# ETRUSCO-2: an ASI-INFN Project of Development and SCF-Test of GNSS Retroreflector Arrays (GRA) for Galileo and the GPS-3

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**17th International Workshop on Laser Ranging**
**and**
**23rd General Assembly of the International Laser Ranging Service**
**Bad Kötzting (Germany), May 16 - 20, 2011**

# Outline

- ETRUSCO-2: ASI-INFN Project of Technological development for GNSS
  - Work program
  - Main hw products
  - SCF-Test-Revision-ET2
- Hollow retroreflectors
- Integrated modeling for GNSS Retroreflector Arrays
- Conclusions

# ETRUSCO-2 (2010-2013)

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

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

LAGEOS used as a reference, standard target

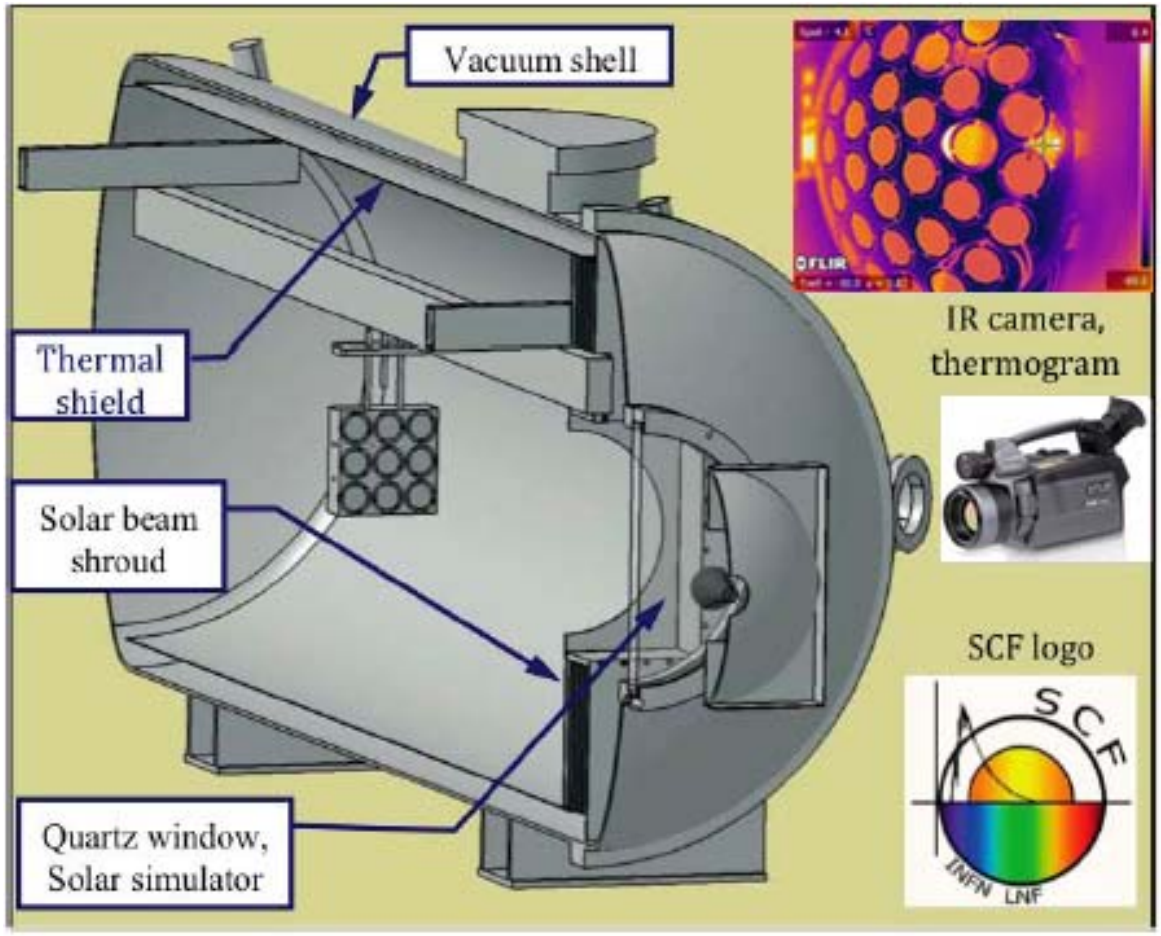
# ETRUSCO-2: work program

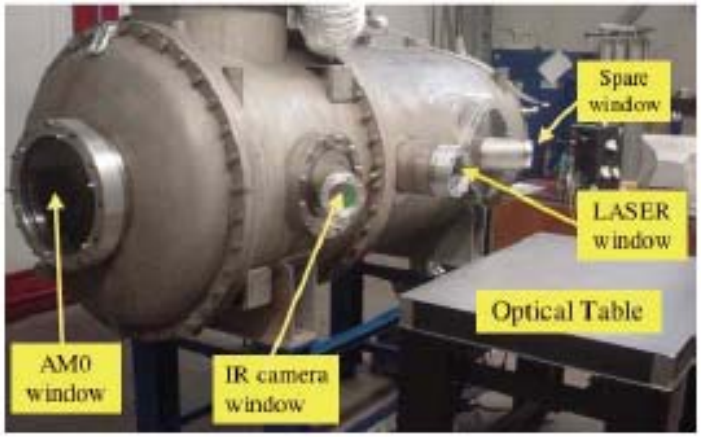

- Continuation of INFN R&D (2006-2009) with a full-blown project of technological development
  - Ranked 4th out of 164 proposal in response to a nation-wide call issued by ASI in 2007
- Targeted to Galileo and GPS-III, open to other GNSS constellations
  - INFN is Prime Contractor
  - Partners:
   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

# ETRUSCO-2: main hw products

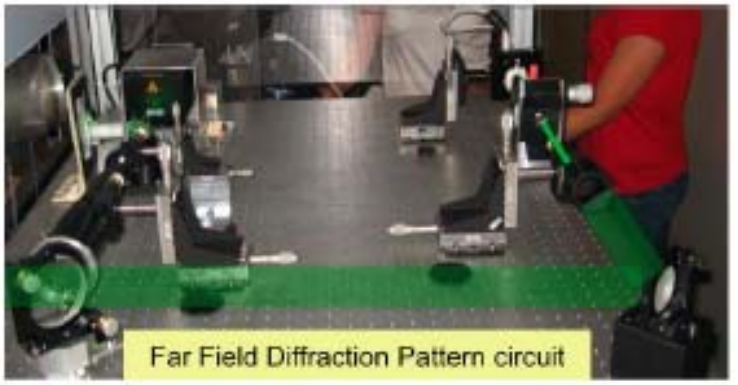

- New SCF-G, optimized for GNSS constellations
  - Inherits from SCF, built in part by SME and in part by INFN
  - Delivered by end of 2011
- Prototype GNSS Retroreflector Array, built with hollow technology, the GRA-H: 7 CCRs of which 6 on a ring and one in the center
  - Inherits from R&D done with GSFC
    - Thermo-Structural modeling presented today
    - SCF-Test: talk by Alessandro Boni
  - Built by SME with INFN supervision and collaboration
  - Delivered by summer 2011
  - SCF-Tested with existing SCF
- Full-size, "standard" GNSS Retroreflector Array, the GRA
  - Choice between hollow or solid retroreflector 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
  - To be SCF-Tested with the new SCF-G

# SLR/LLR Characterization Facility (SCF)




Optical circuit



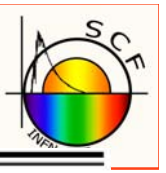

Integrated and concurrent thermal and optical measurements in laboratory-simulated space environment

# The SCF-Test (background IP of INFN)


- Laboratory-simulated space conditions. Concurrent/integrated:
  - Dark/cold/vacuum
  - Sun (AM0) and Earth IR **simulators**
  - Non-invasive IR and contact **thermometry**
  - Payload **roto-translations**
  - **Laser interrogation and sun perturbation at varying angles**
  - Payload **thermal control**
- Deliverables / Retroreflector Key Performance Indicators (KPIs)
  - **Thermal behavior**
    - $\tau_{CCR}$, thermal relaxation time
  - **Optical response**
    - Orthogonal polarizations (for uncoated reflectors)

- Note: reduced, partial, incomplete tests (compared to the full space environment) can be misleading (either optimistic or pessimistic)

# The SCF-Test (background IP of INFN)



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

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# ETRUSCO-2: more on work program

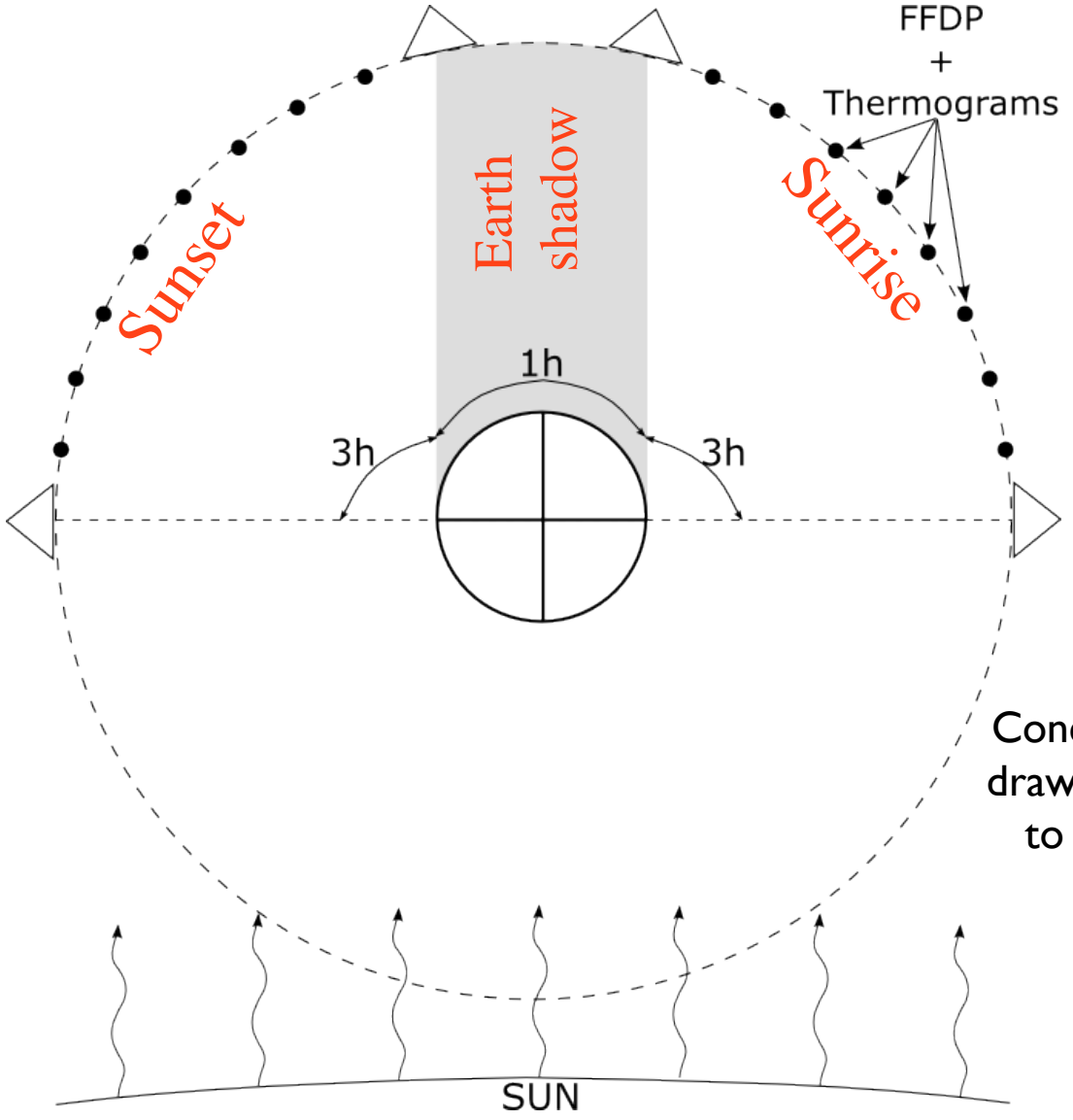
- As part of co-funding, INFN-LNF
  - Makes the SCF-Test standard (see next slide) available to ASI
  - Is completing construction of a class **10,000 Clean Room** (or better), as well as other lab resources, to provide a dedicated infrastructure where the SCF and the SCF-G will be operated
  - Will test GRA-H in 2011 with the SCF
- Will implement into the SCF-Test-Revision-ET-2 the **"critical GNSS orbit TEST"**, developed for Galileo IOV retroreflector prototype
  - Results under ESA-INFN non-disclosure agreement
  - ESA asked authorization to release IOV test results

# SCF-Test of critical GNSS half-orbit

SCF-Testing of orbit **Sunrise-Eclipse-Sunset** probes critical features of the thermal and optical behavior of the CCR: Sunset probes optical breakthrough.

**Galileo orbit**:

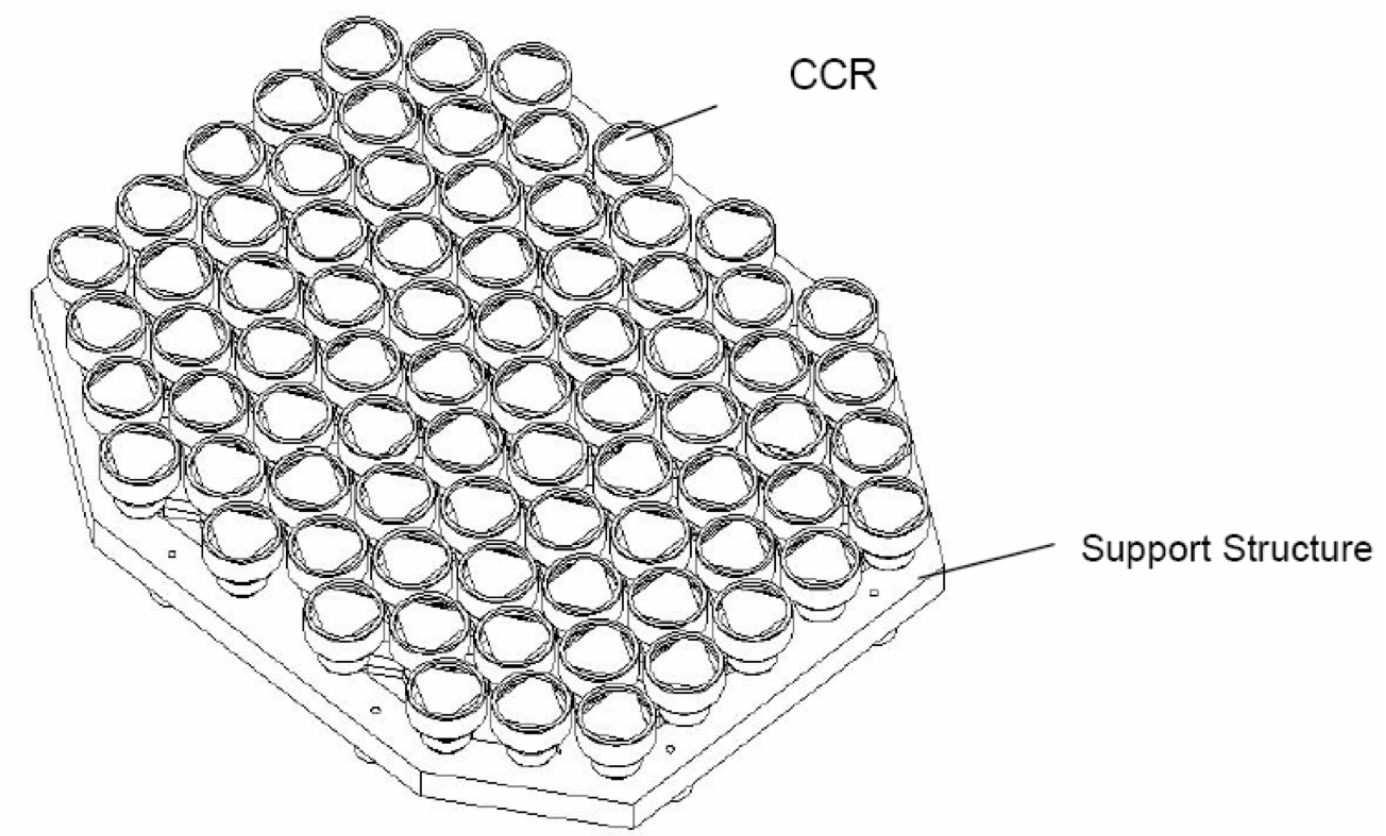
- Altitude = 23222 km
- Period ~ 14 h
- Shadow ~ 1h (cylindrical approximation)



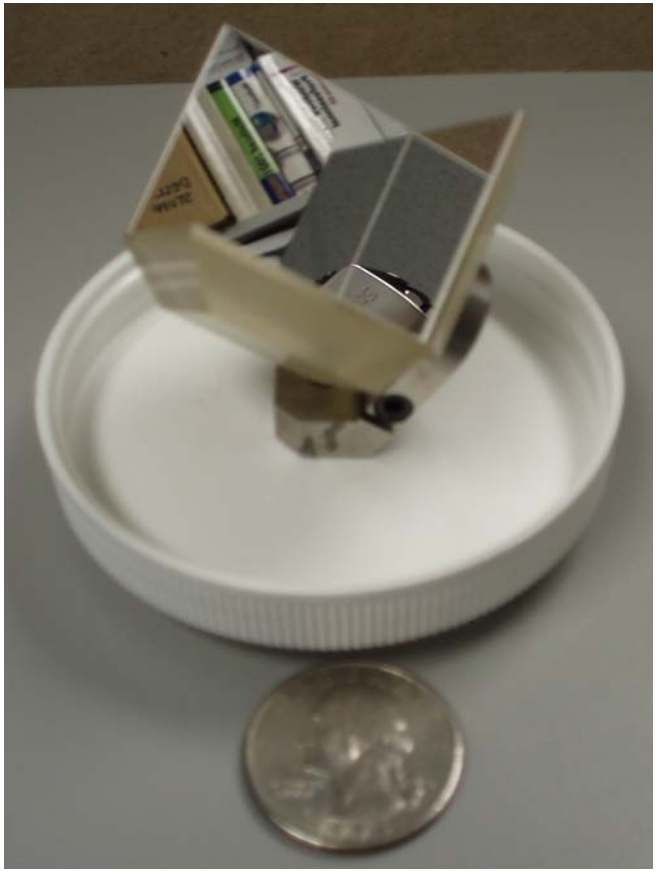

Conceptual drawing not to scale

# The Galileo IOV (In Orbit Validation) array

http://ilrs.gsfc.nasa.gov/docs/ESA-EUING-TN-10206_Issue_3.2.pdf
taken from ILRS website



# Hollow retroreflectors: a new frontier?



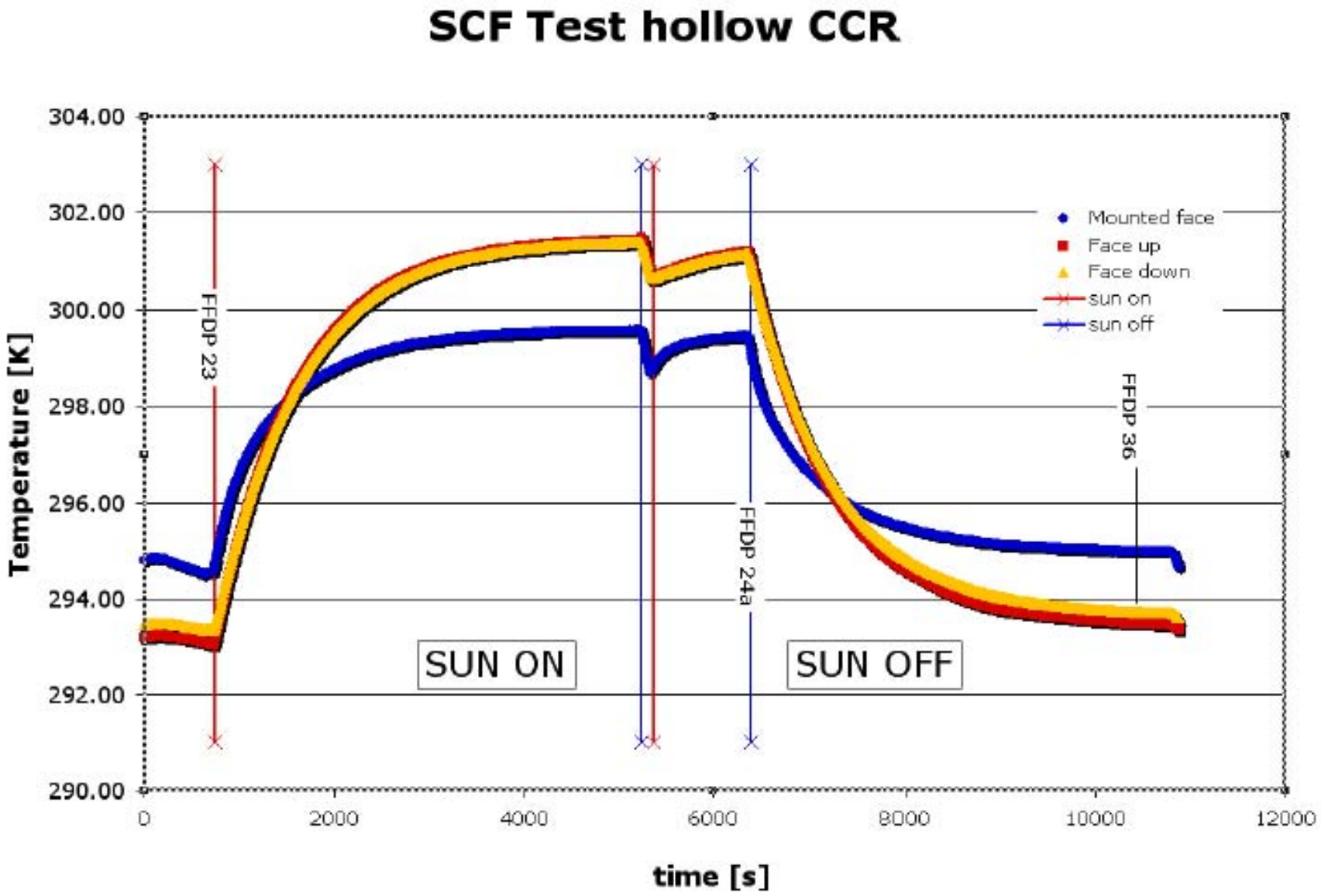
Several advantages, but no space heritage.

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

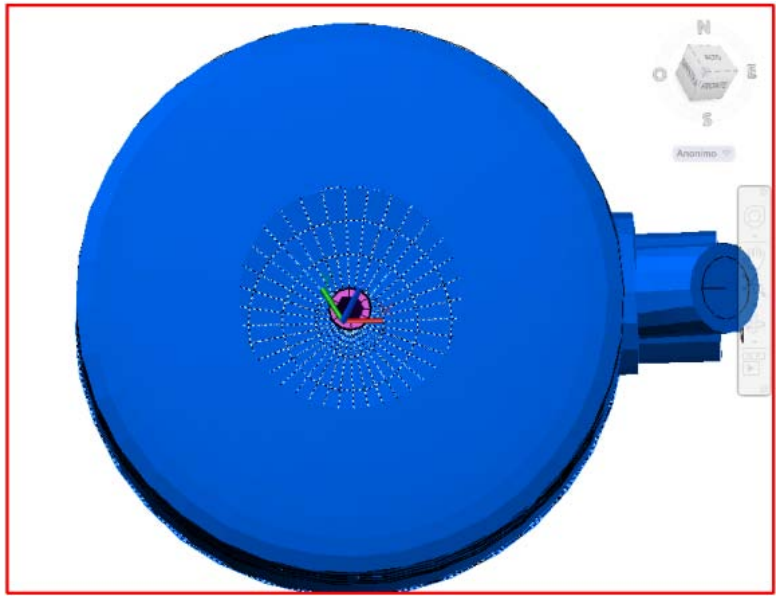
Hollow cube prototype provided by GSFC, was SCF-Tested by INFN-LNF. Substrate is pyrex.

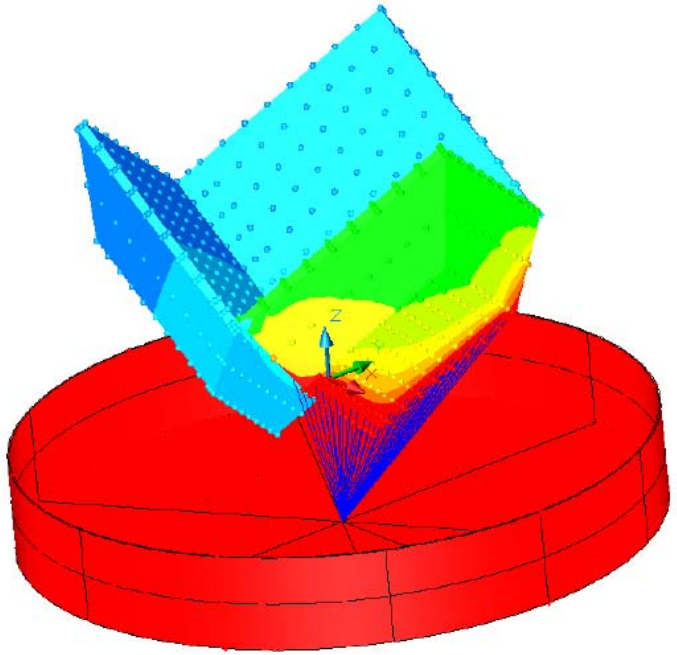
Inside the ETRUSCO INFN program we did the SCF-test and thermo-structural simulations.

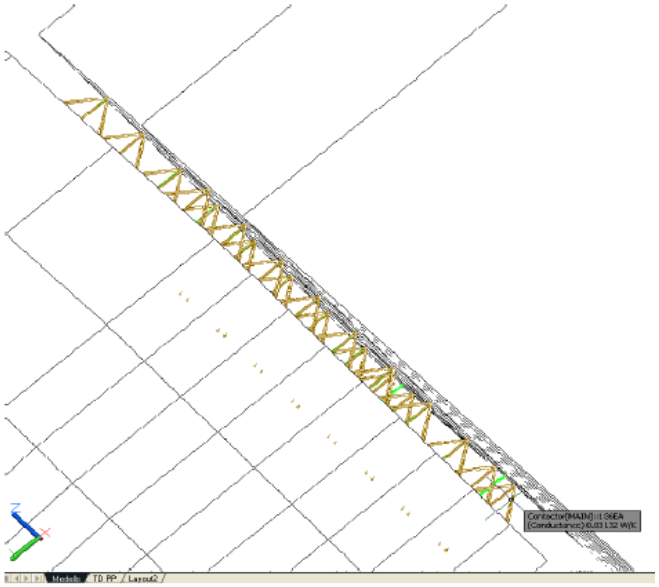
# Thermal measurements on the hollow cube proto faces



# Thermo-Structural model 1/2



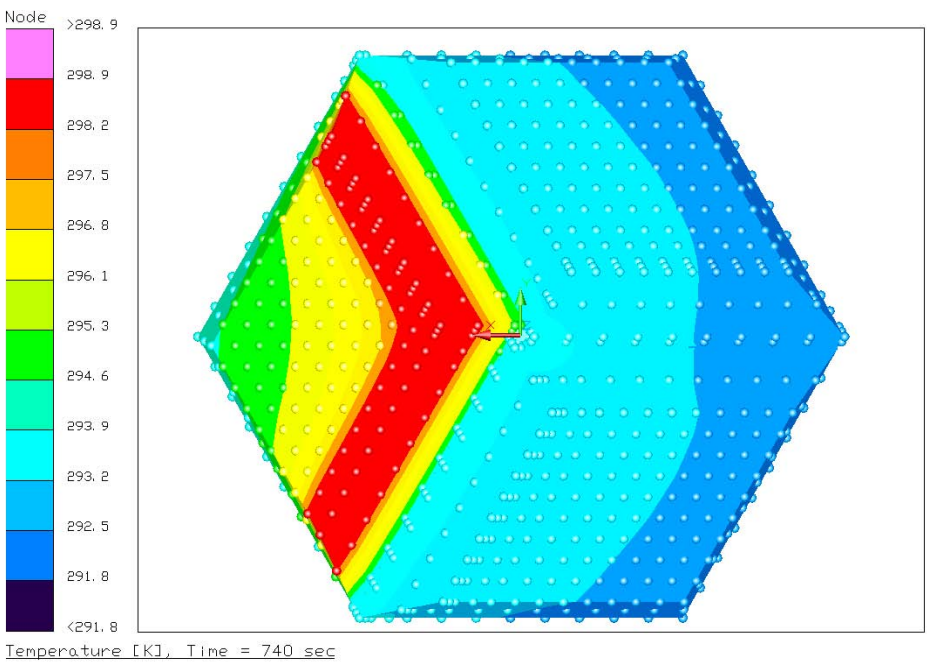


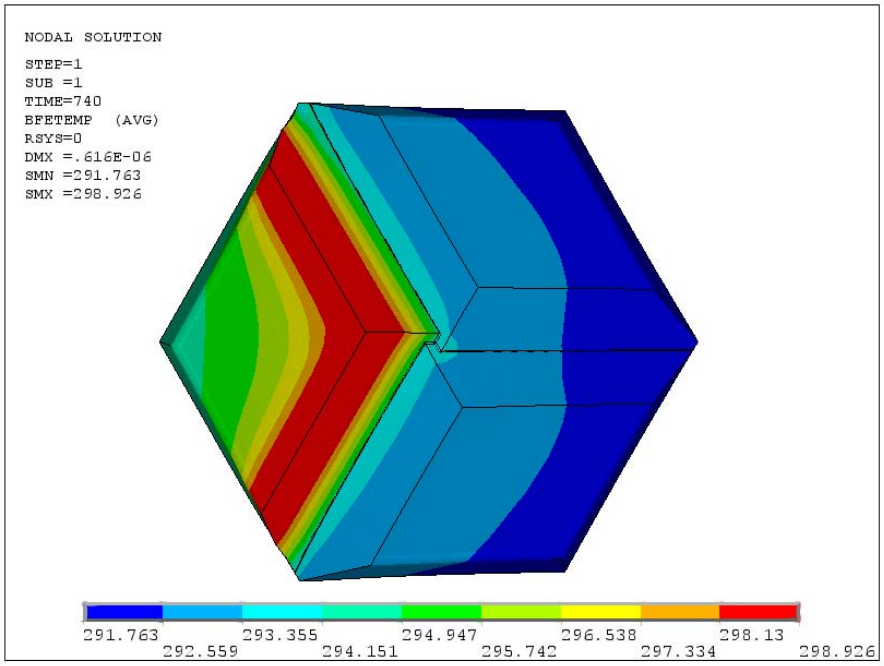


Inside the thermal model of the SCF we placed the model of the hollow cube and tuned the thermal contacts

# Thermo-Structural model 2/2

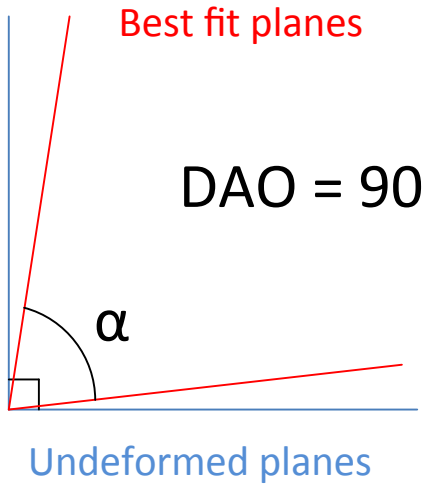
- Results from thermal simulations are the input for structural simulations

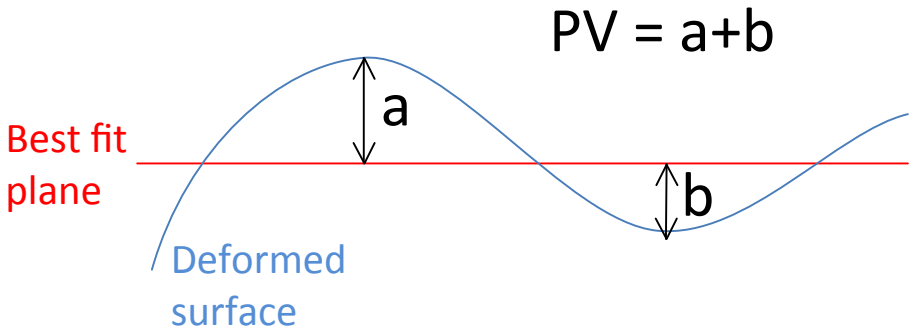


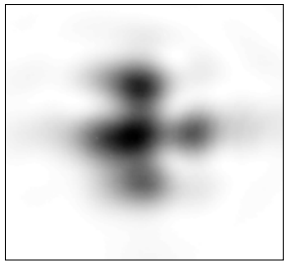
# Optical integrity analysis

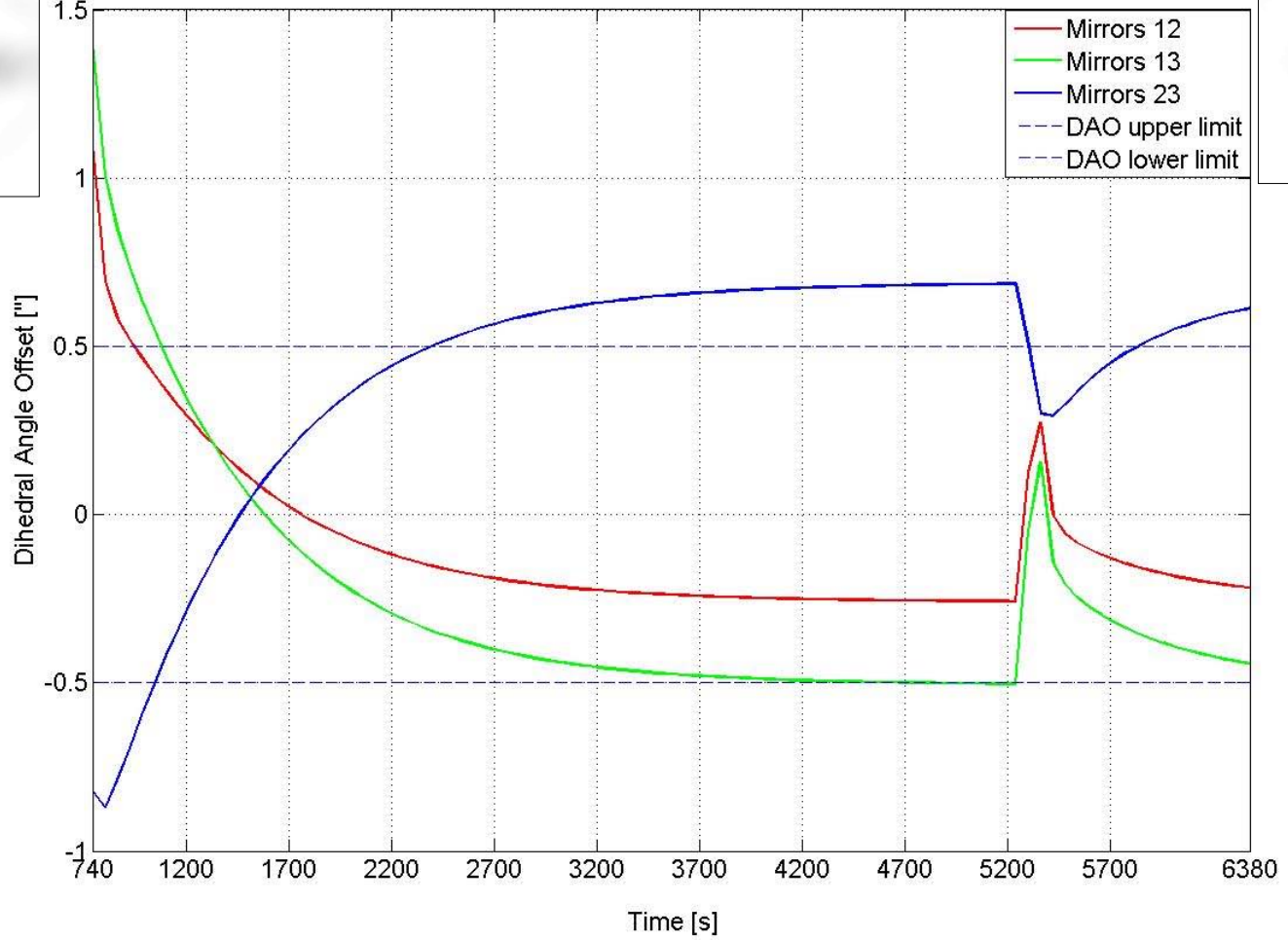
- Structural simulations results are analyzed to check the planarity and the mutual positions of deformed planes

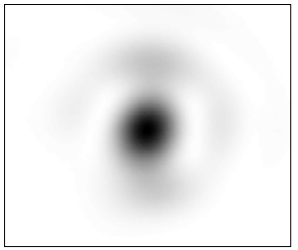


# Comparison with experimental FFDP (Far Field Diffraction Pattern)

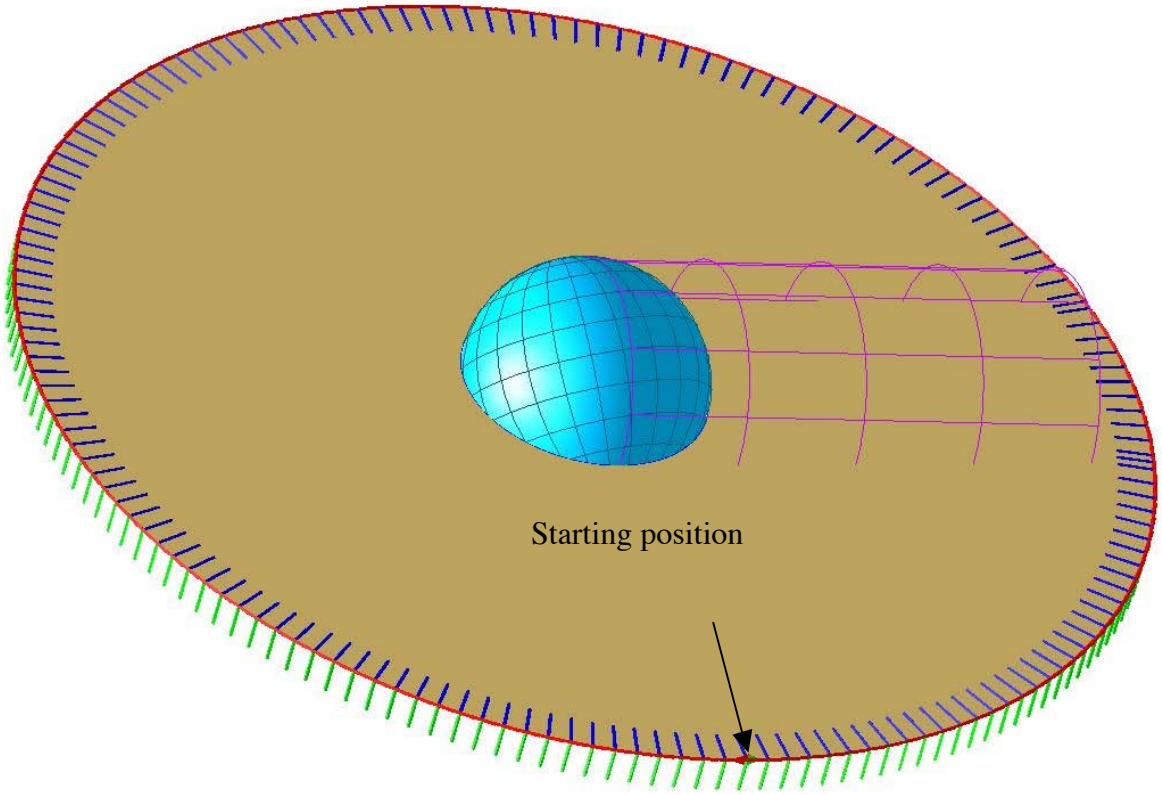


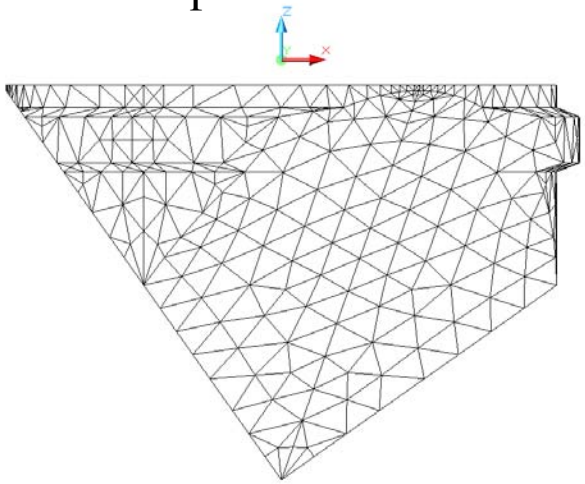


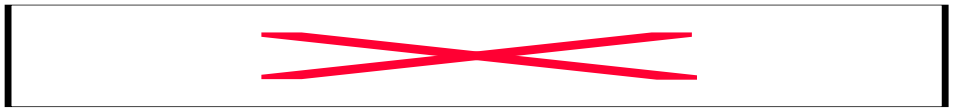



# Thermo – optics modeling integration 1/2

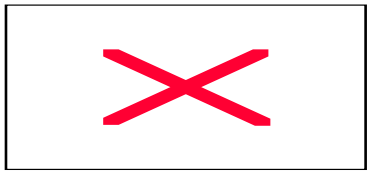
Modeling of the CCR on the GNSS critical orbit. Temperature excursion of the CCR: order of 100 K along the orbit. Uncoated Fused Silica reflector with 33 mm aperture and no Dihedral Angle Offset (perfect corner cube). Orientation is such that, the projection of one edge on the front face, lies on the orbit plane



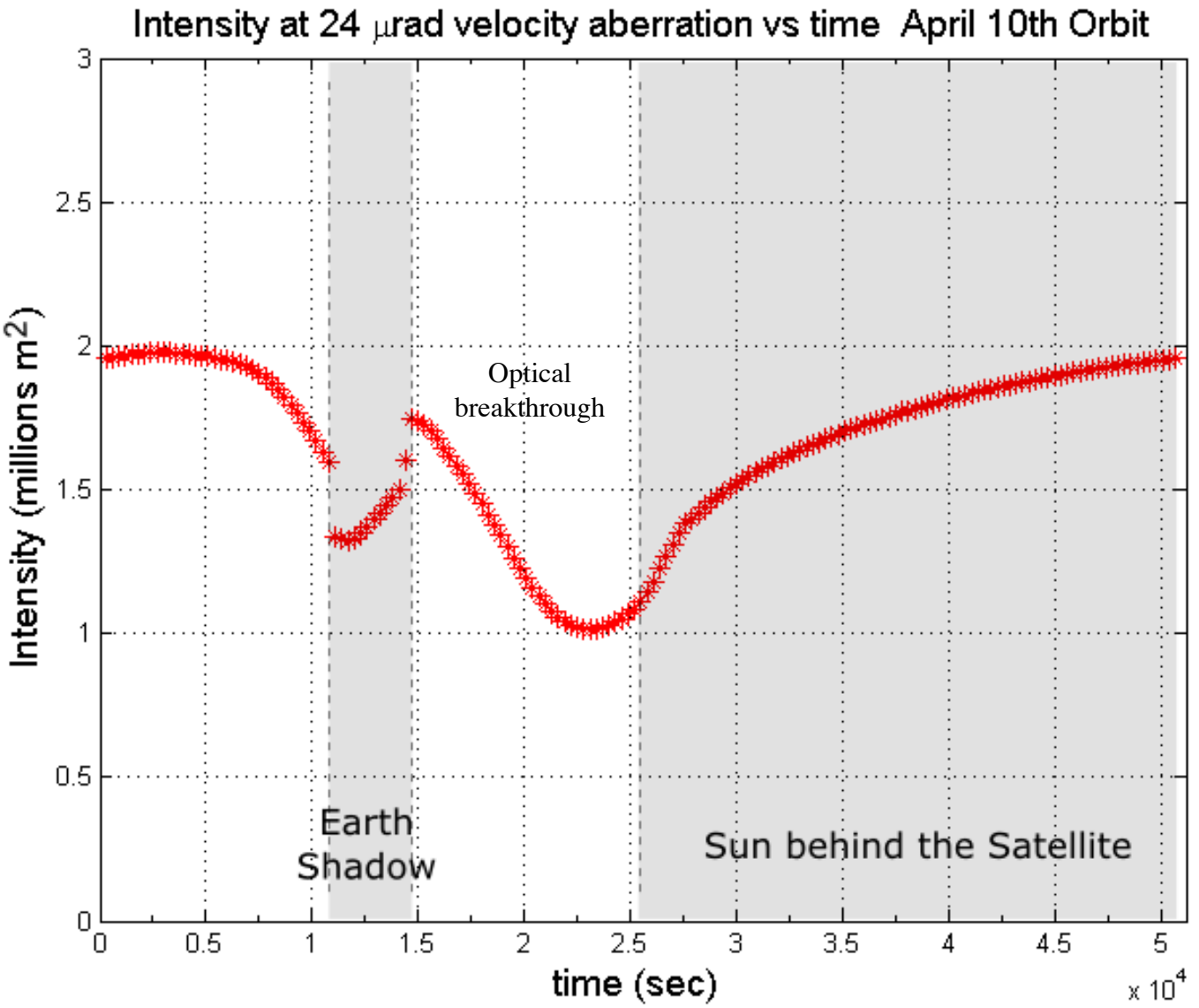





# Thermo – optics modeling integration 2/2



The polarization used for the laser is horizontal (in the orbital plane). Variation of the CCR average FFDP intensity at 24 μrad (velocity aberration for GNSS like satellites) during the orbit



# Conclusions


- SCF-Test: new industry-standard for GNSS, space geodesy, test of relativistic gravity and lunar planetary science
  - For any type of retroreflector in near Earth orbits and on the Moon

- With ETRUSCO-2 (ASI-INFN project) we are doubling and extending our metrological capabilities for retroreflector testing

- We are very interested in collaborating to other programs, with co-funding for anything additional to ETRUSCO-2

# Main 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 DOI 10.1007/s10686-010-9195-0. ASI Phase A study. Work under Contract INAF-RHI n. 20080508-1 for the Phase A Study of the ASI Small Mission MAGIA
- [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-5] March, R., Bellettini, G., Tauraso, R., Dell'Agnello, S., Constraining spacetime torsion with the Moon and Mercury, Physical Review D **83**, 104008 (2011)
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- [RD-8] International Lunar Network (http://iln.arc.nasa.gov/), Core Instrument and Communications Working Group Final Reports:

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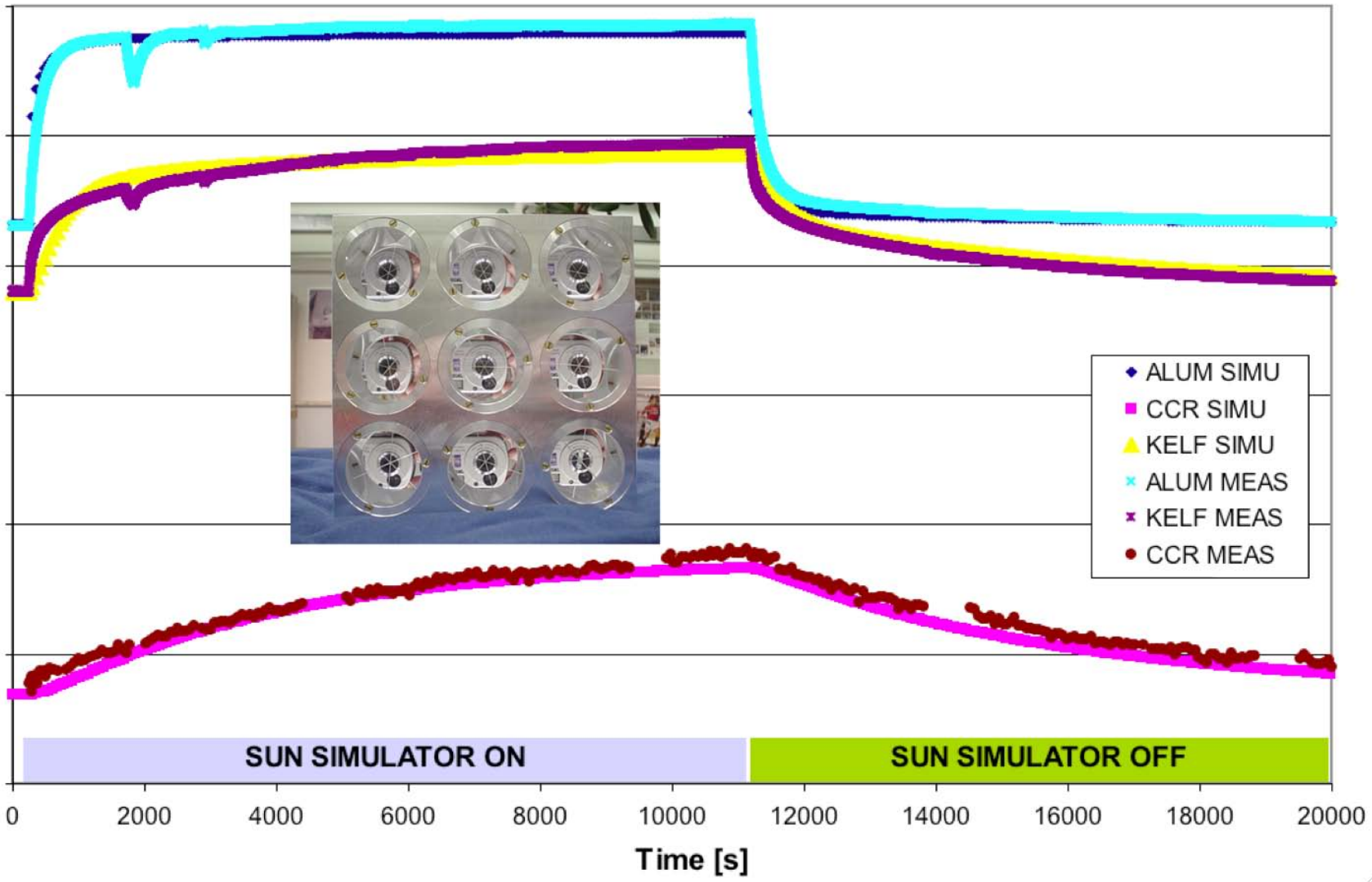
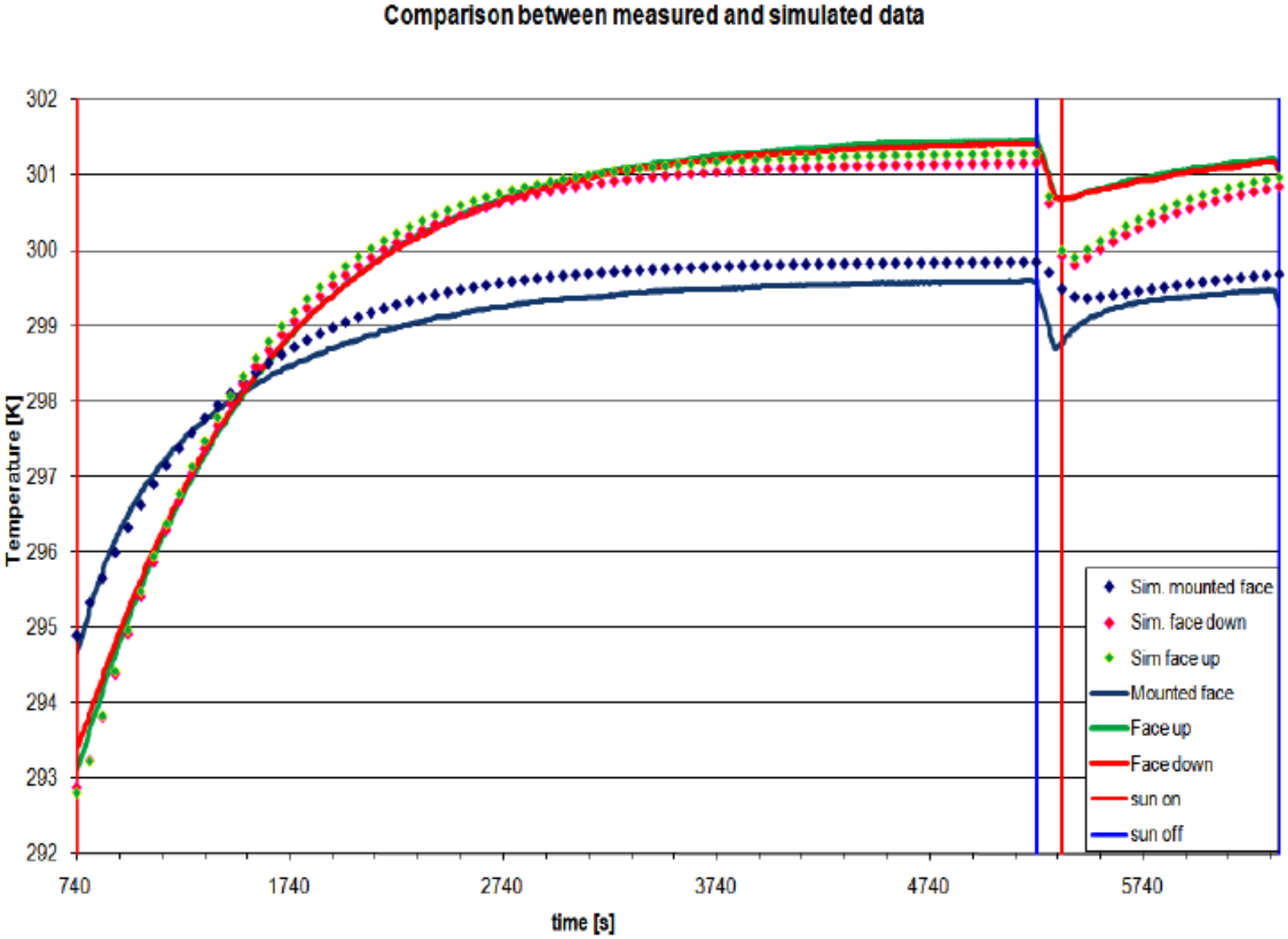
  http://iln.arc.nasa.gov/sites/iln.arc.nasa.gov/files/WorkingGroups/WorkingGroups2.pdf

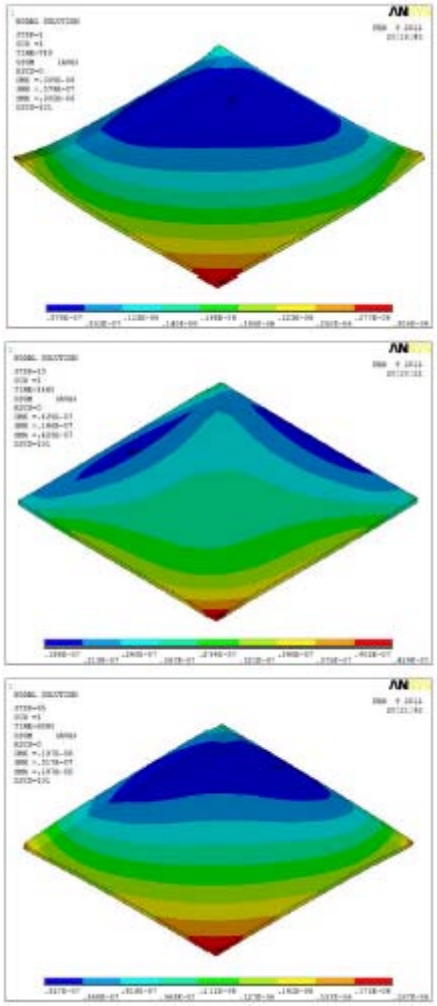
# LAGEOS like array



# Hollow cube tuning



# Hollow face curvature change



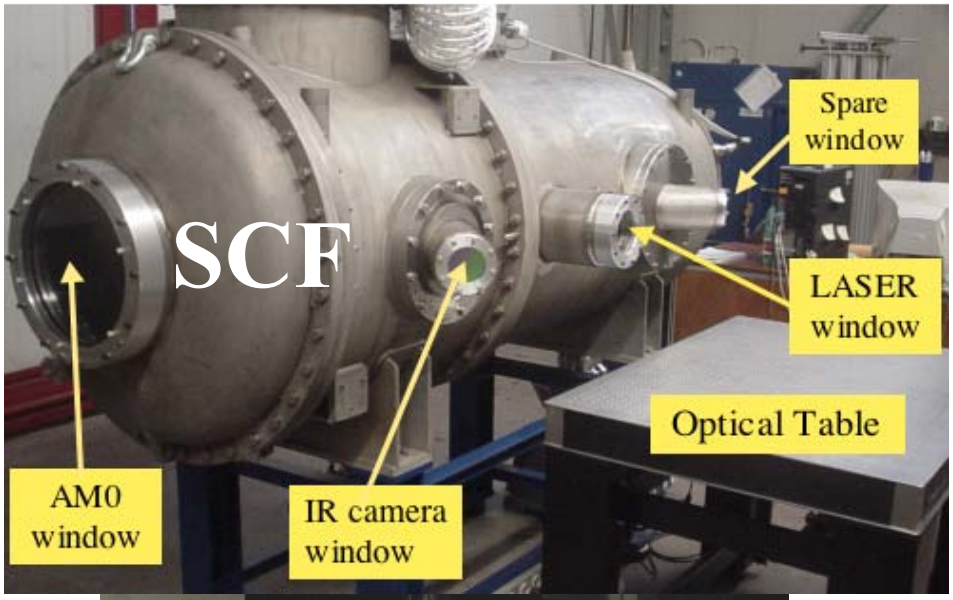
# SLR/LLR work by the SCF Team

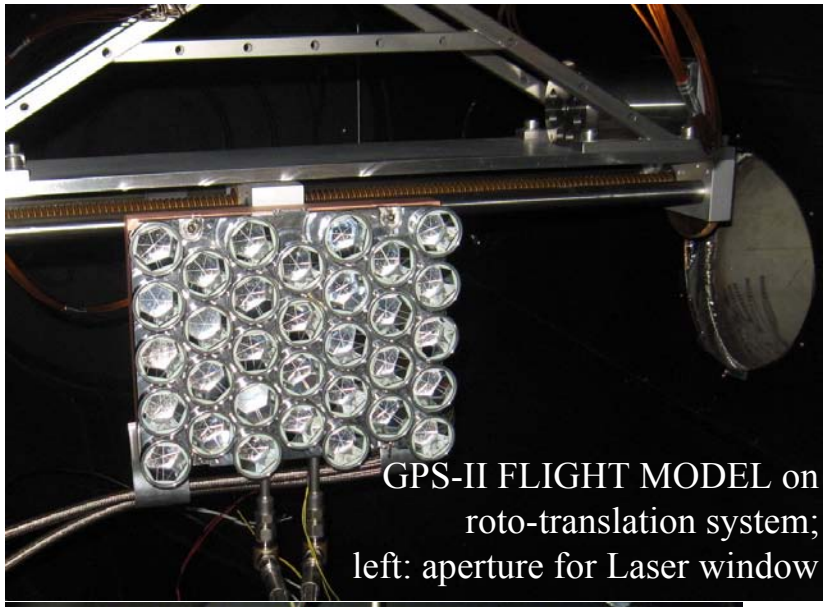

- **First-ever** SCF-Test of:
  - GPS-II retroreflector array **flight model** property of UMD
  - GLONASS and Galileo's GIOVE-A and -B retroreflector prototype by V. Vasiliev
  - LAGEOS Sector **engineering model** property of NASA-GSFC
  - **Hollow** retroreflector prototype provided by GSFC
  - **Galileo IOV** retroreflector prototype property of ESA
  - New generation LLR retroreflector, for:
    - First manned landing - 2006 NASA LSSO Program (the beginning of U. of Maryland and INFN-LNF collaboration LLRRA21/MoonLIGHT)
    - Two ASI studies, including MAGIA for Phase A
    - NLSI "CAN" Project (LUNAR, Directed by J. Burns)
- Response to NASA's ILN anchor nodes Request For Info (RFI)
- Response to ESA's RFI for lunar lander

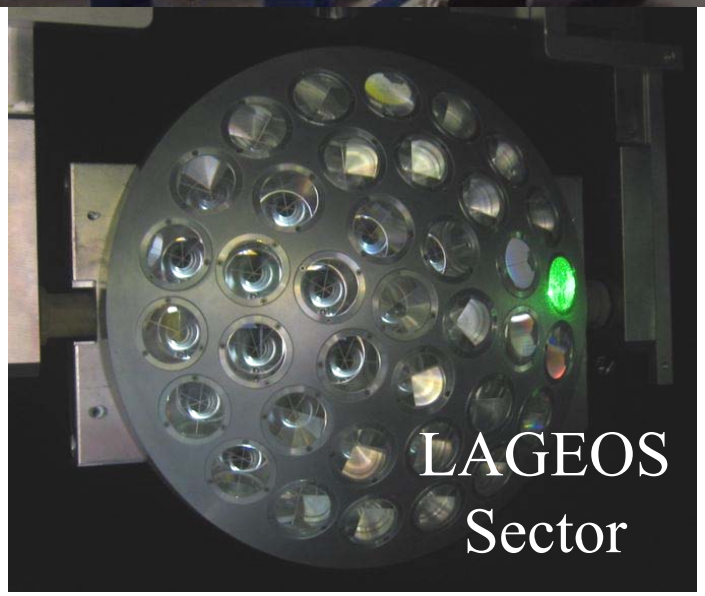
# One past activity for ASI by INFN-LNF (not an SCF-Test)

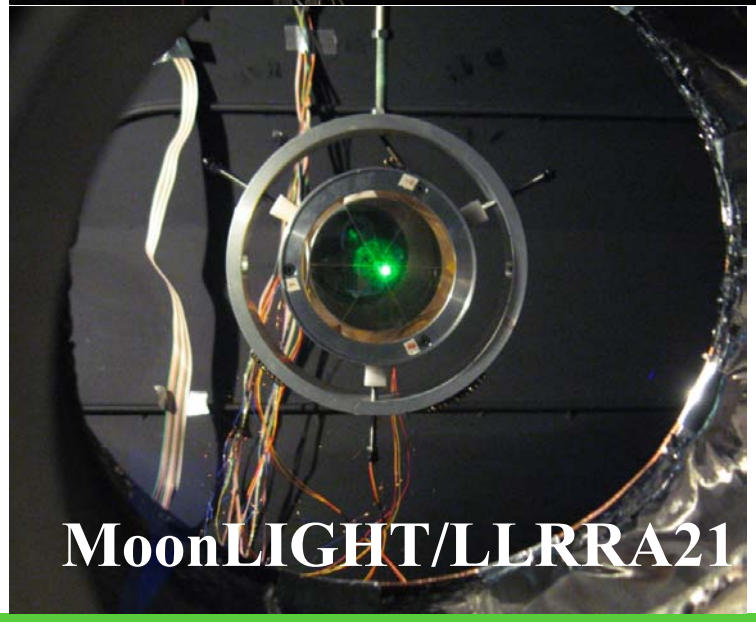
- Industrial optical FFDP acceptance test, in-air and isothermal conditions, of 110 flight reflectors manufactured by Zeiss for the LARES mission
  - Accomplished by INFN-LNF in 3 working weeks before Christmas 2008:
    - At the optics lab with 633 nm wavelength
    - 15 days, enormous amount of retroreflector handling by LNF team, no casualty, completely successful
  - 110 retroreflectors accepted and paid by ASI, on the basis of this test activity by INFN-LNF
  - THIS WAS ONLY AN FFDP TEST IN AIR AND ISOTHERMAL CONDITIONS; NOT AN SCF-TEST
  - ASI reference document: DC-OSU-2009-012

# SLR/LLR Characterization Facility (SCF)



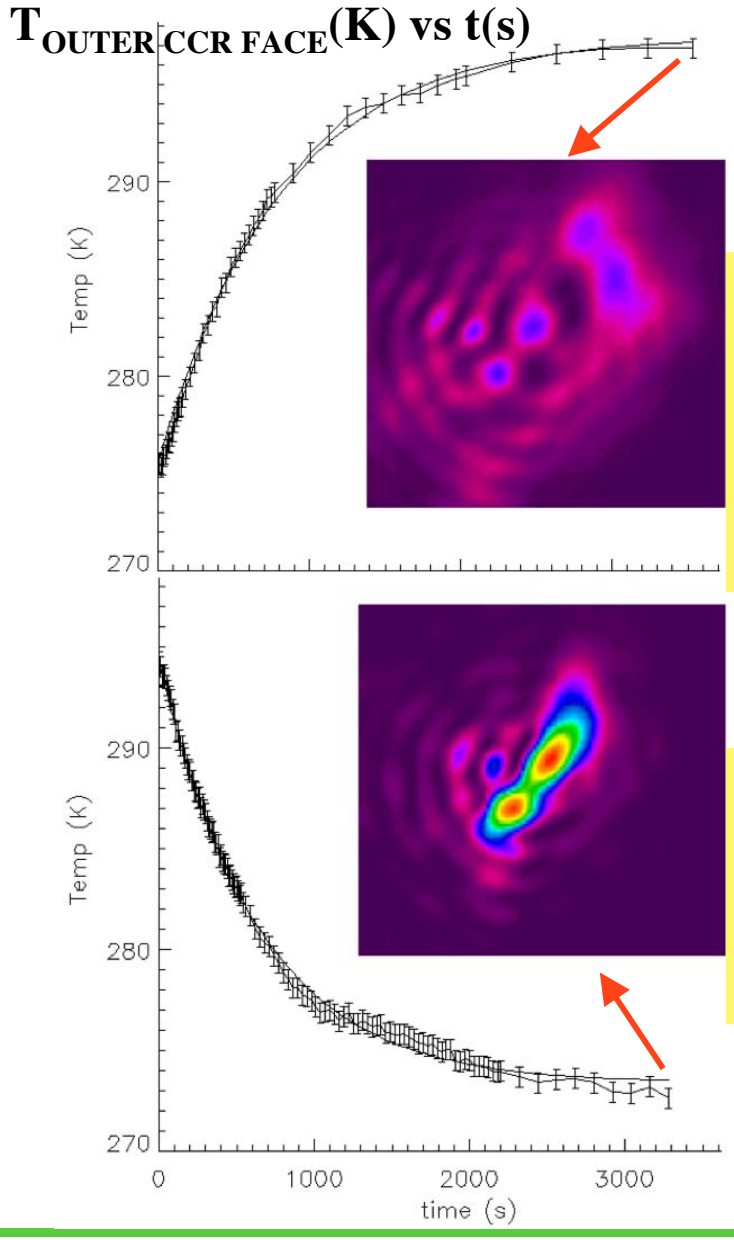
# Test of 3rd GPS flight array made by Soviet Union


Third and last ever made for GPS

~19 x 24 $cm^2$,~1.3 Kg,

32 CCRs

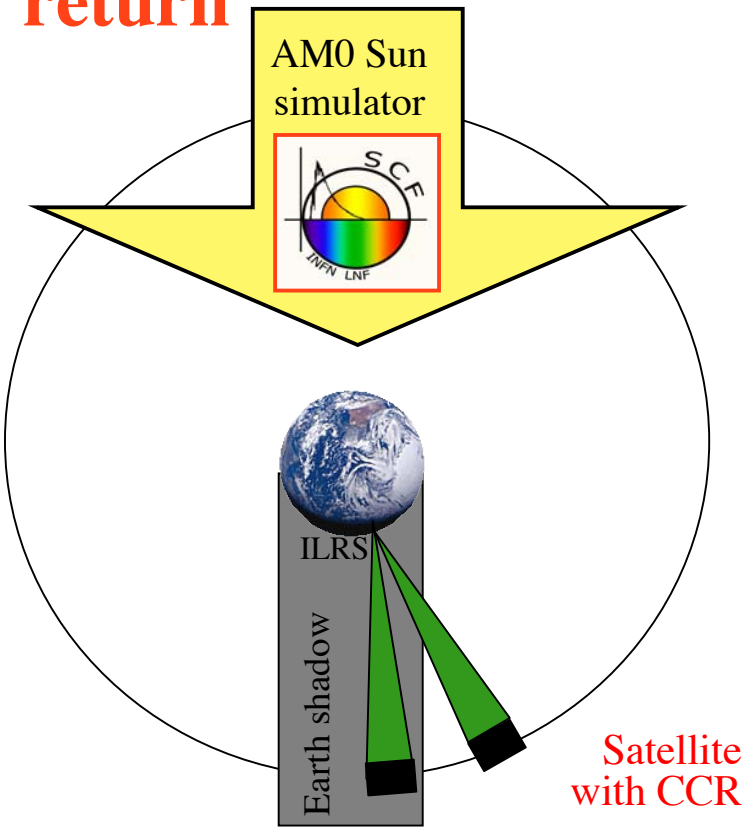
# SCF-Test of GPS flight model




**Sun on**: laser return (FFDP) severely degraded

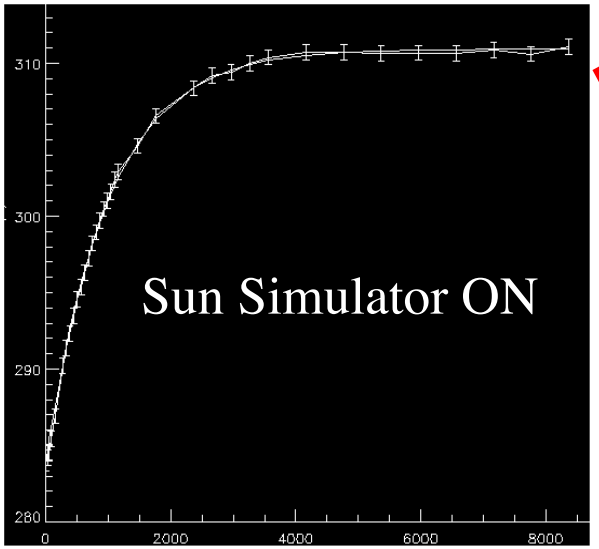
**Sun off**: laser return (FFDP) peaks restored

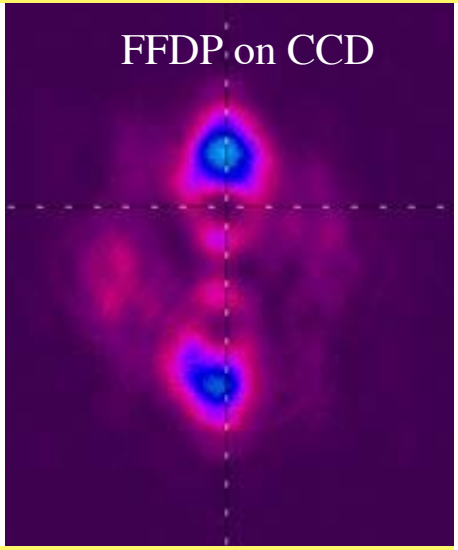
**Factor ~7 reduction of laser return**



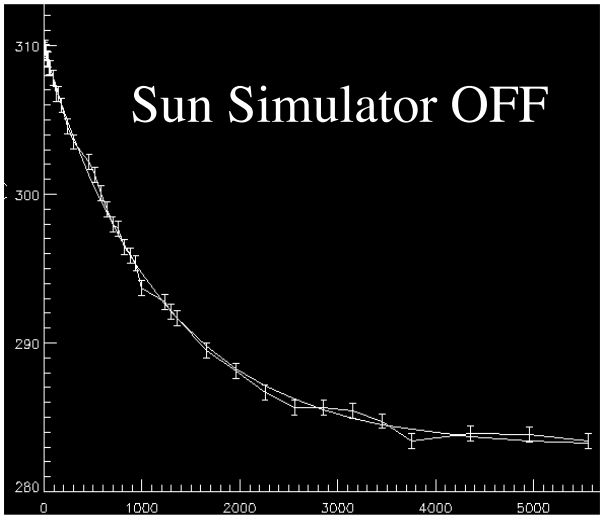
# SCF-Test of GLONASS/GIOVE

**Sun on**: laser return (FFDP) severely degraded

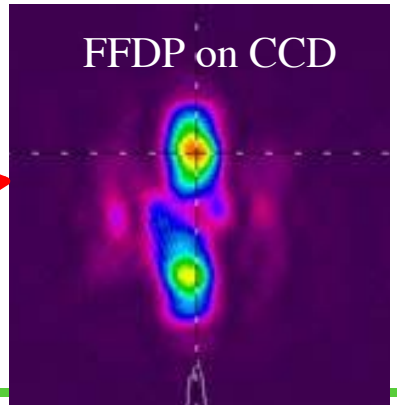


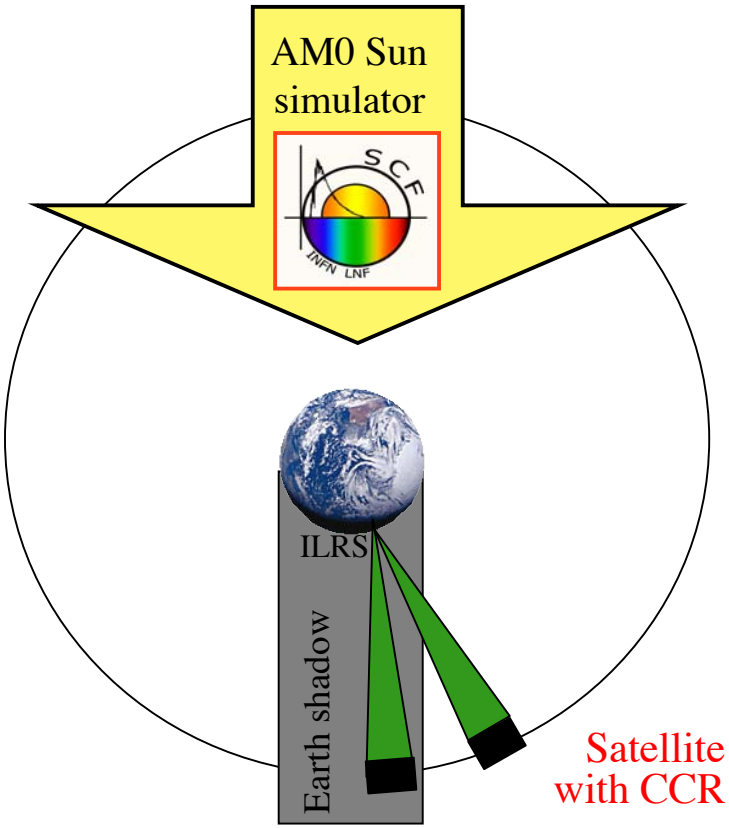




**Factor ~7 reduction of FFDP**




**Sun off**: laser return (FFDP) peaks restored




$T_{OUTER\ CCR\ FACE}$(K) vs t (sec)