Institute of Applied Physics
Friedrich-Schiller-Universität Jena

Metrology and Sensing

Lecture 10-1: Measurement of basic system properties

2021-01-19

Herbert Gross

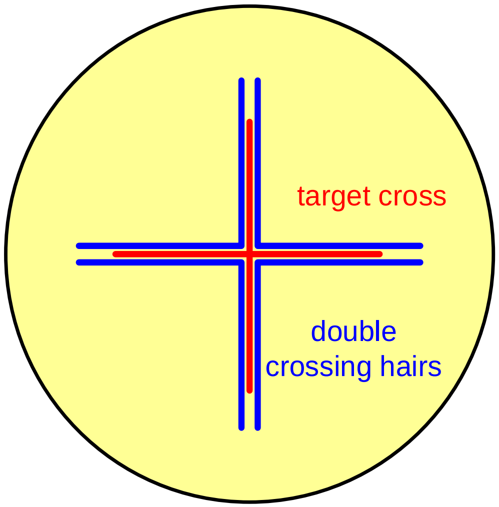
Content

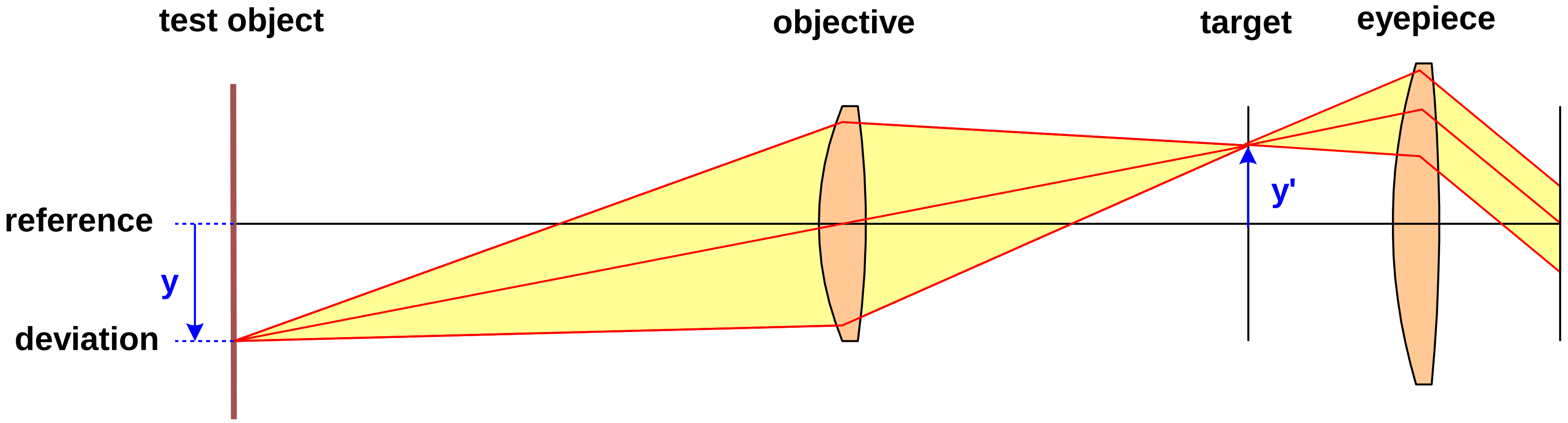
- Autocollimation
- Focal length
- Basic system properties

- Measurement of small lateral displacements

$$x' = m \cdot x$$

- Zero measurement with target cross and crossing hairs





Alignment Telescope

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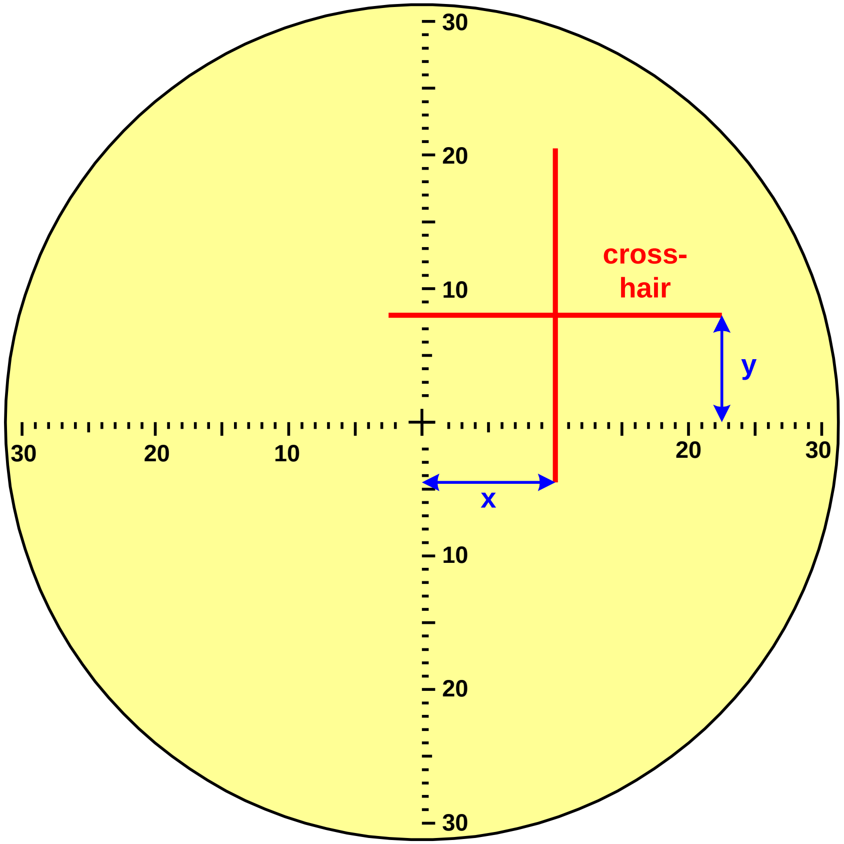
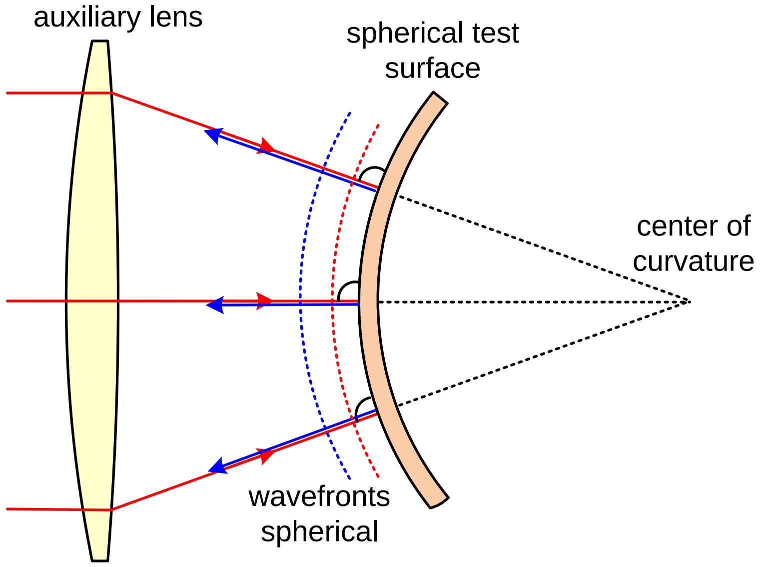
- Deviation in measurement eyepiece quantitatively
- Achievable accuracy depends on focal length
- Accuracy of a few arc seconds possible

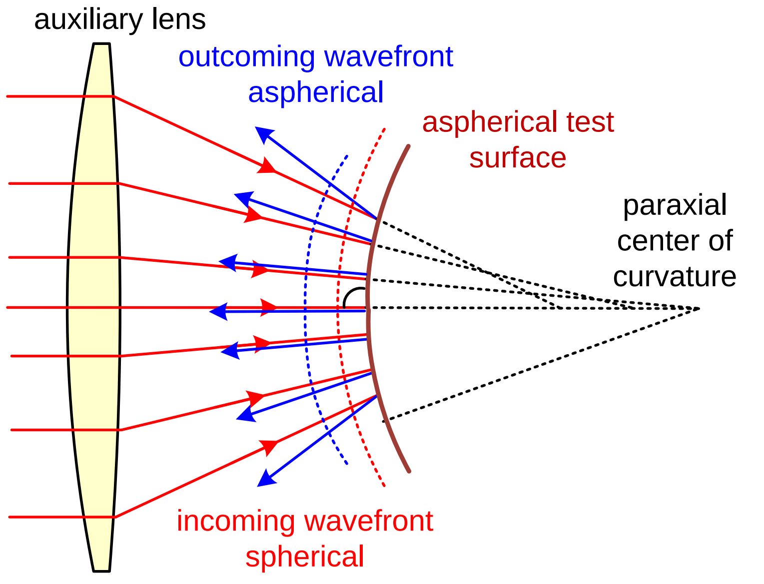


Autocollimation Principle

- Spherical test surface:
  - incoming and outgoing wavefront spherical
  - concentric waves around center of curvature: autocollimation

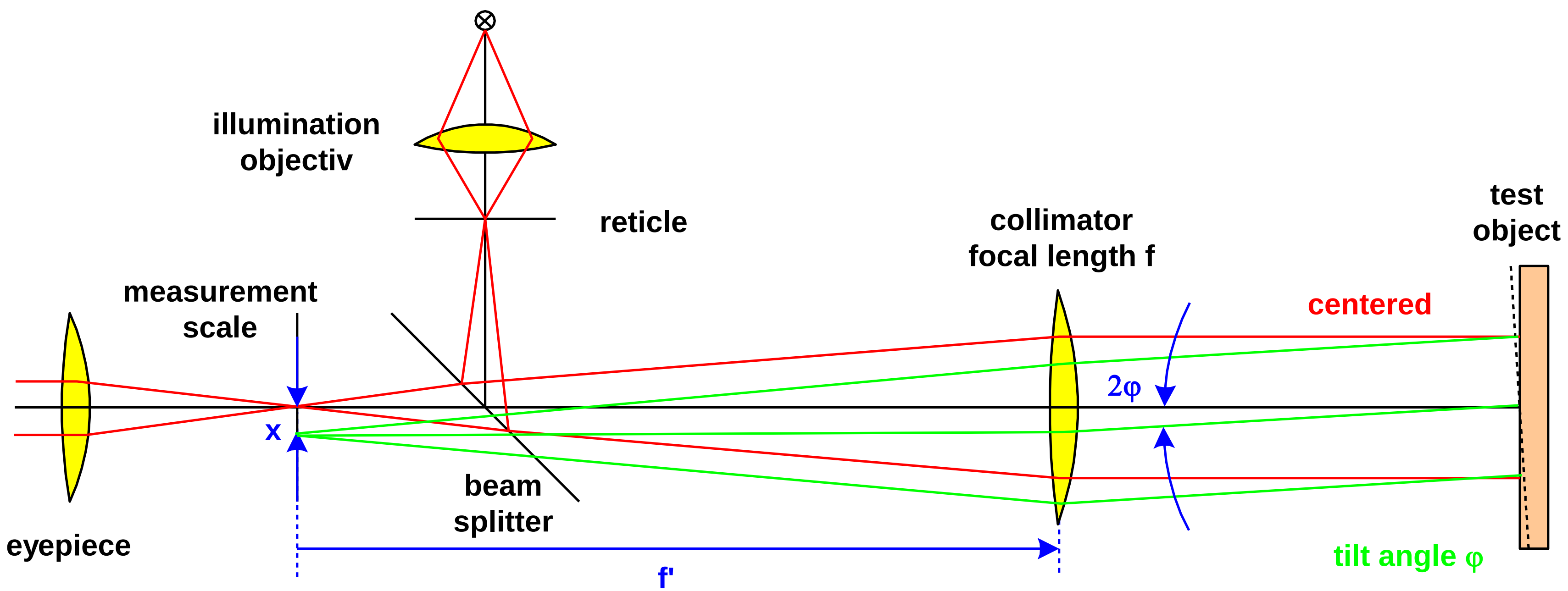


- Aspherical test surface



Autocollimation

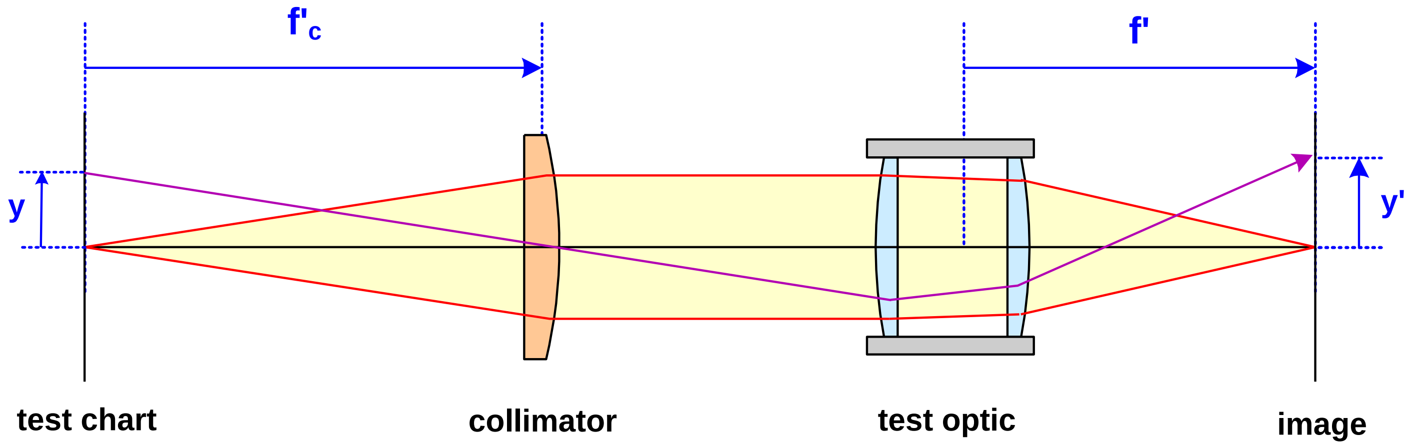
- Measurement of tilt errors (plane or spherical surface) in autocollimation
- Projection of the cross
- Observation of lateral shift in Fourier plane $x = f \cdot 2\varphi$



Measurement of Focal Length with Collimator

- Collimated incident light
- Calibrated collimator with focal length f_c and test chart with size y
- Selection of sharp image plane
- Analysis of image size

$$f' = -f'_c \cdot \frac{y'}{y}$$



Measurement of Focal Length According to Gauss

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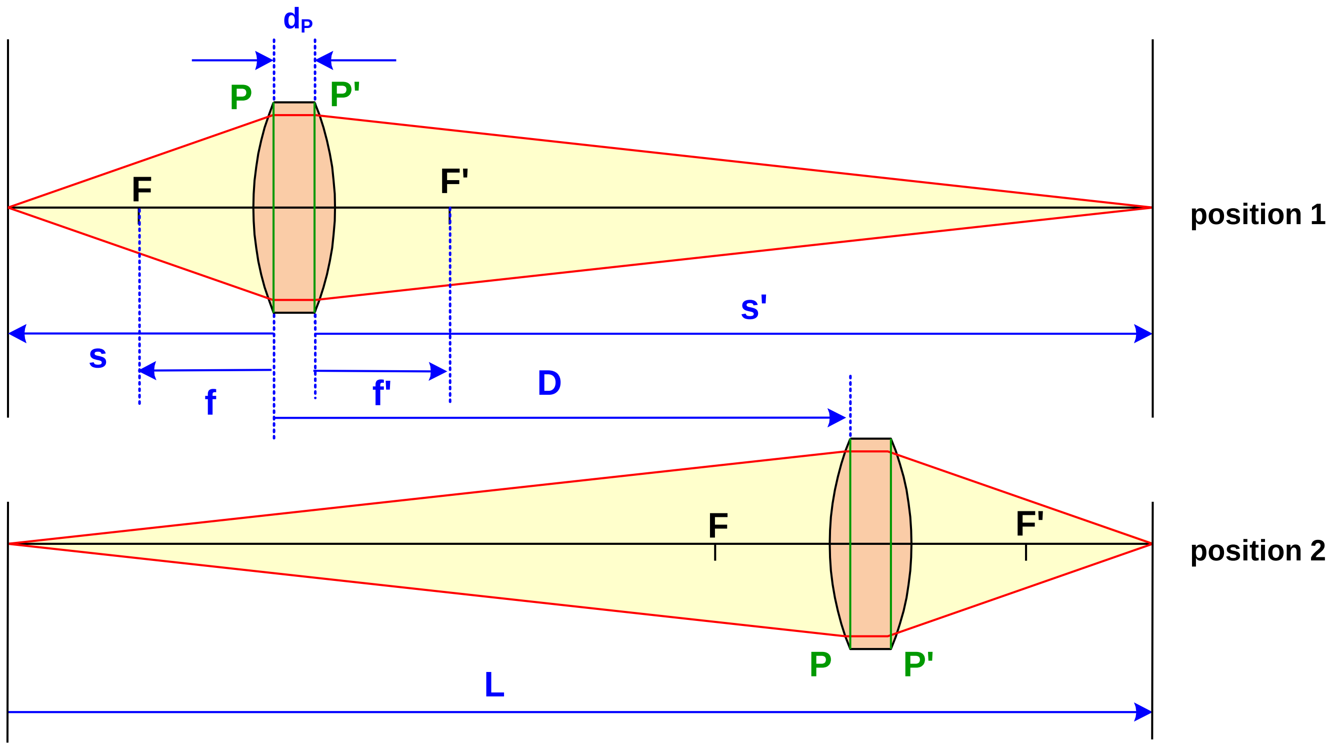
- Setup with distance object-image L > 4f
- Known location of the principal plane P of the system distance d_P between principal planes
- Selection of two system locations with sharp image
- Relative axial shift D between the two setups

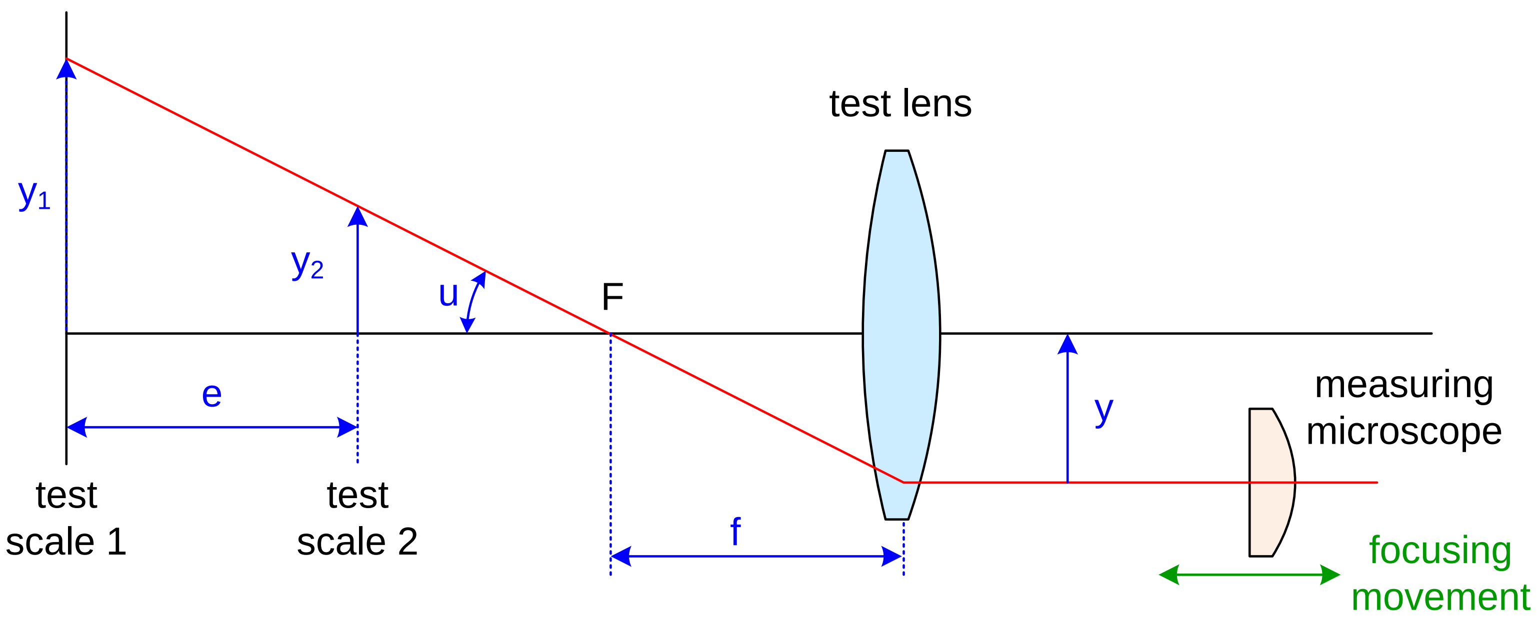
$$f = \frac{L - d_P}{4} - \frac{D^2}{4(L - d_P)}$$



Measurement of Focal Length with Focometer

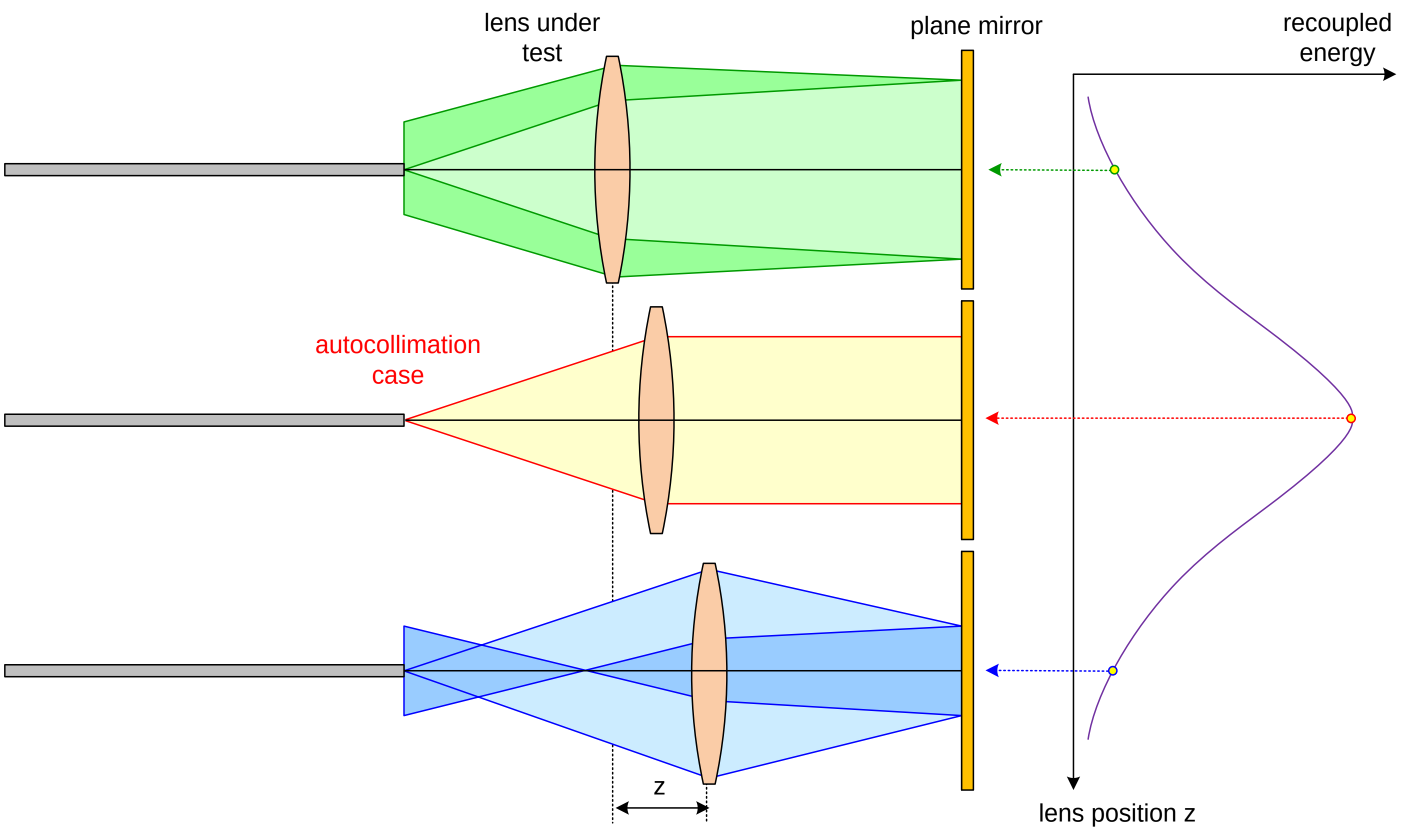
- Telecentric movable measurement microscope with offset y: Abbe focometer
- Focusing of two different test charts with sizes y_1 and y_2
- Determination of the focal length by

$$\tan u = \frac{y}{f} = \frac{y_2 - y_1}{e}$$



Measurement of Focal Length by Confocal Setup

- Setup with fiber and plane mirror for autocollimation
- Change of distance between test lens and fiber
- Analysis of the recoupled power into the fiber (confocal) gives the focal point



Measurement of Focal Length by Moire Deflectometry

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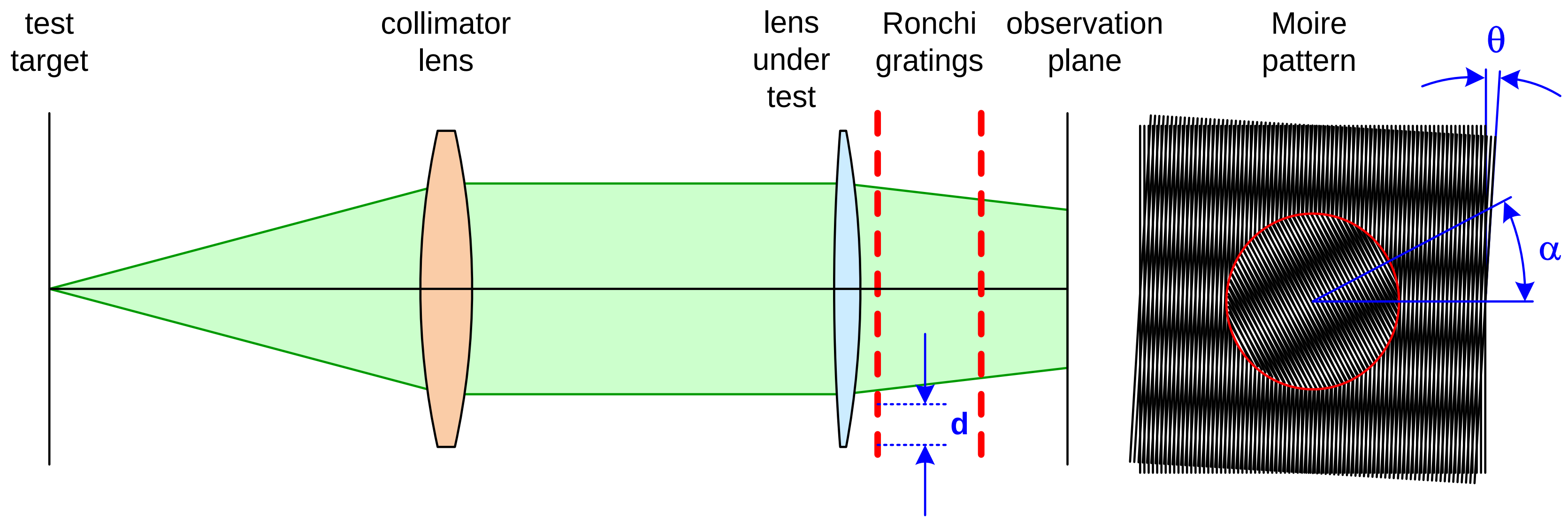
- Setup with collimator and two Ronchi rulings
- System under test is inserted
- Grating period d and azimuthal angle θ between the gratings
- Moire pattern is rotated by angle α, if test lens acts as focussing element
- Radius of curvature R or focal length

$$R = \frac{d}{\theta \cdot \tan\alpha}$$



Determination of Best Focus

- Criteria for best focus:

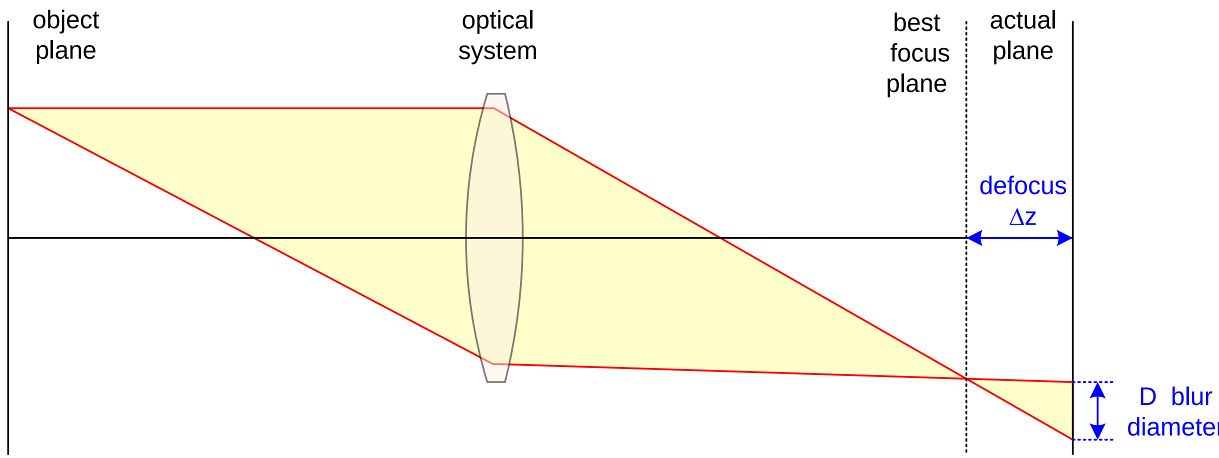
1. Paraxial centre of curvature for the paraxial spherical wave of an on axis object point.
2. Maximum of the Strehl ratio
3. Smallest rms-value of the wave aberration
4. Highest contrast of the modulation of an object feature of given spatial frequency
5. Highest value of the slope of an edge
6. Highest value of the entropy of the detected digital image

- Requirements for focus detection procedure

1. Steep curve dependency to get high accuracy
2. Robust definition to deliver a large dynamic range
3. Suppression of side lobe effects to guarantee an unambiguous solution
4. High frequency pre-filtering to be noise insensitive

Determination of Best Focus

- Blur of defocussed plane



- Minimum of image entropy (w_j is intensity in pixel No j)

$$E = -\sum_j w_j \cdot \log_2 w_j$$

- Maximum of image contrast

Determination of Best Focus

- Measurement by image analysis:

1. Maximum gradient of edges

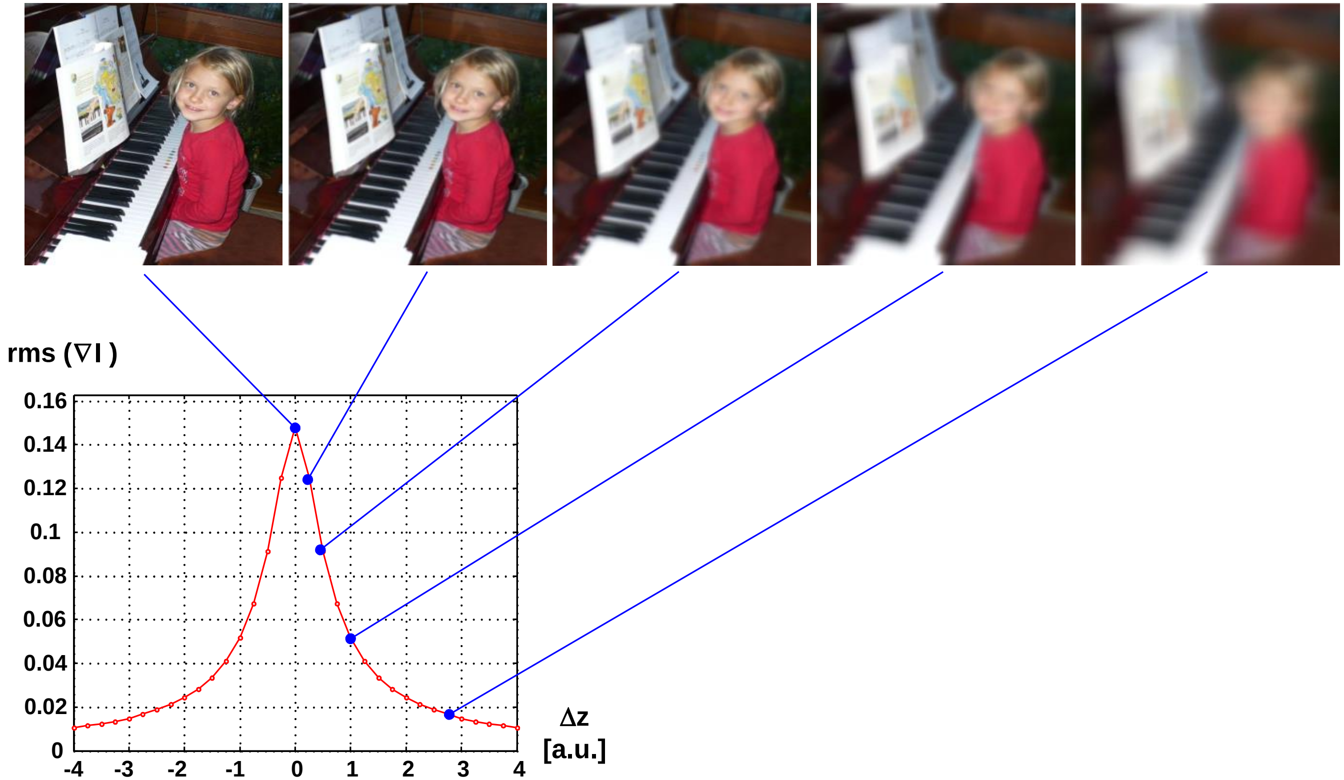
$$g = |\nabla I(x,y)| = \sqrt{\left(\frac{\partial I}{\partial x}\right)^2 + \left(\frac{\partial I}{\partial y}\right)^2}$$

2. Power of gradients

$$G = \iint |\nabla I(x,y)|^2 \, dx\, dy$$

3. Laplacian

$$L = \iint |\nabla^2 I(x,y)|^2 \, dx\, dy$$



Measurement of Transmission

- Reasons for reduced system transmission:
  1. Absorption in the bulk material of the components
  2. Scattering in the bulk materials by inclusions or finite scattering parameters
  3. Absorption in the coatings of the surfaces
  4. Partial reflection or transmission at the coatings at transmissive or reflective surfaces
  5. Blocking of light via mechanical or diaphragm parts of the system due to vignetting
  6. Scattering of light by local surface imperfections or non-perfect polished surfaces
  7. Deflection of light by diffraction of the light at edges
  8. Deflection of light in unwanted higher orders of diffractive elements

- Usually strong dependency on:
  1. field position
  2. wavelength of light
  3. used pupil location
  4. polarization

- Critical:
  1. absolute values for test lens
  2. influence of auxiliary components
  3. change of vignetting and incidence angles

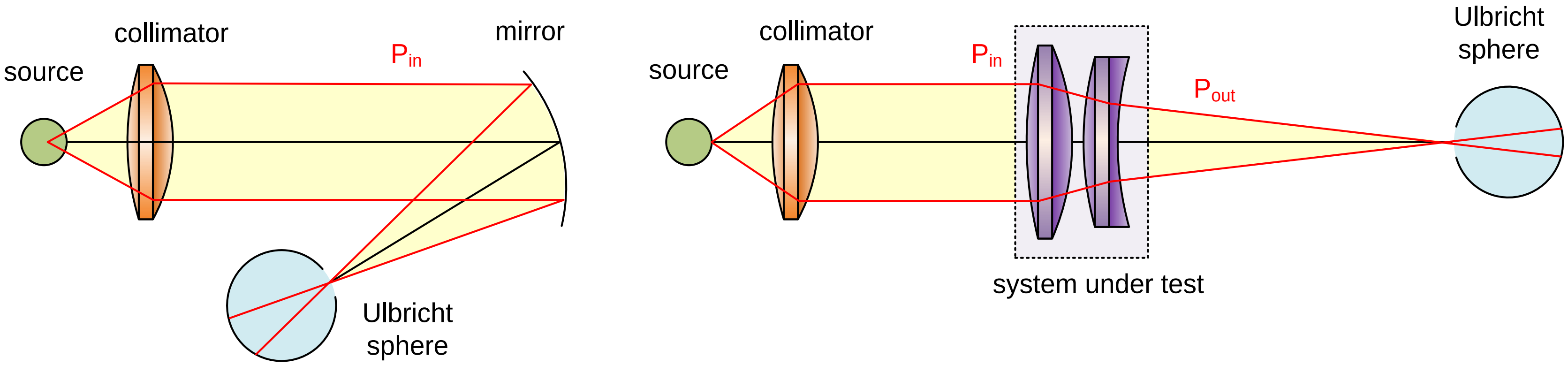
Measurement of Transmission

- Measurement of transmission:

$$T = \frac{P_{out}}{P_{in}}$$

a) Calibration setup

b) Measurement setup



- Reasons for measurement errors:
  1. Absorption in the component materials
  2. Absorption in the coatings
  3. Finite reflectivity of the coatings
  4. Vignetting of the aperture bundle for oblique chief rays
  5. Natural vignetting according for oblique chief rays and projection of tilted planes
  6. False light from surrounding light sources, which reach the image plane
  7. Scattering of light at components of the system mechanical design
  8. False light due to ghost images or narcissus in infrared systems

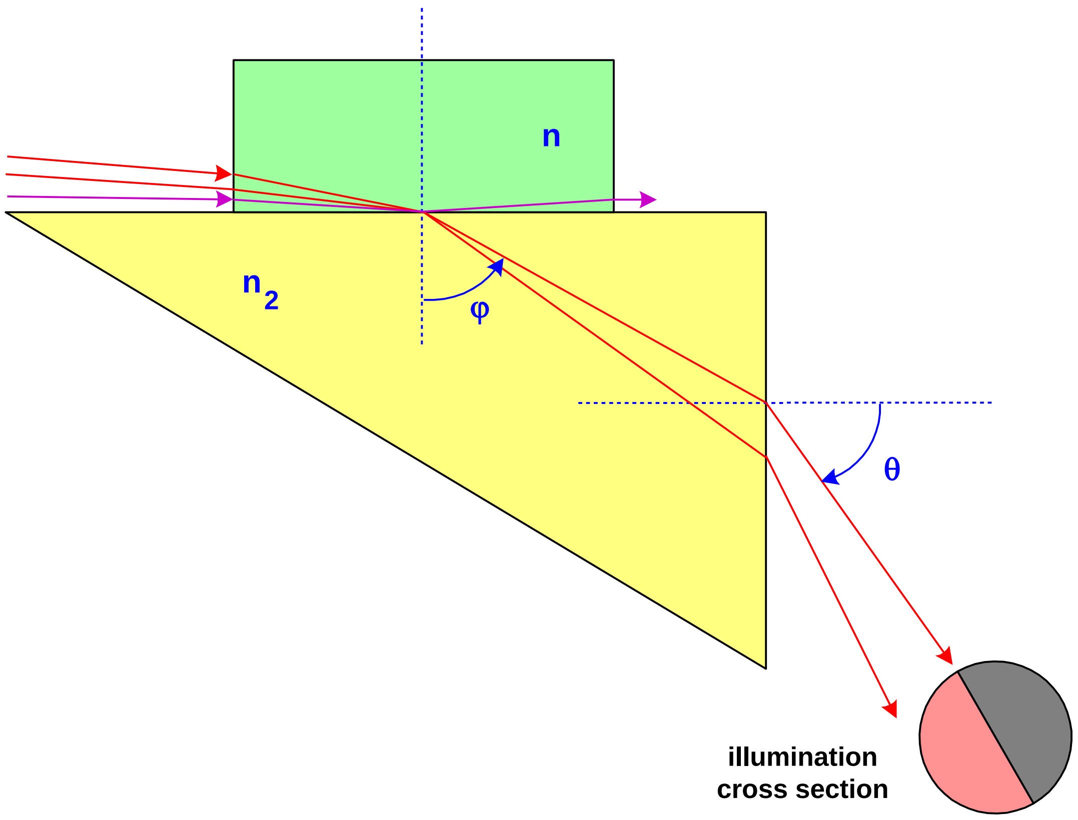
Pulfrich-Refractometer for Index Measurement

- Testsample plate on prism
- Near gracing incidence,
  measurement of total internal reflection at interface
- Sharp shadow boundary of transmitted light beam
- Evaluation

$$\sin\theta = n_2 \cdot \cos\varphi$$

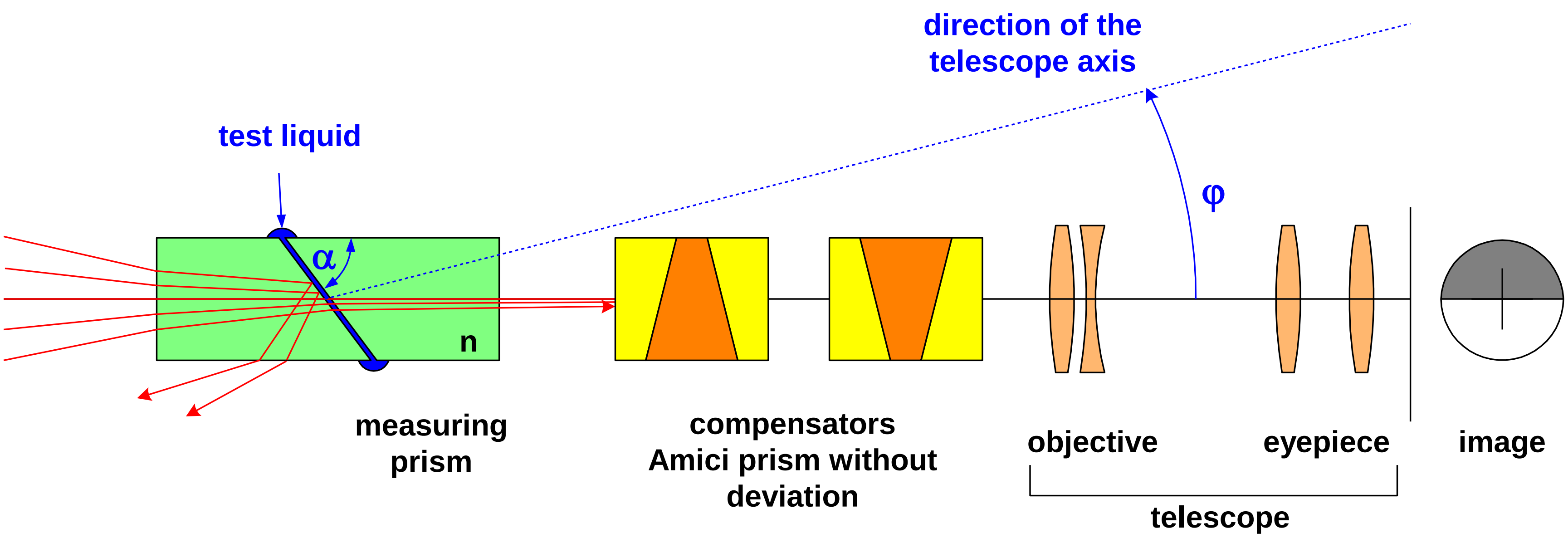
$$n = n_2 \cdot \sin\varphi$$

$$n = \sqrt{n_2^2 - \sin^2\theta}$$



Abbe Refractometer

- Measurement of the refractive index of a liquid
- Thin film of test liquid between prisms,
  adjustment of total internal reflection
- Special setup with direct sight prisms, no color fringes



Töplers Method for Striae Measurement

- Measurement of striae and index inhomogeneities at a plane plate
- Dark field method:
  - direct light blocked
  - deviated and scattered light reaches the camera