Riding the Dark Matter Wave

Novel limits on general dark photons from LISA Pathfinder

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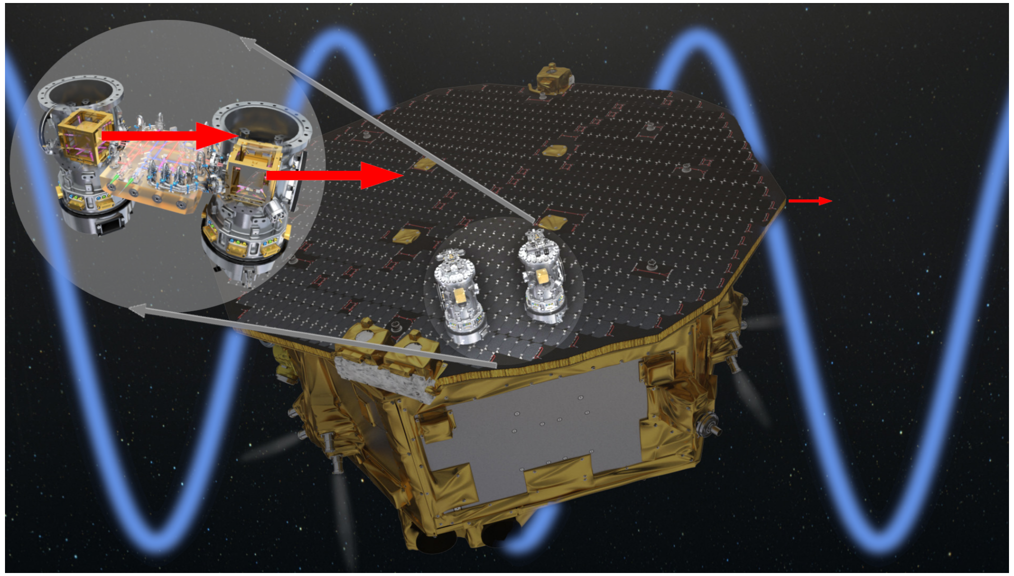


ESA/ATG medialab

3 Ingredients for detecting general Dark Photon Dark Matter

1.) Coupling beyond kinetic mixing

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\epsilon_{\mathrm{KM}}}{2}F'_{\mu\nu}F^{\mu\nu} + \frac{m_{\mathrm{DM}}^2}{2}A'_\mu A'^\mu - \epsilon_g e A'_\mu J_g^\mu \longrightarrow \text{B-L}$$

2.) Field effectively classical with large coherence length

$$\mathbf{A}(t,x) = \mathbf{A}_{\mathrm{DM}} e^{-i\omega t + i\cancel{\mathbf{k}\cdot x + \phi_0}}$$

$\omega \approx m_{\mathrm{DM}}$

$|\mathbf{k}| = m_{\mathrm{DM}}|\mathbf{v}| \ll m_{\mathrm{DM}}$

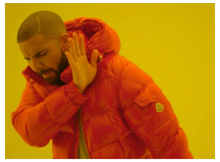
3.) Lorentz-like force induced by the DM background

$$\mathbf{a}(t) \simeq i\omega\epsilon_g e\frac{q}{M}\mathbf{A}_{\mathrm{DM}}e^{-i\omega t} = i\epsilon_g e\frac{q}{M}\sqrt{2\rho_{\mathrm{DM}}}\,\hat{\mathbf{e}}_A\, e^{-i\omega t}$$

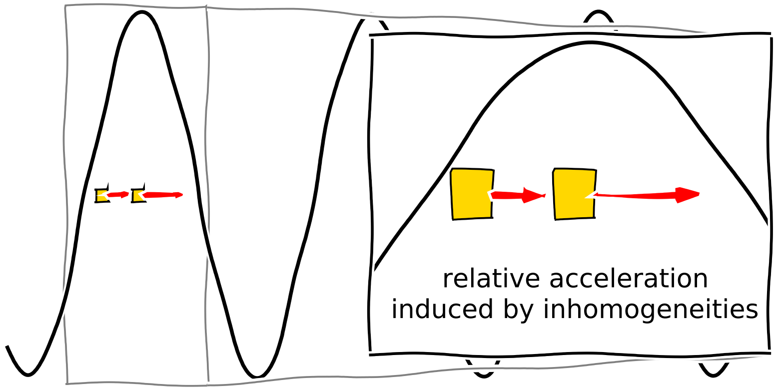
$$\rho_{\mathrm{DM}} = \frac{1}{2}\omega^2|\mathbf{A}_{\mathrm{DM}}|^2$$

The big issue with a small experiment

LPF region of sensitivity $10^{-3}\,\mathrm{Hz} \approx 4 \cdot 10^{-18}\,\mathrm{eV} \;\Rightarrow\; \lambda_c \approx 3 \cdot 10^{11}\,\mathrm{km}$



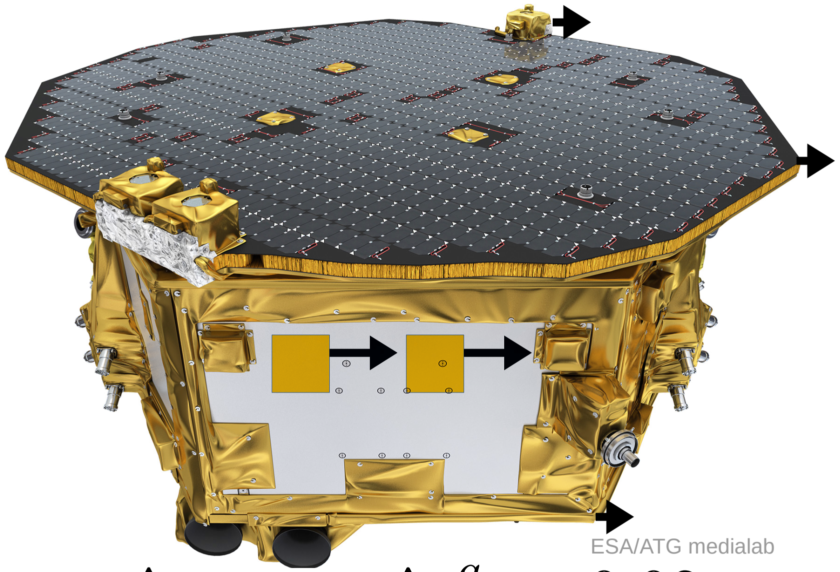
$$\Delta \frac{q}{M} = 0$$



$$\Delta a_{\mathrm{dec}} \propto \frac{L}{\lambda_c} \simeq v m_{\mathrm{DP}} L \approx 10^{-15}$$

Decoherence Method

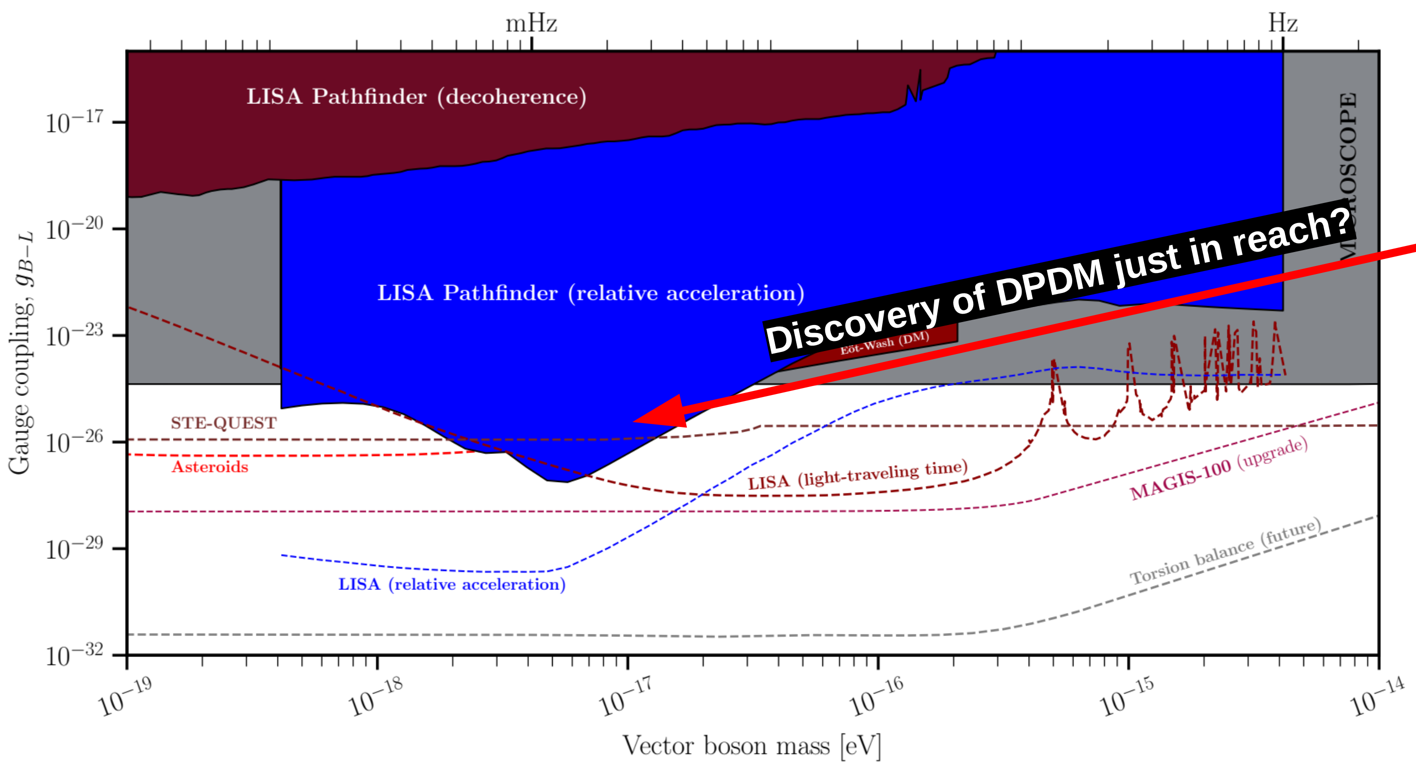
$$\Delta \frac{q}{M} \neq 0$$

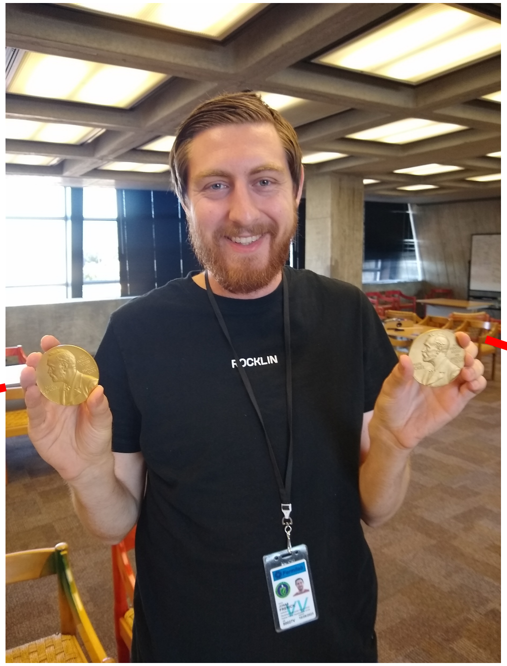


$$\Delta a_{\mathrm{cmr}} \propto \Delta \frac{q}{M} \approx 0.02$$

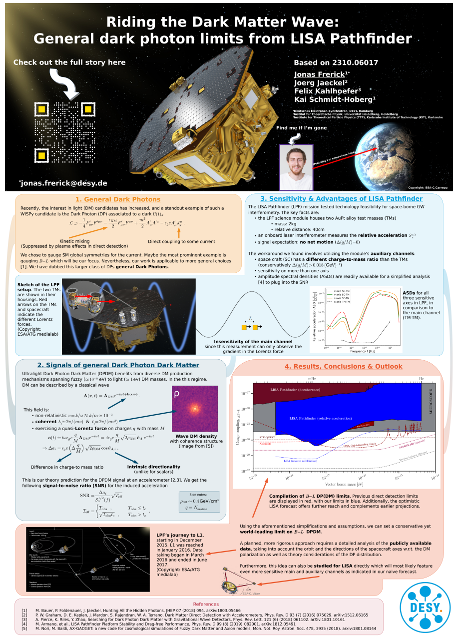
Auxiliary Channel Method

Results





Design of the poster



Thank you for your attention!

Check out my poster for more details

More details on ultralight vector DM

$$\mathbf{A}(t,x) = \mathbf{A}_{\mathrm{DM}} e^{-i\omega t + i\mathbf{k}\cdot\mathbf{x} + \phi_0}$$

$$\rho_{\mathrm{DM}} = \frac{1}{2}\omega^2 |\mathbf{A}_{\mathrm{DM}}|^2 \qquad \omega \approx m_{\mathrm{DM}} \qquad |\mathbf{k}| = m_{\mathrm{DM}}|\mathbf{v}| \ll m_{\mathrm{DM}}$$

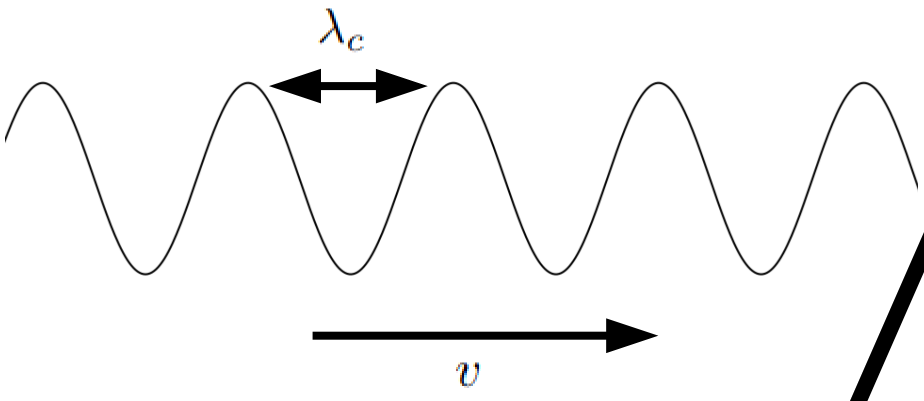
Why only the 3-vector?

$$\partial_\mu A^\mu = 0 \Rightarrow A^0(t) = -\frac{\mathbf{k}\cdot\mathbf{A}(t)}{\omega} \approx \mathbf{v}\cdot\mathbf{A}(t) \ll |\mathbf{A}(t)|$$

Coherence length and time:

$$\lambda_c \simeq 2\pi/(m_{\mathrm{DM}} v)$$

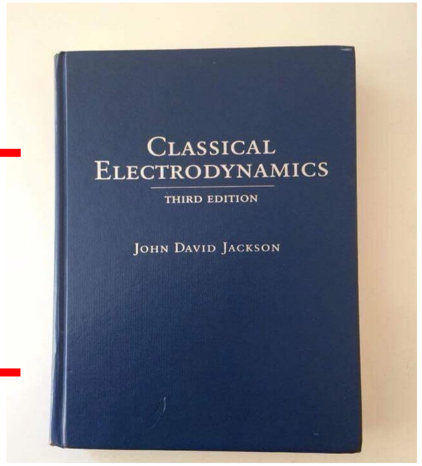
$$t_c \simeq 2\pi/(m_{\mathrm{DM}} v^2)$$



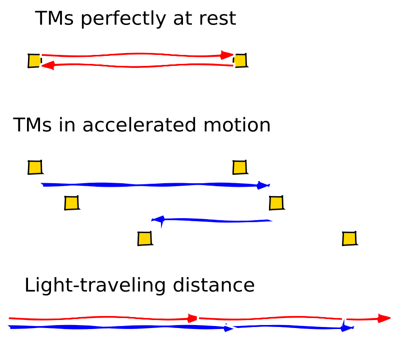
$$\mathbf{A}(t,x) = \mathbf{A}_{\mathrm{DM}} e^{-i\omega t}$$

$$\mathbf{E}_g = -\partial_t \mathbf{A}(t) = i\omega \mathbf{A}_{\mathrm{DM}} e^{-i\omega t}$$

$$\mathbf{a}(t) \simeq i\omega\epsilon_g e \frac{q}{M}\mathbf{A}_{\mathrm{DM}} e^{-i\omega t} = i\epsilon_g e\frac{q}{M}\sqrt{2\rho_{\mathrm{DM}}}\,\hat{\mathbf{e}}_A\, e^{-i\omega t}$$



Main vs auxiliary channel

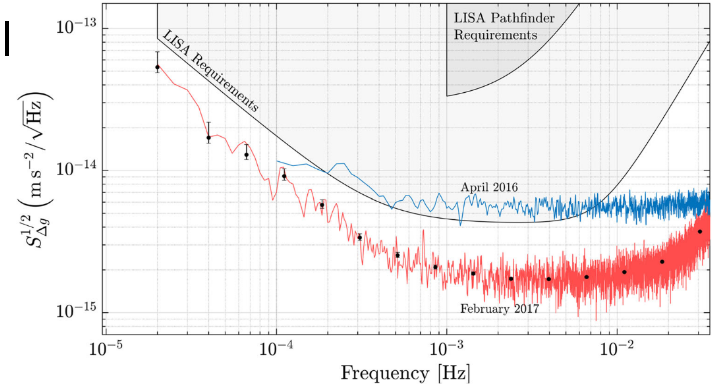


$$\Delta a_{\mathrm{ltt}} \propto (m_{\mathrm{DP}} L)^2 \approx 10^{-24}$$

$$\mathbf{a}(t) \simeq i\epsilon_g e \frac{q}{M} \sqrt{2\rho_{\mathrm{DM}}}\, \hat{\mathbf{e}}_A\, e^{-i\omega t}$$

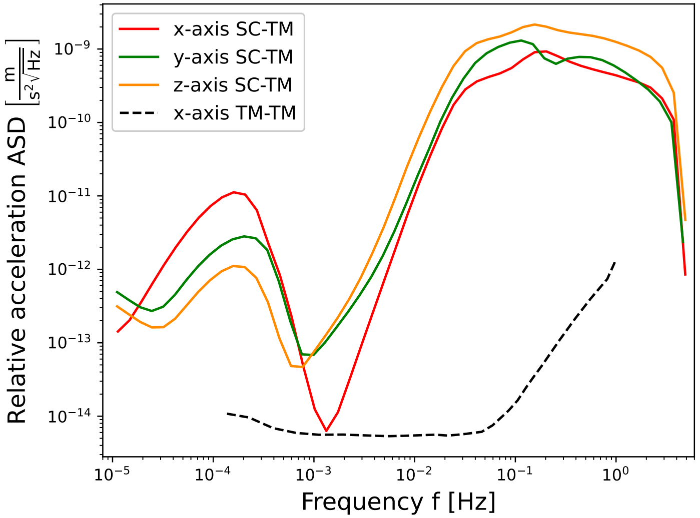
$$\Delta a_i = \epsilon_g e \left(\Delta \frac{q}{M}\right) \sqrt{2\rho_{\mathrm{DM}}} \cos\theta_{A,i}$$

Main channel

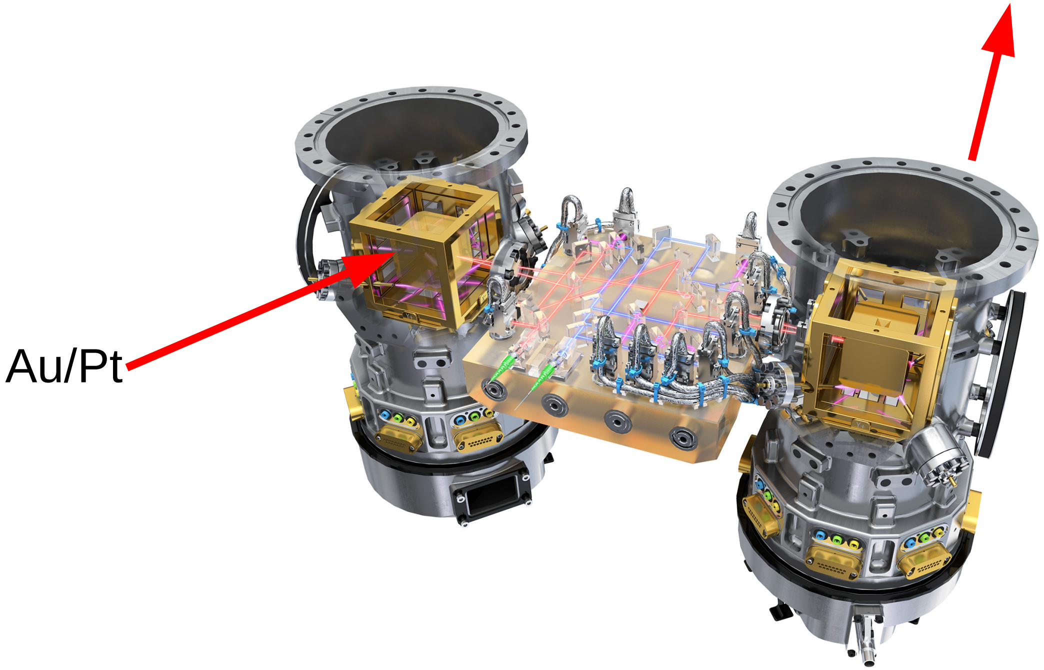


[Armano et al, 2018]

=> Use auxiliary channels!

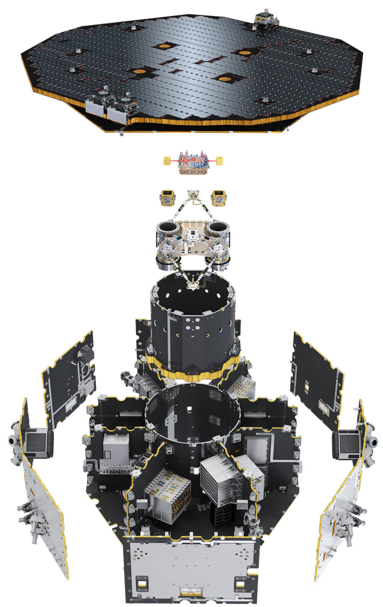


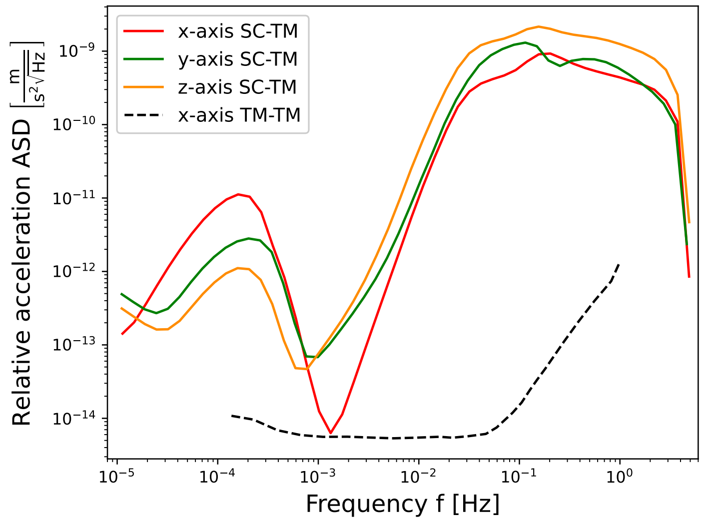
Mixture of lighter elements

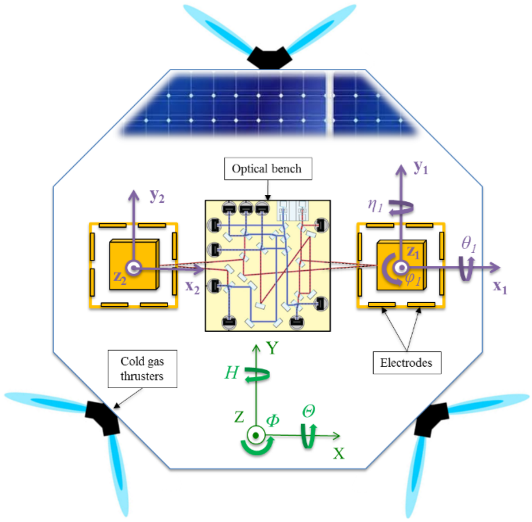


More details on LPF

Material	Au	C	SC-TM
$\left(\frac{q}{M}\right)_{B-L}$ in GeV^{-1}	0.64	0.54	0.018
$\left(\frac{q}{M}\right)_{B}$ in GeV^{-1}	1.0736	1.0737	$1.8 \cdot 10^{-5}$





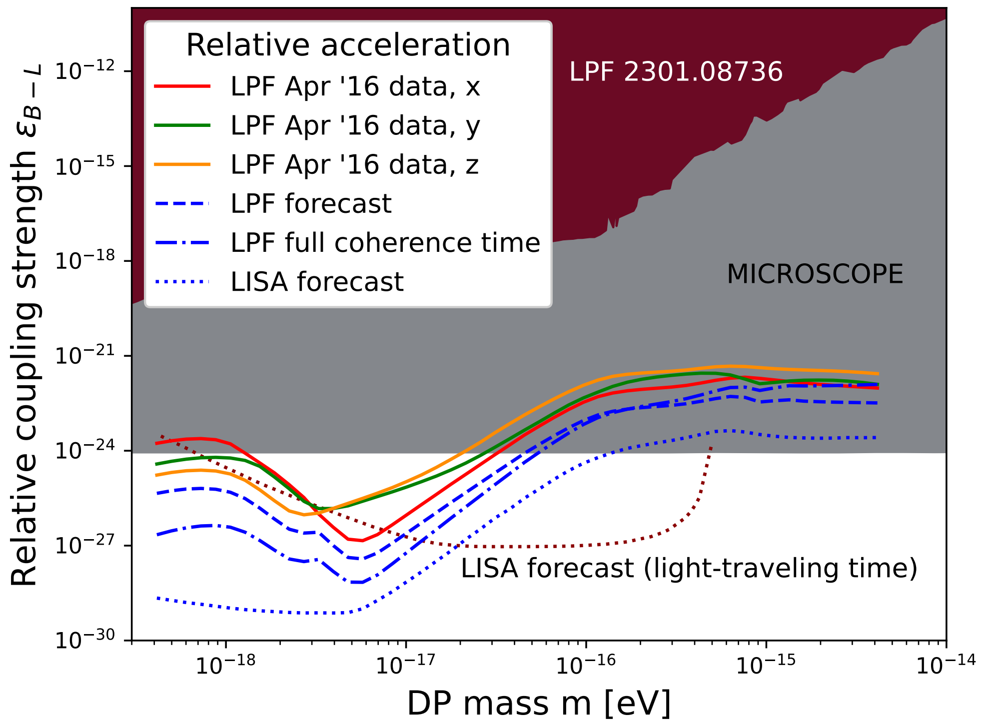


[1812.05491]

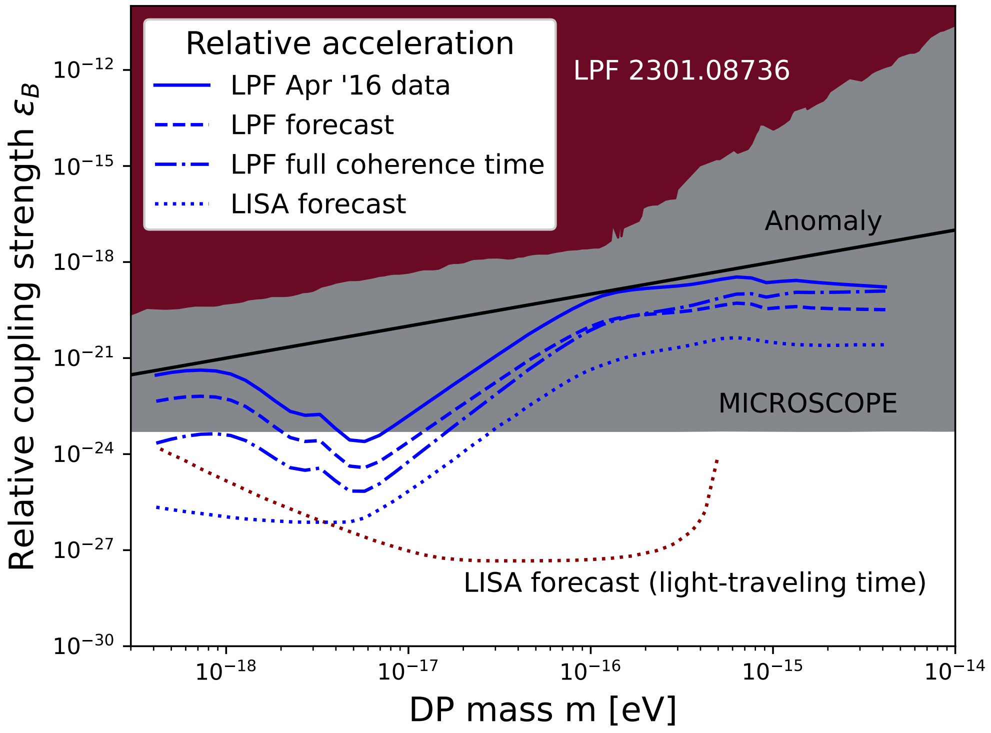
Item	Maximum mass [kg]
Data handling	15.4
Power subsystem	63.1
X-Band comms subsystem	8.3
AOCS	17.5
Structure	83.0
Thermal subsystem	8.8
Micropropulsion subsystem	43.8
Balance mass	17.5
LISA technology package	150
Disturbance reduction system	43
Science spacecraft dry total	450.4

[Racca, Namara]

B-L vs B



Relative acceleration
LPF Apr '16 data, x
LPF Apr '16 data, y
LPF Apr '16 data, z
LPF forecast
LPF full coherence time
LISA forecast
LPF 2301.08736
MICROSCOPE
LISA forecast (light-traveling time)
Relative coupling strength ϵ_{B-L}
DP mass m [eV]



Relative acceleration
LPF Apr '16 data
LPF forecast
LPF full coherence time
LISA forecast
LPF 2301.08736
Anomaly
MICROSCOPE
LISA forecast (light-traveling time)
Relative coupling strength ϵ_B
DP mass m [eV]