

Precision Measurements with Trapped Ions

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Internal quantum state control

State preparation, detection and single-qubit gates with > 99.9% fidelity

Quantum-limited measurement precision

Long coherence times

~ 10 s at optical frequencies
 $Q > 10^{16}$

Strong, switchable interactions

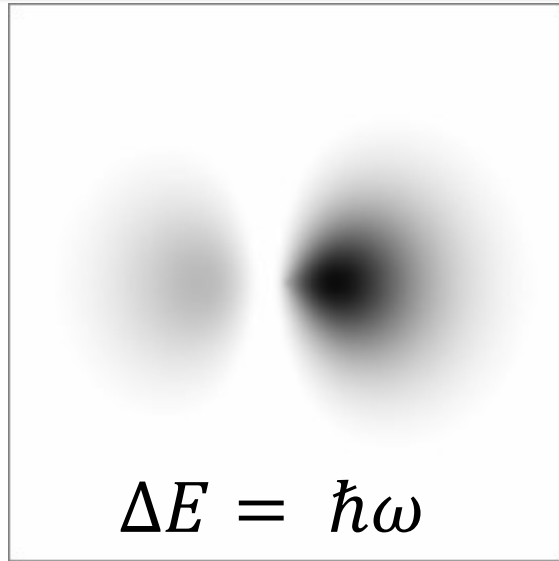
2-qubit gates with >99.9% fidelity

External quantum state control

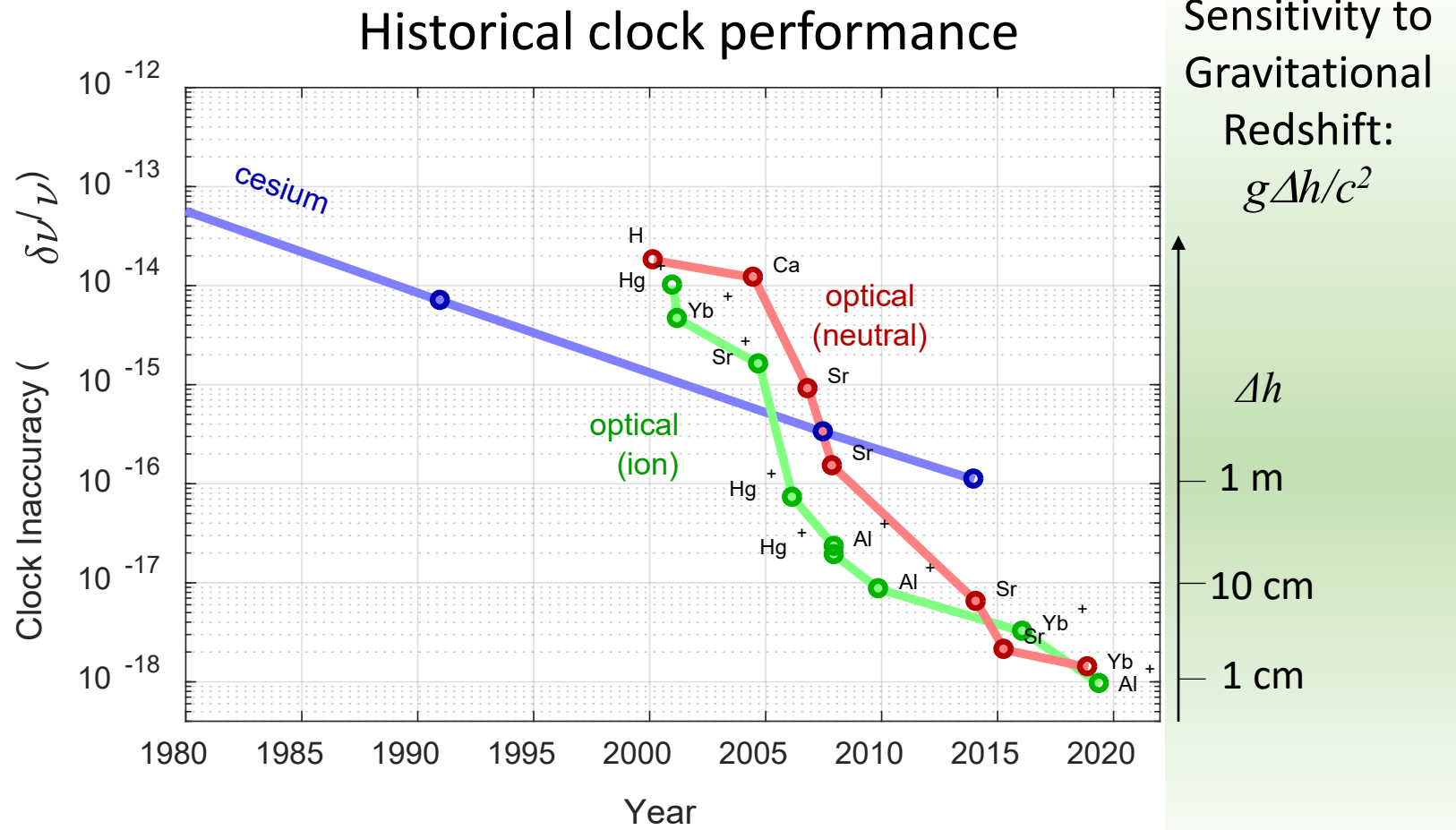
Cooling to the ground state of motion, heating rates ~ 1 quantum/s



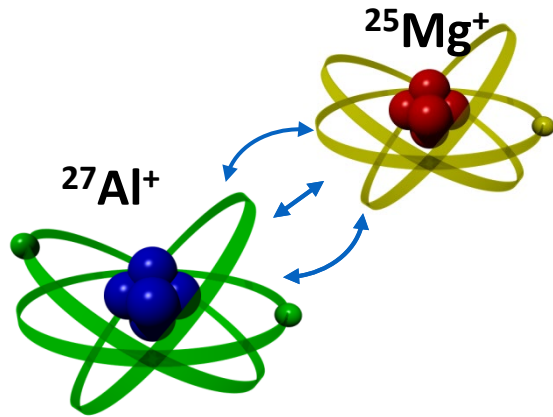
Testing Fundamental Physics with Clocks



Relativistic effects
 Fundamental Constants
 Fundamental Symmetries
 QED effects



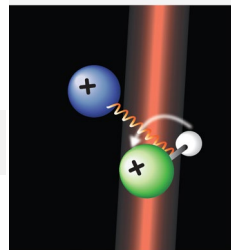
Quantum Logic Spectroscopy



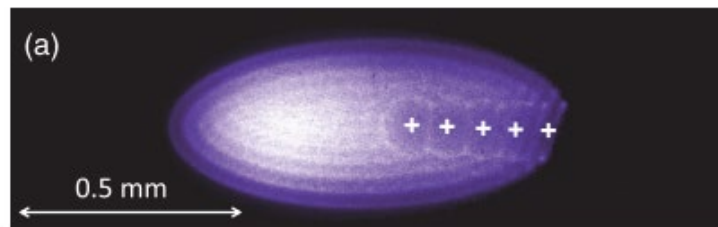
Other systems made accessible

Molecular ions, CaH^+

Chou et al., Nature **545**, 203 (2017)



Highly-charged ions, Ar^{14+}



Schmoeger et al., Science **347**, 1233 (2015)

PERIODIC TABLE
Atomic Properties of the Elements

NIST National Institute of Standards and Technology
U.S. Department of Commerce

FREQUENTLY USED FUNDAMENTAL PHYSICAL CONSTANTS:
1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

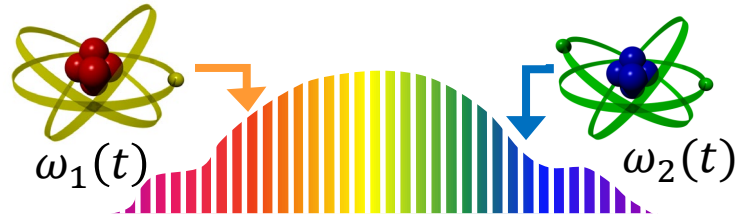
speed of light in vacuum c 299 792 458 m s^{-1} (exact)
Planck constant h 6.626 070 $\times 10^{-34}$ J s
elementary charge e 1.602 177 $\times 10^{-19}$ C
electron mass m_e 9.109 384 $\times 10^{-31}$ kg
proton mass m_p 1.672 622 $\times 10^{-27}$ kg
fine-structure constant α 1/137.035 999
Rydberg constant R_∞ 10 973 731.569 m^{-1}
 $R_\infty c$ 3.289 841 960 $\times 10^{15}$ Hz
 $R_\infty h c$ 13.605 693 eV
electron volt eV 1.602 177 $\times 10^{-19}$ J
Boltzmann constant k 1.380 65 $\times 10^{-23}$ J K^{-1}
molar gas constant R 8.314 5 J $\text{mol}^{-1} \text{K}^{-1}$

Physical Measurement Laboratory www.nist.gov/pml
Standard Reference Data www.nist.gov/srd

Legend:
Solids (white)
Liquids (light blue)
Gases (light green)
Artificially Prepared (light purple)

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H	He																
2	Li	Be	B	C	N	O	F	Ne										
3	Na	Mg	Al	Si	P	S	Cl	Ar										
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba																
7	Fr	Ra																
8	Lanthanides																	
9	Actinides																	

Searching for Ultralight Dark Matter

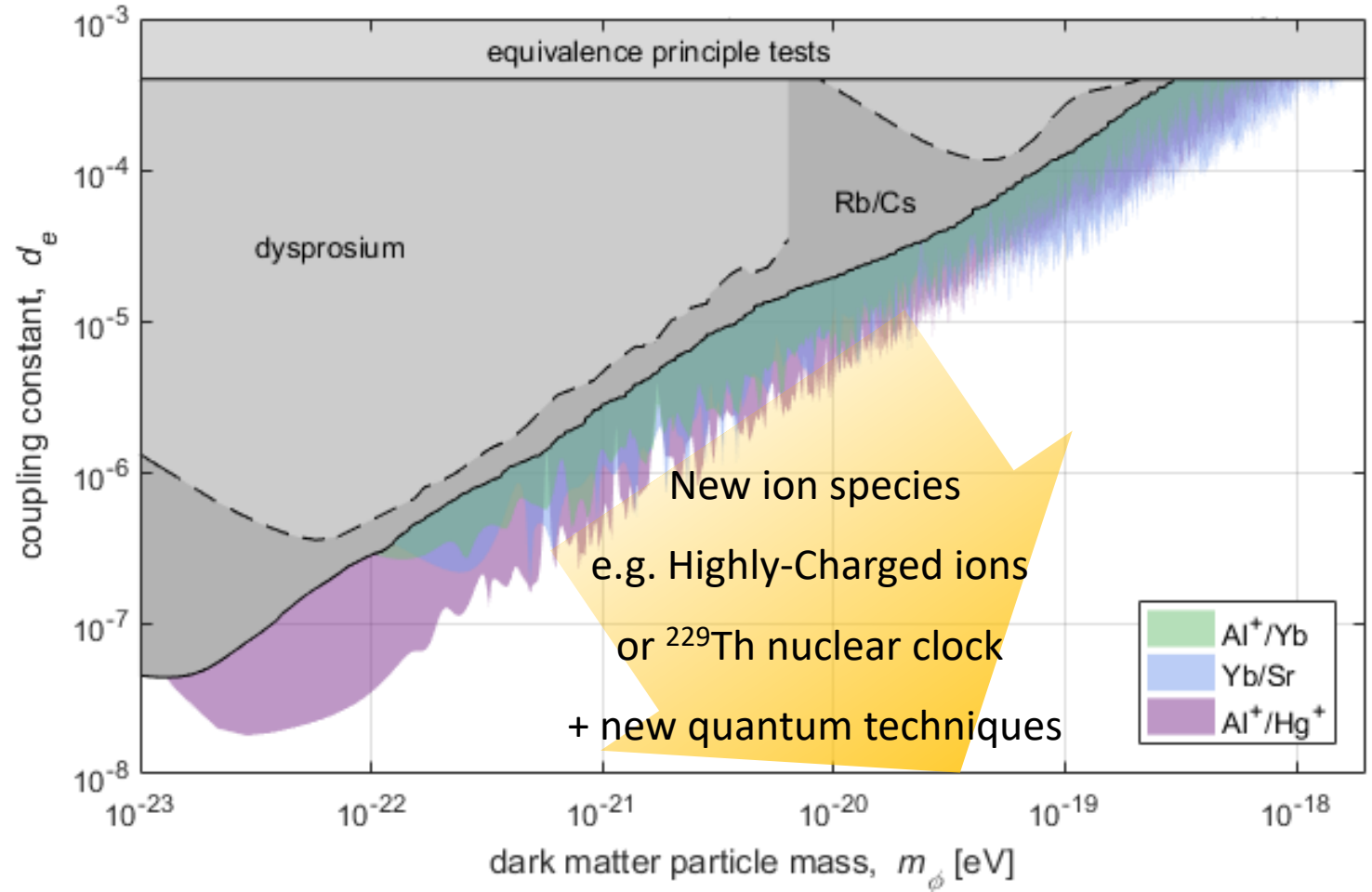


$$R(t) = \frac{\omega_1(t)}{\omega_2(t)}$$

Bosonic dark matter particles behave as a scalar field oscillating at the particle Compton frequency.

$$\omega_{DM} = \frac{m_\phi c^2}{\hbar}$$

Any coupling to SM fields would lead to an oscillation in the frequency ratio.



See also: [Tilburg et al., PRL 115, 011802 \(2015\)](#) and [Hees et al., PRL 117, 061301 \(2016\)](#)

Conclusions

- Trapped ions are a leading platform for atomic clocks and quantum computing.
- Quantum information technology has already had a profound impact on sensing applications, making this platform an interesting case study for quantum sensors.
- The precision and accuracy of atomic clocks coupled with their sensitivity to effects in fundamental physics make them useful in a variety of tests of the standard model.

