

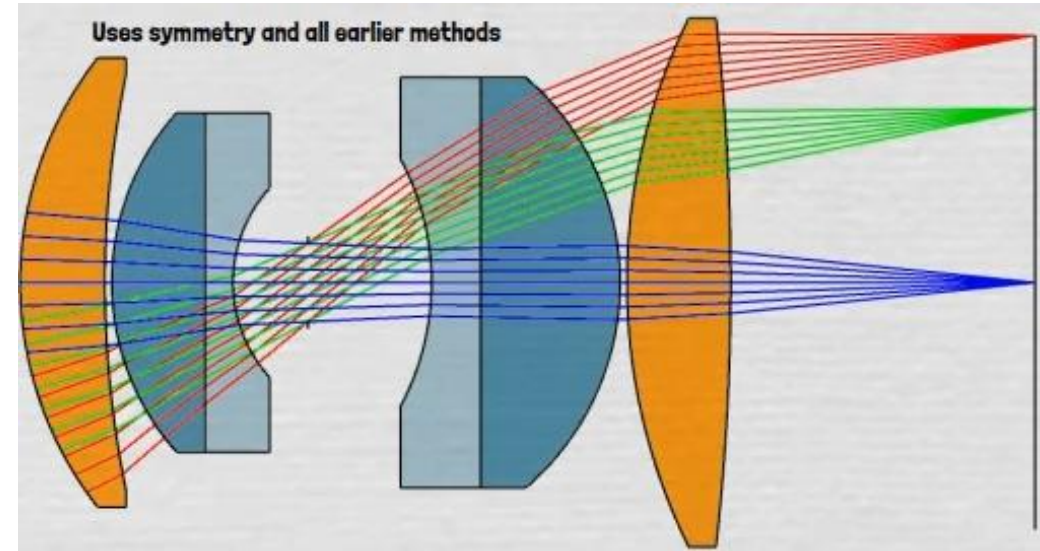


Lectures Notes on Optical Design using Zemax OpticStudio

Design Forms

Ahmet Bingöl

Gaziantep University
Department of Optical
Engineering



Apr 2024

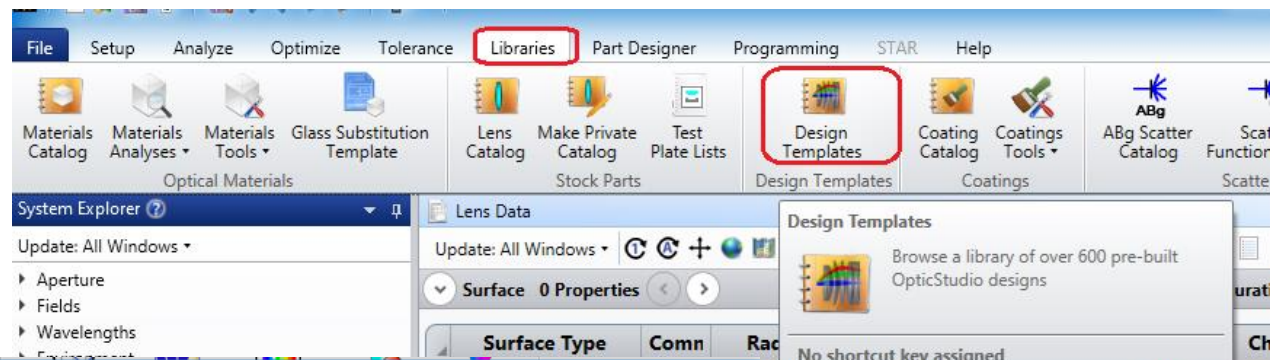
Design Forms

- In the history of optical design, many forms have been proposed for lens designs.
- These can be grouped as singlet, doublet, triplet, ... in terms of the number of lenses.
- In practice, the first step in optical system design is to start with well-known forms that have been studied, tested and approved by many designers.

In this section, we will see some fundamental design forms:

- Camera Objective Lenses
- Mirror Objectives
- Zoom Lenses
- Eyepieces
- Cell Phone Camera Lenses

Design Templates in Zemax



Search Criteria

Exit Pupil Position

Prescription

Exit Pupil Position

System Pressure

System Temperature

Total Track Length

Working F/#

Effective Focal Length

Exit Pupil Diameter

Entrance Pupil Diameter

Entrance Pupil Position

System

Object Distance

Image Distance

Number of Surfaces

Reflective

Author

Notes

Title

Search Results

Front conversion lens

Viewfinder, zoom

AFOCAL OBJECTIVE

SIMPLE 6X24 TELESCOPE

6X24 TELESCOPE

GALILEAN AFOCAL SYSTEM

CYLINDRICAL ANAMORPH

Telescope with Plossl

TIMES FOUR LASER BEAM EXPANDER

TIMES FOUR LASER BEAM EXPANDER

TIMES FOUR LASER BEAM EXPANDER

TIMES FOUR LASER BEAM EXPANDER

OGINO X2 CONVERTER

ZOOM BEAM EXPANDER

8 x 30 Binocular

10X Beam Expander, operation at 10 microns

f/3.5 TRIPLET

F/2 TRIPLET

F/6 TRIPLET

50 INCH f/8 TRIPLET

RADIATION RESISTANT LENS 25 MM f/2.8

TRIPLET OBJECTIVE

TRIPLET OBJECTIVE

TRIPLET OBJECTIVE

COOKE TRIPLET USP 3176582

WIDE-ANGLE COOKE TRIPLET

MICROPHOTOGRAPY OBJECTIVE

COOKE TRIPLET WITH PLASTIC LENSES

TRIPLET TAYLOR

TRIPLET AT F/4 20 DEGREE SEMI-FIELD

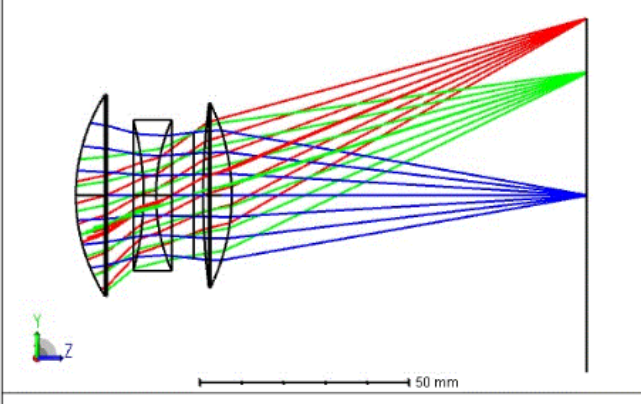
MINUS-PLUS-MINUS TRIPLET

REAR DIAPHRAM TRIPLET

Found 642 Result(s)

Load

Details



50 mm

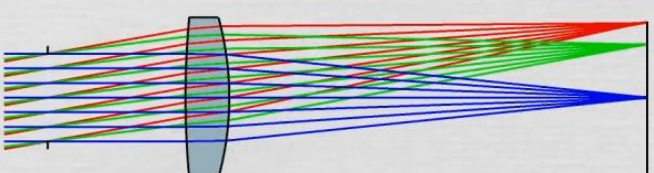
Parameter	Value
Prescription	
Working F/#	2,87335197948903
Total Track Length	121,9416289051
System Temperature	20
System Pressure	1
Exit Pupil Position	-91,6388901815443
Exit Pupil Diameter	33,1912432874823
Entrance Pupil Position	32,635574208848
Entrance Pupil Diameter	35,714
Effective Focal Length	100,000028500613
Performance Seidel	
W311 - Distortion	137,412232851886
W222 - Astigmatism	-10,3377824402642
W220 - Field Curvature	114,003745378694
W131 - Coma	-63,3611276443862
W040 - Spherical	32,9798464452778

CAMERA OBJECTIVE LENSES

Objective Lens Design Forms

Landscape Lens

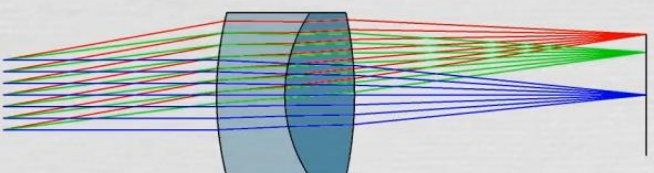
A singlet with the stop separated to give field control



Typical uses: $f/5$ or slower
 $\pm 5^\circ$ field of view or less
 Low-quality image where movement detection may be more important than imaging performance
 Aspheric surfaces and plastic materials make it cheap and easy to make

Color-Corrected Doublet

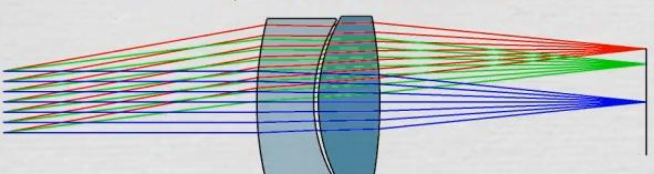
Landscape lens split into a doublet for improved color and field performance



Typical uses: Better imaging quality than Landscape with similar $f/\#$ and field of view
 Must be made from glass rather than plastic.
 - one lens might be plastic
 Aspheric surfaces improve performance

Air-Spaced Doublet

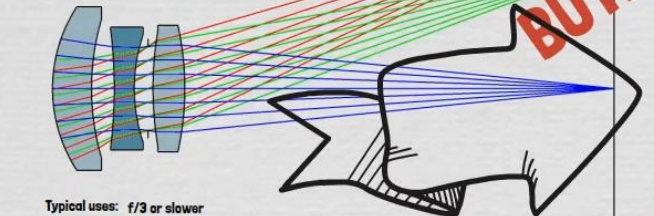
Air gap provides one extra surface for aberration control and increases power of intermediate surfaces



Typical uses: Better imaging quality than cemented doublet with similar $f/\#$ and field of view
 Sensitive to misalignment between the two elements
 Usually provided as mounted assembly
 ~ 3x the cost of cemented doublet

Cooke Triplet

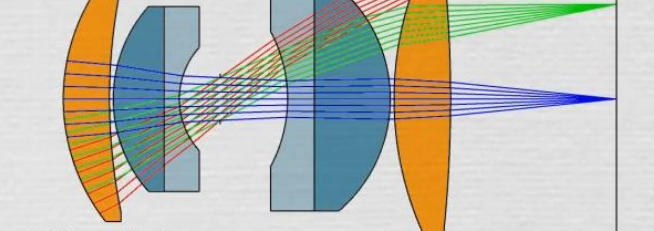
Positive/Negative/Positive shape
 Negative lens provides field aberration control



Typical uses: $f/3$ or slower
 $\pm 20^\circ$ field of view or less
 Widely used in imaging systems
 Capable of approaching diffraction limit over useful field and aperture

Double Gauss

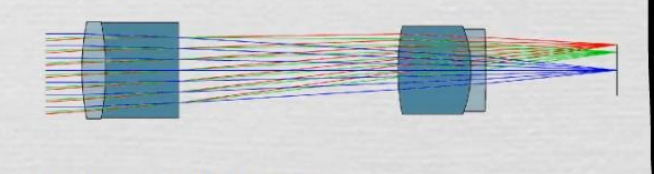
Uses symmetry and all earlier methods



Typical uses: ~ $f/2$ or slower
 $\pm 40^\circ$ field of view or less
 Basis of DSLR and other photographic lenses

Petzval Lens

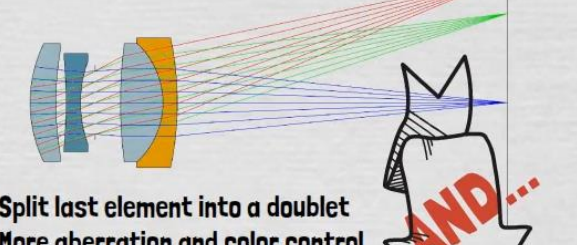
Two positive lenses share imaging duties



Typical uses: ~ $f/4$ with $\pm 4^\circ$ field of view
 Surveillance, spotter, rifle scope
 Excellent imaging at moderate $f/\#$ and low field

Cooke Evolves into Tessar!

Split last element into a doublet
 More aberration and color control



Tessar Evolves into Heliar!

Split first element into a doublet too!



Complex shapes evolve from simpler Basic Shapes

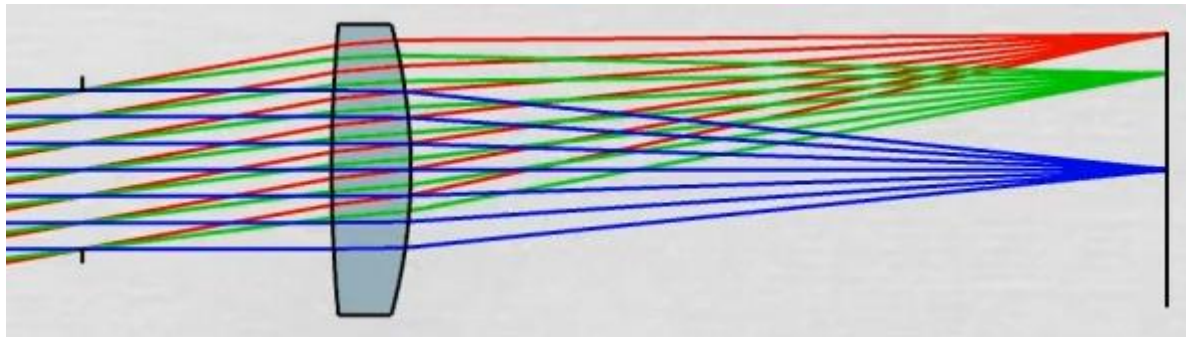
This lets you use faster $f/\#$, higher field of view, better color correction or some mixture of the three

Singlets become doublets
 Doublets can become triplets
 Add extra elements to an existing group
 Use aspheres instead of extra surfaces
 Make changes wherever the dominant aberrations are

[Youtube.com/DesignOpticsFast](https://www.youtube.com/DesignOpticsFast)
 © Copyright 2020 DesignOpticsFast

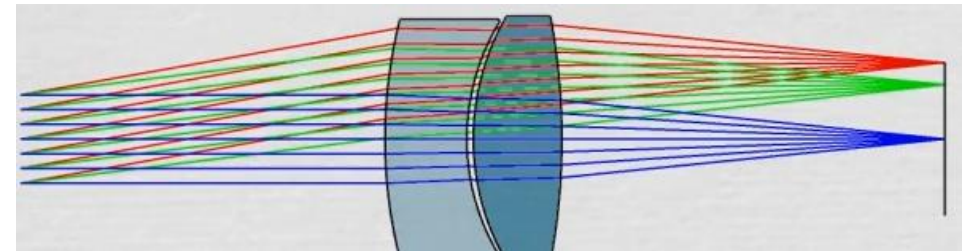
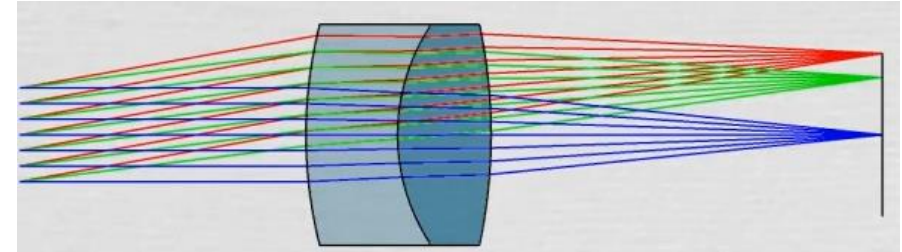
Landscape Lens

- It is single lens
- Typical use of **f/5** or slower
- **FOV < $\pm 5^\circ$**
- FOV can be controlled by aperture stop placed in front of the lens.
- Image quality is low. But, it can be used in movement detection
- Performance can be improved by using aspheric surfaces
- Plastic materials can be used to make it cheap



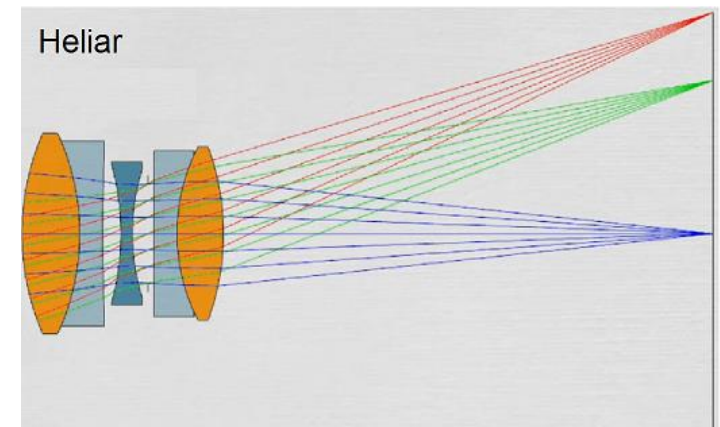
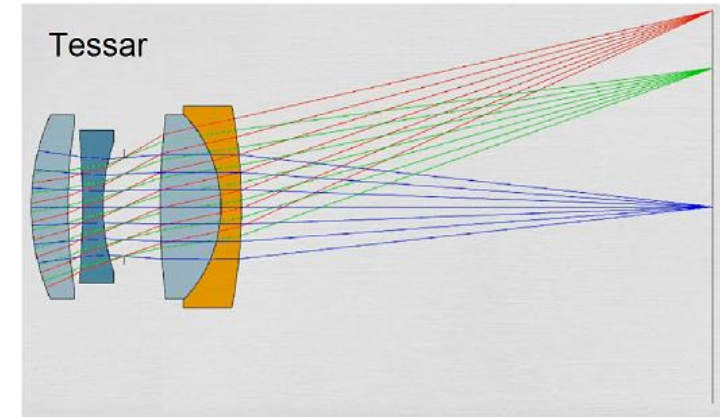
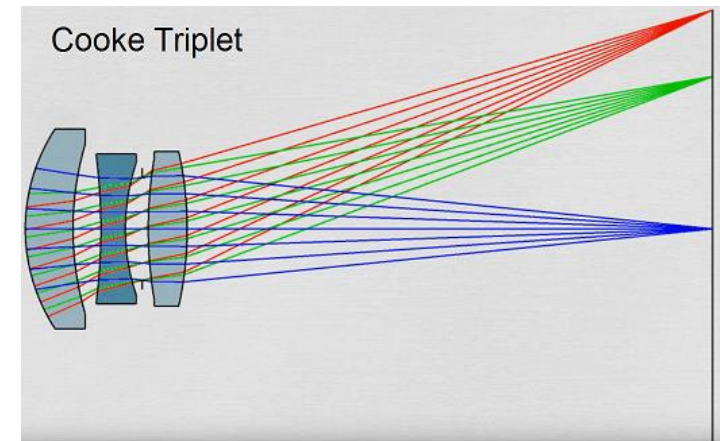
Achromatic Doublets

- Better image quality compared to landscape lens
- **f/5** or slower
- **FOV < $\pm 5^\circ$**
- Two different glasses are used
- Performance can be improved by using aspheric surfaces
- Aberrations are controlled by adding air gap between lenses



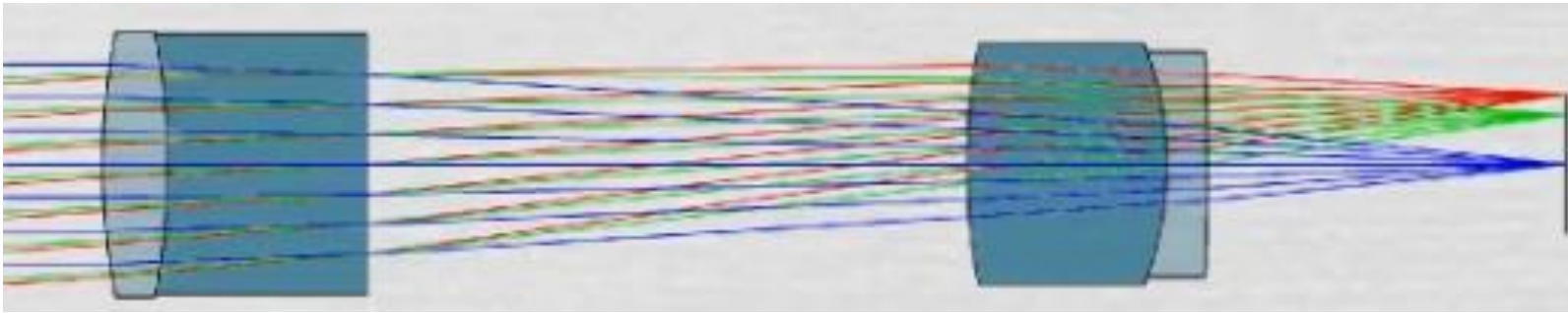
Cooke Triplet

- It is widely used.
- **f/3** or slower
- **FOV < $\pm 20^\circ$**
- Structure is PNP.
Negative lens is used to control FOV.
- AS is in between lenses.
- This triplet can be converted to tessar or heliar to obtain better imaging performance.



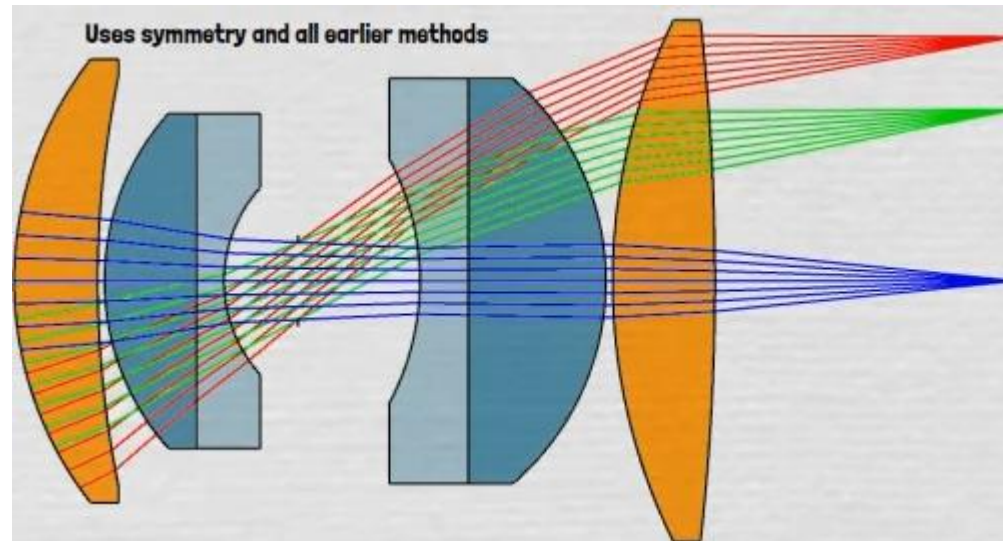
Petzval Lens

- $f/4$ or slower
- $\text{FOV} < \pm 4^\circ$



Double Gauss Lens

- It is symmetric with respect to AS.
- **f/2** slower.
- **FOV < $\pm 40^\circ$**
- Used in DSLR (Digital Single Reflex Camera) photograph machine.



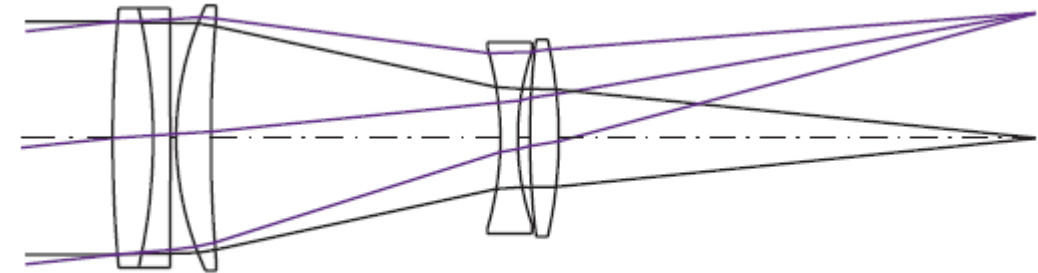
Telephoto Lens

A basic telephoto lens consists of two lens groups (a positive group followed by a negative group). The stop is at or near the front group. The front principal plane is pushed out in front of the lens so that the EFL of a telephoto lens is greater than its physical length (measured from the first lens surface to the image plane). The ratio of the lens length to EFL is called the telephoto ratio.

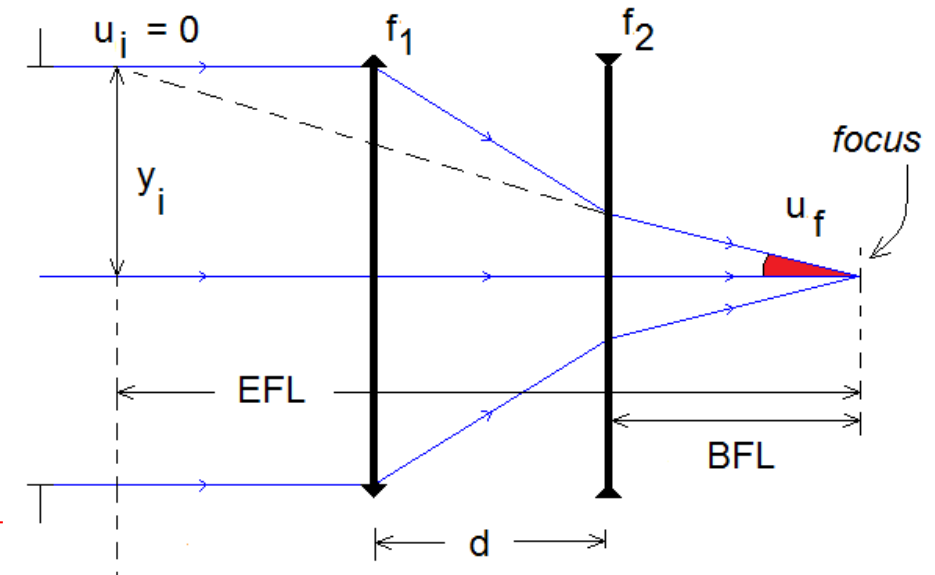
Effective focal length:
$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

Back focal length:
$$BFL = \frac{f_2(d - f_1)}{d - (f_1 + f_2)}$$

Telephoto Ratio:
$$r = \frac{BFL + d}{EFL} < 1$$

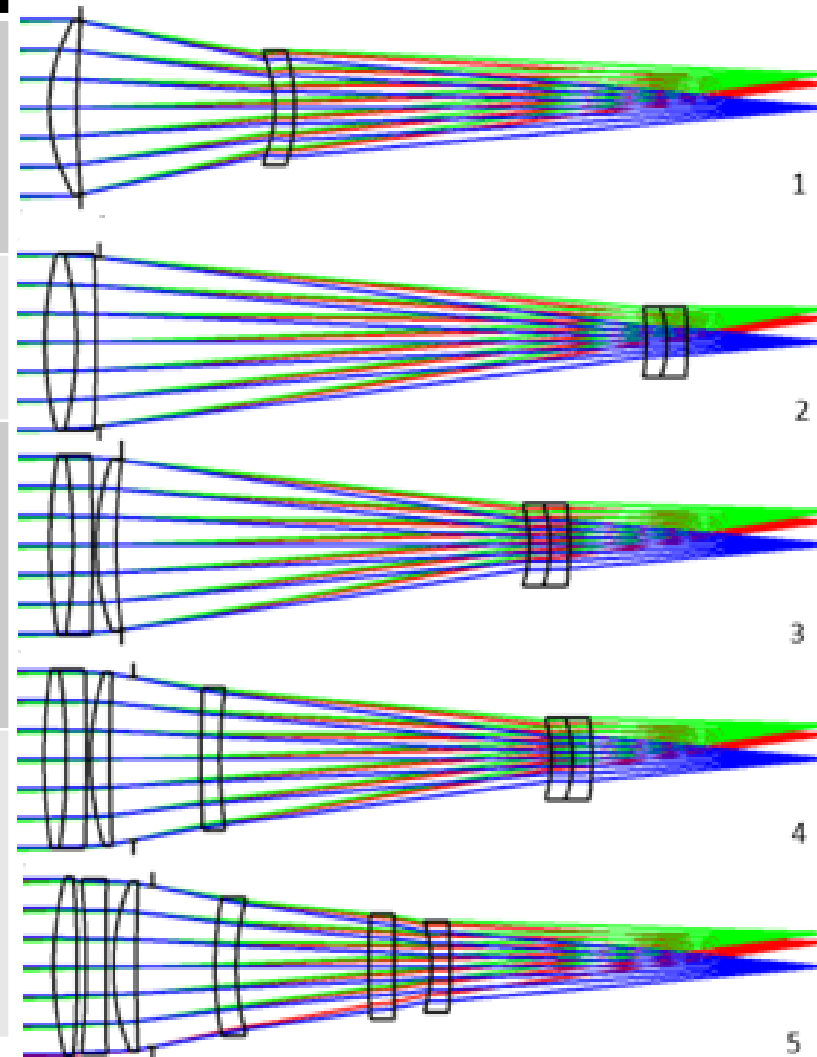


f/5, 6-deg HFOV



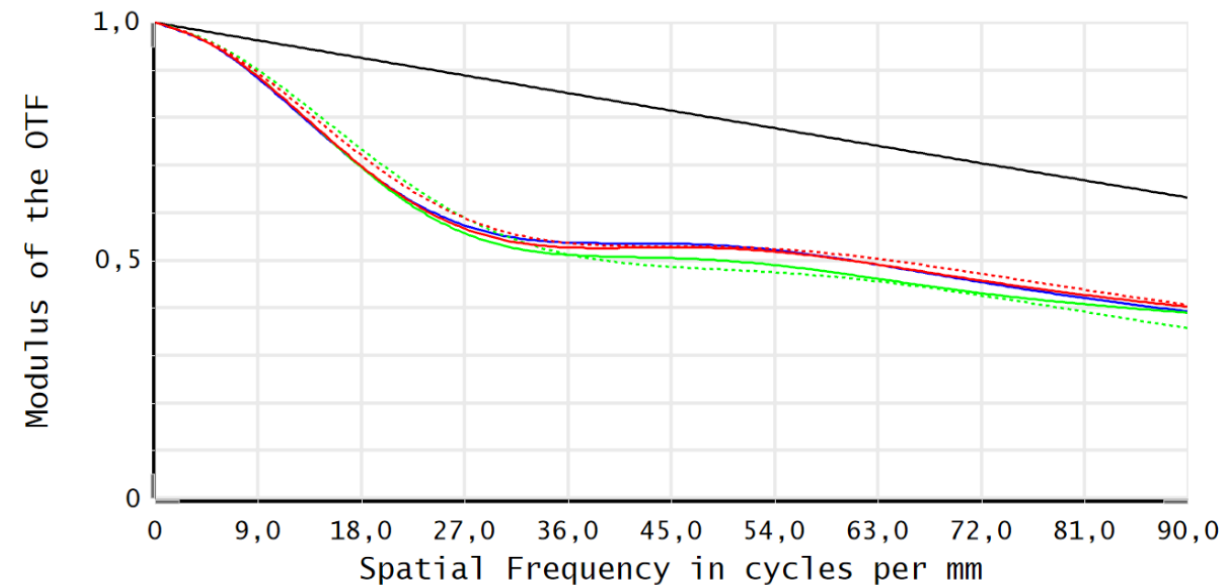
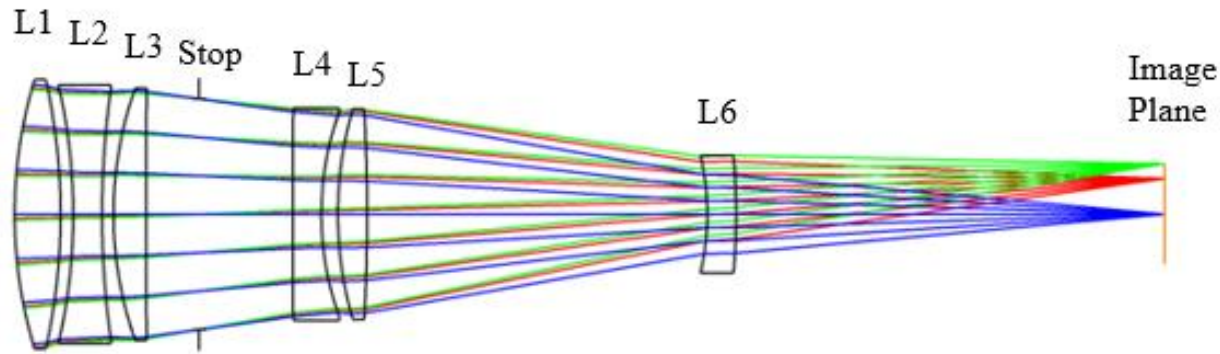
An Example Telephoto Lens Design used in Earh Observation-1

Stages	Explanation
Stage 1	<i>Start with positive and negative lenses with the stop in the middle.</i>
Stage 2	<i>These two lenses are converted to doublet lenses.</i>
Stage 3-4	<i>The lenses are added in front and behind the stop at stages 3 and 4 respectively due to insufficient system performance.</i>
Stage 5	<i>It is optimized again so that doublets in the optical system are separated and a diffraction-limited optic is designed.</i>



An Example Telephoto Lens Design used in Earth Observation-2

The materials used in the design is selected to be radiation resistance for space application.

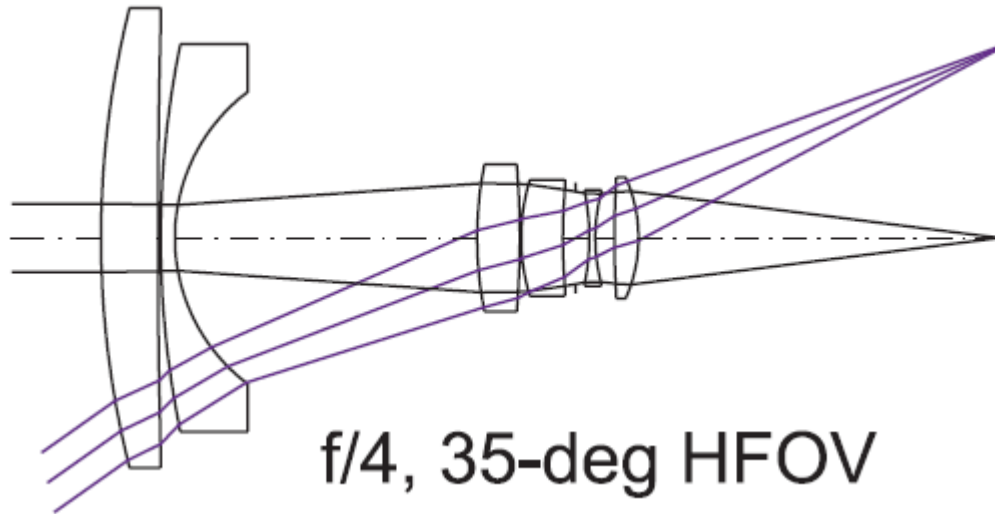


Legend for the graph:

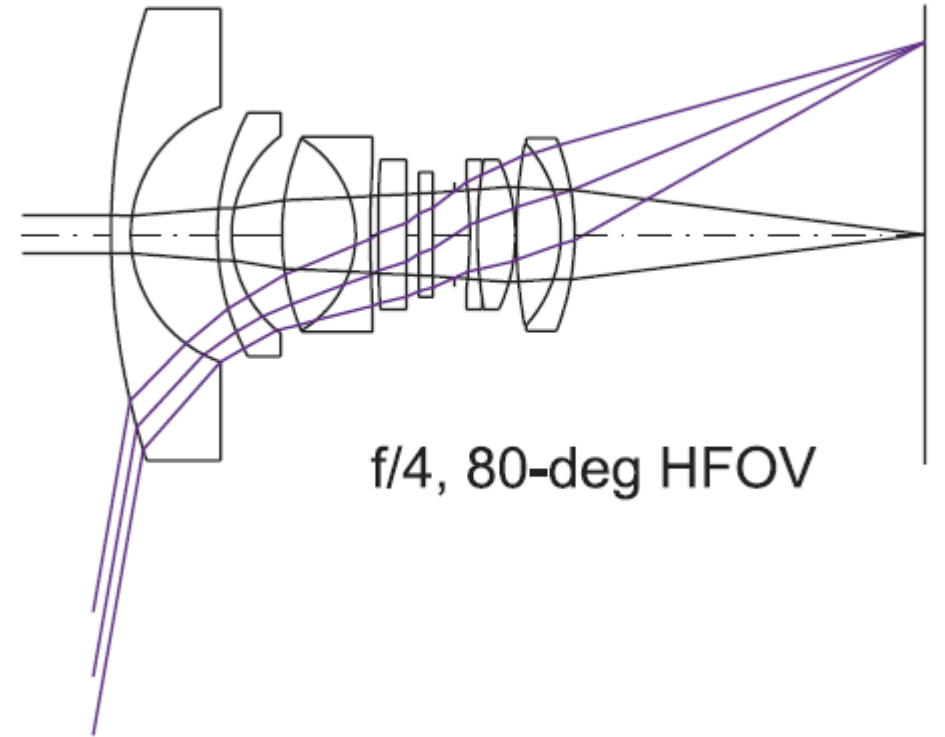
- Diff. Limit-Tangential
- Diff. Limit-Sagittal
- 0,0000 (deg)-Tangential
- 0,0000 (deg)-Sagittal
- 2,0000 (deg)-Tangential
- 2,0000 (deg)-Sagittal
- 1,4142 (deg)-Tangential
- 1,4142 (deg)-Sagittal

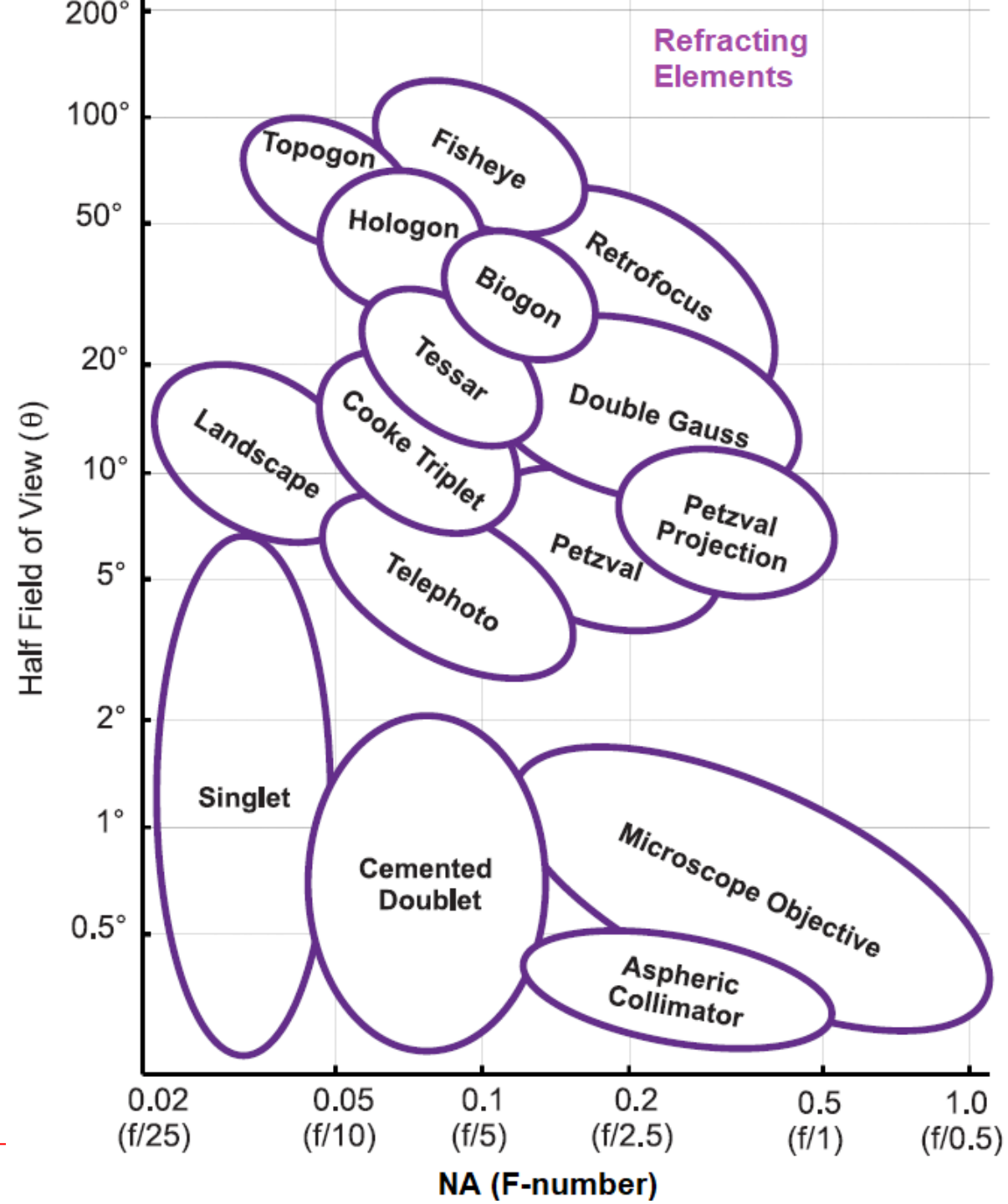
Wide Angle Objectives

Retrofocus



FishEye





MIRROR OBJECTIVES

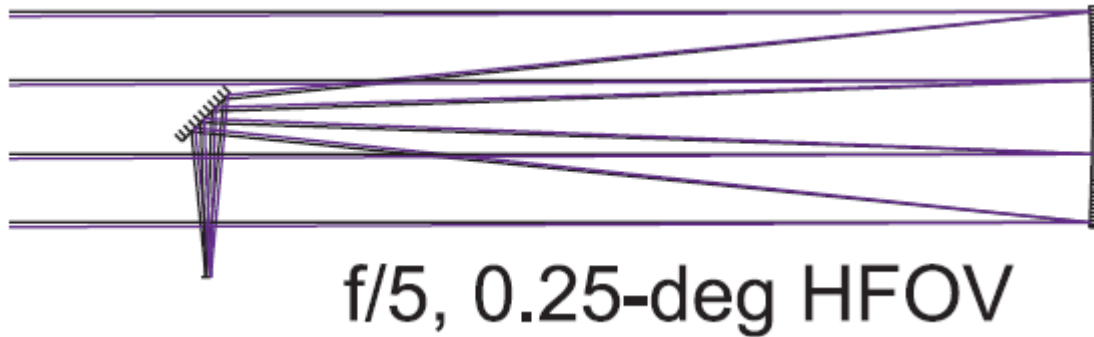
(Telescopes)

Telescopes

Newtonian

Primary: Parabolic

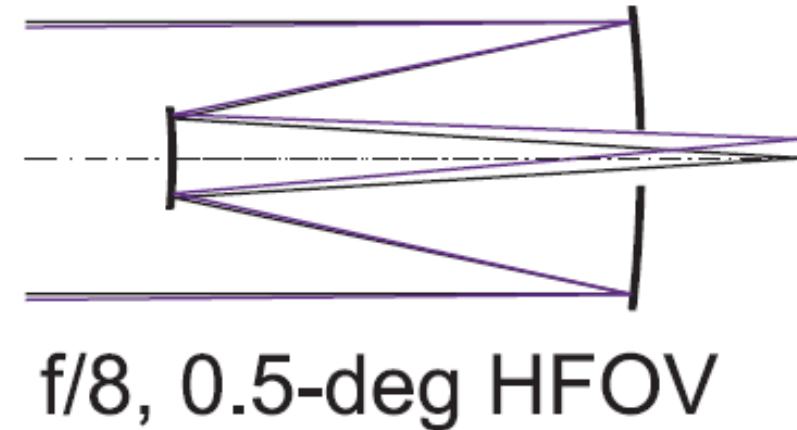
Secondary: Plane



Cassegrain

Primary: Parabolic

Secondary: Hyperbolic



In a first-order layout, the mirror curvatures of any two-mirror system are given by

$$c_1 = \frac{BFL - f}{2df} \quad c_2 = \frac{BFL + d - f}{2dBFL}$$

where f is the effective focal length, d is the separation between the two mirrors, and BFL is the distance from the second mirror to the image.

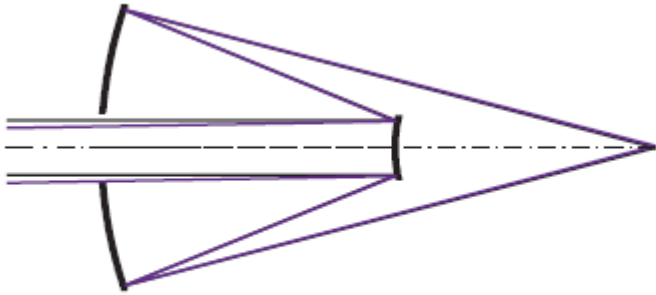
Telescopes

Schwarzschild

Primary: small negative spherical

Secondary: large positive spherical

Used in microscopy



$f/2$, 1-deg HFOV

$$d = 2f \quad c_1 = (\sqrt{5} - 1)f \quad c_2 = (\sqrt{5} + 1)f$$

d = mirror separation

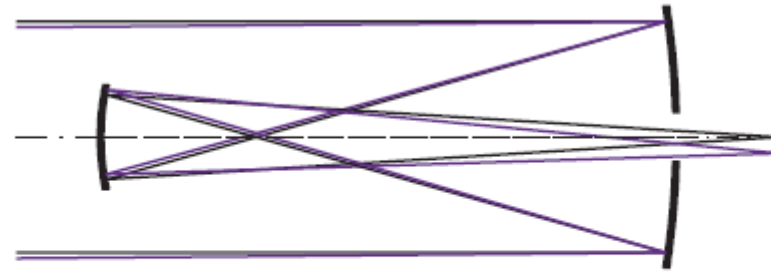
c_1, c_2 = mirror curvatures

f = system focal length

Gregorian

Primary: Parabolic

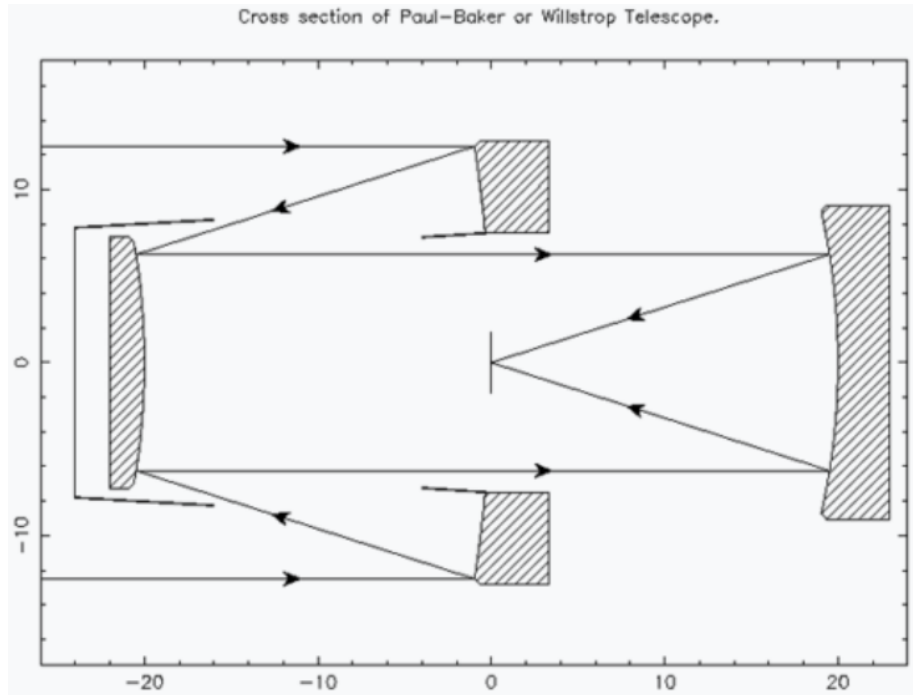
Secondary: Elliptic



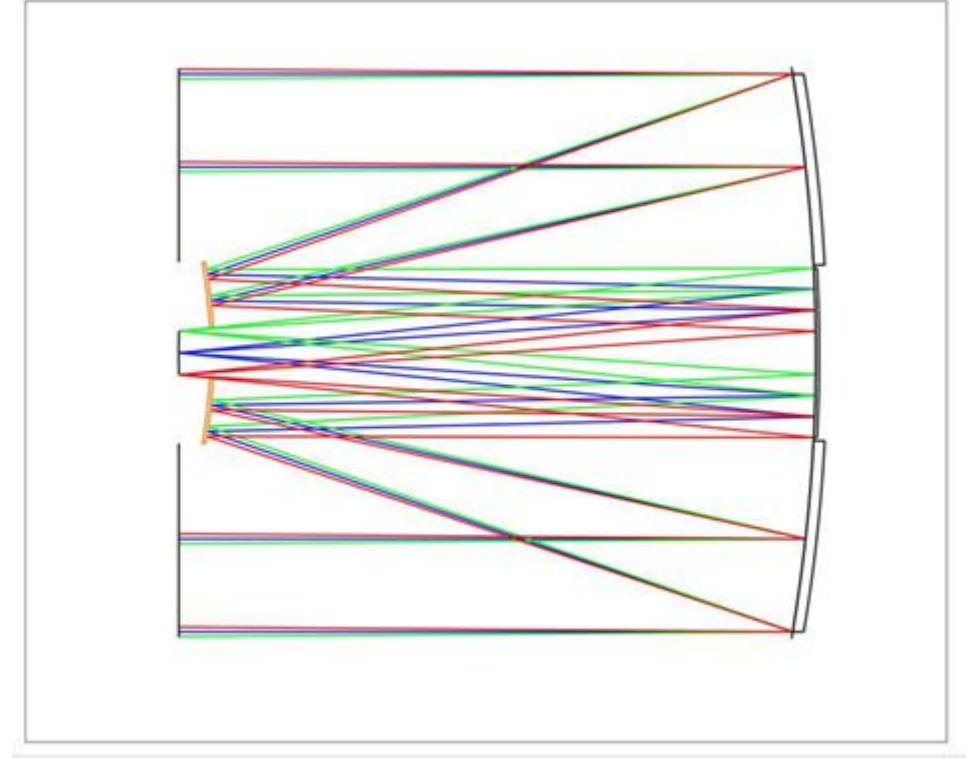
$f/8$, 0.5-deg HFOV

Telescopes

Three-mirror anastigmat is an anastigmat telescope built with three curved mirrors, enabling it to minimize all three main optical aberrations spherical aberration, coma, and astigmatism.



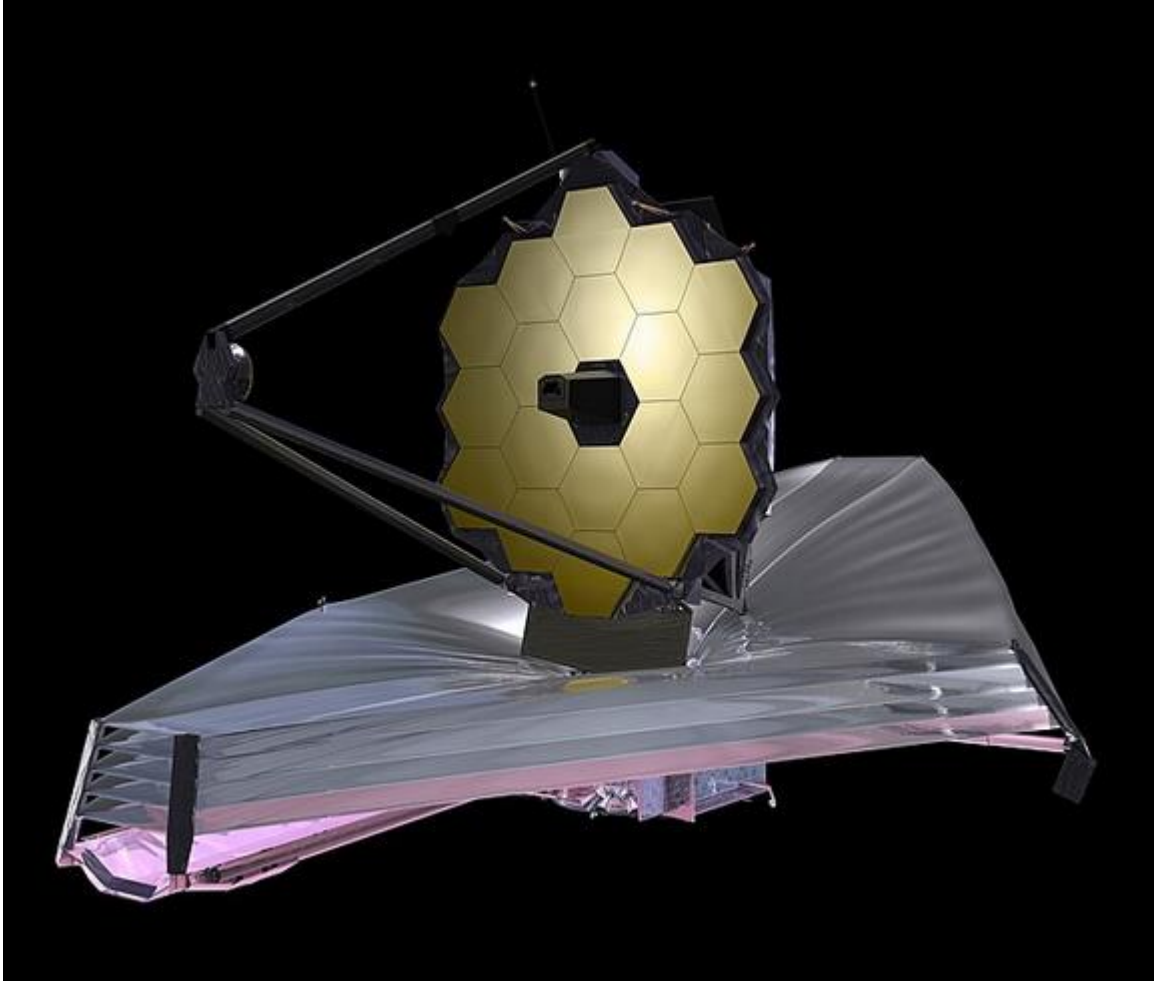
Paul-Baker form



Eisenberg-Pearson Two-mirror Three-surface

James Webb Space Telescope

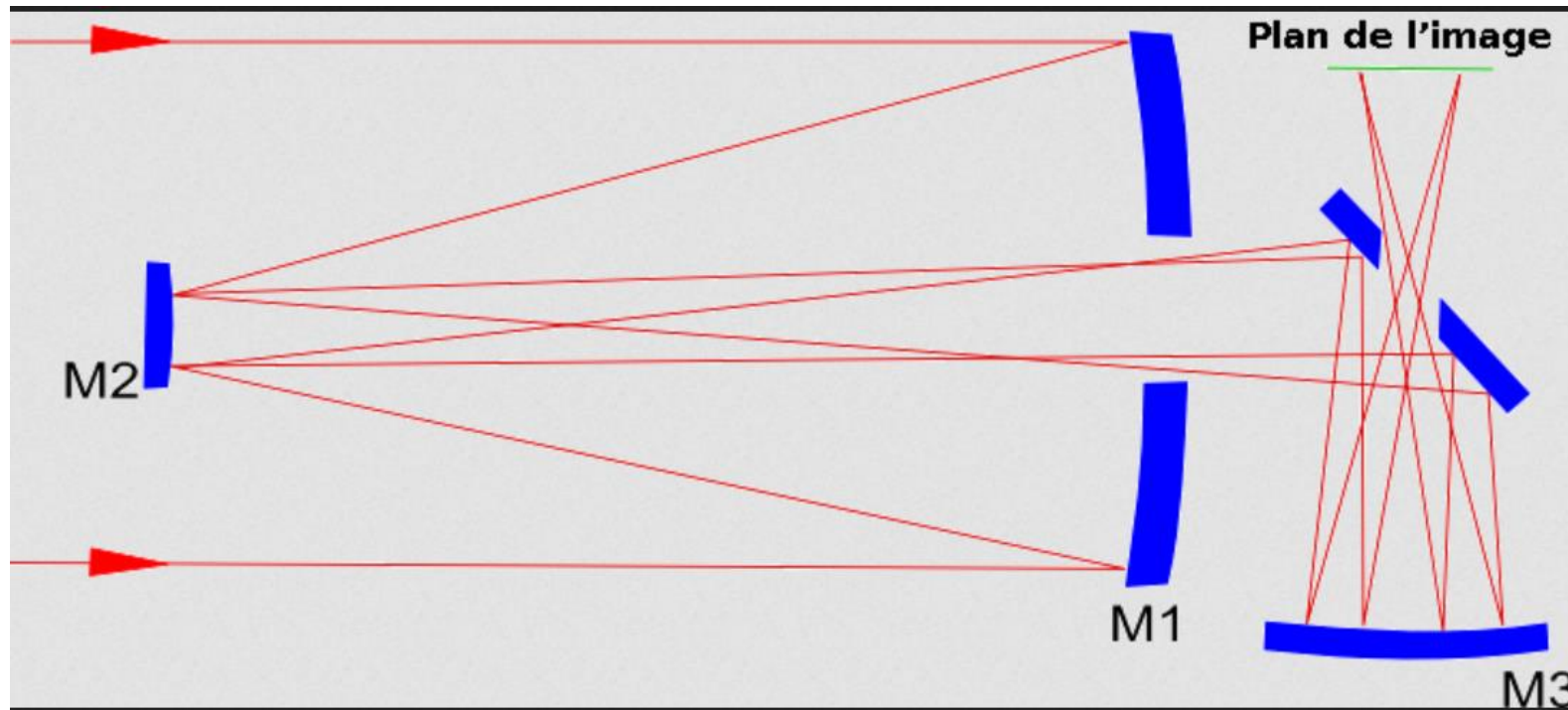
Webb's optical design is a three-mirror anastigmat.



Telescopes

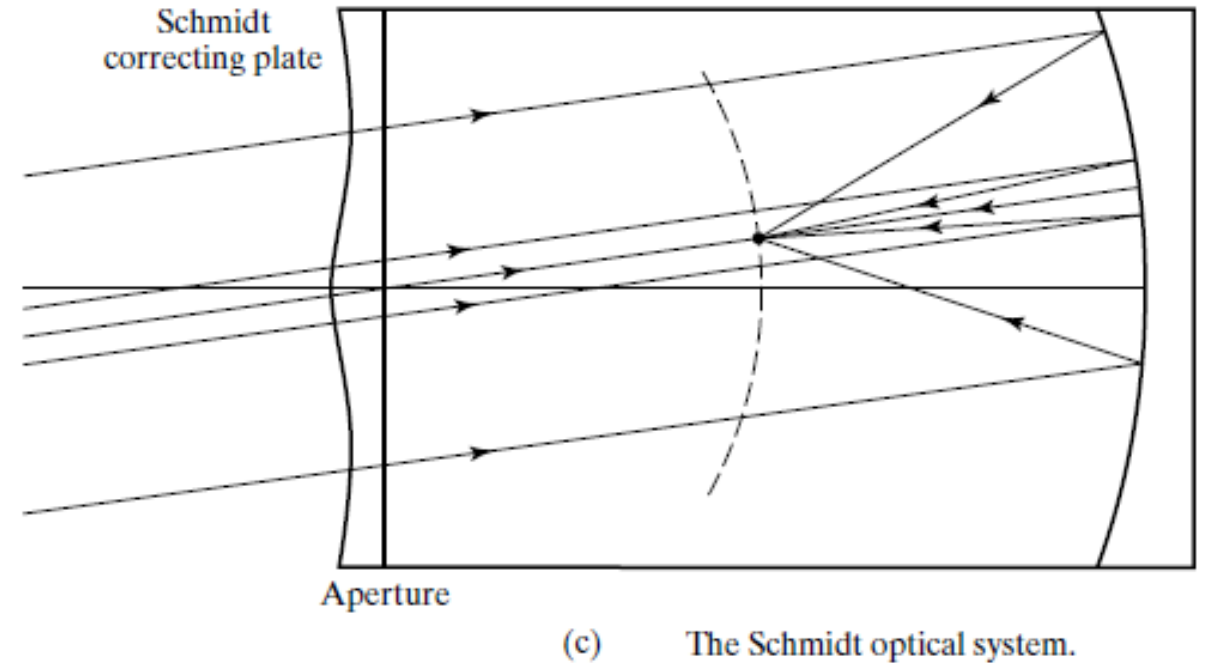
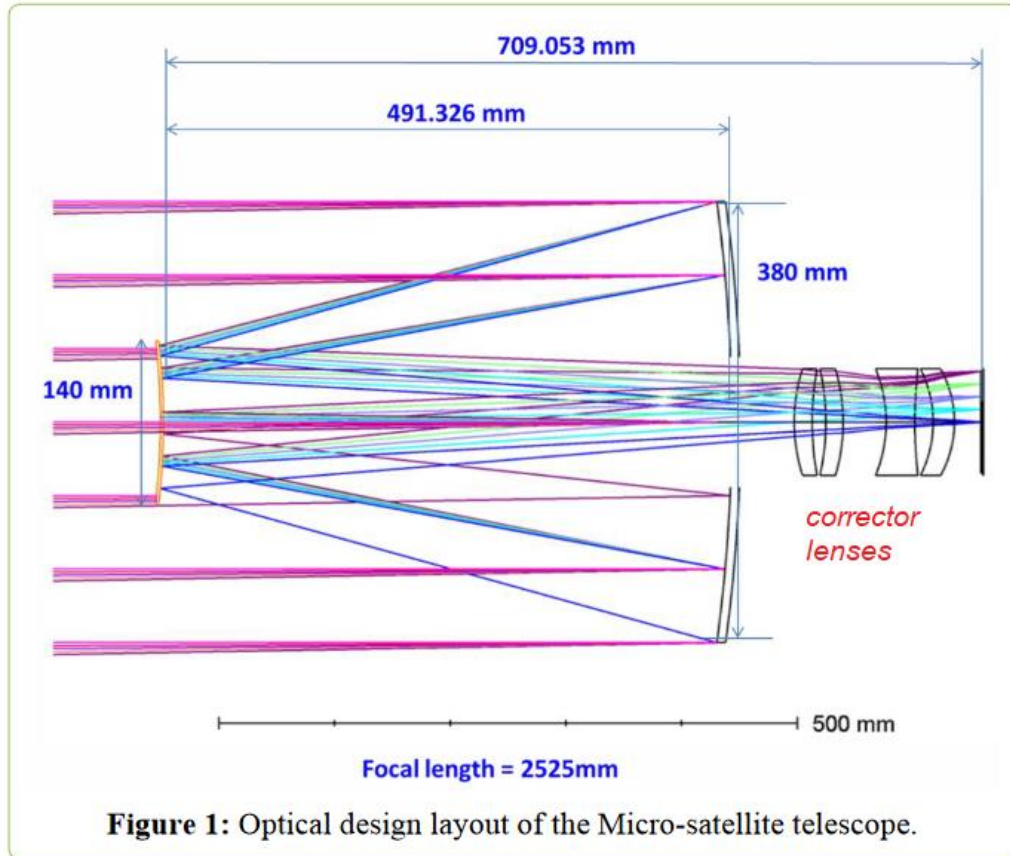
Korsch Telescope

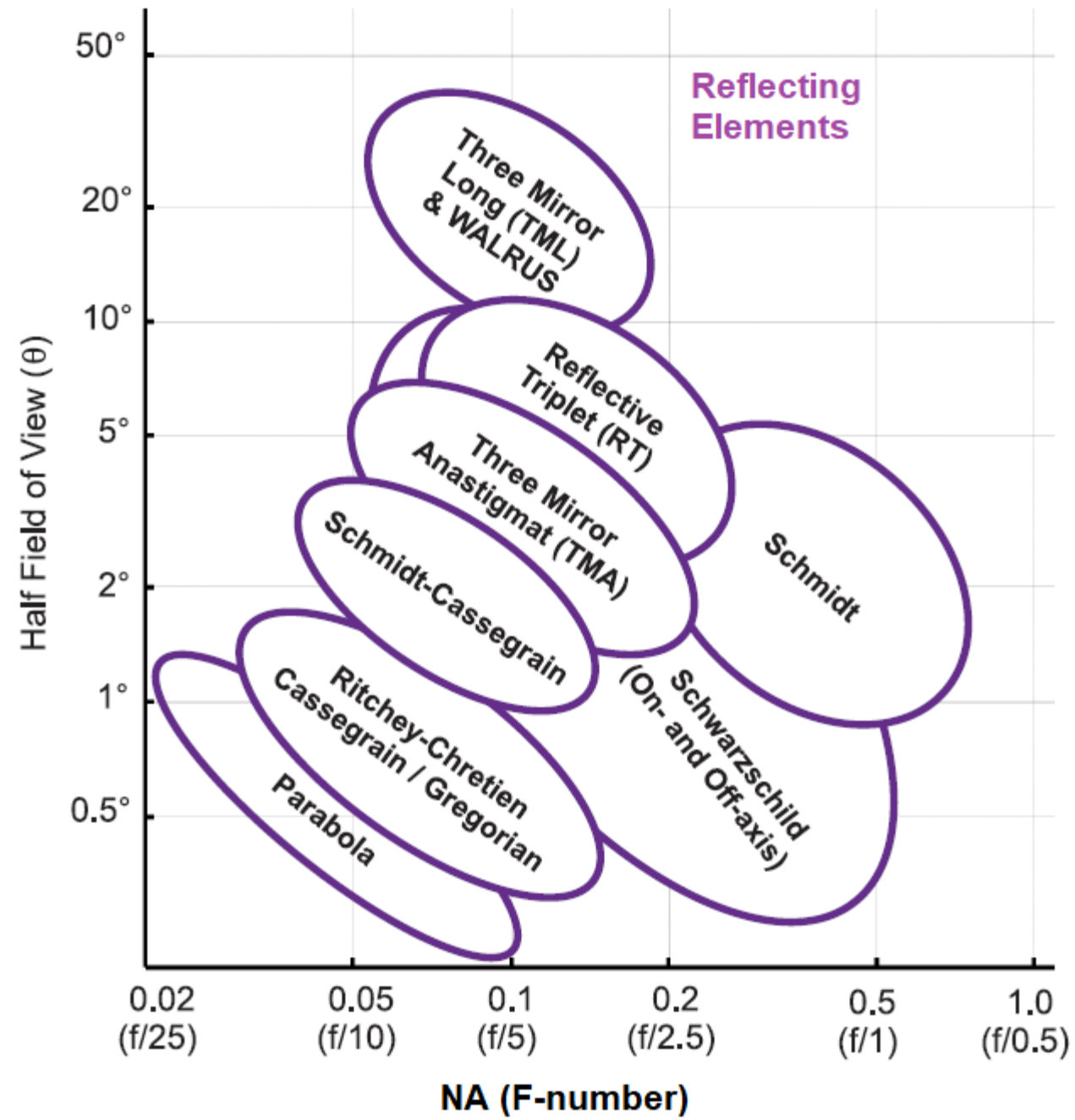
Dietrich Korsch developed a broader range of solutions in 1972. A telescope based on Korsch's design corrects for spherical aberration, coma, astigmatism, and field curvature, allowing for a wide field of view with minimal stray light in the focal plane.



Catadioptric Telescopes

A catadioptric optical system is one where **refraction** and **reflection** are combined in an optical system,





ZOOM LENSES

What is Zoom Lens?

A zoom lens is a mechanical assembly of lens elements for which the focal length (and thus angle of view) can be varied, as opposed to a fixed-focal-length (FFL) lens.

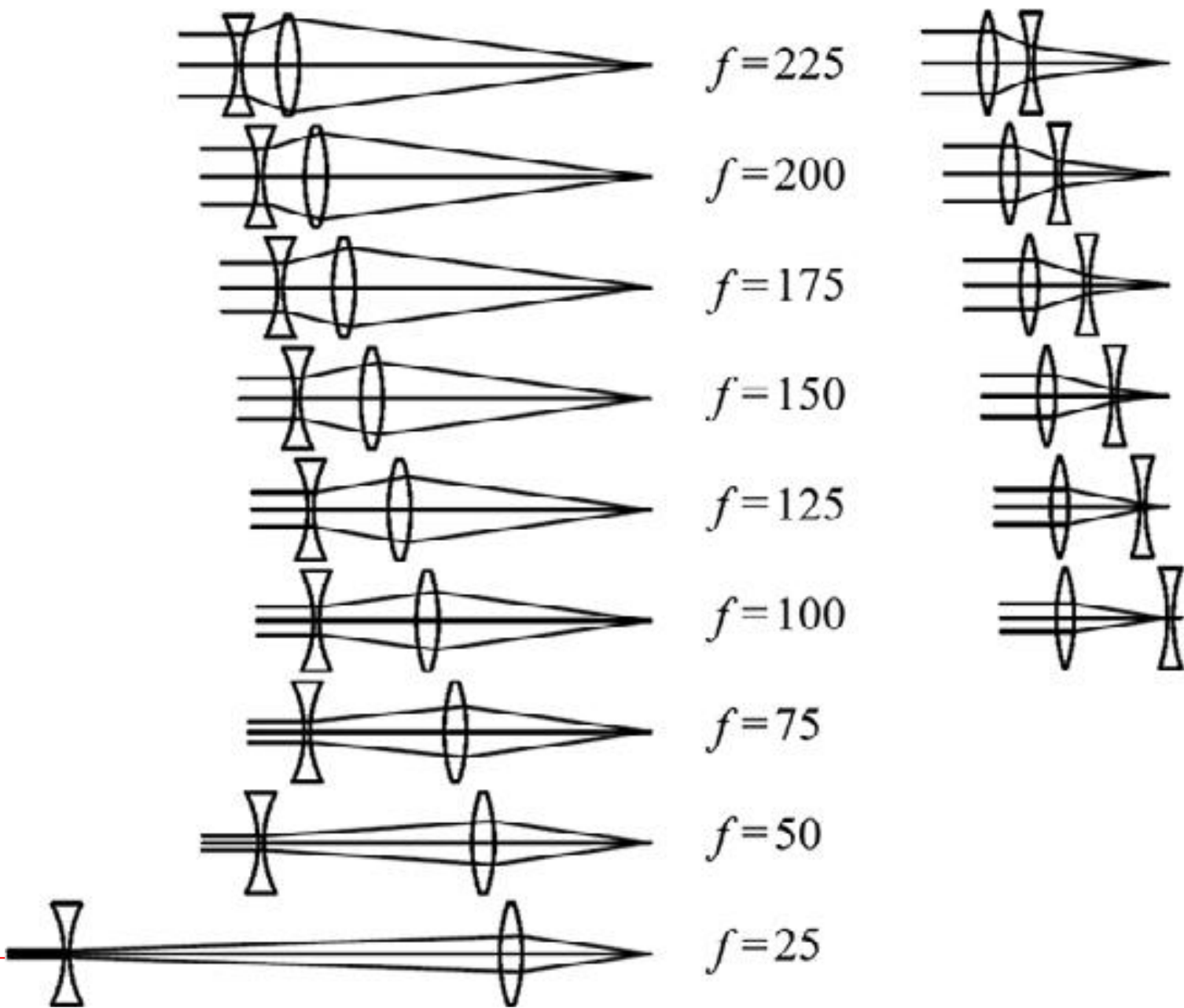
Zoom lenses are often described by the ratio of their longest to shortest focal lengths.

For example, a zoom lens with focal lengths ranging from 100 mm to 400 mm may be described as a 4:1 or "4×" zoom.



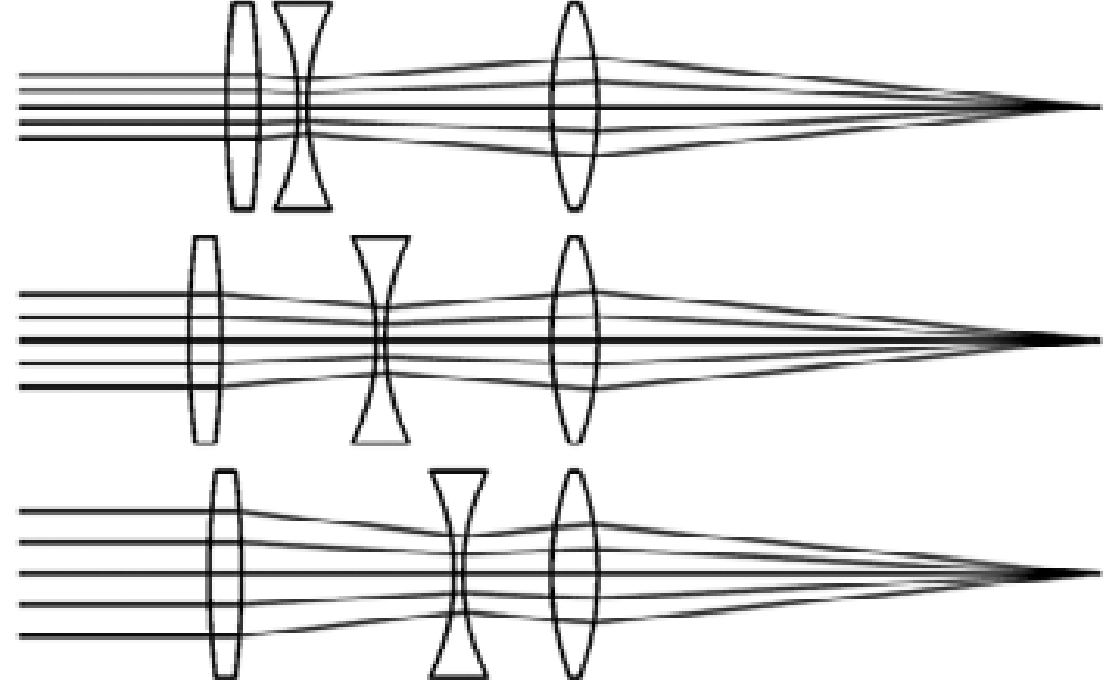
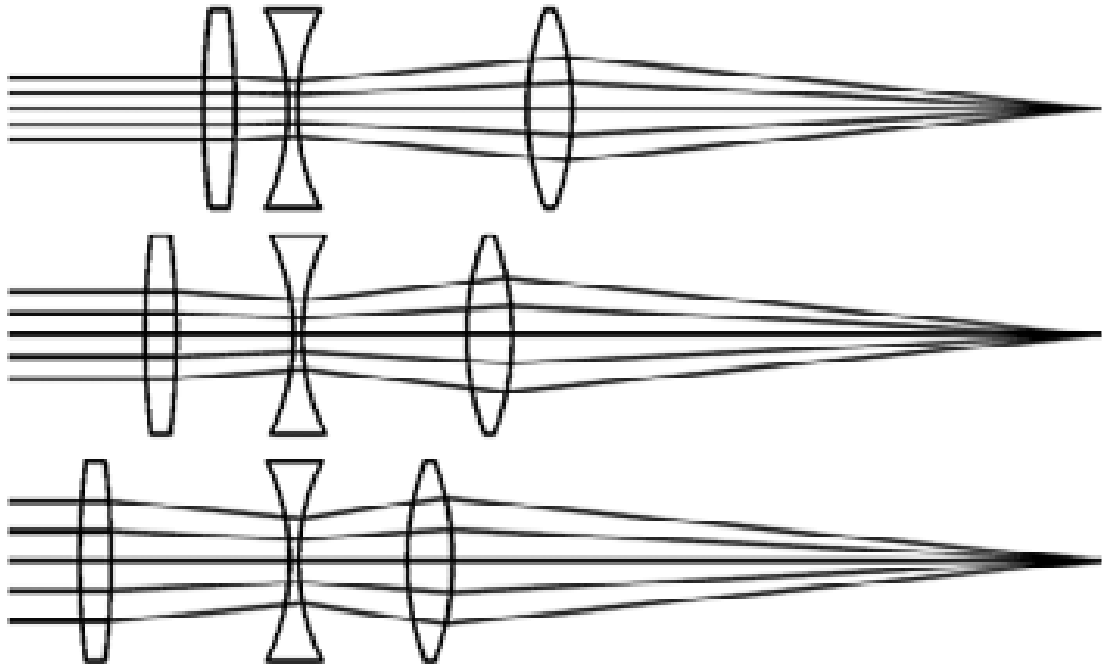
Two-Element Zoom Lenses

These are
Inverse-Telephoto and
Telephoto lenses with focal lengths
 ± 100 .



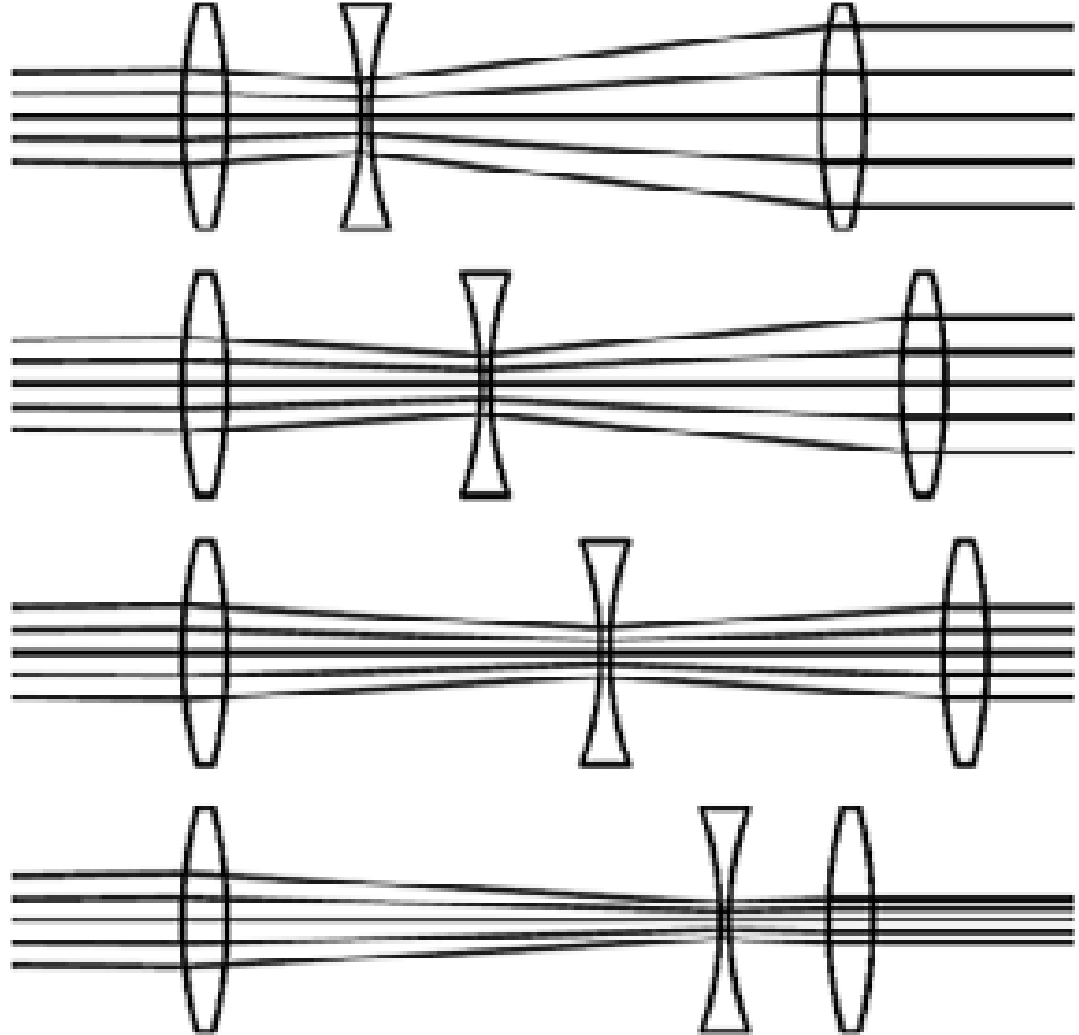
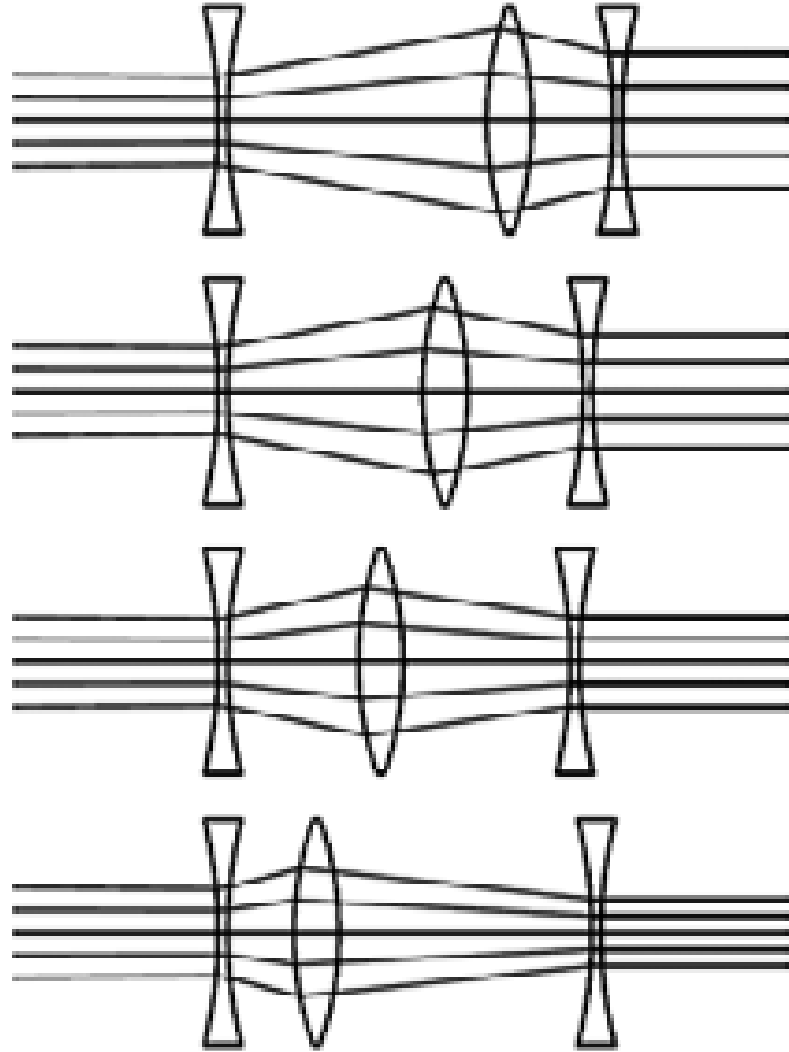
Three-Element Zoom Lenses

Focal systems



Three-Element Zoom Lenses

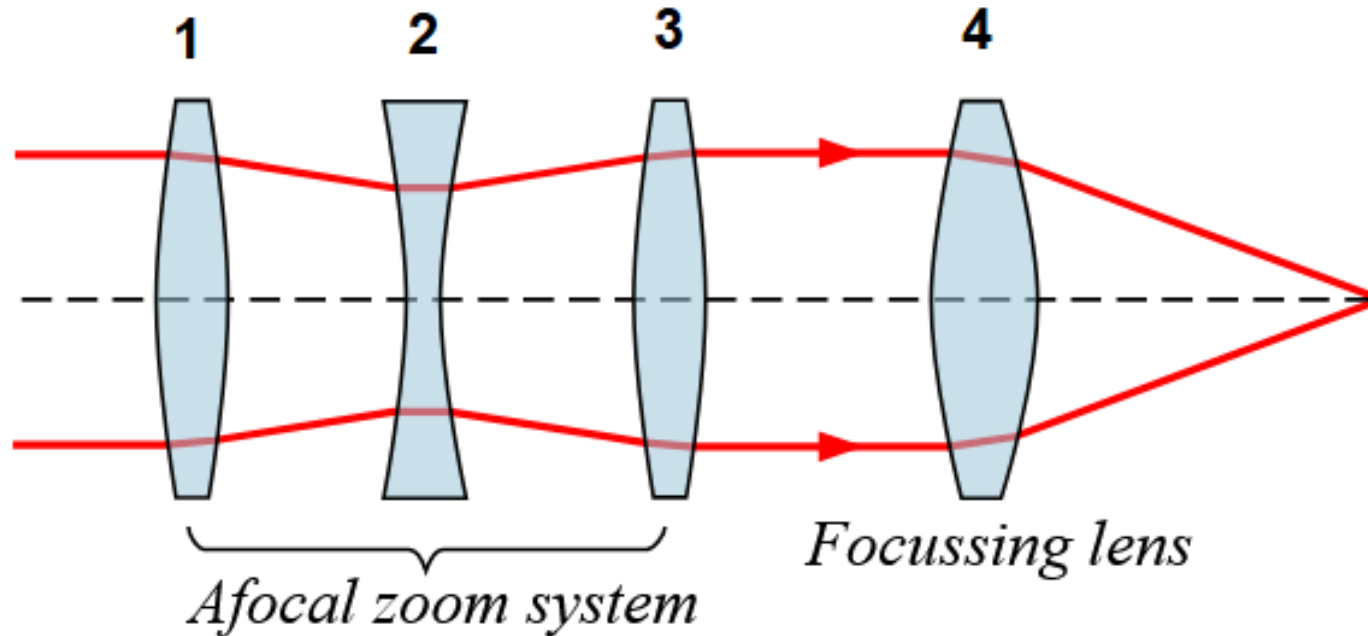
Afocal systems



Four-Element Zoom Lenses

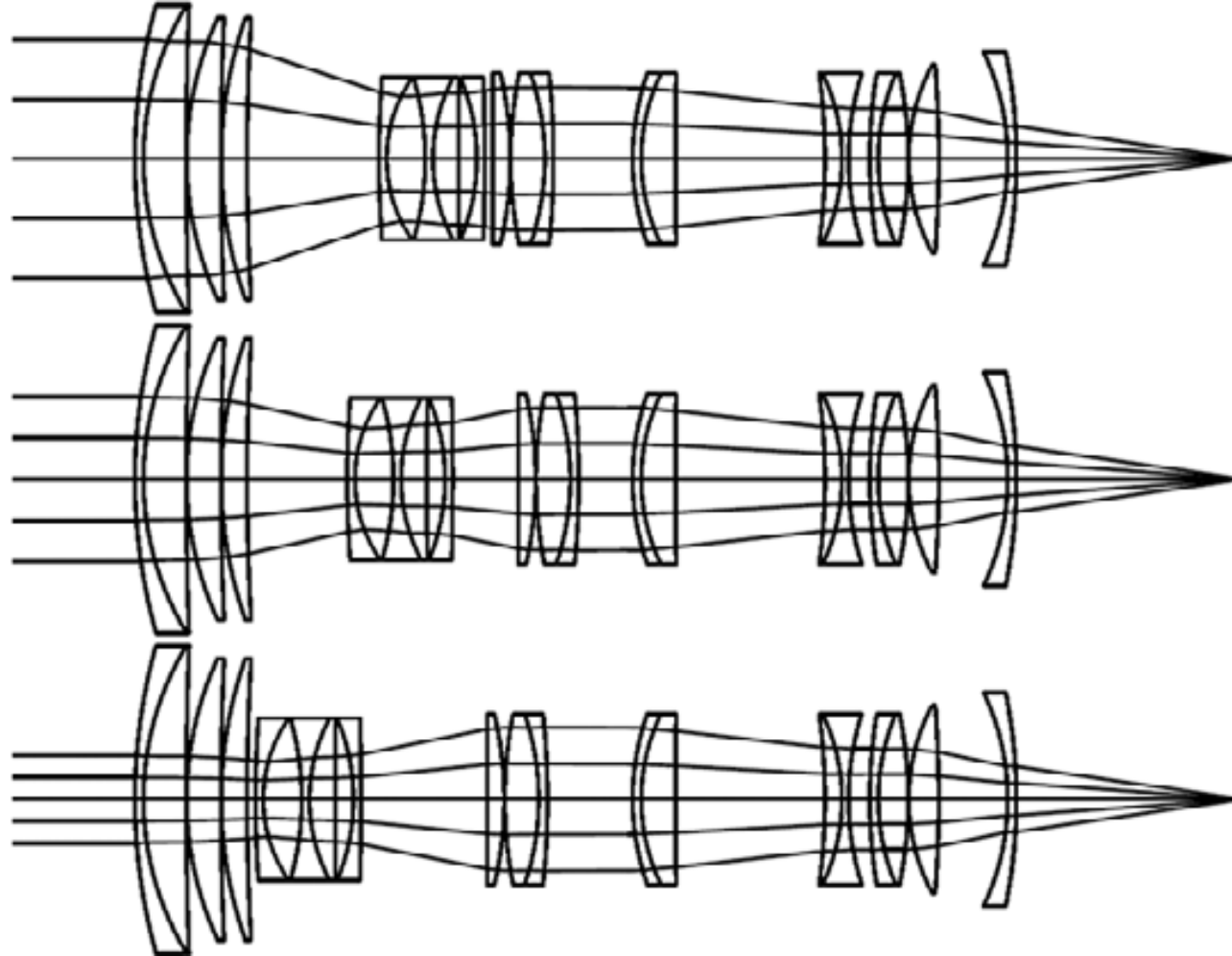
Here is a simple design form.

- Three lenses of the afocal system are L_1 , L_2 , L_3 .
- L_1 and L_2 can move to the left and right, changing the overall focal length of the system. See previous page.



Four-Element Zoom Lenses

This is very advanced example. First group on the left and last group on the right are fixed. Rest of them are moved to change focal length.



US Patent application 20090086321 by Keiko Mizuguchi.

EYEPieces

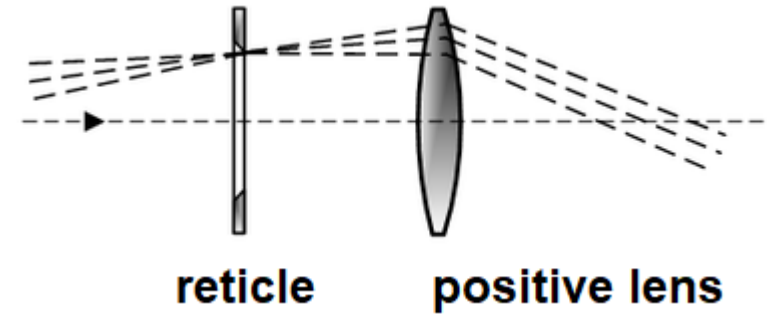
Eyepiece

- An eyepiece, or ocular lens, is a type of lens that is attached to a variety of optical devices such as telescopes and microscopes.
- Eyepiece is used to view a real image that has been formed by optical components located between the eyepiece and the object being viewed (foreoptics).
- For details visit: <https://en.wikipedia.org/wiki/Eyepiece>

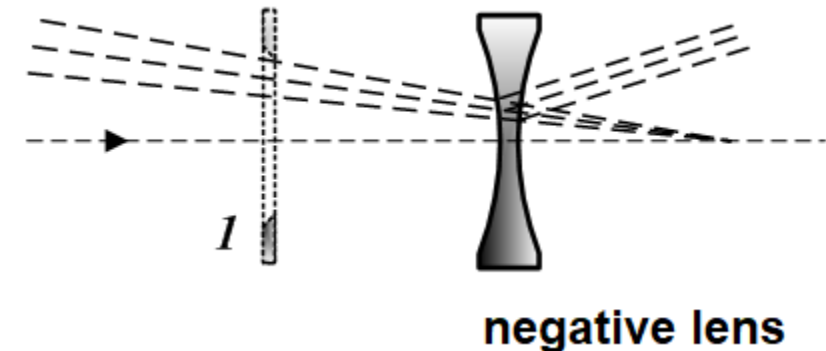


Eyepiece Design Forms

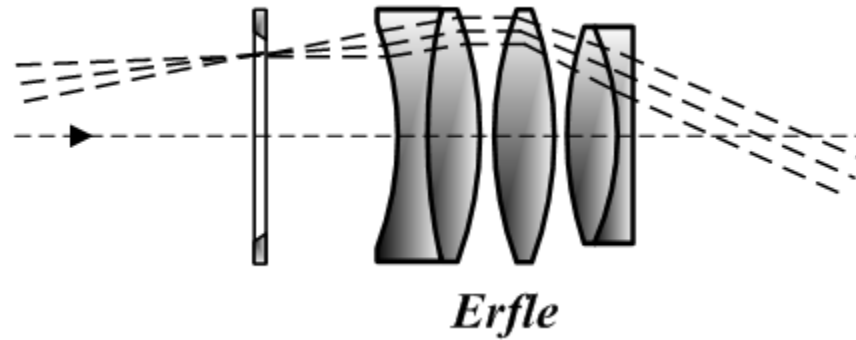
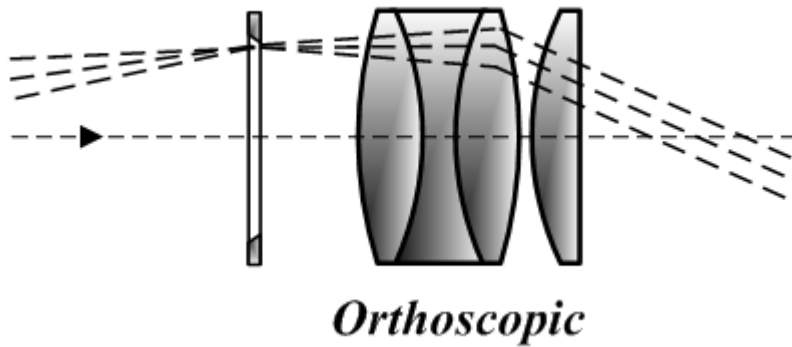
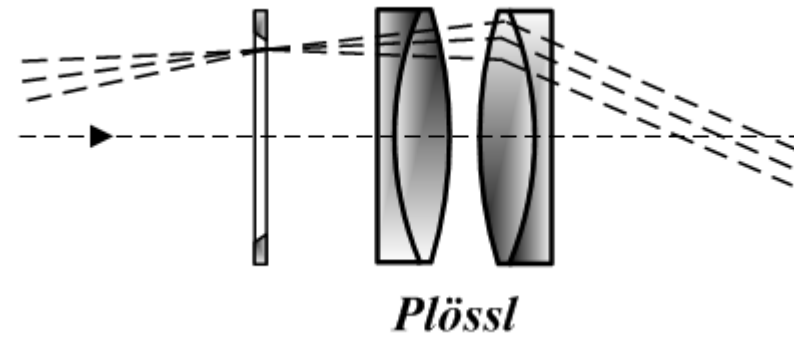
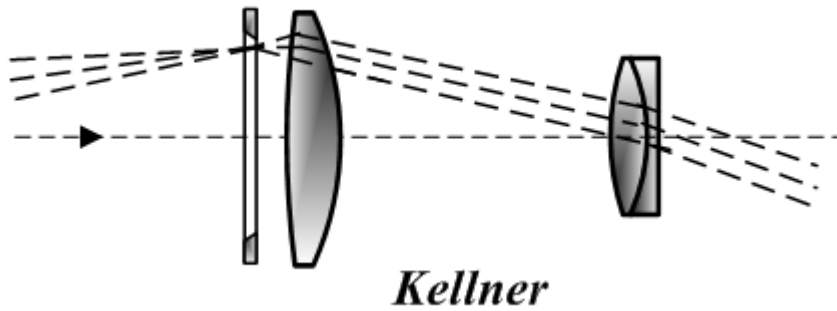
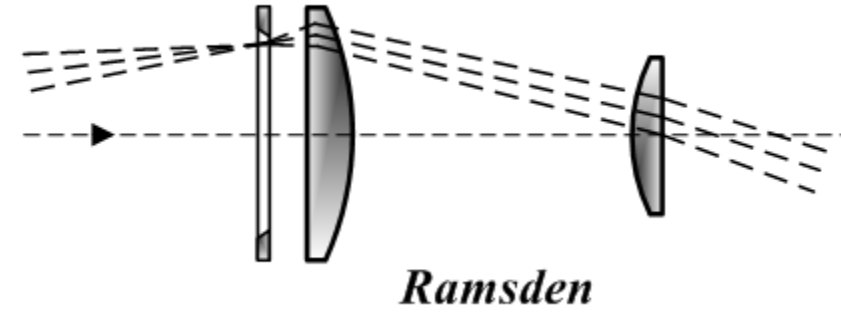
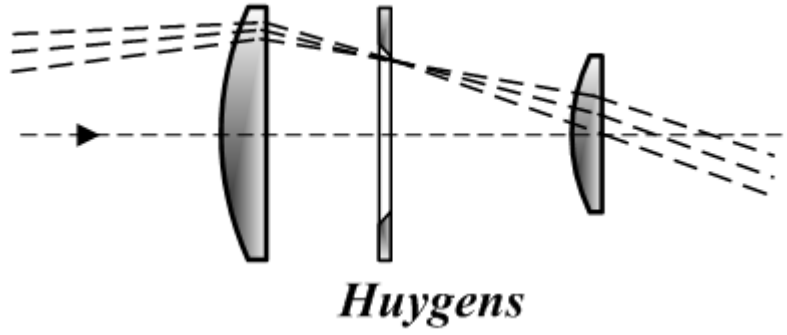
A simple convex lens placed after the focus of the objective lens presents the viewer with a magnified inverted image.



The simple negative lens placed before the focus of the objective has the advantage of presenting an erect image but with limited field of view.



Eyepiece Design Forms



CELL PHONE CAMERA LENSES

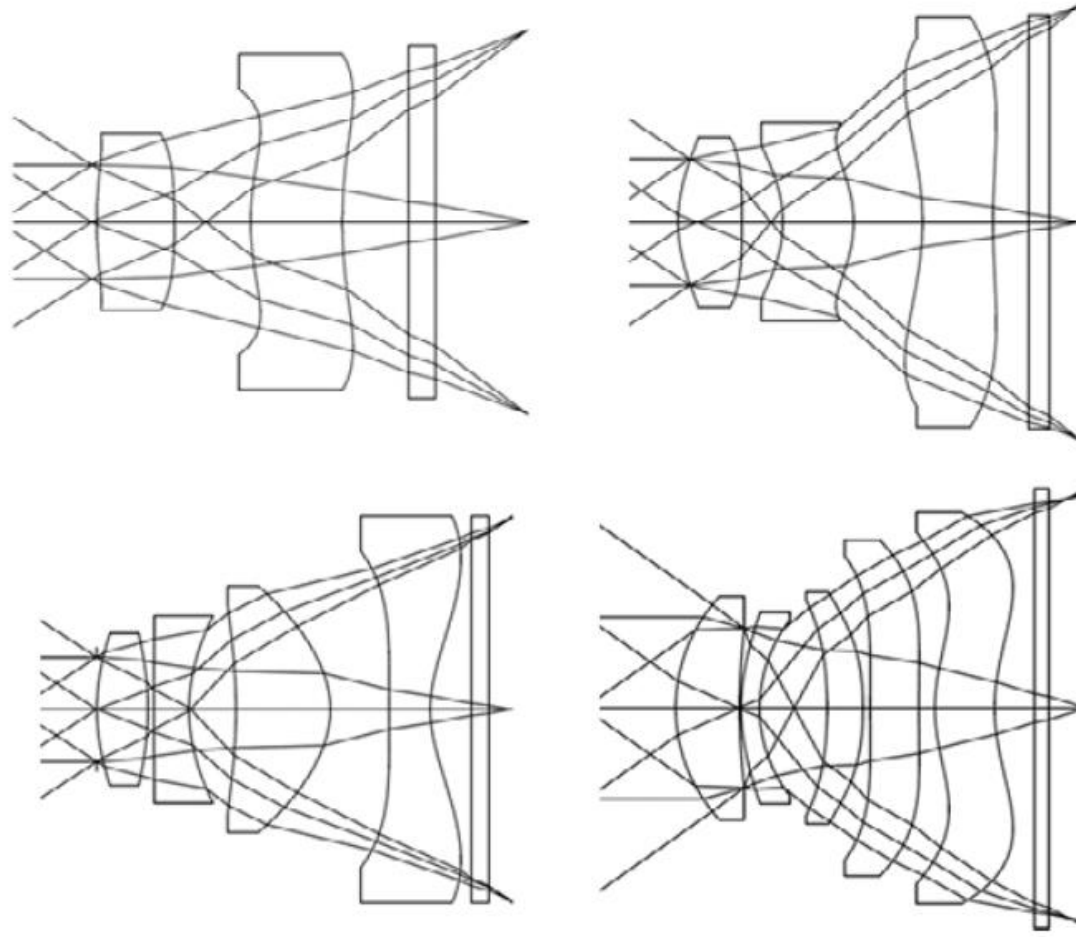
Miniature Lenses

Lenses for mobile phones, have been developed over the last two decades.

Typical mobile phone lens specifications

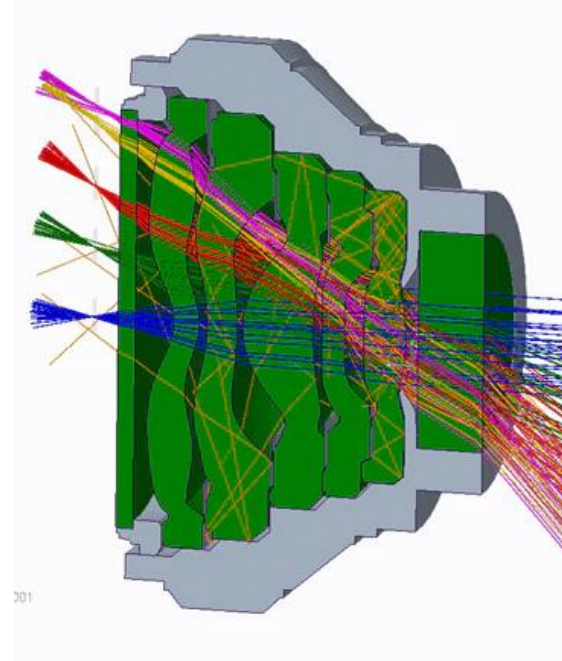
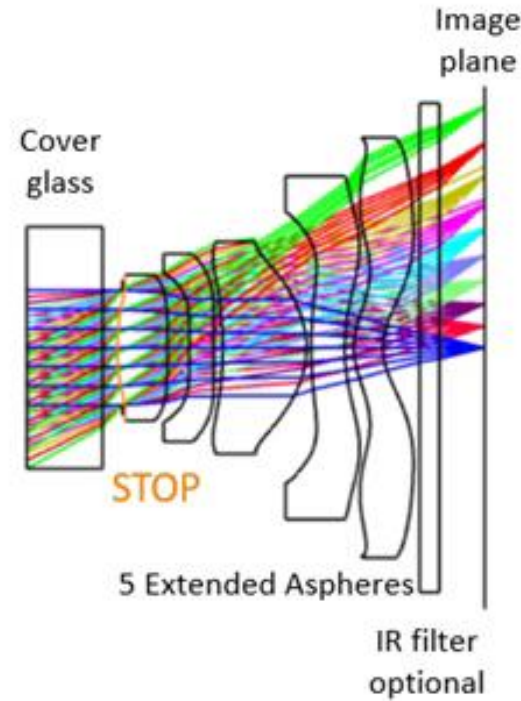
Year	2006	2012	2018
Focal length	3–6 mm	3–5 mm	3–5 mm
FOV	66°	72°	78°
$F/\#$	2.8	2.2–2.4	2.0–1.4
TTL	<5.0 mm	<5.0 mm	<6.0 mm
Distortion	<1–2%	<1–2%	<1–2%
CRA	<24°	<30°	<33°
RI	>50%	>50%	>32%
# lens elements	3–5	4–6	5–8





Mobile phone lens forms with two, three, four, and five lens elements. The plane parallel plate next to the image plane represents an infrared filter.

Designing Cell phone Camera Lenses in Zemax



- <https://support.zemax.com/hc/en-us/articles/7686411841043-Designing-Cell-phone-Camera-Lenses-Part-1-Optics>
- <https://support.zemax.com/hc/en-us/articles/9268028712211-Designing-Cell-phone-Camera-Lenses-Part-2-Optomechanical-Packaging-with-OpticsBuilder>