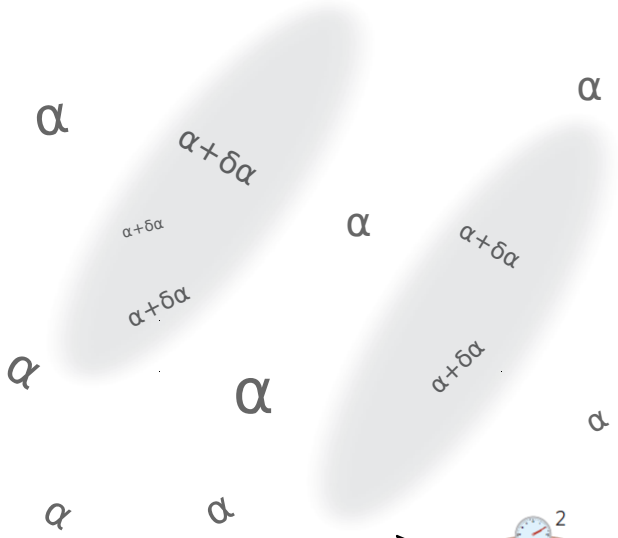
Optical atomic clock as a detector for topological defect dark matter

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)



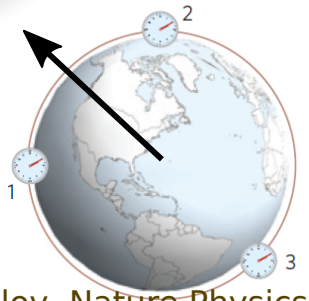
cosmic strings

domain walls

monopoles

...

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



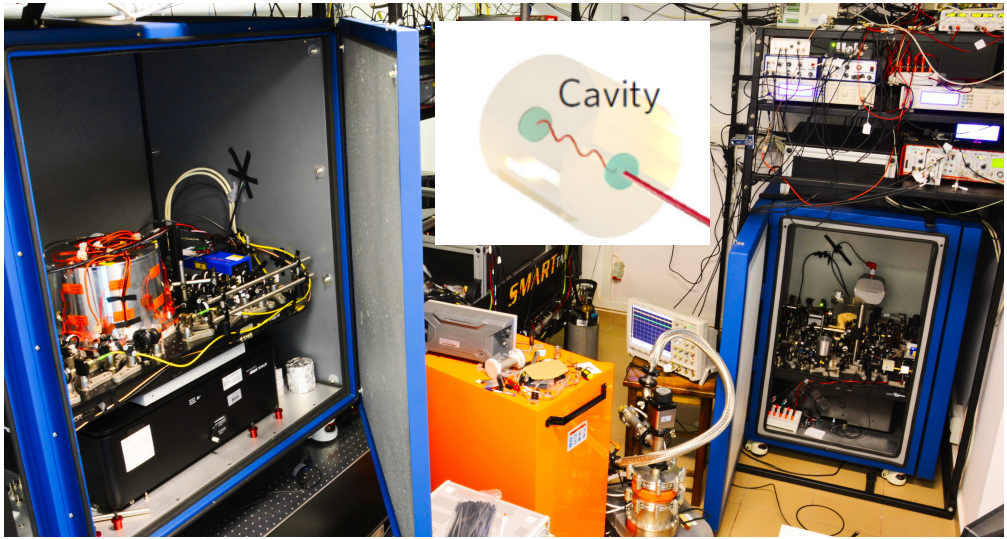
$$\frac{d\omega_0}{\omega_0} = K_\alpha \frac{d\alpha}{\alpha}$$

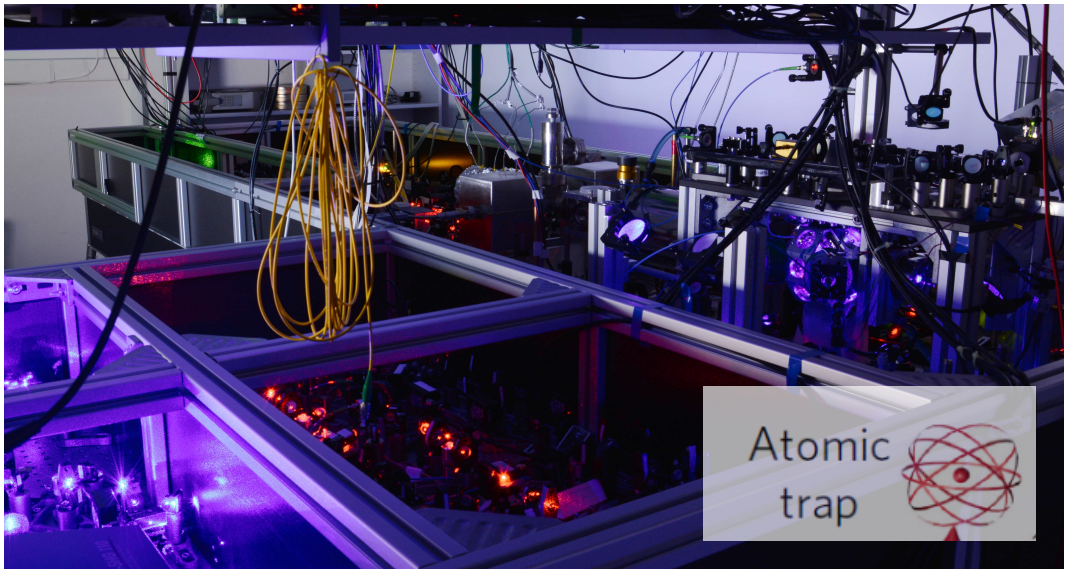
$$\frac{\delta\alpha}{\alpha} = \frac{\phi^2_{\text{inside}}}{\Lambda^2_\alpha}$$

A. Derevianko and M. Pospelov, Nature Physics 10, 933 (2014)

GNOME - S. Pustelny et al., Ann Phys (Berlin) 525, 659 (2013)

Optical atomic clock





The most precise measuring tool

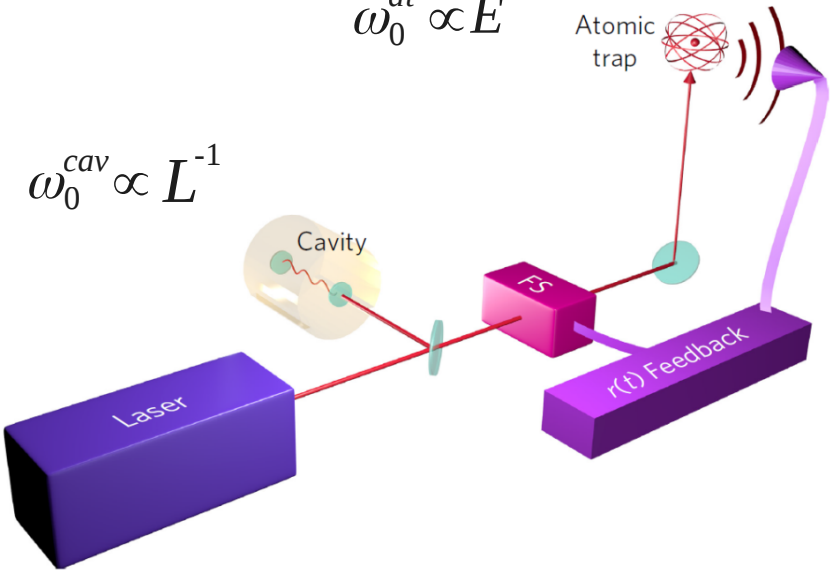
State-of-the-art clocks

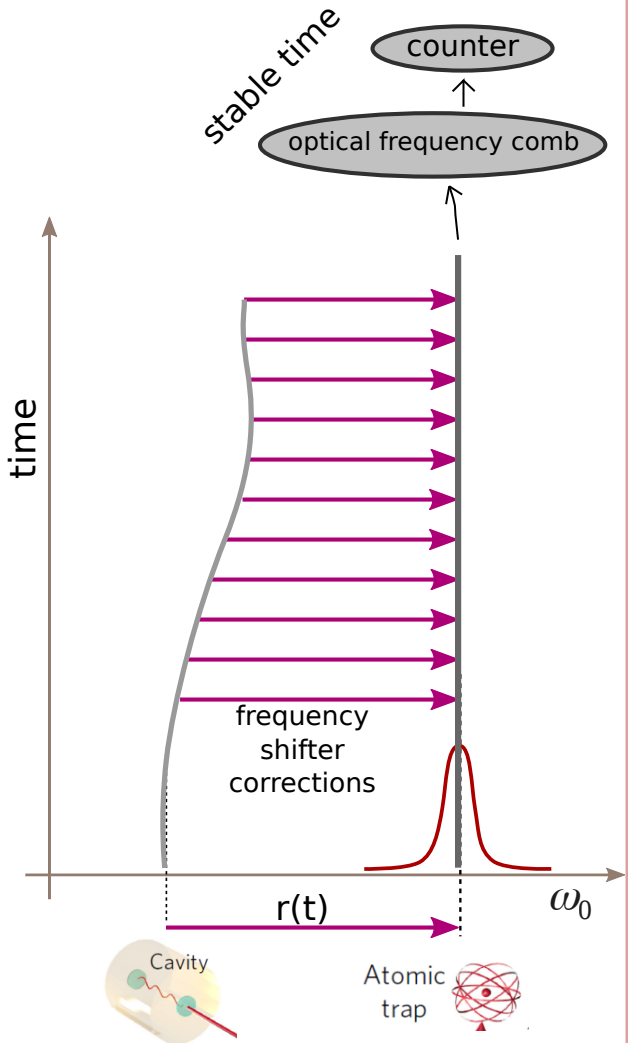
relative uncertainty 10^{-18}

Optical atomic clock

$\omega_0^{at} \propto E$

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



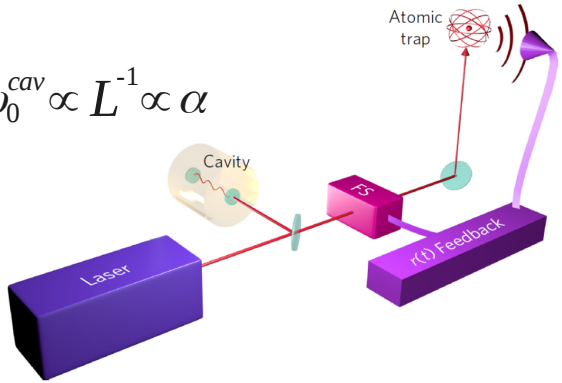


Optical atomic clock

... is sensitive to α variation

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

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

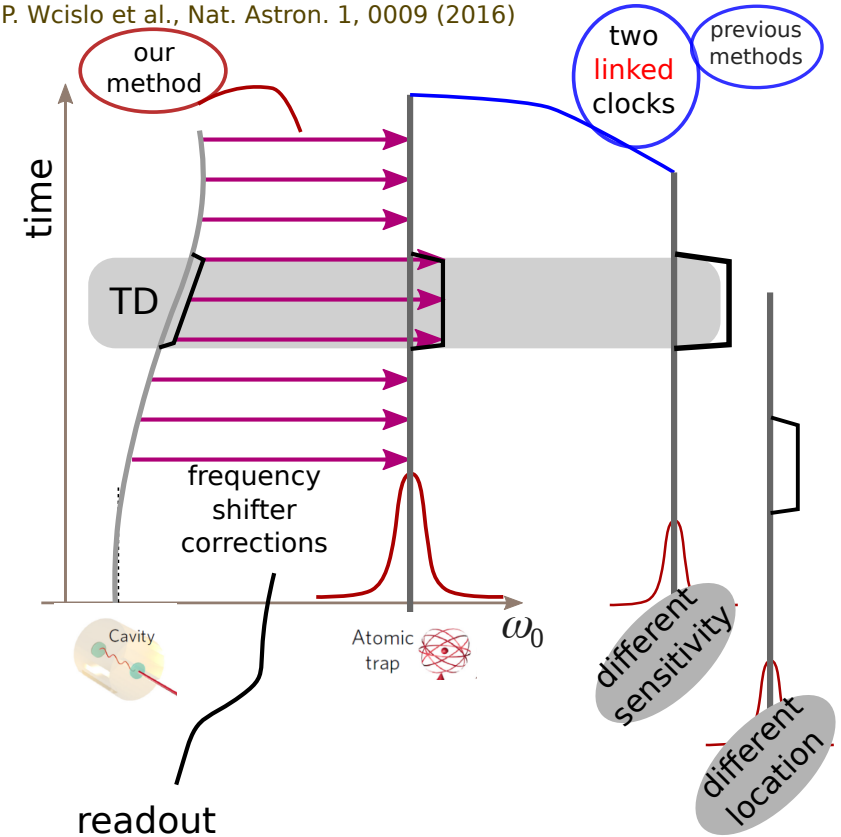


$$\left(-\frac{1}{2}\sum_{i=1}^{n}\nabla_{x_i}^2-\sum_{i,j=1}^{n,m}\frac{Z_j}{r_{ji}}+\frac{1}{2}\sum_{\substack{i,k=1\\ i\neq k}}^{n,n}\frac{1}{r_{ik}}\right)\psi=\epsilon\,\psi$$

$$x_i=\frac{r_i}{a_0} \qquad \epsilon=\frac{E}{E_h}$$

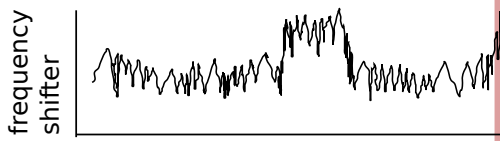
$$a_0=\frac{\hbar}{m\,\alpha\,c} \qquad E_h=\alpha^2 m_e c^2$$

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

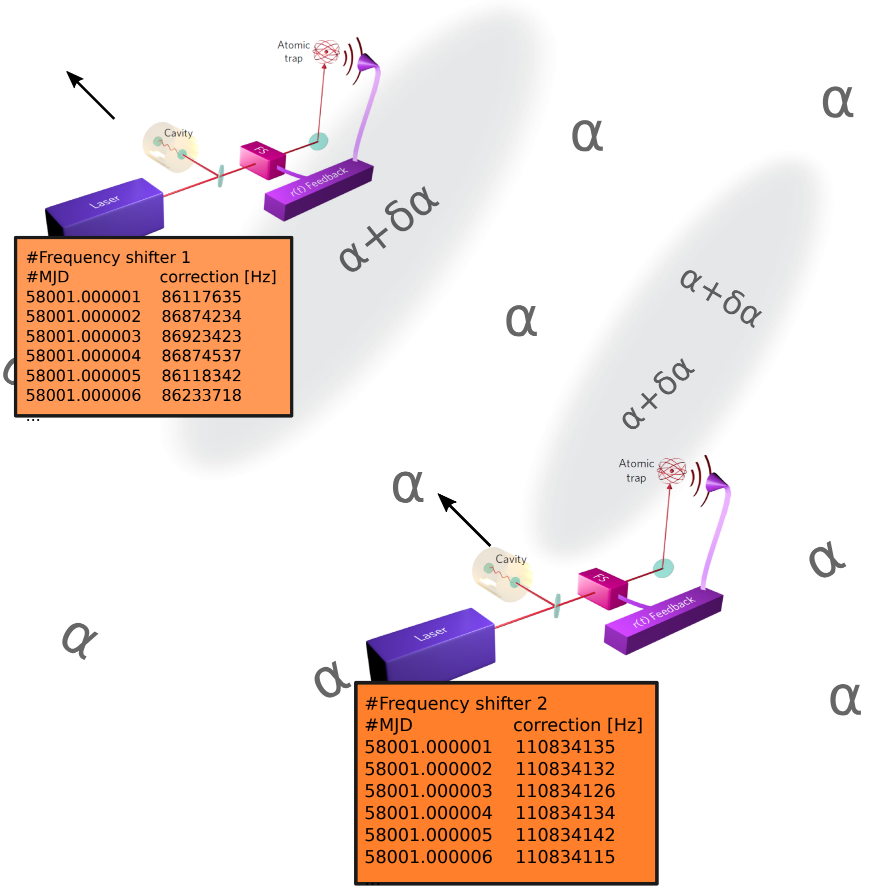


#Frequency shifter

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

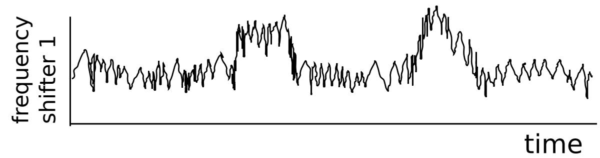


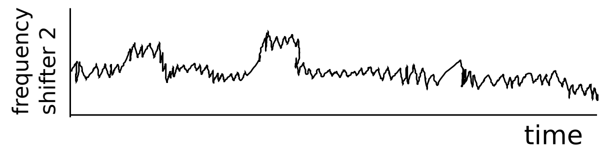
Network of clocks



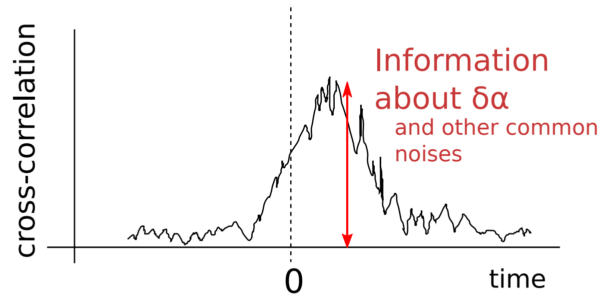
#Frequency shifter 1	
#MJD	correction [Hz]
58001.000001	86117635
58001.000002	86874234
58001.000003	86923423
58001.000004	86874537
58001.000005	86118342
58001.000006	86233718
...	

#Frequency shifter 2	
#MJD	correction [Hz]
58001.000001	110834135
58001.000002	110834132
58001.000003	110834126
58001.000004	110834134
58001.000005	110834142
58001.000006	110834115





$$(r_1 * r_2)(\Delta t) = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} r_1(t) r_2(t + \Delta t) dt$$



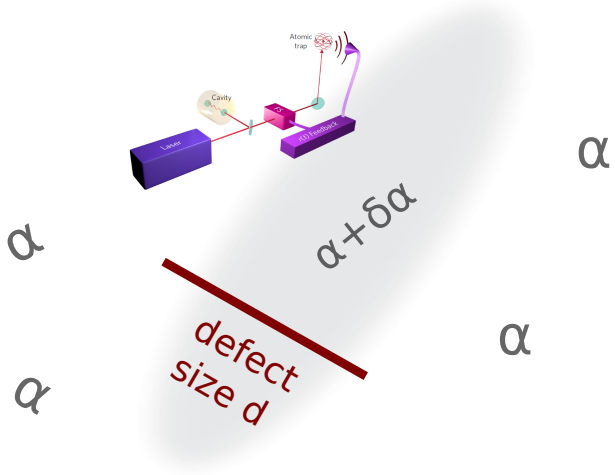
$$\frac{\delta\alpha}{\alpha} < \frac{1}{K_\alpha} \frac{\sqrt{A_0/\eta_T}}{\omega_0}$$

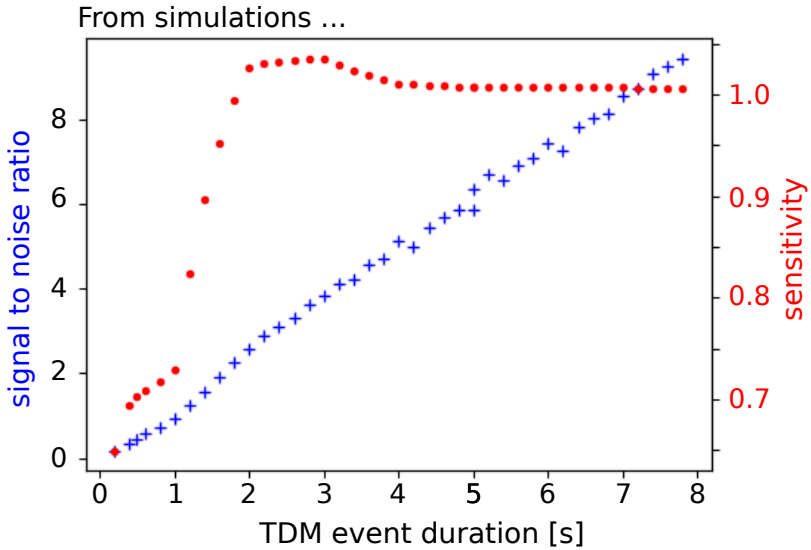
↓

$$\Lambda_\alpha > d^{1/2} \sqrt{\sqrt{\frac{\eta_T}{A_0}} \rho_{TDM} \hbar c K_\alpha \mathcal{T} v \omega_0}$$

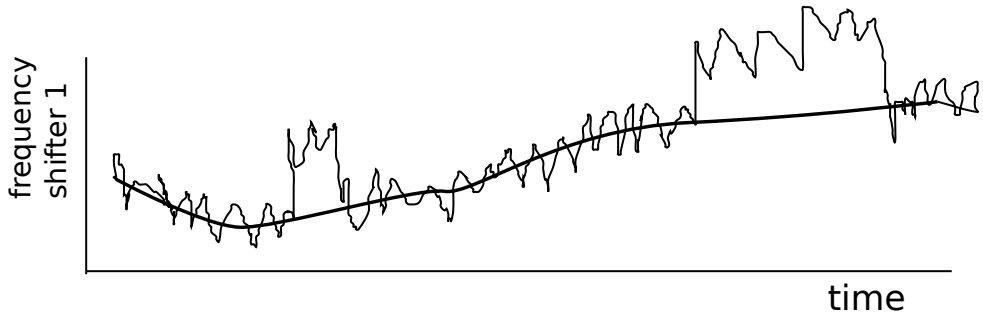
P. Wcislo et al., Nat. Astron. 1, 0009 (2016)

Short events





Long events

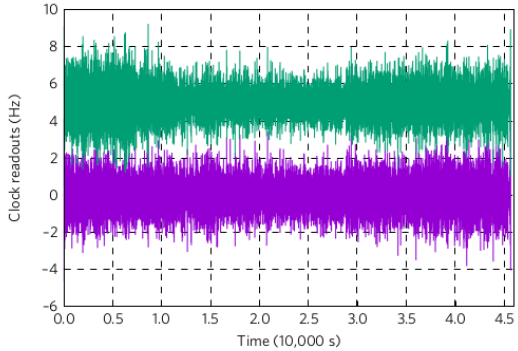


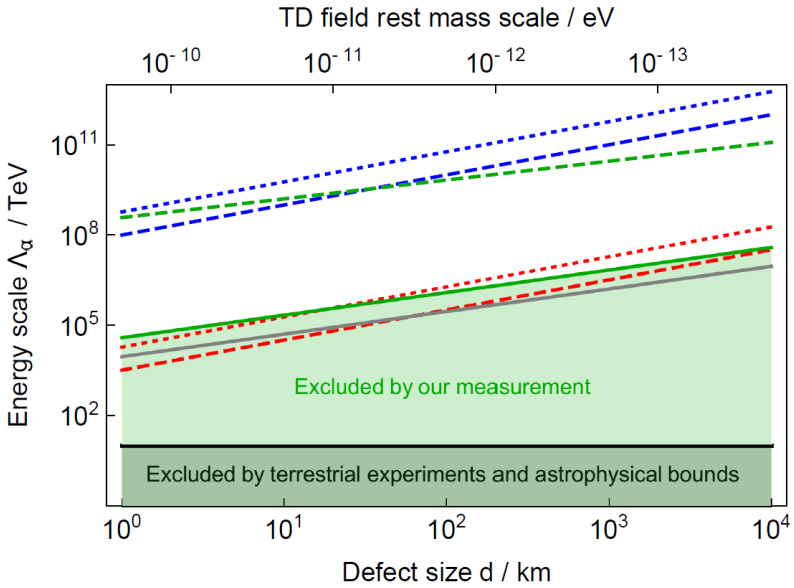
Experimental constraint

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

P. Morzyński, Scientific Reports 5, 17495 (2015)

M. Bober et. al., Measurement Science and Technology 26, 075201 (2015)

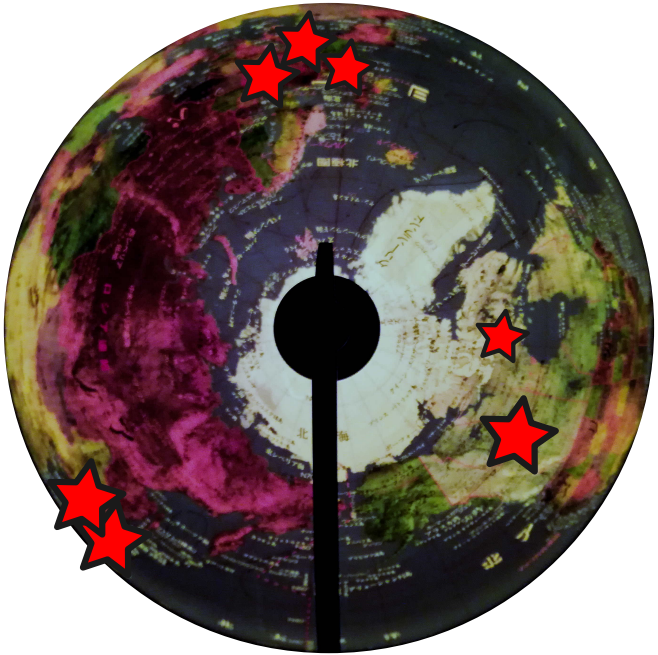




Assumptions:
- one event per 45 700 s
- d = 10 000 km

$$\frac{\delta\alpha}{\alpha} < 5 \times 10^{-15}$$

Summary



- ✓ New method for searching for transient α variation
- ✓ Simplicity and workability
- ✓ Measuring apparatus already exists
- ✓ Results

Thank You for your attention!

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Experimental constraint on dark matter detection with optical atomic clocks

P. Wcisło*, P. Morzyński, M. Bober, A. Cygan, D. Lisak, R. Ciuryło and M. Zawada

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