Jet Propulsion Laboratory
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Searching for new ultra-light fields with atomic sensors

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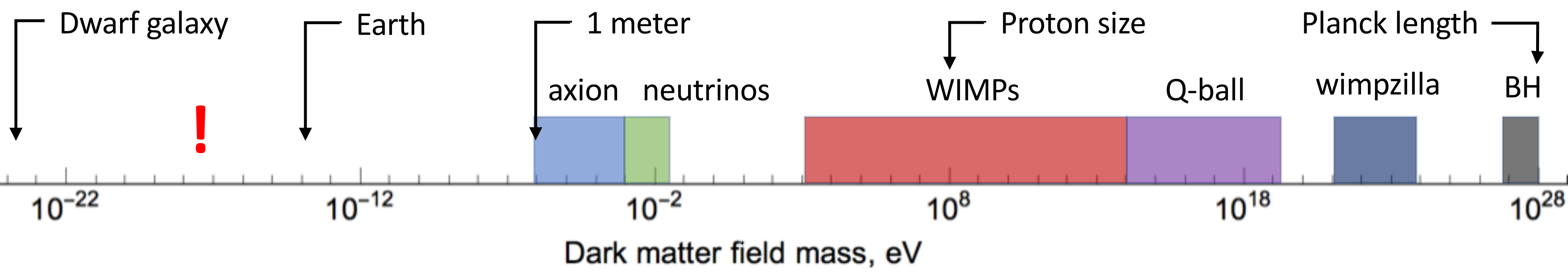
Motivation

- No direct detection of the dark matter to date, while having an overwhelming amount of indirect observations. Importance: 27% of energy content of the Universe, 85% of the mass content.
- Vast range of unexplored masses (about 80%) of the total span 10^{-24} eV - 10^{28} eV. WIMPs are typically tested above GeV and axions above μeV scale.
- Light fields predicted by nearly every new theory beyond the Standard Model.
- Searching for low frequency gravitational waves



Examples of physical effects

Presence of a scalar field (e.g., dilaton or axion dark matter) can induce a change in the fundamental constants that can be measured with atomic clocks:

$$\frac{\delta\alpha}{\alpha} = \left(\frac{\phi}{\Lambda_{\gamma,n}}\right)^n, \quad \frac{\delta m_f}{m_f} = \left(\frac{\phi}{\Lambda_{f,n}}\right)^n, \quad \dots \quad \nu = \text{const} \cdot R_\infty \cdot \alpha^{K_\alpha} \left(\frac{m_q}{\Lambda_{QCD}}\right)^{K_{q\Lambda}} \left(\frac{m_e}{\Lambda_{QCD}}\right)^{K_{e\Lambda}}$$

Presence of a vector field (e.g., B-L dark matter) can induce a variation in the neutron mass (and, therefore, difference between accelerations of different isotopes in a free fall) that can be measured with atom interferometers:

$$\Delta\vec{a}_{B-L}(t,\vec{x}) = \frac{g_{B-L}}{m_N}\left(\frac{Z_a}{A_a} - \frac{Z_b}{A_b}\right)\vec{W}(t,\vec{x})$$

Presence of a gravitational wave will induce a Doppler shift to an electromagnetic signal propagating between an emitter and a receiver:

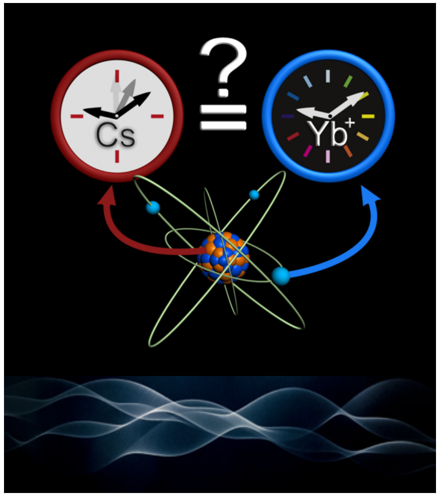
$$X_a(t) = \frac{1}{2}\sum_{P,i,j} \frac{\hat{p}^i_{(a)}\hat{p}^j_{(a)}e^P_{ij}}{1+\hat{\Omega}\cdot\hat{p}_{(a)}}\left(h_P\left[t - \left(1+\hat{\Omega}\cdot\hat{p}_{(a)}\right)D_a\right] - h_P[t]\right)$$

General idea of the first paper

Compare two clocks of different type or spatially separated;
Investigate the two dark matter configurations: dark matter waves or topological defects.

1. Waves with frequency

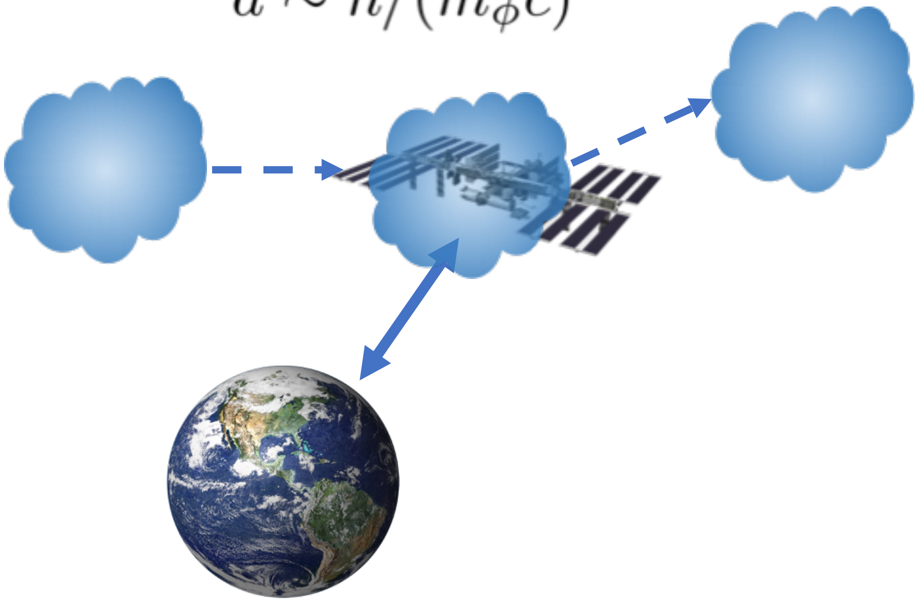
$$f = m_\phi/(2\pi)$$



See also refs on other groups.

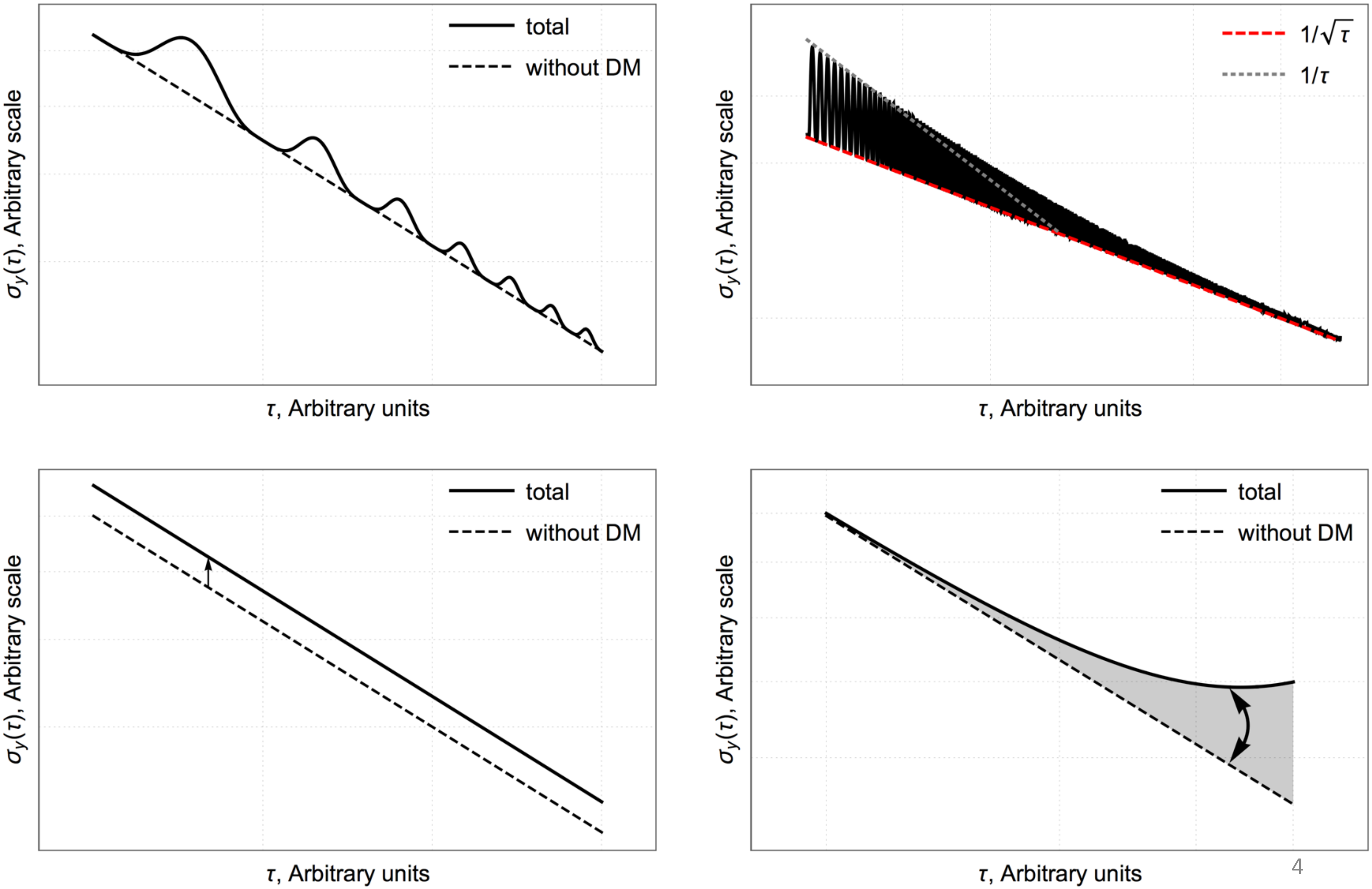
2. Clumps of dark matter of size

$$d \sim \hbar/(m_\phi c)$$



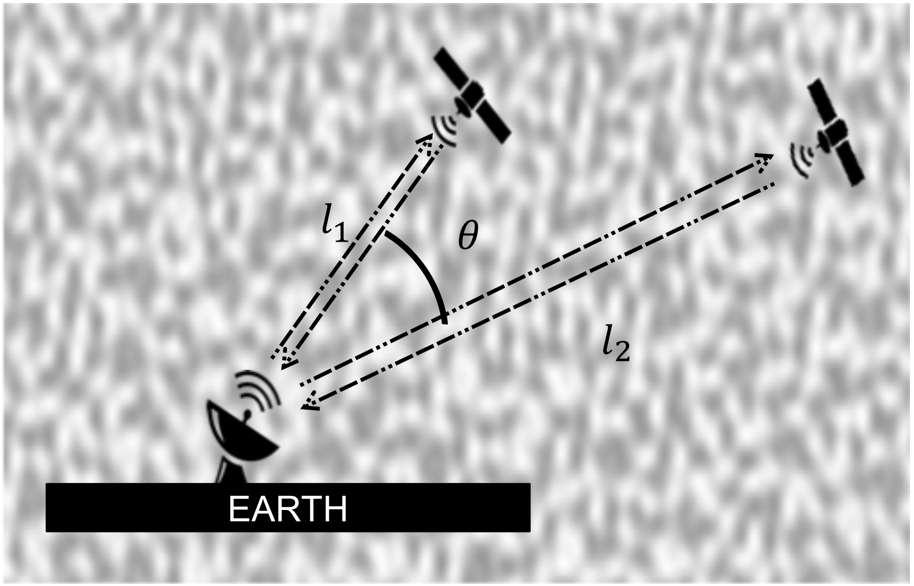
See talk by **Ben Roberts**, A. Derevianko's group.

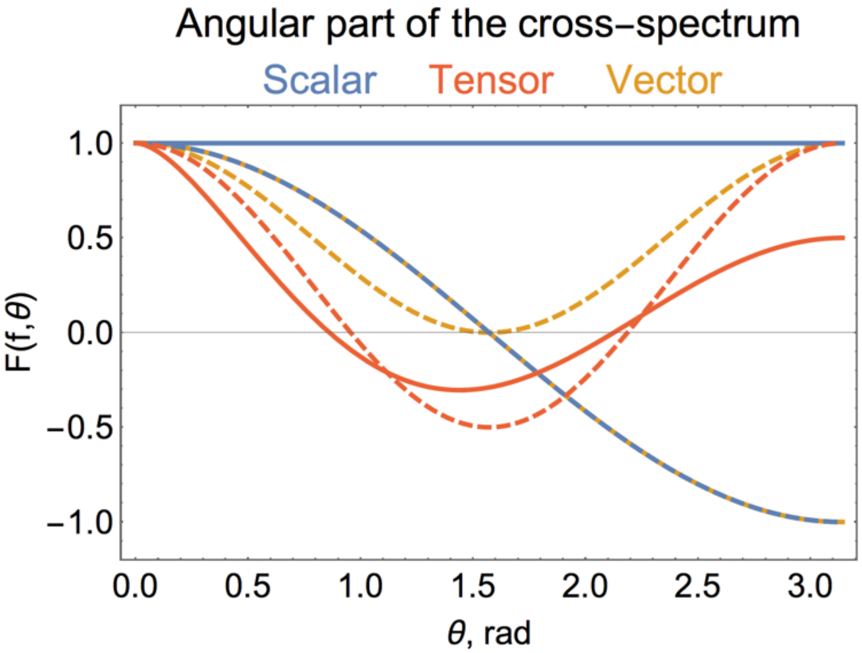
Anomalies in the stability plots



General idea of the second paper

Assume the new fields exist in a stochastic isotropic background. One can measure a cross-spectrum of signals recorded from different atomic sensors. We found exact angular dependence of the cross-spectrum in the long- and short-wavelength limits and proposed statistical methods for analyzing the results of the experiments (please see the paper, a lot of math).





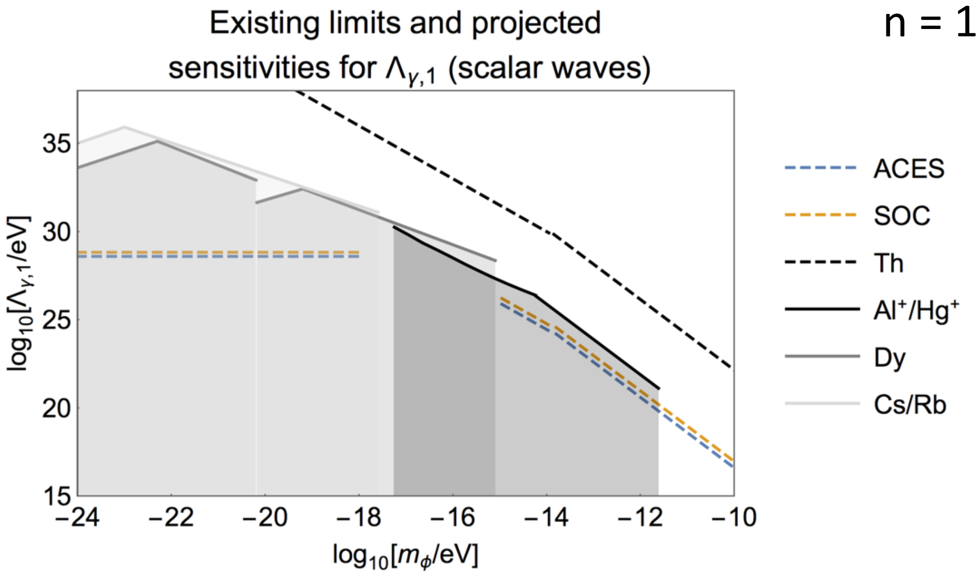
Conclusions

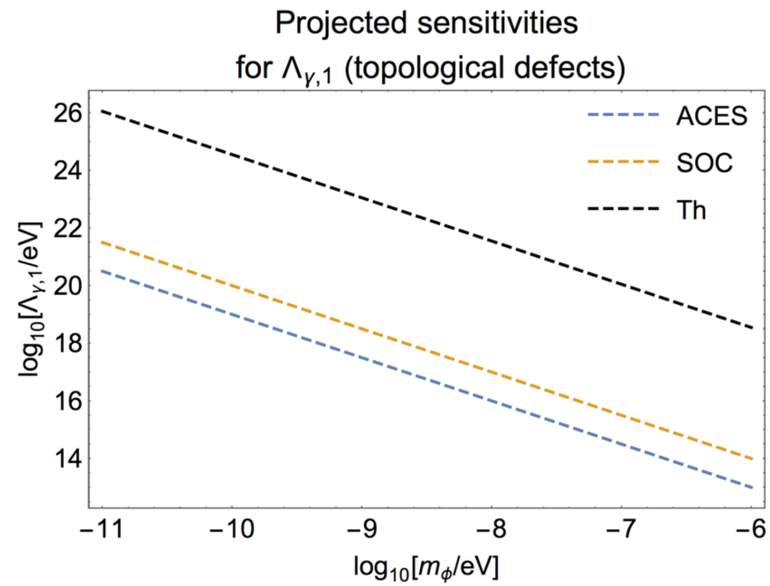
- Comparison of signals recorded by state of the art atomic sensors provides an opportunity for direct searches of ultralight fields (such as dark matter and gravitational waves).
- Ultra-stable atomic clocks can be used for direct probes of variety of hypothetical (pseudo-)scalar fields (such as dilaton dark matter and axions).
- New vector fields can be probed with atom interferometers, while testing the weak equivalence principle.
- Networks of atomic sensors can be used for the search of the stochastic backgrounds of new fields. Combination of data from different detectors together with the long observation time is advantageous for the noise suppression.

This work has been done under supervision of Dr. Nan Yu within the science study of the ACES collaboration project. We are grateful to Slava Turyshev, Eric Burt, Jason Williams, Dmitry Duev and Andrei Derevianko for useful comments and suggestions.

Backup slide (sensitivities)

n = 1:





n = 2: