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Next-Generation Lunar and Martian Laser Retro-Reflectors

Authors : Simone Dell'Agnello

Abstract : There are laser retroreflectors on the Moon and no laser retroreflectors on Mars. Here we describe the design, construction, qualification and imminent deployment of next-generation, optimized laser retroreflectors on the Moon and on Mars (where they will be the first ones). These instruments are positioned by time-of-flight measurements of short laser pulses, the so-called 'laser ranging' technique. Data analysis is carried out with PEP, the Planetary Ephemeris Program of CfA (Center for Astrophysics). Since 1969 Lunar Laser Ranging (LLR) to Apollo/Lunokhod laser retro-reflector (CCR) arrays supplied accurate tests of General Relativity (GR) and new gravitational physics: possible changes of the gravitational constant Gdot/G, weak and strong equivalence principle, gravitational self-energy (Parametrized Post Newtonian parameter beta), geodetic precession, inverse-square force-law; it can also constraint gravitomagnetism. Some of these measurements also allowed for testing extensions of GR, including spacetime torsion, non-minimally coupled gravity. LLR has also provides significant information on the composition of the deep interior of the Moon. In fact, LLR first provided evidence of the existence of a fluid component of the deep lunar interior. In 1969 CCR arrays contributed a negligible fraction of the LLR error budget. Since laser station range accuracy improved by more than a factor 100, now, because of lunar librations, current array dominate the error due to their multi-CCR geometry. We developed a next-generation, single, large CCR, MoonLIGHT (Moon Laser Instrumentation for General relativity high-accuracy test) unaffected by librations that supports an improvement of the space segment of the LLR accuracy up to a factor 100. INFN also developed INRRI (INstrument for landing-Roving laser Retro-reflector Investigations), a microreflector to be laser-ranged by orbiters. Their performance is characterized at the SCF_Lab (Satellite/lunar laser ranging Characterization Facilities Lab, INFN-LNF, Frascati, Italy) for their deployment on the lunar surface or the cislunar space. They will be used to accurately position landers, rovers, hoppers, orbiters of Google Lunar X Prize and space agency missions, thanks to LLR observations from station of the International Laser Ranging Service in the USA, in France and in Italy. INRRI was launched in 2016 with the ESA mission ExoMars (Exobiology on Mars) EDM (Entry, descent and landing Demonstration Module), deployed on the Schiaparelli lander and is proposed for the ExoMars 2020 Rover. Based on an agreement between NASA and ASI (Agenzia Spaziale Italiana), another microreflector, LaRRI (Laser Retro-Reflector for InSight), was delivered to JPL (Jet Propulsion Laboratory) and integrated on NASA's InSight Mars Lander in August 2017 (launch scheduled in May 2018). Another microreflector, LaRA (Laser Retro-reflector Array) will be delivered to JPL for deployment on the NASA Mars 2020 Rover. The first lunar landing opportunities will be from early 2018 (with TeamIndus) to late 2018 with commercial missions, followed by opportunities with space agency missions, including the proposed deployment of MoonLIGHT and INRRI on NASA's Resource Prospectors and its evolutions. In conclusion, we will extend significantly the CCR Lunar Geophysical Network and populate the Mars Geophysical Network. These networks will enable very significantly improved tests of GR.

Keywords : general relativity, laser retroreflectors, lunar laser ranging, Mars geodesy
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