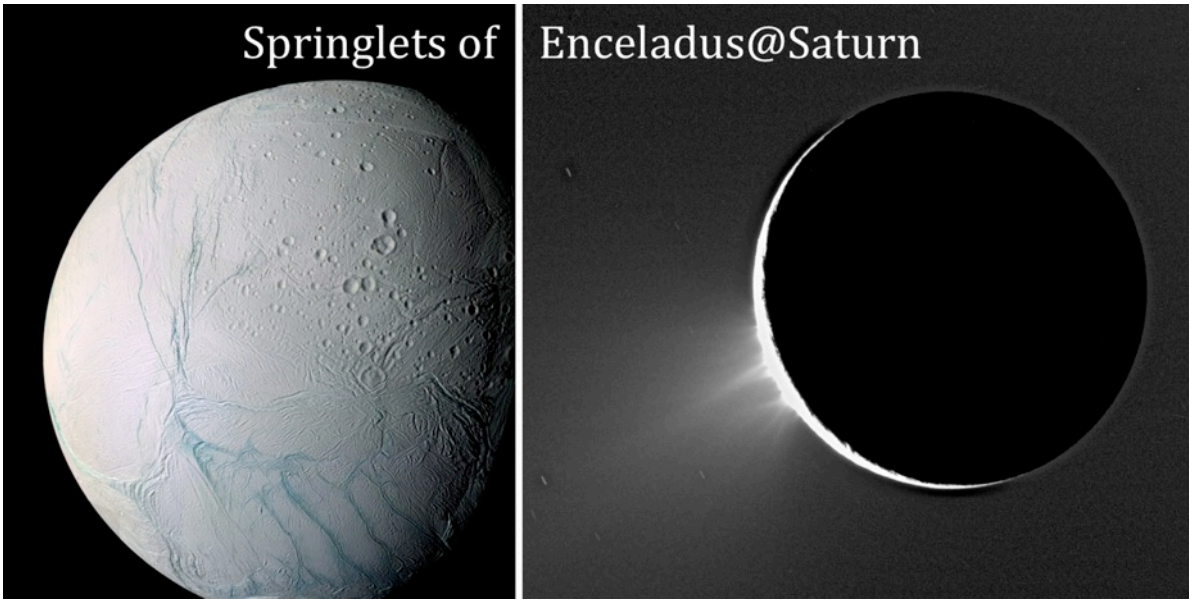
SPRINGLETS

Solar system Payloads of laser Retroreflectors of INfn for General reLativity, Exploration and planeTary Science

Presented to the 19th International Workshop on Laser Ranging

From Earth Orbits to the Springlets of Enceladus



Excerpt from:

Proposal of the Istituto Nazionale di Fisica Nucleare (INFN) to become an Affiliate Member of the NASA – Solar System Exploration Research Virtual Institute (SSERVI)

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The Italian SPRINGLETS Teams are reported in APPENDIX 1

THE SIGNED "AFFILIATE MEMBER COOPERATION" STATEMENT IS REPORTED IN APPENDIX 2

INFN Proposes:

To jointly study and develop technologies for LRAs, their characterization and their applications to laser ranging, laser altimetry and laser communication within missions in the Solar System, including: missions to the Moon that allow for precision testing General Relativity and study of new gravitational physics, as well as selenodesy and lunar exploration; Mars, Phobos, Deimos missions; and, ultimately, missions that support the laser georeferencing of landers and rovers to explore the icy/rocky moons of Jupiter and Saturn (like Encelado) and search there for exolife.
Joint work for select missions in Earth orbit whose LRAs are de-facto ILRS reference payload standards, like LAGEOS, Apollo, JASON; including future geodesy mission concepts comprising LRAs, like GRASP, proposed by NASA-JPL under the coordination of Yoaz Bar-Sever.
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.
Specifically, INFN intends to jointly study and identify innovative LRA technologies, thermal designs, test instruments and test procedures to achieve optimized optical LRA performance with limited or no thermal degradation through exhaustive LRA characterization and/or modeling, for a variety of satellite missions in the Solar System. The activities to be developed under this Proposal will be agreed upon by the Partners involved, and may include topics in the following.

1) **The Moon as a laser-ranged test body for General Relativity – LGN**
    - Development and characterization of a next-generation LLR payload based on the solid fused silica retroreflector technology, inheriting from the design of Apollo, and consisting of a single, large CCR (a passive payload, as Apollo LRAs). This is done in close collaboration with Currie, who is a Guest Scientist of the SCF_Lab (INFN program FAI). Consideration of other technologies as well
    - Study of improved precision tests of General Relativity, new gravitational theories and selenodesy through LLR analysis using the next-generation lunar LRAs as part of an LGN, extending the Apollo/Lunokhod LRAs. Collaboration of SCF_Lab, MLRO, CfA, APOLLO, NASA-GSFC, NASA-SSERVI
    - Studies for deployment of MoonLIGHTs and INRRIs to lunar exploration.
    - Studies for the development of a Quantum Communication lunar network of payloads consisting of optical terminals (see [31] to [34]).
2) **Laser retroreflectors for Mars exploration – MGN**
    Extension of Lunar program to LRAs on Mars and its satellites with US and/or European landing/roving mission in which Italy is involved
    - Next generation Mars laser retroreflectors will include INRRI and adaptations of EO-LRAs. INRRI and/or EO-LRA will be tracked by future Mars orbiters capable of laser ranging, laser altimetry and laser communication, like for example the LOLA, LLCD and iROC payloads. These retroreflectors will be studied for deployment on US Mars landers and rovers and on European landers and rovers with Italian interest and/or involvement
    - Deploying multiple INRRIs on landers and rover will lead over time to the establishment of a MGN. This will allow for the possibility of defining the location of

the Airy-0 prime meridian of Mars using an INRRI-equipped lander (or rover at EOL) laser-located by Mars orbiters (perhaps a future, Mars-adapted version of LOLA whose more accurate mapping will replace MOLA laser altimetry maps). When the operation of an INRRI-equipped vehicle will be terminated, its passive and maintenance-free LRA can still be laser-tracked by future laser-equipped Mars orbiters. Lunar dust studies for LRAs will be extended and adapted to the Mars environment

- Study of PANDORA, which will has heritage from EO-LRAs already developed by INFN. This will allow for an extended study of GR and new gravitational theories, in the Sun-Mars system (two body physics) and Sun-Mars-Jupiter system (three-body physics).

3) **Europa/Enceladus laser Cube Corner Reflectors for Exploration/exolife up to Saturn**
Over the long term, we propose to undertake laser georeferencing of potentially habitable worlds by extending the program described above for Mars to the exploration of icy/rocky moons of Jupiter and Saturn.
4) **ILRS payload standards in Earth Orbits.**
In close collaboration with NASA-GSFC, the characterization of the following ILRS payload standards in Earth Orbits will be continued as a reference figure of merit to be compared to lunar and planetary LRAs described previously: LAGEOS Sector and LRA models of JASON and GNSS.
5) **Connecting the ITRS and ICRS**
Connecting the ITRS, ICRS, LGN, MGN, IGENs via laser communication and ranging throughout the Solar System
   - Support to Apollo, LAGEOS, ETALONS, as primary reference payload standards of the ILRS for LLR and SLR
   - Within INFN-CSN2 work on GR and new gravity analysis for LAGEOS and LARES is carried out by LARASE [14][15], led by David Lucchesi.
6) **Near Earth Asteroids**
Study feasibility of laser-marking NEAs by means of the deployment of LRAs specially designed to support laser tracking of NEAs and contribute to SSA/SST. The latter is a significant activity of NASA and research theme of HORIZON2020 within the EU.
7) **Range Correction**
Study of an upgrade of the SCF_Lab to perform the time-of-flight laser "range correction" of LRAs in representative space conditions. It is reminded that the "range correction" for the LAGEOS-I and LAGEOS-II satellites was performed by NASA-GSFC in the 1970s and 1990s with the LAGEOS satellites kept in air and isothermal conditions (not in lab-simulated space conditions possible at the SCF_Lab), and that the determination and definition of the ITRS origin (Earth center-of-mass, or geocenter) and of the ITRS scale replies predominantly on the correct understanding of LAGEOS range correction. Collaboration between SCF_Lab, ASI-MLRO and NASA-GSFC. This is a fundamental capability, strongly endorsed by the ILRS that should be used to calibrate CCR arrays prior to launch, or to characterize existing/operational LRAs.

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Acronyms and Definitions

AGILE = Astro-rivelatore Gamma a Immagini LEggero
AMS = Alpha Magnetic Spectrometer
APOLLO = Apache Point Observatory Lunar Laser-ranging Operation
ASI = Agenzia Spaziale Italiana
BIPR = Background Intellectual Property Rights
BTF = Beam-Test Facility
CAS = Chinese Academy of Science
CCR = Cube Corner Retroreflectors
CERN = Centre Européenne pour la Recherche Nucléaire
CfA = Harvard-Smithsonian Center for Astrophysics
CNR-IAC = Consiglio Nazionale delle Ricerche (Italian National Research Council) – Istituto per le Applicazioni del Calcolo
CNR-ISC = Consiglio Nazionale delle Ricerche (Italian National Research Council) – Istituto dei Sistemi Complessi
CSN2 = INFN National Scientific Committees n. 2, on astroparticle physics (http://www.infn.it/csn2/)
CSN5 = INFN National Scientific Committees n. 5, on technological physics (http://www.infn.it/csn5/)
DAMPE = DArk Matter Particle Explorer
DAΦNE = Double Annular Φ for Nice Experiments
DoE = US Department of Energy
ECCE-INRRI = Europa/Enceladus Cube Corners for Exploration and Exolife – Instruments for landing/Roving laser Retroreflector Investigations
EO = Earth Observation
EOL = End Of Life
ESA = European Space Agency
ETRUSCO = Extra Terrestrial laser Ranging to Unified gnss Satellite COnstellations
FAI = Fondi Affari Internazionali, INFN Funds for International Affairs
Fermi/GLAST = Fermi Observatory / Gamma Large Area Space Telescope
FNAL = Fermi National Accelerator Laboratory
FTIR = Fourier Transform InfraRed
GAMMA-400 = Gamma Astronomical Multifunctional Modular Apparatus-400
GALA = GAnimede Laser Altimeter
GIOVE = Galileo In-Orbit Validation Elements
GLONASS = Russian GNSS
GLXP = Google Lunar X Prize
GPS =American GNSS
GR = General Relativity
GRASP = Geodetic Reference Antenna in Space
GNSS = Global Navigation Satellite System

HEB = High Energy Beam
HEP = High Energy Physics, i.e., particle physics
HP = Hadron Physics
ICRS = International Celestial Reference System
IGEN = Icy-moons Geophysical and Exolife Networks
ILN = International Lunar Network
ILRS = International Laser Ranging Service
INAF-IAPS = Istituto Nazionale di AstroFisica (Italian National Institute for Astrophysics) - Istituto di Astrofisica e Planetologia Spaziale (Institute for Space Astrophysics and Planetology)
INFN = Istituto Nazionale di Fisica Nucleare, Italian National Institute for Nuclear Physics
INRRI = Instrument for landing/Roving laser Retroreflector Investigations
IOV = In-Orbit Validation
iROC = integrated Radio and Optical Communications
IR = InfraRed
IRSR = InfraRed Synchrotron Radiation
ISF = Internal Special Facility
ITRS = International Terrestrial Reference System
LADEE = Lunar Atmosphere and Dust Environment Explorer
LAGEOS = LAser GEOdynamics Satellite
LARES = LAser RElativity Satellite
LARASE = LAser RAnged Satellites Experiment
LGN = Lunar Geophysical Network
Linac = Linear accelerator
LHC = Large Hadron Collider
LLCD = Lunar Laser Communication Demonstration
LLR = Lunar Laser Ranging
LNF = Laboratory Nazionali di Frascati, Frascati National Labs
LPI = Lunar and Planetary Institute
LOLA = Lunar Orbiter Laser altimeter
LRA = Laser Retroreflector Arrays
LRO = Luna Reconnaissance Orbiter
LSSO = Program (Lunar Sortie Scientific Opportunities
MGN = Mars Geophysical Network
MGS = Mars Global Surveyor
MIT = Massachusetts Institute of Technology
MIUR = Italian Ministry of Instruction, University and Research
MLA = Mercury Laser Altimeter
MLRO = Matera Laser Ranging Observatory
MOLA = Mars Orbiter Laser Altimeter
MoonLIGHT = Moon Laser Instrumentation for General relativity High accuracy Tests
MRR = Modulated Retro Reflector
NASA-ARC = National Aeronautics and Space Admin. – Ames Research Centre
NASA-GRC = National Aeronautics and Space Admin. – Glenn Research Centre
NASA-GSCF = National Aeronautics and Space Admin. – Goddard Space Flight Centre
NASA-JPL = National Aeronautics and Space Admin. – Jet Propulsion Laboratory
NDA = Non Disclosure Agreement
NEA = Near Earth Asteroids
NLSI = NASA Lunar Science Institute
NMC = Non-Minimally Coupled
OGSE = Optical Ground Support Equipment
OPALS = Optical PAyload for Laser communication Science
PANDORA = Phobos AND DeimOs Retroreflector Array
PI = Principal Investigator
SCF_Lab = Satellite/lunar/GNSS laser ranging/altimetry and Cube/microsat Characterization Facilities Laboratory
SEM = Scanning Electron Microscope
SEY = Secondary Electron Yield

SINBAD = Synchrotron INfrared Beamline At DAΦNE
SLR = Satellite Laser Ranging
SSA = Space Situational Awareness
SSERVI = Solar System Exploration Research Virtual Institute (http://sservi.nasa.gov)
SST = Space Surveillance and Tracking
STM = Scanning Tunneling Microscope
UCSD = University of California at San Diego
UMD = University of Maryland
XANES = X-ray Absorption Near Edge Structure
XAS = X-ray Absorption Spectroscopy
XPS = X-ray Photoelectron Spectroscopy

APPENDIX 1: Italian Research Teams

INFN-LNF / SCF_Lab ISF

Simone Dell'Agnello	Ph.D., Physicist	Responsible for SCF_Lab
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Luca Foggetta	Physicist	

ILRS-MLRO: SLR/LLR

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(Chairman of ILRS Governing Board, ASI-Space Geodesy Center, Matera, Italy, Associated to INFN-LNF)

INFN and University of Padova: Laser Quantum Communication and Encryption

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Giuseppe Vallone	Physicist	
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INFN Roma Tor Vergata: LARASE Experiment

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INFN-LNF Internal Special Facilities:

- SCF_Lab: http://www.lnf.infn.it/esperimenti/etrusco/
- DAΦNE-Light : https://web.infn.it/Dafne_Light/
- BTF: http://www.lnf.infn.it/acceleratori/btf/.

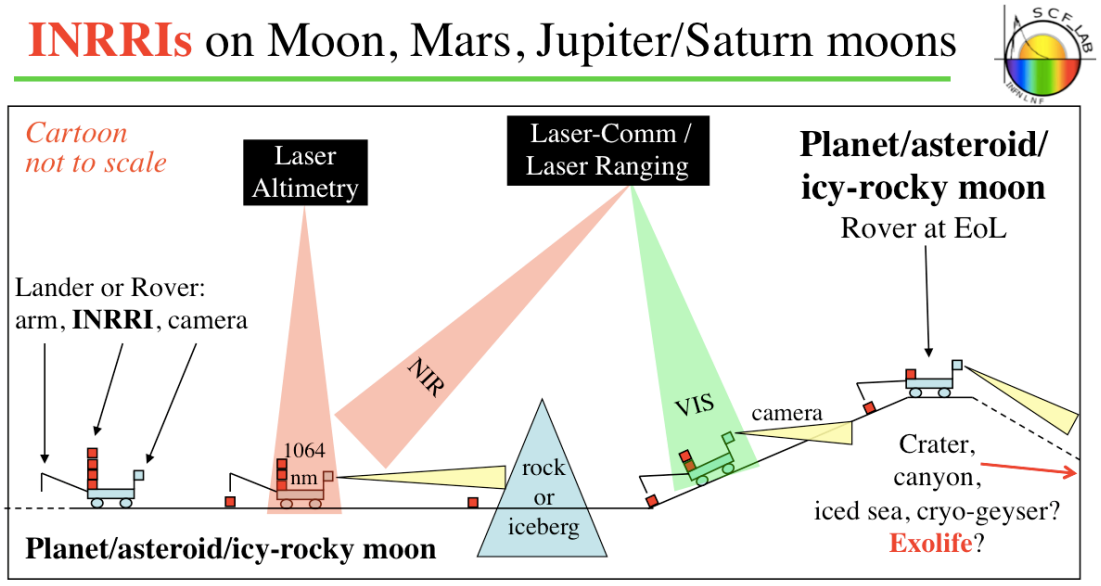

Figure1: Conceptual figure describing CCR networks for Solar System exploration

APPENDIX 2

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.

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.

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