Gravity Gradient Noise from Asteroids

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University of Oklahoma

Remote presentation

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Based on 2011.13833 (accepted by PRD)
with P.W. Graham and S. Rajendran

… and some other ongoing work

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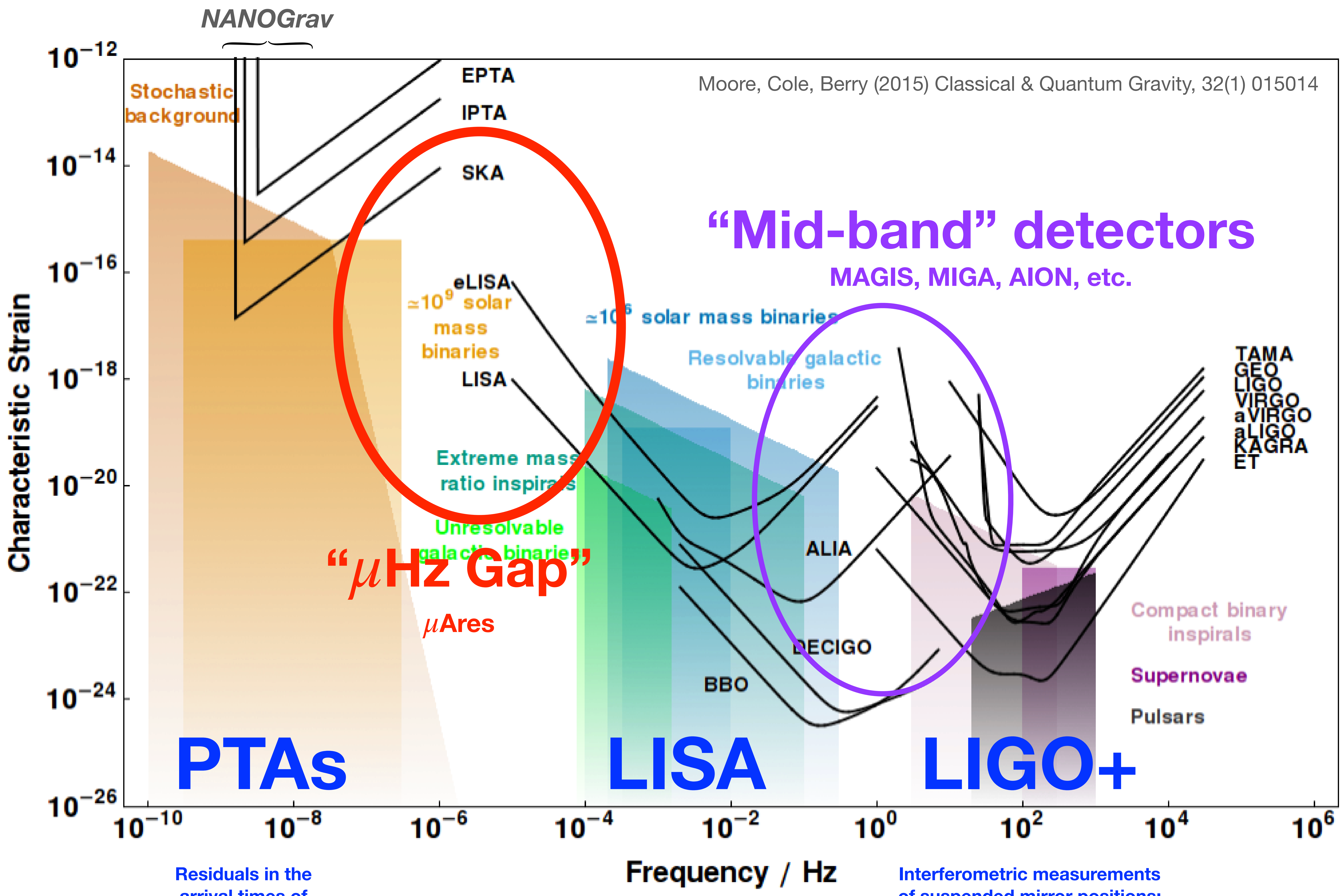
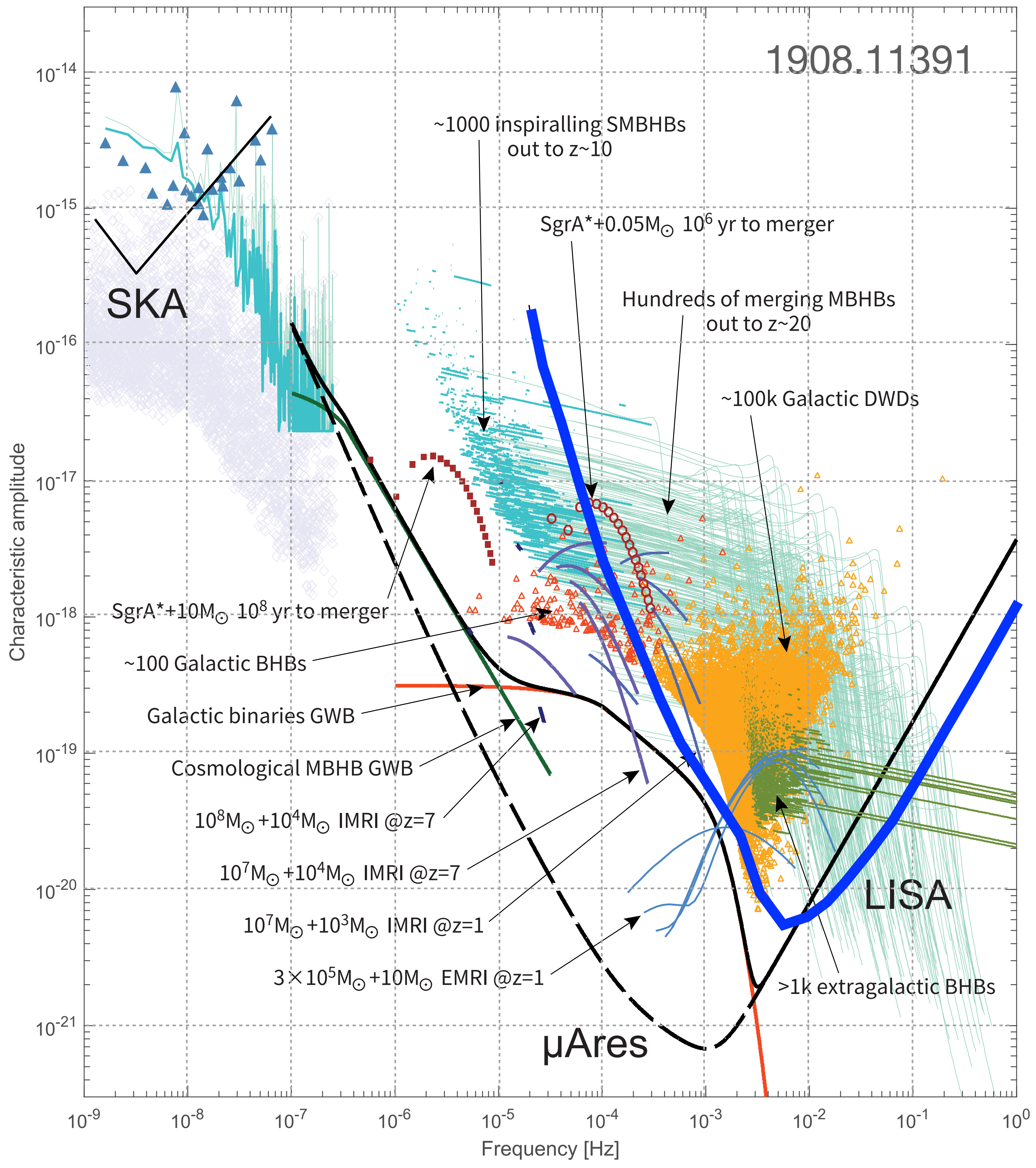
GW Detection Landscape



The μAres detection landscape



Residuals in the arrival times of pulsar pulses

Interferometric measurements of test mass locations; space-based

Interferometric measurements of suspended mirror positions; ground-based

Local-TM—based GW Detection 101

- Measure light travel time (= proper distance) between test masses (TM)

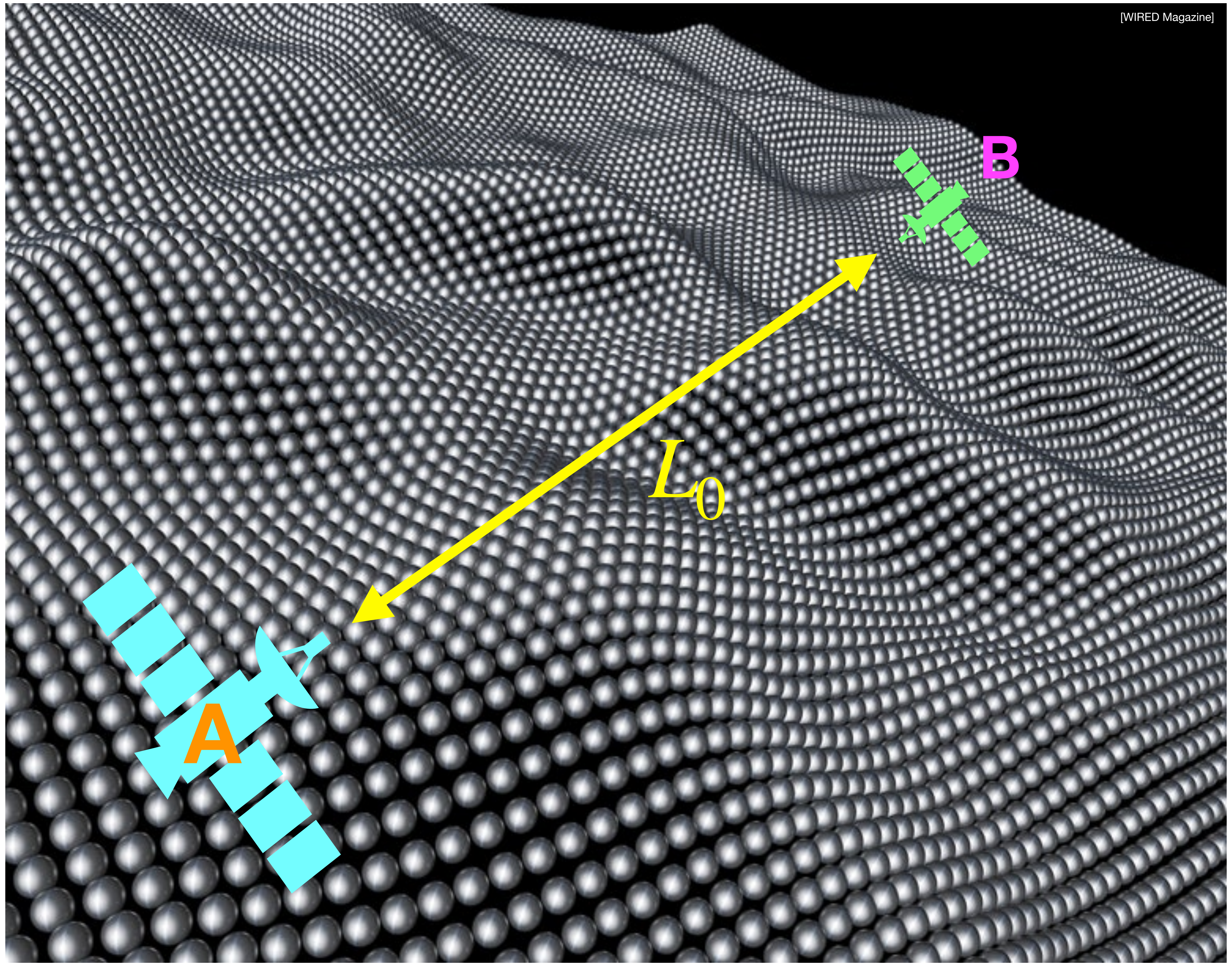
- Emitter (A) sends pulse at $t_A = t_0$;
  receiver (B) gets pulse at $t_B = t_0 + \Delta t$:

$$\Delta t = L_0 \left(1 - \frac{h_0}{2} \cos[\omega_{\rm GW} t_0] \right) + \mathcal{O}(h_0^2)$$

$$[\omega_{\rm GW} L_0 \ll 1]$$

- Effective baseline-projected
  Newtonian acceleration a_L:

$$a \sim \frac{1}{2} h_0 \omega_{\rm GW}^2 L_0 \cos[\omega_{\rm GW} t_0]$$



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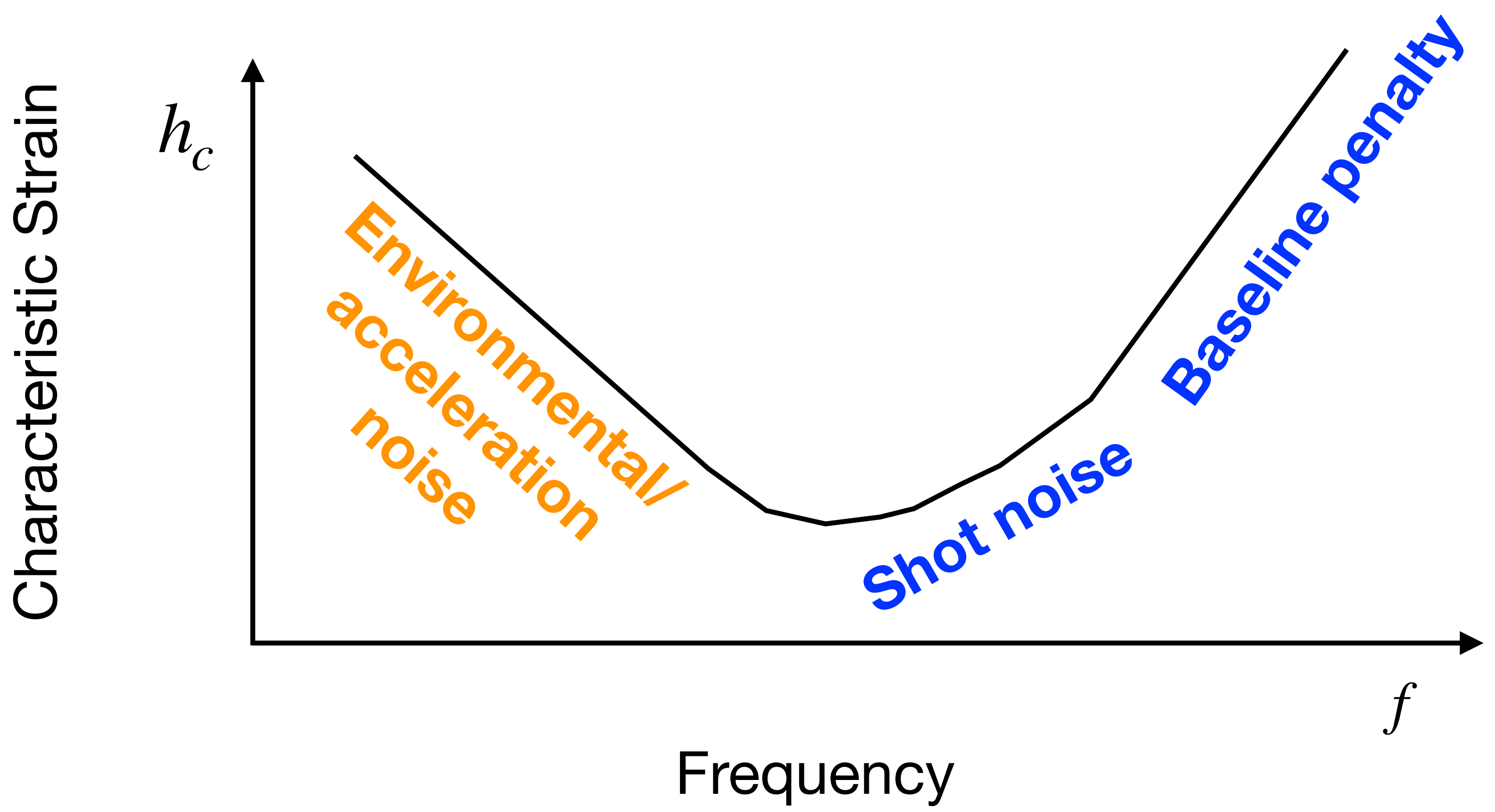
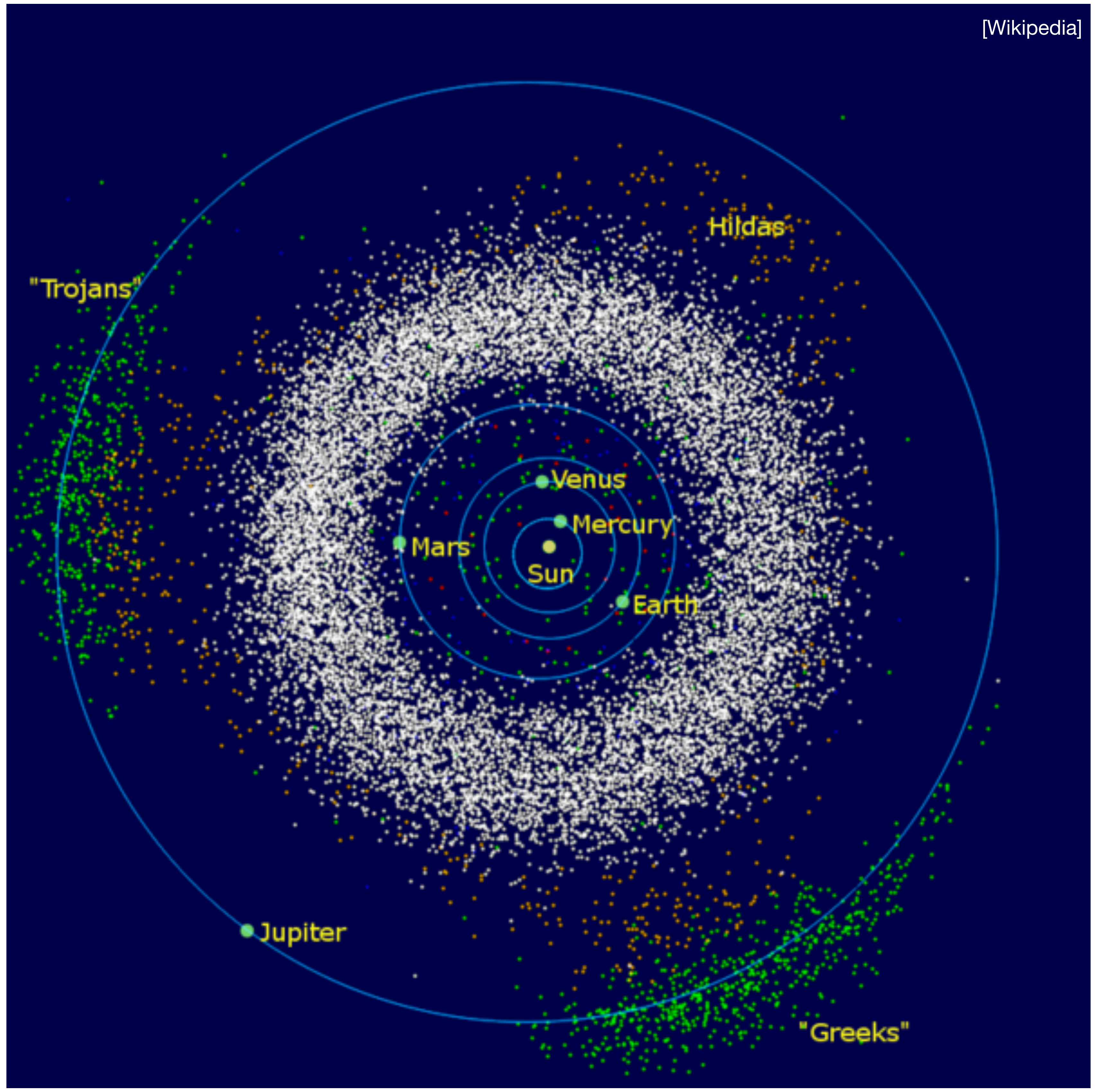
Sensitivity and Dominant Noise



- Local TM detection in the ~10 nHz to ~10 μHz range MUST be space-based (seismic noise, GGN on the ground).
- In-band environmental / acceleration noise in space?
- Observation: orbital motion of bodies in the Inner Solar System have frequencies in this range.
- **Question: Does the gravitational coupling of the orbital motion of Inner Solar System bodies cause in-band noise for space-based TM when attempting GW detection?**

Sources of in-band GGN?

- The Sun, Planets (and Pluto), Moons
  - Relatively few
  - Masses (or $G_N M$) and locations known
  - **<u>Not</u>** noise (model out)
- The Inner Solar System asteroids
  - $\mathcal{O}(10^6)$ objects
  - *Generally,* masses poorly / indirectly determined
  - Locations are known to some extent
  - **NOT** reasonable to assume that one can successfully model these out
  - Asteroid gravity gradient noise (GGN)!



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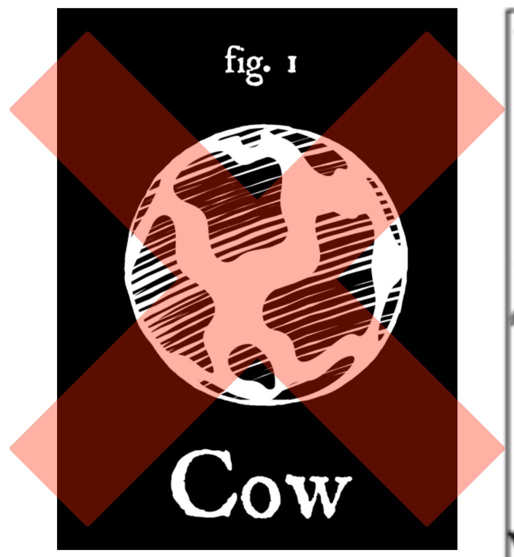
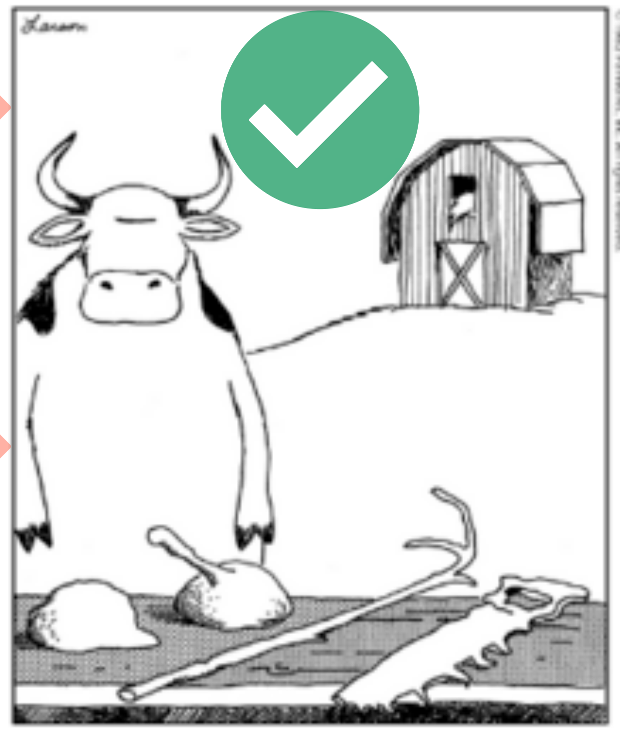
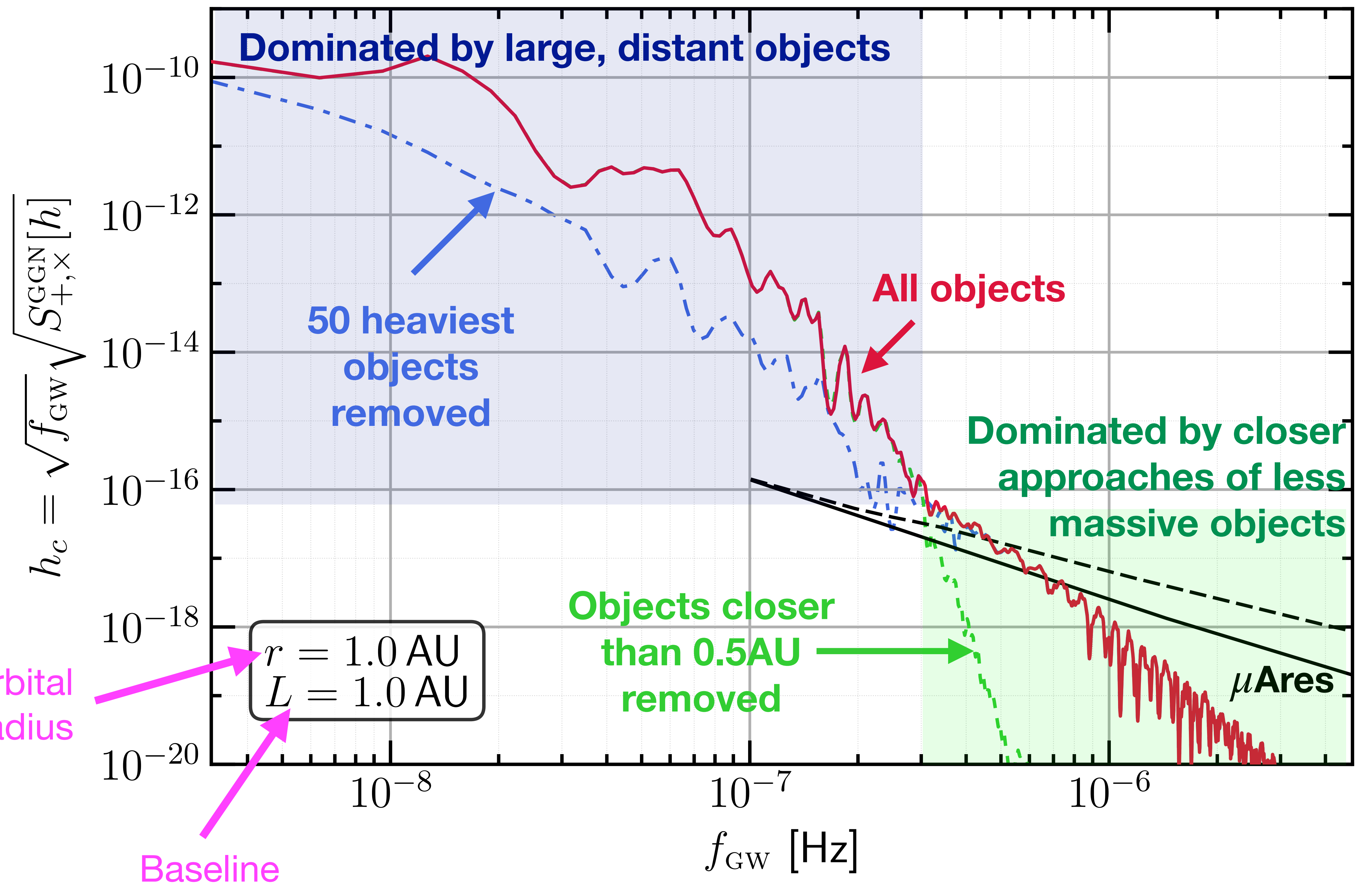
Simulation




Cow tools

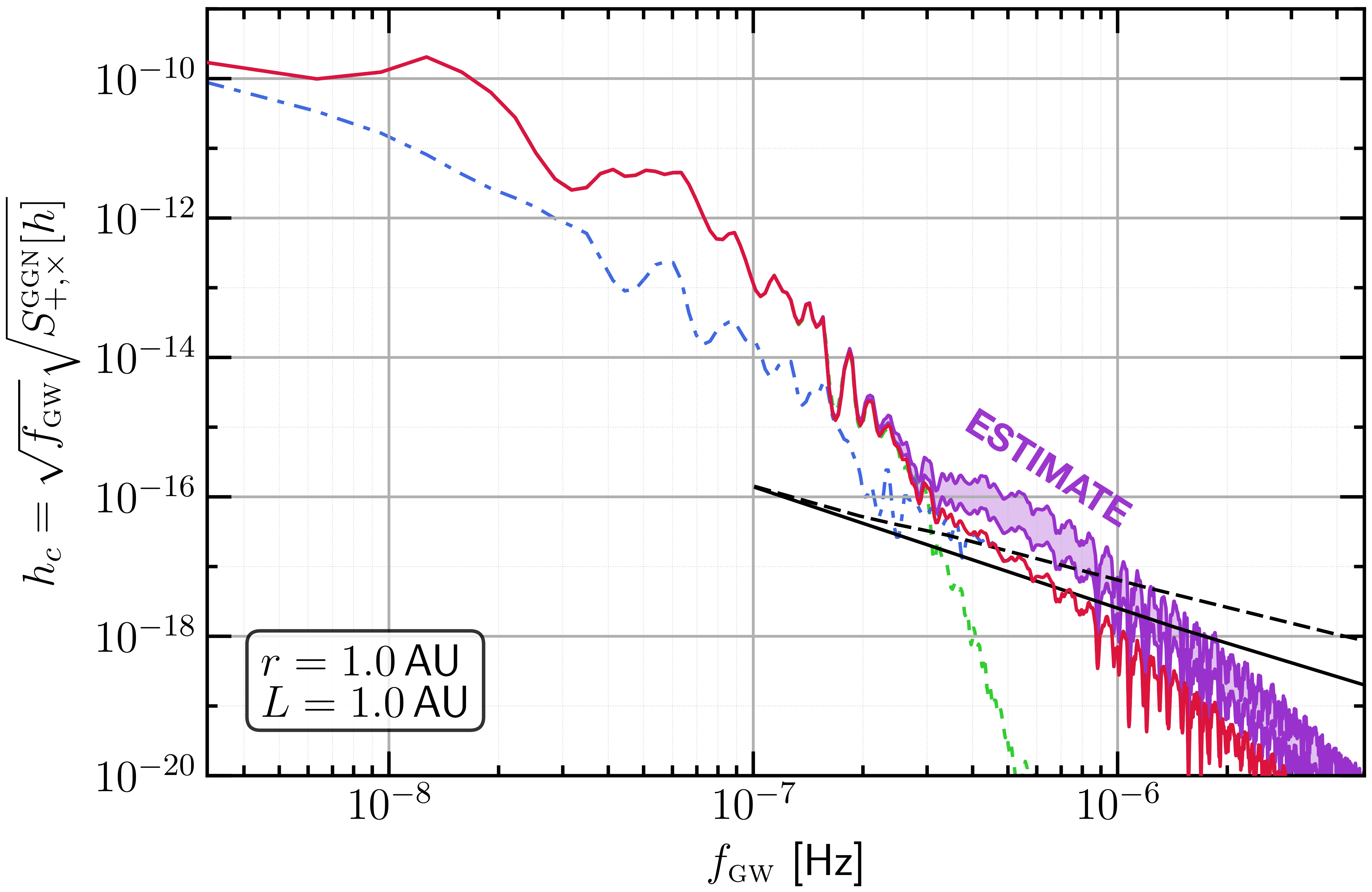
- Use NASA JPL Small-Body Database
- 10-year mission simulation
- Detectors on circular orbit @ 1AU; asteroids on elliptical orbits (not N-body)
- TM accelerations from asteroids $\longrightarrow$ “noise” power spectrum (details) $\longrightarrow$ strain sensitivity.



- Problematic for **ANY** local-TM-based GW detector with Inner Solar System baselines, up to frequencies ~ $(\text{few}) \times 10^{-7}\,\text{Hz}$
- Removing ~50 heavy distant objects does not change this conclusion
- At higher frequency, noise drops off. But only ~1/6 of objects in database used in simulation: missing diameters for smaller, closer passing objects…

High frequency tail

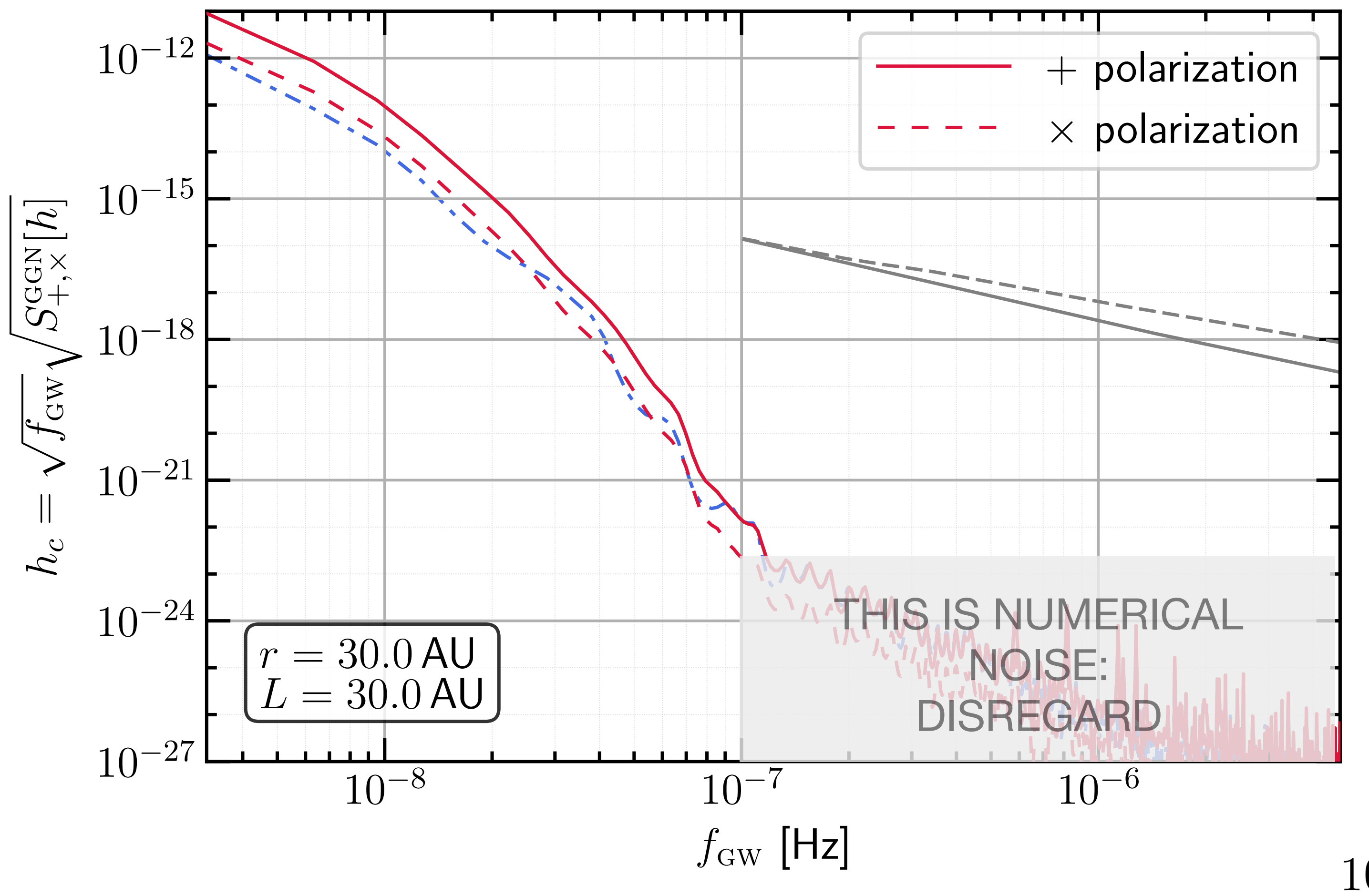
- Approximate estimate of noise in high frequency tail.
- Shape here not computed fully: used a point-estimate at ~μHz.
- Use impact craters on Moon to estimate flux. [LISA Pre-Phase A Report (1999); Shoemaker (1983)]
- Undercounting by 3-10; rescale simulation upward.



- Qualitative conclusions unchanged.
- Actual noise near $\mu\mathrm{Hz}$ not very well known; above that, looks OK.
- Below that, seems very hard to make progress in Inner Solar System.

The path forward?

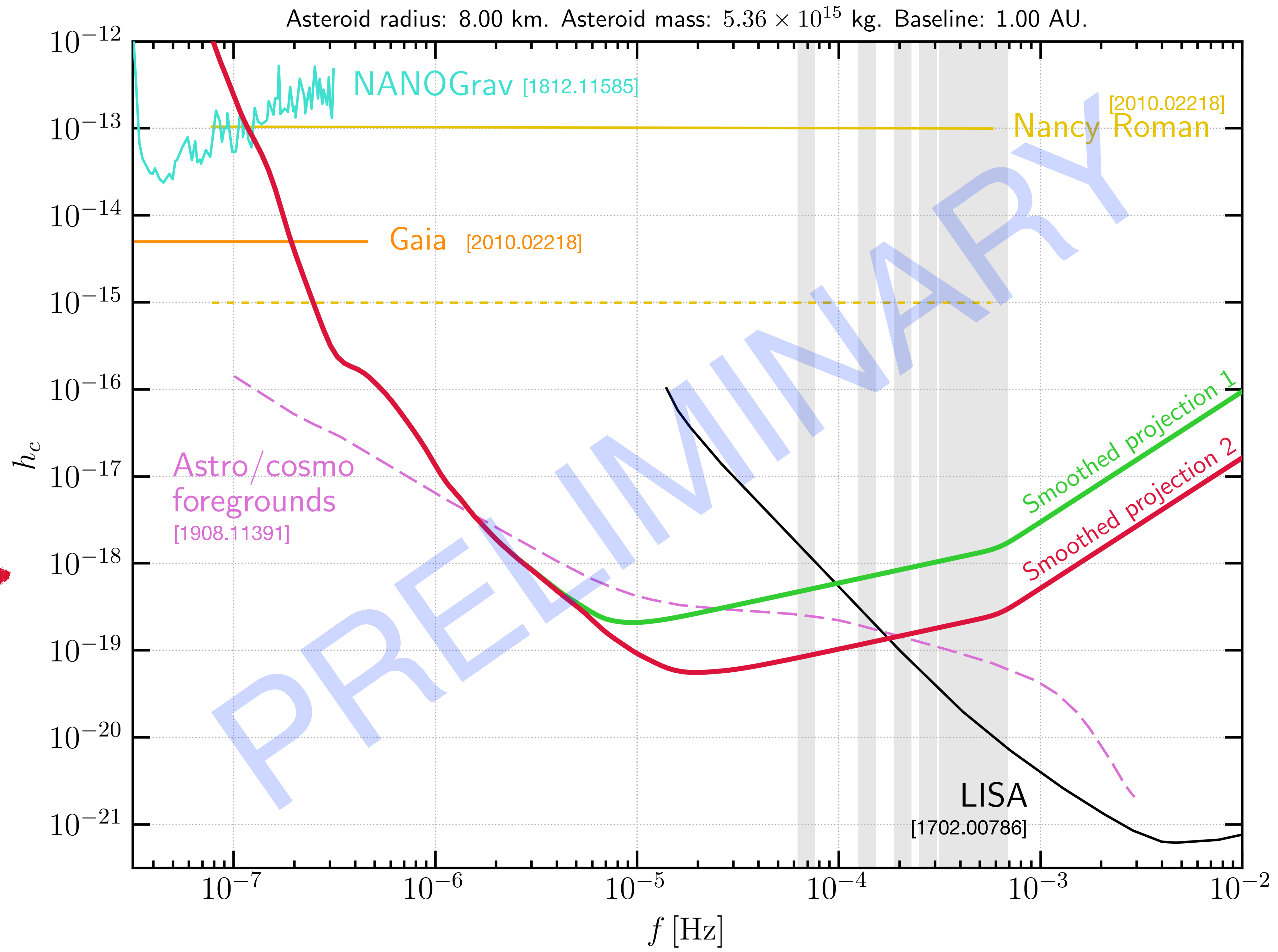
- Go to the Outer Solar System?
  - Technically challenging?



- Baselines that extend outside the Inner Solar System:
  - PTAs - but these lose sensitivity in this band
  - Precision astrometry: Gaia, Nancy Roman, and possibly other precision techniques *[work in progress]*

- Above μHz, can **USE** asteroids as test masses *[work in progress with P.W. Graham, S. Rajendran]*

See recent talk by P.W. Graham at KITP Workshop on Novel Experiments for Fundamental Physics



Conclusions

- Asteroid GGN ⇒ low-frequency GW detection $\left[f \lesssim (\text{few}) \times 10^{-7}\,\text{Hz}\right]$ requires baselines that are not fully contained in the Inner Solar System.
- Simulations robust at these frequencies: large, distant objects dominate.
- Above $f \gtrsim \mu\text{Hz}$, asteroid GGN negligible.
- Situation around $f \sim \mu\text{Hz}$ not fully clear. Possible catalog/simulation incompleteness for smaller, close-passing asteroids; estimate uncertain by factor of 3-10.
- Above $f \gtrsim \mu\text{Hz}$, asteroids themselves could function as test masses for GW detection.