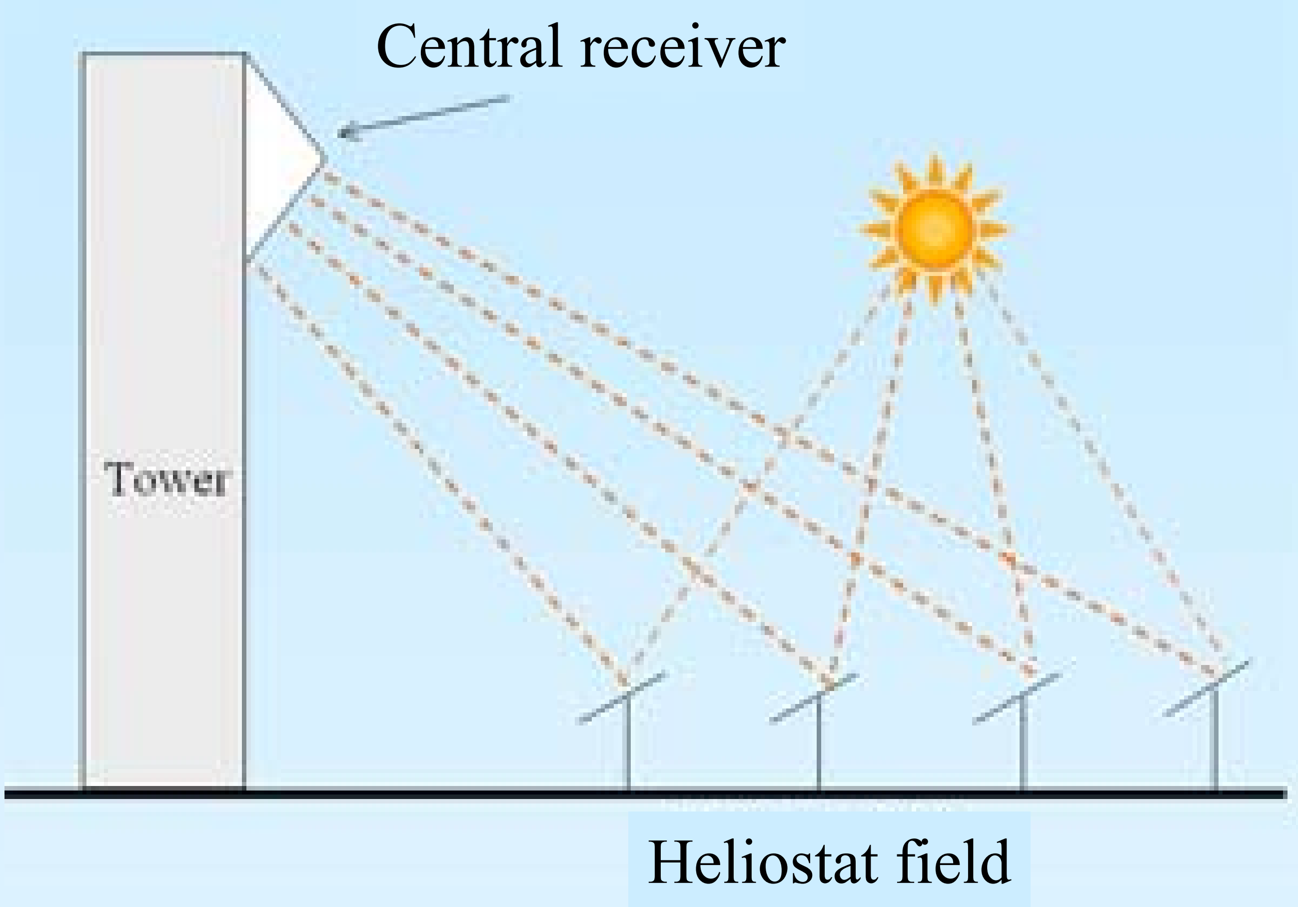
1st Meeting. SOLLAB Flux and Temperature Measurement Group

J. Ballestrín

CIEMAT-Plataforma Solar de Almería (SPAIN)


Central receiver
Tower
Heliostat field

CAMERA / TARGET METHOD: Indirect Heat Flux Measurement

- CCD camera: 14 bit digitization

  1024 x 1280 pixels (pixel size:6.7 µm x 6.7 µm)

  Spatial resolution: 2 mm

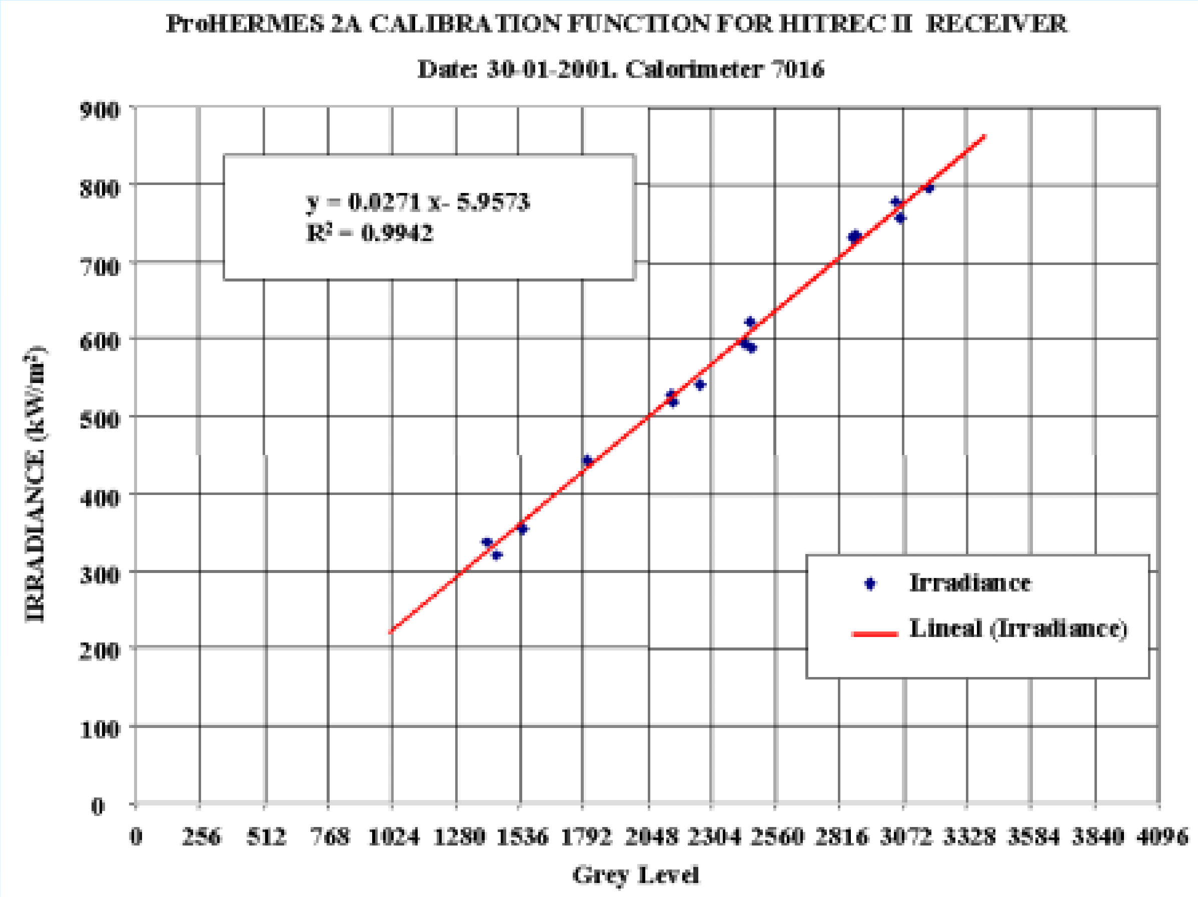
- Lambertian target.

- Water cooled calorimeter (∅ 25 mm)

- From gray levels to kW/m^2.

- Accuracy of heat flux sensor: ± 3-4%

- Accuracy of the power measurement: ± 5-6%


ProHERMES 2A CALIBRATION FUNCTION FOR HITREC II RECEIVER
Date: 30-01-2001. Calorimeter 7016
y = 0.0271 x- 5.9573
R² = 0.9942
IRRADIANCE (kW/m²)
Grey Level
Irradiance
Lineal (Irradiance)
0
100
200
300
400
500
600
700
800
900
0 256 512 768 1024 1280 1536 1792 2048 2304 2560 2816 3072 3328 3584 3840 4096

MDF Direct Heat Flux Measurement

• Array of themopiles (HFM fluxmeters).

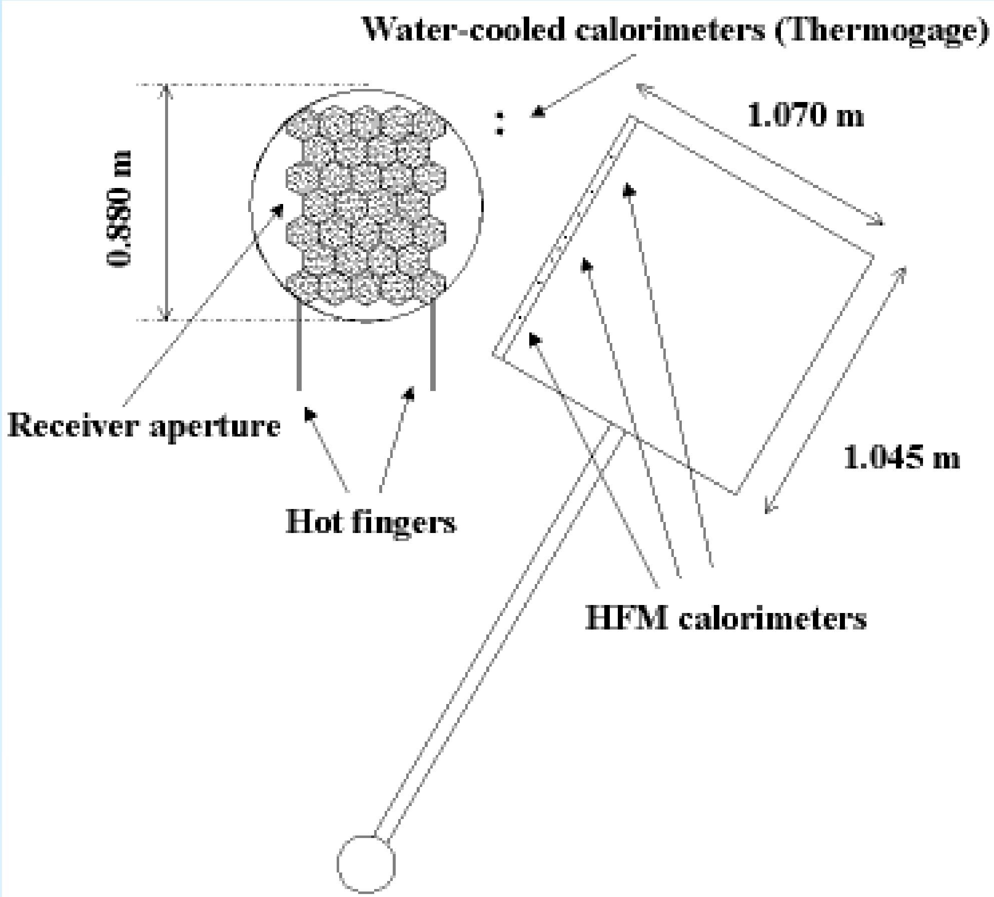
• Small area (∅ 6.32 mm)

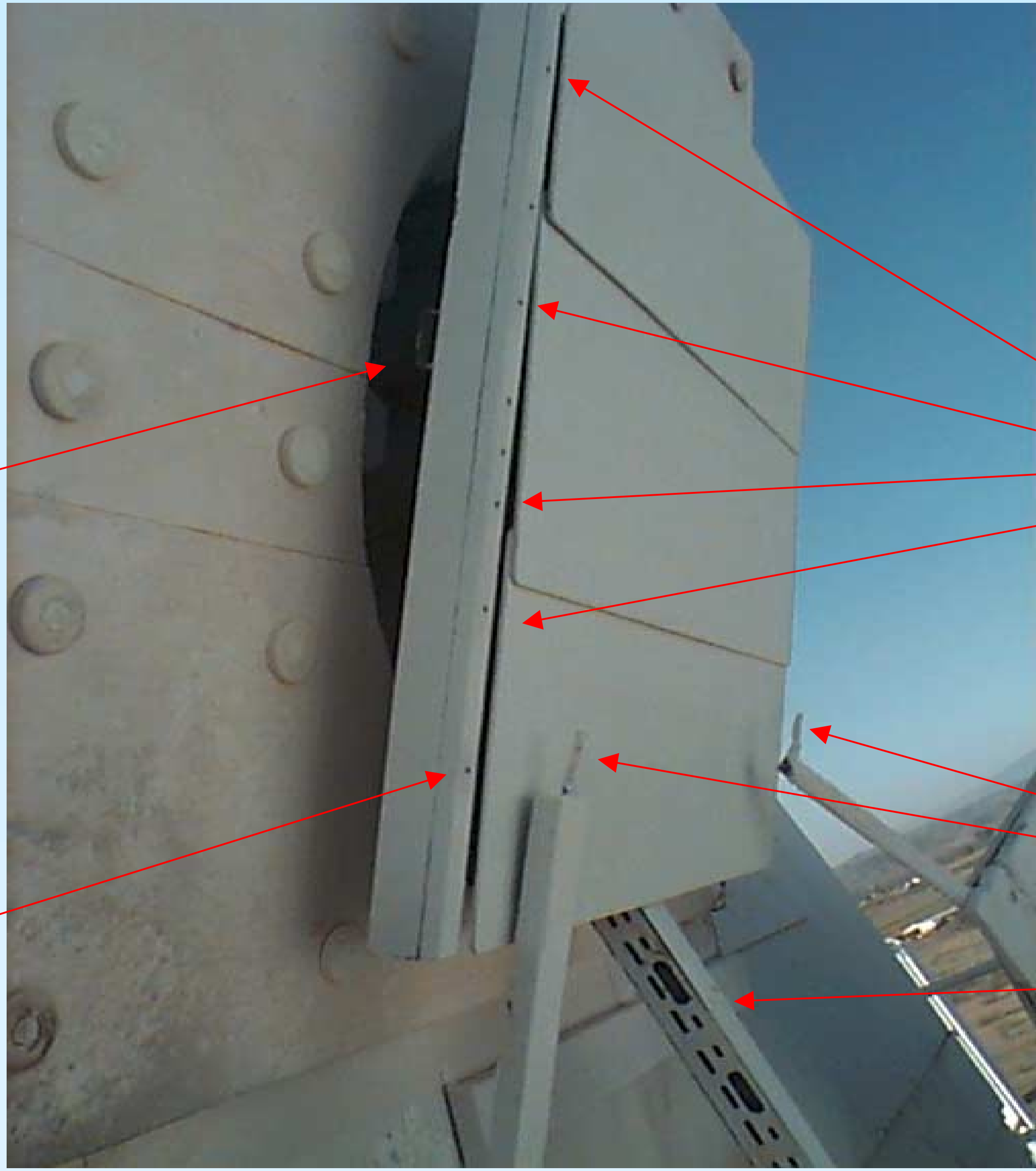
• Response time ~ 10 microseconds.

Measuring without water-cooling.

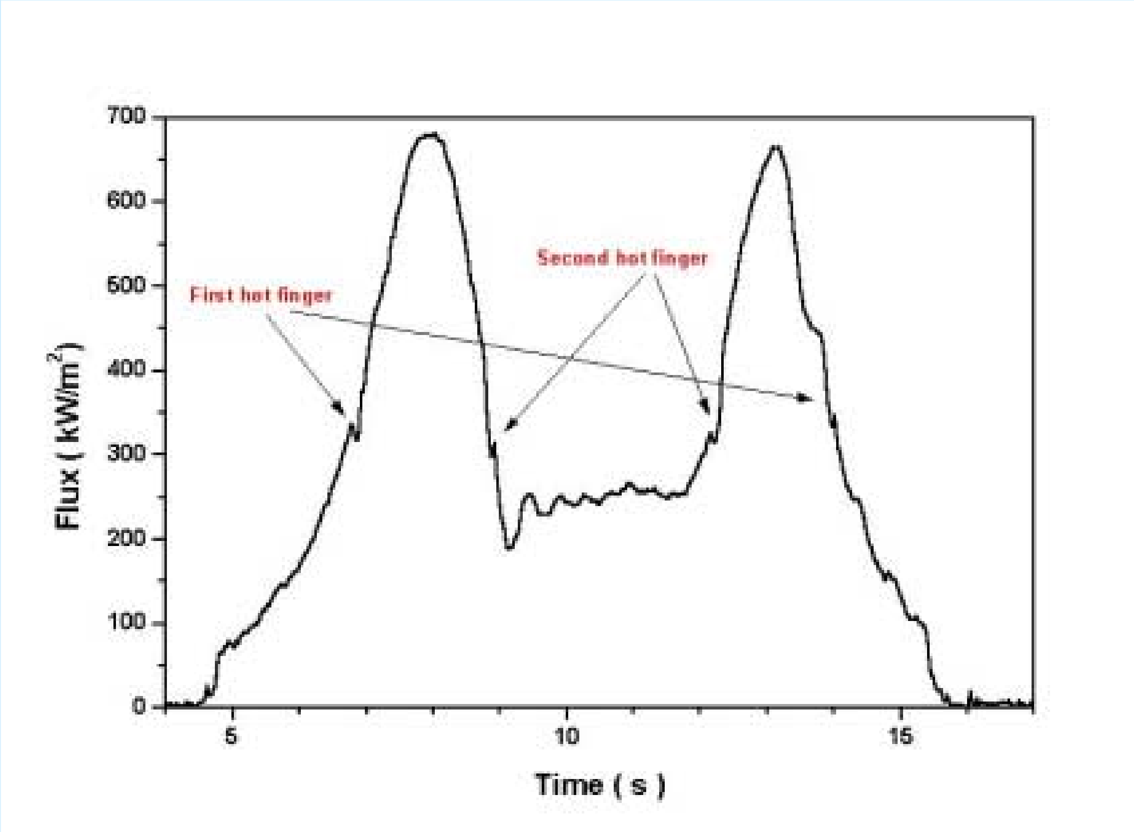
• Accuracy of fluxmeters ± 3%

• Accuracy of the power measurement ± 5-6%

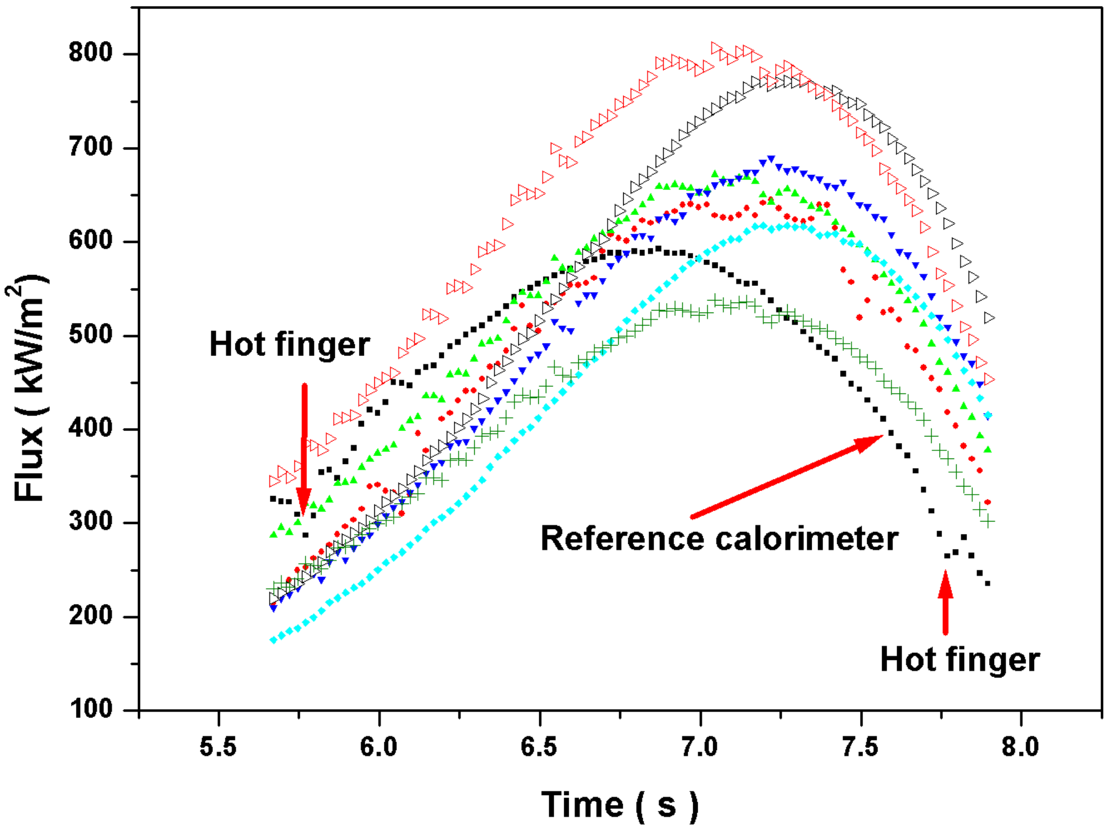

Water-cooled calorimeters (Thermogage)
1.070 m
0.880 m
Receiver aperture
Hot fingers
1.045 m
HFM calorimeters


Receiver
aperture
HFM
calorimeters
Hot fingers
Reference
calorimeter
Rotary rod

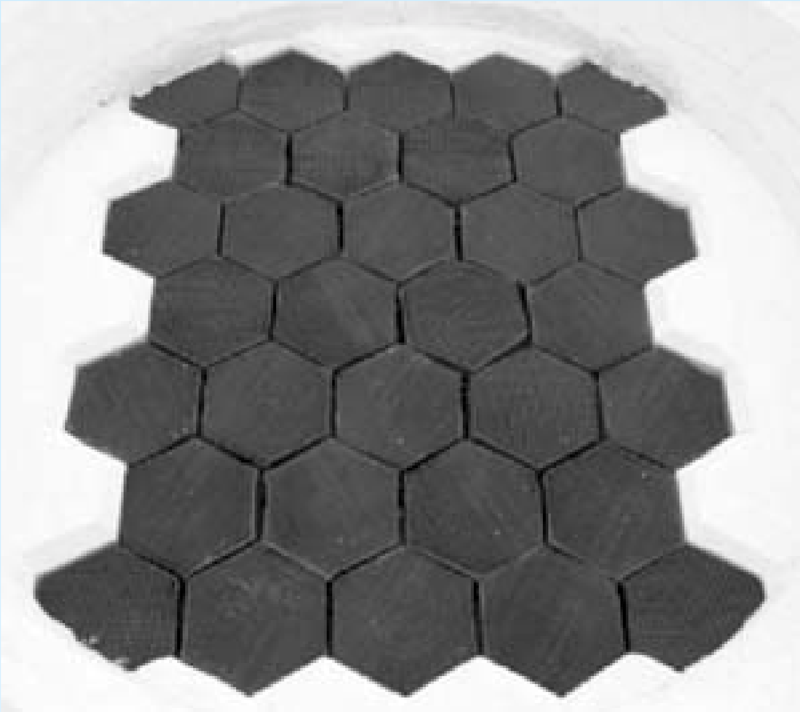
Signal from the reference HFM calorimeter

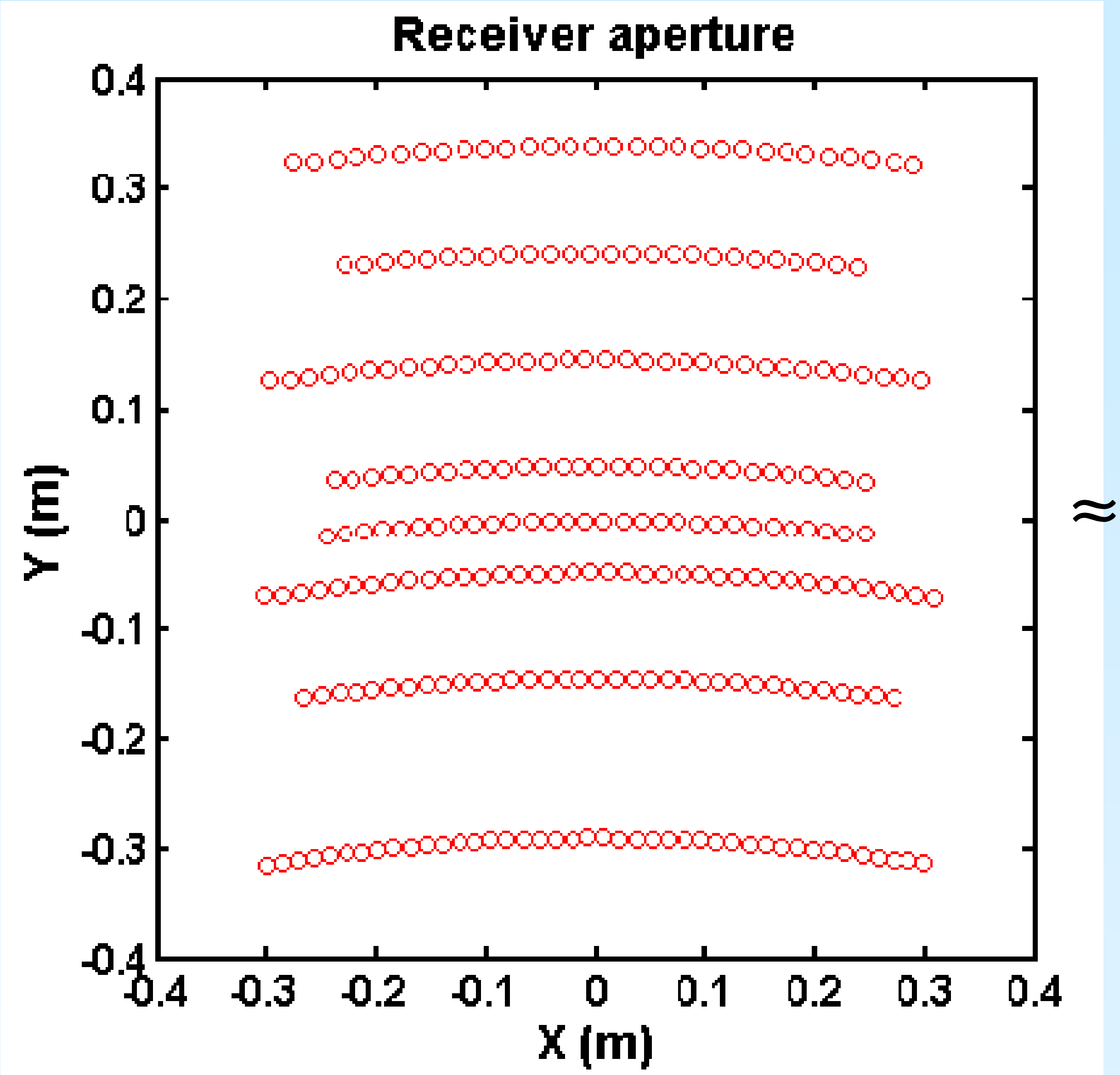


Signals from HFM calorimeters

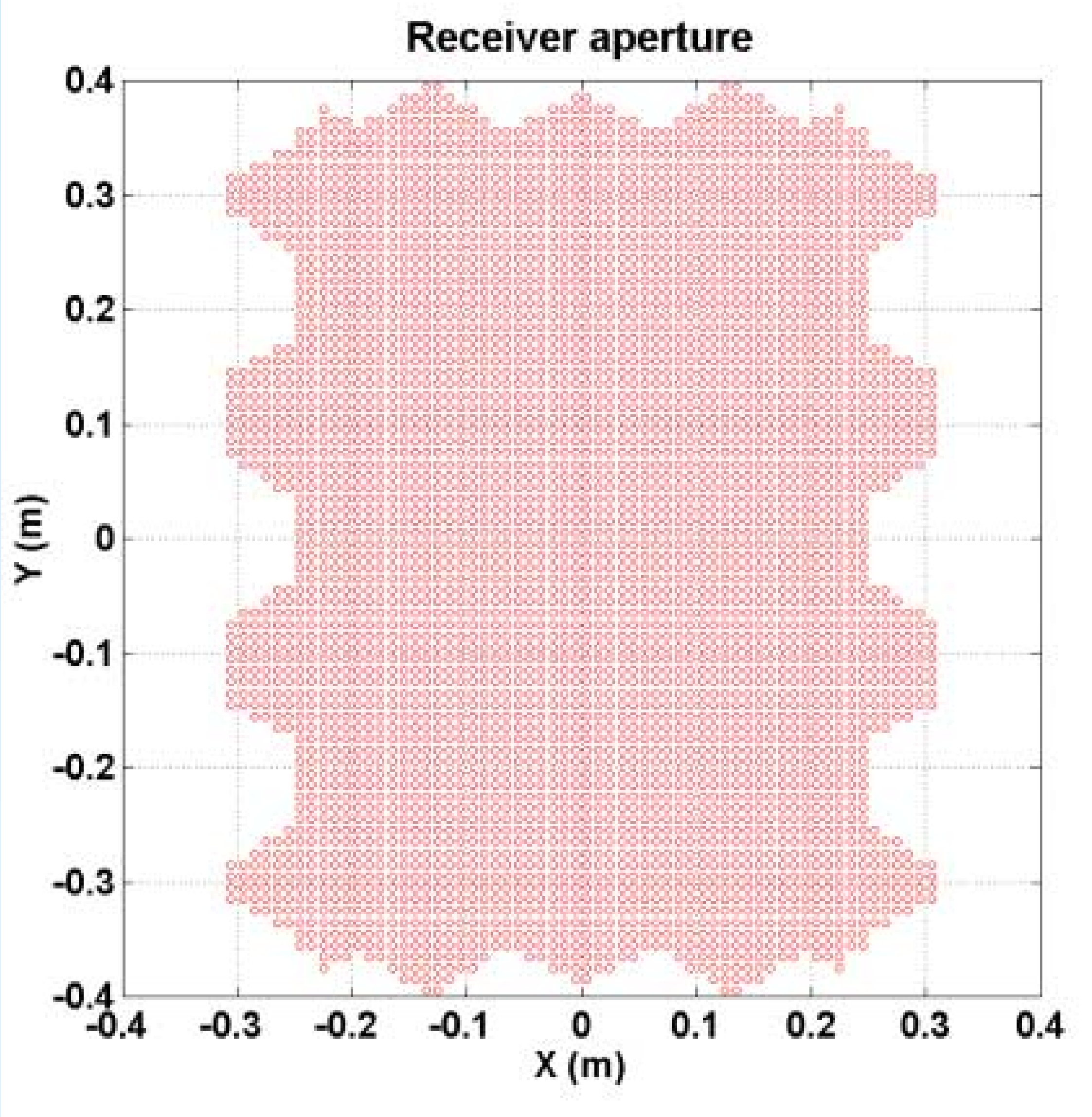


Hitrec II receiver aperture



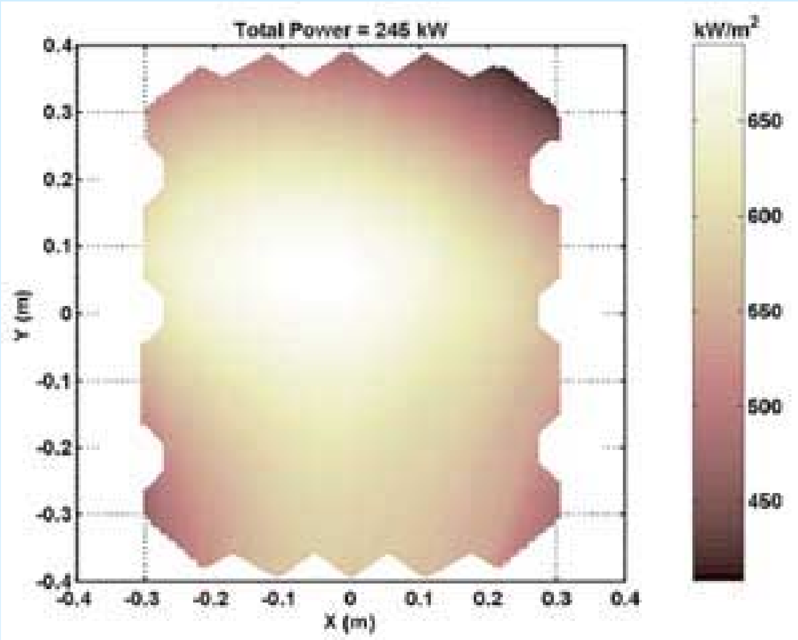

Receiver aperture
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
Y (m)
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
X (m)

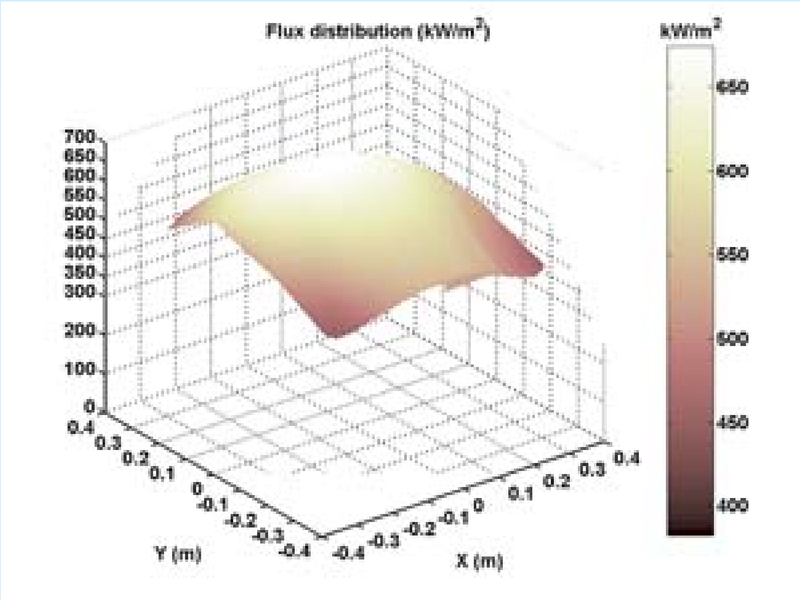
≈ 300 data



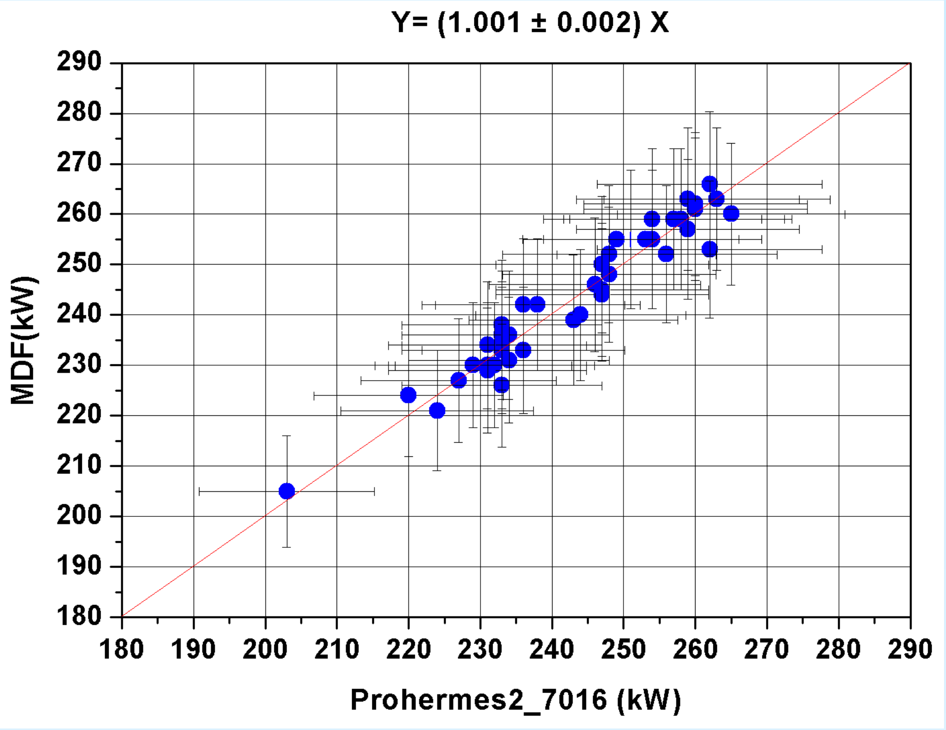
≈ 4000 data

$$\mathbf{P = \frac{A}{n}\sum_{i=1}^{n} F_i}$$


Total Power = 245 kW
kW/m2
650
600
550
500
450
Y (m)
X (m)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4


Flux distribution (kW/m²)
kW/m²
650
600
550
500
450
400
700
650
600
550
500
450
400
350
300
200
100
0
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
Y (m)
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
X (m)

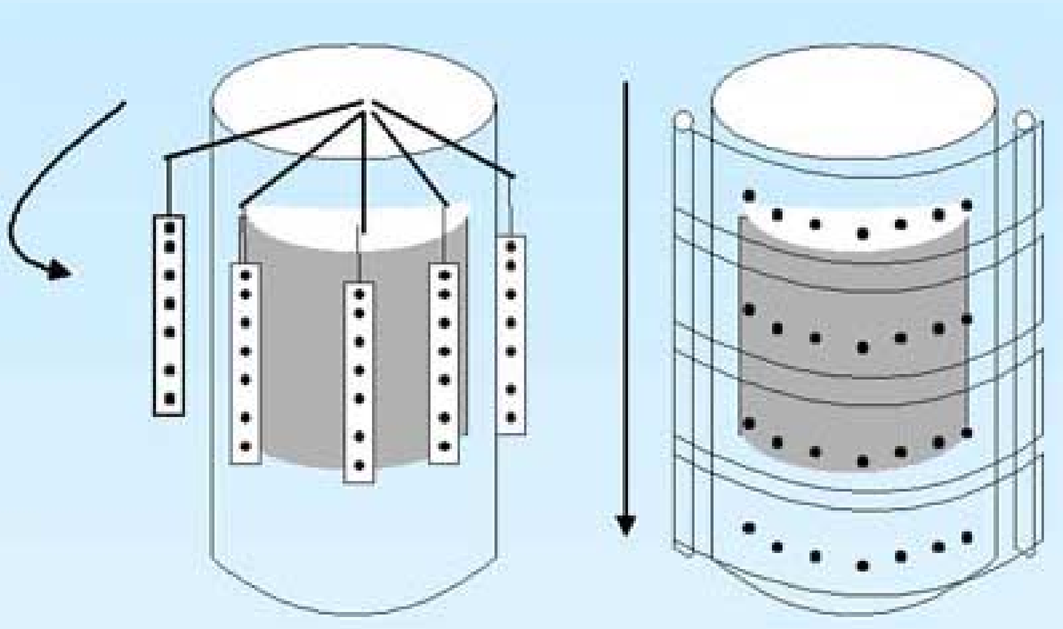
Direct system (MDF) *versus* Indirect system (ProHERMES 2)



Advantages and disadvantages

- Spatial resolution
- Simplicity
- Accuracy

How to measure in a non-plane receiver aperture ?



SUMMARY 1

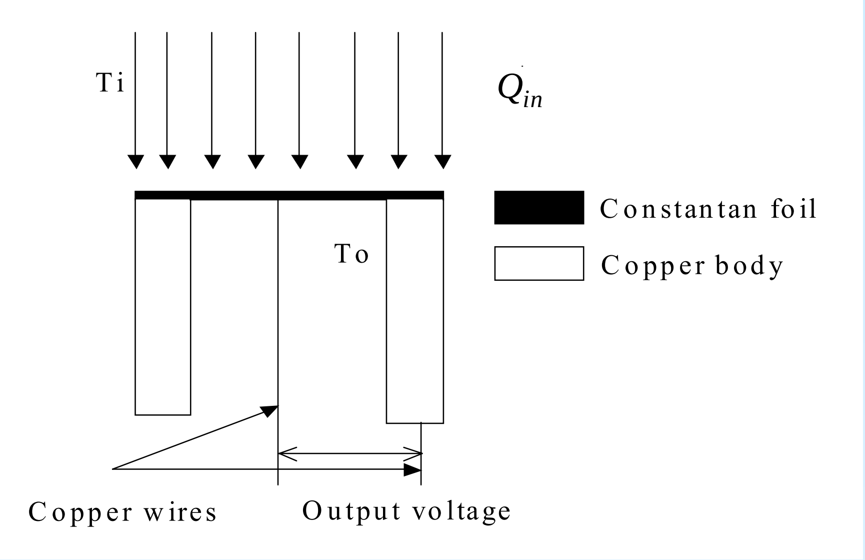
• A hybrid system and procedure for measuring the incident power on the aperture of solar receivers have been demonstrated.

• The advantages of each of the approaches enrich the overall system and thereby the measurements made with it.

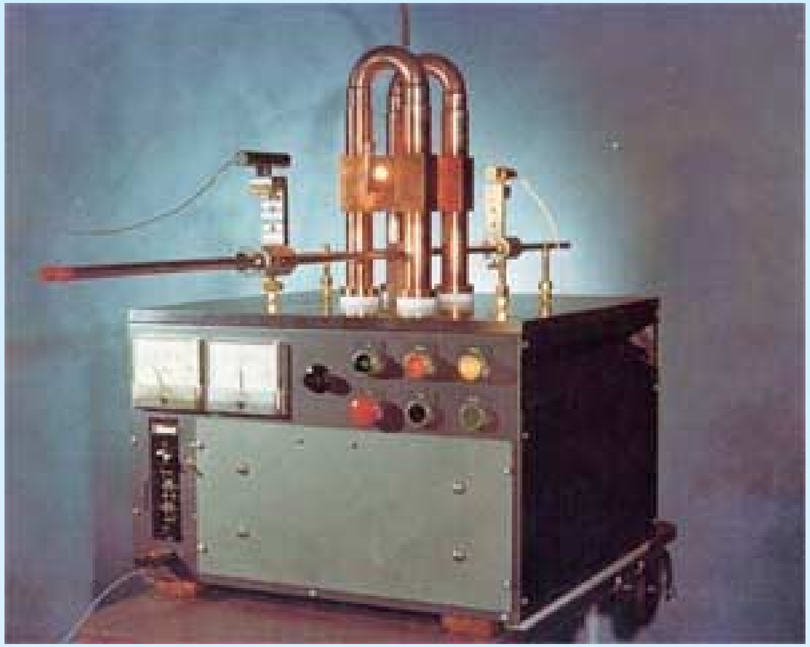
• Working with both systems, it is possible to detect changes in their calibration.

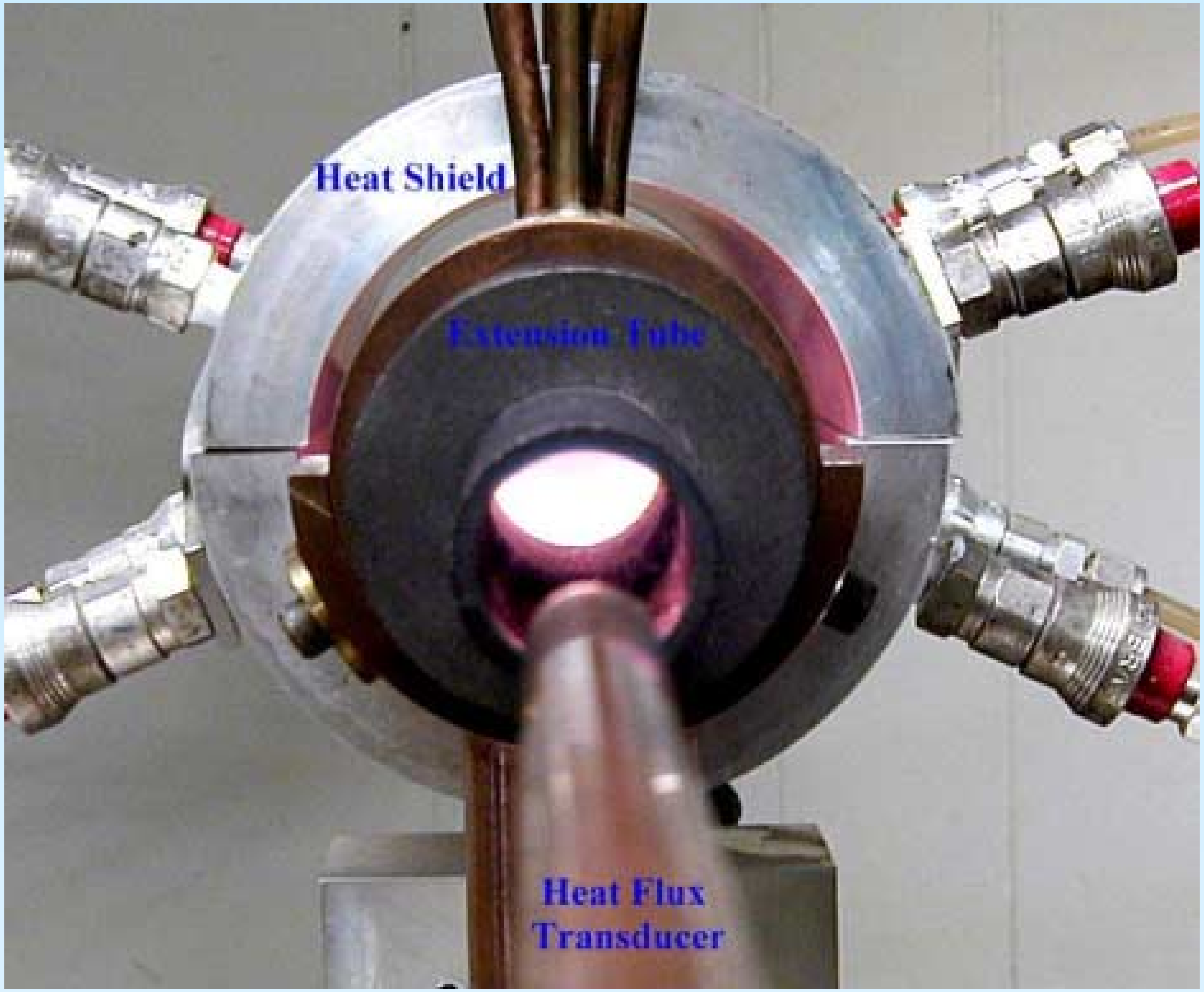
• The good agreement betweeen the two methods allows the use of a heat-flux measurement system based on either the direct or the indirect concept or hybridized, depending on the receiver geometry and the size of the area to be scanned.

GARDON HEAT-FLUX SENSORS



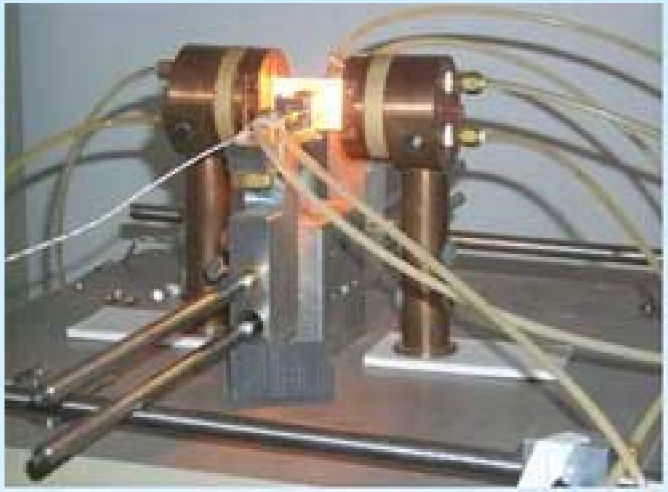
Calibration by using dual cavity black-body

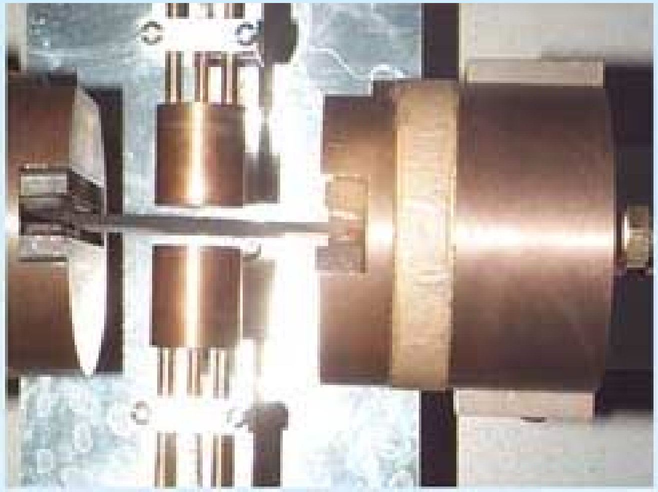




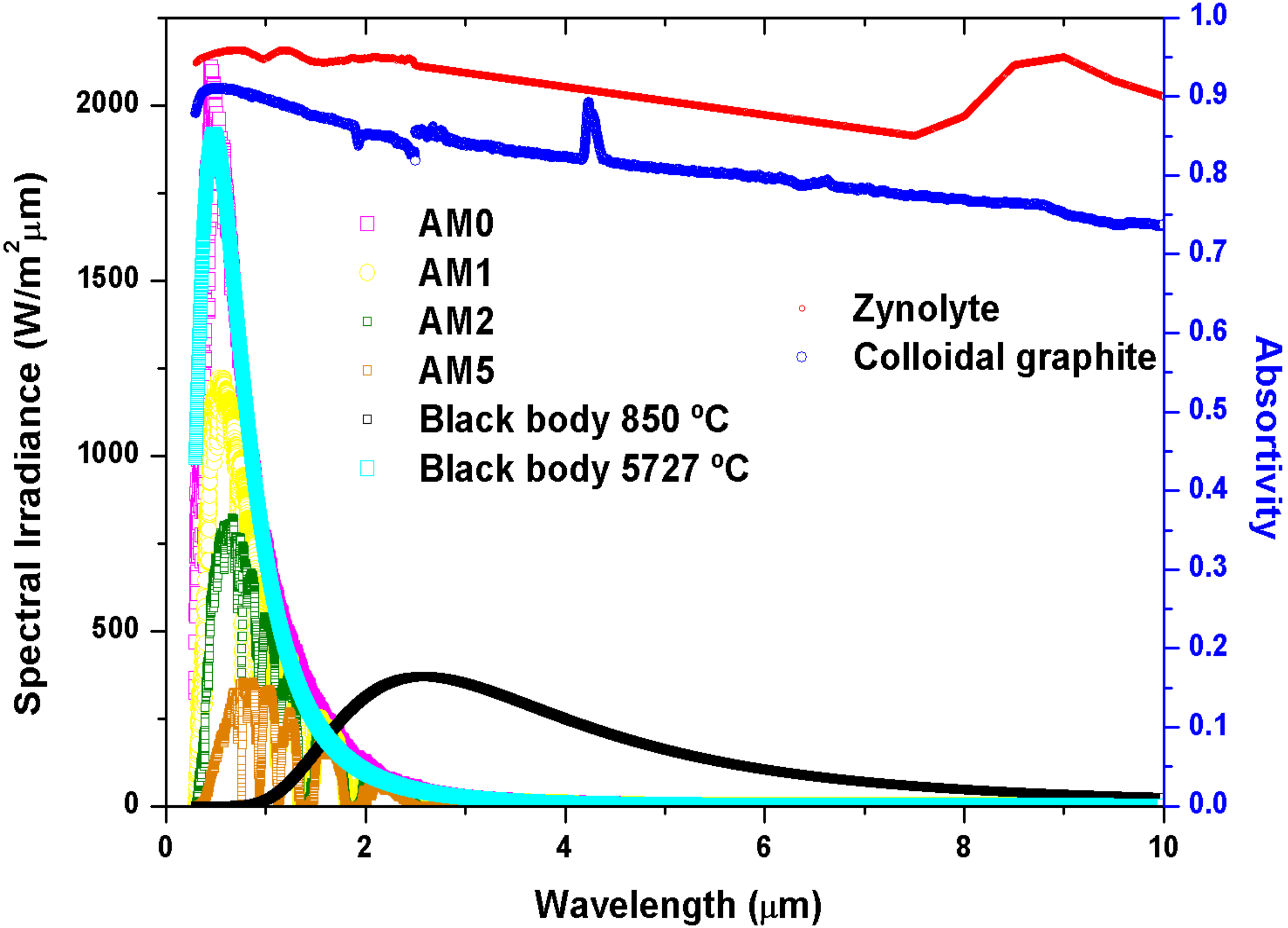
Stefan-Boltzmann law; $\Delta T \rightarrow heat \quad flux \quad error \propto (\Delta T)^3$

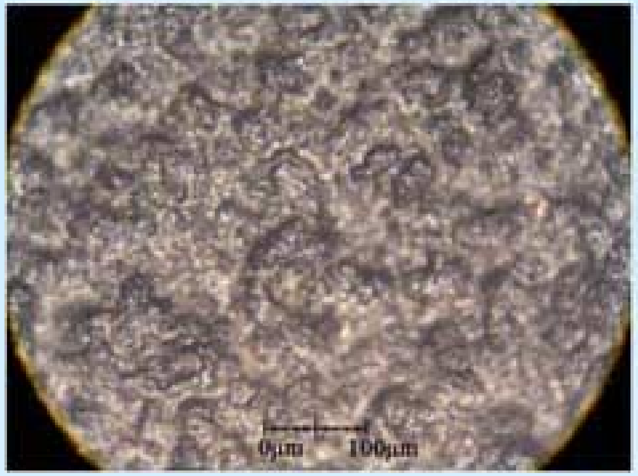
Comparison of calorimeters in the laboratory





Normalized Spectral Distribution (1353 W/m^2, Solar constant)





Zynolyte

Colloidal graphite

Zynolyte:

•The sensor overestimates the solar irradiance by 3.6%

•Solar absortance 95.4 %

Colloidal graphite:

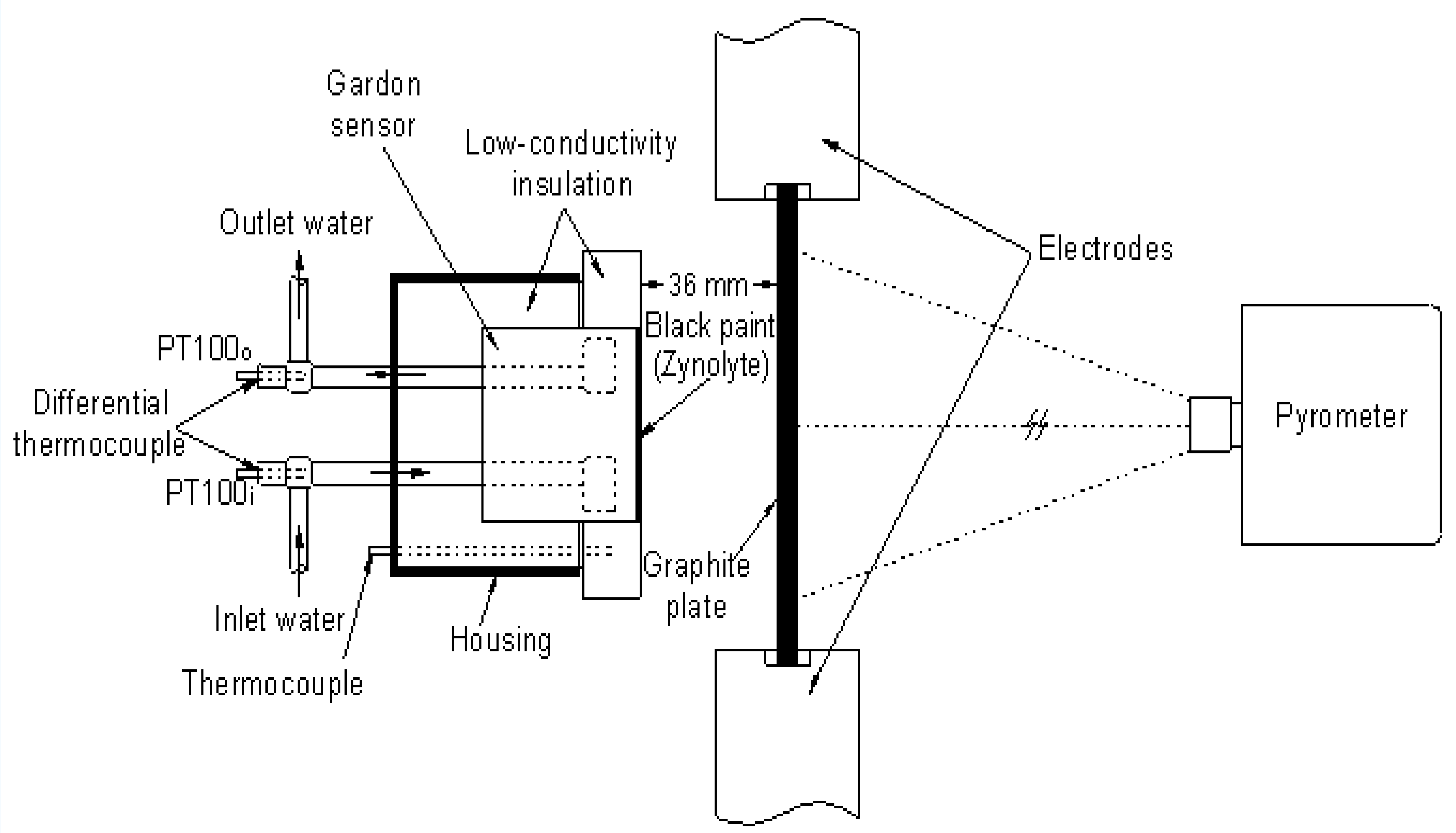
•Coating used over 3500 $kW.m^{-2}$.

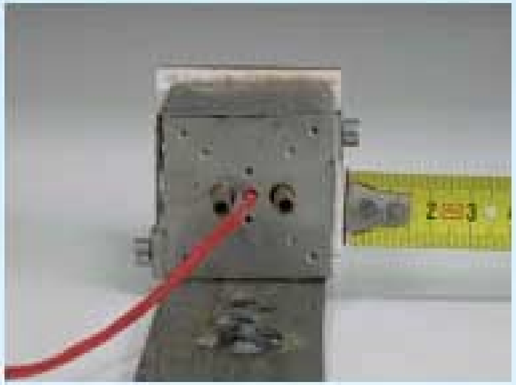
•The sensor overestimates the solar irradiance by 27.9%

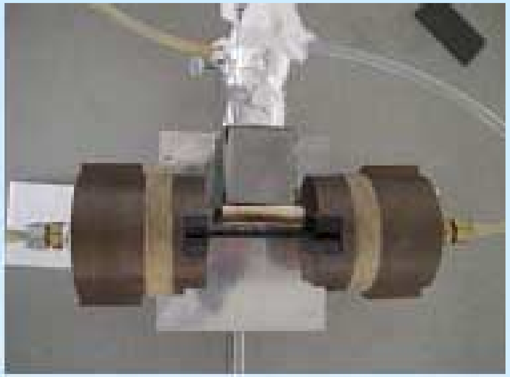
•Solar absortance 84.7 %

CAREFUL WITH SYSTEMS EVALUATED OVER 3500 $kW.m^{-2}$

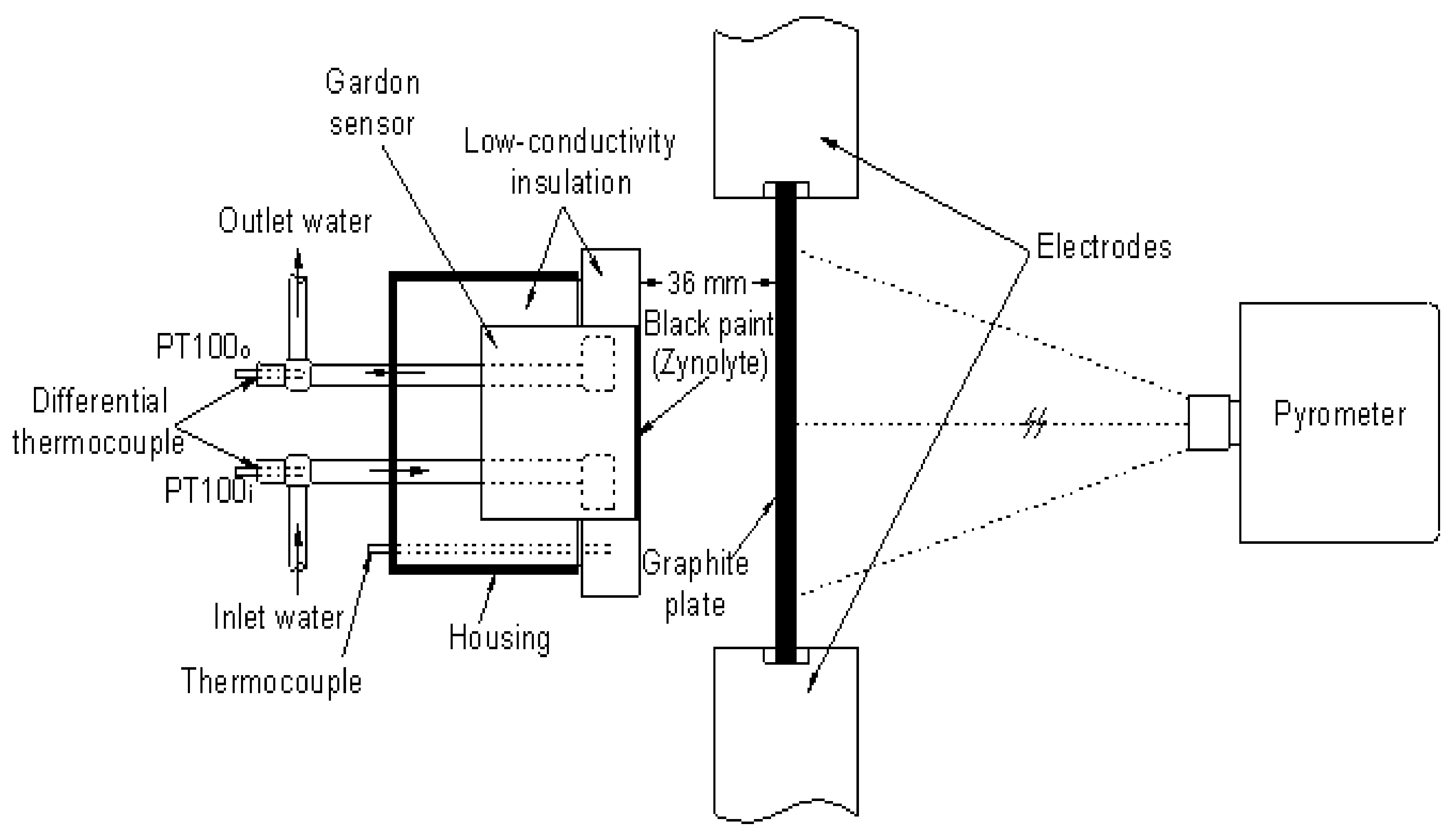
Calibration by using a thermal balance

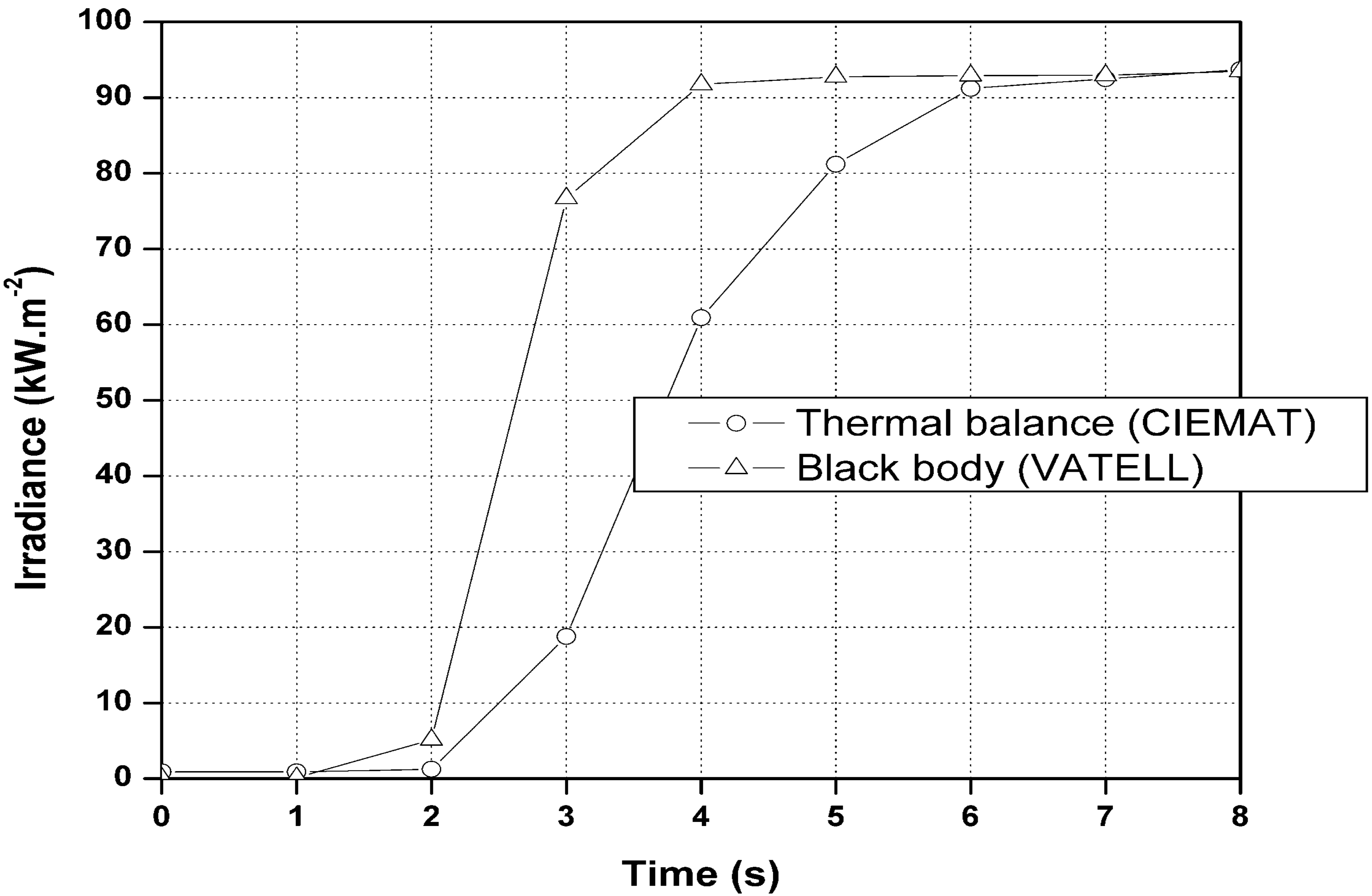




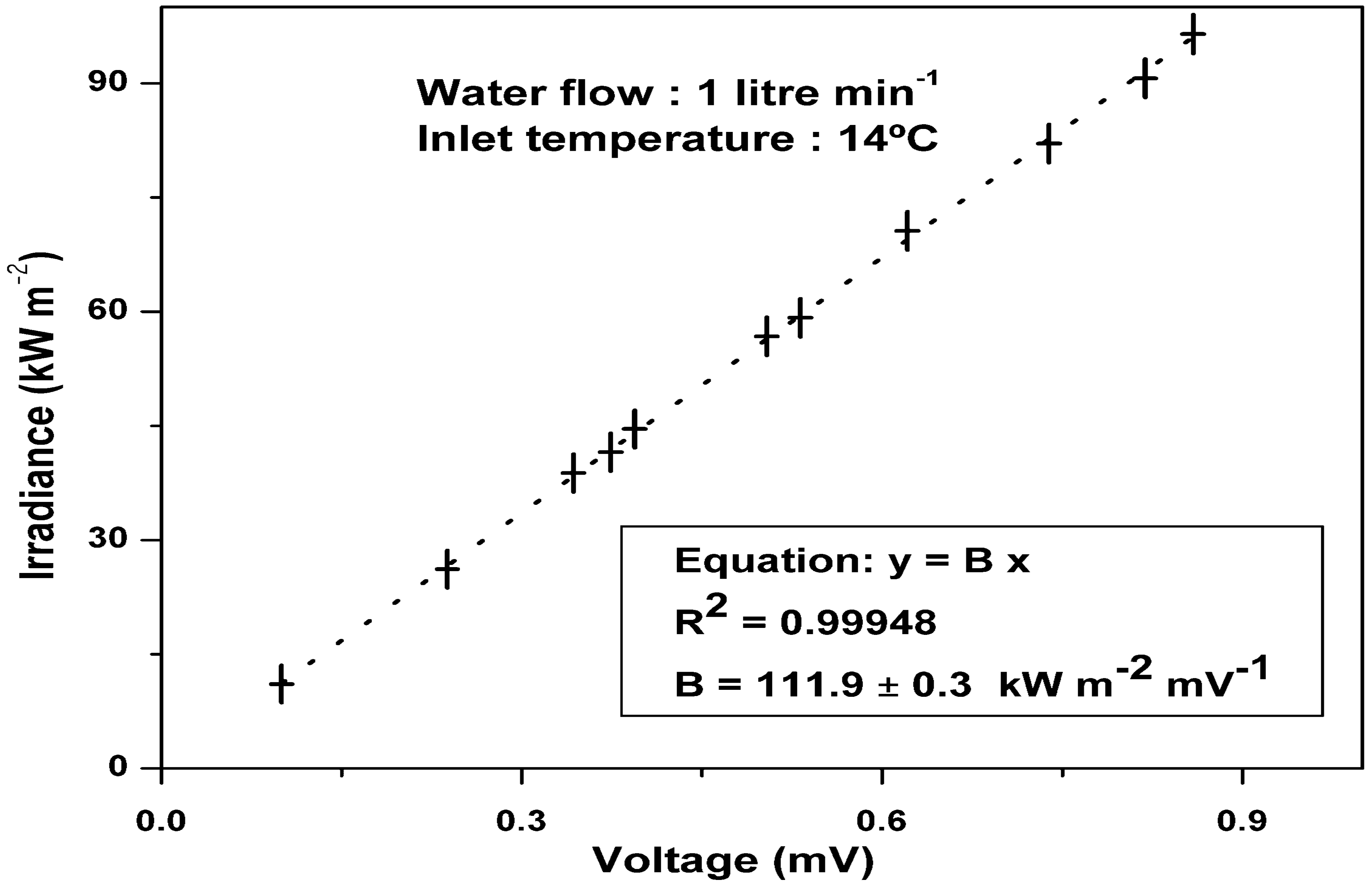


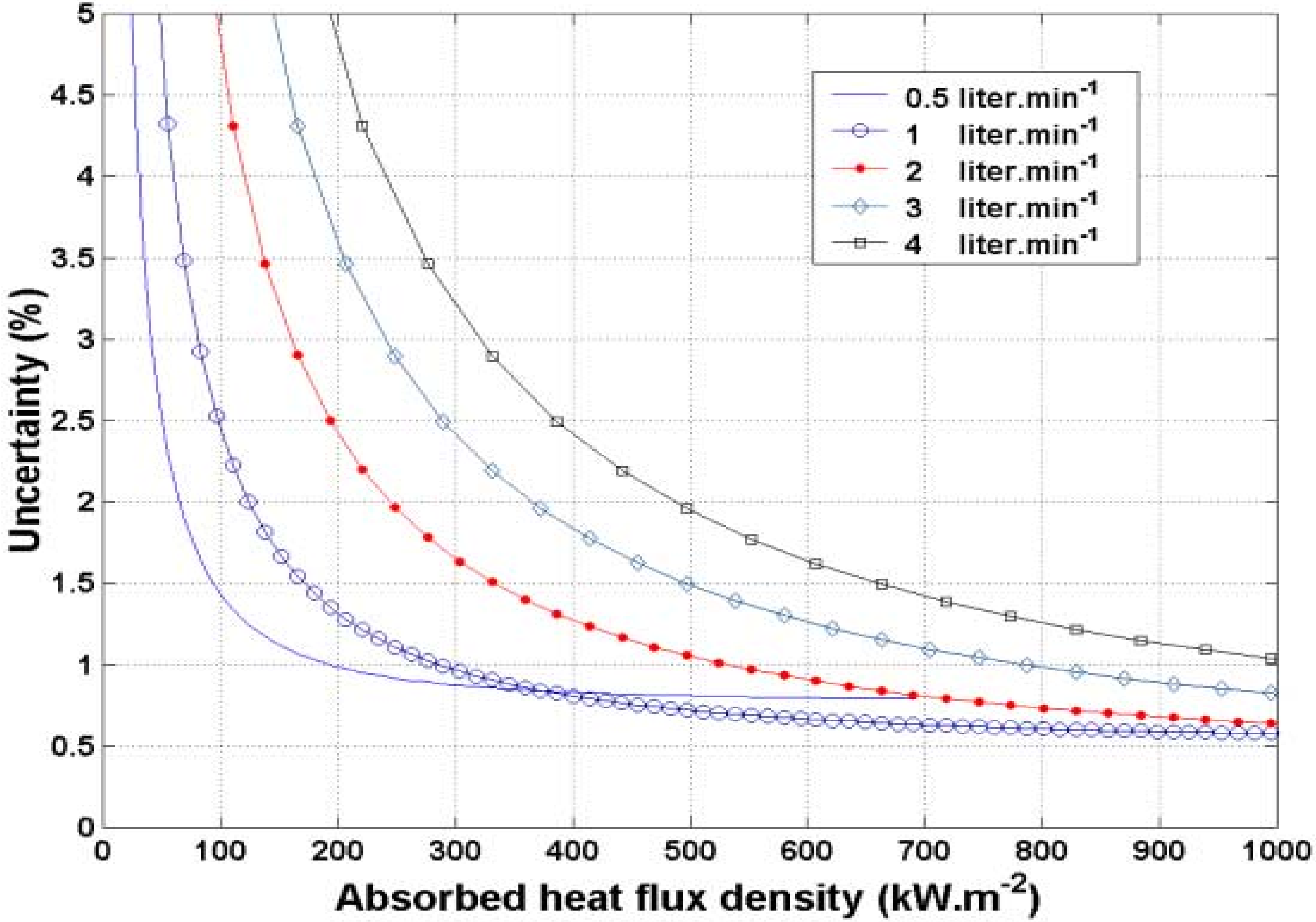
Calibration by using a thermal balance





100
90
80
70
60
50
40
30
20
10
0
Irradiance (kW.m-2)
0
1
2
3
4
5
6
7
8
Time (s)
Thermal balance (CIEMAT)
Black body (VATELL)


Water flow : 1 litre min^{-1}
Inlet temperature : 14ºC
Equation: y = B x
R^2 = 0.99948
B = 111.9 ± 0.3 kW m^{-2} mV^{-1}
Irradiance (kW m^{-2})
Voltage (mV)
0
30
60
90
0.0
0.3
0.6
0.9


0.5 liter.min-1
1 liter.min-1
2 liter.min-1
3 liter.min-1
4 liter.min-1
Uncertainty (%)
Absorbed heat flux density (kW.m-2)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
100
200
300
400
500
600
700
800
900
1000

Water flow (liter.min^{-1})	Inlet Temperature (ºC)	B (kW.m^{-2}.mV^{-1})	ΔB (kW.m^{-2}.mV^{-1})	Uncertainty %	R^2	Repeteability %
0.5	15.5	110.1	0.9	0.9	0.9954	0.7
1	12.5	109.9	0.8	0.8	0.9985	
1	14.5	111.9	0.5	0.5	0.9995	
1	14	111	0.5	0.5	0.9902	
1	13	110	0.3	0.3	0.9932	
1.6	15.0	110.5	0.3	0.3	0.9980	

SUMMARY 2

• An alternative method of calibrating high-heat flux sensors by thermal balance has been presented. The results are in agreement with calibrations obtained using black-body radiation. However, the proposed method has the potential of being more accurate than traditional approaches.

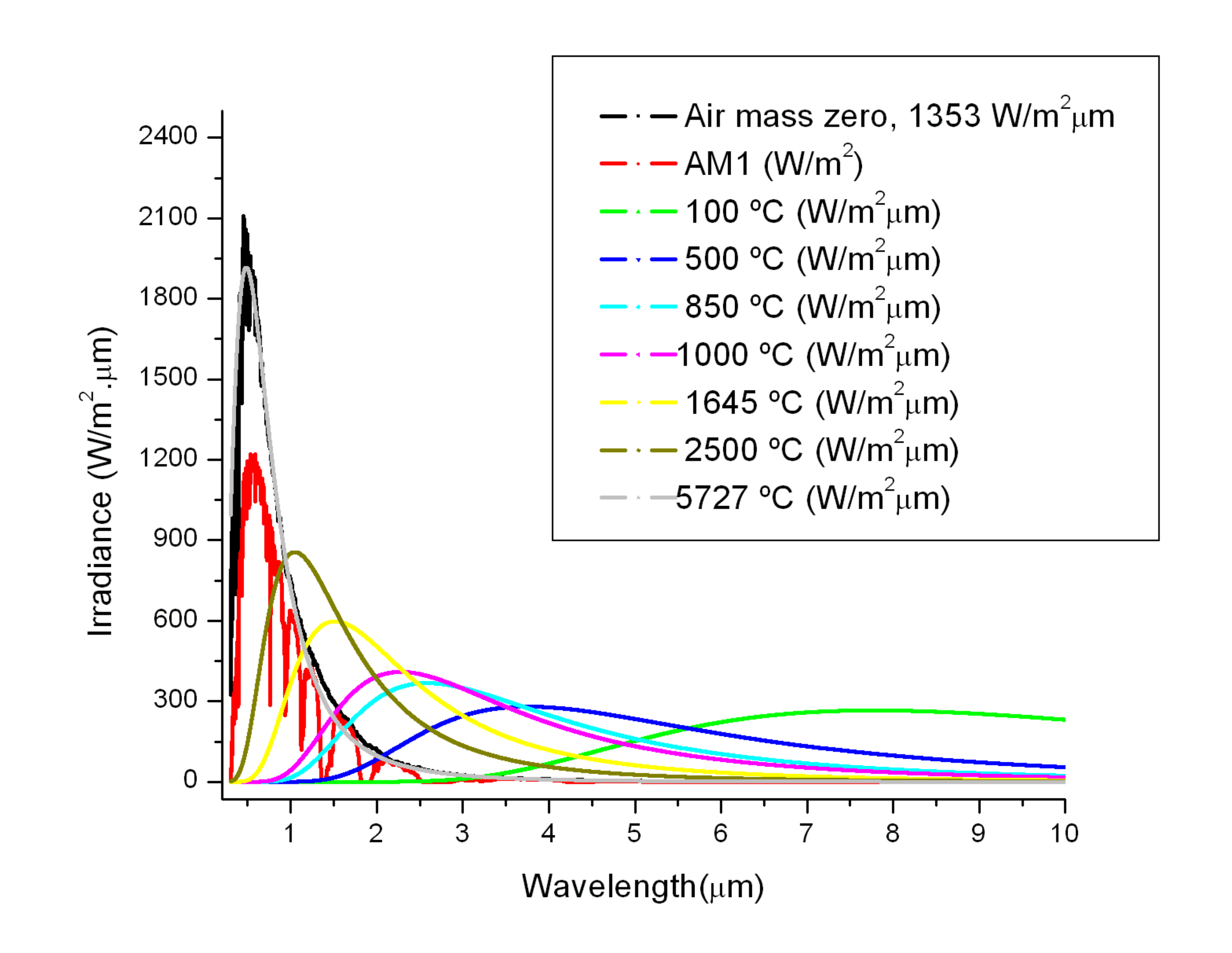
• This new procedure calibrates sensors to correctly measure under conditions of concentrated solar radiation.

• At present, the thermal balance calibration technique in the laboratory is limited to solar irradiances of approximately 100 $kW.m^{-2}$. The next step is to demonstrate this methodology to higher irradiances under non-laboratory conditions in the CIEMAT solar furnace at Plataforma Solar de Almería.

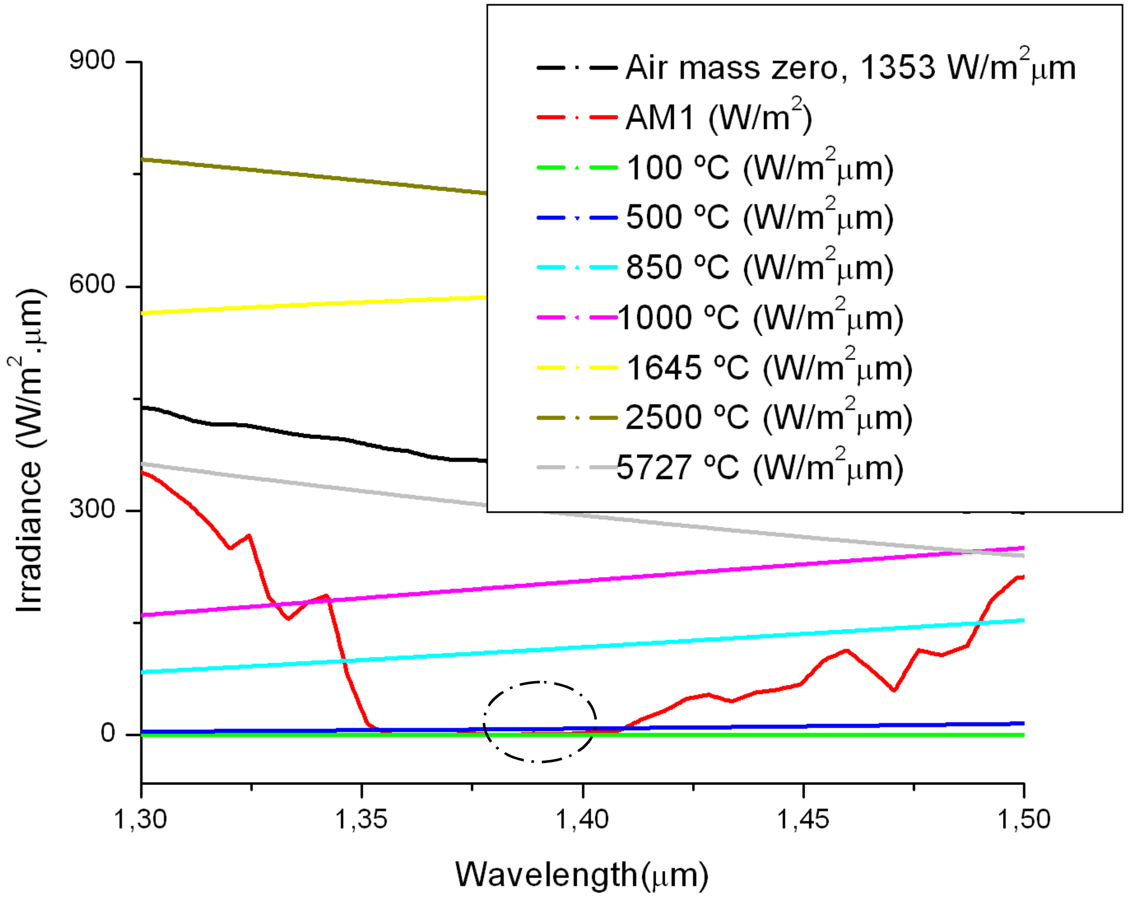
Development of a Radiometry Laboratory

- Spherical black body: 100-1000 ºC (± 0.25 %)
- Cylindrical black body: 300-1700 ºC (± 0.25 %)
- Pyrometer: 600-3000 ºC (± 0.30 %)
- Solar blind pyrometer: 500-2500 ºC (± 0.30 %)
  Pass Band Filter: 1390±20 nm
- Two-color pyrometer: 700-2000 ºC (± 0.50 %)
- Two-color pyrometer: 600-1400 ºC (± 0.50 %)

Solar blind pyrometer: 500-2500 ºC



Pass Band Filter 1390±20 nm



OBJETIVES OF THE LABORATORY

• Periodic calibration of heat flux sensors (Present)

• Periodic calibration of IR pyrometers and cameras (Future)

• Emissivity characterization of material surfaces at high temperatures (Future)