Introducing a new effect in the DIARAD TSI calculation:

Thermal efficiency related to electrical effects

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Outline

- Introduction
- Experimental determination of the local efficiency
- Motivation for a thermal efficiency related to electrical effects
- Determination of the thermal efficiency
- Determination of the TSI
- Impact on the TSI values
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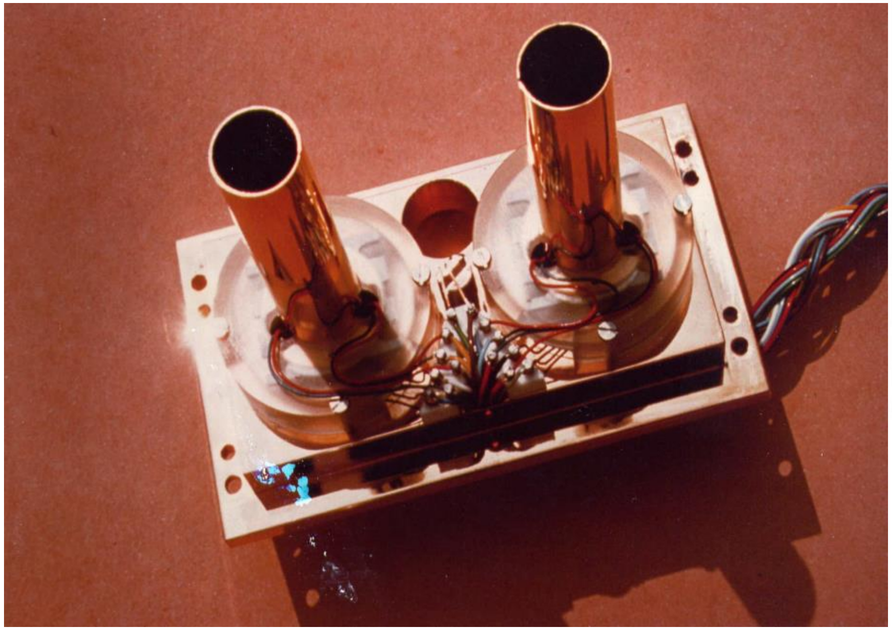
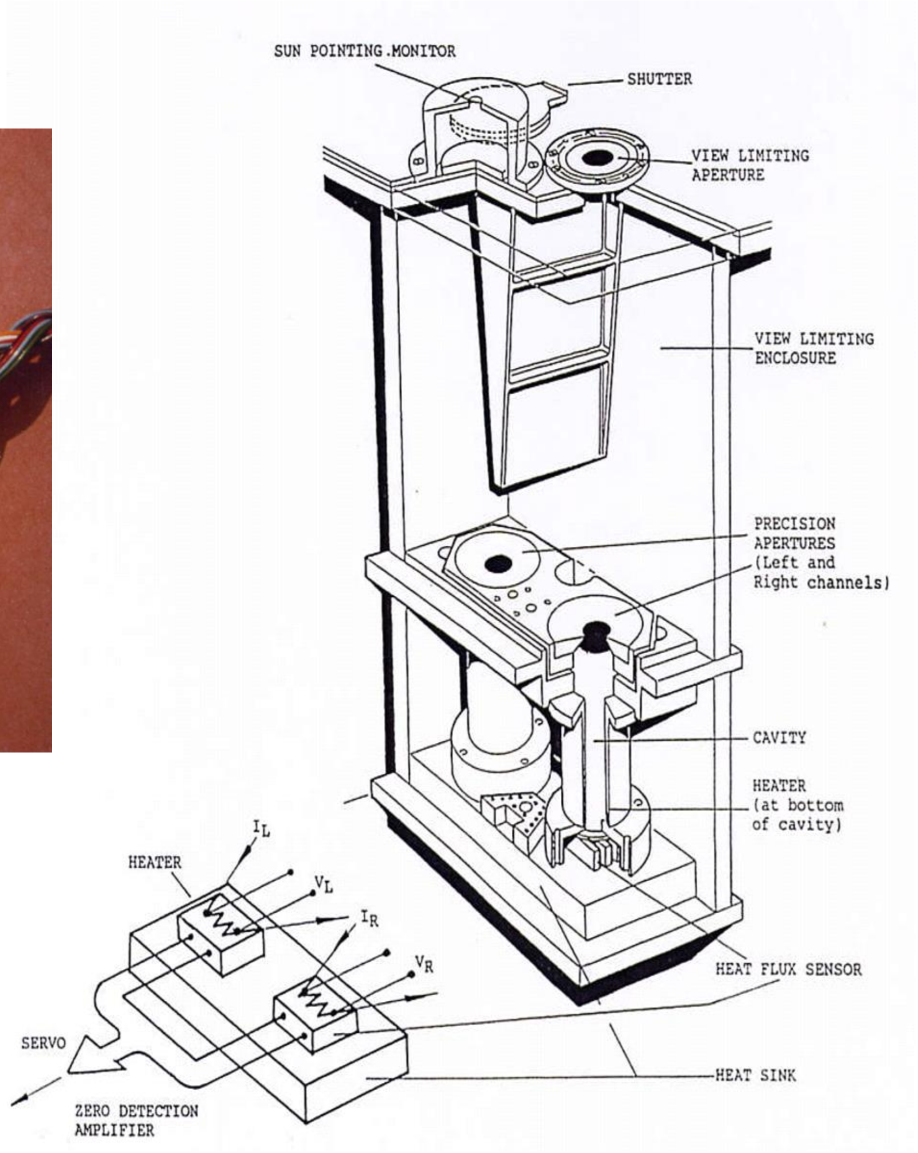
Introduction (1/2):
Concept of the DIARAD radiometer

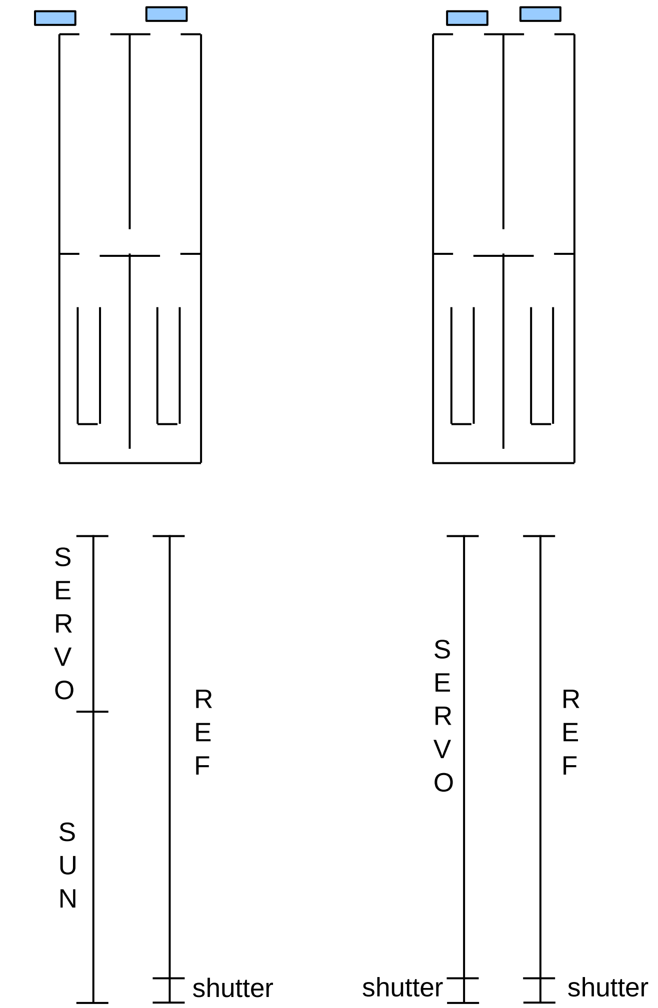




D. Crommelynck

Introduction (2/2): Working principle

Opened state: Closed state:



Equilibrium equations (e.g. A02)

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

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

$$-$$

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

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, ...

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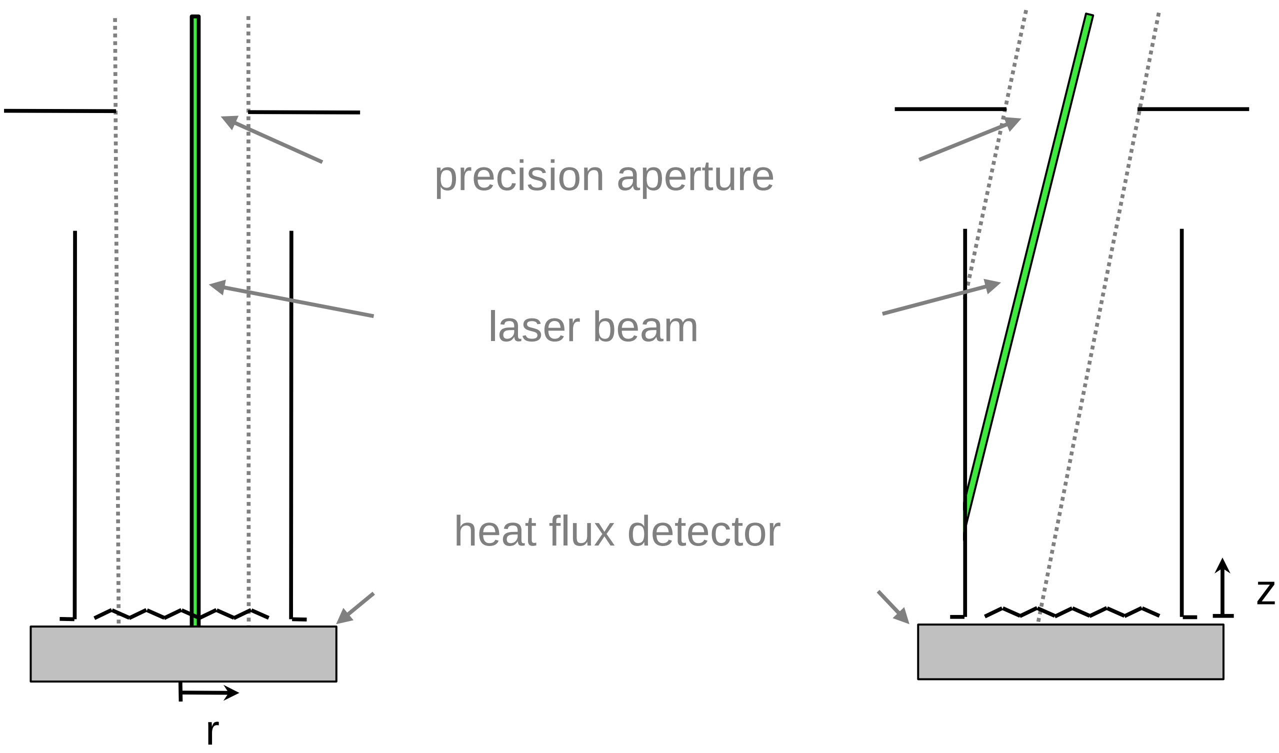
Experimental determination of the local efficiency

PHASE 1:
bottom efficiency distribution experiment

PHASE 2:
sidewall efficiency distribution experiment



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

For each laser position, the power difference is considered between the closed and opened state of the active cavity. This power difference is normalized with the power difference in the center of the bottom of the cavity, which results in a measure of the efficiency:

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

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

→ calculated for left and right channel

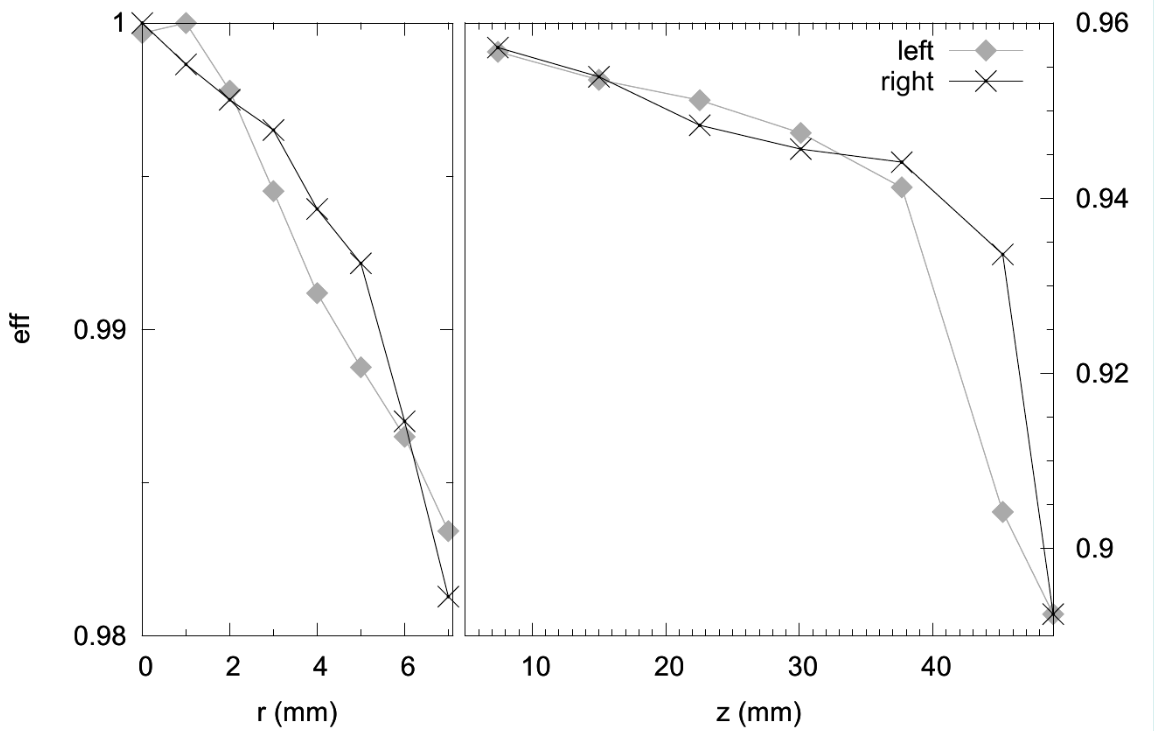


Figure: Relative local efficiency distribution for the left and right cavities of SOVAP. Radial distribution and distribution along the height of the cylinder wall.

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Experimental determination of the local efficiency

These graphs illustrate the efficiency by which absorbed heat is detected, in function of the location at which the heat was originally applied.

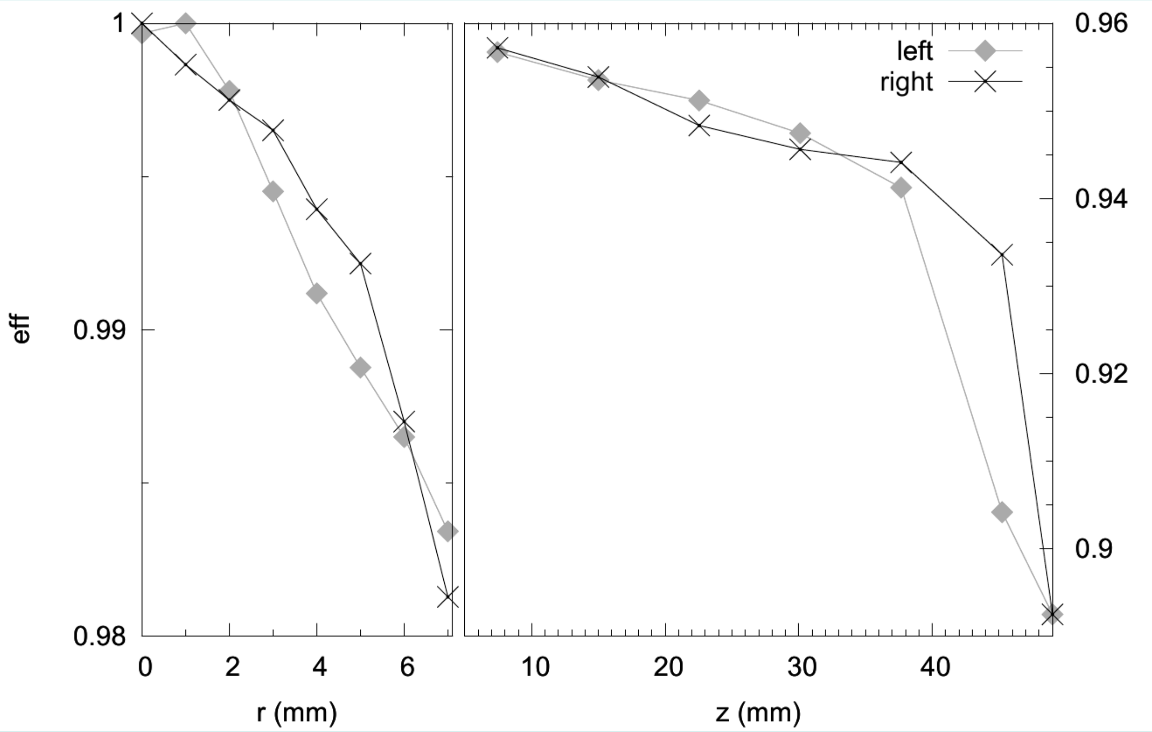

Figure: Relative surface efficiency distribution for the left and right cavities of SOVAP. Radial distribution and distribution along the height of the cylinder wall.

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Motivation for a thermal efficiency related to electrical effects

There exist two power contributions to the cavity:

1) The optical power originating from the sun.

2) The electrical power delivered to the heating resistor.

Both powers are transferred into heat, and the absorbed heat is detected with a certain efficiency.

Motivation for a thermal efficiency related to electrical effects

In previous research:

$\alpha_{th,elect} = 1$

No heat losses were considered for the detection of the heat dissipated by the heating resistor.

→ Assumptions:

1) $\alpha_{th,elect} < 1$

2) The detected heat dissipated by the heating resistor and the heat originating from the sun are both detected with the same LOCAL efficiency.

In other words: that the experimentally measured local efficiency curve can be used for the calculation of $\alpha_{th,elect}$

Experimental verification

Setup:

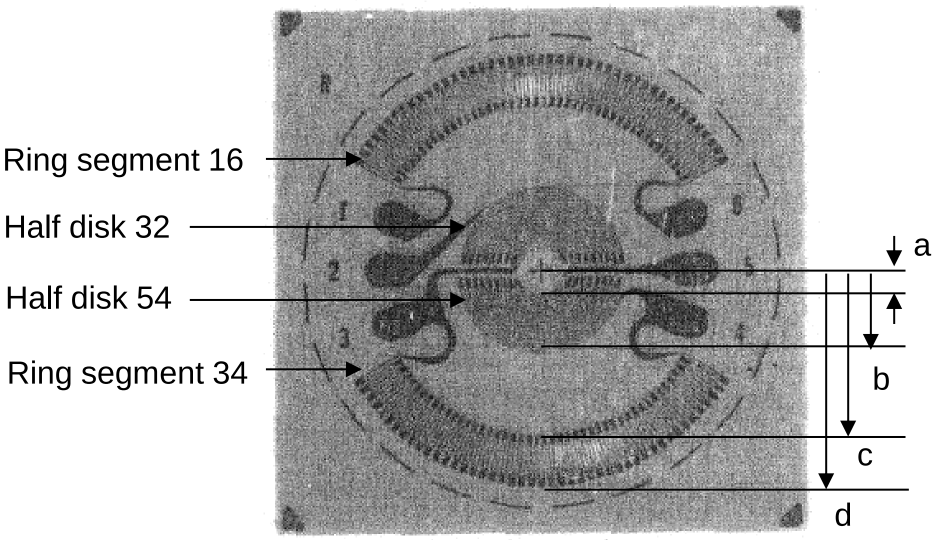
resistor was mounted on the Peltier element

Determination of the sensitivity:

S = Vpel / P
Vpel : voltage over the Peltier
P: input power

Different tests:

for 4 separate regions of the resistor
without and with the tube mounted



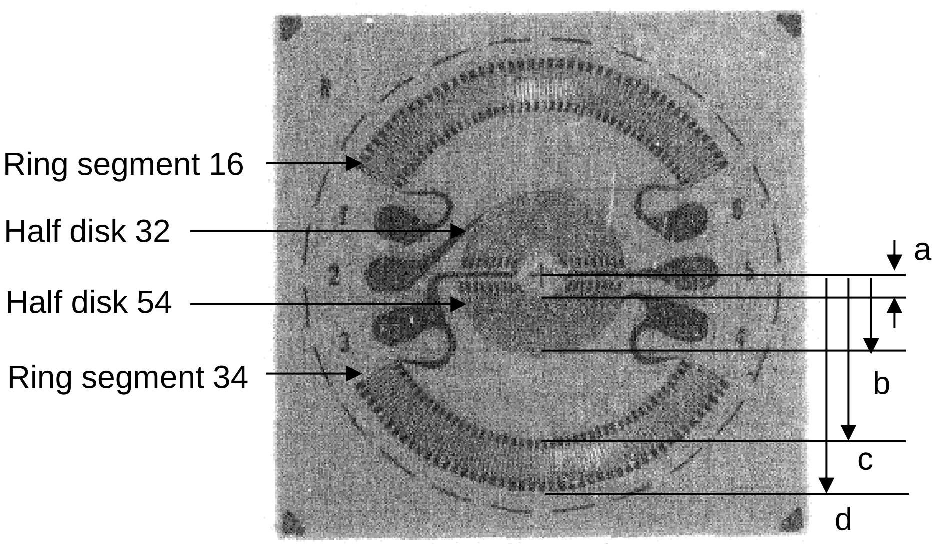
Heating resistor that consists of 4 zones

	r (mm)
a	0.64
b	2.25
c	4.50
d	5.78

Experimental verification

Remarks:

- In case of an electrically generated heat, in the absence of optical power.
- Valid for a cavity without deposited black paint.
- Comparisons between 'half disks' and 'circle segments'.



Heating resistor that consists of 4 zones

Difference in sensitivity *S*:

$$(S_{circle} - S_{disk}) / S_{disk} =$$ **0.7 % without tube**
1.3 % with tube

Conclusions:

- There exists a local sensitivity for the electrical power too: S(x,y)
- The tube reduces the local sensitivity to the electrical power

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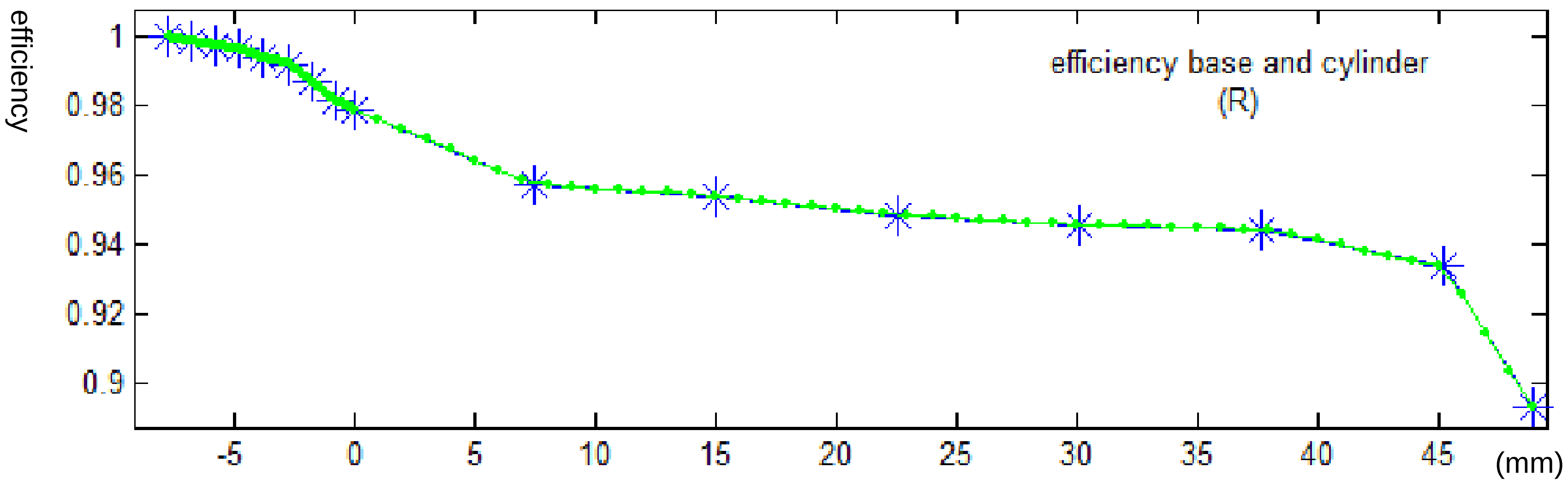
Definition of the thermal efficiency

$$\alpha_{th,elect} = \frac{\text{measured electrical power}}{\text{absorbed electrical power}} < 1$$

$$\alpha_{th,opt} = \frac{\text{measured solar power}}{\text{absorbed solar power}} < 1$$

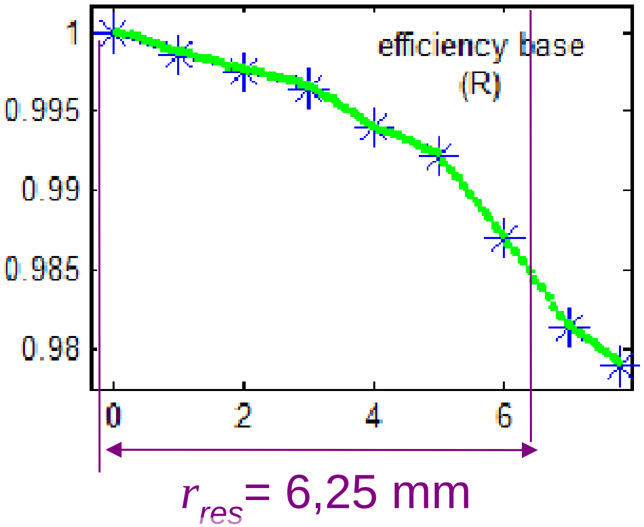
Both parameters are calculated from the experimentally measured local efficiency:



Determination of the thermal efficiency related to electrical effects

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

$$\alpha_{th,elect} = \frac{1}{r_{res}^2} \sum_{n=1}^{N_{res}} \left[r(n)^2 - r(n-1)^2) \right] \quad \left[eff_r(n) - eff_r(n-1) \right] /2$$



Determination of the thermal efficiency related to optical effects

Main term

$$\alpha_{th,opt}\, a_R = a_{paint}\, \overline{eff_r}$$

Correction 1st order reflections

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

Correction 2st order reflections

$$+ (1 - a_{paint})^2\, a_{paint} \sum_{n=1}^{N} \sum_{m=1}^{M} F_{disk-\Delta z_m}\ [F_{\Delta z_m - \Delta r_n}\, eff_r(n) + F_{\Delta z_m - \Delta z_m}\, eff_z(m)]$$

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

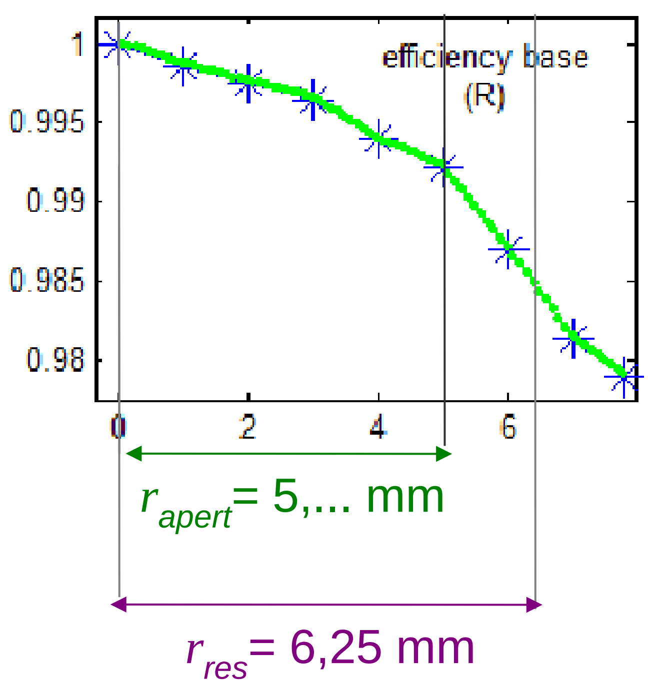
Correction reflection at the mirror

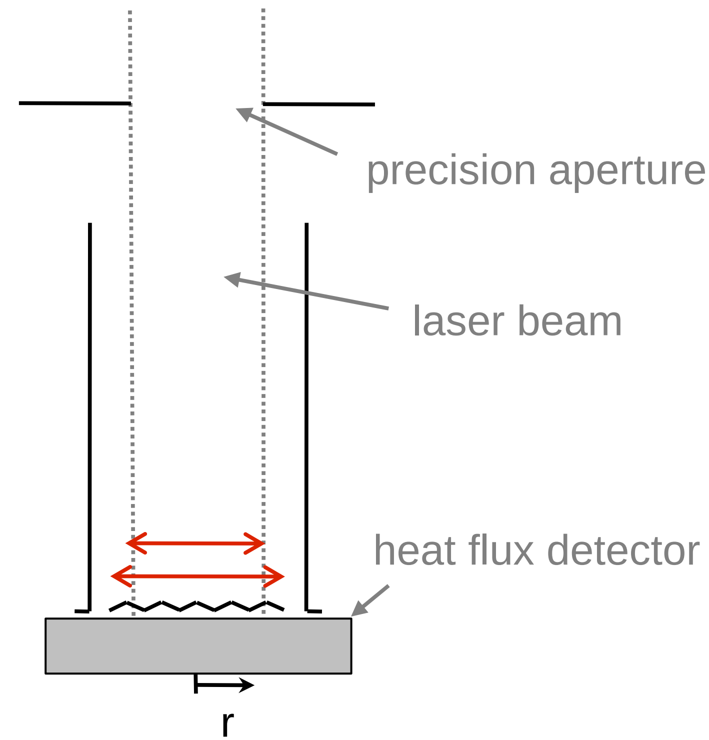
D. Crommelynck, A. Fichot, F. Bauwens

Comparison $\alpha_{th,elect}$ *and* $\alpha_{th,opt}$

$\alpha_{th,elect}$ = mean over area heating resistor

lowest order term of $\alpha_{th,opt}\, a_R$ = mean over (projected) area precision aperture





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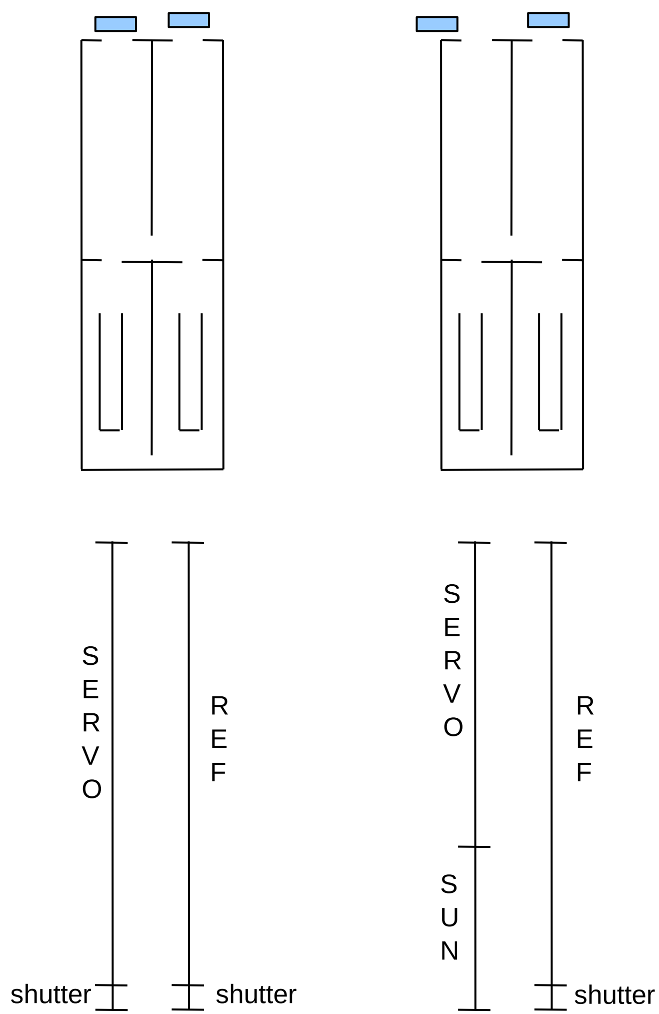
Equilibrium equations (e.g. A02)



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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

Previous:

$$\alpha_{th,opt} P_{SUN} = P_{close} - P_{open} + \alpha_{th,opt} P_{shutter}$$

$$\Rightarrow P_{SUN} = \frac{P_{close} - P_{open}}{\alpha_{th,opt}} + P_{shutter}$$

New approach:

$$\alpha_{th,opt} P_{SUN} = \alpha_{th,elect} P_{close} - \alpha_{th,elect} P_{open} + \alpha_{th,opt} P_{shutter}$$

$$\Rightarrow P_{SUN} = \boxed{\frac{\alpha_{th,elect}}{\alpha_{th,opt}}} (P_{close} - P_{open}) + P_{shutter}$$

= NON-EQUIVALANCE ratio

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, ...

TSI equation

$$I = \frac{1}{S(T)} \frac{\Delta P \frac{\alpha_{th,elect}}{\alpha_{th,opt} A_r} + (P_{shutter} + P_{shutter,refl})(1 + \Sigma_{shutter})}{(1 + \Sigma + \Sigma' + \delta)}$$

$$TSI = \frac{I}{\cos(\theta)} \left(\frac{r}{1\ \mathrm{AU}}\right)^2 \left(1 + \frac{2}{c}\frac{\mathrm{d}r}{\mathrm{d}t}\right)$$

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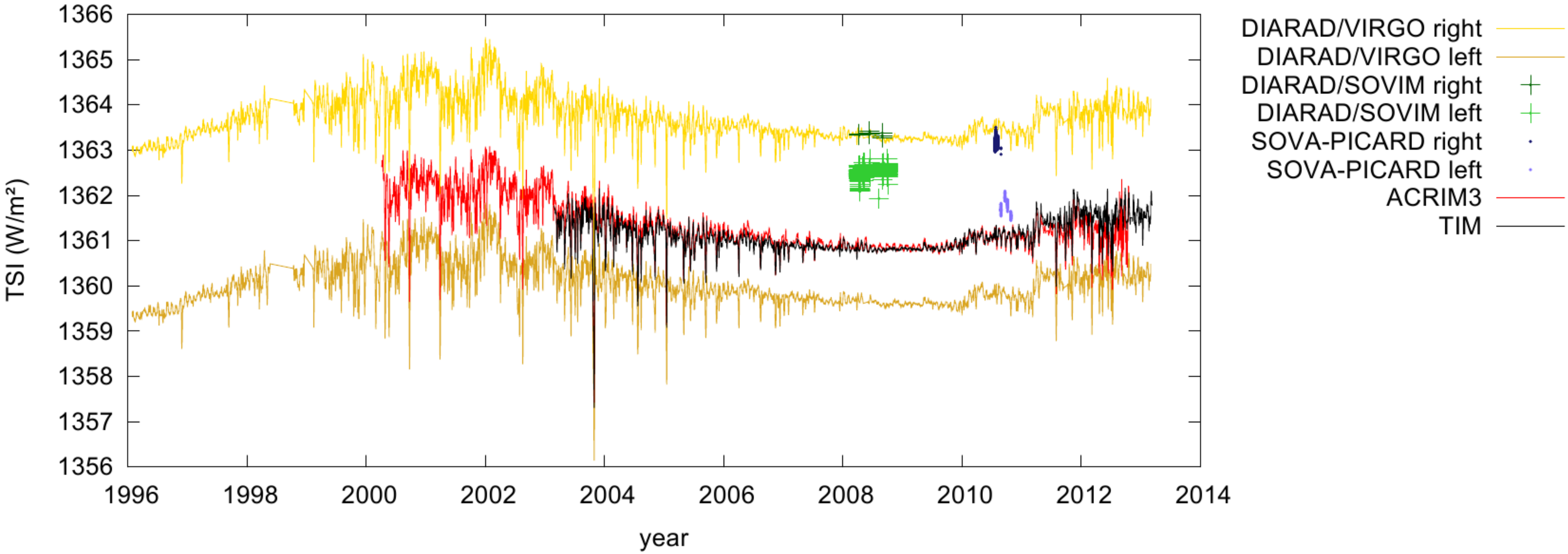
Total Solar Irradiance measurement series



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Conclusions

- The non-equivalence between optical and electrical power contributions inside the cavity was determined and was taken into account in the TSI-equation.

- Introduction of this non-equivalence results in lower TSI values, closer to the TIM, ACRIM and PREMOS values.

- M. Meftah has developed an alternative method for the TSI calculation, based on a theoretical model, which gives comparable results (presentation tomorrow).

Thank you