

The LISA mission: status

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THE SPECTRUM OF GRAVITATIONAL WAVES

Observatories
& experiments

Ground-based
experiment



Space-based observatory



Pulsar timing array



Cosmic microwave
background polarisation



Cosmic fluctuations in the early Universe

Cosmic
sources



Supernova



Pulsar



Compact object falling
onto a supermassive
black hole



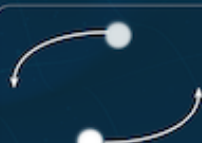
Merging supermassive black holes



Merging neutron
stars in other galaxies



Merging stellar-mass black holes
in other galaxies



Merging white dwarfs
in our Galaxy

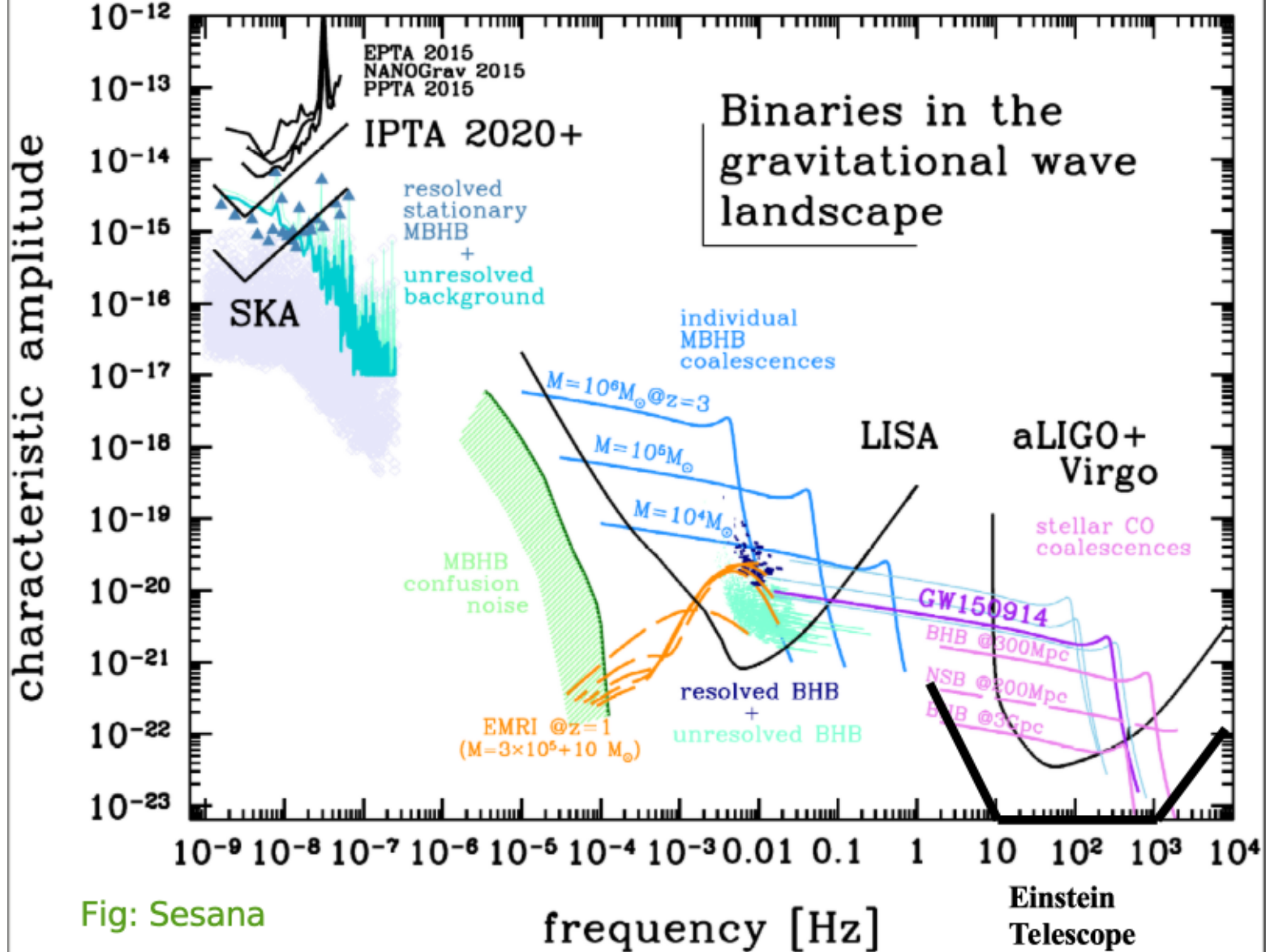
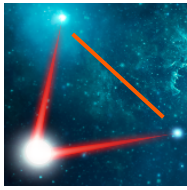
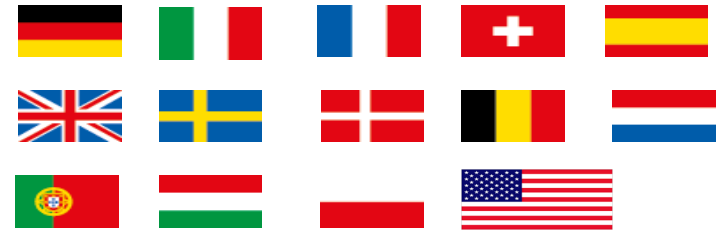
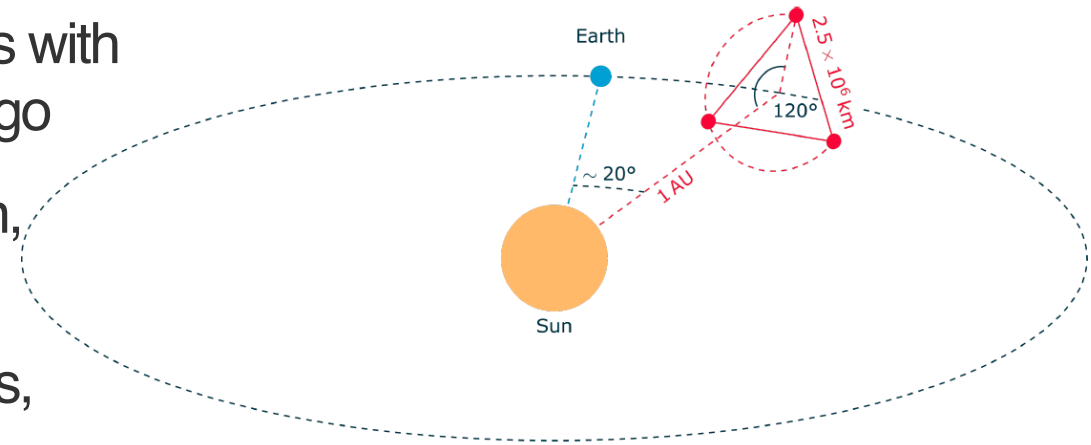


Fig: Sesana



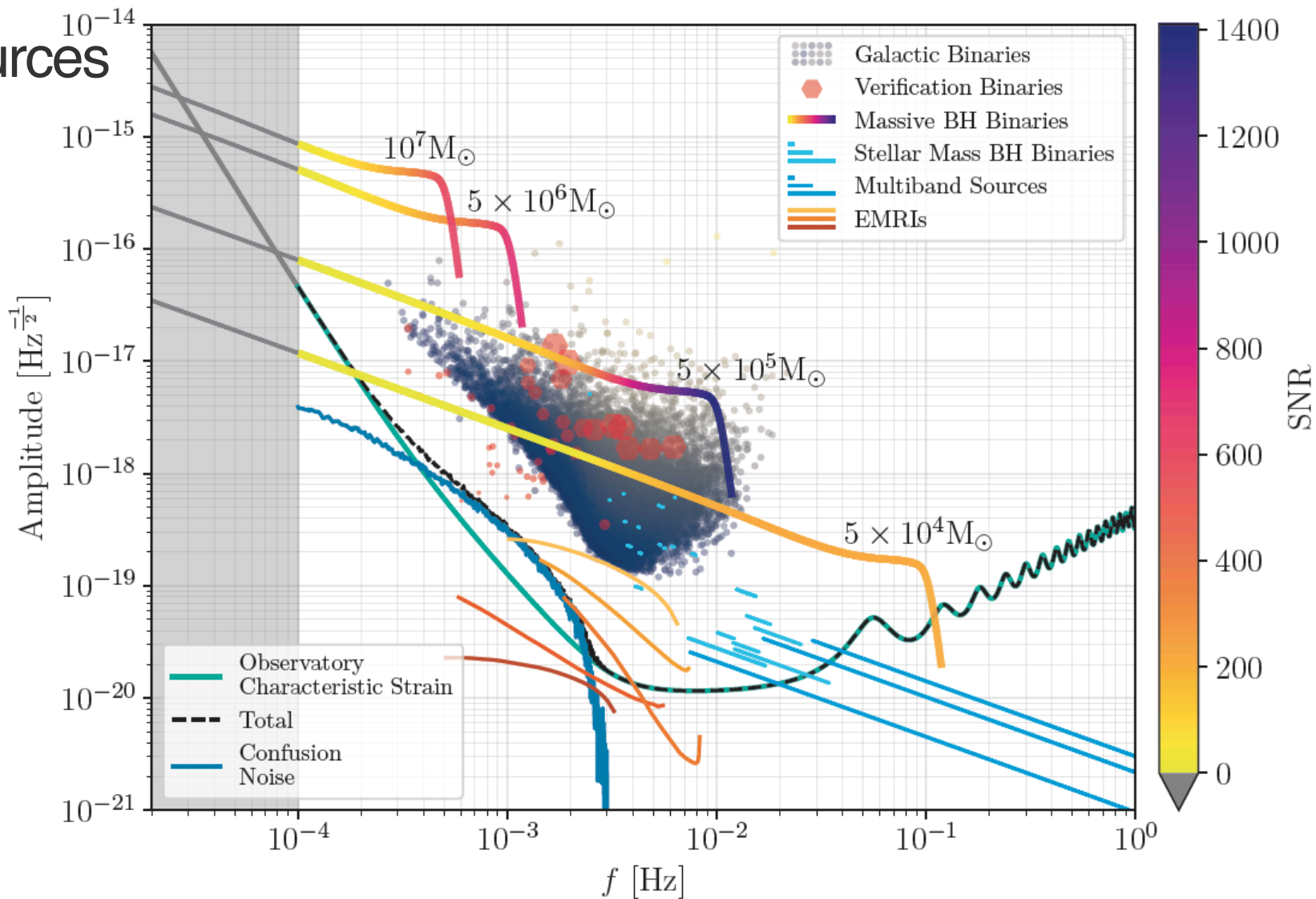
The LISA mission

- ▶ Mission to detect Gravitational Waves with much lower frequency than LIGO/Virgo
- ▶ Three satellites in triangular formation, trailing Earth
- ▶ ESA lead, member state contributions, strong link with NASA
- ▶ Budget: ~2.2B€ (ESA: 1.3B€, NASA: ~500M€, Member states: ~400M€)
- ▶ Sensitive in mHz regime
- ▶ Launch in mid-2030s





Sources

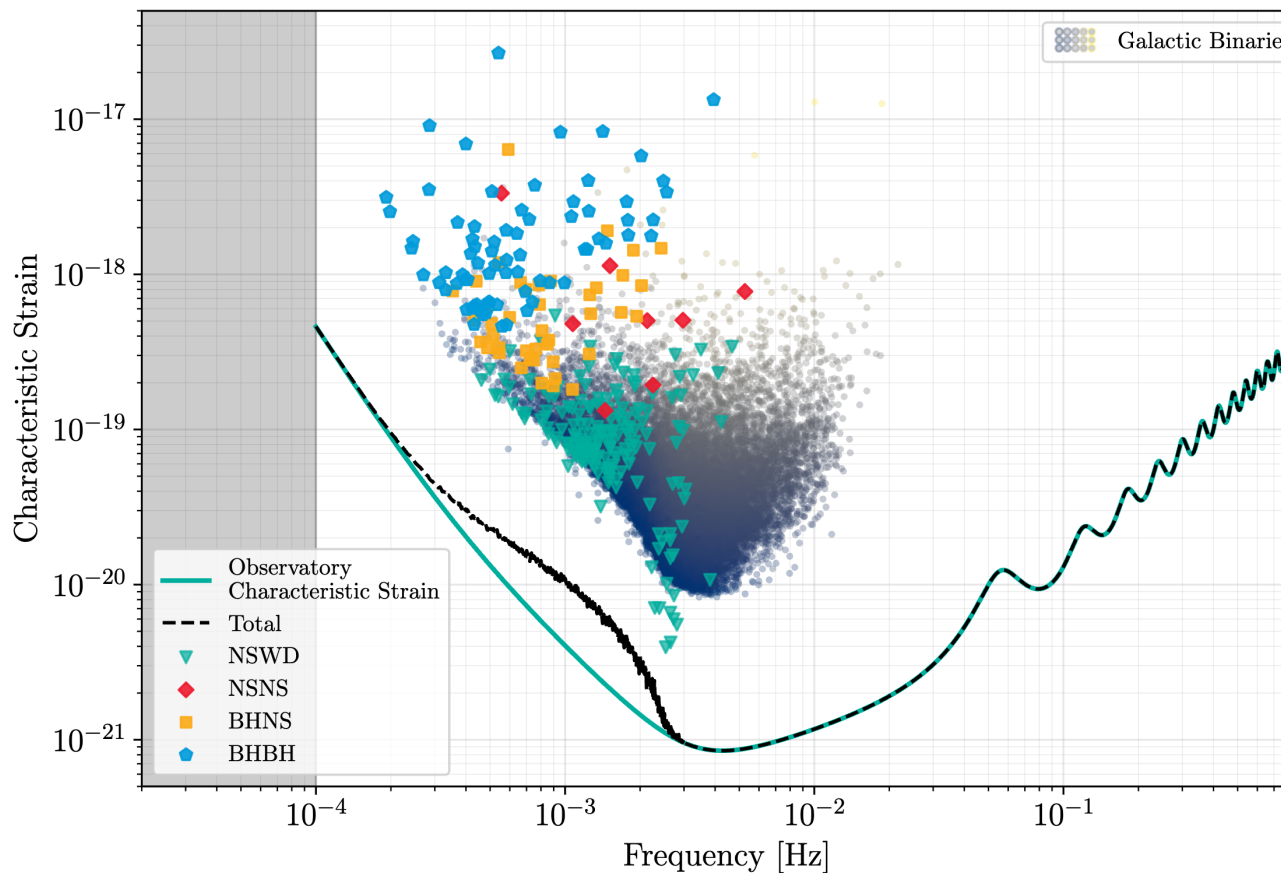




Stellar binaries

- ▶ Thousands of individual detections, mostly white dwarfs
- ▶ Several tens of neutron star/black hole binaries
- ▶ Foreground of millions of binaries
- ▶ Subset detectable with EM instruments
- ▶ Already known binaries: verification sources
- ▶ Many to come (Gaia, LSST etc)

e.g. Korol et al. 2017

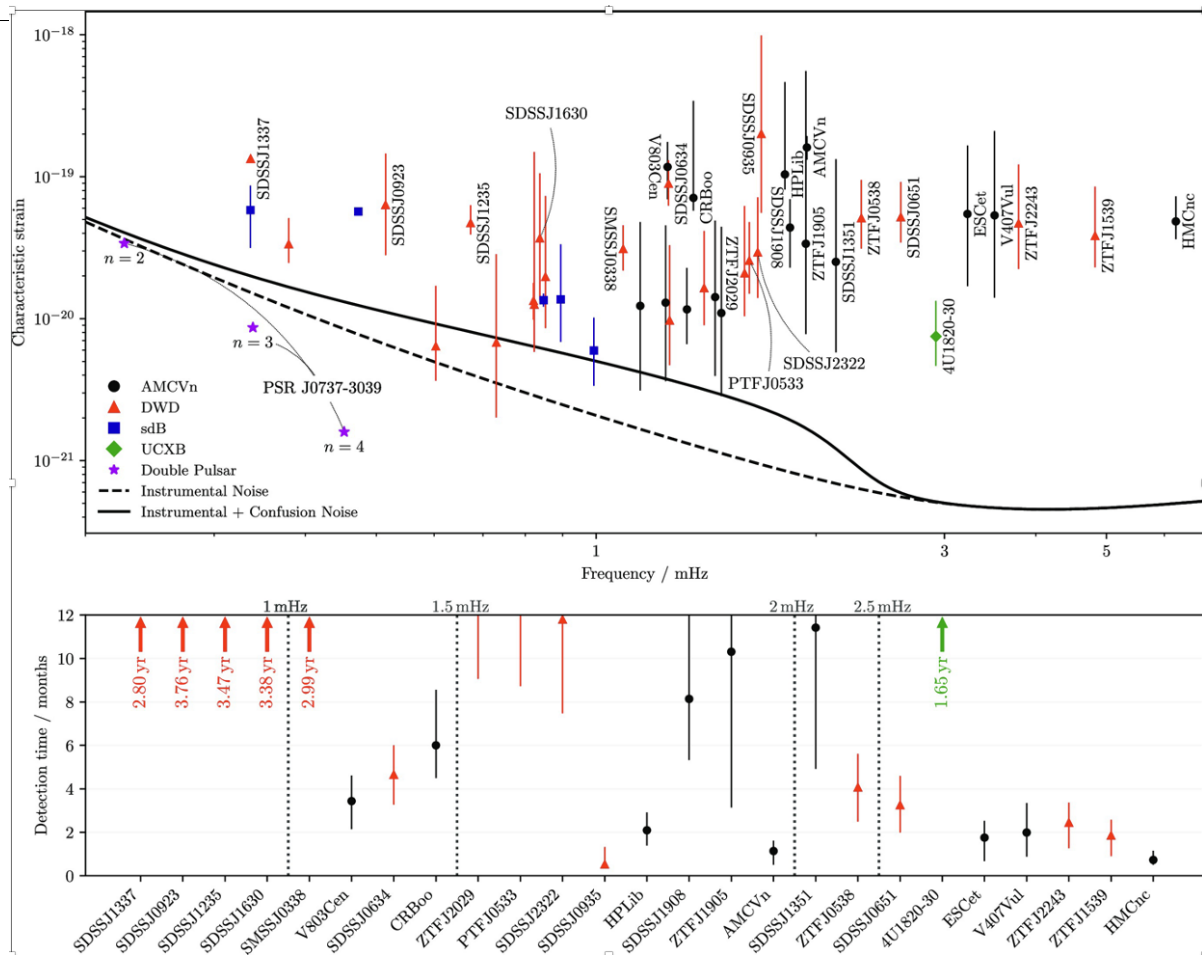


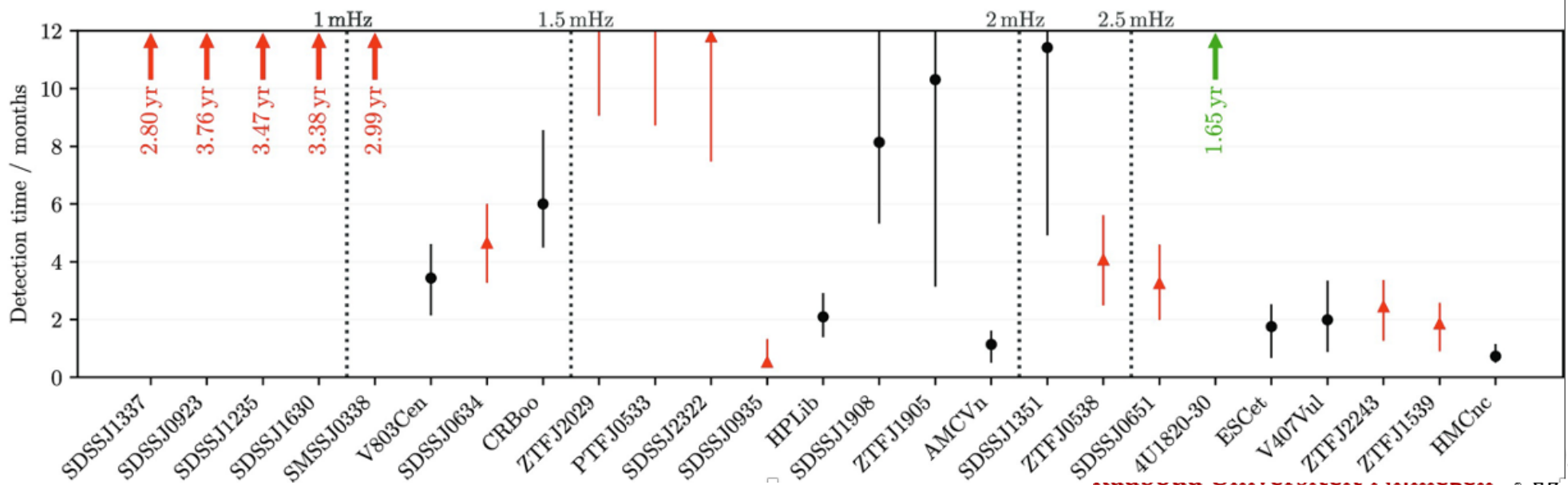
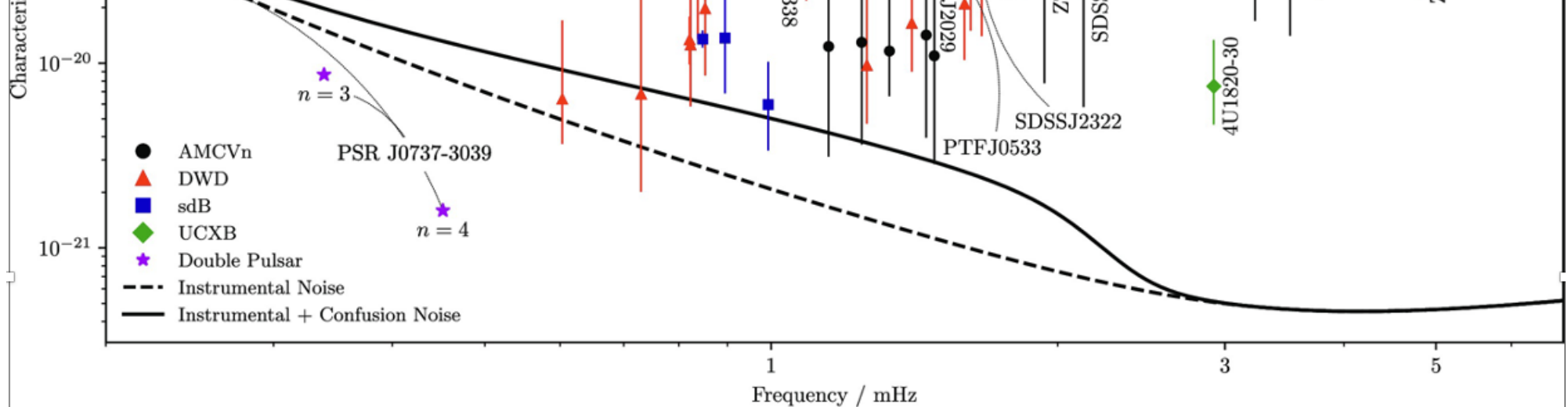


Verification binaries

- ▶ Rapid increase in number
- ▶ Many detectable within a few months
- ▶ Validate the instrument
- ▶ Complementary measurements

Finch et al. 2023

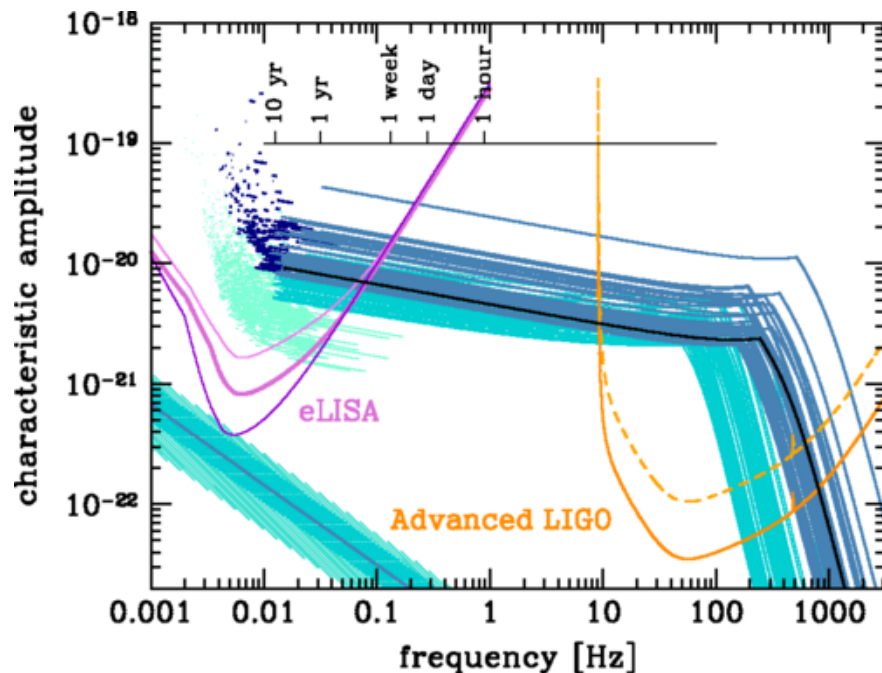






Multi-band sources

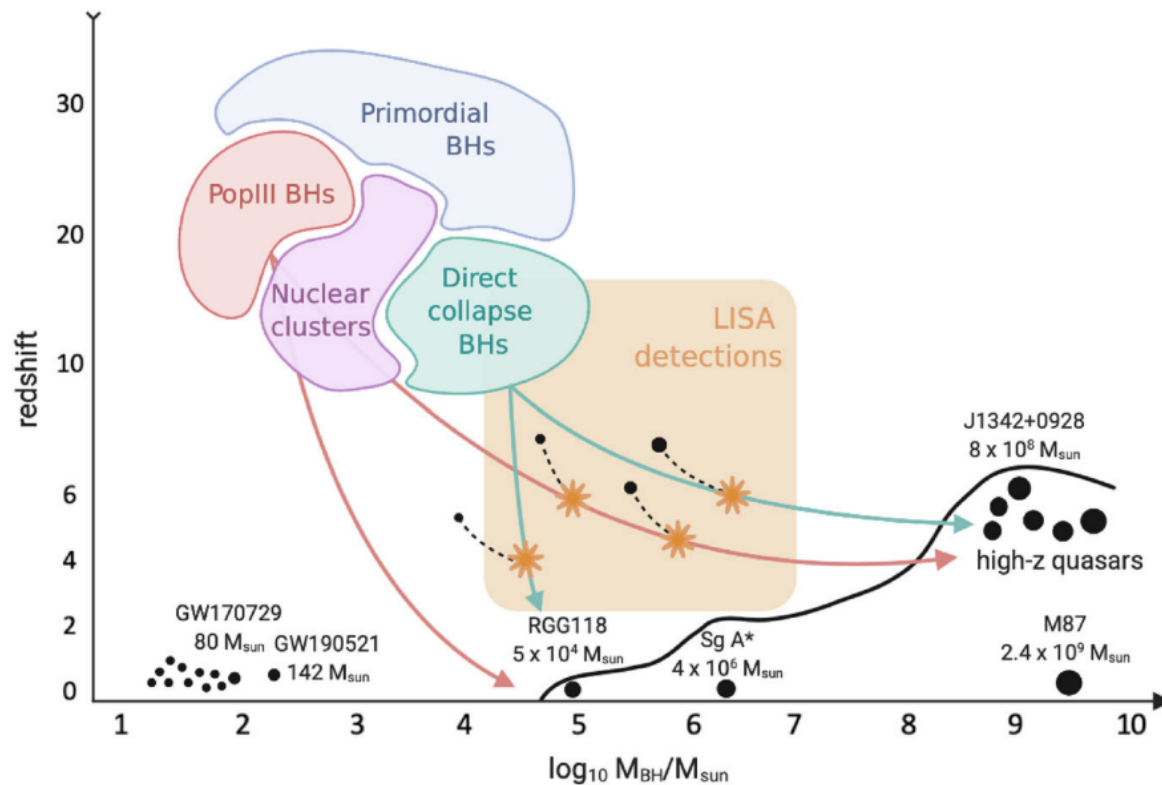
- ▶ Heavy BH can evolve from LISA band to high-f band on human time scales
- ▶ Predict merger
- ▶ Study binary BH formation channels
- ▶ Population likely small

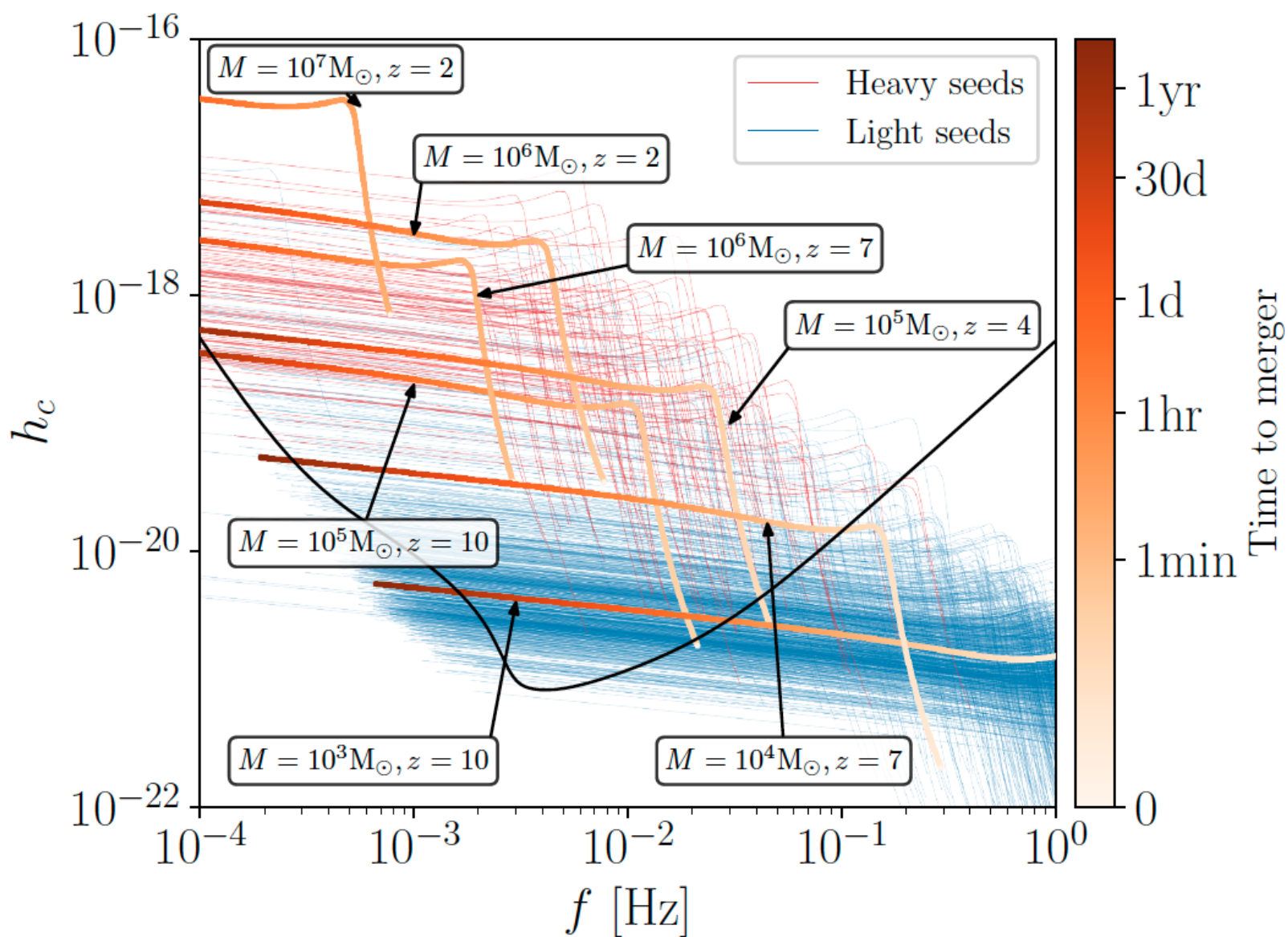




Massive BH formation and evolution

- ▶ How are MBH formed?
- ▶ How do MBH grow in mass
- ▶ How do MBH spins evolve?
- ▶ Some (very) high SNR
- ▶ Rates: few-100/yr

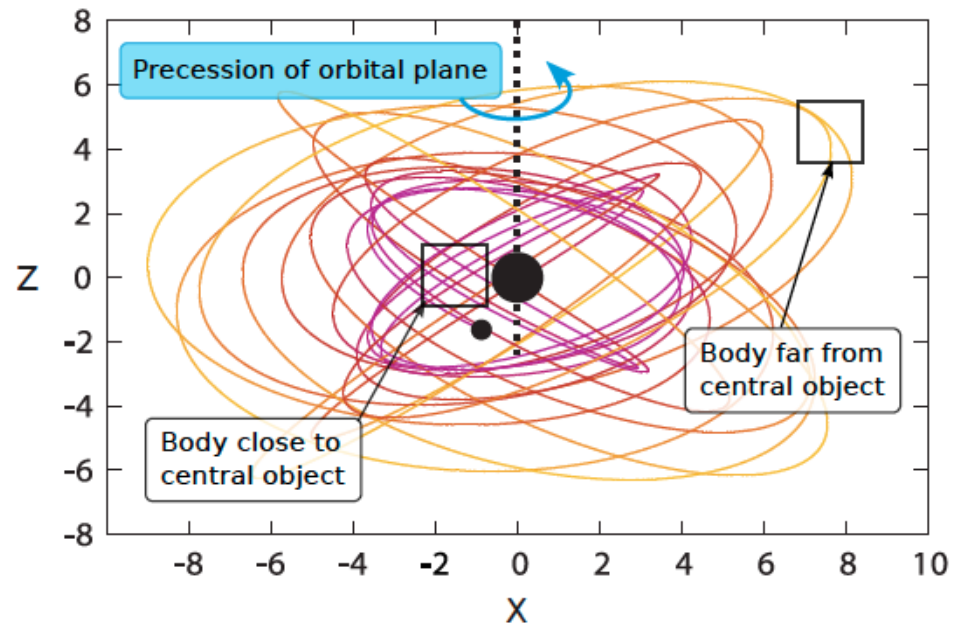






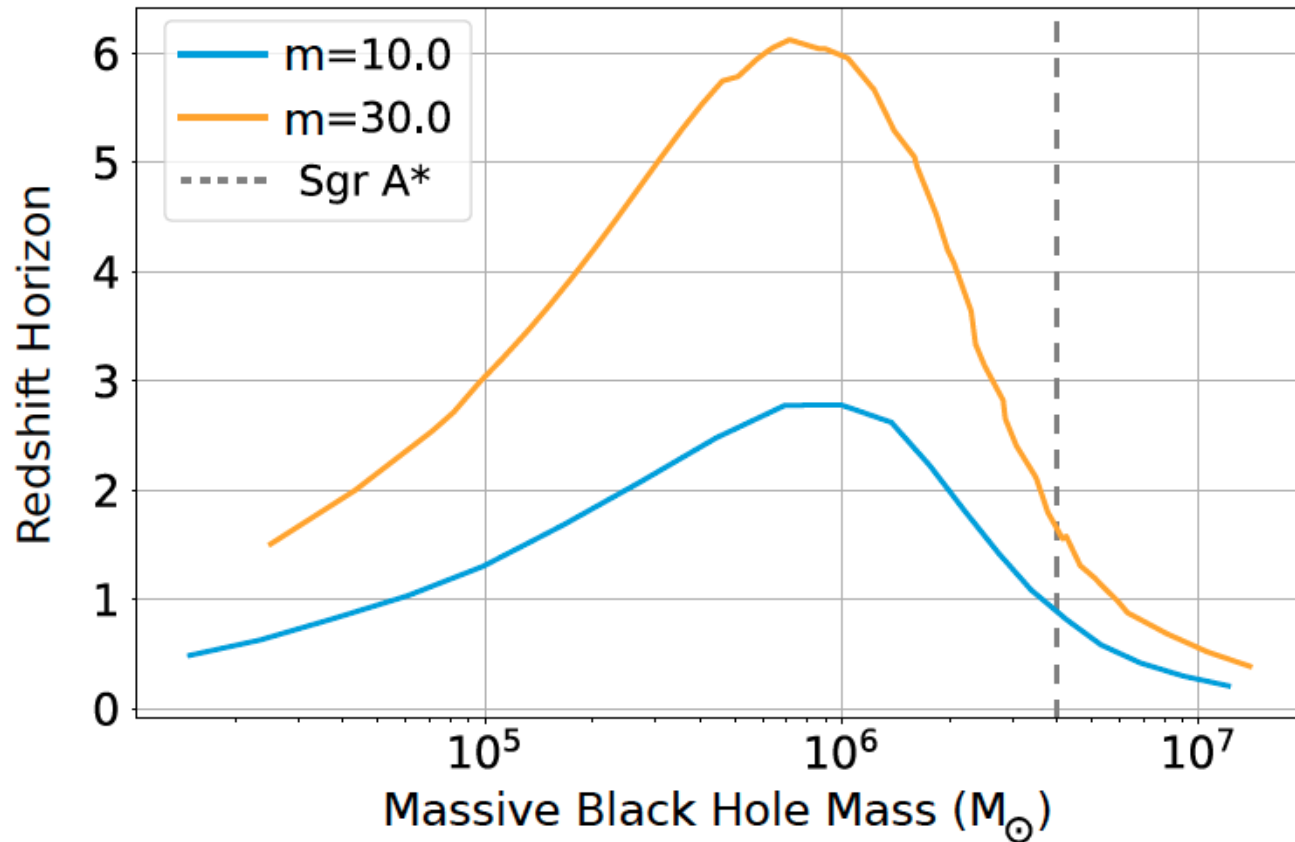
Extreme mass-ratio inspirals

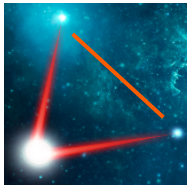
- ▶ Small object spiralling into MBH
- ▶ Test metric (later)
- ▶ Census MBH
- ▶ Study central regions galaxies
- ▶ Discover intermediate mass BH
- ▶ Rates highly uncertain (but informative)





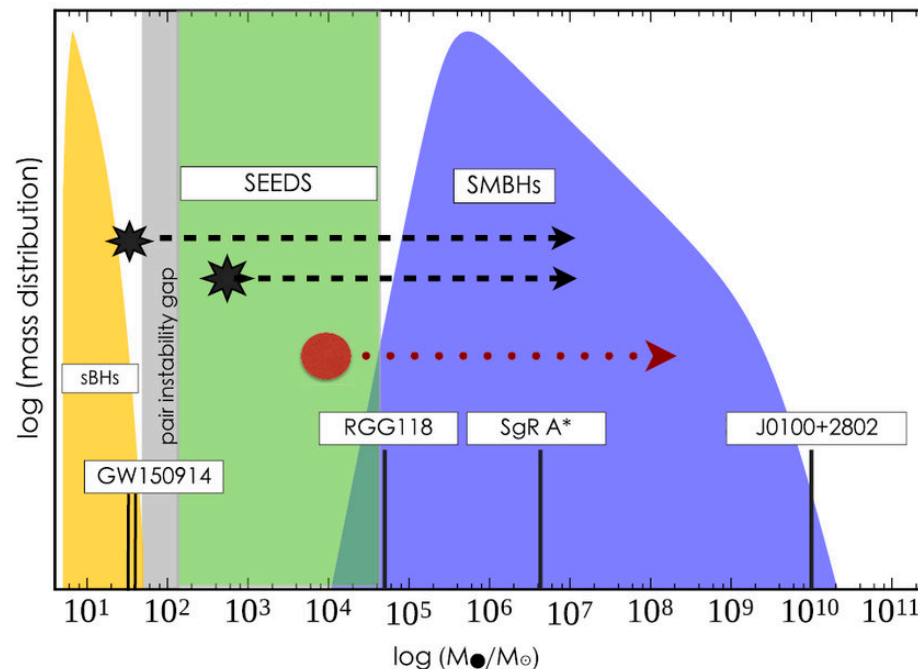
EMRI horizon

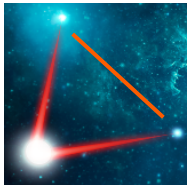




Intermediate Mass BHs

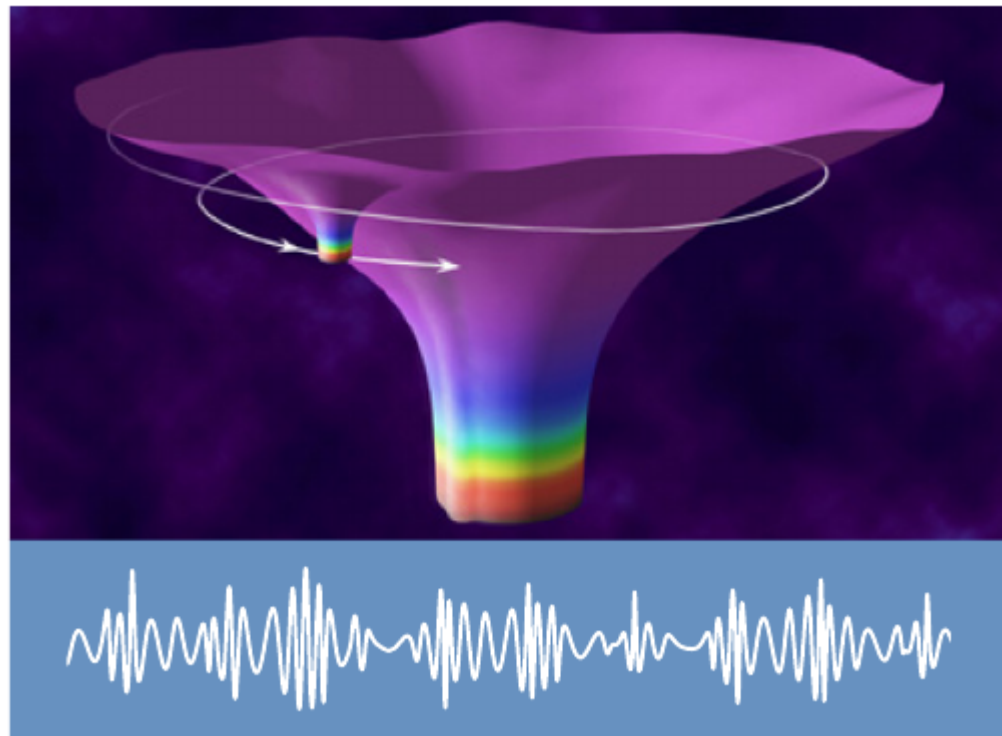
- “Intermediate Mass-ratio inspirals” (IMRIs)
 - MBH + IMBH
 - IMBH + stellar BH
- Will probe the existence and properties of IMBH

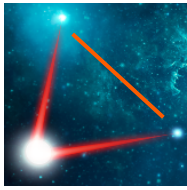




Fundamental physics

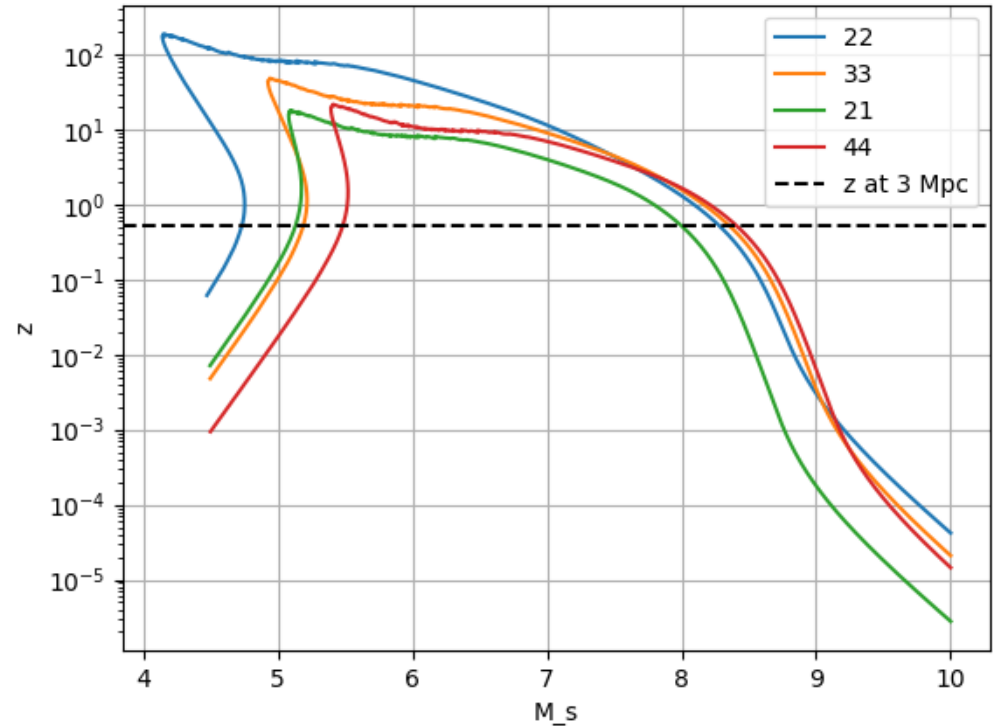
- ▶ High SNR MBH mergers
- ▶ Use EMRIs to explore the multipolar structure of MBH and constrain new light fields
- ▶ Some EM counterparts: EM and GW from same source



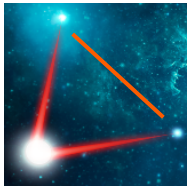


Fundamental physics

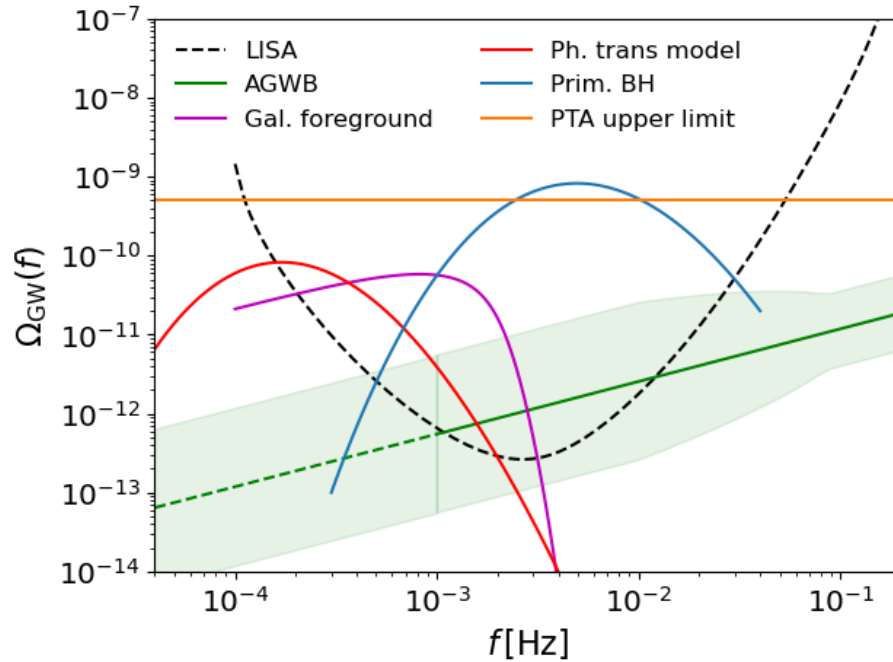
- ▶ Ringdown test of GR
- ▶ Echo's
- ▶ Test No-hair theorem, test for new fields with EMRIs
- ▶ Additional radiation channels and polarisations as signal of non-GR effects, especially with multi-band systems
- ▶ Propagation properties
- ▶ The unknown/unknown sources



Horizon for different ringdown modes



Early Universe signals



► First order phase transitions

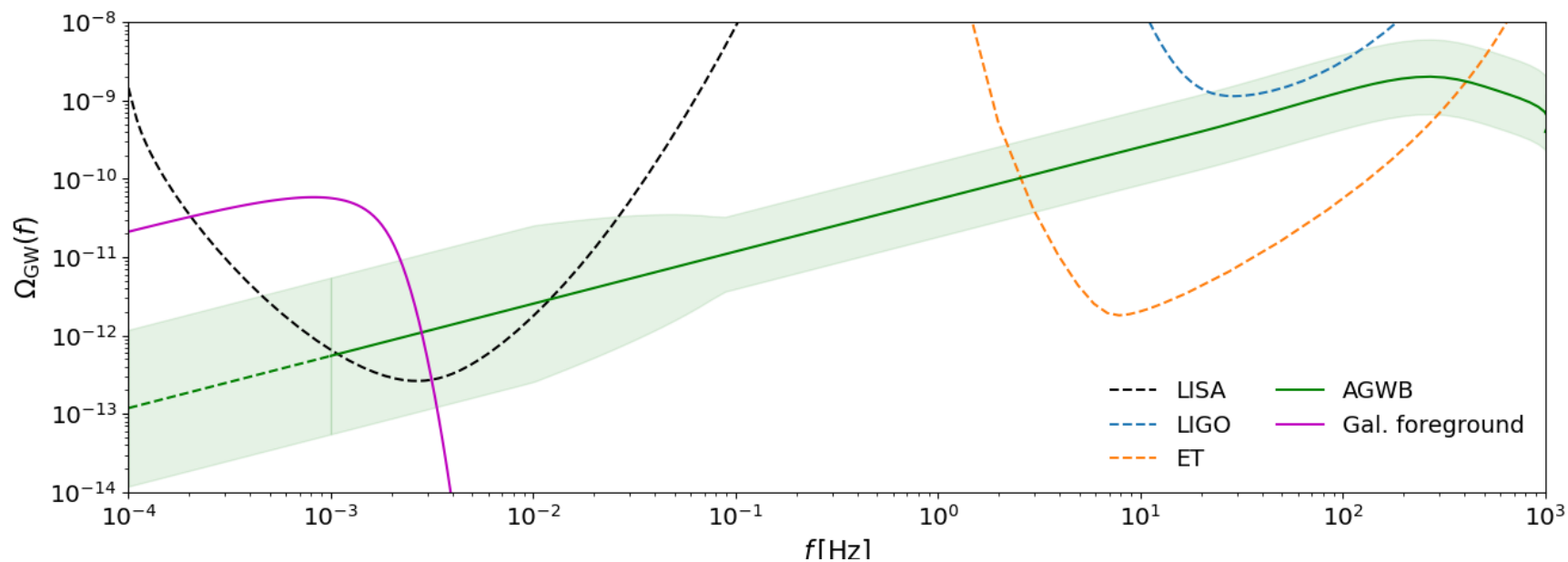
► Primordial black holes

► Cosmic strings

► ...



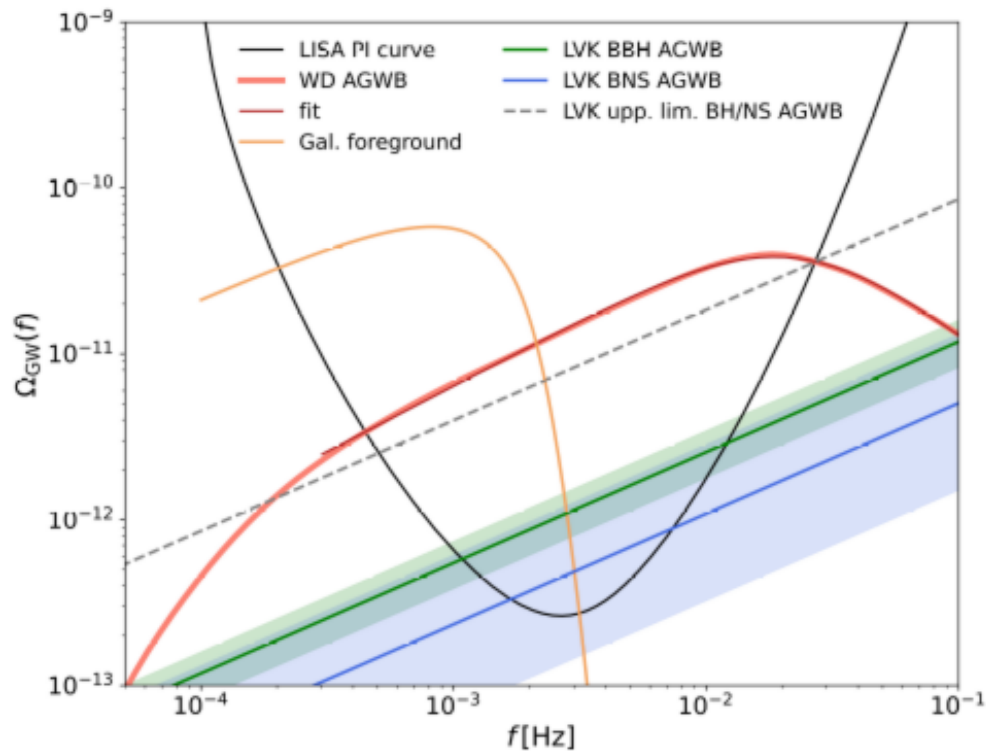
Astrophysical GW background





New calculation (Seppe Staelens)

- Based on SeBa population synthesis
- Formation of double WD(t)
- Map to redshift via star-formation history
- Calculate contribution to Ω_{GW}
- WD AGWB even higher than Farmer & Phinney
- Best fit: double power law (quite good, $<5\%$)
- Index below break 0.79, i.e. higher than $2/3$ [formation binaries in band]
- Above 0.01 Hz, run out of sources, rapid fall-off
- Around 0.1 Hz BH AGWB takes over

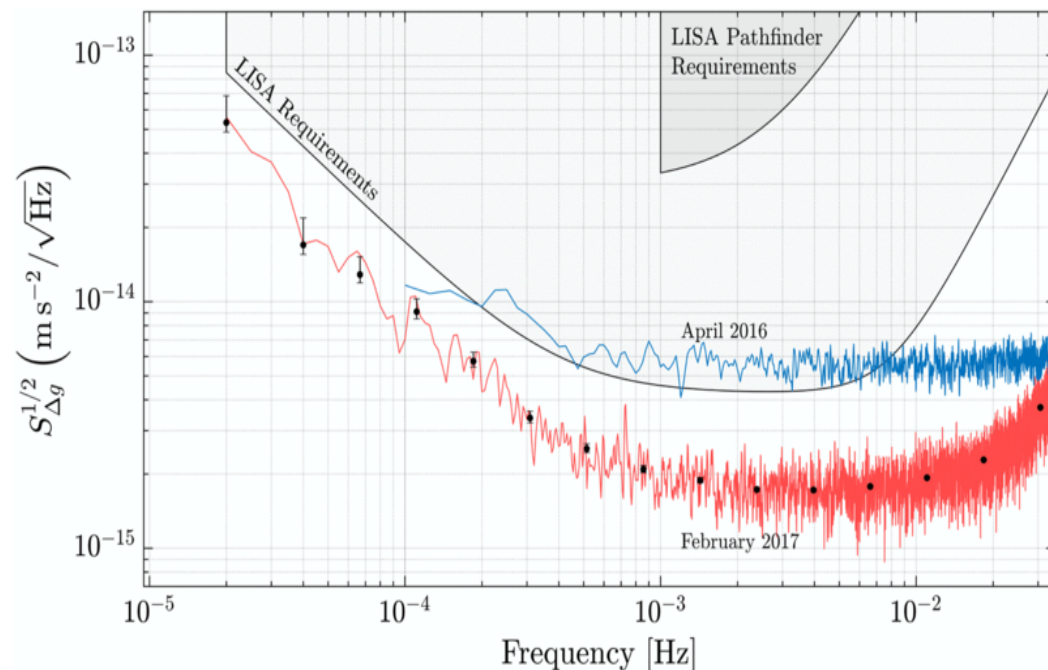




The LISA mission: status



- ▶ ESA LISA Pathfinder, successful technology demonstrator
- ▶ Adoption early 2024
- ▶ Hardware and data processing development NOW
- ▶ NL & B involved, everybody welcome to join LISA-NL/B
- ▶ Launch possible in 2036
- ▶ ~2 years before first data

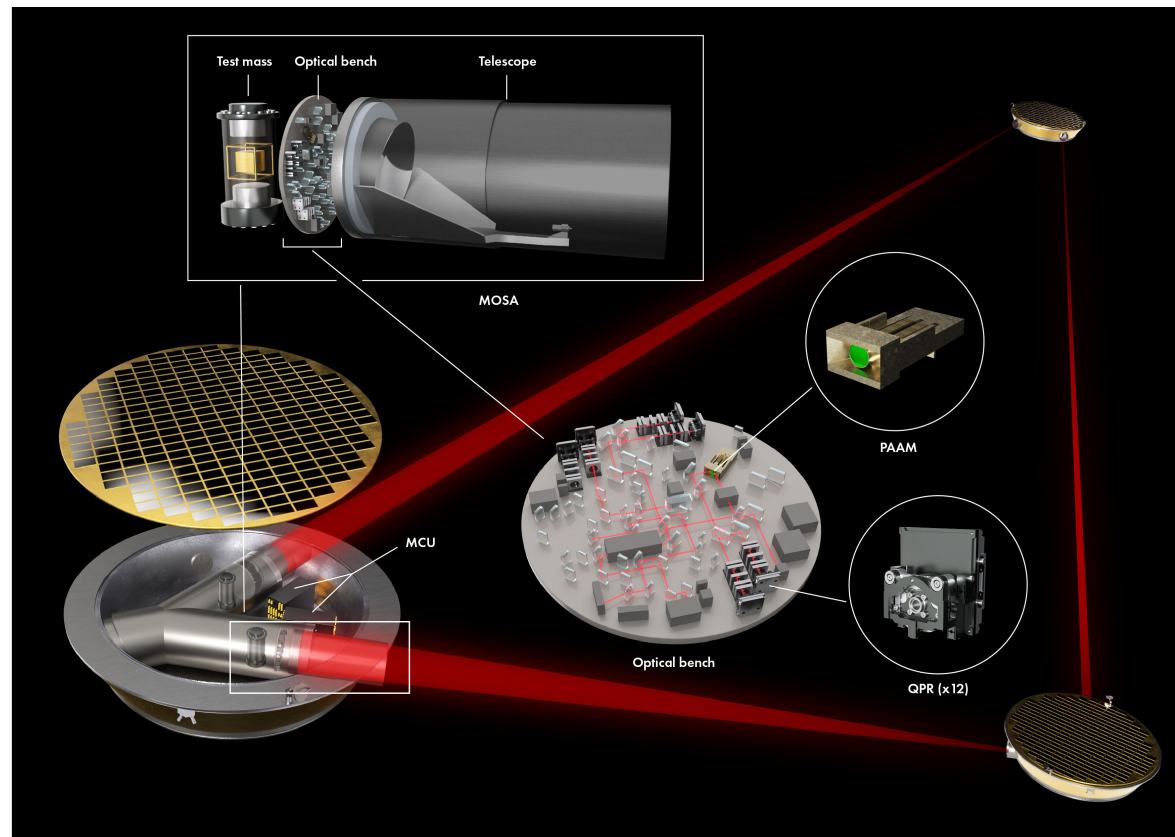


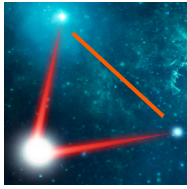


Dutch/Belgian payload contributions

► Technology

- Photodiodes (QPR, Nikhef/SRON, Belgium)
- Point Ahead Angle Mechanism (PAAM, TNO), electronics (SRON)
- Beam Alignment Mechanism incl. electronics (Belgium)
- Mechanism Control Unit (MCU, SRON)
- LISA system engineering
- Instrument performance & Data analysis tools





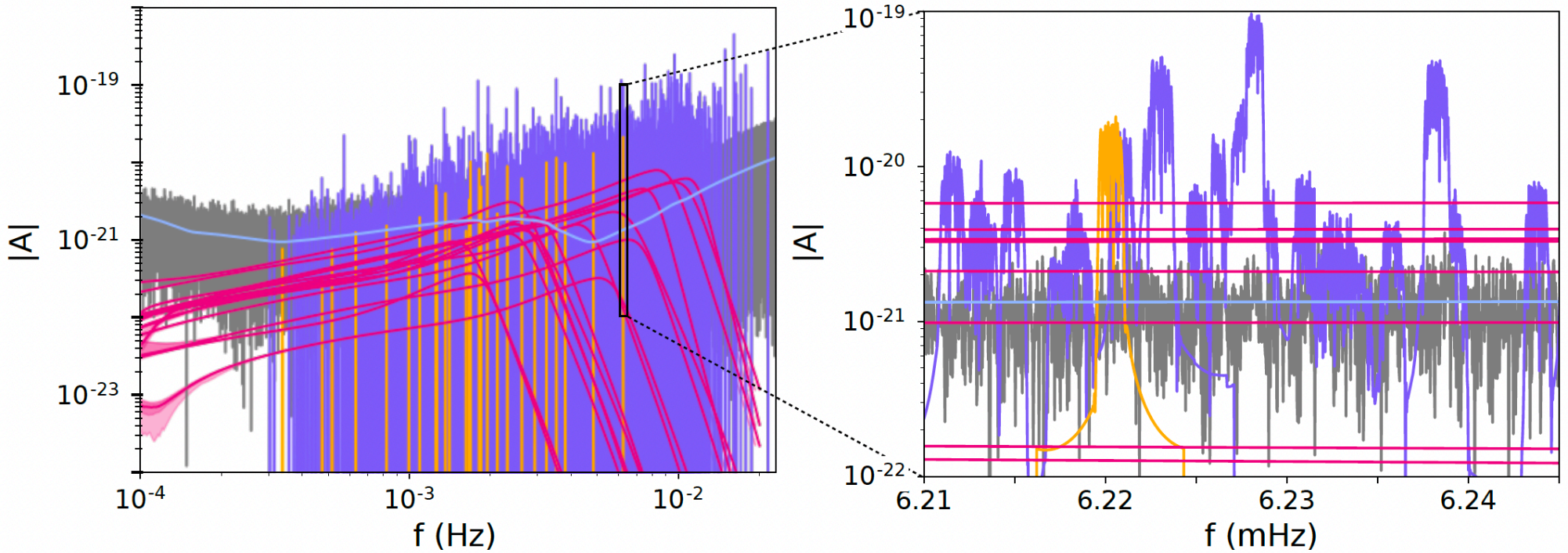
LISA mission adoption

- Aim: technical and programmatic readiness
- Result: ESA budget becomes available
- Multi-step process
 - Review instrument
 - Review mission
 - Multi-lateral agreement (MLA) ESA — Member states
 - Memorandum of Understanding (MoU) ESA — NASA
 - Science Management Plan
 - Balance between validation/proprietary time and open data
 - Difficult discussions with NASA





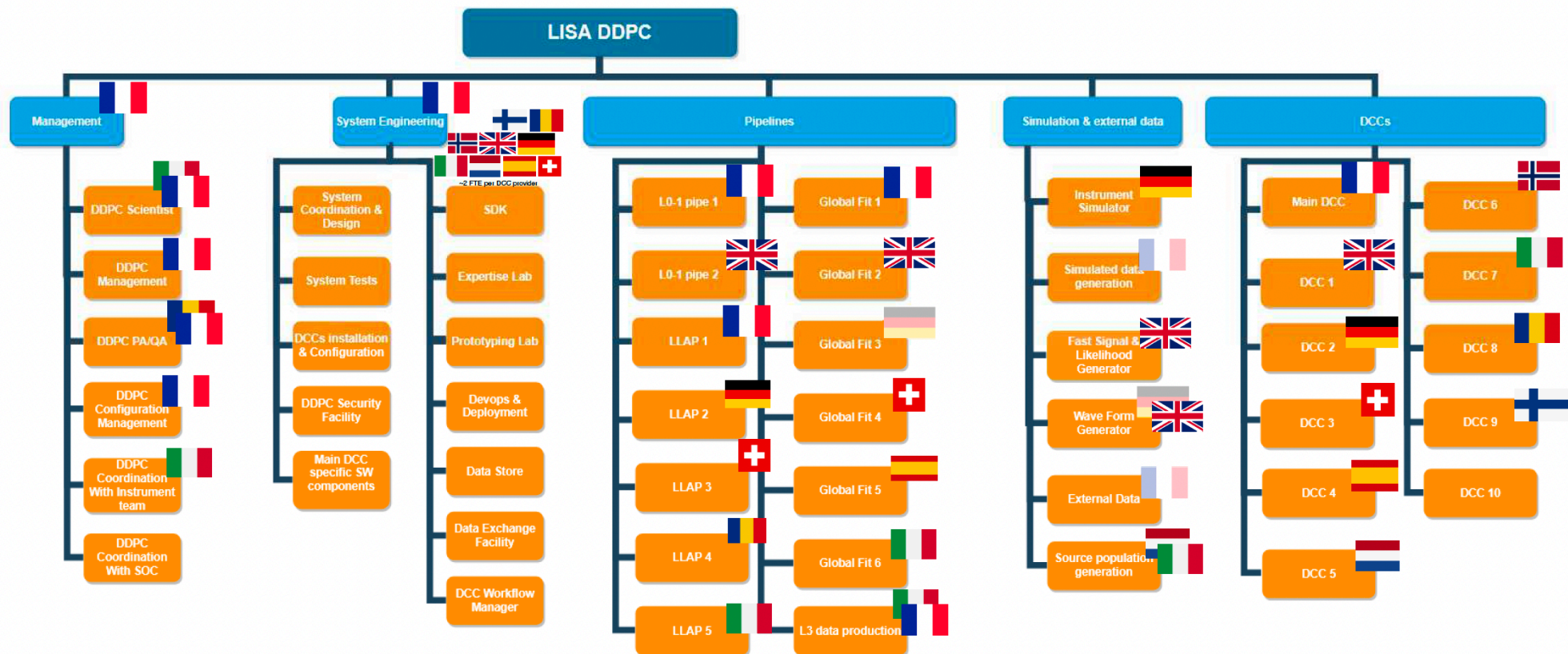
Data analysis challenges

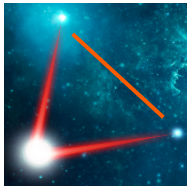




Data processing

DDPC contribution status (07/03/2023)

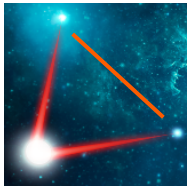




Consortium evolution

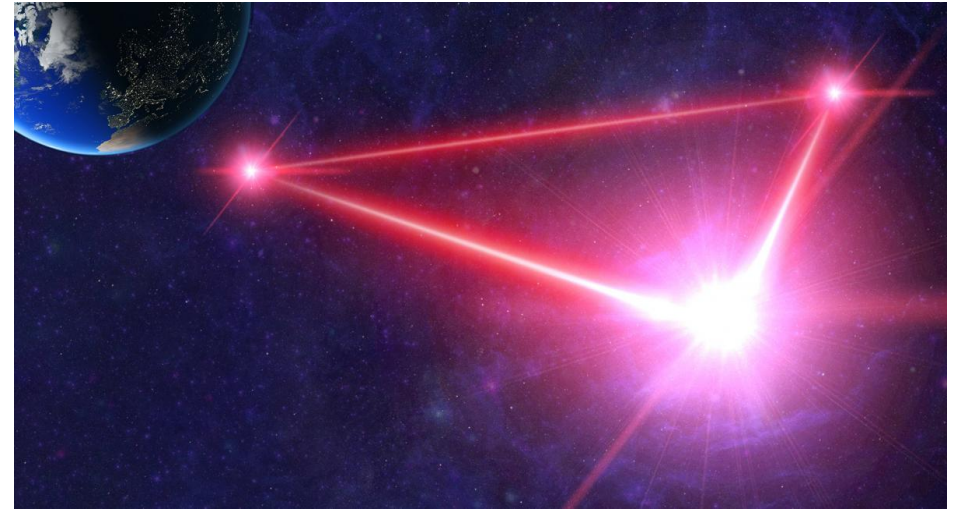
- Role of consortium will change
 - ESA will form LISA Science Team (LST) [likely via open call]
 - Early data access likely via Science Topical Teams
 - Hardware contributions via LISA project
- Consortium will evolve around this
- Currently transition period
- “Consortium Constituent Council” (CCC) will develop new structure/governance in next year





Conclusions

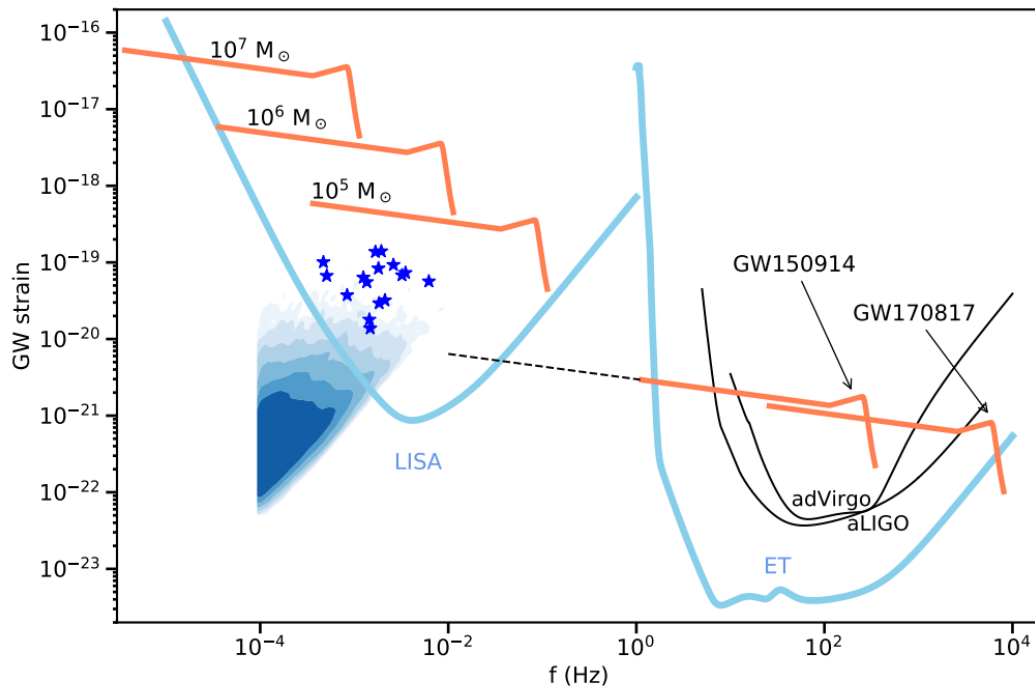
- ▶ LISA will happen in mid 2030s
- ▶ Next steps
 - ▶ Adoption, lots of work, launch...
- ▶ Very diverse science case
 - ▶ Local stellar populations in Milky Way
 - ▶ MBH throughout the Universe
 - ▶ EMRIs
 - ▶ Multi-band sources
 - ▶ Fundamental physics
 - ▶ Cosmology
 - ▶ Early Universe probe
- ▶ Exciting times ahead!



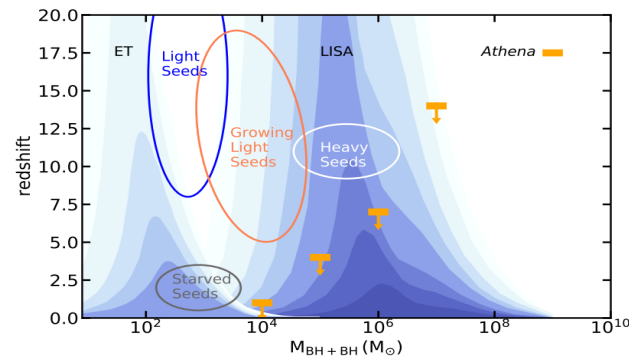
Backup

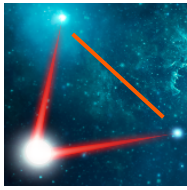


LISA and Einstein Telescope

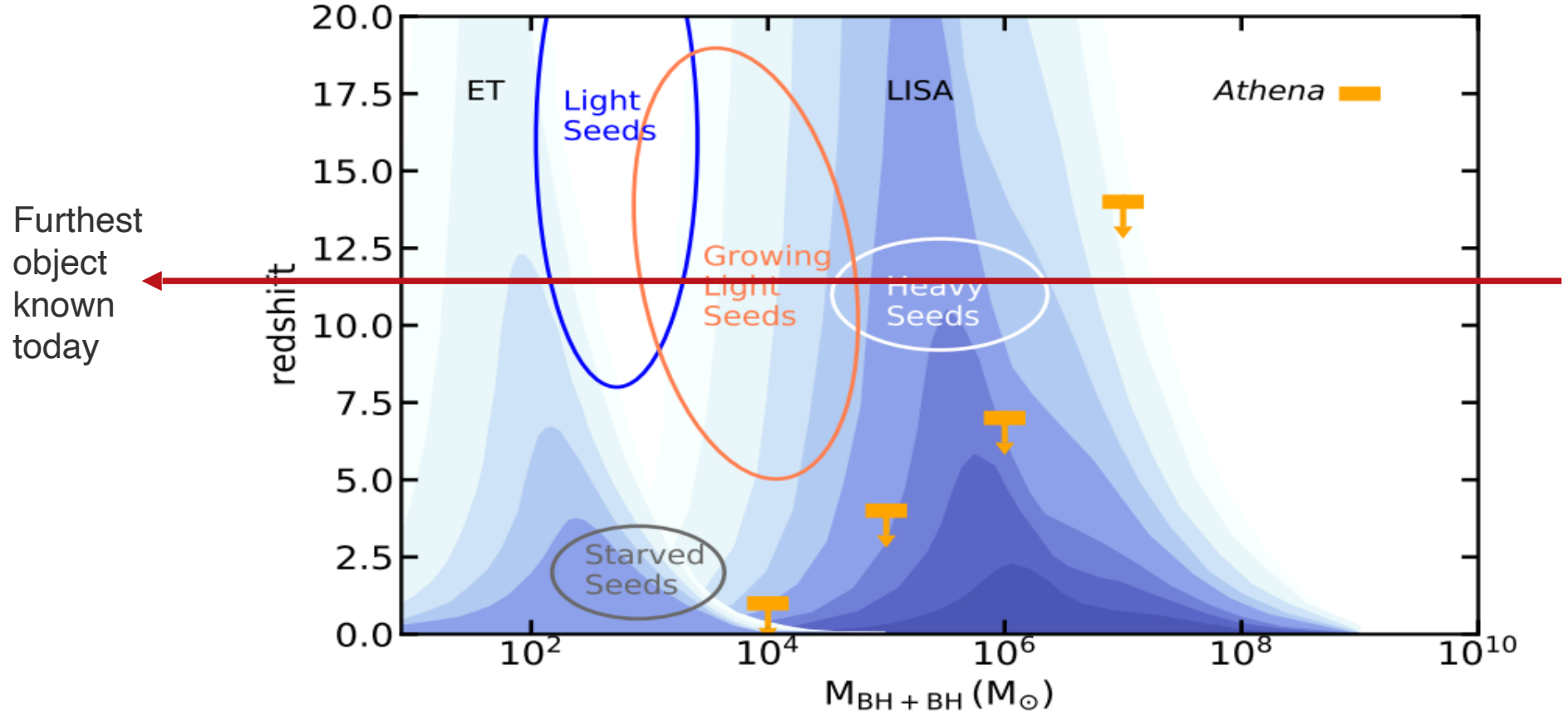


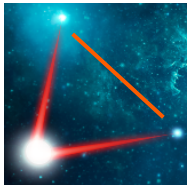
- ▶ LISA & ET complementary in frequency & sources
- ▶ See <https://lisamission.org/> and <https://www.et-gw.eu/>
- ▶ Together probe Universe





LISA and Einstein Telescope





Interferometry in Space

- ▶ Sensitivity aim

$$h = \frac{\Delta L}{L} = 10^{-20} \frac{1}{\sqrt{\text{Hz}}} \rightarrow \Delta L \approx 25 \frac{\text{pm}}{\sqrt{\text{Hz}}}$$

- ▶ Diverging laser

- ▶ Only $(30\text{cm}/6\text{km})^2 \approx 10^{-9}$ of light arrives

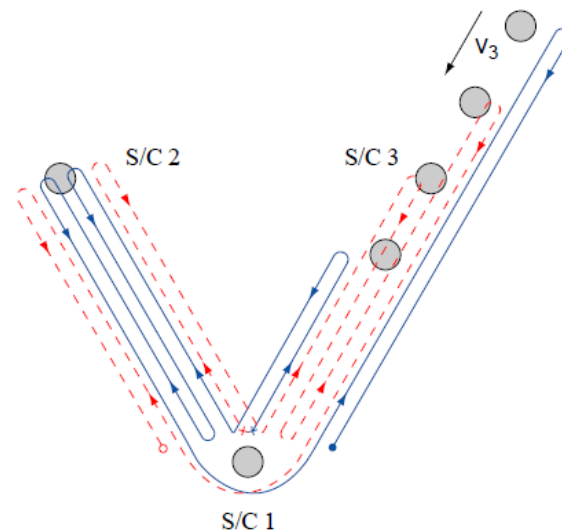
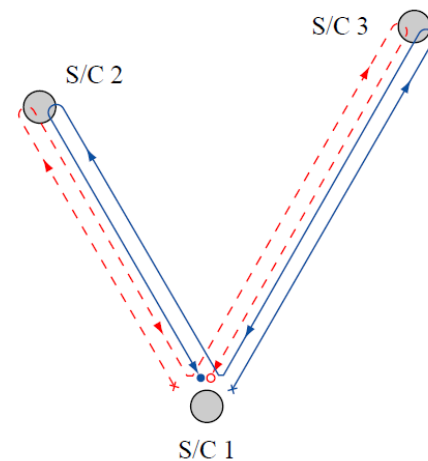
- ▶ Heterodyne interferometry

- ▶ Unequal and changing arms: laser frequency noise

- ▶ Laser frequency noise $\tilde{\nu}(f) = 100 \frac{\text{Hz}}{\sqrt{\text{Hz}}}$

- ▶ Translates into displacement error $(x = \frac{\lambda}{2\pi} \phi)$ of $\tilde{x} = 0.9 \frac{\text{mm}}{\sqrt{\text{Hz}}}$

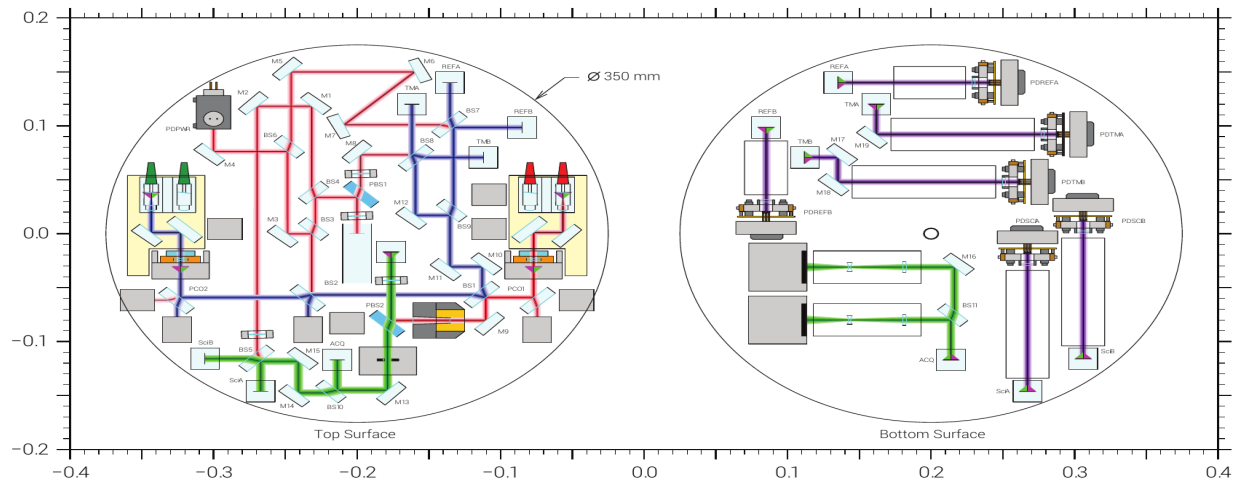
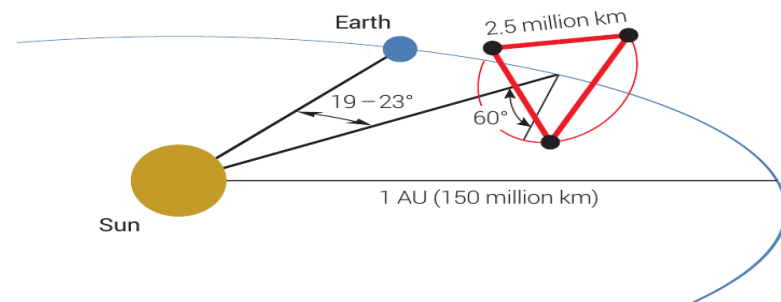
- ▶ Time Delay Interferometry: 9-10 orders of magnitude cancellation (proven)





LISA Mission concept

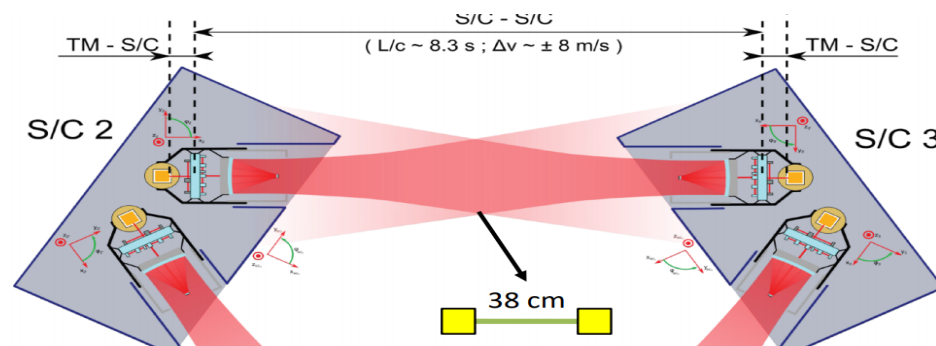
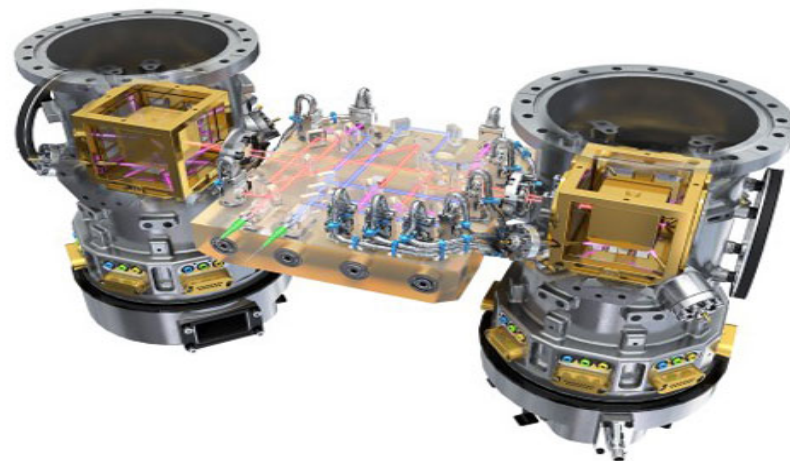
- ▶ 3 space craft
- ▶ 2.5 million km arms
- ▶ TDI
- ▶ Payload supplied by member states
 - ▶ Optical bench, incl. Phase meter
 - ▶ Gravitational Reference System, incl. test masses
- ▶ Lasers and telescopes by NASA
- ▶ Critical technology tested by LISA Pathfinder

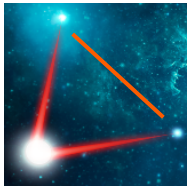




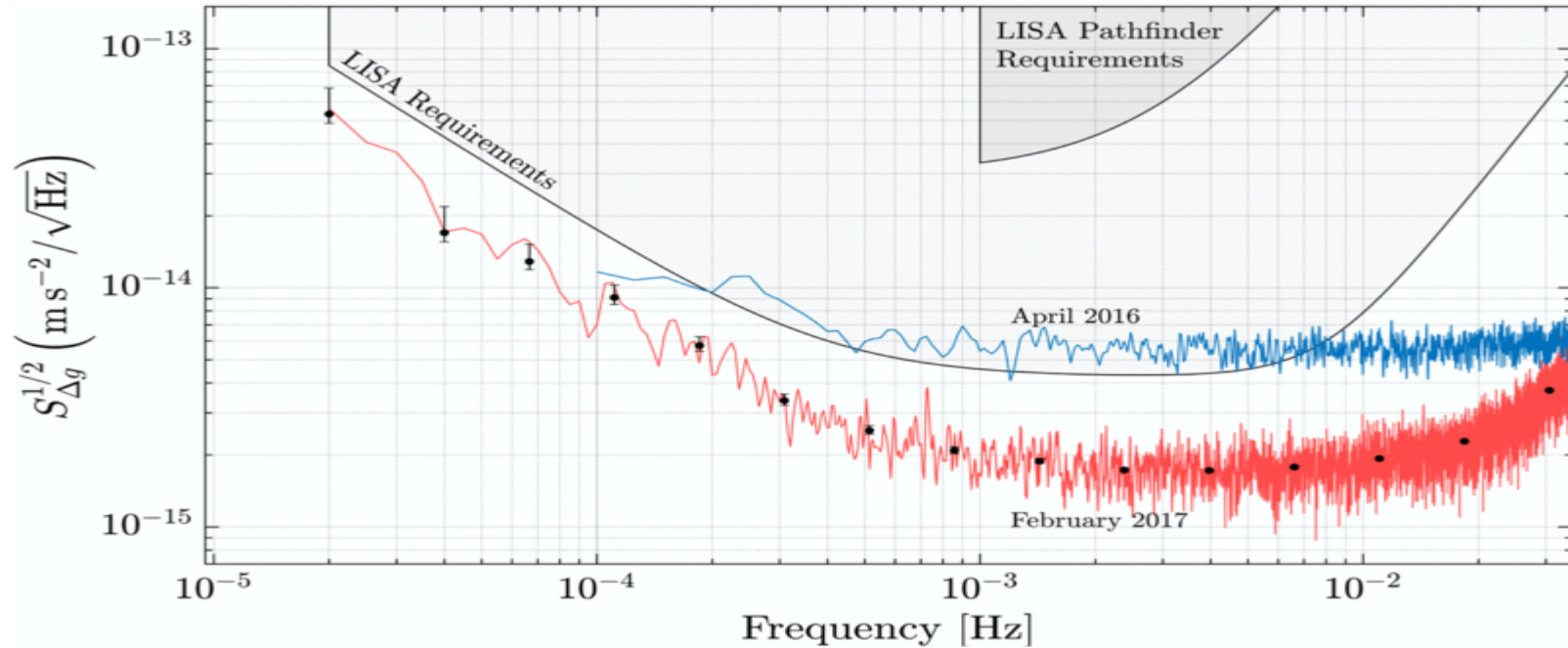
Critical technology: Pathfinder

- ▶ Free floating test masses
- ▶ Drag free control
- ▶ Gravitational balancing
- ▶ Displacement measurement via phase measurement
- ▶ Acceleration noise
- ▶ etc.





LISA Pathfinder



→ Results spectacular: LISA can be built!