SCF_Lab

G. Bellettini (Ass.), G. Bianco (Ass.),
S. Dell'Agnello, G.O. Delle Monache, M. Maiello (Ass.),
R. March (Ass.), M. Martini (AR), C. Mondaini (Art. 15), M. Muccino,
L. Porcelli (Art. 36), L. Salvatori (Art. 15), R. Tauraso (Ass.), M. Tibuzzi (Ass.),
R. Vittori (Ass.), Ioppi (Dott.), Rubino (Dott.), Mauro (Dott.),
Filomena (Ass.), Casini (Bors.), Petrassi (Bors.), Sanclimenti (Bors.).

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1 LaRA, Made-in-Italy Laser Retroreflector Aboard Perseverance

Mars exploration rover Perseverance has reached its destination after a long journey that lasted about 7 months. It is the fifth NASA rover to land on the Red Planet, and its arrival opens a new phase of research in the field of astrobiology on Mars.

The Perseverance rover is taking its first steps in the Martian area called Jezero crater, the basin of an ancient lake, about 500 meters deep, which may have traces of past life.

The rover is a mix of technologies and sensors to lay the groundwork for the next human missions to Mars. LaRA (Laser Retroreflector Array), which is just one of the various technologies, is a micro-reflector developed and built at the National Laboratories of Frascati, on behalf of the Italian Space Agency, by the group *SCFLab*.

In an interview with EE Times Europe, Simone DellAgnello, executive technologist at INFN-LNF (National Institute for Nuclear Physics Frascati National Labs) and principal investigator of 4 laser microreflectors for ESA ExoMars missions, NASAs InSight and Perseverance, highlighted the scientific implications of the project, the features and functions of this device.

1.1 Laser retroreflectors

Retroreflectors are bright, point-shaped position indicators that do not require much maintenance and are able to function independently for decades. Laser retroreflectors are passive, they return laser beams in the same direction it came from. "By measuring the time-of-flight of short laser pulses, the accurate position of artificial satellites, landers, rovers, and celestial bodies can be measured", said DellAgnello. He pointed out that this is applied, for example, to satellites of the GNSS (Global Navigation Satellites System) and to the Moon, where 3 laser retroreflector instruments have been deployed by the Apollo 11, 14 and 15 astronauts and 2 other instruments are installed on the Soviet Lunokhod 1 and 2 rovers.

The operating environment of the Moon and Mars, and space in general, is very difficult for on-board electronics, and all technology must meet testing criteria. The red dust that covers the surface of the planet Mars is one of the problems for any device powered by solar panels. Communications could even be disrupted due to solar flares or frequent dust storms that cover the entire planet. A sterile environment, along with a rarefied atmosphere dominated by carbon dioxide, where there is virtually no oxygen to breathe, makes the operating environment even more difficult for on-board electronics. The temperature cycles of the Moon and Mars undergo a strong excursion, from about $300^o C$ (Moon) to about $250^o C$ (Mars), DellAgnello pointed out.

"Vibrations and pyro-shock mechanical levels are typically harder for missions on Mars, because Mars is farther away, rockets to reach Mars are huge and because the Mars Entry, Descent and Landing sequence can be more complex and violent if compared to lunar landings. On the Moon, dust accumulation is slower than on Mars, but dust is electrostatically charged. Mars has dust storms, which can accumulate dust (more than on the Moon), but also clean it away (as it happened for the Spirit and Opportunity rovers), also thanks to the fact that it is electrically neutral. Lunar reflectors are still working after 50 years of service. Martian payloads must be biologically sterilized very thoroughly to avoid contaminating Mars with life forms from Earth, while this is a less strict requirement for the Moon", said DellAgnello.

1.2 LaRA

LaRA aboard Perseverance is a 2-inch wide dome dotted with holes containing a glass cube corners that have three mirrored faces positioned at 90-degree angles to each other so that light entering the holes is directed in the exact same direction from which it came.

DellAgnello indicated that LaRA underwent several tests before being shipped on Perseverance. Specifically, the wide cycle of the Thermo-Vacuum-Testing, vibration and shock qualification levels and the biological sterilization. "This also requires approval by space agencies of test plans, test procedures, calibrations of all instrumentation involved in the qualification campaign, data processing according to rigorous ASI, ESA and NASA quality and product assurance standards. Finally, one has to deliver a complex and articulated End Item Data Package which has to pass an accurate pre-agreed verification control matrix of requirements," said DellAgnello.

LaRA has been conceived, designed, assembled and tested by SCFLab, the LNF group specialized in this space research. The team is composed of experts in mechanics, optics, physics and electronics to create optimal control and test systems for the verification of devices that will then go into the space environment.

In June 2019, on behalf of the whole group, DellAgnello delivered the LaRa micro-reflector to NASAs Jet Propulsion Laboratory. The LaRa micro-reflector will enable scientists to perform distance measurements using the laser-ranging technique (which some also call laser telemetry), being able to accurately identify the position of Perseverance on the Martian surface, to study martian geophysics, to test Einsteins theory of General Relativity and to make future landings on the Red Planet more precise and safer.

1.3 The next step

Since lasercom terminals are extremely powerful devices, customizable to be easily capable of laser time-of-flight measurements (i.e., laser ranging), DellAgnello is confident this will open the way for the widespread deployment and use of laser retroreflectors all over the solar systems. "INFN-Laboratori Nazionali di Frascati has been working since the 2010s and is ready to deliver the next generation of laser retroreflectors," said DellAgnello.

He added, "We are competing for next generation laser retroreflectors for Galileo 2nd Generation satellites (whose procurement ESA is about to assign to Airbus Defense and Space and to Thales Alenia Space), imminent lunar surface missions by several space agencies and ESAs Hera mission to the Didymos double asteroid."

Perseverance will help us delve into the countless mysteries that still surround the Red Planet. The goal is to look for possible signs of past life, study the geology and collect rock samples. Perseverance brings Ingenuity, a small experimental helicopter-drone that will test the possibility of flying such devices in the weak Martian atmosphere paving the way for mans presence on Mars.

"The LOP-G, Lunar Orbital Platform and Gateway (to Mars and beyond) will gradually both replace (in several ways) the Earth ISS and boost the return to the Moon and a more efficient exploration of Mars in the short term. In the medium to long term, the LOP-G will consolidate the large-scale, pacific and hopefully sustainable exploitation and colonization of the Moon and Mars, both with humans and with more sophisticated robots. For the next Mars exploration and beyond, laser communication technologies will be mandatory for many reasons (enabling fast and high volume data exchange, internet for humans, etc),"said DellAgnello.

The guidance and support of ASI, together with the contribution of Italian research centers, universities and industries will continue to be critical for the consolidation and expansion of the Italian role in space exploration and research within the Martian system.

DellAgnello stated that all the achievements of the SCFLab of INFN-LNF (like LaRA, many other laser retroreflectors, but also physics analysis and theoretical physics papers) would not have been possible without the important contributions of many who worked in this research group since 2005 (too many to mention) and the ones who are currently members of the SCFLab, or that currently give in any case a very significant voluntary contribution to the SCFLab today (as of March 3rd, 2021), listed in the following in alphabetical order:

Bellettini Giovanni, Conti Federico, DellAgnello Simone, Delle Monache Giovanni, Denni Ubaldo, Filomena Luciana, Maiello Mauro, March Riccardo, Mauro Lorenza, Muccino Marco, Mondaini Chiara, Luongo Orlando, Petrassi Matteo, Porcelli Luca, Rossi Costanza, Romujo Castro Alejandro, Rubino Laura, Salvatori Lorenzo, Tibuzzi Mattia, Traini Marco.

"Speaking for the SCFLab: tell us where, in the solar system, you want to shine your laser, and we will deliver you the right laser retroreflector to get your job done," concluded DellAgnello.

2 ESA PROPOSAL-ML100 Pointing Actuator (MPAc)

The MPAc system was designed for the alignment of a retroreflector in azimuth and elevation. Deployment of modern retroreflectors at the lunar surface is a specific target of the Strategy for Science at the Moon. The instrument would address science of both the interior structure and state of the Moon and of relativistic physics.

The retroreflector which will be used is MoonLIGHT 100 (ML 100), a large retroreflector whose structure and dimensions must guarantee an adequate light return from the Moon also avoiding any Lunar Libration issue that dominates the error budget limiting the precision of the experimental tests of gravitational theories.

The final ML100 Pointing Actuator (MPAc) (actuators, structure and retroreflector) shall be integrated on a commercial lunar lander, and must be able to perform two continuous rotations. Azimuth axis actuator (MPAc-A): $\pm 180^o$ around the normal to the (horizontal) lander deck surface on which it is installed. Elevation axis actuator (MPAc-E): $0 - \pm 90^o$ elevation around an axis parallel to the lander deck. The MPAc is similar to dual-axis gimbals used to move/point small communication antennas, but with the following, less restrictive operational requirements: MPAc does not need to do fast movements; MPAc should operate only during the lunar day; MPAc should perform a limited number of pointing operations (while typical antenna gimbals have tested lifetimes of thousands or tens of thousands cycles).

3 Joint Lab KOM-ASI-INFN

The objective of the project is the realization of ASI-INFN joint activities in the field of advanced laser systems for space applications based on laser retroreflectors and precision laser tracking of satellites and the Moon. This will be achieved through the collaboration between ASI and INFN for the sharing of specialist technical-scientific skills in the field. In particular, these were developed for ASI at the Space Geodesy Center (CGS) of Matera and for INFN by

the SCF-Lab (Satellite / lunar laser ranging and altimetry Characterization Facilities Laboratory) team at the National Laboratories of Frascati (LNF).
The programmatic objective of these 5 years of the ASI-INFN project is to capitalize on what was objectively achieved in the 15 years (2004-2018) of life by the INFN-LNF SCF-Lab, the technical-scientific results obtained, the hardware and infrastructure resources built, the experiences and skills acquired, internal and external funding received from various Italian (Agencies, Ministries, Scientific and Technological Commissions), European and non-European sources to consolidate the INFN-ASI partnership as a "twinning" of technical-scientific research between SCF-Lab and MLRO (Matera Laser Ranging Observatory at the CGS). The joint activities are based on the de facto profound synergy between MLRO and SCF-Lab. The first works on the Ground Segment of the SLR/LLR laser tracking as the primary station of ILRS, the second works on the Space Segment as a single laboratory for its ability to supply and qualify advanced laser systems based in particular on laser retro-reflectors (those tracked, precisely, from MLRO). Both represent the state of the art in the two segments of Earth and Space.
In view of concrete mission opportunities and related applications (see the WP of the 3000, WP4000 and WP5000 line), the project requires the continuation of what has already been conducted jointly between ASI and INFN and to extend this collaboration as regards activities, existing, separately available resources, capabilities, HW and SW.
In particular, it will be:

- perfect the development of prototypes and models up to $6 < TRL < 8$;
- qualify LRA for future mission launches;
- support laboratory, analysis (experimental and theoretical) and QA/PA activities;
- guarantee the functioning of the "Internal Special Facilities" of the LNF (SCF-Lab and the new SCF-Lab2).

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