Tracking and shape errors measurement of concentrating heliostats

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Outline

1)General Introduction / Context

2)Backward-Gazing Method

3)Numerical Simulations

4)Experiments and Preliminary Results

5)Conclusion and Outlooks

Different types of CSP Plants

Tower power Plant
(Gemasolar, Spain)

Parabolic Trough
(Shams 1, Abu Dhabi)

Dish Stirling
(Eurodish, Odeillo)

Linear Fresnel
(NOVATEC BIOSOL)

Why must we characterize the concentrators

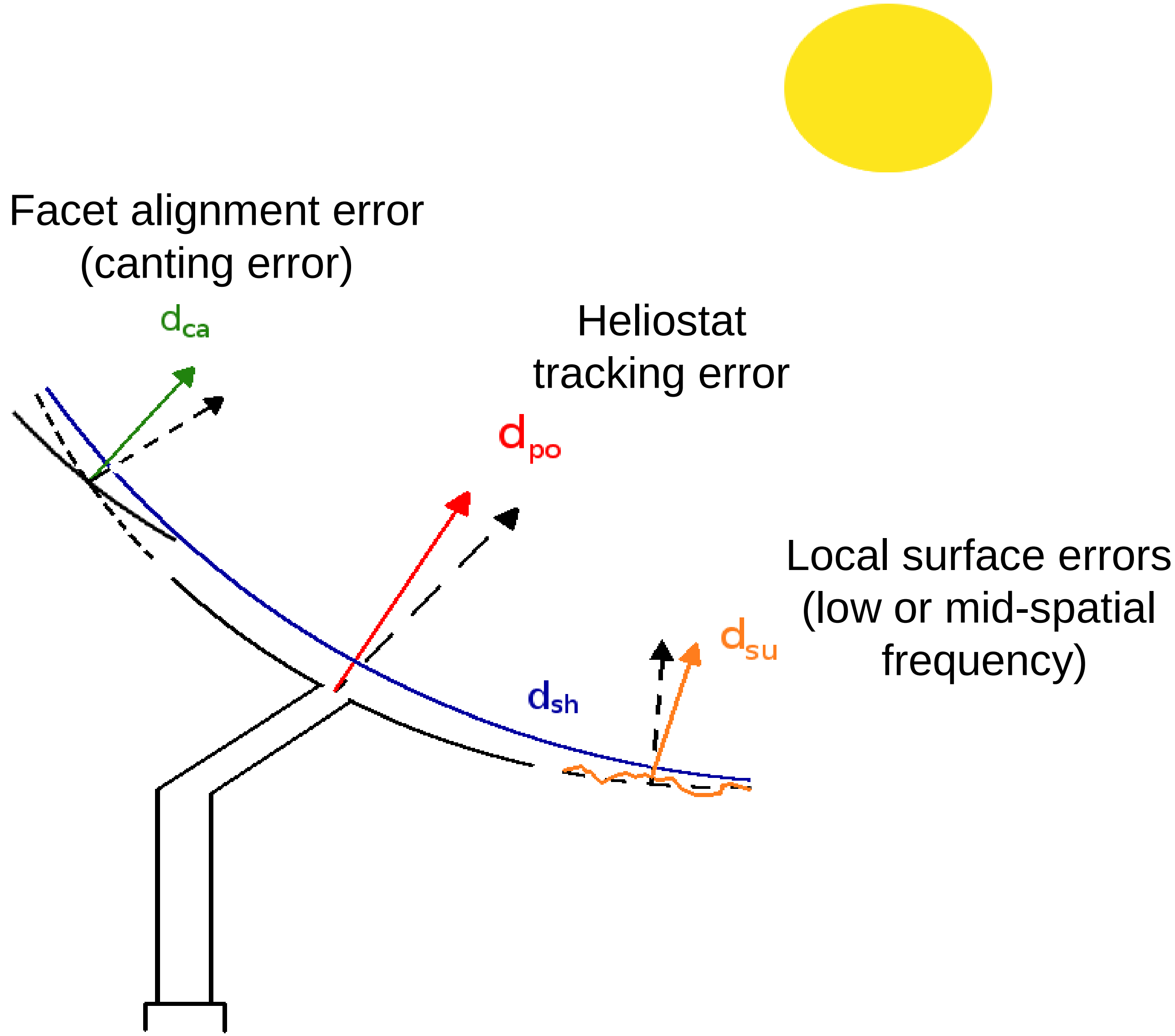
Immediate applications

- Decrease the necessary time to adjust thousands of reflective facets
- Identify damaged facets, to be repaired or replaced

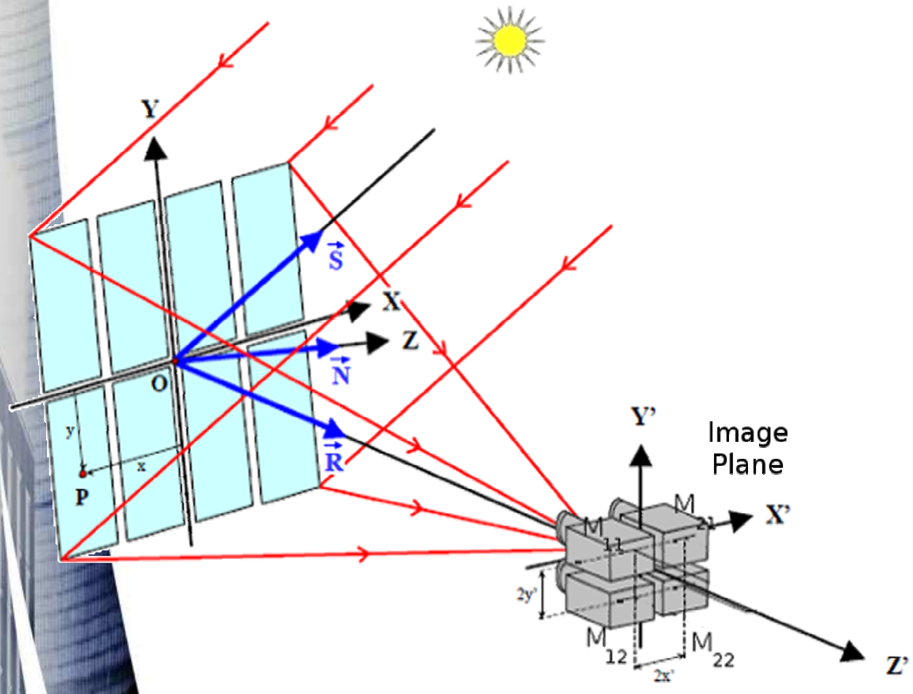
More prospective applications

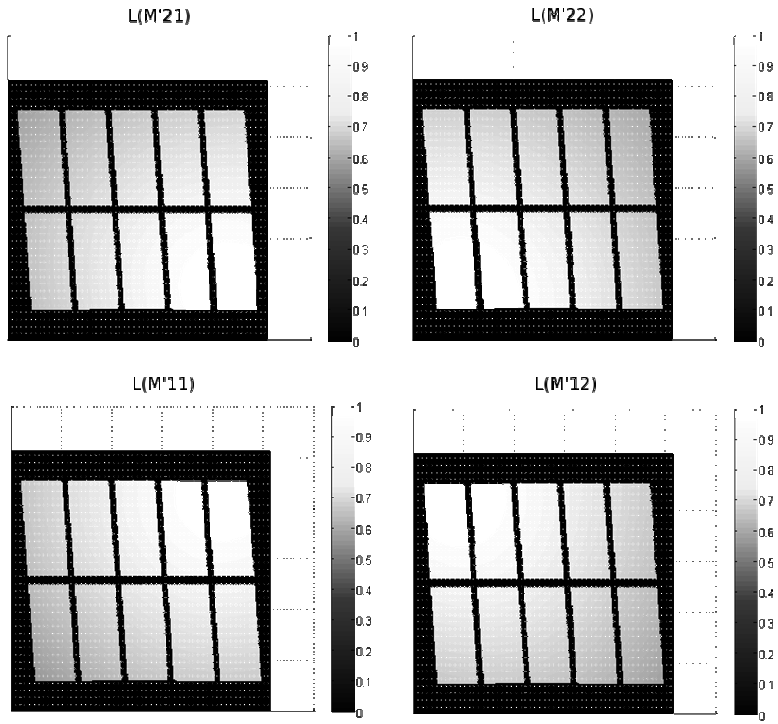
- To evaluate and optimize prototypes
- To predict performance
- To analyze mechanical stress, and the influence of the wind and gravity
- A better control of the heliostat tracking is necessary for the development of pointing strategies

Different types of errors



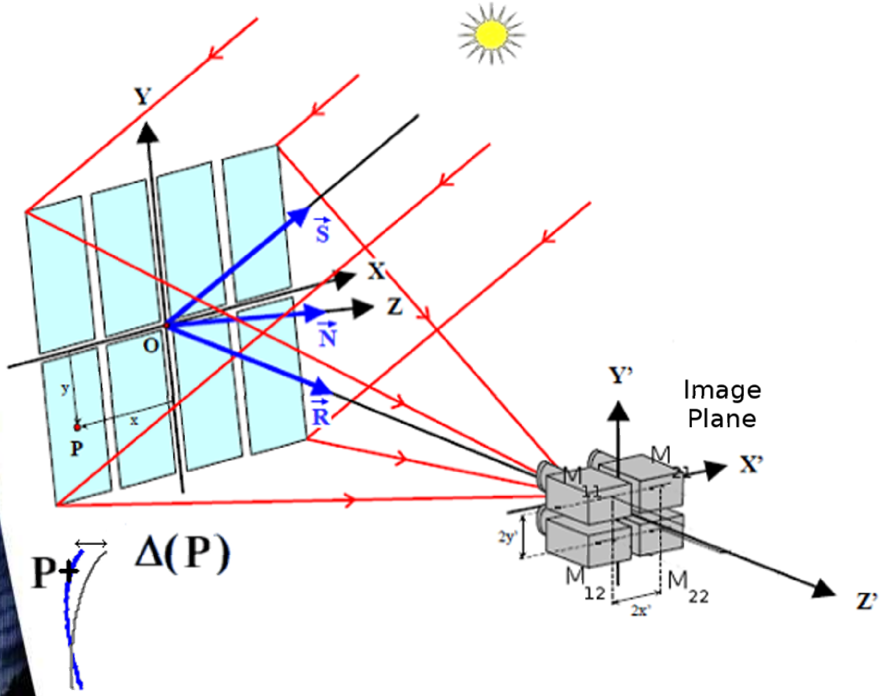
Method's Description

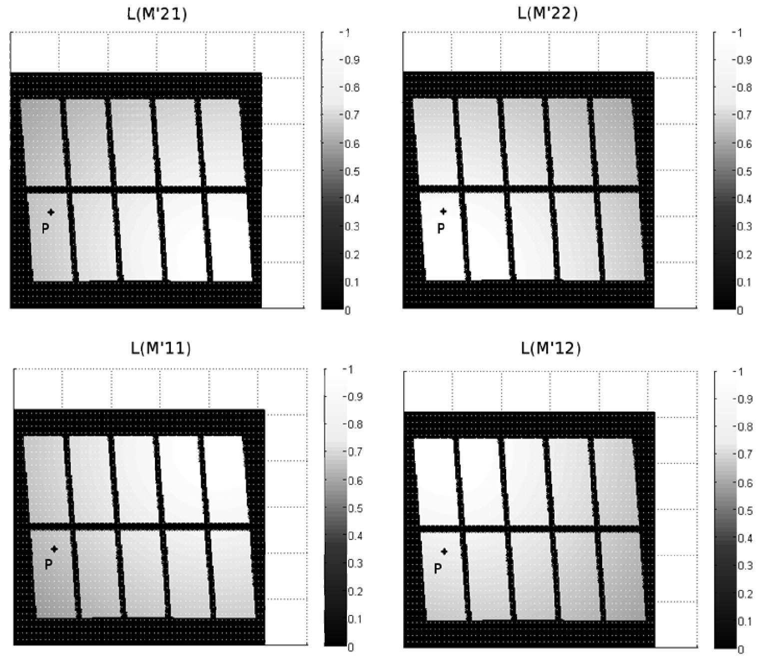




Images of the reflection of the sun on the heliostat are taken from different points of view. By knowing the sun profile, it is possible to reconstruct the optical errors of the mirrors.

Slope Errors Equations



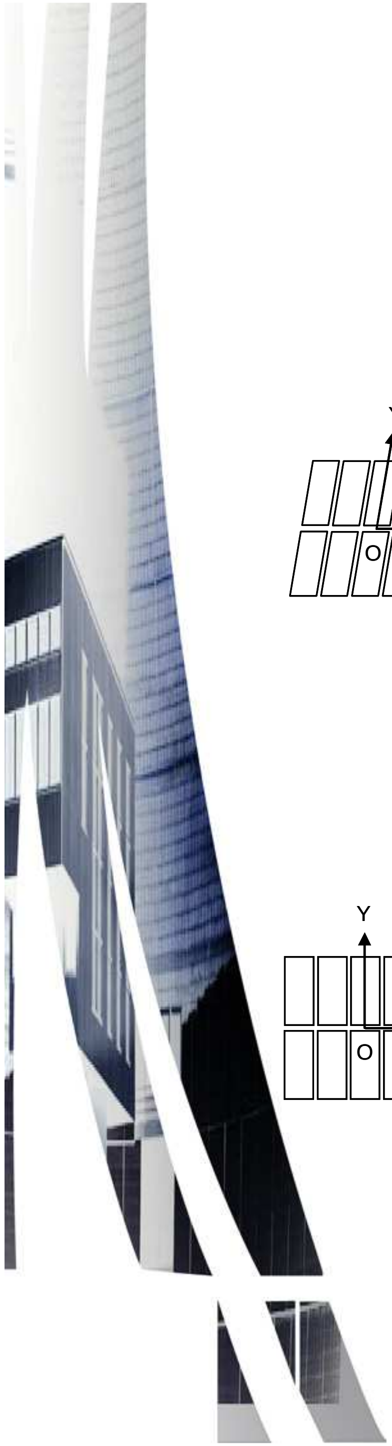


$$\begin{pmatrix} \dfrac{\partial W(P)}{\partial x} \\ \dfrac{\partial W(P)}{\partial y} \end{pmatrix} = D \begin{pmatrix} \dfrac{K_{22}(P)+K_{21}(P)-K_{12}(P)-K_{11}(P)}{8\delta x'} \\ \dfrac{K_{22}(P)+K_{12}(P)-K_{21}(P)-K_{11}(P)}{8\delta y'} \end{pmatrix}$$

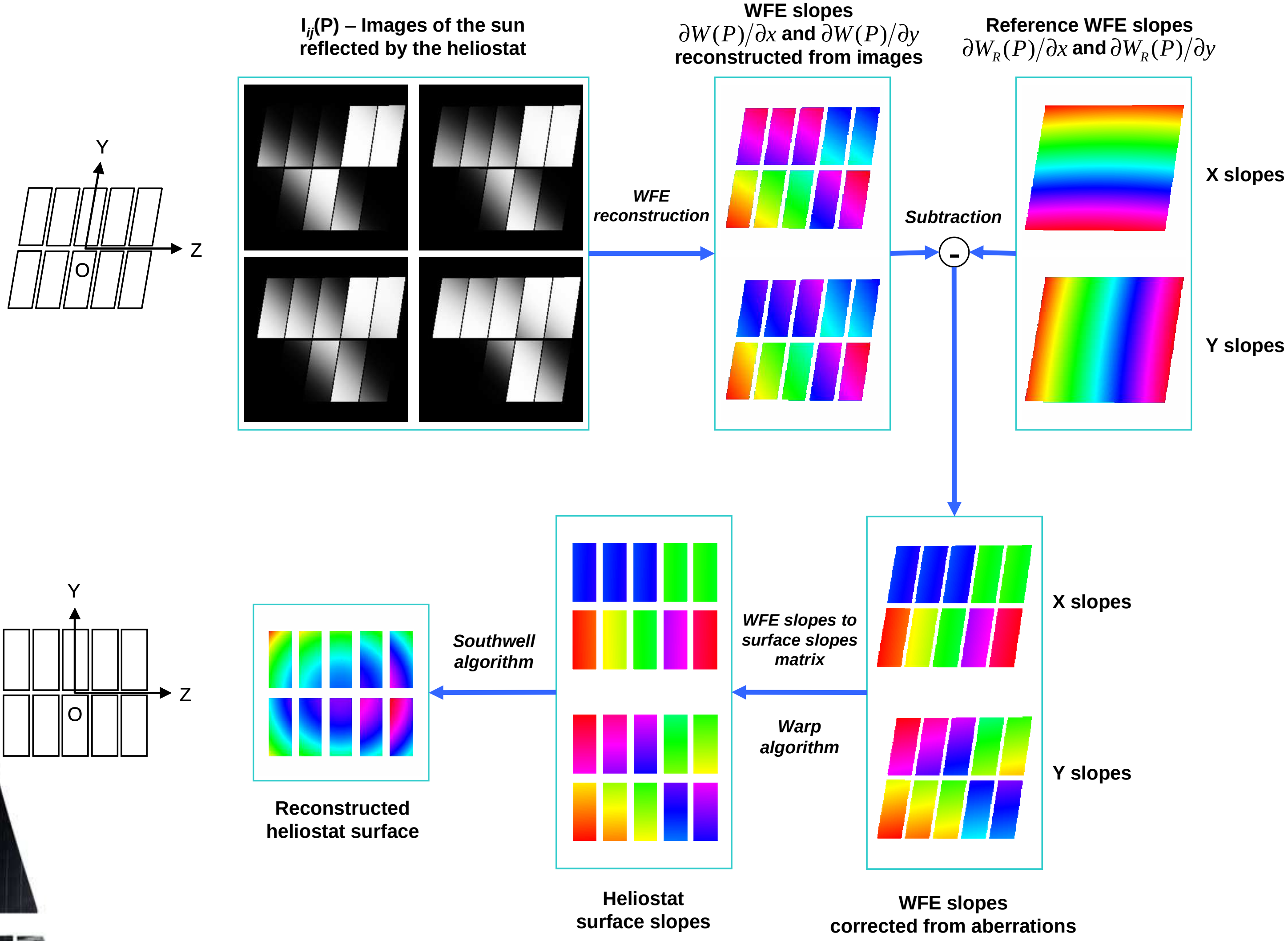
$$\begin{pmatrix} \dfrac{\partial \Delta(P)}{\partial x} \\ \dfrac{\partial \Delta(P)}{\partial y} \end{pmatrix} = \frac{1}{2} \begin{pmatrix} \dfrac{1}{\cos H} & -\tan A \tan H \\ 0 & \dfrac{1}{\cos A} \end{pmatrix} \begin{pmatrix} \dfrac{\partial W(P)}{\partial x} - \dfrac{\partial W_R(P)}{\partial x} \\ \dfrac{\partial W(P)}{\partial y} - \dfrac{\partial W_R(P)}{\partial y} \end{pmatrix}$$

Wavefront reconstruction from the four images

Wavefront to surface slopes transform matrix

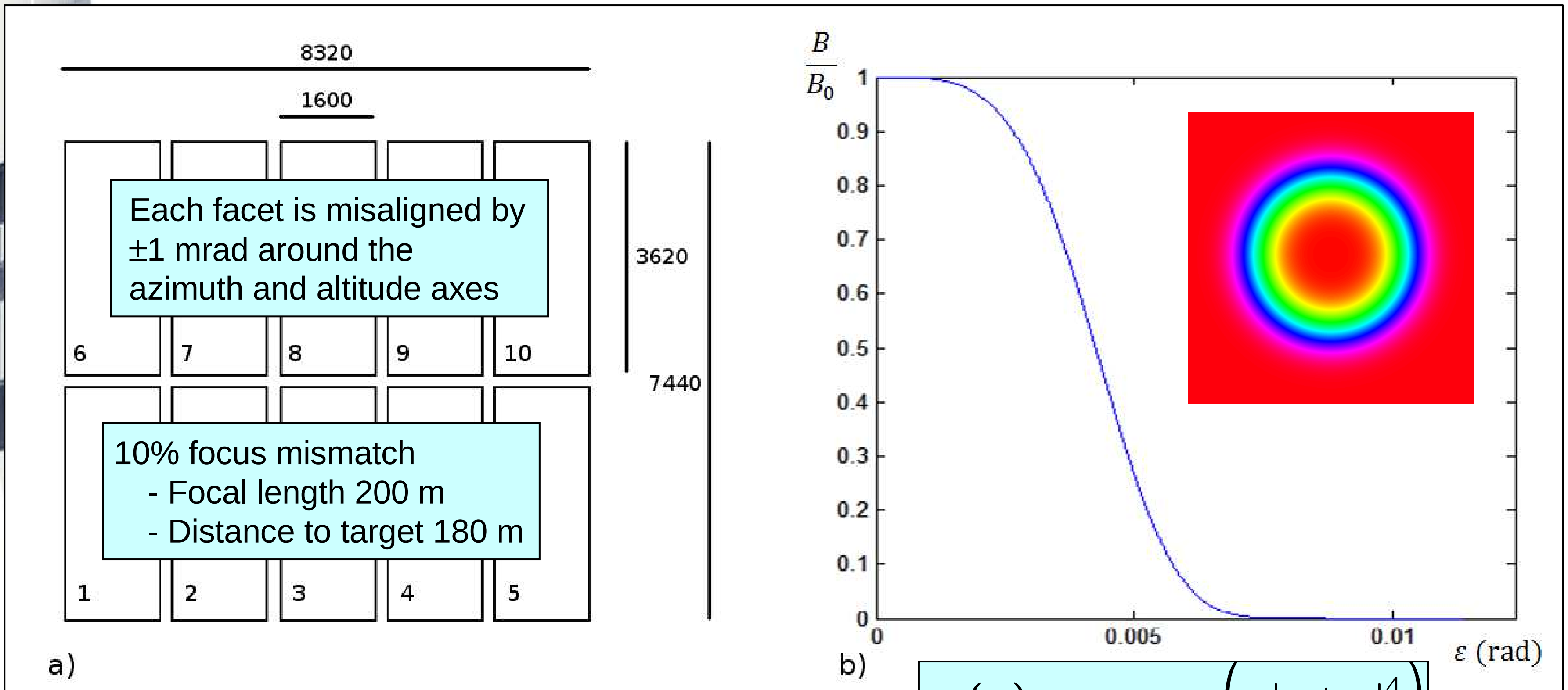


Proceedings



Numerical Simulations

Heliostat and sun models

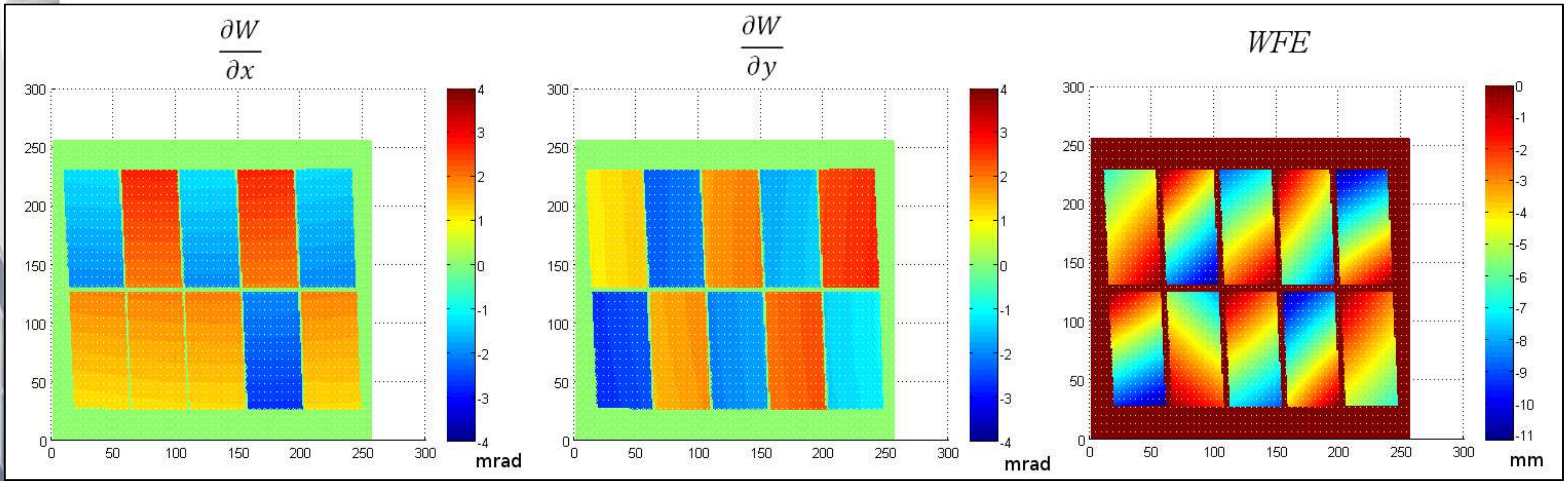


$$B(\varepsilon) = B_0 \exp\left(-\left|\varepsilon/\varepsilon_0\right|^4\right)$$

a) Dimensions of the simulated heliostat in mm
b) Super-Gaussian sun profile with parameter ξ = 4

Numerical Simulations

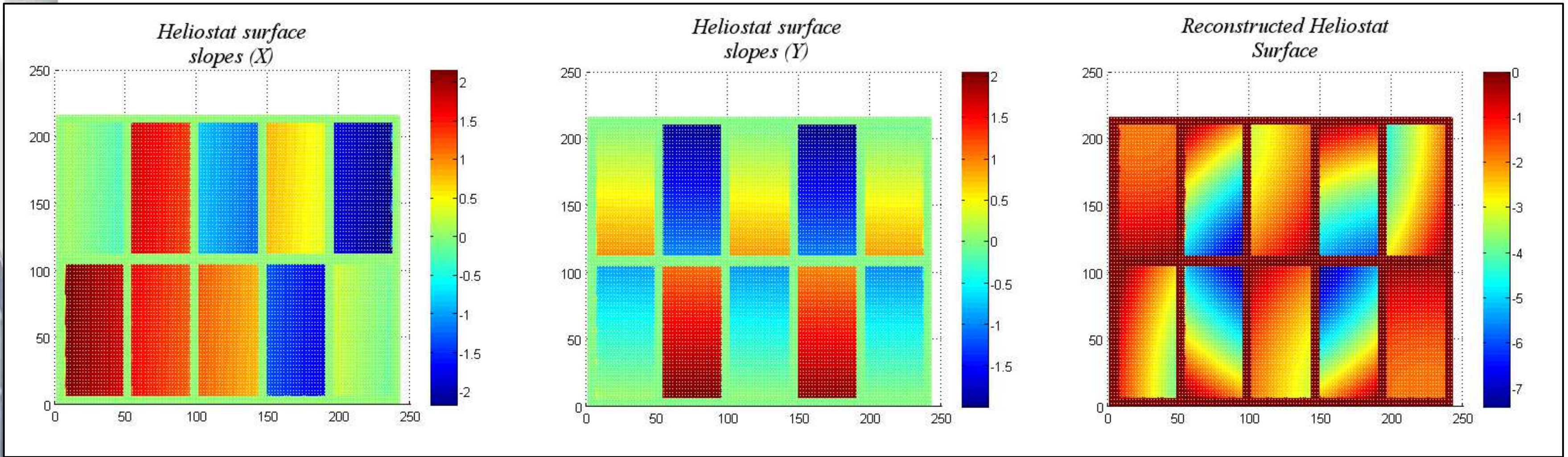
WFE and slopes Reconstruction Errors



		Reference values	Measurement errors
PTV	X slopes (mrad)	5.351	0.039
	Y slopes (mrad)	5.442	0.042
	WFE (mm)	11.164	0.060
RMS	Required : - Wavefront error < 2 mrad - Measurement < 0.2 mrad	1.794	0.007
		1.953	0.009
		3.775	0.009

Numerical Simulations

Surface Reconstruction Errors

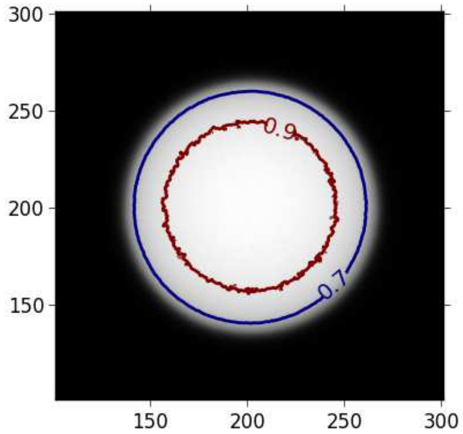


		Reference values	Measurement errors
	X slopes (mrad)	4.243	0.183
PTV	Y slopes (mrad)	3.993	0.185
	Surface (mm)	7.445	0.468
	Required : - Shape error < 1 mrad - Measurement < 0.1 mrad	1.340	0.046
RMS		1.141	0.053
		1.027	0.079

Experiments at THEMIS power plant

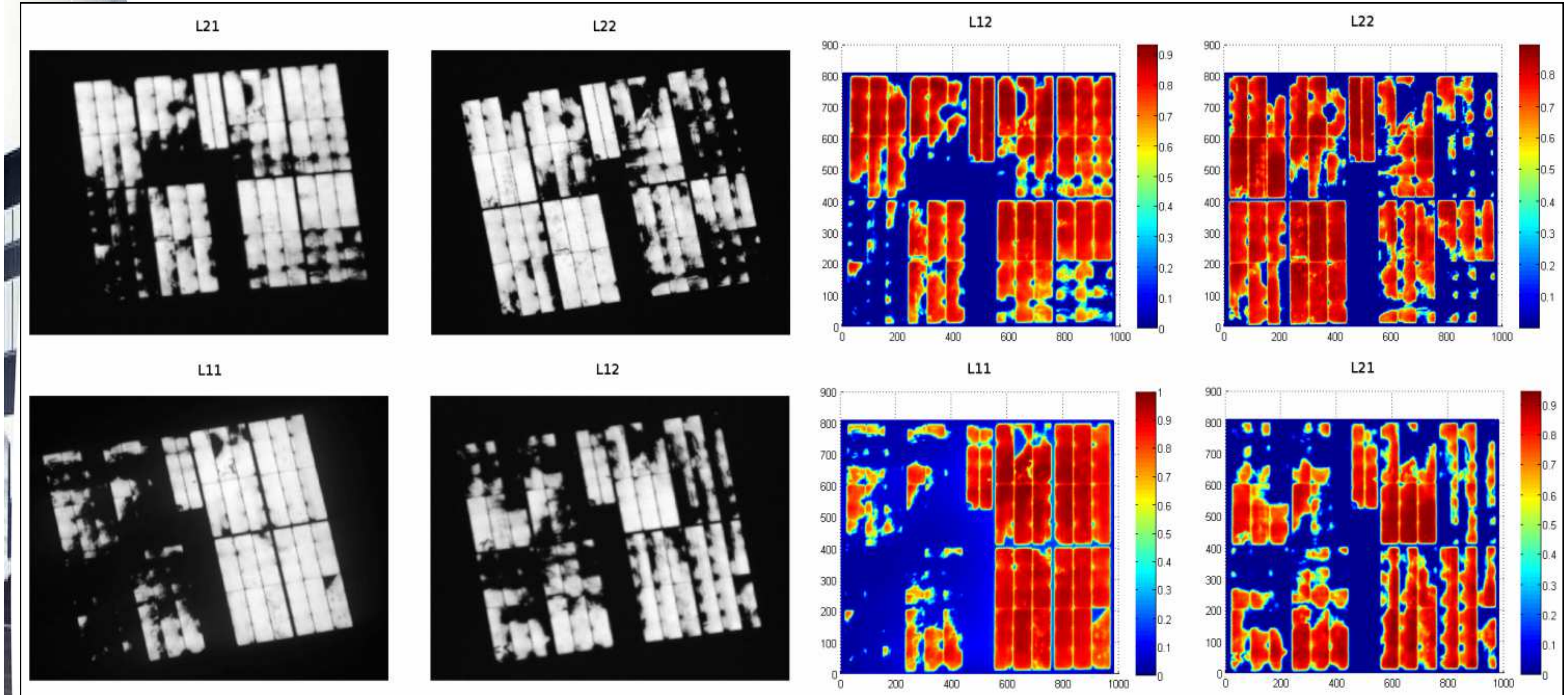
Targasonne – France (Pyrenees Mountains)

A 5th camera is used to calibrating the sun profile during images acquisition



Experiments

Acquisitions and Treatments

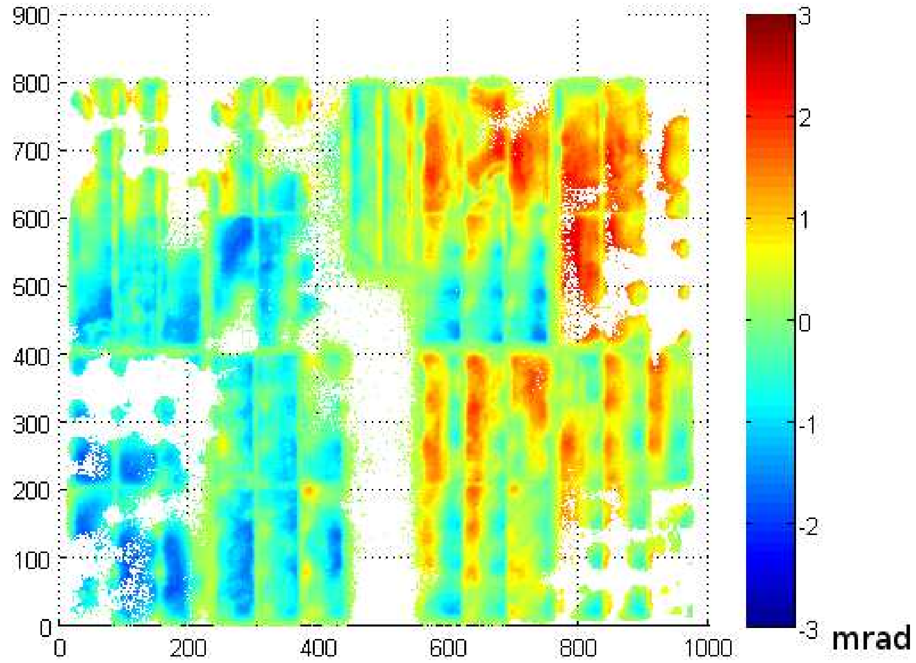


Raw images

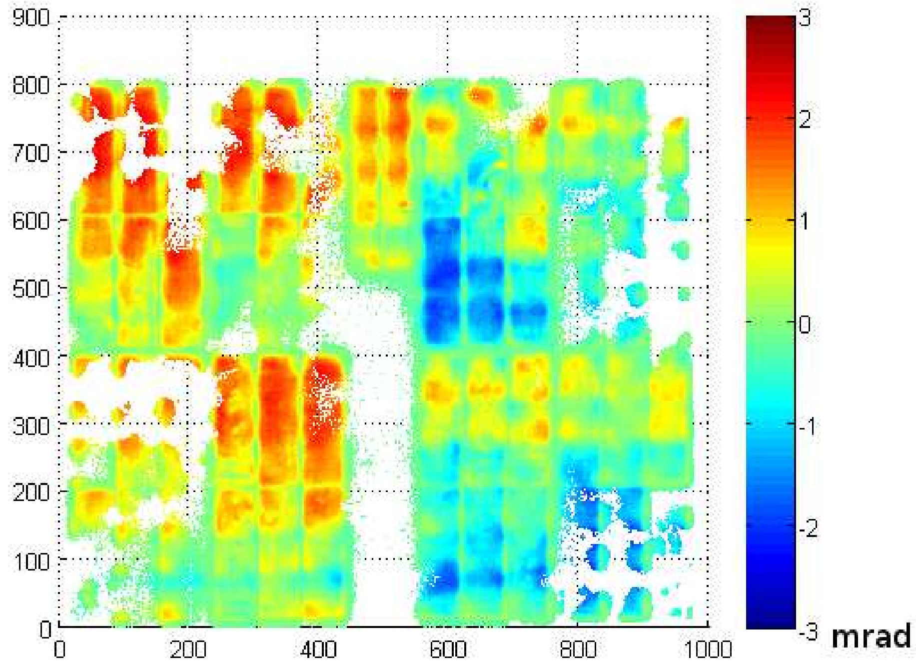
"Rectangularized" images

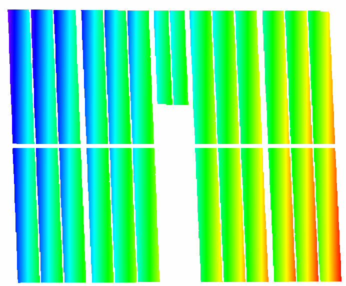
Experiments - Preliminary Results

Wavefront slopes along X

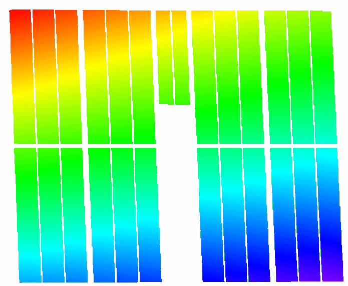


Wavefront slopes along Y





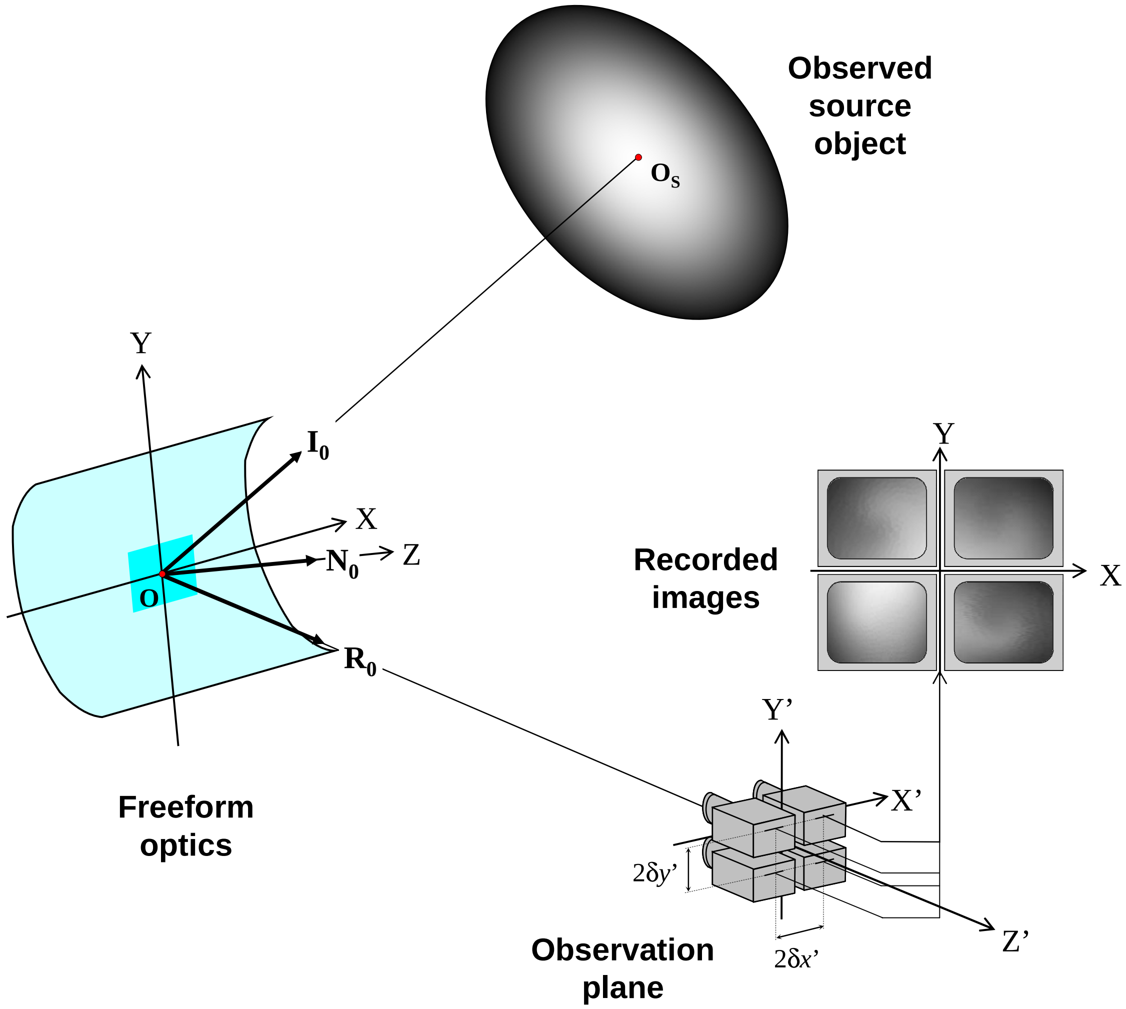
Simulated slopes



Conclusion and Outlooks

- A four cameras **backward-gazing method** to characterize solar concentrators has been described
- Numerical simulations have been performed to validate the method, and to demonstrate that its accuracy is compliant with the requirement for concentrating surfaces in solar power plants
- An experiment has been set-up in THEMIS solar power plant. The method **already works in WFE sensing mode**, but:
  - Image processing has highlighted the difficulty to superimpose the images ("registration")
- The validation of the method in surface shape sensing mode is in progress

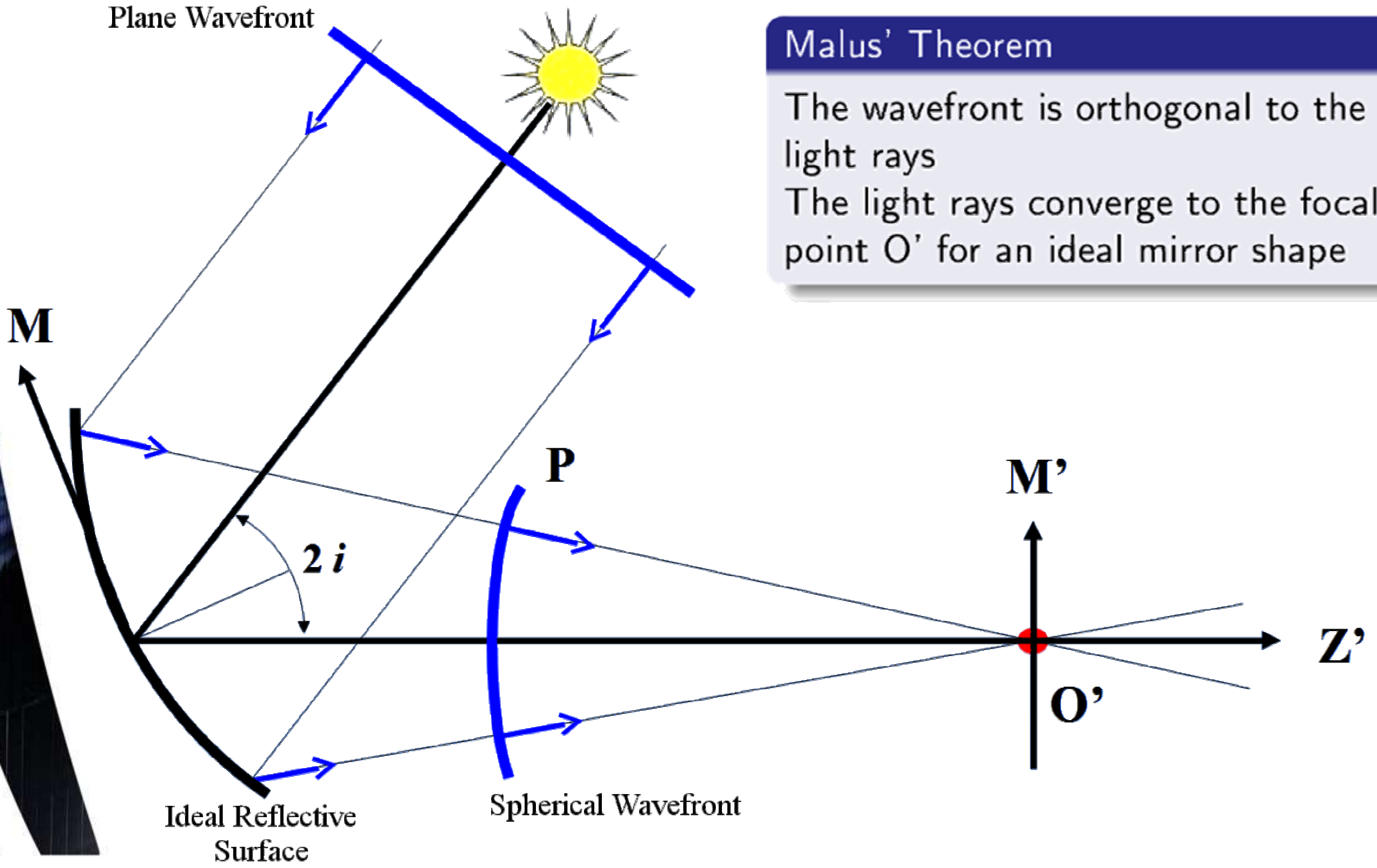
Possible extension to freeform optics metrology



Other slides

Wavefront and shape errors

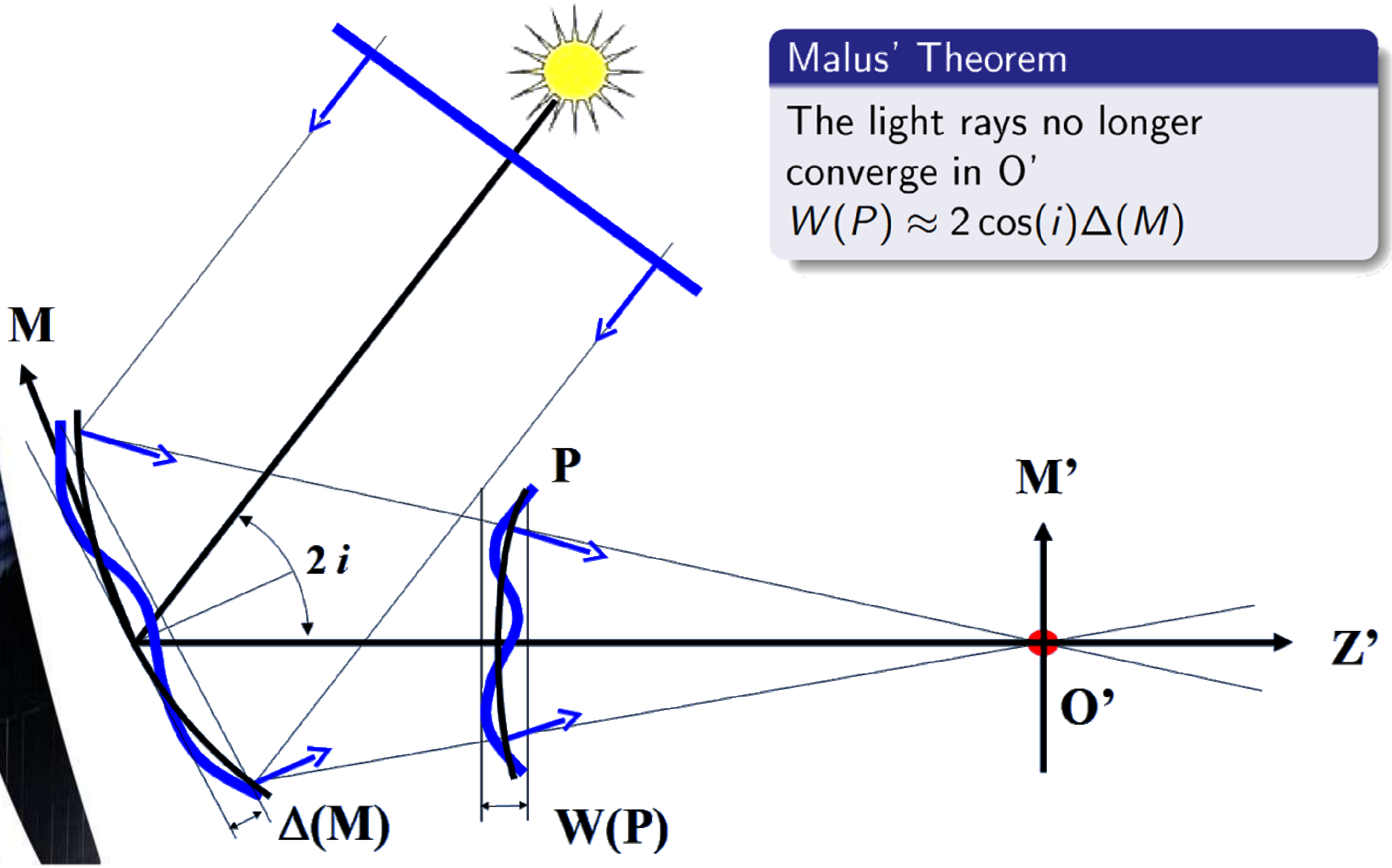
Relation with wavefront



Malus' Theorem

The wavefront is orthogonal to the light rays
The light rays converge to the focal point O' for an ideal mirror shape

Relation with wavefront



Malus' Theorem

The light rays no longer converge in O'

$W(P) \approx 2\cos(i)\Delta(M)$

Relation with wavefront

Nijboer's formulas

$$x' = D\frac{\partial W(P(x,y))}{\partial x}$$
$$y' = D\frac{\partial W(P(x,y))}{\partial y}$$