Measurement Techniques at DLR Solar Research

A. Neumann

- Historical Background
- Fields of Activity
- Different Methods

Solar Research at DLR

Problems and Methods

- Flux Density Mapping
- Absolute Measurements
- Calibration
- Temperature
- Collector Geometry
- Meteo Data
- Sunshape

Historical Remarks

- F&T Measuring Group within SolarPACES
- Participants: CH, D, E, F, IS, USA,..)
- Several Workshops, beginning in 1994
- Intercomparison Campaigns 1996, 1998, 2000

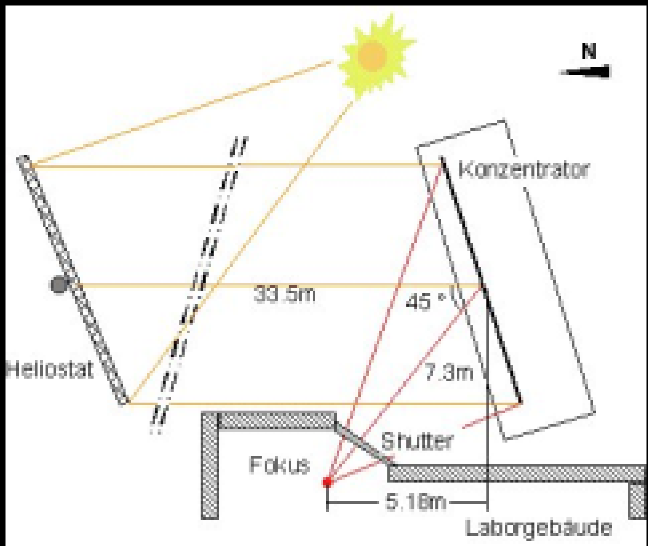
Flux Density

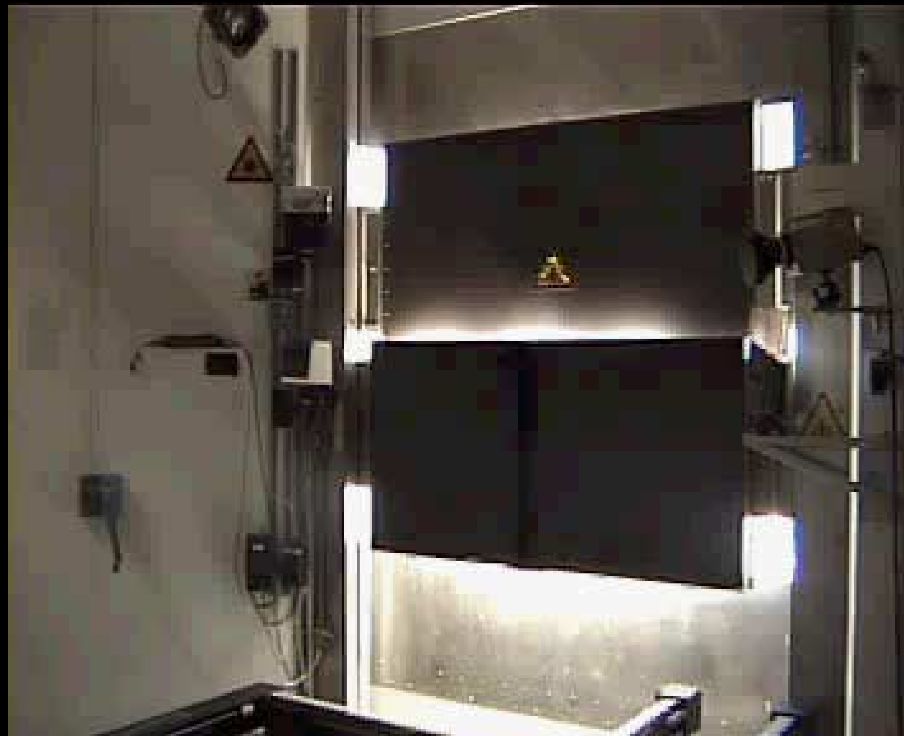
Point Focussing Technology

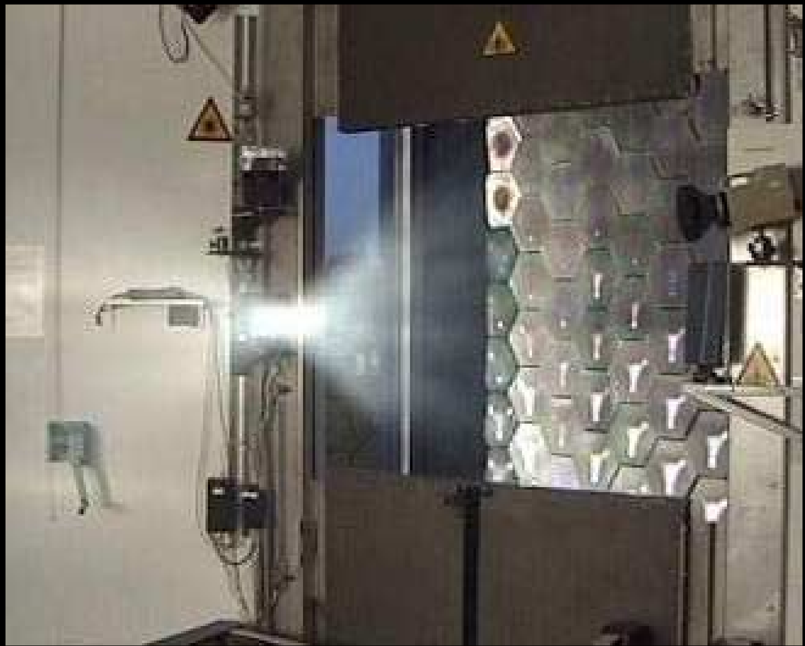
Almería, Spain

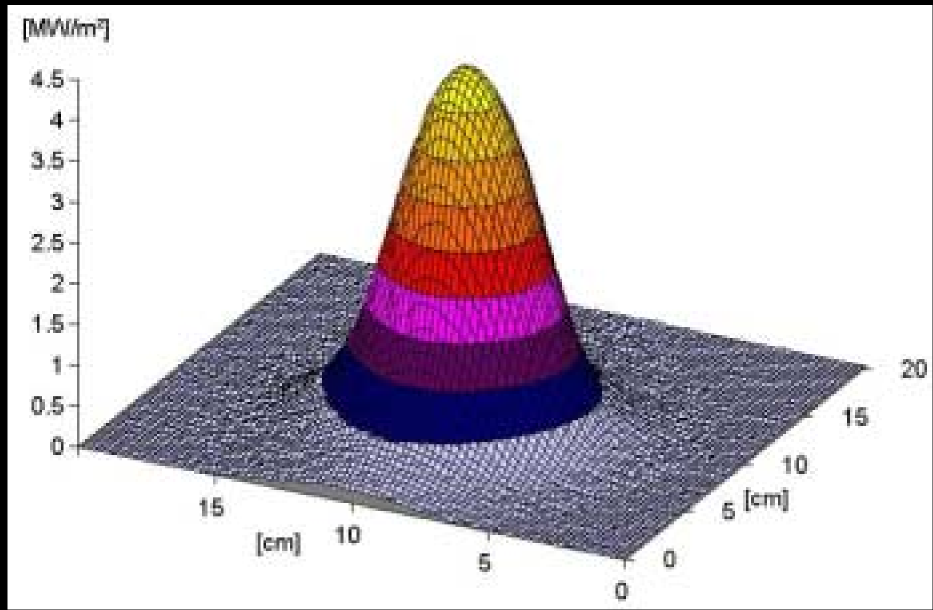
DLR Solar Furnace

The Focus of the DLR Solar Furnace







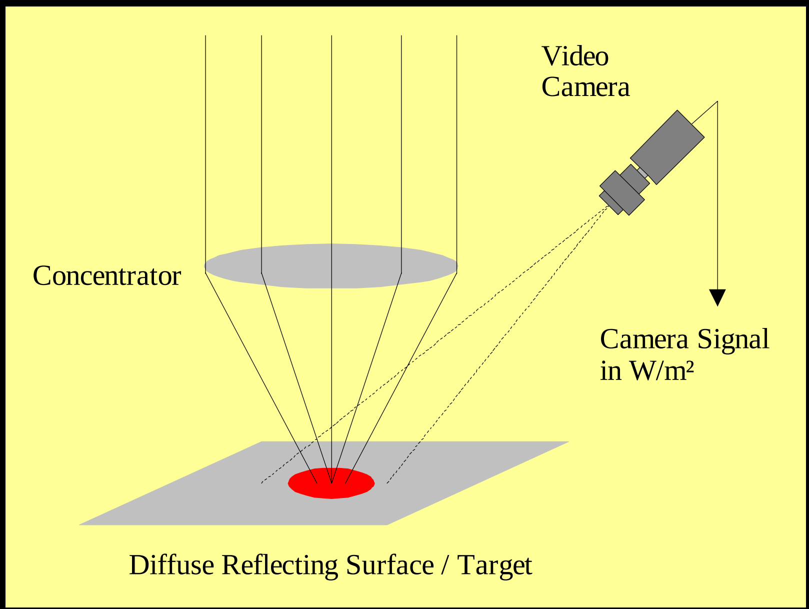


[MW/m²]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
15
10
5
0
[cm]
20
15
10
5
0
[cm]

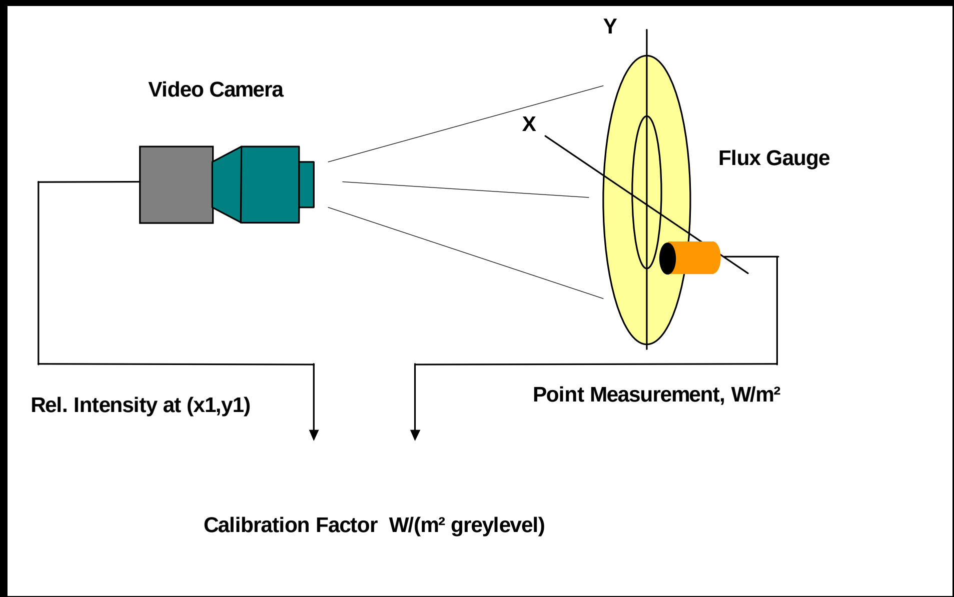
Flux Mapping Basics

Principle

Mapping

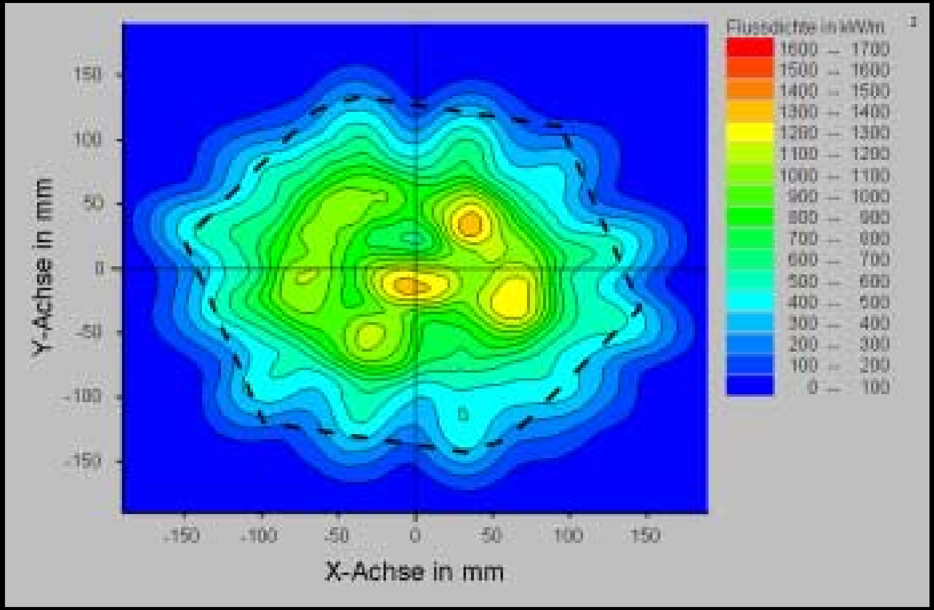


Calibration



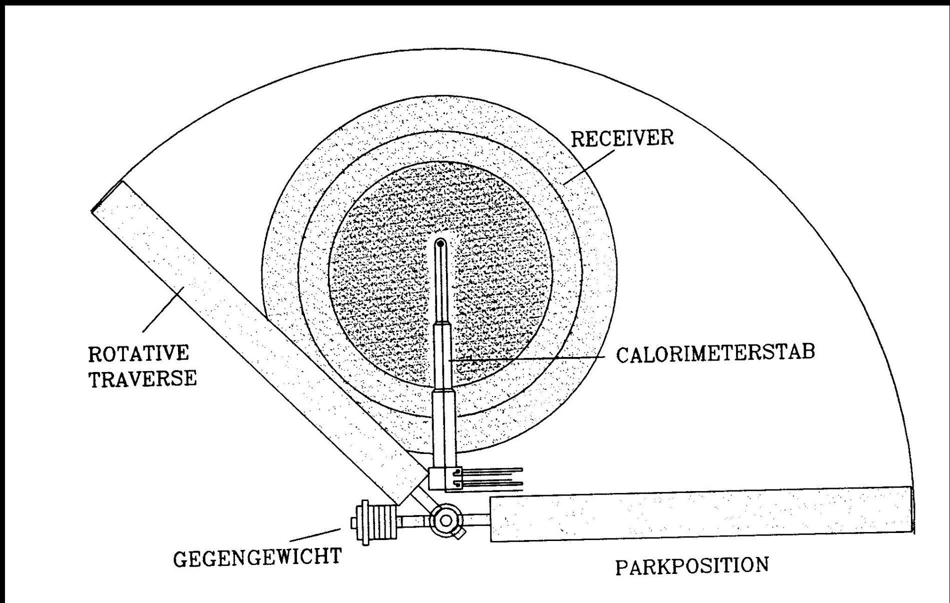
DLR

Mobile Flux Mapper for Dishes

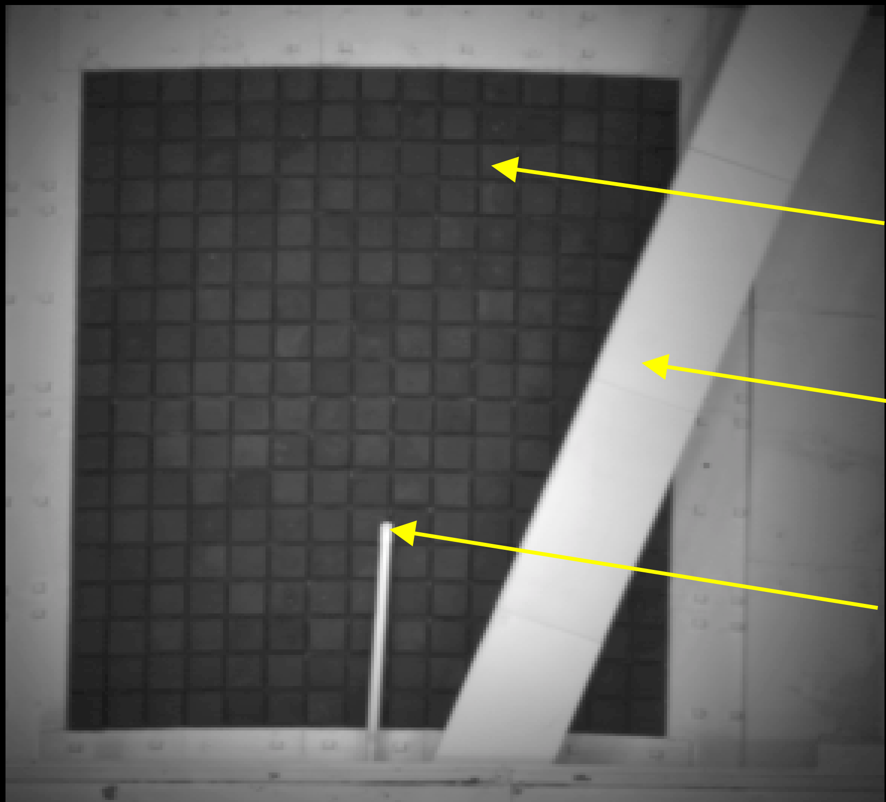


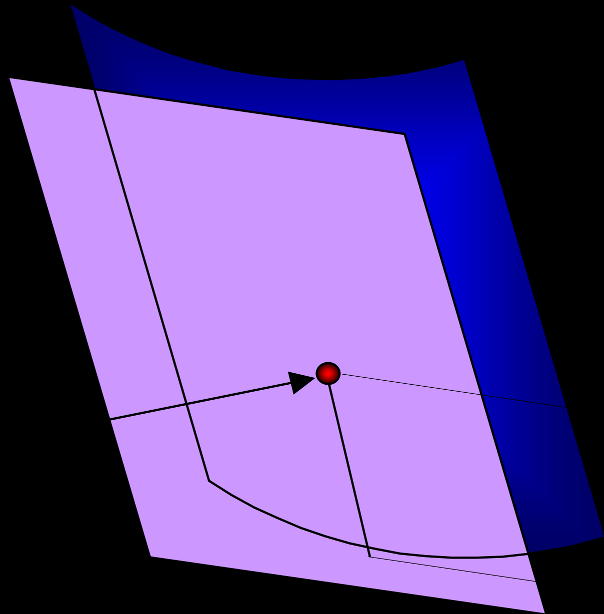
Moving Target for FATMES

Flux Mapping and Calibration on Solar Towers

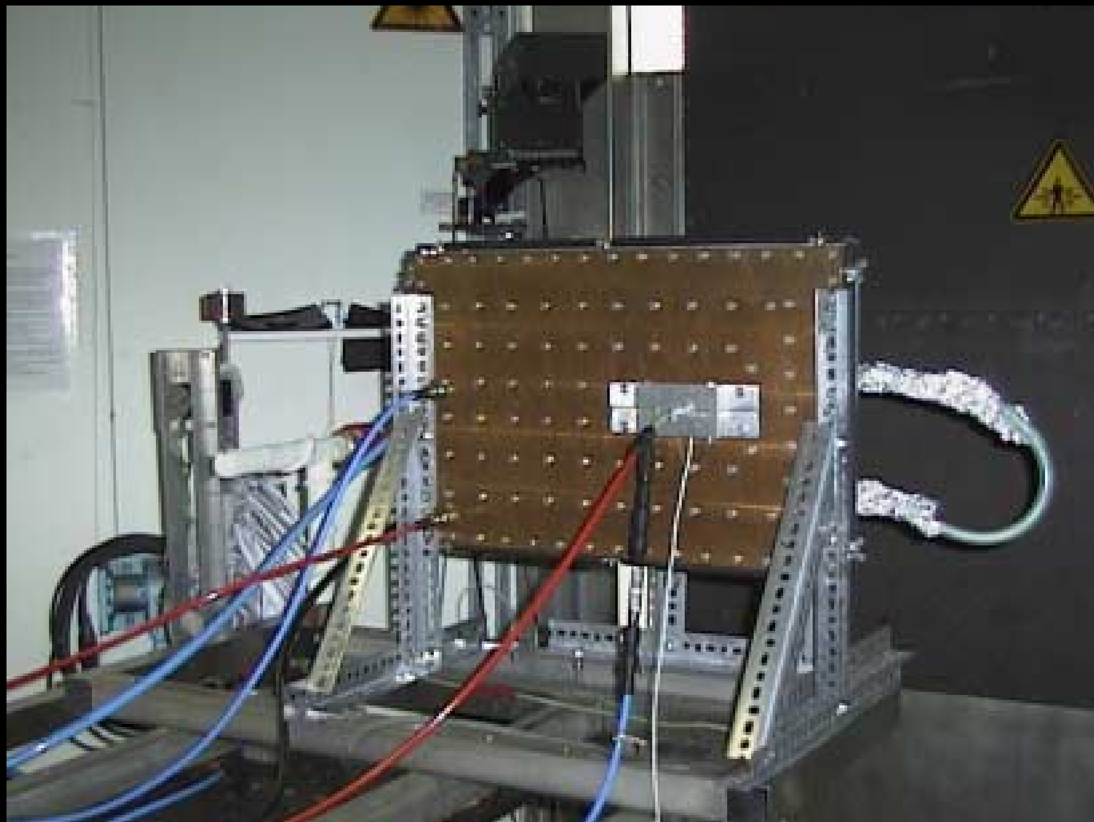


Flux Mapping in Project SOLAIR



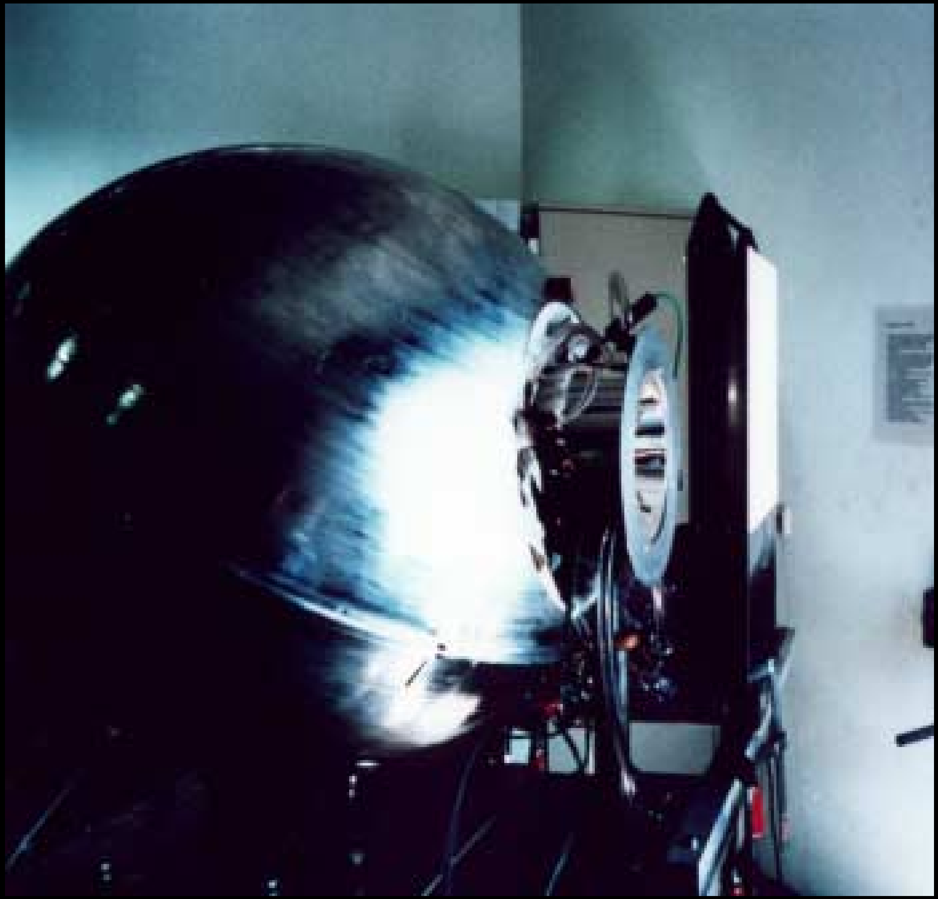


Watercooled Target for FATMES WLT1/2



Calorimeter Development: SunCatch

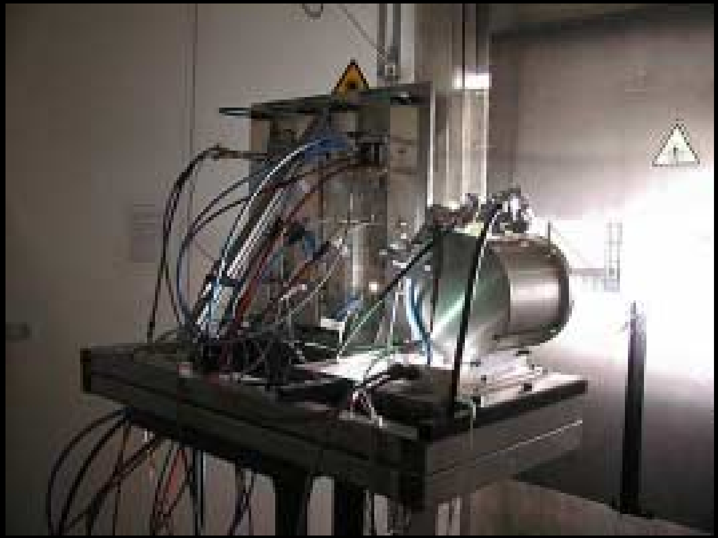
Total Power Calorimeter for DLR Solar Furnace



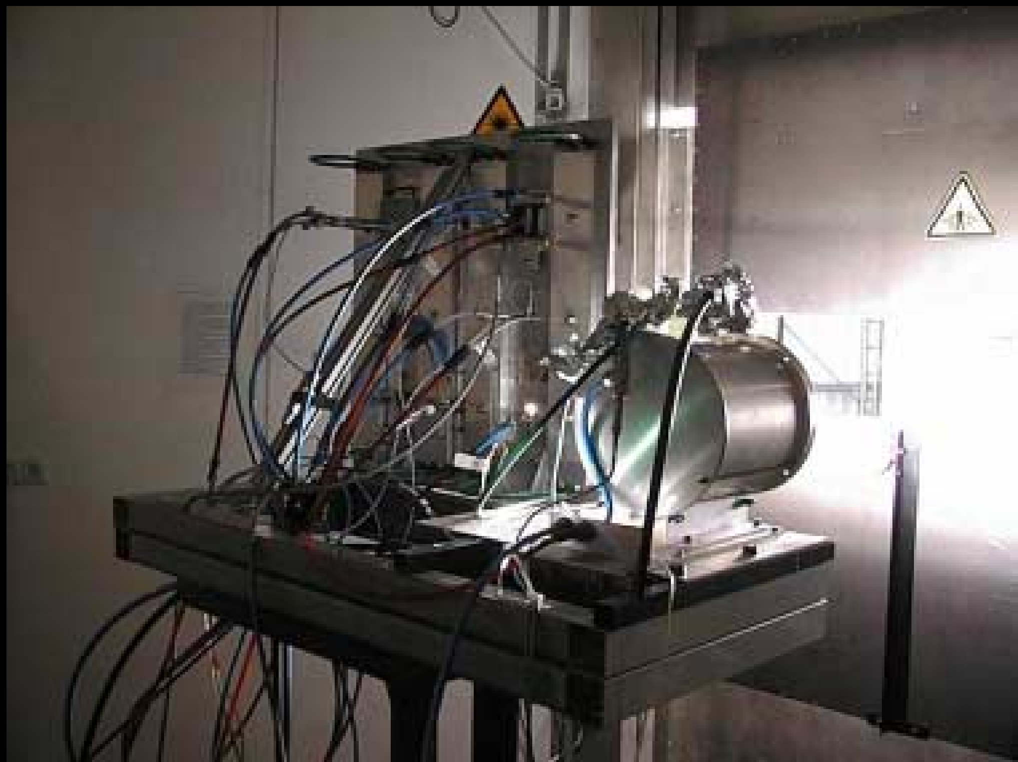
Calorimeter Sting for Calibration at PSA 40 m Tower

Making Good Measurements

- Only a few instruments available (100 kW/m² bis 20 MW/m²)
- Don‘t believe manufacturer specs!
- Comparative Campaigns of Flux Gages



Intercomp 2000: Instruments

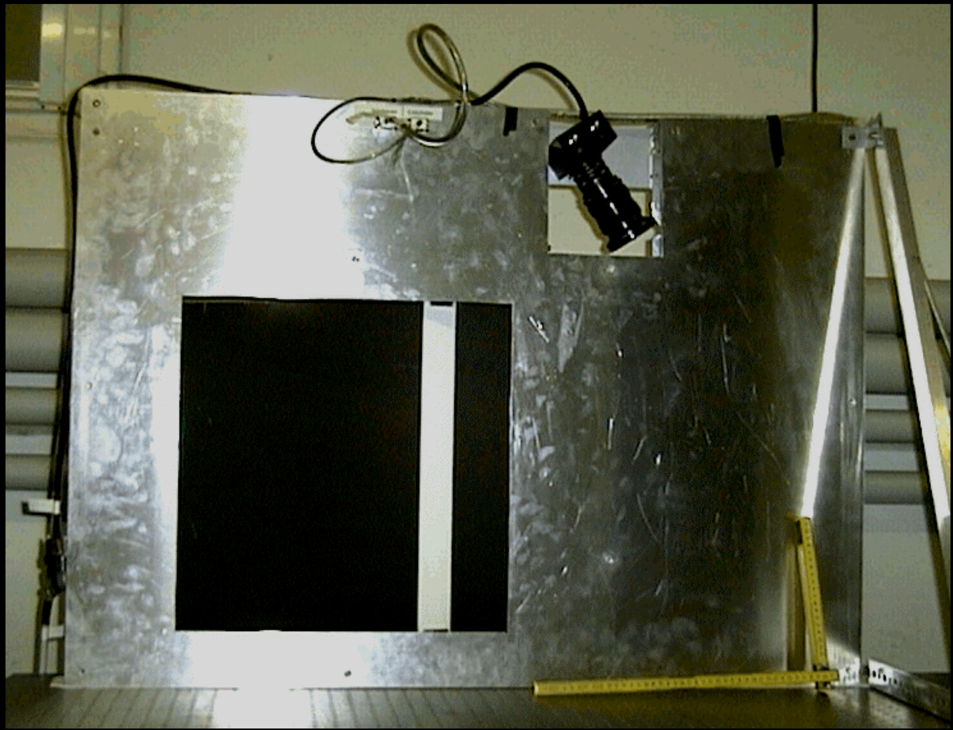


Intercomp 2000

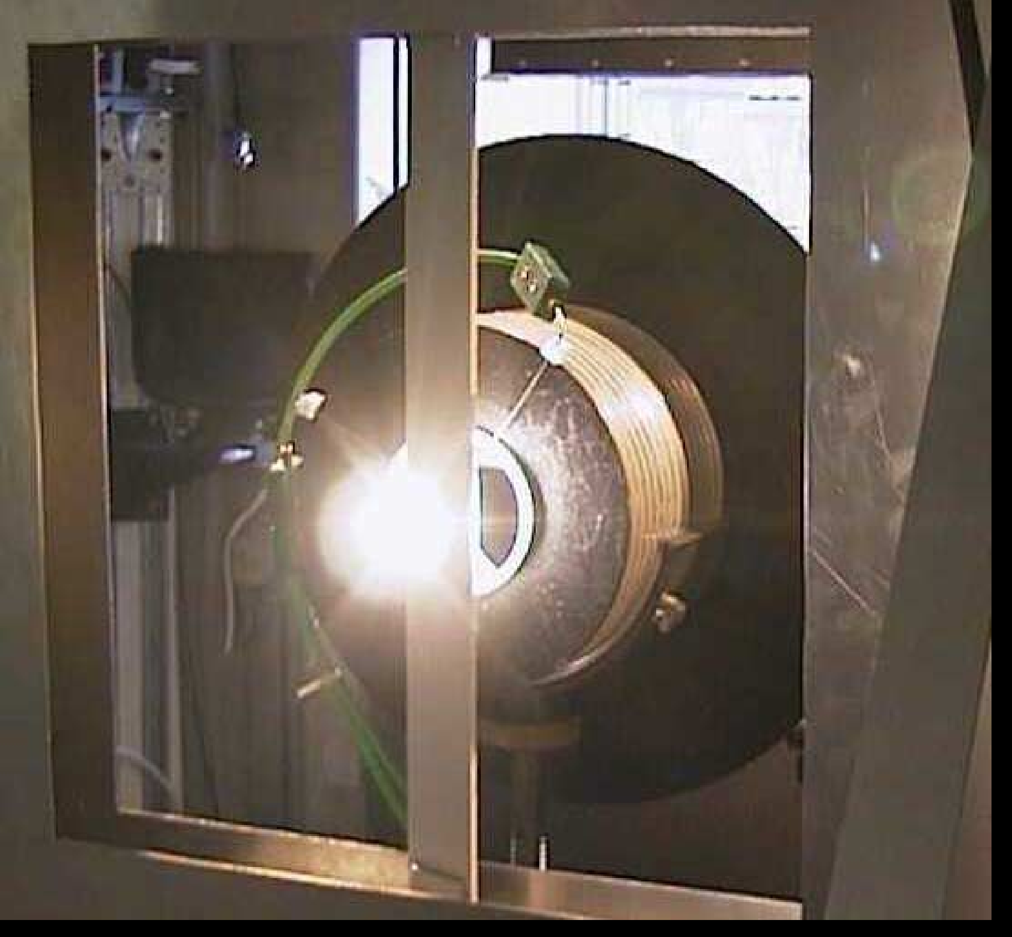
CNRS Team and Solar Furnace Crew

SCATMES

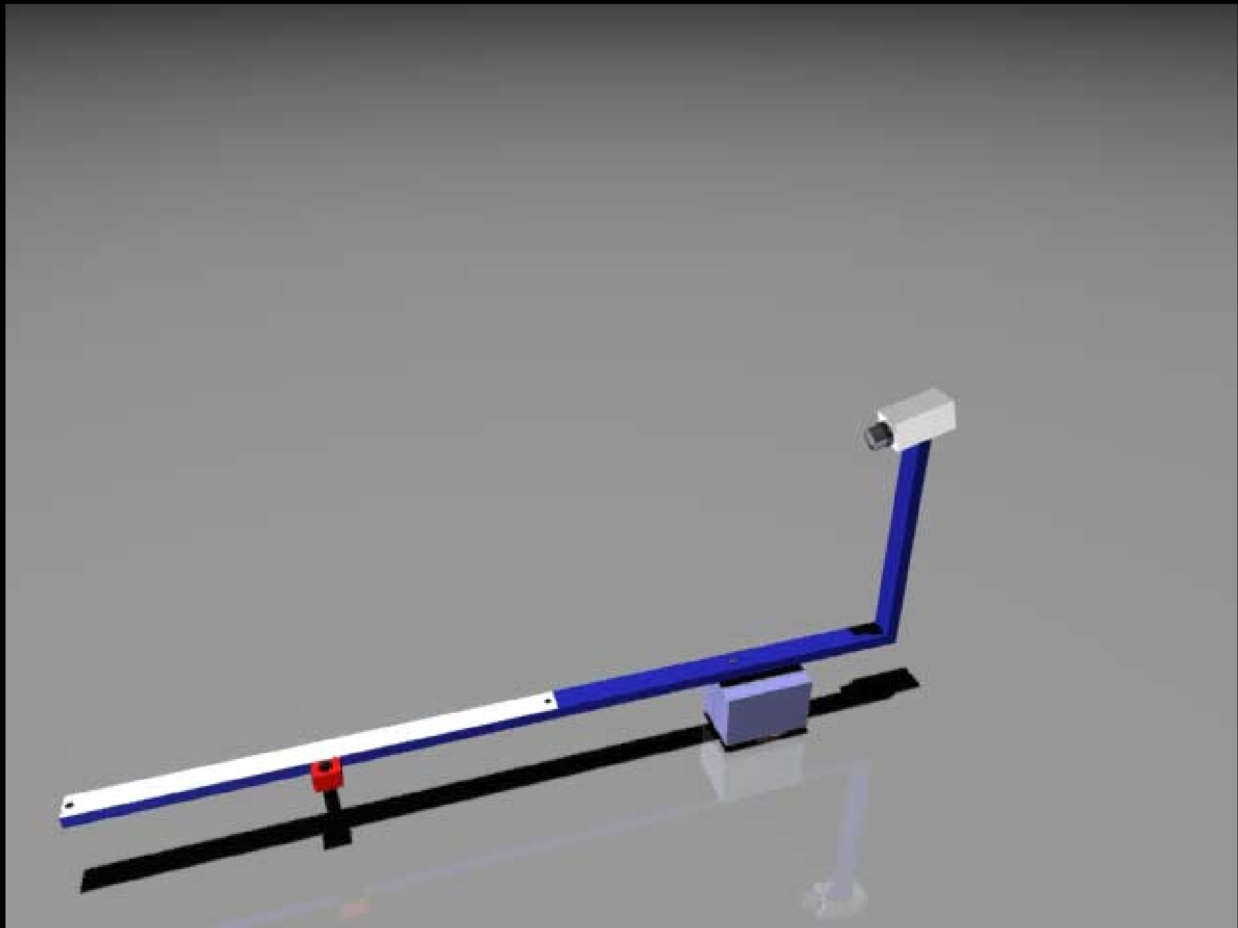
Technical Data of SCATMES	
Size of the Frame (L/H/W)	1100 mm / 800 mm / 60 mm
Measurement Area	450 mm x 450 mm
min. time for one image	2 seconds
time of exposure (per line)	4 ms - 20 ms
max. flux density	0.5 - 5 MW/m²
pixel resolution	1 Pixel per mm
# of pixels p. image (x / y)	500 / 512
max. mass of target	3 kg
velocity of the target	50 mm/s - 250 mm/s



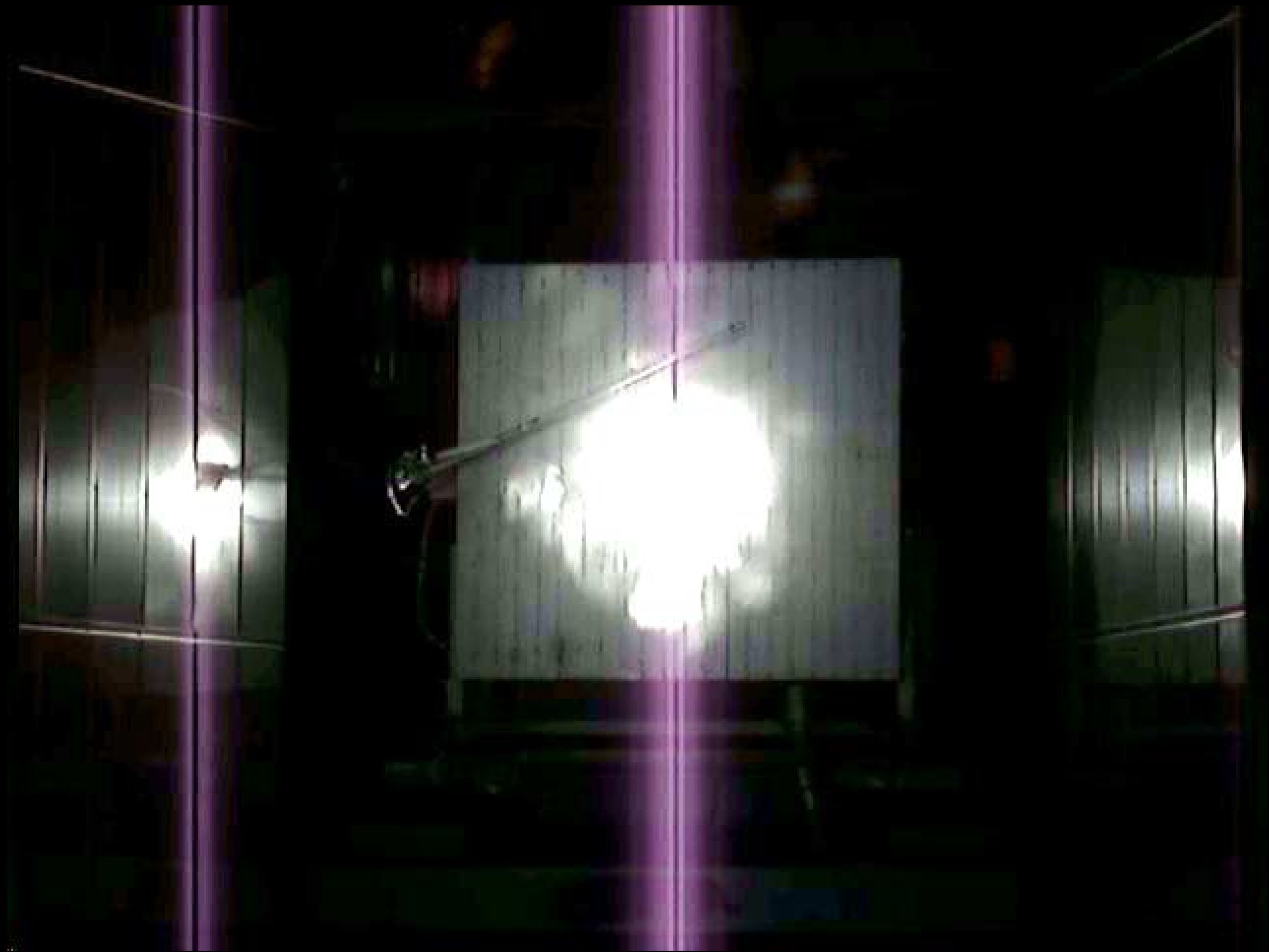
SCATMES During Secondary Concentrator Testing

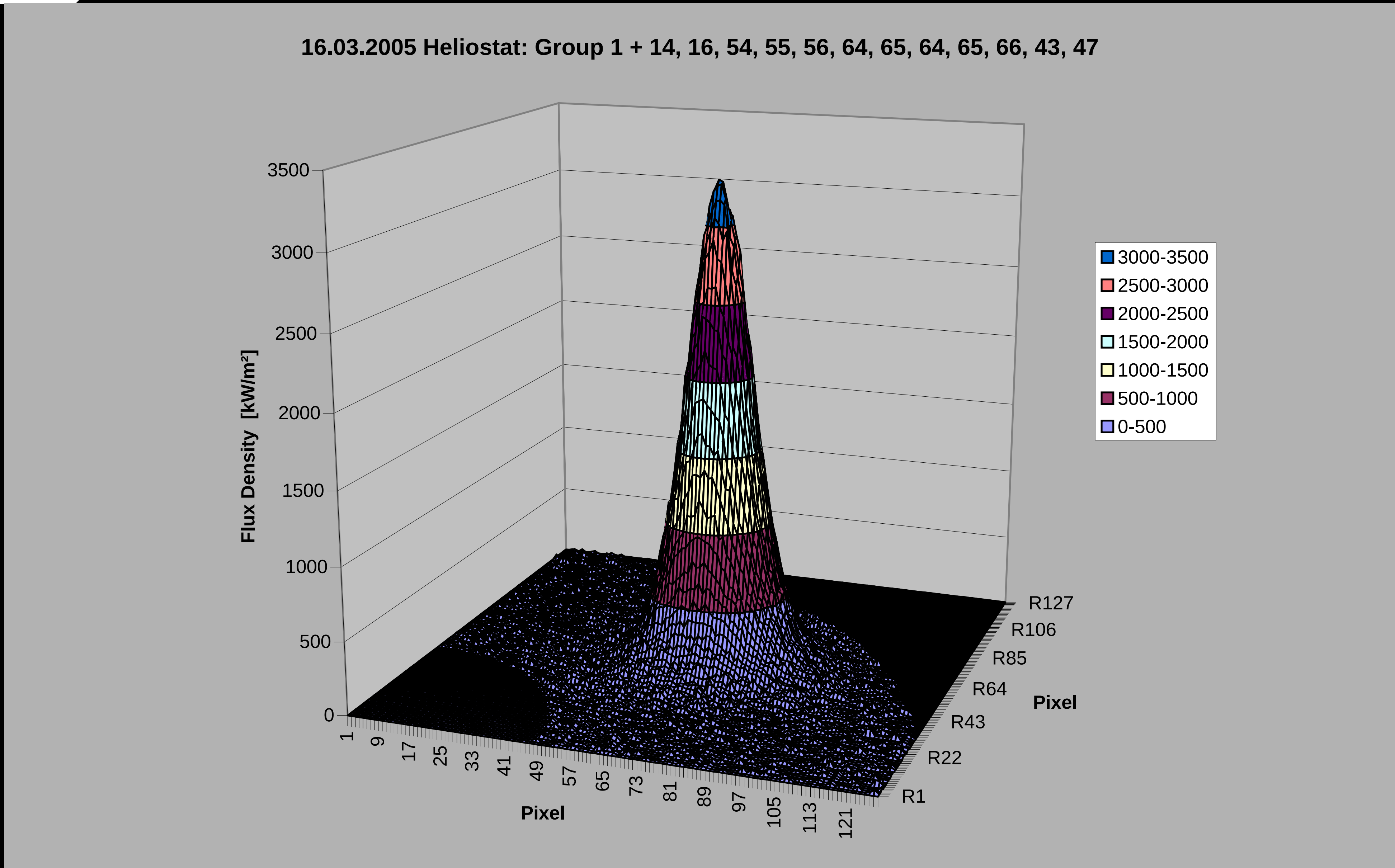


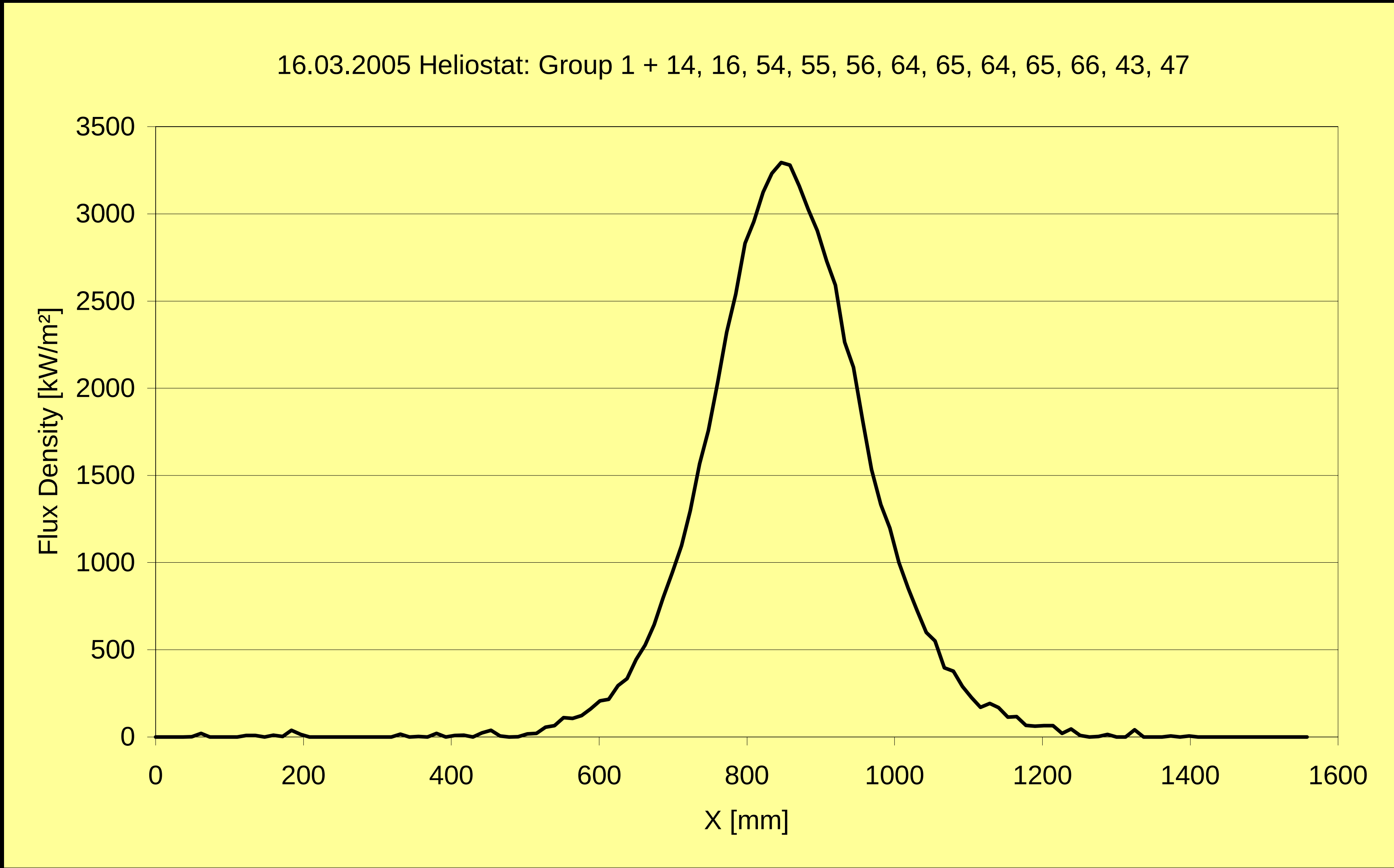
Measurement System BARMES within SOLFACE



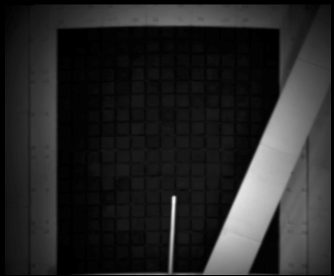
BARMES within SOLFACE

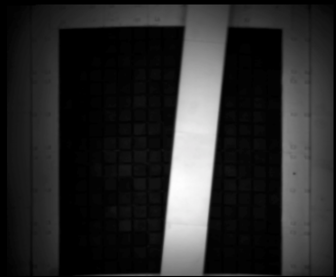


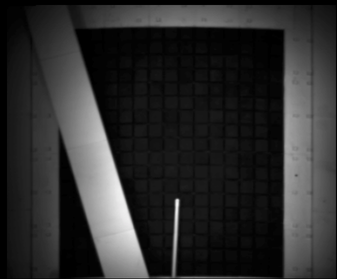

16.03.2005 Heliostat: Group 1 + 14, 16, 54, 55, 56, 64, 65, 64, 65, 66, 43, 47
Flux Density [kW/m²]
3500
3000
2500
2000
1500
1000
500
0
3000-3500
2500-3000
2000-2500
1500-2000
1000-1500
500-1000
0-500
1
9
17
25
33
41
49
57
65
73
81
89
97
105
113
121
Pixel
R127
R106
R85
R64
R43
R22
R1
Pixel

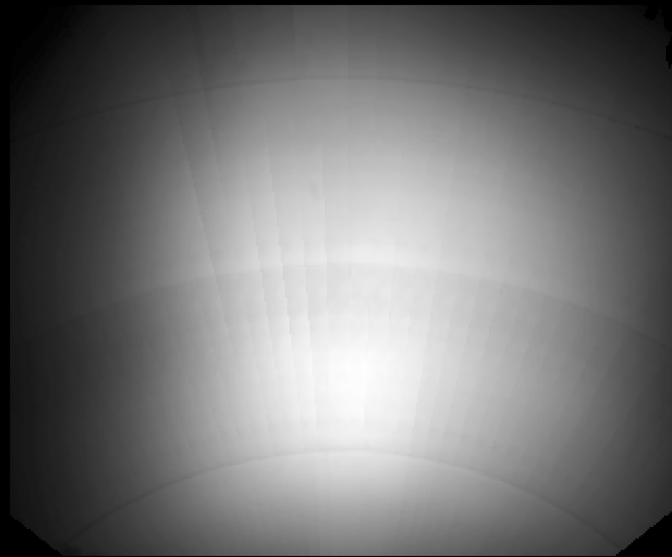

16.03.2005 Heliostat: Group 1 + 14, 16, 54, 55, 56, 64, 65, 64, 65, 66, 43, 47
Flux Density [kW/m²]
3500
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400
1600
X [mm]

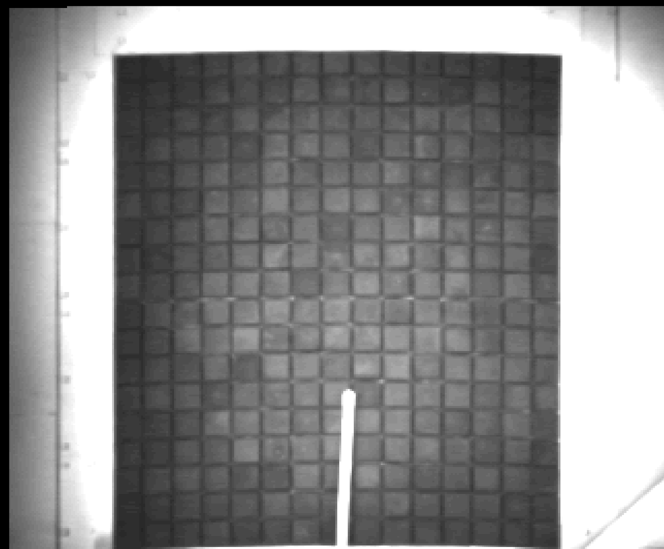
Flux Mapping Using the Receiver as Target



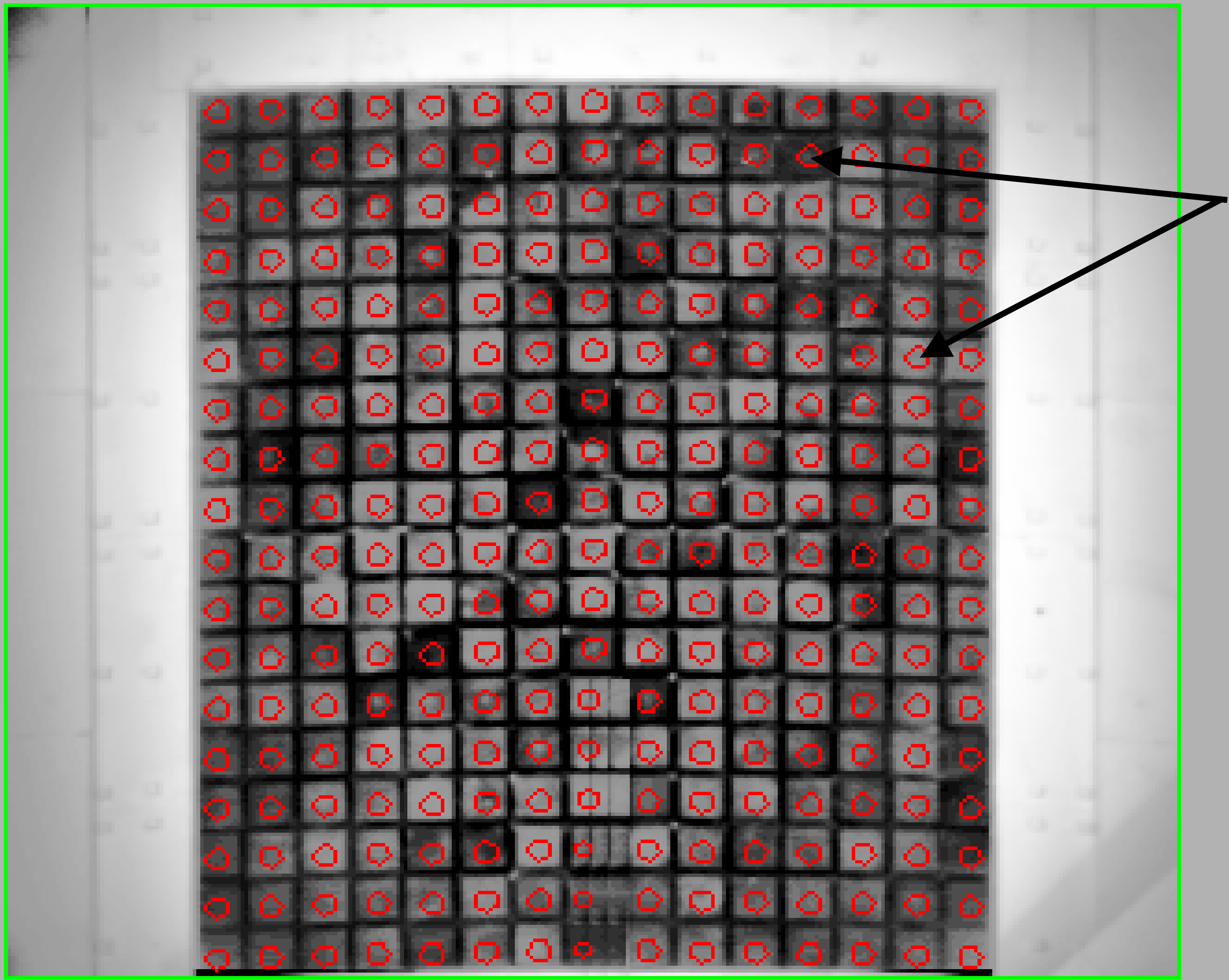








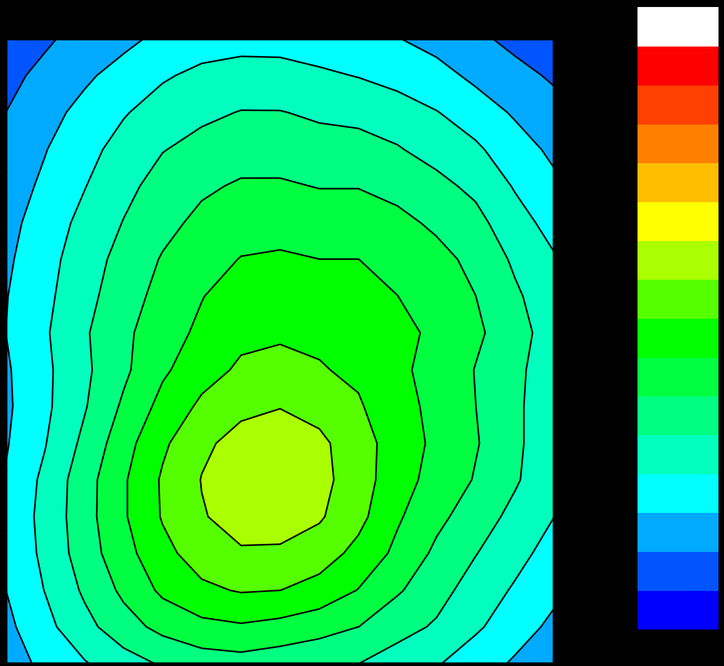
Correction Matrix for Direct Mapping



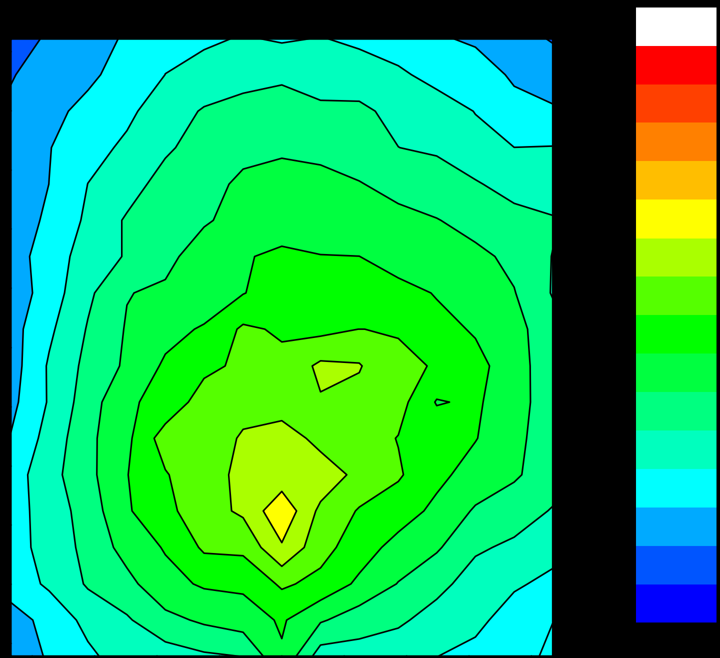
Different cups have different reflectivities

Correction factor by up to ±20%, depending on brightness of absorber cups

Comparison of moving bar technology with direct absorber mapping

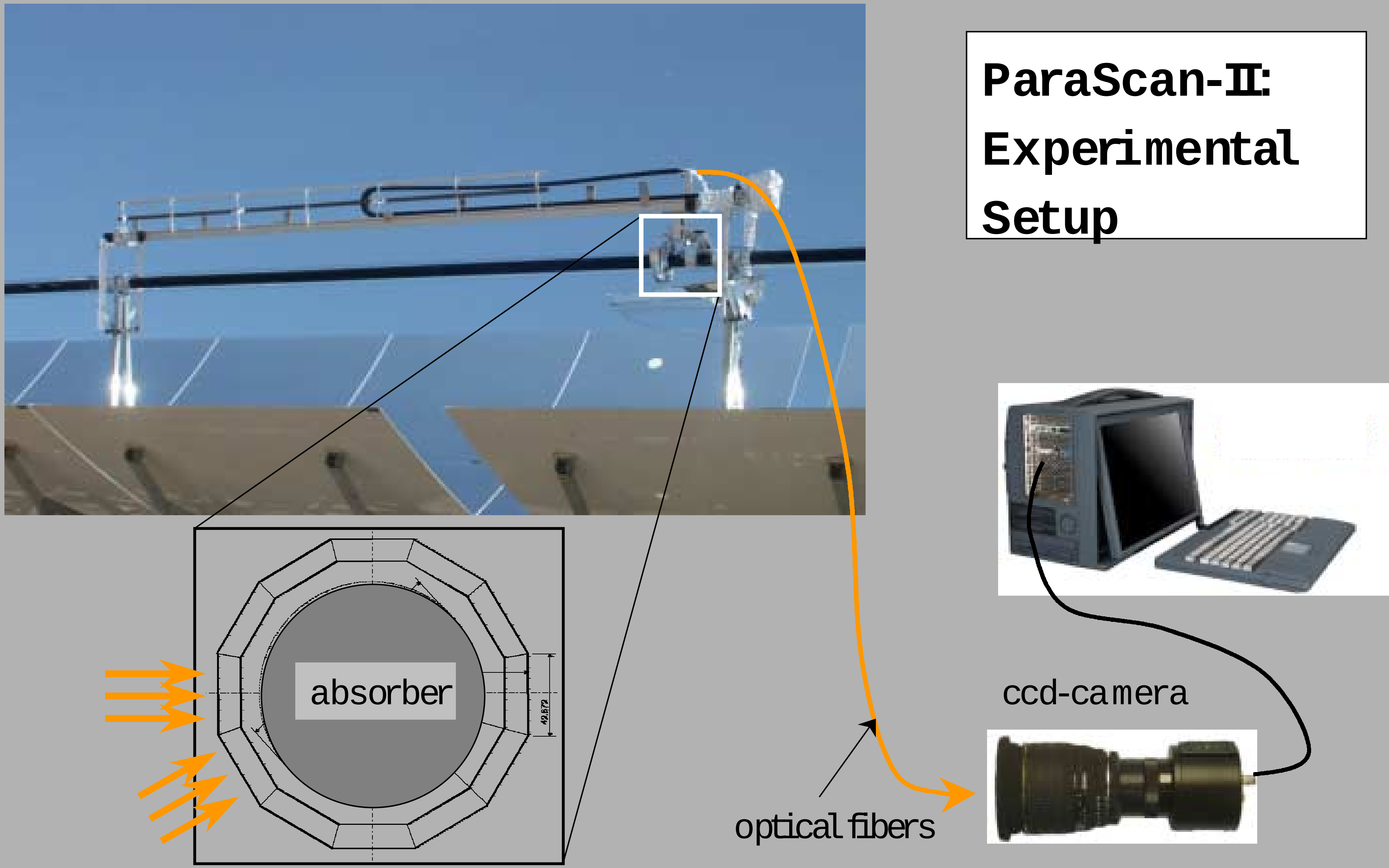


Moving bar flux map

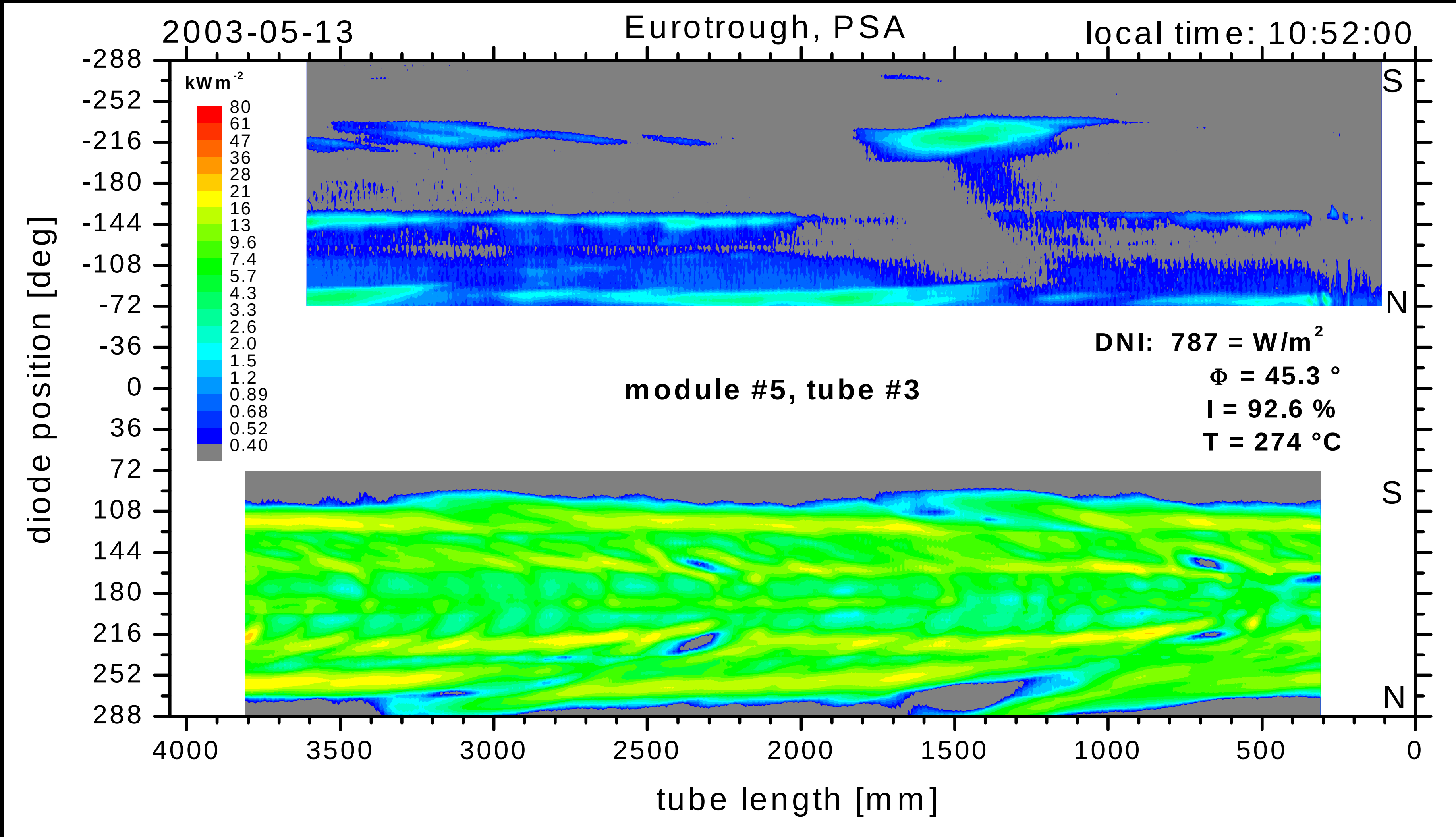


Direct map, using correction matrix

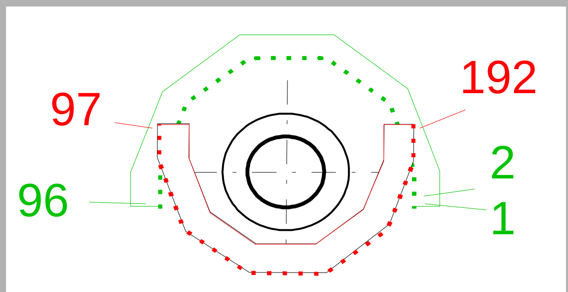
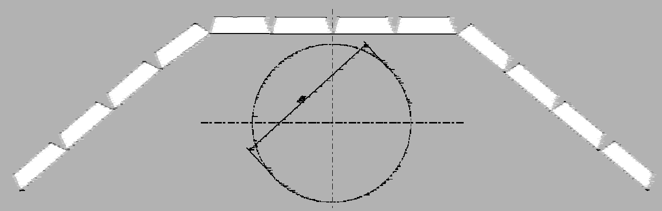
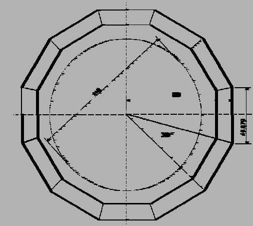
ParaScan-II: Experimental Setup



Parascan flux maps

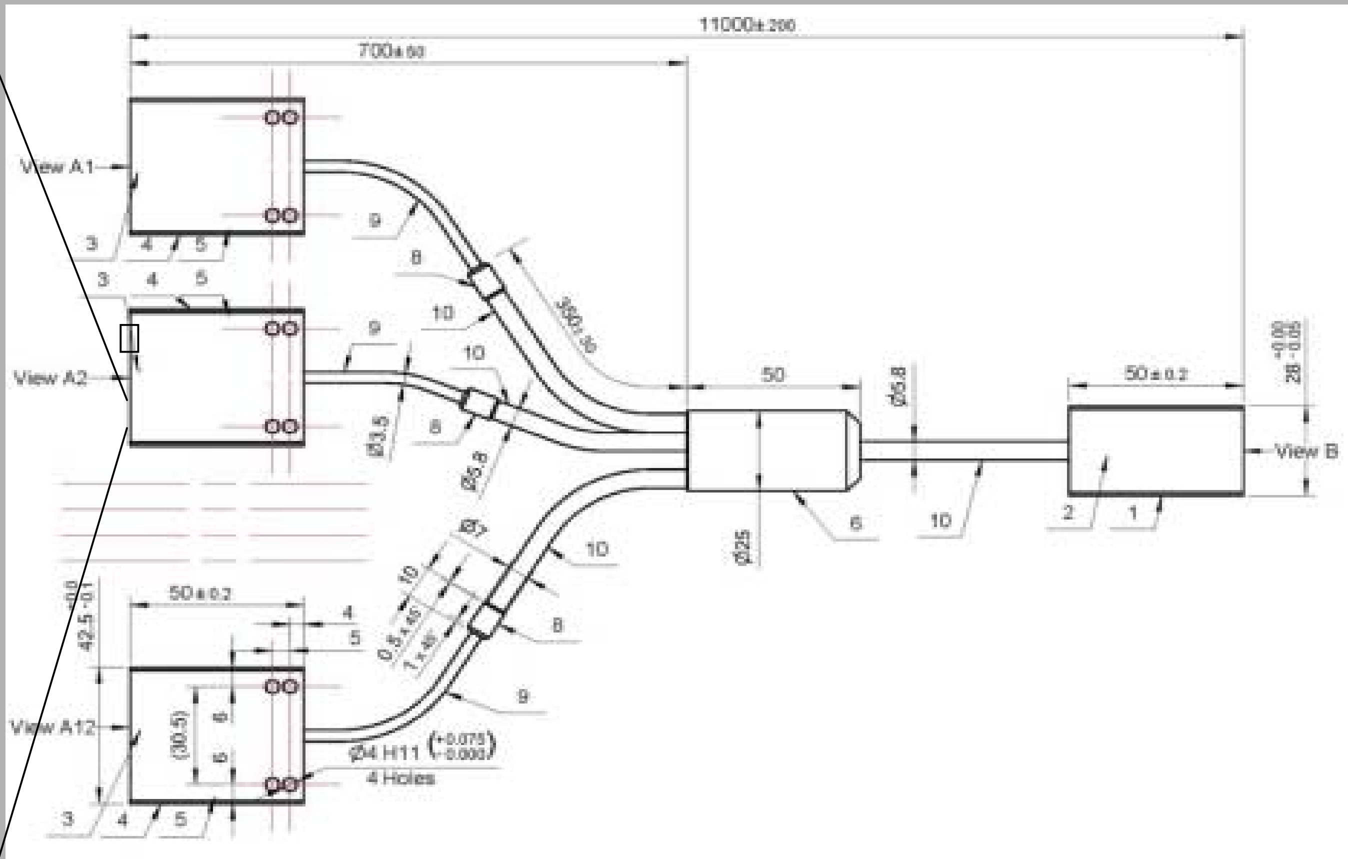


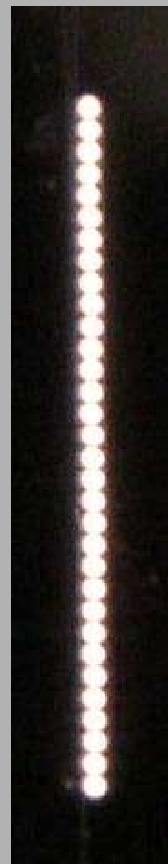
ParaScan-II: Projected Enhancements

disadvantages Parascan I	enhancements Parascan II
sensor is in the hot region	fiber-optics + CCD-camera
big & heavy	smaller & lighter
resolution: ▸ distance of diodes= 4.1 mm	better resolution: ▸ distance of fibers= 2.5 mm
distance to focal line=110 mm	closer to focal line: ▸ distance=80 mm
fixed geometry  	flexible system ▸ extended areas accessible  
arrays not large enough	larger arrays ▸ more accurate registration of losses

12 segments
16 fibers each

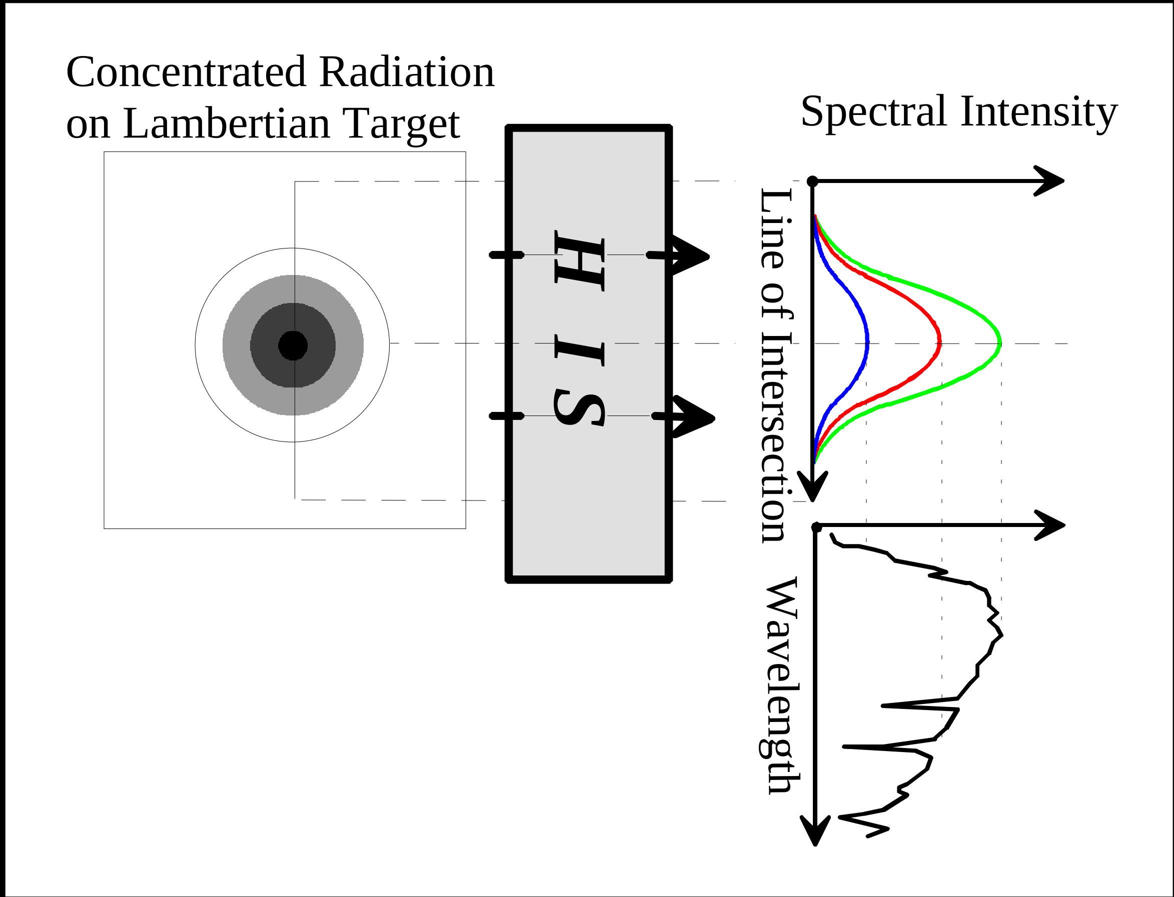
192 fibers





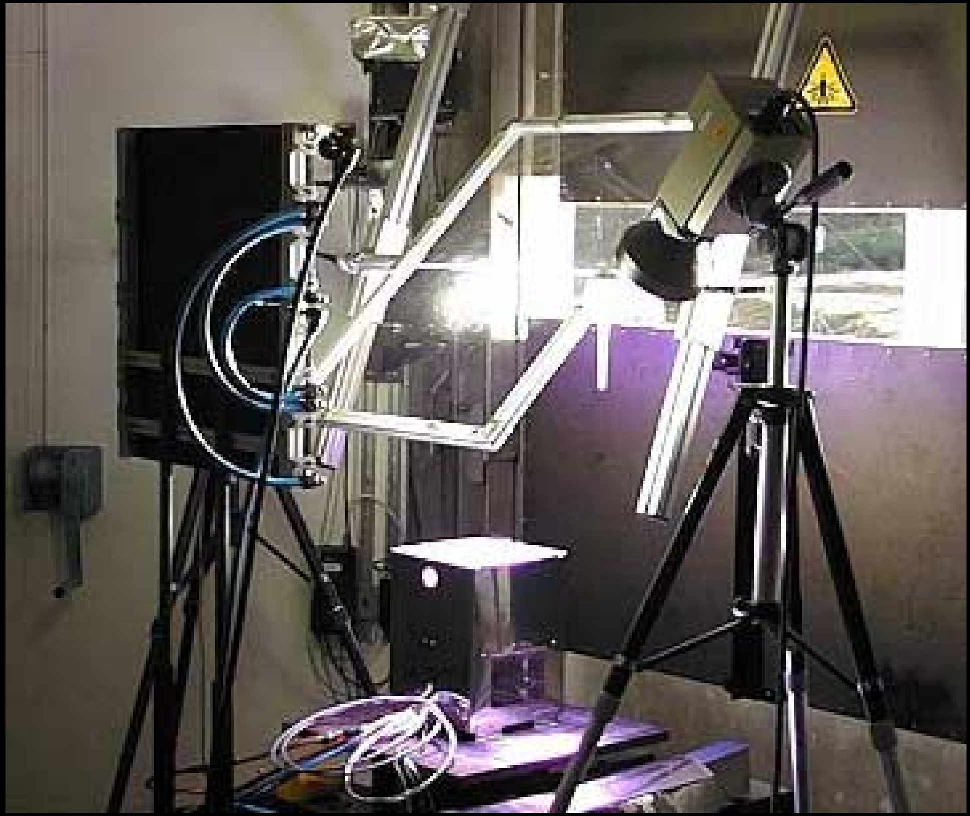
DLR

High Flux Spectrometer



UV Dosimetry

Accelerated paint aging test

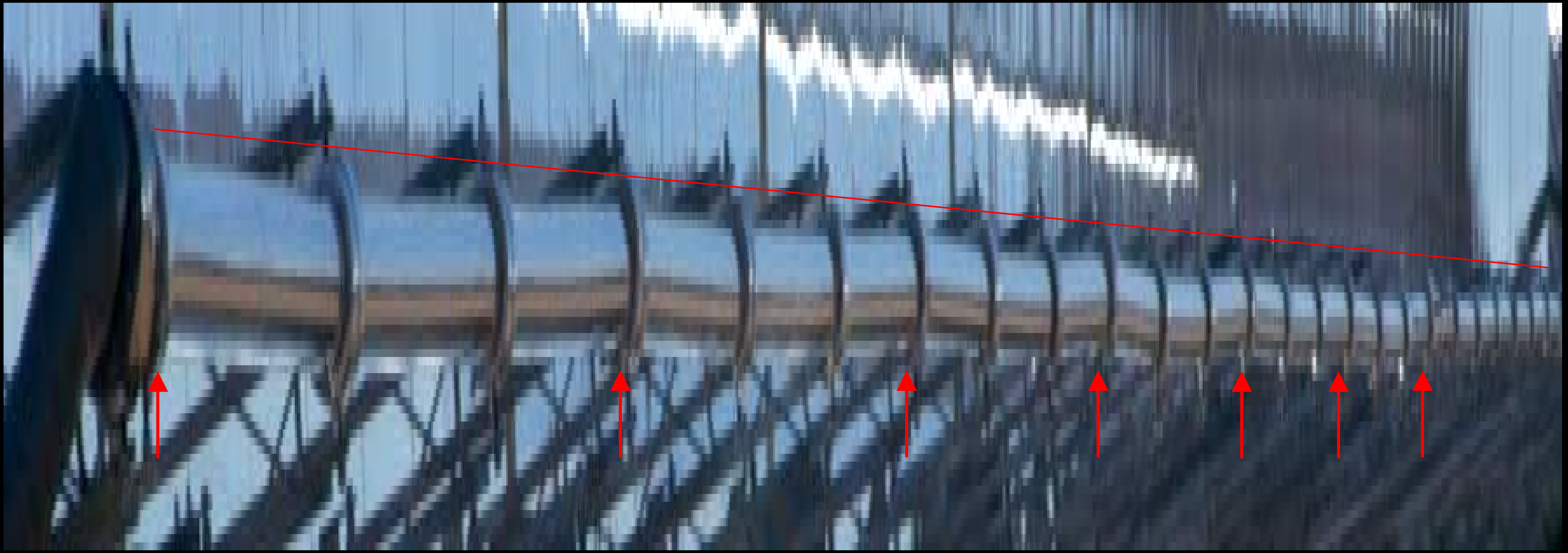


Collector Shape Measurement

Camera Photographs for Absorber Tube Alignment

Camera Photographs for Absorber Tube Alignment

Before alignment

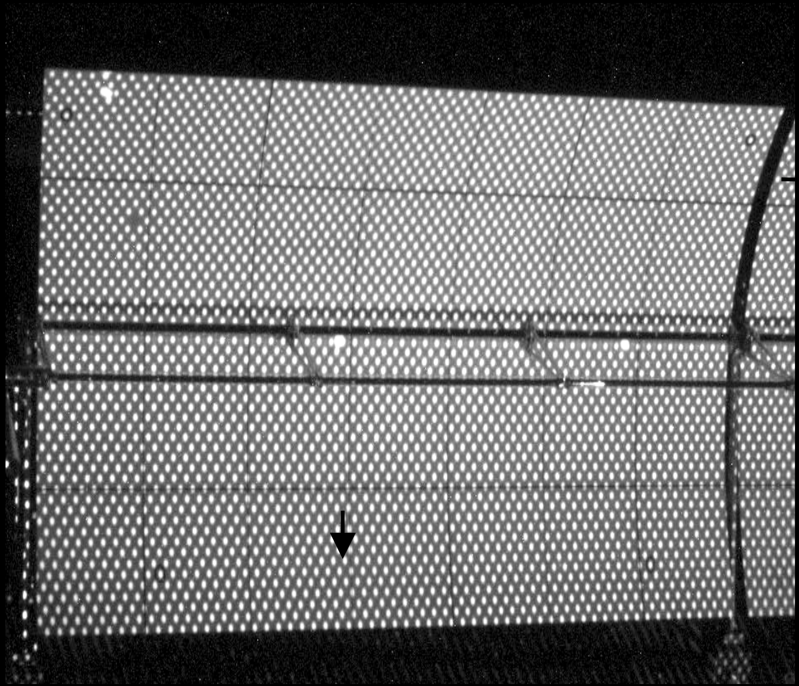


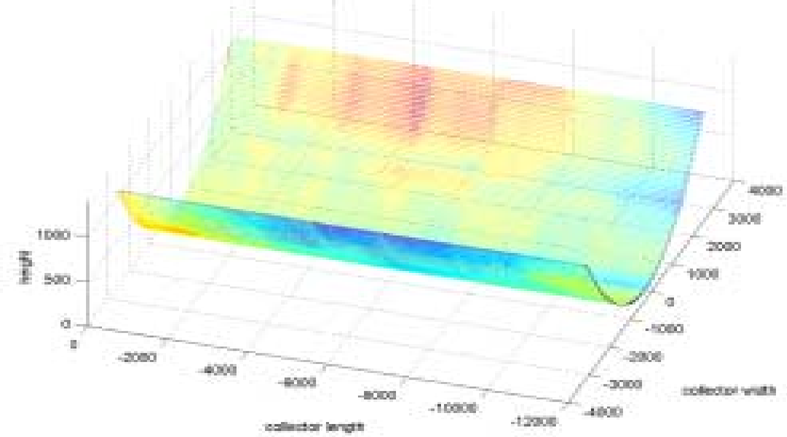
Camera Photographs for Absorber Tube Alignment

After alignment

Photogrammetry

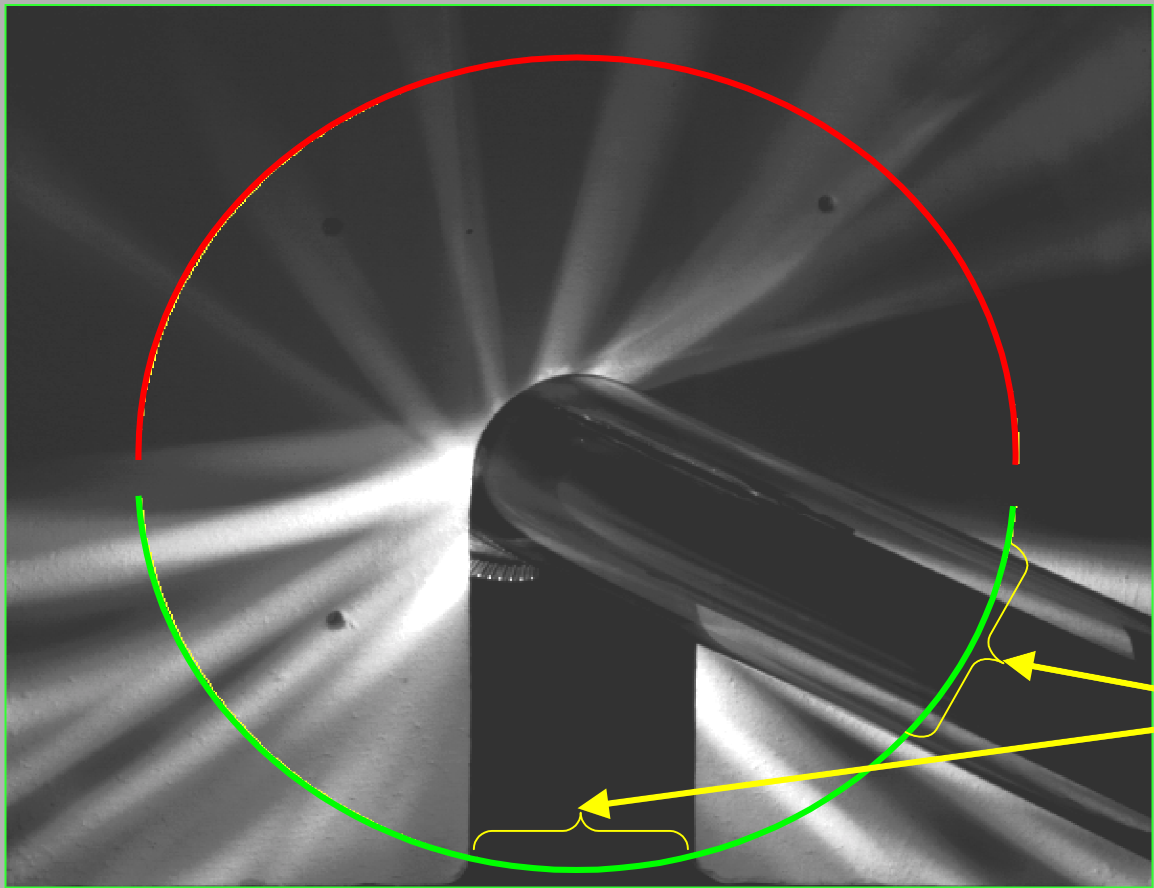
Application on Trough Collector





Camera Target Method for Troughs

Determination of Intercept:
Incoming and missing rays



$$\gamma = 1 - \frac{\int \text{vorbeigehende Strahlung}}{\left(\frac{\int \text{ankommende Strahlung}}{1 - \text{Anteil verdeckter Strahlung}} \right)}.$$

Verdeckter

Strahlungsanteil

Temperature

Solar Blind
Pyrometry

Example: UV Pyrometry

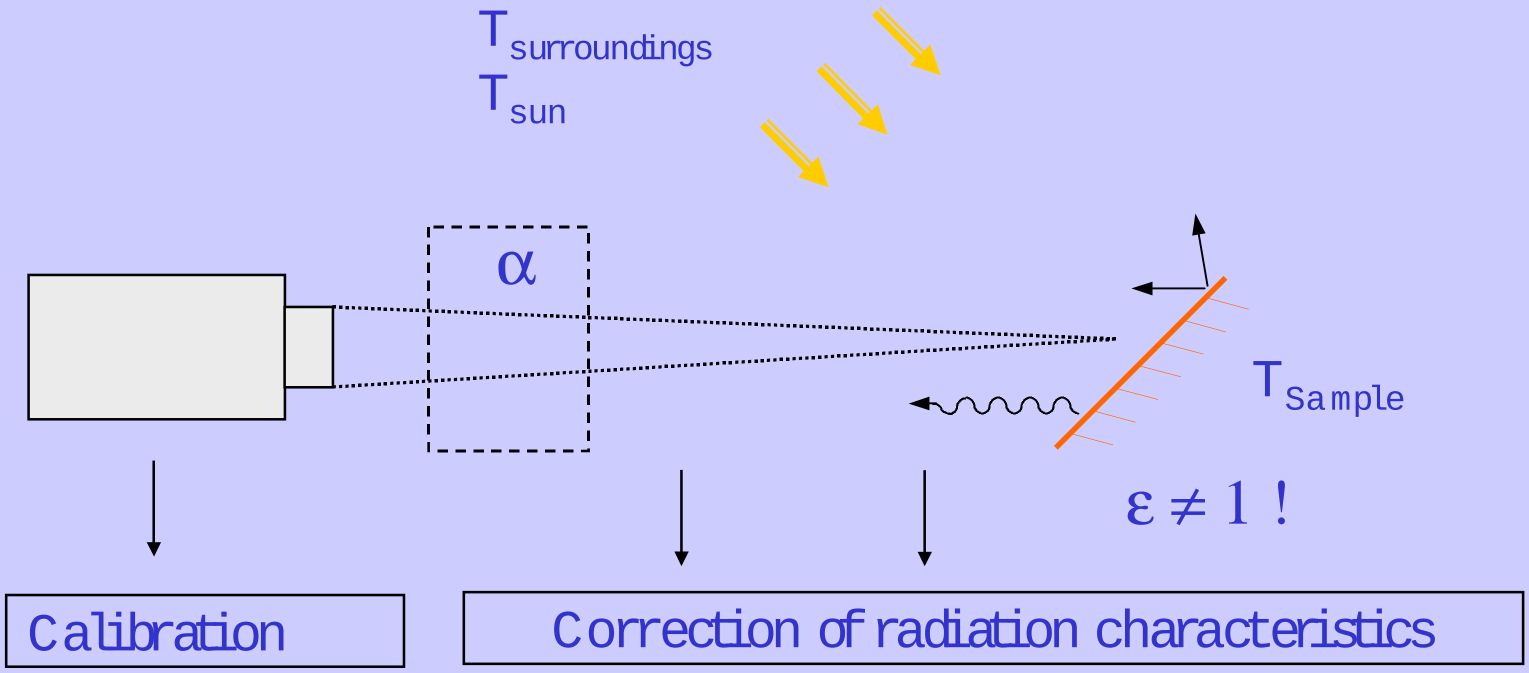
Motivation

- Temperatures up to 2770 K possible
- Surface temperature required for Material Science
- Often large $\Delta\lambda$ for more signal
  Consequence: Difficulties in ε – correction
- Temperature resolution of IR systems decreases with increasing temperatures

Example: UV Pyrometry

Theoretical Background

Fundamentals of Pyrometry



$$M(\varepsilon, T_{samp}, \lambda) = \varepsilon_s \tau_{Sys}(\lambda) \frac{C_1}{\lambda^5 \left(e^{c2/\lambda Tsamp} - 1\right)} + (1 - \varepsilon_s)\tau_{Sys}(\lambda) M_{sun}(\lambda)$$

Example: UV Pyrometry

Theoretical Background

Requirements

- High resolution in temperature
- Small interference of solar radiation
- Enough emitted radiation
- Measurement independent of atmosphere
- Measurement preferably independent of emissivity

Theory

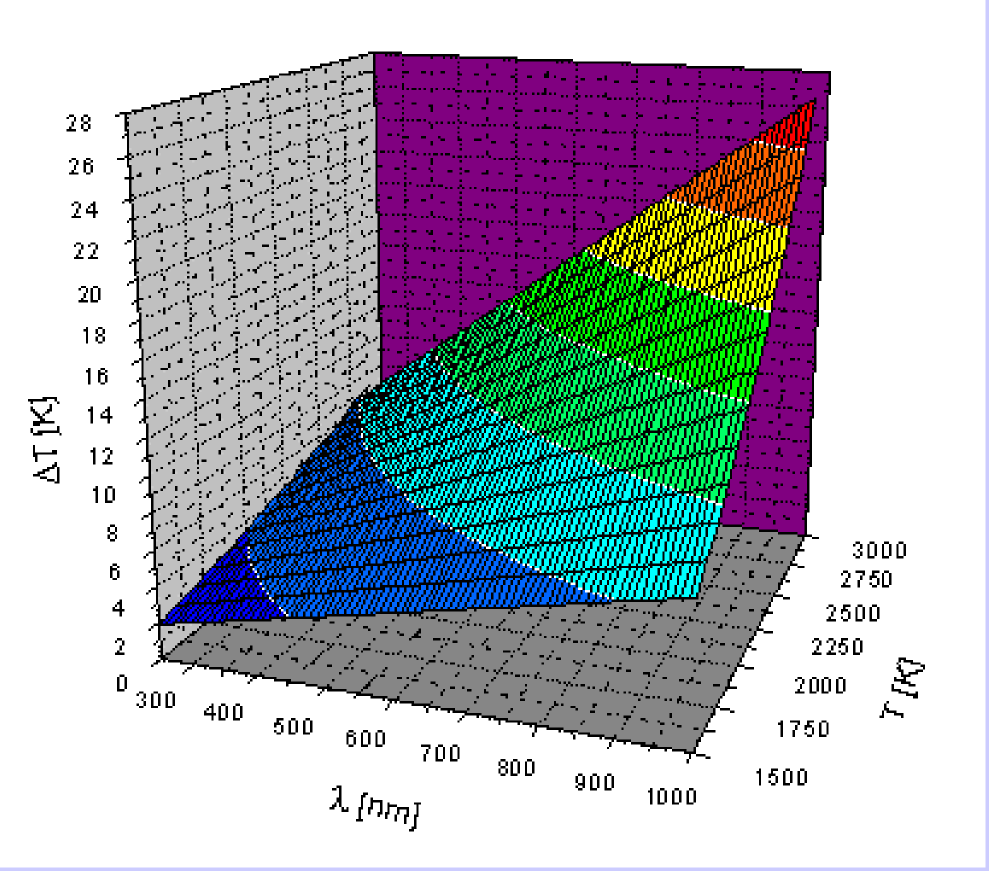
- Radiation laws
- Terrestrial solar spectra
- Atmospheric windows
- Influence of emissivity on temperature measurement

UV radiation:

100-280 nm	280-320 nm	320-400 nm	400-780 nm
UVC	UVB	UVA	Visible

Theoretical Background

Influence of Emissivity on Temperature Measurement



$$dT = \frac{\lambda}{5\lambda_m} \frac{d\varepsilon}{\varepsilon} T$$

Example: T = 2200 K , dε/ε = 5 %

ΔT (12 µm) = 90 K

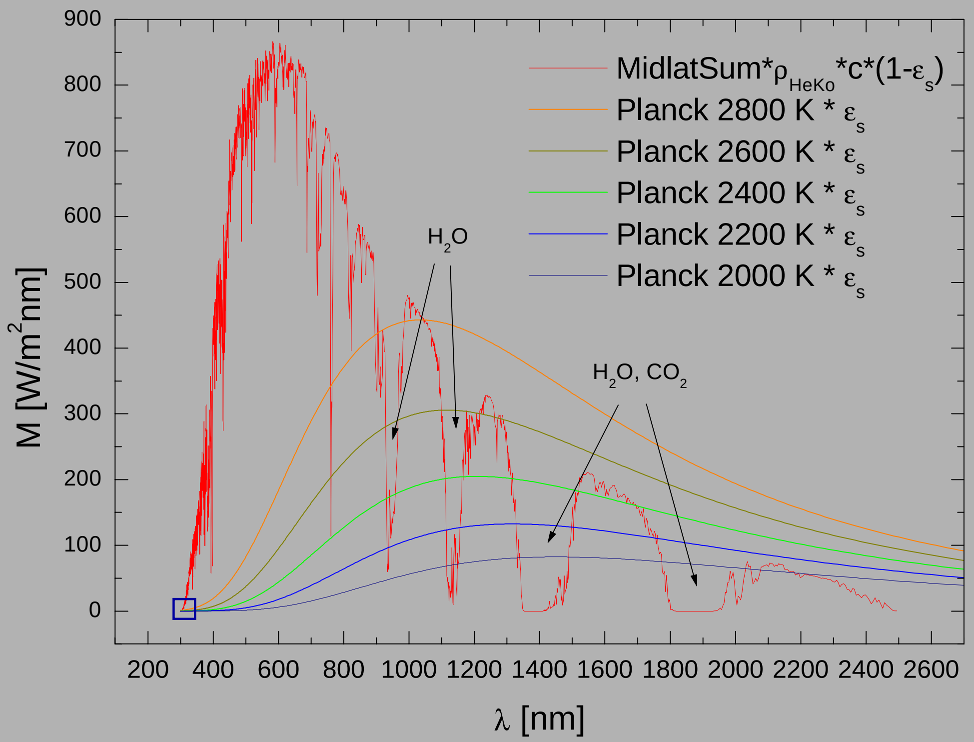
ΔT (1.39 µm) = 23 K

ΔT (0.3 µm) = 5 K

- **Best performance with λ as short as possible**

Example: UV Pyrometry

Terrestrial Solar Spectra & Planck Equation

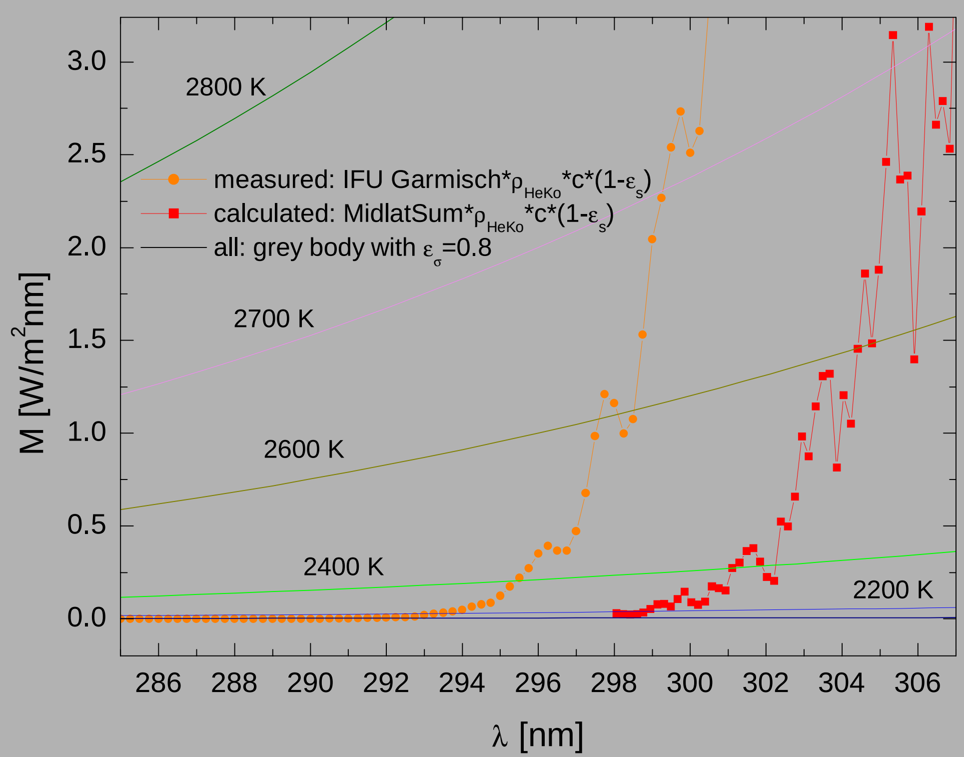


Aspects:

- High resolution at short wavelengths
- Low transmission through atmosphere
- High transmission in optical path
- Strong disturbance due to solar radiation in the visible

Example: UV Pyrometry

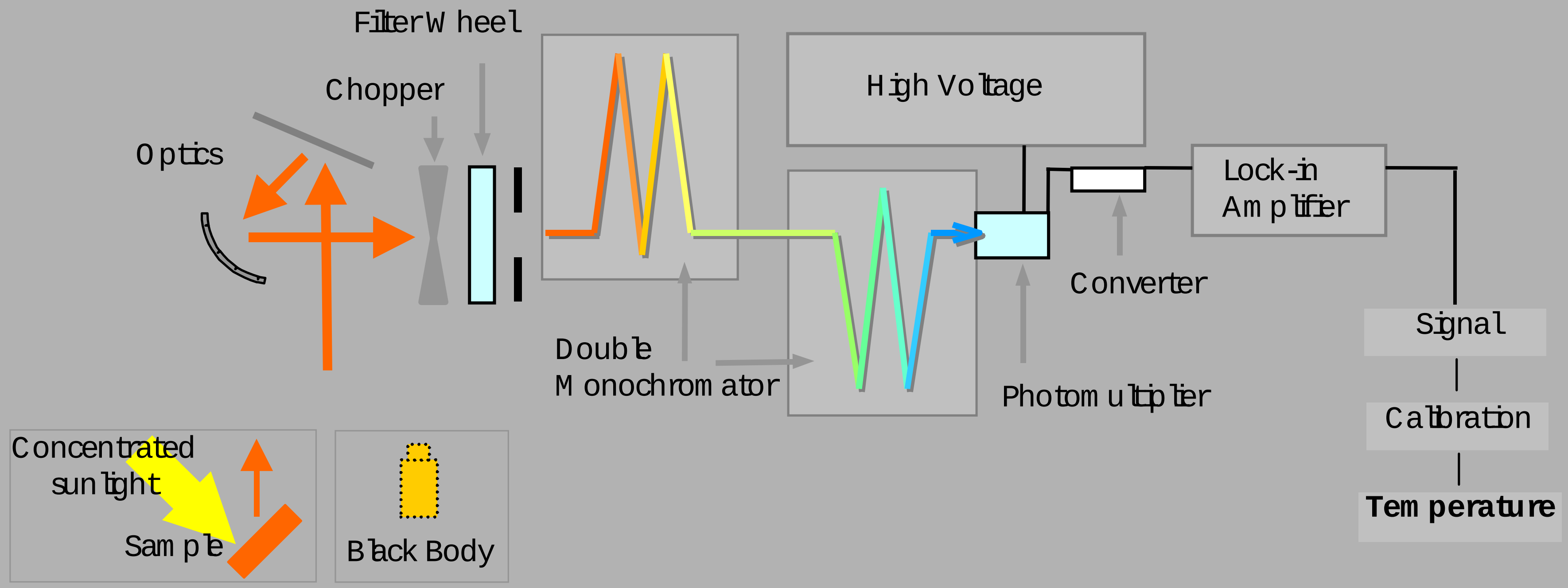
Terrestrial Solar Spectra & Planck Equation



- No measurable terrestrial solar radiation for λ < 290 nm
- UV-B range only applicable for very high temperatures

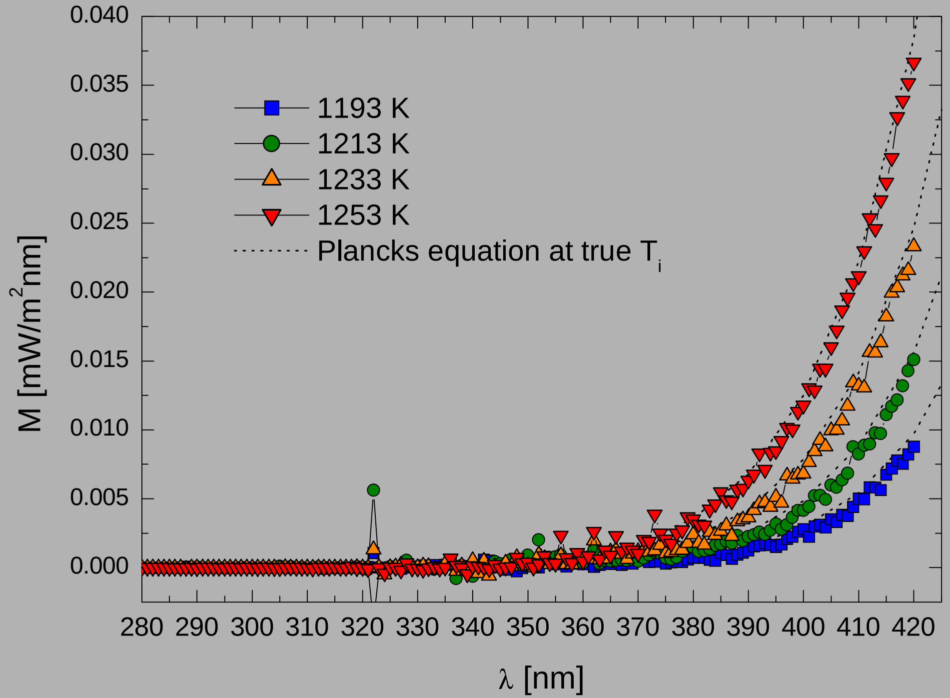
Example: UV Pyrometry

Experiment



Example: UV Pyrometry

Measurements with Black Body up to 1273 K



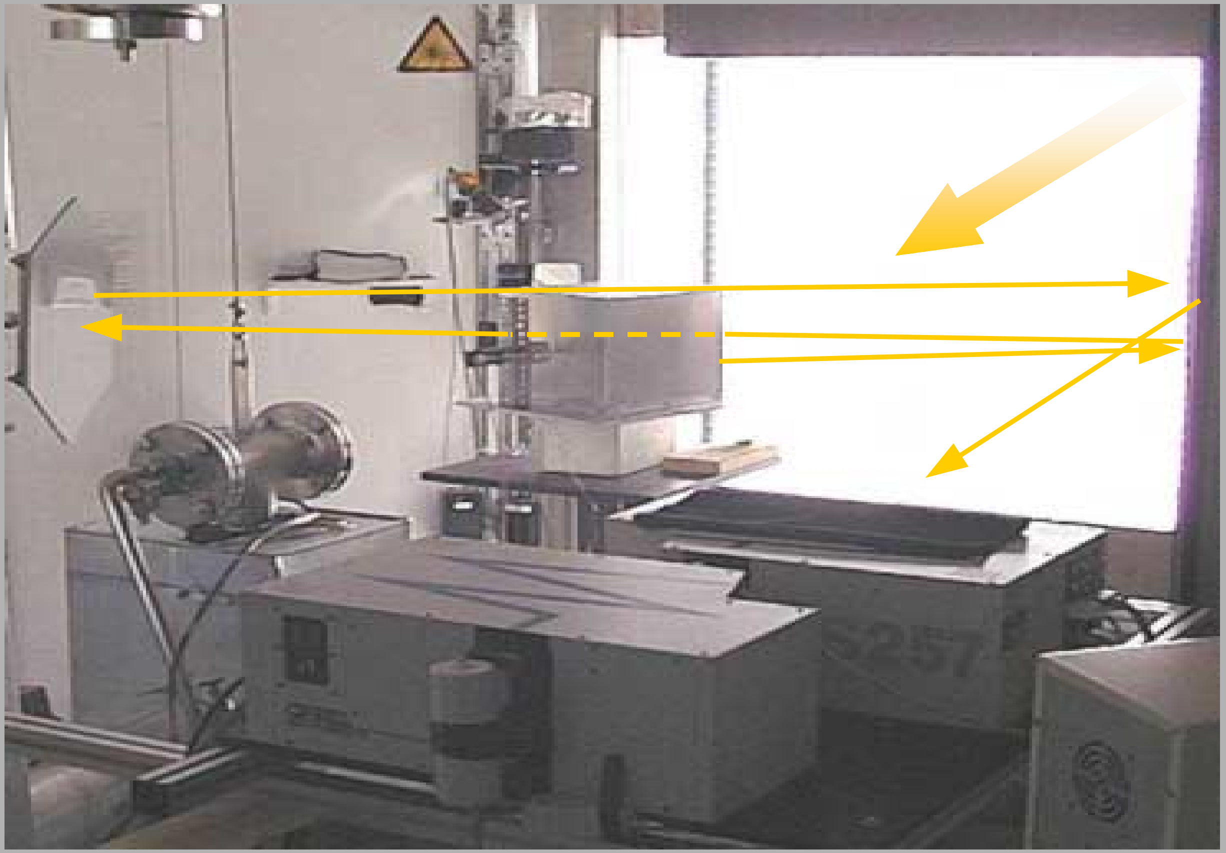
- **Good agreement with Planck but measurement λ > 360 nm required**
- **Different bandwidths for fitting: High s/n ratio more important than wide bandwidth**

- **Verification of measurement and evaluation method**

Example: UV Pyrometry

Setup

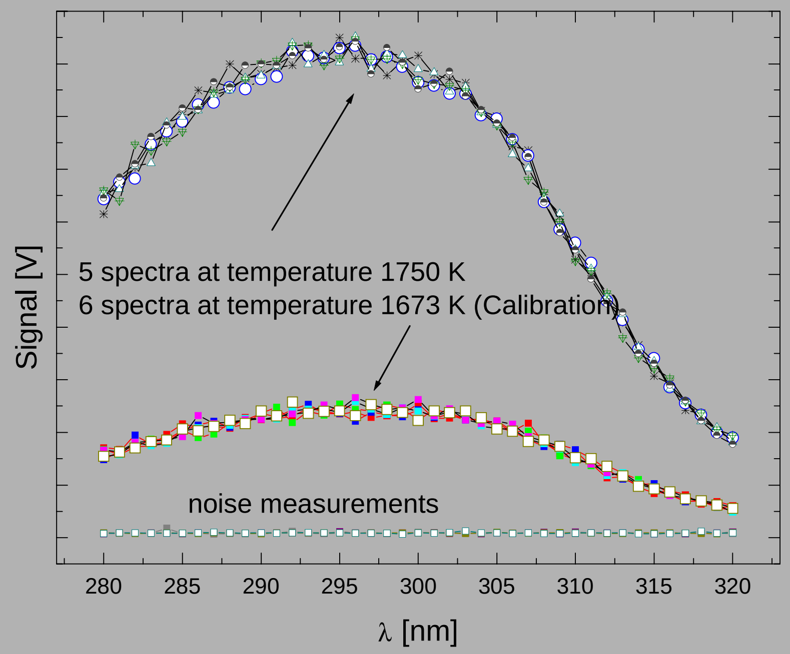
Temperatur Measurements in the Solar Furnace

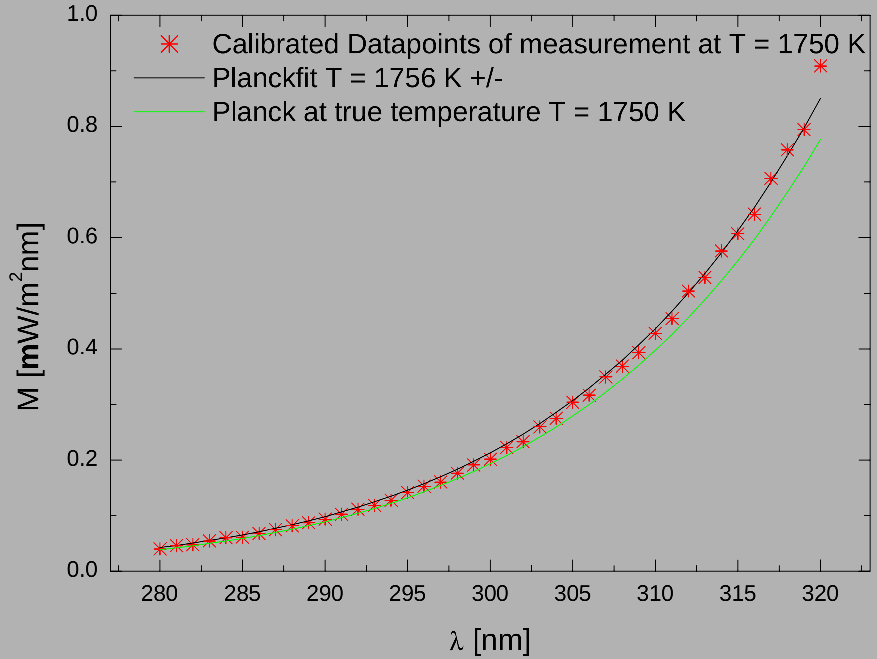


- Calibration with Black Body
- Measurements on ZrO_2, MgO

Example: UV Pyrometry

Measurements with Black Body up to 1770 K



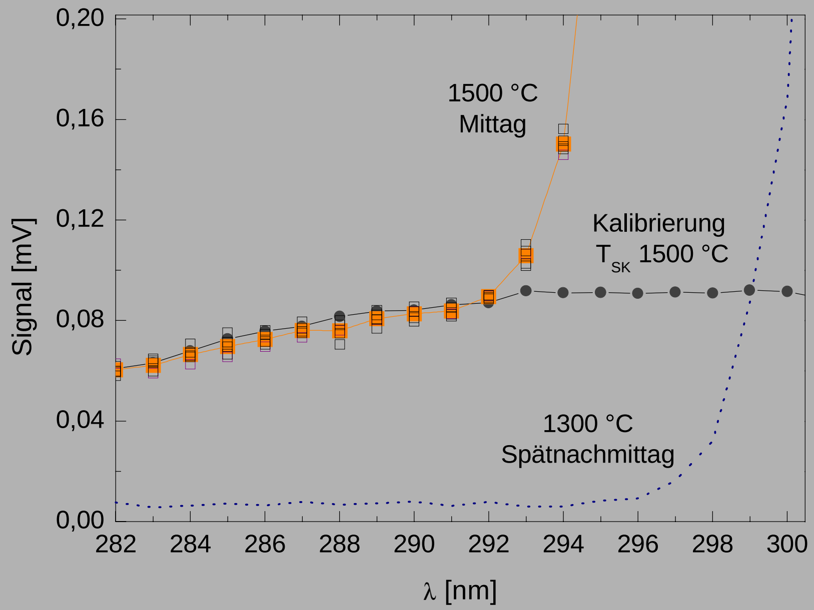


- Higher temperatures permit modification of system for shorter wavelengths

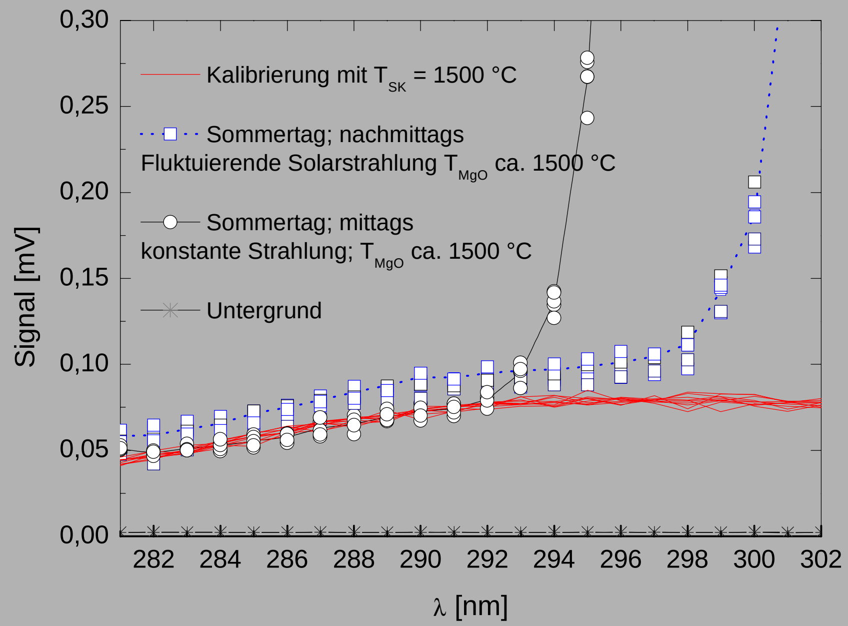
Example: UV Pyrometry

Solar Furnace: Calibration at 1500 °C

Measurement on MgO using $T_{IR\text{-}Kamera,\ \varepsilon=1}$ = 1500 °C



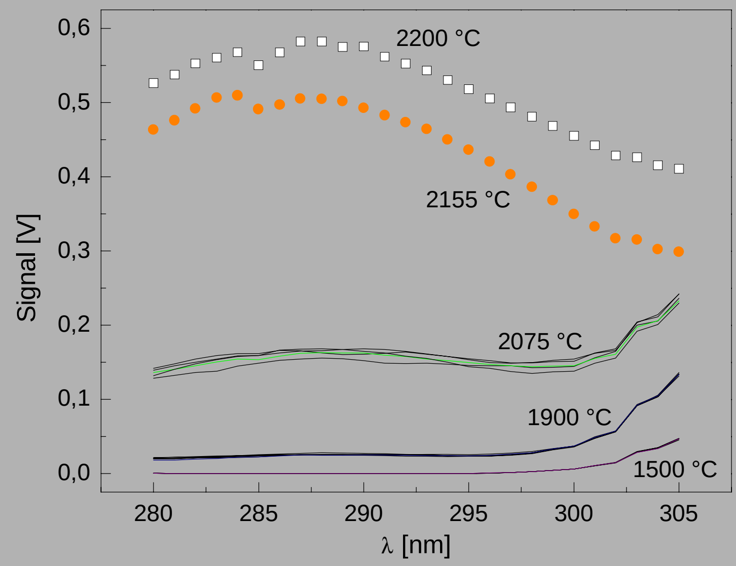
on average

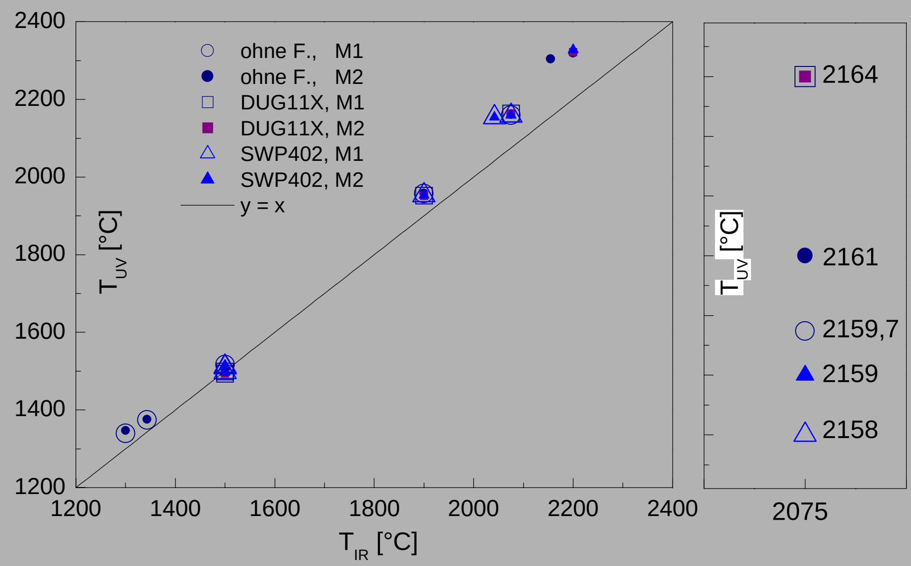


single spectra

Example: UV Pyrometry

Measurements on MgO; high Temperatures





Left: Signal at temperatures as shown by IR camera

Right: „UV temperatures“ versus IR camera temperatures, ε=1, on MgO using different filters

Example: UV Pyrometry

Conclusions and Future Work

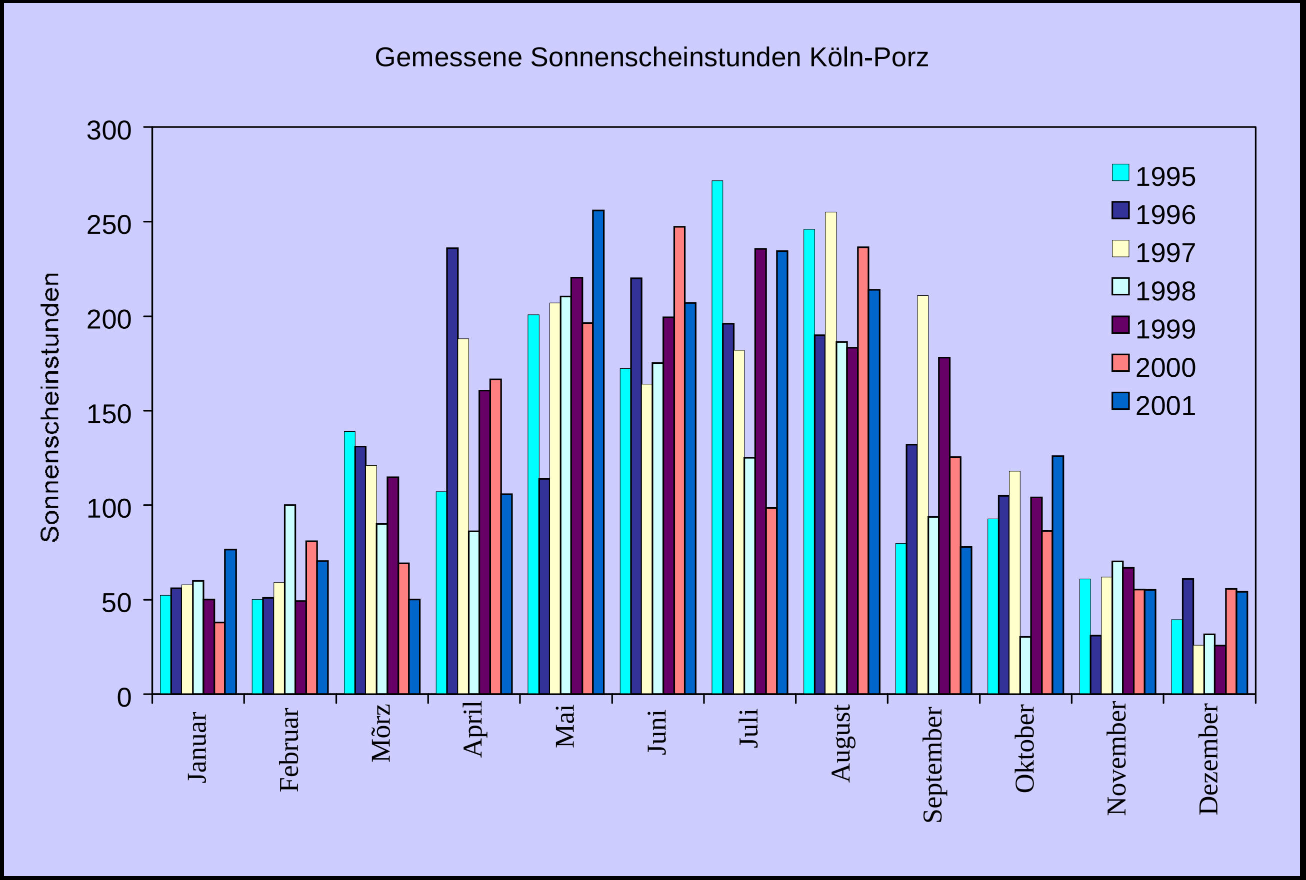
- Wavelengths in UV-B range independent of atmospheric conditions
- Measurements in the UV-B range not sensitive on emissivity
- Sensitive detection system installed and tested
- Tests on black bodies up to T < 1770 K
- Solar blind below 292 nm
- Comparison to IR camera
- Promising features
- Next steps: improve the installation, stiff alignment, add a laser pointer

Meteo Data

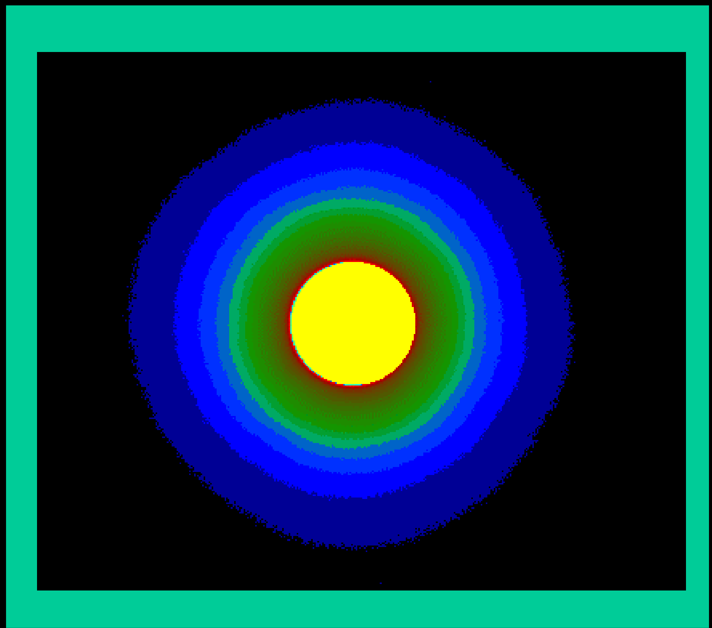
Meteo Station at DLR Cologne

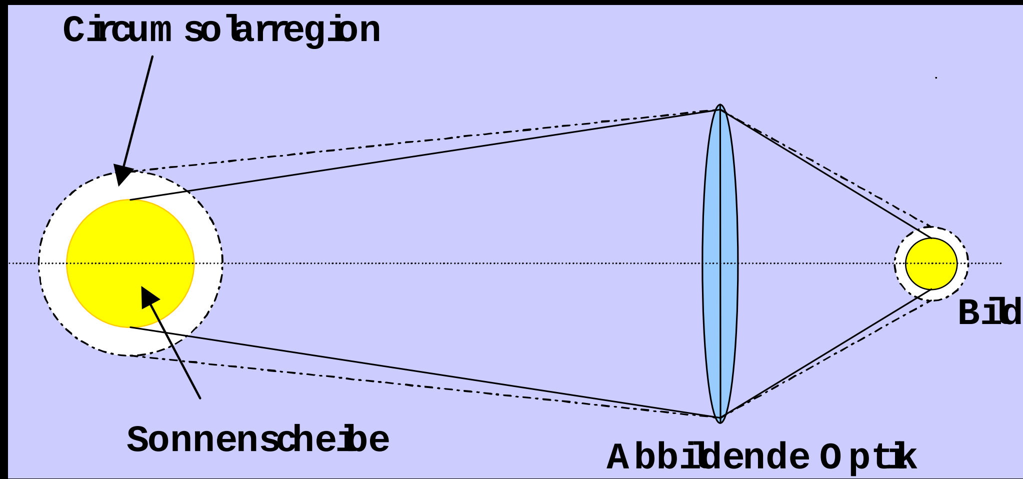
	Hersteller
Direktstrahlung	
Direkt Normal Broadband 280-2500 nm	Eppley NIP
UVA Direkt, 368±5 nm,	Kipp & Zonen CUVA2
UVB Direkt, 306±1 nm	Kipp & Zonen CUVB2
Globalstrahlung	
Global horizontal 285-2800 nm	Kipp & Zonen CM11
Global geneigt 51°	Kipp & Zonen CM11
UV 295-385 nm, geneigt to 51°	Eppley TUVR
UVB Global geneigt to 51°	EKO Instr. MS-210W/D
Diffus	
Diffus horizontal, 285-2800 nm	Kipp & Zonen CM11, Schattenring
Sonstige Signale	
Relative Feuchte	Thies Clima, 1.1005
Temperatur	Thies Clima 1.1005
Windgeschwindigkeit	Thies Clima, 4.3105
Windrichtung	Thies Clima, 4.3120
Niederschlag	Met One Instruments Model 370
Sonnenofen-Statussignale	
Sonnenofentor geöffnet	
Konzentratortor geöffnet	
Shutter geöffnet	
Heliostat zielt auf Standby	
Heliostat zielt auf Konzentrator	

Sunshine Hour Statistics

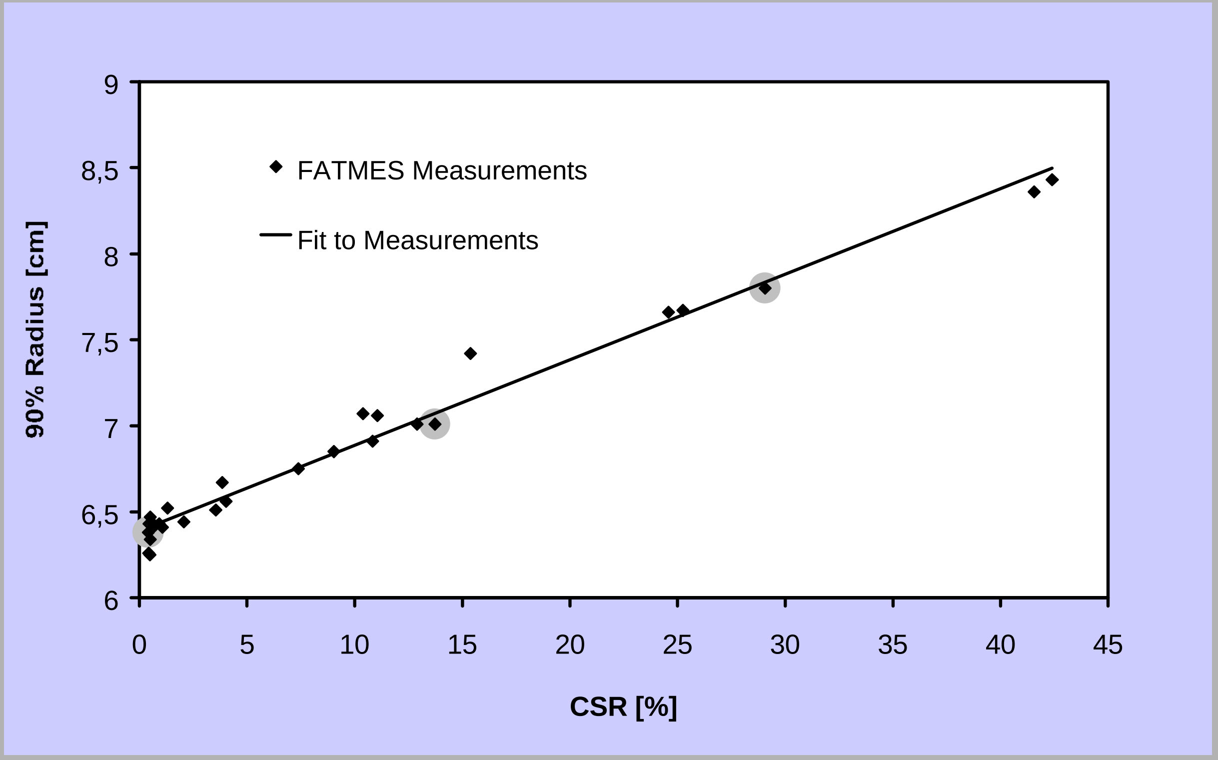


Sunshape





Sunshape


FATMES Measurements
Fit to Measurements
90% Radius [cm]
CSR [%]
9
8,5
8
7,5
7
6,5
6
0
5
10
15
20
25
30
35
40
45

Summary

- Presentation of many technologies
- Some need further development
- Common efforts are very promising