SCF_Lab

Satellite/Lunar/GNSS
laser ranging and altimetry
Characterization **F**acilities **Lab**oratory

SCF_Lab: Applications to Galileo

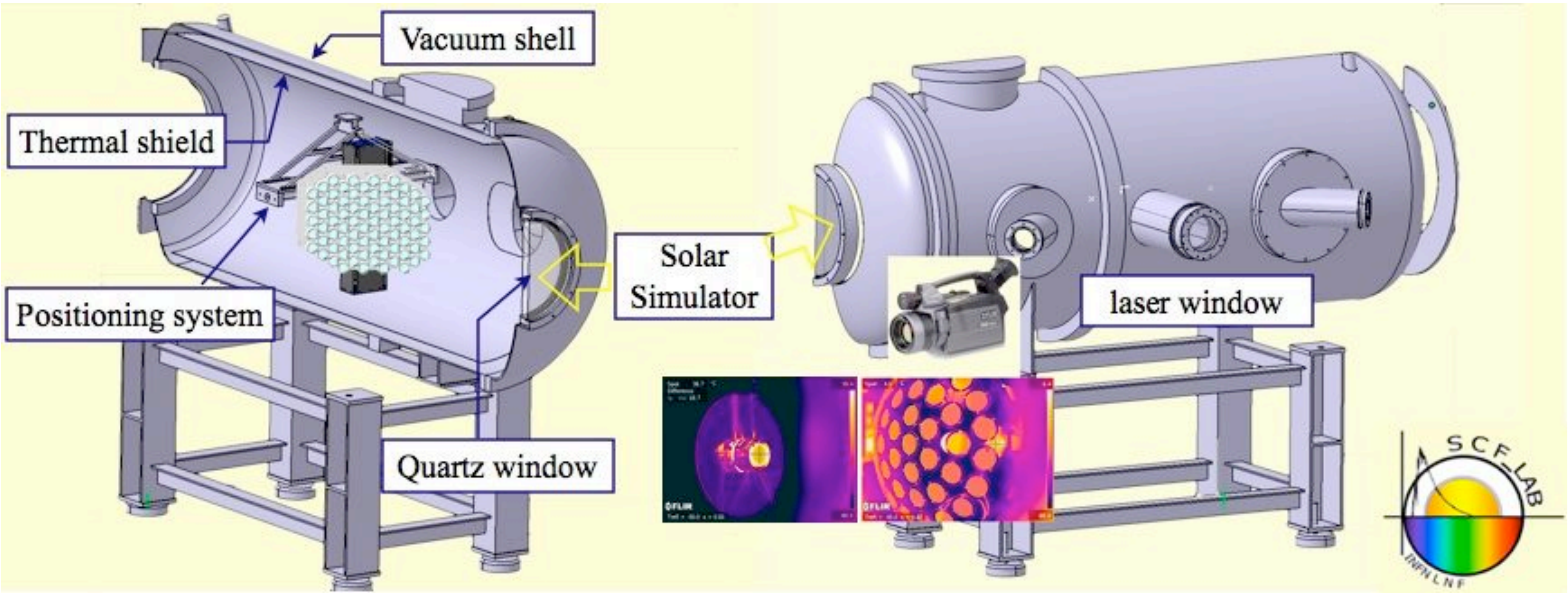
Luca Porcelli
on behalf of **SCF_Lab Group @ INFN-LNF**
www.lnf.infn.it/esperimenti/etrusco

LTL 2014 - 16-19/06/2014

The SCF_Lab

The SCF_Lab and its innovative activity

SCF and SCF-G

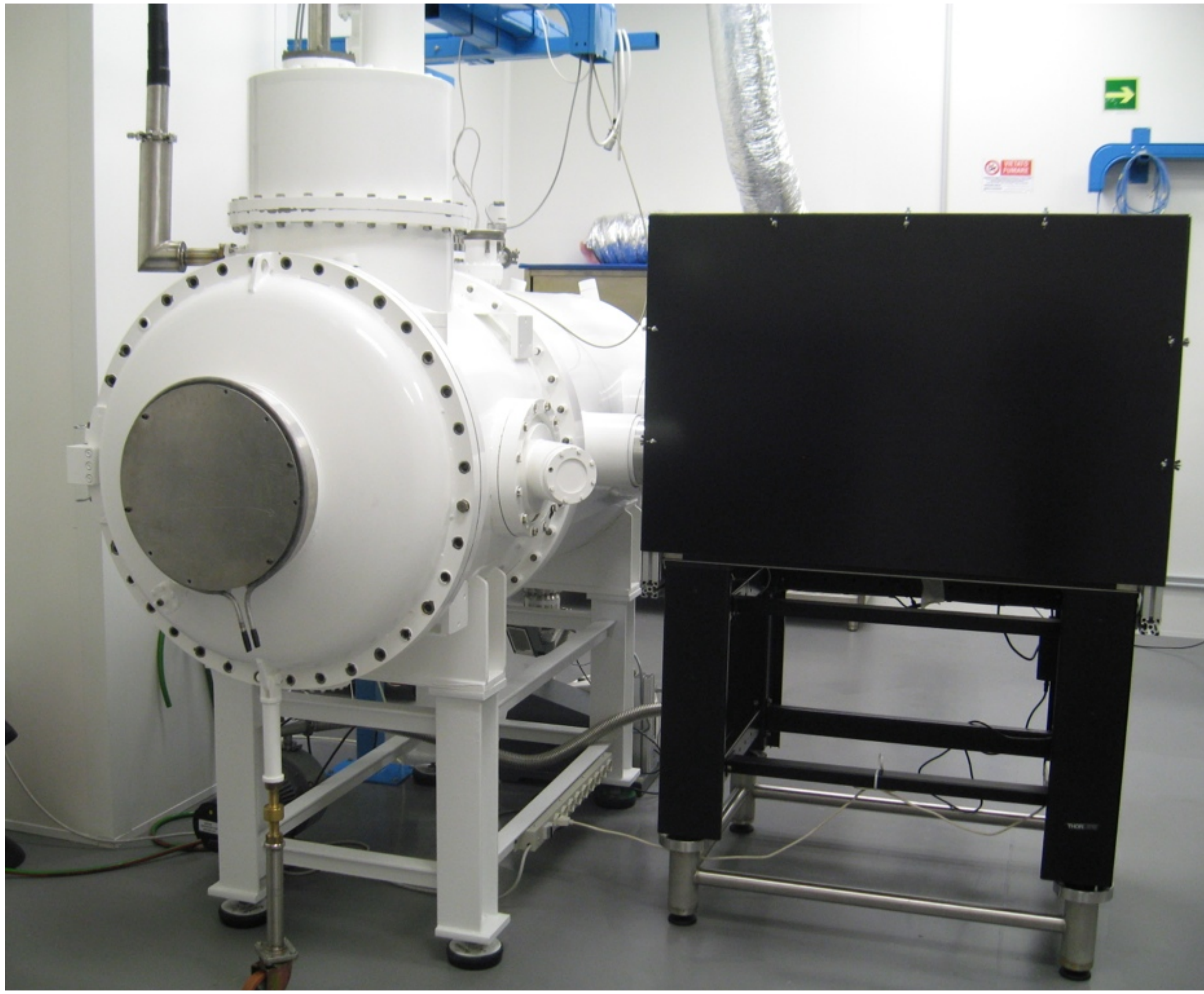


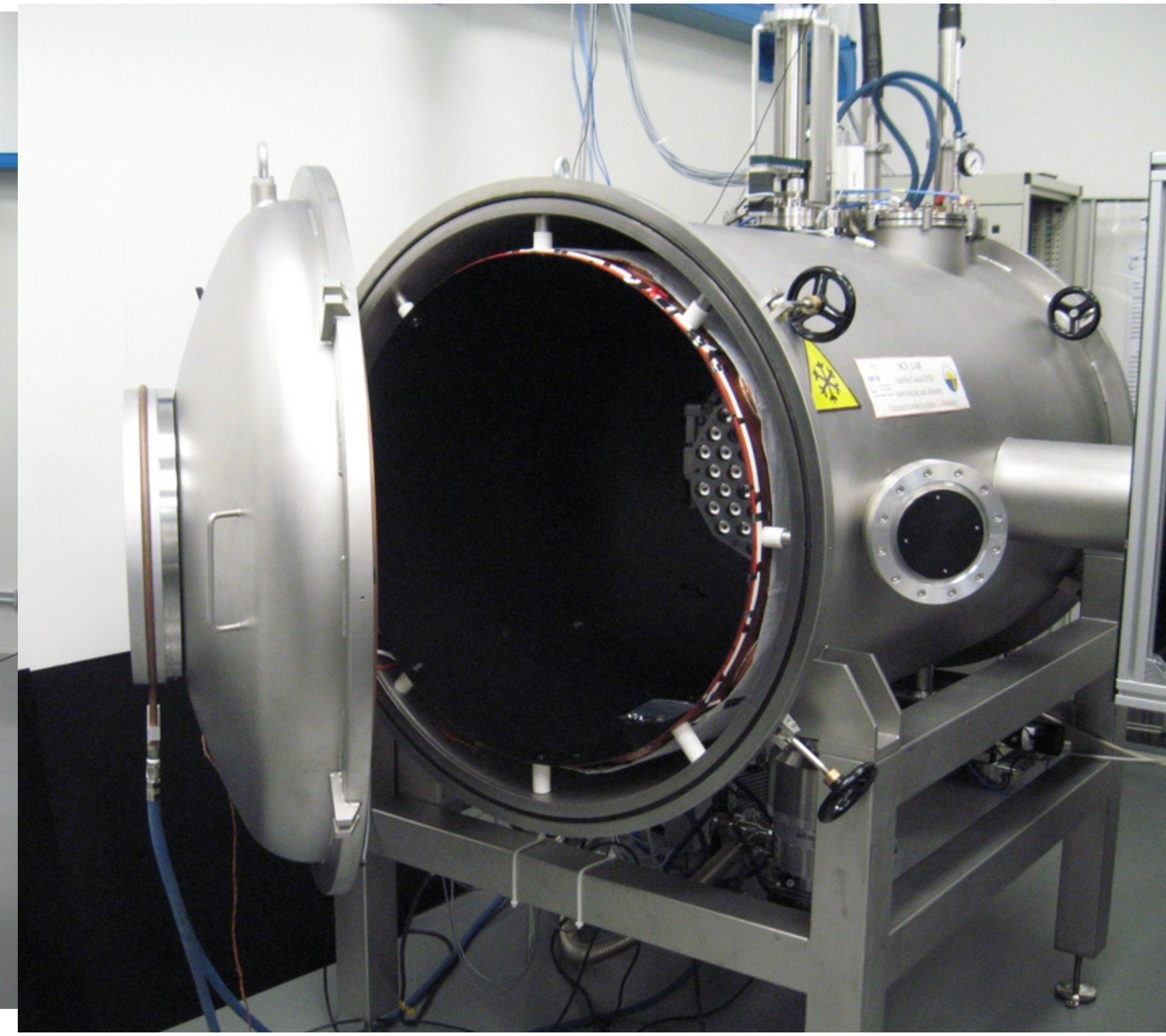
Vacuum + Cold + Sun = Space (at 1 AU from the Sun)

- Cryostat (environment pressure down to ~ 10^{-7} mbar, temperature of the chamber at ~ 80 K, high emissivity cold shield).
- AM0 Solar Simulator.
- FFDP optical table.
- Vacuum pump system, control electronics and computers.

SCF and SCF-G

SCF ***SCF-G***





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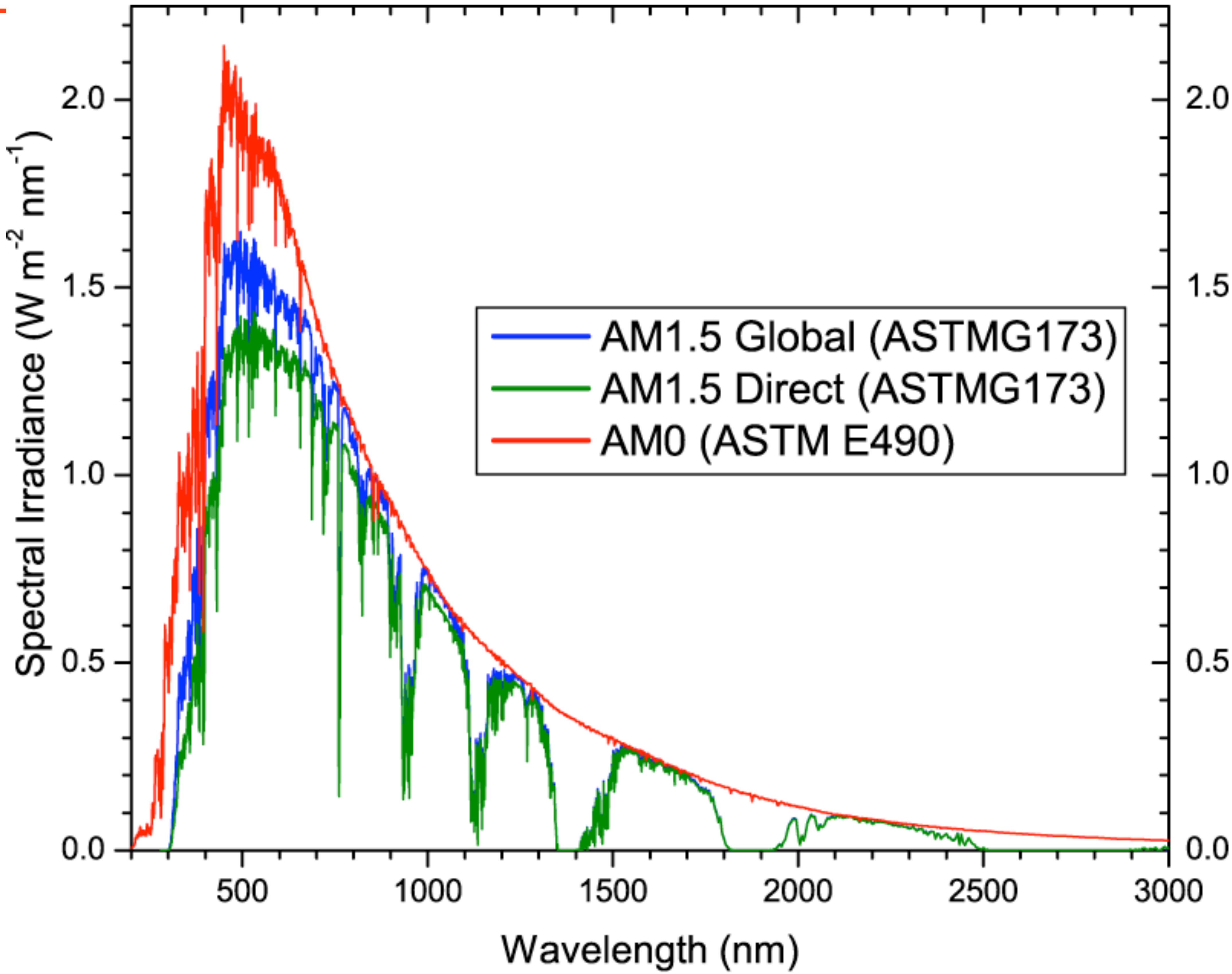
Solar Simulators @ SCF_Lab



www.astm.org/Standards/E490.htm (for AM0) and www.astm.org/Standards/G173.htm (for AM1.5)

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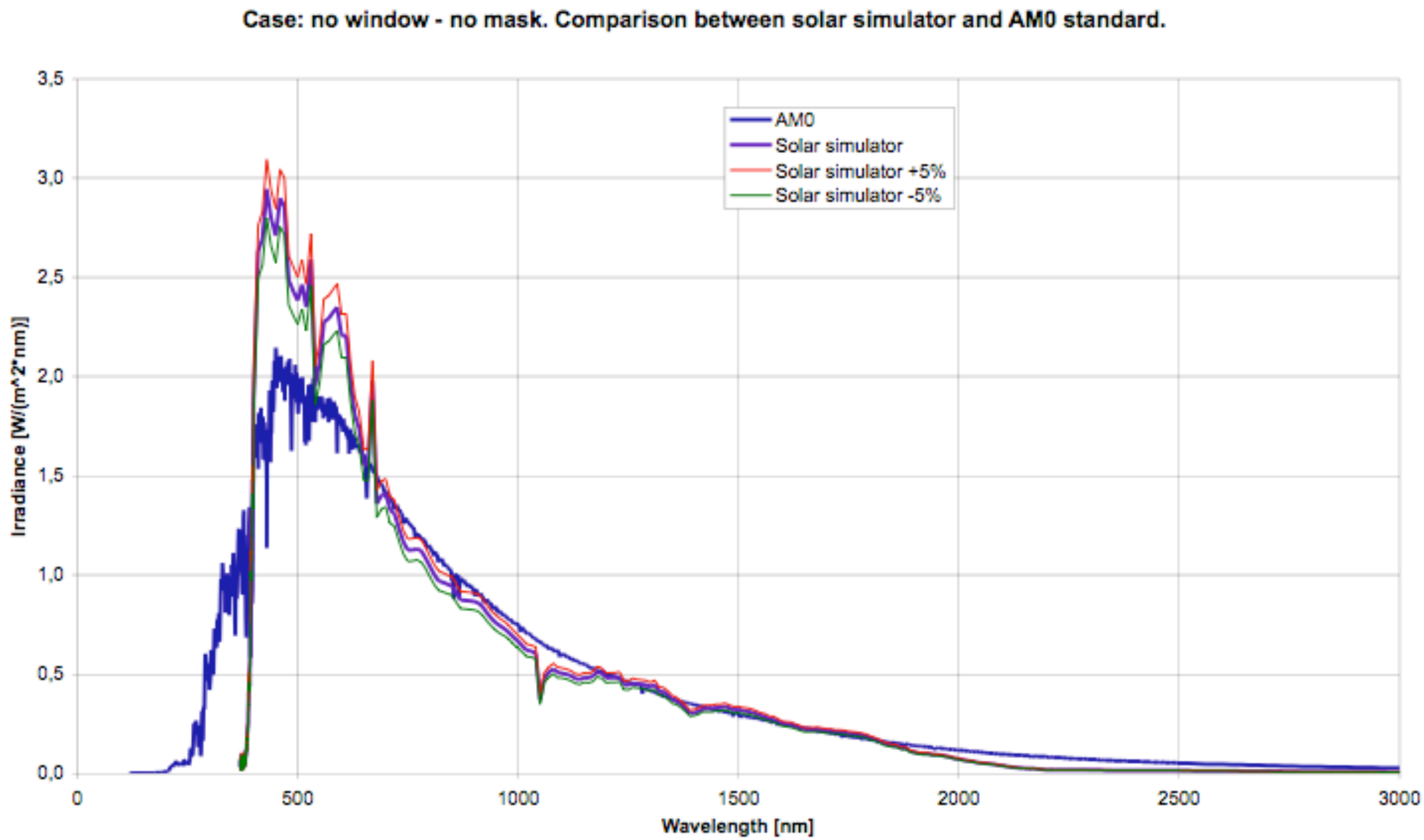

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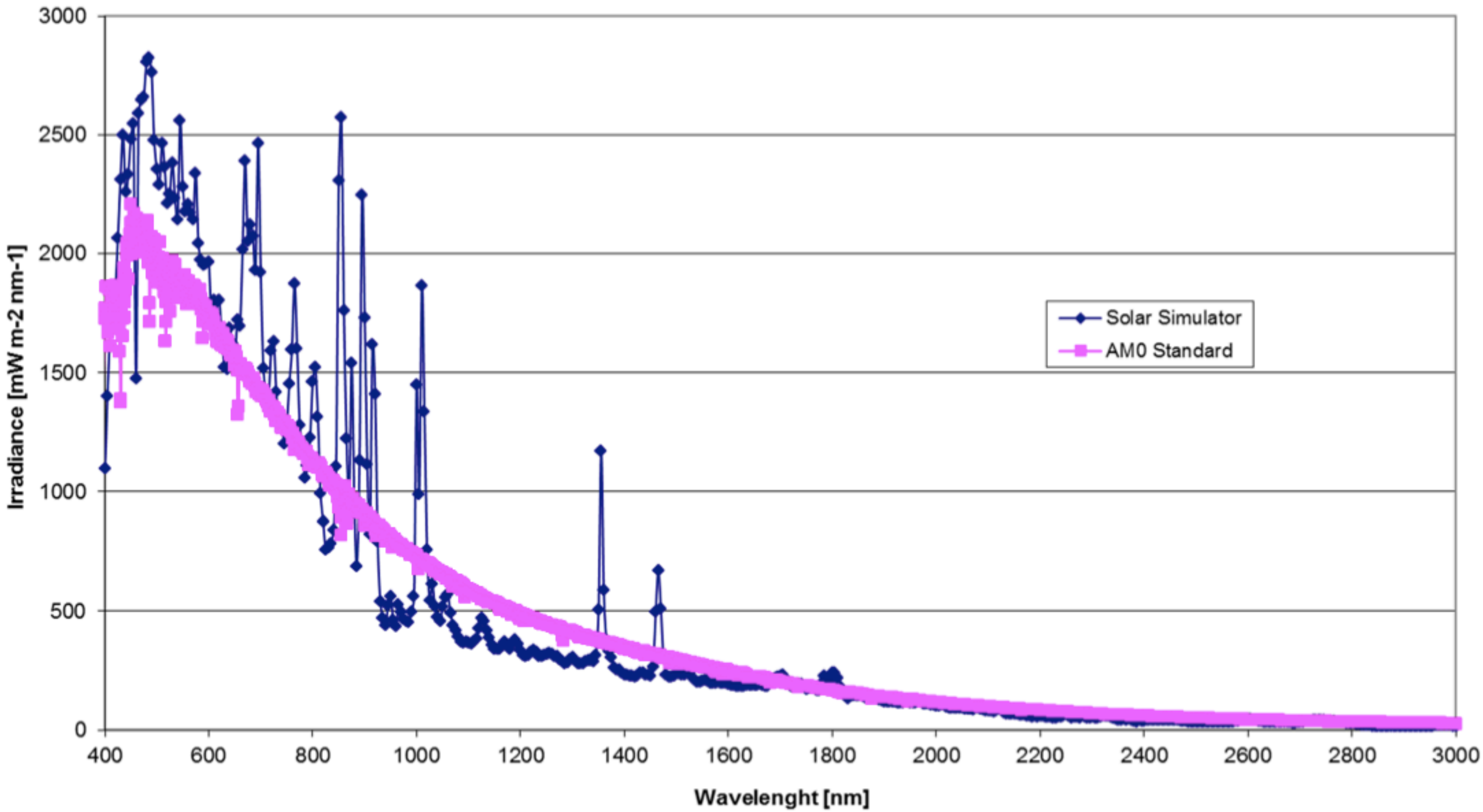

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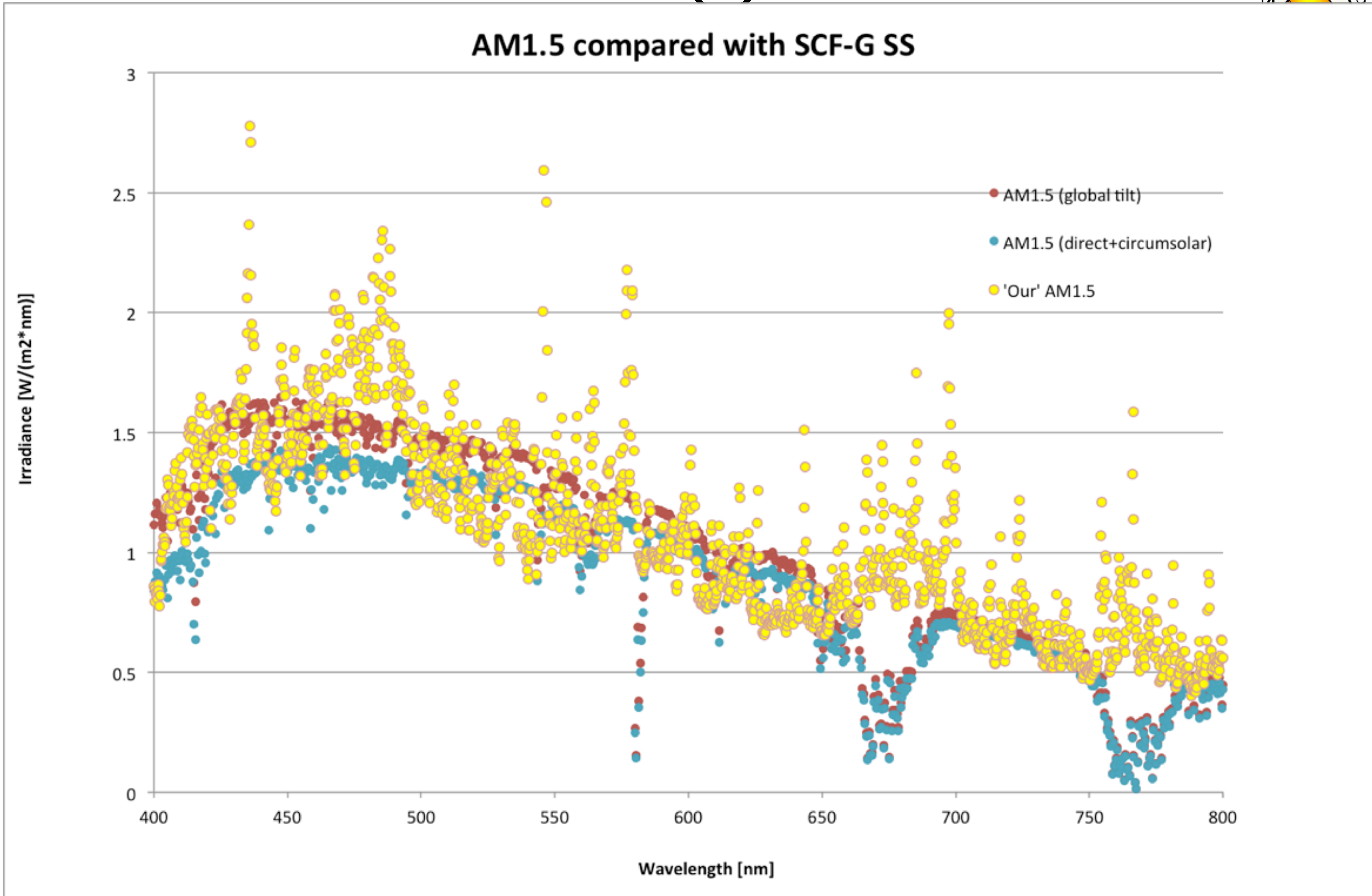

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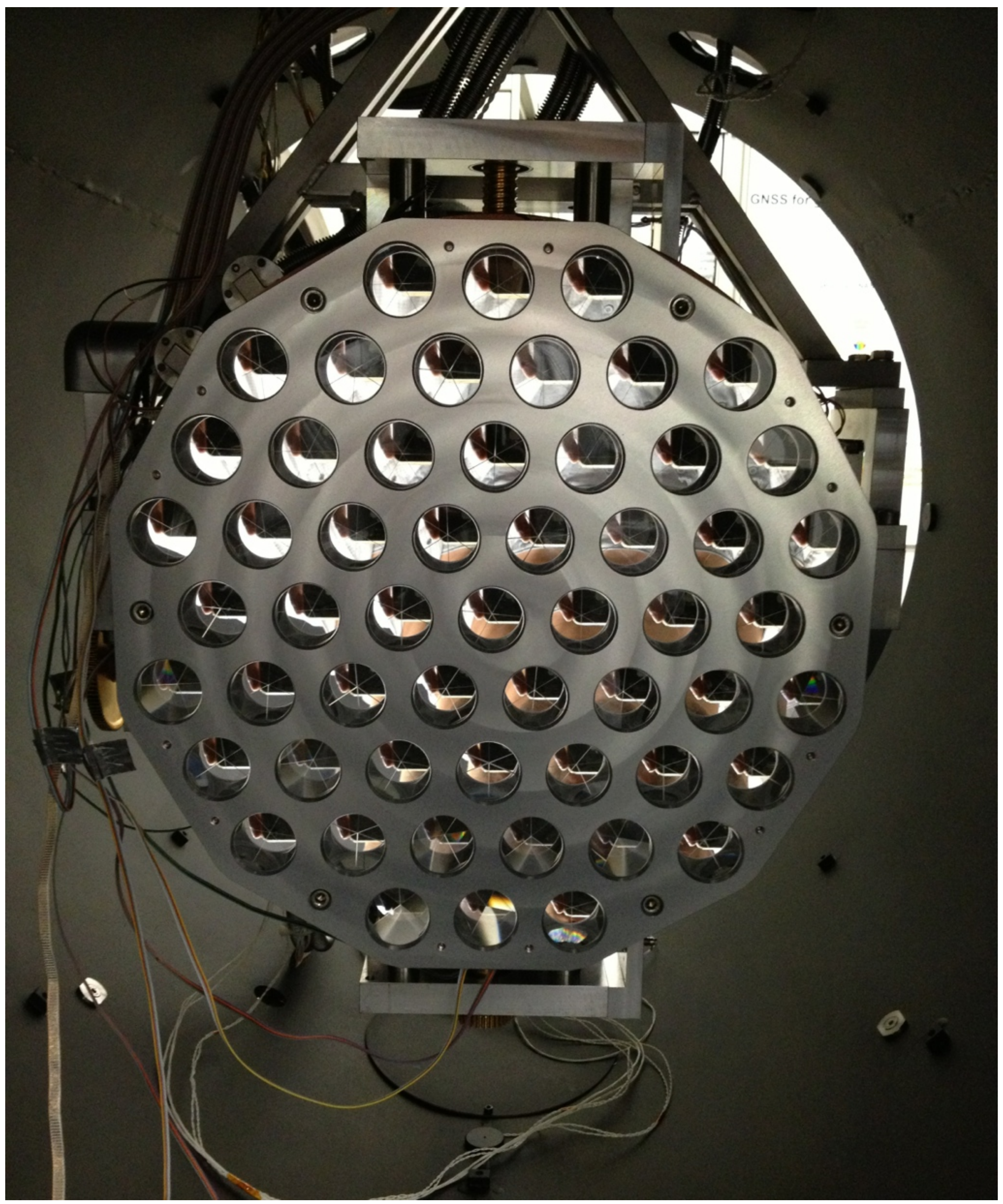
Space characterization at the SCF_Lab

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 of CCRs.
- SCF-Test = Integrated thermo-optic characterization of laser retroreflector (arrays) prototypes before eventual space launch.
- Orbit Test = Simulated orbital measurement.

Comprehensive literature available online at www.lnf.infn.it/esperimenti/etrusco

Galileo: European Union GNSS

Galileo: EU Flagship Programme

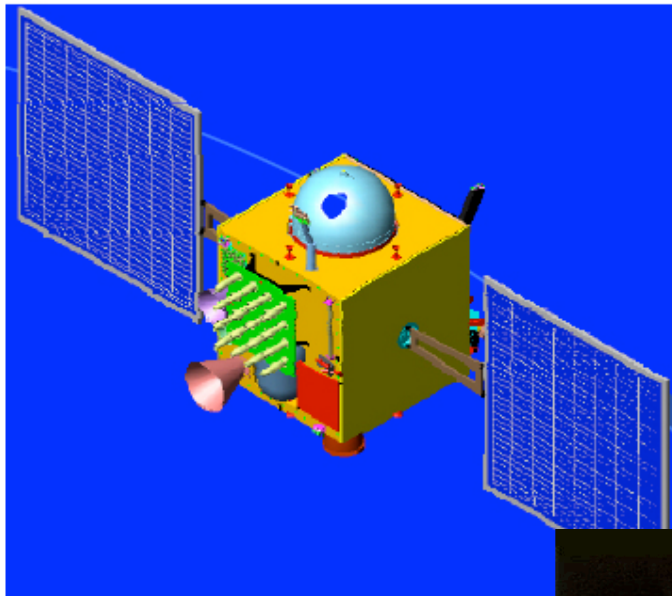
- 30 satellites (27 operational, 3 spares)
- 3 orbital planes (inclination ~ 56˚ w.r.t. the Equator)
- height ~ 23,222 km (MEO)
- orbital period ~ 14 hr
- mass ~ 700 kg
- available power ~ 1420 W (with Sun), 1355 W (w/o Sun)
- lifetime ~ 12 yr (least)
- interoperable with GPS/GLONASS

- 4 to 8 satellites visible from most locations (up/down to +/-75˚ latitude N/S - North Cape latitude)

- everything coordinated by widespread dedicated Ground Segment
- worth ~ 800 G€ per year for EU business

www.gsa.europa.eu

The other stakeholders...



Indian IRNSS:

7 regional satellites,

GEO orbits

Japanese QZSS:

3 regional satellites,

GPS enhancement for Japan

American GPS:

24 global satellites

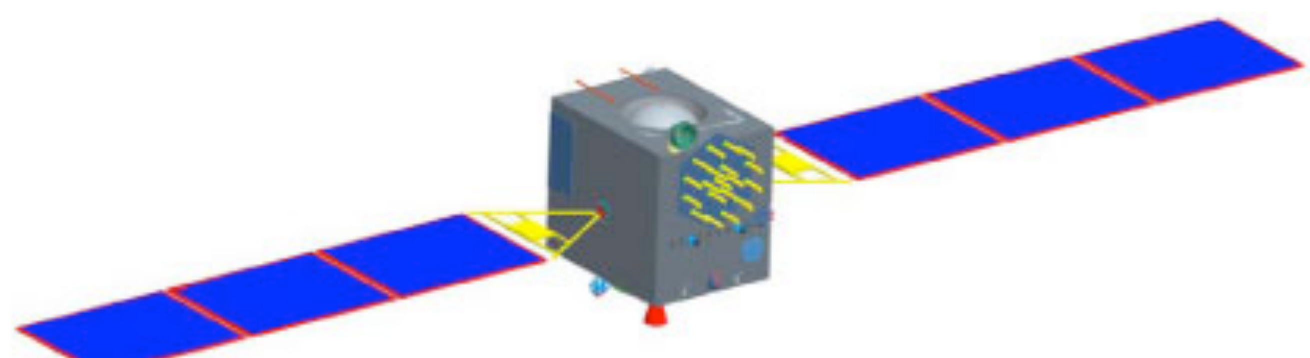
Chinese Compass:

5 regional satellites,

30 global satellites

Russian GLONASS:

30 global satellites



Galileo: EU Flagship Programme

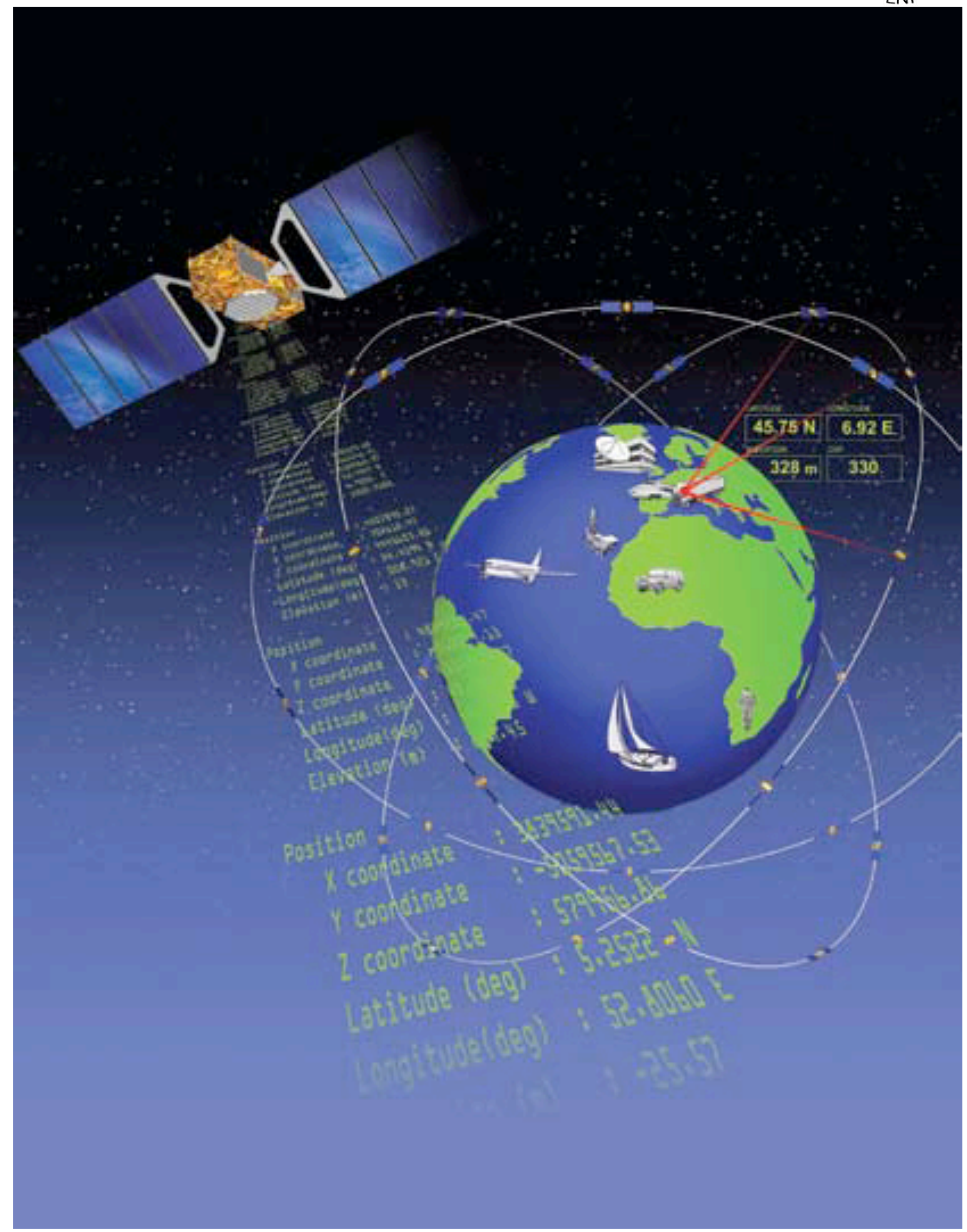
- **Open Service:** the Galileo navigation signal will be accessible by the general public free of charge, providing improved global positioning. It's the only open GNSS!!!

- **Public Regulated Service:** two encrypted signals with controlled access for specific users such as governmental bodies.

- **Search & Rescue Service:** Galileo will contribute to the international Cospas–Sarsat system for search and rescue. A distress signal will be relayed to the Rescue Coordination Centre and Galileo will inform the user that their situation has been detected.

- **Safety-of-Life Service:** standard already available for aviation (ICAO standard) thanks to EGNOS, Galileo will further improve the service performance.

- **Commercial Service:** Galileo will provide a signal for high data throughput and highly accurate authenticated data (time synchronization), particularly interesting for professional users.



Pre-Galileo GIOVE satellites

GIOVE-A is the first GIOVE (Galileo In-Orbit Validation) test satellite. It was successfully launched on 28 December 2005 and served as a benchmark for radio transmissions.

GIOVE-B is the second GIOVE test satellite. It was successfully launched on 27 April 2008 and, together with A, was used to set up and assess future Galileo capabilities and network of ground stations.

www.gsc-europa.eu

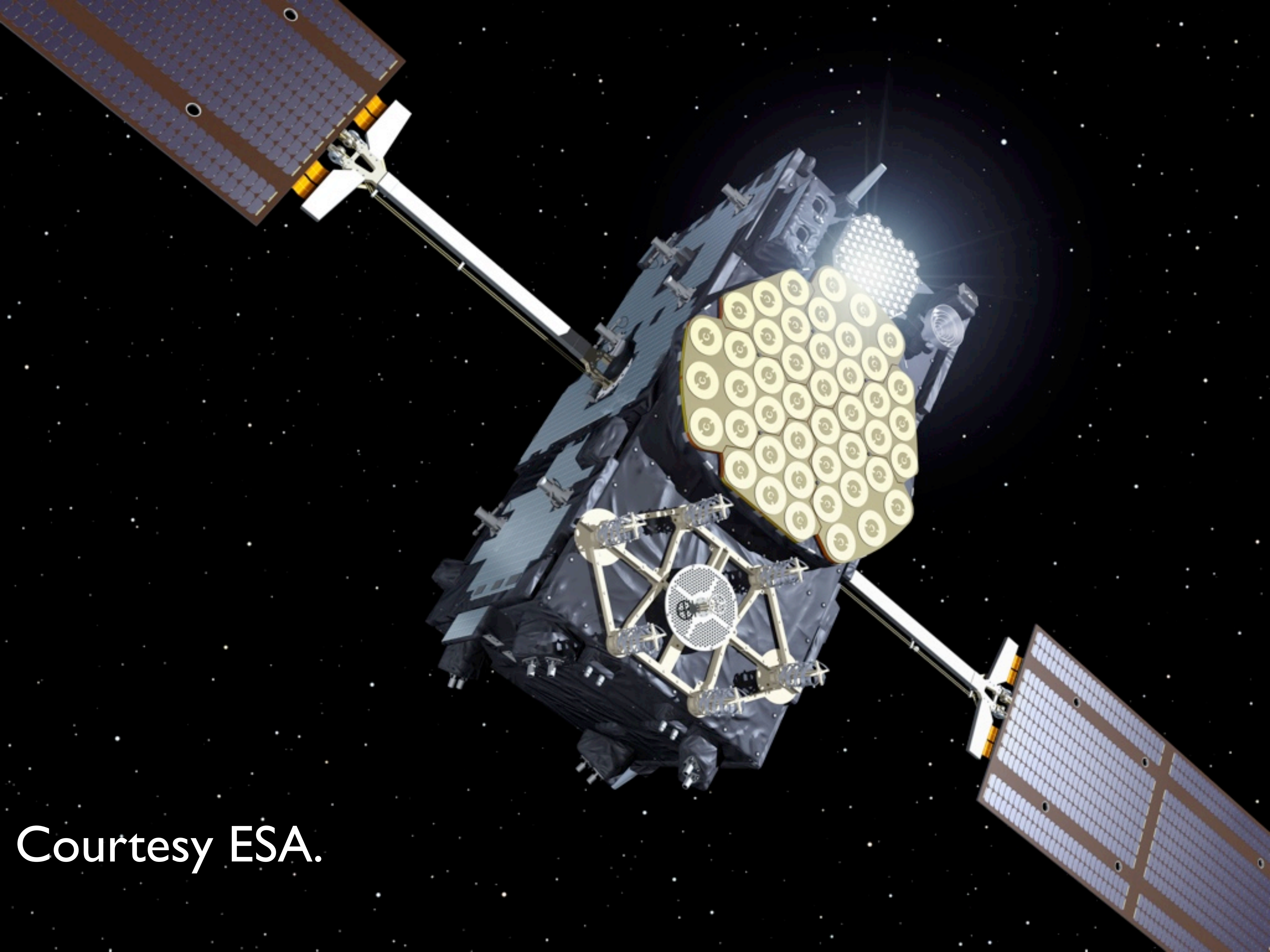
Galileo: EU Flagship Programme

IOV Satellites

IOV (In-Orbit Validation) satellites were launched on 21 October 2011 (GSAT0101 and GSAT0102) and on 12 October 2012 (GSAT0103 and GSAT0104). They much closely match the final design and characteristics of the Galileo FOC (Full Operational Capability) satellite series (except for Search&Rescue feature).

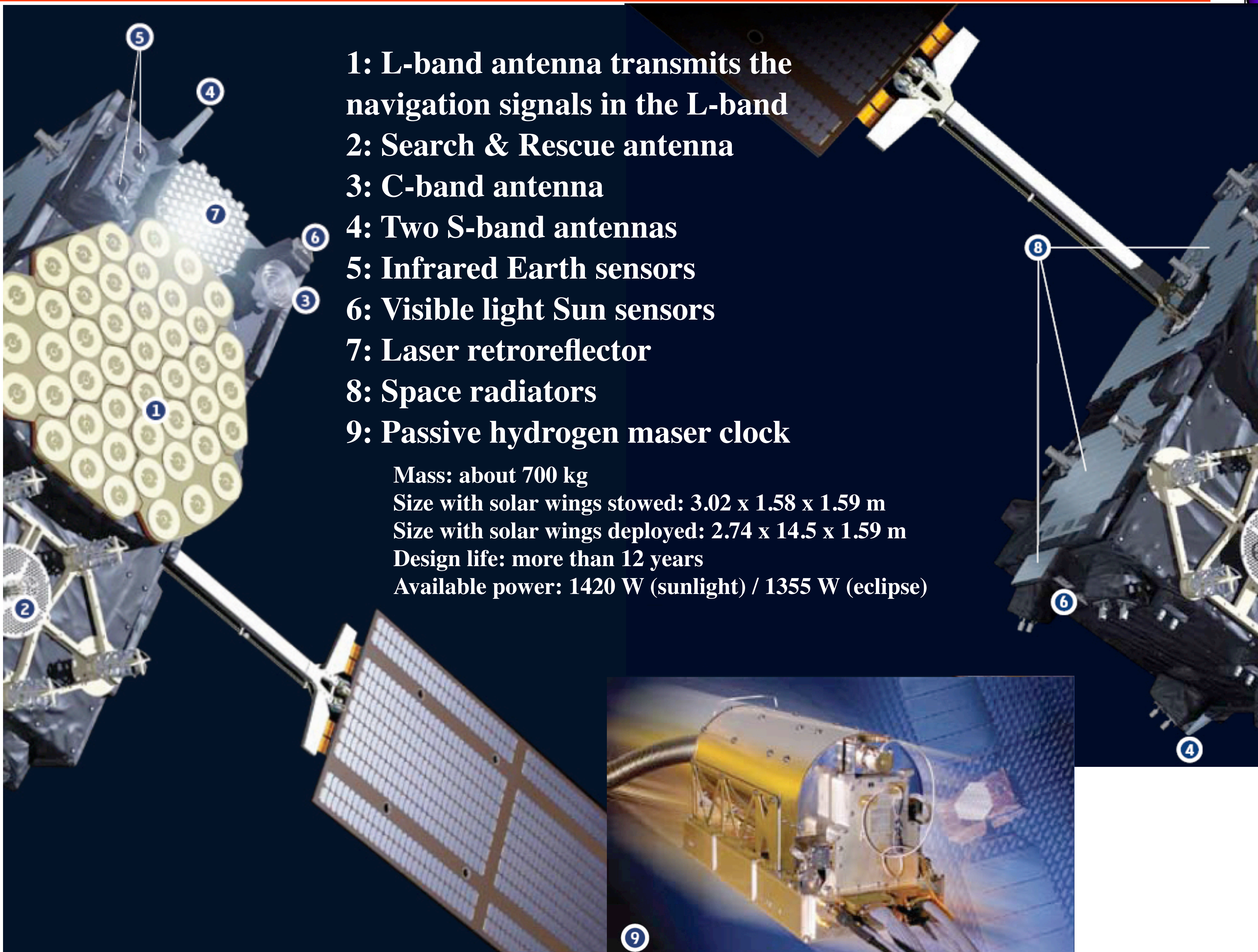
“This first position fix of longitude, latitude and altitude took place at the Navigation Laboratory at ESA’s technical heart ESTEC, in Noordwijk, the Netherlands on the morning of 12 March [2013], with an accuracy between 10 and 15 metres - which is expected taking into account the limited infrastructure deployed so far” (www.esa.int/Our_Activities/Navigation/Galileo_fixes_Europe_s_position_in_history).

www.gsc-europa.eu



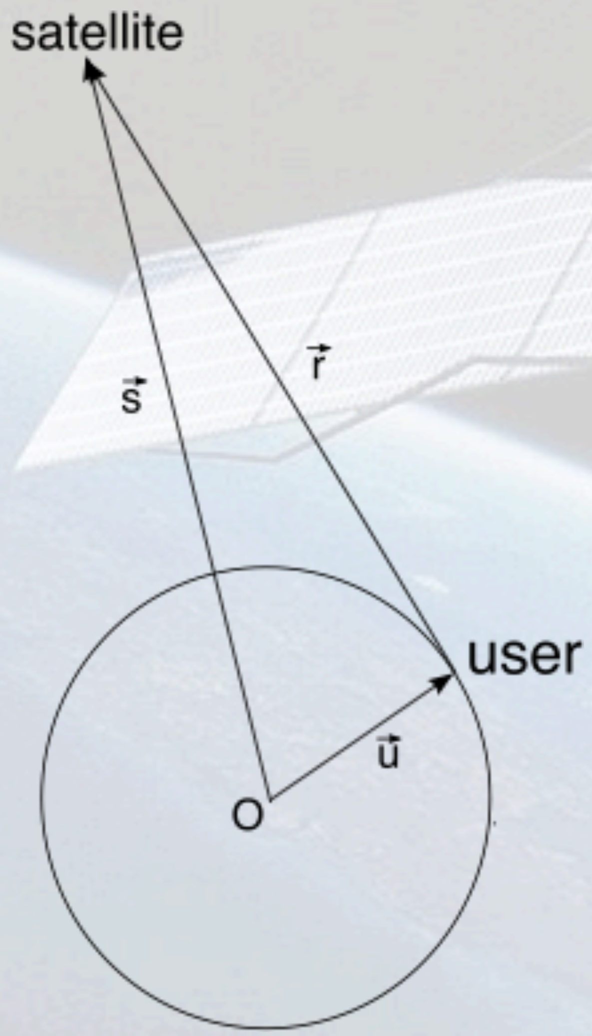
Courtesy ESA.

External anatomy of the Galileo IOV satellite



Satellite Radionavigation Concepts

TOA (Time Of Arrival) of a signal from a well known position



$$\vec{r} = c(T_u - T_s) = c\Delta T$$

$$c\Delta T = \sqrt{(x_s - x_u)^2 + (y_s - y_u)^2 + (z_s - z_u)^2}$$

We need three satellites to find the position of the user.

⇨ T_u and T_s perfectly synchronized

Satellites equipped with atomic clocks... but...
Receiver with non perfect synchronization (simplicity and economy)...

⇩

new unknown quantity

$$c\Delta T = \sqrt{(x_s - x_u)^2 + (y_s - y_u)^2 + (z_s - z_u)^2} + c\delta t_u$$

Satellite Radionavigation Concepts

pseudorange : $\rho = r + c\delta t_u$ need 4 satellites

Non linear system of 4 unknowns $\rho_i = \| \vec{s_i} - \vec{u} \| + c\delta t_u \qquad i = 1, ..., 4$

system solution:
- Linearization around approximate position.
- Kalman filter.

Linearization $\Delta\rho = H\,\Delta X \;\Rightarrow\; \Delta X = H^{-1}\,\Delta\rho$

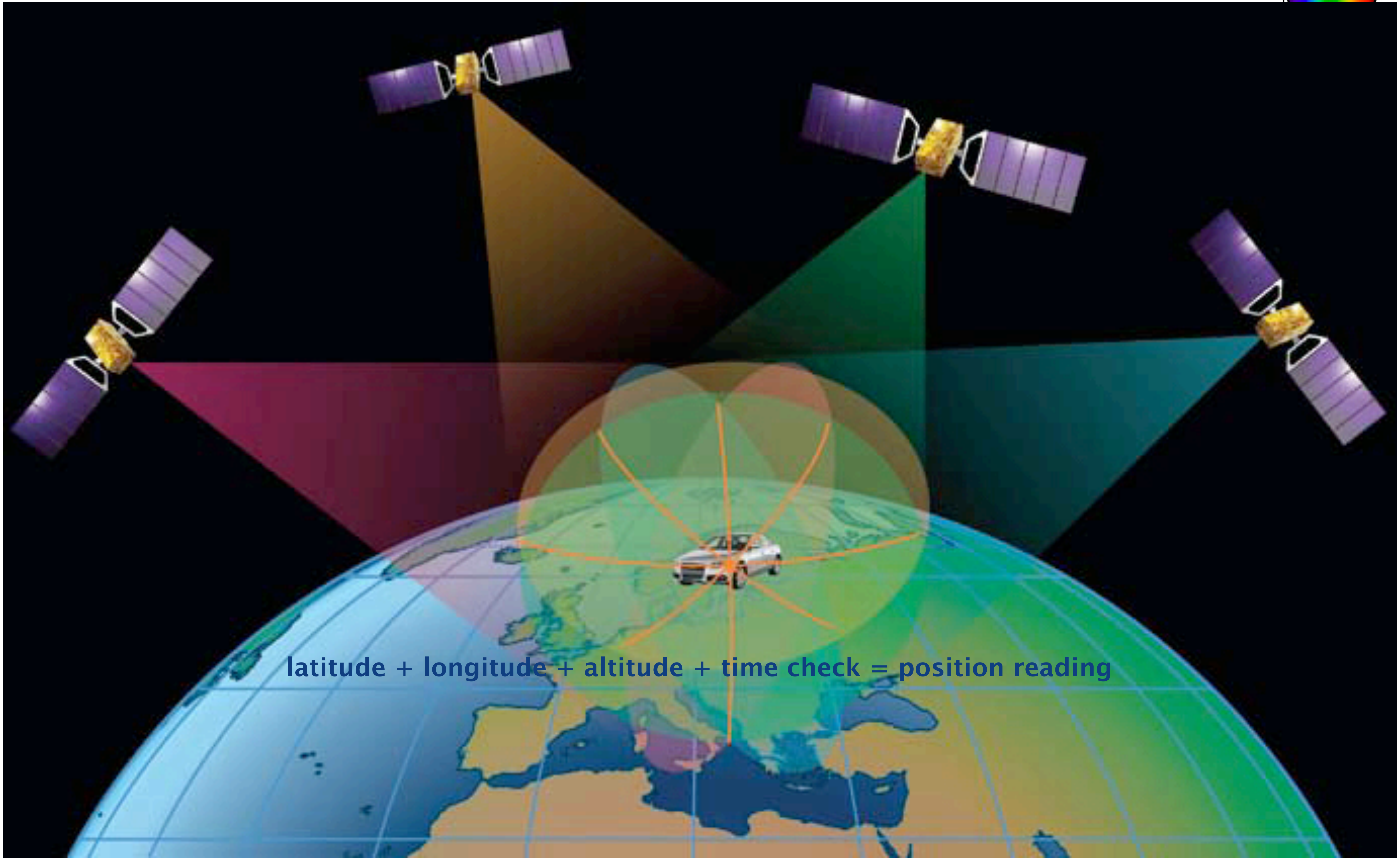
Kalman filter

Kalman filter works recursively and, starting from noisy set of input data, infers parameters of interest of underlying system state.

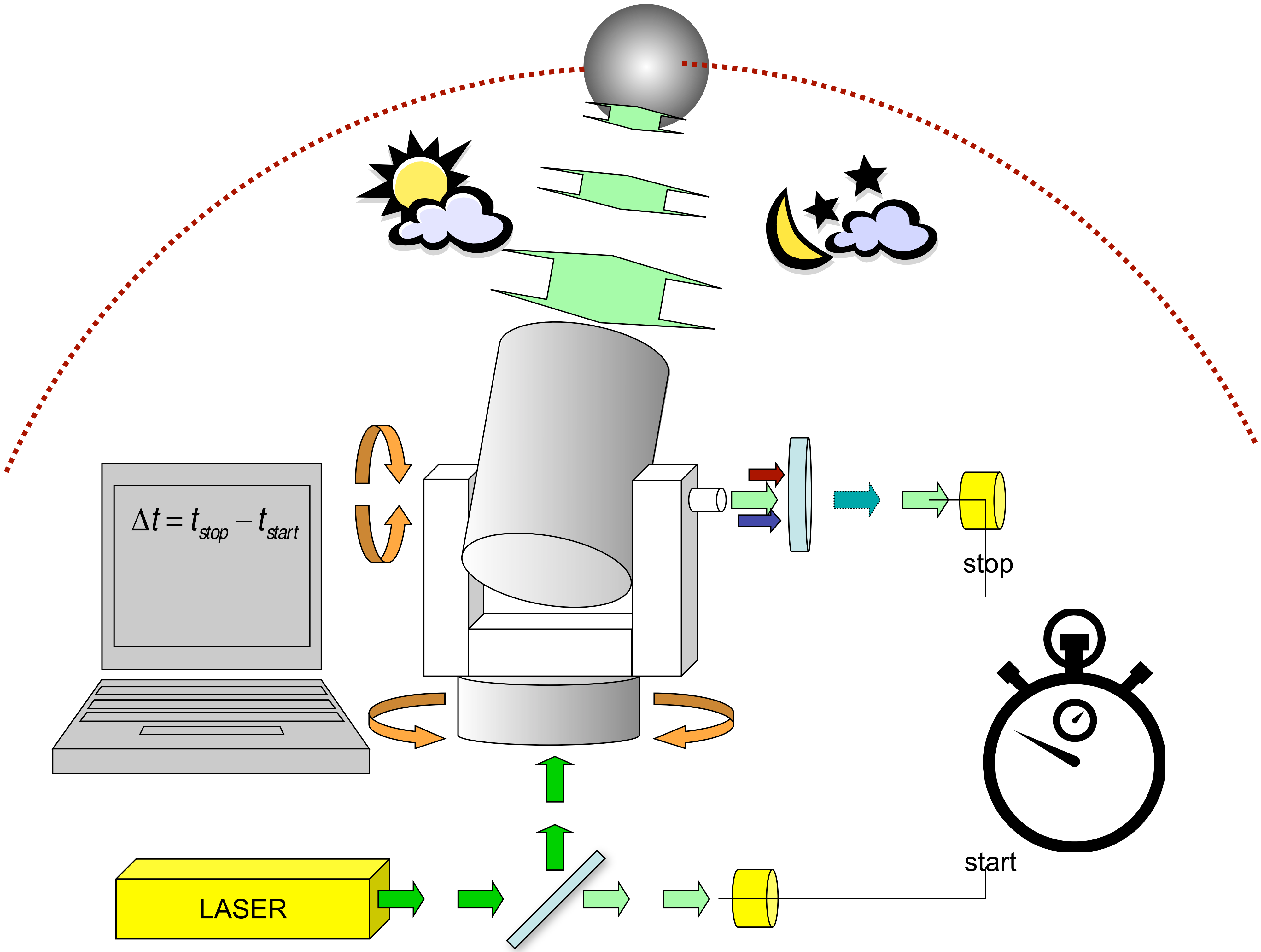
OK, it’s quite hard... You better study it by yourself!!!

[1] Kalman 1960, *A New Approach to Linear Filtering and Prediction Problems*, Journal of Basic Engineering, 82 (Series D): 35-45.
[2] kalmanfilteringgpsins.com - conference in California, next week.

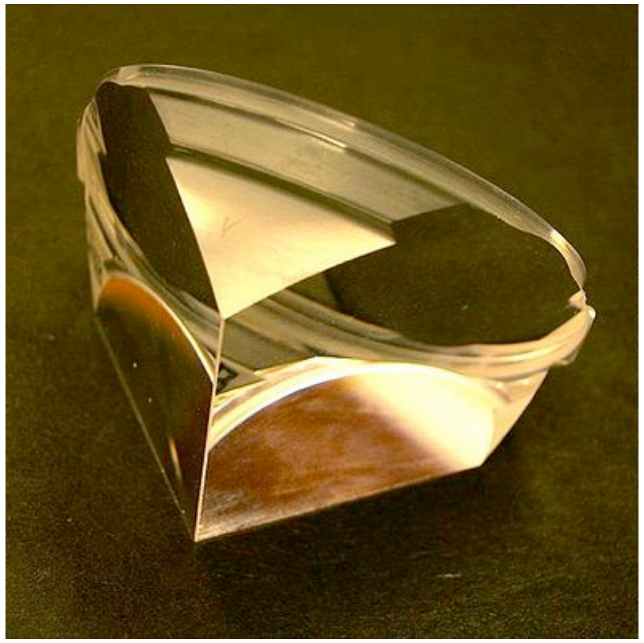
GNSS (Pseudo)Ranging Technique



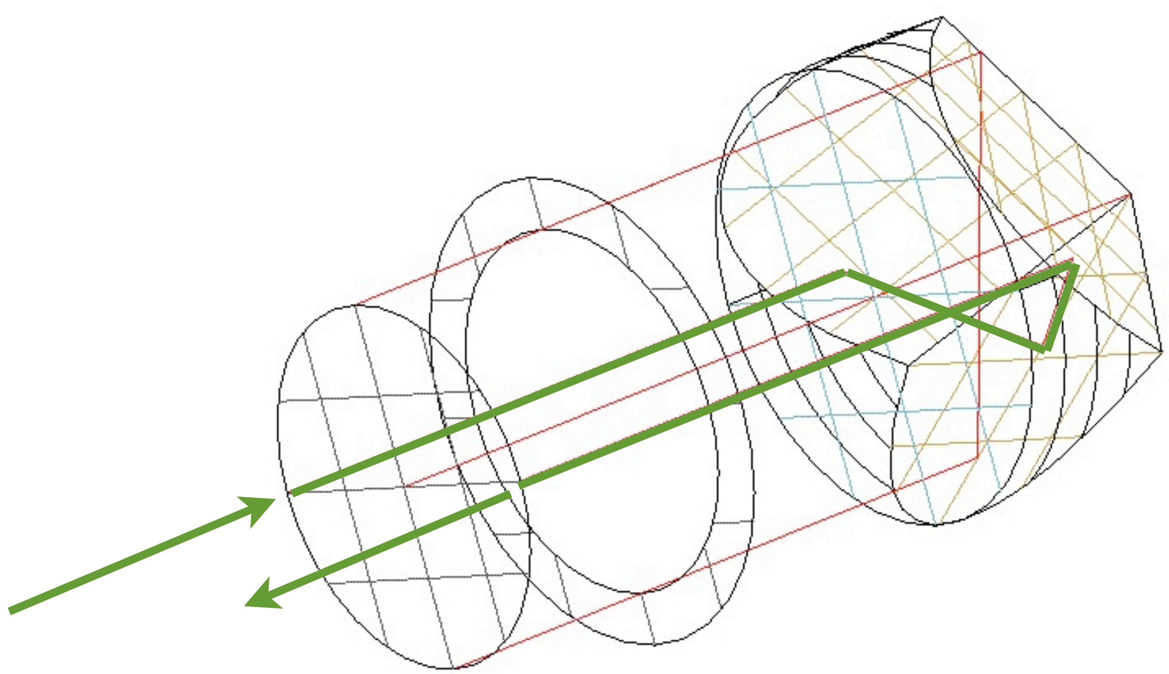
Ranging Technique



Cube Corner Reflector



- A CCR is a prism, usually made of Fused Silica, whose vertex is the corner of a cube.
- Every CCR back face has an angle of 90° with the two remaining faces.
- A ray entering the CCR is retroreflected along the very same incidence path.
- A ray entering the CCR comes out in a point opposite to the origin.



reflection on the three back surfaces through total internal reflection

SLR contribution to GNSS

- Improve accuracy of GNSS satellite orbits.
  - ~1÷10cm for SLR (2hr latency), ~1m for MW (broadcast ephemerides).

- Combined GNSS-SLR orbits.

- Cross link the GNSS and the SLR orbit determination.
  - eliminate uncertainties in the more complex GNSS technique (space borne co-location, or “space ties”, and ground co-locations at stations, or “ground ties”).

- Separate effects of clock modeling from orbit modeling.

- Absolute Calibration of GNSS orbits (w.r.t. ITRF).

- Improve geocenter and scale of length determination, precision and stability of the ITRF.
  - develop additional Galileo Terrestrial Reference Frame (GTRF).

- Improve Time Transfer.
  - (important for an accurate global time scale provided by GNSS).

Galileo and the SCF_Lab

Some Reference Documents

- [RD-1] Dell'Agnello 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] Willis, Preface, ***Scientific applications of Galileo and other Global Navigation Satellite Systems (II)***, J. Adv. Space Res., **47** (2011) 769.
- [RD-3] Currie, Dell'Agnello, Delle Monache, ***A Lunar Laser Ranging Array for the 21st Century***, Acta Astron. **68** (2011) 667-680.
- [RD-4] Dell'Agnello et al., ***Fundamental physics and absolute positioning metrology with the MAGIA lunar orbiter***, Exp. Astron., DOI 10.1007/s10686-010-9195-0.
- [RD-5] Dell'Agnello 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-5] March, Bellettini, Tauraso, Dell'Agnello, ***Constraining spacetime torsion with the Moon and Mercury***, Physical Review D **83**, 104008 (2011).
- [RD-7] March, Bellettini, Tauraso, Dell'Agnello, ***Constraining spacetime torsion with LAGEOS***, arxiv:1101.2791v2 [gr-qc], 24 Feb 2011.
- [RD-8] International Lunar Network (http://iln.arc.nasa.gov/), Core Instrument and Communications Working Group Final Reports:

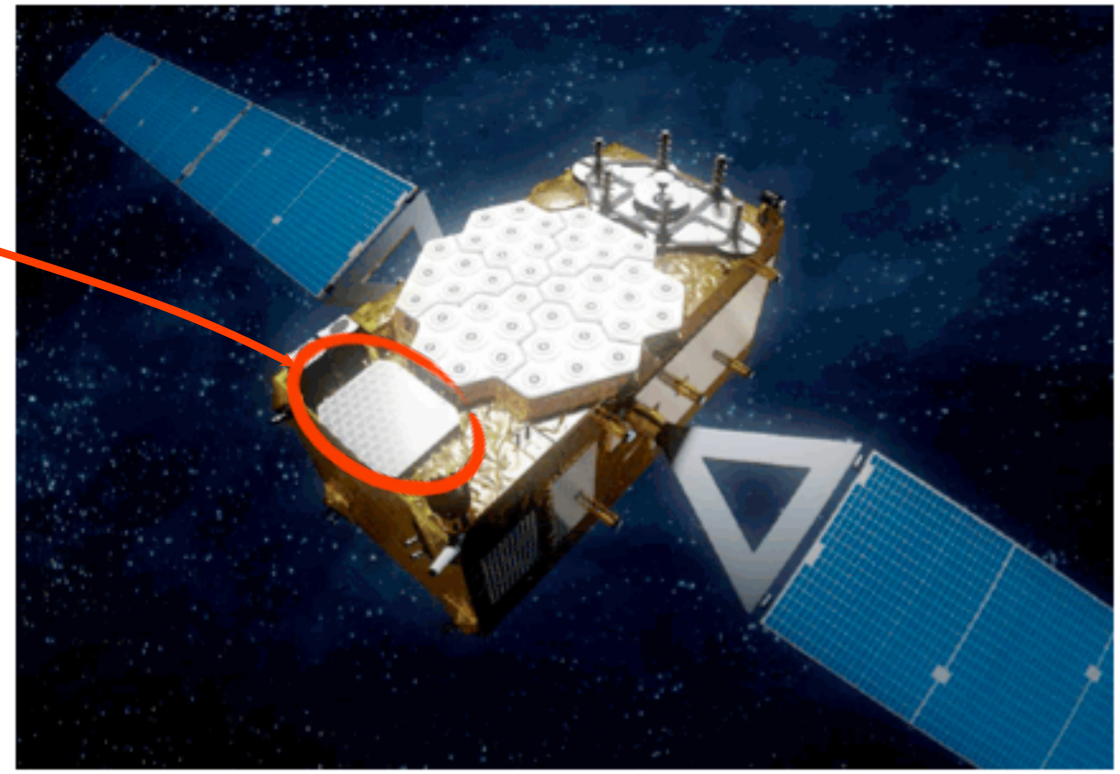
  http://iln.arc.nasa.gov/sites/iln.arc.nasa.gov/files/ILN_Core_Instruments_WG_v6.pdf

  http://iln.arc.nasa.gov/sites/iln.arc.nasa.gov/files/WorkingGroups/WorkingGroups2.pdf

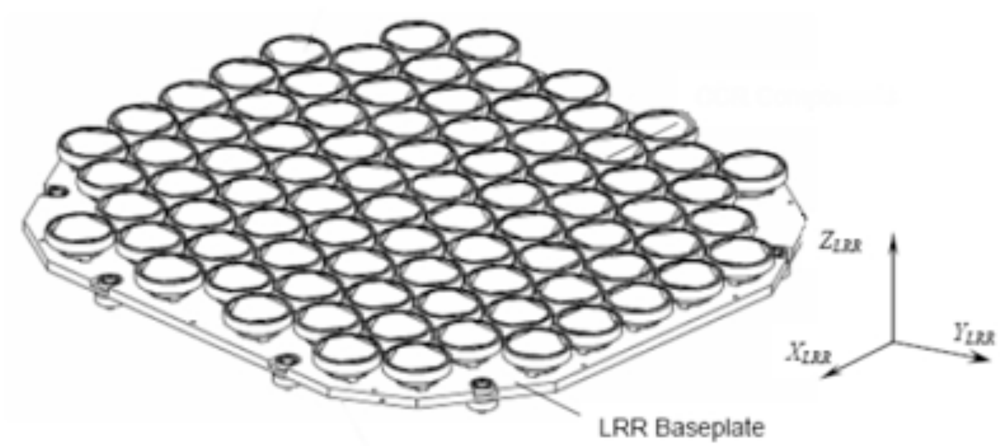
More documents available at **www.lnf.infn.it/esperimenti/etrusco**

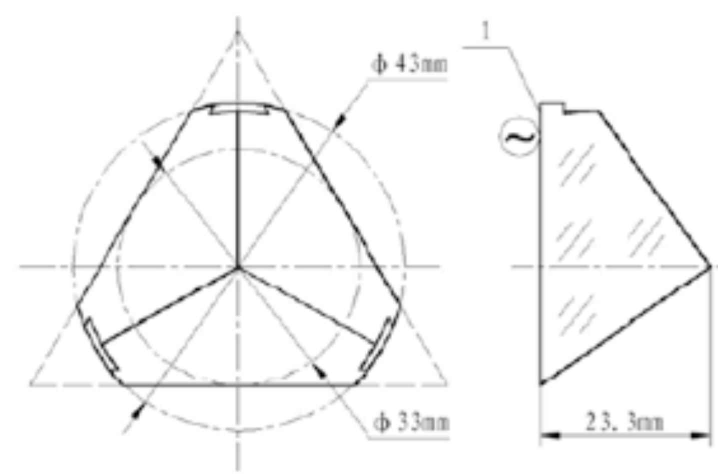
Galileo-IOV Retro-Reflector array

Galileo



Galileo retroreflector array location



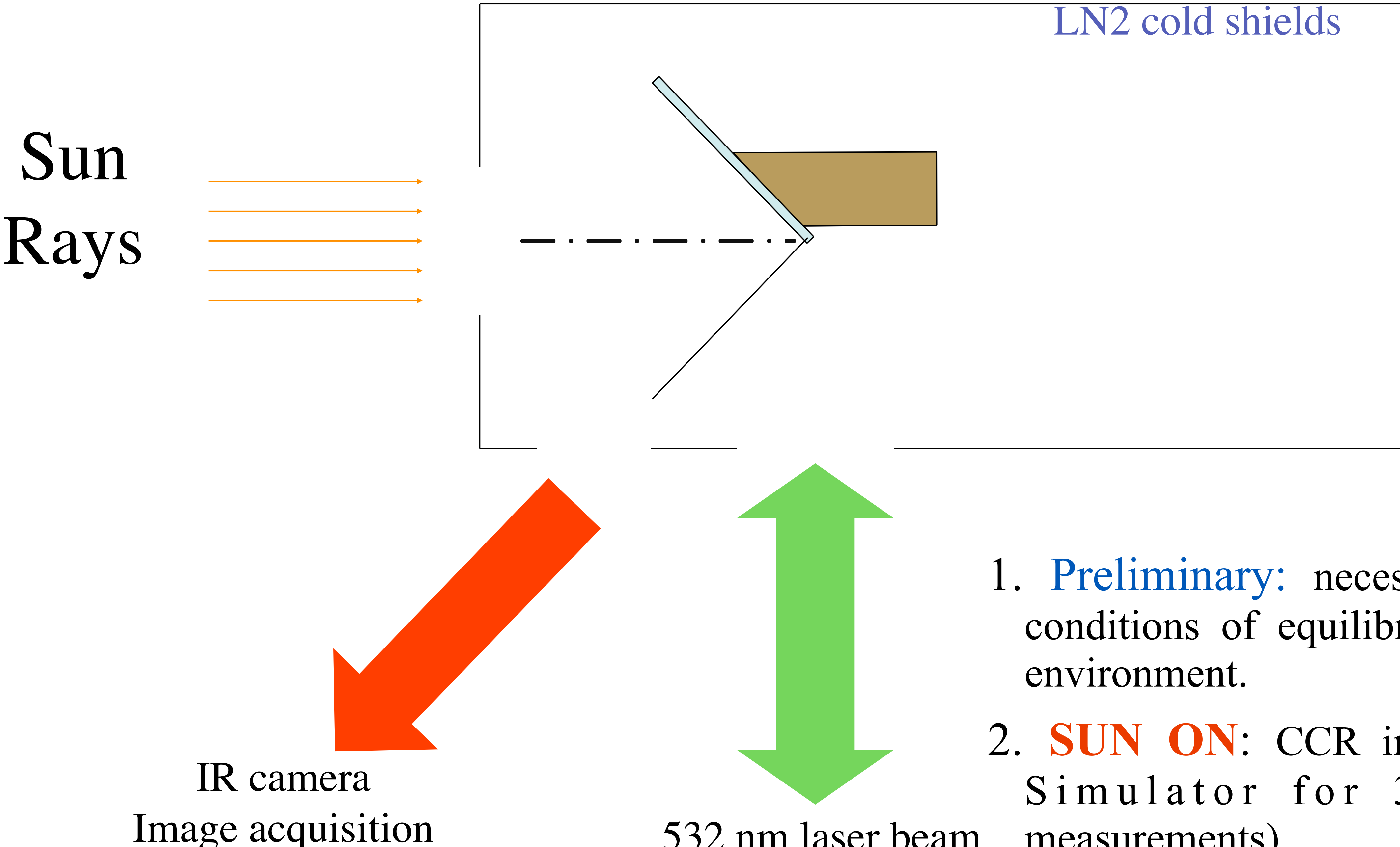


Galileo retroreflector array

Galileo corner cube configuration

Retroreflector information courtesy of ESA

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).

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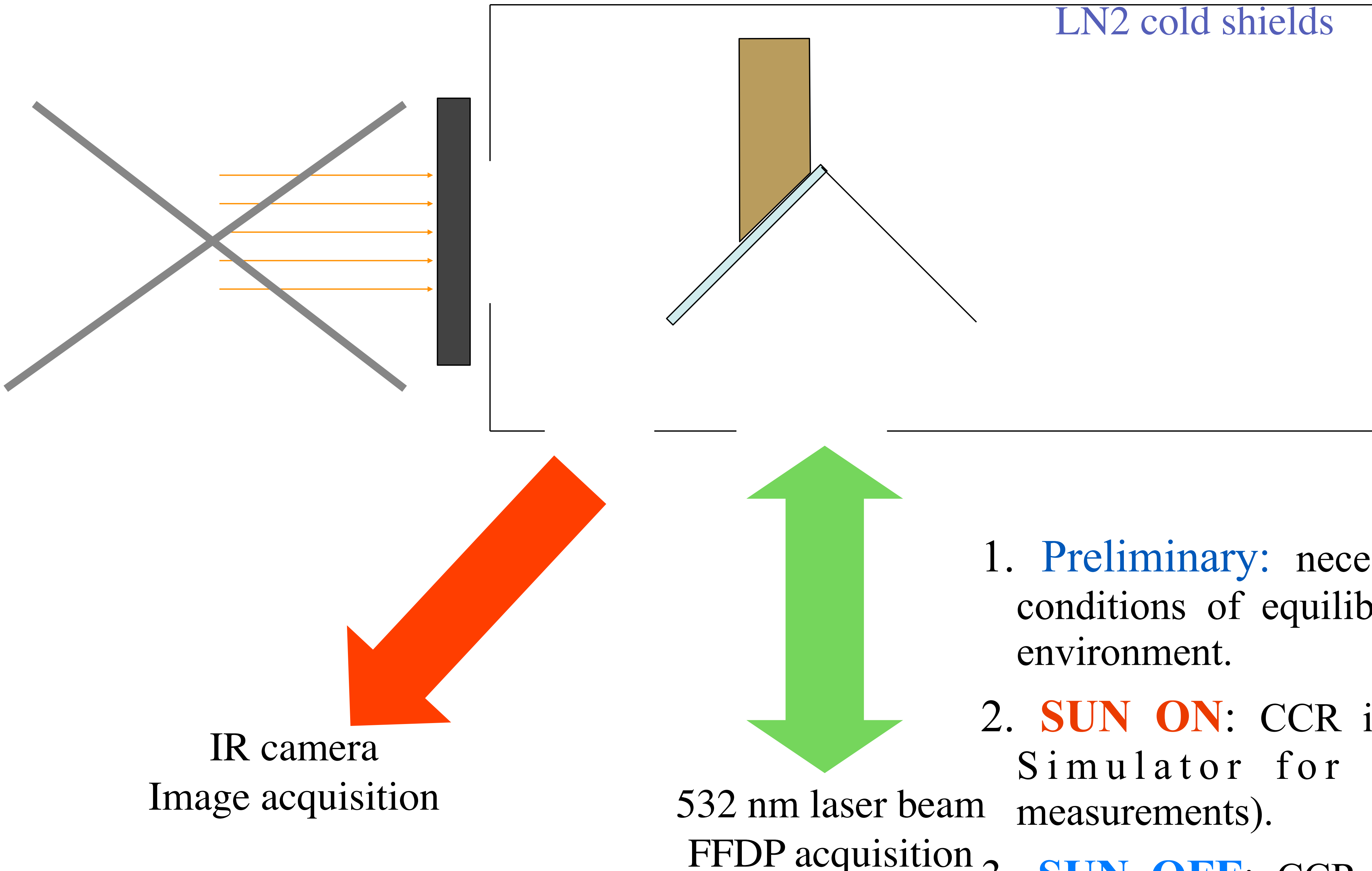

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SCF-Test

Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 47 (2011) 822–842

ELSEVIER

ADVANCES IN 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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[b] *University of Maryland (UMD), Department of Physics, John S. Toll Building, Regents Drive, College Park, MD 20742-4111, USA*
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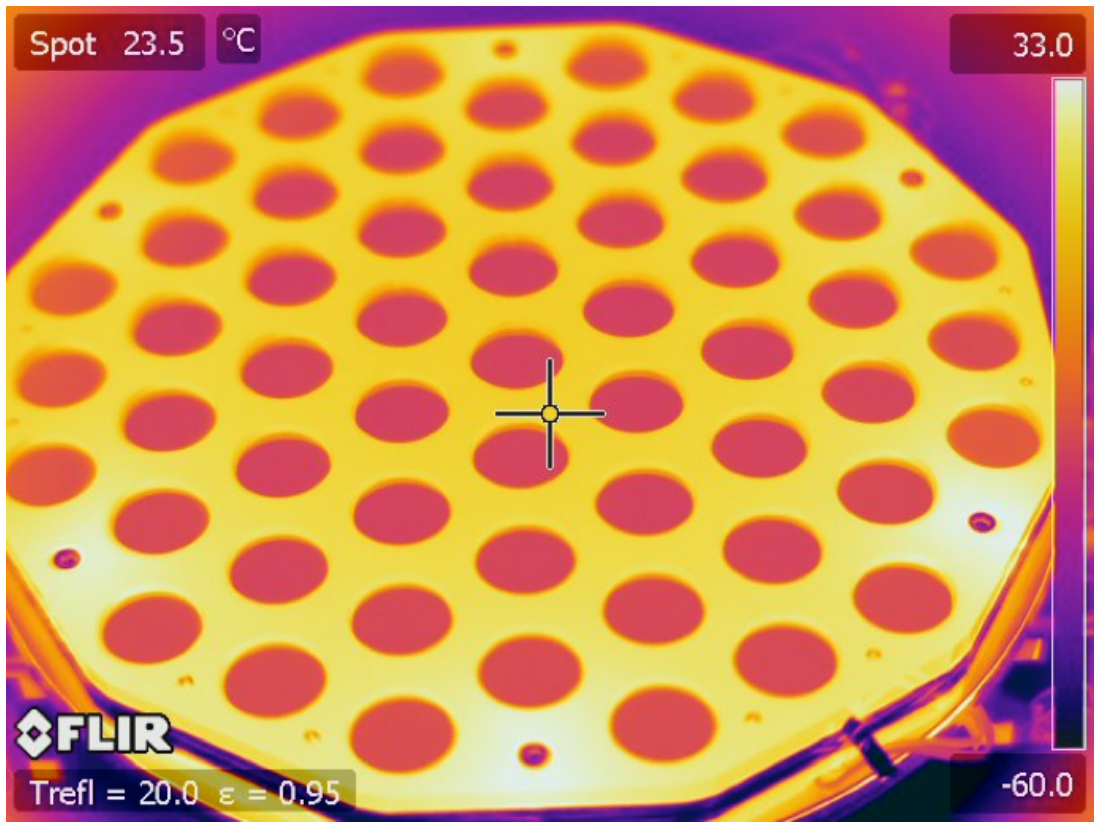
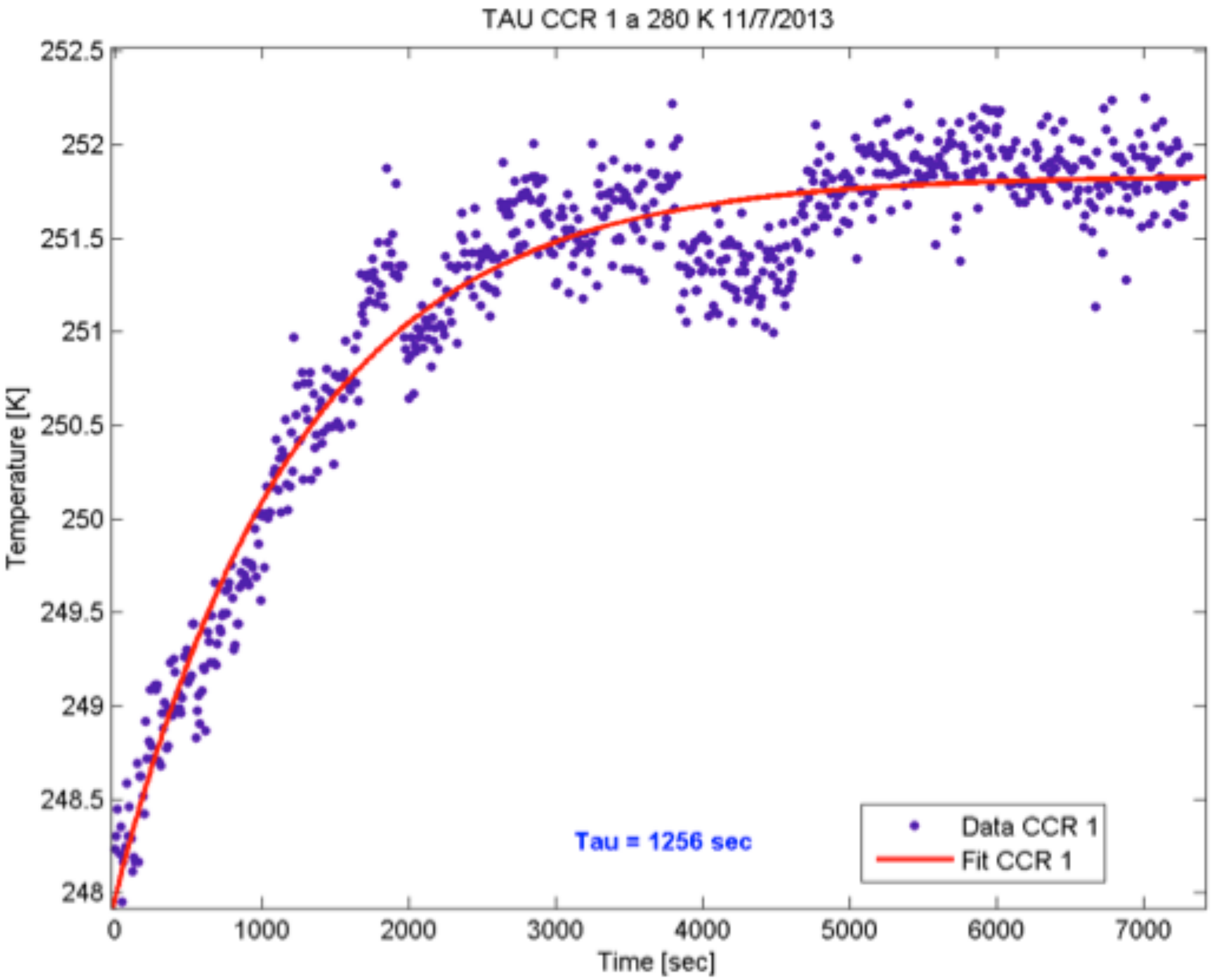
[d] *Agenzia Spaziale Italiana (ASI), Viale Liegi 26, 00198 Rome, Italy*
[e] *University of Rome "Tor Vergata", Dipartimento di Matematica, Via della Ricerca Scientifica, 00133 Rome, Italy*
[f] *Harvard-Smithsonian Center for Astrophysics (CfA), 60 Garden Street, Cambridge, MA 02138, USA*
[g] *ASI, Centro 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-Test deliverables

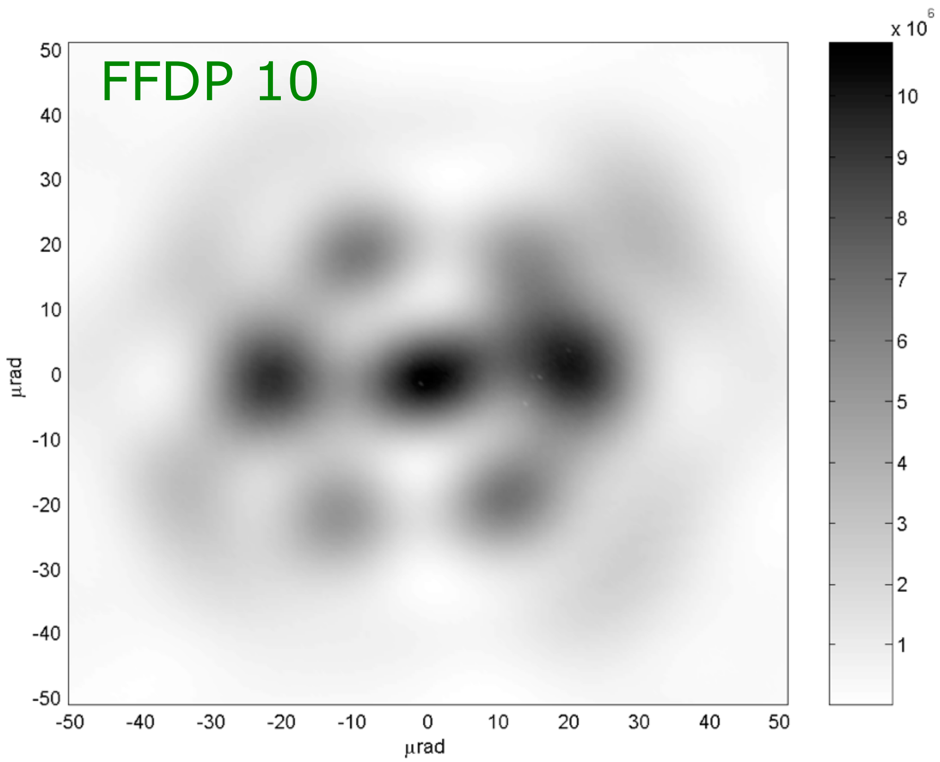
Thermal relaxation times of CCRs

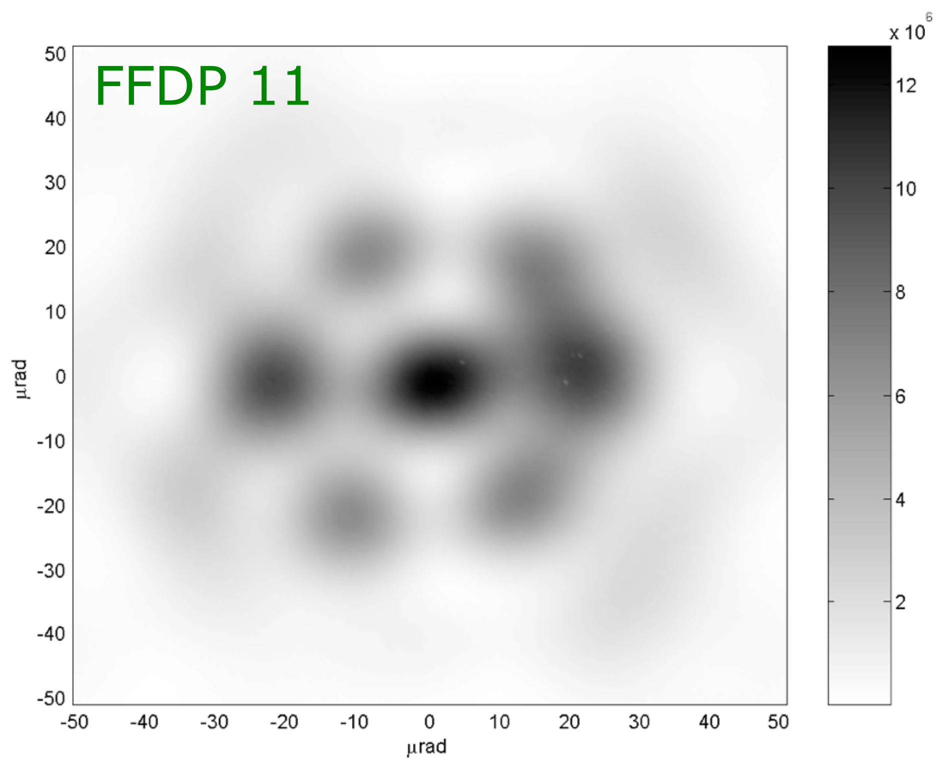


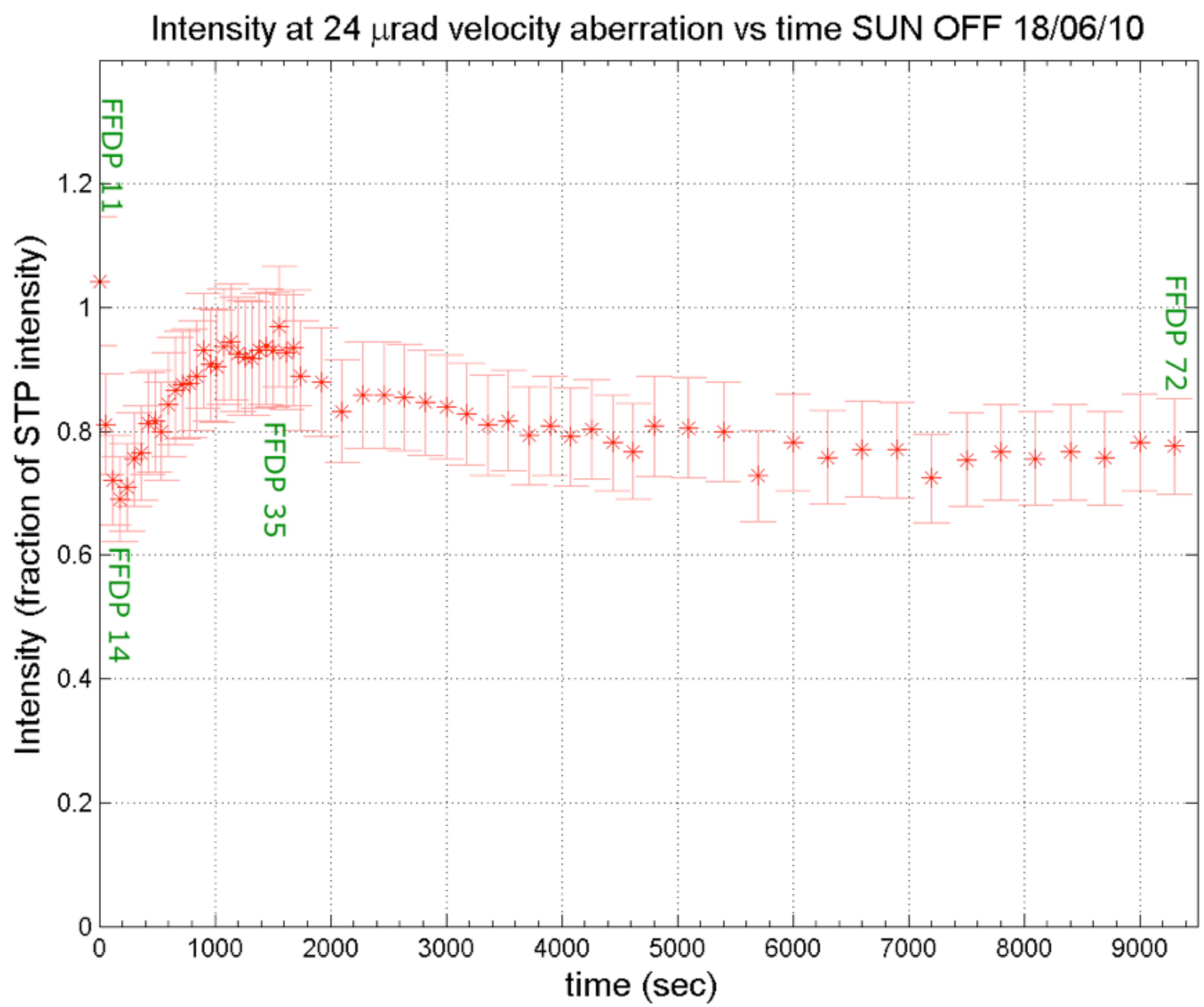


SCF-Test deliverables

FFDP variation during SUN ON/SUN OFF phases



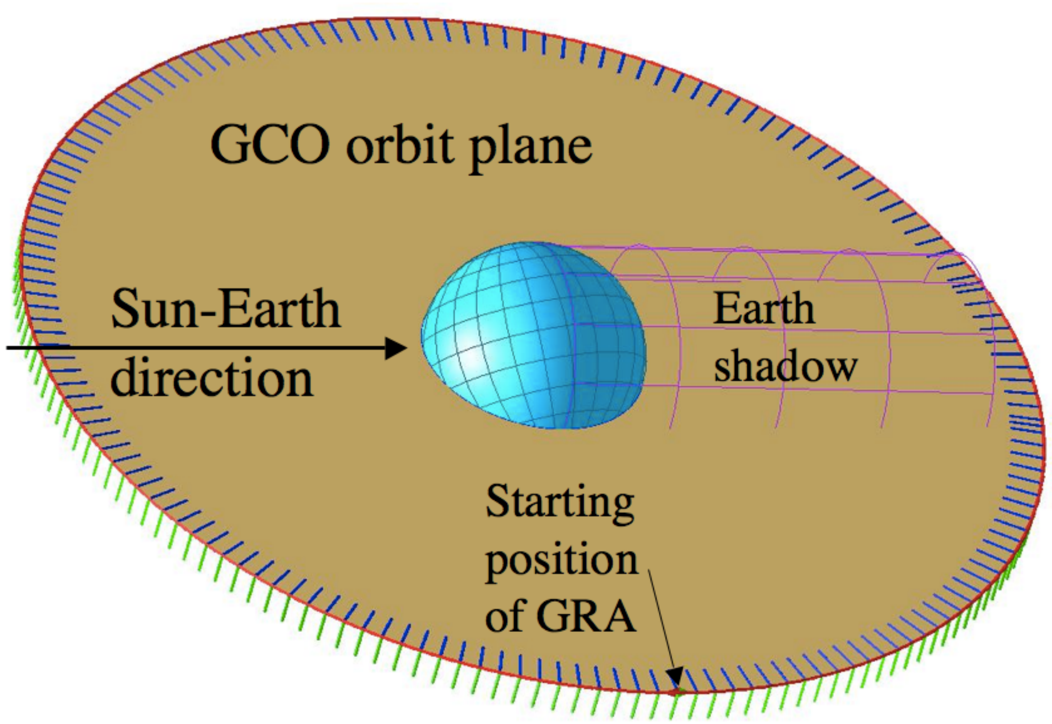


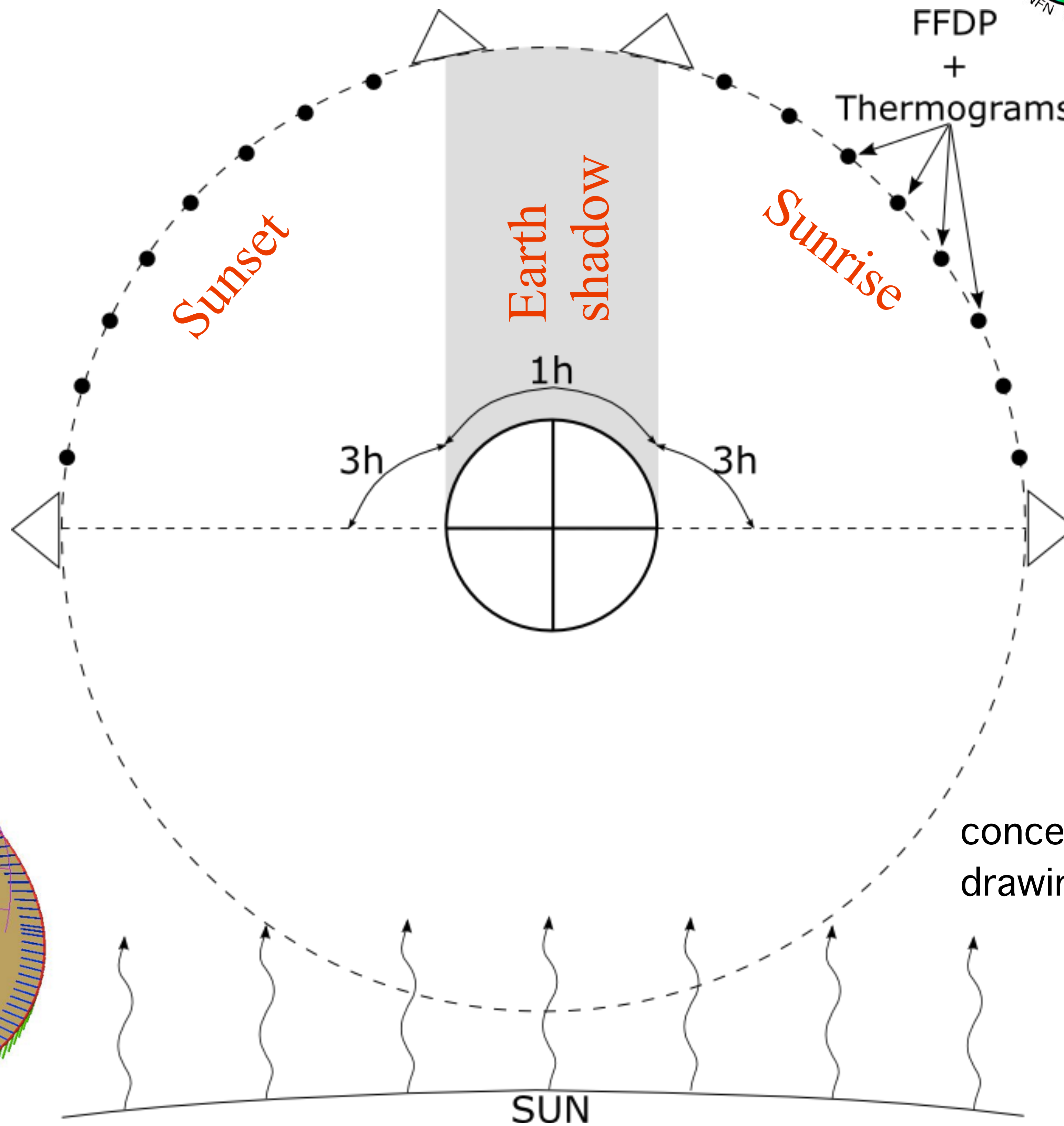


Orbit Test

SCF-testing of GNSS Critical half-Orbit (**GCO**)
Sunrise-Eclipse-Sunrise
probes critical features of the thermal and optical behaviour of the CCR

Galileo orbit:
- altitude = 23222km
- period ~ 14 h
- shadow time duration ~1h (cylindrical approximation)





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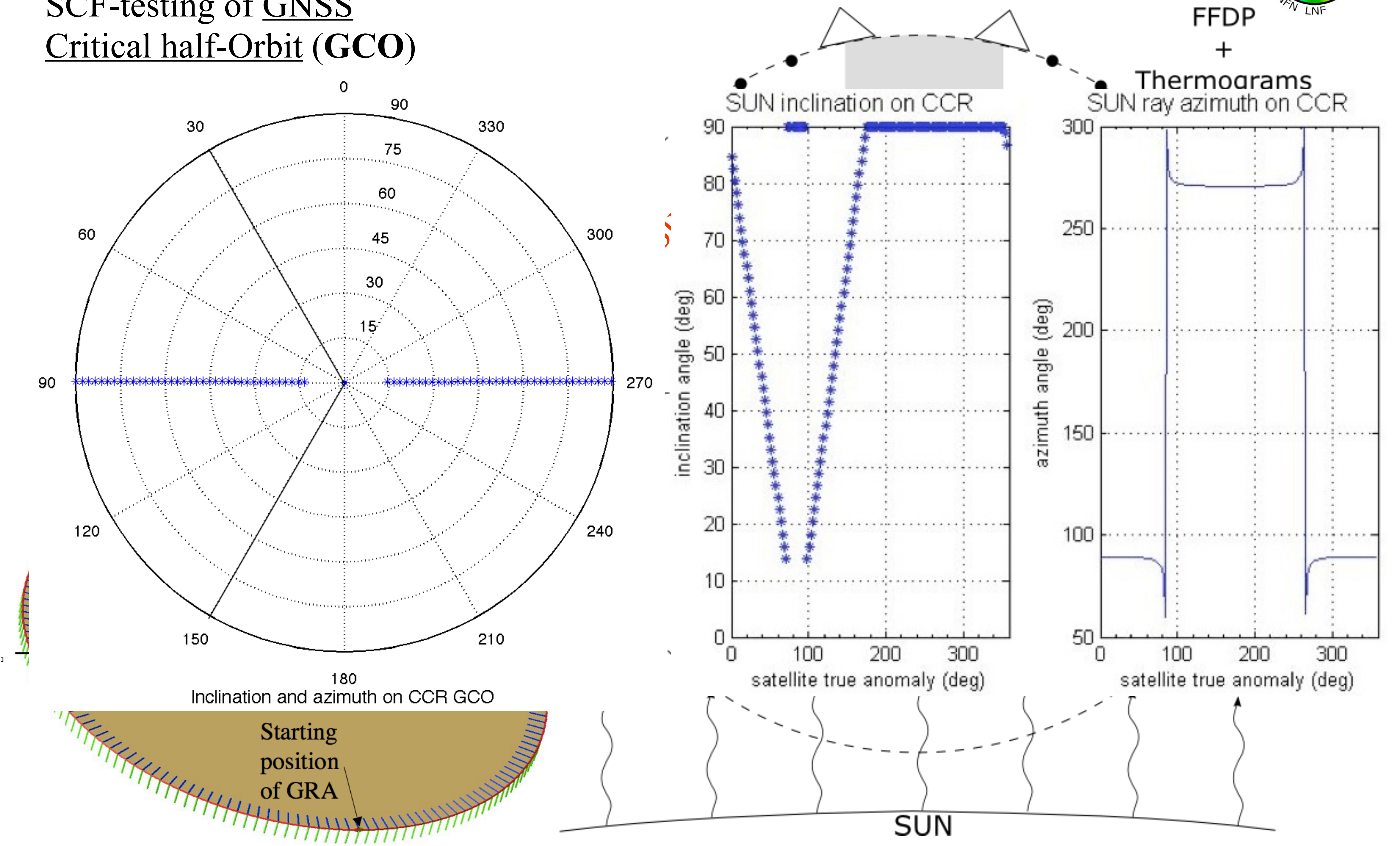
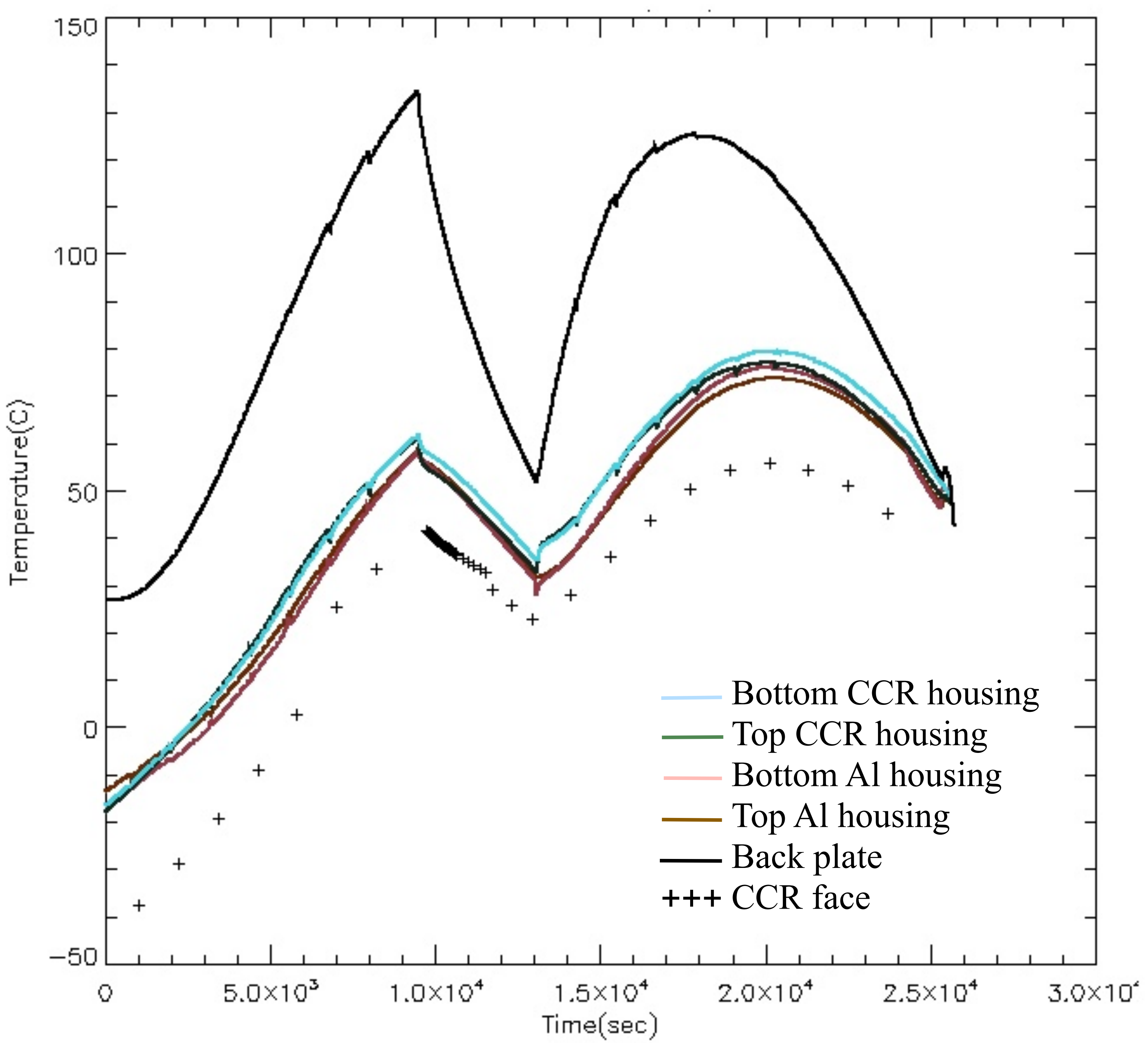
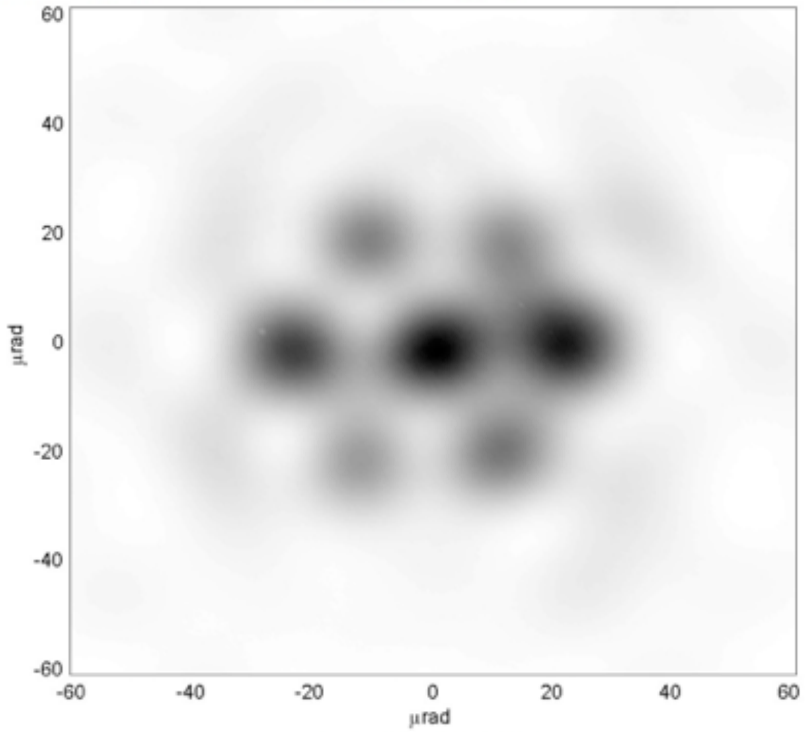


Orbit Test deliverables

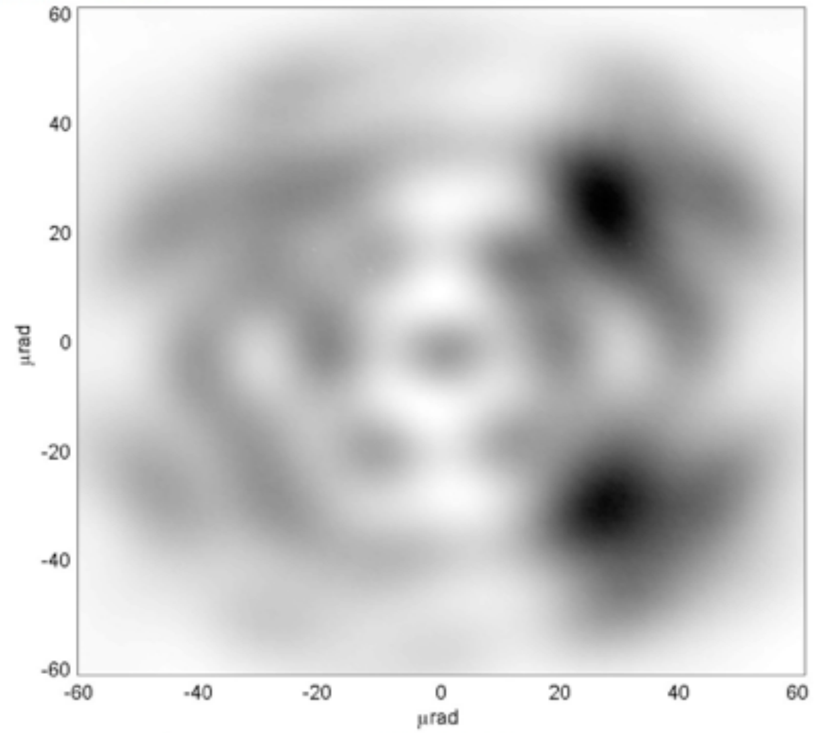


Orbit Test deliverables

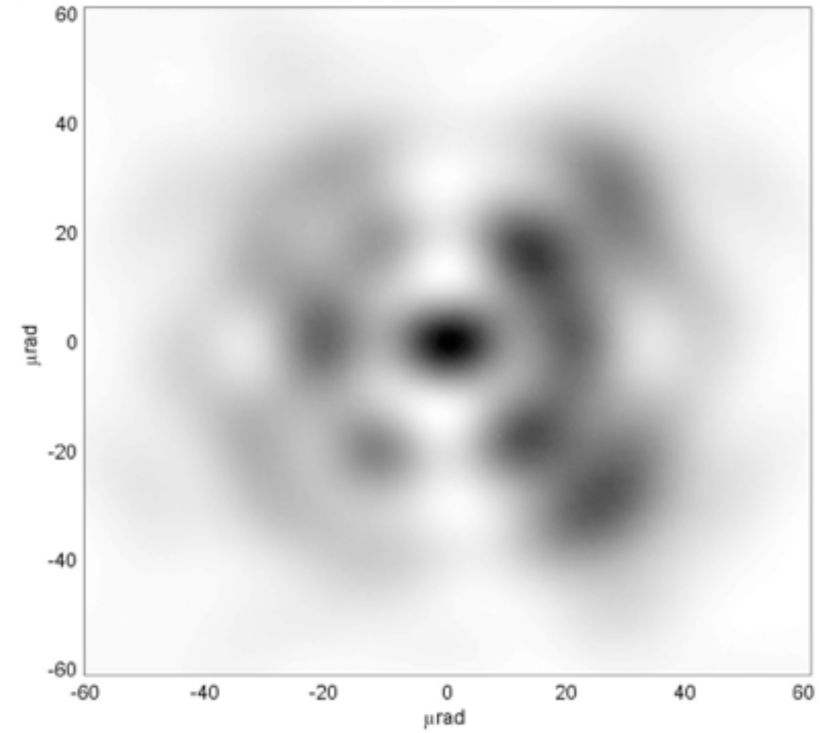
FFDP 14



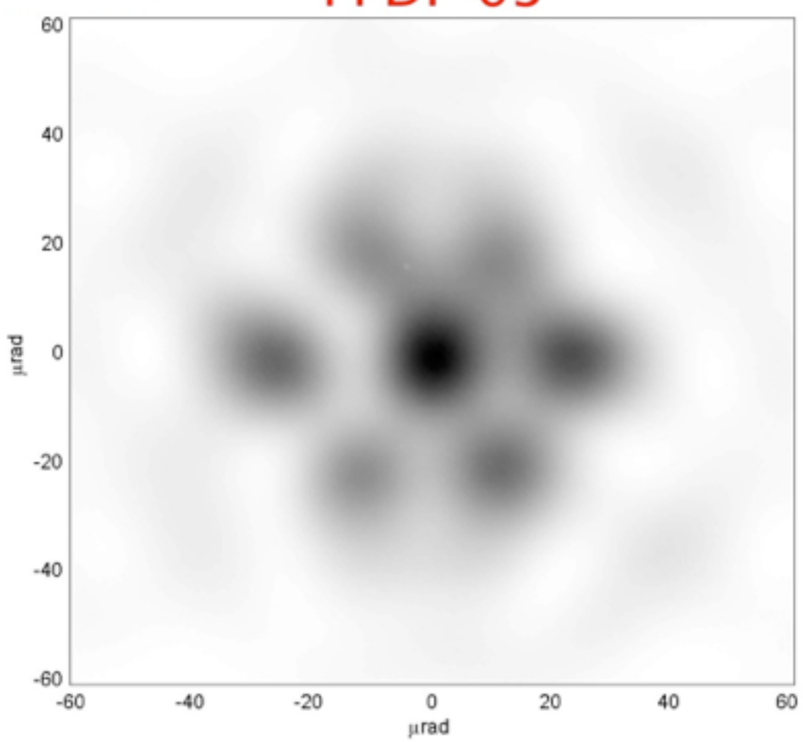
FFDP 20



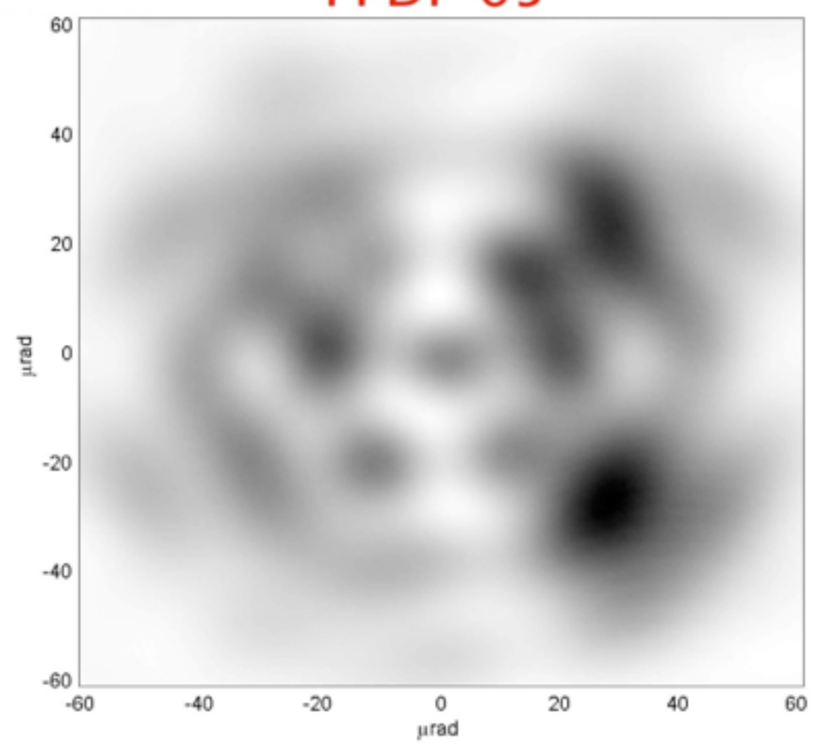
FFDP 23



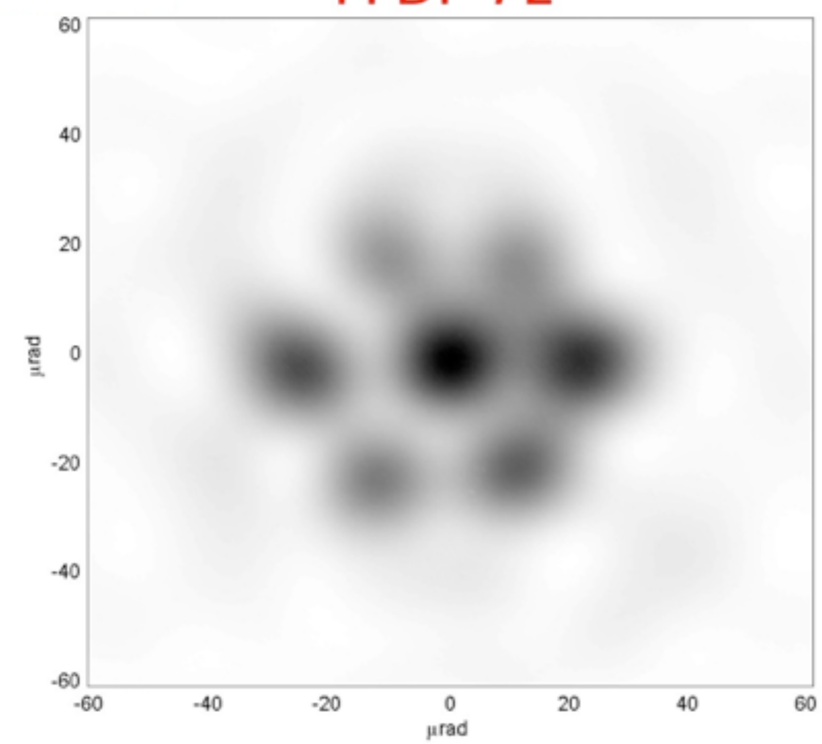
FFDP 63



FFDP 65



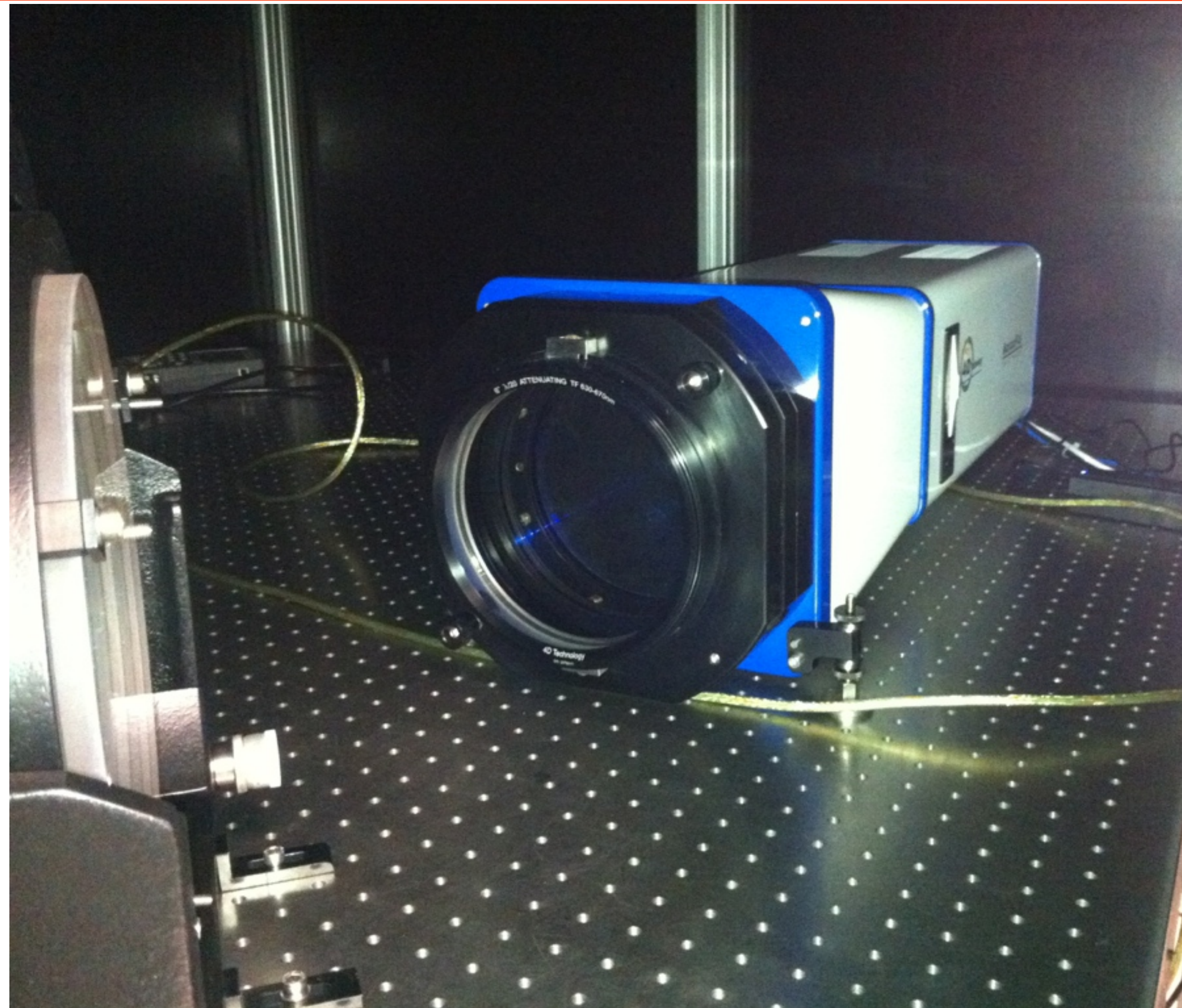
FFDP 72

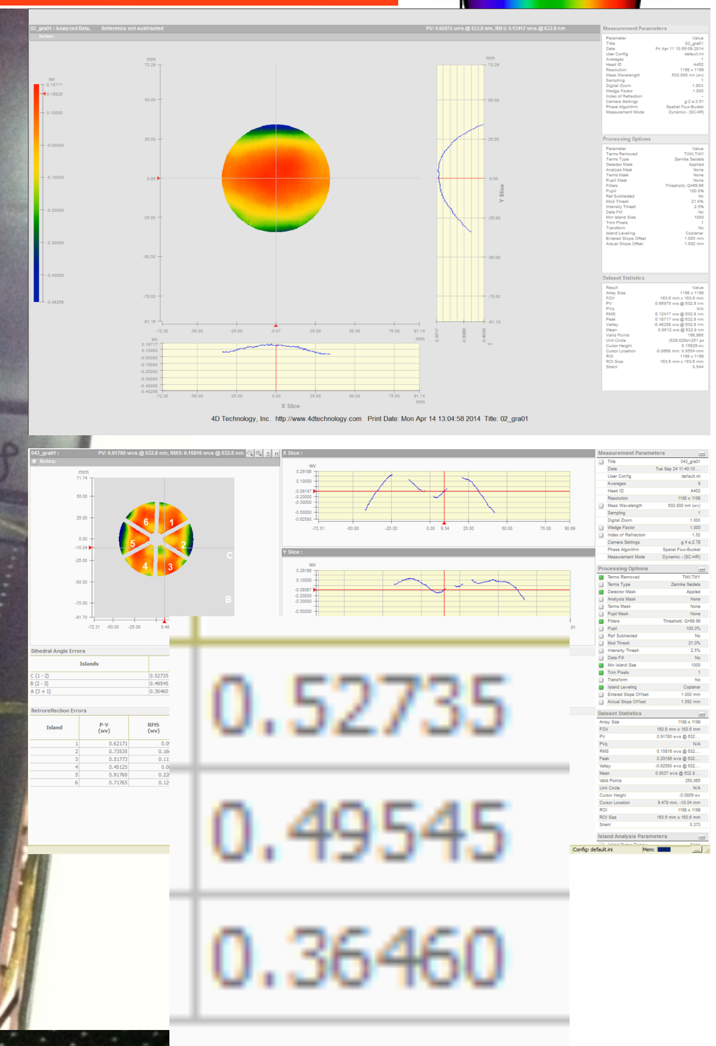


Interferometry @ SCF_Lab

Fizeau laser interferometer for high accuracy shape and transmitted wavefront measurements (e.g., flatness testing, shape measurement, thickness uniformity, ...).

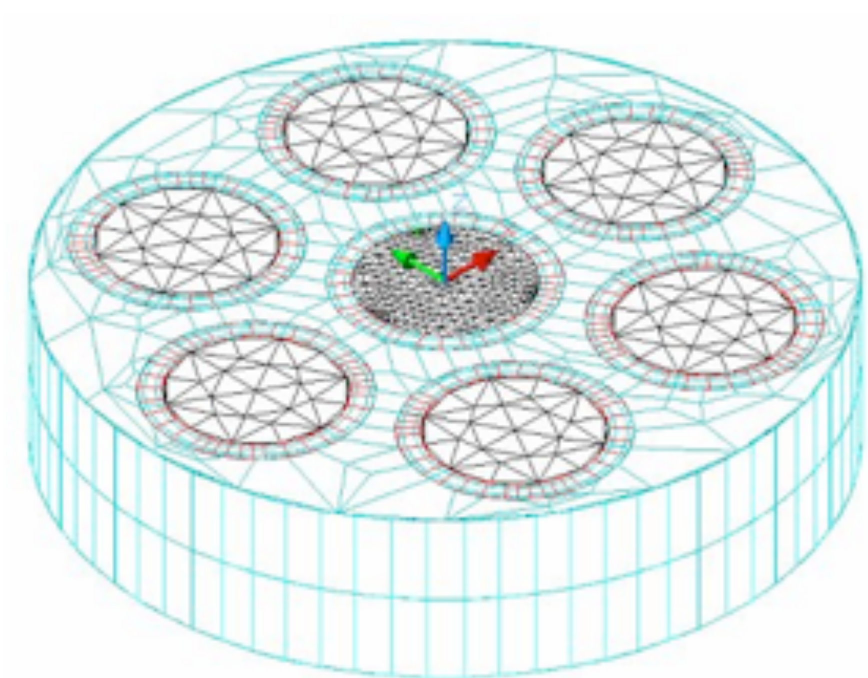
Thanks to 'Premiale' MIUR (Laser Ranging to Galileo), we shall get a 45-cm beam expander to comprehensively test whole payloads!

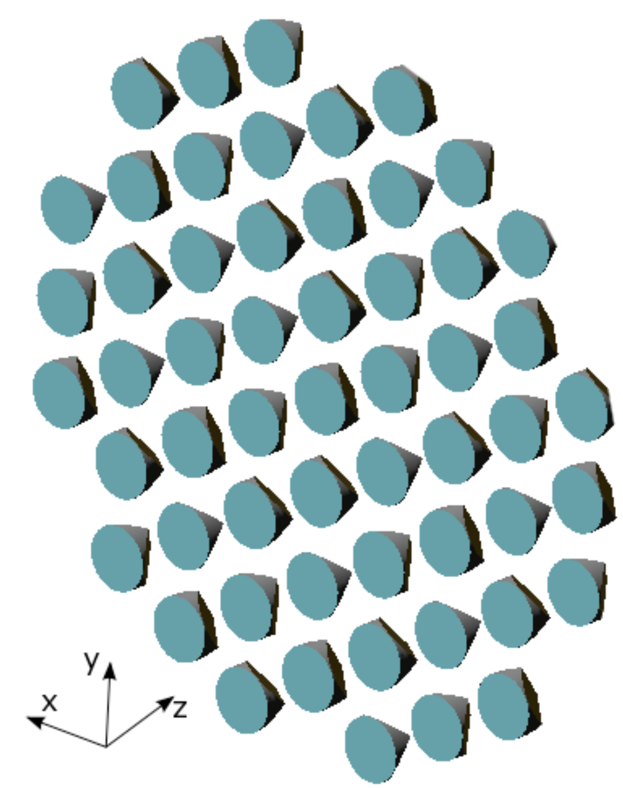




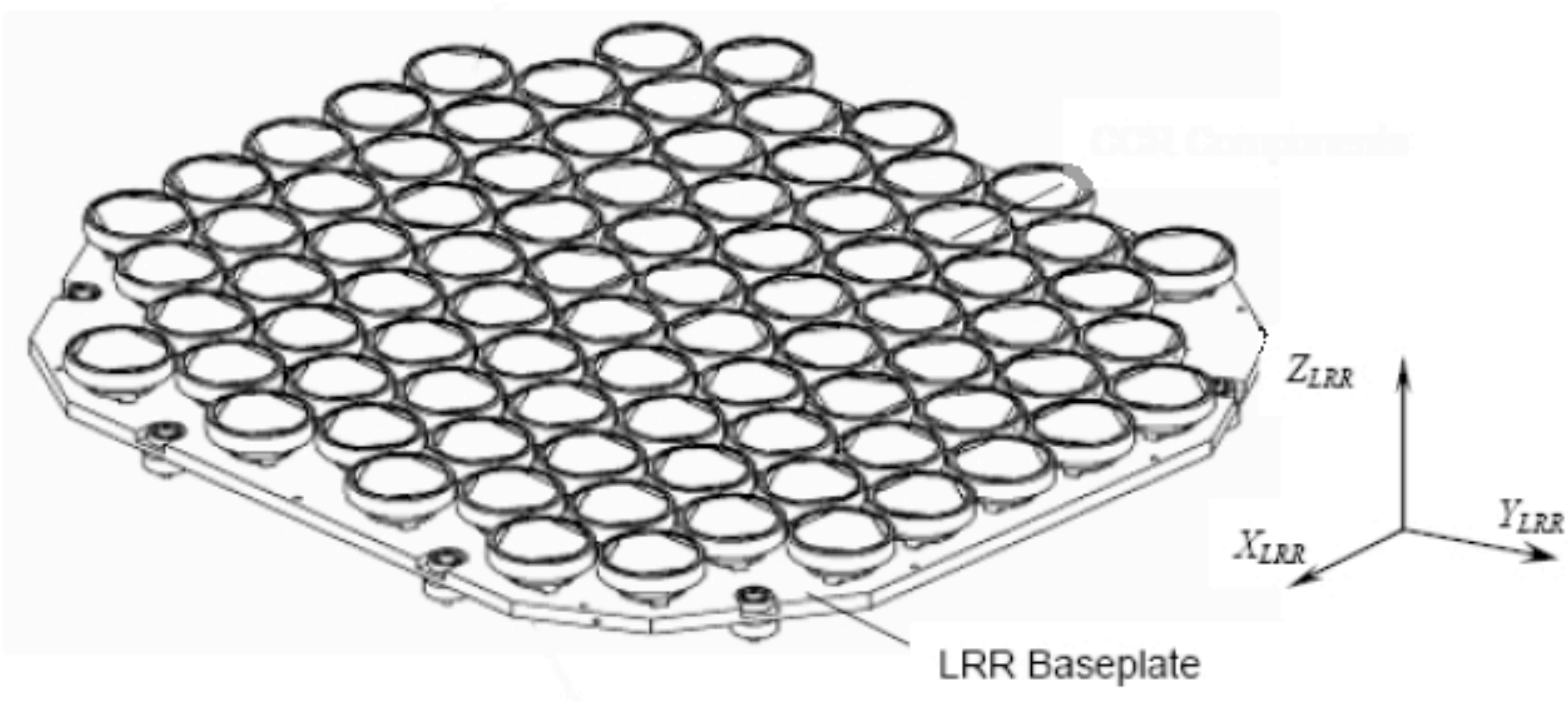
Retroreflector design and simulations

- 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.



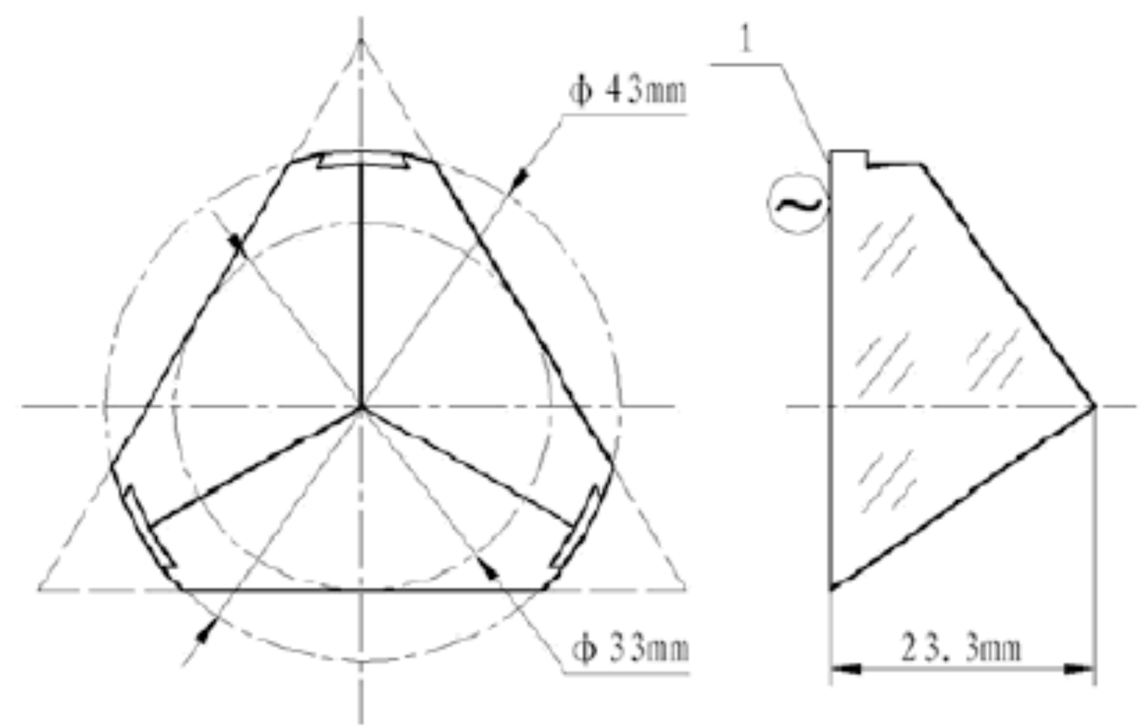


The Galileo IOV (In-Orbit Validation) array



Corner Cube Retroreflectors

- 84 Corner Cube Retroreflectors (CCR).
  - doped fused silica (Suprasil 311) glass tetrahedron.
  - no metallic coating on reflective surfaces.
  - front surface coated with ITO.
  - aperture face is included in a circle of 43 mm diameter.
  - minimum aperture is 33 mm (diameter).
  - height of the tetrahedron is 23.3 mm.
  - iso-static mounting to plate.
  - N = 1.46, critical angle16.9°.
    - covers the entire LRR operating range (Earth radius of 12.44°).
    - no coating, total reflection is obtained without any loss.
  - velocity aberration compensation 24 μrad.
  - CCR are randomly oriented.
  - LRA Centre of Phase TBD after Qualification Tests.
- This information is published in an update to “Specification of Galileo and GIOVE Space Segment Properties Relevant for Satellite Laser Ranging” (ESA-EUING-TN-10206) and in the “Mission Support Request Form”.



Russian GLONASS/GPS/GIOVE-A/B retroreflectors

Al-coated fused silica laser retroreflector technology, with thermal mounting not optimized as LAGEOS and Apollo.
Technology used since the 1980s until 2010s.
Al-coating now abandoned due to SCF-Test results!!!

Third and last GPS flight array ever made by USSR for GPS

~19 x 24 cm^2

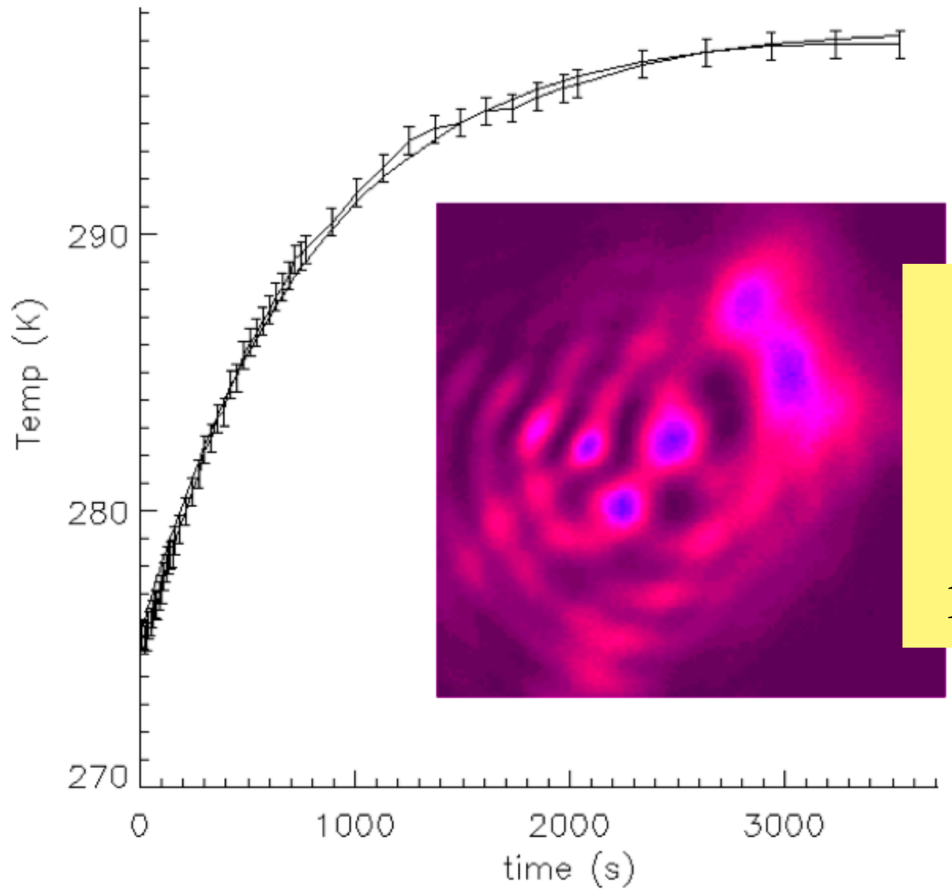
~1.3 Kg,

32 CCRs.

Property of University of Maryland, SCF-Tested at INFN-LNF

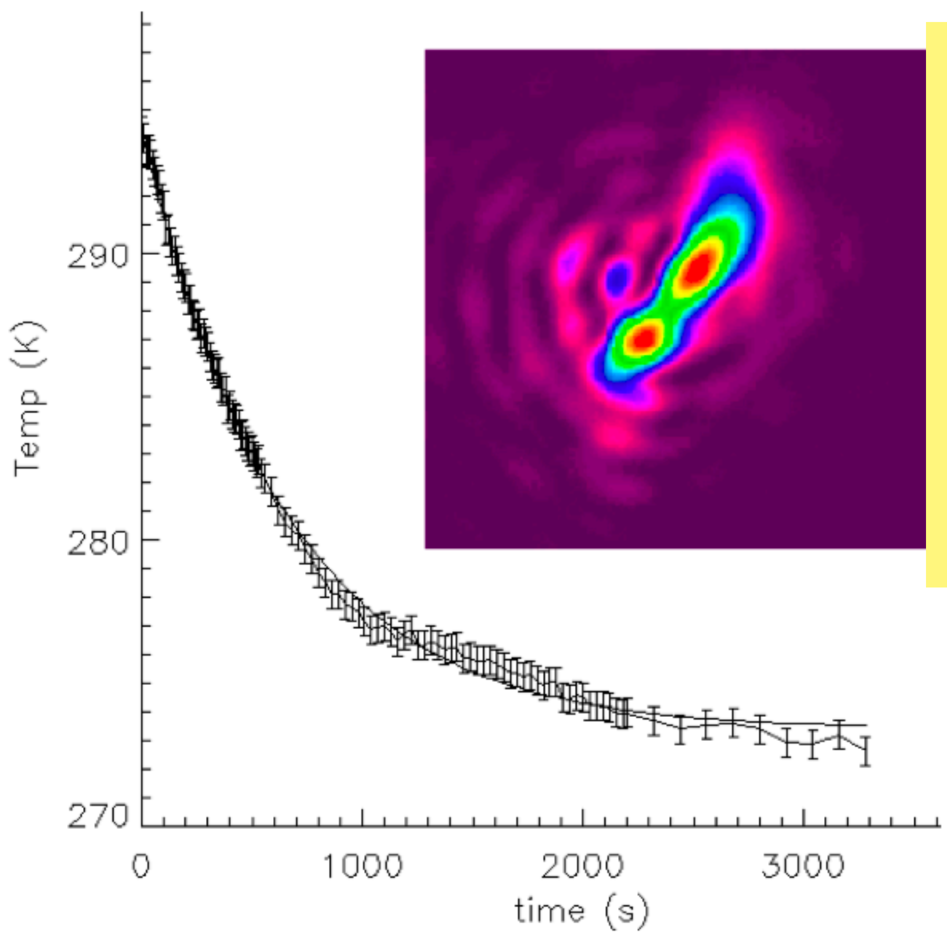
SCF-Test of GPS flight retroreflector @300 K

Thermal and optical behavior during 1 hr of **Sun on** and 1 hr of **Sun off** to simulate the passage into Earth shadow.

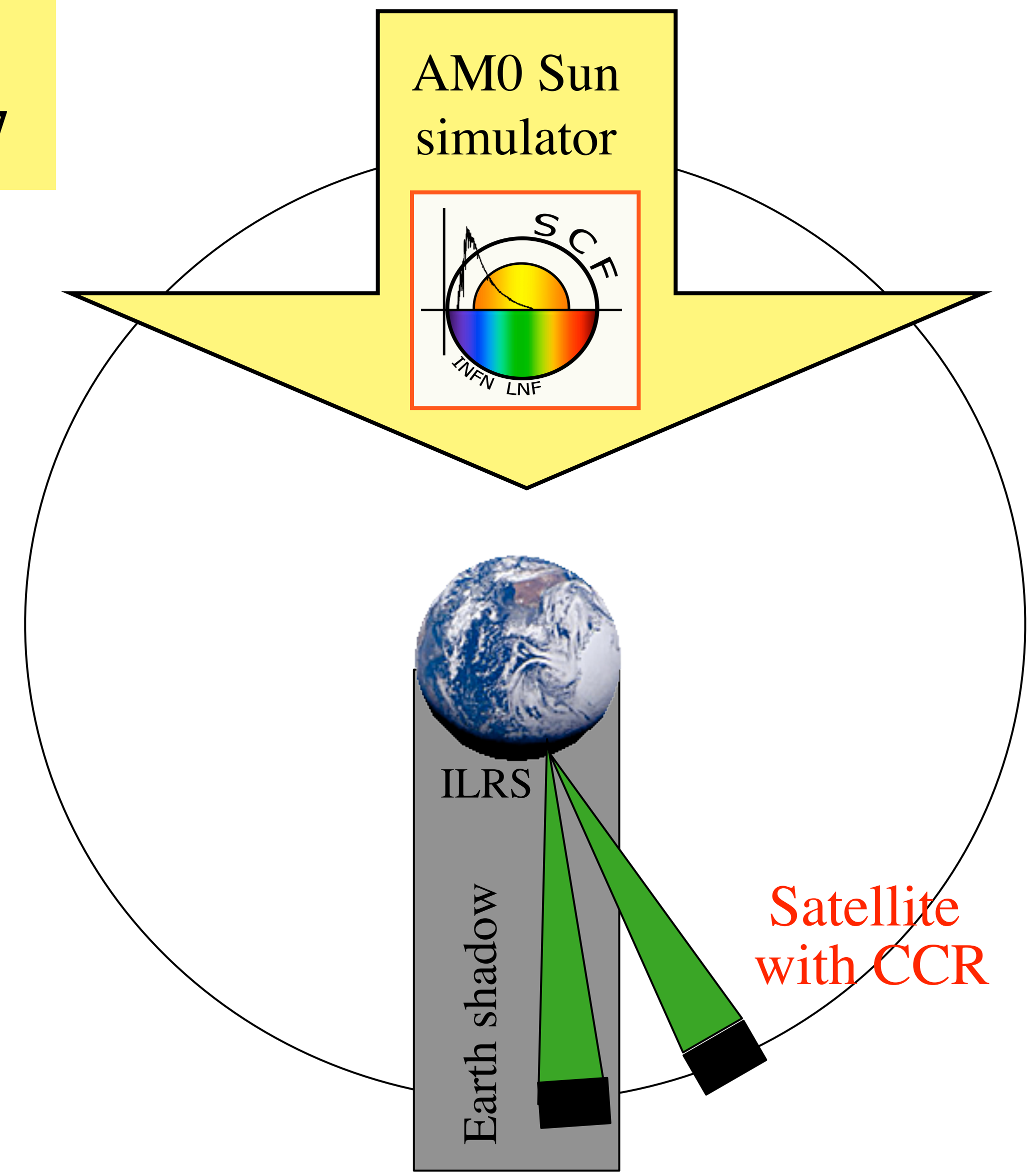


Sun on: laser return(FFDP) severely degraded, reduced by factor ~7

τ_{CCR} = (**720** ± 80) s
ΔT = (21.5 ± 0.6) K



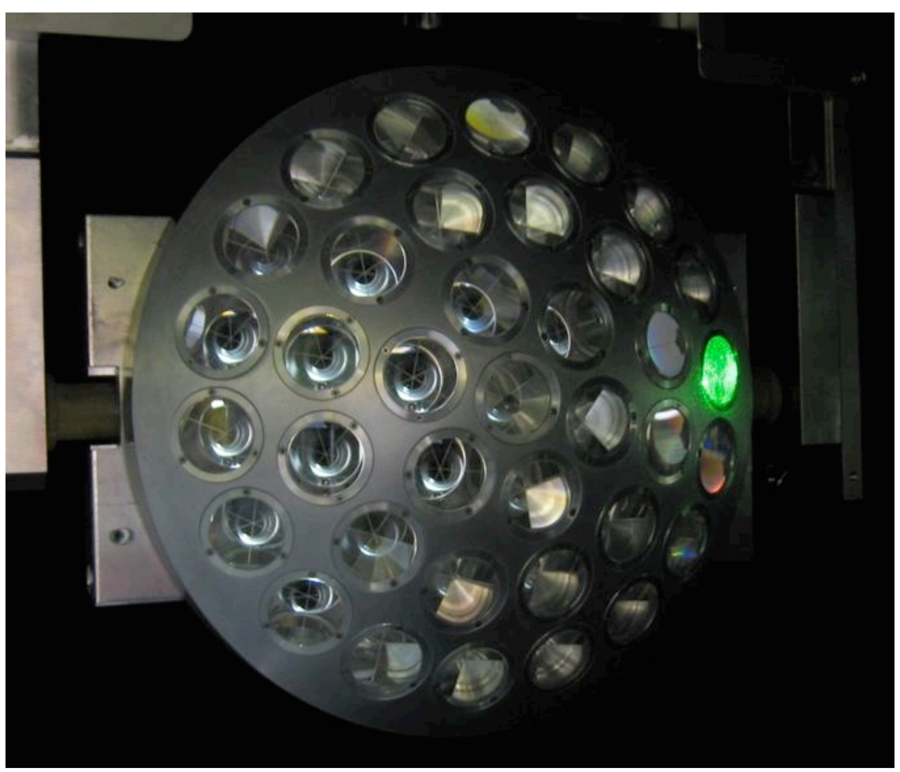
Sun off: laser return (FFDP) intensity restored, at the correct velocity aberration



LAGEOS uncoated SLR payload standard

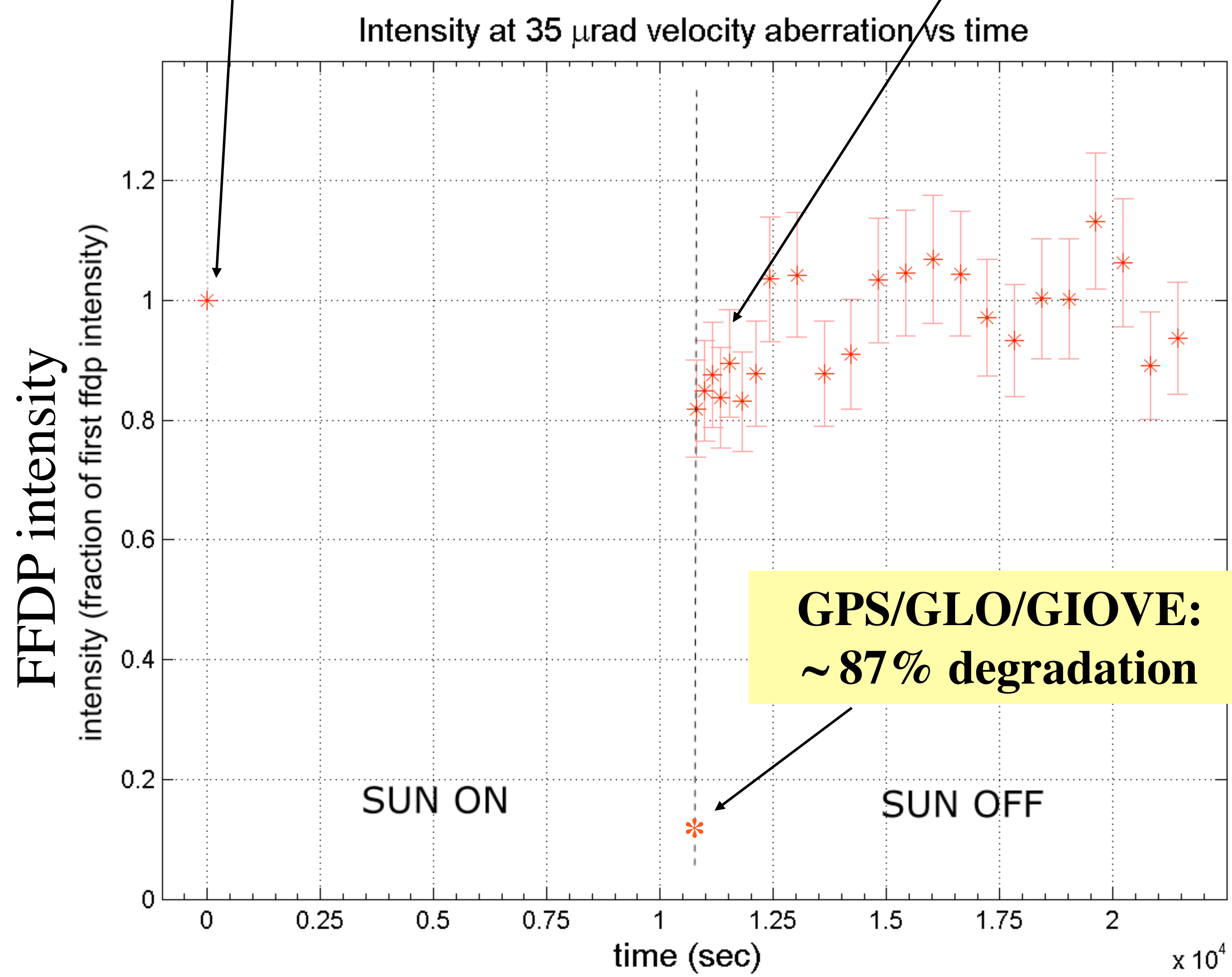
LAGEOS “Sector”, engineering prototype property of NASA-GSFC. Inherits from Apollo.

SCF-Tested @300K at INFN-LNF.



LAGEOS: laser return in space conditions not perturbed by Sun

LAGEOS: minimal degradation of laser return after 3 hr of Sun heating



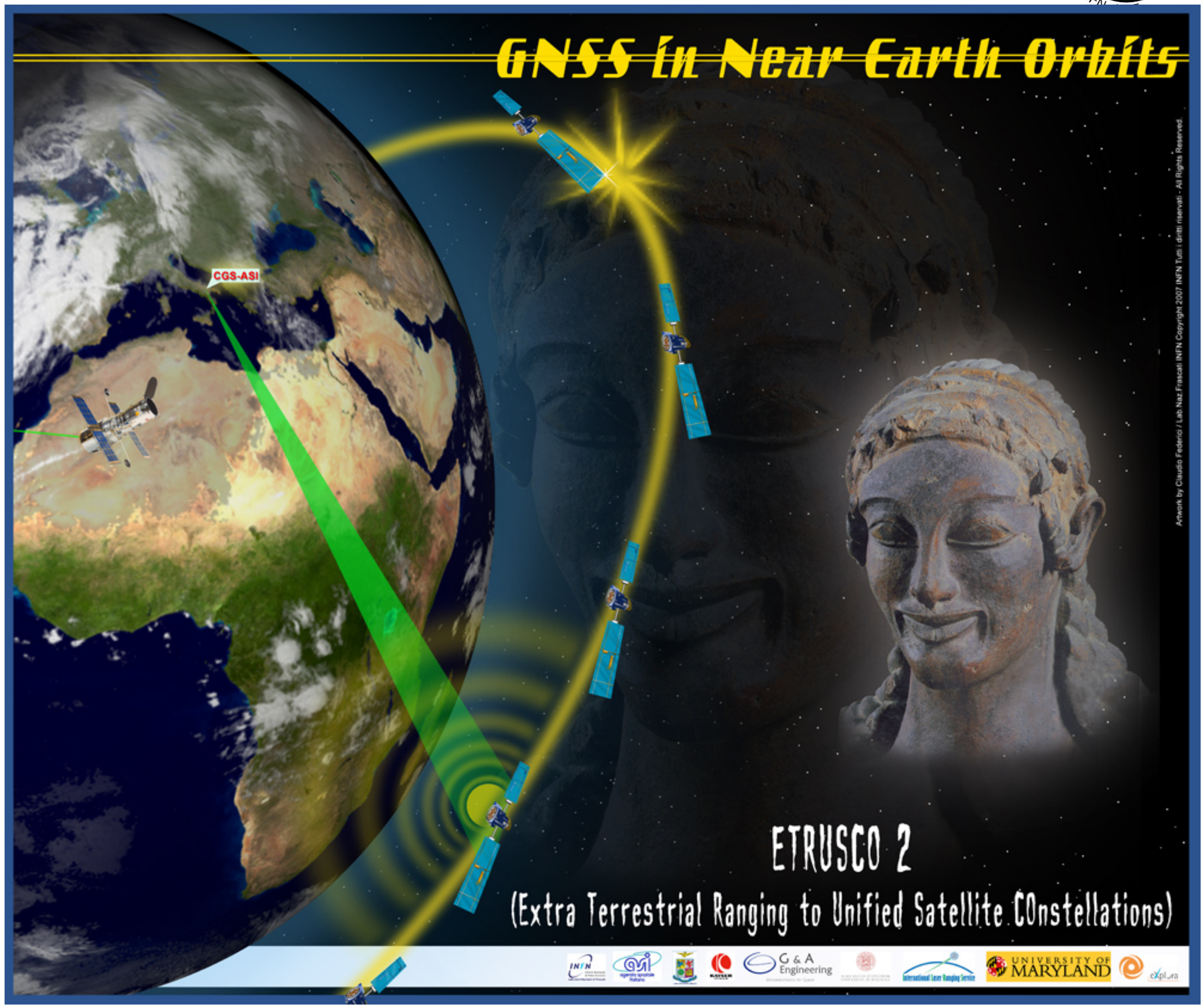
GPS/GLO/GIOVE: ~87% degradation

ETRUSCO-2

ASI-INFN contract n. I/077/09/0.

Development and SCF-Test of GNSS Retroreflector Arrays (**GRA**).

LAGEOS used as a reference, standard target.



ETRUSCO-2: work program

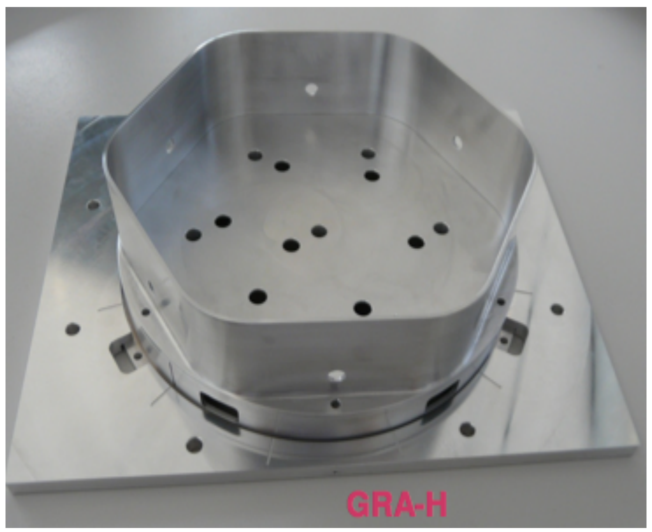
- Continuation of INFN R&D (2006-2009) with a full-blown project of technological development.
  - Ranked 4th out of 164 proposal in response to a nation-wide call issued by ASI in 2007.
- Targeted to Galileo and GPS-III, open to other GNSS constellations.
  - INFN is Prime Contractor.
  - Scientific partners:
    - ASI-CGS (G. Bianco et al), U. of Bologna (S. Zerbini).
  - Three Italian SME sub-contractors.

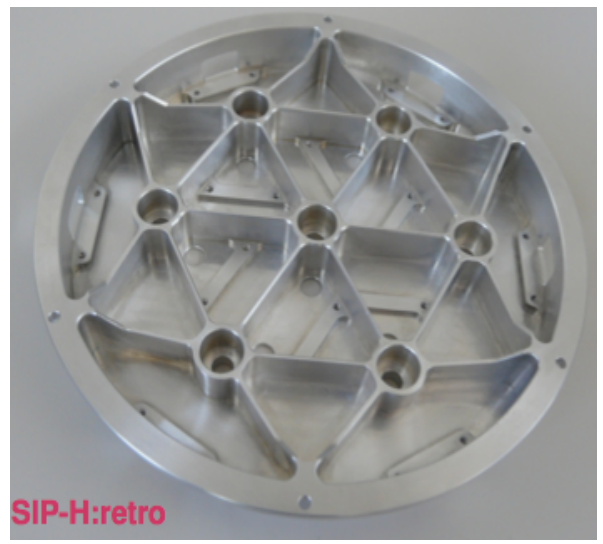
ETRUSCO-2: main hw products

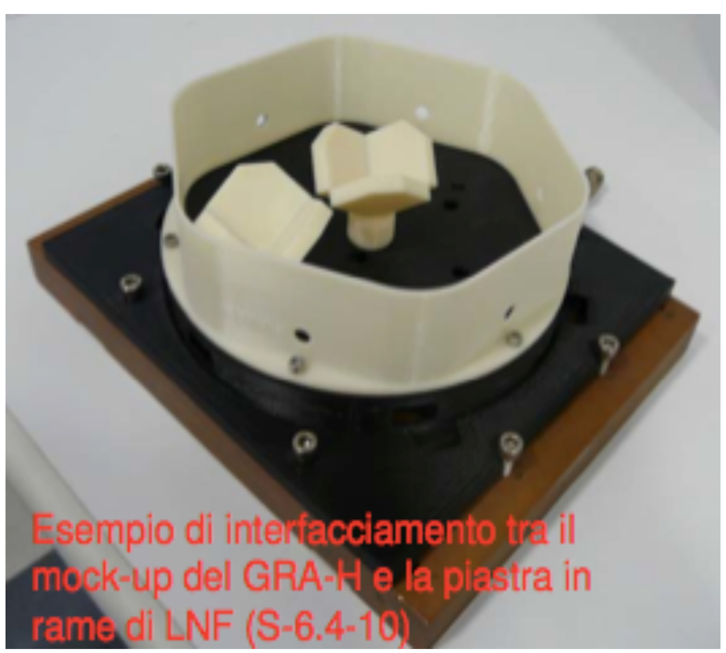
- New SCF-G, optimized for GNSS constellations.
  - Inherits from SCF, built by INFN with SME sub-contractor.
  - Delivered at beginning of 2012.
- Prototype GNSS Retroreflector Array, built with hollow technology, the GRA-H: 7 CCRs of which 6 on a ring and one in the center.
  - Inherits from R&D done with Goddard Space Flight Center.
  - Built by SME with INFN supervision and collaboration.
  - Delivered in summer 2011.
  - SCF-Tested.
- Full-size, "standard" GNSS Retroreflector Array, the GRA
  - Solid retroreflector technology chosen over hollow technology based on outcome of SCF-Test of GRA-H.
  - Design based on recommendations of ***ETRUSCO paper, Adv. Space Res. 47 (2011)***.
  - Delivered in 2012.
  - SCF-Tested.

ETRUSCO-2 SLR payloads

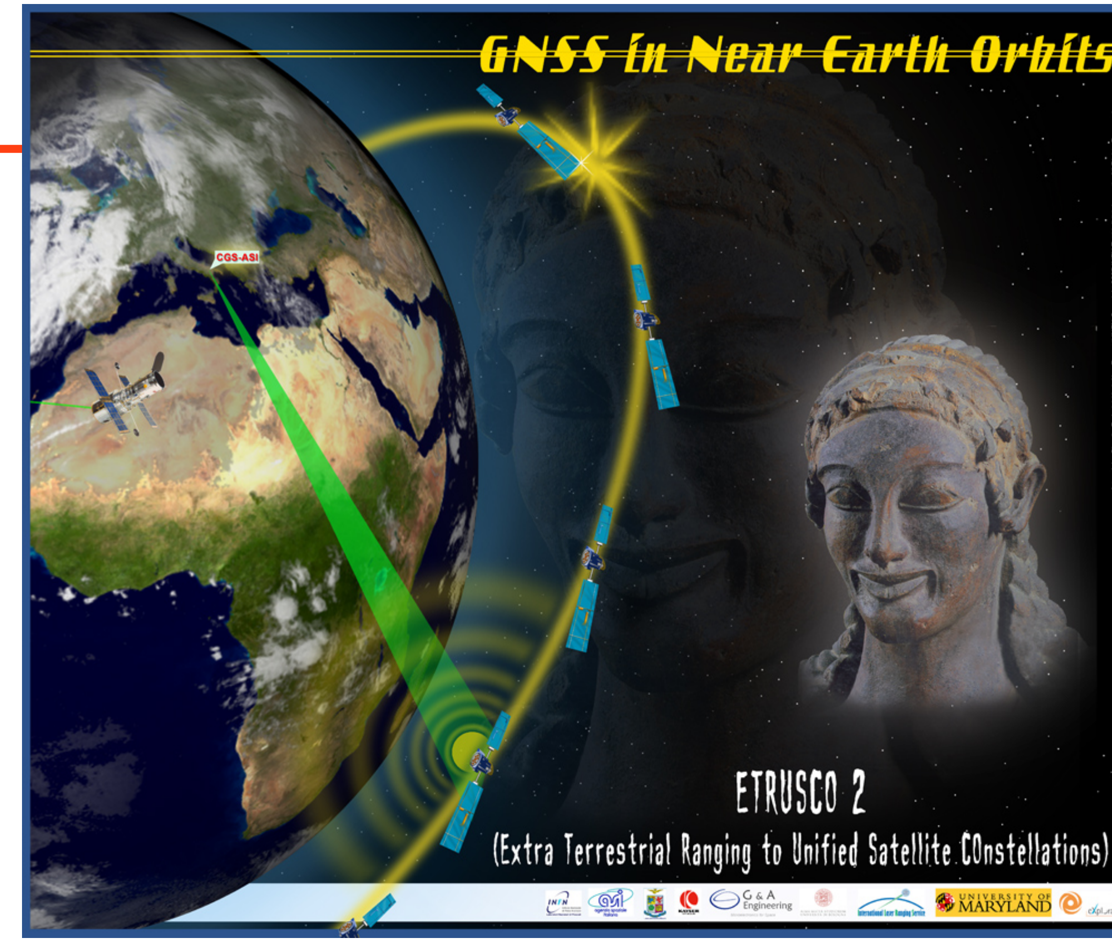
- Two new GNSS retroreflector payloads.



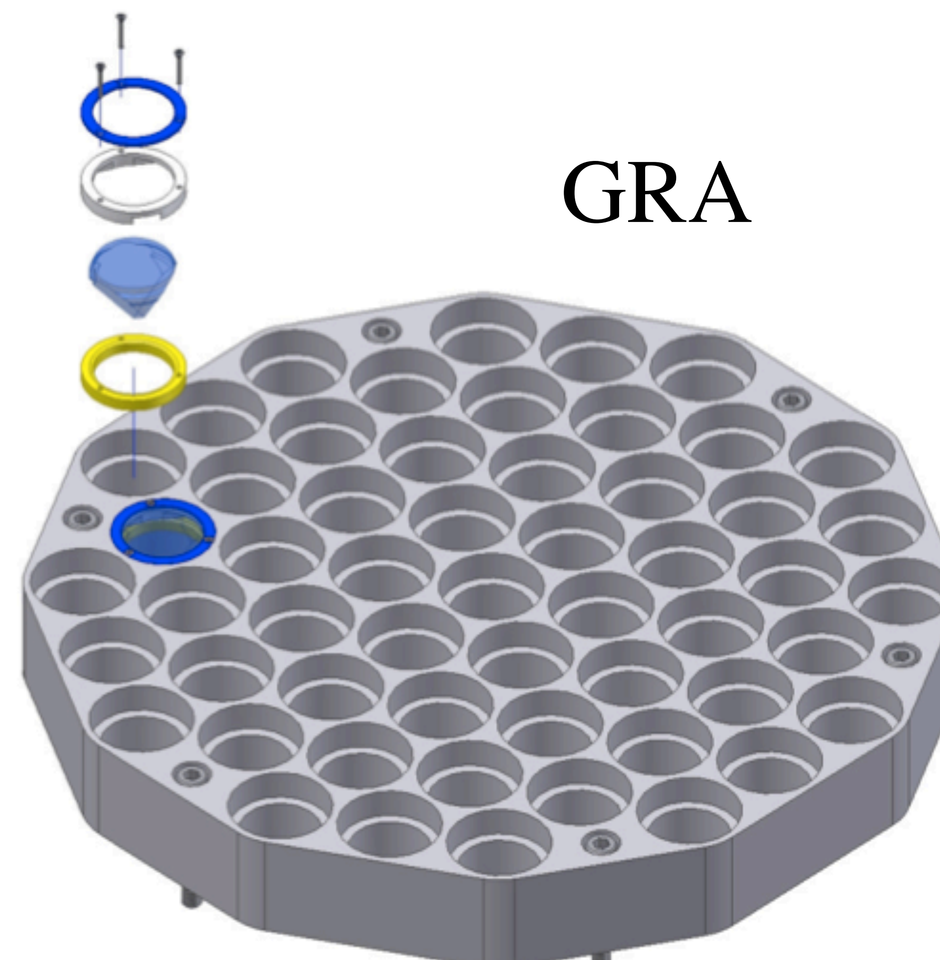




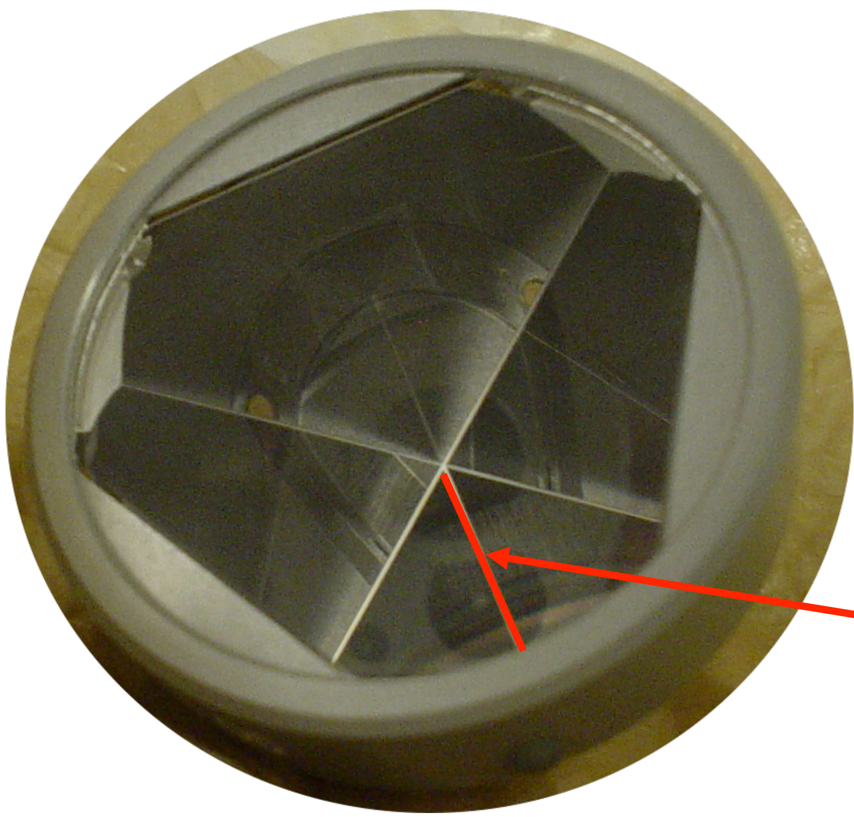
GRA-H



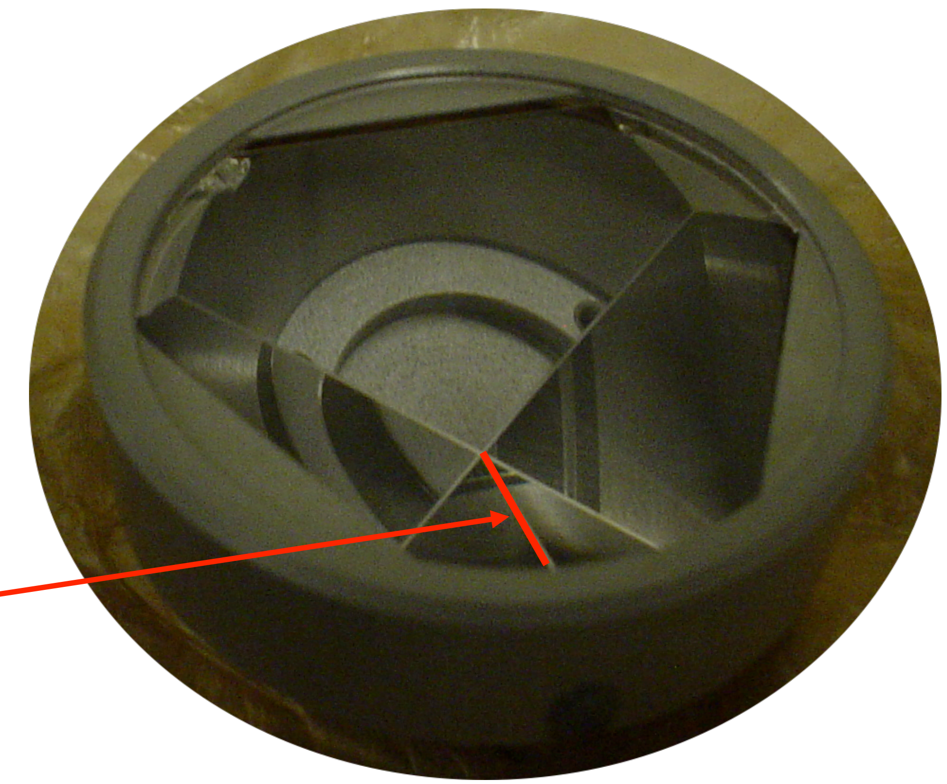
GRA



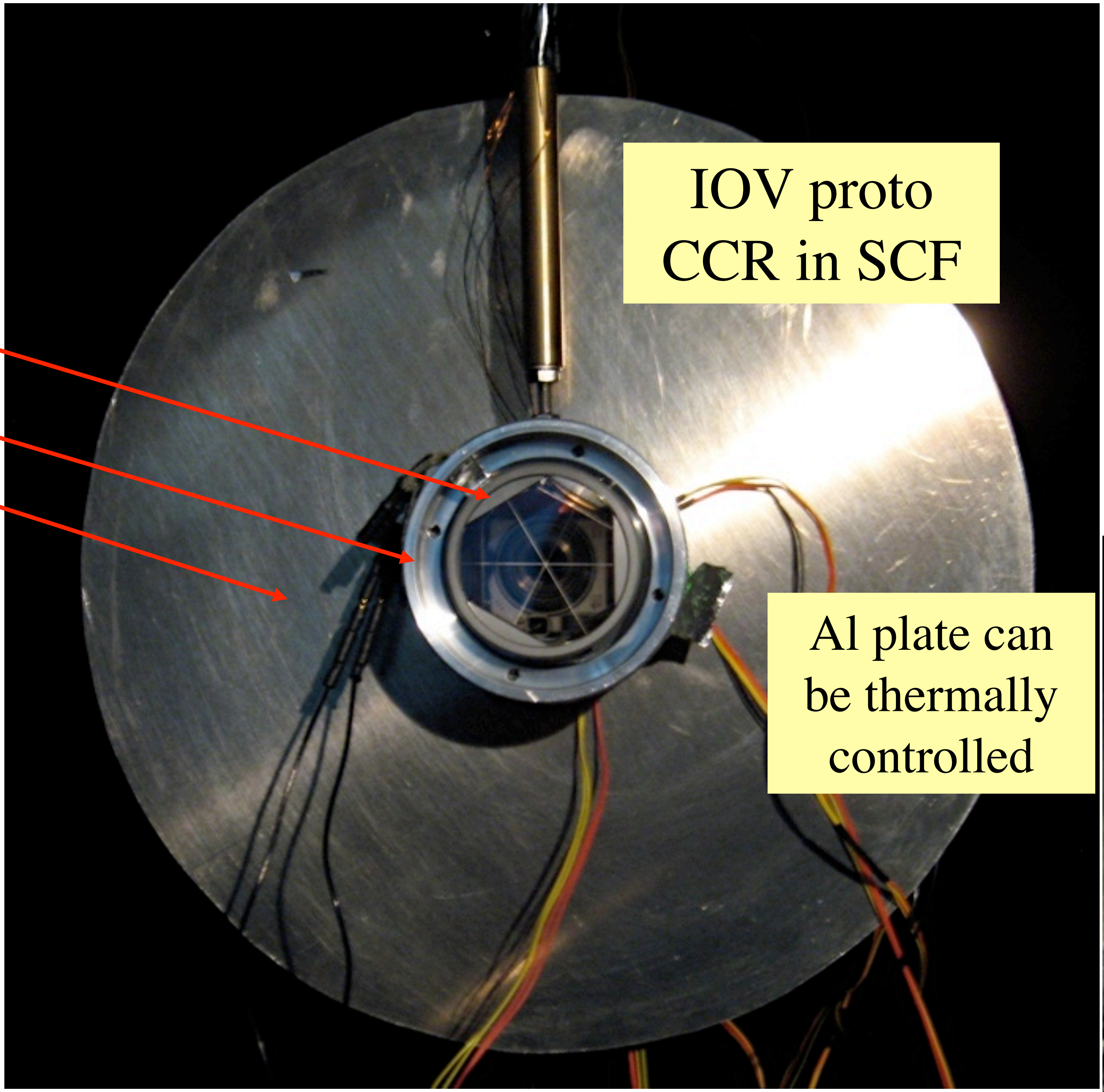
SCF-Testing of a prototype uncoated Galileo IOV CCR



Optical breakthrough (BT)
= loss of total internal
reflection (TIR).
Left photo: camera barely
visible indicates beginning of
BT at ~17° light inclination
towards physical edge.
Right: full BT above 17°

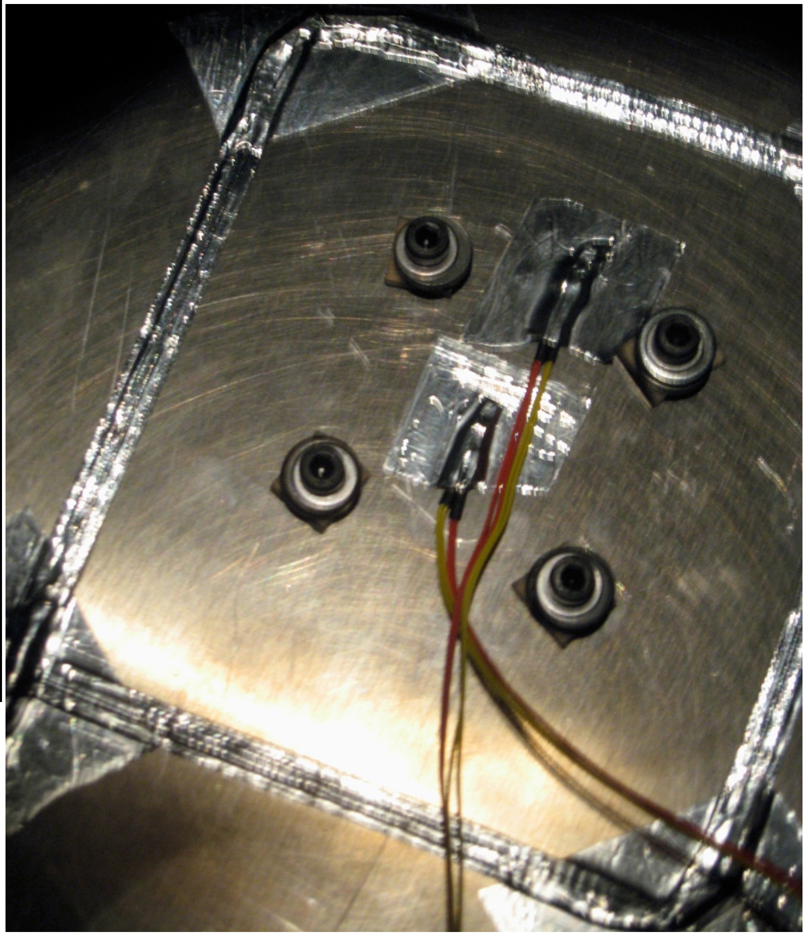


Galileo IOV CCR SCF-Test configuration



CCR housing
Al housing
Al back-plate
inside the SCF

Rear side of
Al back-plate

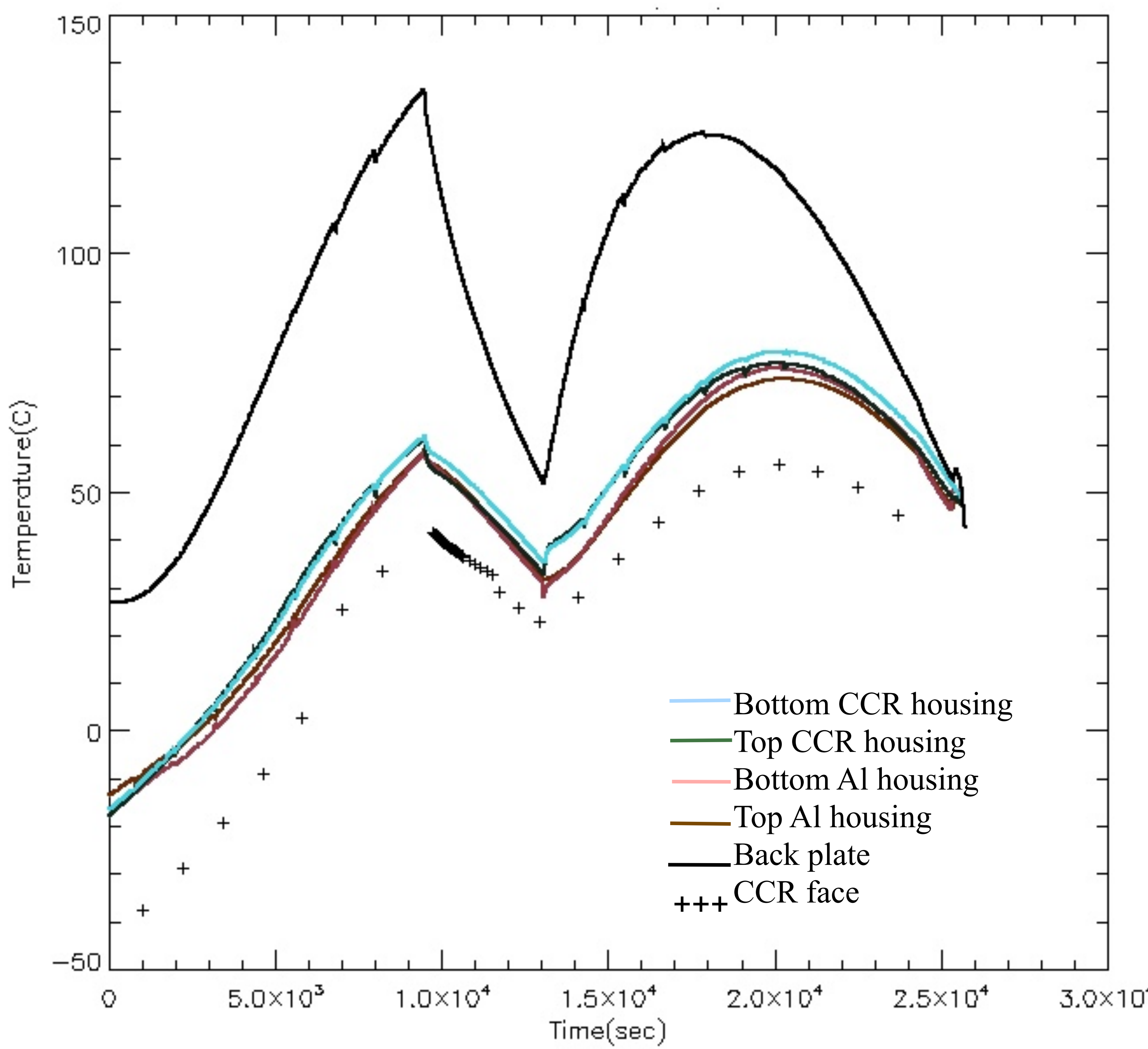


IOV CCR temperature measurements

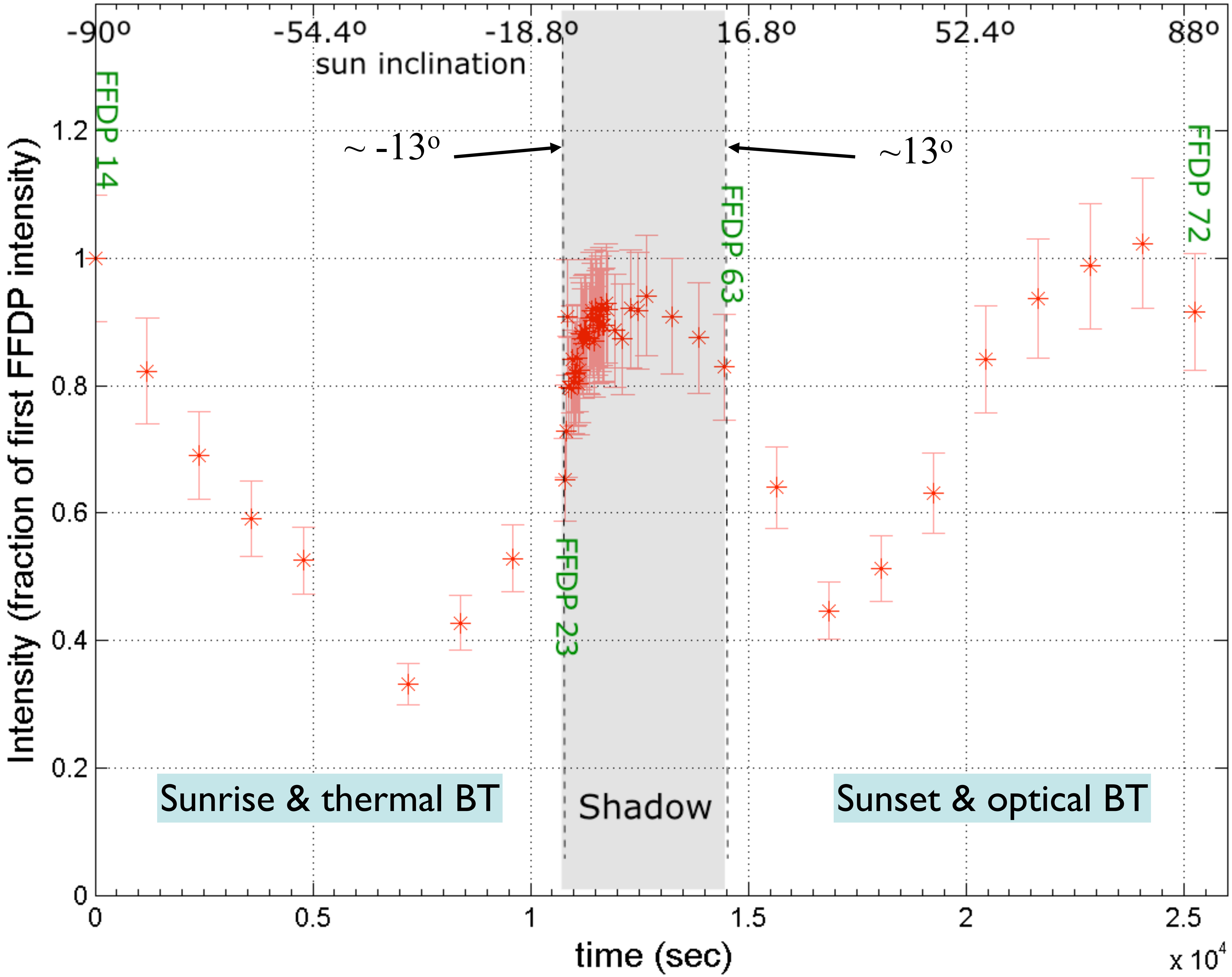
Measured temperatures vs. time (& sun inclination):

- 2 probes on CCR housing.
- 2 probes on Al housing.
- 1 probe on the back-plate.
- IR camera thermograms of the outer CCR face.

Note the very large temperature excursion, >100 K !!!

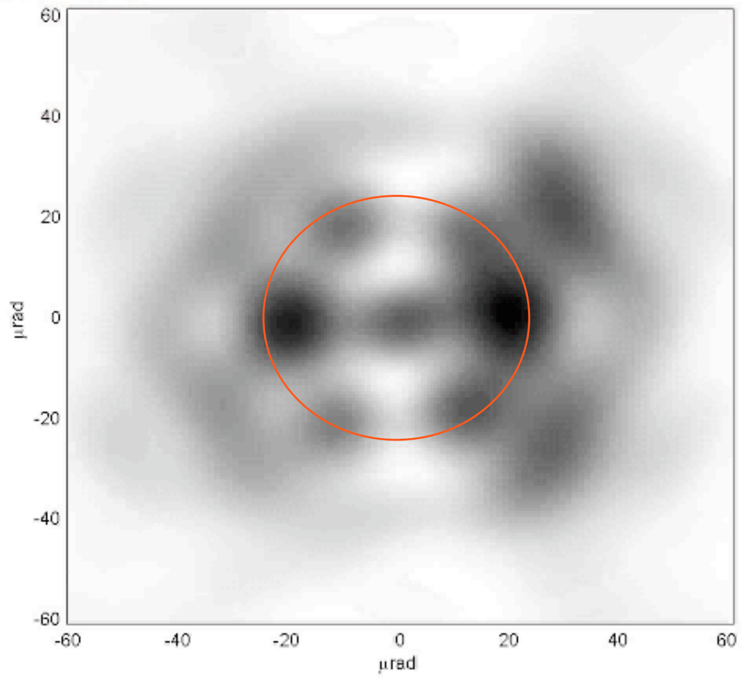


Average relative FFDP intensity at 24 μrad "velocity aberration"

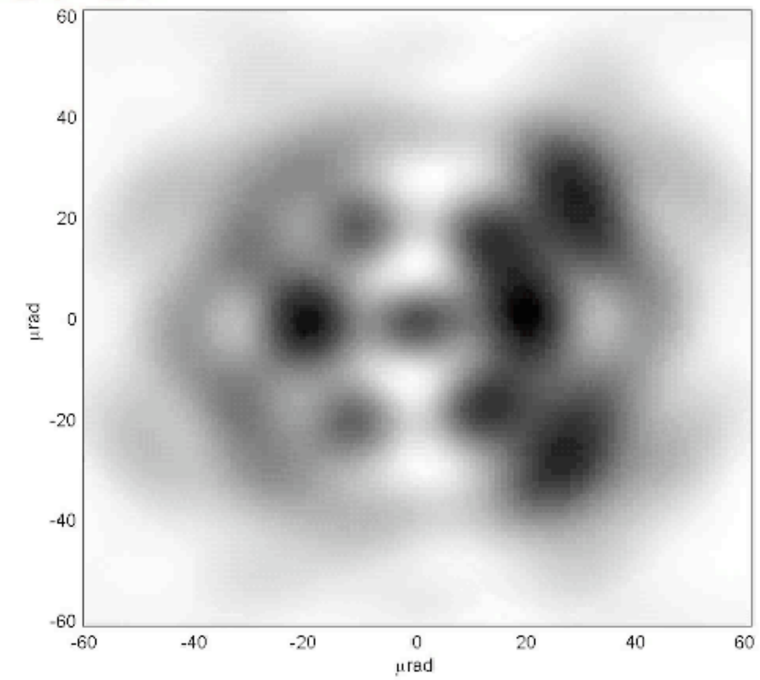


Some IOV FFDPs of previous plots

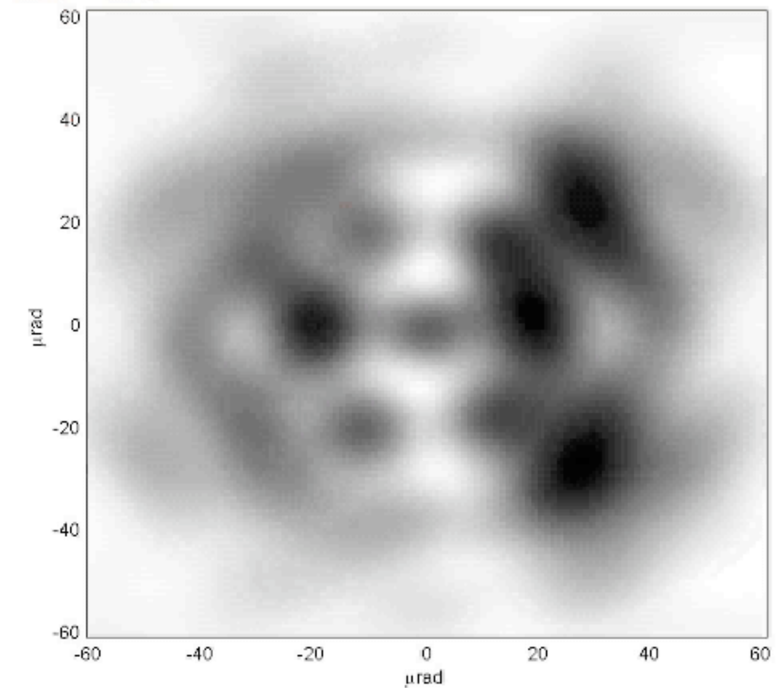
FFDP 16



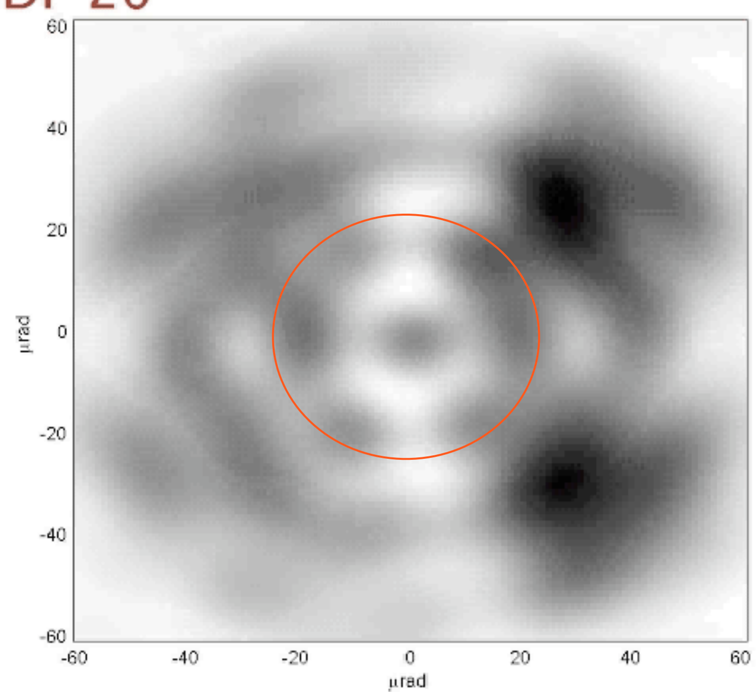
FFDP 17



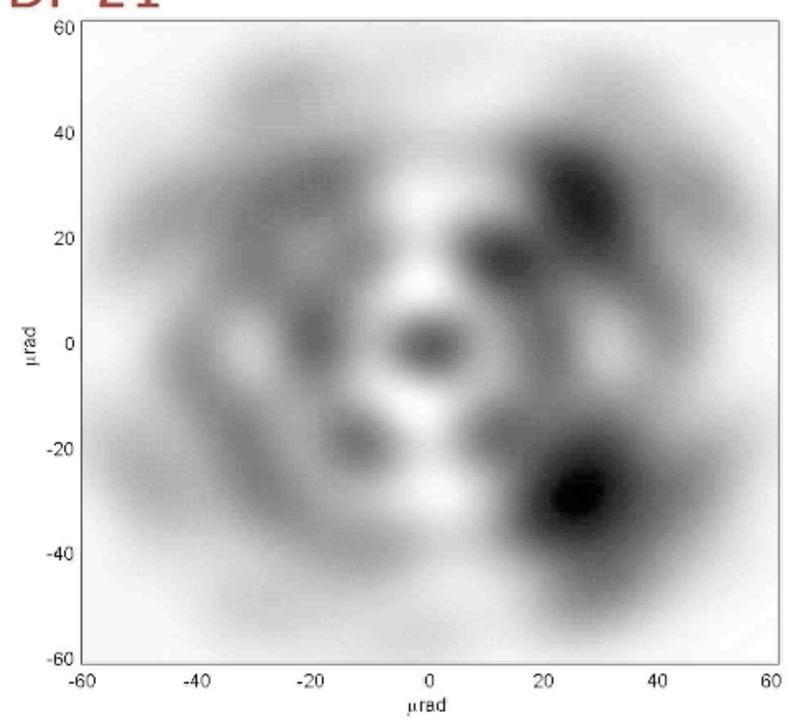
FFDP 18



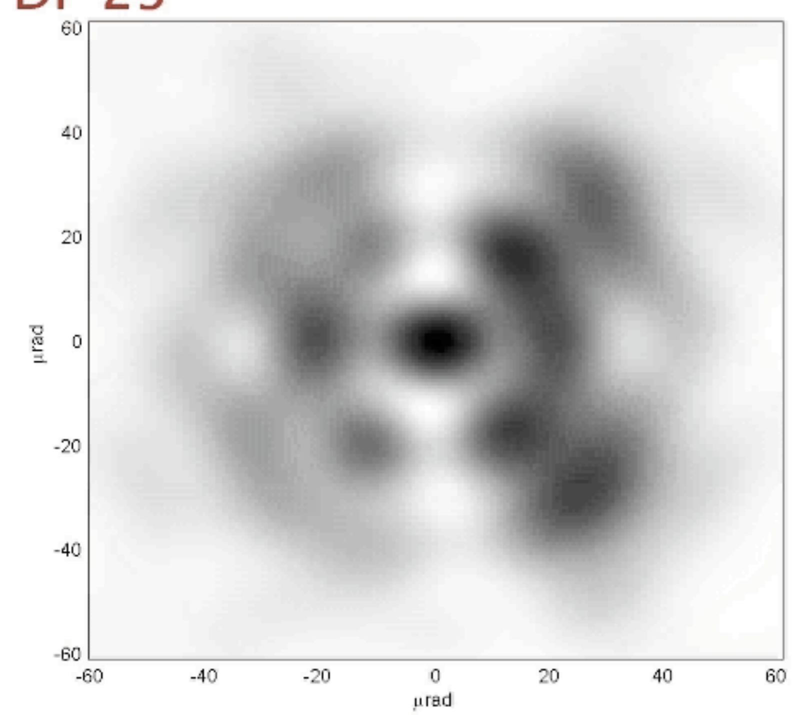
FFDP 20



FFDP 21



FFDP 23



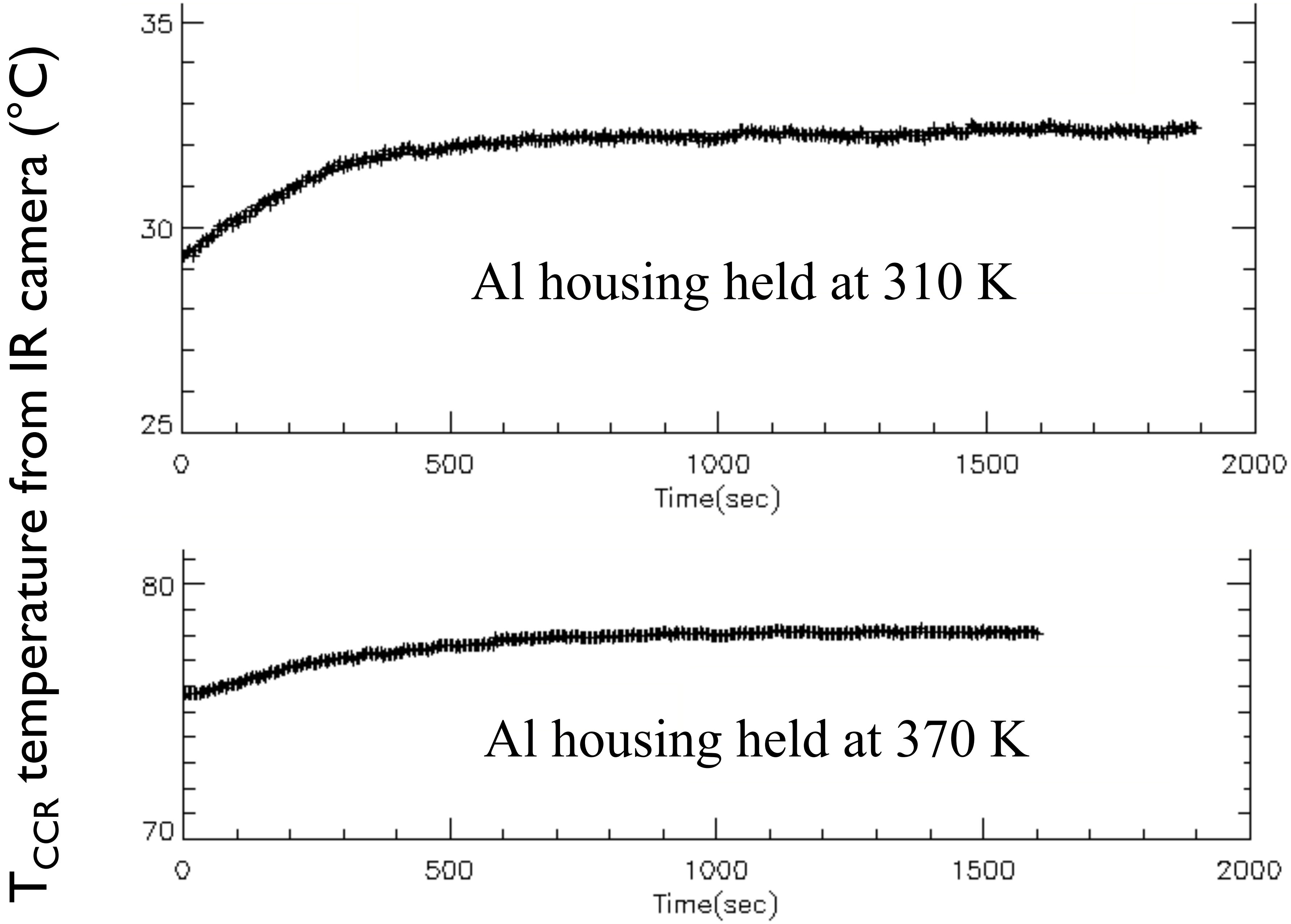
Preliminary indications & comparisons

- IOV GCO: **average** FFDP degradation ~35%.
- (Uncoated) IOV FFDP degradation for 0° sun inclination (also from other SCF-Tests not reported here): ~25%.
- (Al-coated) GPS/GLONASS/GIOVE FFDP degradation for 0° sun inclination: ~ 87%, much larger than IOV.

- **IOV CCR is BETTER than GPS/GLONASS/GIOVE CCRs!!!**

- IOV CCR shows FFDP degradation for expected optical BT inclinations > +17°, and for almost symmetric sun inclinations on the other side, < -17°, <u>where there is no optical BT</u>. We call this effect **"thermal BT"**.
  - ✓ Thermal BT could be due to an IOV CCR mounting scheme with relatively large thermal conductance. Hypothesis has been tested with τ_{CCR} measurements reported in the following.

Measurement of IOV τ_{CCR}



Exponential fits:

τ_{CCR}(T~310K) = **245** s
ΔT = 3.0 °C
T_i = 25.8 °C

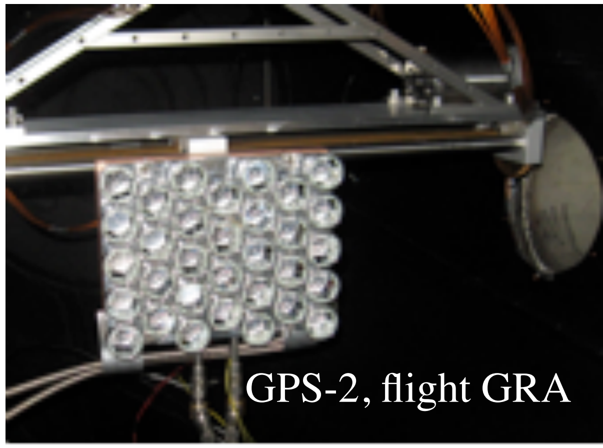
τ_{CCR}(T~370K) = **341** s
ΔT = 2.6 °C
T_i = 75.5 °C

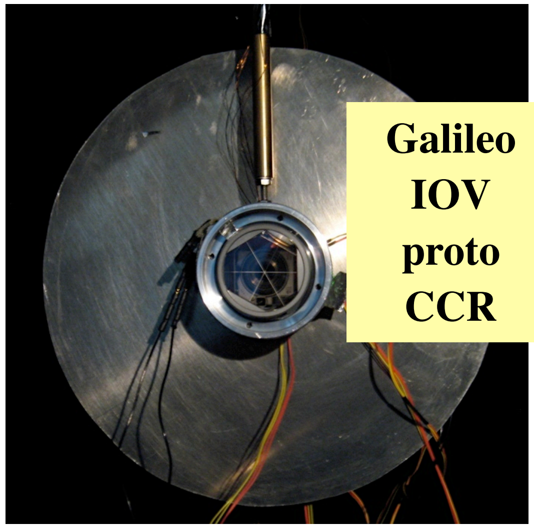
IOV τ_{CCR} increases with T of the Al-housing by ~30%.

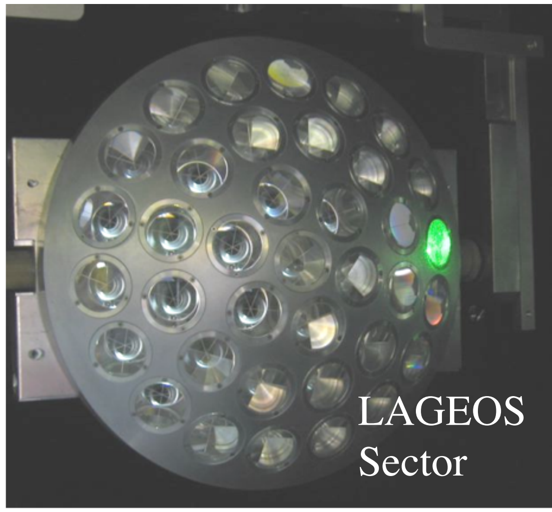
Instead, LAGEOS τ_{CCR} decreases with T of the bulk Al, as $1/T^3$.

Preliminary indications from IOV τ_{CCR}

- IOV $\tau_{CCR} \sim 250$ sec at 310 K, shorter than previous SCF-Test measurements.
  - ✓Al-coated GPS/GLO/GIOVE CCRs of flight array and a prototype CCR: $\tau_{CCR} \sim 700\text{-}1100$ sec
  - ✓Many uncoated CCRs of the LAGEOS "Sector", for which $\tau_{CCR} \sim$ thousands of seconds
- IOV τ_{CCR} increases from 310 K to 370 K by ~30%; this indicates that in the CCR mounting heat conduction dominates.
- For LAGEOS we measured $\tau_{CCR} \sim 1/T^3$; this indicates that radiative heat exchange dominates in an optimized CCR mounting (confirmed by simulations)







Conclusions

Conclusions (I)

- Galileo: Flagship Programme of the European Union.
  - worth ~ 800 G€ per year.

- SCF-Test: new industry-standard for GNSS, space geodesy, test of relativistic gravity and lunar planetary science.

- With ETRUSCO-2 (ASI-INFN project) we doubled and extended our metrological capabilities for retroreflector testing, we built and SCF-Tested a prototype hollow GRA-H and a full-size, standard GRA for all GNSS constellations.

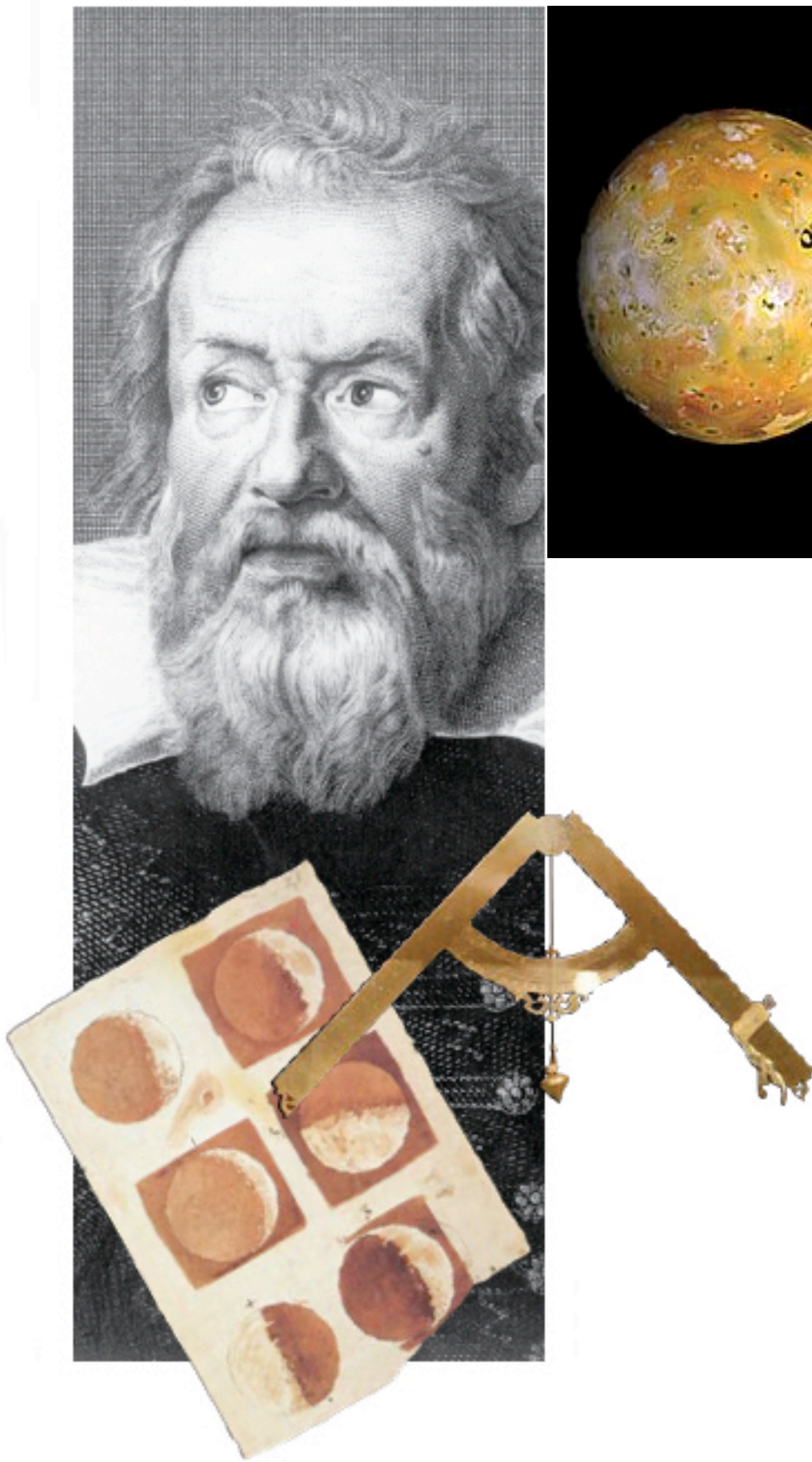
Conclusions (II)

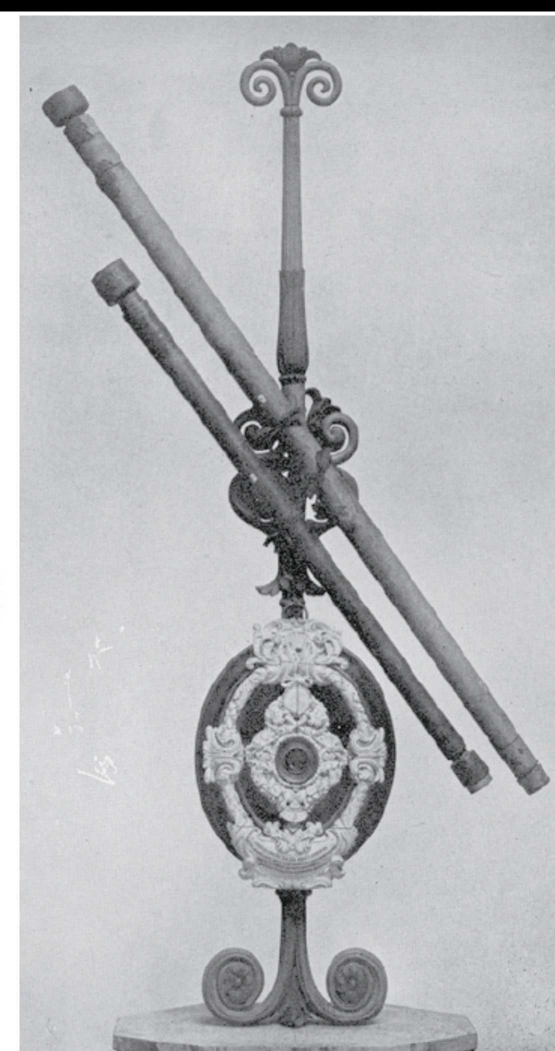
- New SCF-Test/Revision-ETRUSCO-2 (except for the WI) applied to a prototype Galileo IOV CCR.
- **This specific IOV CCR is better than GLONASS/GPS/GIOVE.**
  - **Al-coating removed, finally, on modern GNSS, after 30 years, thanks to our SCF-Test results.**
- Important to SCF-Test more IOV retroreflectors.
- Mandatory to SCF-Test FOC-1 retroreflectors, which are different from IOV (different makers).
- Ultimate goal: develop and SCF-Test best possible GRA for FOC-2, with a pan-European effort, to reduce dependence of Europe's flagship programme from non-European laser retroreflector technologies.
- Discussions underway for GPS-3 and other GNSS constellations: IRNSS, COMPASS, QZSS.

THANKS!

(special thanks to Alessandro Boni and Claudio Cantone for providing slides)

Galileo: Europe’s satellite navigation system





The constellation is named after the Italian astronomer Galileo Galilei (1564–1642), famous as the first to turn a telescope to the sky. His discovery of Jupiter’s largest four moons proved invaluable for early navigation: their orbital motion could be used as a celestial clock, visible from all over Earth.

Why Galileo?

“Galileo is the European global satellite-based navigation system

Until now, global navigation satellite system (GNSS) users around the world have had to depend on American GPS or Russian Glonass signals. Galileo gives users a new and reliable alternative, run by civil, not military authorities.

Satellite positioning is now an essential tool for all forms of transportation; if GNSS signals were switched off tomorrow, truck and taxi drivers, ship and aircraft crews, and millions of average citizens around the world would be lost – literally” (European Global Navigation Satellite Systems Agency - www.gsa.europa.eu).

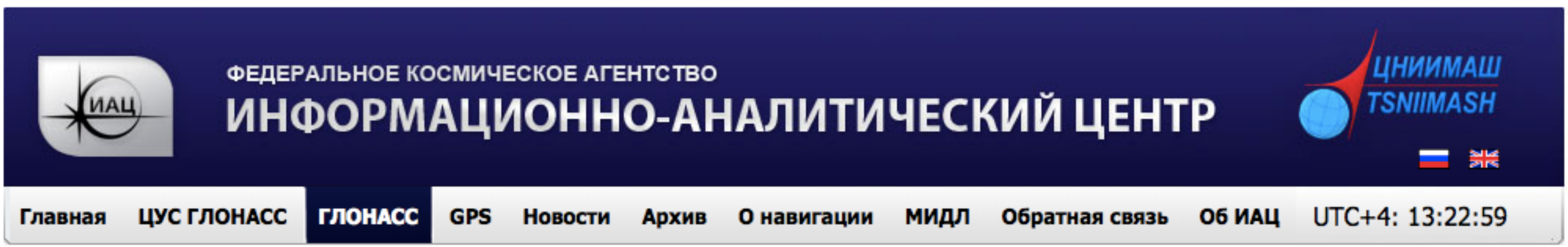
Why Galileo?

Galileo is a strategic program:

- The European Commission (EC) estimates that 6-7% of European GDP, around 800 billion by value, is dependent on satellite navigation.
- The EC and European Space Agency (ESA) joined forces to build Galileo: European users have no alternative today other than to take their positions from US GPS or Russian Glonass satellites.
- By being inter-operable with GPS and GLONASS, Galileo will allow positions to be determined accurately for most places on Earth, even in high rise cities where buildings obscure signals from satellites low on the horizon.
- Galileo will achieve better coverage at high latitudes because satellites will be orbiting at a greater inclination to the equator than GPS.
- Europe will be able to exploit the opportunities provided by satellite navigation to the full extent.

If you want to know more...

www.igs.org



Состав группировки КНС ГЛОНАСС на 16.06.2014г.

Всего в составе ОГ ГЛОНАСС	30 КА
Используются по целевому назначению	24 КА
На этапе ввода в систему	1 КА
Временно выведены на техобслуживание	-
На исследовании Главного конструктора	2 КА
Орбитальный резерв	2 КА
На этапе летных испытаний	1 КА

glonass-iac.ru

Galileo: EU Flagship Programme

Galileo Ground Segment

Satellite navigation relies on the receiver to derive the time and point in space that the signal was emitted, with an extremely high level of accuracy. This information is embedded within the signal itself. But onboard atomic clocks can still drift - and just a billionth of a second clock error corresponds to a 30 cm range error.

300,000,000 m/s x 10^{-9} s = 0,3 m (range error)

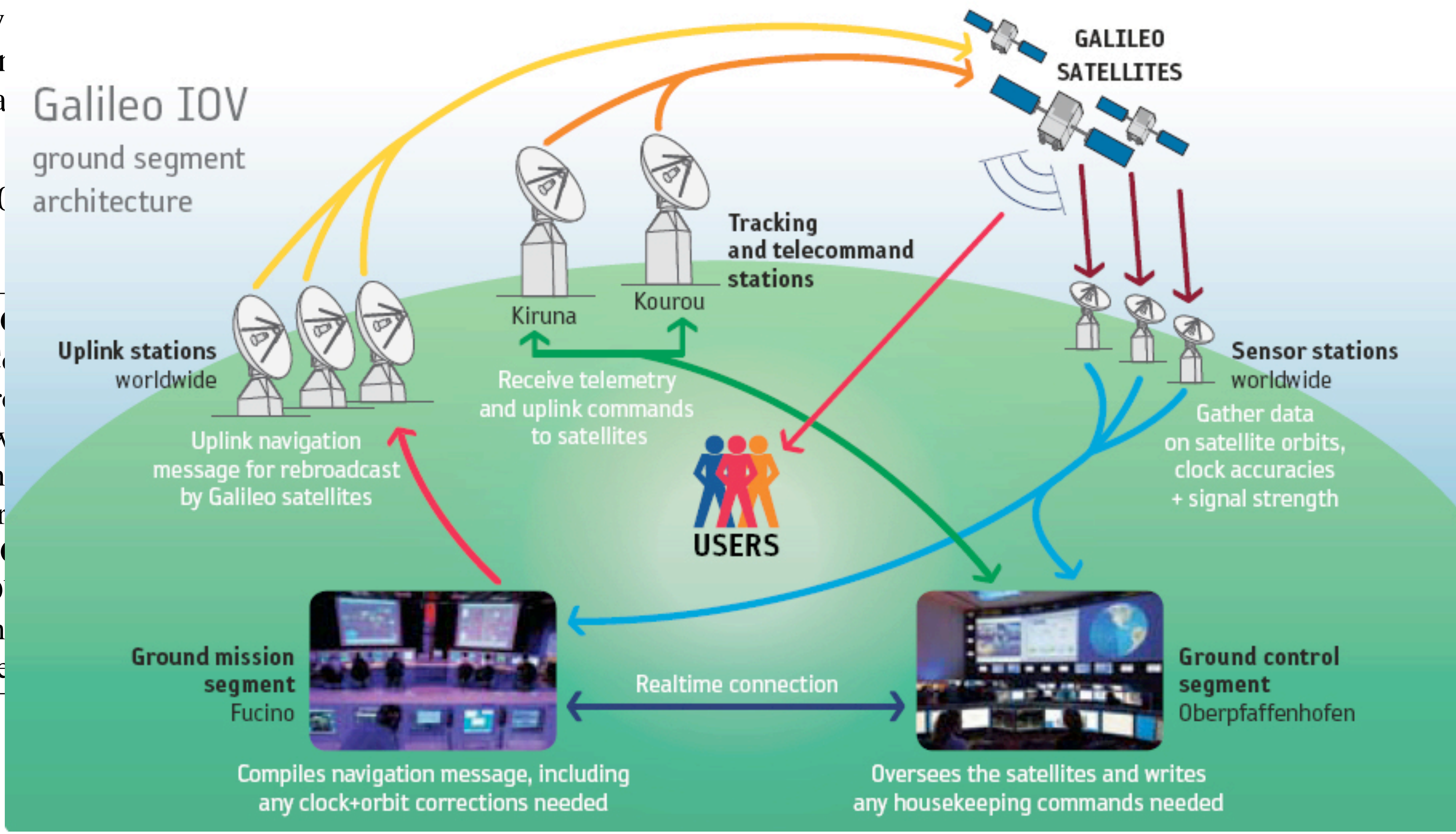
- **Ground Mission Segment (GMS):** in Fucino Control Centre (Italy). It processes data collected from a worldwide network of stations. GMS has two million lines of dedicated software code, 500 internal functions, 400 messages and 600 signals in order to process data.
- **Ground Control Segment (GCS):** in Oberpfaffenhofen Control Centre (Germany). It monitors and controls the constellation with a high degree of automation.

- **Tracking and Tele-Command Stations:** two, at Kiruna in Sweden and Kourou in French Guiana.
- **Uplink Stations:** a network of stations to uplink the navigation and integrity data.
- **Sensor Stations:** a global network providing coverage for clock synchronization and orbit measurements.
- **Data Dissemination Network:** interconnecting all Galileo ground facilities.

www.gsa.europa.eu

Galileo: EU Flagship Programme

Galileo Ground Segment



Galileo: EU Flagship Programme

FOC Satellites

• IOV configuration will be extended to IOC (Initial Operational Capability) by mid-decade.

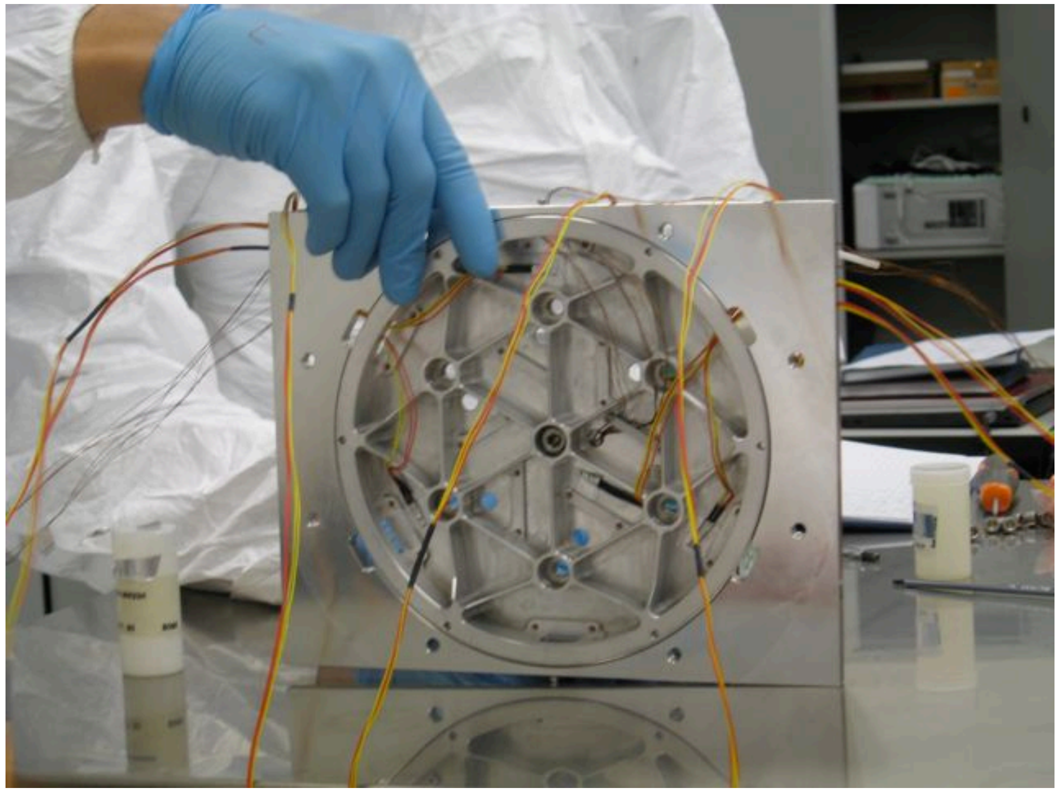
• As the constellation builds up, FOC (Full Operational Capability) will be reached by the end of the decade.

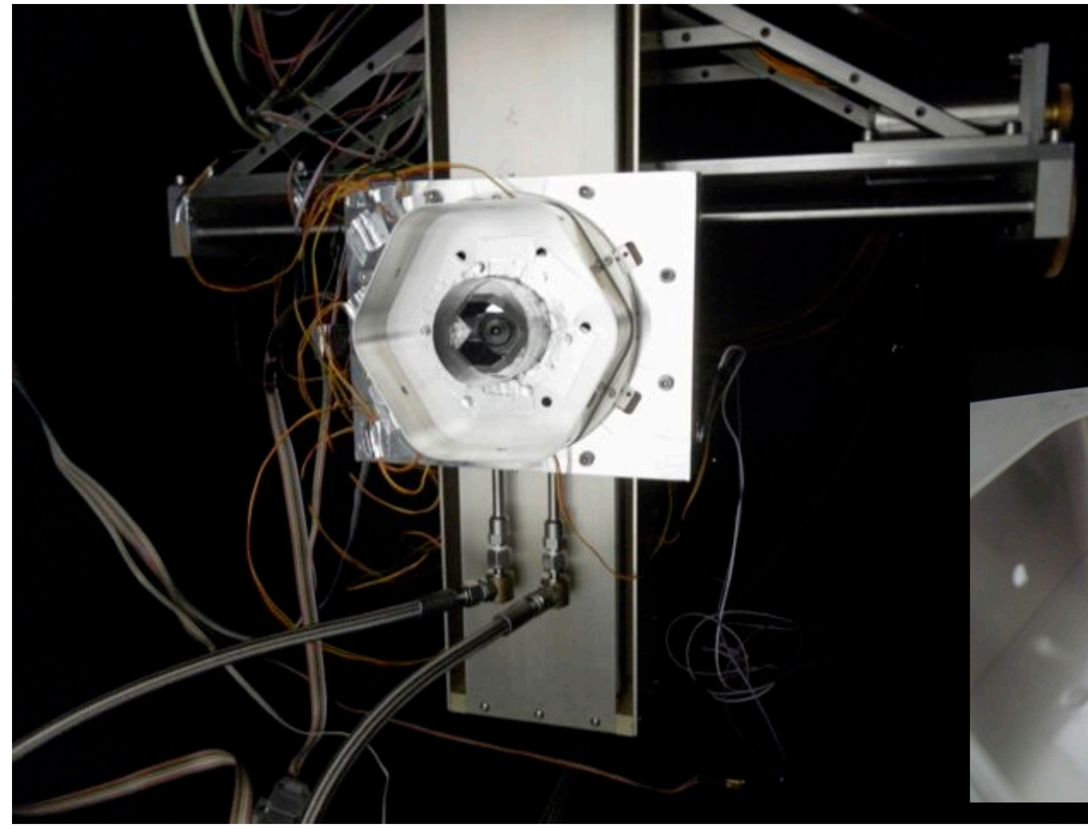
www.gsc-europa.eu

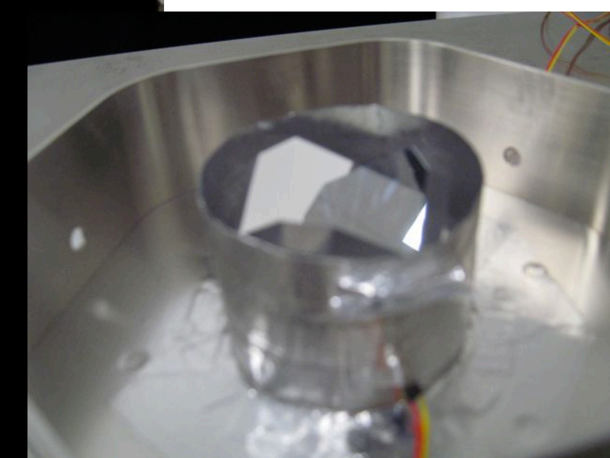
Internal anatomy of the Galileo IOV satellite

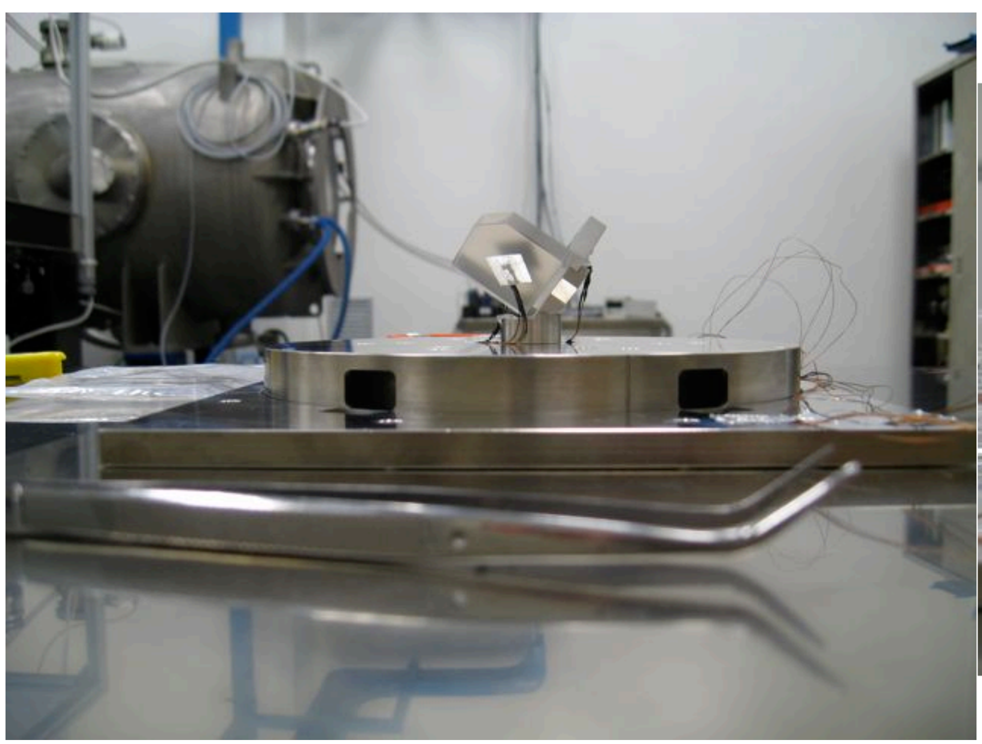
- **Maser (x2) and rubidium (x2) clocks:** The two rubidium atomic clocks and two hydrogen passive maser clocks are the most complex elements of the payload. Both highly stable clocks are the key to obtaining high-quality navigation signals.
  - **Clocks accuracy** ~ $1 / 10^{14}$
- **Clock monitoring and control unit:** provides the interface between the four clocks and the navigation signal generator unit. It also ensures that the frequencies produced by the master clock and active spare are in phase, so that the spare can take over instantly should the master clock fail.
- **Navigation signal generator unit:** generates the navigation signals using input from the clock monitoring and control unit and the uplinked navigation and integrity data from the C-band antenna. The navigation signals are converted to L-band for broadcast to users.
- **Gyroscopes:** measure the rotation of the satellite.
- **Reaction wheels:** control the rotation of the satellite. When they spin, so does the satellite, in the opposite direction. The satellite rotates twice per orbit to allow the solar wings to face the Sun's rays.
- **Magneto-torquer:** modifies the speed of rotation of the reaction wheels by introducing a magnetism-based torque (turning force) in the opposite direction.
- **Power conditioning and distribution unit:** regulates and controls power from the solar array and batteries for distribution to all the satellite's subsystems and payload.
- **Onboard computer:** controls the satellite platform and payload.

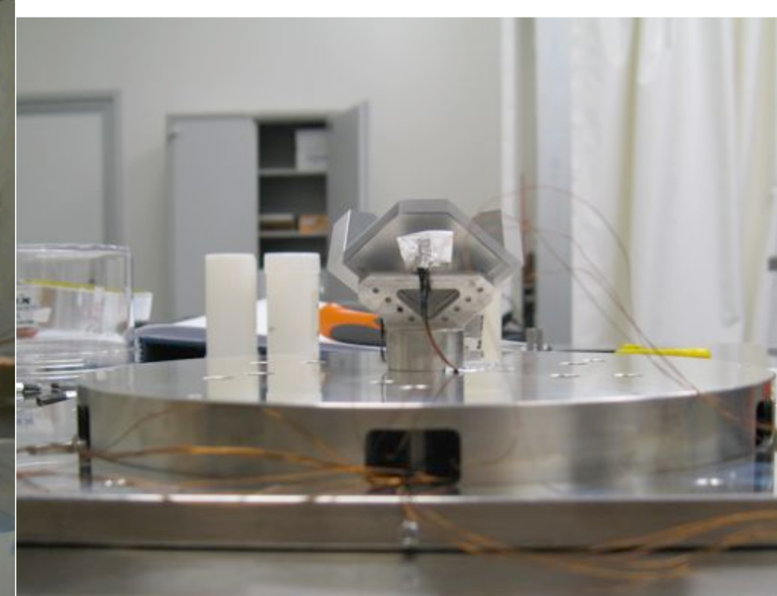
Single HCC test configuration

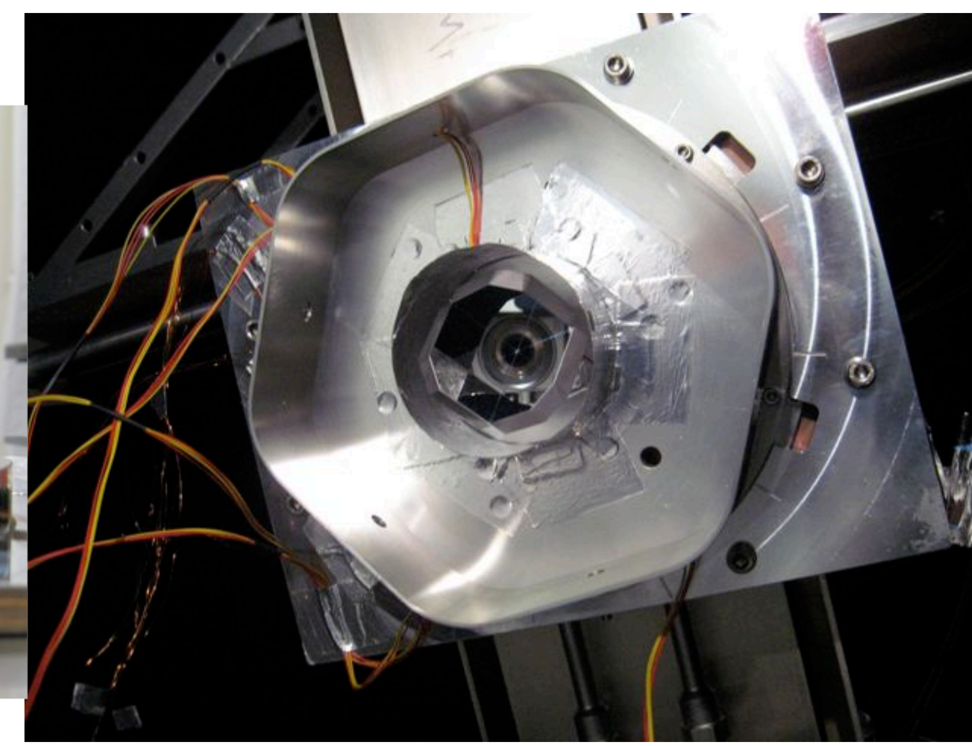






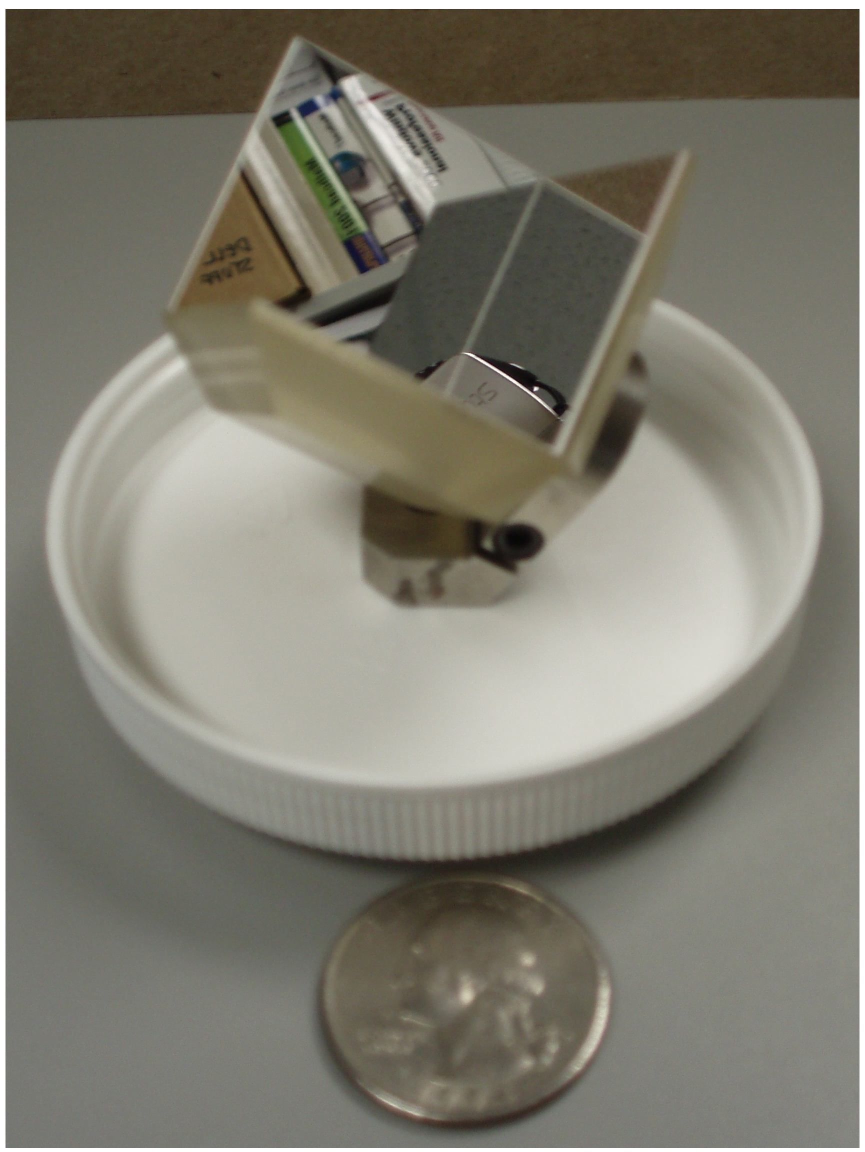






Hollow retroreflectors: a new frontier?

With ETRUSCO (INFN-CSNV) and ETRUSCO-2 (ASI-INFN) we are giving an answer (SCF-Tests and thermo-structural simulations), which depends on the specific payload.



Several advantages, but no space heritage.

Considered for LLR where a very large diameter is needed (4 inches or more).

Hollow cube prototype provided by GSFC, was SCF-Tested by INFN-LNF. Substrate is pyrex.