Institute of Applied Physics
Friedrich-Schiller-Universität Jena

Optical Metrology and Sensing

Lecture 1-1: Introduction

2020-11-03

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Outline

- Introduction
- Optical measurements
- Shape measurement

General Terms of Measurement

- Accuracy:
  In situations where we believe that the measured value is close to the true value, we say that the measured value is accurate (qualitative)

- Precision:
  When values obtained by repeated measurements of a particular quantity exhibit little variability, we say that those values are precise (qualitative)

- Reproducibility:
  Ability for different users to get the same reading when measuring a specific sample.

- Repeatability:
  How capable a gage is of providing the same reading for a single user when measuring a specific sample.

Ref: R. Kowarschik

General Terms of Measurement

- Resolution:
  Smallest amount of input signal change the instrument can detect reliably.
  Reasons for limited resolution: diffraction, noise, hysteresis, discretization.
  Typically it corresponds to half of the sampling rate.

- Sensitivity:
  Smallest signal the instrument can measure.
  Reproducible change of output signal for changes of the measured property

- Tolerance/dynamic range:
  Limiting maximum and minimum values, the system is able to detect

- True value:
  Value of the signal, if the system would be perfect. x_o
  If this is known for a special case, the system can be calibrated (corrected for systematic errors)

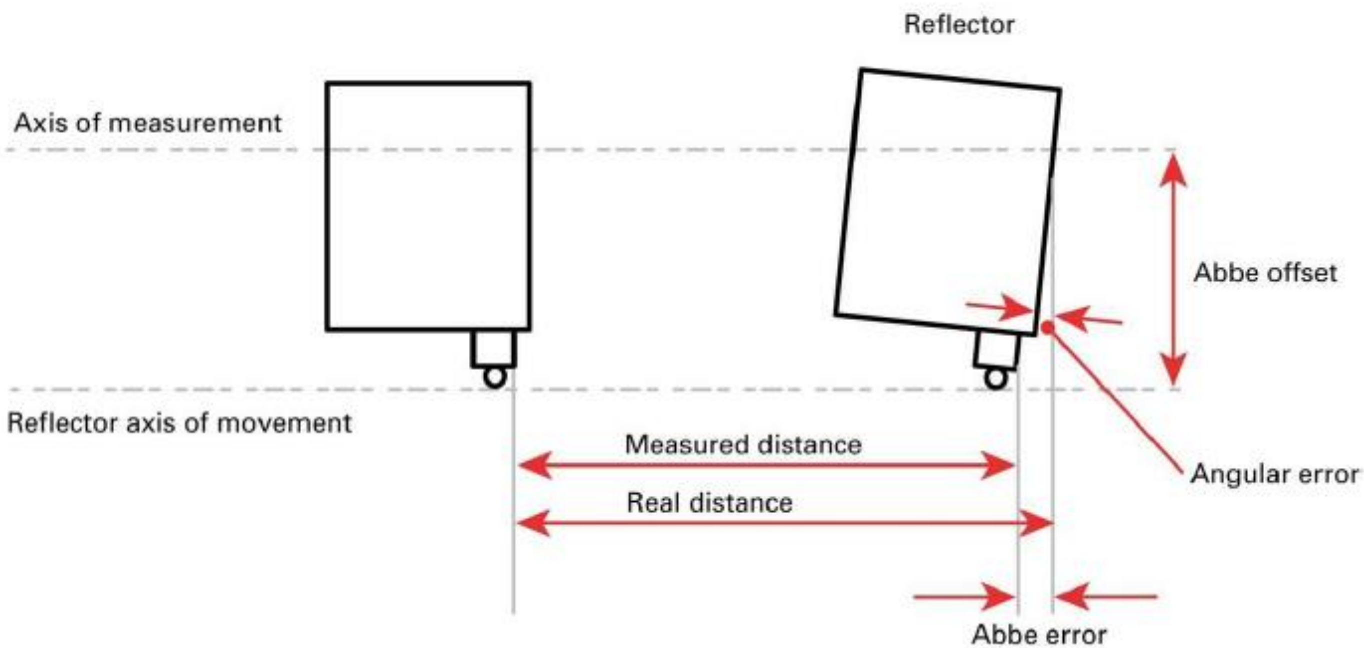
- Measurement error:
  Difference between measure value and true value $\Delta x = x - x_0$

Ref: R. Kowarschik

Abbe Comparator Principle

- Basic idea:
  the measured property and the scale of measurement should aligned
- Avoid the influence of tilt and bending on the result
- Errors due to mechanical means and uncertainties are therefore not affecting the result
- The scale should follow the movements in measurement
- If a tilt α is obtained and y is the Abbe offset, the error is of the range

$$\Delta x = y \cdot \tan\alpha$$



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Optical Methods for Shape Measurement

- Generation of structures for shape measurement:
  1. projection (incoherent imaging of a grid)
  2. interference (mostly coherent)

- Optical methods:
  1. fringe projection (contour lines)
  2. Moire technique (2 sources used)
  3. holographic contouring
  4. speckle contouring
  5. photogrammetry

- Shape measurement for quality control applications
  1. digitization of prototypes
  2. replacement of mechanical systems

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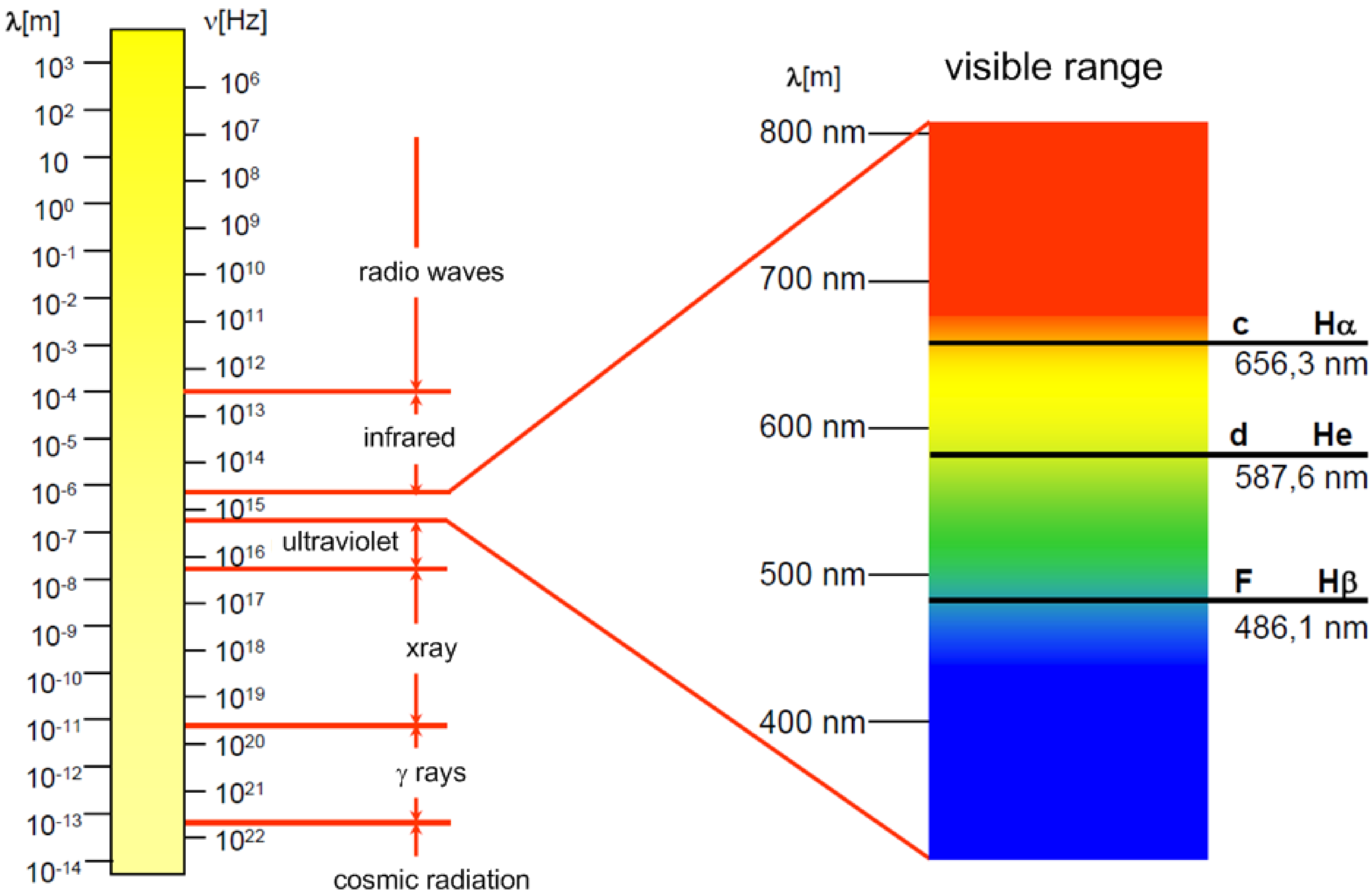
Wavelength Ranges



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Scales and Dynamic Range

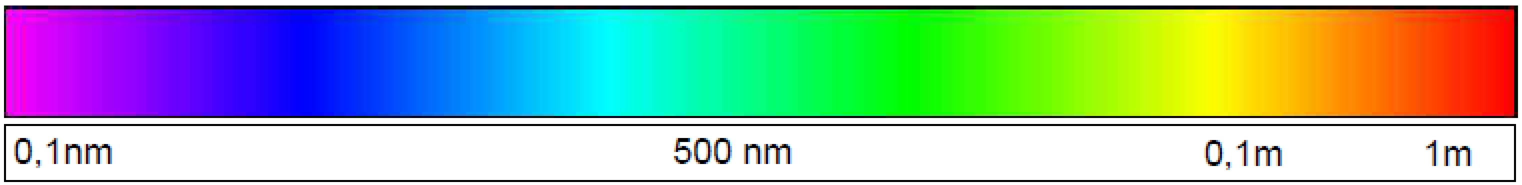
- 10 orders of magnitude for geometrical measurements:

AFM
SNOM

white light
confocal

holographic
speckle

pattern projection



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Optical Measuring Instrument

- Characterization of measuring device:
  1. Test piece / specimen / object scanning / sensing
  2. Measurement signal (material measure, standard, etalon)
  3. Amplification of the signal
  4. Indication of the measured value
- If one of the first three aspects is performed out optically:
  optical measuring instrument
- Methods based on the wave nature of light:
  1. Diffraction
  2. Interference (coherent):
     Interferometer
     Holography
     Speckle techniques
     Laser based measurements

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Classification of Optical Metrology

Measuring properties	coordinates	heights distances 3D shapes roughness
	changes in shape	shifts expansions strain
	deviations	material data internal external
Measuring principles	physical model	geometrical wave optical
	light field	coherent incoherent
	dimension	1D - point 2D - line 3D / 2,5D - surface

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Optical Methods

- Requirements on measurement:
  1. high density of measurement points, spatial resolution
  2. high velocity
  3. contactless
  4. absolute 3D coordinates

- Pros and cons of optical measuring techniques

advantages	disadvantages
contactless	indirect
without back influence	limited resolution
surface related	interaction with surface
fast	material dependent
flexibel and integrabel	
high lateral resolution	

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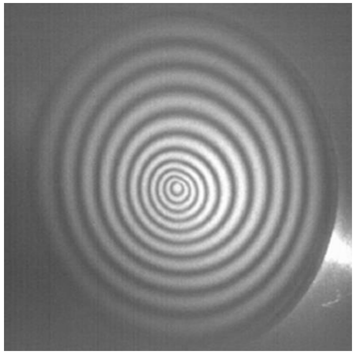
Measurement Quantities

- Interferometric fringes



Primary measured	Derived quantity	Applications
fringe position	phase difference	length standard refractometry length compensation
	phase variation	interference microscopy optical testing
fringe visibility	spectrum of source	spectral profiles
	spatial distribution at source	stellar diameter
full intensity distribution	spectrum of source	interference spectroscopy Fourier spectroscopy
	spatial distribution at source	optical transfer function radio astronomy

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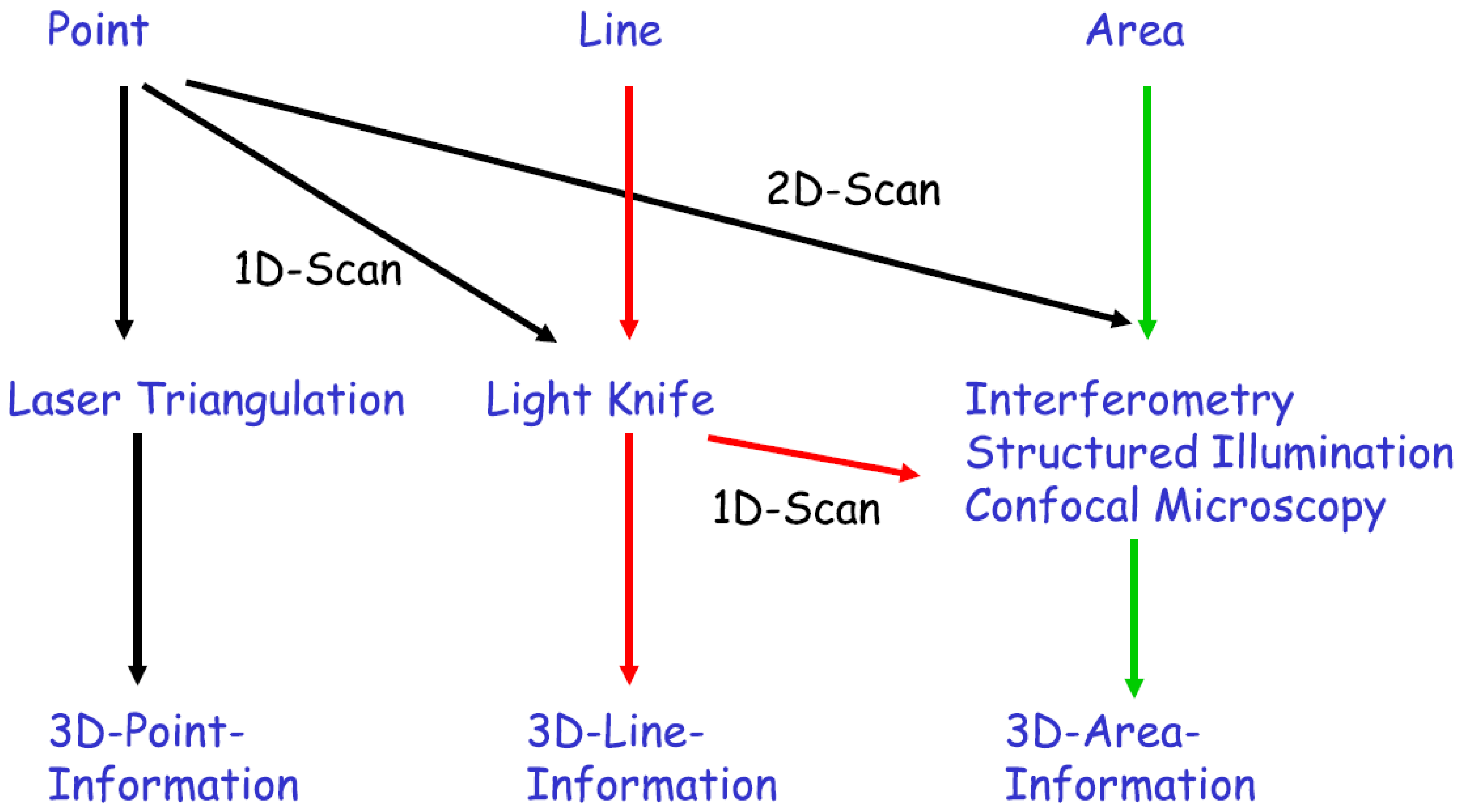
Dimension Classification



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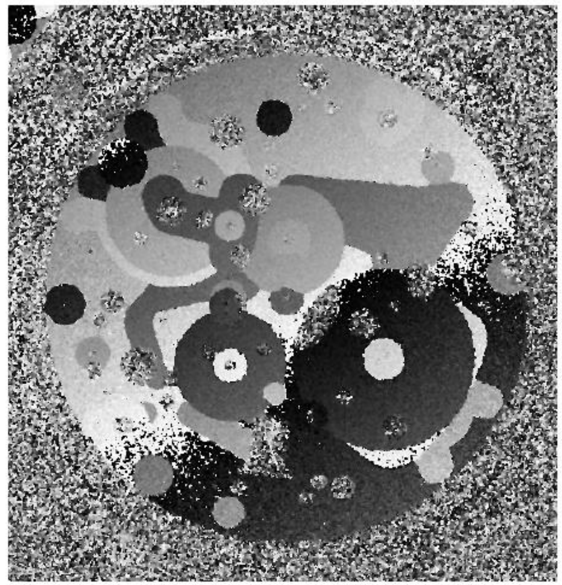
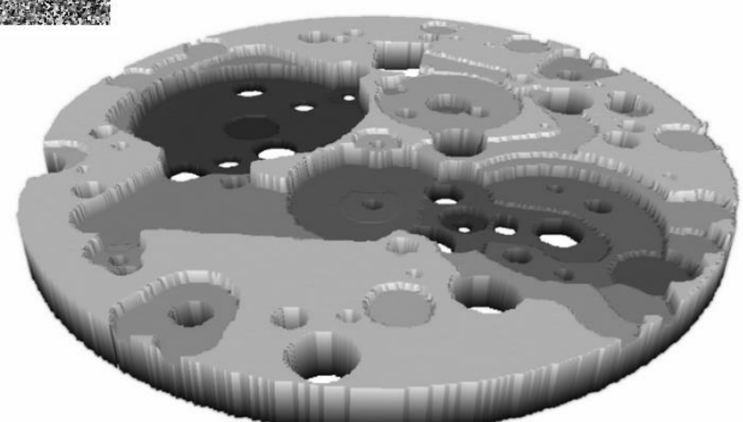
Shape Measurement

- Micro mechanical part

depth map





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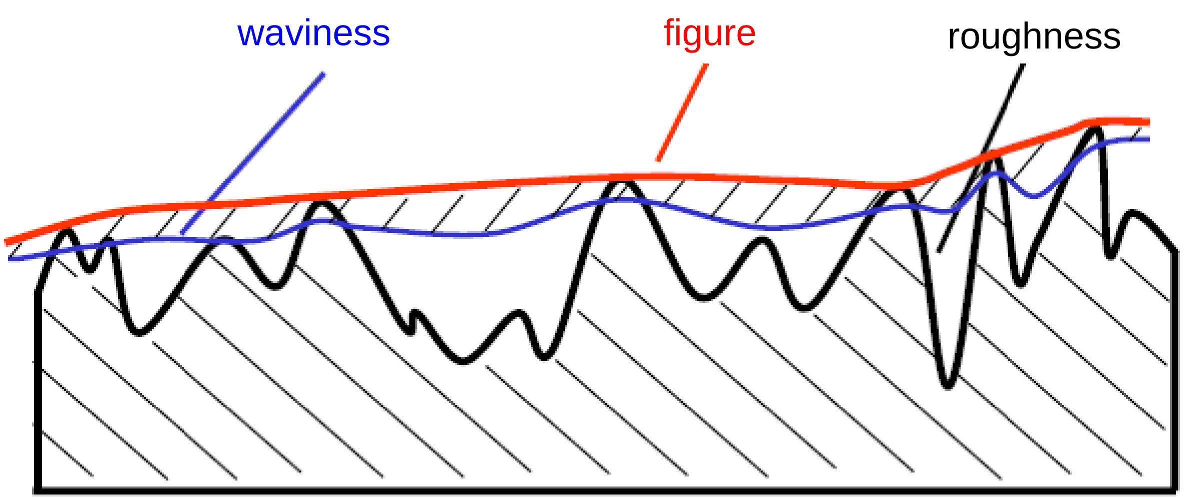
Surface Deviations

- Typical three different ranges according to power spectral density:
  1. figure:
     long range, overall shape
  2. waviness:
     machine oscillations, errors in production
  3. roughness:
     Short term deviations due to manufacturing interaction (grinding, polish,...)



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PSD Ranges

- Typical impact of spatial frequency ranges on PSF
- Low frequencies:
  loss of resolution
  classical Zernike range
- High frequencies:
  Loss of contrast
  statistical
- Large angle scattering
- Mif spatial frequencies:
  complicated, often structured
  fals light distributions