GGI LECTURES ON THE THEORY OF FUNDAMENTAL INTERACTIONS 2023

TABLETOP EXPERIMENTS: LECTURE 3

ULTRALIGHT DARK MATTER DETECTION

Marianna Safronova

https://www.colorado.edu/research/qsense/

https://thoriumclock.eu/

Ultralight dark matter signatures

UDM: coherent on the scale of detectors or networks of detectors

Different detection paradigm from particle dark matter.

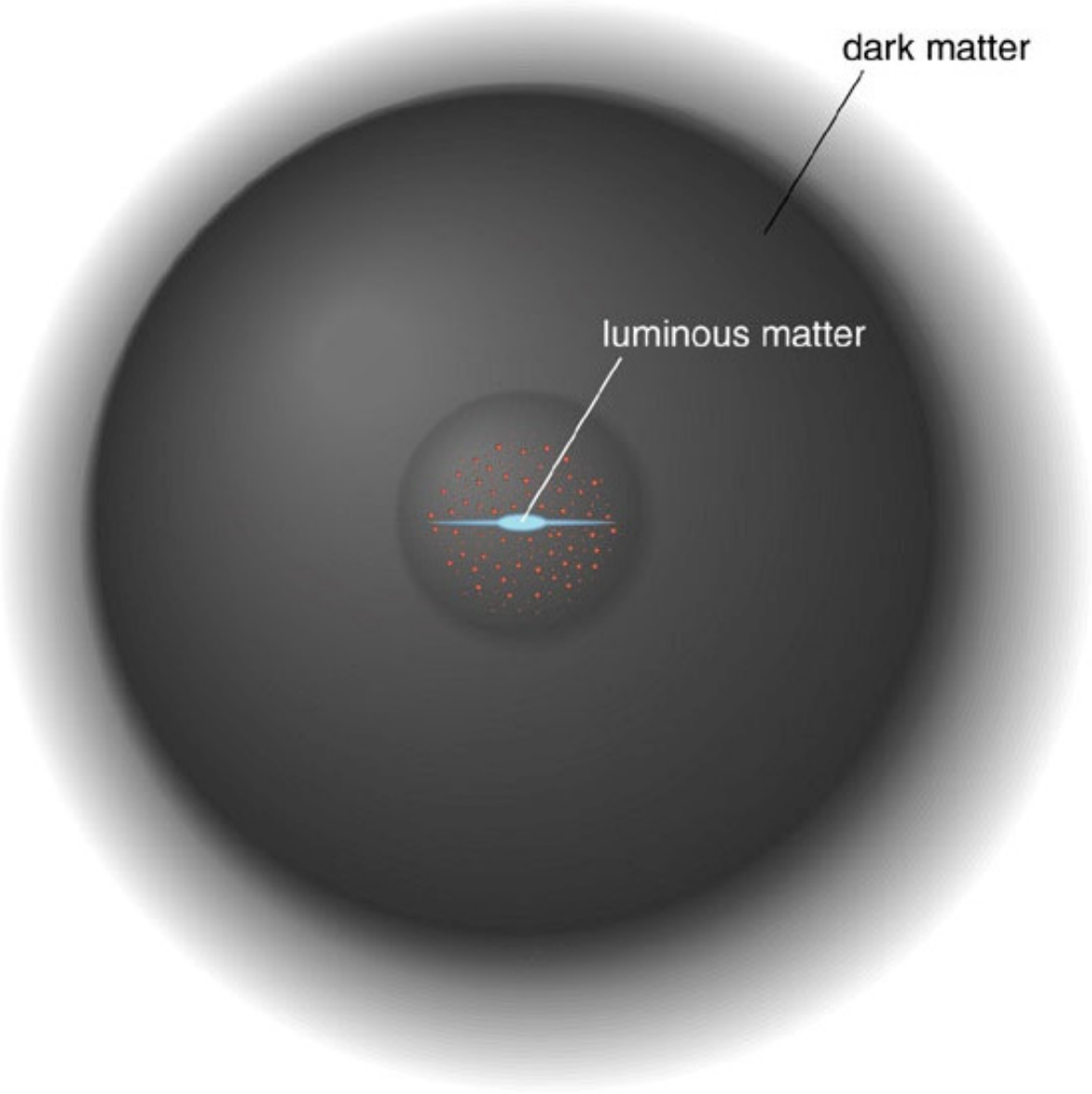
UDM fields may cause:

- ✓ precession of nuclear or electron spins
- ✓ drive currents in electromagnetic systems, produce photons
- ✓ induce equivalence principle-violating accelerations of matter
- ✓ modulate the values of the fundamental “constants” of nature
  - induce changes in atomic transition frequencies and local gravitational field
  - affect the length of macroscopic bodies

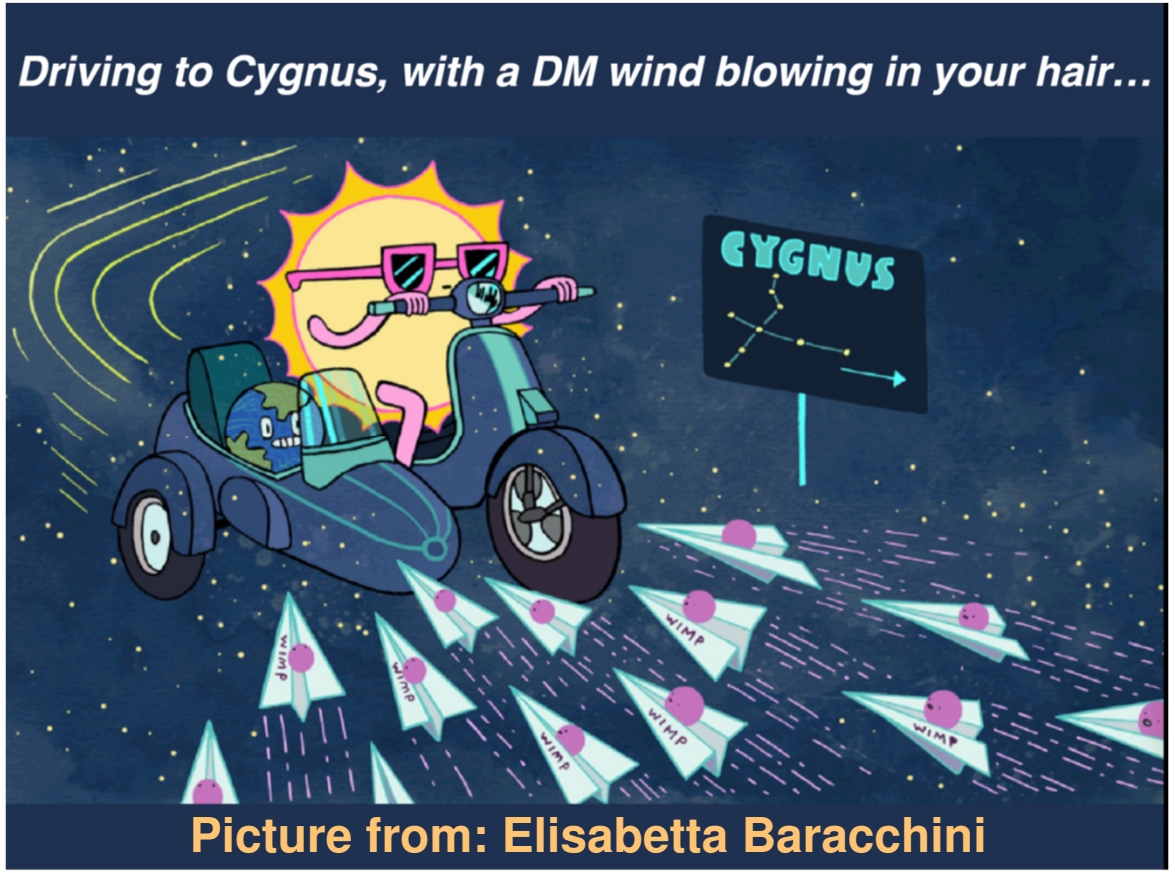
Magnetometers
Microwave cavities
Trapped ions & other qubits
Atom interferometers
Laser interferometers
Optical cavities
Atomic, molecular, and nuclear clocks
Other precision spectroscopy

Various quantum sensors are very sensitive to UDM!

Where is dark matter?



Our visible galaxy is inside of a very large dark matter halo.



http://www.sjsu.edu/people/monika.kress/courses/sci255/

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

arXiv:2203.14915

Snowmass 2021 CF2 Whitepaper
New Horizons: Scalar and Vector Ultralight Dark Matter

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on the Future of Particle Physics (Snowmass 2021)

arXiv:2203.14923

Snowmass 2021 White Paper
Axion Dark Matter

J. Jaeckel[1], G. Rybka[2], L. Winslow[3], and the Wave-like Dark Matter Community [4]

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[3]Laboratory of Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA, USA
[4]Updated Author List Under Construction

Scalar ultralight dark matter

Coupling of scalar UDM to the standard model:

Linear coupling $\boxed{\frac{\phi}{M^*}\mathcal{O}_{\rm SM}}$ $\kappa = (\sqrt{2}M_{\rm Pl})^{-1}$

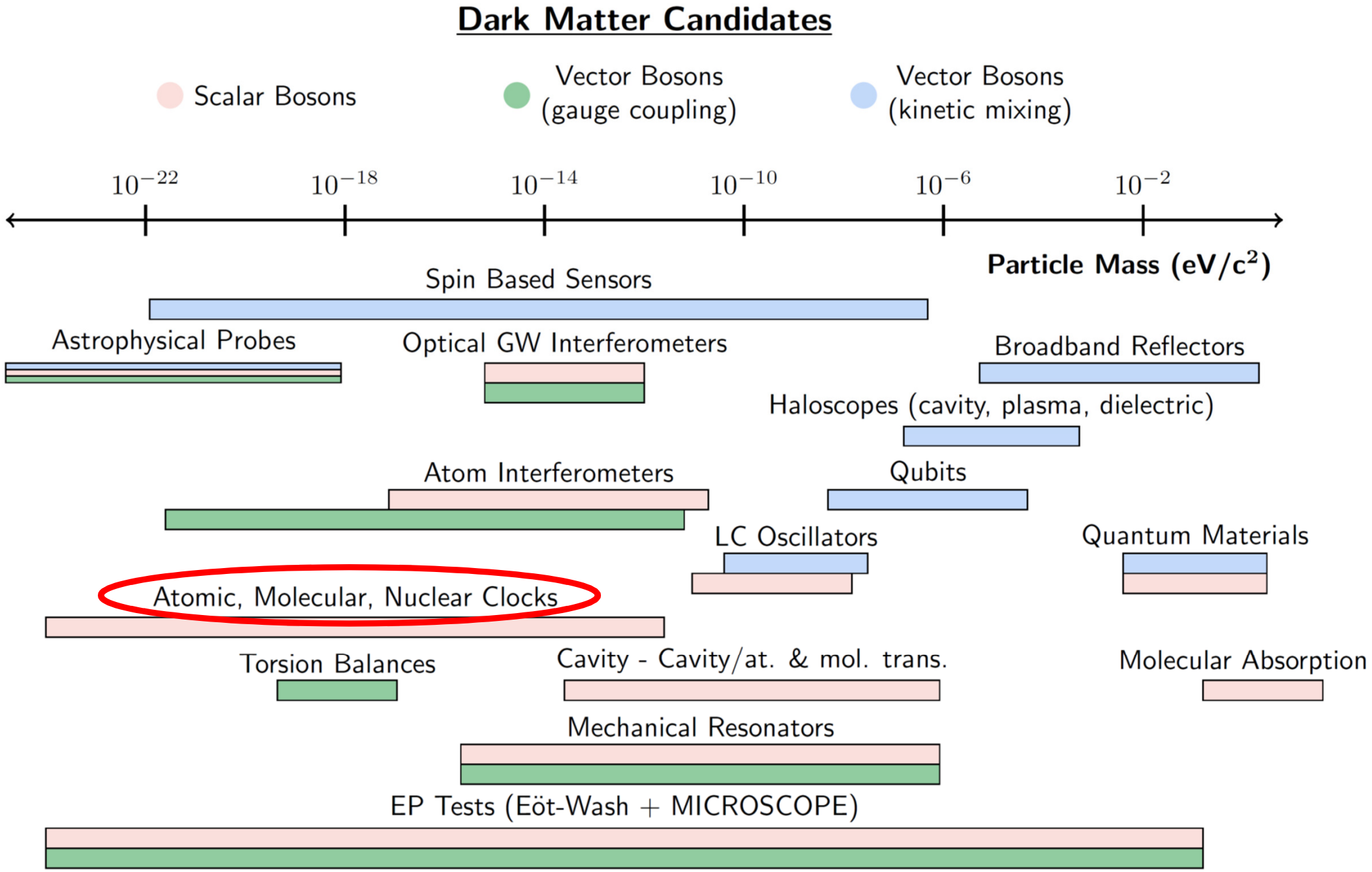
photons electrons gluons quarks

$$\mathcal{L}_{\rm int}^{\rm lin} = \kappa\phi \left\{ \left[\frac{d_e F_{\mu\nu}F^{\mu\nu}}{4} - d_{m_e} m_e \bar{\psi}_e \psi_e \right] - \left[\frac{d_g \beta_3 G^a_{\mu\nu} G^{a\mu\nu}}{2g_3} + \sum_{q=u,d,s} \left(d_{m_q} + \gamma_m d_g \right) m_q \bar{\psi}_q \psi_q \right] \right\}$$

$$\phi(t) \approx \phi_0 \cos(m_\phi t)$$

Scalar UDM will cause **oscillations** of the electromagnetic fine-structure constant α and fermion masses:

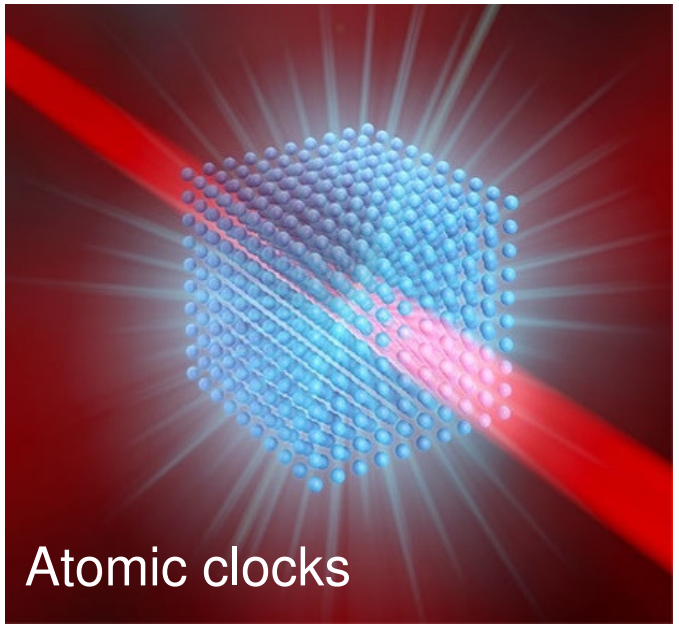
$$\alpha \to \frac{\alpha}{1 - g_\gamma \phi} \approx \alpha(1 + g_\gamma \phi)\,, \quad m_\psi \to m_\psi + g_\psi \phi$$

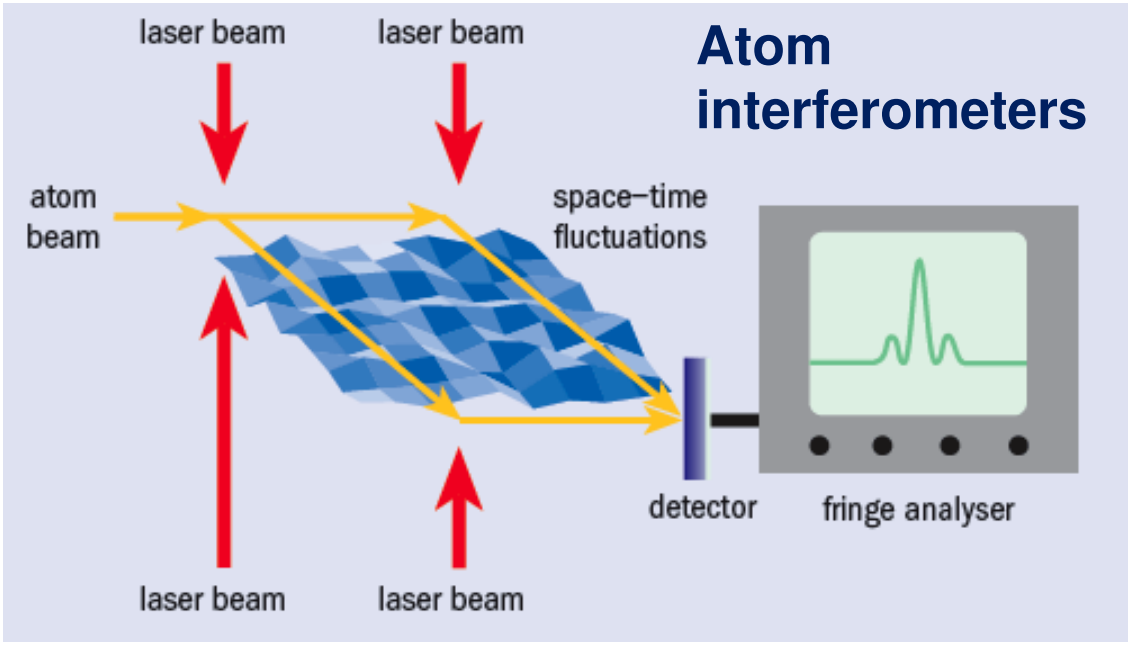


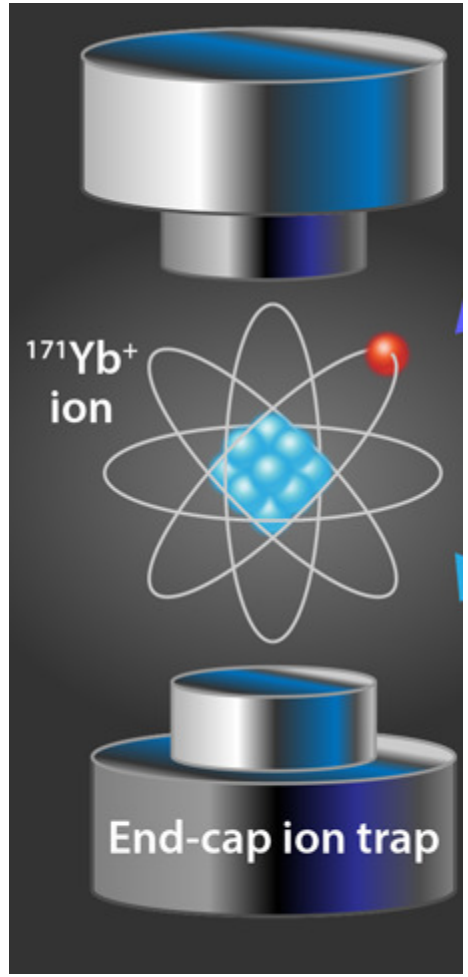
arXiv:2203.14915

Figure credit: Joey Betz, Swati Singh and many other authors

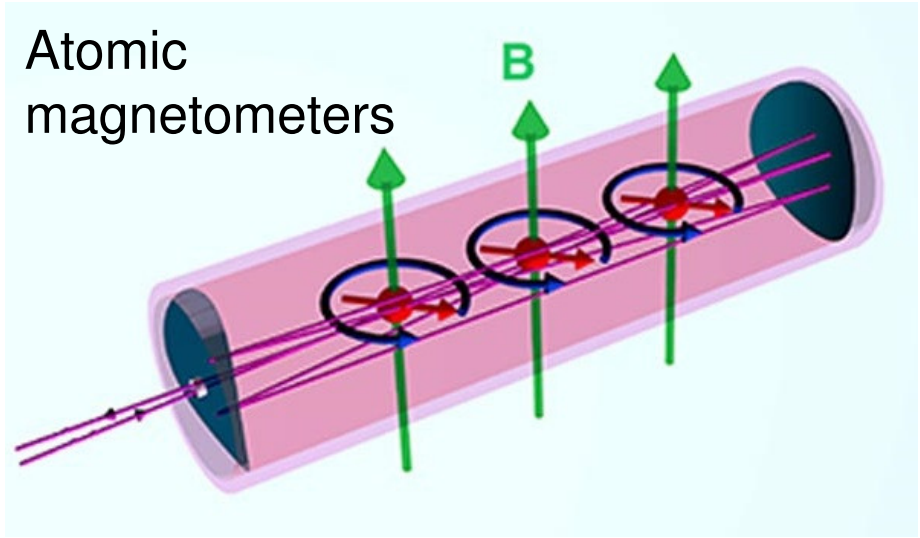
QUANTUM SENSORS

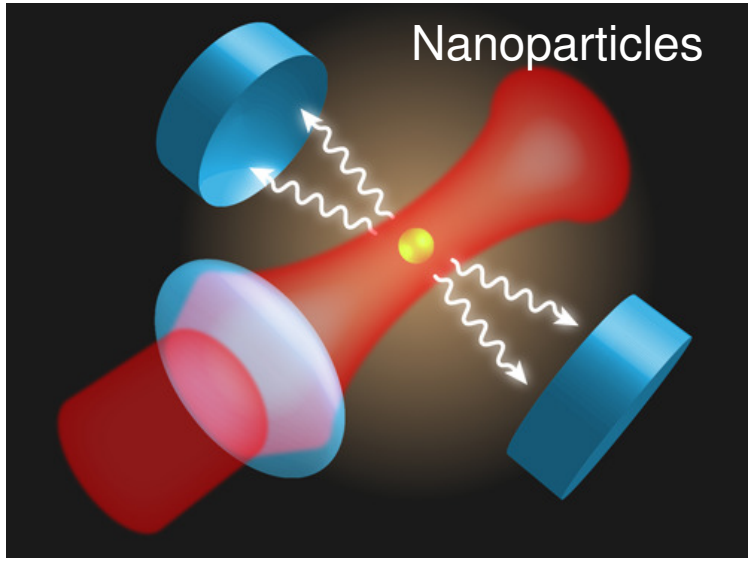






Trapped ions





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