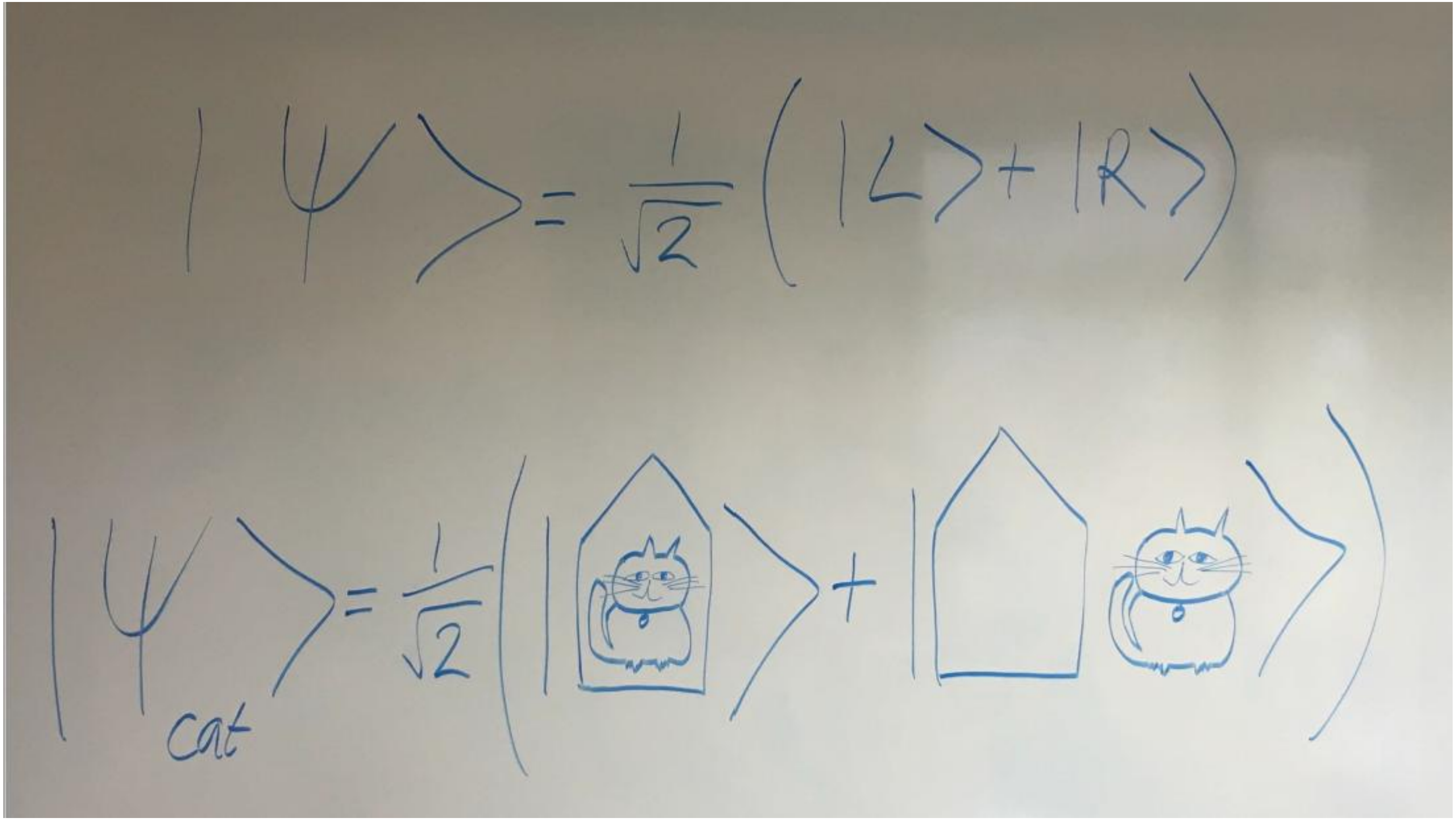
Quantum Sensors

Tanyh

2018/11/16


$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|L\rangle + |R\rangle\right)$
$|\psi_{cat}\rangle = \frac{1}{\sqrt{2}}\left(| \quad \rangle + | \quad \rangle\right)$

Quantum sensing" is typically used to describe one of the following:

I. Use of a quantum object to measure a physical quantity (classical or quantum). The quantum object is characterized by quantized energy levels. Example:

- *Gravity*
- *Magnetic fields*
- *Rotation*
- *Time*
- *THz radiation*
- *Quantum light*

II. Use of quantum coherence (i.e., wave-like spatial or temporal superposition states) to measure a physical quantity.

III. Use of quantum entanglement to improve the sensitivity or precision of a measurement, beyond what is possible classically.

Quantum sensors:

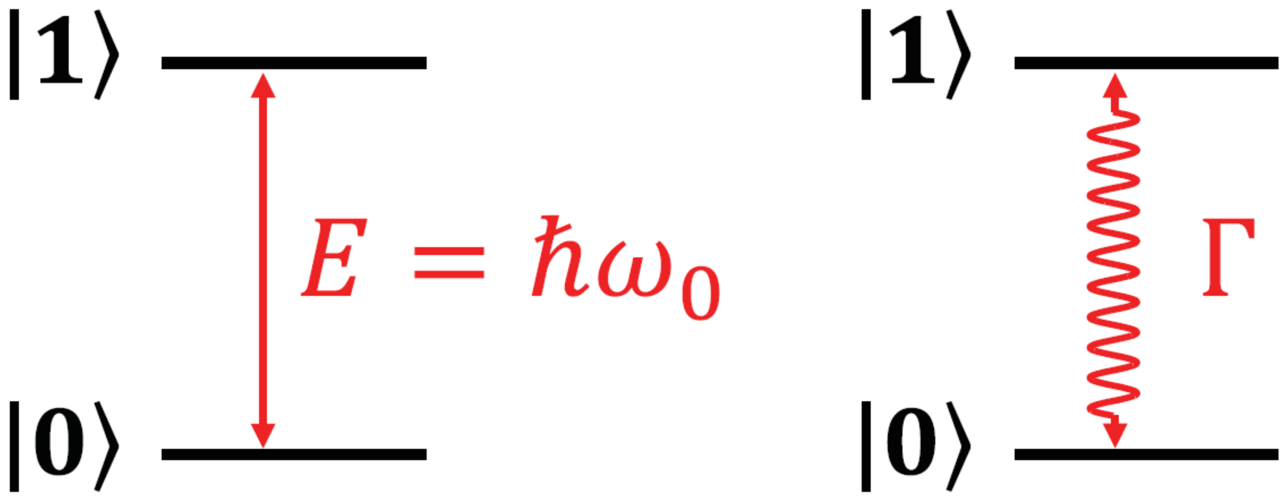
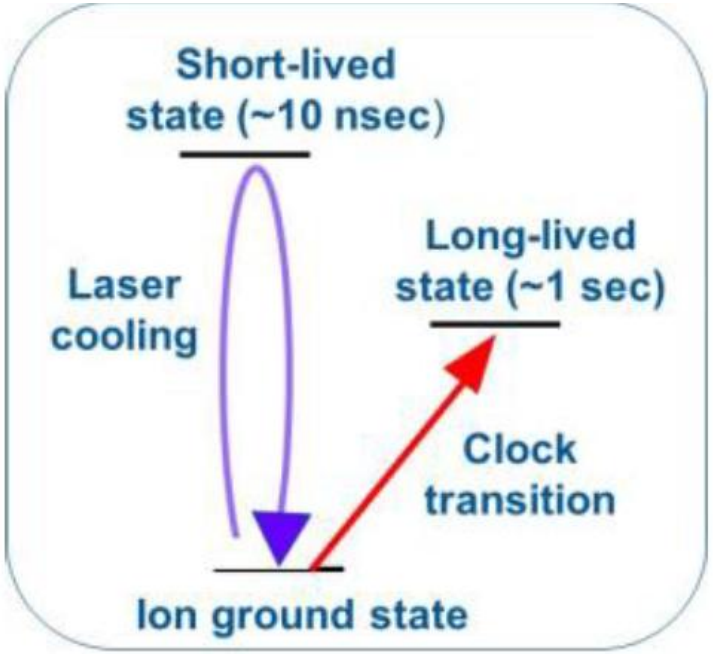
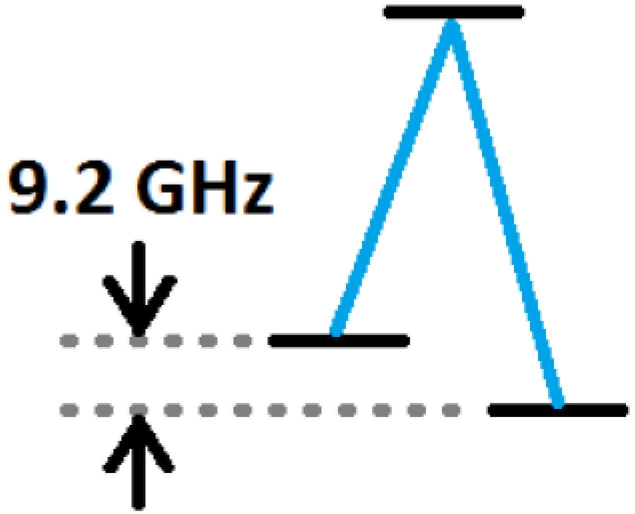


FIG. 1 Basic features of a two-state quantum system. $|0\rangle$ is the lower energy state and $|1\rangle$ is the higher energy state. Quantum sensing exploits changes in the transition frequency ω_0 or the transition rate Γ in response to an external signal V.

Atomic clock:

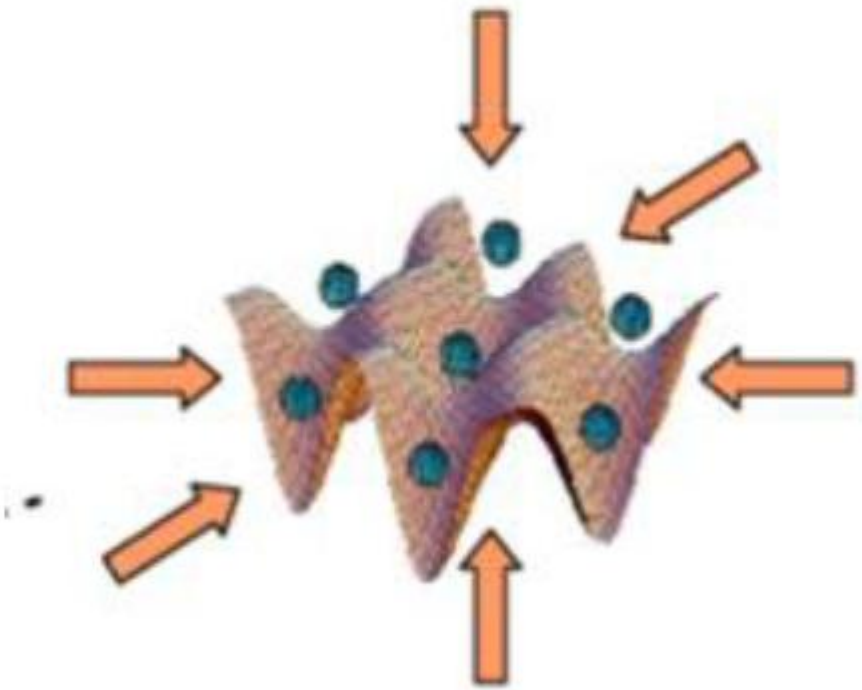




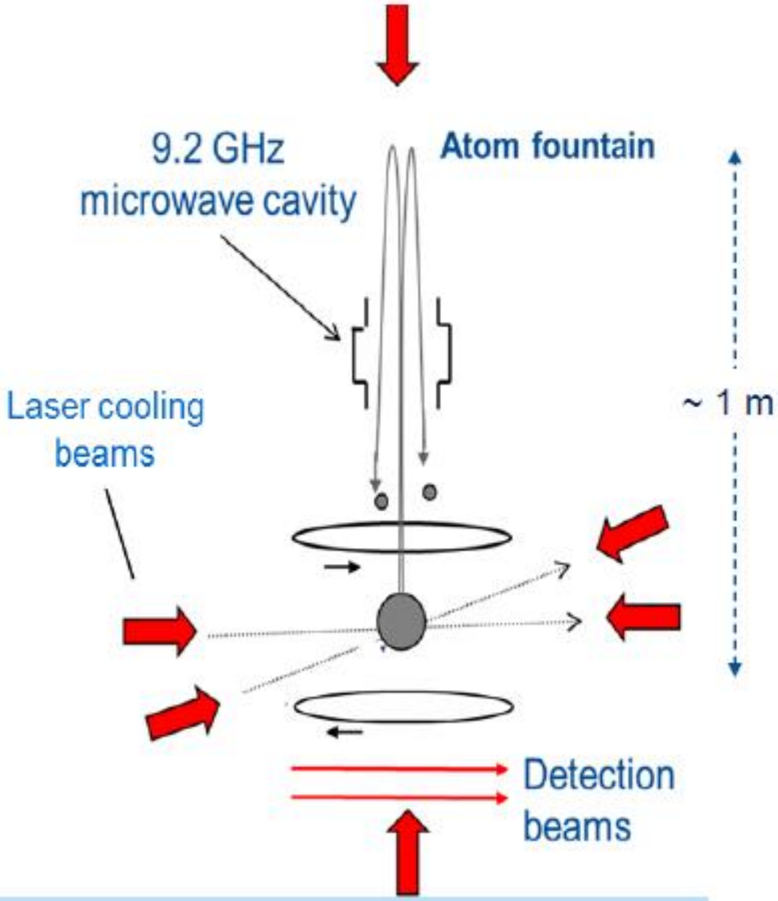
- Laser cooling.
- Sideband cooling to motional ground state.
- Single ion clock quantum jump detection.

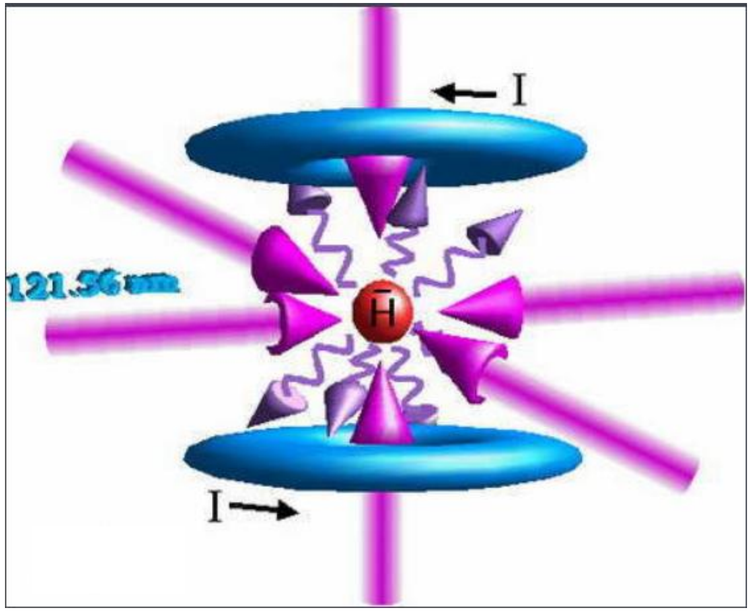
Optical lattice clock:

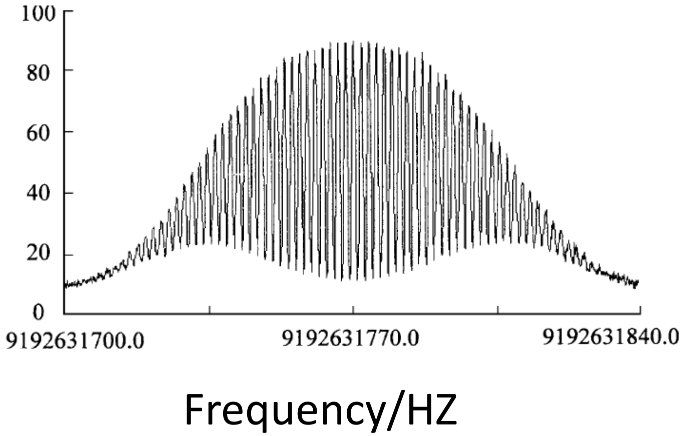
- Atoms in an optical lattice provide an ideal quantum system where all parameters can be controlled.
- This can be used to study effects that are difficult to observe in real crystals.
- They are also promising candidates for quantum information processing.
- The best atomic clocks in the world use atoms trapped in optical lattices.



The Cs Fountain clock for Realization of the Second







Operational Cs fountains at NPL and several other national standards laboratories

Leading systematic frequency uncertainties: $(\sim 1 - 2) \times 10^{-16}$

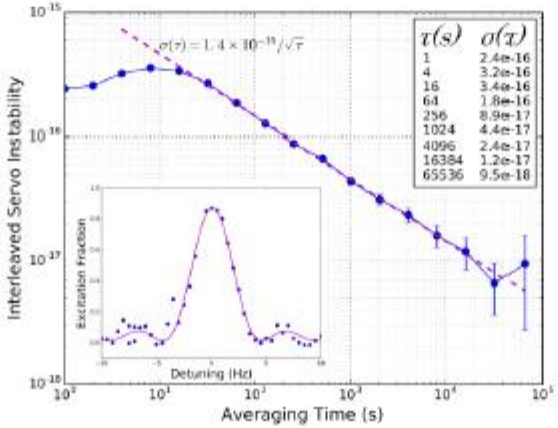
$\leq$ 20 psec per day

Steers TAI and UTC, & underpins optical frequency measurements

NPL reference optical clocks

NPL National Physical Laboratory | QMI Quantum Metrology Institute

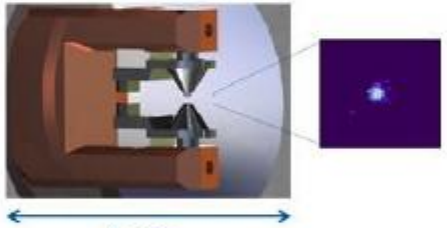
Sr lattice clock



Sr 698 nm clock uncertainty:
1×10^{-17}

Hill et al, IOP Conf series 2016
Also manuscript in prep.

Hyper-Ramsey clock lock
Hobson et al, PRA (RComm) 2016



4 cm

Yb⁺ optical clock

E3 octupole clock systematic uncertainty: 5×10^{-17}
*Godun et al, Phys Rev Letters **113** (2014)*

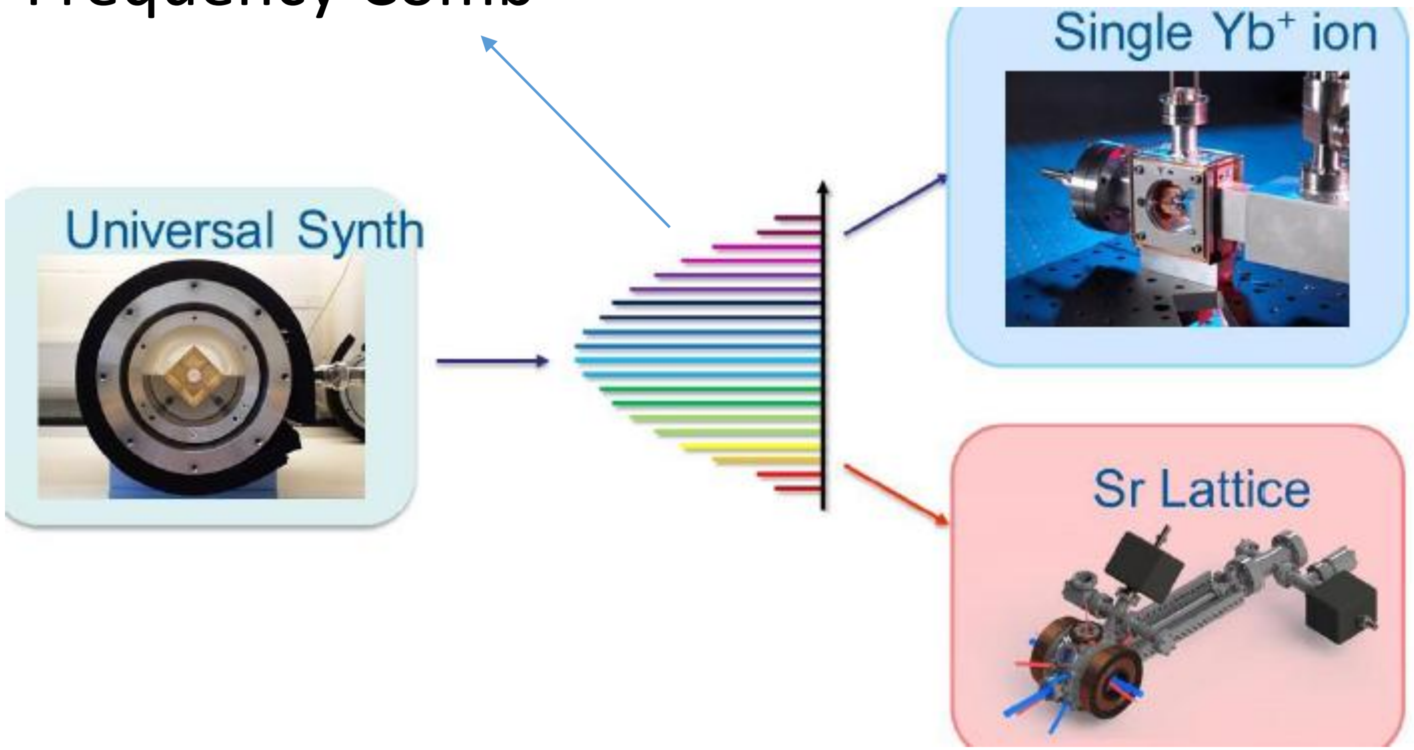
Absolute freq. uncertainty (via TAI): 4×10^{-16}
*Baynham et al, J. Mod. Optics, **65** (2018)*

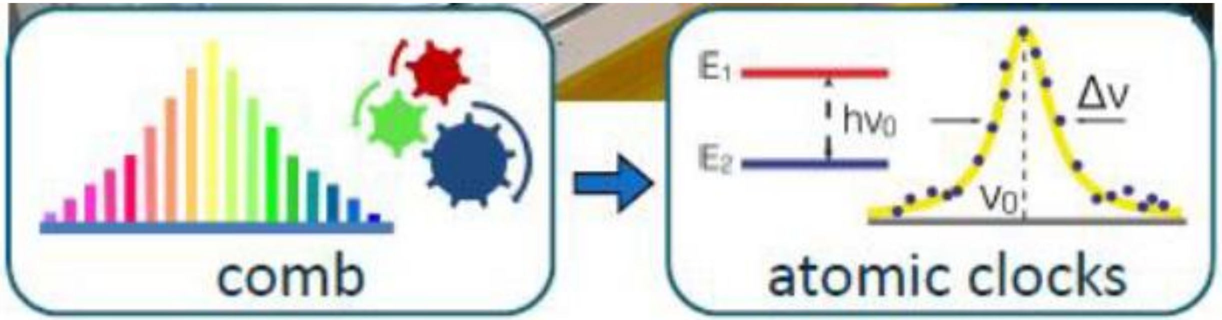
End-cap trap design: *Nisbet-Jones et al. APB (2016)*

Sr⁺ optical clock

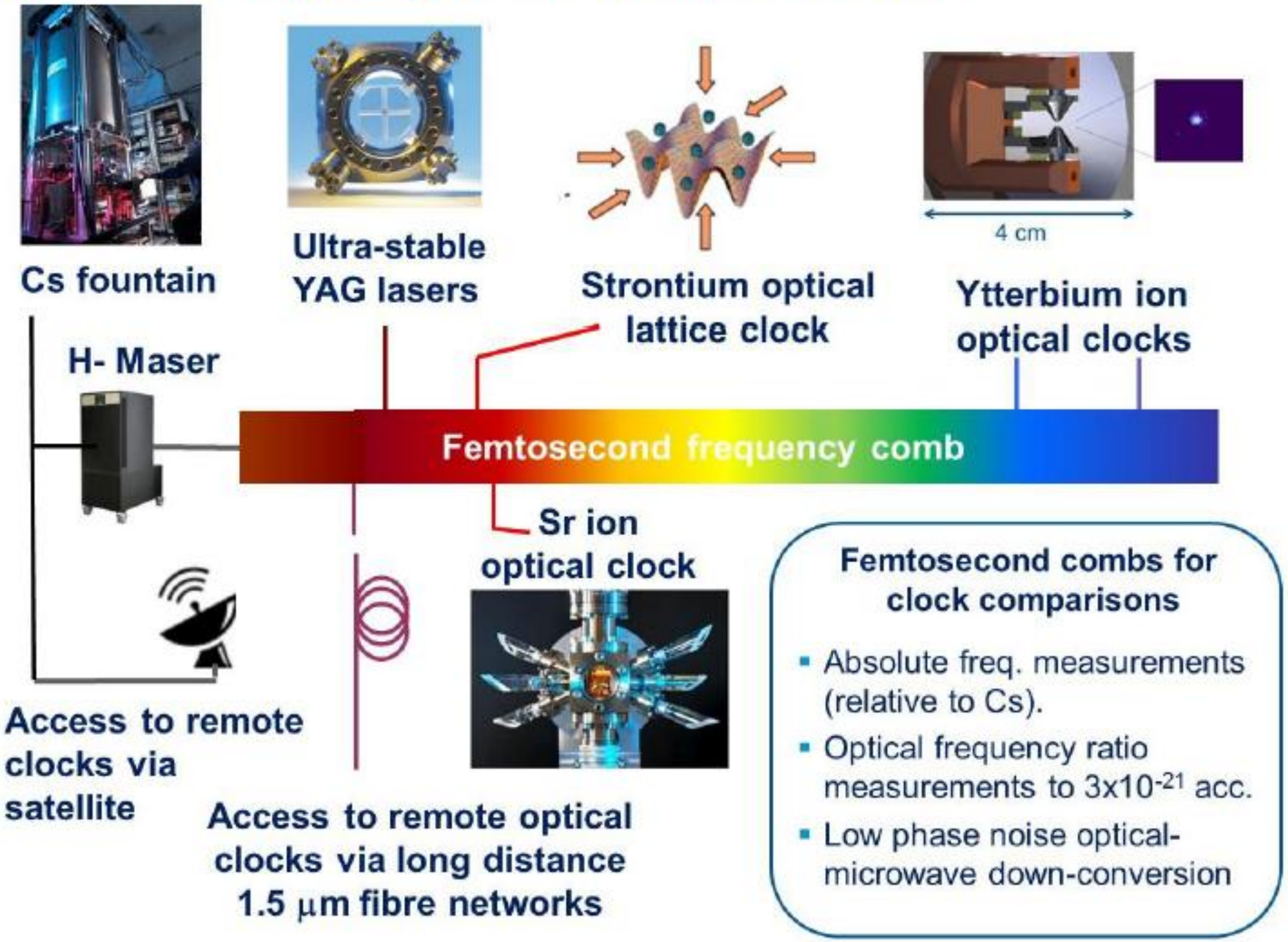
E2 quadrupole systematic uncertainty: 5×10^{-17}
Cs-referenced absolute freq uncertainty: 5×10^{-16}
Two-trap agreement: 4×10^{-17}
Barwood et al, PRA Rapid Comm (2014)

Frequency Comb

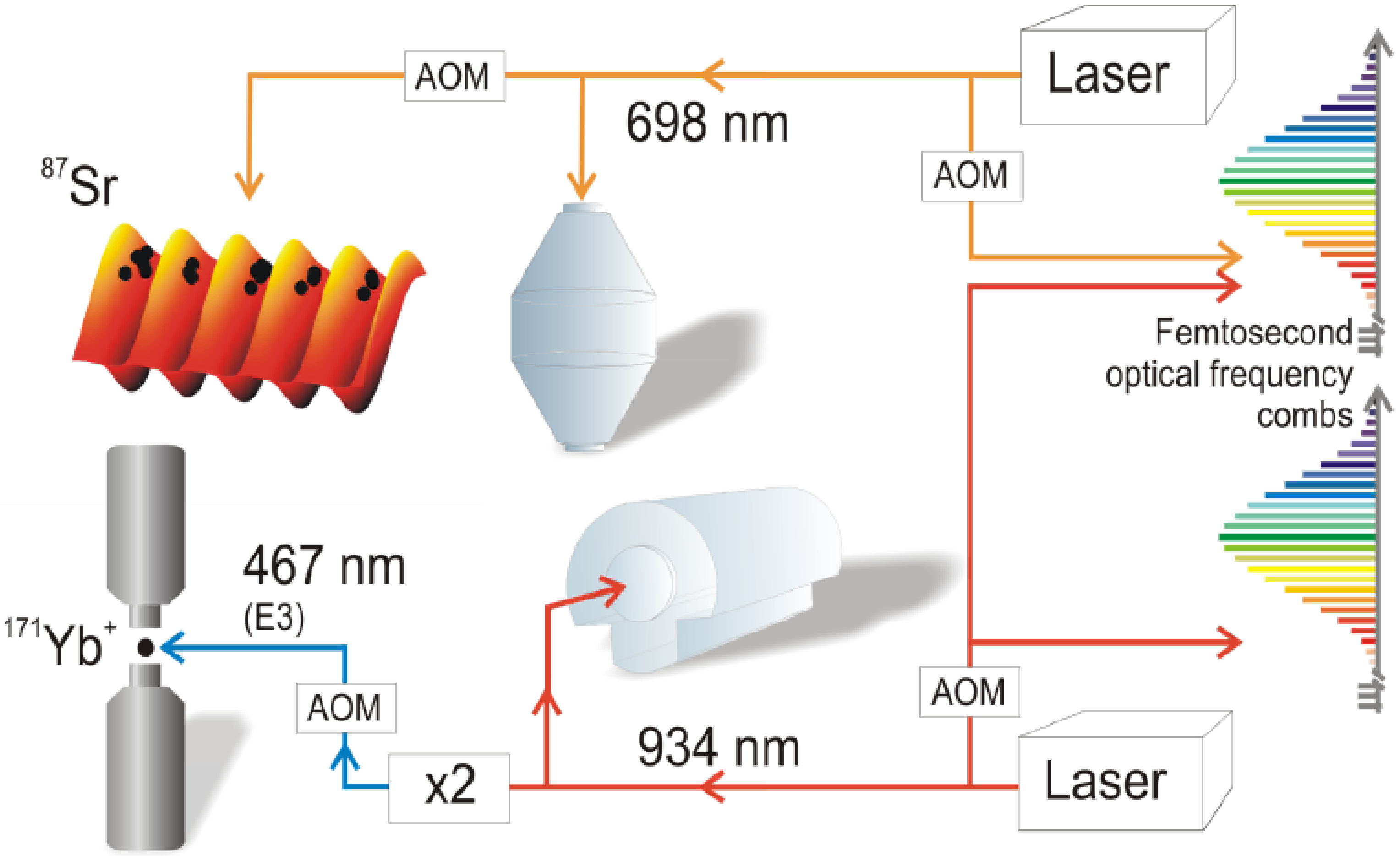




NPL infrastructure for comparing microwave and optical atomic clocks



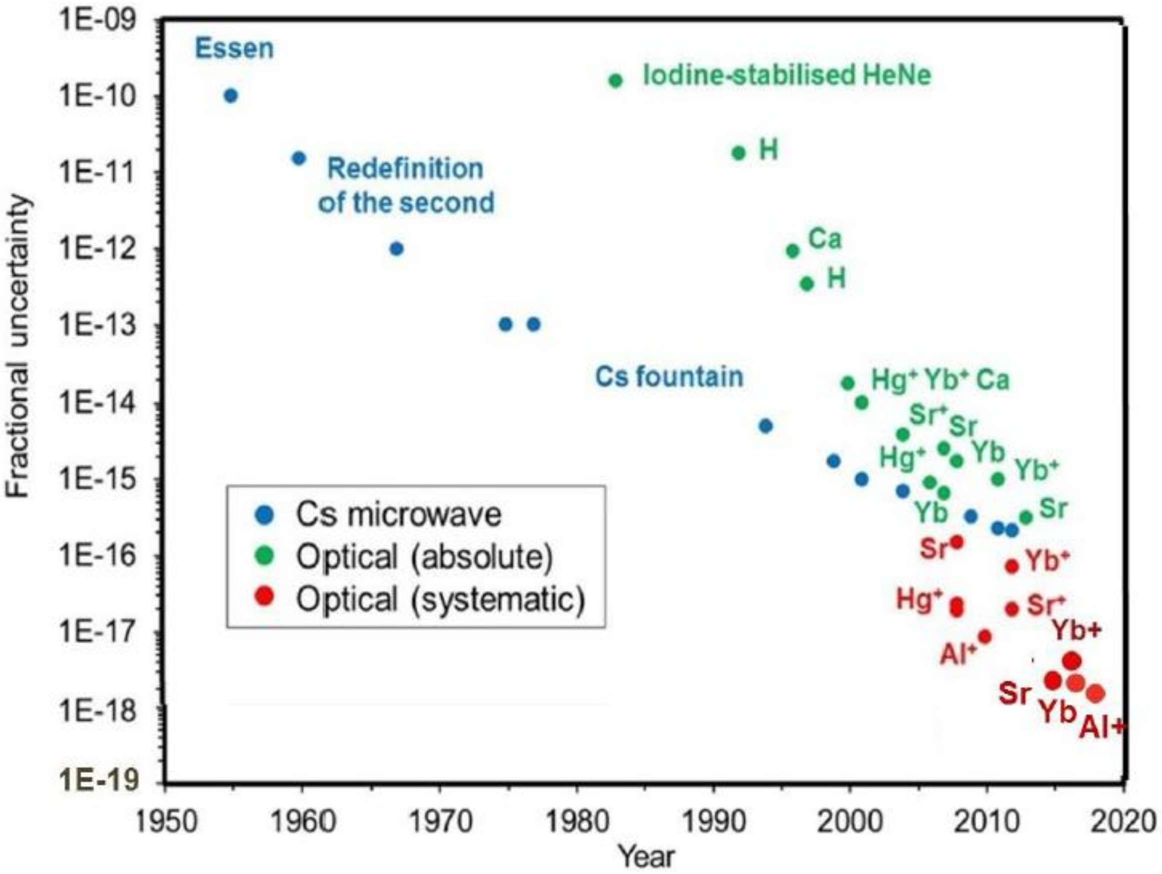
Local clock comparison



Cold Sr optical lattice clock – single cold Yb+ ion comparison

From: PRL 113, 210801 (2014)

Atomic clock evolution



- Optical clocks routinely achieving 10^{-17} - 10^{-18} systematic uncertainty
- Clock frequencies as quantum sensors for fundamental physics and variations in fundamental constants
- Opportunities in lab, distributed clock comparisons, and in space

Thank you

Backup

Some concepts:

Laser cooling refers to a number of techniques in which atomic and molecular samples are cooled down to near absolute zero. Laser cooling techniques rely on the fact that when an object (usually an atom) absorbs and re-emits a photon (a particle of light) its momentum changes. For an ensemble of particles, their temperature is proportional to the variance in their velocity. That is, more homogeneous velocities among particles corresponds to a lower temperature. Laser cooling techniques combine atomic spectroscopy with the aforementioned mechanical effect of light to compress the velocity distribution of an ensemble of particles, thereby cooling the particles.

Sideband cooling is a laser cooling technique allowing cooling of tightly bound atoms and ions beyond the Doppler cooling limit, potentially to their motional ground state. Aside from the curiosity of having a particle at zero point energy, such preparation of a particle in a definite state with high probability (initialization) is an essential part of state manipulation experiments in quantum optics and quantum computing.

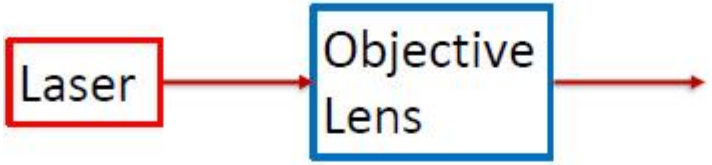
A hydrogen maser, also known as hydrogen frequency standard, is a specific type of maser that uses the intrinsic properties of the hydrogen atom to serve as a precision frequency reference.

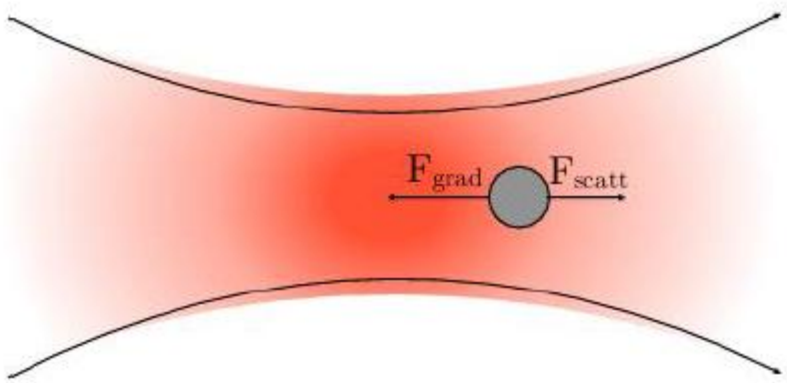
An optical frequency comb is a laser source whose spectrum consists of a series of discrete, equally spaced frequency lines. Frequency combs can be generated by a number of mechanisms, including periodic modulation (in amplitude and/or phase) of a continuous-wave laser, four-wave mixing in nonlinear media, or stabilization of the pulse train generated by a mode-locked laser.

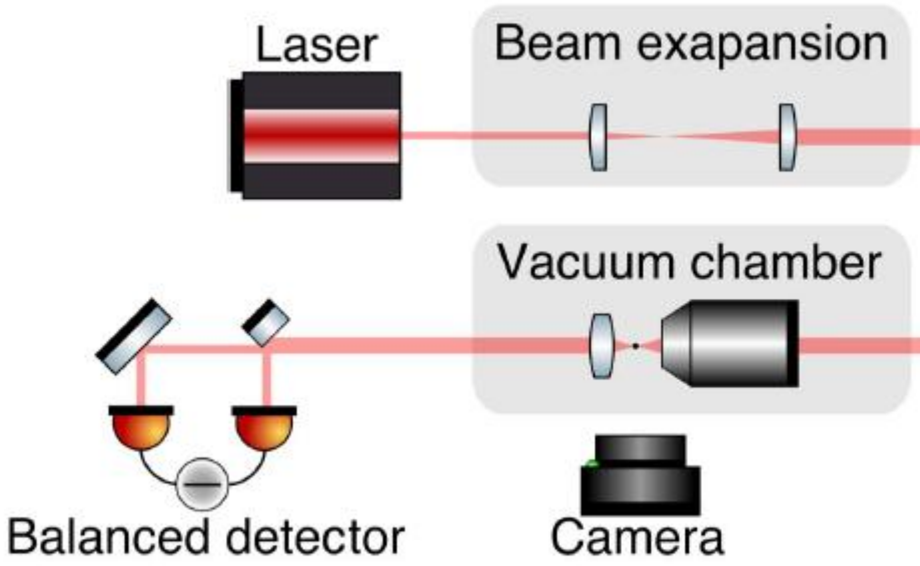
From wikipedia

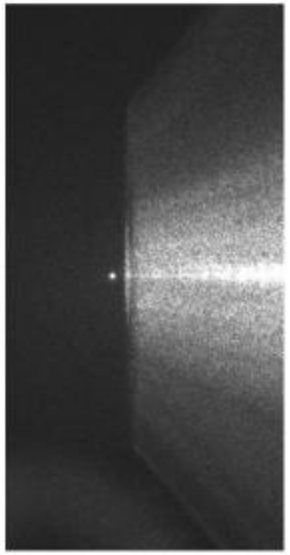
Other experiment:

Signal beam optical trap:









The Experiment is matter and spin superposition in vacuum experiment.