SCF-test of LAGEOS and Glonass retros
+
MoonLIGHT (proposed 2nd generation LLR)

D. Arnold (1), G. Bellettini (2), A. Boni (3) A. Cantone (3), **I. Ciufolini** (4),
D. G. Currie (5), S. Dell'Agnello (3), G. O. Delle Monache (3), M. Franceschi (3),
M. Garattini (3), N. Intaglietta (3), C. Lops (3), A. Lucantoni (6), M. Maiello (3)
M. Martini (3), T. Napolitano (3), A. Paolozzi (6), E. C. Pavlis (7), C. Prosperi (3),
R. Tauraso (2) and **R. Vittori** (8)

(1) NASA-GSFC, USA (2) Univ. of Rome Tor Vergata, Italy, (3) INFN – LNF,
Laboratori Nazionali di Frascati, Italy, (4) **Univ. and INFN of Lecce, Italy**,
(5) Univ. of Maryland, College Park, USA, (6) Univ. of Rome Sapienza, Italy,
(7) Univ. of Maryland, Baltimore, USA, (8) **Italian Air Force /ESA-EAC**

Retro-reflector array characterization @LNF

- The **“SCF-test”** is measurement of
  - Emissivity, reflectivity of CCR and surface (metal) components
  - $T_{surface}$ of CCR and CCR and mounting rings
  - Thermal relaxation time of CCR (τ_{CCR}) and of mounting rings ($\tau_{W\text{-}RING}$)
  - Far field diffraction patterns (FFDP) of each CCR in air
  - FFDP of each CCR in varying space climatic conditions

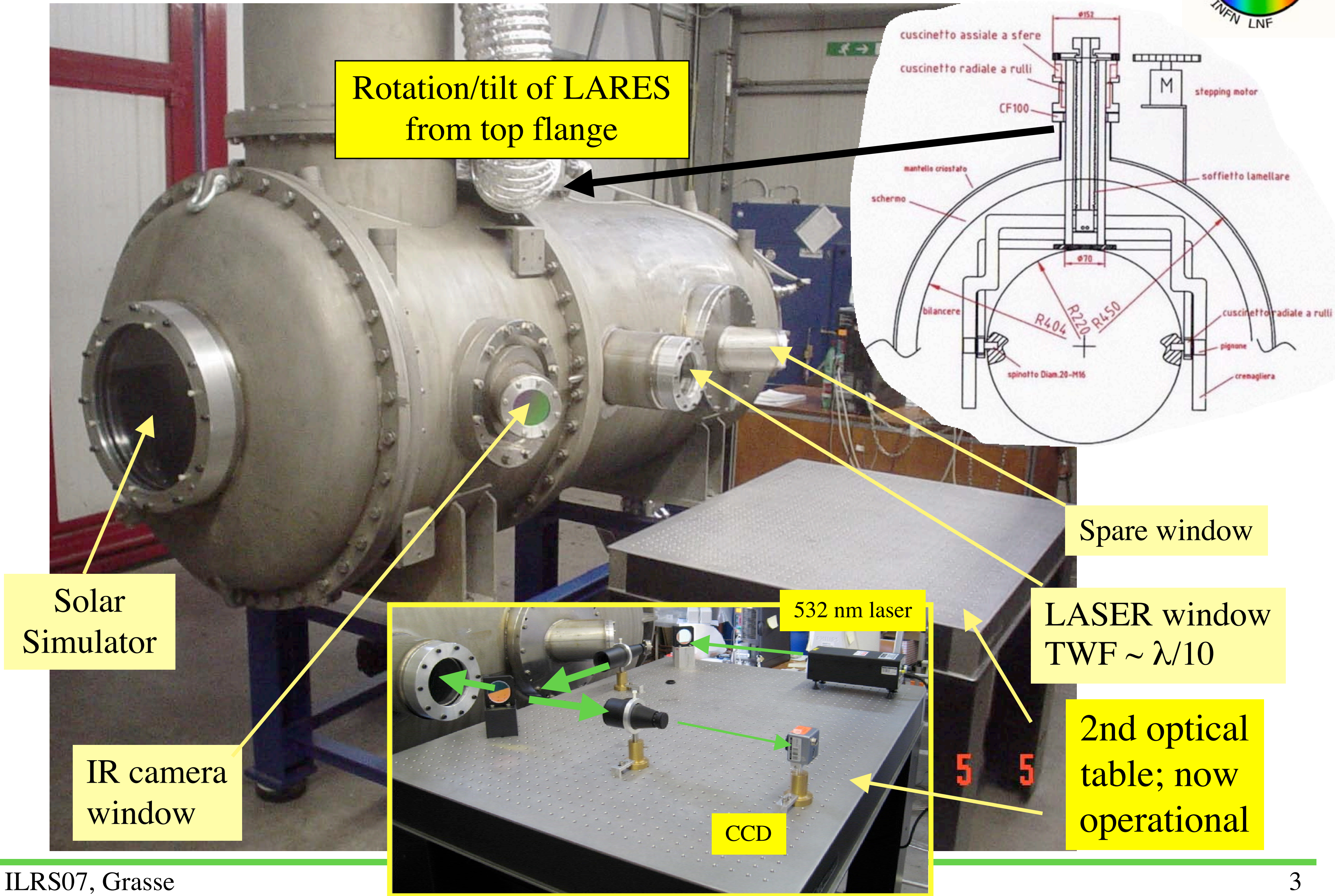
- Thermal models tuned to SCF data (Thermal Desktop by C&RTech)

- Orbital model of THERMAL THRUSTS

- Optical models of FFDP of single CCR and full array (Code V by ORA)

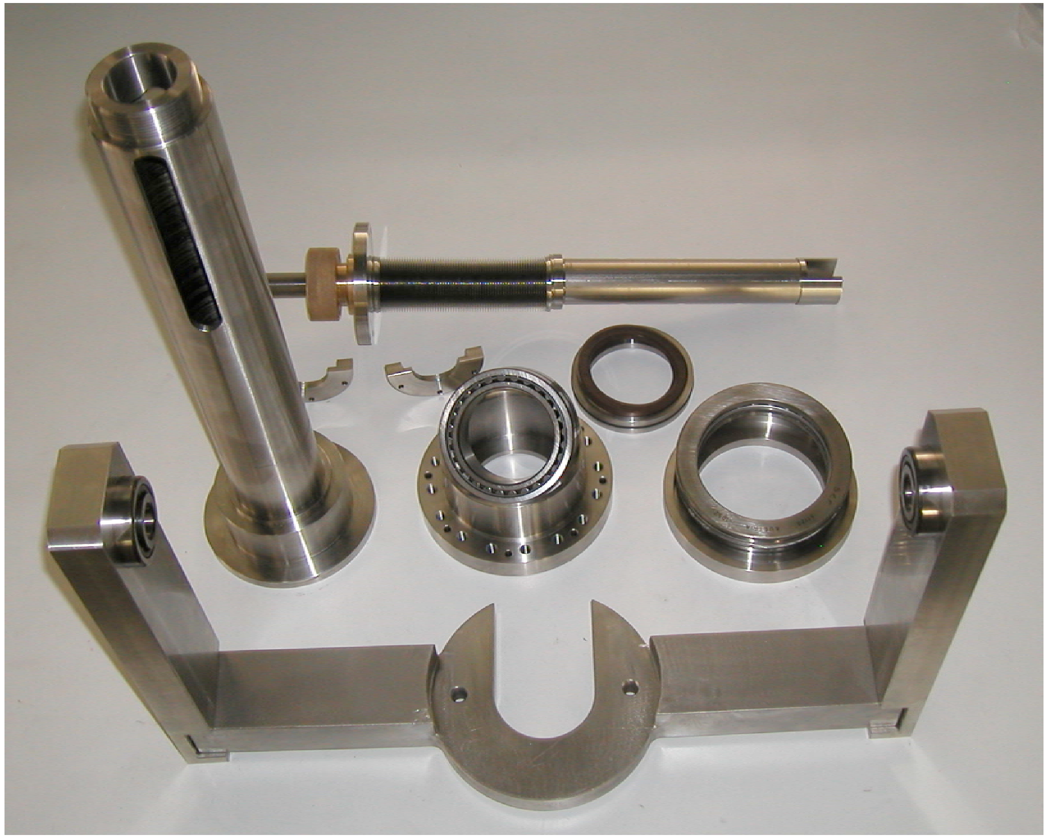
- The important and difficult CoM/Range Correction

Integrated CCR thermal and optical tests

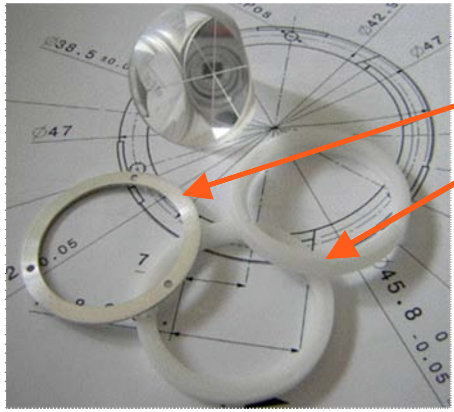


Rotation/tilt of full-tungsten LARES inside SCF

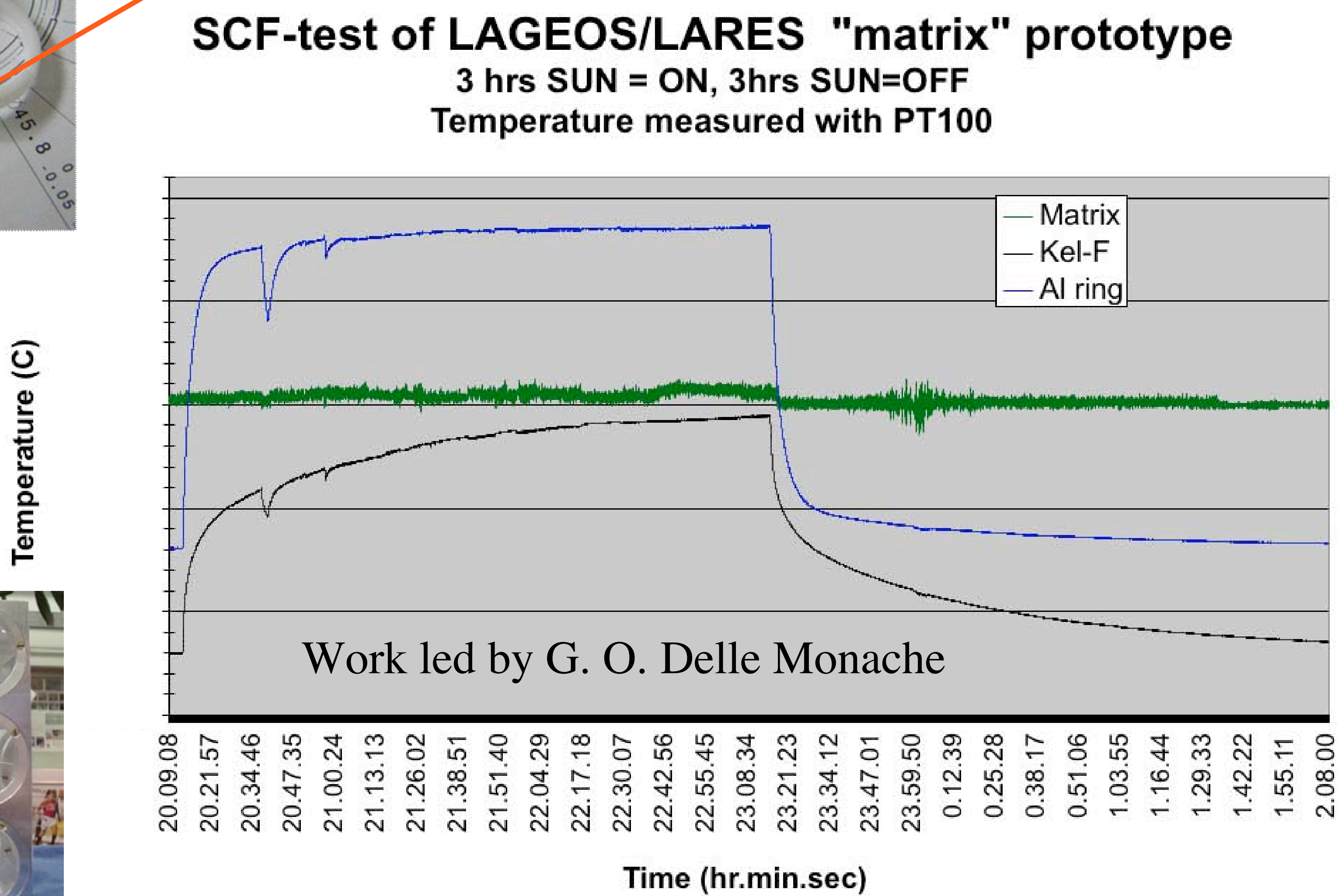
System delivered to LNF on Sep 24. Will sustain the maximal LARES weight of 750 Kg.
Baseline LARES : ~400 Kg weight, 386 mm diameter



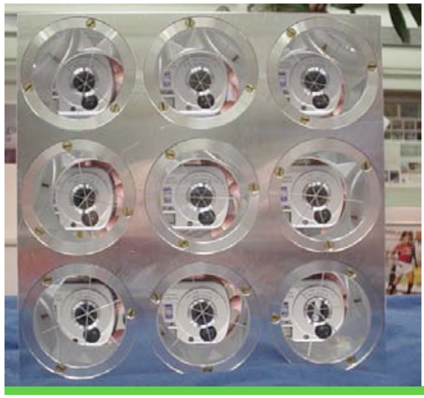
Full-blown thermal SCF-test performed (I)



The Al and plastic (KEL-F) mounting rings of the LARES retro-reflectors

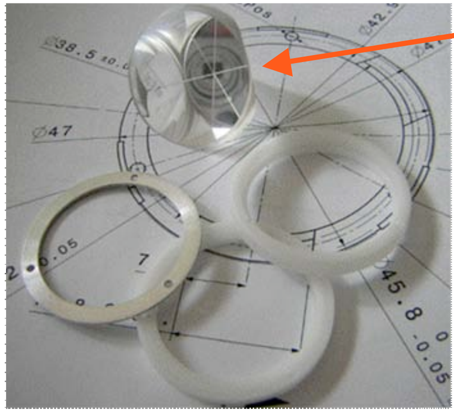


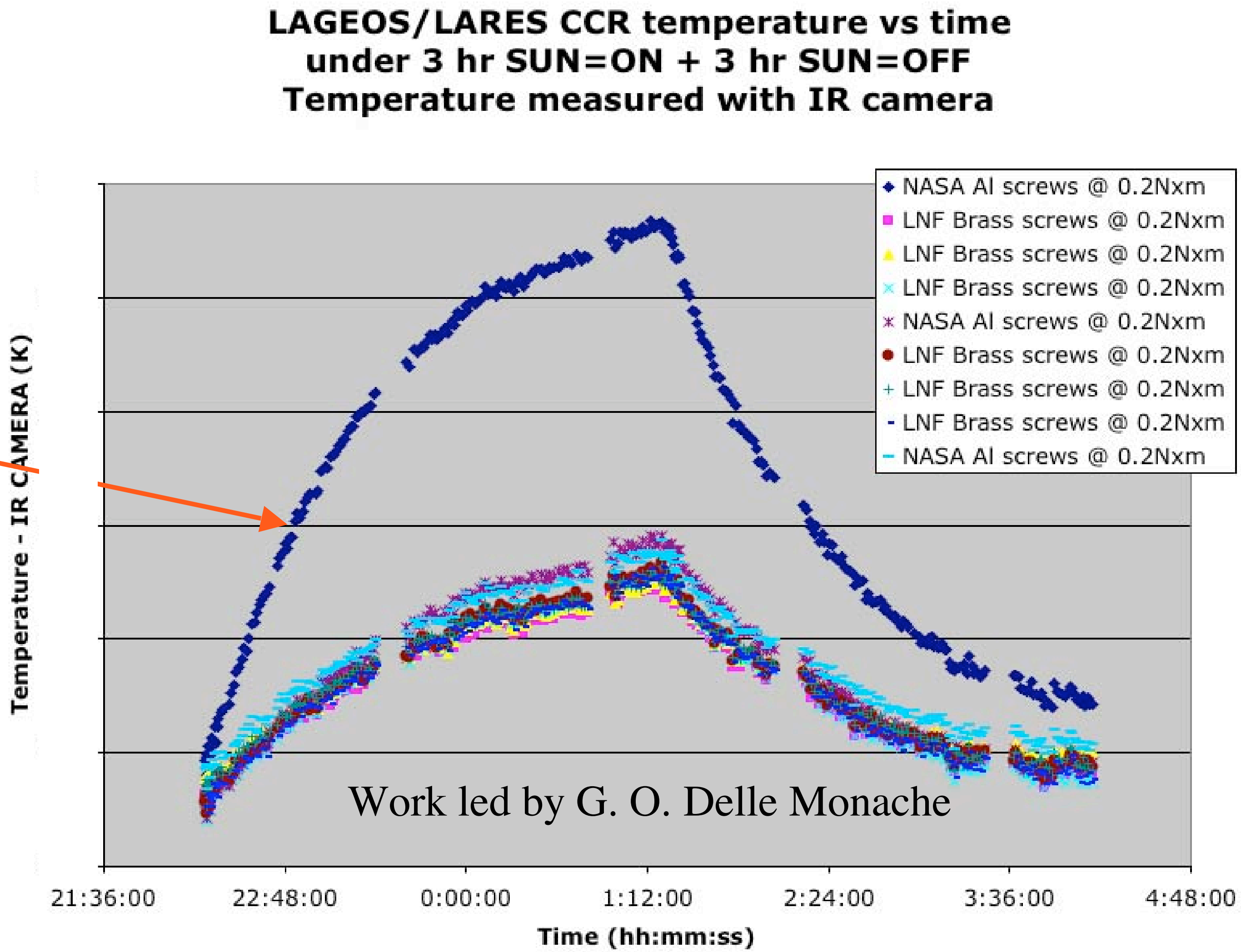
The LNF "matrix"



Full-blown thermal SCF-test performed (I)

The LAGEOS/LARES retro-reflectors





Work led by G. O. Delle Monache

CCR perturbed (as expected) by PT100 probe attached close to its outer surface.

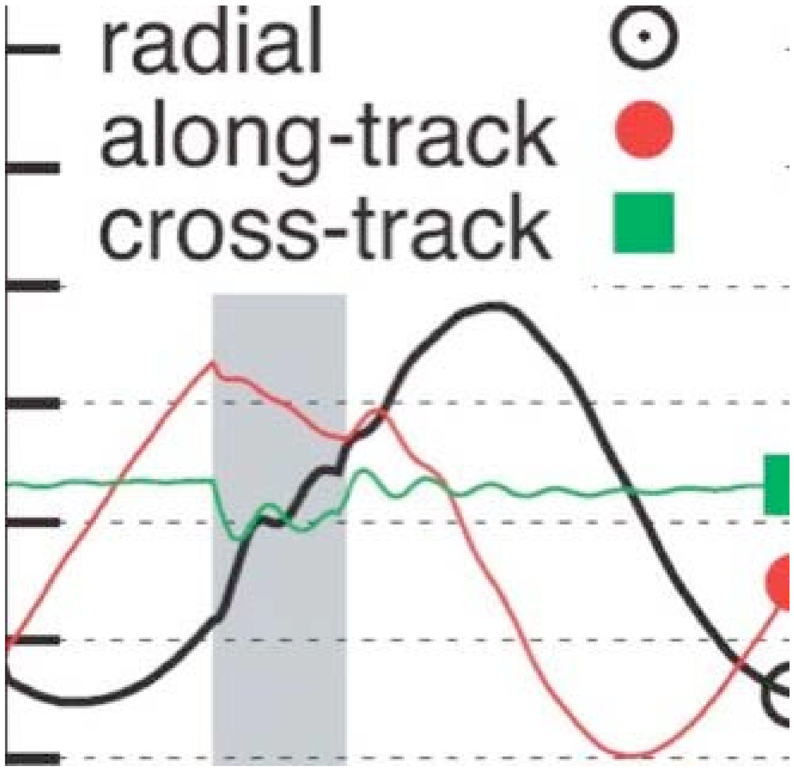
The other 8 CCRs are unperturbed. Their *T vs time* behavior will provide the long-waited **τ_{CCR}, which drives the thermal perturbations**

Thermal thrusts along the orbit

Qualitative comparison of thermal thrusts vs time (one orbit) between:

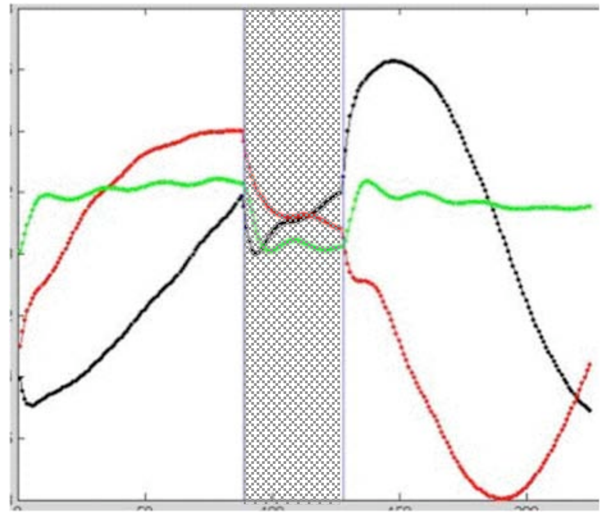
- LageOS Spin Axis Model: based on calculations and Slabinski's '97 work
- LNF model: based on orbital/thermal model tuned to SCF measurements

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

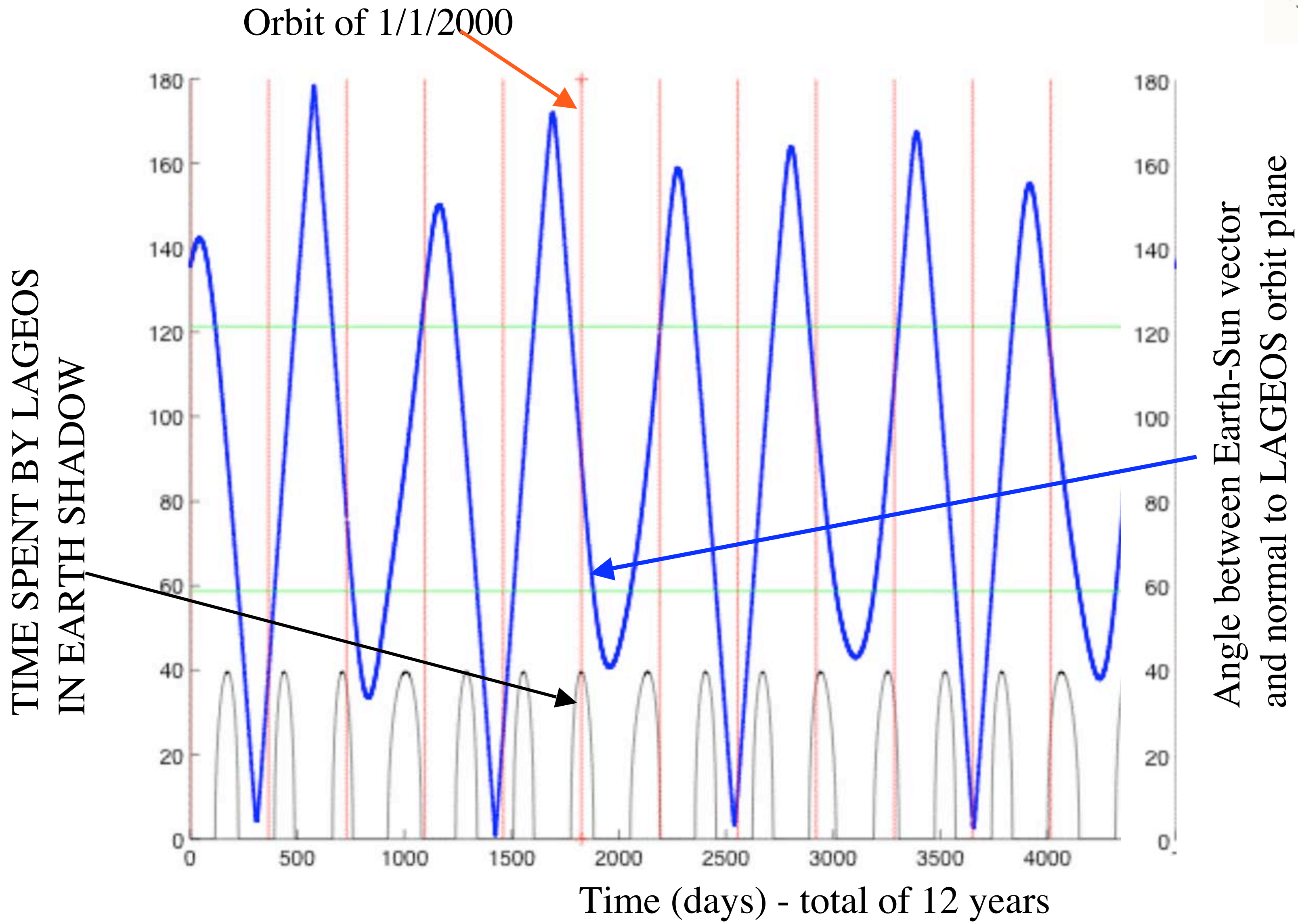


Orbit of **1/1/2000** with longest Earth shadow

LNF model tuned to SCF data
Earth shadow = grey area



Thermal Thrusts: Earth shadow vs time



Measured and simulated optical FFDP

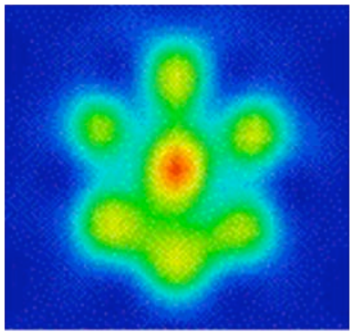
- ✓ LARES offset = 1.5 ± 0.5 arcsec
- ✓ LAGEOS offset = 1.25 ± 0.5 arcsec
- ✓ LAGEOS CCRs at LNF from NASA-GSFC have offset = 0.0 ± 0.5 arcsec
- ✓ **Calibration of absolute scale of measured FFDP angles performed**

NASA-GSFC FFDPs measured @ LNF

Dihedral angle offset = 0.0 arcsec

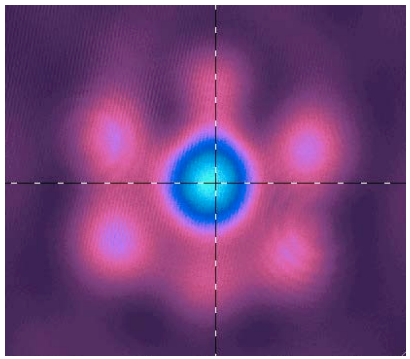
LAGEOS FFDP simulated with CodeV
(sw used for Hubble Space Telescope)

Dihedral angle offset = 0 arcsec

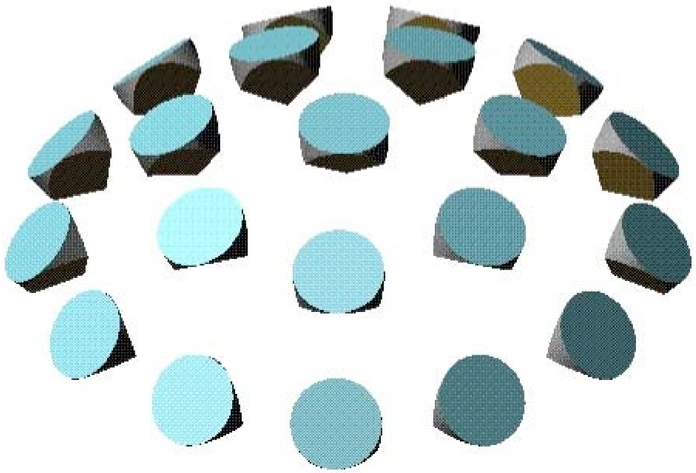


Good agreement

Scale is ± 50 μrad



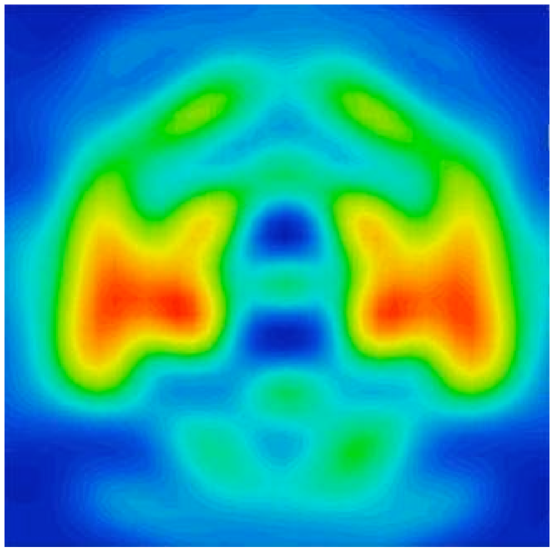
Optical simulation of FFDP of full LARES



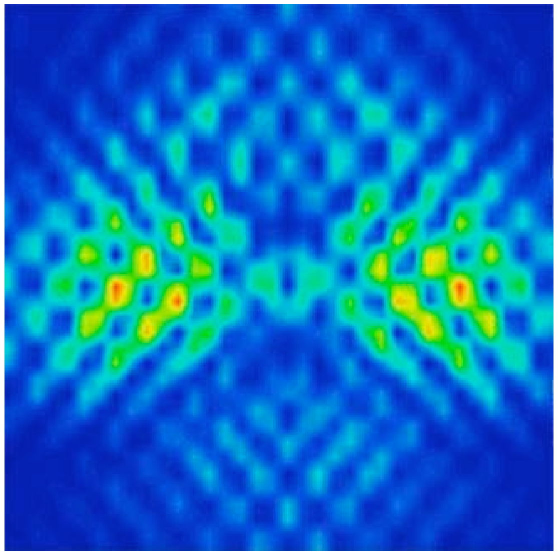
CODE V optical cad simulation:

- laser beam direction normal to polar CCR
- laser polarization horizontal
- random orientation of CCR azimuth
- Nominal CCR dihedral angle offset = **1.5 arcsec**
- FFDP scale in x and y ~ **± 56.5 μrad**

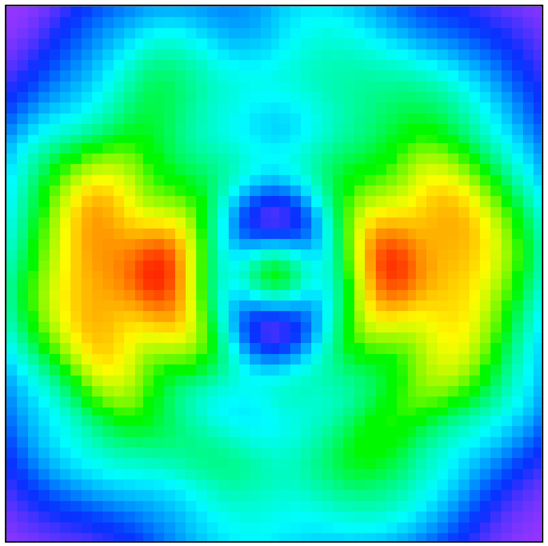
Polar CCR (Code V)



Full LARES, coherent
(Code V, verypreliminary)



Full LARES, incoherent
by D. Arnold



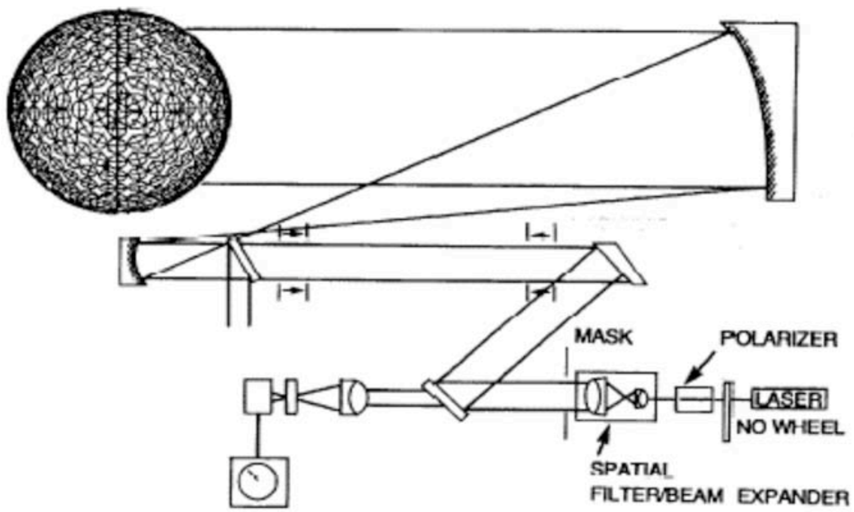
Center-of-Mass calibrations (with ASI-CGS/Matera)

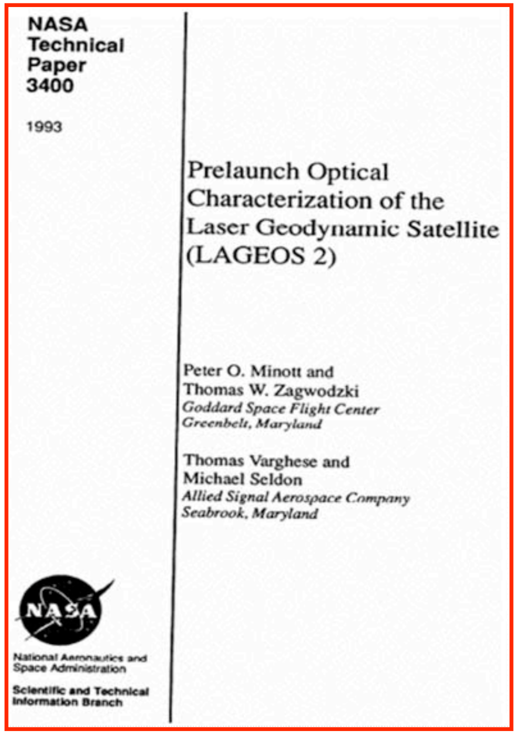
- What correction to go from the CCRs on the surface to the satellite center of mass ?
- This is not, trivially, the radius
- Pulsed laser - Matera
- Streak camera - Matera
- Mirror, large SCF window - LNF
- Electronics for start time, stop time, TDC - LNF

Repeat test with LARES inside the SCF

(never done for LAGEOS)

Methods to define the stop time of the retro-reflected signal with the electronics:
Peak, Centroid, Half max, Constant fraction.
The correction depends on the satellite, the space climatic conditions and on what detection methods the ground stations use (single vs multi-photon detection)




NASA
Technical
Paper
3400

1993

Prelaunch Optical
Characterization of the
Laser Geodynamic Satellite
(LAGEOS 2)

Peter O. Minott and
Thomas W. Zagwodzki
Goddard Space Flight Center
Greenbelt, Maryland

Thomas Varghese and
Michael Seldon
Allied Signal Aerospace Company
Seabrook, Maryland

National Aeronautics and
Space Administration

Scientific and Technical
Information Branch

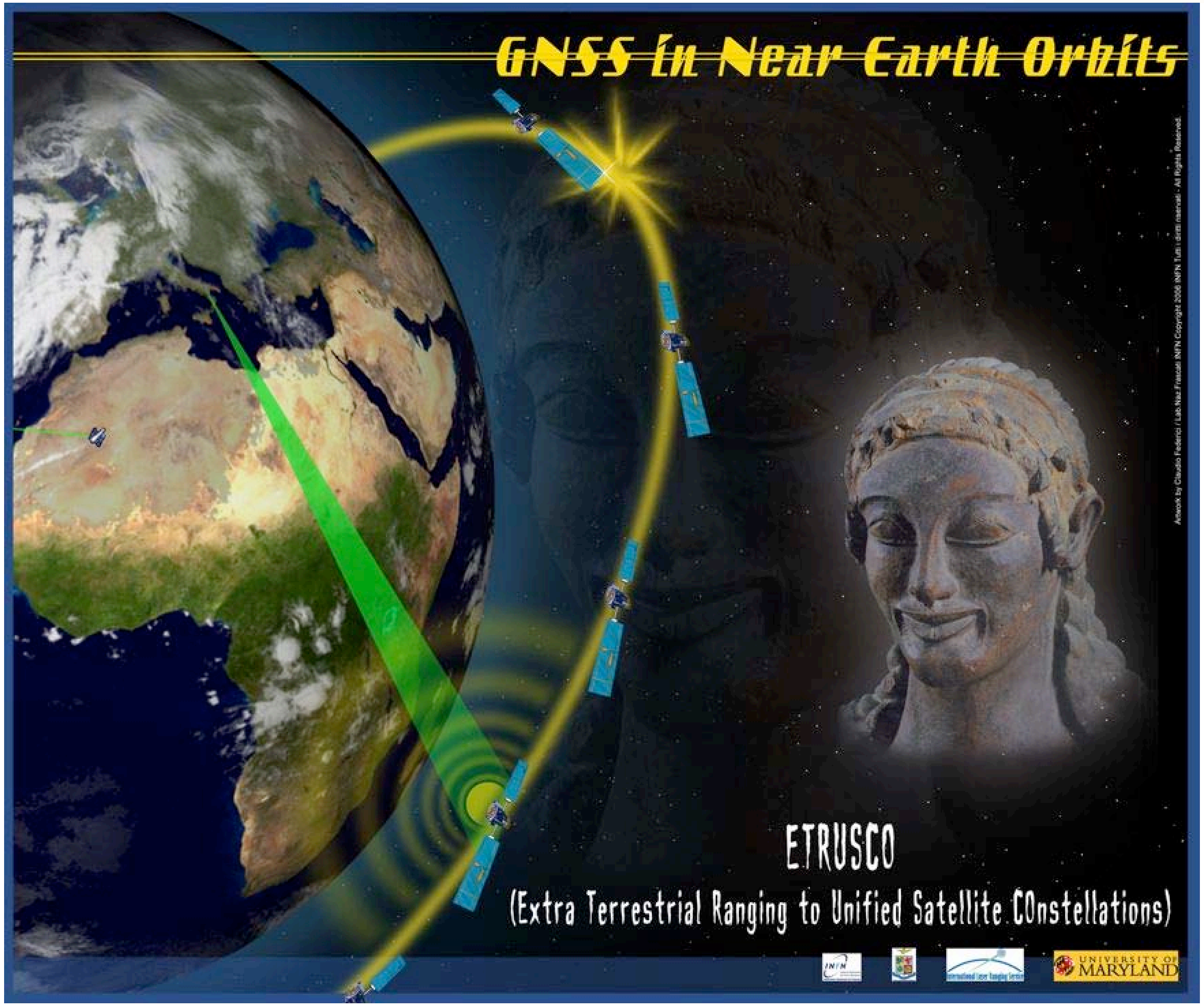
ETRUSCO, INFN experiment on GNSS

S. Dell'Agnello (40%) - Resp.
G. Delle Monache (30%)
C. Cantone (Bors, 30%)
M. Garattini (Bors, 30%)
M. Martini (Bors, 100%)
A. Boni (Bors, 30%)
C. Lops (Bors, 100%)
M. Maiello (Bors, 30%)
G. Bellettini (P.O., 20%)
R. Tauraso (R.U., 20%)

TOTAL = 4.3 FTE

Roberto Vittori (ESA, Aeronautica Militare Italiana, 20%)

LNF support services:
Cryogenics 4 months
SSCR (mechanics) 4 months



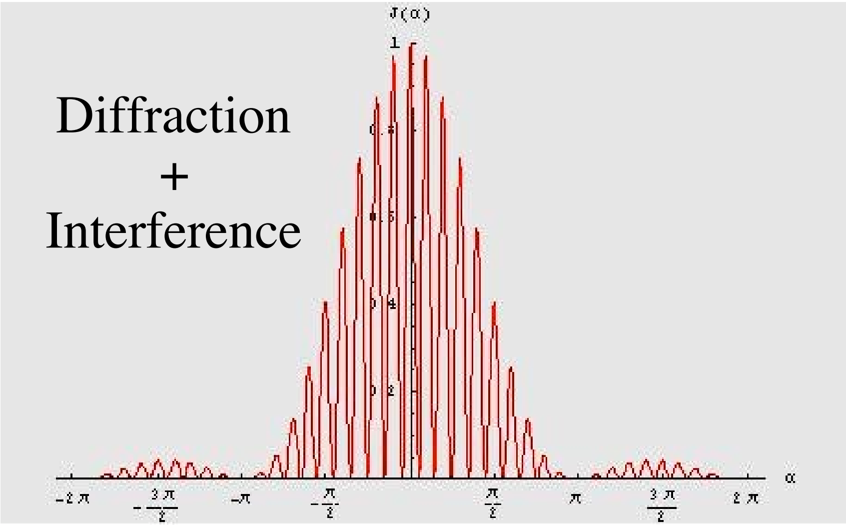
GLONASS CCRs

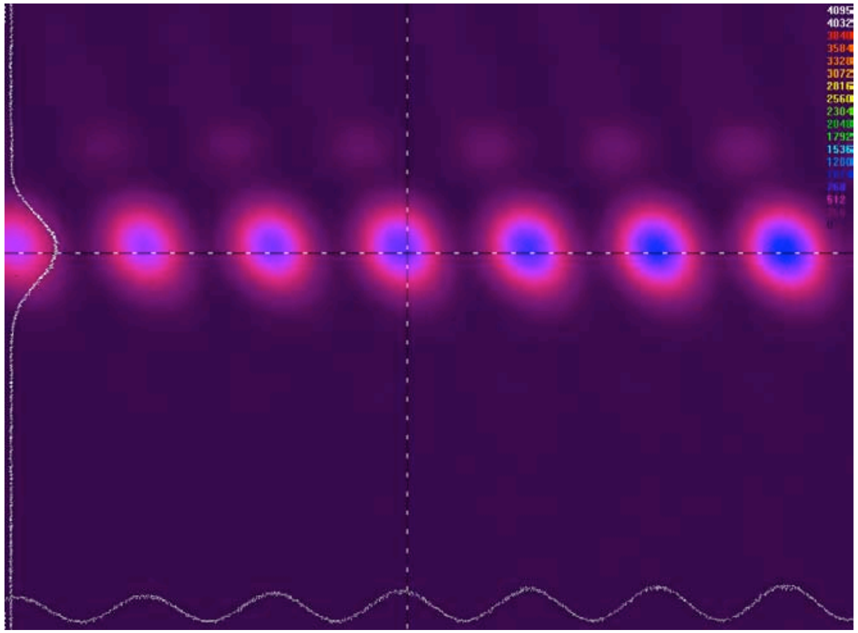
CCRs with polished Al housing are on also on GPS-2-2 and GIOVE-A/B

CCR with white-painted and gray-painted Al housing to compare their thermal behavior with the "standard"

Sent to LNF by V. Vasiliev of IPIE-Moscow for SCF-test
FFDP now done at LNF at STP are consistent with IPIE results.

Angle calibrations w/2-slit interference





$$\Delta x_{pixel} = \vartheta^{INT} \cdot a = \frac{\lambda}{e} a$$

$$\Rightarrow e = \frac{\lambda}{\Delta x_{pixel}} \cdot a$$

100 pixel on CCD

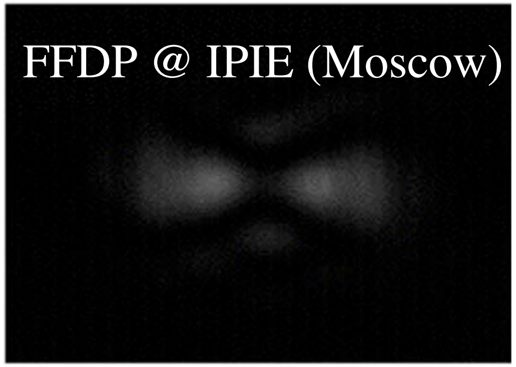
$$\Rightarrow e = 0.5mm$$

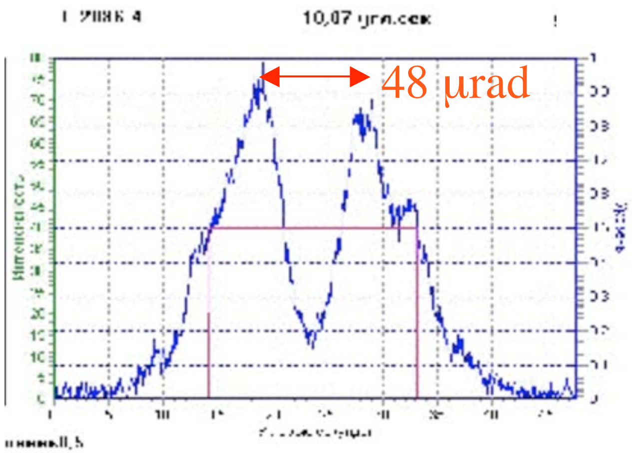
Δx is the distance in pixel between two consecutive interference peaks

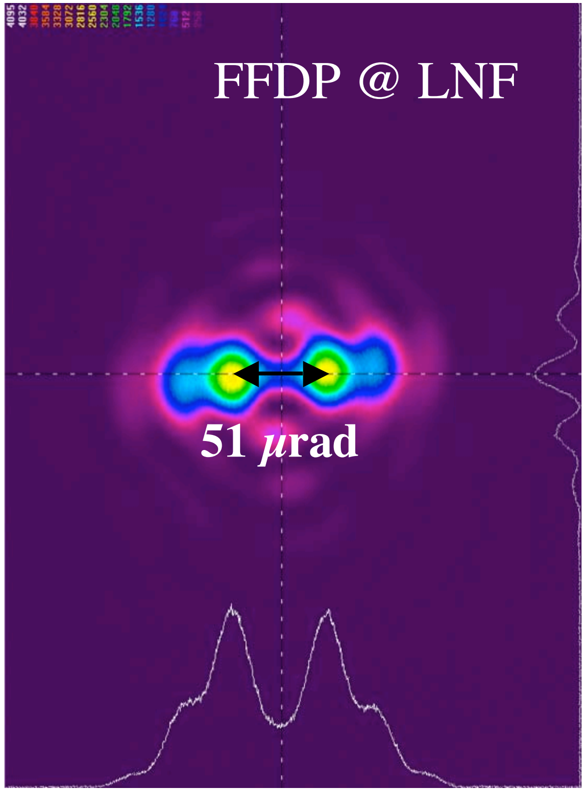
1 pixel = 86/163,21 ≈ 0,53 μrad

Measured GPS/GLONASS FFDPs

Polished Al two-lobe separation ~ 50 μrad

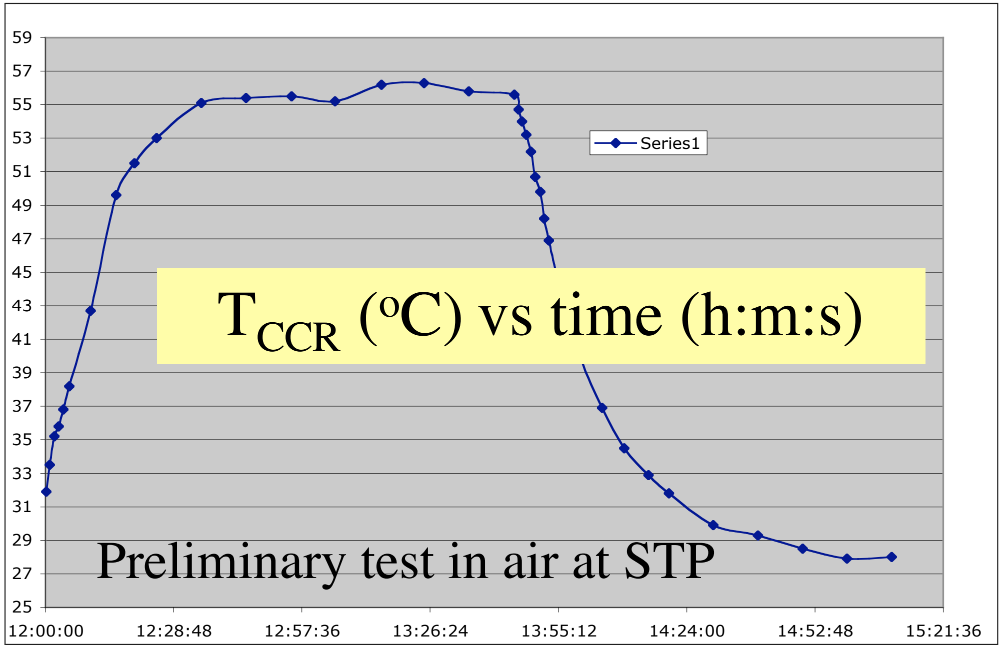


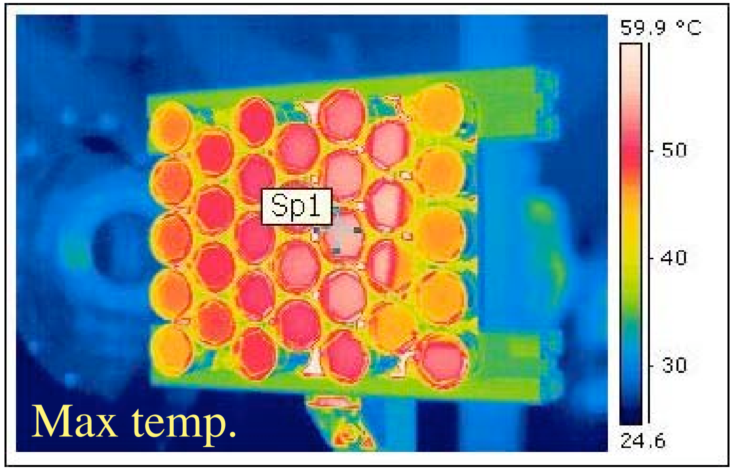


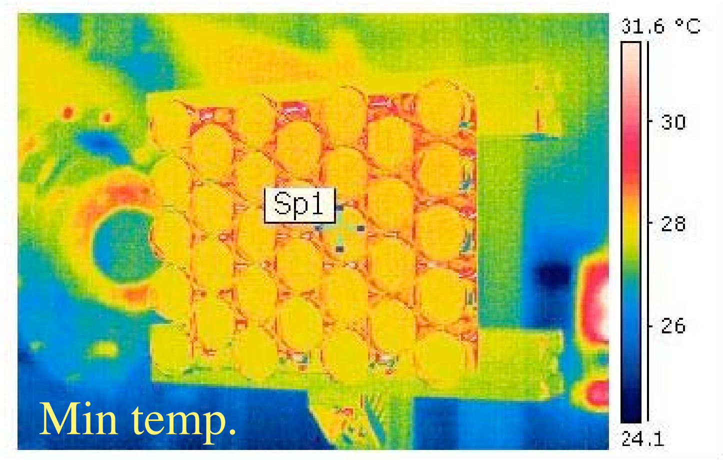


Thermal measurement of GPS-2 array flight model

Thermal relaxation time measured as a preliminary test in air on October 2006







MoonLIGHT

Moon Laser Instrumentation for General relativity High-accuracy Tests

Approved by NASA for the call "Suitcase Science to the Moon"

D. G. Currie (PI)	*University of Maryland at College Park, MD, USA*
R. Vittori	*Aeronautica Militare Italiana, Rome, ITALY*
A. Boni, G. Bellettini, C. Cantone, **S. Dell'Agnello (Co-PI),** G. O. Delle Monache, M. Garattini, N. Intaglietta, M. Martini, R. Tauraso	*INFN-LNF, Frascati (Rome), ITALY*

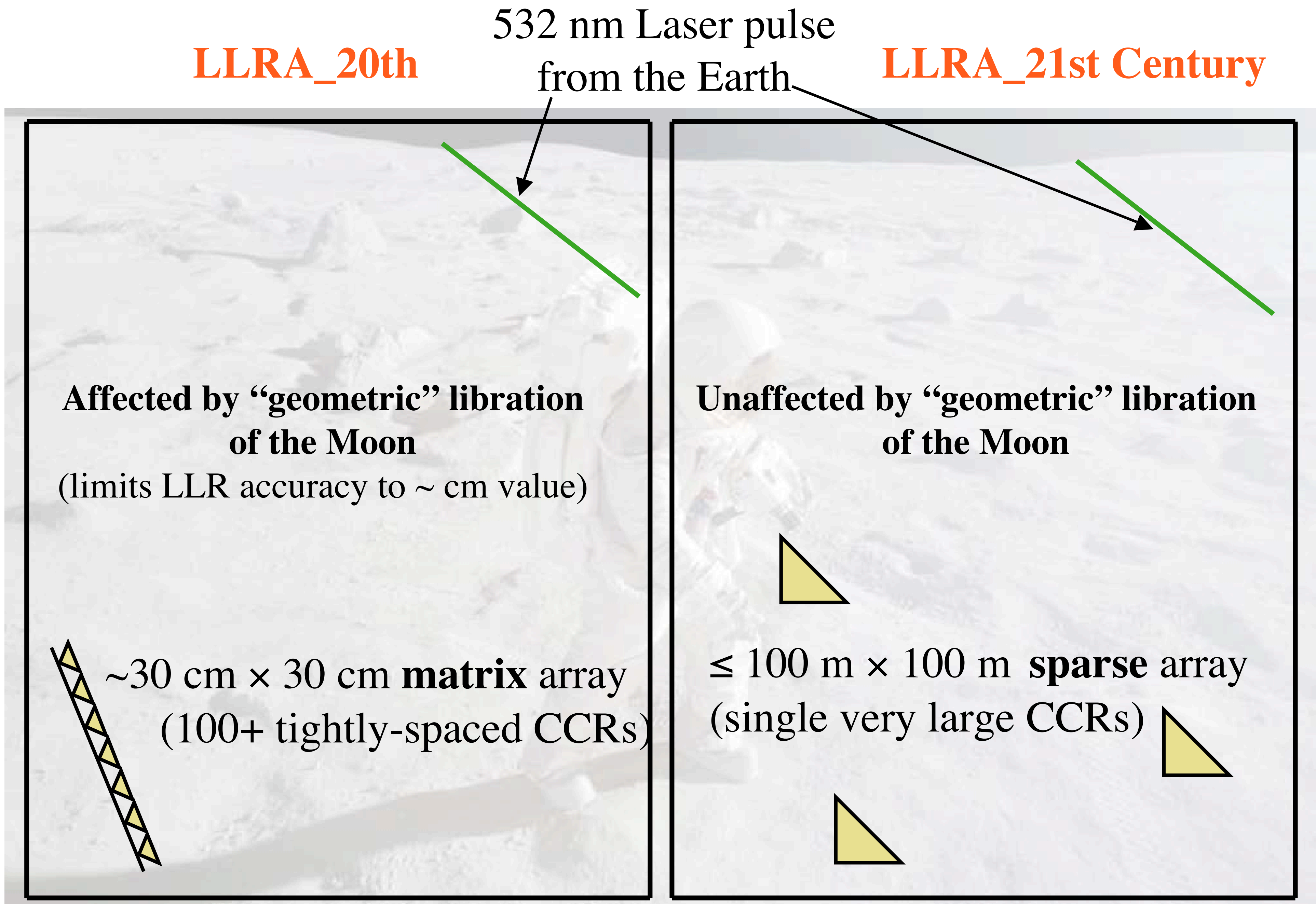
ASI-MLRO, Matera Laser-Ranging Observatory (G. Bianco et al), Matera, ITALY

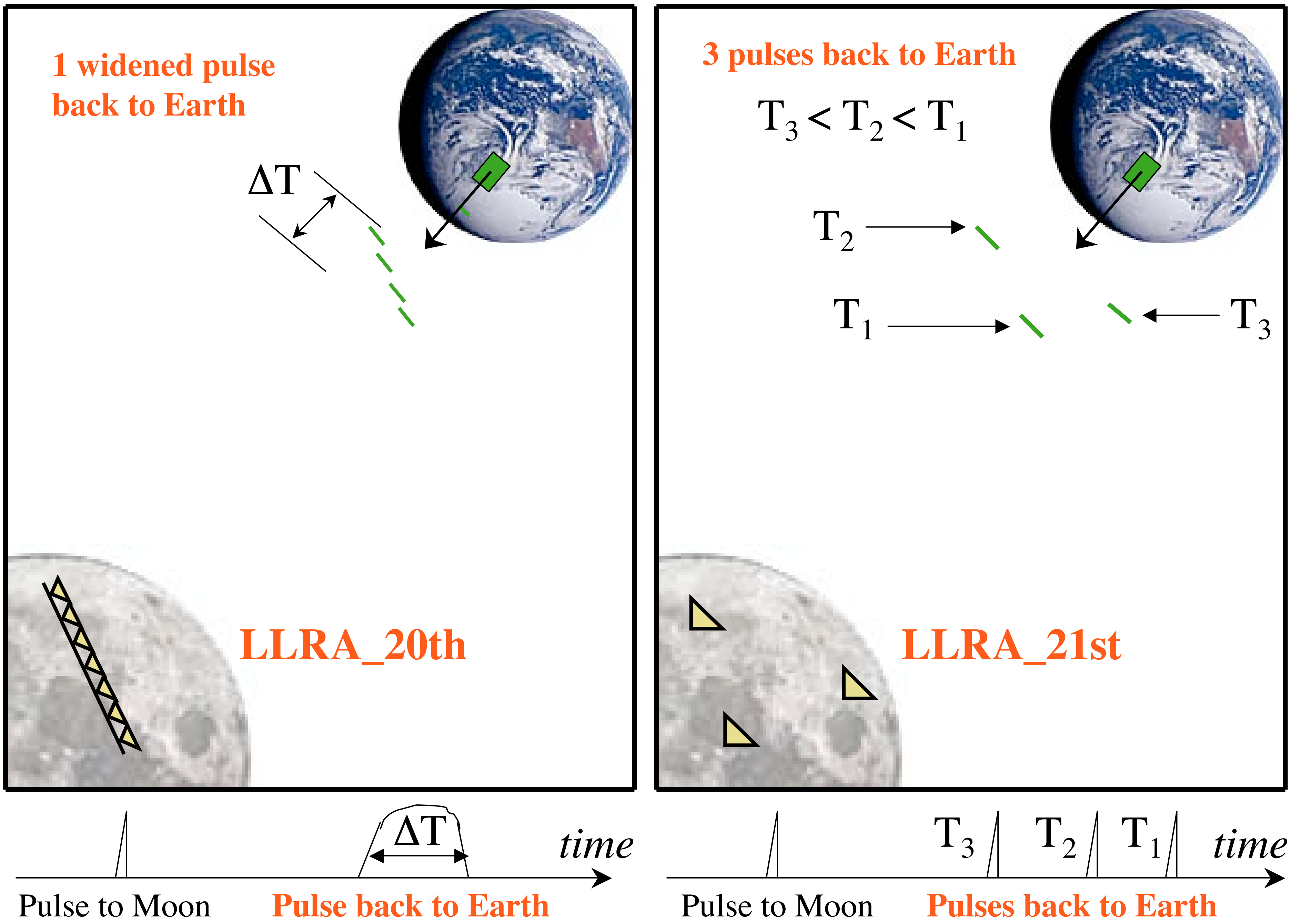
T. Murphy	*University of California at San Diego, CA, USA*
D. Carrier	*Lunar GeoTechnical Institute, Lakeland, Florida, USA*
D. Rubincam	*NASA-GSFC, Greenbelt, MD, USA*
A. Hajian	*U. S. Naval Observatory, Washington DC, USA*

APOLLO Lunar Laser-Ranging Observatory (T. Murphy et al), Los Alamos, USA

THE FUNDAMENTAL, NOVEL IDEA BY D. CURRIE

- IT’A A SPARSE ARRAY OF 8, SINGLE, LARGE CCRa
- IT’A A SPARSE ARRAY OF 8, SINGLE, LARGE CCRs
- IT’A A SPARSE ARRAY OF 8, SINGLE, LARGE CCRs
- IT’A A SPARSE ARRAY OF 8, SINGLE, LARGE CCRs
- IT’A A SPARSE ARRAY OF 8, SINGLE, LARGE CCRs
- IT’A A SPARSE ARRAY OF 8, SINGLE, LARGE CCRs
- IT’A A SPARSE ARRAY OF 8, SINGLE, LARGE CCRs
- IT’A A SPARSE ARRAY OF 8, SINGLE, LARGE CCRs

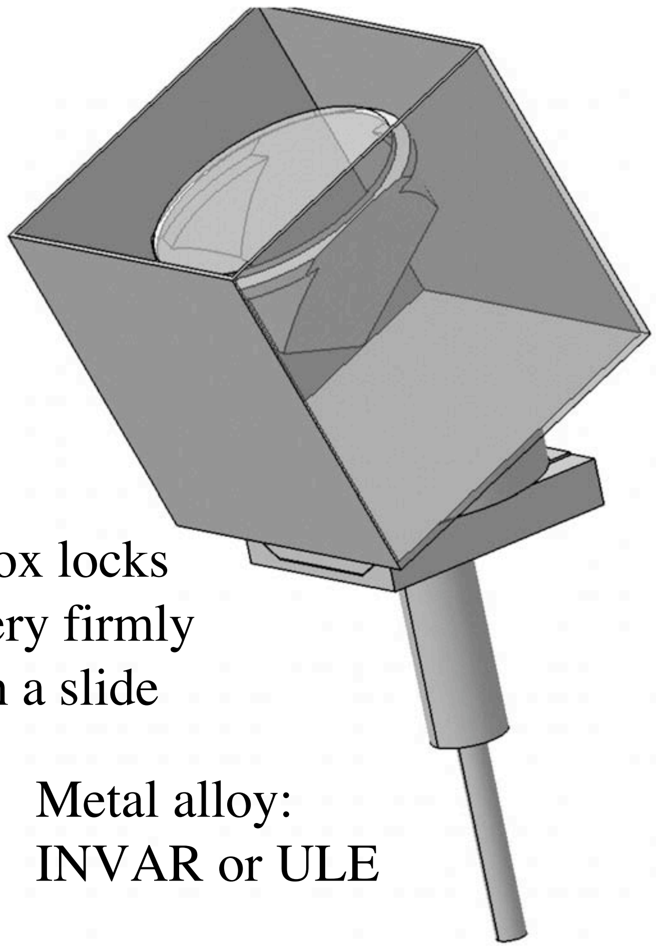

LLRA_20th
532 nm Laser pulse
from the Earth
LLRA_21st Century
Affected by "geometric" libration
of the Moon
(limits LLR accuracy to ~ cm value)
~30 cm × 30 cm matrix array
(100+ tightly-spaced CCRs)
Unaffected by "geometric" libration
of the Moon
≤ 100 m × 100 m sparse array
(single very large CCRs)


1 widened pulse back to Earth
ΔT
LLRA_20th
ΔT
time
Pulse to Moon
Pulse back to Earth
3 pulses back to Earth
T3 < T2 < T1
T2
T1
T3
LLRA_21st
T3
T2
T1
time
Pulse to Moon
Pulses back to Earth

“Suitcase” science to the Moon

Concept design by Astronaut Roberto Vittori

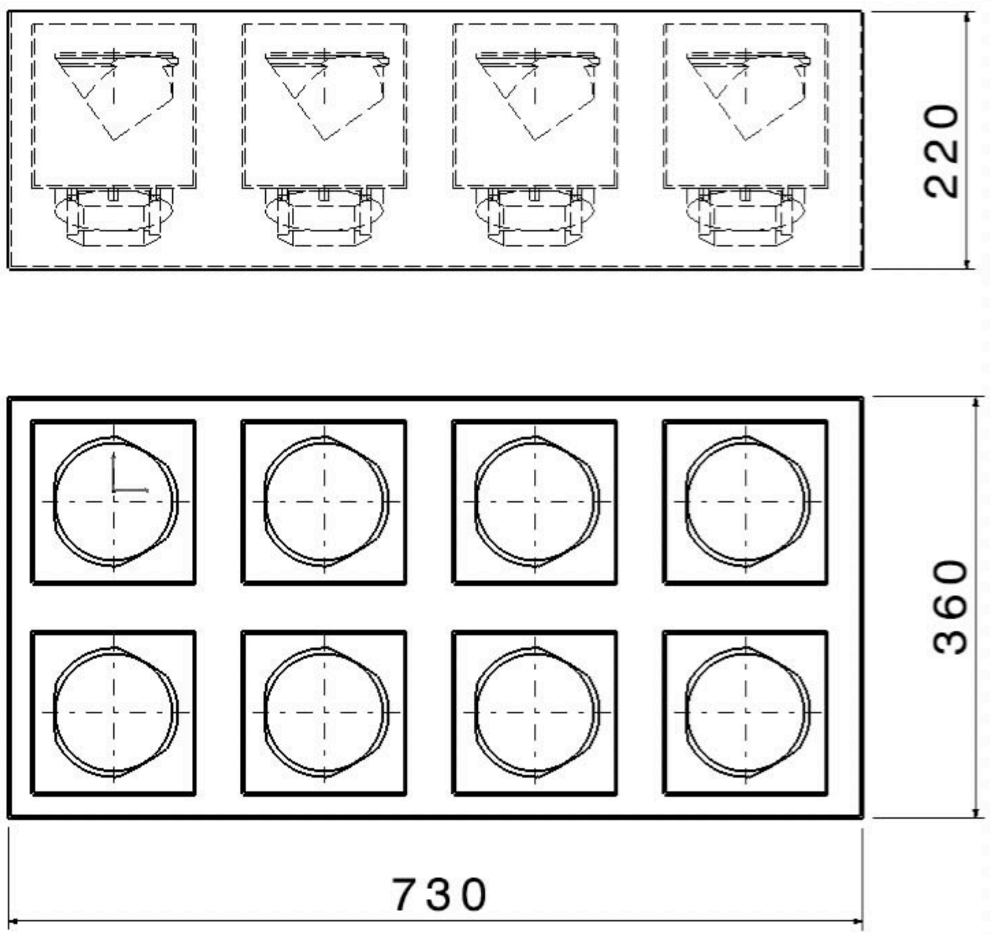
Retro-reflector: 10 cm diam.
Box: 14 cm side



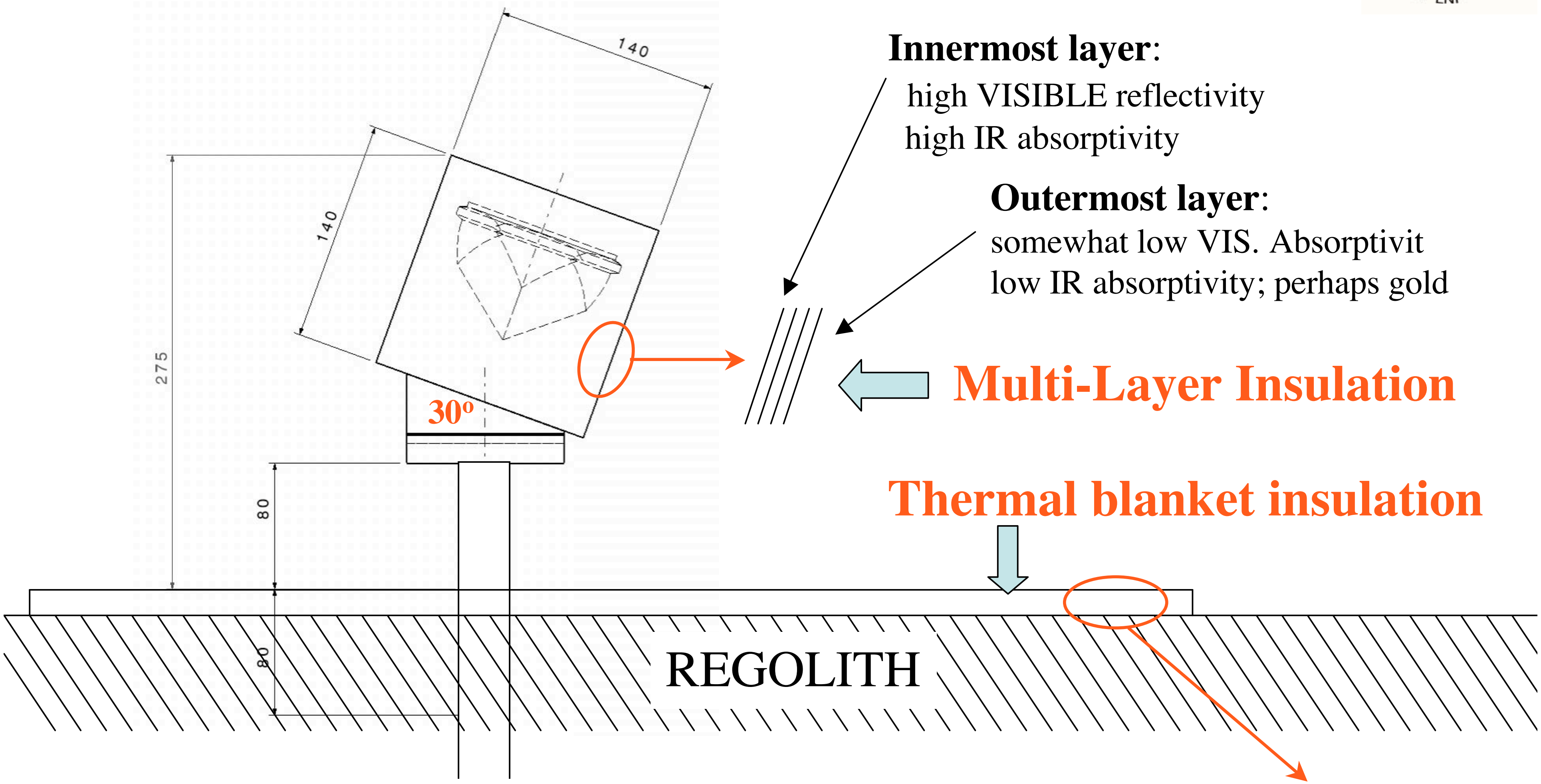
Box locks very firmly on a slide

Metal alloy:
INVAR or ULE

Suitcase for the CCR boxes (mm)



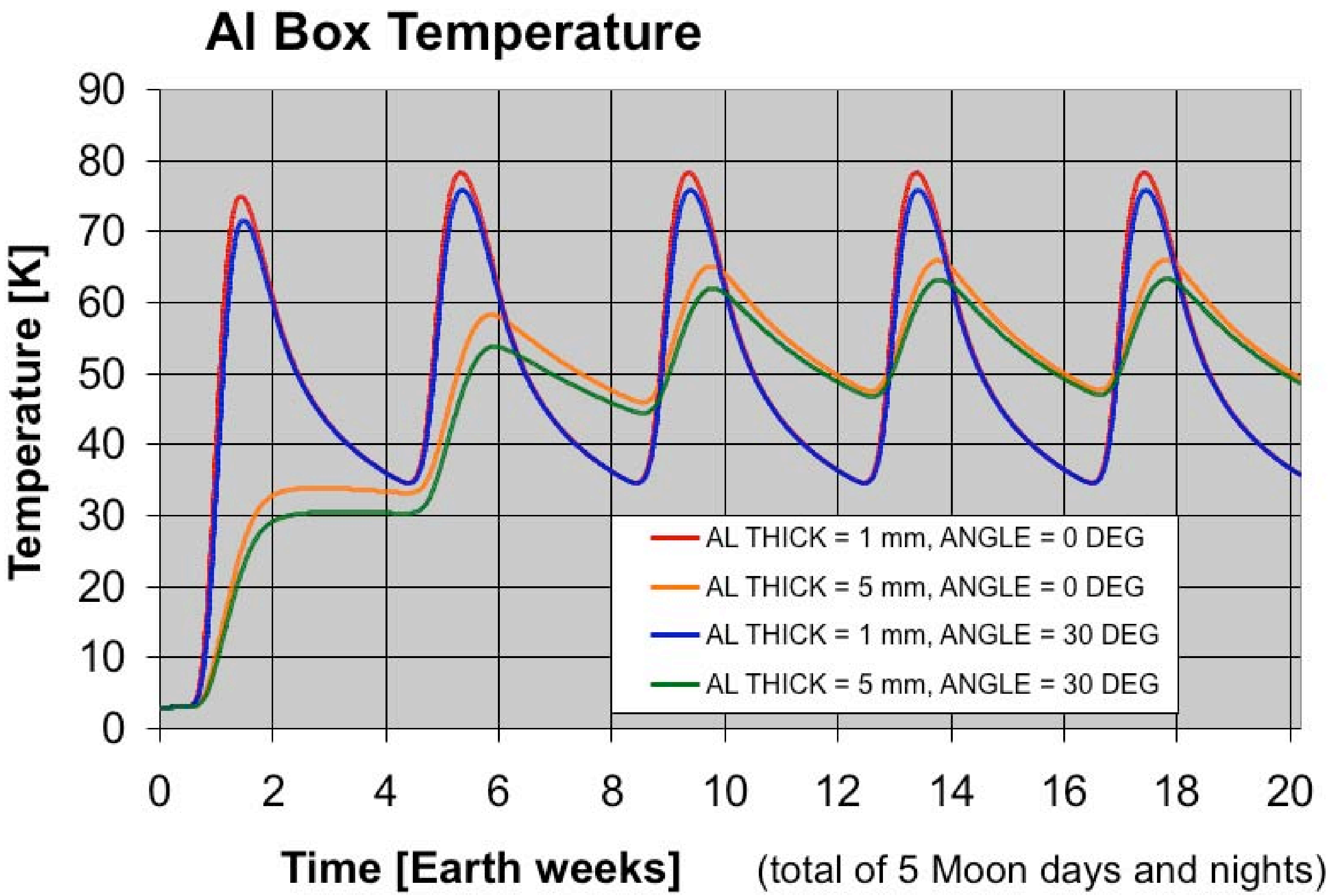
Installation on the surface



Foot in a hole on rock. Best if below 0.50 m of regolith ($\Delta T \sim 2$ K)

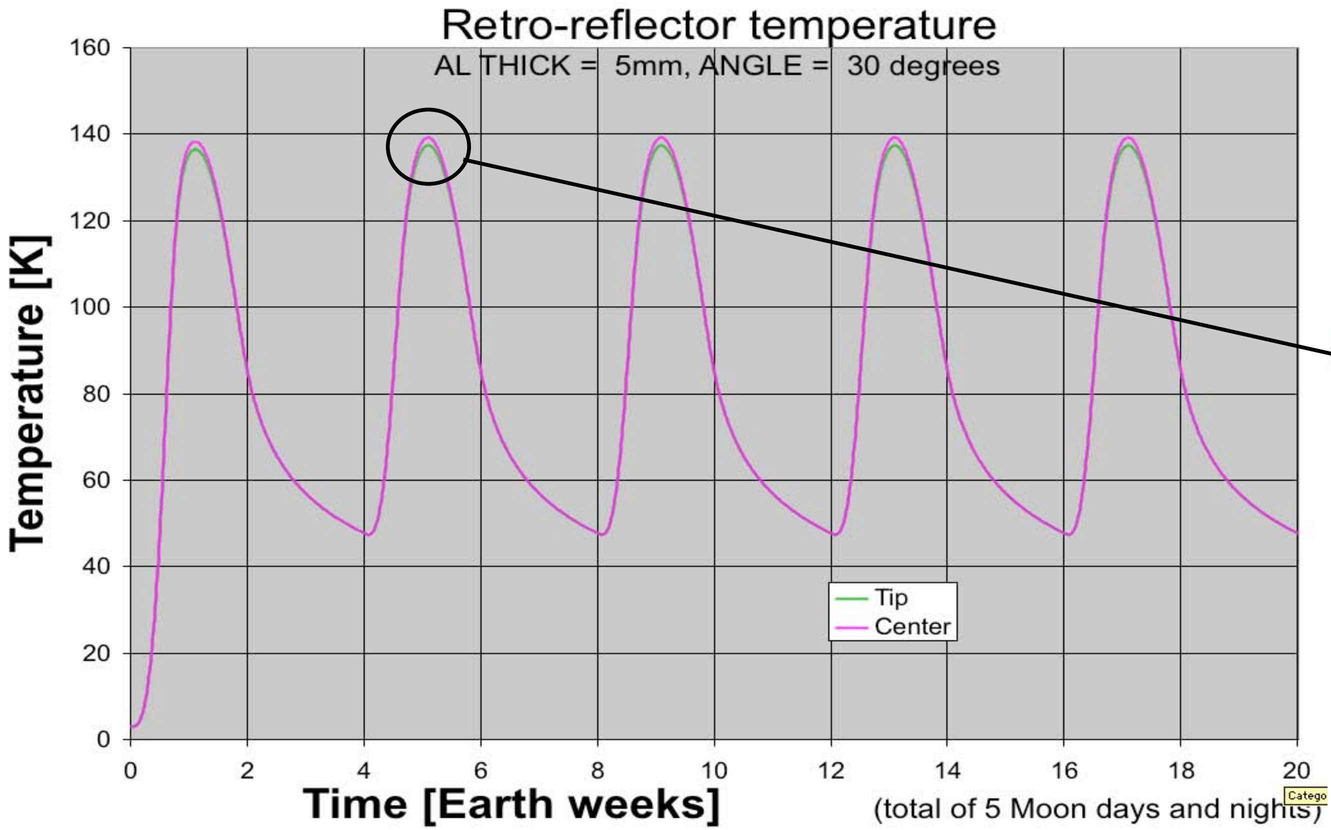
Preliminary thermal analysis: Al box

- Worst case, with Al box temperature floating
  - no thermal link to rock, no MLIs, no ULE …
- Sun illumination: varying intensity, but two fixed angles

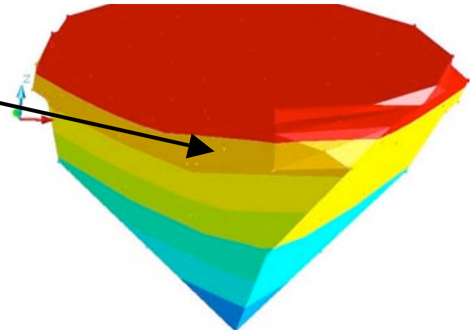


Preliminary thermal analysis: CCR

DESPITE THIS IS THE WORST CASE the thermal CCR conditions are good for integrity of laser signal: cold CCRs work well and T gradient through CCR body is small (< 2 K: variations of the refraction index variations is quite acceptable)



T(center) = 139.2 K



T(tip) = 137.4 K

Conclusion

- We are having a lot of fun with retros for:
  - LAGEOS/LARES
  - GNSS
  - Lunar, 2nd generation

- Full blown thermal measurement done, FFDPs done

- Integration of thermal and optical test READY

- Arnold and Currie will be @LNF for the next three week

- Future plan: COLLABORATION, COLLABORATION, COLLABORATION …..