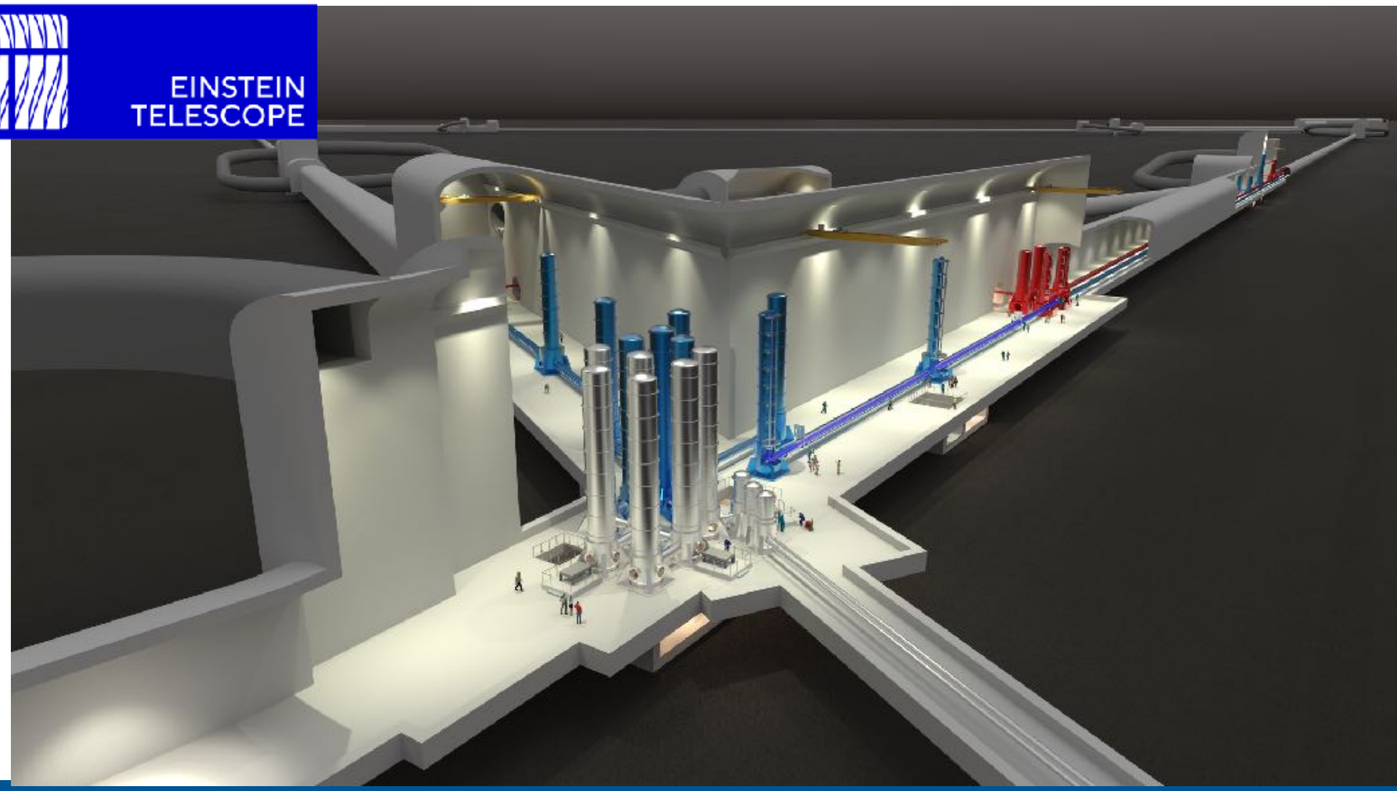
ET and LISA Synergies





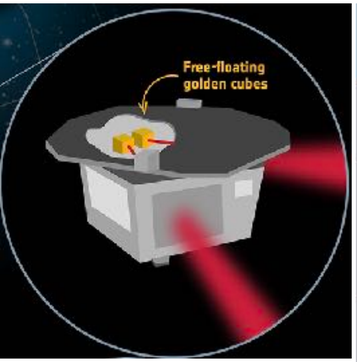
Carlos F. Sopuerta

Instituto de Ciencias del Espacio (ICE-CSIC & IEEC)

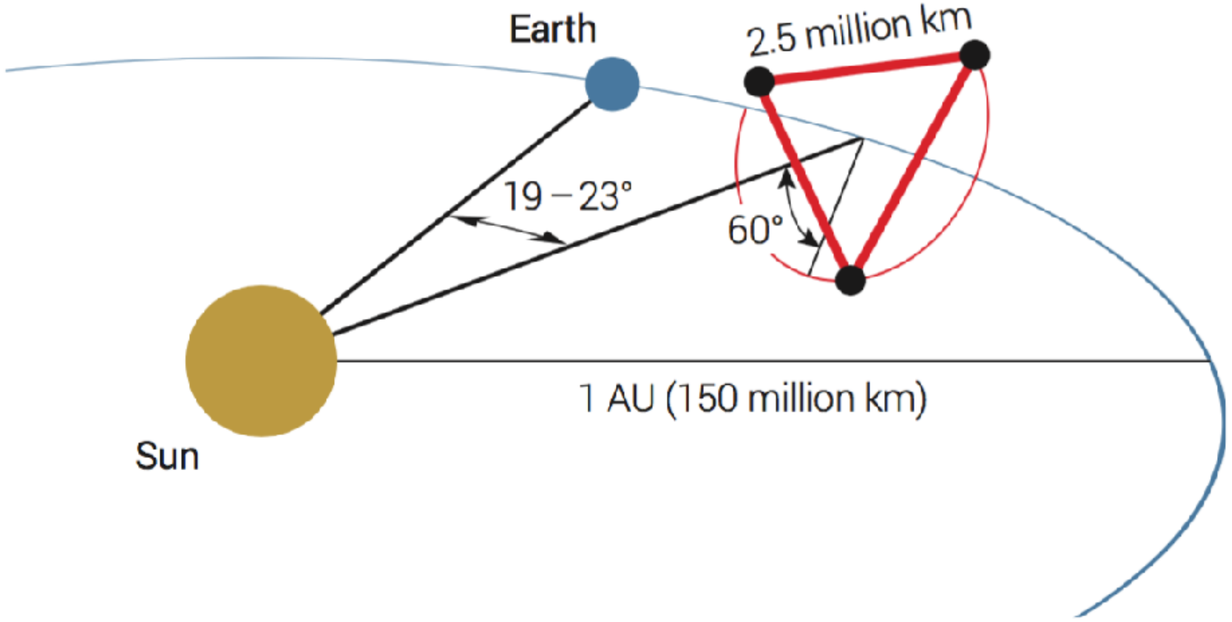
05 November 2026

0.1 mHz < f < 1 Hz Basics of LISA (according to MAR)

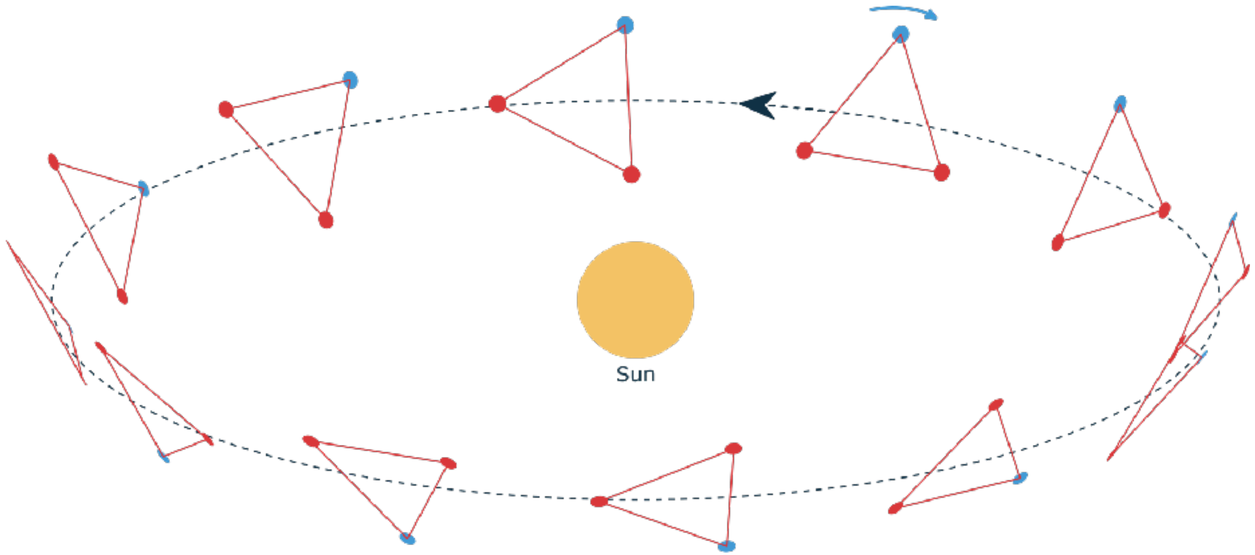
Mission adopted in 2024. Expected Launch in 2035.



Mission	
Duration	4.5 years science orbit • >82 % duty cycle • ~6.25 years including transfer and commissioning
Constellation	Three drag-free satellites forming an equilateral triangle • 2.5×10^6 km separation • trailing/leading Earth by ~20° • inclined by 60° with respect to the ecliptic
Orbits	Heliocentric orbits • semimajor axis ~1 AU • eccentricity $e \approx 0.0096$ • inclination $i \approx 0.96°$

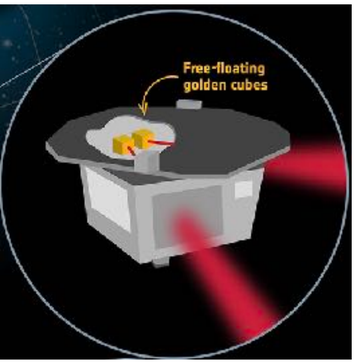


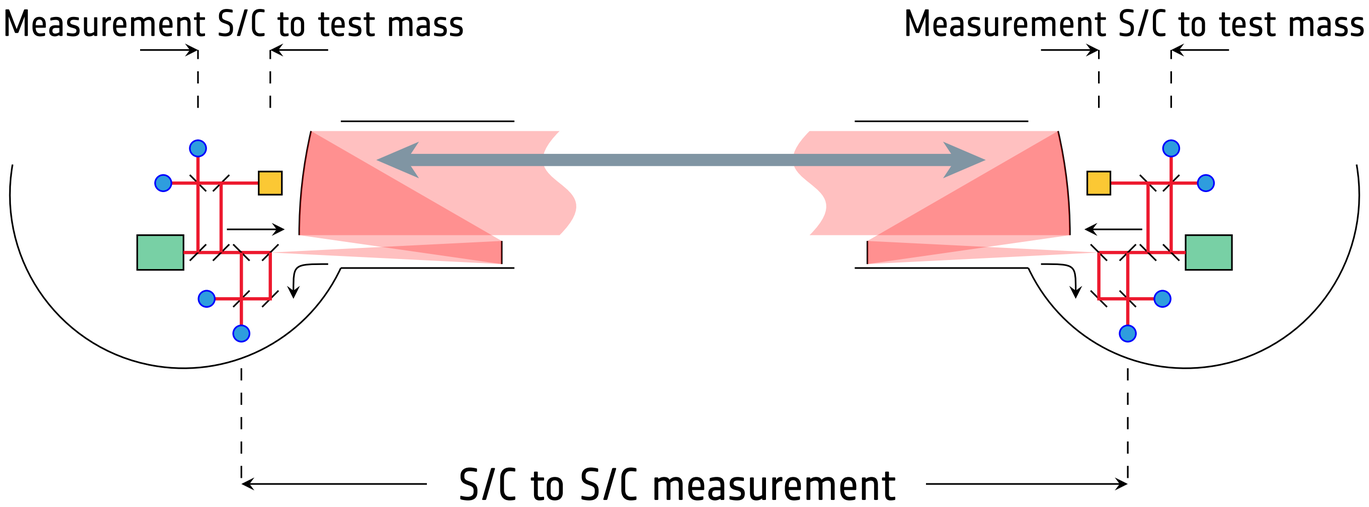
Passive Orbits



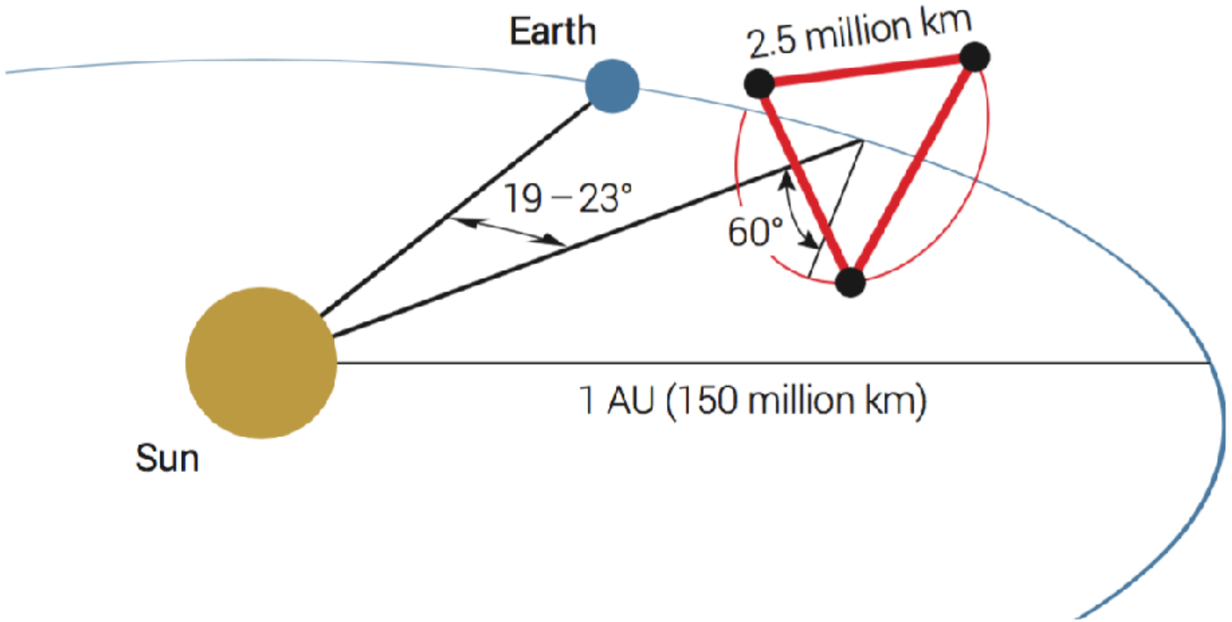
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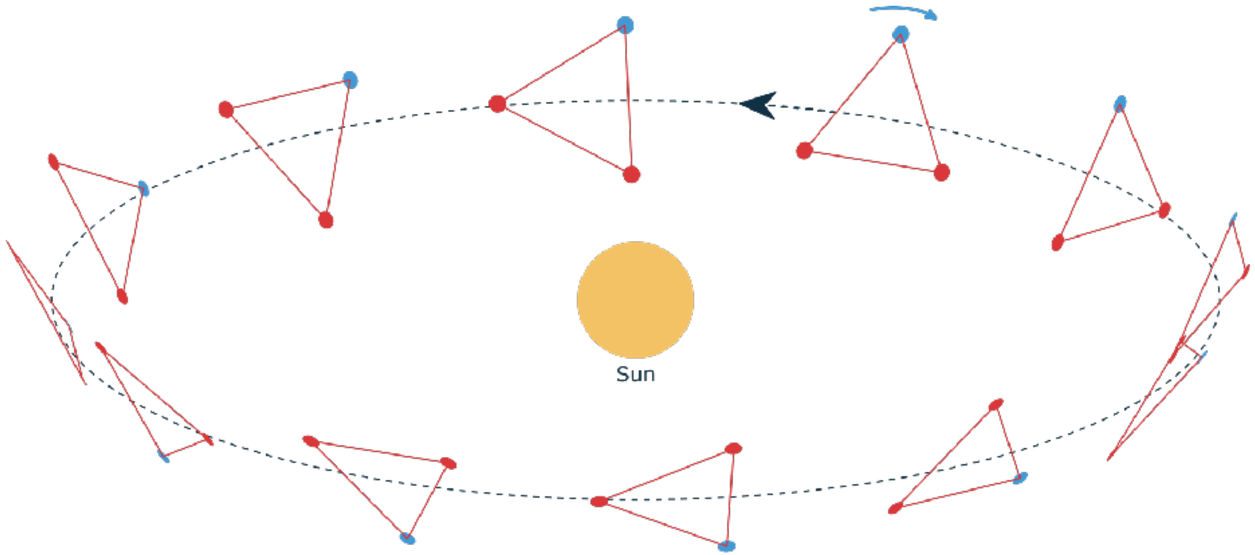
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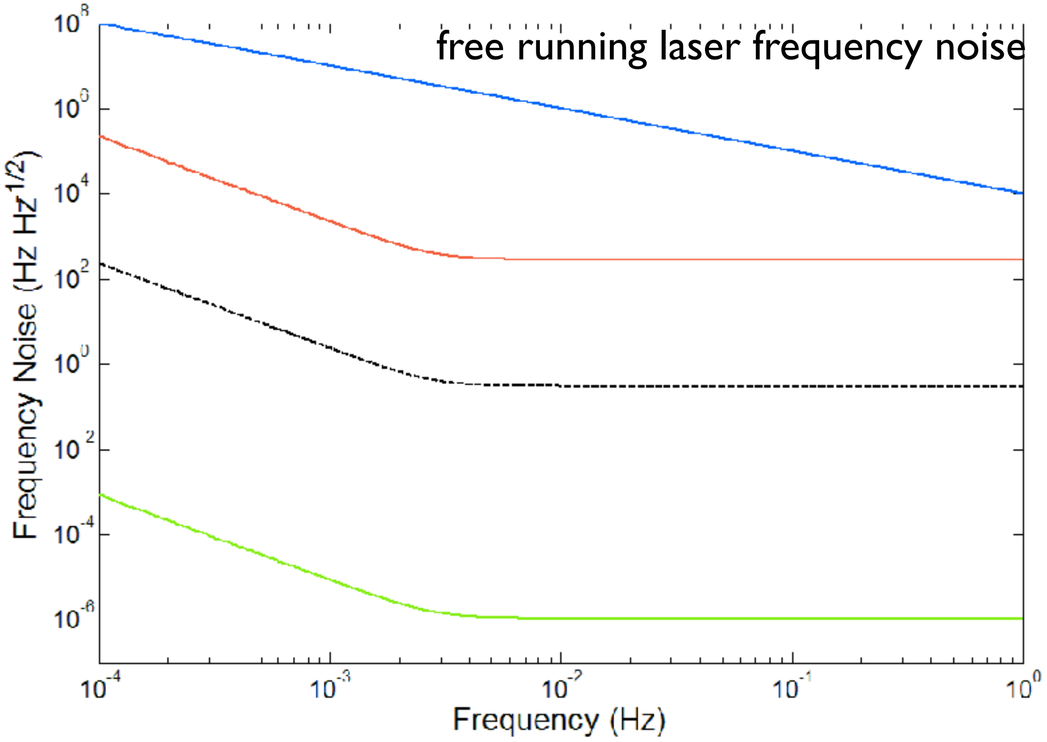
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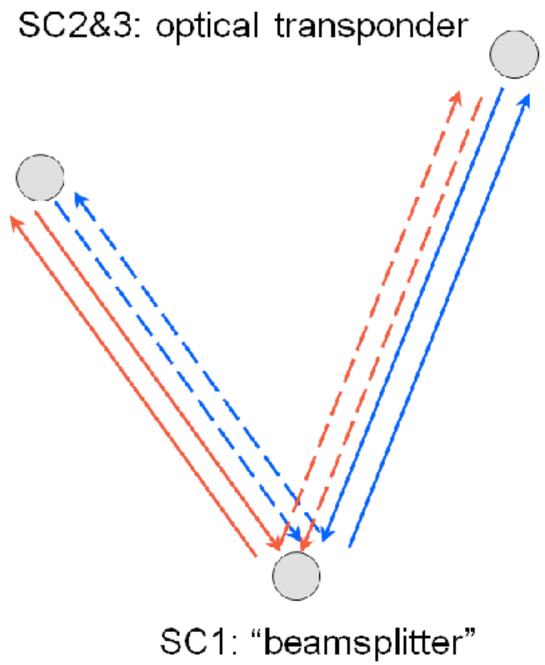


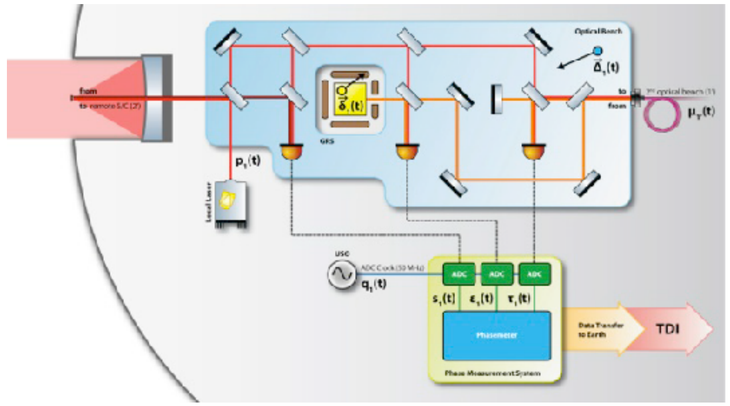


Basics of LISA

✳**Time-delay interferometry** (TDI): Correlations in the frequency noise can be calculated and subtracted by algebraically combining phase measurements from different craft delayed by the multiples of the time delay between the spacecrafts.

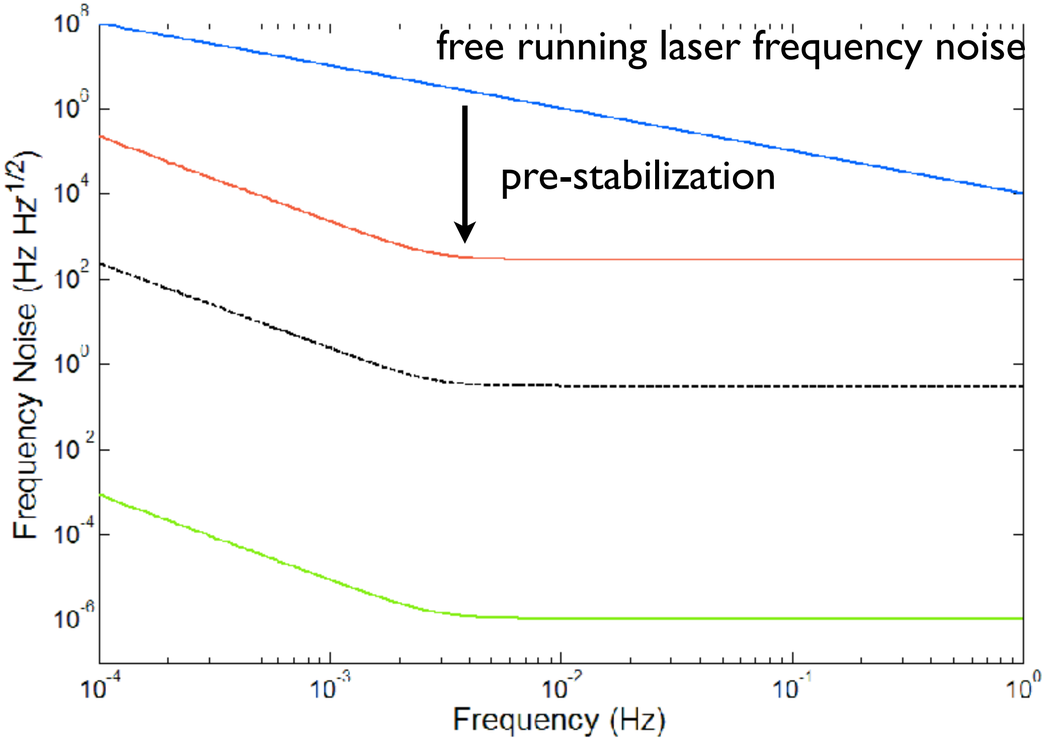


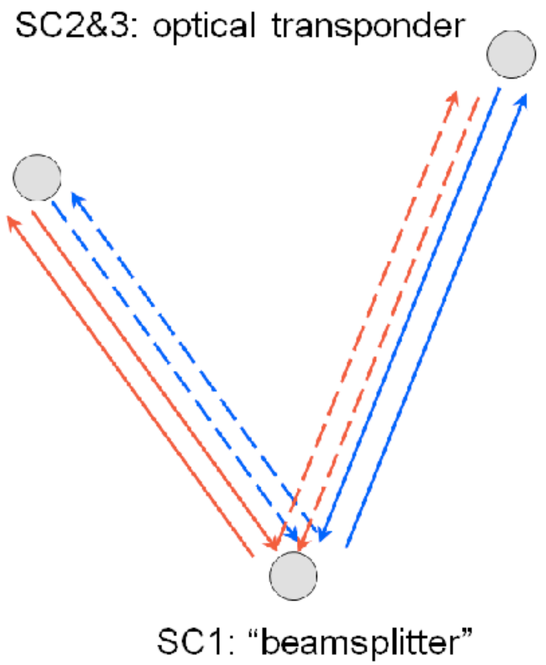


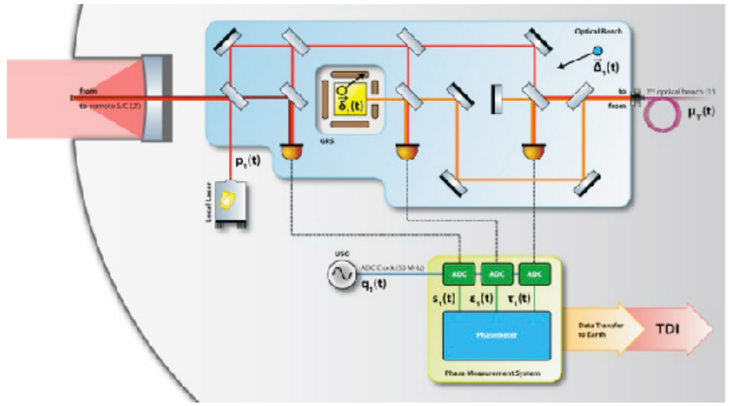


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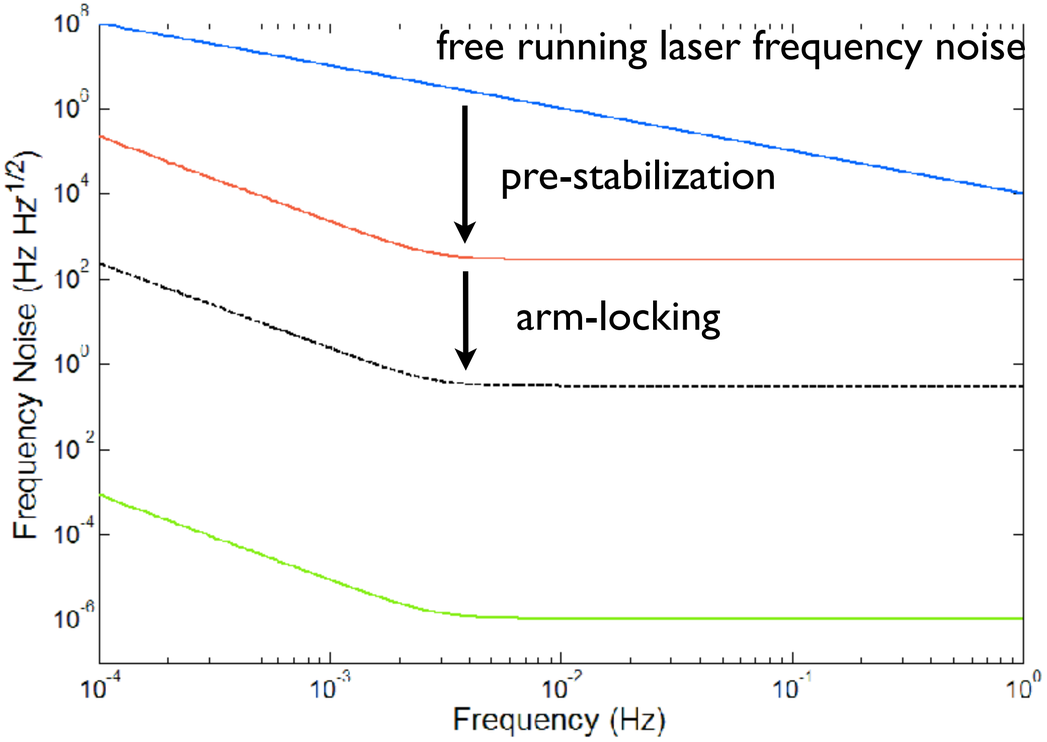


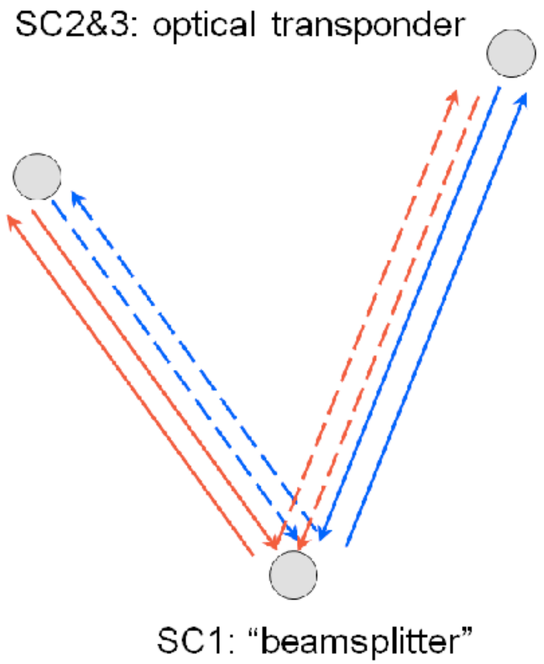


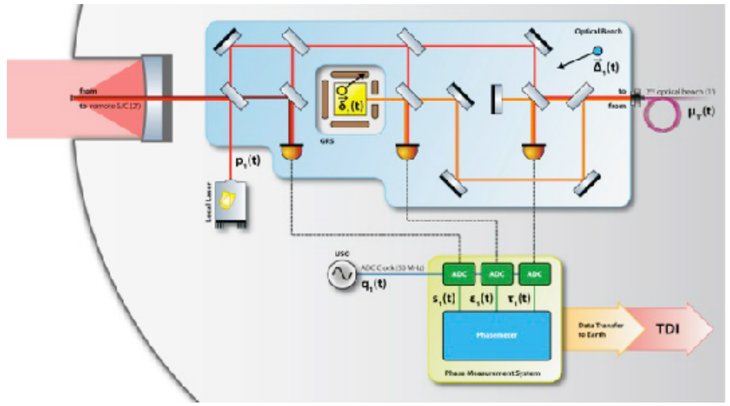


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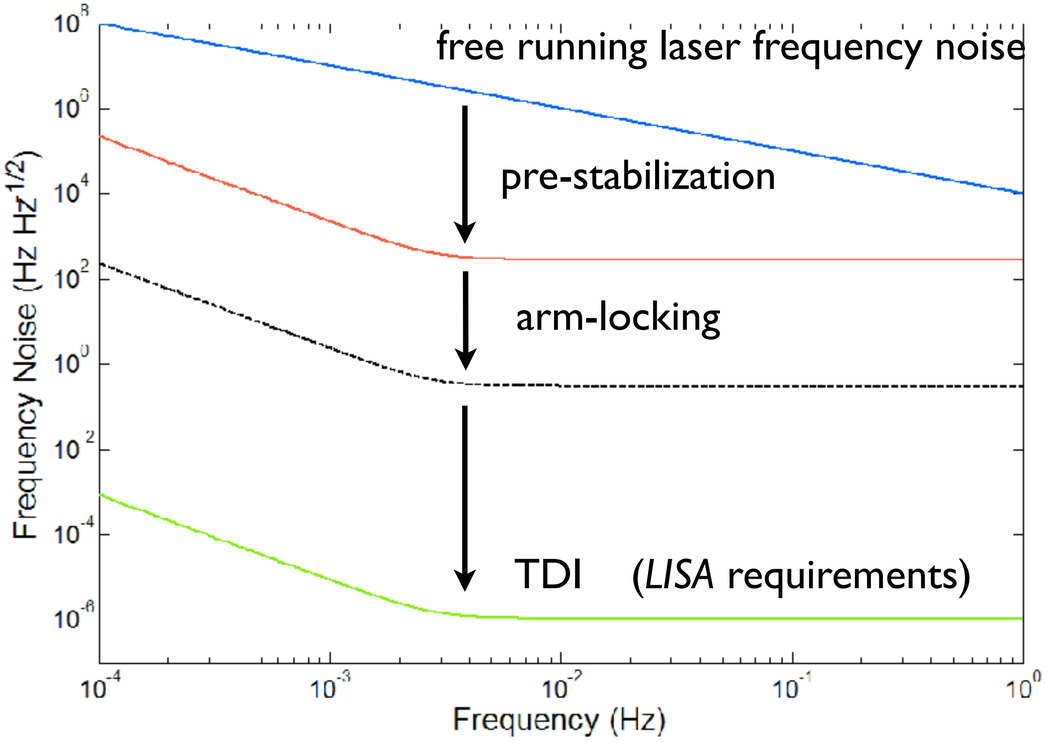


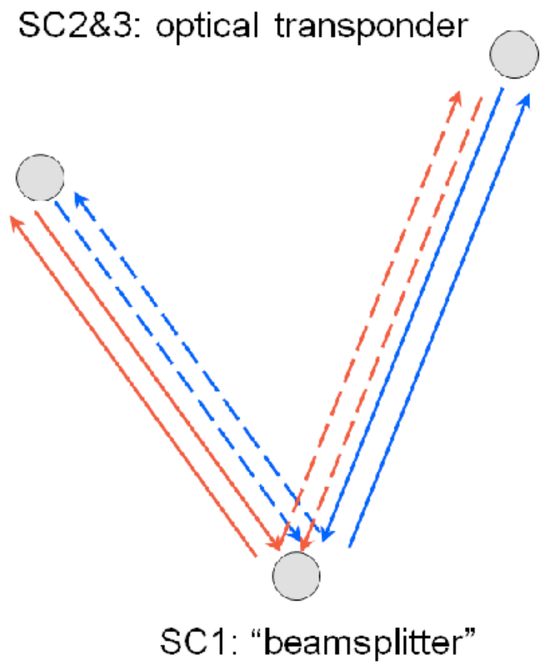


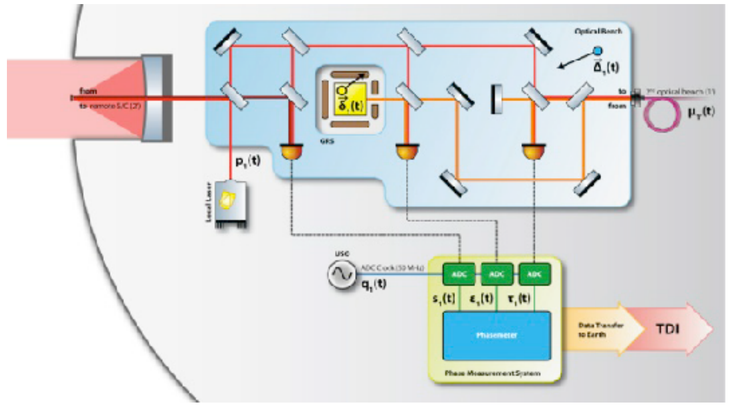


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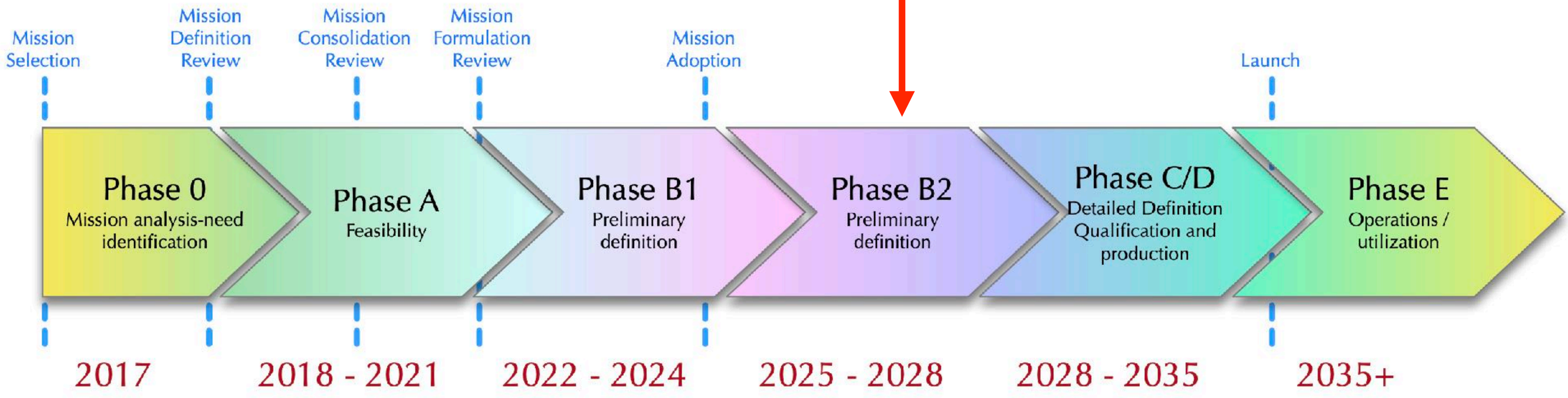


How did we get here?

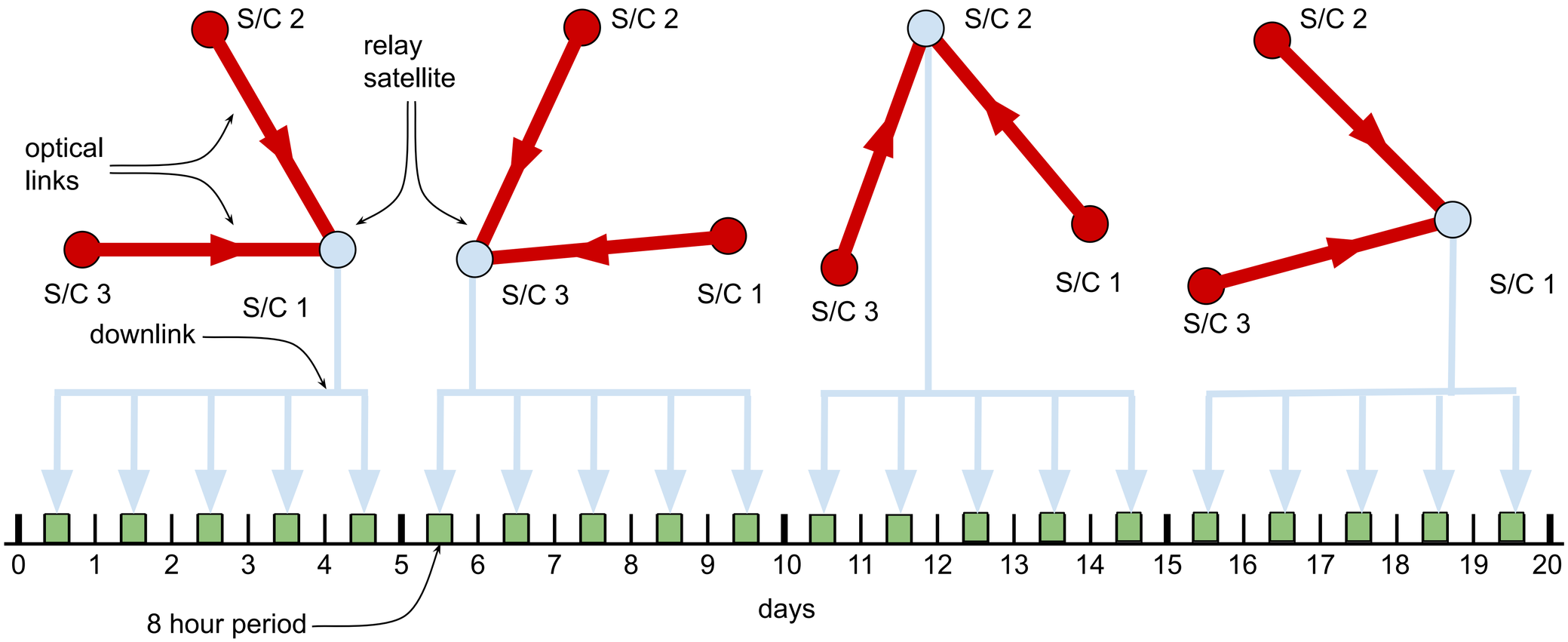
✤ LISA after the selection: Future Missions Department

✳ **2017-2024**: LISA went through the **Mission Preparation Phase**: The Assessment Phase (Phases 0 and A) and Definition Phase (Phase B1), separated by the Mission Formulation Review.

We are now here!

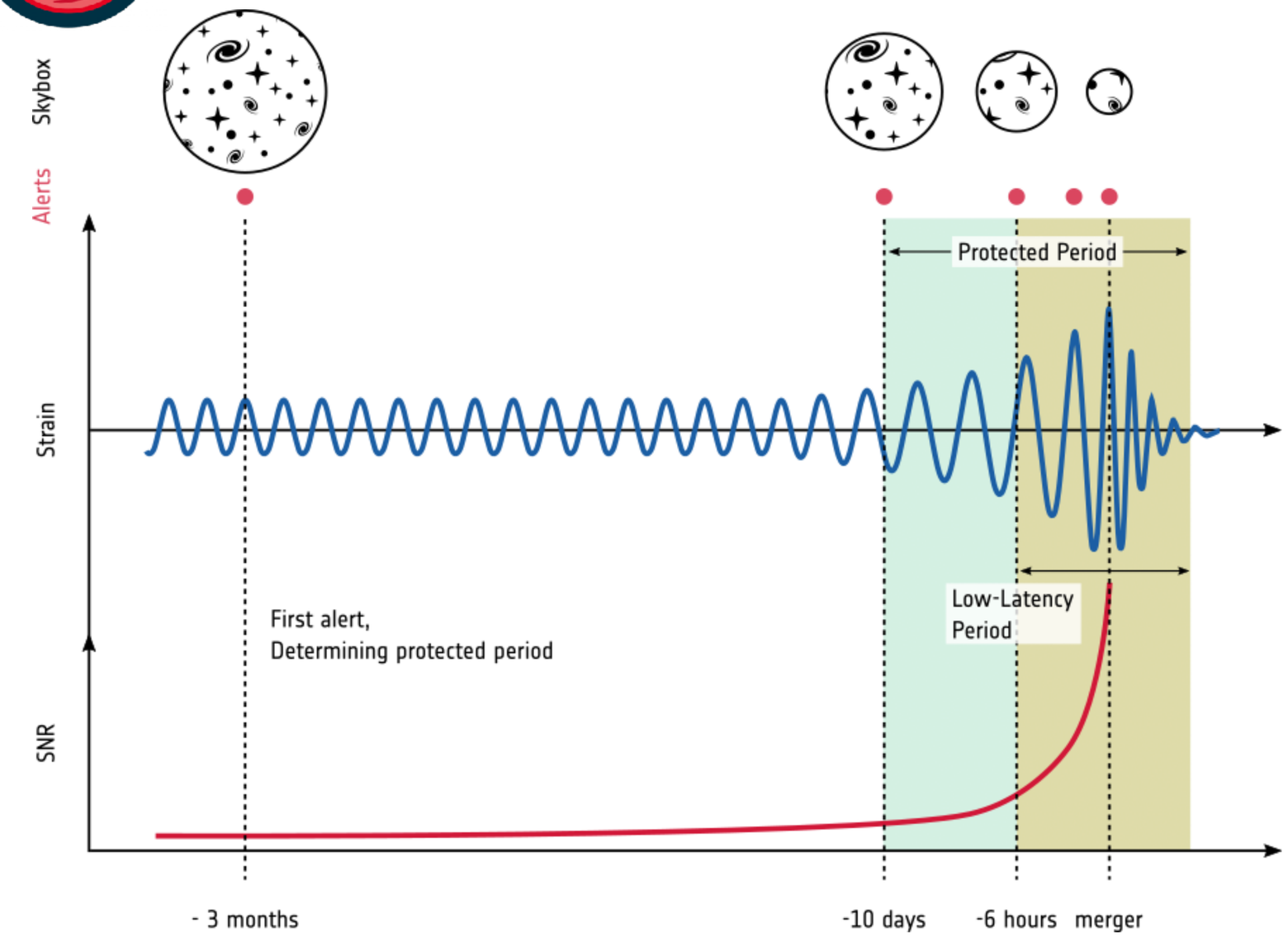


LISA Scientific Operations



Communication with the constellation is done through one of the spacecraft ("relay") for 5 days, establishing a link for 8 hours a day. During these 5 days, the other spacecraft communicate to the relay spacecraft via the existing laser link. After the 5 days, the next spacecraft serves as relay, completing the cycle after 15 days.

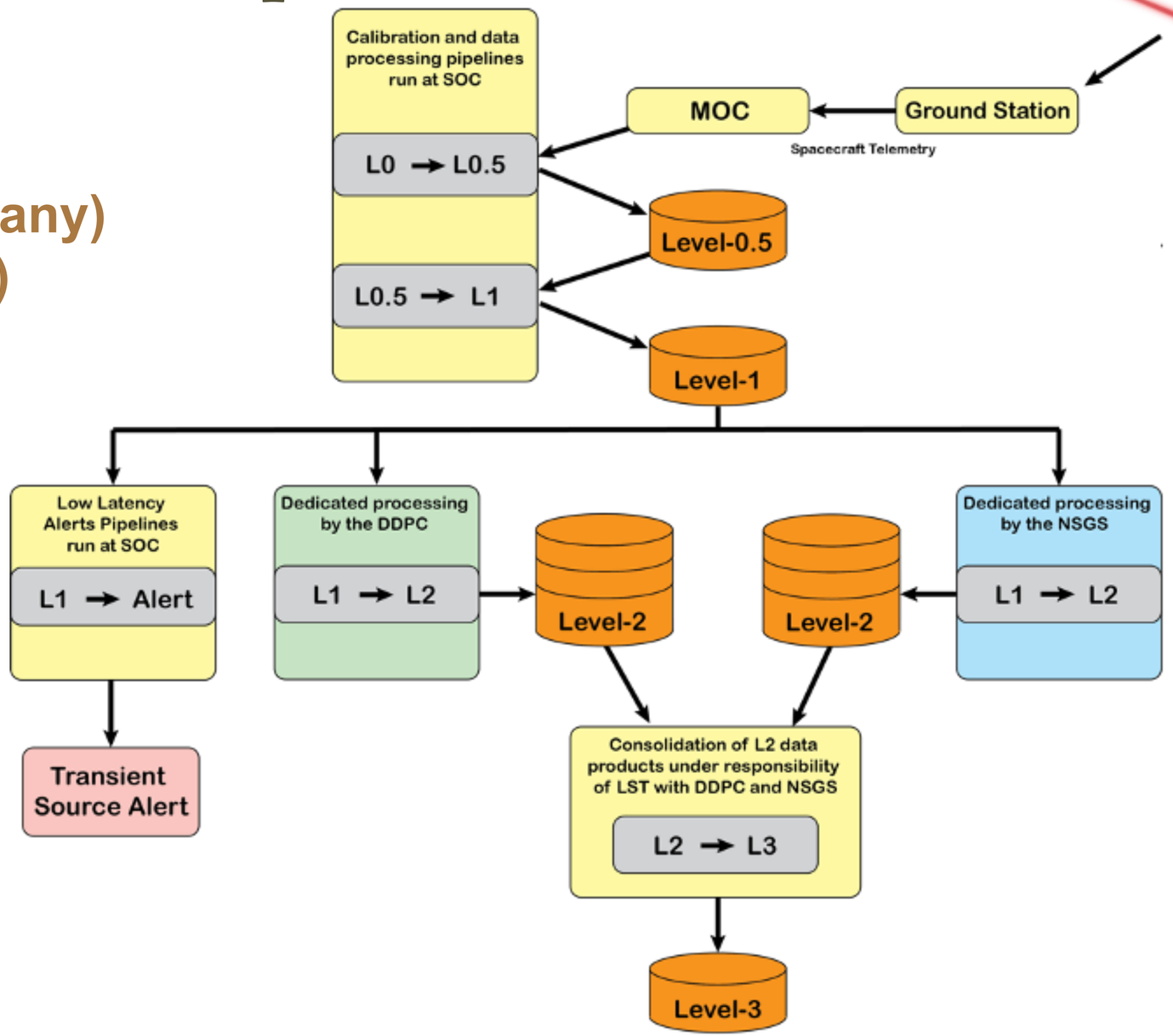
LISA Scientific Operations



The protected period can be requested when the approximate time of the merger of a massive Black Hole binary is known. A few hours before the merger the accumulated signal-to-noise ratio (SNR) increases significantly and the uncertainty region for the sky position ("skybox") shrinks significantly to the point where other observatories can start observations. The low-latency period allows to monitor the continuously shrinking skybox and to update the alerts.

LISA Scientific Operations

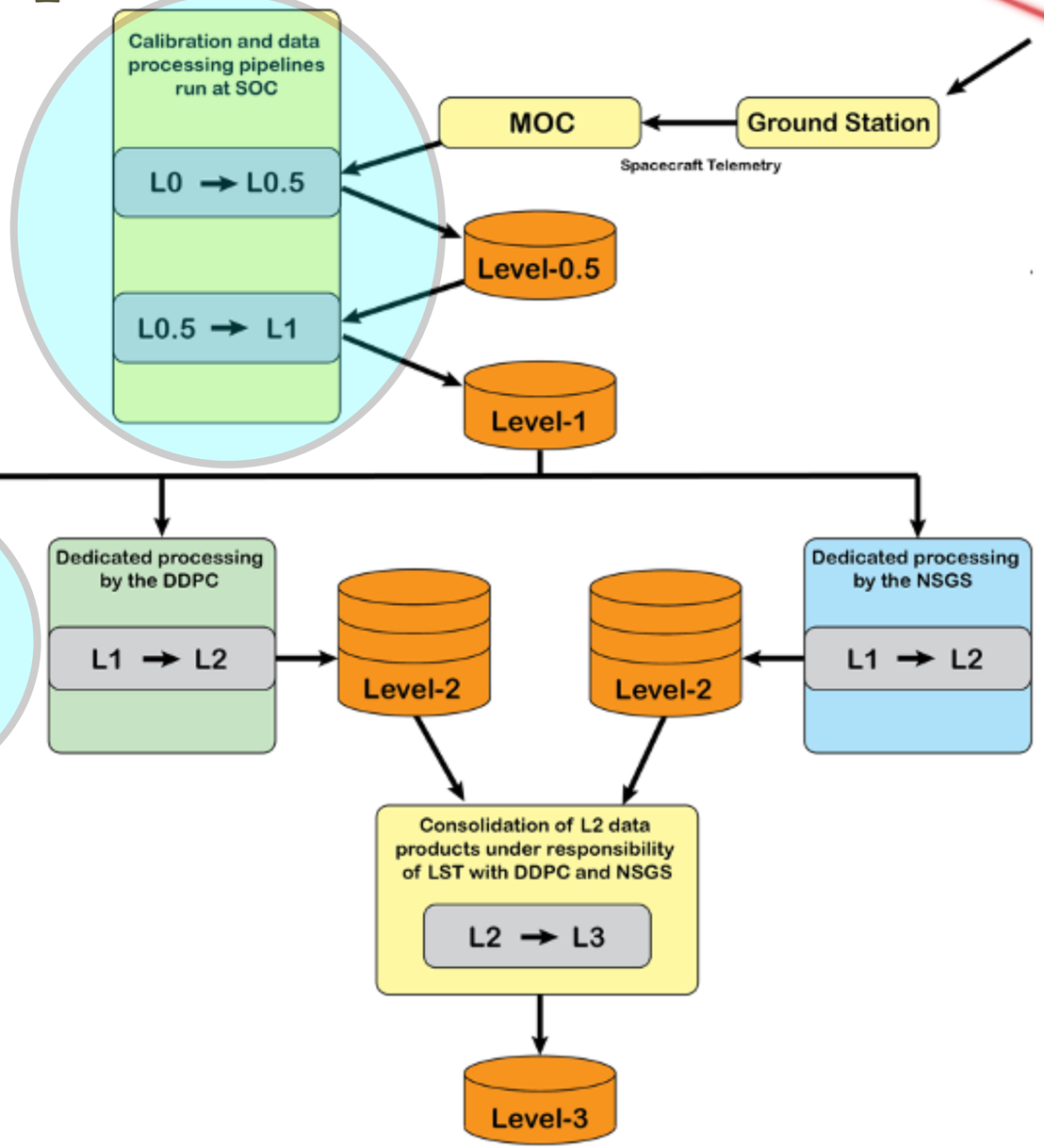
MOC = ESOC (Germany)
SOC = ESAC (Spain)



- **L0 Telemetry: unprocessed at full resolution**
  Time ordered and time-stamped to UTC
- **Level 0.5: Calibrated instrument data**
  Time ordered and time-stamped to UTC
- **Level 1: Time-Delay Interferometry (TDI) combinations**
  At a minimum, A, E, T, X, Y, Z, Sagnac
- **Level 2: Individual detected sources**
  Including posterior probability densities and waveforms
- **Alerts: Transient source alert**
  Including waveform, estimated masses, distance, and sky location
- **Level 3: Catalogue of detected sources**
  Includes the coherent merging of the L2 data products

LISA Scientific Operations

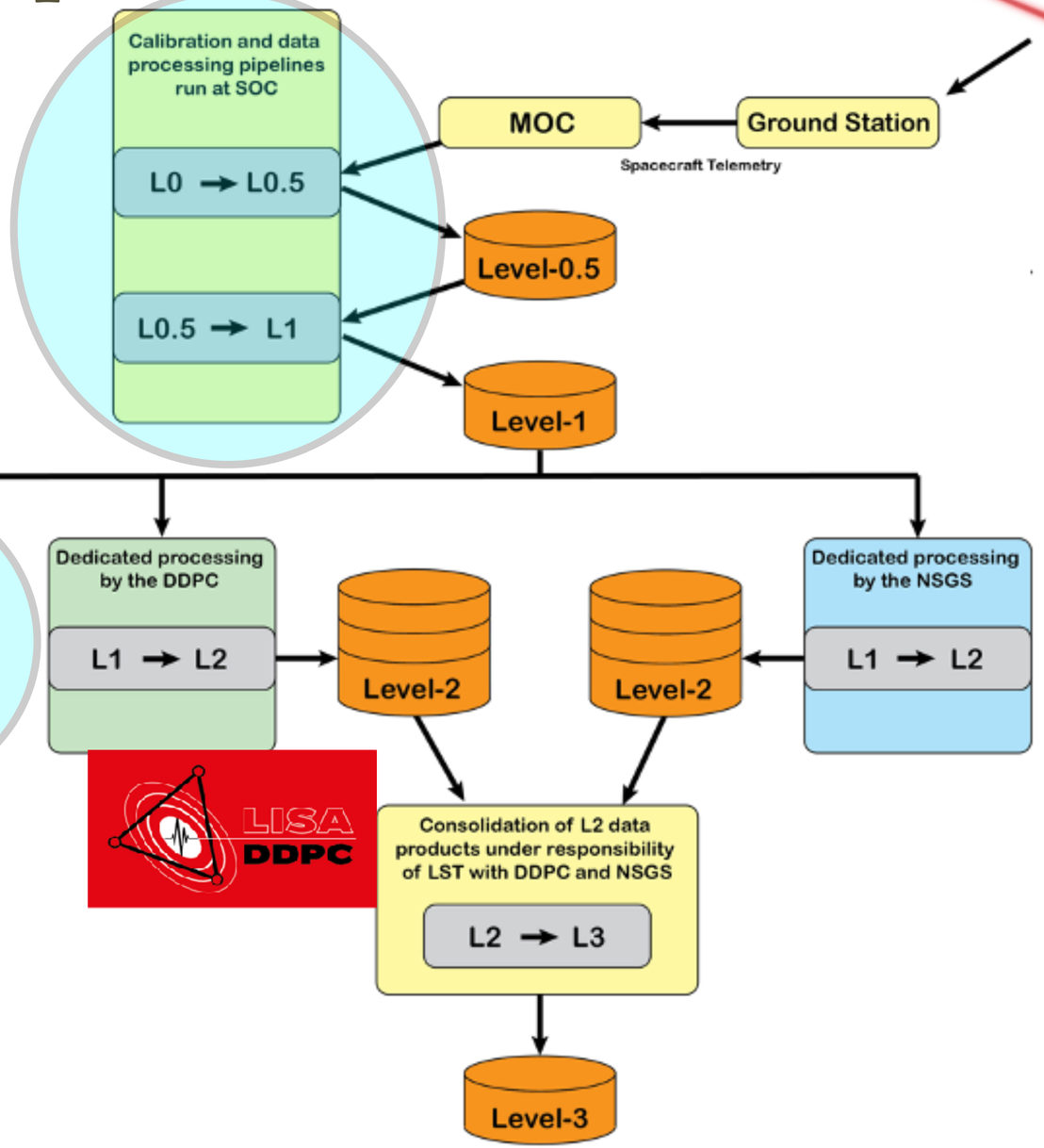
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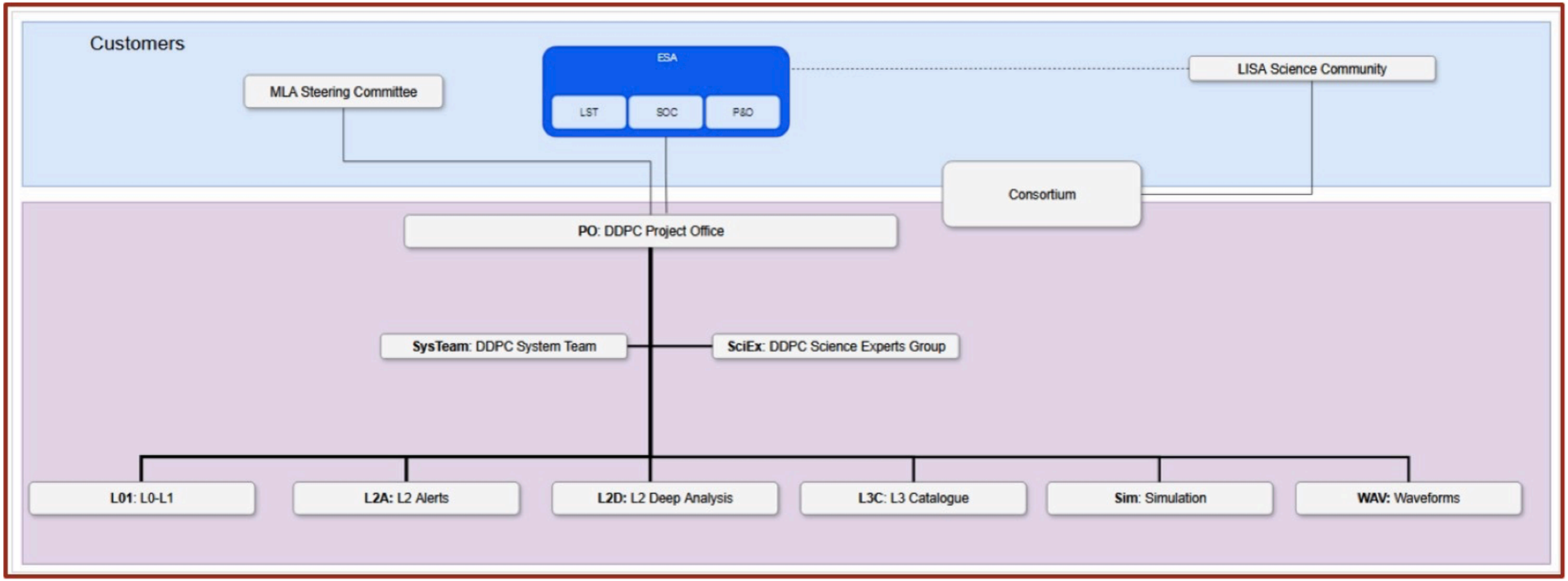
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Carlos F. Sopuerta
Institute of Space Sciences (ICE-CSIC & IEEC)

LISA Distributed Data Processing Centre

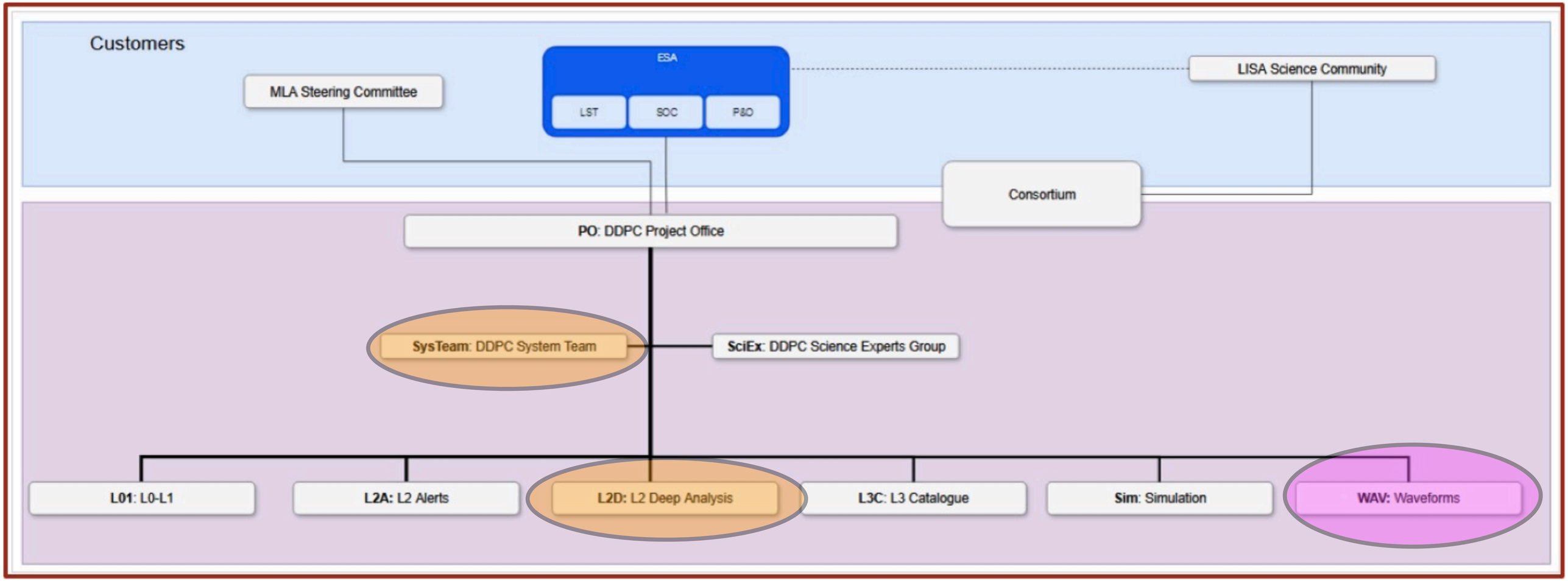
✦Distributed Data Processing Centre (DDPC) Structure



Carlos F. Sopuerta
Institute of Space Sciences (ICE-CSIC & IEEC)

LISA Distributed Data Processing Centre

✦Distributed Data Processing Centre (DDPC) Structure

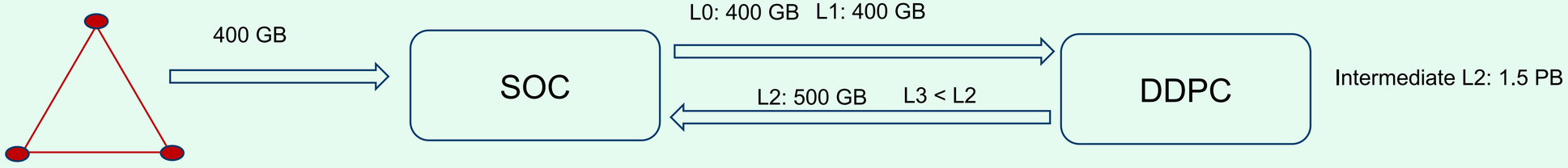


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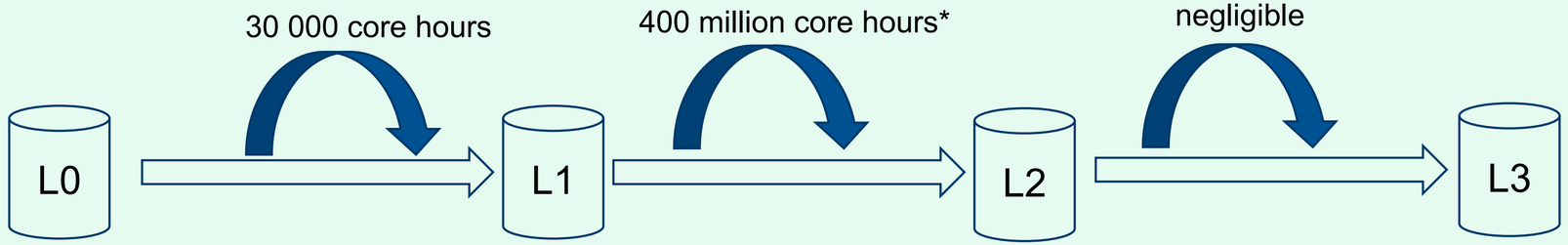
Development of a GFP prototype

Some numbers

Data size per year



Core hours per year



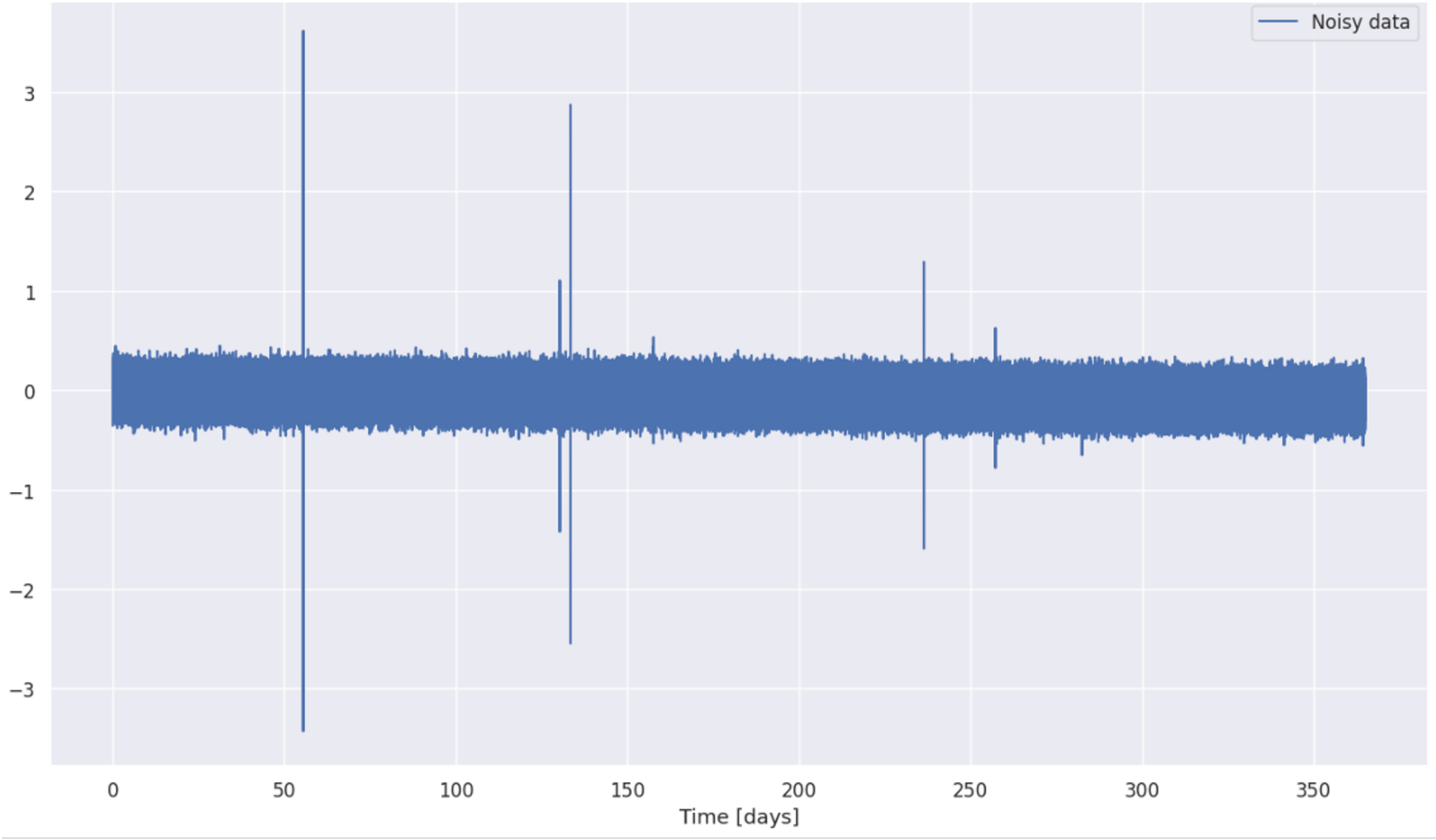
* Considering 2 global fit running in parallel
/!\ Carbon footprint

Carlos F. Sopuerta
Institute of Space Sciences (ICE-CSIC & IEEC)

The Global Fit Problem

✳ Fit the LISA Data to a model including: An instrumental noise model; all the resolvable GW signals (MBHBs, GBs (& VBs), EMRIs, SOBHBs, others?); All the GW foregrounds (GB-foreground, Stochastic-foreground of diverse origin, …).

1-year
LISA data stream

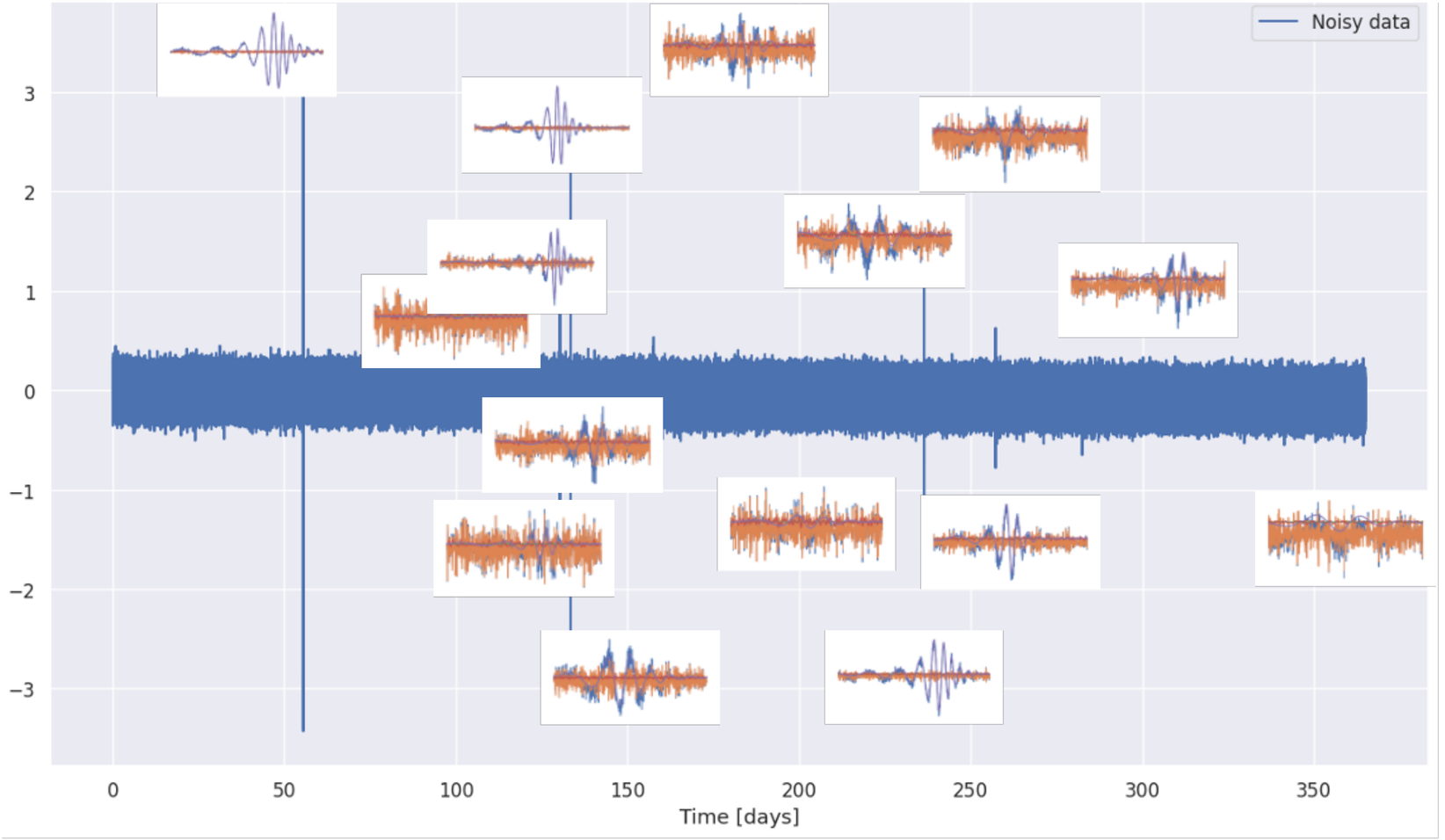


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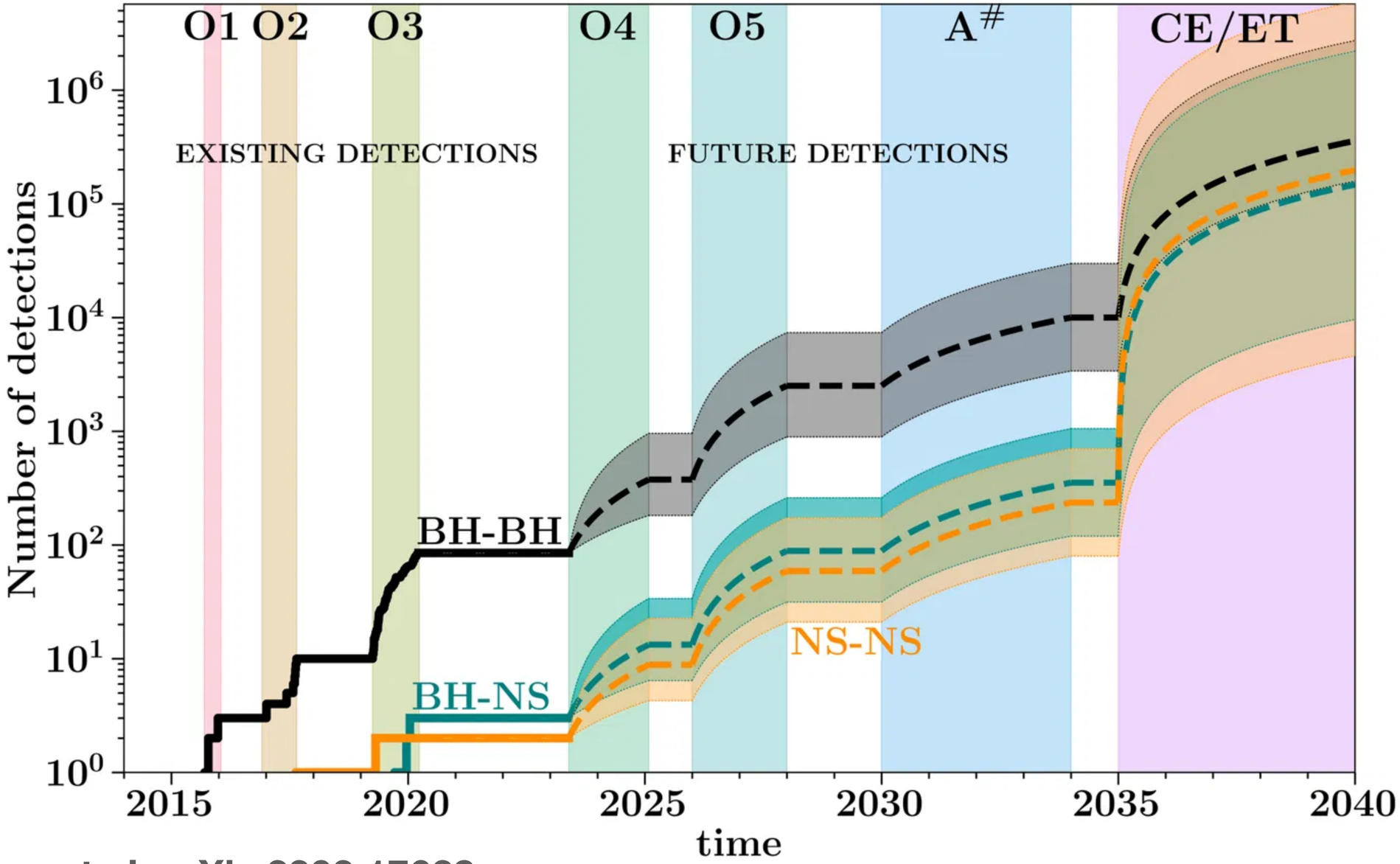
The Global Fit Problem

- **The LISA data strean is expected to contain:**

  - Non-stationary instrumental noise (+glitches, gaps)
  - O(10) MBHBs/year
  - O(10^7) GBs (!!!) Of these, O(10^4) will be individually resolvable.
    There are ~ 37 known GBs: verification binaries
  - O(1-1000) EMRIs
  - O(10^4) SOBHBs
  - SGWBs
  - maybe some surprises...?

✳ The challenge for LISA data analysis is that the data stream contains overlapping GW signals. Individual extraction is not a viable strategy. As we are extracting GW signals the residuals would accumulate and mimic other GW signals.

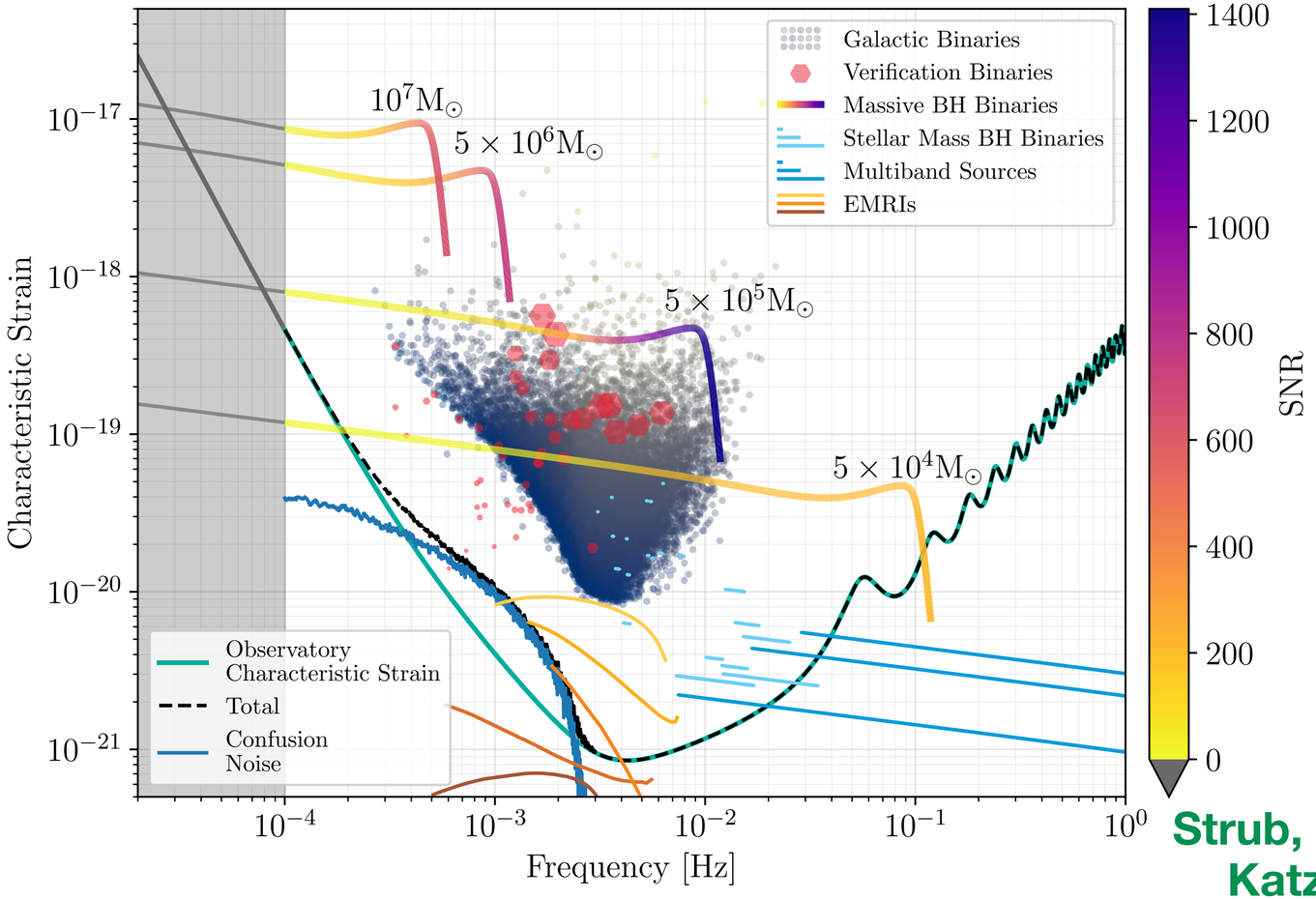
Ground-Based GW Detectors

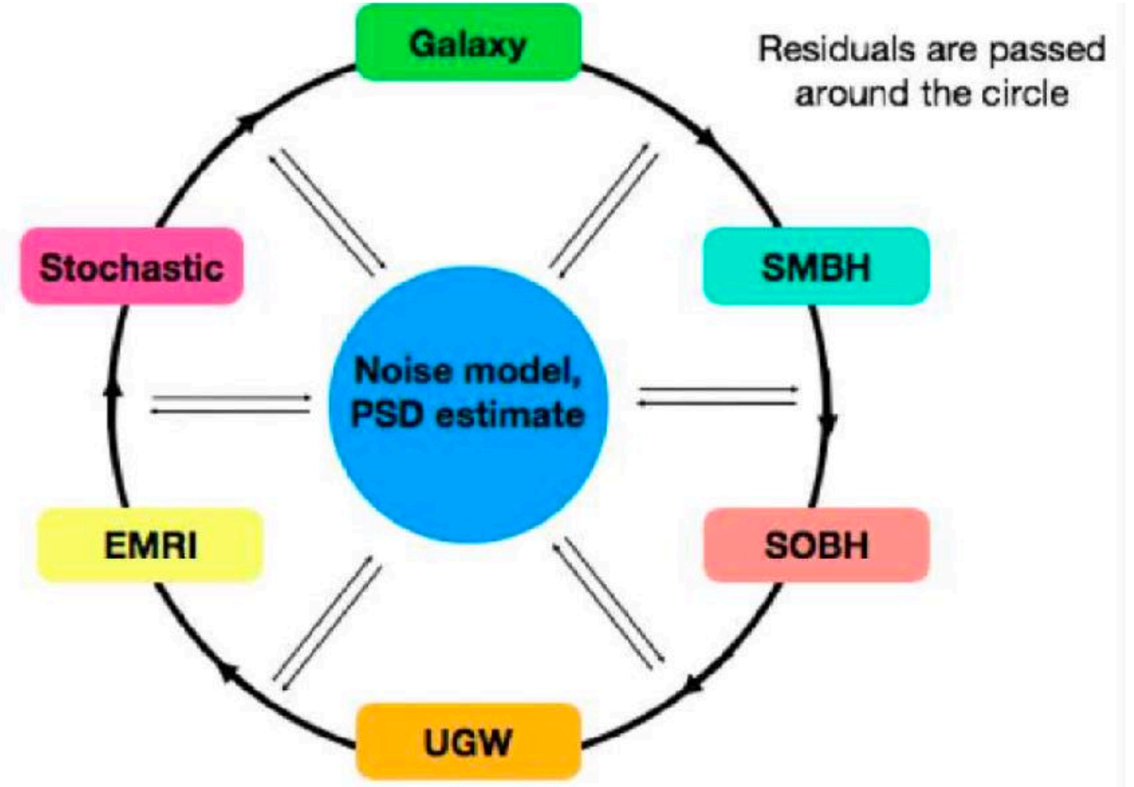


Broekgaarden et al, arXiv:2303.17628

The Global Fit Problem

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Littenberg & Cornish: 2301.03673
Strub, Ferraioli, Schmelzbach, Stähler & Giardini: 2403.15318
Katz, Karnesis, Korsakova, Gair & Stergioulas: 2405.04690
Deng, Babak, Le Jeune, Marsat, Plagnol & Sartirana: 2501.10277

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Institute of Space Sciences (ICE-CSIC & IEEC)

LISA Scientific Operations: LISA Data Challenges

Synergies here?

VTD: 2025

- **Mojito**
- Full enchilada: GBs, MBHBs, EMRIs, SBBH
- Artifacts optional 2 years
- Time iterative analysis,
- Alert pipeline

VTD: 2028

- **Long Island Iced Tea (Adios)**
- Full enchilada + SGWB
- all artifacts, 2 or 3 years
- Time iterative analysis, alert pipeline



Time critical → release

VTD: 2031

- **Aunt Roberta**
- Operational pipeline
- blind , most complete
- Live data
- Alerts



Time critical → release

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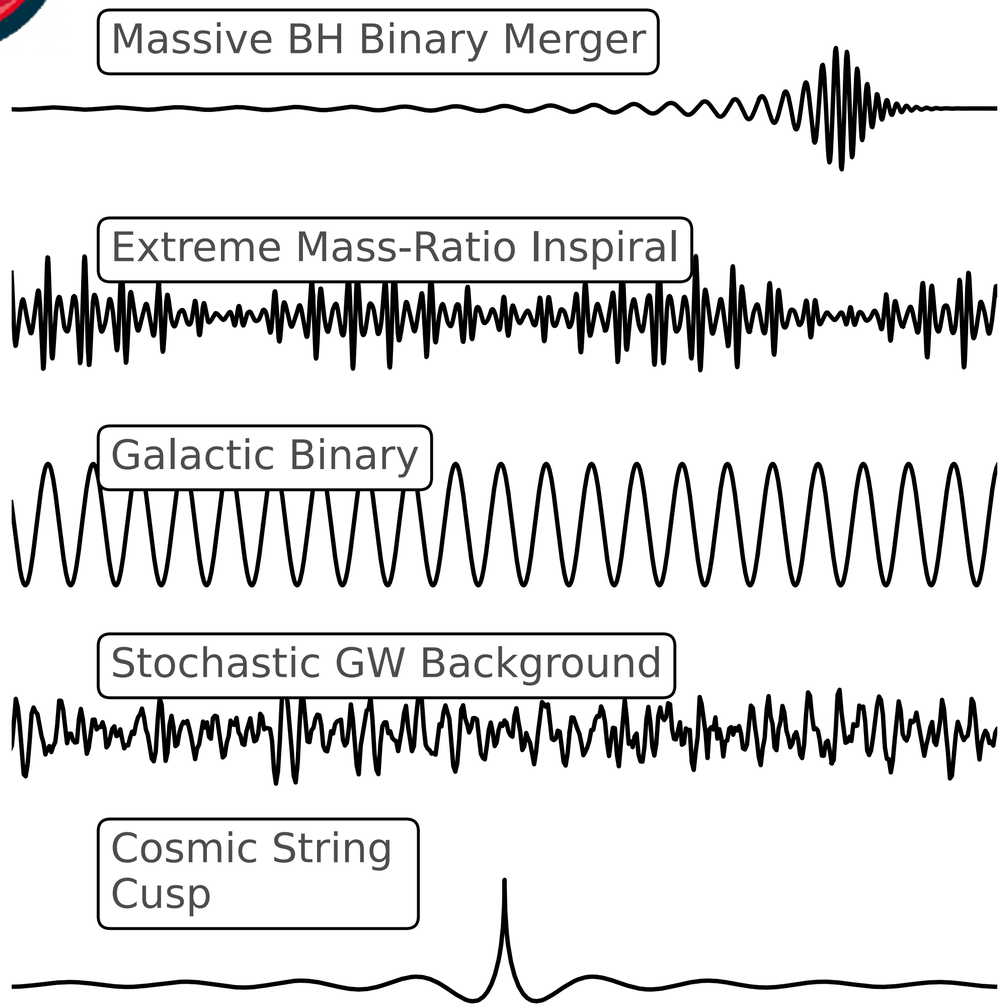
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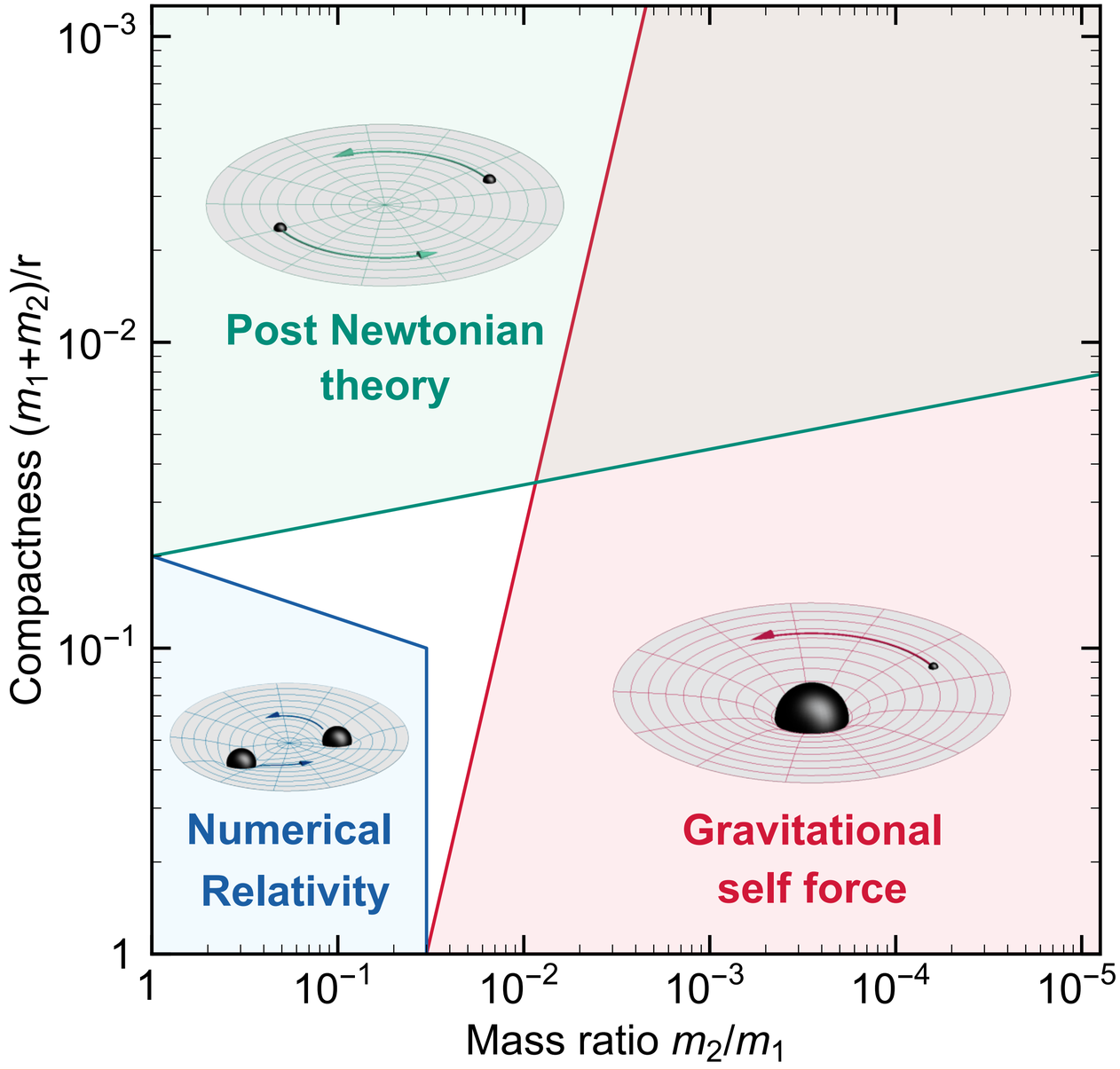
Slides from Stas Babak

LISA Scientific Operations



The importance of accurate, efficient and effective waveforms!

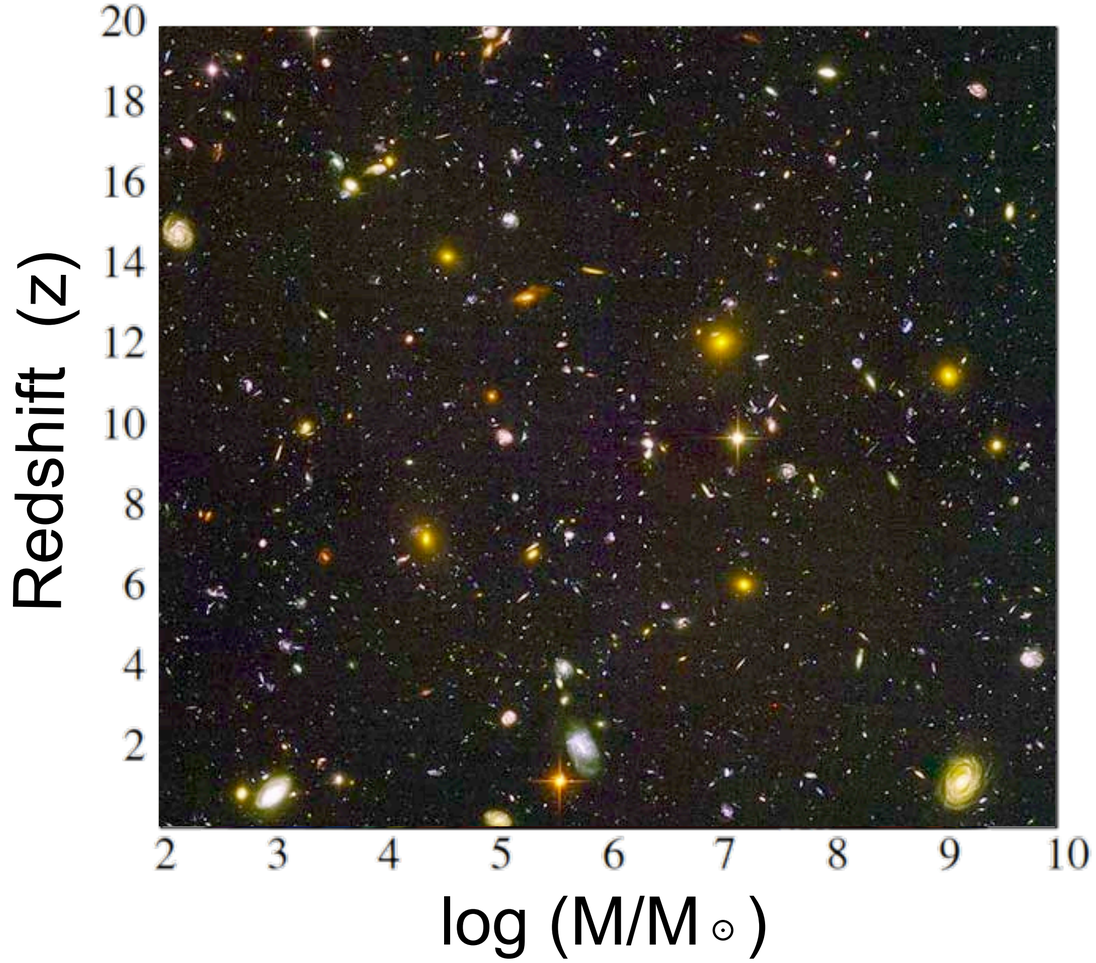
Clear Synergy here!



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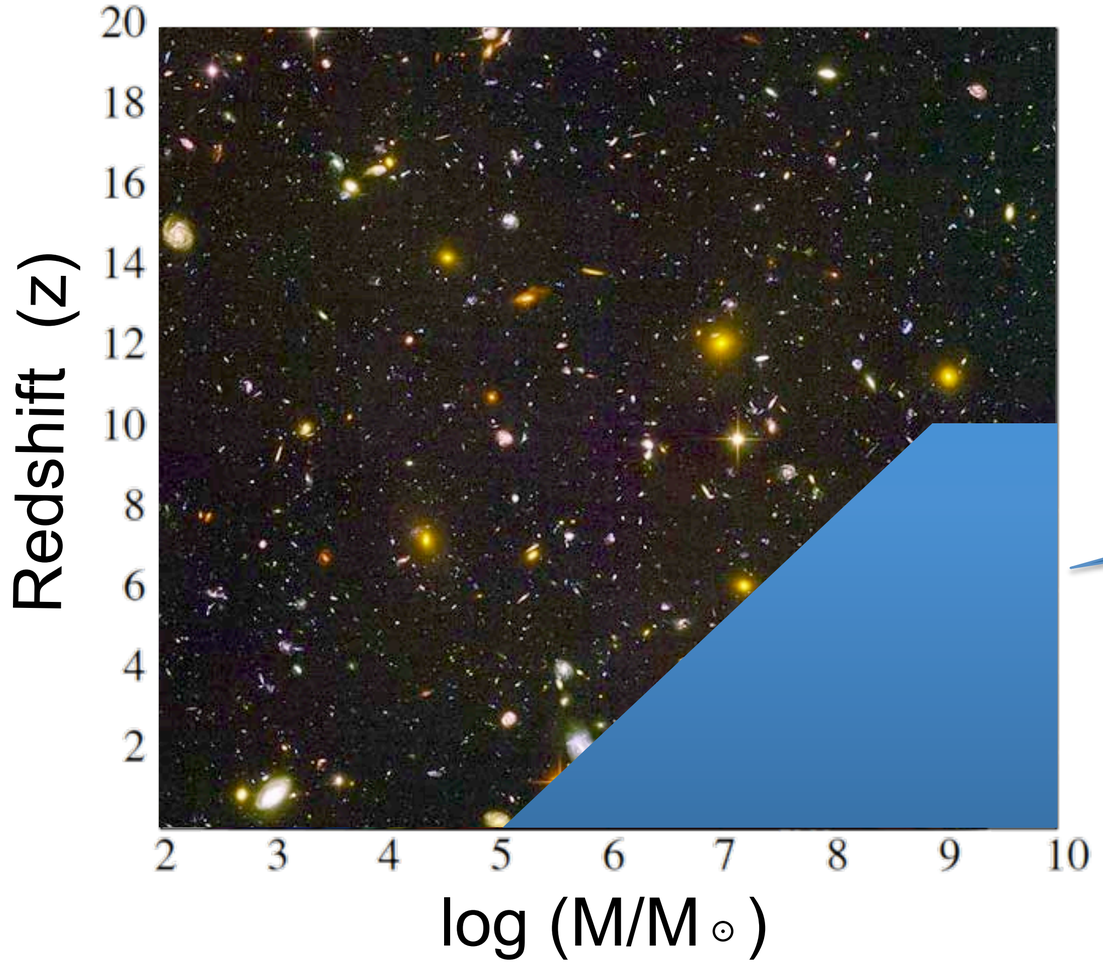
The LISA Scientific Program

✳ Landscape of Astrophysical/Cosmological Black Holes (in the Future):



The LISA Scientific Program

✳ Landscape of Astrophysical/Cosmological Black Holes (in the Future):



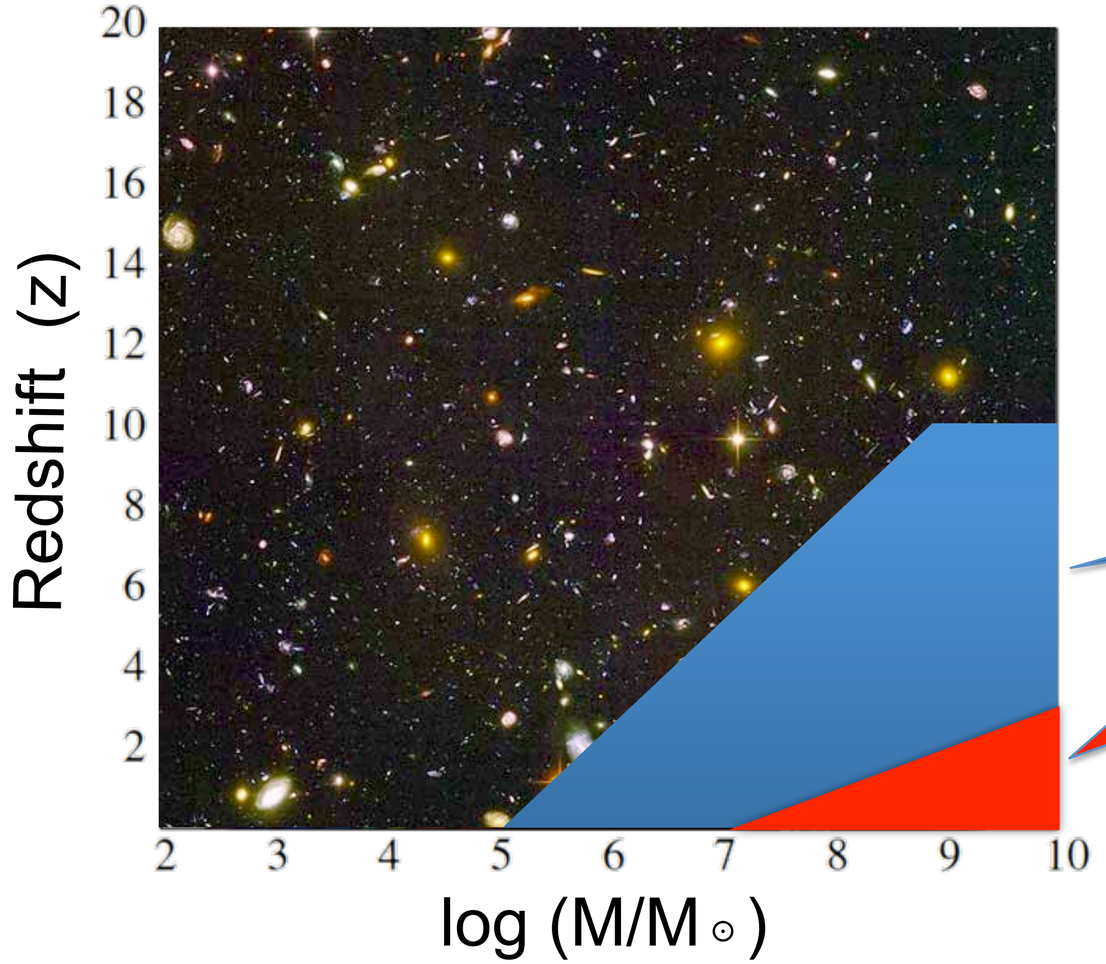




Future EM Obs.
LSST, JWST, EELT

The LISA Scientific Program

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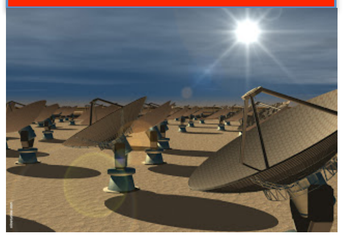






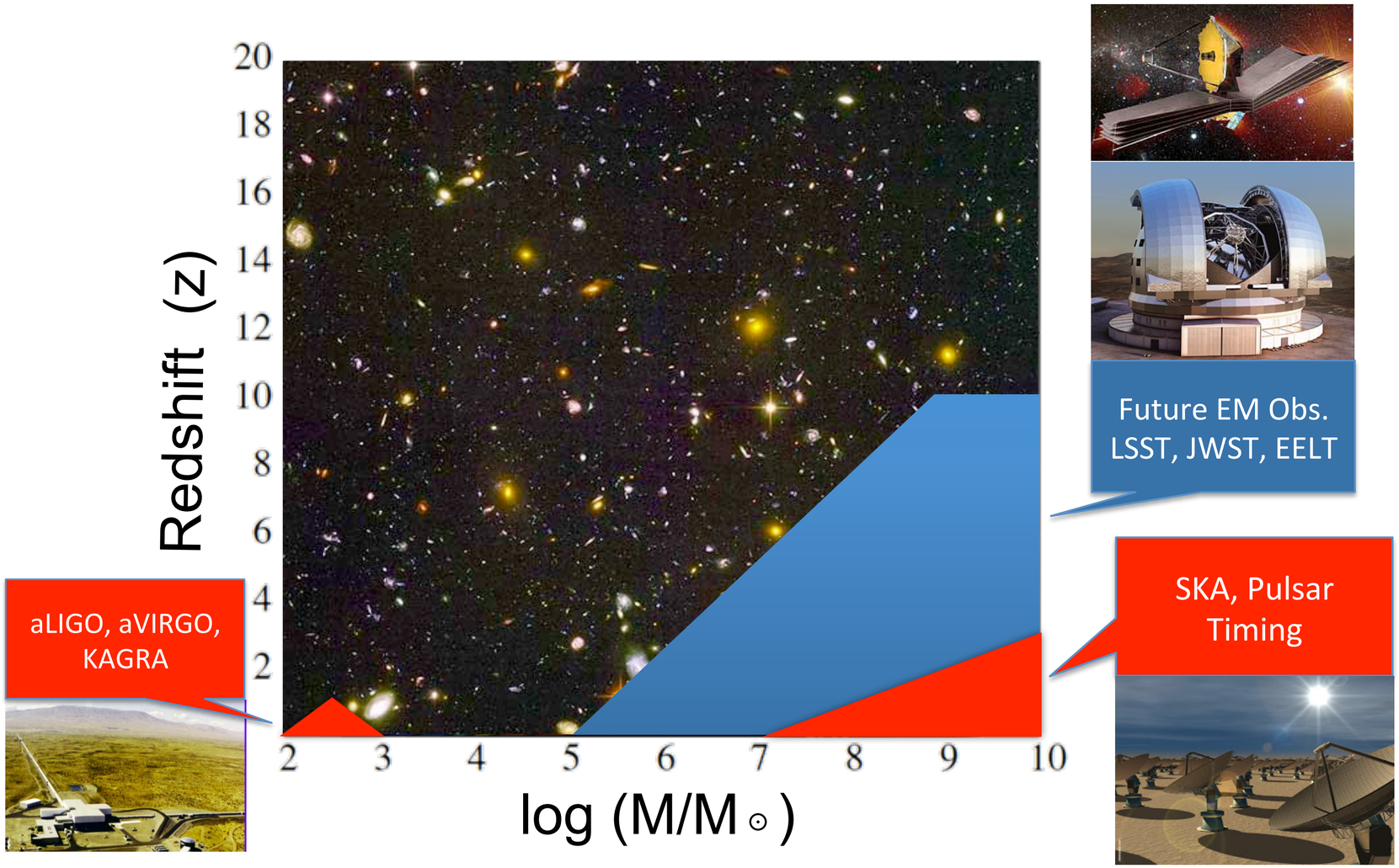
Future EM Obs.
LSST, JWST, EELT

SKA, Pulsar Timing



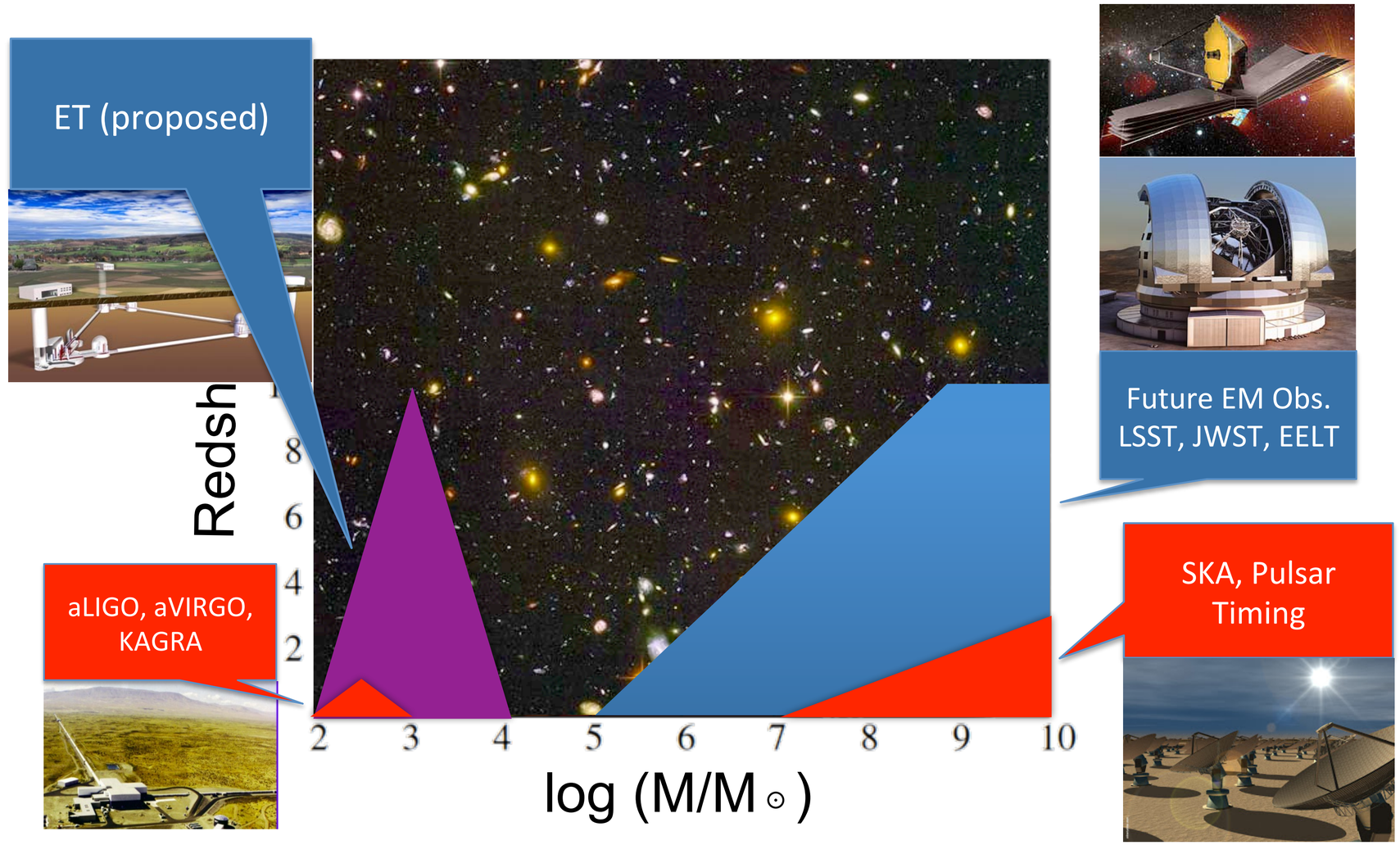
The LISA Scientific Program

✳ Landscape of Astrophysical/Cosmological Black Holes (in the Future):



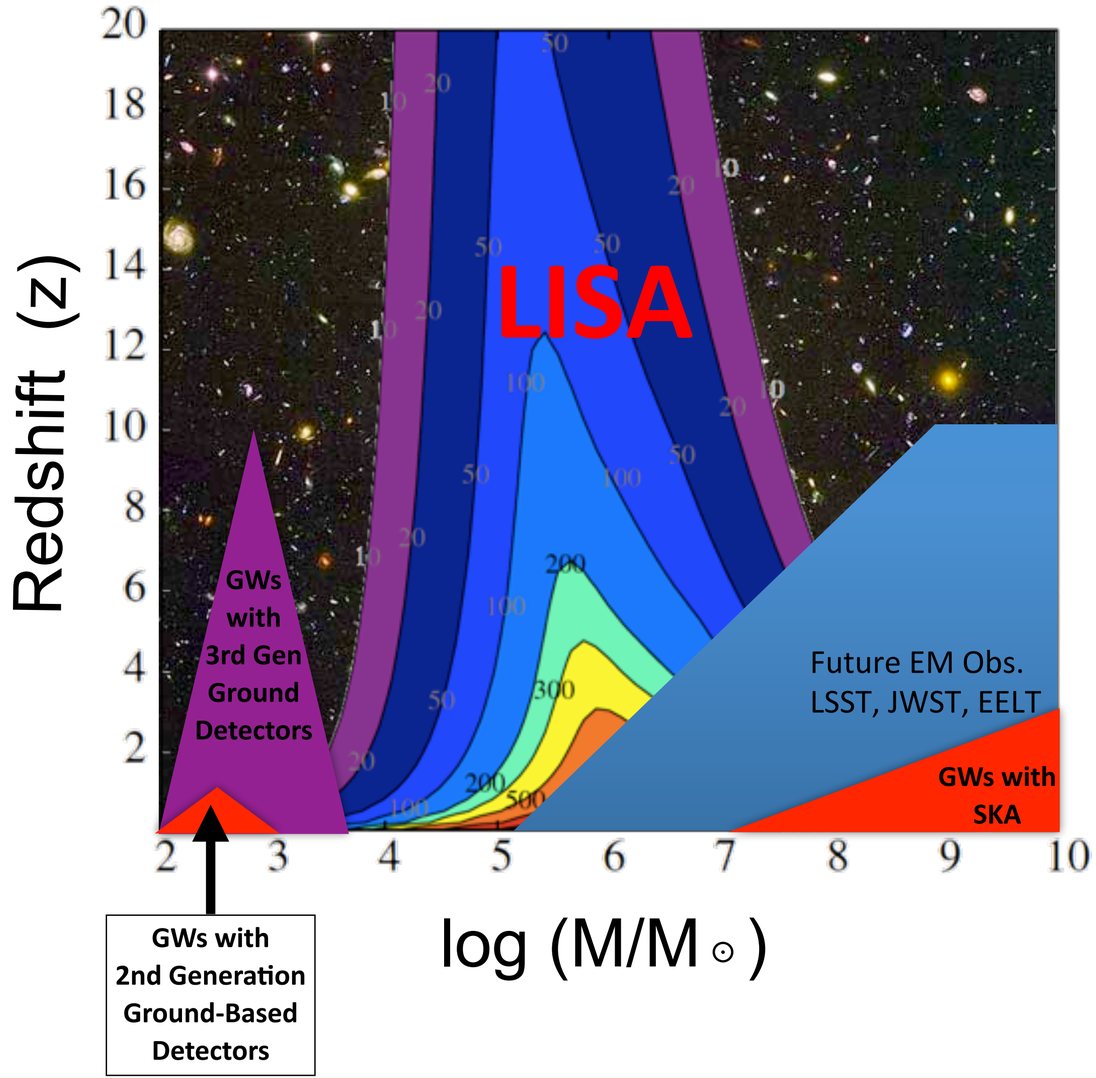
The LISA Scientific Program

✳ Landscape of Astrophysical/Cosmological Black Holes (in the Future):



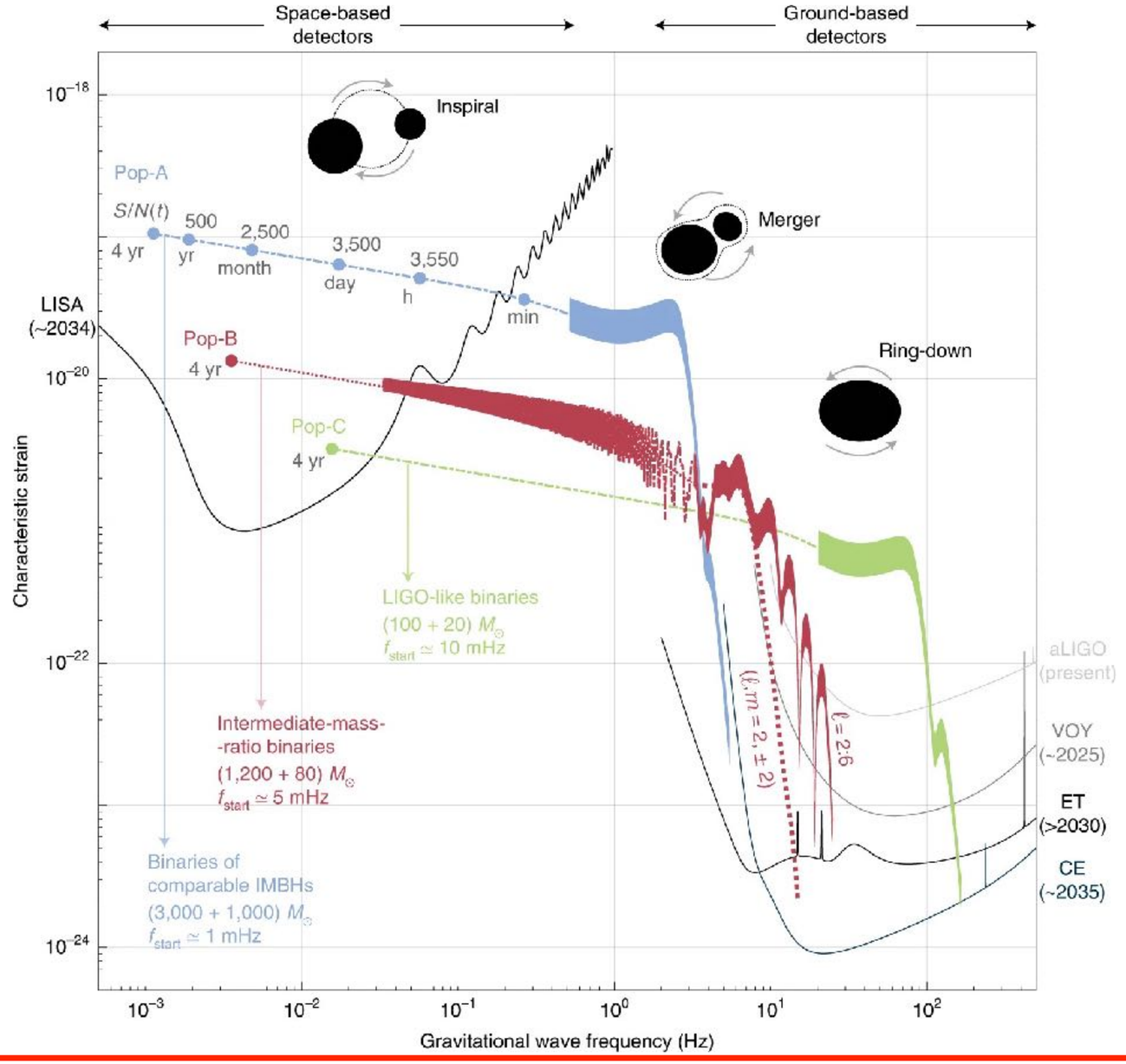
The LISA Scientific Program

✳ Landscape of Astrophysical/Cosmological Black Holes (in the Future):



Multiband GW Astronomy with LISA and ET/CE

From: Jani, K., Shoemaker, D. & Cutler, C. (2020): *Detectability of* ***intermediate-mass black holes*** *in multiband gravitational wave astronomy*. Nat Astron **4**, 260–265



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