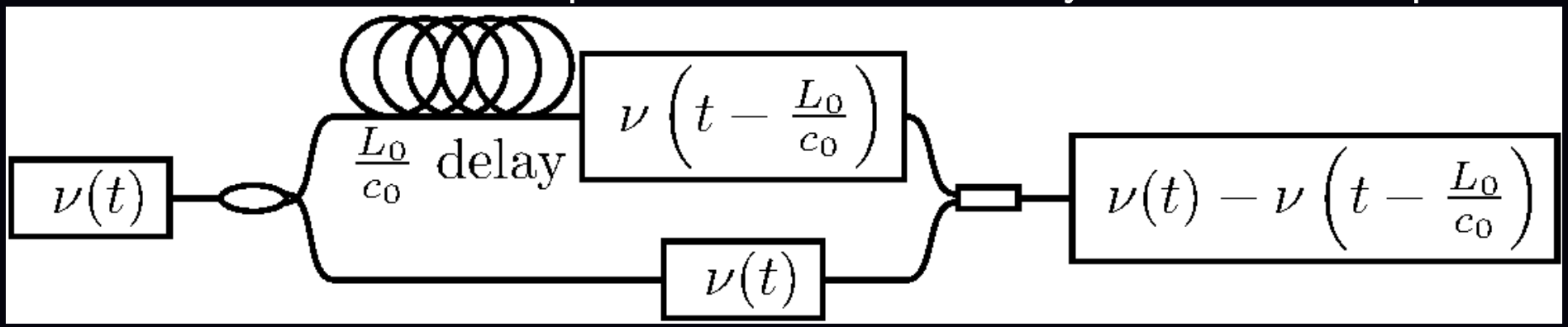
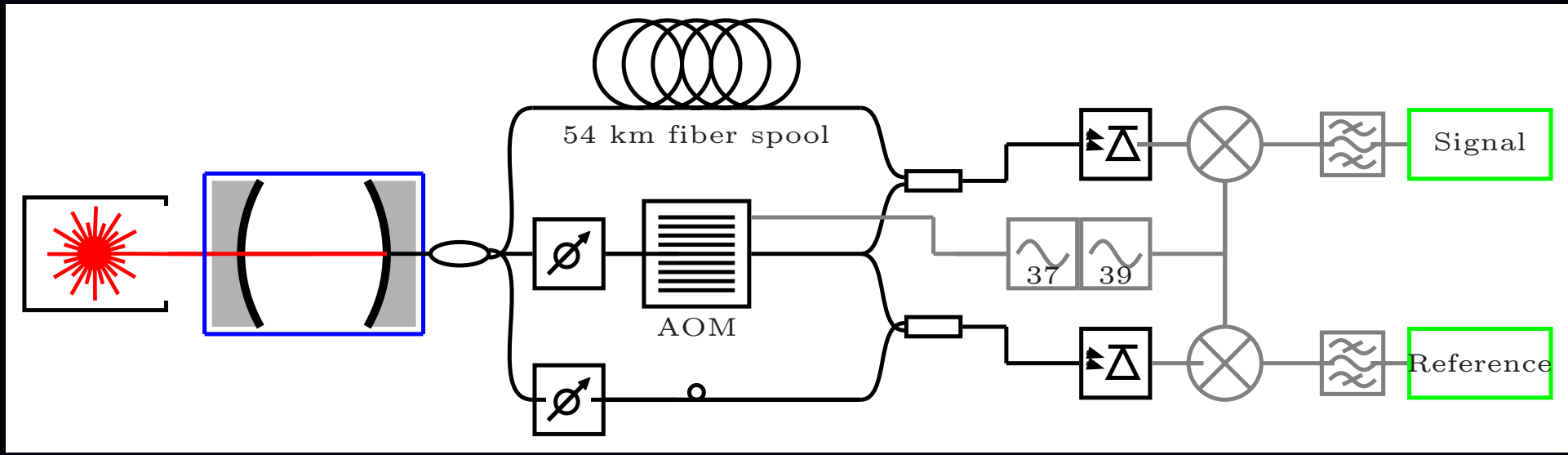
DArk Matter from Non Equal Delays

"DAMNED" allows to compare an ultrastable cavity to itself in the past.



Unequal-arm length Mach-Zender interferometer

Blueprint



Source

1542nm laser source stabilized on an ultra stable cavity, unevenly distributed in three arms.

Delay

Long delay line of $50 \rightarrow 125km$
Short delay line of $1m$
AOM for detection

Detection

Beatnotes
Self-heterodyne
Photodiodes
Ettus X310

Bohr radius oscillation

The fundamental constants oscillation leads to Bohr radius oscillation :

$$a_0 = \frac{\hbar}{m_e c \alpha} \Rightarrow \frac{\delta a_0}{a_0} = -\frac{\delta \alpha}{\alpha} - \frac{\delta m_e}{m_e} = -\left(d_e + d_{m_e}\right)\varphi$$

DAMNED setup oscillations

The two main things affected by the fundamental constants oscillations in our experiment are :

- the cavity ouput frequency : $\omega \propto L_{cavity}^{-1} \propto a_0^{-1}$
- the delay lines $T = nL/c$ decomposed in :
  - the fiber length $L \propto a_0$
  - the fiber refractive index n

C. Braxmaier et al. PRD 64,042001

Cavity frequency oscillation

$$\omega(t) = \omega_0 + \Delta\omega(t) + \delta\omega \sin(\omega_\varphi t)$$

Color code

Nominal value

Noise

Dark matter effect

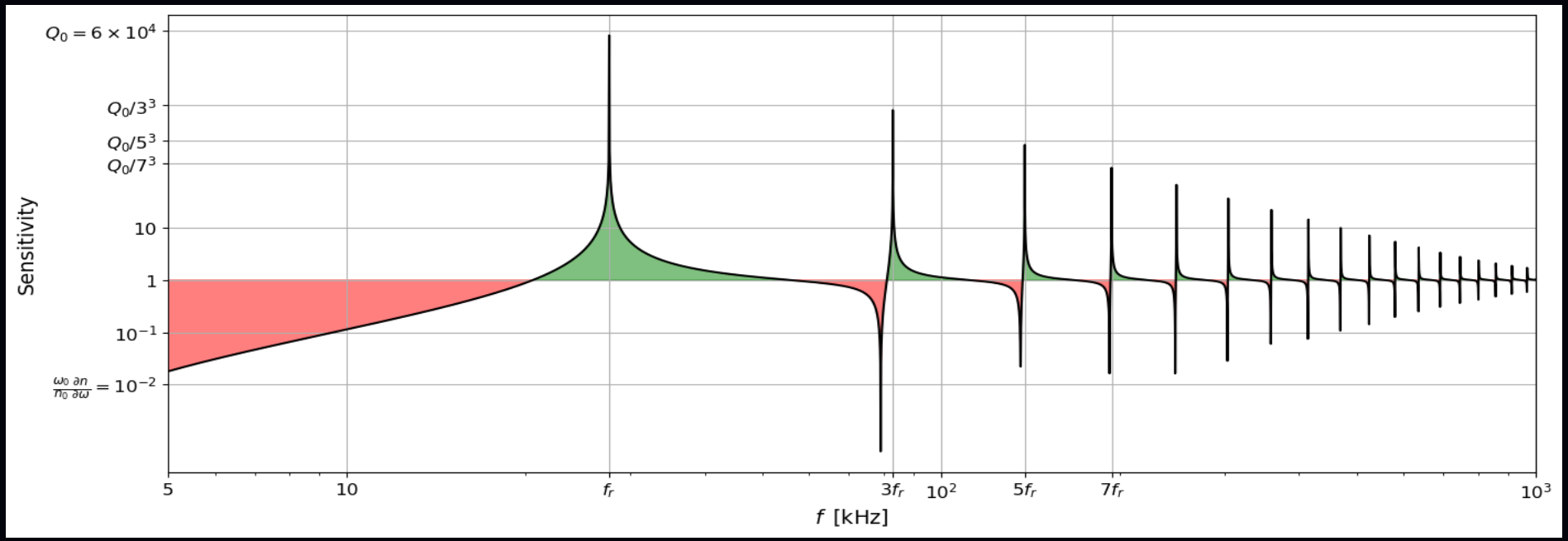
Fiber delay oscillation

$$T(t) = T_0 + \int_{t-T_0}^{t} \frac{\Delta T(t')}{T_0} \mathrm{d}t' + \delta T \sin\left(\omega_\varphi t - \omega_\varphi \frac{T_0}{2}\right) \mathrm{sinc}\left(\omega_\varphi \frac{T_0}{2}\right)$$

Phase difference between the delayed and non delayed signals

$$\Delta\Phi(t) = \omega_0 T_0 + \omega_0 \int_{t-T_0}^{t} \left(\frac{\Delta T(t')}{T_0} + \frac{\Delta\omega(t')}{\omega_0}\right) \mathrm{d}t'$$
$$+ \omega_0 T_0 \left(\frac{\delta T}{T_0} + \frac{\delta\omega}{\omega_0}\right) \sin\left(\omega_\varphi t - \omega_\varphi \frac{T_0}{2}\right) \mathrm{sinc}\left(\omega_\varphi \frac{T_0}{2}\right)$$

Full sensitivity

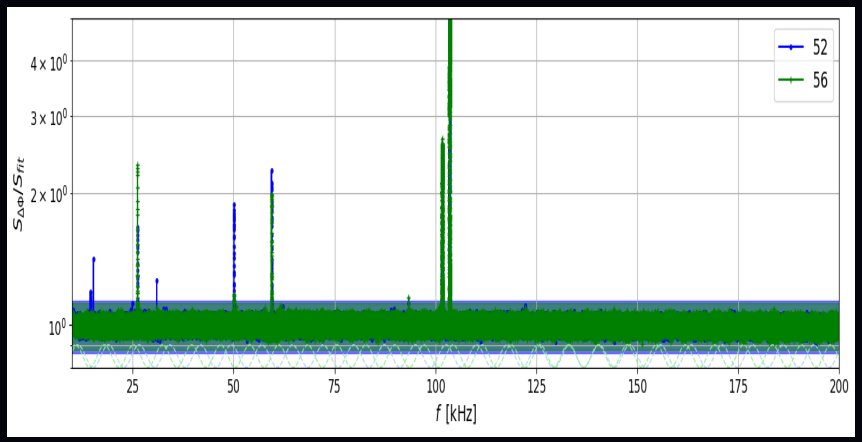


Link to the coupling constants

$$\left(\frac{\delta\omega}{\omega_0} + \frac{\delta T}{T_0}\right) \simeq d_e \varphi_0 \text{"Sensitivity"}$$

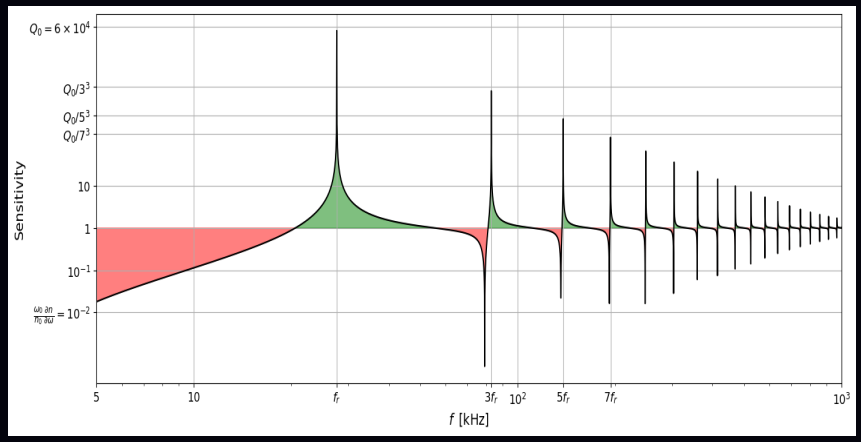
$$\text{or} \simeq d_{m_e} \varphi_0 \text{"Sensitivity"}$$

12 days acquisition



+

Sensitivity

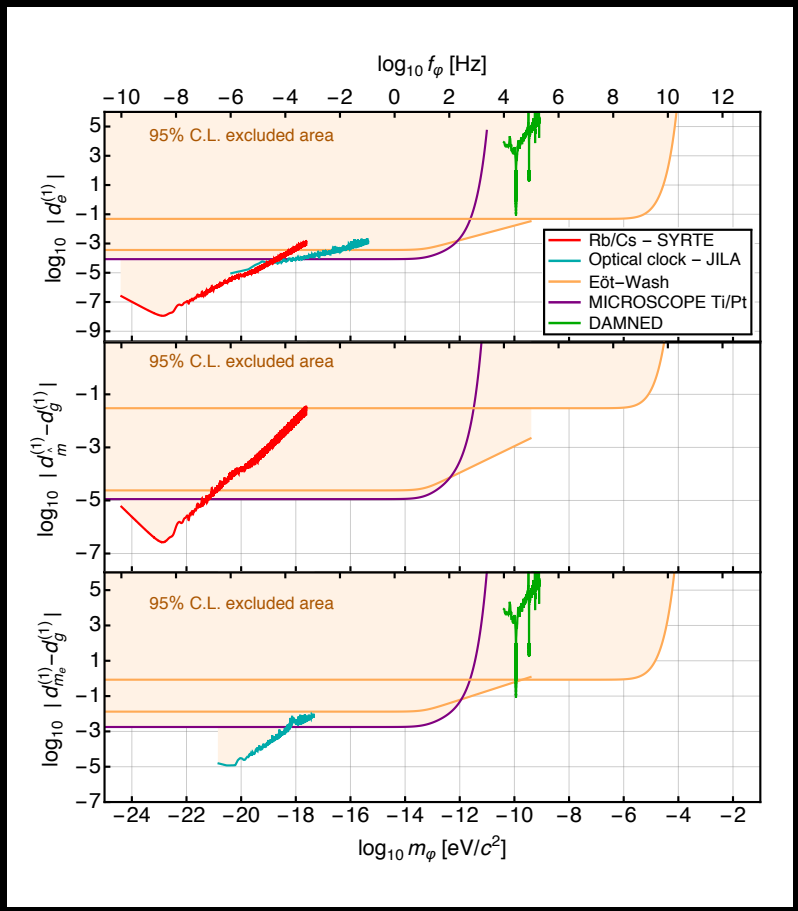


~~Heesian~~ Bayesian analysis

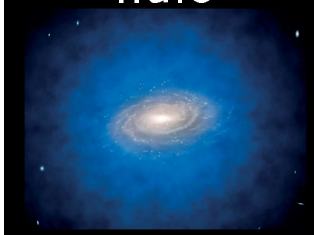
$$-\ln \mathcal{P}(d_x|\mathrm{s}) = \sum_{k=1}^{N} \frac{\frac{|\tilde{s}_k|^2}{2Nf_s S_k}}{1 + d_x^2 \frac{NA_k^2}{4f_s S_k}} + \ln\left(1 + d_x^2 \frac{NA_k^2}{4f_s S_k}\right)$$

A. Derevianko - PRA (2018)

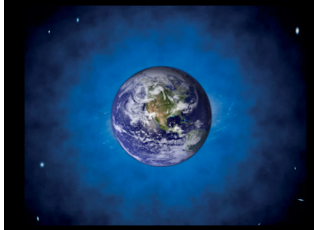
E.S. et al. - PRL (2021)

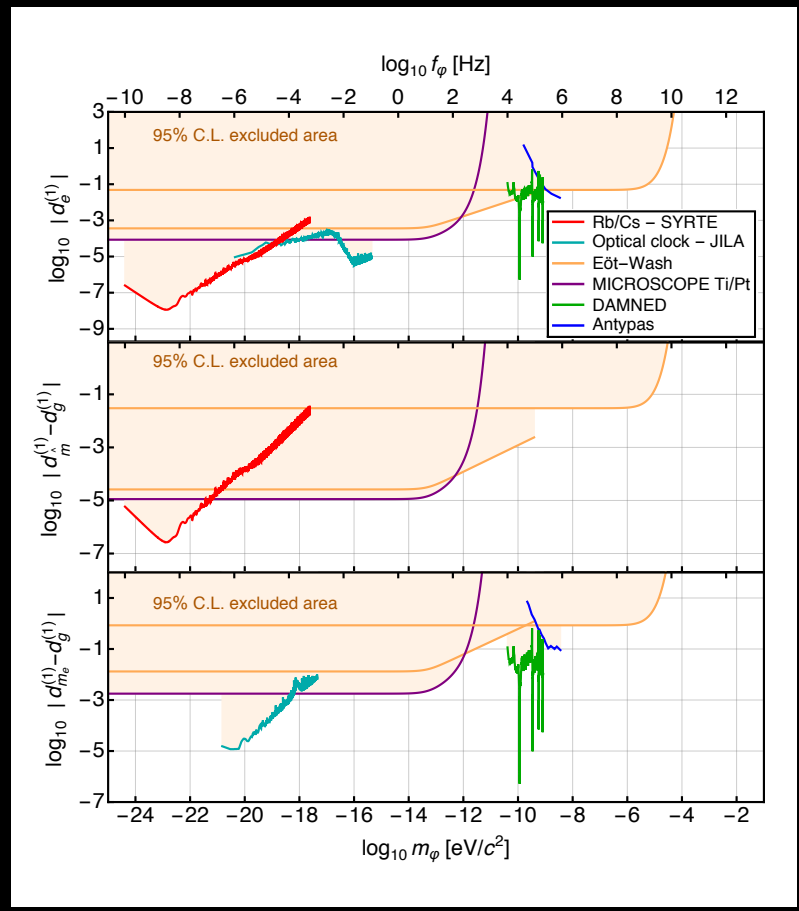


Galactic halo



Earth halo





Phys. Rev. Lett. 126, 051301

Thank you for your attention !