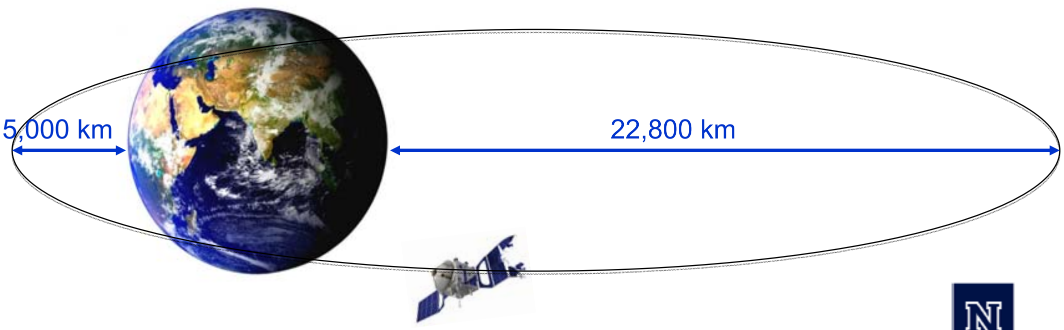
FOCOS Mission Concept – Fundamental physics with an Optical Clock Orbiting in Space



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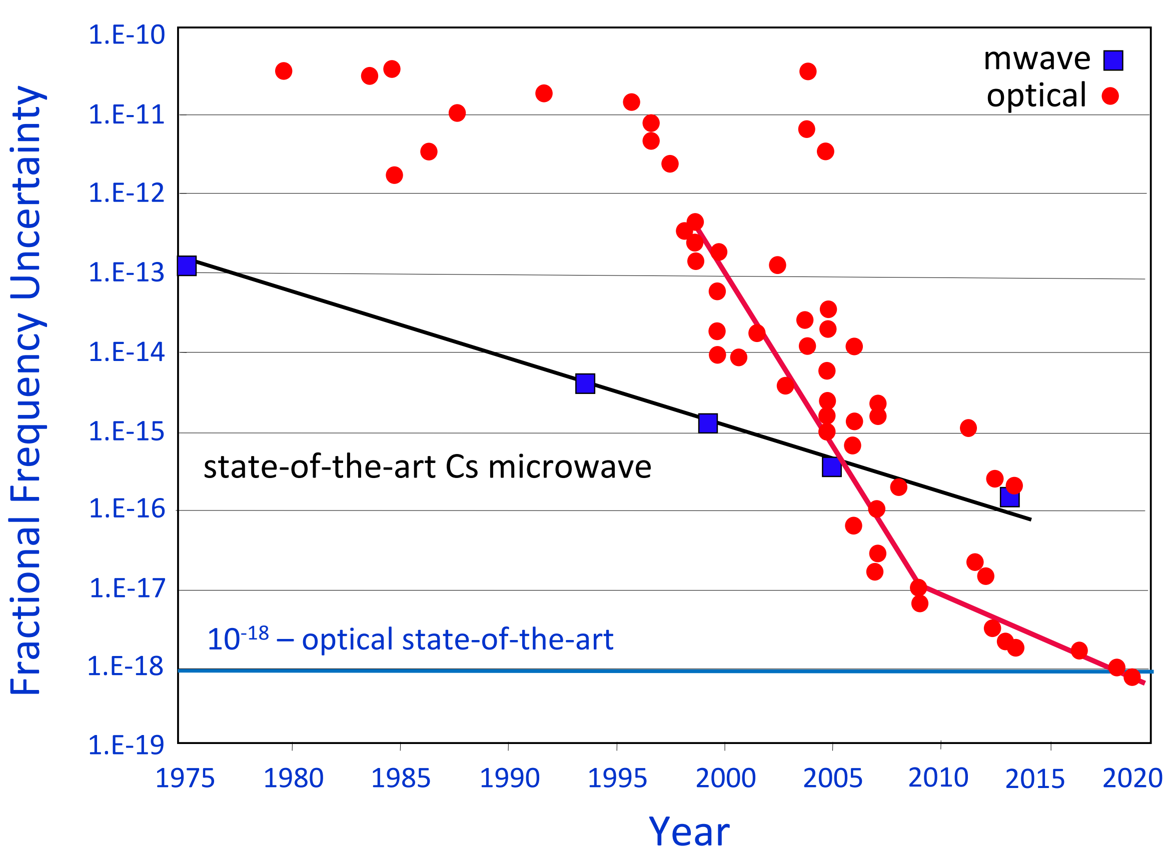
Improvement of the Uncertainty of atomic clocks

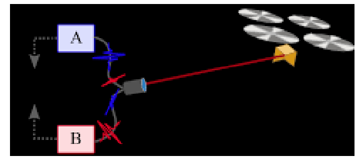


Impacts of Optical Frequency Clocks

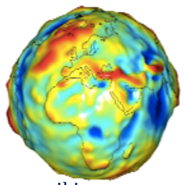
1. Metrology: Redefinition of the SI Second (within the next decade?)

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

Fiber networks over 1,000 km, free-space over 100 km.



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



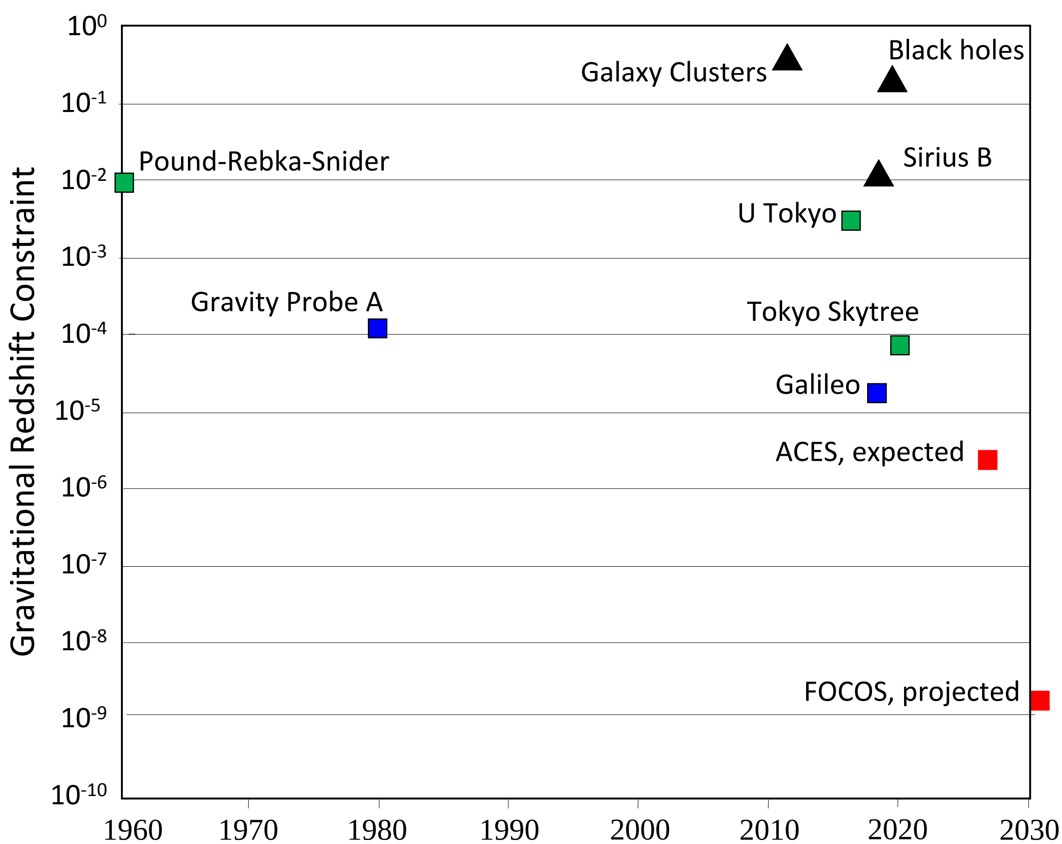
wiki.seg.org

Chronometric geodesy – clocks in space

4. New possibilities for next generation of fundamental physics tests

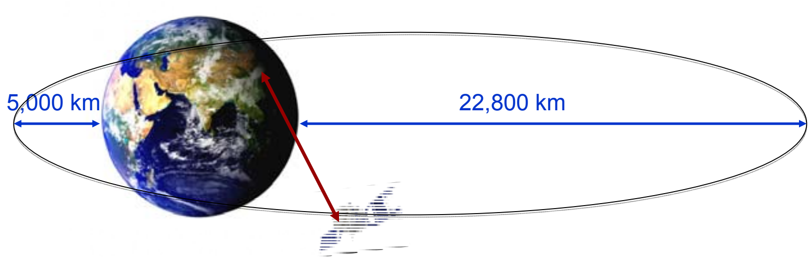
- Test General Relativity with much higher sensitivity
- Search for new physics

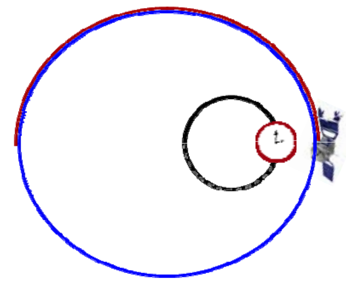
Tests of the Gravitational Redshift



FOCOS Mission concept

A high-performance optical clock in an elliptical orbit





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

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

Range at periapsis known to 1mm (two-way Doppler link) and velocity to 1μm/s.

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

Orbit observation times (2 hours apoapsis, 30 minutes periapsis) enable redshift uncertainty of 2.4×10^{-8} in 1½ 8-hour orbits.

Average 100 orbits to reach 2.4 ppb.

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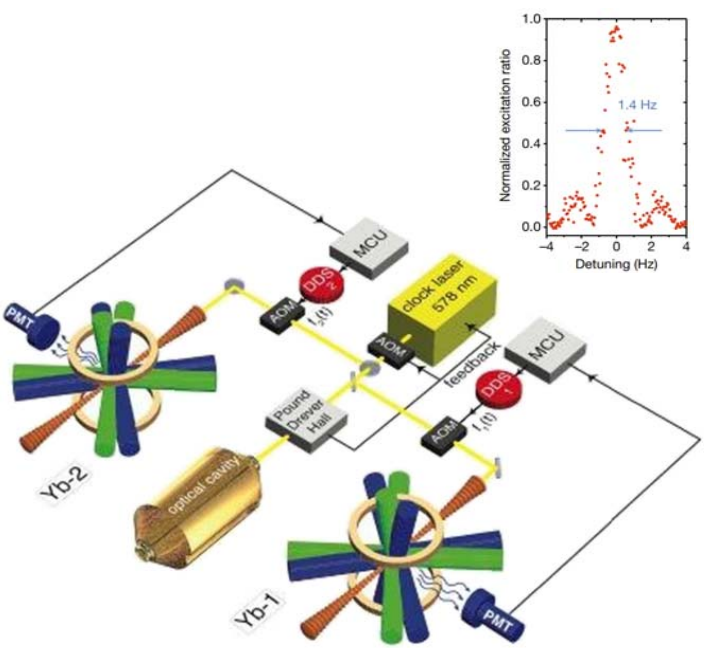
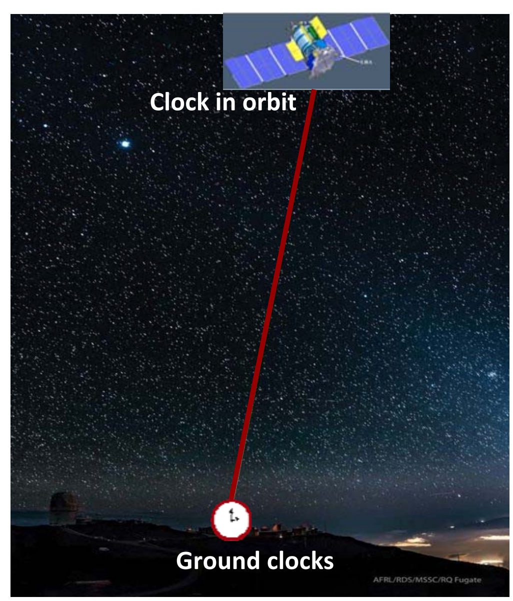
FOCOS Schematic

NIST Dual Yb Optical lattice clock



Two-way optical link

Talk after break by Fabrizio



FOCOS science goals

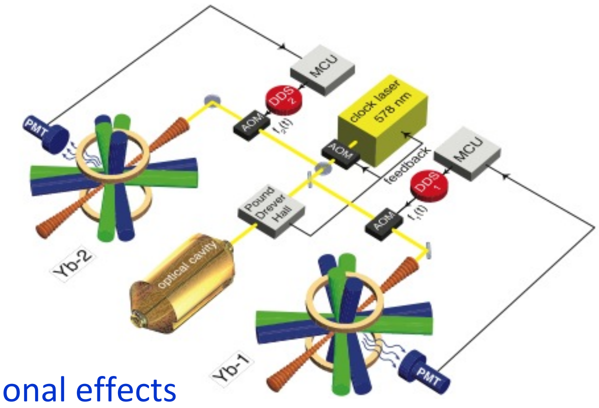
Fundamental physics:

1. Gravitational Redshift – improve the uncertainty by 30,000x to 2 ppb.

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

   Cavity-clock comparisons - orientation and velocity

   Large expected 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)

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FOCOS Science Goals – International Clock Network

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

Fundamental physics:

5. Dark Matter searches in space and on Earth
   – 100 to 1,000 × improvement

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

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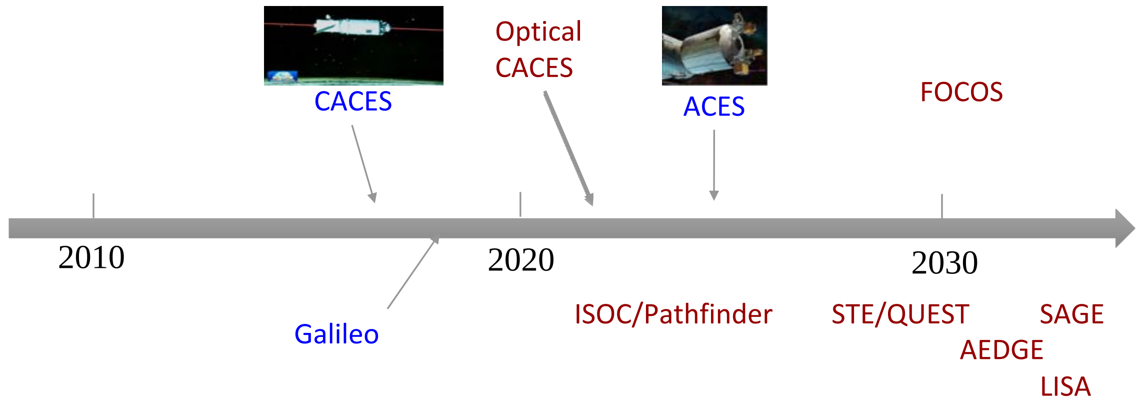
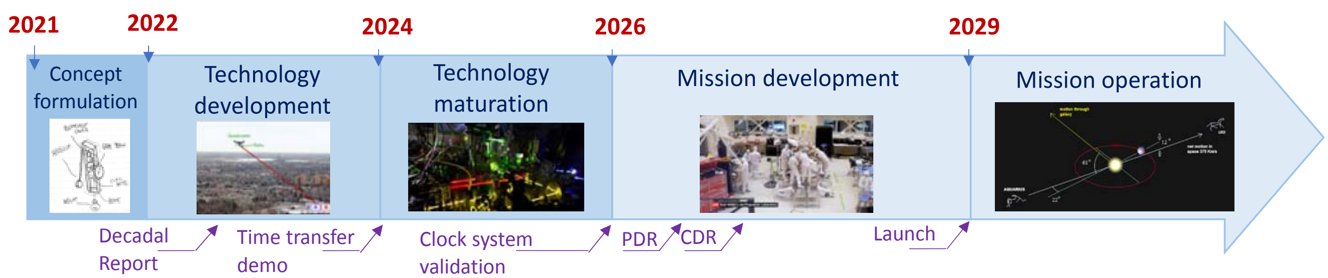
Timelines



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

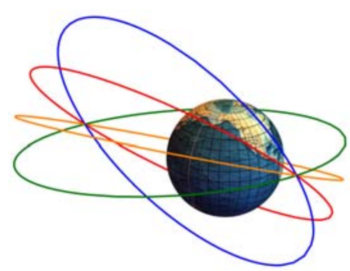


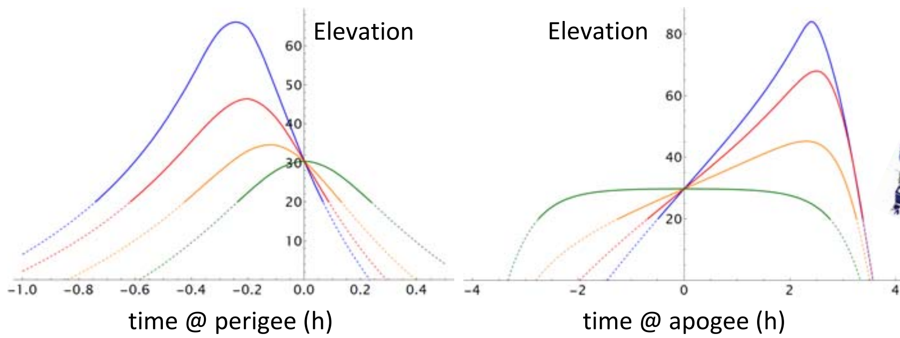
Choice of Orbit

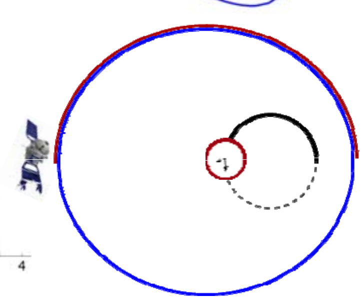
An 8-hour orbit enables observation of periapsis and apoapsis within 12 hours, and reasonable ranges for the laser link.

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° gives equal perigee and apogee maximum elevations of 30° 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.

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FOCOS Size Weight and Power

The first cost estimate ($451M*) for FOCOS conservatively used 500 W and 266 kg.

Actual power used by NIST portable Yb lattice clock is ~500 W (450 kg, 1.9 m^3, A. Ludlow).

Minimal effort to reduce power, mass and size.

Wesley Brand

A recent exercise estimated 200 W for a lattice clock with one comb (+ 50 W telescope and link with a 2nd comb, N. Newbury).

Target for $300M* NASA medium explorer mission class (Explorers Program) is 210 W, 227 kg, and 0.5 m^3.

A modest investment in SWaP development is likely to meet those requirements.

$5 to $10M of development may reduce mission cost by >$150M.*

(SWaP for a $200M* mission: 170 W & 125 kg)

Reducing lattice clock performance does not yield large cost reductions.

*Cost information is for budgeting and planning and is intended for informational purposes only. It does not constitute a commitment on the part of JPL or Caltech.

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