

The background of the slide is a light gray grid with a series of spheres arranged in a regular pattern. Each sphere is rendered with a white grid of latitude and longitude lines, giving it a three-dimensional appearance. The spheres are slightly offset from the grid lines, creating a sense of depth and perspective.

Extra Spacetime Dimensions?

Conor Sayres – Phys 485

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Why Extra Dimensions?

- Combine GR and QM
- Where does the Planck Scale fit?
- String Theory, M-theory....suggest presence of extra spatial dimensions

How can we look for them?

- Particle Accelerators
 - Look for ‘missing’ energy
- Look for deviations from Newtonian gravity
 - More on this later
- Observations of astro-physical phenomena
 - Observe effects of extremely high energy

Gravity Deviations-PPN Formalism

- GR gives specific values for parameters
- We can test (or set bounds for) these values

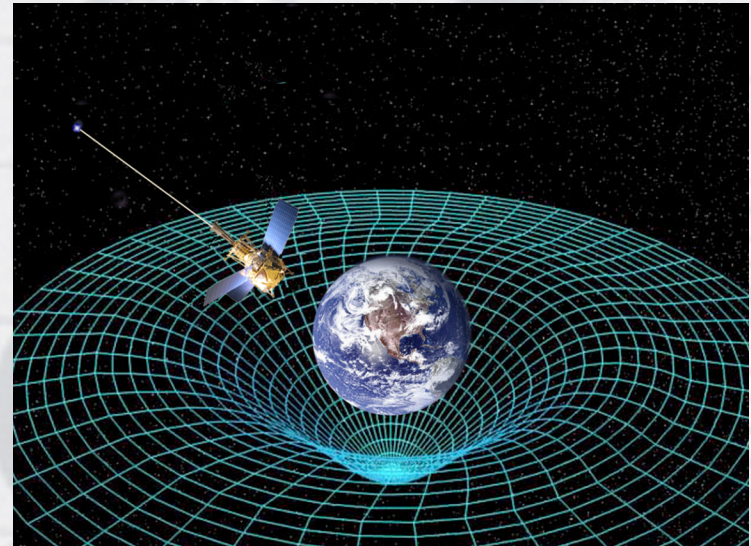
Parameter	Bound	Effects	Experiment
$\gamma - 1$	2.3×10^{-5}	Time delay, Light deflection	Cassini tracking
$\beta - 1$	2.3×10^{-4}	Nordtvedt effect, Perihelion shift	Nordtvedt effect
ξ	0.001	Earth tides	Gravimeter data
α_1	10^{-4}	Orbit polarization	Lunar laser ranging
α_2	4×10^{-7}	Spin precession	Sun axis' alignment with ecliptic
α_3	4×10^{-20}	Self-acceleration	Pulsar spin-down statistics
ζ_1	0.02	-	Combined PPN bounds
ζ_2	$4 \times 10^{-5}\dagger$	Binary pulsar acceleration	PSR 1913+16
ζ_3	10^{-8}	Newton's 3rd law	Lunar acceleration
ζ_4	0.006‡	-	Kreuzer experiment

† Will, C.M., *Is momentum conserved? A test in the binary system PSR 1913 + 16*, *Astrophysical Journal, Part 2 - Letters* (ISSN 0004-637X), vol. 393, no. 2, July 10, 1992, p. L59-L61. [↗](#)

Two cool experiments

- Gravity Probe B (GPB)
 - Decades of preparation
 - Launched 2004
 - Data analysis ongoing

- APOLLO
 - Launched 2005
 - Experiment ongoing



GPB – experimental setup

The Gravity Probe B Experiment

...testing Einstein's Universe

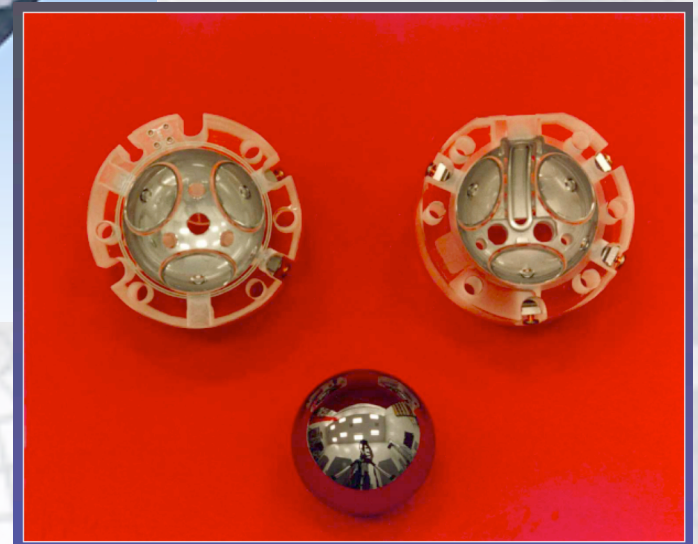
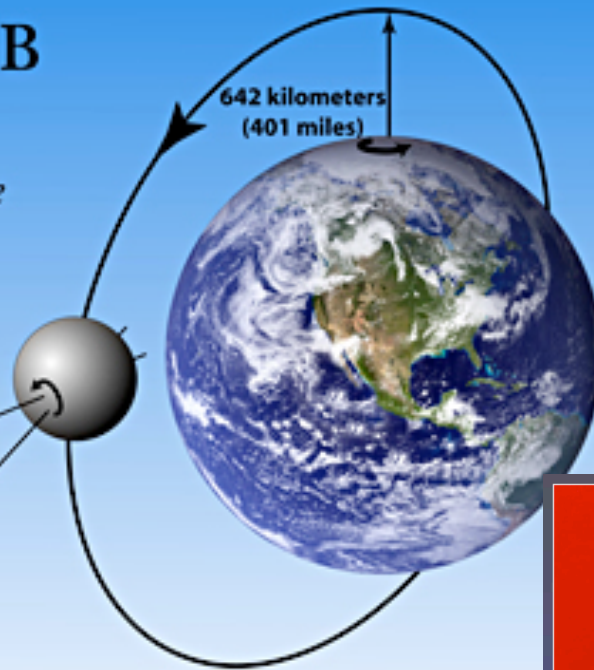
Frame-dragging Effect

0.041 arcseconds/year
(0.000011 degrees/year)

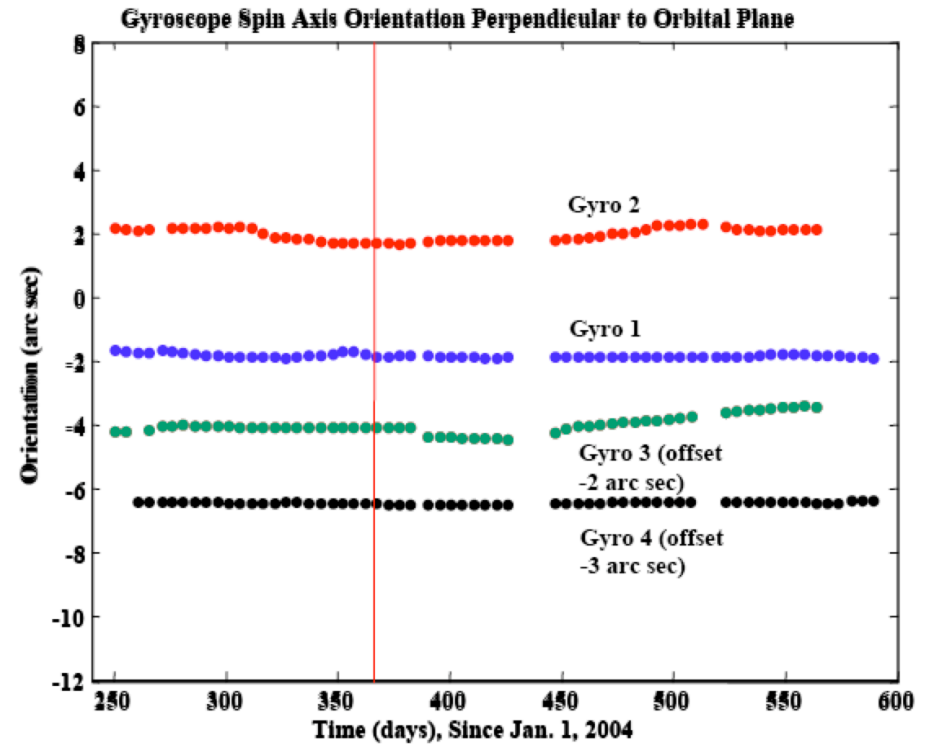
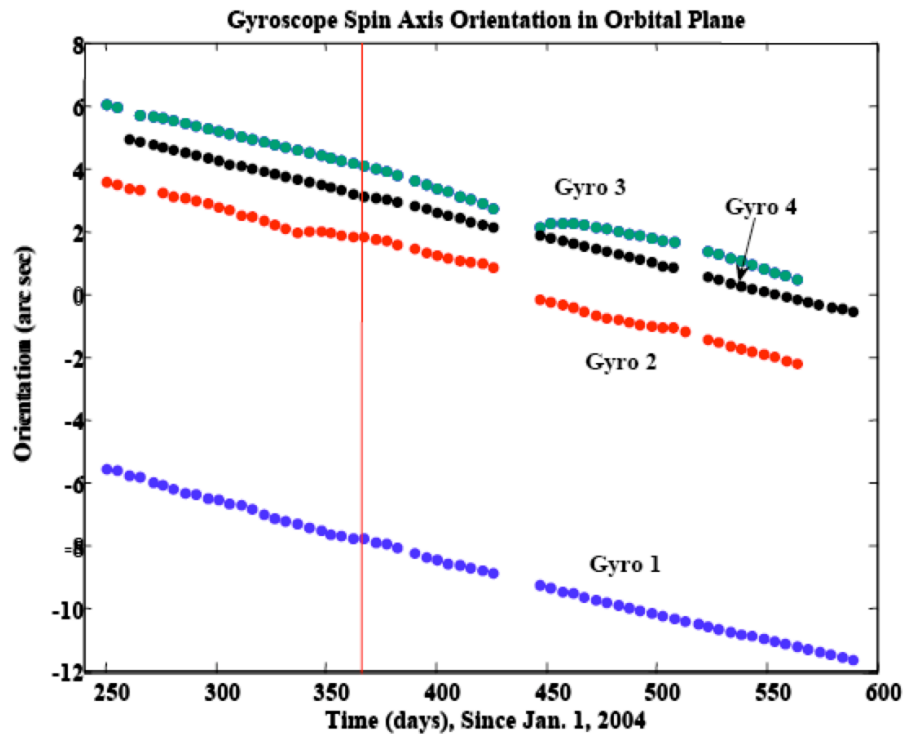
Guide Star
IM Pegasi
(HR 8703)

Geodetic Effect

6.6 arcseconds/year
(0.0018 degrees/year)



GPB – Some Results



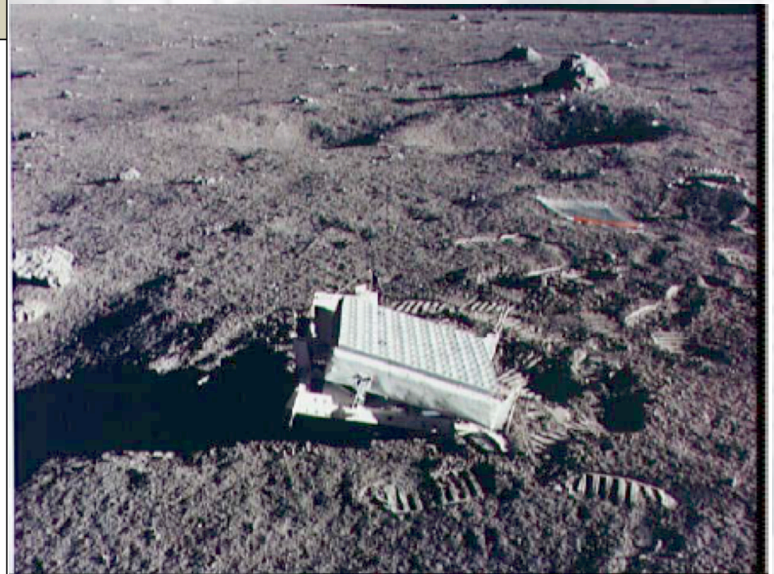
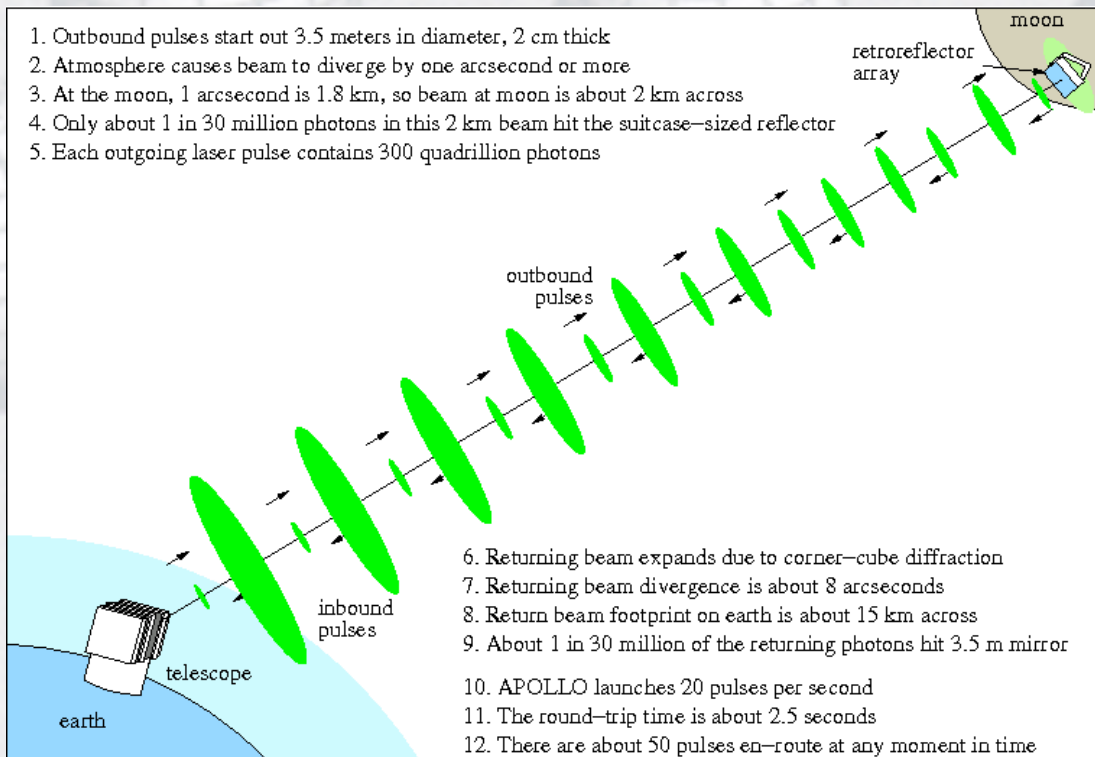
- Geodetic
 - Expected: $-6571 \pm 1 \text{ mas/year}$
 - Measured: $-6638 \pm 97 \text{ mas/year}$
- Frame-dragging
 - Not so clear “Our latest data analysis indicates clear observation of frame-dragging. The statistical uncertainty is 14% ($\sim 5 \text{ marcs/yr}$)”-GPB website claim.

APOLLO – motivations/theory

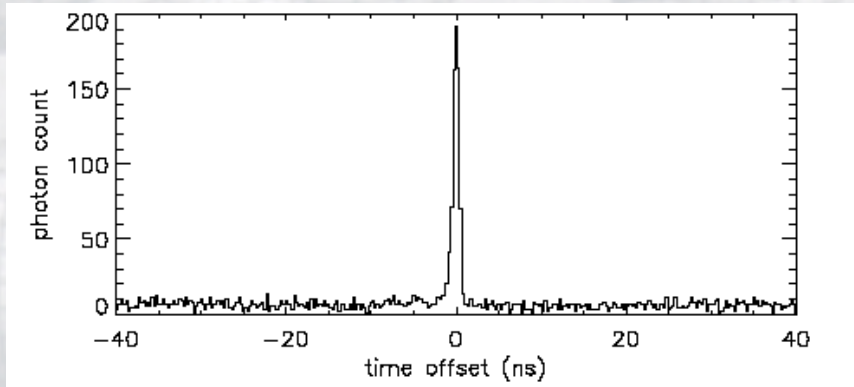
- Lunar Laser Ranging – Strong Equiv Principle
- Look to how Earth and Moon fall towards Sun.
- Nordtvedt Effect
- Existing LLR Data show no SEP violation at 5mm range, APOLLO will probe deeper

APOLLO – experimental setup

- Astronauts have deployed corner reflectors.



APOLLO – Progress



Now - .17 ns range corresponds to 1 inch. Good progress, still working out the kinks.

Later – accuracies to +/- 1 mm



Wrap up/where's it going

- Apollo, and other experiments ongoing (Eot Wash) testing gravity.
- LHC probe higher energy regimes
 - Continue to put bounds on spatial dimension sizes

Bibliography

- Keiser M., Presentation: Gravity Probe B: Data Analysis Challenges, Insights, and Results, April 15, 2007
- Murphy et al. Testing Gravity via Next-Generation Lunar Laser-Ranging, Nuclear Physics B, 2004
- Battat, J. Testing Gravity with APOLLO Apache Point Observatory Lunar Laser-Ranging Operation, 2004
- <http://einstein.stanford.edu/index.html>
- <http://www.physics.ucsd.edu/~tmurphy/apollo/>
- Glorious, infallible, Wikipedia.