The INFN-LNF
Satellite/lunar laser ranging **C**haracterization **F**acility (SCF): results on (LAGEOS and) GNSS

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ILRS International Workshop

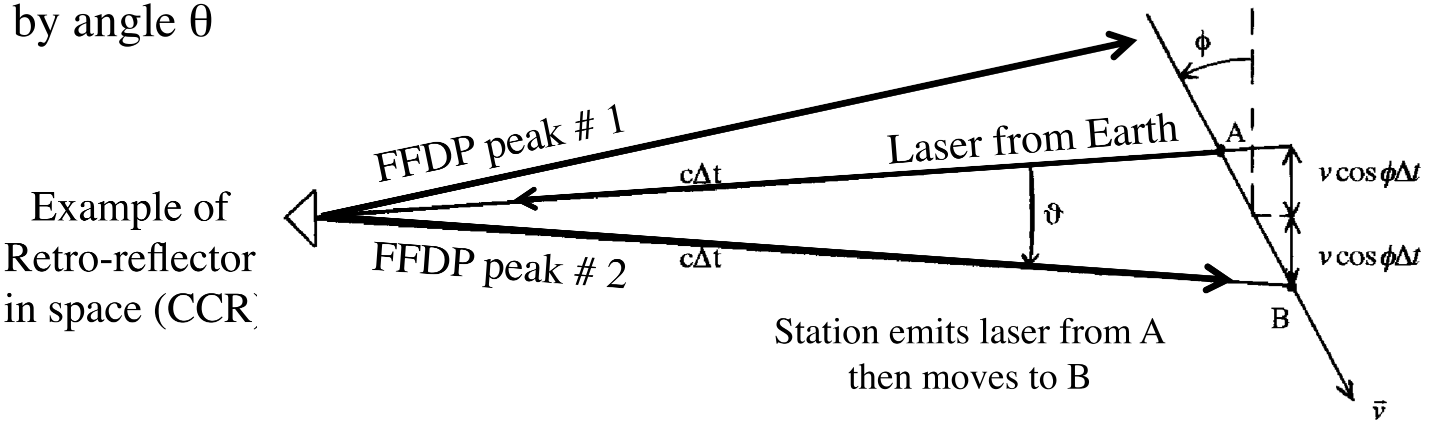
Poznan, Poland, October 13, 2008

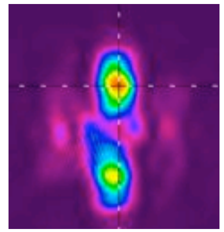
Outline

- Space characterization of laser retro-reflector arrays in space with the SCF
  - The issues, the Facility, the Test
- LAGEOS testing (will skip today due to lack of time)
  - LNF 3x3 prototype; the "sector" prototype; collaboration with GSFC and ILRS; preliminary thermal/orbital/spin model tuned to SCF measurements
- The ETRUSCO INFN experiment on GNSS
  - SCF-Test of the "GPS3" flight model and Glonass-type prototype

CCRs in space: critical thermal & optical issues

- **Velocity aberration**. Relative station-satellite velocity requires expensive non-zero dihedral angle offsets w/0.5 arcsec accuracy to widen laser return (FFDP) to ground by angle θ





FFDP peaks back to ground

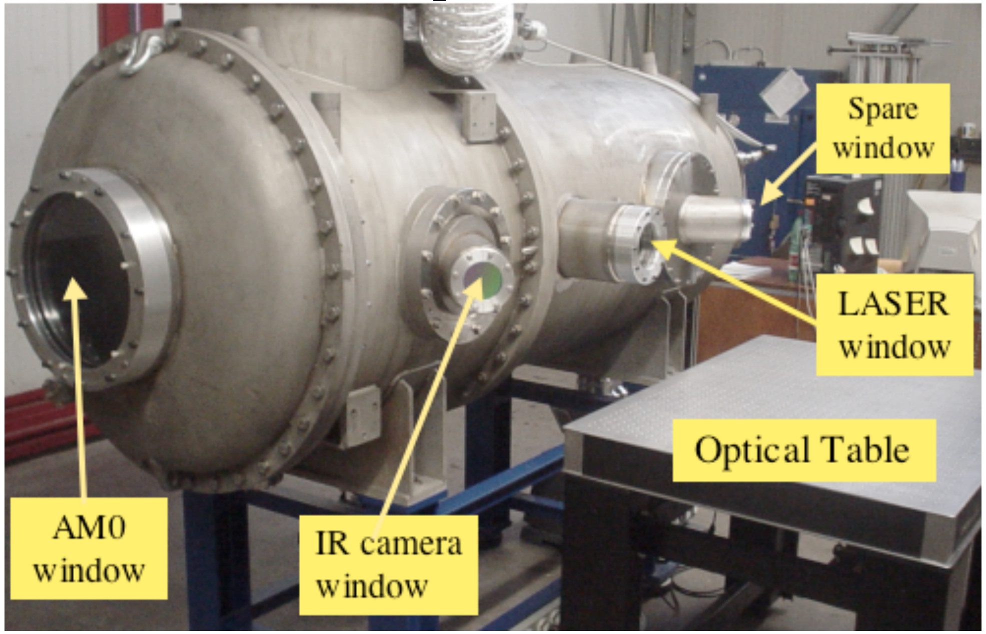
- **Thermal perturbations:** temp. gradients across CCR can degrade laser performance
  - A CCR could work at STP, BUT not in space for thermal reasons
- **Design** CCR array to control thermal and optical properties
- **SCF-Test**: characterize performance at the INFN-LNF dedicated facility

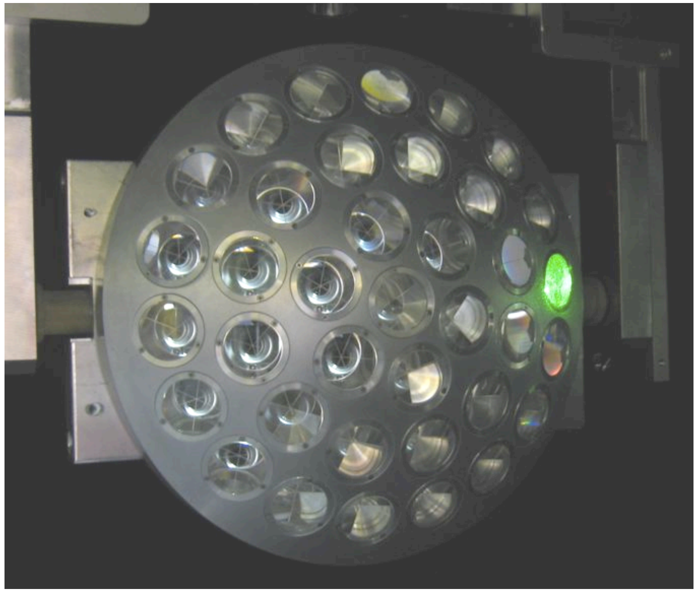
GPS/GLONASS velocity aberration is
$\theta \sim 2\ v/c \cos\phi \sim 25\ \mu rad$
(~ 500 m on the ground)
Achievable with dihedral angle offsets ~ 2”-3”

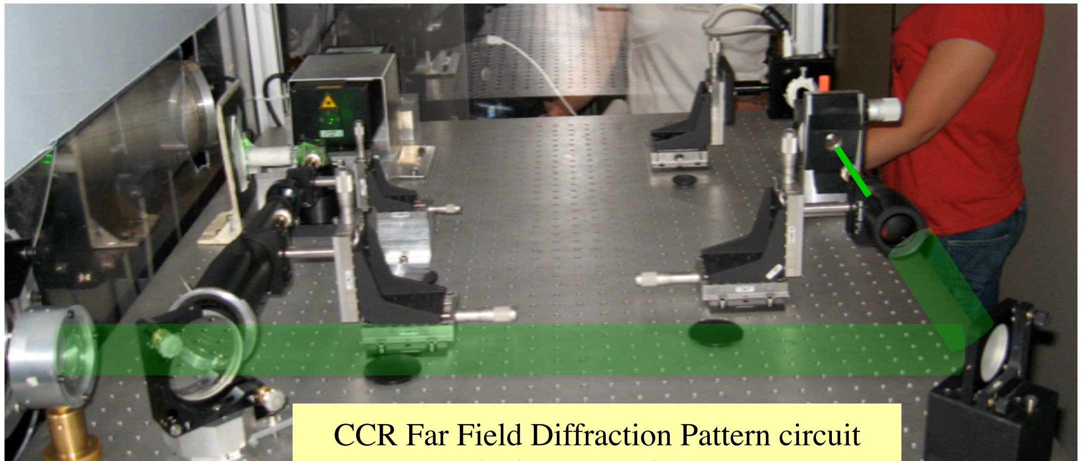
Nominal distance between FFDP peaks is
$2 \times \theta = 50\ \mu rad$=> 1 Km

SCF-Test of LAGEOS “**sector**” proto from NASA-GSFC

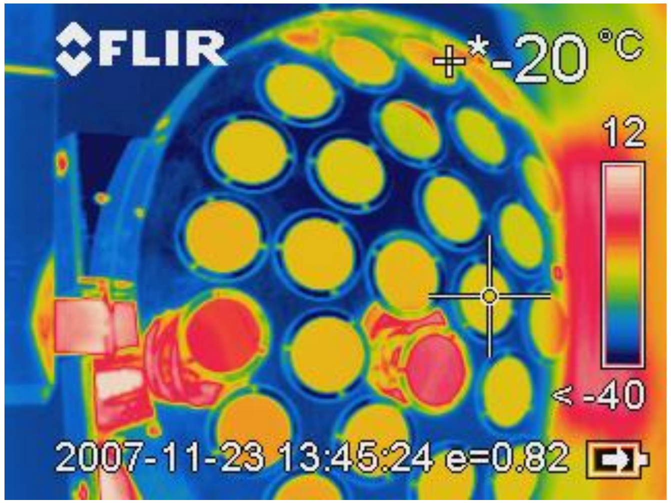
Thermal and optical test of laser retro-reflector array in space conditions







CCR Far Field Diffraction Pattern circuit
CCRs inside or outside the SCF



New space test: the “SCF-Test”

- Space conditions
  - Dark/cold/vacuum, Solar/IR Simulators
  - IR thermometry, laser measurements
- Measurement of
  - IR emissivity & Solar absorptivity of CCR and metal
  - $T_{SURFACE}$ of CCR and metal
  - Thermal relaxation time of CCR (τ_{CCR}), plastic, metal
  - T difference of outer face and inner tip of CCR
  - CCR Far field diffraction patterns (FFDP) in SCF
    - Developing CCR interferogram
  - CCR FFDP at STP
- Thermal and optical model of SCF data, SPACE data

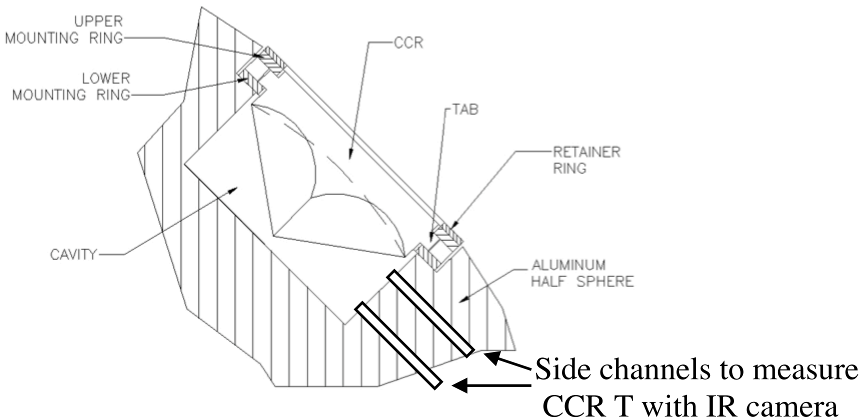
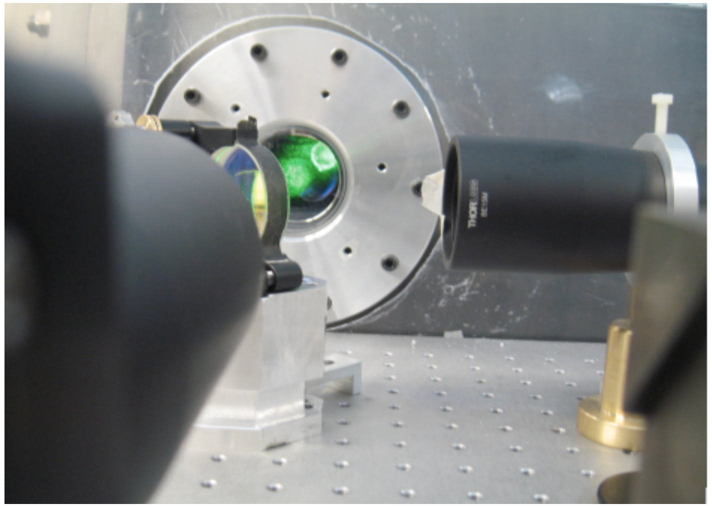
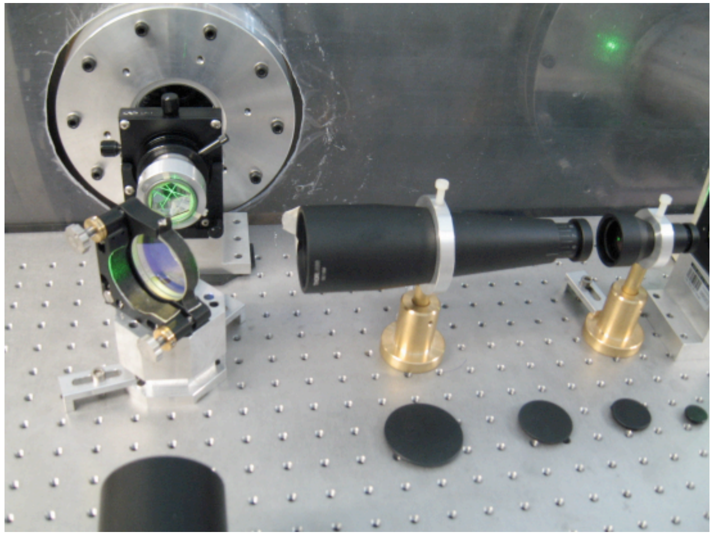


Figure 3. LAGEOS CCR assembly

Glonass CCR “in space”, inside SCF



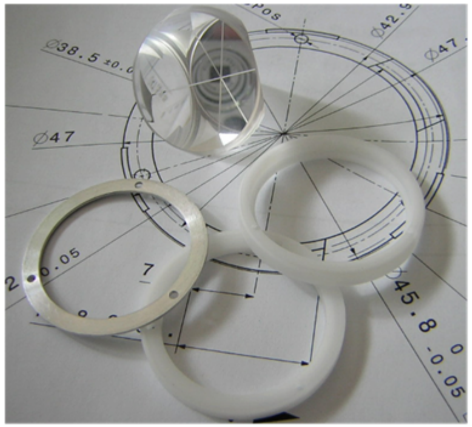
Glonass CCR at STP, outside SCF



LAGEOS: thermal SCF-Test and simulation

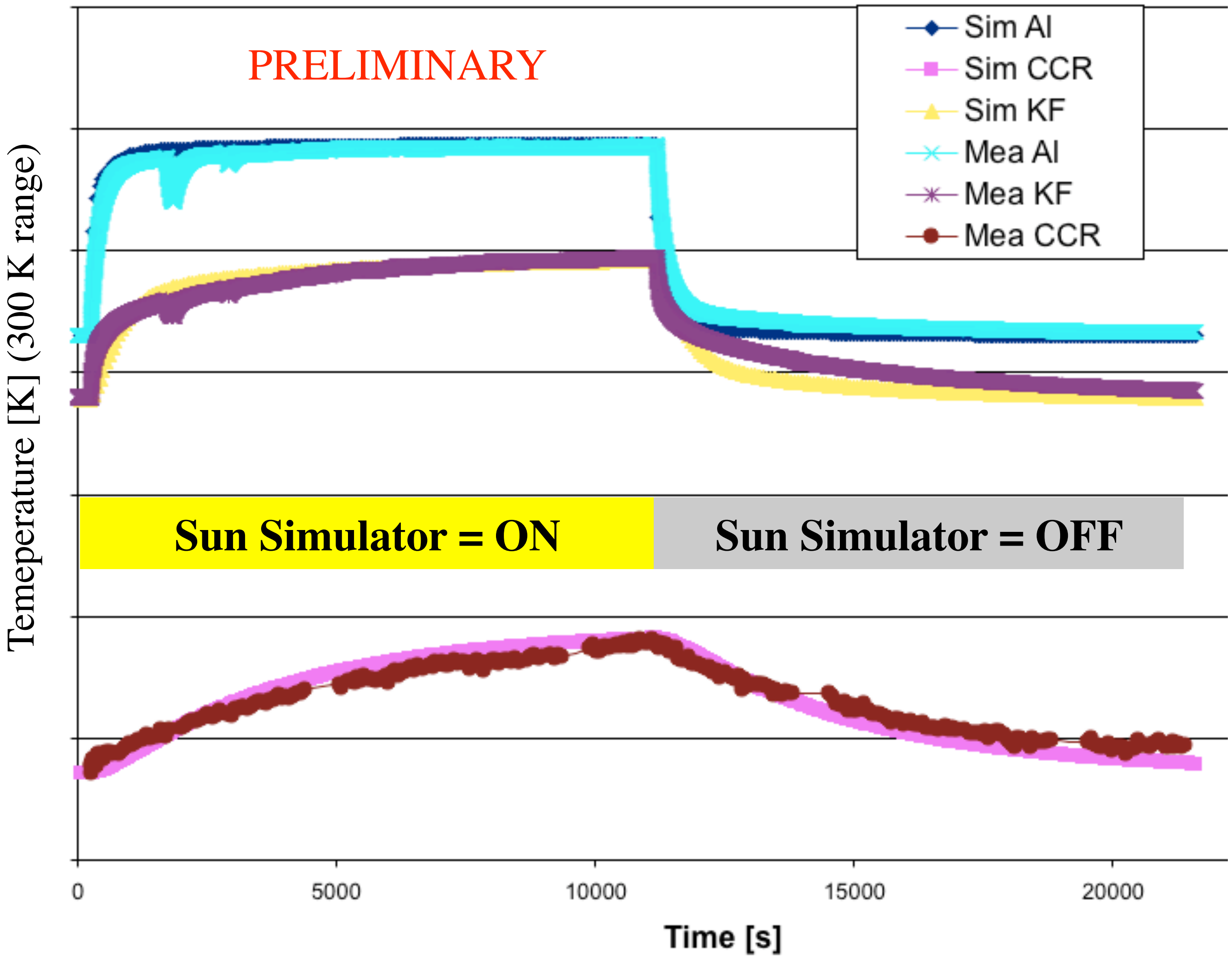
Calculations of CCR thermal relaxation time vary by ~300%. **Our measurement, which was never done before**: $\sigma(\tau_{CCR}) \sim 10\%$ around T~300K

SW suite: Thermal Desktop by C&R-Tech.



SCF work led by Giovanni Delle Monache

Temperature vs time of CCR and mounting rings (see photo)



Thermal NGPs on LAGEOS: orbit, spin, Earth shadow

Comparison of thermal thrusts vs time (one orbit) between:

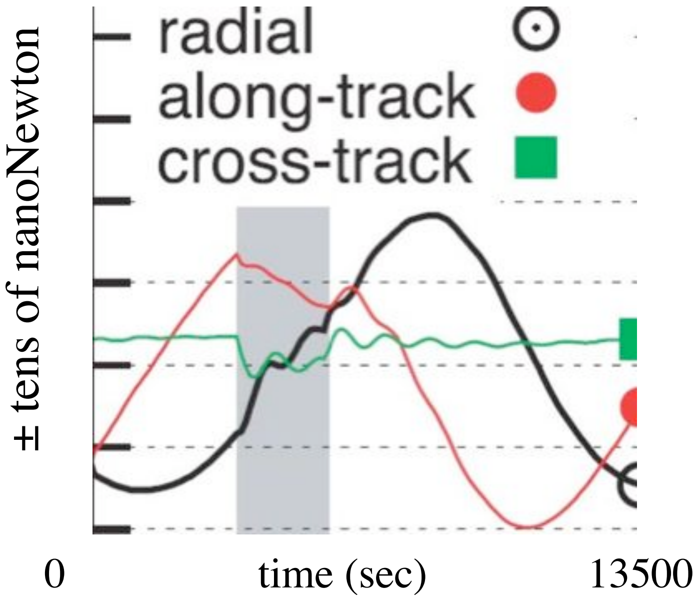
- LageOS Spin Axis Model (LOSSAM): some input data were not measured
- LNF model: based on orbital/thermal FEM model tuned to SCF measurements

Two completely different models agree qualitatively; ours is wholly based on the SCF

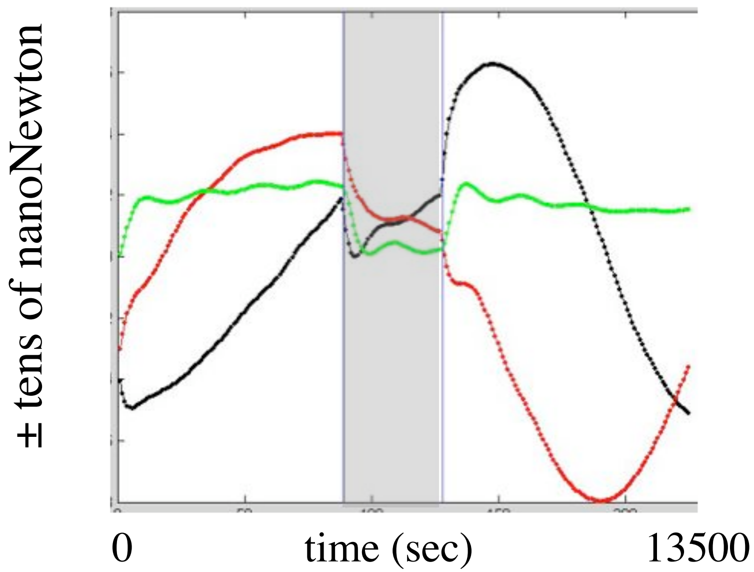
Spin and Orbit of 1/1/2000 (with longest Earth shadow)

PRELIMINARY

LOSSAM (Nacho Andres *et al*)
Earth shadow = grey area



LNF model tuned to SCF data
Earth shadow = grey area



ETRUSCO, a multidisciplinary INFN experiment on GNSS

GALILEO will be a "Unified" constellation: standard MW antennas **AND** laser retro-reflectors on all 30 satellites

GPS-2 has CCRs on two satellites

Collaboration with Ital. Air Force, UMD, MLRO, ILRS, GSFC

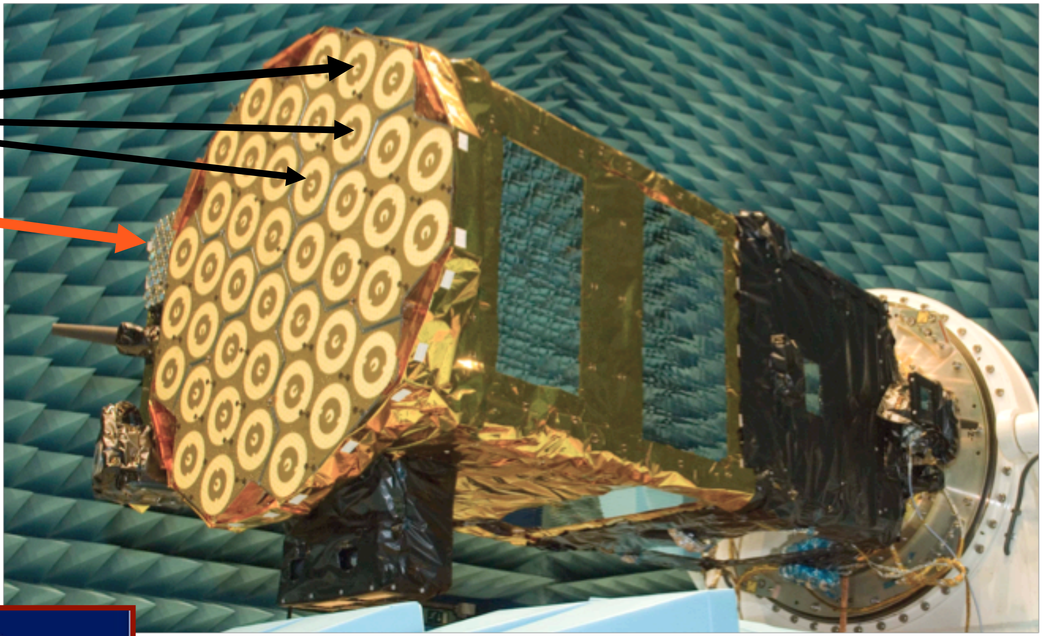
D.G. Currie of UMD, **one of the inventors** of Lunar Laser Ranging, with the 3rd (and last existing) GPS CCR array loaned to LNF, the **"GPS3"**

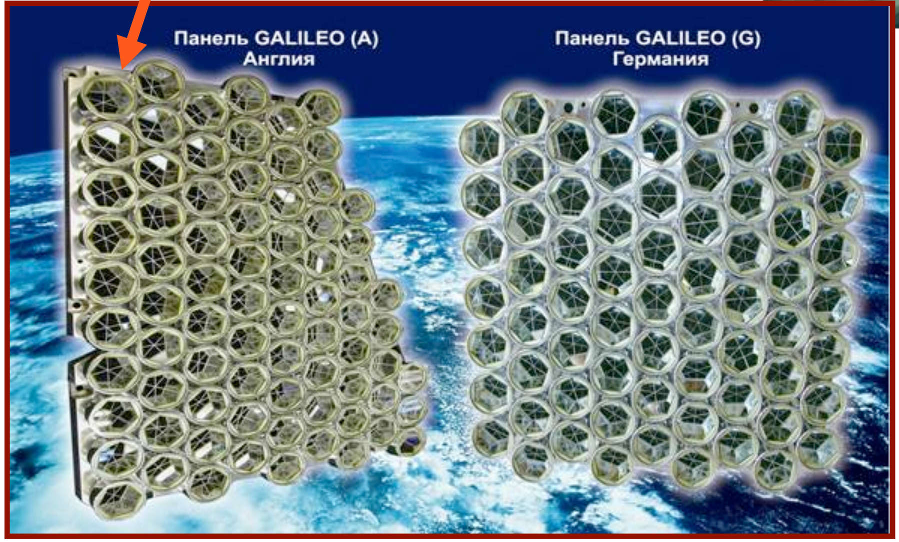
GNSS Retro-reflector Arrays (GRA) on GIOVE-A/B

CCRs like those on Glonass and GPS

MW antennas
and one GRA

GNSS:
Global Navigation
Satellite System

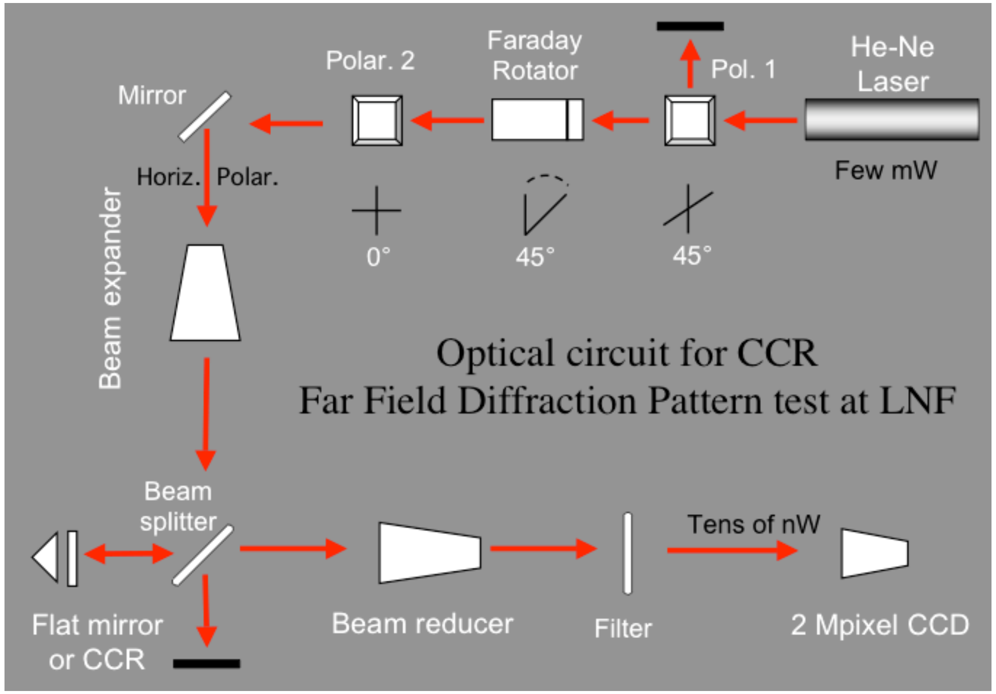




Benefits of laser ranging wrt standard microwave tracking

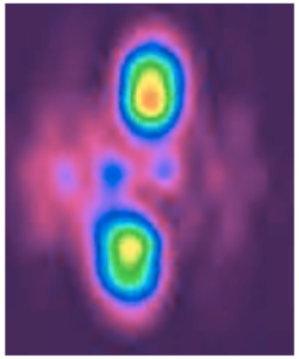
- Absolute positioning wrt Geocenter
- Factor ~10 better positioning
- Long term stability & geodetic memory

Glonass prototypes FFDPs @STP (λ=532 nm)

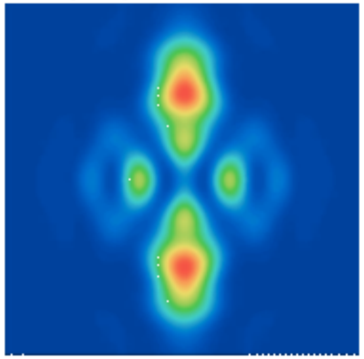


Optical modeling software: CodeV, by ORA

MEASURED PATTERN



SIMULATED PATTERN



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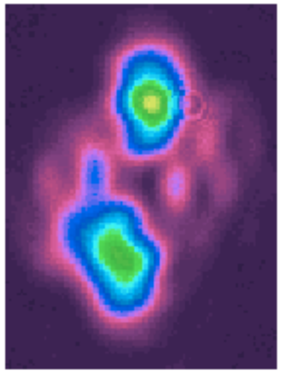

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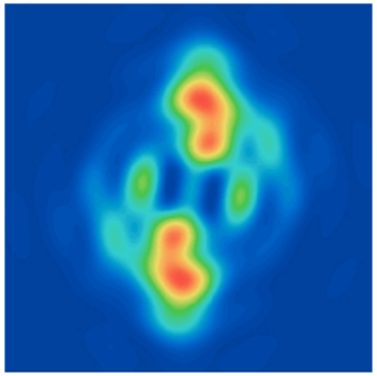
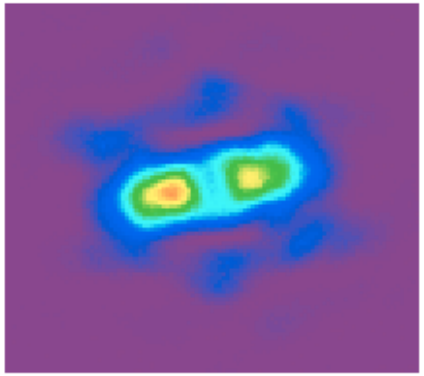
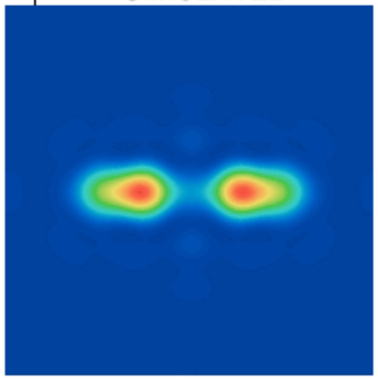


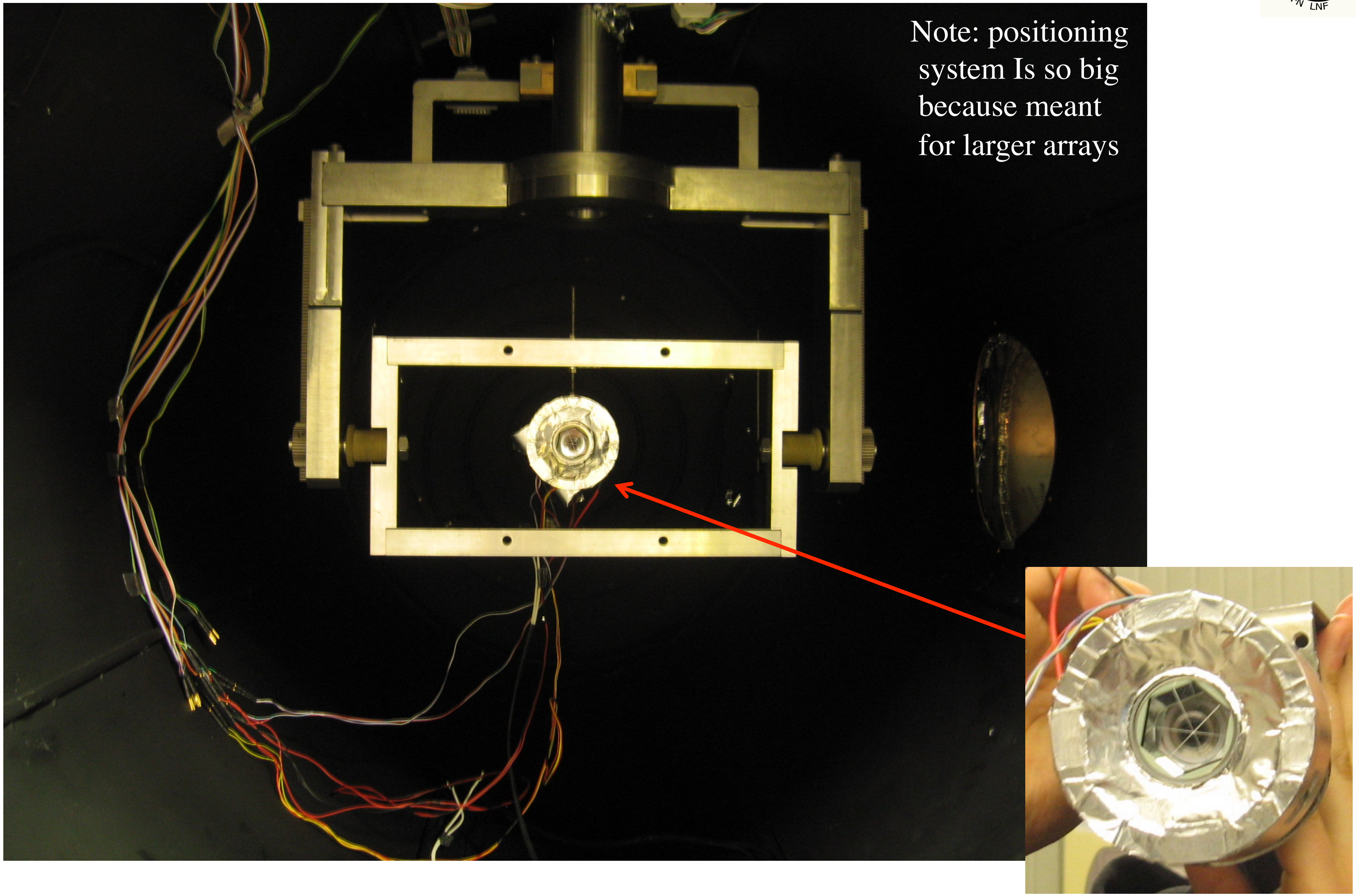
MEASURED



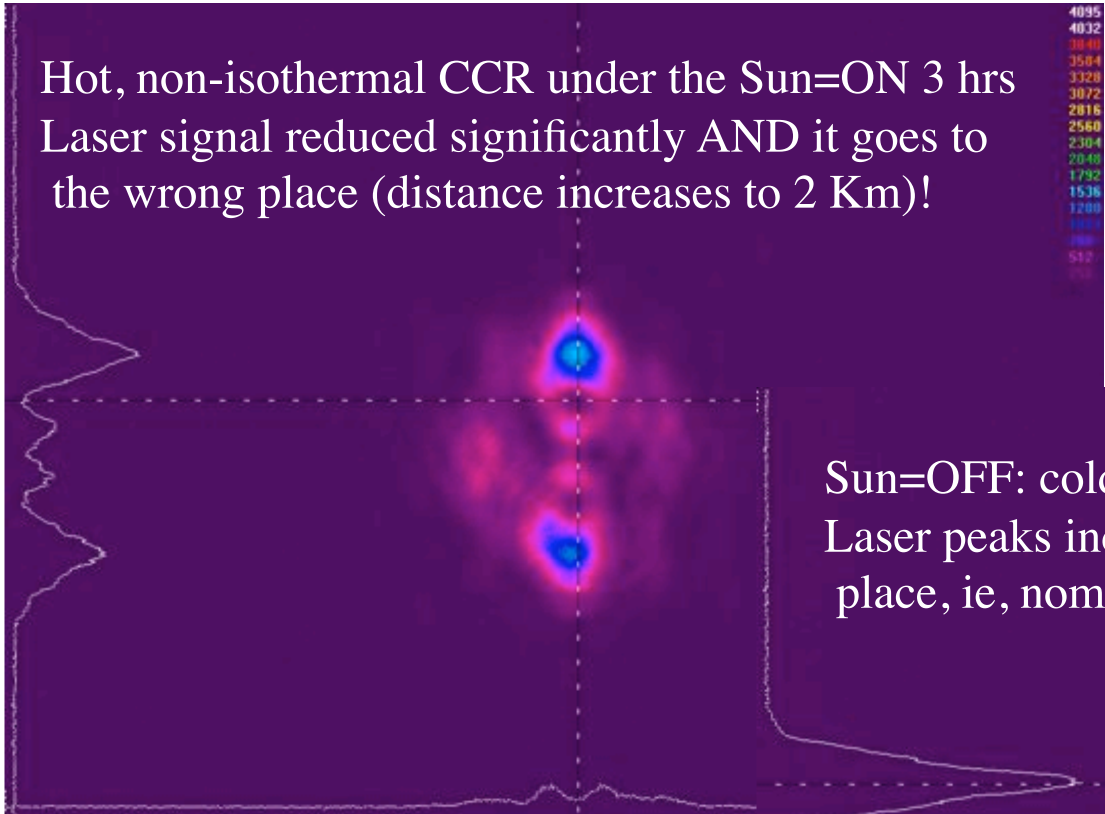
SIMULATED



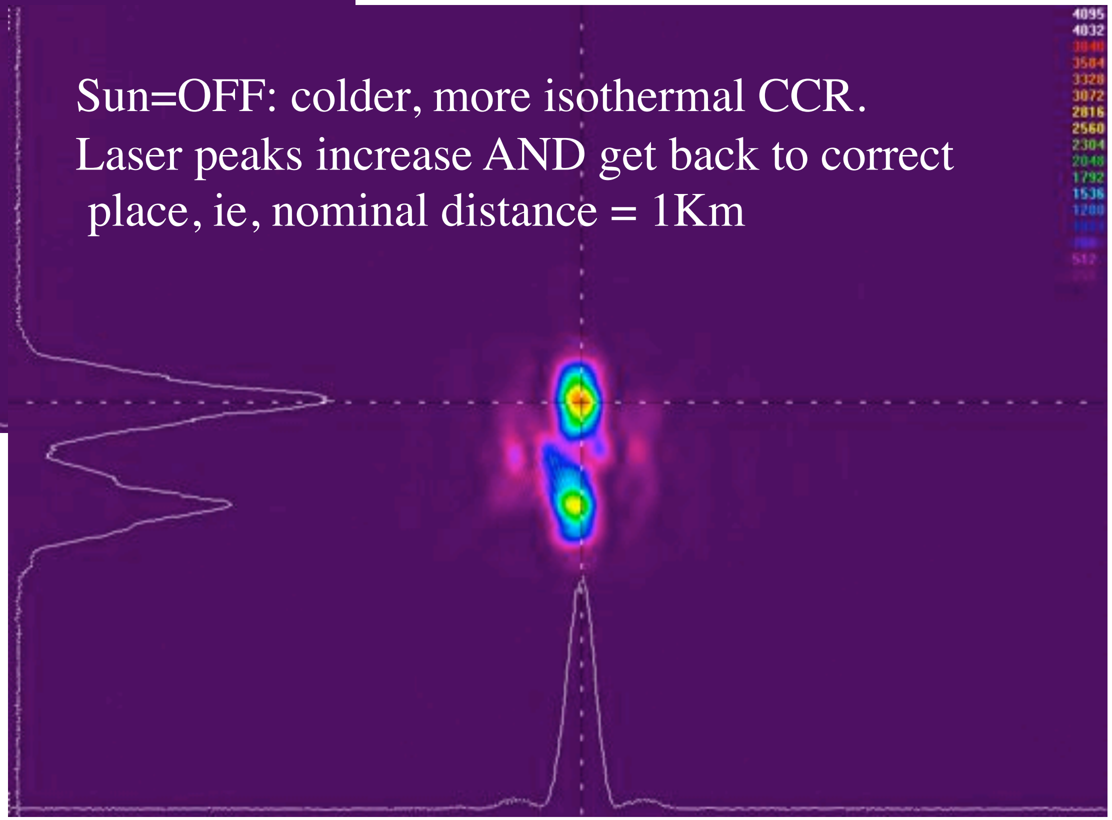
SCF-Test of Glonass Al-coated CCR prototype



SCF-Test of Glonass Al-coated CCR prototype



Significant **loss and spread** out of laser signal

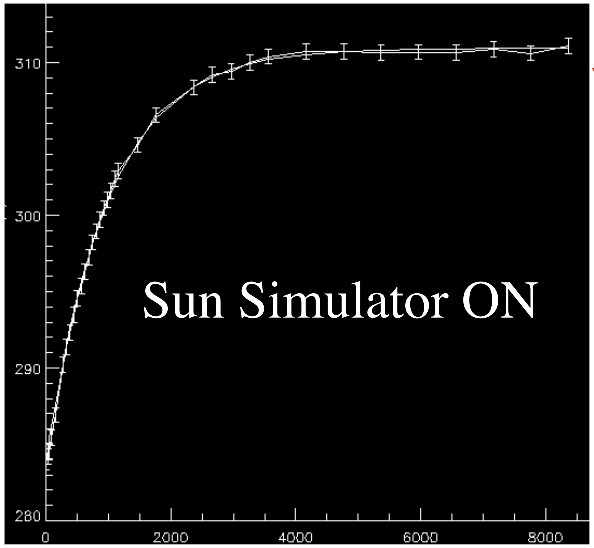


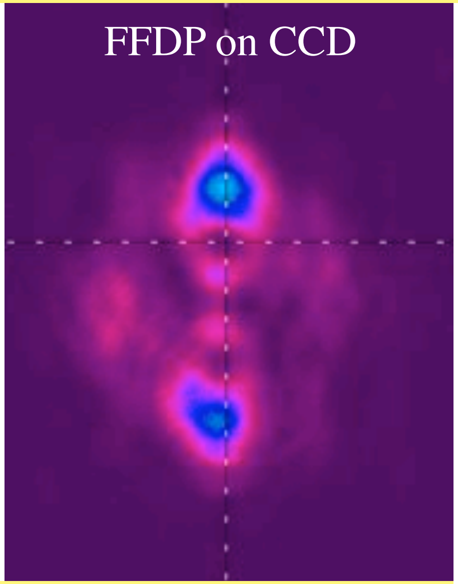
λ=532 nm

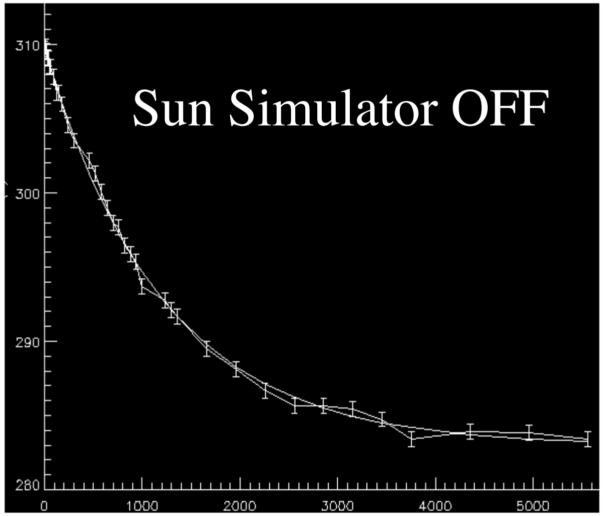
Glonass SCF-Test

Note: sun at 90°, ie, this is a "worst case"

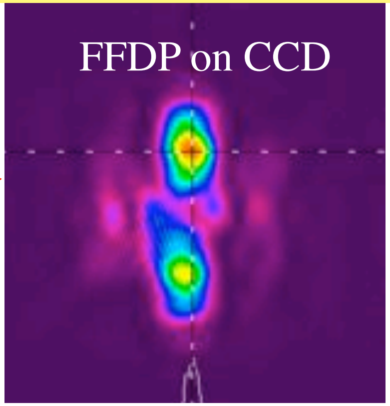
Laser return peaks reduced by factor 2, their distance increased to 2 Km





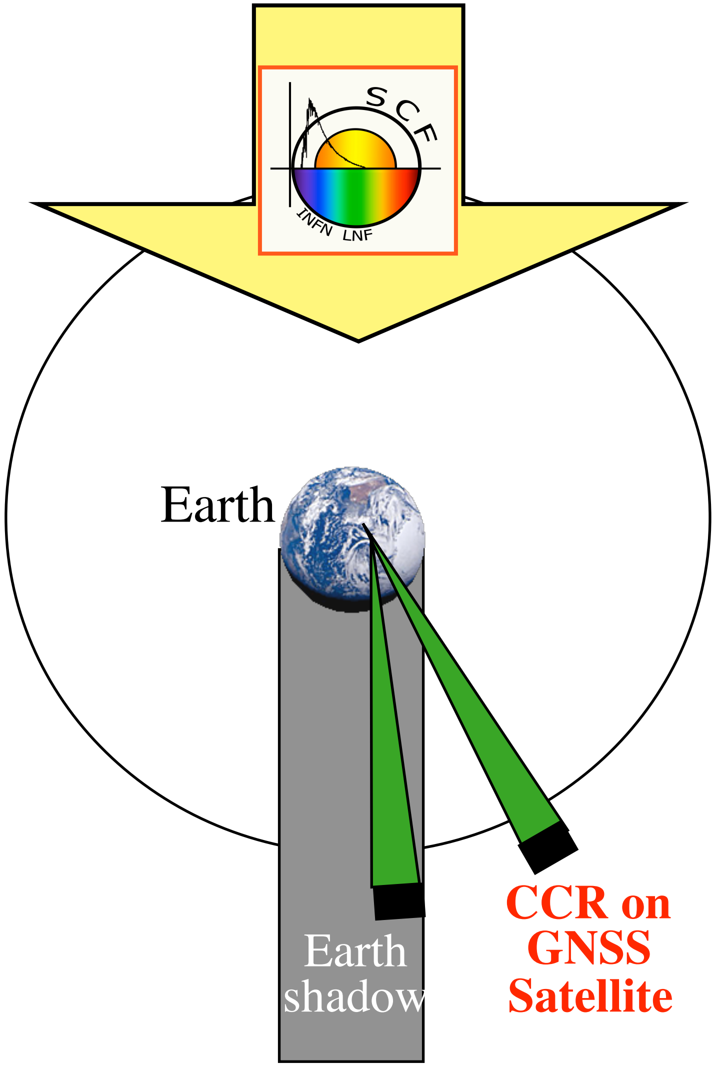


Laser peaks increase AND get back to nominal velocity aberrated distance = 1 Km

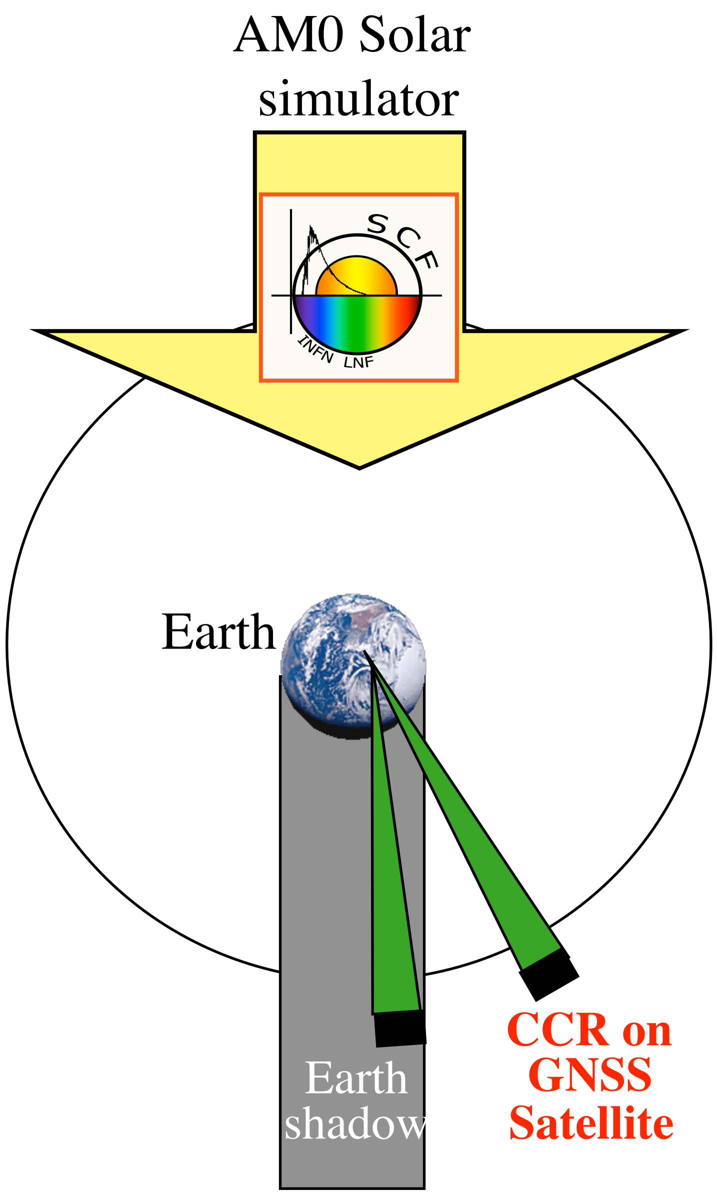


$T_{OUTER\ CCR\ FACE}$(K) vs t (sec)

AM0 Solar simulator



Next: from 90°, "worst case" to "orbit-like" case



NEXT SCF-Tests

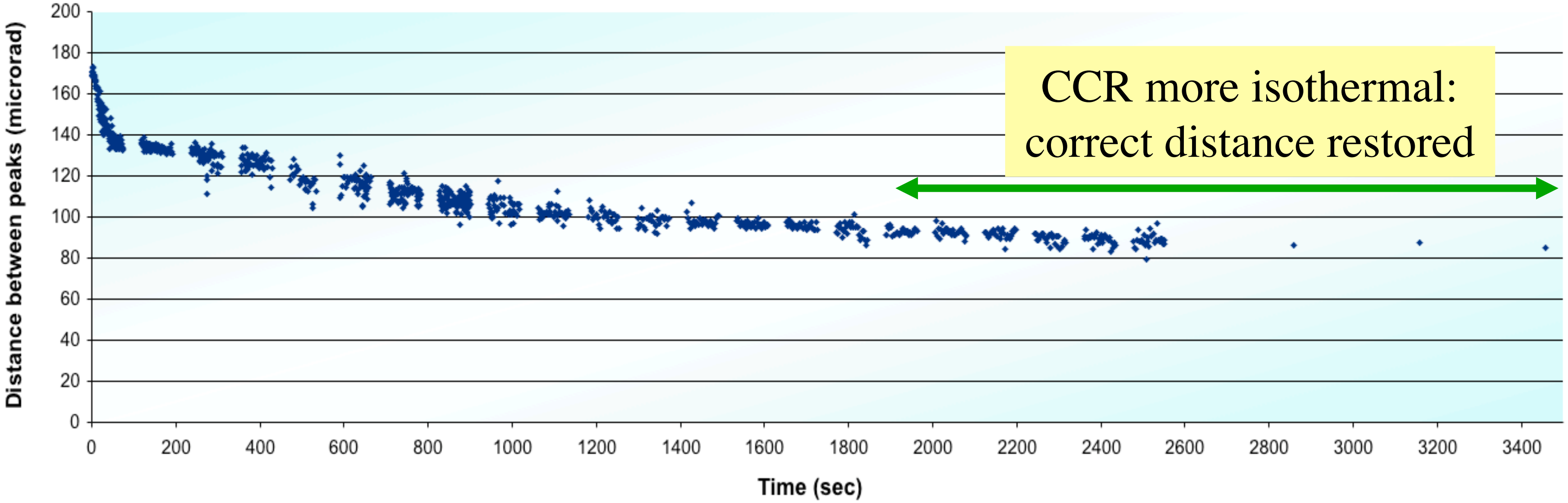
Will rotate slowly the CCR in a ~3-hour, quarter-orbit SCF-Test. Plus ~2 hour shadow.

Thermal effects make FFDP peaks move away from the ‘angular location’ where the stations are

More than one time constant. Candidates:

- CCR back Al-coating
- non-insulating CCR mounting

We will try to disentangle the two effects



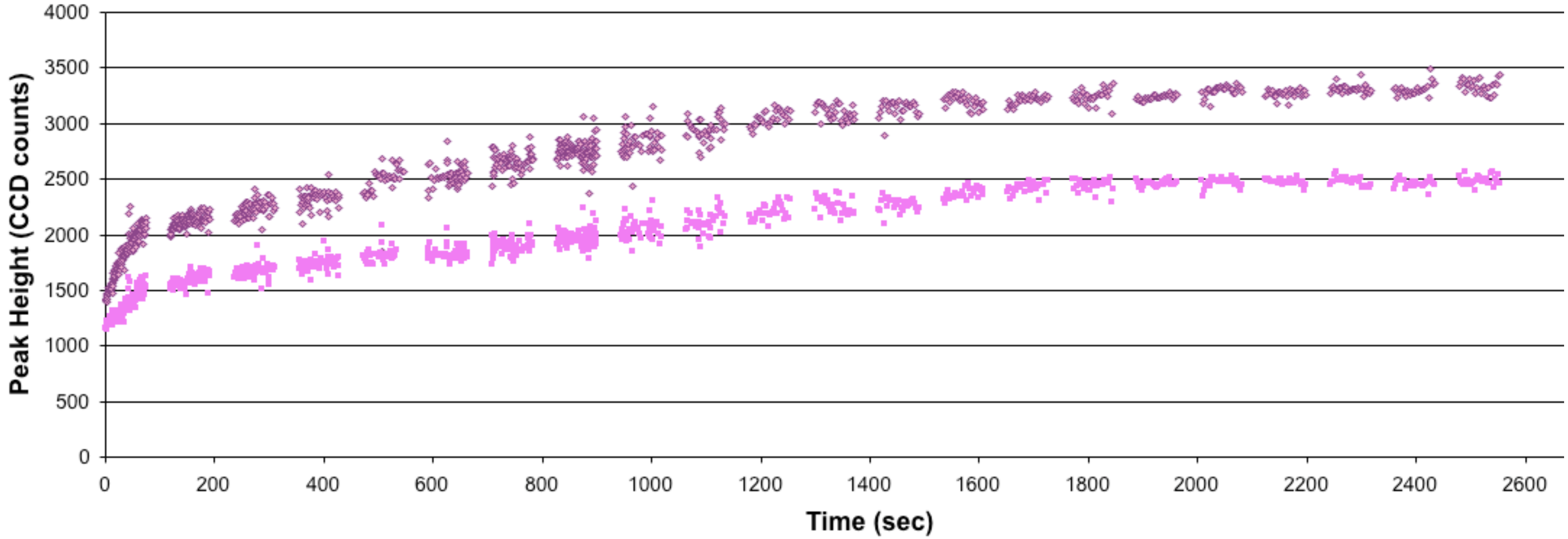
Note: the vertical scale is mis-calibrated by 50/85. The corrected asymptotic distance is ~50 µrad)

Reduction of intensity of laser return

SUN=ON at t<0, SUN=OFF for t > 0
2.5 hours of Sun illumination, then Sun=off and FFDP measurement
This effect has been measured for the very 1st time.
It may help understand the performance of Glonass/GPS CCRs in orbit

CCR non-isothermal: strong reduction of laser signal

CCR more isothermal: laser signal restored



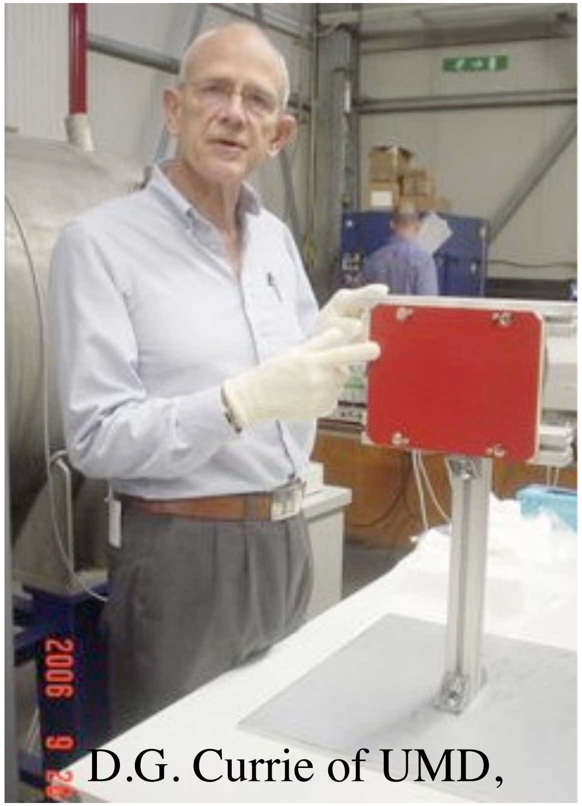
GRA flight model for the GPS-2 (the “GPS3”)

3rd made for GPS-2

Property of Univ. of Maryland, loaned to INFN for space characterization @SCF

19 x 24 cm^2

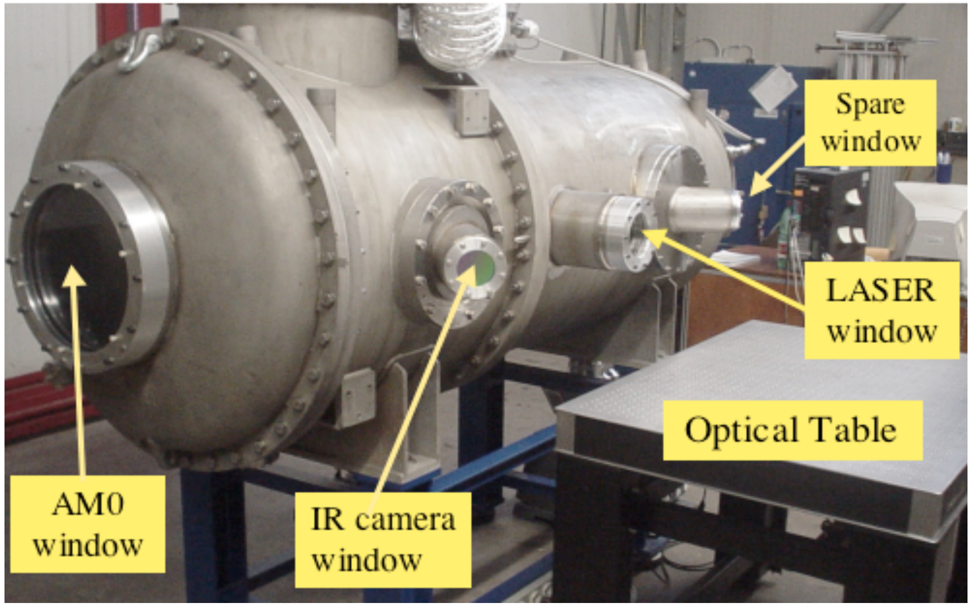
1.3 Kg, 32 CCRs

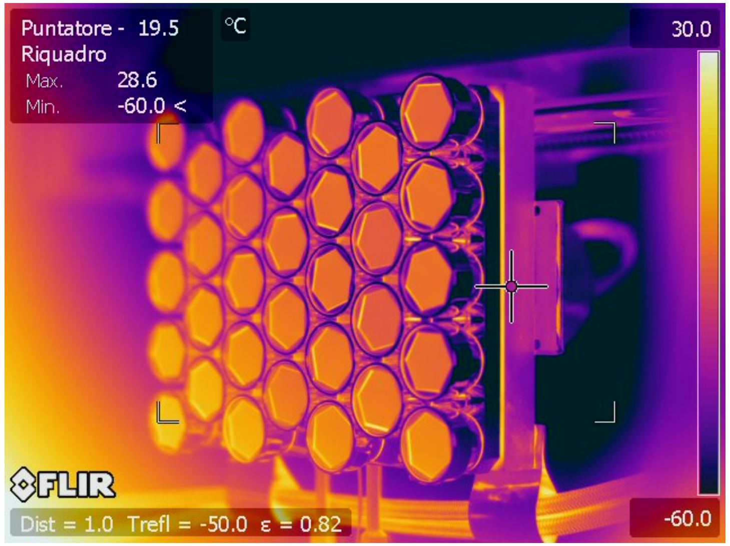


D.G. Currie of UMD, one of the inventors of Lunar Laser Ranging

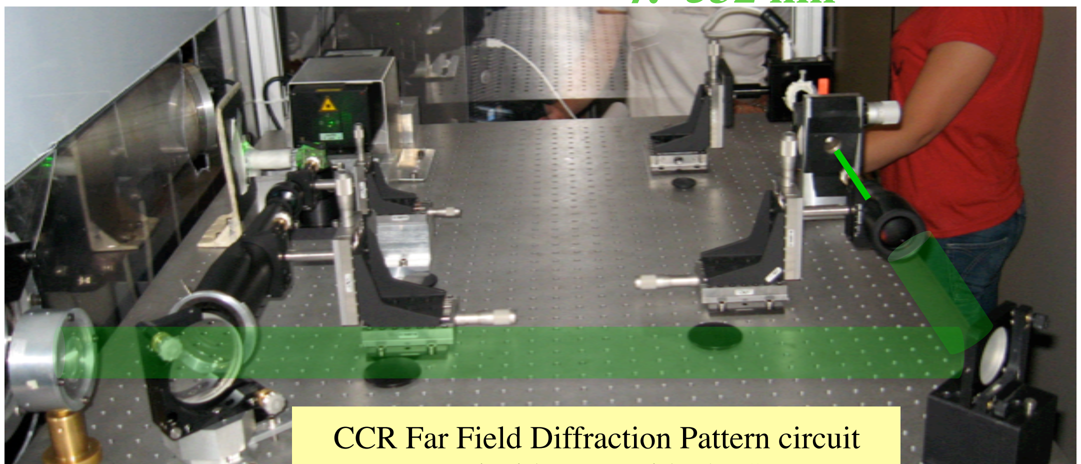
SCF-Test of GPS-2 flight model from Univ. of Maryland

Thermal and laser tests never performed before in space conditions

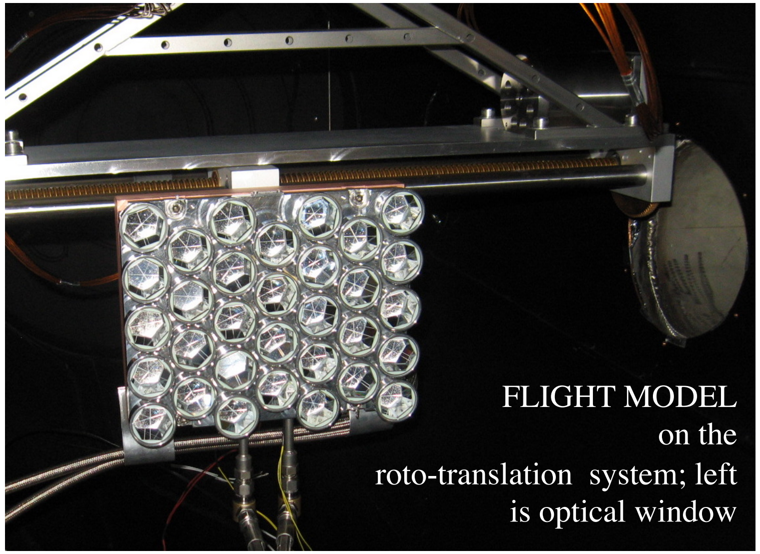




λ=532 nm



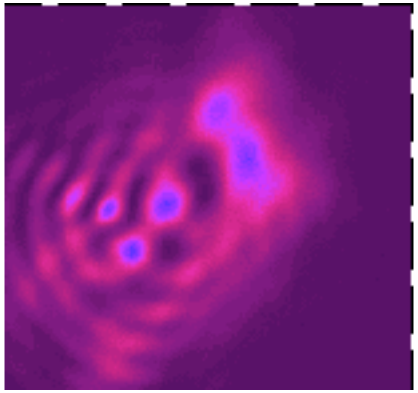
CCR Far Field Diffraction Pattern circuit
CCRs inside or outside the SCF



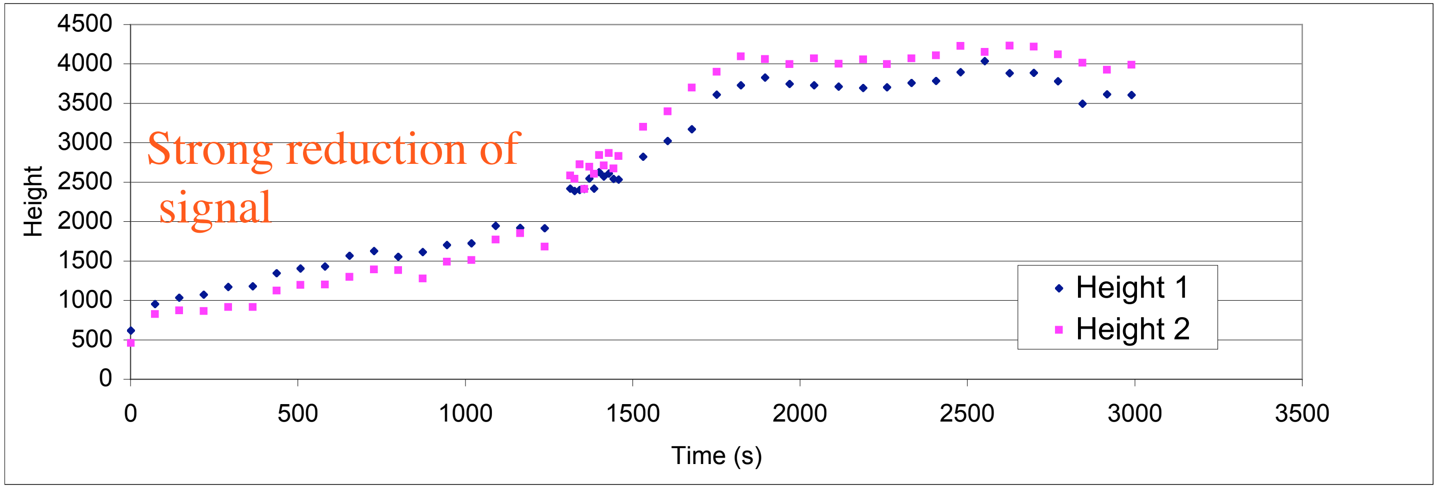
GPS-2 SCF-Test: FFDP spoiled by Sun thermal perturbation

Explanation of problematic performance? To be avoided for GALILEO

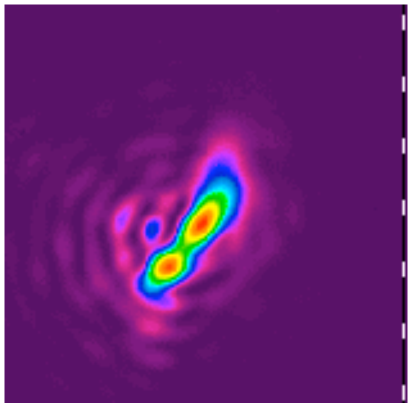
“Hot” FFDP @ t = 0 sec



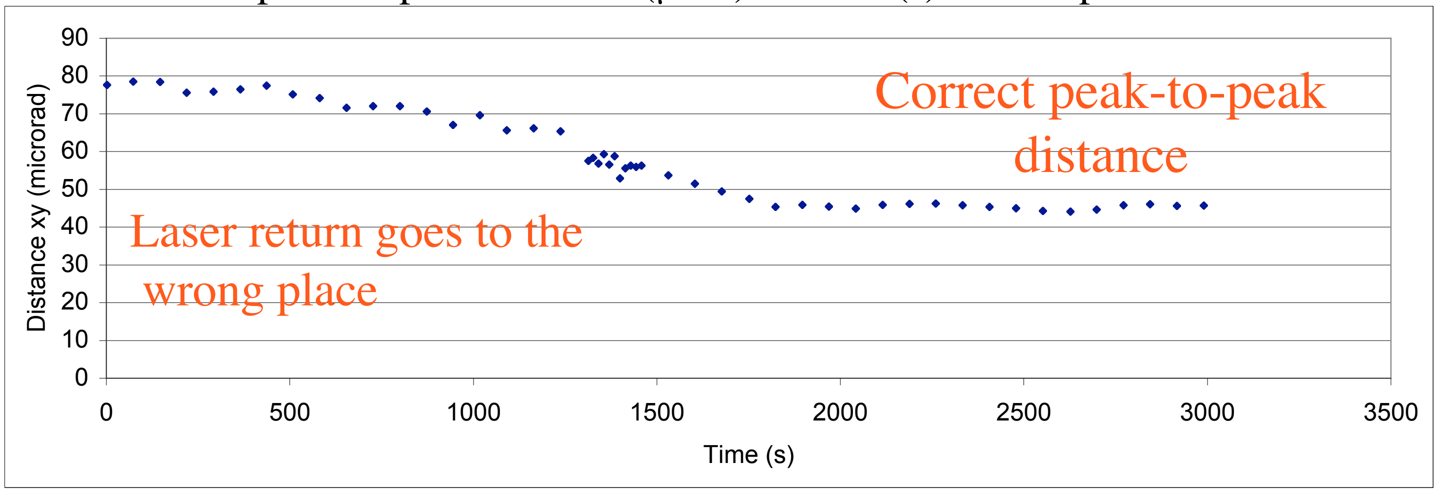
FFDP height (CCD counts) vs time (s) after exposure to Sun



“Cold” FFDP @ t= 3000 sec

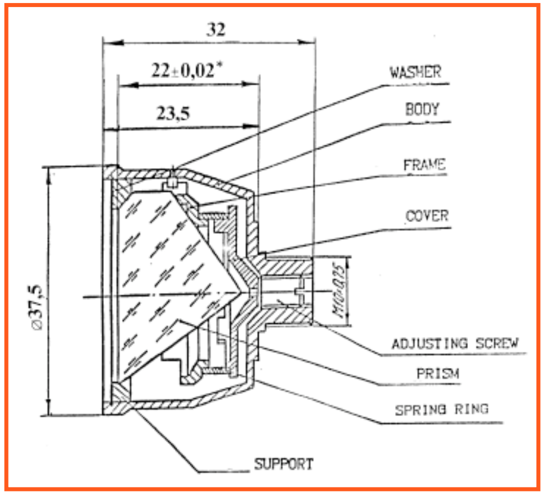


FFDP peak-to-peak distance (μrad) vs time (s) after exposure to Sun

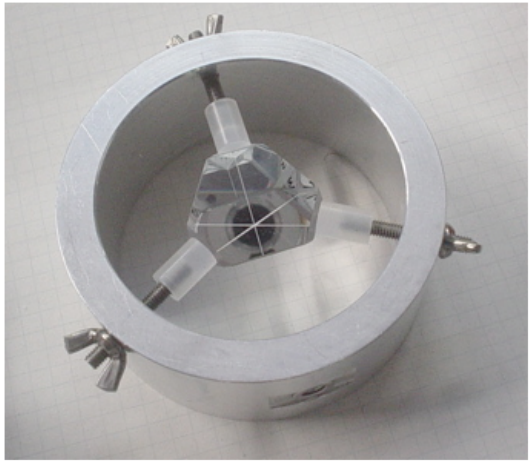


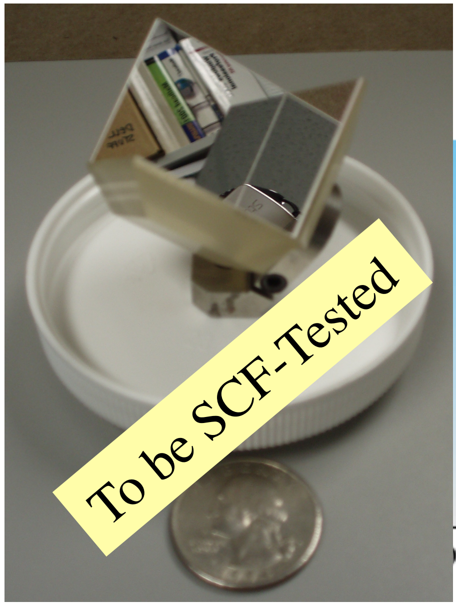
Thermal effects: CCR coating, mounting; the "hollows"

The Glonass/GPS CCR mounting scheme

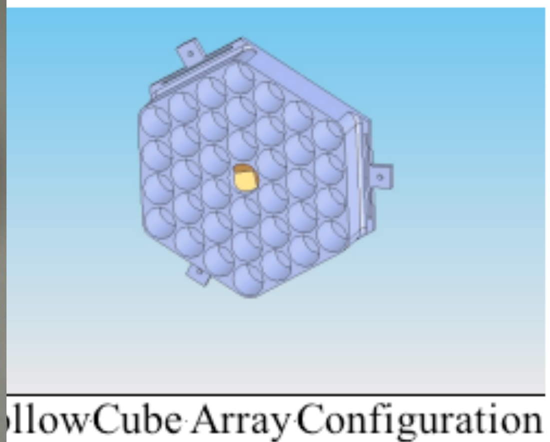


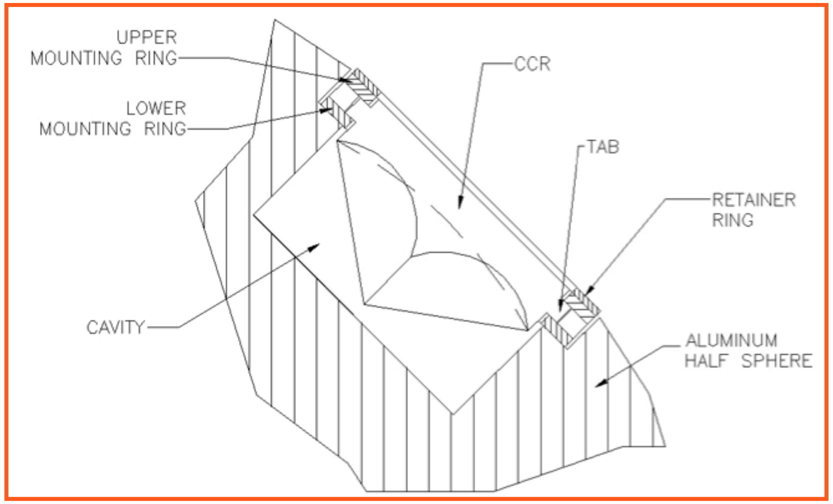
Bare Glonass/GPS CCR, held by KEL-F spacers





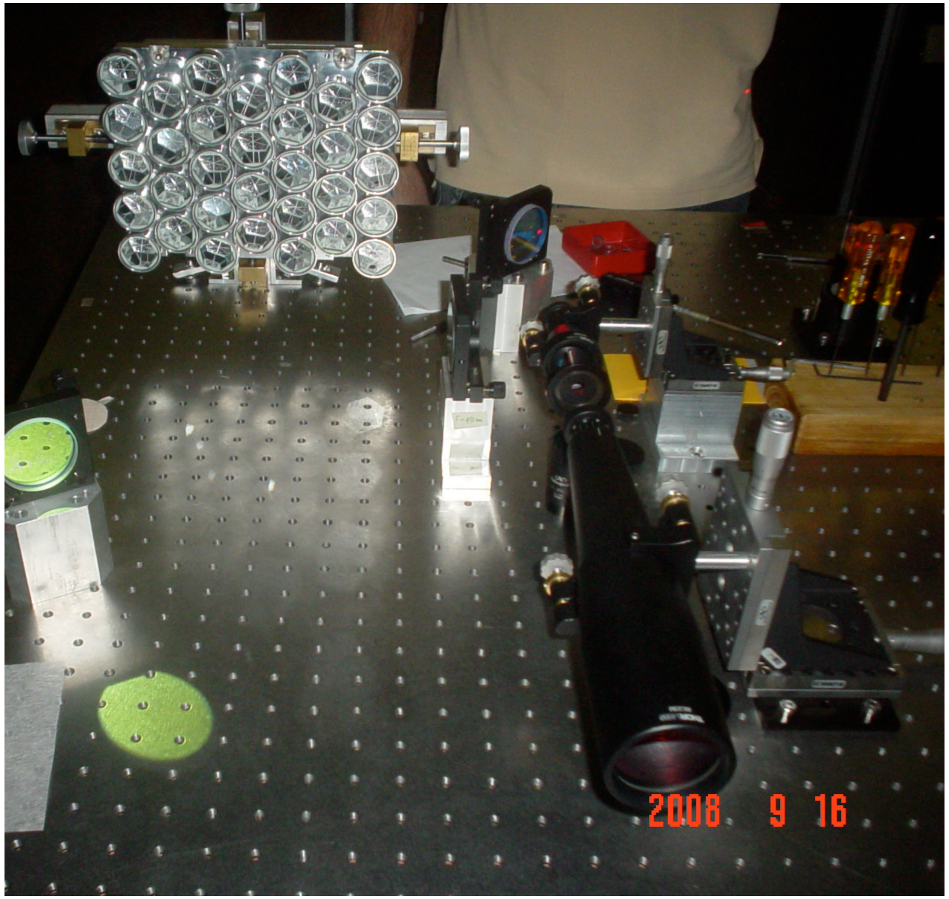
Be or Al **hollow** CCR Proposed by GSFC

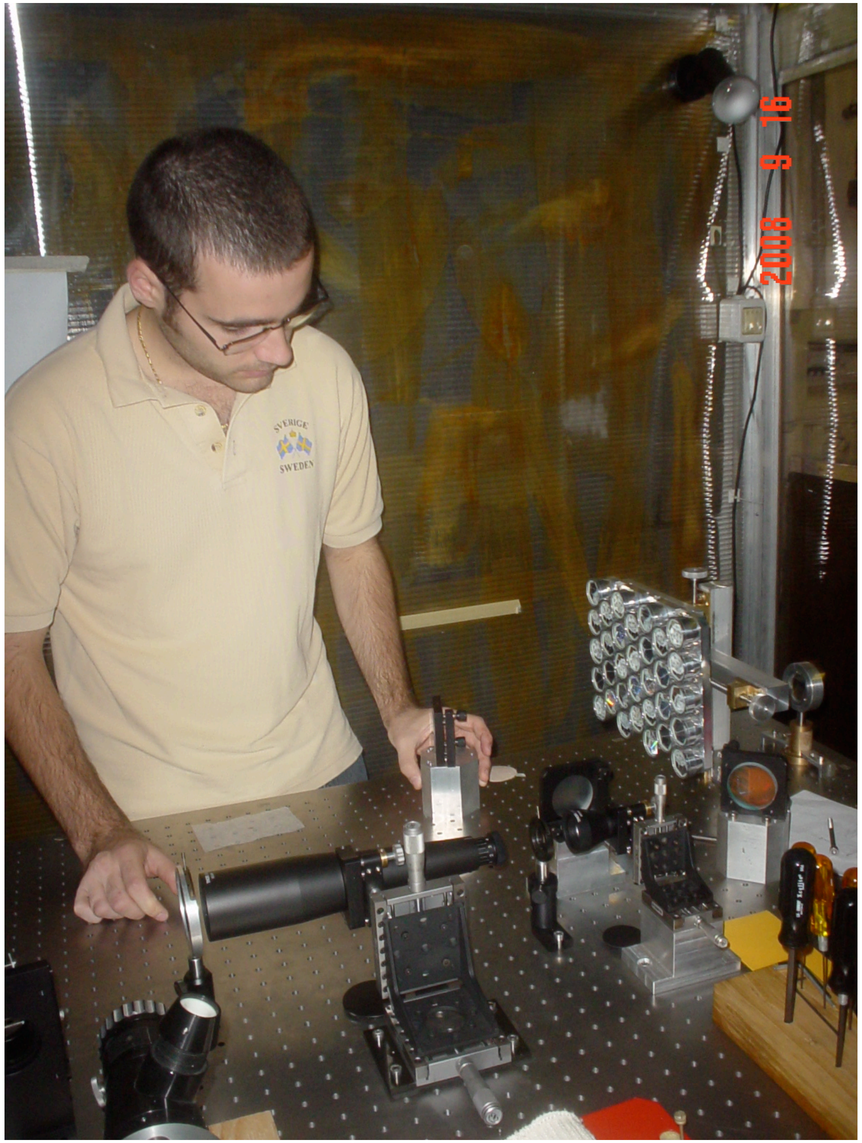




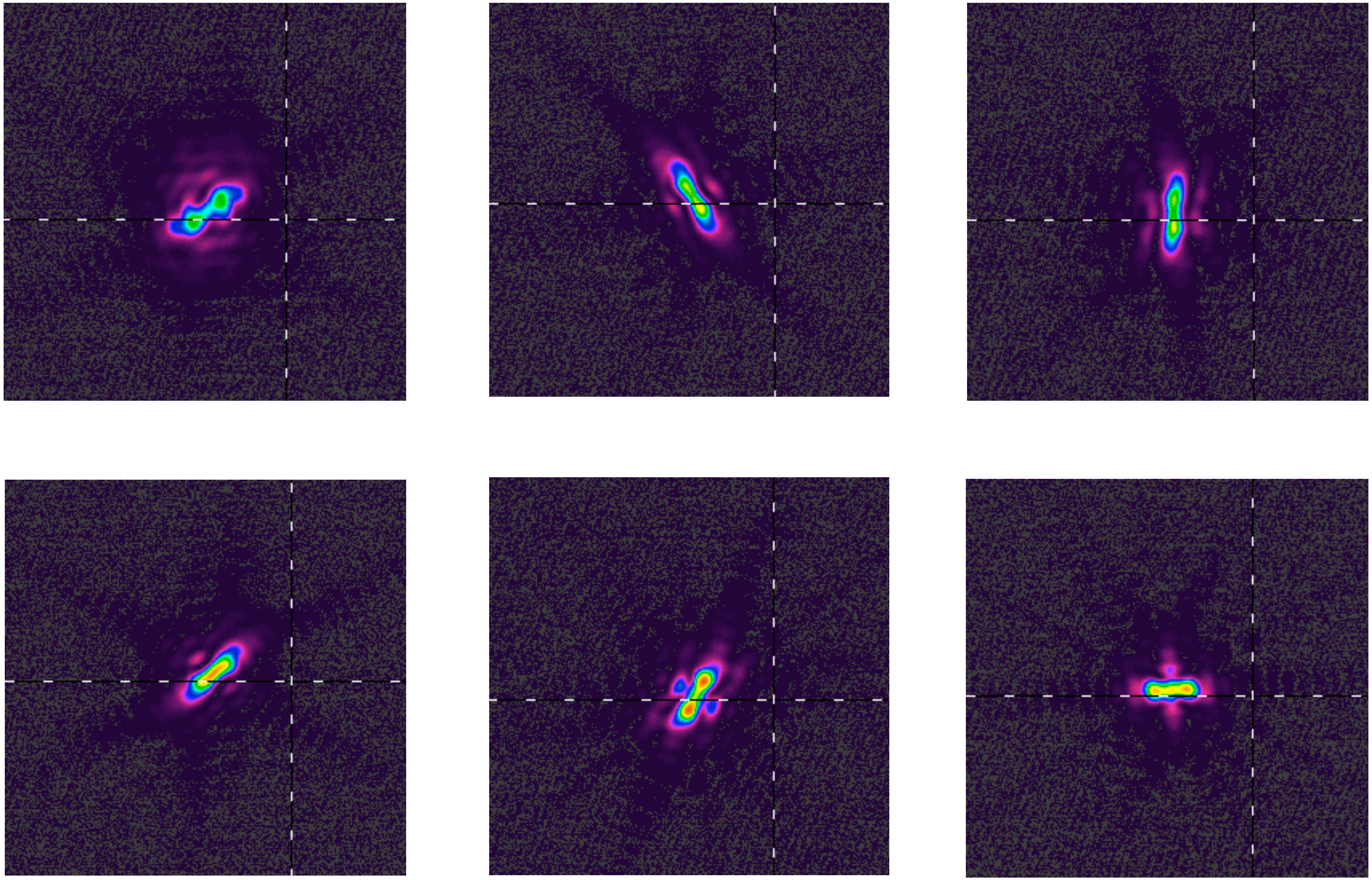
The **uncoated** LAGEOS CCR with its "pristine" mounting scheme

FFDP test of the GPS3 in air (STP), λ=632 nm





GPS3 FFDPs in air (just 6 out of 32), λ=632 nm



…. and 26 more. Next time that D. Currie will be at LNF will do **λ=532 nm**

Conclusions

- At INFN-LNF we developed a dedicated facility to characterize the detailed optical performance and thermal properties of laser retro-reflector arrays in space, the "SCF-Test"

- With the ETRUSCO experiment we:
  - SCF-Tested a few CCR of the GPS-2 flight model and Glonass-type CCR prototype
  - We tested the full GPS-2 flight model in air (STP)
  - Will SCF-Test an innovative hollow retro-reflectors for GPS-3 loaned to LNF by NASA-GSFC

- SCF-Test: effective new tool for the GNSS and for our beloved GALILEO. But also for Space Geodesy and for experimental tests of Gravitation in the Solar System