Next-Generation Laser Retroreflectors for the Science and Exploration of the Moon, Mars and Beyond.

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Introduction. We developed next-generation laser retroreflectors for solar system science and exploration in the framework of the Affiliation membership of INFN to NASA/SSERVI (Solar System Exploration Virtual Institute), INFN National Science Committees n. 5 (devoted to R&D) and n. 2 (devoted to science) [1] and in collaboration with ASI, the Italian Space Agency. Applications cover landing and roving missions to the Moon, Mars (ExoMars 2016 lander, ExoMars 2020 Rover and Mars 2020 Rover) to future or proposed missions to Phobos/Deimos (sample return), icy/rocky moons of Jupiter/Saturn and asteroids/comets (ESA's AIM). These retroreflectors have been or will be fully characterized at the SCF_Lab (Satellite/lunar/gnss laser ranging/altimetry Cube/microsat Characterization Facilities Laboratory), a unique and dedicated infrastructure of INFN-LNF, in Frascati (Rome), Italy (www.lnf.infn.it/esperimenti/etrusco/) [2] and at vibration qualified at certified facilities.

We will present analysis work and simulations performed with CfA's Planetary Ephemeris Program sw package to test General Relativity (GR) and new gravitational physics with missions to the Moon (under an agreement among INFN, Moon Express Inc and the Univ. of Maryland) and Mars, continuing and extending the work done for the Moon with Apollo and Lunokhod cube corner laser retroreflectors (see [3] [4] [5] and refs. by March et al in [6]).

Next-Generation Lunar Laser Retroreflectors

Concerning the Moon, our main goals are lunar exploration, geodesy and precision tests of General Relativity (GR) and new gravitational physics, continuing and extending up to a factor 100 the reach of Apollo and Lunokhod laser retroreflectors. We developed a large (4" = 100 mm optical diameter), single retroreflector (MoonLIGHT, Moon Laser Instrumentation for General relativity High accuracy Tests). Since it is unaffected by the lunar librations that currently limit the accuracy of Lunar Laser Ranging (LLR) to Apollo/Lunokhod reflectors, MoonLIGHT will support significantly measurements by ground stations of the International Laser Ranging Service (ILRS). MoonLIGHT, also dubbed LLRRA21, Lunar Laser Retroreflector Array for the 21st century, is shown in Fig. 1, next to an Apollo laser retroreflector.

Figure 1: MoonLIGHT (4"), Apollo (1.5") reflectors

INFN, UMD and MEI signed a private-public partnership, multi-mission agreement to deploy MoonLIGHT on the Moon (1st mission: end 2017/early 2018). The results of an optical performace characterization of MoonLIGHT carried out at the SCF_Lab is in Fig. 2.

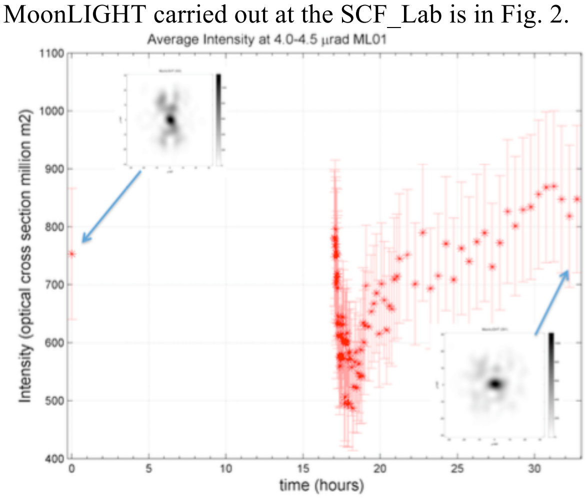

Figure 1: MoonLIGHT laser return (Oprical Cross Section) at 4.0-4.5 µrad velocity aberration.

Current LLR GR tests and improvements expected with MoonLIGHT are shown in Table 1 [7][8].

Gravitational measurement	1^{st} generation LLR accuracy ($\sim$ cm)	next-generation LLR accuracy (1 mm)	next-generation LLR accuracy (0.1 mm)
EP	$< 1.4(10^{-13})$	10^{-14}	10^{-15}
SEP	$< 4.4(10^{-4})$	$3(10^{-5})$	$3(10^{-6})$
β	$< 1.1(10^{-4})$	10^{-5}	10^{-6}
$\dot{G}/G$	$< 9(10^{-13})yr^{-1}$	$5(10^{-14})$	$5(10^{-15})$
Geodetic precession	$6.4(10^{-3})$	$6.4(10^{-4})$	$6.4(10^{-5})$
$1/r^2$ Deviation	$< 3(10^{-11})$	10^{-12}	10^{-13}

Table 1: Current and future LLR test of GR.

First laser retroreflector on the surface of Mars
During Summer 2015 the SCF_Lab Team of INFN-LNF, with support by ASI, carried out an intense activity of final design, manufacturing and testing in order to construct, space qualify and finally integrate INRRI-EDM/2016 on ESA's ExoMars EDM spacecraft (also dubbed 'Schiaparelli'), which was successfully launched on March 14, 2016. INRRI (INstrument for landing-Roving laser Retroreflector Investigation) for the EDM (Entry descent and landing Demonstration Module) 2016 mission is a compact, lightweight, passive, maintenance-free array of eight cube corner laser retroreflectors fixed to an aluminium alloy frame through the use of silicon rubber suitable for space applications. INRRI was installed on the top panel of the EDM Central Bay on October 14, 2015. It will enable the EDM to be laser-located from Mars orbiters, through laser ranging and altimetry, lidar atmospheric observations from orbit, laser flashes emitted by orbiters, and lasercom. One or all of the above means of observation can be supported by INRRI when there is an active, laser-equipped orbiter, especially after EDM end-of-life and for a long time. INRRI goals will cover science (Mars geodesy/geophysics, future Mars test of General Relativity, GR), technology and exploration. Concerning the latter two, INRRI will support *mars-georeferencing* of the EDM landing site, support potential precision lidar-based landing next to the EDM, support test and diagnostics of lasercom for data exchange among Mars orbit, Mars surface and Earth, and it will be a precursor for additional Mars surface retroreflectors on exploration rovers like the ExoMars 2020 of ESA (already foreseen, through ASI) and NASA's Mars 2020 Rover. Infact, recently NASA-HQ formally invited ASI to deliver a flight INRRI unit for Mars 2020. We will describe our innovative payload, hopefully the very first to be deployed safely with the lander Schiaparelli on the Mars surface, its space qualification for the ExoMars EDM 2016 mission and the prospects for its deployment on Mars 2020.

Finally: 1) note that INRRI on the Moon landers, like the one forseen to be deployed on the 1st MEI lander, is to be observed by laser-ranging capable orbiters, like NASA's LRO; 2) we will describe future applications to Phobos sample return, icy/rocky moons of Jupiter/Saturn and to asteroid/comets missions.

References:

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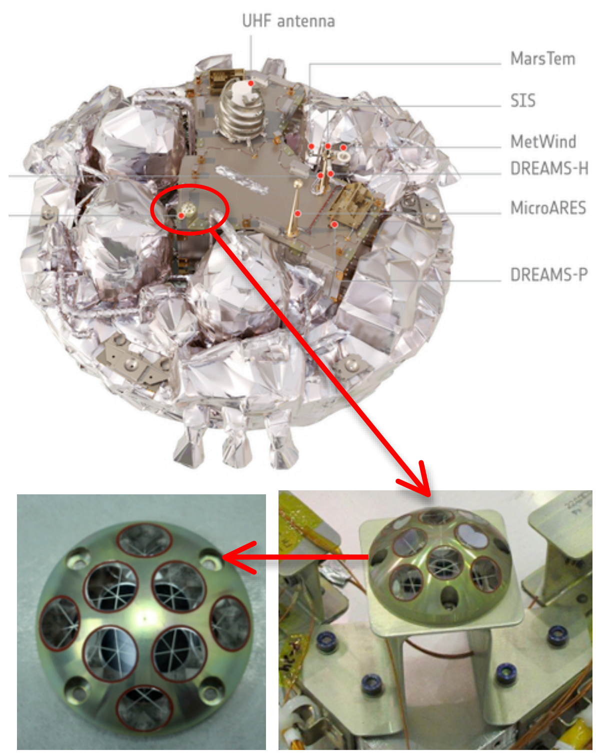

Figure 2. Top picture (courtesy of ESA): Schiaparelli lander with science payloads. Bottom right zoom (courtesy of ESA and Thales Alenia Space Italia): INRRI integrated on the central bay of Schiaparelli. Bottom left: close-up of INRRI.