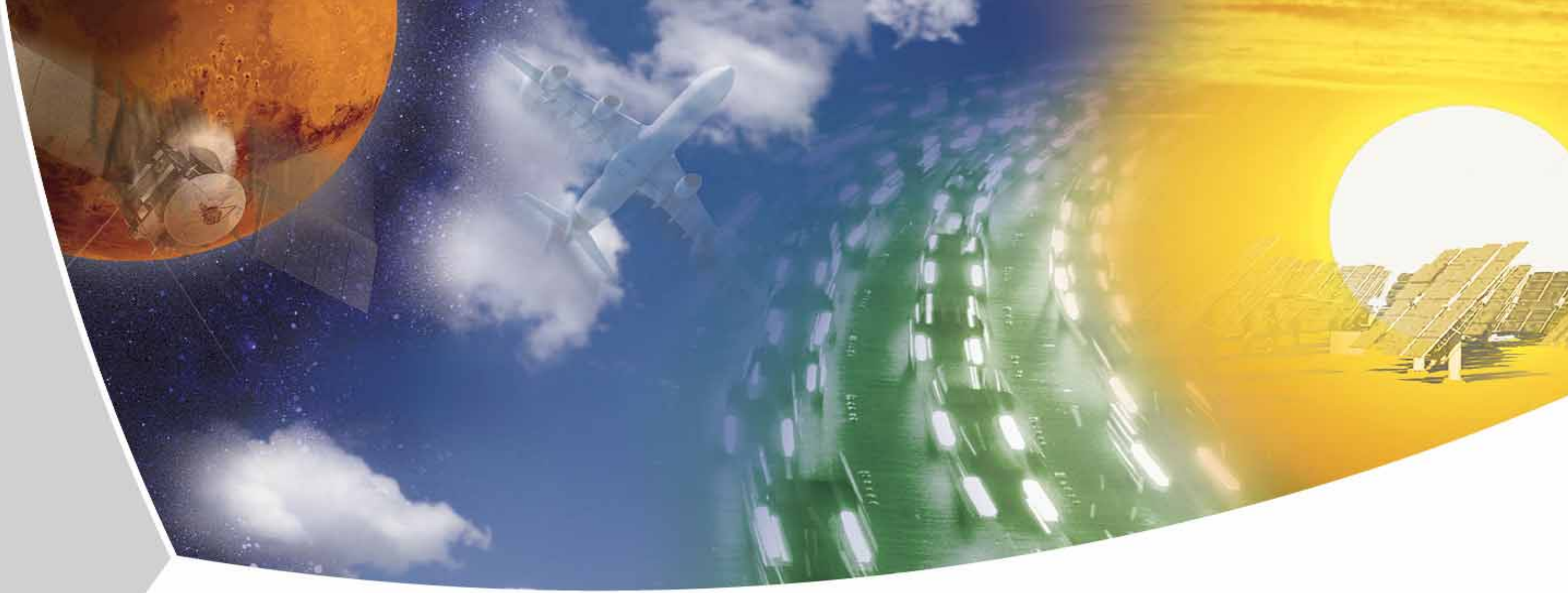


Concentrator Testing

Eckhard Lüpfert, K. Pottler, S. Ulmer, DLR

Tim Wendelin, NREL

NREL Trough Workshop, Golden Denver 2007

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

German
Aerospace Center

EuroTrough at Plataforma Solar de Almería

Concentrating Solar Technology is Ready

- Parabolic trough collectors are state of the art
- Good technical performance
- Components Manufacturers
- Feed-in tariffs, Renewable Energy Portfolios
- Investors
- Projects
- Interesting Revenues

- But what if…
  - a few millimeters spoil the project success?
  - mirrors do not have expected specular reflectance?
  - radiation fails to hit the absorber tube?

Objectives of Concentrator Testing

- Development
  - R&D directed at maximizing performance/cost ratio
  - Requires testing tools that provide detailed data on mirror contour, mirror panel positioning
- Manufacture/Installation
  - QC testing of mirror panels (statistical sampling)
  - Module assembly
  - Requires fast, relatively simple optical characterization to reveal problems & fix
- Maintenance/Operation
  - Many contributors to optical performance (e.g. specularity, mirror distortion, dirt, receiver shape/position)
  - Large fields require simple, fast, effective tools to understand/fix problems & maximize performance

Concentrator Optical Characterization

- Mirror Reflectivity → Spectrometry
- Mirror Optical Accuracy
  - Mirror contour
  - Mirror specularity
- Mirror Panel Alignment
  - Tilt
  - Position
- Receiver Positioning

- Goal: Maximum Energy Intercept on Absorber

- Different tools meet needs of each phase of technology deployment.

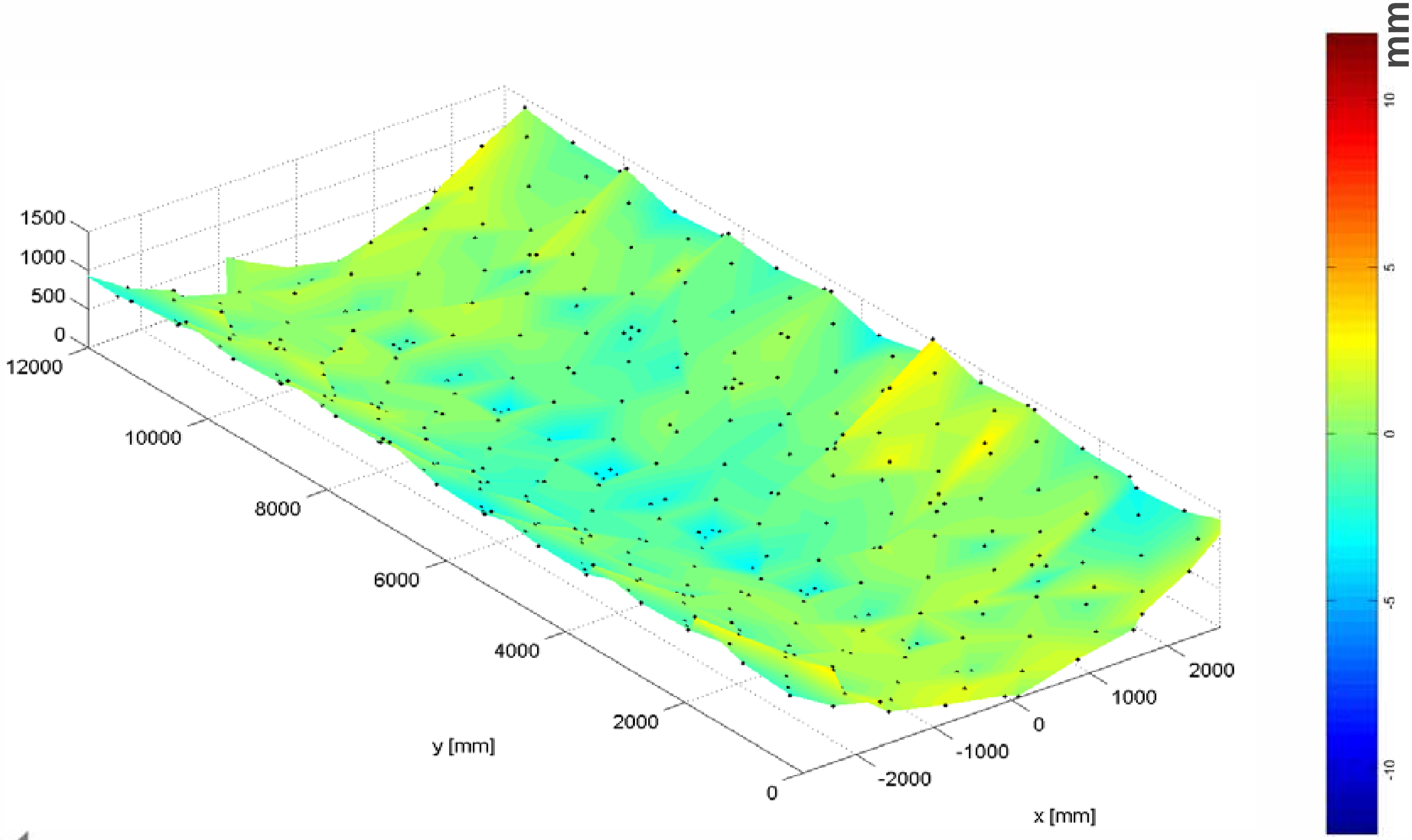
Photogrammetry

- Characterizes surface or structure as Z(x,y),
- Minimal equipment required (still camera/reference grid/software)
- Potential for large mirror areas to characterized this way
- Requires prior surface preparation with reference grid

Geometry und Intercept Analysis with Photogrammetry

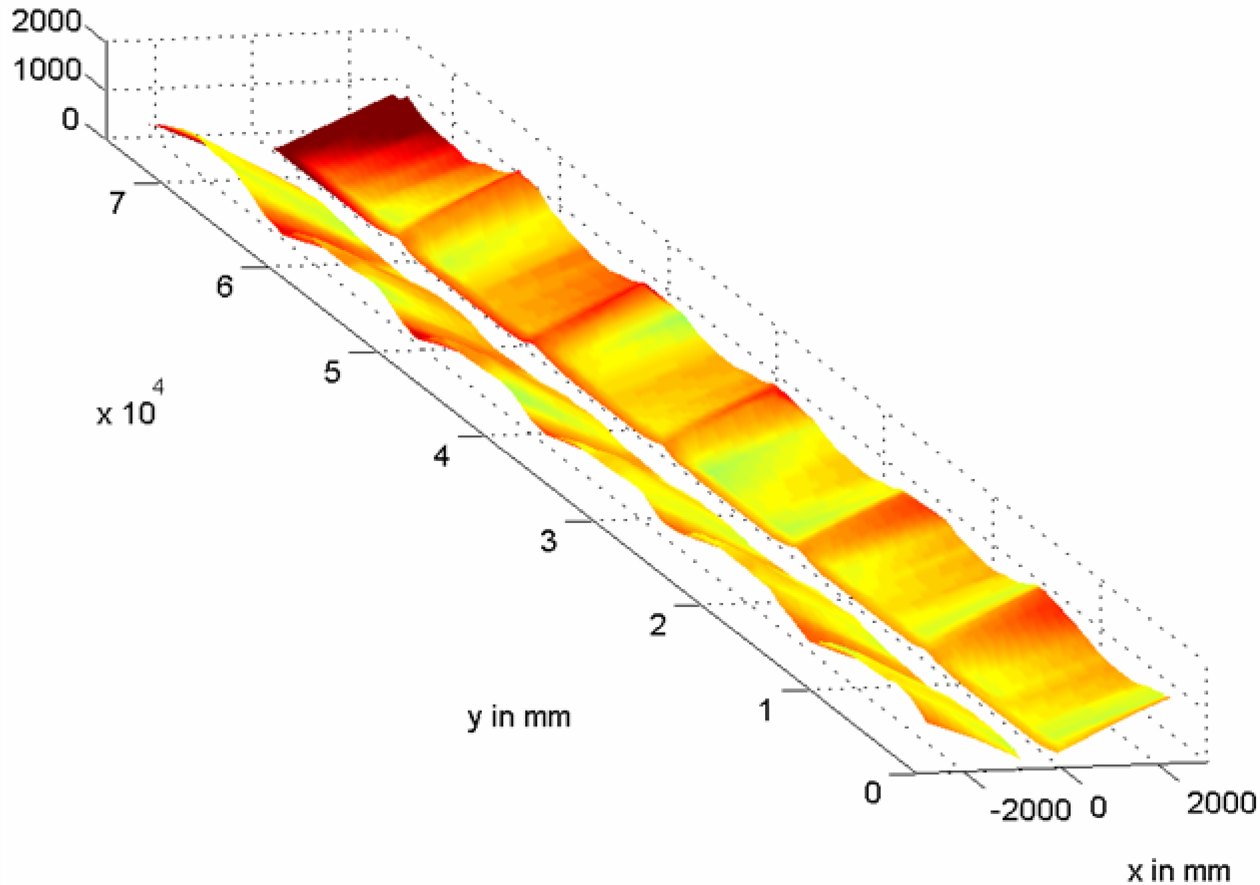
Photogrammetry on Concentrating Collectors

Concentrator Quality in 3 dimensions

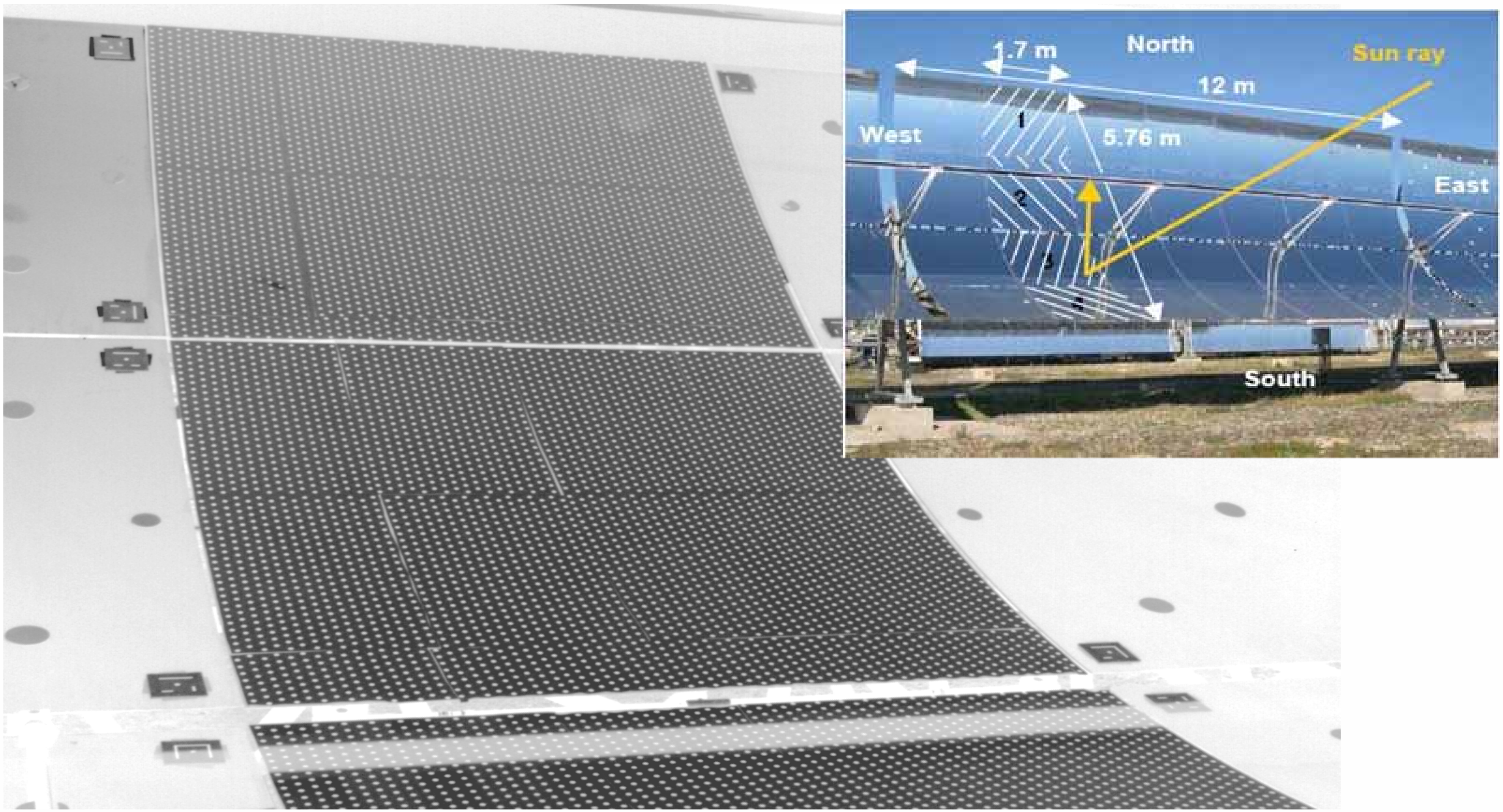


Geometric Precision over Large Collector Areas

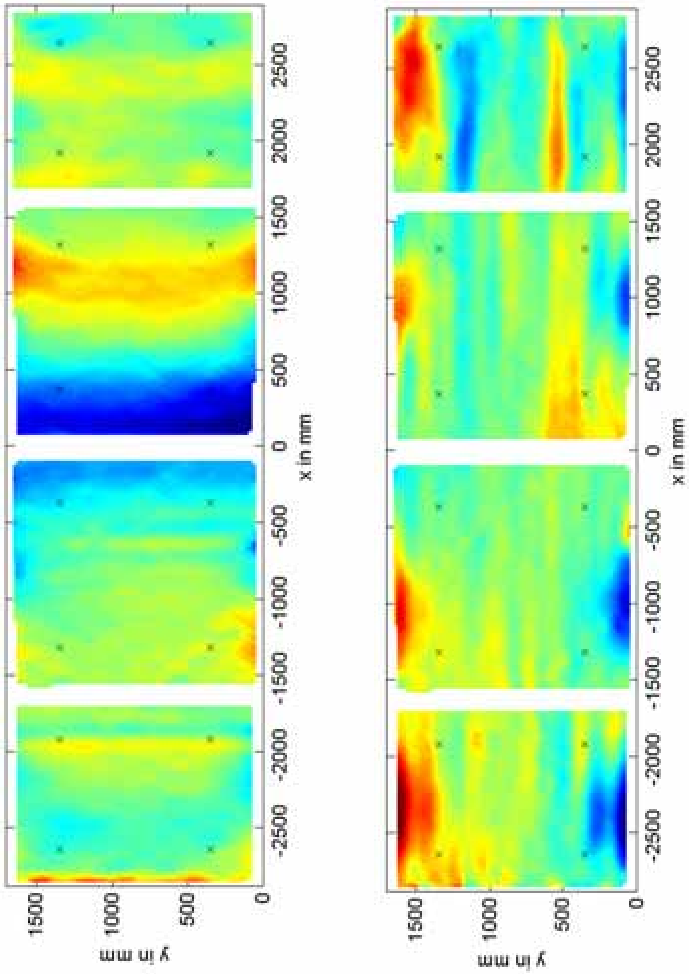
ET150 Collector Shape Variation from west horizontal position to east horizontal position (180° turn)
Deformations due to gravitational forces measured with Photogrammetry



Photogrammetry on Reflector Surface



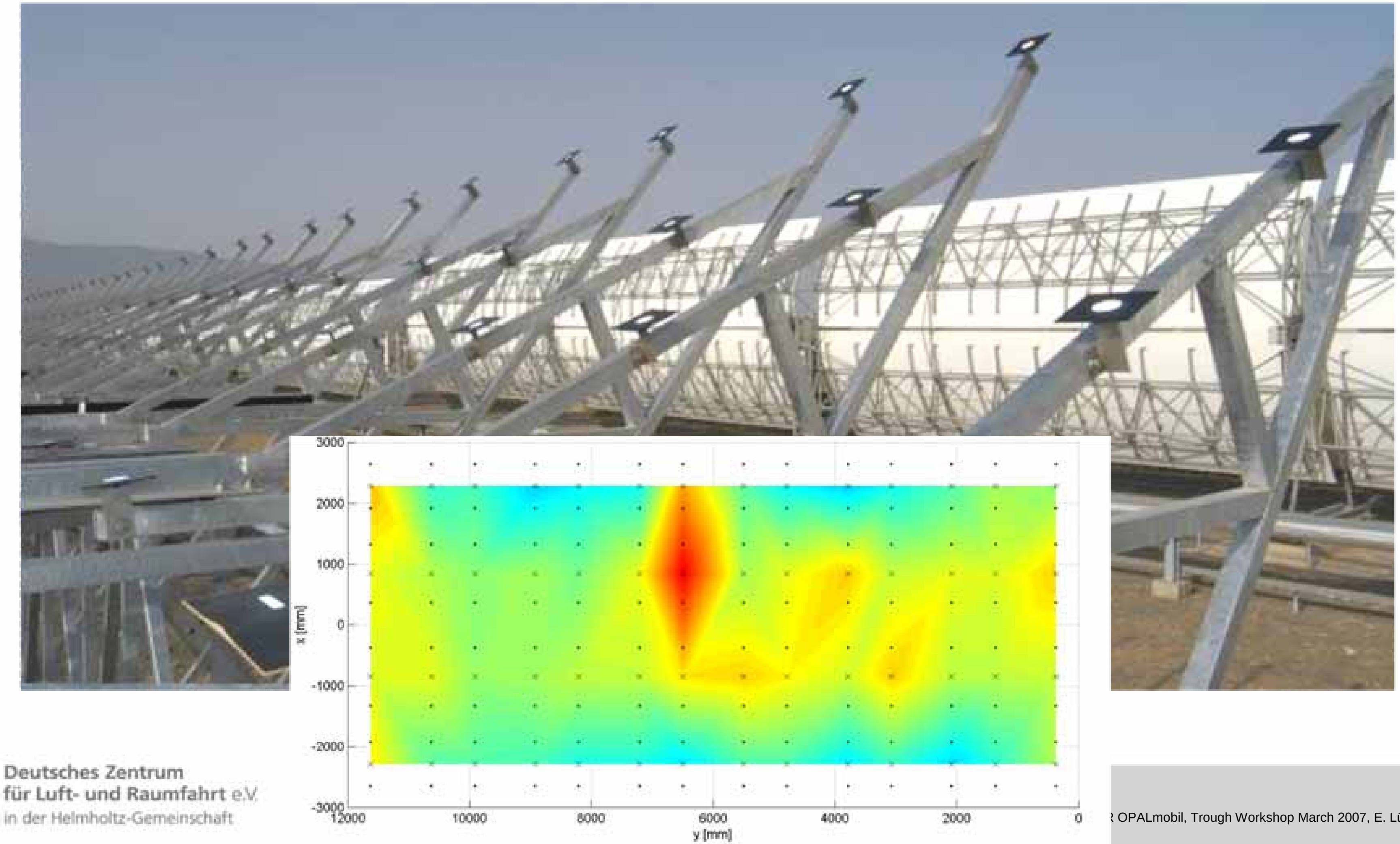
Photogrammetry on Mirrors



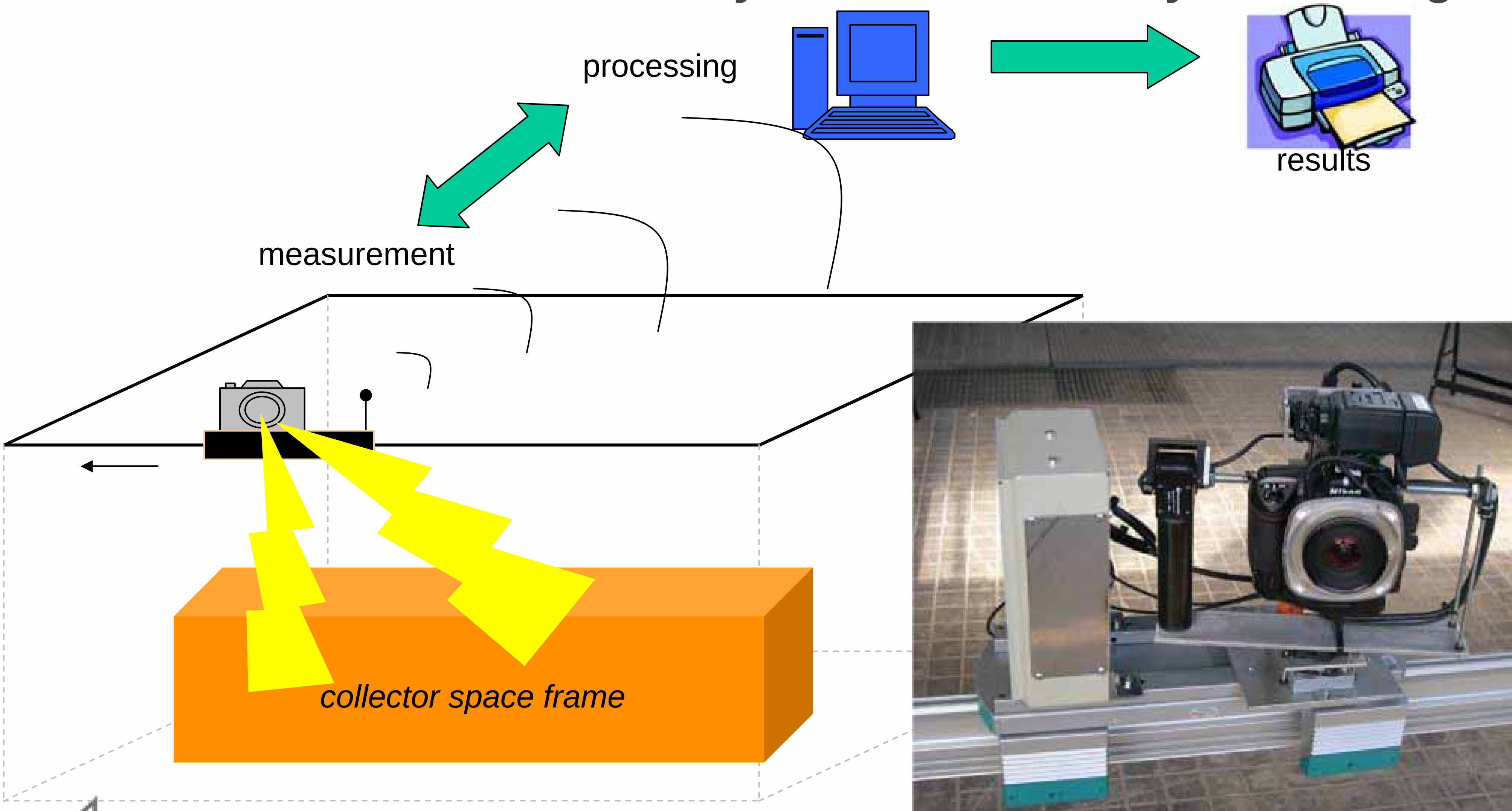
- Measure Mirror Shape
- Measure Slope and Slope Deviations
- Calculate Optical Efficiency
- Measure Deformation due to dead-load etc.

Quality Control during Assembly

Quality Control during Collector Assembly



Automatic Measurement System for Assembly Monitoring



Laser Techniques

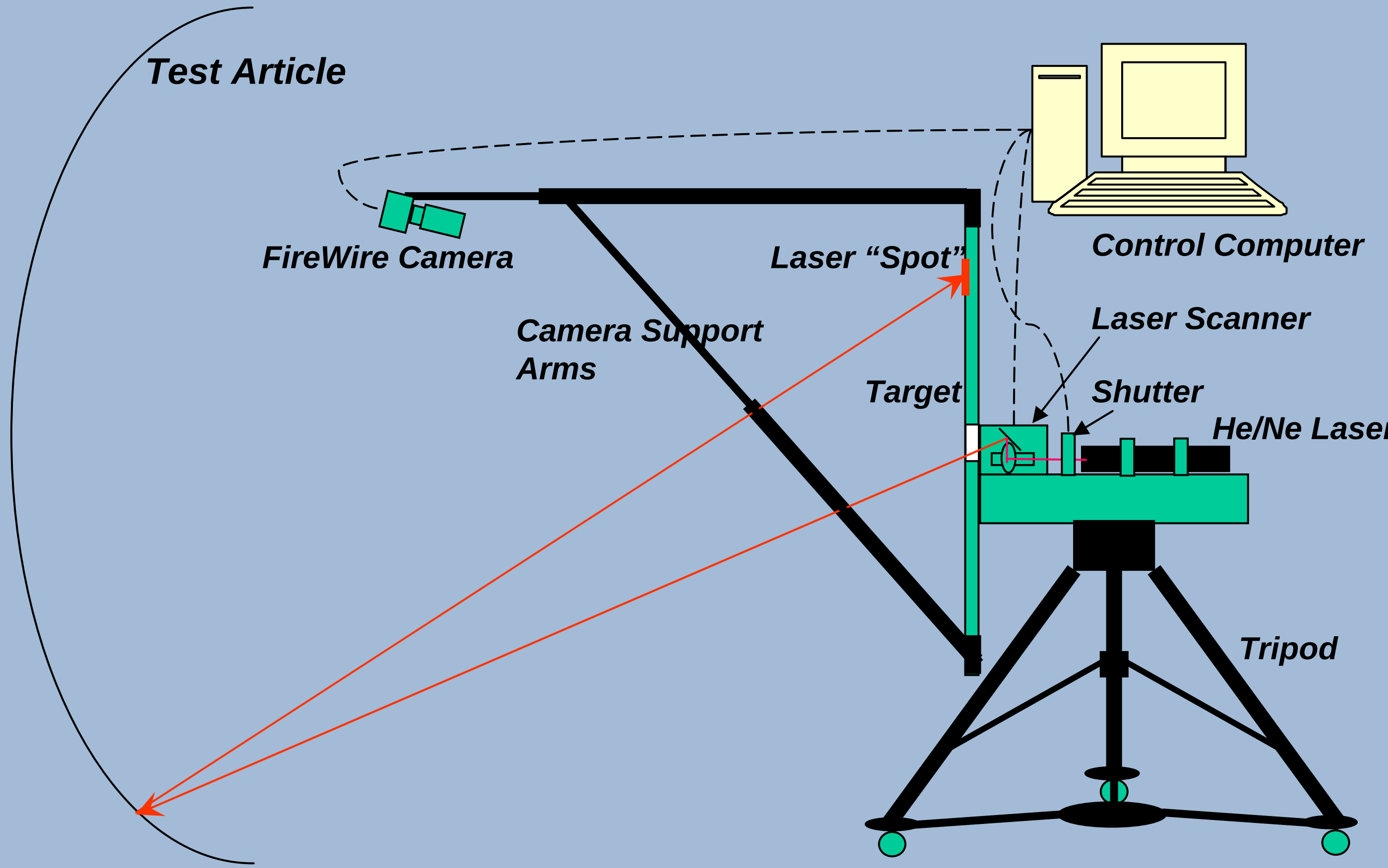
- Laser beam reflected by the concentrator mirror
- Scanning laser
- Analysis of the position of the reflected laser on a target

NREL's Video Scanning Hartmann Optical Testing (VSHOT) of State-of-the-Art Parabolic Trough Concentrators

- Focused on development and manufacturing/installation phases
  - Solargenix Advanced Parabolic Pilot Project
  - Industrial Solar Technology (IST) Parabolic Trough Technology Development Project
- Improved VSHOT for Parabolic Trough Field Measurements
- VSHOT characterized Solargenix, Industrial Solar Technology, LS-2 and LS-3 designs
  - Overall contour
  - Mirror Panel Alignment
  - Module to Module Tilt

VSHOT

- Originally designed for point-focus concentrators
- Adapted for line-focus optics (samples one vertical slice at a time)
- Measures bi-directional surface slope, fits data to user defined shape, reports errors relative to that shape



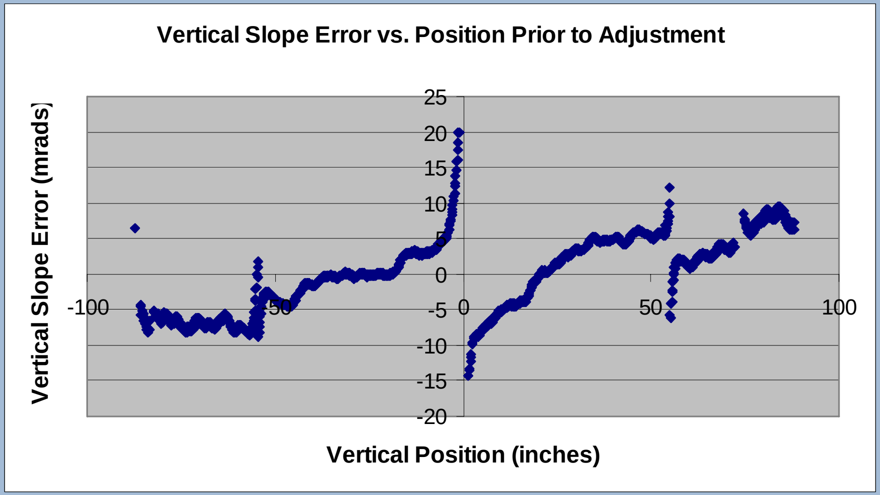
Gossamer Spaceframe

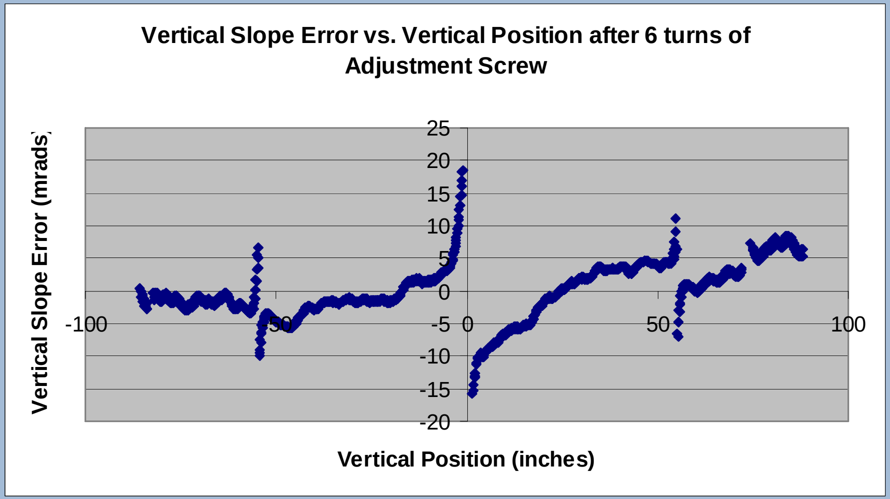
Gossamer Spaceframe Results

- R.M.S. Slope Error ~ 3.0 milliradians or less
- Based in part on these results, Solargenix decided to use Gossamer spaceframe design in their 64 MW El Dorado Valley plant.

Results

- VSHOT as development and manufacturing/installation tool (Solargenix/Starnet)
  - Mirror position/tilt/deformation on module support structure
- Example: Correction of lower panel tilt





Summary VSHOT

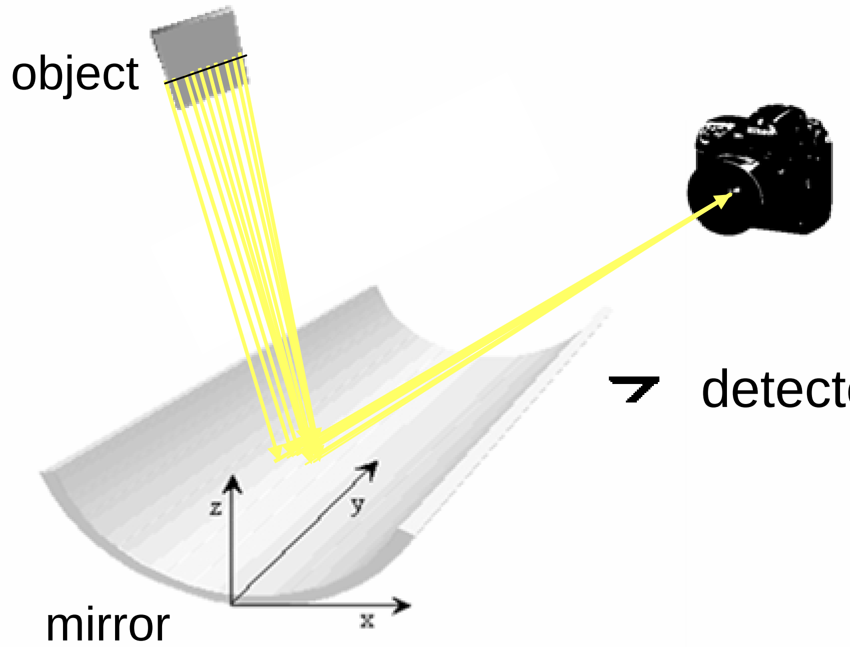
- Optical Testing Critical to all phases of CSP Deployment
- Different tools needed for different phases
- VSHOT is one tool which cuts across all technologies and phases.

“Distant Observer” Techniques
Reflection Image Analysis

- Receiver is imaged, thus couples receiver position/shape to concentrator optics
- Potential for large mirror areas (module level) to be characterized quickly; does not provide point by point surface measurement (i.e. suited to fast module/mirror panel/receiver alignment)
- Examples:
  - Theoretical Overlay Photographic Alignment System (TOP)
  - OPAL Reflector Analysis
  - OPAL Pattern Recognition

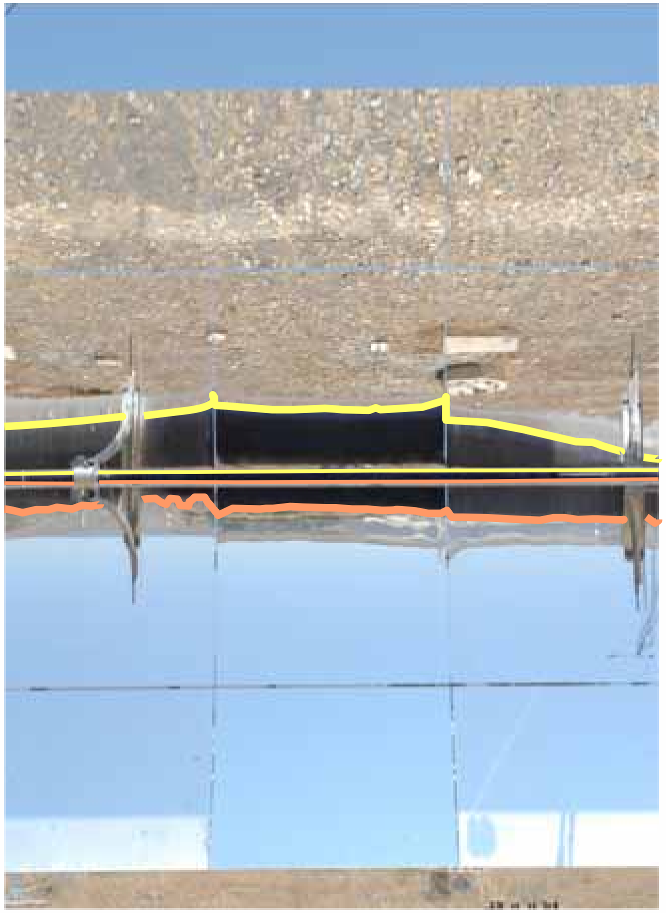
OPAL Reflector Analysis

- Based on image recognition of a target in the reflector
- measure coordinates of many points in one step
    - ***lines/grids instead of points, for higher speed***

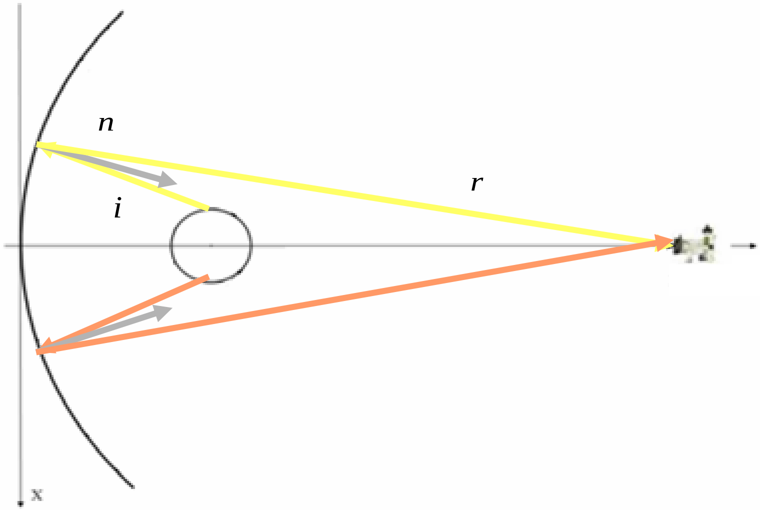


- detector: <u>digital camera</u>
    - – high resolution:
    - – detector data = foto

Absorber Tube Reflection

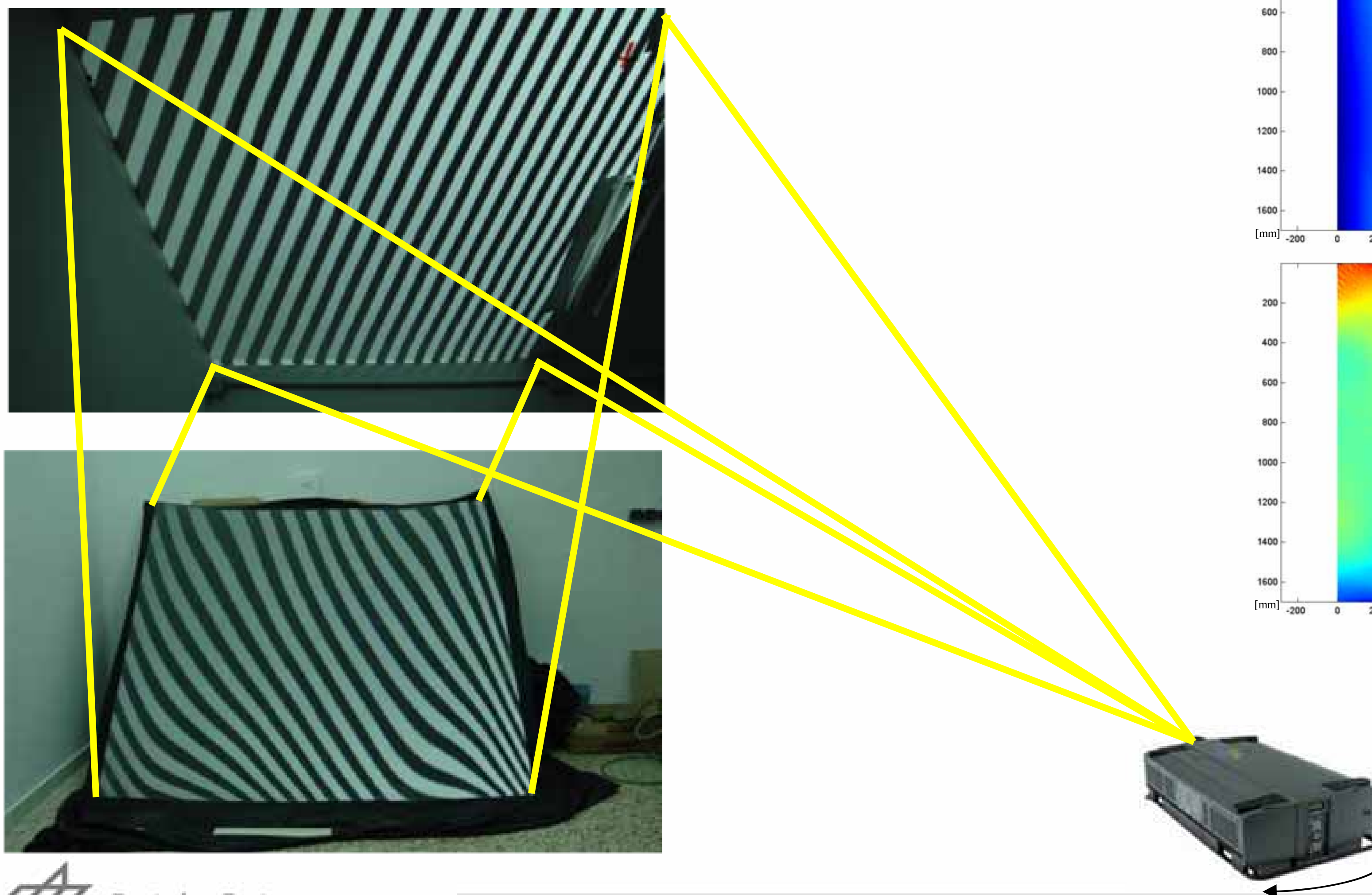


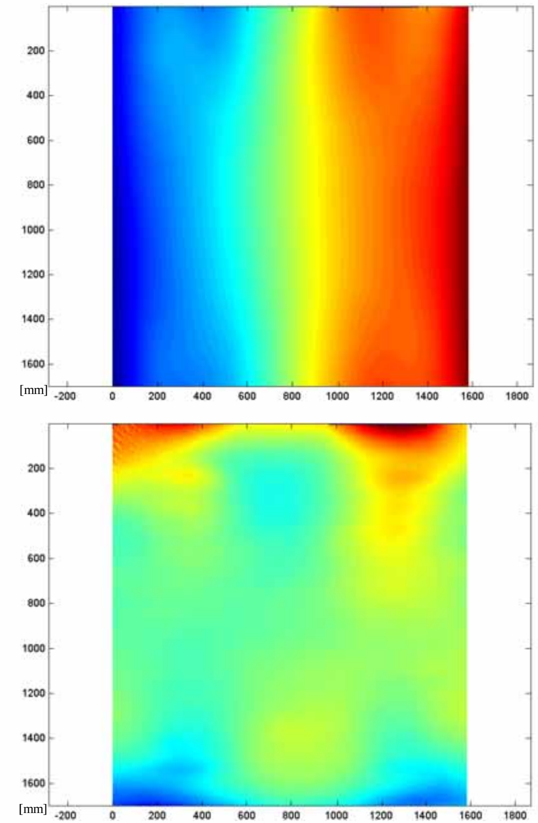
- *image processing:*
  - correct for distortion (lens, perspective)
  - use luminance threshold to find reflected edges



Absorber Tube Reflection

Enhancement with Pattern-Reflection

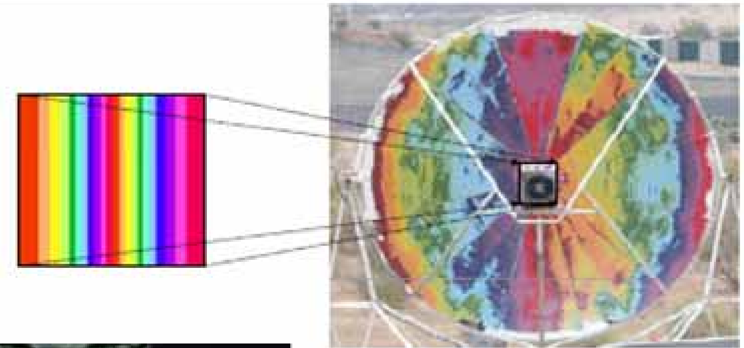


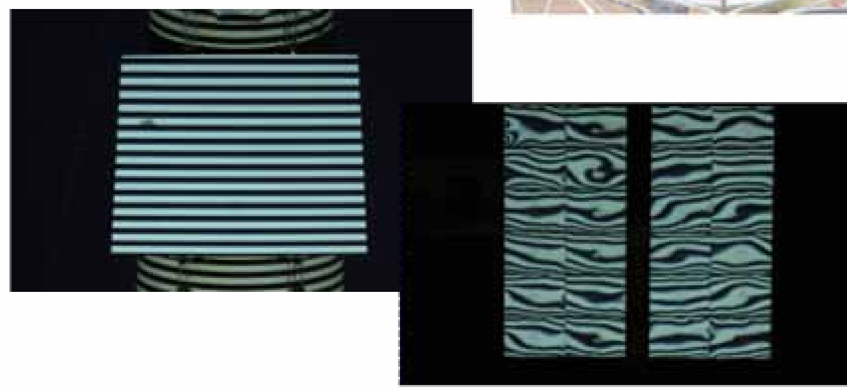


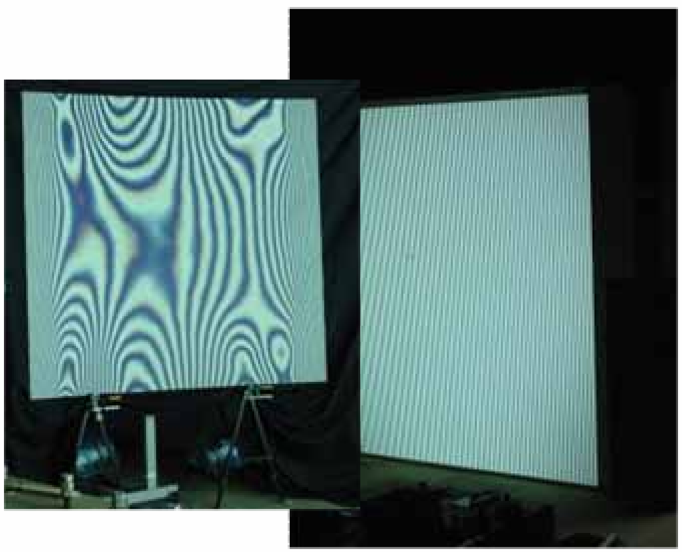
Application Examples

- Troughs, Heliostats, Dishes
- Mirror Facets

- flexible measurement systems
- high spatial resolution and precision
- fast
- industrial application







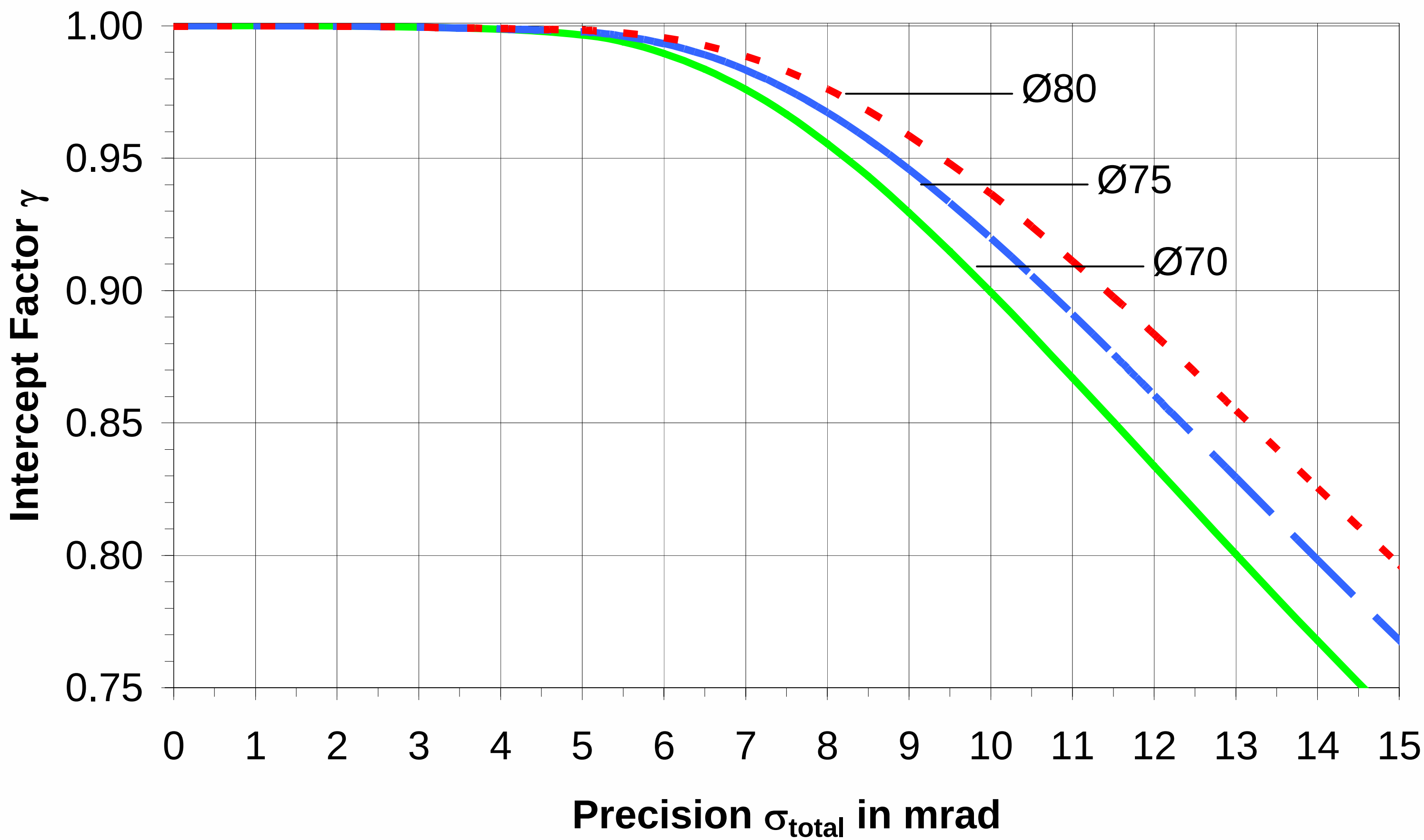
What is the use of all the data?

- Ray-tracing analyses
- Intercept factor calculations

- Conclusions from achieved accuracy
  - Prediction of performance
  - Specifications for component geometry
  - Analysis of mechanical loads by dead weight, by wind

- Prototype evaluations
- Solar field evaluations
- Quality control systems
  - Collector assembly accuracy

Intercepted Energy depends on Collector Accuracy
Ray-Tracing for Interpretation of Results



Summary Concentrator Testing

- Spectrometry on Reflectors (hemispherical, specular)
- 3D-geometry measurement on Reflector surface
- Slope measurements on reflector surface
- Deformation measurements of reflector panels
- 3D-collector metal support structure geometry
- Collector metal support structure slope and deformation analysis
- Tools: Photogrammetry, Reflection Measurement, (flux measurement)

Applications of the Results

- Ray-Tracing Evaluation → Intercept Factor Analysis
- Definition of quality parameters
  (e.g. Root-mean-square slope deviation)
- Application to collector development and evaluation
- Specification for components and assembly
- Quality control, quality assurance during solar field installation
- Solar field performance evaluation, operation supervision