Next-Generation Laser Retroreflectors for Solar System Exploration, Geodesy and Gravitational Physics

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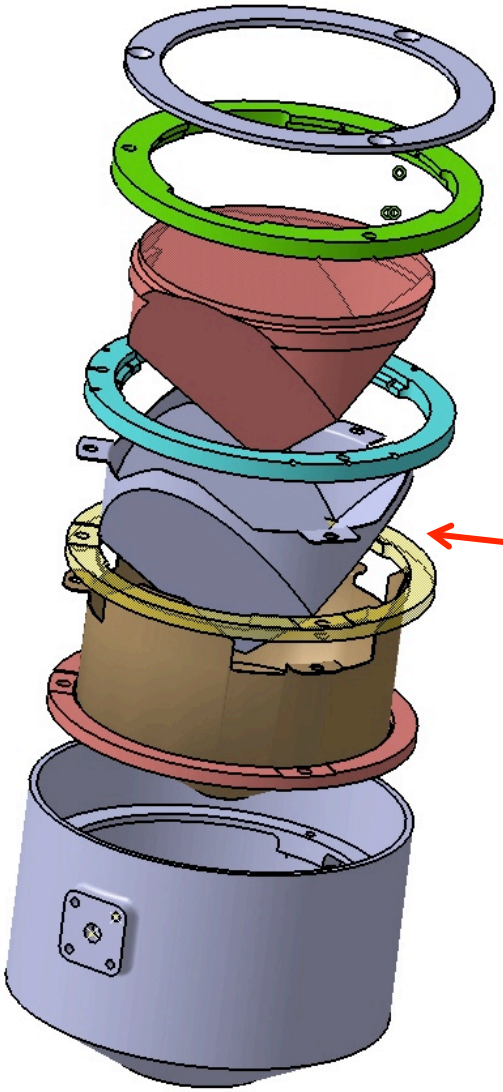
In collaboration with: *International Laser Ranging Service*

Exploration Science Forum 2014, NASA-Ames, USA, July 21, 2014

Laser Retroreflectors, CCRs, for Moon (& beyond)

- Lunar Laser Ranging (LLR, Sun-Earth-Moon gravity)
  - Large lunar reflector by INFN/U. of Maryland, **MoonLIGHT**
    - Ranged by Earth. Improved tests of Gravity up to ×100
  - Solar System micro-reflector by INFN, **INRRI**
    - Ranged by orbiters. Improve exploration, geodesy, gravity
- Laser communication hw can also do laser ranging!
  - LADEE: ~200 psec laser ranging accuracy (ToF)
  - iROC (integrated Radio Optical Communications), proposed by NASA-GRC for a Mars orbiter
  - OPALS (Optical Payload for Laser communication Science) by JPL, now on ISS

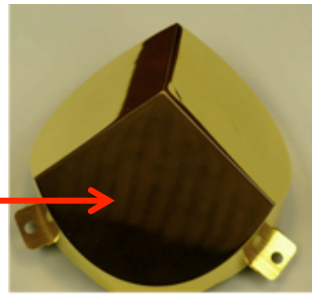
MoonLIGHT-Italy / LLRRA21-US



MoonLIGHT vs. Apollo:

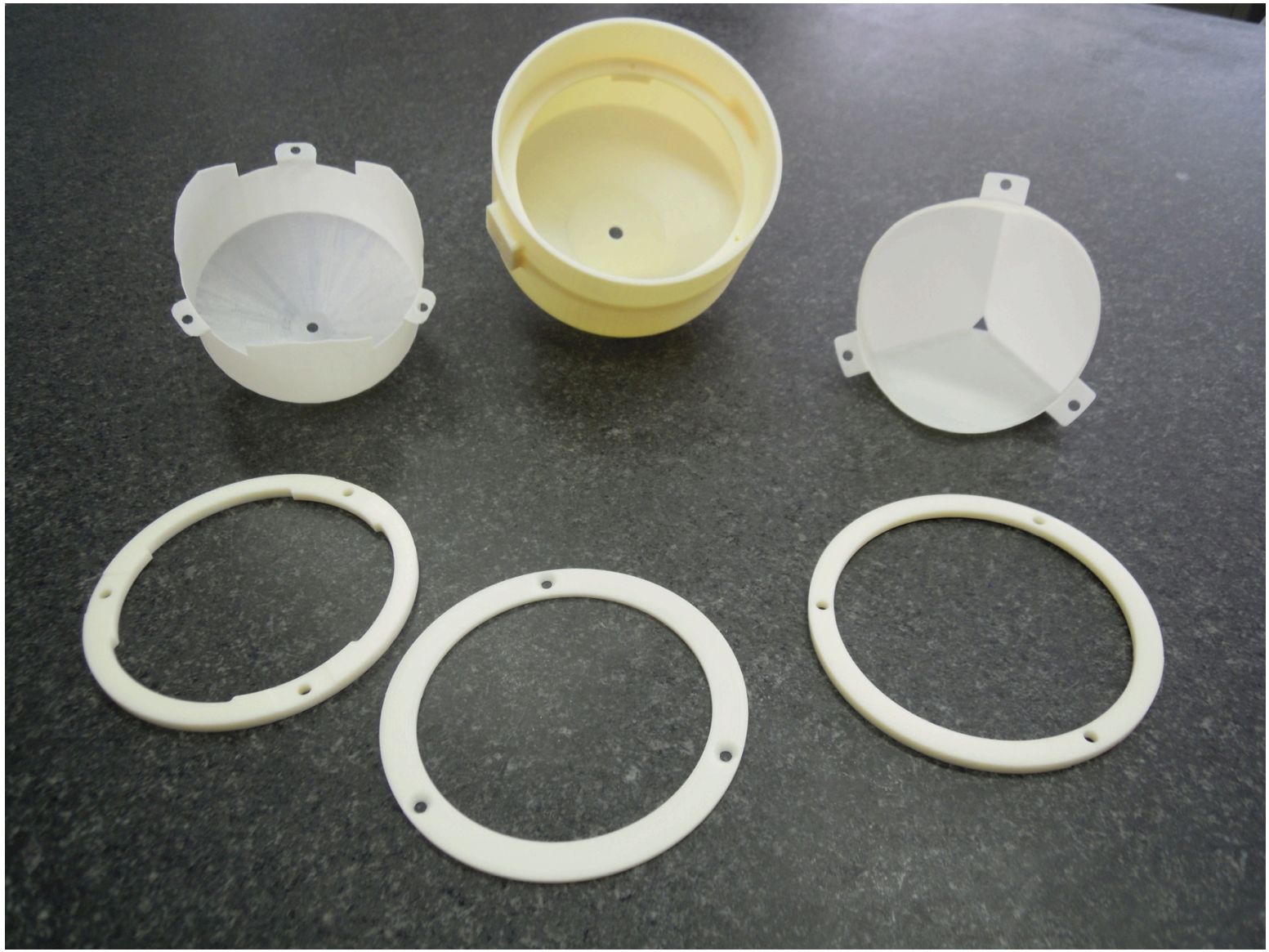
- ∅ = 100 mm vs. 38 mm
- Laser return: better than Apollo 15 (brightest of Apollo/Lunokhod arrays)

INNER CONFORMAL THERMAL SHIELD

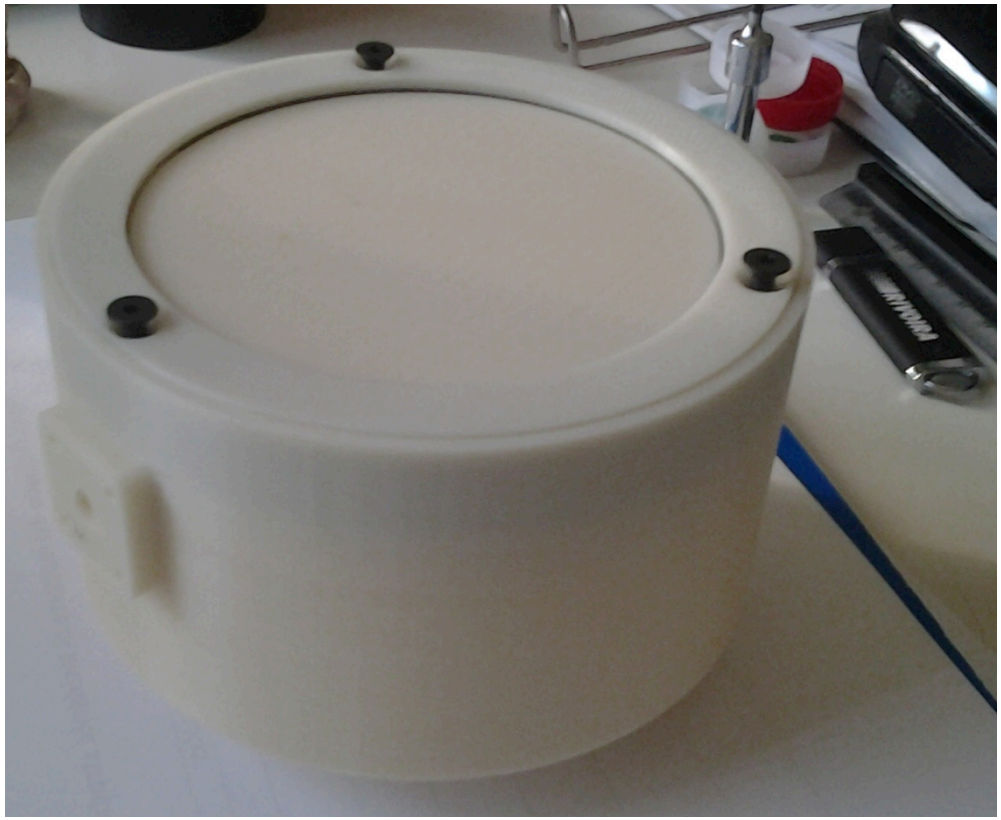


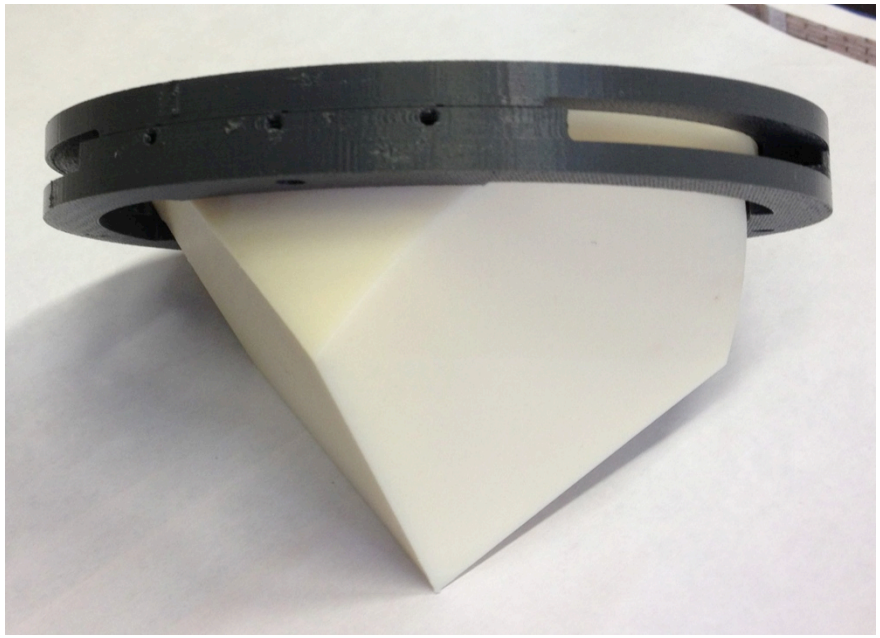
- **New**: no sunshade (simulations: reduced data small impact on science); no dedicated active pointing system
  - ✓ **Mass ~ 1kg**
  - ✓ **Size ~ 130mm × 100mm** (diameter × height)
- Sophisticated thermal design, tight optical specs

MoonLIGHT 3D-printer Model



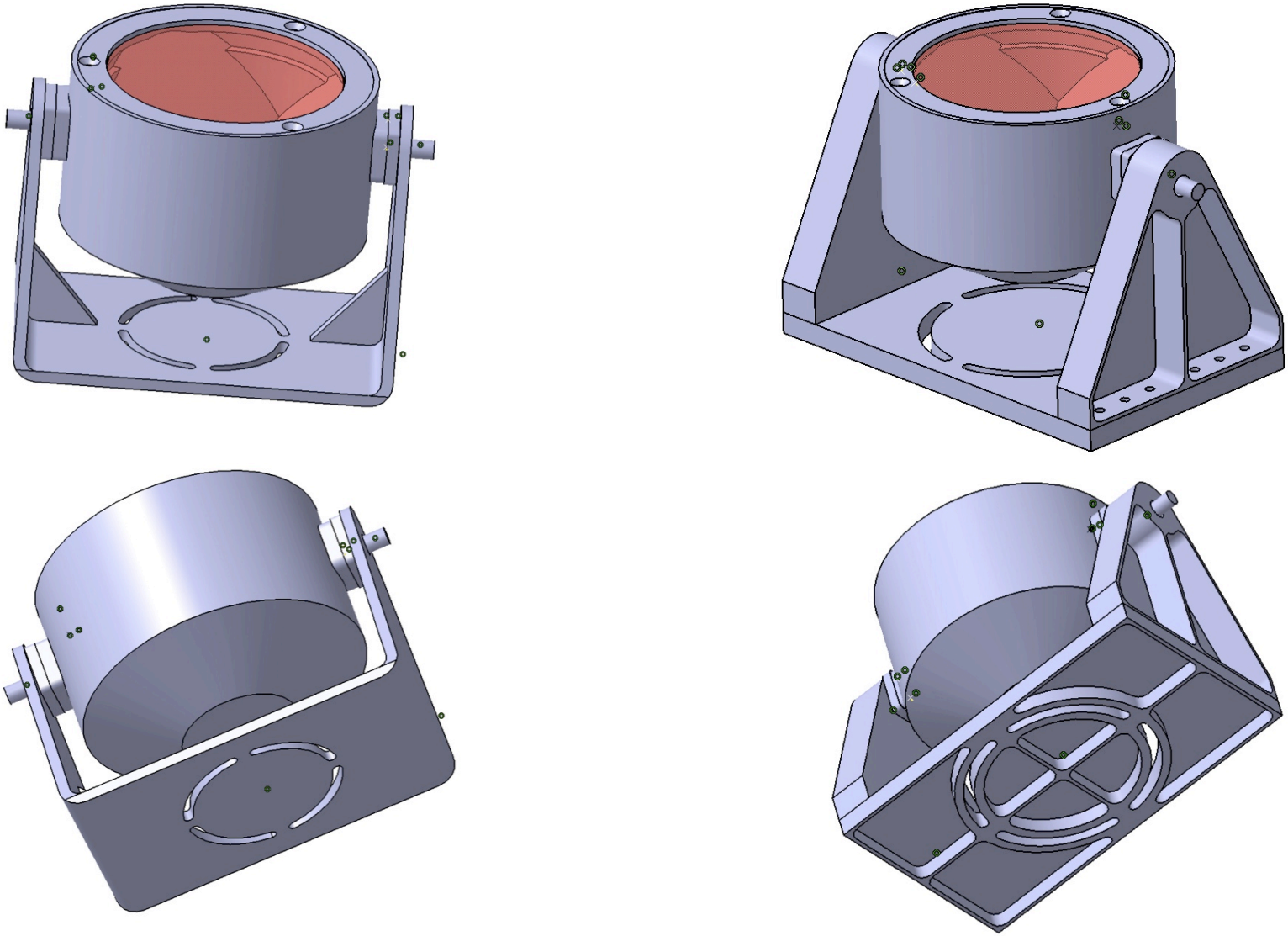
MoonLIGHT 3D-printer Model





MoonLIGHT orientation, fixed for given site

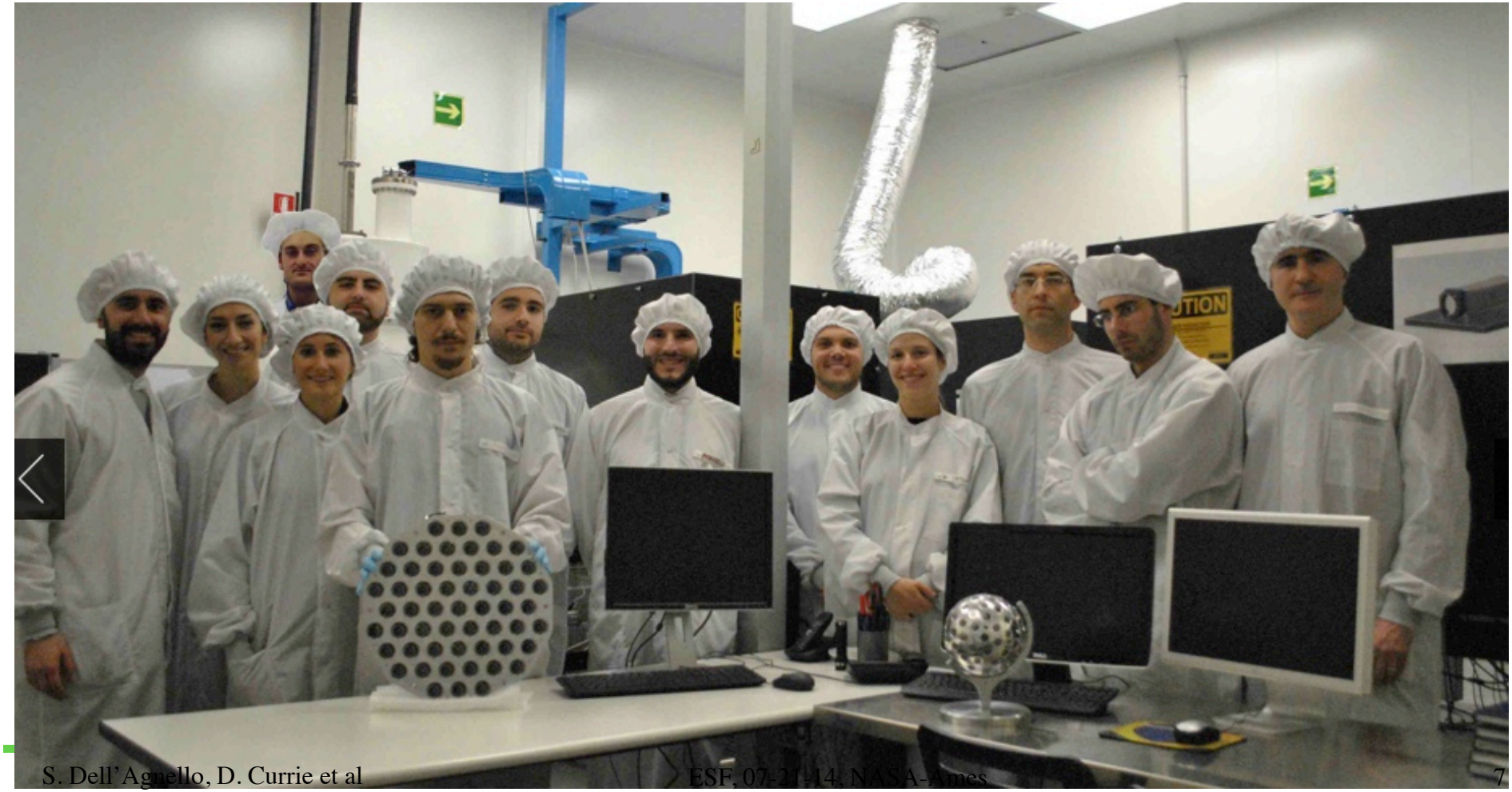
Passive. Preliminary designs



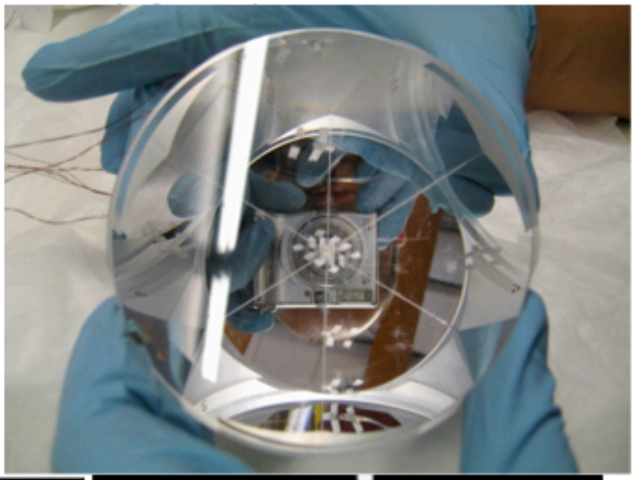
SCF_Lab @INFN-LNF, Frascati (Rome)

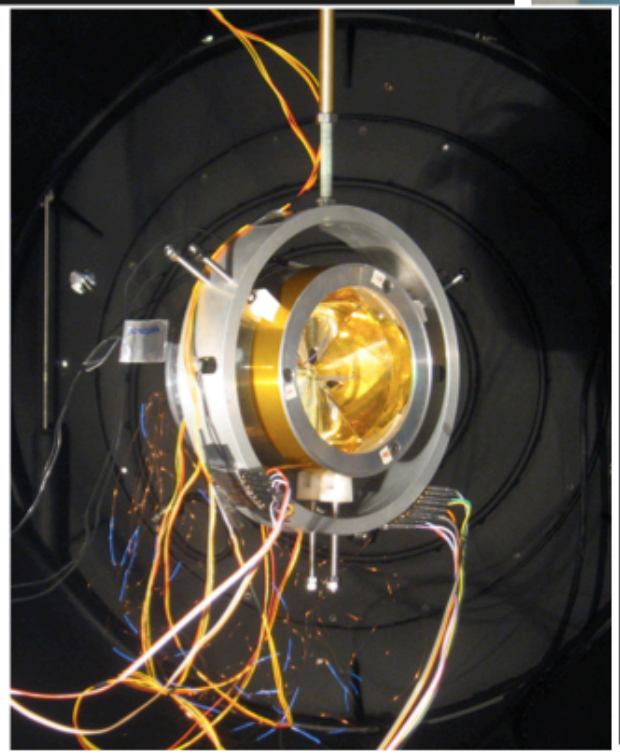
Two unique **OGSE** (Optical Ground Support Equipment) in a clean room for thermal-optical-vacuum characterization of laser retroreflectors

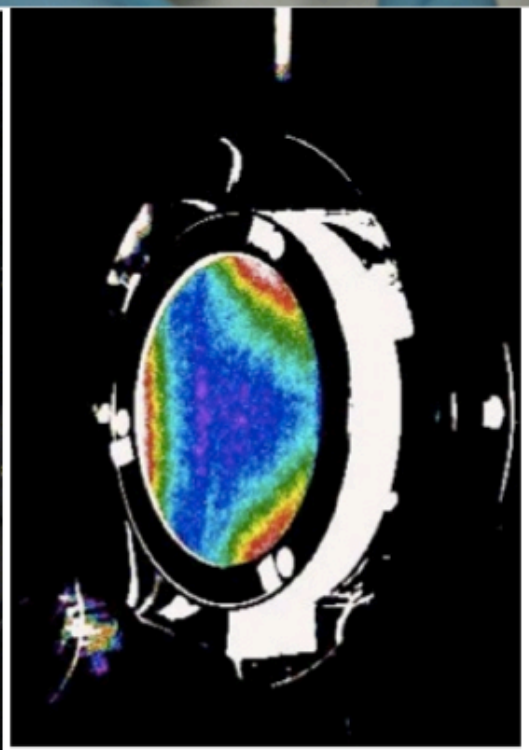
AM0 simulators, IR thermometry, diffraction pattern, Fizeau interfer.

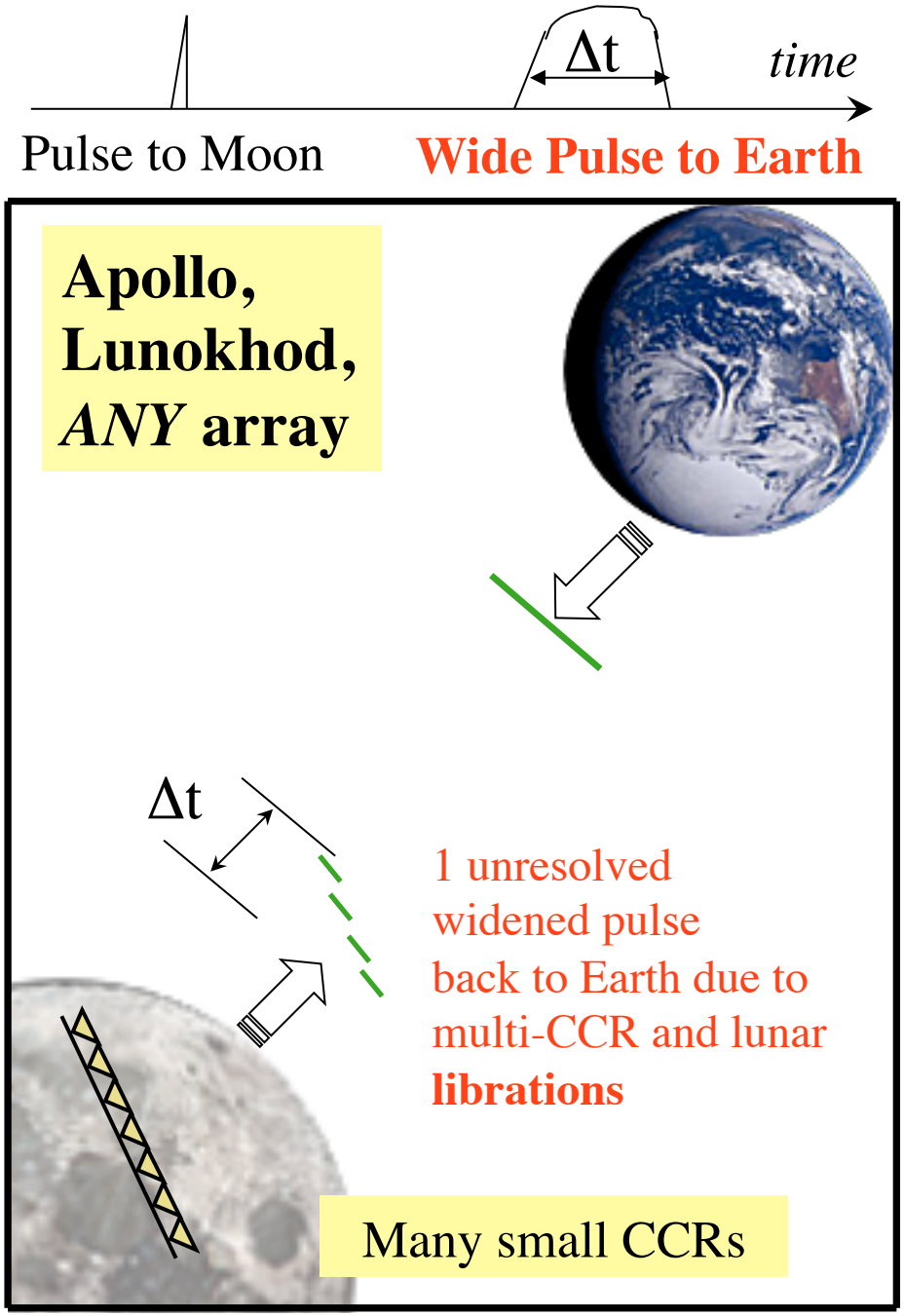


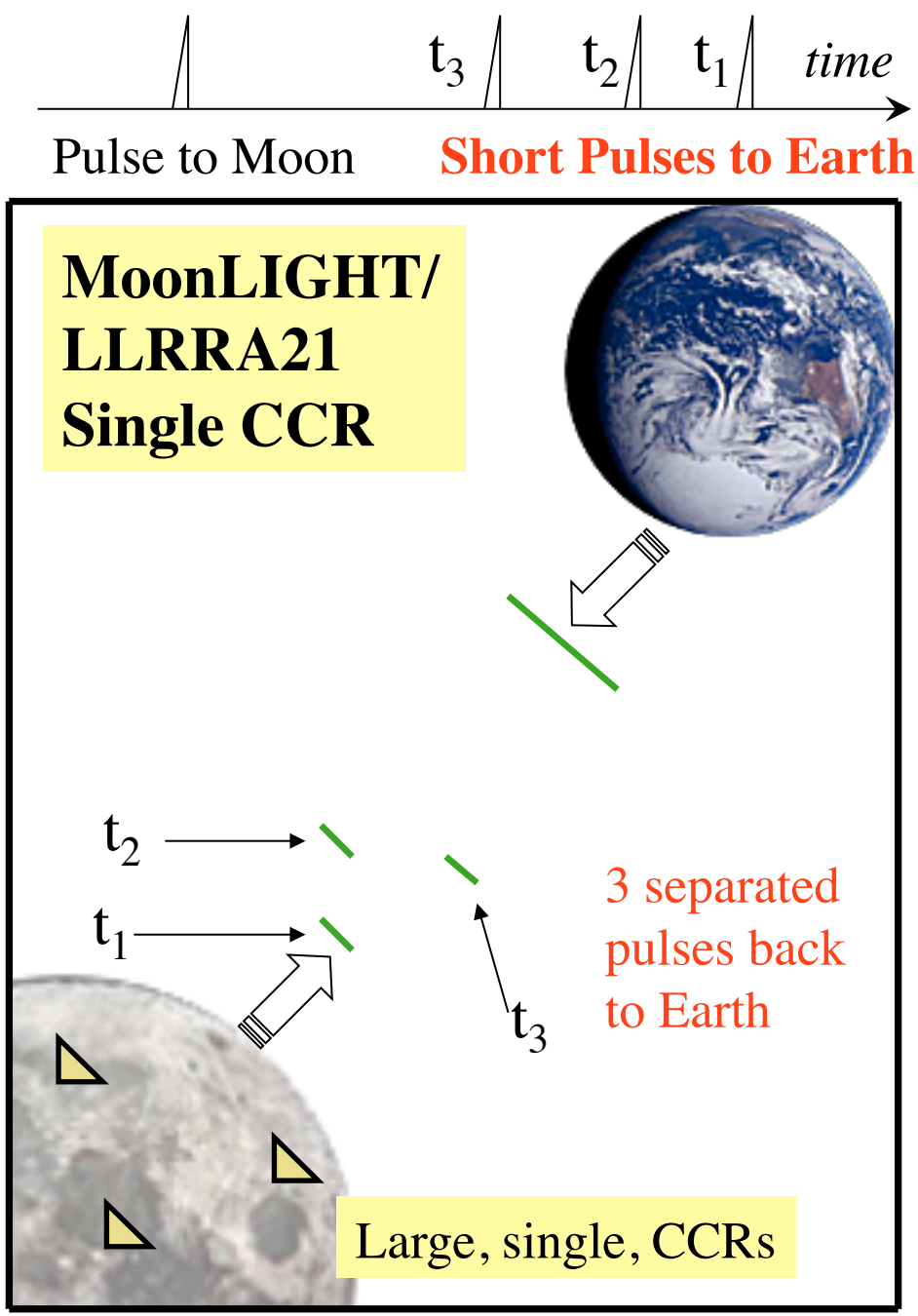
MoonLIGHT characterized @SCF_Lab








Δt
time
Pulse to Moon
Wide Pulse to Earth
Apollo, Lunokhod, *ANY* array
Δt
1 unresolved widened pulse back to Earth due to multi-CCR and lunar **librations**
Many small CCRs


t_3
t_2
t_1
time
Pulse to Moon
Short Pulses to Earth
MoonLIGHT/ LLRRA21 Single CCR
t_2
t_1
t_3
3 separated pulses back to Earth
Large, single, CCRs

LLR tests of General Relativity (×100 improv.)

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

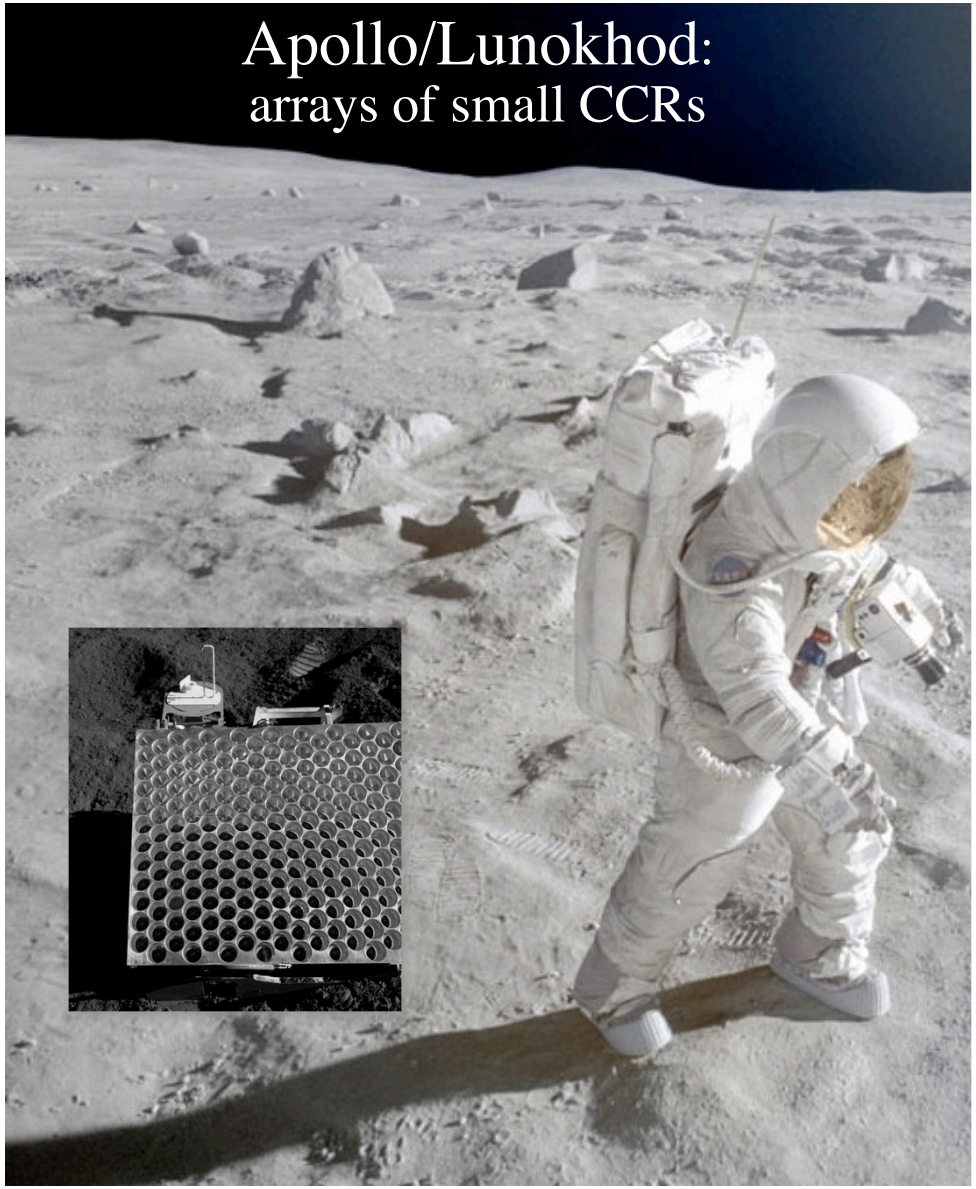
Science measurement / Precision test of violation of General Relativity	Time scale	Apollo/Lunokhod few cm accuracy*	MoonLIGHTs 1 mm	MoonLIGHTs 0.1 mm
Parameterized Post-Newtonian (PPN) β	Few years	$\lvert\beta-1\rvert<1.1\times10^{-4}$	10^{-5}	10^{-6}
Weak Equivalence Principle (WEP)	Few years	$\lvert\Delta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

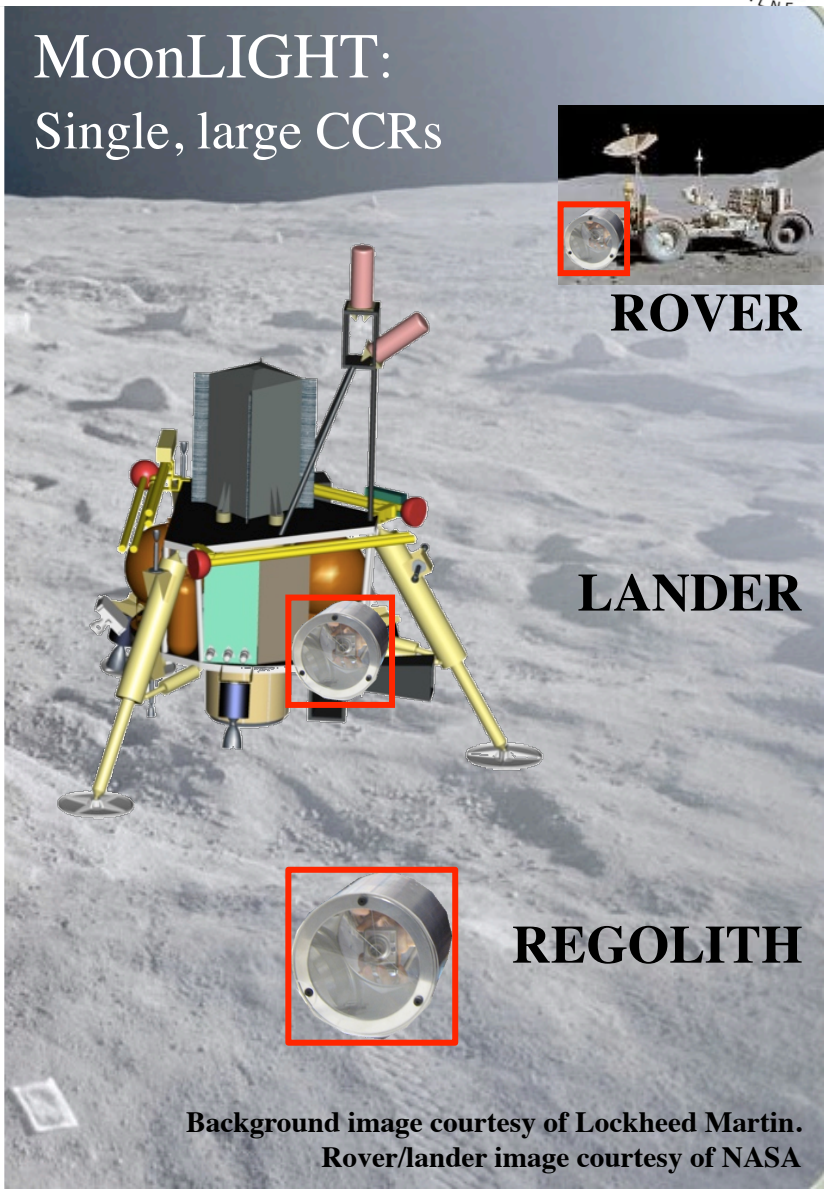
- Geodetic Precession with CfA's Planetary Ephemeris Program (PEP): **1% error**
- **Selenodesy**: measurement of deep interior, complementary to GRAIL
- **Exploration**: precise positioning of landing site and of roving exploration

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

- With MoonLIGHT single, large reflector: 1-few
- With Apollo/Lunokhod/Any array: few thousands

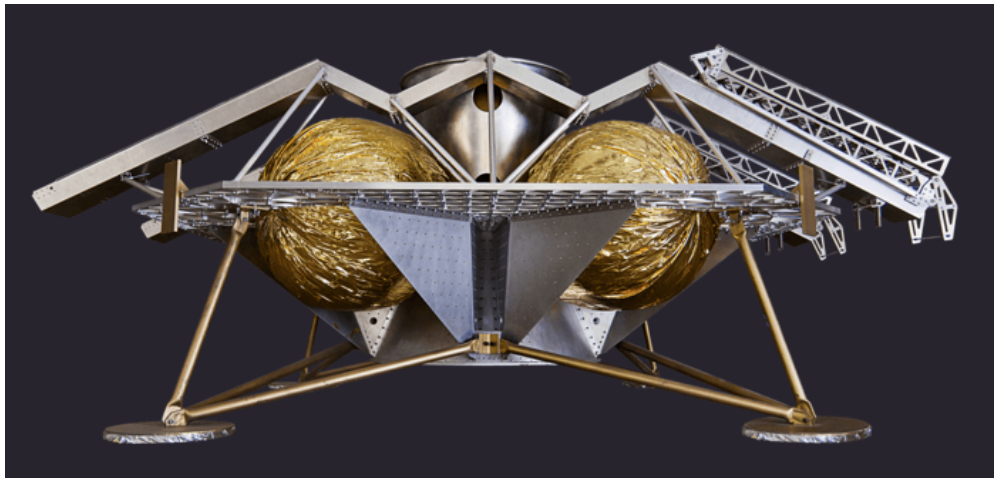
MoonLIGHT (INFN/U. Maryland)





MoonLIGHT & INRRI on GLXP Landers

Moon Express
(picture from
www.moonexpress.com)



Astrobotic
(picture from
www.astrobotic.com)

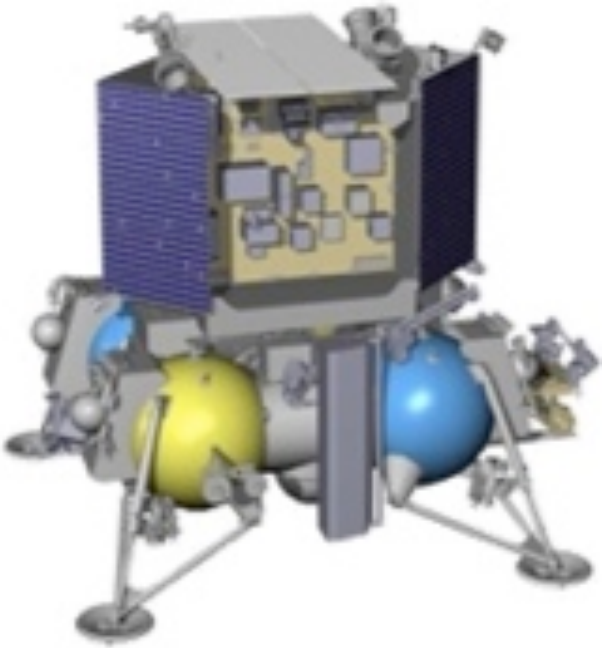
MoonLIGHT-2019 proposal for Luna-27

Italian proposal

- PI: S. Dell'Agnello (INFN-LNF)
- Co-PIs:
  - D. Currie (as INFN-LNF Guest Scientist)
  - G. Bianco (ASI, INFN-LNF, ILRS)
  - R. Vittori (Space Attaché in US, INFN-LNF)

Proposed: 1 MoonLIGHT & 1 INRRI

- Matured also thanks to ESA-IKI/Roscosmos meetings and collaboration
- MoU between RAS and INFN since 1995



Luna-27
(Luna-Resurs 1)
2019

New Gravitational Physics

- New gravity predictions & solar system constraints
  - Extension of General Relativity to include **Spacetime Torsion**
    - PRD **83**, 104008 (2011)
    - GERG (2011) 43:3099–3126
  - Solar System constraints to **Non-Minimally Coupled Gravity**, "$f_1(R)+f_2(R)$"
    - PRD 88, 064019 (2013)
    - arXiv:1403.7251v1 [astro-ph.CO] 27 Mar 2014, approved for publication on Physics Letters B

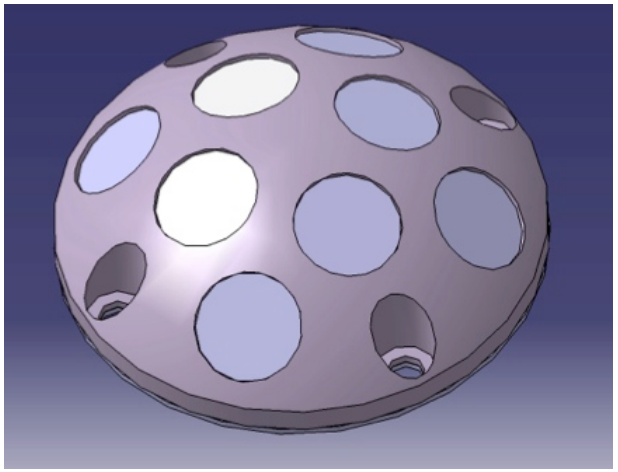
- LLR test of General Relativity
  - Planet and Space Sci 74 (2012)

Laser retroreflector micropayload for

Planetary Exploration, Geodesy, Gravity

INRRI: INstrument for landing-**R**oving laser **R**etroreflector **I**nvestigations

- Laser ranging/communications/altimetry/Lidar investigations by orbiters of Moon, Mars & Solar System moons
  - **Accurate positioning of landing site**
  - **Accurate positioning of roving exploration activity**
  - **Multiple INRRIs: establish planetary geodesy reference frame**
- INRRI is
  - Passive
  - Very lightweight ~50 gr
  - No pointing required

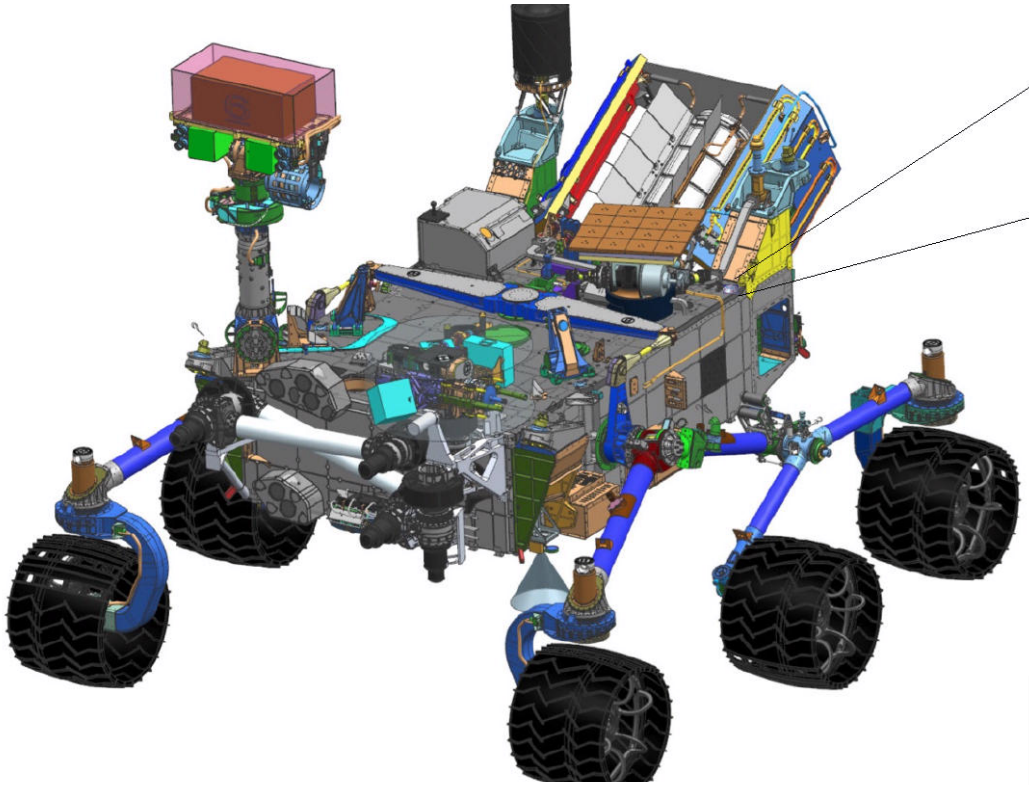


With ASI, INRRI: 50-gr reflector for Mars Rovers

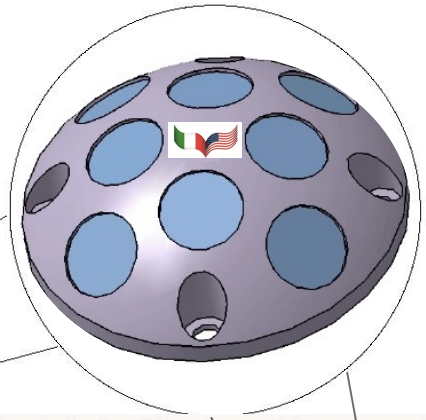
Exploration, Exolife, Lidar, Laser-Comm, Geodesy, Gravity

INRRI-2020

INstrument for landing-**R**oving
laser **R**etroreflector **I**nvestigations



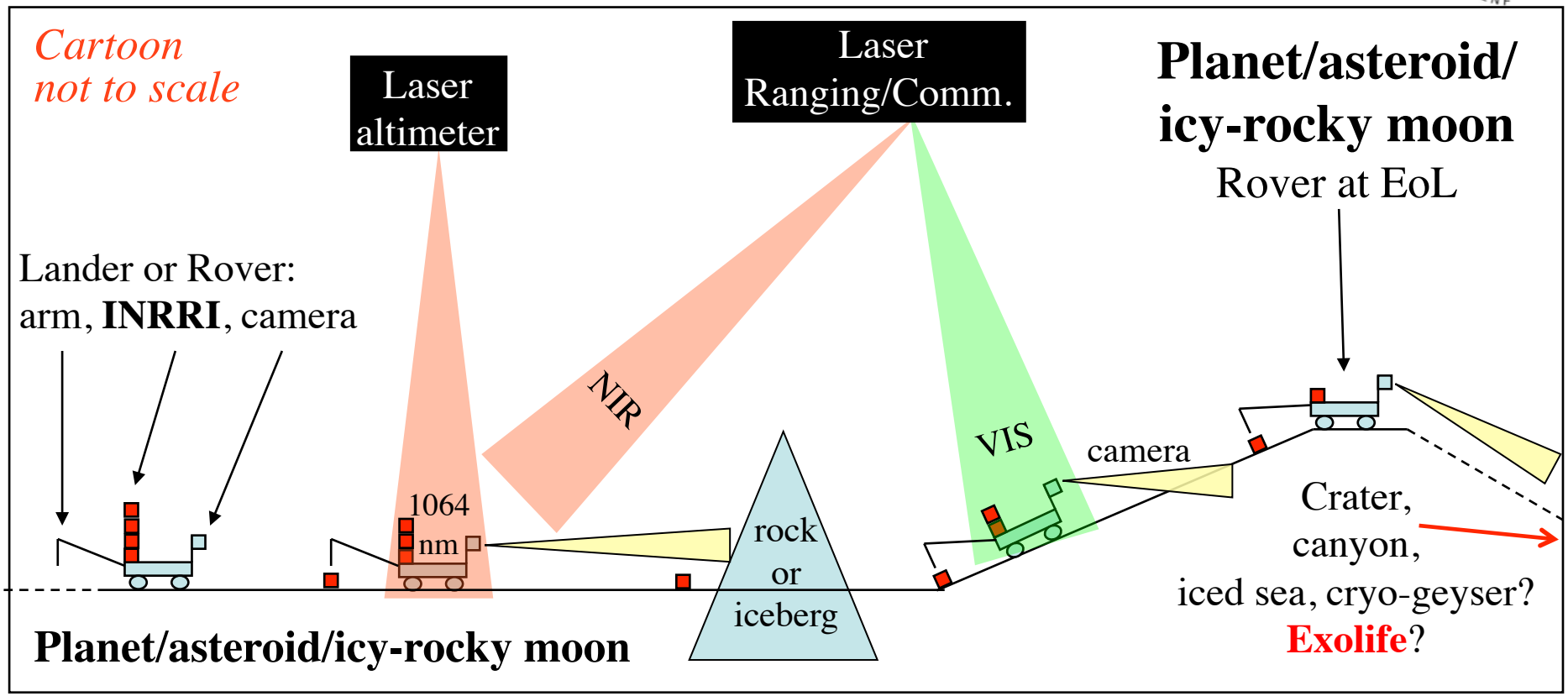
NASA Mars 2020



INRRI-ExoMars

ESA
ExoMars
2018

INRRIs on Moon, Mars, Jupiter/Saturn moons



- Selenolocate lander/rover with laser retroreflector:
  - Laser altimetry at nadir (LRO-like) to rovers/landers at poles of moons
  - Laser ranging (comm.) to reflectors anywhere (LADEE / iROC / OPALS-like)
- **Deploy INRRI networks**. Also on far side of Earth's Moon

Conclusions

- Ongoing MoonLIGHT/INRRI laser retroreflector proposals
  - Moon Express, Astrobotic (GLXP)
  - Luna-27 (Roscosmos/IKI), Chang'e (CNSA)
  - Waiting for Lunar Geophysical Network (C. Neal PI) / NF
- INRRI proposed for: NASA Mars 2020, ESA ExoMars
- **INFN Proposal for Affiliation to NASA-SSERVI**
  - Solar System reflectors for Exploration, General Relativity, Geodesy
  - Close to final, signature on next September
- INFN will host next "European Lunar Symposium" in Frascati, near Rome
    - May 2015. With ASI participation
    - ASI-HQ very close to INFN-LNF, ESA-ESRIN 100 meters away