FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

Mirror qualification for concentrating solar collectors

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FreshNRG Workshop

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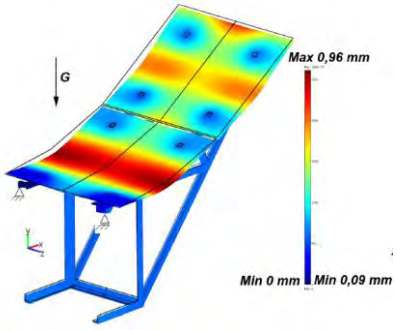
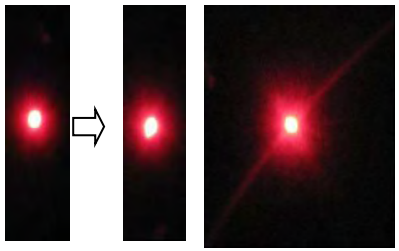
Fraunhofer ISE

Concentrating solar thermal collectors at Fraunhofer ISE





Simulation, modeling and optimization

- Optical design, ray tracing
- Techno-econ. modelling & optimization
- Detailed modelling: FEM, CFD
- Linear Fresnel, trough, tower and dishes

Experimental qualification

- Thermal characterization
- Optical quality and concentration
- Tracking
- Durability testing & lifetime estimation
- Certification (Solar Keymark, SRCC)

Feasibility studies and consulting

AGENDA

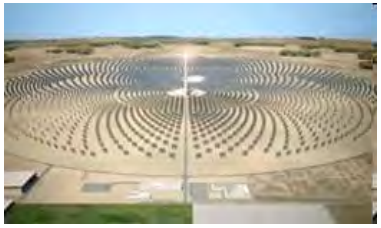
- Concentrating collectors in CSP
- Requirements solar mirrors

- Near-specular reflectance and surface scatter
- Shape and slope accuracy
- Impact of optical errors on collector efficiency

- In-situ characterization, soiling
- Ageing / durability

Introduction

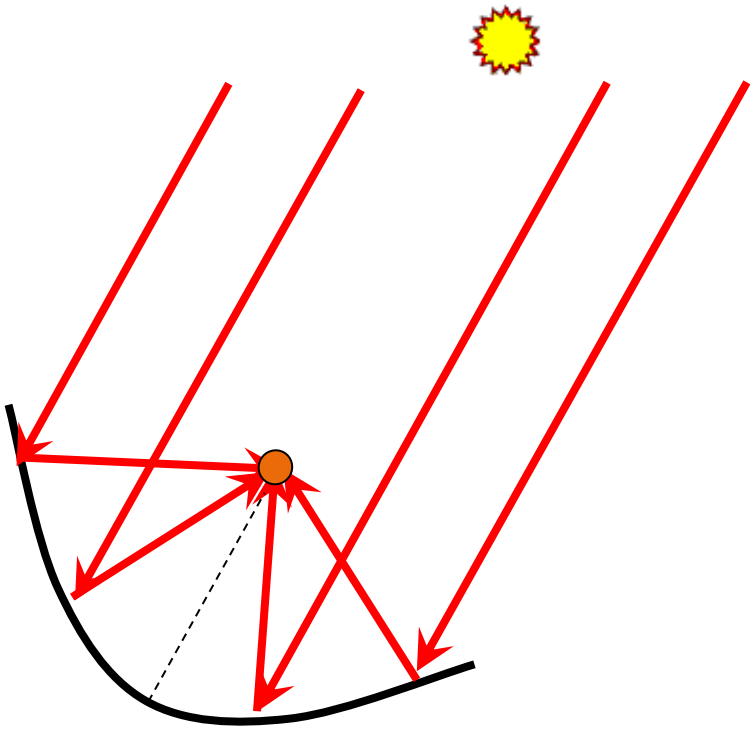
Concentrating solar collectors

Electricity	>450°C		
Electricity, process heat	250-450°C		
Process heat, solar cooling decentralized electricity	150-250°C		
Solar cooling, process heat	80-150°C		

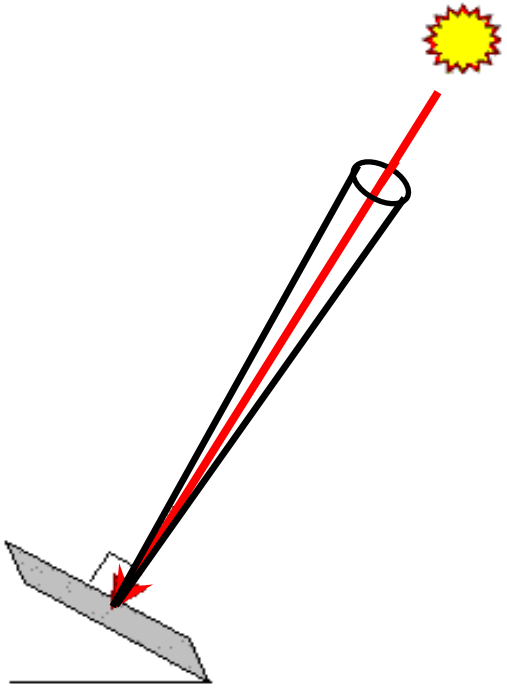
Function of optical components in CSP systems
Concentration of Direct Normal Irradiance (DNI)

- Example: parabolic trough; other CSP technologies correspondingly

Concentrating collector

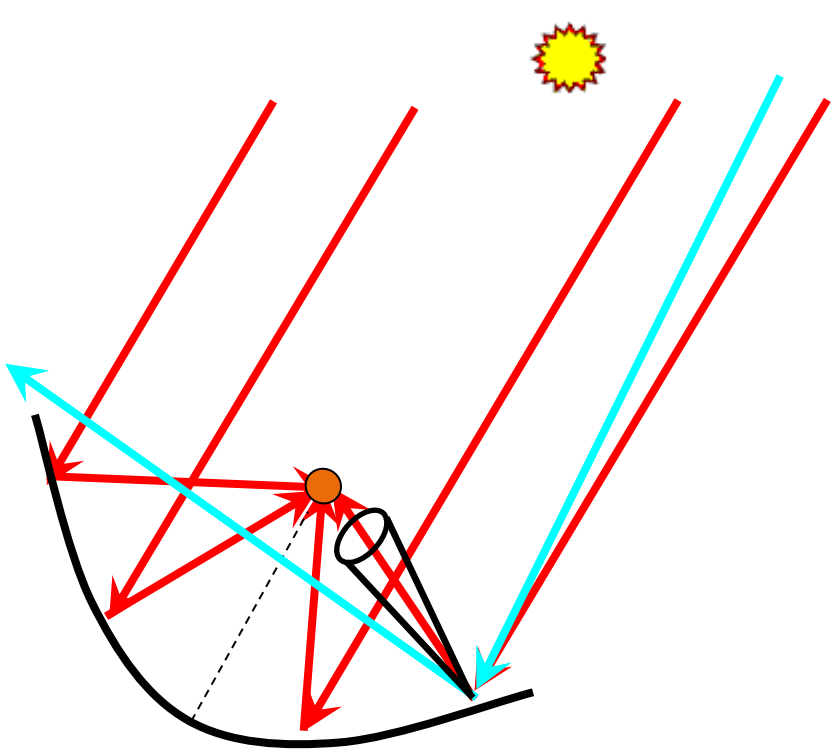


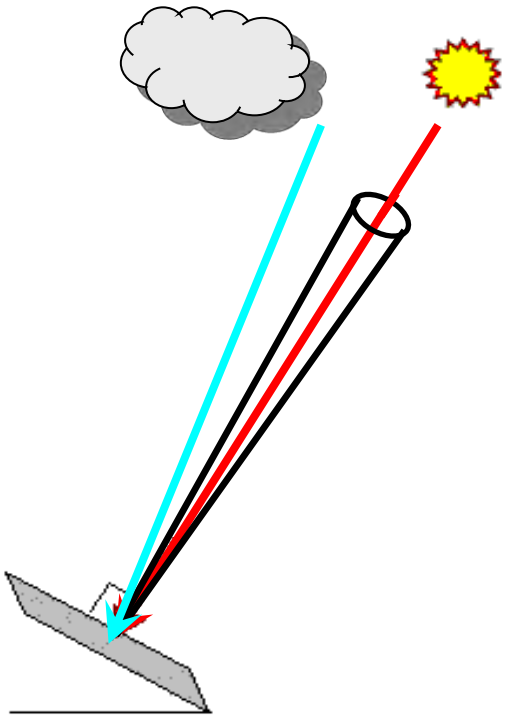
DNI + circumsolar radiation



Function of optical components in CSP systems
Concentration of Direct Normal Irradiance (DNI)

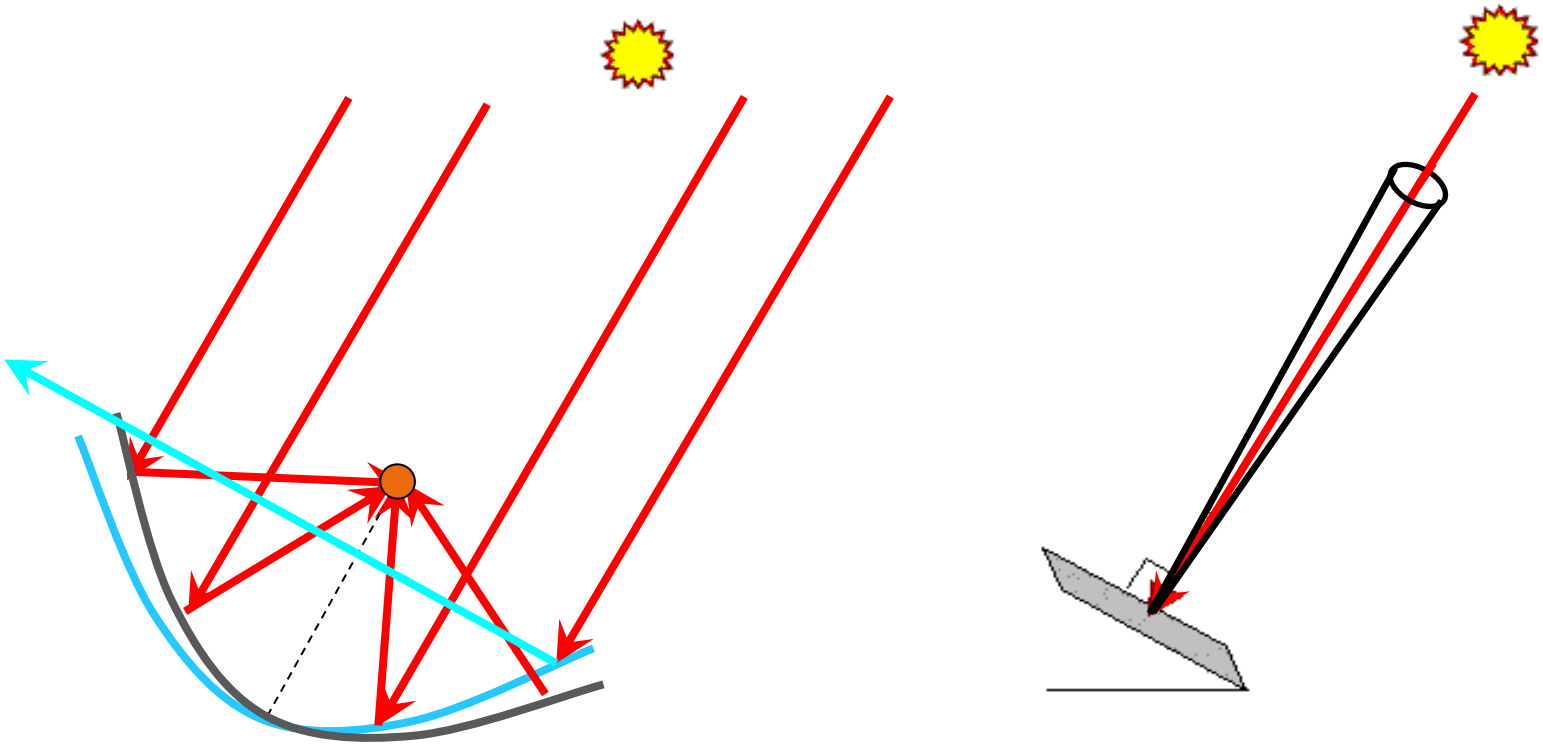
- Radiation not directly from the sun's position: rays missing the receiver



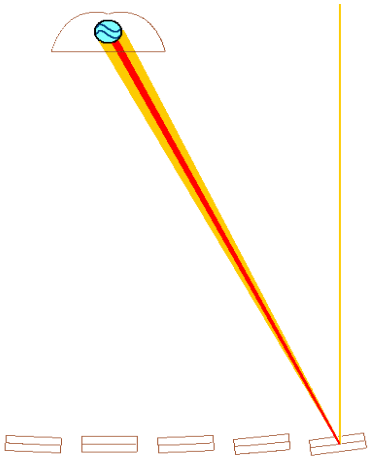


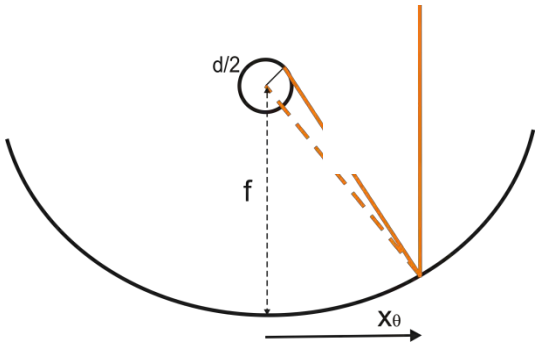
Function of optical components in CSP systems
Concentration of Direct Normal Irradiance (DNI)

- Misaligned reflector: rays missing the receiver



What qualities should a good CSP mirror have?
Multiple sources for optical errors





- High specular reflectance
  - Spectral reflectance and scattering measurement
- Solar rays should be reflected onto the absorber tube.
  - Test slope accuracy after production and mounting
  - Quality control of torsion and misalignment of mirrors, reflectors, collector

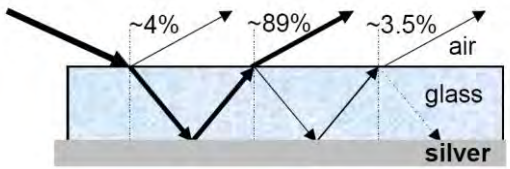
$$\sigma_{opt} = \sqrt{\sigma^2_{specular} + 4\sigma^2_{slope} + \sigma^2_{tracking} + \sigma^2_{displacement}}$$

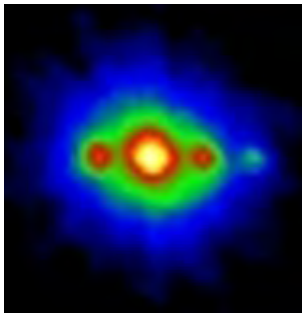
  - Statistical combination

Mirror qualification 1: Reflector

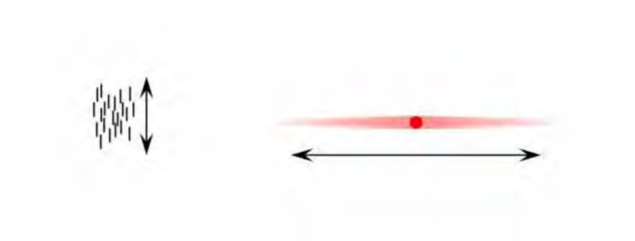
Specular reflectance and optical scatter

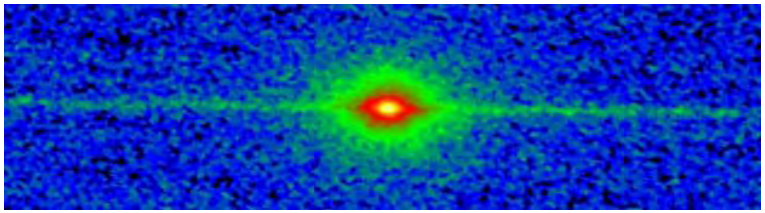
Glass mirrors



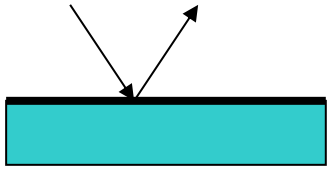


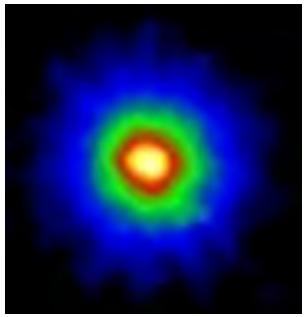
Aluminum sheets





Polymer films





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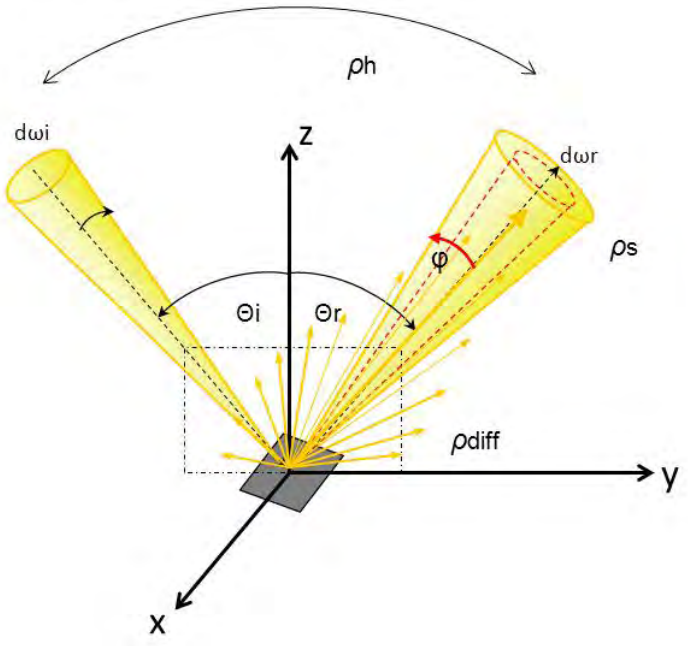
Mirror qualification 1: Reflector

Quality criteria (Solar Paces guidelines)



- Hemispherical reflectance solar weighted with ASTM G- 173

$$\rho_h(SW,\theta,h) = \frac{\sum_i^n \rho(\lambda_i) E_i(\lambda_i) \Delta\lambda_i}{\sum_i^n E_i(\lambda_i) \Delta\lambda_i}$$

- Specular reflectance

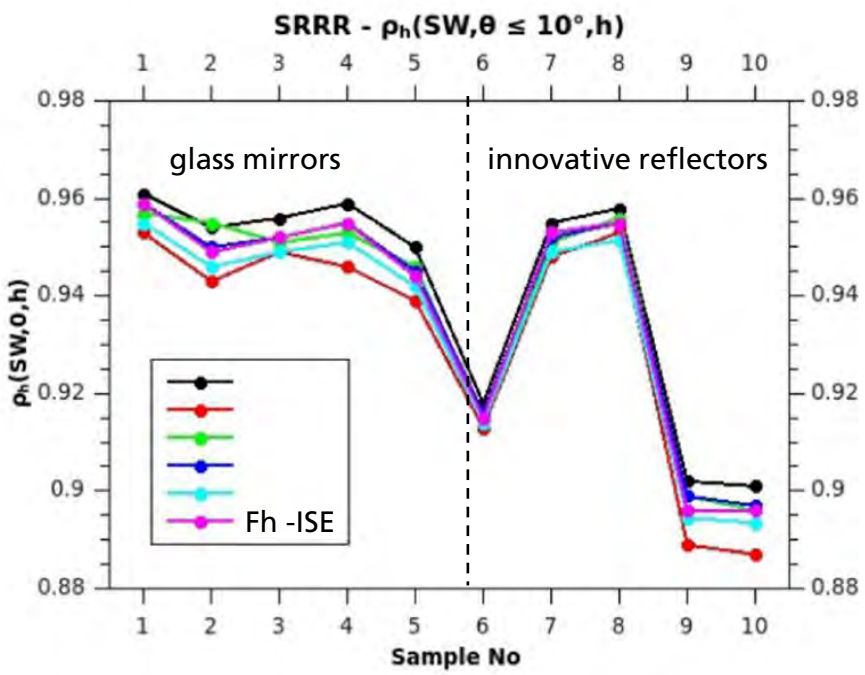
$$\rho_s(\lambda,\theta,\varphi) = \rho_h(\lambda,\theta,h) \int_0^{2\pi} \int_0^{\varphi} d\beta\, d\varphi\, \sin(\varphi)\, R(\lambda,\theta,\varphi)$$

  - Measured at:
    - $\varphi \leq 20$ mrad
    - λ min. three wavelength bands
    - $\theta \leq 15$

→ ρ_h and ρ_s are relevant criteria of quality

Mirror qualification 1: Reflector

Round Robin hemispherical reflectance

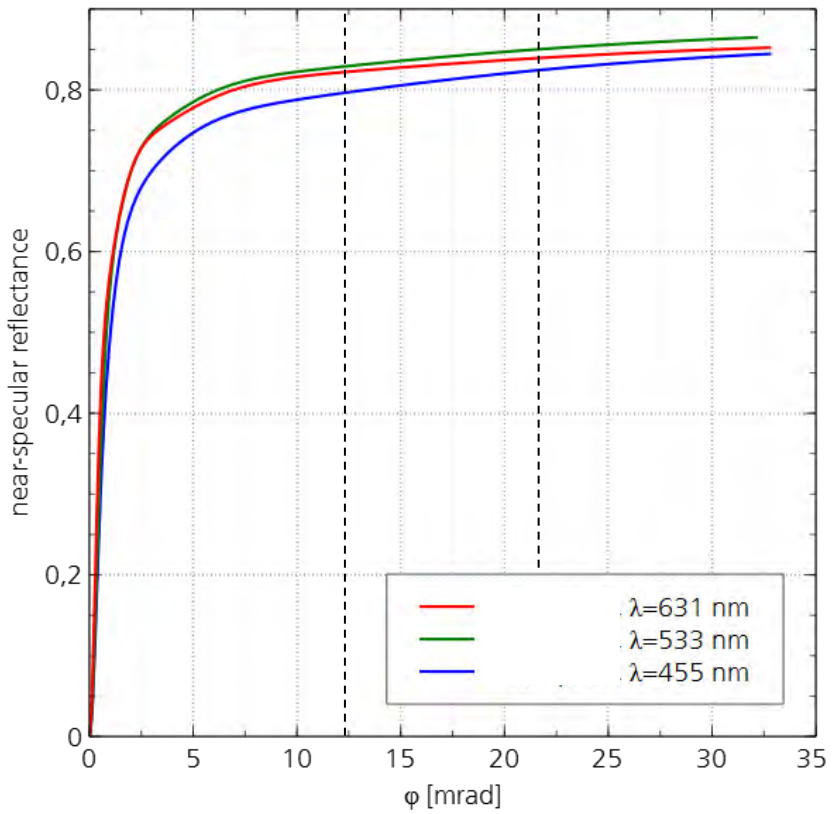


- Results Solar Paces Round Robin, 6 research institutes
- 5 glass mirrors
- 5 innovative reflectors
- Measurement of hemispheric reflectance

→ Good compliance of results for ρ_h

Mirror qualification 1: Reflector

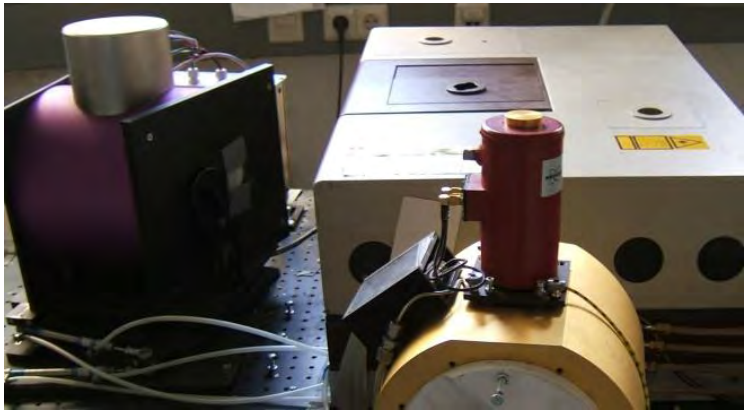
Example: specular reflectance



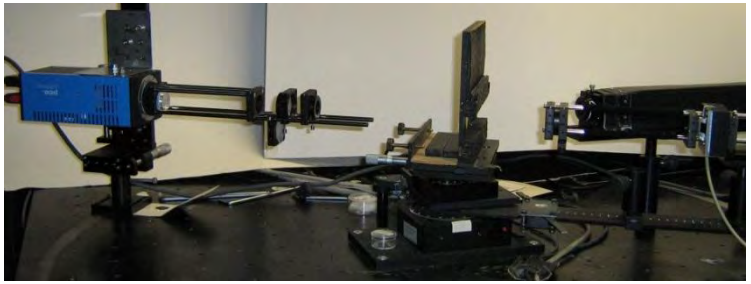
- Example: Aluminum based reflector
- Specular reflectance increases with acceptance angle φ
- Wavelength dependent scattering
- For innovative CSP mirrors careful data correction procedure is important to avoid under-estimation

Mirror qualification 1: Reflector

Test facilities



Fourier spectrophotometer



VLABS – Very Low Specular Reflectance

- Spectrophotometer with integrating spheres for hemispheric and diffuse spectral reflectance
- VLABS CCD imaging

  Light source: LED blue, green and red, spot size on sample
  $0.6 < d10mm$

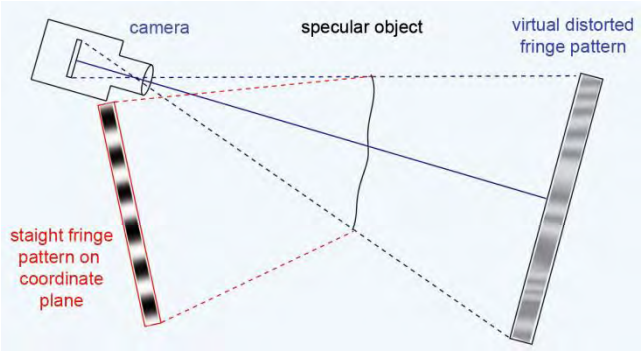
  Incidence angle $8° < \theta < 80°$

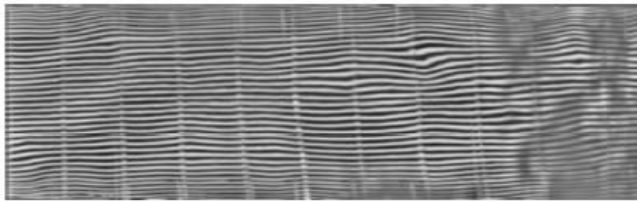
  Acceptance $\varphi < 33$ mrad
- 3- D Goniophotometer, luminance camera

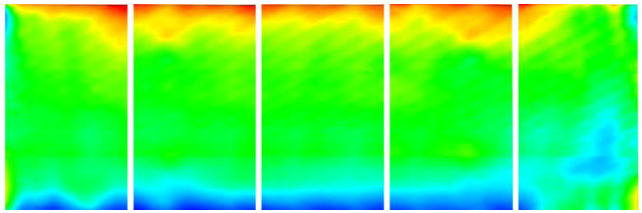
Mirror qualification 2: Shape and slope accuracy

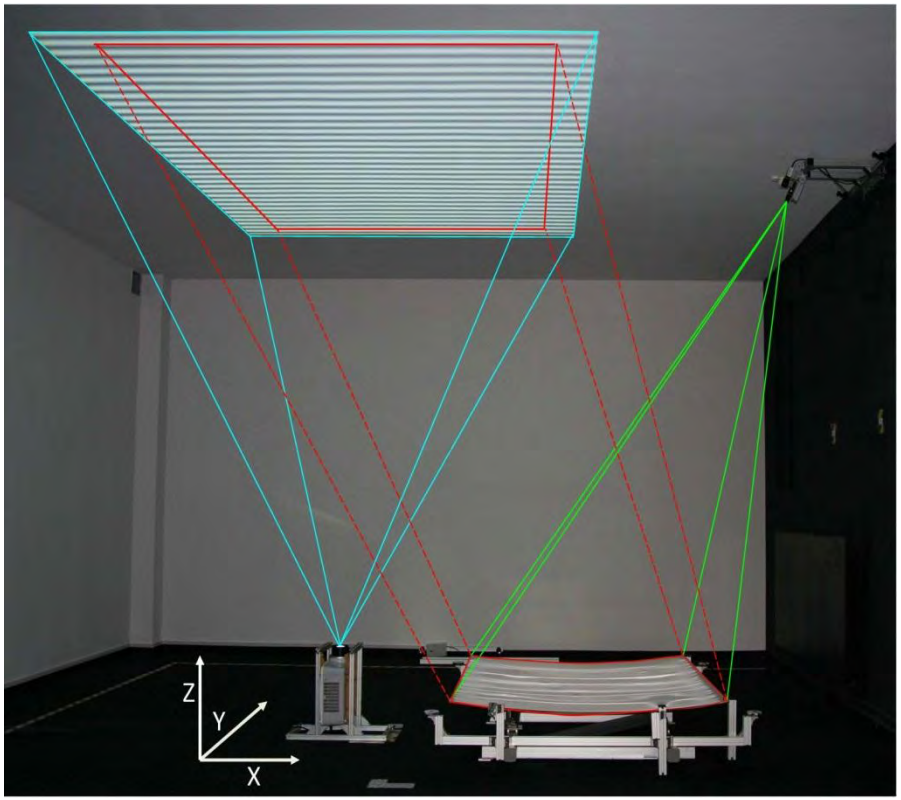
Deviation of local surface slope from ideal shape

- Deflectometry / Fringe reflection technique ➔ 2D map of reflector









Mirror qualification 2: Shape and slope accuracy

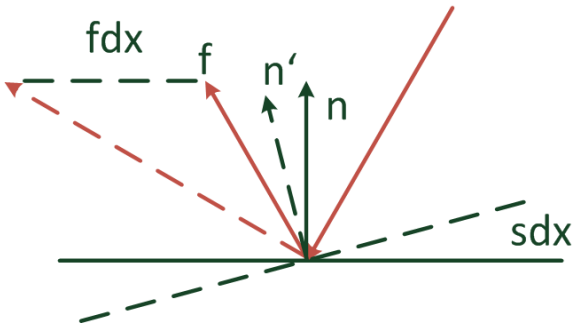
Relevant quality criteria (proposed SP guidelines)

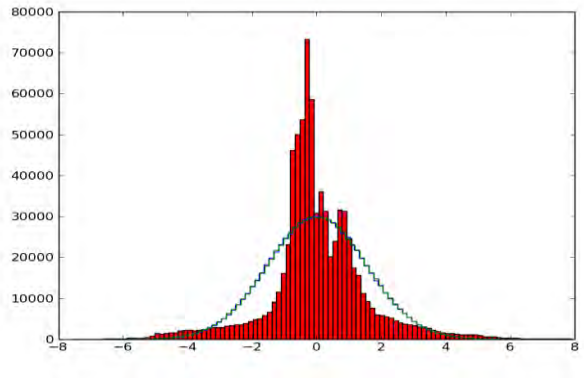
- Local slope deviation sdx

$$sdx = \left(\frac{dz}{dx}\right)_{meas} - \left(\frac{dz}{dx}\right)_{ideal}$$

- Collector dependent local deviation of focal length
  - $fdx \approx 2 \cdot f_{local} \cdot sdx$
  - only relevant for PTC

- Resulting RMS /standard deviation, area weighted
  - $SDx_{RMS} = \frac{1}{\sqrt{A}} \sqrt{\iint sdx^2 dxdy}$
  - $FDx = \sqrt{\sum_{i=1}^{n} \left(fdx_i^2 \cdot \frac{a_i}{A_{tot}}\right)}$





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Mirror qualification 2: Shape and slope accuracy

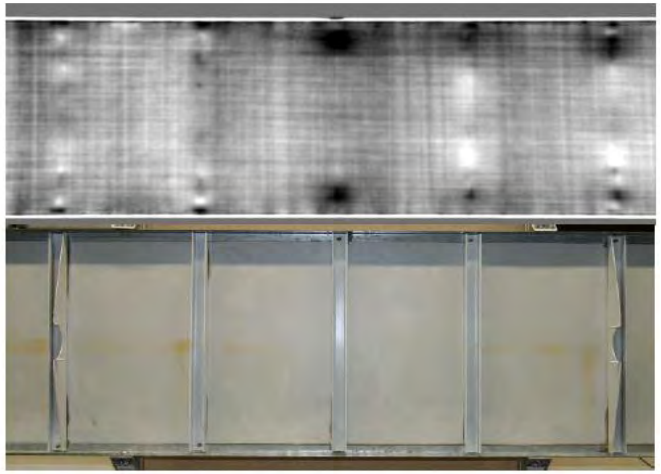
Exemplary results

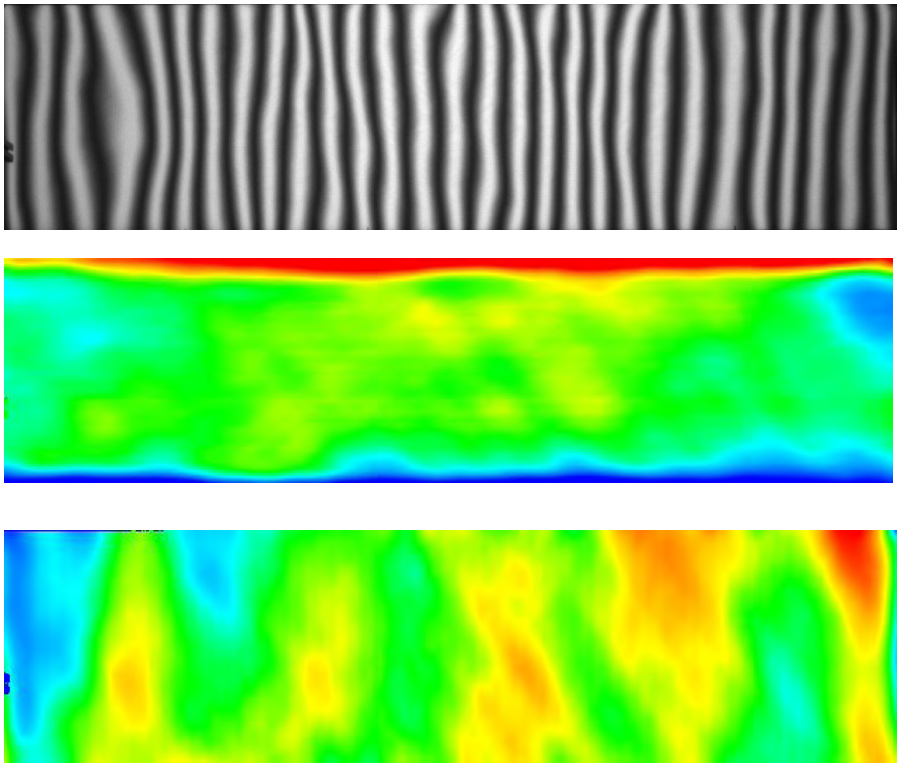
- Fresnel collector mirror
- Good quality mirror →

Distorted pattern, SDx and SDy

- Example: First LFC mirror

- assessment of production ↓





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Mirror qualification 3:
Others

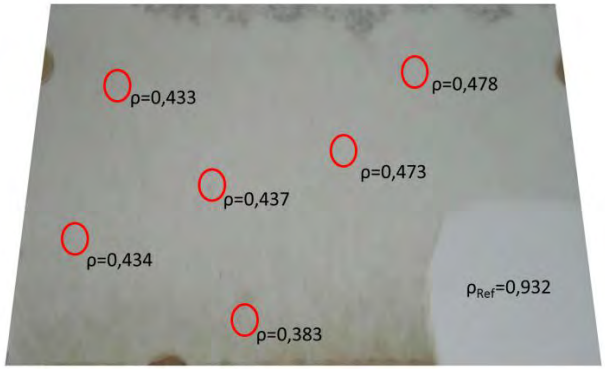
- Alignment of
  - Single mirror sheets on one reflector
  - Reflectors in collector
  - Collector in the field

  ➔ Tachymetry, surveying instruments
  ➔ Photogrammetry

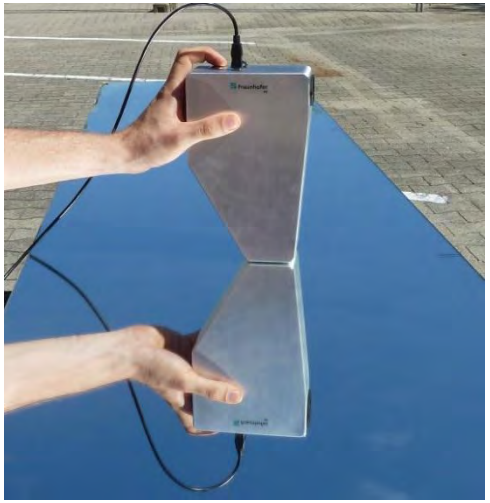
- Tracking accuracy
  - Tilt sensors
  - Luminance imaging of focus on an optical target

In situ qualification 1:
Specular reflectance, soiling

- Special handheld reflectometer
- Specular reflectance for a given angular aperture (corresponding to the acceptance angle of the concentrating collector)

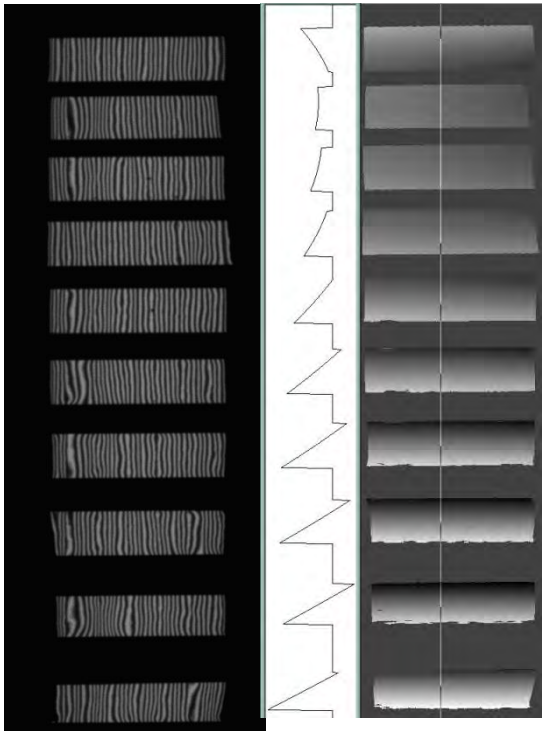


- Soiling investigations
- Mirror degradation



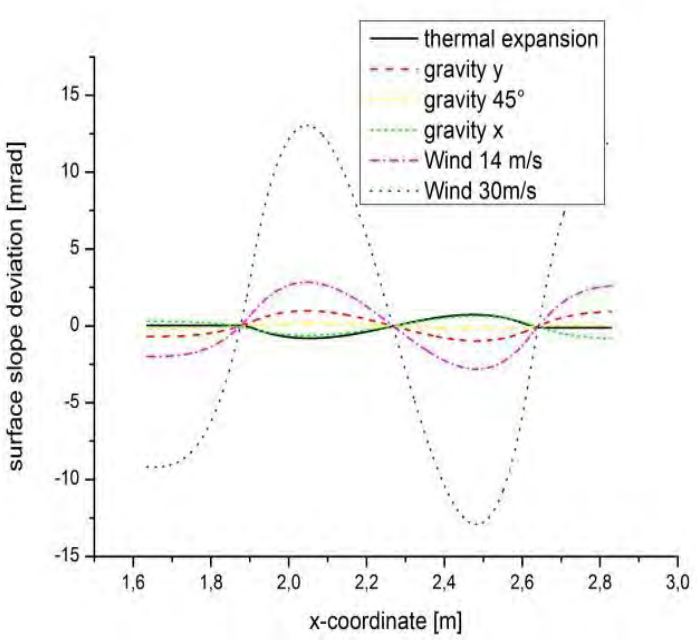
In situ qualification 3:
Shape and alignment

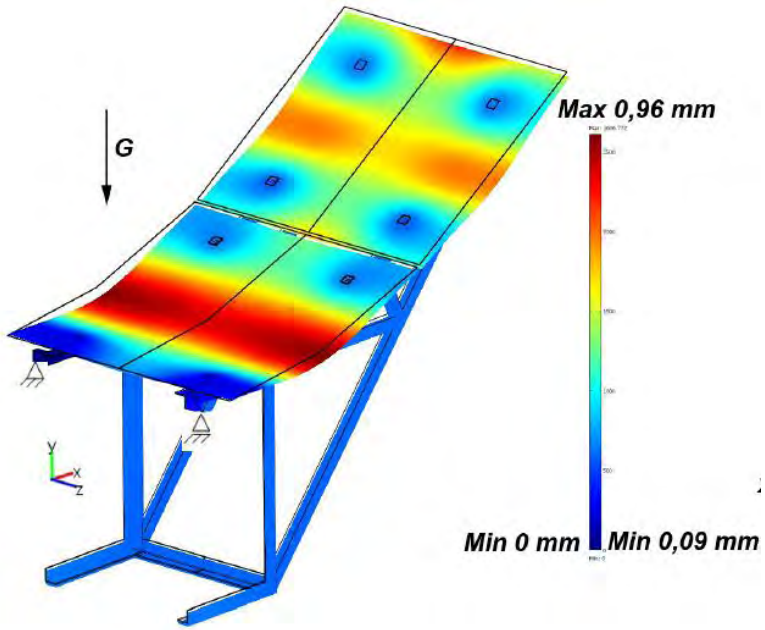
- Below: primary mirror array of linear Fresnel collector via fringe reflection
- Other systems (e.g.: DLR Qfly) unmanned flying vehicle with imaging



Design Optimization
Optional analysis

- FEM analysis of primary reflectors
- Deformation due to gravity, wind loads, thermal expansion

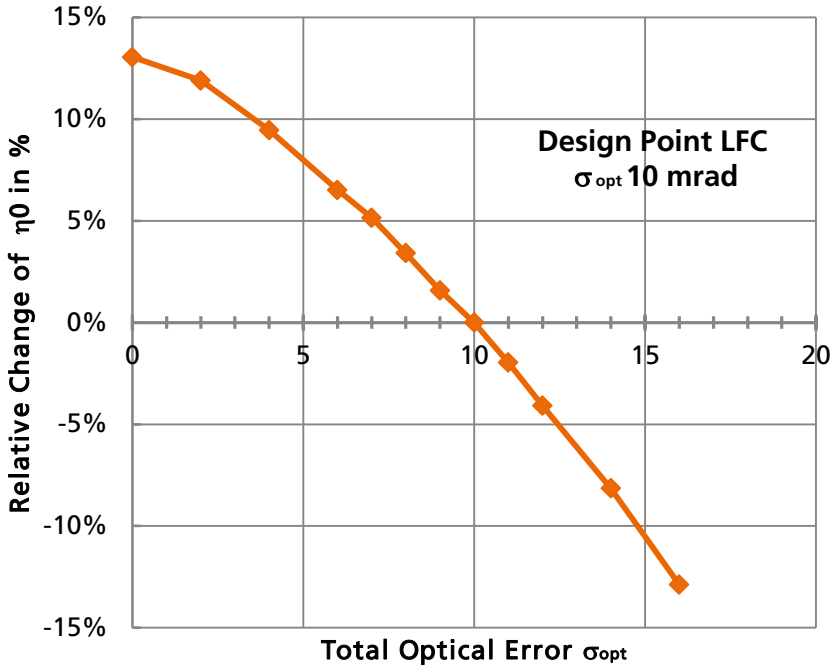


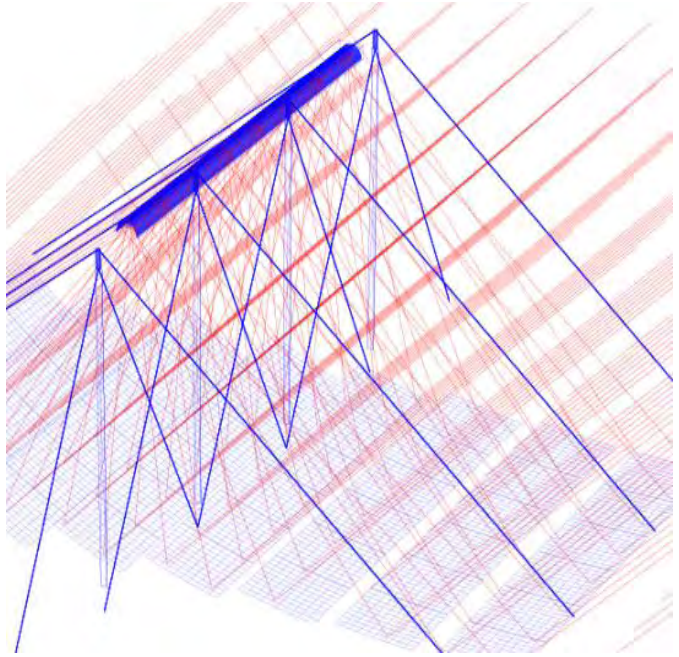


Design Optimization

Example: impact of optical error

- Impact of mirror quality on optical efficiency, LFC

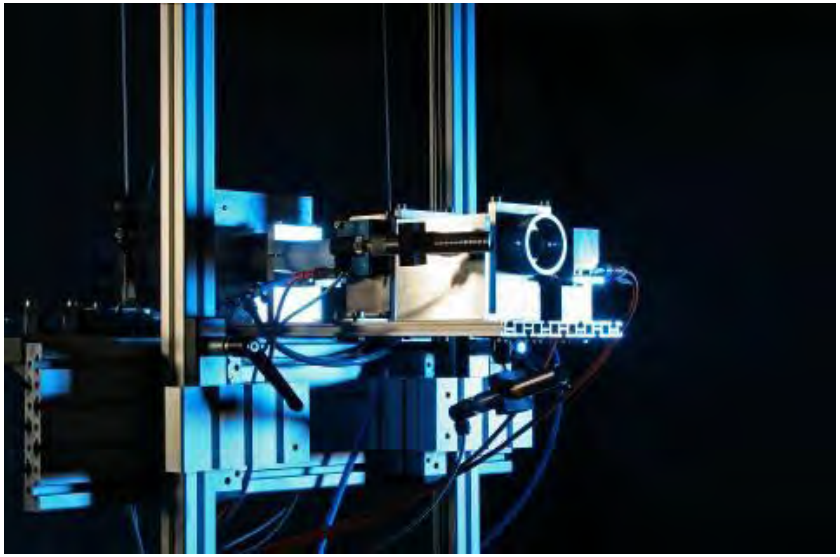




→ Qualification of optical components is important

Durability and Ageing
Hail test

- Excellent reproduction of real ice balls
- Varying speed to choose
- Photo-electric speed measurement
- Laser optics to aim on target



Durability and Ageing

Climate chambers of various size and type

- Combination of temperature, humidity, UV
- Programmable cycling / standardized cycling

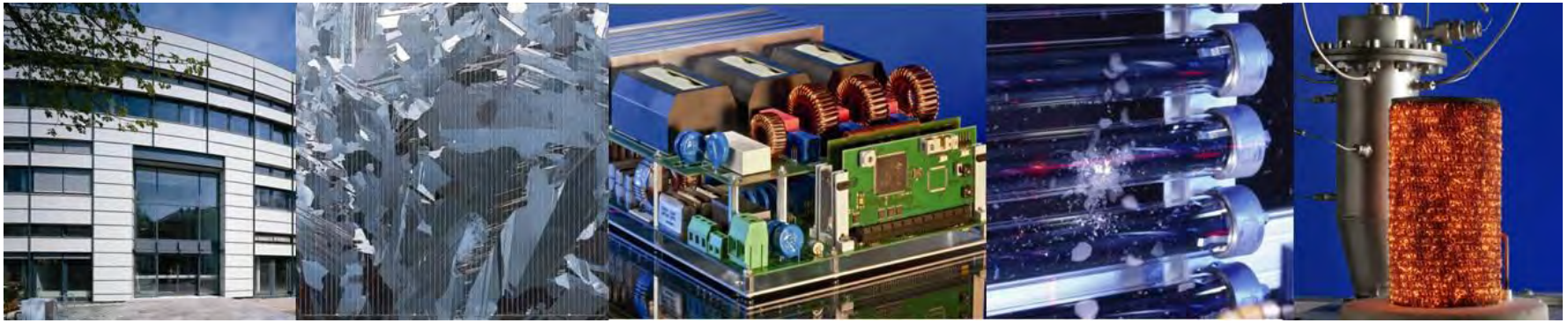
Testing of realistic mechanical loads from wind or snow with “MechTest”

- Integrated in a climate chamber -25°C to 90°C
- Load up to 10000 Pa
- Slope forces
- Dynamic tests
- Long time duration test by

automated test sequences

- Measurement of resulting forces in 3D

Thank you for your attention!



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