EPFL

MICRO-517

Optical Design with ZEMAX OpticStudio

Lecture 10

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Outline

Advanced Topics

- Correction strategies
- Aspheric surfaces
- Coordinate breaks

Correction Strategies

- Color correction
- Changing number of variables
- Symmetries
- Stops and diaphragms
- Field correction

Correction Strategies

Types	Objective				
	Colour	Variables	Symmetry	Stops	Field
Singlet				x	x
Doublet	x			x	x
Apochromat	xx				
Ocular				x	x
Petzval lens	x			x	
Tele-objective	x	x			x
Wide-angle-lens	x	x			xx
Triplet	x	x	x	x	
Tessar, Heliar	x	x	x	x	
Angulon	x	x	x		x
Double Gauss	x	x	x		x
Lister objective	x			x	
Flat-field objective	x		x		x
Stepper lens		x	x		xx
Cassegrain objective		x		x	
Schmidt camera		x	x	x	

Color Correction

Abbe Number

$$V = \frac{n_d - 1}{n_F - n_C}$$

Partial Dispersion

$$P_{F,d} = \frac{n_F - n_d}{n_F - n_C}$$

Achromat

$$K_1 = \frac{V_1}{V_1 - V_2} K \qquad K_2 = -\frac{V_2}{V_1 - V_2} K \qquad \delta_2 K \equiv K_F - K_d = \frac{P_{F,d1} - P_{F,d2}}{V_1 - V_2} K_d$$

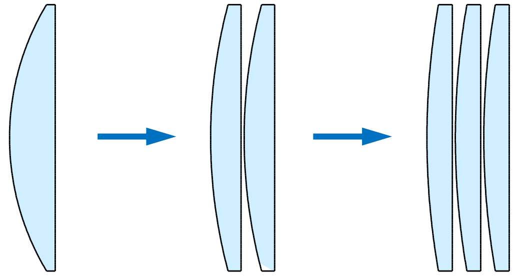
Apochromat

$$K = K_1 + K_2 + K_3 \qquad \frac{K}{V_s} = \frac{K_1}{V_1} + \frac{K_2}{V_2} + \frac{K_3}{V_3} \approx 0 \qquad \frac{K_1 P_{F,d1}}{V_1} + \frac{K_2 P_{F,d2}}{V_2} + \frac{K_3 P_{F,d3}}{V_3} \approx 0$$

Changing Number of Variables

Splitting or adding lenses

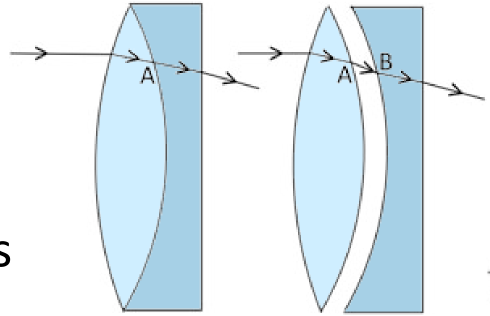
- S_1 and S_2 nonlinear to power
- Reduces the "load" of a system
- Sum of power should remain the same

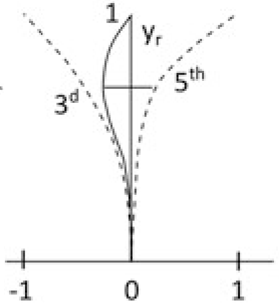


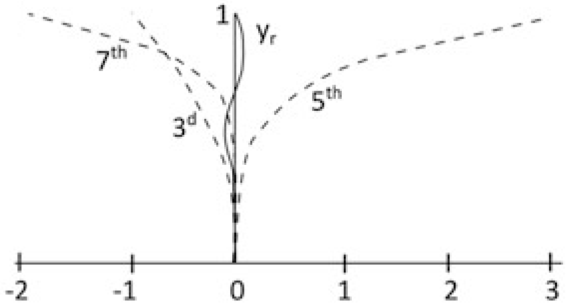
$$\theta^3 > 2\times\left(\frac{\theta}{2}\right)^3 > 3\times\left(\frac{\theta}{3}\right)^3$$

Adding an airspace

- Changes ray height at interface (h_A vs h_B)
- Affects higher-order aberrations more
- Balances 3rd- and high-order aberrations
- More DOM from curvature and distance







Using Aspheres

- First term: conic section
- Significant increase of DOM
- Changes balance of aberrations

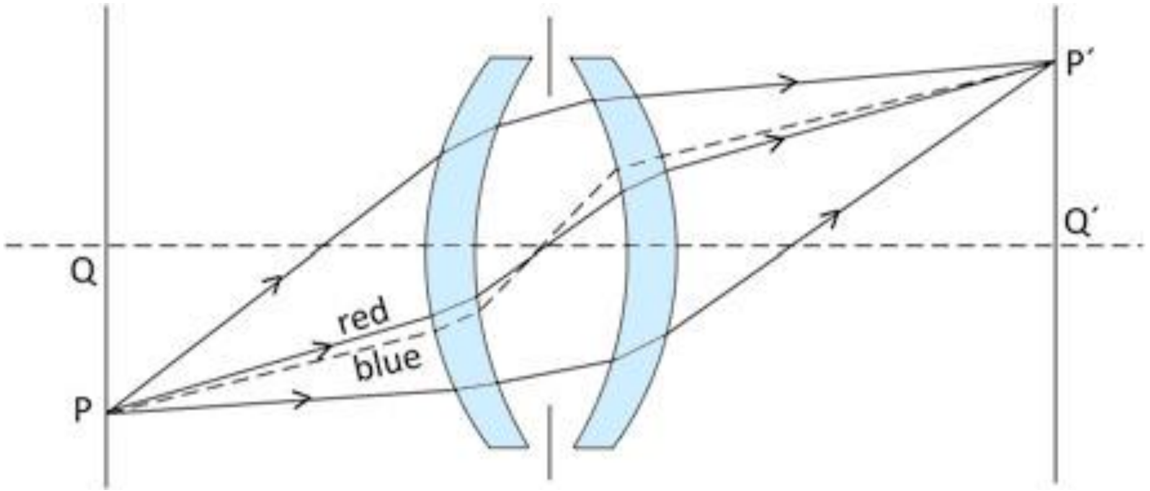
$$sag = \frac{ch^2}{1+\sqrt{1-(1+k)c^2h^2}} + \sum_{i=1}^{N}\alpha_{2i}r^{2i}$$

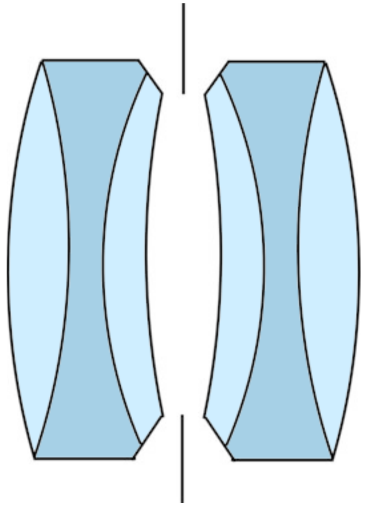
k < -1: hyperboloid
k = -1: paraboloid
k > -1: ellipsoid
k = 0: sphere

Symmetries

Mirror symmetry

- Perfect symmetry: M = -1
- Stop at center of symmetry
- Symmetrical aberrations (spherical) doubles
- Asymmetrical aberrations (coma, distortion, TCA) vanish

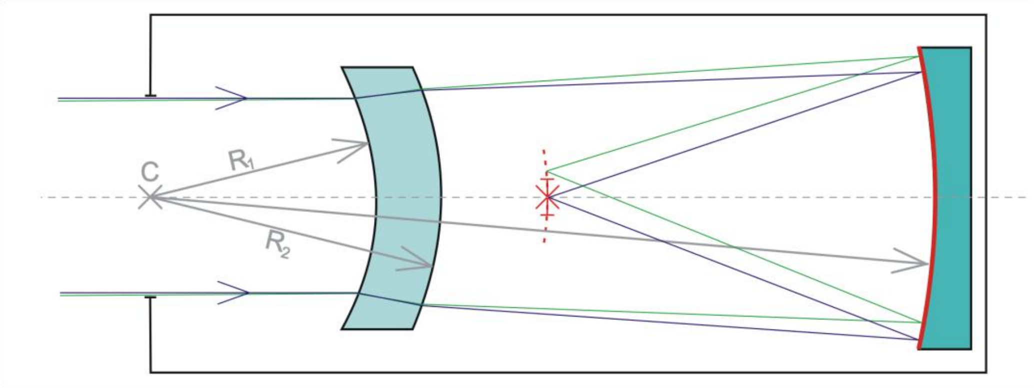




Dagor, P. Rudolph

Concentric systems

- Common center of curvature for all surfaces and stop
- Concentric lens cancels spherical aberration (of all orders)
- Each line through the center is an axis of symmetry

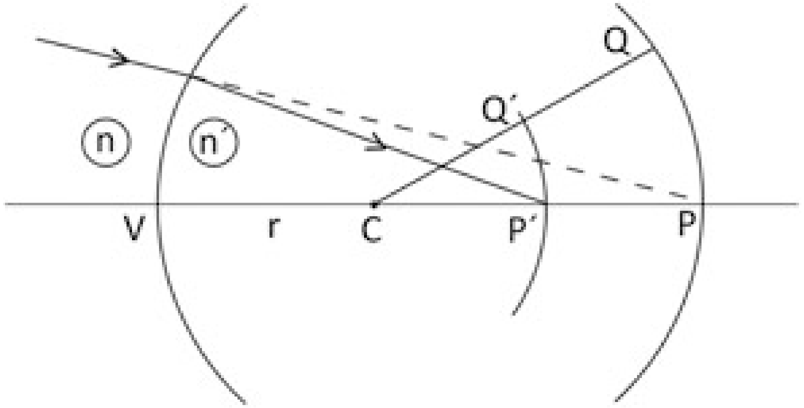


Bouwers telescope objective

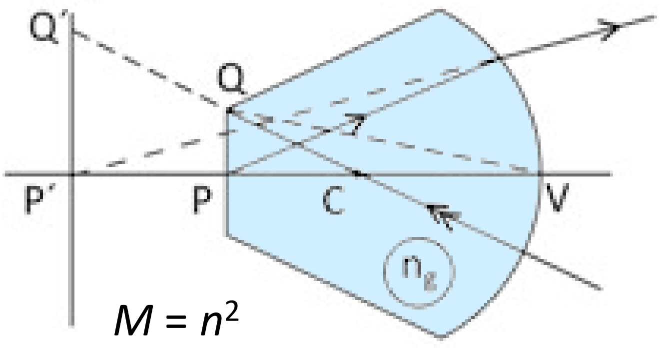
Aplananic Condition

Aplanatic surface

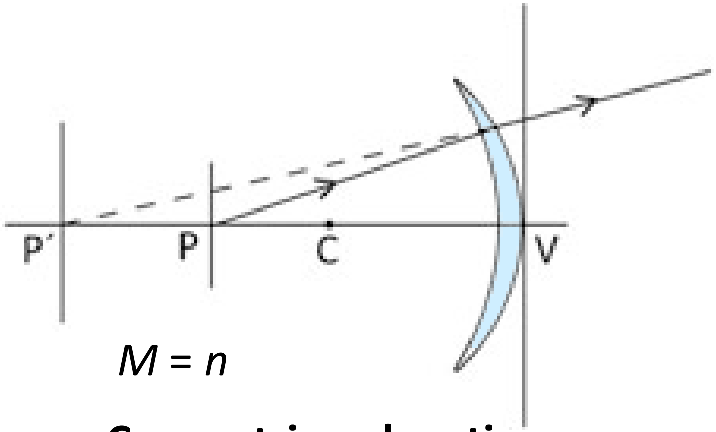
- $CP = n'r / n$, $CP' = nr / n'$
- Can be used as a duplex front in a microscope objective
- $M = n^3$



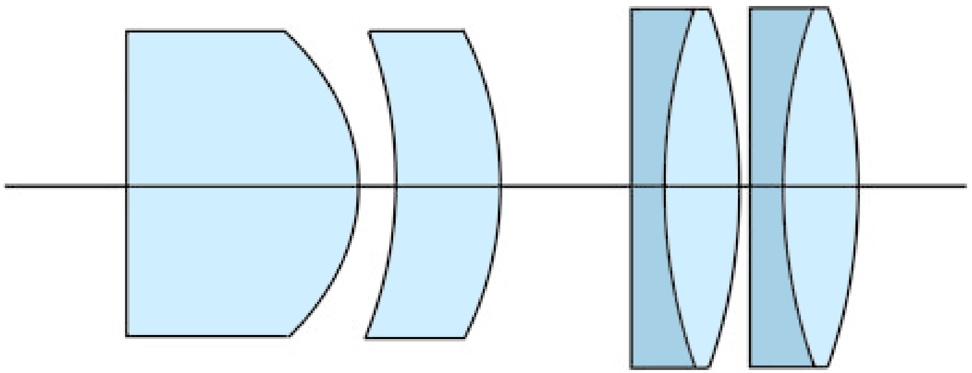
$$CP = \frac{n'}{n} r \qquad CP' = \frac{n}{n'} r$$



Planar-aplanatic

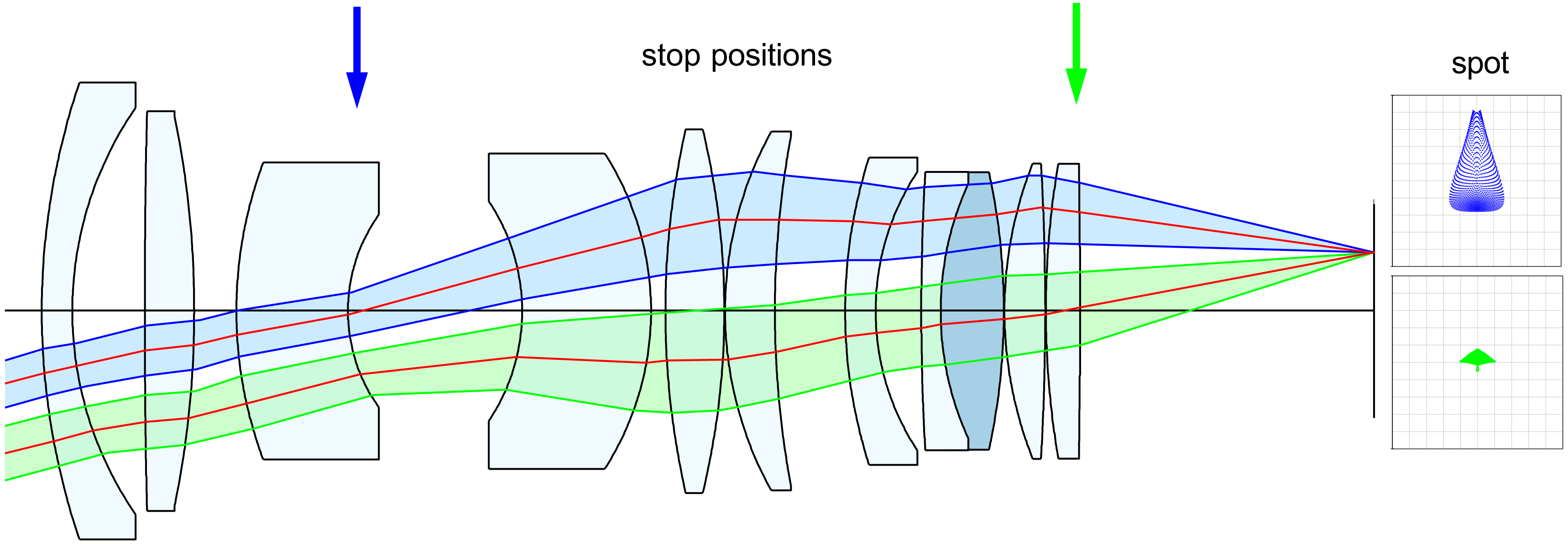


Concentric-aplanatic



Achromat microscope objective NA 0.65/40x

Stops and Diaphragms



Field Correction

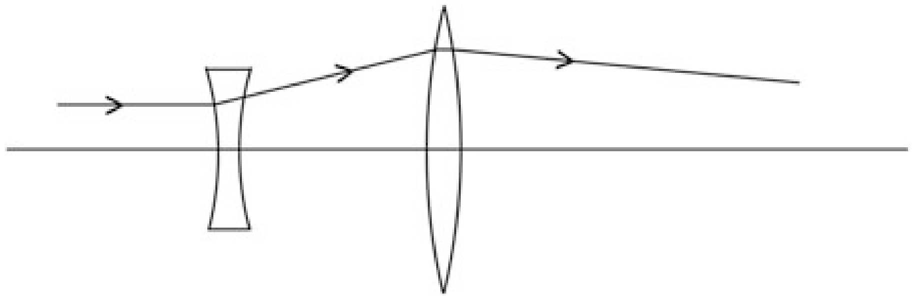
General principle

- Positive lenses with
  - high refractive index
  - large marginal ray heights
  - gives large contribution to power and low weighting in Petzval sum
- Negative lenses with
  - low refractive index
  - small marginal ray heights
  - gives small negative contribution to power and high weighting in Petzval sum

Field Correction

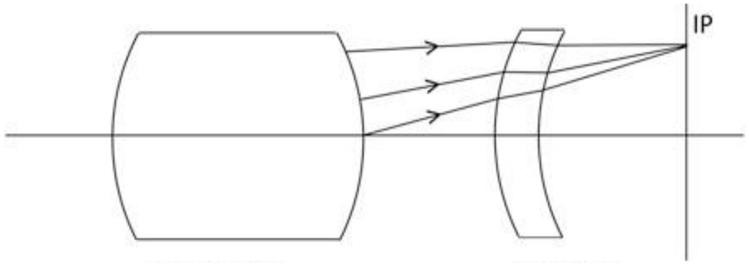
Field Curvature

- Positive lenses with
  - high refractive index
  - large marginal ray heights
  - gives large contribution to power and low weighting in Petzval sum
- Negative lenses with
  - low refractive index
  - small marginal ray heights
  - gives small negative contribution to power and high weighting in Petzval sum



Astigmatism

- A remote stop
- Not too small component distances
- A thin meniscus



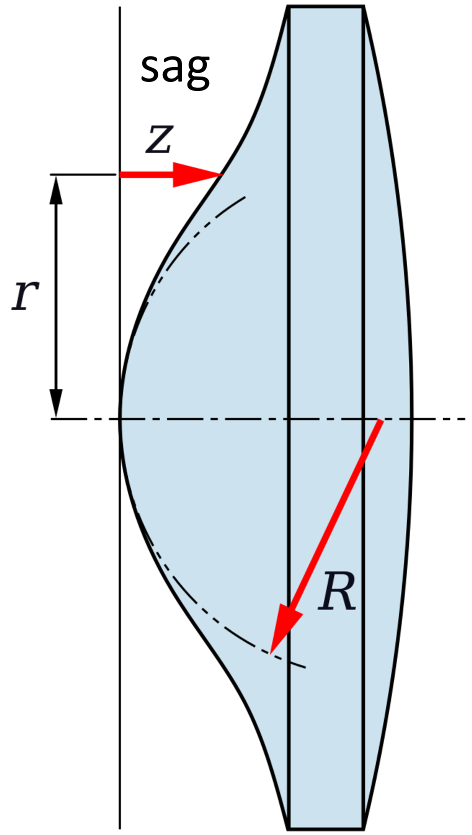
Distortion

- A thin system at the stop
- A system with mirror symmetry, at M = -1
- A concentric systems with a concentric image field
- Contrary to astigmatism and field curvature

Aspheres and Freeforms

- Increase degrees of freedom
- Simplify structure of a lens design
  - Telescopes
  - Photographic lenses
  - High-NA microscope objectives
  - Cellphone cameras
- Excellent performance with a single lens
  - Laser optics
  - Fiber coupling
- Simplify assembly
- Lower manufacturing cost

Modeling of Aspheres



ZEMAX: Aspheric Surfaces

Even Order Asphere

$$z=\frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}}+\alpha_1 r^2+\alpha_2 r^4+\ldots+\alpha_8 r^{16}$$

Extended Even Asphere

$$z=\frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}}+\sum_{i=2}^{N}\alpha_i\rho^{2i}$$

Order up to 480

Odd Order Asphere

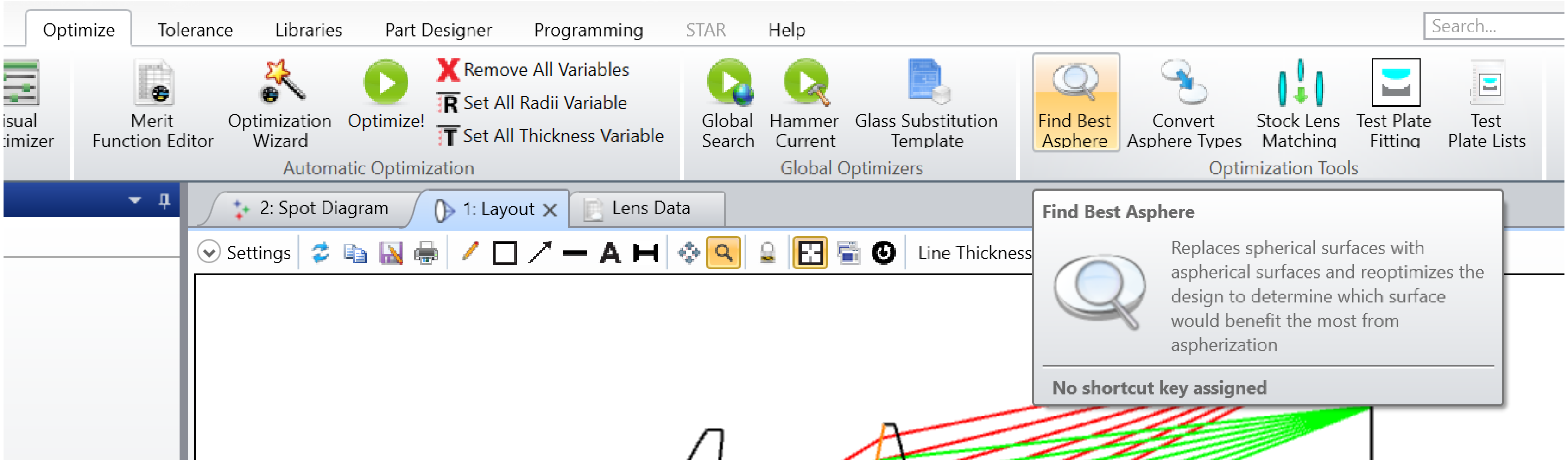
$$z=\frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}}+\alpha_2 r^2+\alpha_3 r^3+\ldots+\alpha_8 r^8$$

Extended Odd Asphere

$$z=\frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}}+\sum_{i=2}^{N}\alpha_i\rho^{i}$$

Order up to 240

ZEMAX OpticStudio: Find Best Asphere



- Locate most efficient surface for aspherization
- Fit surface with best-match coefficients with given order
- Can move design to new solution region

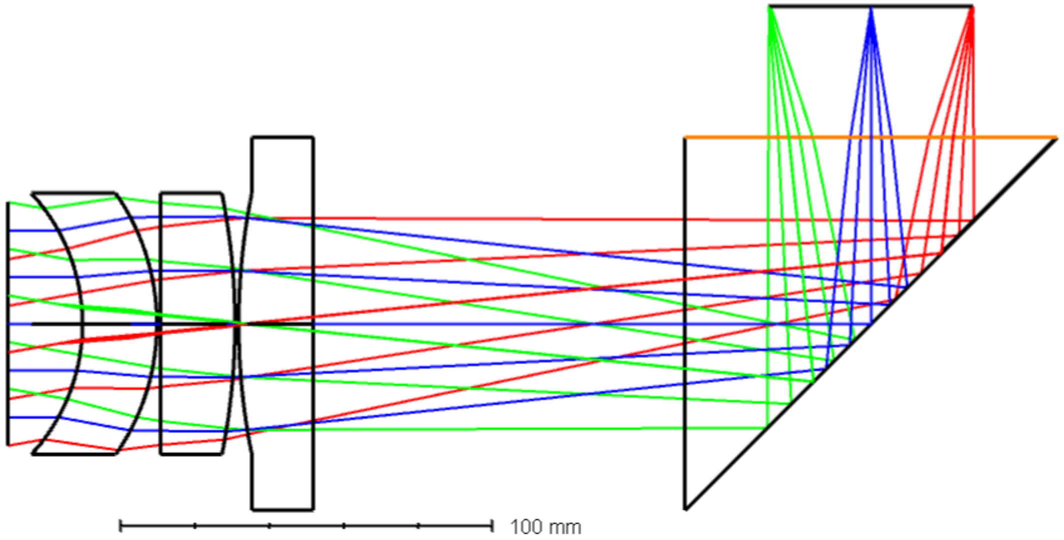
ZEMAX OpticStudio: Coordinate Breaks

Lens Data | 4: Prescription Data

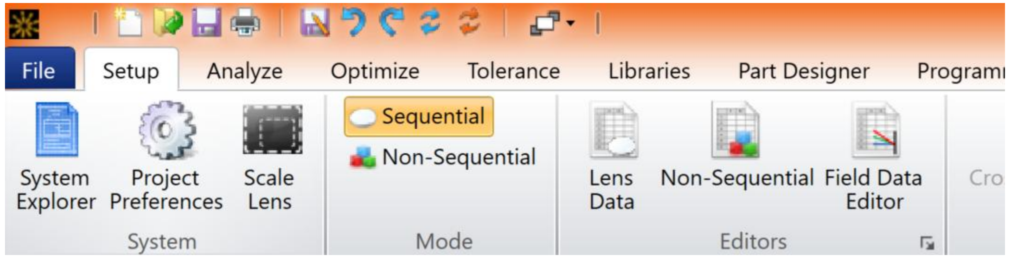
Update: All Windows

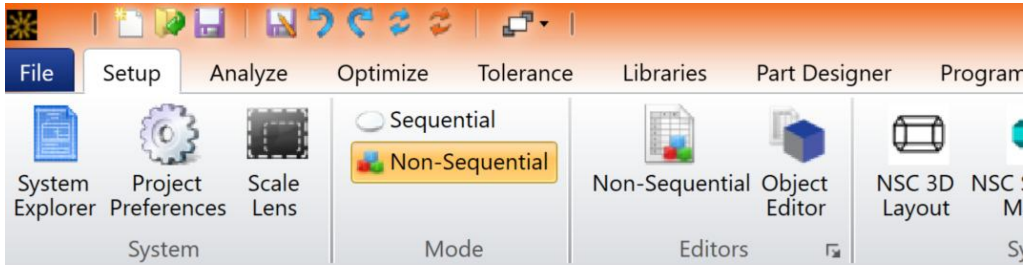
Surface 9 Properties   Configuration 1/1

	Surface Type		TCE x 1E-6	Decenter X	Decenter Y	Tilt About X	Tilt About Y	Tilt About Z	Order
8	(aper) Standard		-						
9	Coordinate Break		-	0.000	0.000	45.000	0.000	0.000	0
10	(aper) Standard		0.000						



ZEMAX OpticStudio: Non-sequential Mode





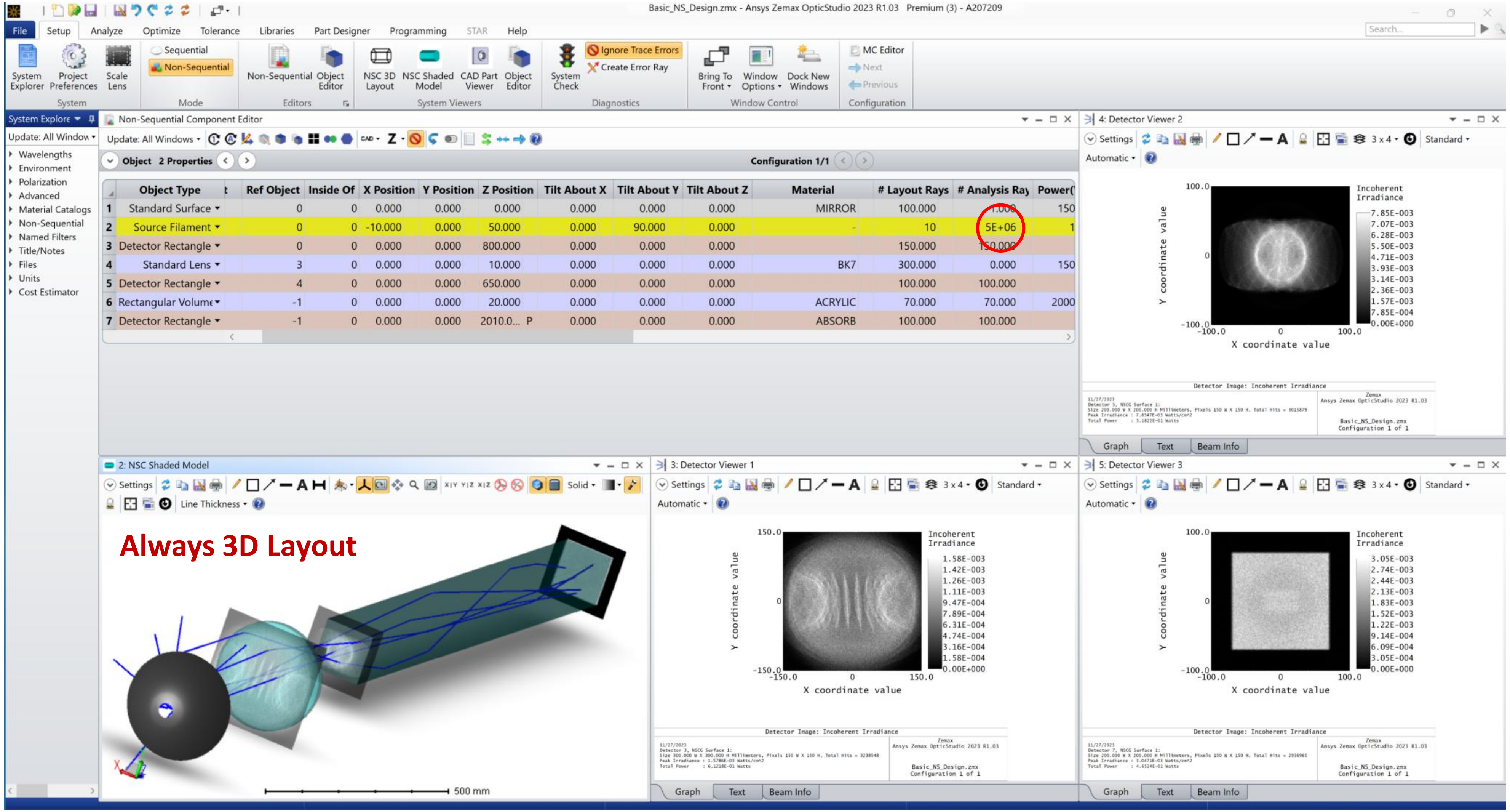
Sequential Mode

- For analysis of imaging systems
- Centered on geometry
- Rays go through surfaces in order
- Rays do not split
- Must define
  - object plan (1 with >= 1 fields)
  - surfaces
  - image plane (1)
- Can contain nonsequential component

Non-sequential Mode

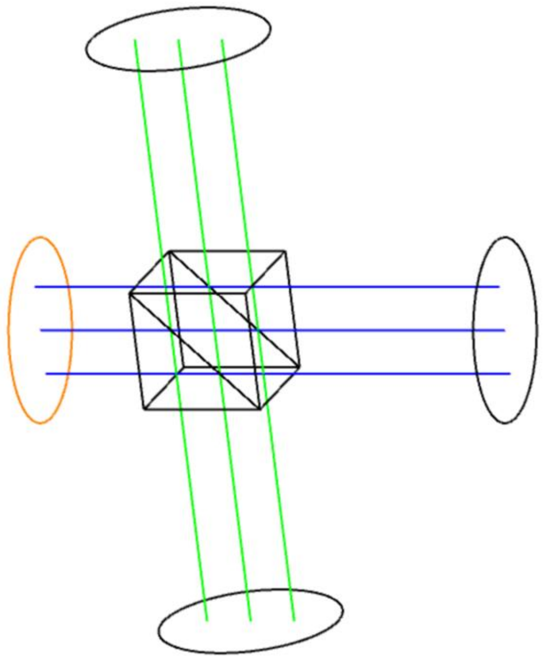
- For analysis of stray light, scattering, or illumination
- Centered on physical quantity
- Rays go through objects in any order
- Rays can be split or scattered
- Must define
  - light source (>= 1)
  - objects
  - detectors (>= 1)

ZEMAX OpticStudio: Non-sequential Mode

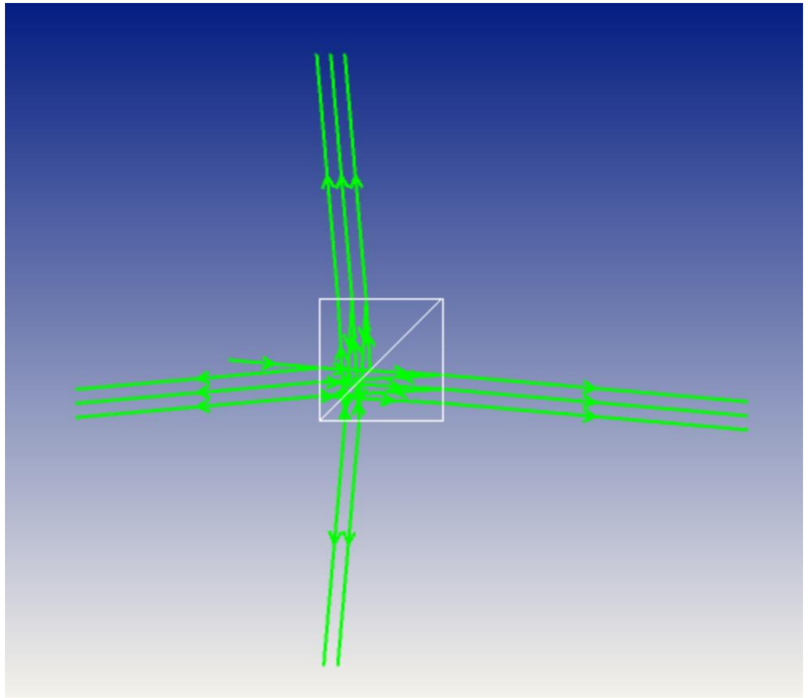


ZEMAX OpticStudio: Beam Splitting

Sequential Mode
Multiconfiguration



Nonsequential Mode



ZEMAX OpticStudio

Hands-on Time

Homework

To be announced