



EPFL

MICRO-517

Optical Design with ZEMAX OpticStudio

Lecture 10

24.11.2025

Ye Pu

Sciences et techniques de l'ingénieur
École Polytechnique Fédérale de Lausanne
CH-1015 Lausanne

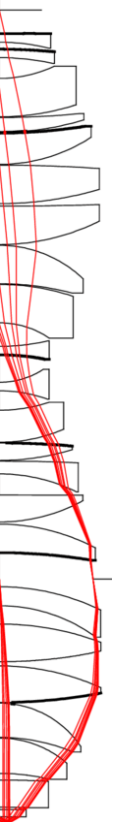
Outline

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

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

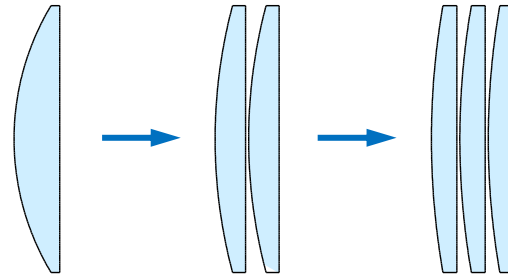
Apochromat

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

Changing Number of Variables

Splitting or adding lenses

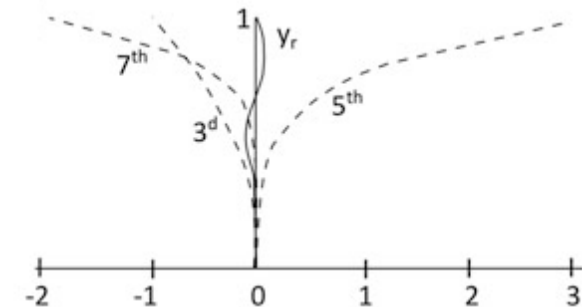
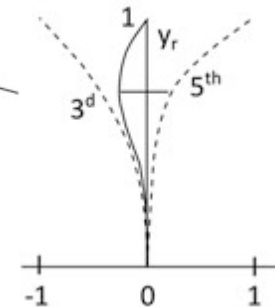
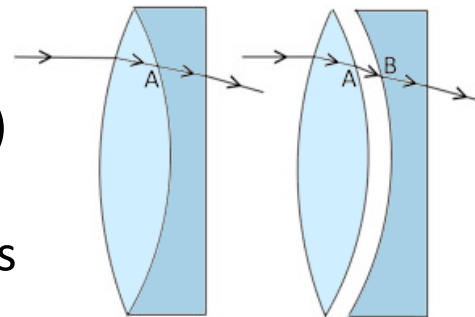
- S_1 and S_2 nonlinear to power
- Reduces the “load” of a system
- Sum of power should remain the same



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

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

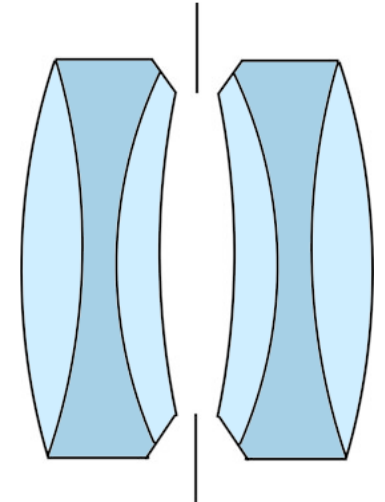
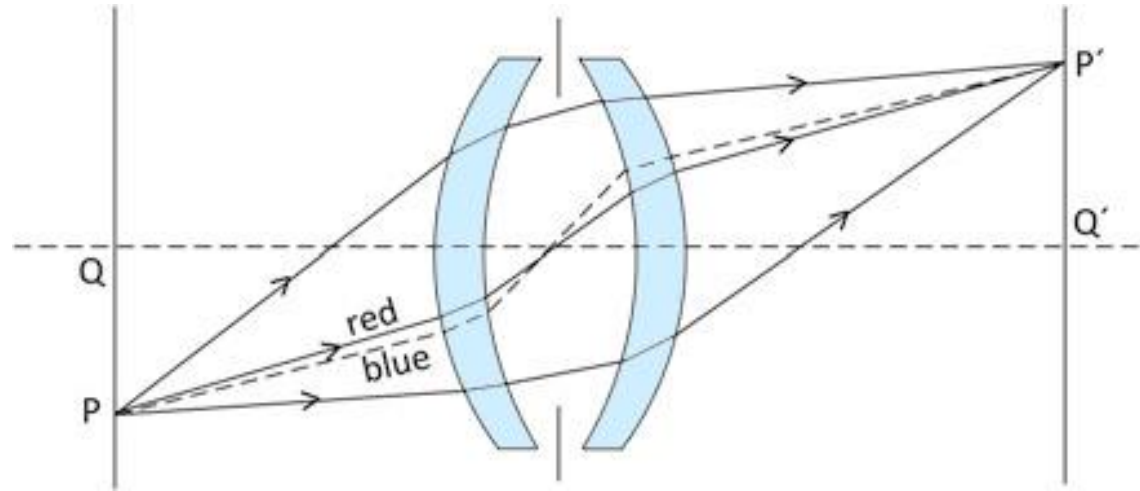
$$sag = \frac{ch^2}{1 + \sqrt{1 - (1+k)c^2h^2}} + \sum_{i=1}^N \alpha_{2i} r^{2i}$$

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

Symmetries

Mirror symmetry

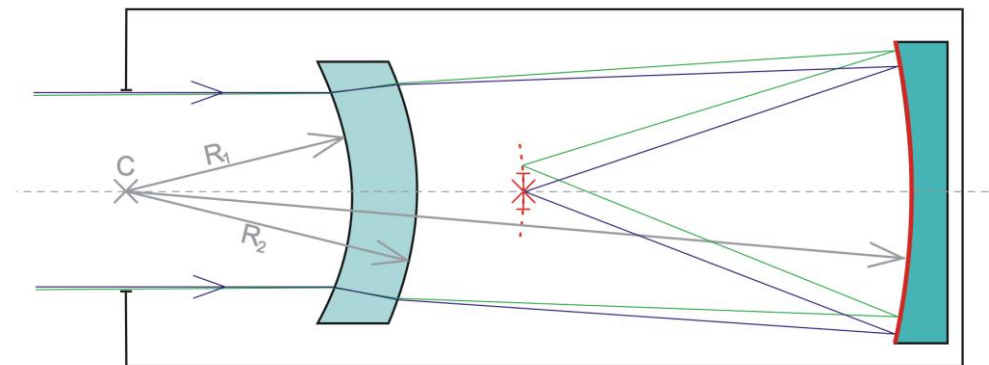
- Perfect symmetry: $M = -1$
- Stop at center of symmetry
- Symmetrical aberrations (spherical) doubles
- Asymmetrical aberrations (coma, distortion, TCA) vanish



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

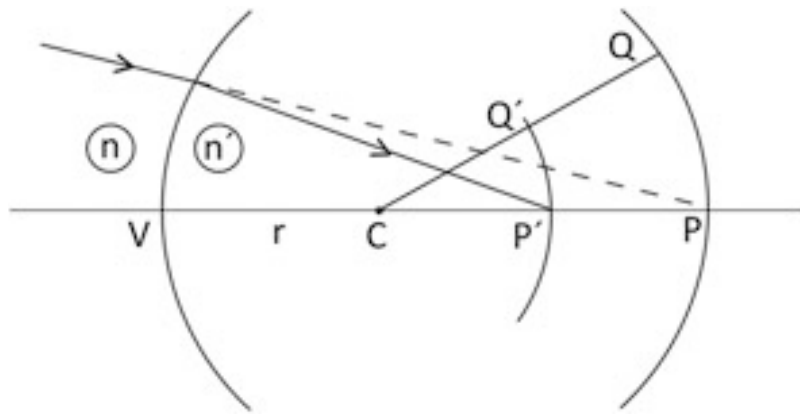
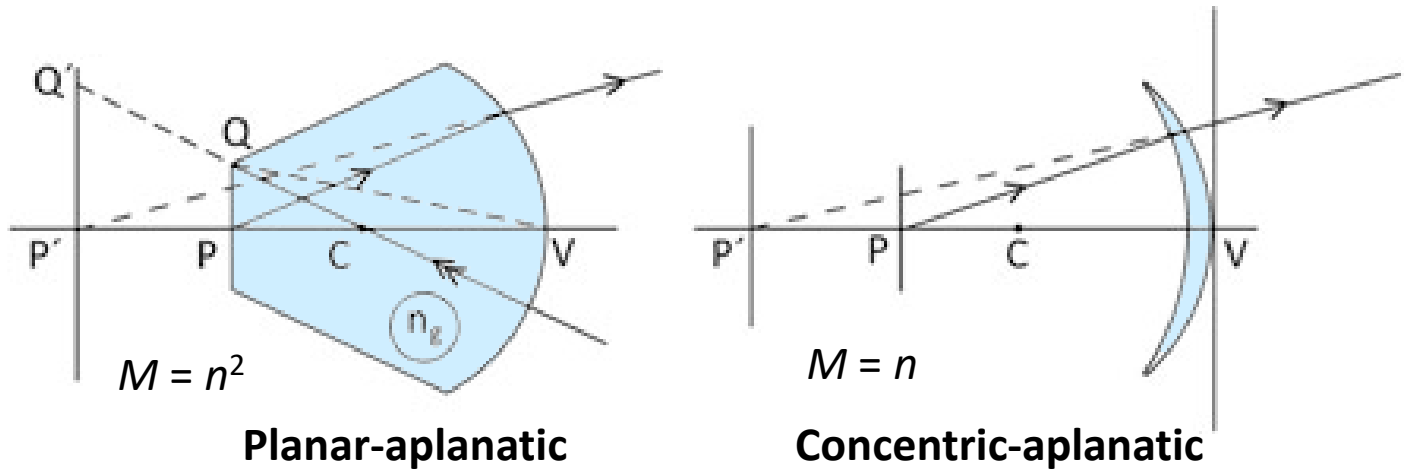


Bouwers telescope objective

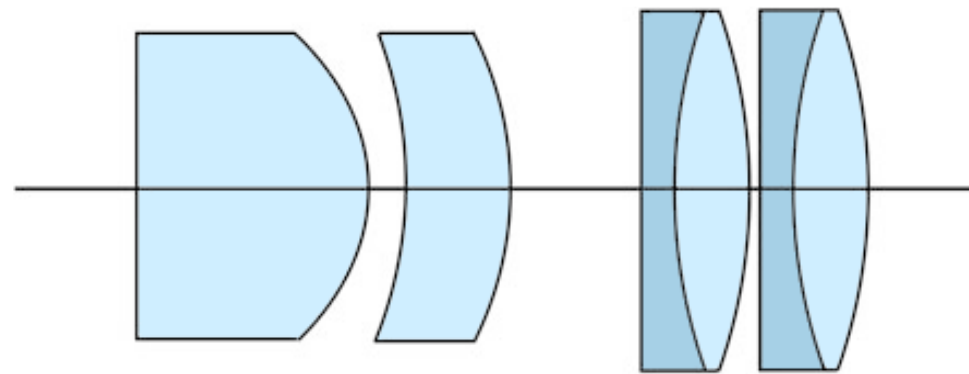
Aplanatic Condition

Aplanatic surface

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

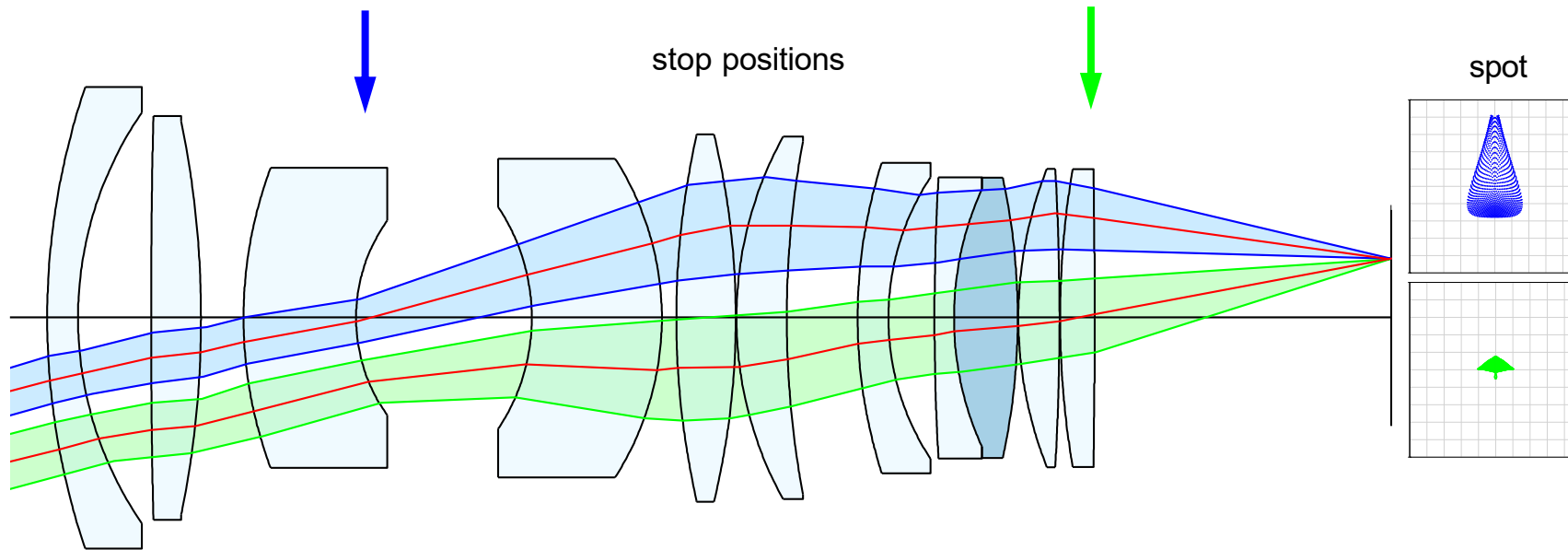


$$CP = \frac{n'}{n} r \quad CP' = \frac{n}{n'} r$$



Achromat microscope objective NA 0.65/40x

Stops and Diaphragms



Field Correction

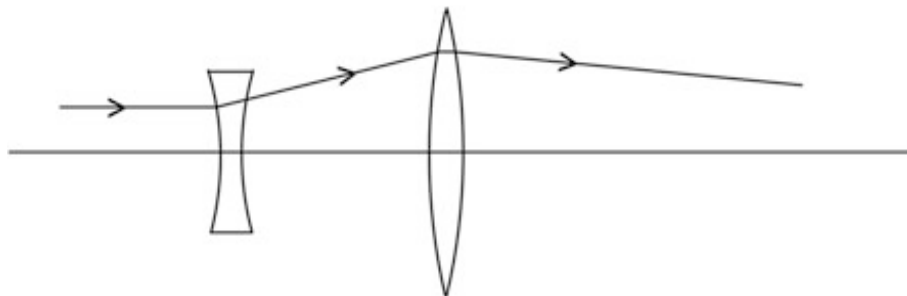
General principle

- 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

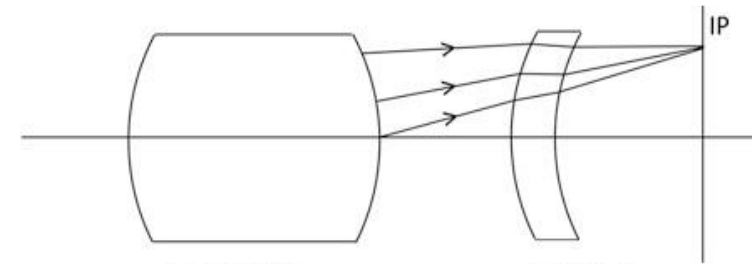
Field Curvature

- 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



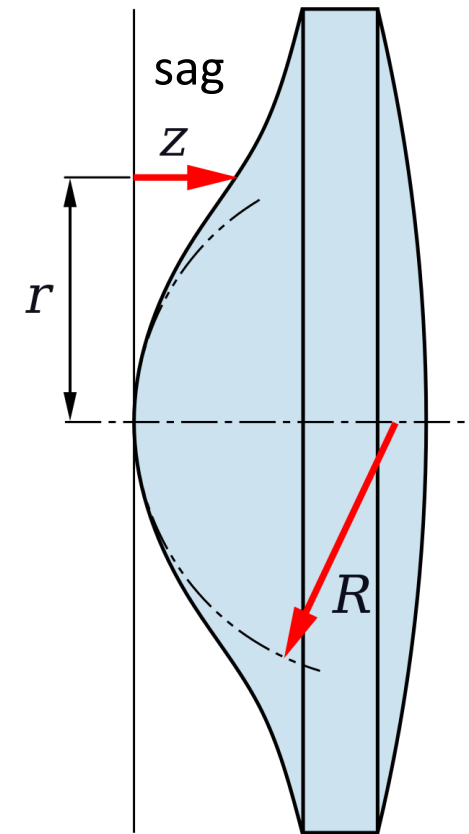
Distortion

- 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

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

Extended Even Asphere

$$z = \frac{cr^2}{1 + \sqrt{1 - (1+k)c^2r^2}} + \sum_{i=2}^N \alpha_i \rho^{2i} \quad \text{Order up to 480}$$

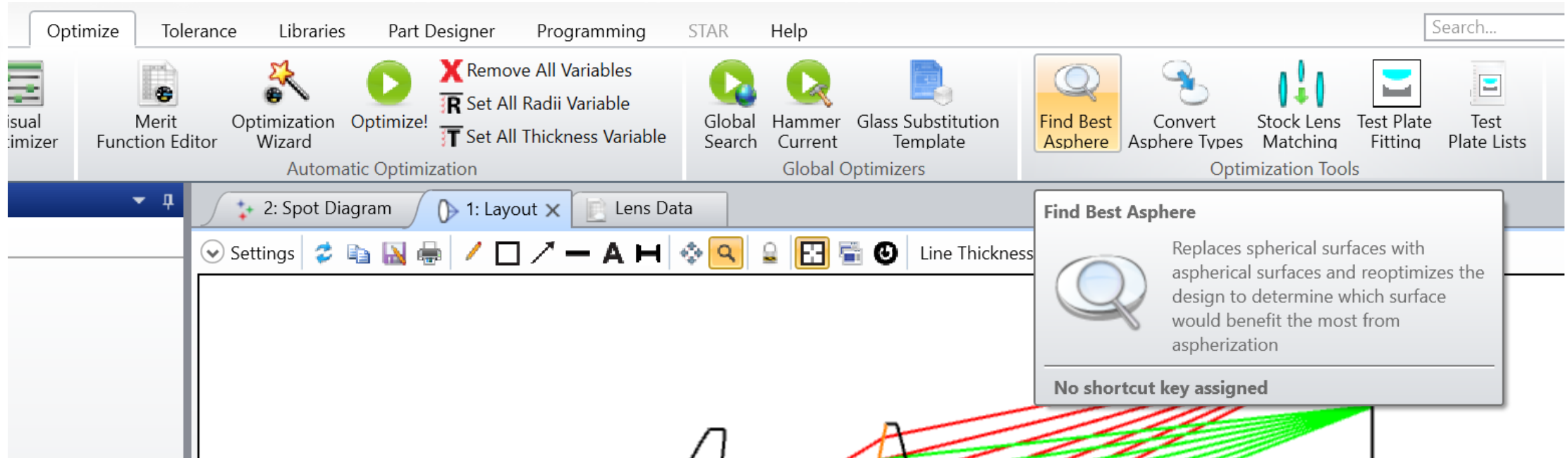
Odd Order Asphere

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

Extended Odd Asphere

$$z = \frac{cr^2}{1 + \sqrt{1 - (1+k)c^2r^2}} + \sum_{i=2}^N \alpha_i \rho^i \quad \text{Order up to 240}$$

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

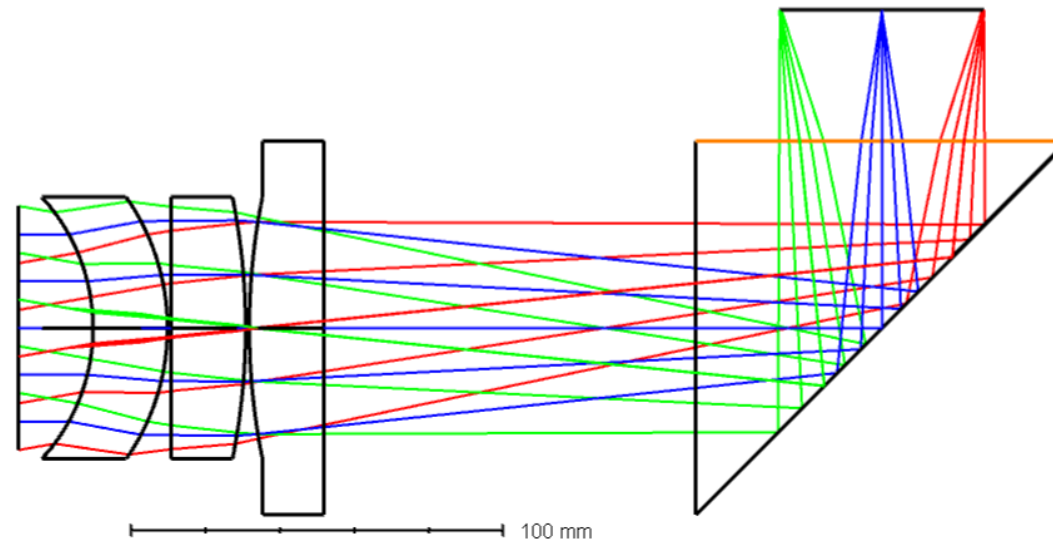
ZEMAX OpticStudio: Coordinate Breaks

Lens Data X 4: Prescription Data

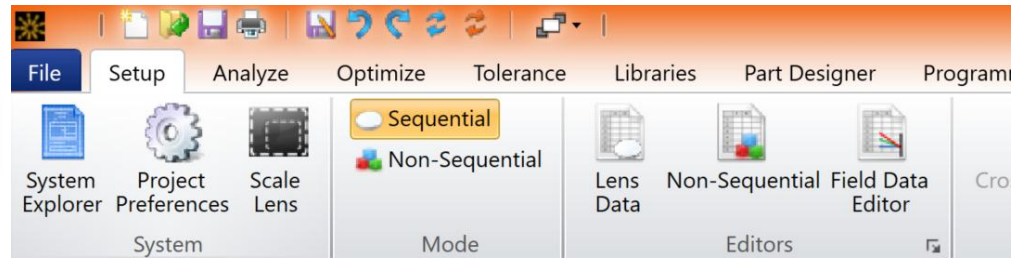
Update: All Windows

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						

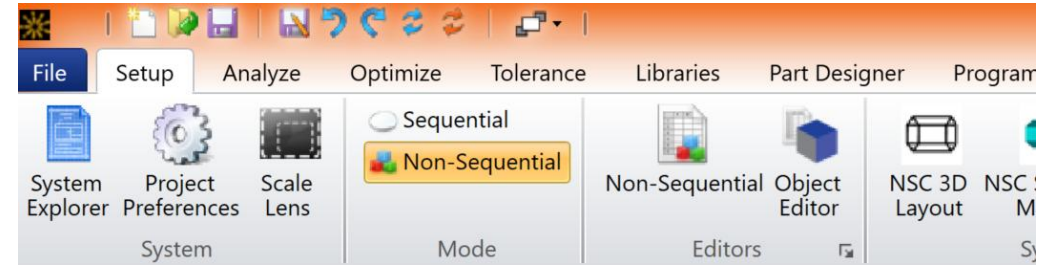


ZEMAX OpticStudio: Non-sequential Mode



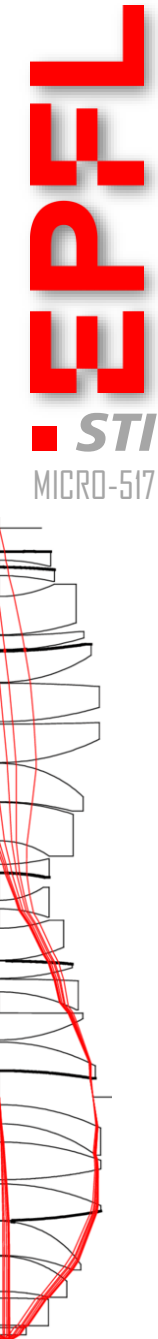
Sequential Mode

- 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

Basic_NS_Design.zmx - Ansys Zemax OpticStudio 2023 R1.03 Premium (3) - A207209

File Setup Analyze Optimize Tolerance Libraries Part Designer Programming STAR Help

System Explorer Project Preferences Scale Lenses Non-Sequential Object Editor NSC 3D Layout NSC Shaded Model CAD Part Viewer Object Editor System Check Ignore Trace Errors Create Error Ray Bring To Front Window Dock New Options Windows MC Editor Next Previous Configuration

System Explore Non-Sequential Component Editor

Update: All Windows Update: All Windows CAD - Z

Object 2 Properties Configuration 1/1

Object Type	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	# Layout Rays	# Analysis Ray	Power
1 Standard Surface	0	0	0.000	0.000	0.000	0.000	0.000	0.000	MIRROR	100.000	1.00E+00	150
2 Source Filament	0	0	-10.000	0.000	50.000	0.000	90.000	0.000		10	5E+06	1
3 Detector Rectangle	0	0	0.000	0.000	800.000	0.000	0.000	0.000		150.000	150.000	
4 Standard Lens	3	0	0.000	0.000	10.000	0.000	0.000	0.000	BK7	300.000	0.000	150
5 Detector Rectangle	4	0	0.000	0.000	650.000	0.000	0.000	0.000		100.000	100.000	
6 Rectangular Volume	-1	0	0.000	0.000	20.000	0.000	0.000	0.000	ACRYLIC	70.000	70.000	2000
7 Detector Rectangle	-1	0	0.000	0.000	2010.0...	P	0.000	0.000	ABSORB	100.000	100.000	

4: Detector Viewer 2

Settings Automatic

Incoherent Irradiance

Y coordinate value

X coordinate value

Detector Image: Incoherent Irradiance

11/27/2023 Detector 2, NSC Surface 2: Size: 200.000 W x 200.000 H #1111detectors, Pixels: 150 W X 150 H, Total Hits = 8015879 Peak Irradiance = 7.842E-03 Watts/cm² Total Power = 5.1822E-01 Watts

3: Detector Viewer 1

Settings Automatic

Incoherent Irradiance

Y coordinate value

X coordinate value

Detector Image: Incoherent Irradiance

11/27/2023 Detector 3, NSC Surface 1: Size: 300.000 W x 300.000 H #1111detectors, Pixels: 150 W X 150 H, Total Hits = 3239548 Peak Irradiance = 1.5798E-03 Watts/cm² Total Power = 6.3228E-01 Watts

5: Detector Viewer 3

Settings Automatic

Incoherent Irradiance

Y coordinate value

X coordinate value

Detector Image: Incoherent Irradiance

11/27/2023 Detector 7, NSC Surface 1: Size: 200.000 W x 200.000 H #1111detectors, Pixels: 150 W X 150 H, Total Hits = 299865 Peak Irradiance = 3.0473E-03 Watts/cm² Total Power = 4.8124E-01 Watts

2: NSC Shaded Model

Settings Automatic

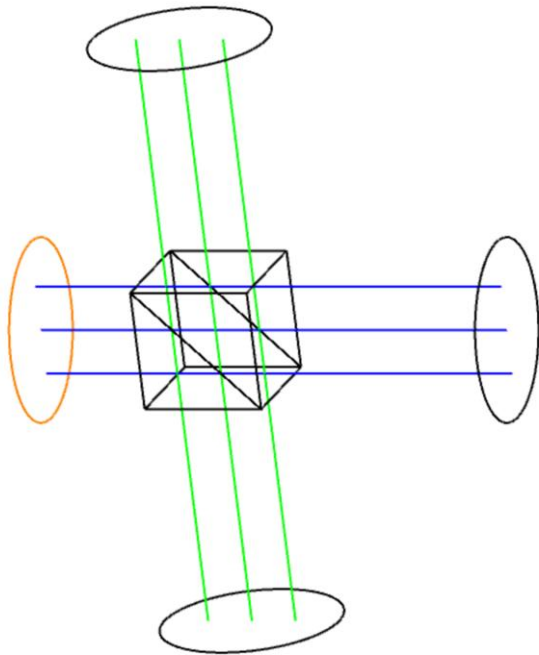
Line Thickness

Always 3D Layout

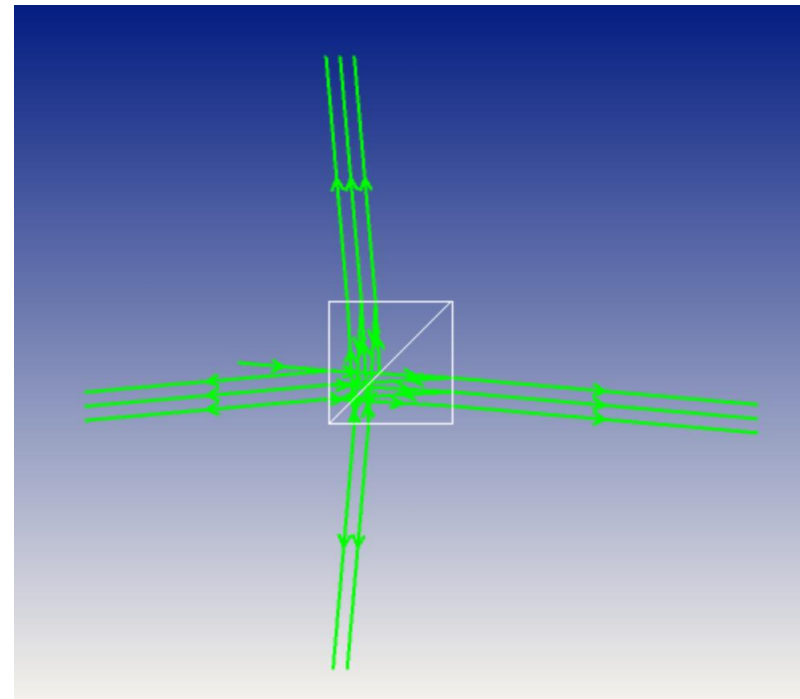
500 mm

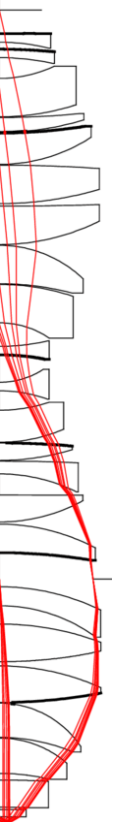
ZEMAX OpticStudio: Beam Splitting

Sequential Mode
Multiconfiguration



Nonsequential Mode



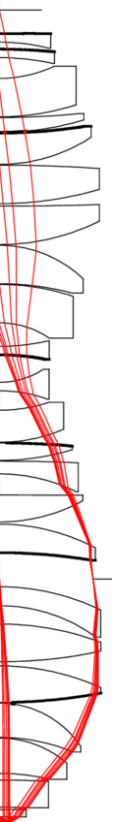


ZEMAX

OpticStudio

Hands-on Time

Homework



To be announced