Design, construction and SCF-Test of a prototype Galileo & GNSS Retroreflector Array of Hollow retroreflectors (GRA-H)

The INFN-LNF SCF Group

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Outline

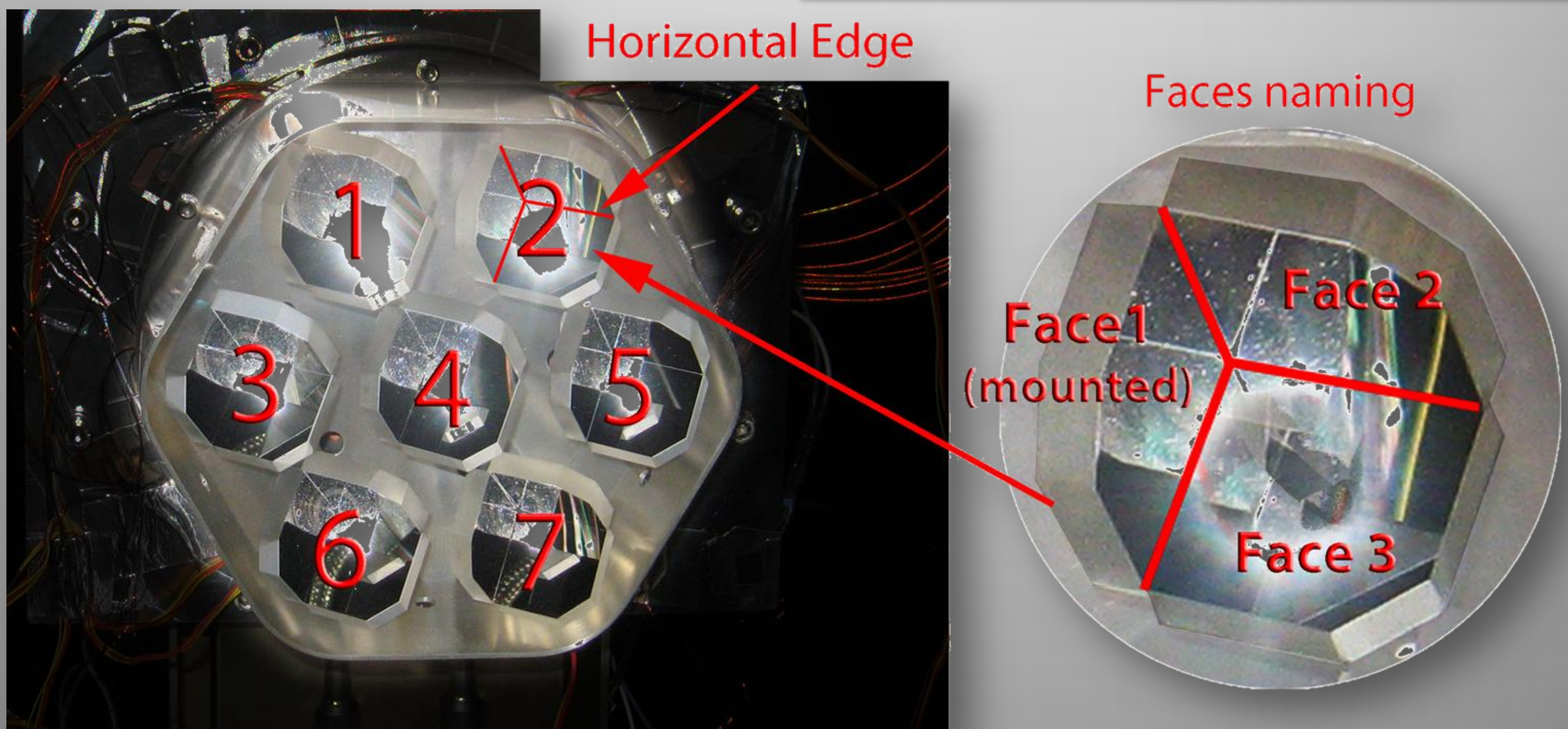
- GRA-H payload description
- GRA-H single CCR SCF-Tests campaign/results
- Ageing effect on the single CCR
- Full GRA-H SCF-Tests campaign/results
- Ageing effect on entire payload
- Structural stability test for the CCR used in the first test
- Conclusions & lessons learned

GRA-H test setup description I

Prototype GNSS Retroreflector Array - Hollow retroreflector technology, GRA-H

7 Hollow Cube Corner reflectors (HCC)

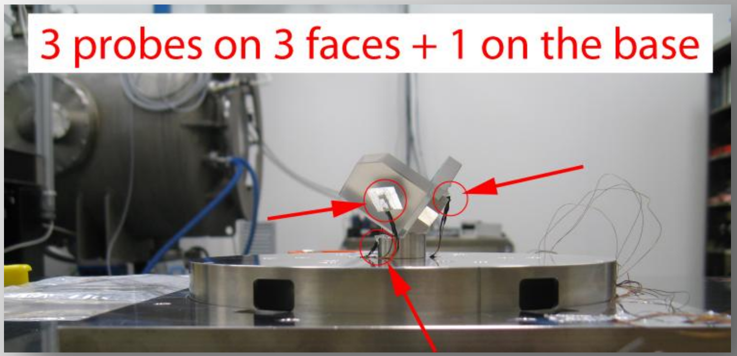
- All made of Pyrex with INVAR stem
- 4 with Al coating, 3 with Ag coating
- All with 0.0+/-0.5 dihedral angle offsets (DAO)
- Array arrangement: 6 on a ring and one in the center

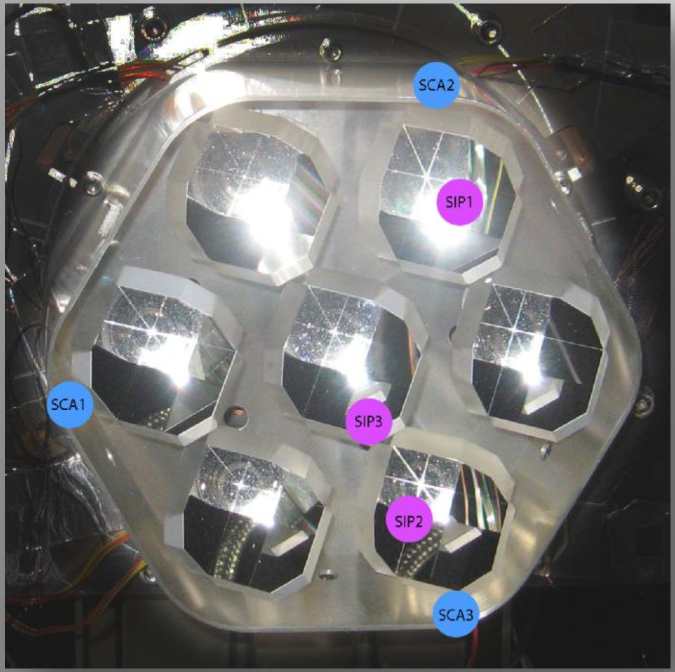


GRA-H test setup description II

Tests campaign main phases:

- Single reference HCC with Al coating
- Complete GRA-H (7 HCCs with Al and Ag coating)
- Structural stability test on a single HCC (the same used for first phase)



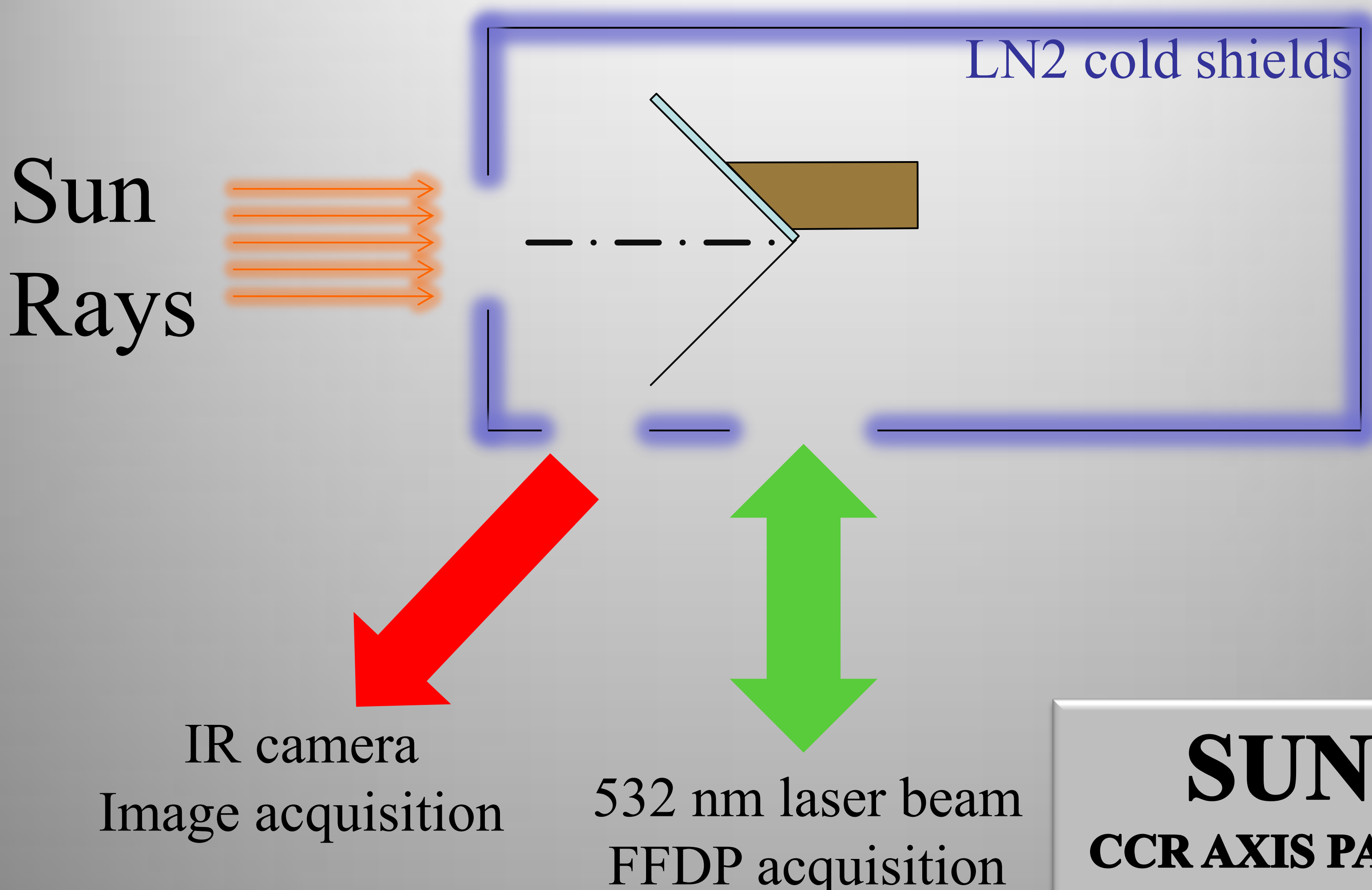


During tests, the payload is subject to thermal stresses typical of real operating conditions, and at the same time, the optical response of each retroreflector is measured.

SCF-Tests campaign main outputs:

- ✓ thermal relaxation time constants of the tested CCRs.
- ✓ FFDP trends, i.e., the optical response over time upon varying environmental conditions and internal temperature gradients

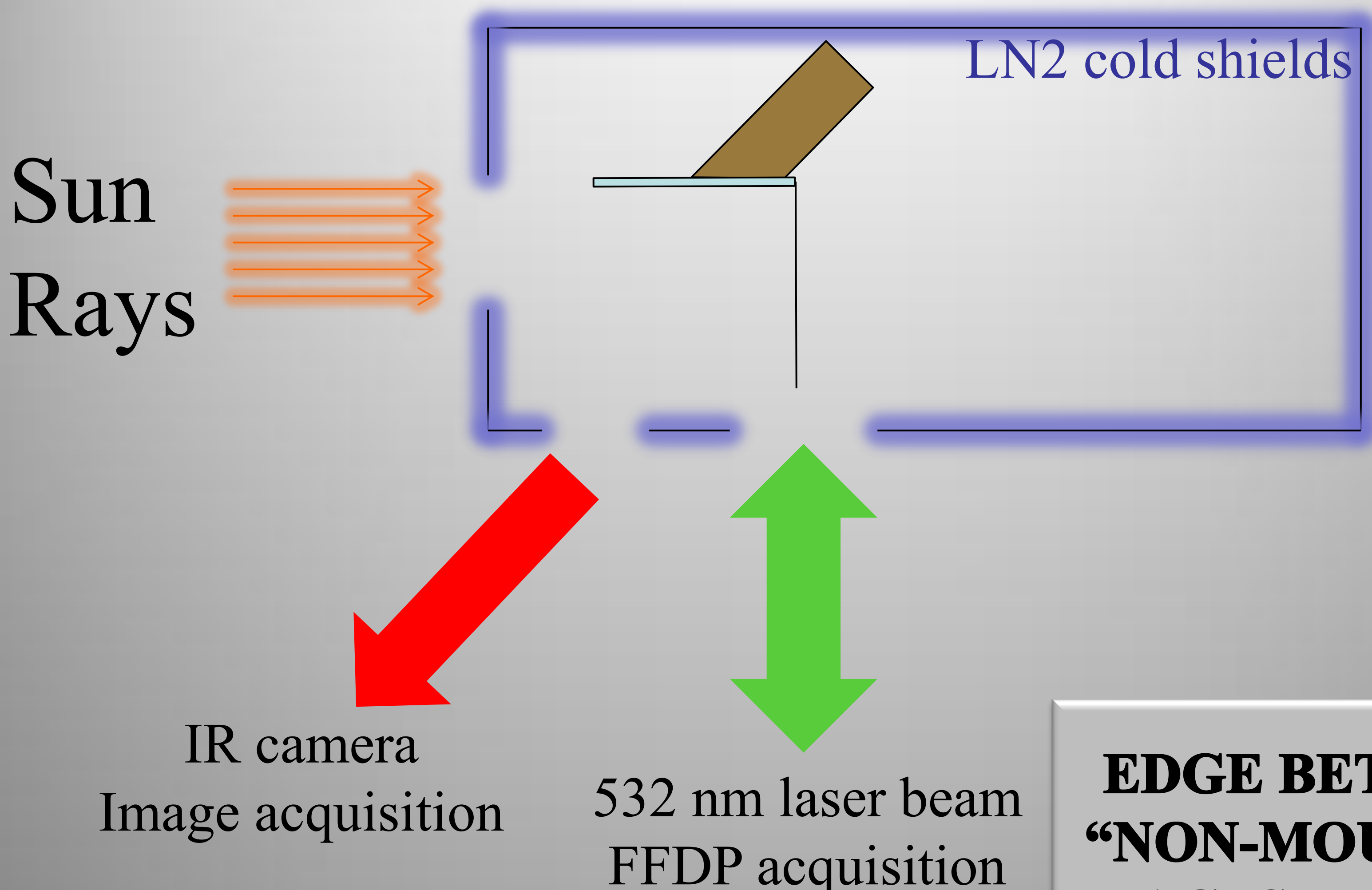
CCR typical relative angles during the SCF-Test



SUN 0°

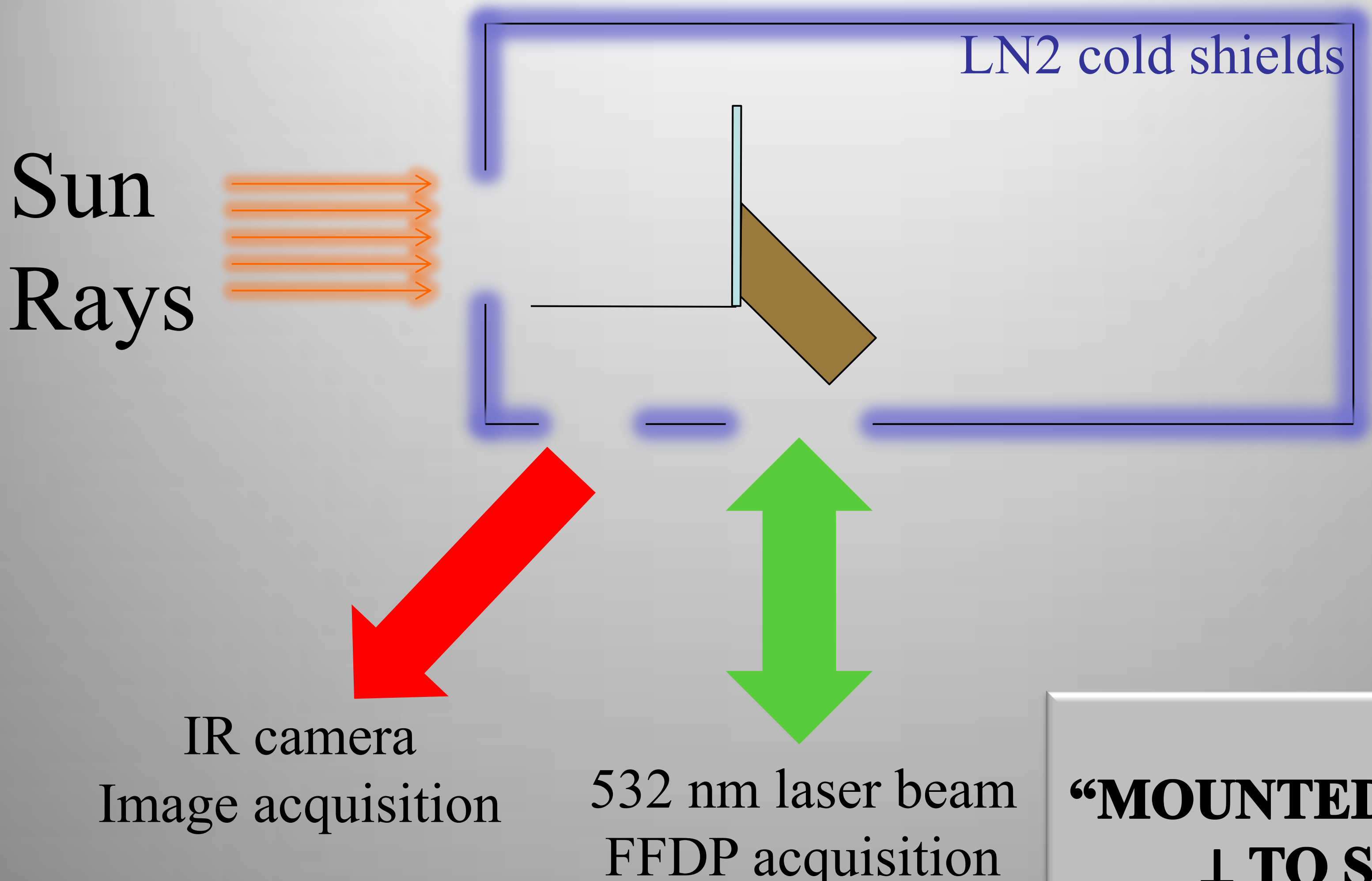
CCR AXIS PARALLEL TO THE SUN RAYS

CCR typical relative angles during the SCF-Test



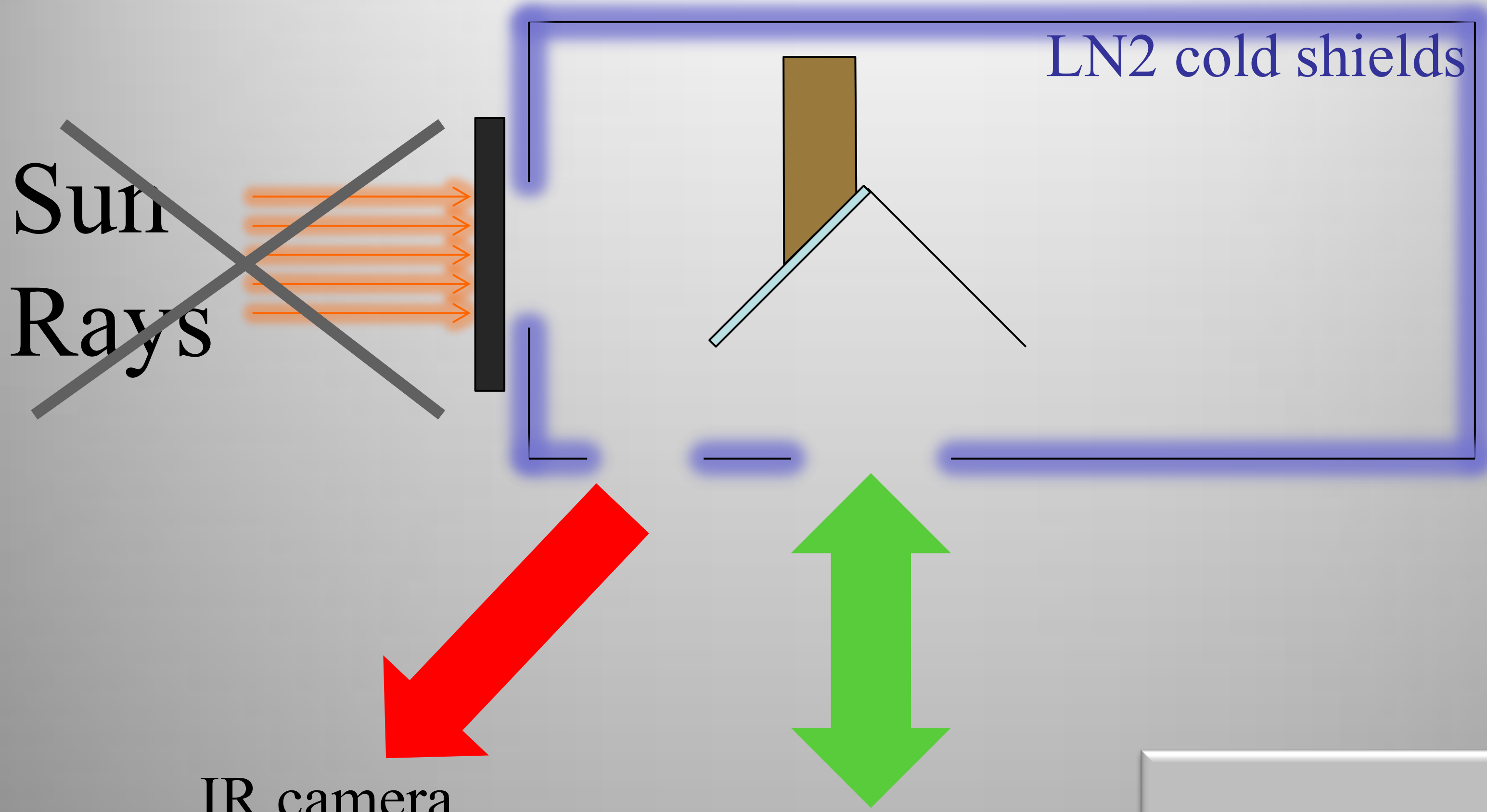
EDGE BETWEEN "NON-MOUNTED" FACES ⊥ TO SUN

CCR typical relative angles during the SCF-Test



"MOUNTED" FACE
⊥ TO SUN

CCR typical relative angles during the SCF-Test

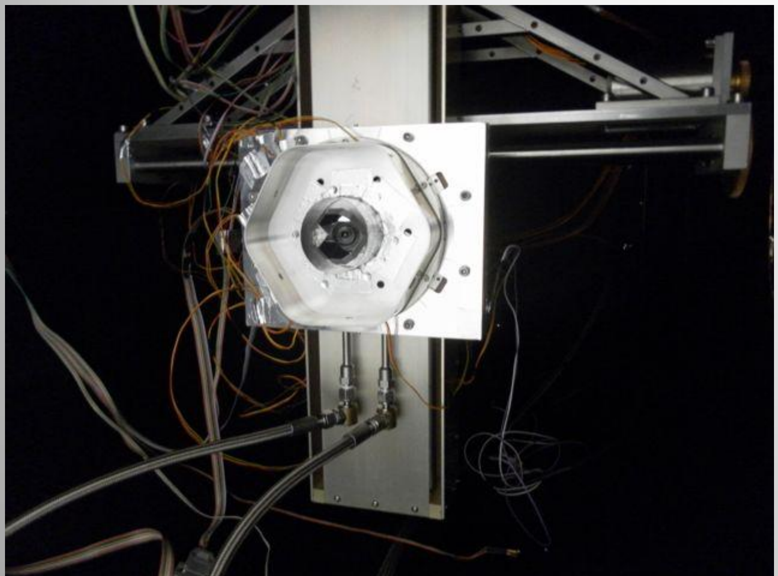


IR camera
Image acquisition

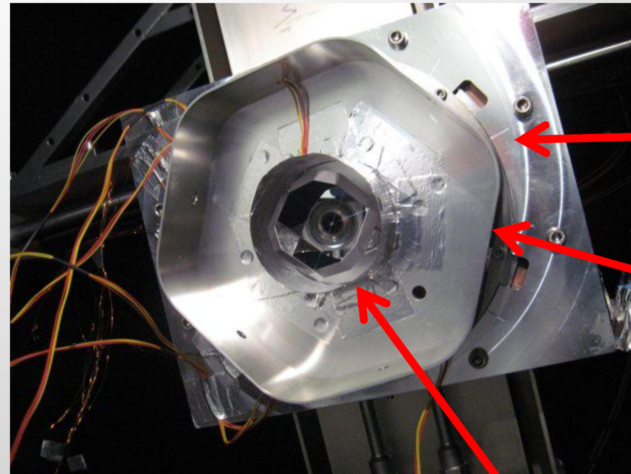
532 nm laser beam
FFDP acquisition

FFDP ACQUISITION

Single Al HCC: test configuration



Central HCC with the wiring for the temperature sensors and the thermal control mounted on the translation stage within the cryostat (note the glycol pipes at the bottom).



SIP-H

SCA-H

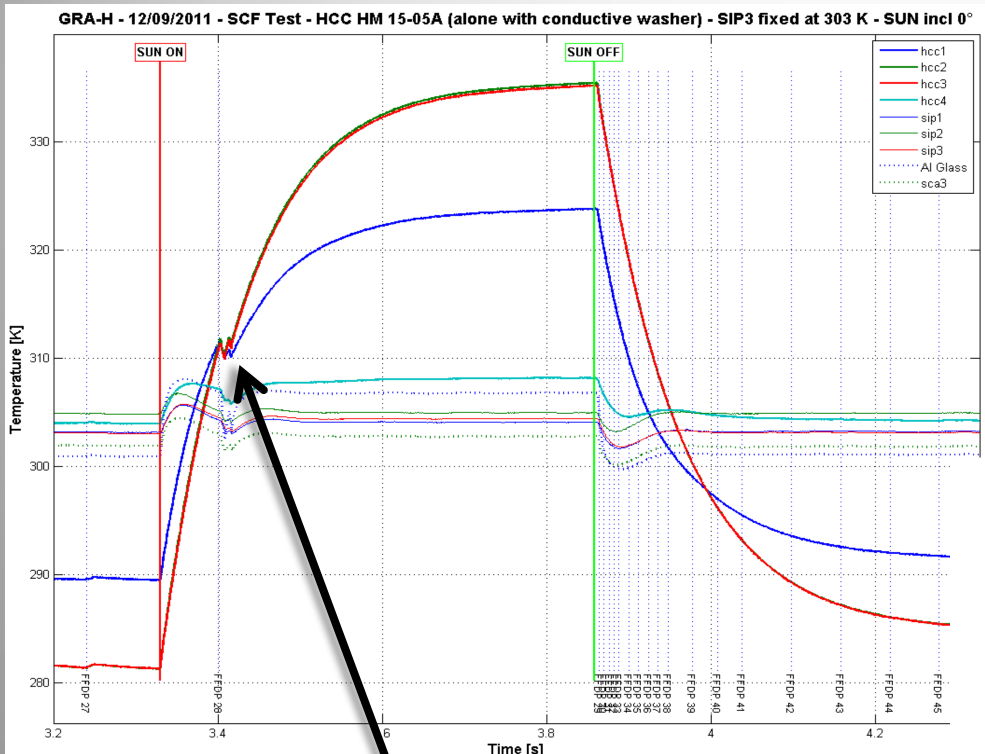
“Aluminum glass”

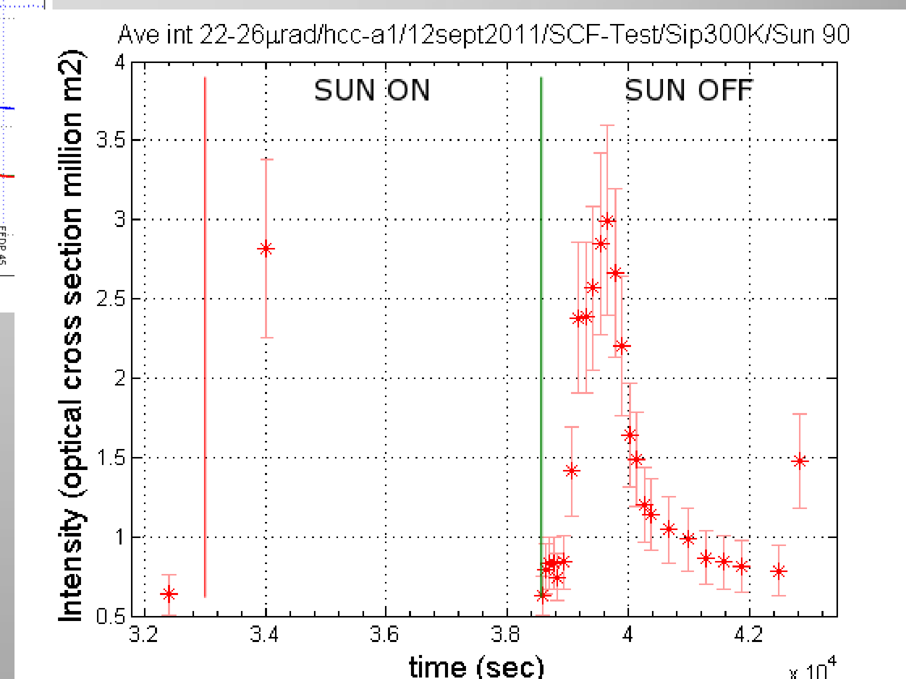
A screen made of thin aluminum to simulate the thermal mass of the missing CCRs that surround the central one in the following tests. The screen has a dedicated probe on its lateral surface.

Extensive testing of single, reference Al HCC to explore limits/features and avoid damage of all HCCs at once

Note: depending on the test session, the HCC was mounted with one steel (conductive) washer or with a G10 (insulating) washer on back side of SIP-H

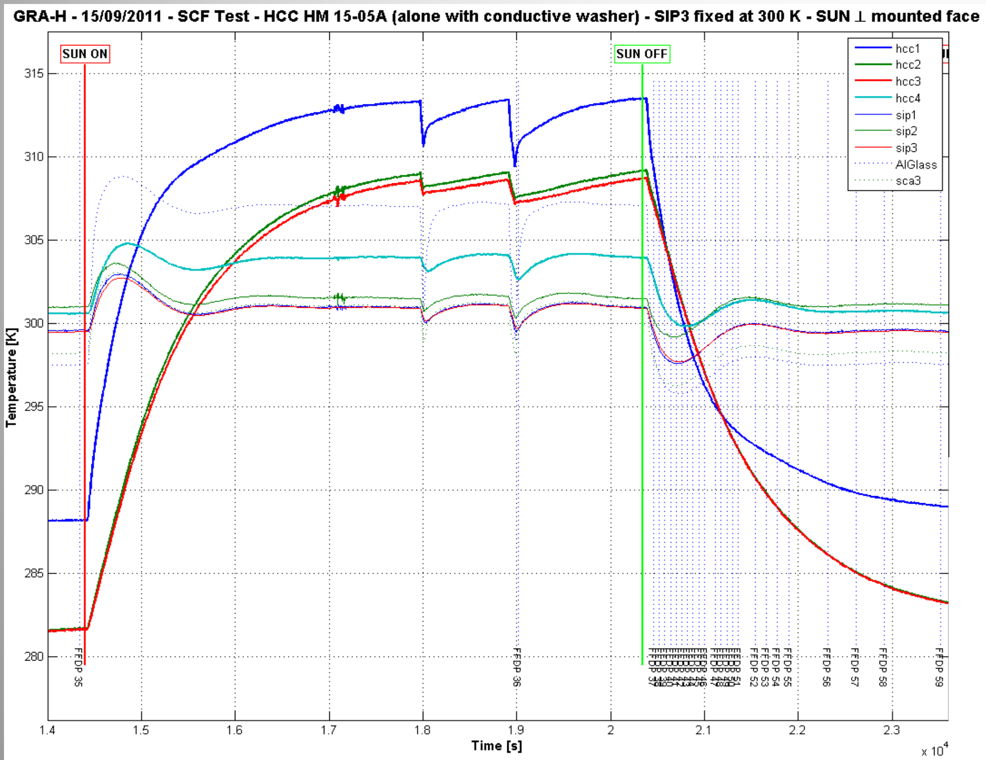
SCF-Test at 300 K

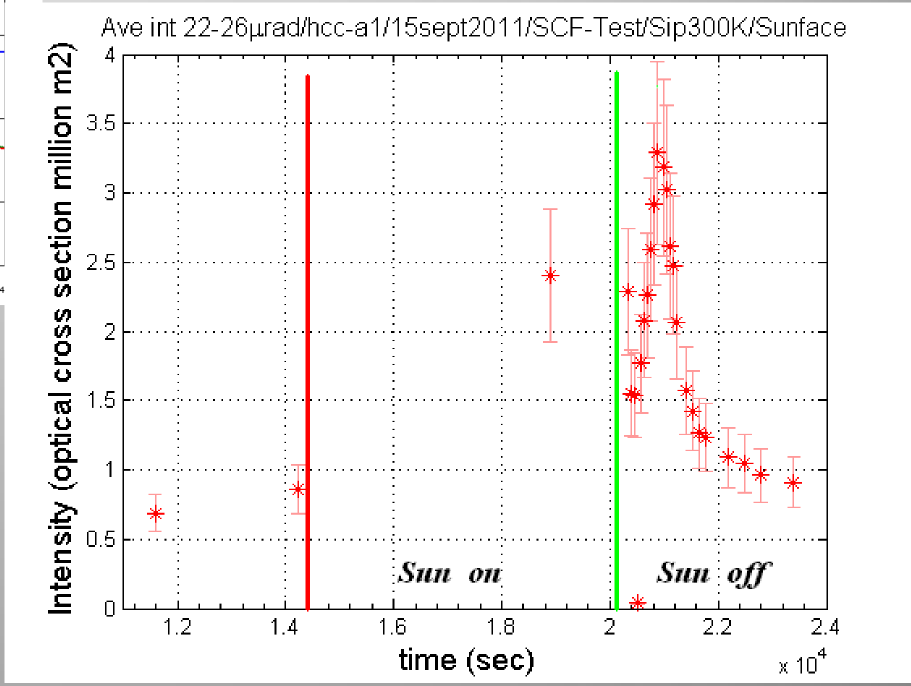




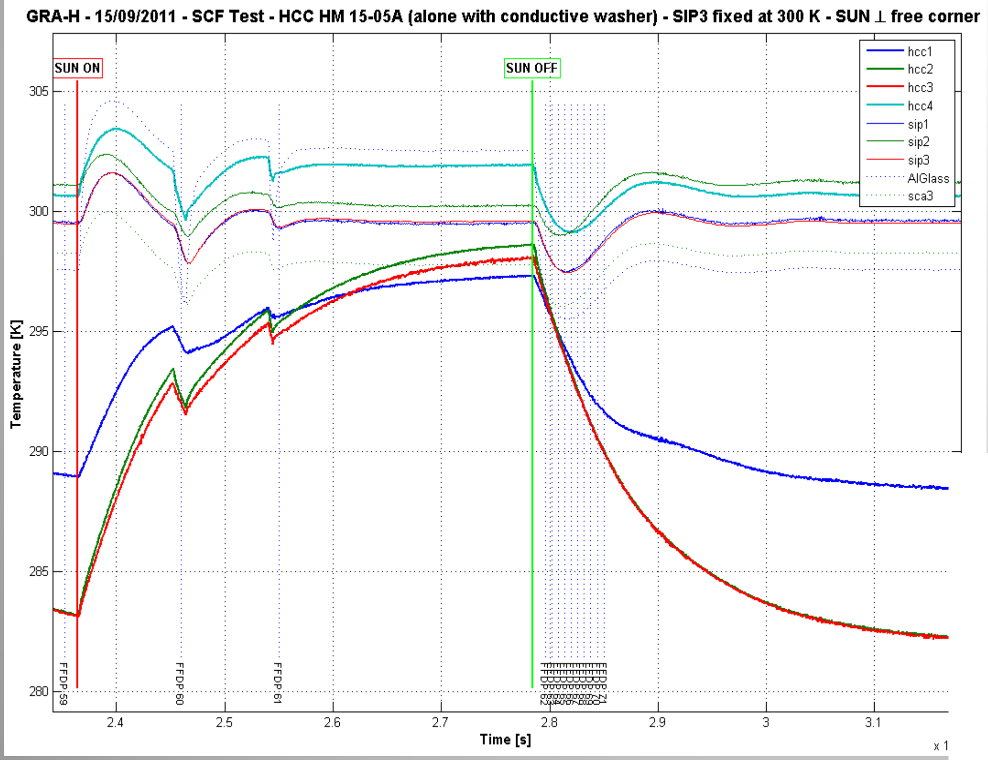
"kinks" in temperature plots are due to rotations to take FFDPs and/or thermograms

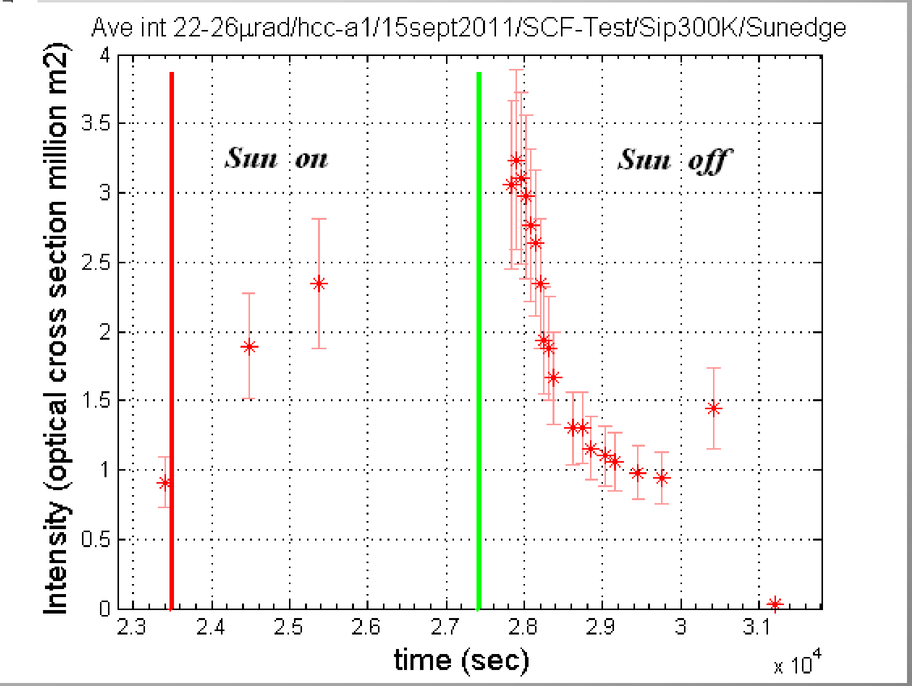
SCF-Test at 300 K, sun ⊥ mounted face hcc1



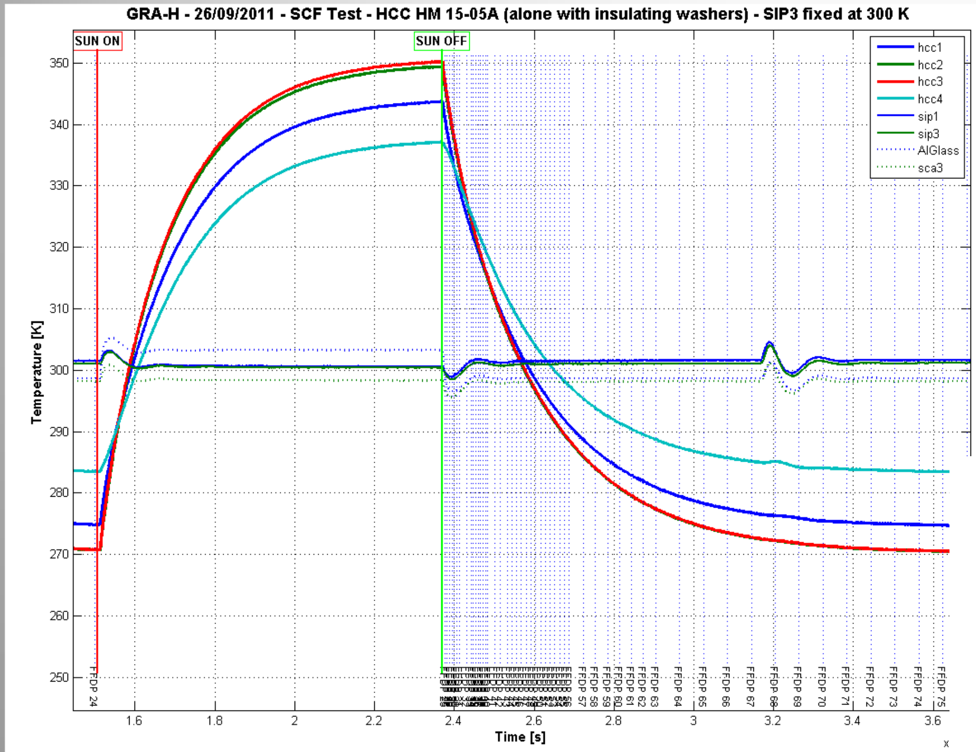


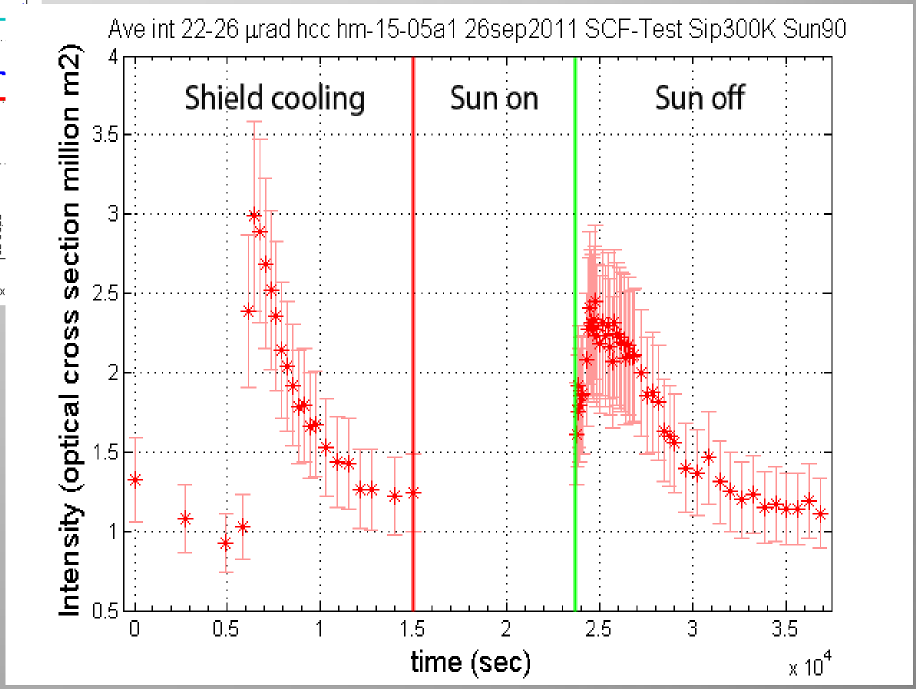
SCF-Test at 300 K, sun ⊥ non-mounted edge





SCF-Test at 300 K with G10 insulating washer

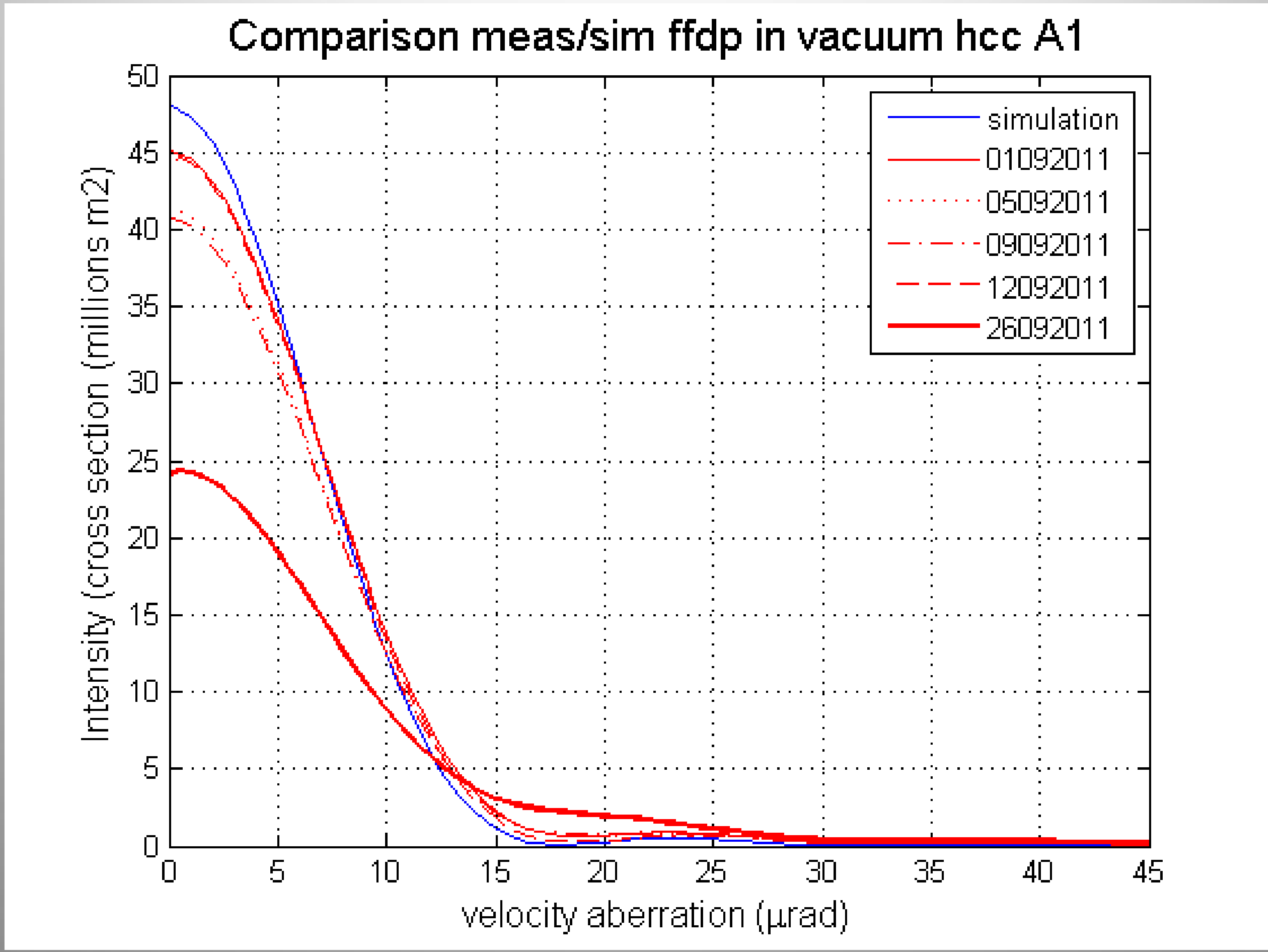




HCC thermal relaxation times (τ)

	Tau of back HCC faces (sec) with probes on pyrex - reference Al HCC (n° 4)								
Heating/cooling date	HCC1 w/mount	HCC2	HCC3	T(SIP) K	G10 washers	Angle / Point to	SUN	EDGE no-mount ⊥ TO SUN	FACE w/mount ⊥ TO SUN
I° heat.	708	909	909	300	no	0° / SUN	ON	no	no
I° cool. 12_09_2011	783	984	995	300	no	90° / LASER	OFF	---	---
I° heat. 14_09_2011	750	922	922	273,8	no	0° / SUN	ON	no	no
II° heat. 14_09_2011	757	987	989	258,8	no	0° / SUN	ON	no	no
I° cool. 14_09_2011	775	1039	1051	273,2	no	90° / LASER	OFF	---	---
II° cool. 14_09_2011	813	1084	1094	258,8	no	90° / LASER	OFF	---	---
I° heat. 15_09_2011	706	919	920	288	no	0° / SUN	ON	no	no
II° heat. 15_09_2011	**546**	1051	1072	300	no	0° / SUN	ON	no	**YES**
III° heat. 15_09_201	623	**832**	**880**	300	no	0° / SUN	ON	**YES**	no
I° cool. 15_09_2011	740	1006	1017	288	no	90° / LASER	OFF	---	---
II° cool. 15_09_2011	508	1051	1081	300	no	90° / LASER	OFF	---	---
III° cool. 15_09_201	696	896	937	300	no	90° / LASER	OFF	---	---
I° heat. 16_09_2011	697	871	906	315	no	0° / SUN	ON	no	no
II° heat. 16_09_2011	**492**	981	1021	315	no	0° / SUN	ON	no	**YES**
III° heat. 16_09_201	687	**849**	**892**	315	no	0° / SUN	ON	**YES**	no
I° cool. 16_09_2011	723	973	987	315	no	90° / LASER	OFF	---	---
II° coll. 16_09_2011	515	1031	1064	315	no	90° / LASER	OFF	---	---
II° cool. 16_09_2011	721	889	932	315	no	90° / LASER	OFF	---	---
heat. 26_09_2011	1806	1636	1635	300	YES	0° / SUN	ON	no	no
cool. 26_09_2011	2162	2072	2064	300	YES	90° / LASER	OFF	---	---
cool. 27_09_2011	1733	1586	1583	315	YES	0° / SUN	ON	no	no
cool 27_09_2011	2012	1939	1932	315	YES	90° / LASER	OFF	---	---

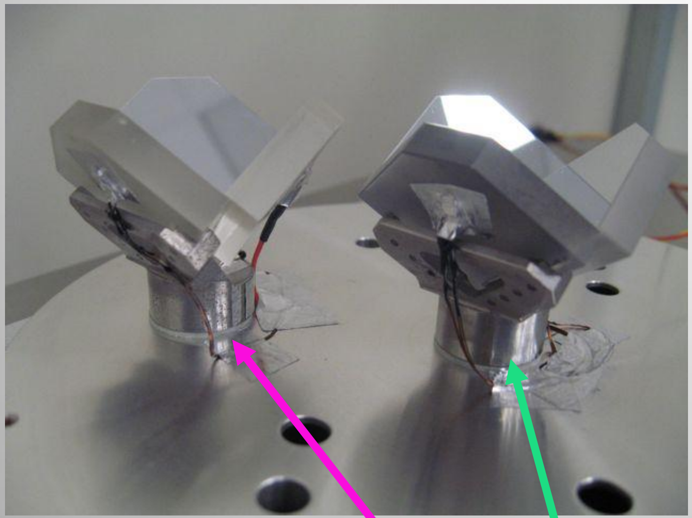
FFDP ageing plot of Al HCC

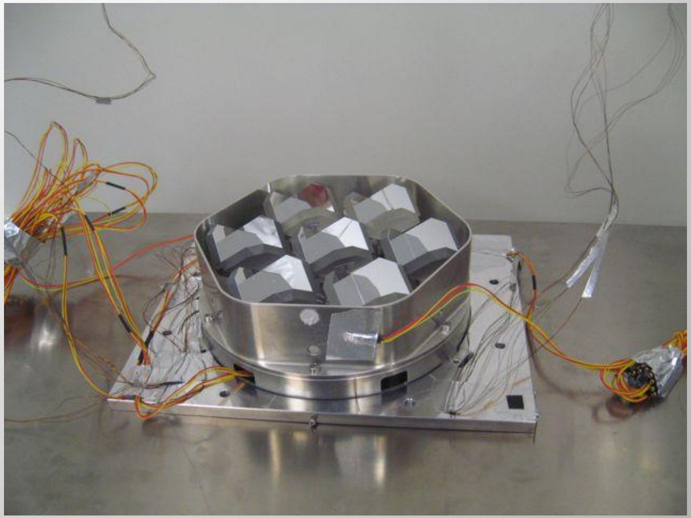


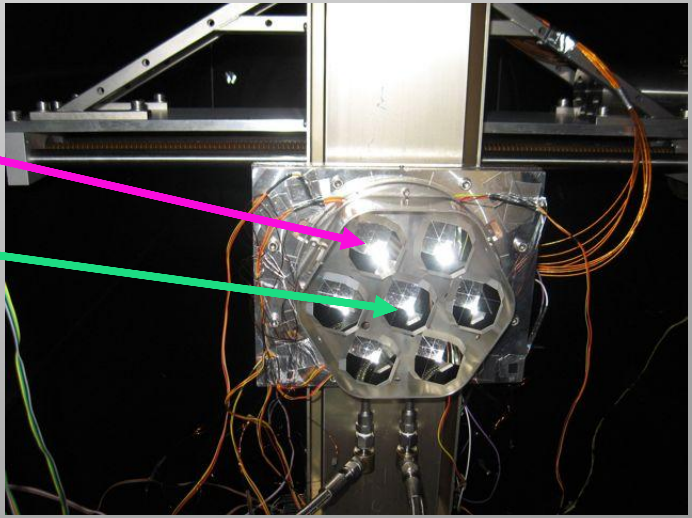
Lessons learned from single Al HCC testing

- After more than 15 test sessions decrease by 55% of the intensity at zero velocity aberration
- Increase of OCS at the GNSS velocity aberration (24 μrad) compared to the nominal OCS. This can be misleading, since the ageing is more severe for the space qualification than the OCS increase.
- OCS increases with thermal gradients, but with large asymmetries in azimuth, while the unperturbed OCS is symmetric. These asymmetries and consequent fluctuations of the laser signal strength are problematic for the operation of SLR ground stations.
- Large thermal gradients among mounted/non-mounted faces still persist

Complete GRA-H test configuration







Ag reference HCC **nº 1**

&

Al reference HCC **nº 4**

FULLY INSTRUMENTED

(4 probes per CCR)

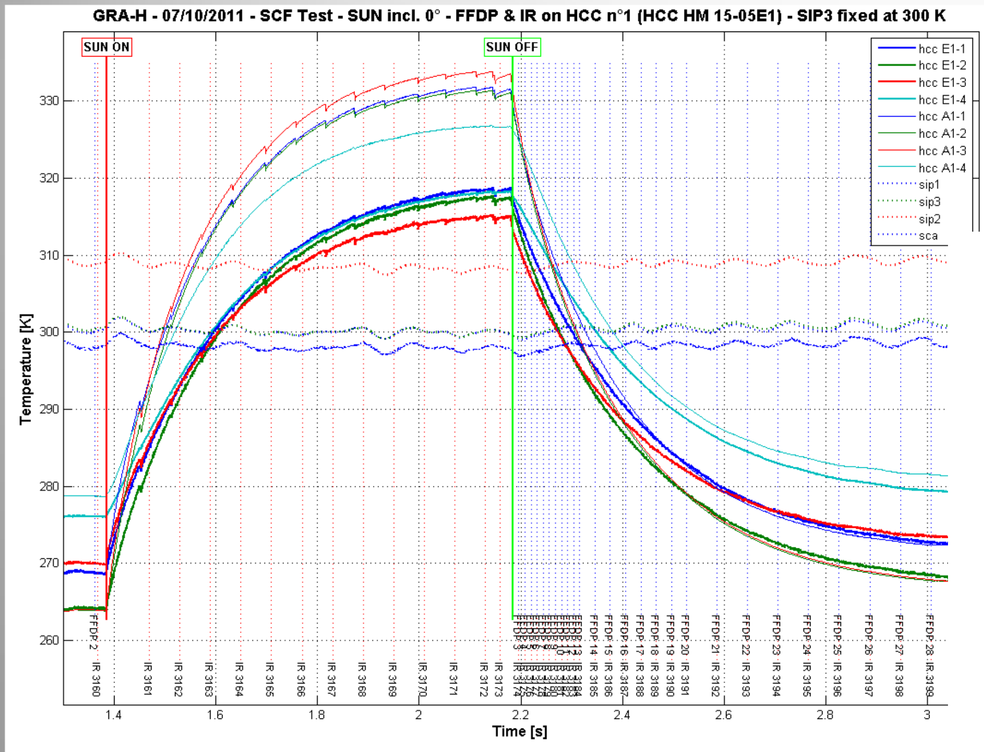
All 7 CCRs insulated from the SIP-H with double G10 washer

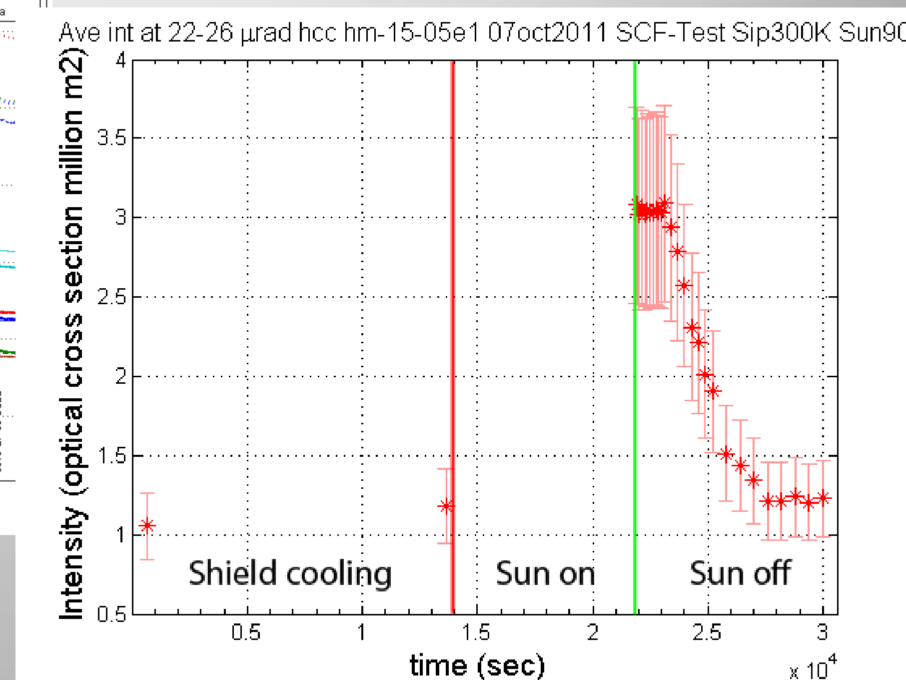
Complete GRA-H: test list

Chronological list of the entire SCF-Test campaign on the complete GRA-H

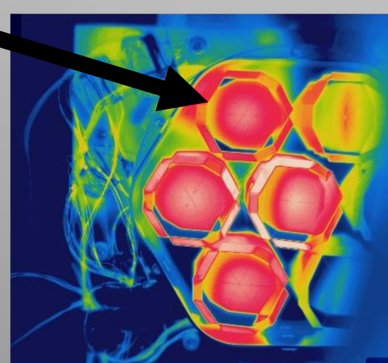
- HCC n°5 (Al coating) at 300K SIP-H set point temperature
- **<u>HCC n°1 (Ag coating) at 300K SIP-H set point temperature</u>**
- HCC n°6 (Al coating) at 300K SIP-H set point temperature
- HCC n°3 (Al coating) at 300K SIP-H set point temperature
- HCC n°2 (Ag coating) at 300K SIP-H set point temperature
- HCC n°7 (Ag coating) at 300K SIP-H set point temperature
- HCC n°1 (Ag coating) at 315K SIP-H set point temperature
- HCC n°1 (Ag coating) at 285K SIP-H set point temperature
- HCC n°4 (Al coating) at 300K SIP-H set point temperature
- HCC n°4 (Al coating) at 285K SIP-H set point temperature
- HCC n°4 (Al coating) at 315K SIP-H set point temperature

SCF-Test of Ag HCC n° 1 at 300 K





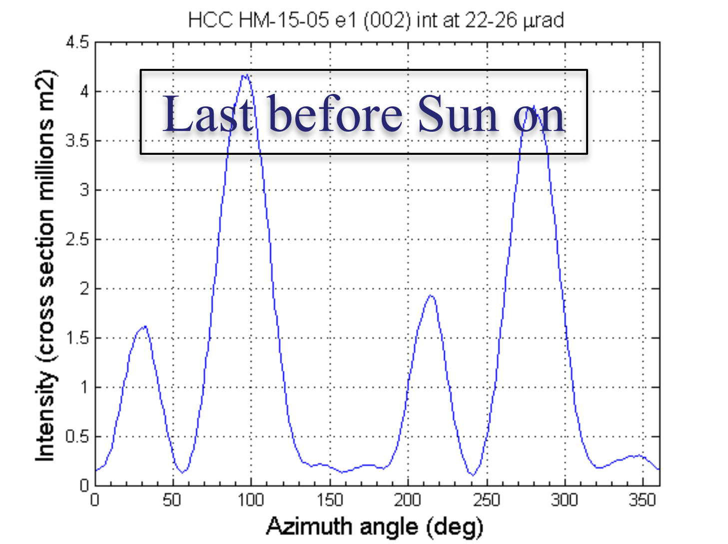
HCC n° 1 (Ag)

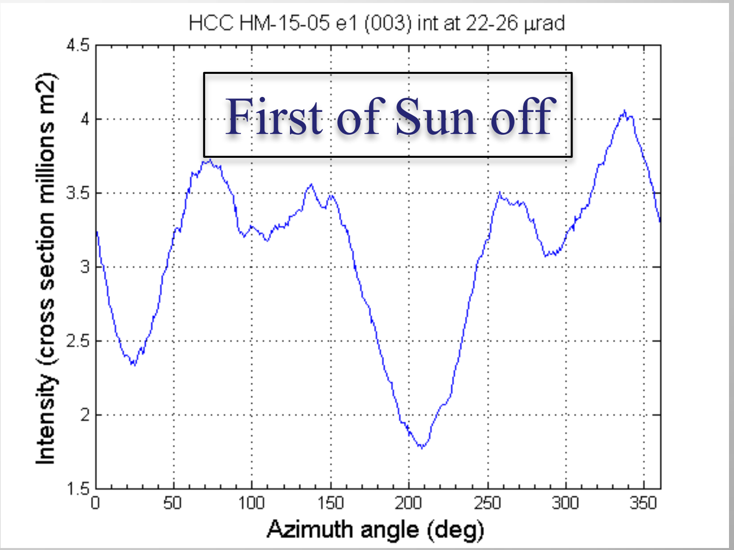


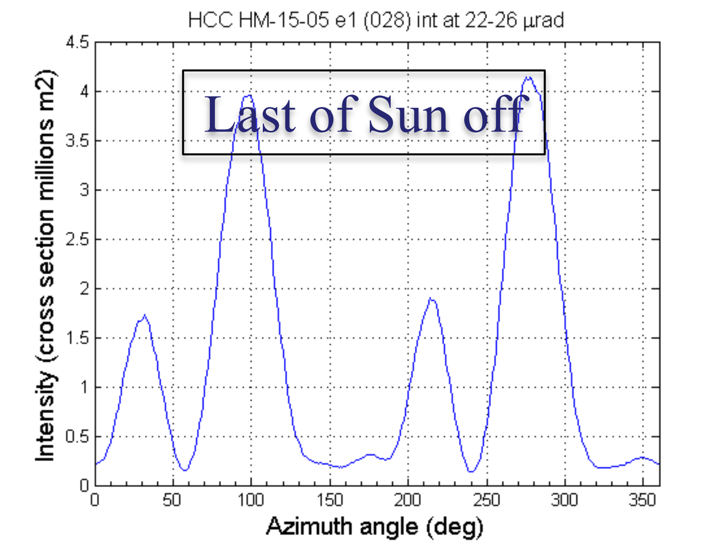
Note: IR image shown only for qualitative purpose. To get quantitative info, IR images need intensive post-processing to adjust $T_{reflected}$, HCC emissivity (ε), etc …

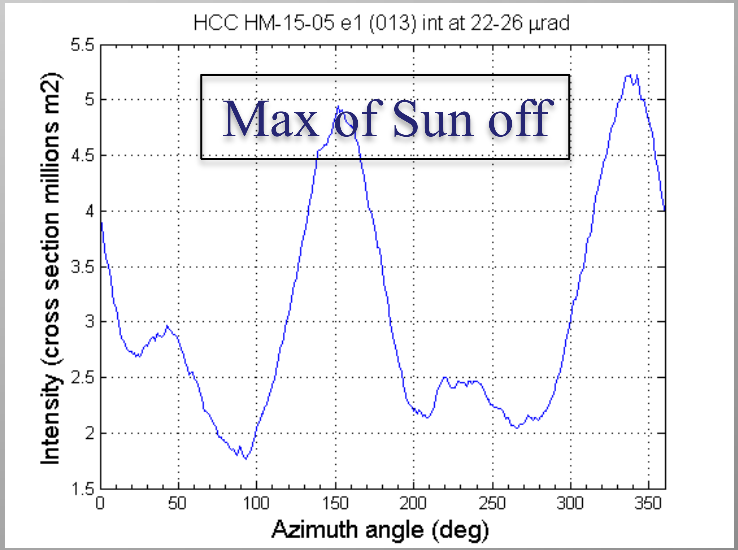
SCF-Test of Ag HCC nº 1 at 300 K

OCS intensity vs. azimuth

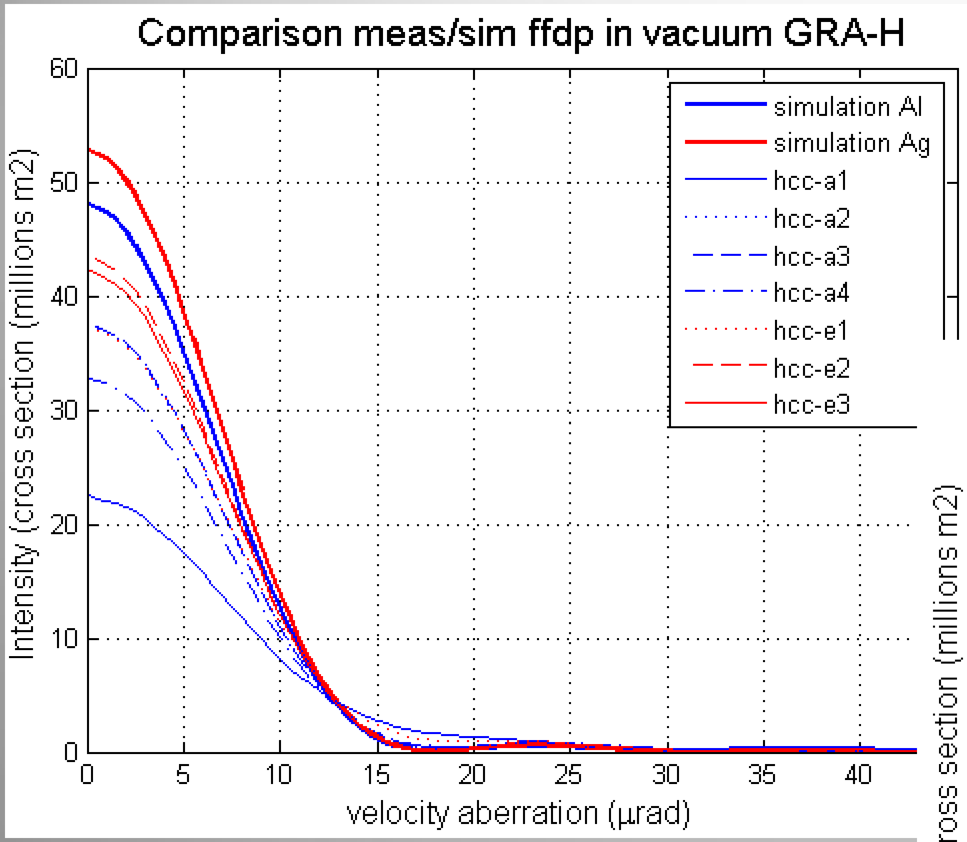


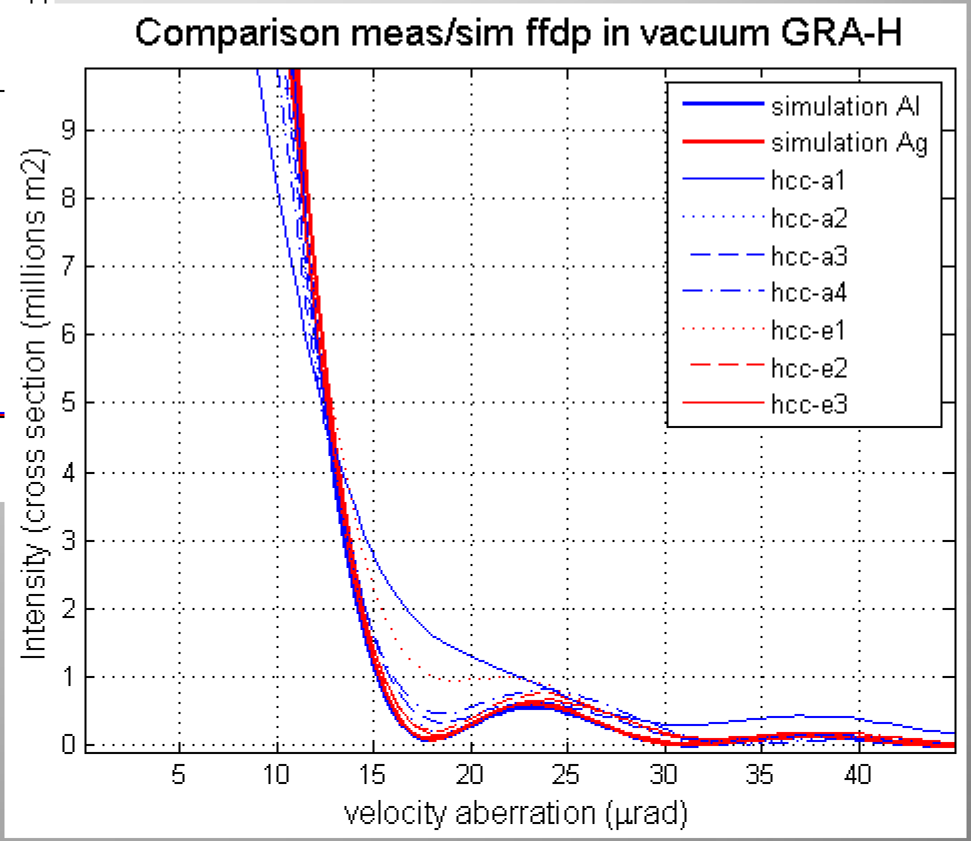




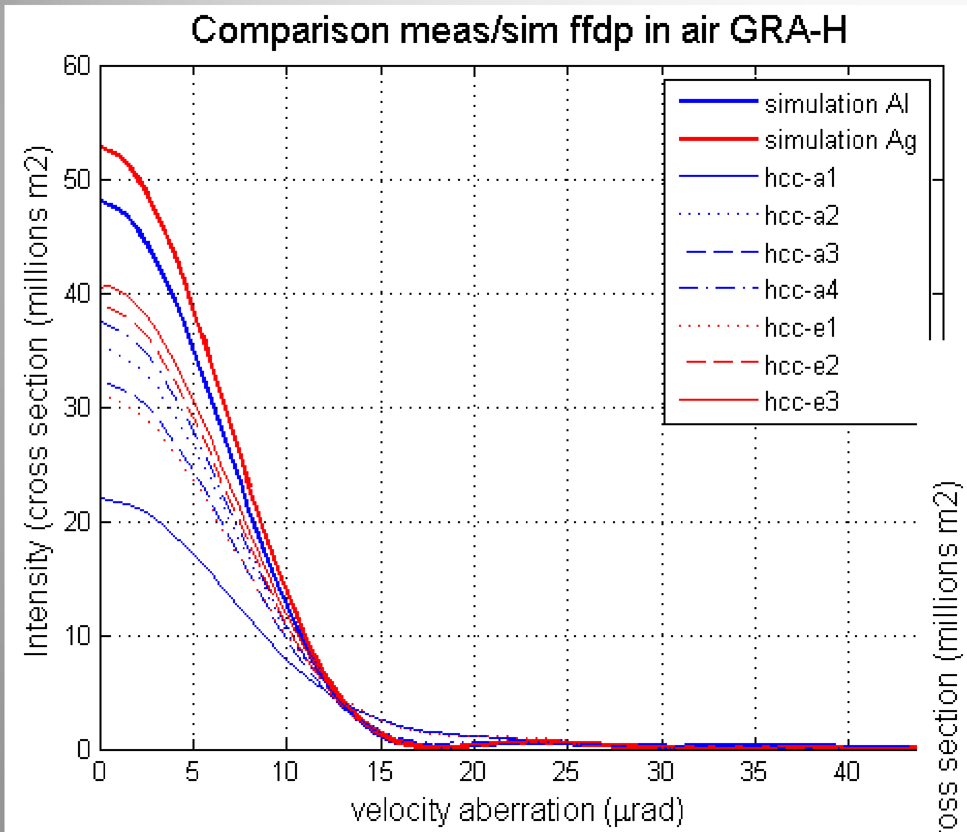


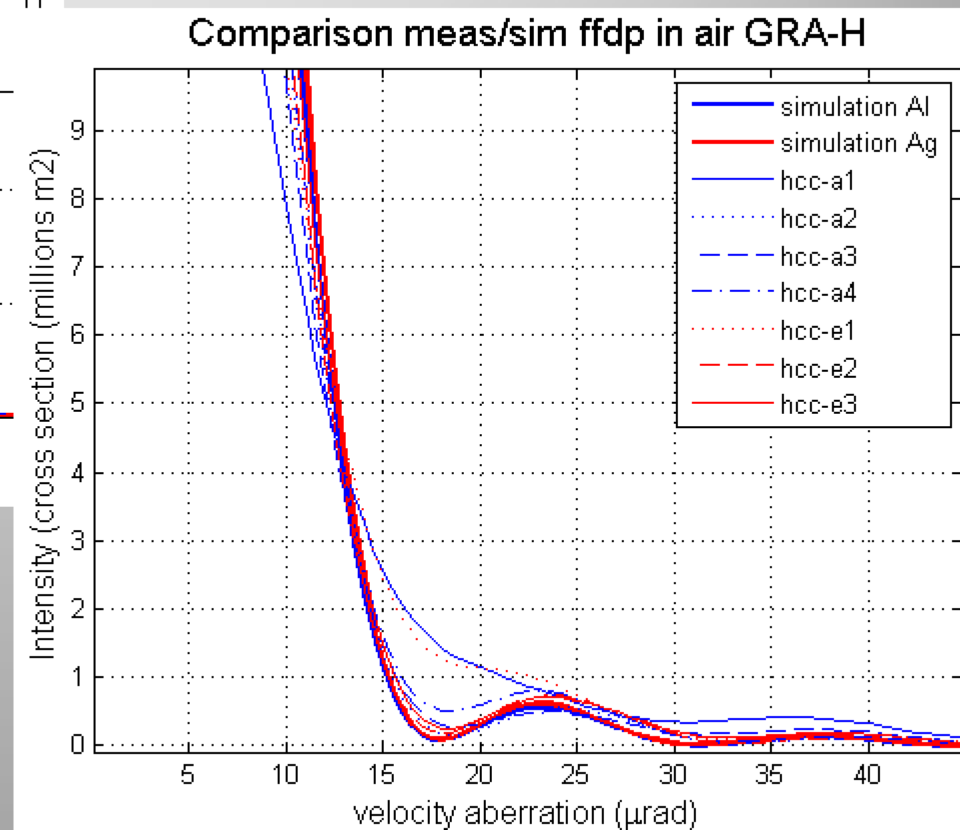
FFDP ageing plots of Ag/Al HCC nº 1/4, Oct. 4





FFDP ageing plots of Ag/Al HCC nº 1/4 Oct. 12



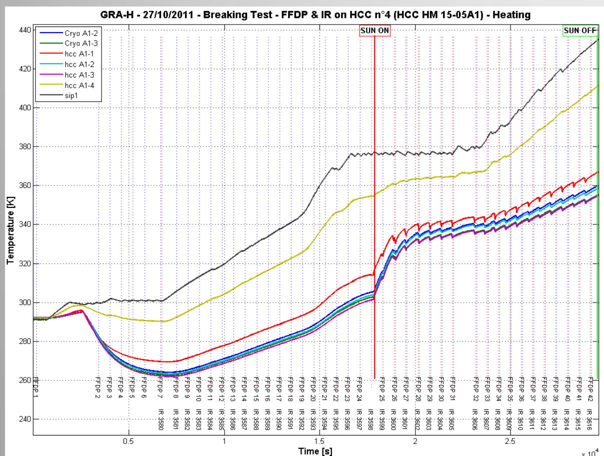


Structural stability test of the Al HCC(n^o4)

- Again, the **Al HCC n^o4** was mounted **alone** at the center of the GRA-H but with **two conductive washers** to enhance the thermal link with the SIP-H
- Temperature cycle in range larger than **[+100 C, -60 C]** range **indicated by ESA** for Galileo and larger than range indicated by NASA for GPS3
  - Heating: with thermal control plate first, then aided by SS
  - Cooling: thermal control and SS off, effect of LN2 shield

Structural stability test: thermal cycles & FFDPs

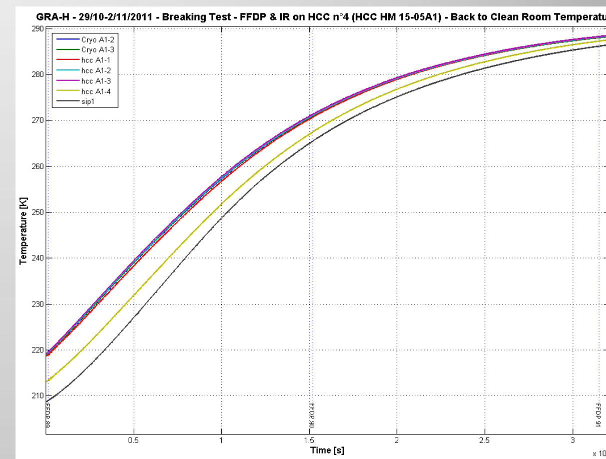
Heating…

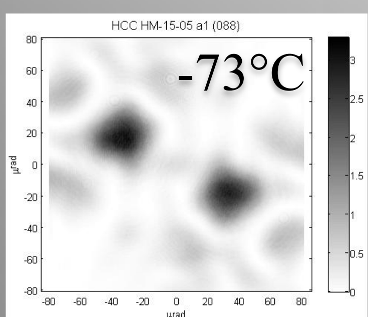


…to +100°C,
then cooling to -73°C,
then…

• • •

…heating back to clean room temp.





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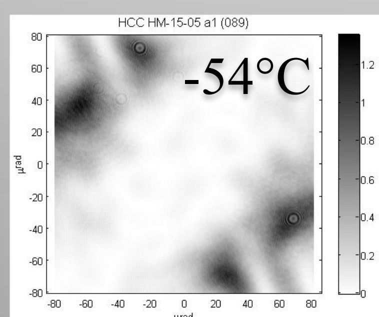

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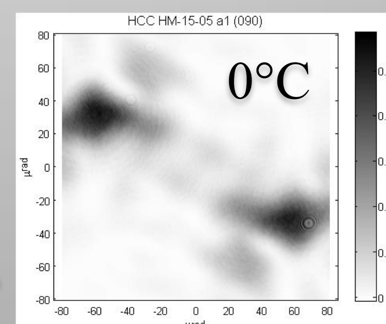

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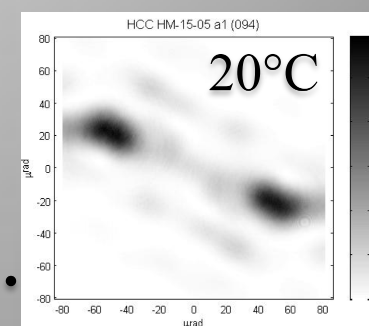
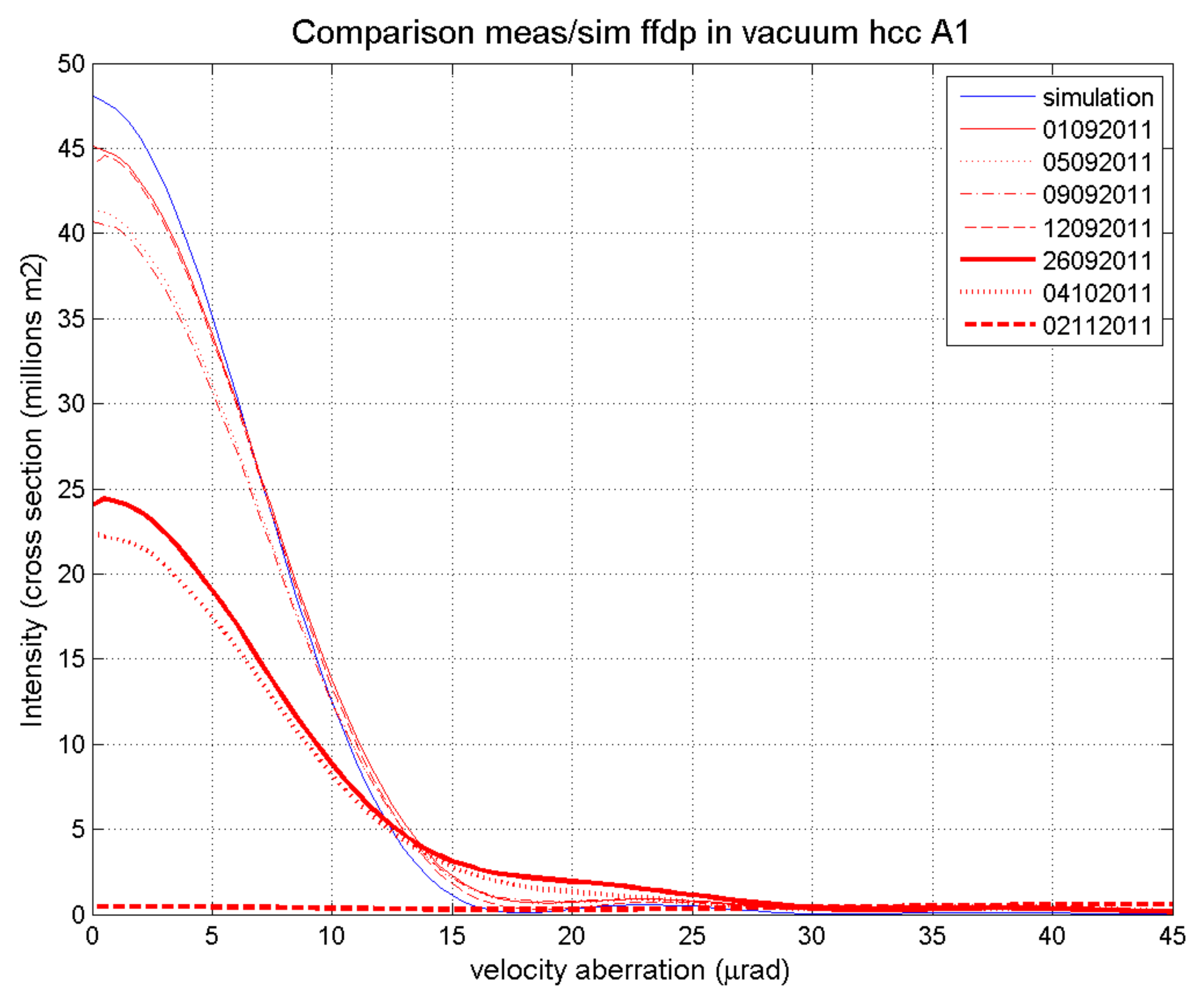


Oct. 28, 2011 → Nov. 7, 2011

FFDP ageing/deformation A1 HCC nº 4



Conclusions and lessons learned from complete GRA-H SCF-Test

- Under SS illumination the Ag HCC n. 1:
  - Has temperature increase significantly lower than the Al HCC n. 4
  - Has significantly longer τHCC than the Al HCC n. 4
- OCS azimuth asymmetries persist and are large
- After these thermo-mechanical stress-fatigue cycles, we have observed a permanent and significant degradation of both the FFDP intensity and shape caused by some structural deformation(s) of Al HCC n. 4. This cycles are a little part of what a GNSS satellite will experience in 15 years of expected lifetime.
- Compensating the decrease of the HCC OCS intensity over time would require more HCCs. The HCC advantage of having less mass can be lost.

The longest SCF-Test ever: 2 months measurements

Men at work in the LNF clean room

Tired, but happy!

Full test details and results reference document:
"ETRUSCO-2 GRA-H SCF-test results"

Thank you for your attention

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