INFN
Istituto Nazionale
di Fisica Nucleare
Laboratori Nazionali di Frascati

SCF_Lab
INFN LNF

Stato dell'arte dei retroriflettori laser per la fisica fondamentale e per esplorazioni

Incontri di Fisica delle Alte Energie (IFAE) 2015

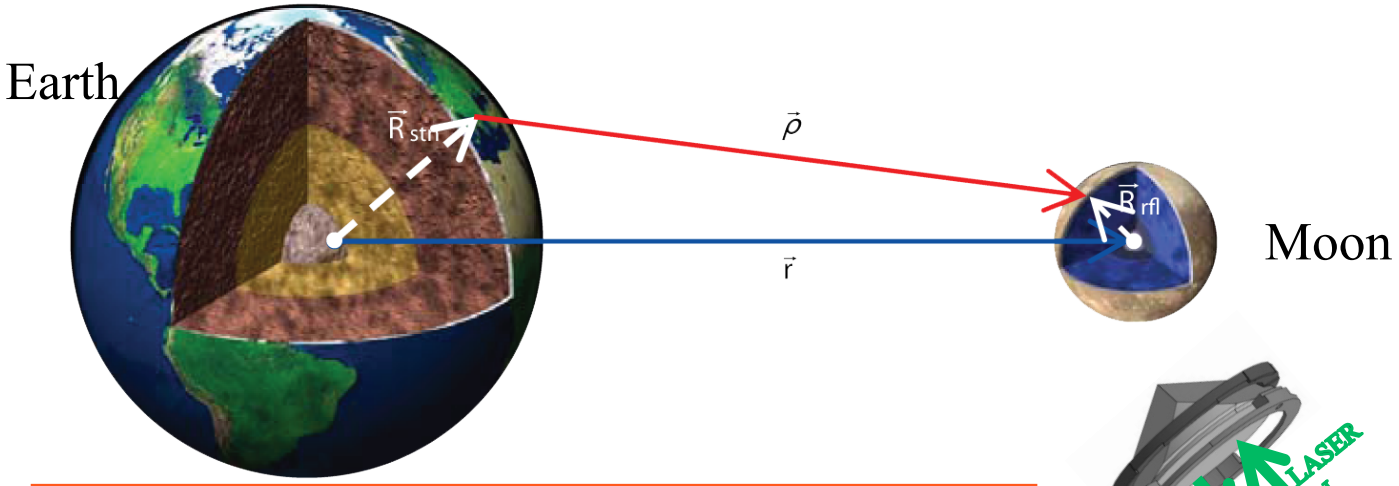
Roma Tor Vergata, 8-10 Aprile 2015

Outline

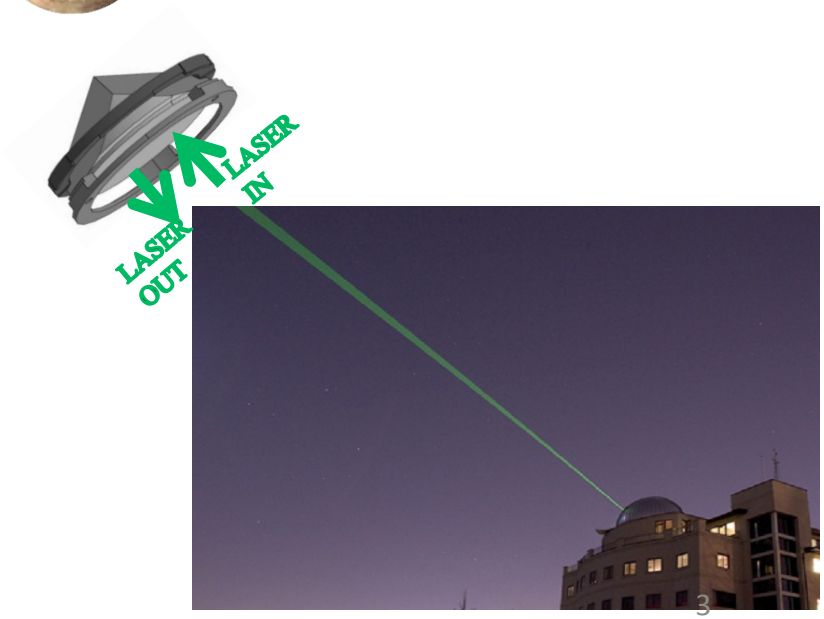
- Laser Retroreflectors and Laser Ranging in Space
- MoonLIGHT, Moon Laser Instrumentation for General relativity High accuracy Tests, experiment of INFN
- Test CCR @ SCF_Lab, INFN-LNF: Unique Test Facility for Laser Retroreflectors in Space
- INRRI, INstrument for landing-Roving laser ranging/altimetry Retroreflector Investigations, and its applications to exploration of Mars system and beyond
- Conclusions

Satellite/Lunar Laser Ranging (SLR/LRR)

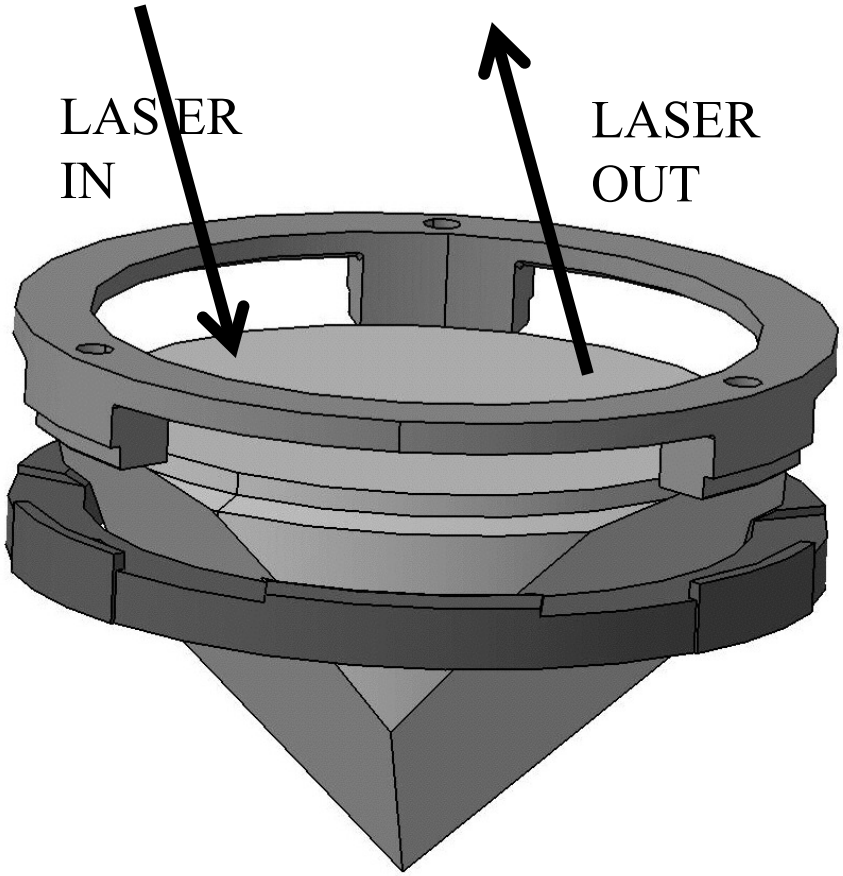
SLR and LLR are precise time-of-flight (ToF) measurements
short laser pulses fired from ground stations to Cube Corner
Retroreflectors CCRs
coordinate by the ILRS = International Laser Ranging Service

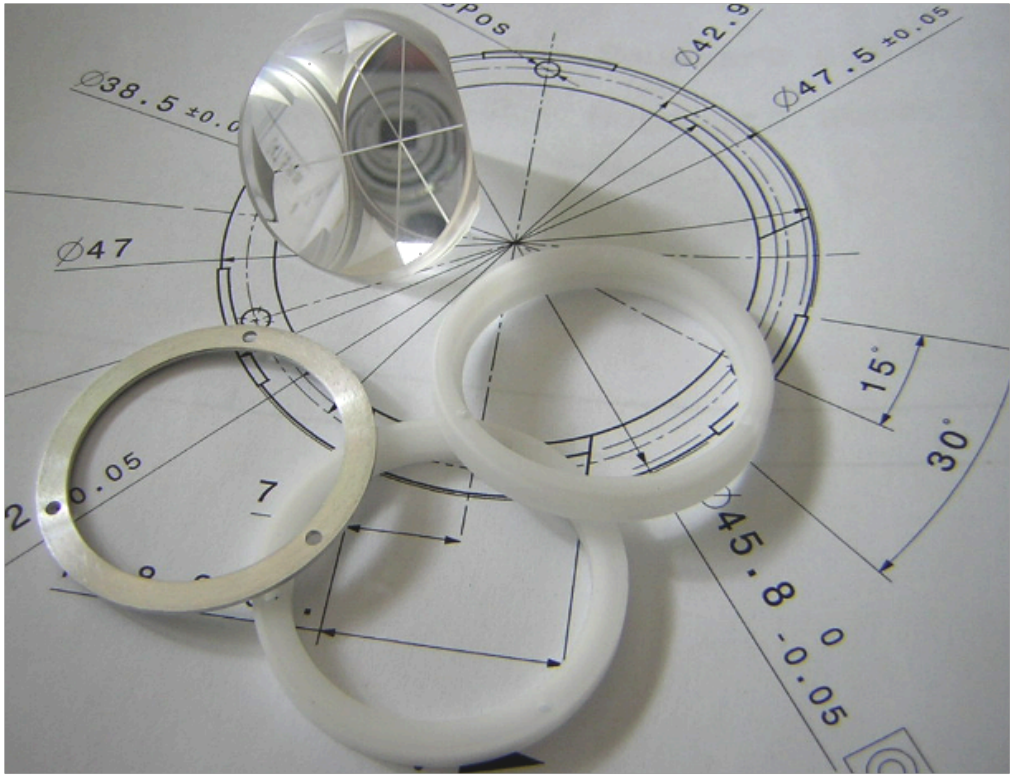


- **Precise** positioning (normal points at mm level, orbits at cm level)
- **Absolute** accuracy (used to define Earth center of mass, geocenter, and scale of length)
- **Passive**, maintenance-free Laser Retroreflector Arrays (**LRAs**)



Cube Corner laser Retroreflectors (CCRs)





Triple (retro)reflection around the corner

SLR/LLR examples

S

L

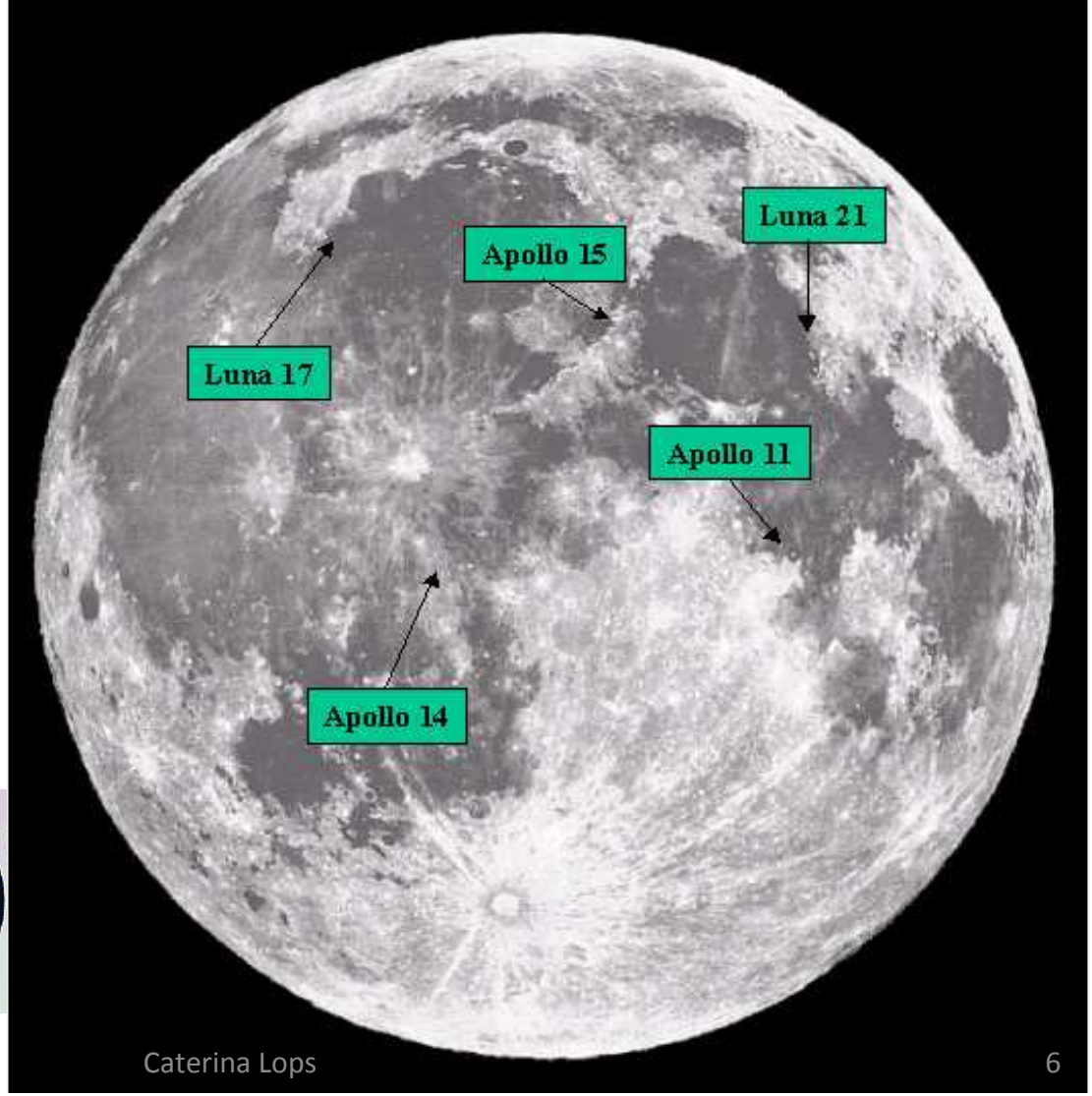
R

Moon (d ~ 380000 km): ToF ~ 2.5 sec
LAGEOS (h ~ 6000 km): ToF ~ 0.05 sec

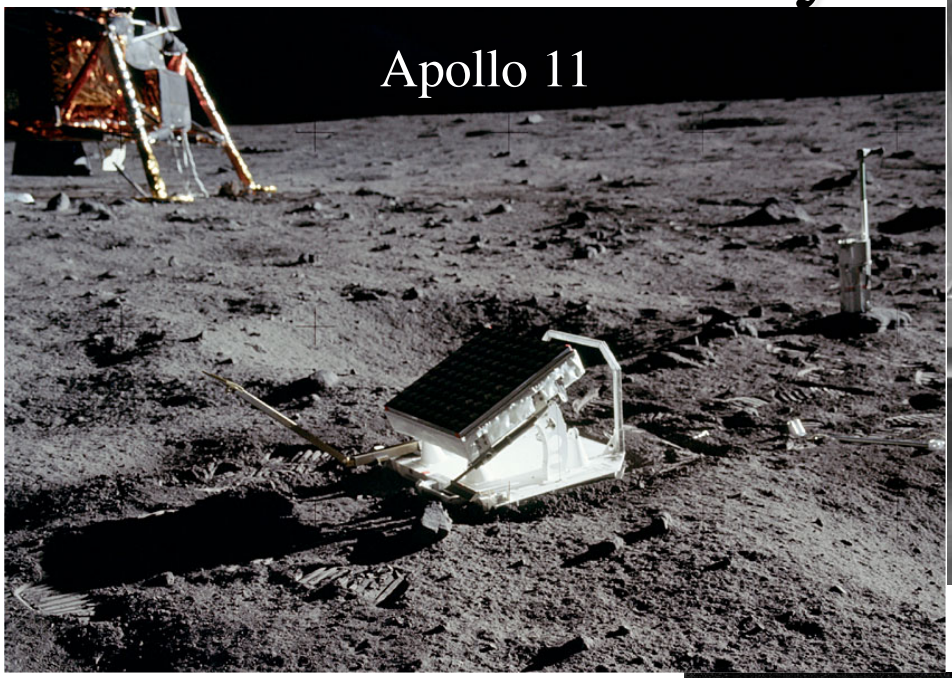
Lunar Laser Ranging

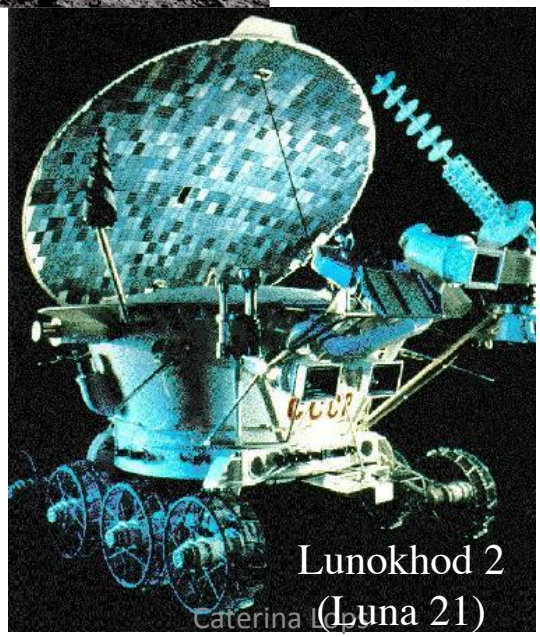
Relative sizes and separation of the Earth–Moon.
An LLR pulse takes 1.255 sec for the mean orbital distance.

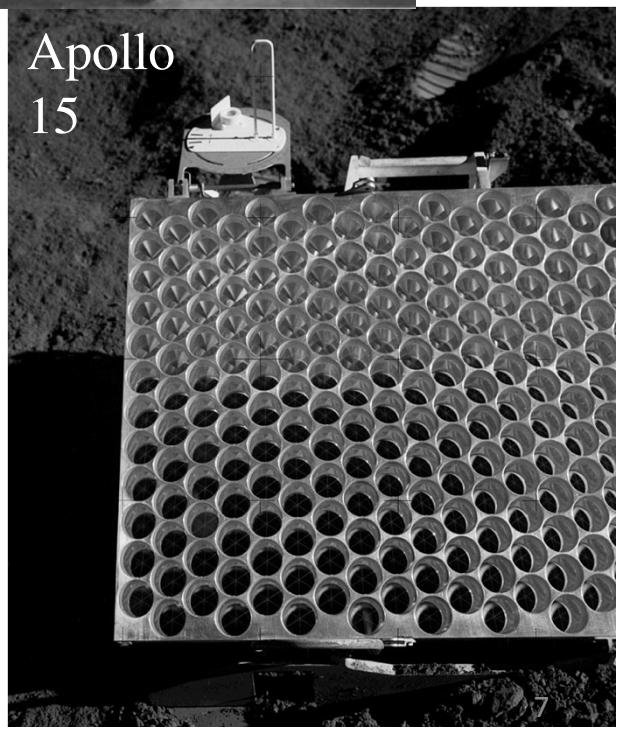
Locations of 1st Gen. Lunar Retroreflector Arrays
Retroreflectors deployed by Apollo 11, 14, 15



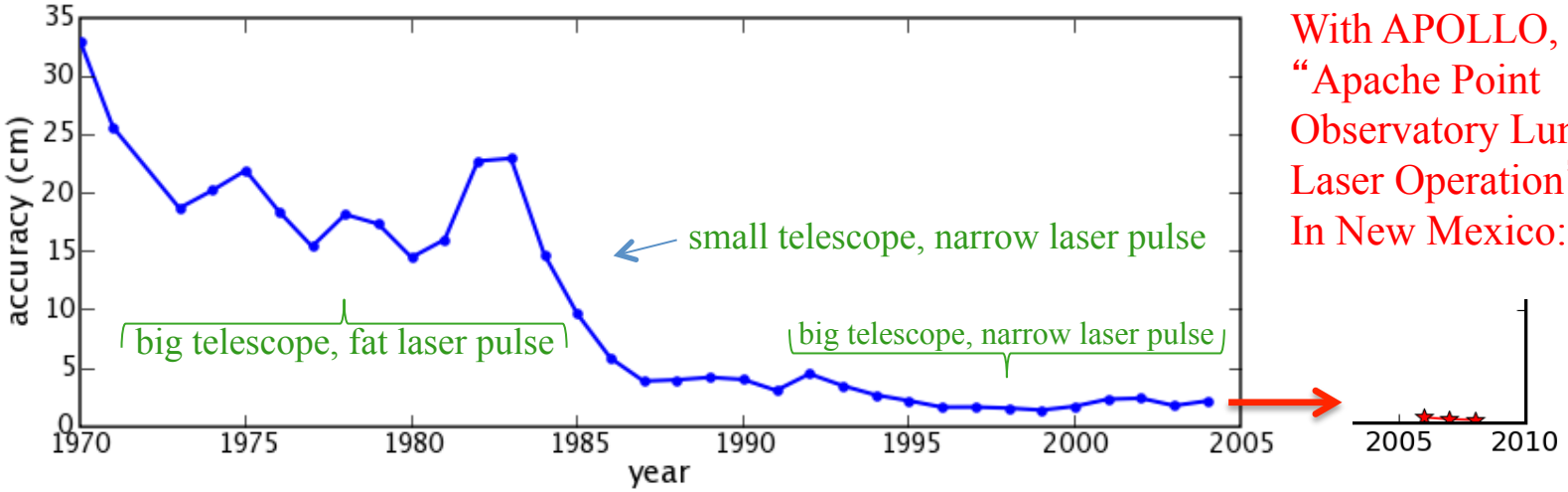
Current LLR arrays



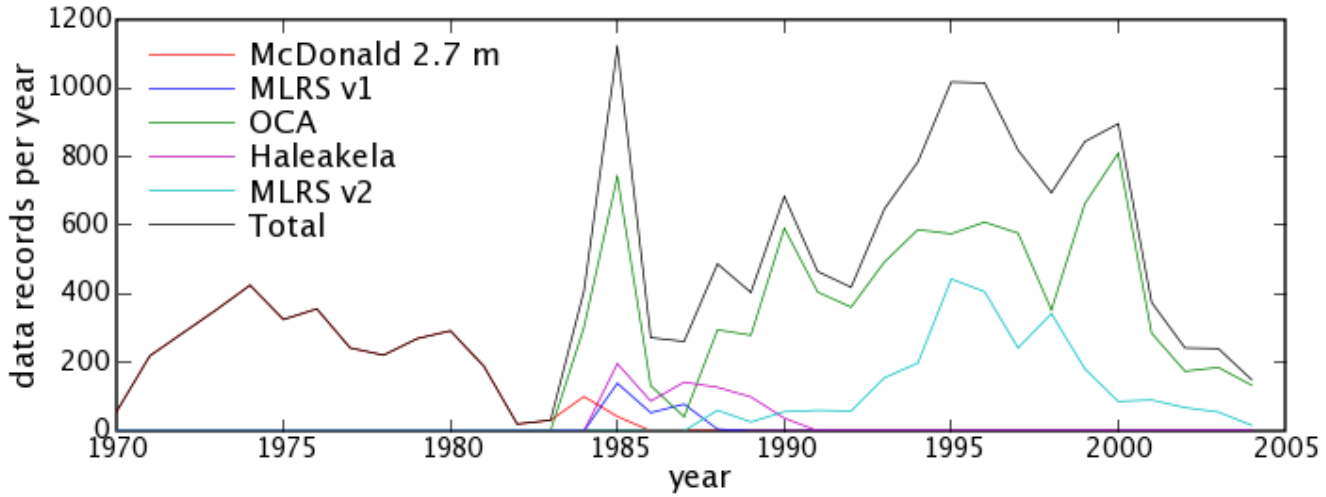




Historic LLR Range Precision



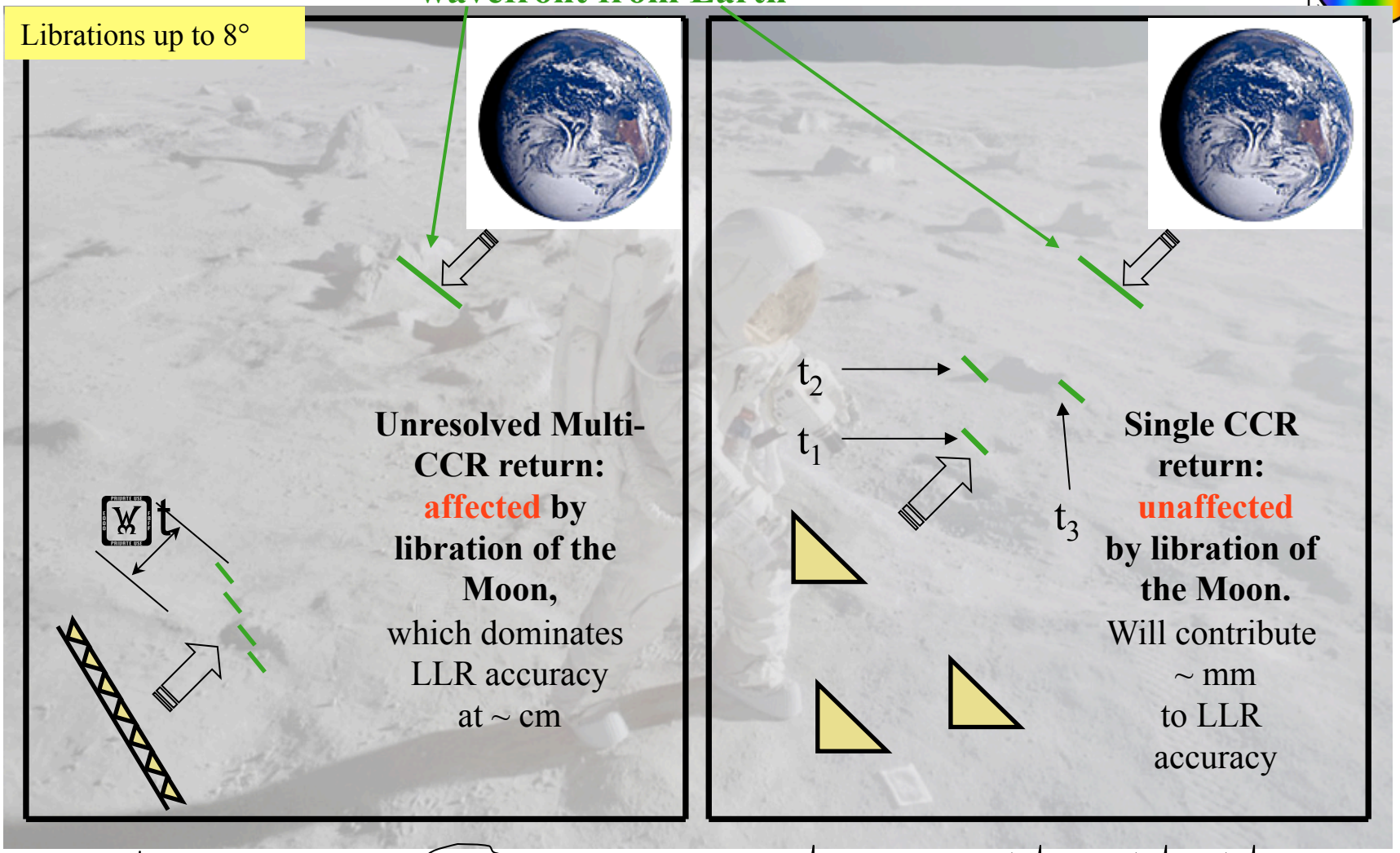
With APOLLO, "Apache Point Observatory Lunar Laser Operation", In New Mexico:



Apollo
LLRRA_20th

532 nm laser wavefront from Earth

MoonLIGHT
LLRRA_21st Century



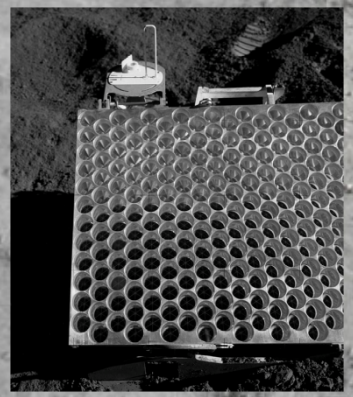
Short Pulse to Moon — **Wide Pulse to Earth**

Pulse to Moon — **Pulses to Earth**

MoonLIGHT-ILN/LLRRA-21 2nd gen. LLR

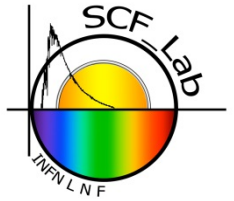
Moon Laser Instrumentation for General relativity High-accuracy Tests-International Lunar Network /Lunar Laser Ranging Retroreflector Array for the 21st century

Apollo 15:
~ m^2 array of small CCRs



MoonLIGHT: distributed large (10cm) CCRs.
Robotic (rover/lander) or manned deployment

Background image courtesy of Lockheed Martin. Rover/lander image courtesy of NASA



Experiment of INFN National Scientific Committee 2 (CSN2) for **2013-2018**:

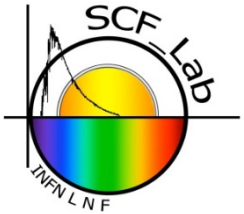
MoonLIGHT-2

Moon Laser Instrumentation for General relativity High accuracy Tests – Phase 2

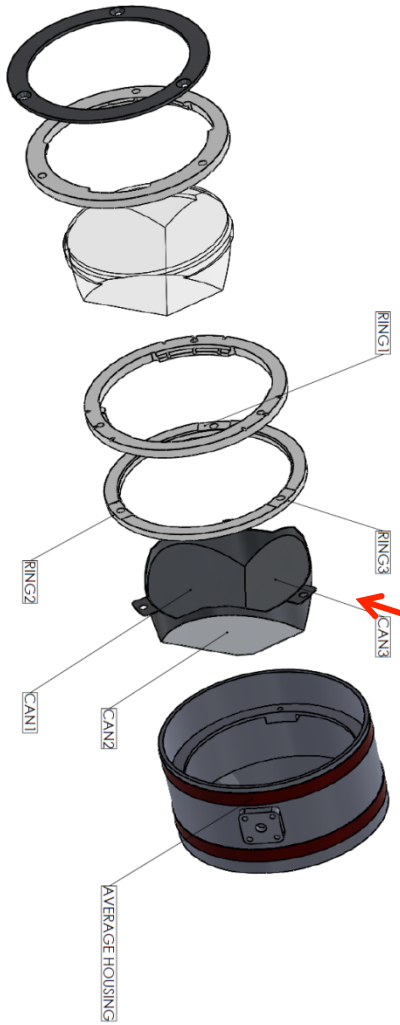
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

SCF_Lab

Satellite/lunar laser ranging/altimetry and cube/microsat **C**haracterization **F**acilities **Lab**oratory



MoonLIGHT cube corner reflector (CCR)

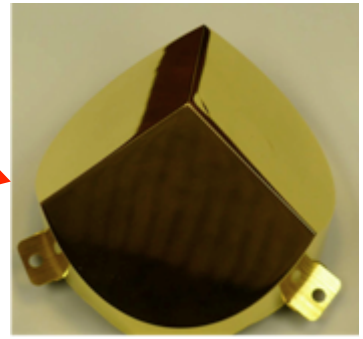


Exploded view of MoonLIGHT

Photo of the MoonLIGHT CCR and of an Apollo CCR

Photos of 3D-printed plastic components of MoonLIGHT

INNER CONFORMAL THERMAL SHIELD (Au-Ag coated)



- Mass ~ 1.3 kg
- Size ~ 150mm (⌀) x 100mm (h)
- Sophisticated thermal design (internal heat shield), tight optical specs

LLR tests of General Relativity

Science measurement / Precision test of violation of General Relativity	Apollo/Lunokhod few cm accuracy*	MoonLIGHT-2 1 mm	MoonLIGHT-2 0.1 mm
Parameterized Post-Newtonian (PPN) β	$\lvert\beta-1\rvert<1.1\times10^{-4}$	10^{-5}	10^{-6}
Weak Equivalence Principle (WEP)	$\lvert\Delta a/a\rvert<1.4\times10^{-13}$	10^{-14}	10^{-15}
Strong Equivalence Principle (SEP)	$\lvert\eta\rvert<4.4\times10^{-4}$	3×10^{-5}	3×10^{-6}
Time Variation of the Gravitational Constant	$\lvert\dot{G}/G\rvert<9\times10^{-13}\mathrm{yr}^{-1}$	5×10^{-14}	5×10^{-15}
Inverse Square Law (ISL)	$\lvert\alpha\rvert<3\times10^{-11}$	10^{-12}	10^{-13}
Geodetic Precession	$\lvert K_{gp}\rvert<6.4\times10^{-3}$	6.4×10^{-4}	6.4×10^{-5}

* J. G. Williams, S. G. Turyshev,and D. H. Boggs, PRL 93, 261101 (2004)

Our measurement of the Geodetic Precession with Apollo/Lunokohd, including new APOLLO station, with Planetary Ephemeris Program (PEP) by CfA: **~1% accuracy**

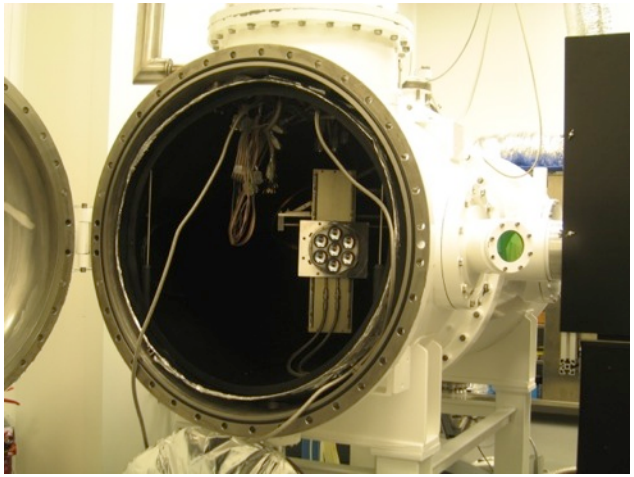
Number of laser returns to make a "standard" ~2-cm LLR range:

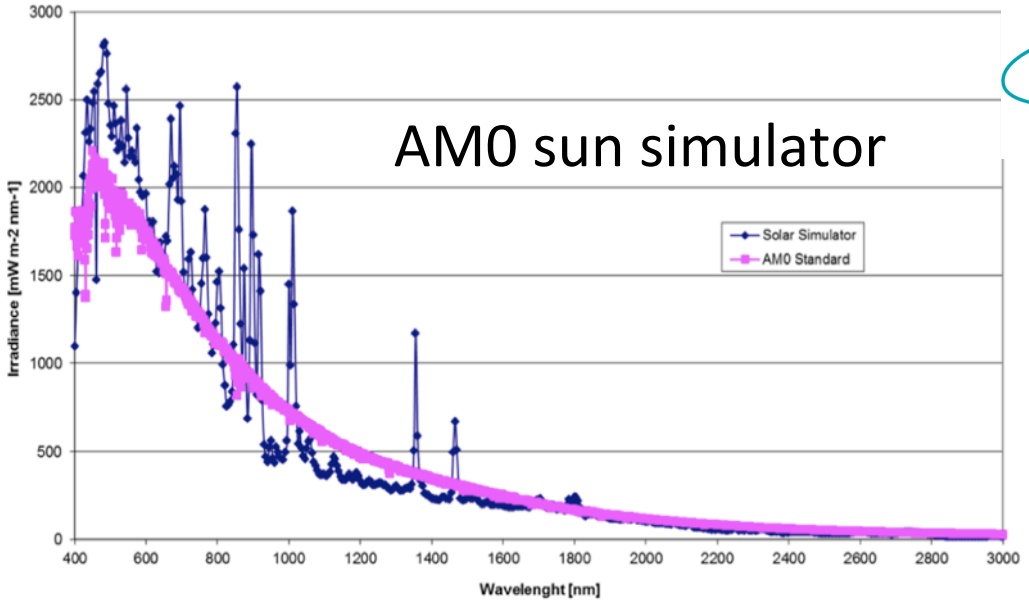
- **MoonLIGHT single, large reflector**: ~1
- Apollo/Lunokhod multi-reflector array: few thousands

SCF_Lab: retroreflector characterization

Satellite/lunar laser ranging/altimetry and Cube/microsat Characterization Facility

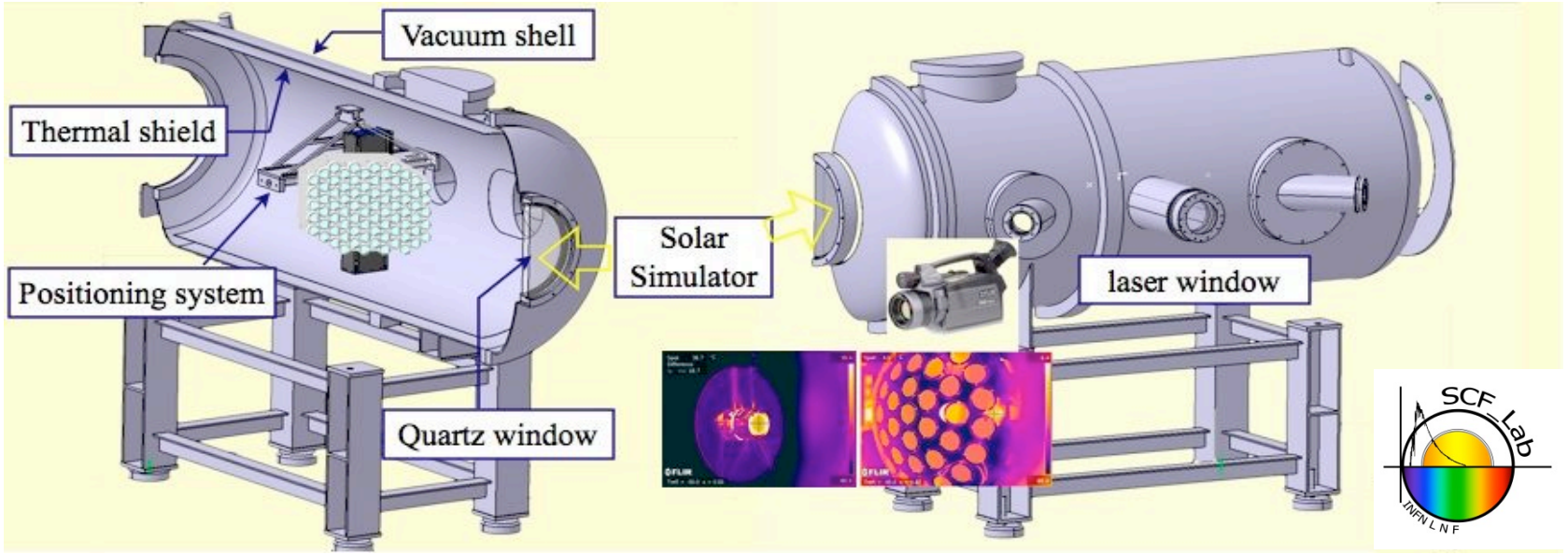
- Two Optical Ground Support Equipment (OGSE)
- SCF (top right) SCF-G (bottom right) dedicated to Galileo, other GNSS
- Two AM0 sun simulators, IR thermometry
- Detailed optical testing
- J. Adv. Space Res. 47 (2011) 822–842

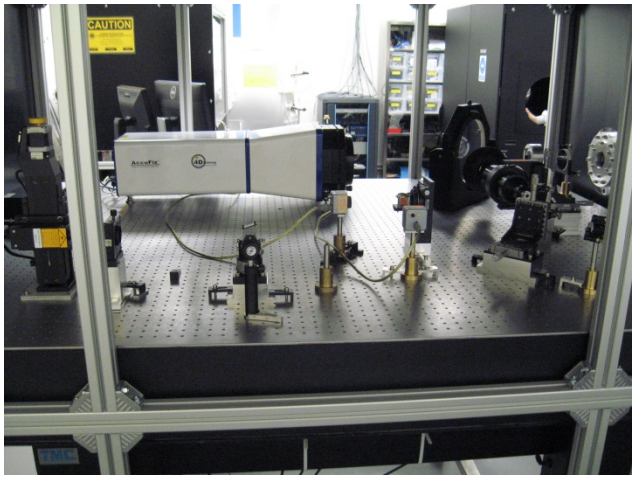


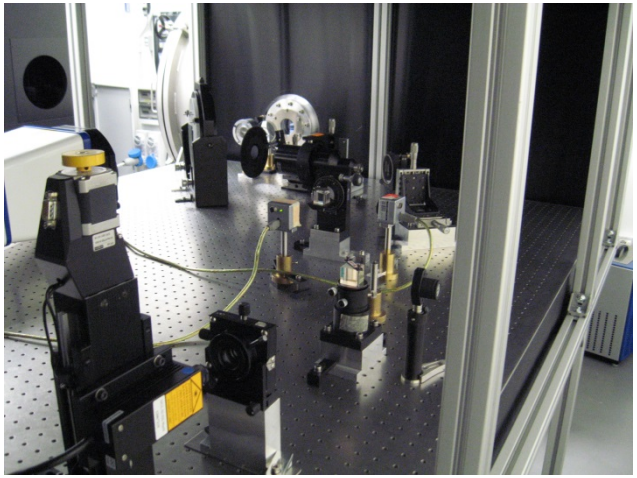


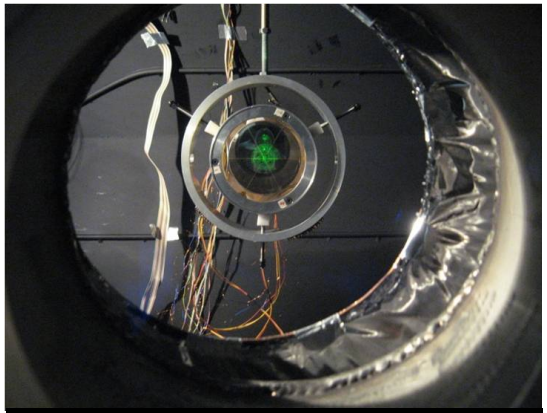
SCF_Lab: retroreflector characterization

(Better than) Class 10000 (ISO 7) Clean Room









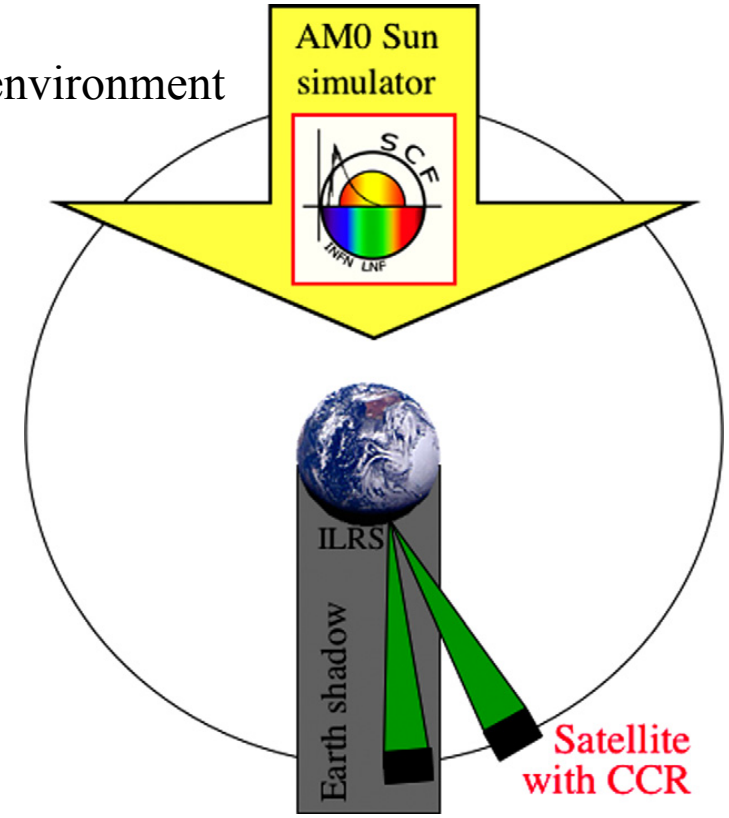
MoonLIGHT inside SCF

SCF-Test: optical & thermal measurements

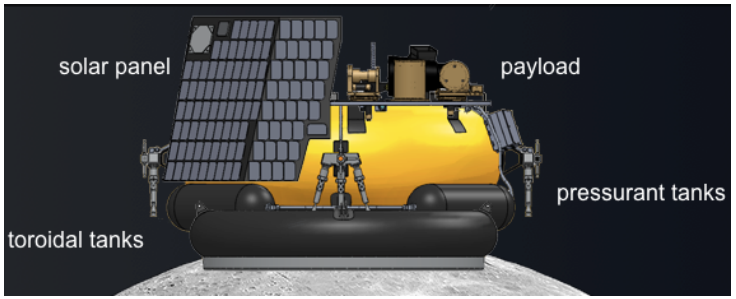
SCF-Test concept: reproduce the passage of a satellite equipped with an LRA, into the Earth shadow and sun illumination.

Exposure of CCR/LRA:

- Low temperature (77K) and vacuum (10^{-6} mbar) of the environment
- Hold the average temperature, T_{AVG}, of the CCR/LRA
  → reached stationary state, FFDP taken
- Sun Simulator (SS) illumination → thermogram taken
- Cool down → FFDP acquired
- Repeat the above measurement for different:
  - Temperature: $T \neq T_{AVG}$
  - SS illumination angles

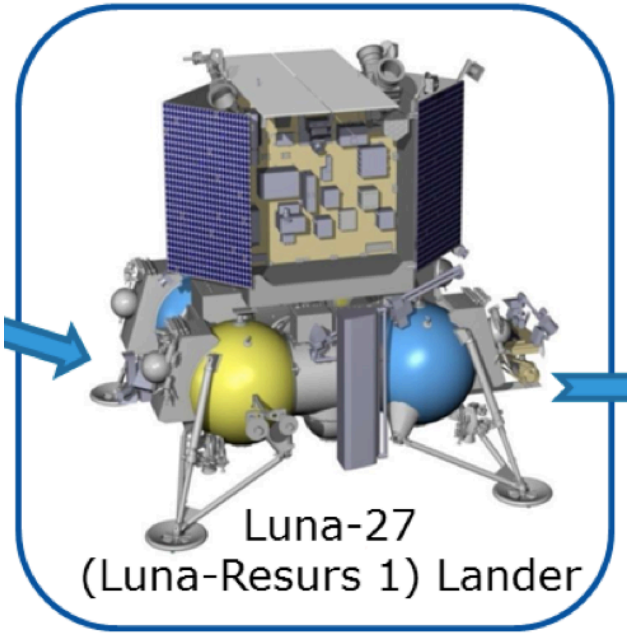


MoonLIGHT Lunar Opportunities



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

- 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
  - Co-Is:
    - D. Currie (INFN-LNF Guest Scientist)
    - G. Bianco (ASI, ILRS, INFN-LNF)
    - R. Vittori (Kosmonaut ×2, Astronaut ×1, INFN-LNF)

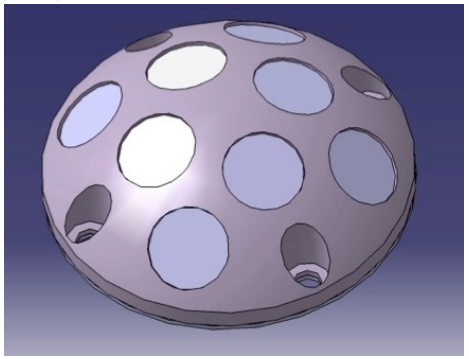


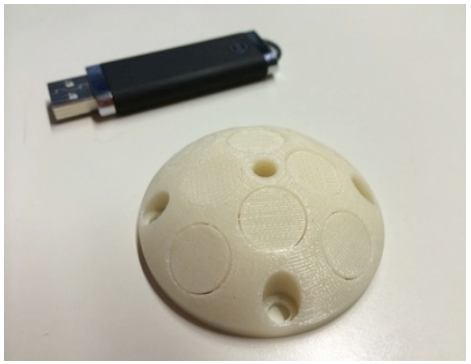
INRRI: **IN**strument for landing-**R**oving laser ranging/altimetry **R**etroreflector **I**nvestigations

- Passive, maintenance-free, lifetime of decades
  - Several geometries/n. CCRs: 5, 7, 8, …

Each CCR is: ~ 1.25mm ⌀, Ag back coated,
DAO: (0.0±0.5) arcsec

  - Lightweight: ~ 30 gr
  - Compact ~ (5cm ⌀ x 2 cm h)
  - No pointing required

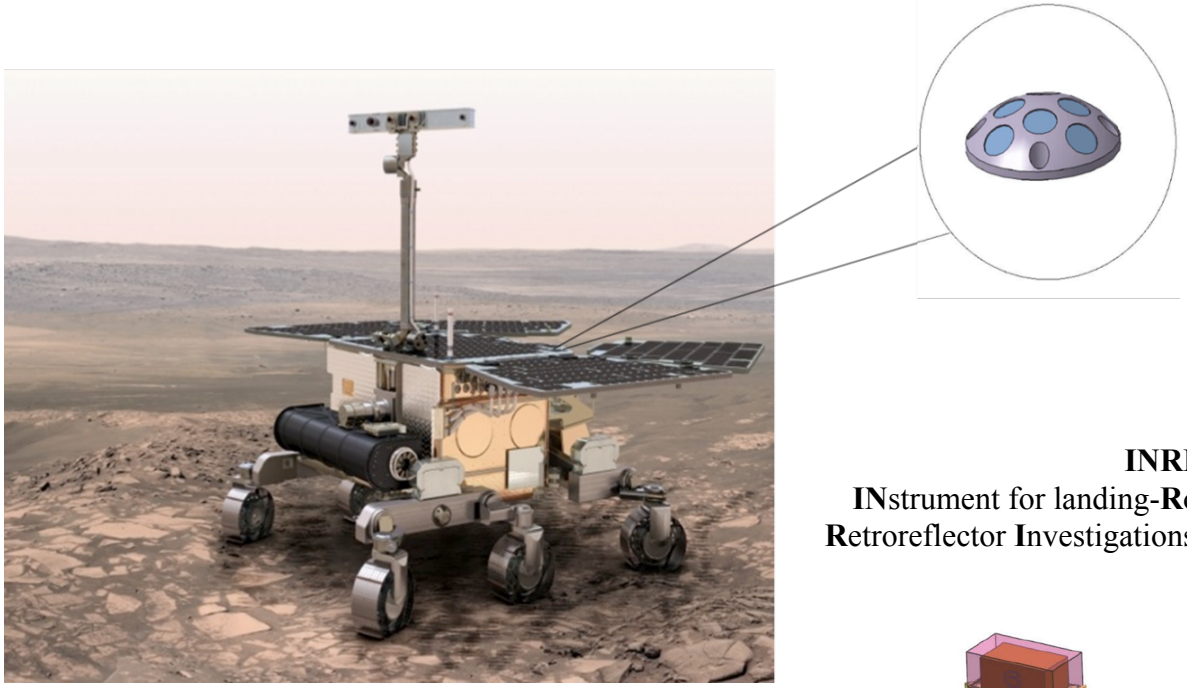




- Geodesy (MGN, Meridian 0). Georeference exploration
- Precision Lidar-based landing
  (return to astrobiologically relevant site)
- Lidar atmosphere trace species detection
- Lasercomm test & diagnostics

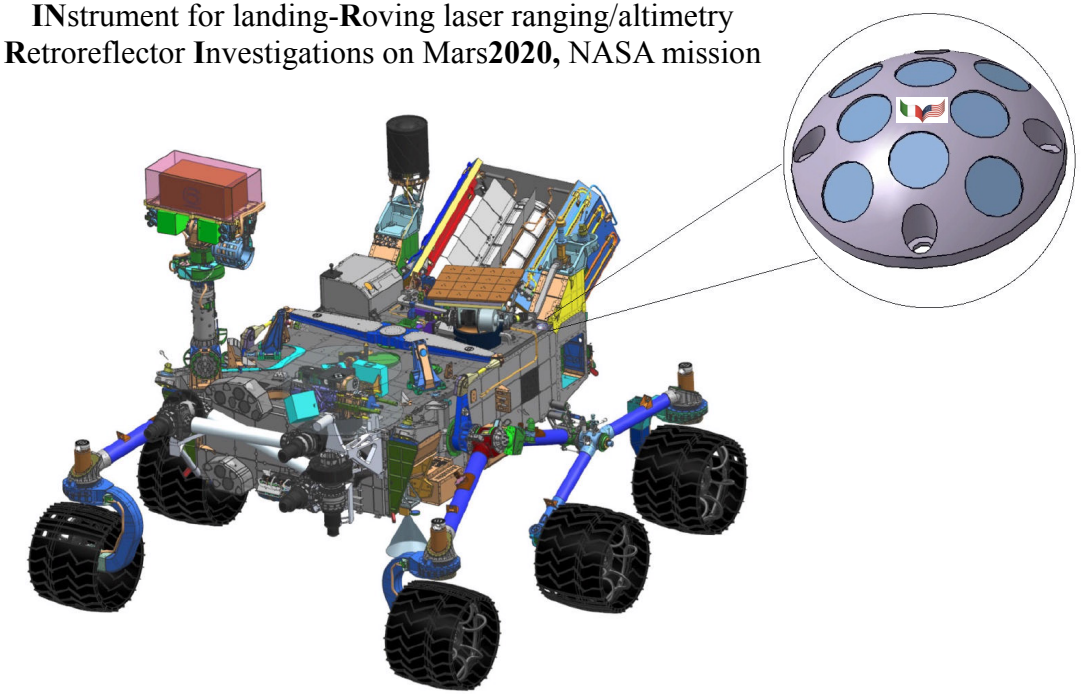
INRRI for Mars Rovers (and Landers)

ExoMars 2018: strategic, cornerstone ESA mission

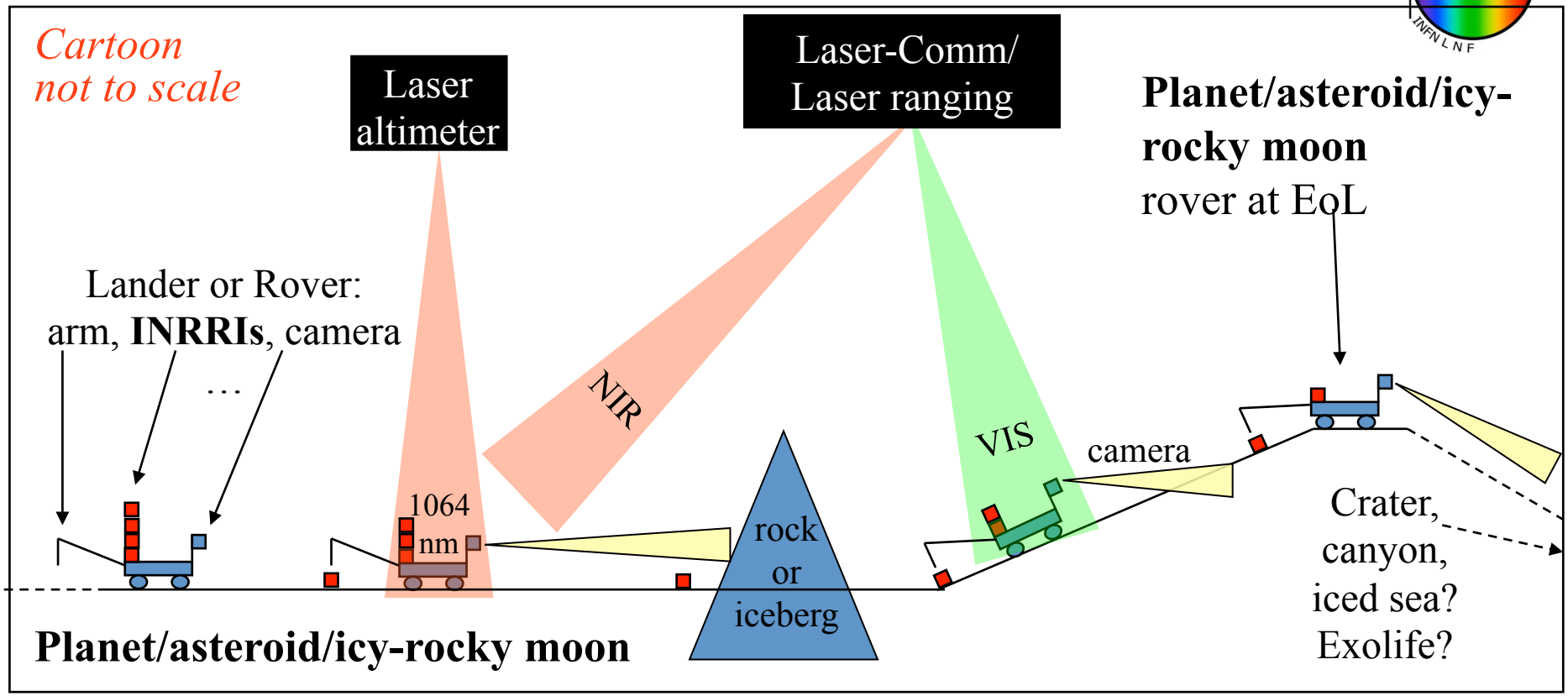


INRRI2020

INstrument for landing-**R**oving laser ranging/altimetry **R**etroreflector **I**nvestigations on Mars**2020,** NASA mission

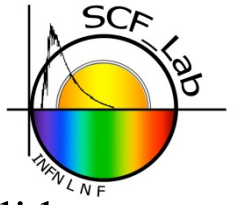


INRRIs on Moon; Mars, Jupiter/Saturn moons



- Selenolocate rover activity from orbiters thanks to CCR (reflector):
  - Laser altimetry at nadir (LRO-like) to rovers at poles of moons
  - Laser ranging with pointing capability to CCRs anywhere (GETEMME-like)
- **Deploy INRRI networks**! Also on far side of Earth's Moon

Conclusions



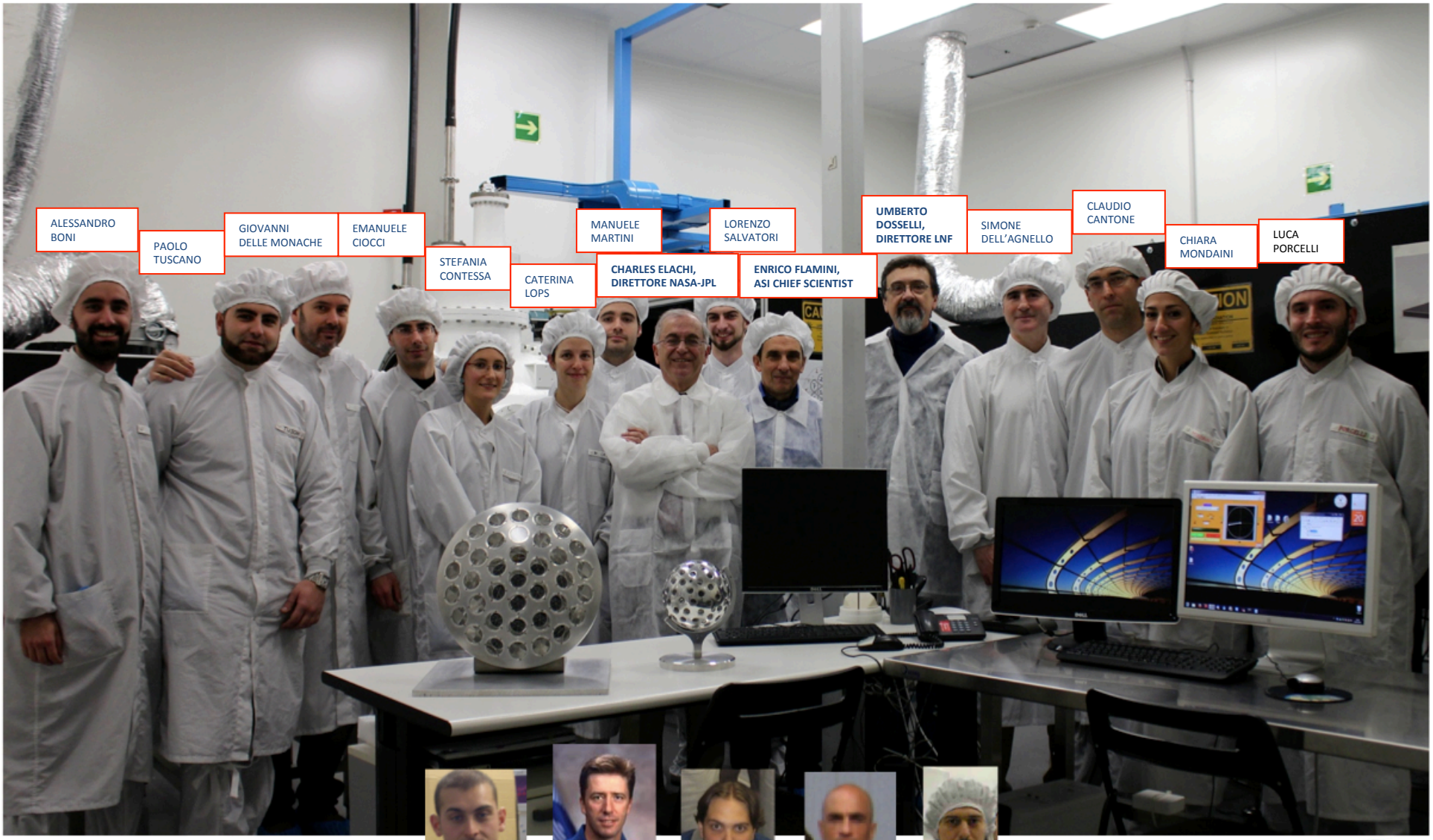
- SCF_Lab @INFN, Italy operates a Unique Test Facility to design, build, validate, characterize, diagnose Laser Retroreflectors in Space

- Improved Tests of Gravity (up to x100) and improved Selenodesy (lunar interior):

  - Refined analysis of, and LLR data from, **Apollo and Lunokhod reflectors**
    - with uninterrupted LLR data since 69, by ILRS; also ASI-Matera from 2010
    - with the analysis program, Planetary Ephemeris Program (**PEP)** with Center for Astrophysics (CfA)
  - Accurate thermal-optical-orbital modeling → with University of Maryland
  - **MoonLIGHT CCR**

- New Enabling Technology for Gravity, Planetary Exploration and Geodesy - **INRRI**

SCF_Lab Group



- L'European Lunar Symposium (ELS), alla sua terza edizione, che si svolgerà ai Laboratori Nazionali di Frascati dell'INFN,

Ci sono 4 sessioni, sui seguenti temi:

Scienza DELLA Luna ,

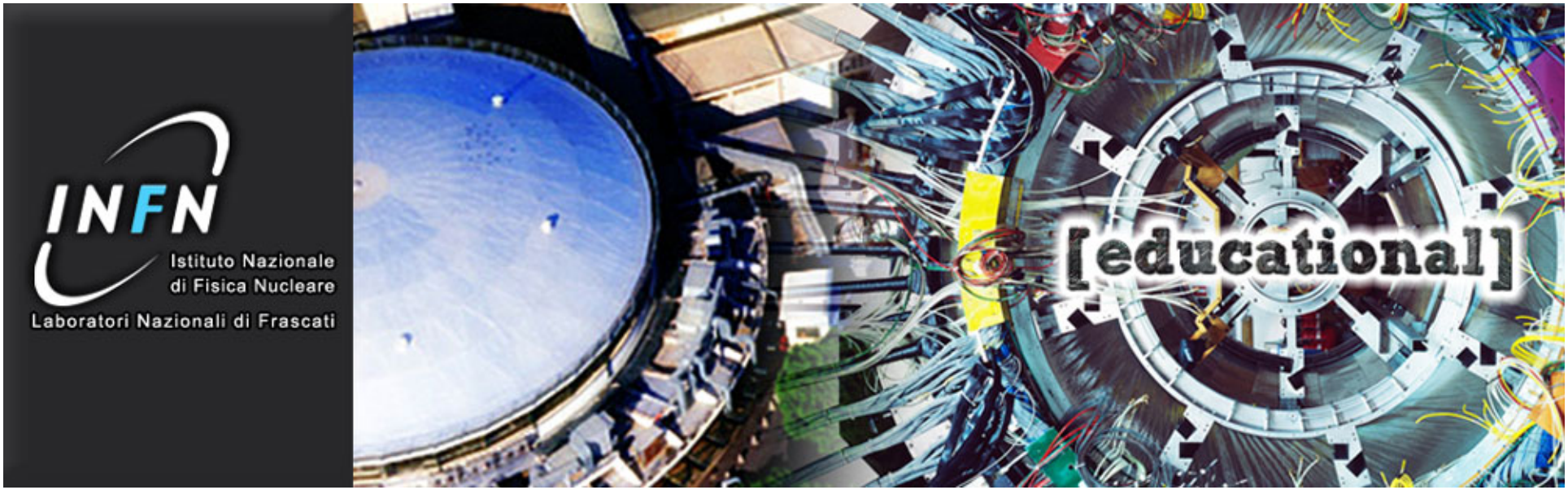
Scienza SULLA Luna,

Scienza DALLA Luna,

Missioni lunari future.

per la durata di 3 giorni: dal 12 al 14 Maggio 2015, sito: http://else2015.arc.nasa.gov

- 15 maggio segue il workshop Global Exploration Roadmap (GER), sito: http://www.globalspaceexploration.org/members
- 12 maggio precede il seminario International Year of Light 2015, sito: https://agenda.infn.it/conferenceDisplay.py?confId=9360



OPEN DAY

Laboratori aperti sabato 23 maggio 2015

http://edu.lnf.infn.it/open-day/