Part 2
Precision Measurements

Section C
Relativity

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Testing the Strong Equivalence Principle in strong field regimes

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A possible functional dependence of the ratio of 'gravitational' mass m_G and 'inertial' mass m_I on the gravitational self-energy E_G,

$$\frac{m_G}{m_I} \equiv 1 + \Delta[E_G/mc^2] = 1 + \eta(E_G/mc^2) + \eta'(E_G/mc^2)^2 + \dots , \qquad (1)$$

is called a *violation of the Strong Equivalence Principle (SEP).*

Weakly self-gravitating bodies are found in the solar system where lunar-laser-ranging data restrict the Nordtvedt parameter η to absolute values smaller than 0.001, (Dickey et al. 1994, Müller et al. 1995). To test higher order contributions one needs to consider strongly self-gravitating bodies such as neutron-stars.

Small-eccentricity binary-star systems consisting of a neutron star ($|E_G|/mc^2 \sim 0.15$) and a white dwarf ($|E_G|/mc^2 \sim 10^{-4}$) are excellent 'laboratories' to test the SEP in a strong-field regime. As shown by Damour and Schäfer (1991) a violation of the SEP would lead to a periodic change in the eccentricity of the orbit of the binary pulsar caused by the galactic acceleration. Thus the observation of *old small-eccentricity long-orbital-period neutron-star white-dwarf binary systems* put (with a certain confidence level) a limit on the violation of the SEP.

Here we investigate newly discovered small-eccentricity binary pulsars with $P_b^2/e > 10^7$ days^2 for testing the SEP: J1455−3330, J1640+2224, J1643−1224, J1713+0747, B1800−27, B1953+29, J2019+2425, J2229+2643 (see Taylor et al. 1993/1995 and references in there)

To be able to get a limit on $|\Delta_p - \Delta_c|$ we have to know two of the four parameters M, m_p, m_c, i (total mass, mass of the pulsar, mass of the white dwarf companion, inclination of the orbit with respect to the line of sight). We use three facts to restrict these parameters for the binary pulsars given here:

- In case of PSR J1713+0747 the Shapiro delay caused by the companion is measured (see Camilo et al. 1994).
- We use $m_p = 1.0 \dots 1.8 M_\odot$ (cf. Finn 1994).
- The mass of the companion white dwarf is restricted by the orbital period (see Rappaport et al. 1995).

Assuming an error of 25% in the determination of the distance of the pulsar from Earth (Taylor and Cordes 1993) we find the following confidence levels for a given value of $\Delta \simeq \Delta_p$ (Wex 1996):

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Pulsar	$\|\Delta\| \leq$ 1%	$\|\Delta\| \leq$ 0.5%	$\|\Delta\| \leq$ 0.4%	$\|\Delta\| \leq$ 0.3%	$\|\Delta\| \leq$ 0.2%
J1455−3330	0.82	0.32	0.00	0.00	0.00
J1640+2224	0.72	0.37	0.08	0.00	0.00
J1643−1224	0.73	0.40	0.23	0.00	0.00
J1713+0747	0.92	0.82	0.77	0.61	0.00
B1953+29	0.74	0.44	0.00	0.00	0.00
J2019+2425	0.80	0.55	0.43	0.21	0.00
J2229+2643	0.83	0.24	0.00	0.00	0.00
B1800−27	0.95	0.92	0.90	0.87	0.80

The values for PSR B1800−27 are not definite limits on a violation of the SEP since the evolutionary history for this binary pulsar is unclear. It might be that PSR B1800−27 is not old enough ($\gg 3 \times 10^7$ years) to provide a test for the SEP.

Combining the results of all the (statistically independent) test systems we find

$$|\Delta| < 0.3\% \qquad (0.5\% \text{ without B1800−27}) \tag{2}$$

with a confidence level (C.L.) of 95%.

This enables us to present limits on the tensor-multi-scalar theories of Damour and Esposito-Farèse. For the two parameters of the second post-Newtonian approximation of tensor-multi-scalar theories (Damour and Esposito-Farèse 1996) we find the (conservative) limit

$$|\varepsilon/2 + \zeta| < 0.03 \qquad (0.05 \text{ without B1800−27}) \tag{3}$$

with a confidence of 95%.

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