Laser retroreflectors as NEO positioning and geodetic targets

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ABSTRACT

In the framework of reserch activities of the INFN Astroparticle Physics Committee (CSN2) and INFN Technology Research Committee (CSN5) and as part of the Affiliation of INFN to NASA-SSERVI (Solar System Exploration Research Virtual Institute, http://sservi.nasa.gov), we are studying the feasibility of laser-marking NEOs (Near Earth Objects) by the deployment of Laser Retroreflector Arrays (LRAs) specially designed to support laser tracking of NEOs and contribute to SSA/SST (Space Situational Awareness and Space Surveillance and Tracking). LRAs are very useful to study the internal NEO geophysics and dynamics, as it is done, for example, on a planetary-body scale with Apollo/Lunokhod LRAs on the Moon, ad as it will be done by AIM (Asteroid Investigation Mission).

We are designing NEO LRA markers for:

- Landing missions of the type of ROSETTA, HAYABUSA-2 and OSIRIS-REX. These reflectors would support laser tracking by Moon, Mars, Jupiter, Saturn orbiters equipped with lasercomm payloads that can also perform time-of-flight laser ranging, as recently demonstrated by NASA's LADEE (Lunar Atmosphere and Dust Environment Explorer) mission. This lasercomm infrastructure for the whole solar system is one of the primary goals of the newly created "Optical Communications Division" inside the NASA Space Communications and Navigation (SCaN) program within HEOMD.
- Asteroid retrieval/redirect missions, which might deliver asteroids in cislunar, and/or Earth-Moon Lagrangian points. These would exploit laser altimetry, mapping of asteroids, laser ranging (time-of-flight) from orbit via lasercomm, *à la* LLCD (Lunar Laser Communications Demonstration) on LADEE, and by LLR-capable stations of the International Laser Ranging Service (ILRS) if the asteroid will come in the vicinity of the Earth. The latter stations include: APOLLO (Apache Point Observatory Lunar Laser ranging Operation) in the USA, GRASSE in France, ASI-MLRO (Matera Laser Ranging Observatory) in Italy.

The study includes LRA models already developed for other destinations (Moon, Mars, airless moons), as well as their evolutions and adaptations to NEOs. Some of LRA models have been (or will soon be) characterized at the SCF_Lab (http://www.lnf.infn.it/esperimenti/etrusco/), a space test facility dedicated to laser retroreflectors, located at INFN-LNF, Frascati, Italy (across the street from ESA-ESRIN). Modeling of LRA optical specifications, deployment and tracking parameters must be done ad-hoc for NEOs, and is a new realm of application of the geodetic techniques of LLR and SLR.

LRA for NEOs: INRRI

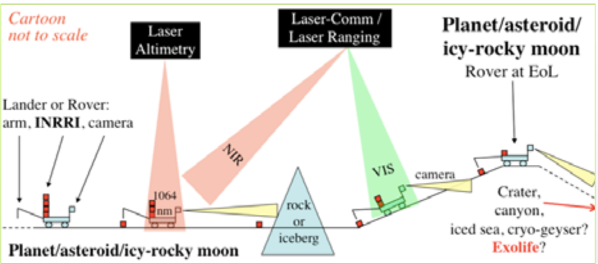
INRRI (INstrument for landing Roving laser Retroreflector Investigation) is a laser retroreflector micropayload of about 30 gr weight and diameter of about 2 inches. It will be laser tracked by orbiters capable of laser ranging and/or laser altimetry and/or laser communication .

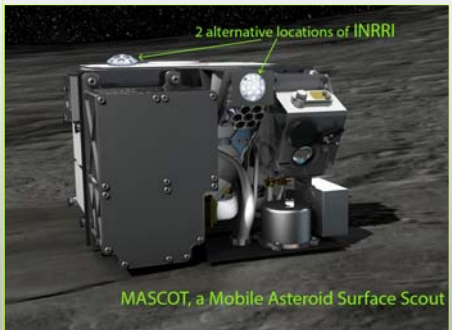
INRRI LRA, equipped with eight CCRs. Diameter is about 2 inches; total mass is about 30 gr

INRRI is developed and characterized at the SCF_Lab to determine landing accuracy, rover positioning during exploration and planetary/Moon's surface georeferencing, this device is a passive, laser wavelength independent, long-lived reference point. INRRI will also enable the performance of full-column measurement of Mars atmospheric trace species. Deployment of three or more LRA of the INRRIs on an asteroid will allow for triangulations by orbiters. The added value of INRRI is its low mass, compact size, zero maintenance and its usefulness for virtually decades.

INRRI will also support laser and quantum communications. This will be possible also because the INRRI laser retroreflectors will be metal back-coated and, therefore, will not change the photon polarization. Laser communication tecnology is one of the key technical innovations in space missions for the future; it could enable to exchange huge amount of scientific data in a reduced time interval. NASA, with the activation of a new Optical Communication Division, is investing strategically on optical communications to exchange exploration data in a much more efficient way. LRO (Lunar Reconnaissance Orbiter) first and then LADEE missions demonstrated feasibility readiness of such technology for space.

The conceptual figure below summarizes the laser tracking of INRRI deployed on the Moon, Mars, Jupiter/Saturn moons, asteroids or comets.



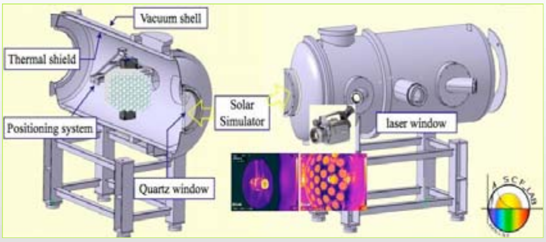


Artist's conception of HY-2 during sampling, also showing MASCOT landed on the surface. CREDIT:JAXA/Akihiro Ikeshita.

SCF_Lab & INRRI Technical Description

The nominal overall design of INRRI is characterized in depth at the unique SCF_Lab (**Satellite/lunar/GNSS laser ranging altimetry and cube-microsat Characterization Facilities Laboratory**). Potential LRA performance deficiency or deviation from nominal are identified thanks to the diagnostic/verification provided by the so-called "SCF-Test", a highly specialized thermal-optical vacuum test in space conditions accurately simulated in the laboratory, that has been uniquely developed at the SCF_Lab in the last years of R&D by INFN, also with the co-funding of ASI. The fabrication, test and verification/calibration plan is entirely carried out at INFN-LNF, in the framework of the SCF_Lab, which is a permanent LNF infrastructure devoted to laser retroreflectors for scientific, technological research and industrial services.

Advanced retro-reflectors models on display: the LAser GEOdynamics Satellite (LAGEOS) Sector (on loan from NASA-GSFC; larger sphere in image) and the laser-ranged test mass to test 1/r2 in deep space (from an INFN-ASI study for a JPL mission concept; smaller sphere in image). Photo Credit: SCF_Lab/ Simone Dell'Agnello/ INFN



Schematic view of SCF cryostat with IR thermograms of CCRs under test

As an example, we report that an INRRI prototype has been be designed for lunar applications and realized to guarantee the sufficient intensity for the ranging measurement at near-Infrared and Infrared lasers used for lasercomm, laser altimetry, as well as at standard laser ranging wavelengths (532 nm). Measurements of the optical performance can be performed on the existing optical table, equipped with a green laser, and on an upgraded optical table able to measure FFDP (Far Field Diffraction Pattern) at infrared wavelength (namely 1064 nm and 1550 nm).

Assuming an altitude of a few hundred km of the laser-equipped orbiter, the relevant OCS (lidar Optical Cross Section) for INRRI detection is around 11 microrad. In our case, this is an OCS ~0.16-0.55 million m^2 (for 1064 nm and 532 nm respectively) , which is a laser return signal significantly larger than the low-threshold detectability of current/past laser altimeters of NASA missions, and only a little larger than the full-scale receiver value.

INRRI-D & INRRI-S

INRRI-D LRA, equipped with sixteen CCRs. Diameter is about 1.5 x 2 inches; total mass is about 50gr

We have designed LRA options in such a way to be observed by lasers and guarantee sufficient light return from very wide viewing angles, because their position/orientation after the deployment could not be certain (see PHILAE's experience).

Our studies led to the design of INRRI-D(isc) (on the left) and INRRI-S(phere) (on the right). The baseline INRRI-D consists of two INRRIs specularly tightened to each other, while INRRI-S has a new own design, that guarantees an omnidirectional response to lasers, at the cost of some more mass and some extra cost, since it counts 8 CCRs more than INRRI-D. These models (INRRI, INRRI-D or INRRI-S) are different options to choose from depending on the specific mission and the details of its deployment on the targeted NEO.

INRRI-S LRA, equipped with twenty four CCRs. Diameter is about 2 inches; total mass is about 65gr