Title: Testing the Validity of the Equivalence Principle via Noon-Midnight Doppler Compensation in the GPS System

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With generative structuring assistance from ChatGPT (OpenAI)

Abstract

We propose an experiment based on GPS satellite clocks to probe the validity of the Equivalence Principle (EP). We focus on the apparent absence of a classical first-order Doppler effect due to the geocentric system's acceleration in the solar gravitational field. This missing effect is potentially compensated by a gravitational redshift arising from a uniform external potential. This compensation parallels that of the Pound-Rebka experiment, suggesting that the observed null result may not reflect coordinate cancellation, but a physical effect. We argue that if the Doppler contribution should exist objectively in both GCRS and BCRS, then its absence in observation implies a real gravitational influence of the solar potential on local time, in contradiction with a strong form of the EP.

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1. Introduction

The Equivalence Principle (EP) is a foundational concept in general relativity, stating that local experiments in a freely falling frame cannot detect the presence of a gravitational field. While the EP has been tested in numerous forms, GPS systems provide an opportunity to test it in an astrophysical context with unprecedented clock precision (ns and sub-ns).

In this work, we focus on a potential first-order Doppler effect in GPS signals observed in the Geocentric Celestial Reference System (GCRS), which moves with acceleration relative to the Barycentric Celestial Reference System (BCRS) due to the Sun's gravitational field. If this acceleration produces a Doppler shift that is subsequently canceled by a gravitational redshift from a uniform solar potential, it would mirror the classical compensation observed in the Pound-Rebka experiment.

This suggests that the solar gravitational field affects GPS clocks in a physically observable way, and not merely as a coordinate artifact, thus challenging the strong version of the EP.

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2. TCG-TCB Differential Transformation and the Role of the Solar Potential

According to IAU 2000 resolutions, the relation between the Barycentric Coordinate Time (TCB) and Geocentric Coordinate Time (TCG) includes a term depending on the external gravitational potential and the velocity of Earth's center:

$$\frac{dTCG}{dTCB} = 1 - \frac{1}{c^2}\left(\frac{v_E^2}{2} + U_{\text{ext}}(\vec{x}_E)\right) + \mathcal{O}(c^{-4})$$

Here, U_{ext} represents the solar potential at the geocenter. The key insight is that this term appears despite the uniformity of the potential, suggesting a dependency of time flow on gravitational background even in locally free-falling frames.

This casts doubt on the claim that GCRS observers are truly shielded from external gravitational effects, a central assumption in EP.

3. Doppler Effect and Its Frame Invariance

The classical first-order Doppler effect is known to be invariant under coordinate transformations. In both GCRS and BCRS, the relative velocity difference between signal emitter and receiver contributes identically to frequency shifts. In BCRS, the GPS satellite and Earth receiver are in non-inertial motion due to orbital acceleration. Therefore, a Doppler shift is expected.

If this shift is not observed in GCRS, it cannot be attributed to coordinate choice. The physical effect must be either present or somehow canceled by another influence.

4. Noon–Midnight Signal Analysis and Gravitational Compensation

The expected frequency shift between a GPS satellite on the 'noon' side (closest to the Sun) and on the 'midnight' side (opposite direction) due to first-order Doppler should manifest in GCRS because of its acceleration. The magnitude of this effect is similar to the solar gravitational redshift over Earth's diameter ($\sim 10^{-12}$).

Empirically, no such shift is observed — nor is the gravitational component seen independently. The most plausible explanation is that these two contributions cancel, exactly as in the Pound–Rebka experiment where gravitational redshift compensates for a velocity-related Doppler shift.

This cancellation would be physical, not coordinate-based — implying a violation of the EP.

5. Experimental Consequences and GPS Clock Data

Studies such as those by Kenneth L. Senior, Jim Ray, Ronald L. Beard, and Demetrios Matsakis have identified unexplained periodic variations in GPS satellite clocks, some of which could be reinterpreted through the lens of Doppler-gravitational compensation.

A targeted test would involve analyzing clock frequency variations for a GPS satellite (e.g., PRN01) over a week, correlating shifts with the solar direction angle. The absence or presence of the expected signal can provide empirical input to assess whether the Doppler term is compensated by the external gravitational field.

6. Conclusion

We argue that the absence of a first-order Doppler term in GCRS GPS signal analysis, despite its theoretical necessity, suggests a real compensation by solar gravitational potential. This compensation parallels the Pound–Rebka experiment and implies that even a uniform external field has observable local effects. Such a conclusion would signal a violation of the strong form of the Equivalence Principle and motivate renewed experimental focus using high-precision satellite data.

References

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