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Solar System Expansion and Strong Equivalence Principle as seen by the MESSENGER mission

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The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft orbited the planet Mercury from March 2011 to April 2015. The Radio Frequency (RF) telecommunication subsystem onboard enabled precise range-rate and range observations to characterize the properties of the planet interior with the radio science investigation. Furthermore, this dataset represents a great opportunity to test Einstein's Theory of General Relativity (GR) and to study the evolution of the Sun from accurate measurements of Mercury's ephemeris.

The MESSENGER range data showed a precision of 1-2 m outside of superior solar conjunctions (Sun-Mercury-Earth angles $> 35^{\circ}$). These accurate observations of the spacecraft relative distance to Earth's Deep Space Network (DSN) stations allowed us to measure precisely the precession of Mercury's perihelion that relies on GR Parameterized Post-Newtonian (PPN) coefficients γ and β, the gravitational parameter ($GM_{\odot}$) and the flattening (J_2) of the Sun, and the gravitomagnetic Lense-Thirring effect.

We processed MESSENGER range-rate and range data of the full mission that includes three Mercury flybys (January and September 2008, and September 2009) with a novel technique that is based on the co-integration and co-estimation of the MESSENGER and Mercury orbits. This method and the seven-year data span enabled us to test the Strong Equivalence Principle (SEP) and to measure the expansion of Mercury's orbit due to the time variation of the solar gravitational constant.

Our results confirm the validity of the SEP with a significantly improved uncertainty of the Nordtvedt parameter η=(-6.6$\pm$7.2)$\times 10^{-5}$. Furthermore, we estimated the time variation of the Sun's gravitational parameter $G\dot{M}_{\odot}/GM_{\odot}$=(-6.13$\pm$1.47)$\times 10^{-14}$ yr^{-1}, which is fully in agreement with the expected solar mass loss due to the solar wind and interior processes. This new measurement thus also gives an important constraint on $\left|\dot{G}\right|/G$ to be less than 4×10^{-14} yr^{-1}.