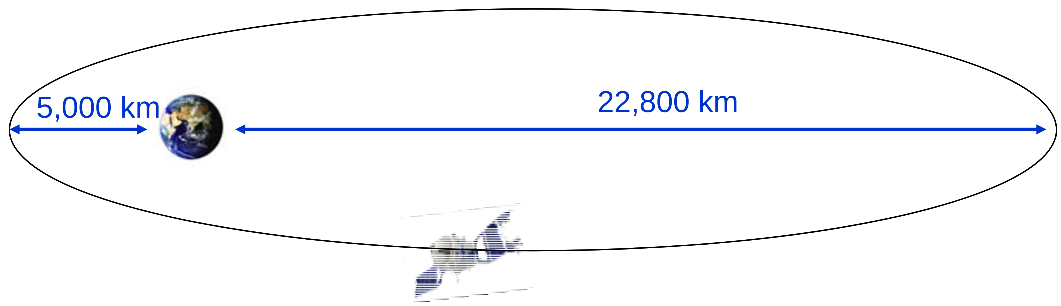
FOCOS – Fundamental physics with an Optical Clock Orbiting in Space



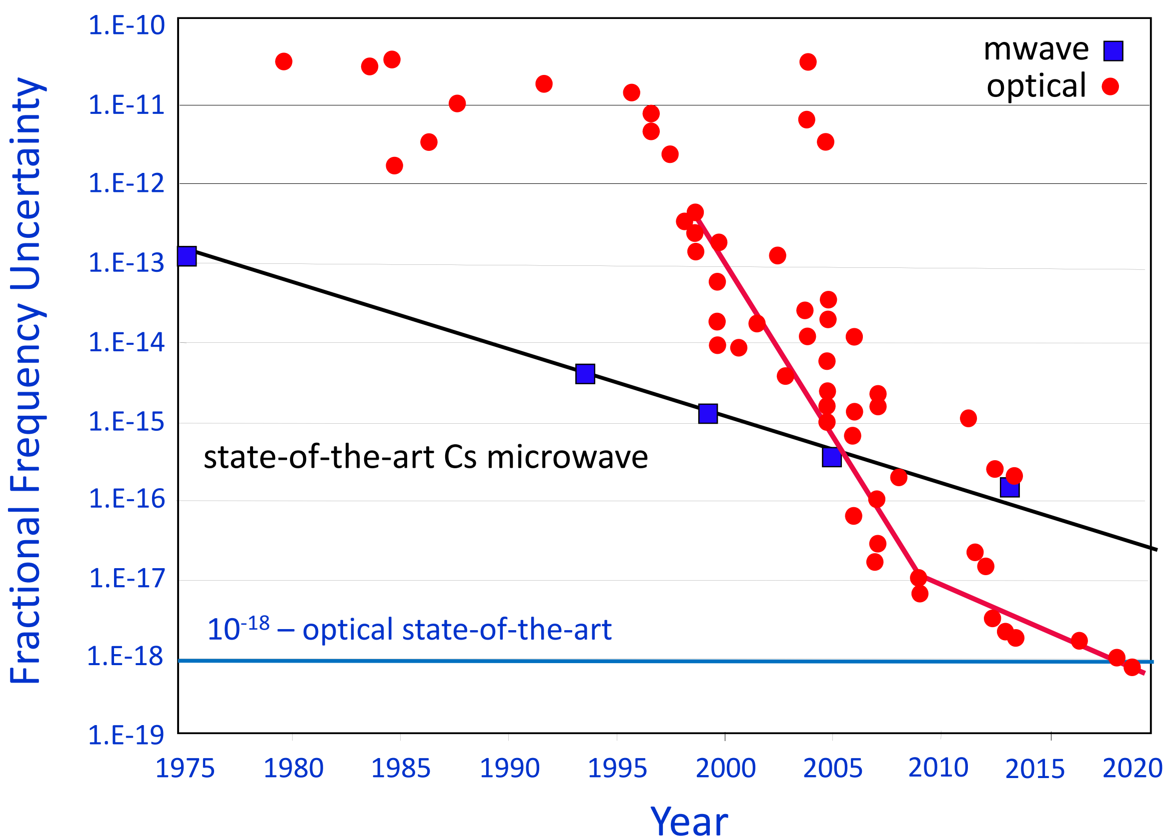
Science Definition Team

Chris Oates, NIST
Kurt Gibble, Penn State U.
Leo Hollberg, Stanford U.
Nate Newbury, NIST
Nan Yu, JPL

Collaborators

Andrei Derevianko, U. of Nev.-Reno
Marianna Safronova, U. of Del.
Laura Sinclair, NIST

Improvement of the Uncertainty of atomic clocks

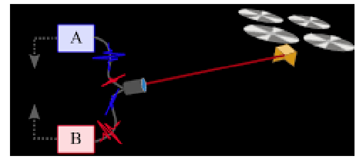


Impacts of Optical Frequency Clocks

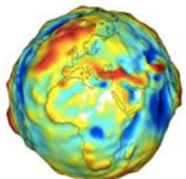
1. Metrology: Redefinition of the SI Second (within a decade?)

2. Time Transfer: clock performance surpasses long-distance time transfer capabilities (10^{-18} vs. 10^{-16})

Fiber networks over 100's km, free-space over 10's of km



3. Geodesy: clock performance exceeds geodetic knowledge at higher altitudes. 10^{-18} = 1 cm

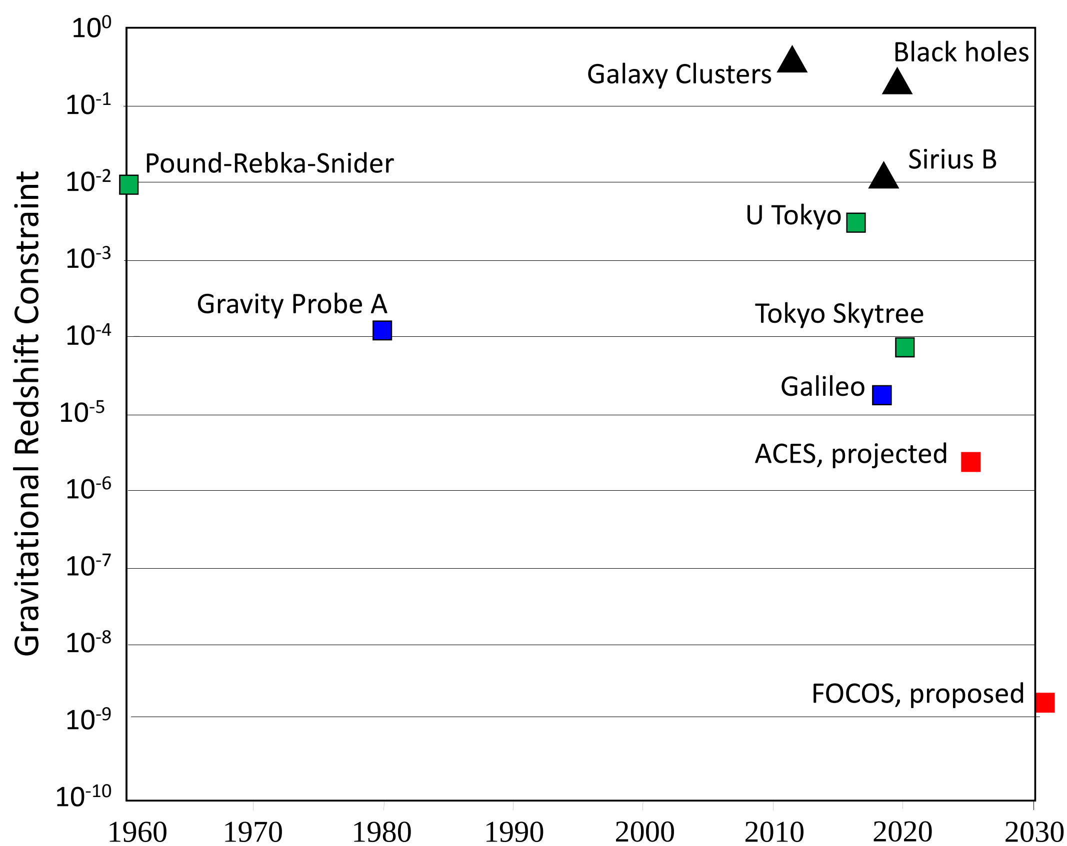

wiki.seg.org

Chronometric geodesy – clocks in space

4. New possibilities for next generation of fundamental physics tests

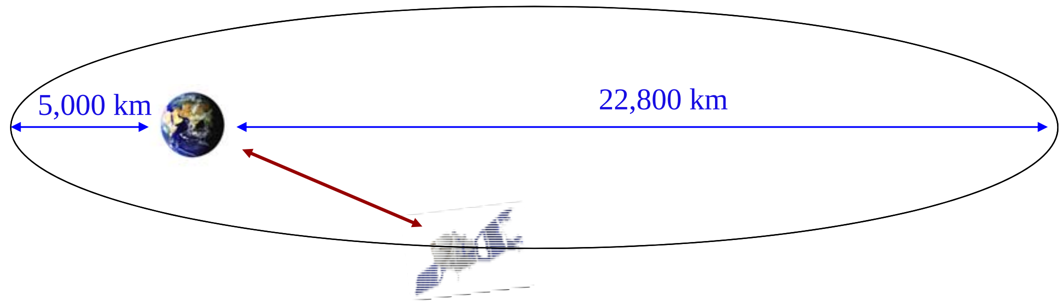
- Test General Relativity with much higher sensitivity
- Search for new physics

Tests of the Gravitational Redshift



FOCOS Mission concept

A high-performance optical clock in an elliptical orbit



Optical clock performance: $1 \times 10^{-16}\ t^{-1/2}$, 1×10^{-18} uncertainty

Optical link: $<1 \times 10^{-16}\ t^{-1}$, $< 5 \times 10^{-19}$ bias

Orbit location/velocity known to 5 mm/ mm/s (two-way Doppler link)

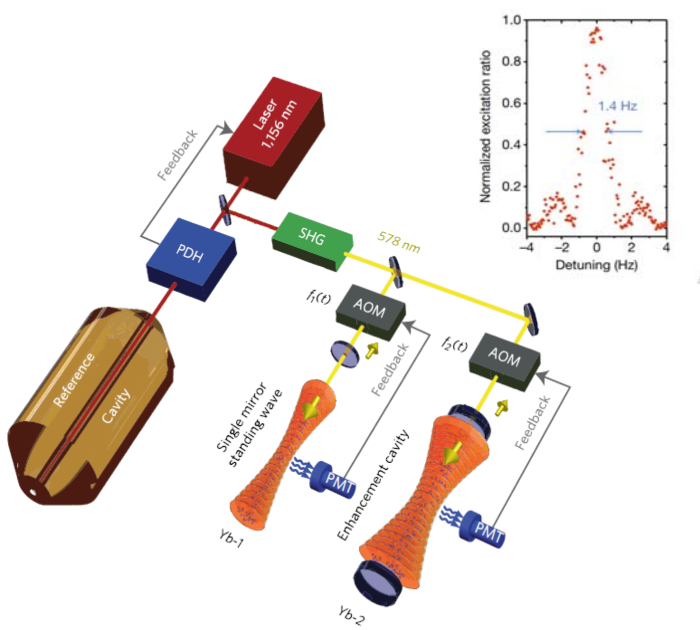
Orbit modulates gravitational potential: 2.4×10^{-10} variation

Orbit observation times (2 hours apogee, 30 minutes perigee) enable redshift uncertainty of 2.4×10^{-8} in a single 8-hour orbit.

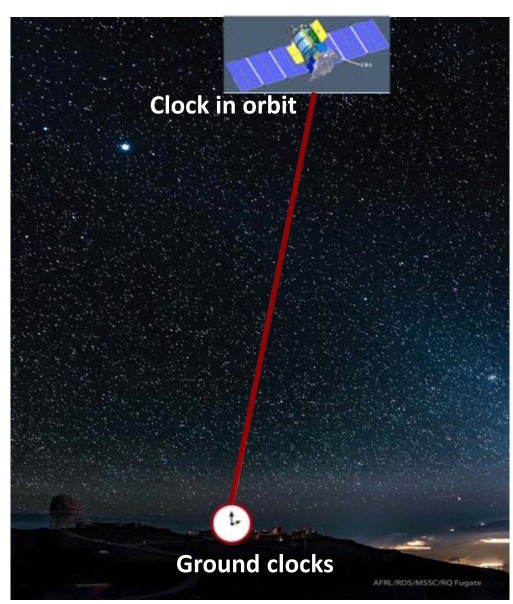
Average 100 orbits to reach 2.4 ppb.

FOCOS Schematic

Dual Yb Optical lattice clock



Two-way optical link

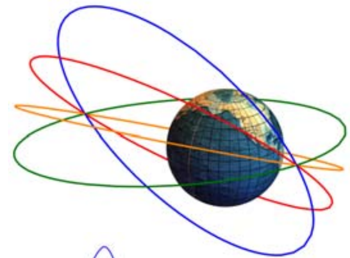


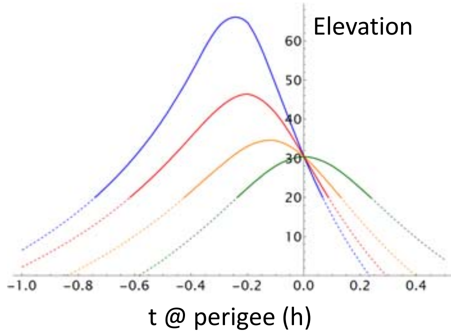
Choice of Orbit

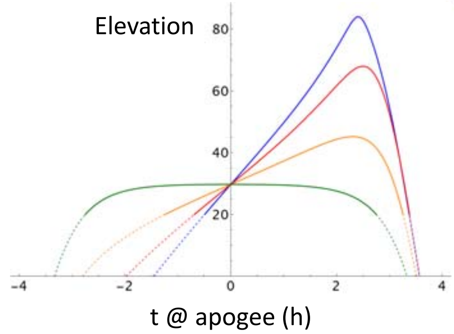
An 8-hour orbit enables observation of periapsis and apoapsis within 12 hours, and reasonable ranges for the laser link.

Decreasing the perigee altitude gives a larger redshift variation, at the cost of observation time (and drag for very low perigees).

An orbit inclination of 9.3° gives equal perigee and apogee maximum elevations of 30.4° at 40° N for a 5,000 km perigee altitude.







Detailed analysis is needed to determine precise period, RAAN, perigee altitude … to optimize worldwide visibility and redshift measurement.

FOCOS science goals

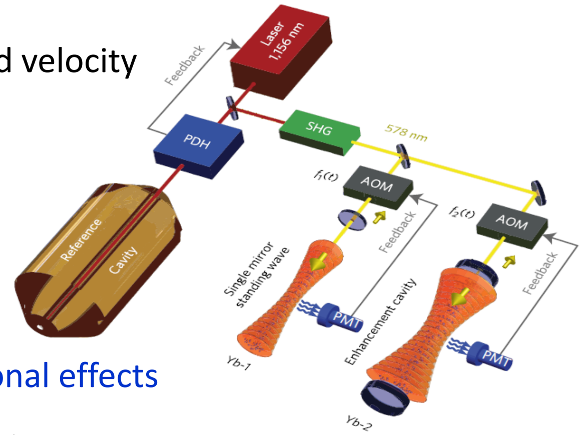
Fundamental physics:

1. Gravitational Redshift – improve the uncertainty by 30,000x

2. Local Lorentz Invariance (Kennedy-Thorndyke tests - SME coefficients)

   Cavity-clock comparisons - orientation and velocity

   Potential gains in sensitivity



3. Test higher-order relativistic and gravitational effects

   Requires precision orbit determination

   GRACE, etc. for the gravitational field

4. Post-Newtonian effects on the satellite orbit (through two-way link data)

FOCOS Science Goals – International Network

Improved network of earth clocks – a step towards a space network.

Fundamental physics:

5. Dark Matter searches in space and on Earth
6. LPI tests – e.g., drifts of fundamental constants

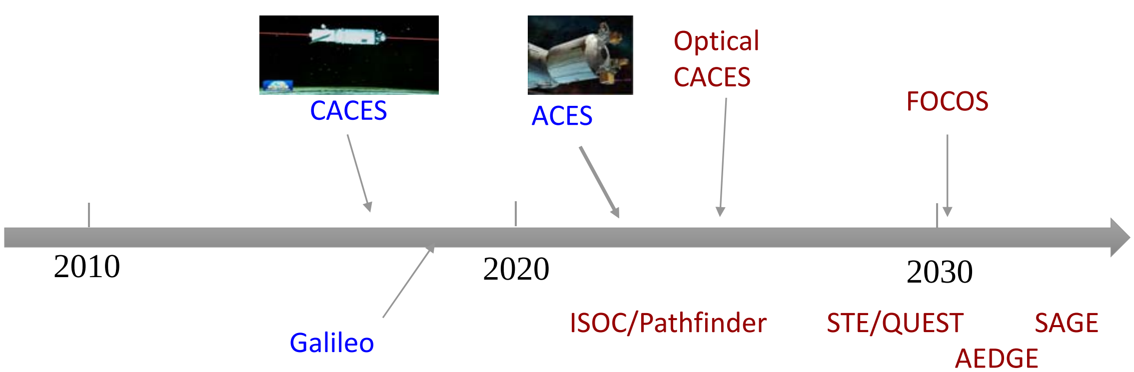
Timing applications:

7. Worldwide timing: ns to ps level
8. Precision geodetic referencing at the mm-level
9. Space-time reference

ACES

Pathfinder-style mission for future atom interferometry (Equivalence Principle), clock constellation in space, laser/atom-based gravity wave detection

Timelines



(Updates in other talks)

Open US call for white papers, due Oct 31st: nationalacademies.org, Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032

International collaborations are sought: SWaP research, reference cavities, lasers and link hardware, theoretical contributions …