How Does LISA Work?

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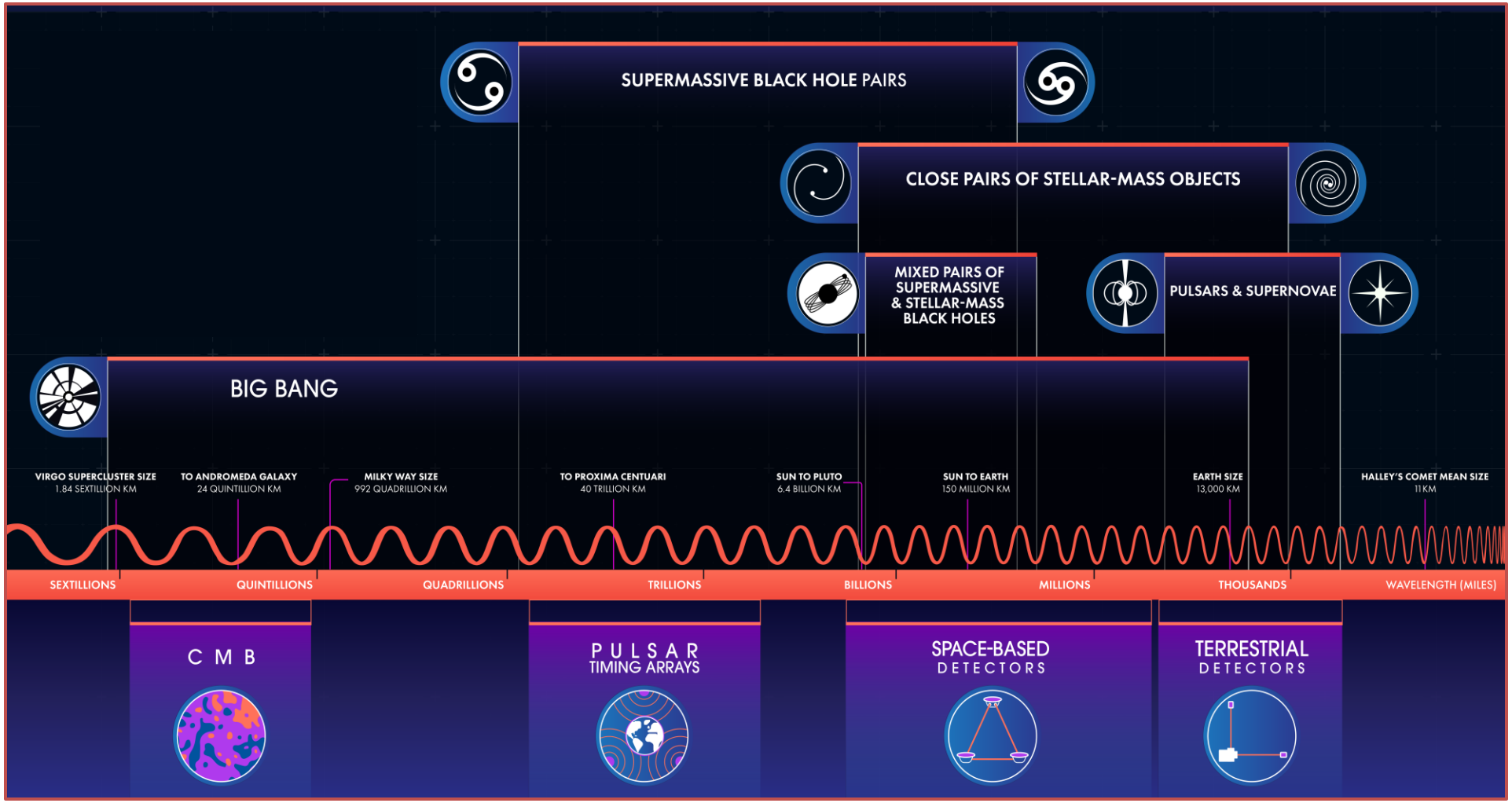
AAS 245 LISA Workshop

The GW Spectrum

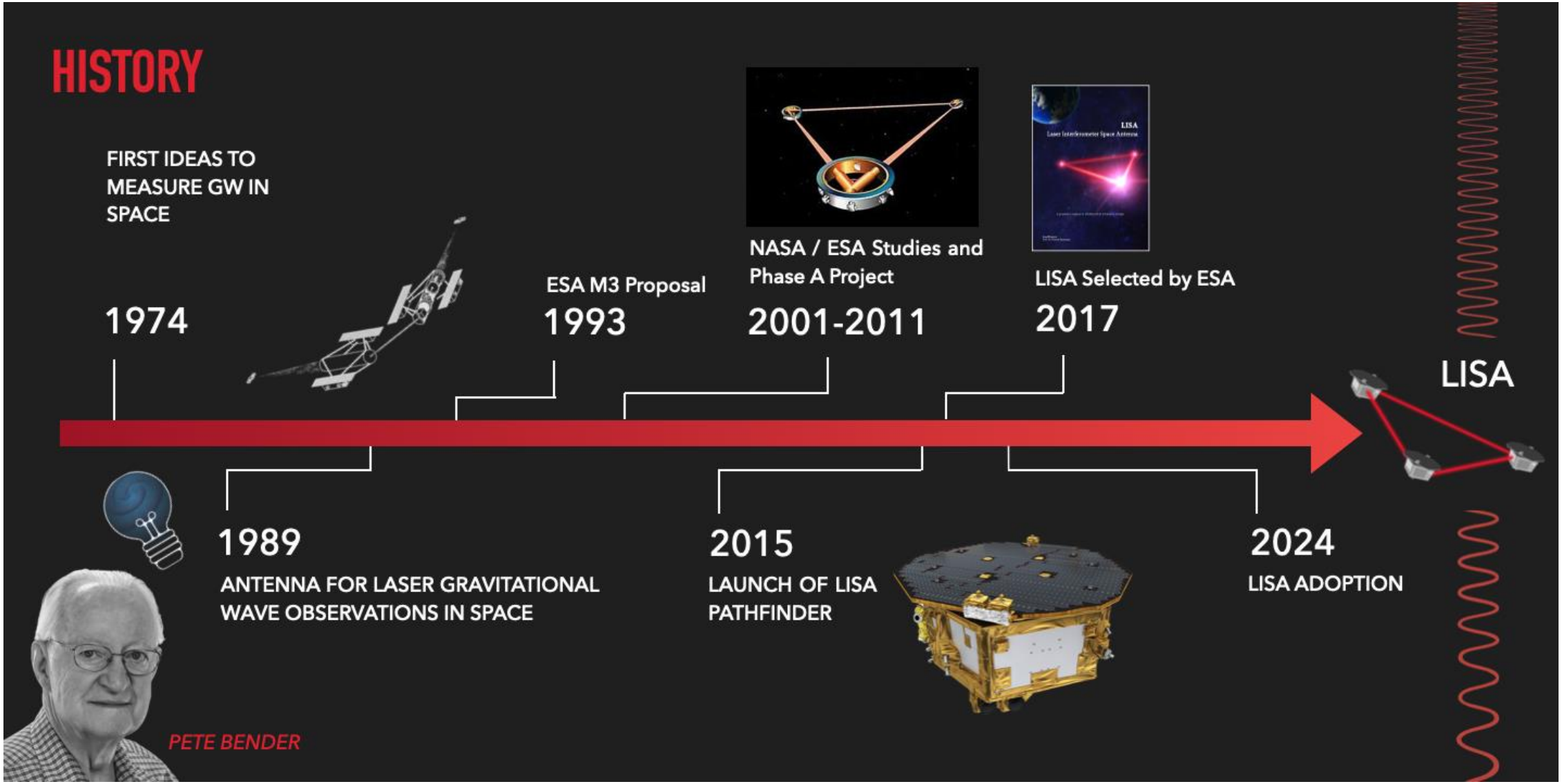
Broad spectrum of wavelengths / frequencies

Different astrophysical and cosmological sources in each band

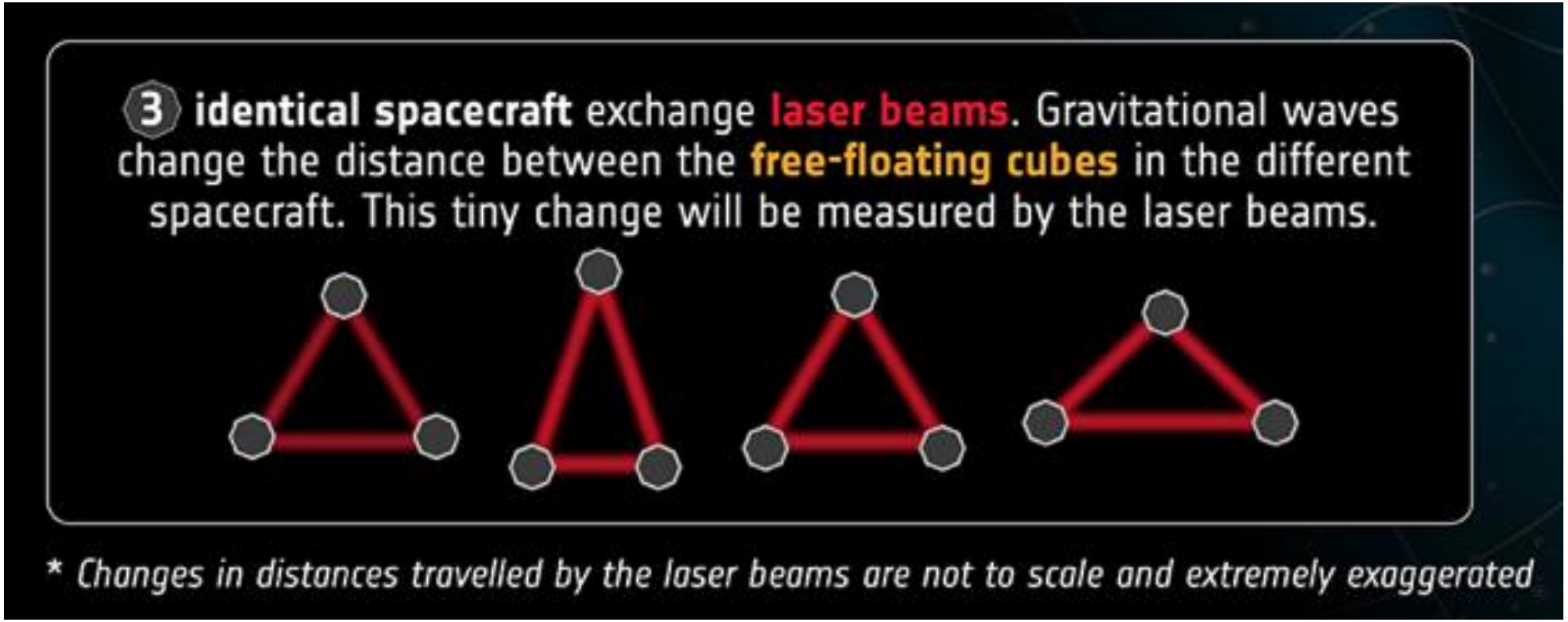
Different detection techniques required for each band



LISA Concept History

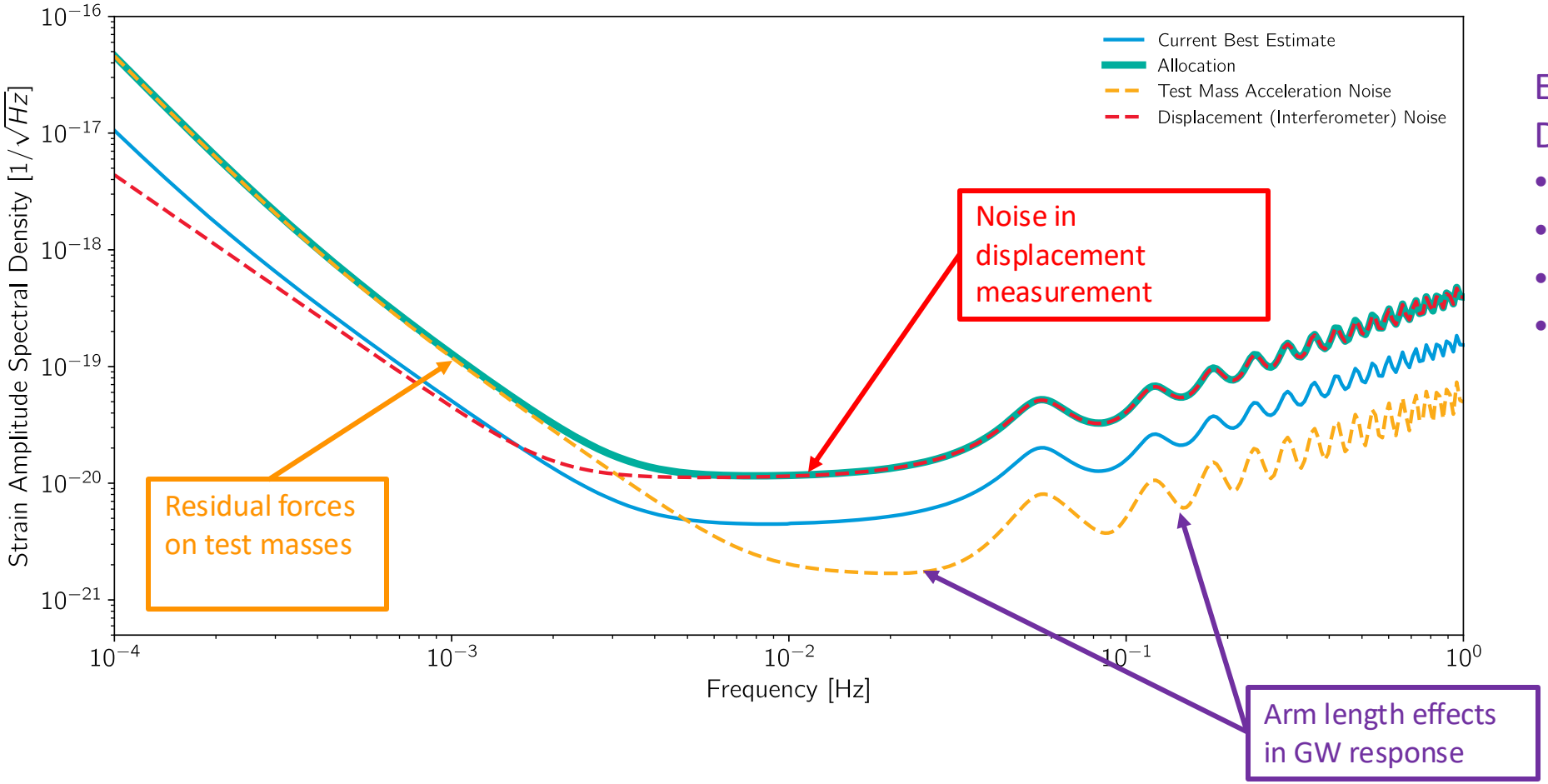


Measurement Principle



The LISA instrument is the constellation

Measurement Requirements



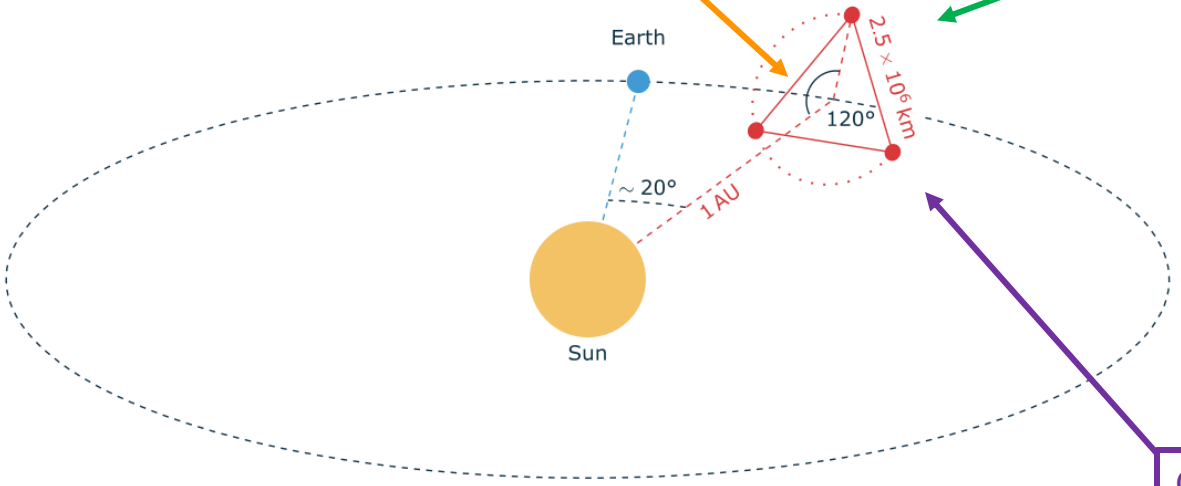
ESA Mission Requirements Document includes

- Strain requirement
- Mission duration
- Data latency
- …

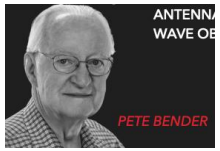
Arm lengths + Duration = Orbit Design

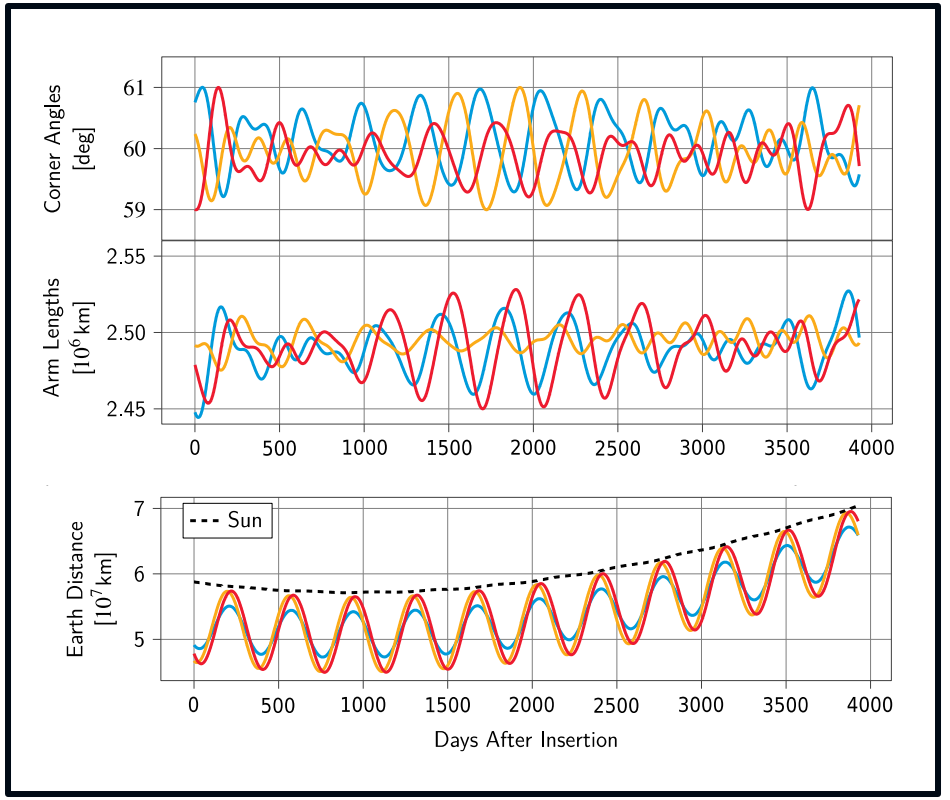
Earth-SC distance ranges 45~70 Mkm

Constellation rotates once per year around barycenter

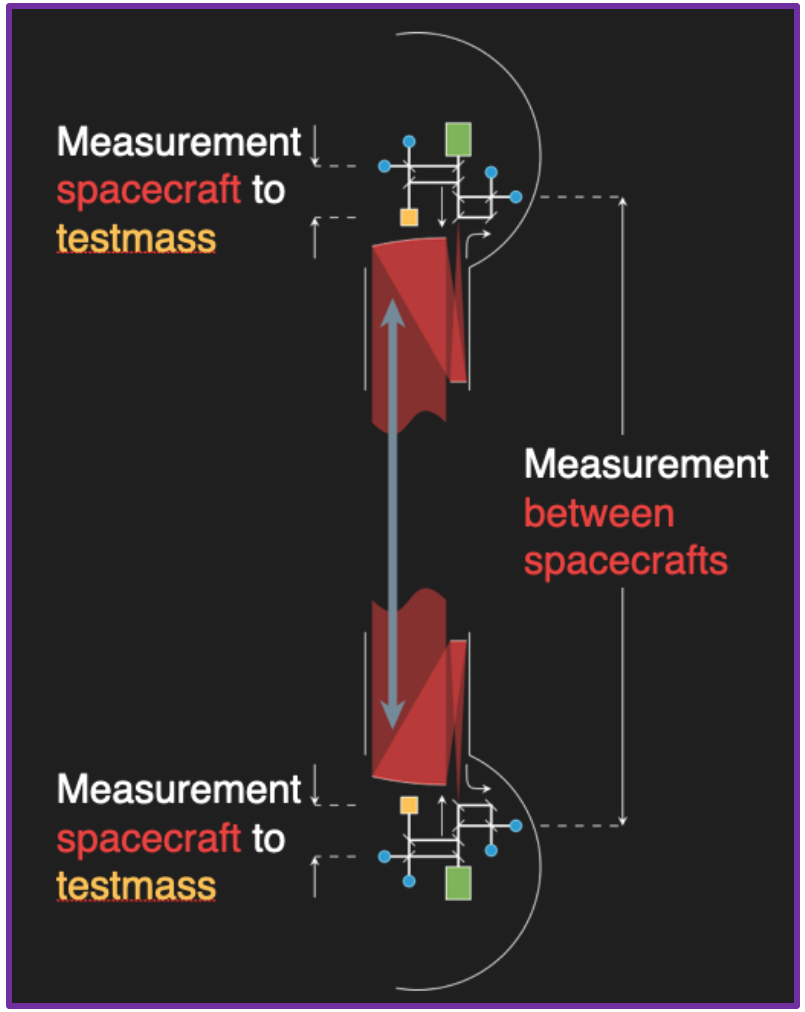


Constellation plane inclined at 60° w.r.t. ecliptic

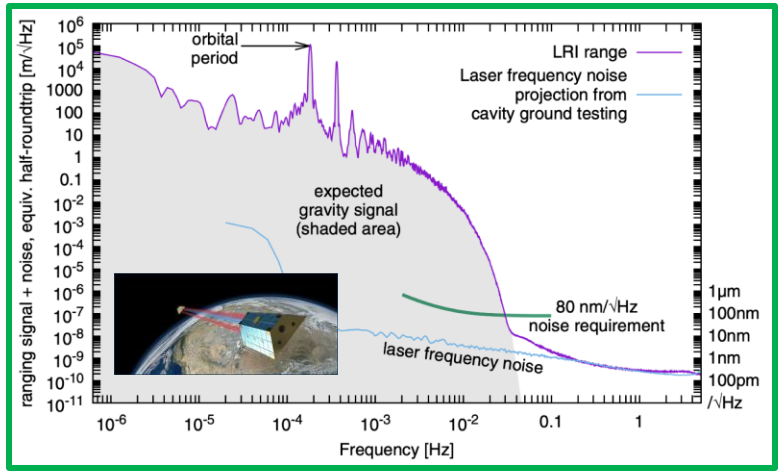




Displacement: Long-baseline interferometry

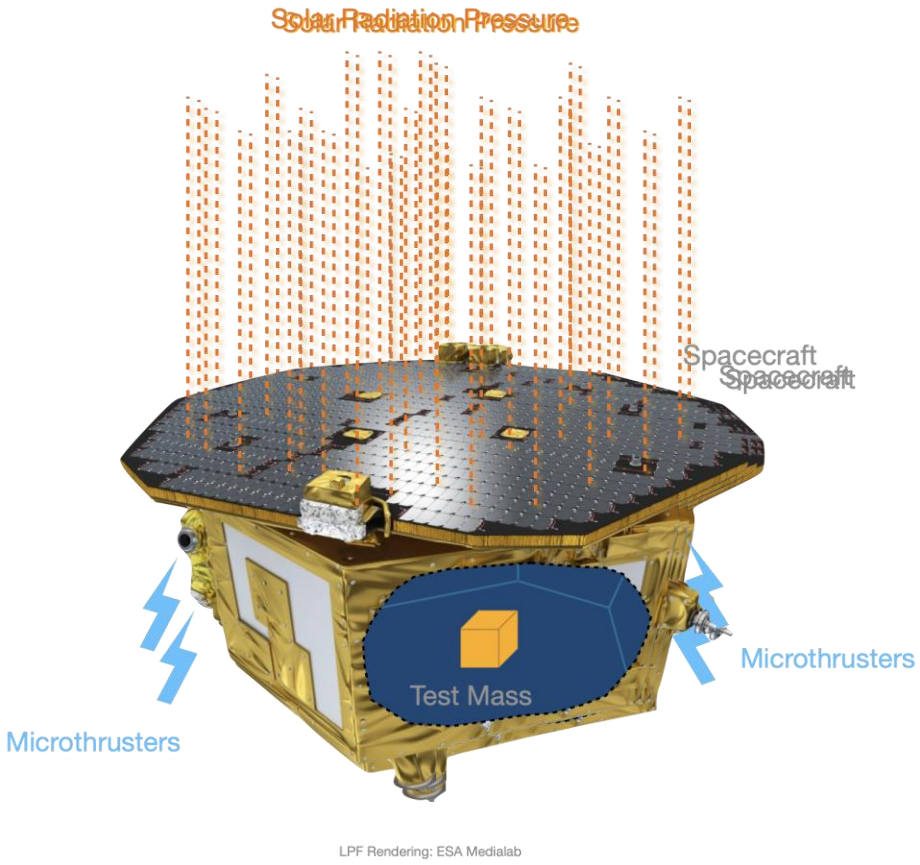


- Optical Interferometry: use optical phase to measure length changes.
  - 10pm ~ 10µcycles
  - Fundamental limit is photon counting statistics (aka shot noise). Need to transfer sufficient power between SC
- Heterodyne: different frequencies
  - Each arm vertex has its own laser
  - Make a series of one-way measurements, each limited by oscillator noise
  - Combine signals on ground to reject common oscillator noise and retain differential GW signal

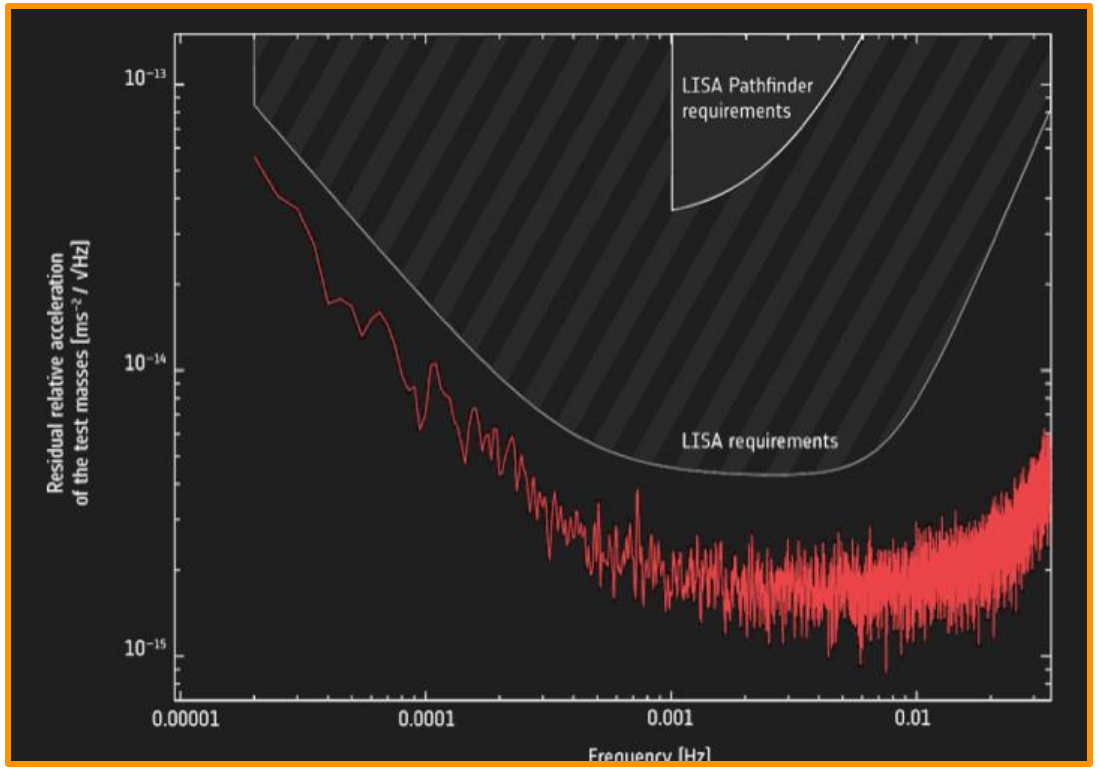


- Similar measurement with LRI on GRACE-FO
- Single 300km baseline
- Sub-nm noise floor, limited by oscillator noise

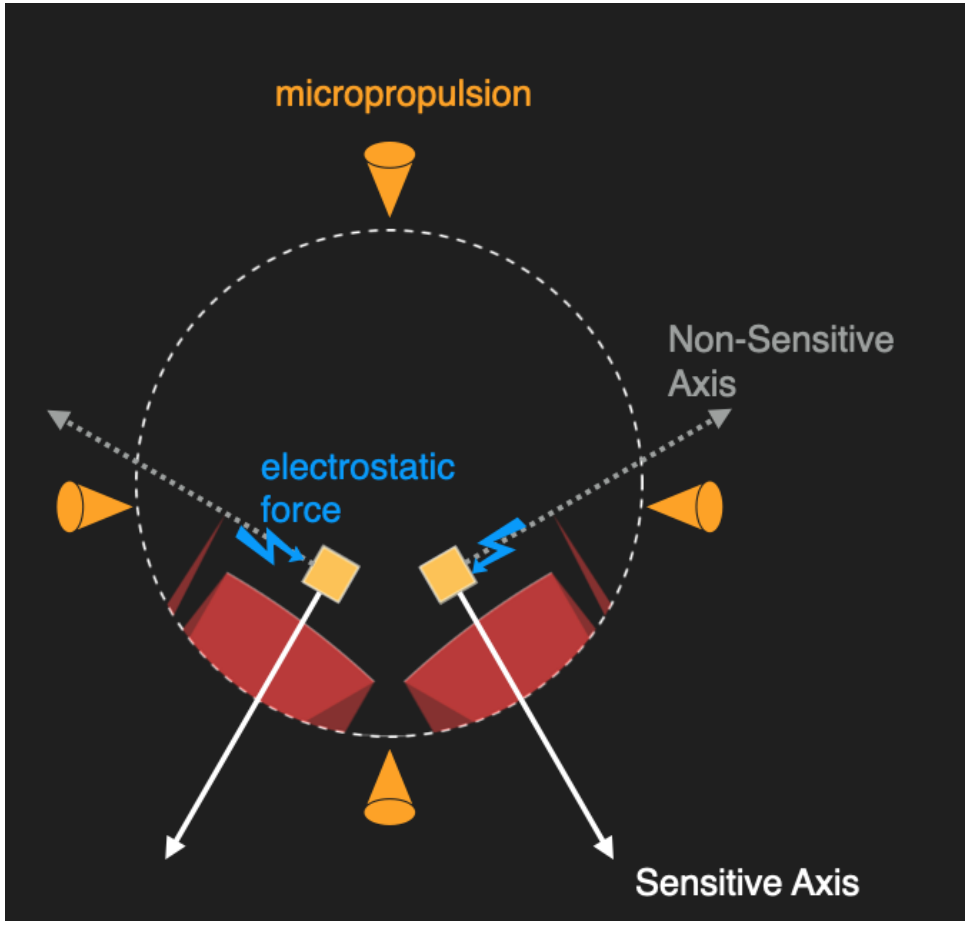
Disturbance Reduction: drag-free flight



LPF Rendering: ESA Medialab

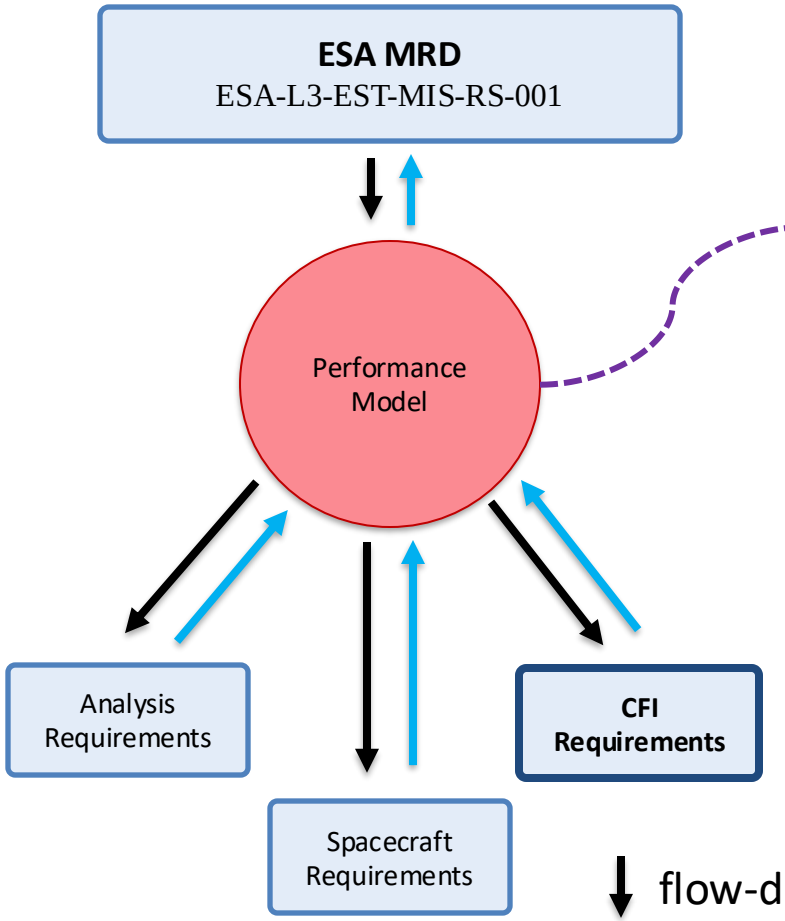


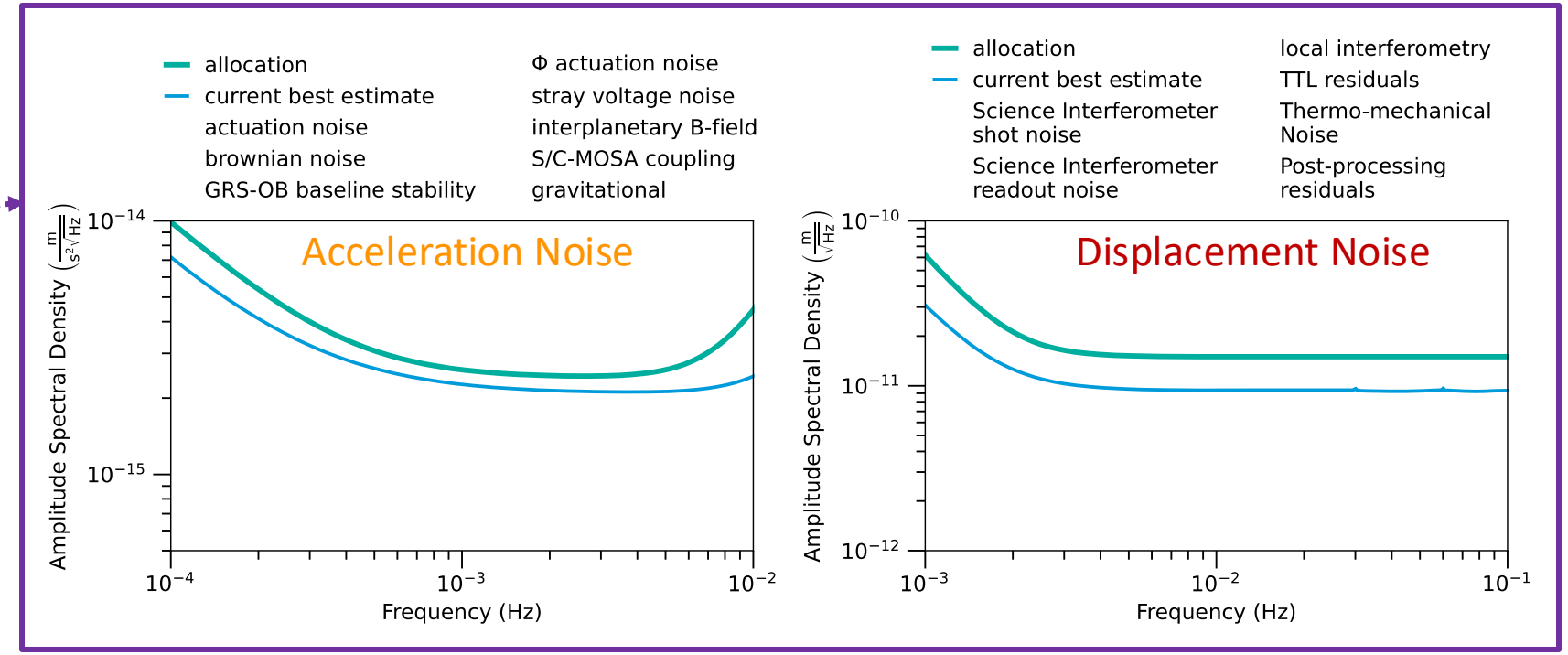
Disturbance Reduction for LISA



- Each TM is “drag-free” along sensitive axis
  - Electrostatic forcing of TMs in orthogonal directions
  - S/C translates and rotates to follow TMs
- Residual forces on the TM
  - Molecular / pressure
  - Electrostatic
  - Magnetic
  - Gravitational
  - Radiative

Performance Model



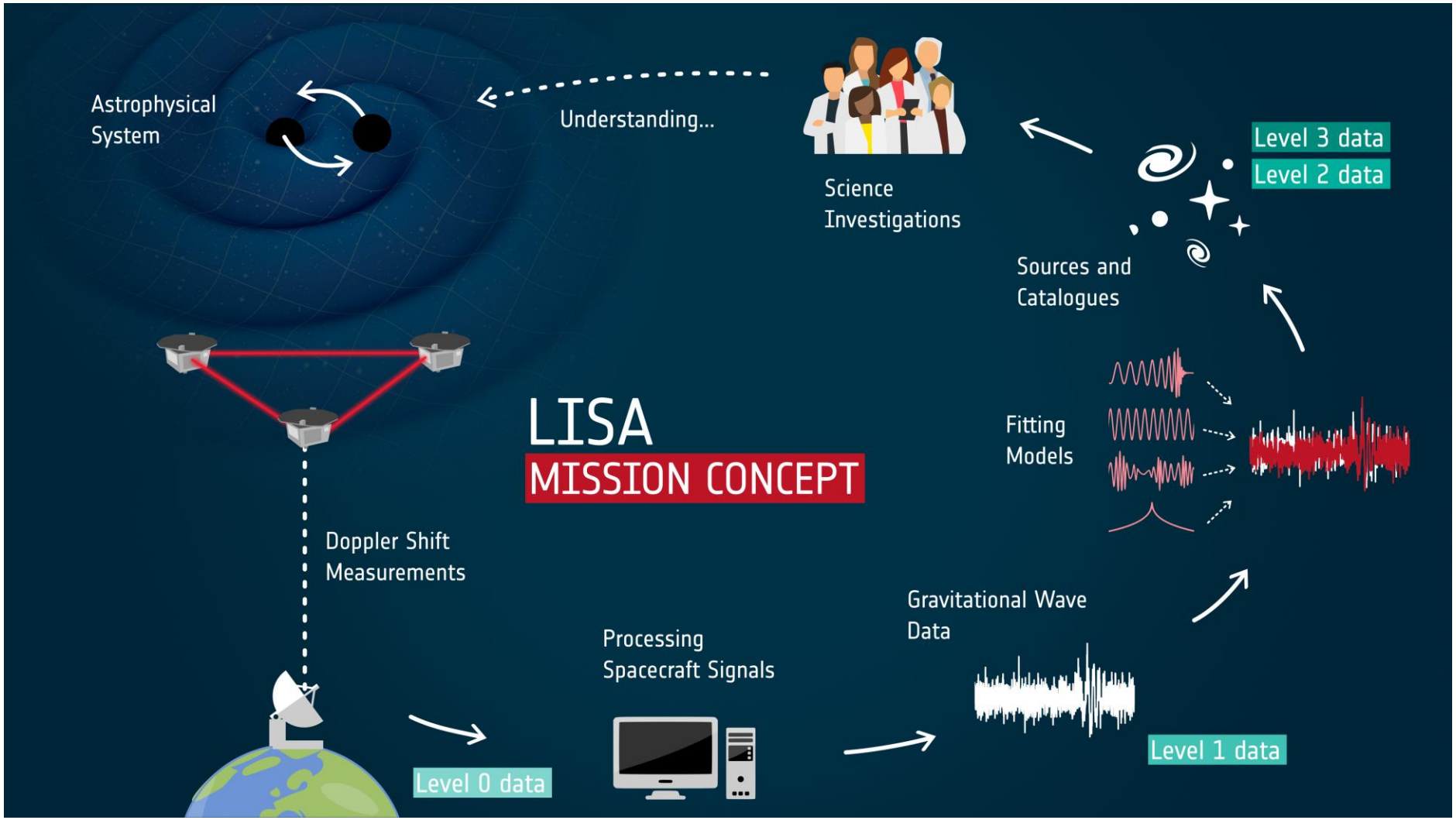


* This is a simplified illustration, the performance model has 100s of terms.

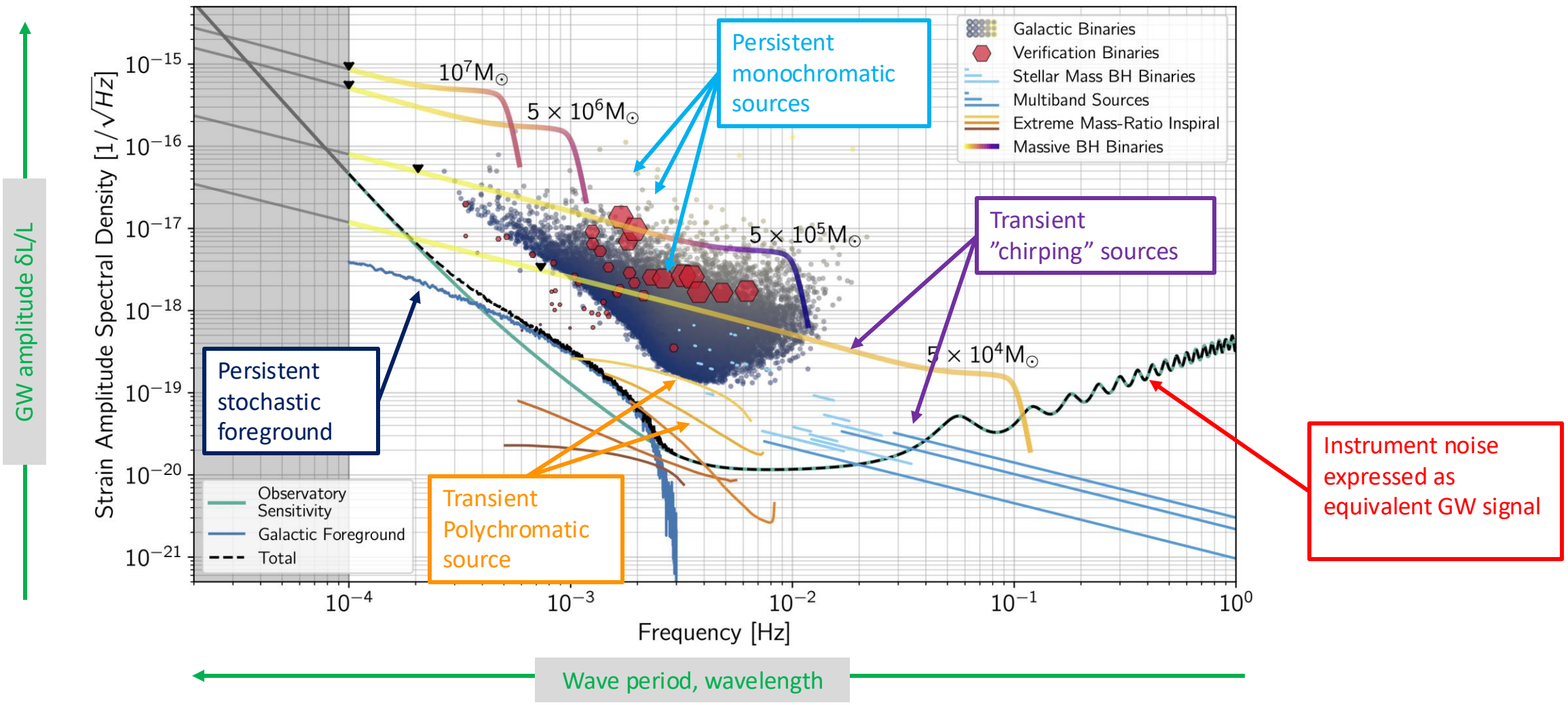
flow-down

validation

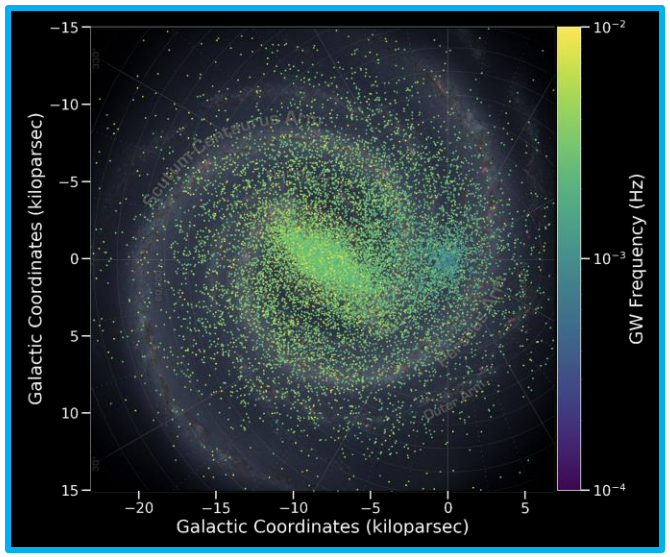
Analysis Overview



Why millihertz? *Lots of sources and science!*

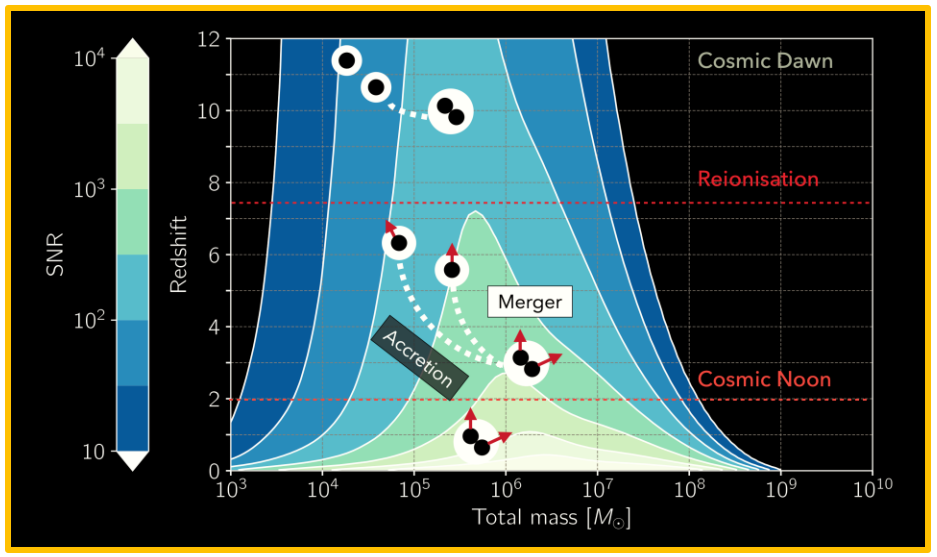


Science Highlights



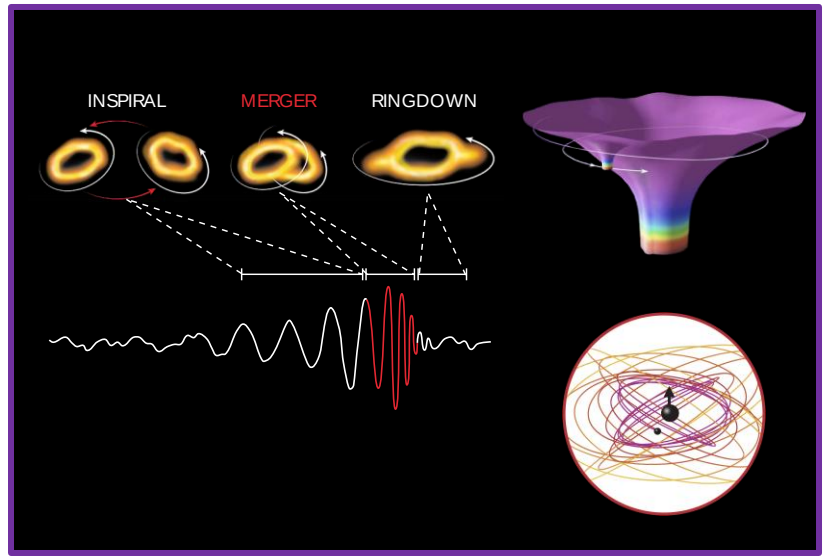
Census of compact binary objects in the Milky Way

- How do binary stars evolve?
- Formation history of our galaxy



Survey of massive black hole binaries across the visible universe

- How do black holes and their host galaxies co-evolve?
- Potential multimessenger targets with accreting MBH mergers



Precision tests of extreme gravity

- Does GR accurately describe the most exotic gravitational systems in the universe?