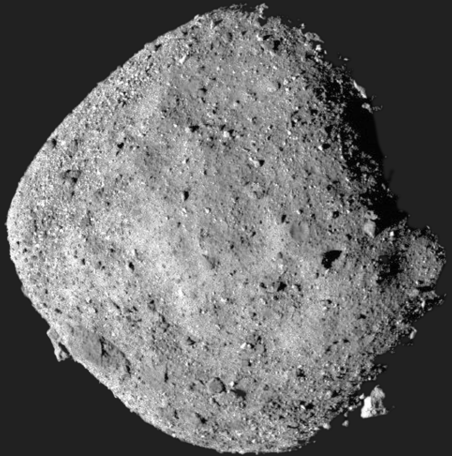
Probing Ultralight Dark Photon Dark Matter with Asteroids



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Johns Hopkins University

Based on Phys. Rev. D 107, 043004 (2023)
[arXiv/2210.09324] with Michael Fedderke

Takeaways

1. GW experiments do double-duty as DM detectors

2. Asteroid ranging can bridge the μHz gap

3. Asteroids are the most sensitive probe of dark photon DM

Takeaways

1. GW experiments *(based on test masses)* do double-duty as DM detectors
2. Asteroid ranging can bridge the μHz gap *a modest proposal..*
3. Asteroids are the most sensitive probe of *(B, B-L coupled)* dark photon DM *for some range of masses*

Double Duty

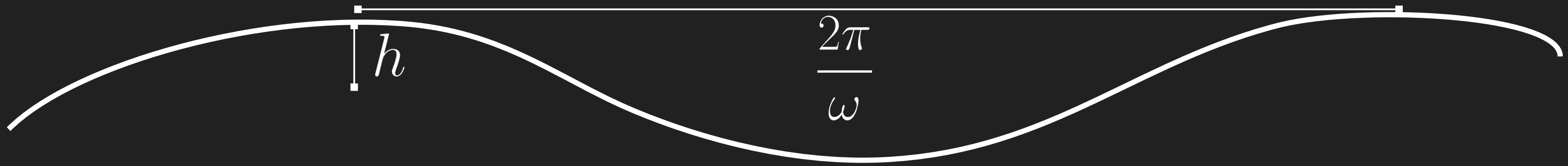
GWs cause fluctuations in the measured separation between test masses

So can dark photon DM!

The GW Case

Perturbs metric & induces strain

$$ds^2 = -dt^2 + (1 + h\sin(\omega(t - z)))dx^2 + dz^2 + (1 - h\sin(\omega(t - z)))dy^2$$



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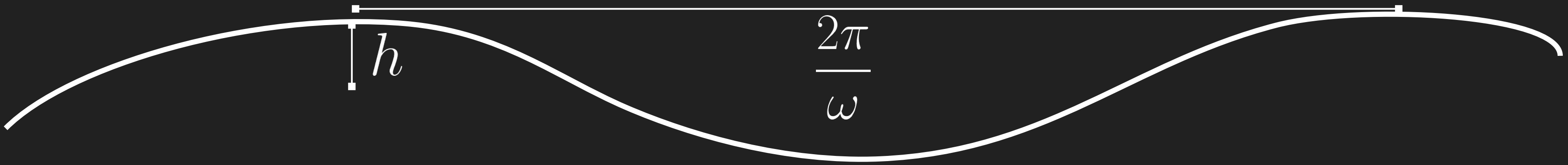
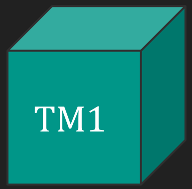
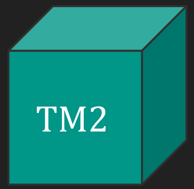




$$\Delta a(t) \sim hL\omega^2 \sin(\omega t)$$

$$\implies \Delta L(t) \sim hL\sin(\omega t)$$



$$L + \Delta L$$

The Dark Photon DM Case

Massive $U(1)_S$ with coupling to SM current

$$\mathcal{L} \supset \frac{1}{4} V_{\mu\nu} V^{\mu\nu} + \frac{1}{2} m_{\mathrm{DM}}^2 V_\mu V^\mu - \varepsilon_S e V_\mu J_S^\mu$$

The Dark Photon DM Case

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Makes up an appreciable fraction of DM

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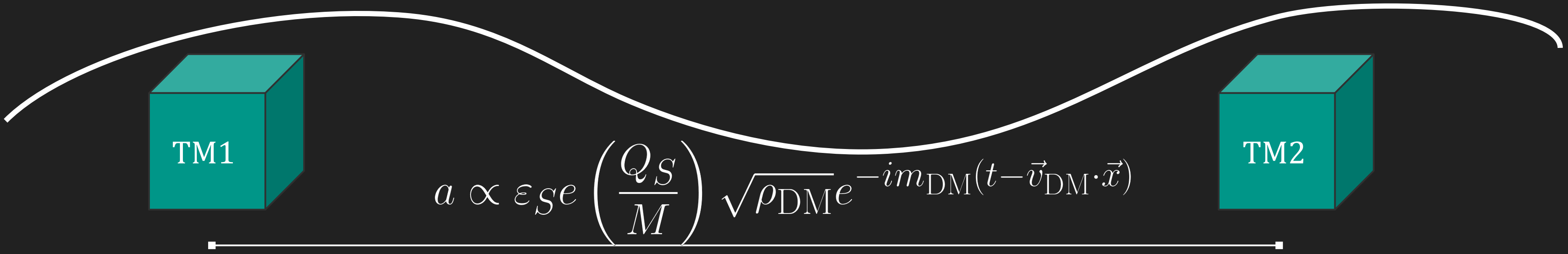
Makes up an appreciable fraction of DM

$$a \propto \varepsilon_S e \left(\frac{Q_S}{M} \right) \sqrt{\rho_{\mathrm{DM}}}$$

$$\frac{Q_S}{M} \approx \begin{cases} 1/\mu_a & S = B \\ 1/2\mu_a & S = B - L \end{cases}$$

The Dark Photon DM Case



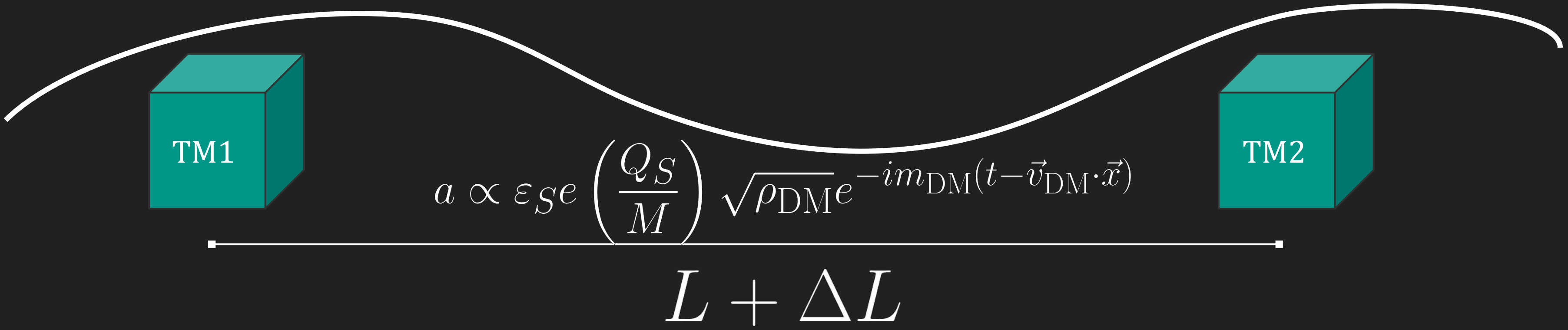
$$a \propto \varepsilon_S e \left(\frac{Q_S}{M}\right) \sqrt{\rho_{\rm DM}} e^{-i m_{\rm DM}(t - \vec{v}_{\rm DM} \cdot \vec{x})}$$

$$L + \Delta L$$

The Dark Photon DM Case

Two contributions to fluctuations of the baseline:

$$\left(\frac{\Delta L}{L}\right)_{\text{spatial grad}} \propto \varepsilon_S e \left(\frac{Q_S}{M}\right) \frac{\sqrt{\rho_{\text{DM}}}}{m_{\text{DM}}^2 L} (m_{\text{DM}} L v_{\text{DM}})$$



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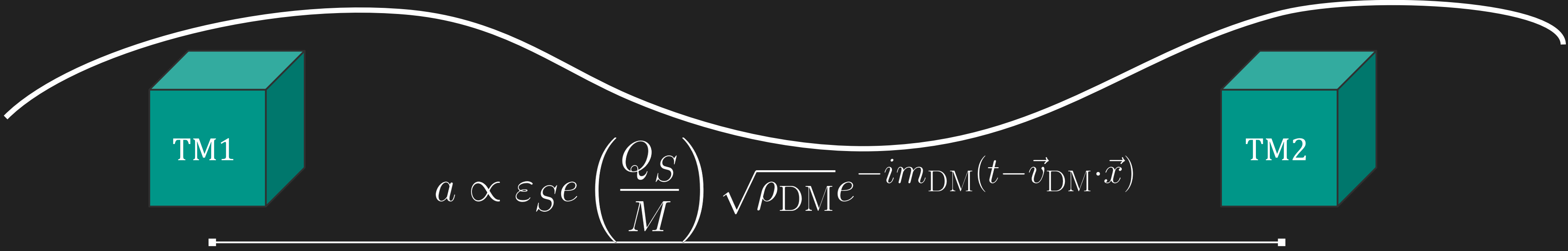
$$\left(\frac{\Delta L}{L}\right)_{\text{travel time}} \propto \varepsilon_S e \left(\frac{Q_S}{M}\right) \frac{\sqrt{\rho_{\text{DM}}}}{m_{\text{DM}}^2 L} \sin^2\left(\frac{1}{2} m_{\text{DM}} L\right)$$



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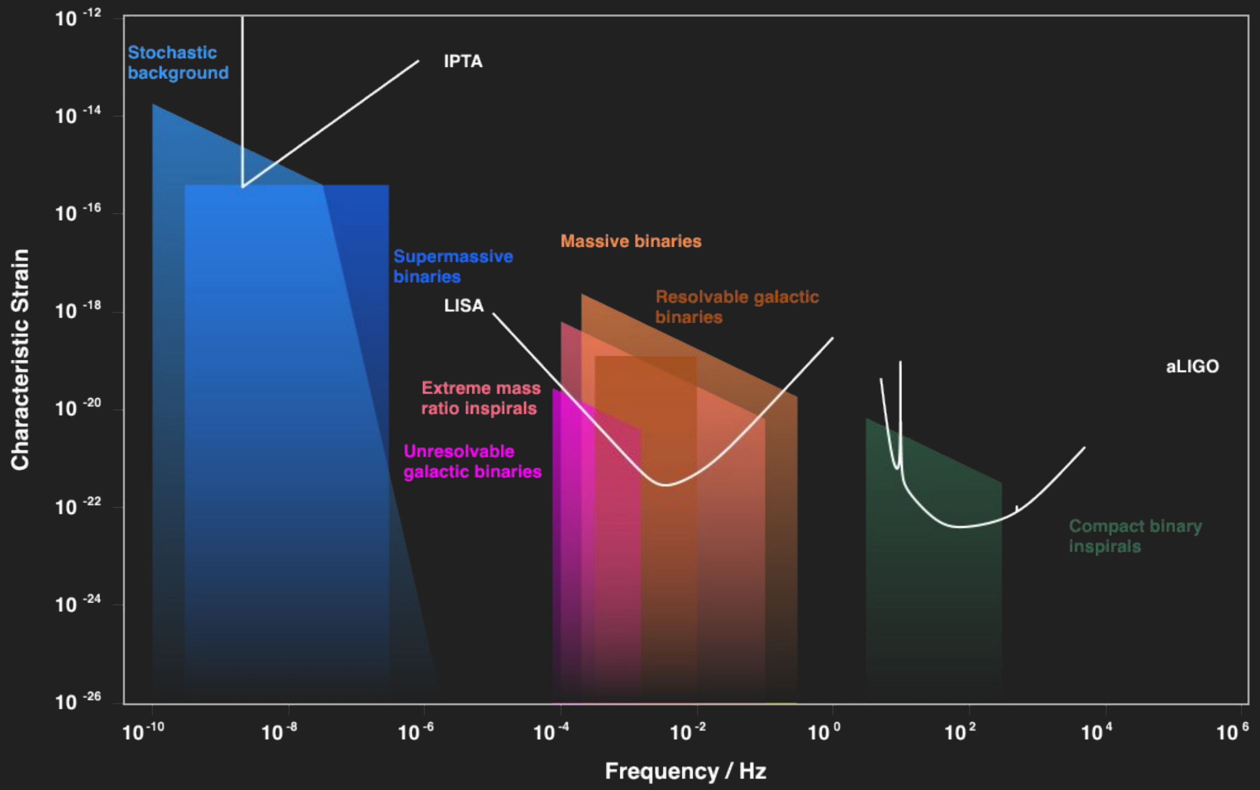
$$L + \Delta L$$

The μHz Gap

Source: GWPlotter



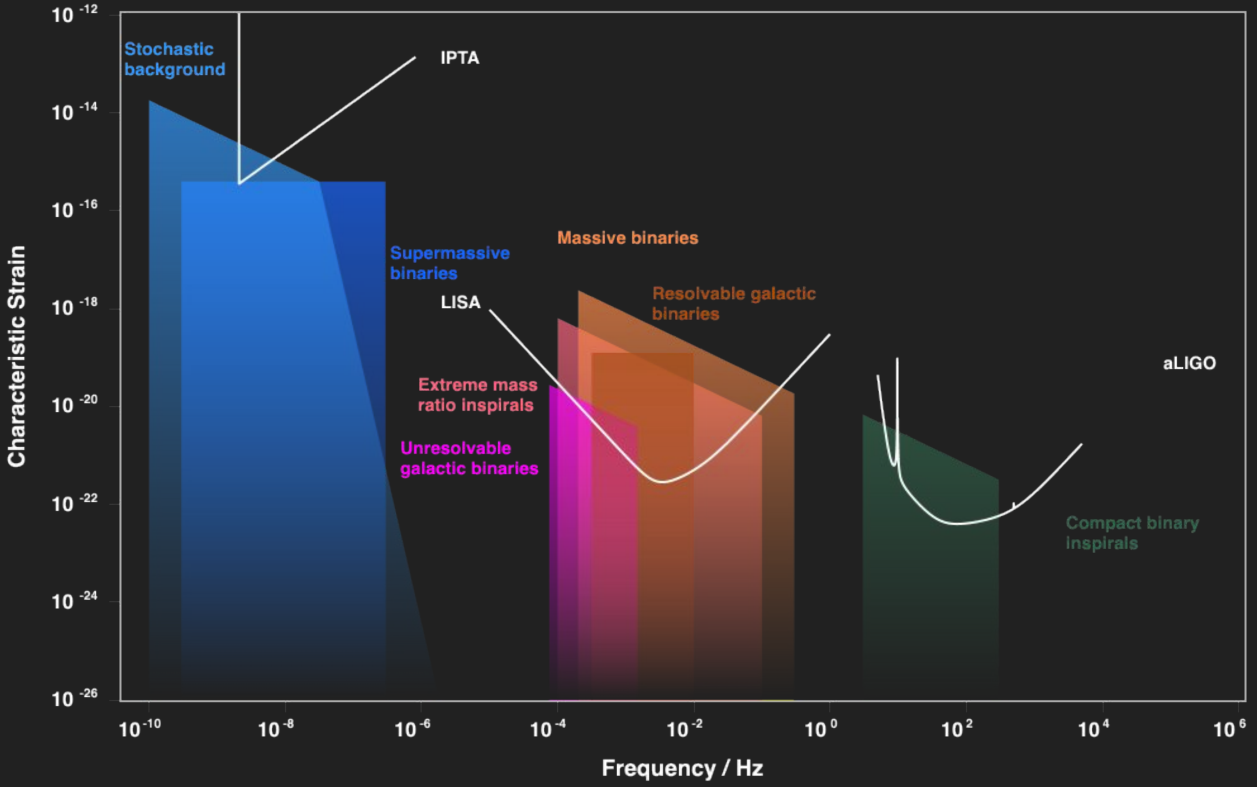
The μHz Gap

Requires measuring AU baseline with μm precision!

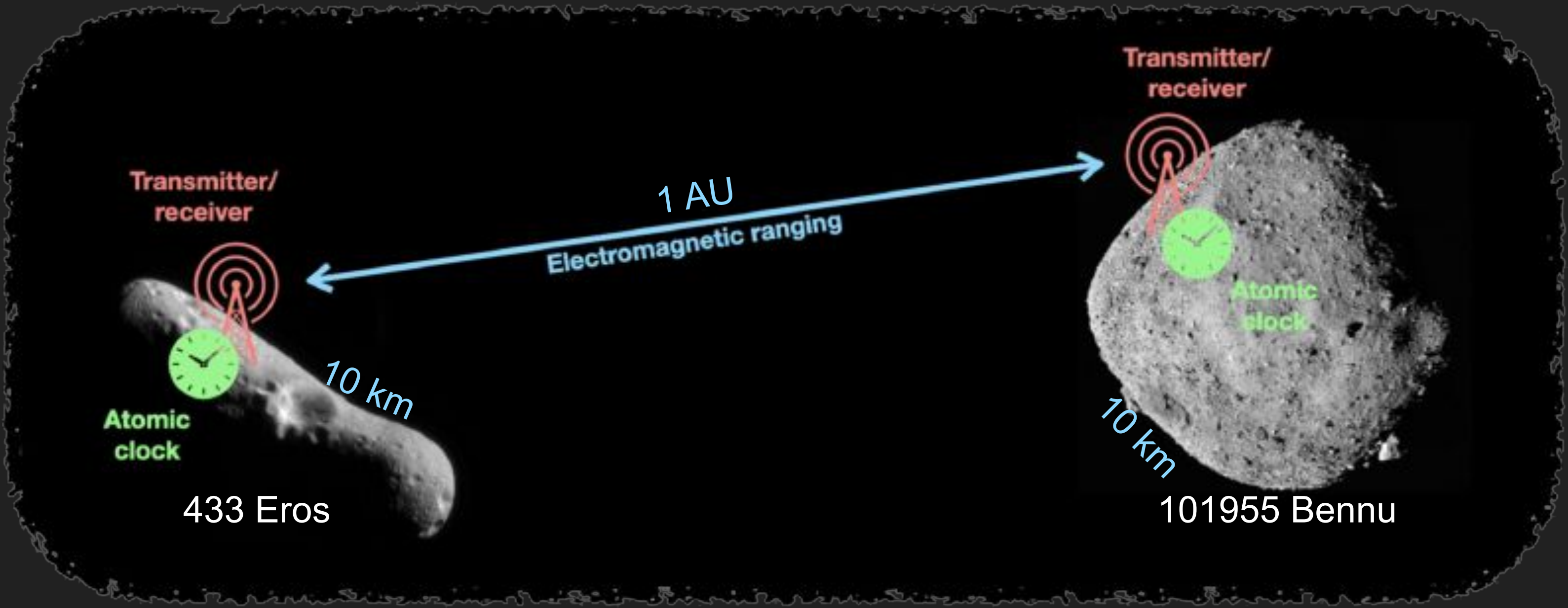
Test masses need to be:

- Appropriately spaced
- Close to Earth
- Large and stable

Source: GWPlotter

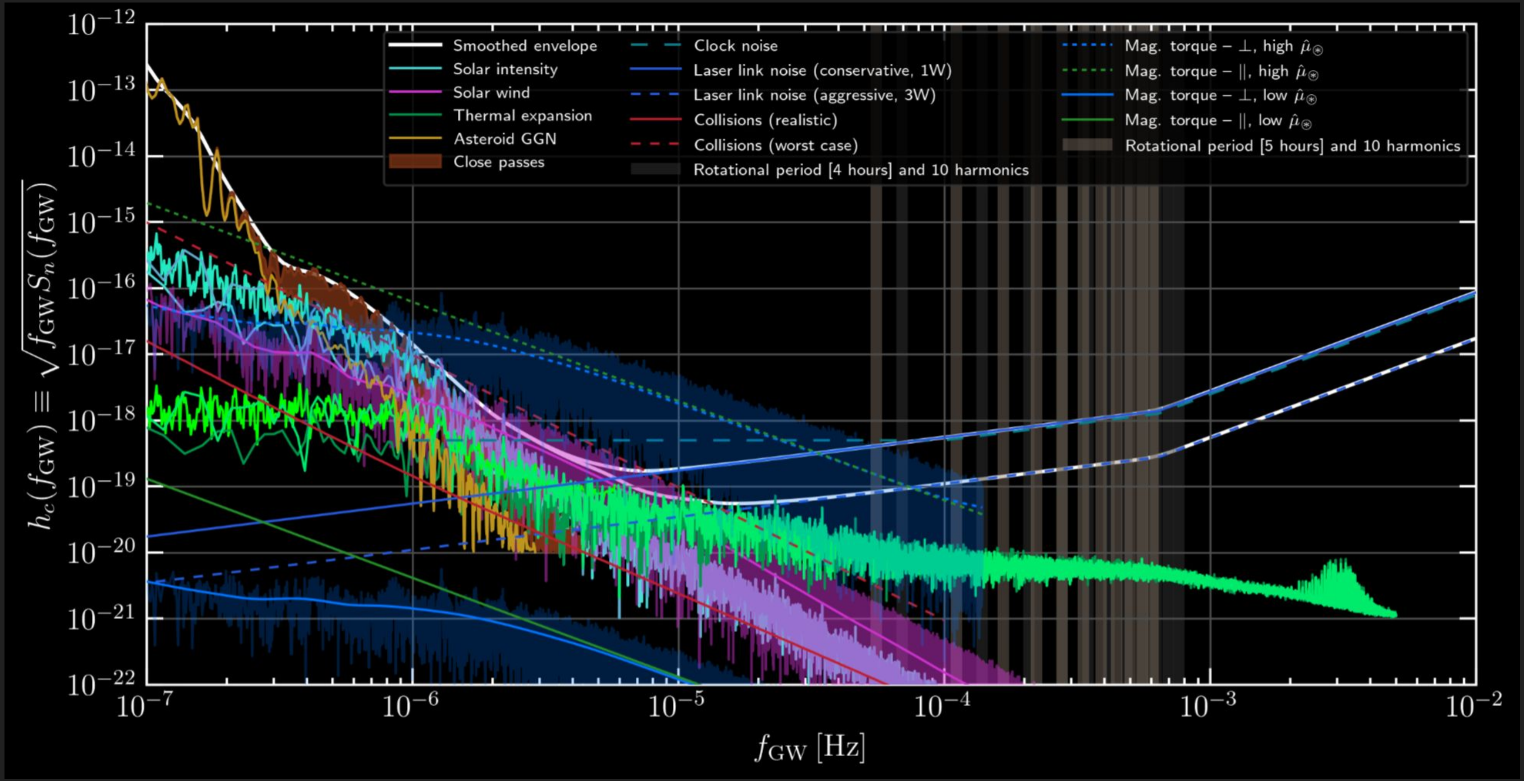


Enter... asteroids



Source: arXiv/2112.11431

Noise Appears Manageable



Source: arXiv/2112.11431

Putting it all together

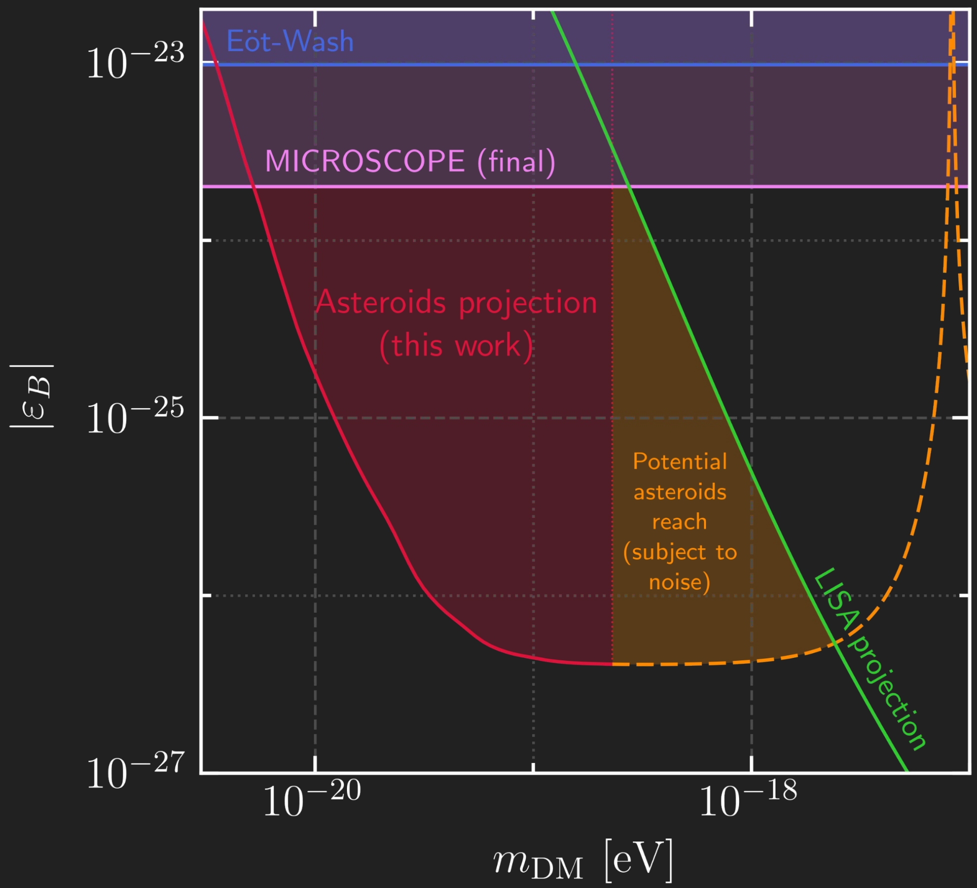
Strain sensitivity

↓

ΔL sensitivity

↓

Reach on dark photon DM coupling



Putting it all together

Existing constraints from static EP tests—no assumptions on f_{DM}

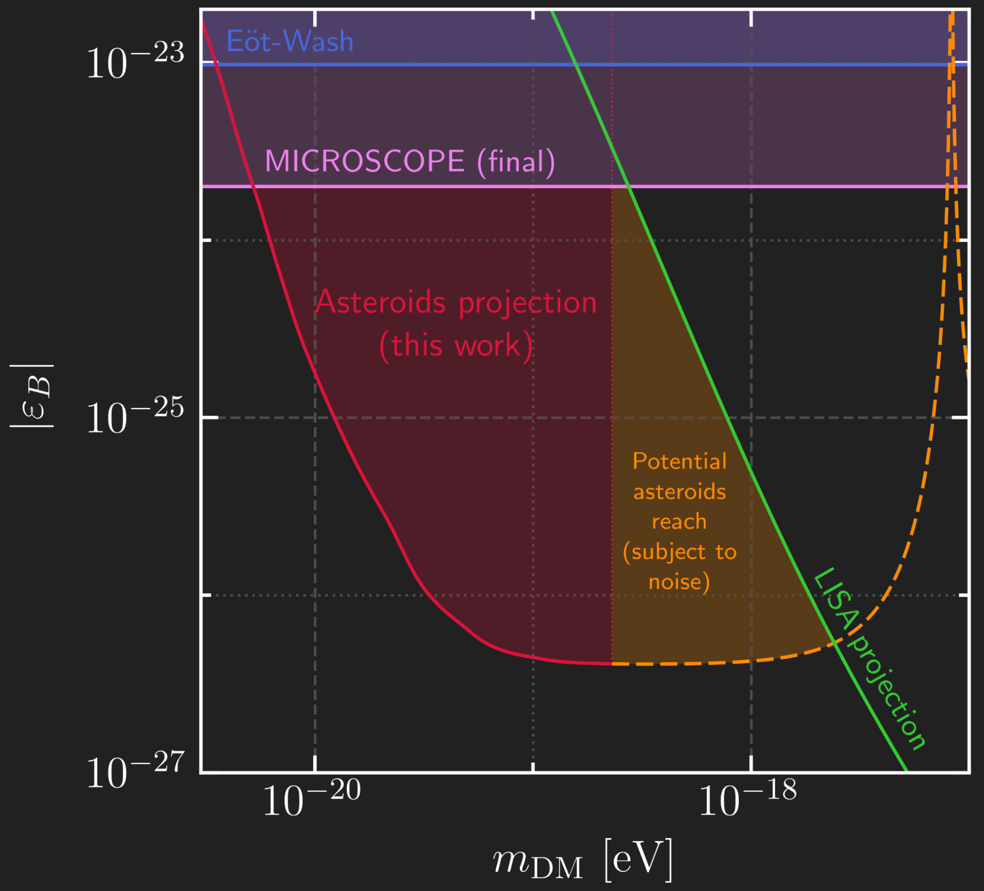
Strain sensitivity

↓

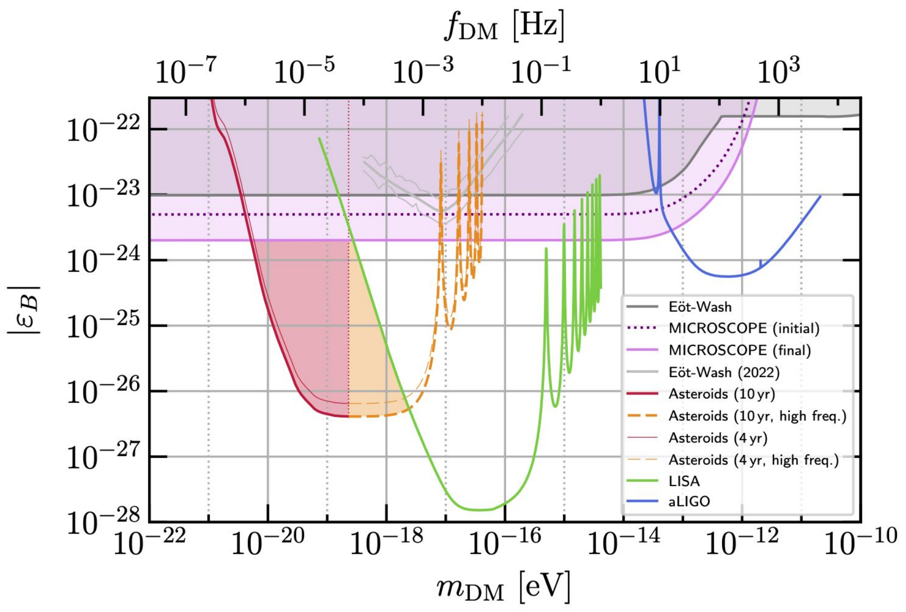
ΔL sensitivity

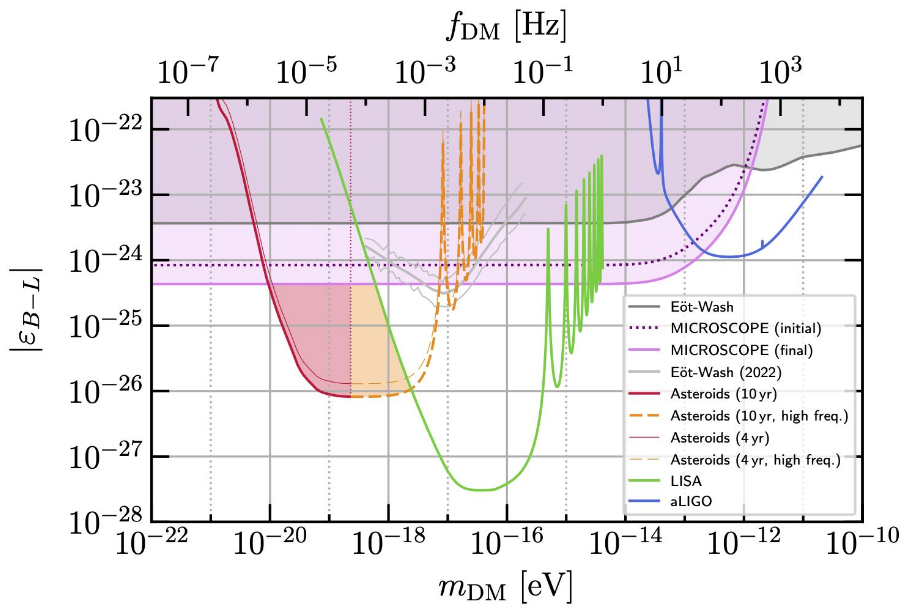
↓

Reach on dark photon DM coupling



The Full Picture (in the light of day)





Additional motivation for an ambitious project!

Thank you!