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

Marianna Safronova
Department of Physics and Astronomy
University of Delaware, Delaware
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
- JILA eEDM
- Imperial College
- PolyEDM
- ThO
- HfF$^+$, ThF$^+$
- YbF
- 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
- Hg
- Xe
- Ra
- EDMs
- TIF (proton EDM)

**Enhanced parity violation**
- ZOMBIES
- Parity violation observation in Yb (Mainz)
- First PV observation with multiple isotopes
- Fr experiments (FRIUMF & Japan)

**CPT tests**
- $\bar{p}, \bar{H}$

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.

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

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

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

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

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

Microwave cavities: HAYSTAC
AMO: measurements beyond quantum limits

Axion and ALPs searches
CASPER-electric, solids (coupling to gluons)
CASPER-wind, Xe (coupling to fermions)

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, ...