Roundtable: EDMs, atomic parity violation, and gravity signatures and synergies with the AMO physics program

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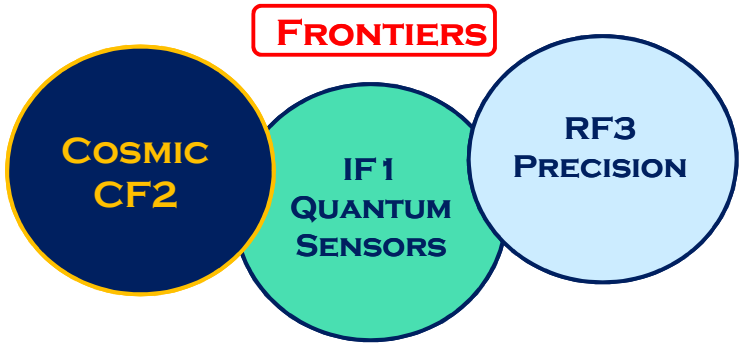
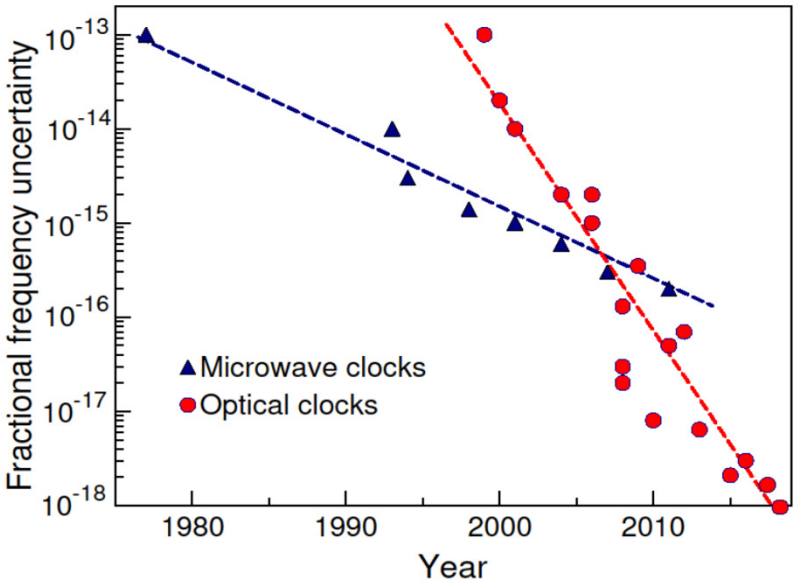
Extraordinary improvement in Atomic, Molecular and Optical (AMO) quantum sensors since 2013 Snowmass



Three orders of magnitude improvement in precision of atomic clocks in 15 years



Explosive growth in the use of quantum sensors in high energy physics since the previous Snowmass Community Study

- Fundamental symmetry studies (P-, CP- and CPT-violation)
- Dark matter, fifth forces and dark energy searches
- Searches for violation of the equivalence principle
- Tests of general relativity
- Searches for variations of fundamental constants
- Gravitational wave detection in other wavelength regions

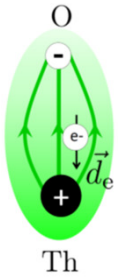
Wide range of AMO quantum sensor technologies

- Ultracold atoms, ions, molecules, and molecular ions
- Atomic, molecular, and nuclear clocks & other precision spectroscopy
- Atom interferometers
- Optical interferometers
- Magnetometers
- Microwave and optical cavities
- Mechanical resonators

Fundamental symmetries with AMO quantum science: eEDM

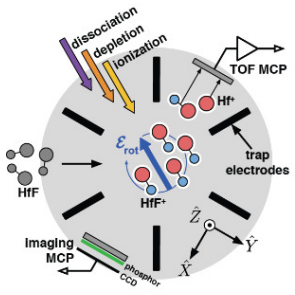
Searches for electron electric-dipole moment (eEDM)

Advanced ACME



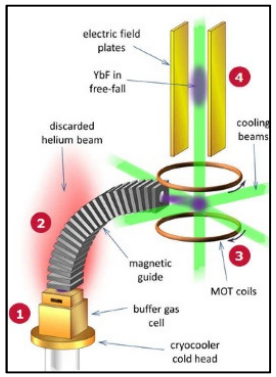
ThO

JILA eEDM



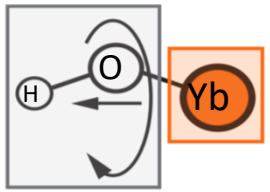
HfF^+, ThF^+

Imperial College



YbF

PolyEDM



Also NMQM search

YbOH, …

EDMs: complementary probes for TeV-scale new physics

Progress since the last Snowmass

- **2014: Order of magnitude improvement in electron EDM (ACME experiment)**
- **2017: Complementary JILA eEDM limit with molecular ions**
- **2018: Another order of magnitude from second generation ACME experiment**

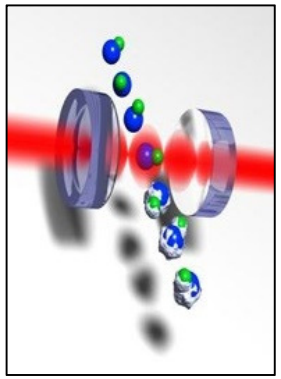
Many advances are coming:

- Rapid progress in ultracold molecule cooling and trapping
- New experiments for orders of magnitude improvements with polyatomic molecules
- Molecules with Ra and other radioactive species
- “Spin squeezed” entangled states

Fundamental symmetries with AMO quantum science

Searches for hadronic EDMs

CeNTREX

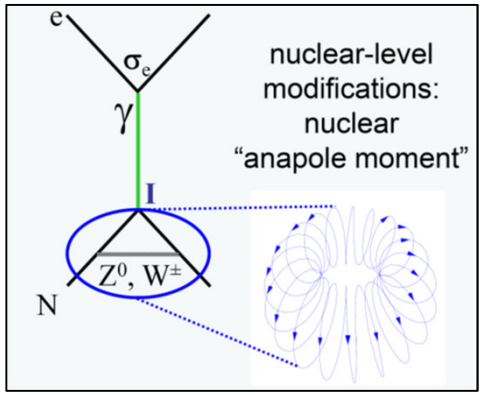


TlF (proton EDM)

Hg
Xe
Ra
EDMs

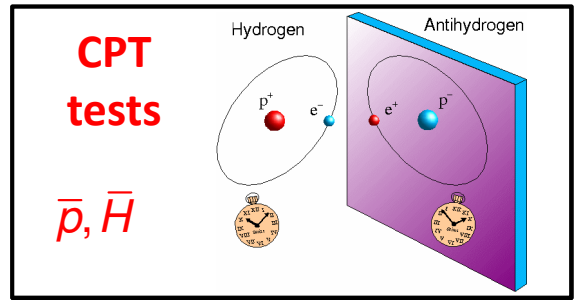
Enhanced parity violation

ZOMBIES



Parity violation observation in Yb (Mainz)
First PV observation with multiple isotopes

Fr experiments (FRIUMF & Japan)



BASE and ALPHA in the Top 10 of Physics Breakthroughs 2021

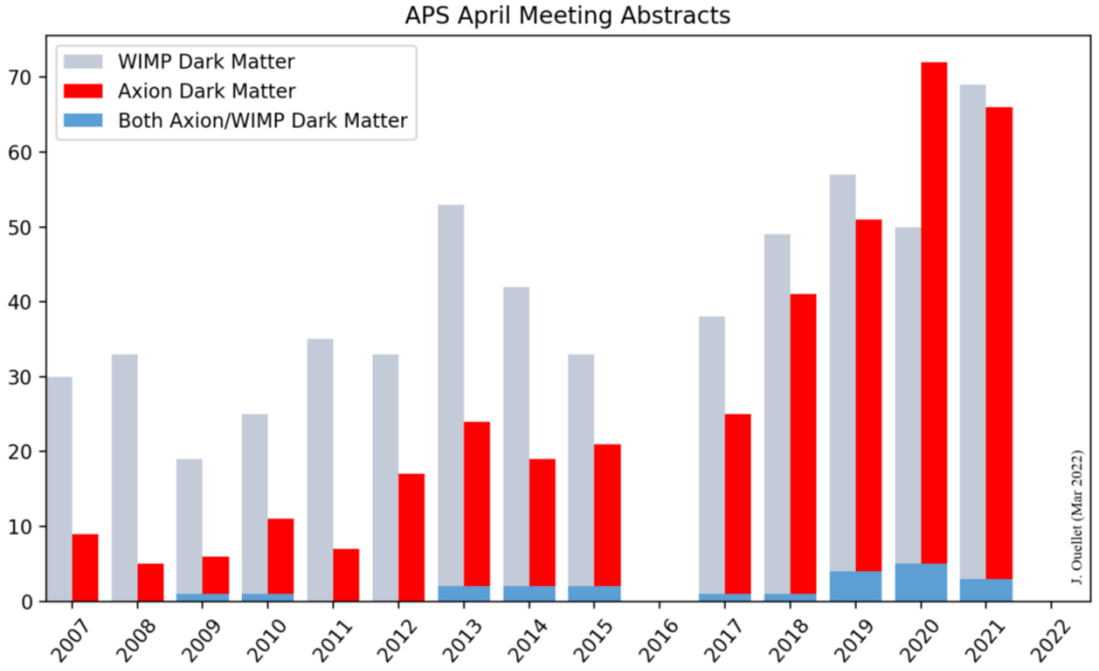
2021: Laser cooling of antihydrogen atoms & observation of the laser-driven 1S–2S transition in samples of laser-cooled antihydrogen atoms for drastically improve spectroscopic and gravitational studies of antihydrogen.

2021: The Baryon Antibaryon Symmetry Experiment (BASE): Sympathetic cooling of a trapped proton

Synergies with cosmic frontier: wave-like dark matter (WLDM)

The key idea: at masses less than 1 eV, particles cross the wave-particle divide and start behaving as waves.

WLDM is coherent on the scale of detectors or networks of detectors so detection techniques are inherently quantum.



WLDM: Fast growing community J. Ouellet

The community road map, theory, cosmology, and experimental details are presented in two community white papers:

Axion Dark Matter arXiv:2203.14923

Editors: J. Jaeckel, G. Rybka, L. Winslow

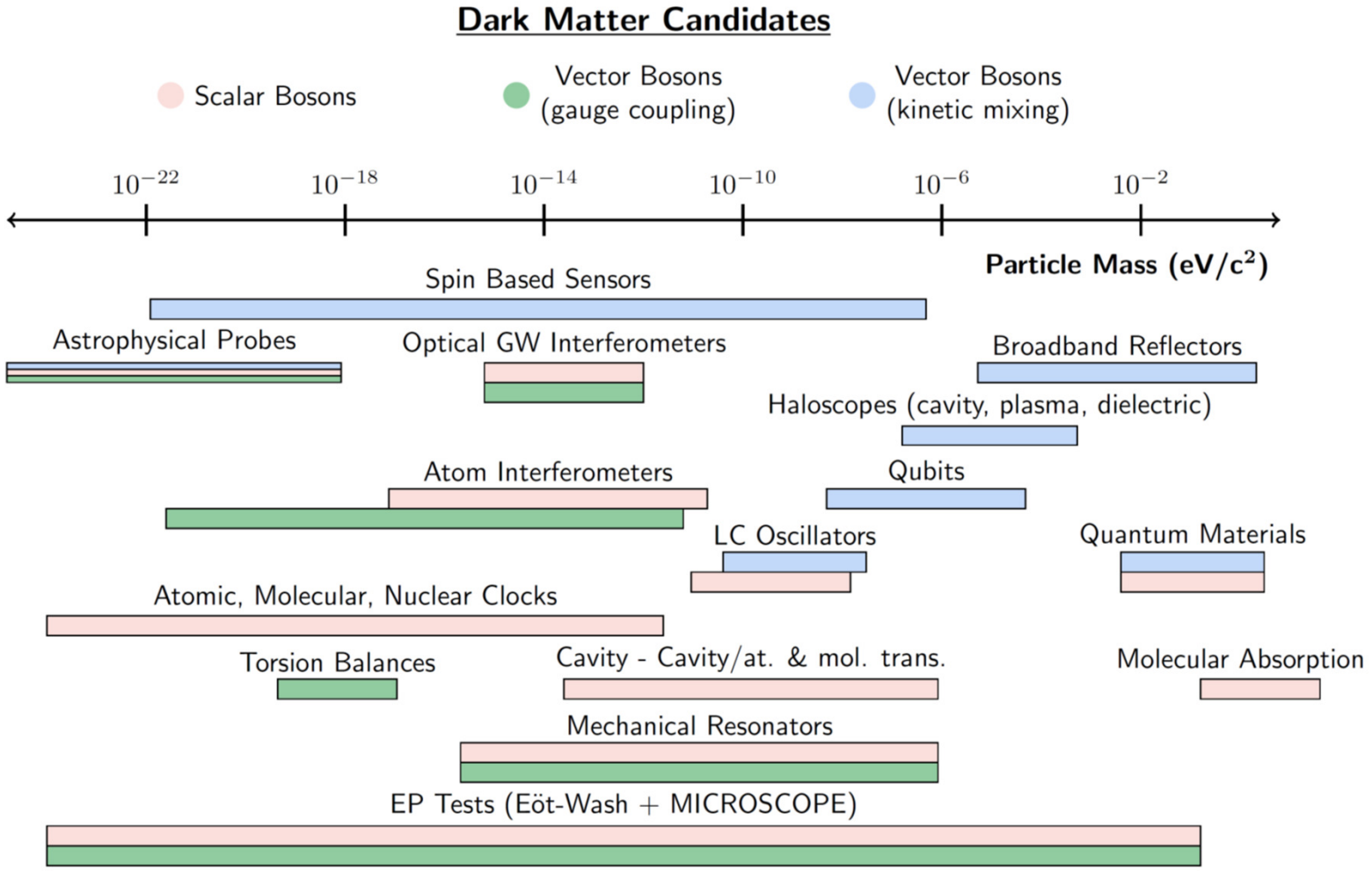
New Horizons: Scalar and Vector Ultralight Dark Matter arXiv:2203.14915

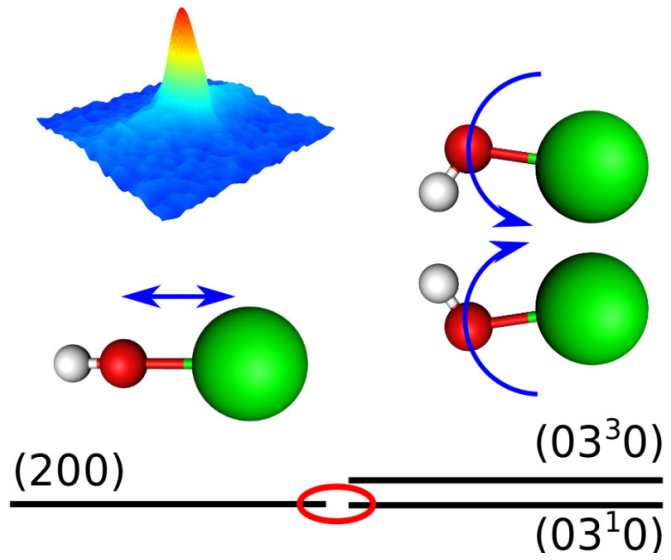
Editors: M. Safronova and S. Singh

Many these dark matter searches share AMO quantum technologies with EDM searches and other fundamental symmetry RF3 studies

Picture credits: Lindley Winslow

Synergies with cosmic frontier: wave-like dark matter (WLDM)





SrOH: similar molecular techniques with eEDM searches

Best projected limits for scalar DM with coupling to electrons

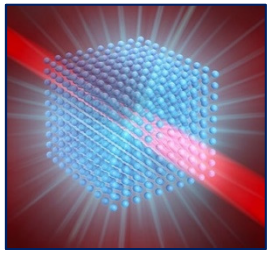
Other precision quantum sensor experiments for HEP science

Atomic and Nuclear Clocks & Cavities

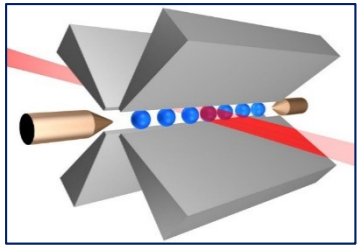
Major clock & cavities R&D efforts below, also molecular clocks, portable clocks and optical links

BSM searches with clocks

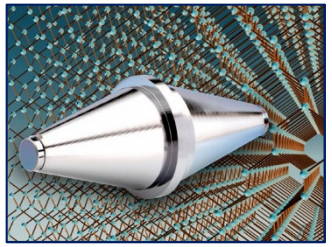
- Searches for variations of fundamental constants
- Ultralight scalar dark matter & relaxion searches
- Tests of general relativity
- Searches for violation of the equivalence principle
- Searches for the Lorentz violation



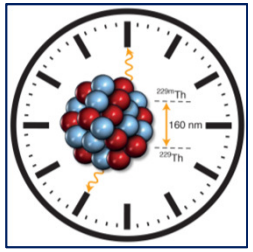
3D lattice clocks



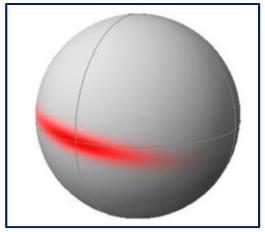
Multi-ion & entangled clocks



Ultrastable optical cavities



Nuclear & highly charge ion clocks



Measurements beyond the quantum limit

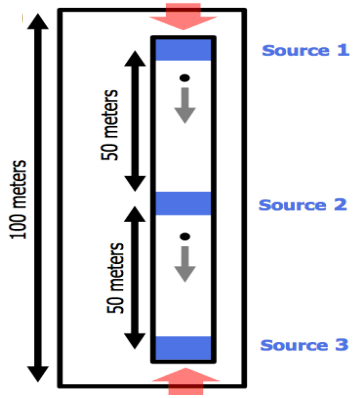
Atom interferometry

Ultralight scalar DM

Violation of the equivalence principle

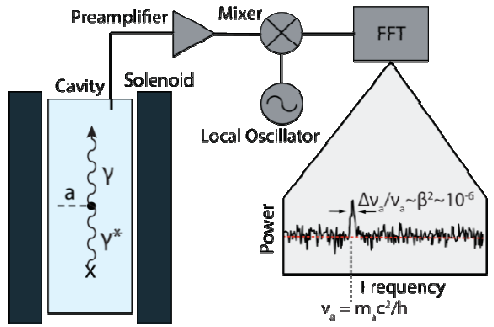
Prototype gravitational wave detectors

MAGIS-100 Fermilab



MIGA , AION, ZIGA

Axion and ALPs searches

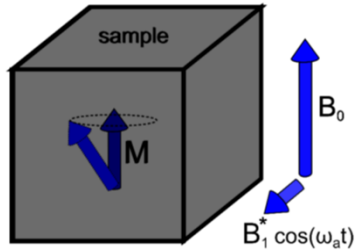


Microwave cavities: HAYSTAC

AMO: measurements beyond quantum limits

CASPEr-electric, solids

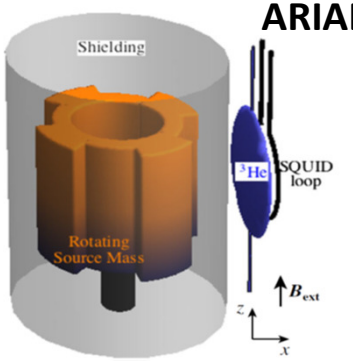
(coupling to gluons)



CASPEr-wind, Xe

(coupling to fermions)

ARIADNE



Resonantly detecting axion-mediated forces with NMR

Many other current & future experiments: GNOME, tests of the gravity-quantum interface, and HUNTER, SHAFT, ORGAN & UPLOAD (axions), solid-state directional detection with NV centers (WIMPs), doped cryocrystals for EDMs, Rydberg atoms, …