A network of clocks for measuring the stability of fundamental constants

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Birmingham


NPL


Sussex

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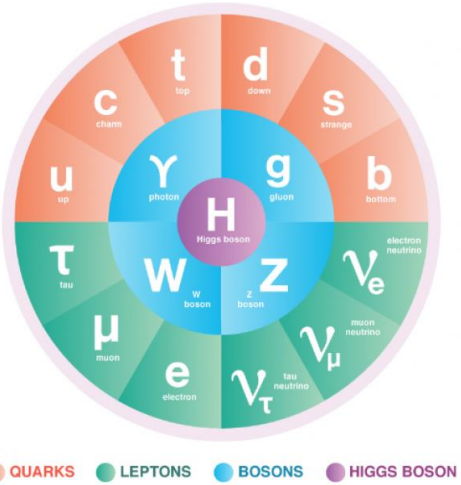
Background

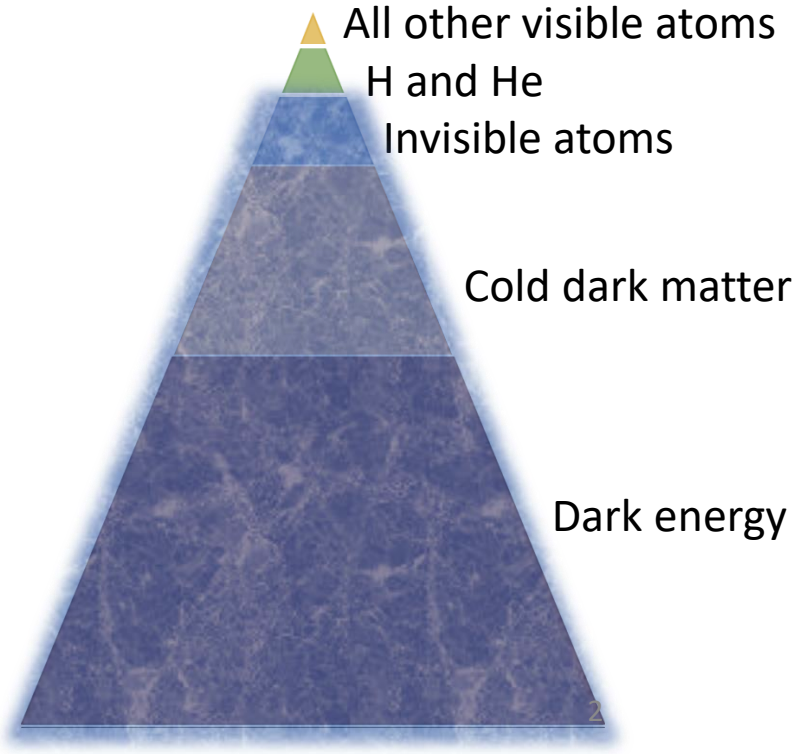


- The Standard Model and General Relativity are very successful theories, but the SM only accounts for 5% of the energy balance of the Universe

- The SM has 19 parameters, supposed to be immutable, referred to as fundamental constants.

- This assumption needs to be tested.

- Any variations of fundamental constants would give us evidence of revolutionary new physics



Background

- WIMP searches have been unsuccessful so far, DM searches are then moving towards well-motivated DM candidates with smaller masses

- Precision measurement techniques based on AMO quantum sensors are well suited to look for DM candidate with masses $<10^{-9}$ eV

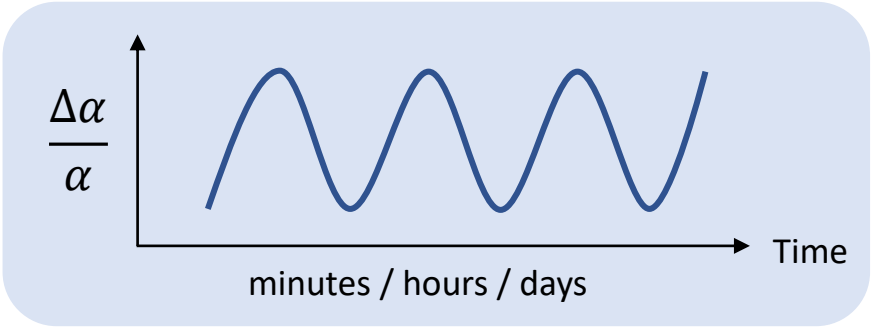
- Light DM candidate have large mode volume occupation number -> can be treated as classical fields

- Scalar fields $\mathcal{L}_{scalar} \supset \frac{\phi^n}{\Lambda_\gamma^n} F_{\mu\upsilon}F^{\mu\upsilon} - \sum_f \frac{\phi^n}{\Lambda_f^n} m_f \bar{f} f$

  - Λ_γ^n alter the fine structure constant α, Λ_f^n the fermionic masses -> manifest as variations of fundamental constants

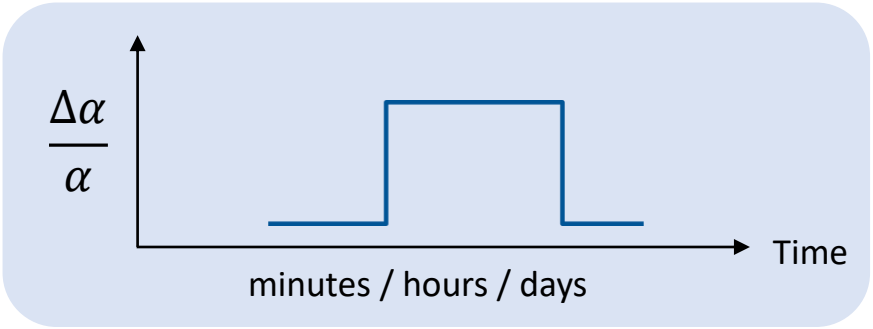
Look for variations on different timescales

- Oscillations



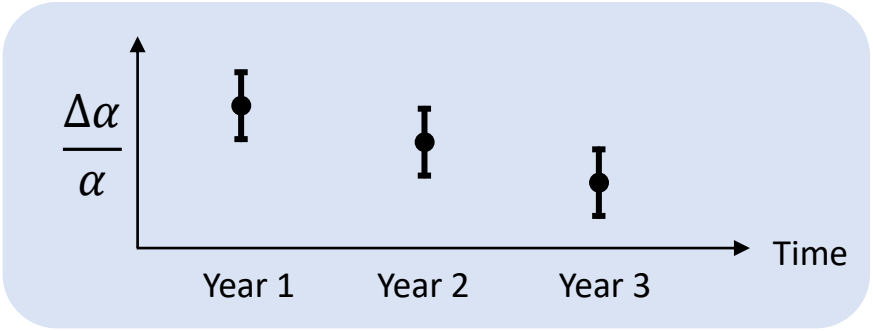
Very light DM

- Fast transients



DM- topological defects

- Slow drifts



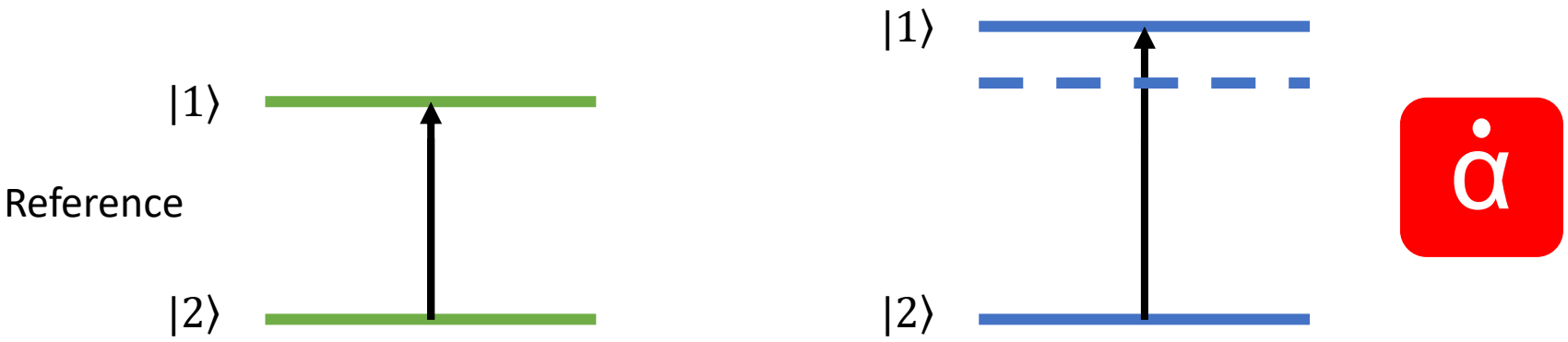
New physics

How to measure variations of fundamental constants

- Spectroscopy lends itself to measure variations of:

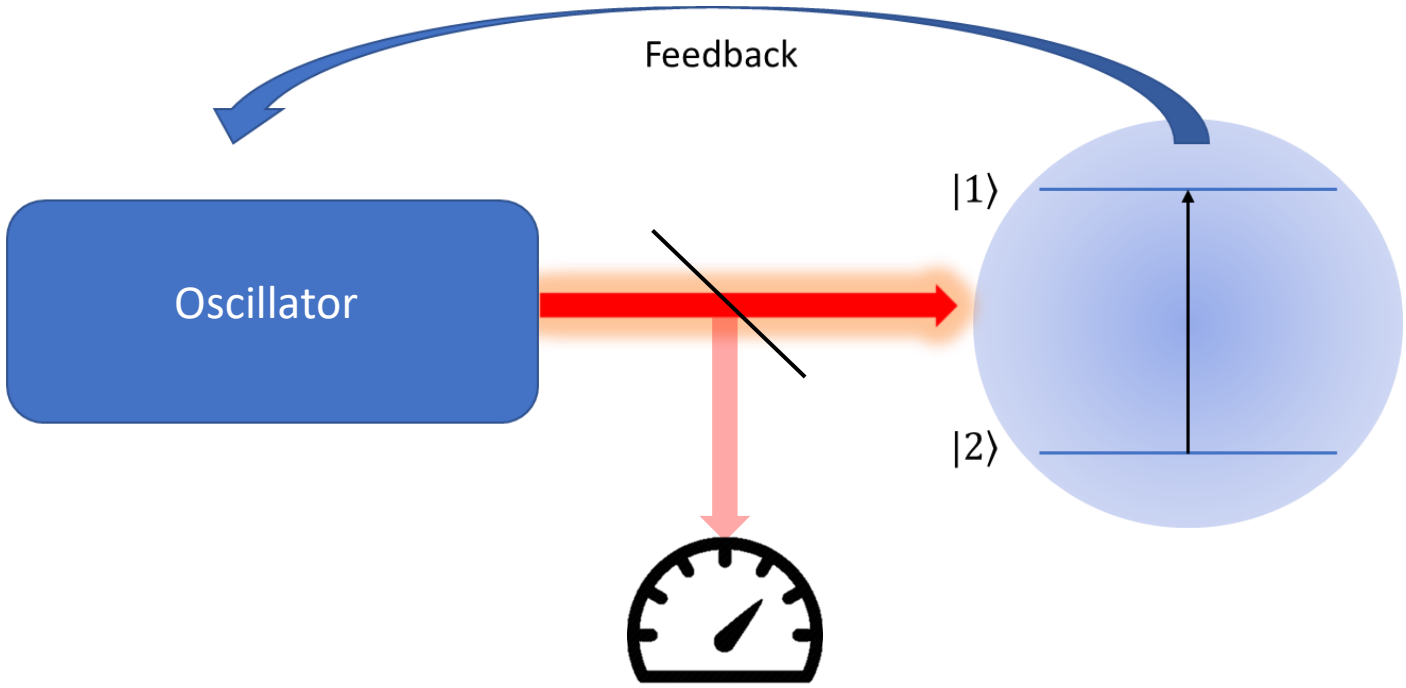
$$\alpha = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{\hbar c} \qquad \mu = \frac{m_p}{m_e}$$

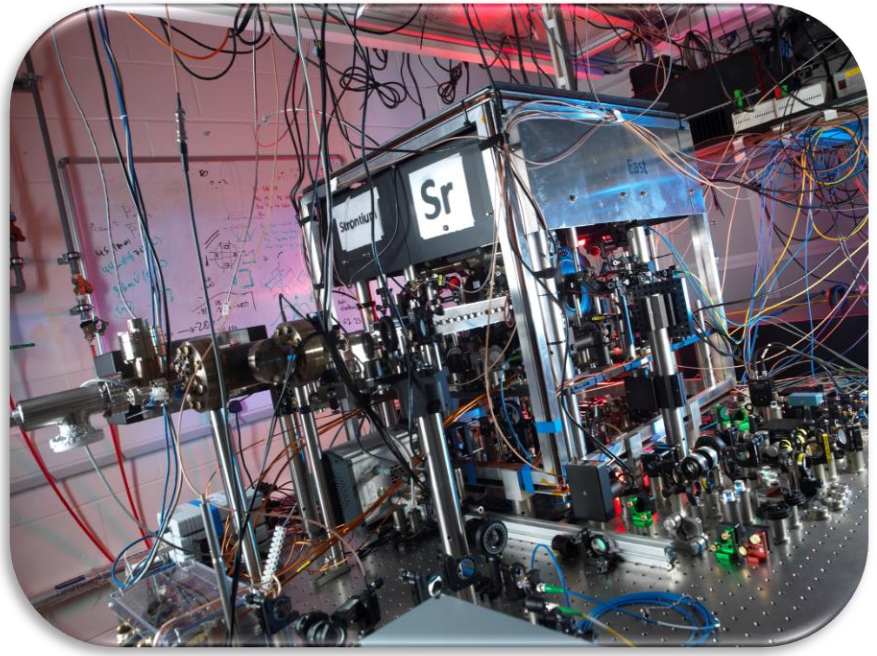
- Choose two (or more) transitions with DIFFERENT sensitivity to the variation of fundamental constants and compare them



Atomic clocks

- Extremely high-precision spectroscopy



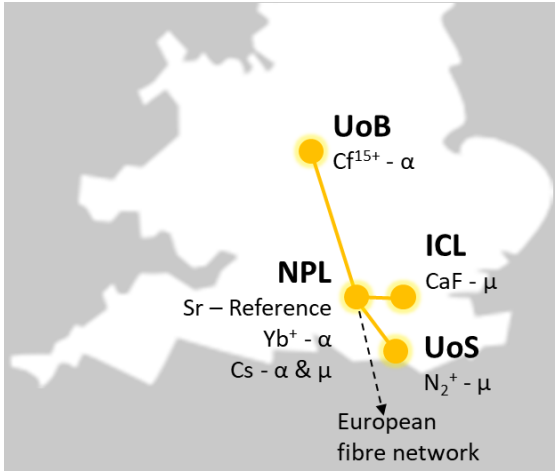


- Stability and accuracy at the 10^{-19} level

The QSNET project

- **Search for variations of fundamental constants of the Standard Model, using a network of quantum clocks**

- A unique network of clocks chosen for their enhanced sensitivities to variations of **α** and **μ**

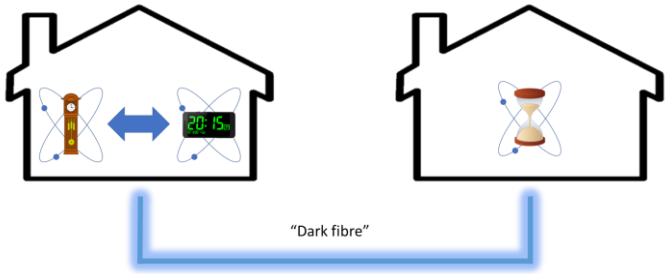


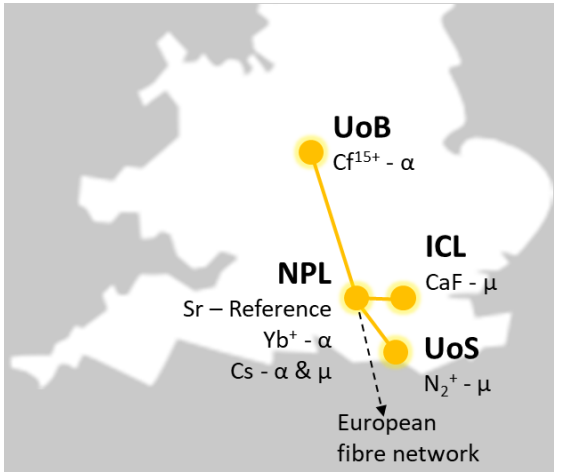
Clock		Kα	Kμ
Higly-charged ion clock	Cf^{15+} (775 nm)	59	0
Atomic clock	Yb^{+} (467 nm)	-5.95	0
Molecular ion clock	N_2^{+} (2.31 μm)	0	0.5
Molecular clock	CaF (17 μm)	0	0.5
Atomic clock	Sr (698 nm)	0.06	0
	Cs (32.6 mm)	2.83	1

- The quantum clocks will be linked, essential to do clock-clock comparisons

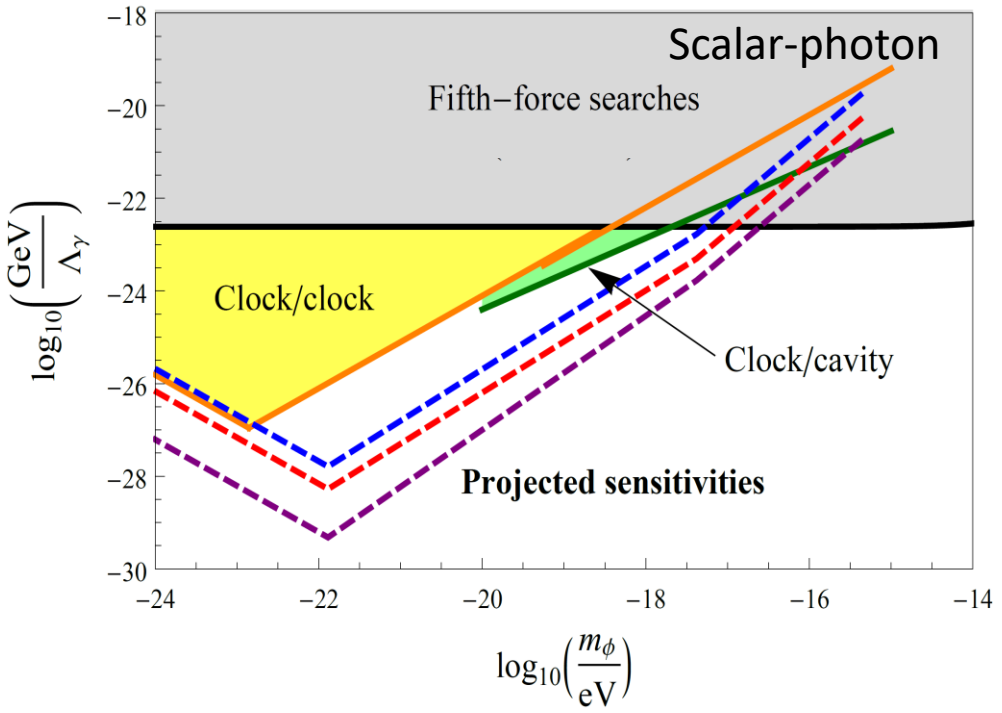
The network approach

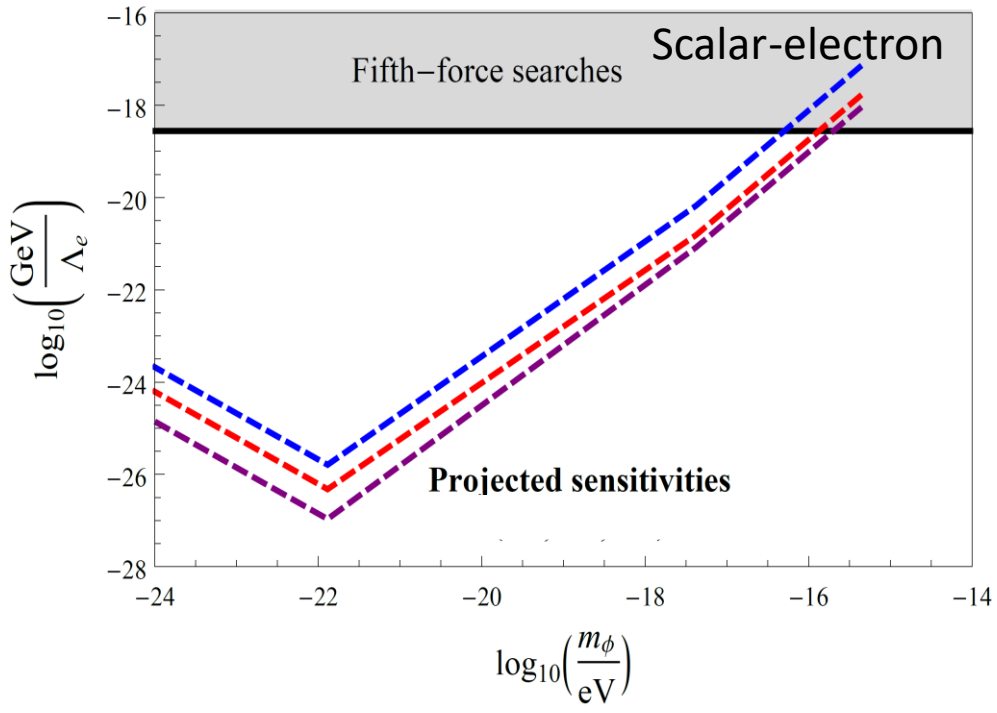
- Needed to perform clock-clock comparison at the ultimate level of accuracy and optimally exploit existing expertise
- Sensors with similar sensitivities and different systematics are necessary to confirm any measurements and reject false positives
- Multimessenger detection, discriminate between dark-standard matter couplings.
- The possibility of detecting transient events such as topological defects in dark matter fields or oscillations of dark matter
- A new versatile and expandable national infrastructure with possible further applications in and beyond fundamental physics.





QSNET Dark matter exclusion diagrams



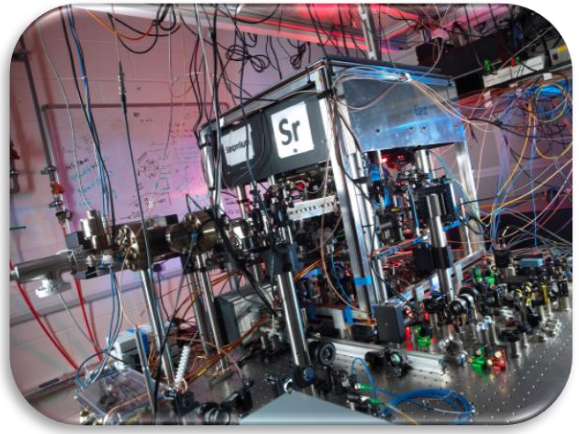


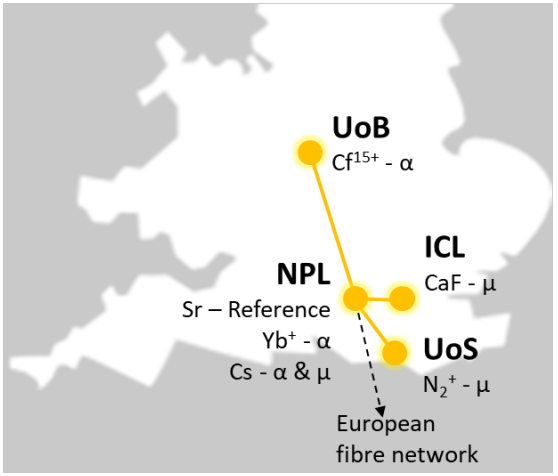
- Large DM mass range
- Multimessenger detection
- Higher order couplings
- Test of quantum gravity

QSNET in a nutshell

α μ

- Extending and exploiting world-class expertise and capabilities developed in NQTP
- Inexpensive table-top experiments with next generation quantum technology
- A unique opportunity for discovery, improving current limits on variations of α and μ by orders of magnitude
- Potential for game-change results on short timescale





Thank you

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