SUPREME-QG: Space-borne Ultra-Precise Measurement of the Equivalence Principle Signature of Quantum Gravity

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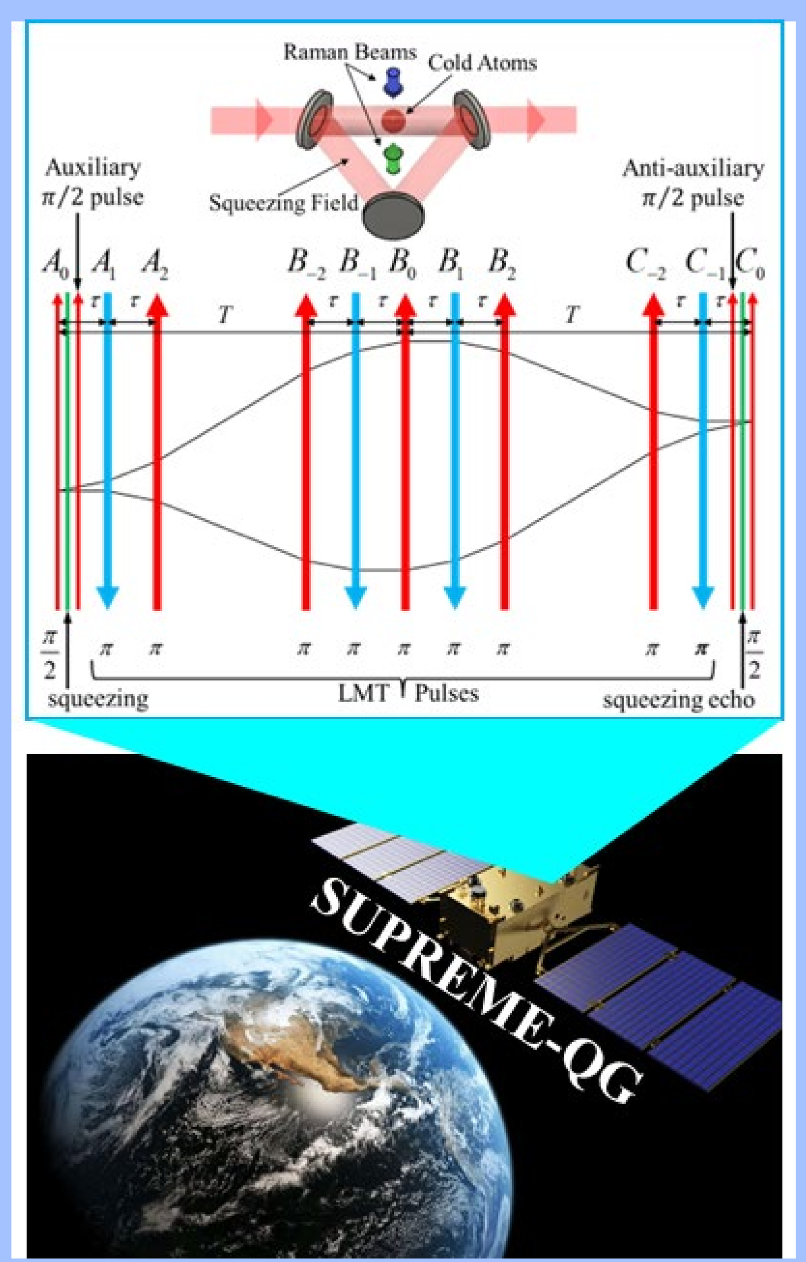


Innovation

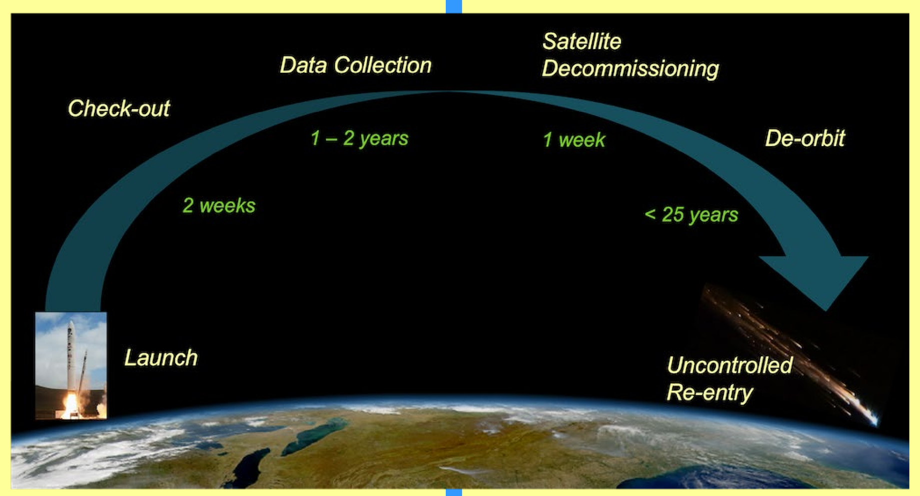
- Detect violation of the Equivalence Principle (EP) predicted by theories of quantum gravity (TQG) by measuring the Eotvos parameter with extreme precision using Entanglement-Enhanced Dual Species Atom Interferometer (AI), augmented by large momentum transfer (LMT).
- Use a radically new technique which generates the maximally entangled quantum state of atoms: the Schroedinger cat (SC) state.
- This technique would strongly suppress effects of excess noise, and reach a sensitivity five orders of magnitude better than what has been achieved using classical accelerometers for the Eotvos parameter.

Impact

- If EP violation is observed, the version of TQG that agrees most closely with the result would form the foundation for a complete theory governing the universe, including its birth: the Big Bang.
- A null result would force physicists to conceive an entirely new approach to addressing the irreconcilability of GR and QM.
- The LMT-augmented SC-state AI (SCAI), configured for both accelerometry and rotation sensing, can lead to revolutionary improvements in inertial navigation and gravitational cartography.

Mission

- The proposed experiment is compact and rugged. As such, it can be carried out on a dedicated LEO satellite, under a mission possibly named *Space-borne Ultra-Precise Measurement of the Equivalence Principle Signature of Quantum Gravity* (SUPREME-QG).
- It will be a low-cost class D mission, with very few operational requirements other than the need to reduce vibrations and pointing jitter, as a primary payload on a dedicated launch vehicle, or a secondary payload.
- The main mission, lasting one to two years, will have frequent data downlinks to select ground station(s).

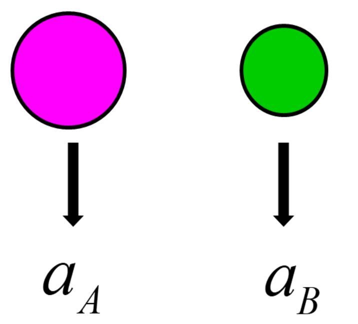


Approach

- Terrestrial experiment will be carried out to demonstrate an LMT-augmented SCAI for both ^{85}Rb and ^{87}Rb, using cold atoms from a spatially co-located dual species trap.
- Possible sources of systematic noise would be studied, techniques to suppress these would be identified, and experimental parameters necessary for reaching the target sensitivity would be determined.
- This will pave the way for designing an experiment to be carried out on a low earth orbit satellite, for measuring the Eotvos parameter at a level of ~ 10^{-20}.

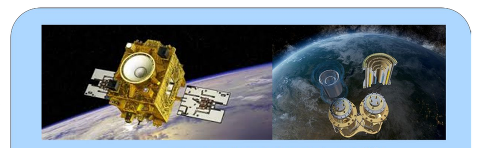
•Eotvos Parameter

$$\eta \equiv \frac{|a_A - a_B|}{[(a_A + a_B)/2]}$$

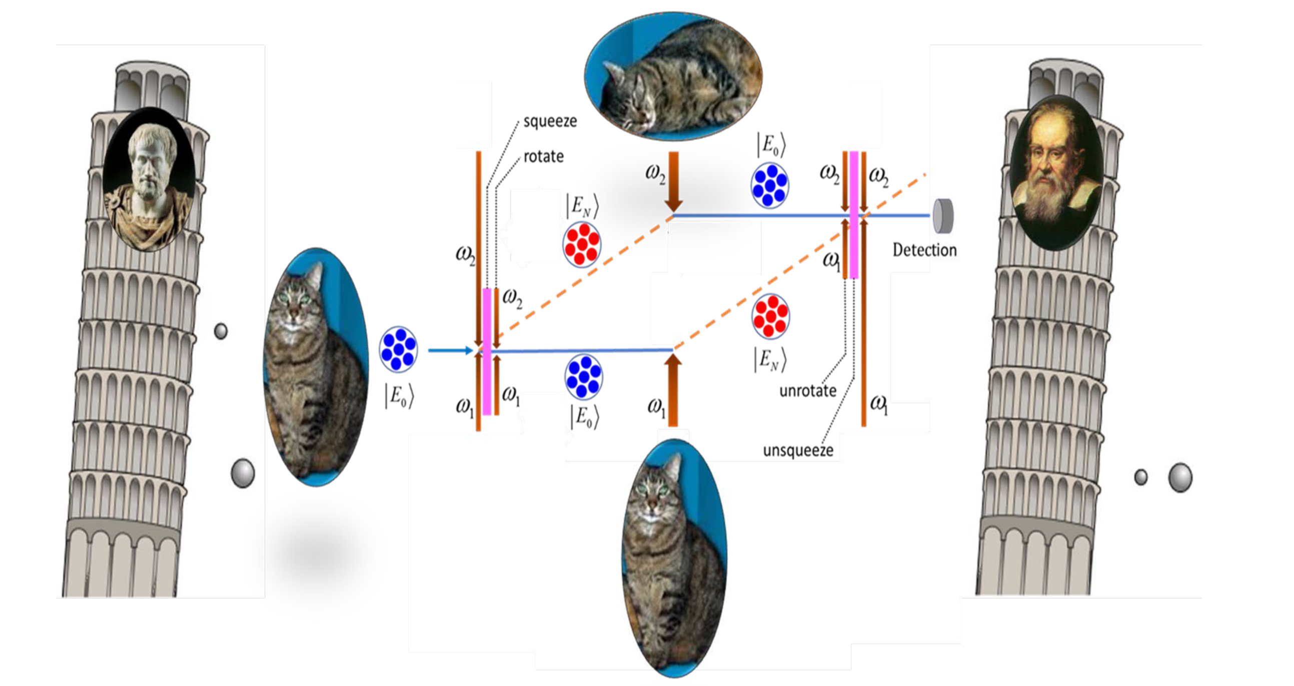


•Tested to be null at the level of ~10^{-15} so far

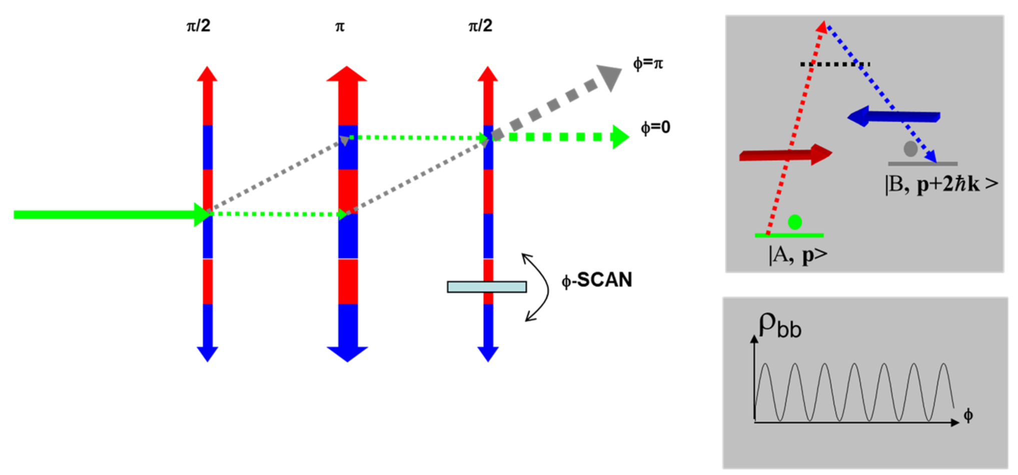
•Quantum Gravity theories predict violation at the level of ~10^{-18}



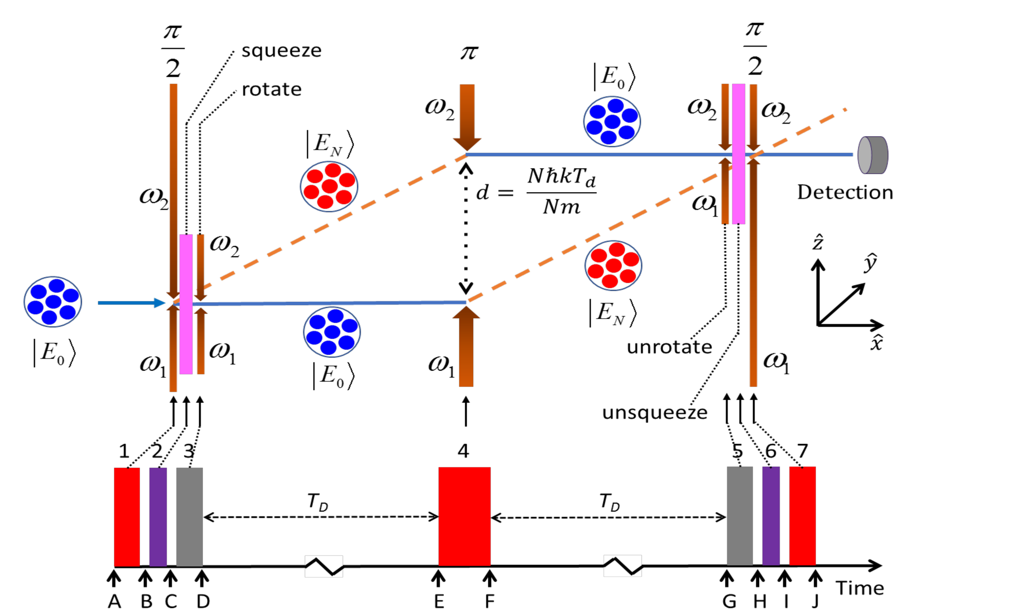
MICROSCOPE (~10^{-15})



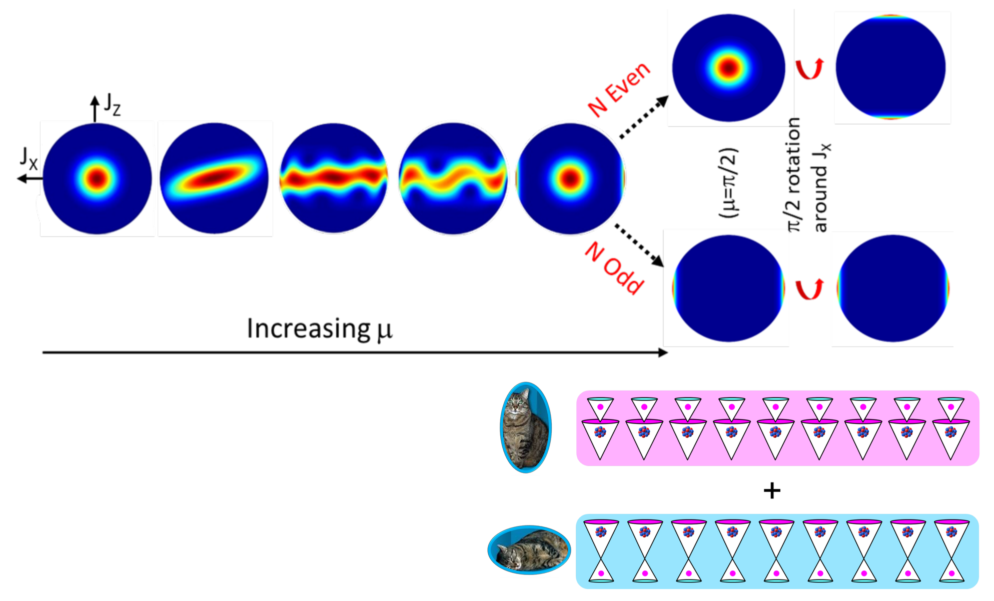
Our goal is to make a Schroedinger Cat state based atom interferometer to reach this sensitivity limit



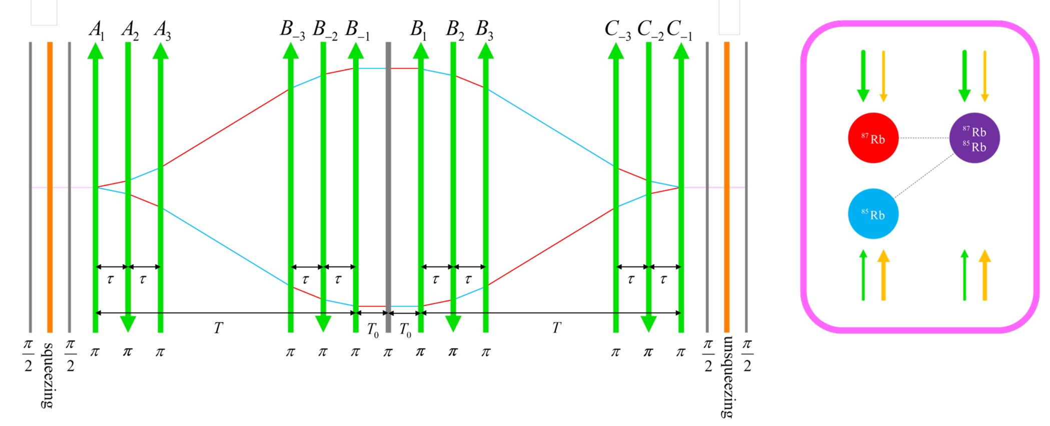
Basic Atom Interferometric (AI) Accelerometer

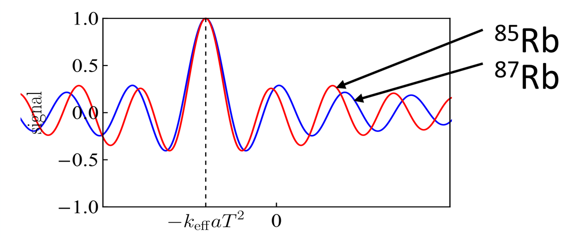


Pulse sequence used for a Schroedinger Cat Atom Interferometric Accelerometer



Schroedinger Cat Created via Spin Squeezing

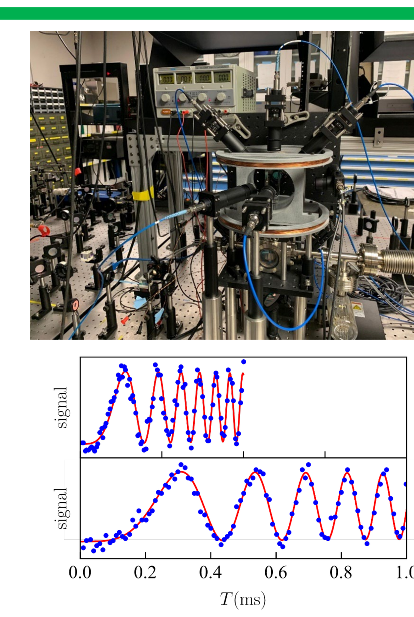




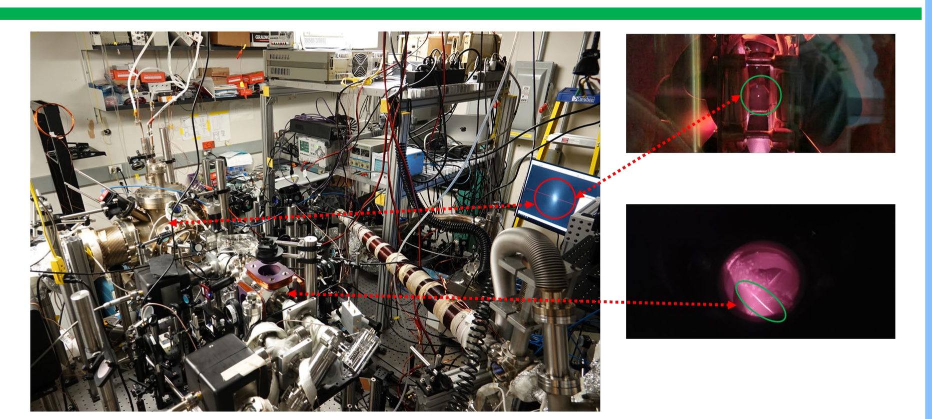
Reference: Large-Momentum Transfer Dual Species Spin-Squeezed Atom Interferometer (Physical Review D 108, 024011 (2023)

Large Momentum Transfer (LMT) Dual Species Schroedinger Cat Atom Interferometric Accelerometer

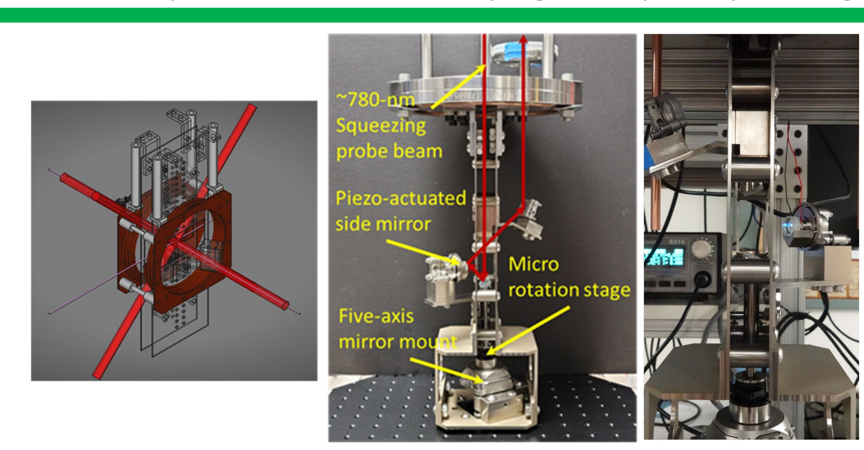
STATUS OF EXPERIMENTAL EFFORT



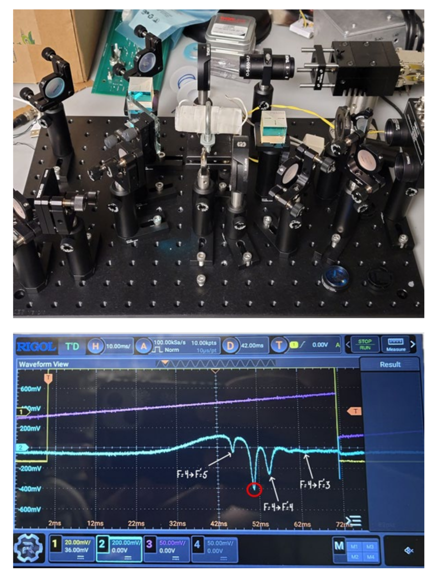
LMT Atom Interferometer Operational



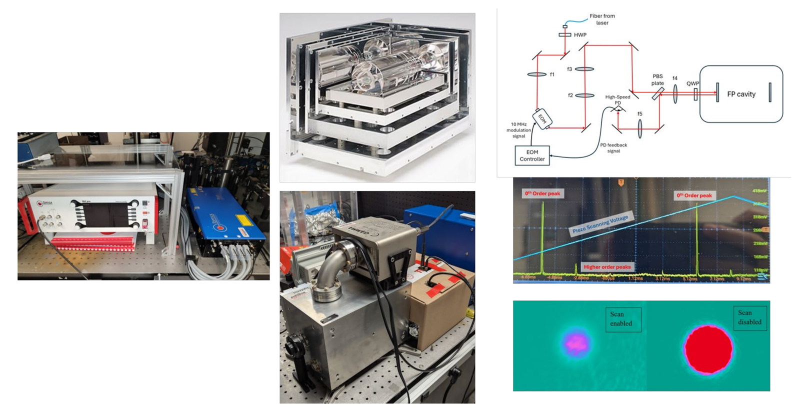
Getter loaded 3D Magneto-Optic Trap (MOT), to be Loaded by 2D MOT when Carrying Out Spin-Squeezing



Spin Squeezing Cavity Fully Assembled, to be Loaded into the Main Chamber after Optimization



Squeezing Cavity to be Locked to a Laser at 852 nm which in turn is locked to a transition in Cs



Spin Squeezing Laser Stabilized to a Super-Cavity with a Finesse of 250K, reducing linewidth to ~1 kHz