Optical atomic clock as a detector for topological defect dark matter

Piotr Morzyński
Nicolaus Copernicus University, Toruń, Poland
National Institute of Information and Communications Technology, Koganei, Tokyo
JSPS fellow
Dark matter in the form of topological defects

A. Vilenkin, Physics Reports 121, 263 (1985)

\[
\alpha_{\text{eff}} \approx \alpha \times \left(1 + \frac{\phi(x, t)^k}{\Lambda_{k, \gamma}^k}\right)
\]


\[
\frac{d\omega_0}{\omega_0} = K_\alpha \frac{d\alpha}{\alpha}
\]

\[
\frac{\delta \alpha}{\alpha} = \frac{\phi_{\text{inside}}^2}{\Lambda_{\alpha}^2}
\]

A. Pustelny et al., Ann Phys (Berlin) 525, 659 (2013)
Optical atomic clock

The most precise measuring tool

State-of-the-art clocks

relative uncertainty $10^{-18}$
Optical atomic clock

\[ \omega_0^{at} \propto E \]

\[ \omega_0^{cav} \propto L^{-1} \]
**Optical atomic clock**

... is sensitive to $\alpha$ variation

$$\omega_0^{at} \propto E \propto \alpha^2$$

$$\omega_0^{cav} \propto L^{-1} \propto \alpha$$

\[\left(-\frac{1}{2} \sum_{i=1}^{n} \nabla^2 x_i - \sum_{i,j=1}^{n,m} \frac{Z_j}{r_{ji}} + \frac{1}{2} \sum_{i,k=1}^{n,n} \frac{1}{r_{ik}}\right) \psi = \epsilon \psi\]

\[\chi = \frac{r_i}{a_0}\]

\[a_0 = \frac{\hbar}{m \alpha c}\]

\[E_h = \alpha^2 m_e c^2\]

\[\varepsilon = \frac{E}{E_h}\]

P. Wcislo et al., Nat. Astron. 1, 0009 (2016)

Two linked clocks

Different sensitivity

Different location

Readout

Frequency shifter

# Frequency shifter
# MJD                  correction [Hz]
58001.000001    110834135
58001.000002    110834132
58001.000003    110834126
58001.000004    110834134
...

Piotr Morzynski, Nagoya 9.01.2018
Network of clocks

\[
\frac{\delta \alpha}{\alpha} < \frac{1}{K_\alpha \omega_0} \sqrt{\frac{A_0}{\eta^2}}
\]

\[
\Lambda_\alpha > d^{1/2} \sqrt{\frac{\eta^2}{A_0} \rho_{TM} \hbar c K_\alpha \mathcal{T} v \omega_0}
\]

Information about \(\delta \alpha\) and other common noises

P. Wcislo et al., Nat. Astron. 1, 0009 (2016)
**Short events**

From simulations ...

![Signal to noise ratio vs. TDM event duration graph](image)

**Long events**

![Frequency shifter 1 vs. time graph](image)
Experimental constraint

Two optical atomic clocks with neutral $^{88}\text{Sr}$ atoms trapped in optical lattices

P. Morzyński, Scientific Reports 5, 17495 (2015)
M. Bober et. al., Measurement Science and Technology 26, 075201 (2015)
Summary

- New method for searching for transient $\alpha$ variation
- Simplicity and workability
- Measuring apparatus already exists
- Results
Thank You for your attention!

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Piotr Morzynski, Nagoya 9.01.2018