Finding the Missing Universe

Briefing to the National Academy Committee on Biological and Physical Sciences in Space

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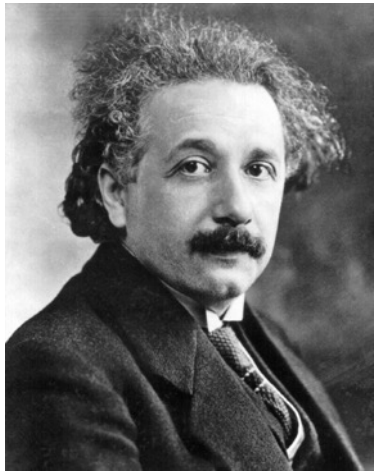
BPS

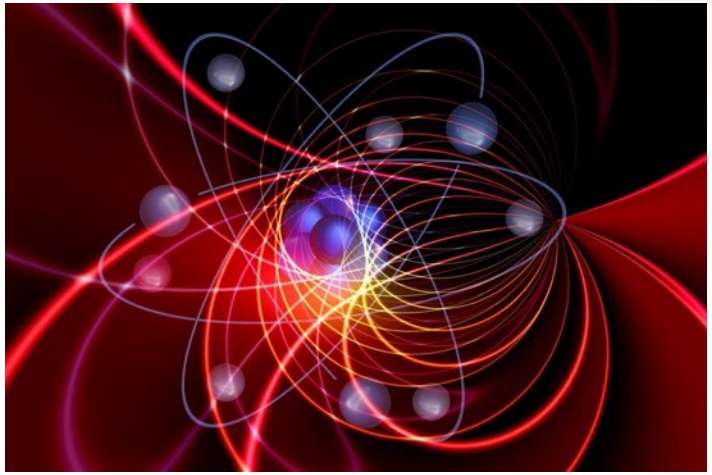
Biological & Physical Sciences

National Aeronautics and Space Administration

The Overarching Goal

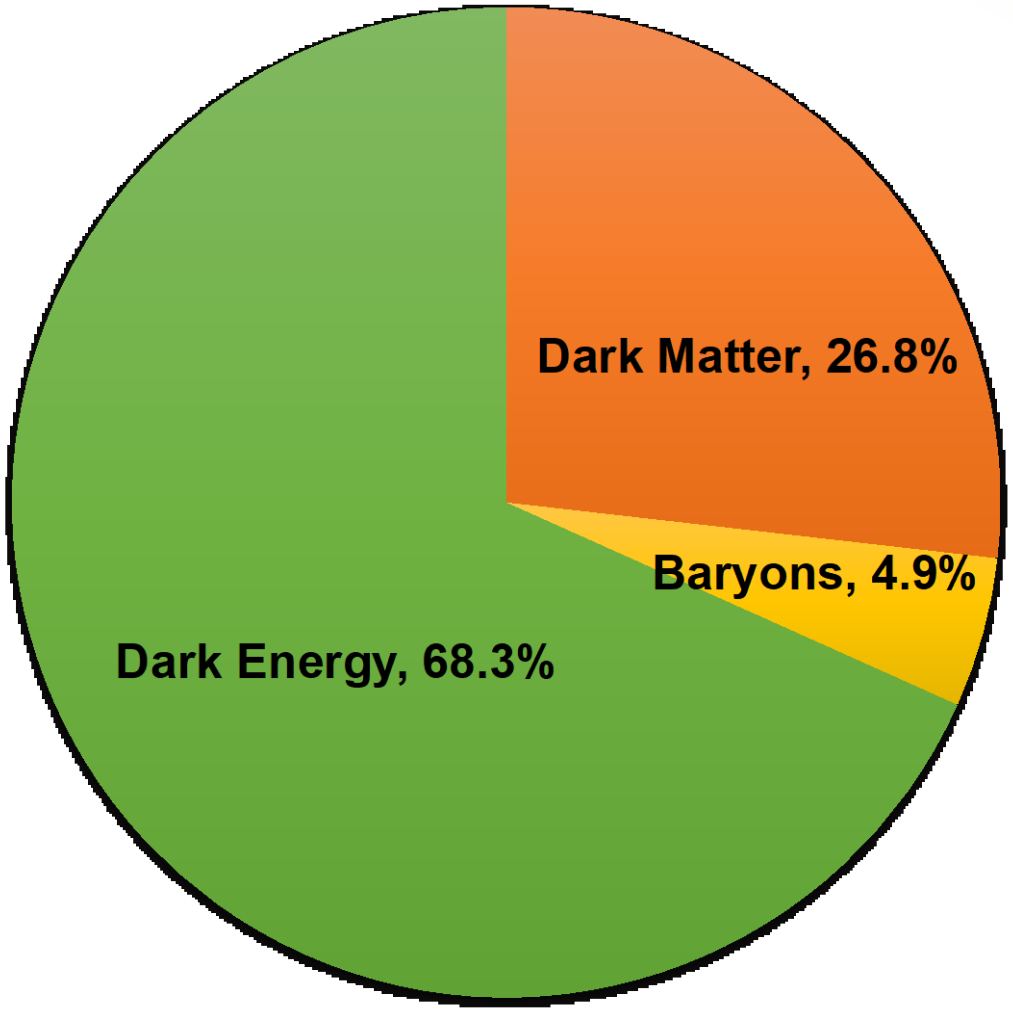
Just as the development of **General Relativity** and **Quantum Mechanics** a century ago to explain perplexing observations ushered in an unprecedent revolution in science and technology, discoveries in our current perplexing and hidden universe may usher in the next great revolution in science and technology.





BPS Decadal Survey Key Science Question #11. What new physics, including particle physics, general relativity, and quantum mechanics, can be discovered with experiments that can only be carried out in space?

The Missing Universe



95% of the universe is dark to us.

Only 5% is stuff we can see (baryons).

And, where's the antimatter?

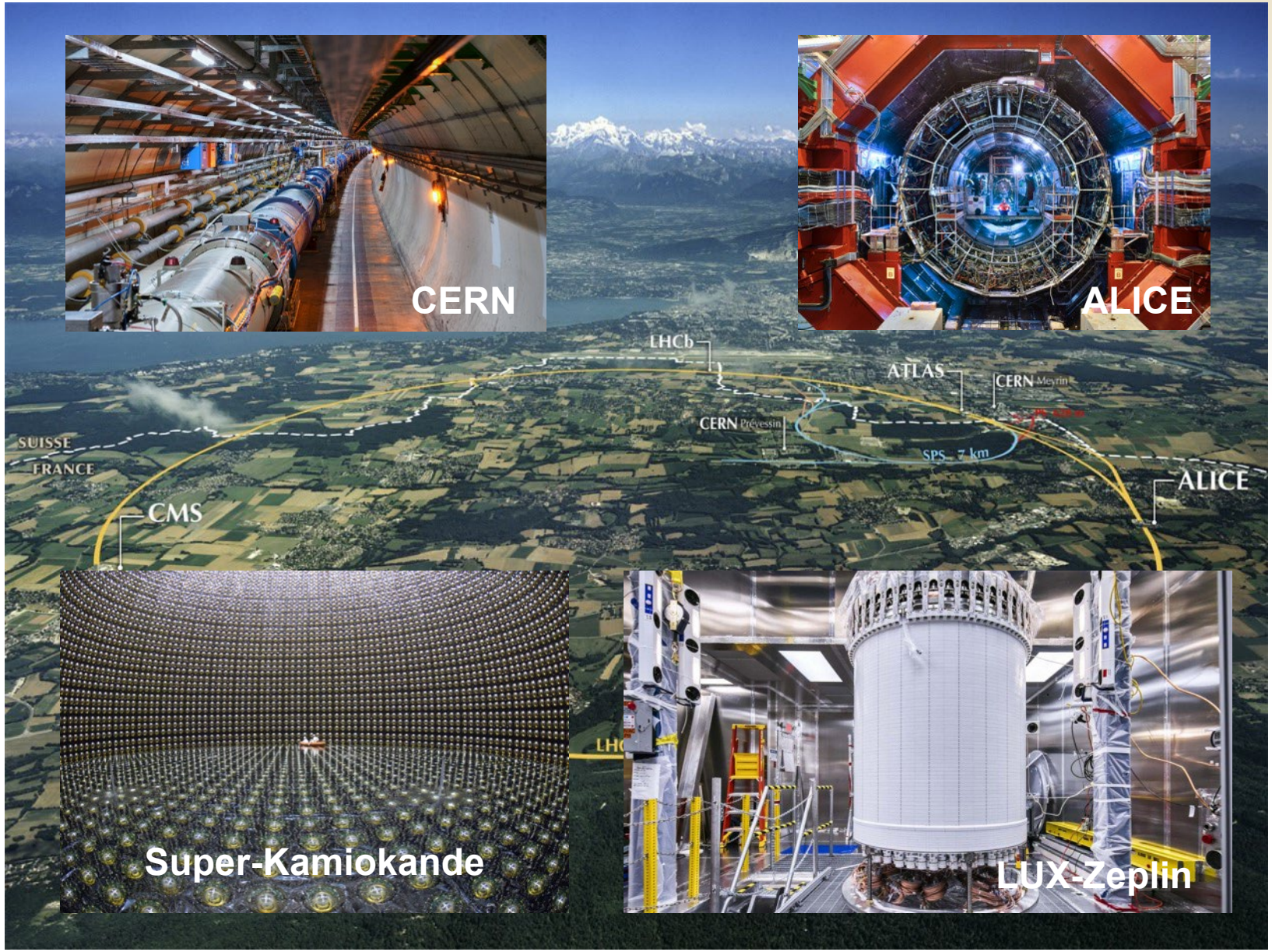
Our theories say there should be equal amounts of matter and antimatter. And, we shouldn't be here!

General Relativity and the Standard Model can't explain this.

Are they wrong or just incomplete?

And why can't gravity and quantum mechanics be unified?

Our giant laboratories have found no physics beyond the Standard Model



No Super-Symmetry
No Proton Decay
No Axions
No WIMPs
(Weakly Interacting Massive Particles)

Maybe we are looking in the wrong place.

A Different Search Space

Dark Matter

- Most searches have been looking for massive particle-like, dark matter candidates (m≫1eV/c^2).
  - Perhaps, the search should be for ultra-light candidates.
- Look for a dark matter field as variations in fundamental constants.

Dark Energy

- Dark energy is seen at the cosmic scale (acceleration of the universe) but not at the galactic-to-terrestrial scale.
- Maybe dark energy has a screening effect caused by the presence of matter.
- Precision tests of the Equivalence Principle with individual (cold) atoms might avoid the screening.

Baryon Asymmetry

- Baryon asymmetry might be revealed in violations of Local Lorentz Invariance that manifest as tiny shifts in atomic spectra as a function of orientation relative to some velocity vector.

Quantum Gravity

- Precise comparisons of phase changes between classical and entangled photons over large changes in gravitational potential (e.g., ground to space) would test quantum mechanics in curved spacetime (gravity).

Needed Observations

New Theories

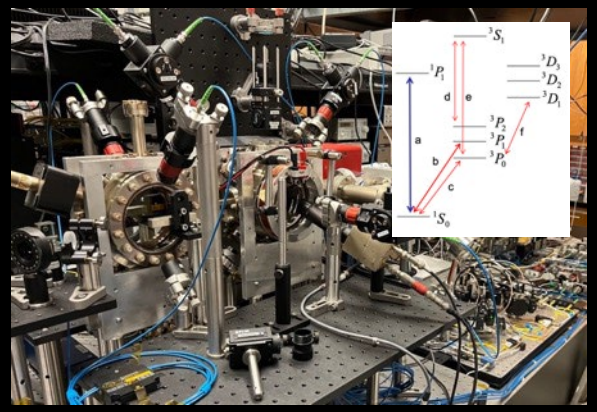
- Many of the (field) theories beyond the Standard Model predict violations of the Einstein Equivalence Principle to explain dark matter, dark energy, baryon asymmetry, and quantum gravity.
- These violations may be seen as tiny deviations in gravitational redshift, variations of fundamental constants, violations of symmetries, or in the existence of new forces.

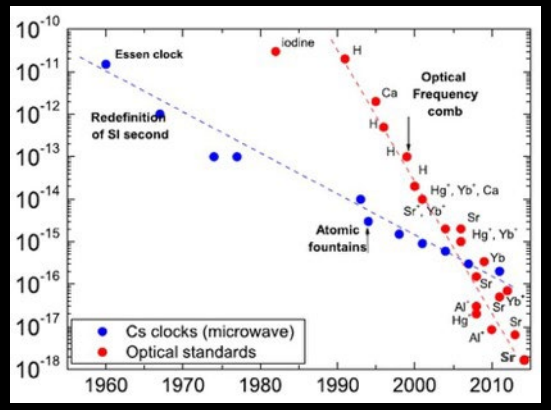
Needed Precision

- In order to test these theories, ultra-precise techniques are required.
- Such precision is not possible on the Earth.
- The space environment offers the potential to get beyond the noise and limitations of the terrestrial environment and achieve orders-of-magnitude greater measurement precision.
- Space also provides access to large velocities, long distances, and large changes in gravitational potential, not possible on the Earth.

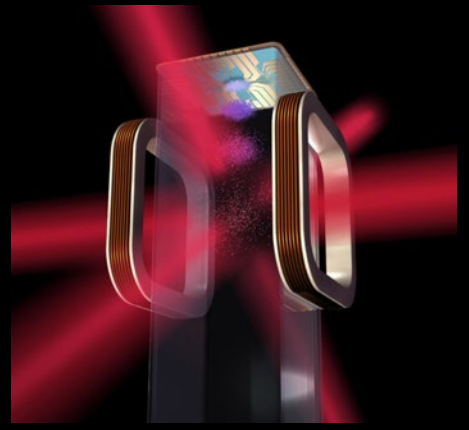
The Precision Techniques Are All Quantum-based

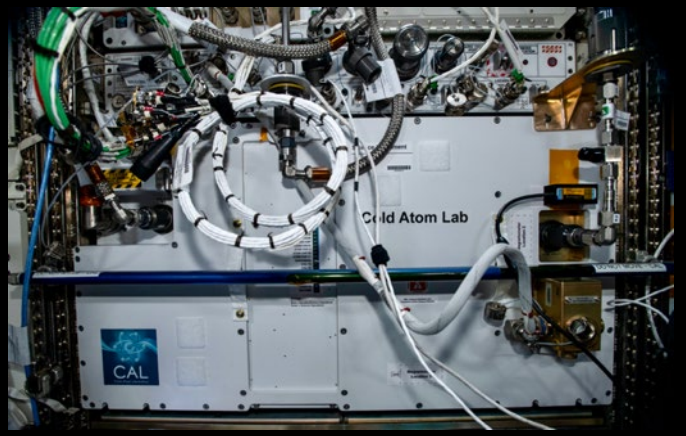
Atomic Clocks



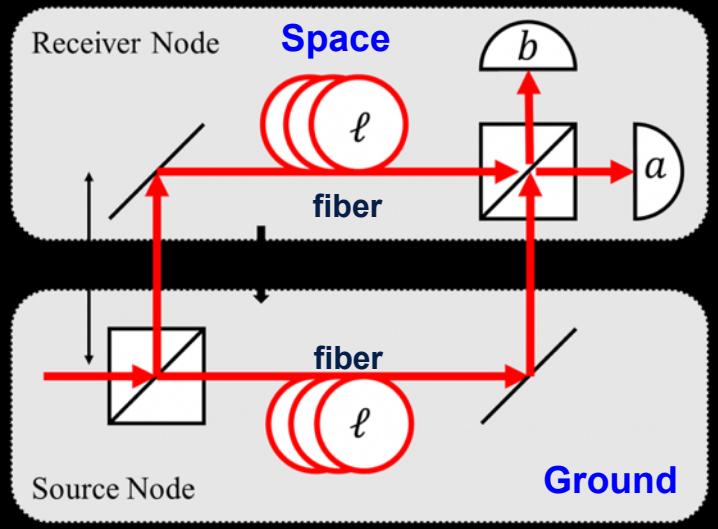


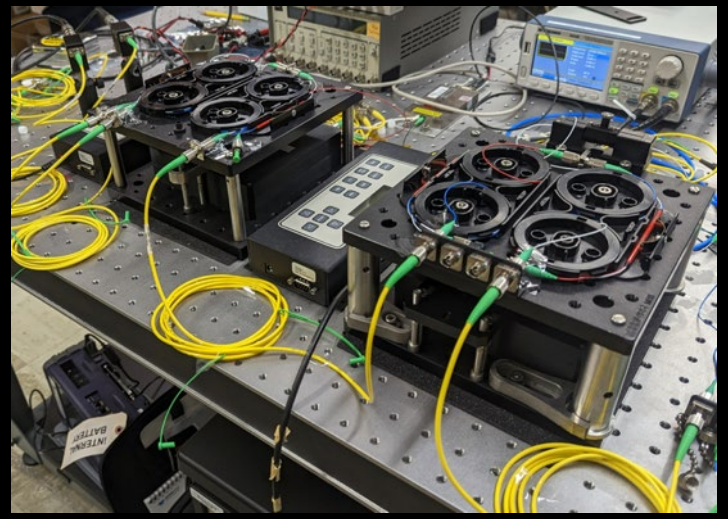
Atom Interferometry



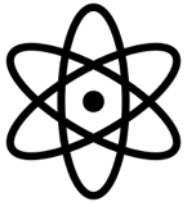
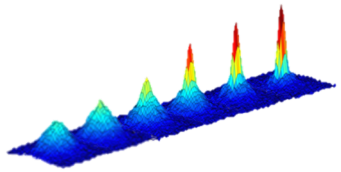


Quantum Entanglement

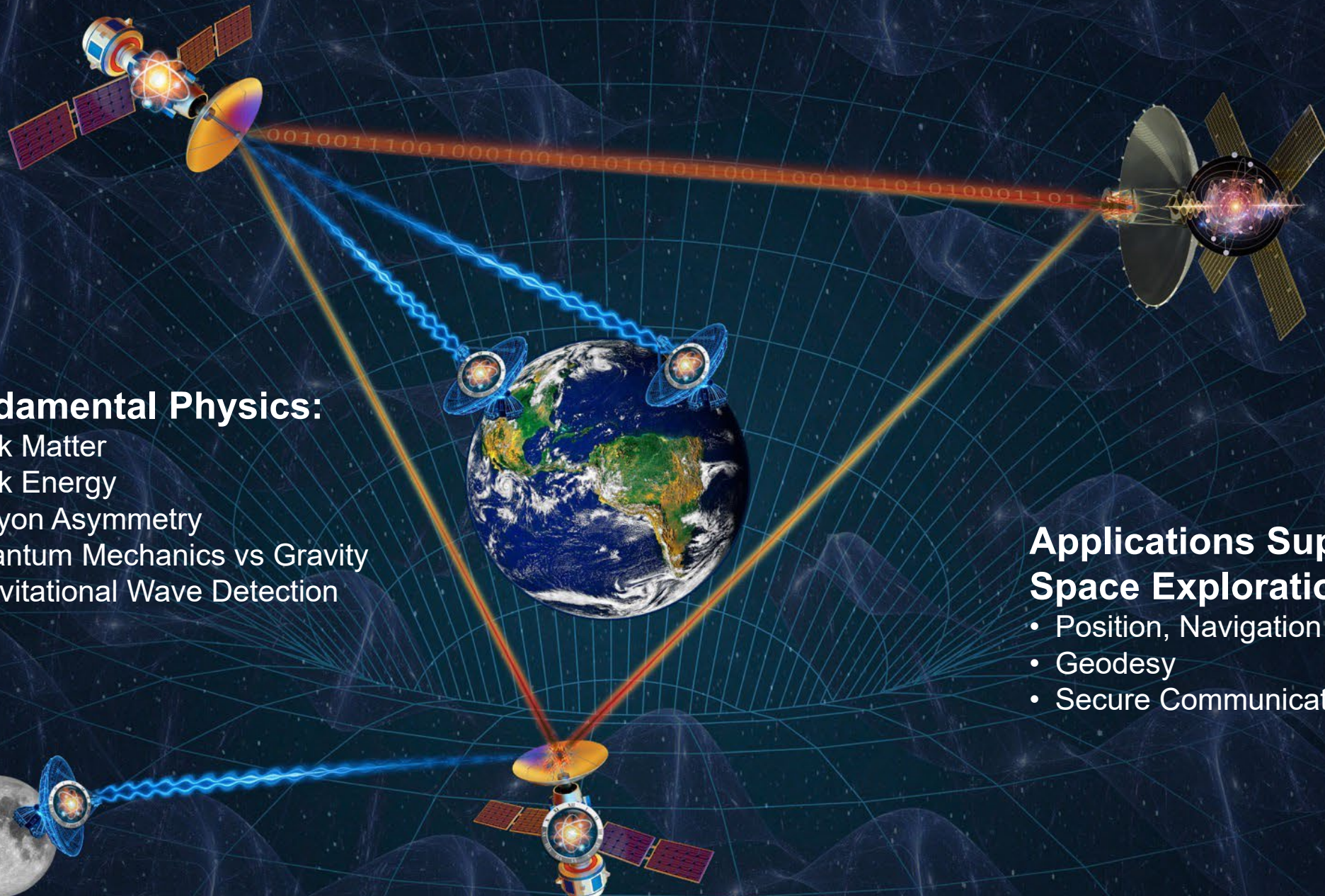




NASA Fundamental Physics Program

	Ground	Space	Future
Atomic Clocks 	Ground Lattice Clock (JPL, WI)	ISS **ACES** (ESA) 2025	Deep Space Optical Clock; Clock Networks
Atom Interferometry 	Tractor Atom Interferometry (ARL); Drop Tower **D3E3** (DLR) 2025	ISS **CAL** 2018; ISS/CLD **BECCAL** (DLR) 2027	CLD Atom Interferometry; Free-flying Atom Interferometry Network
Quantum Entanglement 	Quantum Networks on Curved Space-Time; Ground 10km **DSQL, AST** 2025; Mountain Top **DSQL** 2025	ISS **SEAQUE** 2024; *Small Sat **QEYSSat** (CSA) 2027*	Ground-to-Space Interferometry; Earth-to-Moon Interferometry

The 30-year vision: **Space-based Network of Ultra-Precise Quantum Sensors**



Fundamental Physics:

- Dark Matter
- Dark Energy
- Baryon Asymmetry
- Quantum Mechanics vs Gravity
- Gravitational Wave Detection

Applications Supporting Space Exploration:

- Position, Navigation and Timing
- Geodesy
- Secure Communication