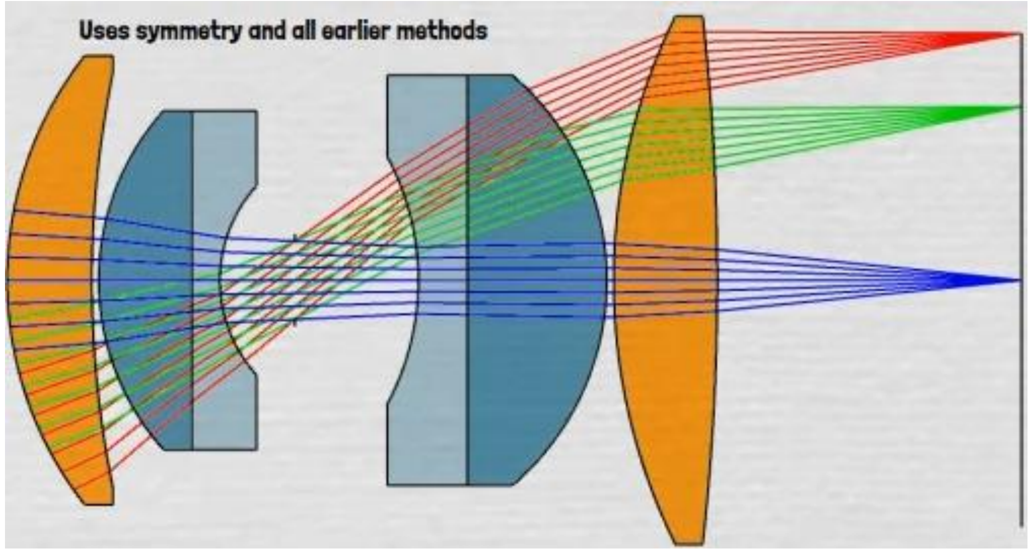
Lecture 12

Design Forms



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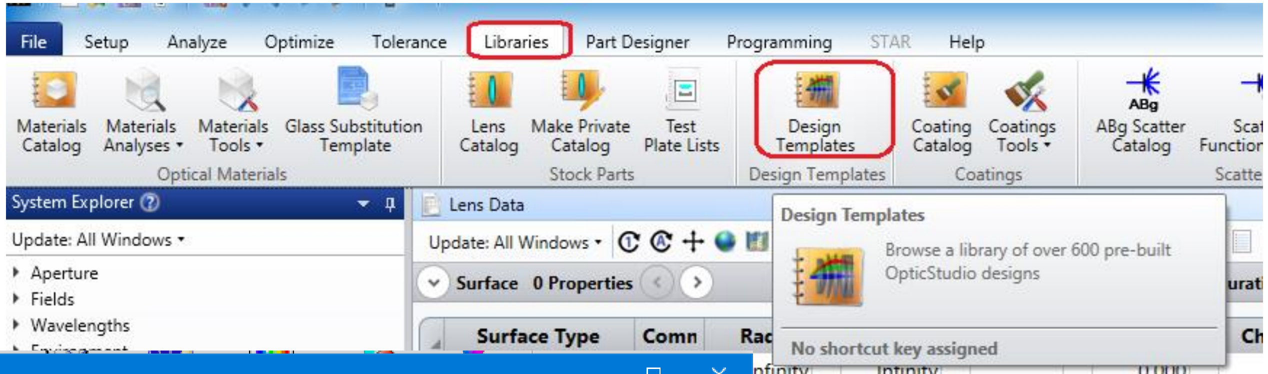
Design Forms

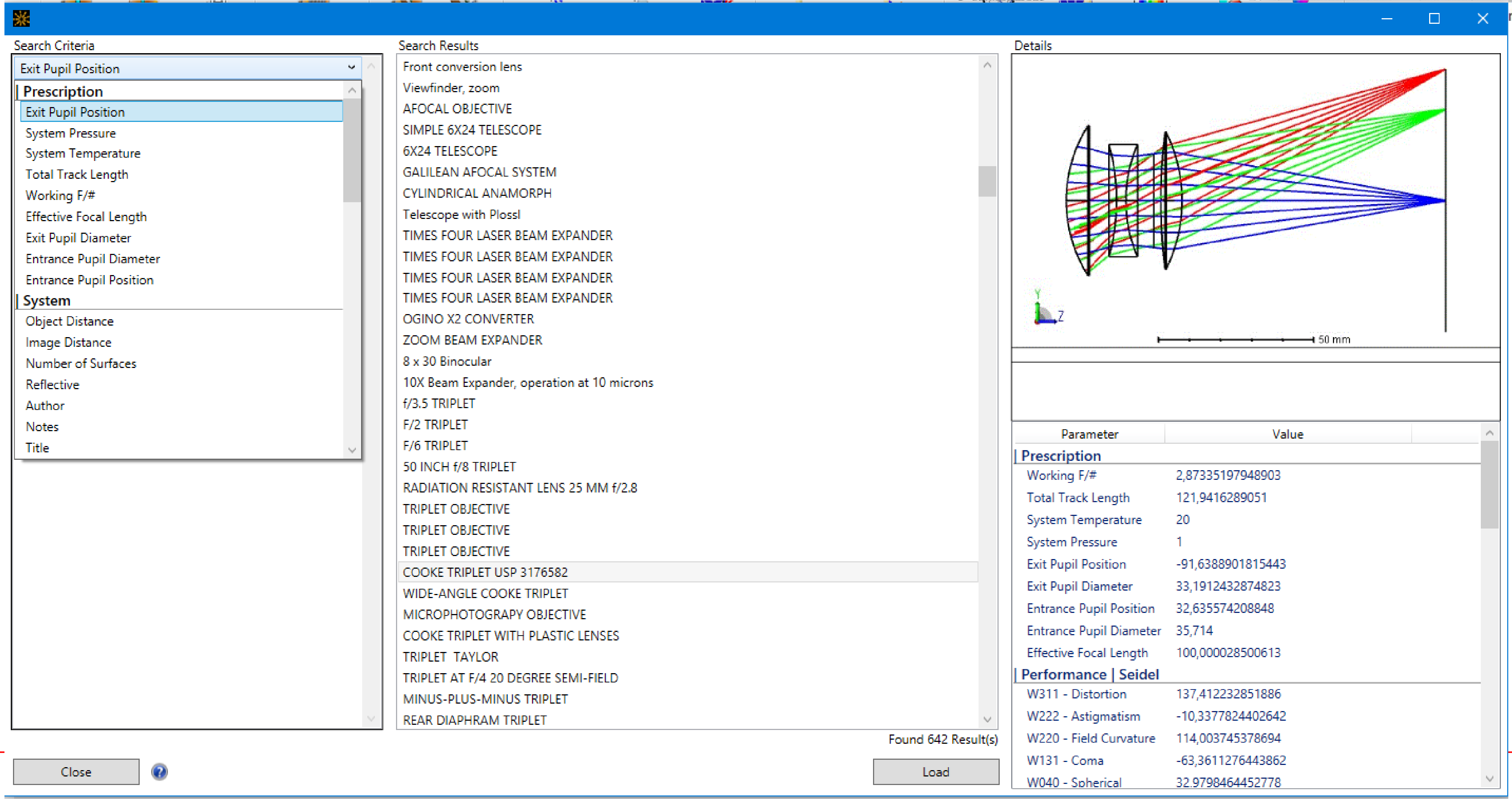
- In the history of optical design, many forms have been proposed for lens designs.
- These can be grouped as singlet, doublet, triplet, … in terms of the number of lenses.
- In practice, the first step in optical system design is to start with well-known forms that have been studied, tested and approved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

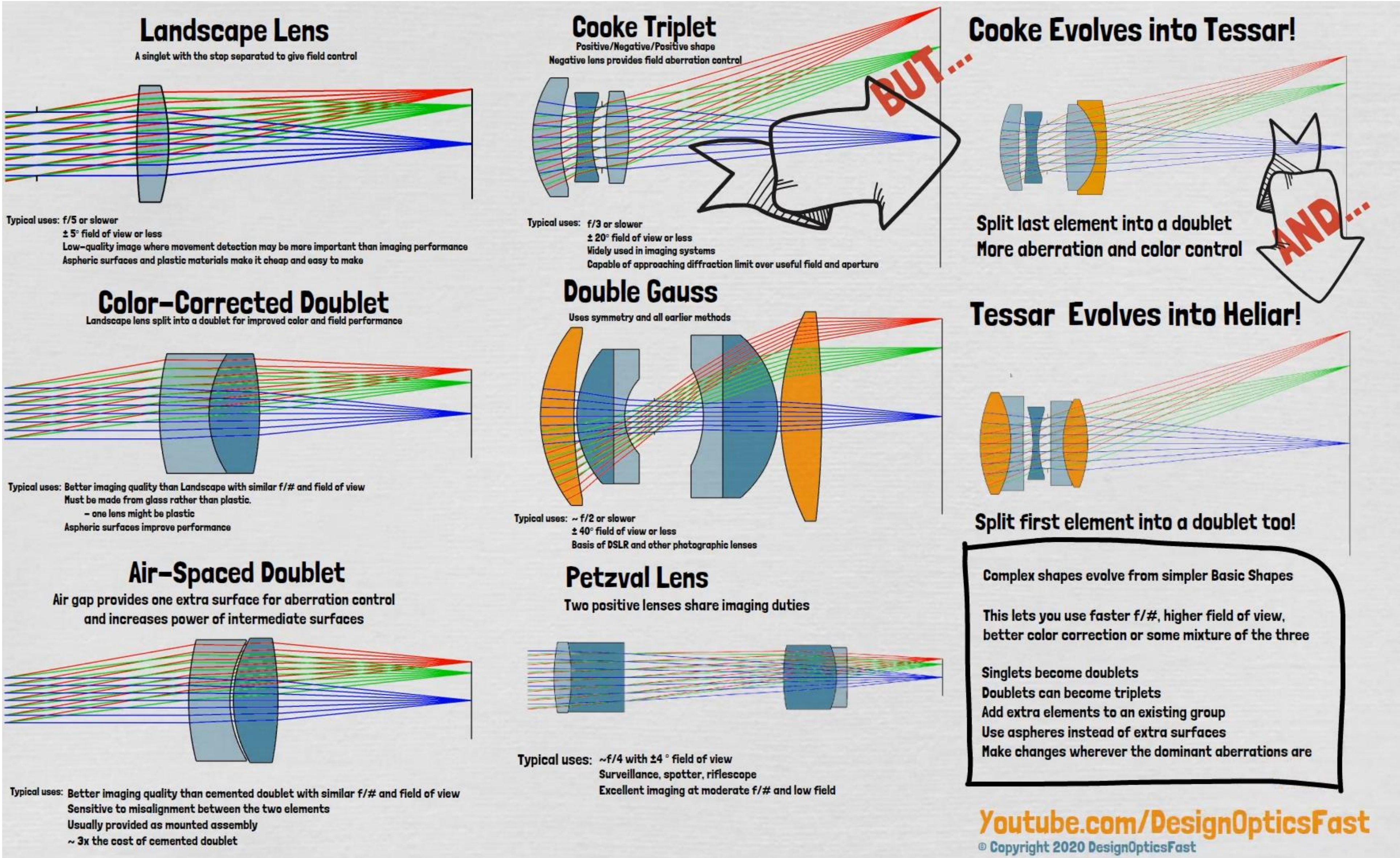
Design Templates in Zemax





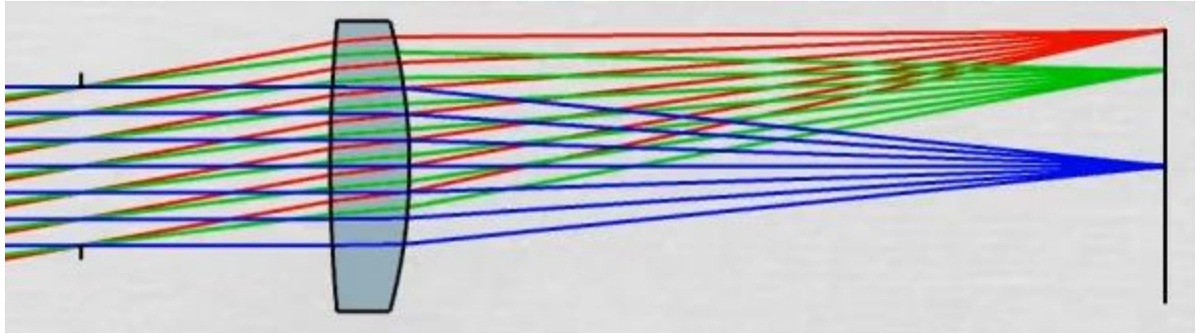
CAMERA OBJECTIVE LENSES

Objective Lens Design Forms



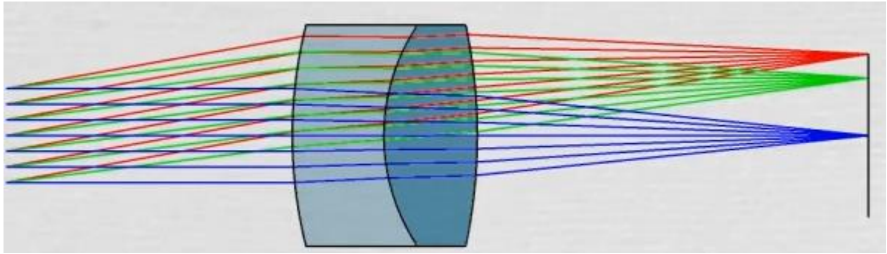
Landscape Lens

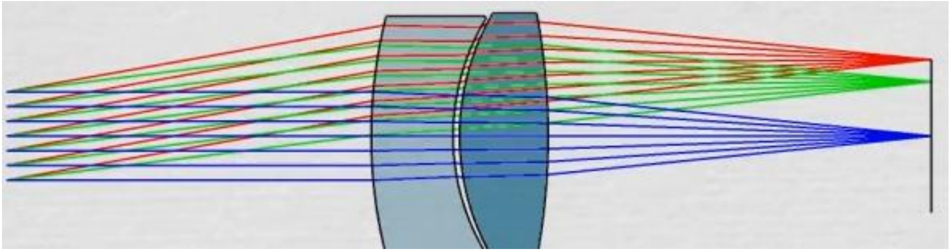
- It is single lens
- Typical use of **f/5** or slower
- **FOV < ±5º**
- FOV can be controlled by aperture stop placed in front of the lens.
- Image quality is low. But, it can be used in movement detection
- Performance can be improved by using aspheric surfaces
- Plastic materials can be used to make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



Achomatic Doublets

- Better image quality compared to landscape lens
- **f/5** or slower
- **FOV < ± 5º**
- Two different glases are used
- Performance can be improved by using aspheric surfaces
- Aberations are controlled by adding air gap between lenses

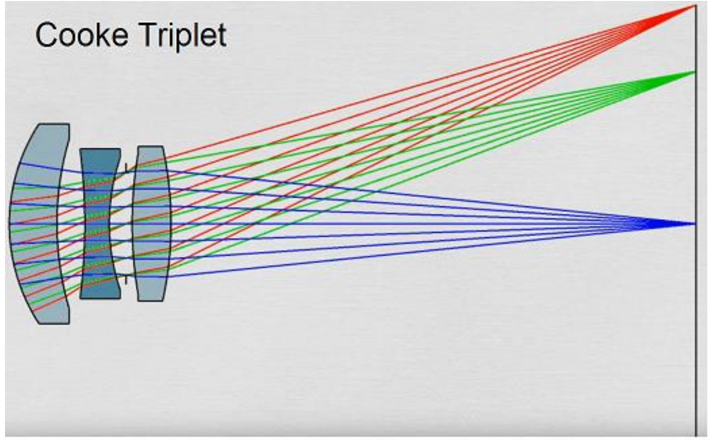


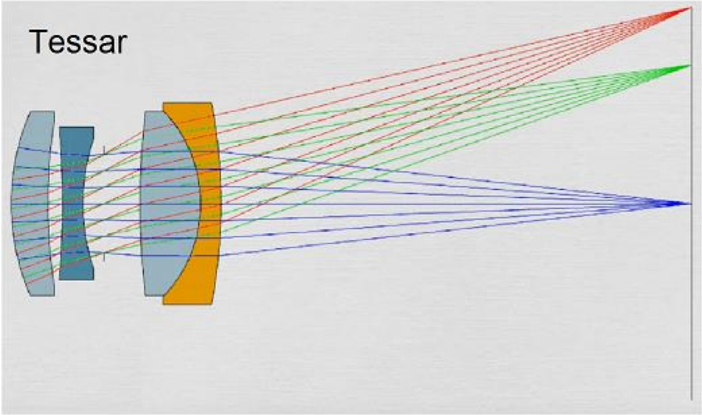


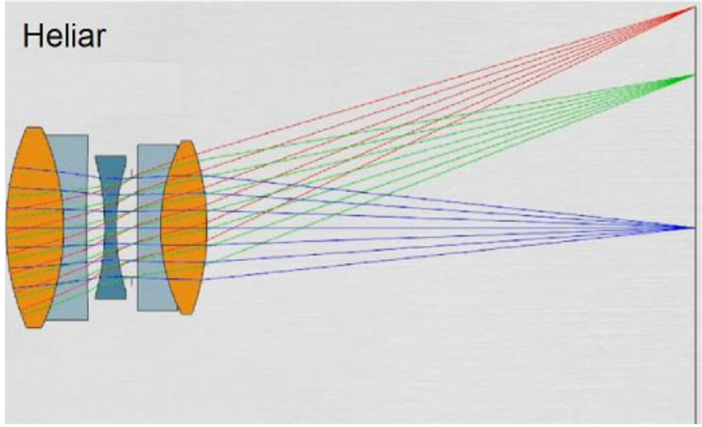
Cooke Triplet

- It is widely used.
- **f/3** or slower
- **FOV < ±20º**
- 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.

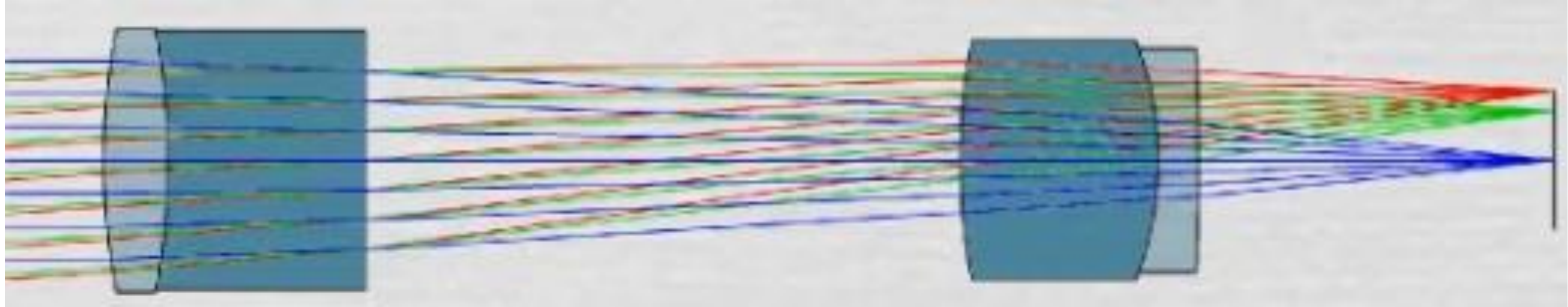






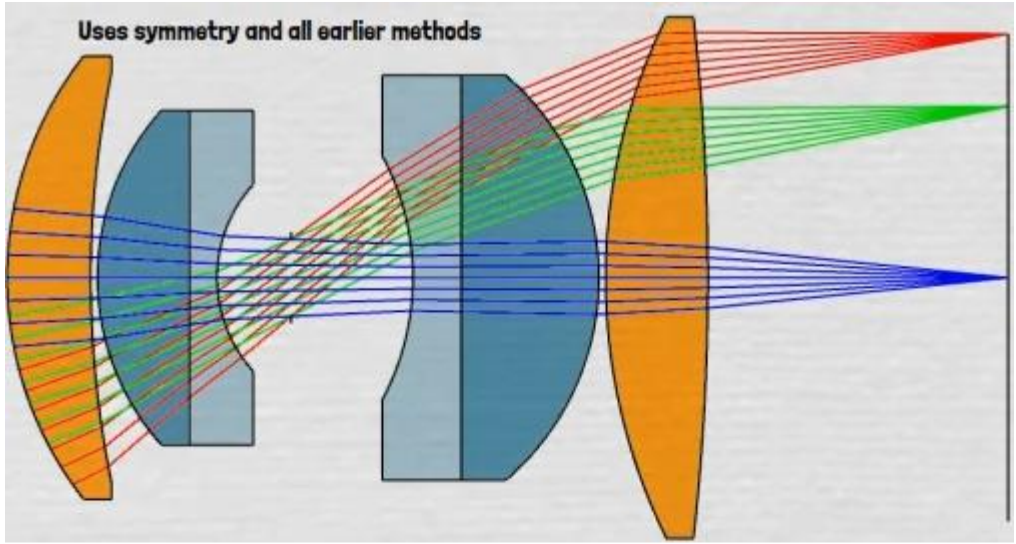
Petzval Lens

- **f/4** or slower
- **FOV < ±4º**



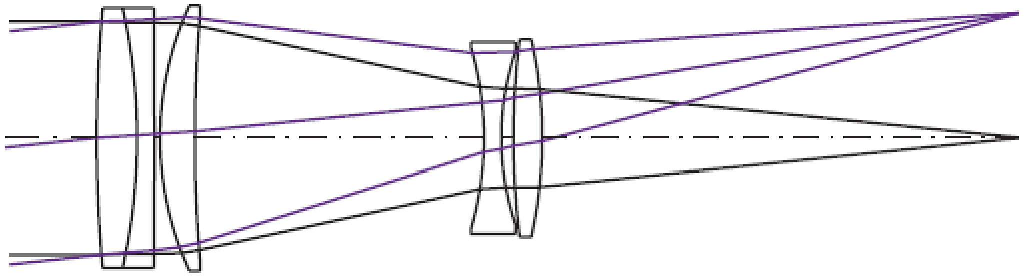
Double Gauss Lens

- It is symetric with respect to AS.
- **f/2** slower.
- **FOV < ±40º**
- 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.



f/5, 6-deg HFOV

Effective focal length:

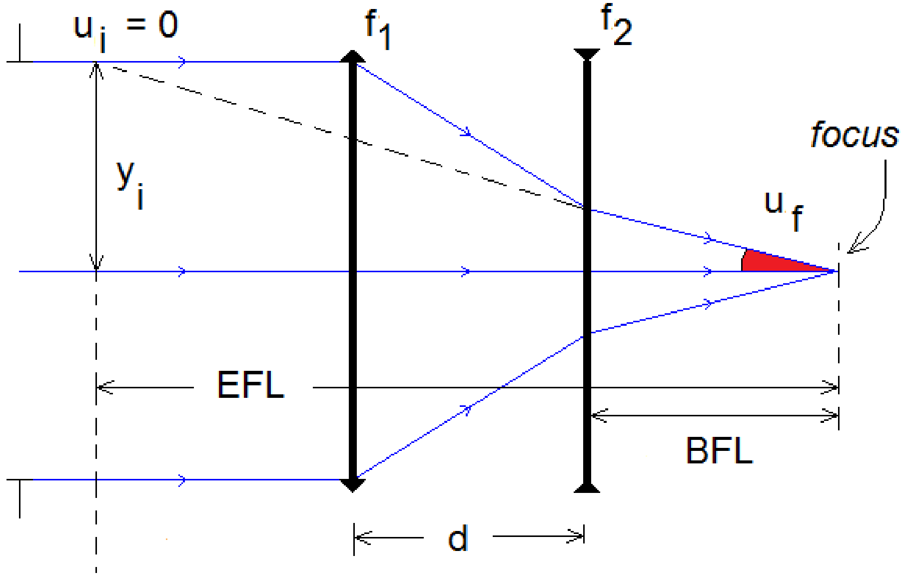
$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

Back focal length:

$$BFL = \frac{f_2(d - f_1)}{d - (f_1 + f_2)}$$

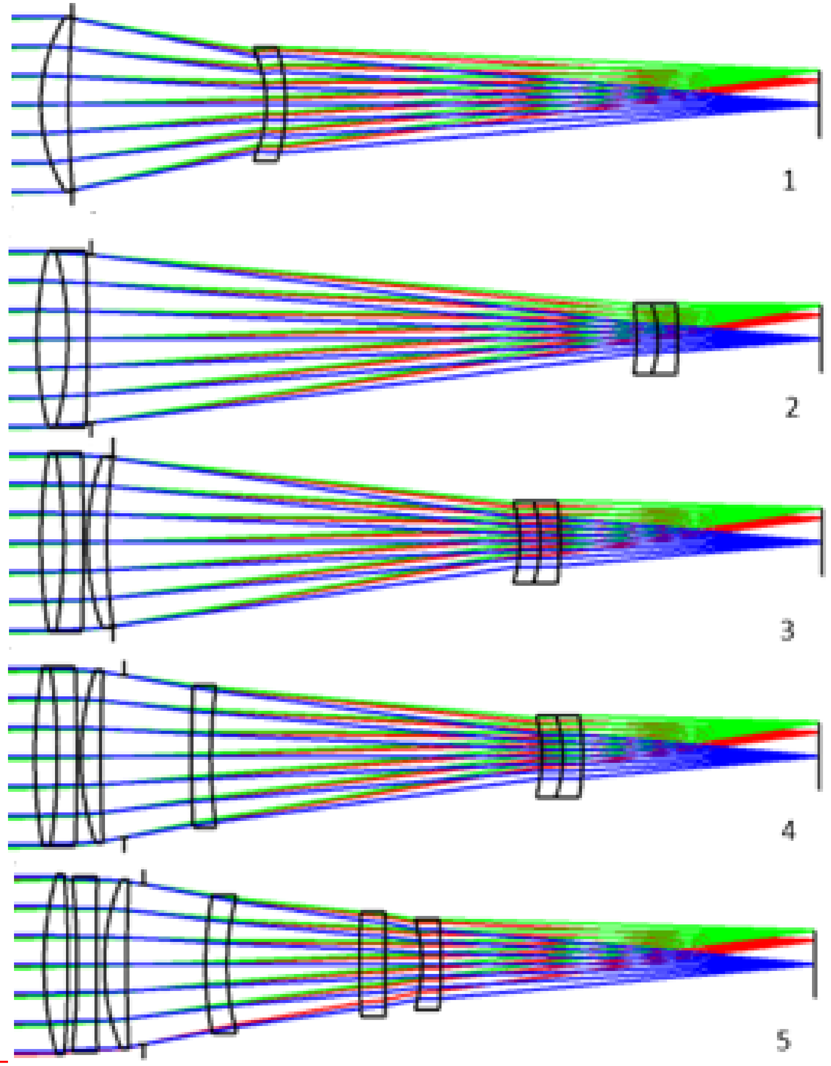
Telephoto Ratio:

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



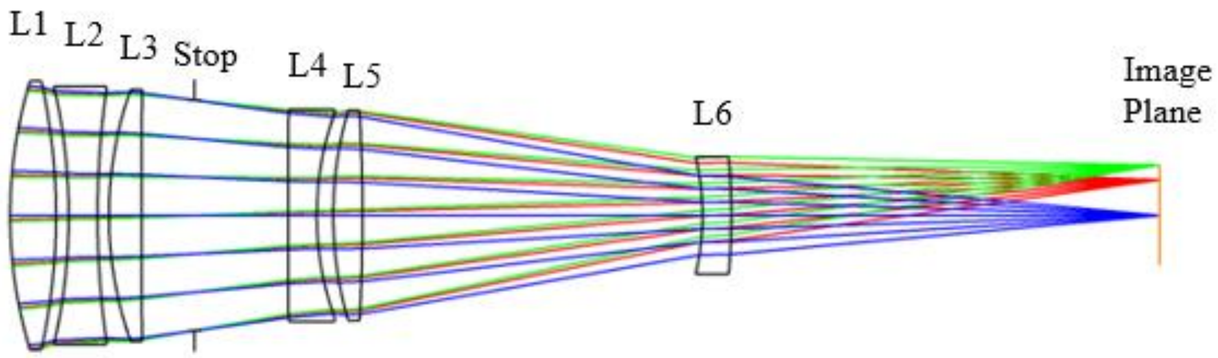
An Example Telephoto Lens Design used in Earh Observation-1

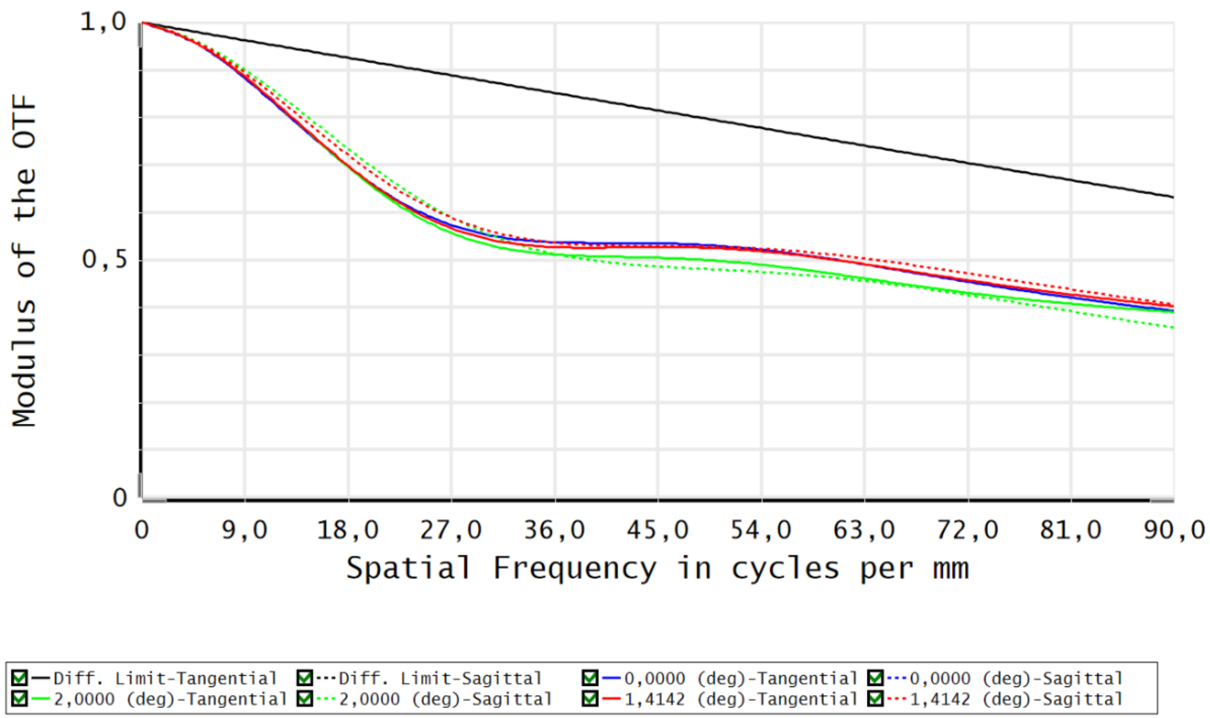
Stages	***Explanation***
Stage 1	*Start with positive and negative lenses with the stop in the middle.*
Stage 2	*These two lenses are converted to doublet lenses.*
Stage 3-4	*The lenses are added in front and behind the stop at stages 3 and 4 respectively due to insufficient system performance.*
Stage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



An Example Telephtoto Lens Design used in Earh Observation-2

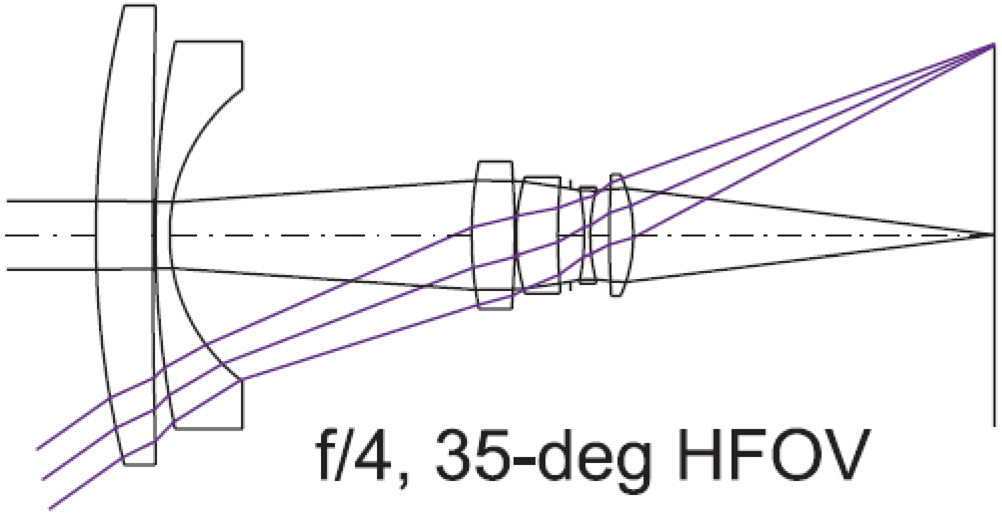
The materials used in the design is selected to be radiation resistance for space application.



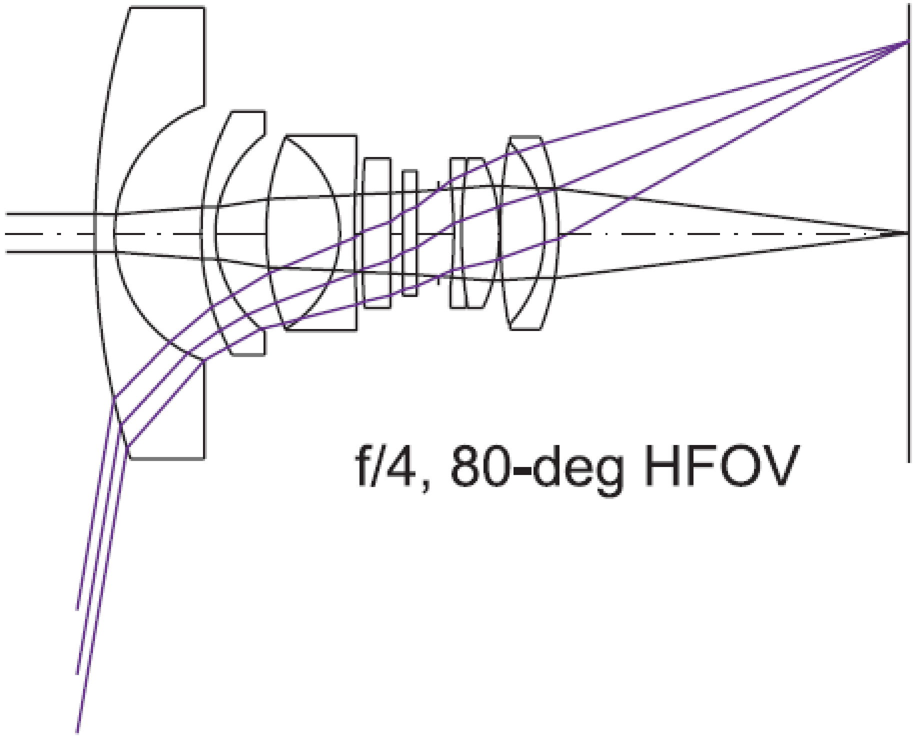


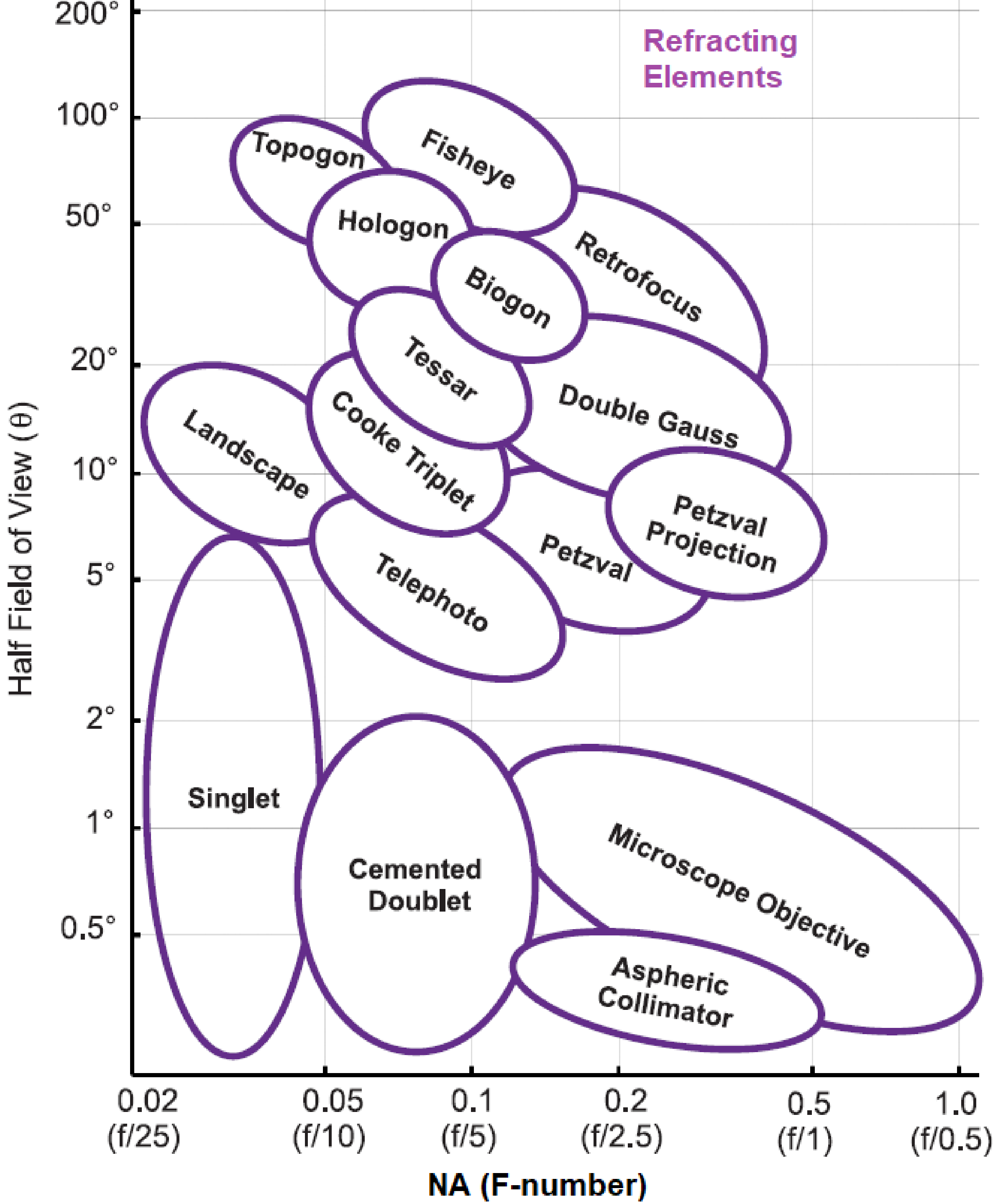
Wide Angle Objectives

Retrofocus



FishEye




Refracting Elements
Half Field of View (θ)
200°
100°
50°
20°
10°
5°
2°
1°
0.5°
Topogon
Fisheye
Hologon
Retrofocus
Biogon
Tessar
Double Gauss
Landscape
Cooke Triplet
Petzval Projection
Petzval
Telephoto
Singlet
Cemented Doublet
Microscope Objective
Aspheric Collimator
0.02 (f/25)
0.05 (f/10)
0.1 (f/5)
0.2 (f/2.5)
0.5 (f/1)
1.0 (f/0.5)
NA (F-number)

MIRROR OBJECTIVES

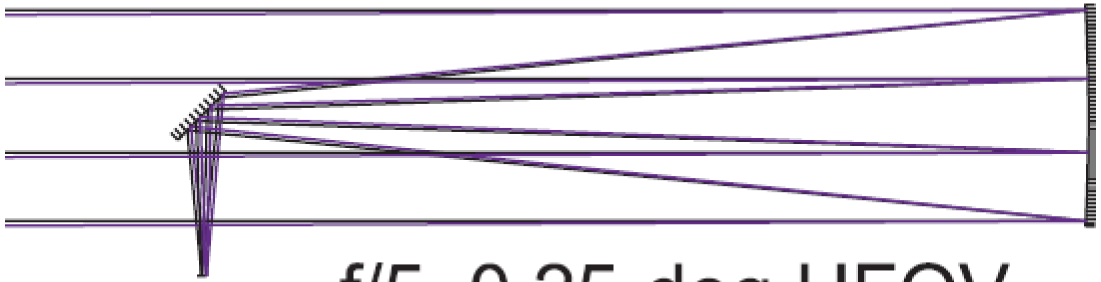
(Telescopes)

Telescopes

Newtonian

Primary: Prabolic

Scondary: Plane

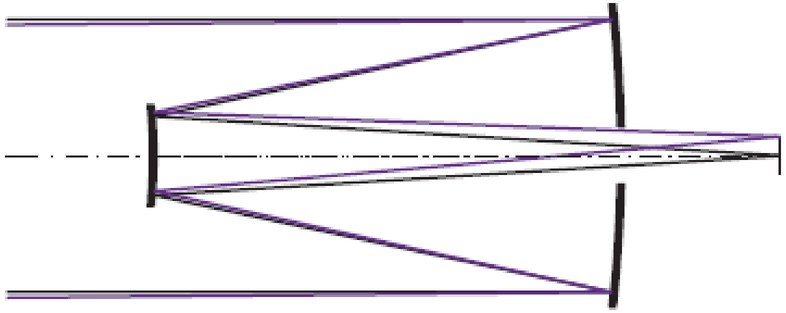


f/5, 0.25-deg HFOV

Cassegrain

Primary: Parabolic

Scondary: Hyperbolic



f/8, 0.5-deg HFOV

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

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

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.

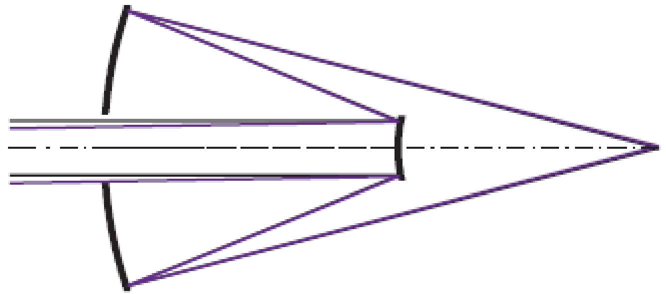
Telescopes

Schwarzshild

Primary: small negative spherical

Scondary: large positive spherical

Used in microscopy



f/2, 1-deg HFOV

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

d = mirror separation

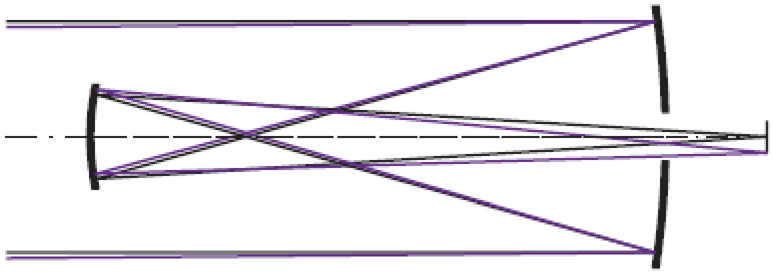
c_1, c_2 = mirror curvatures

f = system focal length

Gregorian

Primary: Parabolic

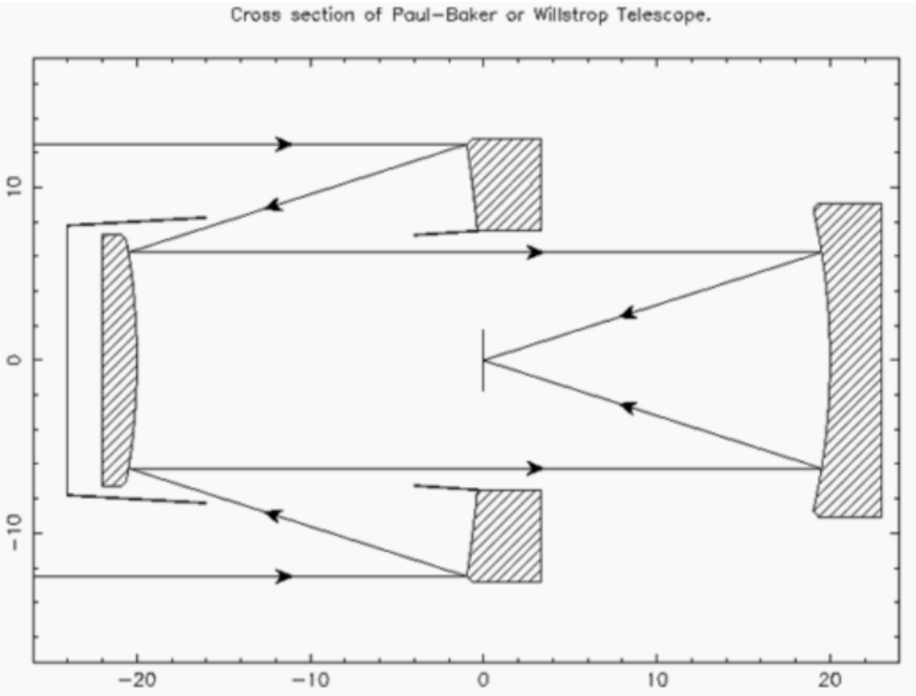
Secondary: Elliptic



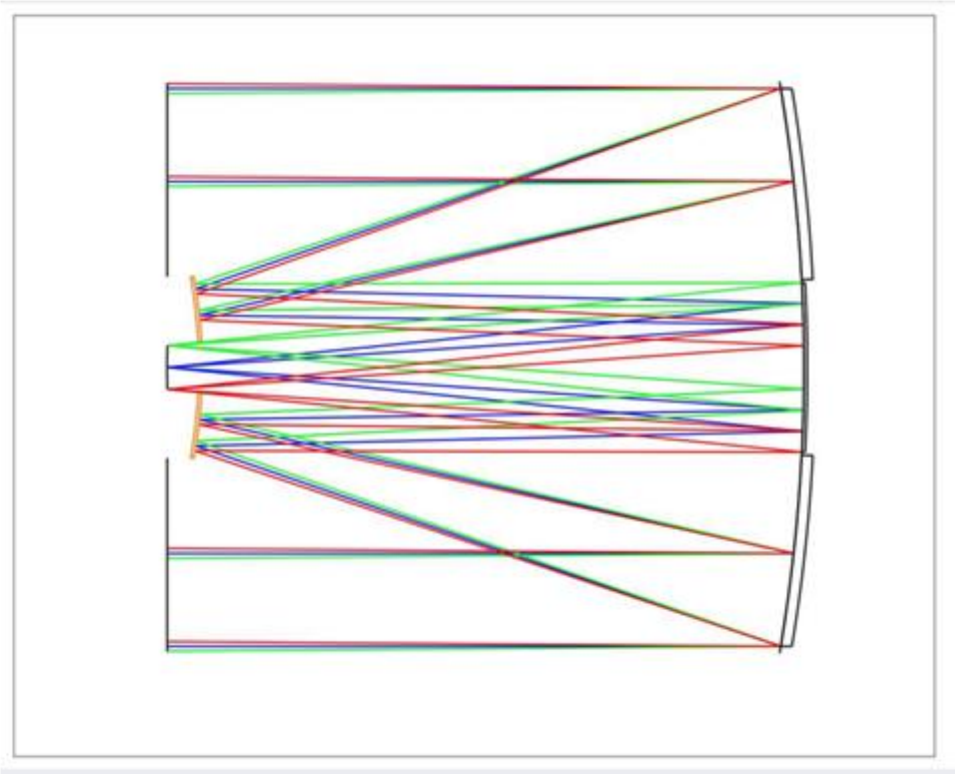
f/8, 0.5-deg HFOV

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

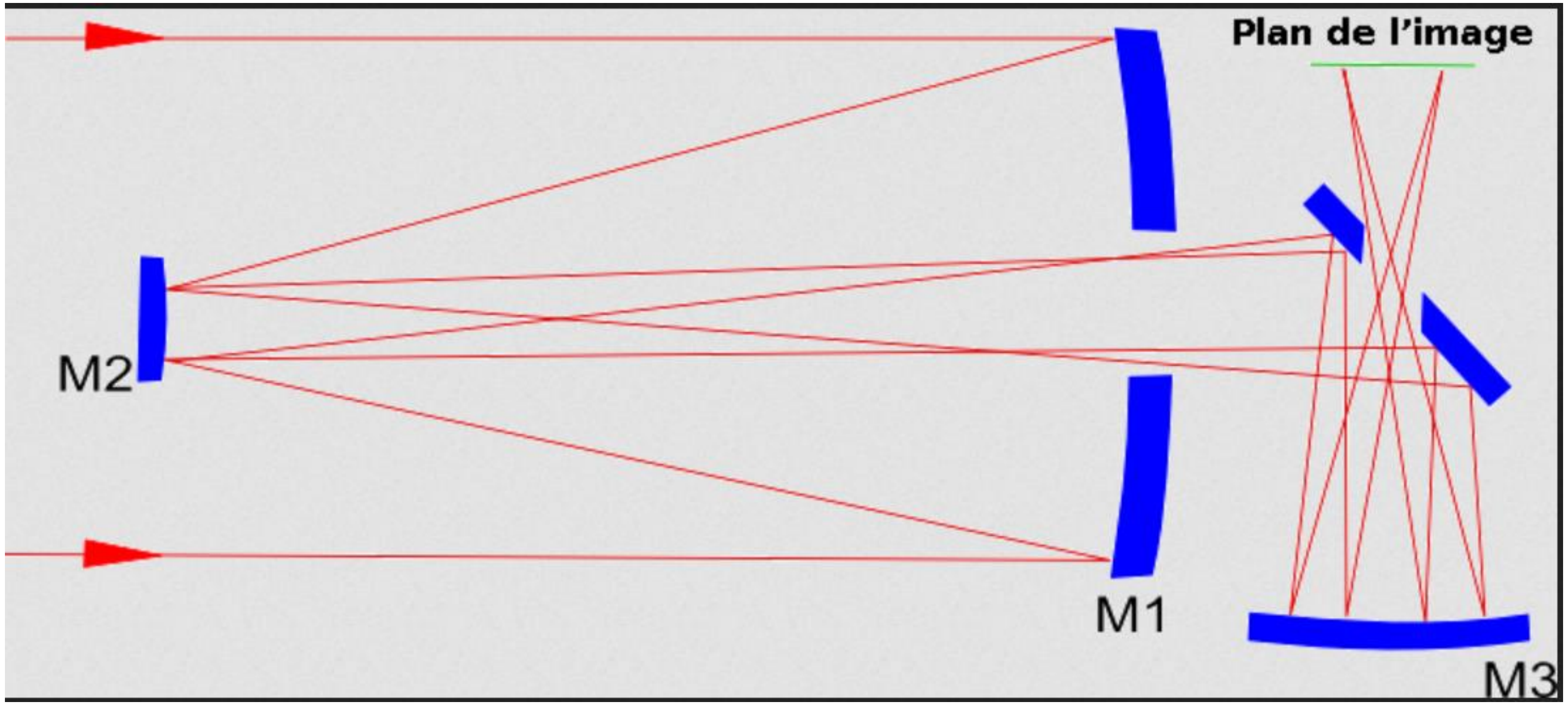


Eisenberg-Pearson Two-mirror Three-surface

Telescopes

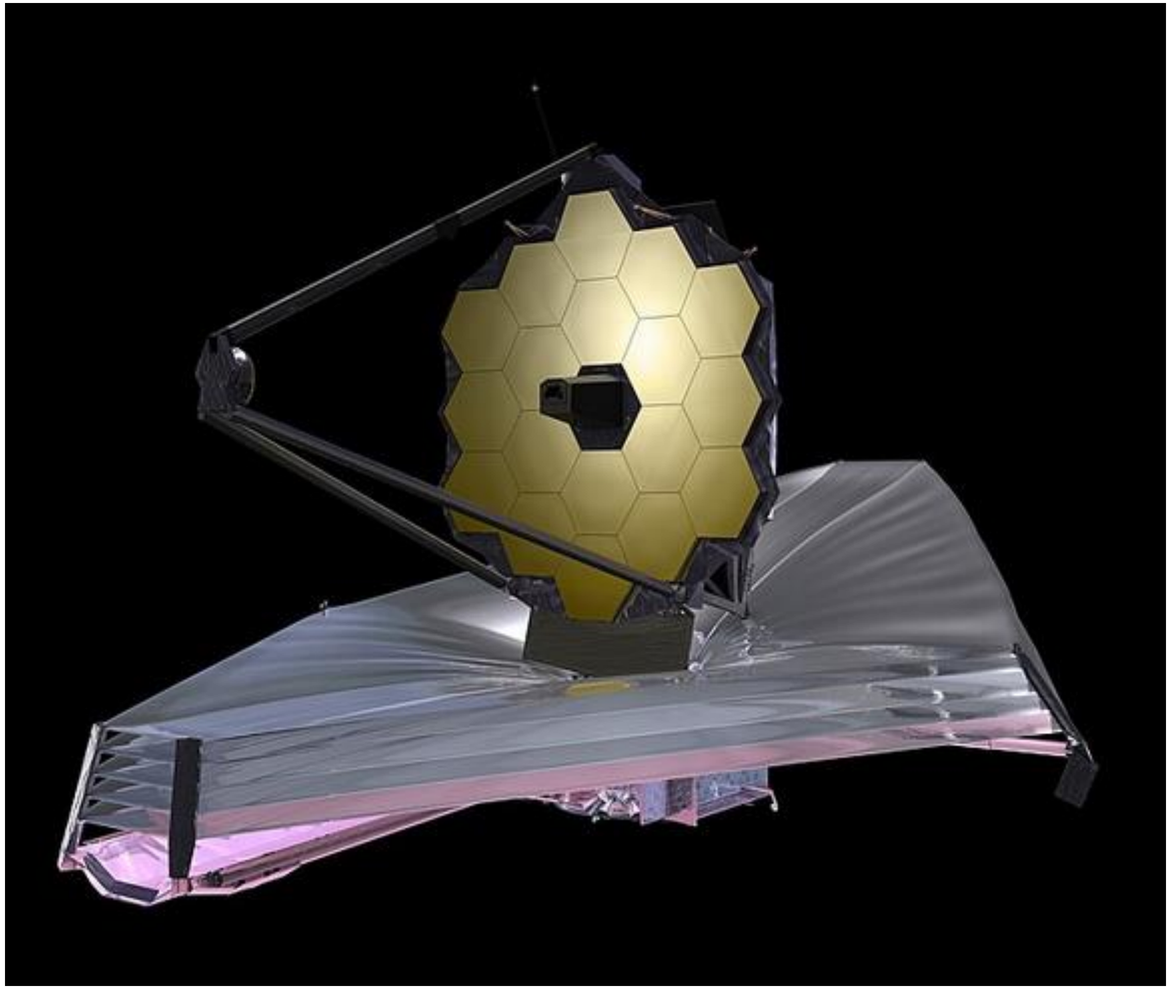
Korsch Telescope

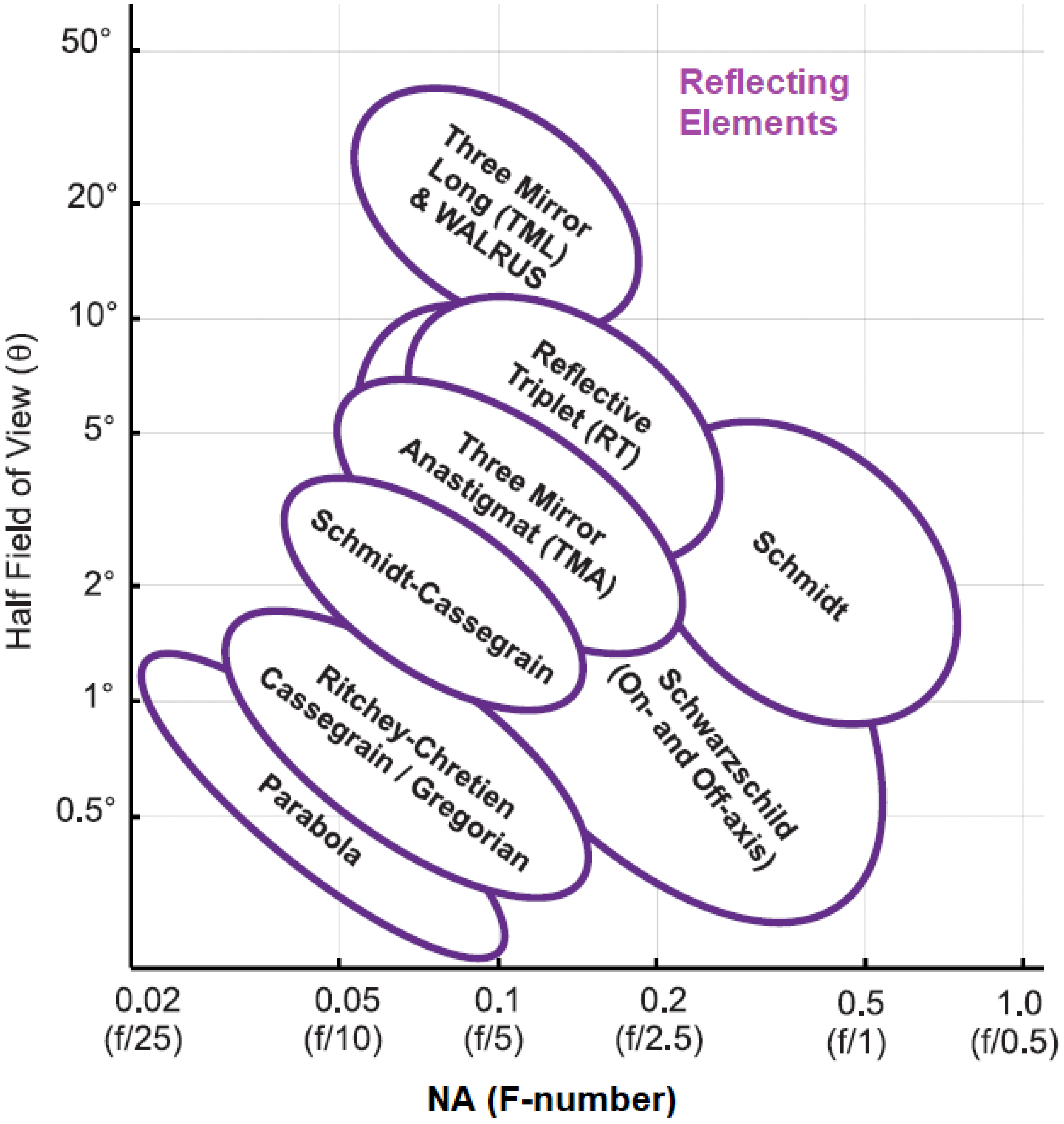
Dietrich Korsch developed a broader range of solutions in 1972. A telescope based on Korsch's design corrects for spherical aberration, coma, astigmatism, and field curvature, allowing for a wide field of view with minimal stray light in the focal plane.



James Webb Space Telescope

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




Reflecting Elements
Three Mirror Long (TML) & WALRUS
Reflective Triplet (RT)
Three Mirror Anastigmat (TMA)
Schmidt
Schmidt-Cassegrain
Ritchey-Chretien Cassegrain / Gregorian
Schwarzschild (On- and Off-axis)
Parabola
50°
20°
10°
5°
2°
1°
0.5°
Half Field of View (θ)
0.02 (f/25)
0.05 (f/10)
0.1 (f/5)
0.2 (f/2.5)
0.5 (f/1)
1.0 (f/0.5)
NA (F-number)

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.

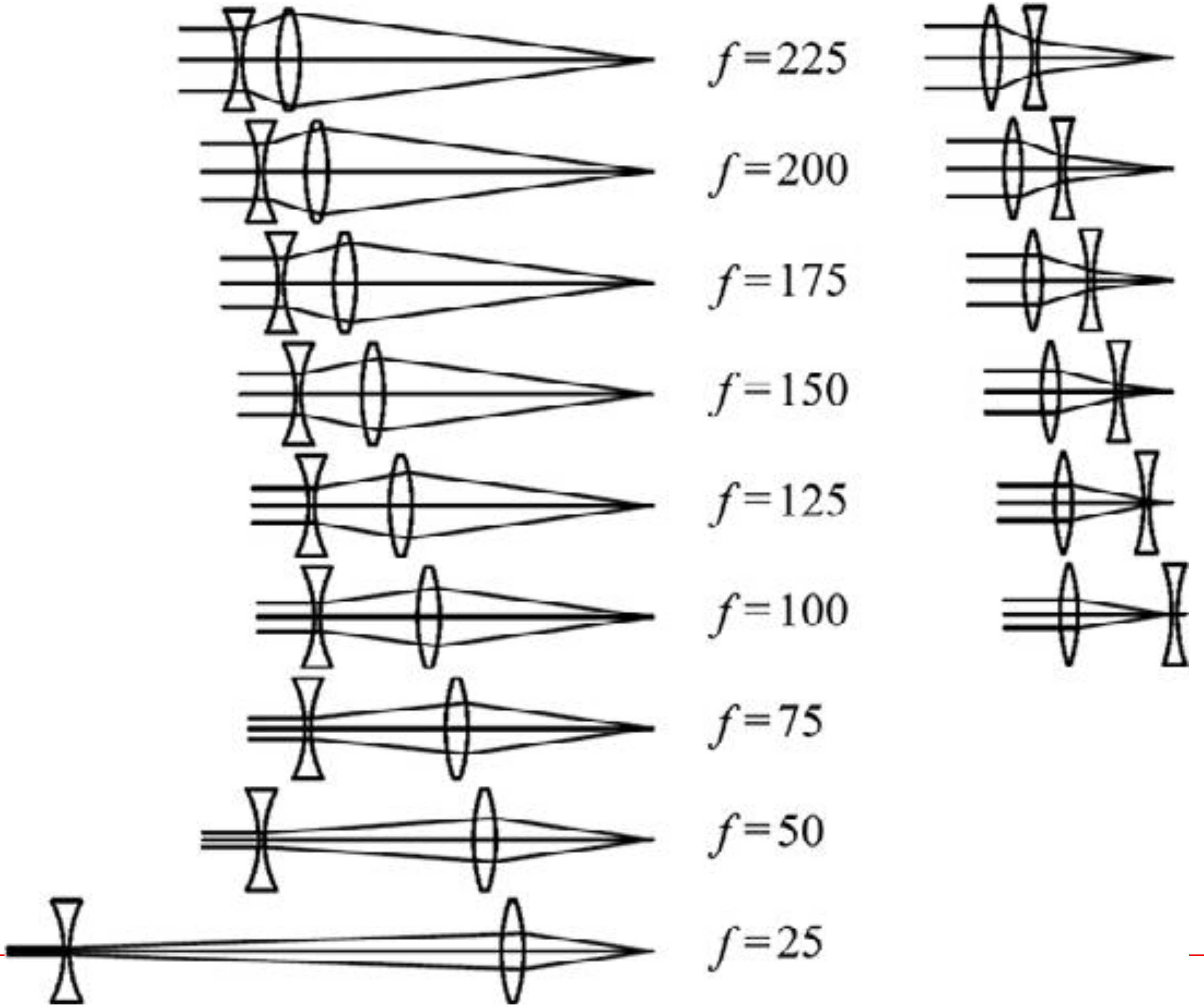
Two-Element Zoom Lenses

These are

Inverse-Telephoto and

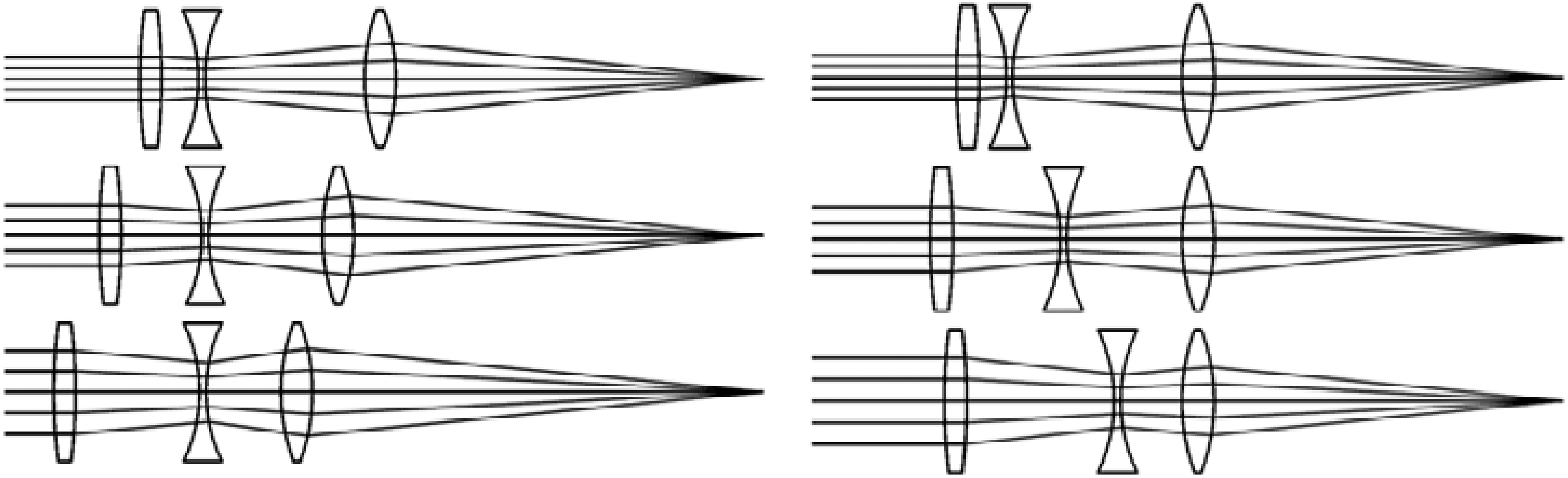
Telephoto lenses with focal lengths

±100.



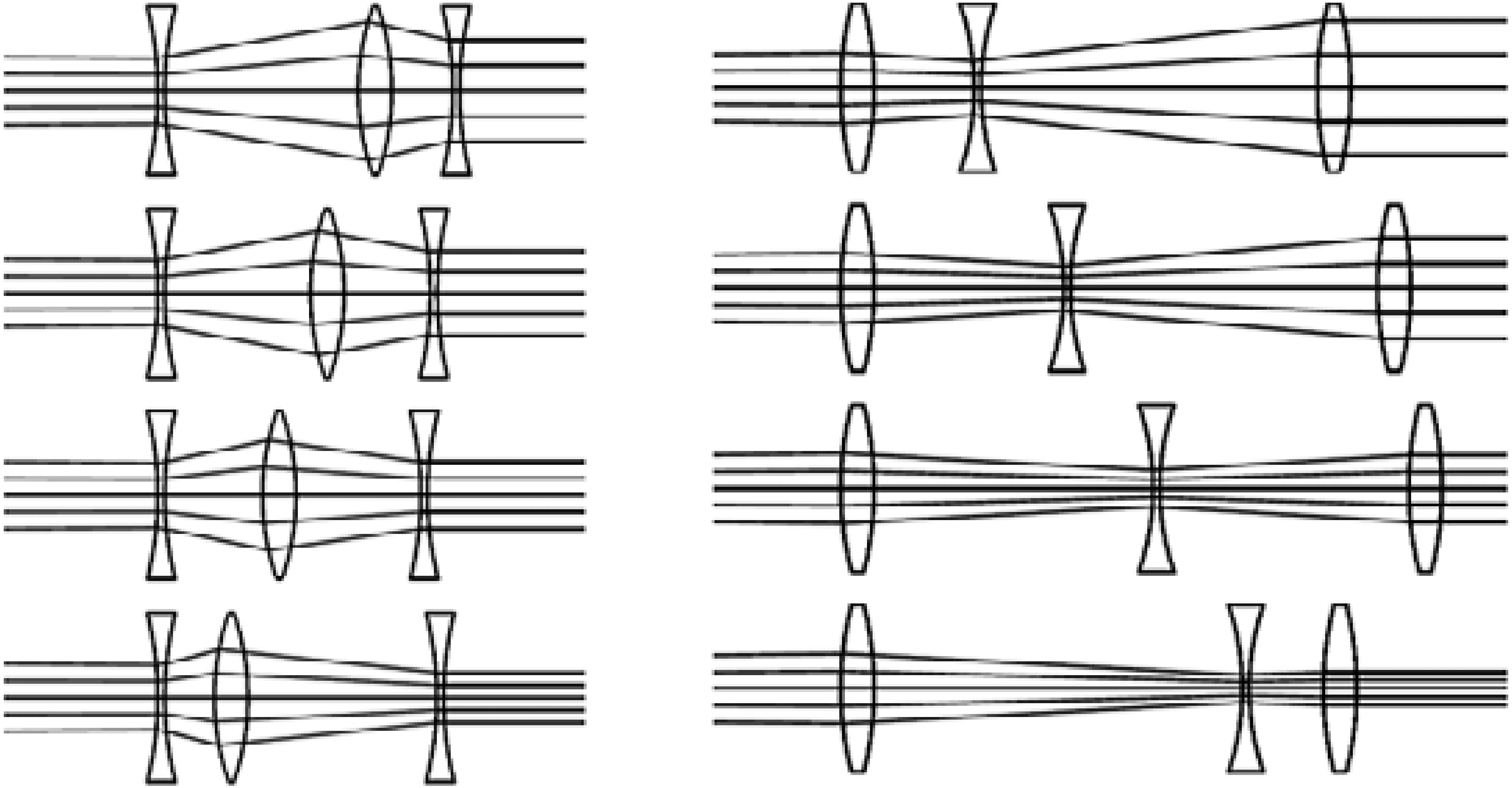
Three-Element Zoom Lenses

Focal systems



Three-Element Zoom Lenses

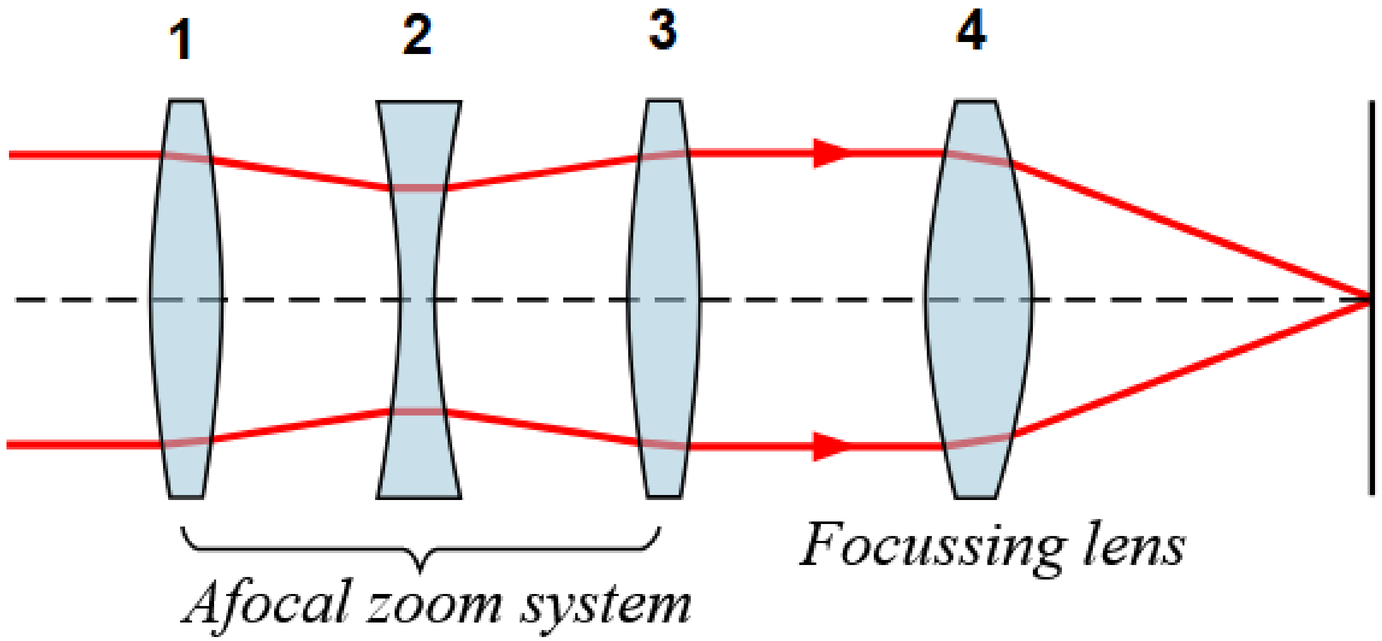
Afocal systems



Four-Element Zoom Lenses

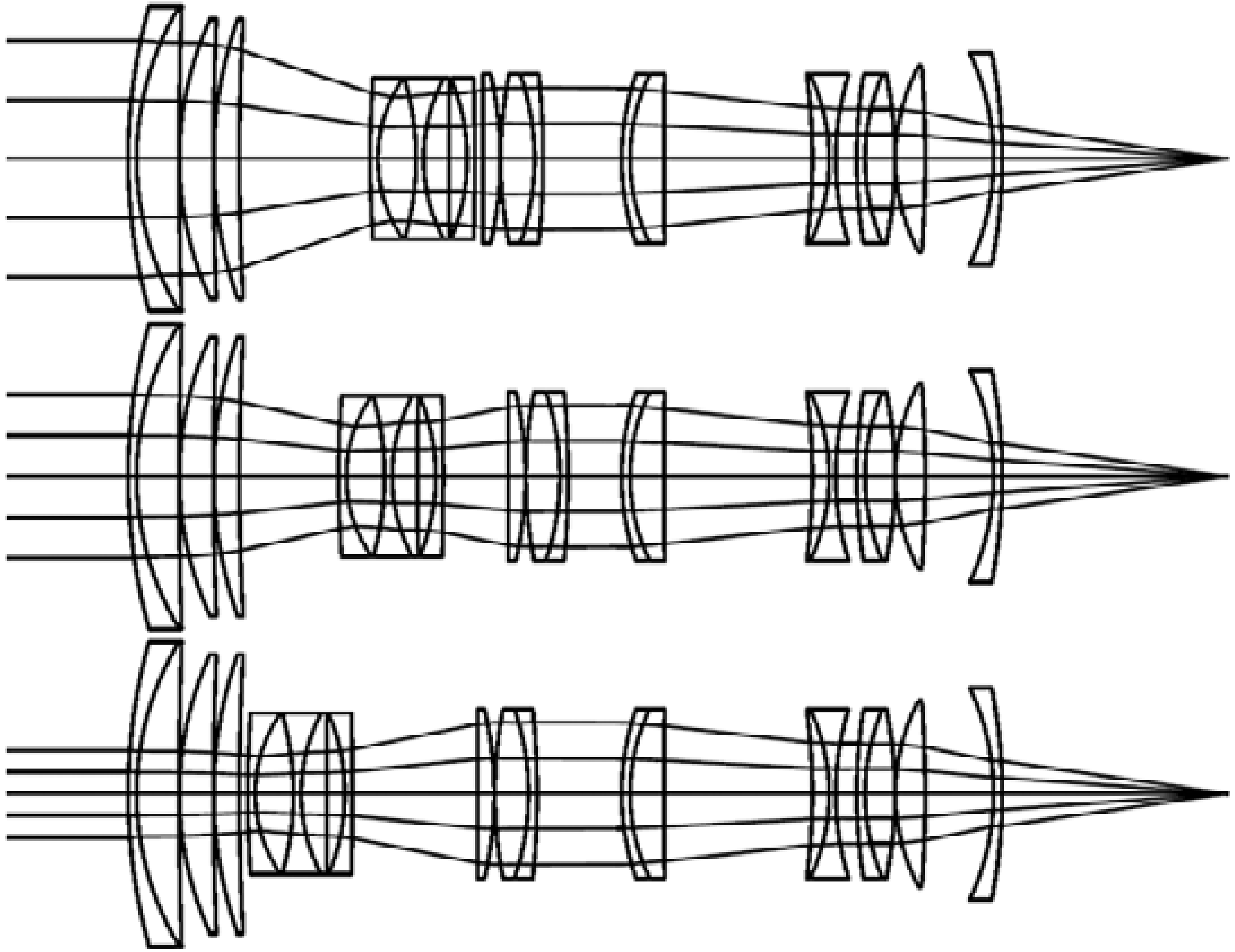
Here is a simple design form.

- 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

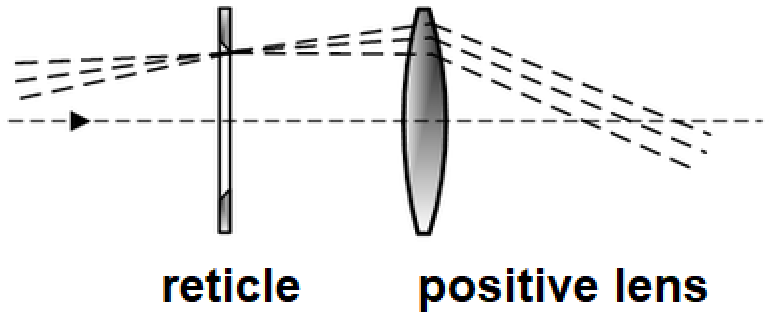
- An eyepiece, or ocular lens, is a type of lens that is attached to a variety of optical devices such as telescopes and microscopes.

- 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).

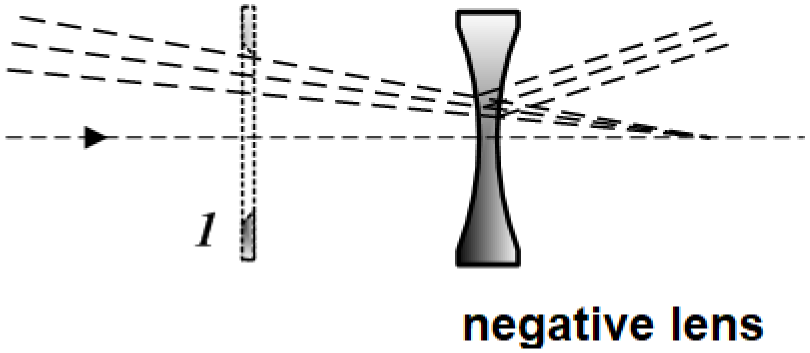
- For details visit: https://en.wikipedia.org/wiki/Eyepiece

Eyepiece Design Forms

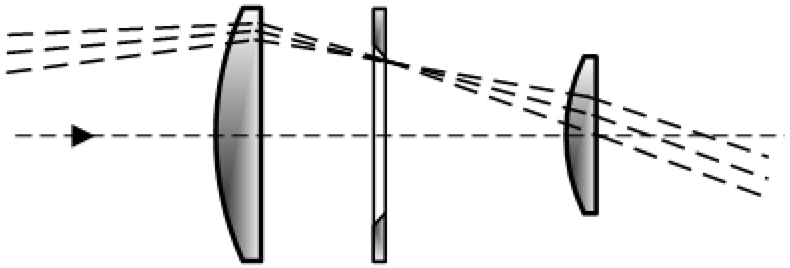
A simple convex lens placed after the focus of the objective lens presents the viewer with a magnified inverted image.



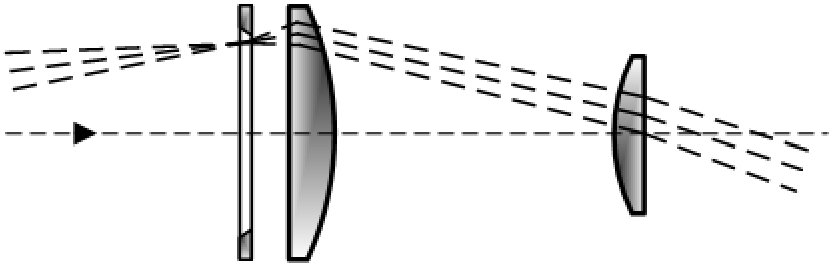
The simple negative lens placed before the focus of the objective has the advantage of presenting an erect image but with limited field of view.



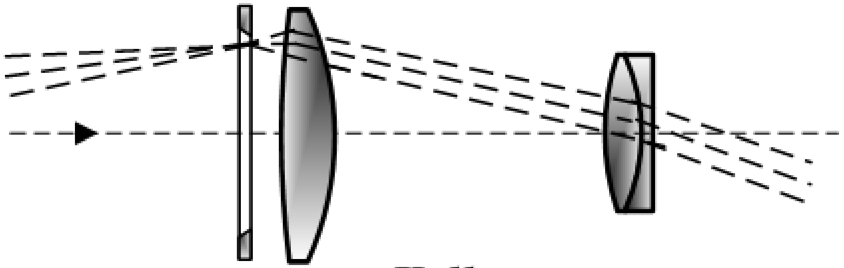
Eyepiece Design Forms



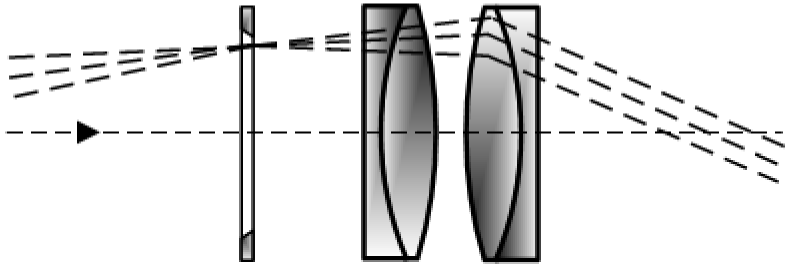
Huygens



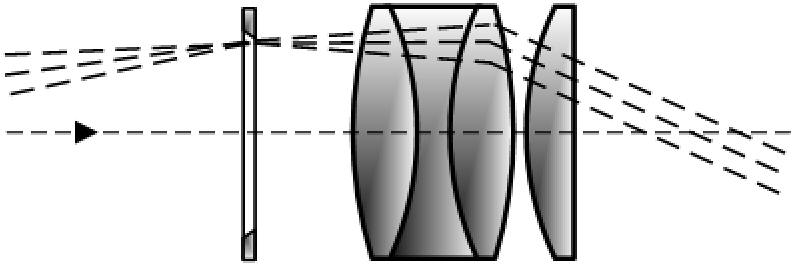
Ramsden



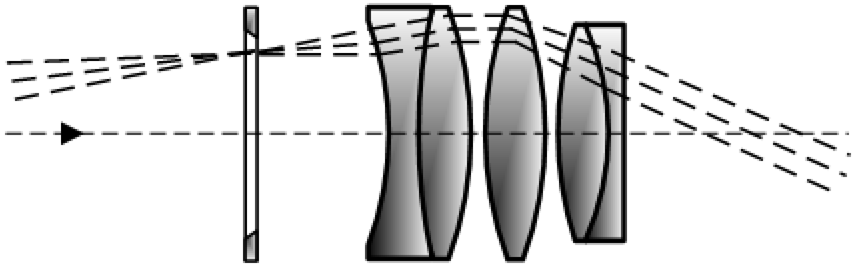
Kellner



Plössl



Orthoscopic



Erfle

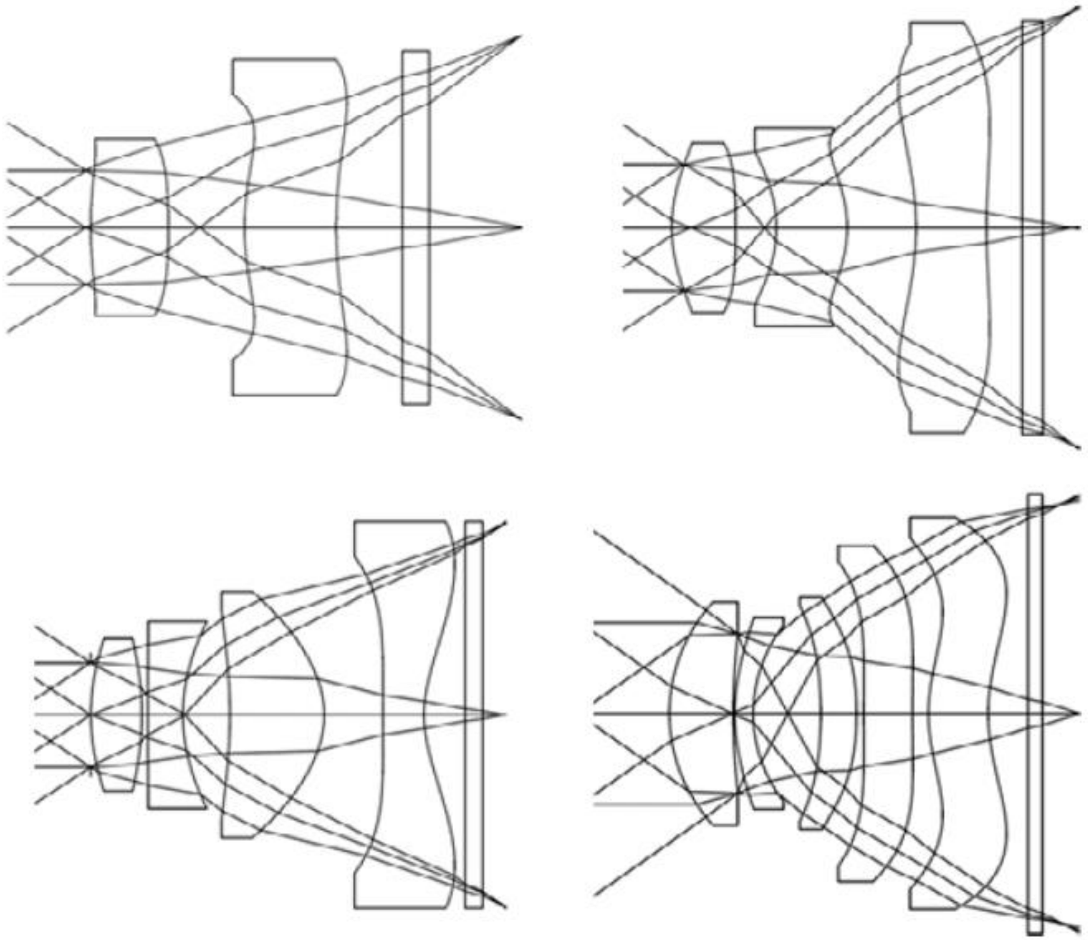
CELL PHONE CAMERA LENSES

Miniature Lenses

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

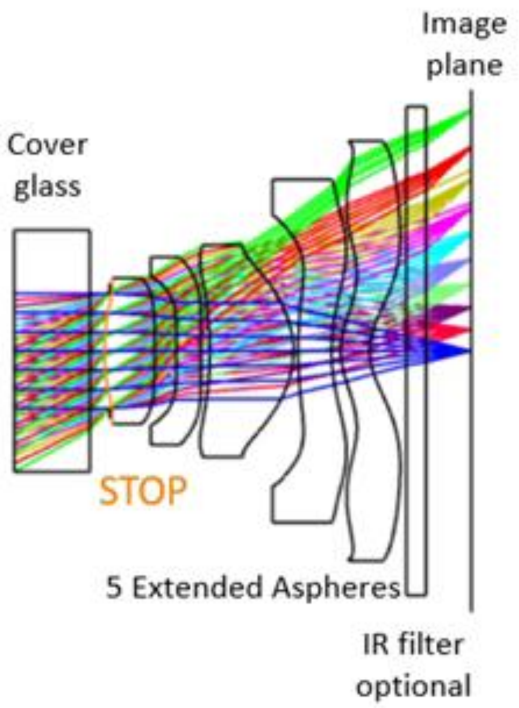
Typical mobile phone lens specifications

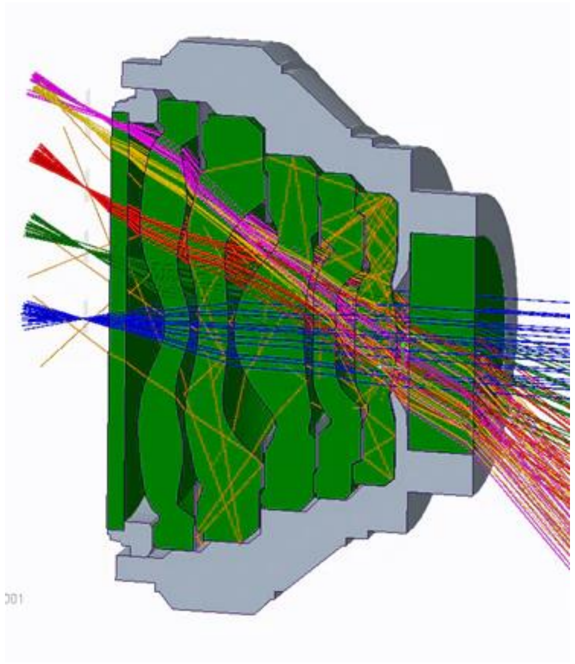
Year	2006	2012	2018
Focal length	3–6 mm	3–5 mm	3–5 mm
FOV	66°	72°	78°
F/#	2.8	2.2–2.4	2.0–1.4
TTL	<5.0 mm	<5.0 mm	<6.0 mm
Distortion	<1–2%	<1–2%	<1–2%
CRA	<24°	<30°	<33°
RI	>50%	>50%	>32%
# lens elements	3–5	4–6	5–8



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

Designing Cell phone Camera Lenses in Zemax





- https://www.zemax.com/blogs/news/designing-cell-phone-camera-lenses-part-1-optics
- https://www.zemax.com/blogs/news/designing-cell-phone-camera-lenses-part-2-optomechanical-packaging-with-opticsbuilder