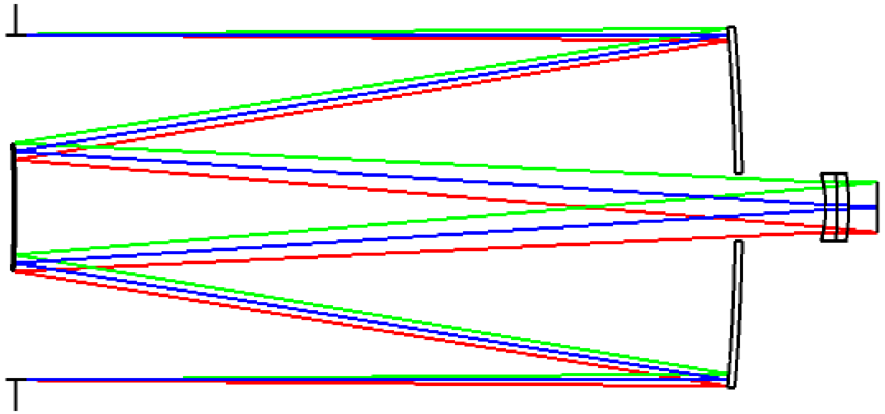
Lectures Notes on Optical Design using Zemax OpticStudio

Reflecting Telescopes



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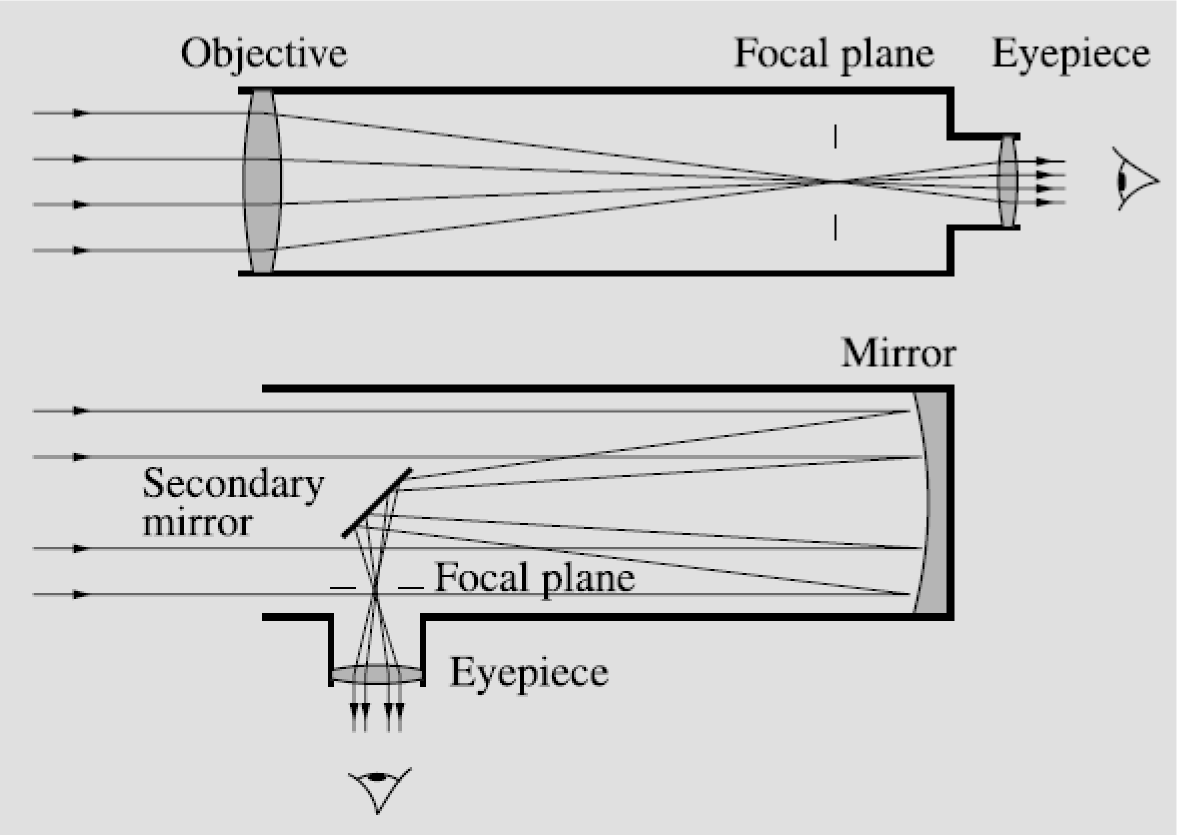
Telescope

- Telescopes are designed to aid in viewing distant objects, such as the planets in our Solar System.

- There are two different types:
  - **refracting telescopes**
    uses a combination of lenses
  - **reflecting telescopes**
    uses a mirrors and a lenses



Some Basic Reflecting Telescopes

1. Newtonian Telescope

- Uses two mirrors: parabolic and flat.
- Typical f-numbers: f/3 . . . f/10.
- Total length of telescope is in the order of focal length of mirror.

2. Cassegrain Telescope

- Uses two mirrors: parabolic and convex hyperbolic.
- Typical f-numbers: f/8 . . . f/15.
- Primary and secondary focal foints are the foci of the hyperbola.
- Total length of the telescope is much shorter than Newtonian for the same primary focal length.

3. Gregorian Telesscpope

- Uses two mirrors: parabolic and concave elliptical.
- The primary and secondary focal points of this telescope are the foci of the ellipse.

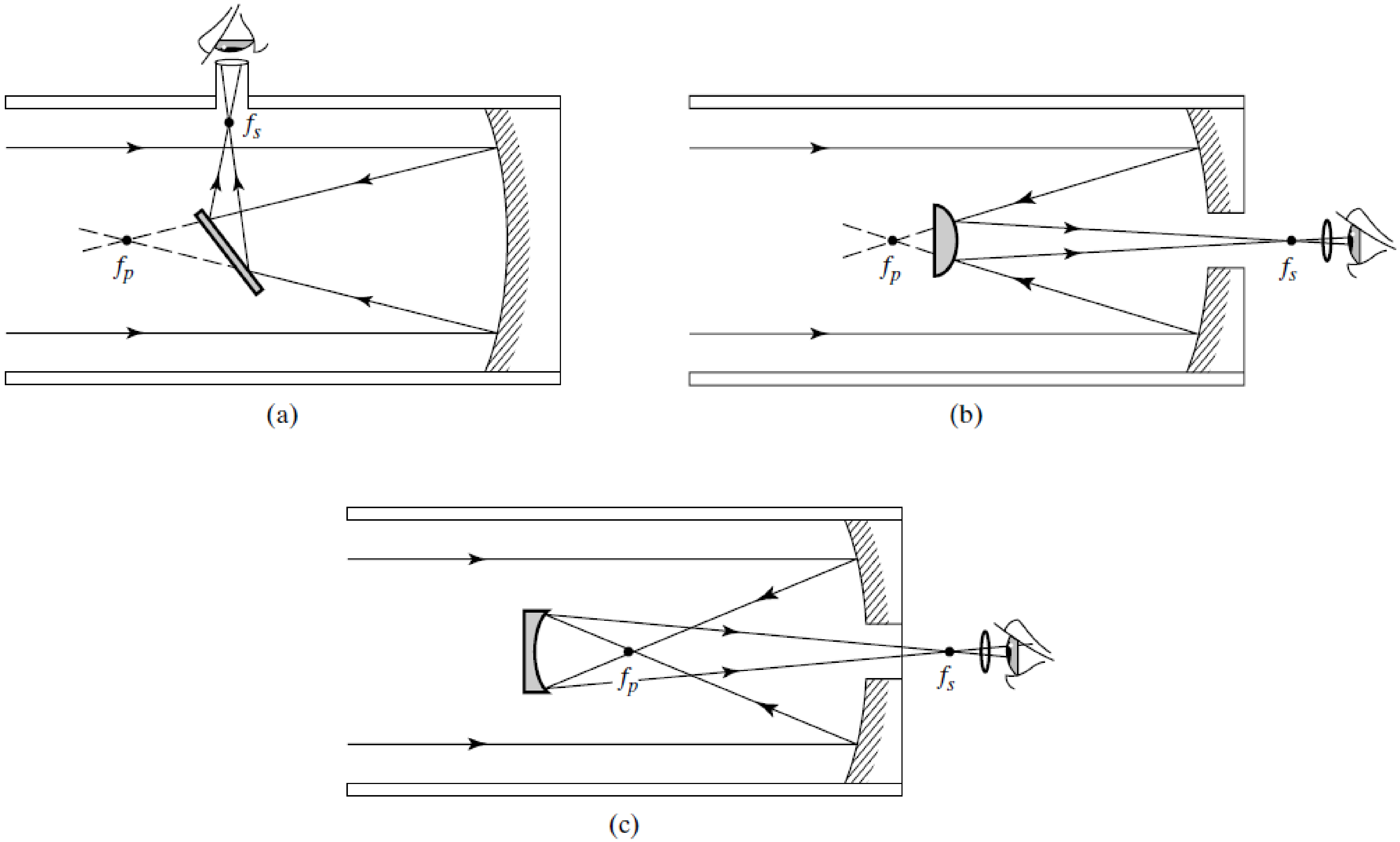


Figure 34 Basic designs for reflecting telescopes. (a) Newtonian telescope. (b) Cassegrain telescope. (c) Gregorian telescope.

Our Newtonian Telescope Project

http://www1.gantep.edu.tr/~bingul/hezarfen

- The largest *reflecting* telescopes in the world are at the Keck Observatory on Mauna Kea, Hawaii at an elevation of **4145 meters**.
- Two telescopes with **diameters of 10 m**, each containing 36 hexagonally shaped, computer-controlled mirrors that work together to form a large reflecting surface.

Example: Newtonian Telescope

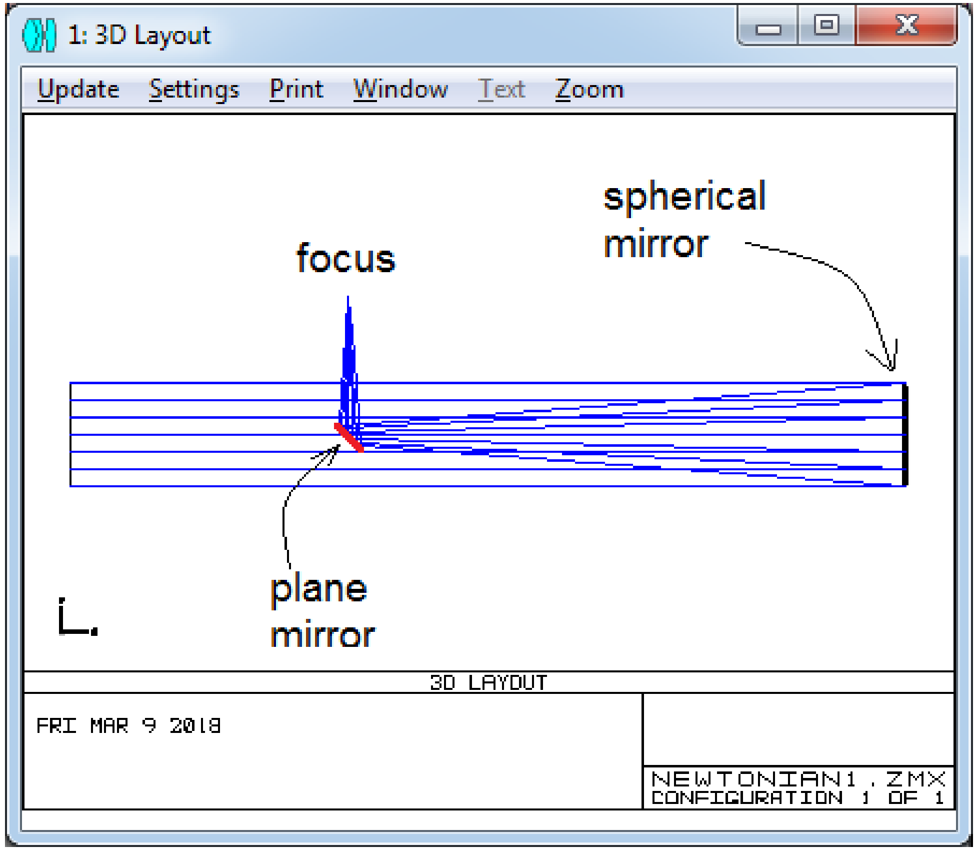
(a) In Zemax, fulll the simulation of the Newtonian Telescope; one concave mirror and one flat mirror. Let the entrance pupil 150 mm, radius of curvature of the mirror is |R| = 1.5 m and the distance between primary and secondary mirror is 0.6 m. Image plane is placed at a distance 0.2 m from the flat (secondary) mirror.

(b) What is the geometric radius of the spot diagram on the image plane?

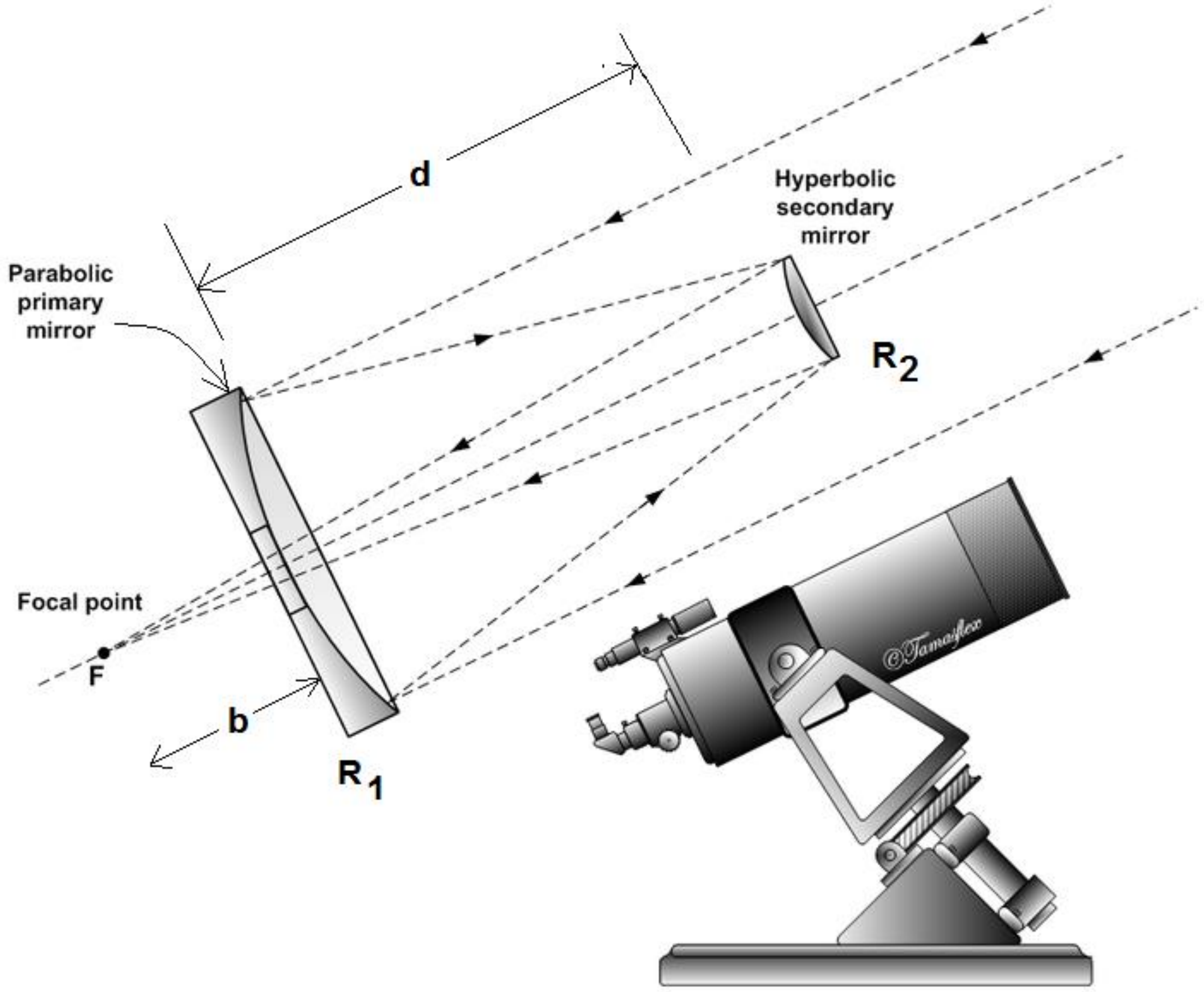
(c) What is the dimension of secondary mirror?

(d) Determine the location of image plane where we have a minimum spot size.

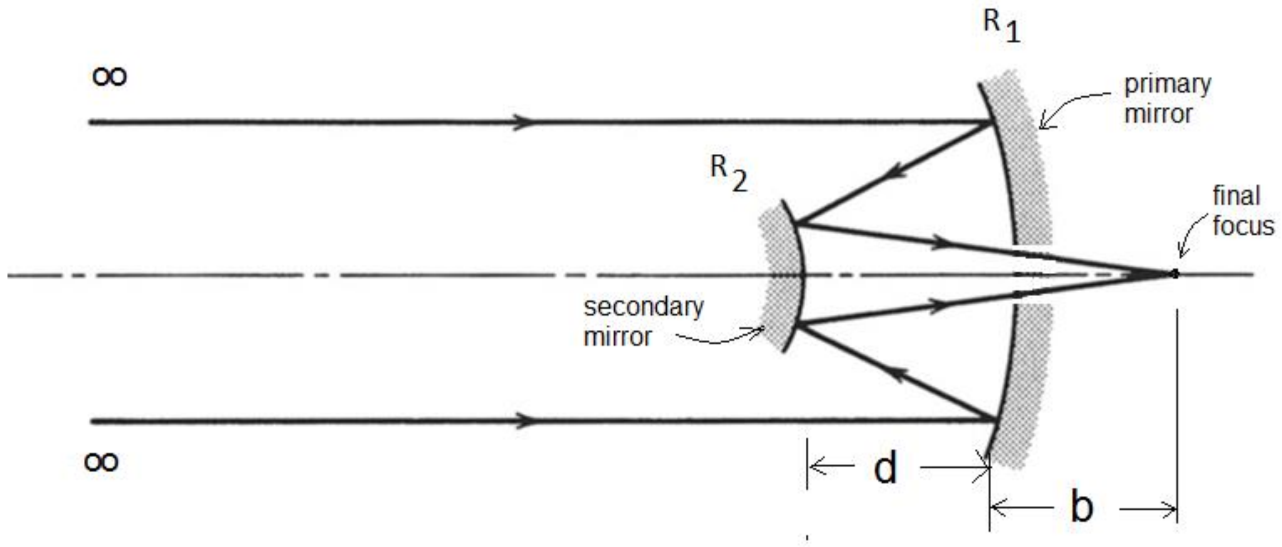
(e) What is magnification of the telesccope with an eyepiece having focal length of 20 mm?



Cassegrain Telescope



R_1 = radius of primary (first) mirror
R_2 = radius of secondary mirror
d = distance between mirrors
b = back focal distance (BFD)
f = focal length of the telecscope
$f_1 = R_1/2 < 0$ (focal length of Mirror 1)
$f_2 = R_2/2 < 0$ (focal length of Mirror 2)



For two spherical mirrors, we can obtain the following equations via paraxial ray tracing:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

$$d + b = \left(1 - \frac{d}{f_1}\right) f$$

Example: Cassegrain Telescope

Implement a Cassegrain Telescope whose system parameters are:

System focal length f = 800 mm

Distance between mirrors d = 200 mm

Back focal distance (BFD) b = 50 mm

Primary mirror diameter D = 200 mm

We have two equations:

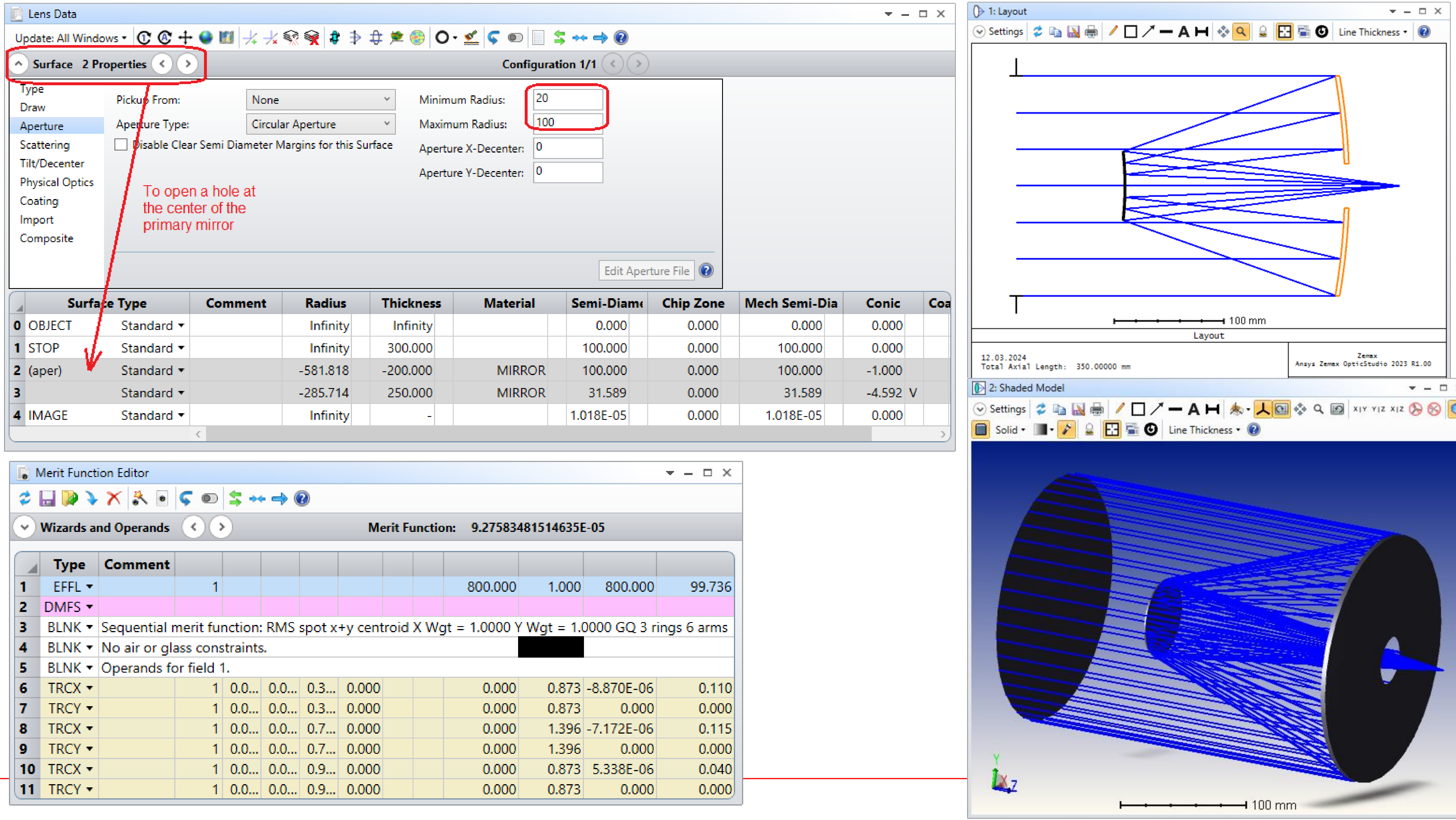
$$\frac{1}{800} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{200}{f_1 f_2} \qquad\qquad 250 = 800(1 - \frac{200}{f_1})$$

Solving for focal lengths and radii of the mirrors:

f_1 = +290.909 mm => $|R_1|$ = 581.818 mm

f_2 = −142.857 mm => $|R_2|$ = 285.714 mm

Note that the total distance of telescope is b+d = 250 mm. Focal length is f = 800 mm.


Lens Data
Update: All Windows
Surface 2 Properties
Configuration 1/1
Type
Draw
Aperture
Scattering
Tilt/Decenter
Physical Optics
Coating
Import
Composite
Pickup From: None
Aperture Type: Circular Aperture
Disable Clear Semi Diameter Margins for this Surface
Minimum Radius: 20
Maximum Radius: 100
Aperture X-Decenter: 0
Aperture Y-Decenter: 0
Edit Aperture File
To open a hole at the center of the primary mirror
Surface Type | Comment | Radius | Thickness | Material | Semi-Diame | Chip Zone | Mech Semi-Dia | Conic | Coa
0 OBJECT Standard | Infinity | Infinity | | 0.000 | 0.000 | 0.000 | 0.000
1 STOP Standard | Infinity | 300.000 | | 100.000 | 0.000 | 100.000 | 0.000
2 (aper) Standard | -581.818 | -200.000 | MIRROR | 100.000 | 0.000 | 100.000 | -1.000
3 Standard | -285.714 | 250.000 | MIRROR | 31.589 | 0.000 | 31.589 | -4.592 V
4 IMAGE Standard | Infinity | - | | 1.018E-05 | 0.000 | 1.018E-05 | 0.000
Merit Function Editor
Wizards and Operands
Merit Function: 9.27583481514635E-05
Type | Comment
1 EFFL 1 800.000 1.000 800.000 99.736
2 DMFS
3 BLNK Sequential merit function: RMS spot x+y centroid X Wgt = 1.0000 Y Wgt = 1.0000 GQ 3 rings 6 arms
4 BLNK No air or glass constraints.
5 BLNK Operands for field 1.
6 TRCX 1 0.0... 0.0... 0.3... 0.000 0.000 0.873 -8.870E-06 0.110
7 TRCY 1 0.0... 0.0... 0.3... 0.000 0.000 0.873 0.000 0.000
8 TRCX 1 0.0... 0.0... 0.7... 0.000 0.000 1.396 -7.172E-06 0.115
9 TRCY 1 0.0... 0.0... 0.7... 0.000 0.000 1.396 0.000 0.000
10 TRCX 1 0.0... 0.0... 0.9... 0.000 0.000 0.873 5.338E-06 0.040
11 TRCY 1 0.0... 0.0... 0.9... 0.000 0.000 0.873 0.000 0.000
1: Layout
Settings
Line Thickness
100 mm
Layout
12.03.2024
Total Axial Length: 350.00000 mm
Zemax
Ansys Zemax OpticStudio 2023 R1.00
2: Shaded Model
Settings
Solid
Line Thickness
100 mm

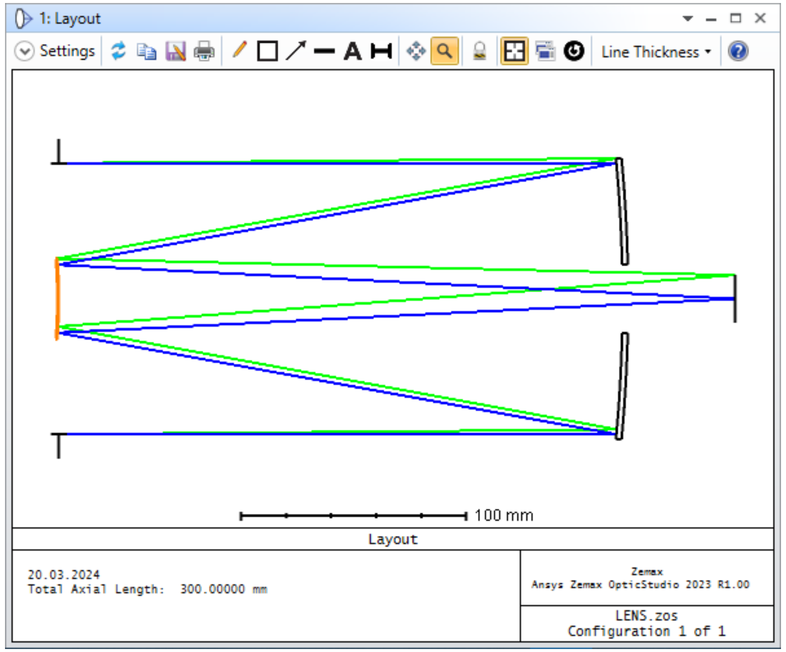
Cassegrain Design with Field Corrector Lenses

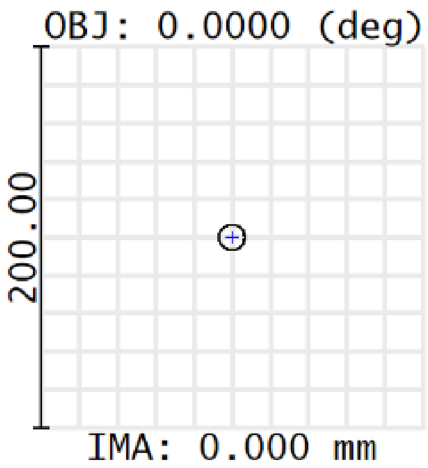
The typical Cassegrain design is known for its excellent on-axis optical performance but tends to perform poorly in off-axis applications.

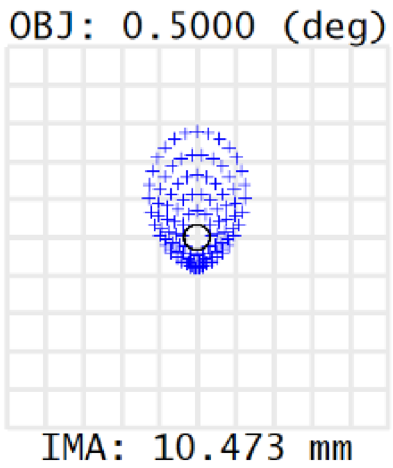
For parabolic mirror, third order angular aberration is given by:

$$AA3 = 3a_1 y^2 \theta / R^2 + 2a_2 y \theta^2 / R + a_3 \theta^3$$

E.g. Cassegrain design with f/10, D= 120 mm, and FOV = 1º.







Cassegrain Design with Field Corrector Lenses

To improve off-axis performance usually a field corrector lens system is added to the mirror system before image sensor.

Note:
If we want to design Cassegrain Telescope whose target (final) focal length F with a corrector lens,

1. Design Cassegrain mirror system with focal length a bit grater or smaller than the target F.
   Namely, two-mirror focal length should be:
   $F' = F + \Delta F$ or $F' = F - \Delta F$
2. Add corrector lenses and optimize full system to reach target focal length, F.

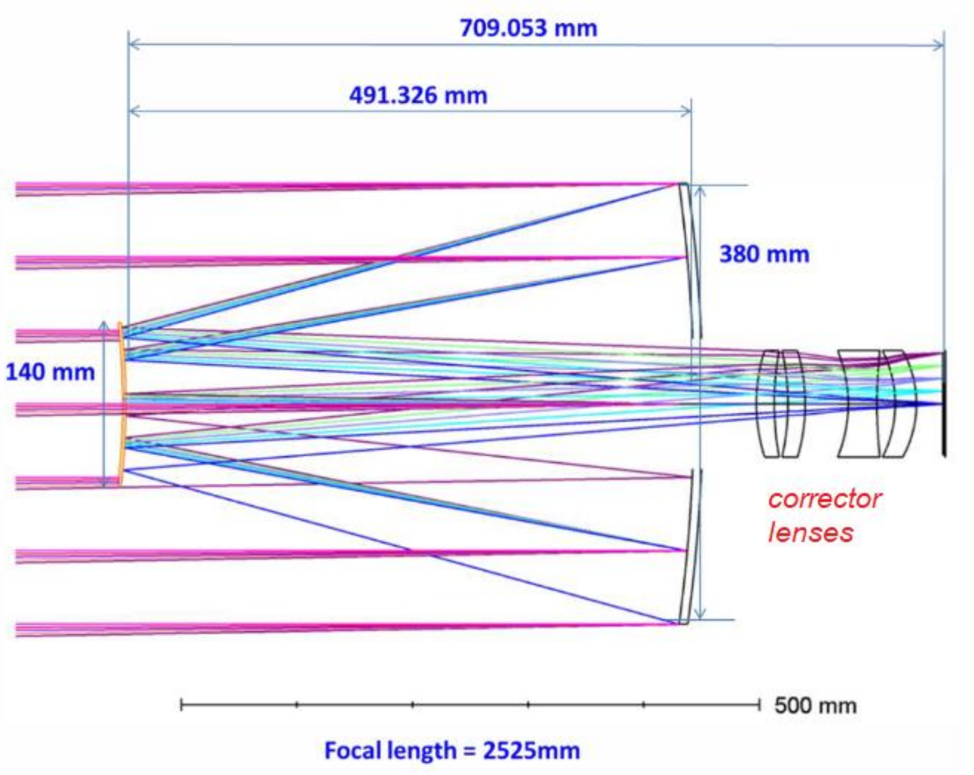


Figure 1: Optical design layout of the Micro-satellite telescope.

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Example: Cassegrain Telescope with Corrector Design

Design a Cassegrain Telescope with corrector to satisfy the following specifications:

EFFL = 1000 mm

F/# = 10

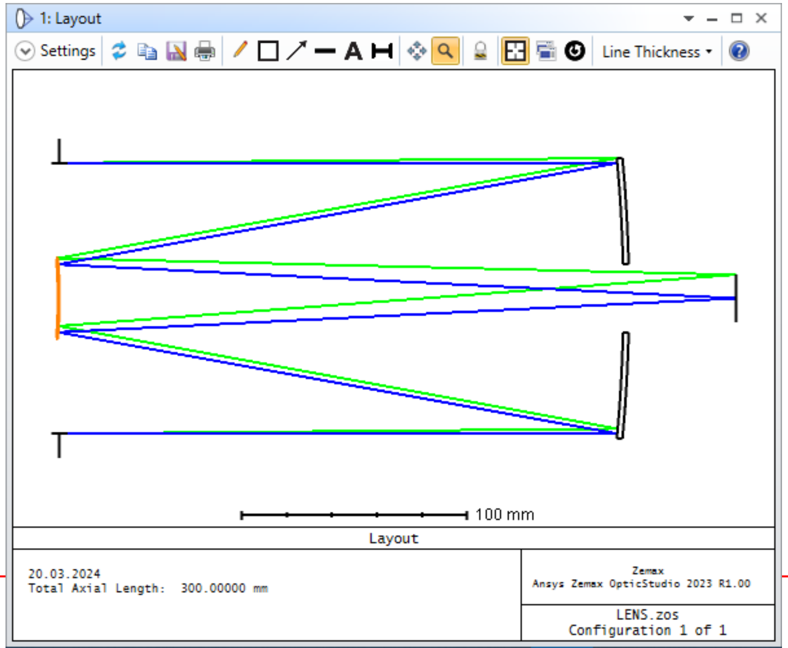
WAVE = F, d, C (visible)

FOV = 1^o

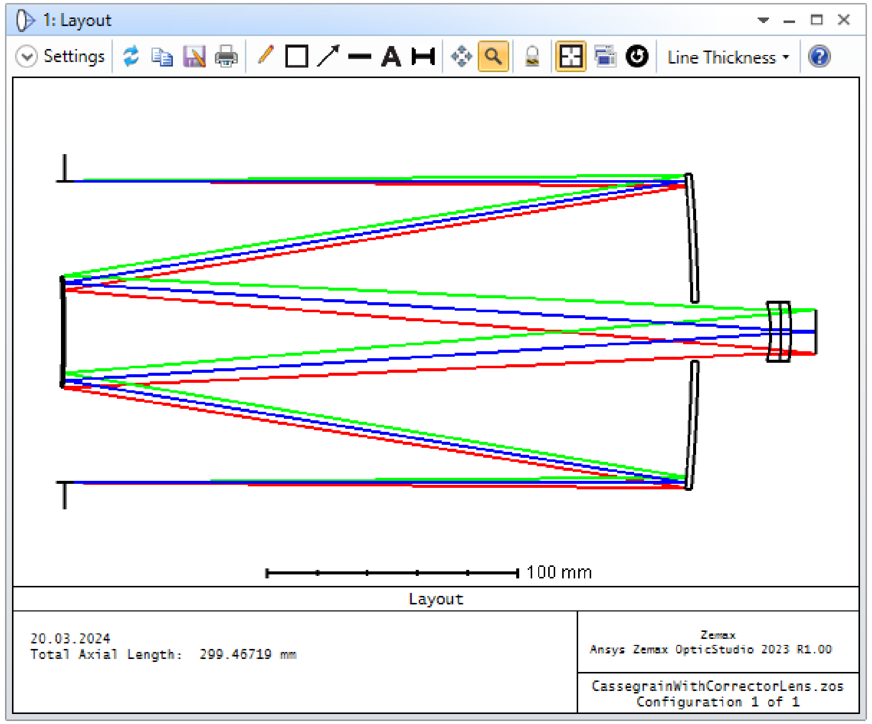
TOTR < 300 mm

Step 1: Design Cassegrain mirrors such that system focal length is F' = 1200 mm as follows:

	Surface Type		Comn	Radius	Thickness	Material	Semi-Diame	Chip Zone	Mech Semi-Dia	Conic
0	OBJECT	Standard		Infinity	Infinity		Infinity	0.000	Infinity	0.000
1	STOP	Standard		Infinity	250.000		60.000	0.000	60.000	0.000
2	(aper)	Standard		-666.667	-250.000	MIRROR	62.156	0.000	62.156	-1.000
3		Standard		-230.769	300.000	MIRROR	17.782	0.000	17.782	-3.130
4	IMAGE	Standard		Infinity	-		10.528	0.000	10.528	0.000



Step2: Add a doublet lens and optimize the system as follows. Notice F = 1000 mm.



Merit Function Editor

Wizards and Operands — Merit Function: 0.000351778933714607

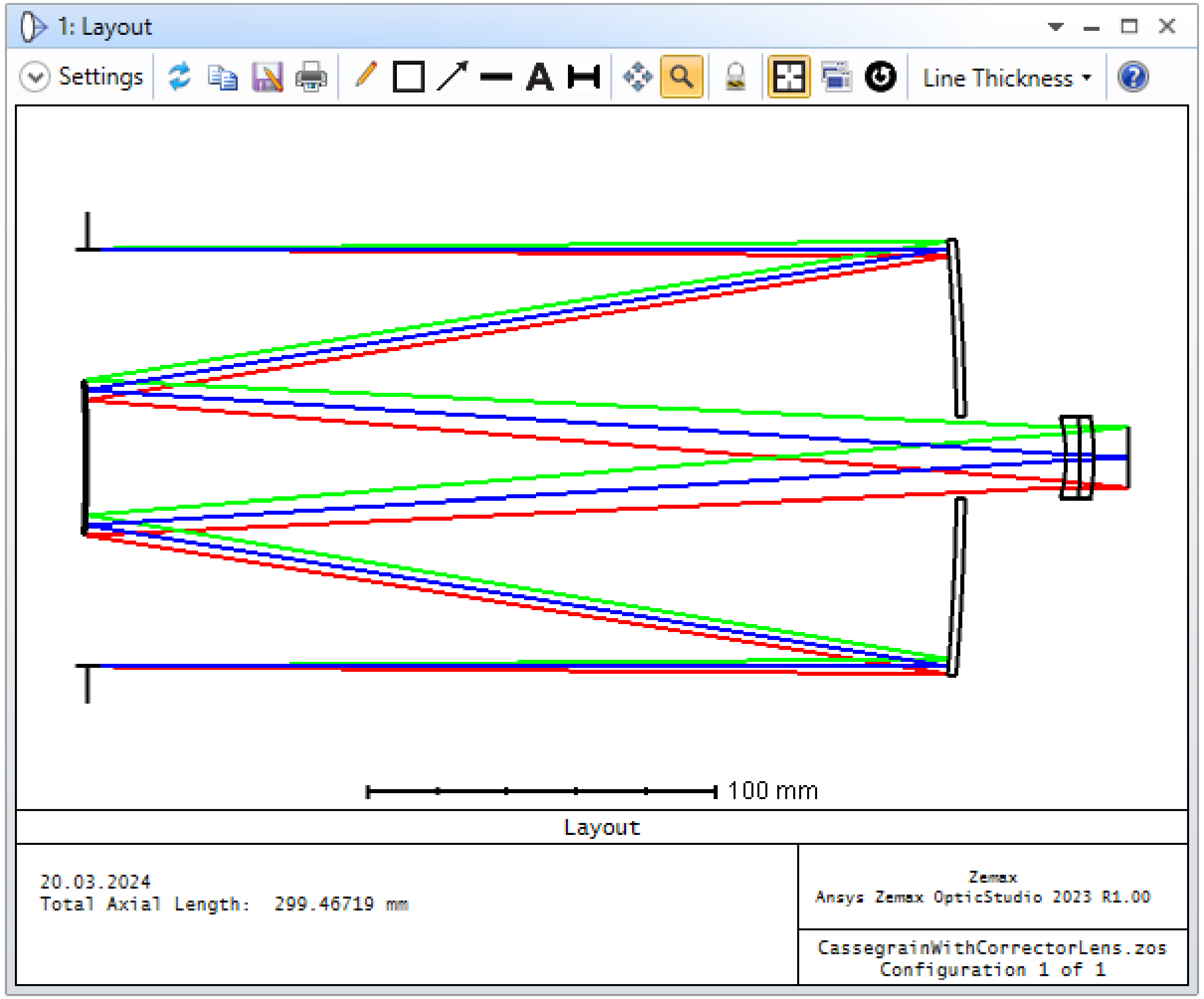
	Type	Surf1	Surf2	Target	Weight	Value	% Contrib
1	EFFL		1	1000.000	1.000	1000.000	5.176E-10
2	TOTR			0.000	0.000	299.467	0.000
3	OPLT	2		300.000	1.000	300.000	0.000
4	DMFS						
5	BLNK	Sequential merit function: RMS spot x+y centroid X Wgt = 1.0000 Y Wgt = 1.0000 GQ 3 rings 6 arms					

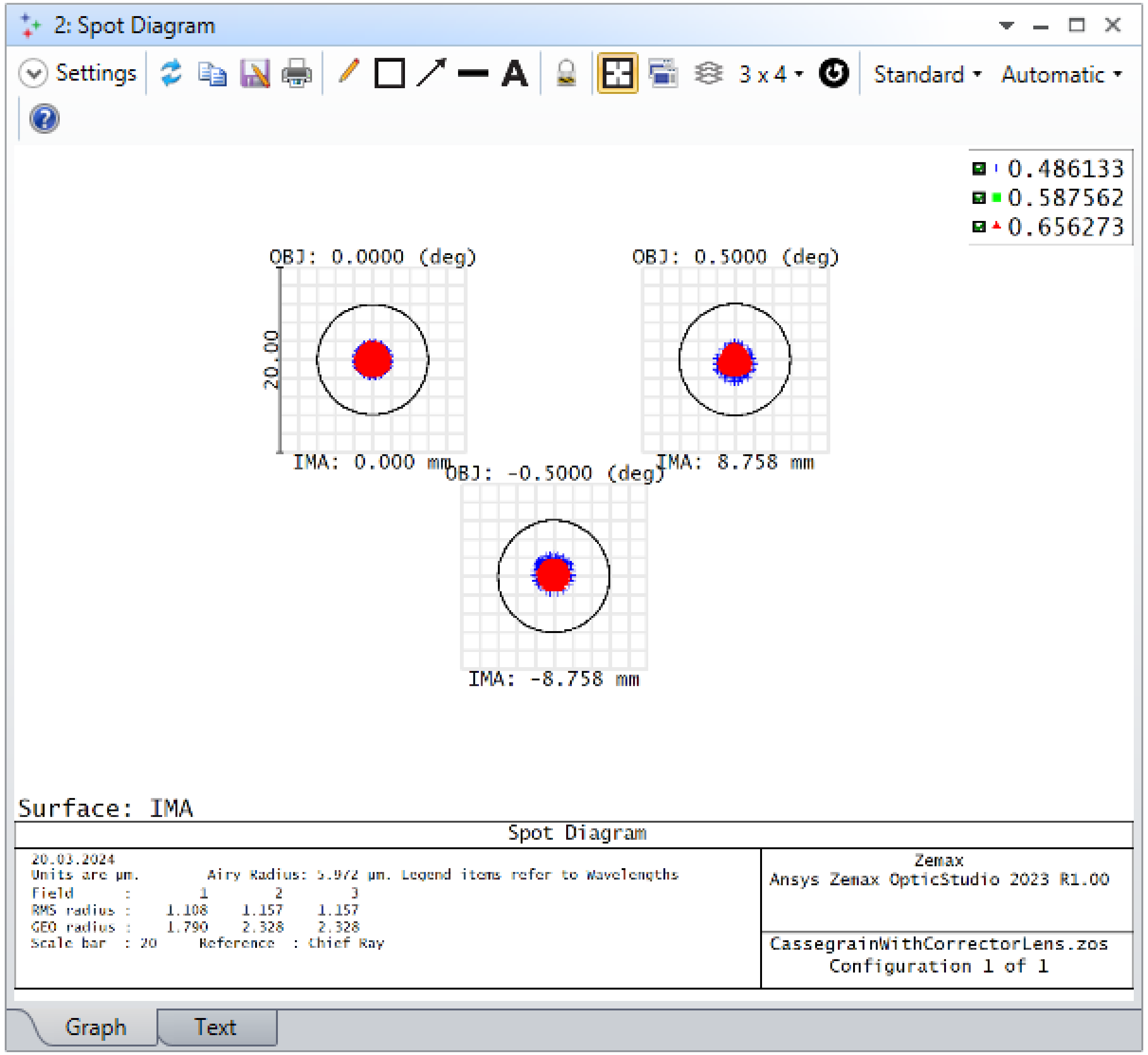
Lens Data

Update: All Windows

Surface 1 Properties — Configuration 1/1

		Surface Type	Comn	Radius	Thickness	Material	Clear Semi-	Chip Zone	Mech Semi-Dia	Conic
0	OBJECT	Standard		Infinity	Infinity		Infinity	0.000	Infinity	0.000
1	STOP	Standard		Infinity	250.000		60.000	0.000	60.000	0.000
2	(aper)	Standard		-736.836 V	-250.000	MIRROR	62.159	0.000	62.594	-1.205 V
3		Standard		-395.780 V	281.467 V	MIRROR	22.271	0.000	22.271	-8.518 V
4	(aper)	Standard		-42.971 V	4.000	N-BK7	12.000 U	0.000	12.000	0.000
5	(aper)	Standard		-168.166 V	4.000	N-SF2	12.000 U	0.000	12.000	0.000
6	(aper)	Standard		-68.005 V	10.000		12.000 U	0.000	12.000	0.000
7	IMAGE	Standard		Infinity	-		8.759	0.000	8.759	0.000


1: Layout
Settings
Line Thickness
100 mm
Layout
20.03.2024
Total Axial Length: 299.46719 mm
Zemax
Ansys Zemax OpticStudio 2023 R1.00
CassegrainWithCorrectorLens.zos
Configuration 1 of 1


2: Spot Diagram
Settings
3 x 4
Standard
Automatic
0.486133
0.587562
0.656273
OBJ: 0.0000 (deg)
20.00
IMA: 0.000 mm
OBJ: 0.5000 (deg)
IMA: 8.758 mm
OBJ: -0.5000 (deg)
IMA: -8.758 mm
Surface: IMA
Spot Diagram
20.03.2024
Units are µm. Airy Radius: 5.972 µm. Legend items refer to Wavelengths
Field : 1 2 3
RMS radius : 1.108 1.157 1.157
GEO radius : 1.790 2.328 2.328
Scale bar : 20 Reference : Chief Ray
Zemax
Ansys Zemax OpticStudio 2023 R1.00
CassegrainWithCorrectorLens.zos
Configuration 1 of 1
Graph
Text