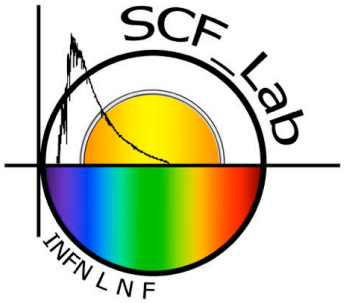
SCF_Lab @ INFN-Frascati,

a test facility for:

accurate laser positioning in space

& cube/microsatellites

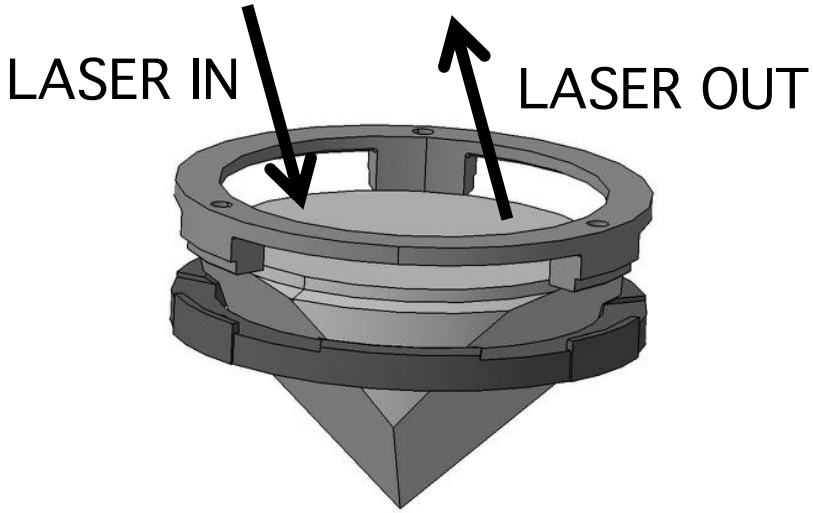
Dell'Agnello S. (INFN-LNF) for the SCF_Lab Team,
http://www.lnf.infn.it/esperimenti/etrusco/
INFN – Laboratori Nazionali di Frascati (Rome), Italy
Nov 26, 2018



Outline

- SCF_Lab & ASI-Matera Joint Laboratory
- Space diagnostics capabilities
- Laser Ranging to Galileo
- Lunar Laser Ranging
  - Apollo 50th anniversary in 2019
- Italian microreflectors on Mars (*tonight*, *again*)

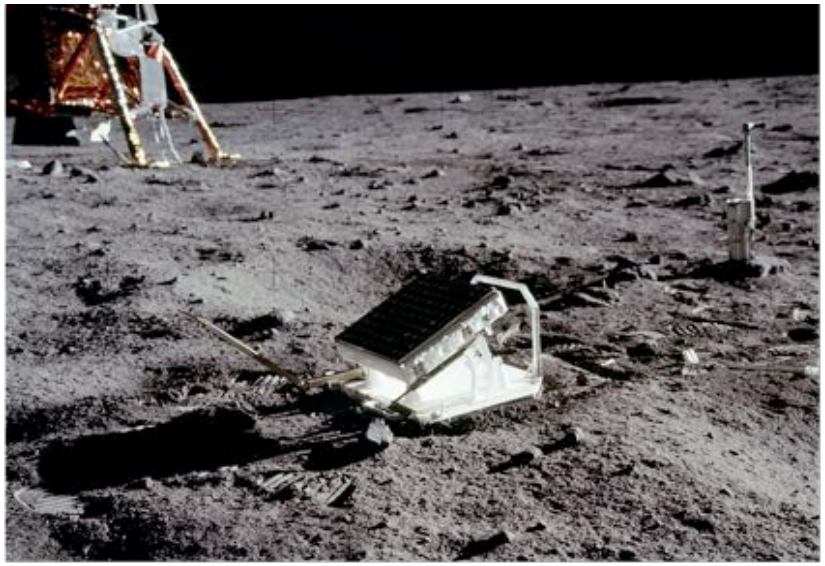
Laser Retroreflectors



Satellite Laser Ranging (SLR)

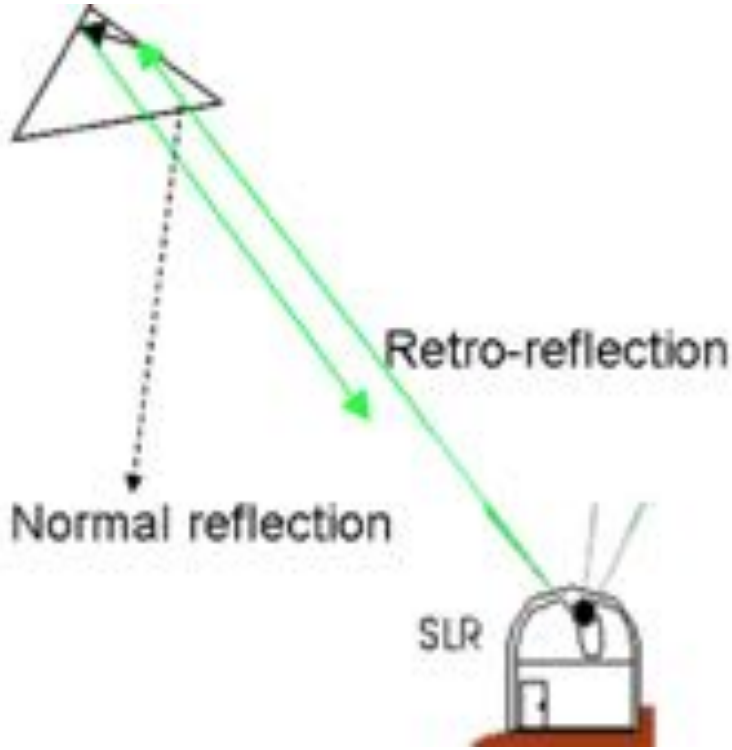
Lunar Laser Ranging (LLR)

Time of flight measurement



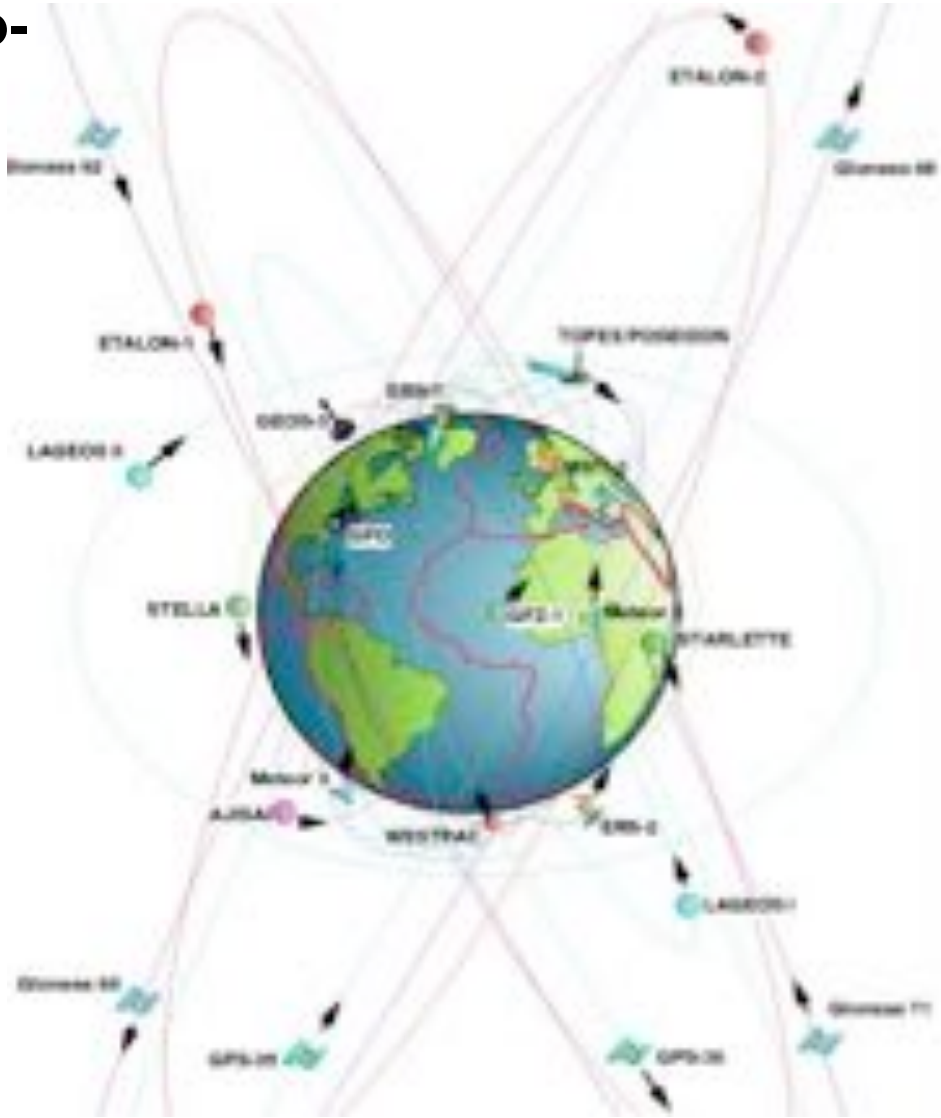
S
L
R

- **Apollo**: The Moon as a test mass (1969)
- **LAGEOS**: "cannon-ball", point-like test-masse covered with retroreflectors
- Orbit accuracy ~ 1 cm; less in the future



International Terrestrial Reference System (ITRS)

- **Cartesian coordinate system co-rotating with the Earth**
- Origin = Geocenter = foci of LAGEOS & LAGEOS-2 orbits
- Scale: LAGEOS & quasar VLBI
- Axis orientation: quasars



LAGEOS

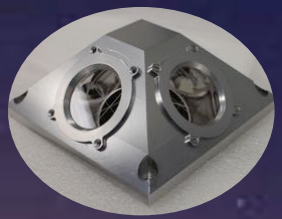
International Laser Ranging Service

SPACE DISCIPLINE: Laser Retroreflectors & Ranging

INFN – ASI – MAECI – DEFENCE
collaboration/contracts with:
NASA, ESA, CNSA, ISRO, USGS,
NOAA, US industries, CAS, Univs ...

Moon

Mars, Europa



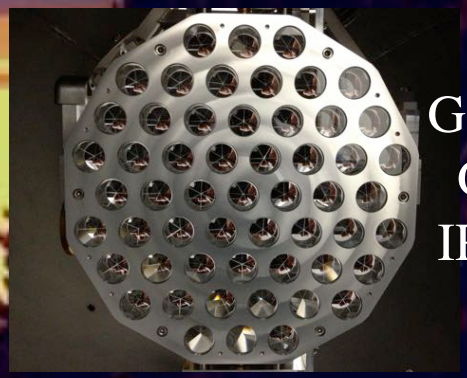
Earth Observation

Phobos/Deimos

Comet/
asteroid

ASI – Matera
Laser Ranging
Observatory

LAGEOS
LARES-2



Galileo,
GPS,
IRNSS

Ground segment, **laser ranging**:

ASI - Matera Laser Ranging Observatory

Space segment: **laser retroreflectors**

SCF_Lab & "SCF-Test" (IPR of INFN)

ELSEVIER

ScienceDirect

Advances in Space Research 47 (2011) 822–842

SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

Creation of the new industry-standard space test of laser retroreflectors for the GNSS and LAGEOS

S. Dell'Agnello [a,*], G.O. Delle Monache [a], D.G. Currie [b], R. Vittori [c,d], C. Cantone [a], M. Garattini [a], A. Boni [a], M. Martini [a], C. Lops [a], N. Intaglietta [a], R. Tauraso [e,a], D.A. Arnold [f], M.R. Pearlman [f], G. Bianco [g], S. Zerbini [h], M. Maiello [a], S. Berardi [a], L. Porcelli [a], C.O. Alley [b], J.F. McGarry [i], C. Sciarretta [g], V. Luceri [g], T.W. Zagwodzki [i]

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[c] *Aeronautica Militare Italiana, Viale dell' Università 4, 00185 Rome, Italy*
[d] *Agenzia Spaziale Italiana (ASI), Viale Liegi 26, 00198 Rome, Italy*
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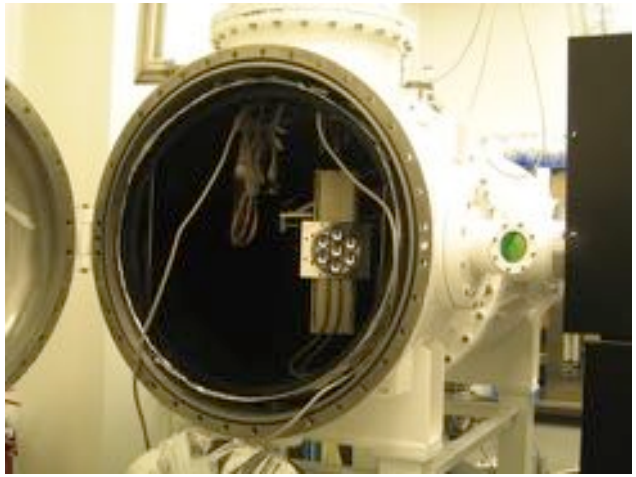
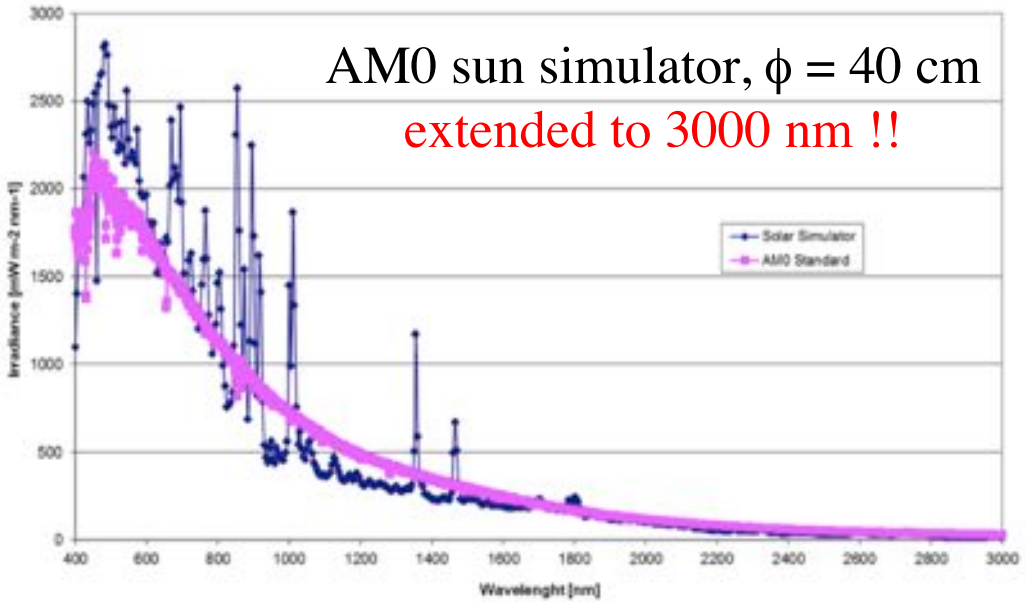
[f] *Harvard-Smithsonian Center for Astrophysics (CfA), 60 Garden Street, Cambridge, MA 02138, USA*
[g] *ASI, Centro di Geodesia Spaziale "G. Colombo" (ASI-CGS), Località Terlecchia, P.O. Box ADP, 75100 Matera, Italy*
[h] *University of Bologna, Department of Physics Sector of Geophysics, Viale Berti Pichat 8, 40127 Bologna, Italy*
[i] *NASA, Goddard Space Flight Center (GSCF), code 694, Greenbelt, MD 20771, USA*

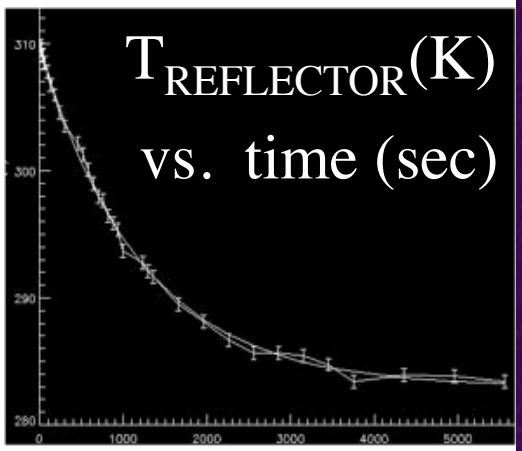
SCF_Lab: retroreflector, cube/microsat test

- Two Optical Ground Support Equipment (**OGSE**)
- **SCF** (top right); also lunar and altimetry
- **SCF-G** (bottom right) dedicated to GNSS
- Two AM0 sun simulators, IR thermometry
- Optical testing: Far Field, Fizeau interferometry
- *J. Adv. Space Res. 47 (2011) 822–842*



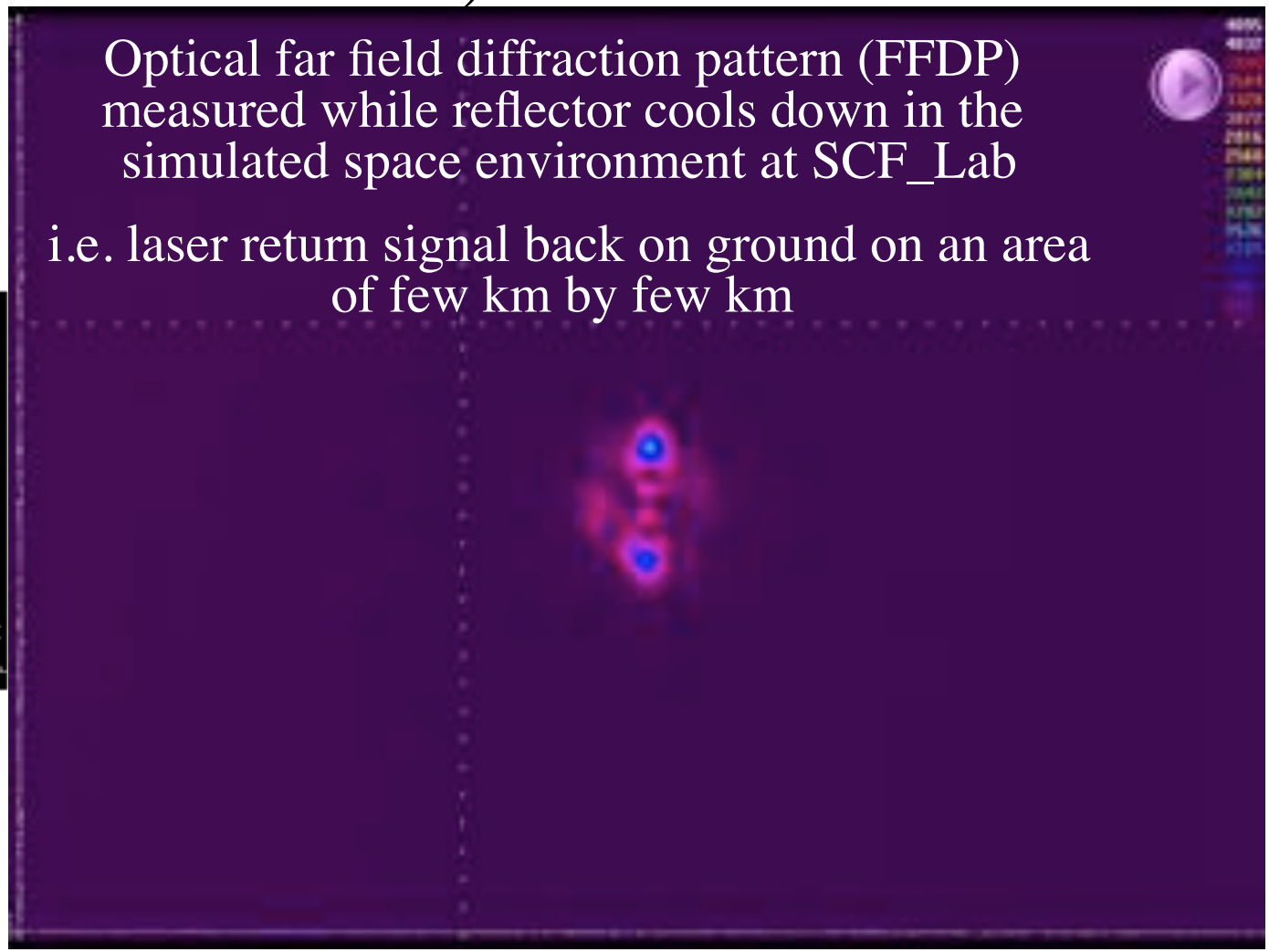


Test of retroreflector optical performance in space conditions (old generation GLONASS, GPS, GIOVE)

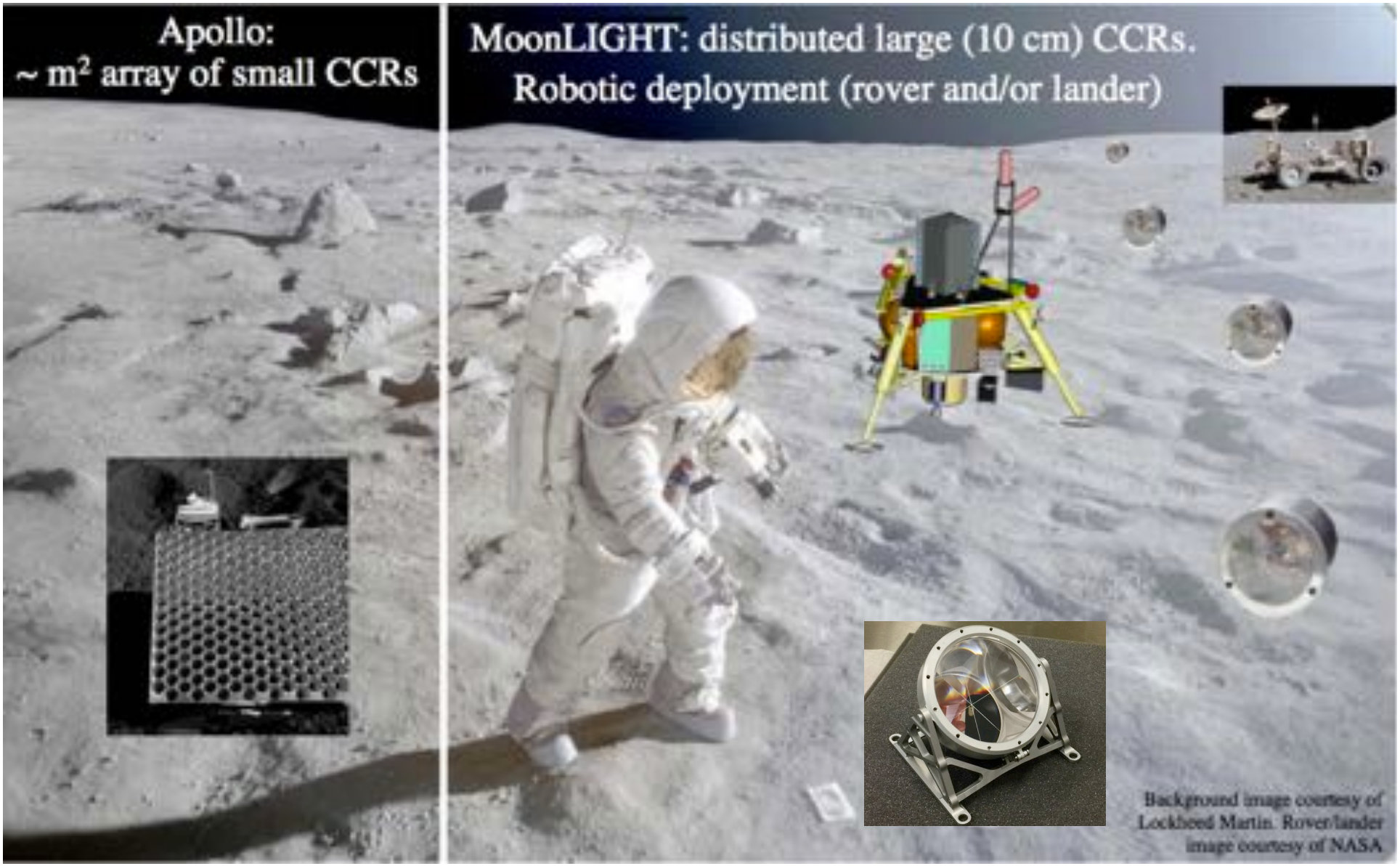


Optical far field diffraction pattern (FFDP) measured while reflector cools down in the simulated space environment at SCF_Lab

i.e. laser return signal back on ground on an area of few km by few km



Italian lunar reflectors for US industrial missions



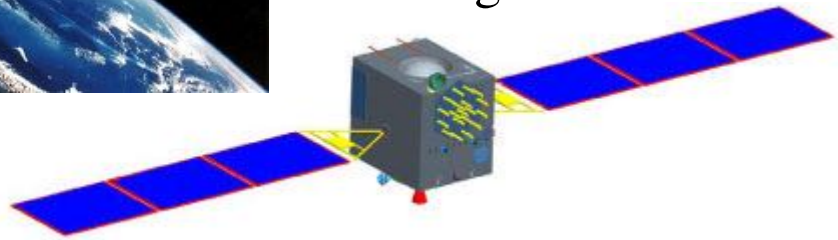
GNSS = Global Navigation Satellite System

Towards ~100 satellites with laser retroreflectors

Galileo: 30 satellites

GLONASS, GPS, GIOVE, Galileo IOV, IRNSS: **SCF-Tested !!**

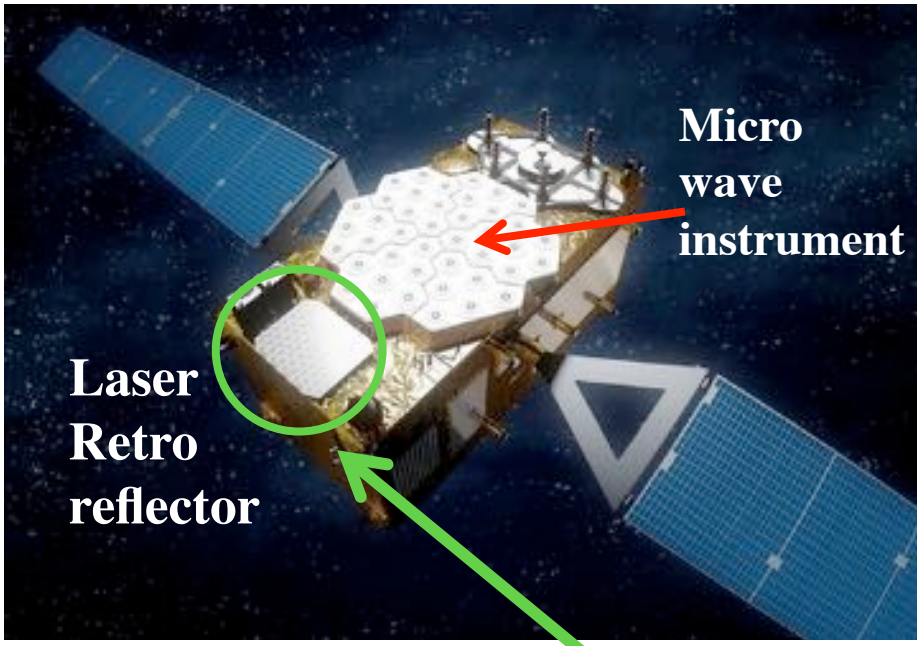
Chinese Compass/
Beidou: ~20 global,
+5 regional satellites



Russian GLONASS: 24
global satellites:

Satellite Laser Ranging (SLR) to Galileo IOV

Position measurement to cube corner retroreflectors (**CCR**) with short laser pulses and a time-of-flight technique (H-maser clocks on satellite and ground stations)



- **PRECISE POSITIONING**
  Normal points at mm level, orbits at cm level
- **ABSOLUTE ACCURACY**
  Defines Earth **geocenter** and the **scale** of length
- **PASSIVE, MAINTENANCE-FREE**
  LASER Retroreflector Array (**LRA**)

Benefits of laser positioning of Galileo

- Laser ranging provides the only independent and absolute validation of Galileo orbits at cm-mm
  - Good radial orbit accuracy ➔ calibrate Galileo atomic clocks
  - Detection of systematic errors !
  - Verification and diagnostics of models of orbit perturbations
    - solar radiation pressure, Earth albedo, s/c manoeuvers, Earth eclipses, …)
- Combined microwave and laser orbits are
  - More accurate and more stable orbits
  - Have absolute reference to geocenter and scale of ITRS

Very specialized diagnostic instruments:

Reflectometer / Emissometer

Surface Optics Corporation

Portable handheld optical measurement instrument

The SOC410 Series Reflectometers are portable contact measurement devices designed to take precise, accurate reflectance and emittance measurements. Made with an ergonomic power-drill design, the SOC410 Series lets you easily take measurements in-the-field or around the lab— no cords or external batteries necessary. The world's biggest defense, aerospace, and energy companies rely on SOC410 data.

410 Series Customers

NASA BOEING Raytheon SAIC AMERICA'S NAVY

Very specialized diagnostic instruments:

IR cameras

Left: word's best commercial IR camera

FLIR X6901sc SLS

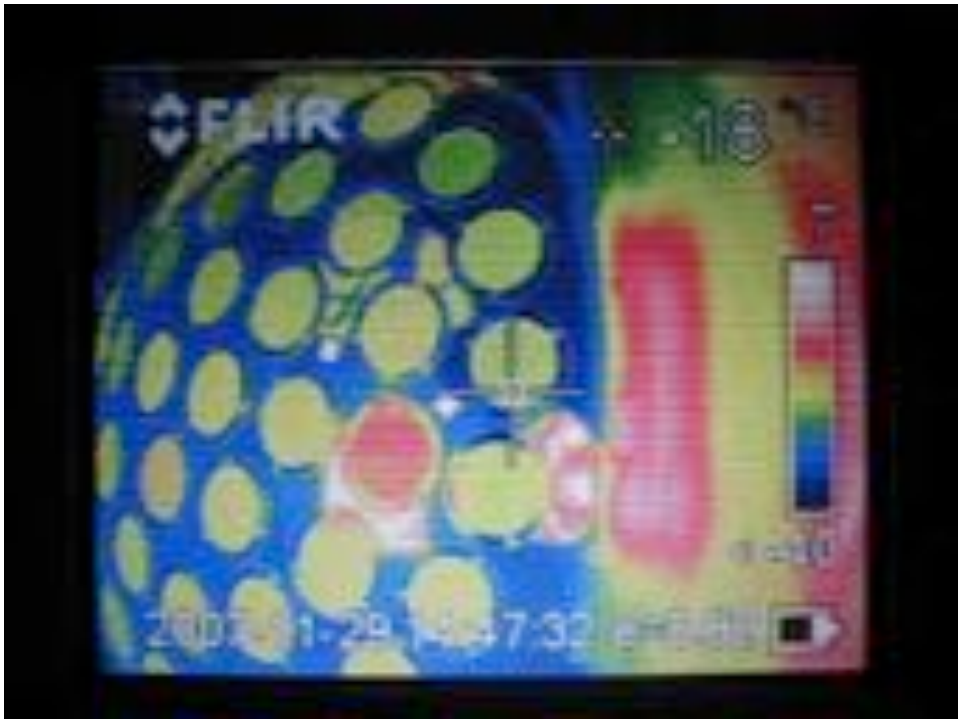
ThermaCam sc640

SCF movie of thermal behavior

SCF-Test of LAGEOS Sector:

IR movie of Sector moving from AM0 (sun simulator) window to laser window at 90°. IR camera is in between.

SCF thermal (IR) movie =>

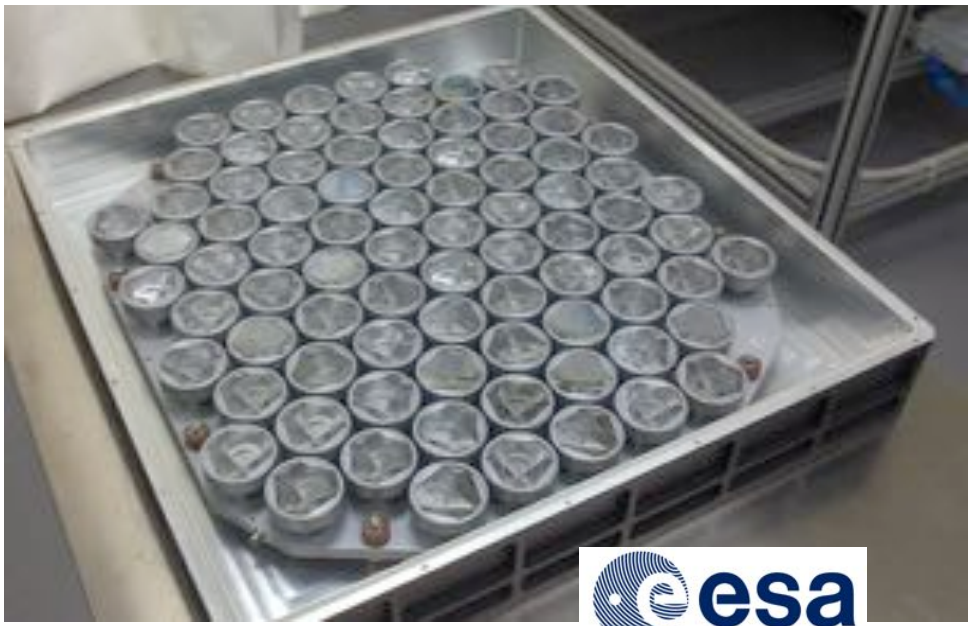


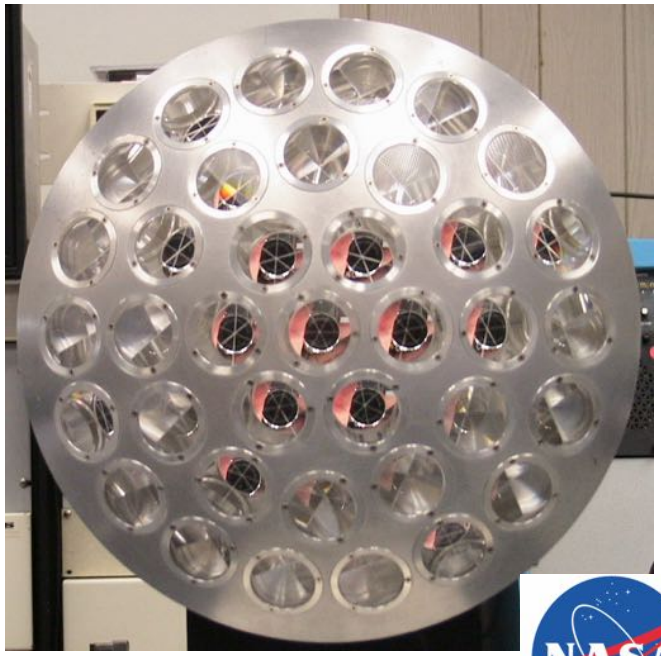
For ESA's test of Galileo reflectors, rotation accomplished in ~few seconds

MIUR Project "Laser Ranging to Galileo"

Prestigious payloads loaned to INFN

- Galileo IOV **FM** model by China, property of ESA, Left
- LAGEOS Sector **EM** property of NASA-GSFC, Right

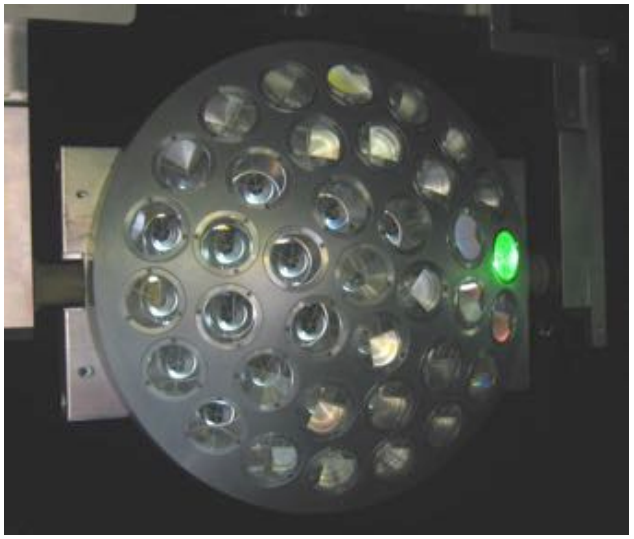




Test of optical performance in space conditions

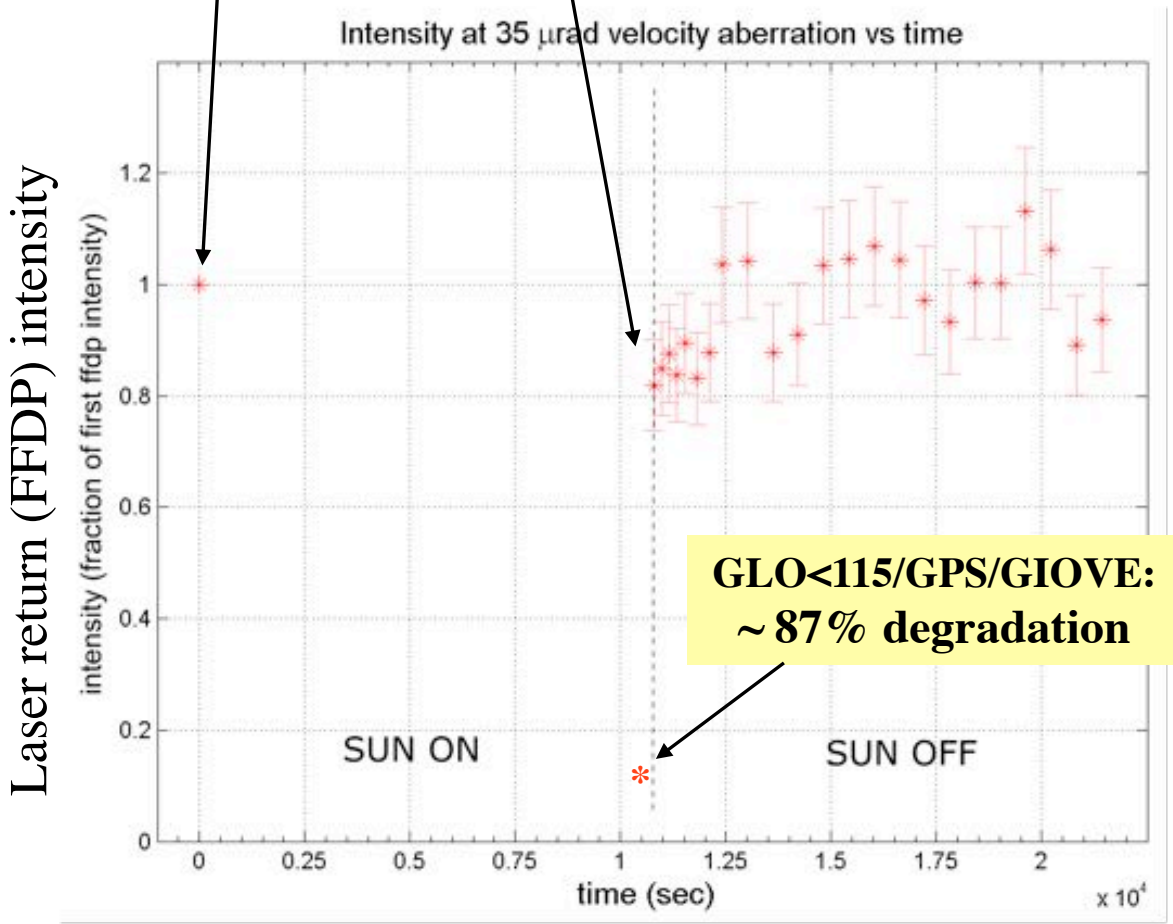
LAGEOS IS THE

GOLD STANDARD



LAGEOS: unperturbed laser return

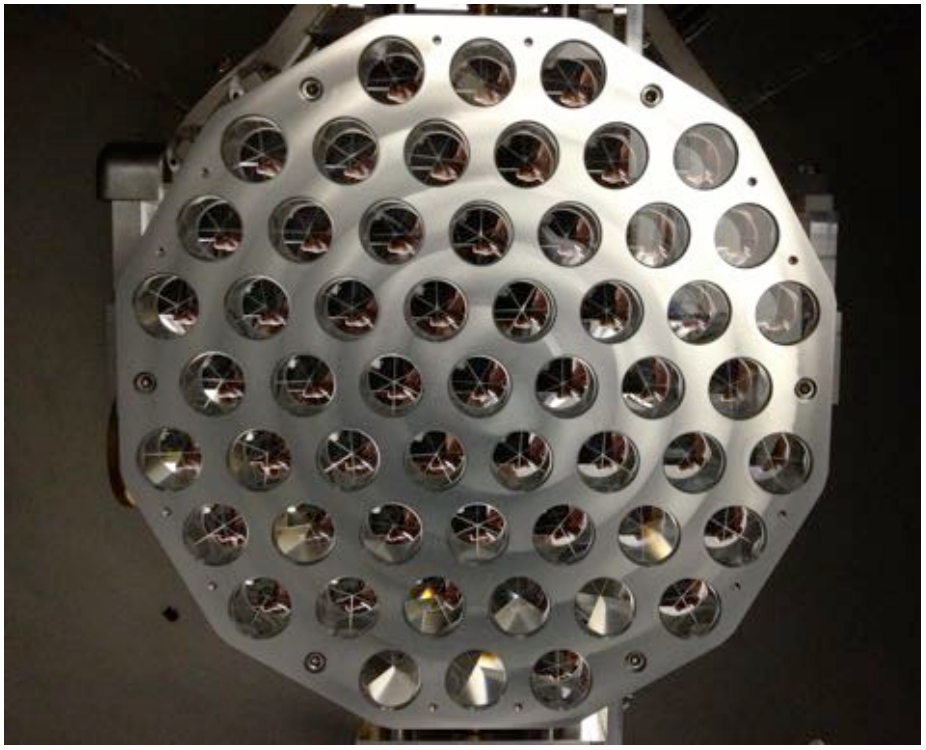
LAGEOS: ~10% degradation of laser return after 3 hour exposure to Sun simulator



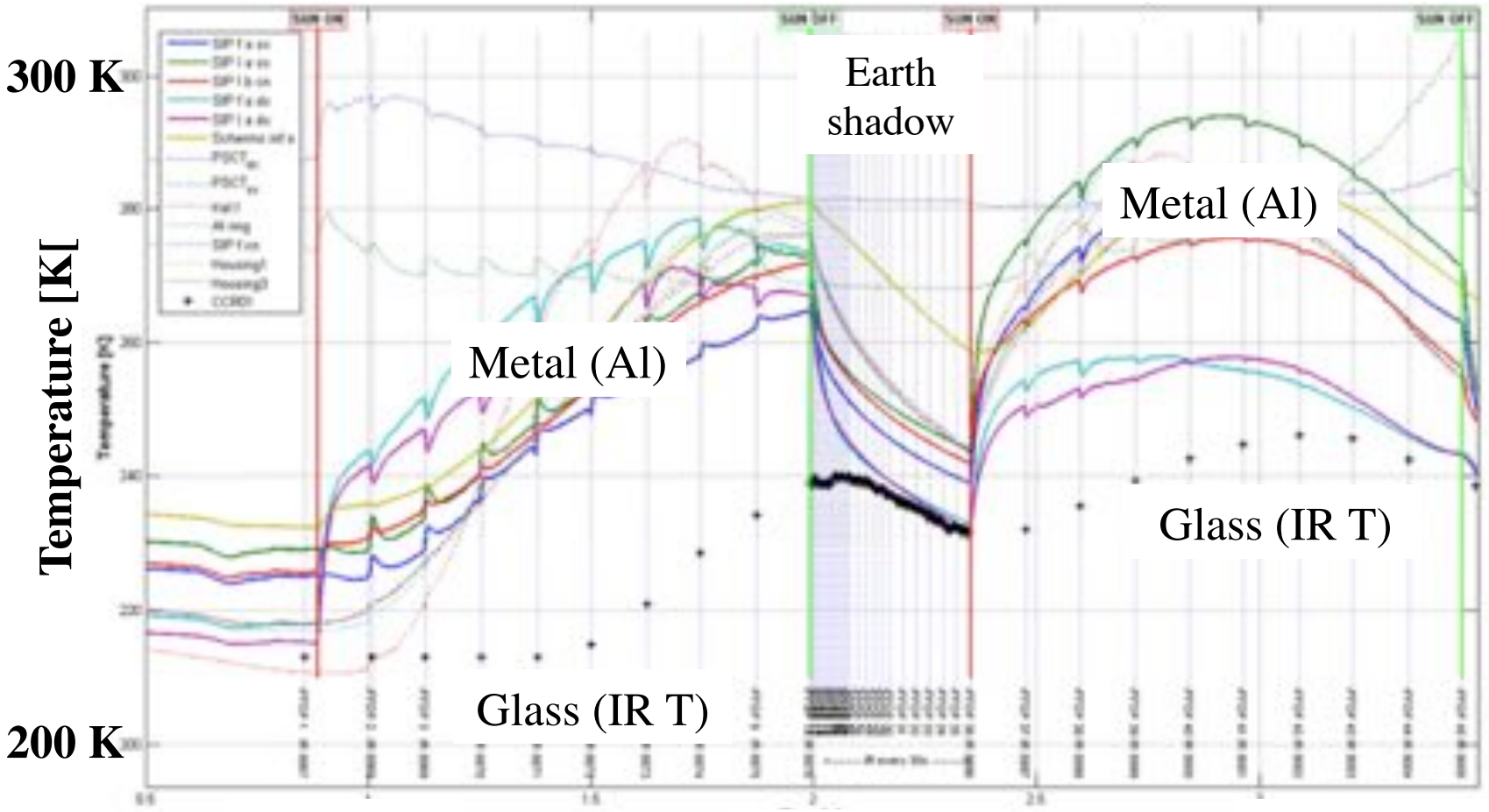
GLO<115/GPS/GIOVE: ~87% degradation

INFN laser retroreflector instrument, evolved and significantly improved from a model developed by a previous INFN-ASI project.

Already proposed to Thales Alenia, Airbus, OHB for Galileo Transition Satellites & Galileo 2G

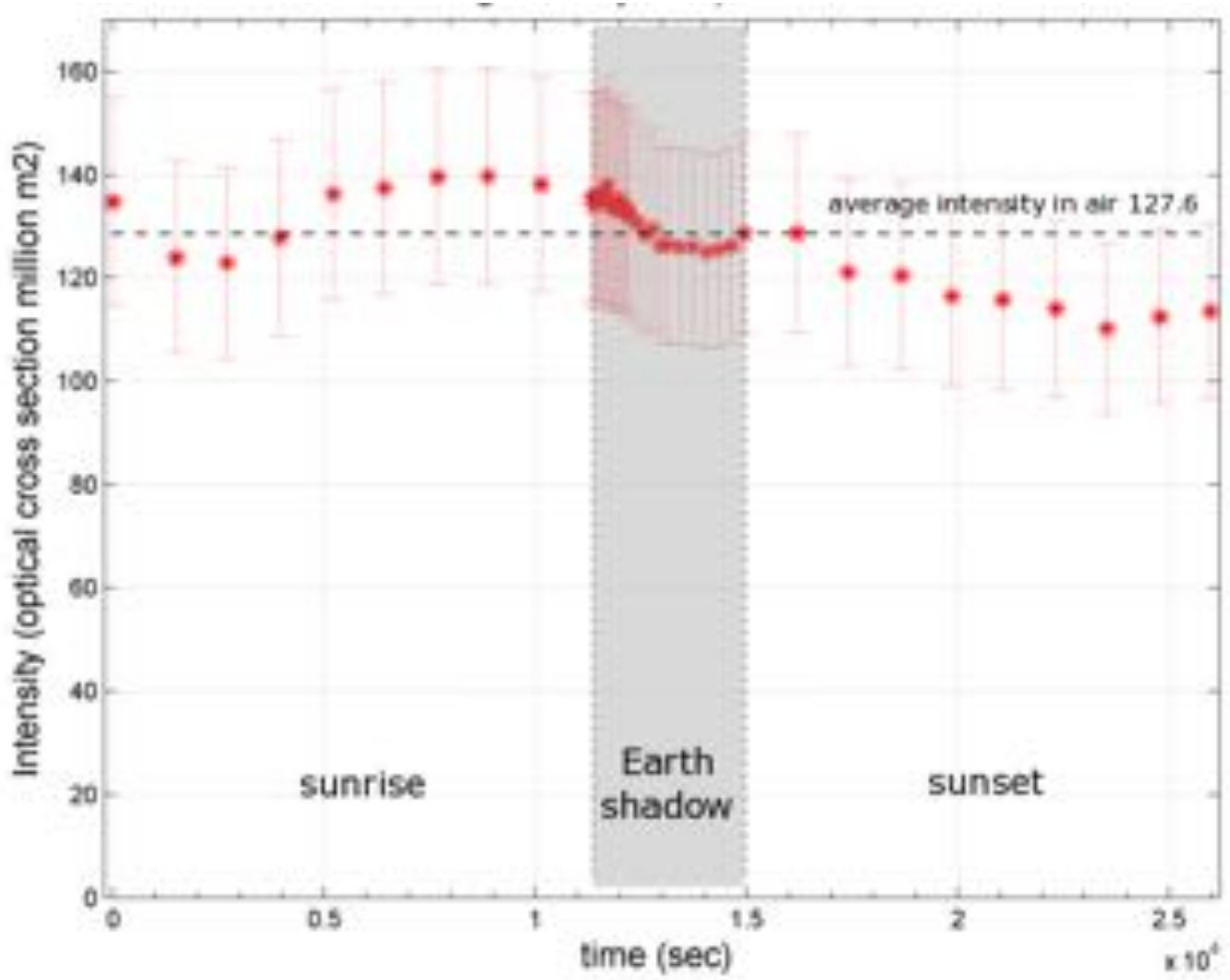


Test of thermal behavior in space conditions



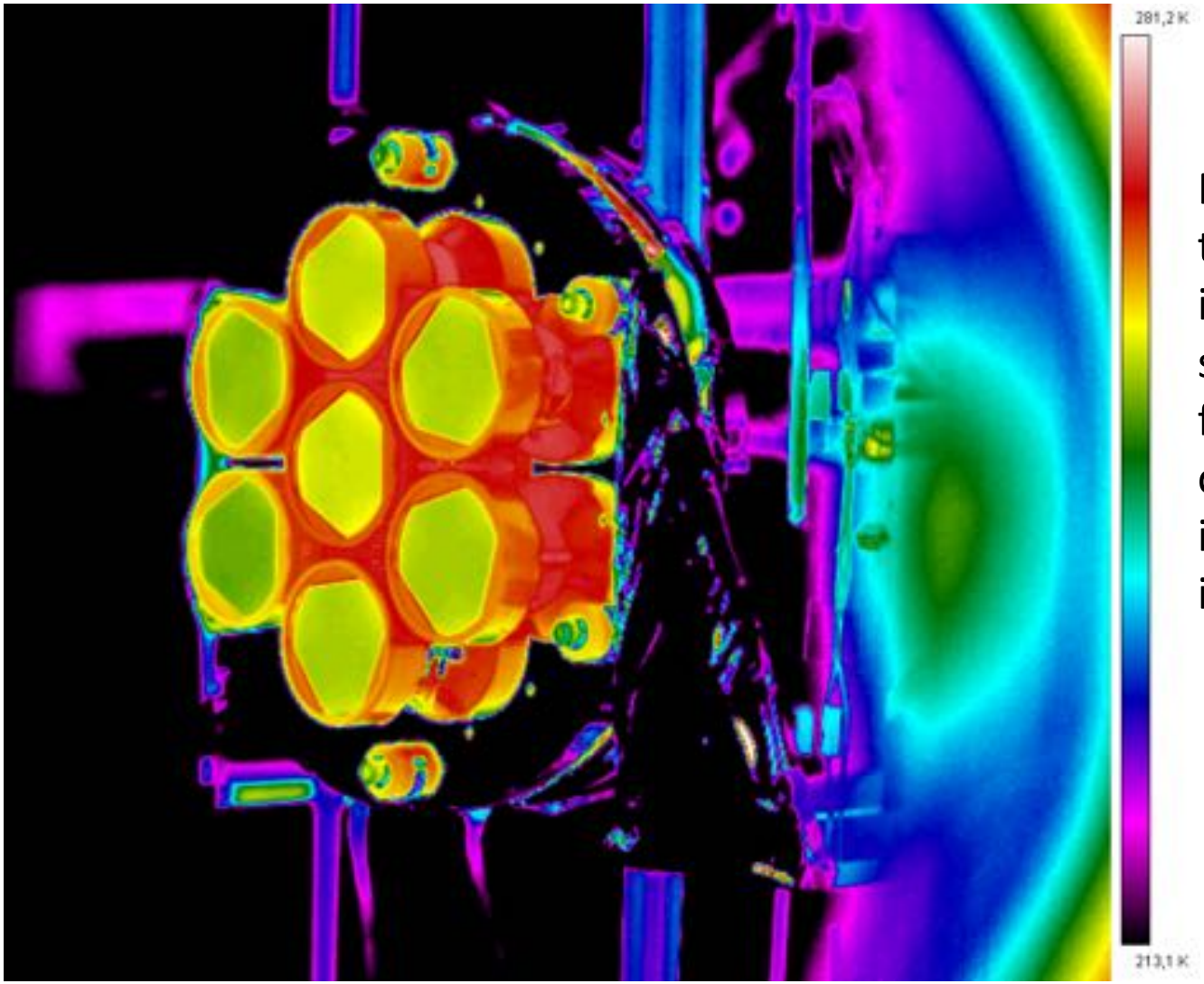
Test of optical performance in space conditions

On average: no (or marginal) performance loss within errors



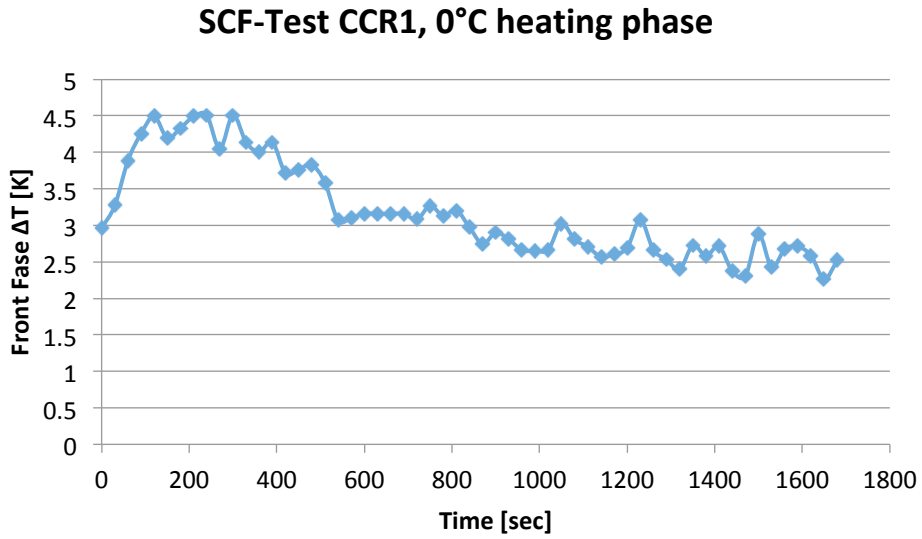
Non-invasive InfraRed camera diagnostic

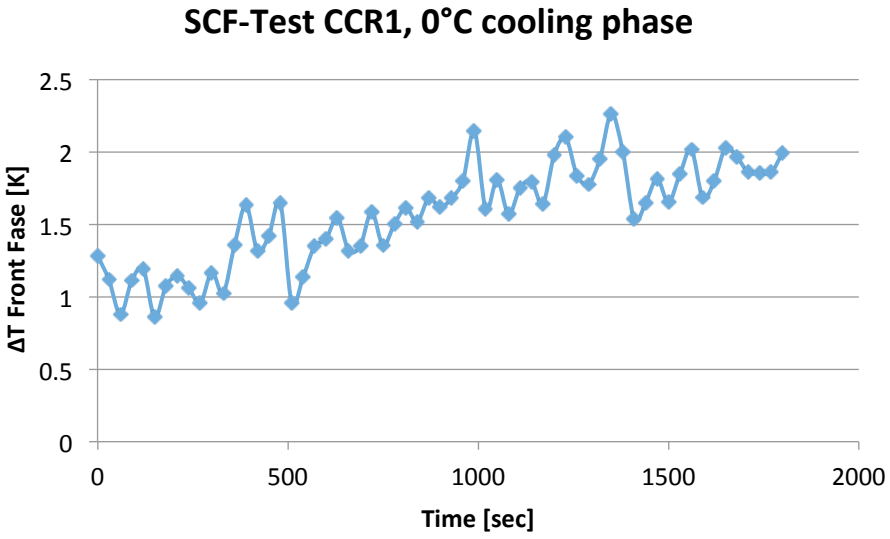
Infrared Image of GALILEO IOV retroreflectors during SCF-Test at 0°C, heating phase

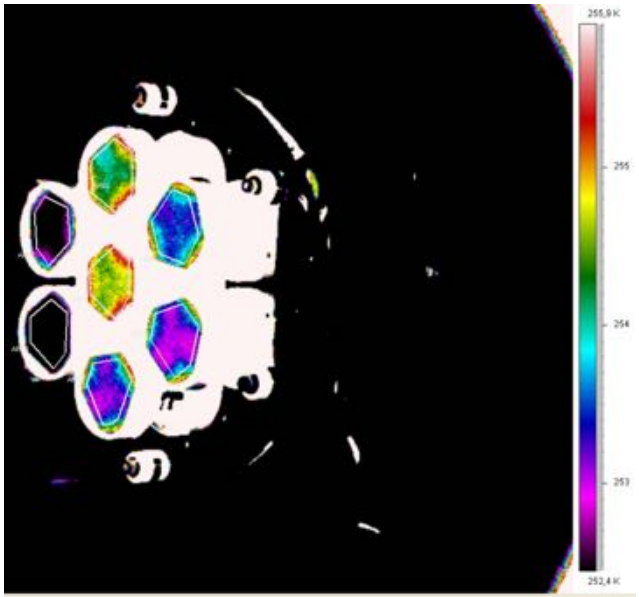


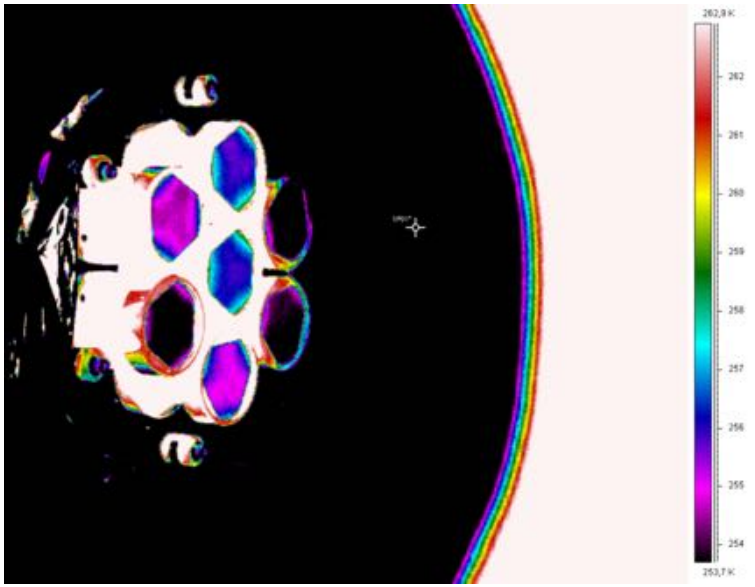
Measuring front-face temperature useful to identify unwanted hot spots, performance faults, excess mount conductance, imperfect thermal insulation, ...

Mirror Front Face Temperature Gradient









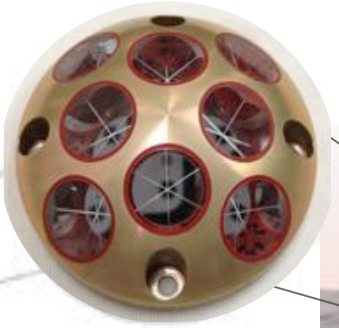
Mars General Relativity & geodesy

with Italian microreflectors

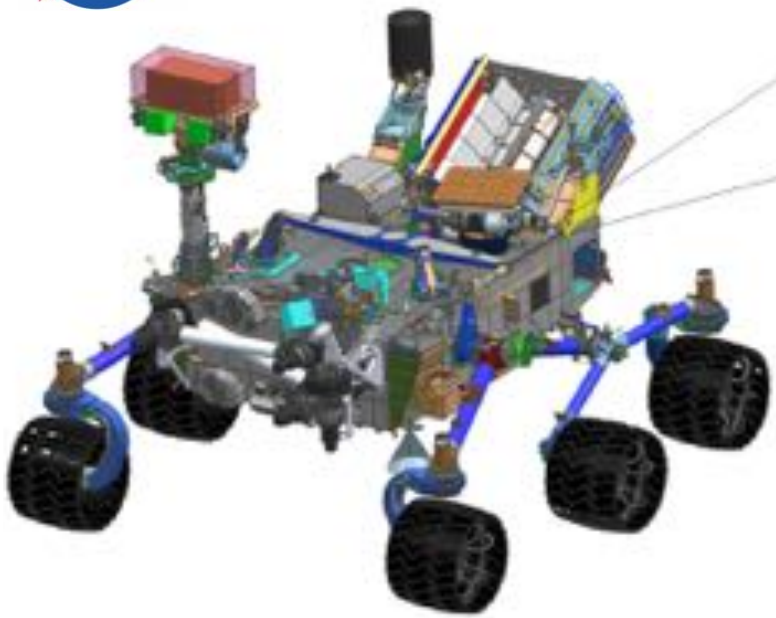
NASA: **InSight (*TONIGHT*)** Lander, Mars 2020 Rover

ESA-ASI: Schiaparelli 2016 Lander, ExoMars 2020 Rover

NASA Mars 2020

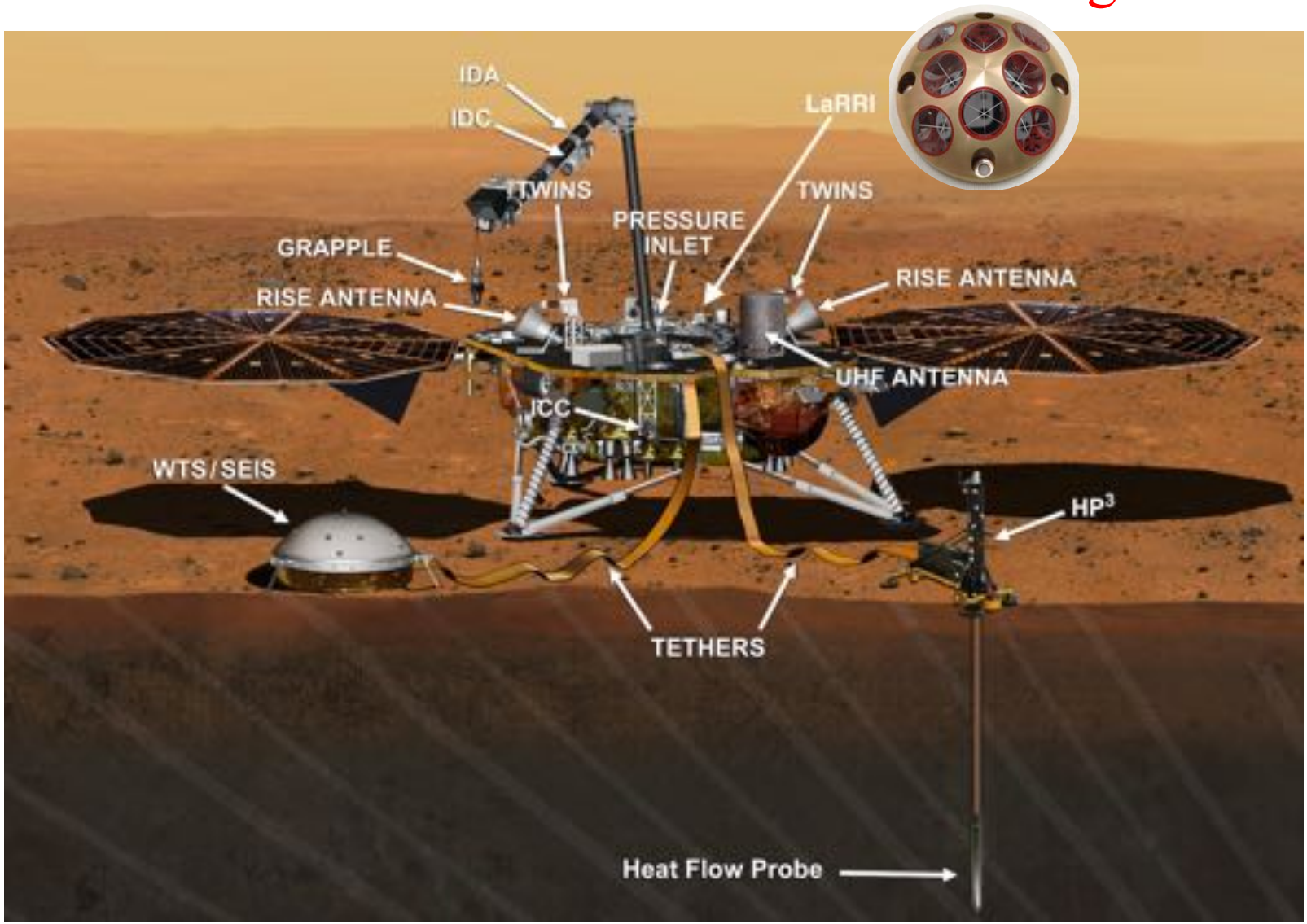


ESA-ASI ExoMars 2020



NASA InSight landing on Mars tonight, with

LaRRI = Laser Retroreflector for InSight



INFN-ASI Partnership to NASA-SSERVI

Signed in Rome
September 2014 & in
Washington
June 2017

INFN proposal to NASA:
laser retroreflectors for the whole solar system

Right: SSERVI news, visit by C. Elachi (JPL) & E. Flamini (ASI Chief Scientist)

SSERVI International Partnerships

Eight international partnerships collaborate with U.S. based SSERVI researchers on a no-exchange-of-funds basis.

Canada
PI: Gordon Osinski,
U. of Western Ontario

Germany
PI: Ralf Jaumann
DLR

Israel
PI: Shlomi Amon
Ben-Gurion U. at the Negev

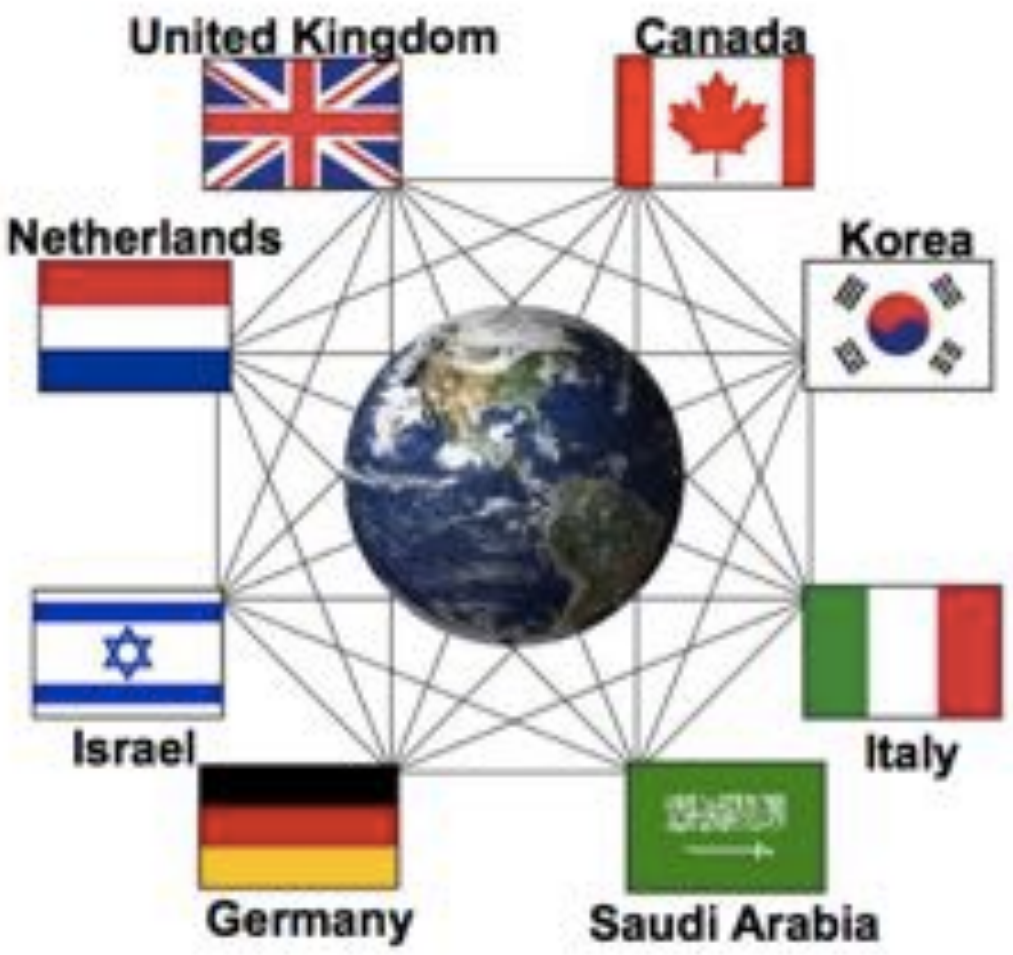
Italy
PI: Simone Dell'Agnello
INFN

Kingdom of Saudi Arabia
PI: Abdulaziz Alothman
King Abdulaziz City for Sci & Tech (KACST)

Korea
PI: Gwangyeok Ju
Korean Aerospace Research Institute (KARI)

Netherlands
PI: Wim van Westrenen
VU U. Amsterdam

United Kingdom
PI: Mahesh Anand,
Open U.



**Additional Partnerships under development include Australia and France*

Acronyms and definitions

1. AM0: Air Mass Zero
2. ASI: Agenzia Spaziale Italiana
3. CCR: Cube Corner Retroreflector
4. ESA: European Space Agency
5. FFDP: Far Field Diffraction Pattern
6. FOC: Full Orbit Capability
7. GCO: GNSS Critical Orbit
8. GMES = Global Monitoring for Environment and Security
9. GNSS : Global Navigation Satellite System
10. GPS: Global Positioning System
12. GTRF: Galileo Terrestrial Reference Frame
13. ILRS: International Laser Ranging Service
14. IOV: In Orbit Validation
12. IPR: Intellectual Property Rights
13. ITRF: International Terrestrial Reference Frame
14. ITRS: International Terrestrial Reference System
15. KPI: Key Performance Indicator
16. OCS: Optical Cross Section
17. LAGEOS: LAser GEOdynamics Satellite
18. SCF: Satellite/lunar/GNSS laser ranging and altimetry Characterization Facility
19. SCF-G: Satellite laser ranging Characterization Facility optimized for GNSS
20. RASNAL = Retroreflector Array for SatNAv Laser ranging
21. SLR: Satellite Laser Ranging
22. WI: Wavefront Interferogram

Some Reference Documents

- [RD-1] Dell'Agnello, S., et al, **Creation of the new industry-standard space test of laser retroreflectors for the GNSS and LAGEOS**, J. Adv. Space Res. **47** (2011) 822–842.
- [RD-2] P. Willis, Preface, Scientific applications of Galileo and other Global Navigation Satellite Systems (II), J. Adv. Space Res., **47** (2011) 769.
- [RD-3] D. Currie, S. Dell'Agnello, G. Delle Monache, **A Lunar Laser Ranging Array for the 21st Century**, Acta Astron. **68** (2011) 667-680.
- [RD-4] Dell'Agnello, S., et al, Fundamental physics and absolute positioning metrology with the MAGIA lunar orbiter, Exp Astron, October 2011, Volume 32, Issue 1, pp 19-35 ASI Phase A study.
- [RD-5] Dell'Agnello, S. et al, **A Lunar Laser Ranging Retro-Reflector Array for NASA's Manned Landings, the International Lunar Network and the Proposed ASI Lunar Mission MAGIA**, Proceedings of the 16th International Workshop on Laser Ranging, Space Research Centre, Polish Academy of Sciences Warsaw, Poland, 2008.
- [RD-6] International Lunar Network (http://iln.arc.nasa.gov/), Core Instrument and Communications Working Group Final Reports.
- [RD-7] Yi Mao, Max Tegmark, Alan H. Guth, and Serkan Cabi, Constraining torsion with Gravity Probe B, Physical Review D **76,** 104029 (2007).
- [RD-8] March, R., Bellettini, G., Tauraso, R., Dell'Agnello, S., **Constraining spacetime torsion with the Moon and Mercury**, Physical Review D **83**, 104008 (2011).
- [RD-9] March, R., Bellettini, G., Tauraso, R., Dell'Agnello, S., **Constraining spacetime torsion with LAGEOS**, Gen Relativ Gravit (2011) 43:3099–3126.
- [RD-10] **ETRUSCO-2: An ASI-INFN project of technological development and "SCF-Test" of GNSS LASER Retroreflector Arrays**, S, Dell'Agnello, 3rd International Colloquium on on Scientific and Fundamental Aspects of the Galileo Programme, Copenhagen, Denmark, August 2011