OPTICAL DESIGN

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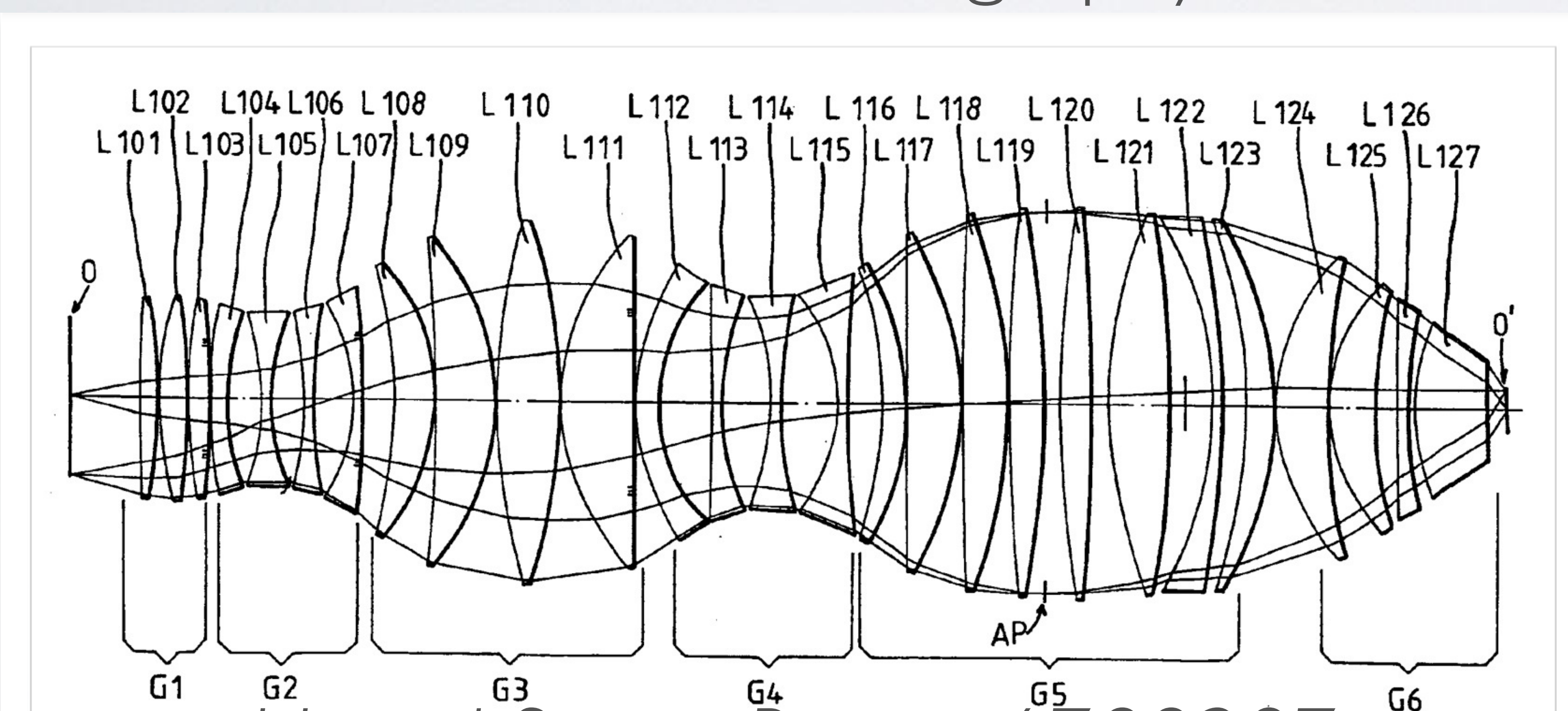
State-of-the-art Lithography Lens



United States Patent 6788387

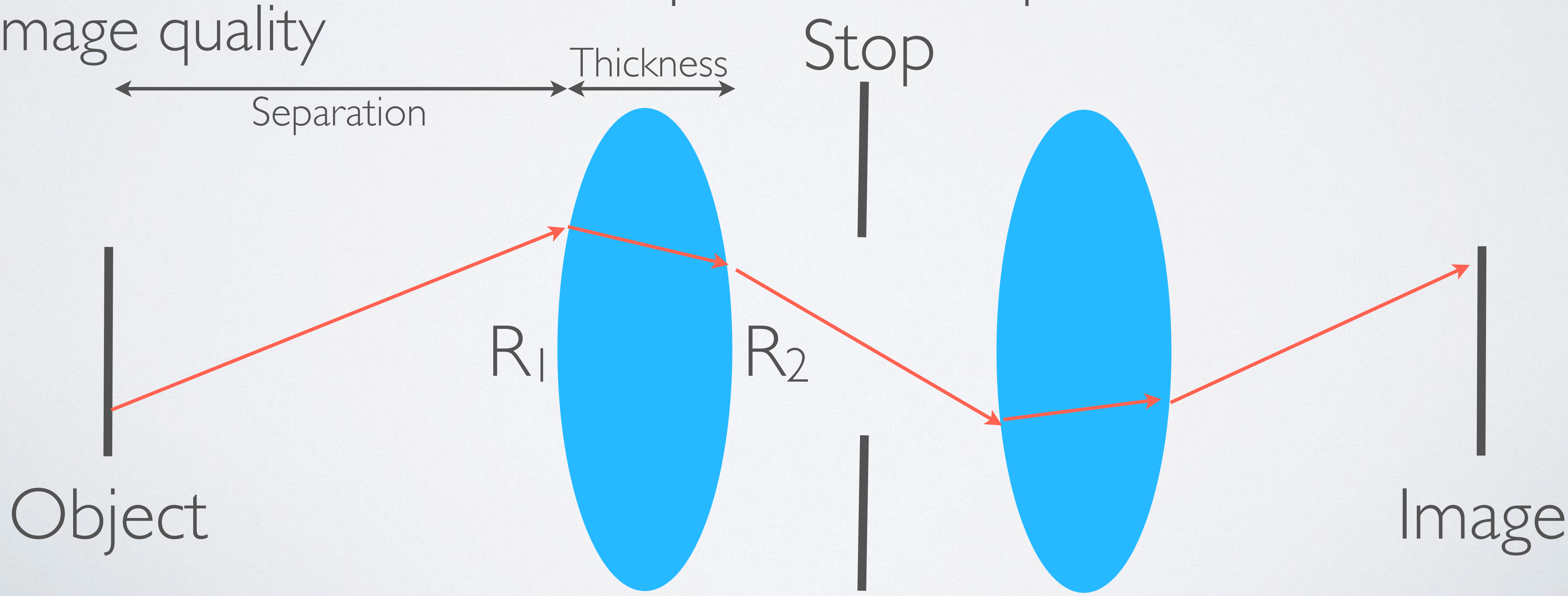
Credit: Nature Pub

WHERE DO YOU START?

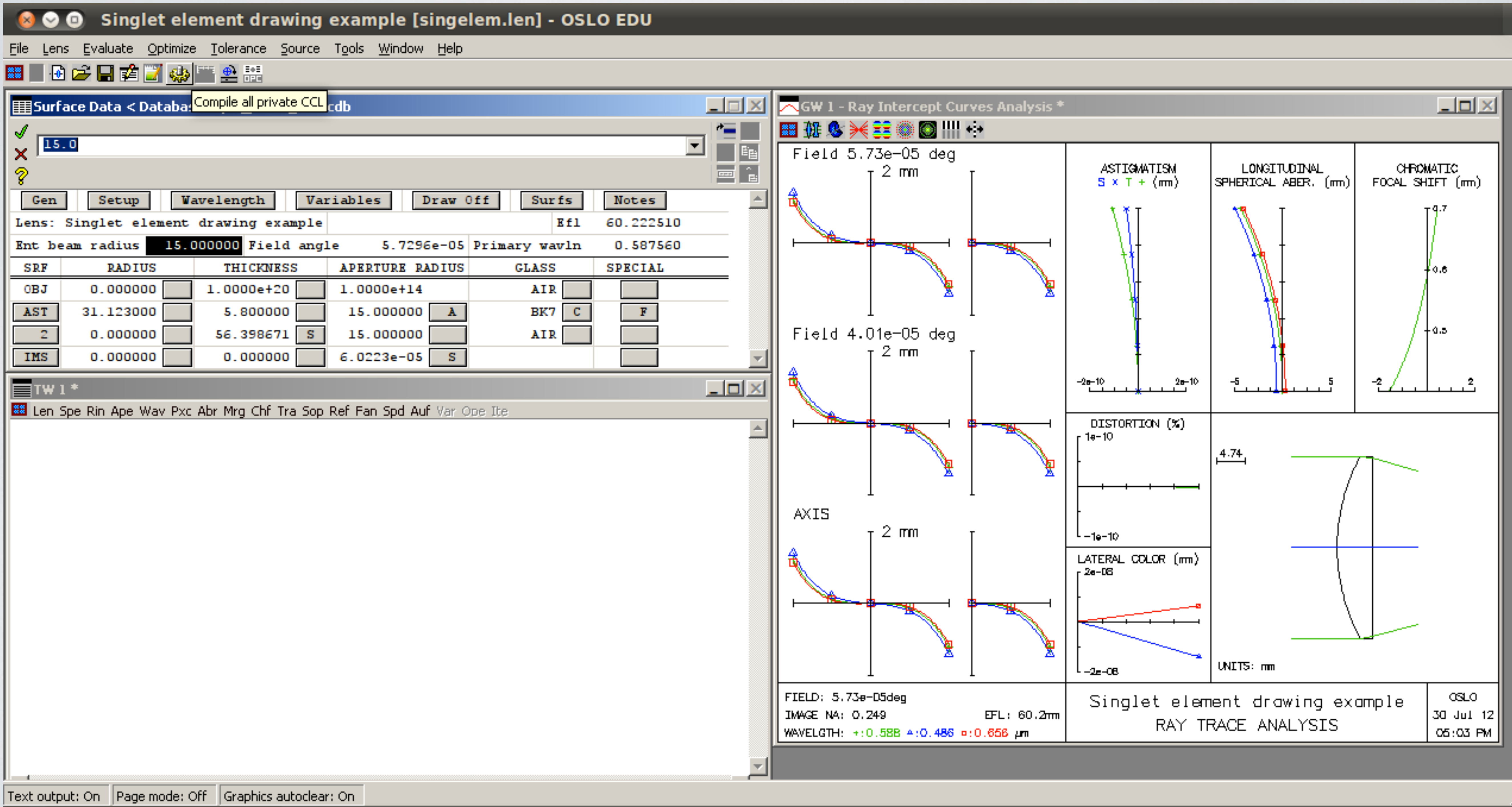
- System Requirements:
  - Field-of-view
  - Resolution
  - Wavelength
  - Sensitivity
  - Mechanical Constraints
  - Environment
- Other Considerations:
  - Cost
  - Timescale
  - Complexity
  - Manufacturability

LENS DESIGN SOFTWARE

- Ray trace codes (e.g. Zemax, Code V, OSLO) that trace rays through optical systems to determine their performance
- They use sequential ray tracing to determine optical parameters
- One can evaluate various performance parameters such as image quality



OSLO-EDU



Optics Software for Layout and Optimization

INPUT FORMAT

Gen | Setup | Wavelength | Variables | Draw Off | Surfs | Notes

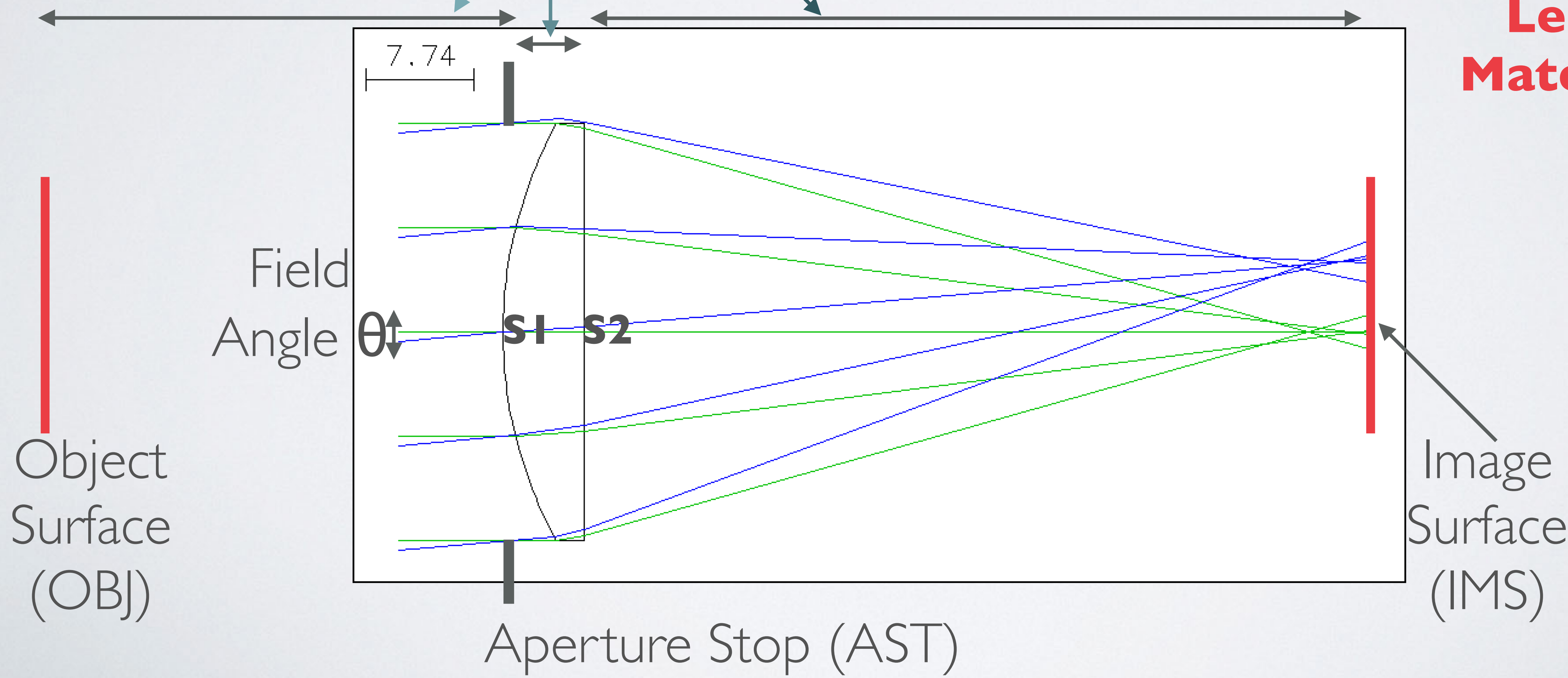
Lens: Singlet element drawing example — Efl 60.222510

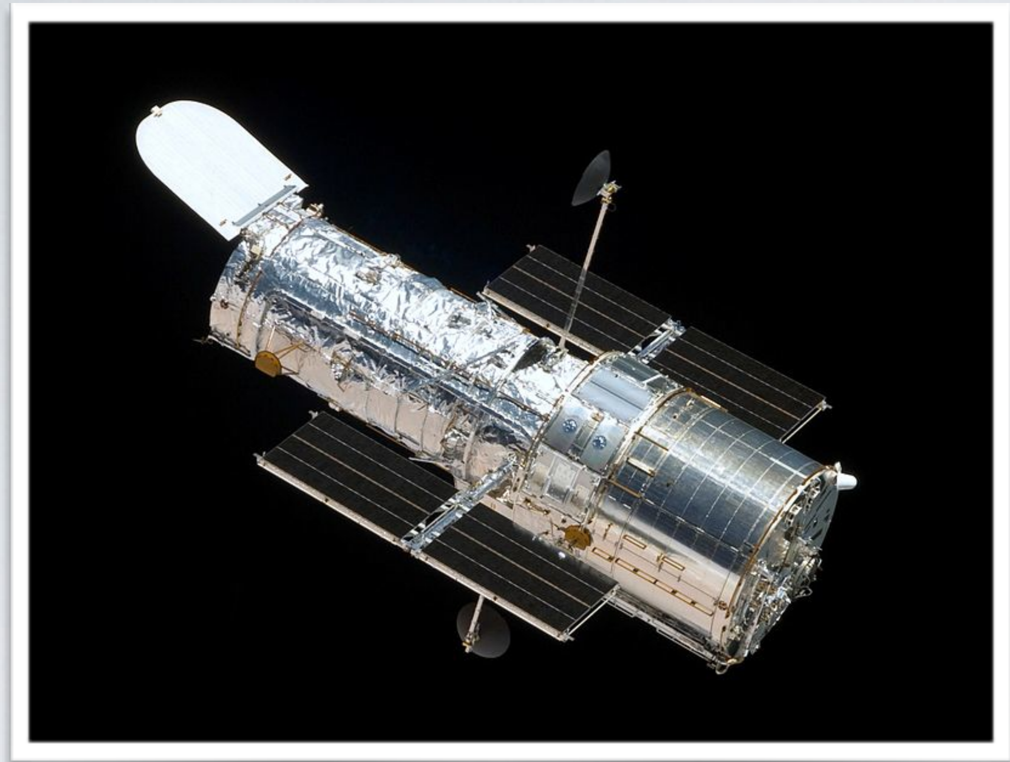
Ent beam radius 15.000000 Field angle 5.000000 Primary wavln 0.587560

SRF	RADIUS		THICKNESS		APERTURE RADIUS		GLASS		SPECIAL
OBJ	0.000000		1.0000e+20		8.7489e+18		AIR		
AST	31.123000		5.800000		15.000000	A	BK7	C	F
2	0.000000		56.398671	S	15.000000		AIR		
IMS	0.000000		0.000000		5.268787	S			

LENS S1 S2

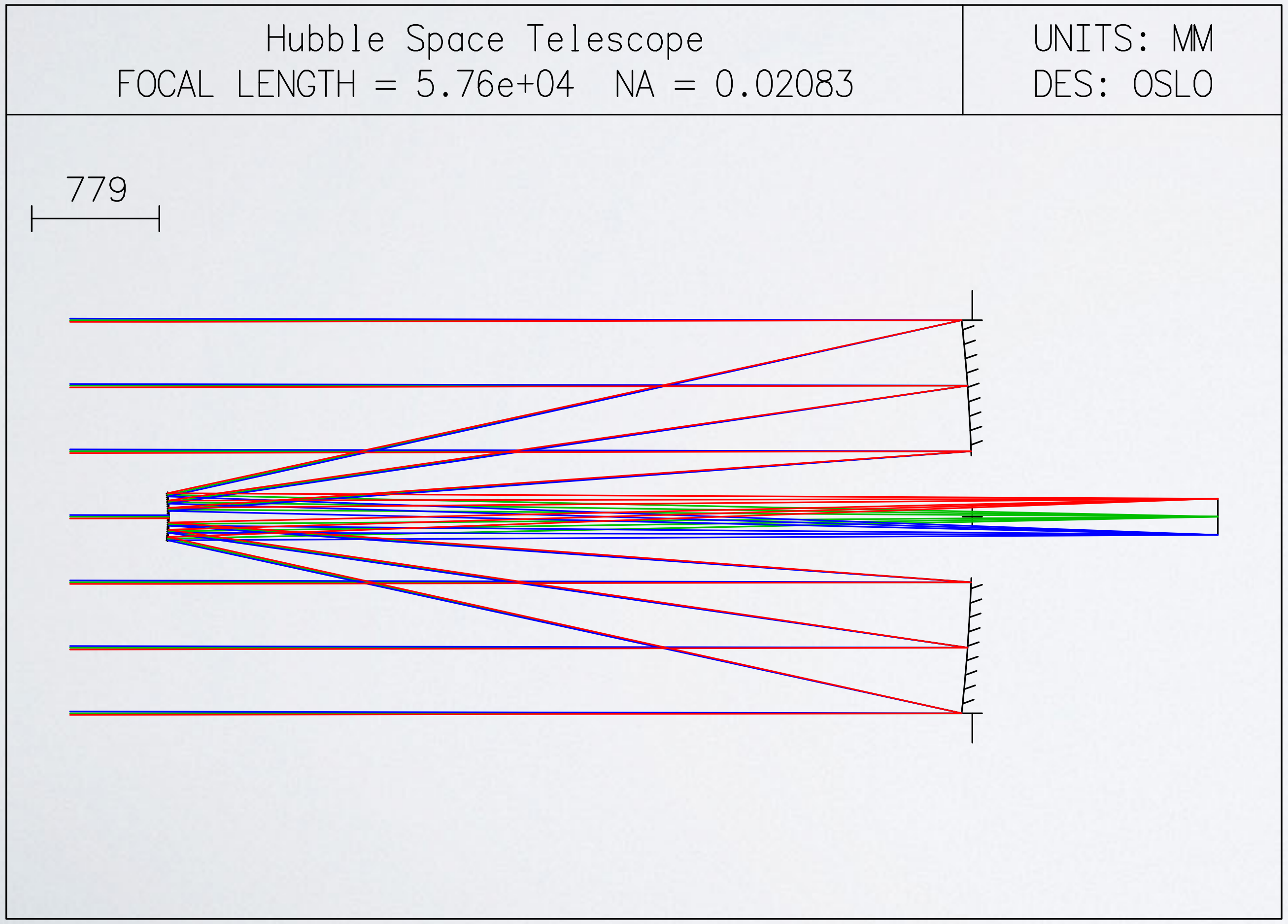
Lens Material



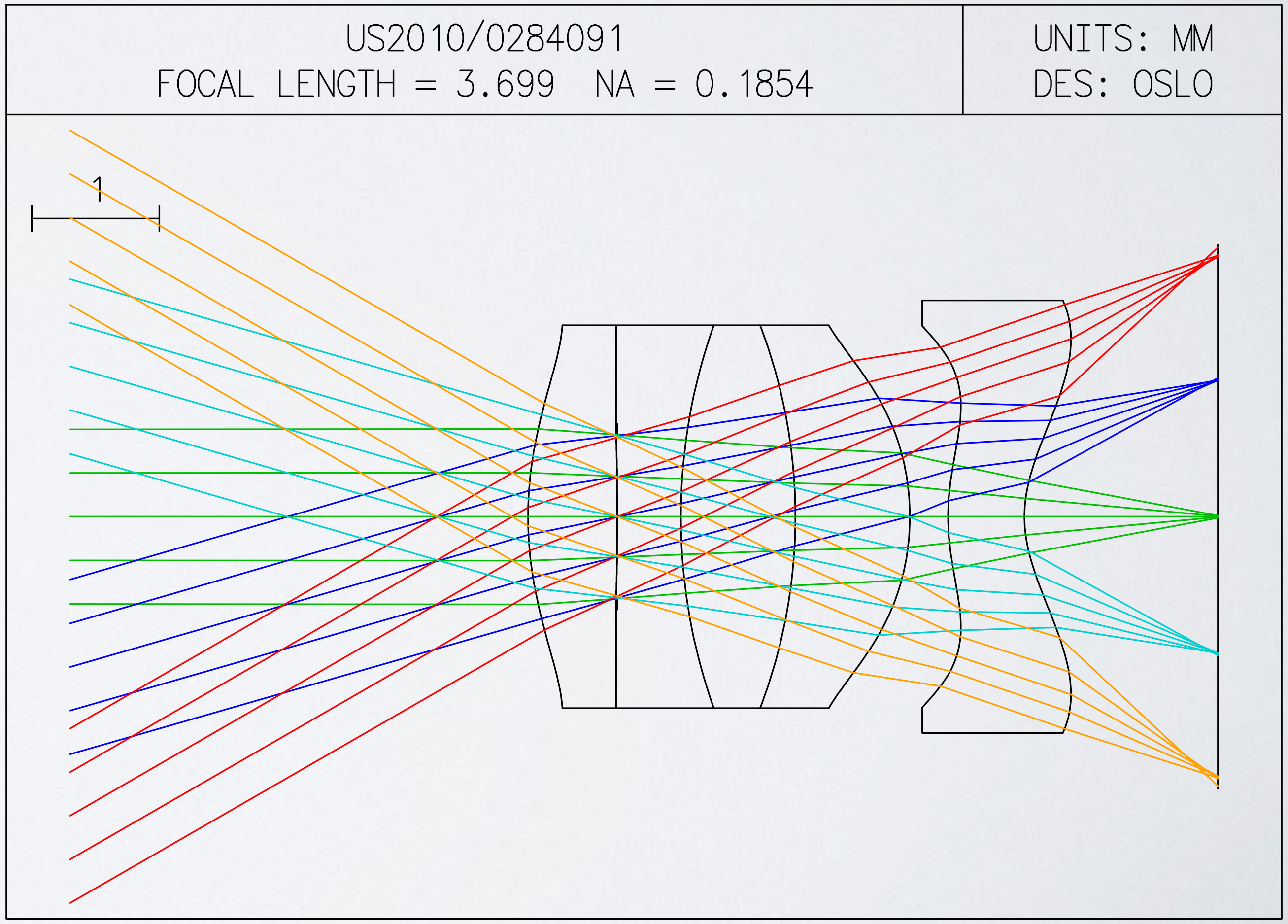


(Credit: Wikipedia)

Cellphone Camera
(Credit: Carl Zeiss)



Hubble Space Telescope



Sony Cellphone Camera Patent

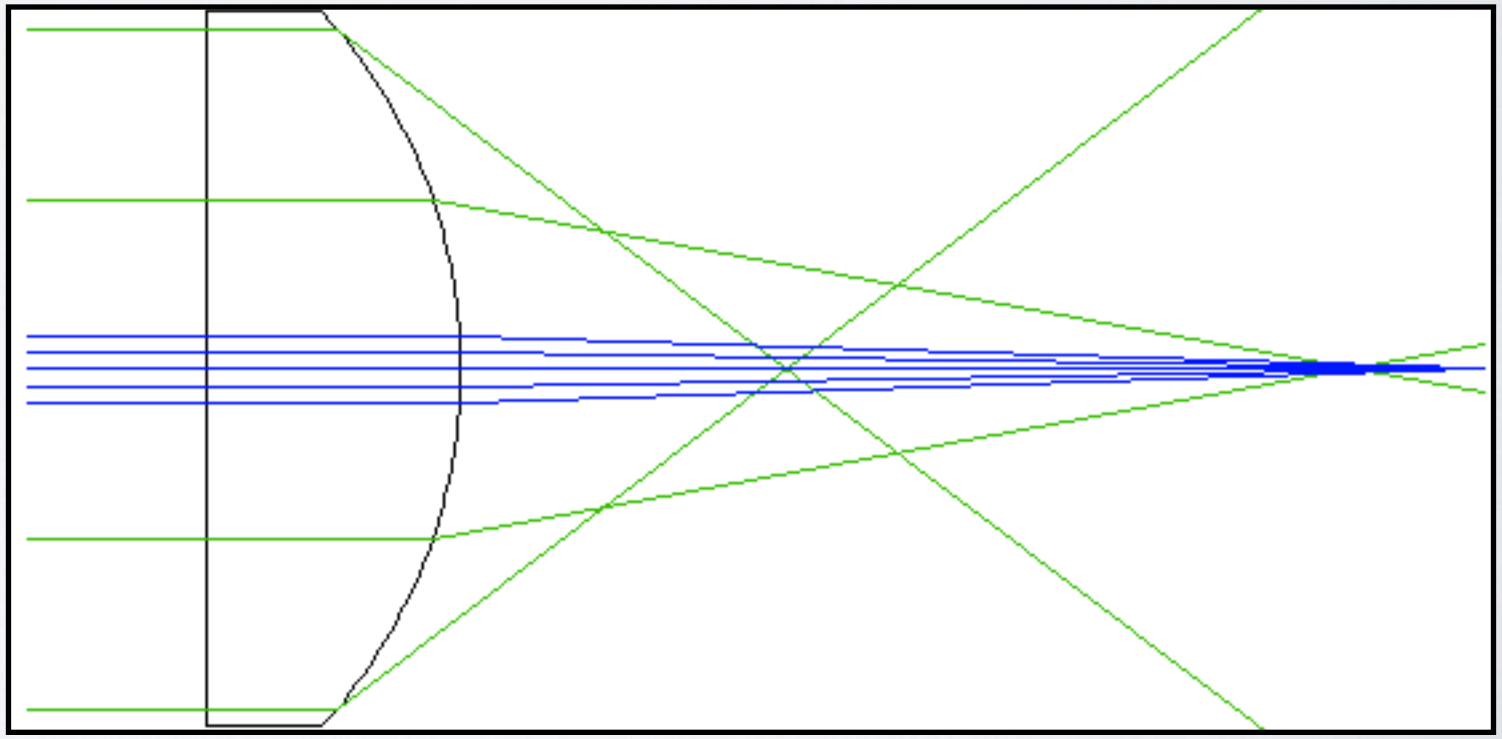
3RD ORDER OPTICS

$$\sin\theta = \boxed{\theta} - \boxed{\frac{\theta^3}{3!}} + \frac{\theta^5}{5!} \quad \ldots$$

Paraxial Optics
(1st order)

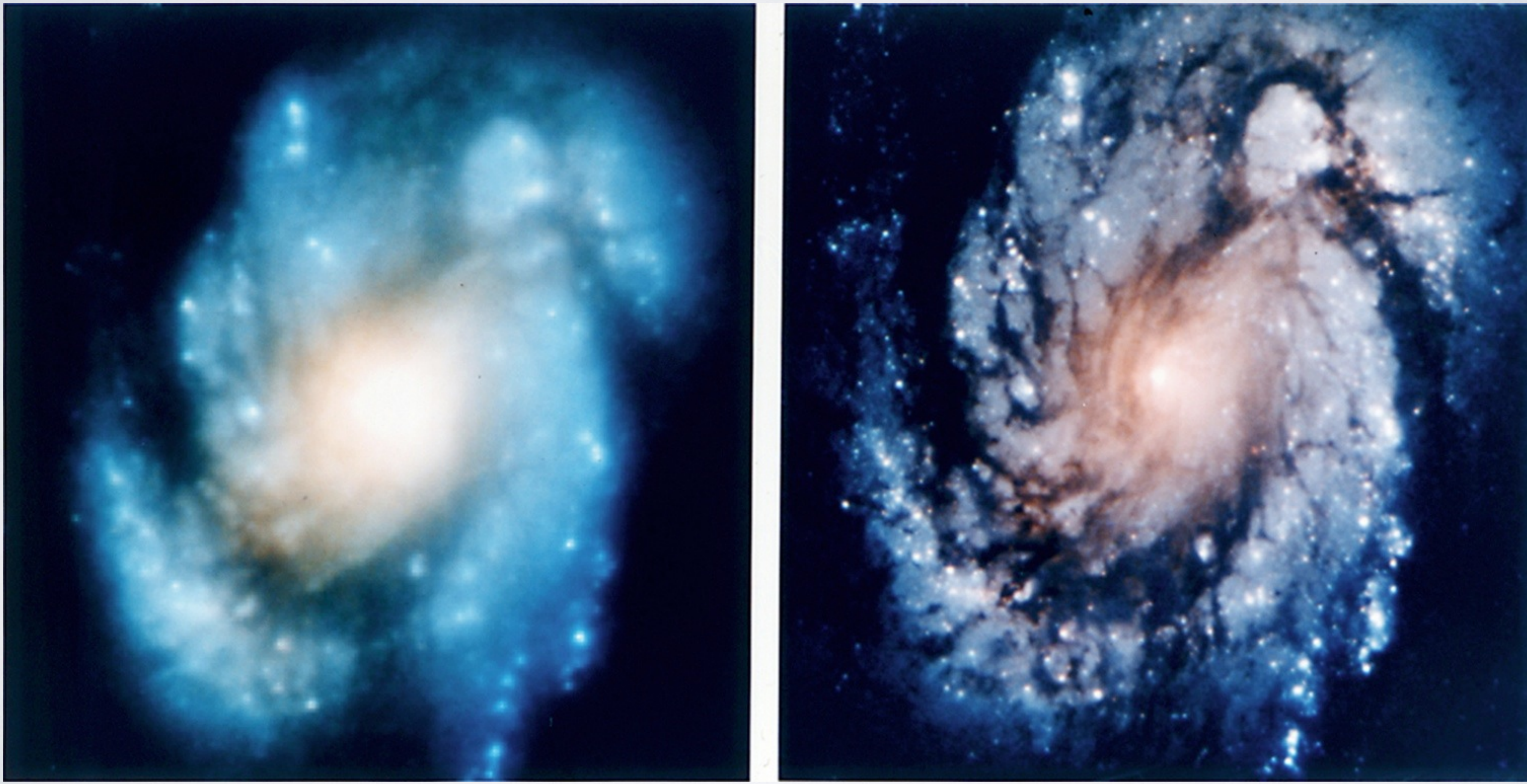
Geometric Aberrations
(3rd order)

- If you use spherical surfaces, the paraxial approximation breaks down at larger incident angles, which produces optical aberrations



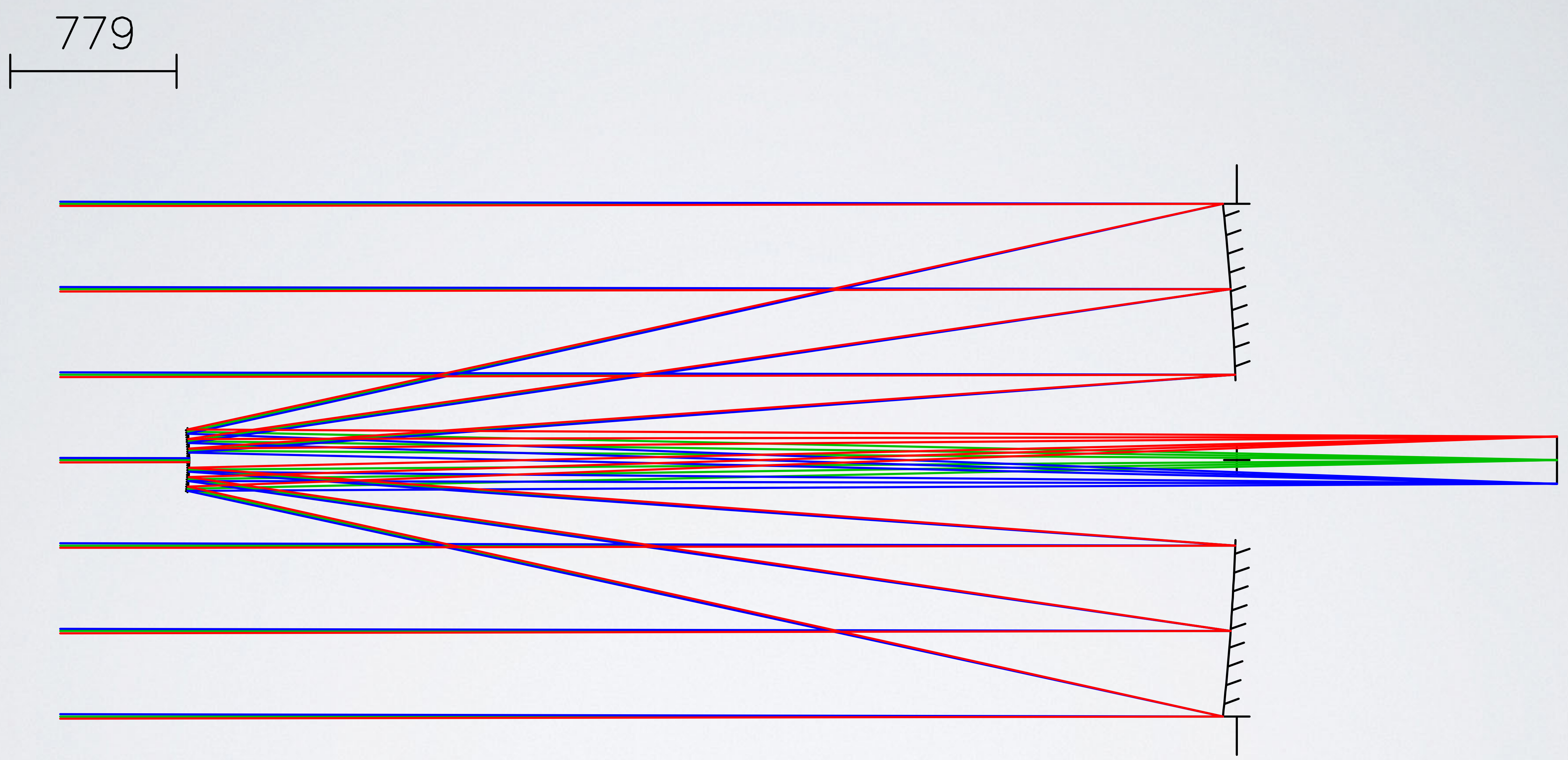
f/1.5 spherical planoconvex lens

OPTICAL ABERRATIONS



Well-defined formalism exists that predicts optical performance

Hubble Space Telescope FOCAL LENGTH = 5.76e+04 NA = 0.02083	UNITS: MM DES: OSLO



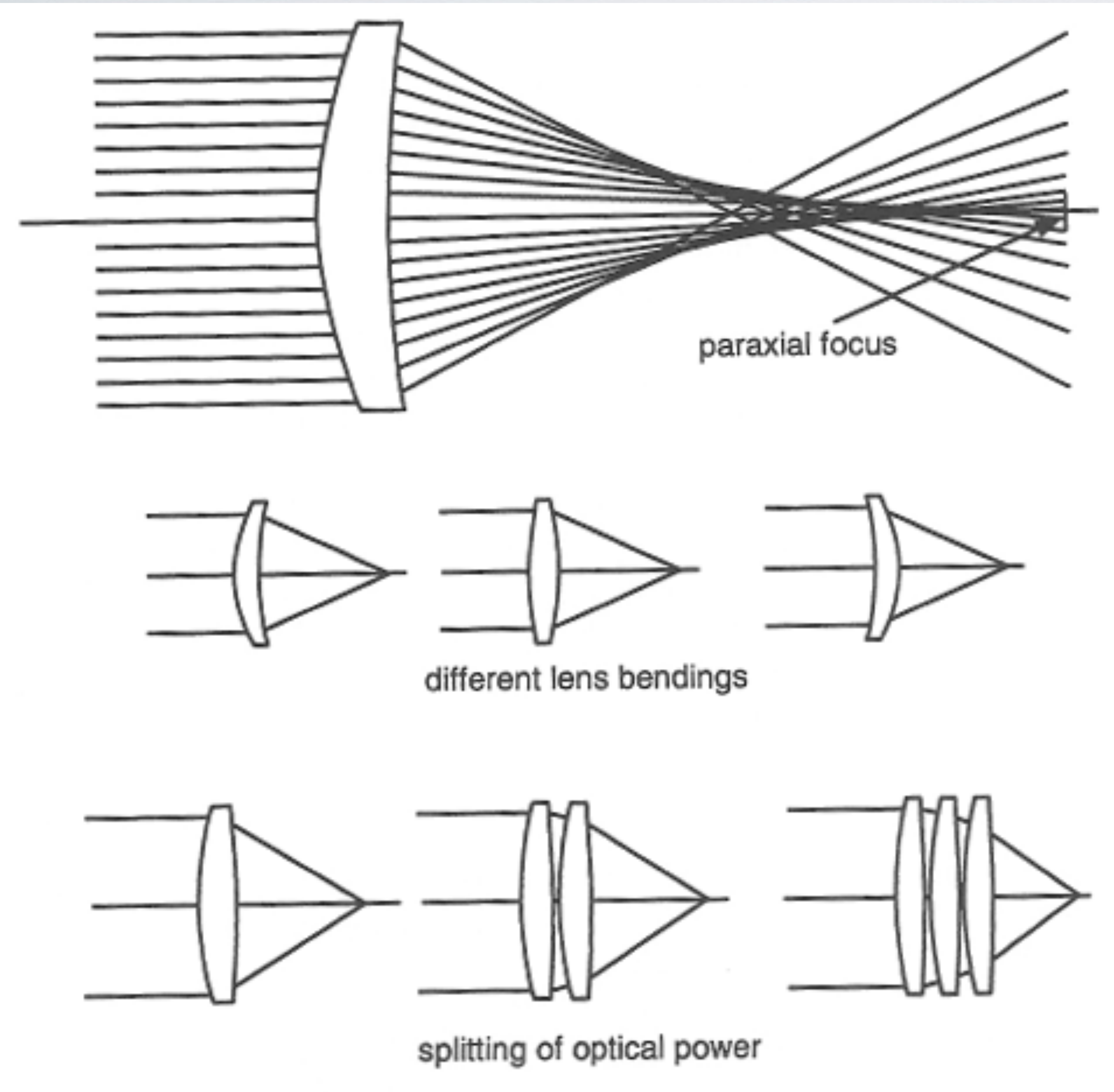
ABERRATIONS

- MONOCHROMATIC ABERRATIONS
  - Spherical
  - Coma
  - Field Curvature
  - Astigmatism
  - Distortion

- CHROMATIC ABERRATIONS
  - Axial Colour
  - Lateral Colour

Seidel Aberrations

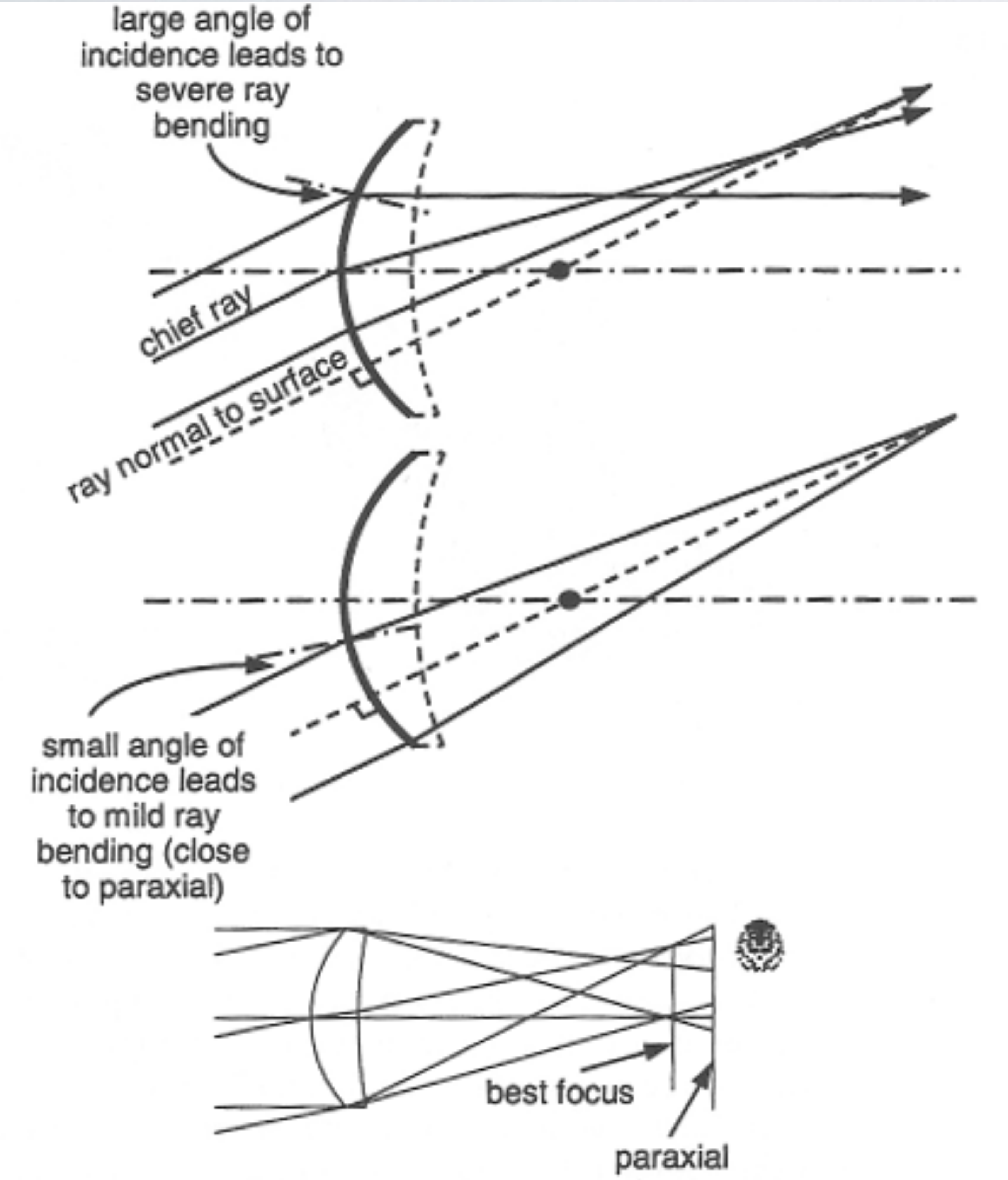
SPHERICAL ABERRATION



Credit: Optical System Engineering

- Field independent aberration
- Strong function of f/#
- Methods of reduction
  - Slow optics
  - Lens bending
  - Lens splitting

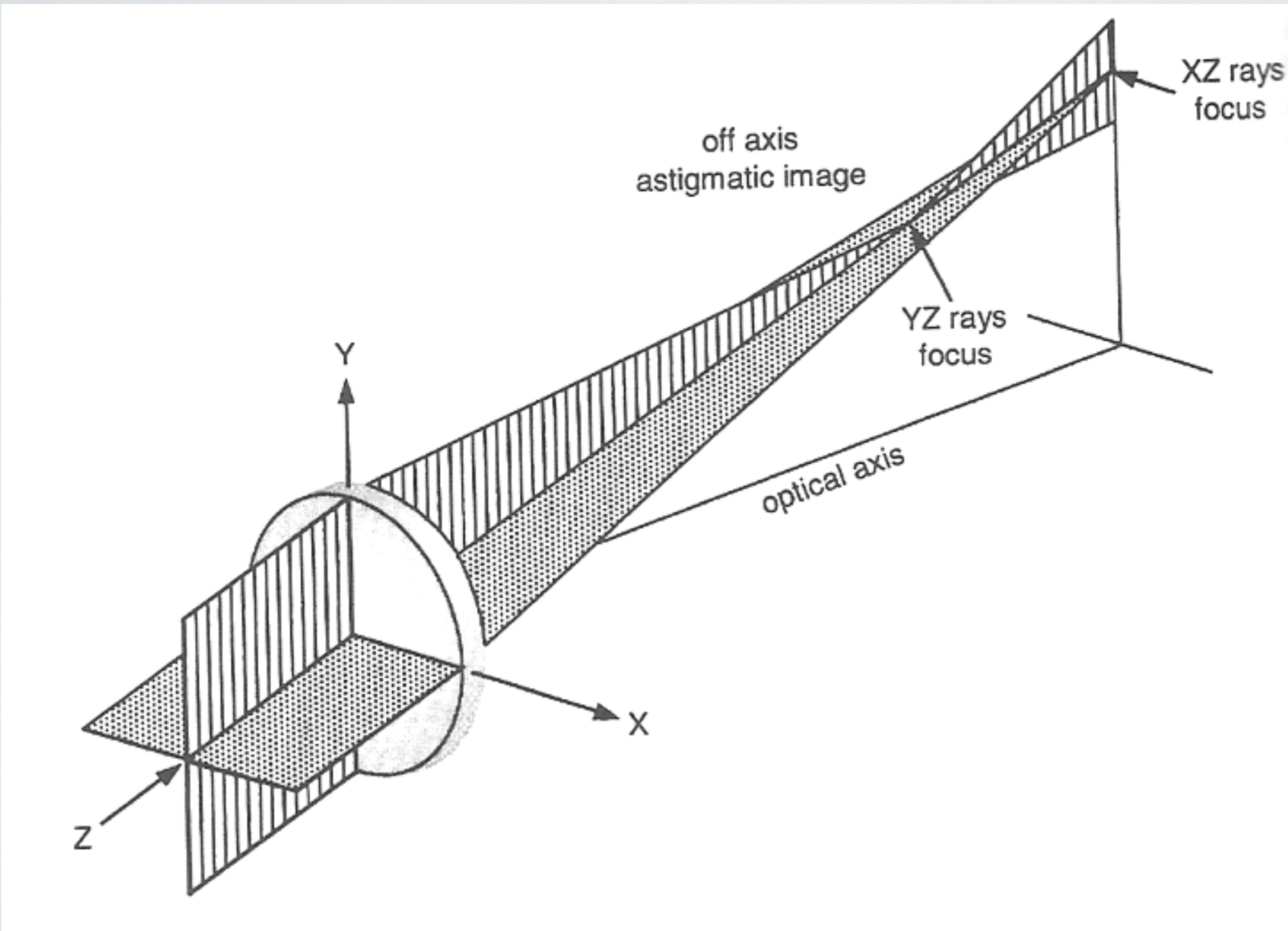
COMA



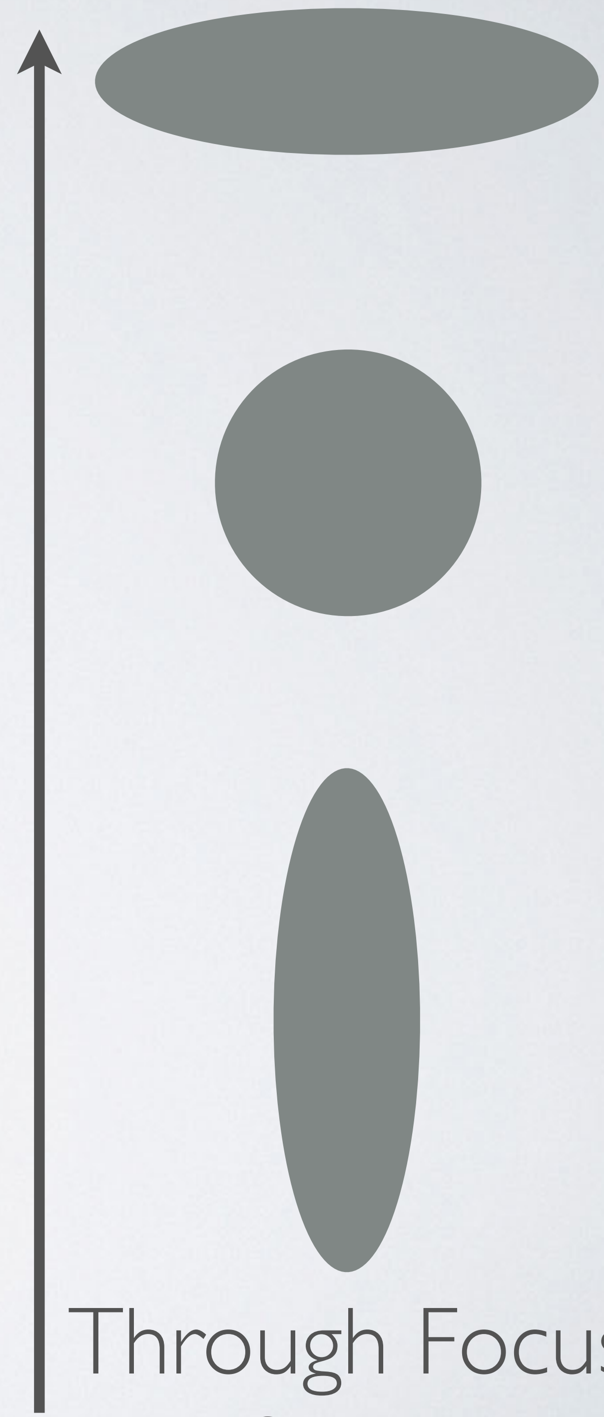
Credit: Optical System Engineering

- Field dependent aberration
- Methods of reduction
  - Shift aperture stop
  - System symmetry

ASTIGMATISM

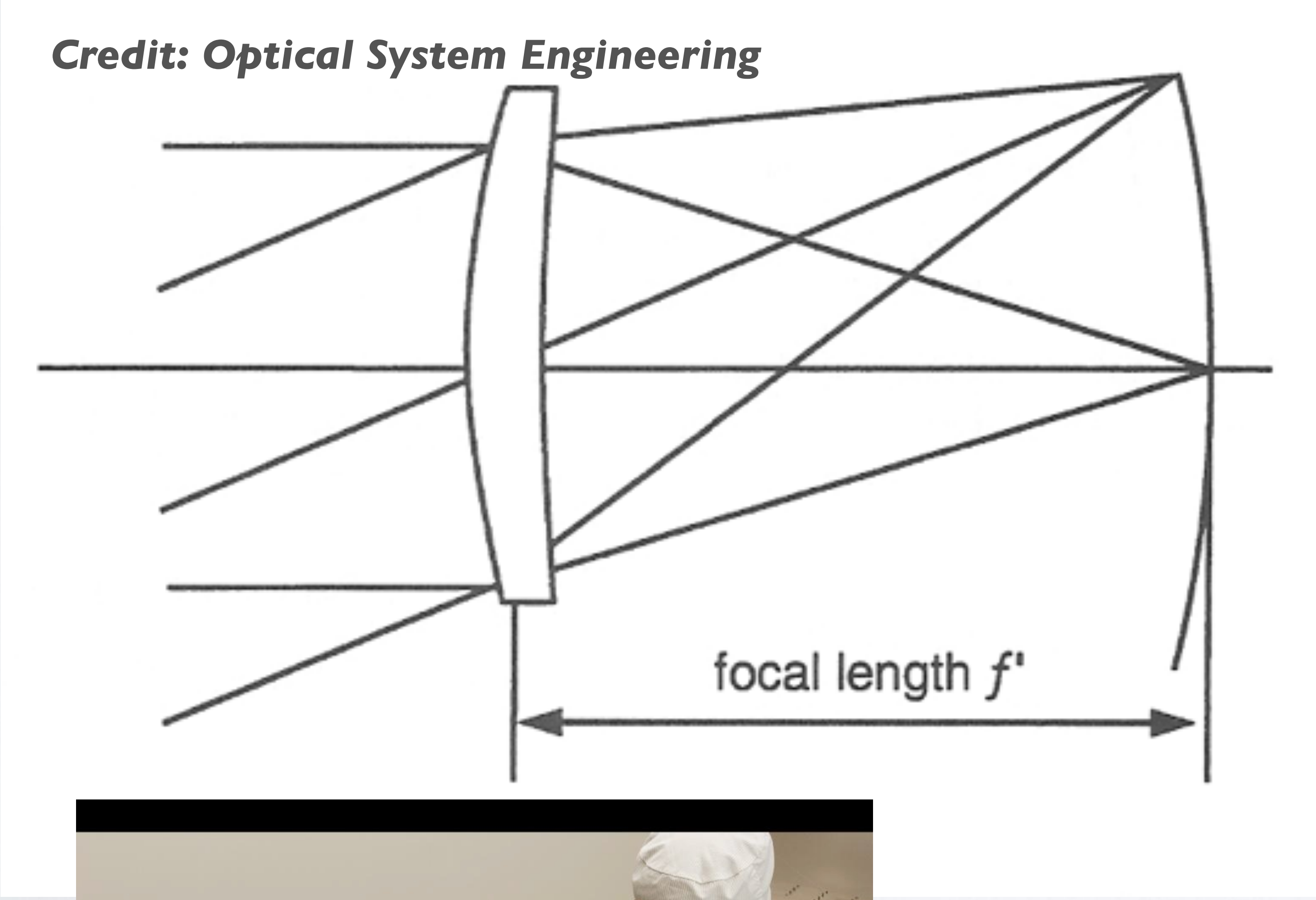


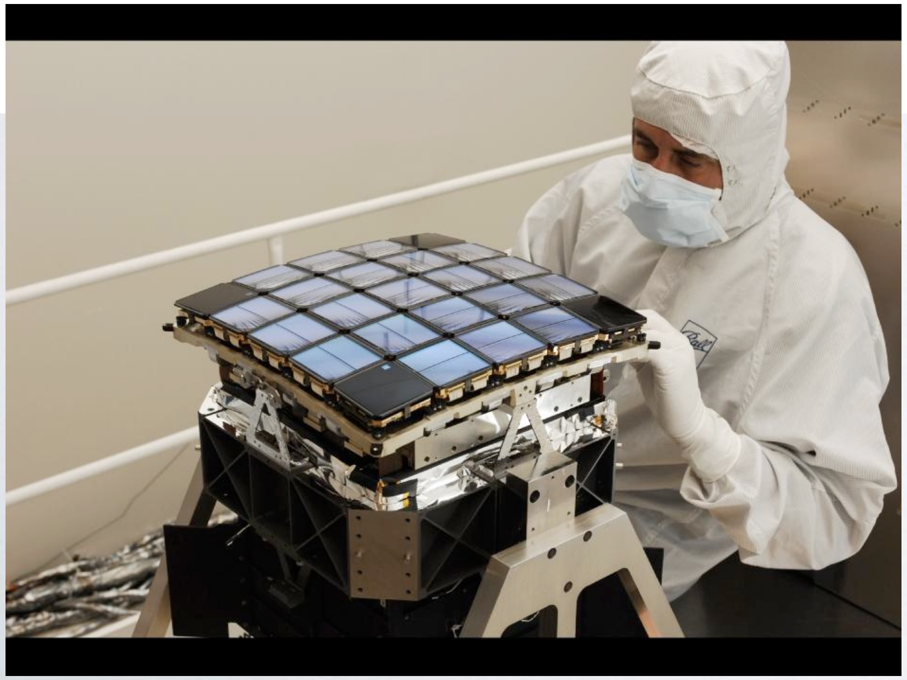
Credit: Optical System Engineering



Through Focus
Spots

FIELD CURVATURE

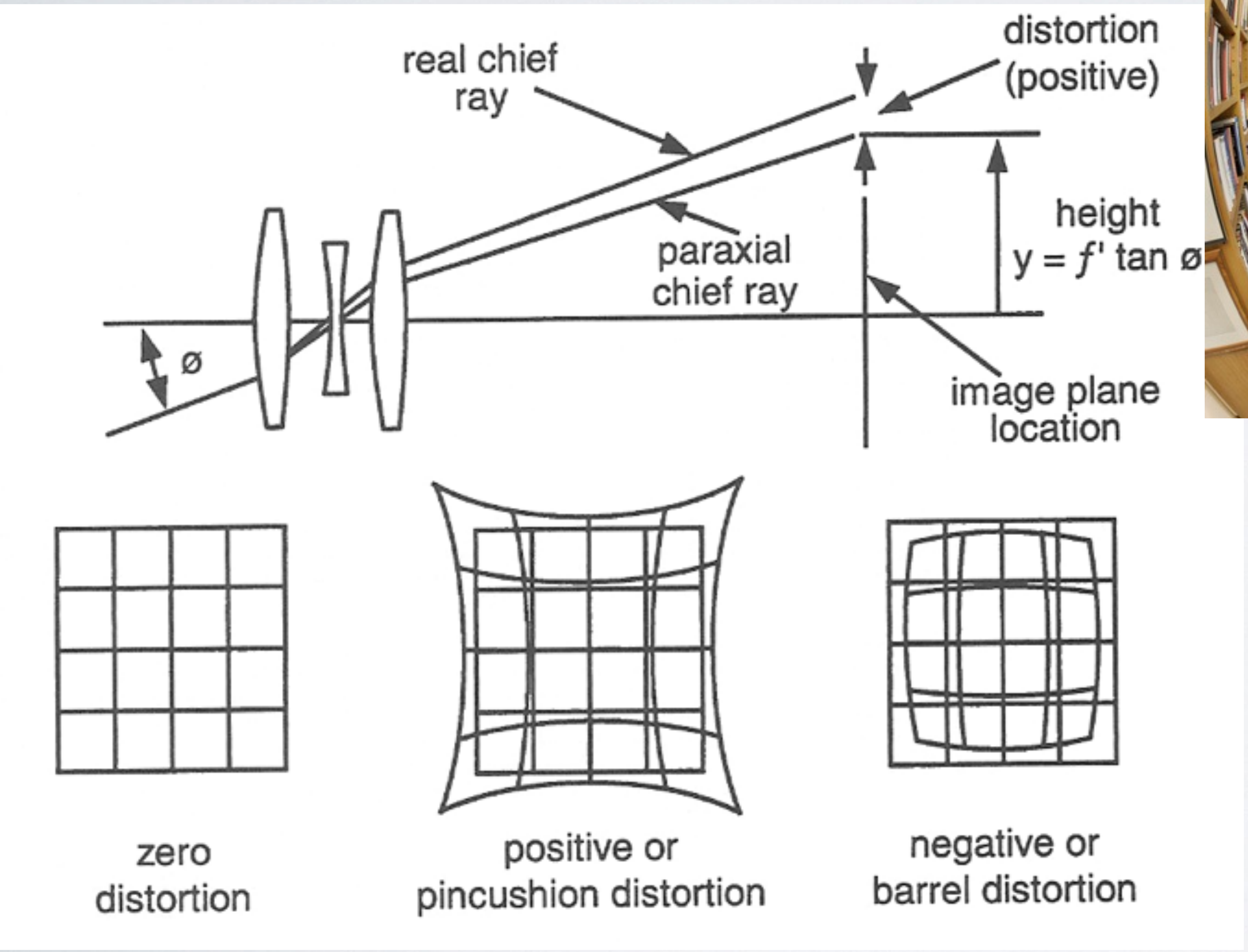




Kepler Focal Plane

- Curved focal plane
- Methods of reduction
  - Curved focal plane
  - Field flattener
  - Negative astigmatism

DISTORTION


real chief ray
distortion (positive)
paraxial chief ray
height
y = ƒ' tan ø
ø
image plane location
zero distortion
positive or pincushion distortion
negative or barrel distortion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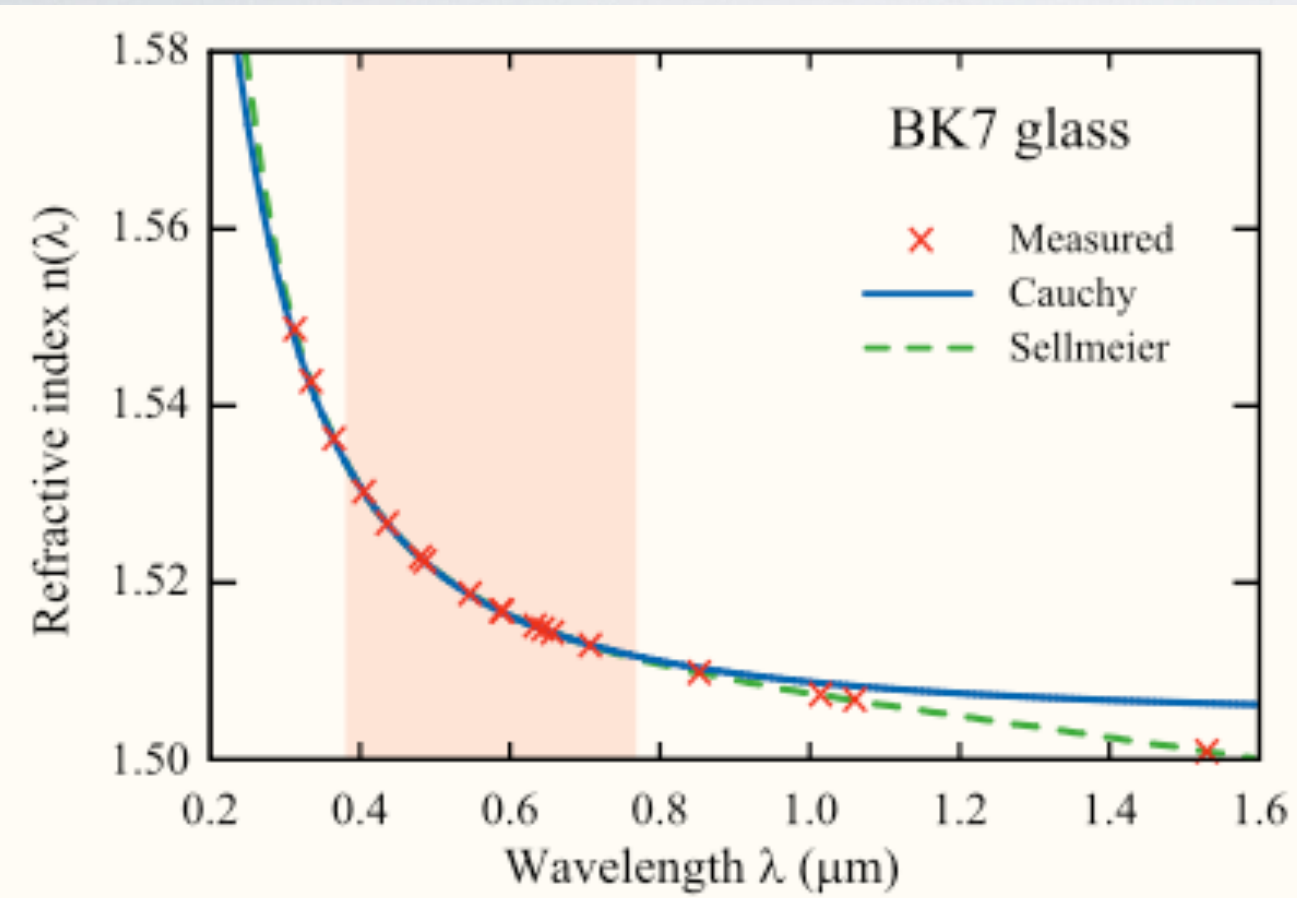
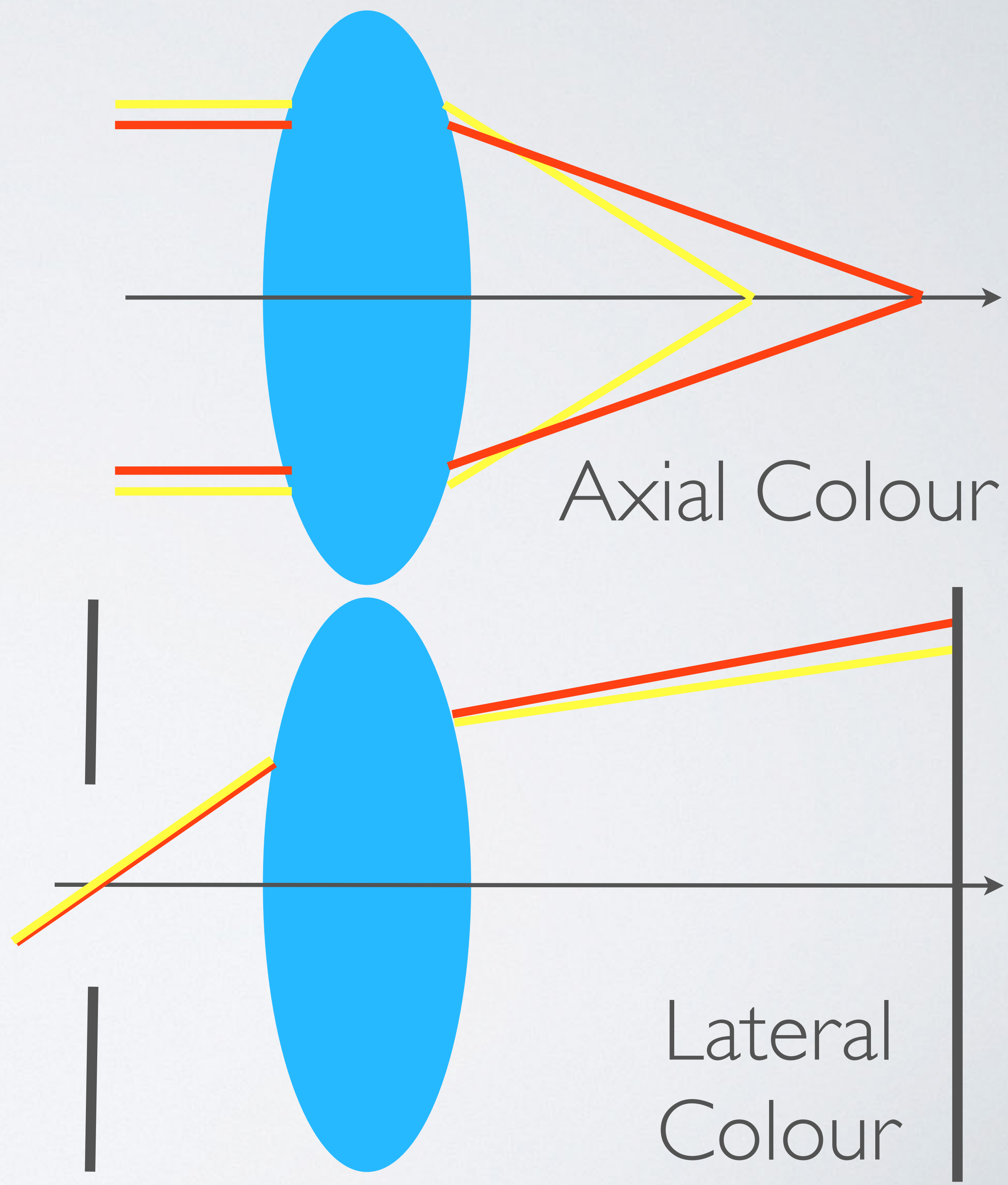
CHROMATIC ABERRATION

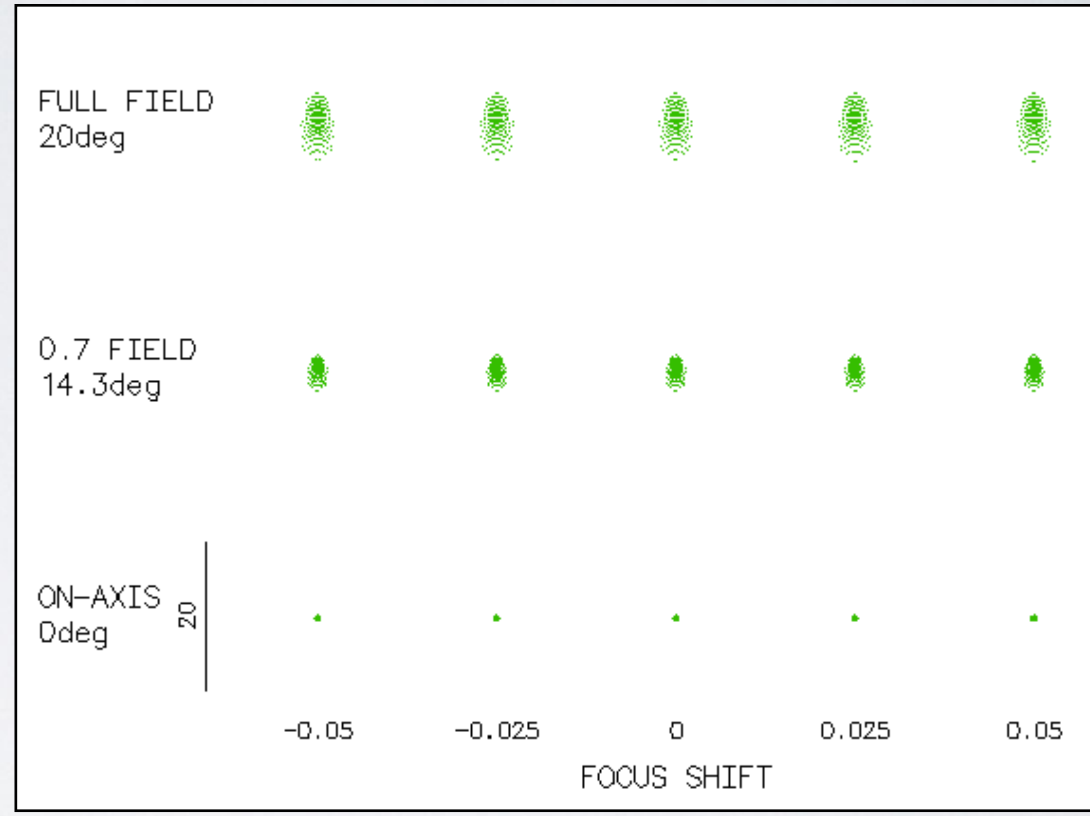


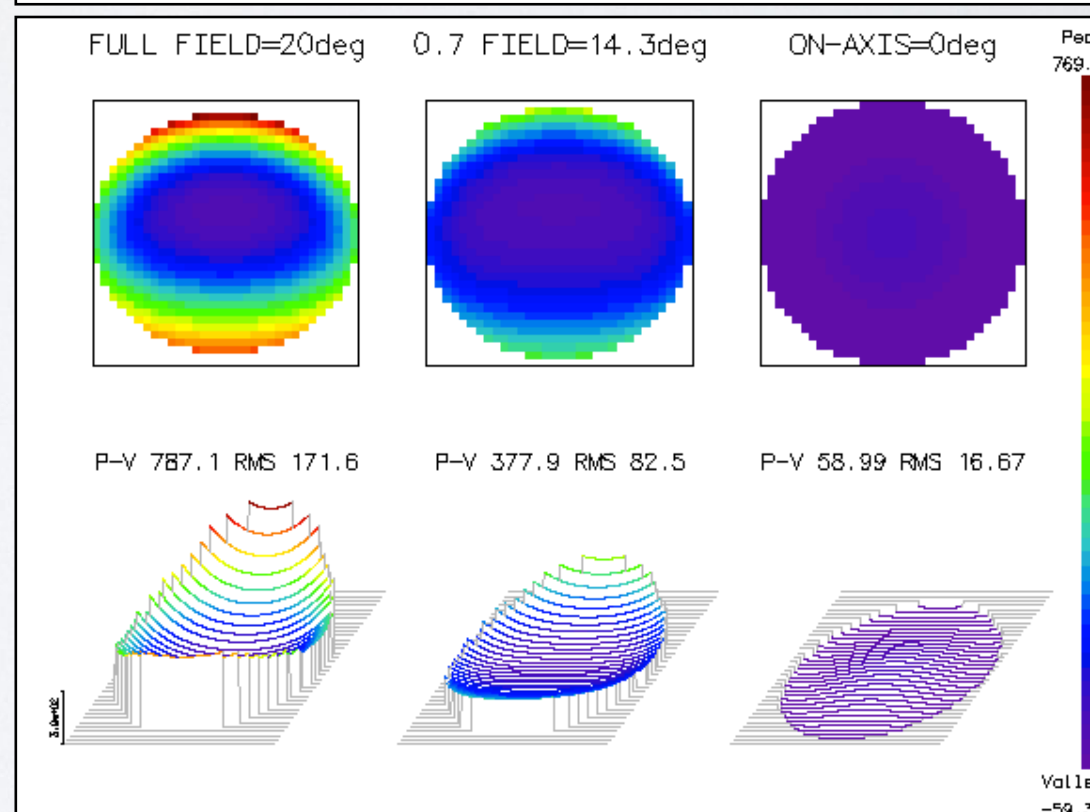
- Index of refraction of glass varies with wavelength
- Outside the scope of lab



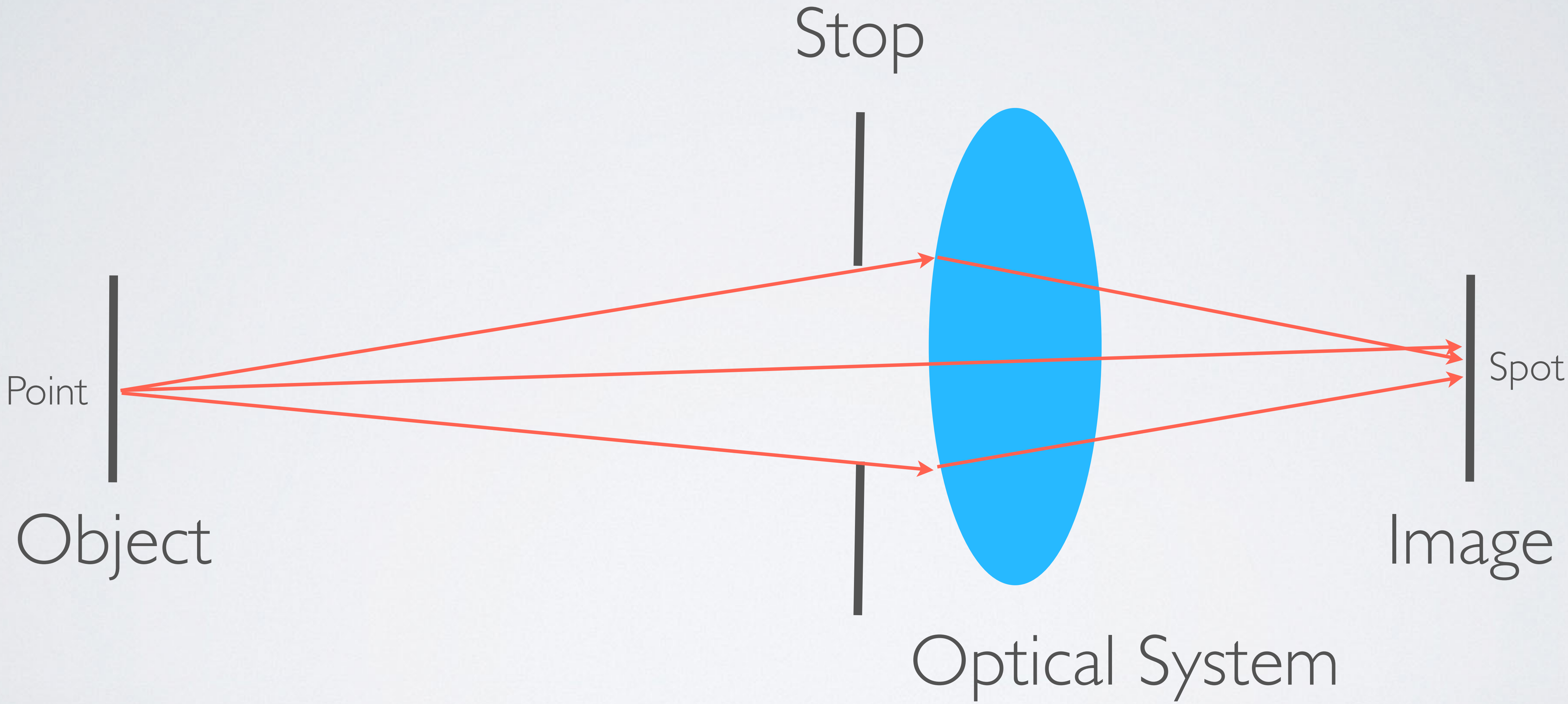
IDENTIFYING ABERRATIONS

- Many Methods:
  - Spot Diagrams
  - Optical Path Difference Plots
  - Seidel Coefficients
  - Zernike Polynomials
  - Ray Fans
  - Encircled Energy

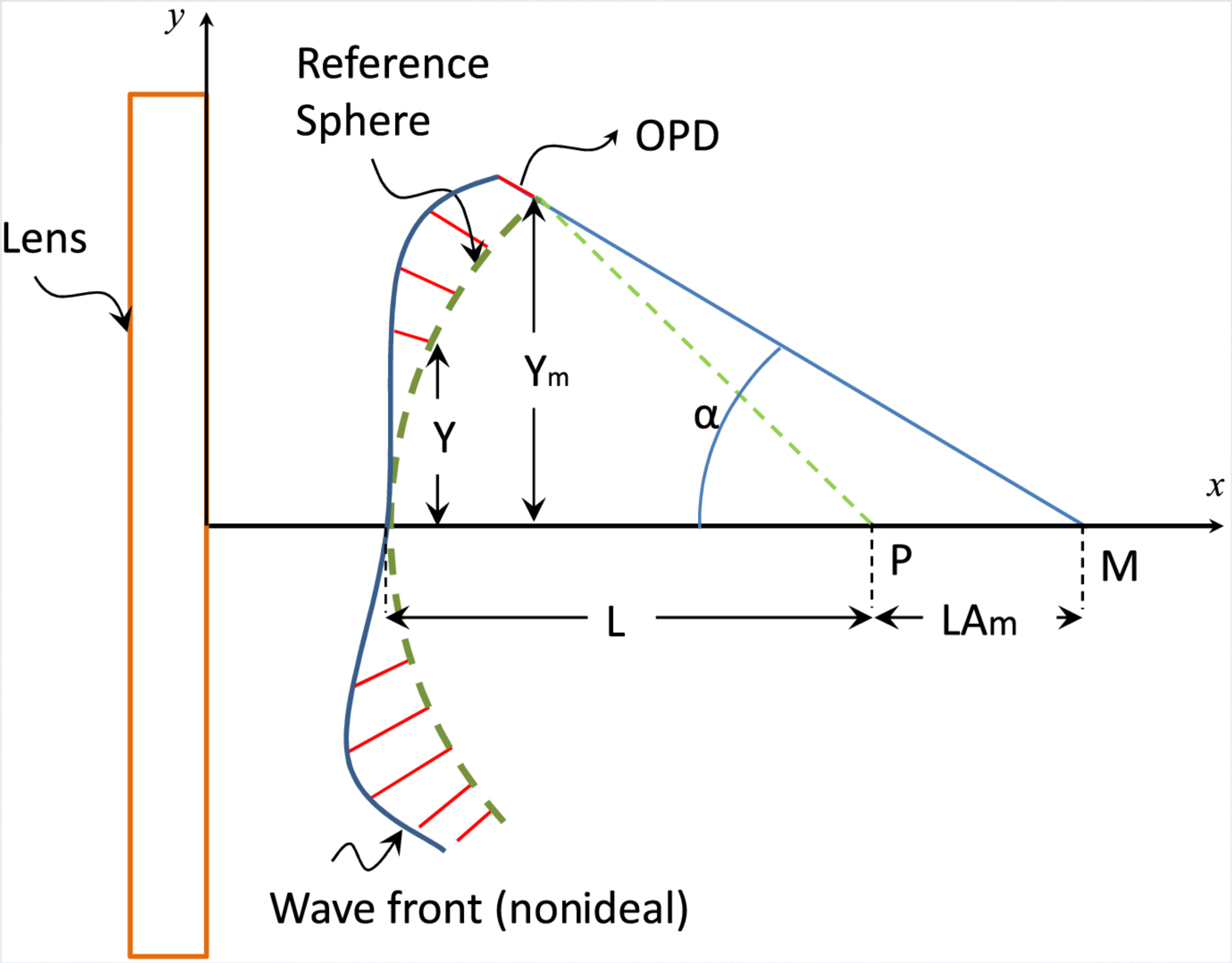




SPOT DIAGRAM

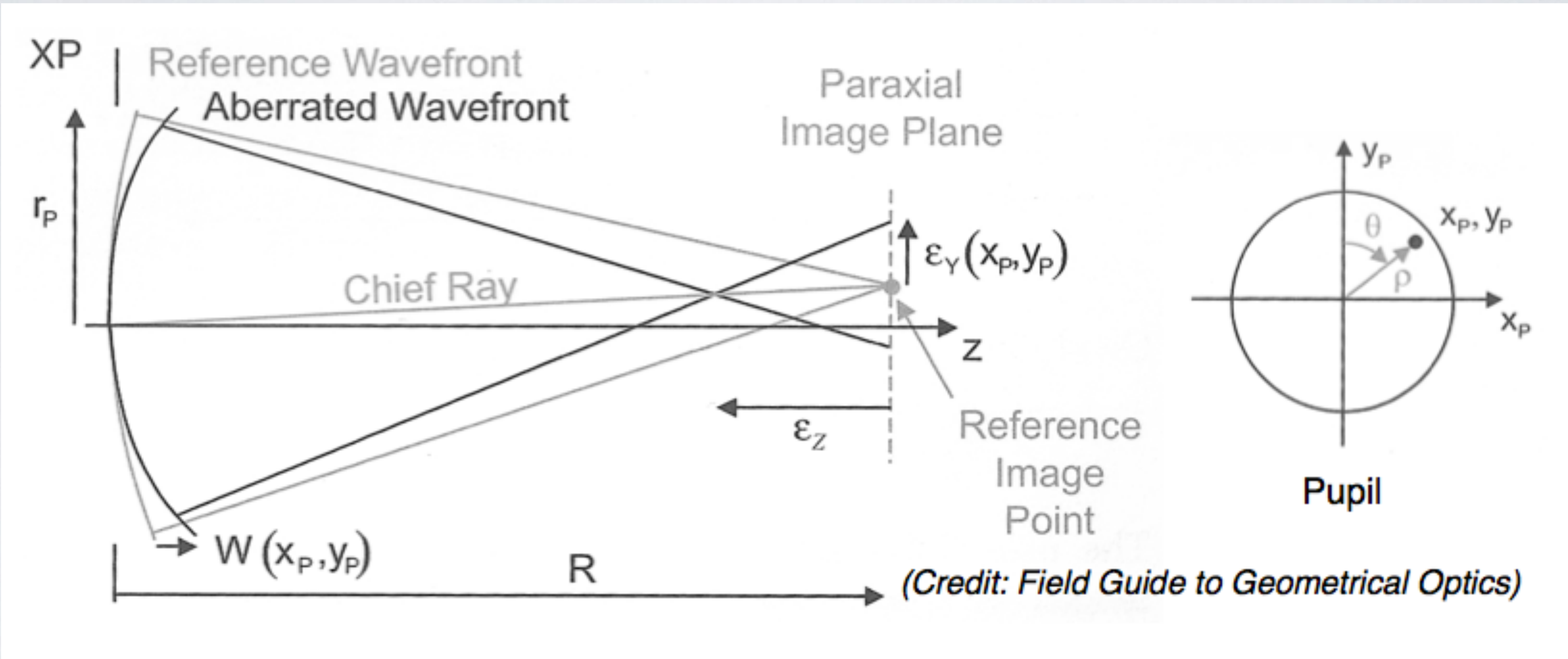


OPTICAL PATH DIFFERENCE



(Credit: OSA)

ABERRATION THEORY
SEIDEL COEFFICIENTS



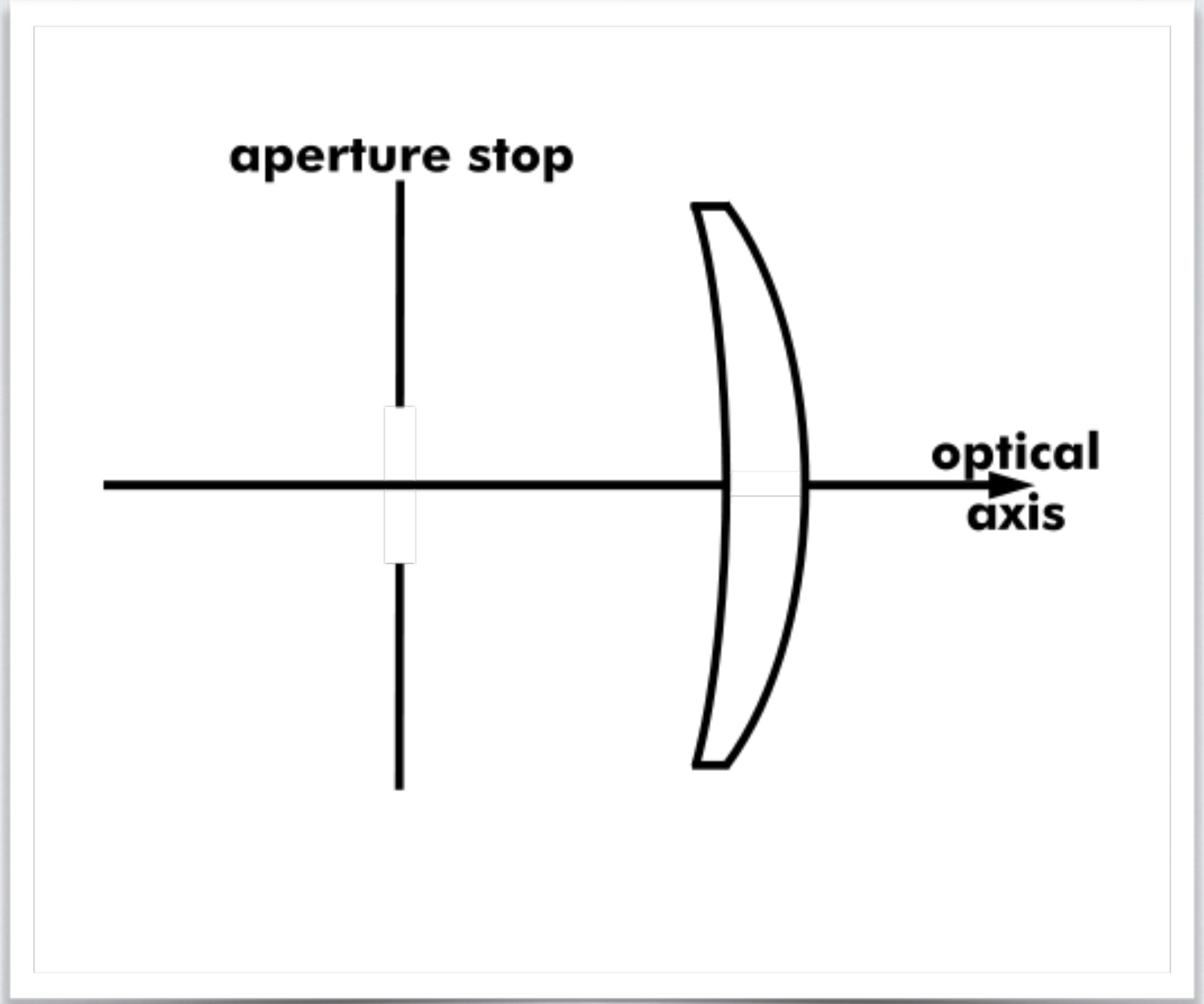
$$OPD = W(\rho, \theta, H) = W_{040}\rho^4 + W_{131}H\rho^3\cos\theta + W_{222}H^2\rho^2\cos^2\theta + W_{220}H^2\rho^2 + W_{311}H^3\rho\cos\theta$$

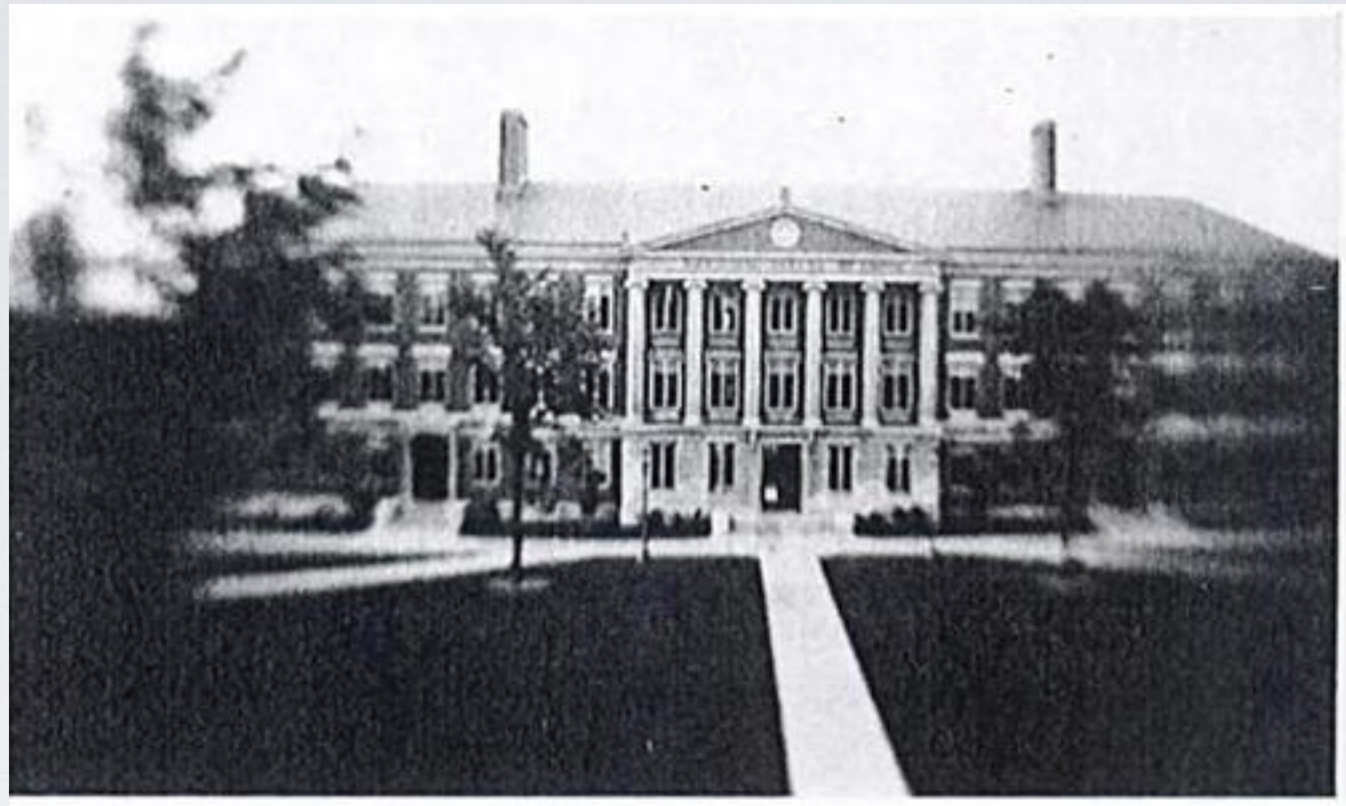
Optical Path Difference — Spherical — Coma — Astigmatism — Field Curvature — Distortion

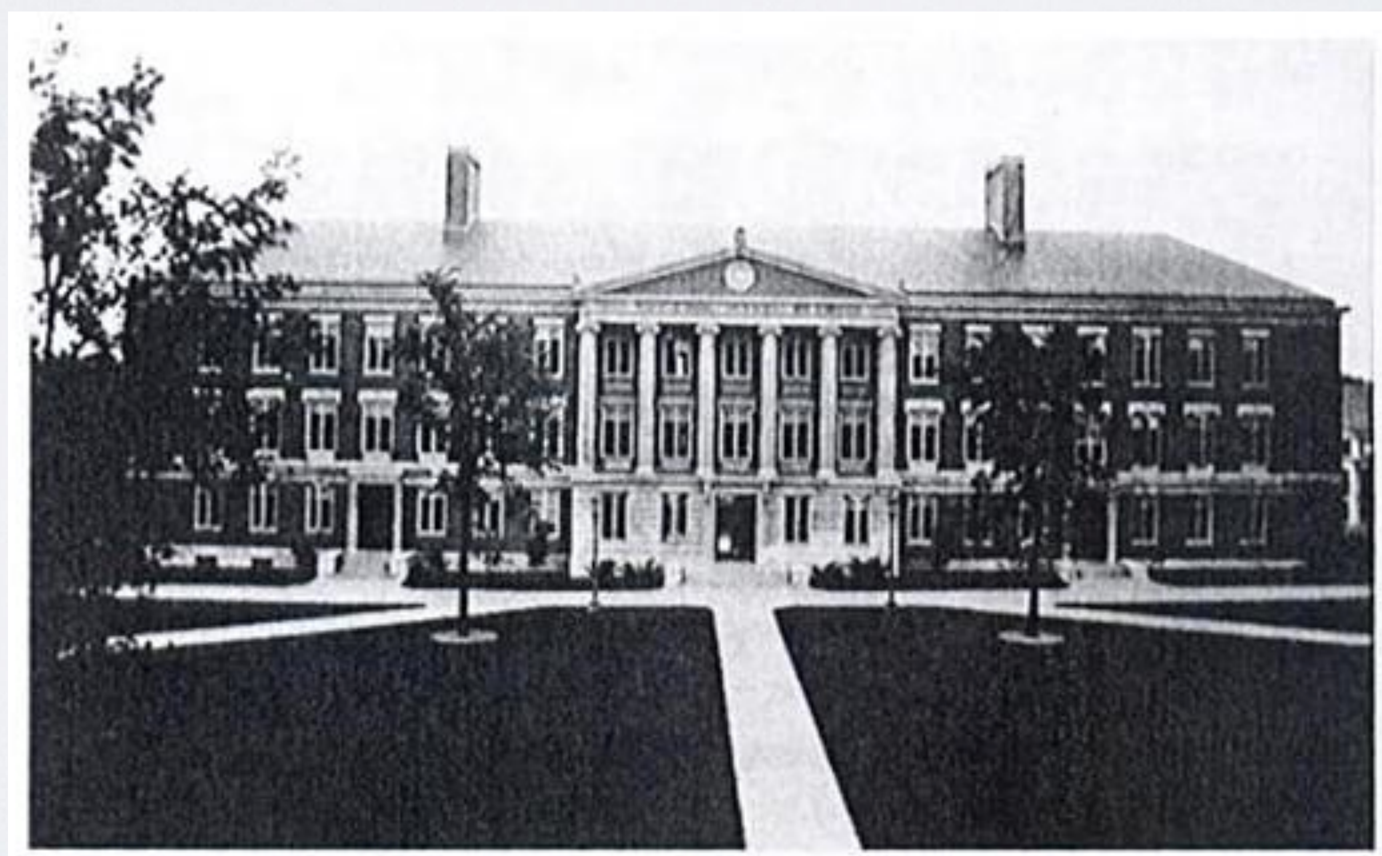
LAB ACTIVITY

1. **Learn to use optical design software**
2. **Construct your own lens**
3. **Identify geometric aberrations**
4. **Correct for those aberrations**

LANDSCAPE LENS







REFERENCES

- Optical System Design (Fischer)
- Astronomical Optics (Schroeder)
- Lens Design Fundamentals (Kingslake)
- Field Guide to Geometrical Optics (Greivenkamp)