Mission history and overview

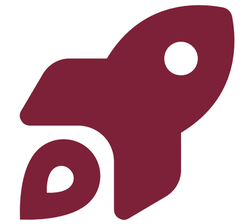
LISA yesterday, today, and tomorrow…

ÉCOLE DE PHYSIQUE DES HOUCHES

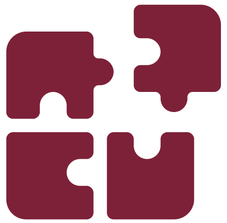
Jean-Baptiste Bayle – 7 October 2025 – LISA School for Early-Career Scientists (Les Houches)

Roadmap

History & detections



LISA mission recent develop.



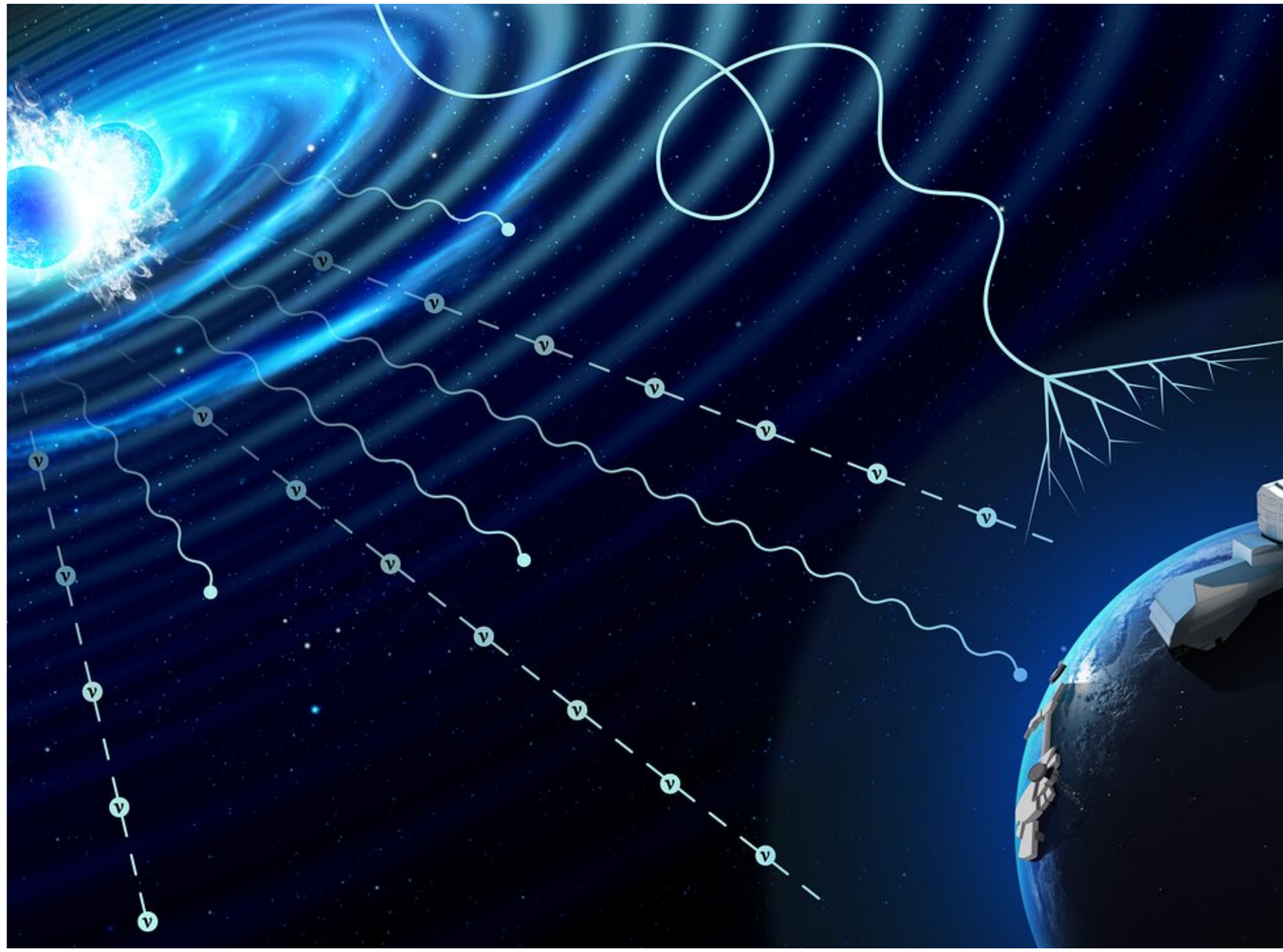
How is LISA organized?

Perspectives and summary

A very brief history of gravitational-wave detection

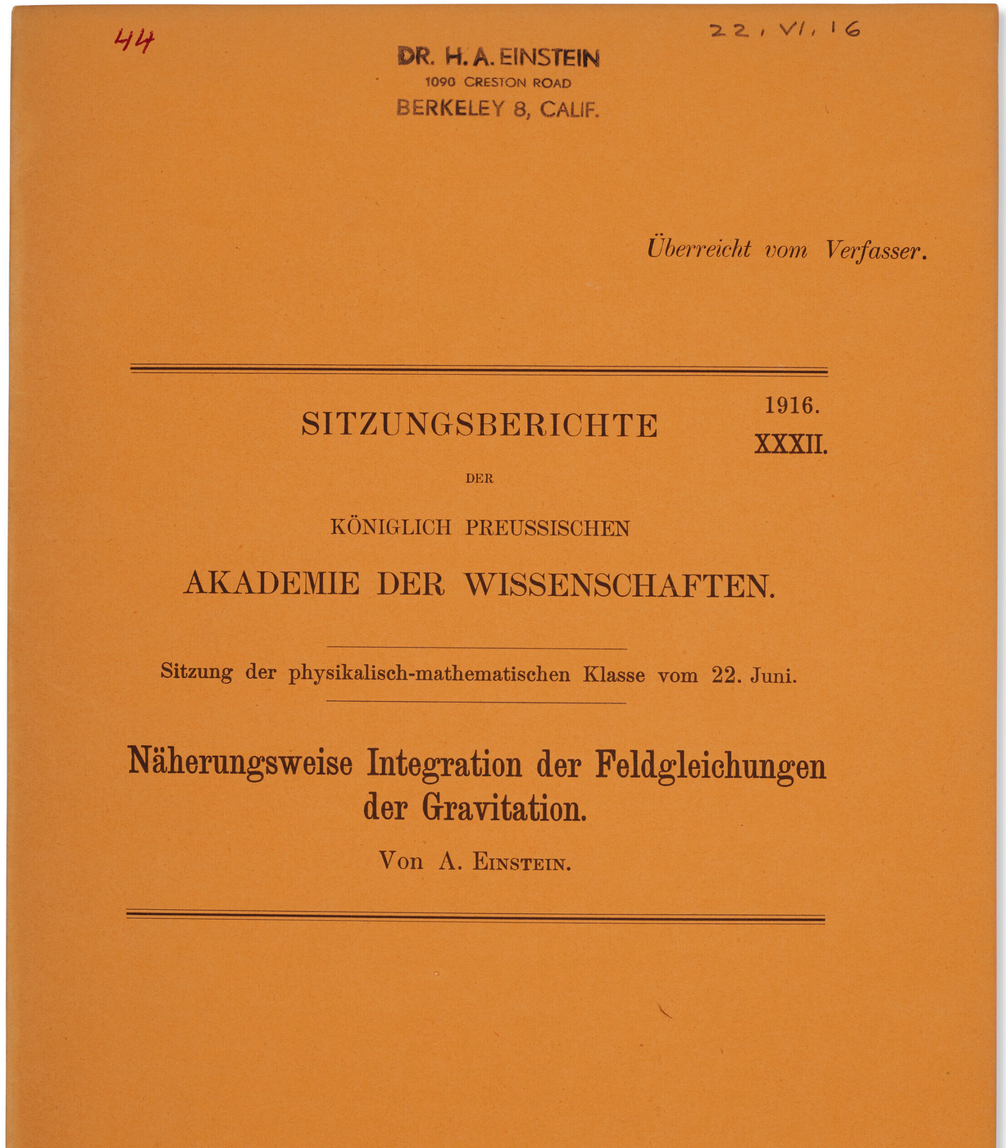
Why gravitational waves matter

- **New messenger** – Gravitational waves carry information about motion of massive bodies, not light emitted from them
- **Probe strong gravity directly** – Reveal phenomena invisible to telescopes: black-hole mergers, extreme-mass-ratio inspirals, early-Universe backgrounds
- **Complements light & particles** — Multi-messenger astronomy (GW + EM + neutrinos) gives a complete cosmic picture



Einstein's prediction

- **Einstein predicts gravitational waves (1916-1918)**
  - Solutions of the linearized Einstein equations
  - Ripples of curvature propagating at *c*
- **Early skepticism**
  - Einstein himself doubted detectability
  - Debates with Eddington, Rosen (30s) about whether they carry energy
- **Conceptual leap**
  - Transverse, quadrupolar strain $h = \Delta L/L \sim 10^{-21}$ for astrophysical sources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22, VI, 16

DR. H. A. EINSTEIN
1090 CRESTON ROAD
BERKELEY 8, CALIF.

Überreicht vom Verfasser.

SITZUNGSBERICHTE 1916. XXXII.

DER

KÖNIGLICH PREUSSISCHEN

AKADEMIE DER WISSENSCHAFTEN.

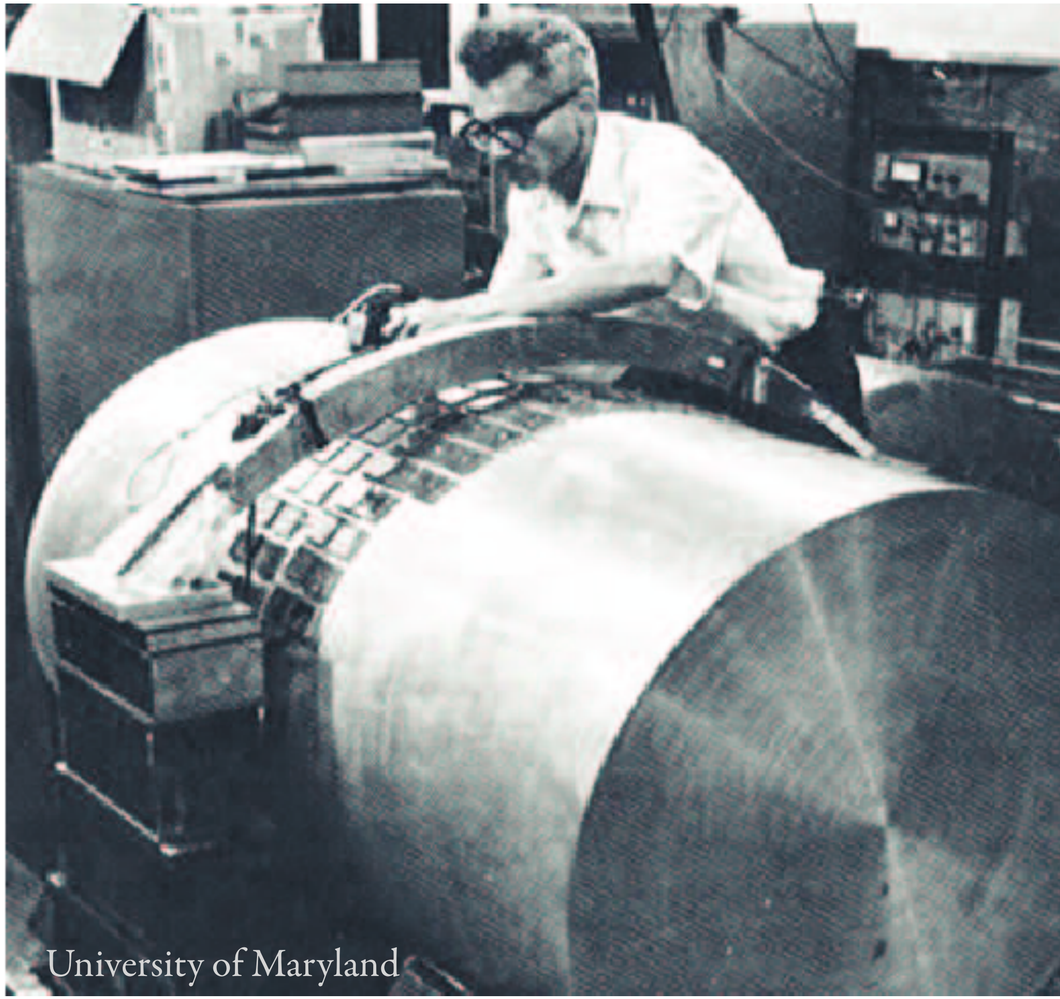
Sitzung der physikalisch-mathematischen Klasse vom 22. Juni.

Näherungsweise Integration der Feldgleichungen der Gravitation.

Von A. Einstein.

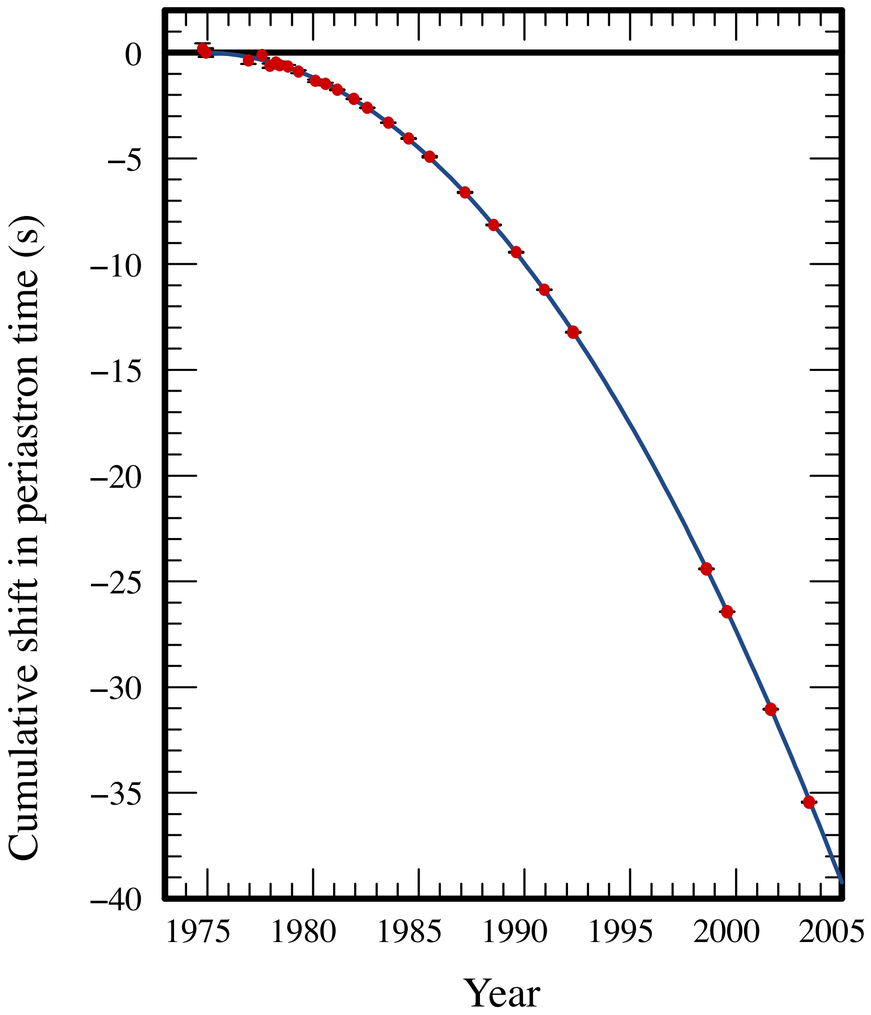
Weber’s resonant bars

- **Joseph Weber** (University of Maryland, late 1950s) **built massive aluminum cylinders** (2x1m, 1 ton) **to resonate at ~1 kHz**
- **Detection principle**
  - A passing GW excites the bar’s fundamental mode
  - Piezoelectric sensors detect nanometric oscillations
- **In 1969, Weber announces detections!**
  - Claimed coincident signals between two bars (Maryland & Chicago): first GW “events”
- **Follow-up & legacy**
  - Others failed to reproduce; controversy ensued
  - Inspired decades of improvements


University of Maryland

The Hulse–Taylor binary pulsar

- **Orbital decay observed on PSR B1913+16**
  - Period decreases by ≈ 76 μs per year
  - **Matches energy loss predicted by GW emission**
- **First experimental confirmation**
  - Proved GWs are real and carry energy away from the system
  - Precision agreement better than 0.2 %.
  - **Nobel Prize 1993** awarded to Hulse & Taylor “for the discovery of a new type of pulsar, providing a unique laboratory for testing general relativity”
- **Validated GR radiation theory** → motivated long-baseline interferometers (Weiss, Thorne, Drever)



The long road to LIGO and Virgo

- **Idea (early 70s)**
  - Rainer Weiss (MIT) analyzes noise sources; proposes km-scale laser interferometer for GW detection
  - Parallel work: Ron Drever

- **Building the network**
  - 80s-90s: prototypes at MIT, Glasgow, Garching, Pisa
  - 1992: NSF approves LIGO
  - 1994: Virgo project launched by

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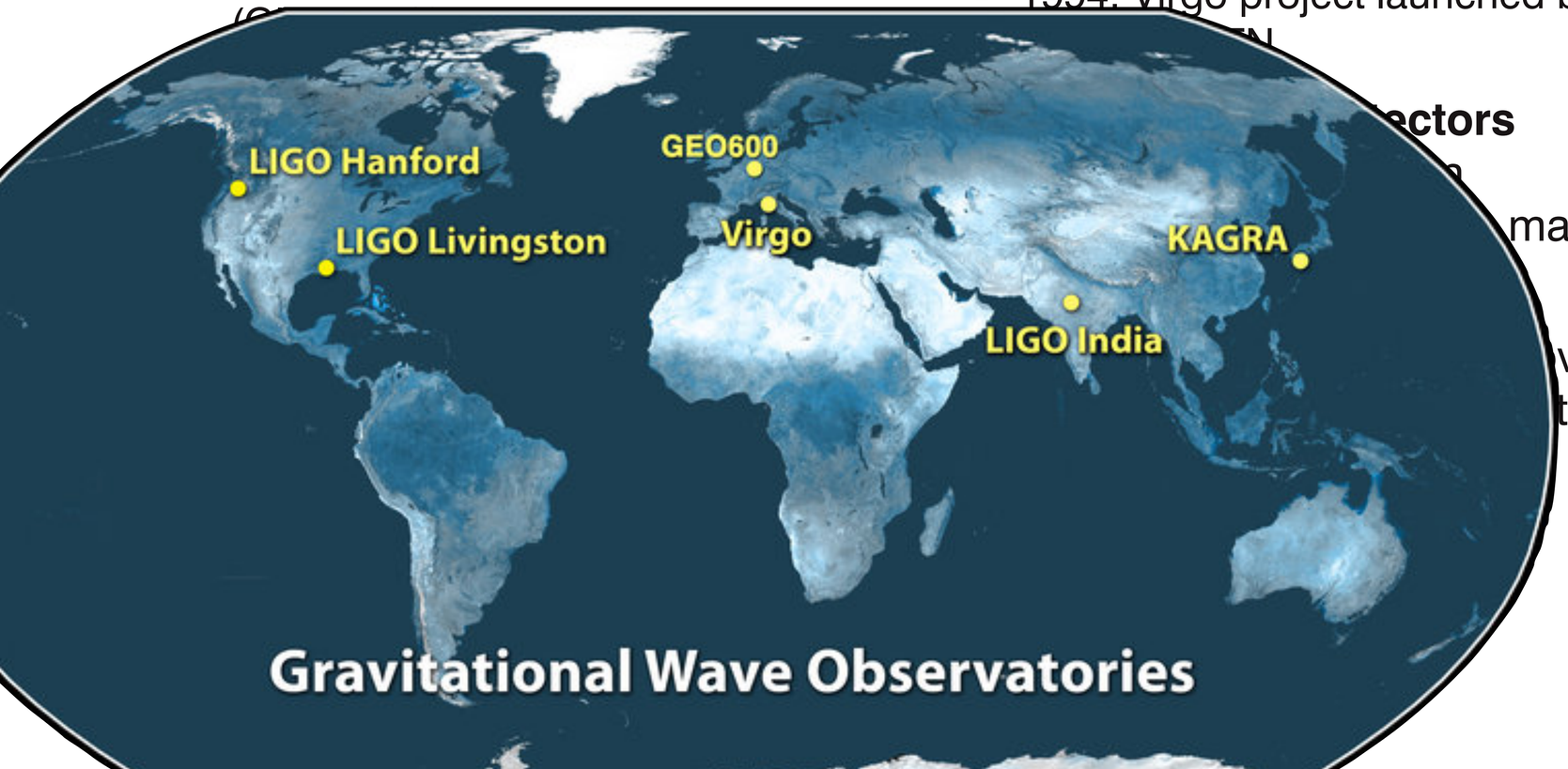
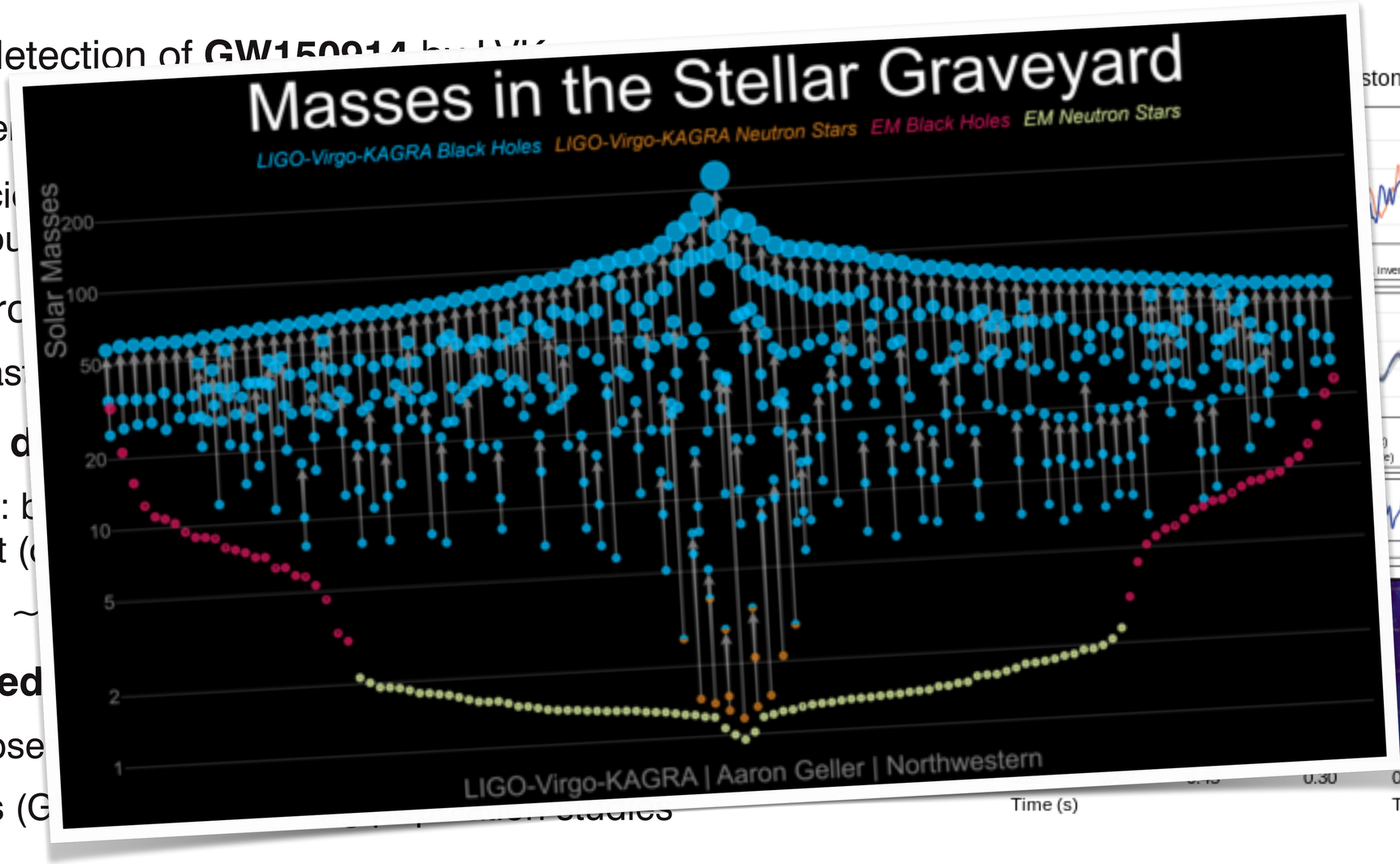
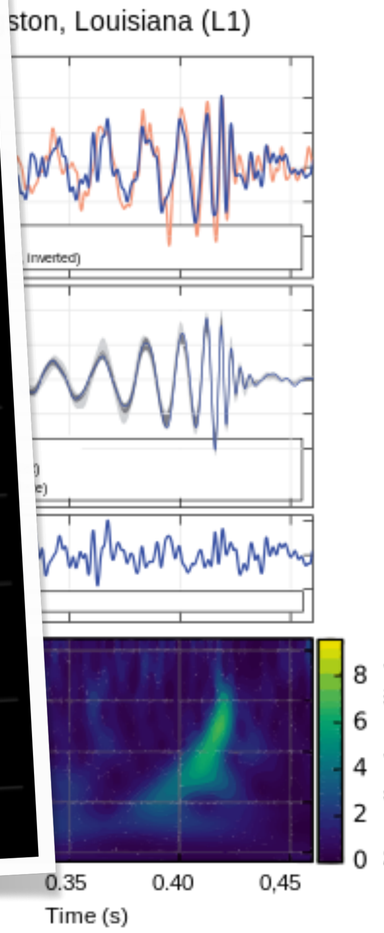



Virgo detector

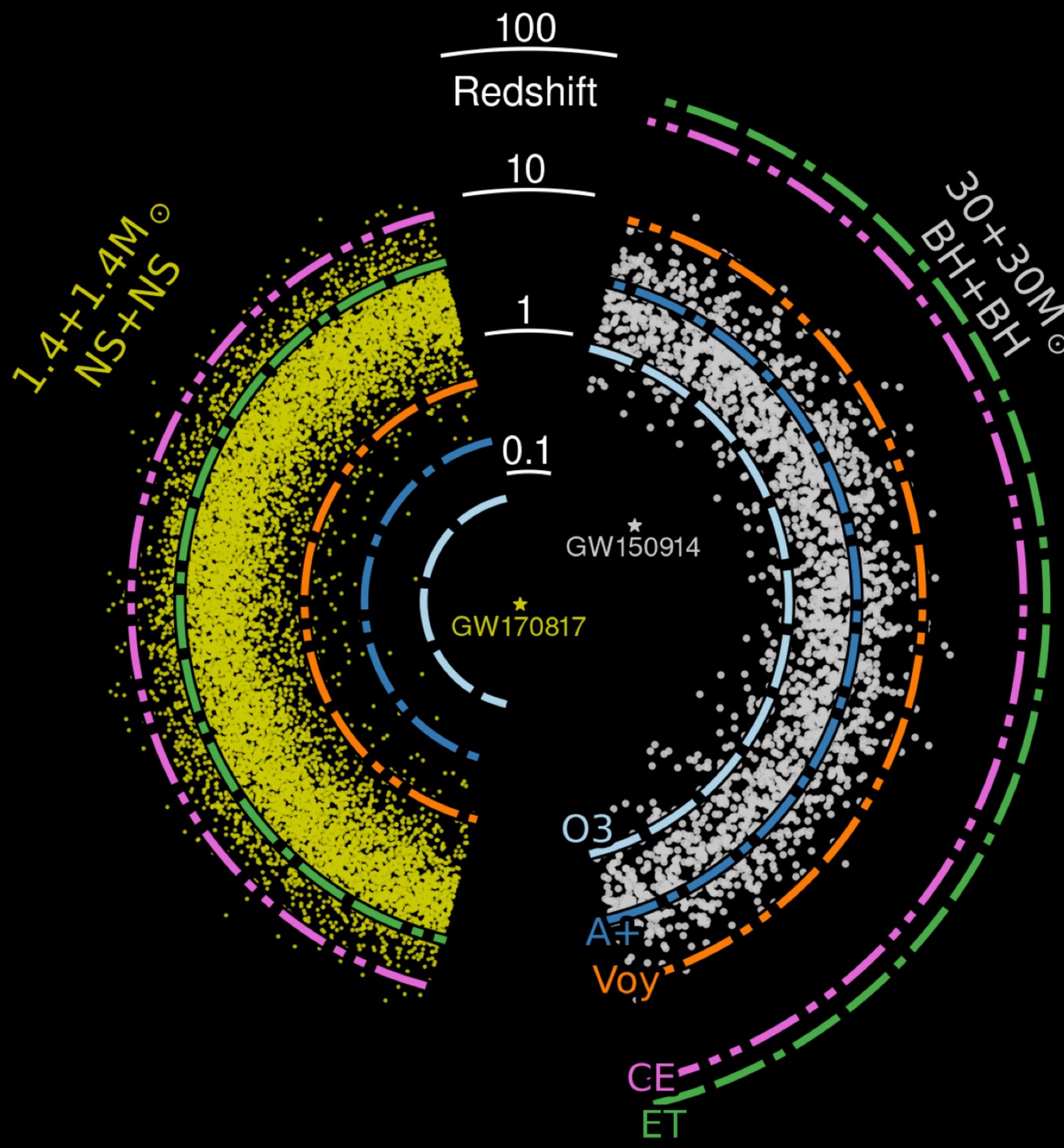
The first detections

- **Sep. 2015**, detection of **GW150914** by LVK
  - BHB merger
  - Clear coinci
    unambiguou
- First direct pro
  - Confirms las
- **Subsequent d**
  - GW170817: b
    counterpart (
  - As of 2025, ~
- **Ground-based**
  - Network obse
  - Catalogues (G



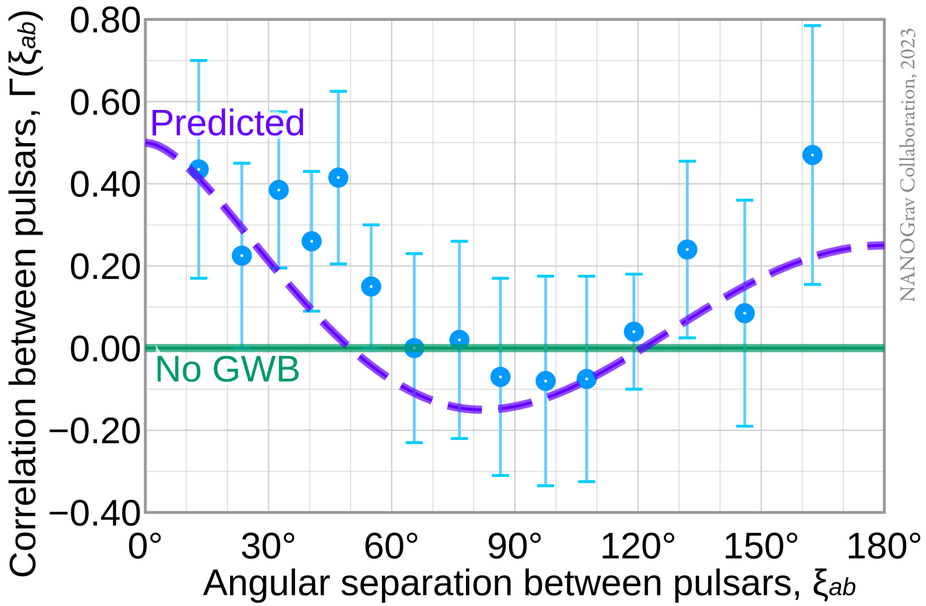


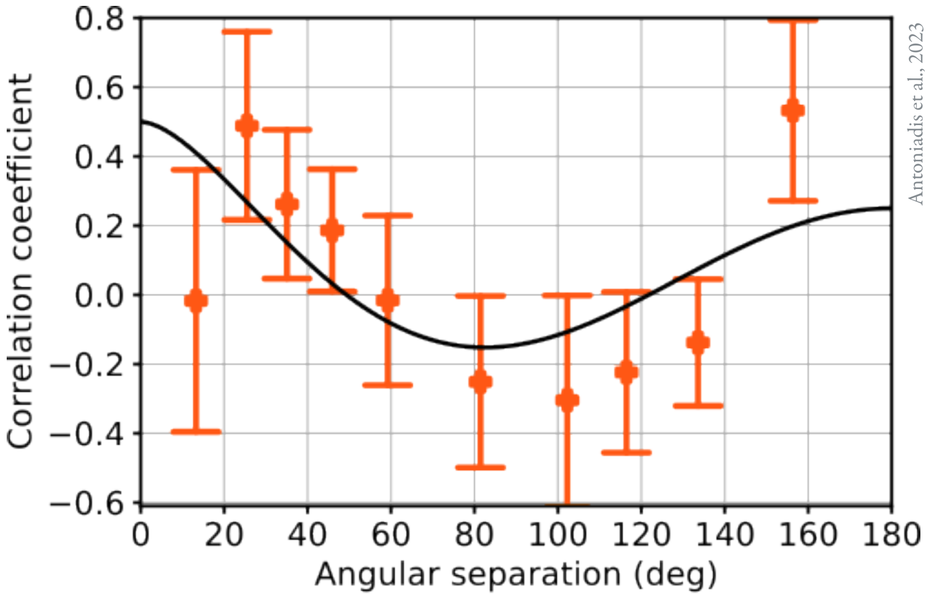
Abbott at al., 2016


100
Redshift
10
1
0.1
1.4+1.4M⊙
NS+NS
30+30M⊙
BH+BH
GW150914
GW170817
O3
A+
Voy
CE
ET

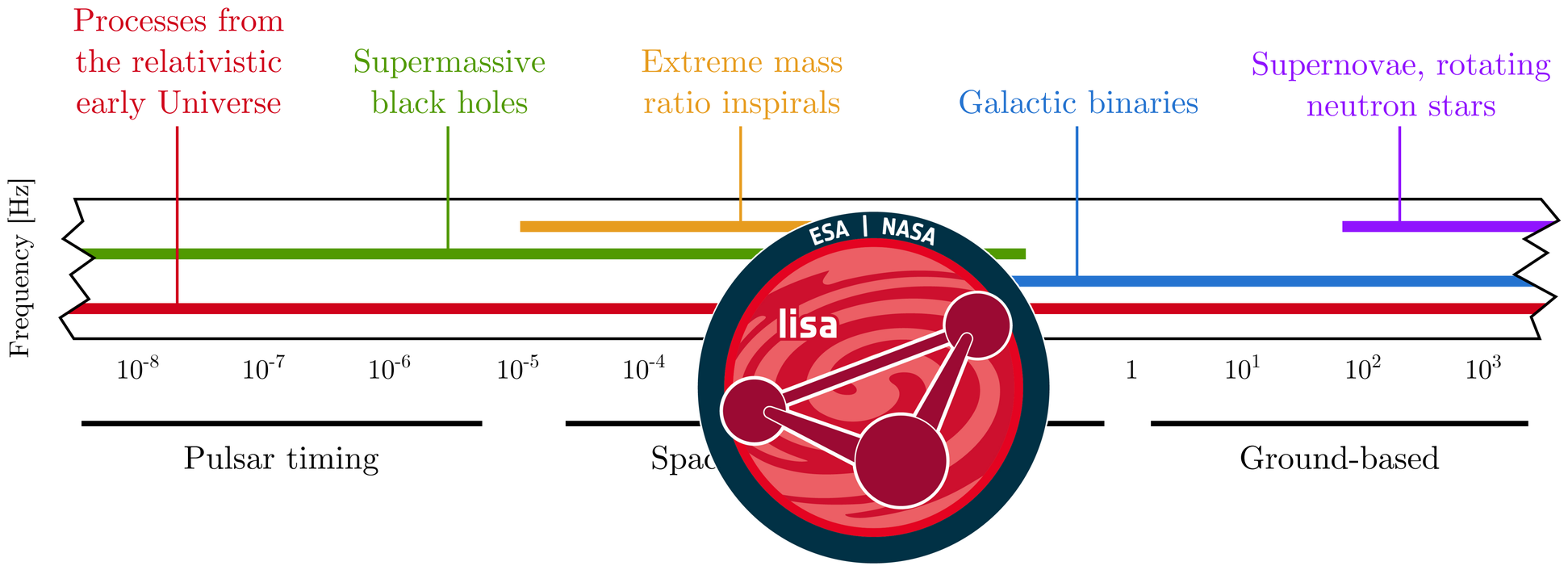
Pulsar timing arrays

- **Concept**
  - Millisecond pulsars = ultra-stable cosmic clocks
  - GWs slightly advance or delay the pulse TOAs
  - By timing many pulsars, one can detect correlated variations
- **Frequency band** ~1–100 nHz (years to decades) produced by inspiraling MBHB before merger
- **PTA network**
  - IPTA: NANOGrav (US/Canada), EPTA (Europe), PPTA (Australia), CPTA (China)
  - Decades of precision radio timing data
  - **In 2023-2024, all reported common-spectrum, spatially correlated noise** (Hellings & Downs) → **first evidence of a gravitational-wave background**



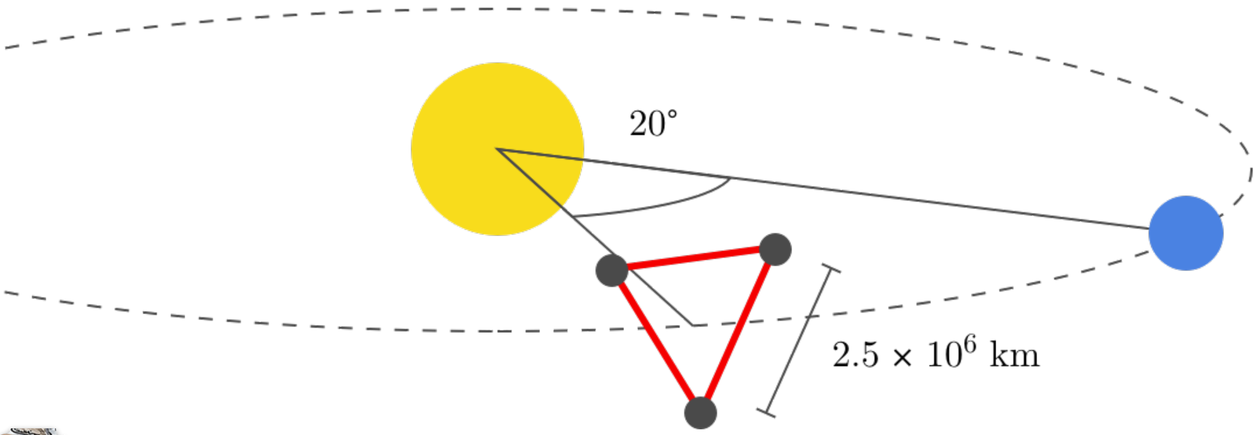


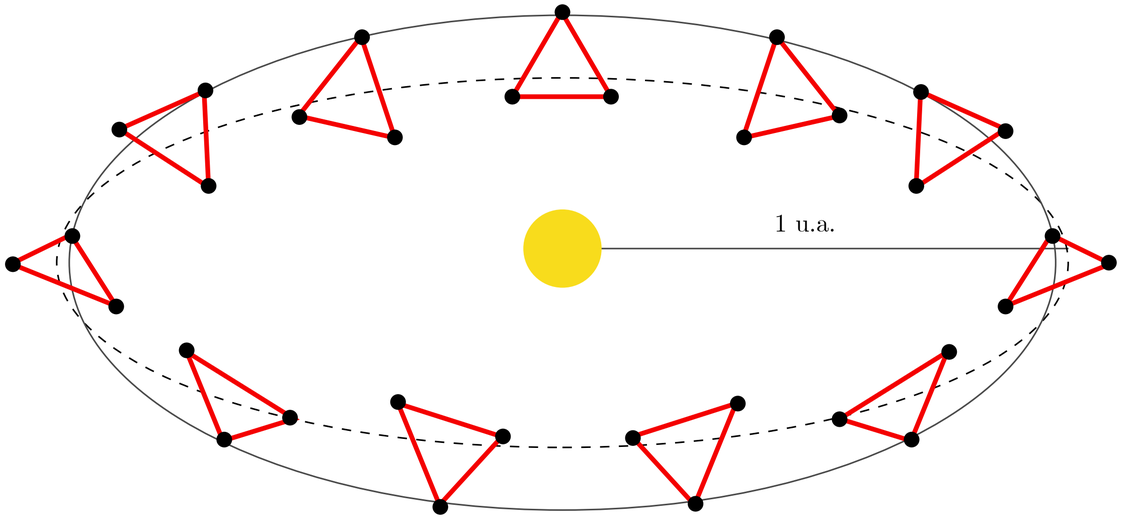
The LISA mission

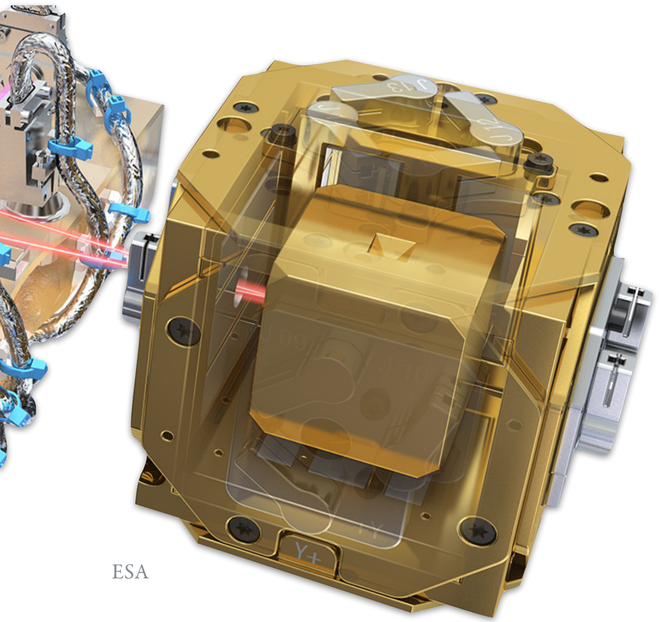


The LISA mission and its recent developments

The LISA mission





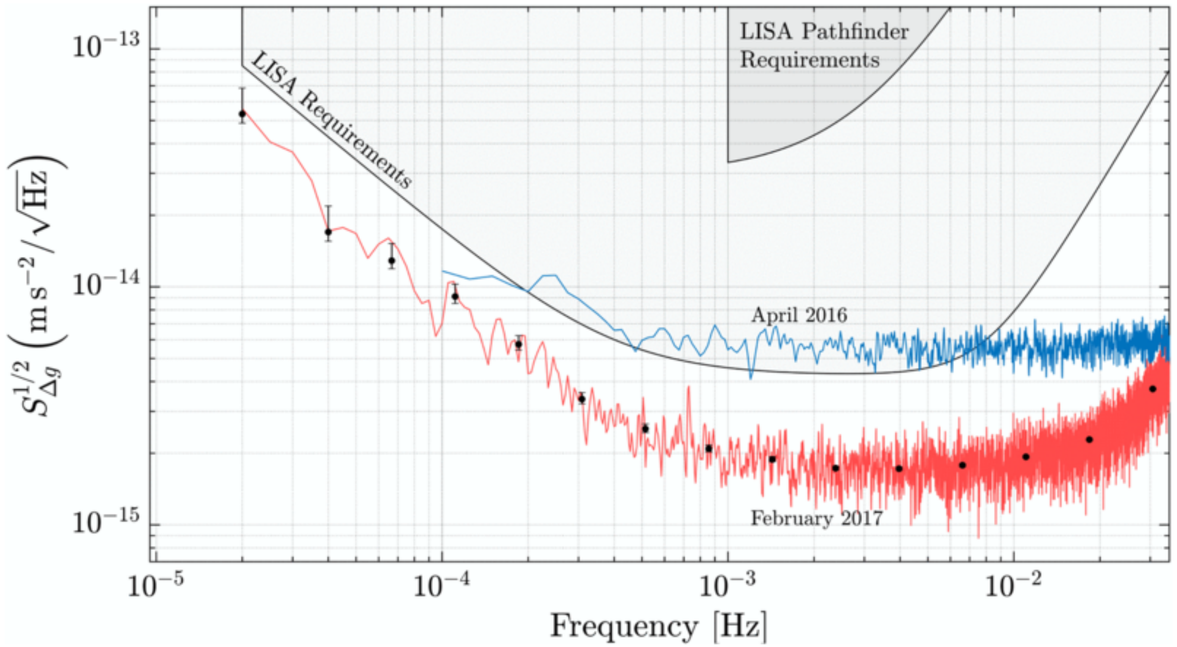


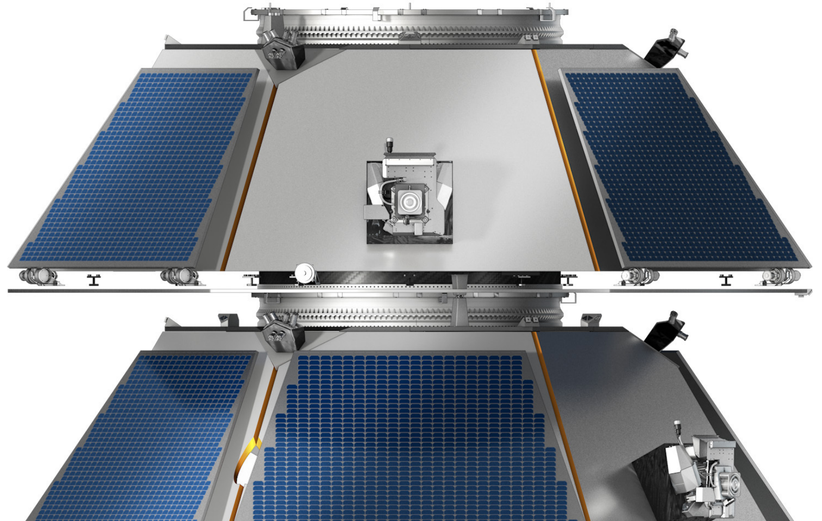
ESA

- ESA-led mission with NASA participation
- **3 spacecraft in equilateral triangular formation**, barycenter trailing the Earth in heliocentric orbit
- Each spacecraft host free-falling gold-platinum cubic test masses, used as **inertial references**
- **TM separations are monitored using laser interferometry**

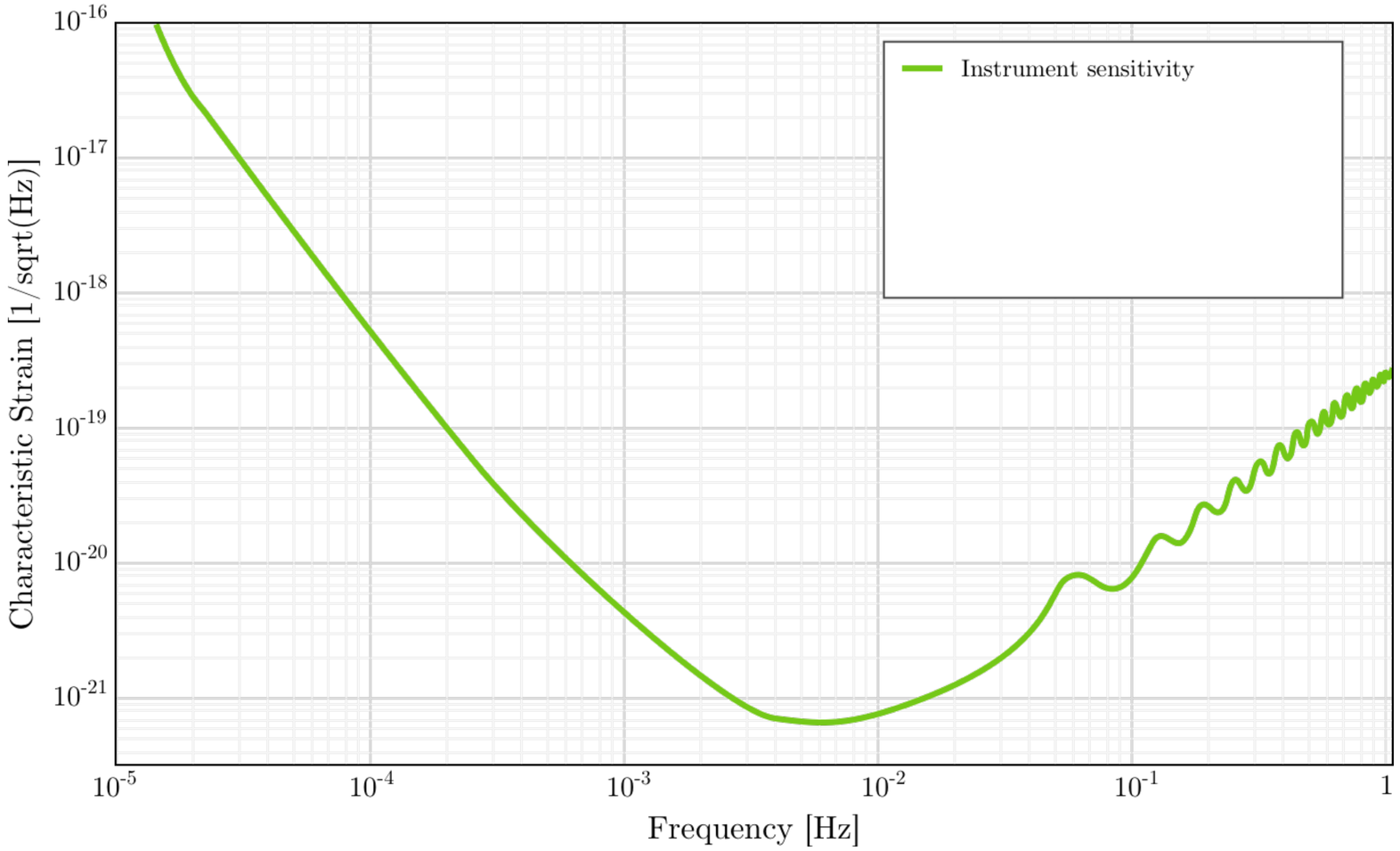
The LISA mission

- **Key technologies**
  - Drag-free operation (TM in geodesic motion)
  - Precision interferometry in space (sub-fm)
  - **LISA Pathfinder (2015–2017) proved performance beyond requirements**
- **Timeline**
  - January 2025: ESA adoption
  - 2025 – 2029 : detailed design & manufacturing
  - 2030 – 2032 : spacecraft integration & testing
  - **Nominal launch date ≈ 2035** on Ariane 6
  - 2037 : science operations phase (4+6 years)





Sources in the LISA band



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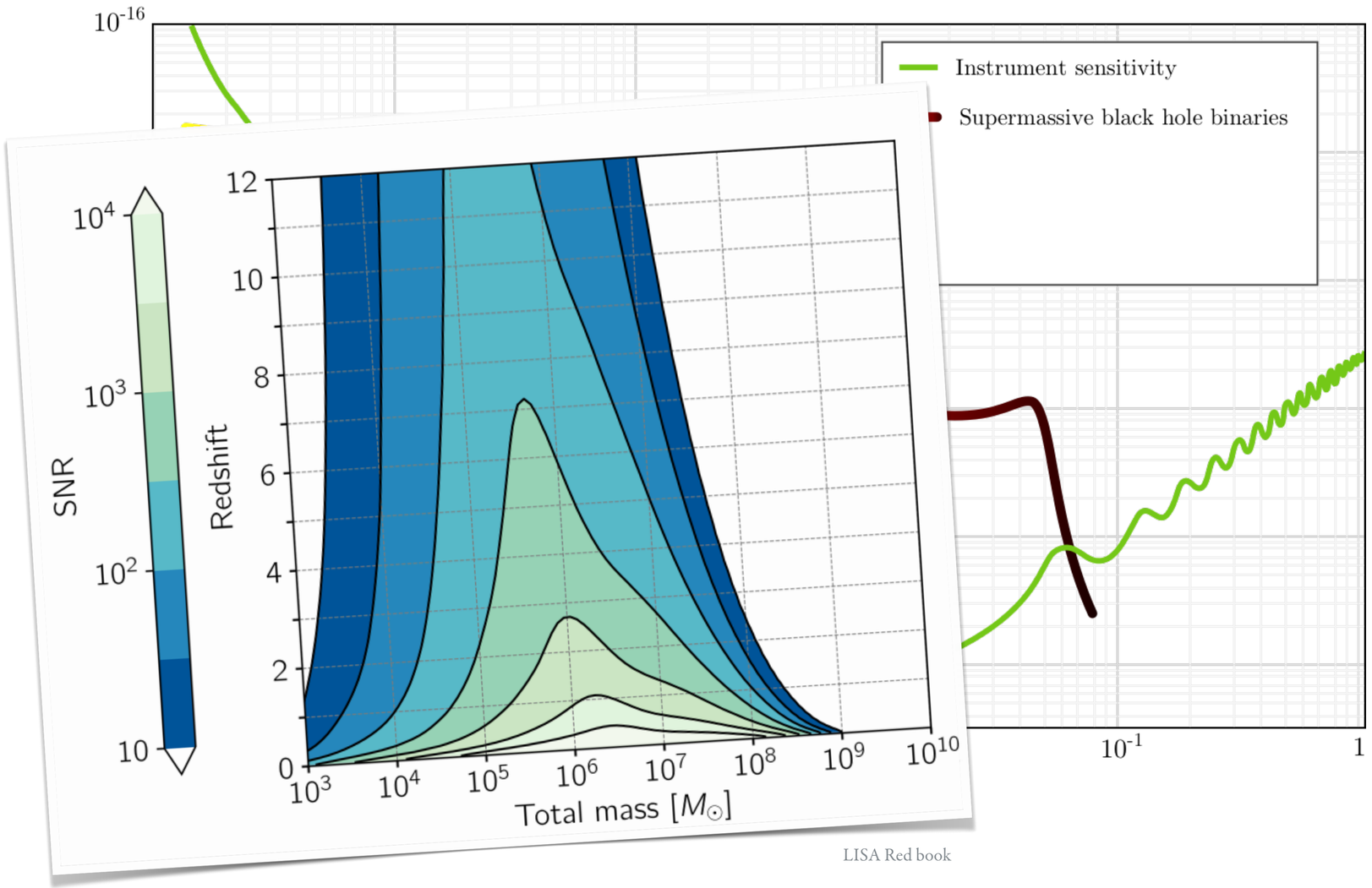
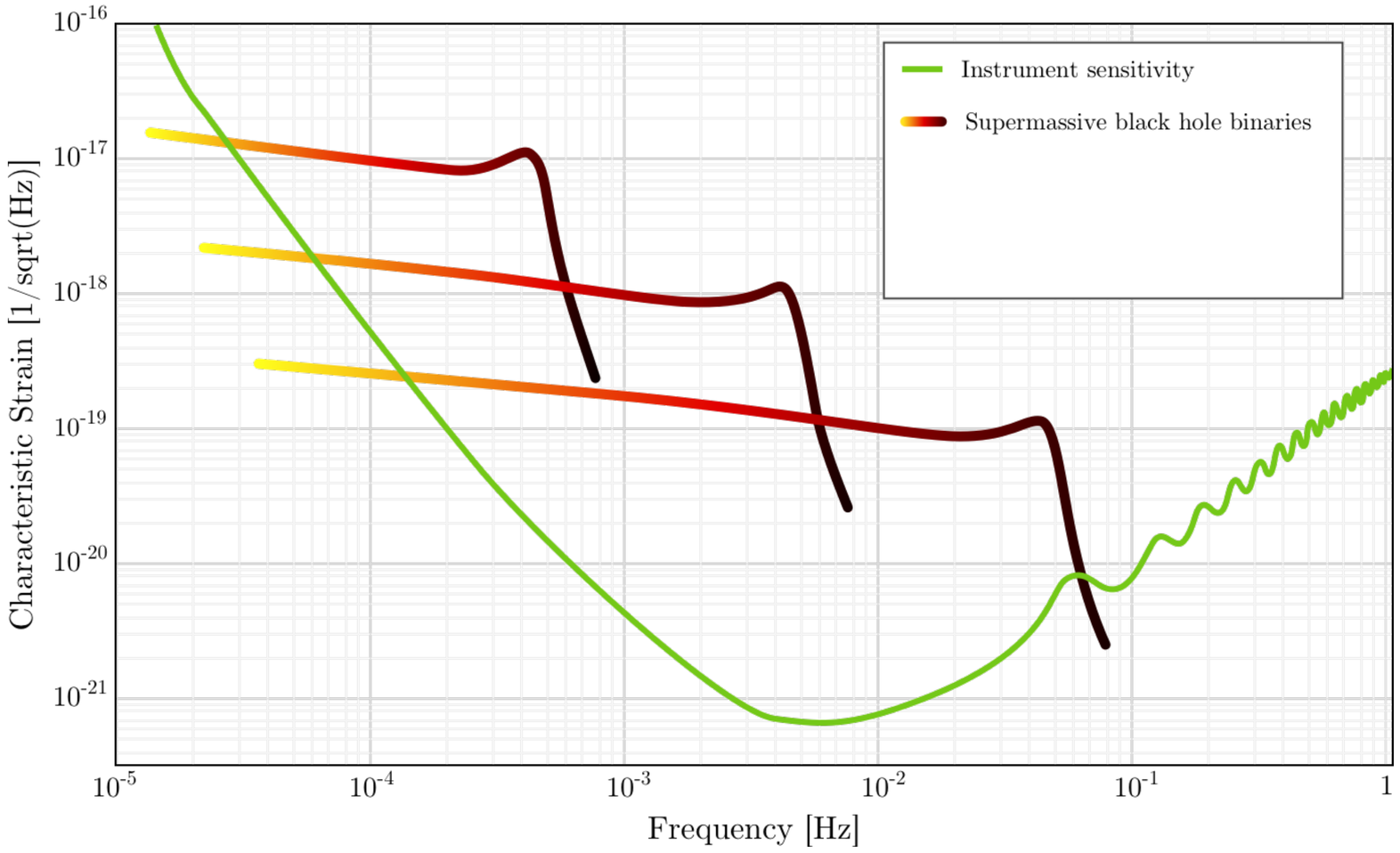


LISA Red book

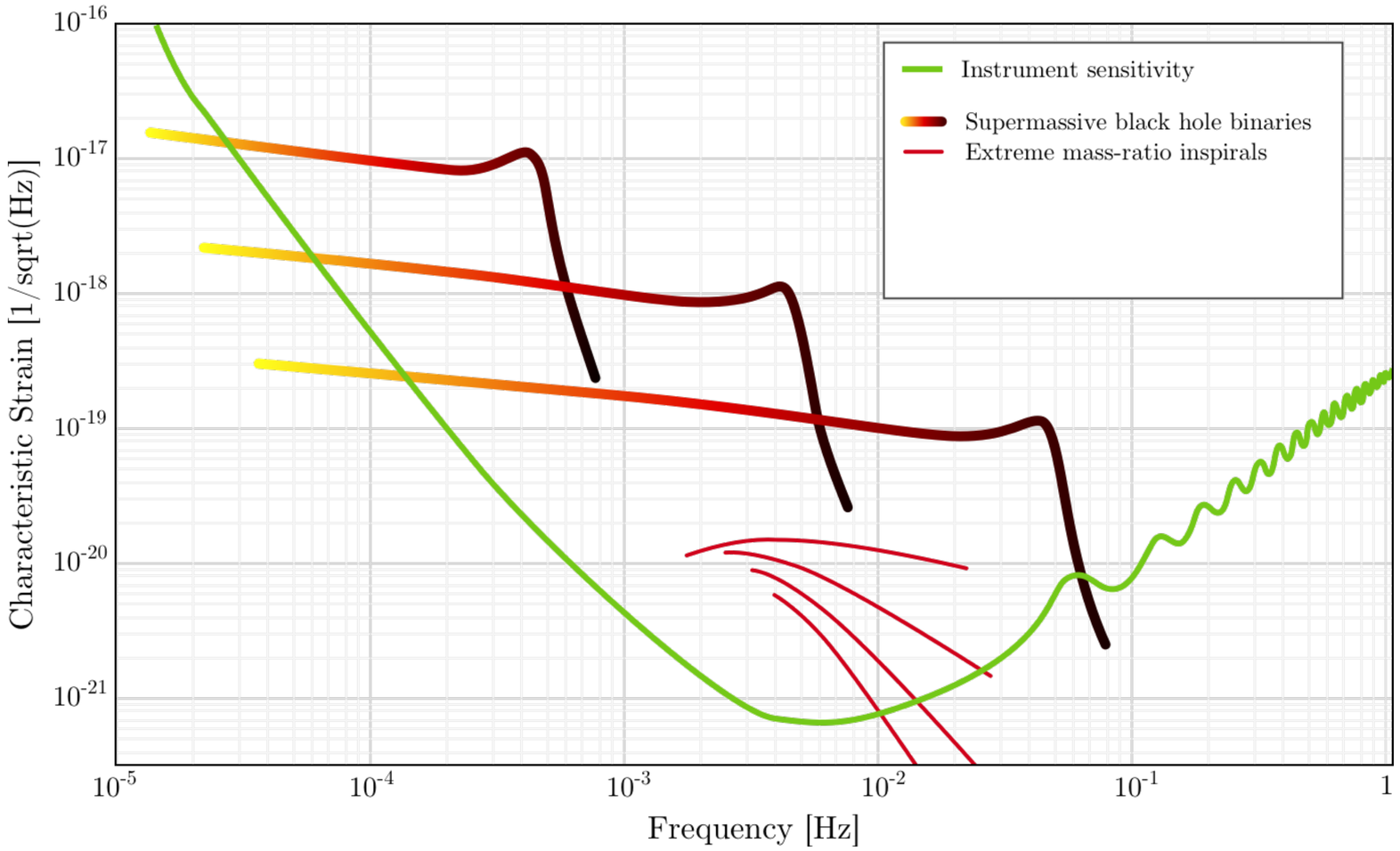
- Unexplored segment of black-hole binary mass spectrum ($10^4 - 10^7 M_\odot$), hours to month
- 10-100 events per year
- Up to very high redshifts, when first galaxies formed
- Tracing origin and evolution across history
  - Discover seeds
  - Growth mechanism
  - EM counterparts
- Fundamental physics
  - Tests of GR with ringdown
  - Beyond-GR emission and propagation

Sources in the LISA band



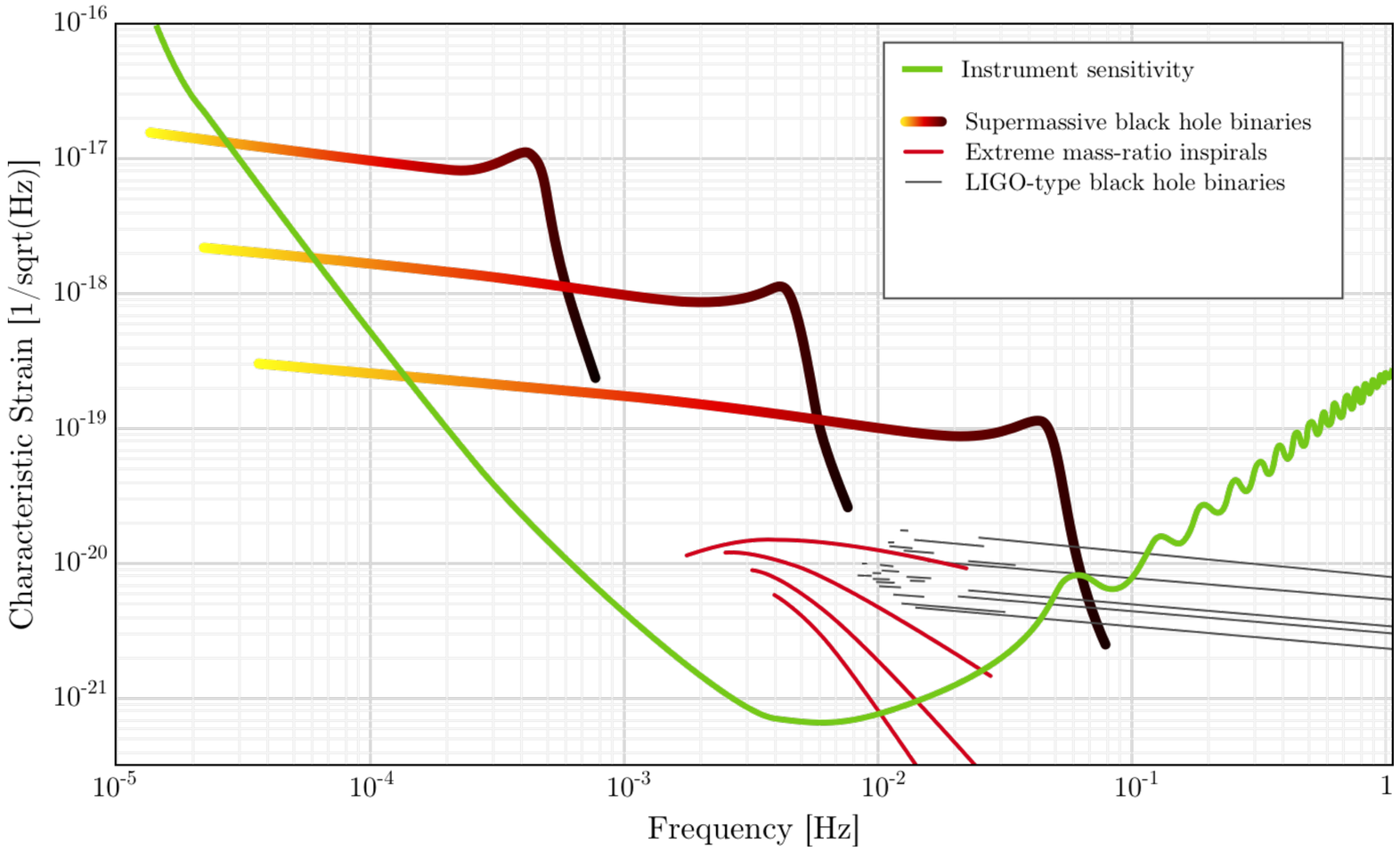
- Unexplored segment of black-hole binary mass spectrum ($10^4 - 10^7 M_\odot$)
- Up to very high redshifts, when first galaxies formed
- Cosmology
  - Measure Hubble constant beyond z∼2
  - Bright (EM counterpart) or dark sirens (statistical correlations with galaxy surveys)

Sources in the LISA band



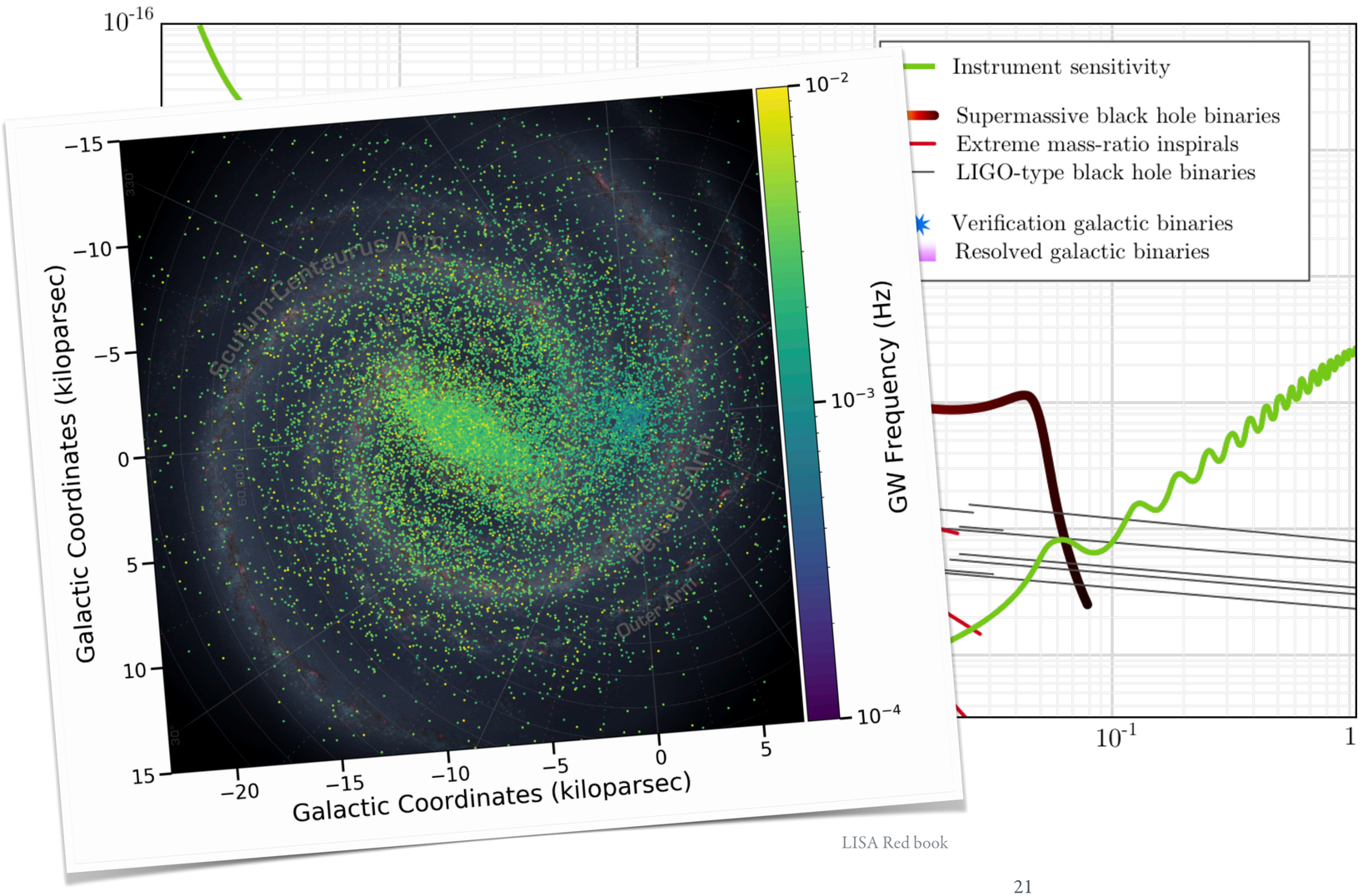
- Observe single MHBs at center of galaxies or in dense clusters with EMRIs
- Probe the properties and environments
  - Mass and spin distrib.
  - Physical dynamical processes near them

Sources in the LISA band



- Stellar-mass black-hole binaries up to hundreds of years before merger
- Questions on black-hole astrophysics
  - Formation channels
  - Probing environment (accretion disks, pair instability gap, hierarchical mergers)
  - EM counterparts

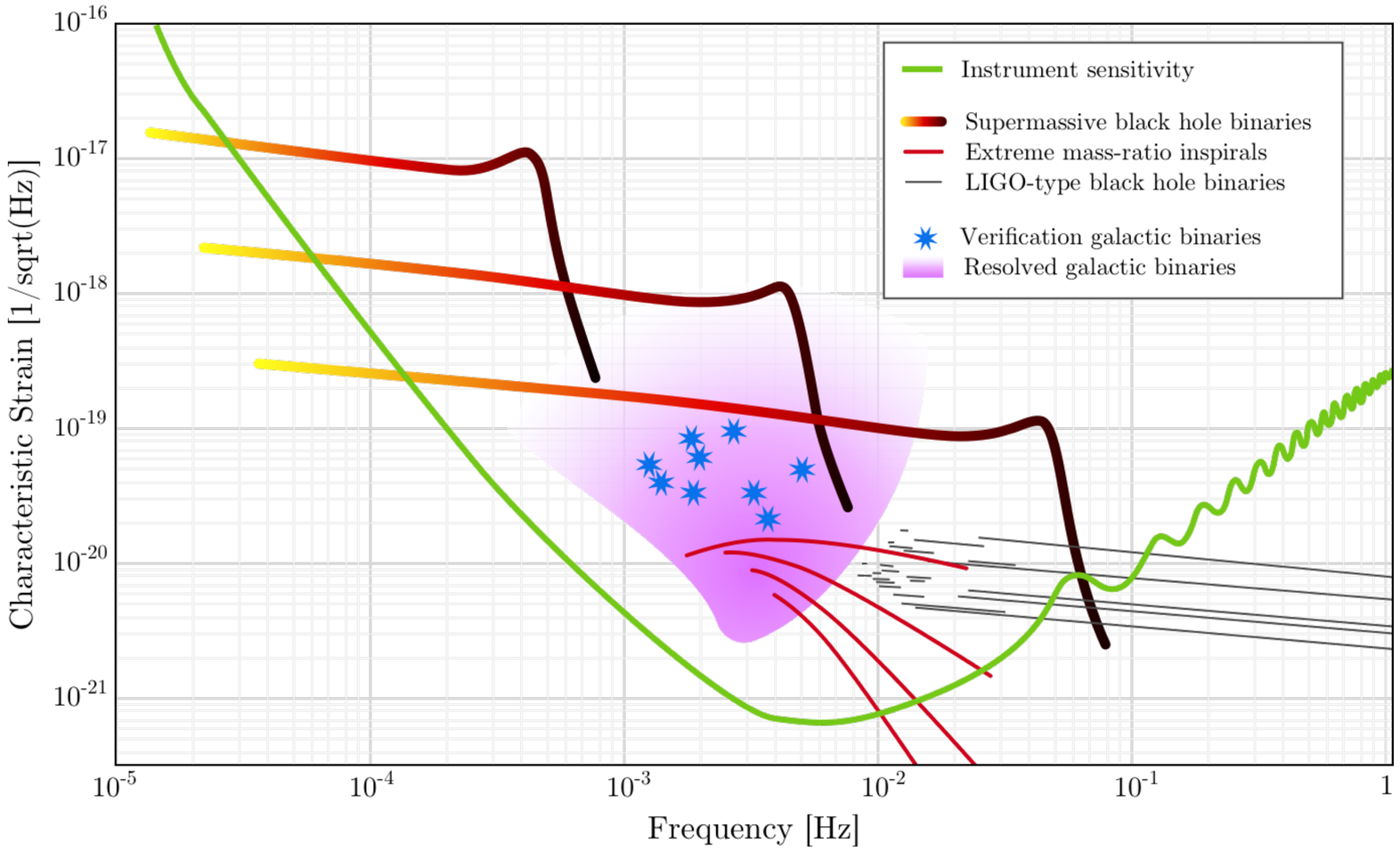
Sources in the LISA band



LISA Red book

- Millions of compact binary systems in the Galaxy emitting continuous quasi-monochromatic signals
  - Verification binaries
  - Some tens of thousands are expected to be resolved
  - Unresolved residuals will form a “confusion noise”
- Many astrophysical questions
  - Formation and evolution (role of mass transfer, tides, etc).
  - Mass and spatial distribution for Galaxy mapping (population studies)

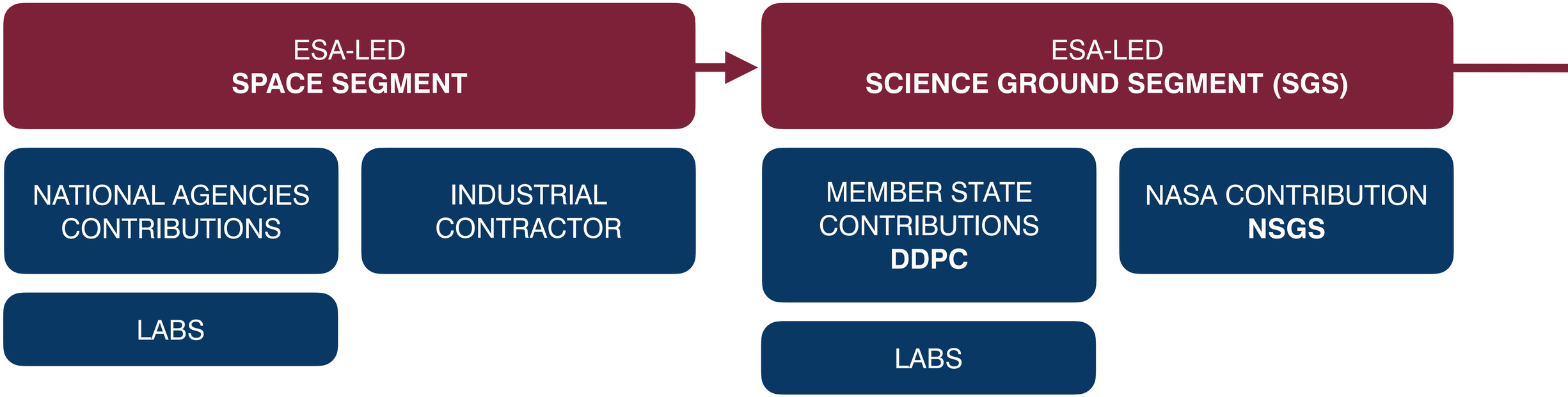
Sources in the LISA band



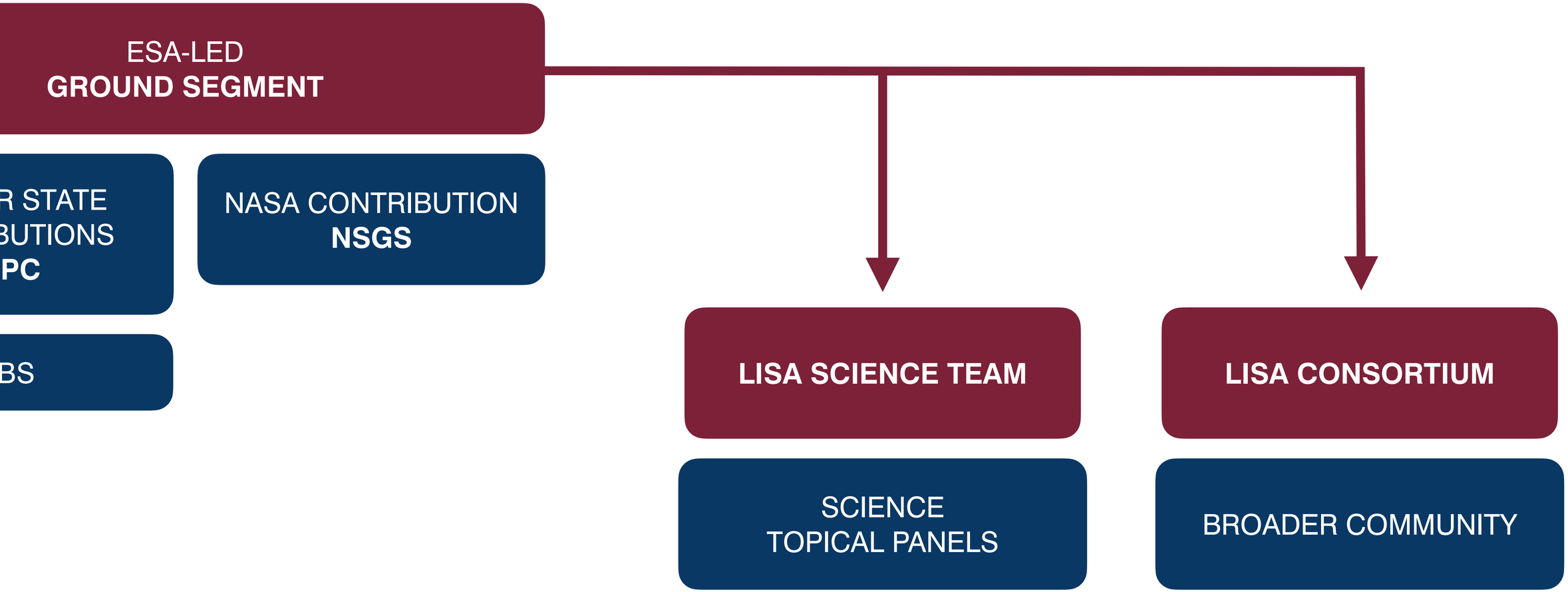
- Astrophysical background
  - Better constrain stellar BHB population models
  - Presence of EMRI background?
- Potential cosmological backgrounds from processes in the early Universe
  - First-order phase transitions
  - Cosmic strings
- Unforeseen sources

Agencies, Consortium, ground segment – how is LISA organized?

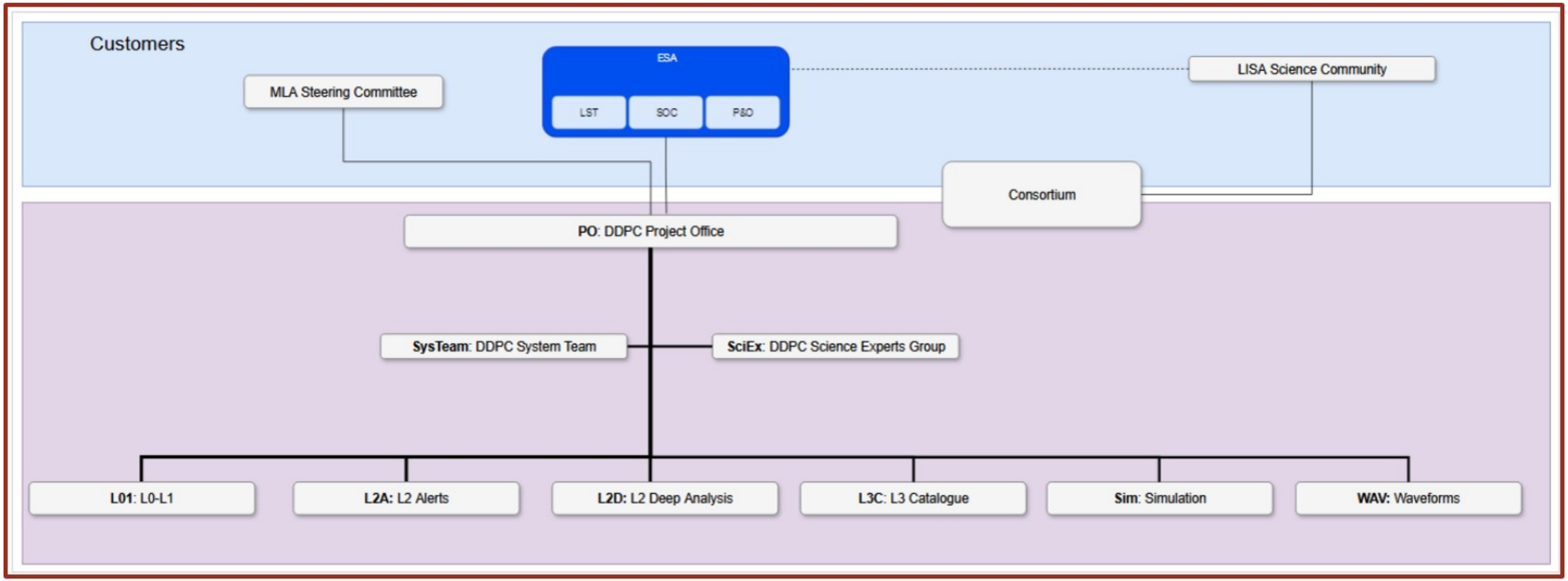
Overall architecture

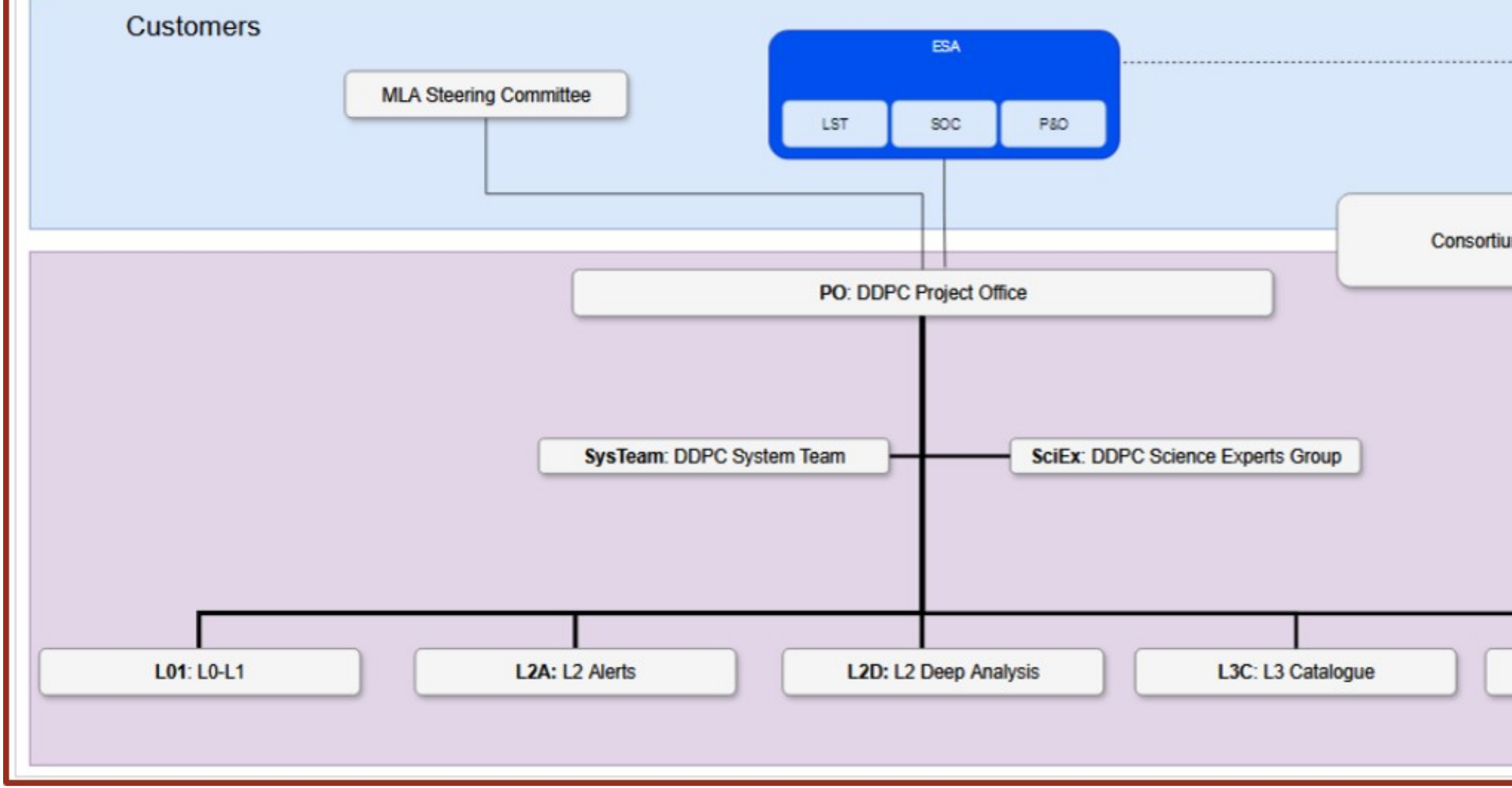


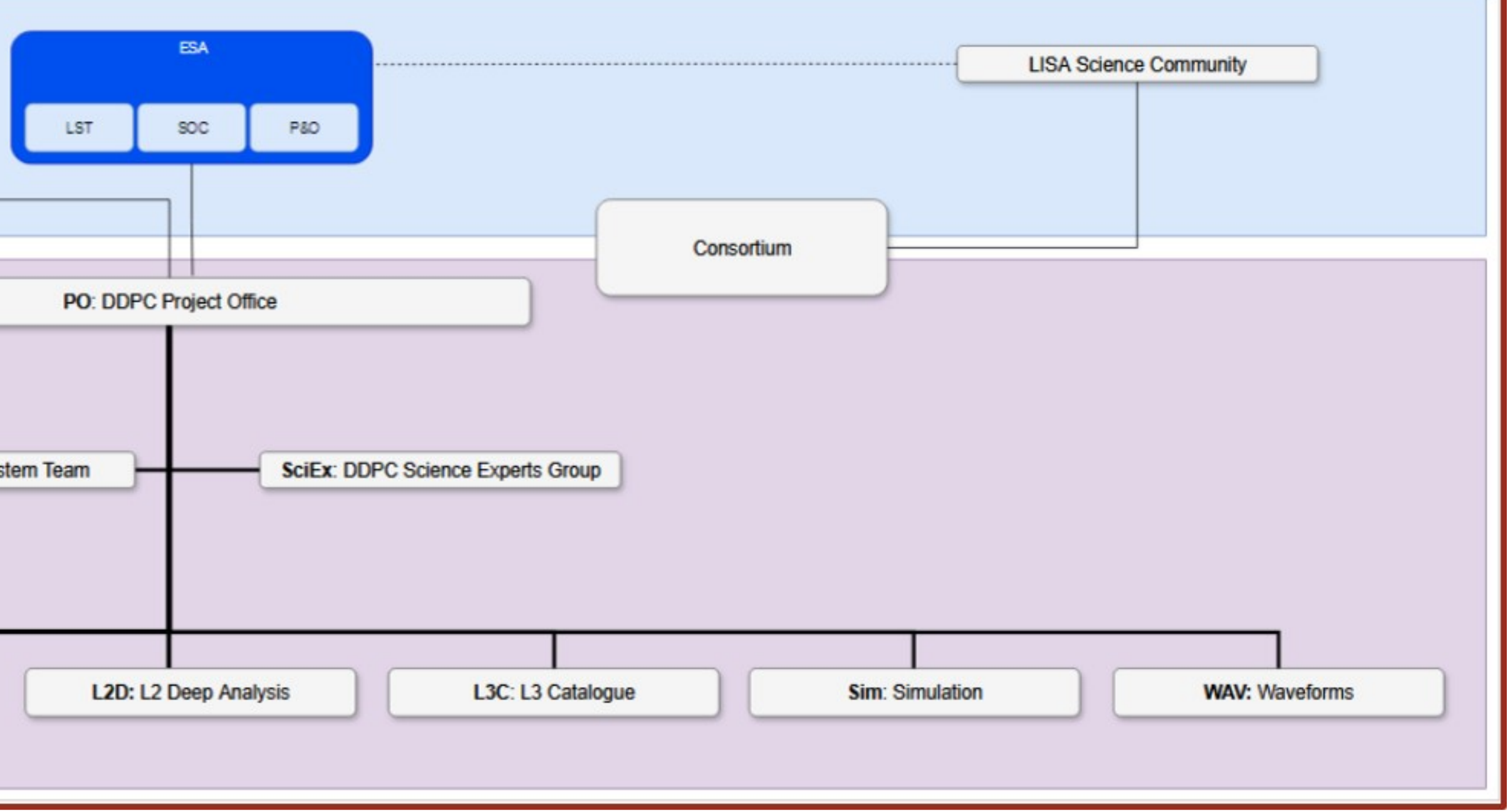
Overall architecture



DDPC at a glance




Customers
ESA
MLA Steering Committee
LST
SOC
P&O
Consortiu
PO: DDPC Project Office
SysTeam: DDPC System Team
SciEx: DDPC Science Experts Group
L01: L0-L1
L2A: L2 Alerts
L2D: L2 Deep Analysis
L3C: L3 Catalogue


ESA
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LISA Science Community
Consortium
PO: DDPC Project Office
stem Team
SciEx: DDPC Science Experts Group
L2D: L2 Deep Analysis
L3C: L3 Catalogue
Sim: Simulation
WAV: Waveforms

Data publication

- **First LISA data release** will take place **1 year after the start of data taking**
- Will be accompanied by a **catalogue of sources produced by DDPC & NSGS**
- Science will be done during this early release science time by a set of **science topical panels**, to be selected via an open call
  - A set of key science papers will also be written during ERST
  - Responsibility of the LISA Science Team
- Following the first data release, **data will be released every 6 months**, accompanied by updated catalogues and minimal documentation
- No further science interpretation will be done on data not yet publicly released
- => need for a **Consortium that represents the wider LISA scientific community**

LISA Consortium

"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."

- **Key roles of Consortium:** prepare for science delivery and deliver science beyond the first data release; provide human resources for LST; support the community
- The Consortium does not have de-facto privileged access to data!

LISA Consortium

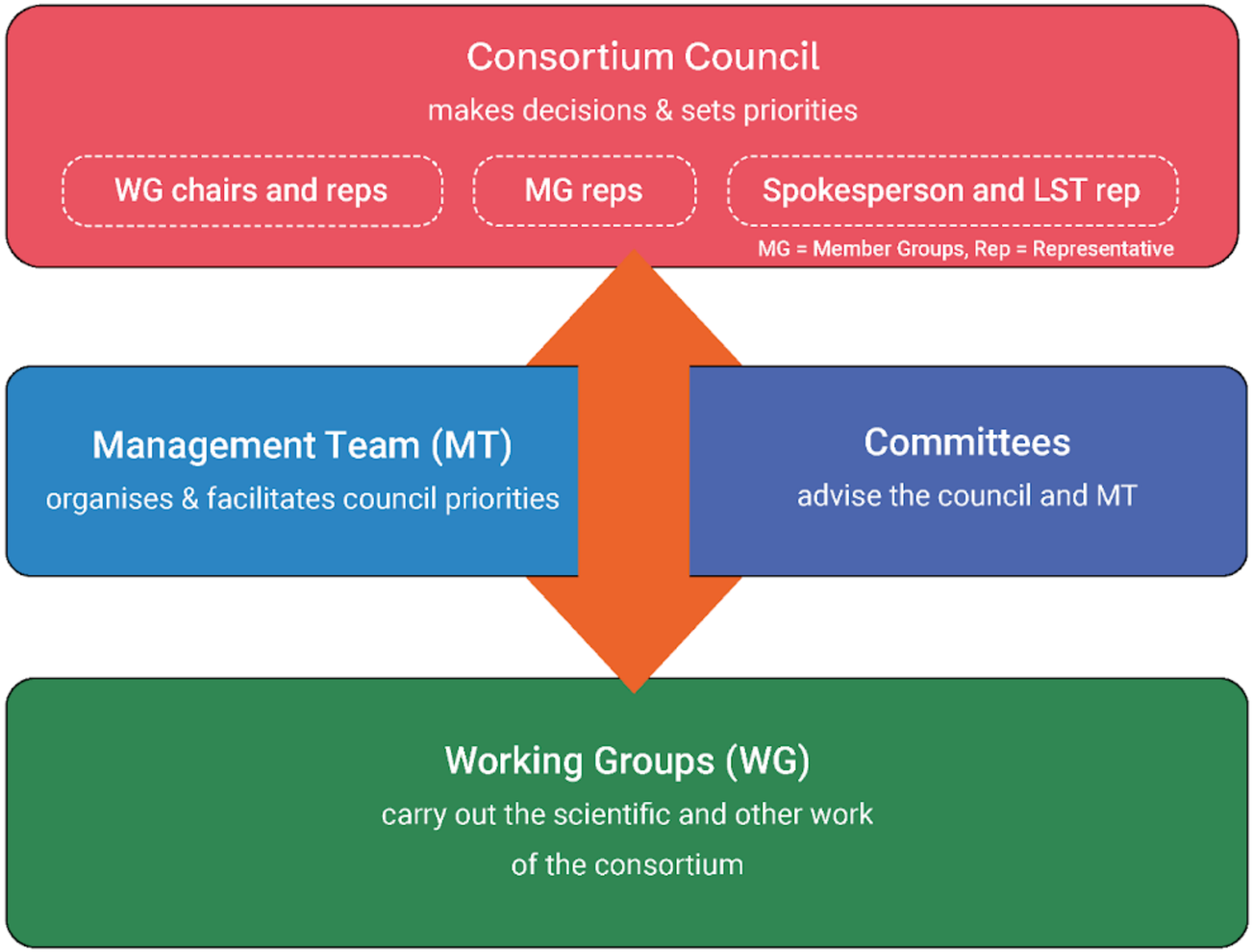
COMMUNITY MEMBER

- **Mainly to be informed**
- No work on deliverables, no service tracking
- Can change to core at any time

CORE MEMBER

- **Requires commitment** to one of the working groups
- Service tracking with 1 pledge and 1 statement every year
- Can switch back to community if quota not reached
- Can be part of decision bodies of the Consortium

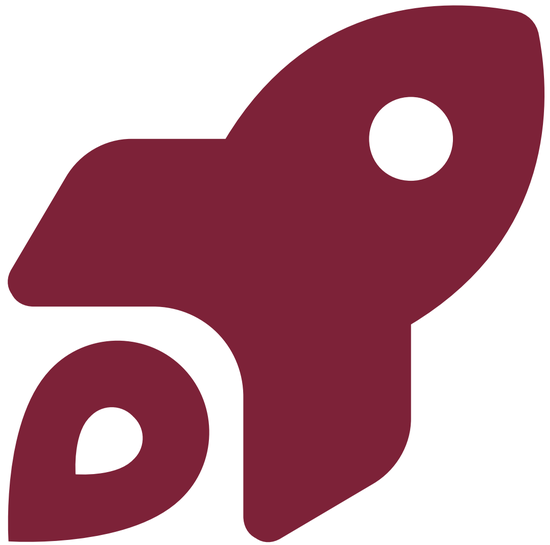
LISA Consortium



- **Science working groups**
  - Astrophysics
  - Cosmology
  - Data analysis R&D
  - Fundamental physics
  - Instrument simulation and processing
  - Instrumentation
  - Waveform
- **Other working groups**
  - Communication
  - Early-career scientists

Perspectives and summary

Summary



- From Einstein’s equations to a functioning network of GW observatories in a century
- **Gravitational physics is a new, vibrant field**
  - Many exciting prospects for the years to come
  - Important synergies (multi-band and multi-messenger science)
  - LISA is a global, collaborative effort
- You will be the ones to handle the LISA data
  - LISA launch around 2035
  - Still many challenges and open questions to explore
  - Its success will rely on the people in this room!

How to get involved

- **Join the LISA Consortium**
  - Open to PhDs, postdocs, engineers, data scientists
  - Participate in Working Packages
  - Sign up via https://signup.lisamission.org
- Play with past and future **LISA Data Challenges**
  - Check out https://lisa-ldc.in2p3.fr for existing datasets
  - DDPC might release new datasets
- Build your network and start collaborations