NEW TESTS OF LOCAL LORENTZ INVARIANCE AND LOCAL POSITION INVARIANCE OF GRAVITY WITH PULSARS

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New tests are proposed to constrain possible deviations from local Lorentz invariance and local position invariance in the gravity sector. By using precise timing results of two binary pulsars, i.e., PSRs J1012+5307 and J1738+0333, we are able to constrain (strong-field) parametrized post-Newtonian parameters \(\hat{\alpha}_1\), \(\hat{\alpha}_2\), \(\hat{\xi}\) to high precision, among which, 
\[|\hat{\xi}| < 3.1 \times 10^{-4}\] (95% C.L.) is reported here for the first time.

**Keywords:** Local Lorentz Invariance; Local Position Invariance; Pulses

1. Introduction

The Einstein equivalence principle (EEP) is a far-reaching concept in the heart of many gravity theories. If EEP is valid, then gravitation must be a curved-spacetime phenomenon. As a direct consequence, gravity theories which fully embody EEP are the so-called “metric theories of gravity”\(^{16,17}\). The validity of EEP involves three different aspects, namely the weak equivalence principle, the local Lorentz invariance (LLI), and the local position invariance (LPI)\(^{17}\).

In the parametrized post-Newtonian (PPN) framework\(^{16–18}\), we present the orbital dynamics of binary systems from a generic semi-conservative Lagrangian, based on which, new tests of strong-field LLI-violating PPN parameters, \(\hat{\alpha}_1\) and \(\hat{\alpha}_2\), are proposed\(^9\). New limits are obtained from small-eccentricity relativistic neutron star (NS) white dwarf (WD) systems, PSRs J1012+5307\(^5,6\) and J1738+0333\(^4\). Here we briefly summarize the analysis and results of Ref.\(^{10}\). We also propose a new test of the strong-field LPI-violating PPN parameter, \(\hat{\xi}\), and get a new limit 
\[|\hat{\xi}| < 3.1 \times 10^{-4}\]. All limits in this proceeding contribution correspond to 95% confidence level, and the PPN parameters with “hat” represent the strong-field generalization of the weak-field PPN parameters (without hat). The preferred frame is assumed to be defined by the isotropic CMB background.

2. Local Lorentz invariance

LLI violation in the gravity sector is described by \(\alpha_1\) and \(\alpha_2\) in the PPN framework\(^{18}\) and these two parameters are constrained by various observations of geophysics, Solar System, and pulsar timing experiments\(^{2,3,7–9,13,14}\). Recently in Ref.\(^{10}\), we find that the effects of \(\hat{\alpha}_1\) and \(\hat{\alpha}_2\) on the binary orbital dynamics decouple and manifest characteristic signatures when the orbital eccentricity is small (see Fig. 1 in Ref.\(^{11}\) for illustrations), hence they can be constrained individually.
Damour and Esposito-Farèse are the first to work out the effects of $\hat{\alpha}_1$ on orbital dynamics of pulsar binaries. After dropping $\hat{\alpha}_2$ related terms, they found that in the limit of a small eccentricity, $\hat{\alpha}_1$ induces a polarization of the orbit. The effect linearly depends on $\hat{\alpha}_1$ and the binary velocity with respect to the preferred frame, $w$. Due to unknown angles, previous methods can only get probabilistic limits on $\hat{\alpha}_1$. Ref. 10 demonstrates that, given a sufficiently long observing time span, the large periastron advance would be able to overcome probabilistic assumptions. By utilizing the limits of eccentricity variations, we get a robust and conservative constraint,

$$\hat{\alpha}_1 = -0.4^{+3.7}_{-3.1} \times 10^{-5},$$

from PSR J1738+0333. It surpasses the current best limit from LLR by a factor of five.

In the limit of a small eccentricity, $\hat{\alpha}_2$ induces a precession of the orbital angular momentum around $w$. It changes the orientation of the orbital plane with respect to the Earth. After subtracting other potential astrophysical and gravitational contributions, we get a combined limit from PSRs J1012+5307 and J1738+0333,

$$|\hat{\alpha}_2| < 1.8 \times 10^{-4}.$$

This limit is still three orders of magnitude less constraining than the limit given in Ref. 8, however, it is obtained for a strongly self-gravitating body.

### 3. Local position invariance

LPI violation is described by the Whitehead’s term, characterized by $\xi$. Even for fully conservative theories of gravity one may have a $\xi \neq 0$. From its Lagrangian, we can immediately identify its analogy with the $\alpha_2$ term by replacing $w$ into $v_G \equiv |\Phi_G|^{1/2}n_G$ and $\alpha_2$ into $-2\xi$, where $\Phi_G$ is the Galactic potential at the position of the binary, and $n_G$ is the direction of the Galactic acceleration. Hence, for small-eccentricity binaries, $\xi$ induces a precession of orbital angular momentum around $n_G$, which causes a change in the binary orientation. The same analysis done for $\hat{\alpha}_2$ in Ref. 10 applies to the $\hat{\xi}$ test. The probability distributions of $\xi$ from PSRs J1012+5307, J1738+0333, and their combination are illustrated in Fig. 1 (cf. Fig. 4 in Ref. 10). From their combination, we get

$$|\hat{\xi}| < 3.1 \times 10^{-4},$$

which surpasses the limit from the non-detection of anomalous Earth tide in gravimeter data by one order of magnitude.

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Fig. 1. Probability distributions of $\xi$ from binary pulsars PSRs J1012+5307 (dotted blue), J1738+0333 (dashed red) and their combination (solid black).

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