ETRUSCO: Extra Terrestrial Ranging to Unified Satellite Constellations

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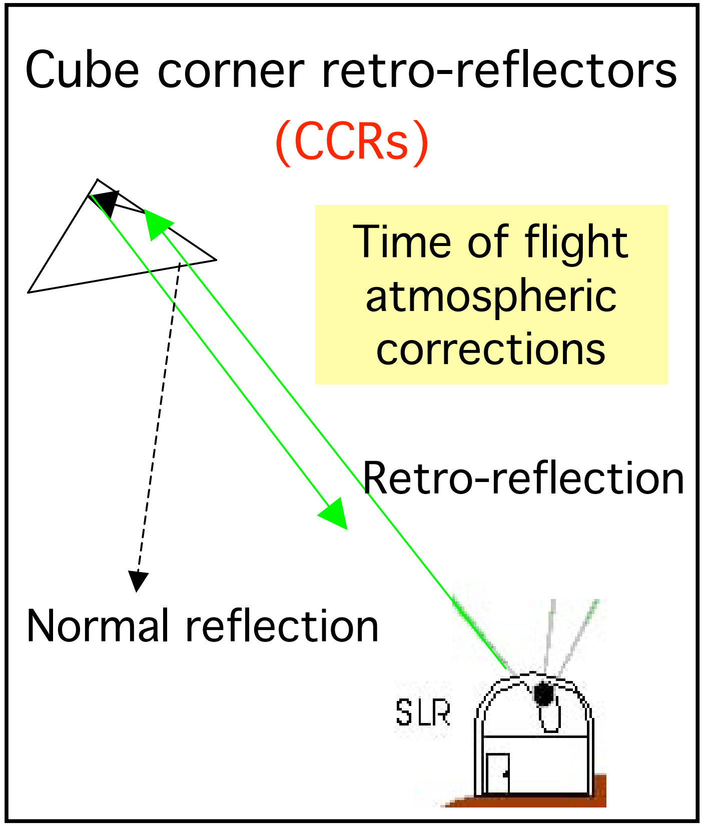
Vulcano Workshop, May 2008

Outline

- Introduction to the technology
  - PAYLOAD: Laser Retro-Reflectors in space
  - TECHNIQUE: Satellite Laser Ranging
  - GNSS: Global Navigation Satellite System (Glonass, GPS, GALILEO)
- INFN experiment ETRUSCO
  - New industry-standard space test of laser retro-reflectors in space
  - “SLR Characterization Facility” (SCF) at INFN-Frascati
- Test of GPS-2 flight payload and Glonass prototypes
- Conclusions

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



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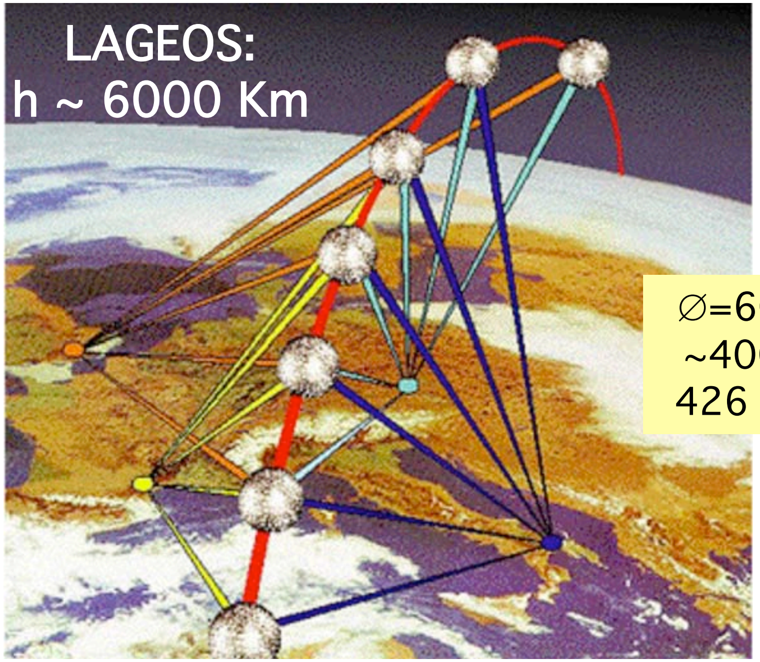
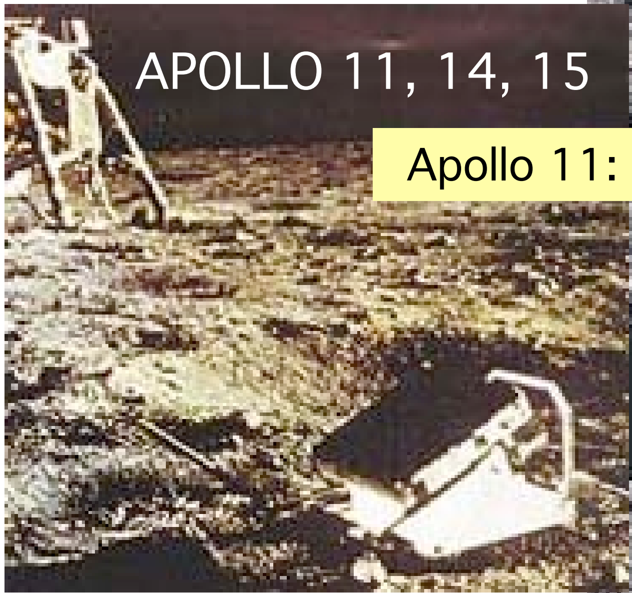


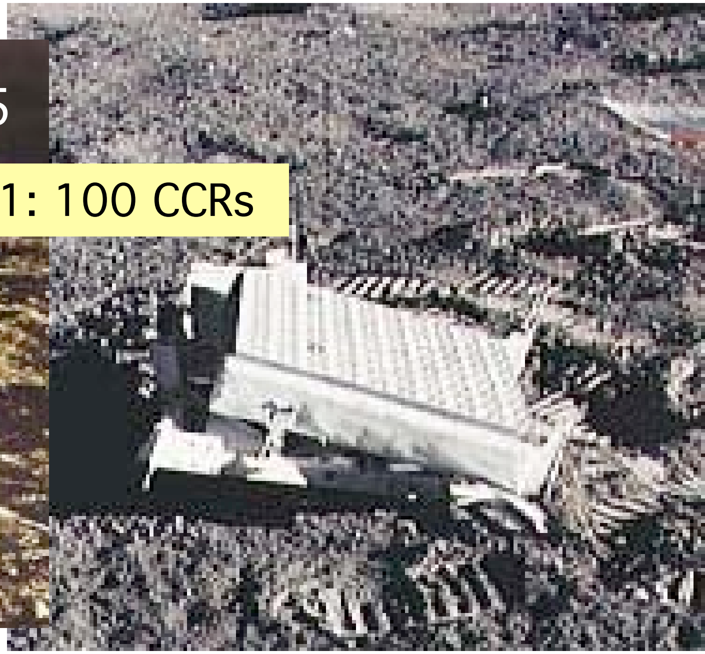
∅=60 cm
~400 Kg
426 CCRs

The most (precise). AND. (cost-effective) distance measurement in space

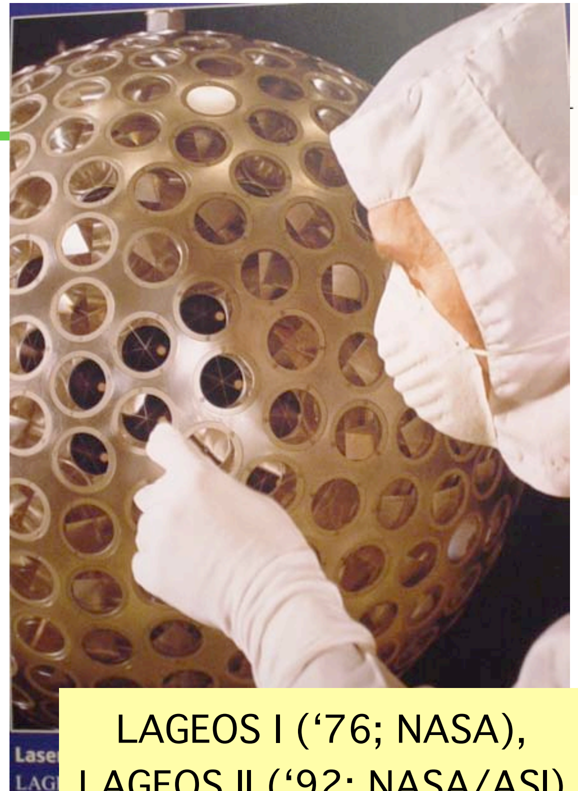
(few millimeters to 1-2 centimeters) .AND. (100K€ to M€)

APOLLO 11, 14, 15





Apollo 11: 100 CCRs



LAGEOS I (‘76; NASA),
LAGEOS II (‘92; NASA/ASI)

Flight payload for GPS-2 @INFN-LNF:
32 CCRs (property of Univ. Maryland)

LAGEOS prototype @INFN-LNF

(property of NASA)

SLR: Space Geodesy, Satellite Navigation

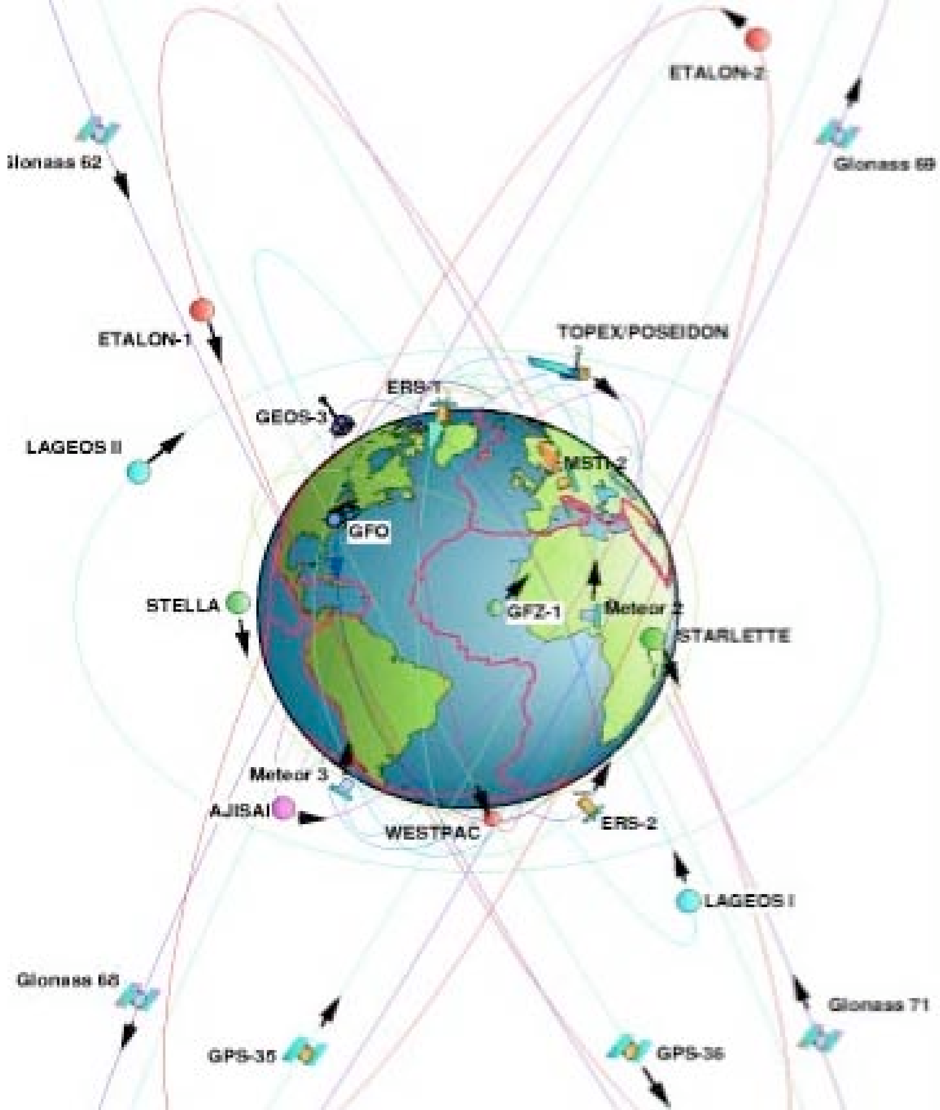
Altitudes: few hundreds km (LEOs), ~20K Km (GNSS), 36K Km (GEO)

Int. Terrestrial Reference Frame (ITRF):
- Geocenter
- Scale of length

defined uniquely by SLR / LAGEOS

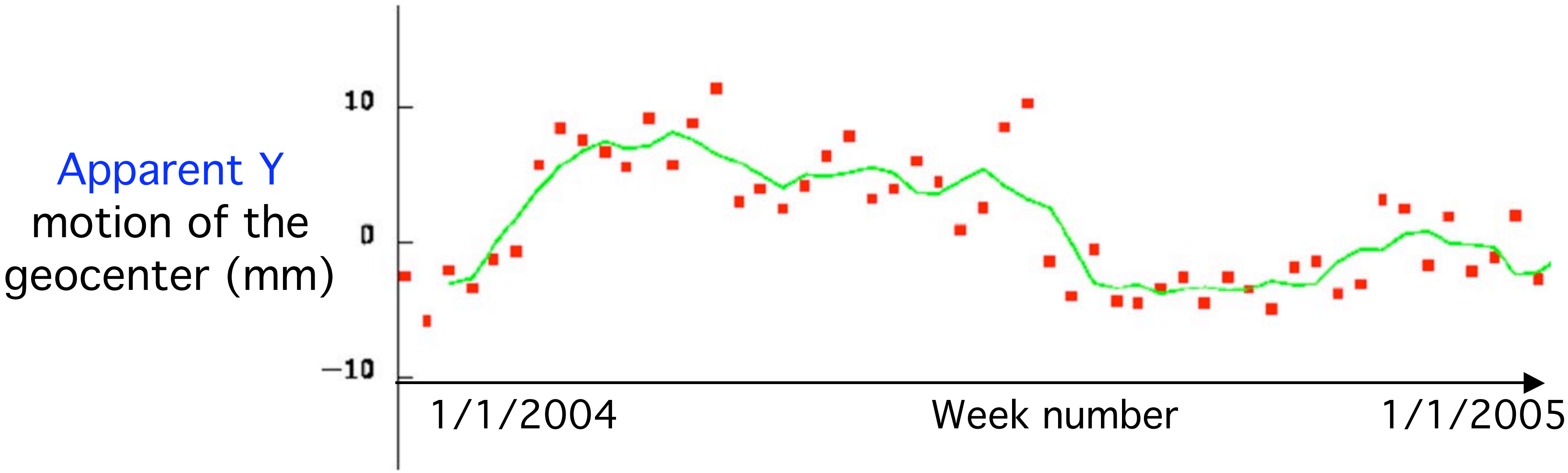
International Laser Ranging Service

SLR constellation in NEO



The MAIN Space Geodesy application of SLR/LAGEOS

Apparent movement of the Geo-center Y position every Tuesday from 1/1/2004 al 1/1/2005 (green is average)

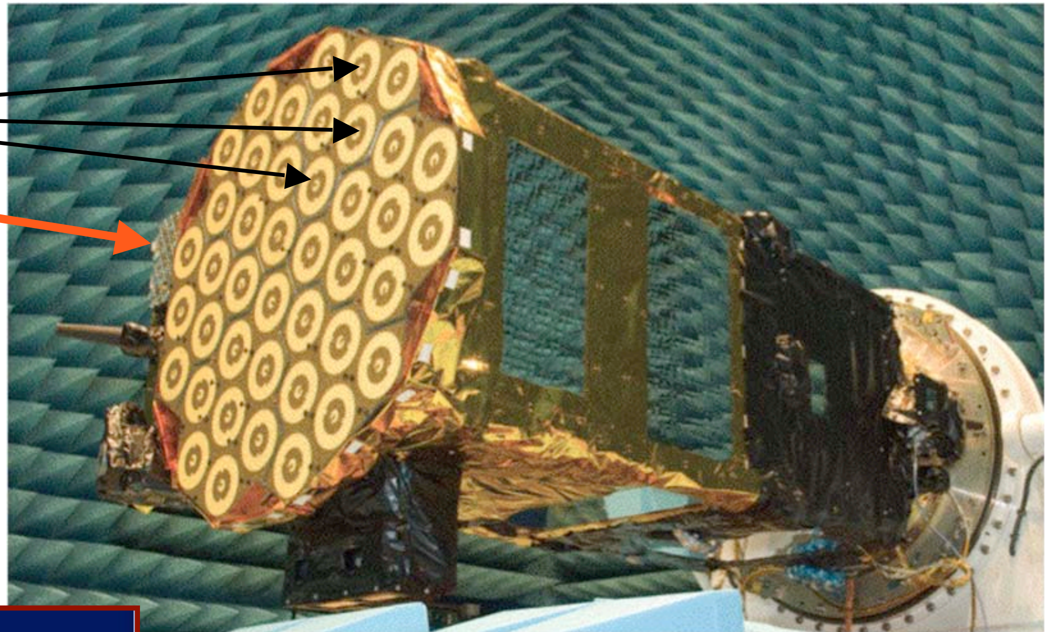


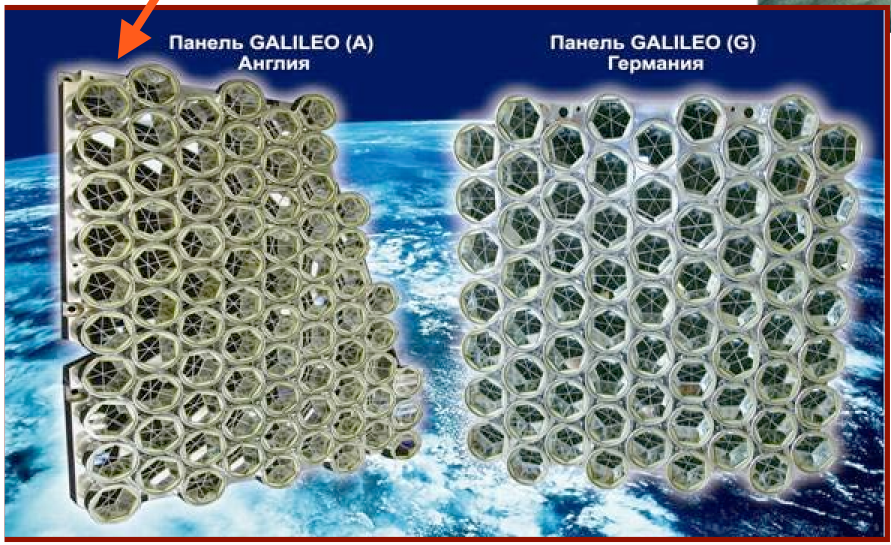
Courtesy of E.C. Pavlis
ILRS05 workshop

International Laser Ranging Service

GNSS Retro-reflector Arrays (GRA) on Giove-A/B, the prototypes of GALILEO

MW antennas and one GRA





Benefits of laser ranging wrt standard microwave tracking

- Absolute positioning wrt Geocenter
- Factor 10-20 better positioning
- Long term stability & geodetic memory

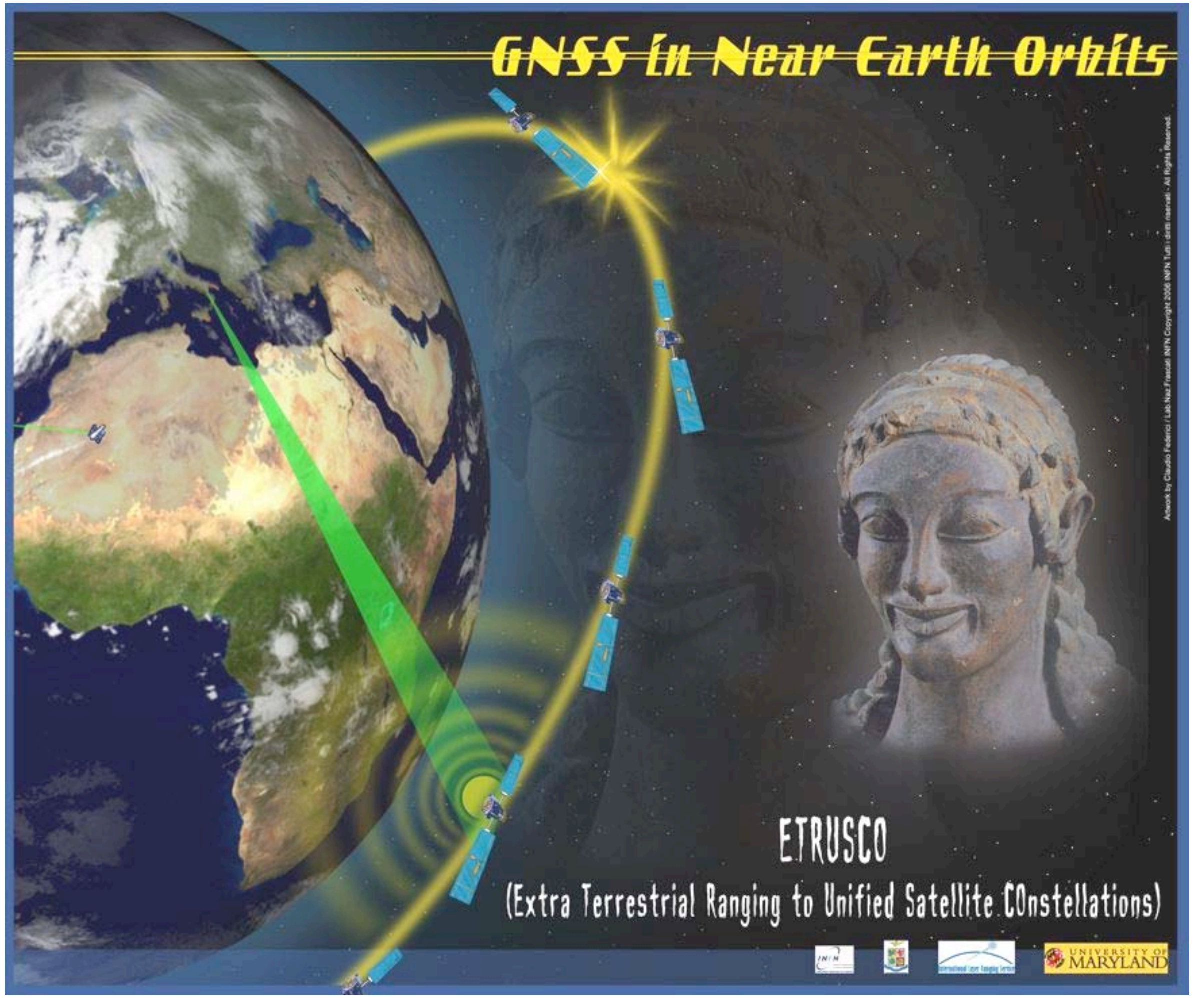
ETRUSCO

GALILEO is a "Unified" constellation:
standard MW tracking **AND** satellite laser ranging on all 30 satellites
GPS-2 has CCRs only on one active satellite

Development of a new industry- standard space characterization of GRA

Proposal submitted to **FP7-GALILEO**

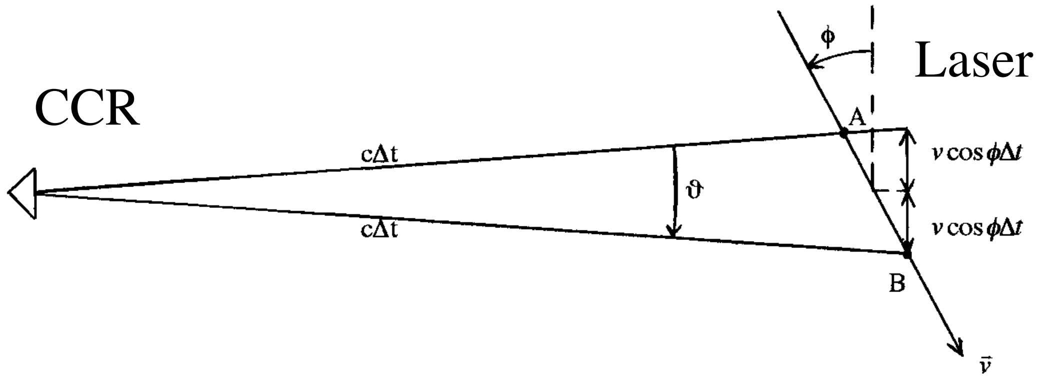
GPS-3
R&D with NASA- GSFC on innovative hollow CCRs



Why a thermal and optical test "in space"?

- **Thermal perturbations by SUN / EARTH.** T gradients across CCR ==> gradients of index of refraction, *dn/dT*, which CAN/DO degrade far field diffraction pattern

- **Velocity aberration**. Relative station-satellite velocity requires non-zero dihedral angle offsets (DAO) w/0.5 arcsec accuracy



- **Design** GRA payload to control thermal and optical properties

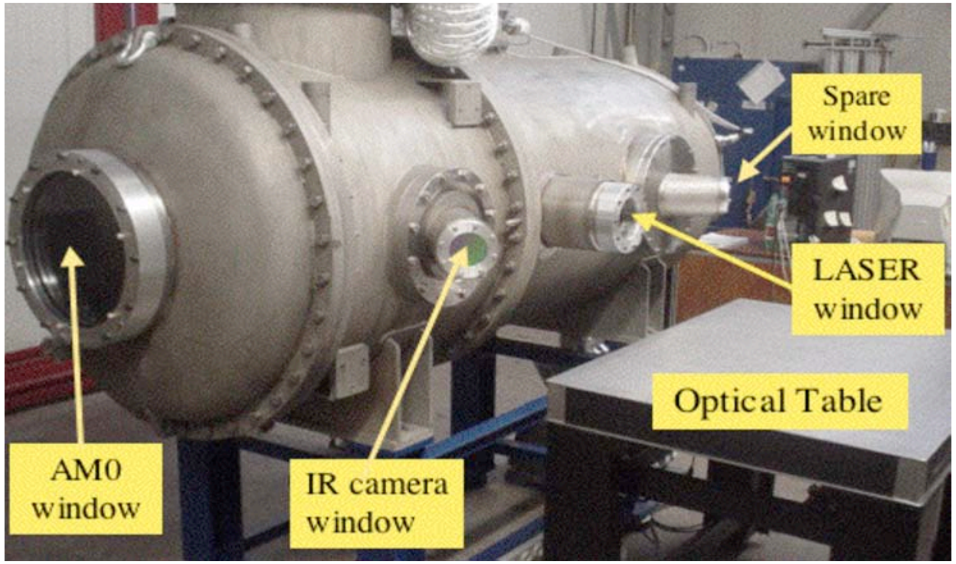
- **SCF-Test**
  - Check DAO at STP
  - New space facility at INFN-LNF to characterize performance

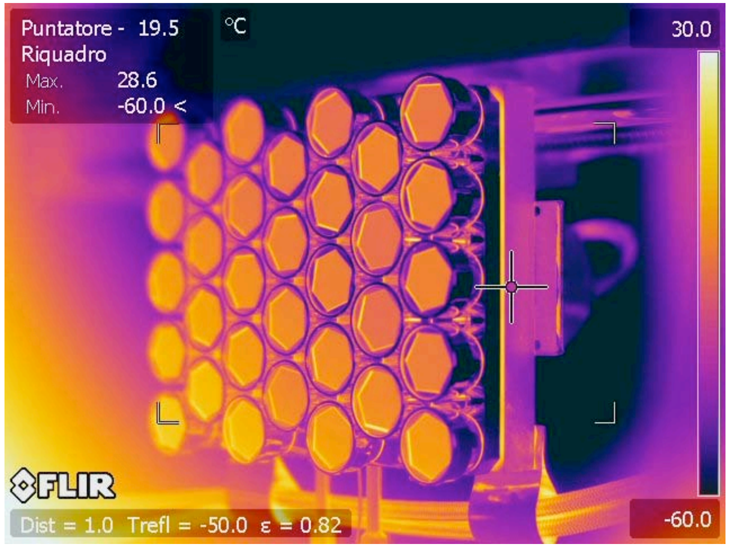
GPS velocity aberration:

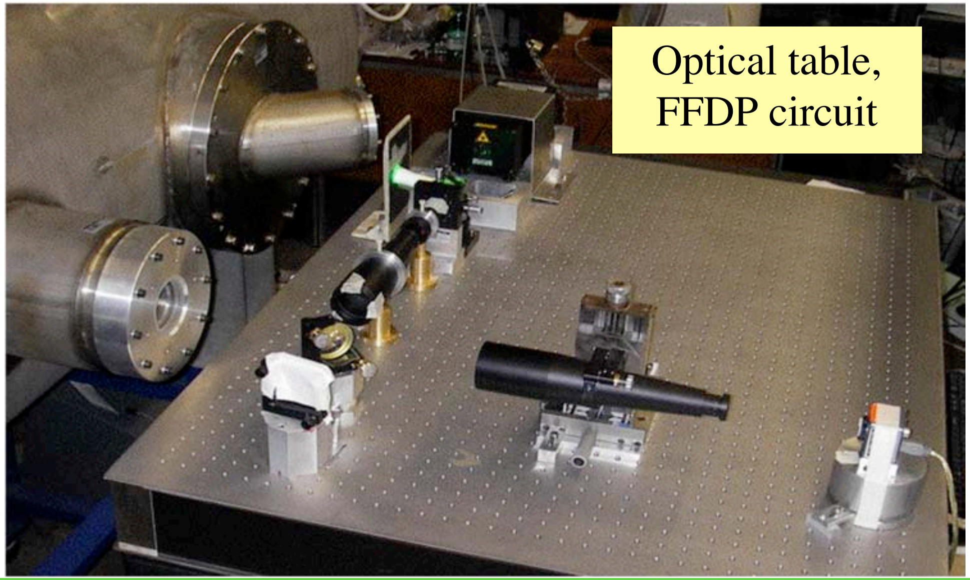
$\theta \sim 2$ v/c $\cos\phi \sim 25$ microrad,
$\theta \times$ altitude ~ 500 m
DAO = 2-3 $\pm$ 0.5 arcsec.

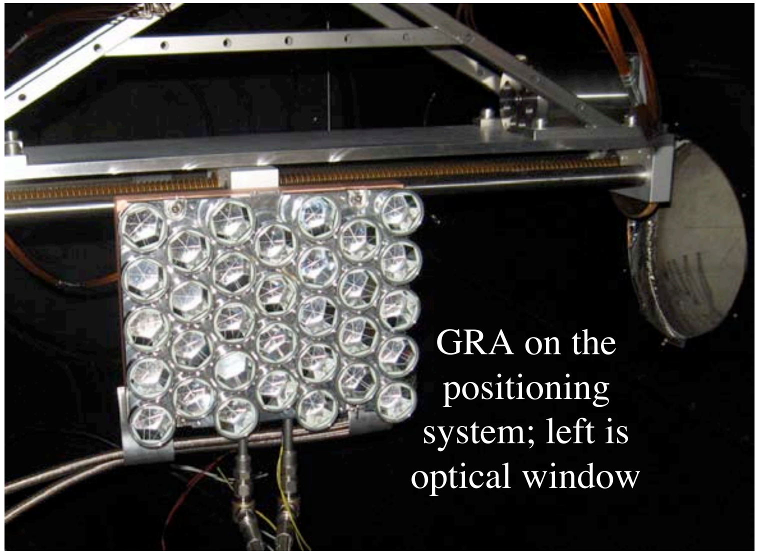
SCF-Test of GPS-2 flight model from USA

Thermal and laser tests never performed before in space conditions





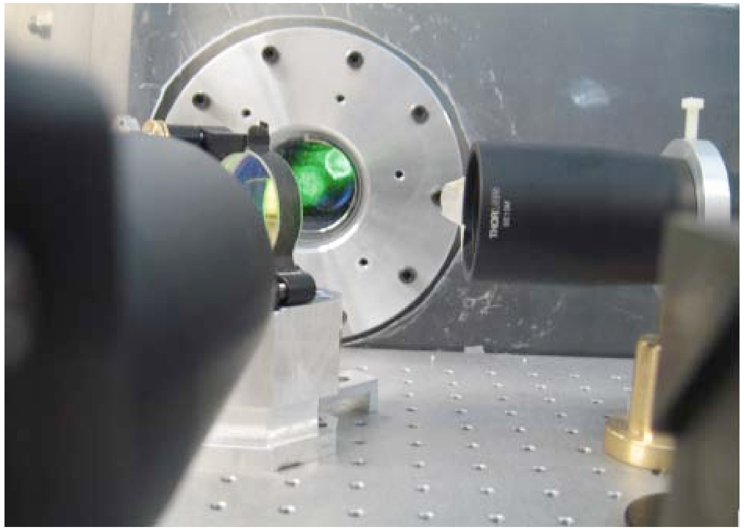




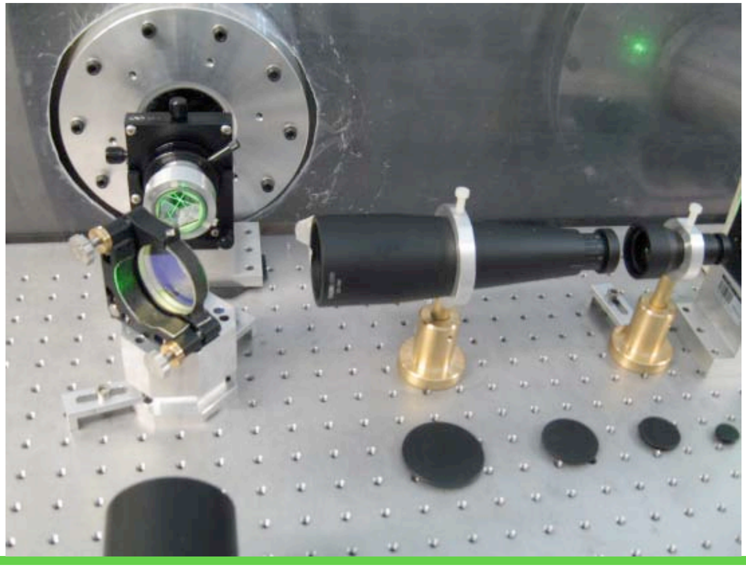
New space standard: the "SCF-Test"

- Space conditions
  - Dark/cold/vacuum
  - Solar Simulator
  - IR thermometry
  - Laser measurements
- Measurement of
  - IR emissivity and Solar absorptivity of CCR and metal
  - $T_{SURFACE}$ of CCR and metal
  - Thermal relaxation time of CCR (τ_{CCR}), plastic metal
  - Far field diffraction patterns (FFDP) in SCF
  - FFDPs also at STP
- Thermal and optical model of
  - SCF data
  - SPACE data

CCR "in space", inside SCF



CCR at STP, outside SCF

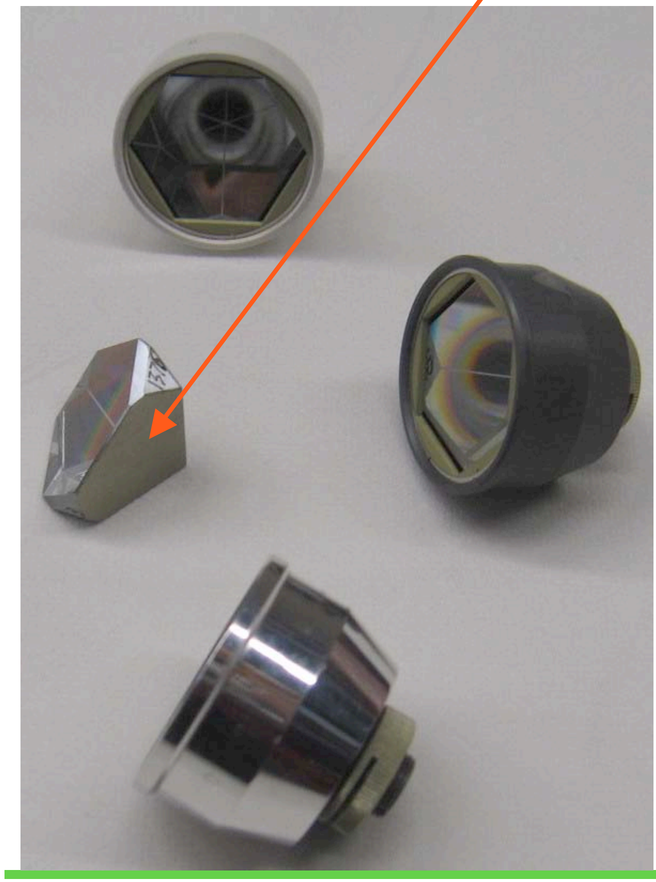


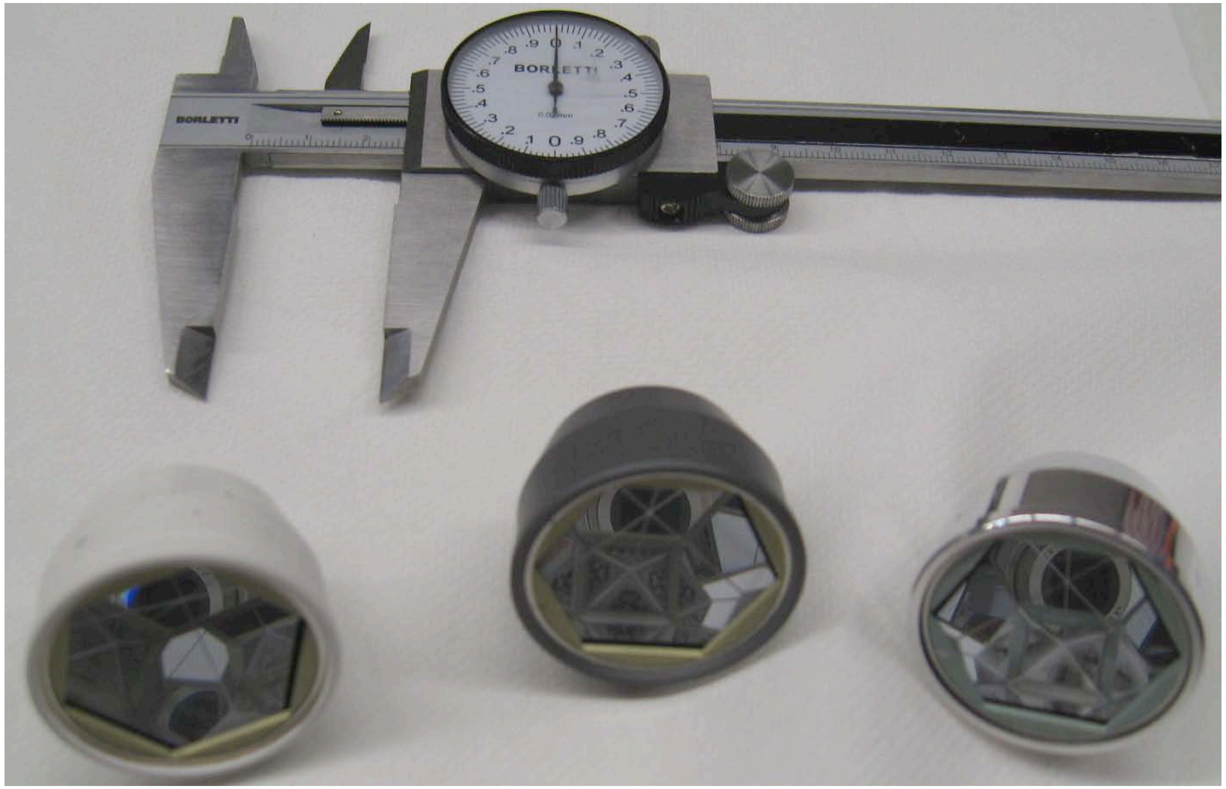
Glonass/GPS-2/GIOVE laser retro-reflectors

CCRs with polished Al housing are also on and GIOVE-A/B
Important: CCR are **Al-coated** in the back: **this causes part of the thermal problems**

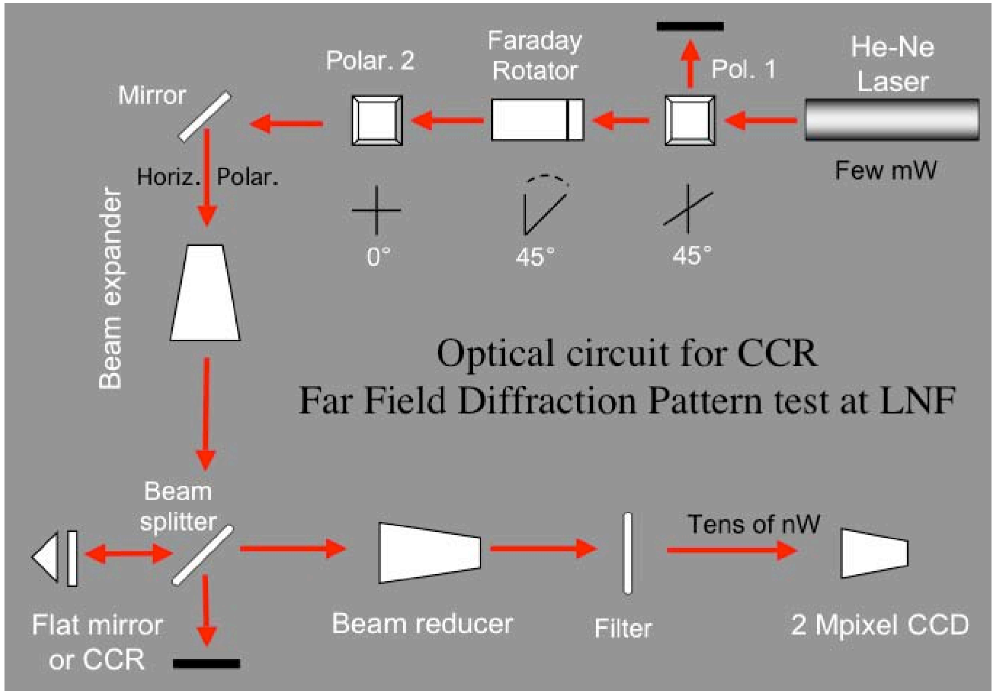
Sent to LNF by V. Vasiliev of IPIE-ROSKOSMOS of Moscow for SCF-Test

<u>Only one passed the FFDP acceptance test on velocity aberration at STP (the white)</u>



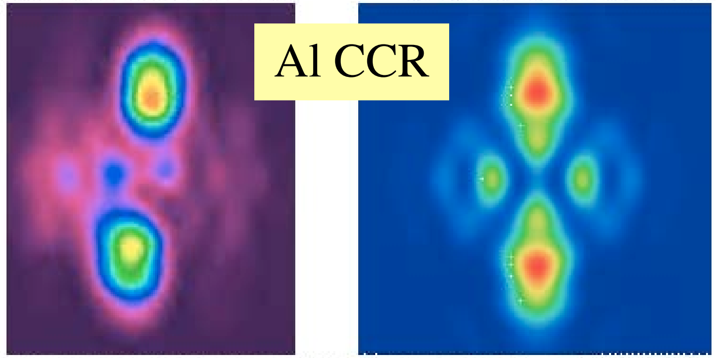


Glonass/GPS/GIOVE laser ranging response @STP



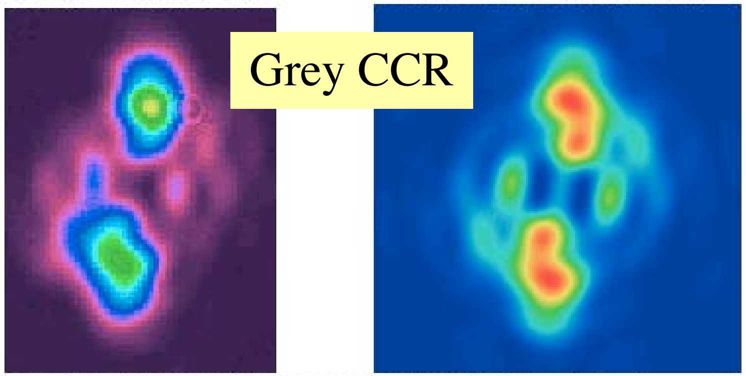
Optical circuit for CCR
Far Field Diffraction Pattern test at LNF

MEASURED PATTERN | SIMULATED PATTERN



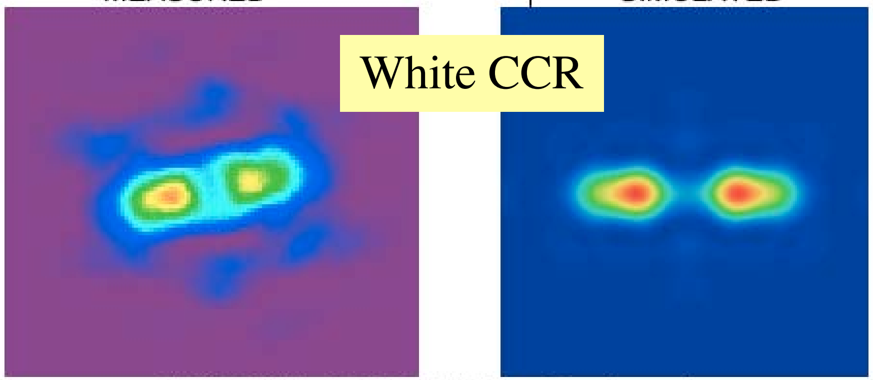
MEASURED VELOCITY ABERRATION ~97 microrad
SIMULATED DIHEDRAL ANGLE OFFSETS ~ 0 – 2.8 – 2.8 ARCSEC

MEASURED PATTERN | SIMULATED PATTERN



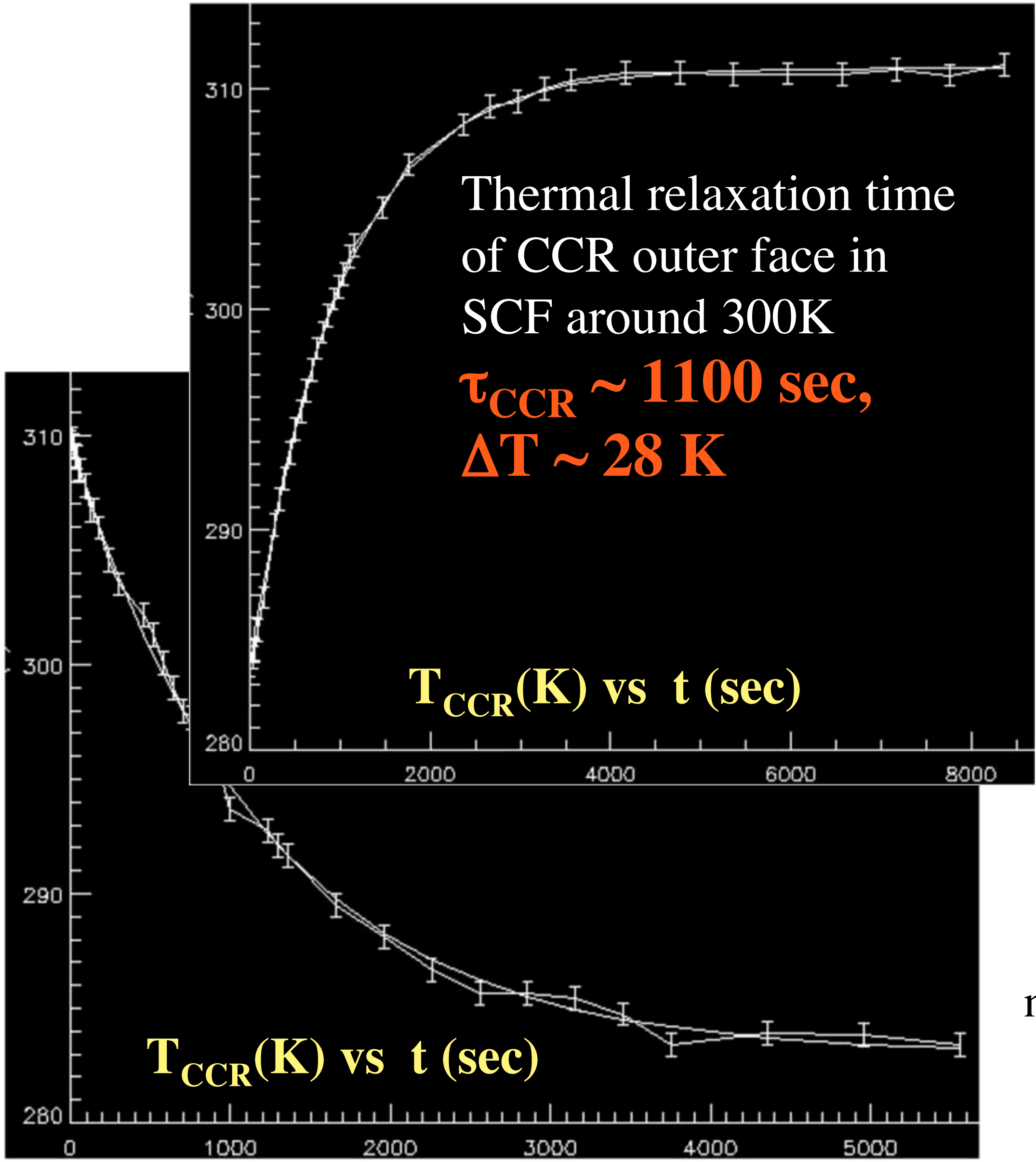
MEASURED VELOCITY ABERRATION ~ 77 microrad
SIMULATED DIHEDRAL ANGLE OFFSETS ~ 0.8 – 2.0 – 3.0 ARCSEC

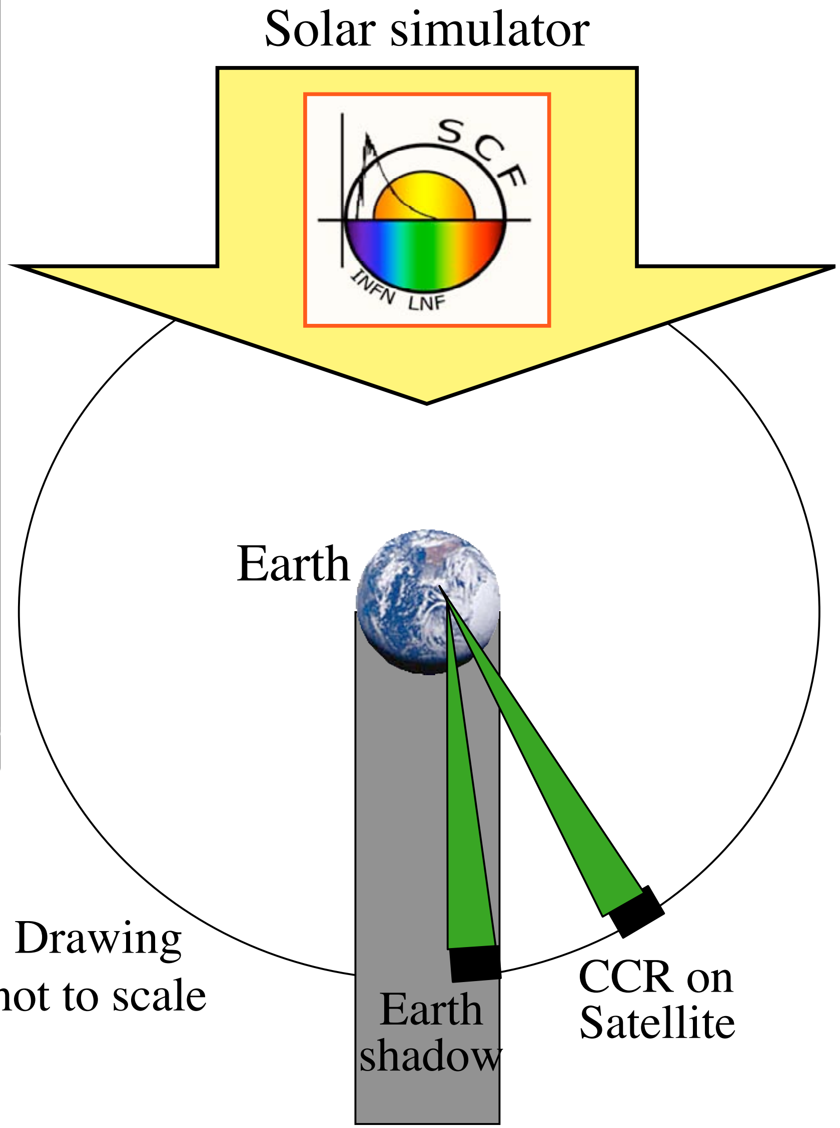
MEASURED | SIMULATED



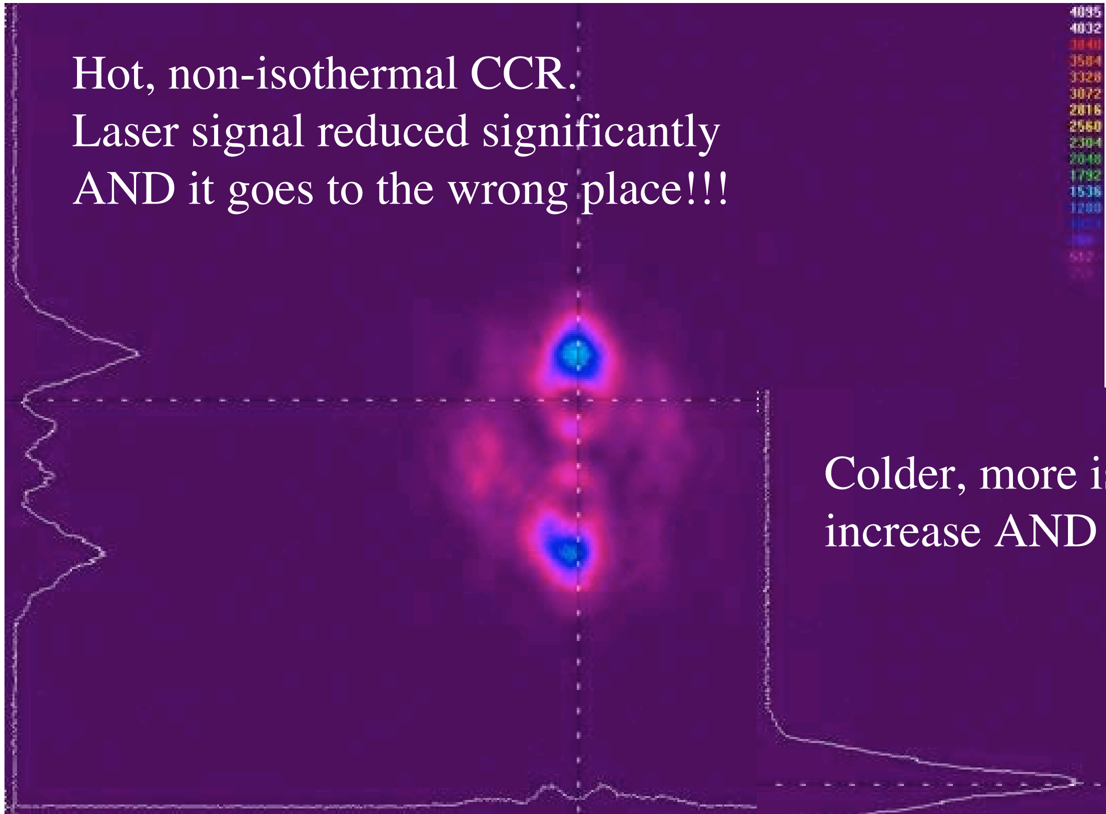
VELOCITY ABERRATION ~ 58 microrad
SIMULATED DIHEDRAL ANGLE OFFSETS ~ 3.1 – 0.0 – 0.0 ARCSEC

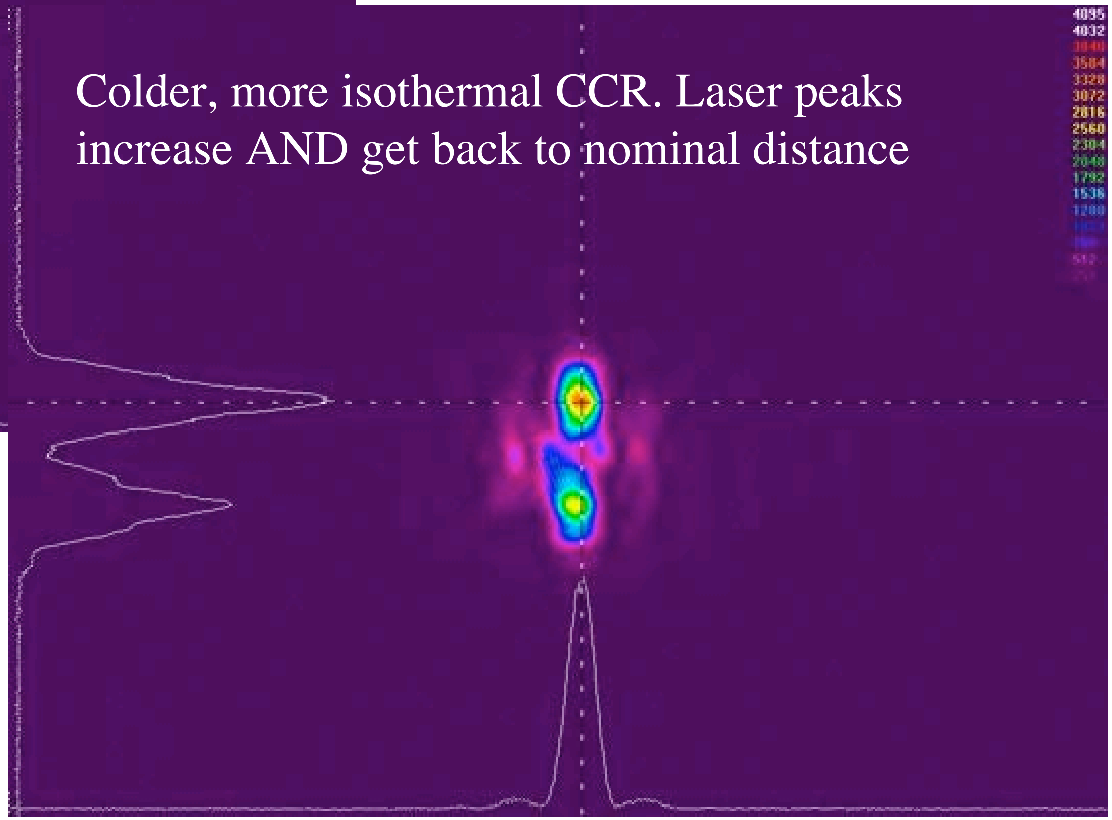
SCF-Test: Sun ON then Sun OFF (Earth eclipse)





Unacceptable **loss and spreading** of laser signal





Strong Reduction of retro-reflected laser signal

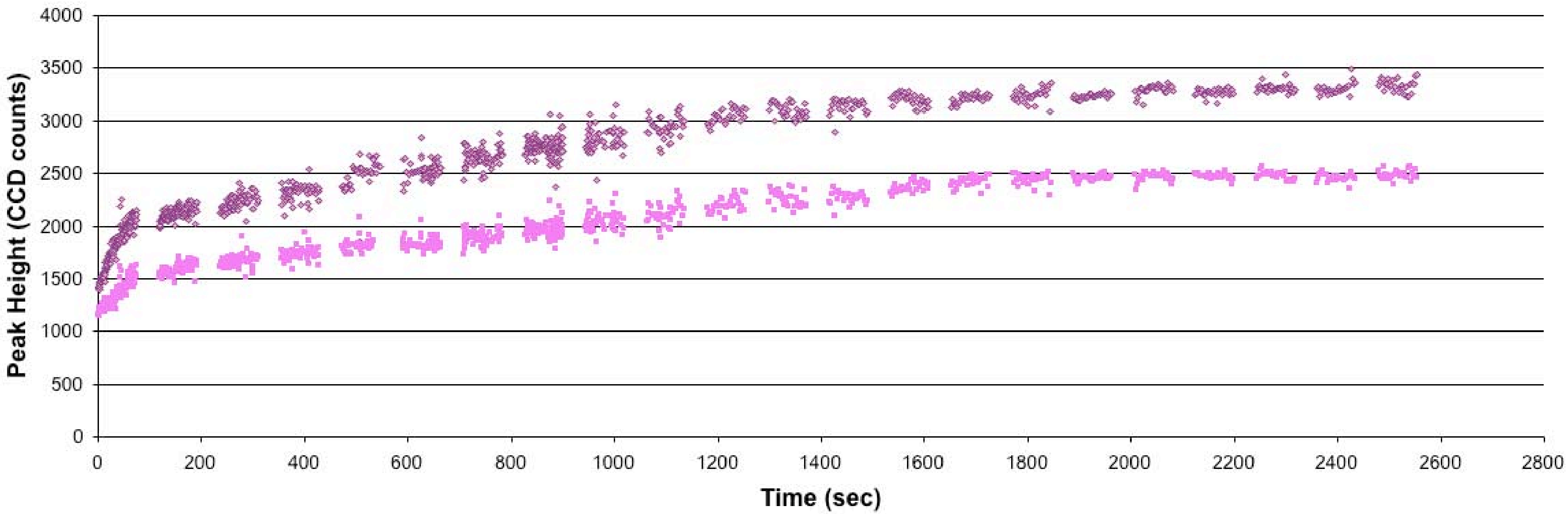
SUN=ON at t=0, SUN=OFF for t > 0

Effect measured for the very 1st time.

It explains the historically troubled performance of Glonass/GPS retros

CCR non-isothermal: strong reduction of laser signal

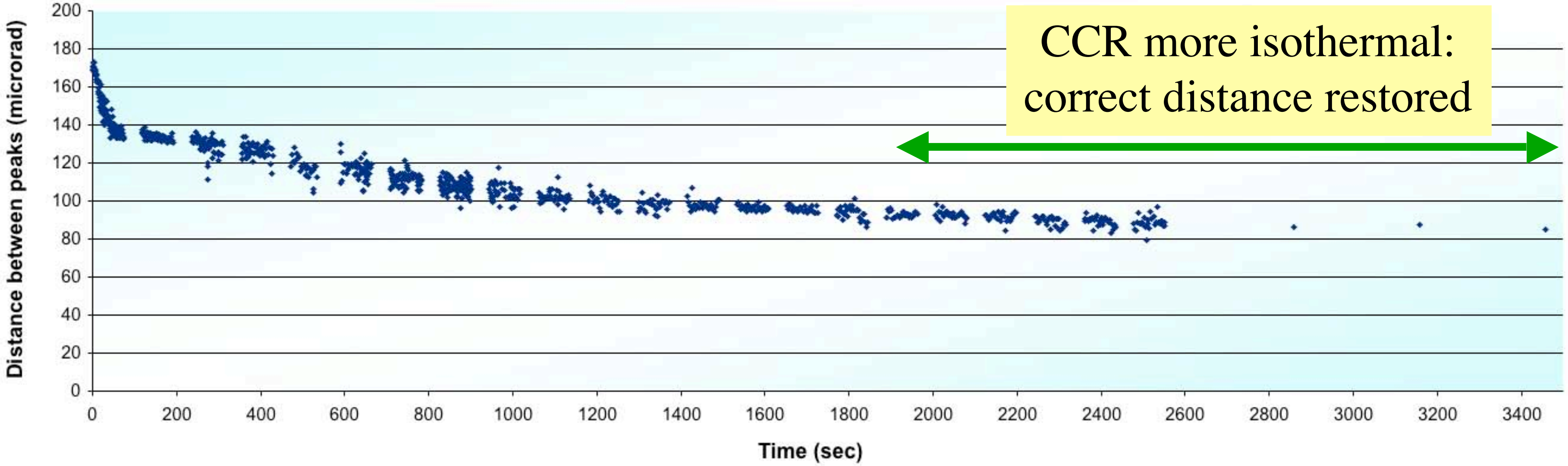
CCR more isothermal: laser signal restored



Laser signal retro-reflected to the wrong place

There seem to be more than one time constant. Candidates:

- CCR back Al-coating (and we knew it …)
- non-insulating CCR mounting => **MAIN PROBLEM?**

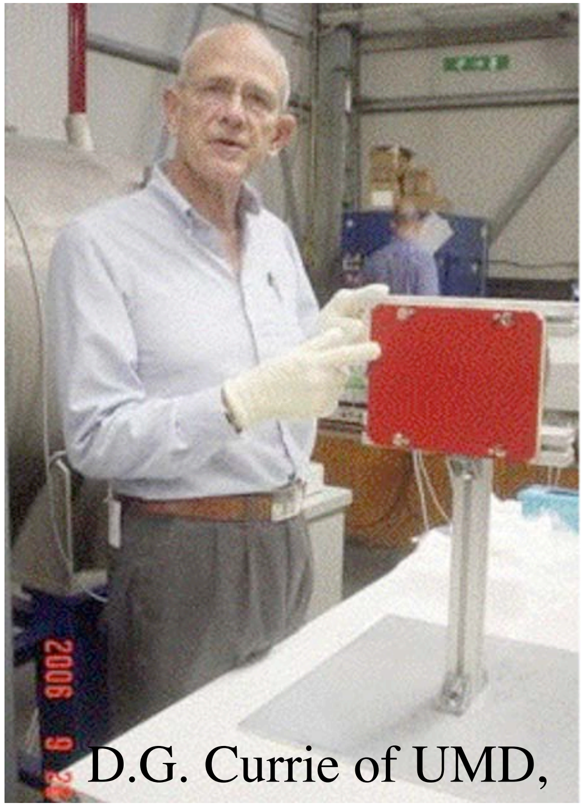


GRA flight model for the GPS-2

<u>3rd and last one so far for GPS-2</u>. Made by IPIE-Moscow.
Basic CCR identical to the ones on GIOVE-A/B and GLONASS.
Property of Univ. of Maryland, loaned to INFN for space characterization @SCF

Flight model, to be launched on GPS-2

19x24 cm^2
1.3 Kg, 32 CCRs

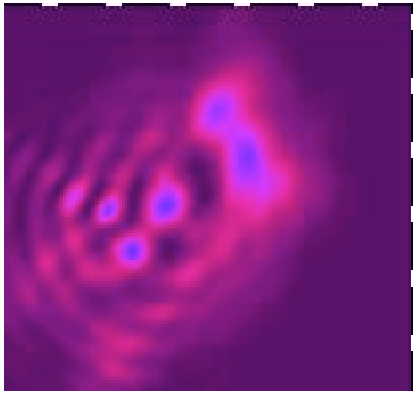


D.G. Currie of UMD, **one of the inventors** of Lunar Laser Ranging

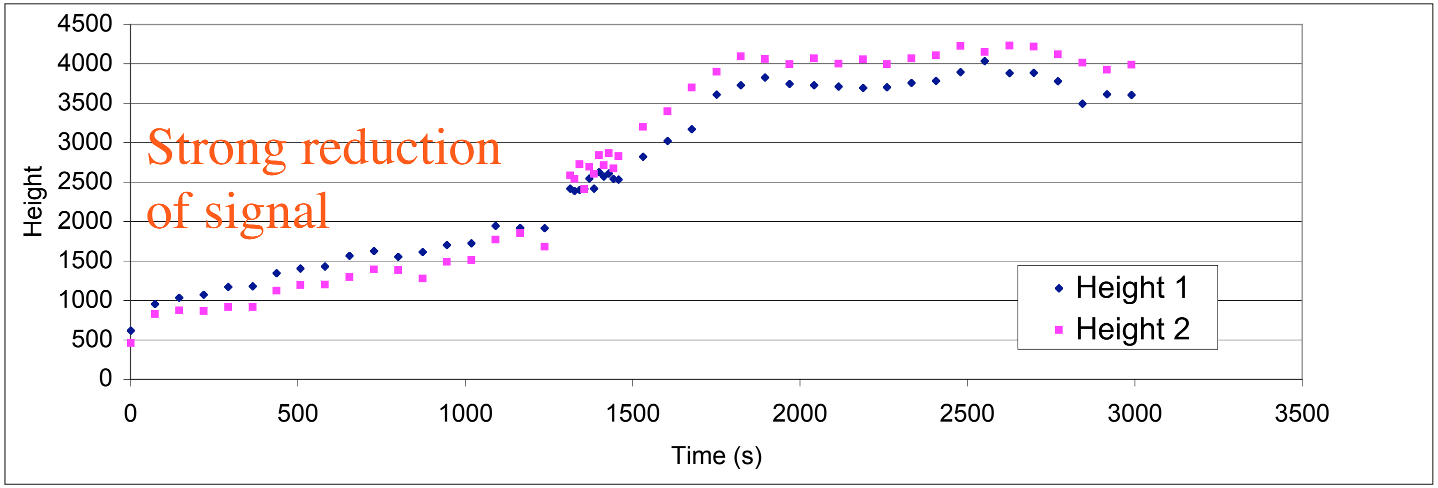
GPS-2 SCF-Test: FFDP spoiled by Sun thermal perturbation

Experimental explanation of long-standing issue. To be corrected for GALILEO

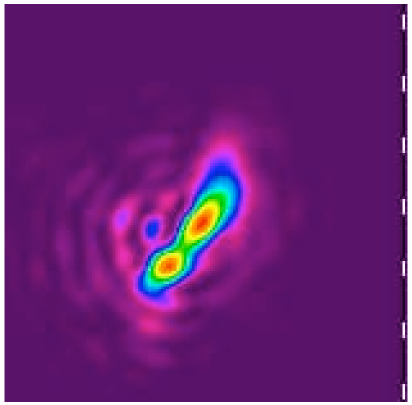
FFDP with Sun ON
@time = 0 sec



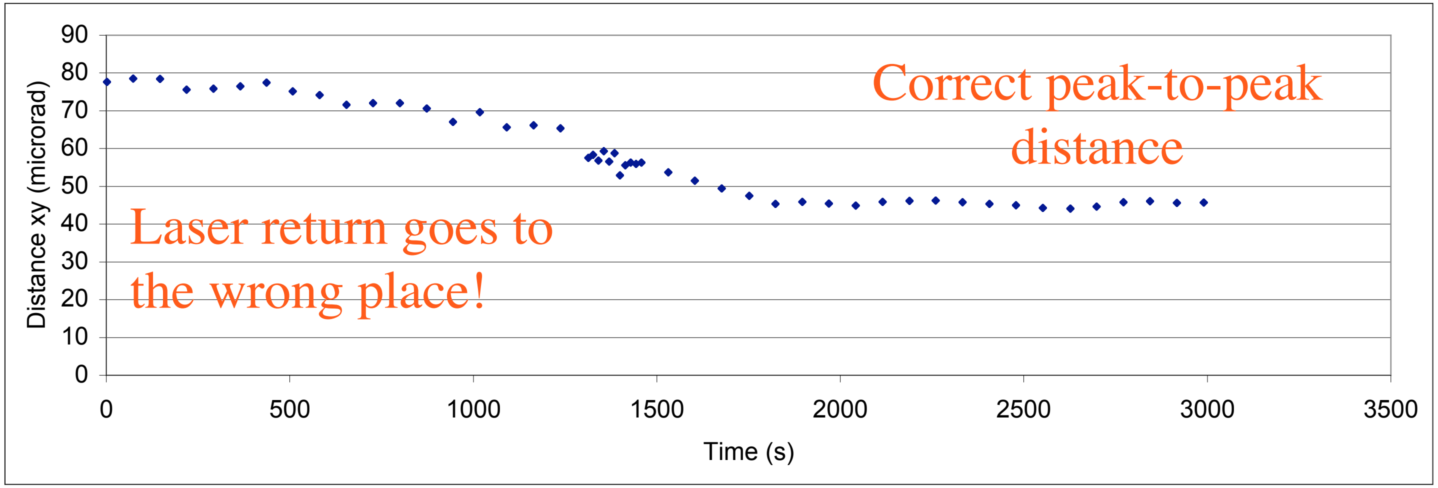
FFDP height (CCD counts) vs time (s) after exposure to Sun



FFDP with Sun OFF
@ time= 3000 sec



FFDP peak-to-peak distance (μrad) vs time (s) after exposure to Sun



Current design of GALILEO GRA

- Length: 522 mm
- Width: 424 mm
- Height: 45 mm
- 78 Non-coated fused silica mirrors
- Mass: 4.7 kg

- Same CCR of Glonass/GPS: Ø ~ 27 mm but **without Al-coating**
- CCR mounting scheme in the cavity and on the back plate: **same as Glonass/GPS**

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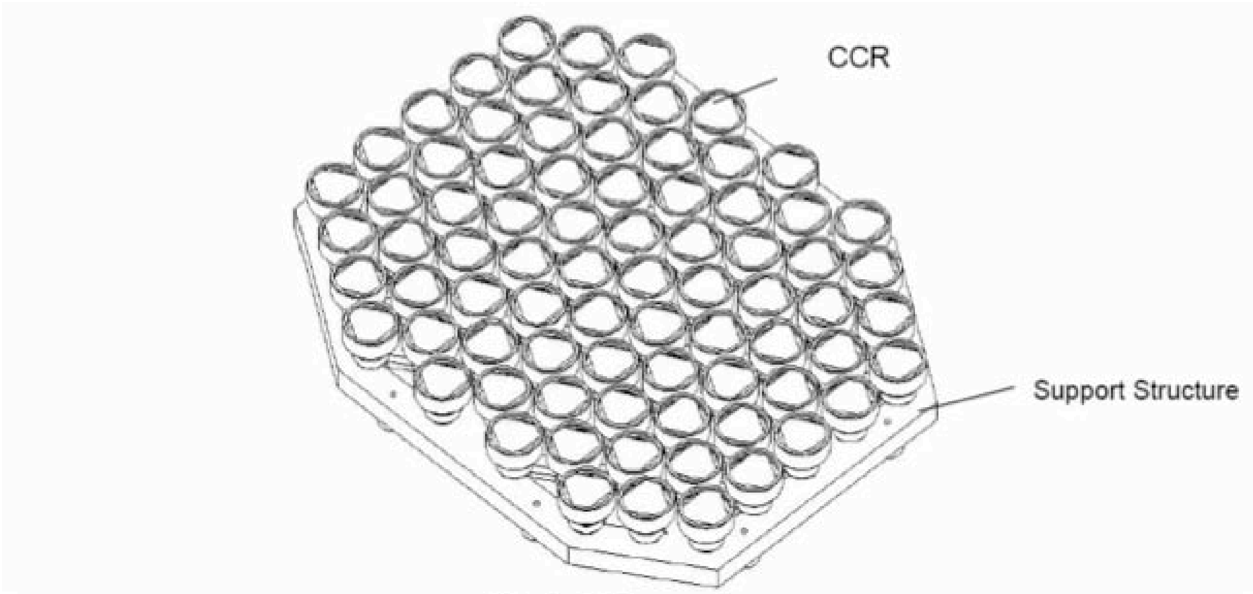
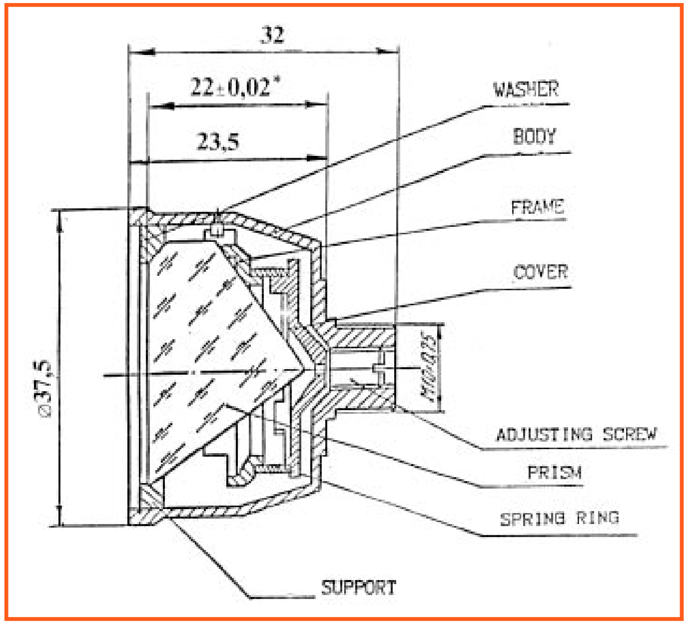


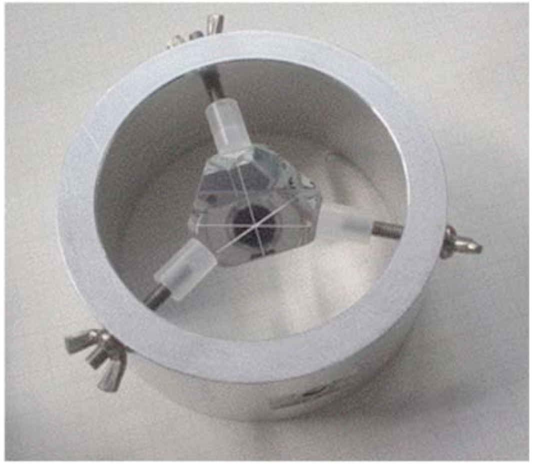
Fig 4. LRR top view

Thermal effects: CCR coating, mounting, new concepts

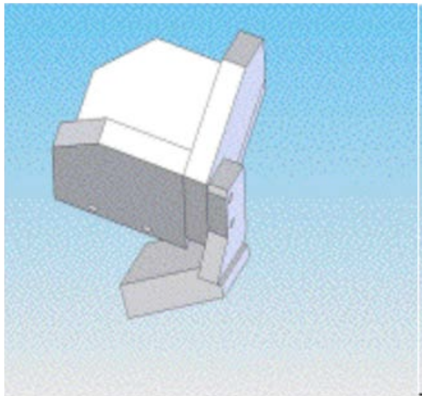
The Glonass/GPS CCR mounting scheme



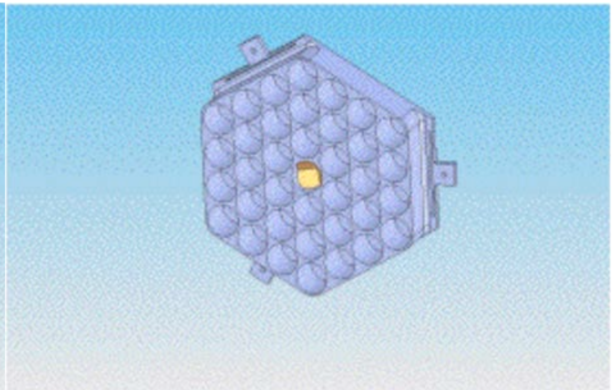
Naked Glonass/GPS CCR, held by KEL-F spacers



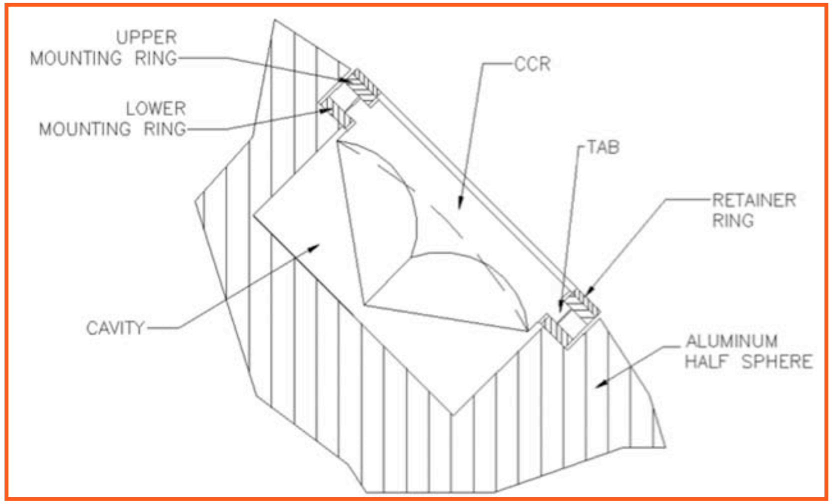
Be or Al **hollow** CCR proposed by NASA-GSFC for GPS-3



SingleHollowCube



HollowCube Array Configuration



The **uncoated** LAGEOS CCR with its pristine mounting scheme

Conclusions

- We developed a new facility and space characterization, the "SCF-Test" of laser retro-reflector arrays
  - Glonass/GPS/GALILEO prototypes
  - LAGEOS prototypes
  - GPS-2 flight model

- Waiting for outcome of proposals for industrial SCF-Testing of GALILEO GRA at INFN-LNF

- The SCF-Test is an important new tool for experimental tests of Gravitation in the Earth-Moon system