Advanced Laser Retroreflectors for Solar System (Human) Exploration, Geophysical Networks and Lasercomm

Alessandro Boni for the SCF_Lab & collaboration team

NASA Exploration Science Forum, NASA-AMES (USA) 21-23 July 2015

SCF_Lab Team & collaborators

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- **ASI-MLRO** (Centro di Geodesia Spaziale, Matera): P. Bianco
- **Univ. Padova** (Laser Quantum Communication and Encryption): P. Villoresi, G. Vallone
- **INFN-Napoli**: G. Esposito, E. Battista
- **Center for Astrophysics**: J. Chandler, I. Shapiro
- **University of Maryland**: D. Currie
- **University of California San Diego** (APOLLO laser ranging station): T. Murphy

SCF_Lab website: **http://www.lnf.infn.it/esperimenti/etrusco/**

Outline

- Description of INFN-NASA/SSERVI affiliation
- Moon: MoonLIGHT/LLRA21
- Planetary geophysical networks (Moon, Mars): INRRI
- icy/rocky moons: INRRI and other payloads
- Conclusions

INFN-NASA/SSERVI Affilitation

- SPRINGLETS is the "affiliation" research partnership between INFN and NASA-SSERVI, the **Solar System Exploration and Research Virtual Institute**, centrally managed by NASA-ARC (Ames Research Center):
  - http://sservi.nasa.gov

- INFN is the first italian partner of the SSERVI

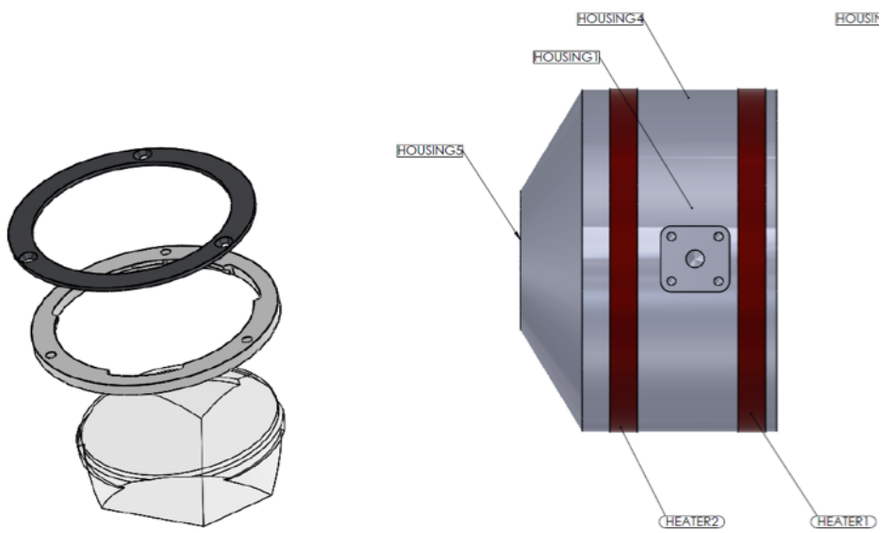
- To Jointly study and develop technologies for LRAs, their characterisations and their applications to laser ranging, laser altimetry and lasercomm within missions in the Solar System
- Allow INFN and NASA to jointly exchange information about the LRA development and characterisation in order to maximize the laser positioning accuracy, laser orbit coverage and laser return strength of future missions involving laser ranging, laser altimetry and laser communication throughout the Solar System.

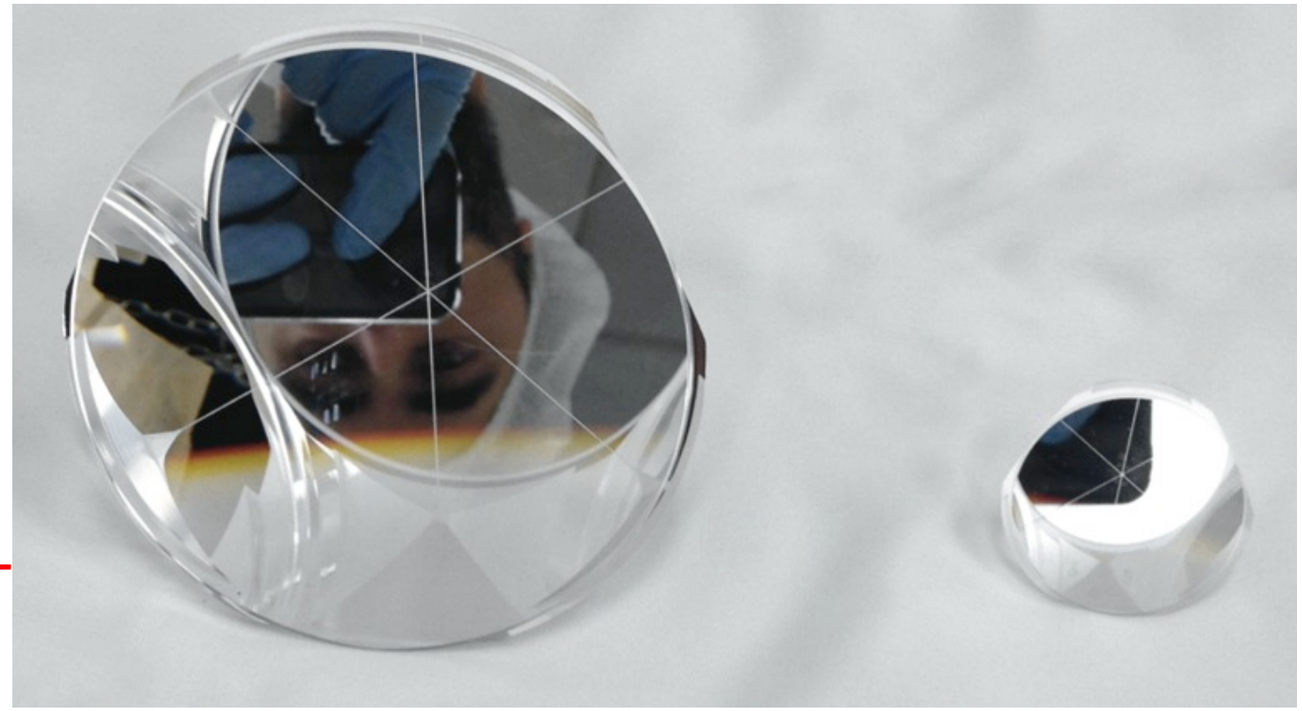
LRA: **laser retroreflector array**

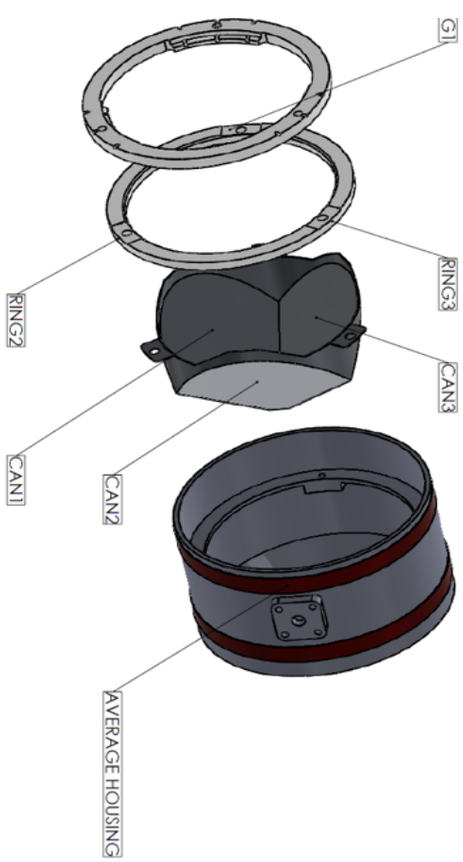
Next generation retroreflector MoonLIGHT/LLRA21

Moon Laser Instrumentation for General relativity High accuracy Test

Largest, optically most accurate Suprasil reflectors ever







MoonLIGHT single reflector vs. Apollo reflector arrays
(Suprasil 311 vs. Suprasil 1):

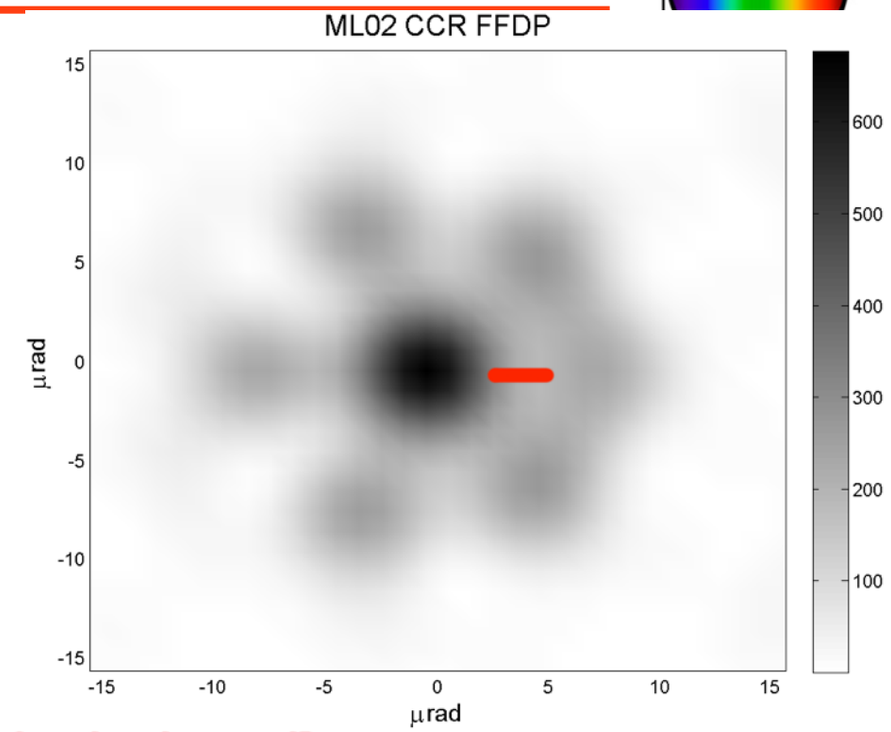
- Optical specs wave/10 RMS (**best ever**) vs. wave/4
- Dihedral angles accuracy: 0.2 (**best ever**) vs 0.5 arcsec
- Single reflector 100 mm vs. array of 100-300 reflectors of 38 mm
- Laser return equal to current Apollo 15 (brightest array) due to degradation, likely due to dust deposit

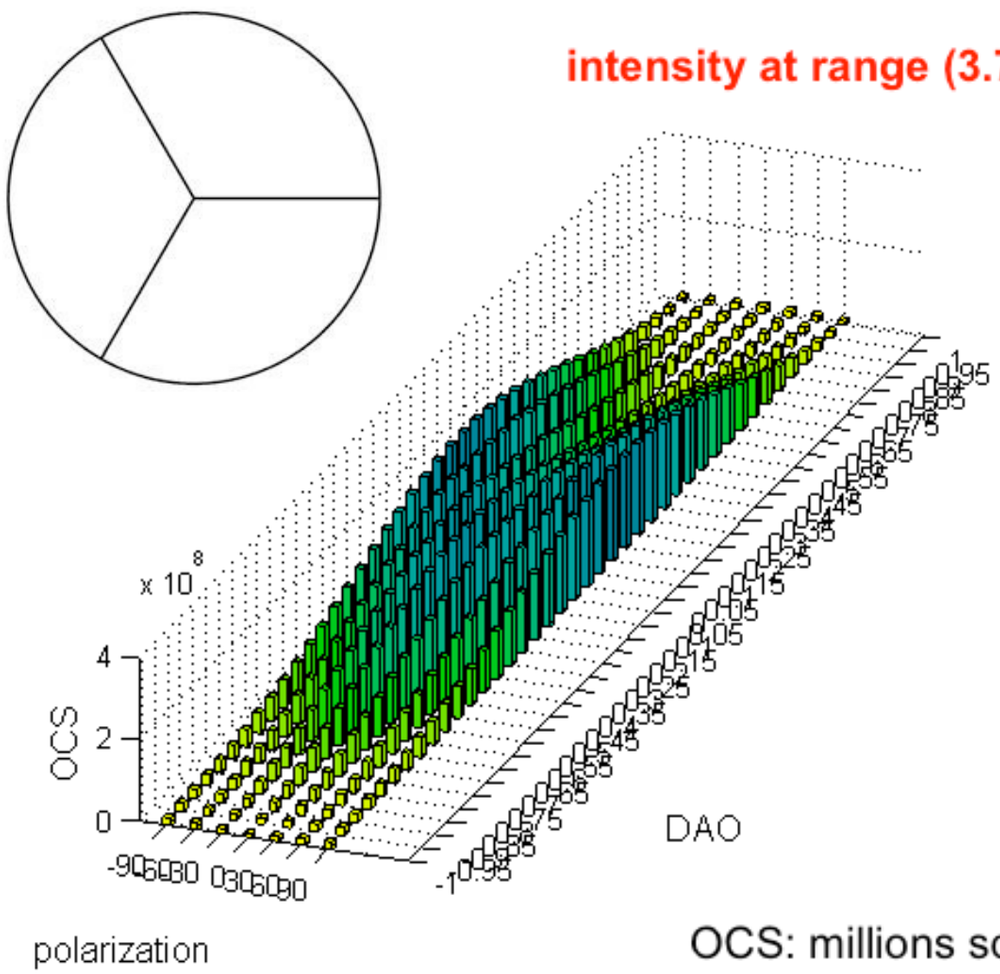
Science with Lunar Laser Ranging

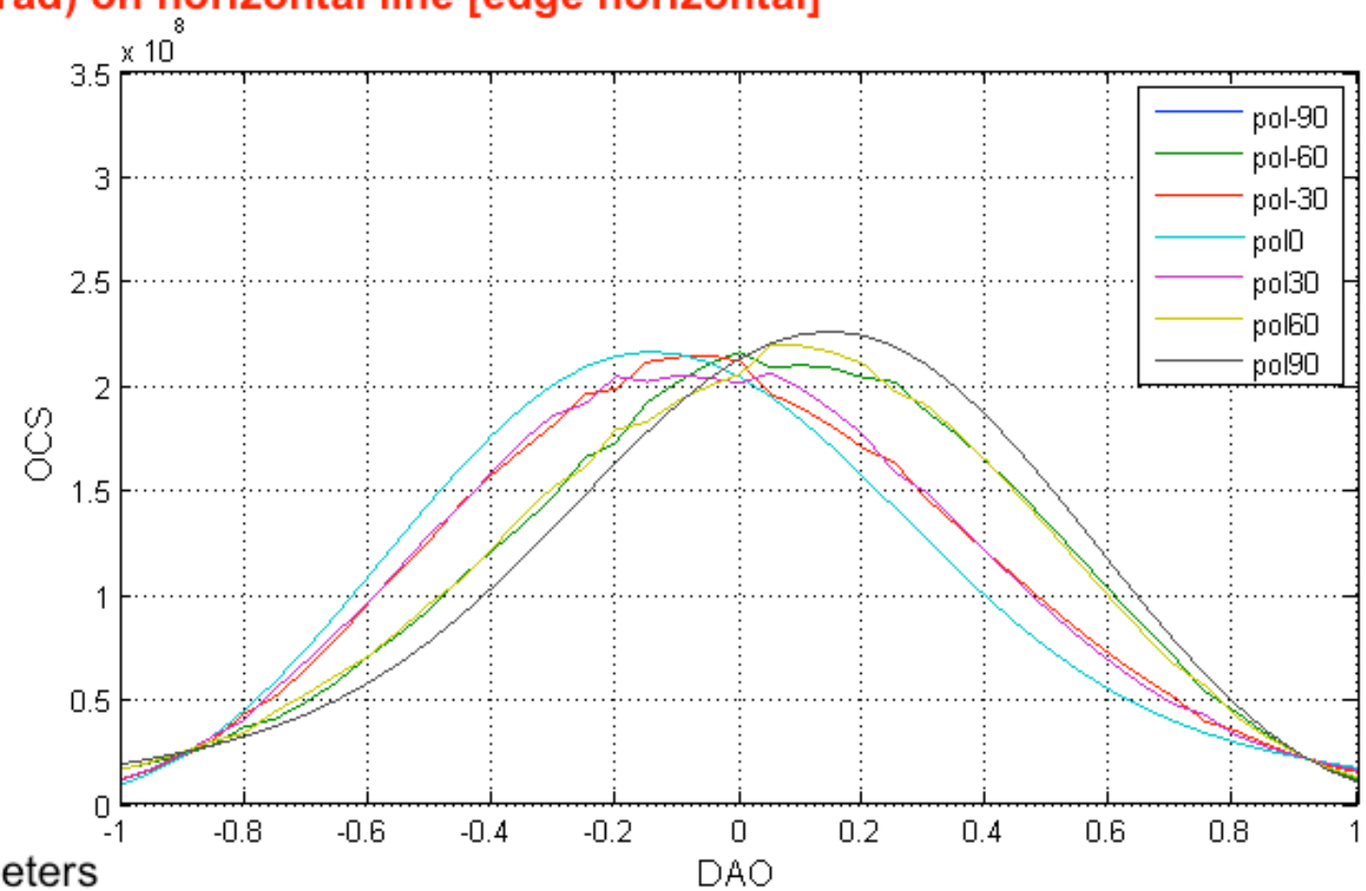
- Planetary physics, lunar interior.
- LLR test of general relativity (GR: PPN β, Gdot/G, geodetic precession, …)
  - Planet and Space Sci 74 (2012), *Martini, Dell'Agnello et al*
  - Nucl Phys B 243–244 (2013) 218–228, *Currie, Dell'Agnello et al*
- LLR and SLR constraints to general relativity with Spacetime Torsion
  - PRD **83**, 104008 (2011), *March, Bellettini, Tauraso, Dell'Agnello*
  - GERG (2011) 43:3099–3126, *March, Bellettini, Tauraso, Dell'Agnello*
- Solar System constraints to Non-Minimally Coupled Gravity, "f1(R)+f2(R)" theories
  - PRD 88, 064019 (2013), *Bertolami, March, Páramos*
  - Physics Letters B 735 (2014) 25–32, *Castel-Branco, Páramos, March*

MoonLIGHT optical design

- Front face diameter: 100 mm
- Material: Suprasil 311 (**uncoated**)
- Dihedral Angle Offsets (DAO): (0.0, 0.0, 0.0) arcsec or (0.6, 0.0, 0.0) arcsec
- CCR orientation to laser beam: depends on the DAO
- Laser polarization: the best choice depends on the choice of DAO



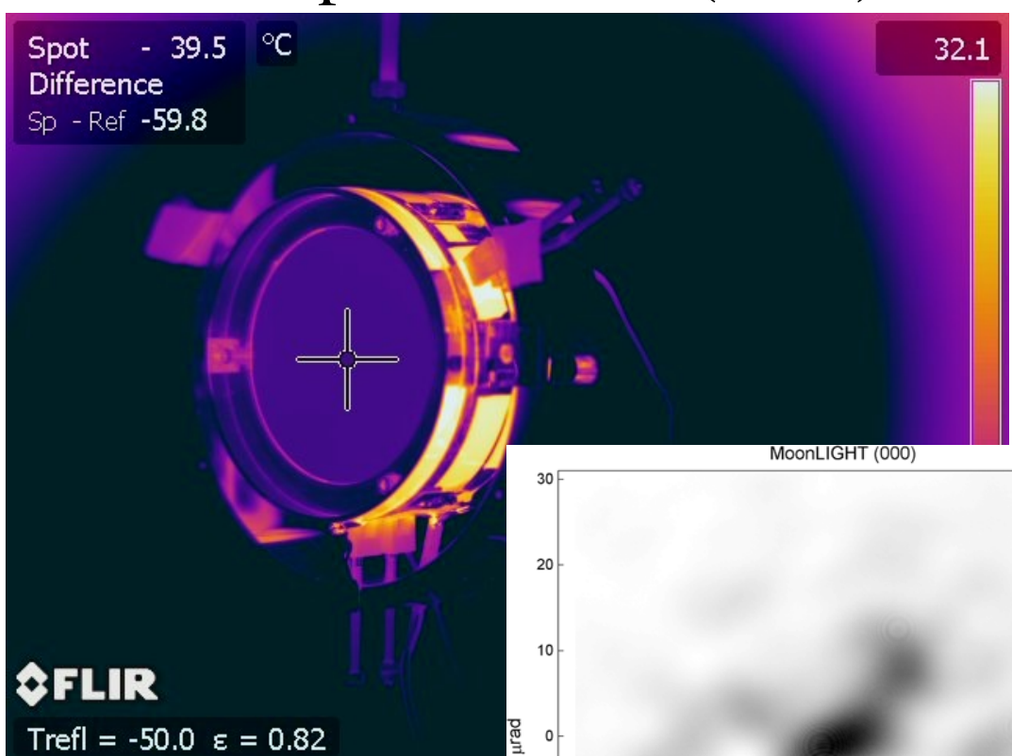


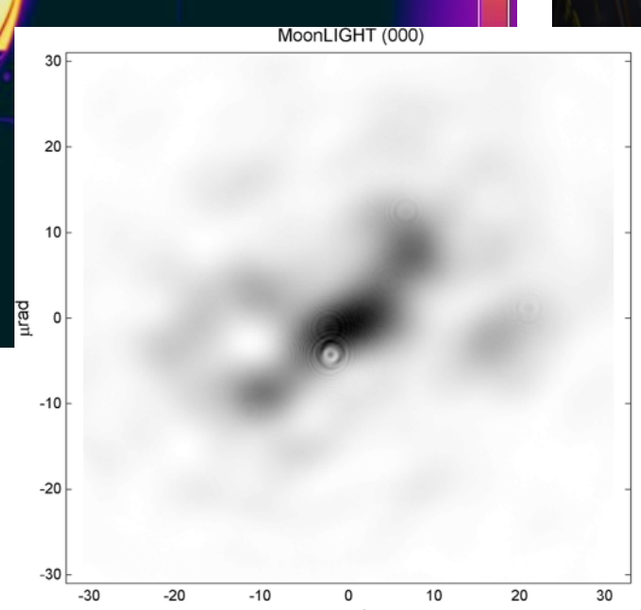


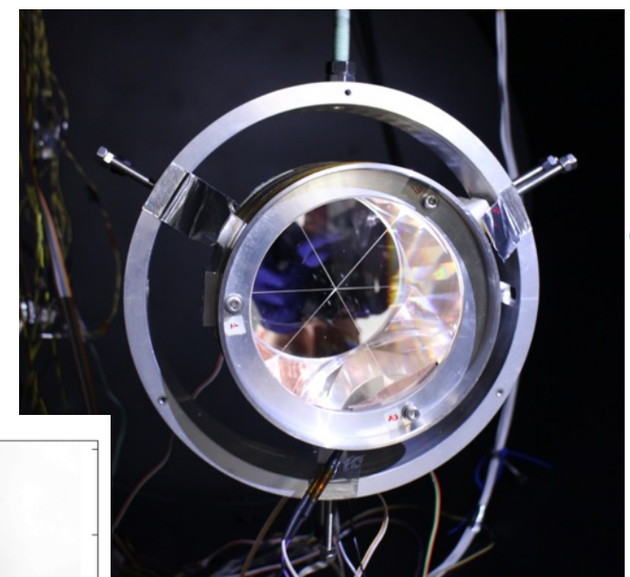
OCS: millions square meters

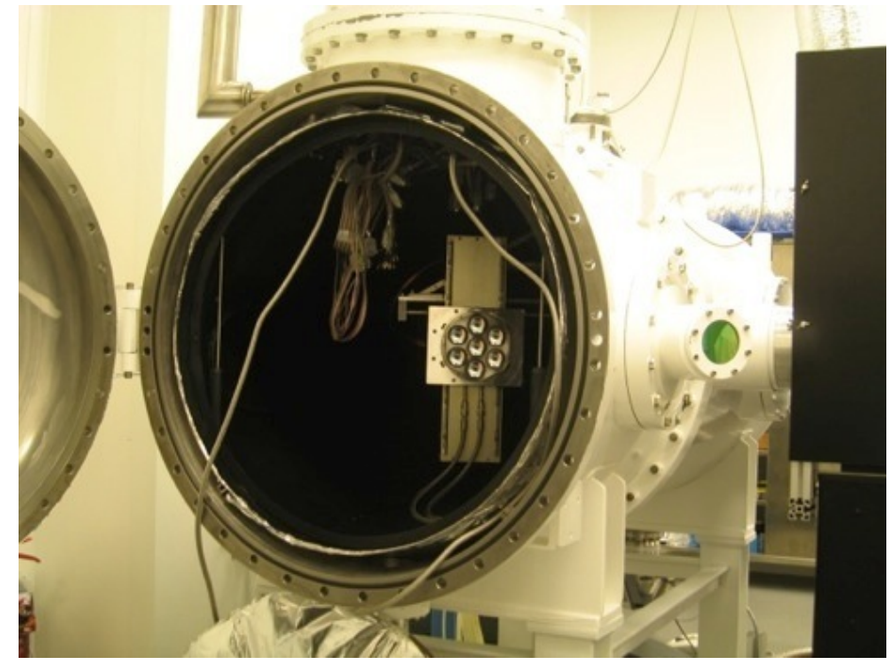
SCF_Lab: space characterization facility

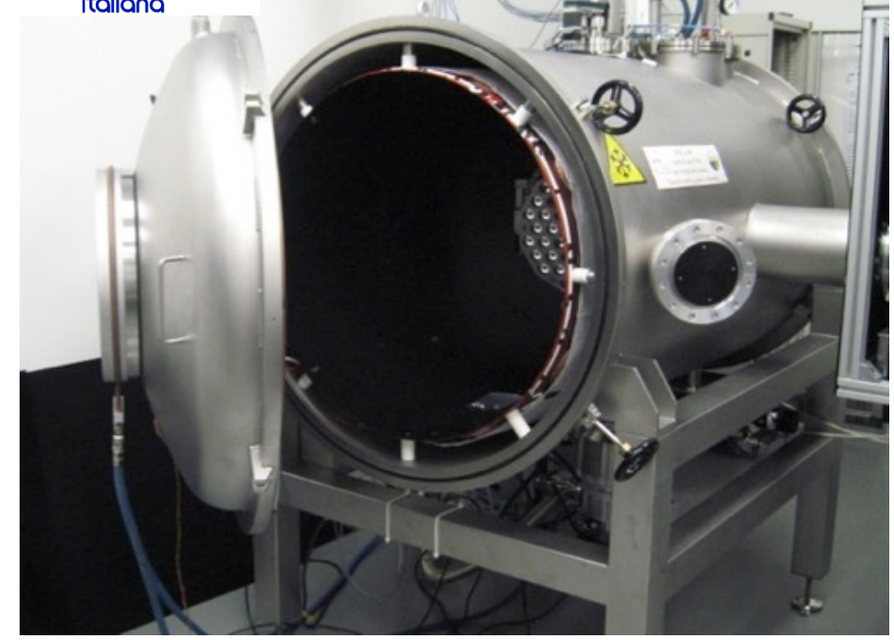
- Two Optical Ground Support Equipment (**OGSE**)
- (Better than) Class 10000 (ISO 7) Clean Room
- **SCF** (top, INFN), for whole Solar System
- **SCF-G** (bottom) dedicated to Galileo, other GNSS
- Two AM0 sun simulators, InfraRed thermometry
- Detailed reflector optical performance testing
- J. Adv. Space Res. 47 (2011) 822–842











MEDIA RELEASE

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Moon Express Announces First International Multi-Mission Payload Agreement with The INFN National Laboratories of Frascati and the University of Maryland

"MoonLIGHT" Lunar Laser Ranging Array Will Bring New Insights into General Relativity

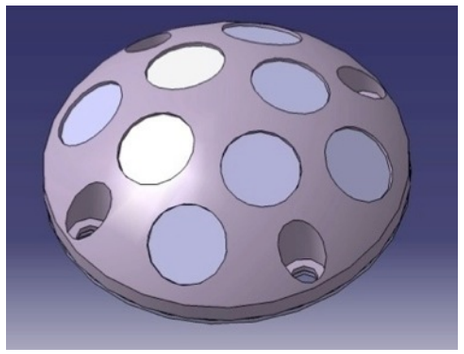
Frascati, Italy (May 15th, 2015) – Moon Express, Inc. (MoonEx) has announced a multi-mission payload agreement with The National Laboratories of Frascati (INFN-LNF) and the University of Maryland to deliver a new generation of lunar laser ranging arrays to the Moon. Under the agreement, "MoonLIGHT" instruments will be carried on the first four Moon Express missions and used in conjunction with Apollo Cube Corner (CCR) Retroreflector arrays to test principles of Einstein's General Relativity theory, add to international scientific knowledge of the Moon, and increase lunar mapping precision that will support the company's future lander missions.

"MoonLIGHT" Payload Agreement Announcement in Frascati, Italy. L-R: Jack Burns, CU; Doug Currie, UMD; Simone Dell'Agnello, INFN-LNF; Bob Richards, Moon Express

The payload announcement was made today in Frascati, Italy, right after the European Lunar Symposium, during a Global Exploration Roadmap workshop of the International Space Exploration Coordination Group (ISECG), attended by officials national space agencies and lunar scientists from around the world.

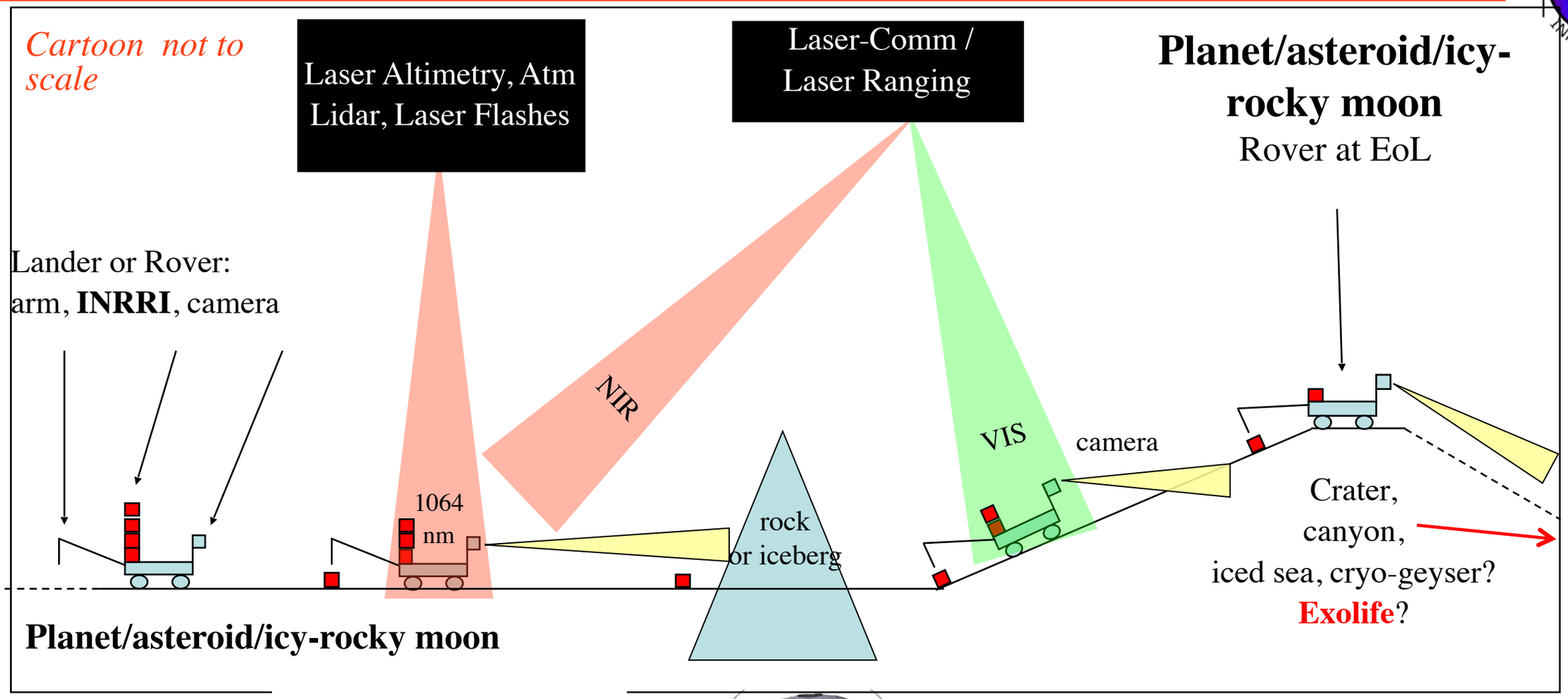
INRRI: Instrument for landing-Roving laser Retroreflector Investigation

- Laser retroreflector device passive, maintenance-free, lifetime of decades
  - Lightweight
  - compact
  - no pointing required

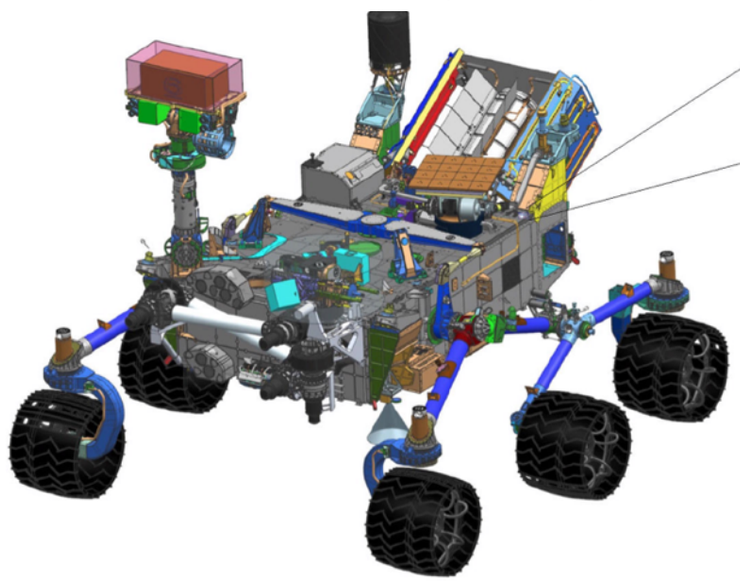


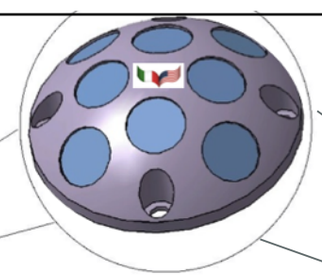
- Enabling technology for science and exploration
  - **accurate positioning of landing site and roving exploration activity**
  - laser altimetry (many lunar, Mars, Mercury laser altimeters, ie by NASA)
  - **lasercomm test & diagnostics** (wavelength independent)
  - georeference exploration activity
  - definition of Meridian 0 (Mars 'Greenwich')
  - Mars Geo/physics Network (MGN) with multiple arrays
  - LIDAR atmosphere trace species detection
  - LIDAR-based landing (return to astrobiologically relevant site)
  - topography/geodesy by laser flashes + visual cameras
  - GR test improvements with an MGN in the long term (PPN Gamma, Gdot/G)

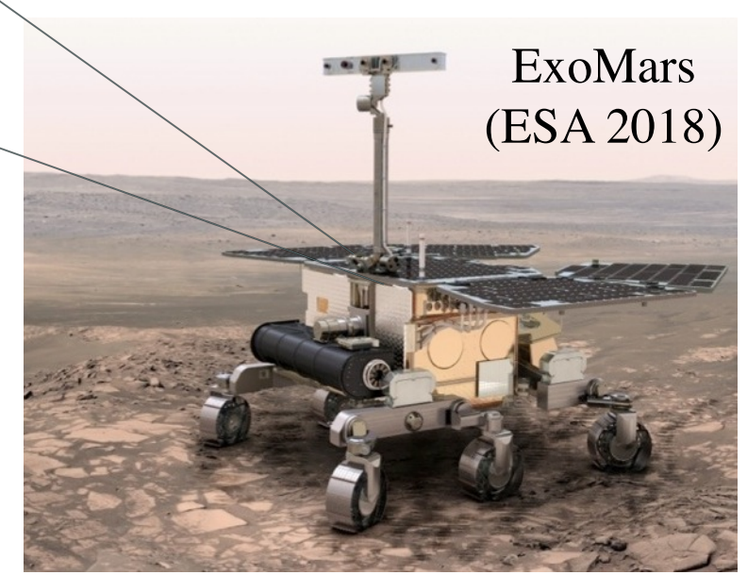
INRRIs on Moon, Mars, Jupiter/Saturn moons, NEO



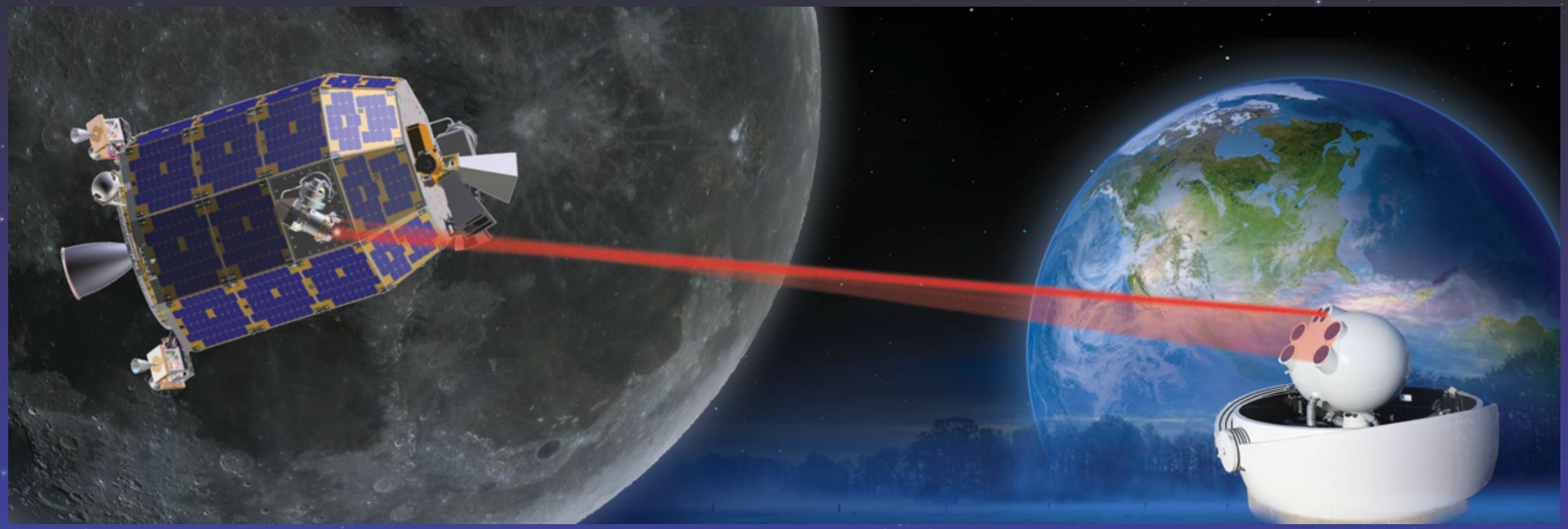
Mars 2020 (NASA)







LADEE
NASA's First, Historic Lasercom Mission

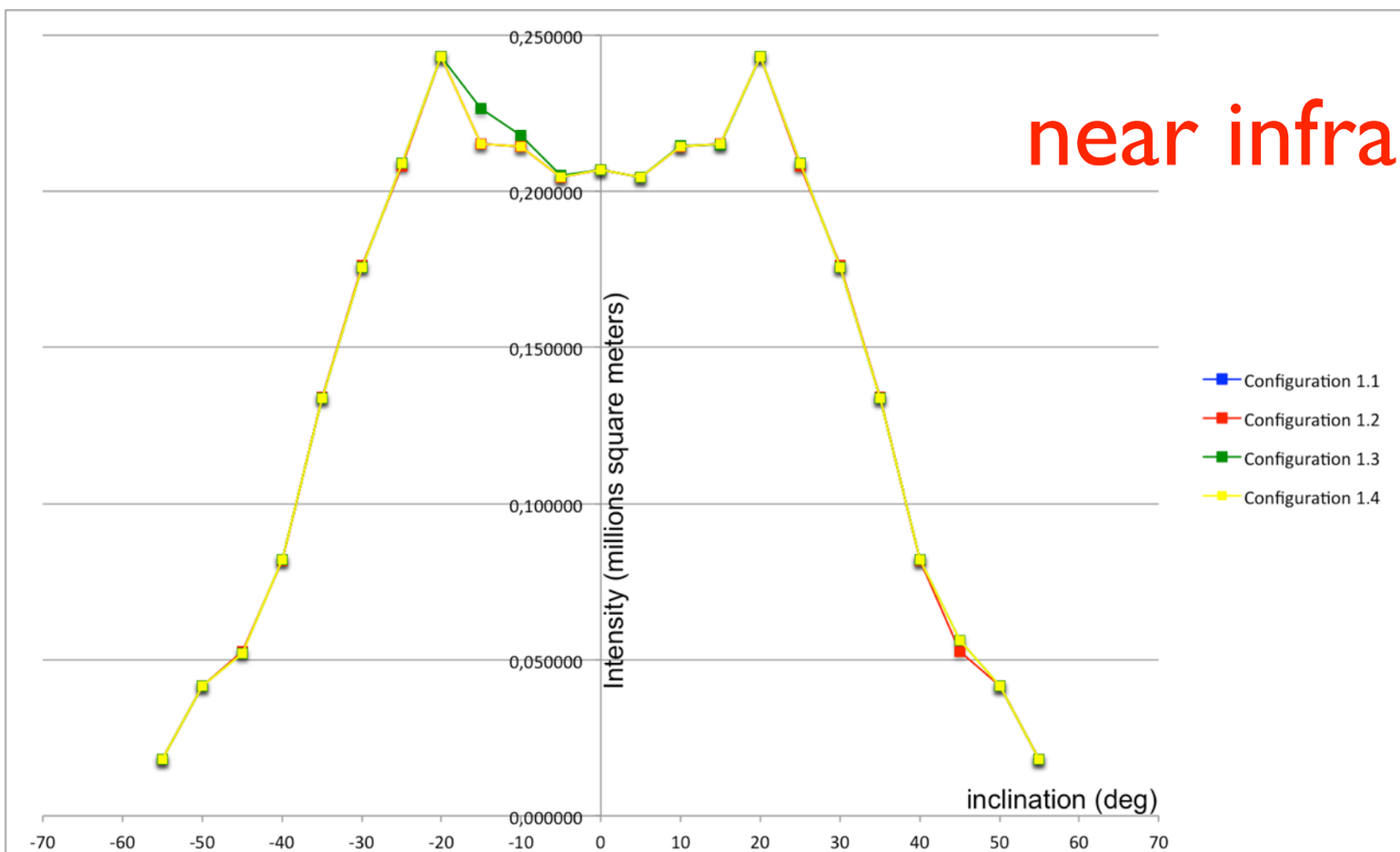


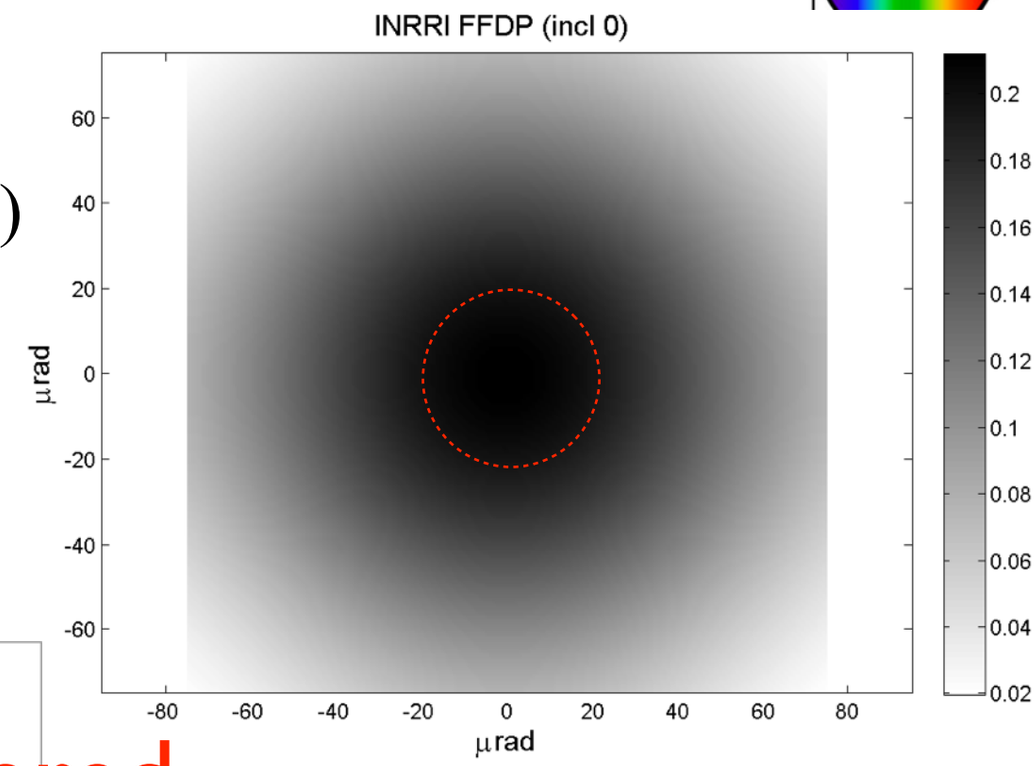
The Lunar Laser Communication Demonstration (LLCD), Flown to the Moon in September 2013

NASA GSFC, MIT Lincoln Laboratory, NASA JPL, ESA

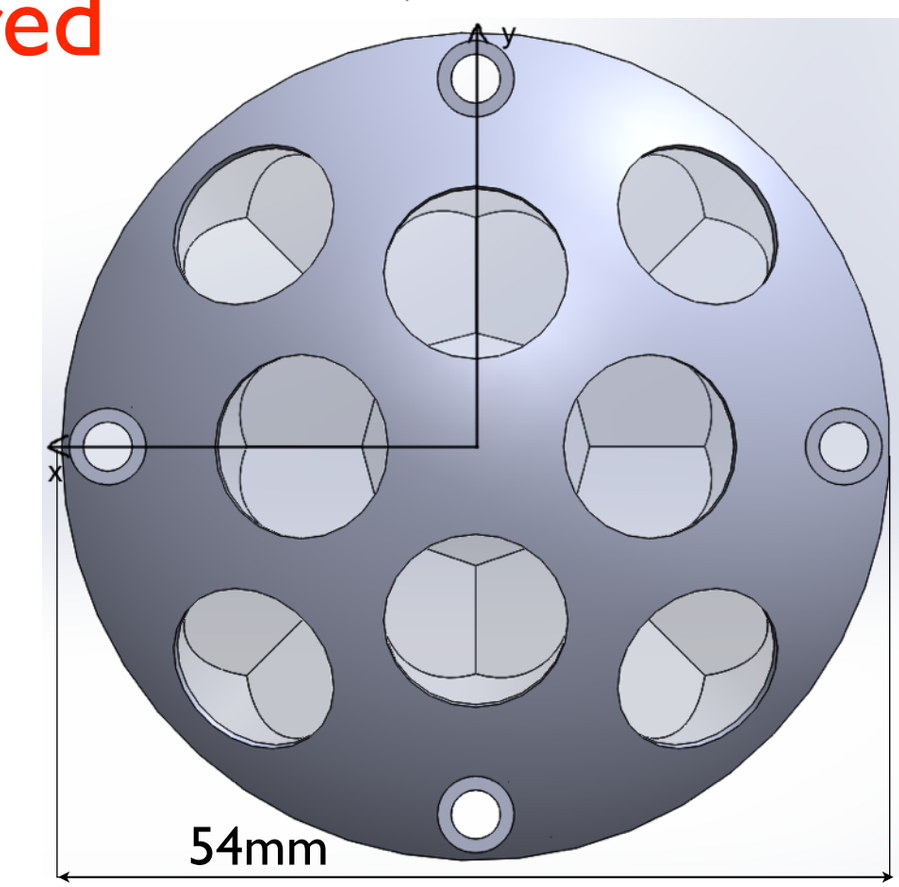
INRRI optical design

- Front face diameter: 1/2 inch
- Material: Suprasil 1
- Dihedral Angle Offsets (DAO): (0.0, 0.0, 0.0) arcsec (**coated**)
- number of CCRs 8
- CCRs orientation: not relevant
- Field of View: ~ 74º



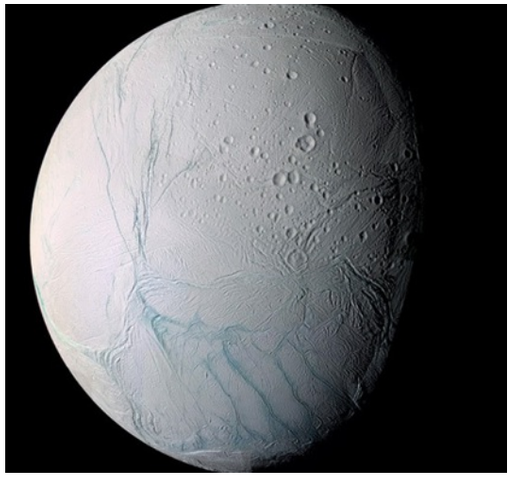


near infrared

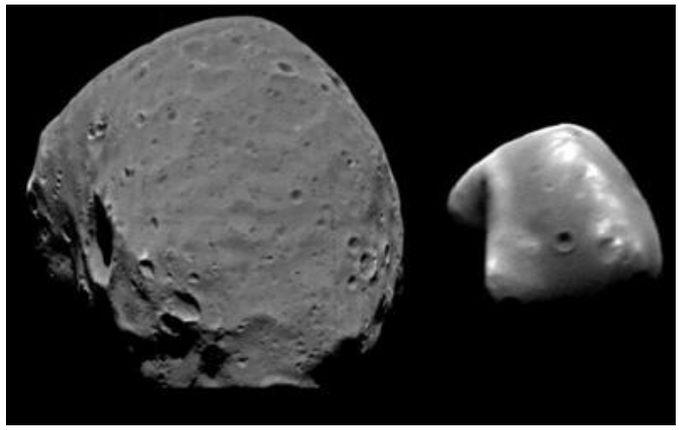


LRAs to icy/rocky moons

Deploy INRRI or other midsize LRAs on spacecraft/rovers that will orbit/land around icy/rocky moon of external solar system planets



- Europa/Enceladus cube corners for Exploration/ Exolife
  - recent NASA Europa AO did not include landing/roving



- Laser ranging to Phobos and Deimos
  - ranging from spacecrafts to perform some planetary science as well as general relativity
- Lots of activity by NASA and ESA for asteroid retrieval, redirection, deflection.
  - study laser marking NEAs by means of LRAs designed to support laser tracking of NEAs

Summary

- INFN/SCF_Lab has unique experimental & design expertise in laser ranging instrumentation for solar system exploration.

- MoonLIGHT/LLRA21 retroreflector for next generation lunar laser ranging is under package optimisation.

- INFN & Univ. of Maryland agreement with Moon Express Inc. to carry MoonLIGHT retroreflector on Moon express.

- INRRI retroreflector array aids/enhances some of science that can be done on Mars/Moon/planetary moons

Thank you for your attention.

Any question?

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SCF_Lab website: **http://www.lnf.infn.it/esperimenti/etrusco/**