Carl Zeiss SMT

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**ACTOP 2008:
Presentation
Carl Zeiss
Laser Optics**

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LO-GOO

Oct. 9, 2008

Outline

- Zeiss has decades of experience as optics manufacturer. Dedication to mirror fabrication and in particular to synchrotron optics.
- Capabilities
  - » Geometries dimensions and extras
  - » Tour: From inquiry to finished mirror: recent CAD capabilities
- Glimpse on general achievements
  - » Figure residuals (rms slope and hight errors)
  - » Strongly deformed surfaces (2D aspheric)
  - » Tight geometry specifications
- Metrology
  - » Overview devices in operation
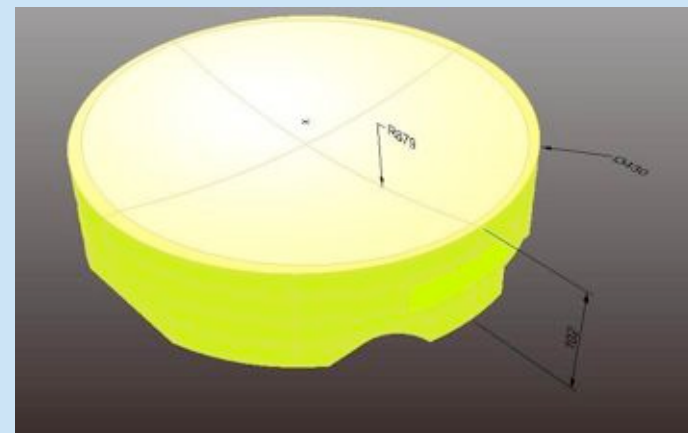 - » Examples on cross comparison
- Summary

Range of dimensions and geometries
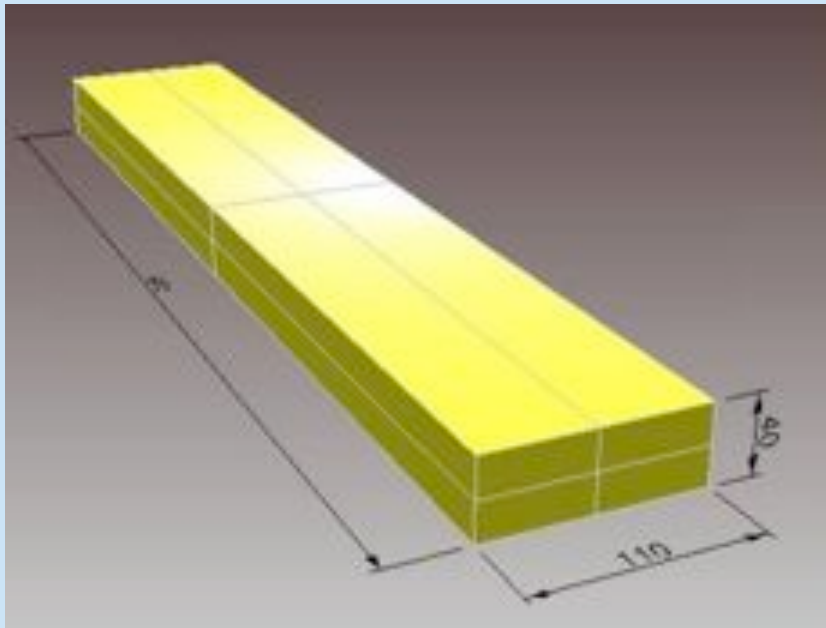

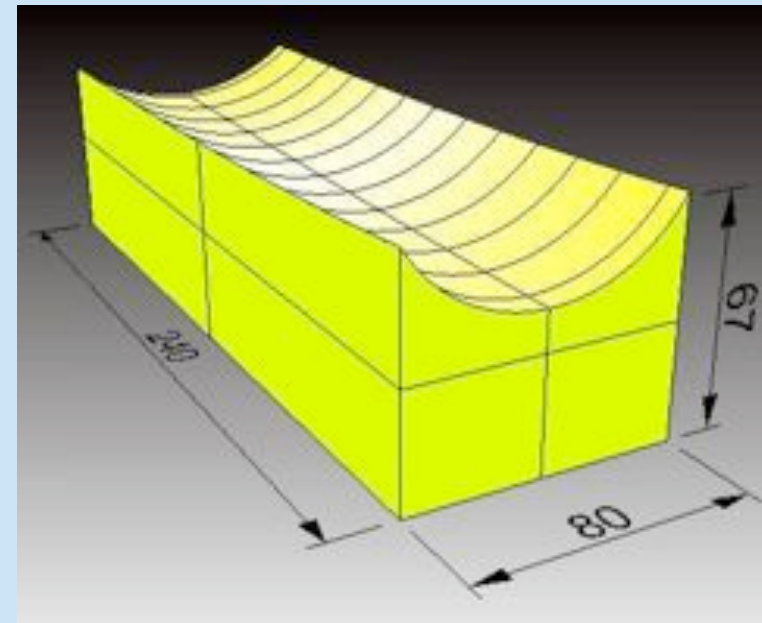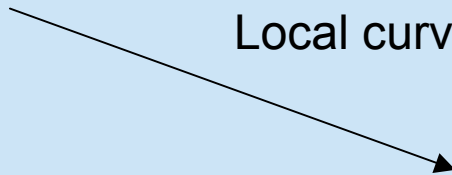From a few cm length to large apertures above 1 m …
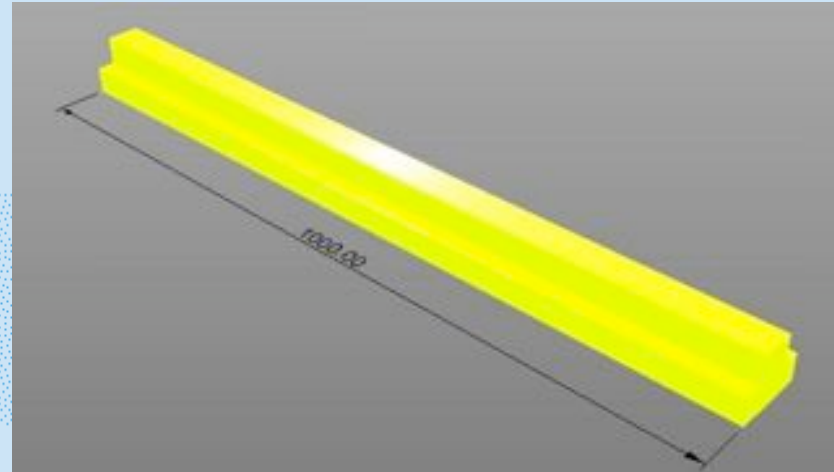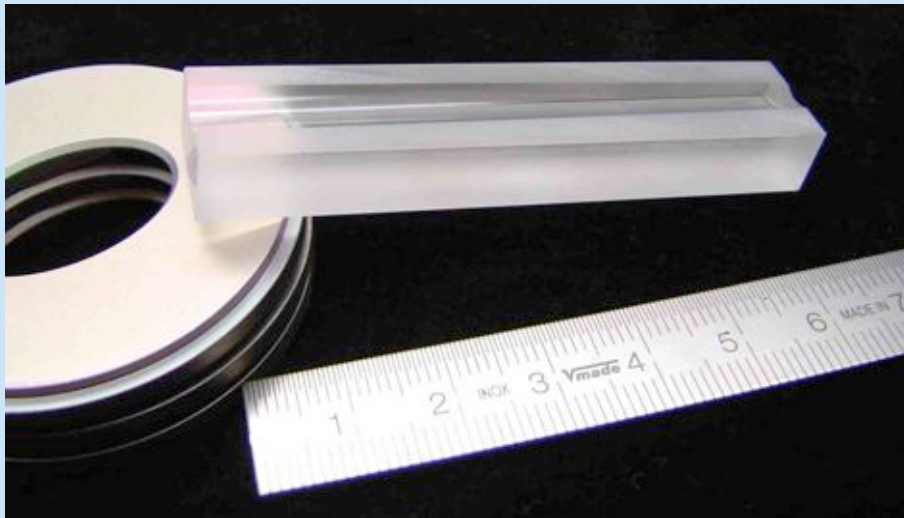
10-50 x

Range of dimensions and geometries

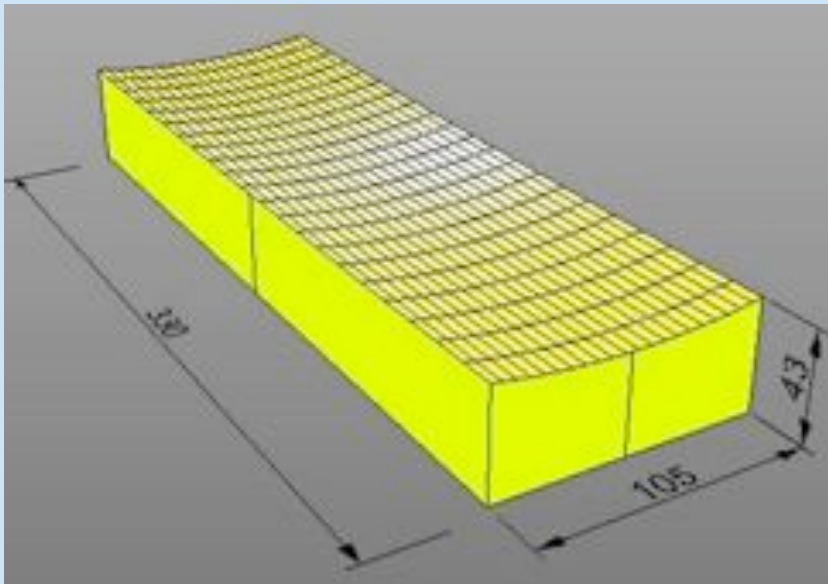… from a flats to full 2D freeform geometries …
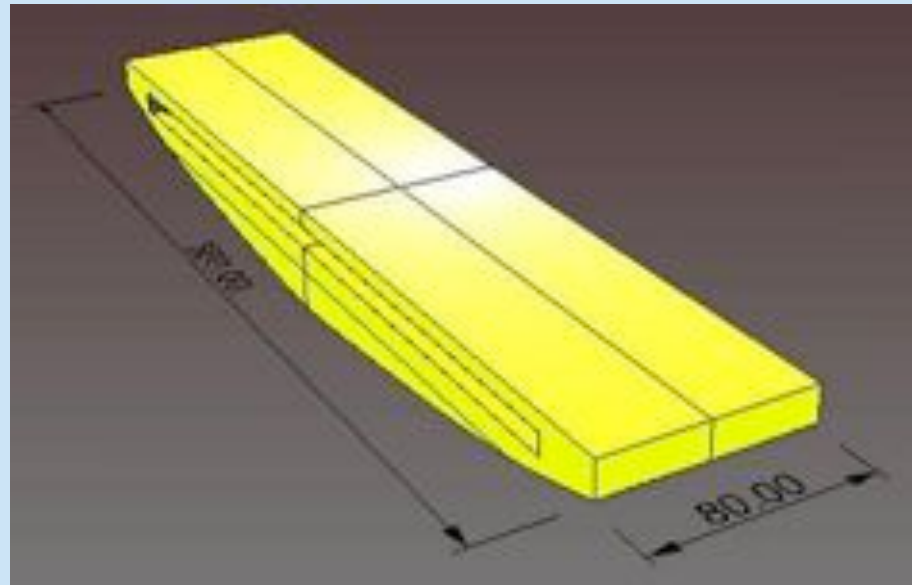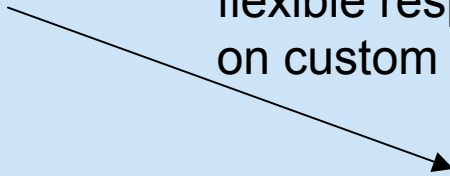

Local curvature

Complex mounting features

… from simple cuboidal to freeform custom substrates.

flexible response
on custom design

From inquiry to finished mirror

M1

Geometry: Elliptic cylinder

Incident angle: 89 deg

Incident arm r1 : 5370 mm

Emit arm r2: 1230 mm

Substrate dimensions: 160 L x 40 W x 40 T mm +/- 0.5 mm

Substrate material: SiO2

Optical active area: 140 L x <10 mm W

Slope errors: < 0.5 arcsec meridional

                        < 2 arcsec sagittal

Surface roughness: < 0.3 nm rms

Coating: Au 40 nm with < 5nm Cr binding layer

customer specifications
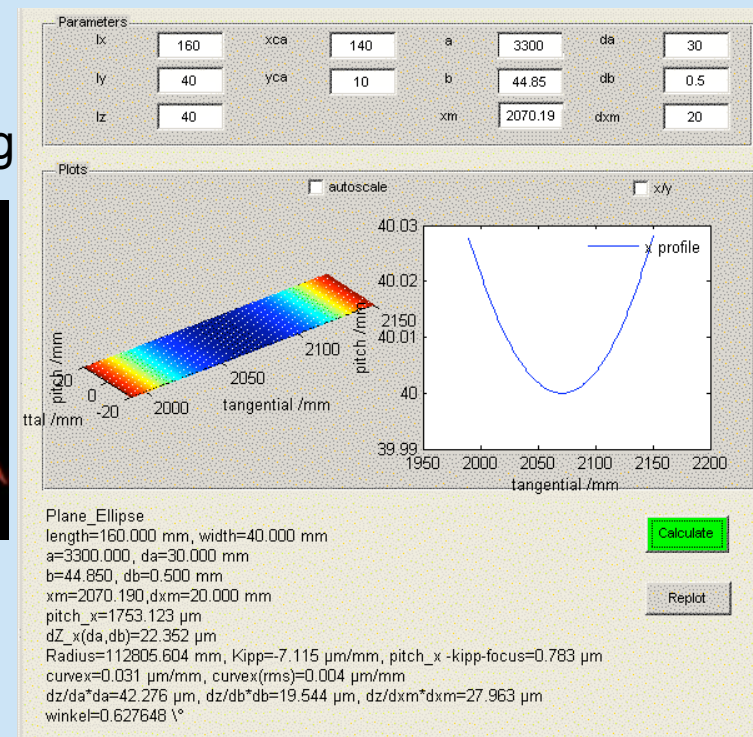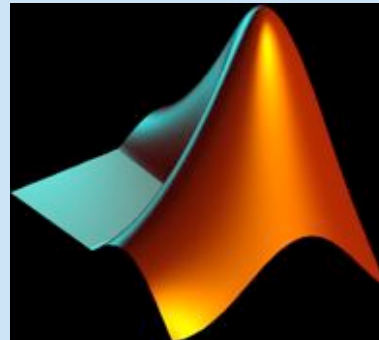
mirror ready for shippment

The full CAD supported process I

Customer specifications

MatLab based data processing

M1
Geometry: Elliptic cylinder
Incident angle: 89 deg
Incident arm r1 : 5370 mm
Emit arm r2: 1230 mm
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Parameters

lx	160	xca	140	a	3300	da	30
ly	40	yca	10	b	44.85	db	0.5
lz	40			xm	2070.19	dxm	20

Plots

☐ autoscale   ☐ x/y

Plane_Ellipse
length=160.000 mm, width=40.000 mm
a=3300.000, da=30.000 mm
b=44.850, db=0.500 mm
xm=2070.190,dxm=20.000 mm
pitch_x=1753.123 µm
dZ_x(da,db)=22.352 µm
Radius=112805.604 mm, Kipp=-7.115 µm/mm, pitch_x -kipp-focus=0.783 µm
curvex=0.031 µm/mm, curvex(rms)=0.004 µm/mm
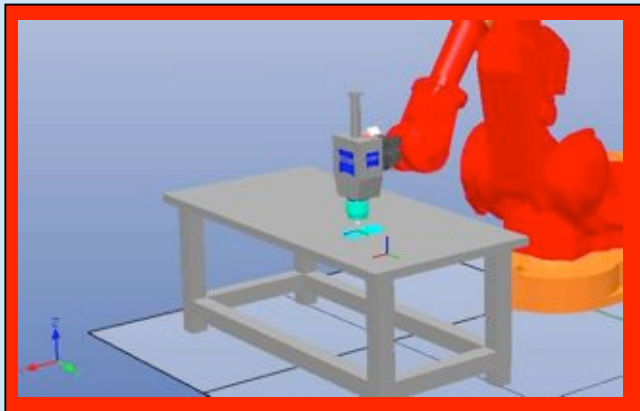dz/da*da=42.276 µm, dz/db*db=19.544 µm, dz/dxm*dxm=27.963 µm
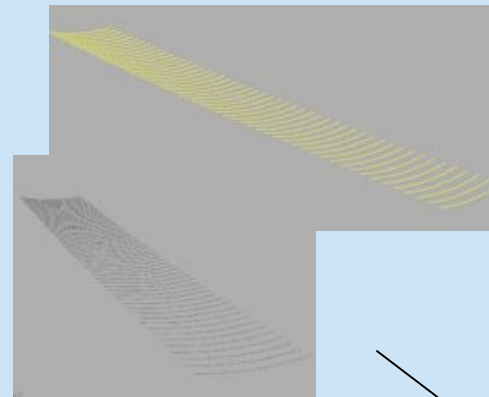winkel=0.627648 \°

Calculate

Replot

The full CAD supported process II

Generation of pointclouds for
NonUniformRationalB-Splines
based CAD Models

point clouds

NURBS based
surface modeling

Figuring Software
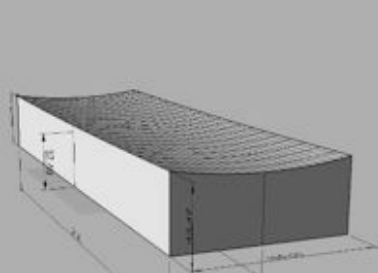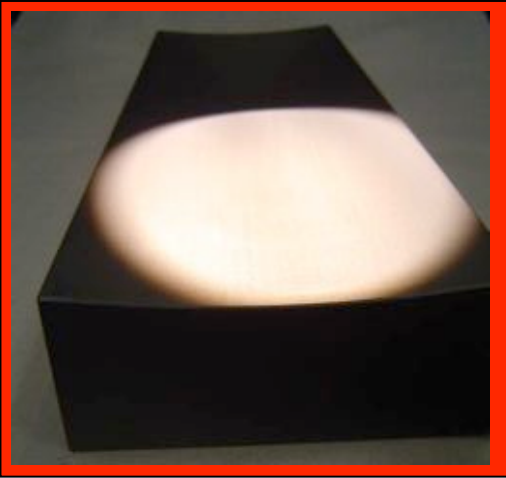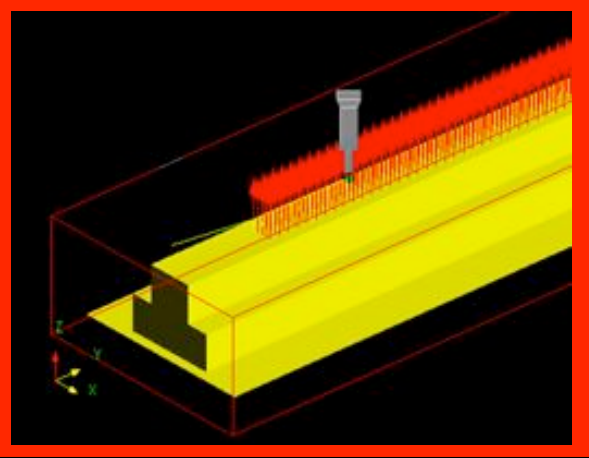
The full CAD supported process III

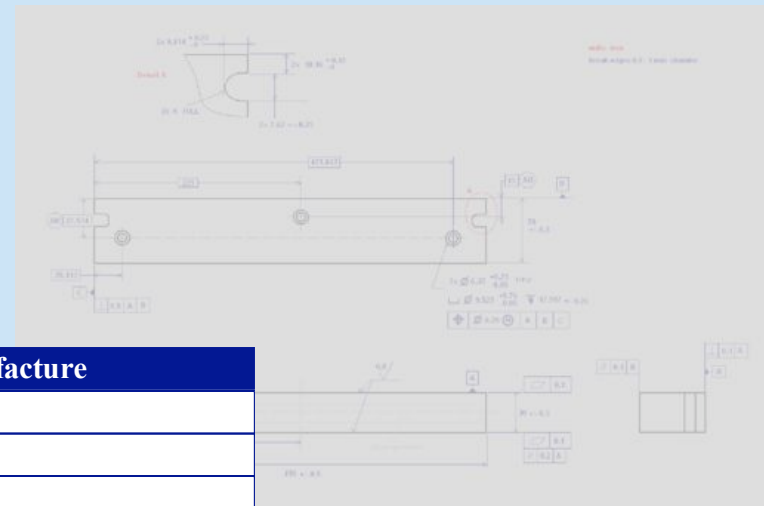3D Metrology

Standard CAD Model
(IGES, VDA, …)

premachined
substrates

Recent achievements: example cylindrical mirrors

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Challenges:

- low residual slope errors
- low figure roughness (height error)
- tight radius specification
- full roughness specification (MSRF + HSFR)

Features	Specification / Manufacture	
Material	Si <100>	
Dimensions	> 400 x 20 mm^2	
Clear aperture	> 385 x 10 mm^2	

Properties	Specification	Results
Geometry	cylinder radius: 150 km < R < 195 km	in spec.
Slope Error	tangential :: 0.25 µrad rm sagittal: 2.0 µrad rms	0.19 µrad rms 1.60 – 1.68 µrad rms
Height Error	< 2.0 nm rms	1.55 nm rms
Surface Roughness	MSRF: 5.2 – 1000 µm ≤ 0.25 nm rms HSFR : 0.02 – 2 µm ≤ 0.4 nm rms	< 0.095 nm rms 0.12 – 0.20 nm rms

Recent Achievements: 1D aspheres (plane ellipse)

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Challenges:

- aspherical shape
- very low residual slope errors
- medium μ-roughness specification (MSRF)
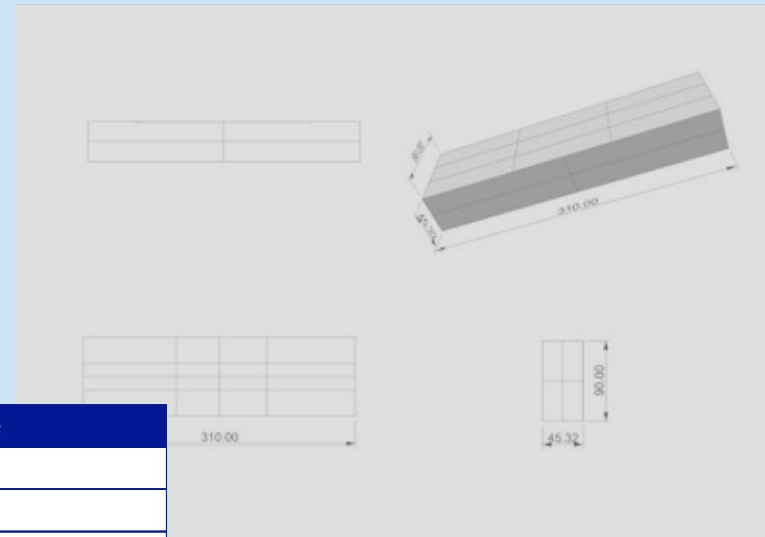
Features	Specification / Manufacture	
Material	fused silica	
Dimensions	> 200 x 40 x 50 mm ^{3}	
Clear aperture	> 150 x 5 mm ^{2}	
Coating	50 nm standard coating	

Properties	Specification	Results
Elliptical parameters	semiaxes: $a \sim 15000 +/- 30$ mm $b \sim 60 +/- 0.1$ mm off-axis: $x_M \sim 14000 +/- 32$ mm	as specified (1)
Slope Error	meridion al: 0.2 arcsec rms sagittal: 1.0 arcsec rms	0.18 arcsec rms 0.9 arcsec rms
Surface Roughness	≤ 0.5 nm rms	0.31 − 0.4 3 nm rms (2)

Recent Achievements: 2D asphere (paraboloid)

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Challenges:

- strongly aspherical shape (local curvature)
- very small sagittal radius (50-60 mm)
- low sagittal slope error (1.8 ")
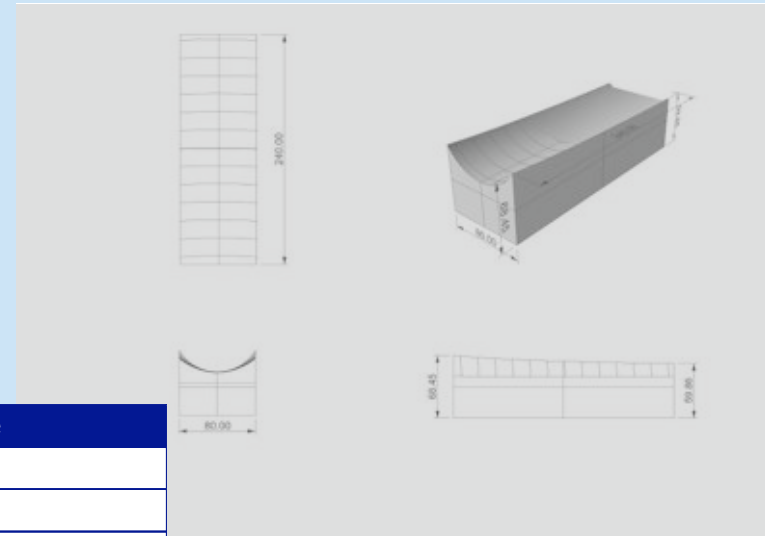
Features	Specification / Manufacture	
Material	zerodur®	
Dimensions	> 190 x 30 x 50 mm^3	
Clear aperture	> 15 0 x 20 mm^2	
Coating	50 nm standard coating	
Properties	**Specification**	**Results**
Parabola parameters	Vertex : R ~ 4.0 +/- 0.05 mm off-axis : x_M ~ 400 +/- 1 mm	as specified
Slope Error	meridion al: 5.0 arcsec rms sagittal: 2.0 arcsec rms	arcsec rms 1.8 arcsec rms
Surface Roughness	≤ 0.5 nm rms	0.35 nm rms

Metrology overview (3D CMM metrology)

M400 – extended precision tactile CMM
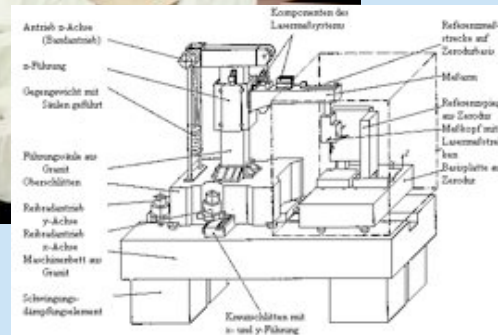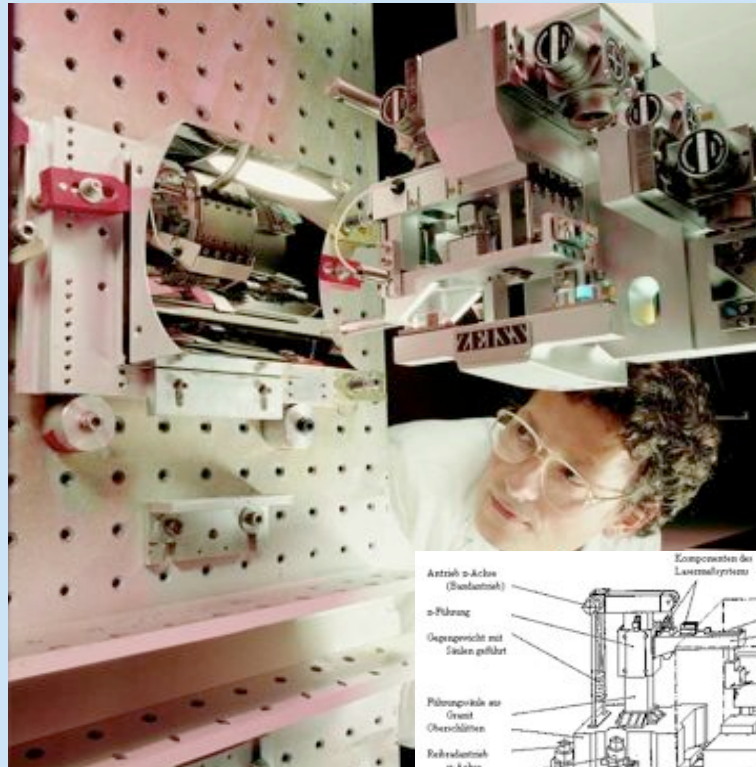
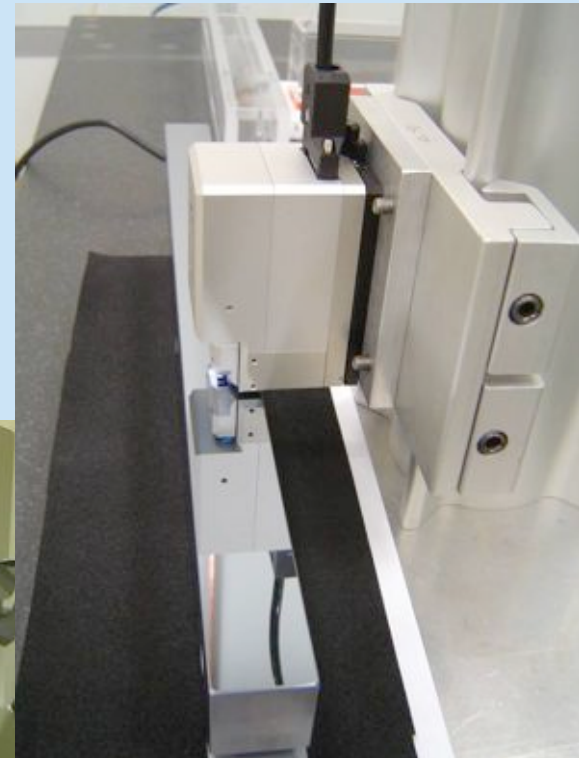UPMC – high precision tactile CMM

Metrology overview (Promap, AFM)
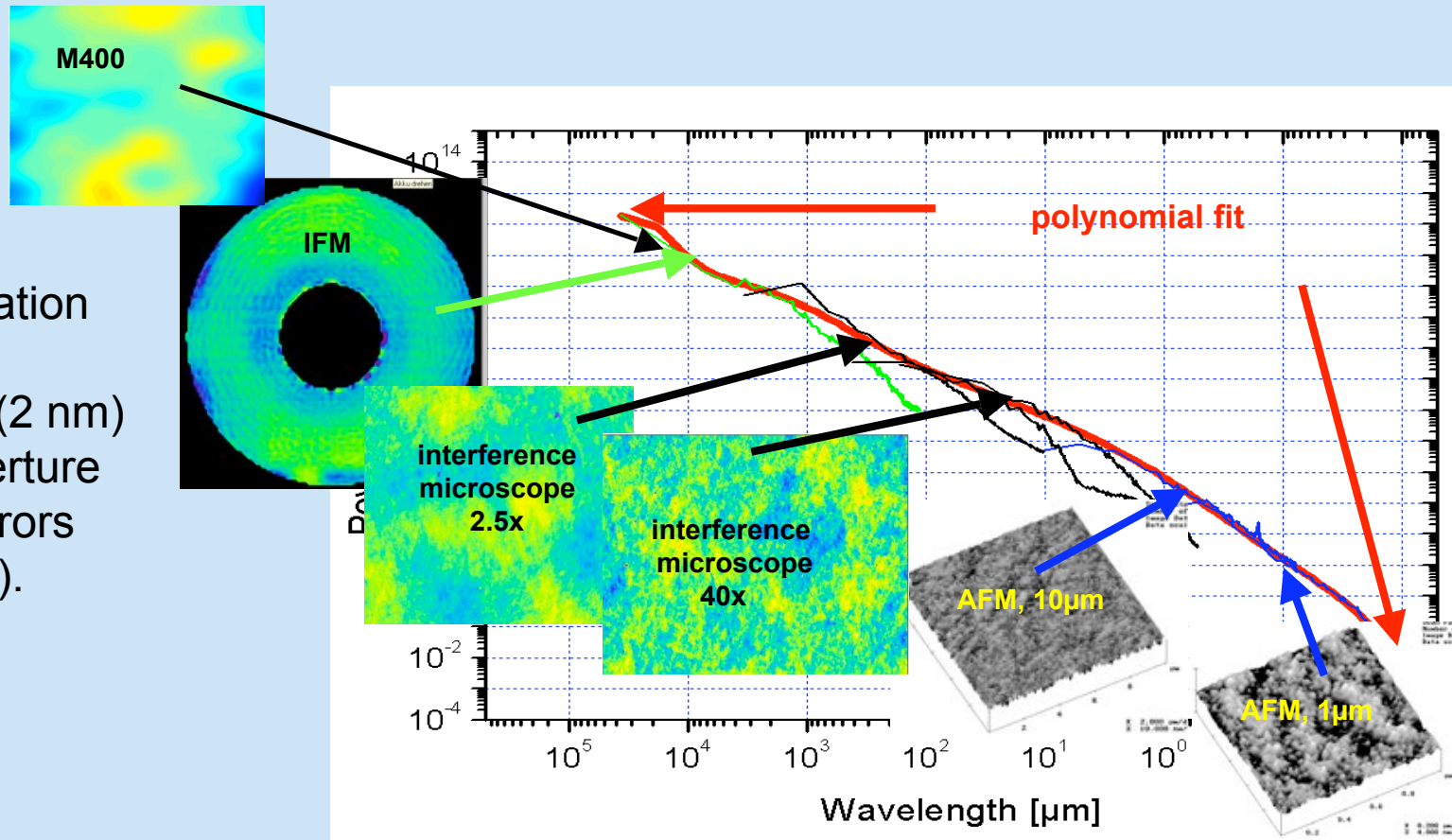
MSFR (Promap µ-interferometer)

HSFR (AFM)

Metrology overview (PSD)

Full sample
characterization
from AFM
roughness (2 nm)
to clear aperture
of large mirrors
(1 m length).

M400

IFM

polynomial fit

interference
microscope
2.5x

interference
microscope
40x

AFM, 10µm

AFM, 1µm

10^{14}

10^{-2}

10^{-4}

10^5 10^4 10^3 10^2 10^1 10^0
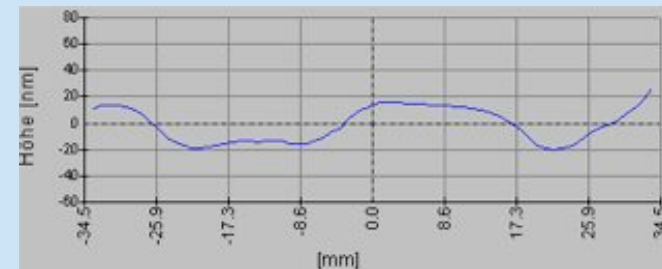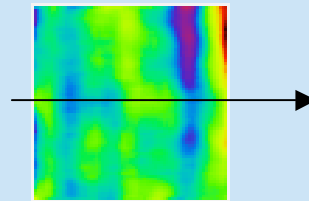
Wavelength [µm]

Metrology crosscomparison I

1D- Si cylinder: Metrology Interferometer + CGH vs. M400 tactile CMM

Fig.1: Comparison of tactile and interferometric measurements of a cylindrical optical surface. Quasi interferogram (top) from multi profile scan and interferogram (bottom) are shown. Note the good agreement in the order of few nm.
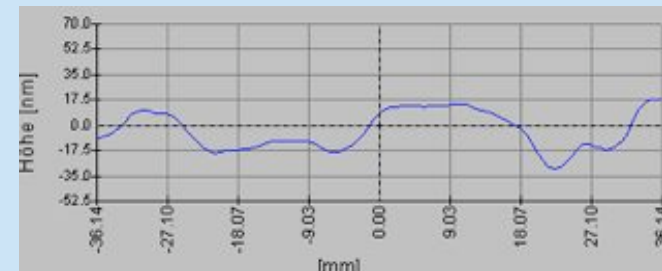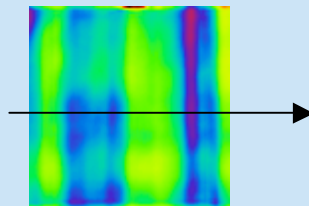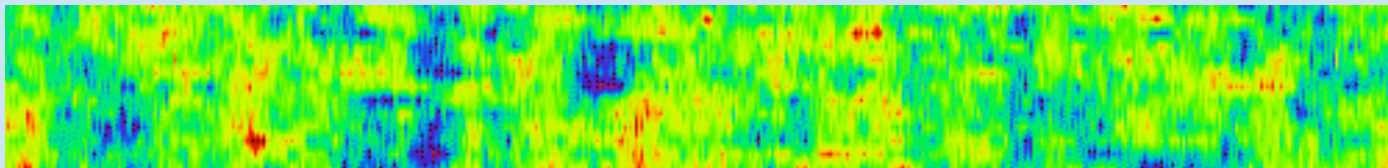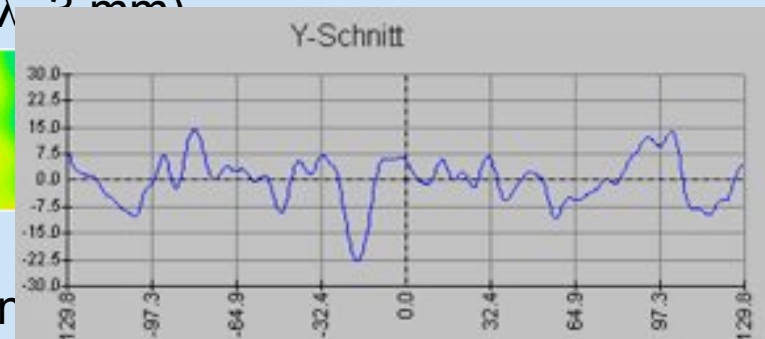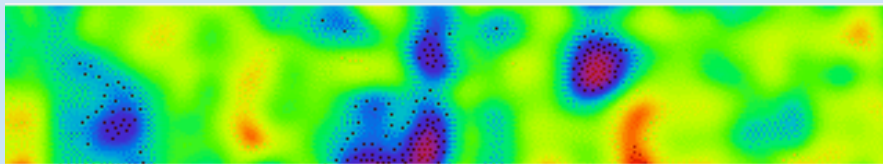
Metrology crosscomparison II

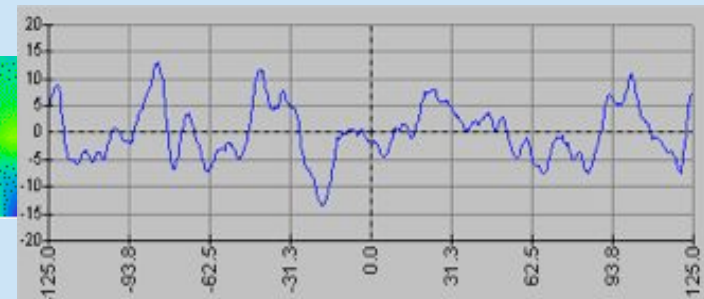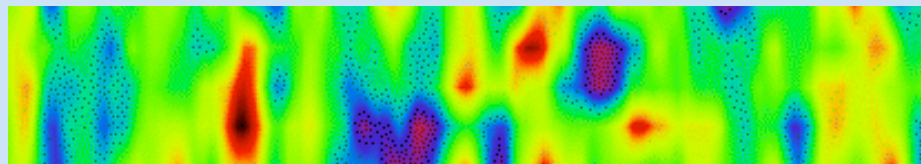2D-Quarz ellipse, specification sagittal slope error < 0.1 arcsec

M400 data single run, raw data

M400 mean from 3 scans and low pass (cutoff at λ 3 mm)

LTP measurement: after data integration and 2D in
  line scans

Summary

- **Capabilities**
  - » Various geometries dimensions, substrate materials and customer defined features feasible
  - » Recently approved CAD capabilities give high flexibility
- **Recent achievements**
  - » low residual slope errors (< 0.2 arcsec rms)
  - » low figure roughness (< 2 nm rms)
  - » "very" aspheric surfaces
- **Metrology**
  - » Metrology at Carl Zeiss covers the entire wavelength scale from few nm to clear aperture (> 1 m)
  - » Metrology is often the deciding limitation for ultra precise mirror fabrication
  - » cross comparison of figure error is ongoing process

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We make it visible