NASA-SSERVI and INFN Partnership
"SPRINGLETS":
Solar system Payloads of laser Retroreflectors of INfn for General reLativity, Exploration and planeTary Science

Simone Dell'Agnello (PI & Primary Contact)
INFN - Laboratori Nazionali di Frascati (Rome), Italy
For the SPRINGLETS Teams

19th ILRS Workshop, Annapolis, MD, USA, October 7, 2014

Outline

- Description of INFN – NASA/SSERVI Partnership

- SPRINGLETS goals

- SPRINGLETS work topics areas for long-term collaboration
  – Moon, Mars system, icy/rocky moons of Jupiter/Saturn

- Conclusions

SPRINGLETS: INFN Italian Research Teams

- **INFN-LNF / SCF_Lab**: S. Dell'Agnello (PI), G. Delle Monache, R. Vittori, C. Cantone, A. Boni, G. Patrizi, C. Lops, L. Porcelli, M. Martini, E. Ciocci, S. Contessa, L. Filomena, M. Tibuzzi, P. Tuscano, C. Mondaini, R. March, G. Bellettini, R. Tauraso, F. Muto, L. Salvatori, N. Intaglietta, A. Stecchi, E. Bernieri, M. Maiello
- **INFN-LNF / DAΦNE-Light** (Synchrotron, IR/VIS/UV/X radiation facility): A. Balerna (PI), M. Cestelli-Guidi, E. Pace, R. Larciprete, A. Di Gaspare, R. Cimino
- **INFN-LNF / BTF** (Beam Test Facility, particle physics facility): P. Valente (PI), B. Buonomo, L. Foggetta
- **ILRS & ASI-MLRO** (Matera Laser Ranging Observatory): G. Bianco
- **INFN & Univ. Padova** (Laser Quantum Communication and Encryption): P. Villoresi (PI), G. Vallone, M. Schiavon, M. Tomasin, P. Salvatori
- **INFN Roma Tor Vergata / LARASE** (LAser RAnged Satellite Experiment): D. M. Lucchesi (PI), R. Peron, M. Visco, G. Pucacco

US Collaborators

SLR/LLR/Lasercomm community

- S. Merkowitz, J. Mc Garry, M. Pearlman, J. Degnan, D. Smith
- D. Currie, T. Murphy, J. Chandler, I. Shapiro, C. Neal
- B. Abhijit, M. Hoffmann, D. Raible

Planetary science/Exploration community (PIs of SSERVI-funded projects)

- **W. Farrell**, NASA Goddard MD
- **T. Glotch**, Stony Brook University NY
- **J. Heldmann**, NASA Ames CA
- **M. Horanyi**, University of Colorado in Boulder CO
- **D. Kring**, Lunar and Planetary Institute in Houston TX
- **C. Pieters**, Brown University in Providence RI
- **W. Bottke**, Southwest Research Institute in Boulder CO
- **D. Britt**, University of Central Florida in Orlando FL
- **B. Bussey**, Johns Hopkins University APL in Laurel MD

INFN-NASA/SSERVI Affiliation

- 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/nlsi-central/
  - http://sservi.nasa.gov/international/.
- INFN is the first Italian Partner of the SSERVI

Keywords for following slides:

LRA = Laser Retroreflector Array

CCR = Cube Corner Retroreflector

Lasercomm = Laser-communication & laser ToF payload

NASA-SSERVI & INFN *formal statement (I)*

National Aeronautics and Space Administration – Istituto Nazionale di Fisica Nucleare Solar System Exploration Research Virtual Institute Affiliate Member Cooperation

15 September 2014

The National Aeronautics and Space Administration (NASA) of the United States of America is pleased to recognize the Istituto Nazionale di Fisica Nucleare (INFN) of the Italian Republic as an Affiliate level partner with the NASA Solar System Exploration Research Virtual Institute (SSERVI). With this honor, NASA recognizes INFN as the formal representative of Italy's Solar System science community.

INFN's impressive proposal to SSERVI offers scientific and technological expertise to further the broad goals of Solar System science in many important ways, including INFN's unique expertise with Laser Retroreflector Arrays (LRAs). LRA technology and applications promise to provide great support for future exploration missions to the Moon, Mars, Phobos, Deimos, as well as other planets and their moons in the Solar System. The affiliation will allow INFN and SSERVI to collaborate to improve future scientific undertakings. In addition, INFN and SSERVI will work to further the SSERVI goal of supporting the next generation of space scientists.

NASA-SSERVI & INFN *formal statement (II)*

This affiliation covers scientific collaboration as specified in the charter for SSERVI. Certain additional activities such as, for example, joint U.S./Italy mission development, the exchange of export controlled information, or the creation of intellectual property, will need to be covered by separate, legally binding, international agreements.

With the establishment of INFN as a SSERVI Affiliate, the SSERVI Central Office will work with INFN to develop a public announcement as well as plan for future joint scientific undertakings, including establishment of systems to facilitate virtual collaboration. NASA and INFN look forward to fruitful scientific collaborations through this affiliation including the development of future mission concepts and would hope that future plans might lead to future agreements between the relevant United States of America and Italian Republic organizations.

NASA and INFN are confident that this partnership will result in more great scientific discoveries in Solar System science for both of our nations, as well as furthering the SSERVI goal of understanding the Moon, near-Earth objects, Phobos, Deimos, and their environments.

Gregory K. Schmidt
Deputy Director
Solar System Exploration Research Virtual Institute
NASA Ames Research Center

Fernando Ferroni
President
Istituto Nazionale di Fisica Nucleare

Sep. 15, 2014, SSERVI website

INFN-NASA/SSERVI Affiliation goals

- To jointly study and develop technologies for LRAs, their characterization and their applications to laser ranging, laser altimetry and lasercomm within missions in the Solar System

- This Affiliation is intended to allow INFN and NASA to jointly exchange information about the LRA development and characterization 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.

Support for missions in Earth Orbits

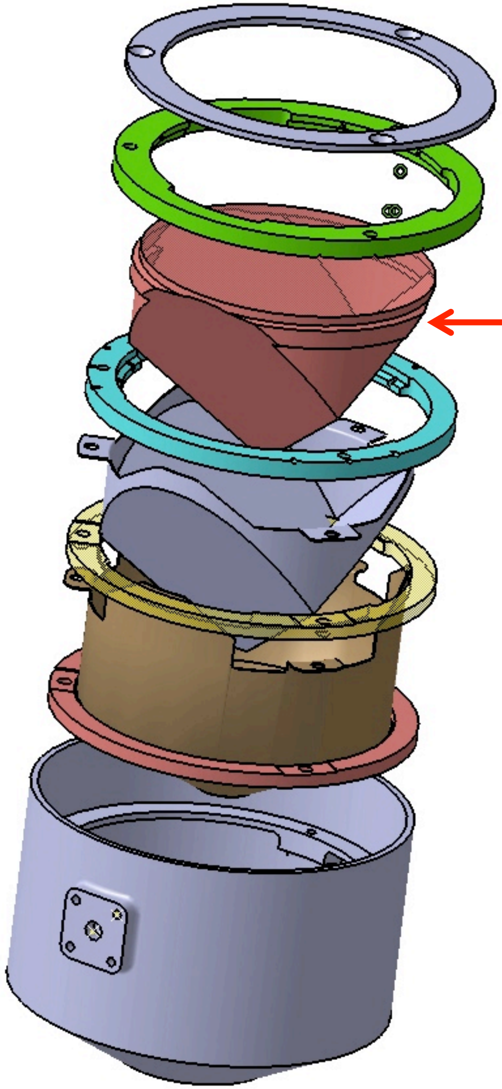
- Joint work for missions in Earth orbit whose LRAs are:
  - De-facto ILRS reference payload standards, like:
    - LAGEOS, Apollo, JASON
      - Continued support to NASA "LAGEOS Sector" (now at SCF_Lab)
  - Future geodesy missions with LRAs, like GRASP (Geodetic Reference Antenna in Space; JPL, Y. Bar-Sever)
  - GPS-III
    - Our GNSS expertise
      - Talk by Alessandro Boni
      - Poster on 'Laser Ranging to Galileo'
        - » MLRO & SCF_Lab upgrades: new laser, large laser beam expander

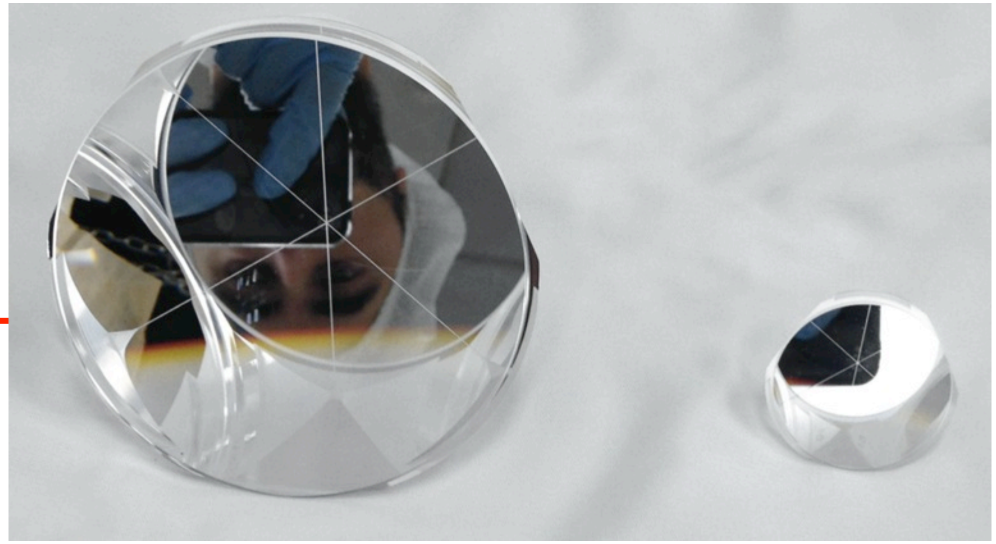
Specific work/study topics: da Moon

- Work on topics below is on-going and/or consolidated
- The Moon as a laser-ranged test body for General Relativity
  - Next-generation **single, large CCR** "MoonLIGHT / LLRA21"
    - D. Currie, Univ. of Maryland
    - Italian Teams: SCF_Lab, MLRO, Padua (see talk by M. Martini)
- **Microreflector**, "INRRI"
  - Device for planetary geodesy and georeferencing rovers and landers
  - Motivated by success of LLCD (Lunar Laser Comm. Demo) on LADEE (Earth-Moon laser ToF @ 220 psec accuracy)
- Cubesats for Earth, LunarCubes, and solar system exploration
  - NOTE: Full thermal (Sun-albedo-IR) and vacuum characterization of Cubesats available at the SCF_Lab

MoonLIGHT / LLRA21

(Moon Laser Instrumentation for General relativity High accuracy Tests)

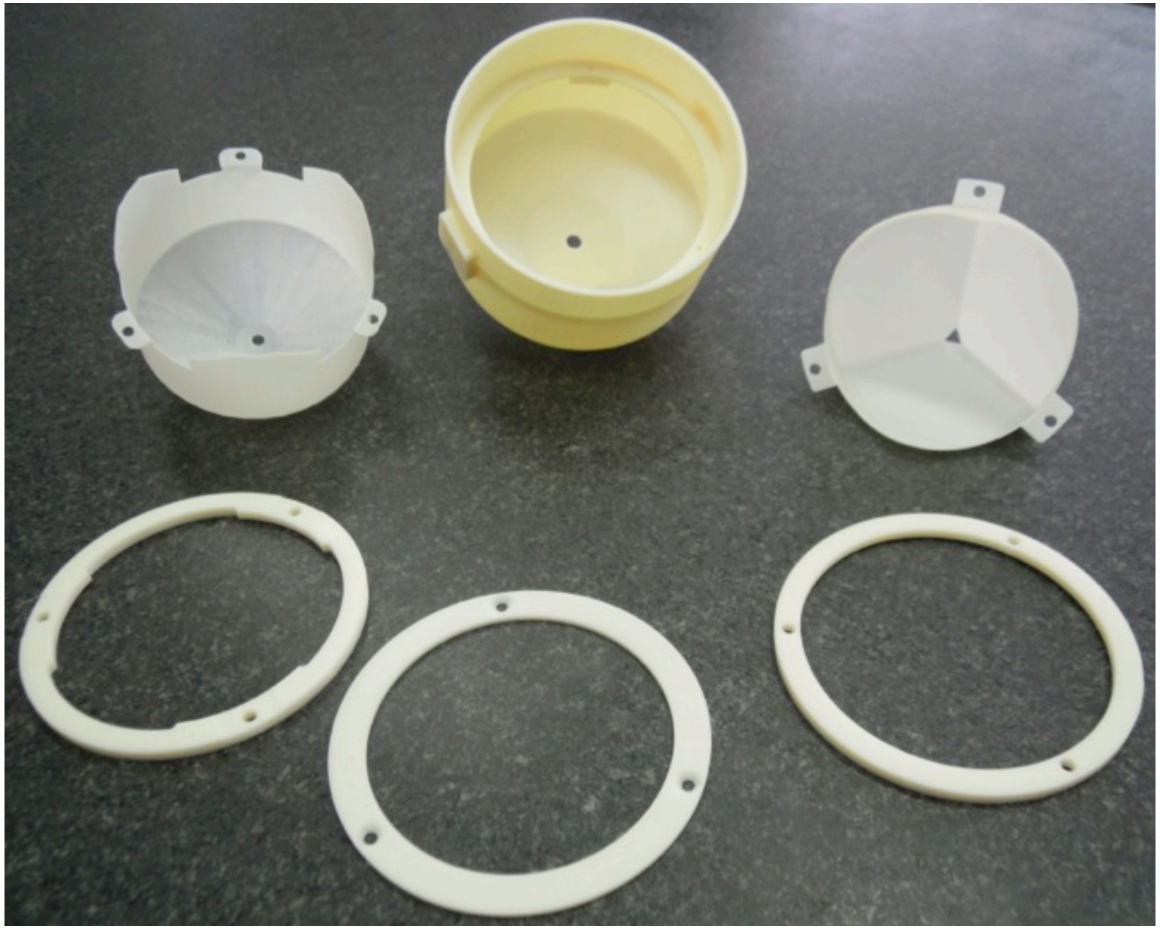




MoonLIGHT vs. Apollo:

- Suprasil 311 vs. Suprasil 1
- Optical specs wave/10 RMS vs. wave/4
- Single reflector 100 mm vs. array of 100-300 reflectors of 38 mm
- Laser return better than Apollo 15, ‘brightest’ of Apollo arrays, due to A15 degradation, likely due to dust deposit

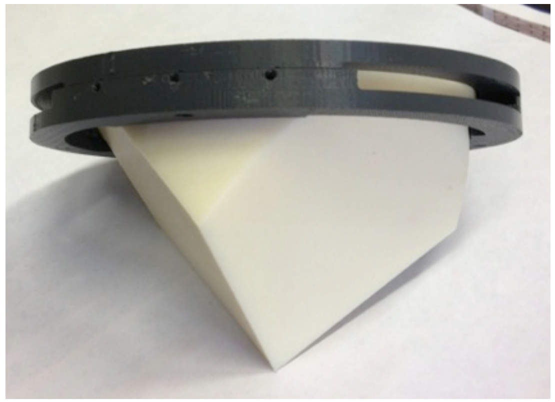
MoonLIGHT 3D-printed model built in Italy



Full retroreflector package

∅ ~ 130 mm × h ~100 mm

Retroreflector: **∅ = 100 mm**



General Relativity, New Gravity Physics

- 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, "$f_1(R)+f_2(R)$" theories
  - PRD 88, 064019 (2013), *Bertolami, March, Páramos*
  - Physics Letters B 735 (2014) 25–32, *Castel-Branco, Páramos, March*
- LAGEOS II pericenter GR precession, non-Newtonian gravity (see poster by D. Lucchesi)
  - PRL 105, 231103 (2010), PRD 89, 082002 (2014), *Lucchesi, Peron*

NON-MINIMALLY COUPLED (NMC) GRAVITY
R. March et al

- Accelerated expansion of the Universe can be explained (by Bertolami et al.): without introducing dark energy, with an action functional including non-minimal coupling between the matter lagrangian $\mathcal{L}_m$

  and geometry, with two functions $f_1(R)$ and $f_2(R)$, where R is the space curvature

$$S = \int \left[f_1(R) + \left(1 + \lambda f_2(R)\right) \mathcal{L}_m \right] \sqrt{-g}\, dx^4$$

$f_1(R) = R$ and $\lambda\, f_2(R)=0$ give Einstein's general relativity

Non-Minimally Coupled Gravity:

Constraints to and “csi” and “m” parameters of the theory by LLR data in the context of Yukawa effects

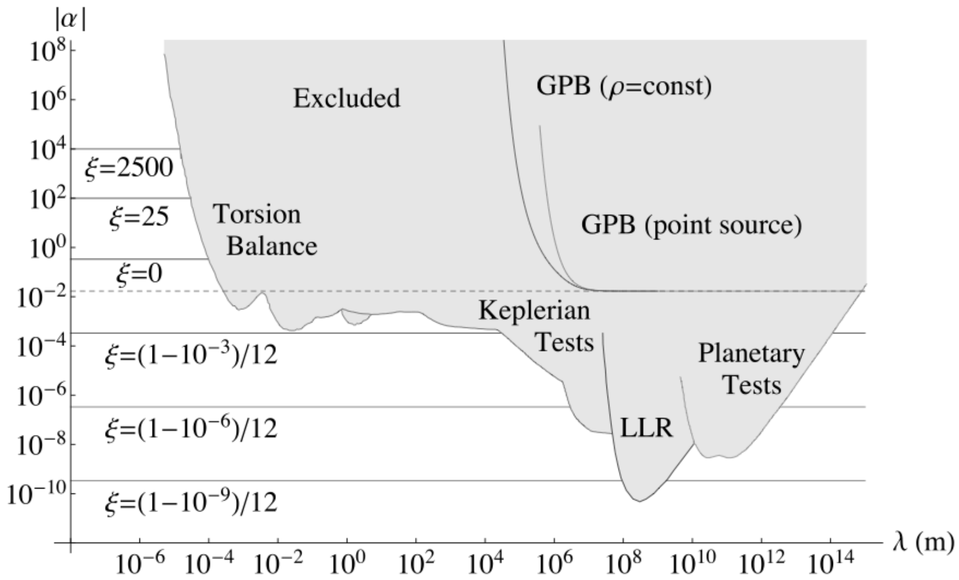


Fig. 2. Yukawa exclusion plot for α and λ. Adapted from Refs. [41,46].

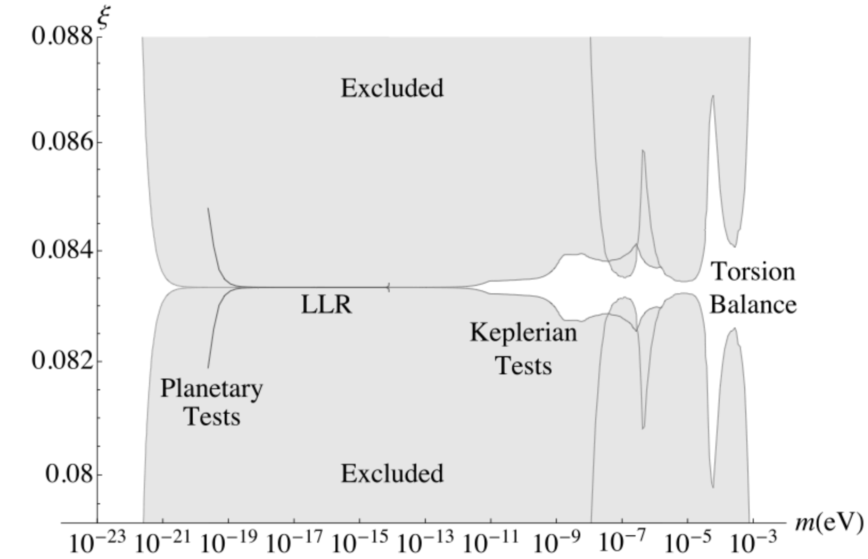


Fig. 3. Exclusion plot for the dimensionless relative strength ξ and characteristic mass scale m.

Physics Letters B 735 (2014) 25–32,
Castel-Branco, Páramos, March

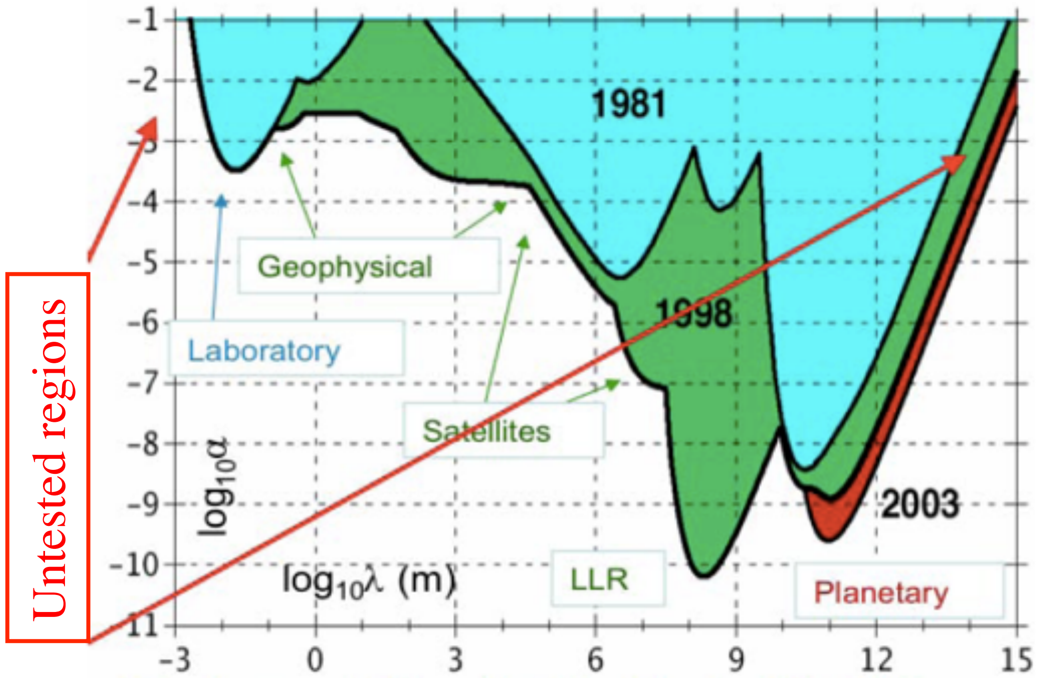
Limits on $1/r^2$ deviations with LLR: up to $\alpha < 10^{-12}$

MoonLIGHT designed to provide accuracy <1mm or better on space segment (the CCR)

If other error sources on LLR will improve with time at the same level, MoonLIGHT CCRs will **improve α limits from ~10^{-10} to ~10^{-12} at scales λ ~10^6 meters**

Limits on Yukawa potential:

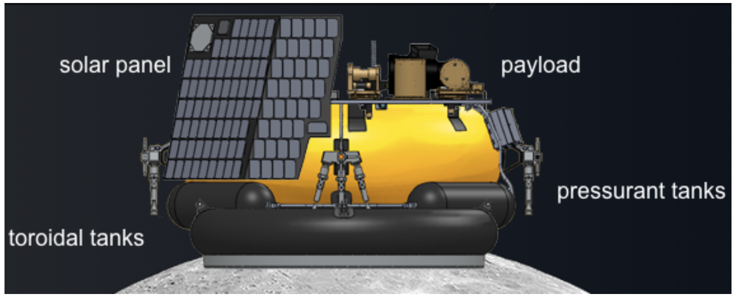
$\alpha \times$ (Newtonian-gravity) $\times e^{-r/\lambda}$



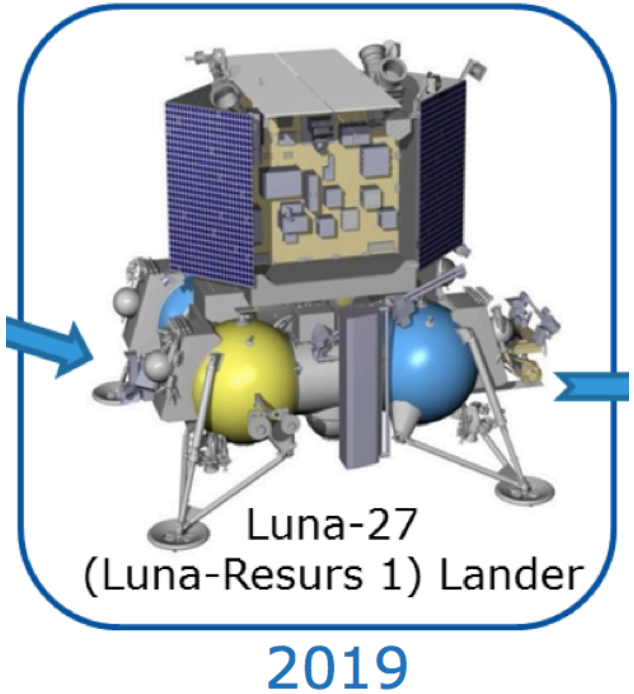
Courtesy : J. Coy, E. Fischbach, R. Hellings, C. Talmadge, and E. M. Standish (2003)

MoonLIGHT/INRRI opportunities

- **Moon Express**, lander for Google Lunar X Prize, 2015



- Proposal to IKI-RAS/Roscosmos for the Lander **Luna-27**
  - Also thanks to good ESA-Russia relations
  - RAS-INFN valid MoU since mid 1990s
  - PI: S. Dell'Agnello
  - Co-PI and Russian Curator:
    - A. Sokolov (RES. & PROD. CORP. «PSI»)
  - Co-Is:
    - D. Currie (INFN-LNF Guest Scientist)
    - G. Bianco (ASI, ILRS, INFN-LNF)
    - R. Vittori (Kosmonaut ×2, Astronaut ×1, INFN-LNF)

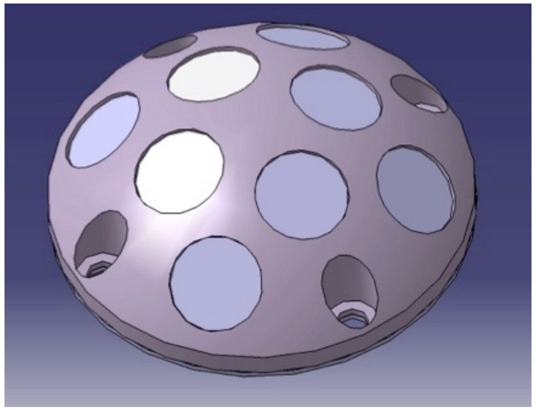


Da Martian system

- Work on laser retroreflectors for Mars exploration started
- Motivated by important effort on lasercomm by NASA, ESA:
  - Mars Lasercomm terminals by JPL and NASA-GRC
  - ESA: OGS @Tenerife, Alphasat-Sentinel 1A; OPALS @ISS by JPL
- Goals
  - Mars surface LRAs: light, compact, laser-located by orbiters
  - Georeferencing of rover exploration activity
  - Multiple INRRIs on landers/rovers can help
    - Establish a MGN (Mars Geophysical Network)
    - Define the Prime Meridian (now the Airy-0 crater)
  - Atmospheric trace species detection by space-borne lidar
  - Lasercomm test and diagnostics (wl independent)
- PANDORA (Phobos AND DeimOs laser Retroreflector Array)

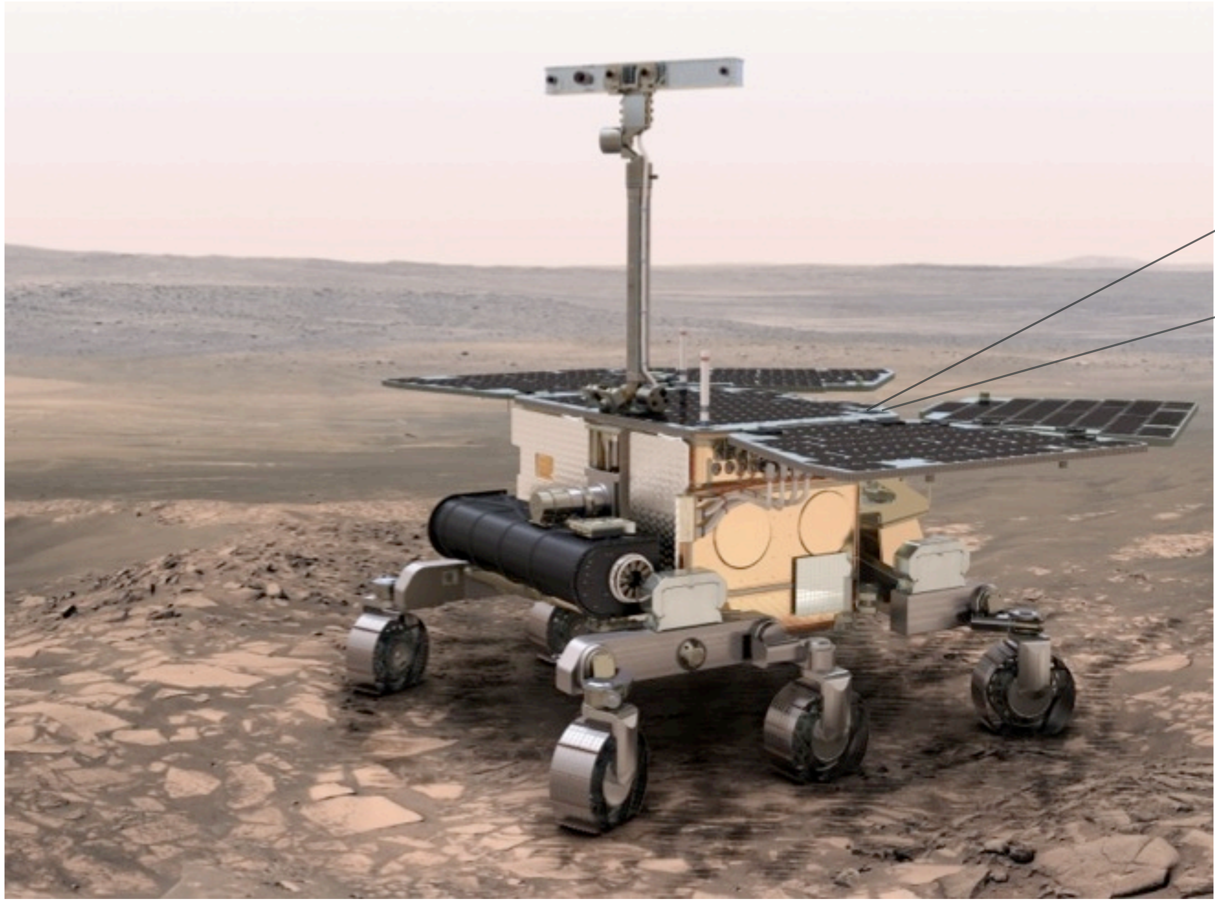
INRRI: INstrument for landing-Roving laser Retroreflector Investigations

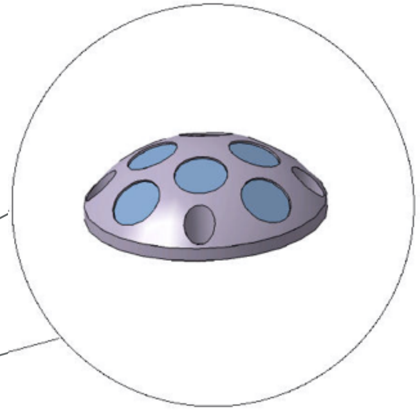
- Laser ranging, lasercomm, by orbiters (LADEE-like)
  - **Accurate positioning of landing site**
  - **Accurate positioning of roving exploration activity**
  - **Multiple INRRIs: establish MGN**
- Lasercomm check/calibration. Lidar atmosphere investigations on Mars
- Passive, compact
  - Very lightweight
  - No pointing required



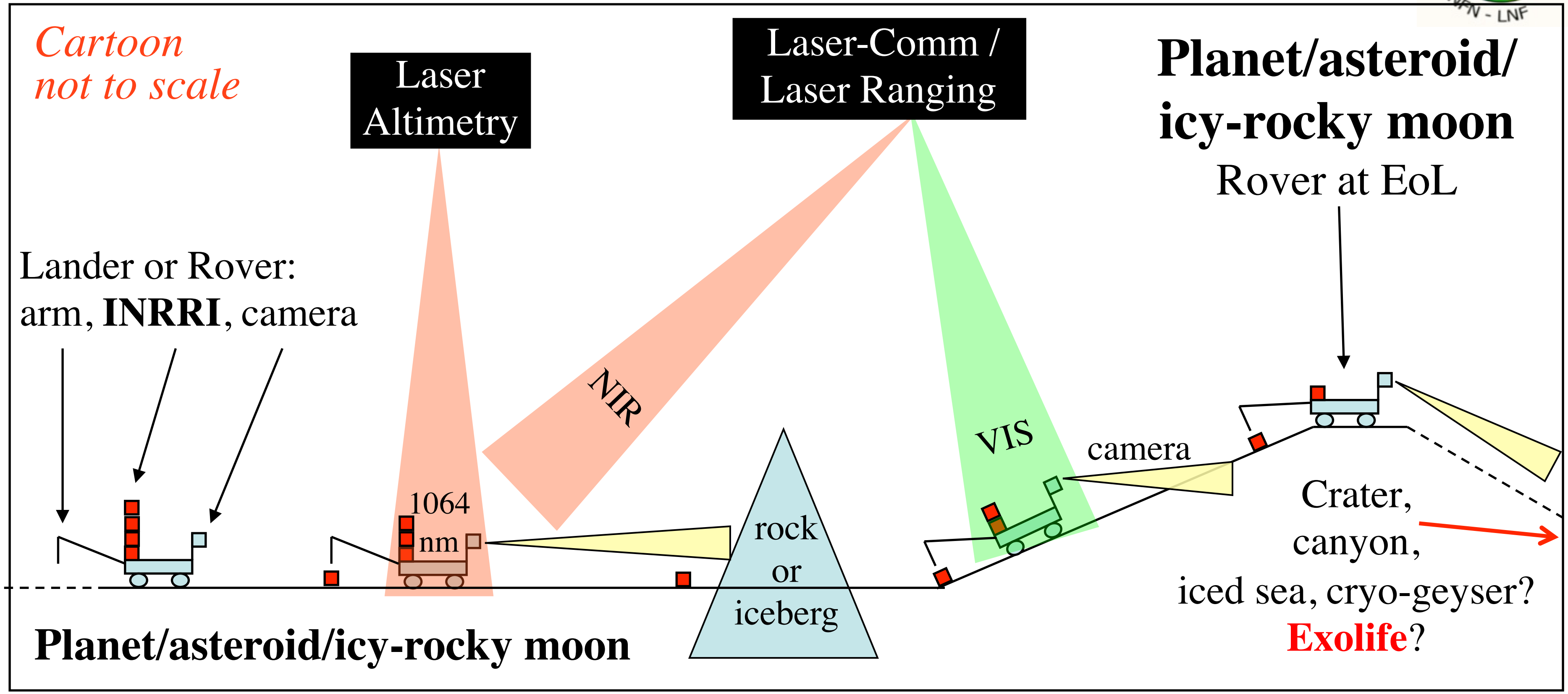
INRRI for Mars Rovers (and Landers)

- Geodesy (MGN, Meridian 0). Georeference exploration
- Lidar atmosphere trace species detection
- Lasercomm test & diagnostics





INRRIs on Moon, Mars, Jupiter/Saturn moons

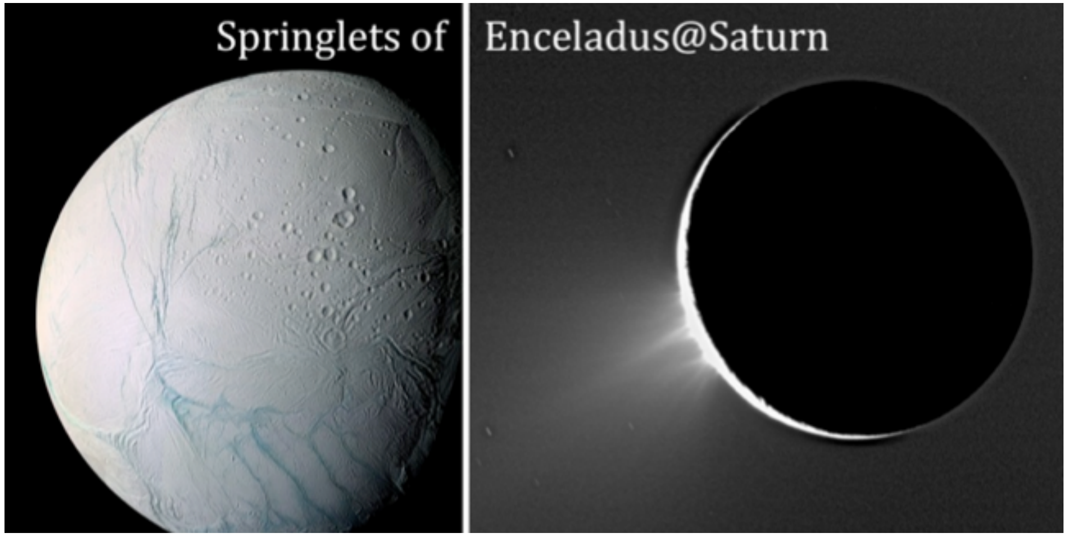


- Selenolocate Rover/Lander with laser retroreflector:
  - Laser Ranging (Comm) to reflectors anywhere (LLCD/iROC/OPALS-like)
  - Laser Altimetry at nadir (LRO-like) to rovers/landers only at poles of moon(s)
- **Deploy INRRI networks**. Also on far side of Earth's Moon

Da icy/rocky moons

- Europa/Enceladus Cube Corners for Exploration/Exolife
  - Recent NASA Europa AO did not include landing/roving
- Connecting the ITRS and ICRS
  - Link/tie Earth-Moon, Mars, Europa/Encelado retroreflectors and their networks via lasercomm, ranging an altimetry, throughout the Solar System, up to the

    Springlets of Enceladus



Conclusions (& plan for the next 10 years)

- INFN-NASA/SSERVI Partnership based on current SCF_Lab activity, extended to laser retroreflector technologies that can support Solar System exploration and science beyond the Moon

- But always keep support for LRAs for Earth orbits (LAGEOS, Apollo, Galileo/GPS, …)

(Near Earth) Asteroids

- Lots of activity by NASA and ESA: asteroid retrieval, redirection, (ion-beam) deflection …
- Study laser-marking NEAs by means of LRAs designed to support laser tracking of NEAs and contribute to SST
  - Recently proposed also by J. Williams at JPL (and at this workshop!)
  - Laser tracking with LRAs useful not only to monitor NEA positions, but also to guide directed forms of energy or ballistic interceptors