INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

SCF_Lab

Satellite/Lunar/GNSS
laser ranging/altimetry and cube/microsat
Characterization Facilities Laboratory

Optimization and characterization of laser retroreflectors at the SCF_Lab

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Laboratori Nazionali di Frascati (LNF)-INFN, Frascati, Italy

Frascati, 20/10/2015

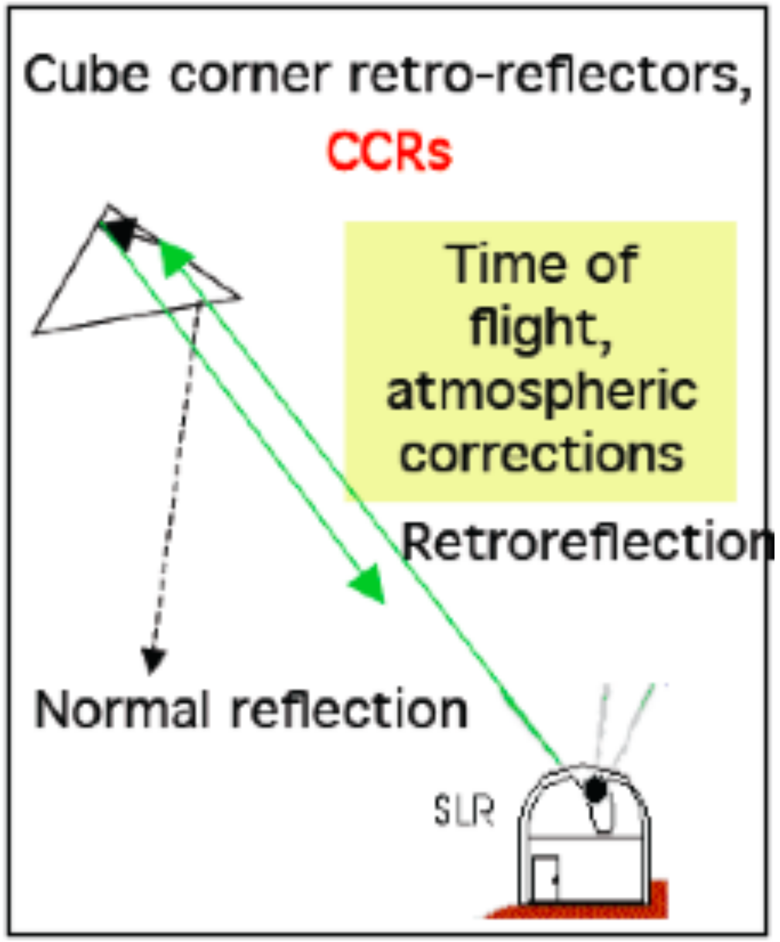
Outline

- Introduction to Satellite and Lunar Laser Ranging
- SLR applications to Earth observation missions
- SLR applications to Global Navigation Satellite System (GNSS)
- Laser Ranging to the Moon
- The SCF_Lab and its innovative activity: characterization of laser retroreflectors in representative space conditions
- The SCF_Lab activities

Leonard explaining Laser Ranging

Satellite Laser Ranging

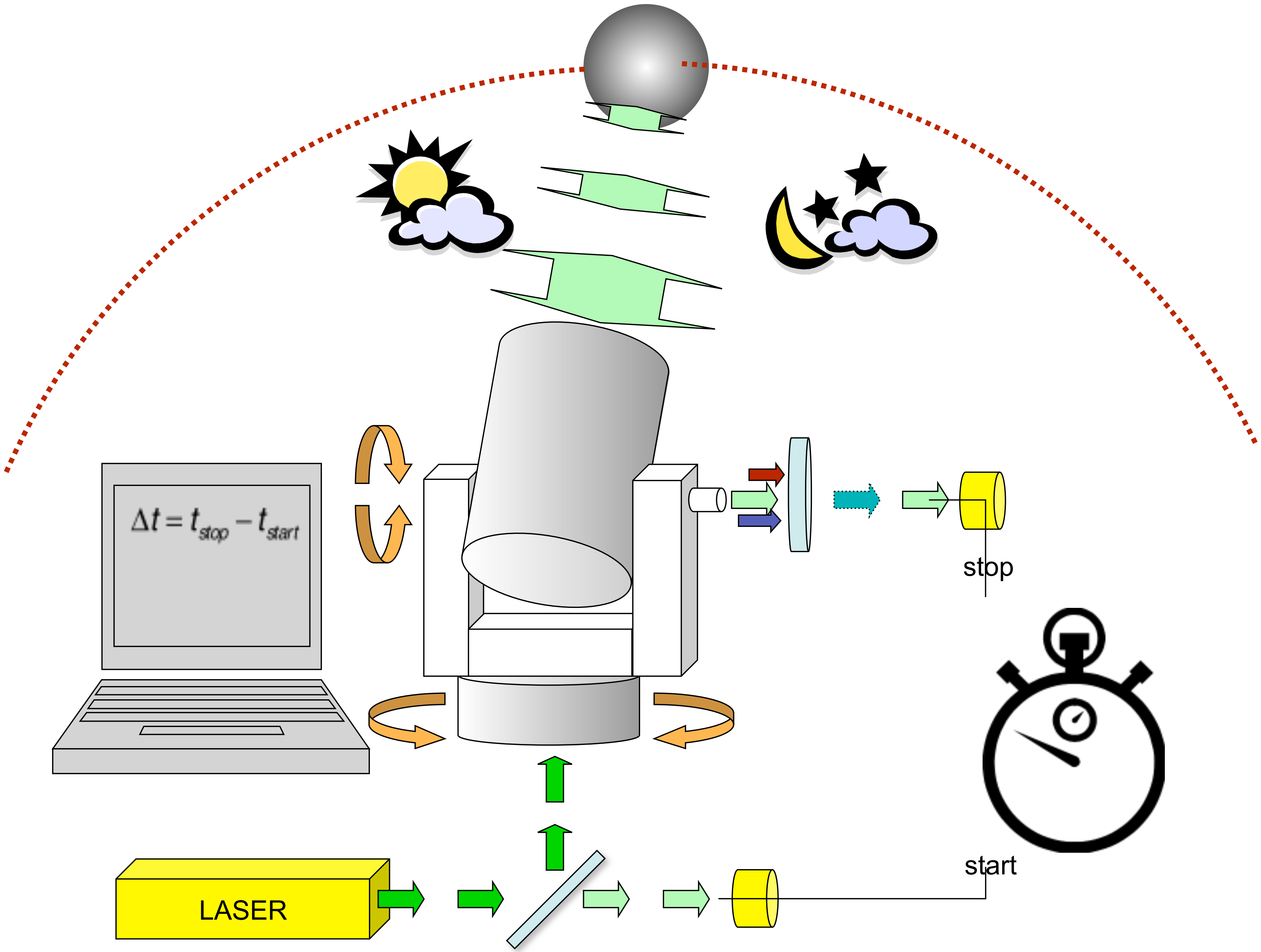
Satellite Laser Ranging (SLR)
Lunar Laser Ranging (LLR)
Time of flight measurements



Greenbelt (MD) SLR station

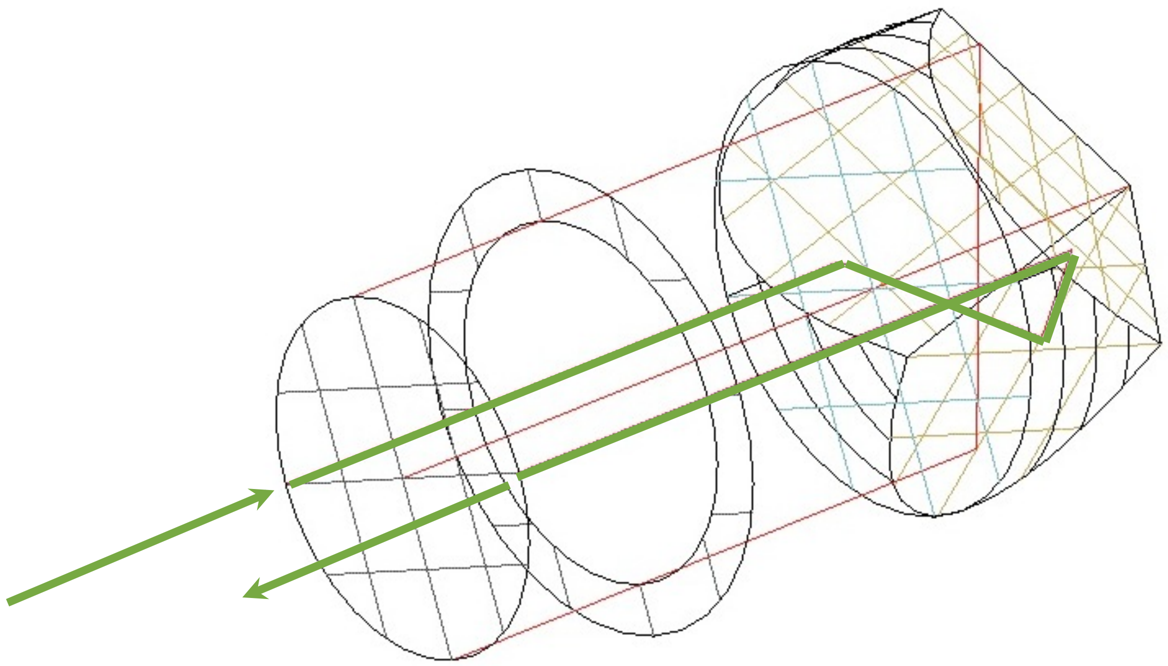
The most precise and cost effective distance measurement in space
(few millimeters to few centimeters) and (100K€ to M€)
Laser interferometry much more precise but much more expensive/difficult

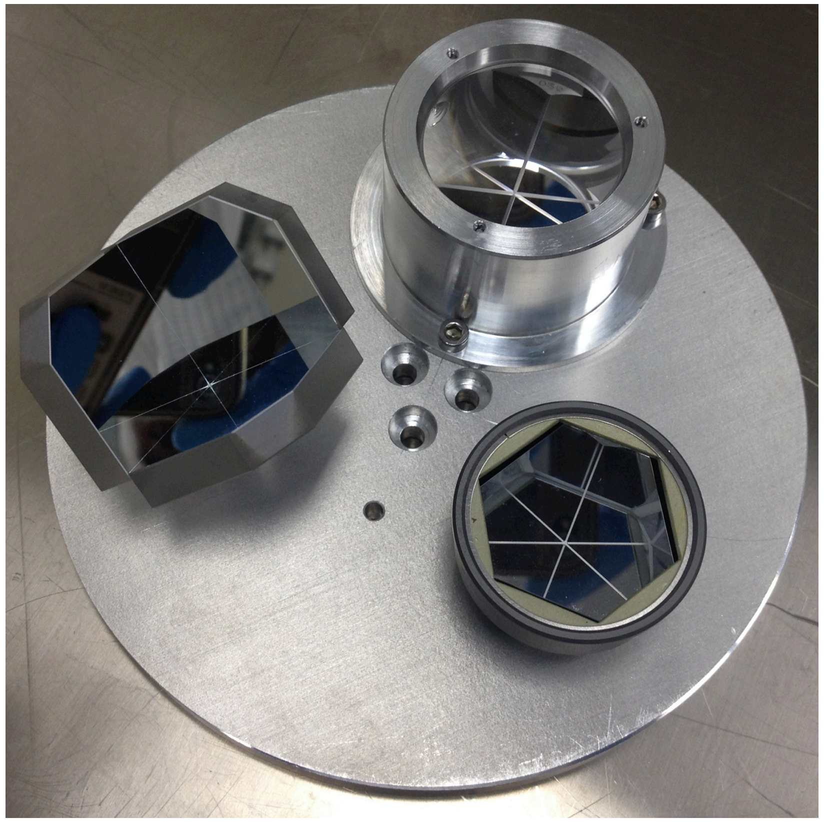
Ranging technique



Corner Cube Reflector

- A CCR is a prism, usually made of Fused Silica, whose vertex is a corner of a cube. Each one of the back faces has an angle of 90° with another.
- A ray entering the CCR is retroreflected along the same direction.
- A ray entering the CCR, comes out in a point opposite to the origin.

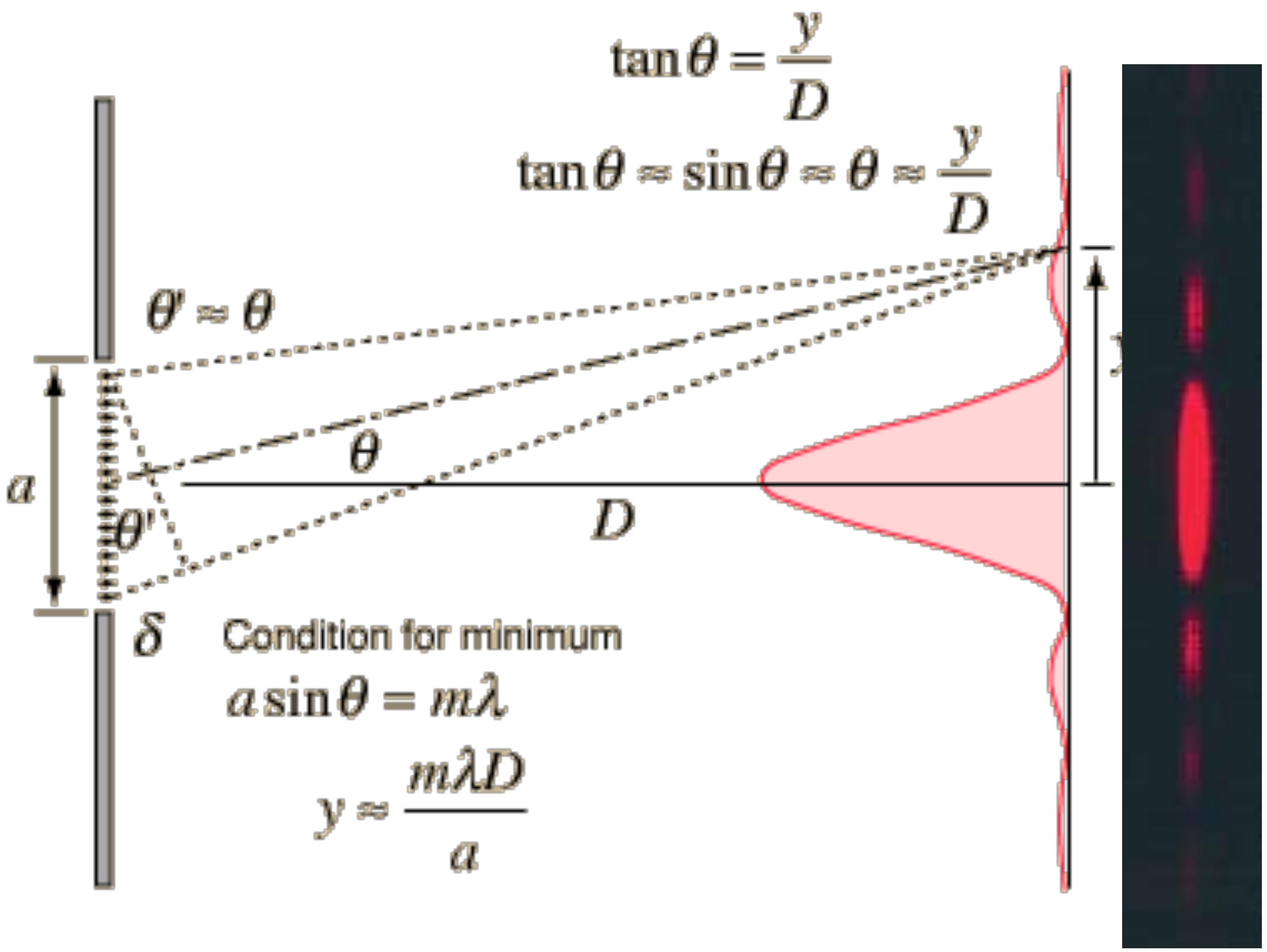


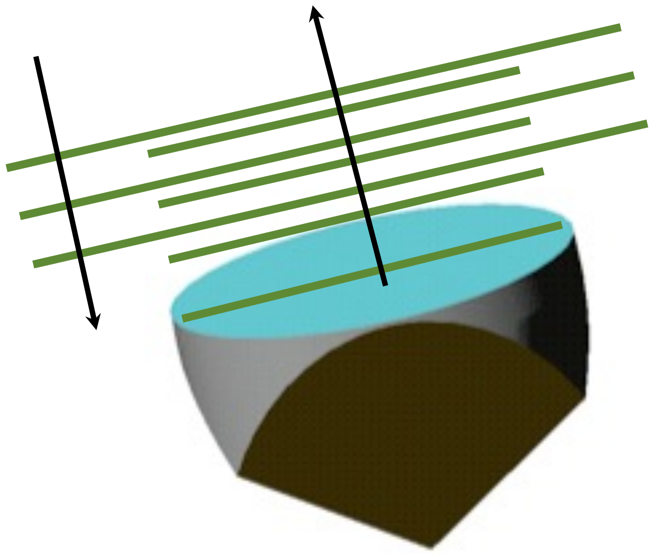


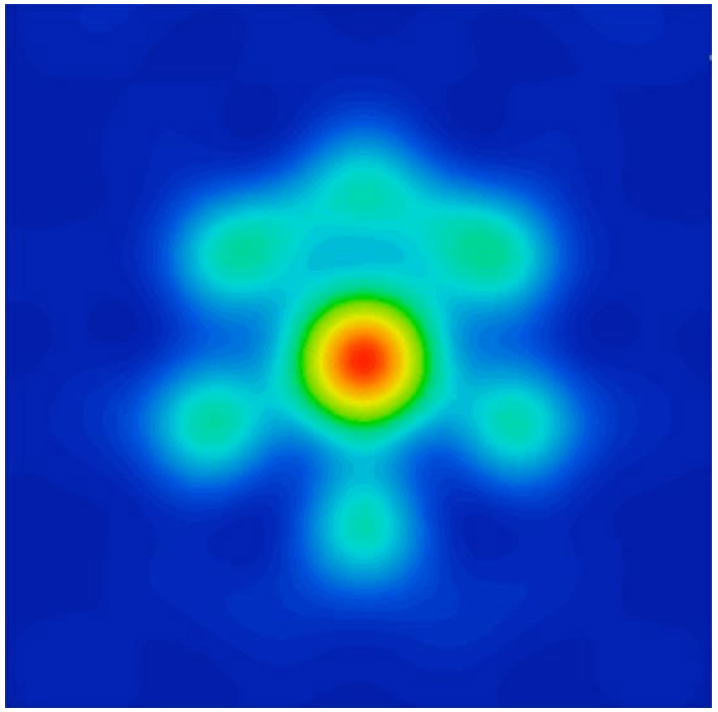
reflection on the three back surfaces through total internal reflection

Far Field Diffraction Pattern

Diffraction is a phenomenon that occurs when a wave passes through an obstacle or a limited portion of space. On a distant screen a plane wave will result to have a known intensity variation.





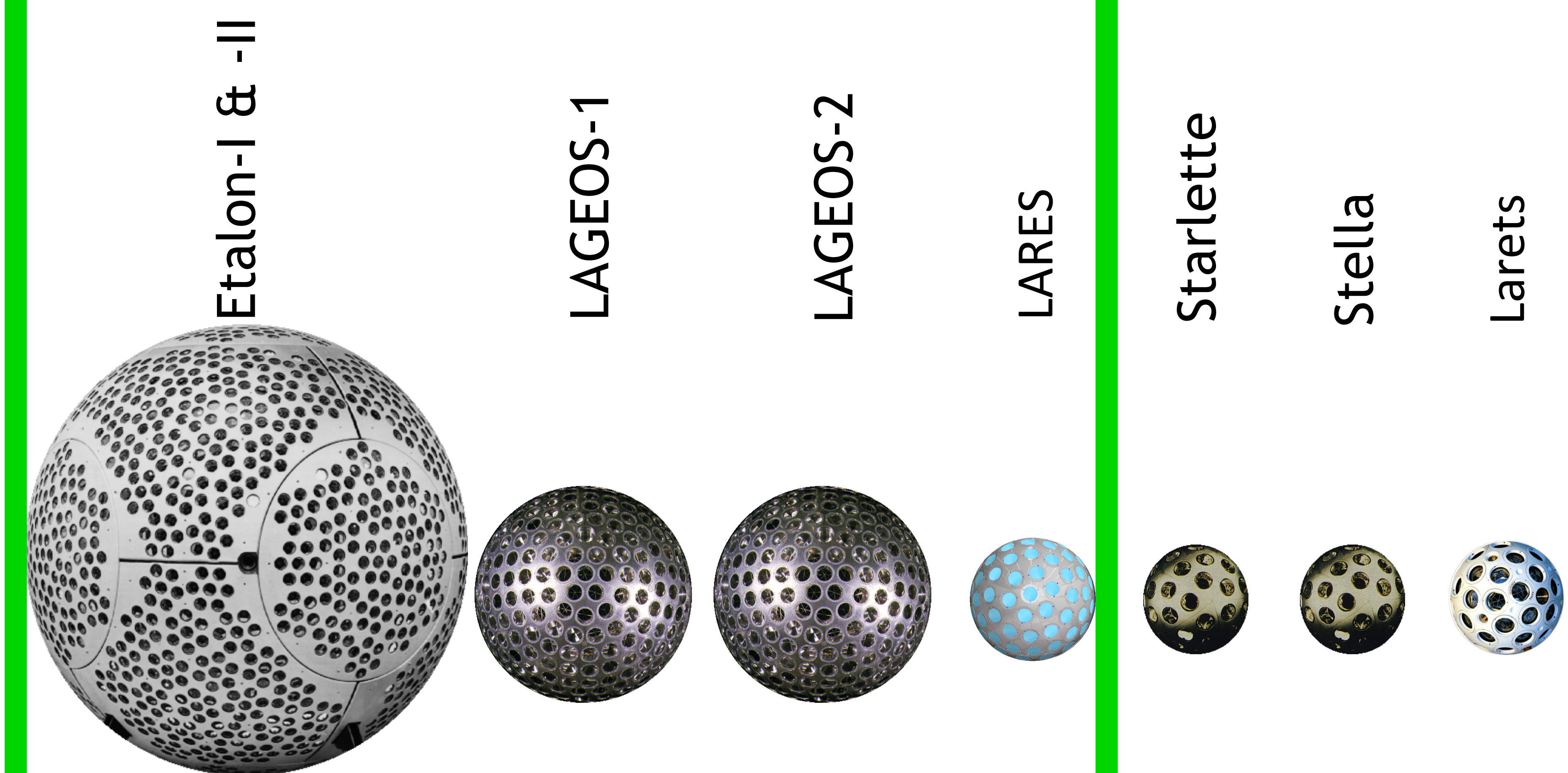


Laser Ranging Applications

Geodetic satellites

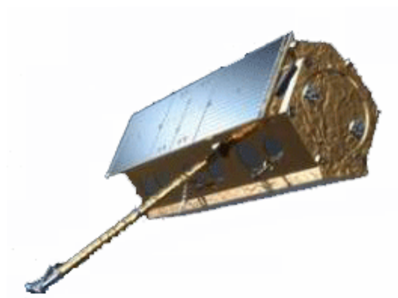
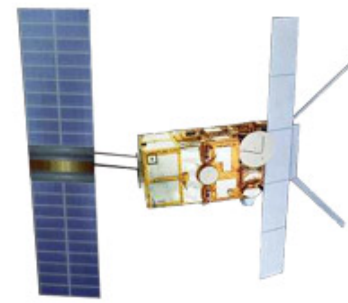
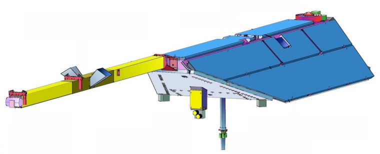
(Earth geocenter and Inertial frame)

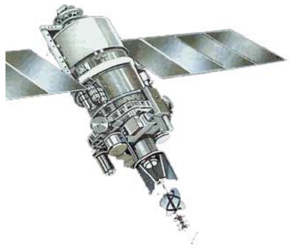
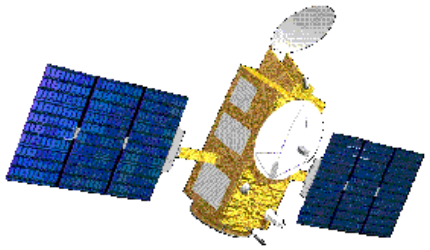
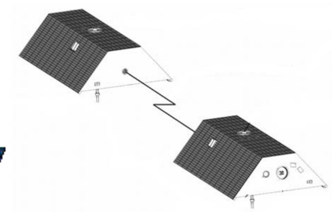
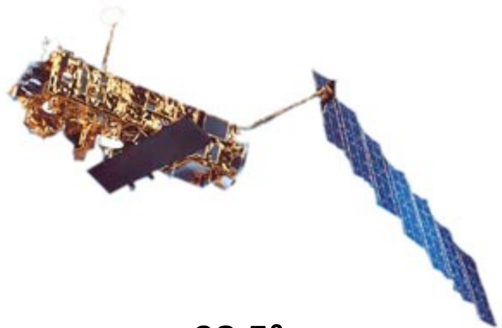
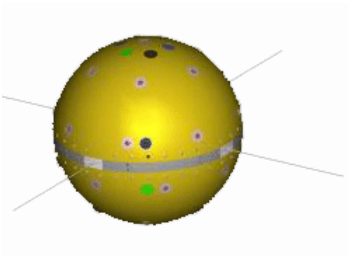
ITRF Constellation



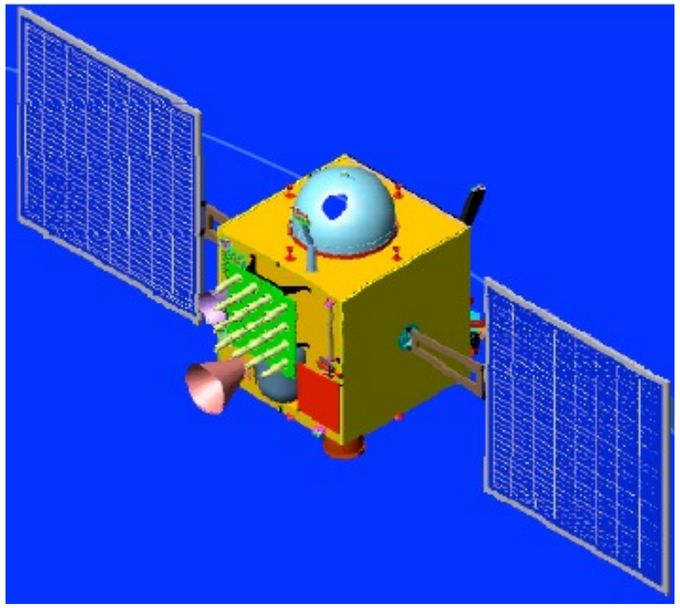
	Etalon-I & -II	LAGEOS-1	LAGEOS-2	LARES	Starlette	Stella	Larets
Inclination	64.8°	109.9°	52.6°	69.5°	50°	98.6°	98.2°
Perigee ht. (km)	19,120	5,860	5,620	1450	810	800	691
Diameter (cm)	129.4	60	60	36	24	24	24
Mass (kg)	1415	407	405.4	387	47.3	47.3	23.3

Earth Observation satellites

	GFO-1	ERS-1	Terra-SAR-X	ERS-2	CHAMP
					
Inclination	108°	98.5°	97.4°	98.5°	87.27°
Perigee ht. (km)	800	780	514	785	474
Mass (kg)	300	2,400	1,230	2,516	400

	Meteor-3M	Jason-2	GRACE	Envisat	ANDE-RR
					
Inclination	99.64°	66°	89°	98.5°	51.6°
Perigee ht. (km)	1,012	1,336	450	796	250
Mass (kg)	2.477	500	432/sat.	8,211	50

SLR on GNSS



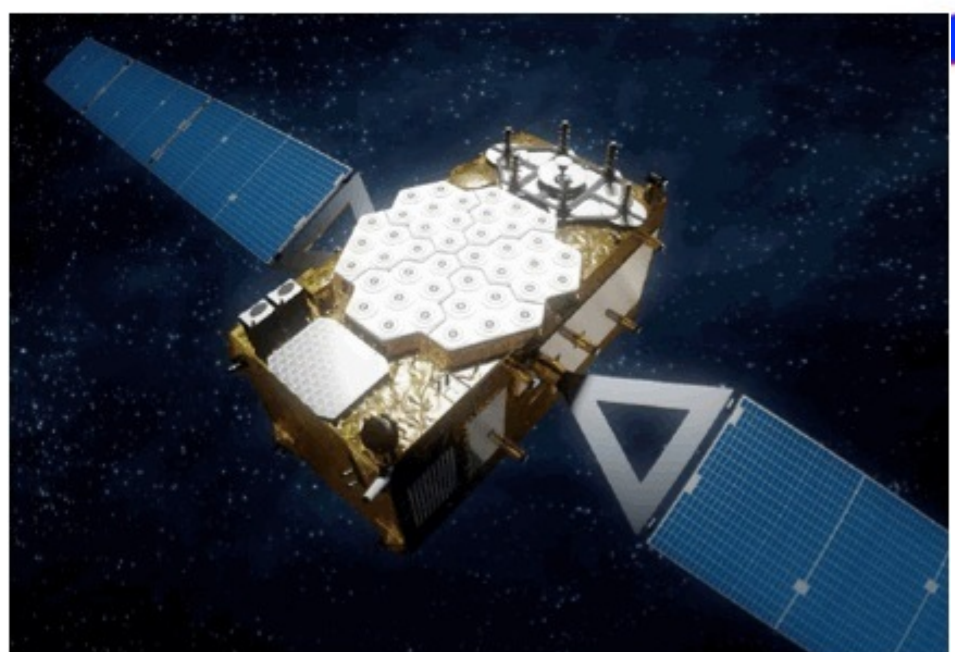
Indian IRNSS: 7 regional satellites

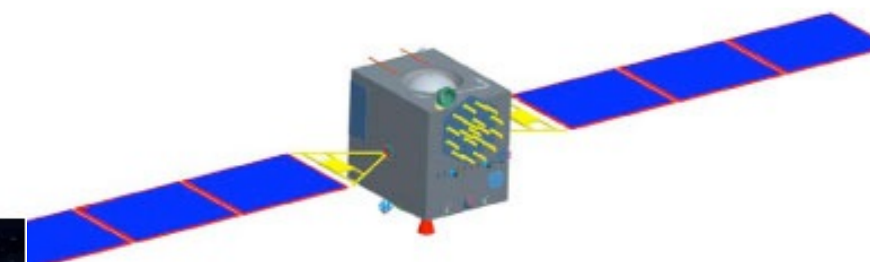
American GPS: 24 global satellites

Japanese QZSS: 3 regional satellites

Russian GLONASS: 24 global satellites

European Galileo: 24 global satellites





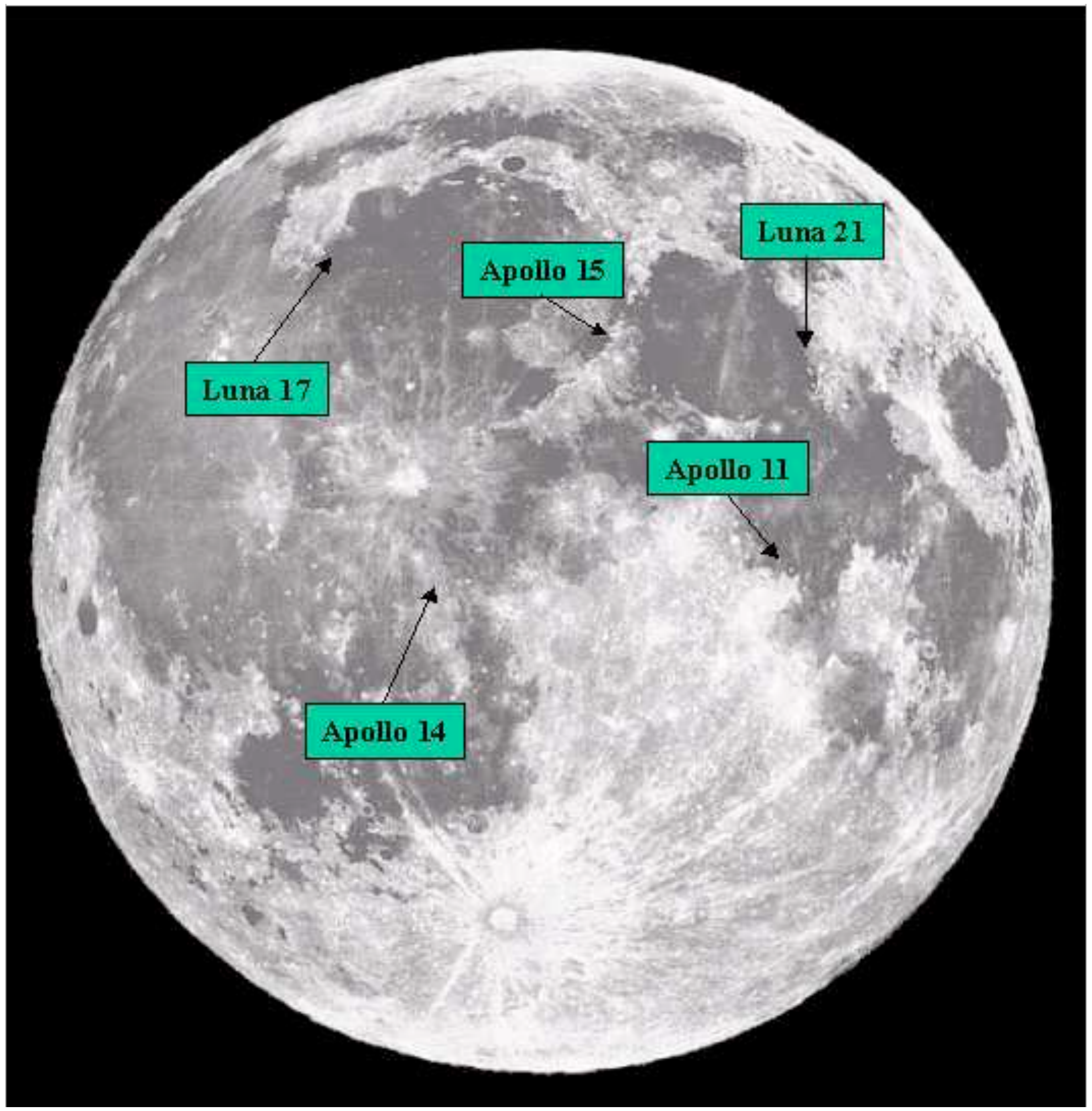
Chinese COMPASS: 30 global and 5 regional satellites

Ranging to the Moon

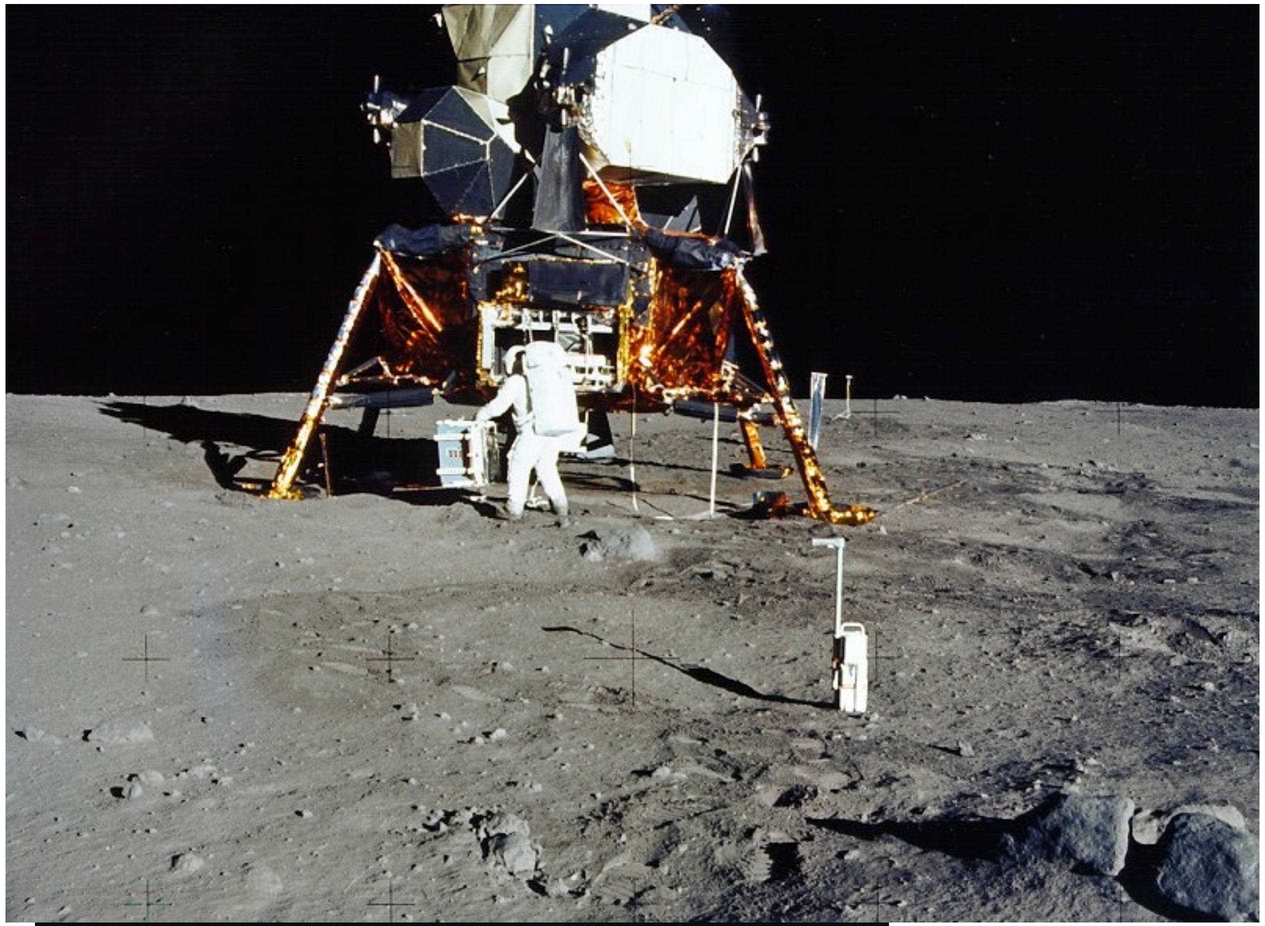
Lunar Laser Ranging: ToF/orbit at 2 cm ~ $5 \cdot 10^{-11}$ of Earth-Moon distance

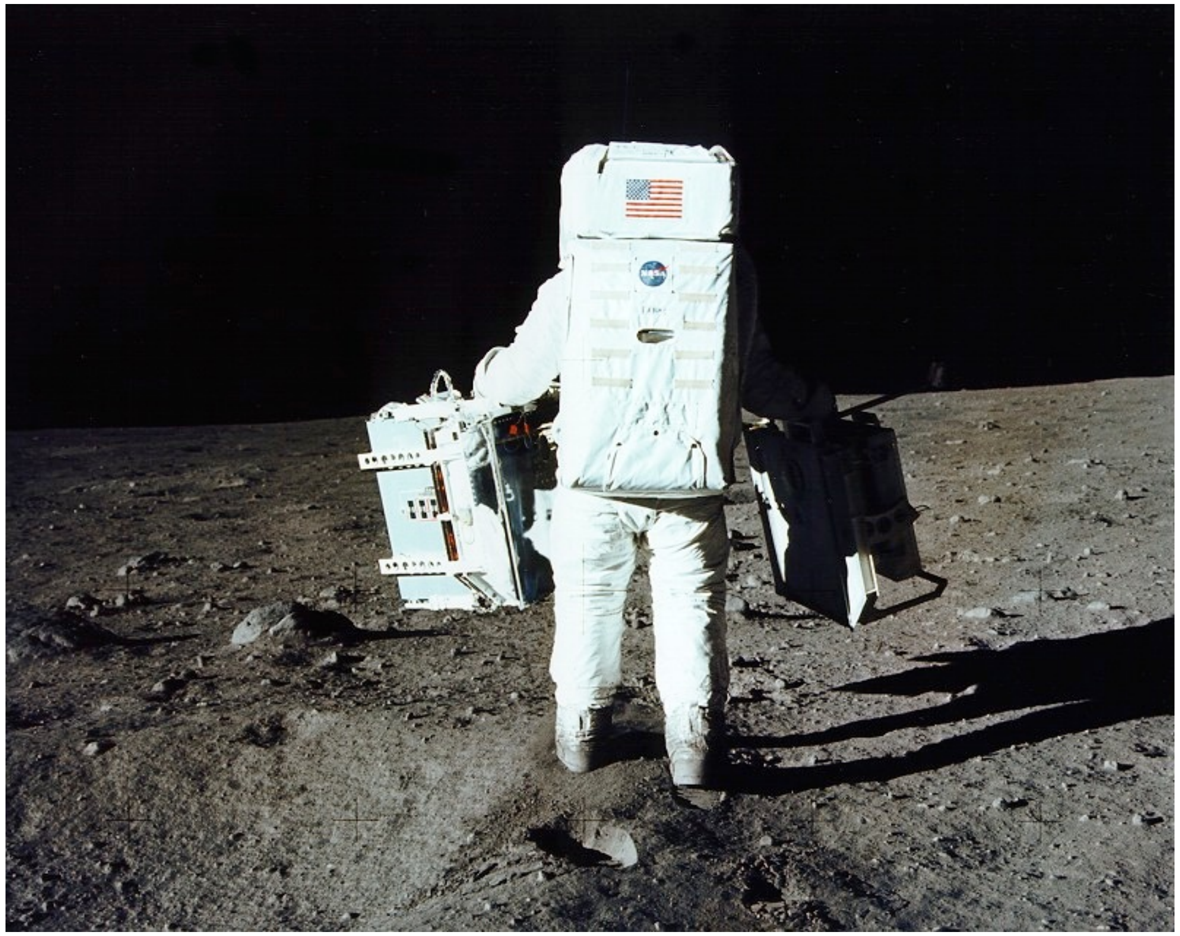
Relative sizes and separation of the Earth–Moon. LLR tof ~ 2.6 sec (2-way)

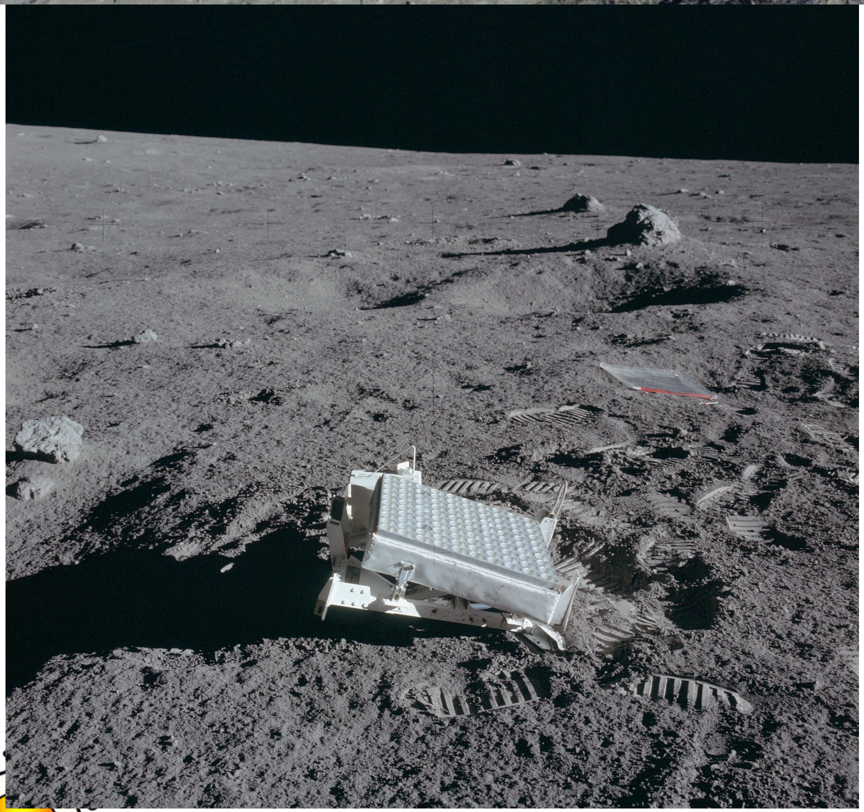
Locations of 1st Generation LLR Arrays



Apollo 11 mission



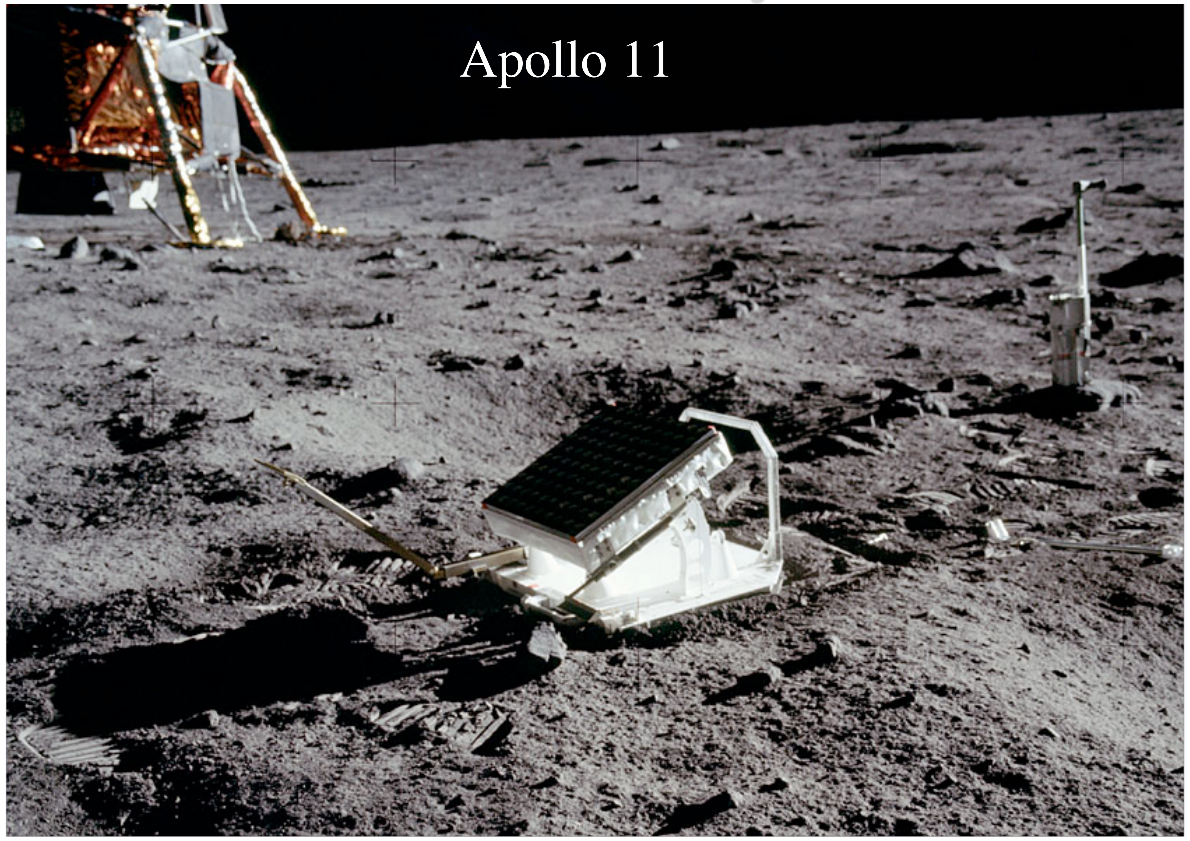


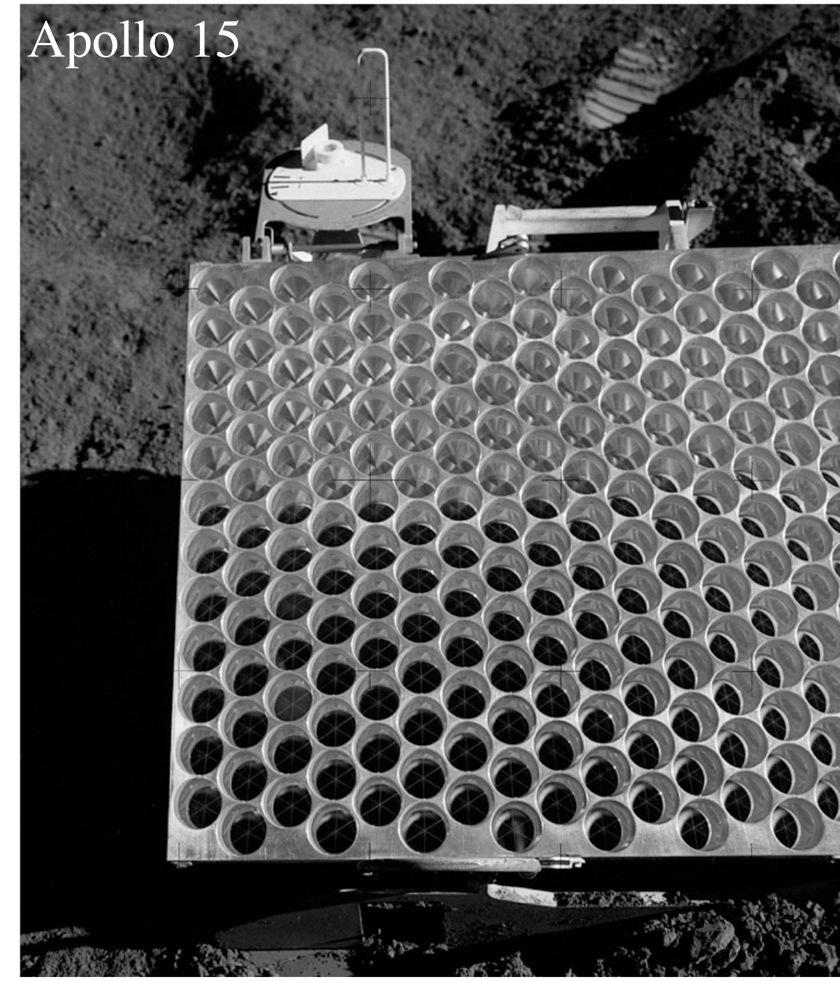


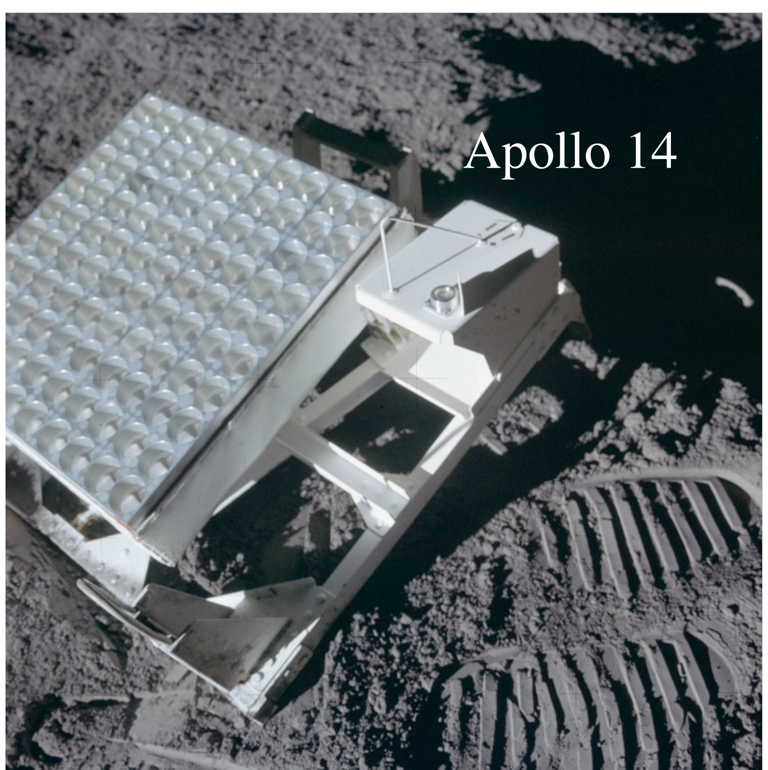
LLR: only Apollo experiment still providing data since July 20, 1969

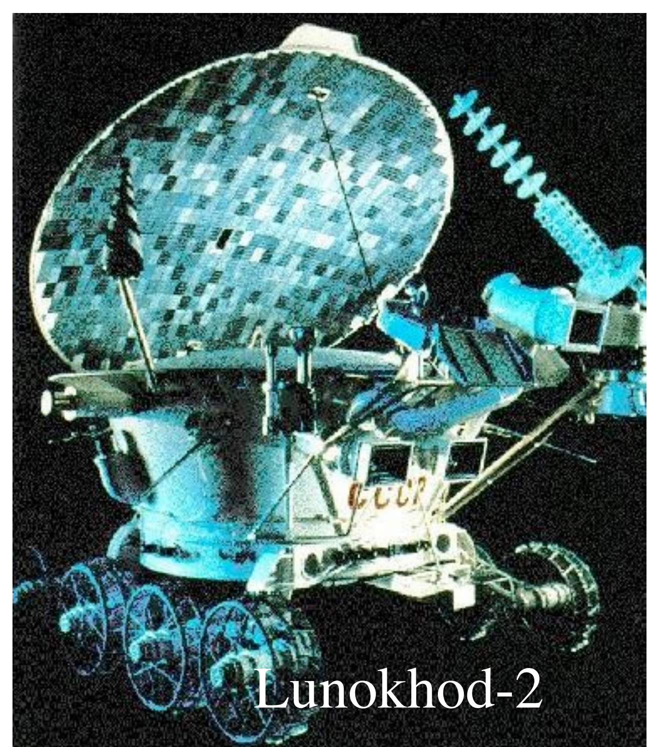
Lunar Laser Ranging arrays

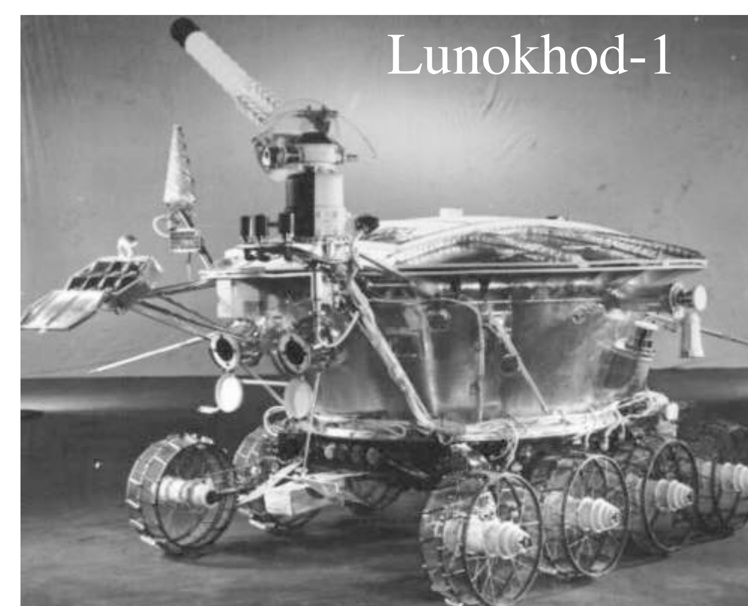
1st Gen. Lunar Reflector Arrays









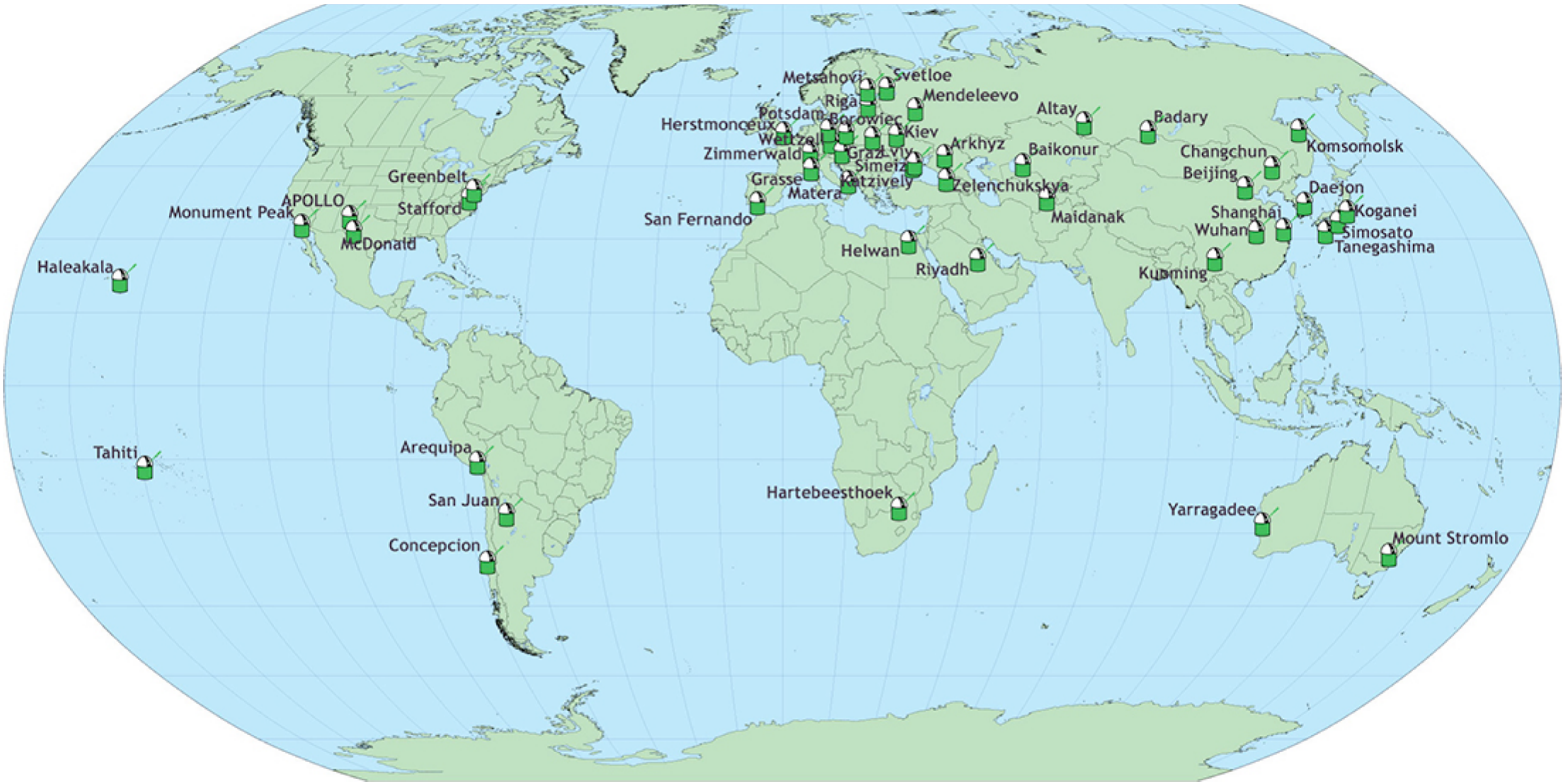


Test of GR with LLR

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

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

International Laser Ranging Service



A network of about 40 ground stations routinely track satellites equipped with retroreflectors and give information about their orbit. 4 stations in the world track the Moon

Matera Laser Ranging Station

MLRO

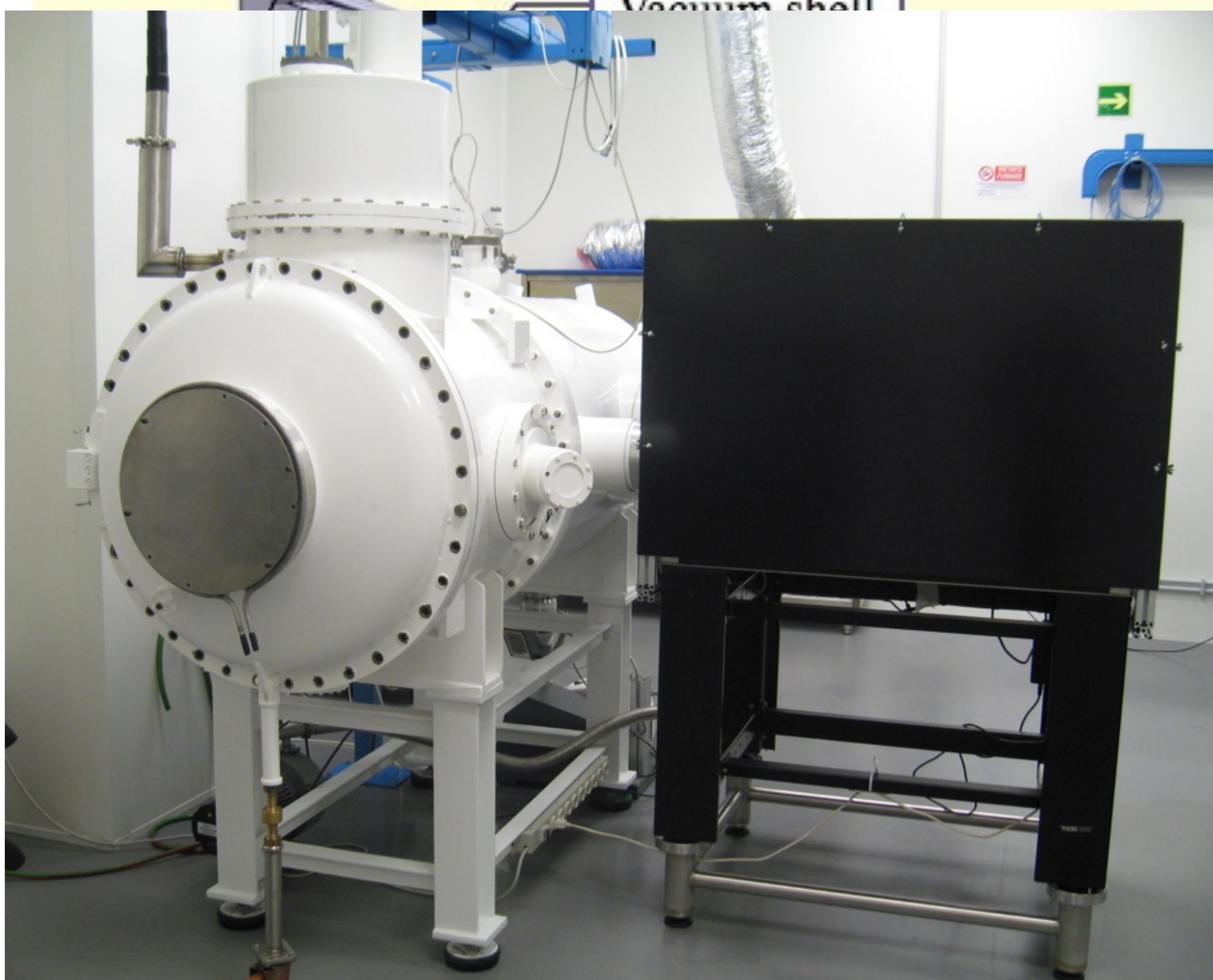
The SCF_Lab and its activities

The SCF_Lab

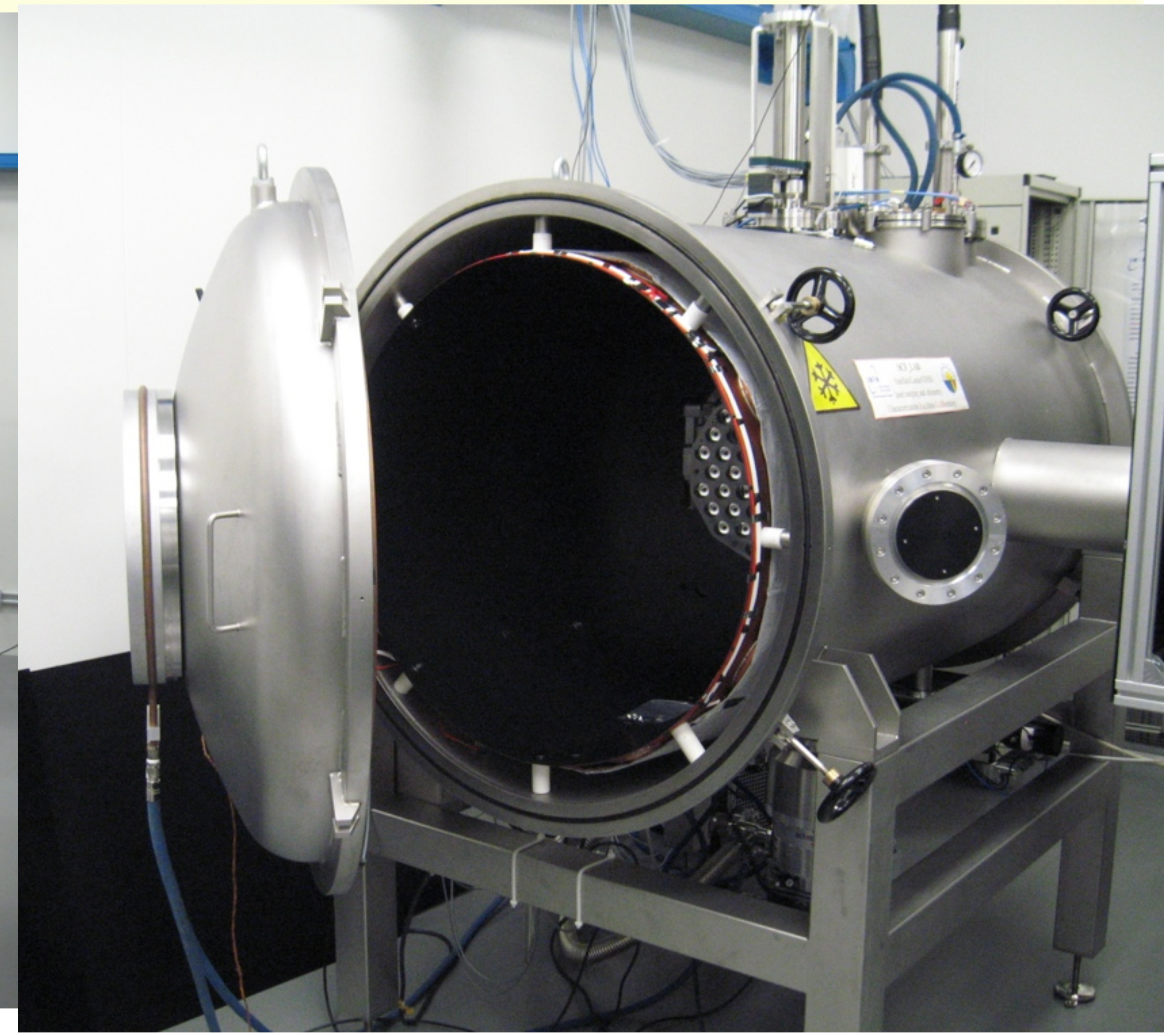
SCF and SCF-G

(Satellite/lunar/GNSS laser ranging/altimetry and cube/microsat Characterization Facility)

SCF



SCF-G



- environment pressure down to 10^{-6} mbar
- temperature of the chamber at ~ 80K
- high emissivity cold shield
- solar radiation through a Solar Simulator replicating AM0

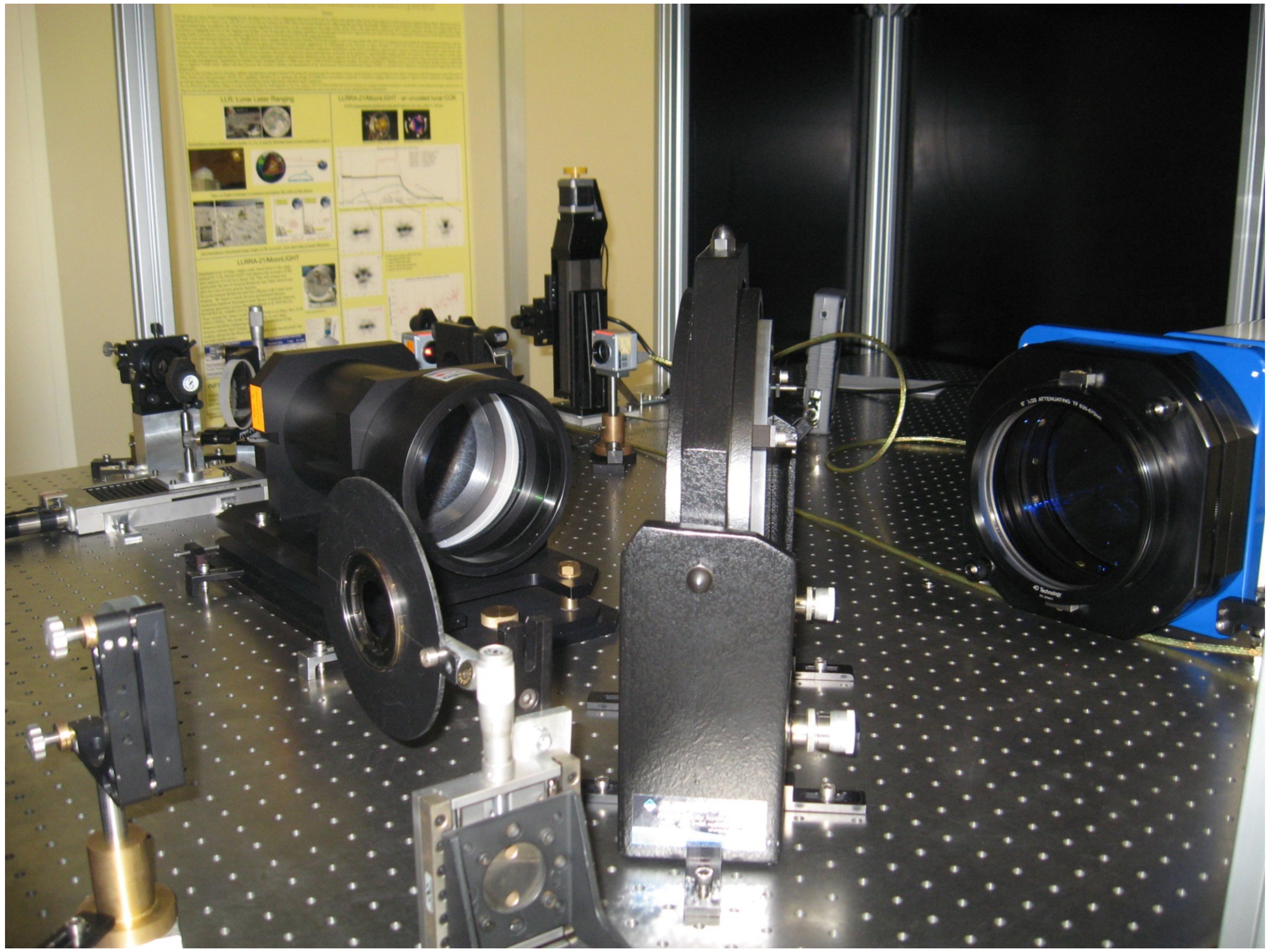
SCF_Lab measurement equipments

Temperature

Invasive: platinum RTD probes

Non-invasive: InfraRed Camera

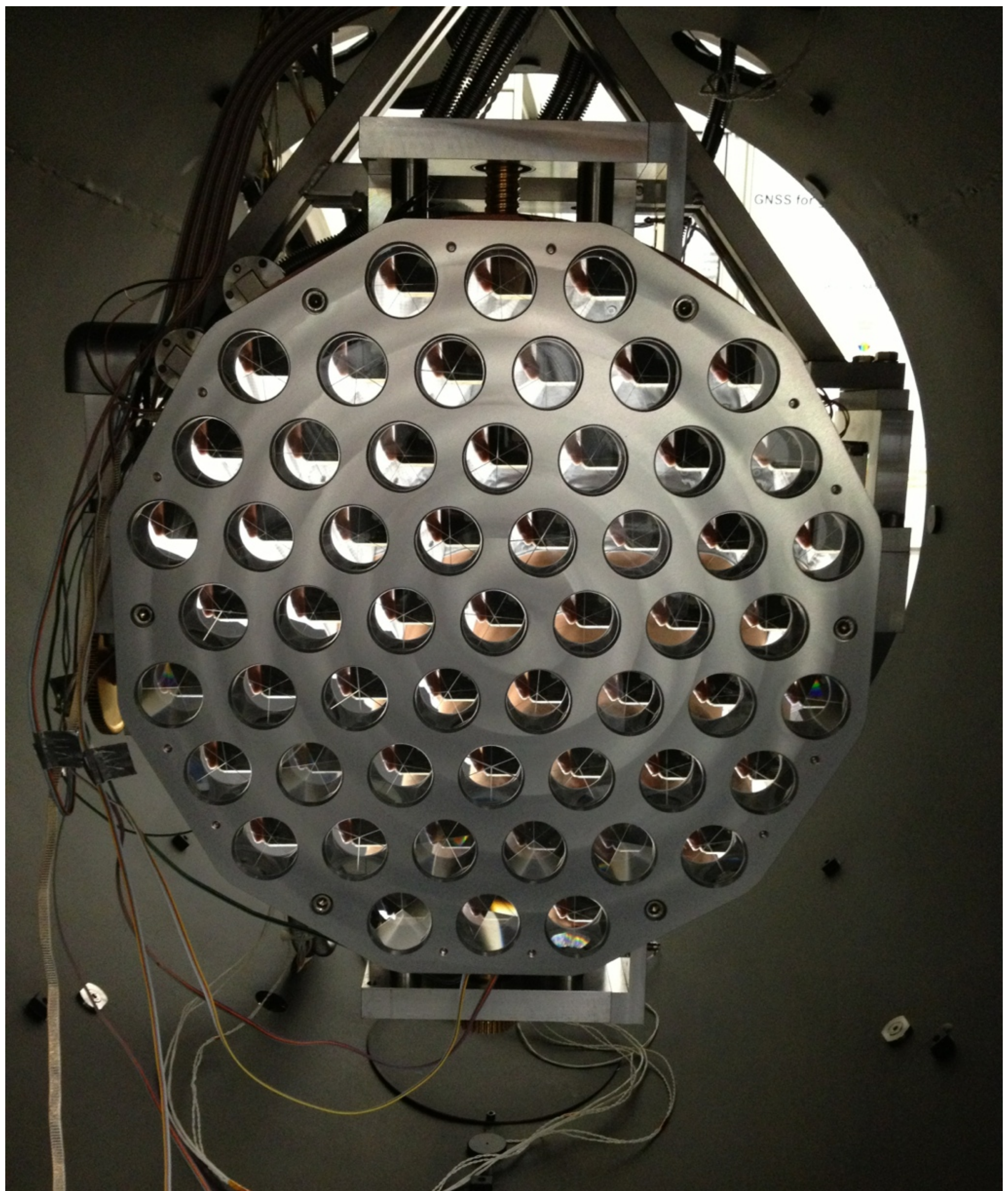
Optical Response



Optical circuit for FFDP measurement

Space characterization at the SCF_Lab

The purpose of the SCF_Lab measurements is to characterize the whole payload, retroreflectors and their supporting structure under realistic space conditions, in order to determine their compliance to design specification and variation of performance in space.



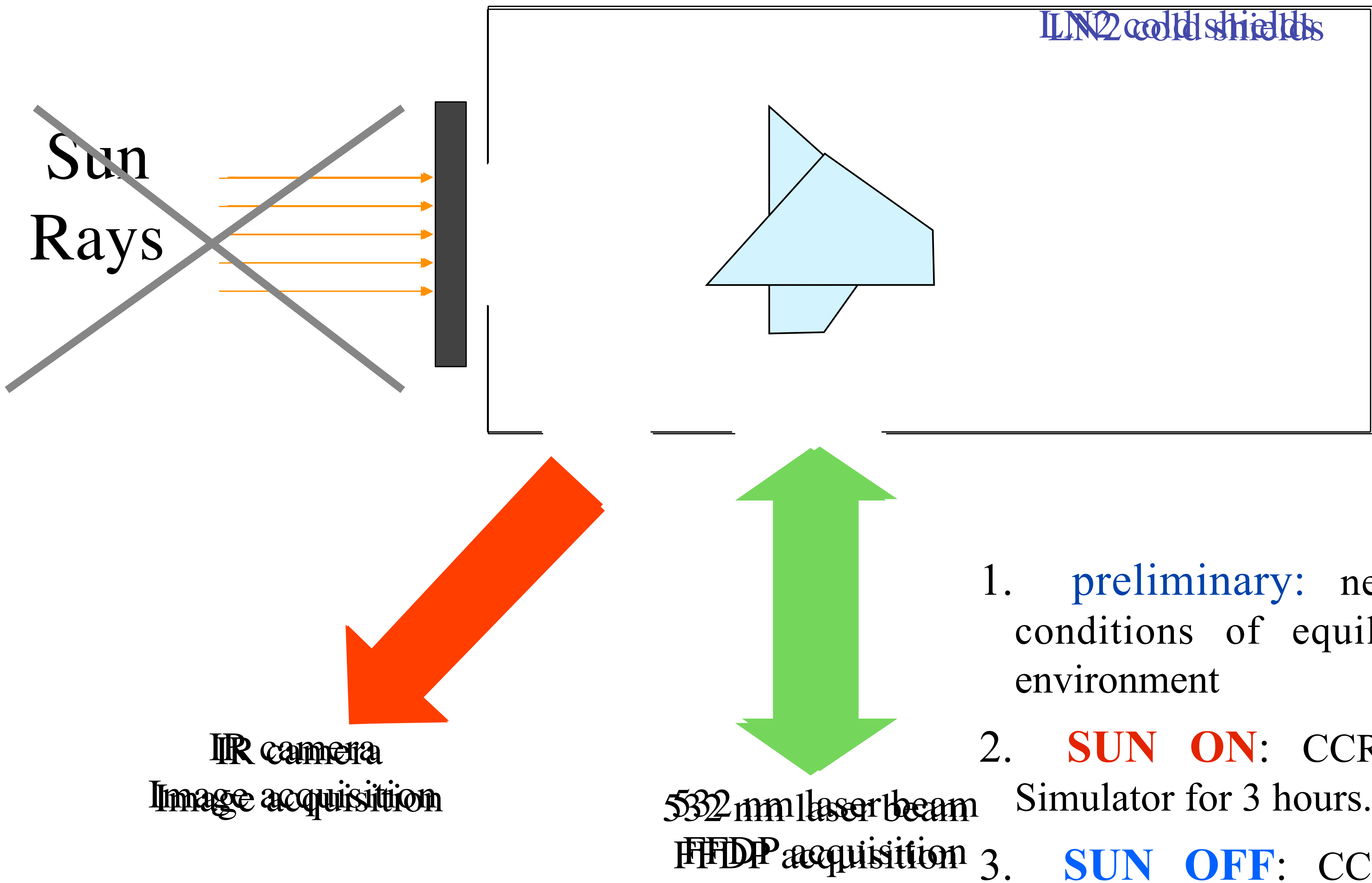
SCF_Lab measurements

- Far Field Diffraction Pattern (FFDP) measurement in Air of CCRs
- SCF-Test
- Simulated orbital measurement

S. Dell'Agnello, et al., **Creation of a New Industry-Standard Space Test of Laser Retroreflectors for GNSS and LAGEOS**, J. Adv. Space Res., DOI: 10.1016/jasr.2010.10.022

S. Dell'Agnello et al., **ETRUSCO2: an ASI-INFN project of technological development and SCF-Test of GNSS Retroreflector Arrays**, 3rd Int. Colloquium-Galileo Science, Copenhagen, Sept 2011

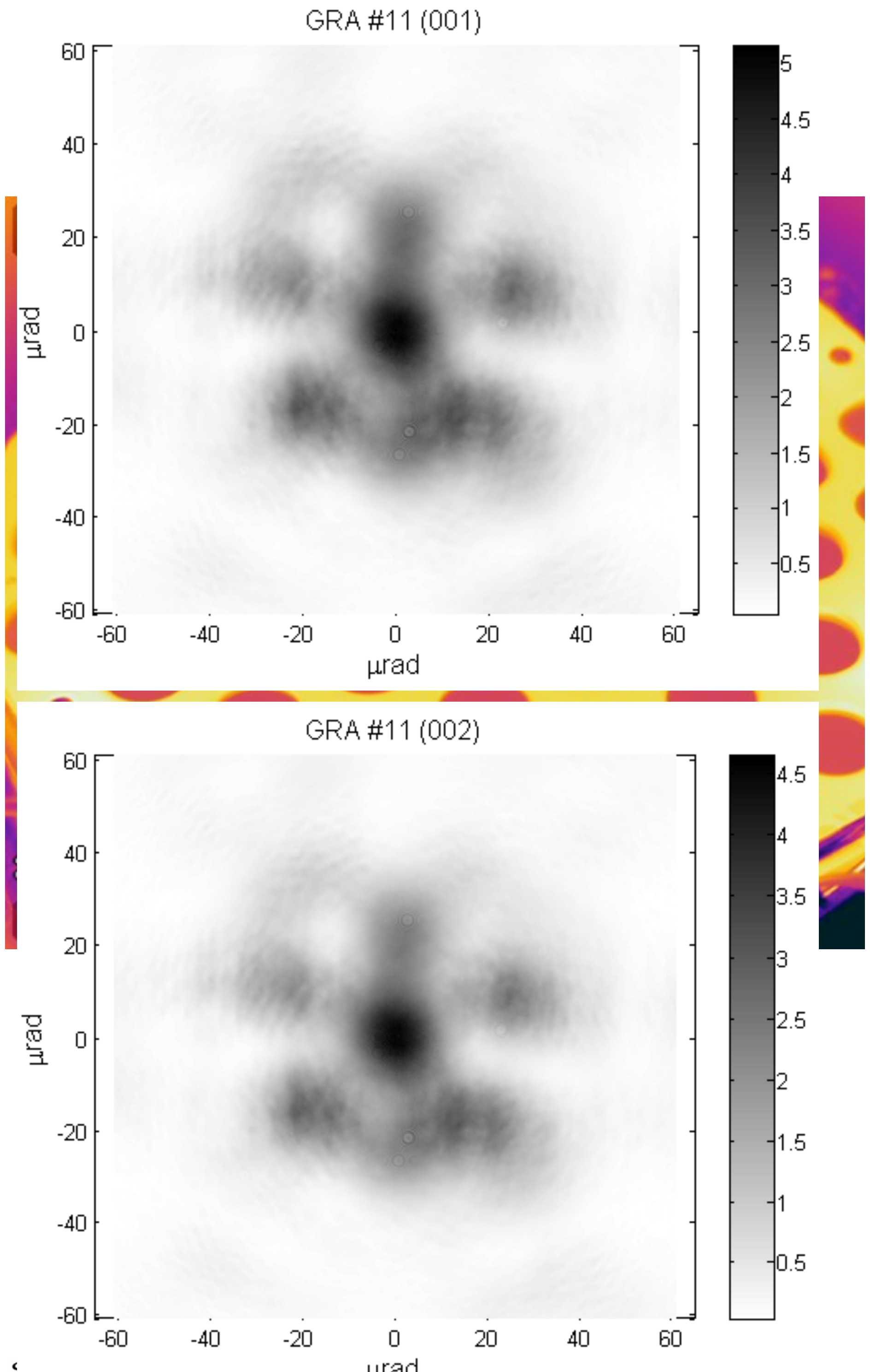
SCF-Test

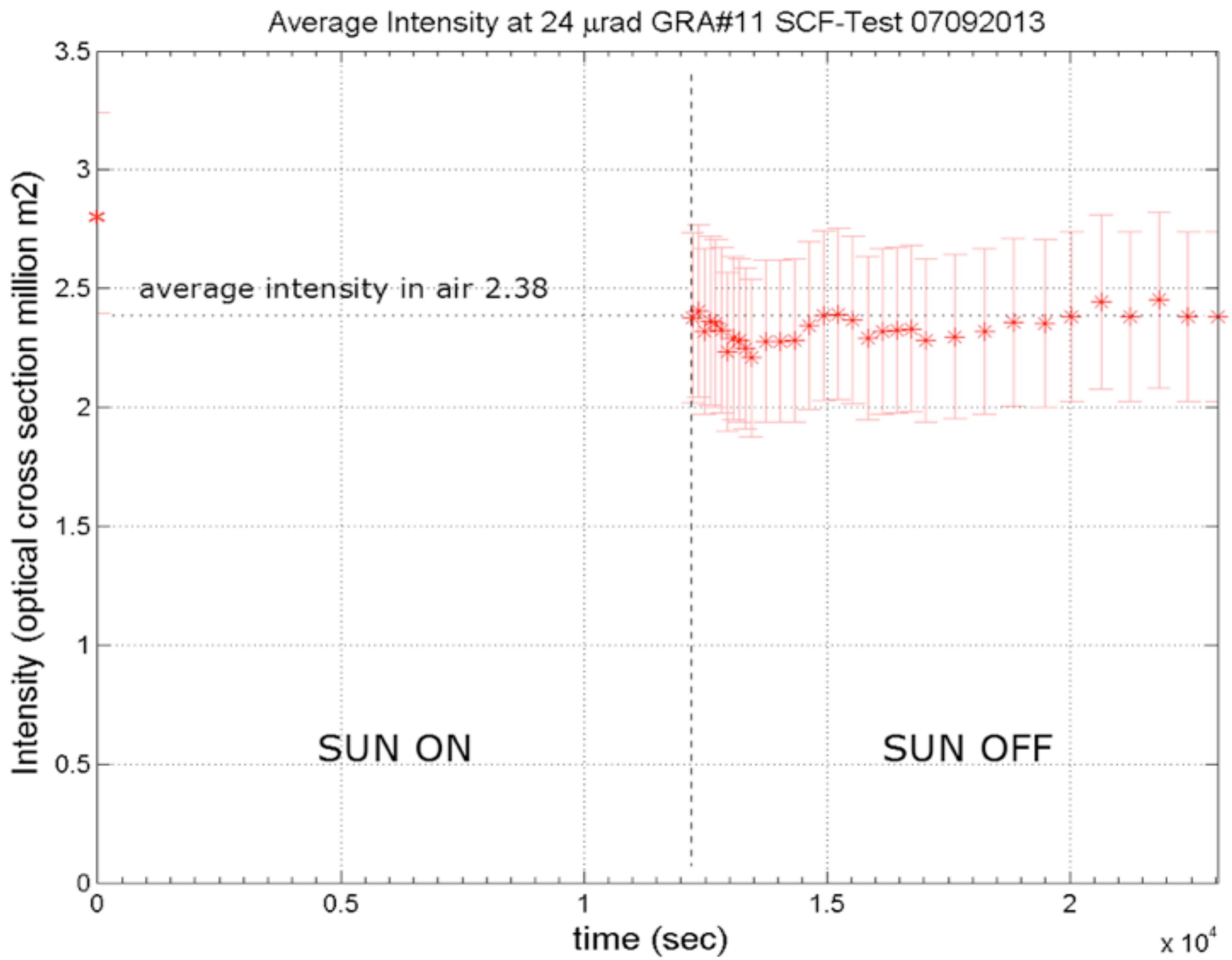


1. preliminary: necessary to achieve conditions of equilibrium with space environment
2. **SUN ON**: CCR in front of Solar Simulator for 3 hours. (IR measurements)
3. **SUN OFF**: CCR in front of laser window (IR and FFDP measurements)

SCF-Test deliverables

FFDP variation during SUN ON/SUN OFF phases
Thermal relaxation times of CCRs



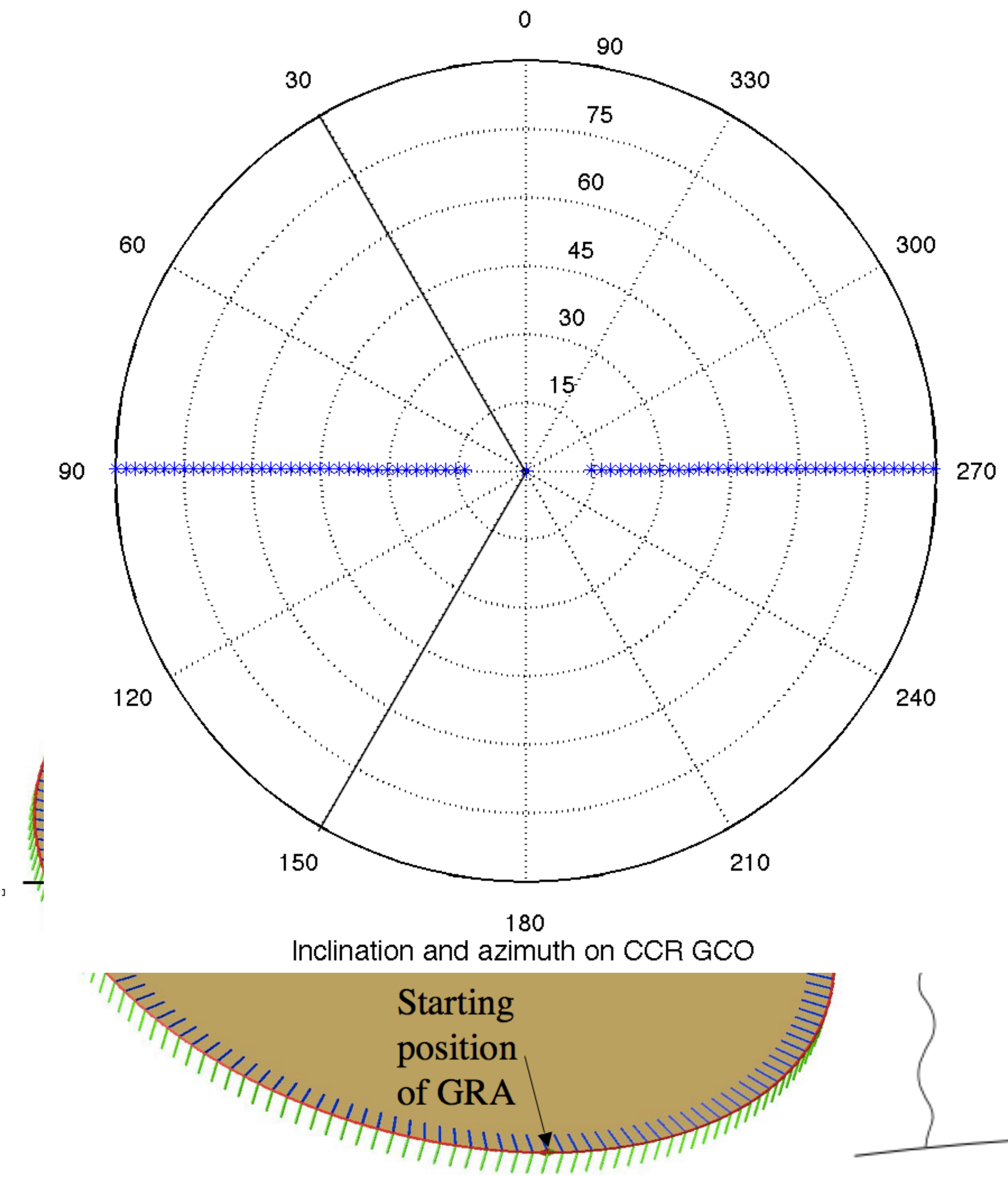


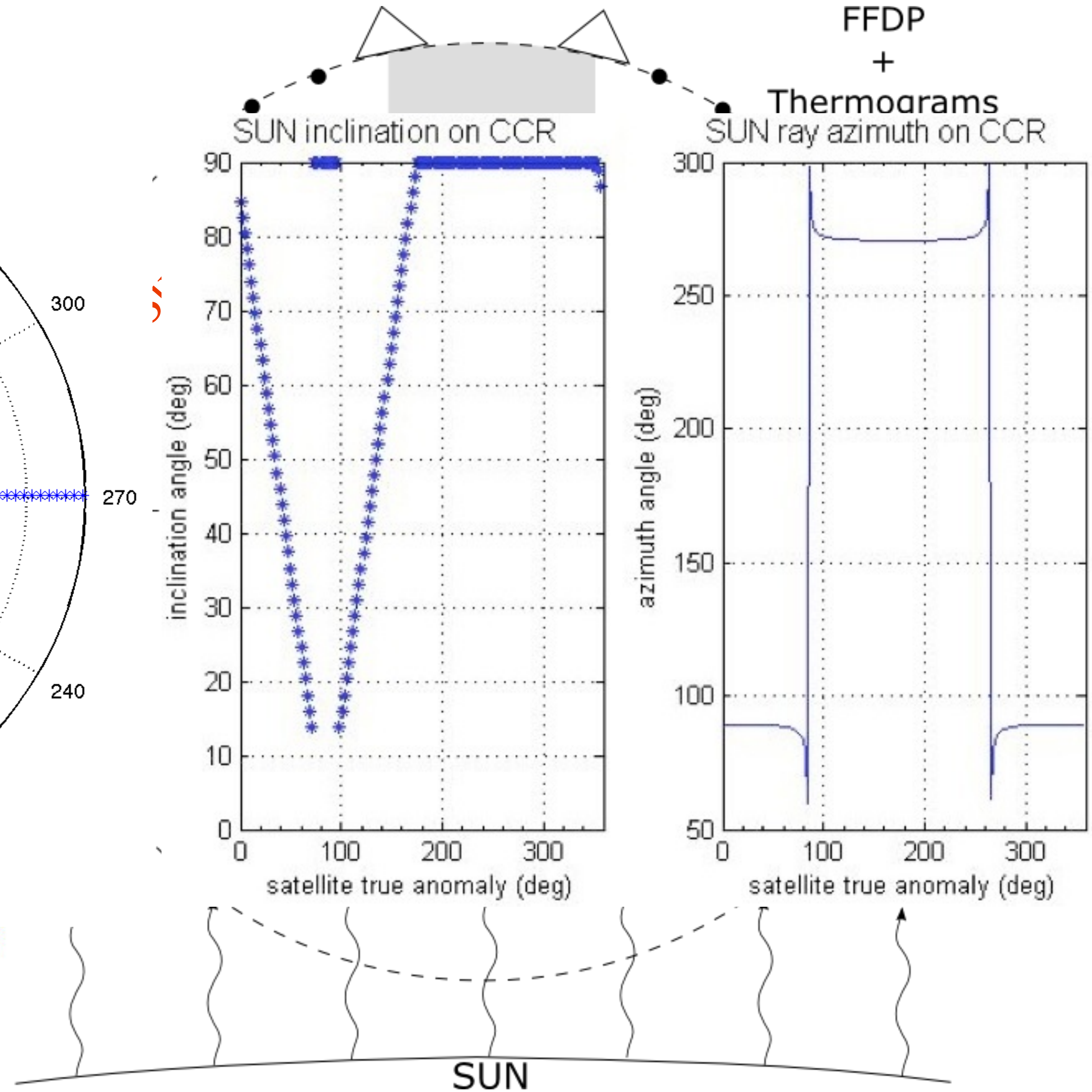
Optical Cross Section variation at the Galileo velocity aberration ~24μrad

GRA @ 300 K

Orbit Test

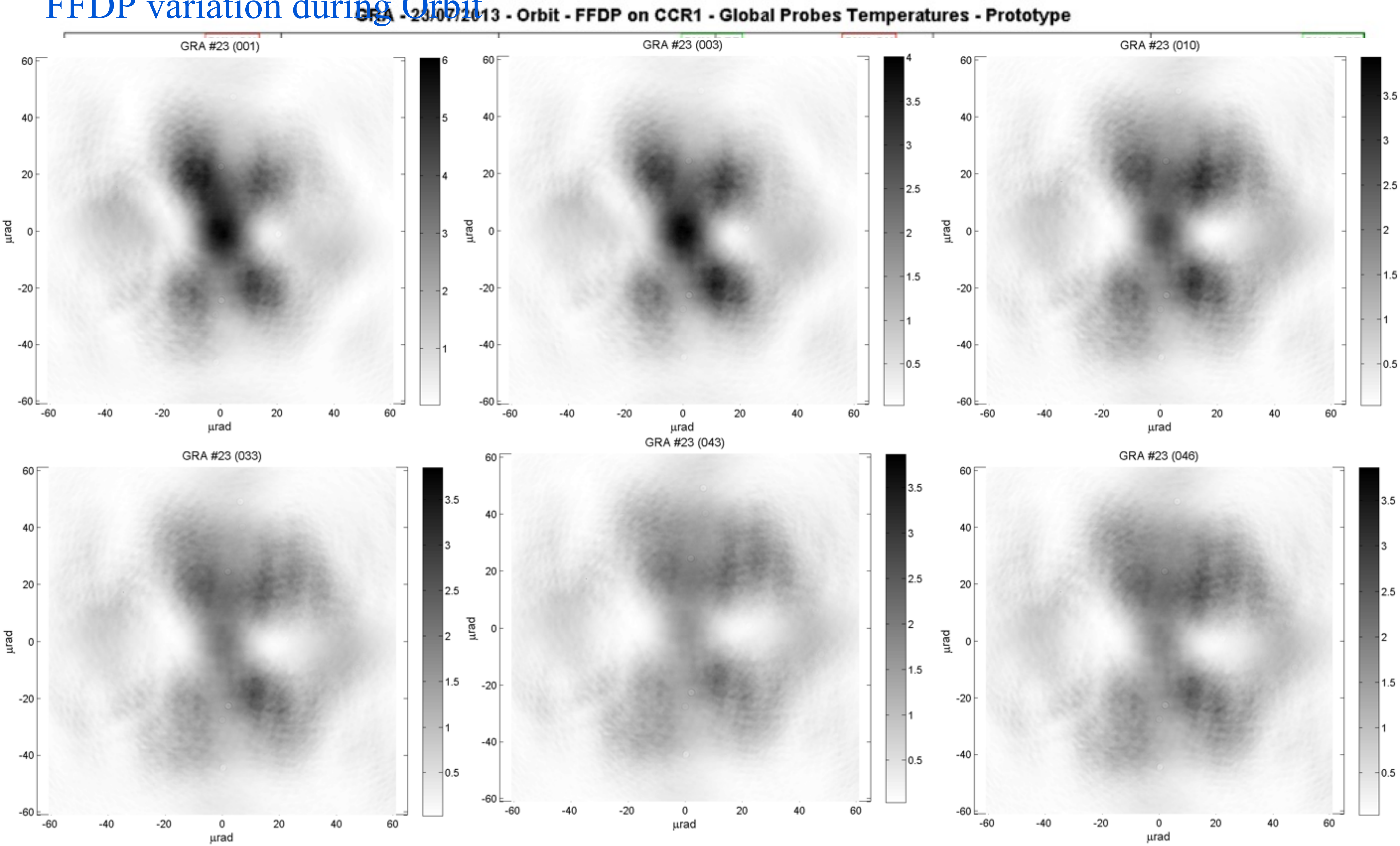
SCF-testing of GNSS Critical half-Orbit (**GCO**)





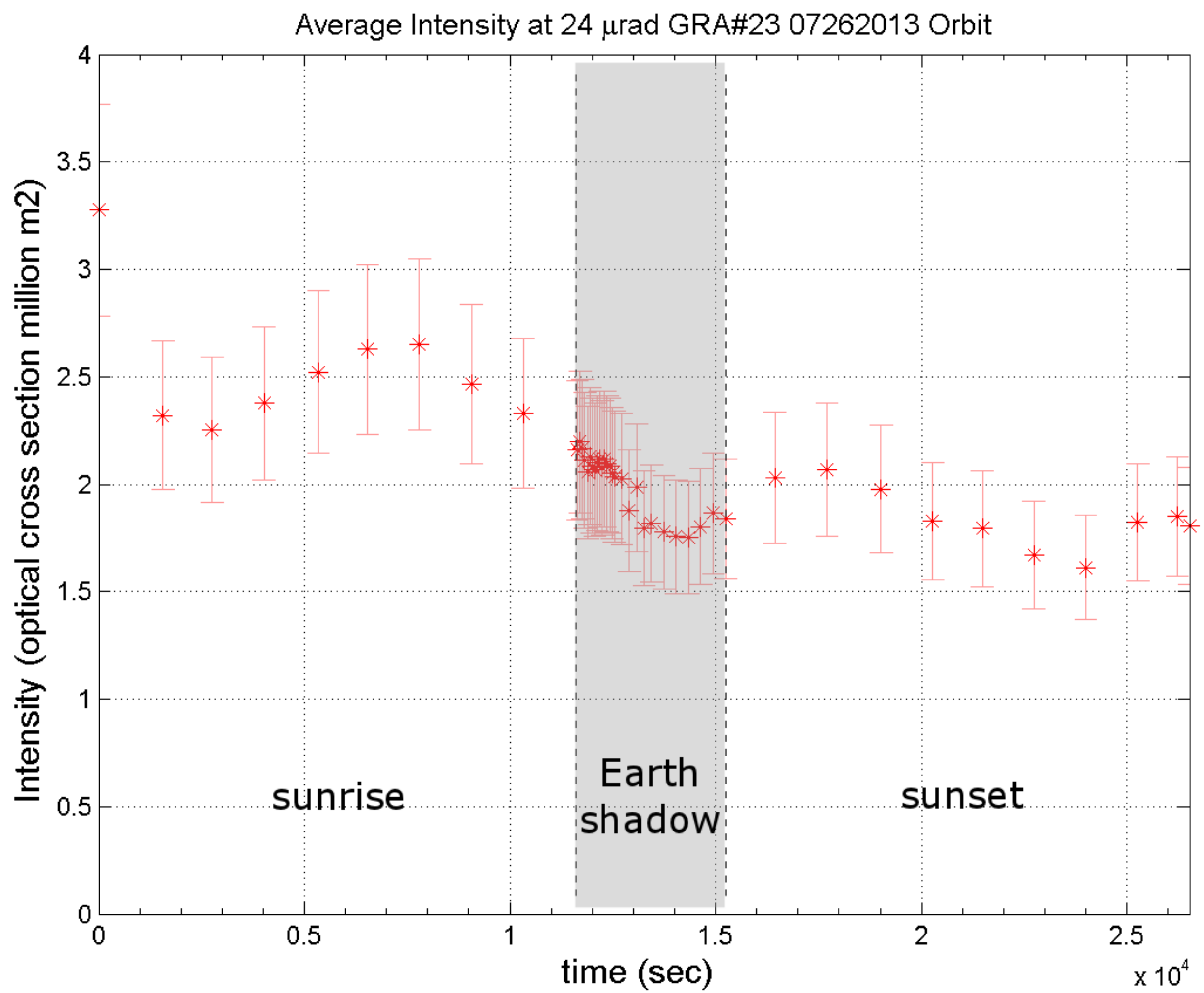
Orbit Test deliverables

FFDP variation during Orbit



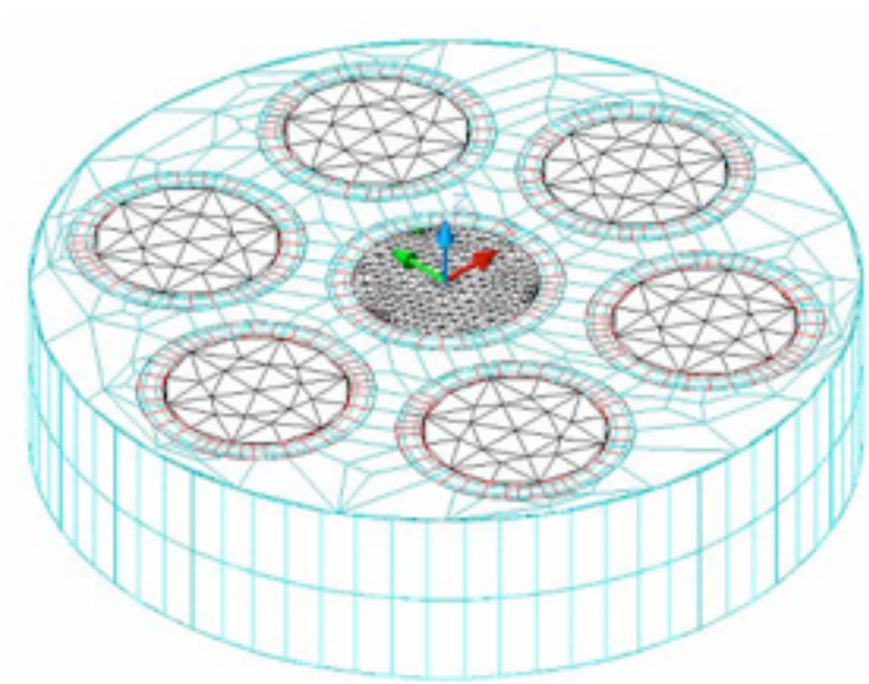
Orbit Test deliverables

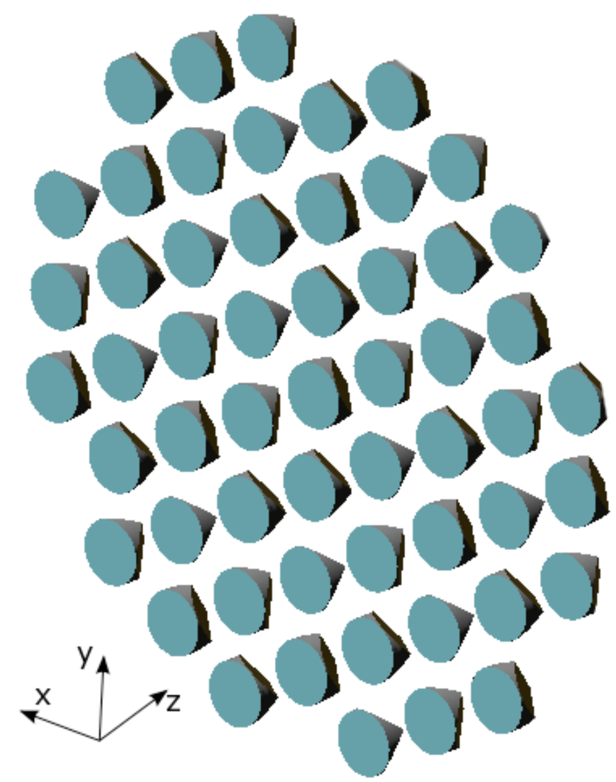
Optical Cross Section variation at the Velocity Aberration of the satellite



Retroreflector design and simulations

- Optical model of single retroreflectors and payloads
- Structural and thermal studies of retroreflector payloads
- Integrated thermal/optical simulations of retroreflector payloads in characteristic orbits.
- Fine tuning of simulated models with SCF_Lab measurements
- Mechanical drawing of designed payloads

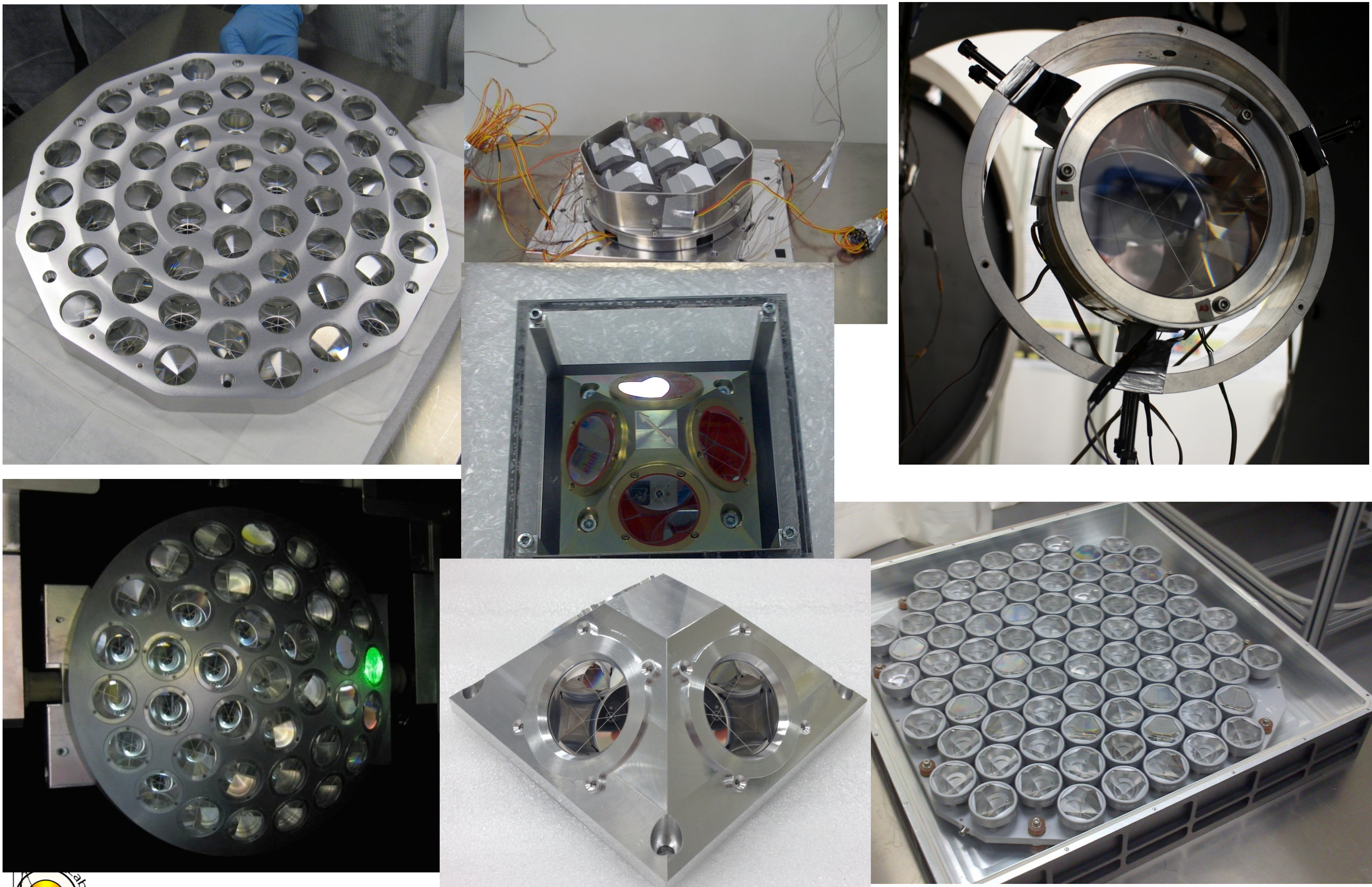




SCF_Lab projects

- Collaboration with NASA to characterize **LAGEOS** satellite CCRs.
- Characterized retroreflectors for ASI satellite LARES.
- Characterization of a **Galileo-IOV retroreflector** for ESA.
- **ETRUSCO-2** project for design and characterization of a retroreflector payload for the GNSS (GRA)
- Design and characterization of a retroreflector payload for the **next generation Lunar Laser Ranging**, in collaboration with University of Maryland.
- SCF_Lab measurements of current GNSS retroreflector payloads (**IRNSS** and **Galileo**).
- Design of payloads for next generation **Earth observation satellites**.
- Design of payloads for **laser altimetry** on solar system planets and moons (Mars and Moon)
- Affiliation with **NASA SSERVI Institute** for Solar System Exploration

SCF_Lab projects



Thank you for your attention!

SCF_Lab website: http://www.lnf.infn.it/esperimenti/etrusco/