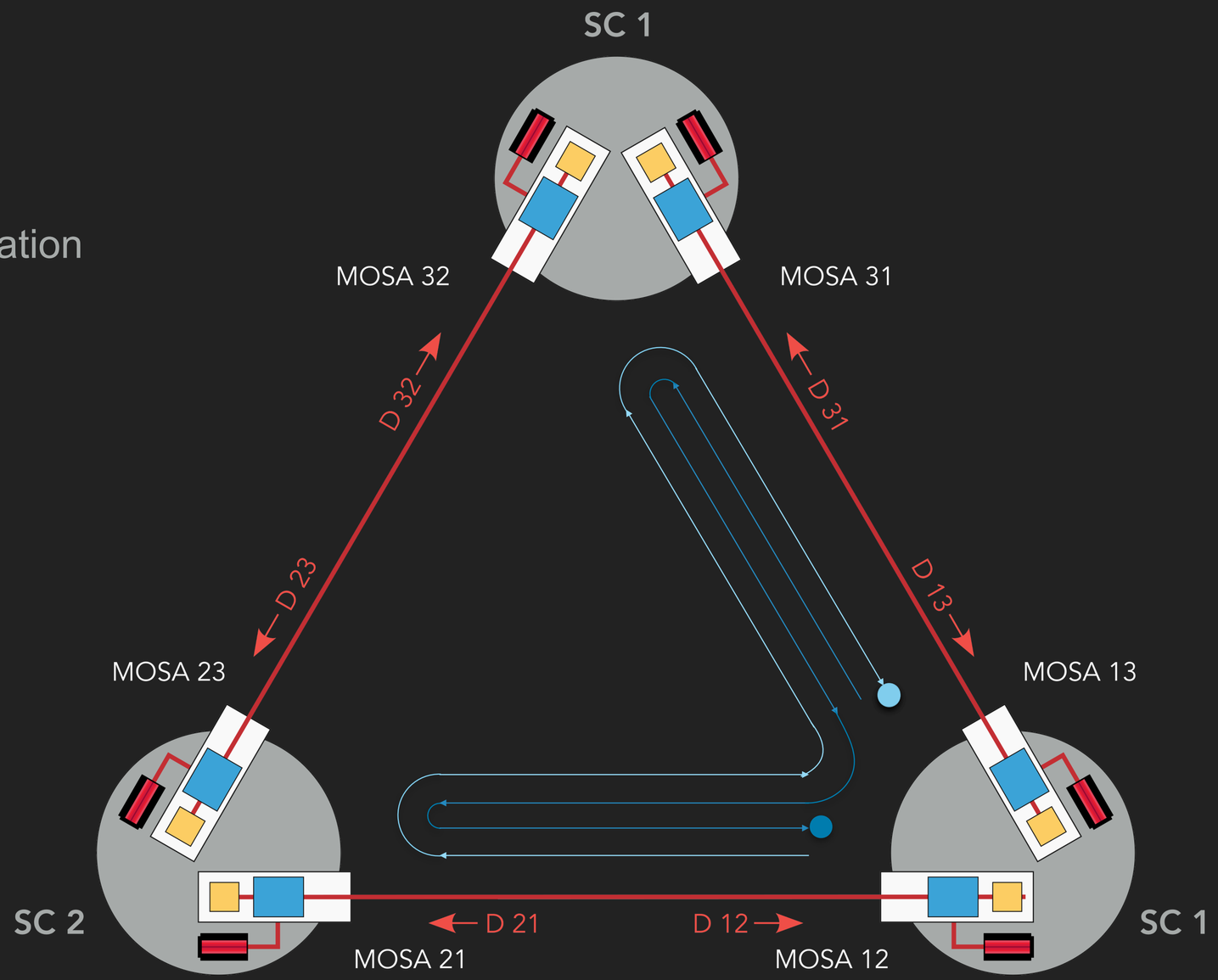


TIME DELAY INTERFEROMETRY

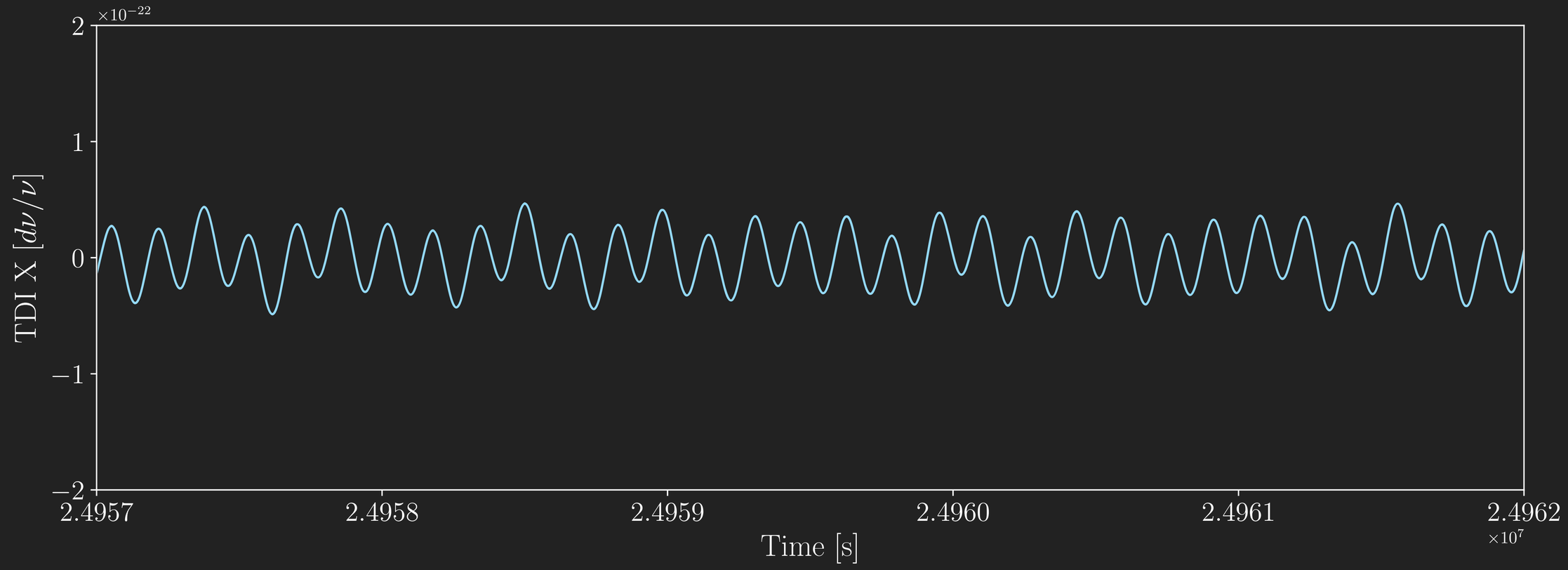
Combinations of delayed measurements

Example of Michelson equivalent TDI combination

$$
\begin{aligned}
X_1 = {} & \eta_{13} \\
& + \mathbf{D}_{13}\eta_{31} \\
& + \mathbf{D}_{13}\mathbf{D}_{31}\eta_{12} \\
& + \mathbf{D}_{13}\mathbf{D}_{31}\mathbf{D}_{12}\eta_{21} \\
& - \big(\eta_{12} \\
& \quad + \mathbf{D}_{12}\eta_{21} \\
& \quad + \mathbf{D}_{12}\mathbf{D}_{21}\eta_{13} \\
& \quad + \mathbf{D}_{12}\mathbf{D}_{21}\mathbf{D}_{13}\eta_{31}\big)
\end{aligned}
$$

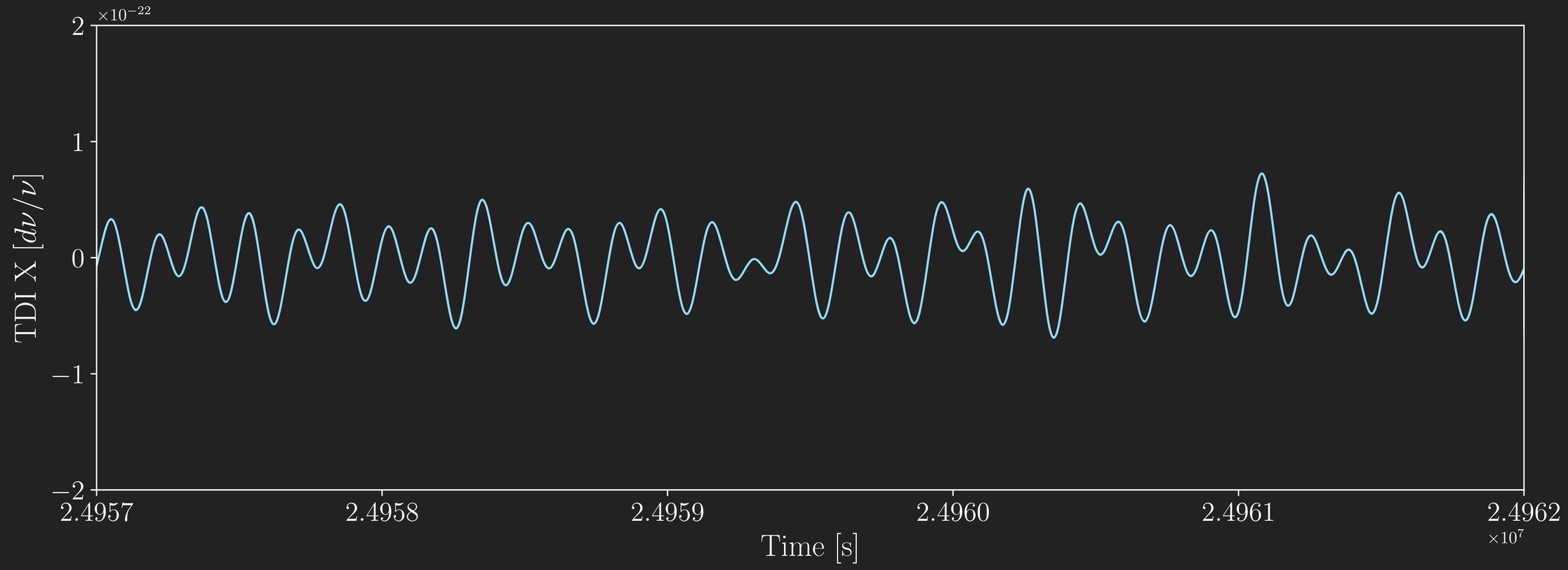


LEVEL 1 DATA (L1) : Time-Delay Interferometry (TDI) variables (GW strain)



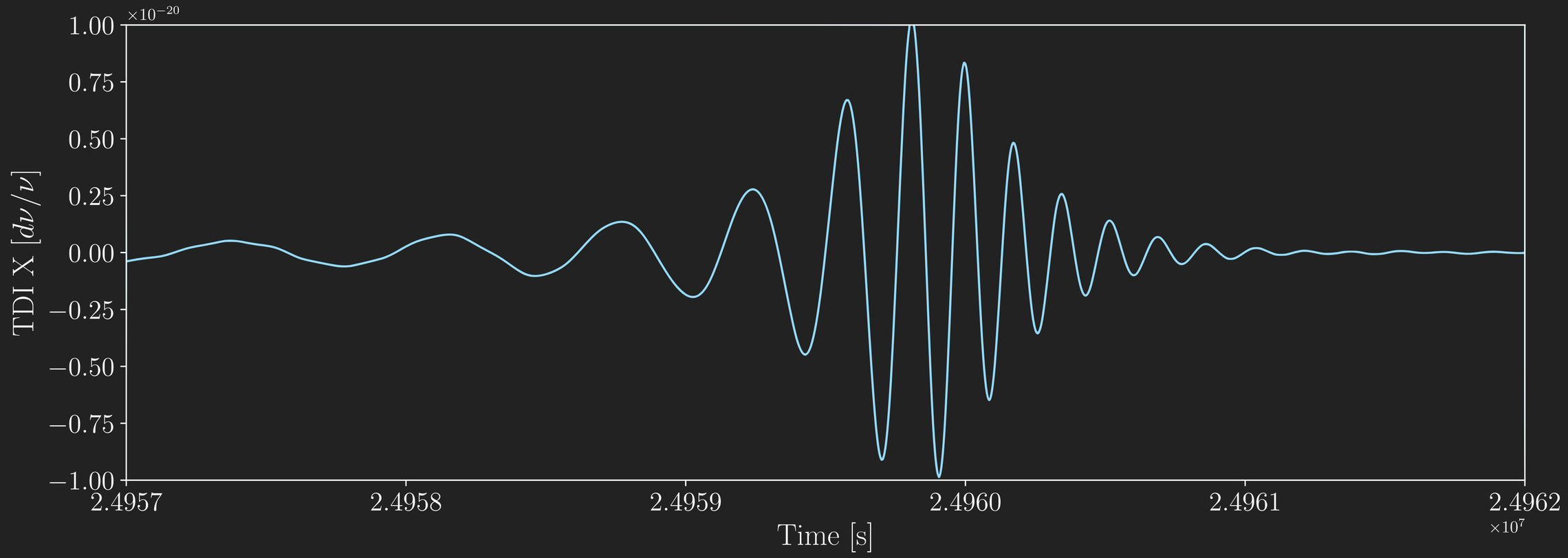
Verification GBs

LEVEL 1 DATA (L1) : Time-Delay Interferometry (TDI) variables (GW strain)



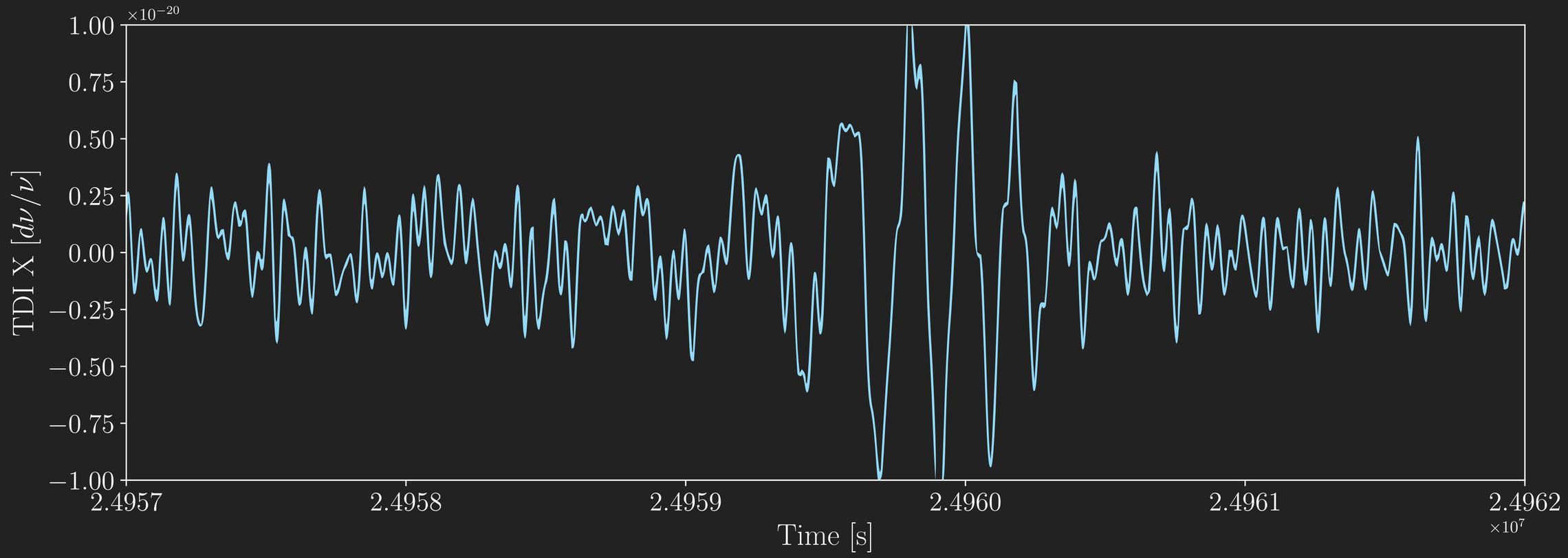
Verification GBs + EMRI

LEVEL 1 DATA (L1) : Time-Delay Interferometry (TDI) variables (GW strain)



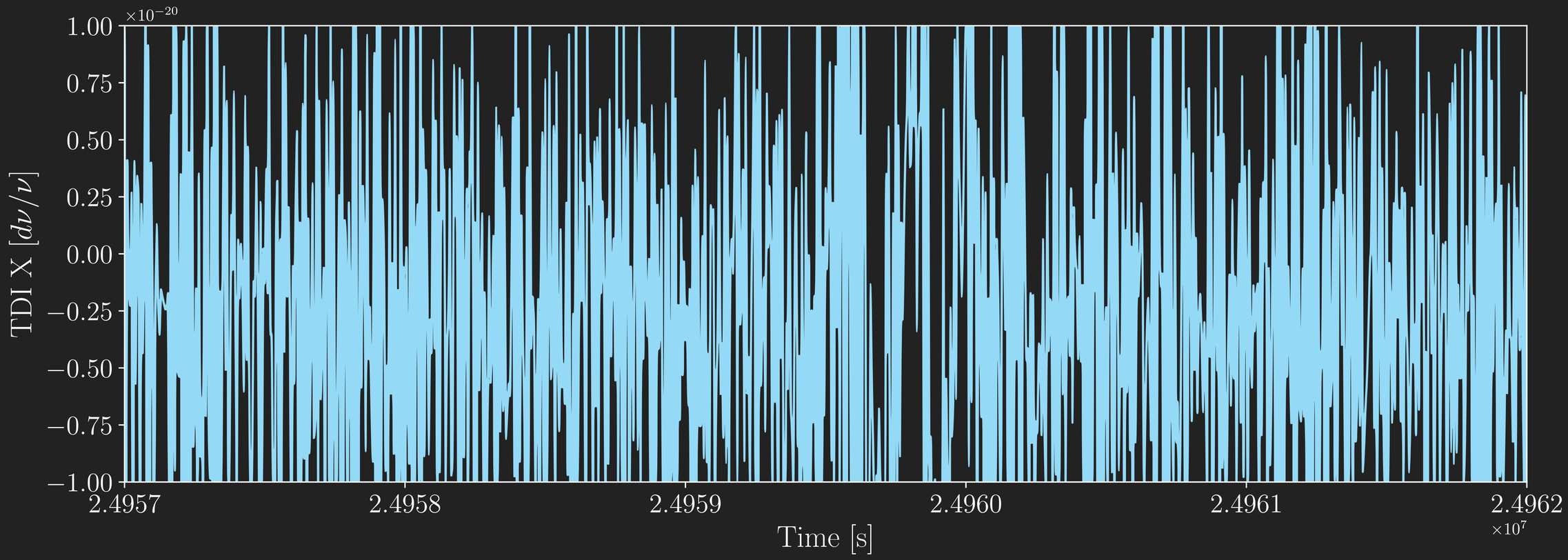
Verification GBs + EMRI + MBHB

LEVEL 1 DATA (L1) : Time-Delay Interferometry (TDI) variables (GW strain)



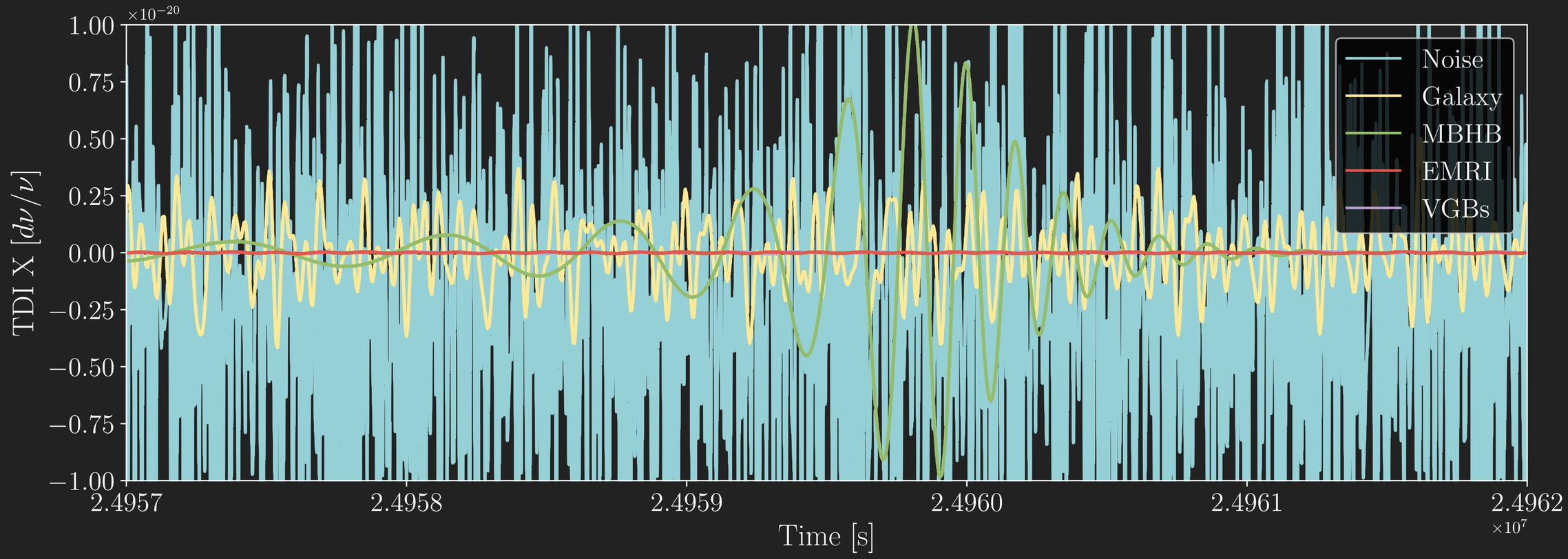
Verification GBs + EMRI + MBHB + Galaxy

LEVEL 1 DATA (L1) : Time-Delay Interferometry (TDI) variables (GW strain)



Verification GBs + EMRI + MBHB + Galaxy + Noise

LEVEL 1 DATA (L1) : Time-Delay Interferometry (TDI) variables (GW strain)



Verification GBs + EMRI + MBHB + Galaxy + Noise

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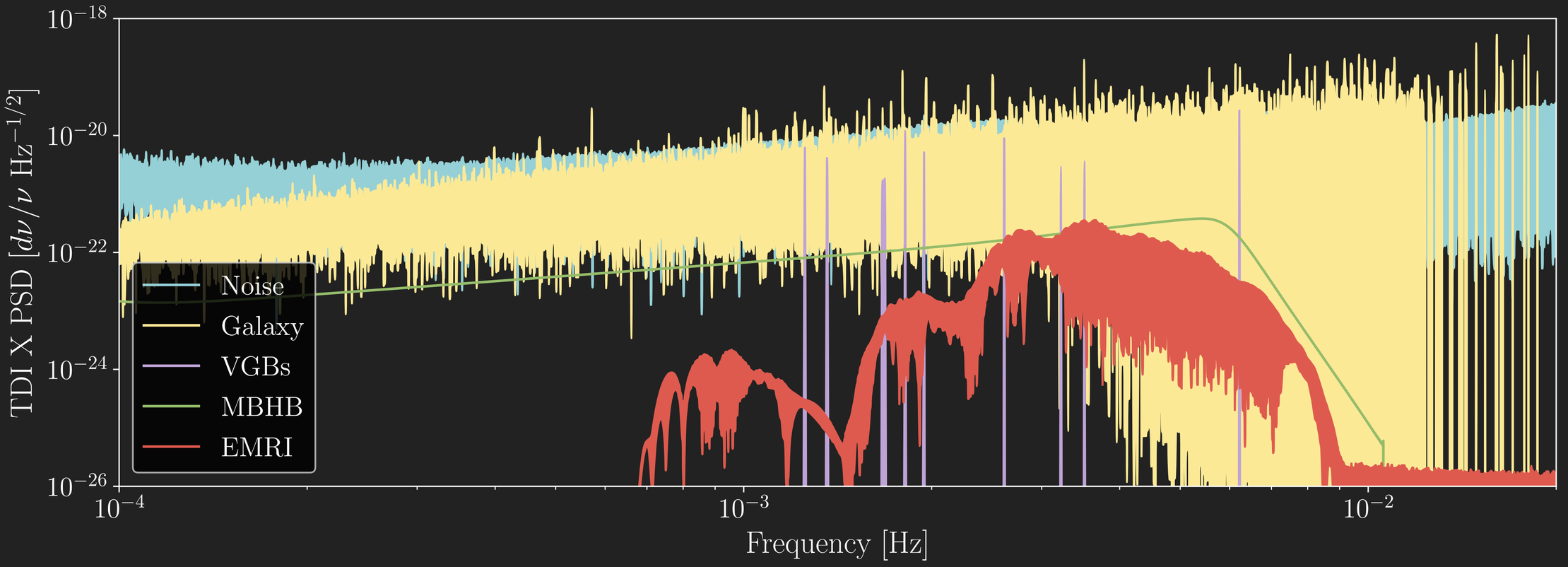
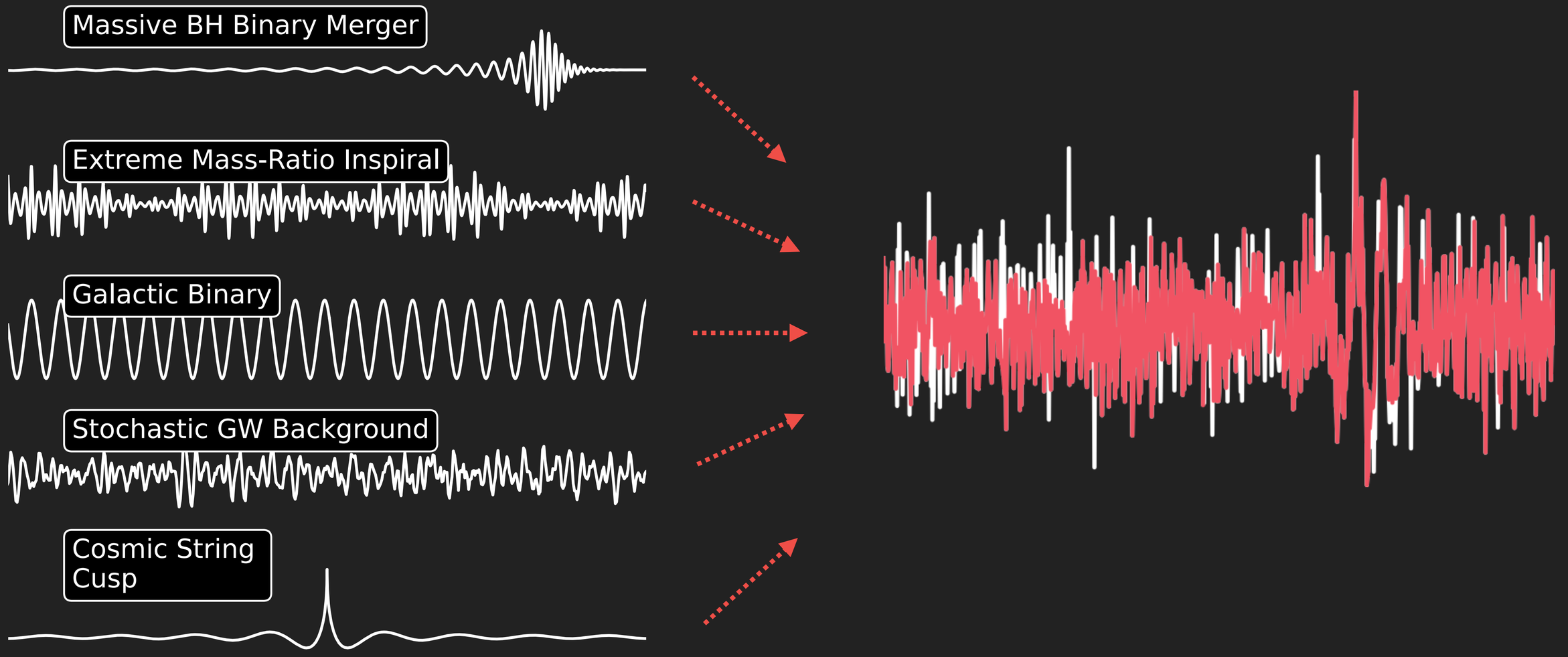


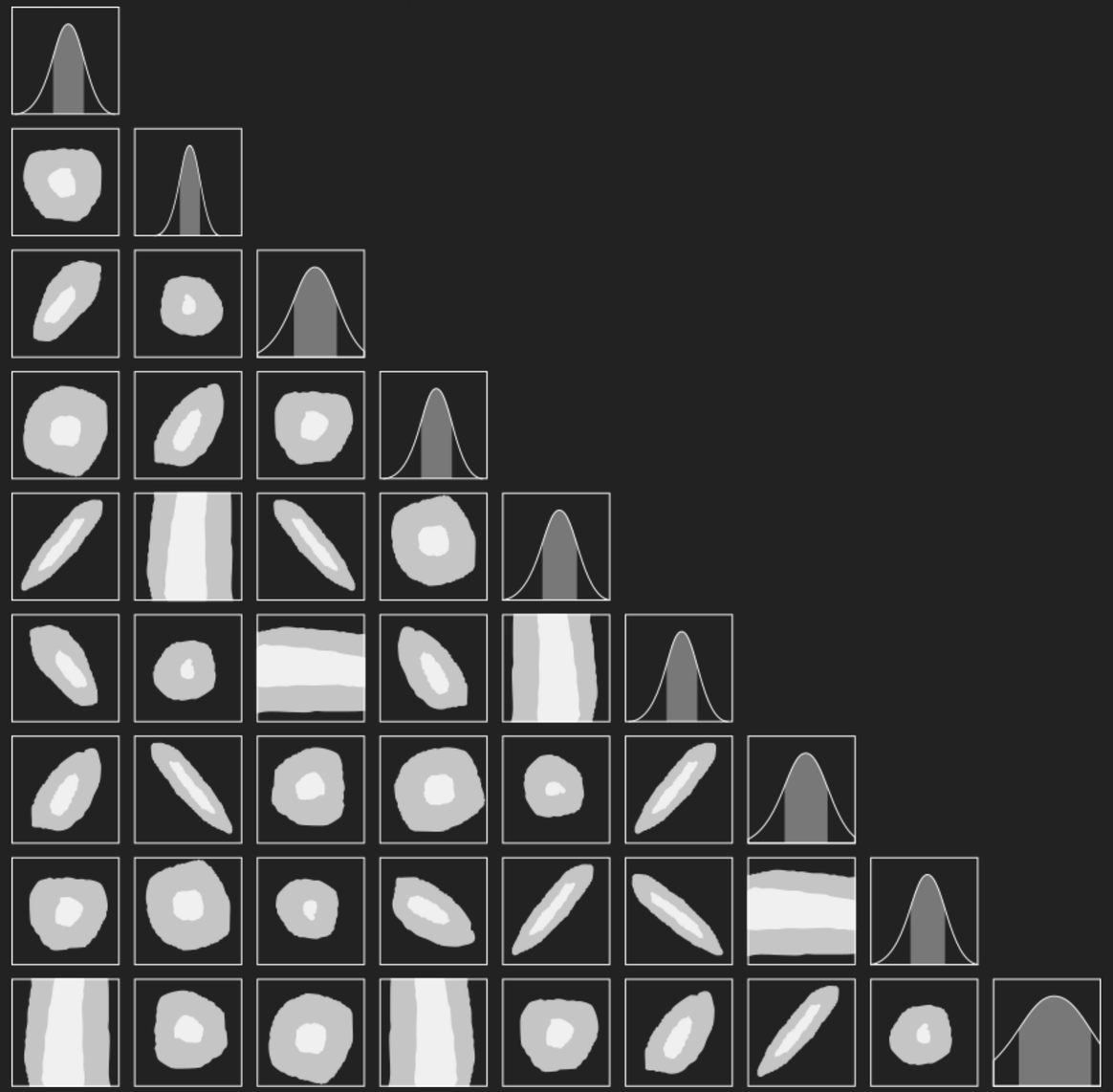
Verification GBs + EMRI + MBHB + Galaxy + Noise

WAVEFORMS – TO PERFORM THE GLOBAL FIT



LEVEL 2 DATA (L2) :

Output from a global fit pipeline, statistical evidence for candidate sources



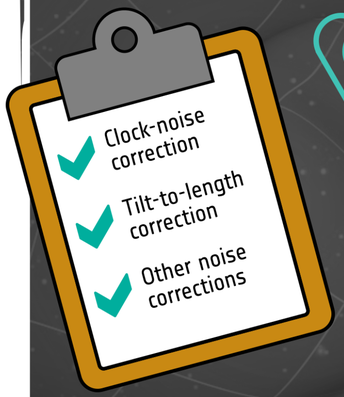
LEVEL 2 DATA (L2) :

Output from a global fit pipeline, statistical evidence for candidate sources

>60 000 parameters after 1 year ....

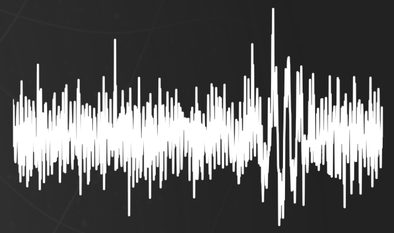
DATA ANALYSIS

Level 0 data

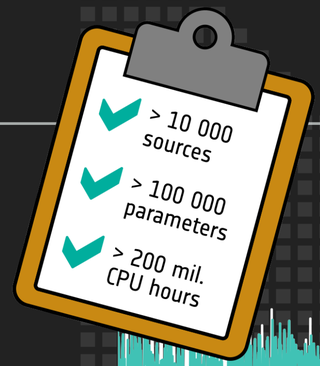


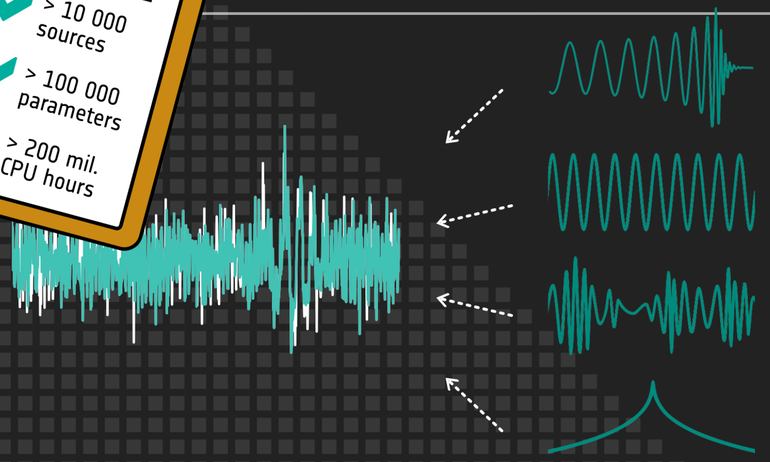


Time Delay Interferometry



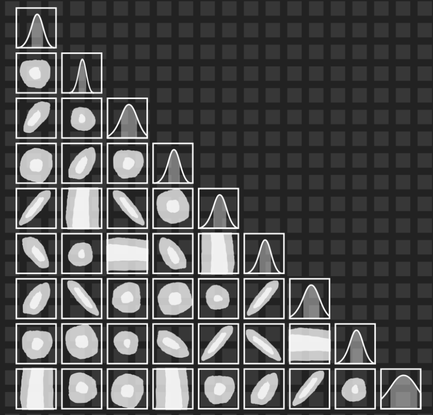
Level 1 data





Global Fit

Level 2 data

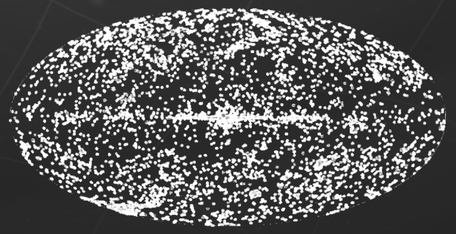


Bringing data togeter

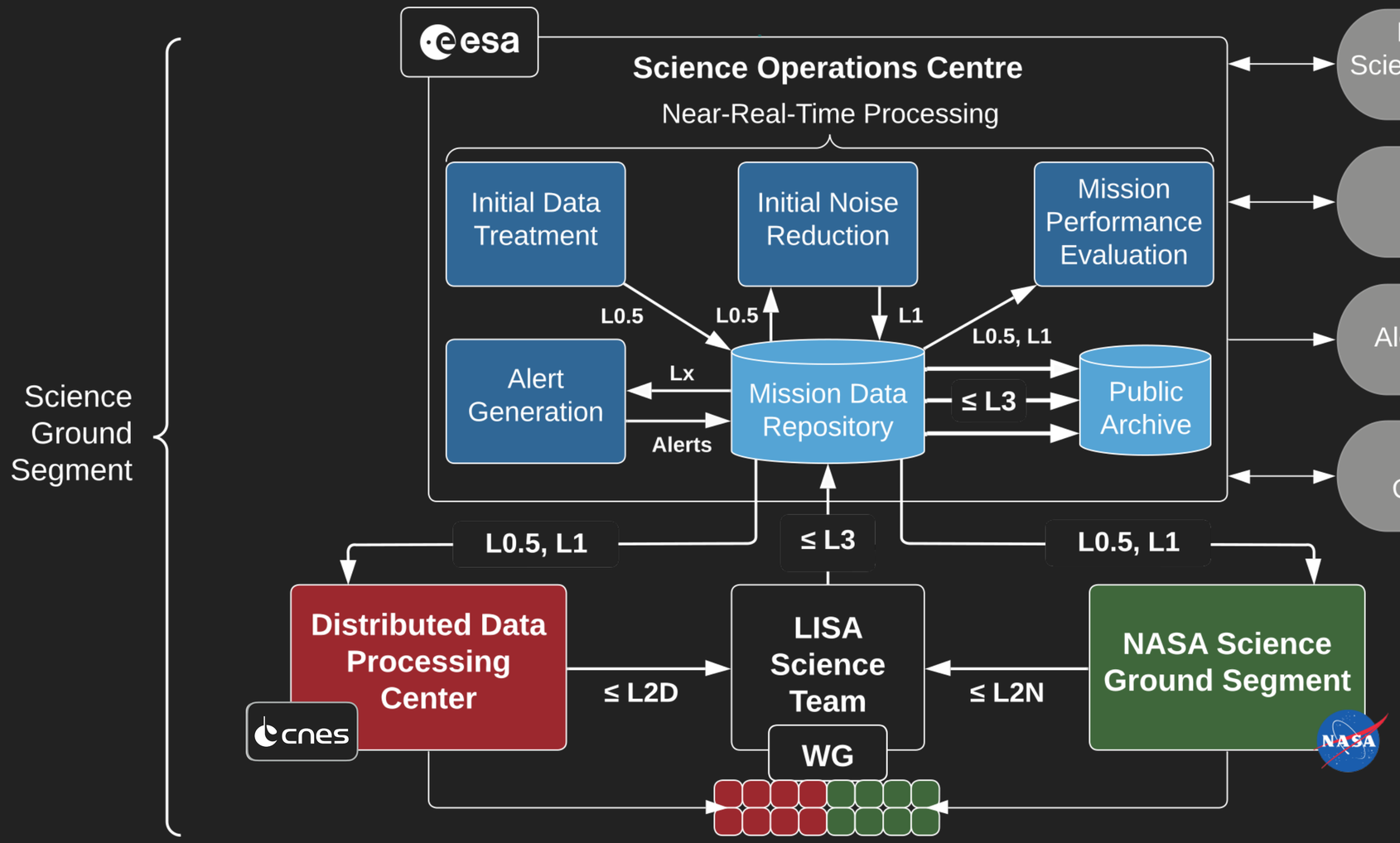


EXPERT TEAM

Level 3 data



SCIENCE GROUND SEGMENT





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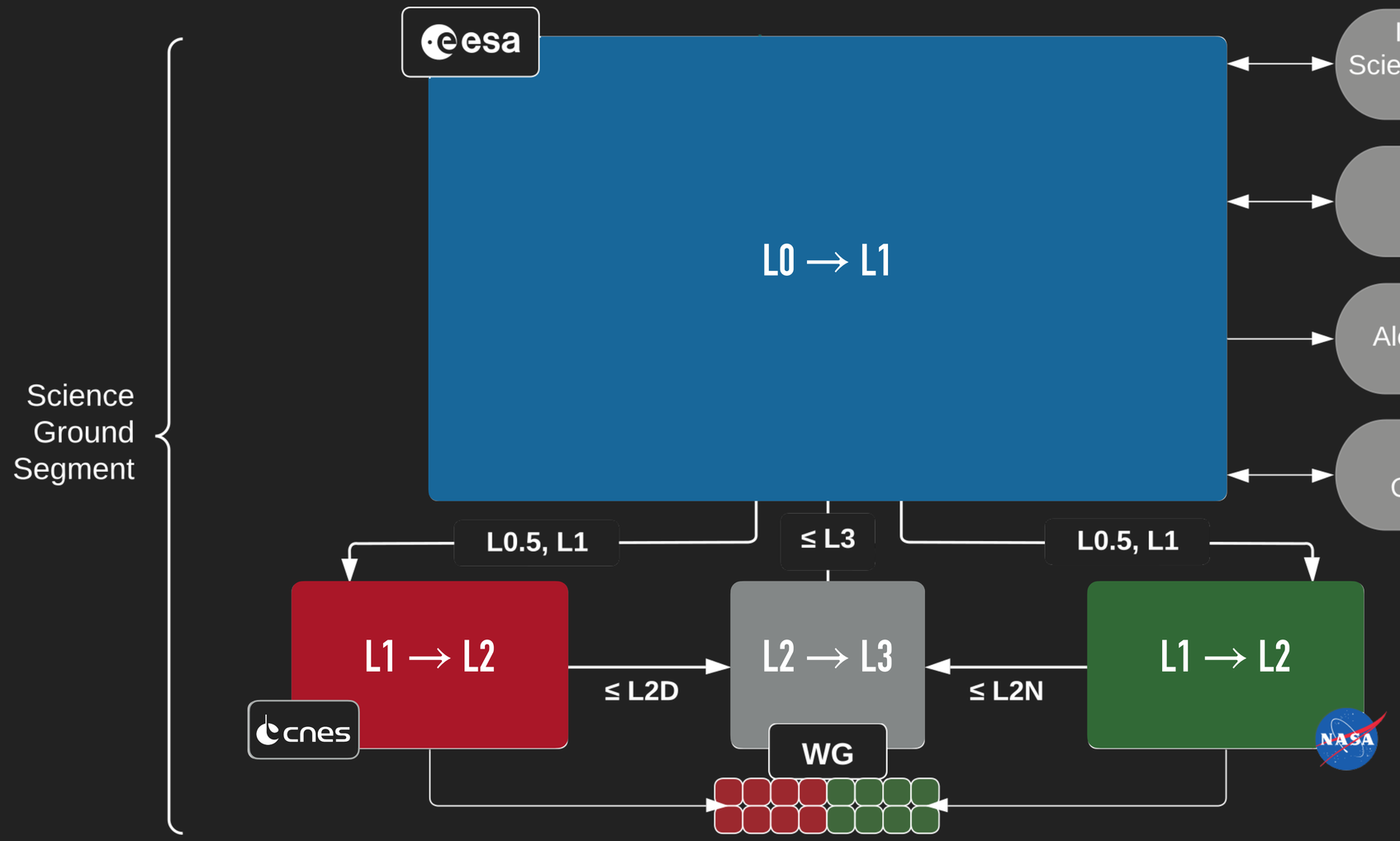
SCIENCE GROUND SEGMENT





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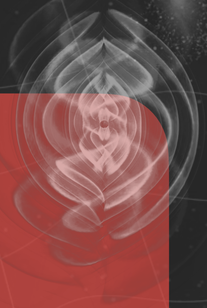
LISA - SUMMARY

SCIENCE



- **Galactic Binaries**
- **Massive Black Holes**
- **Extreme-mass ratio inspirals**
- Stellar-mass black holes
- **Fundamental Physics**
- **Cosmology**
- Stochastic Background
- **Unforseen Sources**

MISSION



- 3 Identical Spacecraft
- Triangle trailing/leading earth
- **Armlength: 2.5mil km**
- Payload:
  - Gravitational Reference System
  - Interferometric Detection System
  - Lasers
  - Telescopes
- **Now:** Prime has started work. Payload preliminary design reviews ongoing.
- **Launch 2035**

DATA



- **Challenge:** Very high initial noise in the data.
- Time Delay Interferometry - **L1**
- Global Fit - **L2**
- Bringing data together - **L3**
- Collaboration between ESA, NASA and the member states.

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