ESA-INFN Contract No. 4000108617/13/NL/PA

Thermo-optical vacuum testing of Galileo IOV laser retro-reflectors of GALILEO IOV LRA

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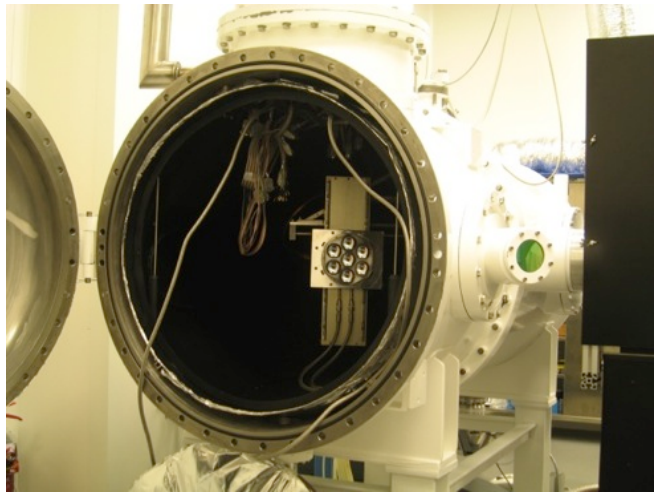
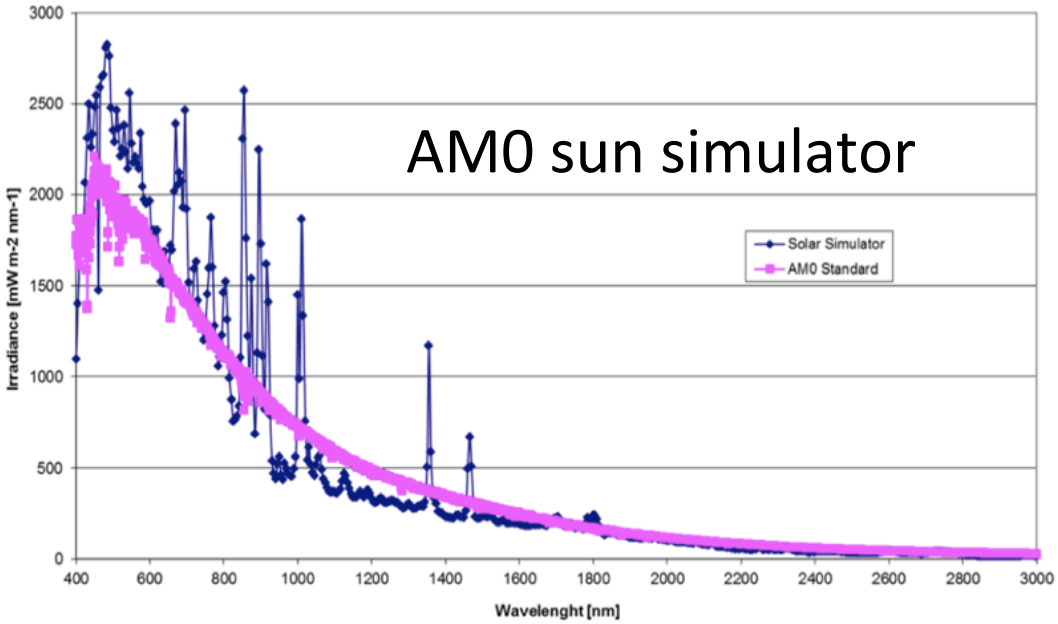
SCF_Lab: CCR characterization

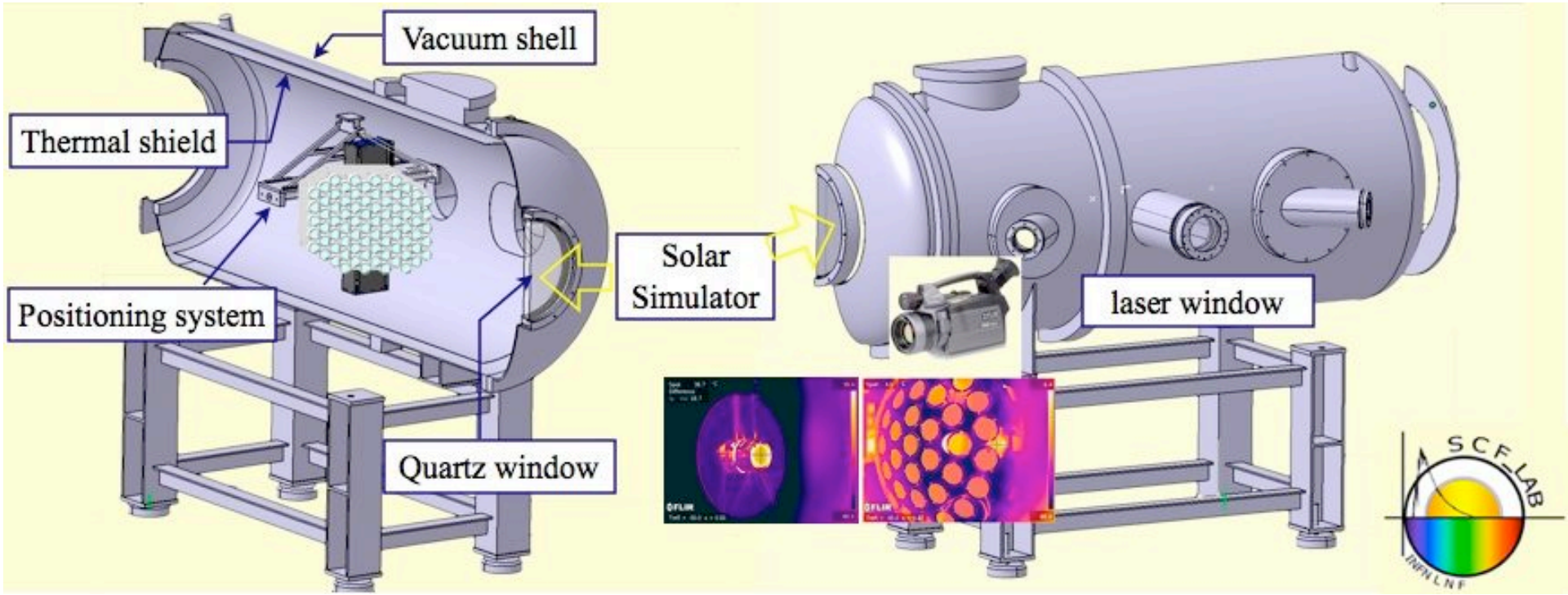
- Two Optical Ground Support Equipment (OGSE).
- SCF (top right) & SCF-G (bottom right) dedicated to Galileo, other GNSS.
- Two AM0 sun simulators, IR thermometry.
- Detailed optical testing.
- J. Adv. Space Res. 47 (2011) 822–842.





SCF_Lab: CCR characterization

- Two Optical Ground Support Equipment (OGSE).
- Class 10000 (ISO 7) clean room.



Test article

Test article ➔ 7 CCRs cluster assembled on the EM LRA base plate in a hexagonal axial symmetric configuration.

➔ base plate designed to allow its temperature control according.

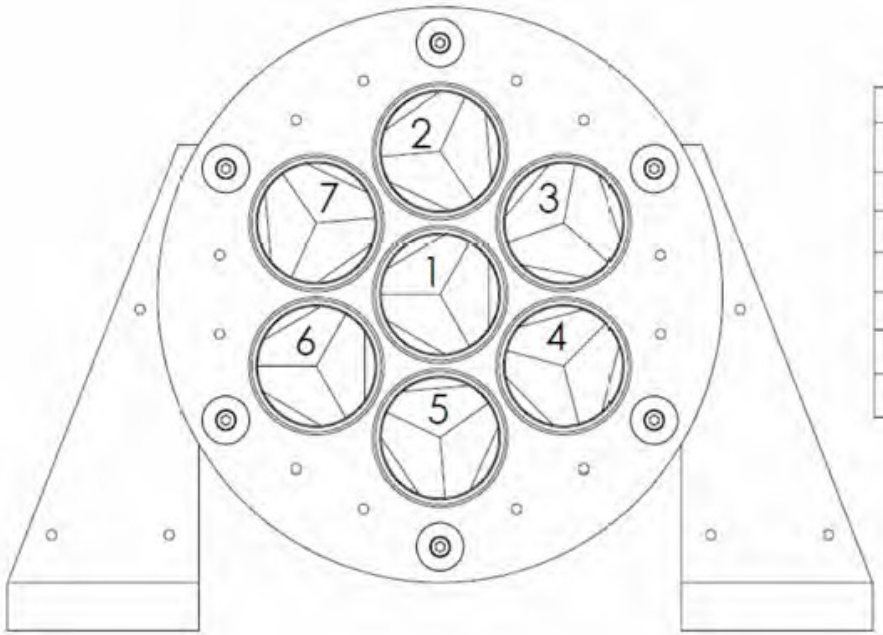
➔ base plate has integrated radiators and is provided with TCS to simulate orbital transient conditions.

EM LRA (engineering Model Laser Retroreflector Array)

➔ instrumented with 7 PT 100 RTDs to measure the temperature of the CCRs housing.

➔ assembled on the 3-axis movement system of the SCF facility, to be exposed to the Sun simulator, SCF cold wall and SCF optical window for laser interrogation.

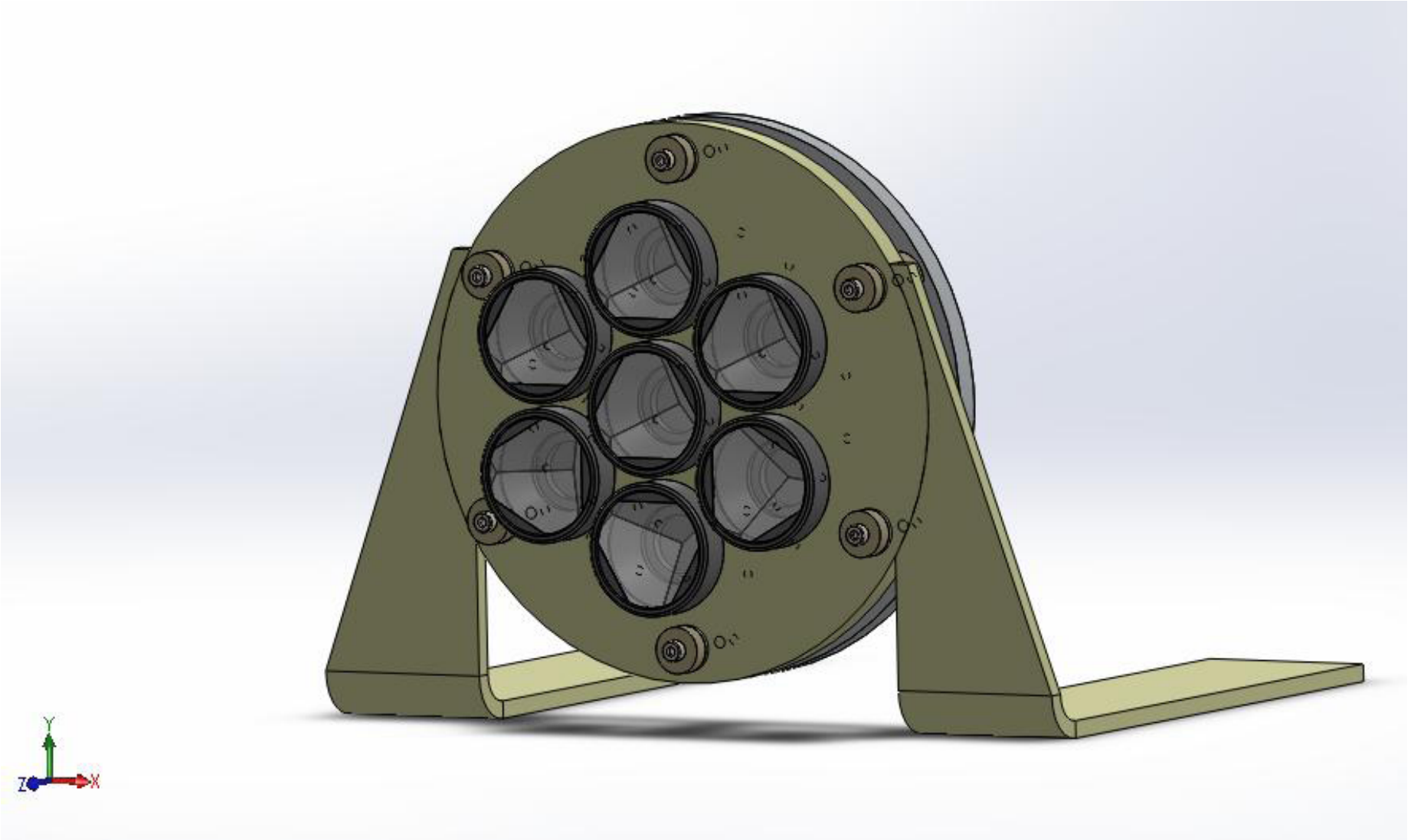
Test article



CCR	Serial	Orient.
1	LRR-S10-05	30°
2	LRR-S10-03	25°
3	LRR-S10-06	11°
4	LRR-S10-08	45°
5	LRR-S10-04	55°
6	LRR-S10-10	30°
7	LRR-S10-07	85°

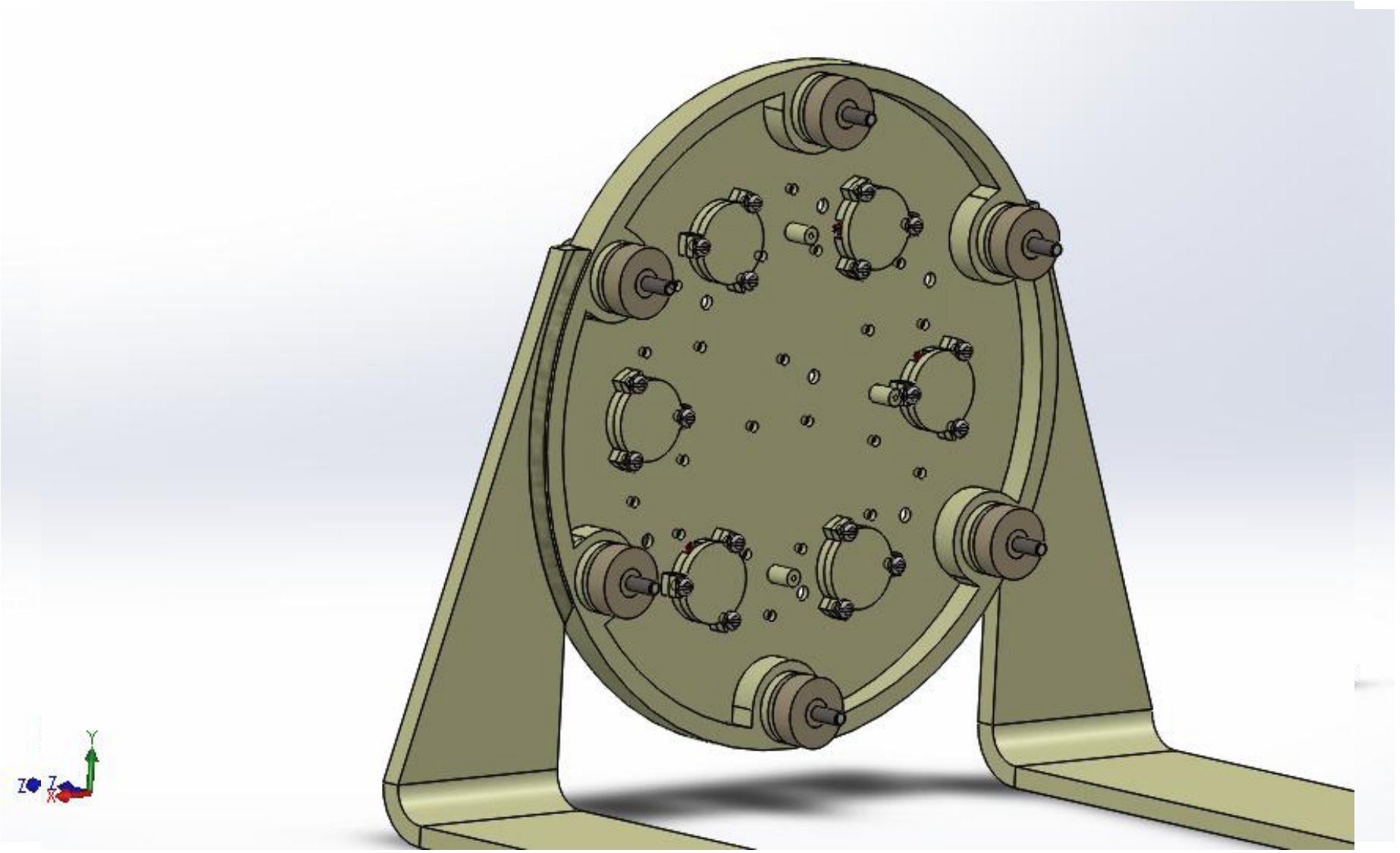
CCRs and their orientation.

Test article



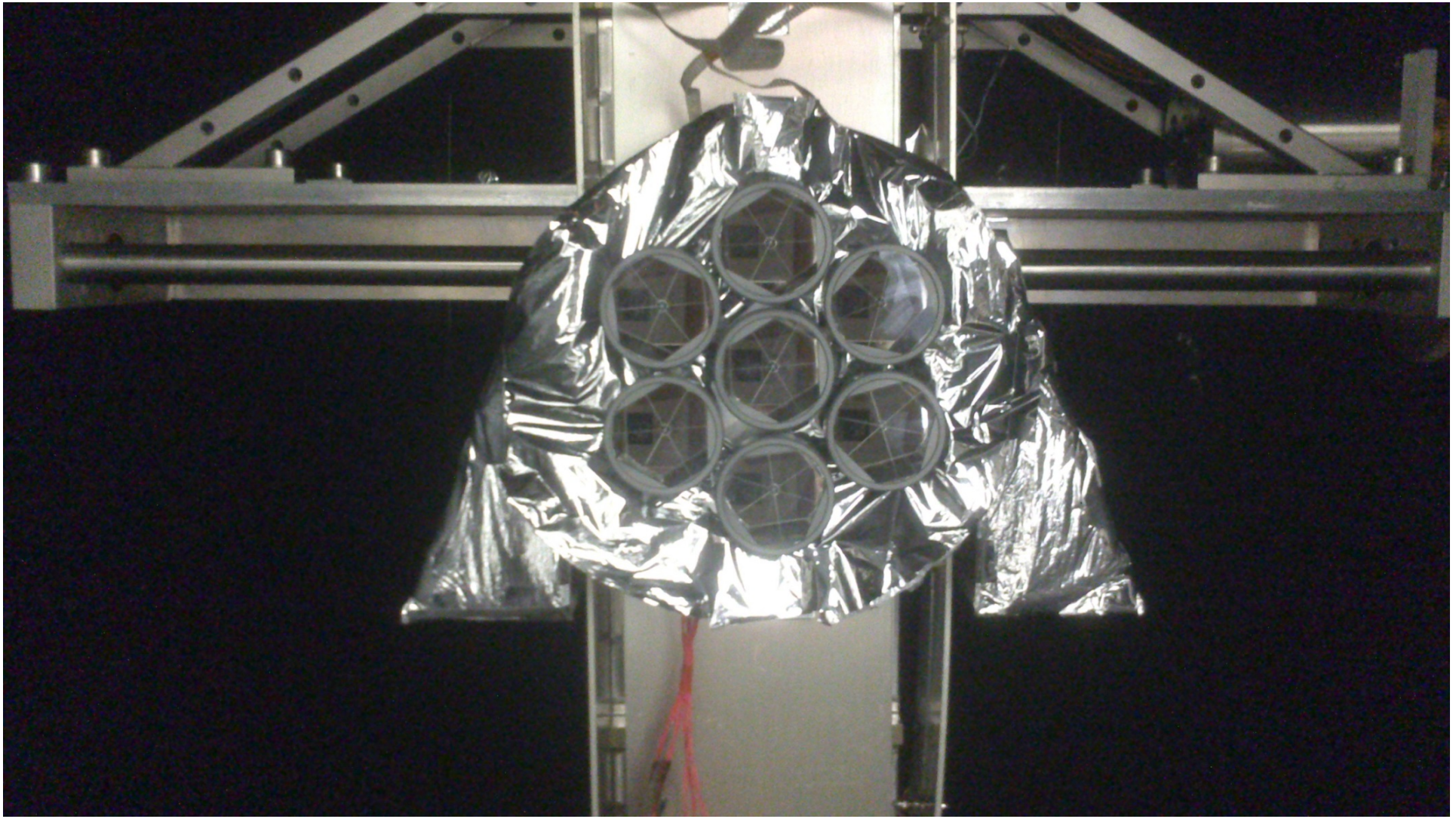
Base plate front CAD (extracted from LNF-GAL-DDR-002-0).

Test article



Base plate rear CAD (extracted from LNF-GAL-DDR-002-0).

Test article



Assembly set up and ready for testing.

Test conditions

The test accounts for 3 different conditions:

Isothermal test	**EM LRA in air at room temperature**
Default SCF-Test	**EM LRA in SCF thermal vacuum with 3 different starting T cases**
GCO test	**EM LRA in SCF thermal vacuum in GCO conditions**

Test success criteria

Review of success criteria as per:

LNF-GAL-TP-001-0 "Test Plan" and references therein.

1.1.4 REQUIREMENTS TO BE VERIFIED

ID	Requirement	Condition	Value [m^2] (*)
1	Single CCR Optical Cross Section intensity unit	Air Isothermal	$0.55x10^6/2.14\ x10^6$
2	Single CCR Optical Cross Section intensity unit	SCF-Test	$0.55x10^6/2.14\ x10^6$
3	Single CCR Optical Cross Section intensity unit	GCO	$0.55x10^6/2.14\ x10^6$

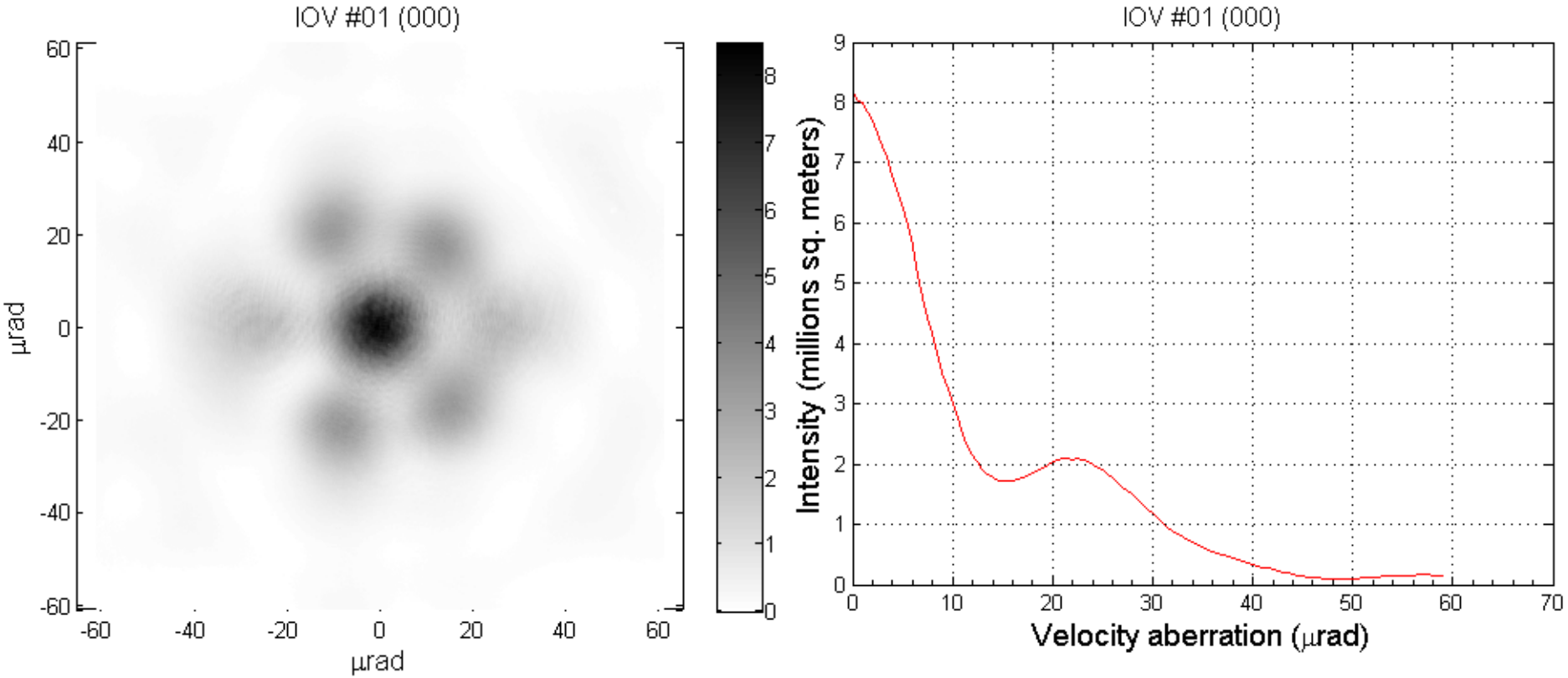
"A reference for the performance should be the Far Field Diffraction Pattern (FFDP) of a Galileo IOV retroreflector in its design specifications. In particular it should be verified the **average intensity** at the velocity aberration of a Galileo satellite, which is 24 µrad" [LNF-GAL-TP-001-0]. The aforementioned average intensity should be compatible with values stated in the table.

In air and isothermal test

- In Air and Isothermal conditions.
- Array fixed at movement system.
- Dedicated analyses to extract information.

In air and isothermal test

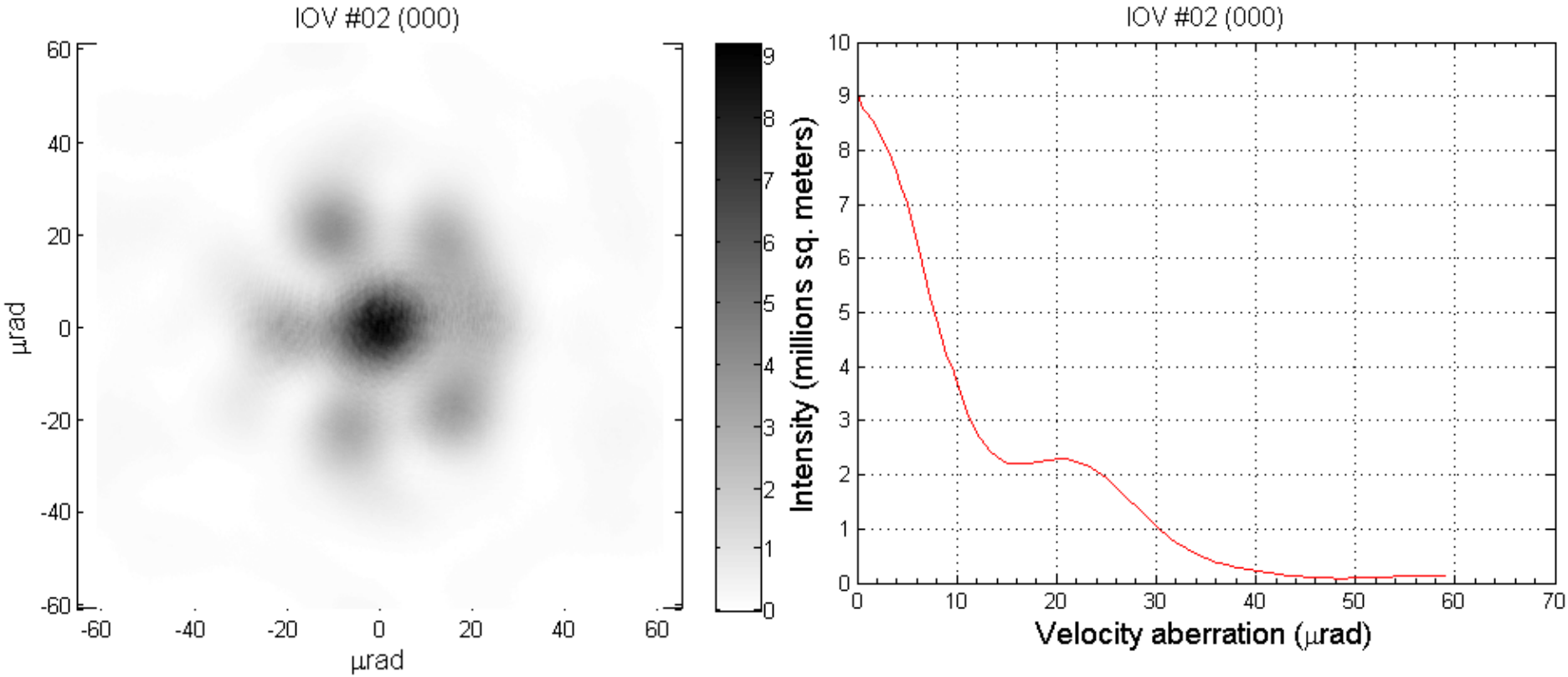
FFDP and the intensity versus VA plots



Left: FFDP; right: average intensity versus velocity aberration of CCR #1.

In air and isothermal test

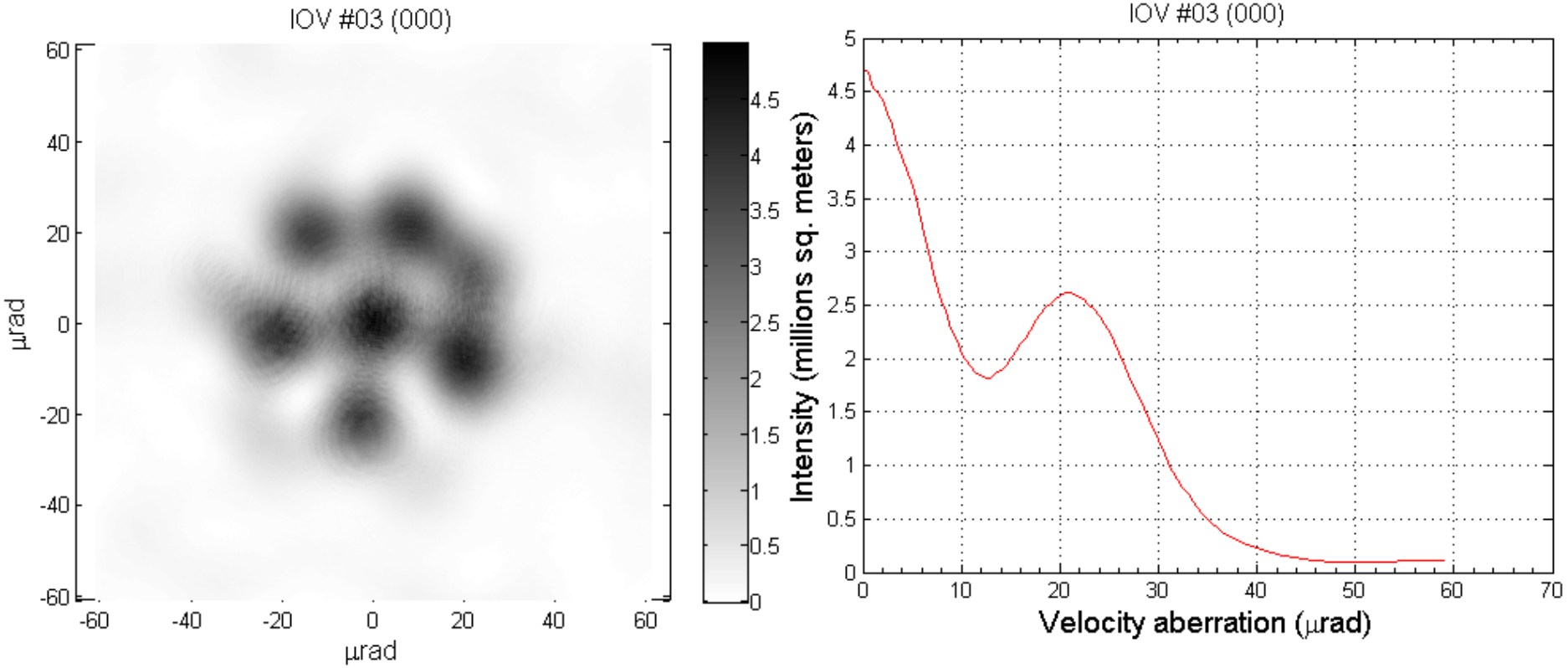
FFDP and the intensity versus VA plots



Left: FFDP; right: average intensity versus velocity aberration of CCR #2.

In air and isothermal test

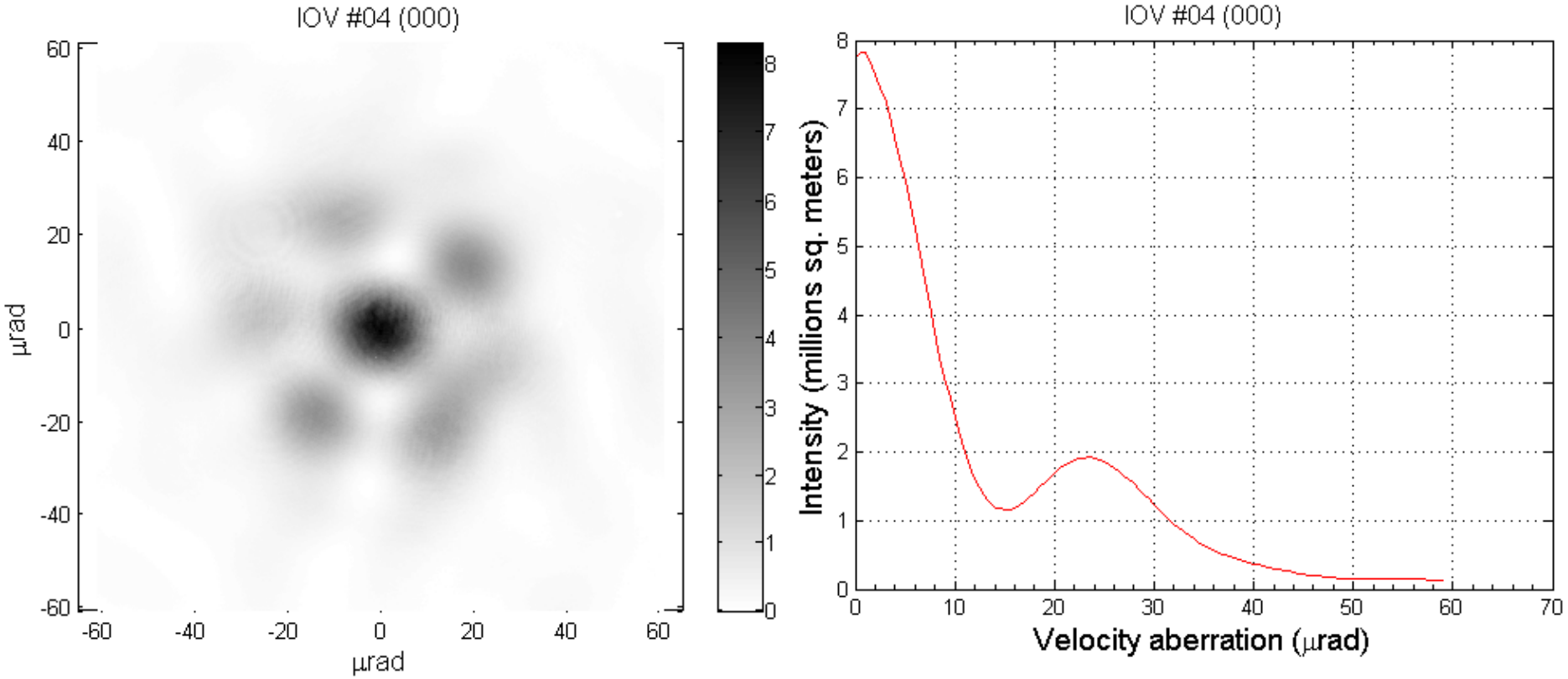
FFDP and the intensity versus VA plots



Left: FFDP; right: average intensity versus velocity aberration of CCR #3.

In air and isothermal test

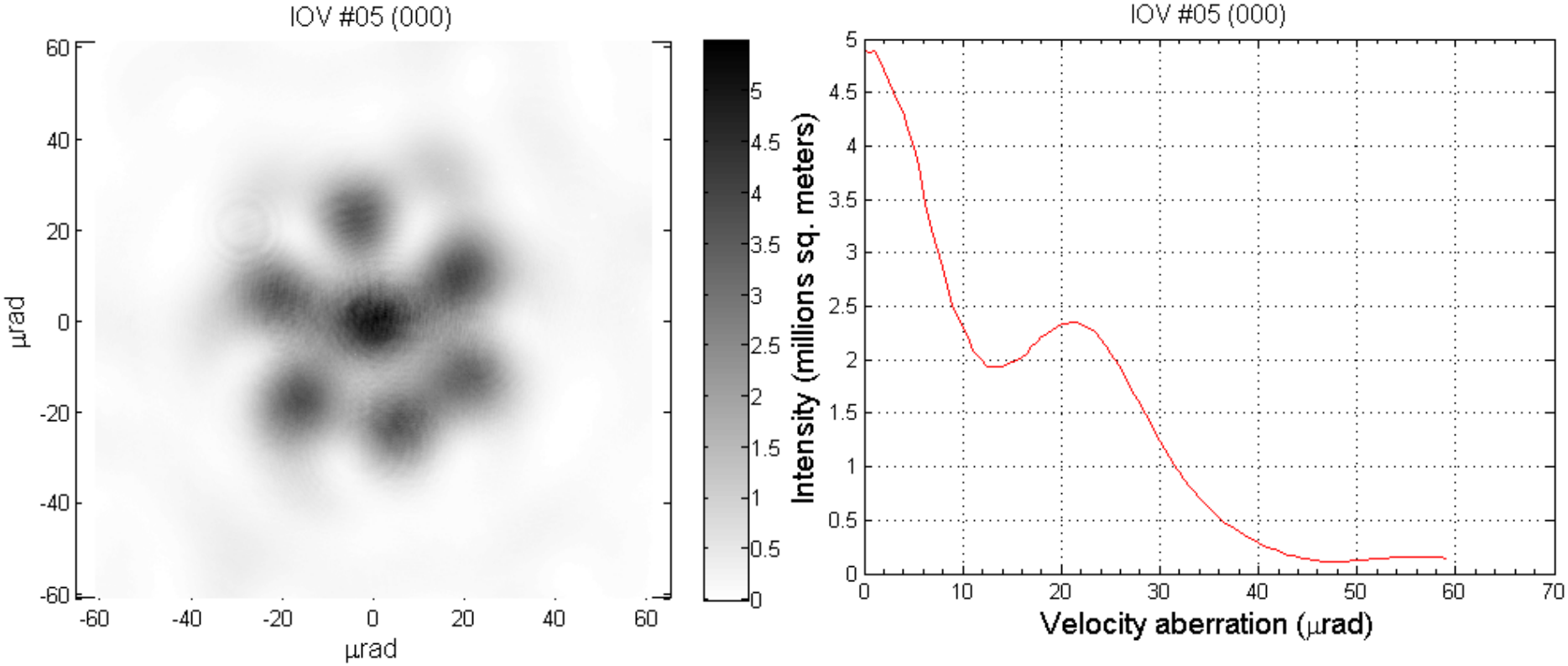
FFDP and the intensity versus VA plots



Left: FFDP; right: average intensity versus velocity aberration of CCR #4.

In air and isothermal test

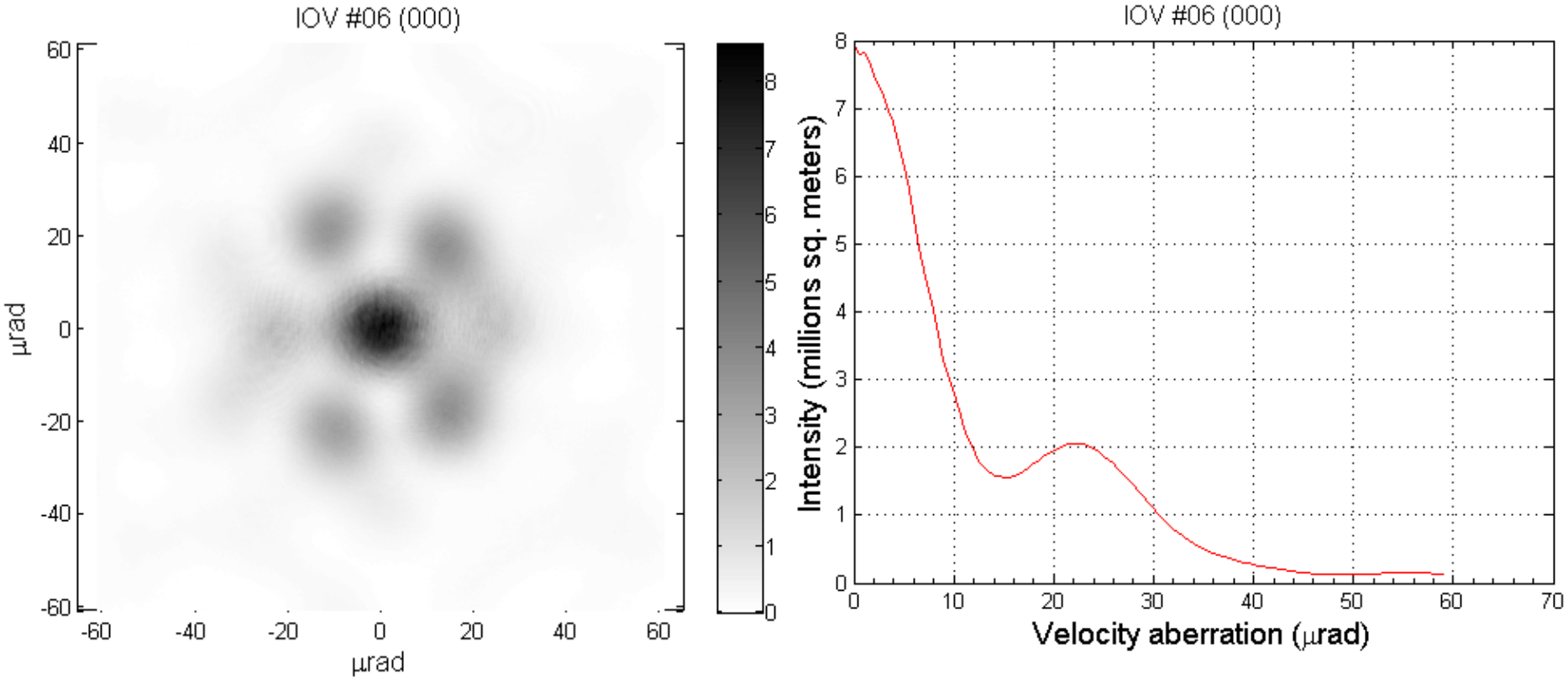
FFDP and the intensity versus VA plots



Left: FFDP; right: average intensity versus velocity aberration of CCR #5.

In air and isothermal test

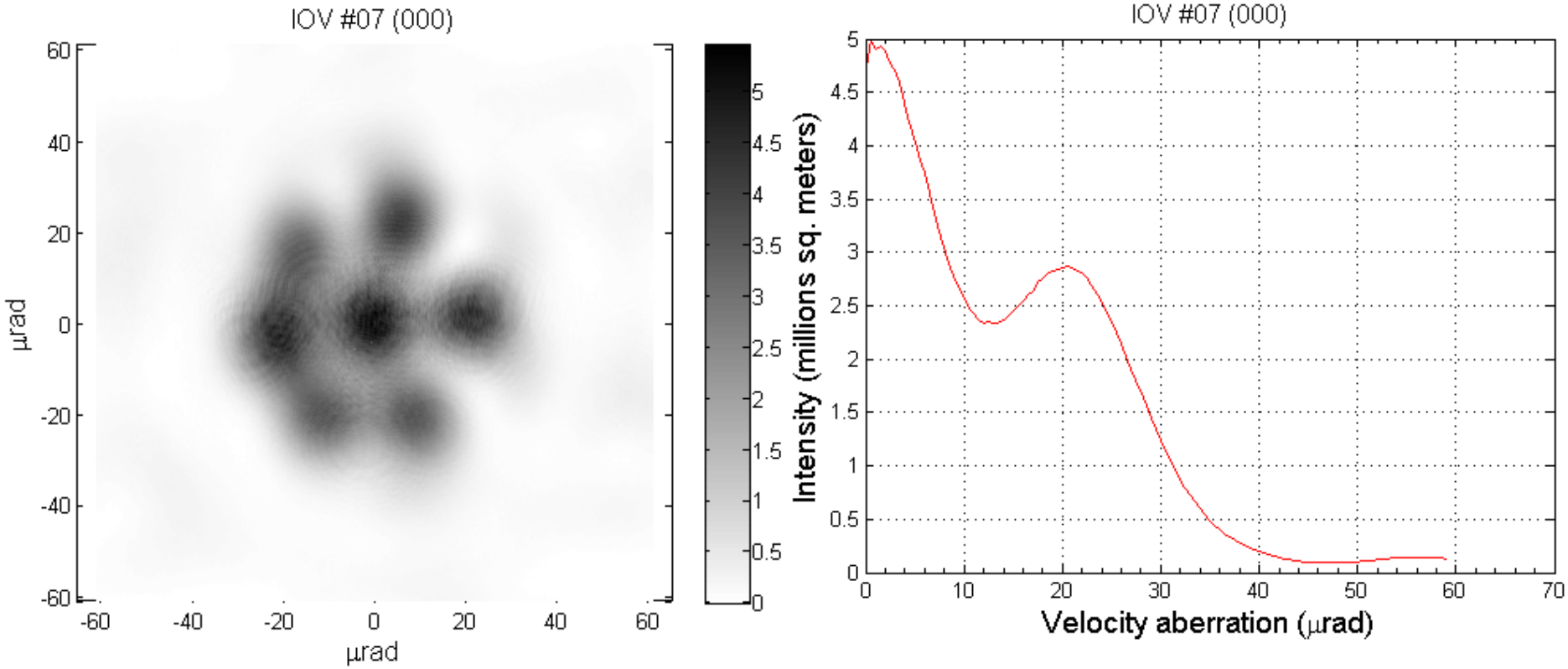
FFDP and the intensity versus VA plots



Left: FFDP; right: average intensity versus velocity aberration of CCR #6.

In air and isothermal test

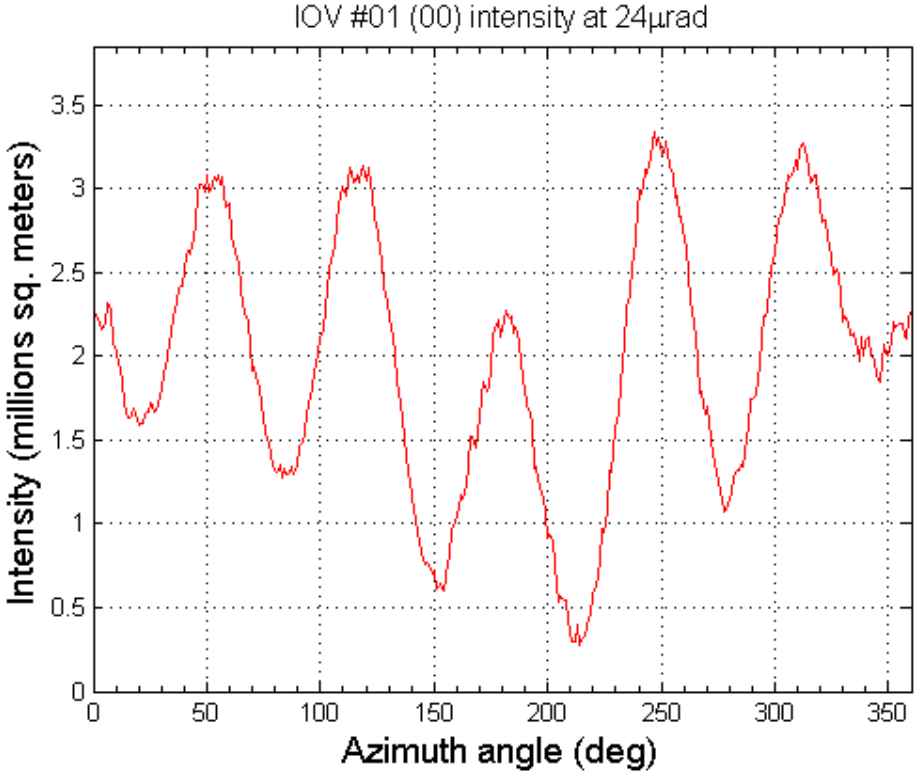
FFDP and the intensity versus VA plots

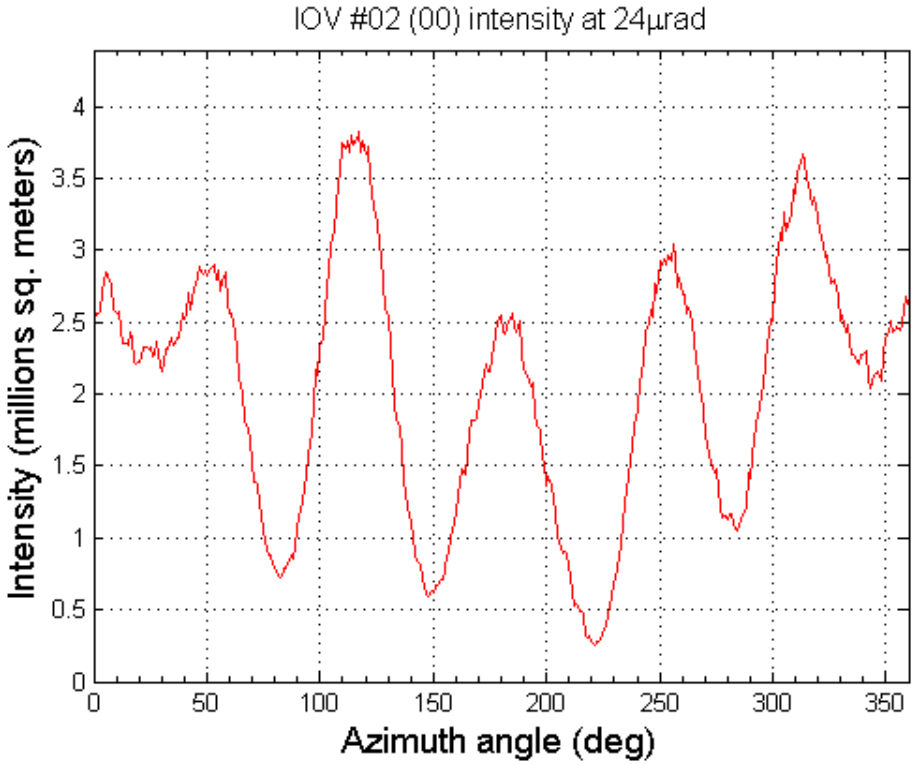


Left: FFDP; right: average intensity versus velocity aberration of CCR #7.

In air and isothermal test

Intensity at the VA of Galileo-IOV (24 µrad)

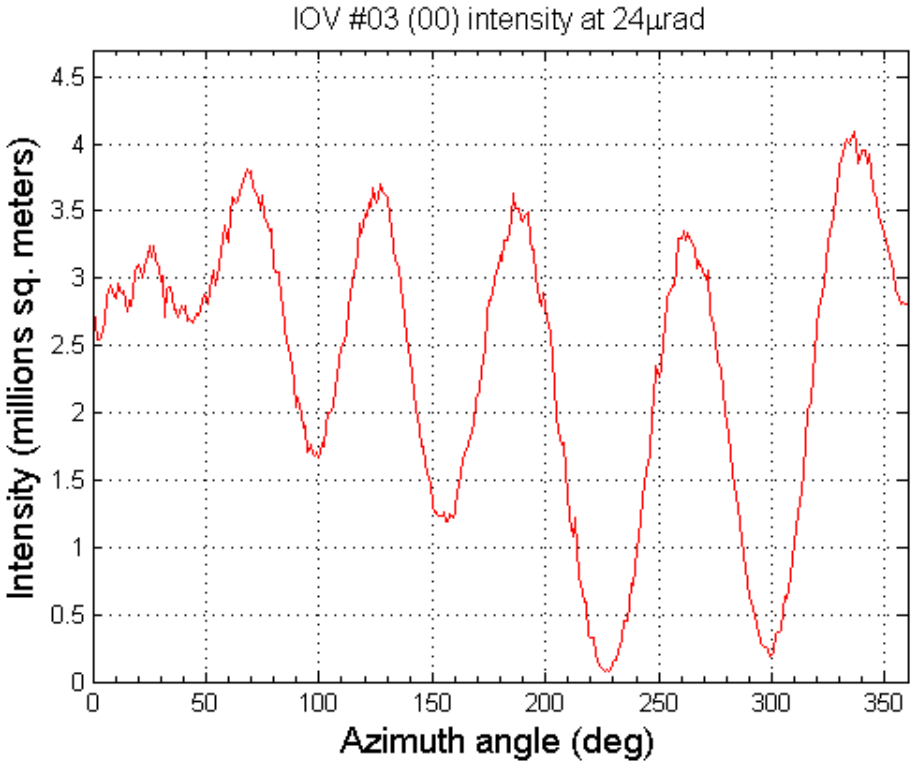


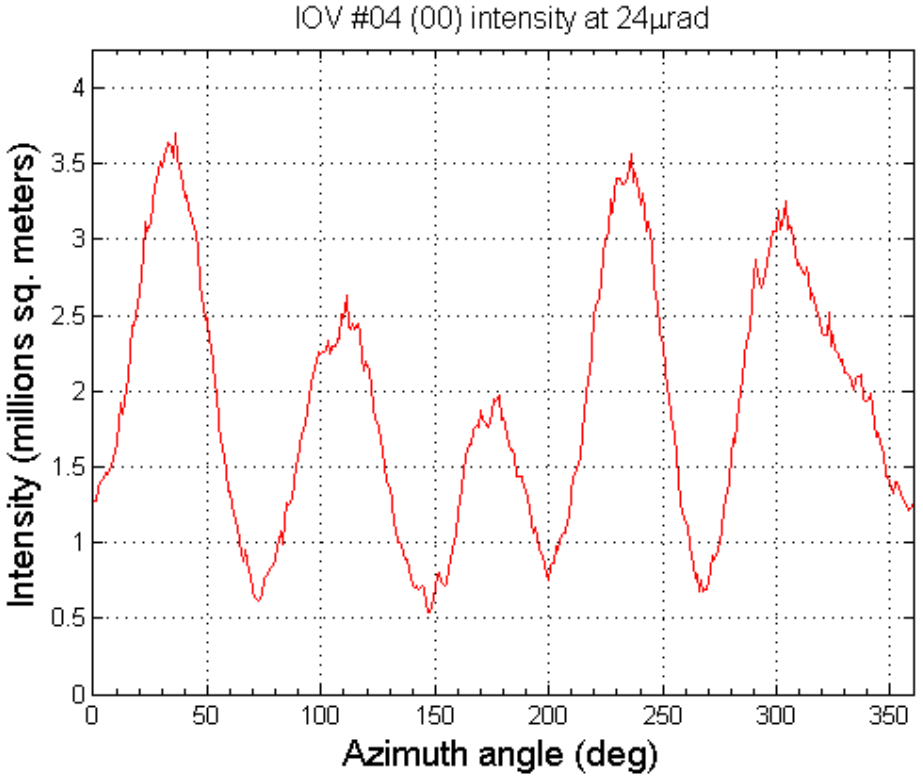


Left: CCR #1; right: CCR #2.

In air and isothermal test

Intensity at the VA of Galileo-IOV (24 µrad)

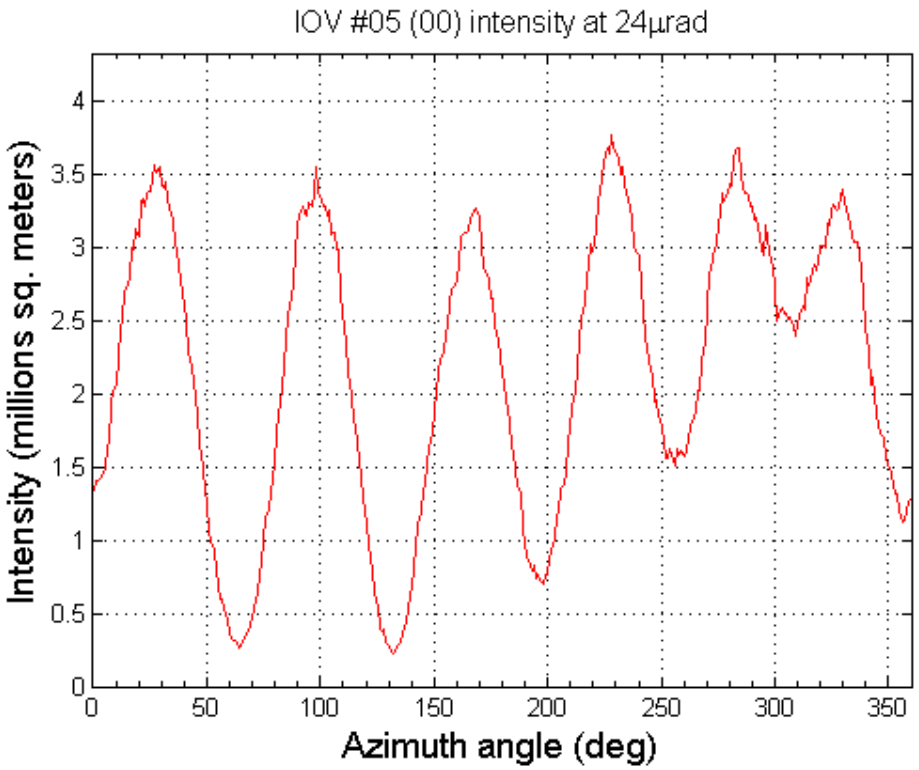


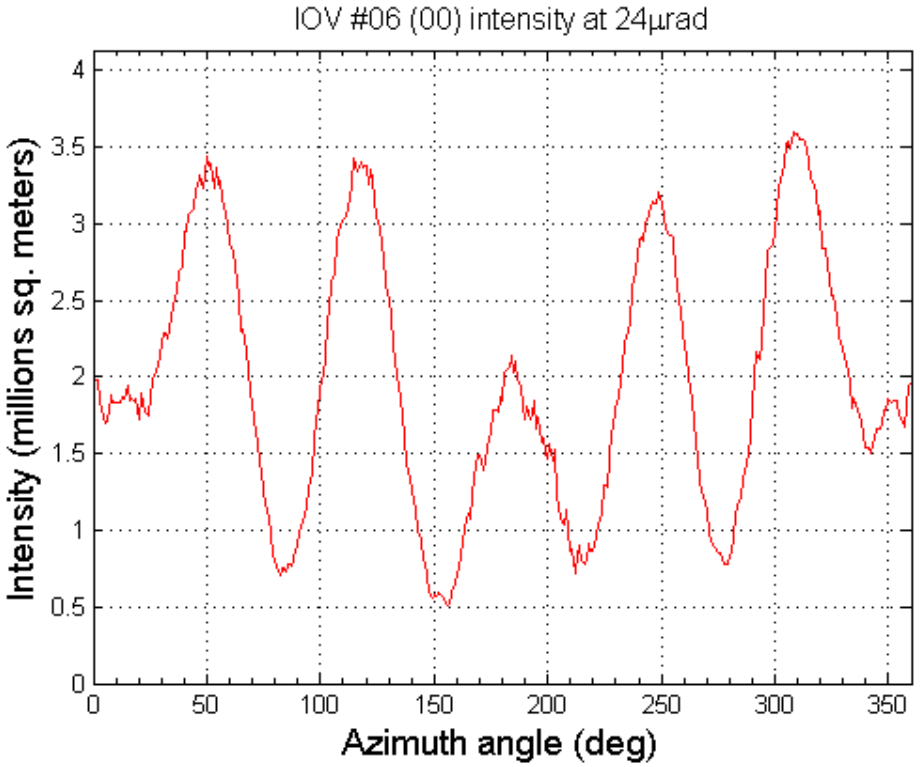


Left: CCR #3; right: CCR #4.

In air and isothermal test

Intensity at the VA of Galileo-IOV (24 µrad)

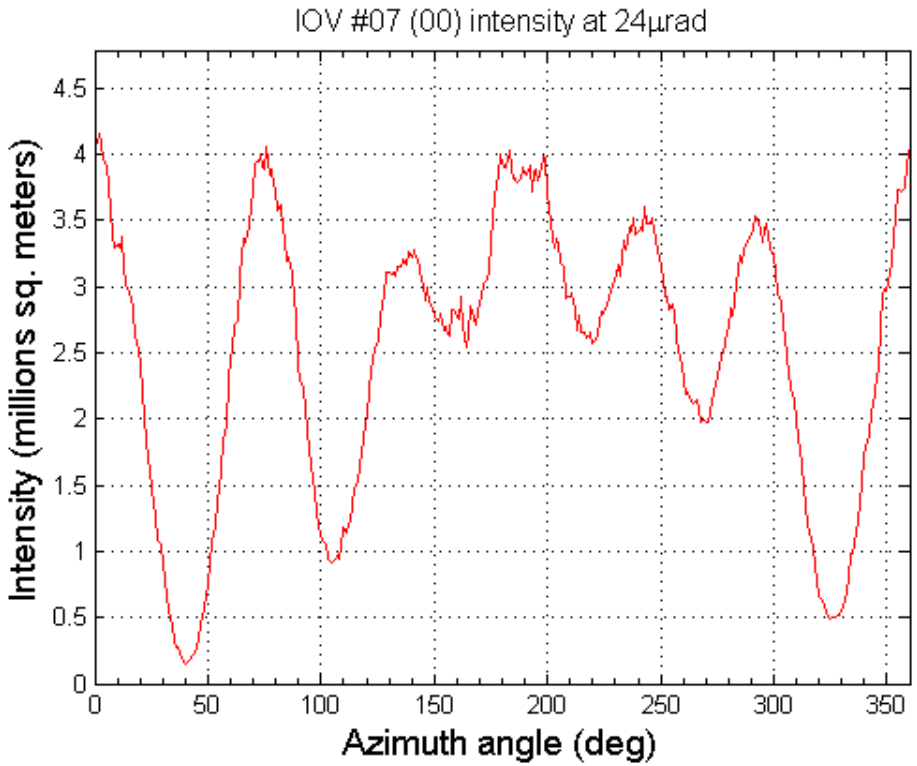




Left: CCR #5; right: CCR #6.

In air and isothermal test

Intensity at the VA of Galileo-IOV (24 µrad)



CCR #7.

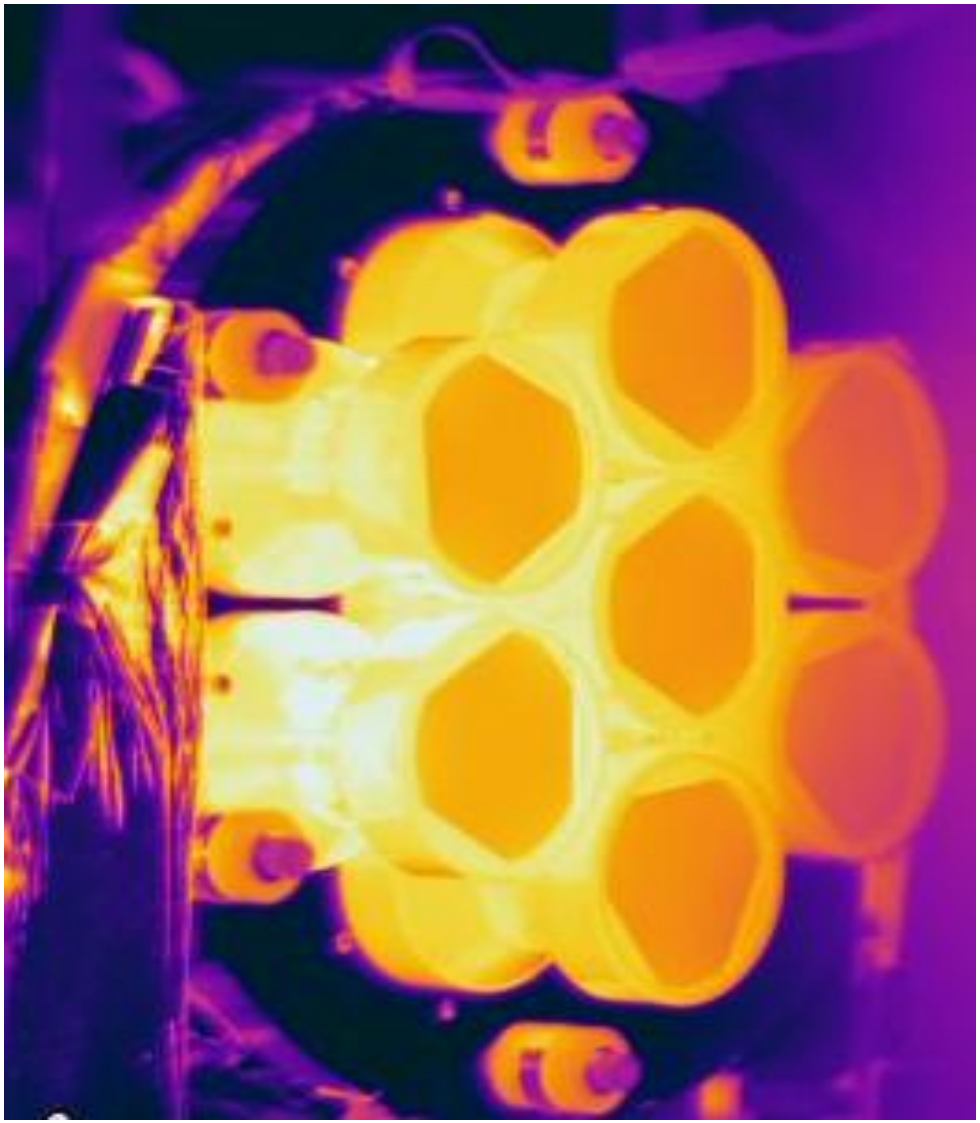
SCF-Test

- CCR 1 and CCR7.
- Thermal relaxation time of retroreflector (τ_{CCR}).
- Optical response.
- Array fixed at movement system.
- Dedicated analyses to extract information.

SCF-Test - Thermal analysis

- 3 different SCF-Test with:

  T_{PLATE}=-40°C - T_{PLATE}=0°C - T_{PLATE}=+45°C.
- For every test: IR data at least for 30m SUN ON phase + 30m SUN OFF phase.
- 1IR/30s both for SUN ON and SUN OFF.
- IR Pictures analysis with dedicated SW in order to obtain the front face CCR temperature vs time.
- The data are then processed with an IDL SW in order to obtain the characteristic thermal relaxation time τ_{ccr}.
- In addition we acquired the temperature variation of the seven temperature probes (PT100) positioned on the rear of each CCR mounting of the array.



SCF-Test - Thermal analysis

We computed both τ_{CCR1} and τ_{CCR7} using data from CCR1's SCF-Test.

The overall results (average of τ_{CCR} mean for all T_{plate} temperatures) give:

$$\tau_{CCR} = (600 \pm 50)\ s$$

SCF-Test - Optical analysis

There are hundreds of plots to show…

CCR 1 @ T = + 45 ˚ C

FFDP and the intensity versus VA plots

Intensity at the VA of GALILEO-IOV (24 µrad)

CCR 1 @ T = 0 ˚ C

FFDP and the intensity versus VA plots

Intensity at the VA of GALILEO-IOV (24 µrad)

CCR 1 @ T = - 45 ˚ C

FFDP and the intensity versus VA plots

Intensity at the VA of GALILEO-IOV (24 µrad)

CCR 7 @ T = + 45 ˚ C

FFDP and the intensity versus VA plots

Intensity at the VA of GALILEO-IOV (24 µrad)

CCR 7 @ T = 0 ˚ C

FFDP and the intensity versus VA plots

Intensity at the VA of GALILEO-IOV (24 µrad)

CCR 7 @ T = - 45 ˚ C

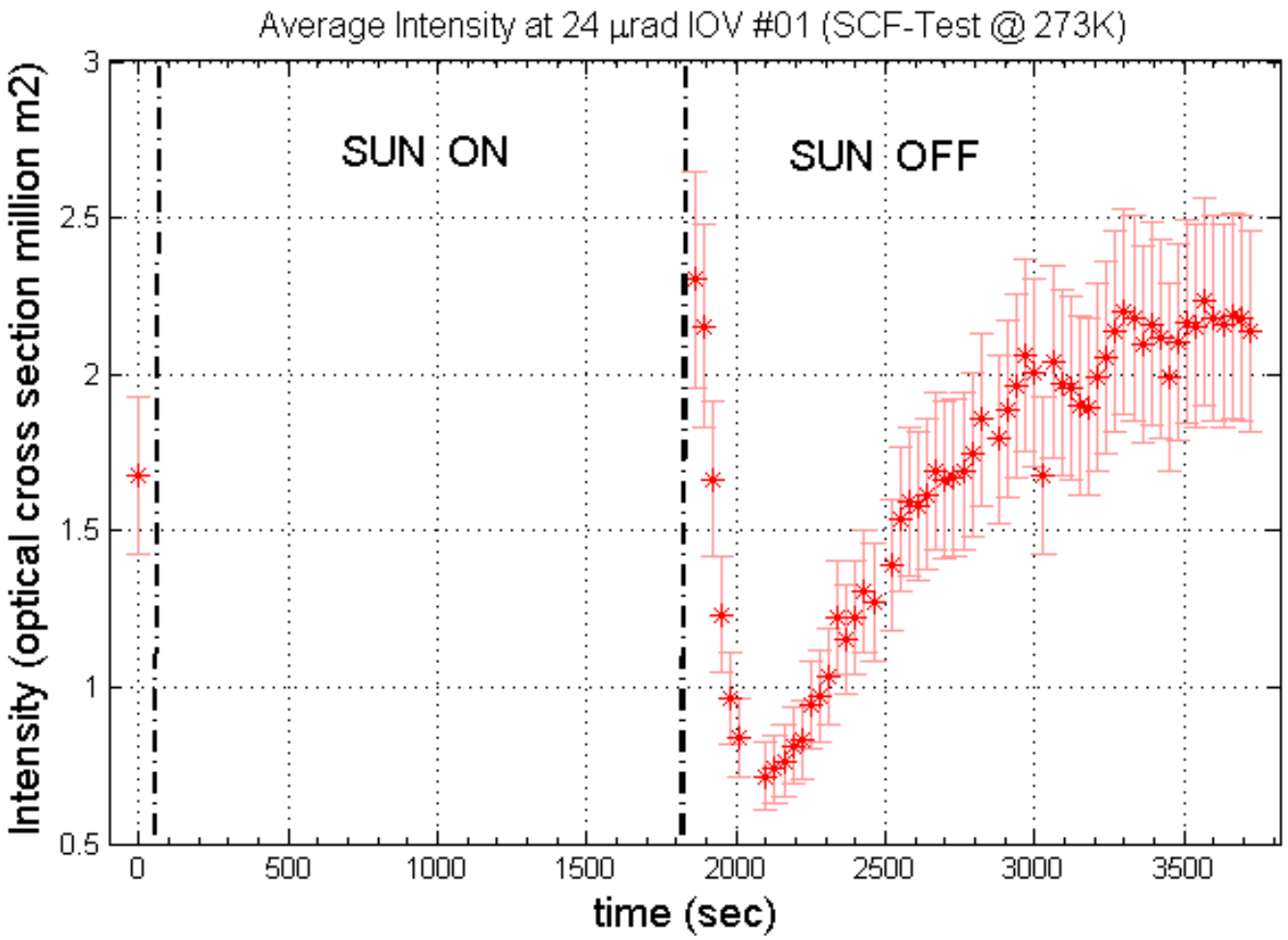
FFDP and the intensity versus VA plots

Intensity at the VA of GALILEO-IOV (24 µrad)

SCF-Test - Optical analysis

CCR 1 @ T = 0 ˚ C

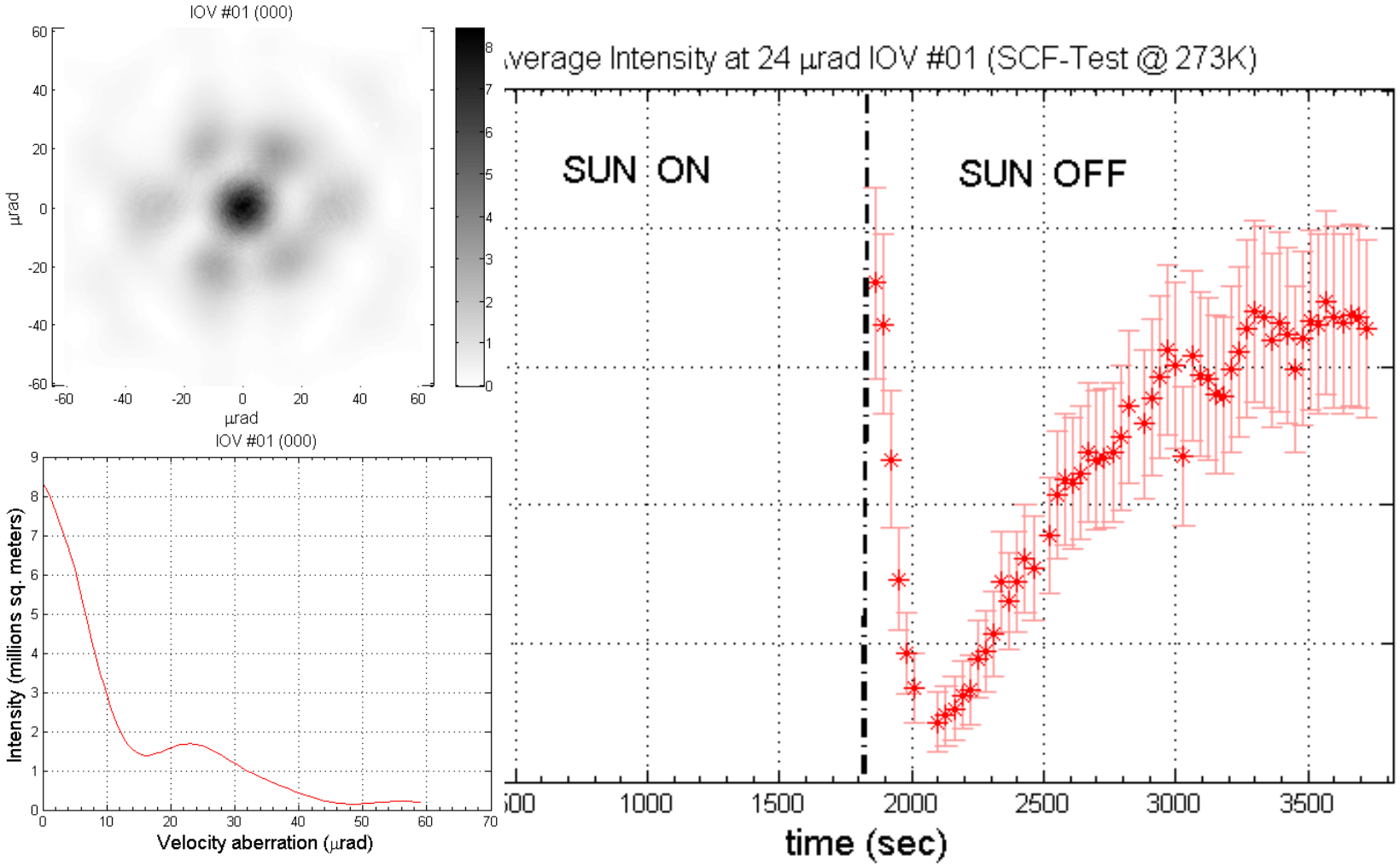
24 µrad intensity variation during SCF-Test



SCF-Test - Optical analysis

CCR 1 @ T = 0 ˚ C

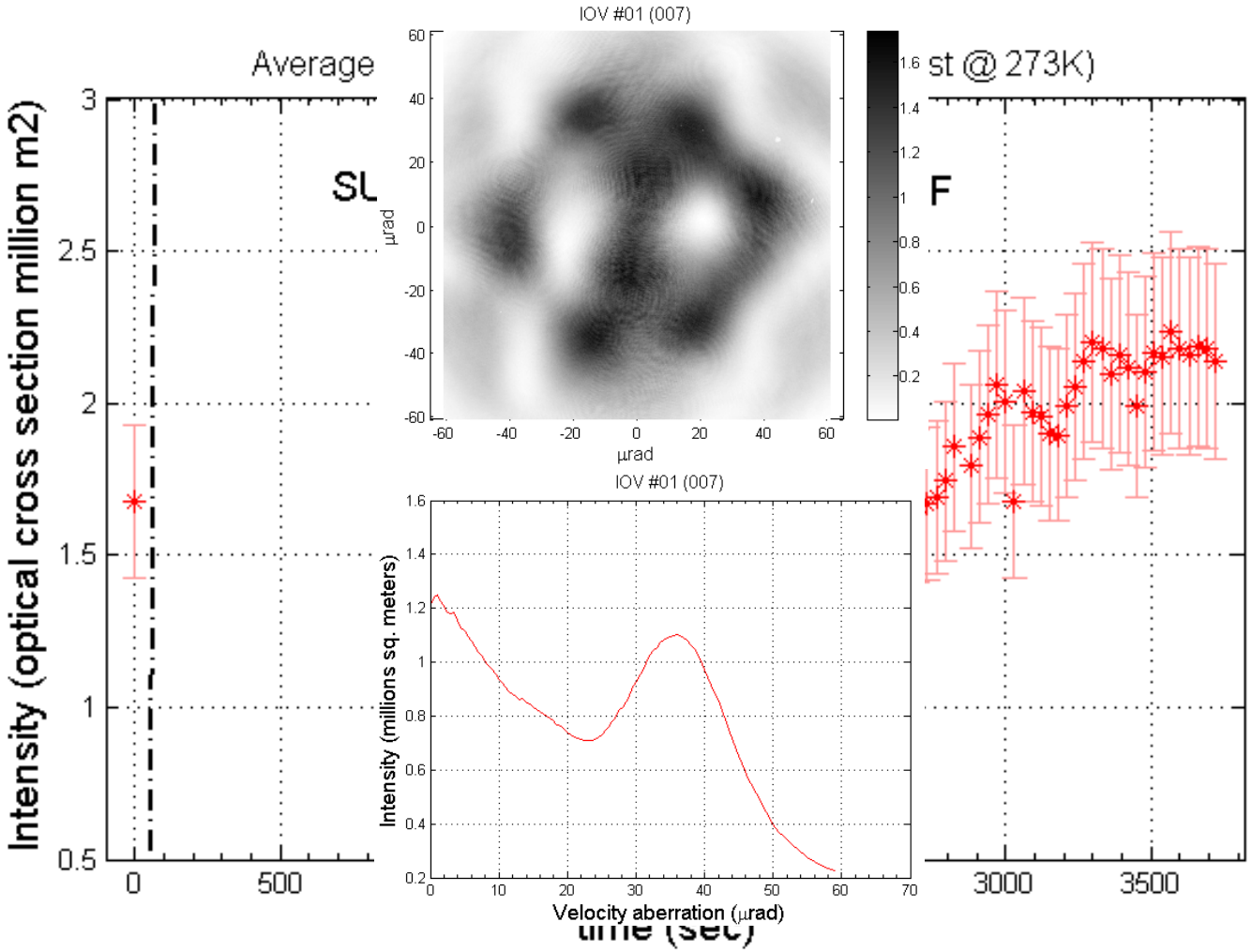
24 µrad intensity variation during SCF-Test



SCF-Test - Optical analysis

CCR 1 @ T = 0 ˚ C

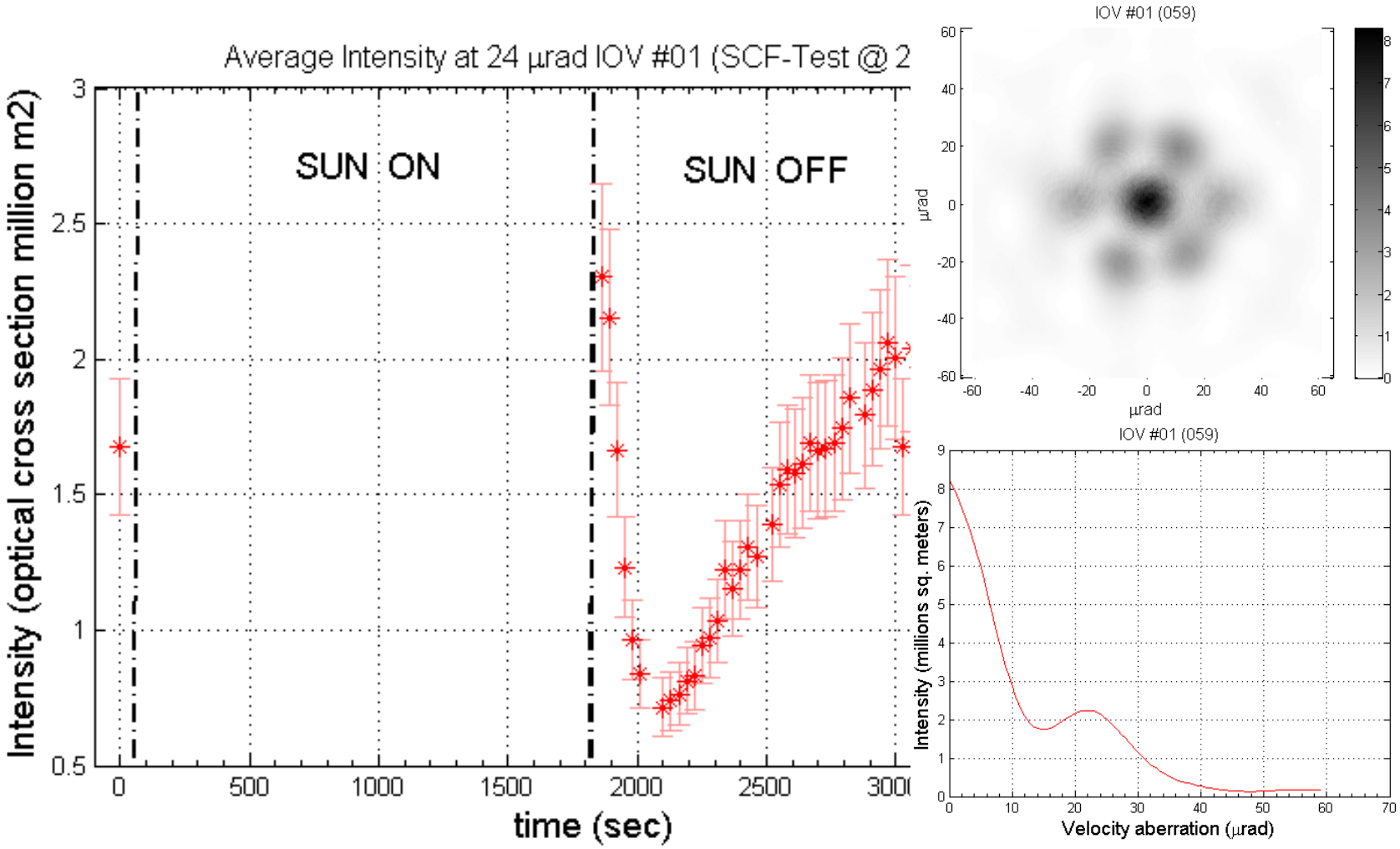
24 µrad intensity variation during SCF-Test



SCF-Test - Optical analysis

CCR 1 @ T = 0 ˚ C

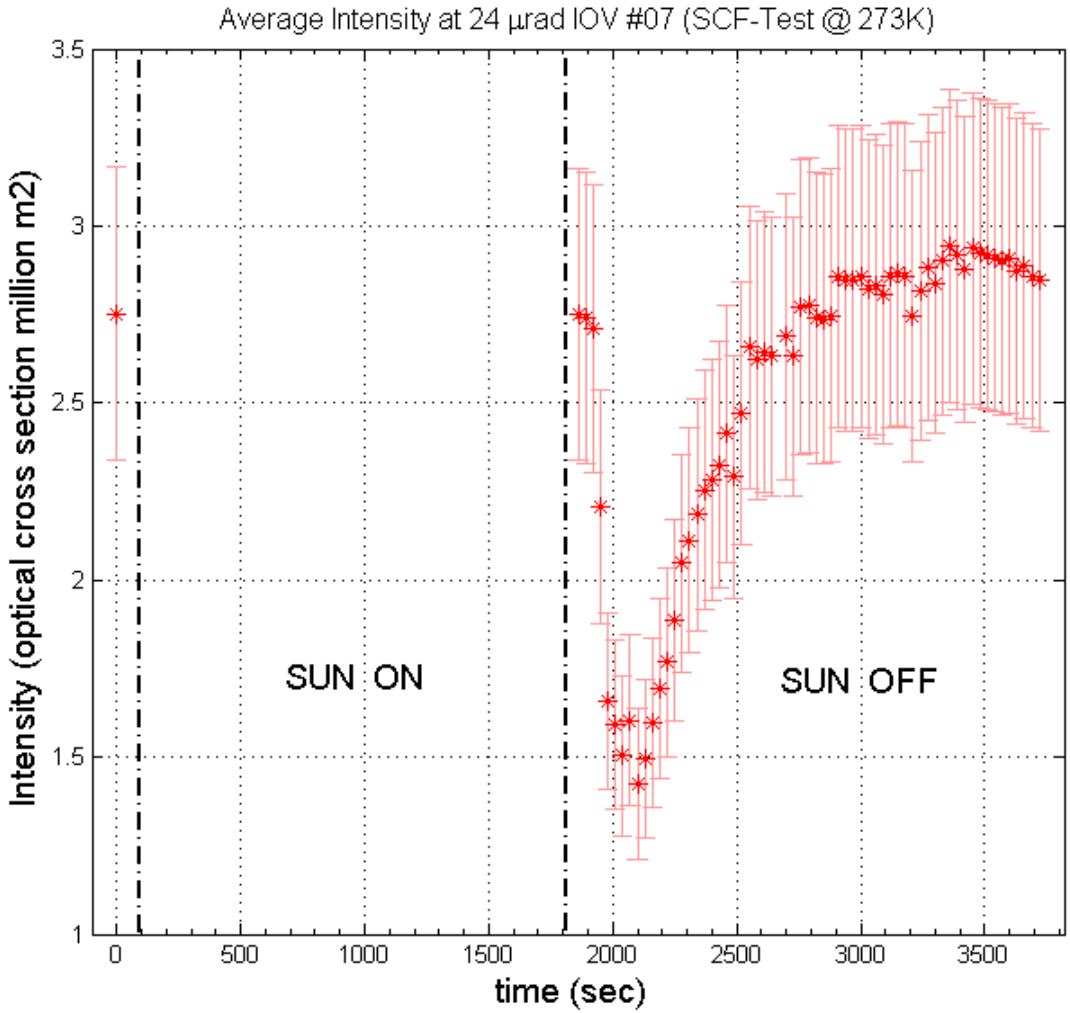
24 µrad intensity variation during SCF-Test



SCF-Test - Optical analysis

CCR 7 @ T = 0 ˚ C

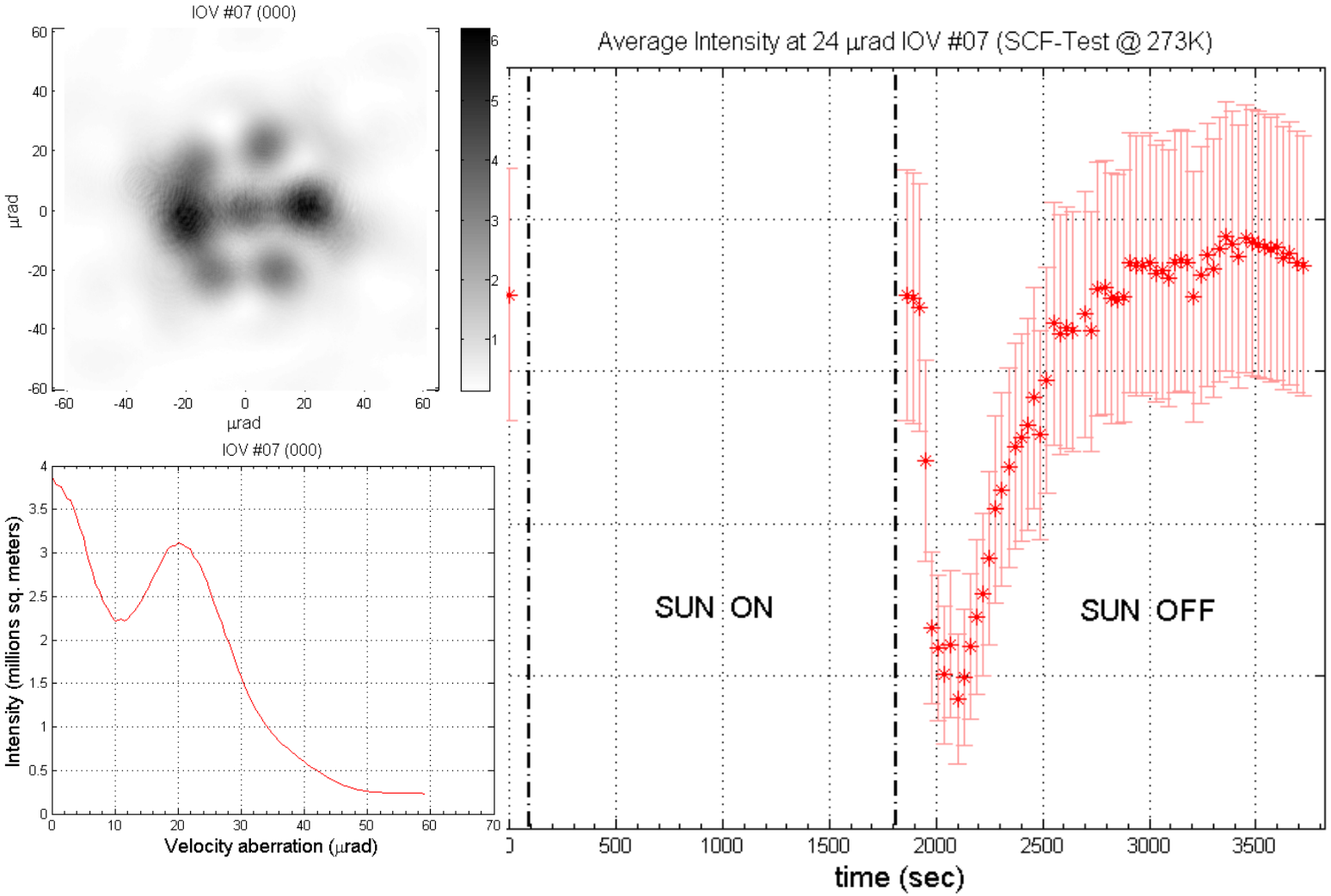
24 µrad intensity variation during SCF-Test



SCF-Test - Optical analysis

CCR 7 @ T = 0 ˚ C

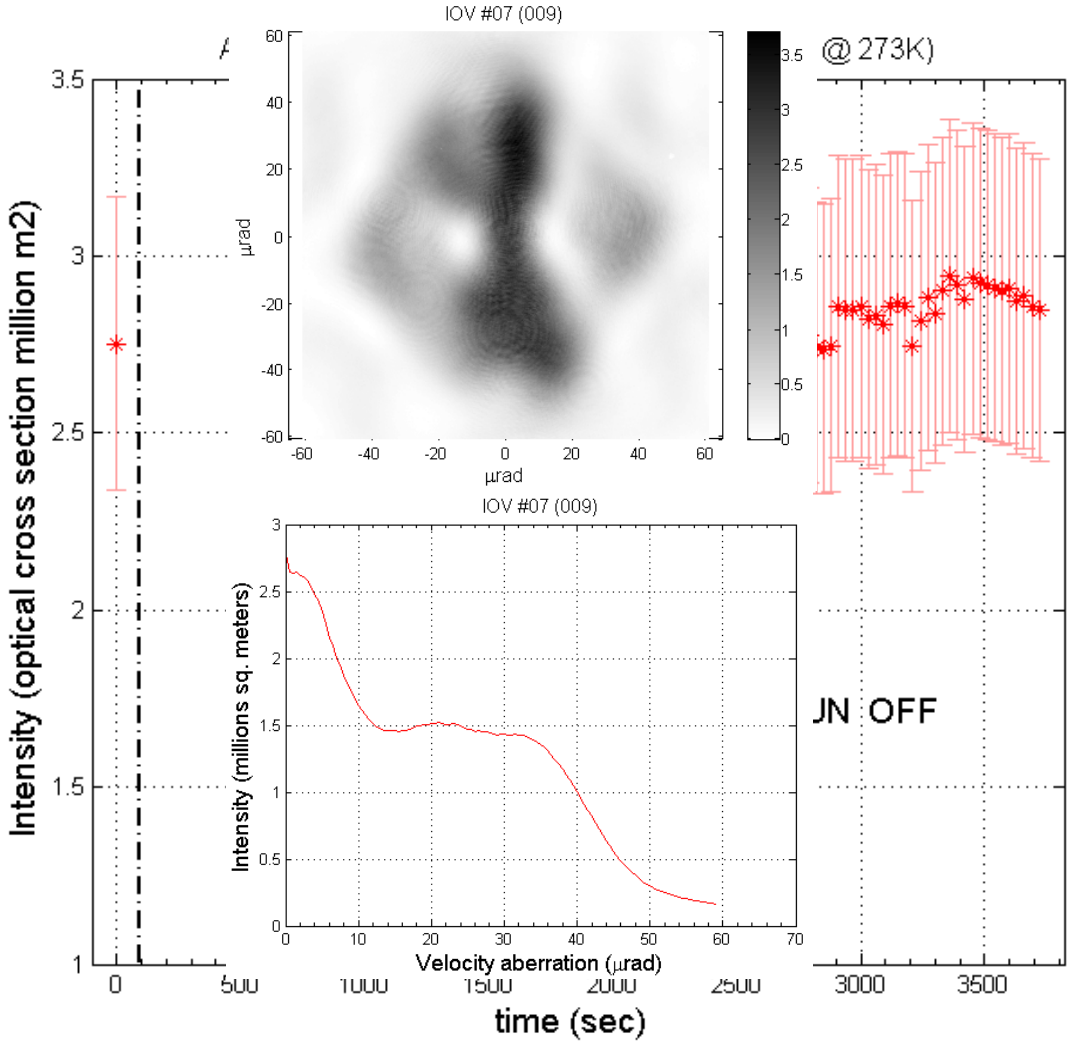
24 µrad intensity variation during SCF-Test



SCF-Test - Optical analysis

CCR 7 @ T = 0 ˚ C

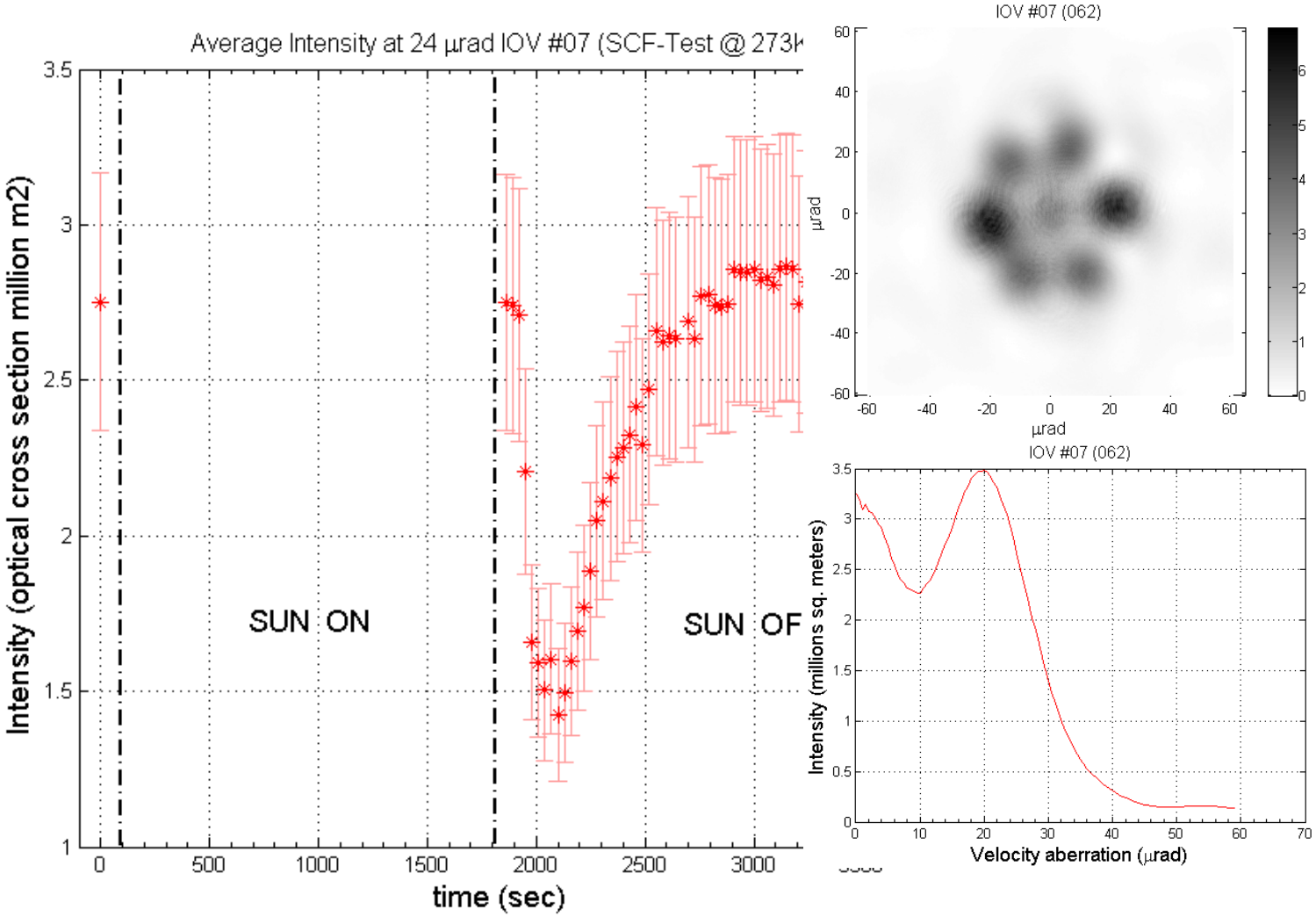
24 µrad intensity variation during SCF-Test



SCF-Test - Optical analysis

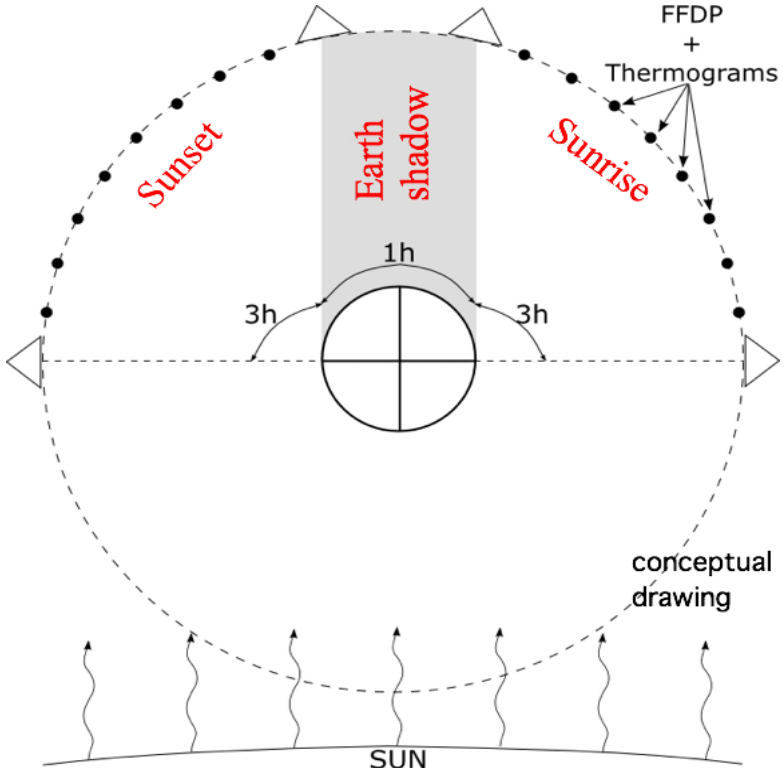
CCR 7 @ T = 0 ˚ C

24 µrad intensity variation during SCF-Test



Orbit Test

- Initial condition: payload to cold shield (-90°) and plate at steady state at -45°C.
- Sunrise (3h): 1FFDP+1IR every 20m.
- Earth Shadow (1h): 1IR every 30s, 1FFDP/min for first 15m, 1FFDP/2m for next 15m, 1FFDP/ 30m for last 30m.
- Sunset(3h): 1FFDP+1IR every 20m.



2 orbits:
- **CCR1**
- **CCR7**

Optical analysis of CCR1 orbit

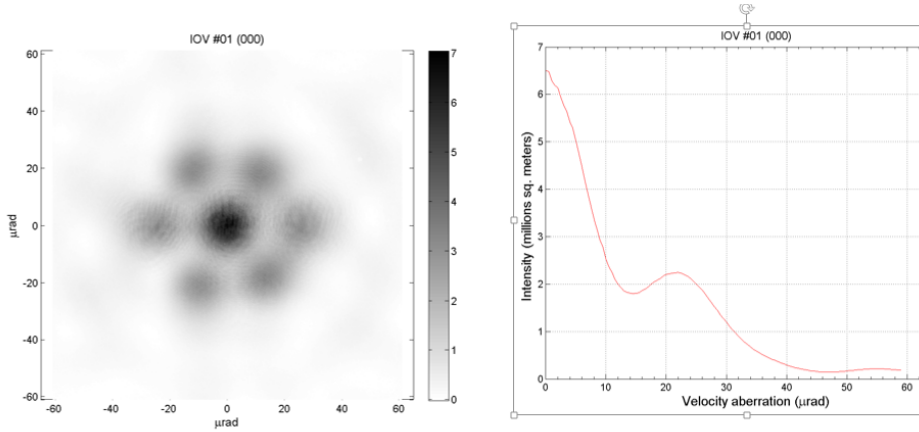


Figure 458 - Left: FFDP; right: average intensity versus velocity aberration of CCR #1 (000).

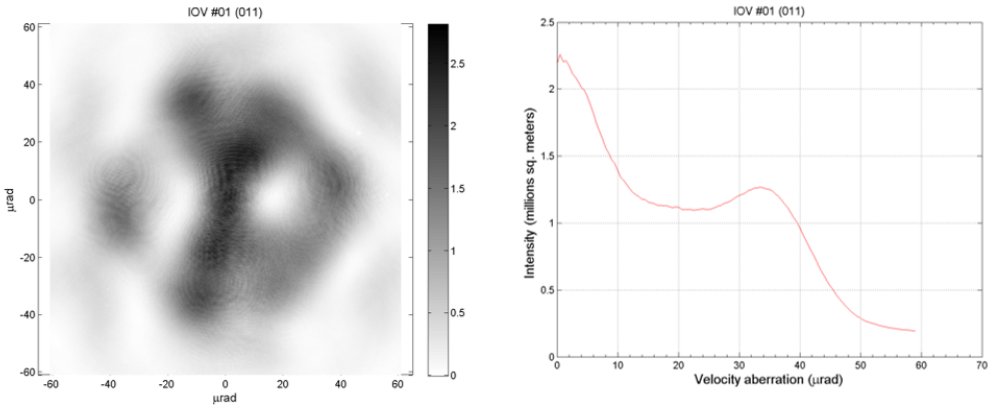


Figure 469 - Left: FFDP; right: average intensity versus velocity aberration of CCR #1 (011).

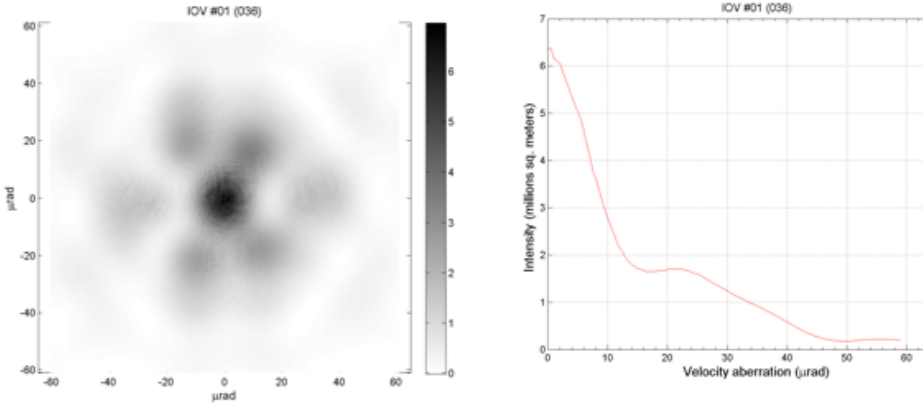


Figure 494 - Left: FFDP; right: average intensity versus velocity aberration of CCR #1 (036).

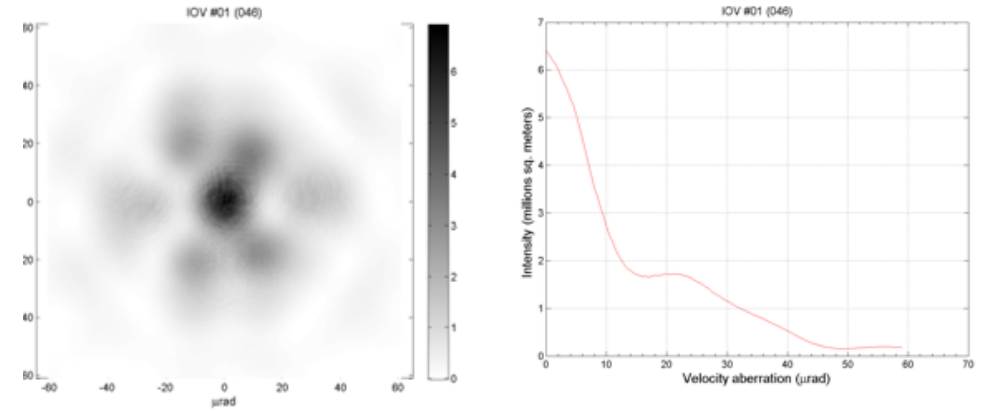
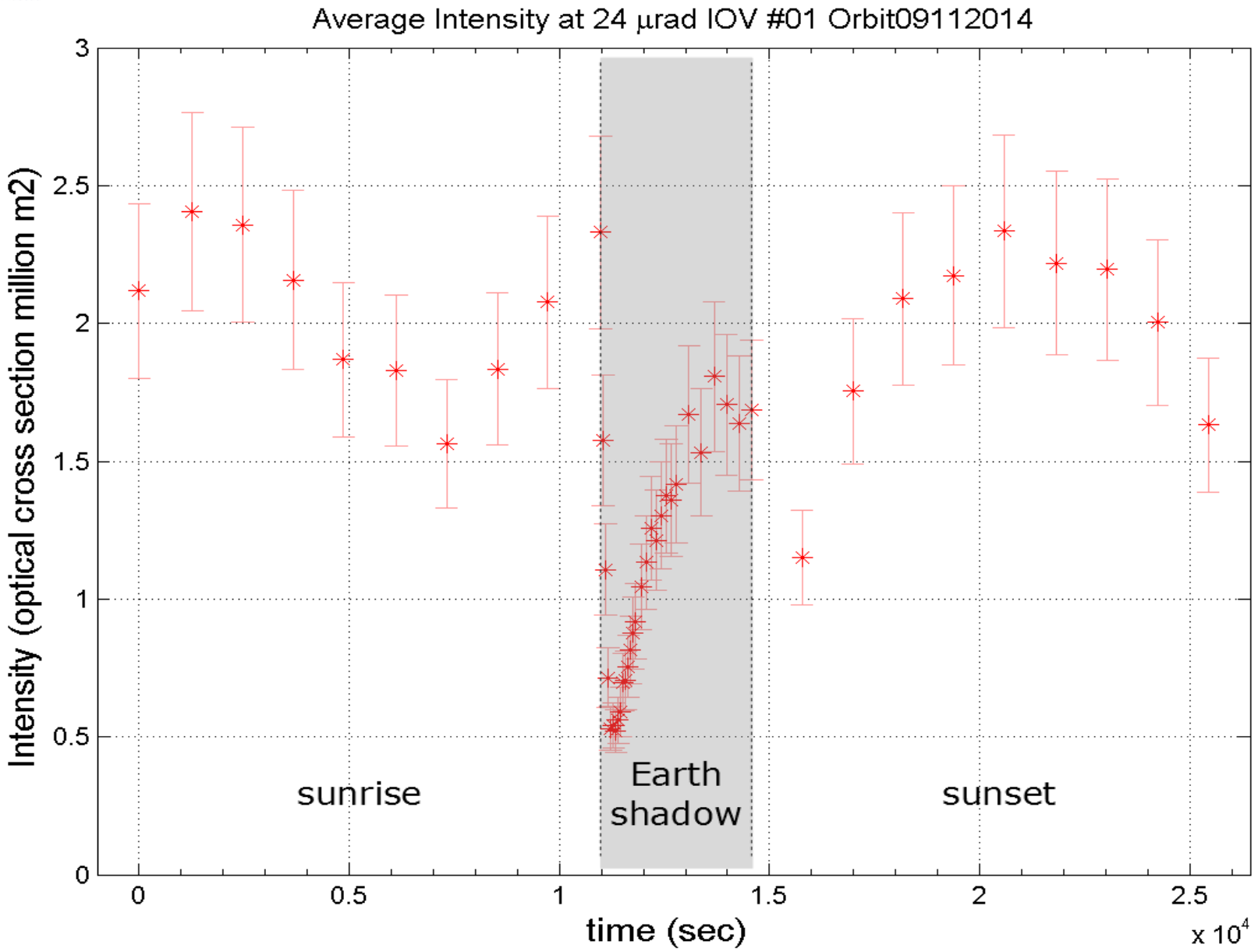
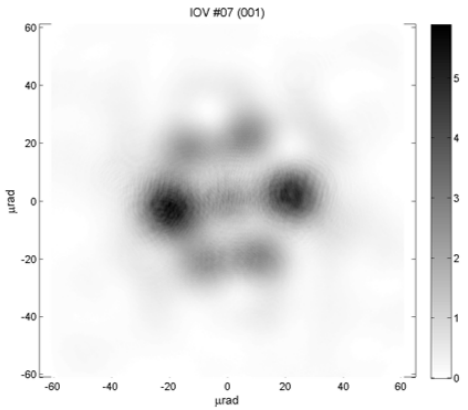


Figure 504 - Left: FFDP; right: average intensity versus velocity aberration of CCR #1 (046).

Optical analysis of CCR1 orbit



Optical analysis of CCR7 orbit



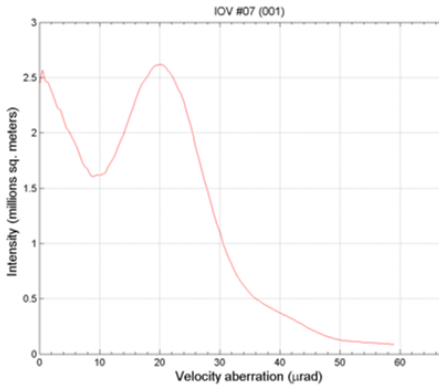
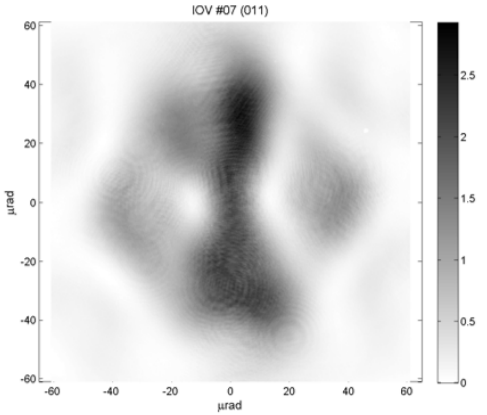


Figure 531 - Left: FFDP; right: average intensity versus velocity aberration of CCR #7 (001).



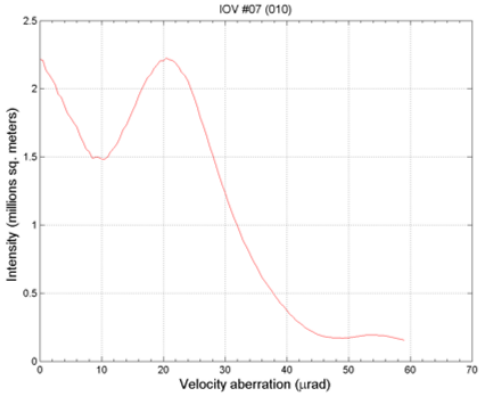
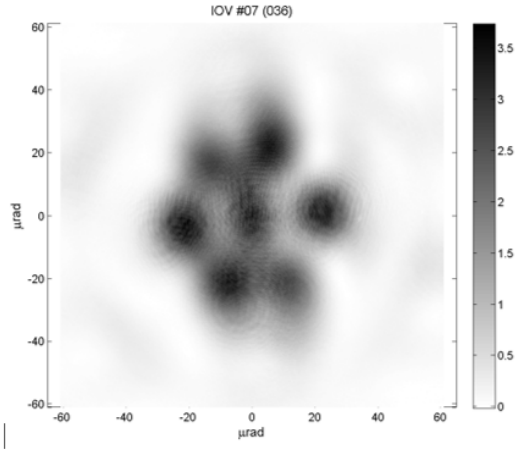
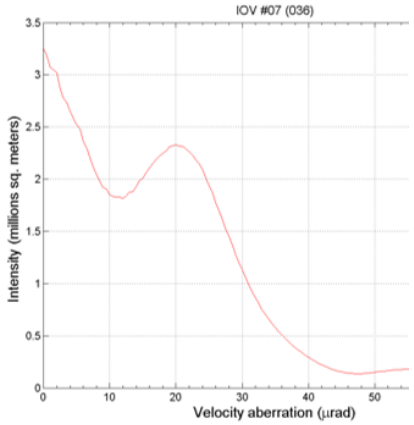
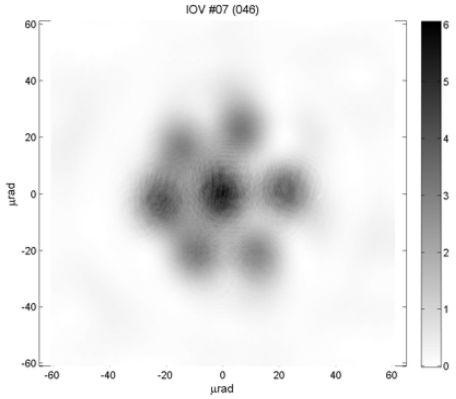


Figure 541 - Left: FFDP; right: average intensity versus velocity aberration of CCR #7 (011).







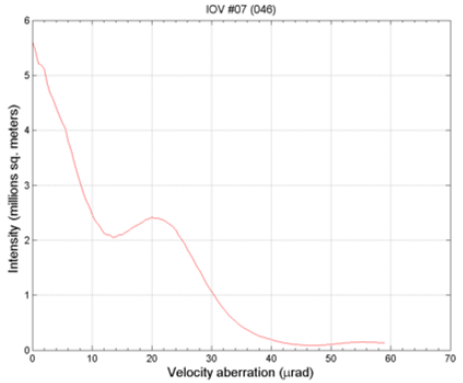
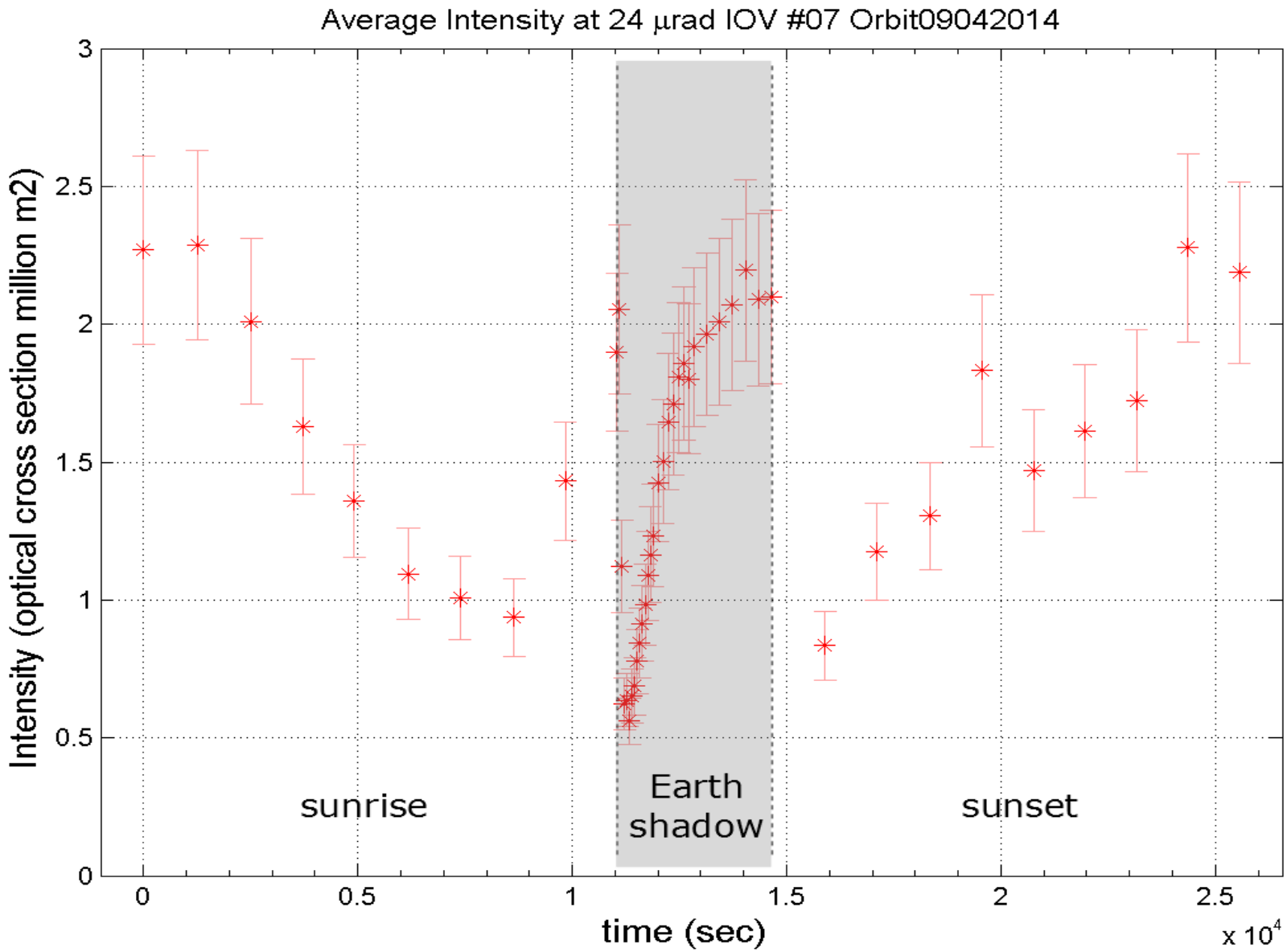


Figure 576 - Left: FFDP; right: average intensity versus velocity aberration of CCR #7 (046).

Optical analysis of CCR7 orbit



Laser Ranging to Galileo

’Premiale’ Project funded by Ministry of Research (MIUR).

Laser Ranging to Galileo
(ASI-INFN, 2015-16)

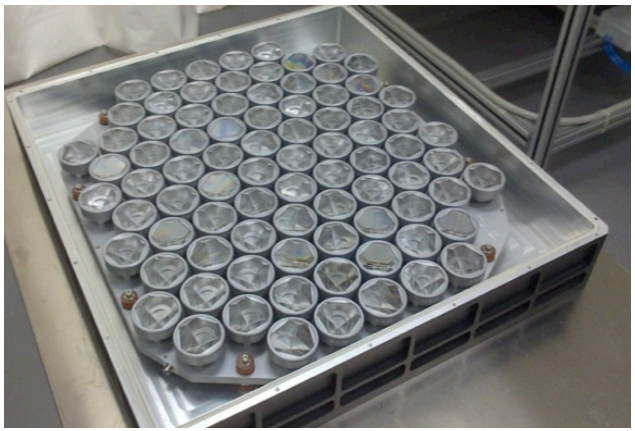
ETRUSCO-2
(ASI-INFN, 2010-15)

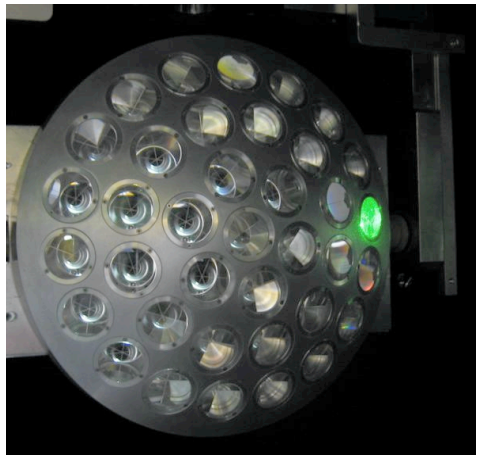
ETRUSCO
(INFN, 2006-09)

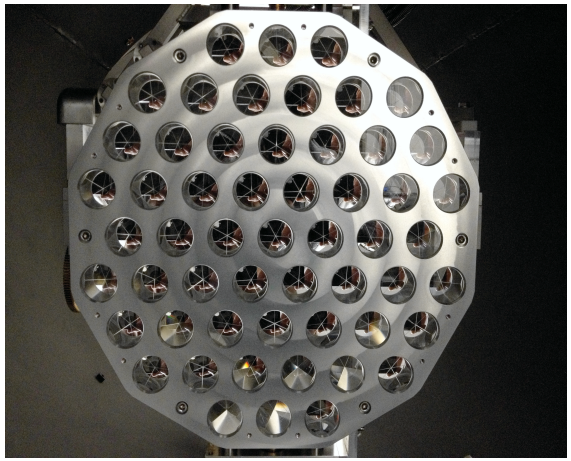
Laser Ranging to Galileo

Laser Ranging to Galileo

- ASI & INFN instrumentation upgrades (MLRO & SCF_Lab)
- ASI Laser ranging and SCF-Test of Galileo, GRA and LAGEOS





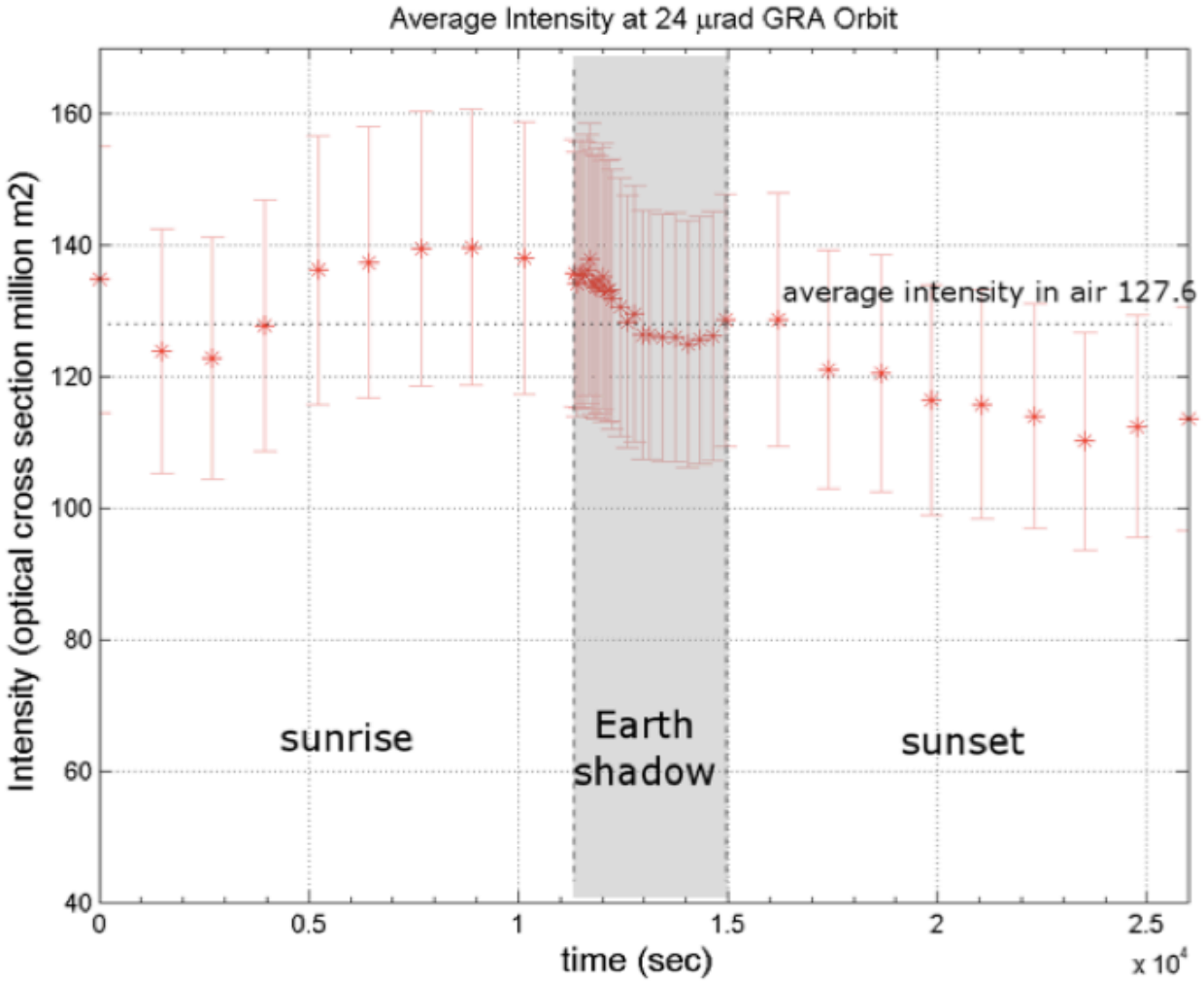


Macro-Activity 1 Year 1 and 2	**Macro-Activ. 2** Year 1	**Macro-Activ. 3** Year 1	**Macro-Activity 4** Year 2	**Macro-Activity 5** Year 2	**Macro-Activity 6** Year 2	**Macro-Activity 7** Year 2
MLRO-SCF_LAB Harmonization: Harmonization of MLRO and SCF_LAB upgrades and integration of the results of the upgraded MLRO and SCF_LAB (includes Management)	**MLRO@CGS**: Equipment Upgrade	**SCF_LAB@LNF**: Infrastructure Upgrade	**Upgraded MLRO**: Laser Ranging to LRAs onboard Galileo satellites	**Upgraded SCF_LAB**: Lab Characterization of Galileo LRA Flight Model (on loan to LNF from ESA)	**Upgraded MLRO**: Laser Ranging to LAGEOS	**Upgraded SCF_LAB**: Lab Characterization of LAGEOS Engineering Model (on loan to LNF from NASA)

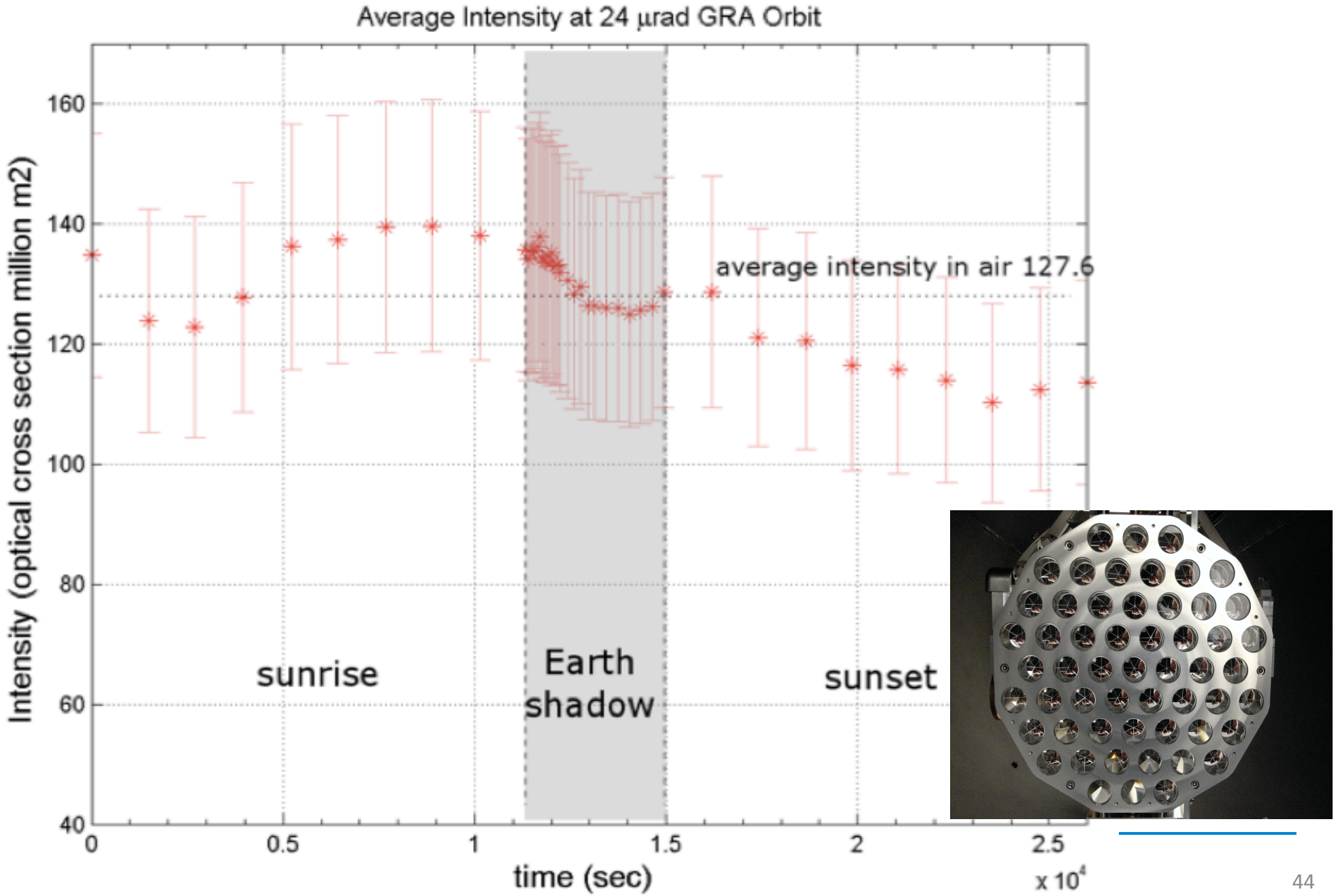
LRA = Laser Retroreflector Array

GRA and Galileo-IOV reflector performance

- GRA (GNSS Retroreflector Array) by INFN-ASI: 3.5 kg, 400 mm diameter; lighter/smaller than Galileo IOV.
- No degradations within ±15% errors (note scale of plot).
- http://www.lnf.infn.it/esperimenti/etrusco/documents.html.



GRA and Galileo-IOV reflector performance



AD's and RD's

APPLICABLE AND REFERENCE DOCUMENTS

AD1 GNSS laser retroreflector array optical performance requirements, ILRS - TECMMO/ 2012/318, Issue 1, 02/10/2012.

AD2 ESA Contract No. 4000108617/13/NL/PA - Thermo-optical vacuum testing of Galileo IOV laser retro-reflectors.

AD3 Technological challenges of SLR tracking of GNSS constellations, presented at the ILRS 2009 Technical Workshop, Metsovo (Greece).

AD4 CGI-NCRI, LRR Interface Control, Document GAL-CH-LRR-SUB-ICD-A-013, Issue 2, Revision 2, 16/02/2009.

AD5 Thermo-optical vacuum testing of Galileo IOV laser retro-reflectors of GALILEO IOV LRA project - EM LRA Detailed Design Report, Doc. LNF-GAL-DDR-001-1.

AD6 Thermo-optical vacuum testing of Galileo IOV laser retro-reflectors of GALILEO IOV LRA project - Engineering Model LRA SCF TEST PLAN, Doc. LNF-GAL-TP-001-1.

RD1 ECSS-E-ST-10-02C "Verification" (as replacement of ECSS-E-10 PART 2A mentioned on Appendix 3 of the Contract).

RD2 ECSS-E-ST-10-03C "Testing".

RD3 ECSS-E-HB-10-02-A "Verification guidelines".

RD4 ECSS-Q-20-07A "Quality assurance for test centers".

Thanks!