# LISA Update

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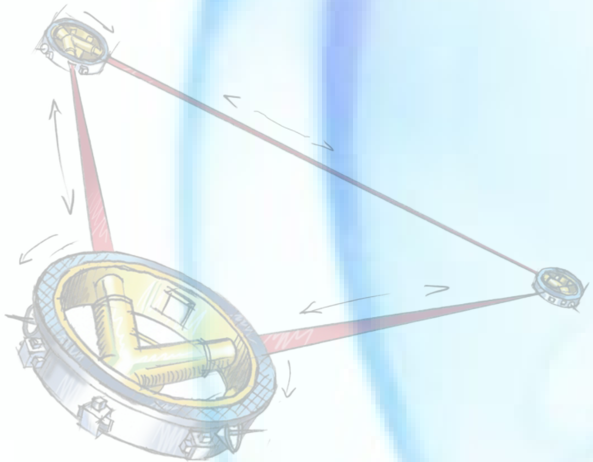
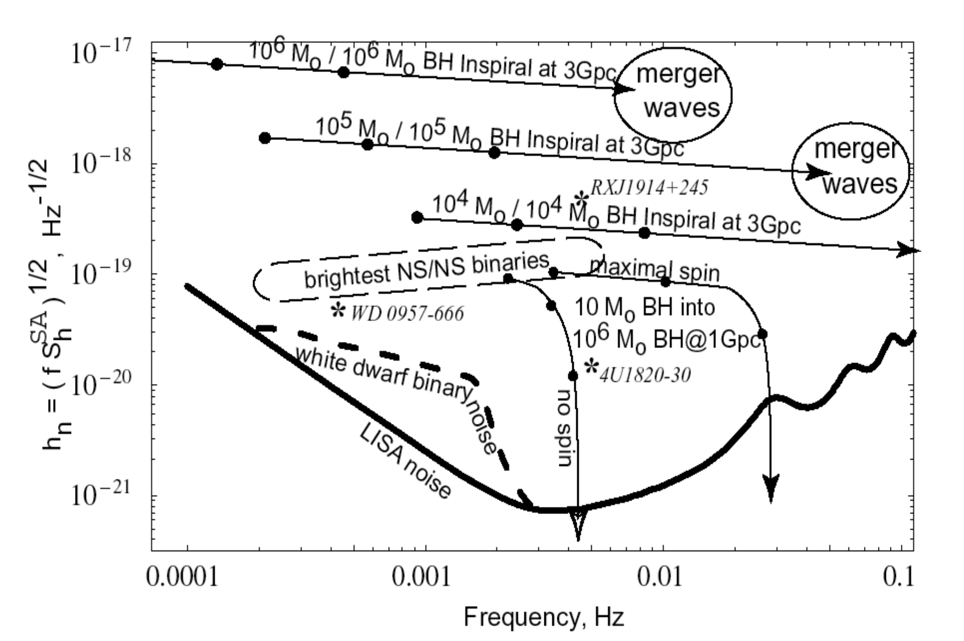


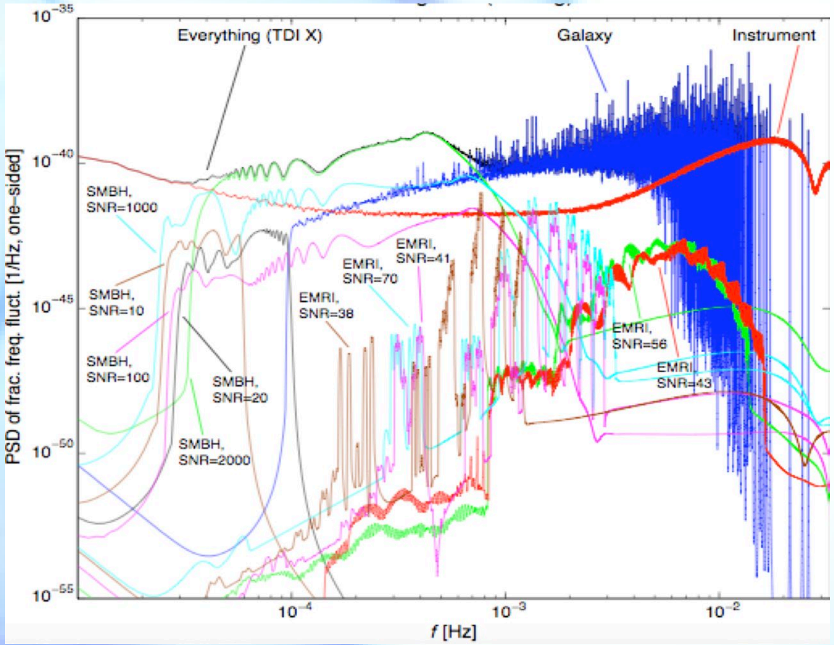
# Historic Science Goals

- Massive Black-Hole Binaries (MBHBs, $10^5 - 10^8\ M_\odot$) as tracers of galaxy-BH coevolution throughout cosmic history (i.e. to $z \approx 20$ or beyond)
- Extreme Mass Ratio Inspirals (EMRIs, an MBH and a stellar-mass compact object) as GR laboratories and probes of galactic nuclei
- Galactic binaries (millions of unresolvable double white dwarfs, $\mathcal{O}(10^4)$ resolvable WDWDs, some (?) resolvable NS and BH binaries)
- Primordial stochastic background

# Historic Science Goals




Cutler *et al.*, GR16, 2001




MLDC, 2008

# Evolution of Science Goals

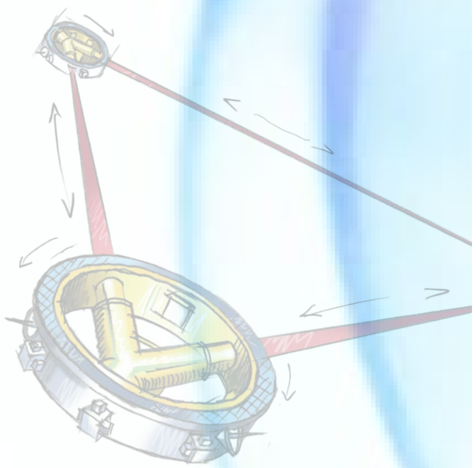
- MBHBs (at $1 \lesssim z \lesssim 20$) and EMRIs (at $z \lesssim 1$) can probe cosmology when combined with EM observations
  - “standard sirens”: GW measures $D_L$, EM measures z
- MBHBs likely not in vacuum, so EM a go
- Improved evidence for intermediate mass BHs (IMBHs, $10^2 – 10^4\ M_\odot$), motivates case for IMBHBs and IMRIs
- Relatively high LIGO BHB event rate and large masses implies LISA will observe some LIGO binaries ~10 years before merger – “multiband GW astronomy”
- Pulsar timing arrays set more stringent limits on non-exotic primordial stochastic backgrounds with LISA instrumental and foreground limits

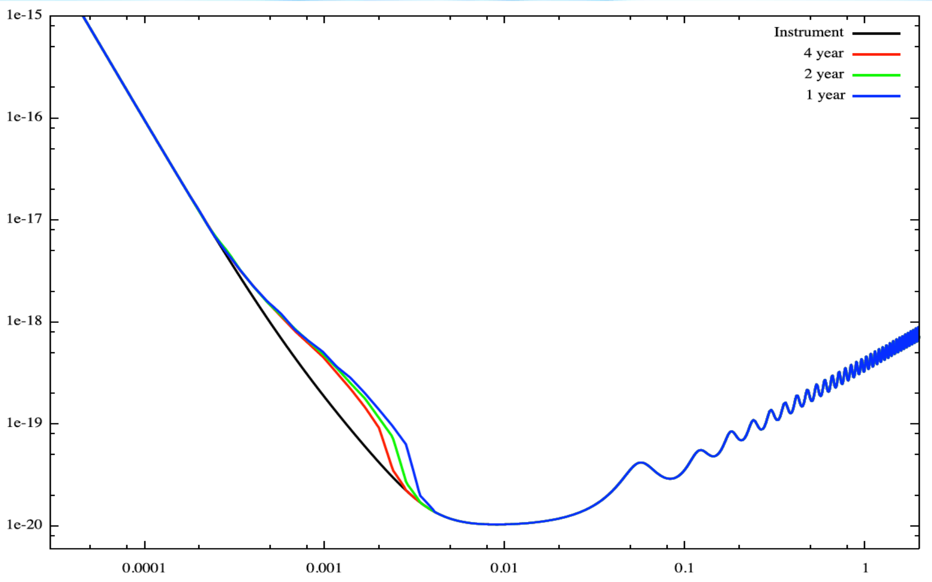
# 2037 Landscape

- Some science has been/will be scooped by others
  - E.g. the “discover gravitational waves first” ship has sailed…
- First galaxies probed by CHIME and others (21-cm cosmology)
- Early galaxy evolution observed by JWST
  - Silver lining – nothing else can probe on the scale of the MBHB at $z \gtrsim 10$, so BH-galaxy coevolution best done with (non-contemporaneous) LISA+JWST
- Expansion history/distance scale will be measured to better than 1% with WFIRST
  - GW+EM have different systematics, could become competitive in large N limit
- MBHs observed at large z with Athena, LSST, SKA

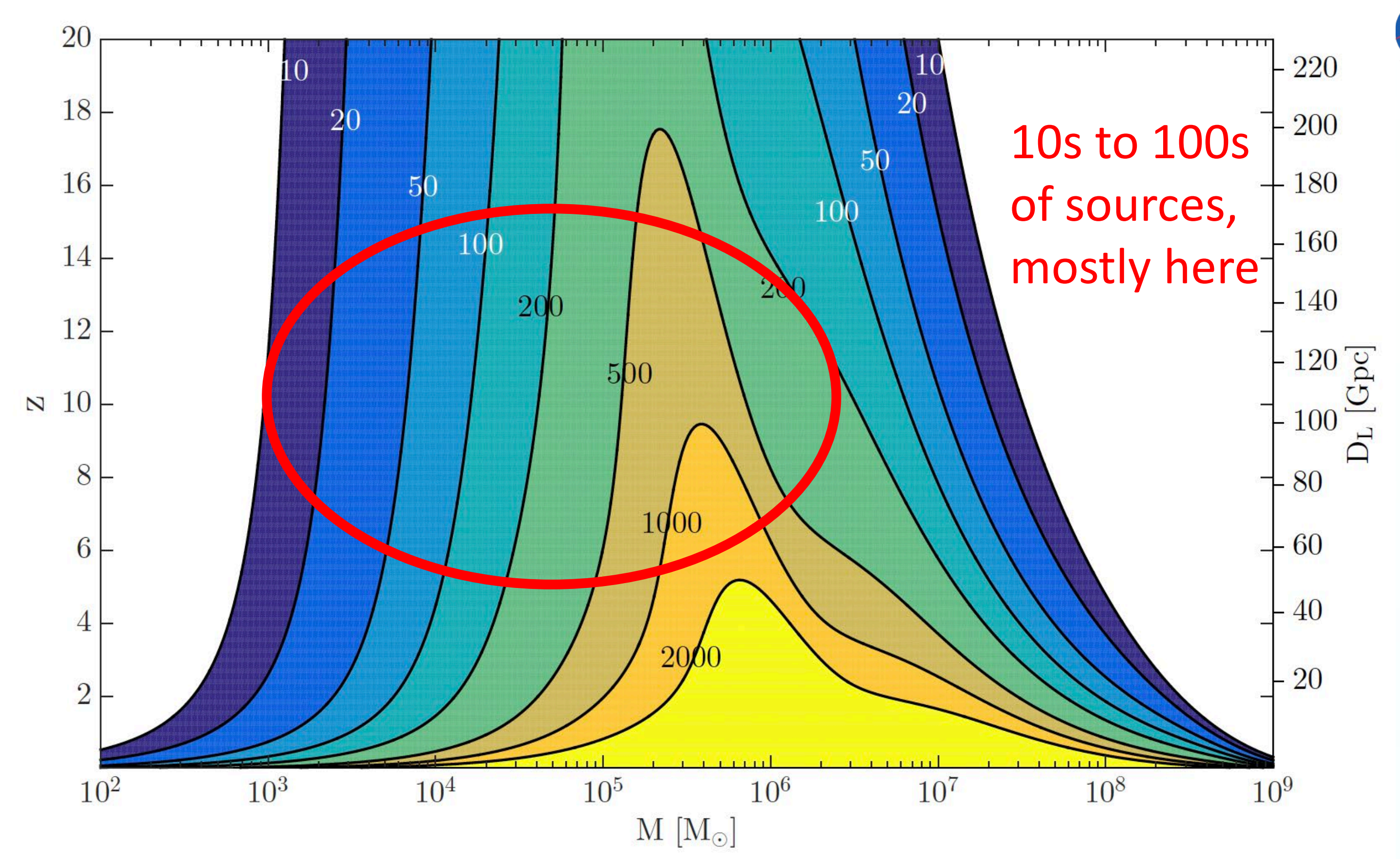
# LISA Sensitivity

- Sensitivity curve determines event rate, and science ***when other variables are fixed.***
- Low frequency sensitivity set by acceleration noise, high set by optical path noises (shot and “other”) and response.
- Galactic confusion foreground near the “bottom of the bucket” becomes better resolved with longer mission lifetimes.



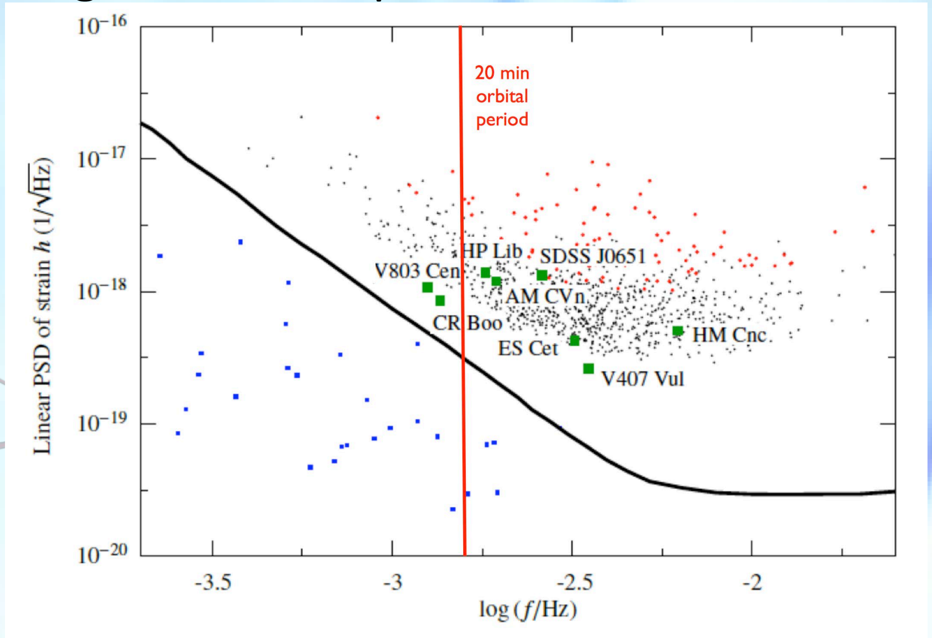


# MBHB Sensitivity



# Galactic Binary Sensitivity

- Number of known WDWD "verification binaries", $\mathcal{O}(10^4)$ more will be resolved.
- Nontrivial signals (e.g. resonances), EM counterparts (e.g. tidal heating) make these more interesting than in the past.

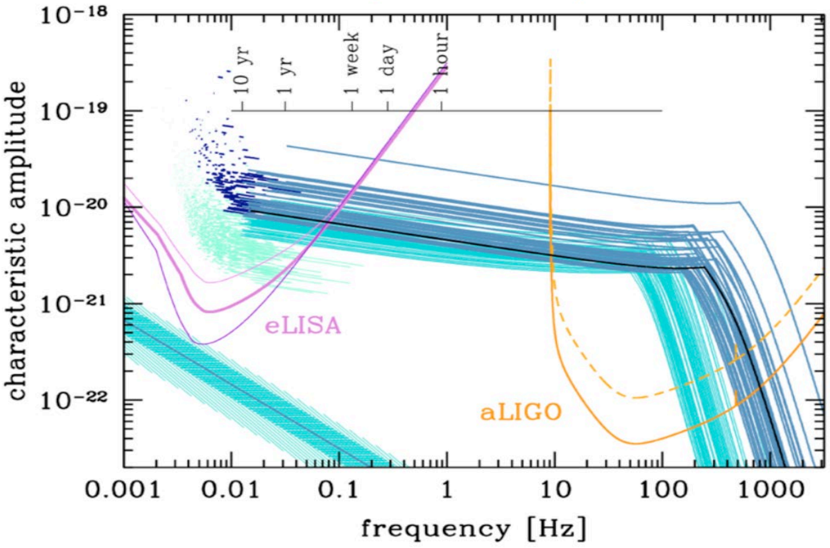


# EMRI and SOBHB Sensitivity

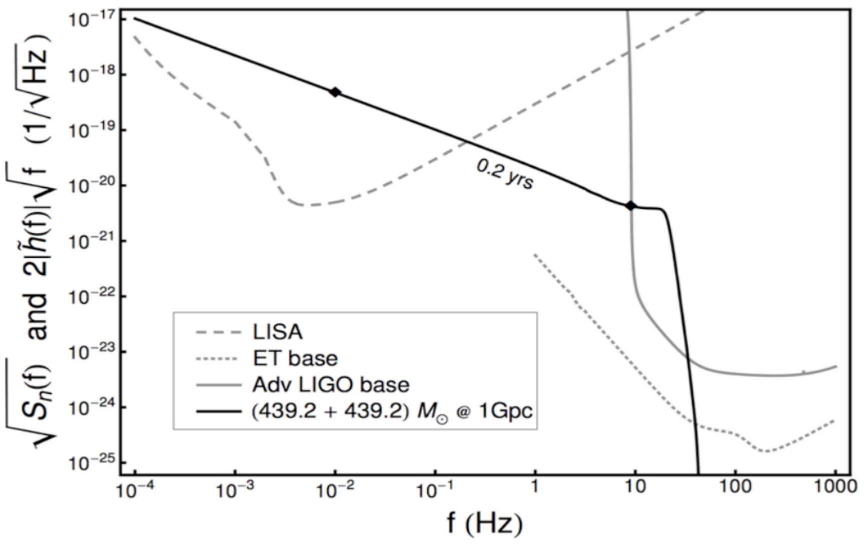
- Very sensitive to depth of bucket, 0 event rate possible
- EMRIs have very complicated, rich dynamics (e.g. resonances)
  - Great for carrying info, brutal for modeling
  - Can probe nuclear stellar and gas distribution
  - Can test GR iff we can model them well enough

- SOBHBs can be localized by LISA years before merger
  - Merger viewed from the ground by Voyager/Einstein Telescope

(Sesana 2016)

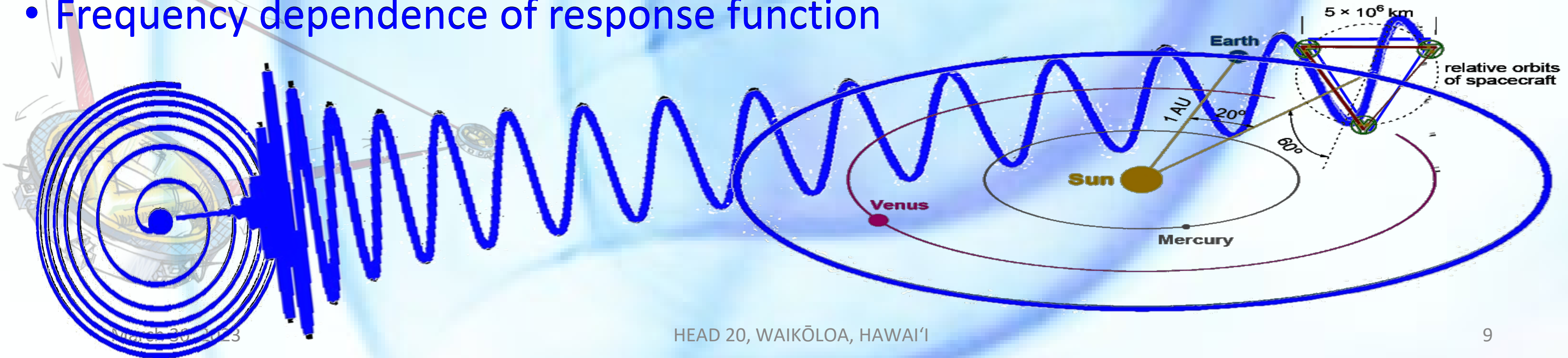



(Amaro-Seoane & Santamaria 2010)



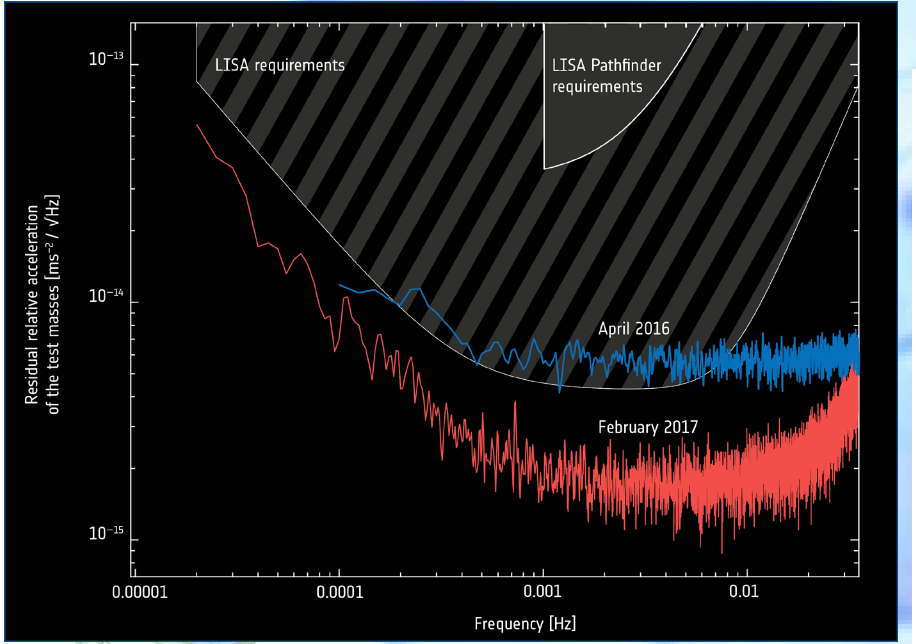
# How will LISA measure parameters?

- SNR is only one of the considerations
- Intrinsic parameter dependence of waveforms (for MBHBs, q, $S_1$, $S_2$, e)
- Independent waveform channels, with different frequency and spatial dependencies (aka TDI observables)
- Annual doppler modulation
- Frequency dependence of response function

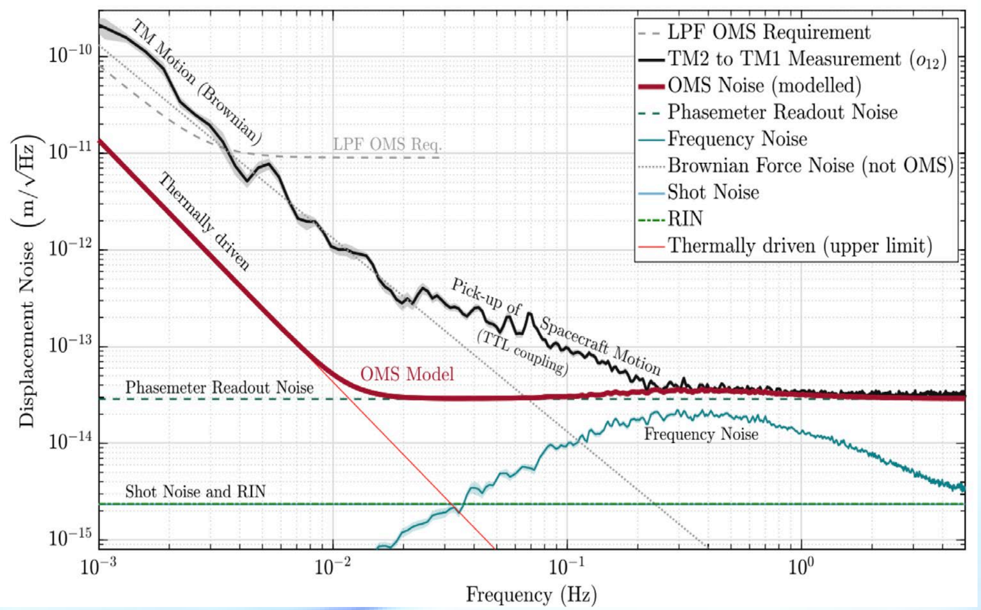


# LISA Pathfinder

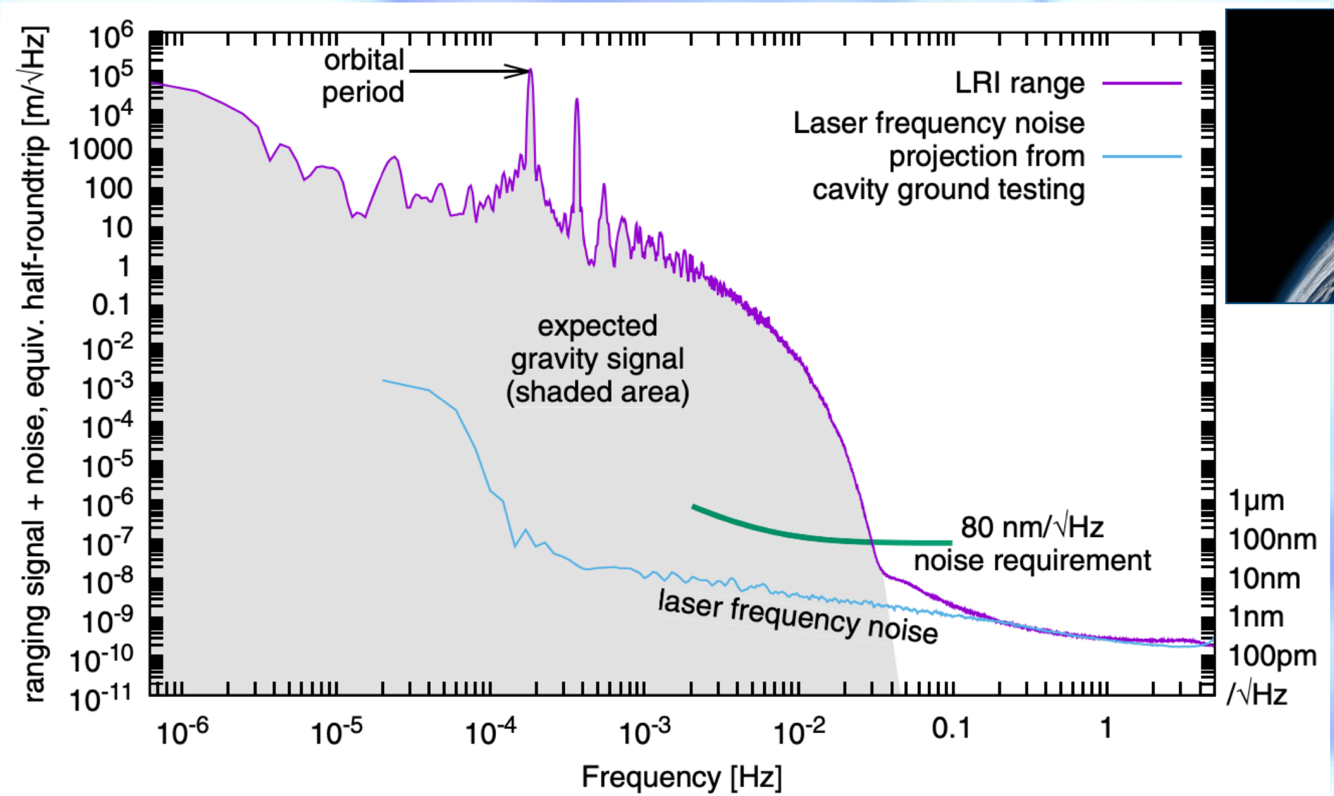
Acceleration noise suppression far exceeded LPF goals, validate performance at LISA levels

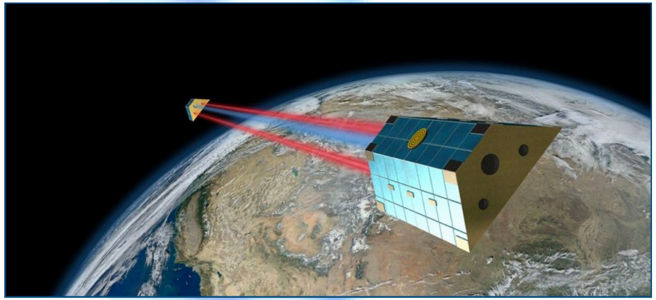



Only local interferometry, but at femtometer level



# GRACE-FO



- Replaced GRACE geodesy mission
- 2 spacecraft in low-Earth (~500km) orbit, separated by 220km
- Laser link, based on LISA technology, supplements primary microwave link

# Outlook

- Mission currently in design stage (ESA Phase A)
- Mission "Adoption" in 2023-2034
  - Final design / cost / schedule
  - Finalize roles and responsibilities
- Mission launch in mid- to late-2030s
  - Science begins launch + 2 years
  - 4 years baseline, 10 years total