Sova-Picard TSI Results /
Revision of the value of the Solar Constant

Els Janssen, Steven Dewitte, André Chevalier

Solar Metrology needs and methods Oct. 9 2014

Team

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Outline

- Introduction
- DIARAD/Sova-Picard (Sova-P): operational modes
- The Sova-P TSI data series
- The revision of the efficiency correction factor
- TSI data composites
- Conclusions

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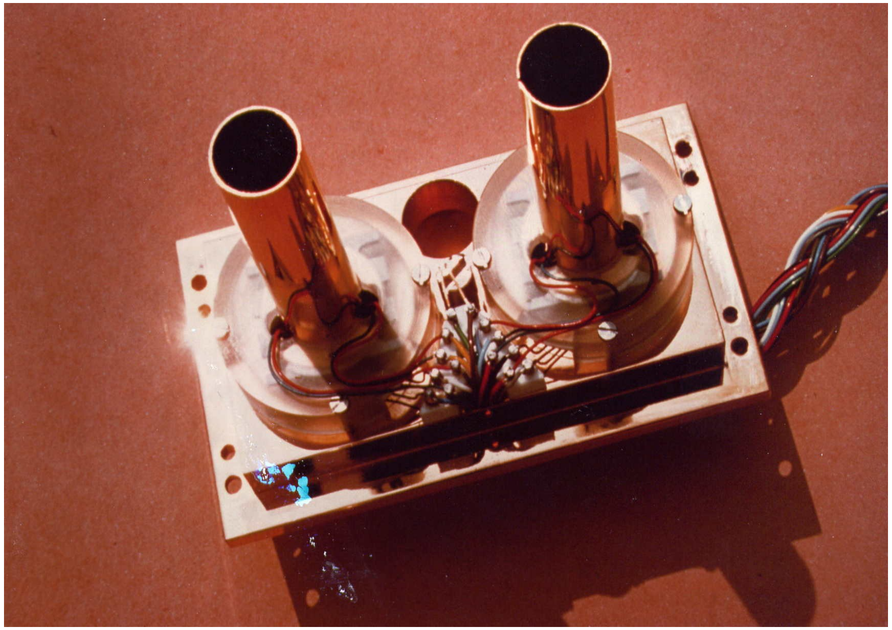
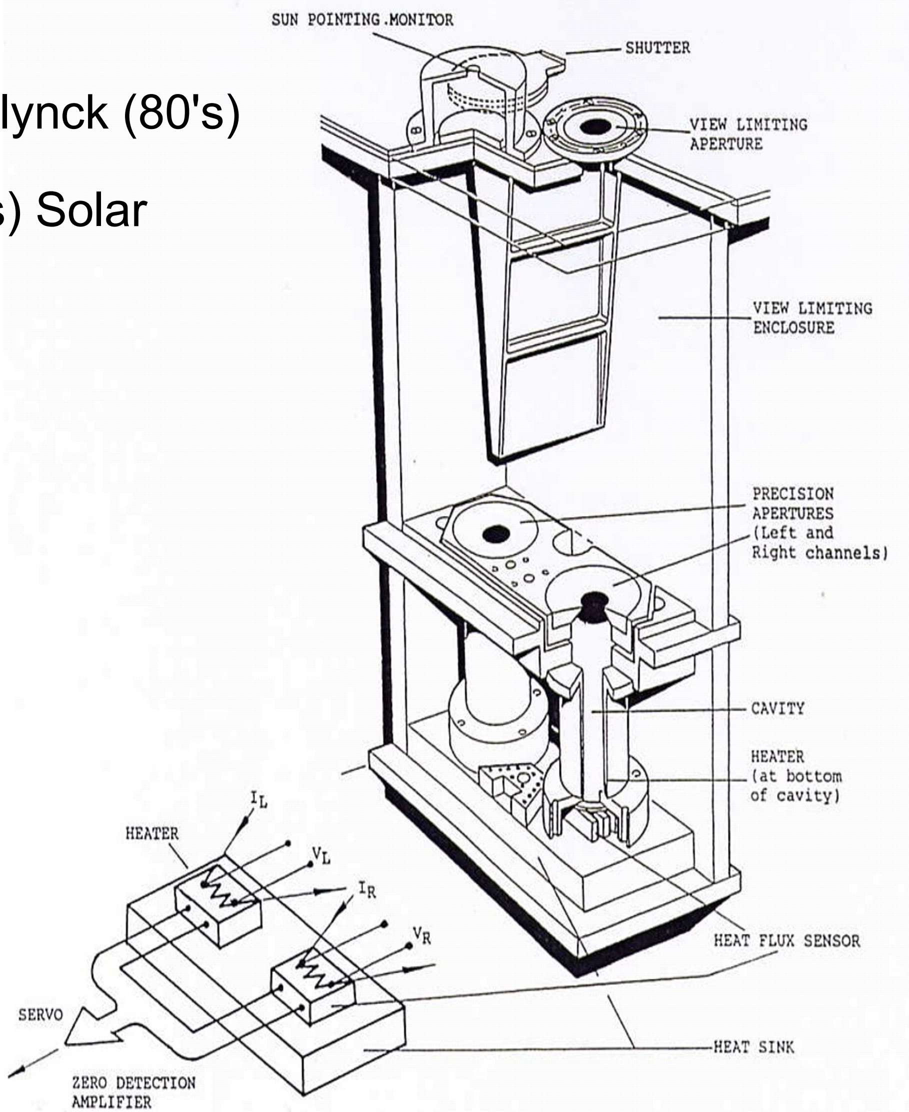
Introduction:
Concept of the DIARAD radiometer

- Differential Absolute RADiometer DIARAD
- Instrument designed at RMIB by D. Crommelynck (80's)
- Measurement of the Total (at all wavelengths) Solar Irradiance (TSI)
- 11 space missions with 6 instruments





Introduction:
The Picard satellite

CNES mission

Microsatellite from the Myriade series

90 cm x 80 cm x 110 cm

150 kg

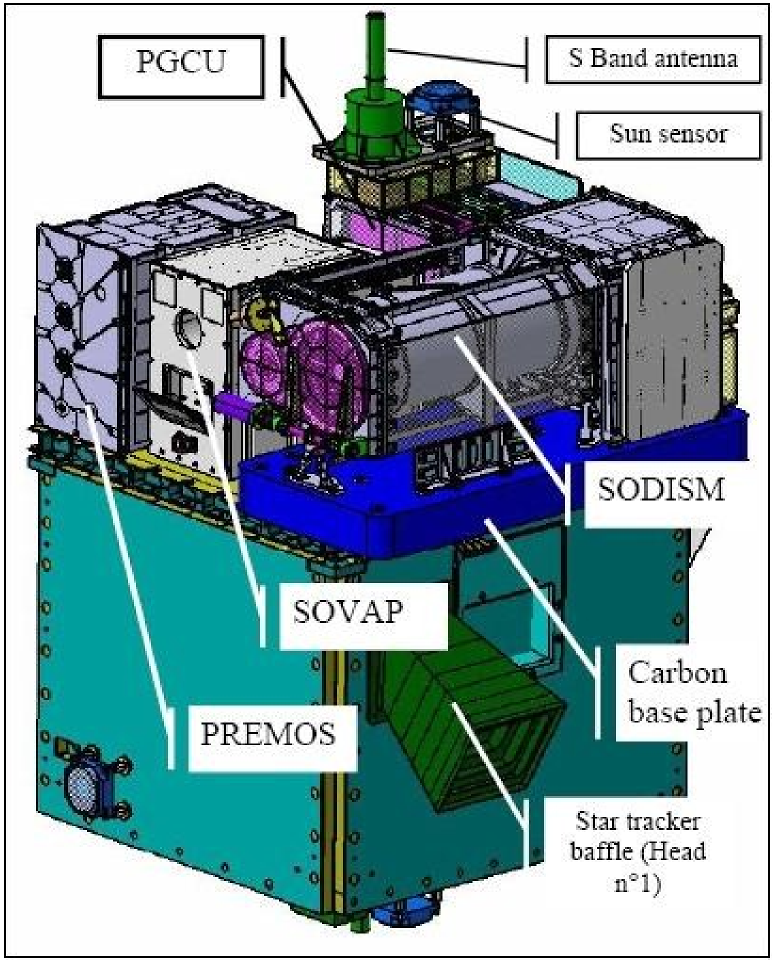
Sun-synchronous orbit around Earth

Altitude 725 km

Launch: **June 15, 2010**

Controlled shutdown: **April 4, 2014**

One functional DIARAD instrument remains in space (since > 18 years): DIARAD/Virgo on board of SOHO (NASA, ESA)

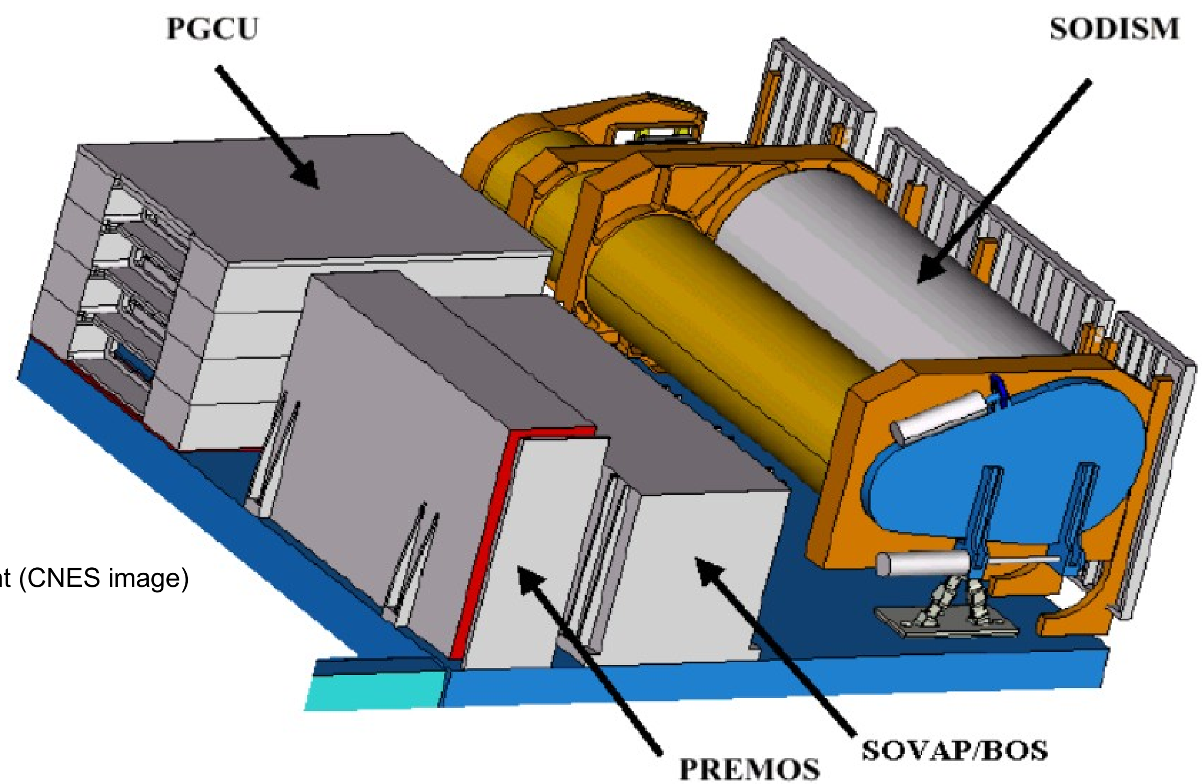


Payload on Picard (CNES image)

Introduction:
Solar Variability - Picard

Solar Variability – Picard consists of two instruments:

- DIARAD: absolute TSI measurements
- Mounted together with the Bolometric Oscillation Sensor (BOS): relative measurements (P. Zhu, M. van Ruymbeke, ROB)



Picard Sensor complement (CNES image)

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Working principle

DIARAD electrical substitution cavity radiometer

Equilibrium equations (e.g. A02):

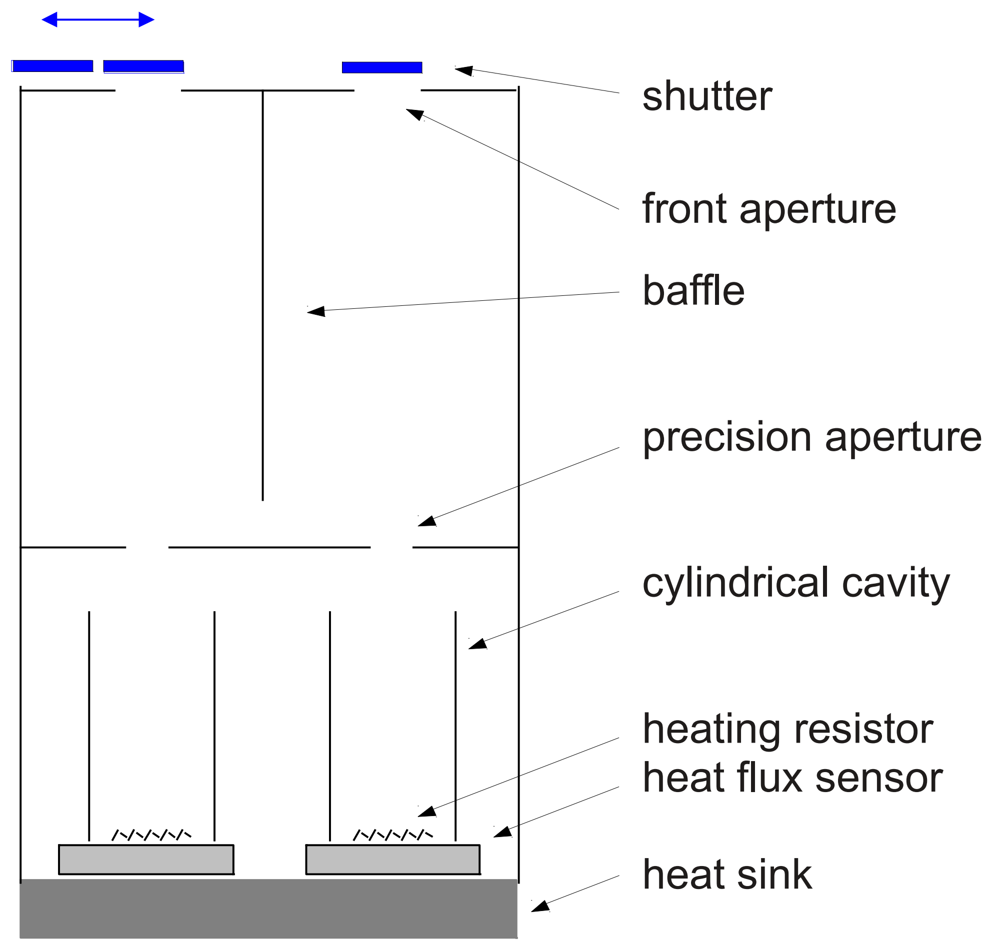
$$P_{SUN} + P_{open} = P_{ref} + P_{shutter}$$

$$P_{close} + P_{shutter} = P_{ref} + P_{shutter}$$

$$-$$

$$P_{SUN} = P_{close} - P_{open} + P_{shutter}$$

A servo system continuously regulates the electrical dissipated heat in the active cavity, such that the total measured power is equal for both cavities



D. Crommelynck

DIARAD / Sova-P main operational modes

Nominal modes

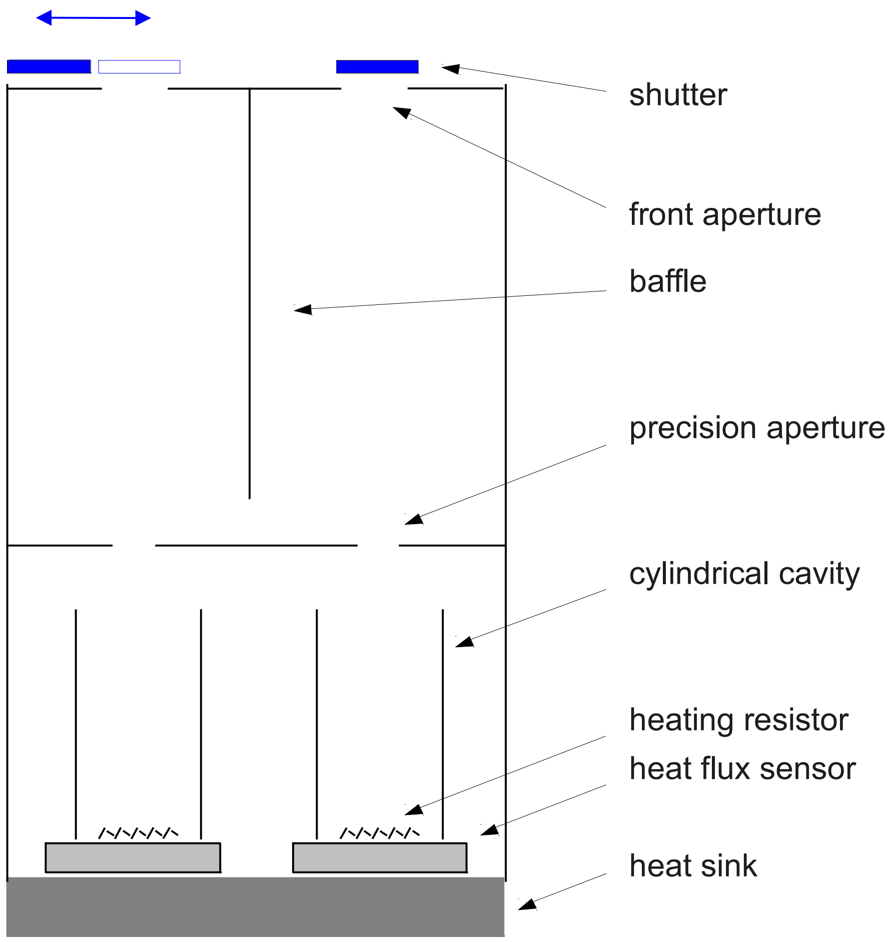
→ **'LEFT MODE'**:
left cavity = active (Mode A02)

→ **'RIGHT MODE'**:
right cavity = active (Mode A03)

Non-nominal modes

→ **'NEW LEFT MODE'**:
left cavity = active + opened right shutter (Mode A15)

→ **'NEW RIGHT MODE'**:
left shutter closed, right shutter opened (Mode R10)



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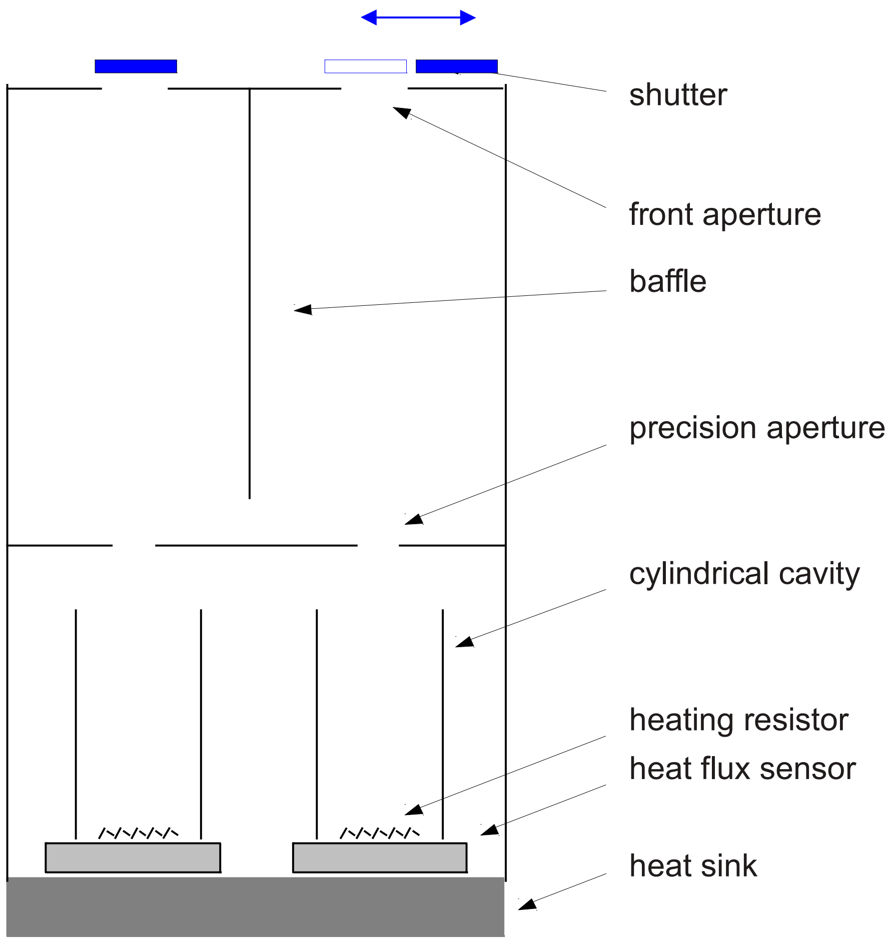
(Mode R10)



DIARAD / Sova-P main operational modes

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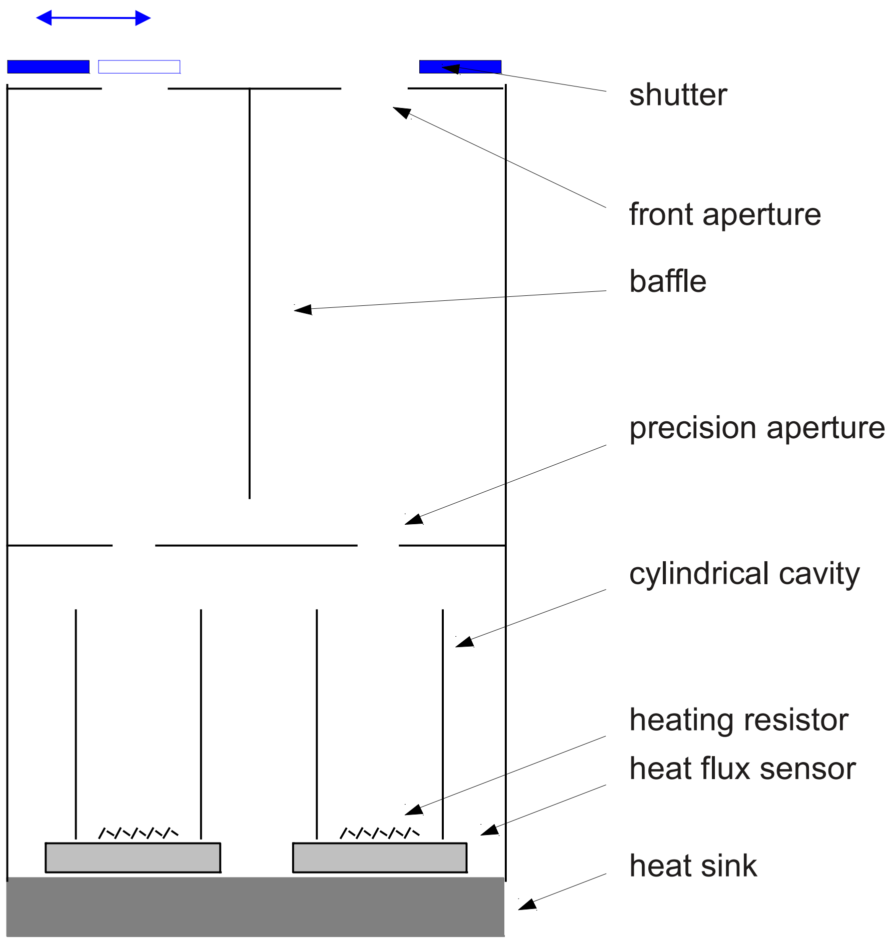

DIARAD / Sova-P main operational modes

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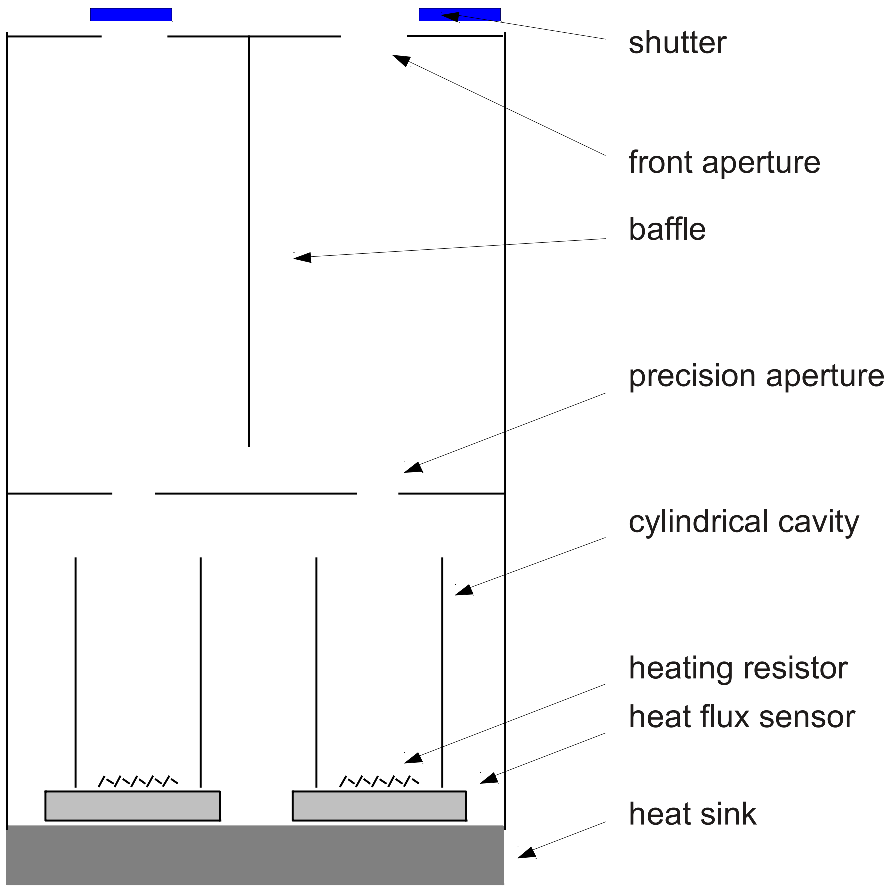

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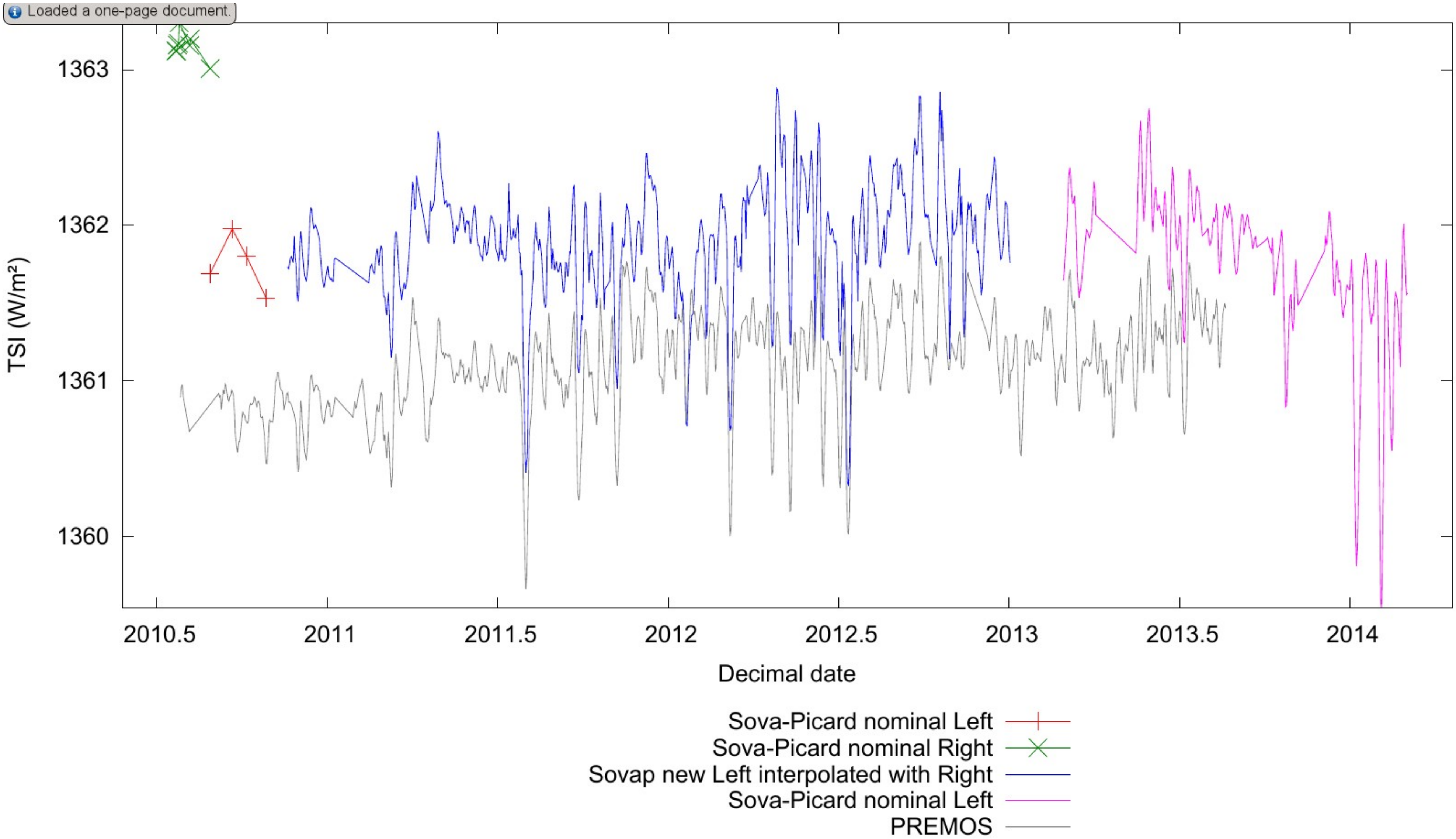
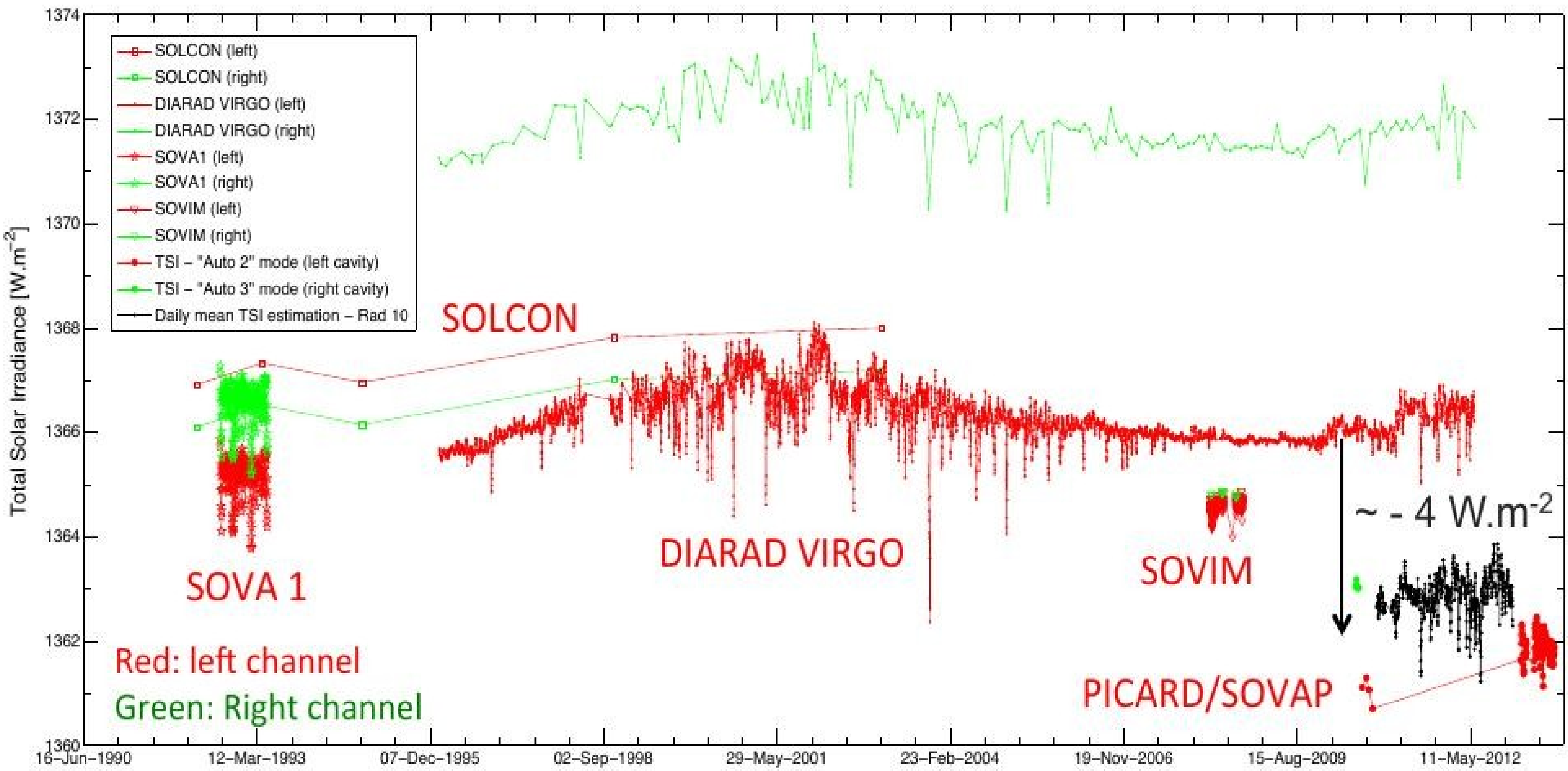
Sova-Pc Daily mean TSI



RMIB Instruments TSI



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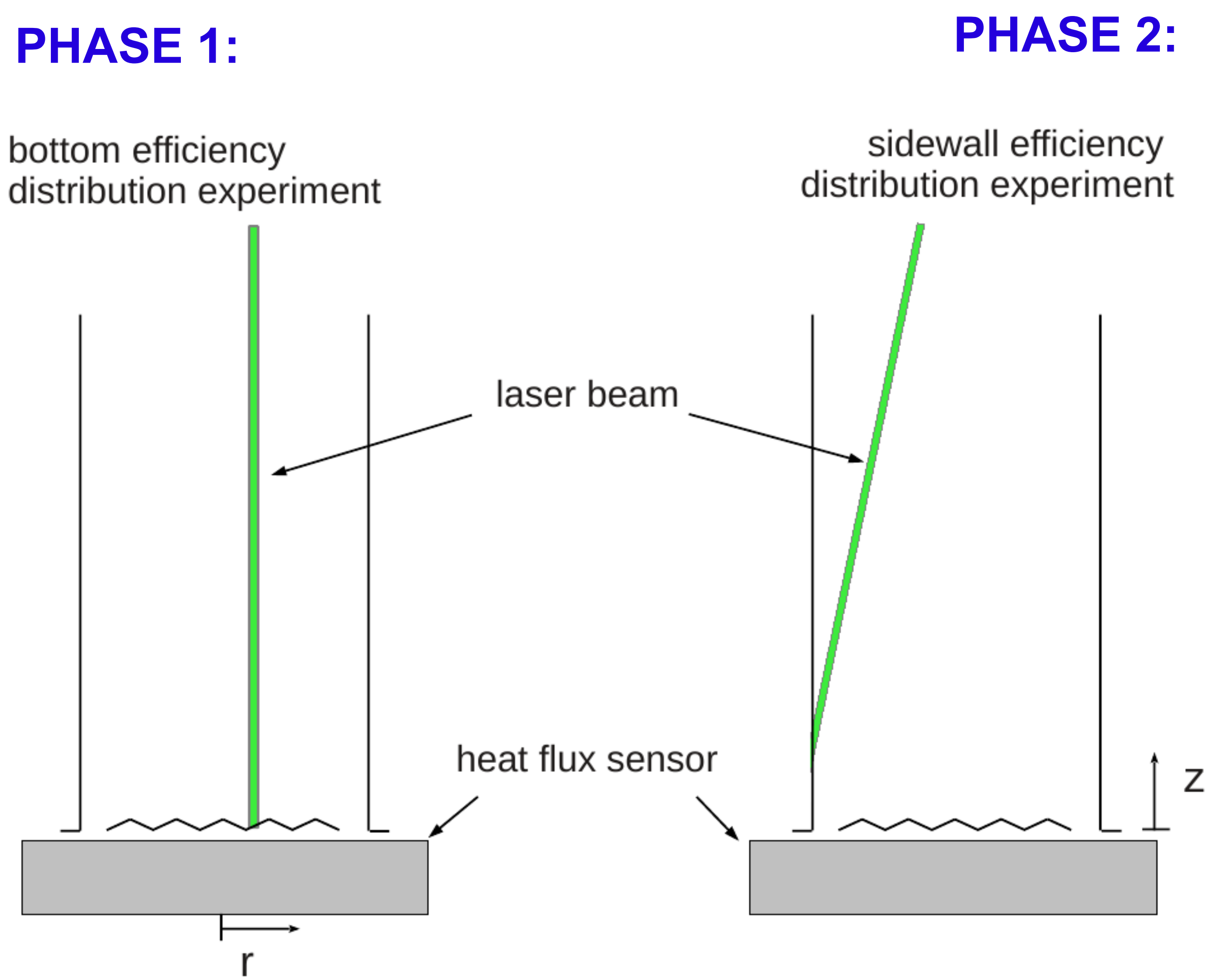
Experimental determination of the local efficiency



D. A. Crommelynck, 'Fundamentals of absolute pyrheliometry and objective characterization', NASA Conference Publication 2239, (1982)

D. Crommelynck, A. Chevalier, C. Conscience

Experimental determination of the local efficiency

$\Delta P = P_{close} - P_{open}$

Local efficiency = $\Delta P \; / \; \Delta P(r=0)$

The graphs below show the relative efficiency by which absorbed heat is detected, in function of the location at which the heat was originally applied.

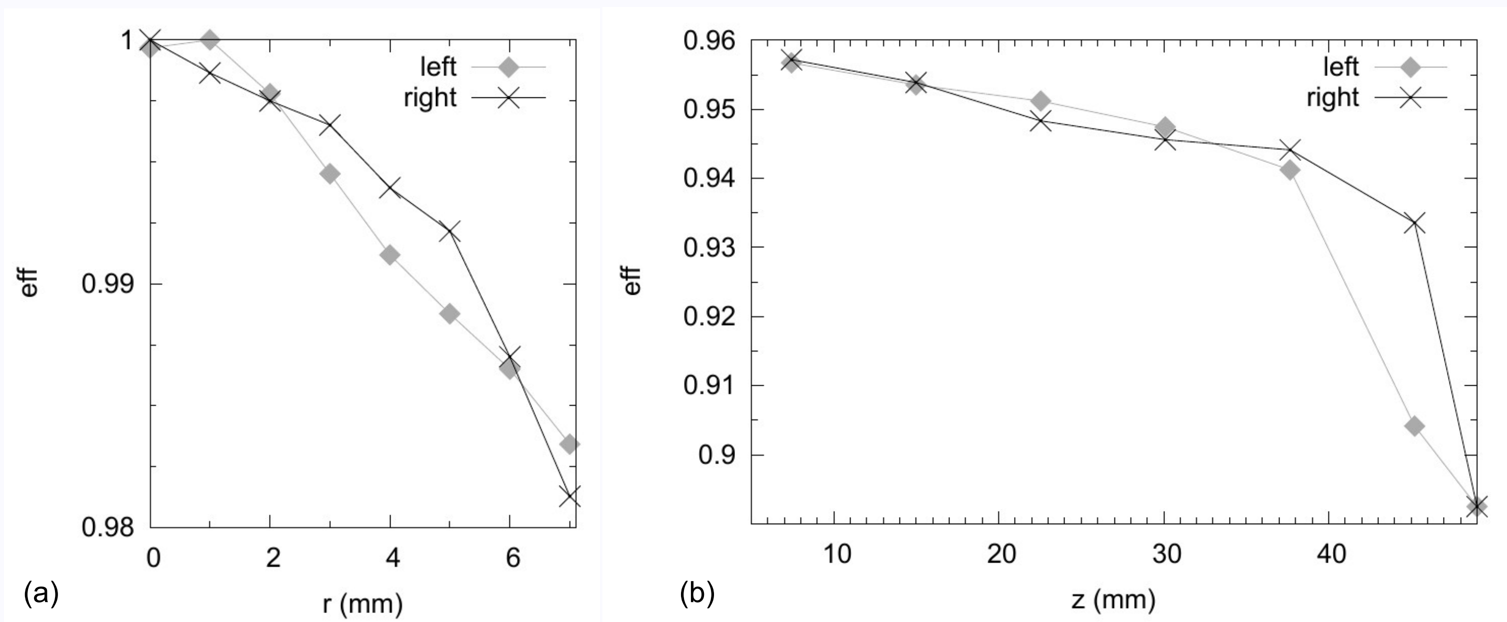
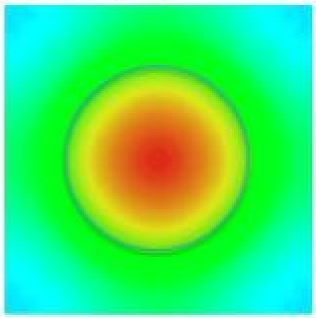


Figure: Relative surface efficiency distribution for the left and right cavities of SOVAP. Radial distribution (a) and distribution along the height of the cylinder wall (b).

D. Crommelynck, A. Chevalier, C. Conscience

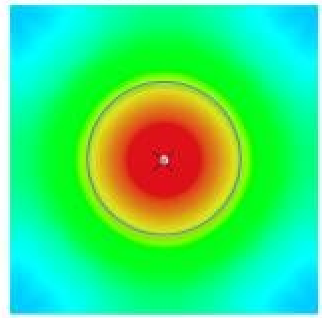
Efficiency parameters

Heating resistor area
Ø 12.5 mm



Right channel (r)
Closed (cl)

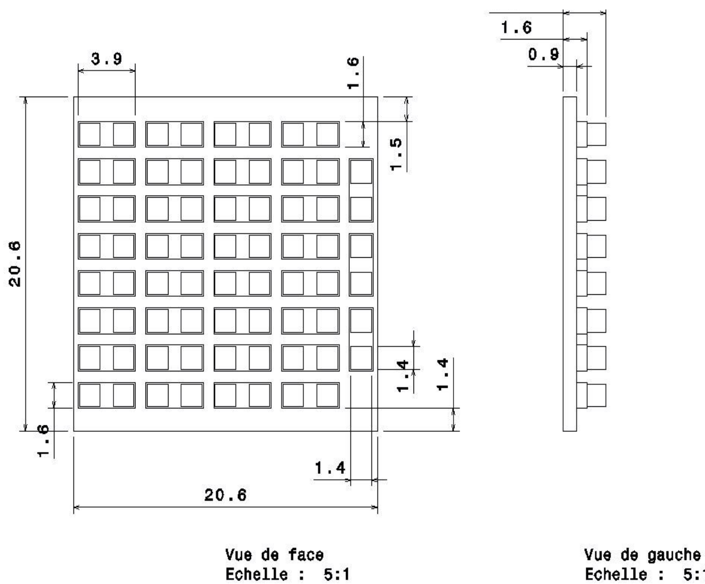
Solar flux area
Ø 10.0 mm



Right channel (r)
Open (o)

$$P_{cl,r} = P_{o,r} + P(Si_r) \longrightarrow \Delta T_{cl,r} \neq \Delta T_{o,r}$$

$$V_{cl,r}(\Delta T_{cl,r}) \neq V_{o,r}(\Delta T_{o,r})$$

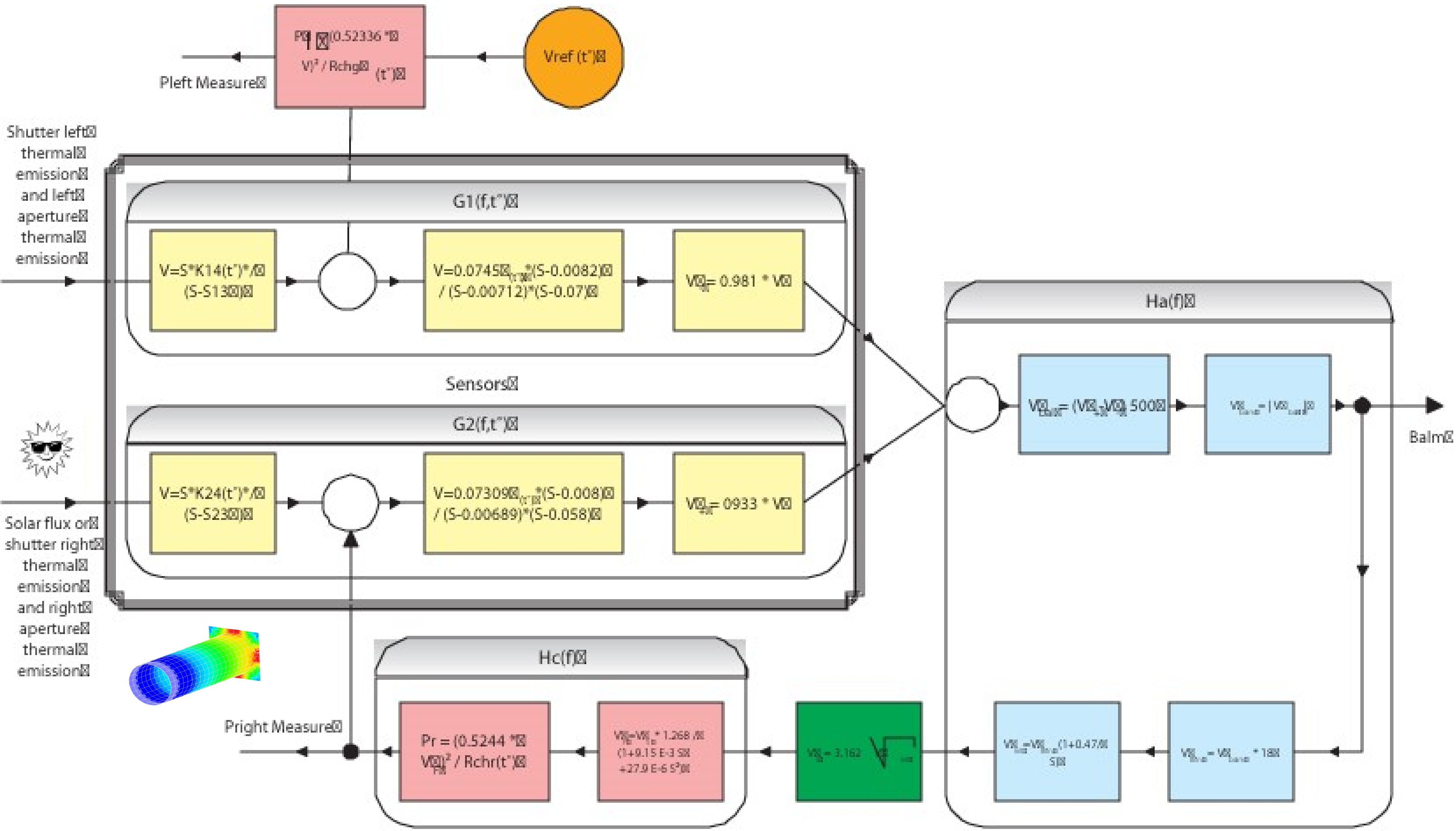


$$\eta_{th,o} = \frac{\text{detected power}}{\text{absorbed optical solar power}}$$

$$\eta_{th,e} = \frac{\text{detected power}}{\text{dissipated electrical power}}$$

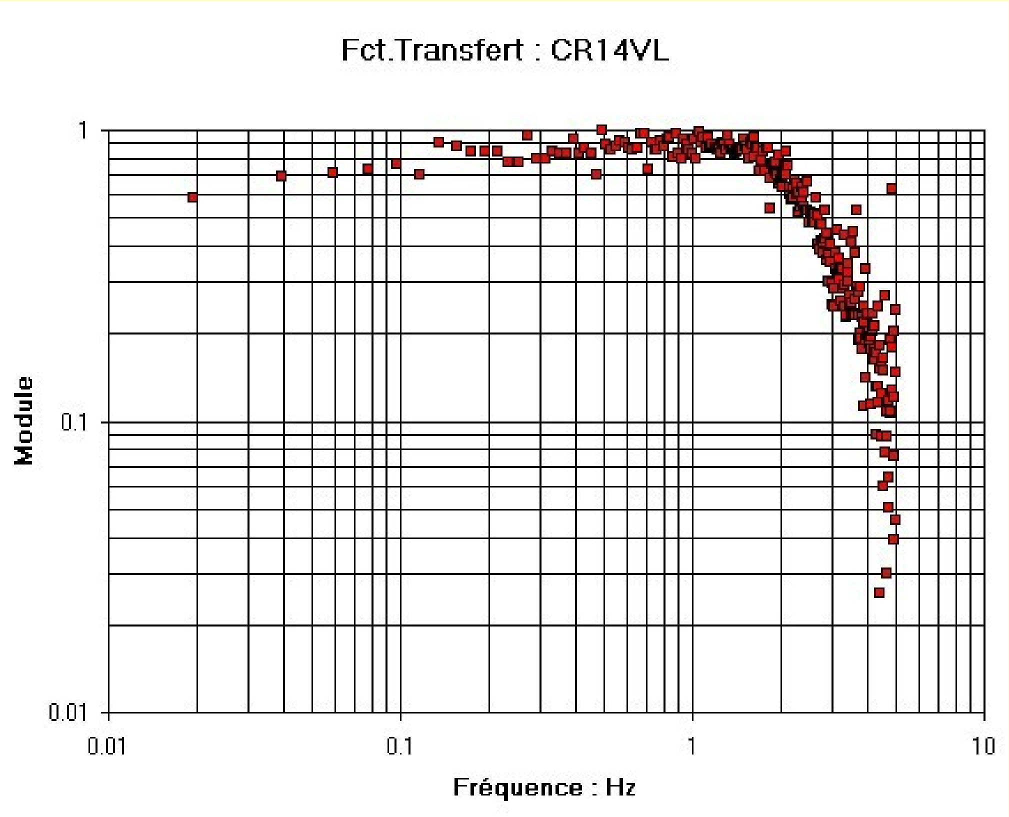
Both parameters are calculated from the experimentally measured local efficiency resulting by the detection through the 70 Peltiers junctions.

Feedback loop

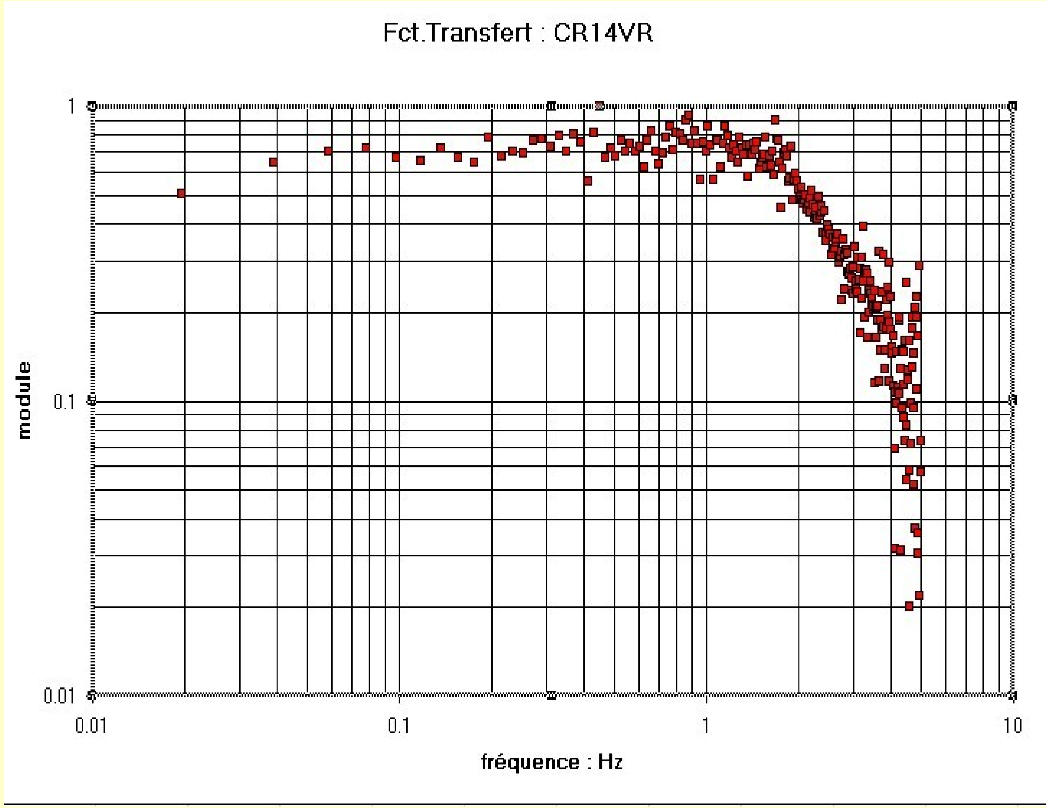


The bandwidth of the closed feedback loop

Mode A02



Mode A03



The left and right frequency response is of the order of 1HZ

Determination of the thermal efficiency related to optical effects

$$\eta_{th,o}\, A_r \;=\; \alpha_{paint}\, \overline{eff_r}$$

Main term

$$+\,(1-\alpha_{paint})\;\;\alpha_{paint} \sum_{m=1}^{M} eff_z(m)\; F_{disk-\Delta z_m}$$

Correction 1st order reflections

$$+\,(1-\alpha_{paint})^2\;\alpha_{paint} \sum_{m=1}^{M} F_{disk-\Delta z_m}$$

$$\cdot\left[\sum_{n=1}^{N} eff_r(n)\; F_{\Delta z_m-\Delta r_n} + \sum_{m'=1}^{M} eff_z(m')\; F_{\Delta z_m-\Delta z_{m'}}\right]$$

Correction 2nd order reflections

$$+\,(1-\alpha_{paint})\;(1-\alpha_{mirror})\;\overline{eff_r}\;\;F_{disk-mirror}$$

Correction reflection at the mirror

D. Crommelynck, A. Fichot, F. Bauwens
S Dewitte, E. Janssen

Determination of the thermal efficiency related to electrical effects

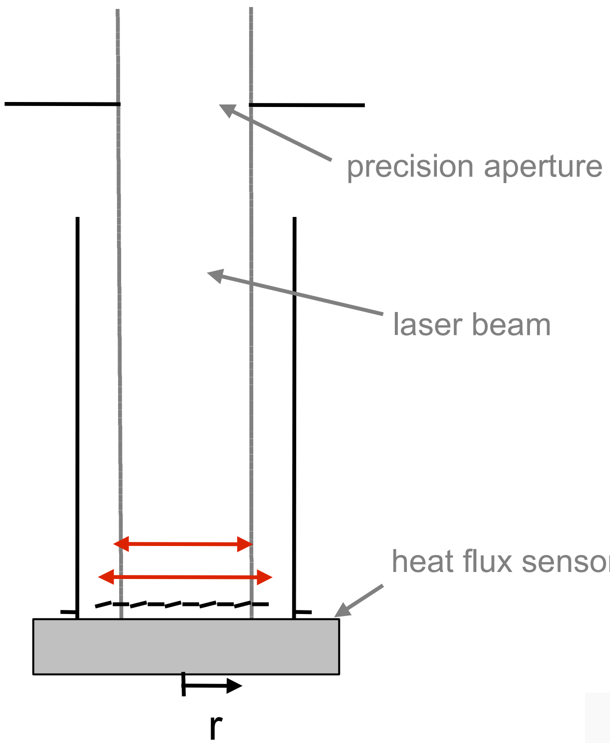
$\eta_{th,e} =$ *mean efficiency over the area of the heating resistor (radius r_{res}) at the base*

$$\eta_{th,e} = \frac{1}{r_{res}^2} \sum_{n=1}^{N_{res}} (r_n^2 - r_{n-1}^2) \cdot \frac{eff_r(n) + eff_r(n-1)}{2}$$

Differences with respect to the 'optical' parameter:

- Geometrical area in which the heat is dissipated
- The absorption factor of the paint is not taken into account (*)
- No reflections are taken into account (*)

(*) since the power is dissipated locally on the heat flux sensor



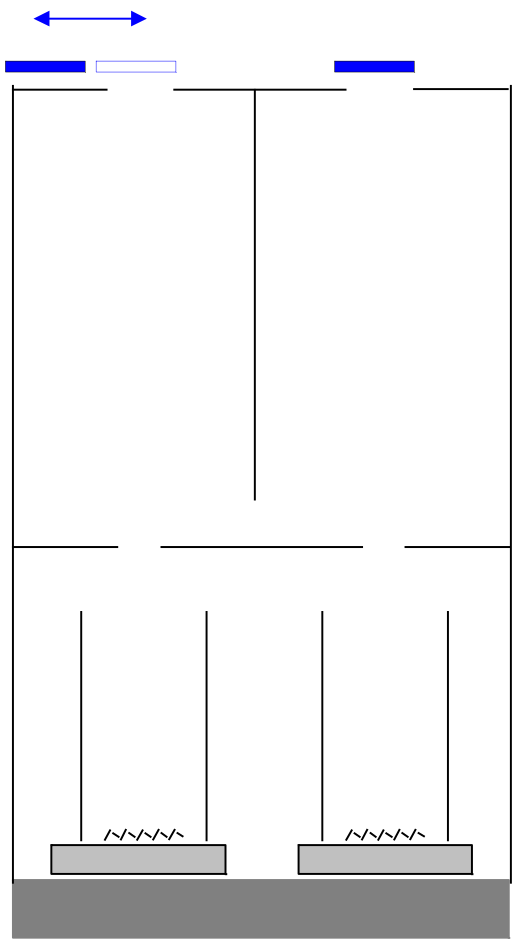
Equilibrium equations

$$P_{SUN} + P_{open} = P_{ref} + P_{shutter}$$

$$P_{close} + P_{shutter} = P_{ref} + P_{shutter}$$

$$P_{SUN} = P_{close} - P_{open} + P_{shutter}$$

Basic equations WITHOUT additional effects: diffraction and scattering at the front aperture, backscattering at the optical baffle, emissivity of the shutter, reflection at the shutter, absorptivity of the cavity, thermal expansion of the precision aperture, ...



Equilibrium equation
Corrected for thermal efficiency

'Traditional' approach: $$\eta_{th,o}\, A_r\, P_{SUN} = P_{close} - P_{open} + \eta_{th,o}\, A_r\, P_{shutter}$$

$$\Rightarrow\ P_{SUN} = (P_{close} - P_{open})\,\frac{1}{\eta_{th,o}\, A_r} + P_{shutter}$$

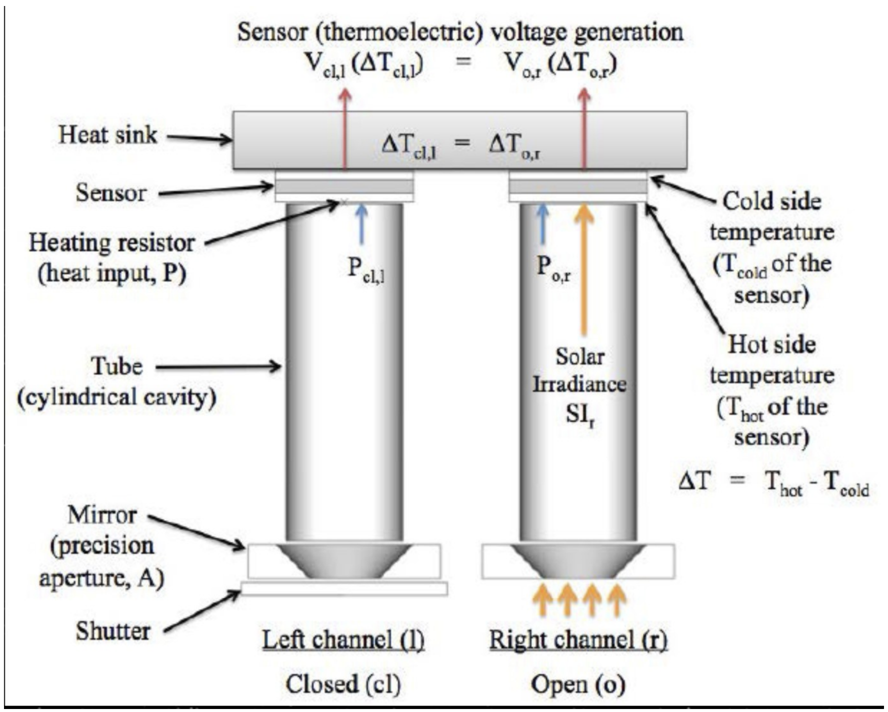
New approach: $$\eta_{th,o}\, A_r\, P_{SUN} = \eta_{th,e}\, P_{close} - \eta_{th,e}\, P_{open} + \eta_{th,o}\, A_r\, P_{shutter}$$

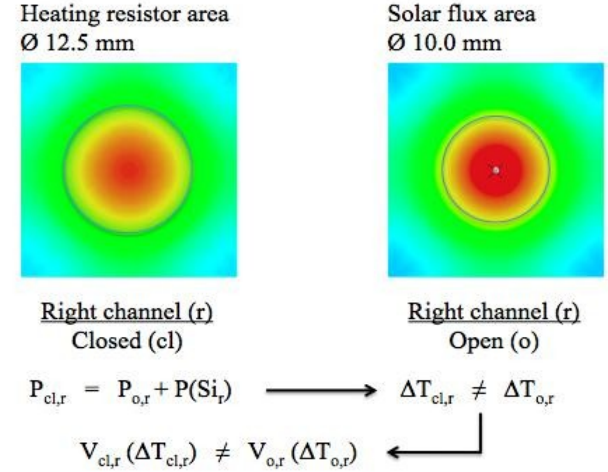
$$\Rightarrow\ P_{SUN} = (P_{close} - P_{open})\,\frac{\eta_{th,e}}{\eta_{th,o}\, A_r} + P_{shutter}$$

= NON-EQUIVALANCE ratio
resulting from the different topology
of heat distribution on sensor

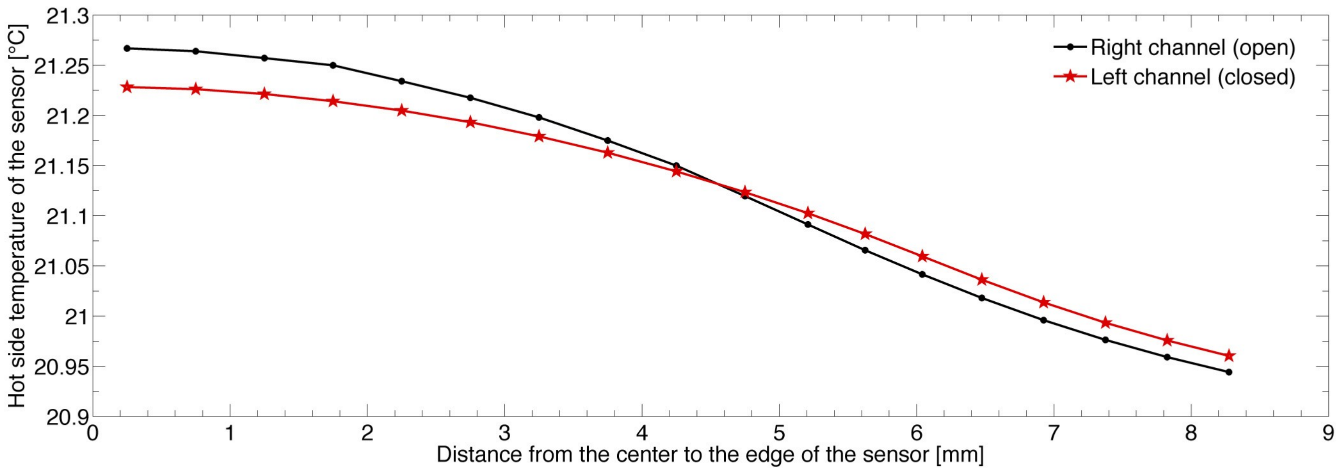
Basic equations WITHOUT additional effects: diffraction and scattering at the front aperture, backscattering at the optical baffle, emissivity of the shutter, reflection at the shutter, absorptivity of the cavity, thermal expansion of the precision aperture, ...

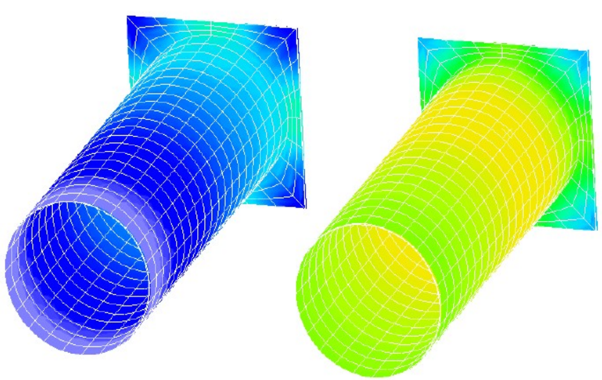
Δpor in flight for SovaP





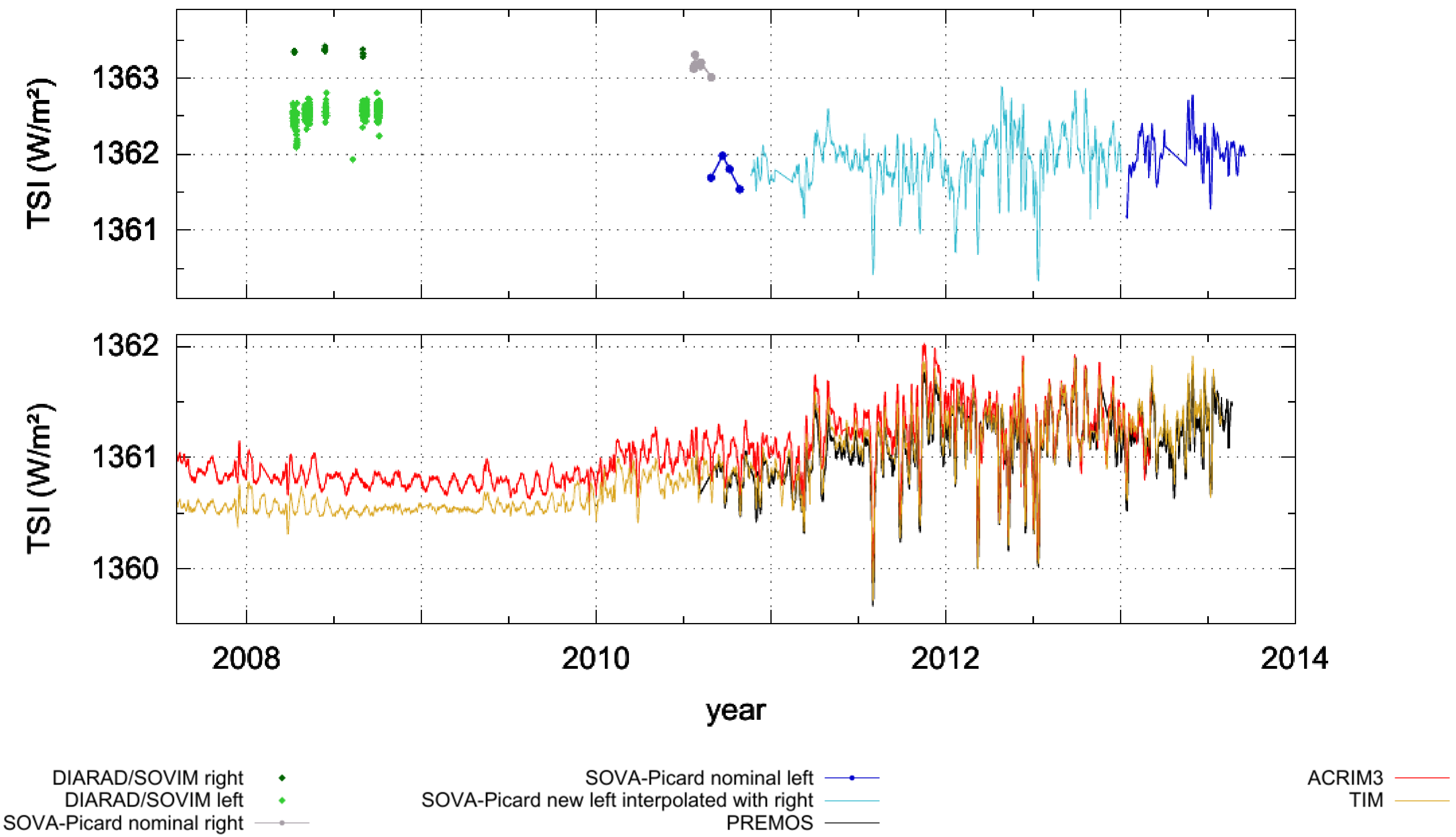
State	Parameters	Right channel - "closed"	Right channel - "open"
Non-equilibrium	$P(SI_r)$	–	0.10681 W
	P_r	$P_{cl,r} = 0.10681$ W + 0.06 W	$P_{o,r} = 0.06$ W
	T_{cold}	20^oC	20^oC
	T_{hot}	21.0789^oC	21.0808^oC
	$V_{cl,r}/V_{o,r}$	15.631×10^{-3} V	15.661×10^{-3} V
Equilibrium	$\Delta P_{o,r}$	0.3×10^{-3} W	–
	T_{cold}	20^oC	20^oC
	T_{hot}	21.0808^oC	21.0808^oC
	$V_{cl,r}/V_{o,r}$	15.661×10^{-3} V	15.661×10^{-3} V



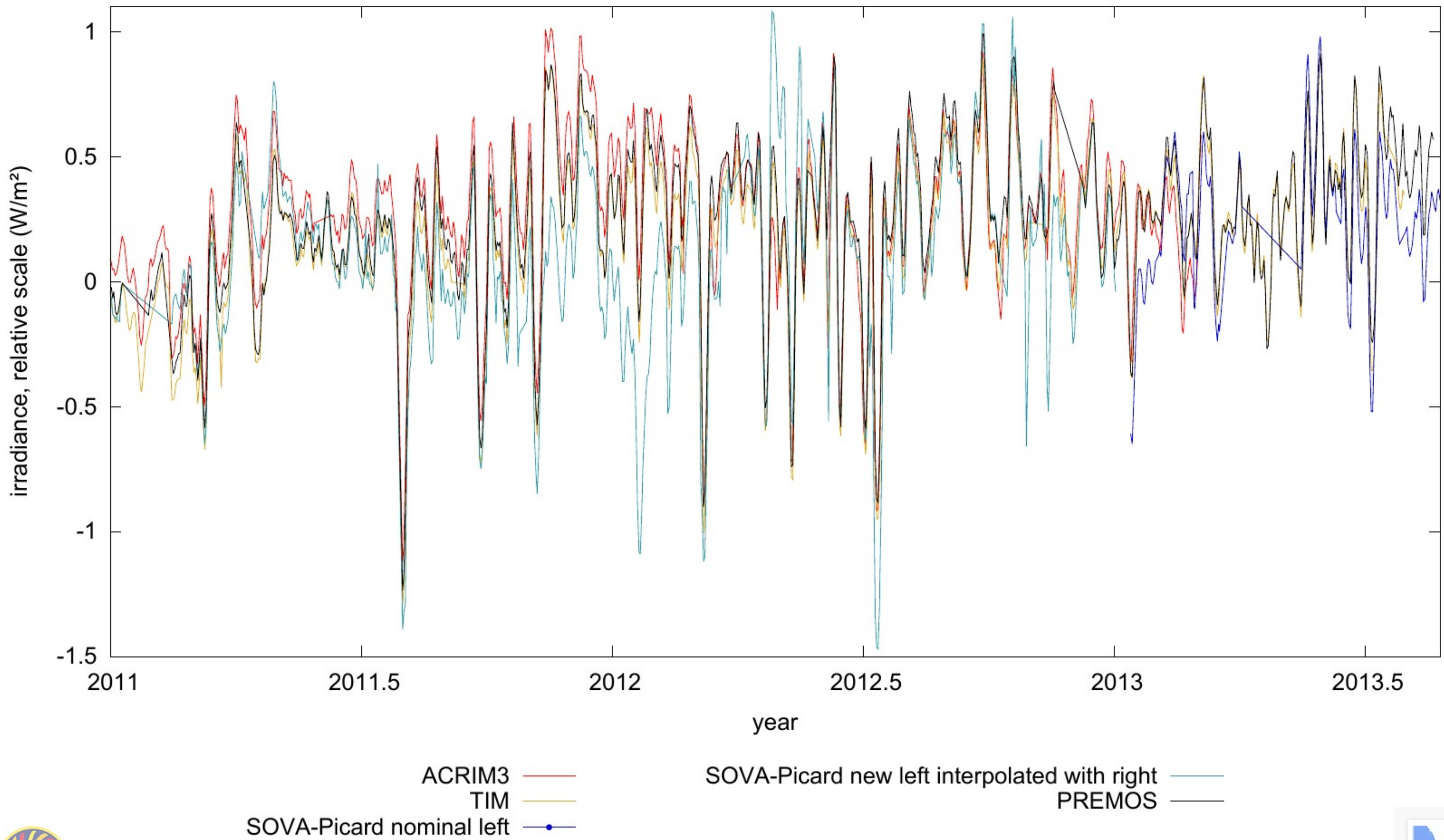


Impact on the TSI values

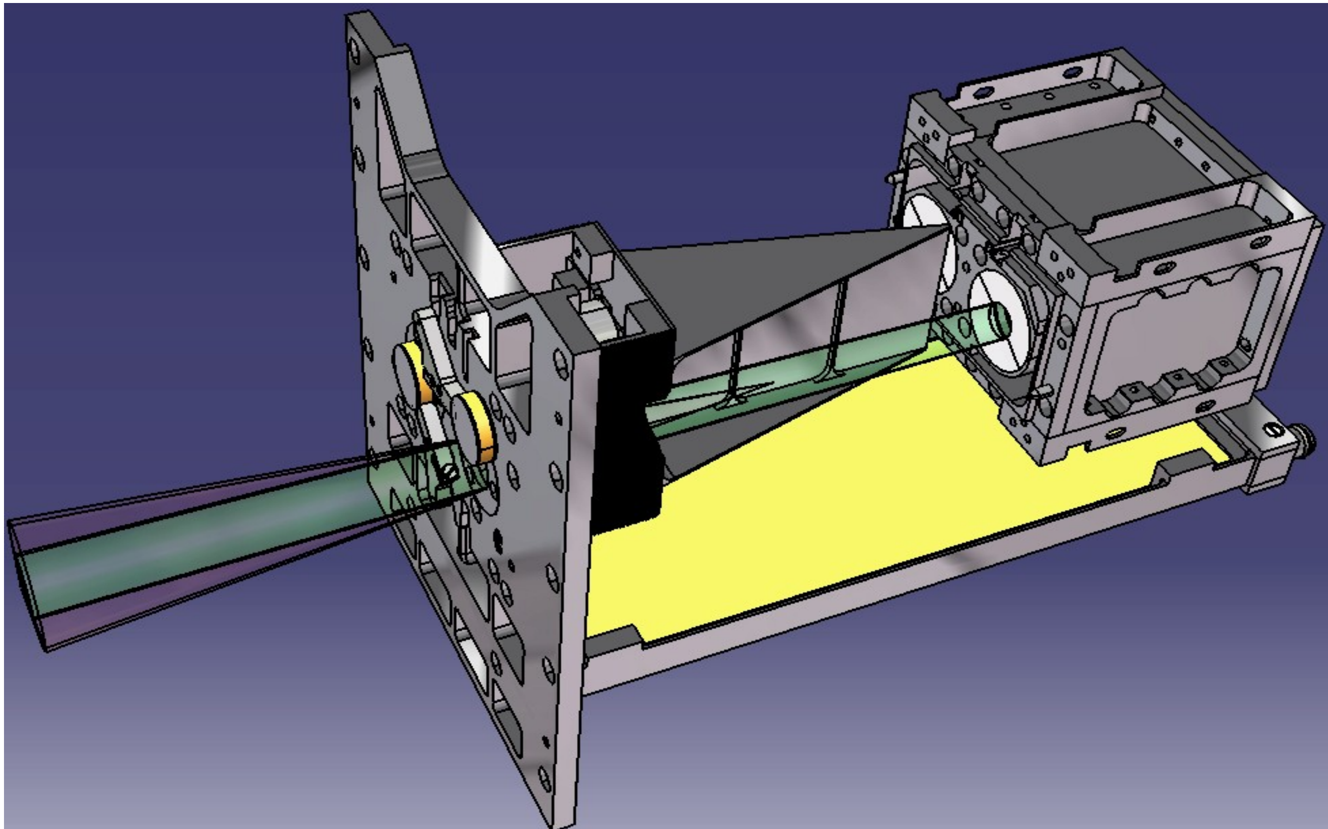
Values lowered by 8 and 5 W/m² (Sova-P) 2 W/m² (Sovim), but still higher than the values of the other TSI teams:

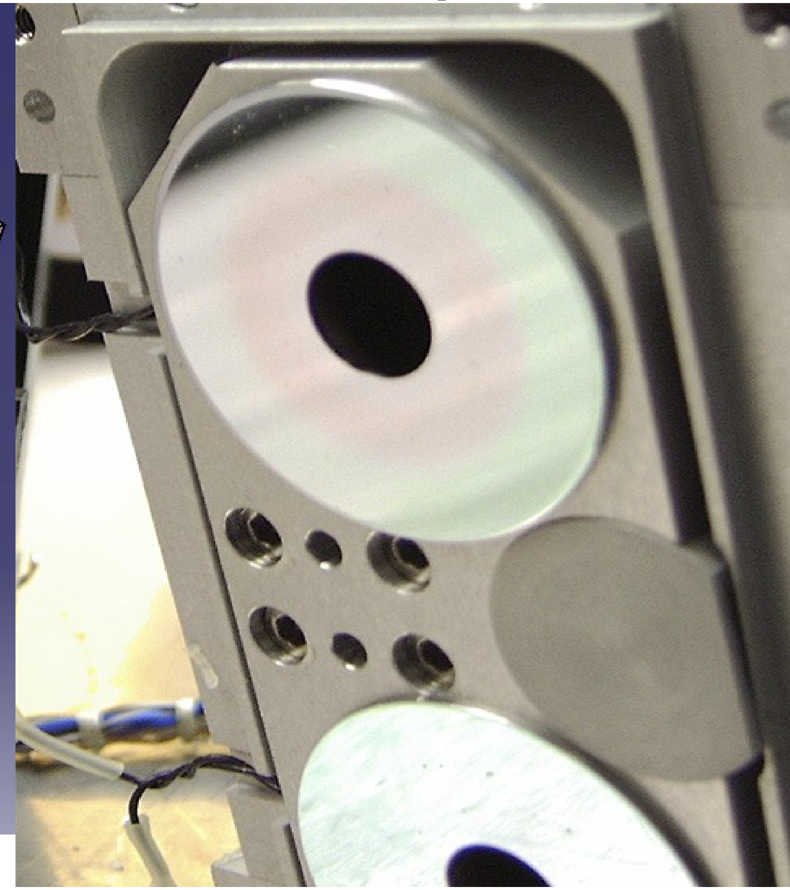


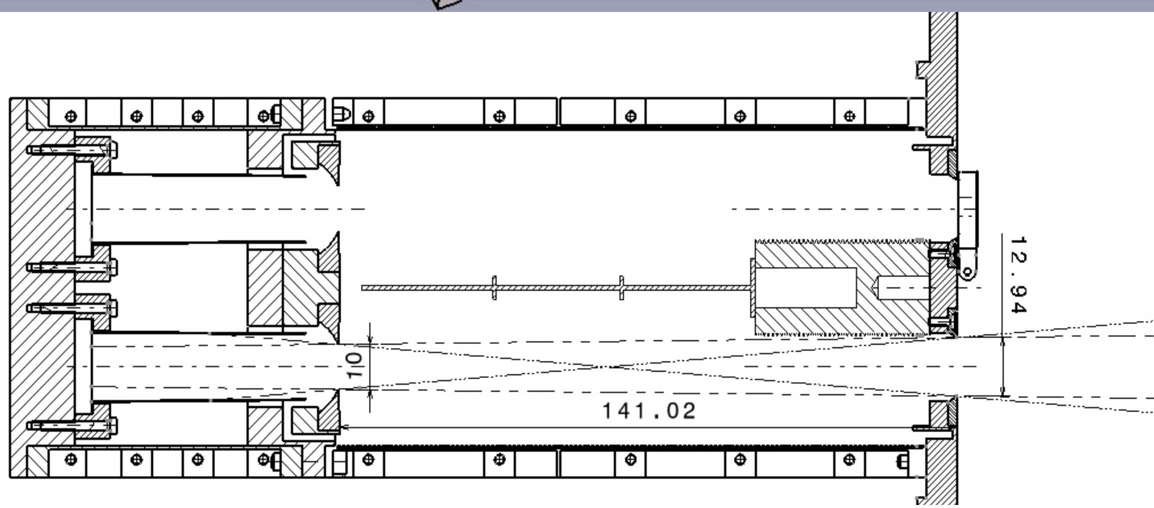
Comparison to other TSI radiometers



Views of Sova-P field of view and SOVA aperture

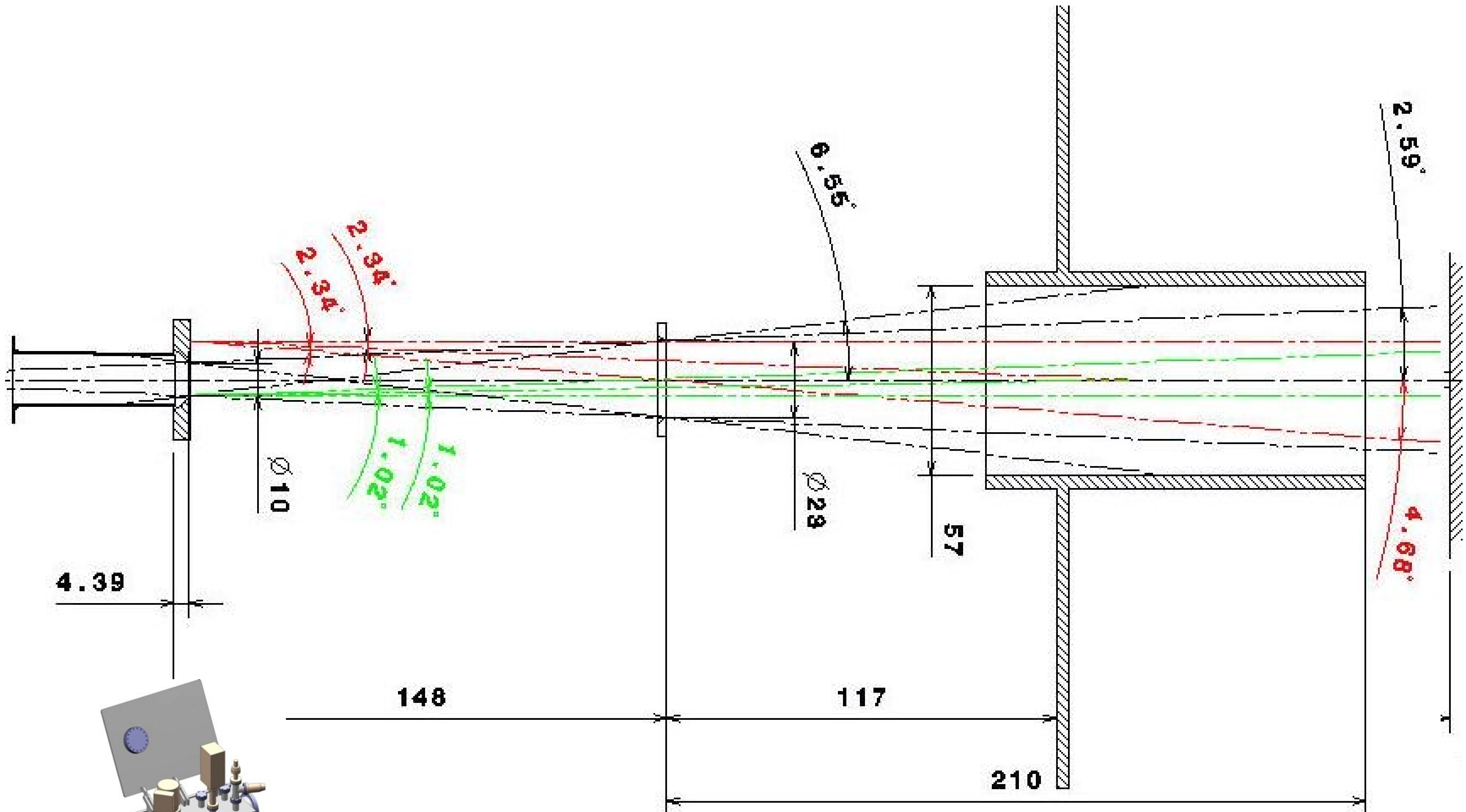


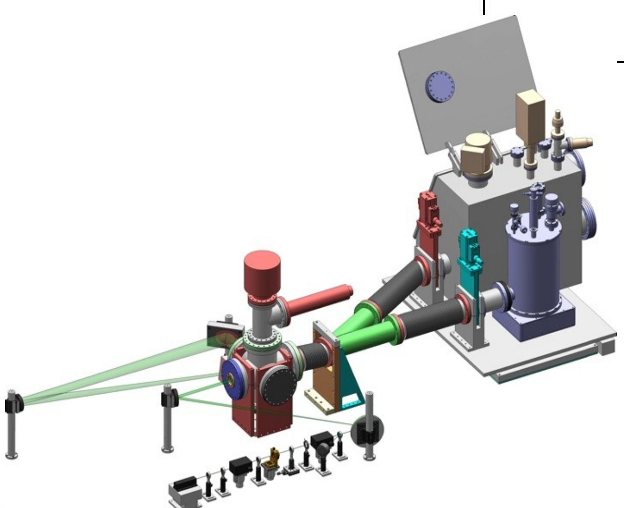




Comparison at LASP(*) TSI Radiometer Facility (TRF)

View of **SOVA** (Eureca) optical geometry





(*) Laboratory for Atmospheric and Space Physics, Colorado

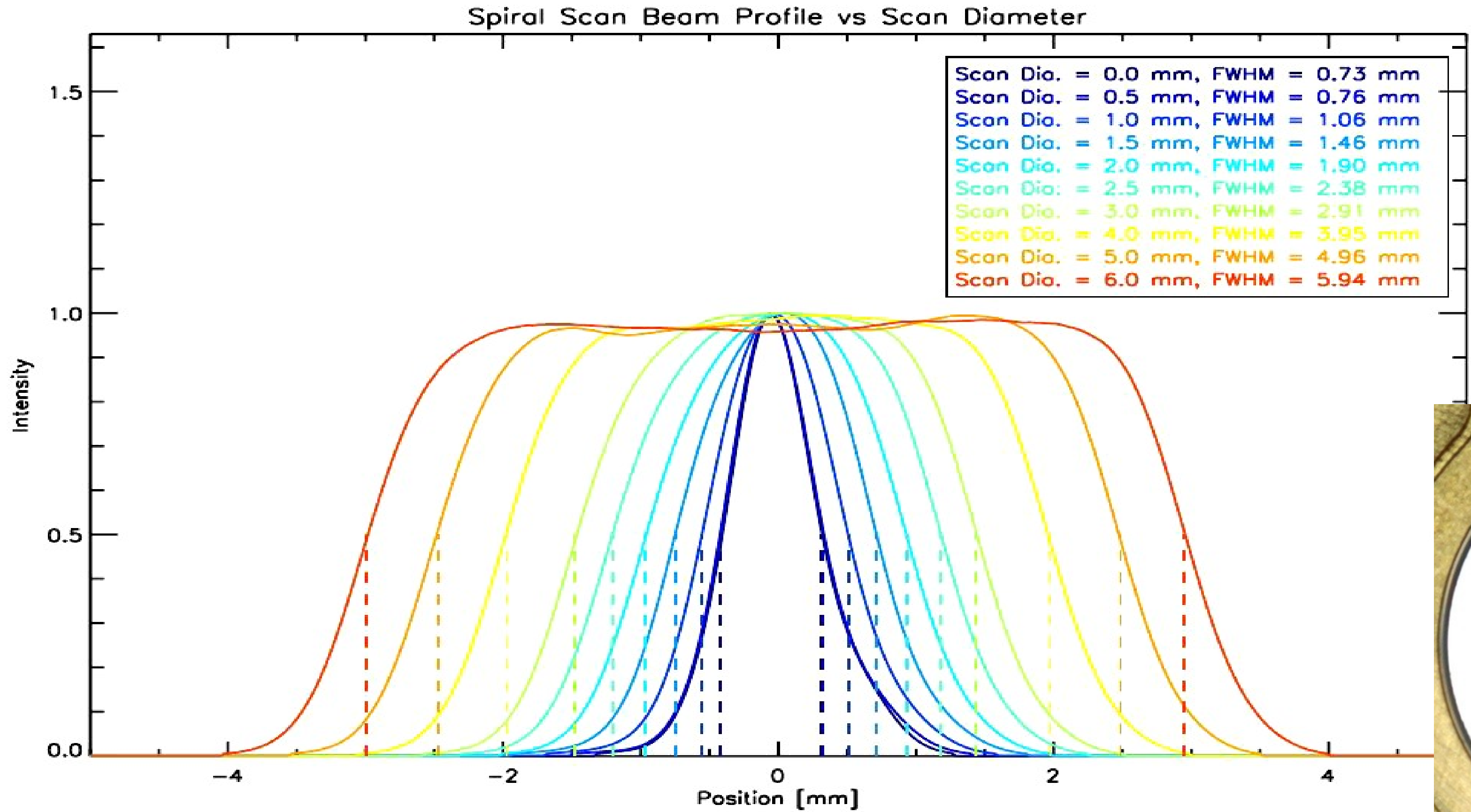
Post-Flight Comparison at LASP(*)
TSI Radiometer Facility (TRF)

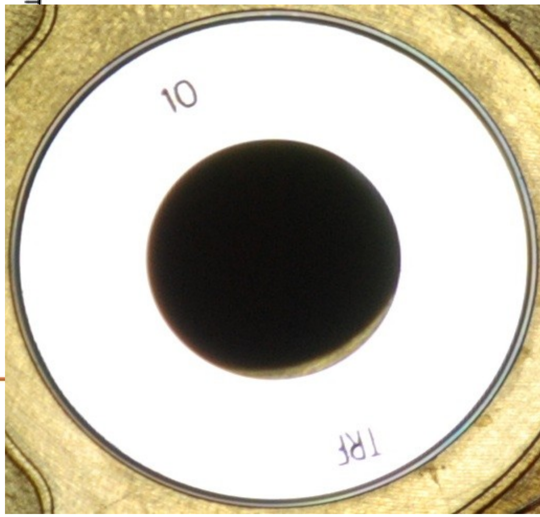
- Sova : instrument characterised in november 1980
- Sova: Diarad type radiometer that flew on Eureca in 1992, brought back to ground by space shuttle (retrievable instrument)
- Comparison compaign with the LASP TRF cryogonic radiometer in May-June 2013
- Outcome of the tests:
  - Power comparison
  - Diffuse light
  - Diffraction
  - Irradiance comparison

(*) Laboratory for Atmospheric and Space Physics, Colorado

Comparison at LASP

Power comparison





Values with 3mm disk shaped beam after alignement of Cryo front aperture and corrected SOVA data based on non-equivalence

the 07/06 value : Sova / Cryo : 1,00000279 (one experiment)

Before this alignement : Sova / Cryo : 1,000053 (mean of 5 experiments)

Good agreement ==> Validation of corrected efficiency.

Comparison at LASP(*)

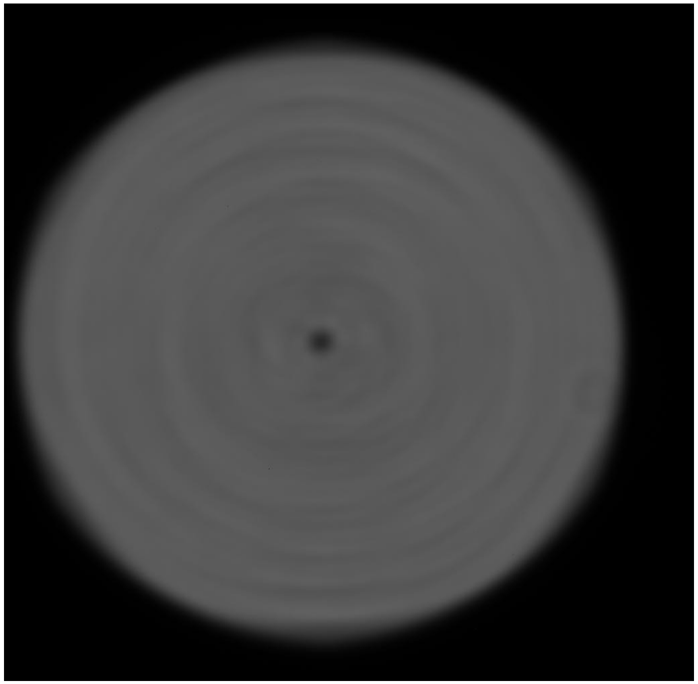
Diffuse light

- Diffuse light: similar to cryo

13/6 14 to 19 mm annulus 900 ppm measured both by SOVA and CRYO
12/6 19 to 25 mm annulus 522 ppm measured by CRYO, the excess signal of Sovar is attributed to diffraction on its view limiting aperture.
10/6 17 to 20 mm annulus 200 ppm measured both by SOVA and CRYO

Comparison at LASP

Difraction light



- Diffraction: result comparable with our theoretical correction factor (717 ppm calculated with PMOD program)
- 12/6 19 to 25 mm annulus 0,0005576
- SOVA-CRYO power relative to 10 mm disc power in case of uniform irradiance

Comparison at LASP

Irradiance light

- Irradiance comparison:
  - 6/6 13 mm disc : 1,00316
  - 13/6 14 mm disc : 1,002549
  - 12/6 19 mm disc : 1,00314
  - 12/6 25 mm disc with Sovar diff. Correction : 1,00248$_{1}$

- difference of ±2500 ppm. ==> Ongoing discussion.

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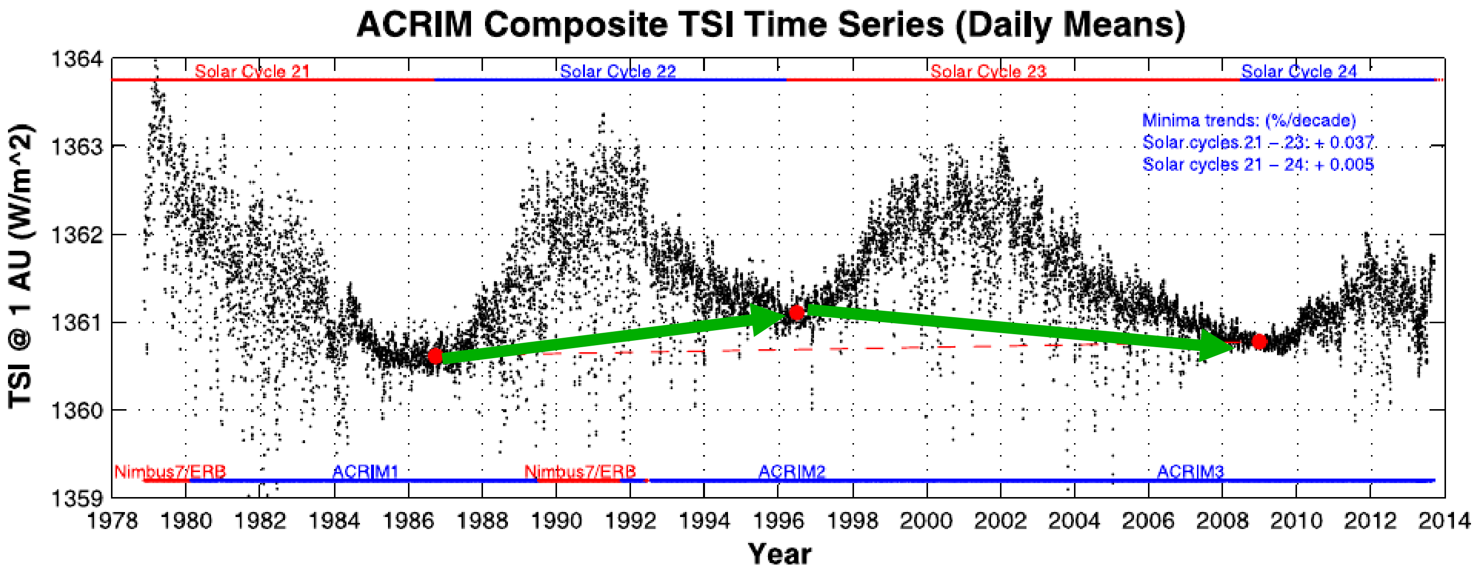
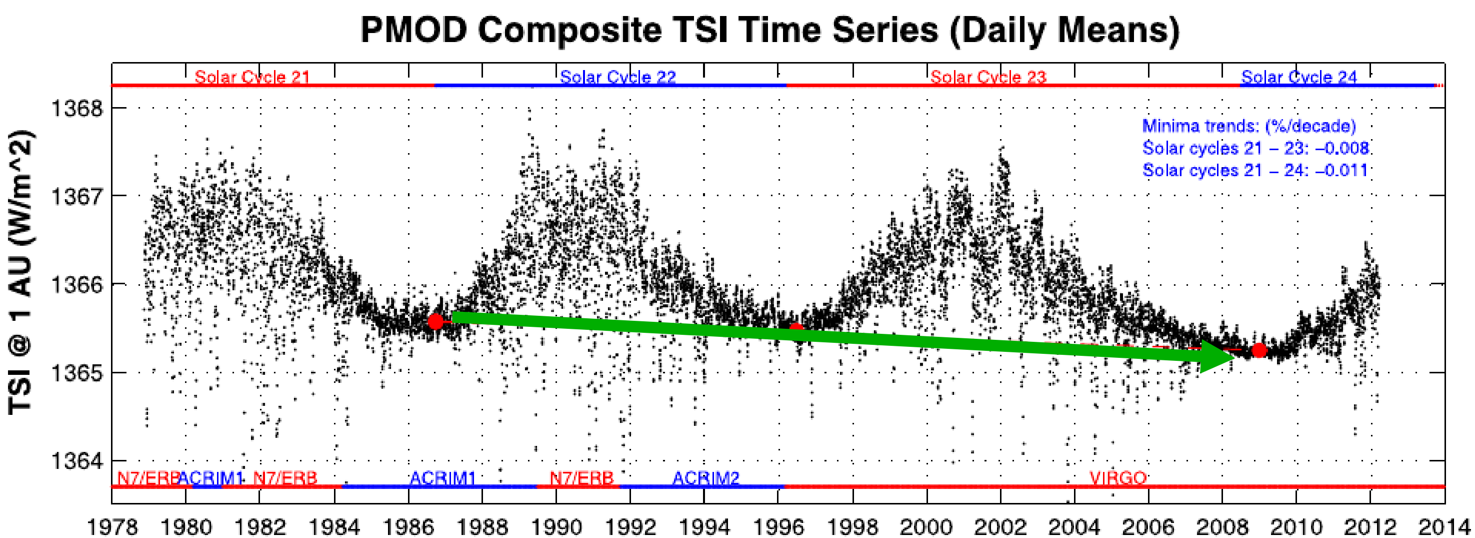
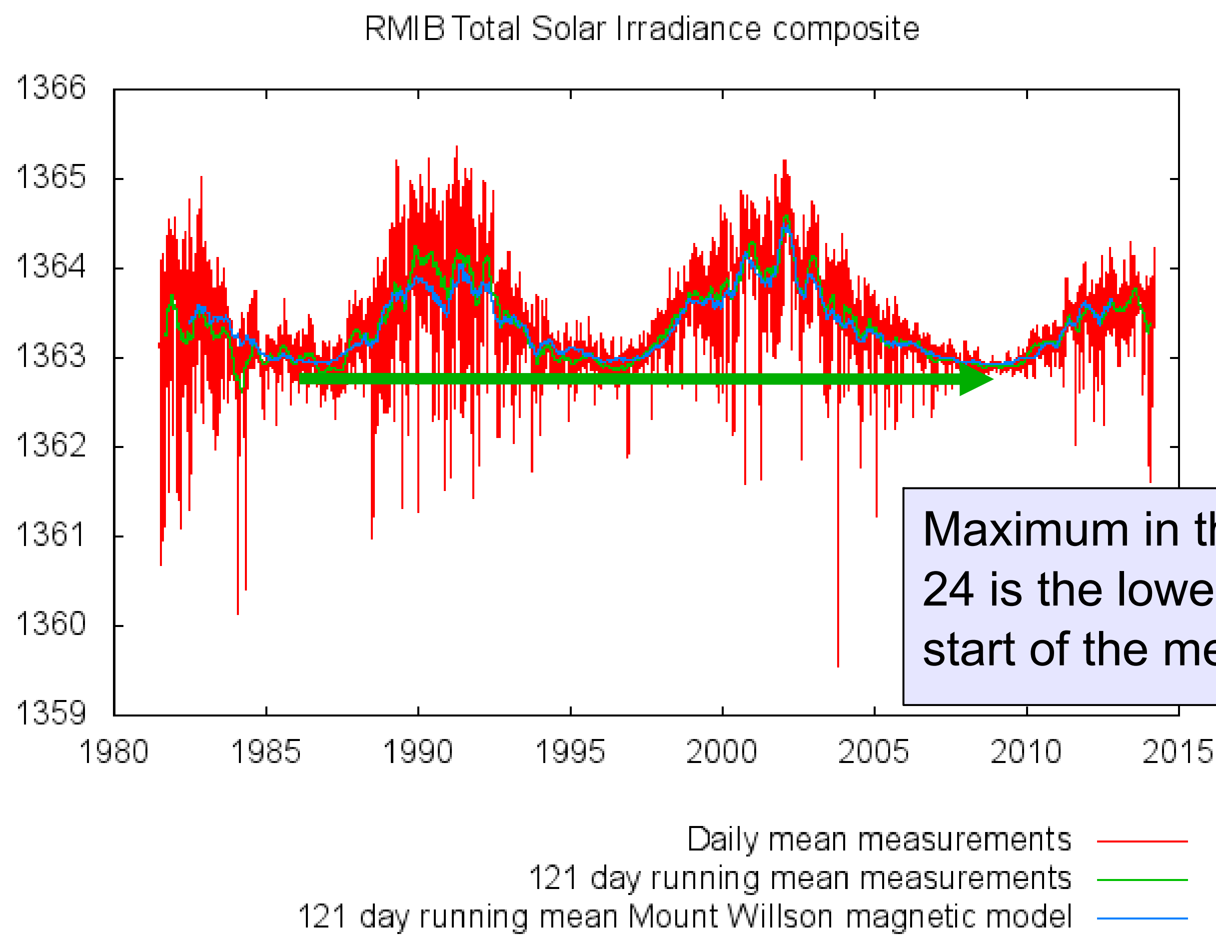
Comparison with ACRIM and PMOD composites





Scafetta and Willson Astrophys Space Sci DOI 10.1007/s10509-013-1775-9 (2014)

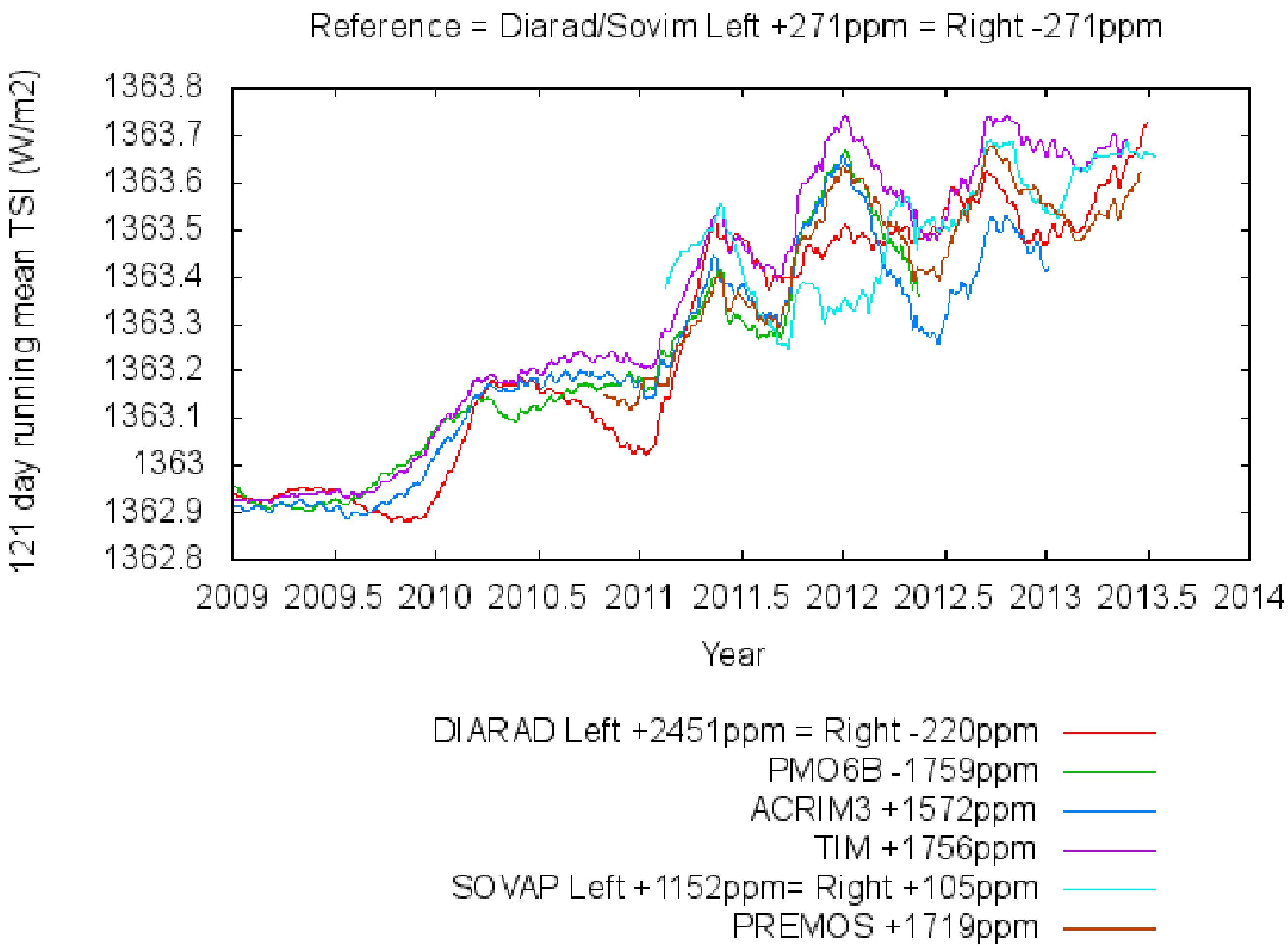
RMIB TSI data composite



Maximum in the current cycle 24 is the lowest since the start of the measurements

The latest version of our TSI composite can be found in
ftp://gerb.oma.be/steven/RMIB_TSI_composite/

Cycle 24 increase: different instruments



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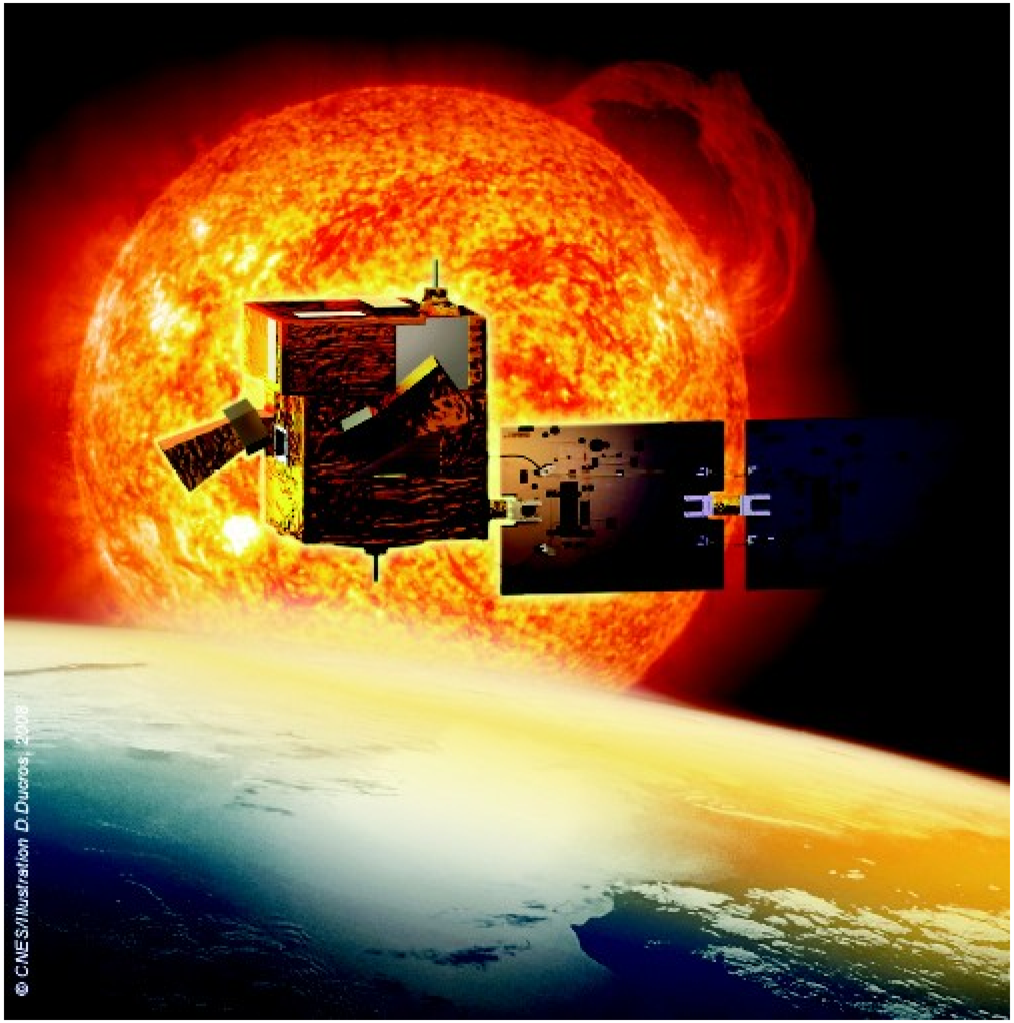
Conclusions

- Sova-P provides TSI results over the time interval June 2010 to March 2014.
- The absolute accuracy of the Sova-P TSI values is less during the period when we had problems with the right shutter.
- However, Sova-P provides a useful contribution to the monitoring of the current cycle 24, which is the lowest maximum since the start of the TSI measurements from space in 1978.
- The DIARADs efficiency correction factor has been revised due to the understanding of the non-equivalence inherent to all ESRs. This results in lower TSI values, closer to the TIM, ACRIM and PREMOS values, but still higher.
- Retrievable instruments are an asset for metrology.
- Some optical results are set-up dependant.

Needs

- Before flight characterisations.
- Instrumental equation.
- Traceability to known standards.
- Post flight assesement of degradation of parameters in the Instrumental equation. Retrievable instruments are an asset for metrology.
- Different instruments and designs is an asset for solar missions.
- Different optical characterisation procedure may help further understanding of results dependant from set-up .



Satellite Picard (CNES illustration D. Ducros 2008)

Thank you