The History of Telescopes and Binoculars

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How eBay Made Me an Expert in Antique Optics

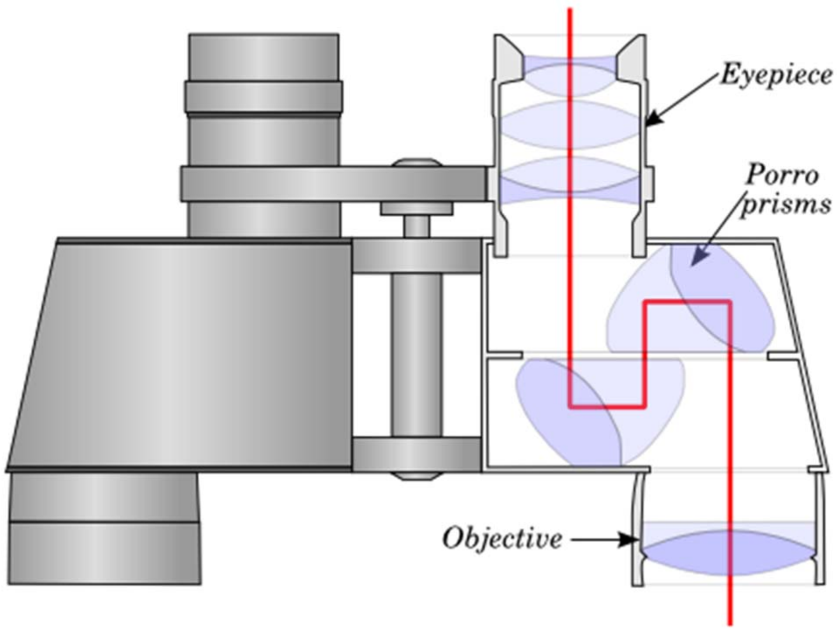
Unless noted, the instruments in this presentation are from the Museum of Optics at the College of Optical Sciences, University of Arizona.

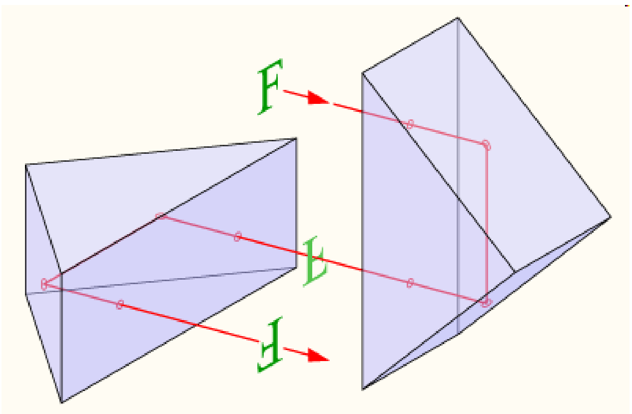
They can be viewed on-line at www.optics.arizona.edu/museum

Modern Prism Binoculars

In astronomical telescopes the image is inverted.

In order to obtain the proper image orientation, binoculars make use of a prism assembly to erect the image.

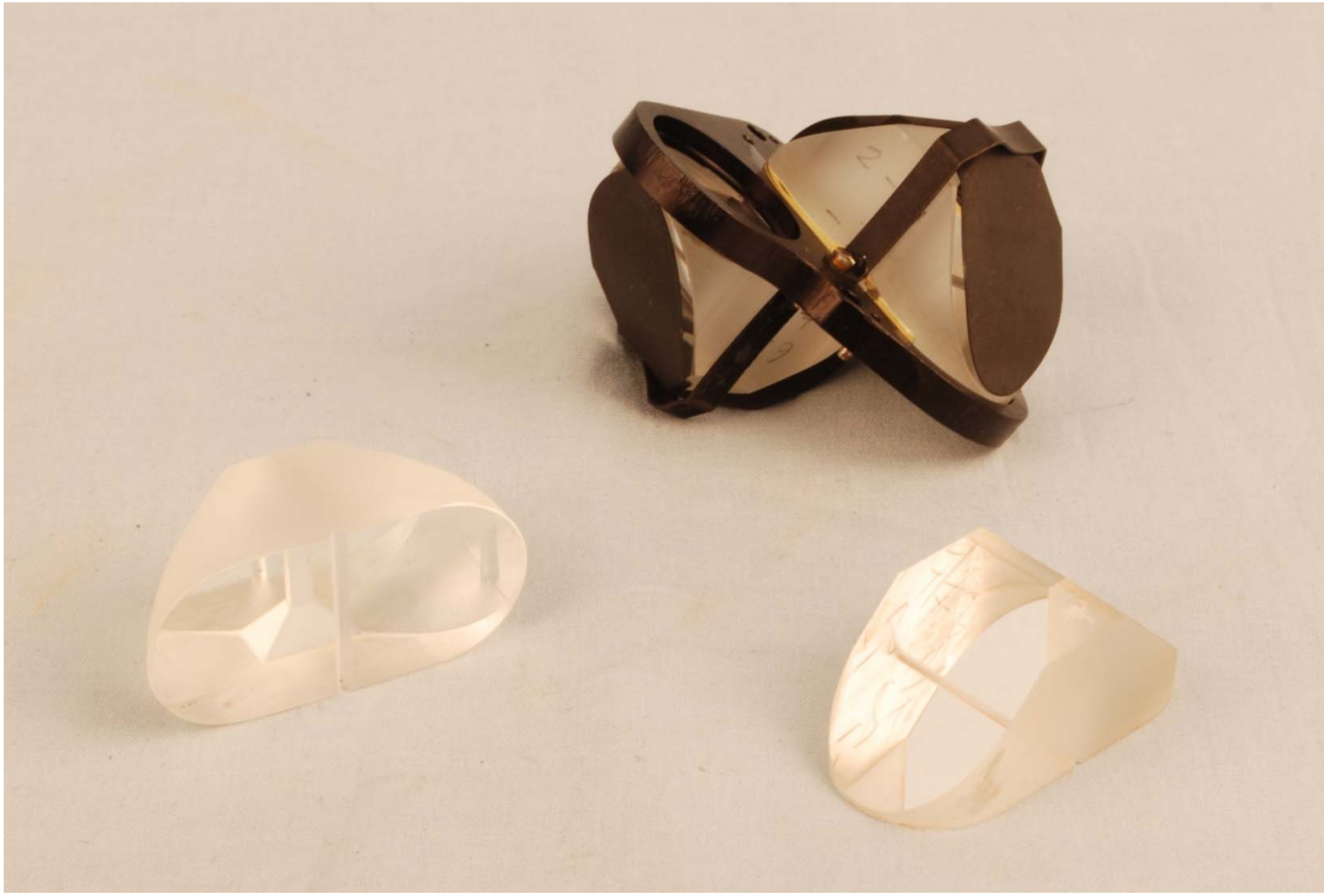




Porro Prism System

This type of prism can be considered to be a series of flat mirrors.

Porro Prism System



The reflections are often based upon total internal reflection.

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Audience Participation - Quiz

When was the Porro Prism System invented?

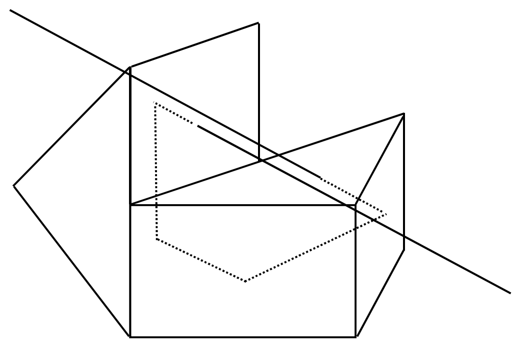
a) 1704

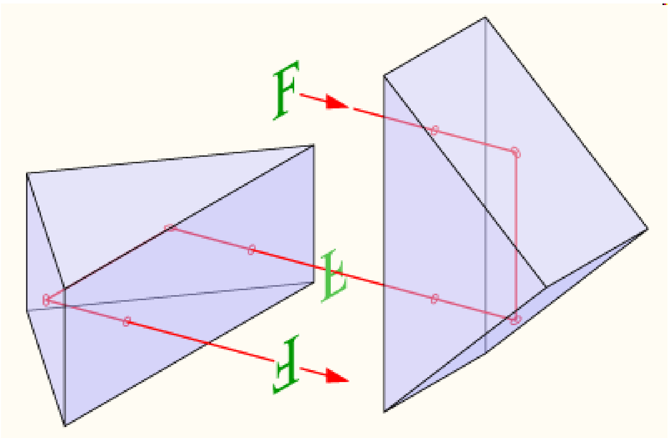
b) 1754

c) 1804

d) 1854

e) 1904





Glass and Brass

The development of practical handheld refracting telescopes and binoculars is much more than the story of optical design.

Advances in mechanical design, manufacturing technology, materials and optical glass were critical.

The availability of precision brass tubing in the mid-1700s played a crucial role in the history of optical instrumentation.

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In the Beginning…

September 25, 1608

Hans Lipperhay was provided a letter of introduction in order to present his invention to the States-General in The Hague of the Netherlands for the purpose of obtaining a patent:

“a certain device by means of which all things at a very great distance can be seen as if they were nearby, by looking through glasses…”

1570-1619, German-Dutch

A Week Later…

October 2, 1608

Hans Lipperhay receives a request from the States-General:

“to ascertain … whether he could improve it so that one could look through it with both eyes.”

In Other Words…

"That's nice, but we have two eyes."

Follow-ups…

October 4, 1608

Committee is formed “for the purpose of examining and trying the instrument in question on the tower of the quarters of His Excellency” and “to negotiate with the inventor about the fabrication, within one year, of six such instruments made of rock crystal.”

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Success, but…

December 15, 1608

Members of the committee report "that they have seen the instrument for seeing far with two eyes, invented by the spectacle-maker Lipperhay, and have found the same to be good."

However, "since it is evident that several others have the knowledge of the invention for seeing far, the requested patent be denied the petitioner,…"

Conclusions…

The patent process in the 1600s was very efficient.

Prototype development may have been even more efficient.

The development of binoculars began almost concurrently with the development of the telescope.

Telescopes and Binoculars

The development of binoculars began almost concurrently with the development of the telescope.

The modern configuration of the refracting terrestrial telescope was in place by perhaps the late 1600s but certainly by the mid-1700s.

The modern form of prism binoculars were not available until 1894.

Why did the design of binoculars take more than twice as long as telescopes to evolve?

John E. Greivenkamp and David L. Steed

Additional Requirements for Binoculars

- Two telescopes for magnifying distant objects
- Matched magnifications of the two telescopes
- Erect images
- Handheld
- Individually focusable, but preferably jointly focusable
- Parallel optical axes of the two telescopes
- Adjustable interpupillary separation

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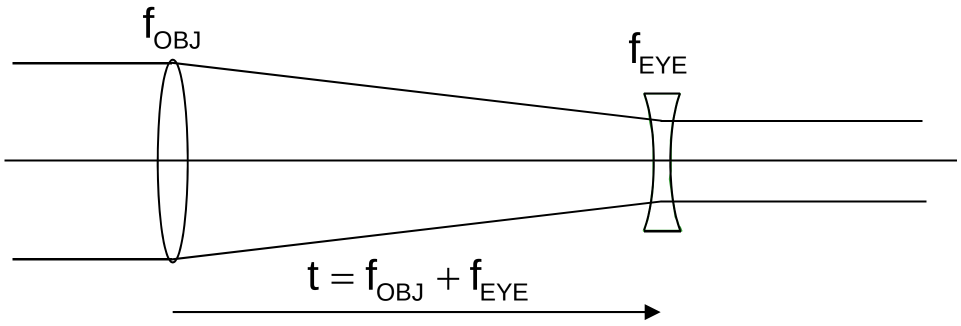
Brief History of the Telescope

1608: Dutch (or Galilean) Telescope



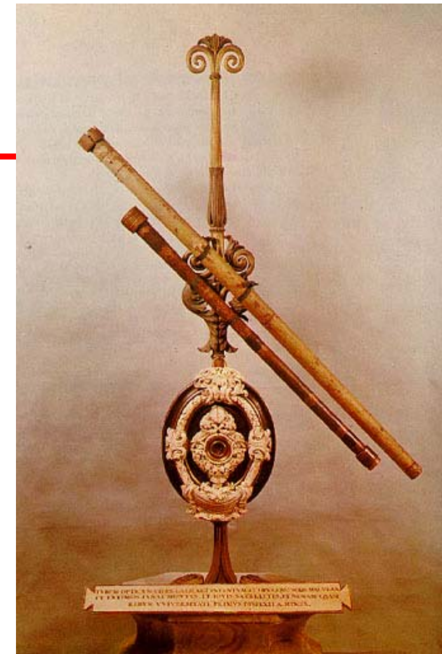
- Erect image
- Usually a low magnification
- Often short and compact
- Small field of view

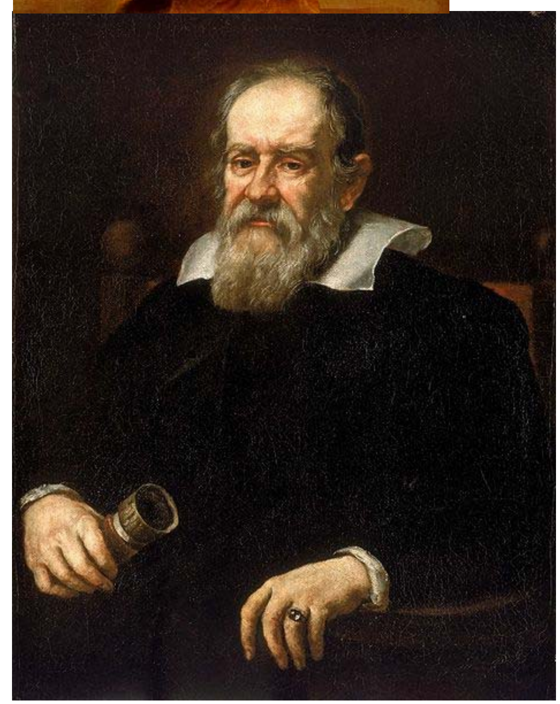
Lipperhay
1570-1619, German-Dutch

Galileo’s Telescopes

Galileo Galilei used a long high-magnification version of this design for his famous astronomical observations.

Galileo produced his first telescopes in 1609 (3-10X) with later improved telescopes with magnifications up to 20-30X. In 1610, he published his observations on the moon, the moons of Jupiter and the constellations and the Milky Way (*Starry Messenger*). Other observations included the rings of Saturn, the phases of Venus and sunspots.





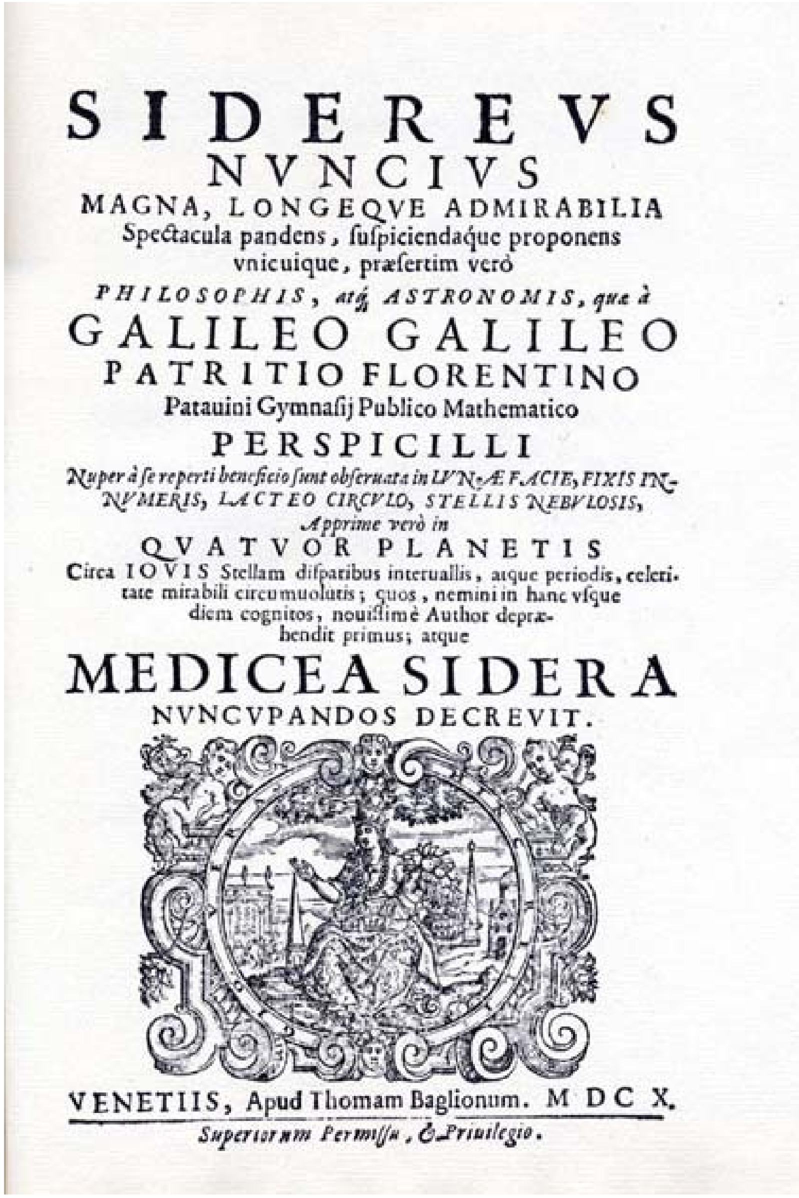
Galileo; 1564-1642, Italian

Galileo's Telescopes

Galileo Museum, Florence

This 21X telescope from 1609-10 has a plano-convex objective lens with diameter of 37 mm, an aperture of 15 mm, and a focal length of 980 mm. The telescope is 927 mm long with a field of view of 15 arc min.

Starry Messenger


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in LVNÆ FACIE, FIXIS IN-NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeritate mirabili circumuolutis; quos, nemini in hanc vsque diem cognitos, nouissimè Author depræhendit primus; atque
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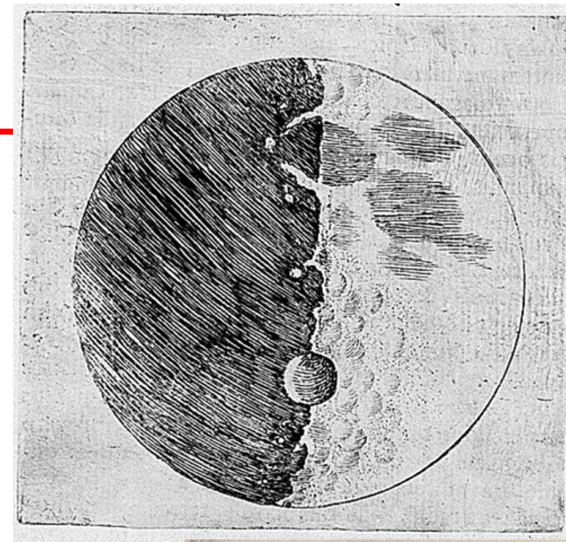

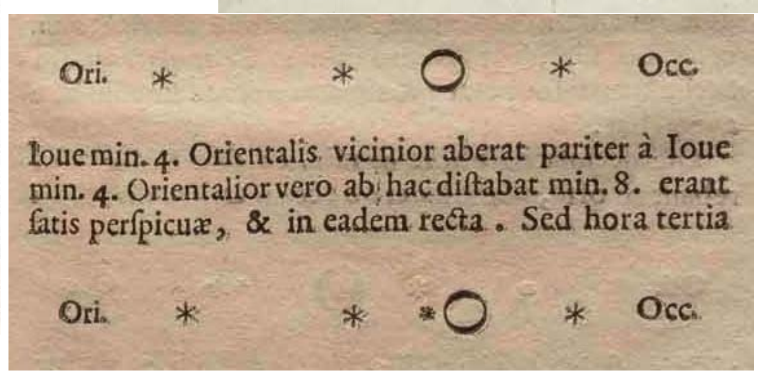
Ori. * * ○ * Occ.
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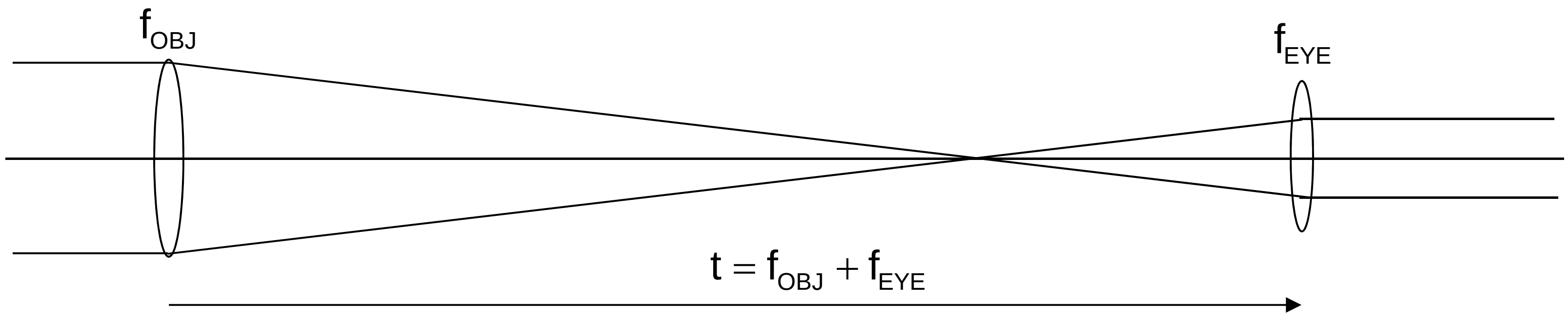
Brief History of the Telescope

1611: Astronomical (or Keplerian) Telescope



- Proposed by Johannes Kepler in 1611
- Christoph Scheiner constructs first Keplerian telescope in 1617

- Inverted Image
- Higher magnification
- Longer length
- Good field of view

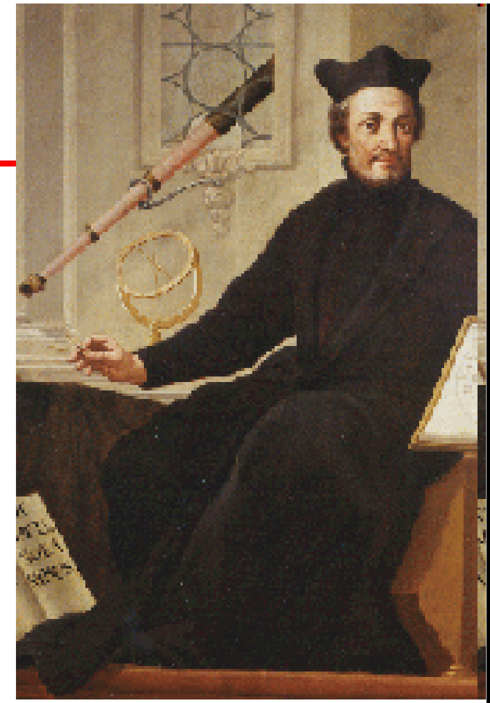
Kepler; 1571-1630, German

Brief History of the Telescope

Circa 1635: Terrestrial or Relayed-Keplerian Telescope

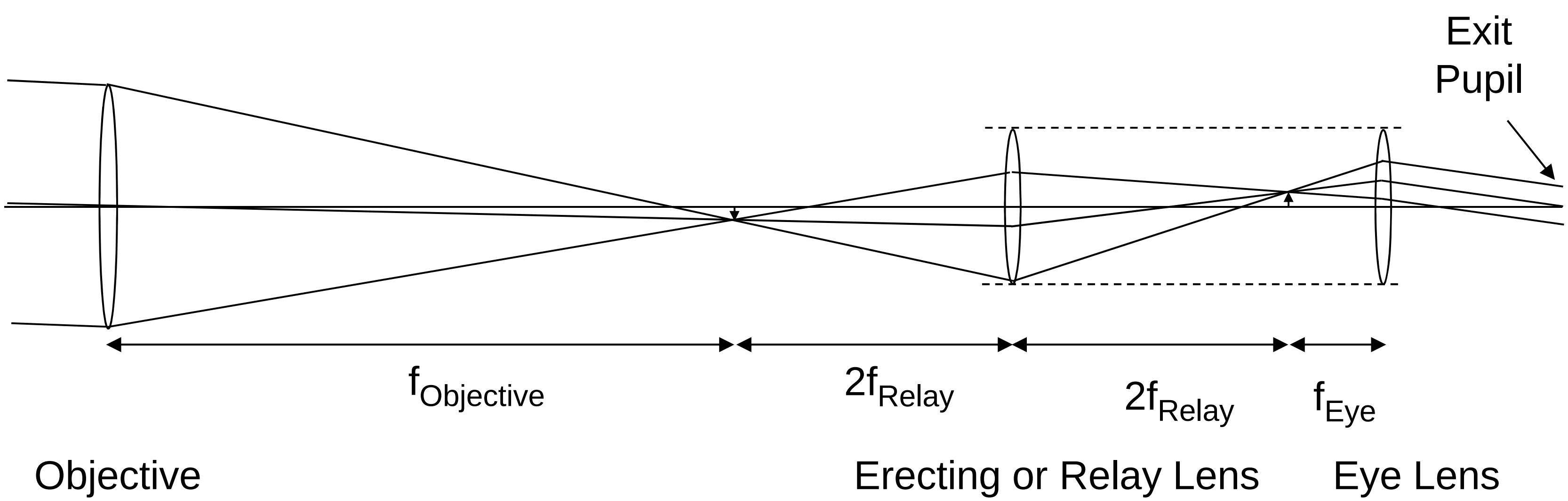
- Christoph Scheiner introduces a single erecting lens to produce an erect image.

Scheiner Erecting System or "Two-Lens Eyepiece"



Scheiner

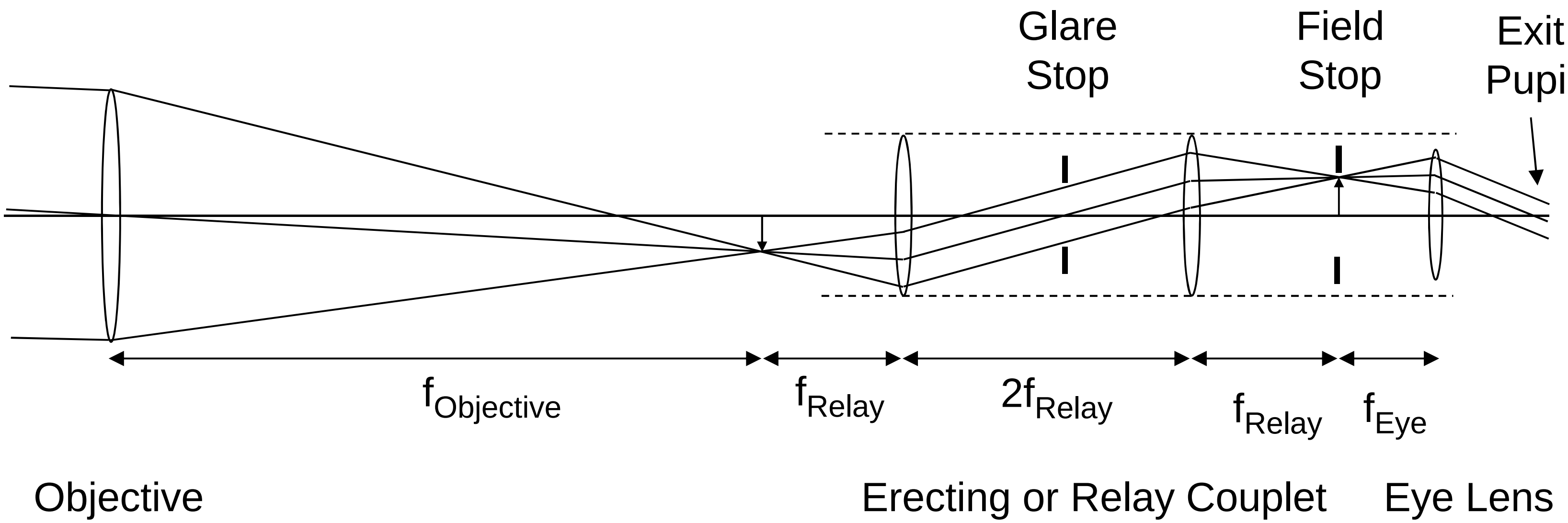
1573-1650, German-Austrian



Brief History of the Telescope

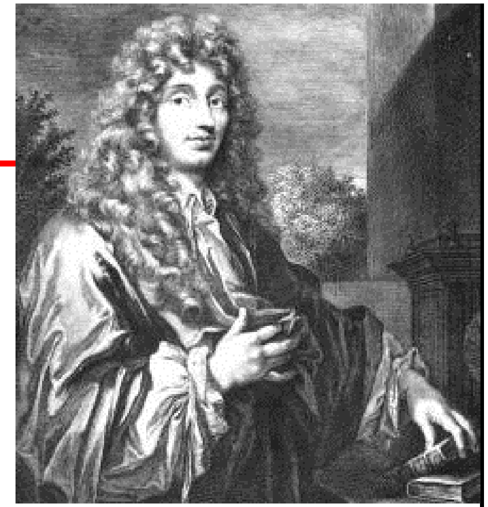
1645: Anton Maria Schyrle de Rheita (1604-1660) used a two element erecting couplet to produce a practical terrestrial telescope with an erect image and acceptable magnification and field of view.

Schyrle Erecting System or "Three-Lens Eyepiece"



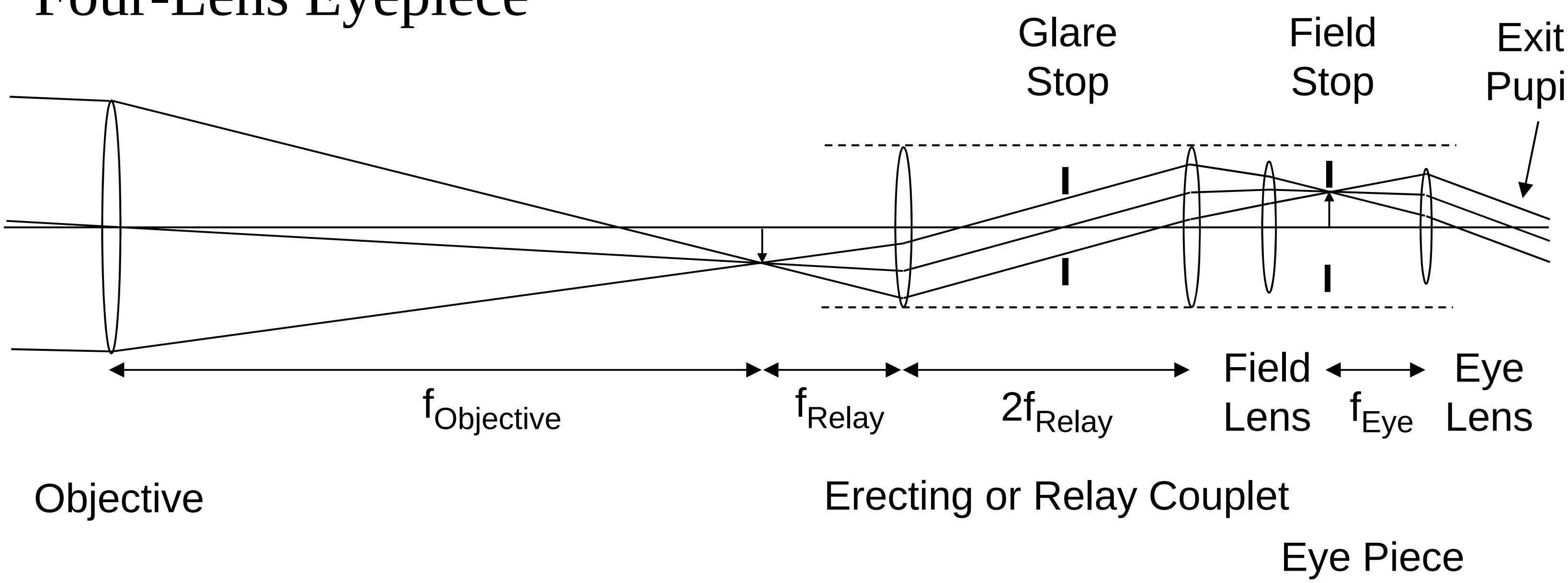
Brief History of the Telescope

1662: Christian Huygens invents the two lens eyepiece incorporating both an eye lens and a field lens.



Huygens; 1629-1695, Dutch

Schyrle-Huygens Erecting System or "Four-Lens Eyepiece"



In some telescopes, an additional field lens was inserted at or near the first intermediate image resulting in a five-lens eyepiece.

Brief History of the Telescope

There is some evidence that the four-lens eyepiece was in use in the late 1600s, however it fell out of favor until the mid-1700s.

While there were improvements to follow, most notably the achromatic objective in the mid-1700s, the modern design form of the terrestrial refracting telescope was firmly in place by this time.

The use of brass tubes also began in the mid-1700s.

The vast majority of telescopes produced were not intended for astronomical use, but for nautical and military purposes.

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Schyrle Erecting System

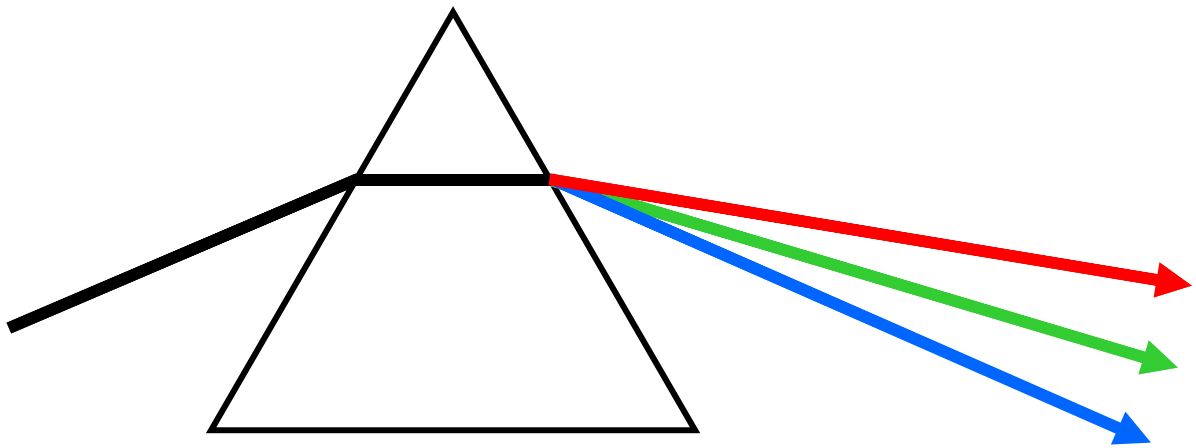
Unsigned, English, circa 1750

Single-draw pre-achromatic telescope with a wooden barrel. The telescope has an overall length of 570 mm.

Dispersion

When light goes through the a dispersing prism, different colors are bent by different amounts.

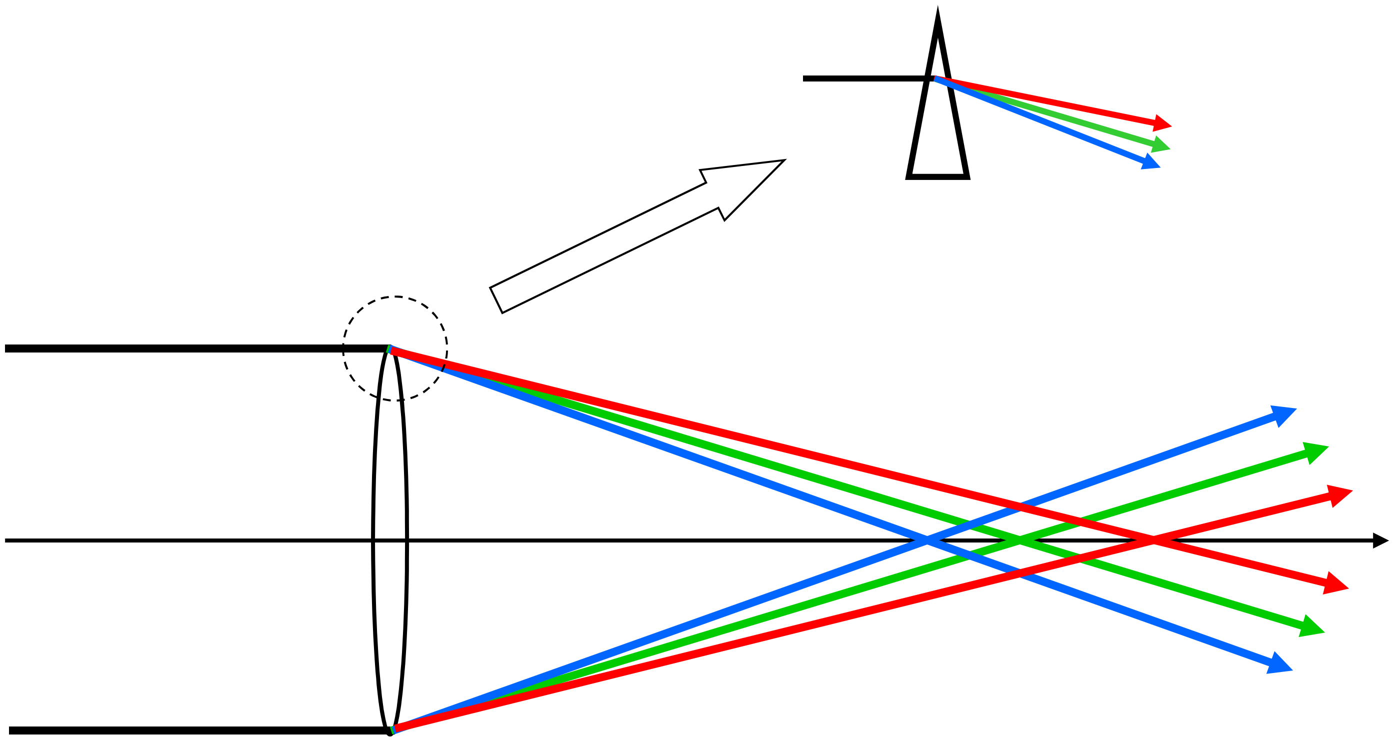
Blue is bent more than red.



Chromatic Aberration

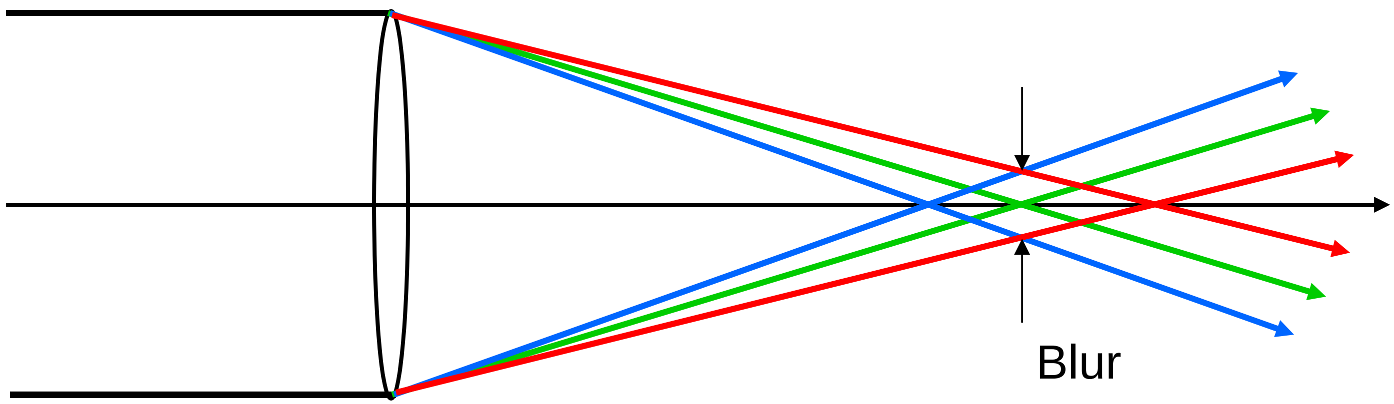
The edge of a simple lens looks like a dispersing prism.

Different colors are brought to focus at different distances.

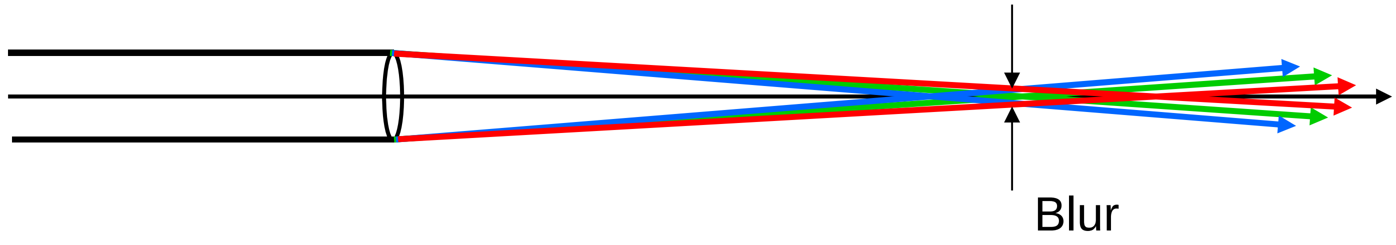


Pre-Achromatic Telescopes

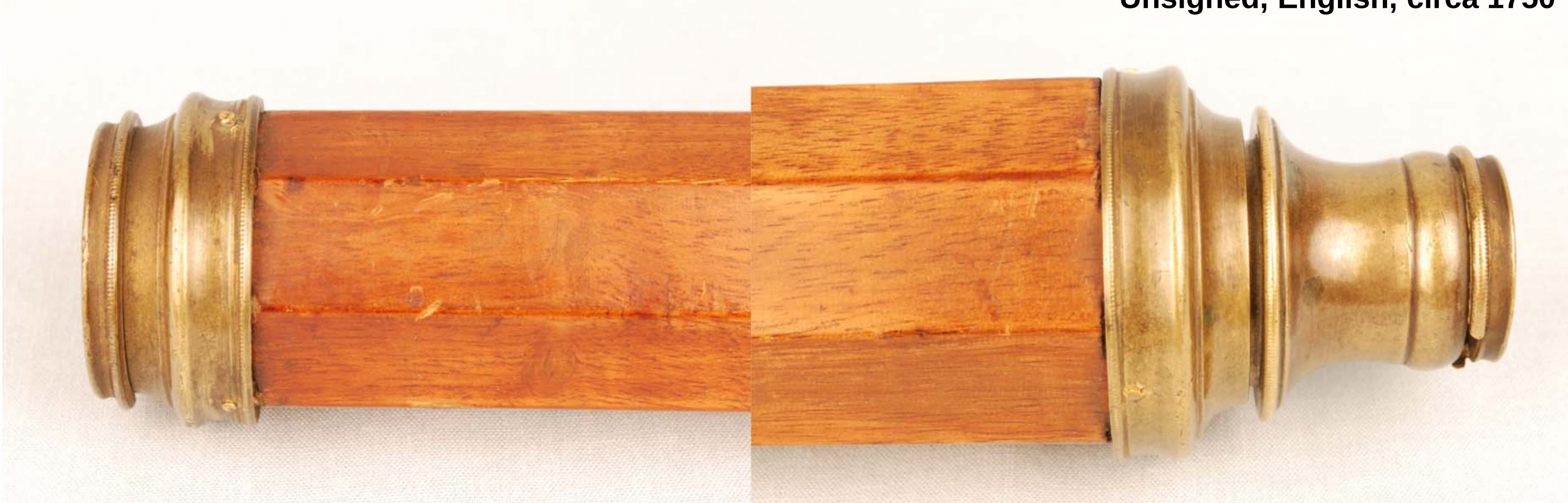
The blur associated with the chromatic aberration of the objective lens limits the performance of a telescope.



To reduce the blur, a small objective lens is required. The light collection efficiency of refracting telescopes is limited.



Reverse Taper Telescope



Unsigned, English, circa 1750

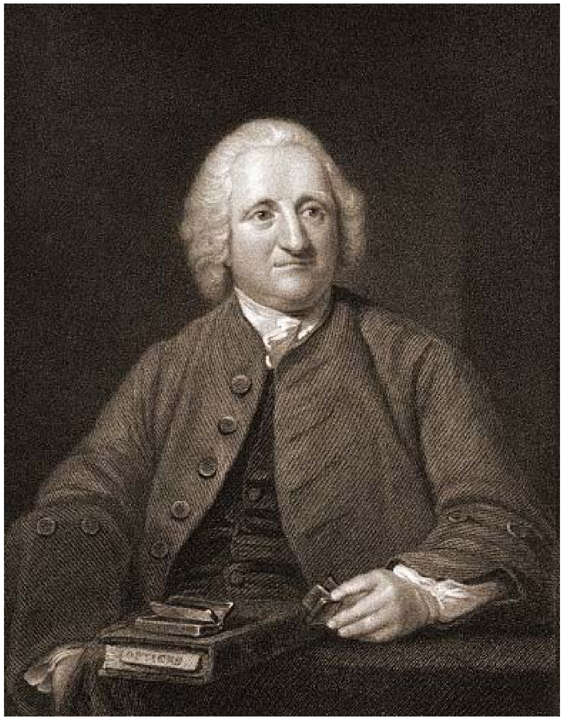
The objective end of the telescope is smaller than the eye end.

Chromatic Aberration Correction

In the early 1700s, it was believed that chromatic aberration was fundamental and could not be corrected.

Even Isaac Newton mistakenly held this belief!

In the mid-1700s, the work of Chester Moor Hall and John Dollond led to the development of the achromatic objective.

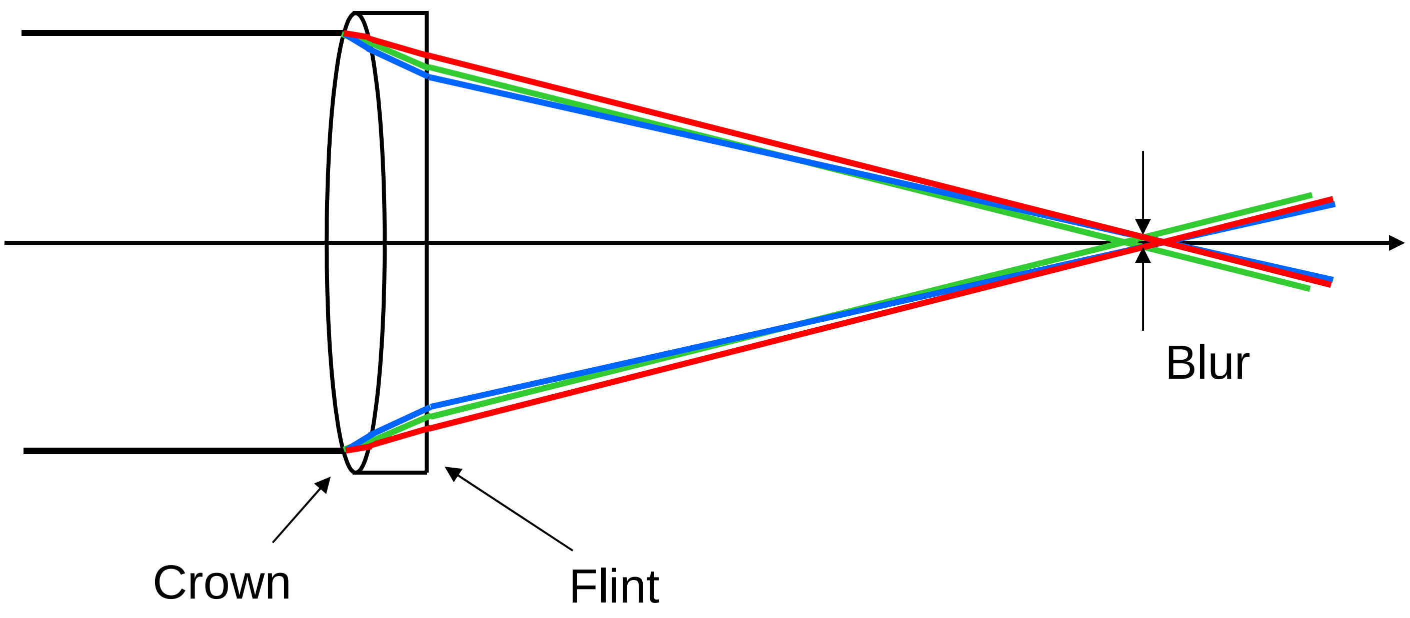


John Dollond
1706-1761, English

Achromatic Objective or Doublet

Two lens elements with different dispersive properties are combined into a single objective lens.

Red and blue light are made to focus at the same location and a greatly reduced image blur results even with large diameter lenses.



The Story of the Achromatic Doublet

The original inventor is Chester Moor Hall, a Barrister in London. In 1733, he commissioned two different opticians, Edward Scarlett and James Mann, to each make one of the lens elements.

By chance, both opticians subcontracted the work to the same man, George Bass. Chester Moor Hall then continued to keep his invention secret.

Chester Moor Hall
1703-1771, English

The Story of the Achromatic Doublet

Around 1750, George Bass told John Dollond about the achromatic lens he had made, or at least the fact that different glasses have different dispersing powers. Dollond then began a series of experiments using different types of glass.

Dollond's son, Peter, saw the commercial advantages and once they had made test lenses, patented the invention in 1758.

Peter Dollond
1731-1821, English

Achromatic Doublet Patent

Chester Moor Hall twice attempted to challenge the patent.

He lost his case on the grounds that the person who should profit by the invention is the one who benefits the public by it, not one who keeps it locked in his desk drawer.

This was a landmark decision in patent law that remains in place to today.

Dollond went on to become the dominant manufacturer of telescopes in the late 1700s and early 1800s. The name "Dollond" became a synonym for a telescope.

Achromatic Telescopes

Paper Telescopes

Through the mid-1700s, telescopes were made of paper rolled into tubes with leather or vellum coverings.

The leather or vellum provided some level of water resistance.

The lens cells and protective rings on draws were made of turned wood, horn and sometimes ivory.

Italian Paper Telescope

Leonardo Semitecolo, Venice, early 1700s

This telescope has a Schyrle erecting system and is constructed with paper tubes covered in decorated velum. It is 850 mm in length and the main barrel is 55 mm in diameter.

Precision Brass Tubing

Brass, which is an alloy of copper and zinc, is an ancient material, but is much more difficult to produce than bronze (copper and tin). High quality brass was not readily available until the 1700s.

Brass tubes were first seen in microscopes in the 1740s and were commonly used in telescopes from around 1750.

The brass was prepared for drawing by rolling a sheet of the metal into a cylinder that was wrapped around a mandrel that defines the inner diameter of the tube. The abutting edges of the cylinder were silver soldered together. The brass cylinder was then drawn with great force through a steel die. A series of dies was used to produce the desired wall thickness or outer diameter.

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Objective Lens Mounts

Turned Horn with Retaining Ring

Leonardo Semitecolo, Venice, early to mid-1700s

Turned Wood with Retaining Ring

Unsigned, German, early to mid-1700s

Brass Cell with Dust Slide and Aperture Ring

Unsigned, English, mid-1700s

Brass Cell with Spun-Over Edge

Dollond, London, circa 1800

Brass Cell with Retaining Ring

Harris & Son, London, mid-1800s

Binoculars

Binoculars

There are two different approaches for binoculars:

Dutch or Galilean Telescopes

Keplerian Telescopes

These two types of systems evolved in parallel. Attempts at both were made starting in the 17th century.

In both cases, the difficulties of alignment, focusing, and magnification match made reproducible manufacturing almost impossible.

Precursors to Galilean Binoculars

Beginning in the early 1700s, small Galilean telescopes, called spyglasses or prospect glasses, had become common.

Dollond, London

Dollond, London

Chevallier, Paris

Ramsden, London

Ramsden, London

The magnifying power is 2-3X. Larger optics and achromatic objectives allowed for increased field of view by the late 1700s.

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Wedgwood Monocular – Late 1700s

Opera Glasses

1823: J. F. Voigtländer (1779-1859) patented the combination of two achromatic spyglasses into a pair of opera glasses by using a frame with two bridges. “Kaiserliches Privileg zur Herstellung von Doppel-Theater-Perspektiven” or “Imperial Privilege for the Production of Double-Theater-Perspectives.”

Voigtländer, 1823

Voigtländer Opera Glasses

Voigtländer, 1823

Opera Glasses

1825: J. P. Lemiére of Paris improved upon this design by adding a third bridge between the two eye tubes and focusing mechanisms. Adjustments for interpupillary distance are shown.

An early design was focused by turning the barrel or body of one of the telescopes to drive the motion of the eye tubes.

French, early 1800s. The eyepiece inscriptions read "Par Brevet de Perfectionnement," or "by patent of improvement."

Focusing Knob and Bridging Frame

Later approaches used a central focusing knob with a threaded screw.

French, mid-1800s

The connecting frame evolved to allow more "nose room."

Unsigned, French, mid-1800s

Tiffany and Co., Paris, late 1800s

Ornate Opera Glasses

Mother of pearl

French, late 1800s

Ornate Opera Glasses

Decorative patterned enamel

French, mid to late 1800s

Ornate Opera Glasses

Painted enamel with designs, portraits and scenes

American and French, late 1800s

Aluminum came into use in the late 1800s.

Folding or Collapsible Opera Glasses

R&J Beck, London

Aitcheson, London

Aitcheson, London

All early 1900s

Triple-Magnification Opera Glasses

French, late 1800s

A knob on the side rotates turrets in both eyepieces to bring one of three different eye lens into place to achieve three different magnifications:

Theatre ~2.5X; Field ~3X; Marine ~4X.

Optical Improvements

Optical performance also improved during the later 1800s as opera glasses were available with triplet objectives and triplet eye lenses for a total of 12 lenses in the pair (although doublets were more common).

Larger diameter lenses were also used.

This combination resulted in reduced chromatic aberration and wider field of view.

The magnification remained limited to about 3X.

Field Glasses

Larger Galilean binoculars with a maximum magnifying power was about 5-6X. These field glasses were widely used for military and other applications through WWI.

Field glasses took advantage of aluminum when it became available in the late 1800s.

Galilean Binoculars

Both opera glasses and field glasses have the advantage of being relatively simple optical systems, but suffer from the low magnification and limited field of view inherent to Galilean telescopes.

Twin Telescopes

Two Keplerian telescopes with Schyrle erecting lenses (terrestrial telescopes).

The configuration tended to be relatively long due to the number of optical elements.

There were a number of early attempts starting in the 1600s to construct binoculars of this form.

The manufacturing issues include alignment, magnification match and focusing.

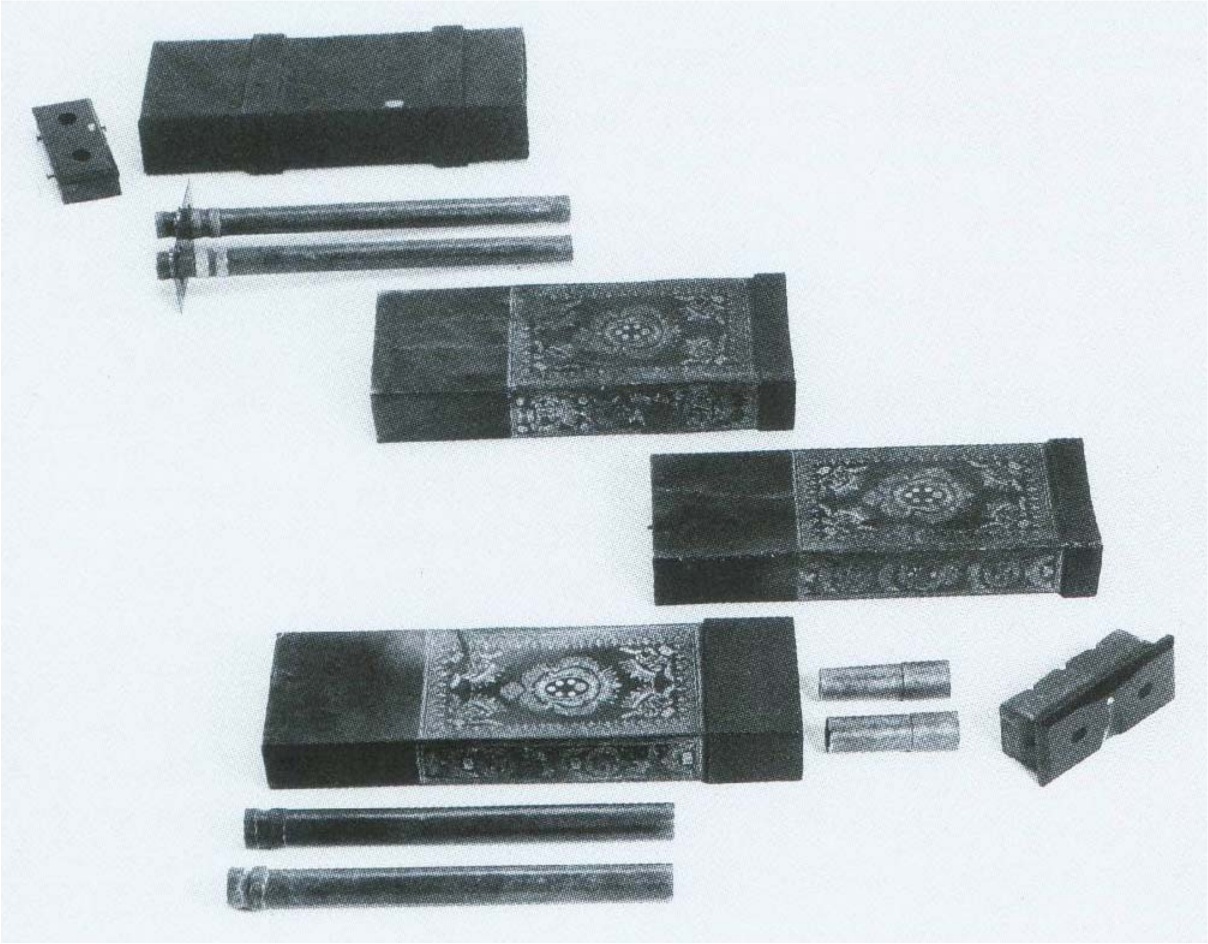
Because of the longer length, higher magnification and more complicated optical systems, these issues are more severe with twin telescope binoculars than Galilean binoculars.

Chérubin d'Orleans - 1675

Istituto e Museo di Storia Della Scienze, Firenze

Chérubin d'Orleans - 1675

These binoculars used a three-lens eyepiece design – Schyrle erecting system.



Istituto e Museo di Storia Della Scienze, Firenze

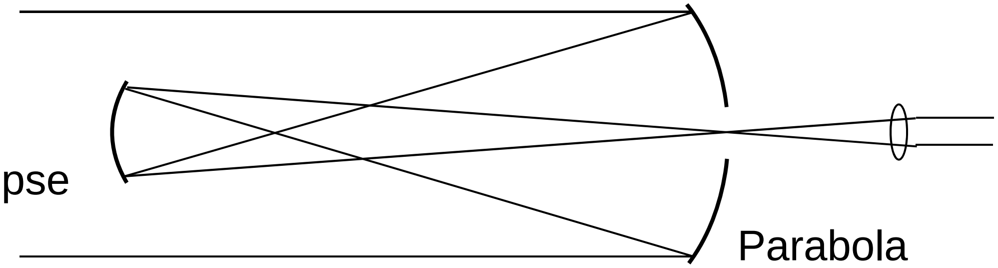
Reflecting Binoculars

Two Gregorian telescopes – the mirror equivalent of a relayed Keplerian telescope.

1710-1768, Scottish

James Short, circa 1760. From the collection of Rolf Willach (Taegerwilen, Switzerland)

Gregorian Telescope



English, late 1700s

Twin Telescope Binoculars

By the mid-1800s, mechanical and optical technology allowed twin telescope binoculars to be produced.

G&S Merz, Munich, circa 1860

Twin Telescope Binoculars

Late 1800s

Use Schyrle-Huygens erecting system or four-lens eyepiece.

The large binoculars are 750 mm long.

The small twin telescopes collapse for storage to under 120 mm.

The magnifying powers range from about 5X to 20X.

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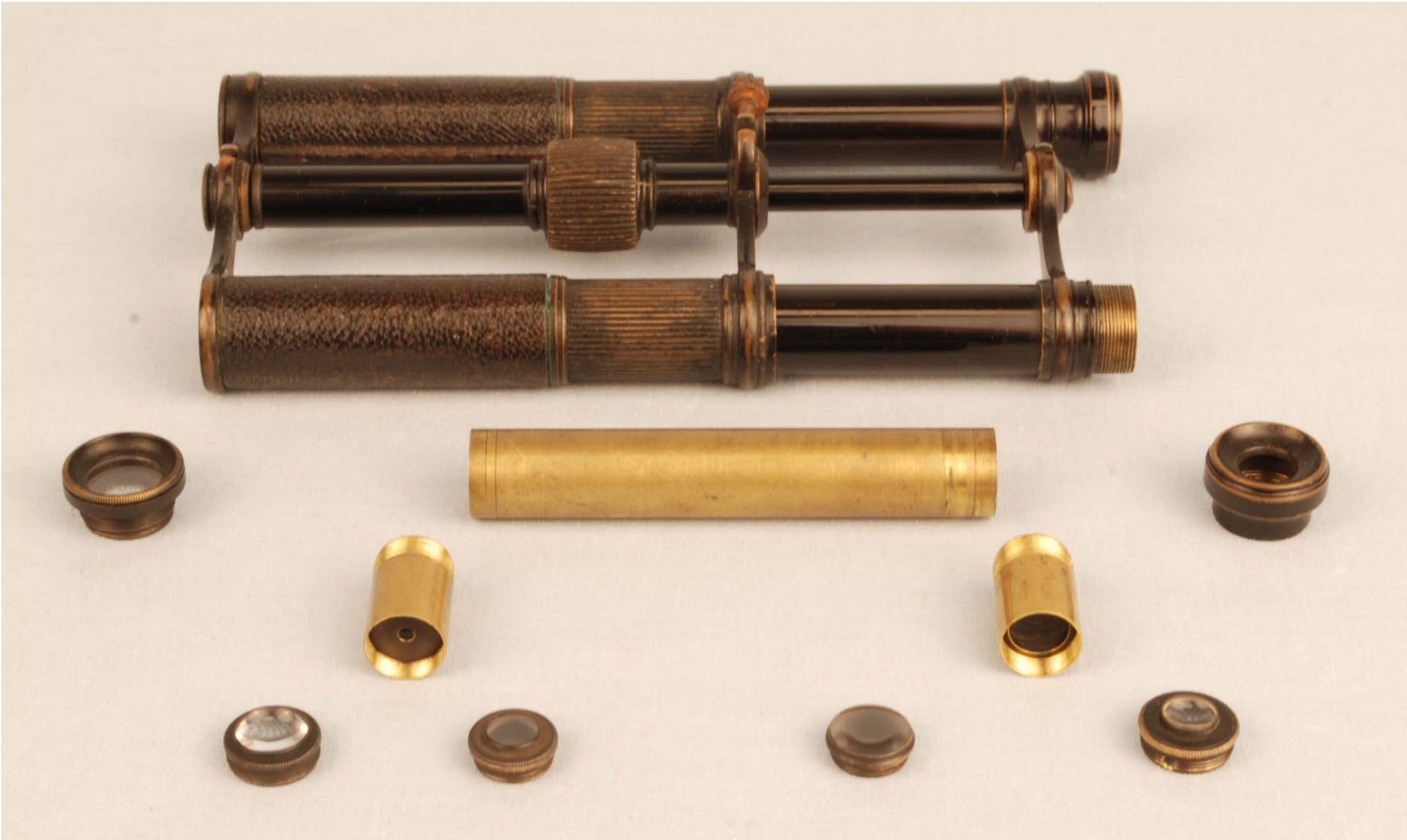
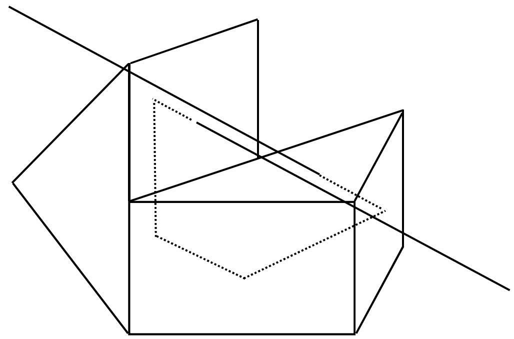
Optical System of Twin Telescopes



The life of this technology was abruptly ended by the advent of prism binoculars in the 1890s.

Porro Prism System

1854: Ignatio Porro



1801-1875, Italian

Attempts to fabricate prism binoculars after the invention of the Porro prism system failed primarily due to poor glass quality.

The folded optical path through even a small Porro prism system can be 60 mm or more.

A small amount of inhomogeneity or stria in the glass can destroy the image quality of the binoculars.

Zeiss, Schott, and Abbe (Jena, Germany)

The association of Carl Zeiss with the glass maker Otto Schott resulted in the production of the high quality prisms that were essential for successful Porro prism binoculars.

Ernst Abbe provided the optical design of these binoculars.

These high-performance modern binoculars were first sold in 1894.

Carl Zeiss (1816-1888)

Otto Schott (1851-1935)

Ernst Abbe (1840-1905)

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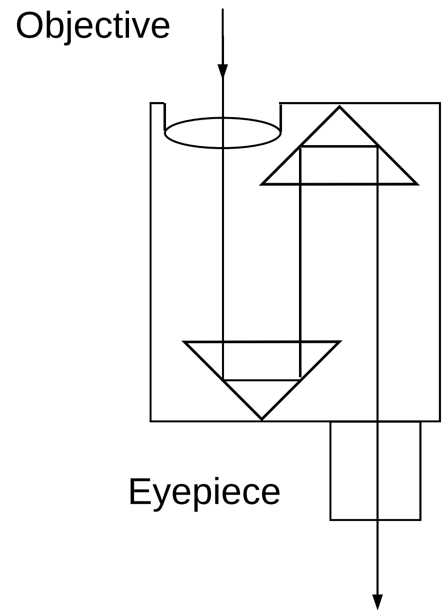
Zeiss Feldstecher

6X15; Serial Number 306 - 1895

Prism Mounting



Prism Dimensions:	15x32 mm
Index:	1.513
Abbe Number:	63

Zeiss Feldstecher 8X20. Serial Number 4976, 1897

Roof Prisms

It appears that Giovanni Amici was the first to add a roof surface to a prism in the mid-1800s.

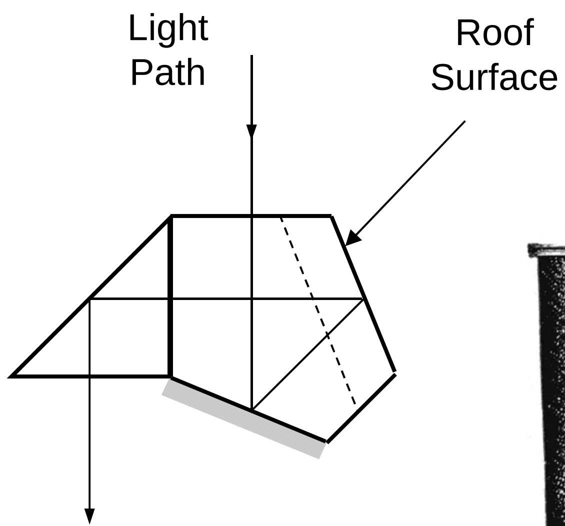
The Amici or roof prism deviates light by 90º.

1786-1863, Italian

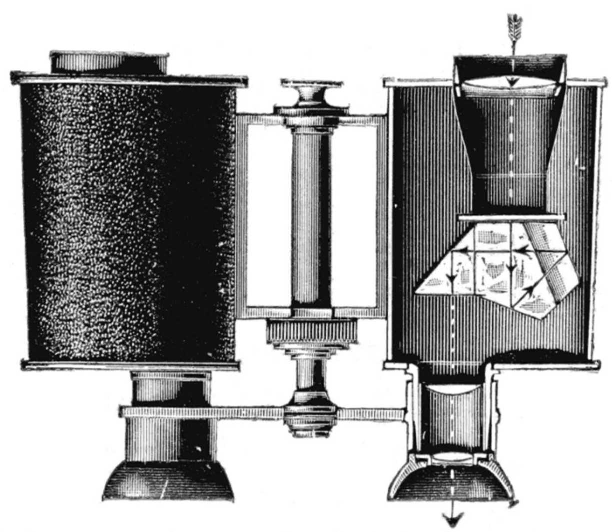
Roof Surface Prisms and Binoculars

In 1897, erecting prism systems incorporating roof surfaces were introduced into binoculars.

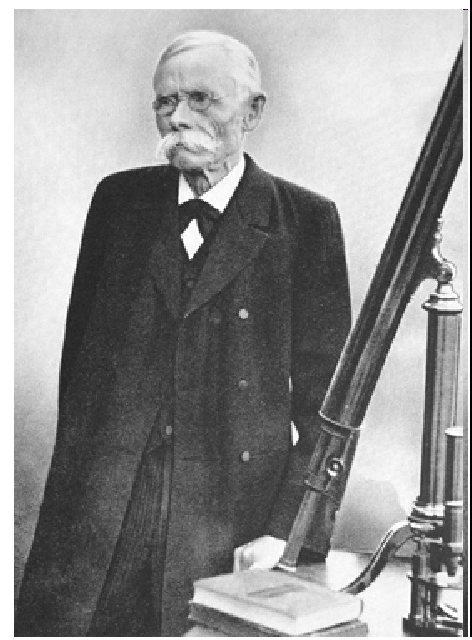
They were first used in a penta-prism configuration by the firm of Hensoldt in Wetzlar, Germany.



Combination of a reflex prism and a right-angle prism – four reflections.



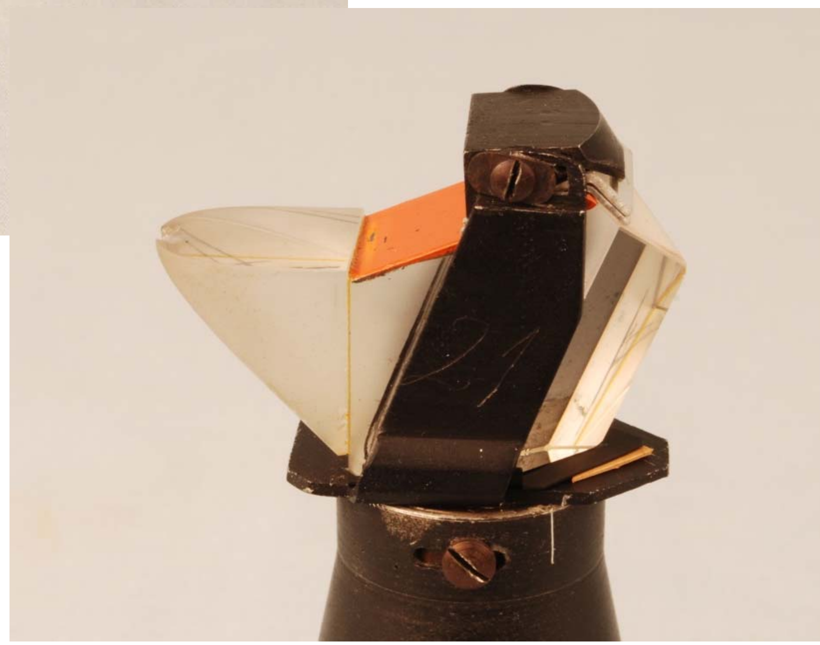
Moritz Carl Hensoldt
1821-1903, German



Hensoldt Penta-Prism Binoculars

10x50
1903
Cast Aluminum Bodies

Hensoldt Penta-Prism Binoculars



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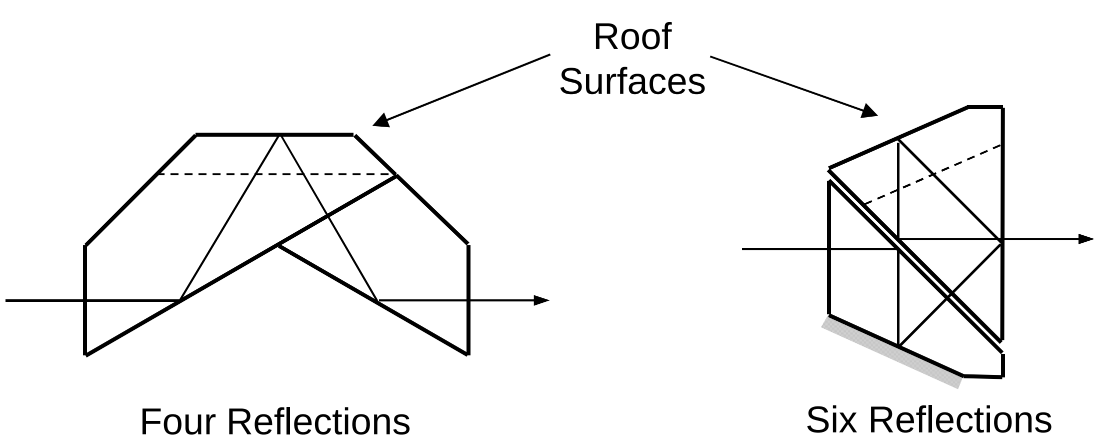
Abbe-Köenig Erecting Prism

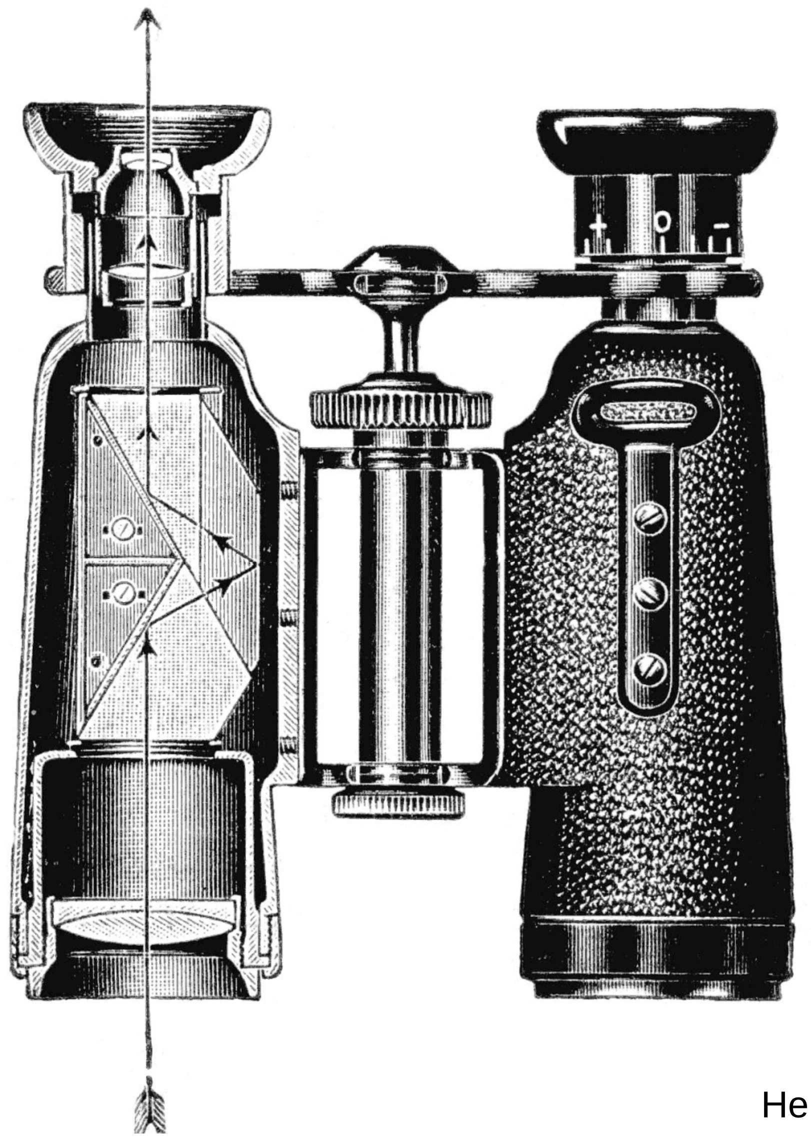
The Abbe-Köenig prism appears in the early 1900s.

With this prism, image erection is obtained without a displacement of the optical axis.

While still used today, the Abbe-Köenig prism is the precursor of the Pechan-roof prism (also know as a Schmidt-Pechan prism - 1964) in modern roof-prism binoculars.



Abbe-Köenig Prism Binoculars



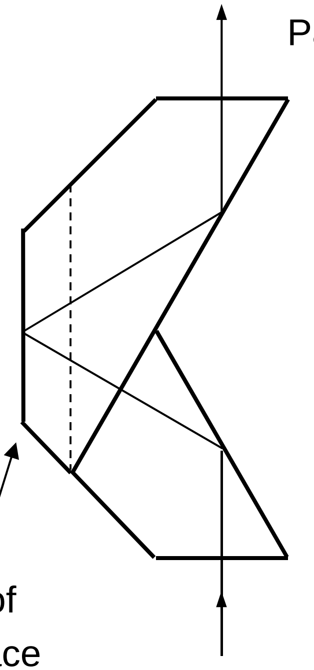
Hensoldt, Wetzlar 1905

Abbe-Köenig Prism Binoculars

Jagd-Dialyt 7x44 S/N 13486
Hensoldt, Wetzlar

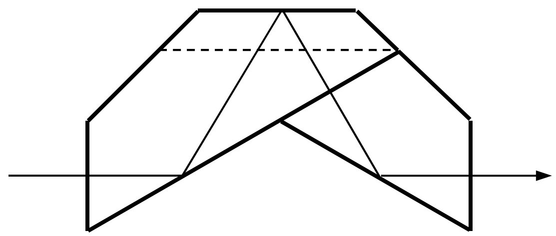
Abbe-Köenig Prisms

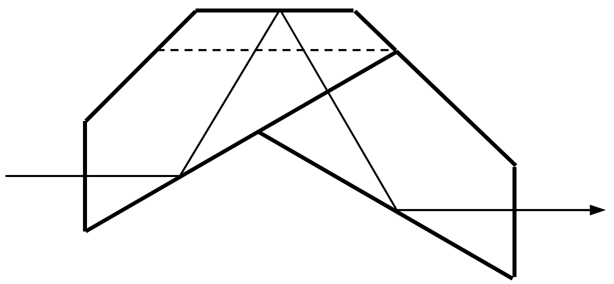
Hensoldt, Wetzlar, Germany, early 1900s)



Asymmetric Abbe-Köenig Prism

Some asymmetry can be built into the Abbe-Köenig prism to provide an offset of the optical axis. This is useful for large diameter objective lenses.

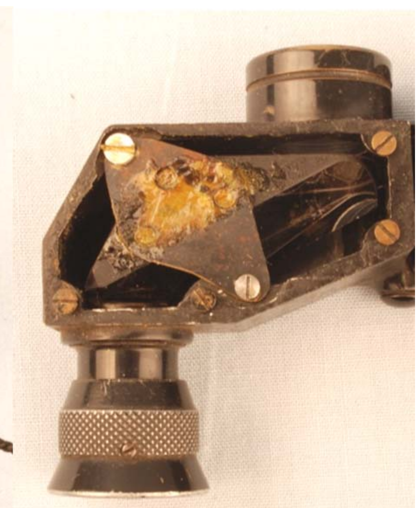


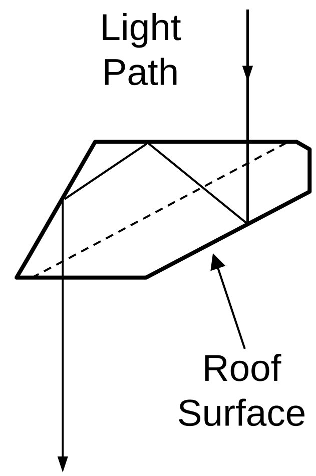


Sprenger-Leman Prism Binoculars

In 1898, Hensoldt introduced a more compact arrangement using a Leman prism.

By 1907, Zeiss was also producing binoculars incorporating roof surfaces.

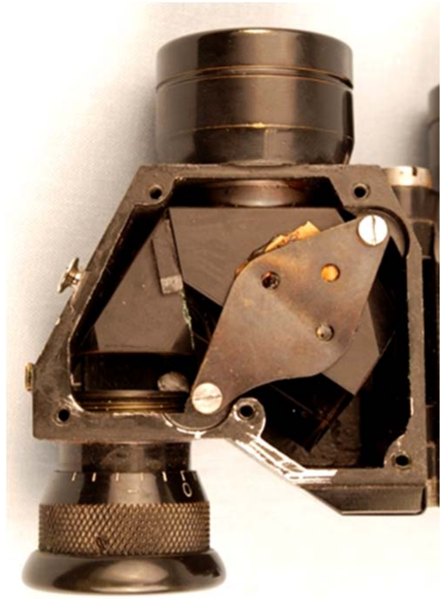


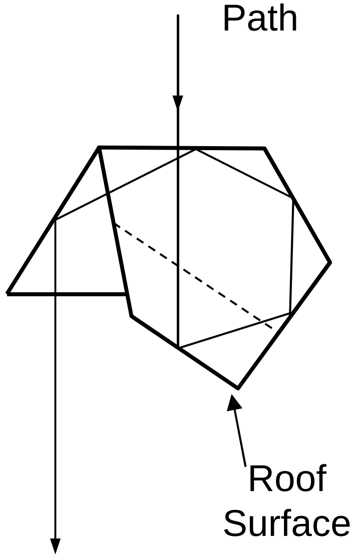


Four Reflections

Theatis 3½X ; J.D. Möller, Wedel, Germany, late 1920s

Möller Prism Binoculars





Six Reflections

Tourox 8X; J.D. Möller, Wedel, Germany, mid-1920s

Conclusions

The development of handheld telescopes and binoculars was considered from an engineering perspective.

The requirements for binoculars are much more complicated than for telescopes.

Terrestrial refracting telescopes were able to reach their modern design form in a little over a century, while it took binoculars nearly three centuries.

Advances in mechanical design, manufacturing technology, materials and optical glass were critical.

The availability of precision brass tubing in the mid-1700s played a crucial role in the history of optical instrumentation.

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