Institute of Applied Physics
Friedrich-Schiller-Universität Jena

Metrology and Sensing

Lecture 6-3: Wavefront sensors

2020-12-08

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Content

Miscellaneous methods

- Knife and slit scan
- General filter approach
- Ronchi method

Knife Edge Method

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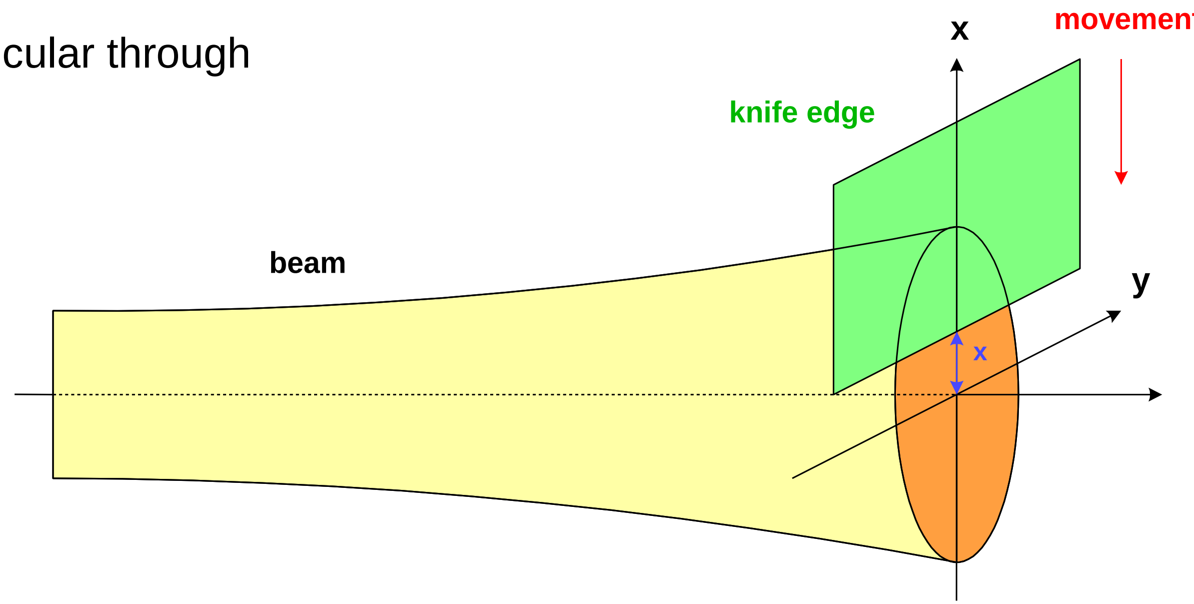
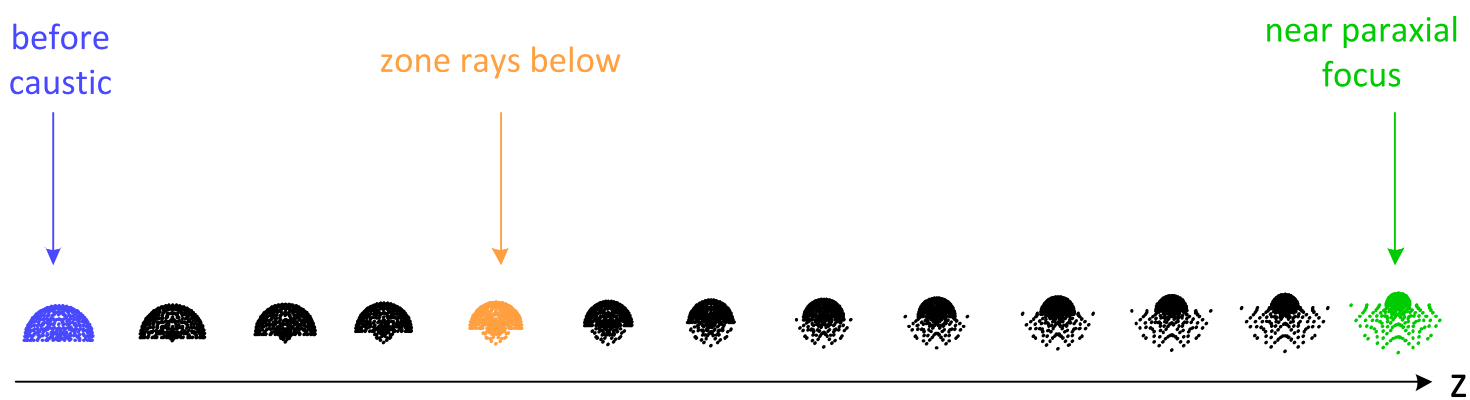
- Moving a knife edge perpendicular through the beam cross section

- Relationship between power transmission and intensity: Abel transform for circular symmetry

$$P(x) = 2\int_x^\infty \int_\xi^\infty \frac{I(r)\,r\,dr}{\sqrt{r^2-\xi^2}}\,d\xi$$

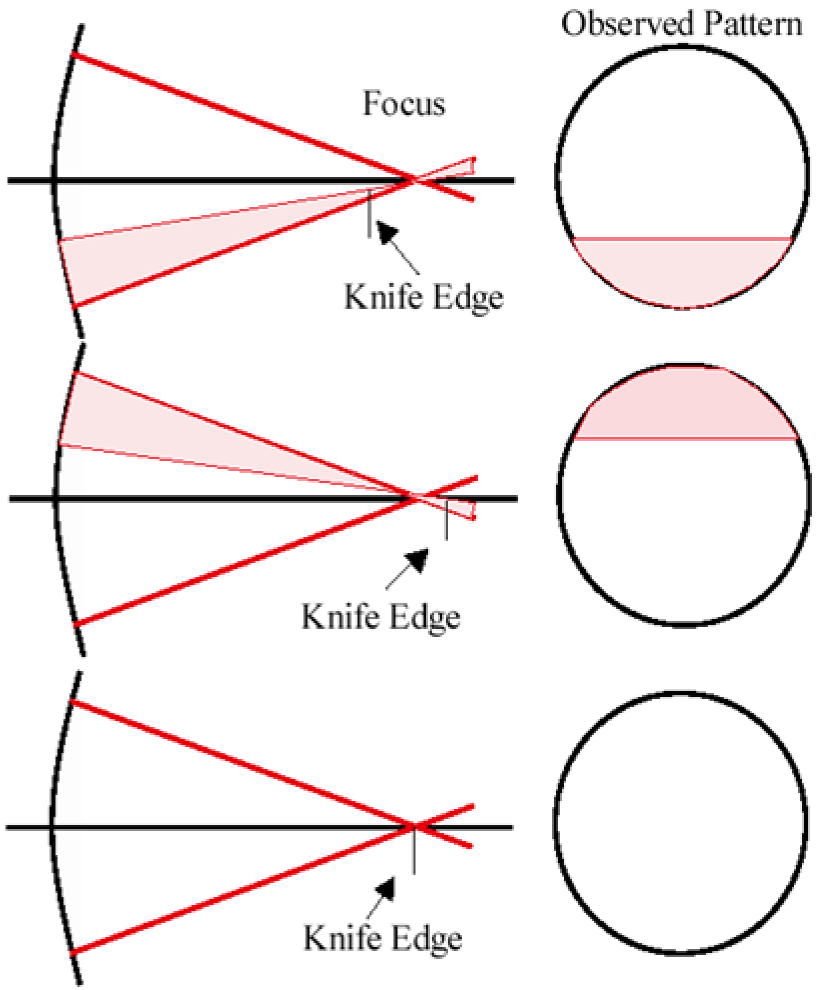


- Example: geometrical spot with spherical aberration



Indirect Wavefront Sensing

- Foucault knife edge method



Knife Edge Test

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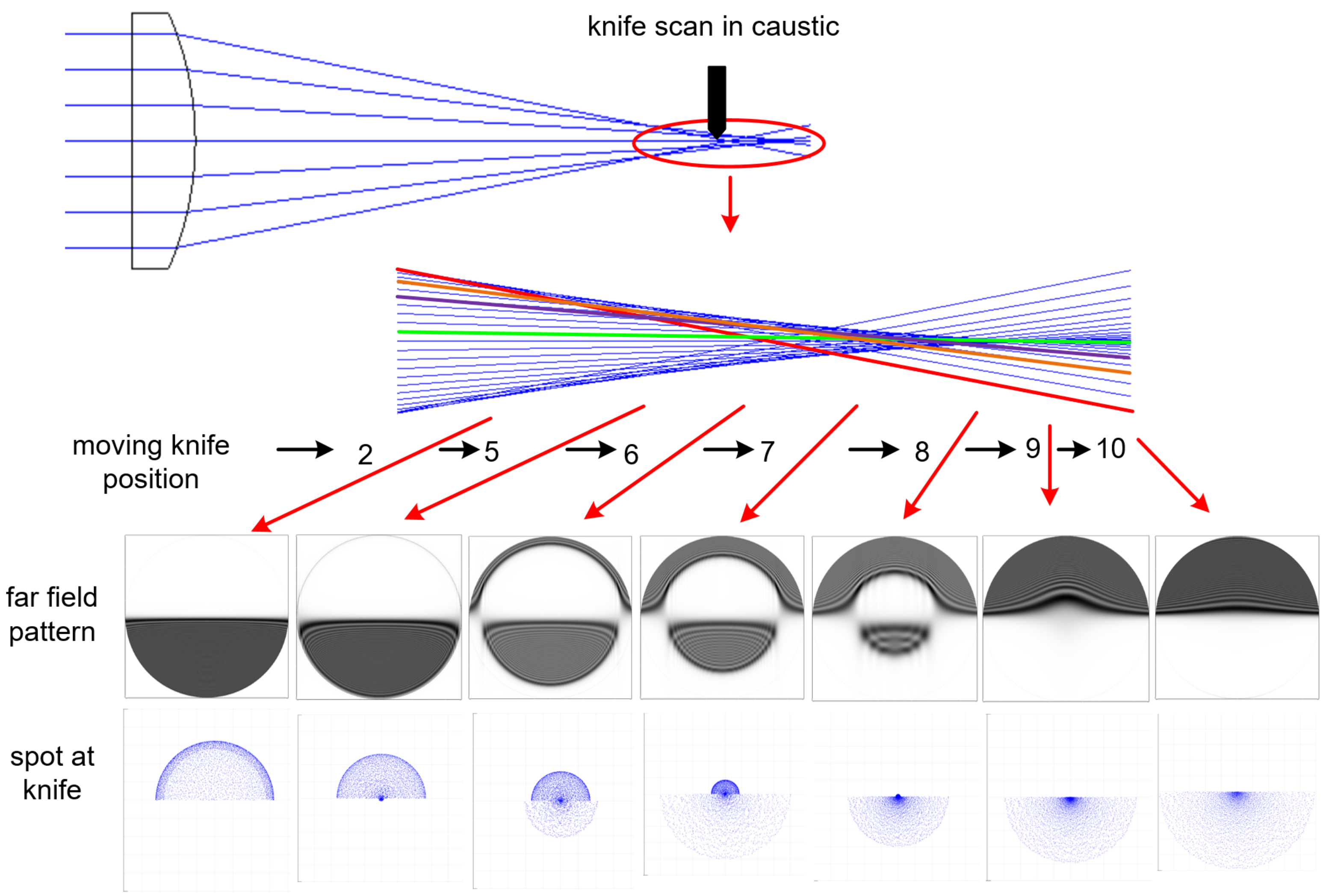
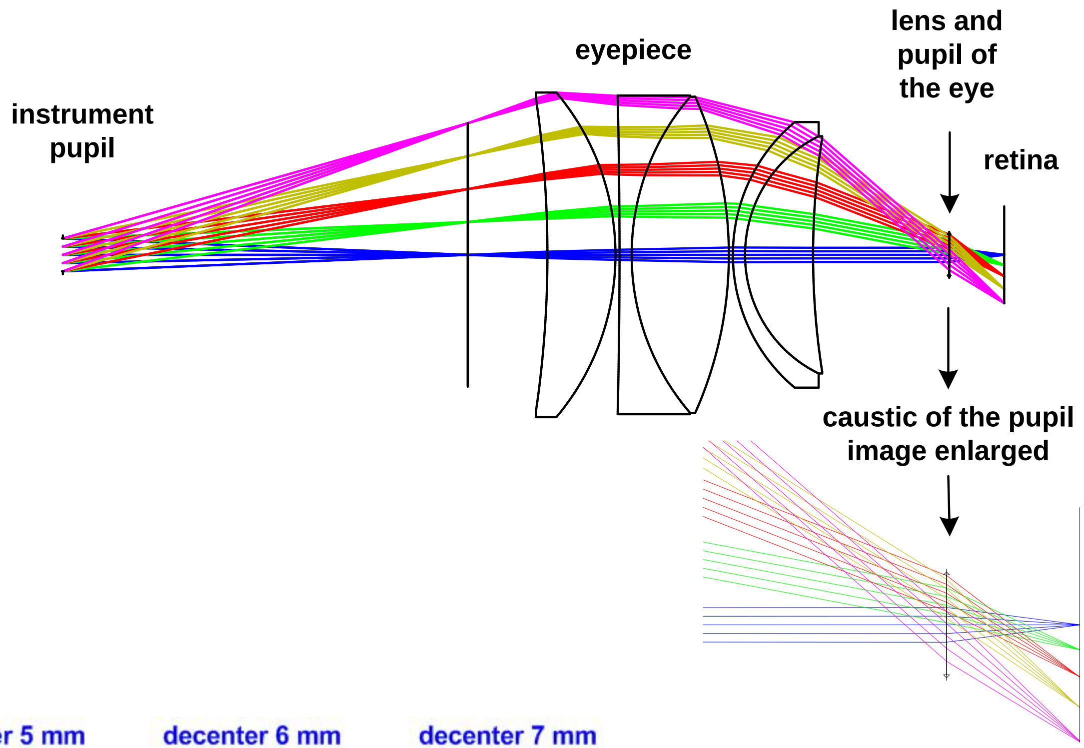
- Caustic in case of spherical aberration

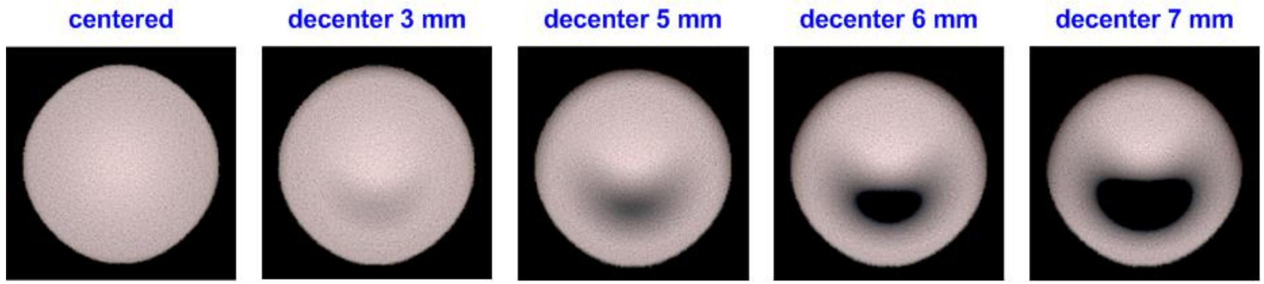


Zonal Aberration

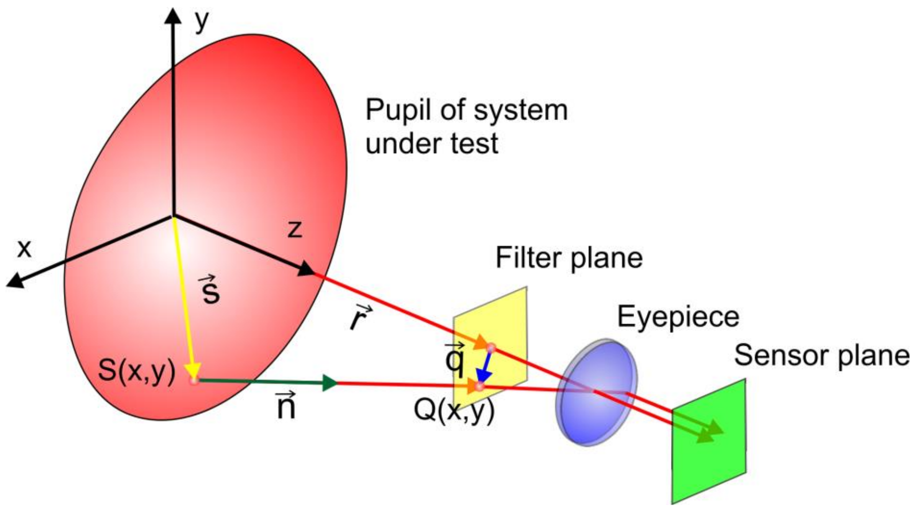
- Eyepiece with strong zonal pupil aberration



- Illumination for decentered pupil :
  dark zones due to vignetting
  Kidney beam effect



Filter Techniques



- Idea:
  Wave under test E(x,y) is passing a complex filter F(x,y)

$$F(x,y) = T(x,y) \cdot e^{i\psi(x,y)}$$

- The transmitted field E'(x,y) is given in the far field as Fourier transform by

$$E'(x,y) = \int_{y_q=-\infty}^{\infty} \int_{x_q=-\infty}^{\infty} F(x_q,y_q) \cdot E(x_q,y_q) \cdot e^{i2\pi \frac{x_q x + y_q y}{\lambda \cdot r}} dx_q dy_q$$

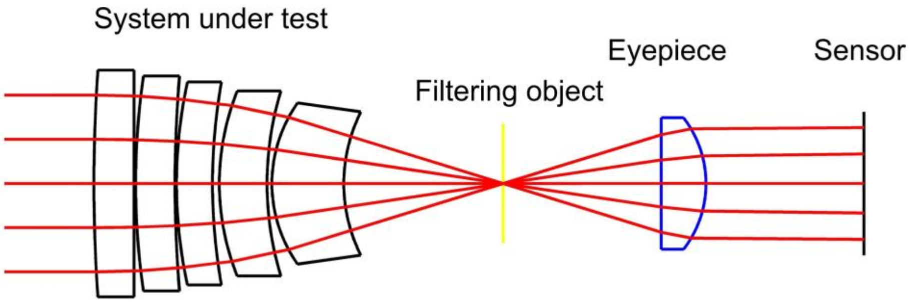
- The filter can modify the field by:
  1. the amplitude by T(x,y)
  2. the phase by Ψ(x,y)
  with different geometries

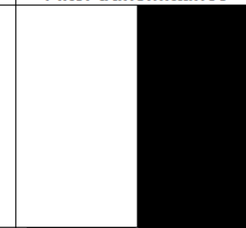
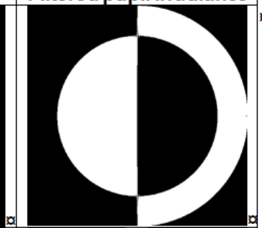
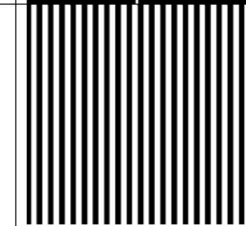
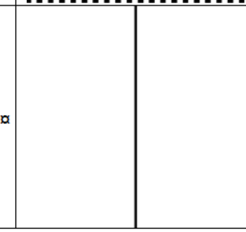
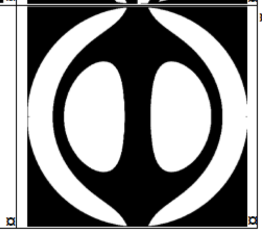
- A corresponding reconstruction algorithm allows to recover the desired information of the field E(x,y)

Ref: B. Dörband

General Filter Techniques

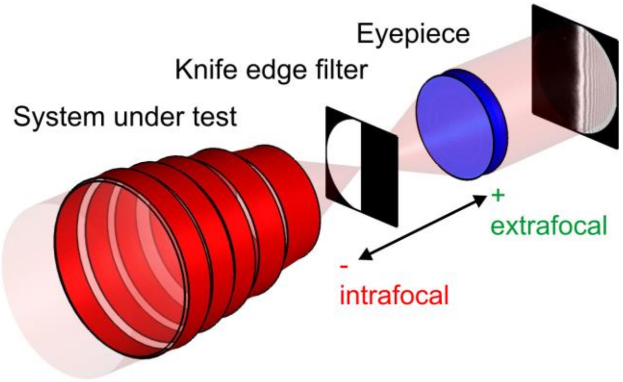
- Generalized concept: filtering the wave
- Realizations:
  1. Foucault knife edge
  2. slit
  3. Toepler schlieren method
  4. Ronchi test
  5. wire test
  6. Lyot test (λ/4 wire)

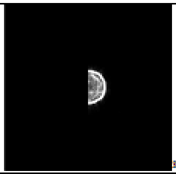
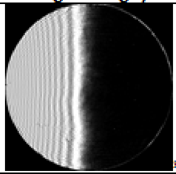
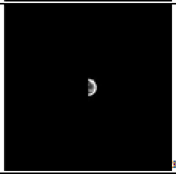
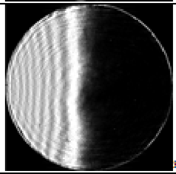
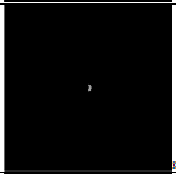
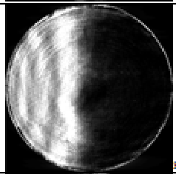
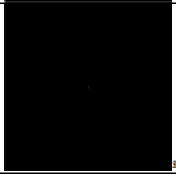
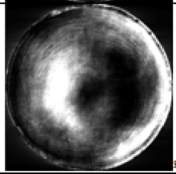
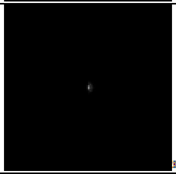
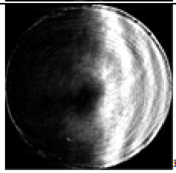
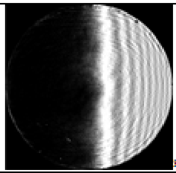
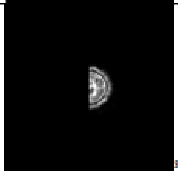
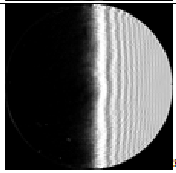


	Filter function	Filter transmittance	Filtered pupil irradiance
(a) Foucault knife edge test	$T(x,y)=\begin{cases}0 & x<0\\ 1 & x\geq 0\end{cases}$		
(b) Toepler Schlieren test	$T(x,y)=\begin{cases}0 & \lvert x\rvert>\frac{b}{2}\\ 1 & \lvert x\rvert\leq\frac{b}{2}\end{cases}$		
(c) Ronchi test	$T(x,y)=rect(2\pi b)$		
(d) Wire test	$T(x,y)=\begin{cases}0 & \lvert x\rvert\leq\frac{b}{2}\\ 1 & \lvert x\rvert>\frac{b}{2}\end{cases}$		

General Filter Techniques

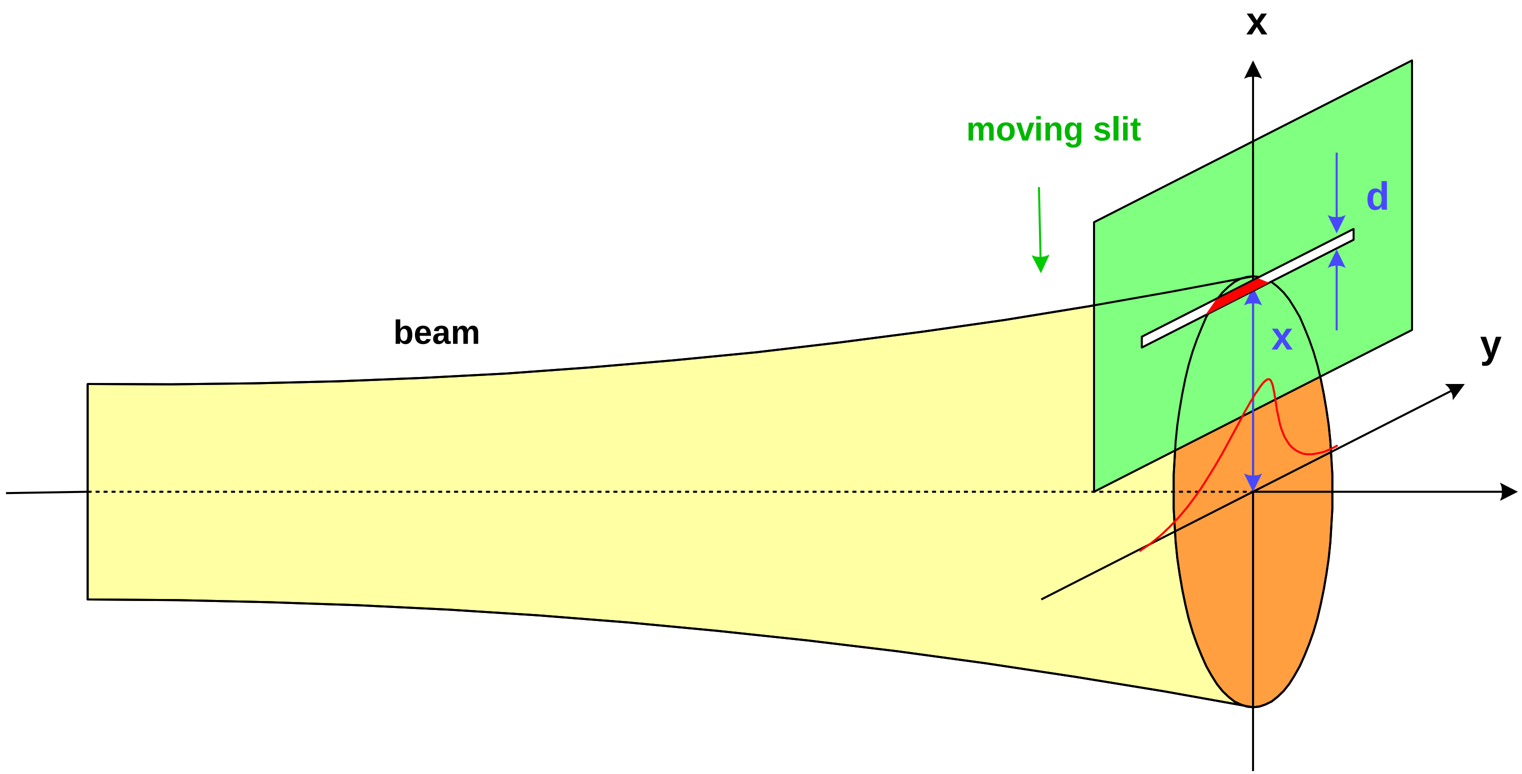
- Knife edge filter for defocussing
- Changing intensity distribution as a function of the filter position



Position of knife edge	Irradiance in knife edge plane	Image in sensor plane (knife edge image)
–10000 nm defocus		
–5000 nm defocus		
–2000 nm defocus		
0 nm defocus		
+2000 nm defocus		
+5000 nm defocus		
+10000 nm defocus		

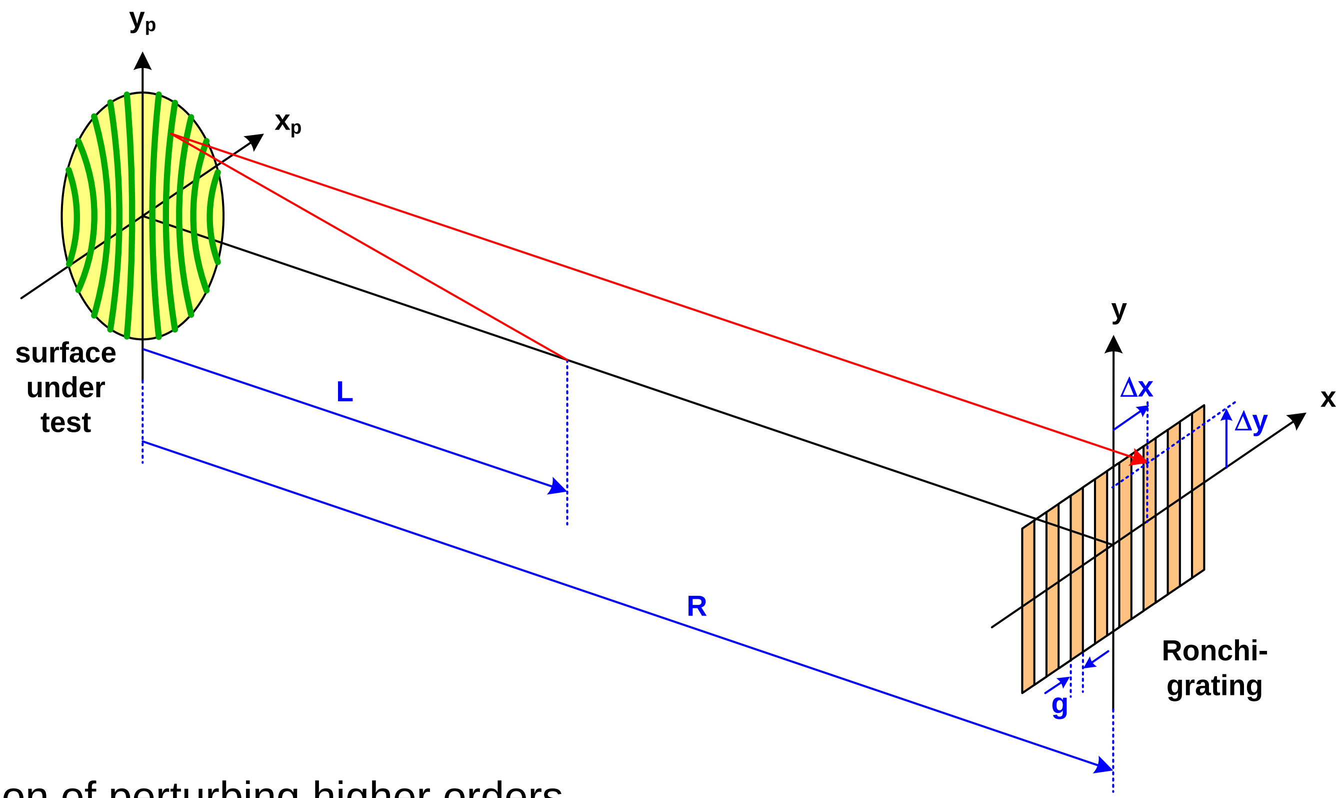
Slit-Scan-Method

- Method very similar to moving knife edge
- Integration of slit length must be inverted:
  - inverse Radon transform
  - corresponds to tomographic methods



Ronchi Method

- Setup:
  - simple rectangular linear grating
  - corresponds to classical fringe projection



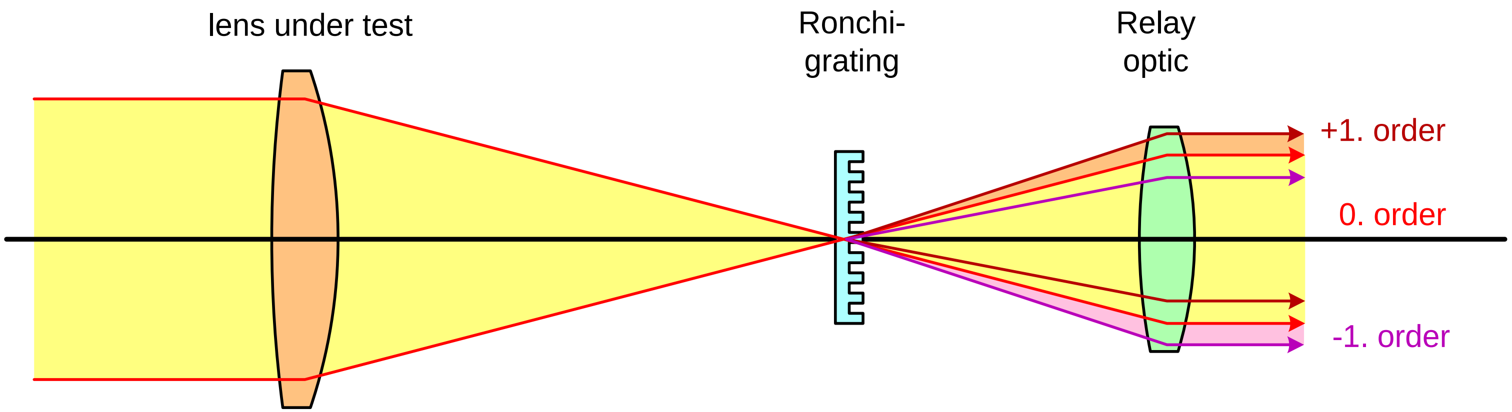
- Problem: superposition of perturbing higher orders

Ronchi Method

- Measurement of surfaces by fringe deformation
- Grating creates reference: fringe of 1st order after Ronchi grating
- Evaluation of the lateral aberrations of the wavefront by

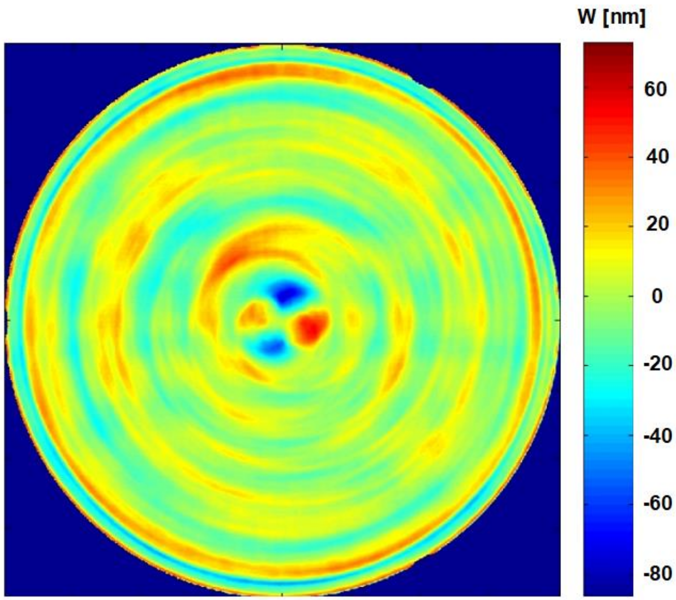
$$\frac{\partial W}{\partial x_p} = -\frac{\Delta x}{R} \quad , \quad \frac{\partial W}{\partial y_p} = -\frac{\Delta y}{R}$$

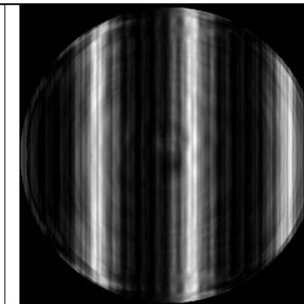
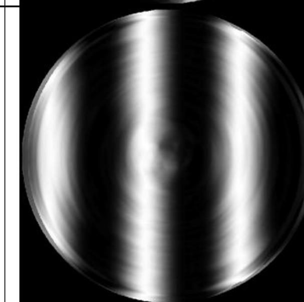
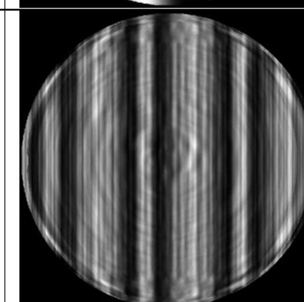
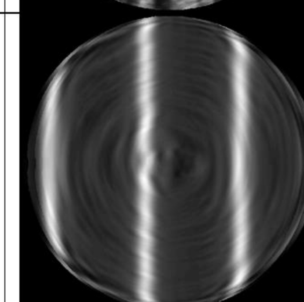
- Explanation geometrical or wave-optical



Ronchi Test Filters

- Filter function is a linear grating
- Different realizations:
  1. amplitude or phase
  2. rectangular or sinusoidal variation
- Example images of a Ronchi test for the following wavefront



Ronchi test (rectangular amplitude grid)	$T(x,y) = \frac{1+sign(\cos(2\pi bx))}{2}$ $\psi(x,y) = 0$	
Ronchi test (sinusoidal amplitude grid)	$T(x,y) = \frac{1+\cos(2\pi bx)}{2}$ $\psi(x,y) = 0$	
Ronchi test (rectangular λ/2 phase grid)	$T(x,y) = 0$ $\psi(x,y) = i\pi \frac{1+sign(\cos(2\pi bx))}{2}$	
Ronchi test (sinusoidal λ/2 phase grid)	$T(x,y) = 0$ $\psi(x,y) = i\pi \frac{1+\cos(2\pi bx)}{2}$	

Ref: B. Dörband

Ronchi Method

- Ronchi pattern of low order aberrations
- Complex evaluation of patterns