OSHER LIFELONG LEARNING INSTITUTE

Opticks:

Optical Instruments

from Ancient Times to the Present

Replica of Newton's 3rd Reflecting Telescope (*ca* 1672)

Session 3
Golden Age

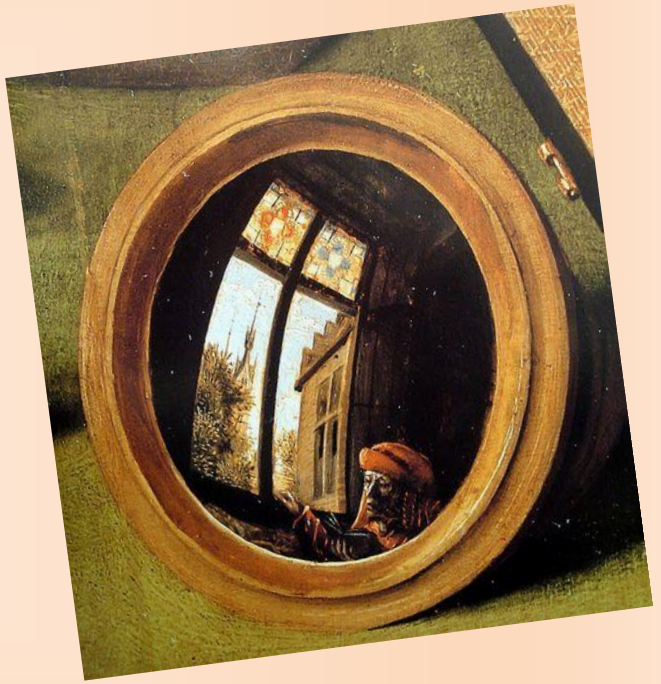
OLLI at Illinois
Spring 2022

D. H. Tracy

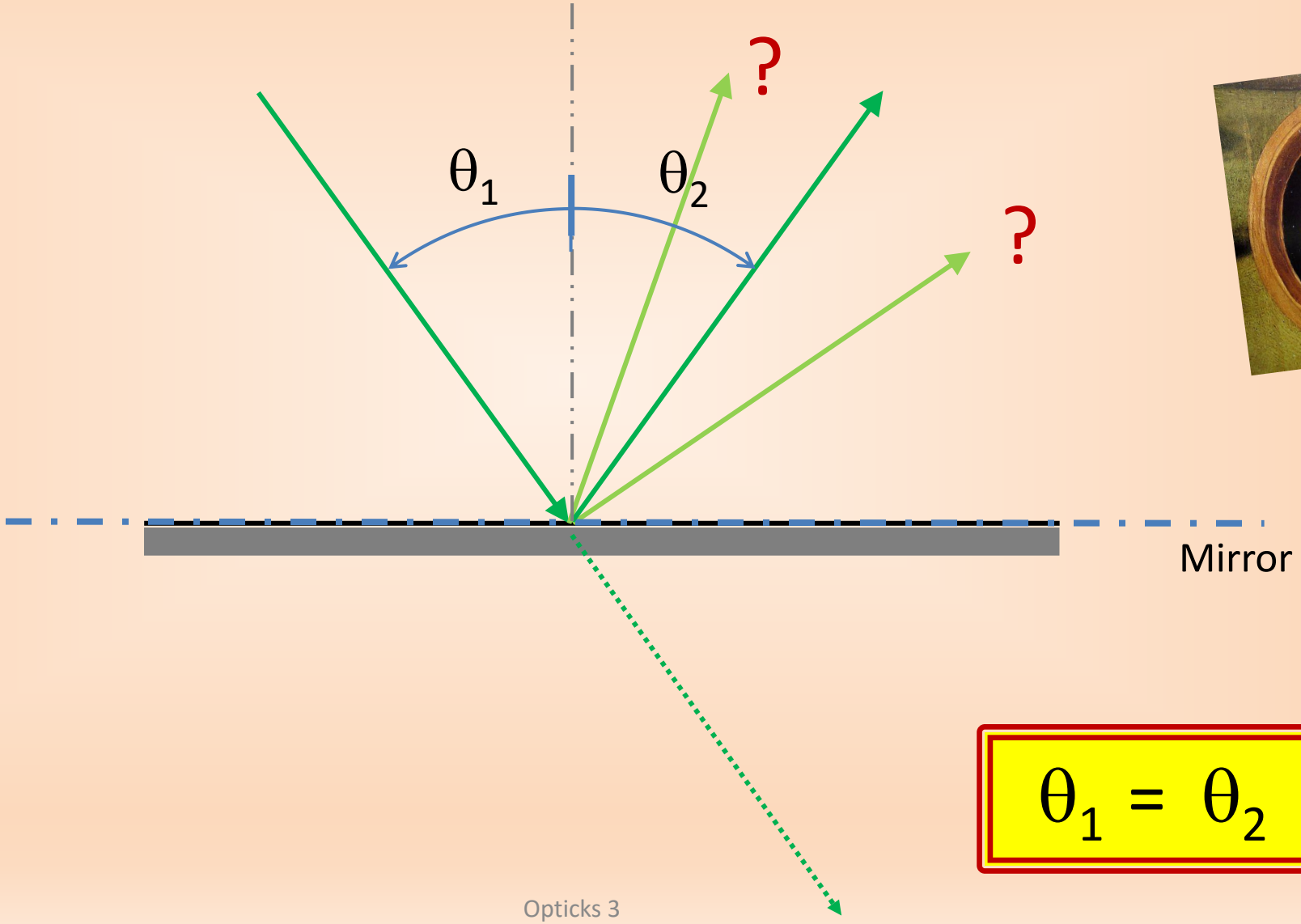
Course Outline

1. Beginnings: Optics in the Ancient World and the Middle Ages; Mirrors and Lenses
2. Renaissance and Pre-Renaissance developments. The eye. Early telescopes & microscopes. Art and Optics.
3. Newton's contributions leading to 18th and 19th Century developments in Optical instruments.
4. Modern Optics and the methods used to design and build them. Lasers, fiberoptics, holograms, space telescopes, semiconductor lithography, gravity wave detectors, and the camera in your cell phone.

More Craft than Science



The Law of Reflection Was Known Since Ancient Times

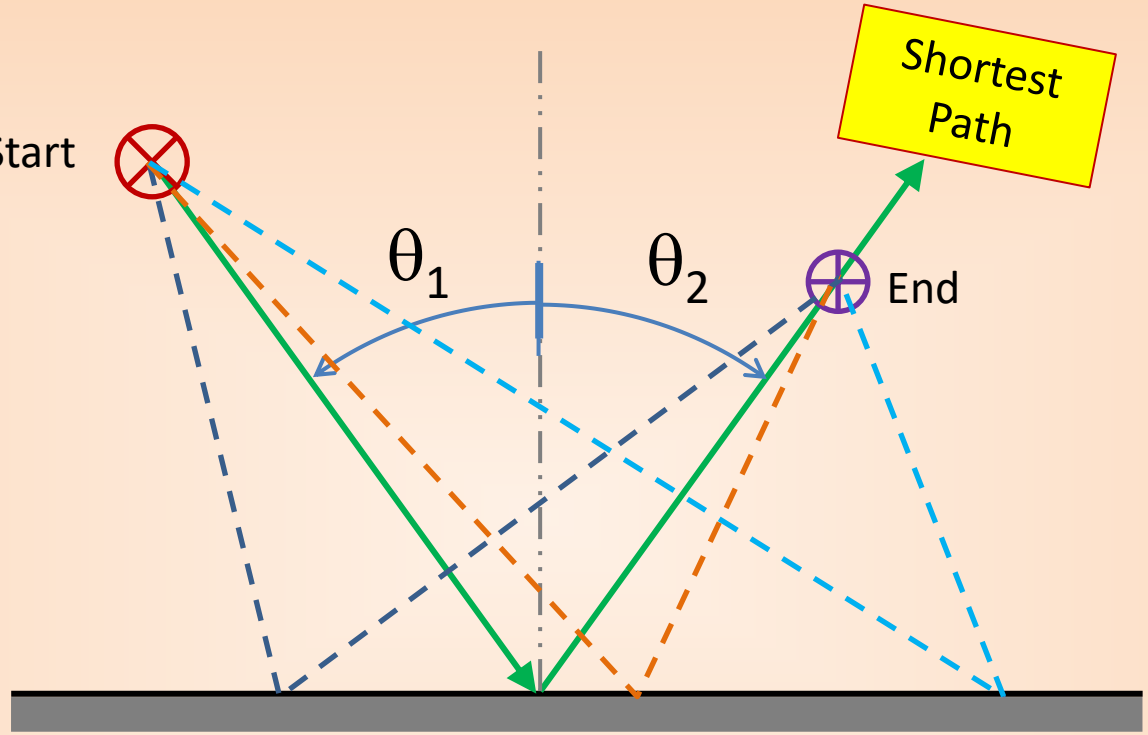


$$\theta_1 = \theta_2$$

The Law of Reflection Was Known Since Ancient Times

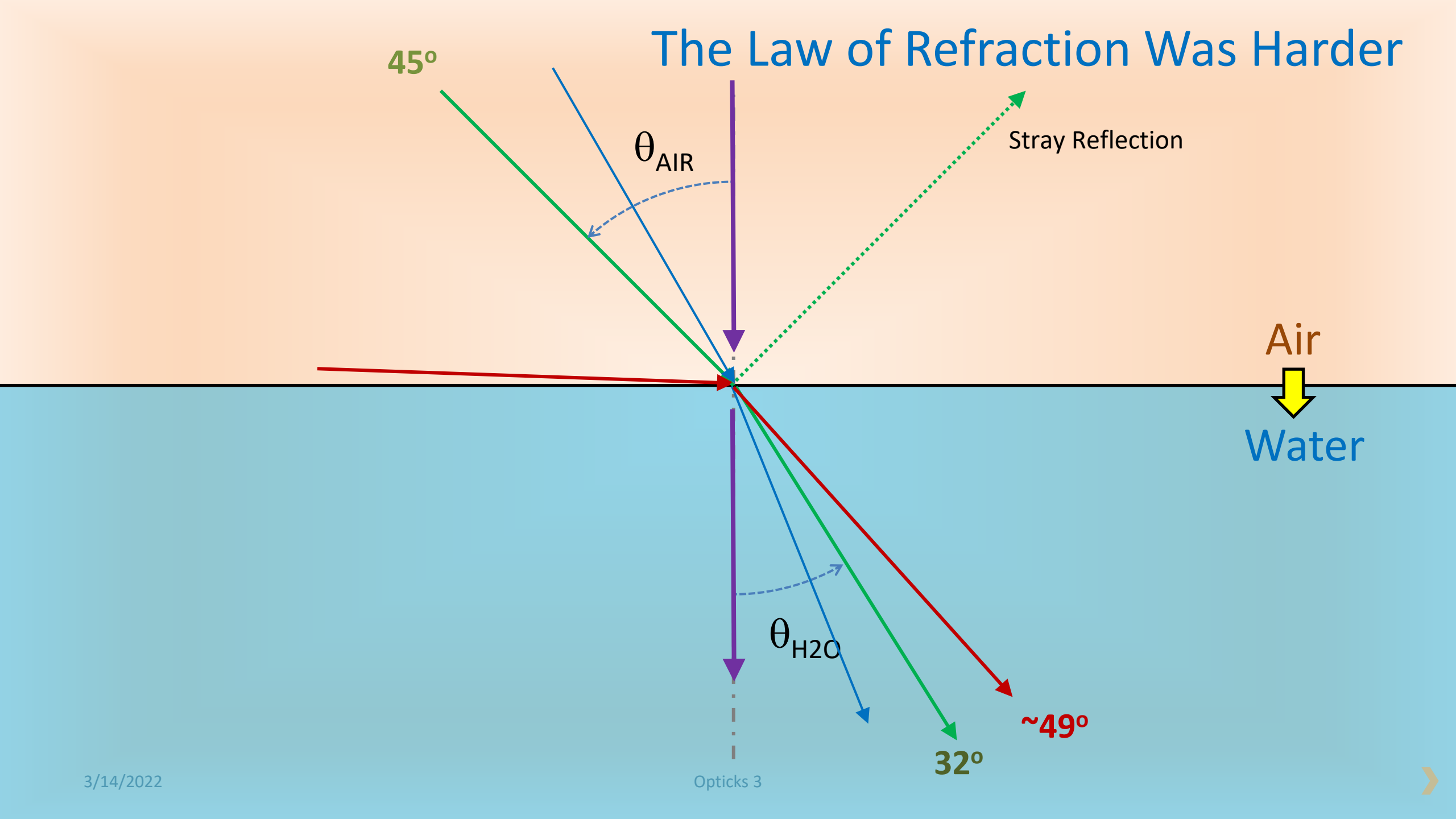
Hero of Alexandria
ca 10-70 CE

Anticipated Fermat's Principle of Least Time



$$\theta_1 = \theta_2$$

The Law of Refraction Was Harder



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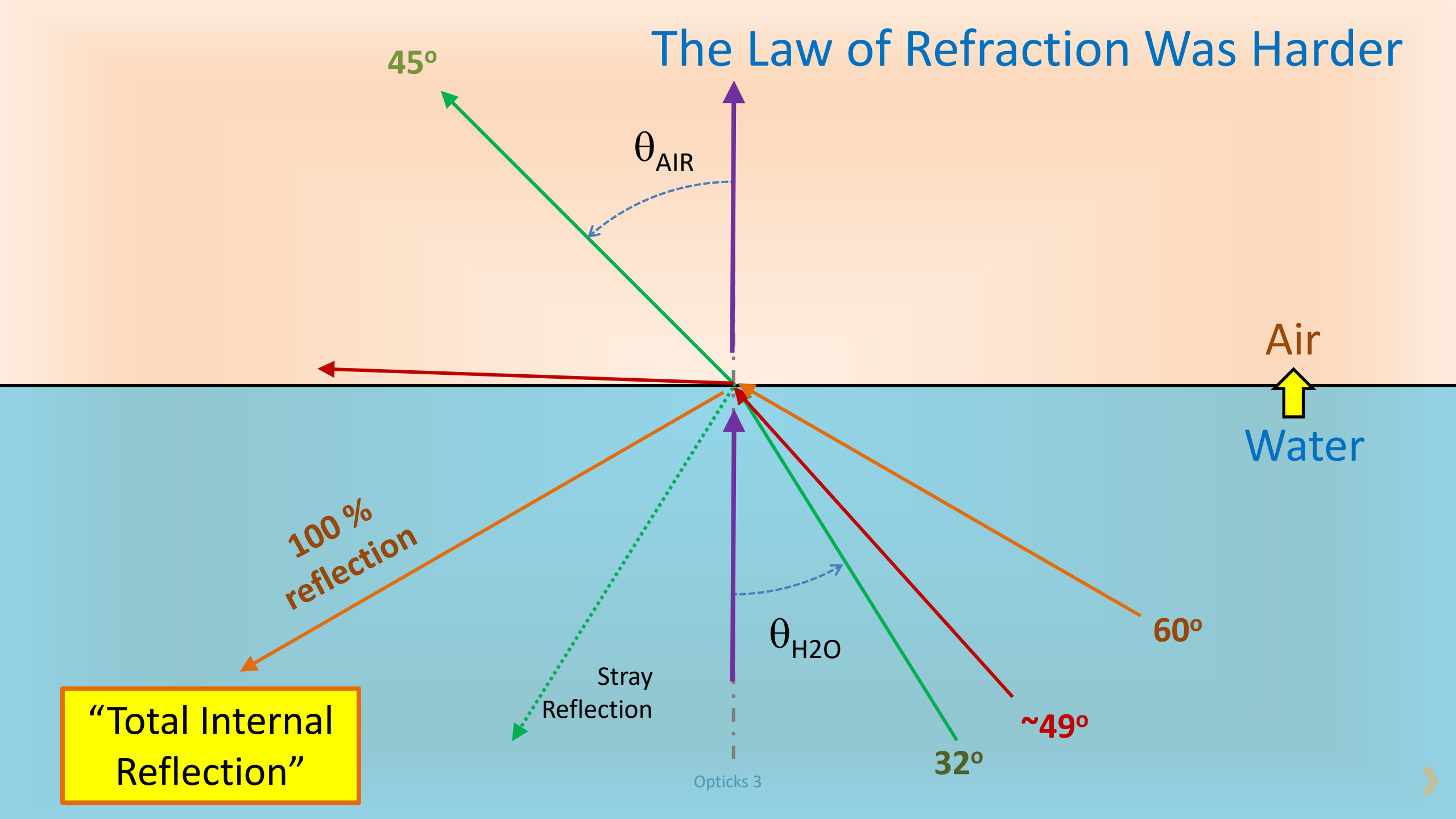
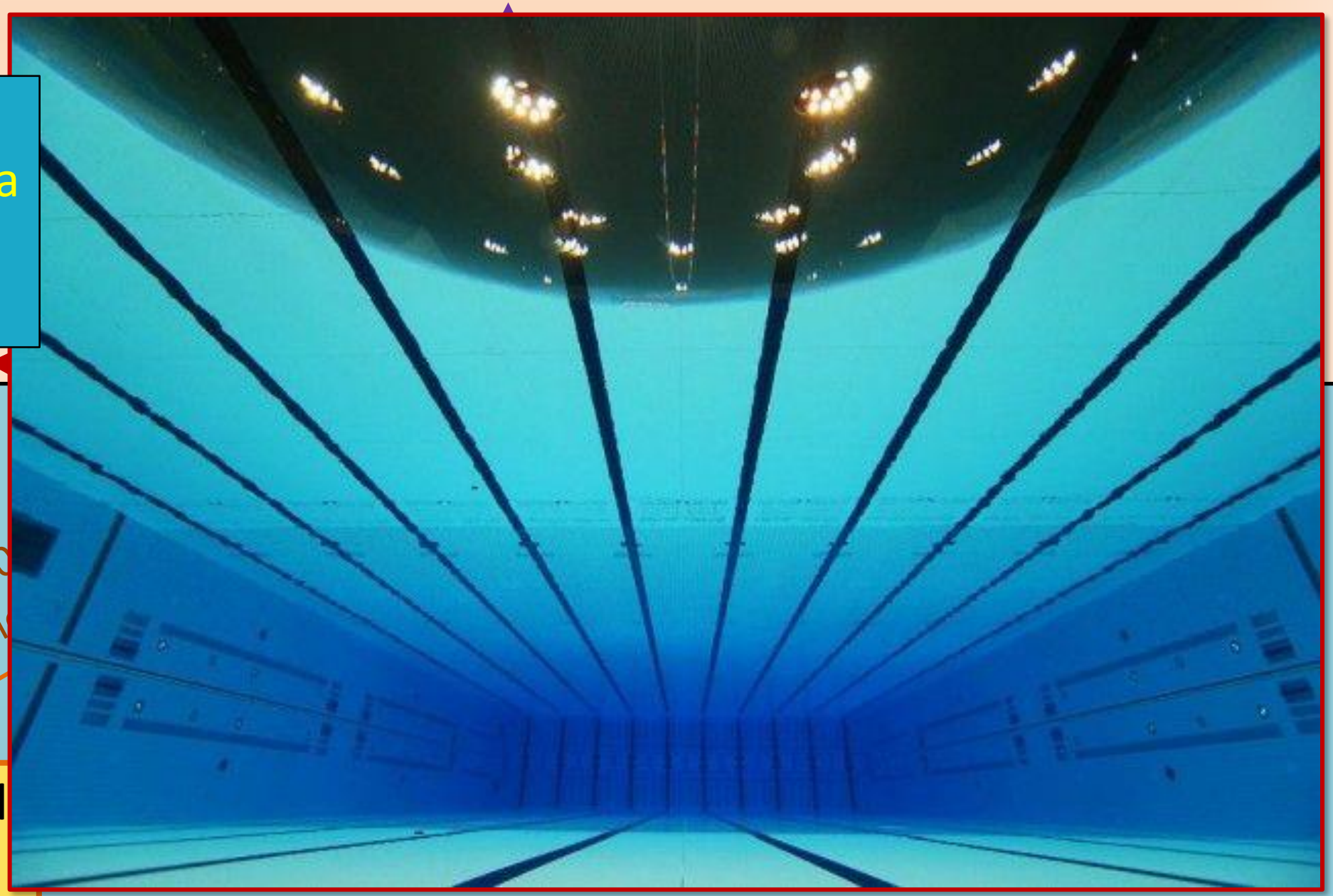


The Law of Refraction Was Harder

45°

Fish Eye View from a Swimming Pool

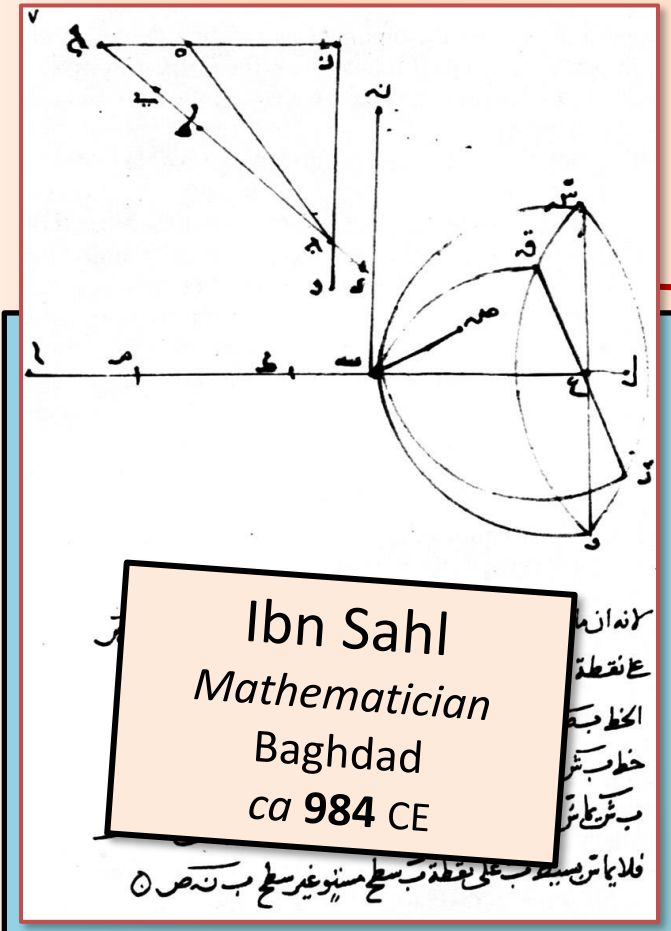


100
refl

"Total Internal Reflection"

The Law of Refraction Was Harder

People who figured out the correct Law

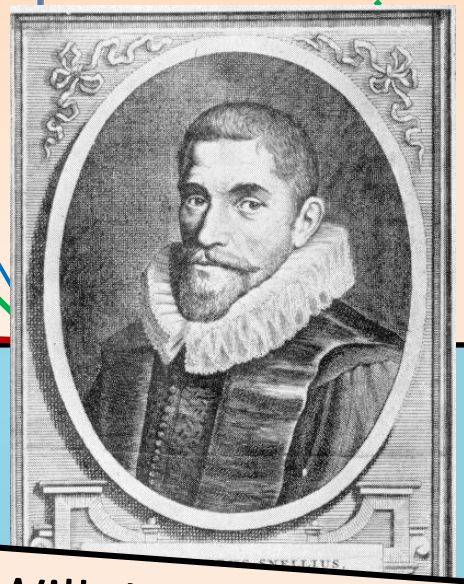


Ibn Sahl
Mathematician
Baghdad
ca **984** CE

45°

θ_{AIR}

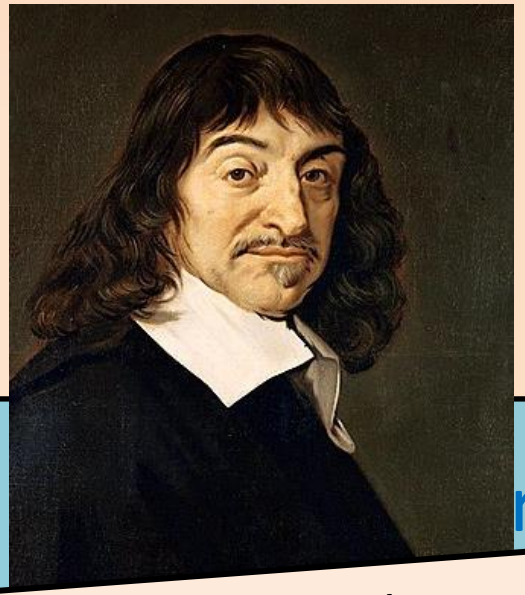
Thomas Harriot
Astronomer
English
ca **1601** (not published)



Willebrord Snellius
Mathematician
Dutch
ca **1621** (not published)

In English Speaking Countries:
"Snell's Law"

Stray Reflection



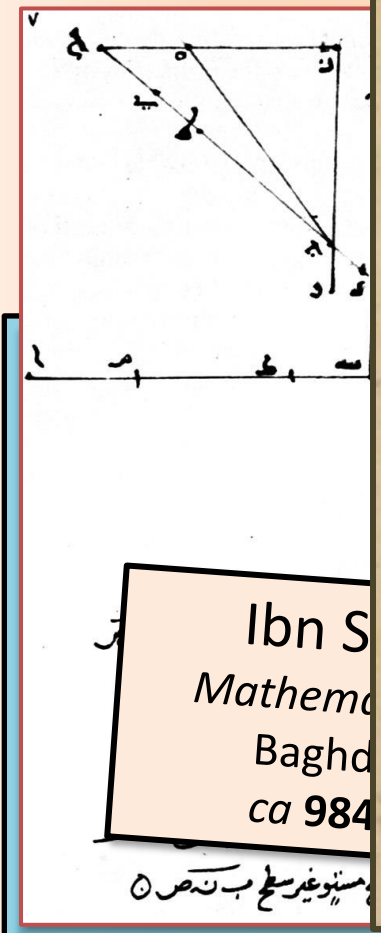
René Descartes
French Mathematician
(Worked in Holland)
Dioptrique (**1637**)

In France:
"Descartes' Law"

The Law of Refraction Was Harder

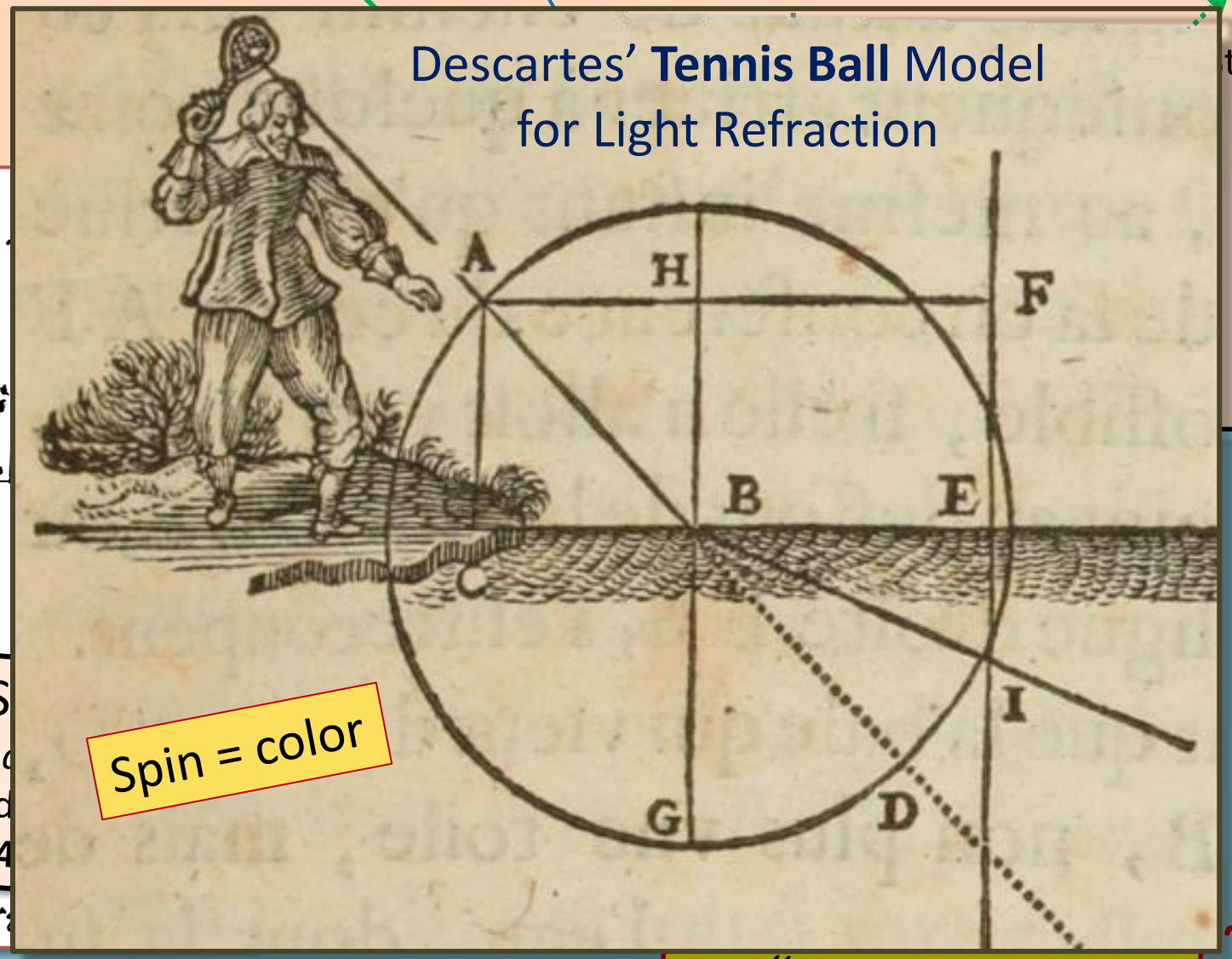
45°

tray Reflection

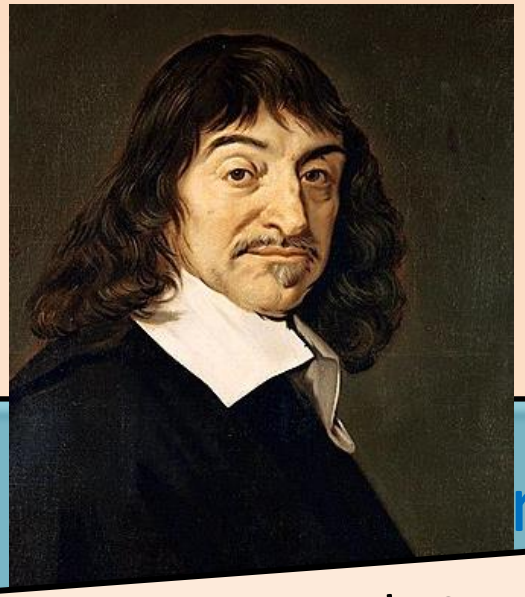


Ibn S
Mathema
Bagh
ca **984**

Descartes' **Tennis Ball** Model
for Light Refraction



Spin = color



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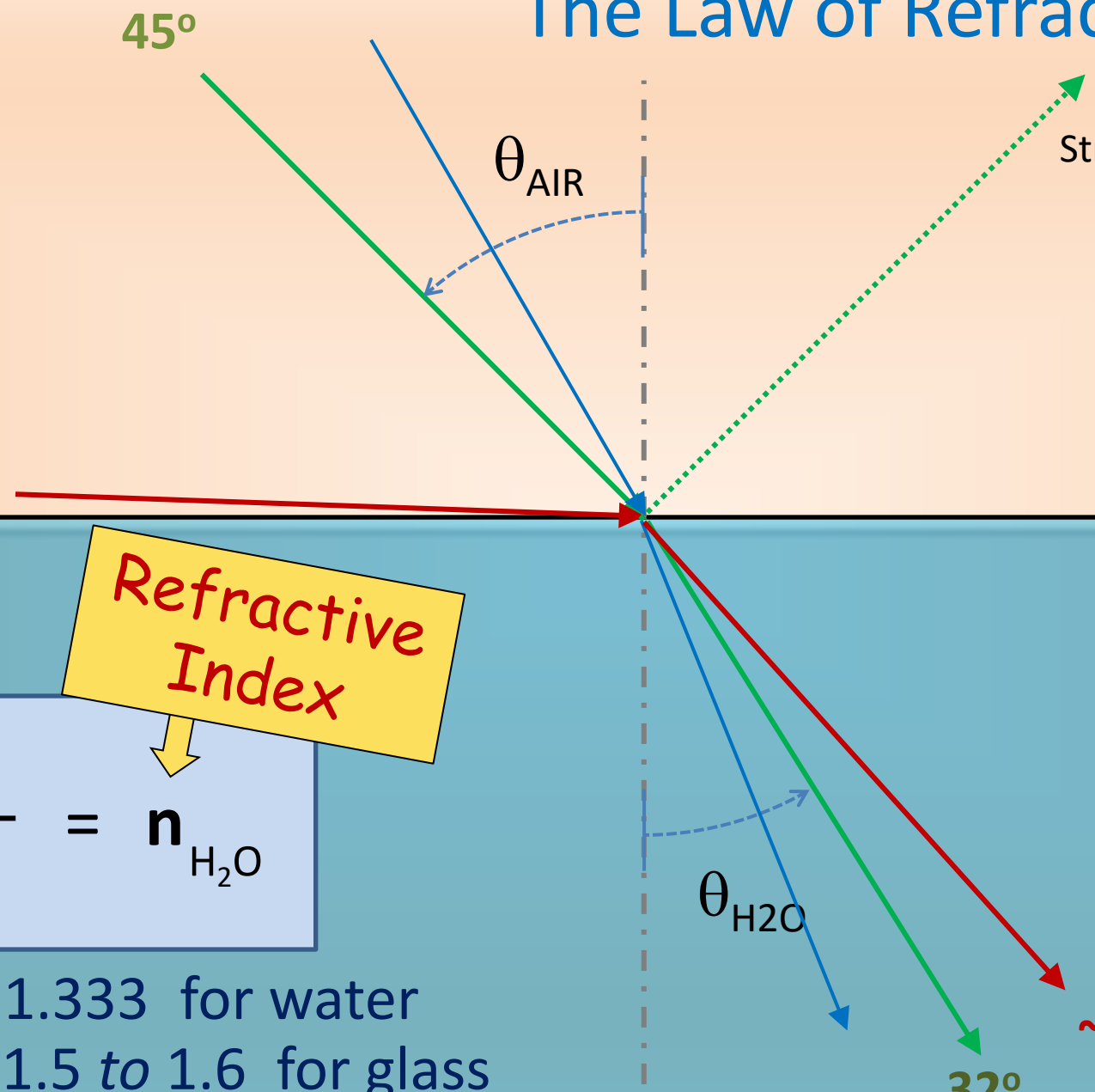
In France:
"Descartes' Law"

"Snell's Law"

The Law of Refraction Was Harder



Stray Reflection

René Descartes
French Mathematician
(Worked in Holland)
Dioptrique (**1637**)

In France:
"Descartes' Law"

Snell's Law:

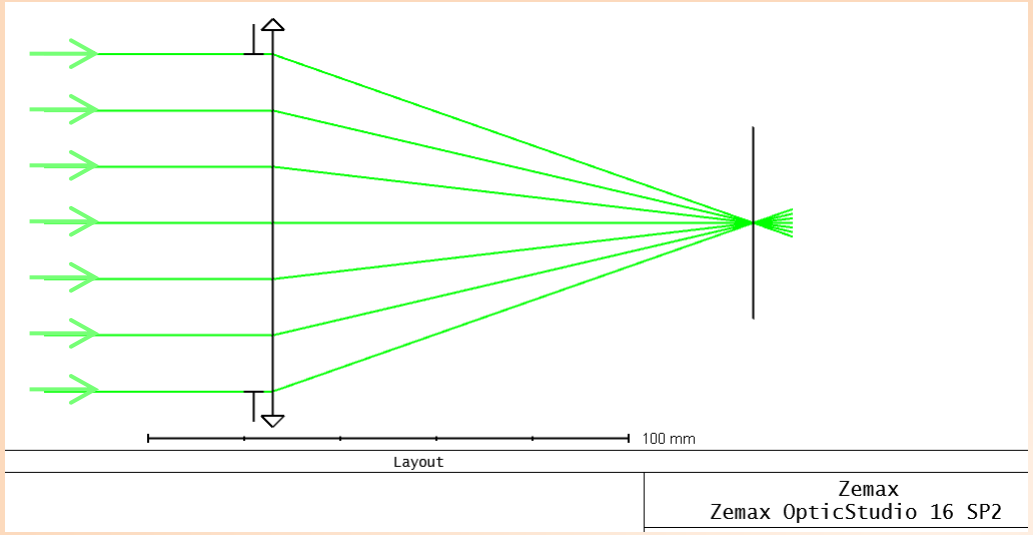
Refractive Index

$$\frac{\sin \theta_{AIR}}{\sin \theta_{H2O}} = n_{H_2O}$$

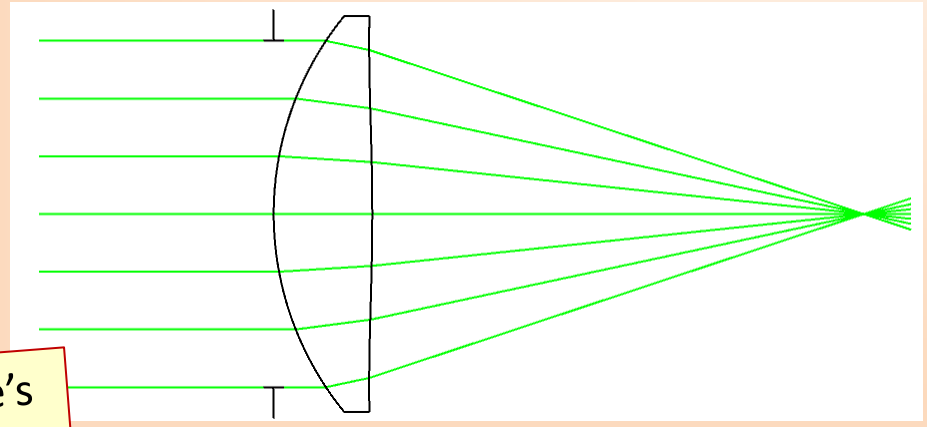
1.333 for water
1.5 *to* 1.6 for glass
2.42 for diamond

Why Early Lens Instruments Were Poor

Ideal Lens



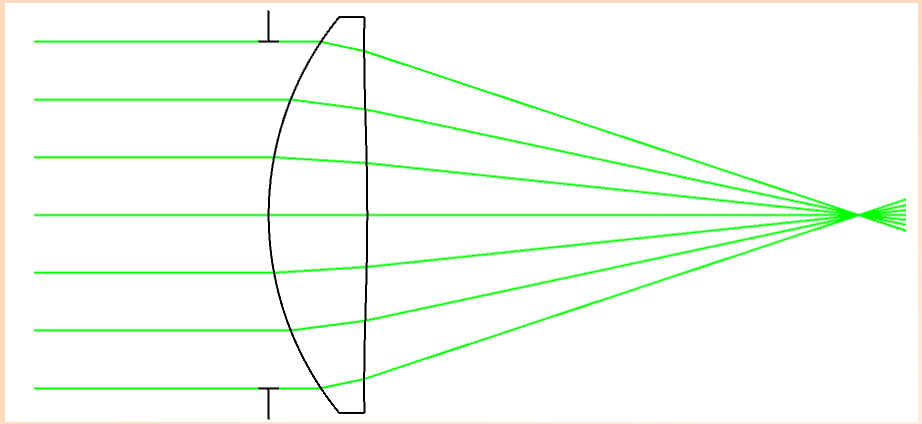
"Perfect" Lens
ca 1600 CE



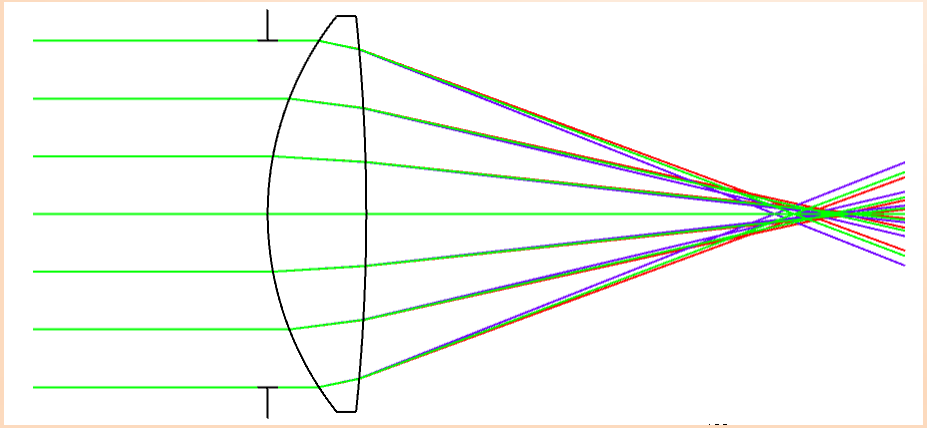
Using Descarte's Design

Why Early Lens Instruments Were Poor

"Perfect" Lens *ca* 1600 CE



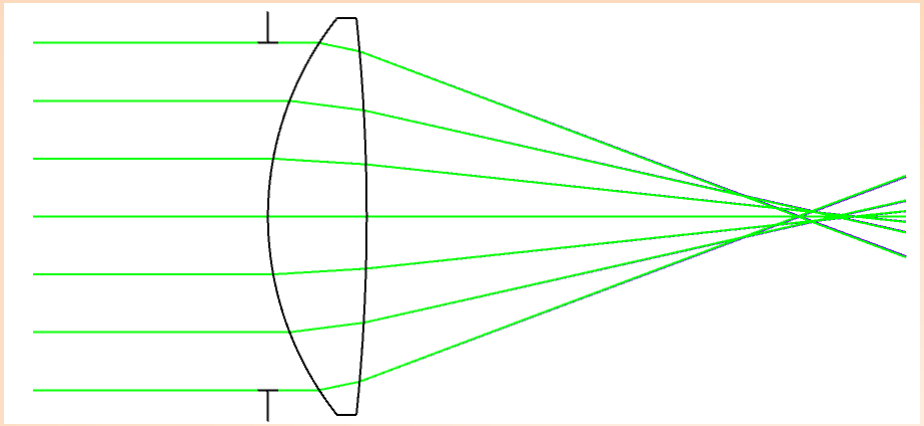
Real Lens *ca* 1600



Why Early Lens Instruments Were Poor: 2 Main Issues

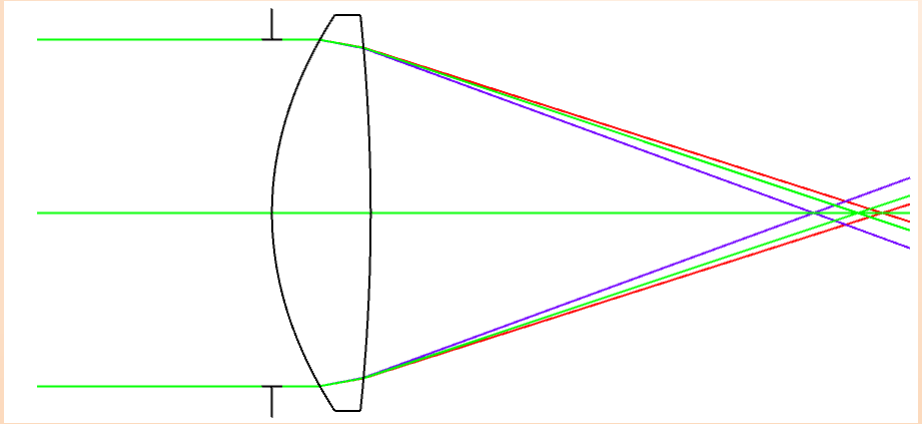
① Spherical Aberration

(alone)



② Chromatic Aberration

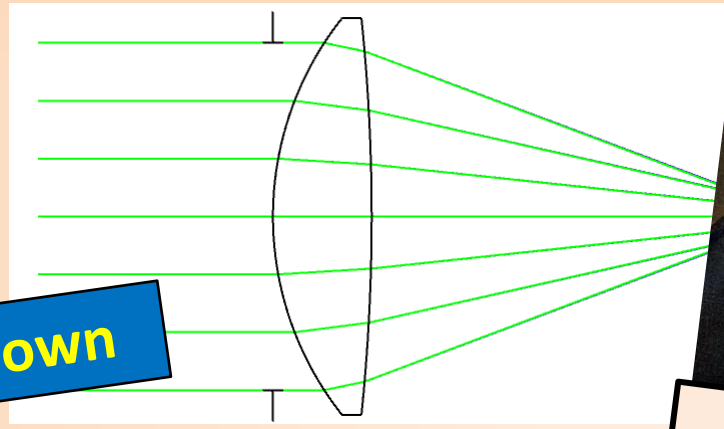
(alone)



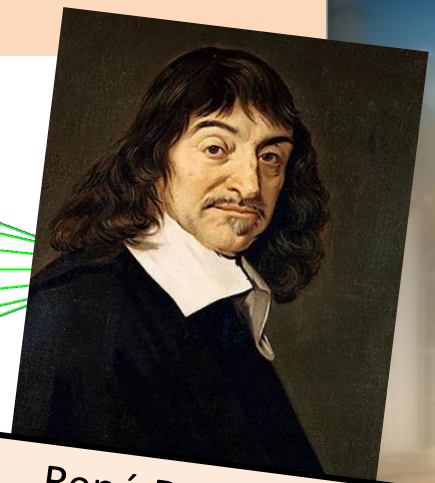
Why Early Lens Instruments Were Poor: 2 Main Issues

①

Spherical Aberration



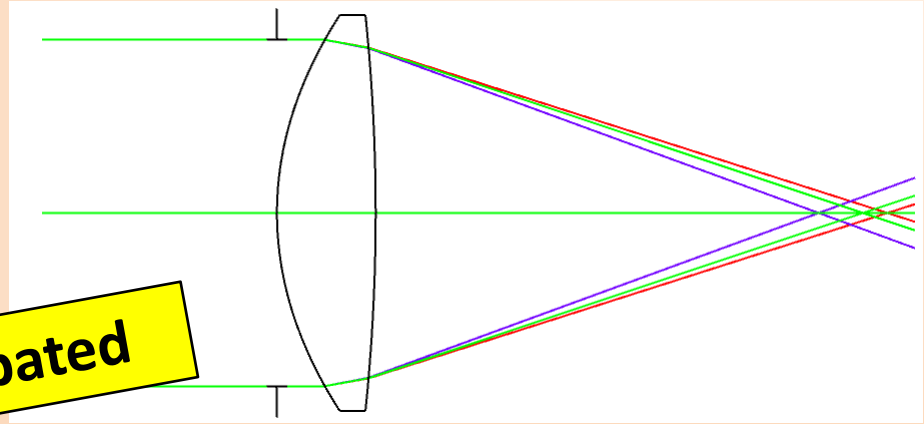
Very well known



René Descartes
Dioptrique (**1637**)

②

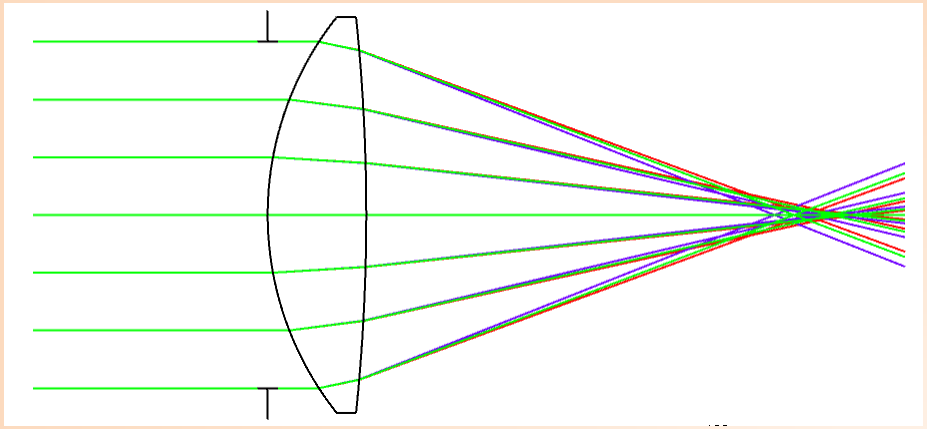
Chromatic Aberration



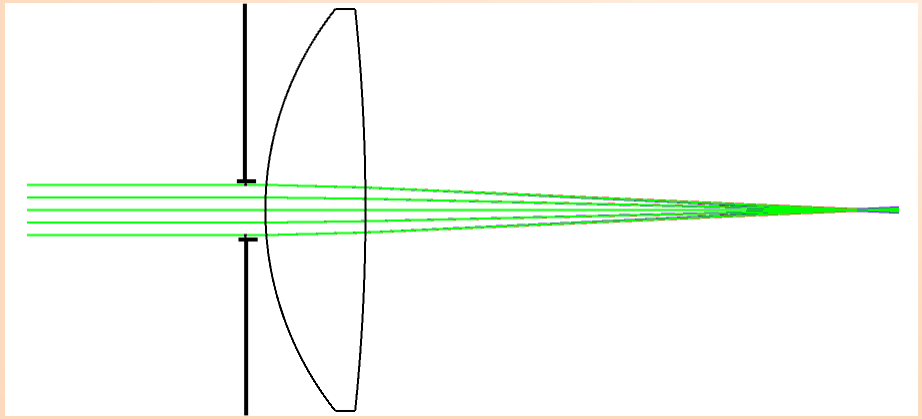
Not Anticipated

Stopping Down May Help

Real Lens



Real Lens with Reduced Aperture



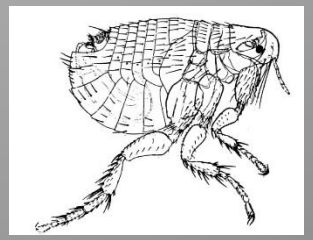
Isaac Newton
Sculpture
Trinity College
Chapel
Roubiliac

Trinity College, Cambridge

Newton earns BA 1665

Bubonic

The Great Plague of London 1665-1666



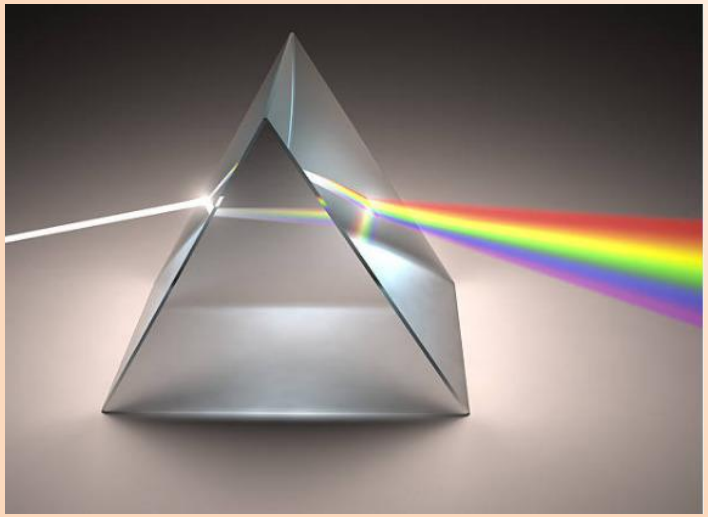
Woolsthorpe Manor

60 miles North of Cambridge

One project Newton started in 1666 was to try to grind **aspherical lenses** to eliminate spherical aberration…

…but he soon got diverted onto a tangent.

"in the beginning of the Year 1666 … I procured me a Triangular glass-Prisme, to try therewith the celebrated Phenomena of Colours."

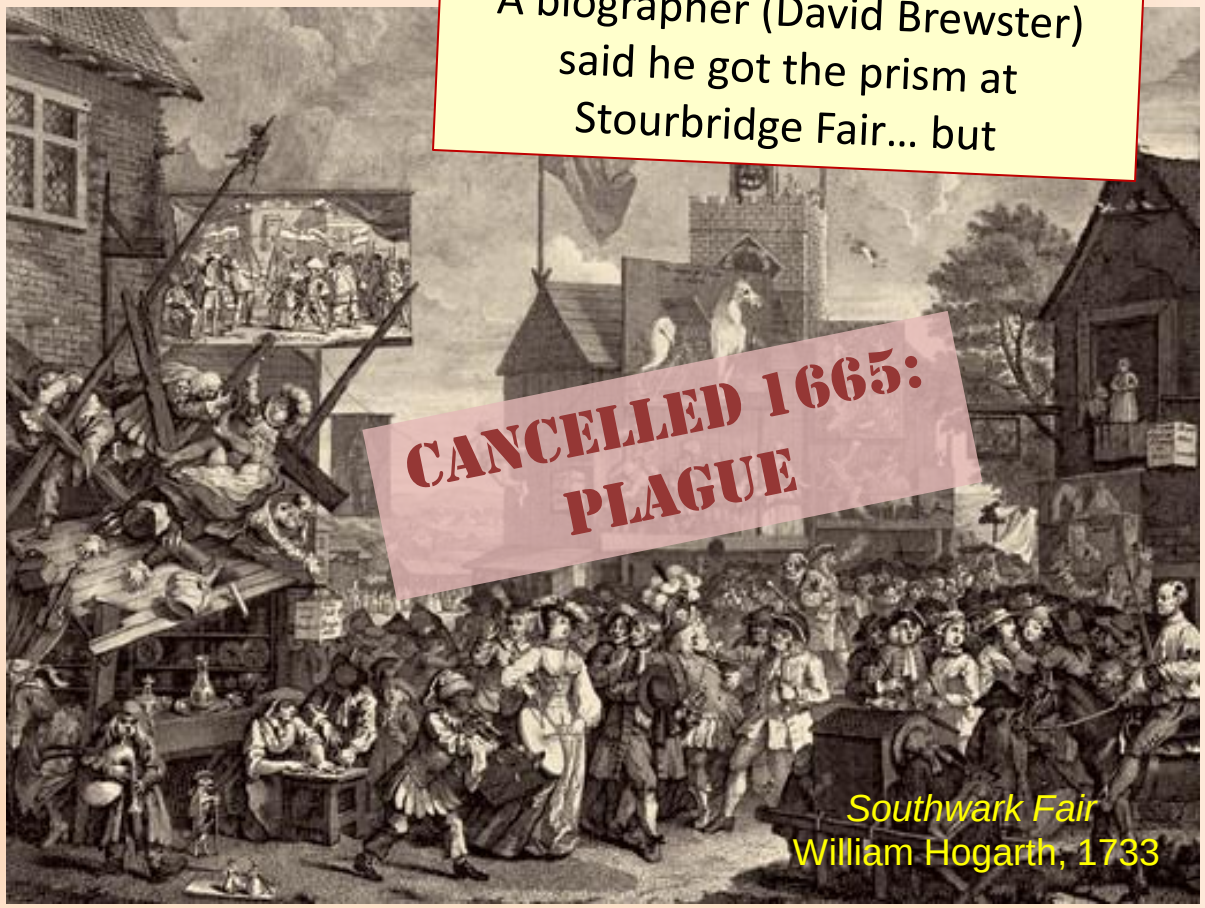


Stourbridge Fair

Held every September in Cambridge

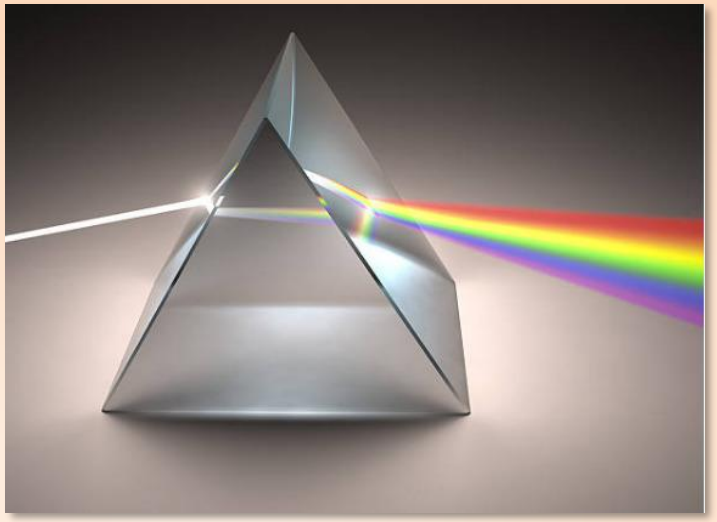
Vendors from all over Europe

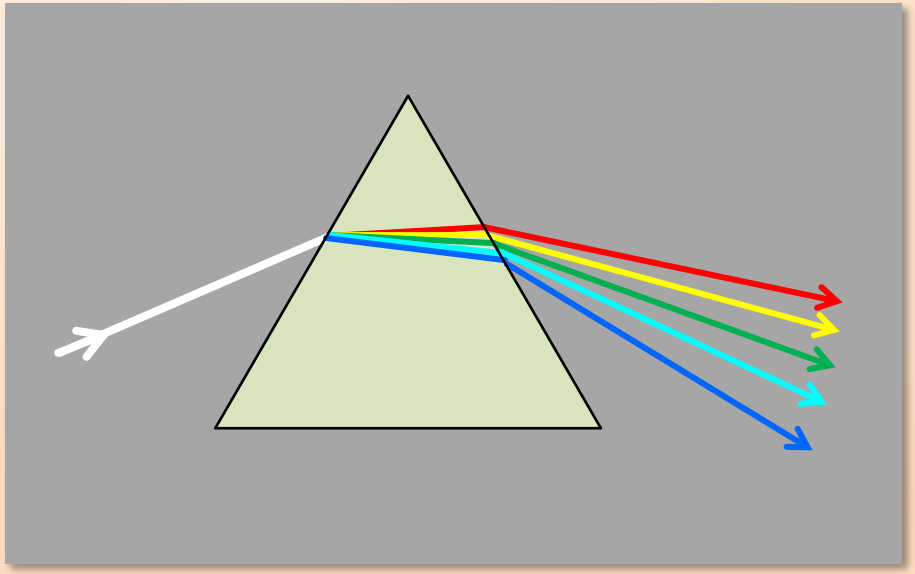
A biographer (David Brewster) said he got the prism at Stourbridge Fair… but

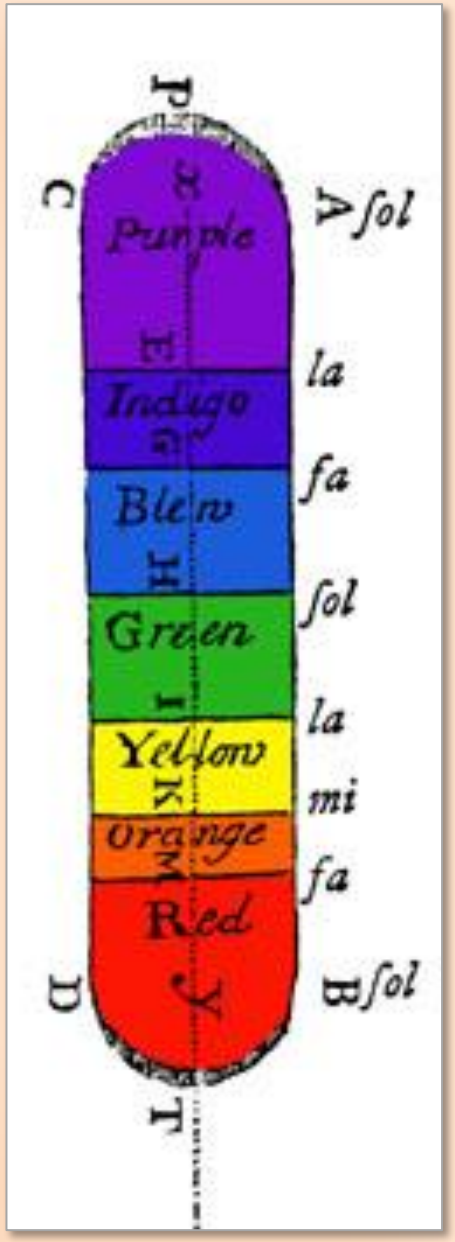


Southwark Fair
William Hogarth, 1733

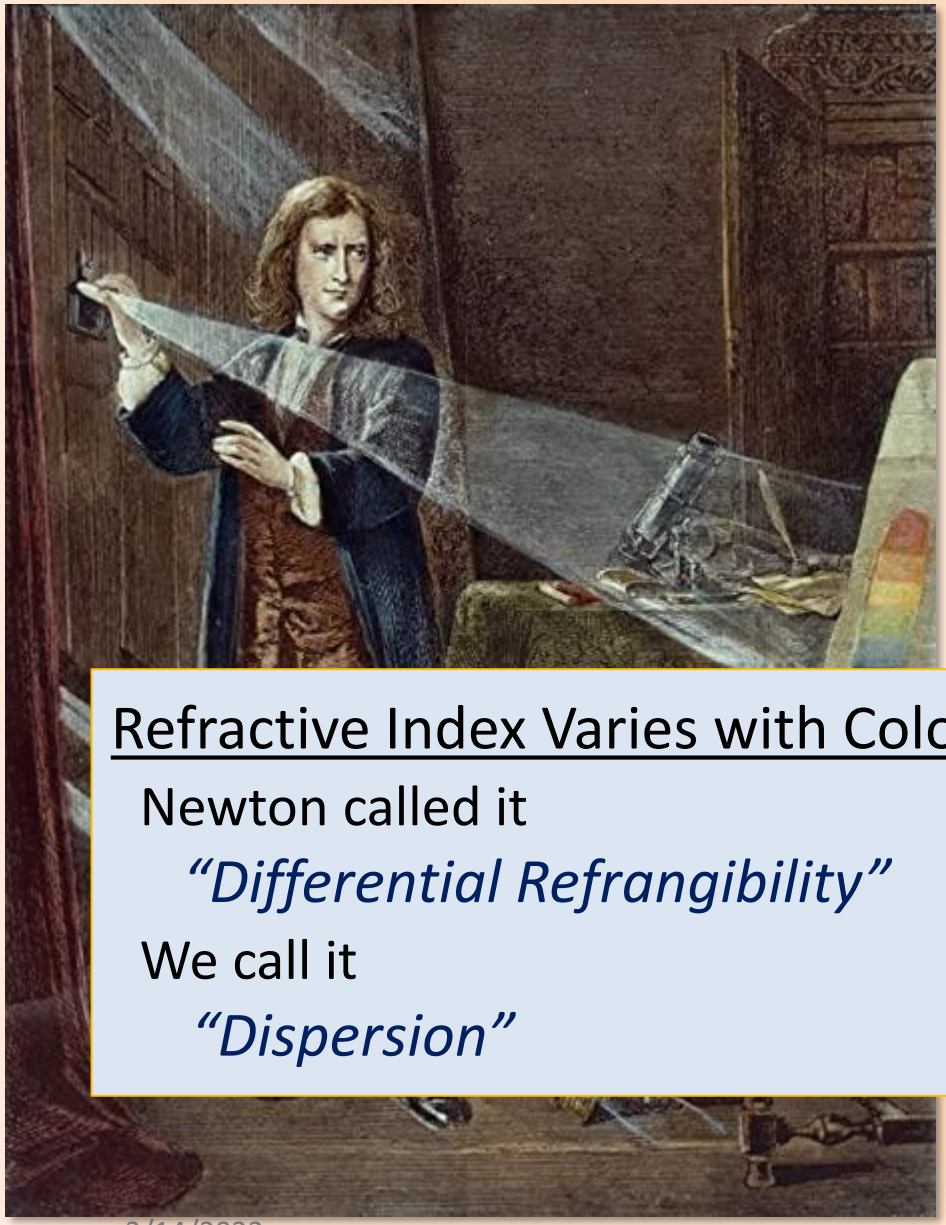
The First Experiment



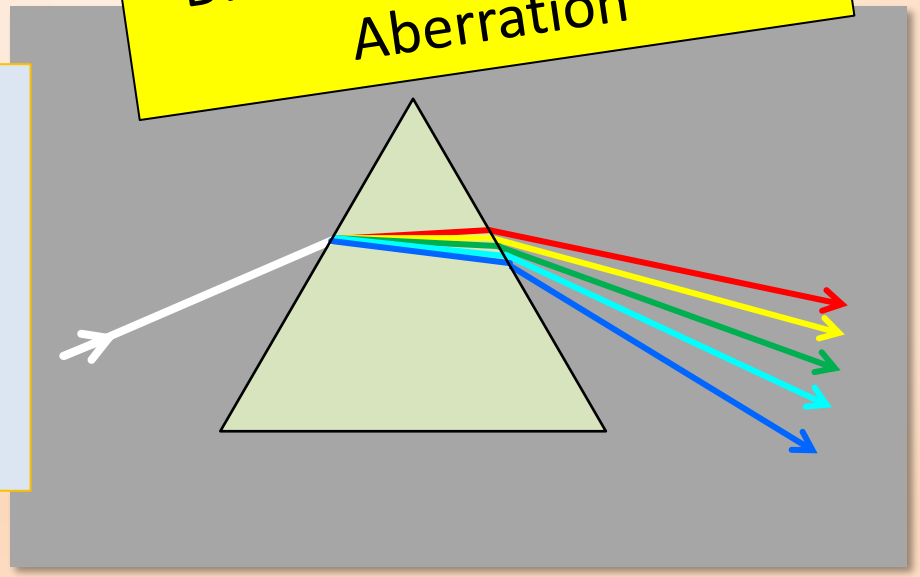


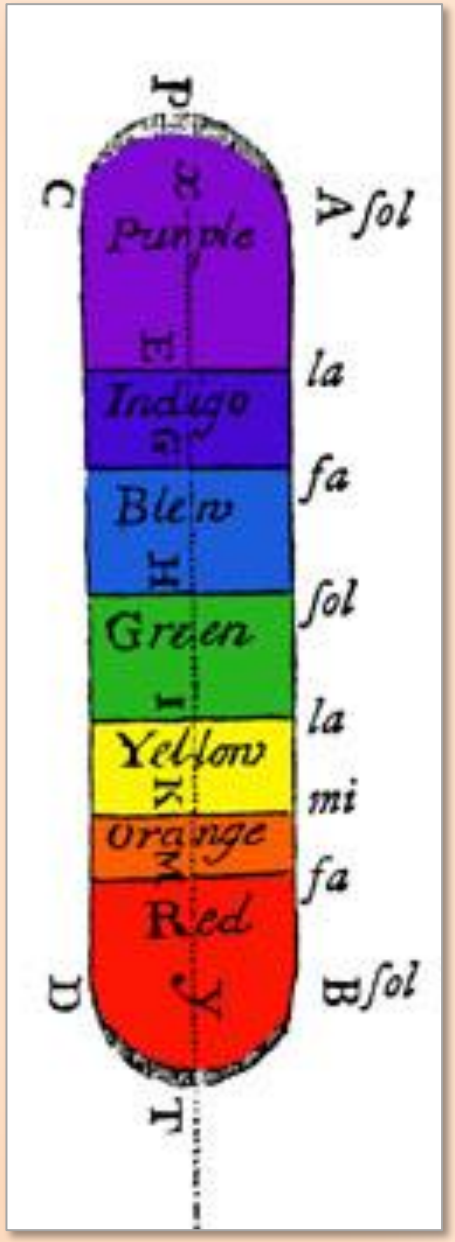


The First Experiment



Discovery of Chromatic Aberration





Refractive Index Varies with Color

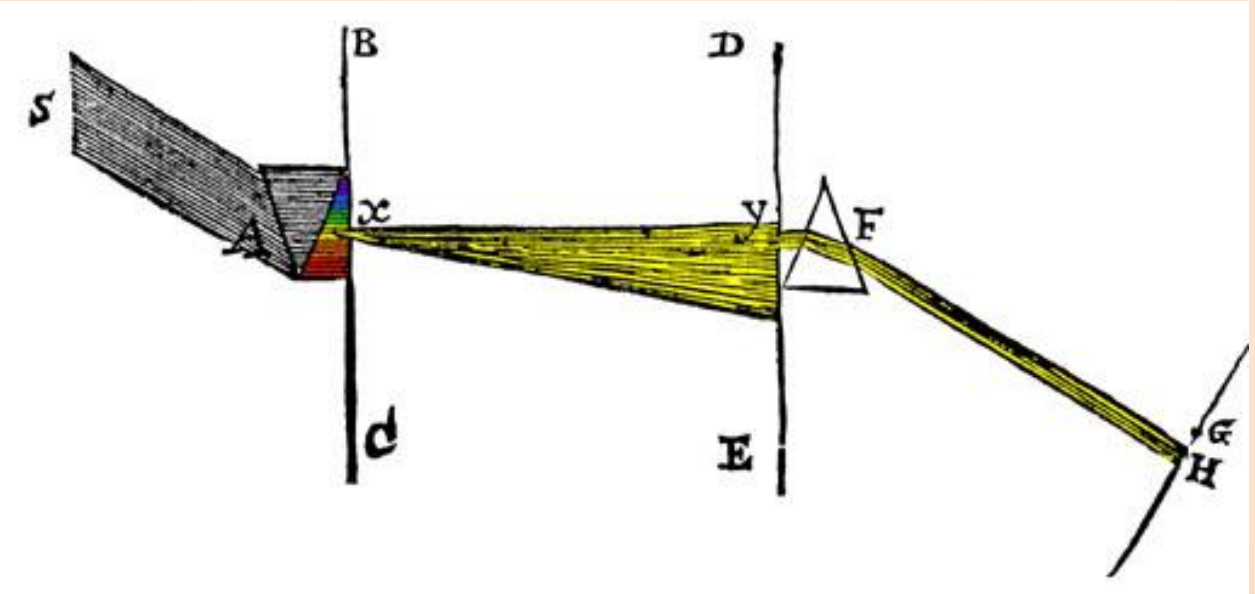
Newton called it

"Differential Refrangibility"

We call it

"Dispersion"

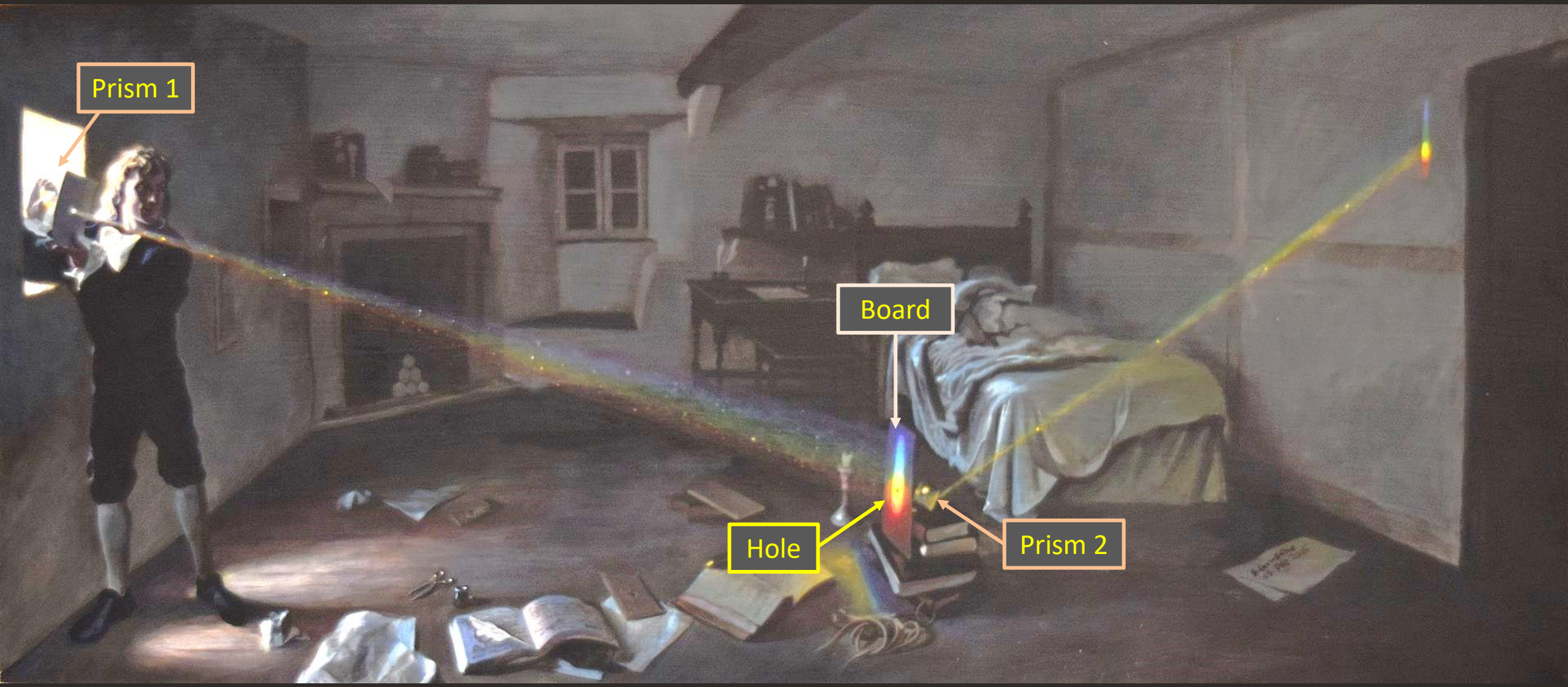
Some time later, perhaps 1668…



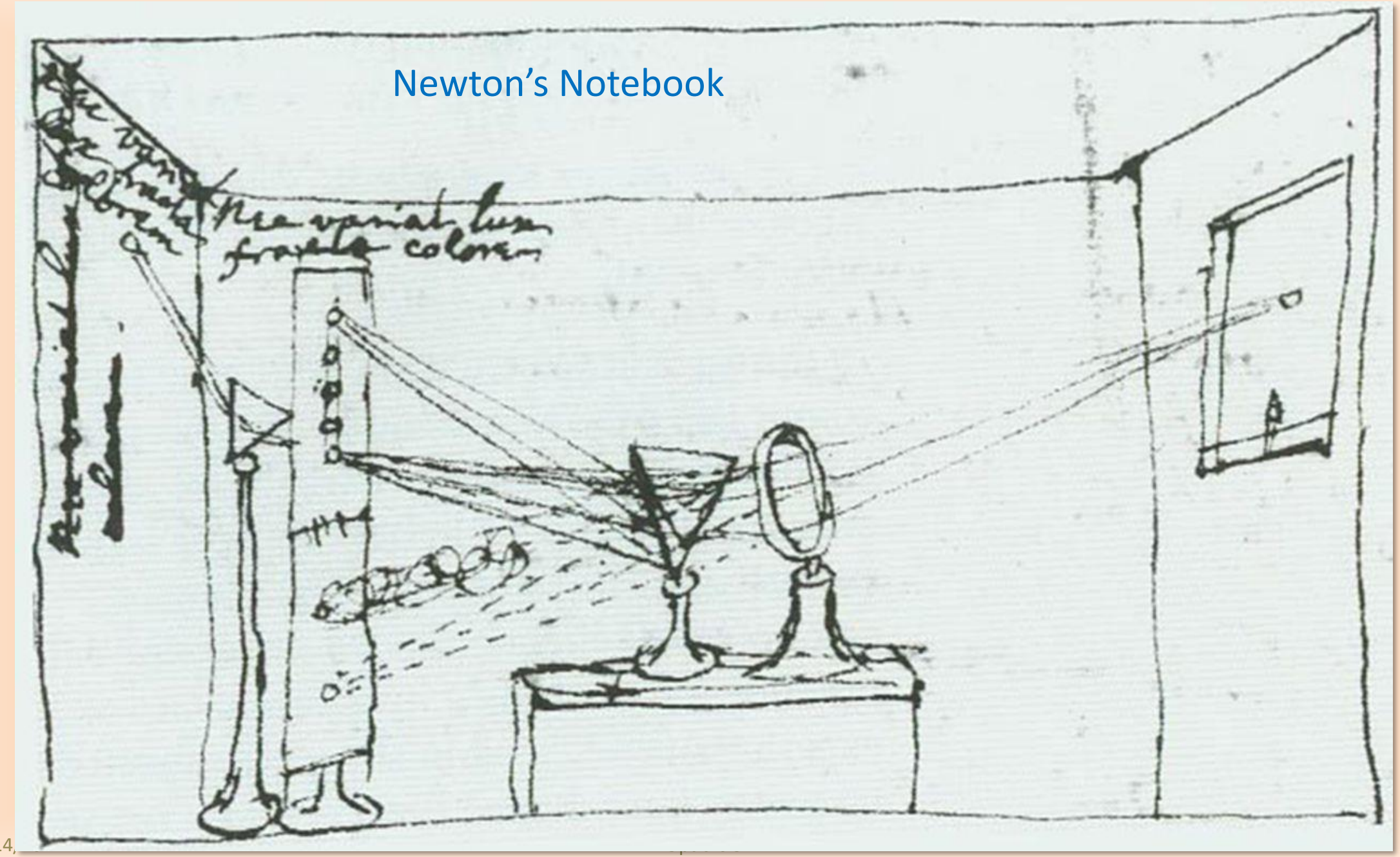
Newton’s Experimentum Crusis: Artist’s Simplified Version

Sascha Grusche

Newton's 'Experimentum Crusis': *Artist's Simplified Version*



Newton's Notebook



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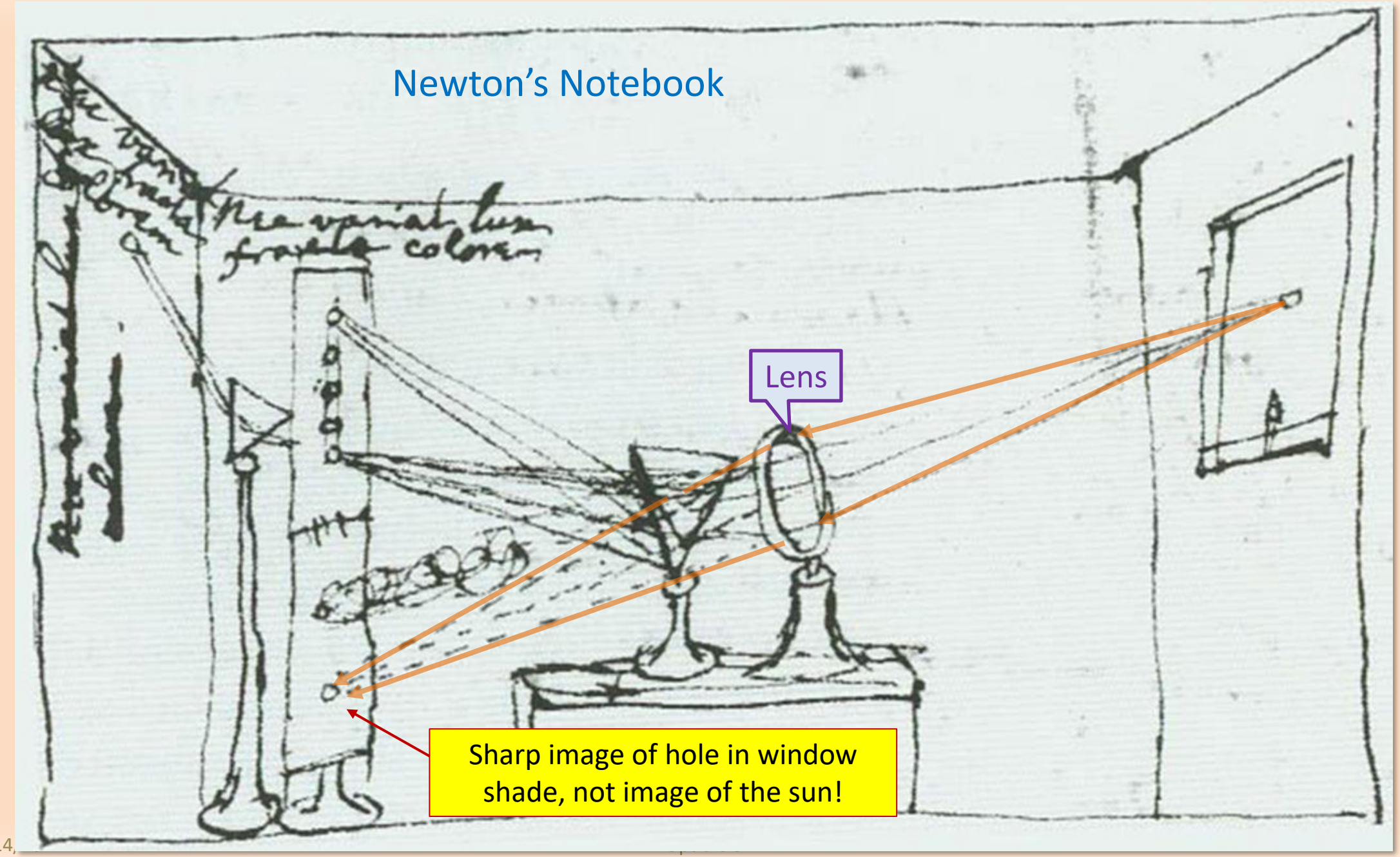

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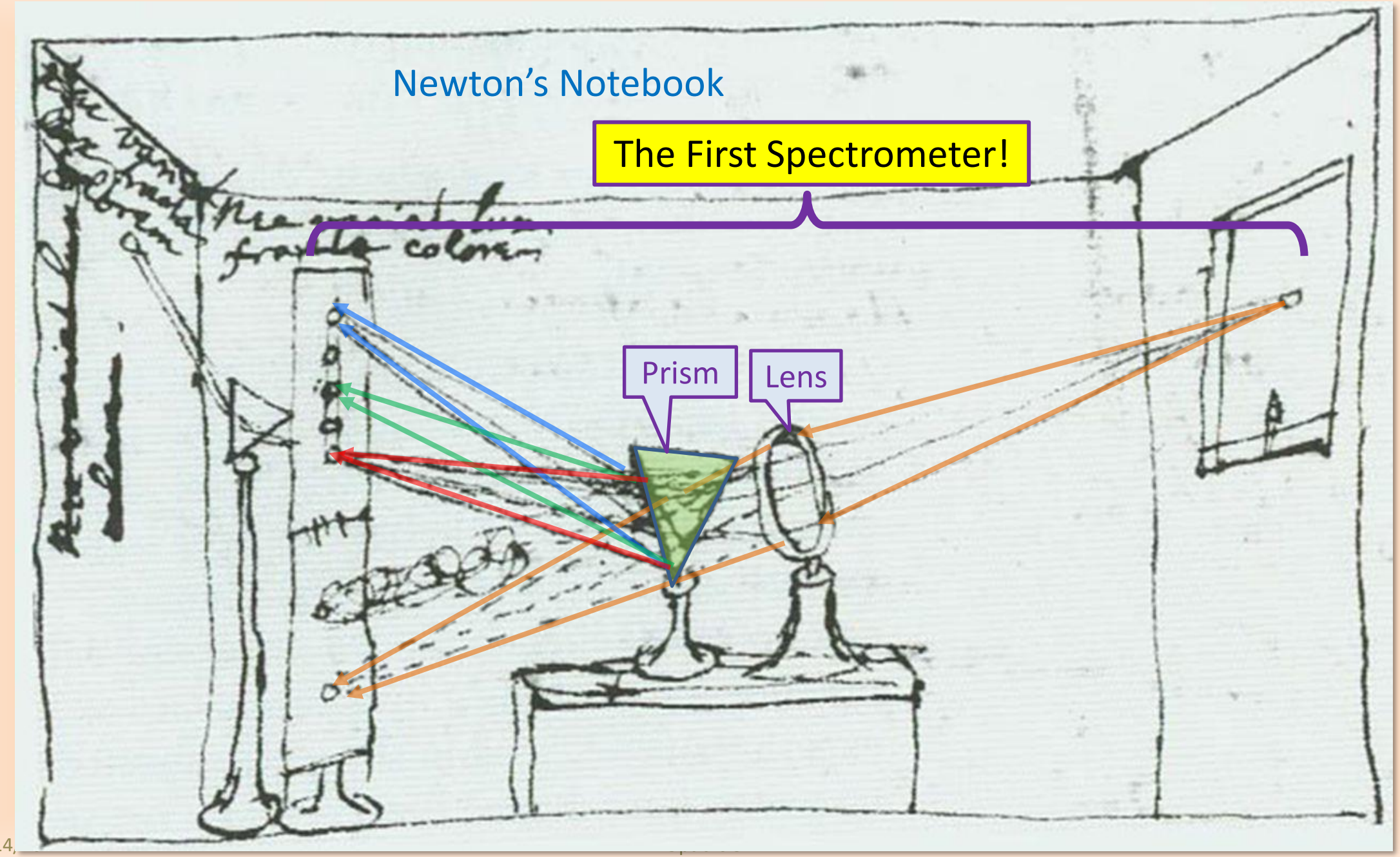

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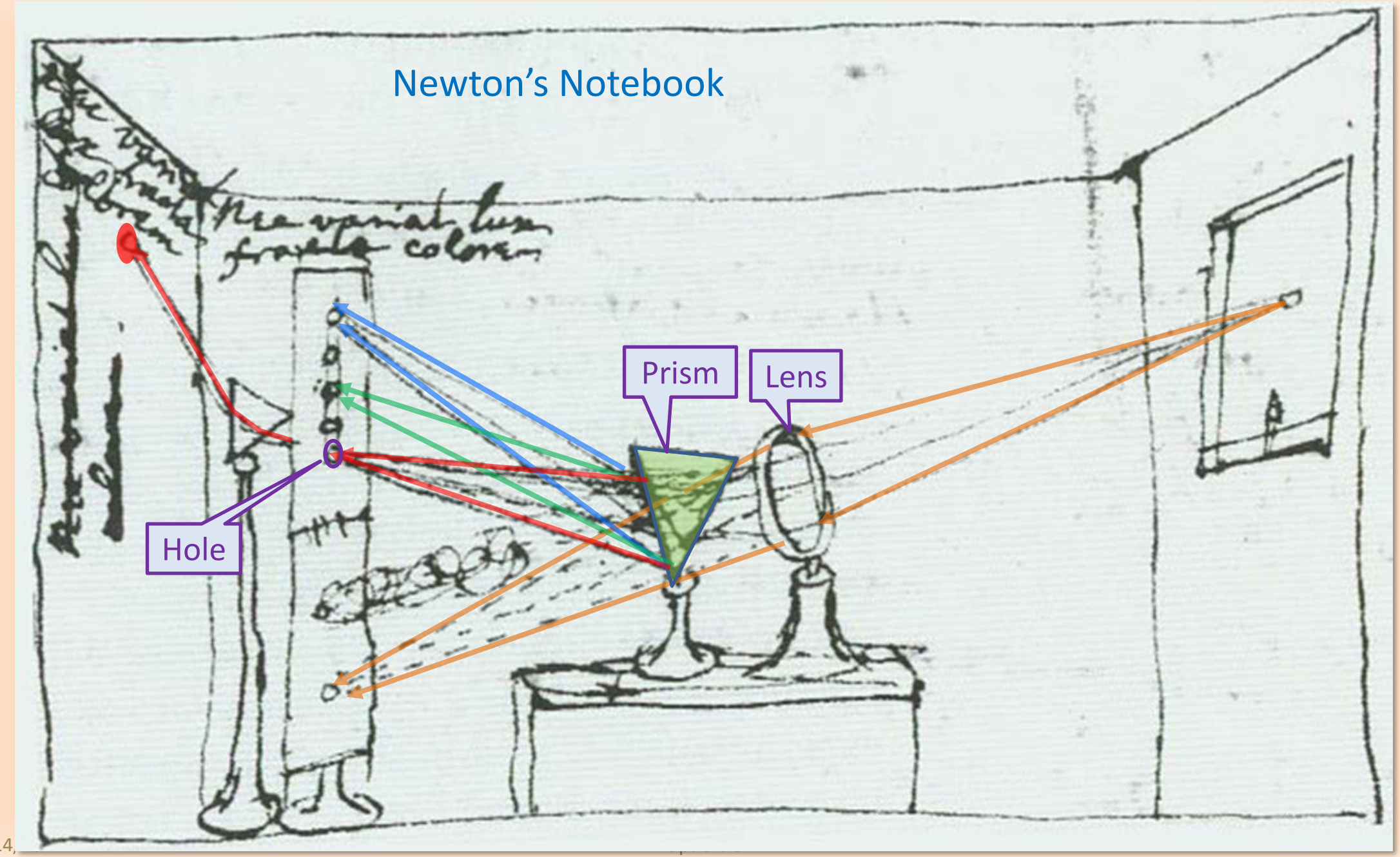


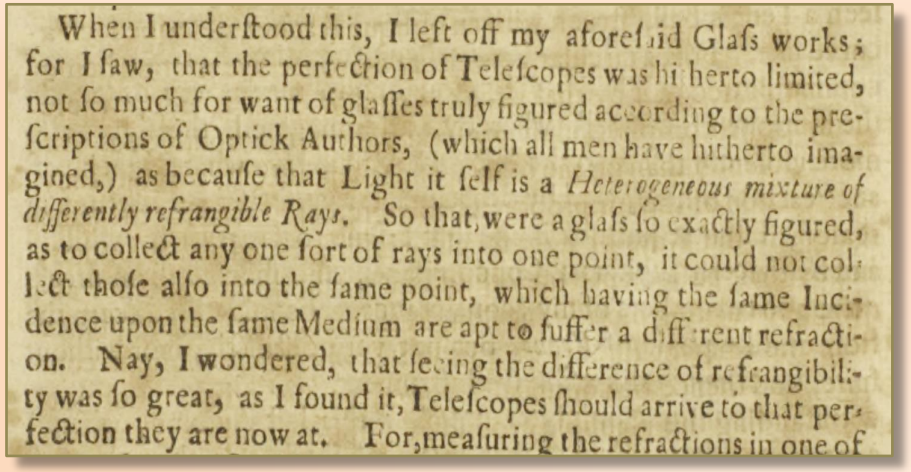
Newton's Notebook

The First Spectrometer!

Prism

Lens

When I understood this, I left off my aforesaid Glass works; for I saw, that the perfection of Telescopes was hitherto limited, not so much for want of glasses truly figured according to the prescriptions of Optick Authors, (which all men have hitherto imagined,) as because that Light it self is a *Heterogeneous mixture of differently refrangible Rays*. So that, were a glass so exactly figured, as to collect any one sort of rays into one point, it could not collect those also into the same point, which having the same Incidence upon the same Medium are apt to suffer a different refraction. Nay, I wondered, that seeing the difference of refrangibility was so great, as I found it, Telescopes should arrive to that perfection they are now at. For, measuring the refractions in one of



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'A Letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; containing his New Theory about Light and Colors'

Philosophical Transactions of the Royal Society
Feb 19, 1672

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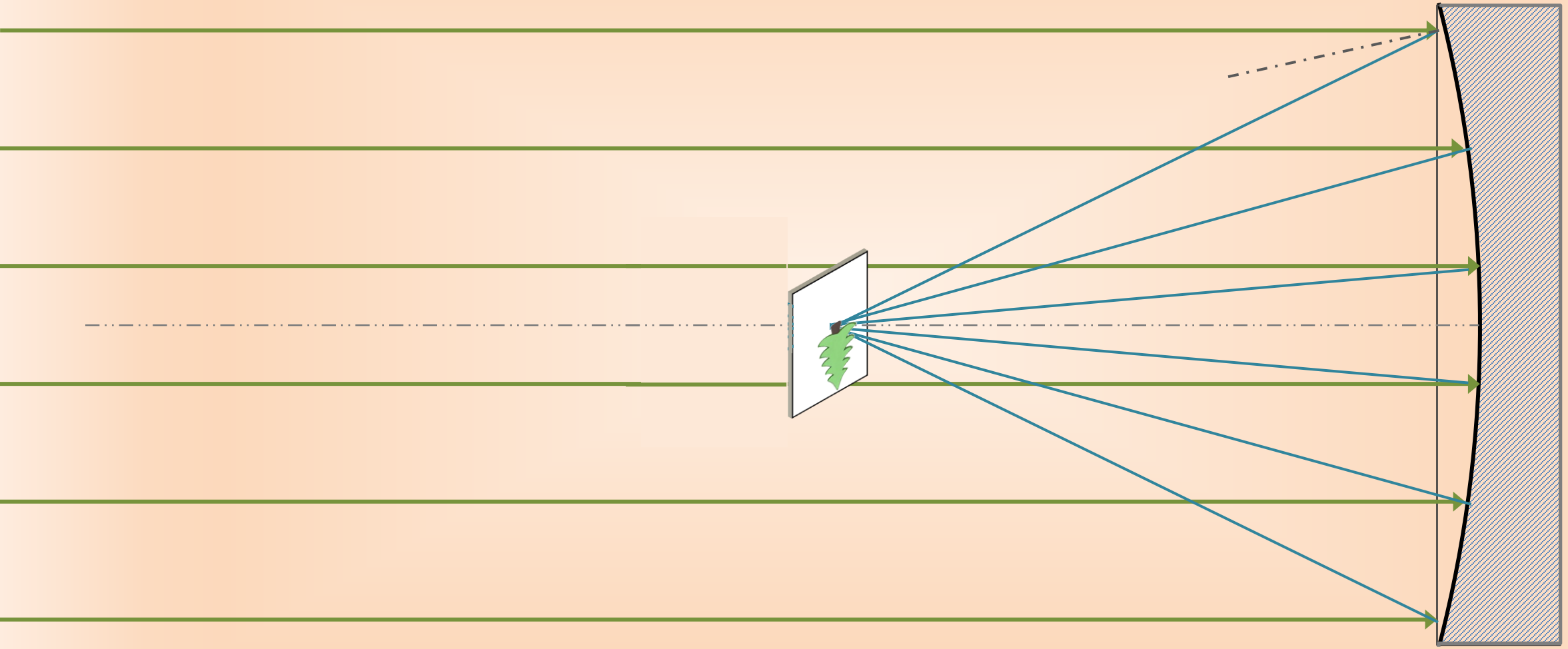
Giving up on Lenses for Telescopes due to Chromatic Aberration, Newton turns to **Mirrors**



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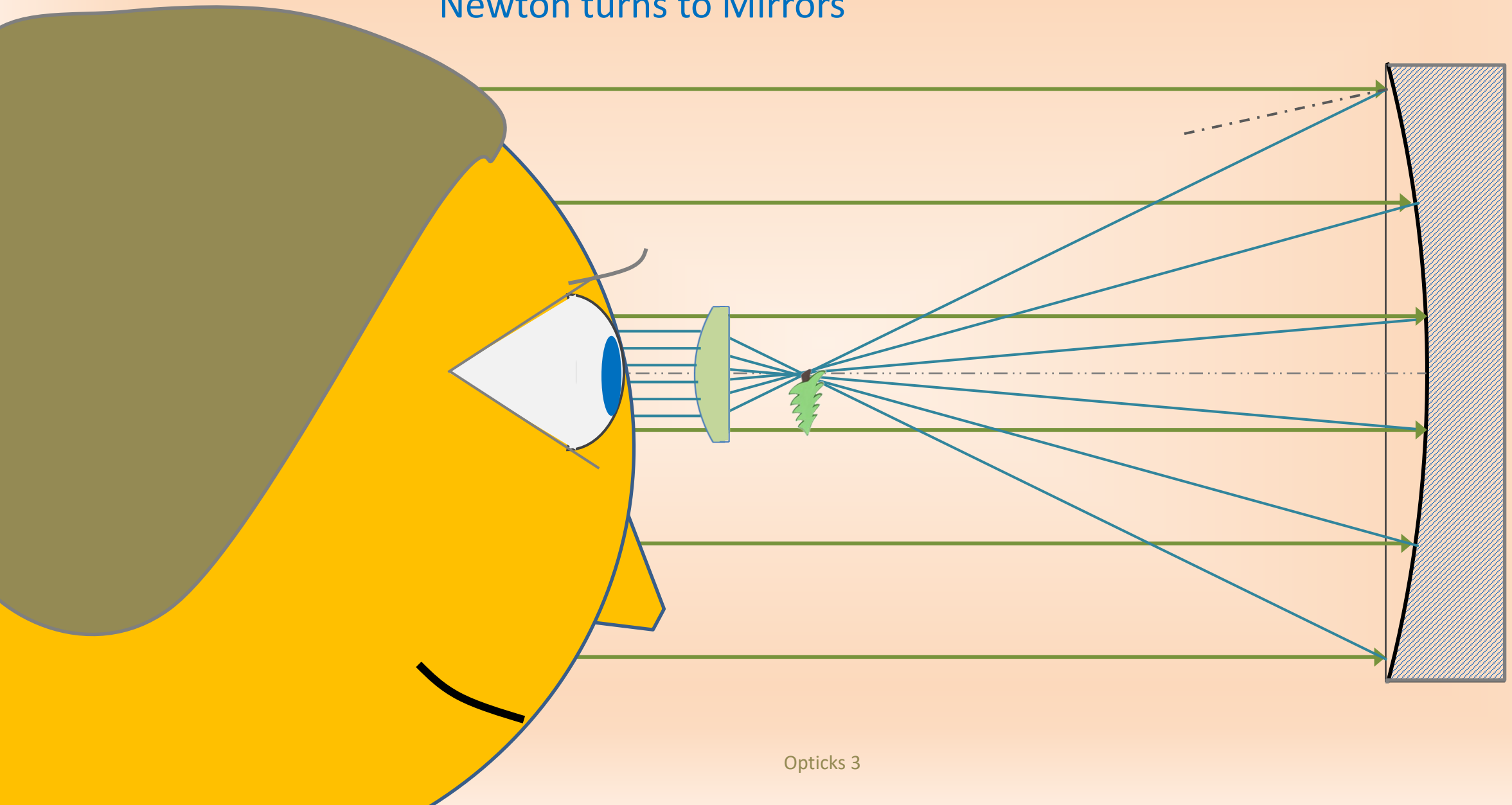

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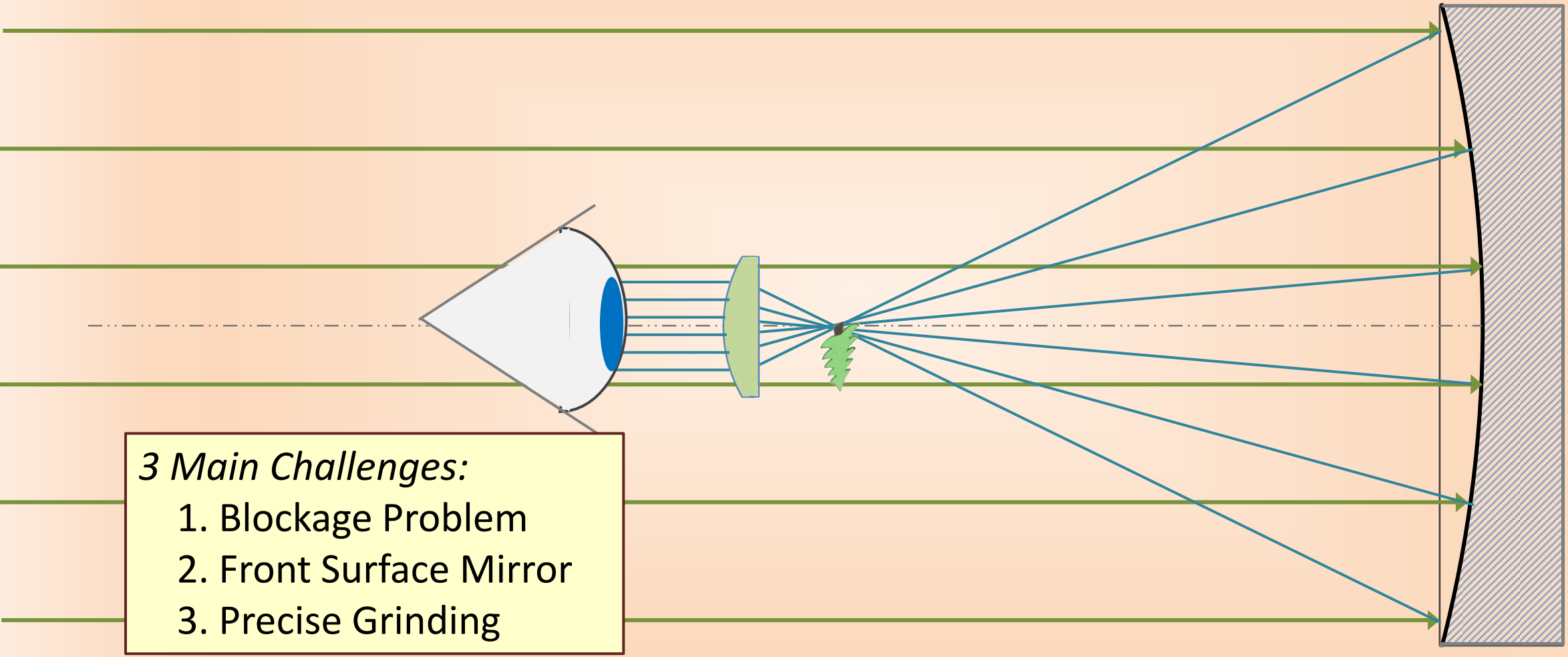
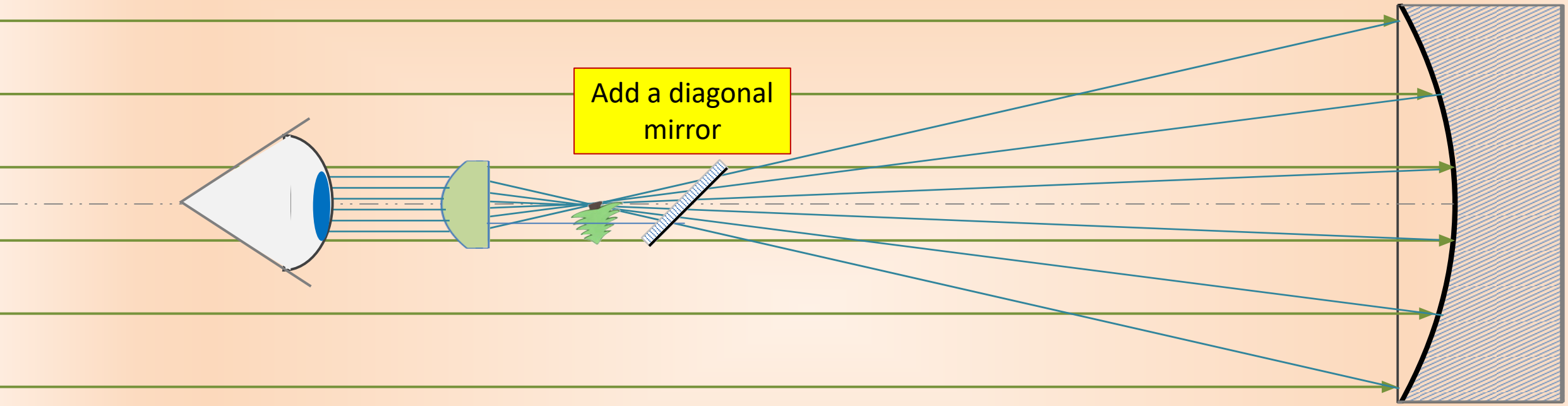


3 Main Challenges:

1. Blockage Problem
2. Front Surface Mirror
3. Precise Grinding

Giving up on Lenses for Telescopes due to Chromatic Aberration, Newton turns to Mirrors



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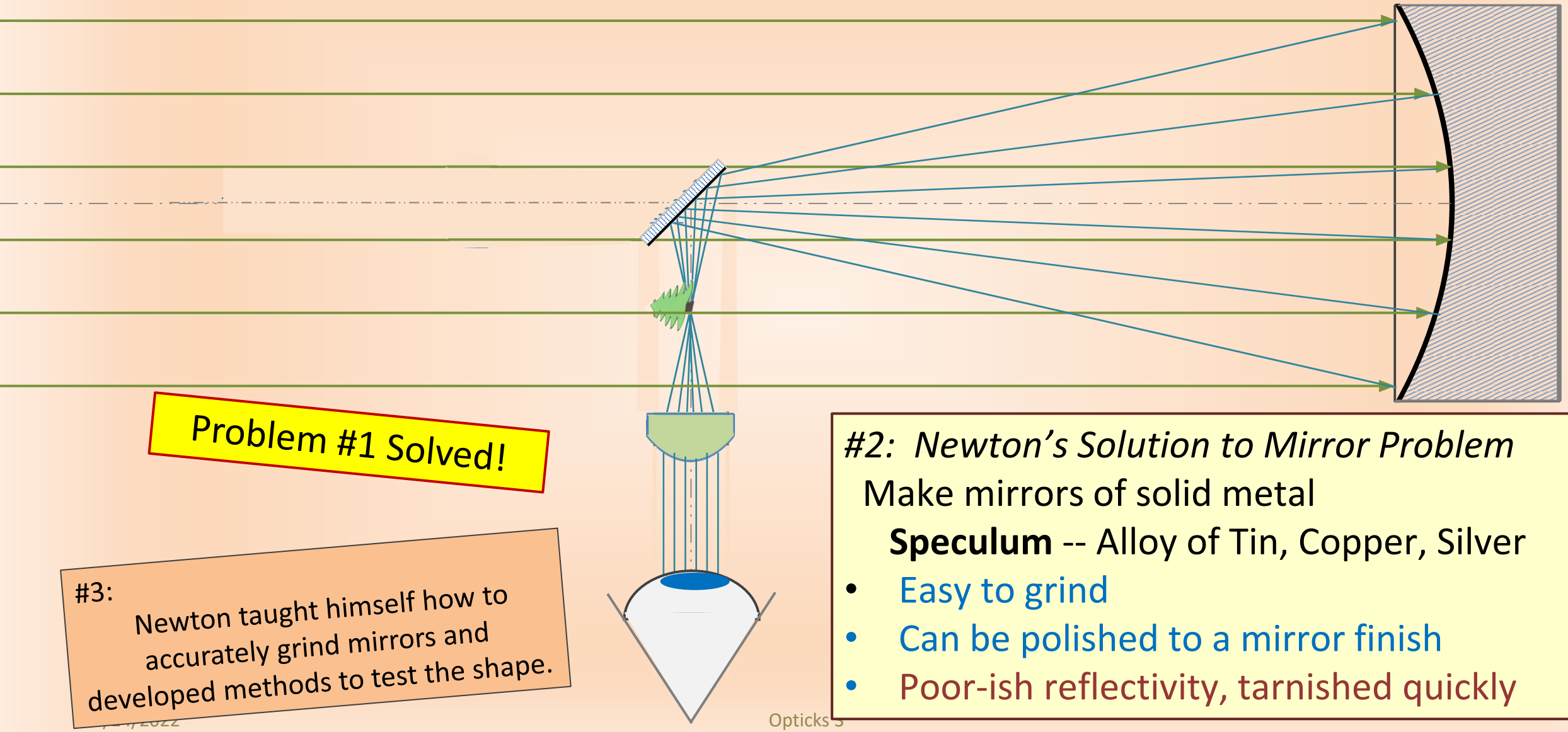


Problem #1 Solved!

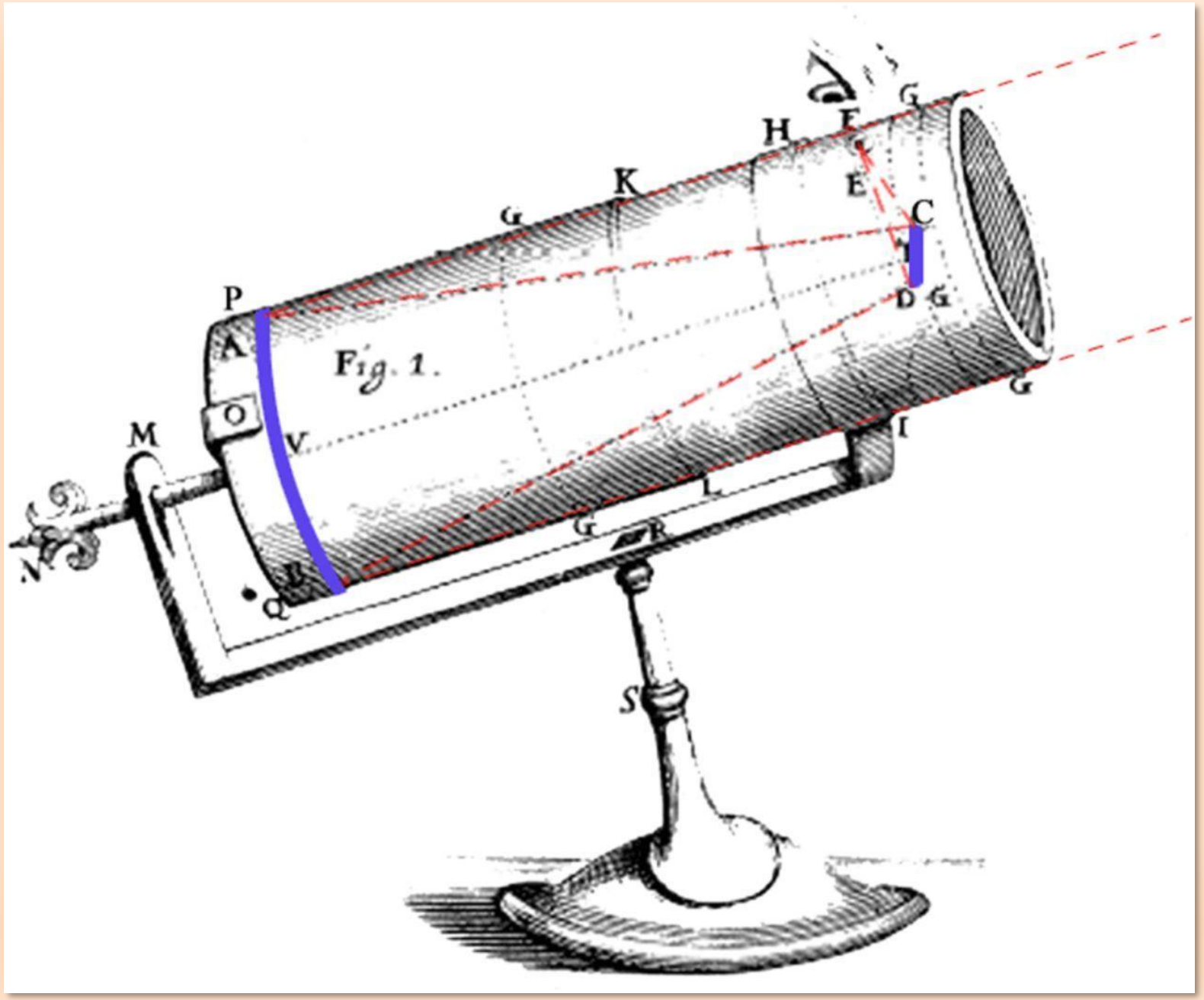
#3: Newton taught himself how to accurately grind mirrors and developed methods to test the shape.

#2: Newton's Solution to Mirror Problem

Make mirrors of solid metal

Speculum -- Alloy of Tin, Copper, Silver

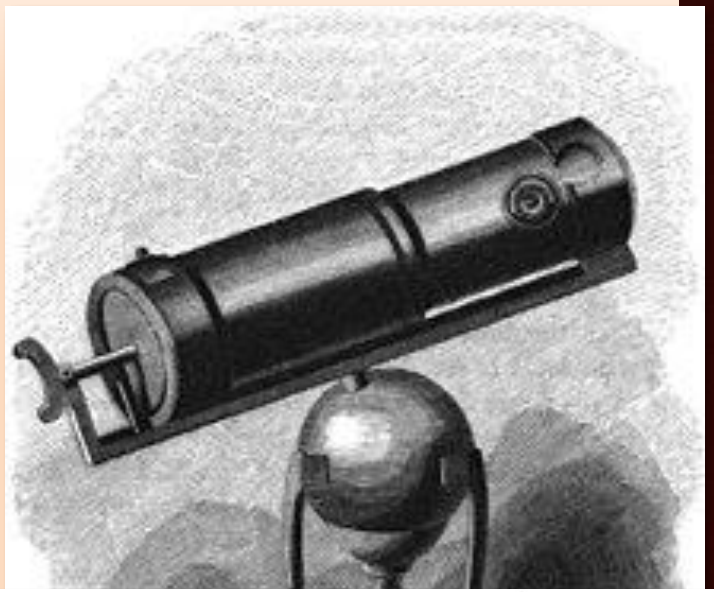
- Easy to grind
- Can be polished to a mirror finish
- Poor-ish reflectivity, tarnished quickly

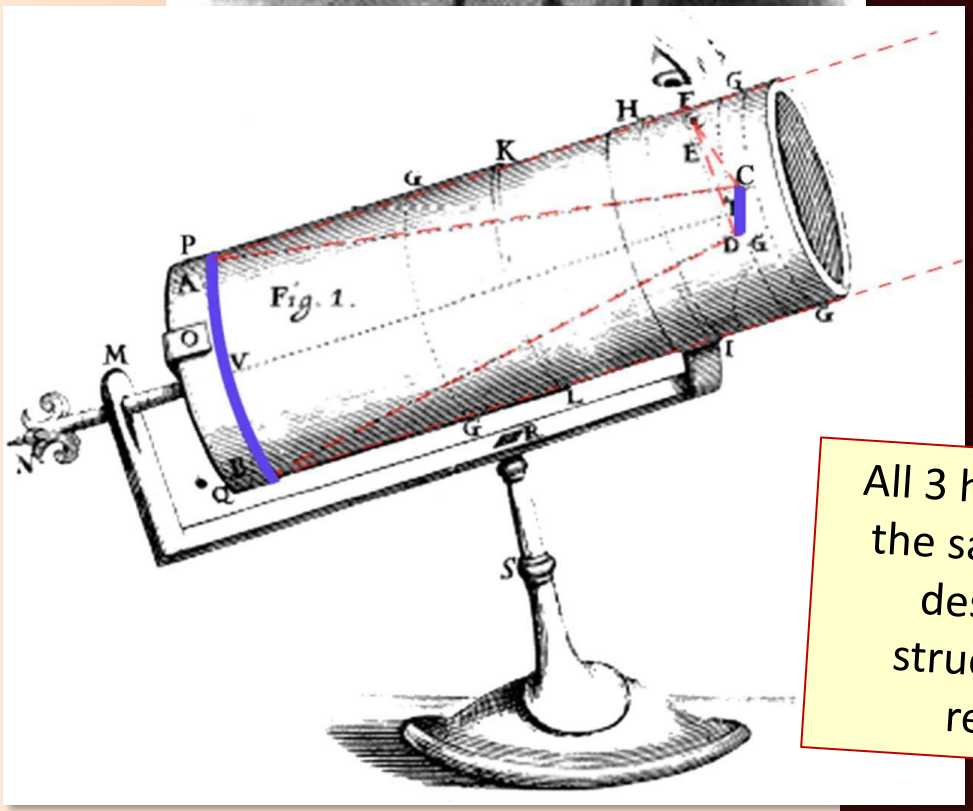


First Prototype built in 1668

Second Version shown to Royal Society late 1671

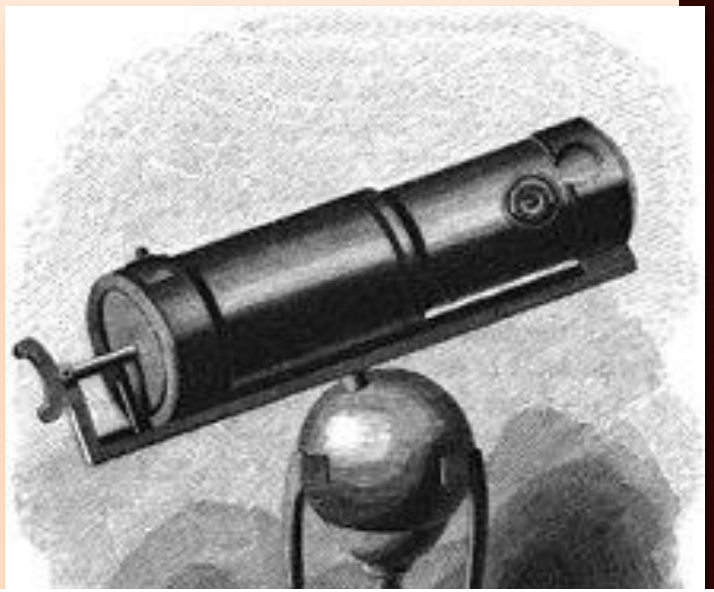
Patricia Fara, *Philosophical Transactions A (2015)*

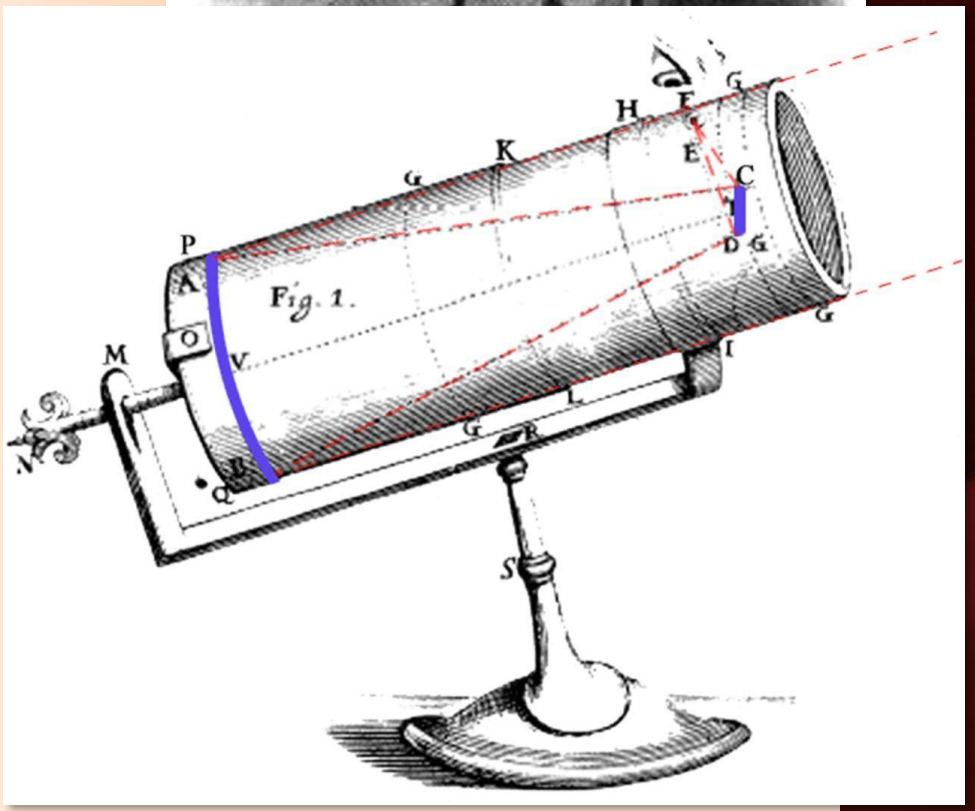




All 3 had basically the same optical design, but structure was refined.

Replica of Newton's 3rd Reflecting Telescope (~1672)



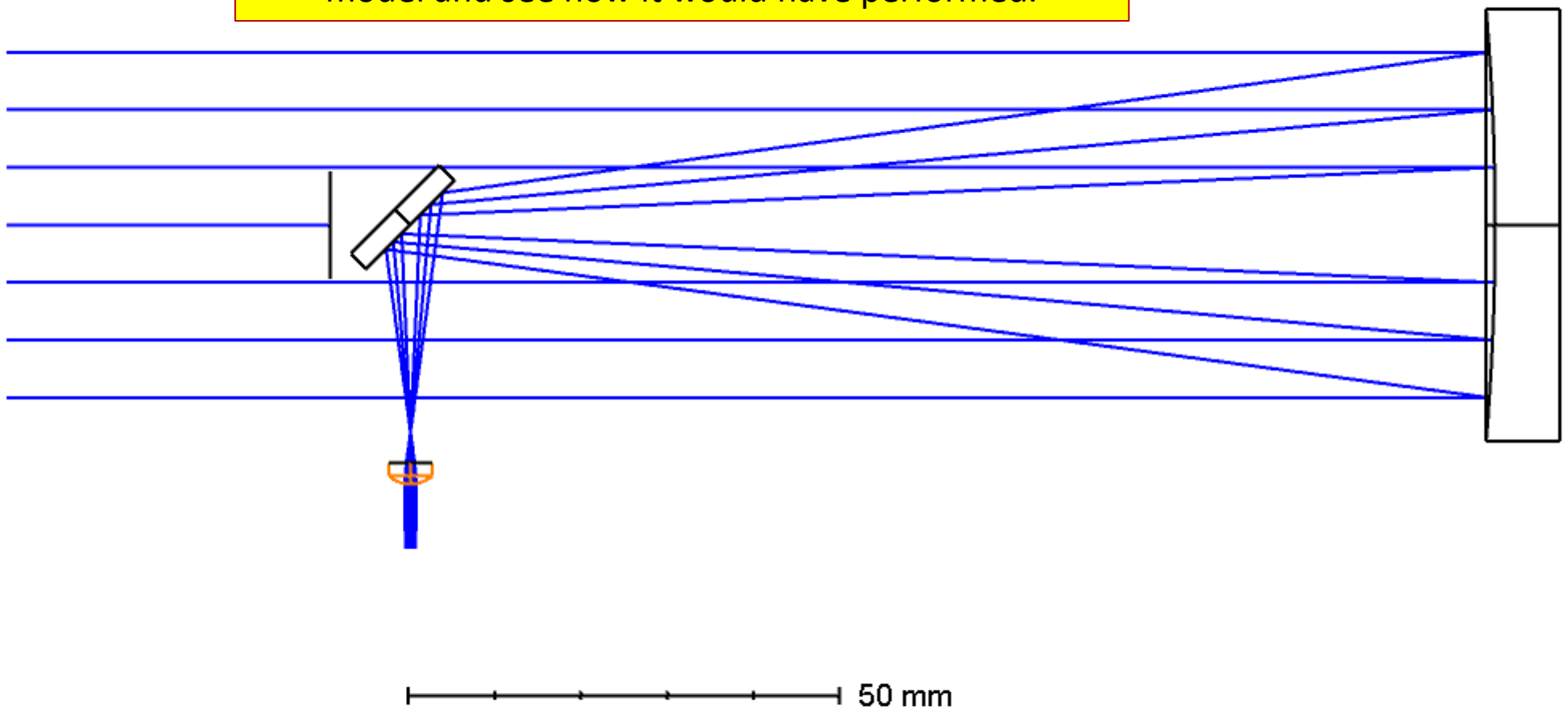


Tiny size amazed the Royal Society

7”

Replica of Newton’s 3rd Reflecting Telescope (~1672)

Since Newton provided full details of the optical design, we can put it into a modern optical ray tracing model and see how it would have performed.



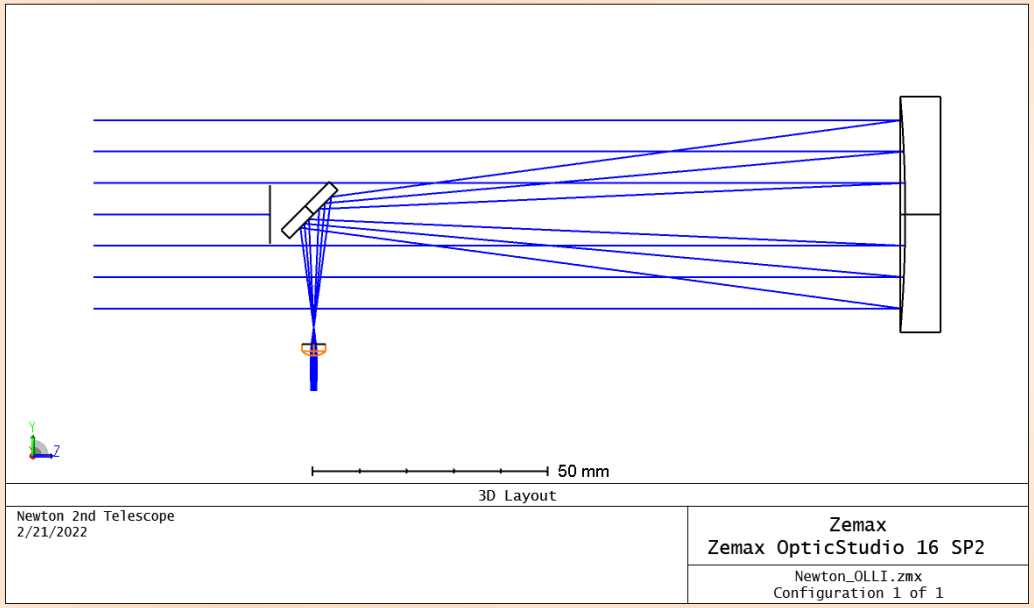
3D Layout

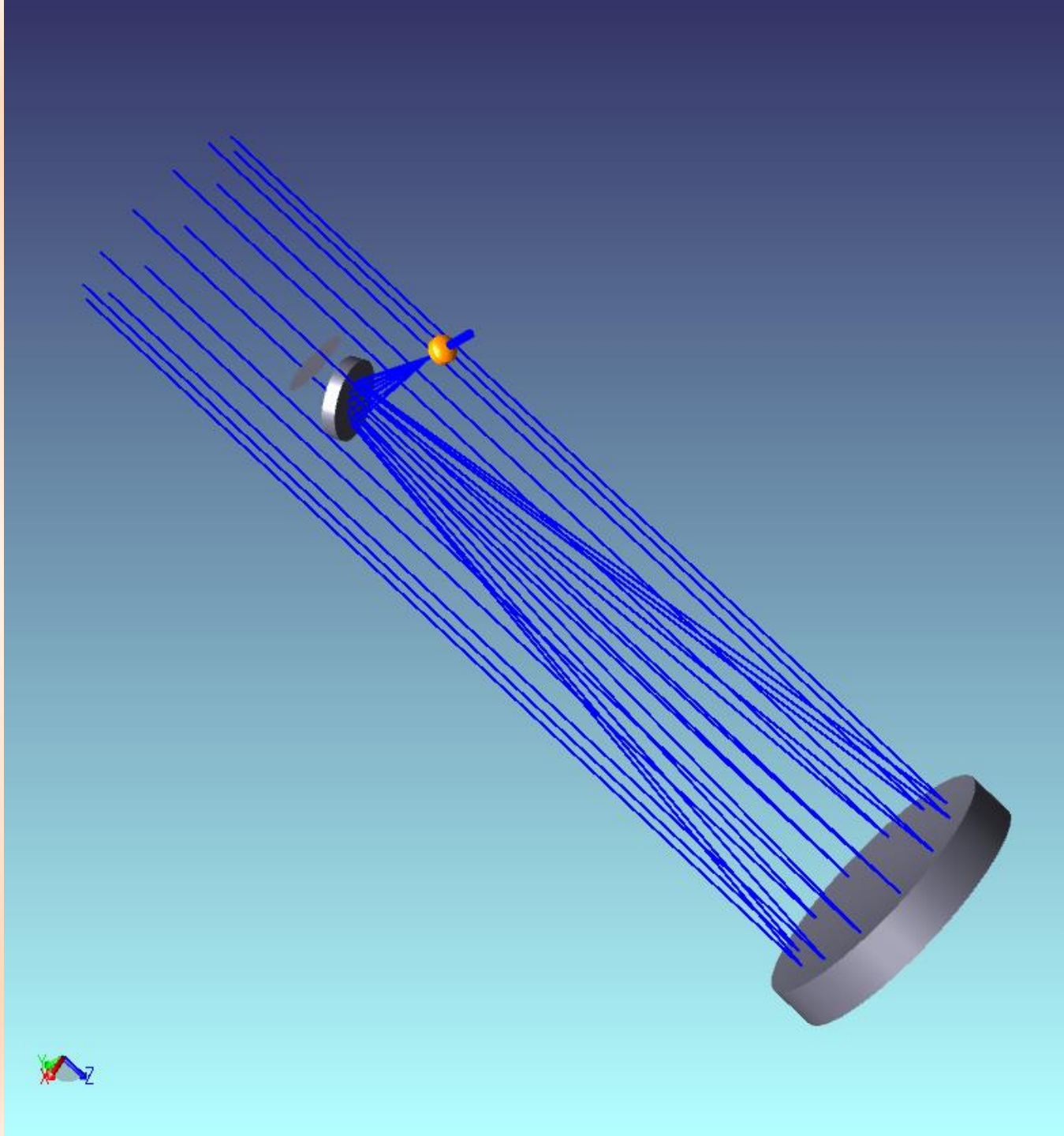
Newton 2nd Telescope
2/21/2022

Zemax
Zemax OpticStudio 16 SP2

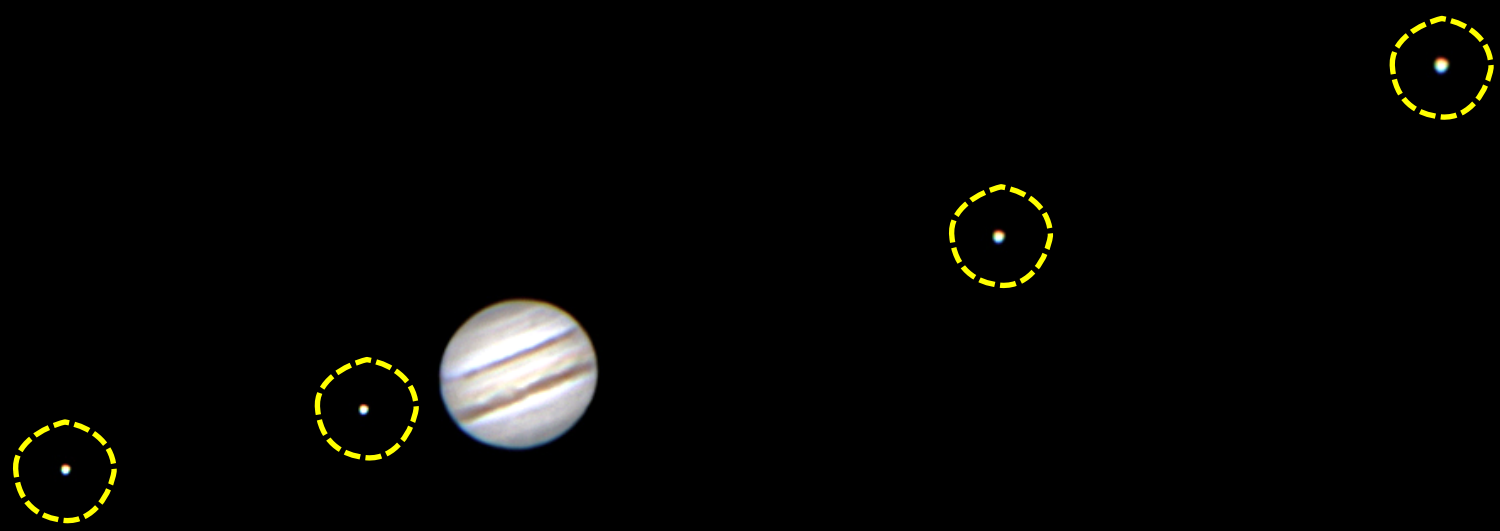
Newton_OLLI.zmx
Configuration 1 of 1

Ray Trace Model of Newton's 2nd Telescope





Modern high resolution image of Jupiter with the 4 Galilean moons.



Sky & Telescope (2019)

Joshua Rhoades PHOTOGRAPHY

The computed image Newton could have seen if he fabricated the optics accurately…

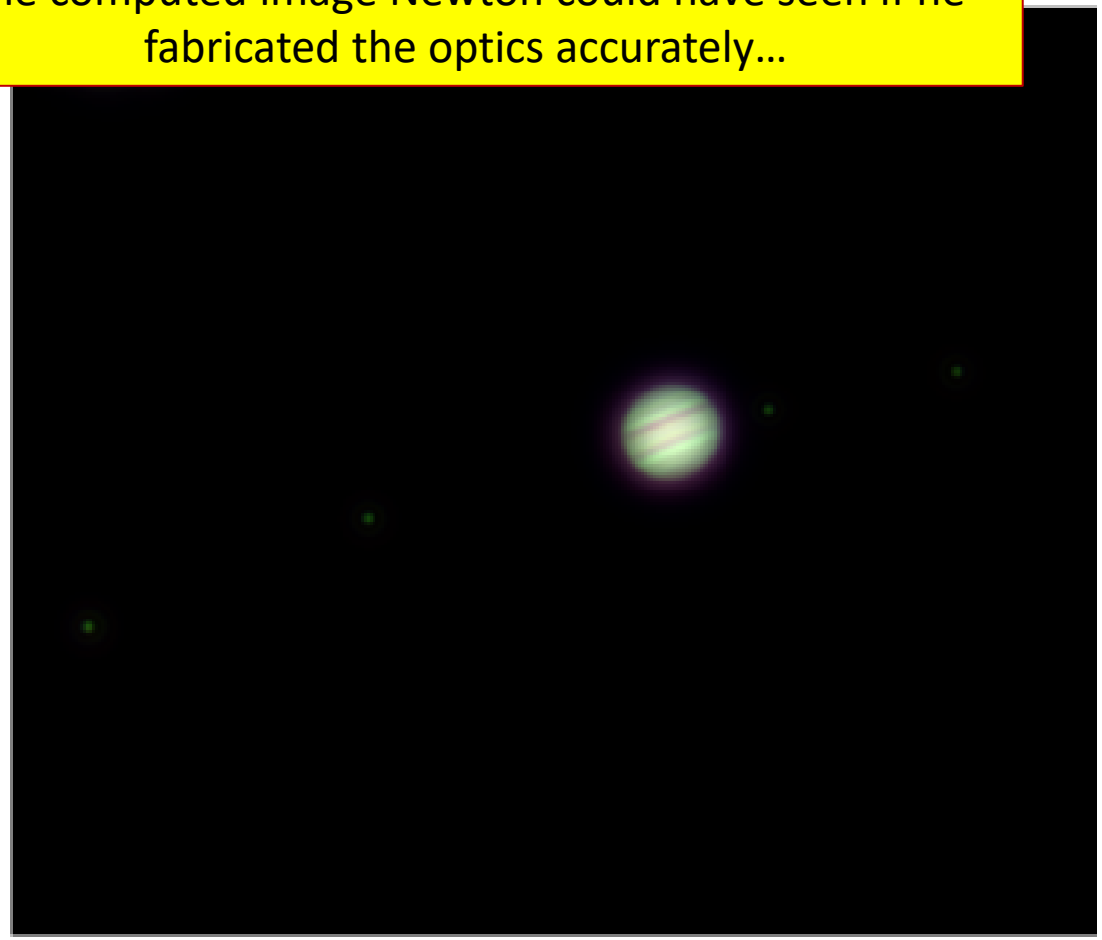
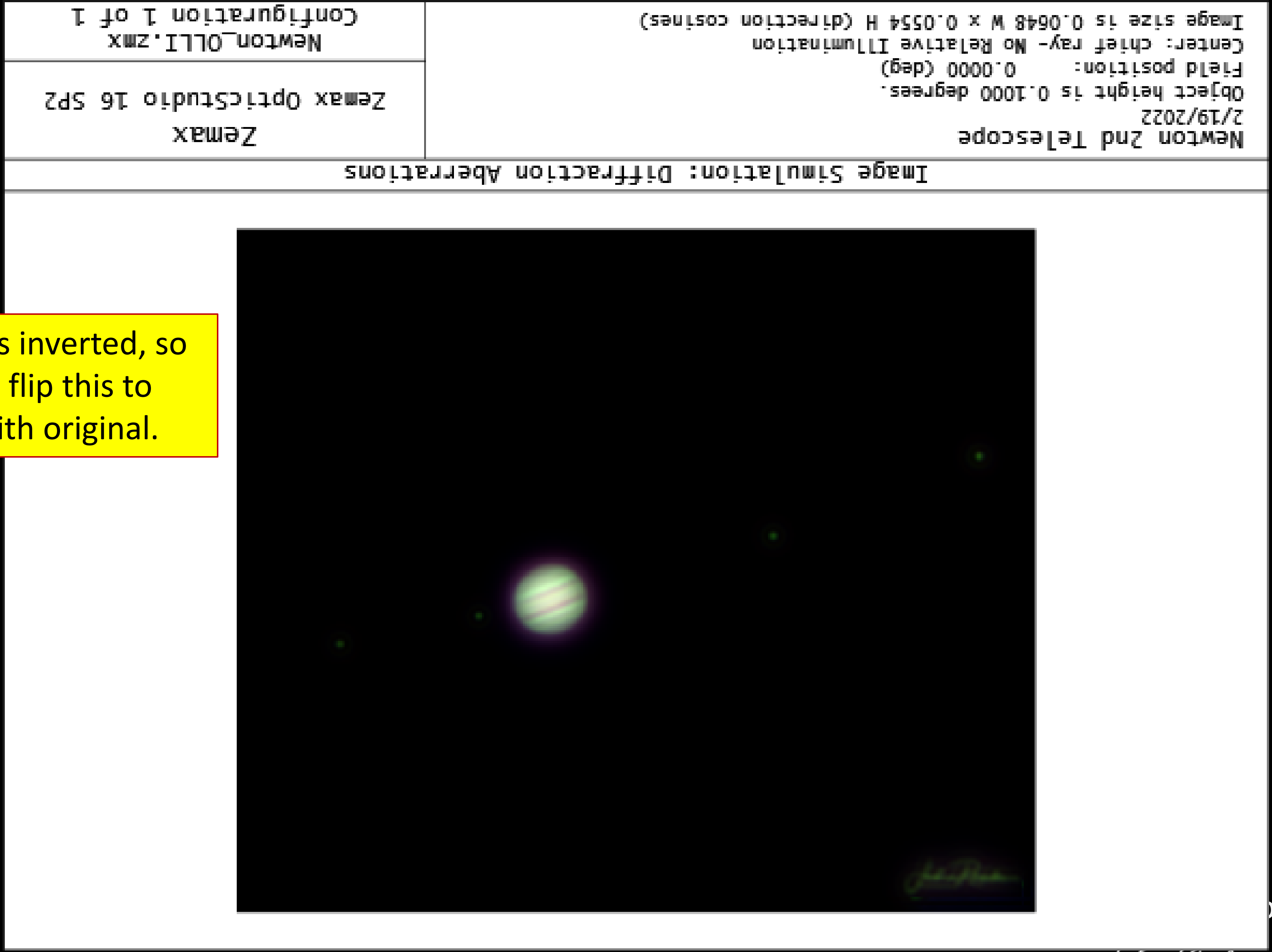


Image Simulation: Diffraction Aberrations

Newton 2nd Telescope
2/19/2022
Object height is 0.1000 degrees.
Field position: 0.0000 (deg)
Center: chief ray- No Relative Illumination
Image size is 0.0648 W x 0.0554 H (direction cosines)

Zemax
Zemax OpticStudio 16 SP2

Newton_OLLI.zmx
Configuration 1 of 1



His image was inverted, so we have to flip this to compare with original.

pe (2019)

Zoom in ...

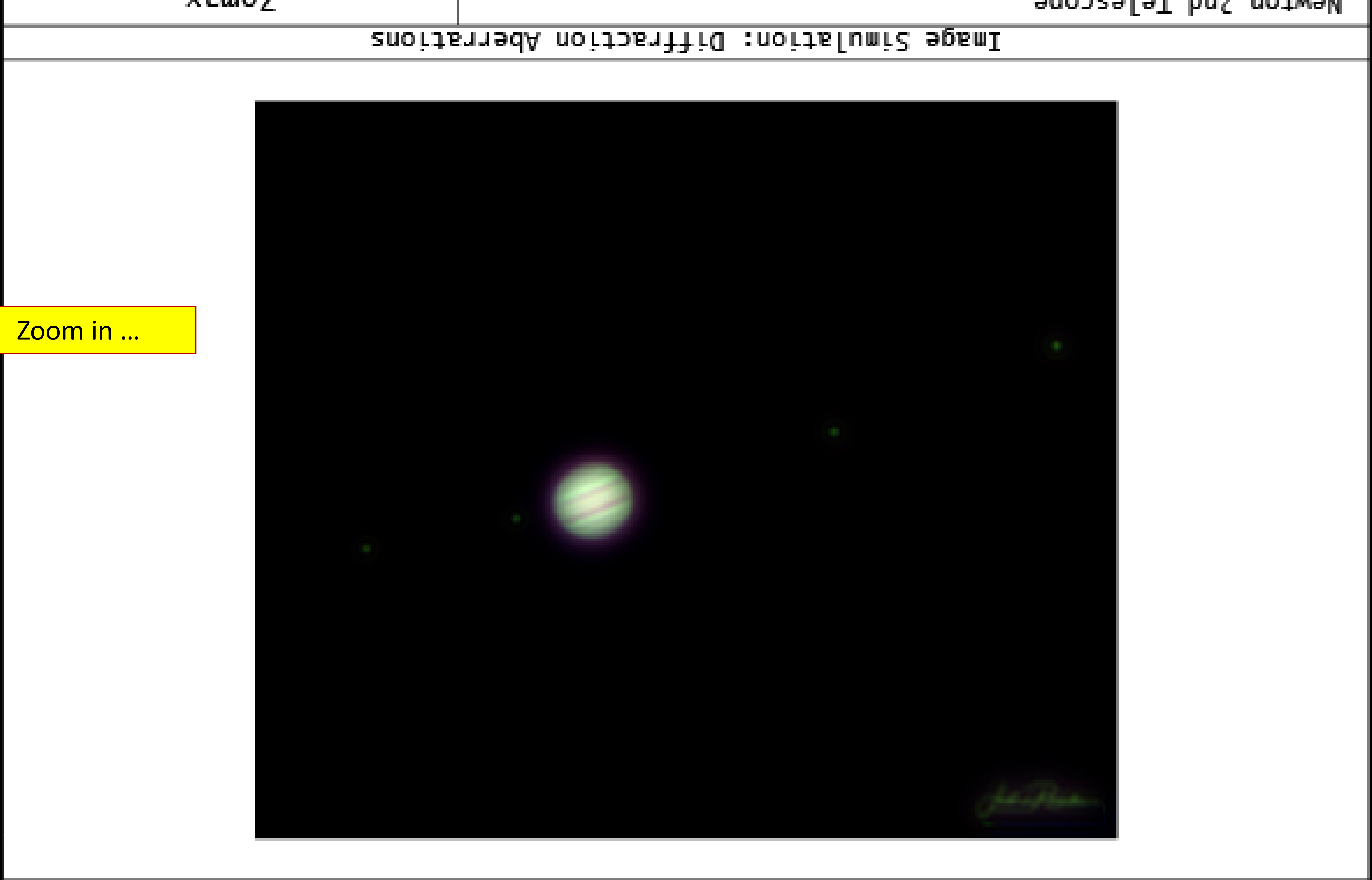


Image Simulation: Diffraction Aberrations
Newton 2nd Telescope
Zemax

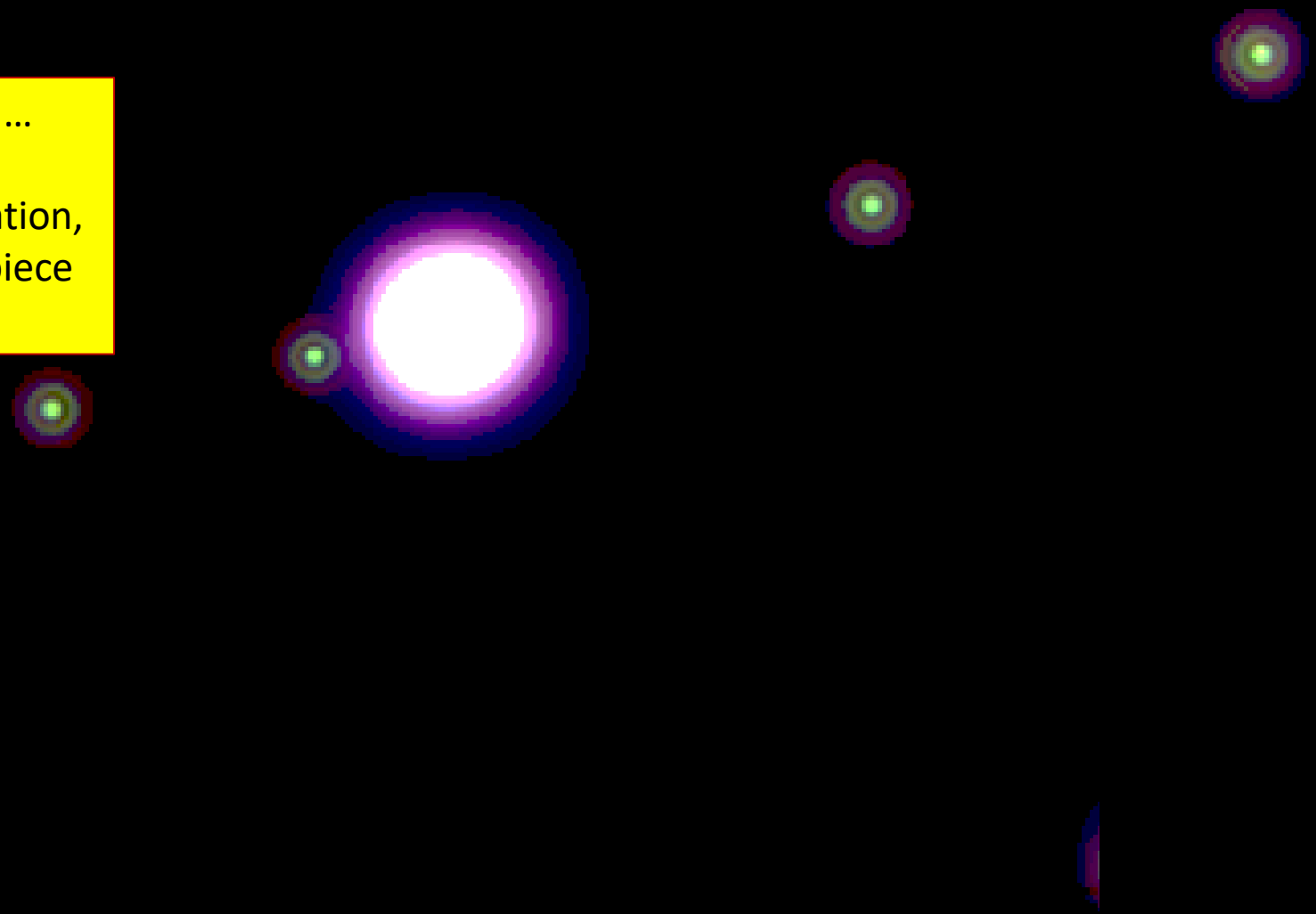
3/14/2022

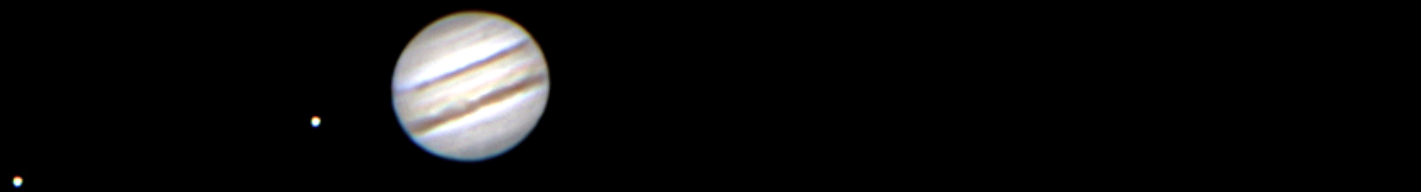
"…and by degrees so far perfected an instrument … by which I could discern Jupiter's 4 Concomitants, and showed them diverse times to two others of my acquaintance. "

Newton's letter to Royal Society Feb 6, 1672

Brighten the image …

Note chromatic aberration, due to refractive eyepiece lens.





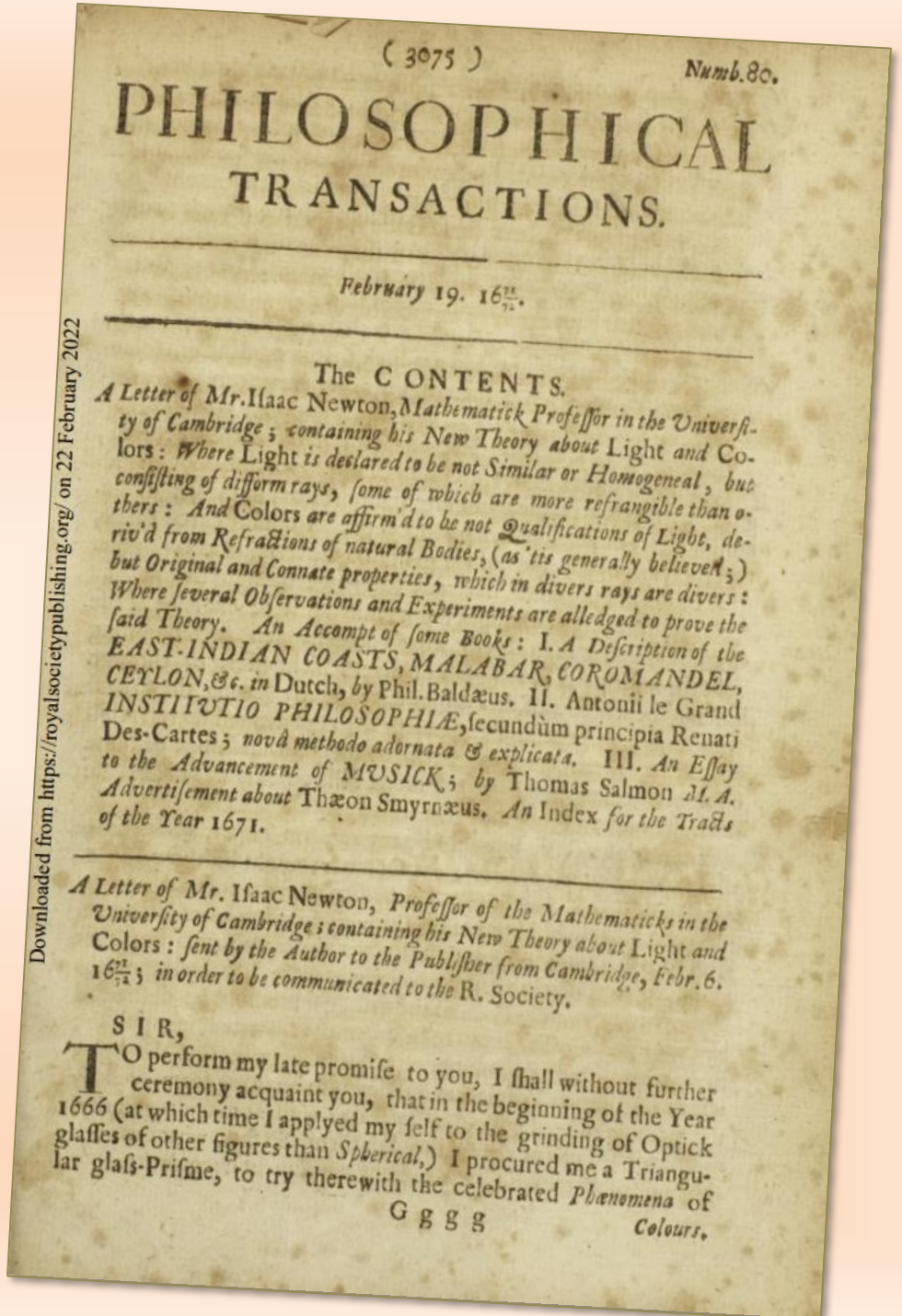
Finally, after showing his second Telescope to the Royal Society, Newton publishes his Experiments on Color

3 Results:

- Newton is elected to the Royal Society
- Starts a spirited exchange with critics, especially Robert Hooke.
- The controversy sends him into a funk

‘A Letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; containing his New Theory about Light and Colors’

Philosophical Transactions of the Royal Society
Feb 19, 1672
13 Pages


(3075) Numb. 80.

PHILOSOPHICAL TRANSACTIONS.

February 19. 16$\frac{71}{72}$.

The CONTENTS.

A Letter of Mr. Isaac Newton, *Mathematick Professor in the University of Cambridge; containing his New Theory about* Light *and Colors: Where* Light *is declared to be not Similar or Homogeneal, but consisting of differing rays, some of which are more refrangible than others: And* Colors *are affirm'd to be not Qualifications of Light, deriv'd from Refractions of natural Bodies, (as 'tis generally believed;) but Original and Connate properties, which in divers rays are divers: Where several Observations and Experiments are alledged to prove the said Theory. An Accompt of some Books: I. A Description of the* EAST-INDIAN COASTS, MALABAR, COROMANDEL, CEYLON, *&c. in* Dutch, *by* Phil. Baldæus. II. Antonii le Grand INSTITUTIO PHILOSOPHIÆ, *secundùm principia* Renati Des-Cartes; *novâ methodo adornata & explicata.* III. *An Essay to the Advancement of* MUSICK; *by* Thomas Salmon *M. A. Advertisement about* Thæon Smyrnæus. *An* Index *for the Tracts of the Year* 1671.

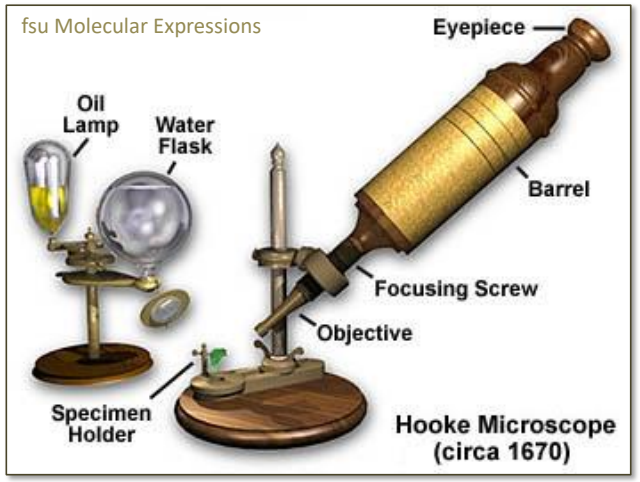
A Letter of Mr. Isaac Newton, *Professor of the Mathematicks in the University of Cambridge; containing his New Theory about* Light *and* Colors: *sent by the Author to the Publisher from Cambridge, Febr.* 6. 16$\frac{71}{72}$; *in order to be communicated to the* R. Society.

SIR,

TO perform my late promise to you, I shall without further ceremony acquaint you, that in the beginning of the Year 1666 (at which time I applyed my self to the grinding of Optick glasses of other figures than *Spherical,*) I procured me a Triangular glass-Prisme, to try therewith the celebrated *Phænomena* of

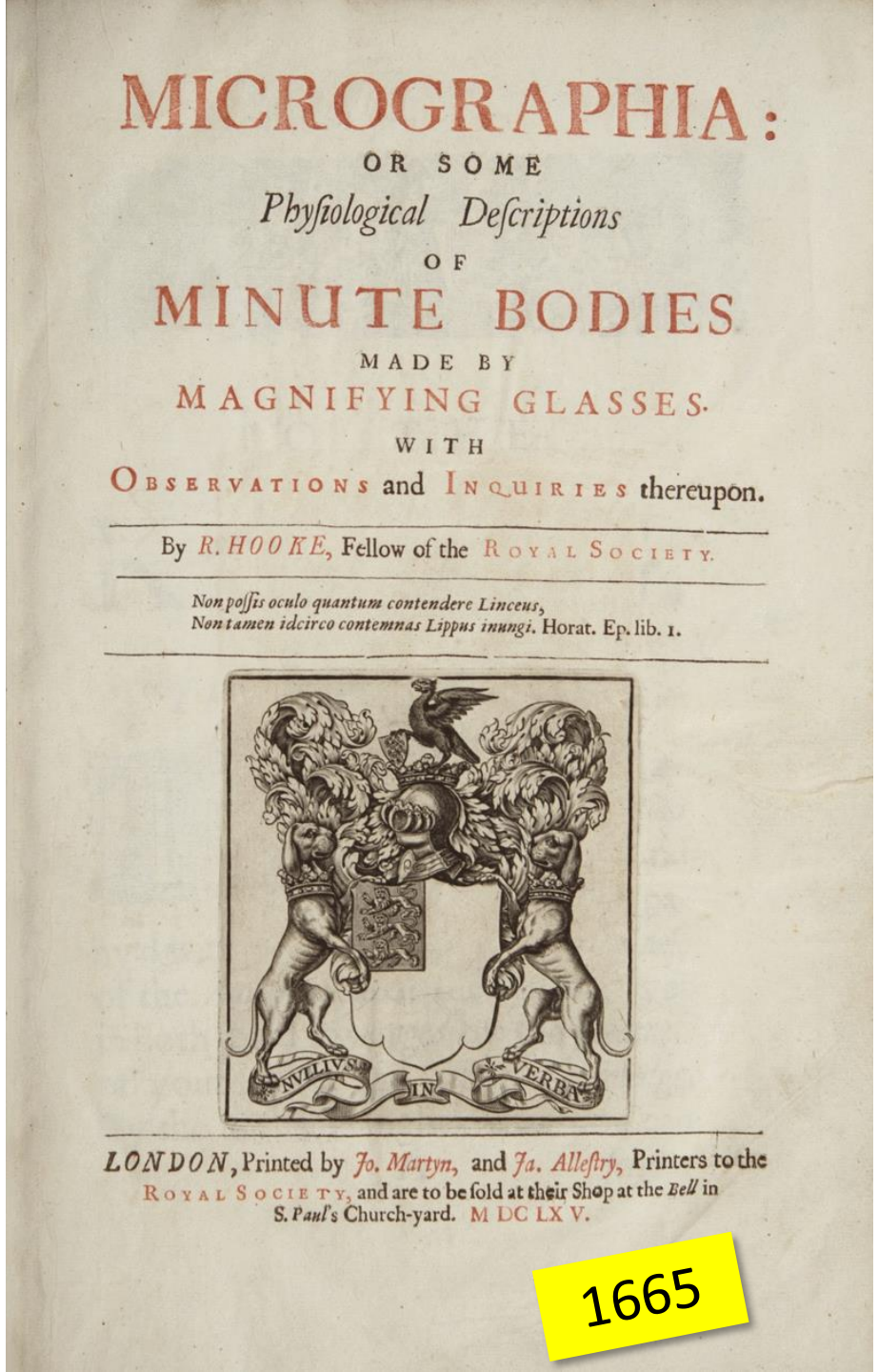
Remember him?

Robert Hooke
1635-1703
London
Polymath
Curator of Experiments at Royal Society



National Museum of Health & Medicine, Bethesda MD

Opticks 3



MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES.
WITH
OBSERVATIONS and INQUIRIES thereupon.

By *R. HOOKE*, Fellow of the ROYAL SOCIETY.

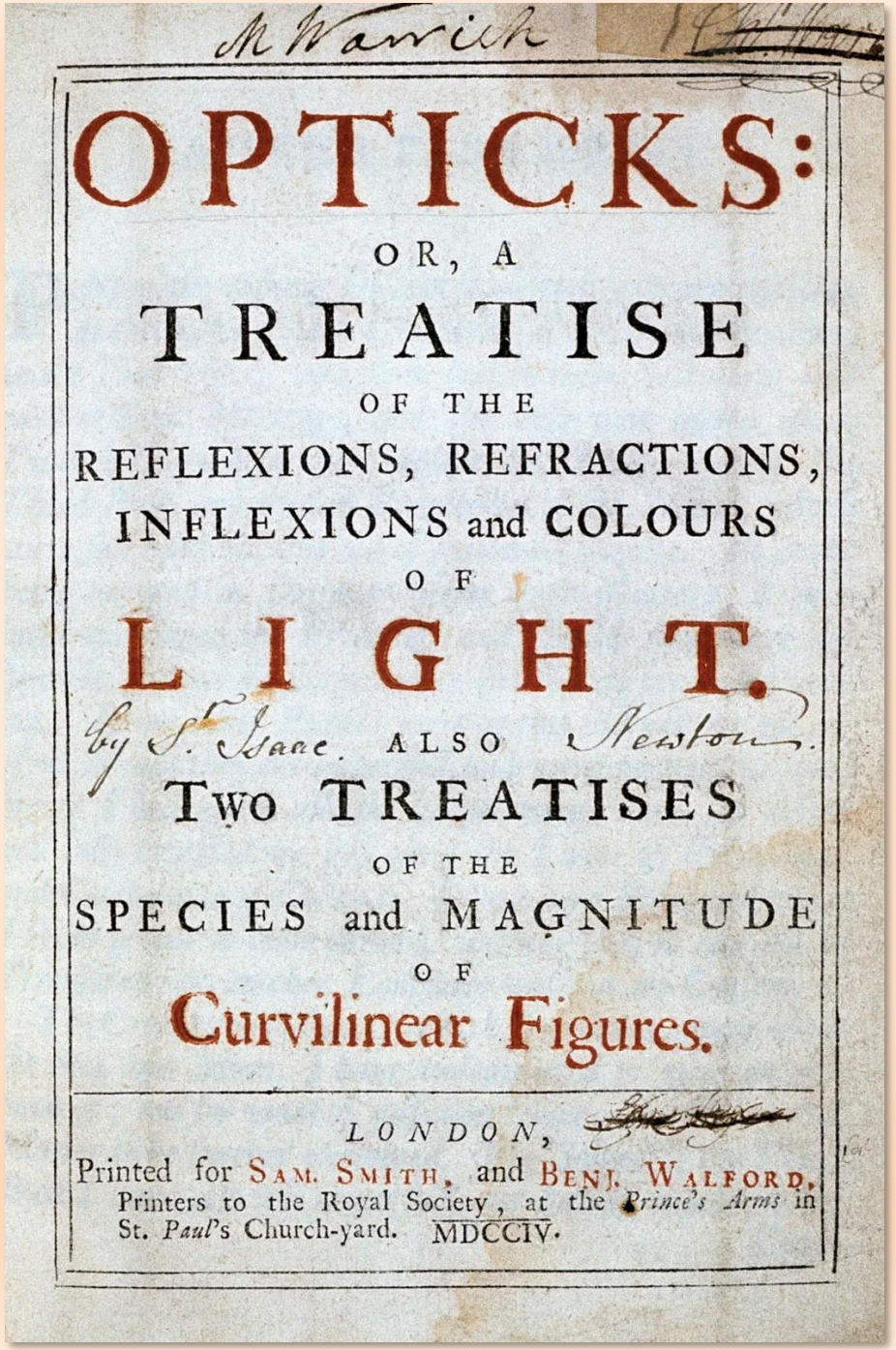
Non possis oculo quantum contendere Linceus,
Non tamen idcirco contemnas Lippus inungi. Horat. Ep. lib. 1.

NVLLIVS IN VERBA

LONDON, Printed by *Jo. Martyn*, and *Ja. Allestry*, Printers to the ROYAL SOCIETY, and are to be sold at their Shop at the *Bell* in S. *Paul's* Church-yard. M DC LX V.

1665

Over 30 years later, after nemesis Hooke dies, Newton publishes *Optiks* in 1704



R Warrick

OPTICKS:

OR, A

TREATISE

OF THE

REFLEXIONS, REFRACTIONS,

INFLEXIONS and COLOURS

OF

LIGHT.

by S^r Isaac. ALSO Newton.

Two TREATISES

OF THE

SPECIES and MAGNITUDE

OF

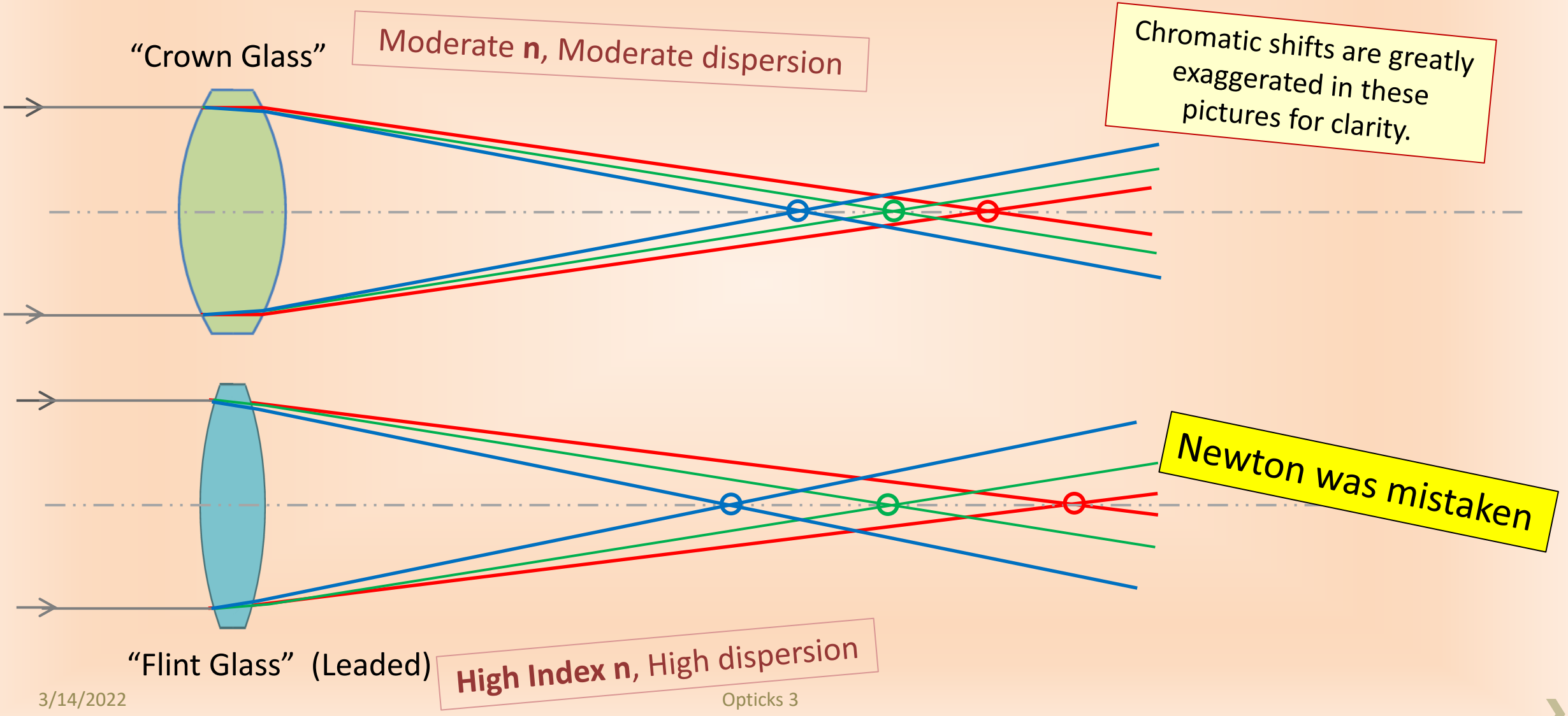
Curvilinear Figures.

LONDON,

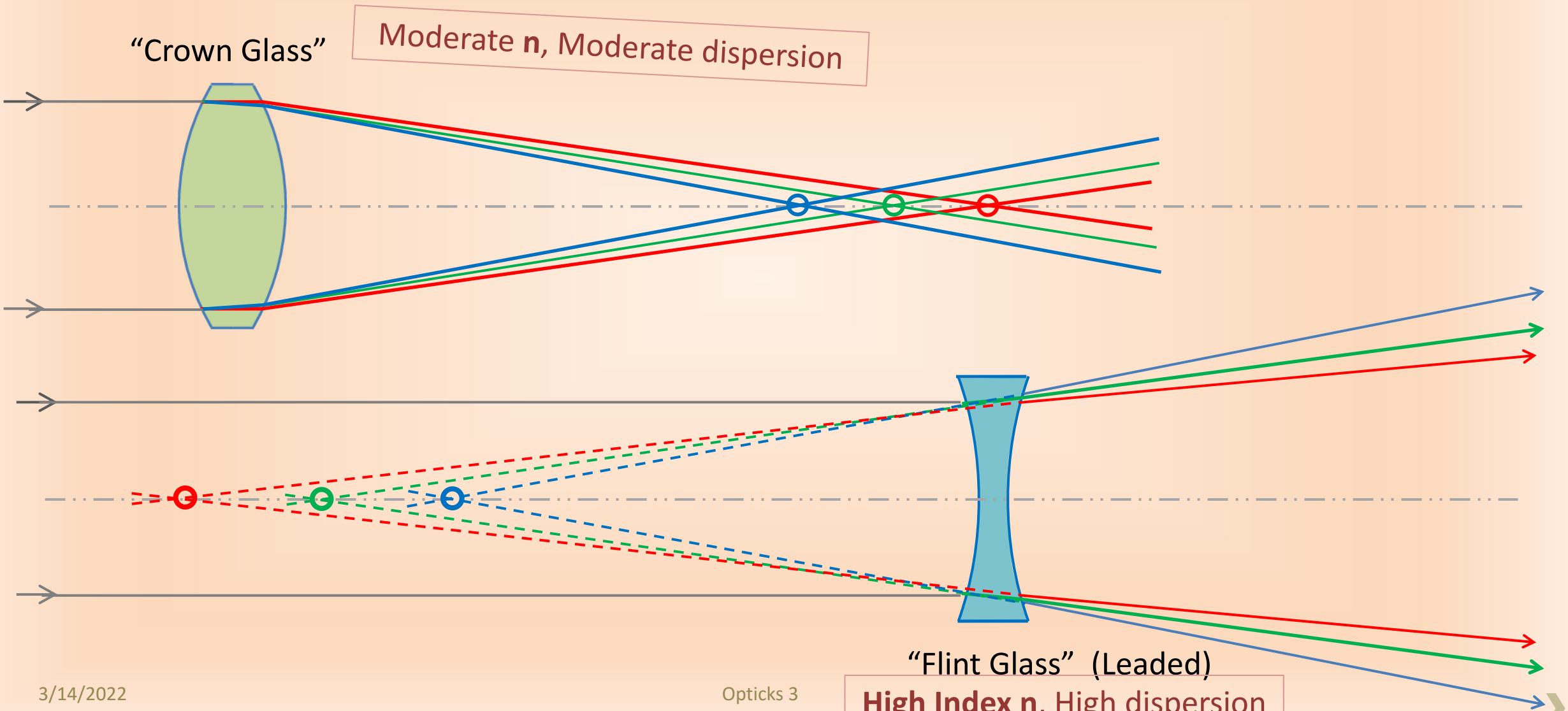
Printed for SAM. SMITH, and BENJ. WALFORD,
Printers to the Royal Society, at the *Prince's Arms* in
St. *Paul's* Church-yard. MDCCIV.

Encyclopedia Britannica

But Newton made a serious mistake …
he thought that all optical media had the *same* dispersion



What if we combined a *Convex* Crown Glass lens with a *Concave* Flint Glass lens?



But what if we made the Concave diverging lens weaker?

We have an Achromatic Lens!

"Crown Glass"

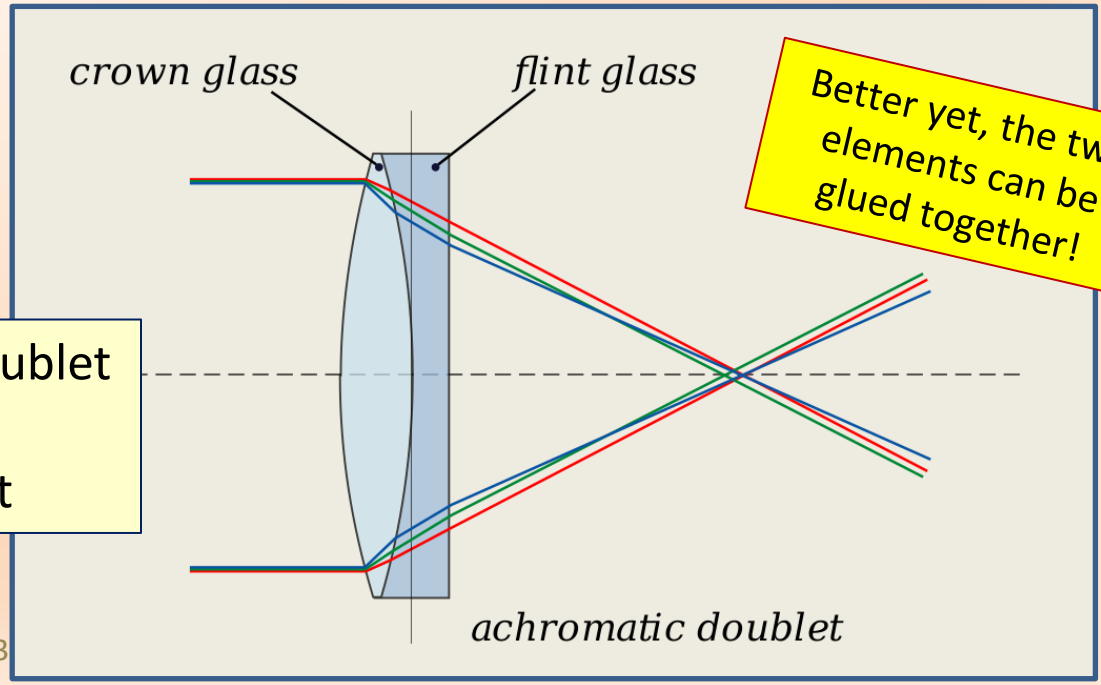
Original focus of Crown lens

Resulting focus of Composite lens

Weak "Flint Glass" Concave Lens

High Index n, High dispersion

Cemented Doublet
or
Achromat

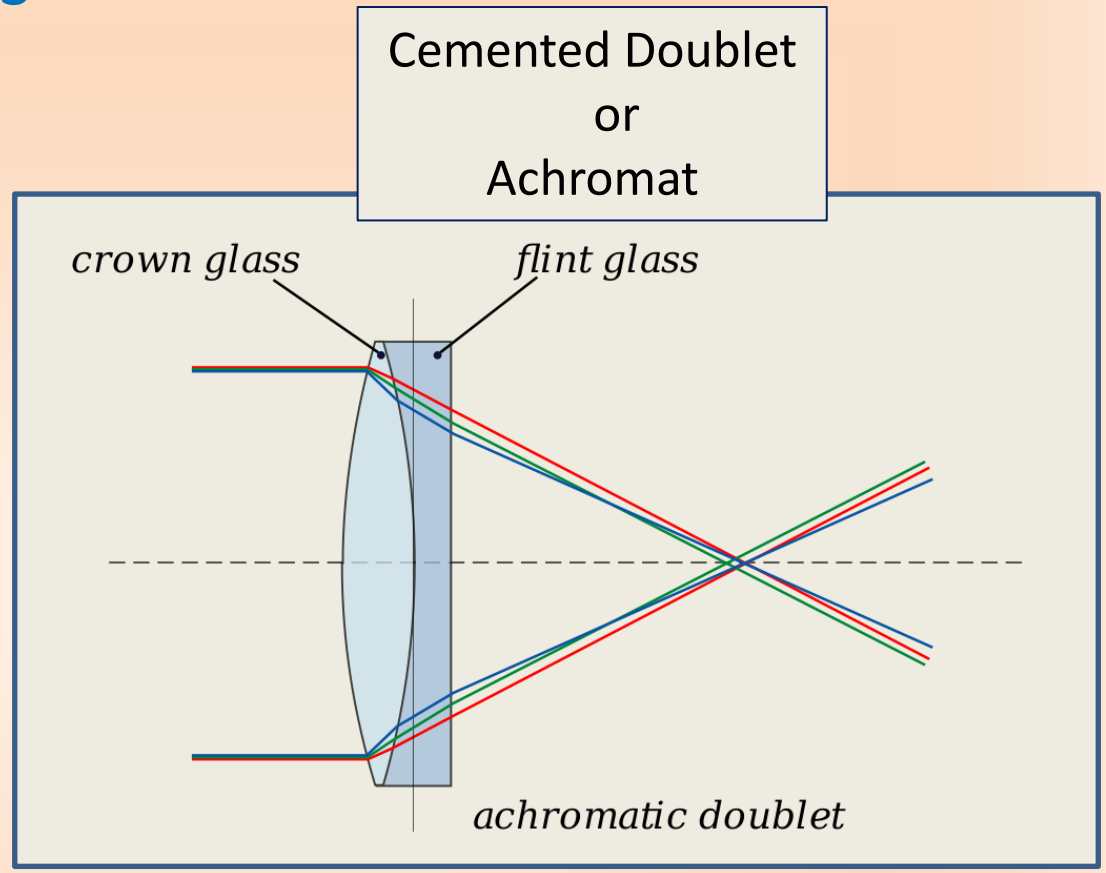


Better yet, the two elements can be glued together!

The Invention of the Achromatic Lens

Chester Moore Hall
English Lawyer and Amateur Optician

- Hall came up with the idea of the Achromat in 1729
- He needed
  - a **Crown** glass (+) lens
  - a **Flint** glass (-) lens
- *Wanted to keep the invention secret.*
- So he ordered each from a different Optician!
- But each Optician sub-contracted the job to the same craftsman, one **George Bass,** who figured it out.



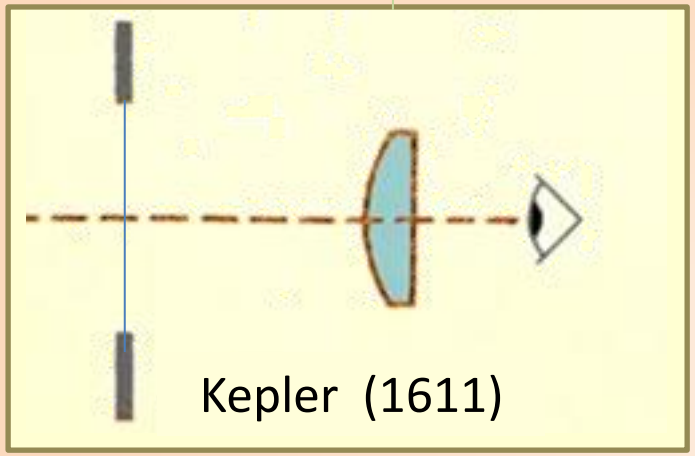
Bass later told an Instrument maker, **John Dolland**, about it.
Dolland patented the Achromat in 1758

What about Spherical Aberration?

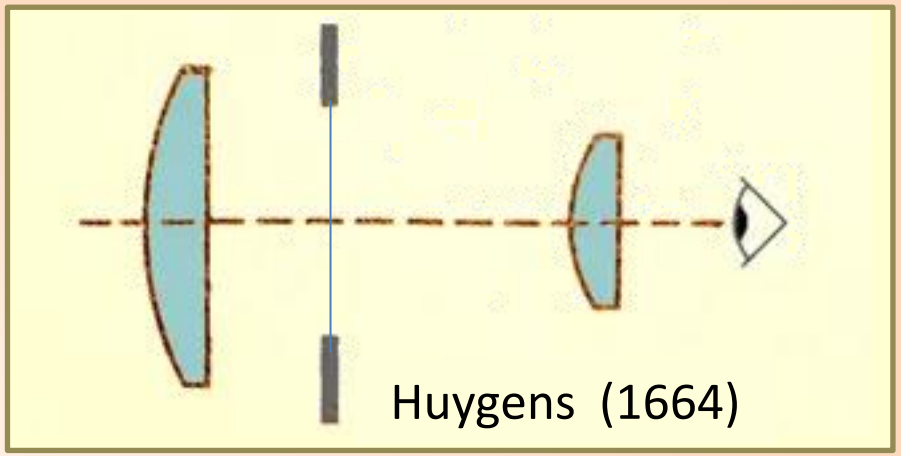
1. Use non-Spherical Surfaces Hard!
2. Use more Spherical surfaces

Eyepieces of the 17th Century

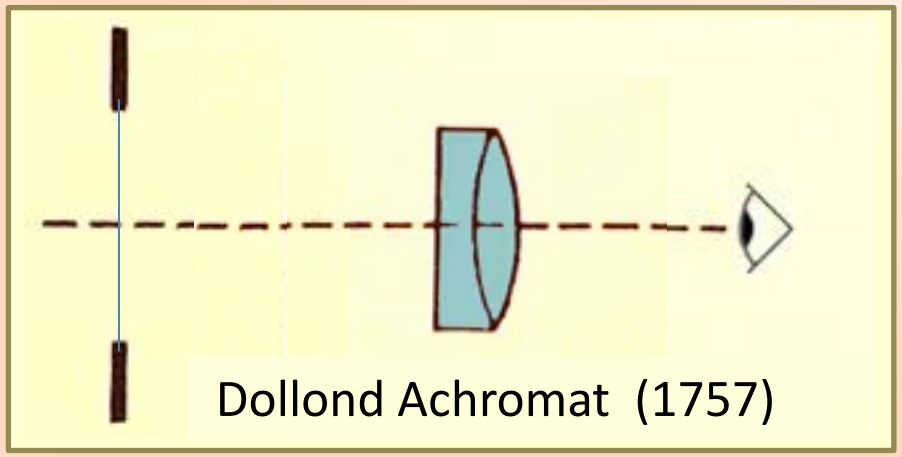
Adding more spherical surfaces could reduce or minimize spherical aberration…



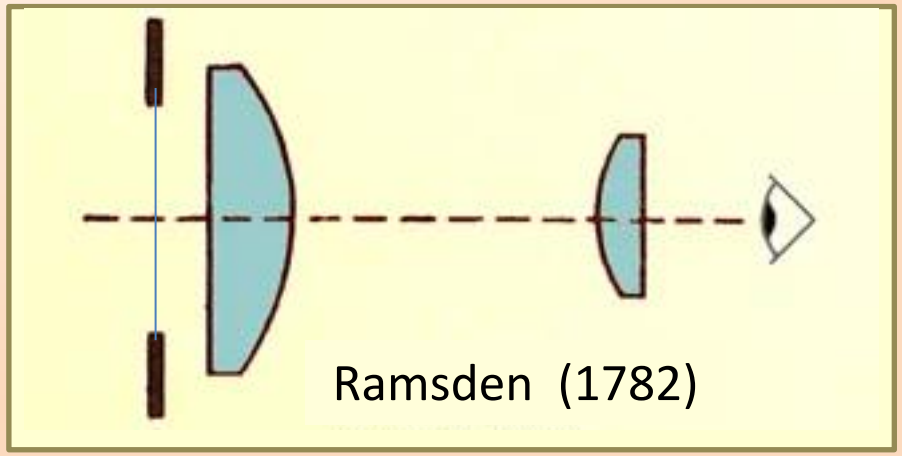
Kepler (1611)



Huygens (1664)

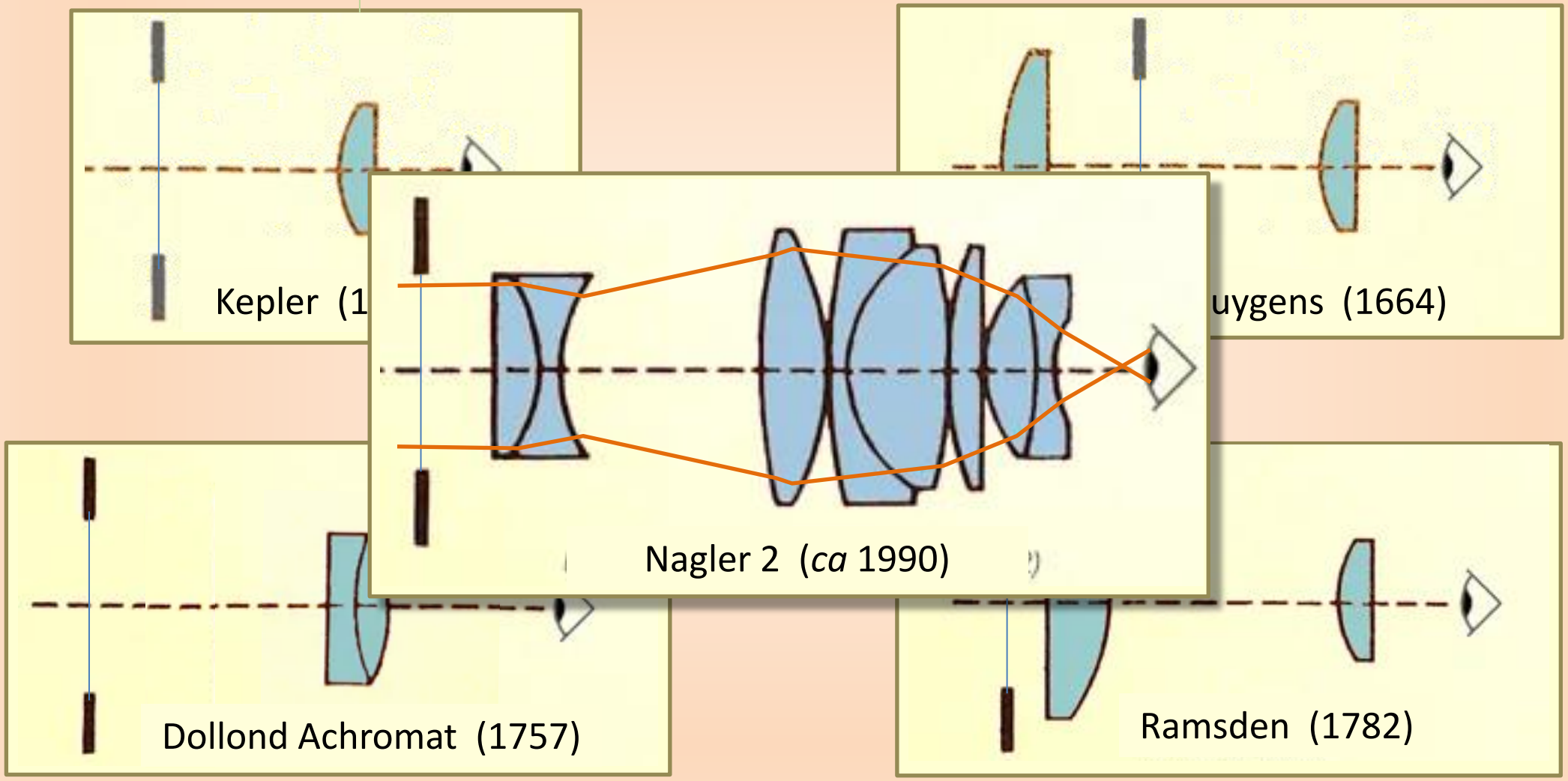


Dollond Achromat (1757)

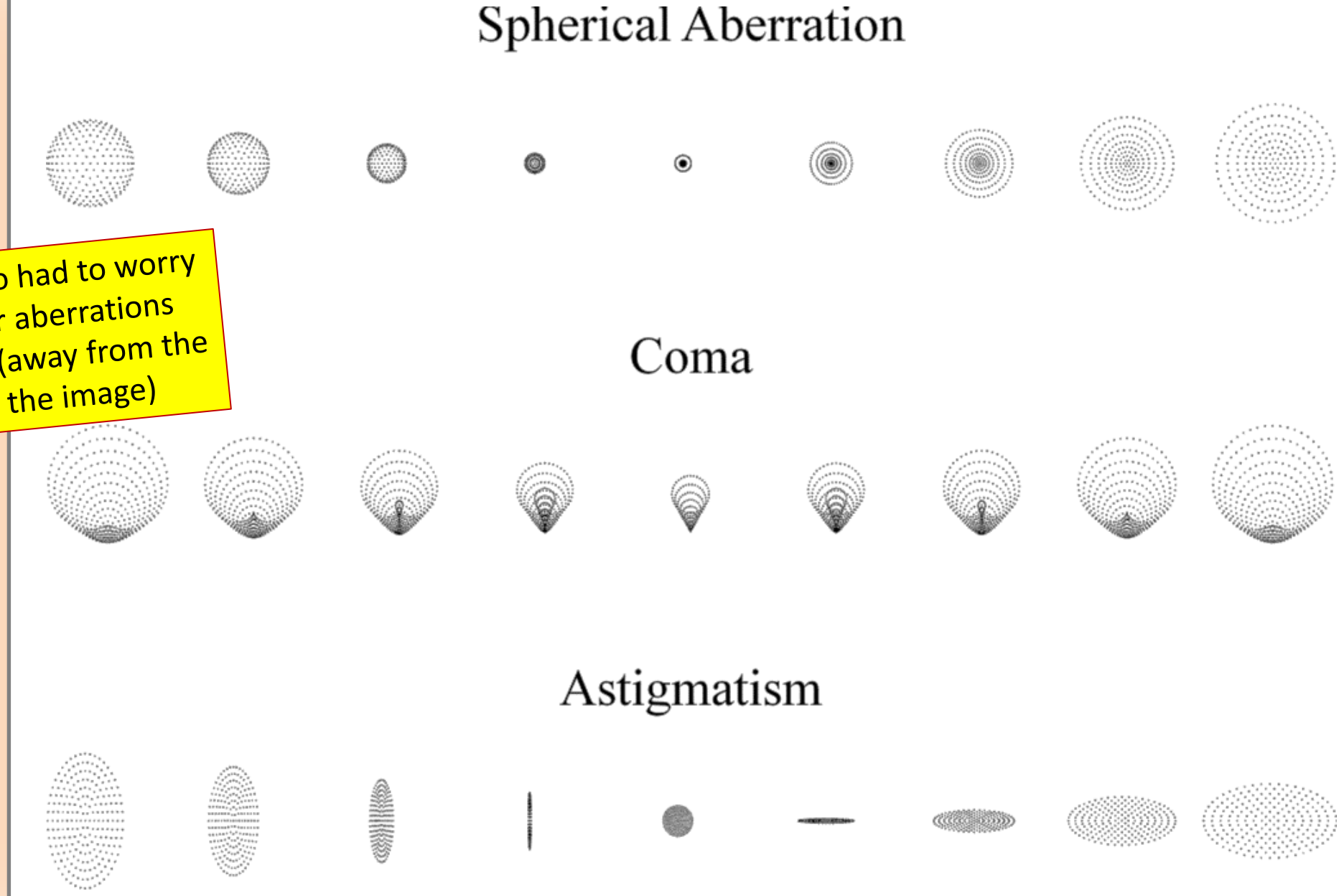


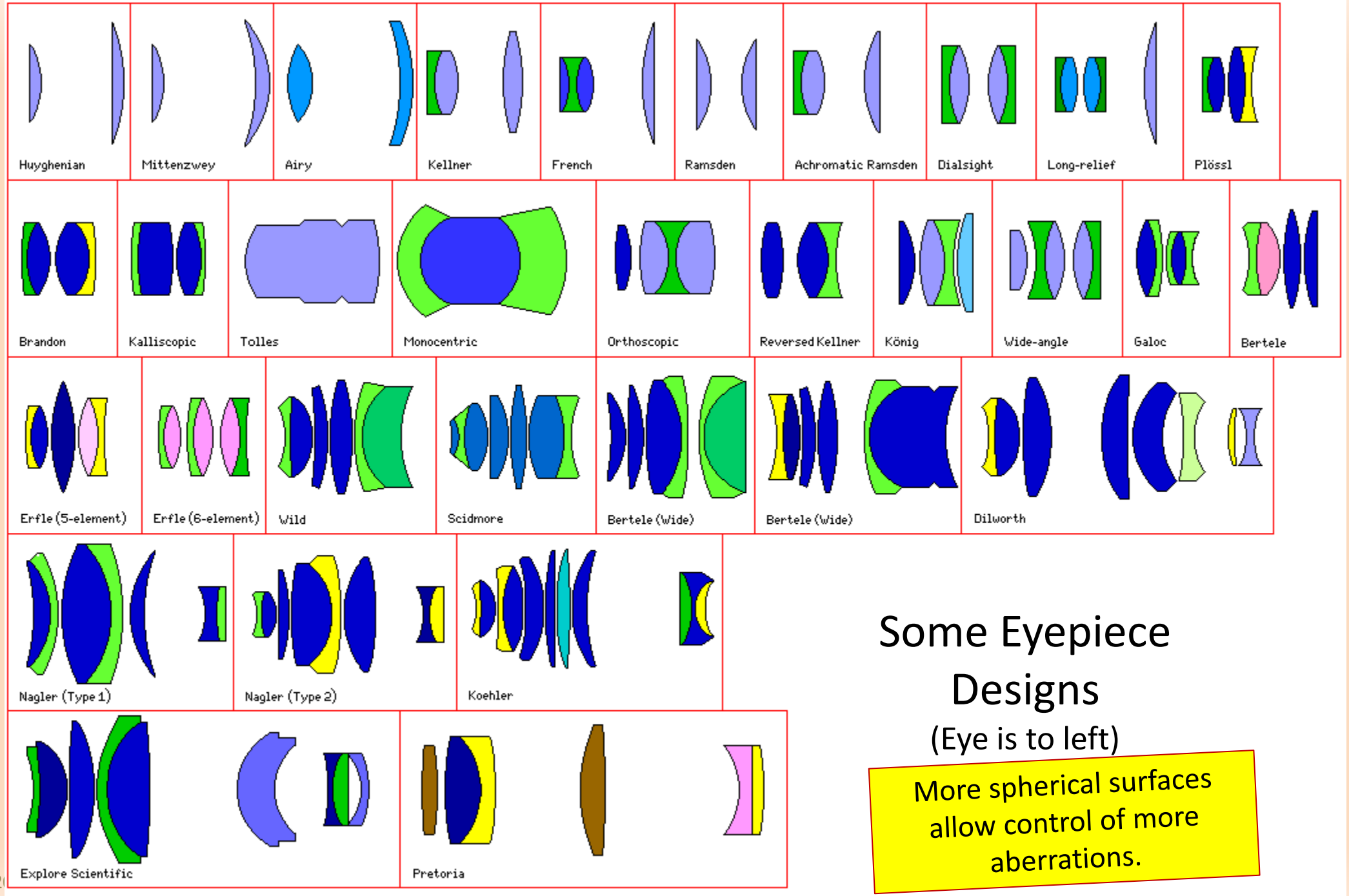
Ramsden (1782)

Eyepieces of the 17th Century



Designers also had to worry about other aberrations seen off-axis (away from the center of the image)

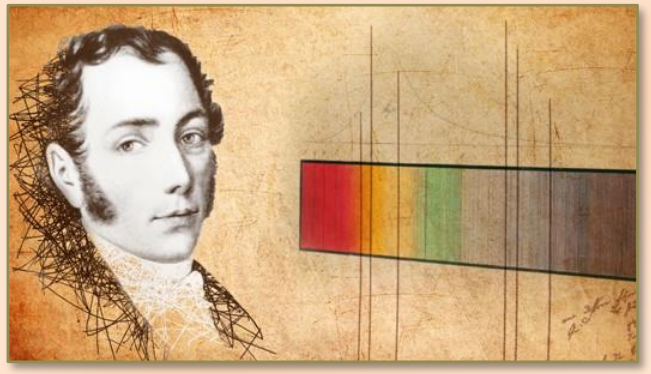




Some Eyepiece Designs

(Eye is to left)

More spherical surfaces allow control of more aberrations.

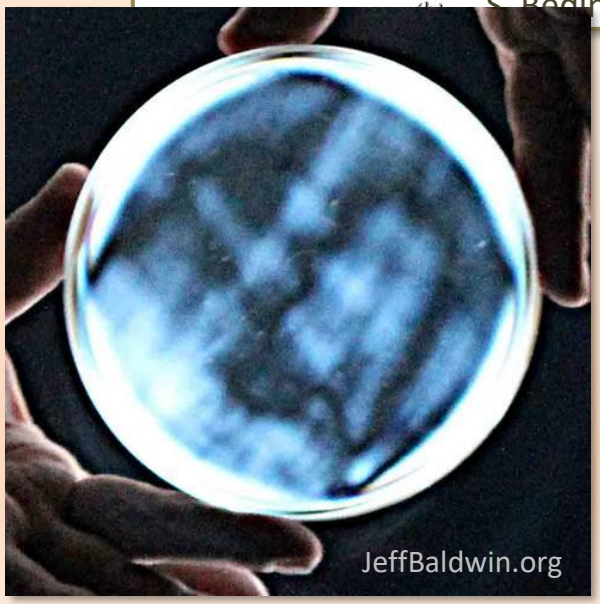


Joseph von Fraunhofer
1787-1826 (age 39)
Optical Instrument Manufacturer & Scientist

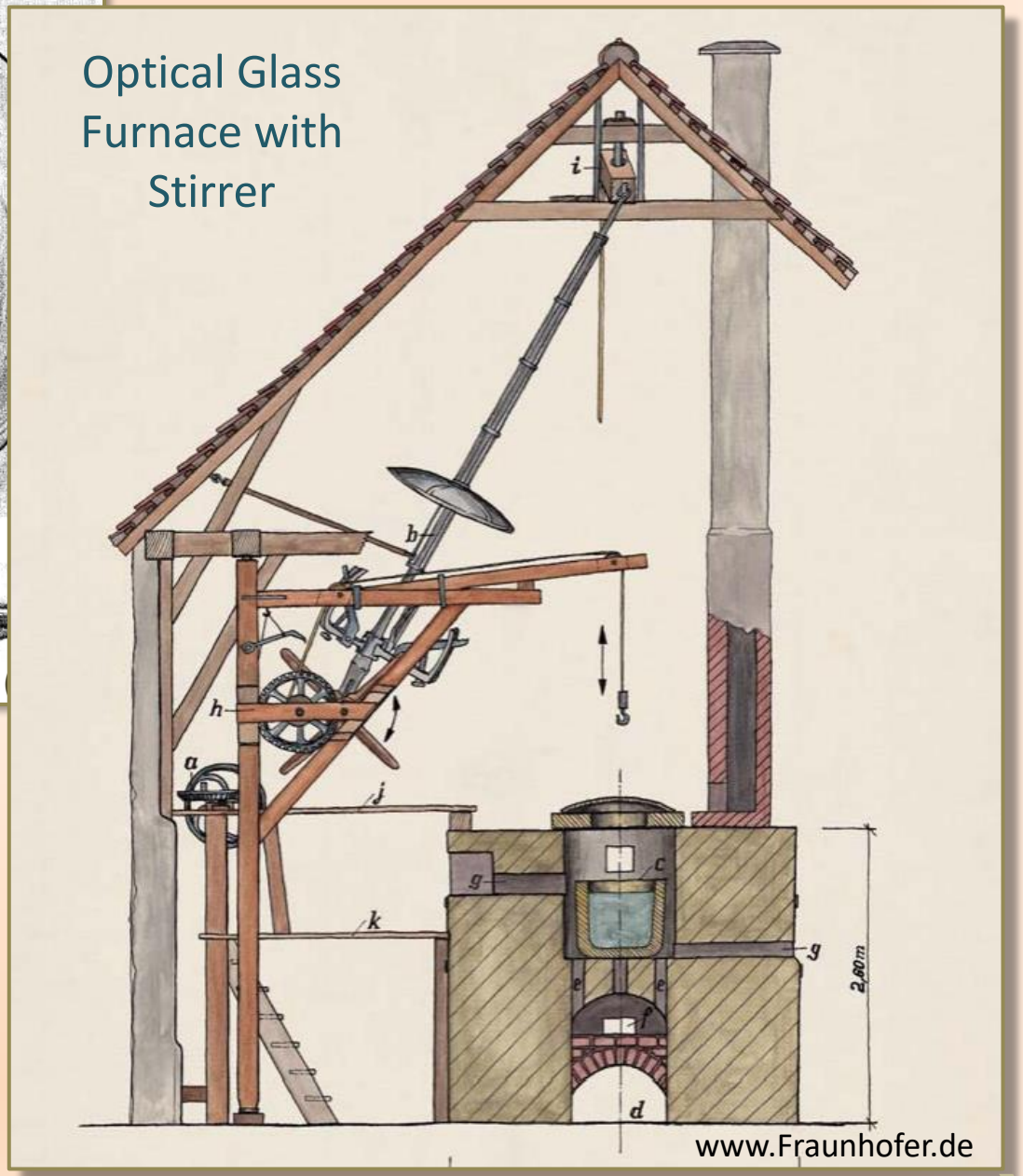
Accidental

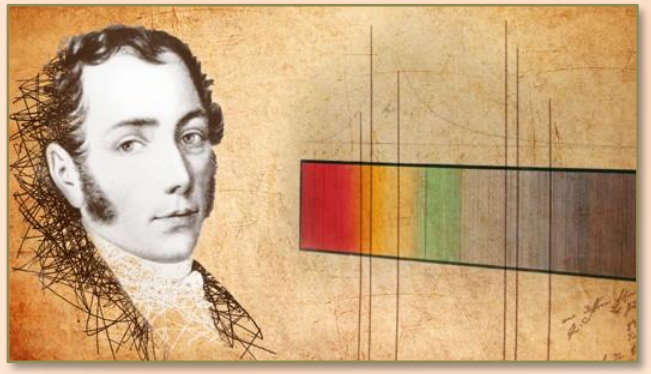
Vertically integrated manufacturer:

- Glass making
- Lens grinding
- Optical design
- Instrument design



Optical Glass Furnace with Stirrer





Joseph von Fraunhofer
1787-1826 (age 39)
Optical Instrument Manufacturer
*& **Scientist***

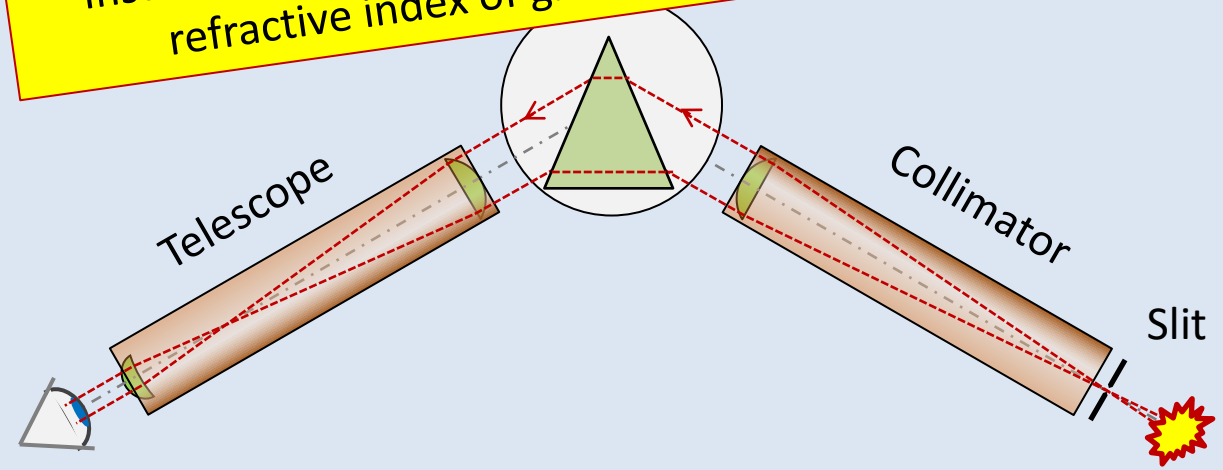
Vertically integrated manufacturer:

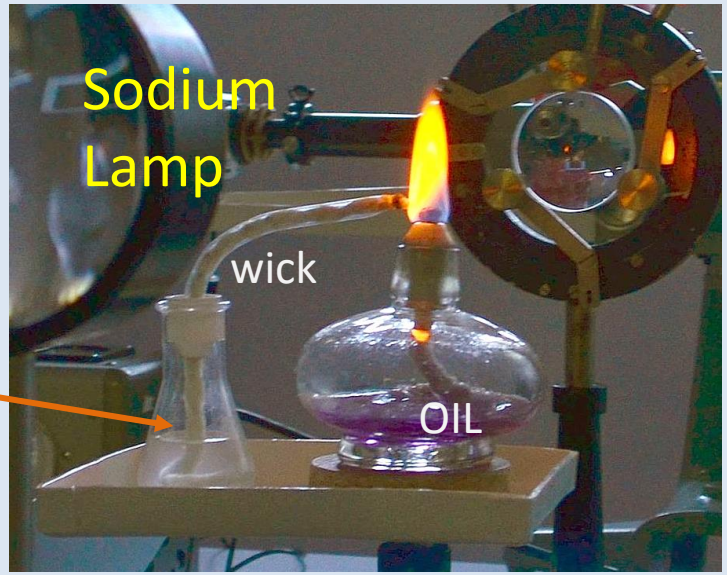
- Glass making
- Lens grinding
- Optical design
- Instrument design

Need *accurate* Refractive Index measurements for glass

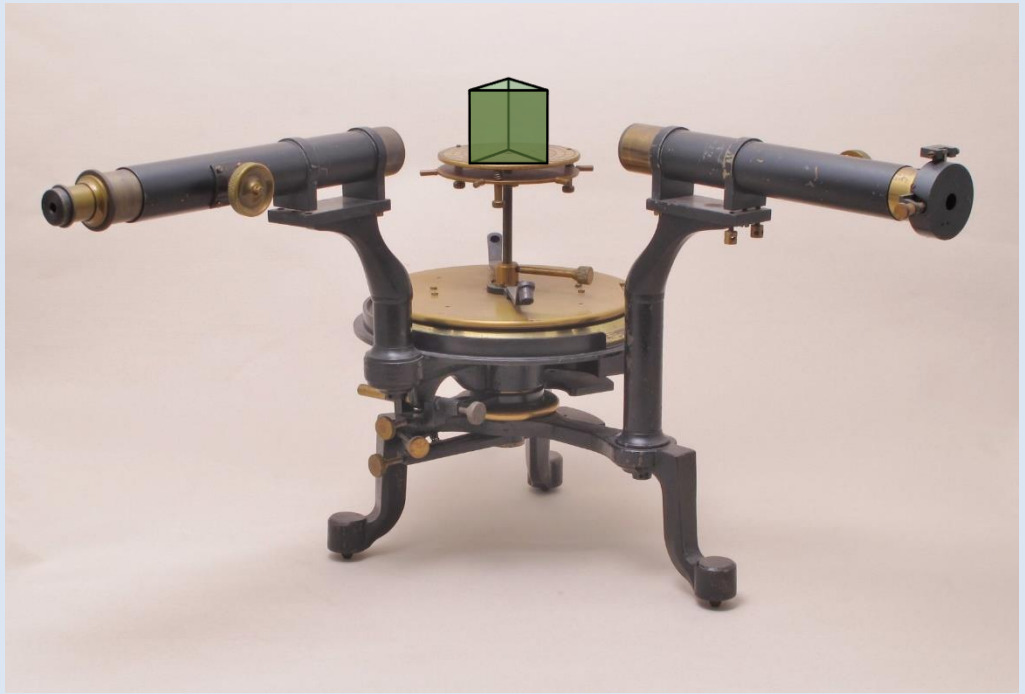
The Prism Spectroscope

Instrument that can be used to measure refractive index of glass in prism



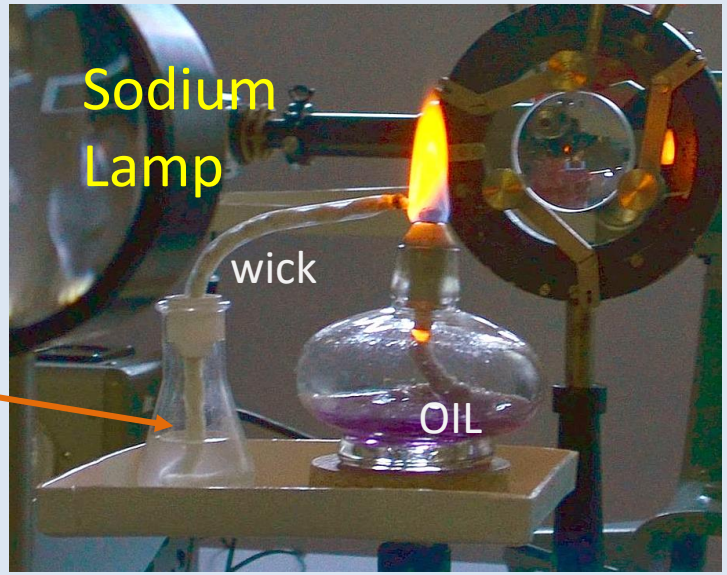


Salt water

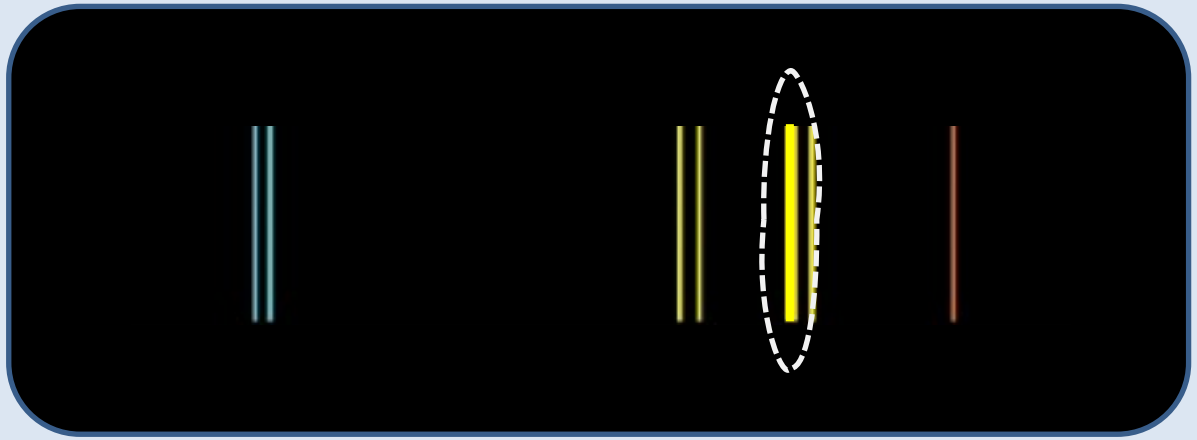


One light source Fraunhofer used to measure index was a Sodium lamp…

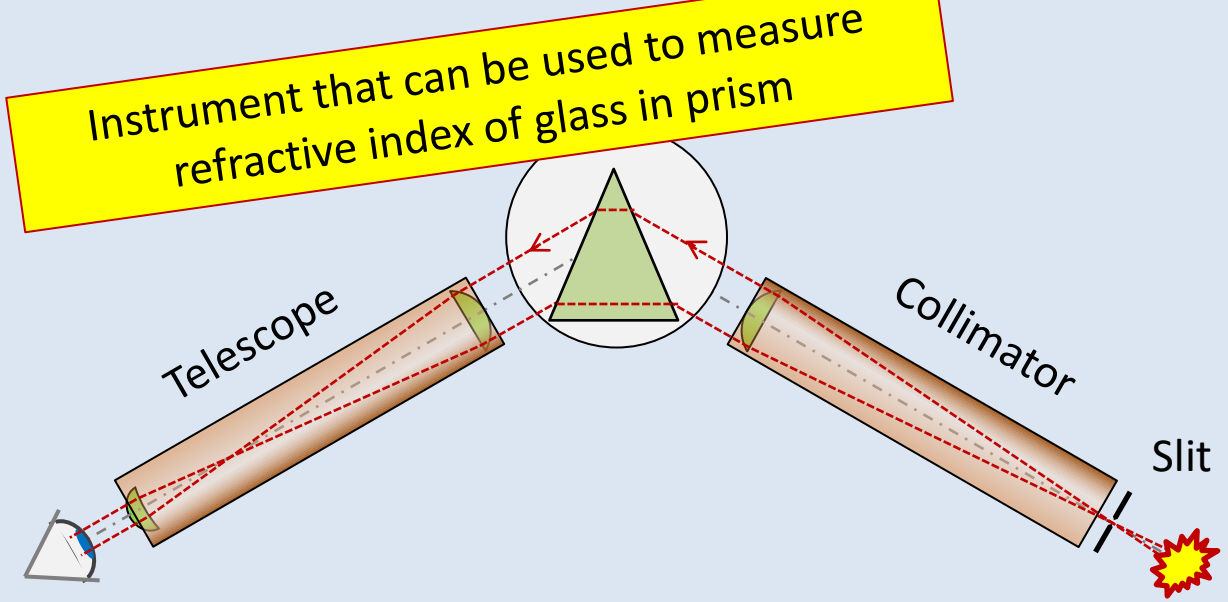
The Prism Spectroscope

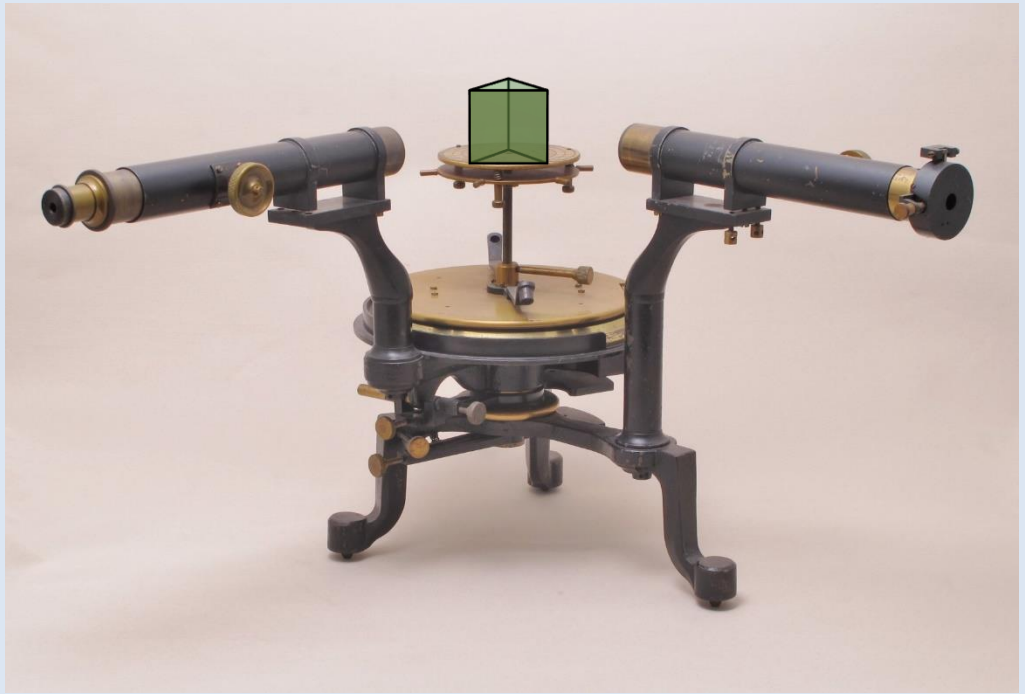


Salt water

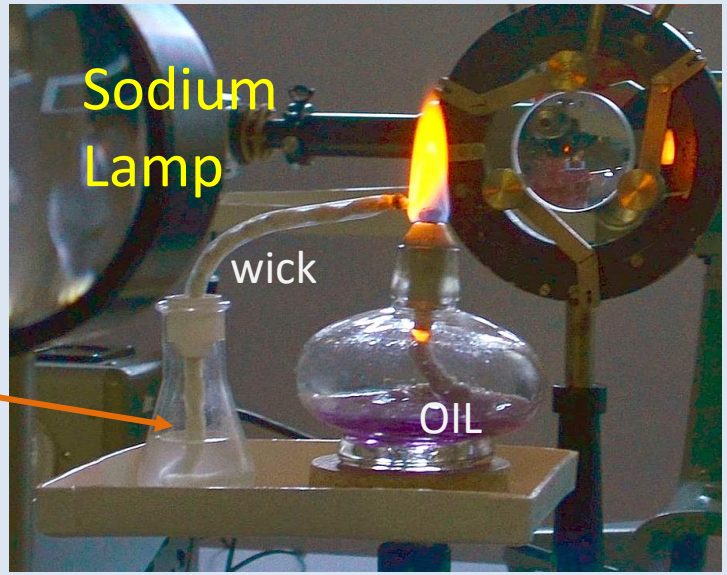


Instrument that can be used to measure refractive index of glass in prism

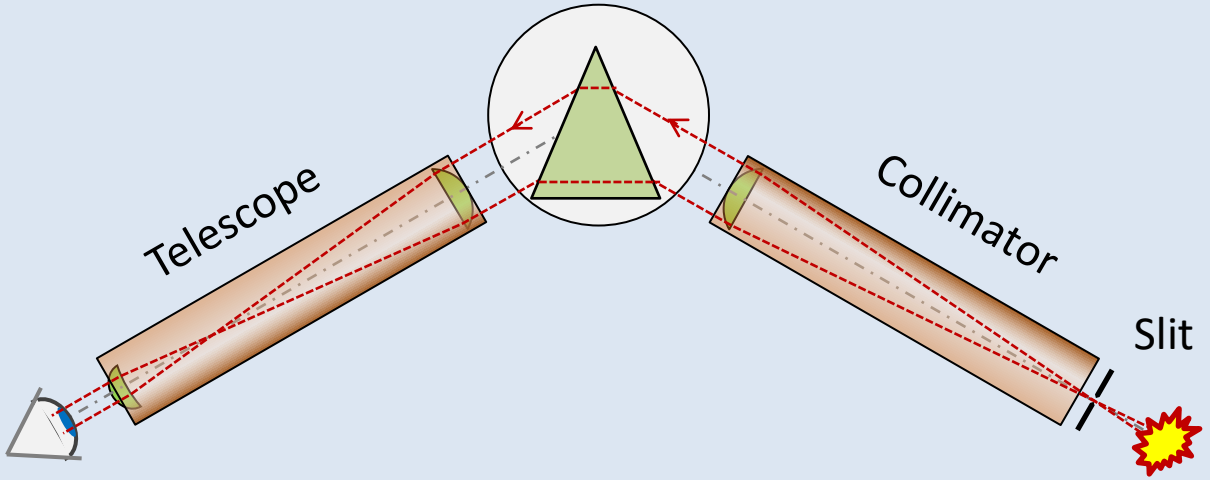


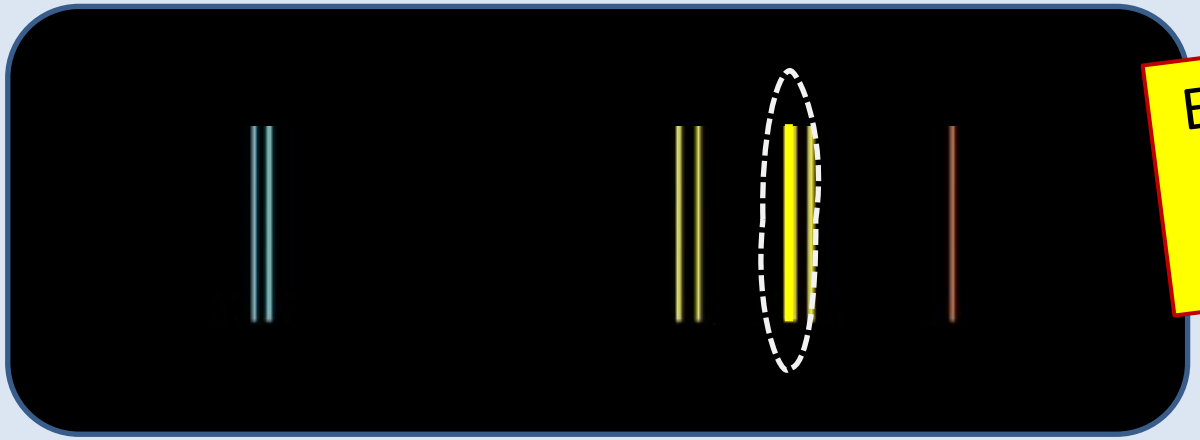


The Prism Spectroscope

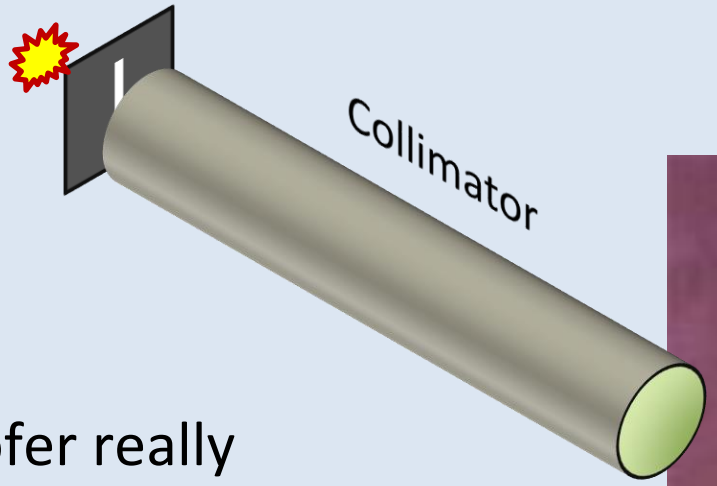


Salt water





Ever since, glass Refractive Index has been Measured Using the Yellow Sodium Line



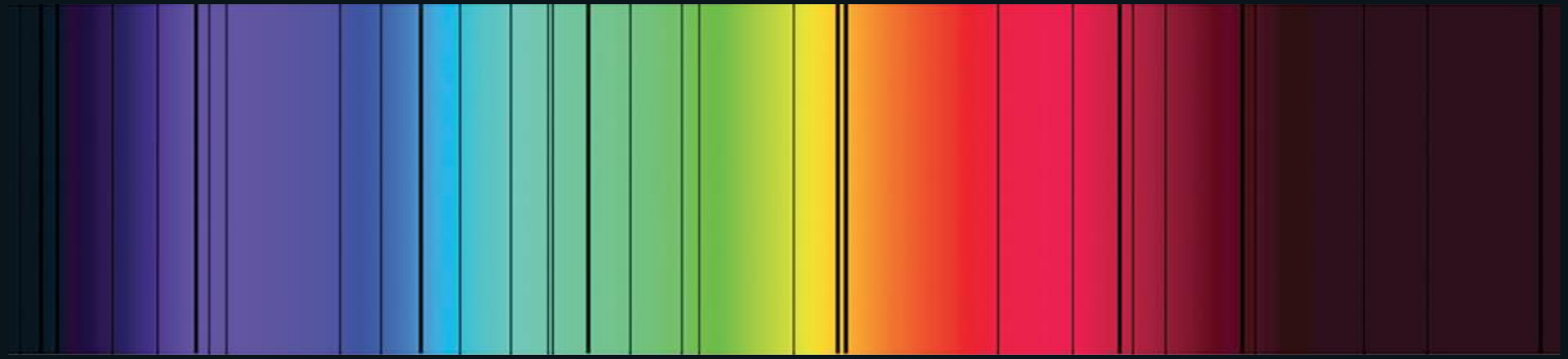
Did Fraunhofer really invent the Spectroscope?

Artistic Imagining of Fraunhofer demonstrating his Spectroscope

…without a Collimator or Source!

Fraunhofer.de

Then in 1814 Fraunhofer directed Sunlight into his Spectroscope



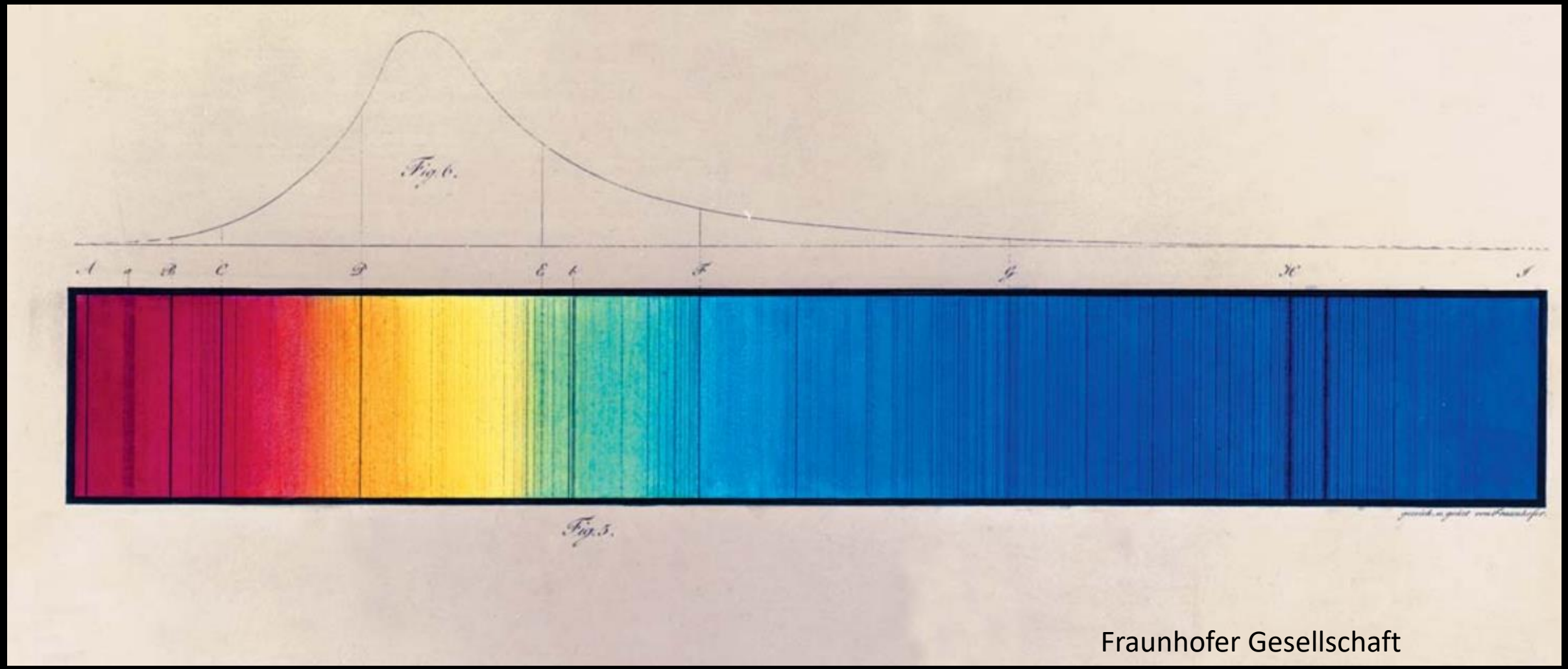
These dark lines are now called ‘Fraunhofer Lines’

There are thousands of them

… although Wollaston first saw some of them in 1802

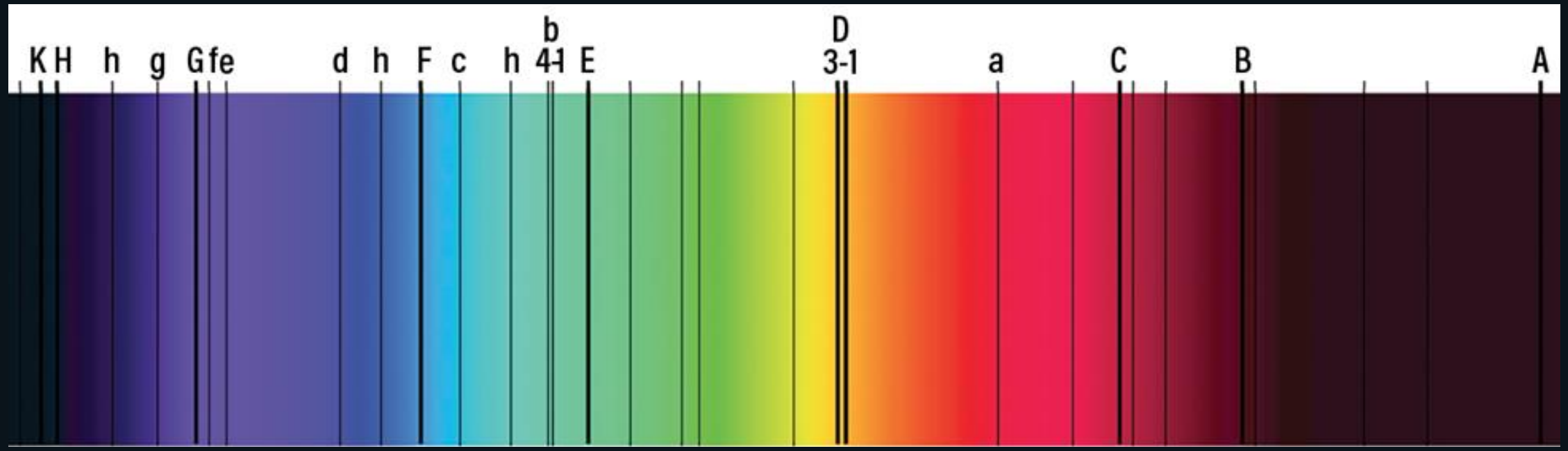
There was no photography –

so Fraunhofer drew and colored the spectrum he saw by hand

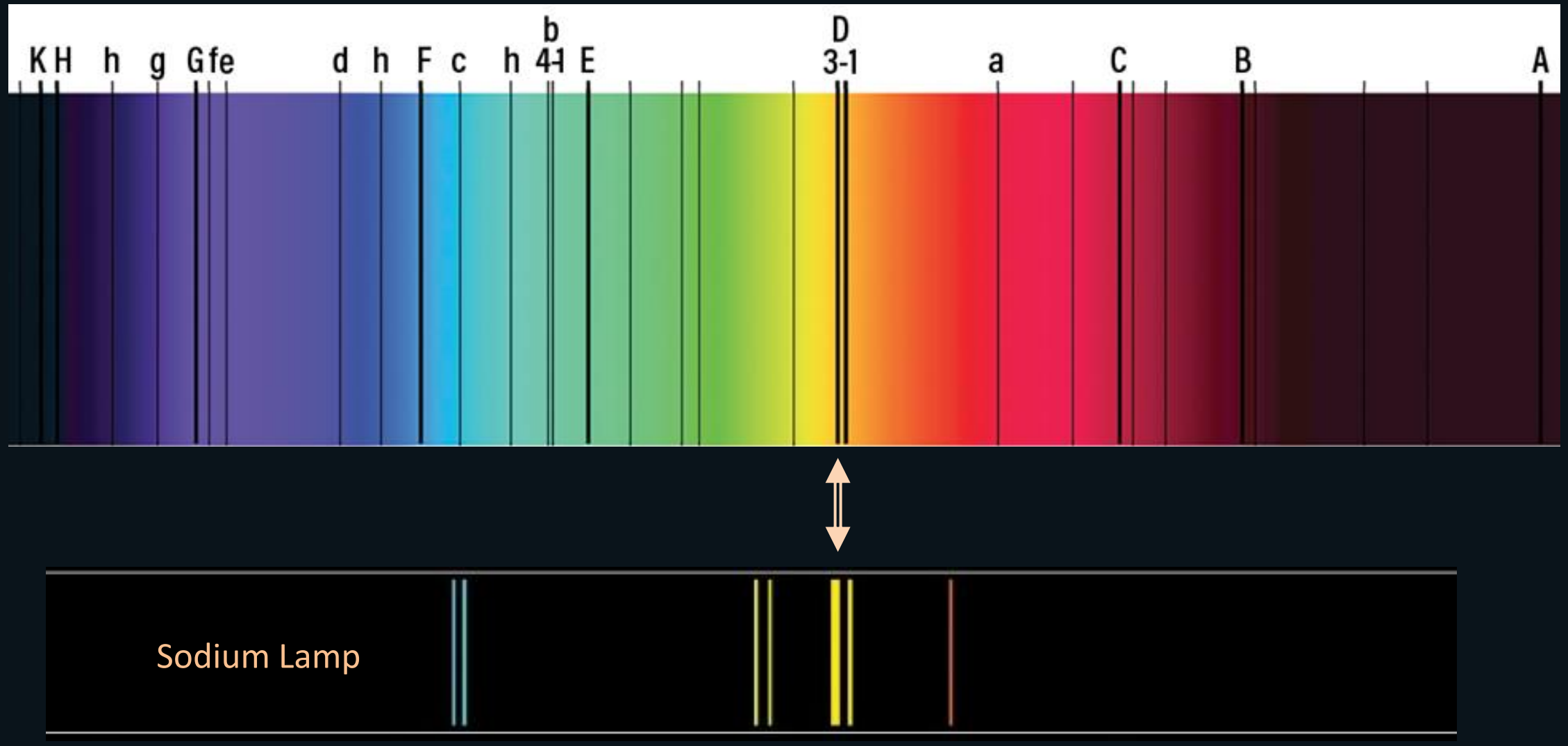


Fraunhofer Gesellschaft

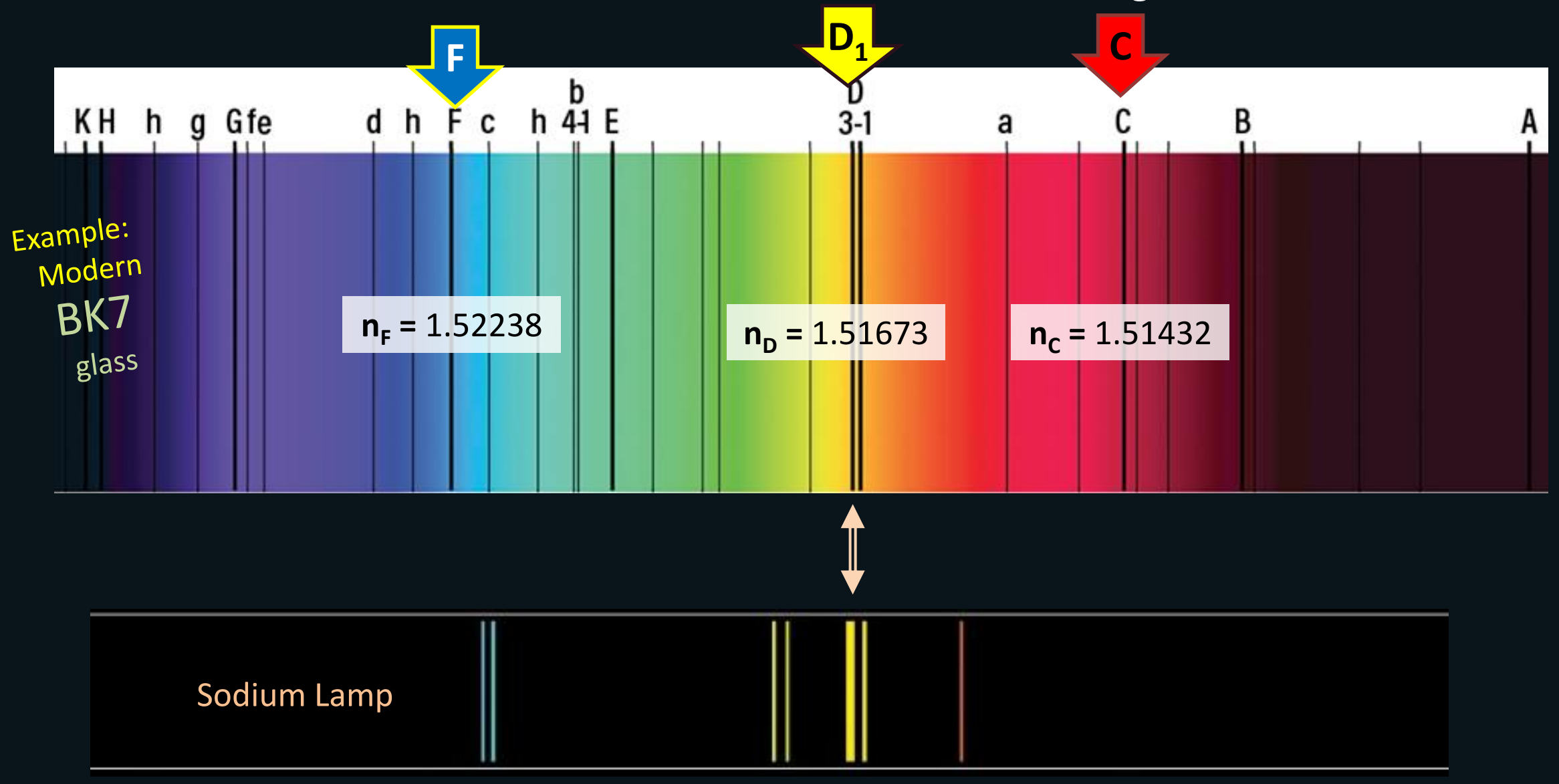
He tabulated over 500 of the dark lines, and gave names to many of them



Then he compared the Solar spectrum to the Sodium Lamp Spectrum



Then he used several lines to measure Refractive Index of his glasses



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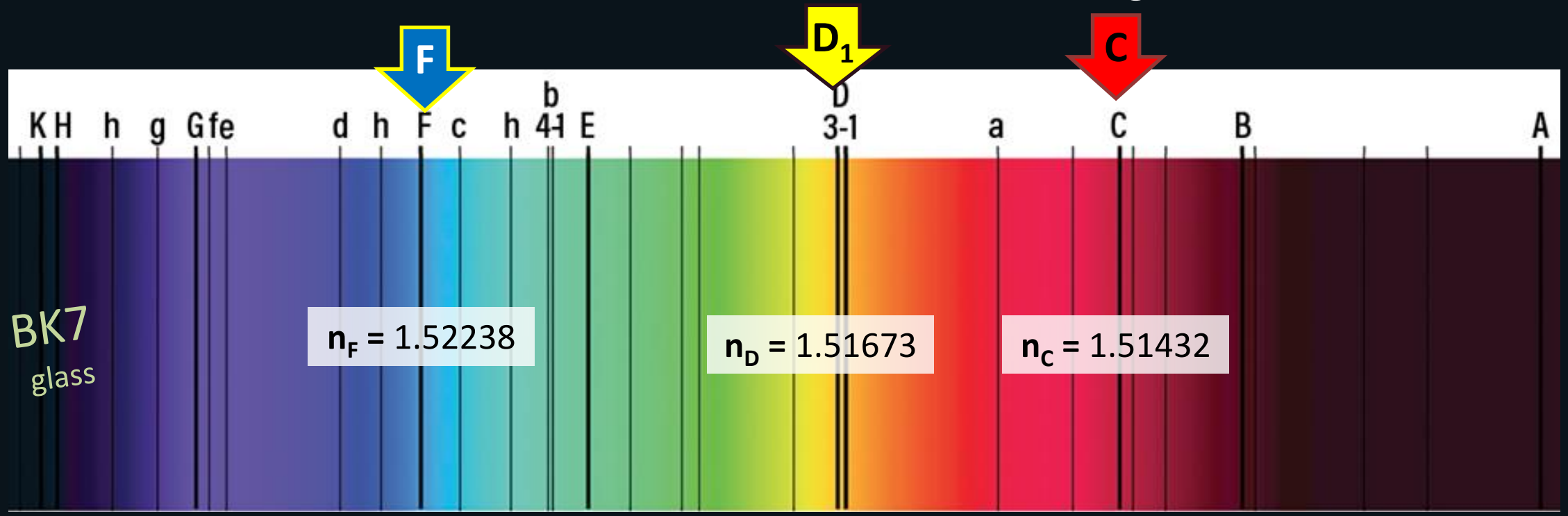
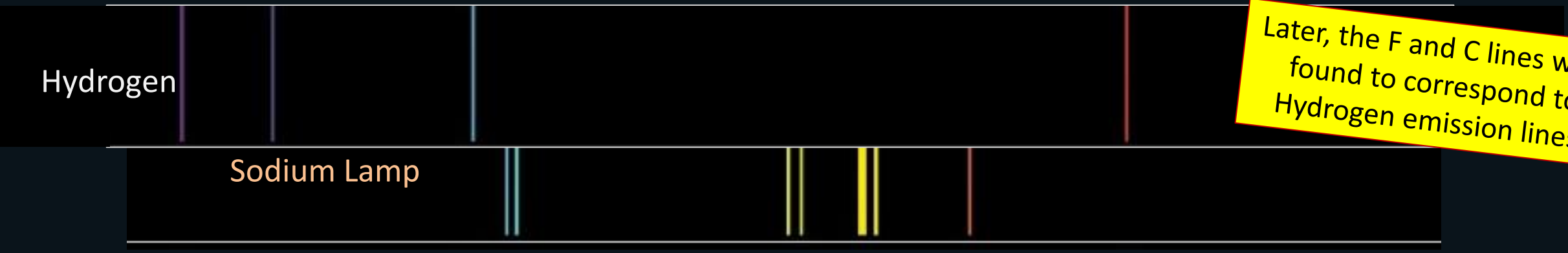




Later, the F and C lines were found to correspond to Hydrogen emission lines.

Fraunhofer's 1824 "Dorpat Refractor"

9.5 Inch (24 cm) Objective
4 m Focal Length

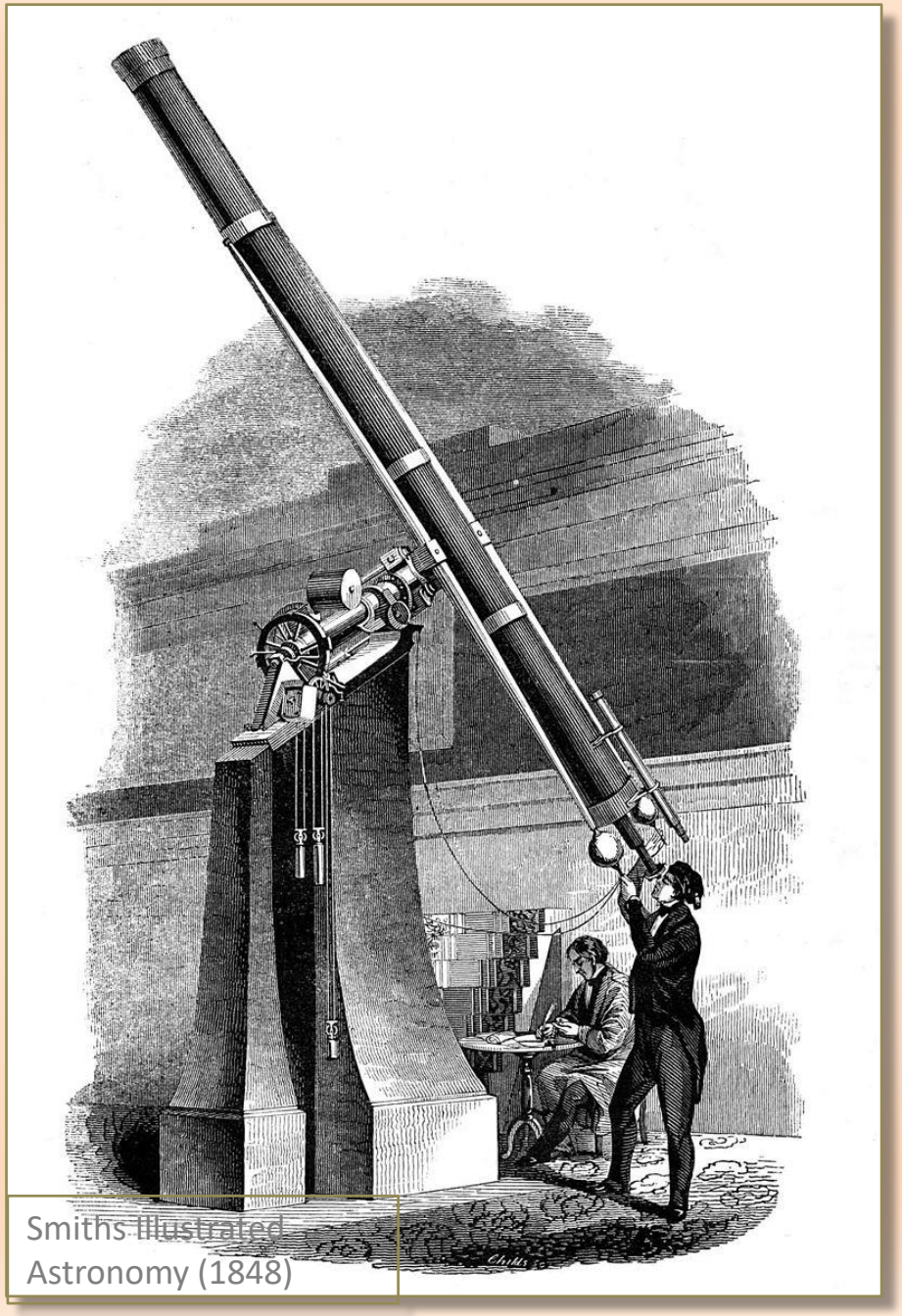
Used to discover Neptune

now at University of Tartu
Estonia

All these developments allowed Fraunhofer's Institute to build superior telescopes, of larger and large sizes.

“Merz and Mahler”
11 Inch Refractor
1848

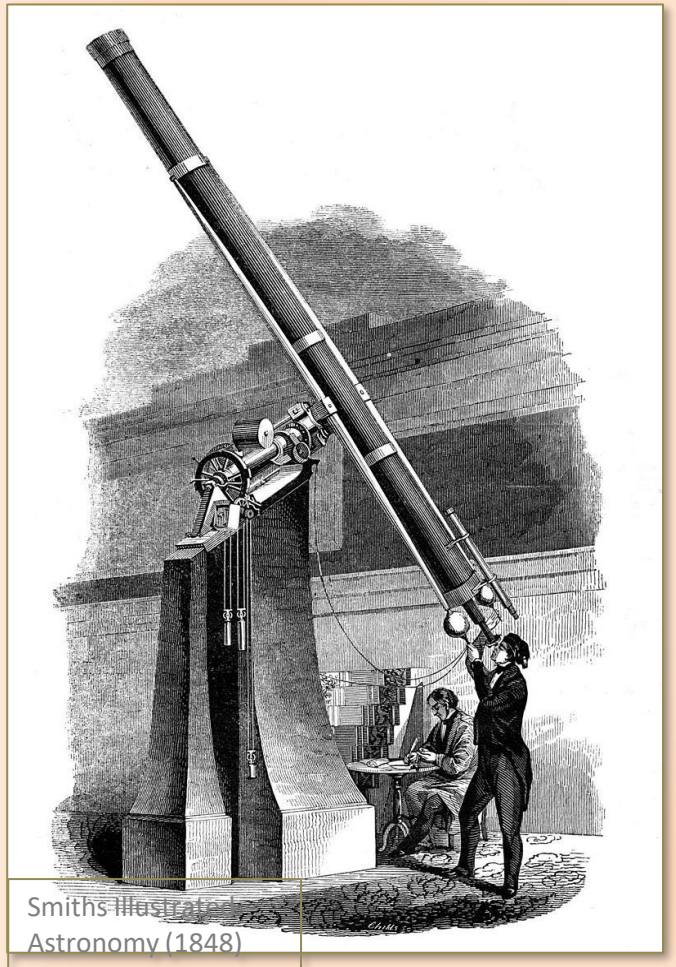
Cincinnati Observatory



Smiths Illustrated Astronomy (1848)

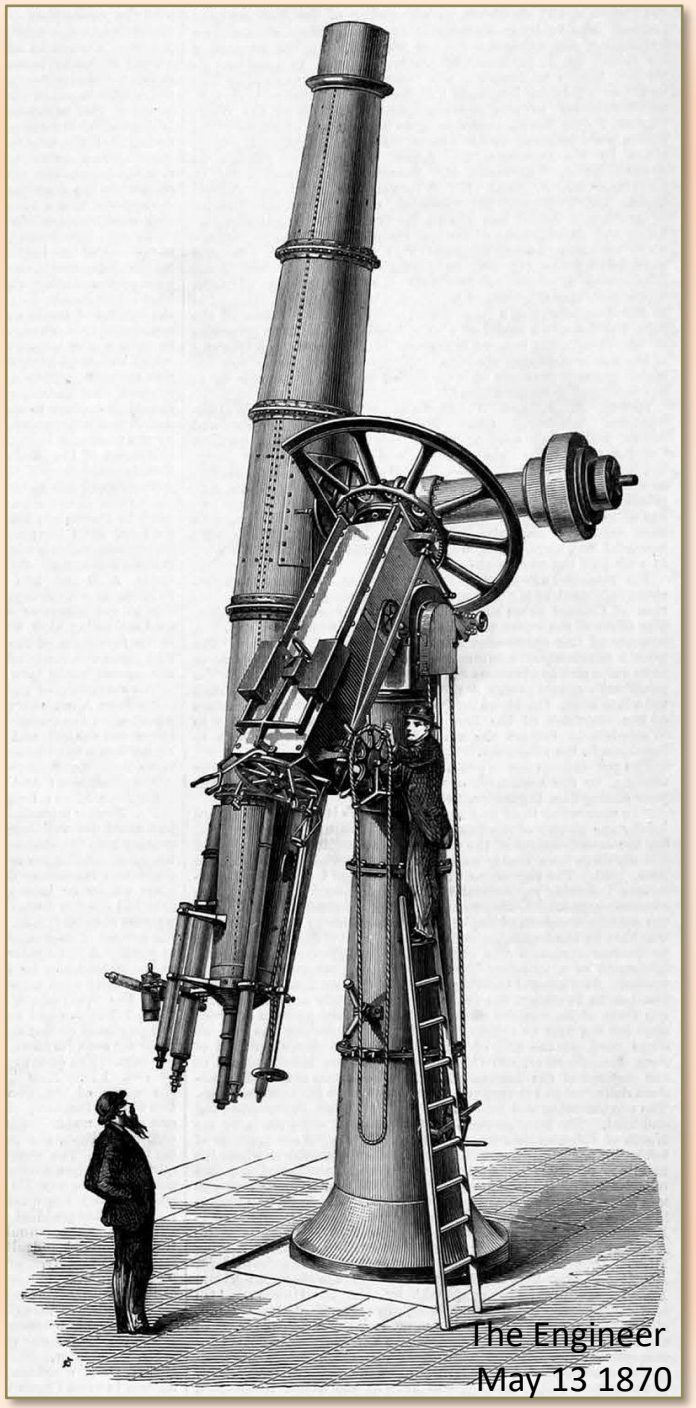
The race to bigger telescopes was on.

"Merz and Mahler"
11 Inch Refractor
1848
Cincinnati Observatory



Smiths Illustrated Astronomy (1848)

3/14/2022



The Engineer
May 13 1870

Newall Refractor
25 Inch
Built 1862-1870

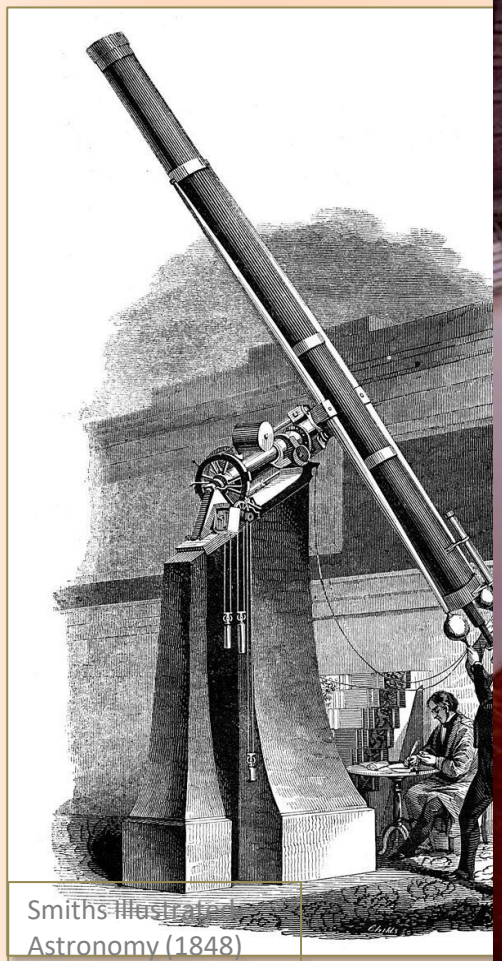
Installed in
Gateshead, England

Donated to Cambridge University ~1885

Used until 1930's

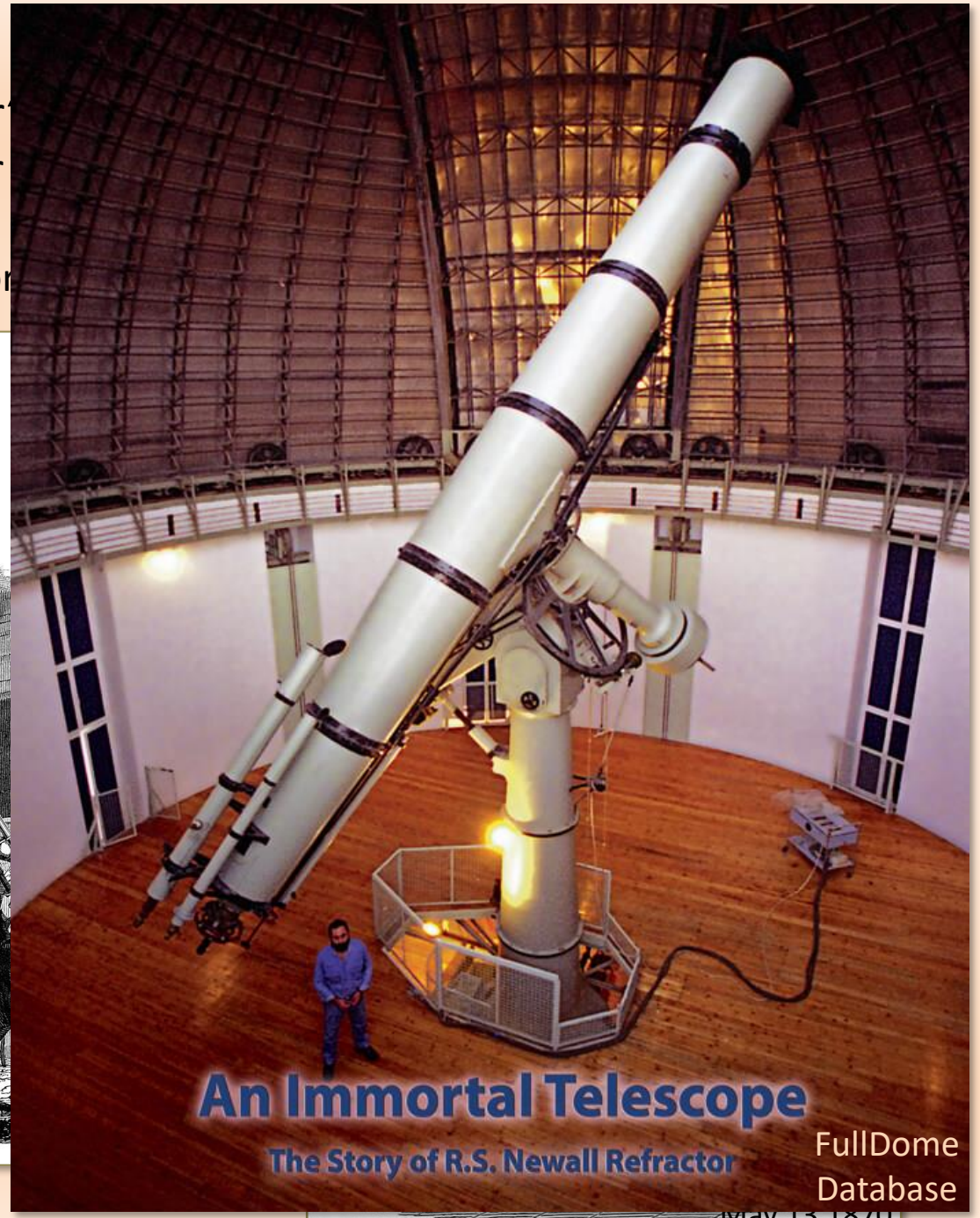
Now in Athens

"Merz and Mahler
11 Inch Refractor
1848
Cincinnati Observator



Smiths Illustrated Astronomy (1848)

3/14/2022



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25 Inch
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Installed in
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Donated to Cambridge University ~1885

Used until 1930's

Now in Athens

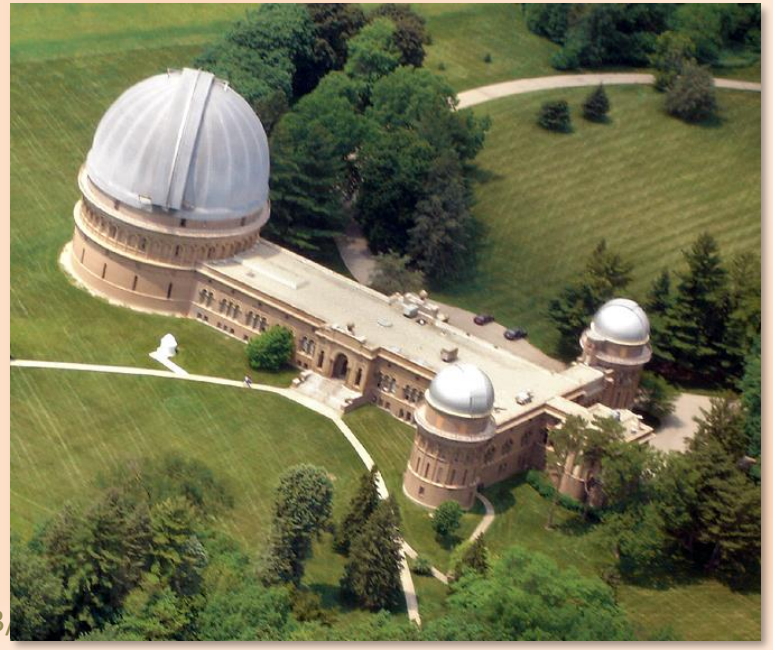
Yerkes Refractor

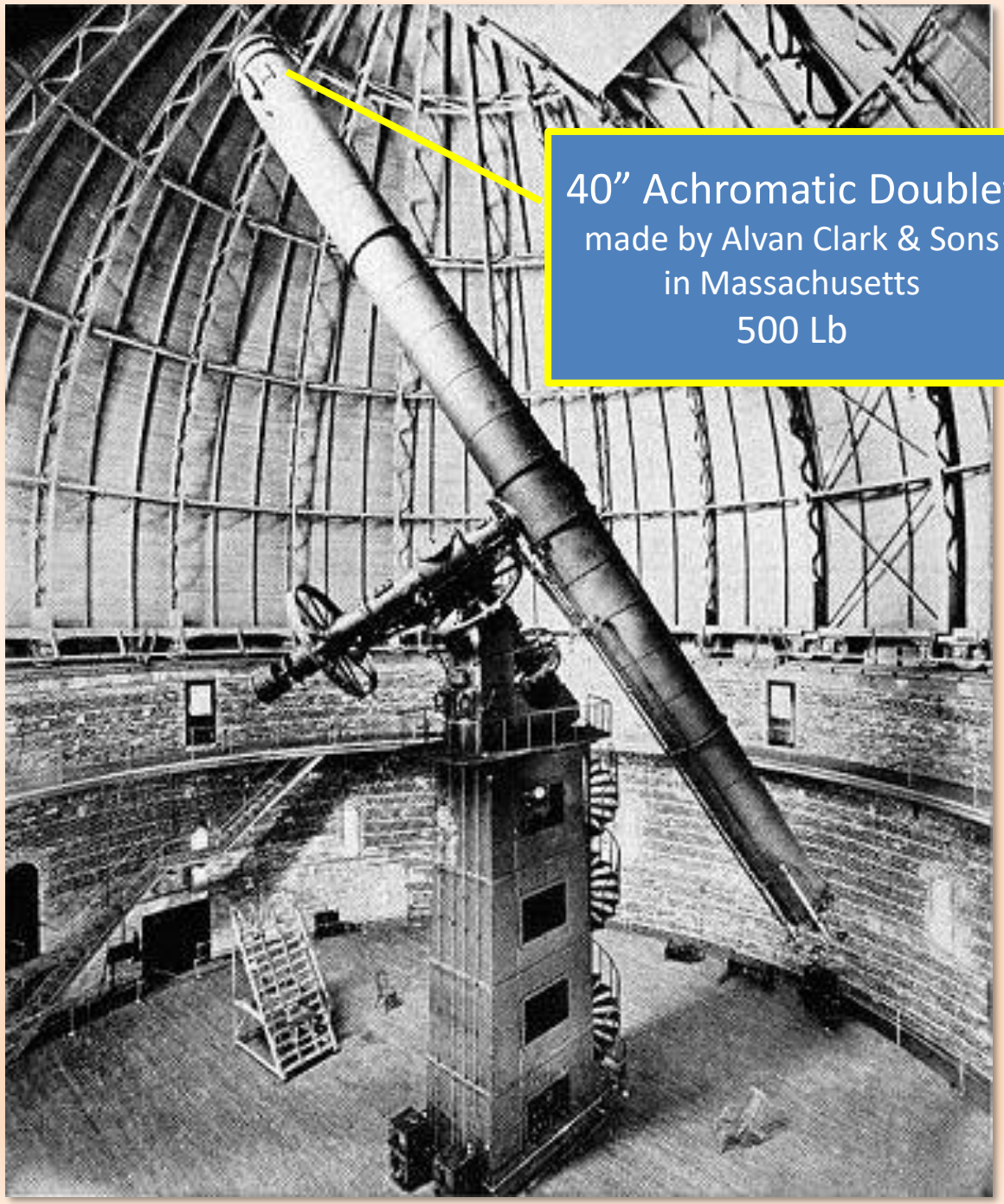
40 inch (102 cm)

19 m Focal Length

1897

Yerkes Observatory
Williams Bay, WI
U of Chicago





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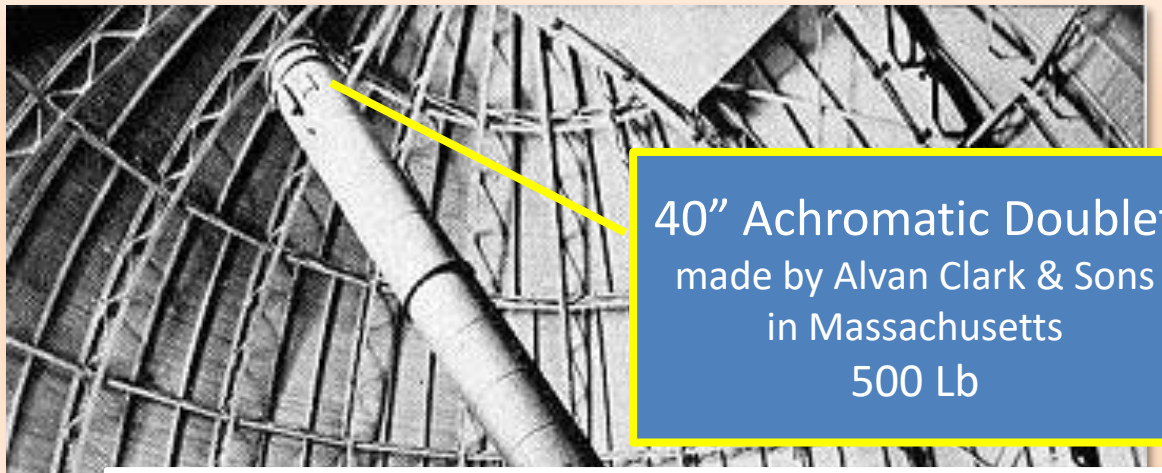
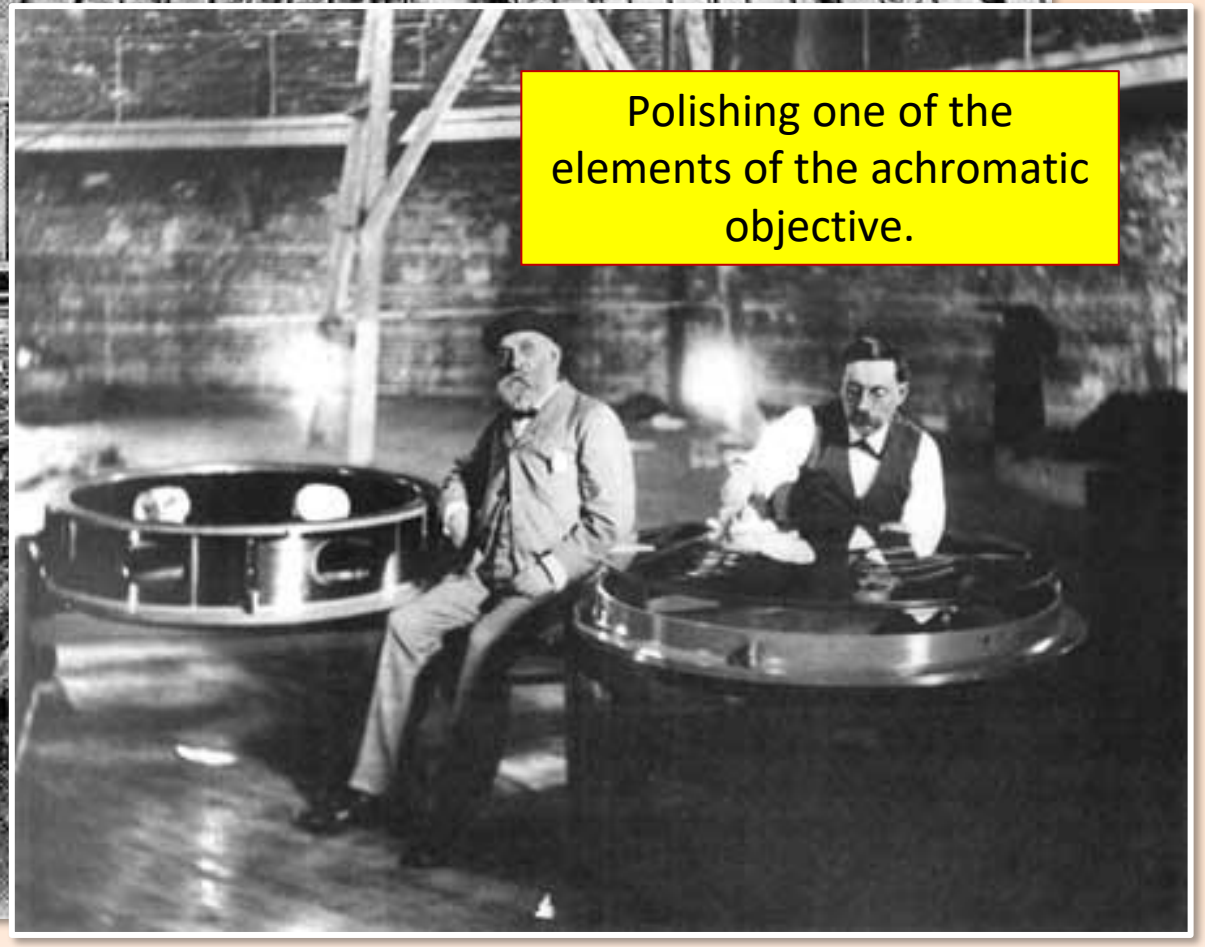


40” Achromatic Doublet
made by Alvan Clark & Sons
in Massachusetts
500 Lb



Polishing one of the elements of the achromatic objective.

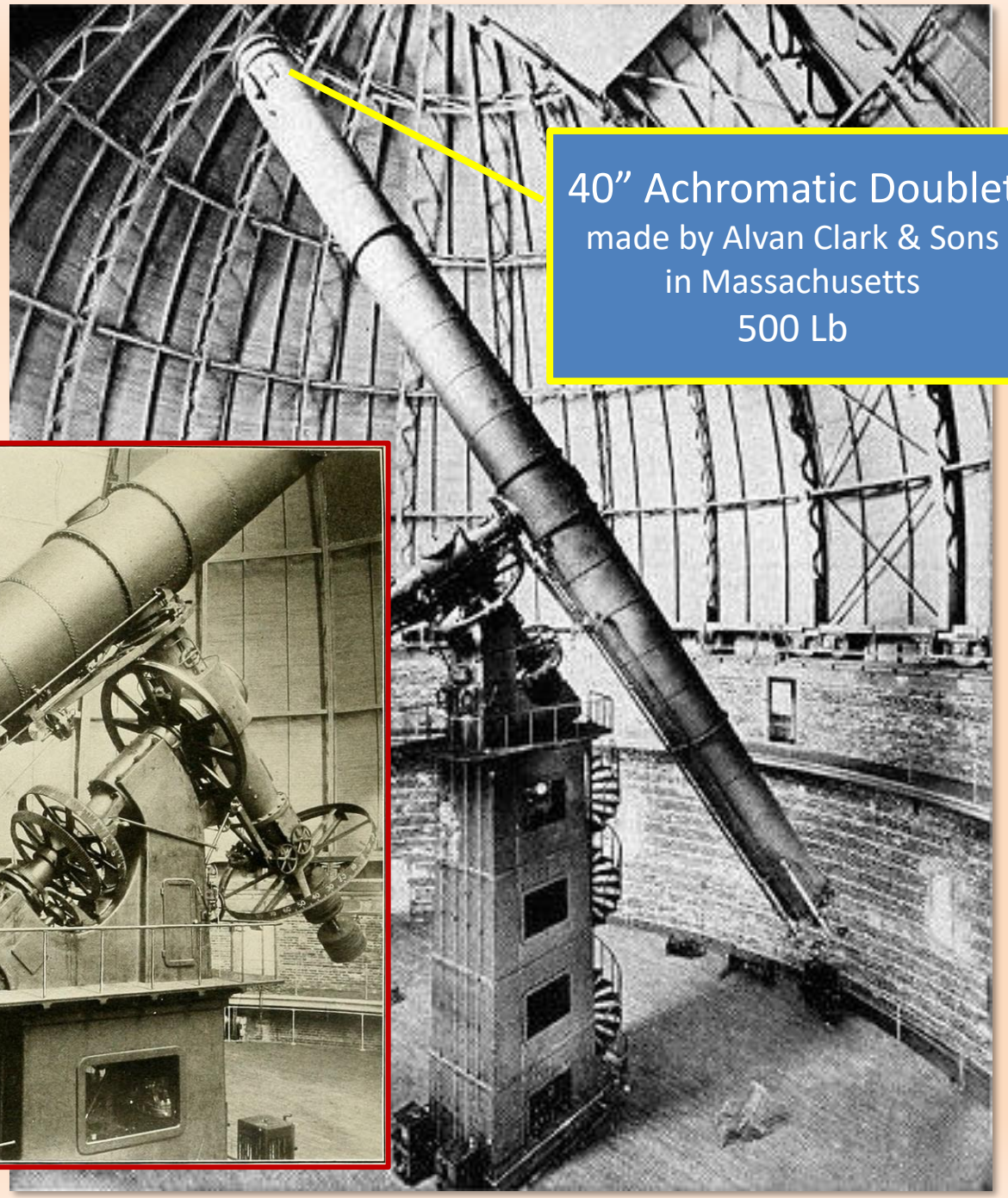
Yerkes Refractor

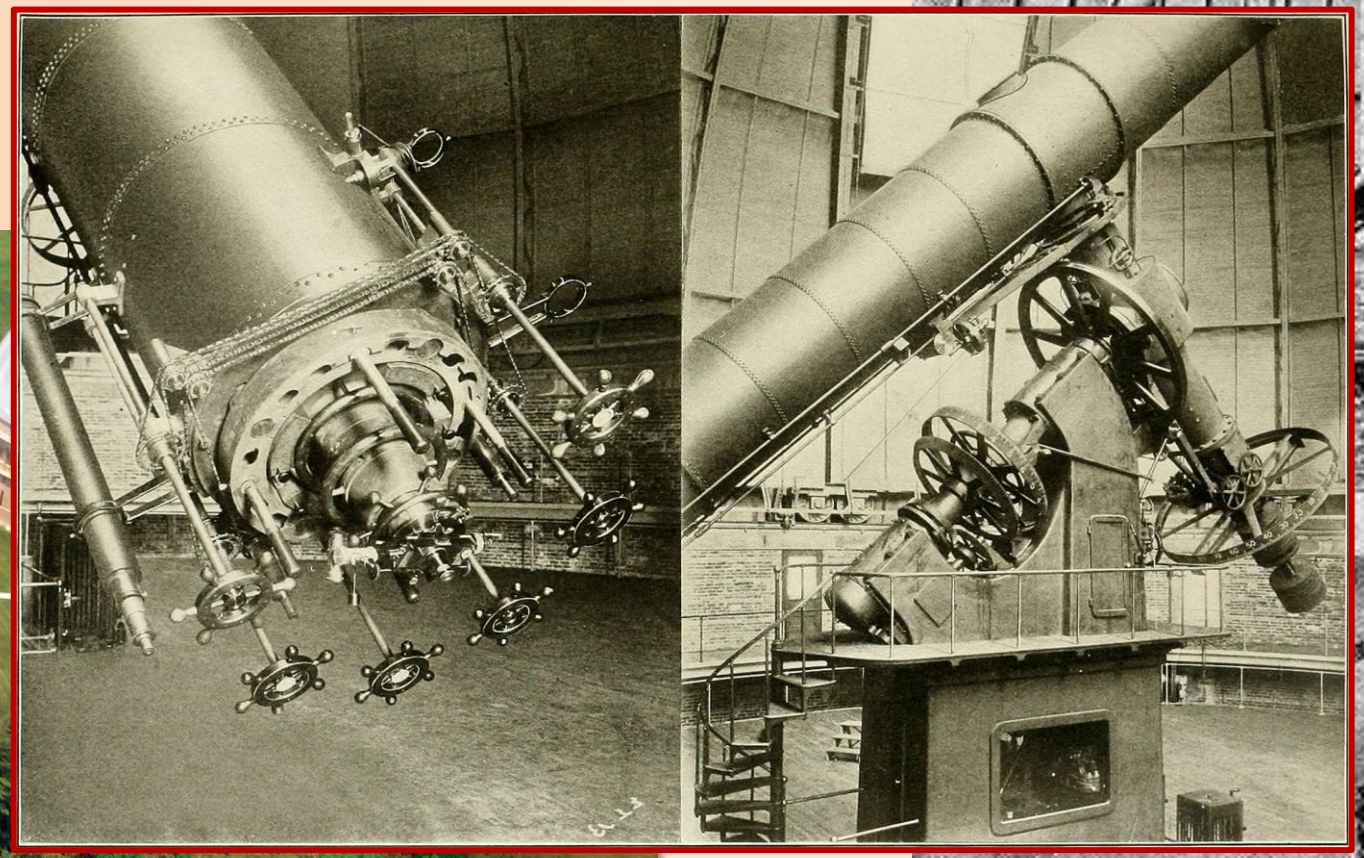
40 inch (102 cm)

19 m Focal Length

1897

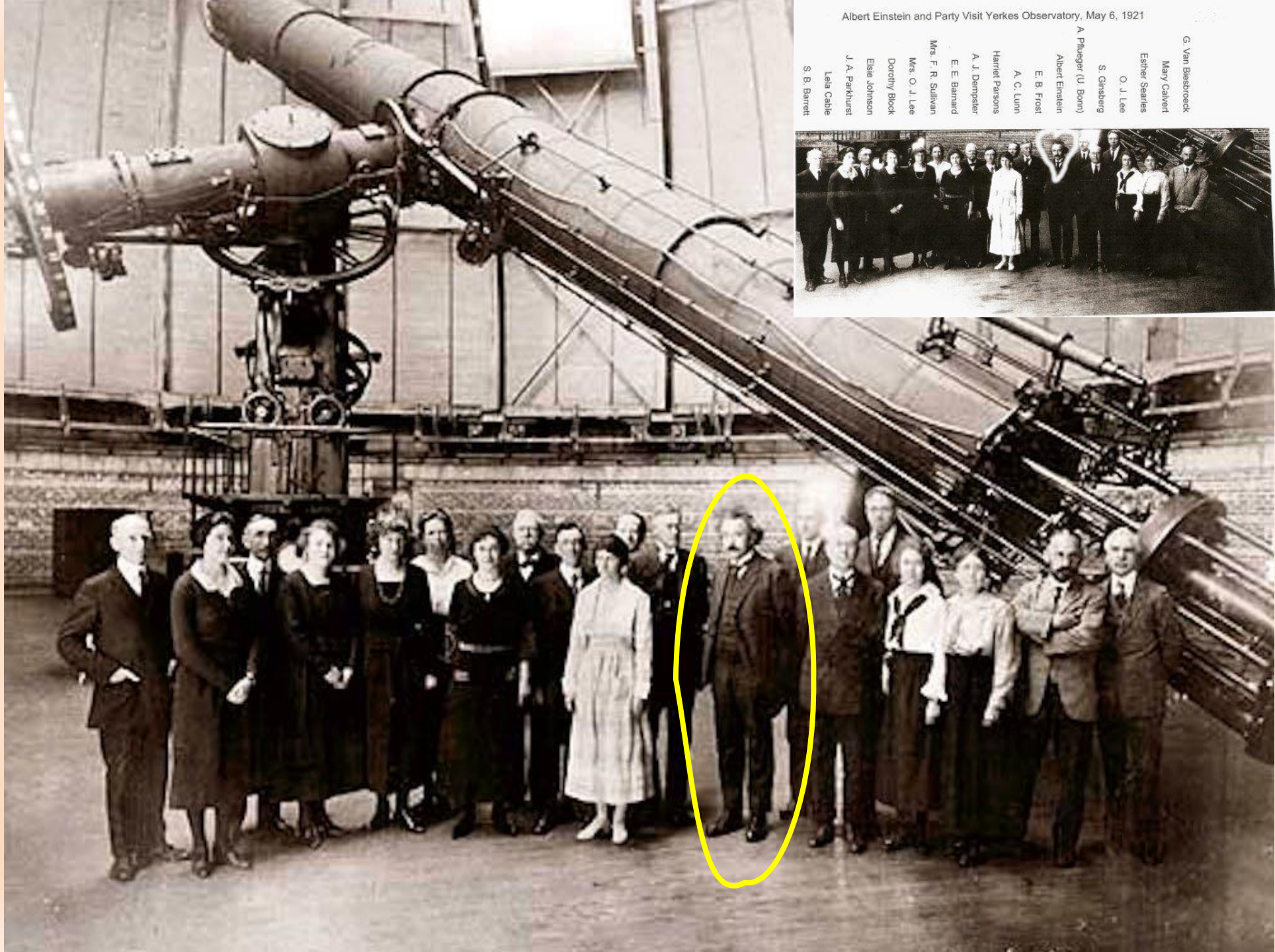
Yerkes Observatory





Albert visits the Yerkes Refractor

May 6, 1921



The UI 12 Inch Refractor

15 ft Focal Length

1896

Achromatic Doublet

(Flint in Front!)

Jack Sparrow used state-of-the-art Refractive optics…

Pirates of the Caribbean (Disney 2003) Johnny Depp and Geoffrey Rush

Pirates of the Caribbean (Disney 2003) Johnny Depp and Geoffrey Rush

Most refractors were small terrestrial telescopes

at first constructed from cardboard tubes covered with Vellum ….

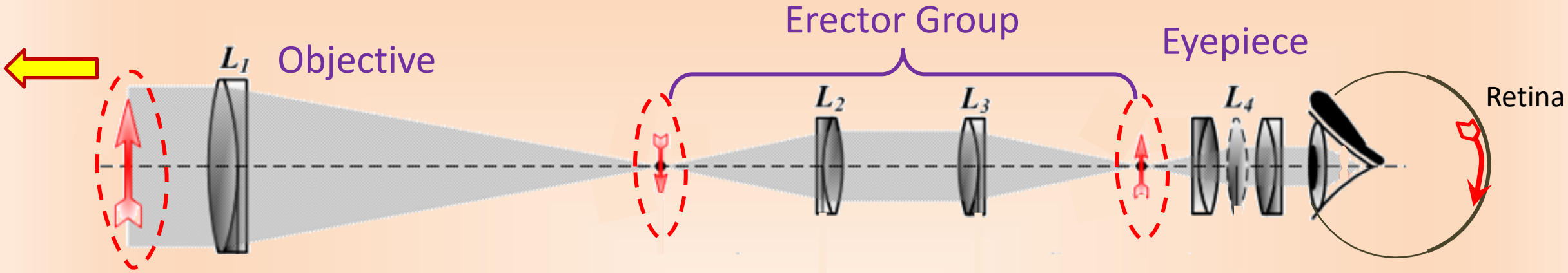
Greivenkamp & Steed, Proc SPIE Vol 8129 (2011)

Most refractors were small terrestrial telescopes

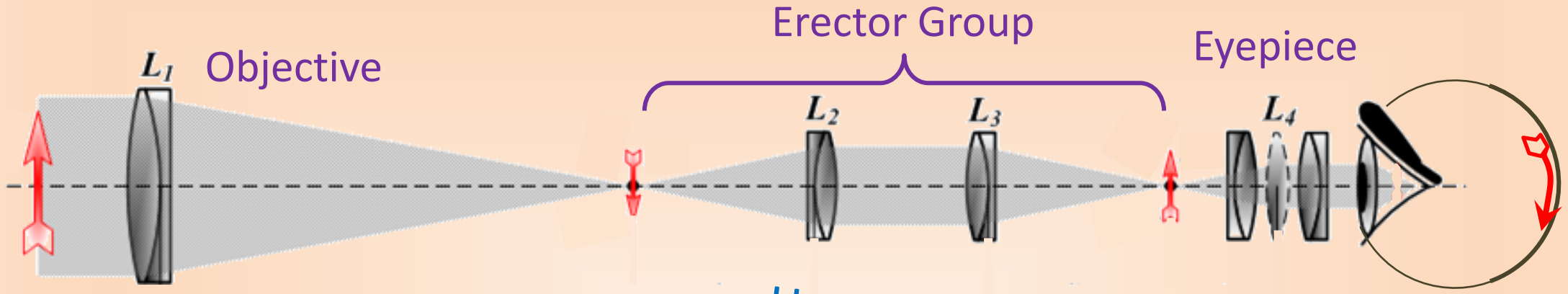
then, from mid-18th century, of brass tubing

Dolland Terrestrial Refractor
(19th Century)
HeritageAuctions.com

Terrestrial Refracting Telescope



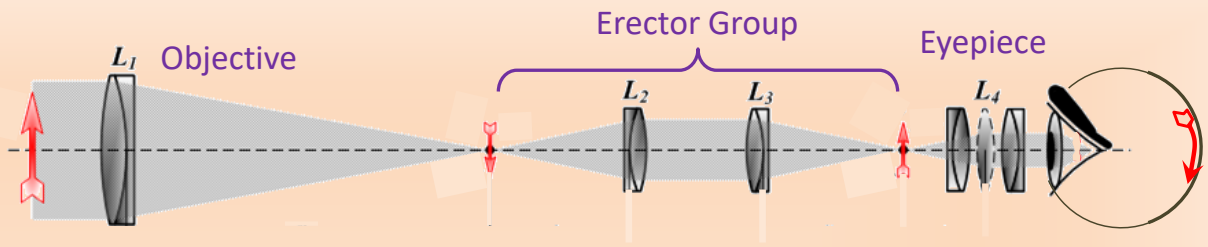
Terrestrial Refracting Telescope

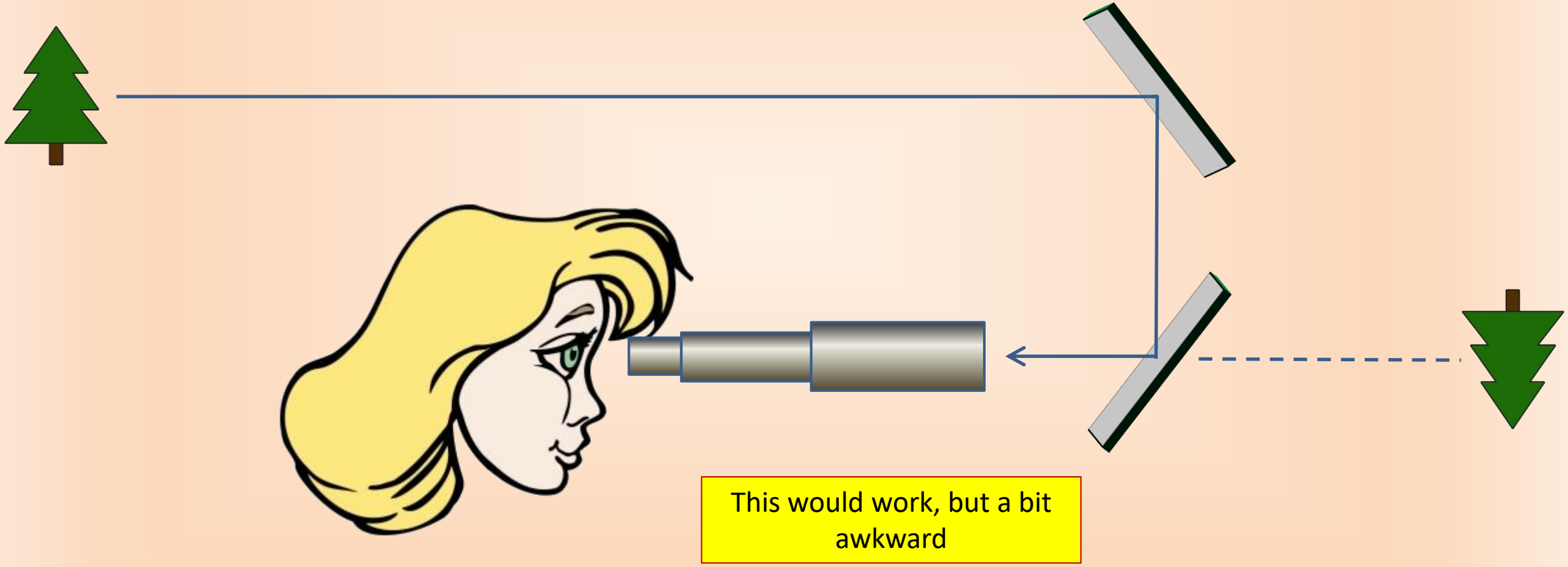


How can we eliminate this Erector?

… and reduce the excessive length of the terrestrial telescopes?

Erecting with Mirrors





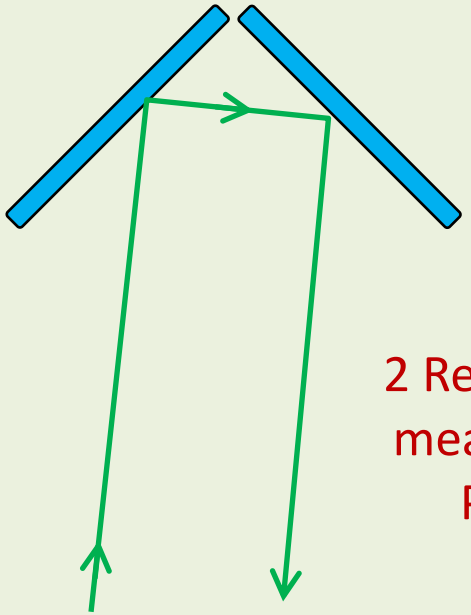
This would work, but a bit awkward

Mirror Reflection flips the **Parity** from *even* to *odd*

Two Mirror Reflections flip the Parity back to *even*…
and so on.

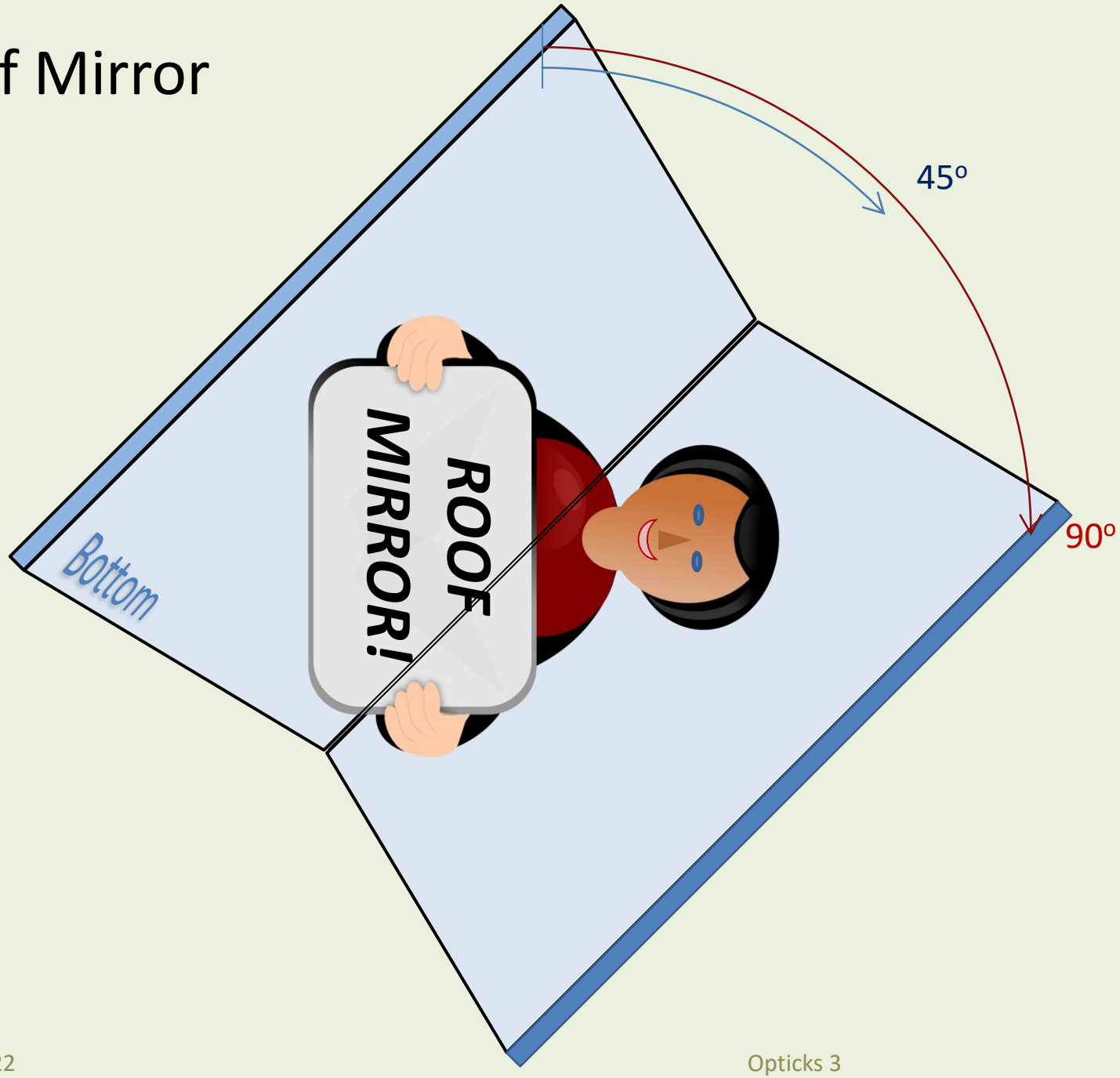
Roof Mirror

Top View of Roof Pair

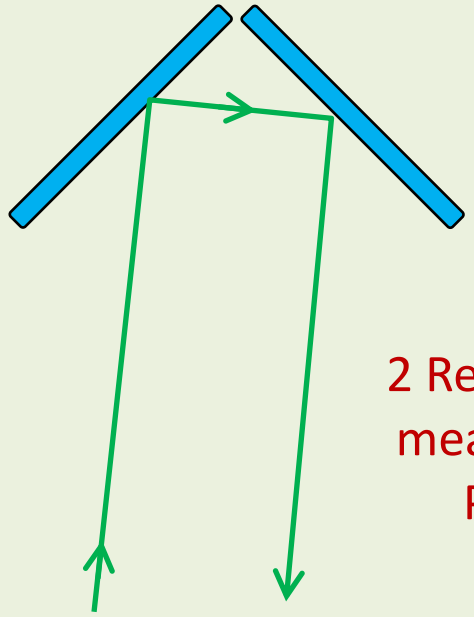


2 Reflections means Even Parity

Roof Mirror



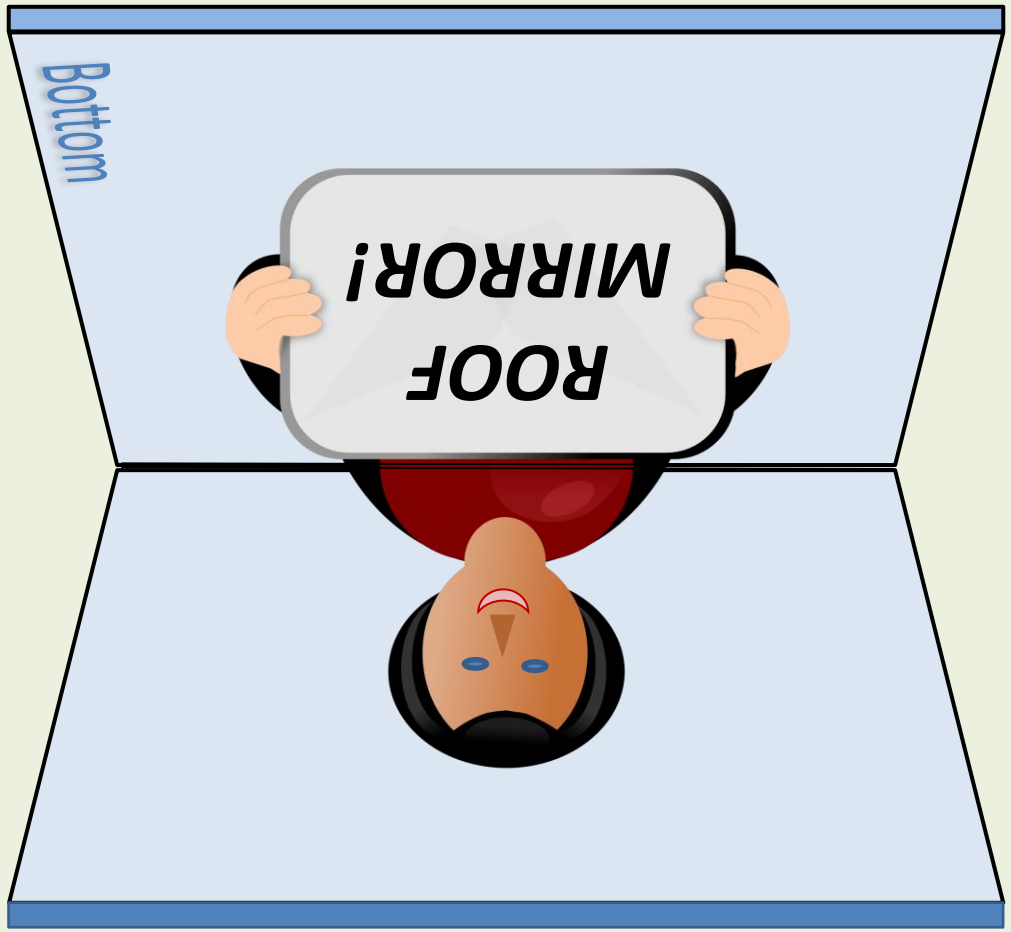
Top View of Roof Pair



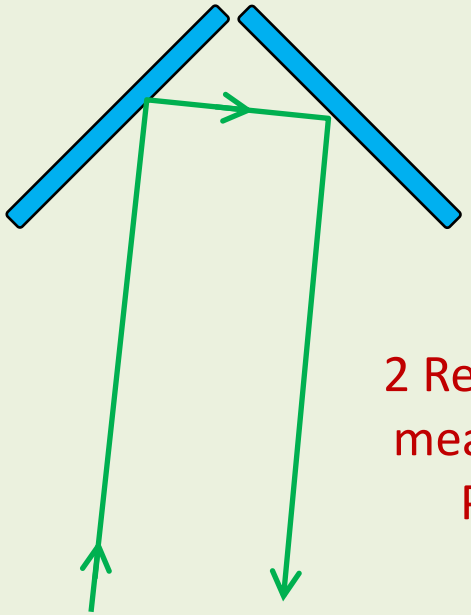
2 Reflections means Even Parity

Image Rotates Exactly Twice the Roof Rotation!

Roof Mirror



Top View of Roof Pair

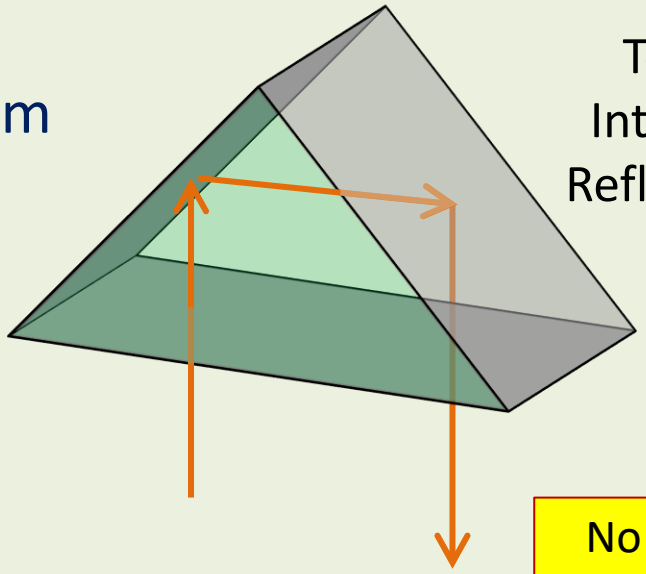


2 Reflections means Even Parity

Image Rotates Exactly Twice the Roof Rotation!

Roof Mirror: A Better Version

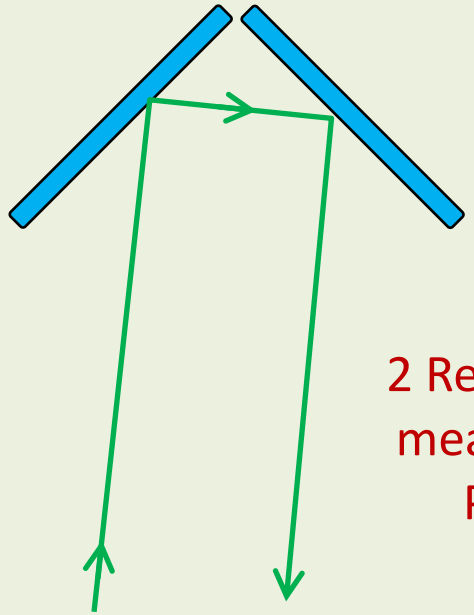
Roof Prism
or
Porro Prism
(1847)



Total
Internal
Reflection

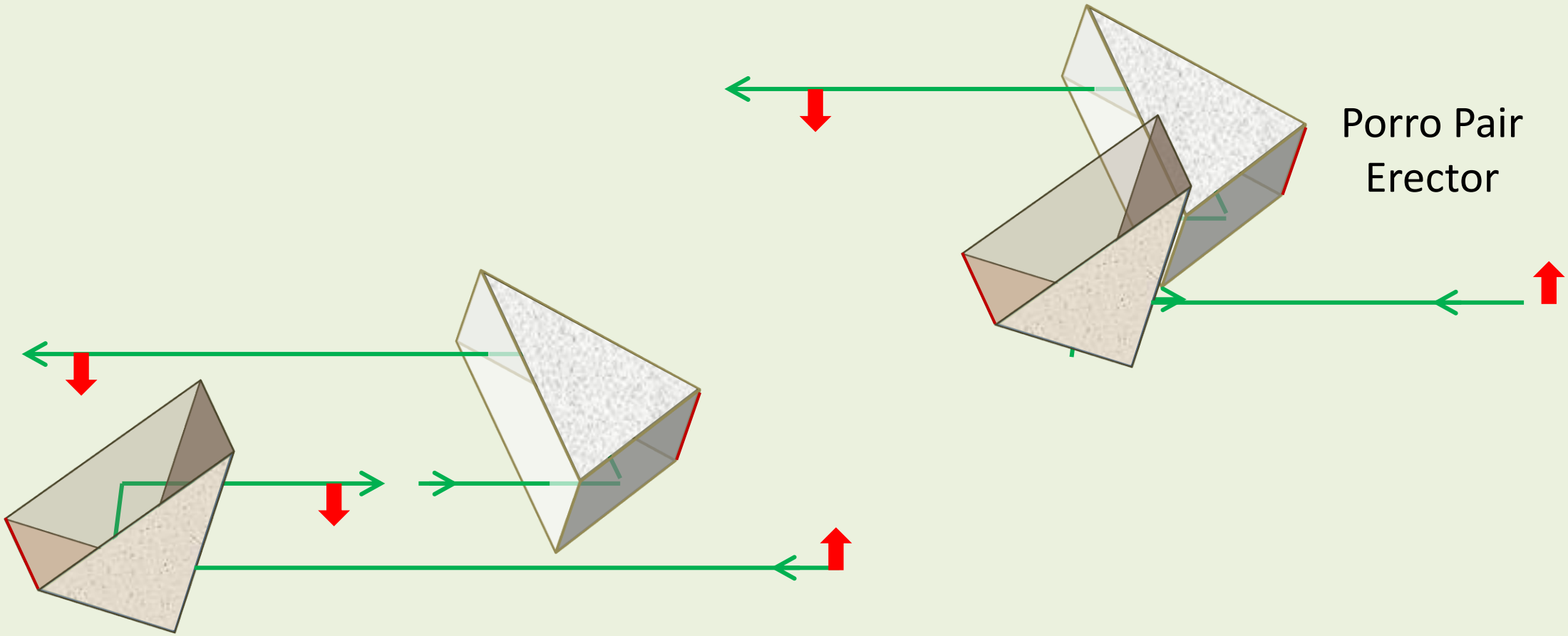
No silver or other coating needed on reflecting surfaces!

Top View of Roof Pair

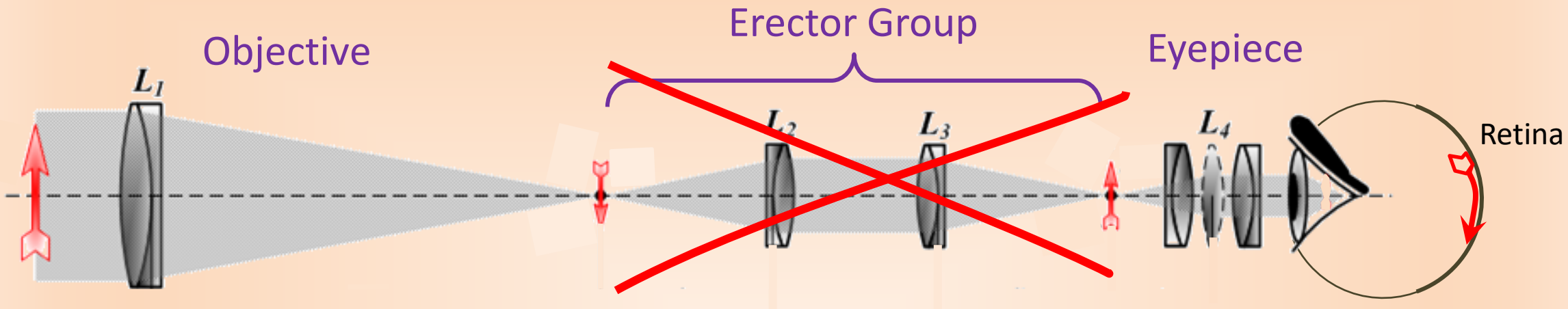


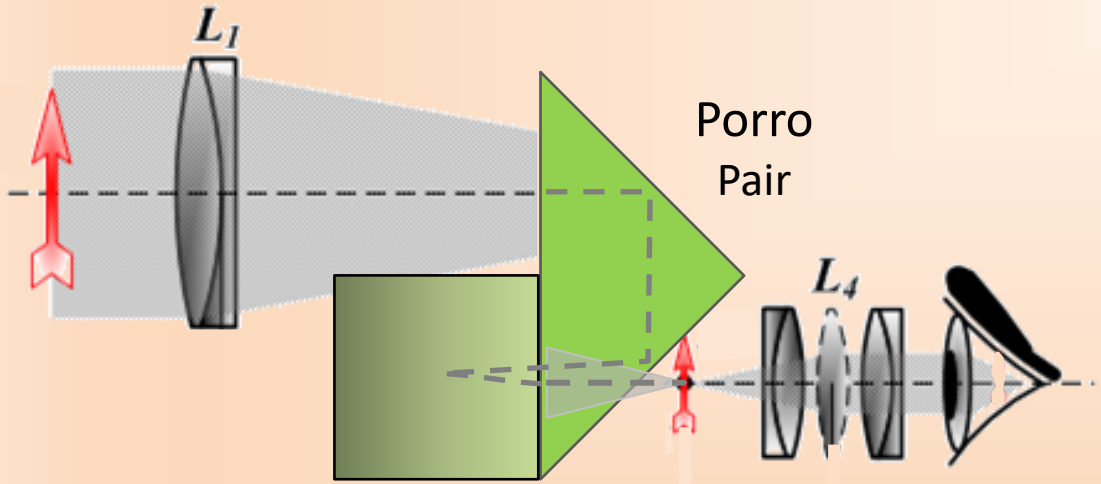
2 Reflections means Even Parity

A Pair of Porro Prisms performs an Inversion



Terrestrial Refracting Telescope: A Compact Erector





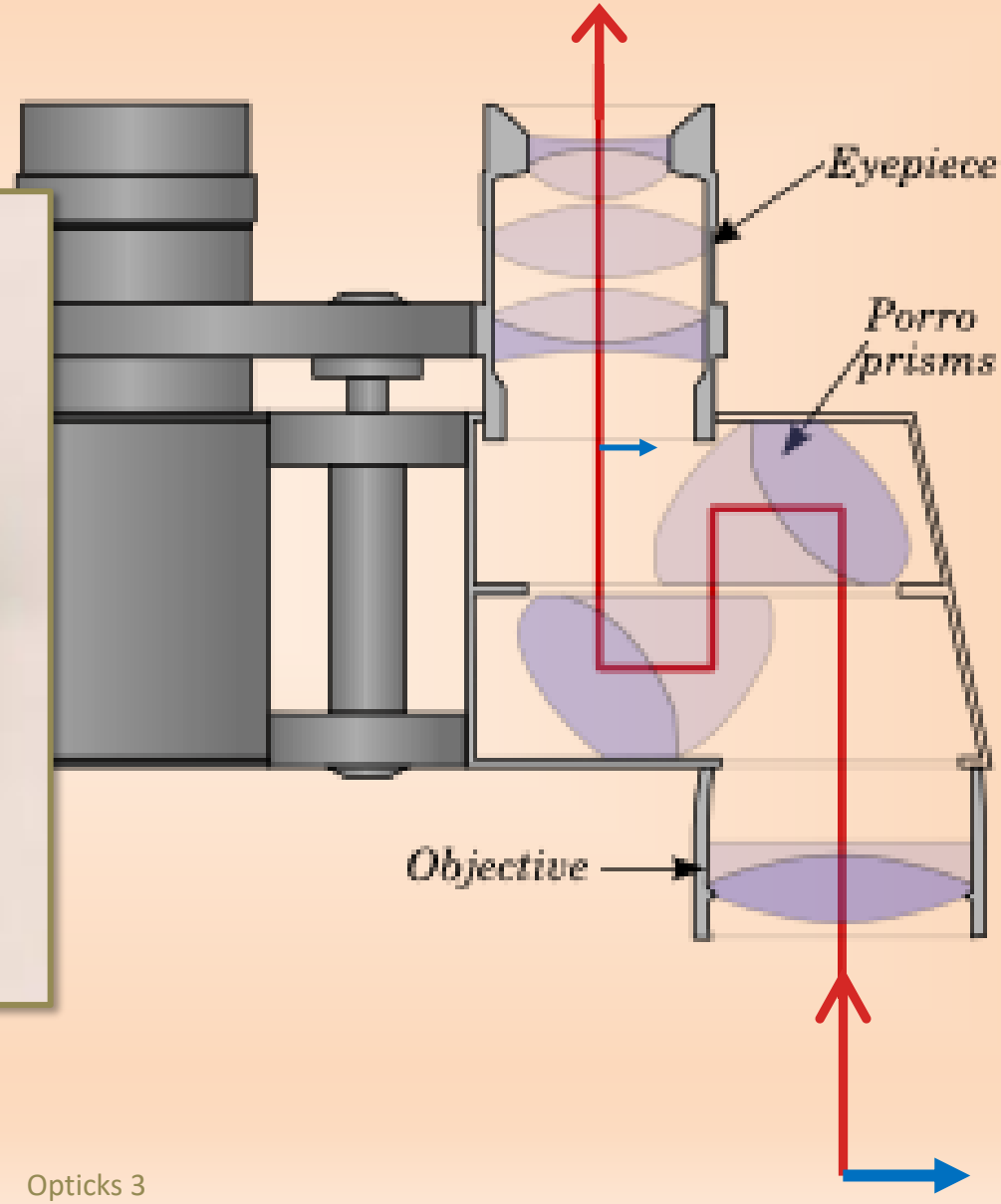
Huge reduction in length

Modern Spotting Scope

Ricoh-Pentax

Two of these make a Pair of Binoculars

Zeiss 8x (1897)



Greivenkamp & Steed, Proc SPIE Vol 8129 (2011)

But plenty of Binoculars were built the old-fashioned way

French Mid-1800's

Galilean Opera Glasses

Greivenkamp & Steed, Proc SPIE Vol 8129 (2011)

But plenty of Binoculars were built the old-fashioned way

Greivenkamp & Steed, Proc SPIE Vol 8129 (2011)

1817 Invention of the Kaleidoscope

καλός	εἶδος	σκοπέω
kalos	*eidos*	*skopeō*
"beautiful”	“shape“	“to examine"

David Brewster

Scottish Physicist

(1781 – 1868)

1817 Invention of the Kaleidoscope

καλός εἶδος σκοπέω

kalos *eidos* *sk*

"beautiful" "shape" "to

David Brewster

Scottish Physicist

(1781 – 1868)

No. CLXXXVI. SECOND SERIES. Nov. 1817.

Specification of the Patent granted to DAVID BREWSTER, *of Edinburgh, Doctor of Laws; for a new Optical Instrument, called* "The Kaleidoscope," *for exhibiting and creating beautiful Forms and Patterns, of great use in all the ornamental Arts.* Dated July 10, 1817.

With two Wood Engravings.

TO all to whom these presents shall come, &c.

1817 Invention of the Kaleidoscope

καλός εἶδος σκοπέω

kalos *eidos* *sk*

"beautiful" "shape" "to

David Brewster

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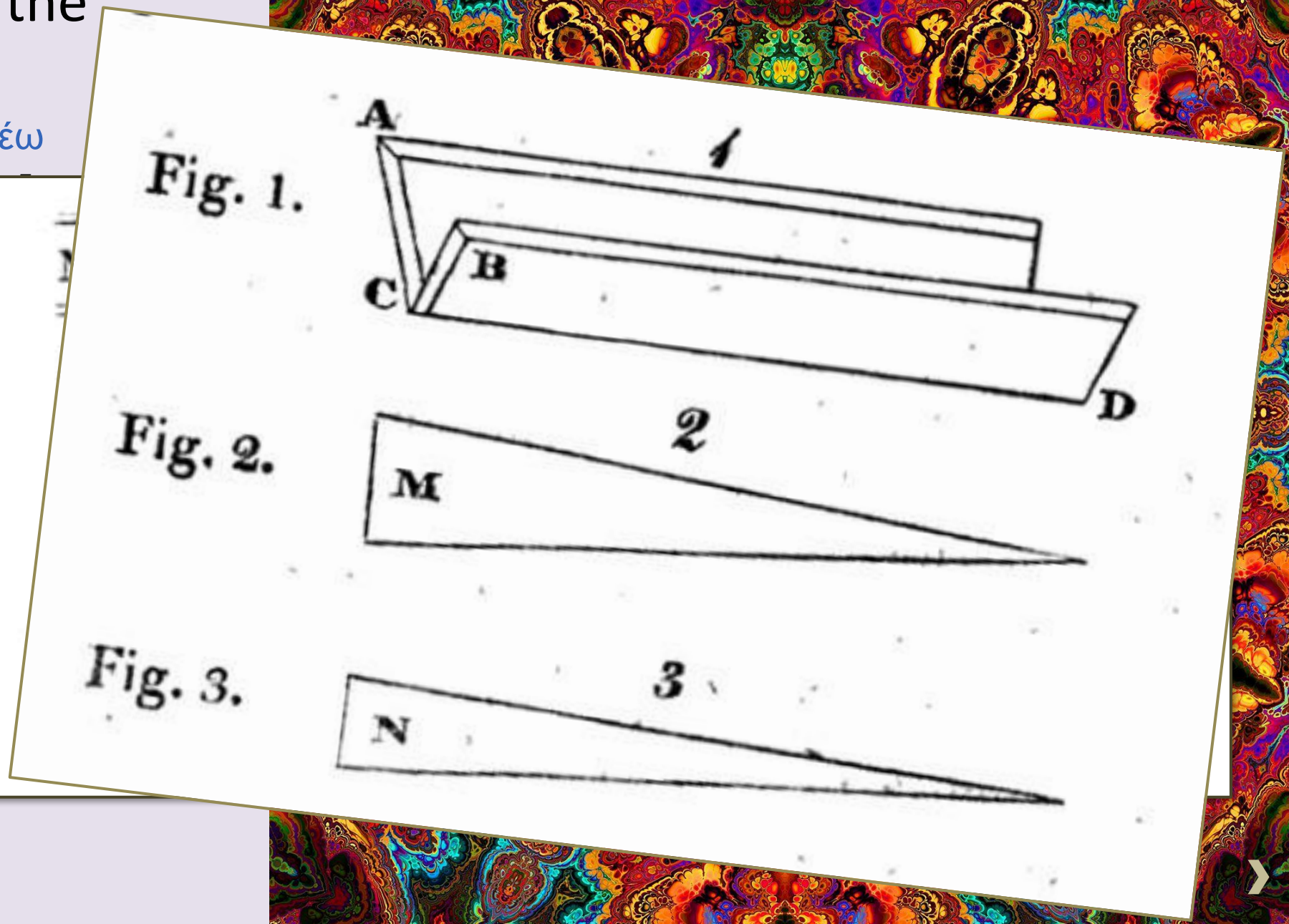
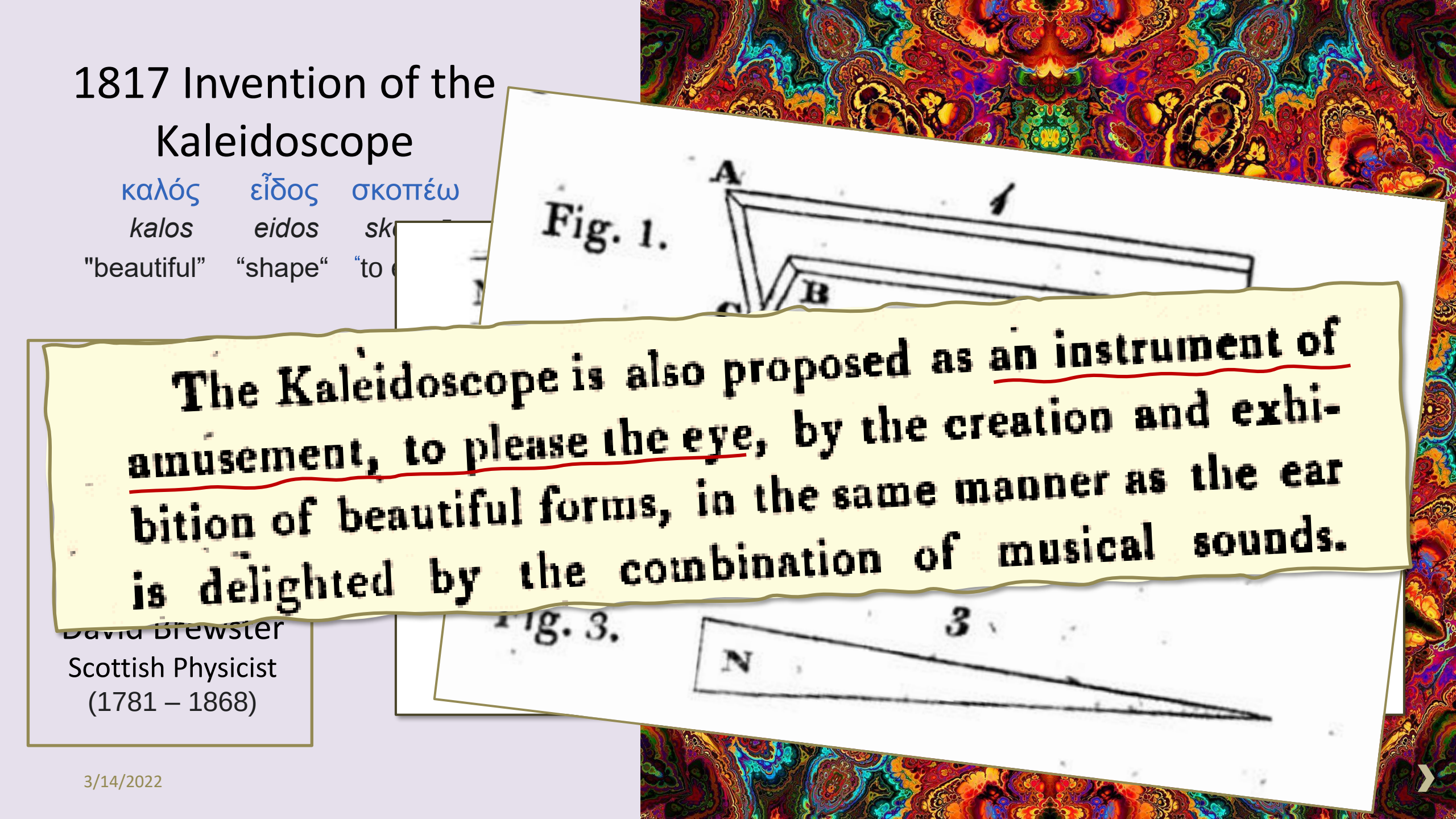


1817 Invention of the Kaleidoscope

καλός *kalos* "beautiful"

εἶδος *eidos* "shape"

σκοπέω *skop* "to



The Kaleidoscope is also proposed as an instrument of amusement, to please the eye, by the creation and exhibition of beautiful forms, in the same manner as the ear is delighted by the combination of musical sounds.

David Brewster
Scottish Physicist
(1781 – 1868)

1817 Invention of the Kaleidoscope

καλός εἶδος σκοπέω

kalos *eidos*

"beautiful" "shape"

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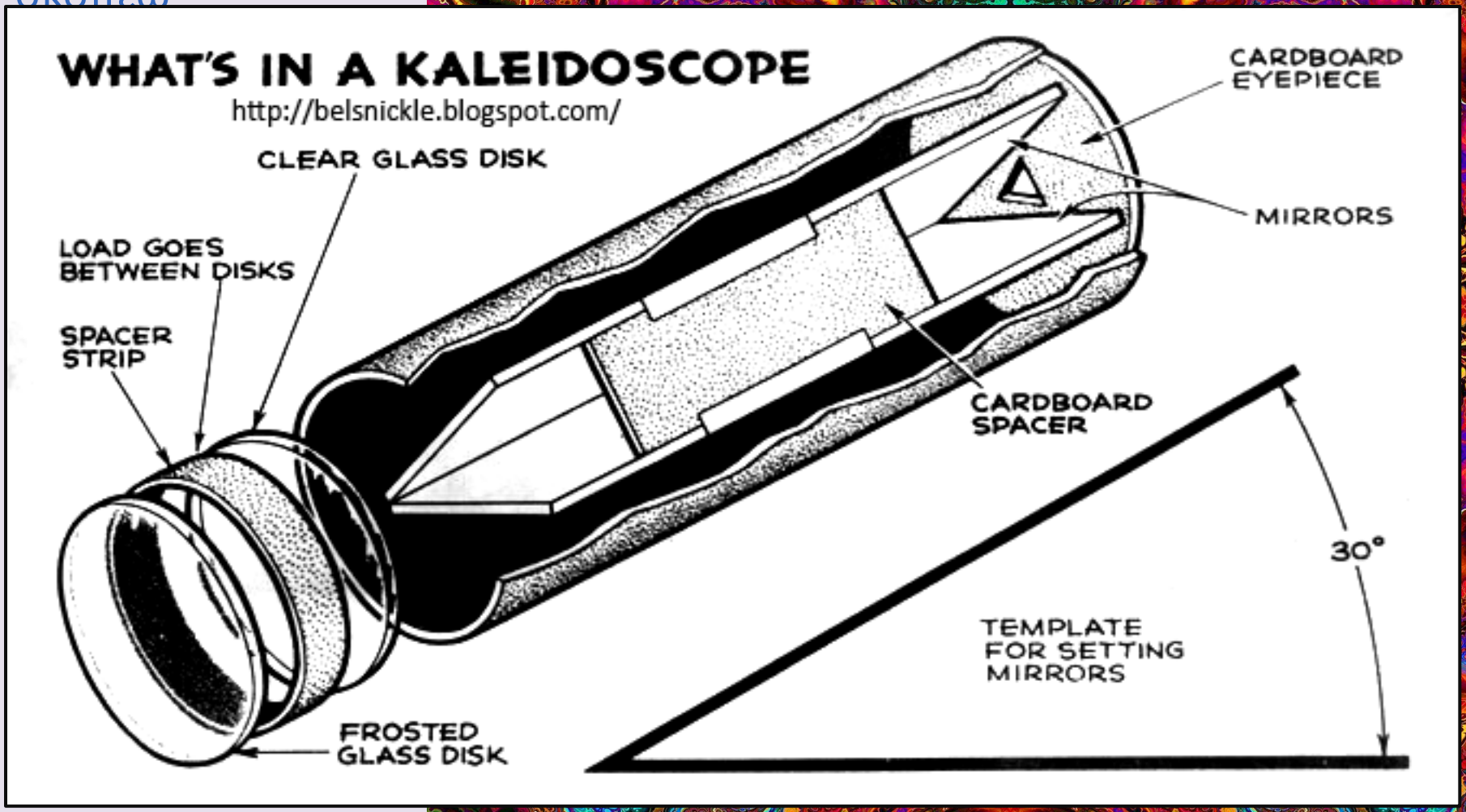
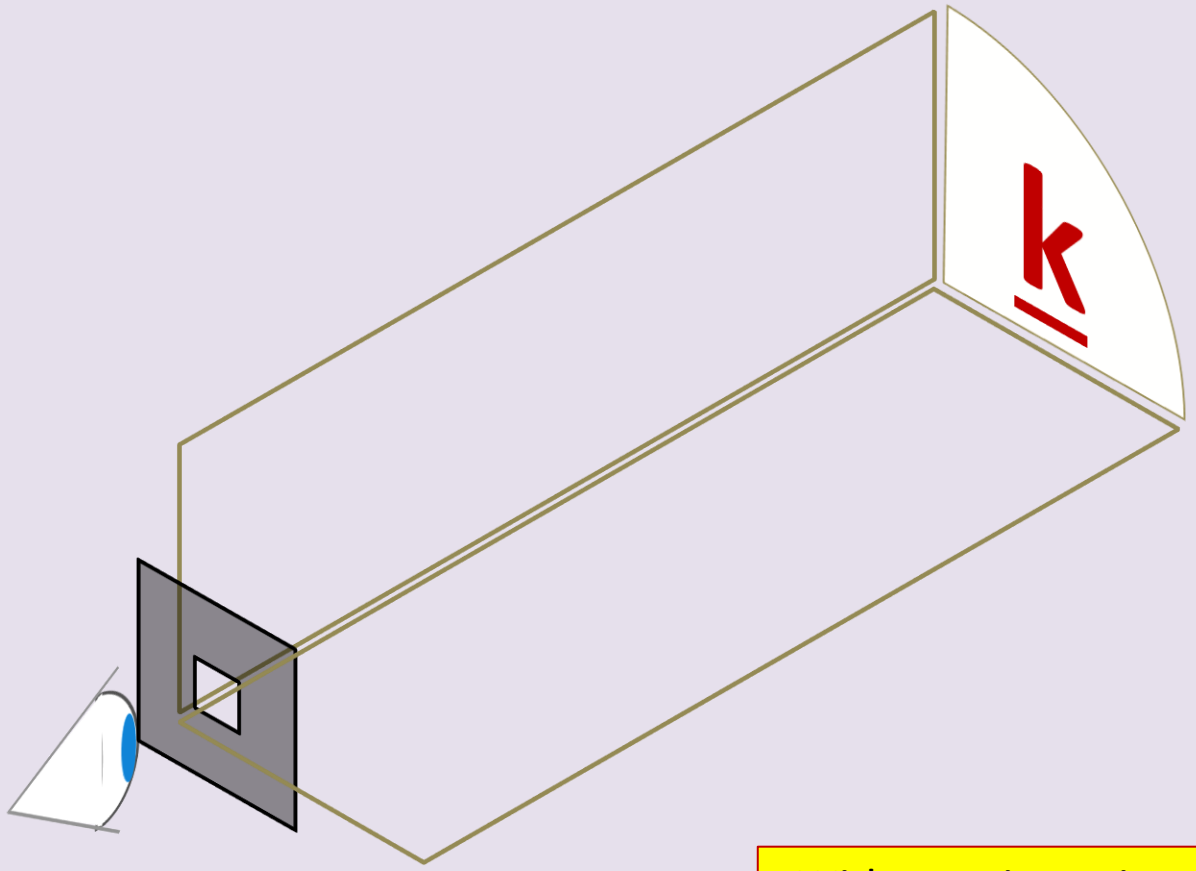
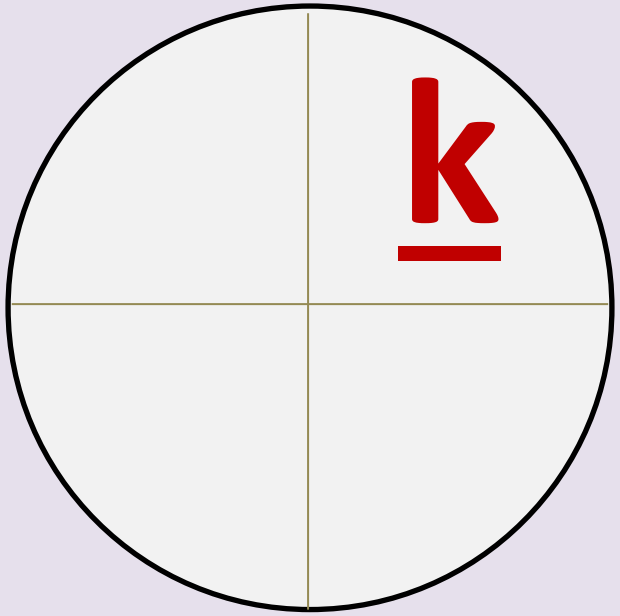


How a simple 90° Kaleidoscope Works

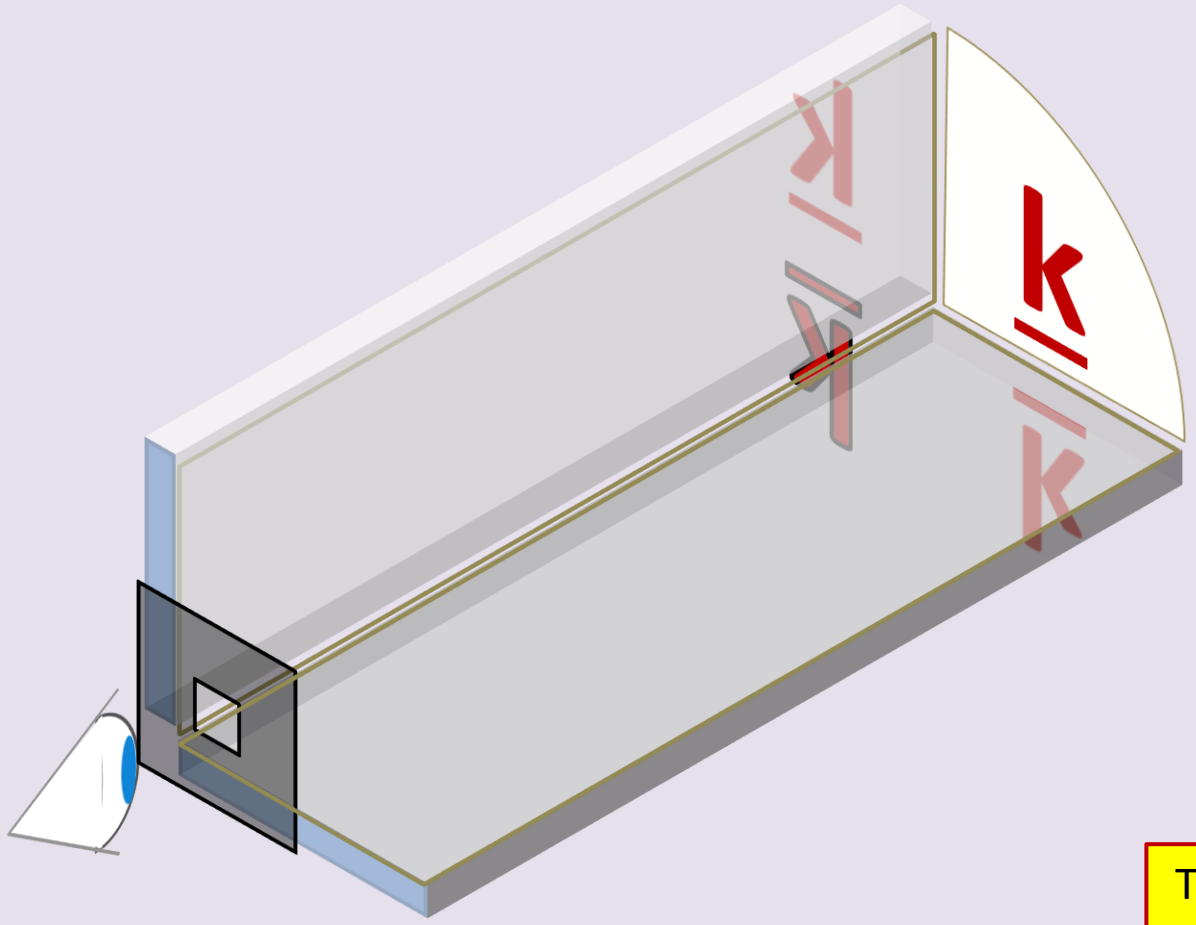


View

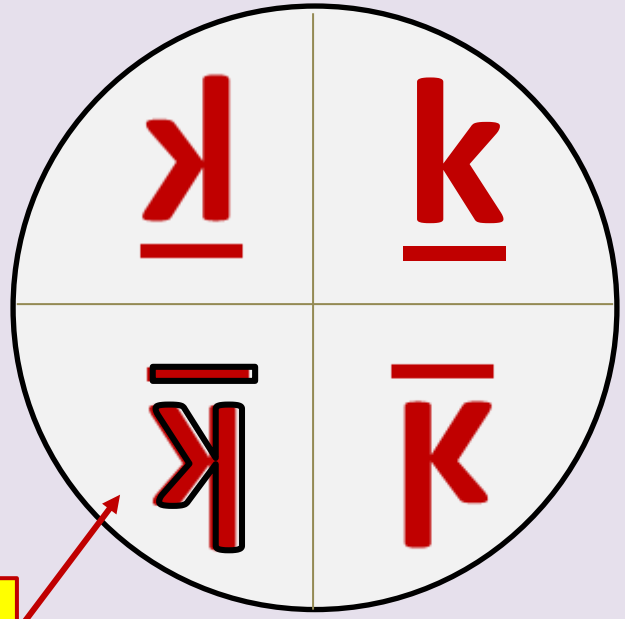


With no mirrors installed…

How a simple 90° Kaleidoscope Works

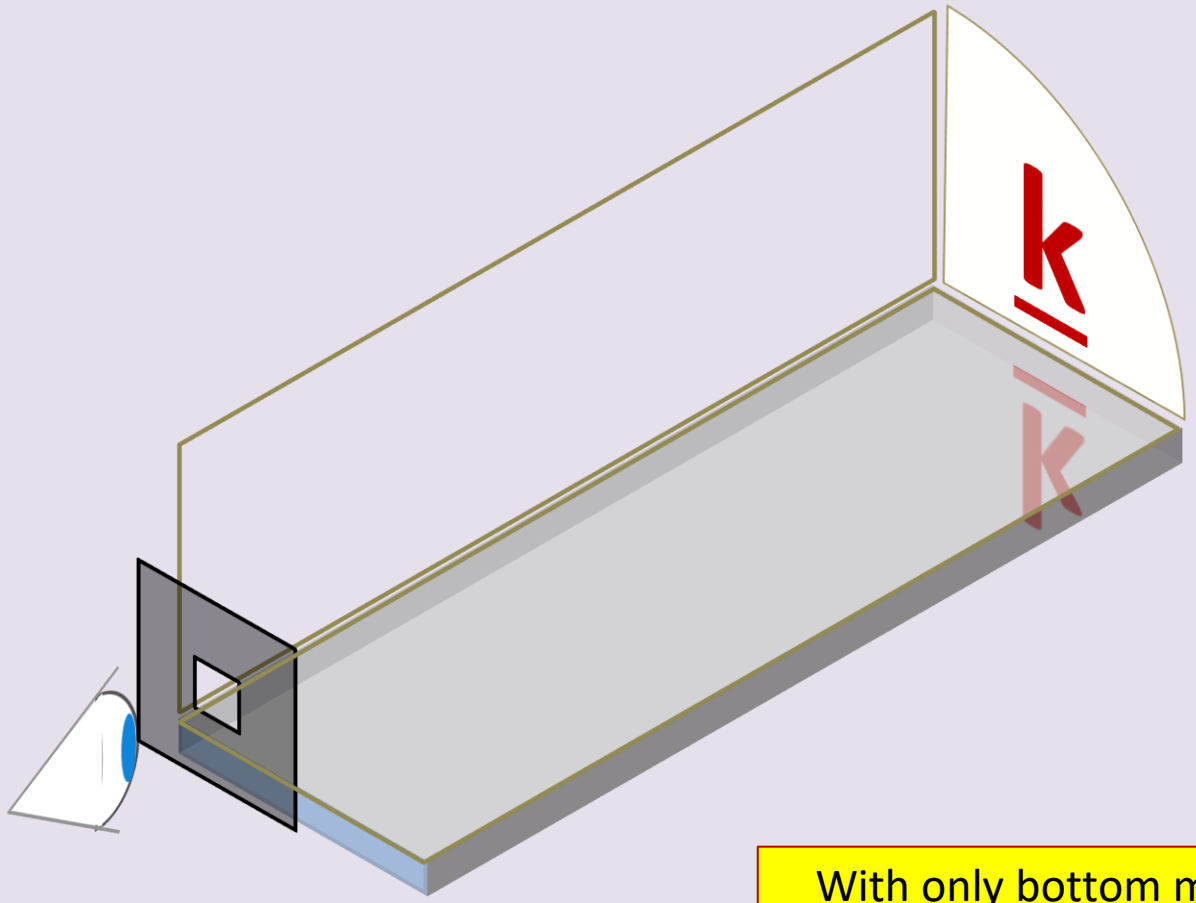


View

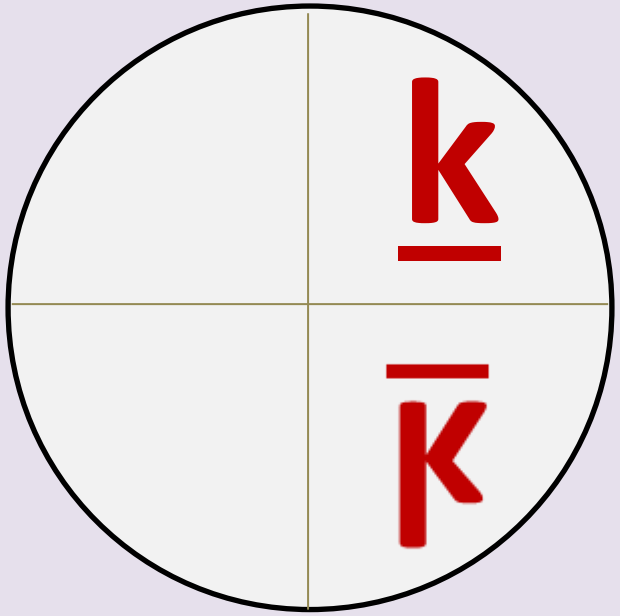


This image formed 2 different ways!

How a simple 90° Kaleidoscope Works

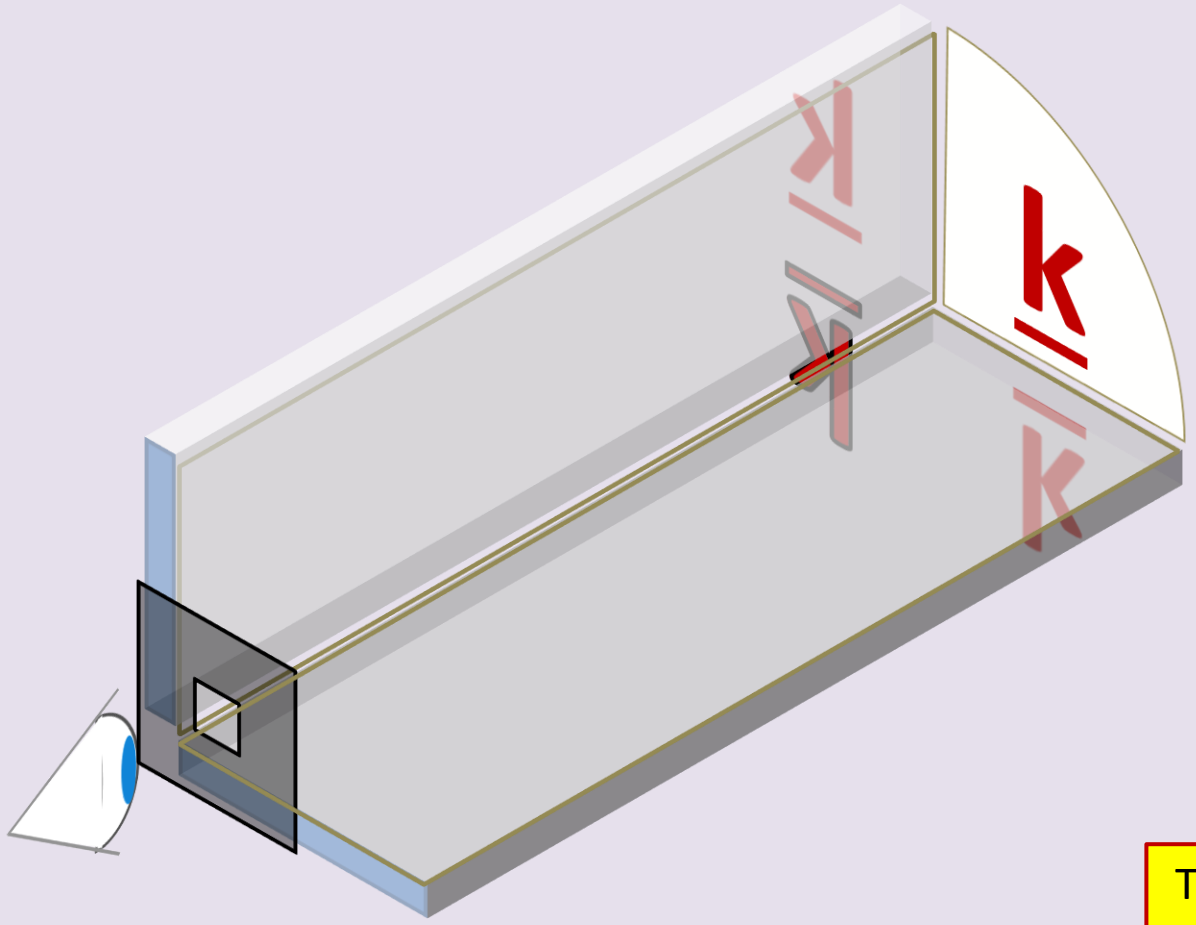


View



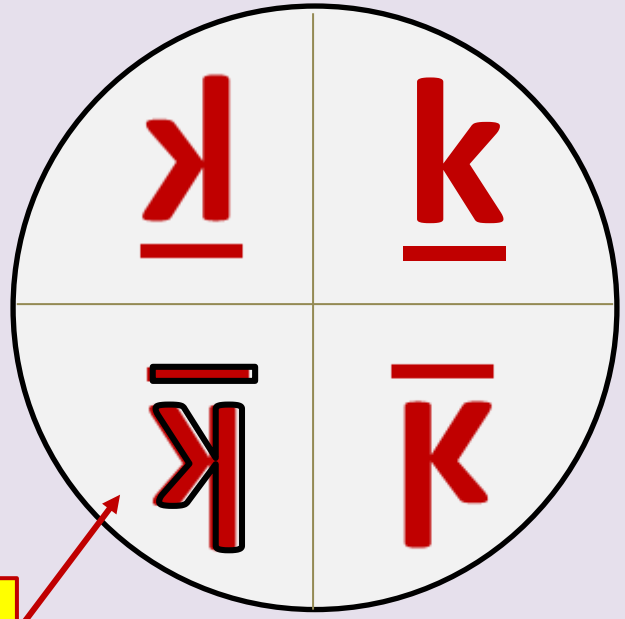
With only bottom mirror installed…

How a simple 90° Kaleidoscope Works



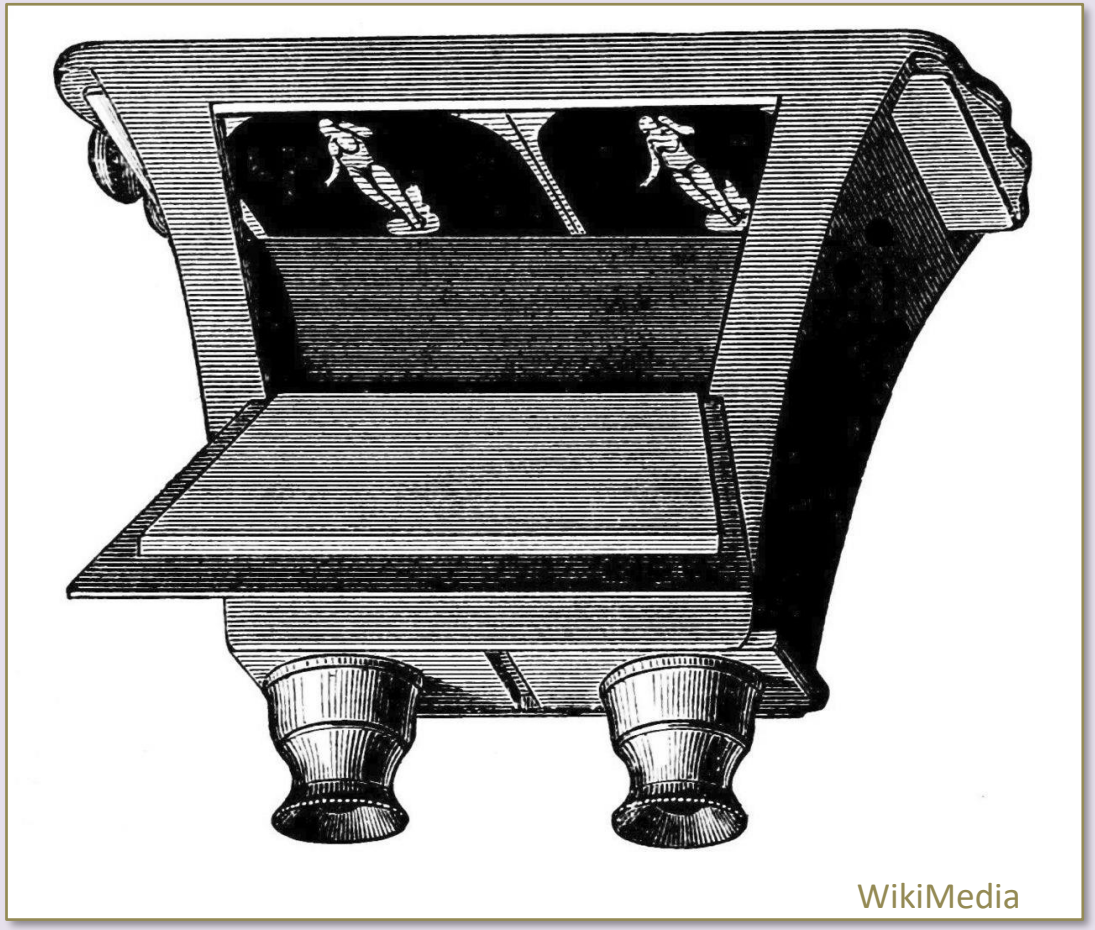
With both mirrors installed…

View



This image formed 2 different ways!

Brewster's "Lenticular Stereoscope" (1849)



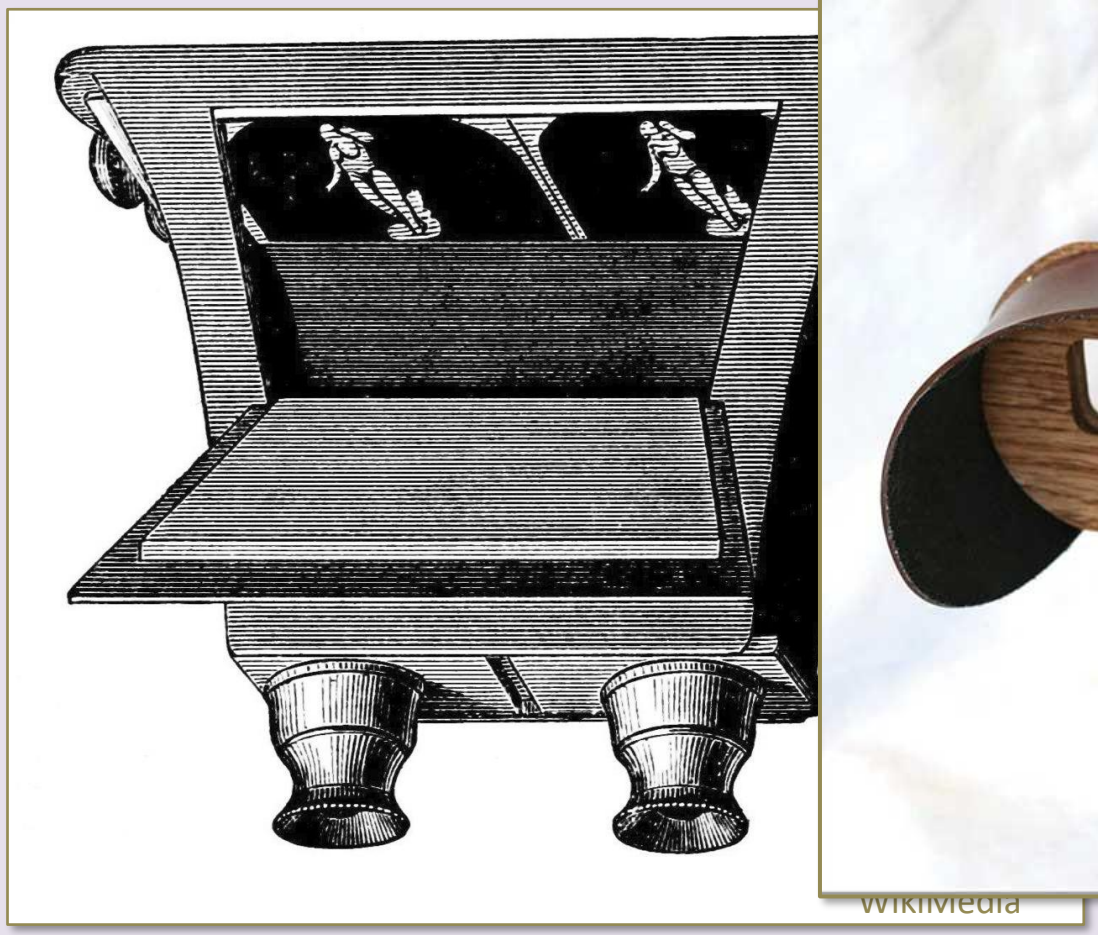
WikiMedia

ca 1870
Museo Scienza e Tecnologia Milano

Stereo pair cards existed. Brewster's innovation was to add lenses to make viewing much less painful.

Immediate sensation, 250 thousand units sold!

Brewster's "Lenticular Stereoscope" (1849)



Wikimedia

Photonics.com

ca 1870

Museo Scienza e Tecnologia Milano

A cheaper version

Brewster's "Lenticular Stereoscope" (1849)

A major content industry was spawned

ca 1850-1870

Martin Laroche V & A Museum

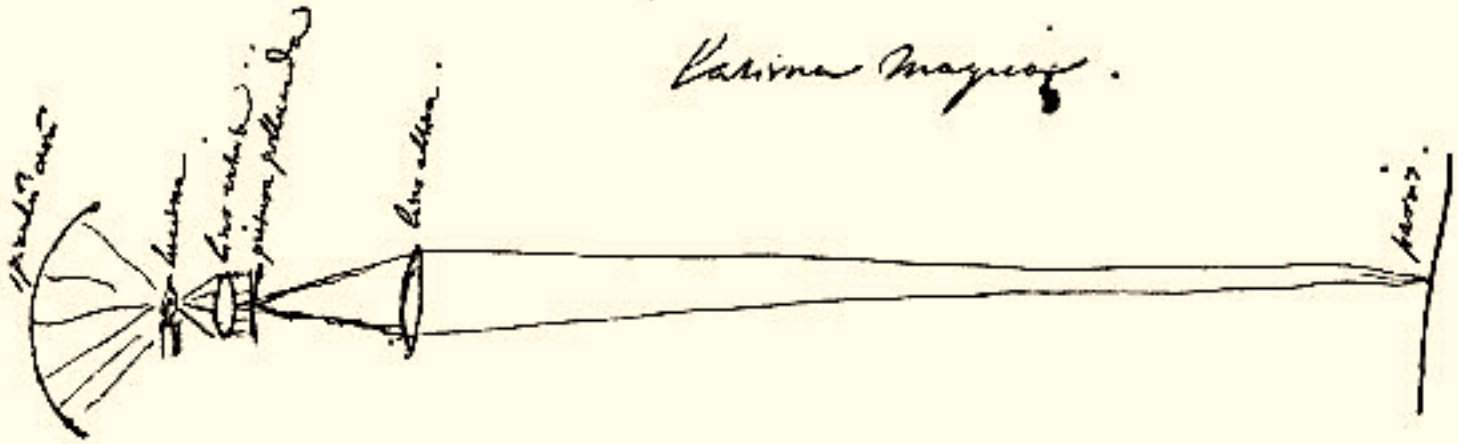
logia Milano

Brewster's "Lenticular Stereoscope" (1849)

MAGIC LANTERN

Christiaan Huygens
1629-1695
Dutch Physicist

Built and demonstrated a Magic Lantern *ca* 1659



Huygens Sketch 1695

MAGIC LANTERN

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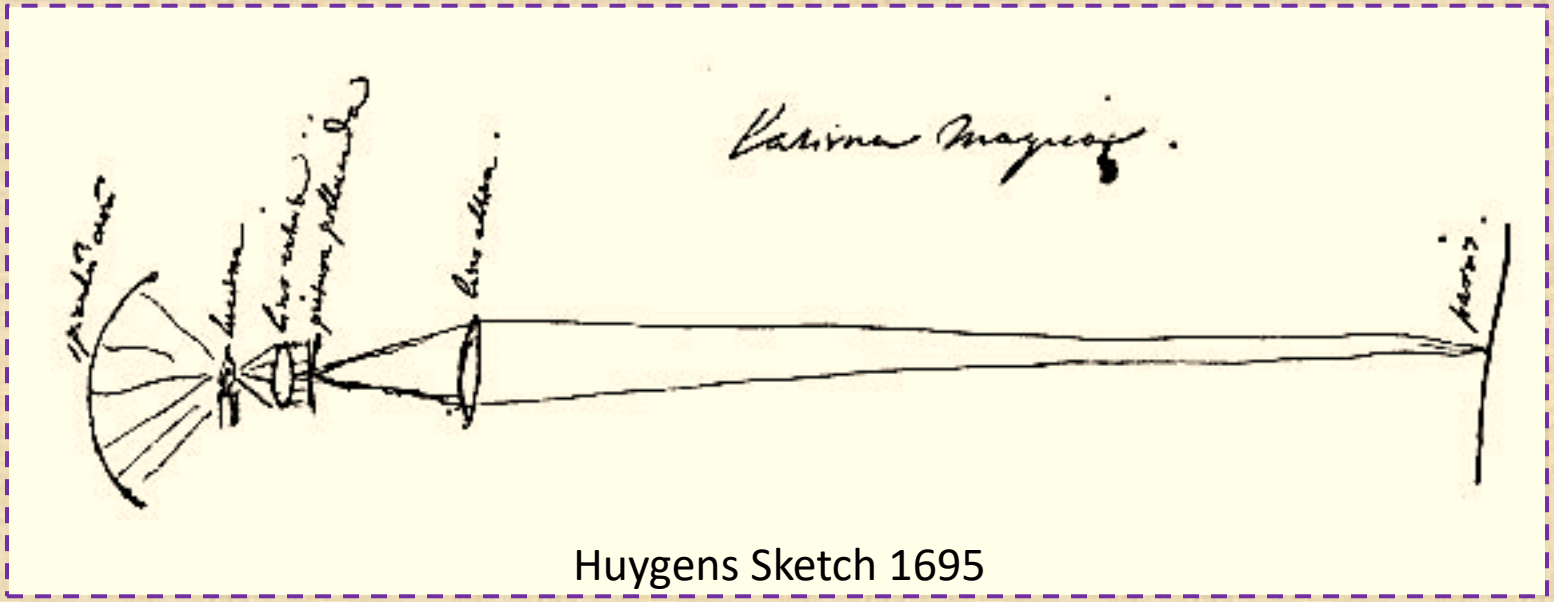
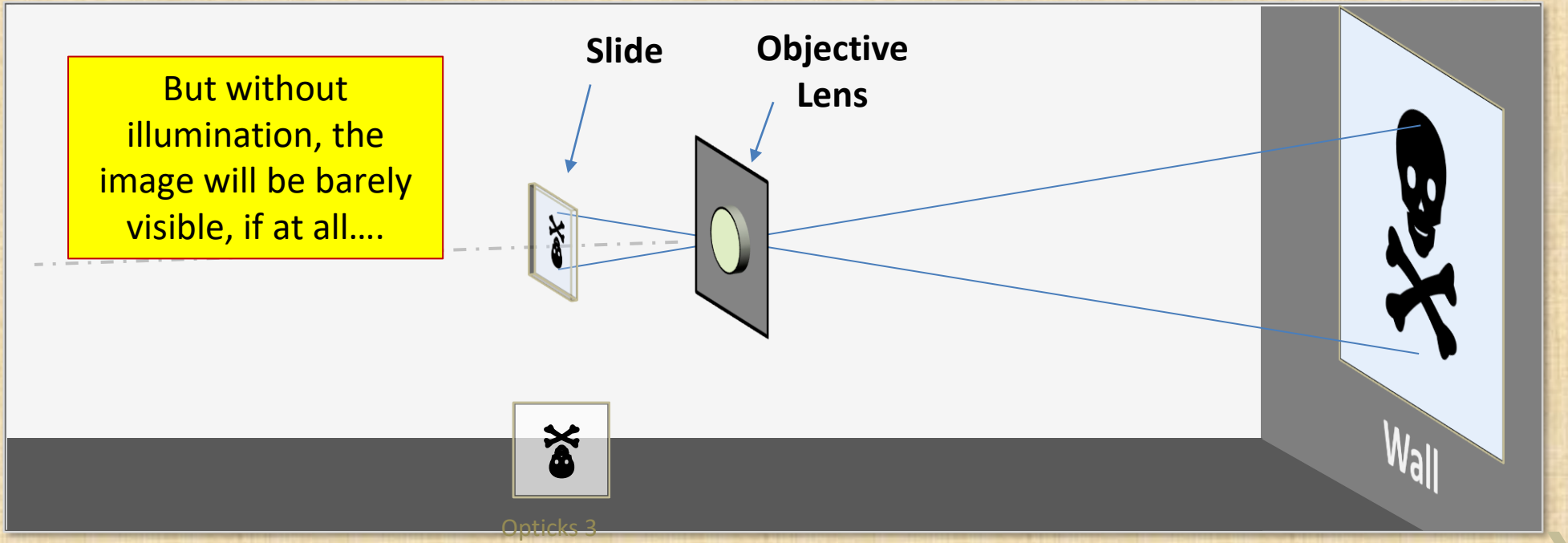


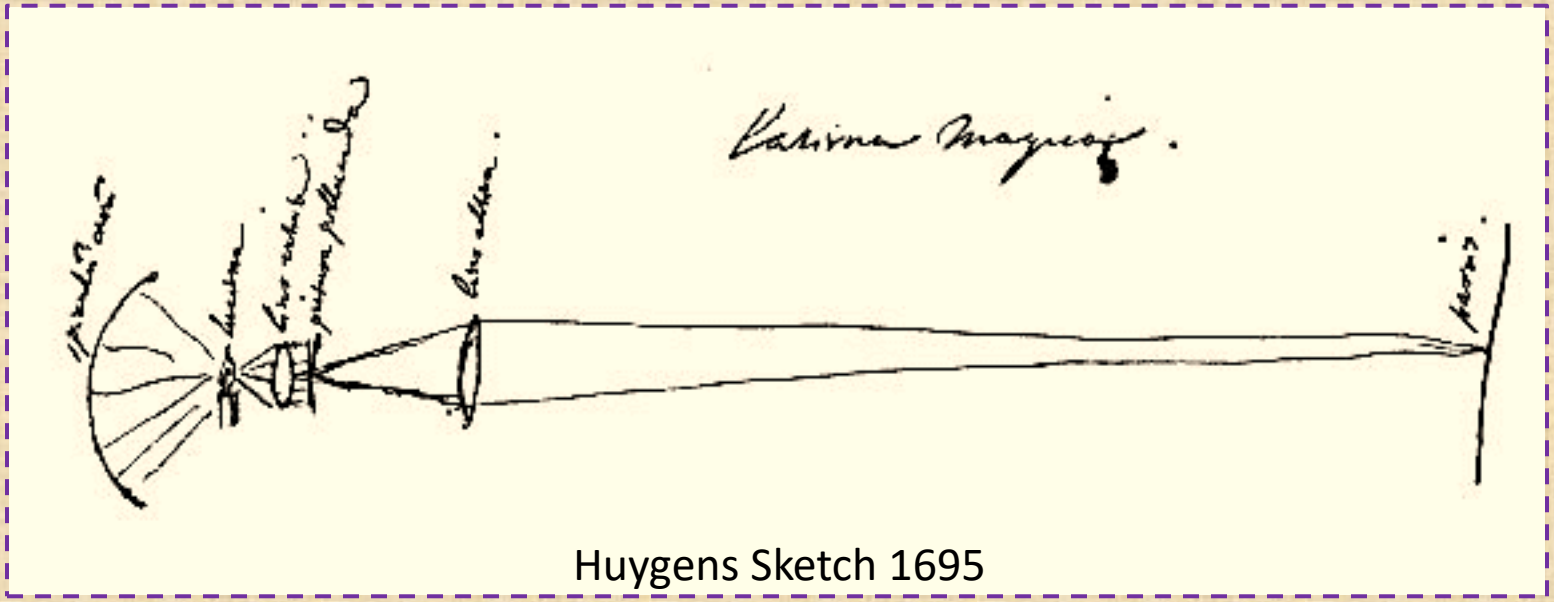
Huygens Sketch 1695



MAGIC LANTERN

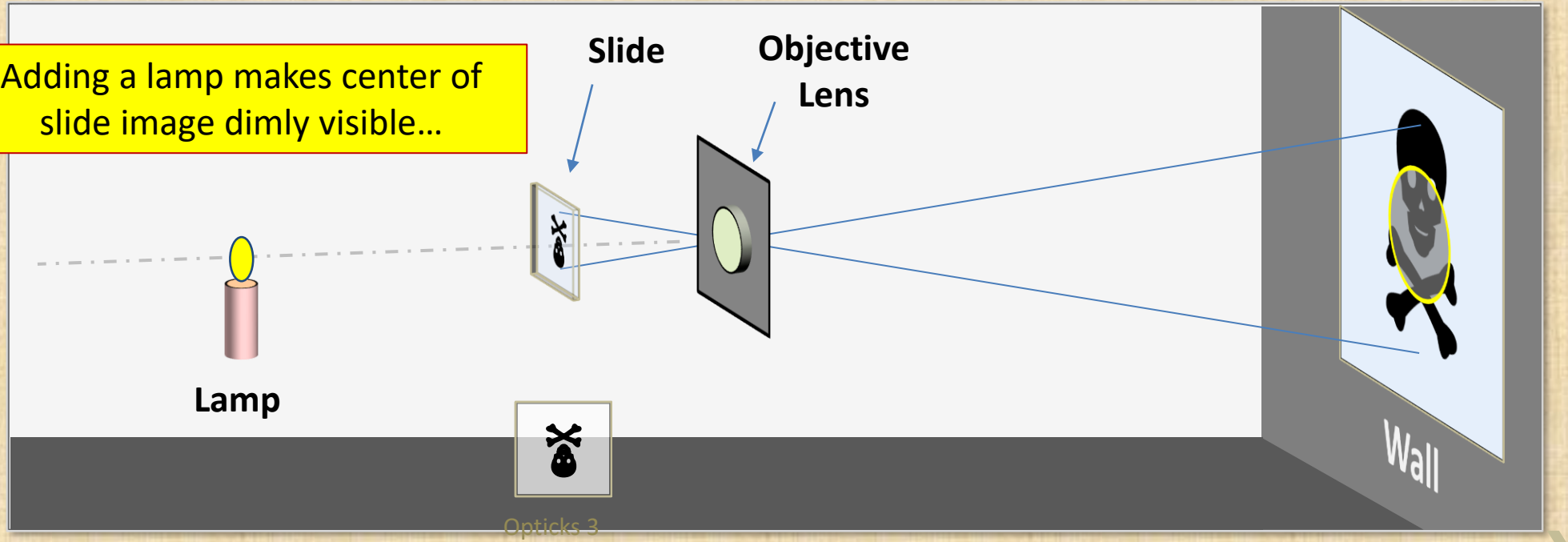
Christiaan Huygens
1629-1695
Dutch Physicist

Built and demonstrated a Magic Lantern *ca* 1659



Huygens Sketch 1695

Adding a lamp makes center of slide image dimly visible…



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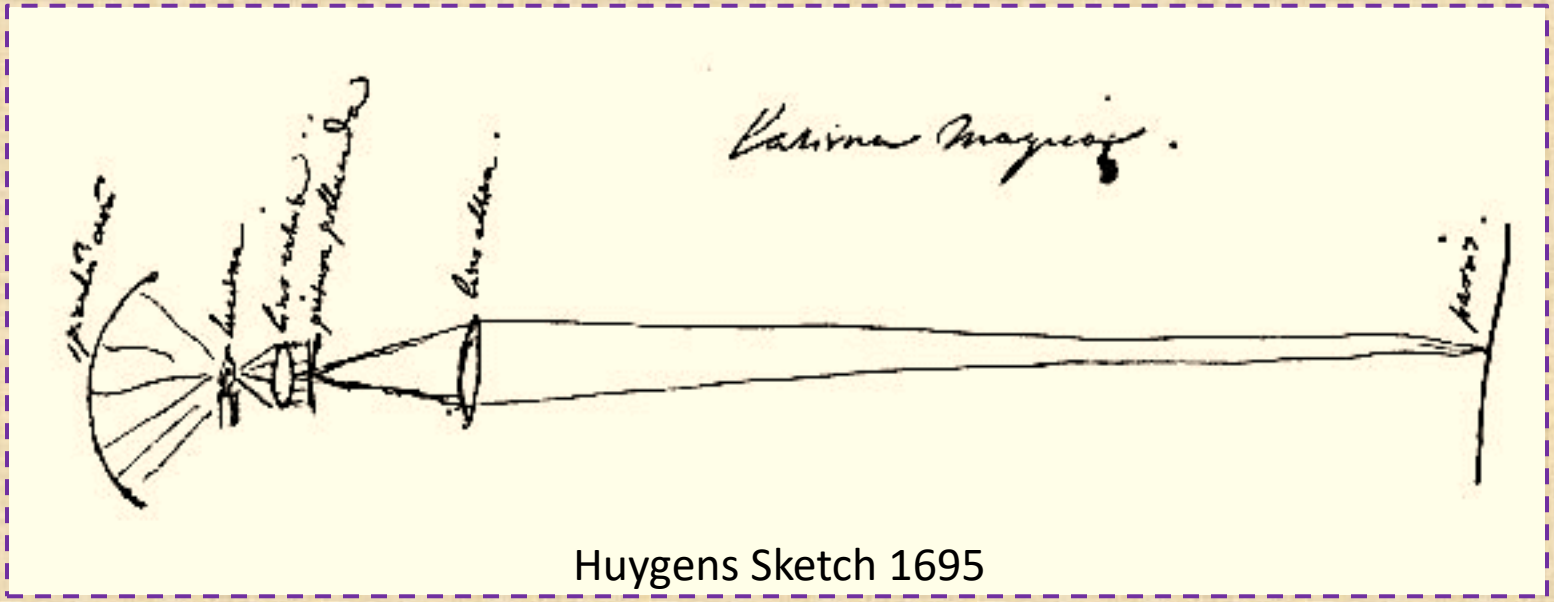
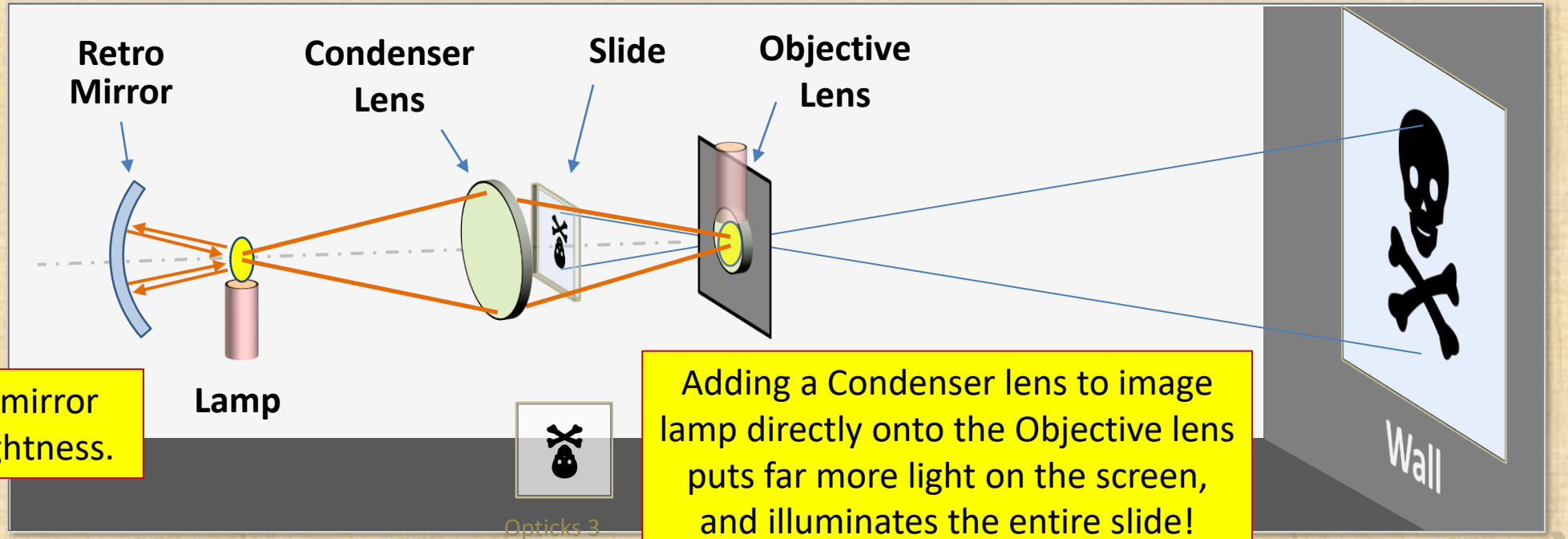


Huygens Sketch 1695



Adding a retro-mirror doubles the brightness.

Adding a Condenser lens to image lamp directly onto the Objective lens puts far more light on the screen, and illuminates the entire slide!

MAGIC LANTERN

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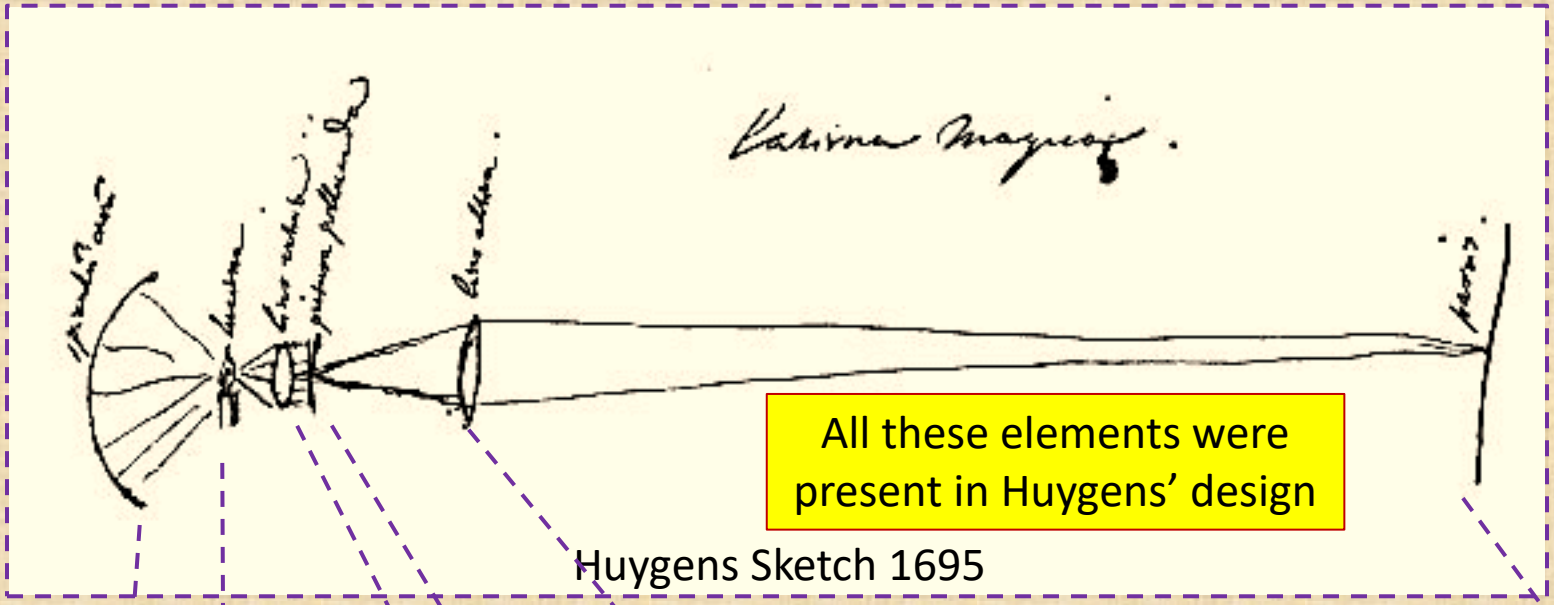
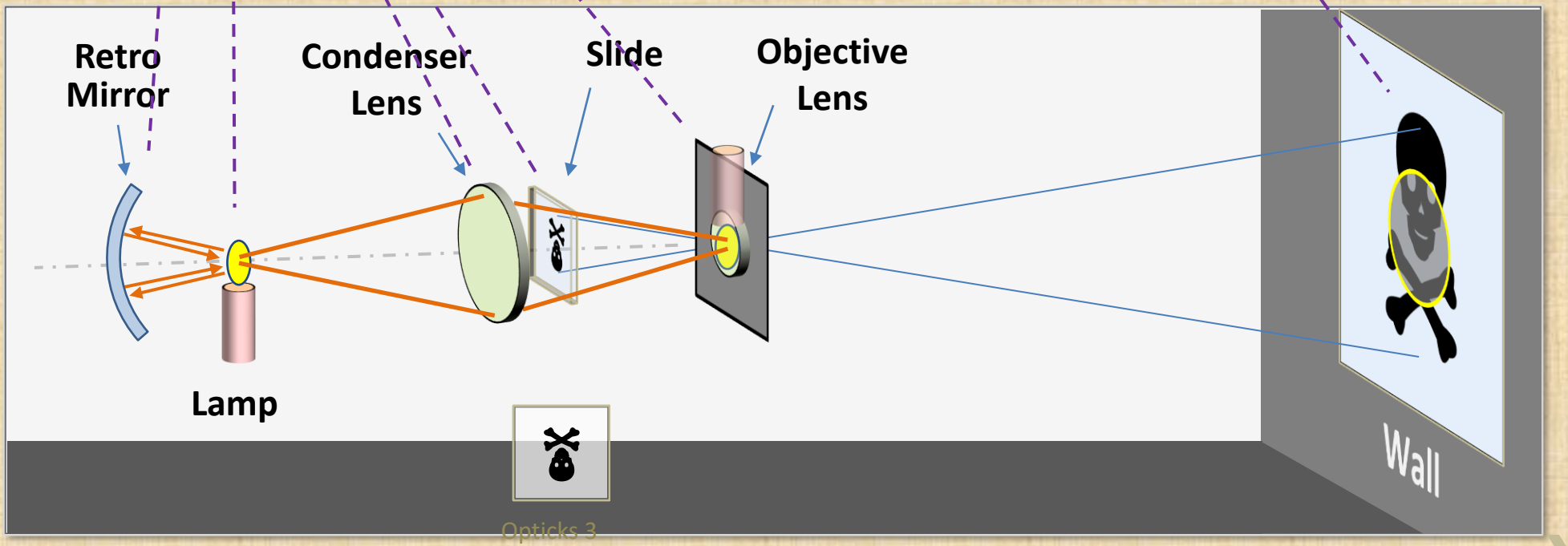


Huygens Sketch 1695



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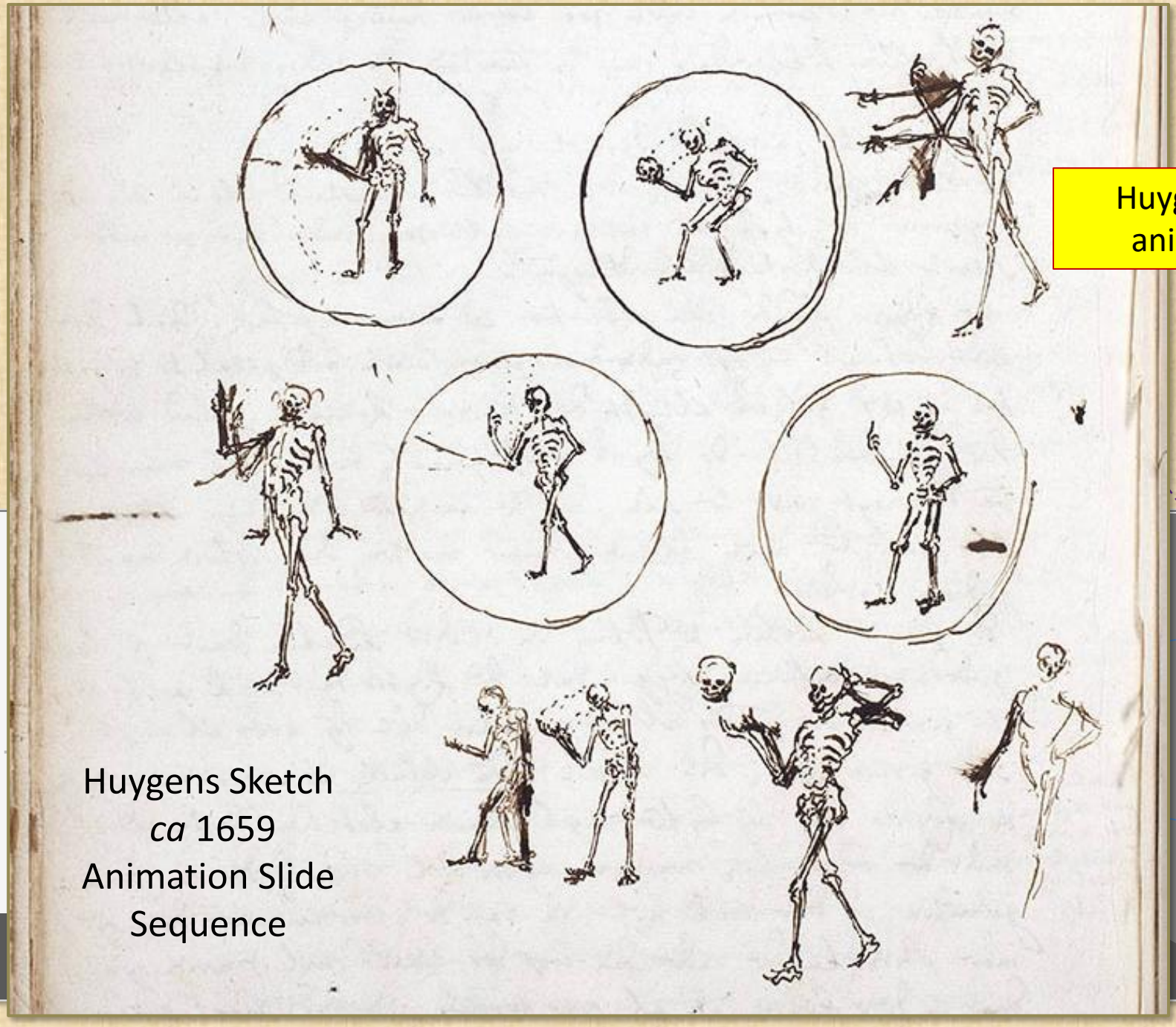


Huygens Sketch
ca 1659
Animation Slide Sequence

Huygens did animation

MAGIC LANTERN

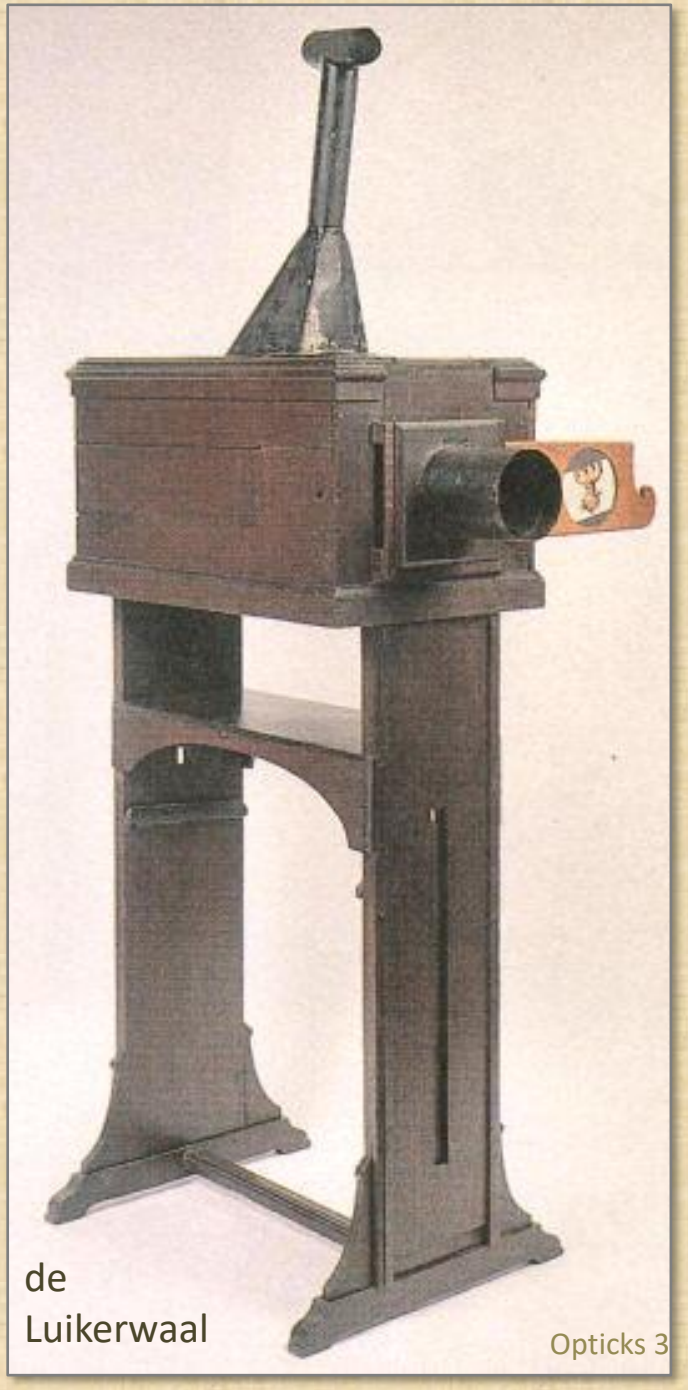
Oldest surviving Magic Lantern?

1720 or earlier

Jan van Musschenbroek
Dutch Instrument Maker

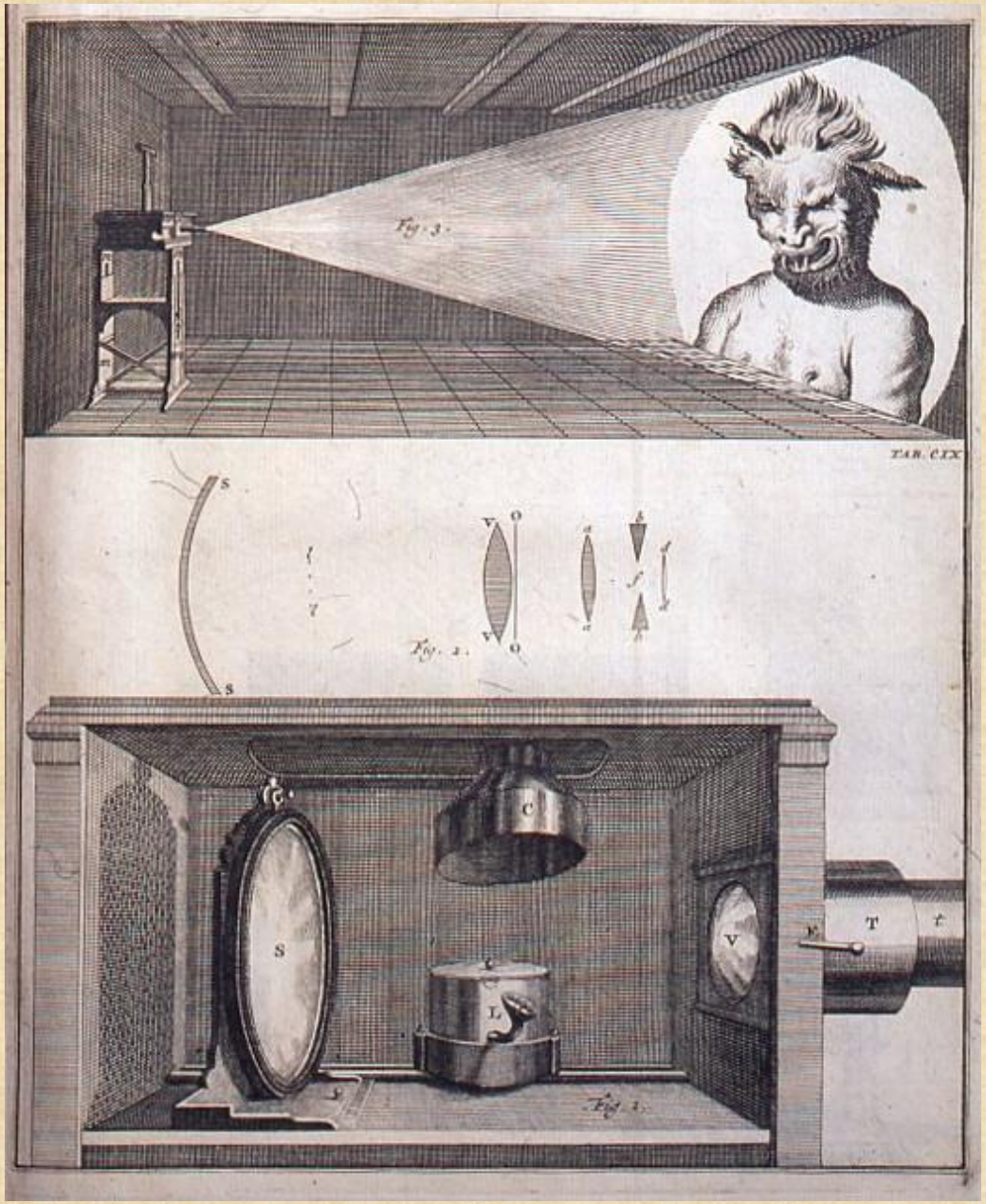
Museum Boerhaave
Leiden

from collection of Prof Gravesande



de Luikerwaal

Opticks 3



from Willem Gravesande's 1720 book *Physices Elementa Mathematica*

MAGIC LANTERN

Oldest surviving Magic Lantern?

1720 or earlier

Jan van Musschenbroek
Dutch Instrument Mak

Museum Boerhaav
Leiden

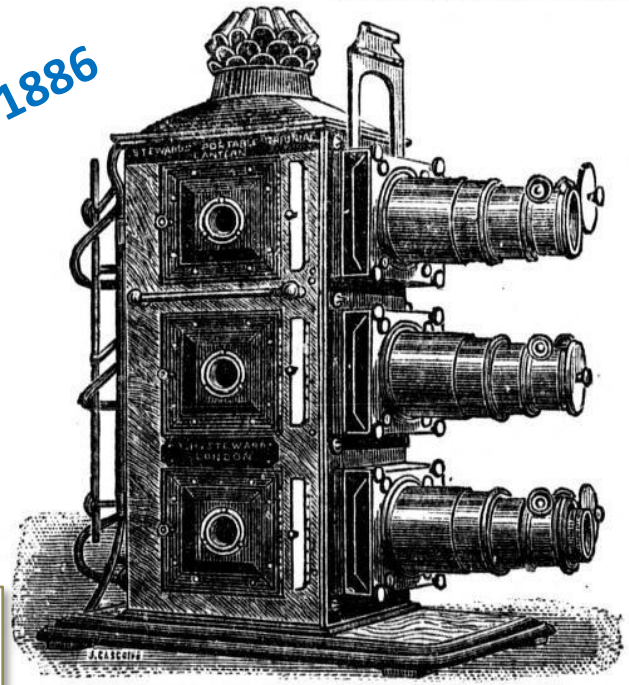
from collection of Prof Gravesande

from Willem Gravesande's 1720 book
Physices Elementa Mathematica

MAGIC LANTERNS EVOLVE

"Bi-Unial"

1886



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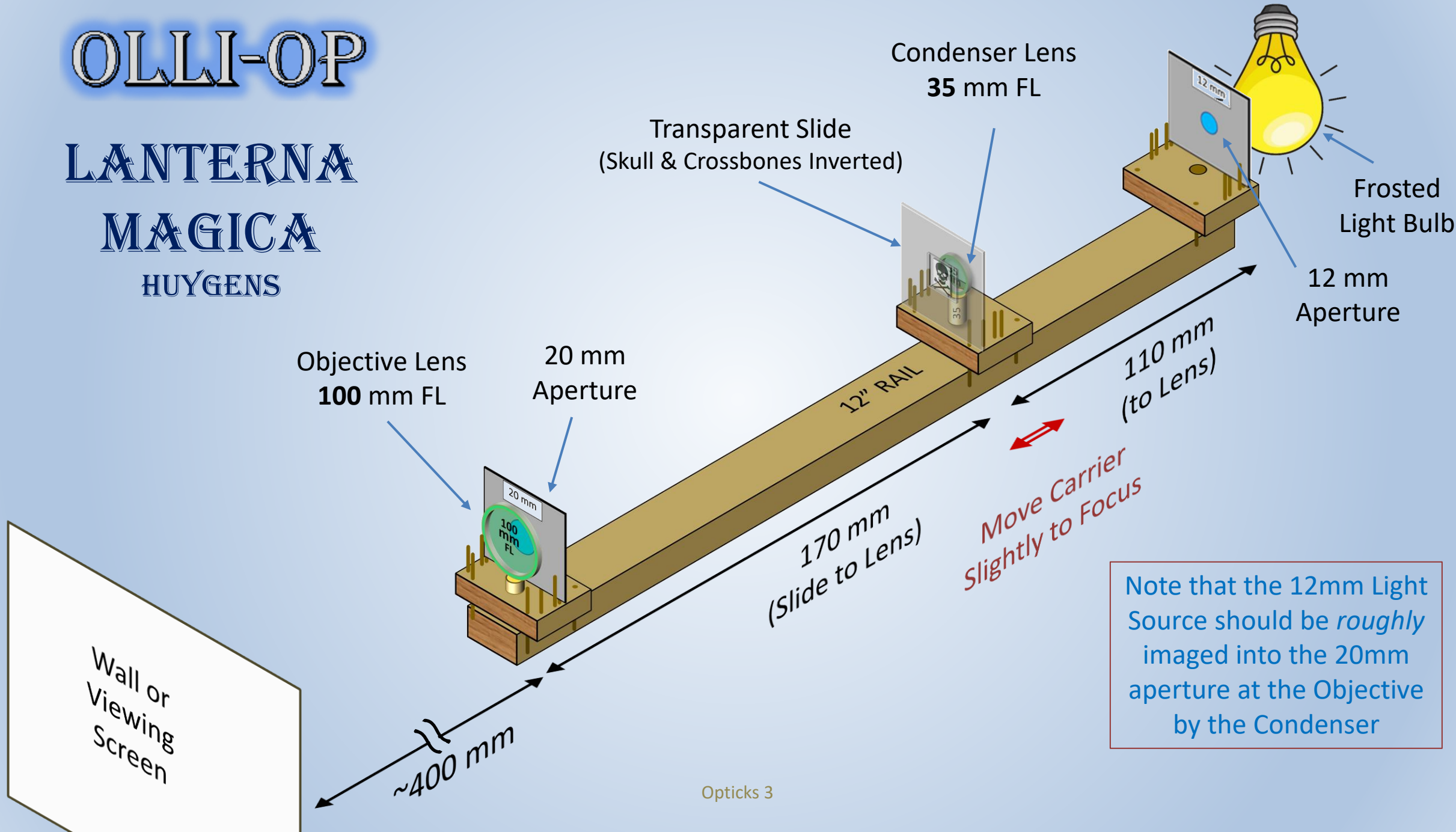
MAGIC LANTERNS EVOLVE

OLLI-OP

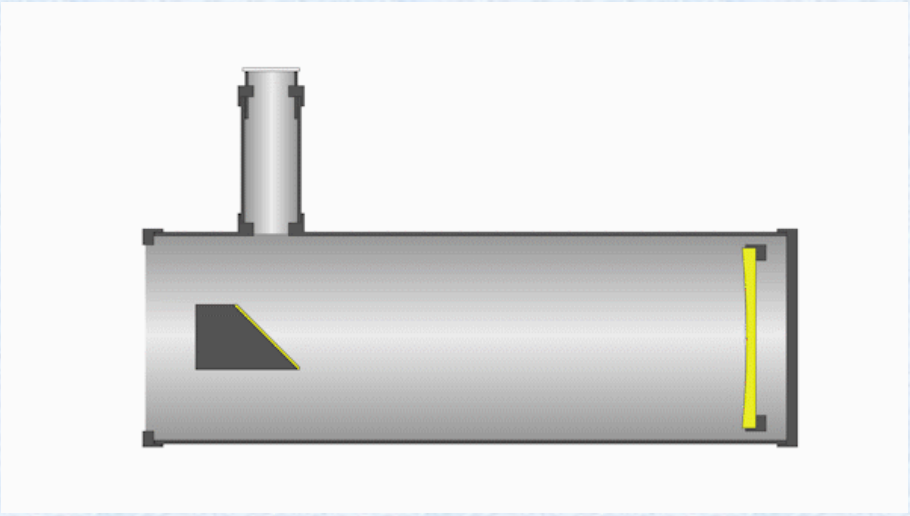
LANTERNA MAGICA

HUYGENS

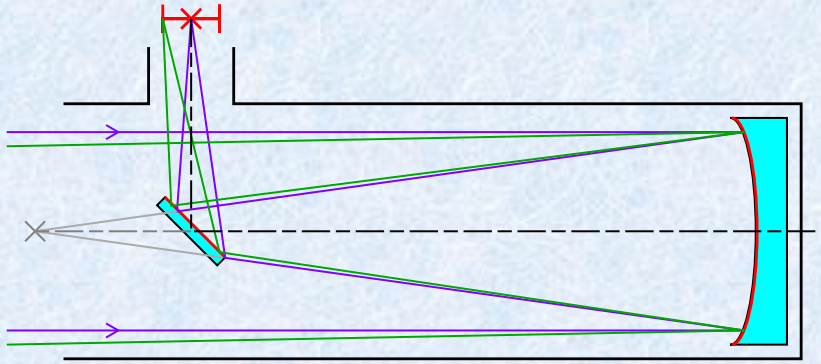


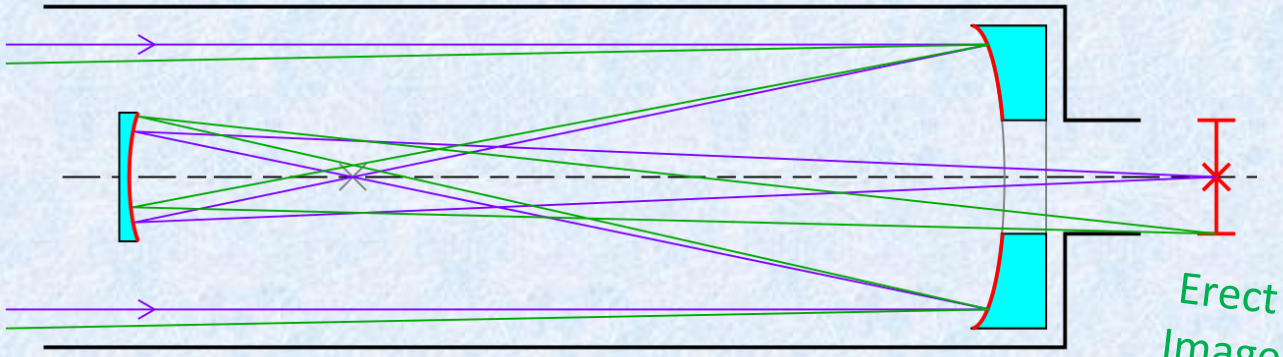
Note that the 12mm Light Source should be *roughly* imaged into the 20mm aperture at the Objective by the Condenser

What About Newton's Reflecting Telescopes?



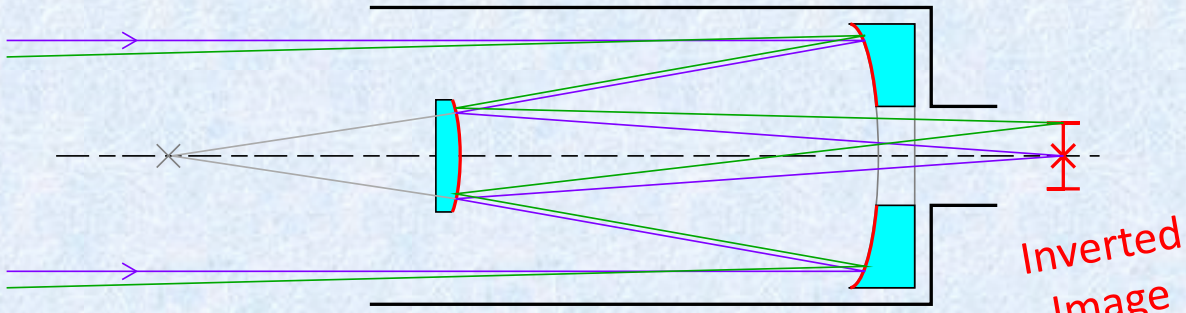
Newton's Solution
built in 1668





Gregorian
James Gregory (Scottish) 1663 *Optica Promota*

Proposed, not built



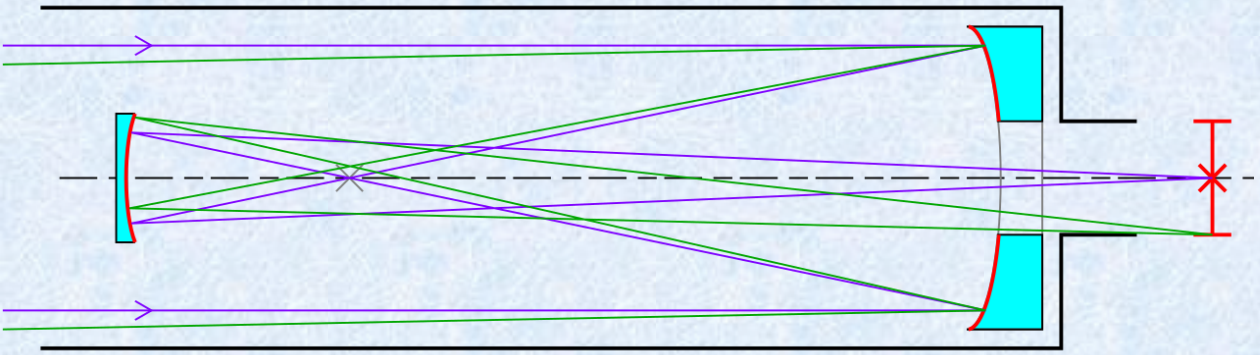
M. Cassegrain
Proposed ca 1663

Proposed, not built

James Short
Edinburgh
Instrument
Maker

Made over 1300
Telescopes
mid 1700's
Mostly
Gregorian

…including several large Gregorians, up to 19.5"

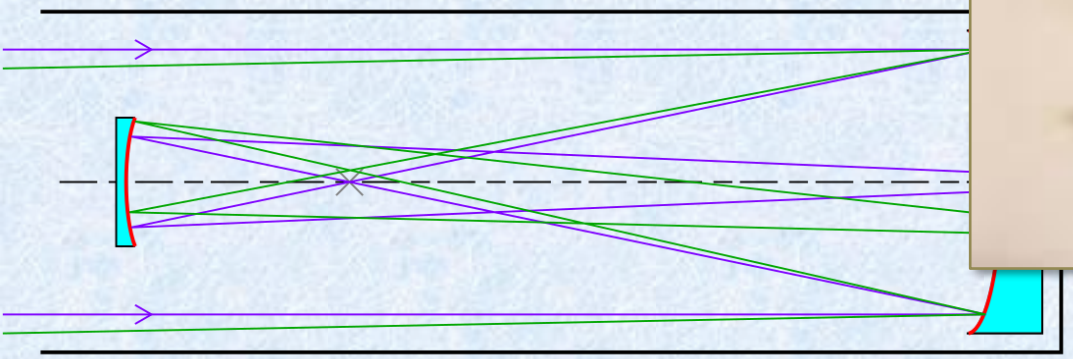


4.5 inch
Gregorian
Reflector
(1737)

James Short
Edinburgh
Instrument
Maker

Made over 1300
Telescopes
mid 1700's
Mostly
Gregorian

...including se
large Gregor
up to 19.



Binocular Version
ca 1760

4.5 inch
Gregorian
Reflector
(1737)

Inventor of the Cassegrain Design:

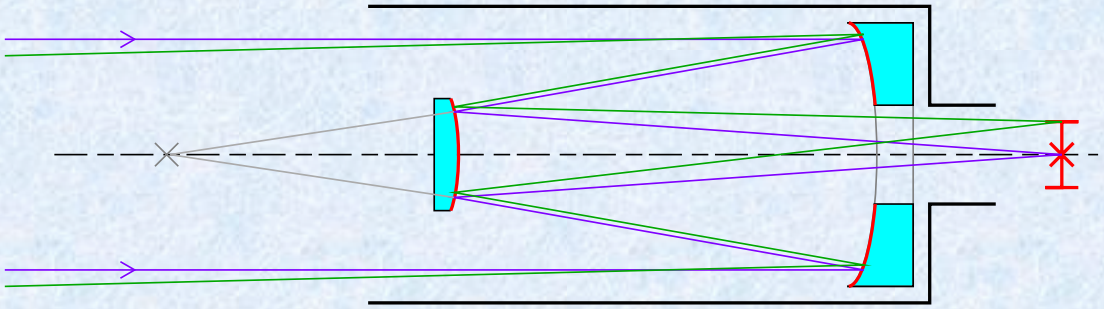
Laurent Cassegrain ?

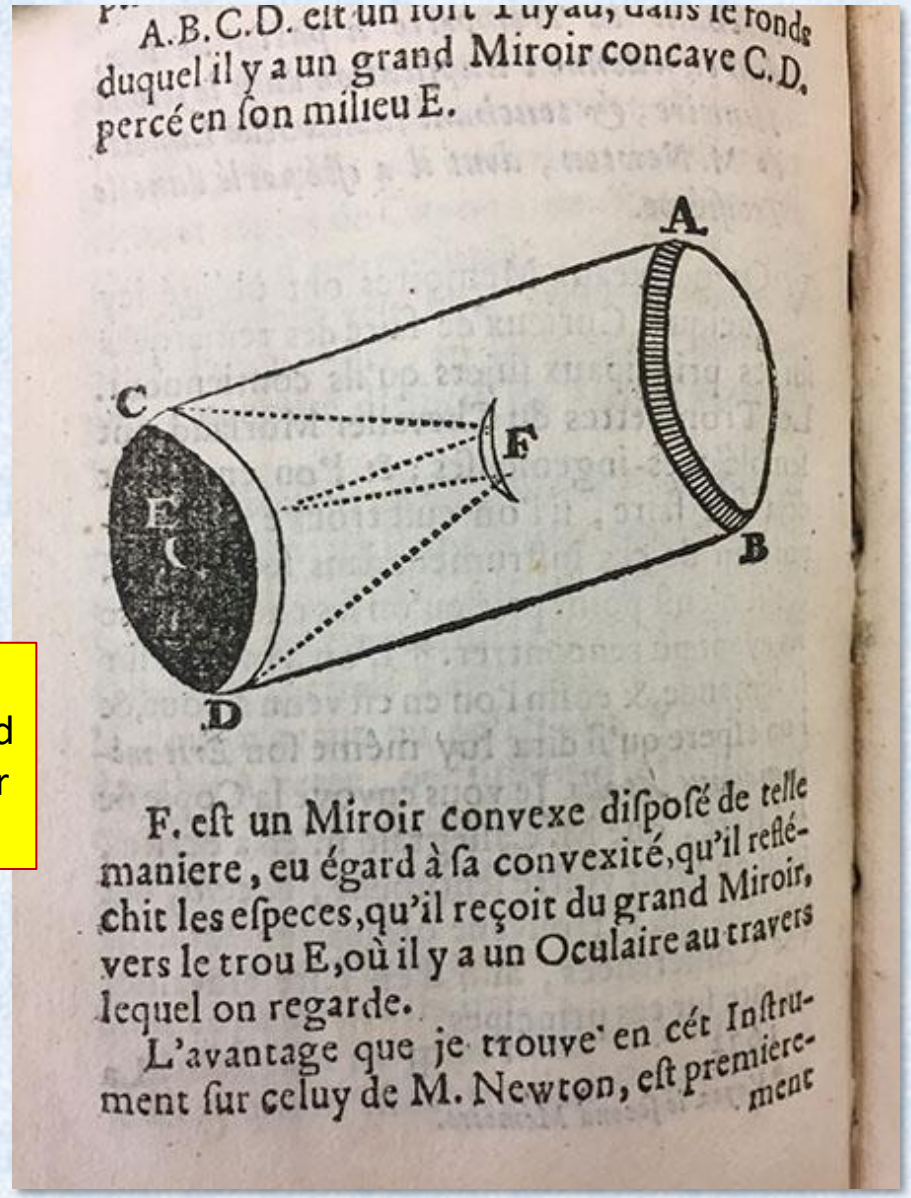
Catholic Priest

Chartre Region

(*ca* 1629-1693

Idea came to light only via another author who had heard about it, referred to originator only as M. Cassegrain.





Journal des Scavans (1672)

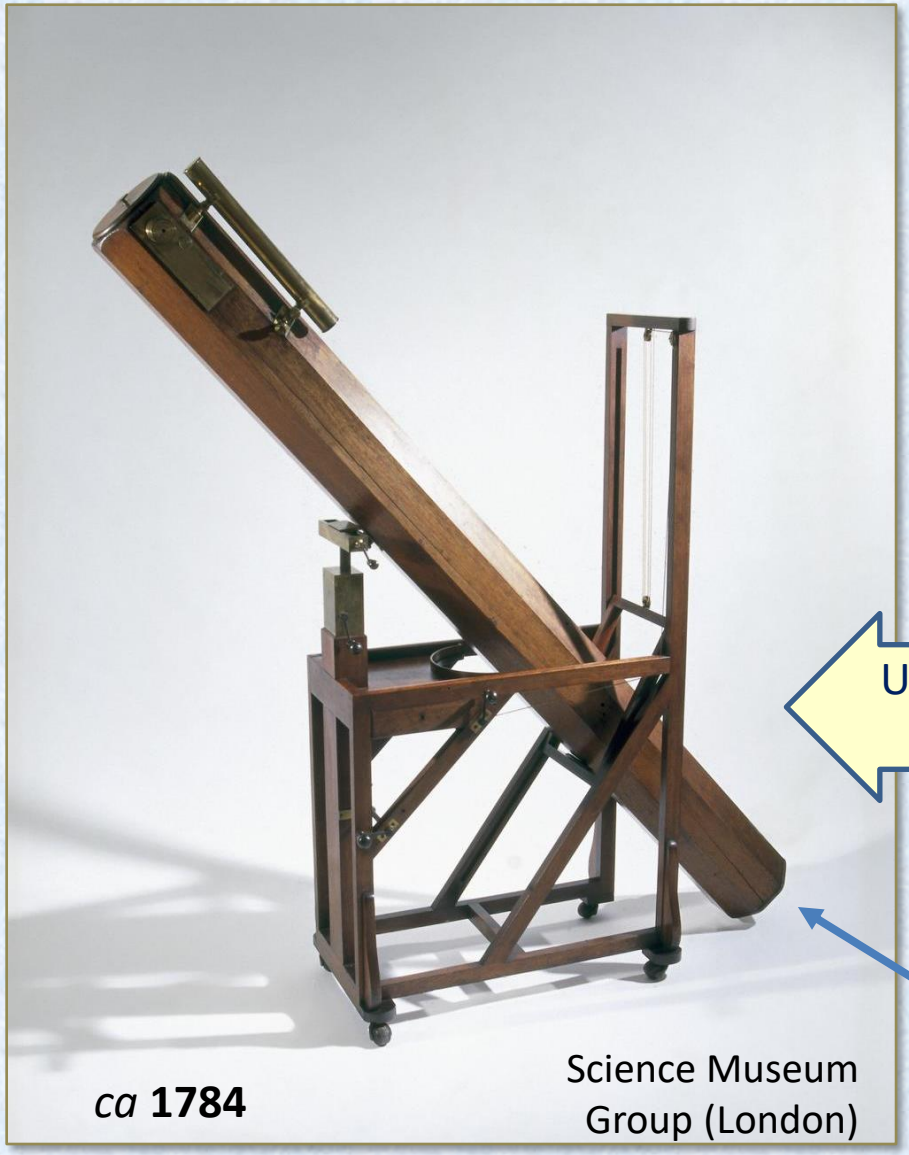
Meet the Herschels: German-British Astronomers

William
1738-1822

Caroline
1750-1848

Brother & Sister

They built over 60 complete Reflecting Telescopes and hundreds of mirrors, from 6 inch to 49 inch diameter, beginning in 1774



ca **1784**

Science Museum Group (London)

Two examples of Herschel
6 1/8” Diameter
7 ft Focal Length
Newtonian Reflectors

Used to Discover Uranus 1781?

“Caroline’s Telescope”

Speculum Metal Mirrors

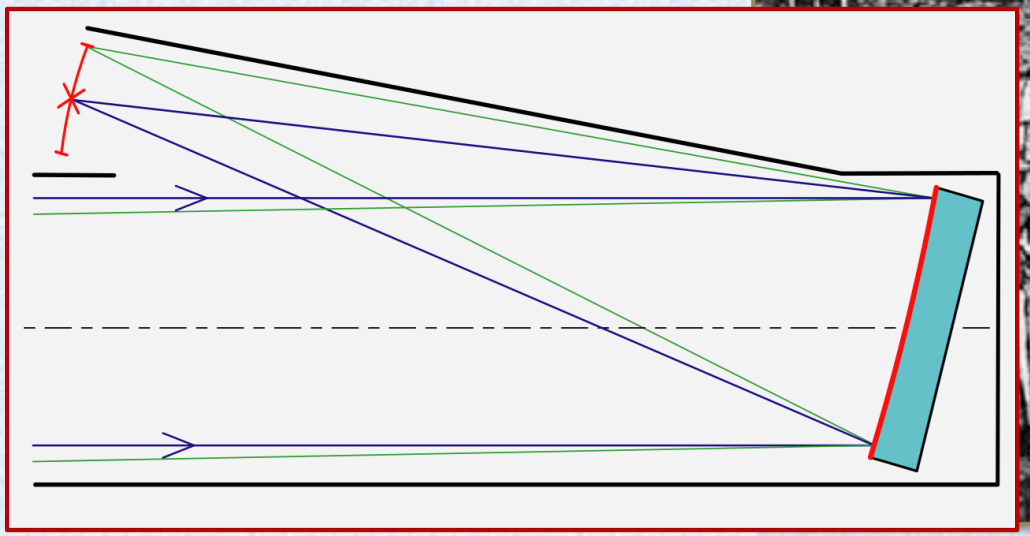
ca **1795**?

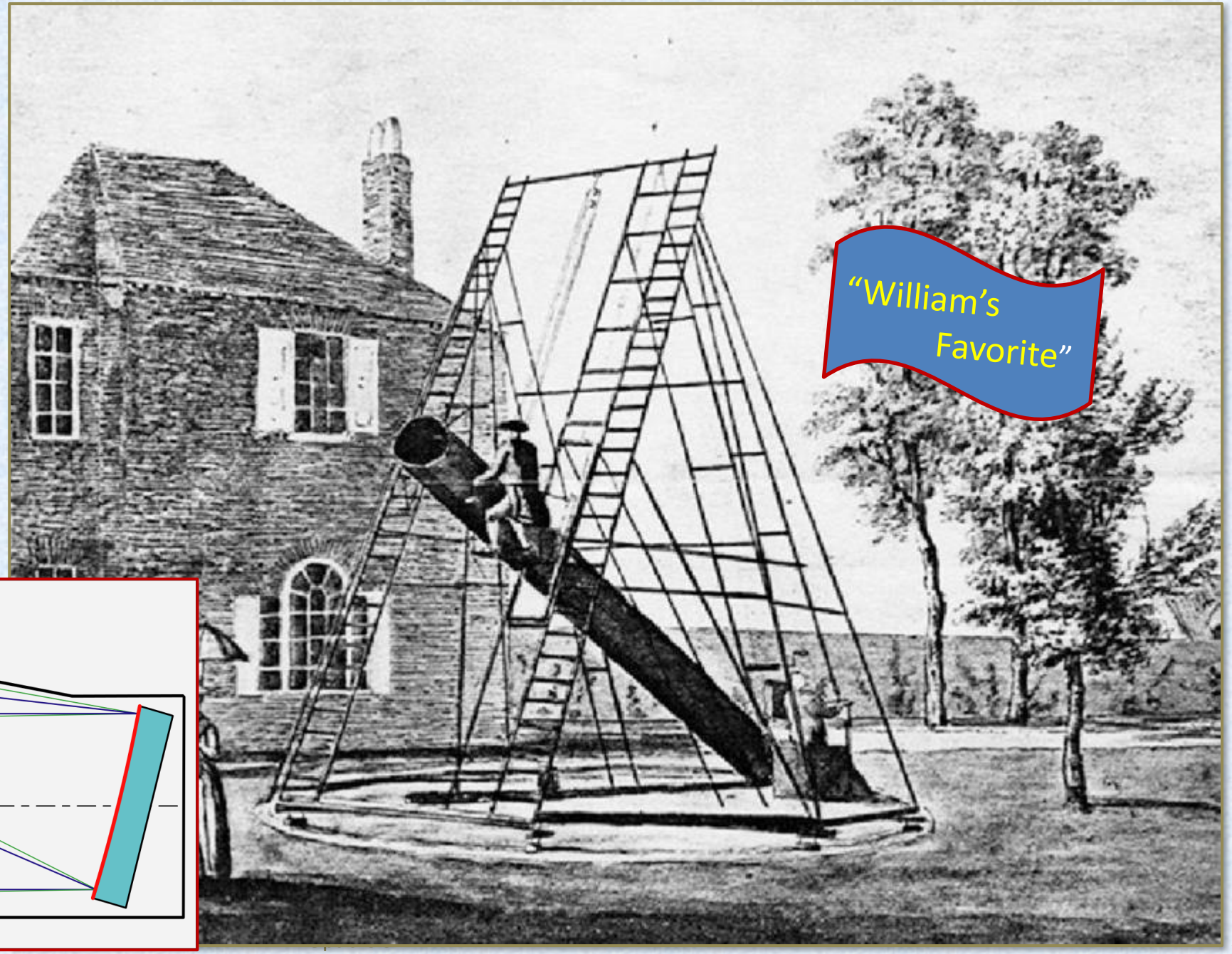
Science Museum Group (London)

They worked their way up to a 20 Foot Focal Length Reflector by 1783

~ 18 “ Diameter

A new Off-Axis design was used, now called **Herschel-Lomonsov**



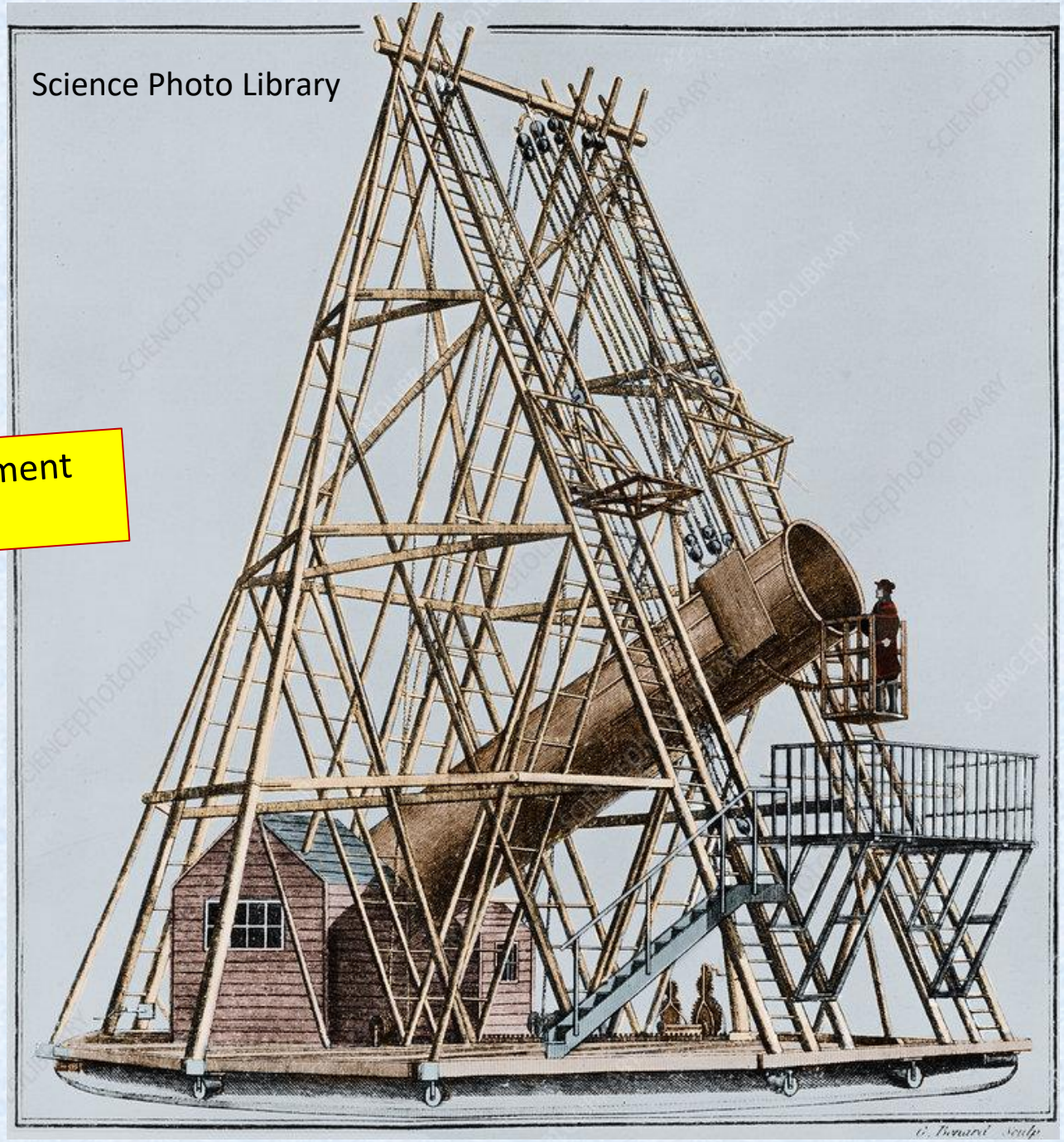


The Great Forty-Foot Telescope

constructed from 1785-89 at the Herschel Observatory in Slough, England

49 inch Speculum Mirror

Built using government grant funds.



It was a public sensation….

…but not very useful for Astronomy

The Great Forty-Foot Telescope

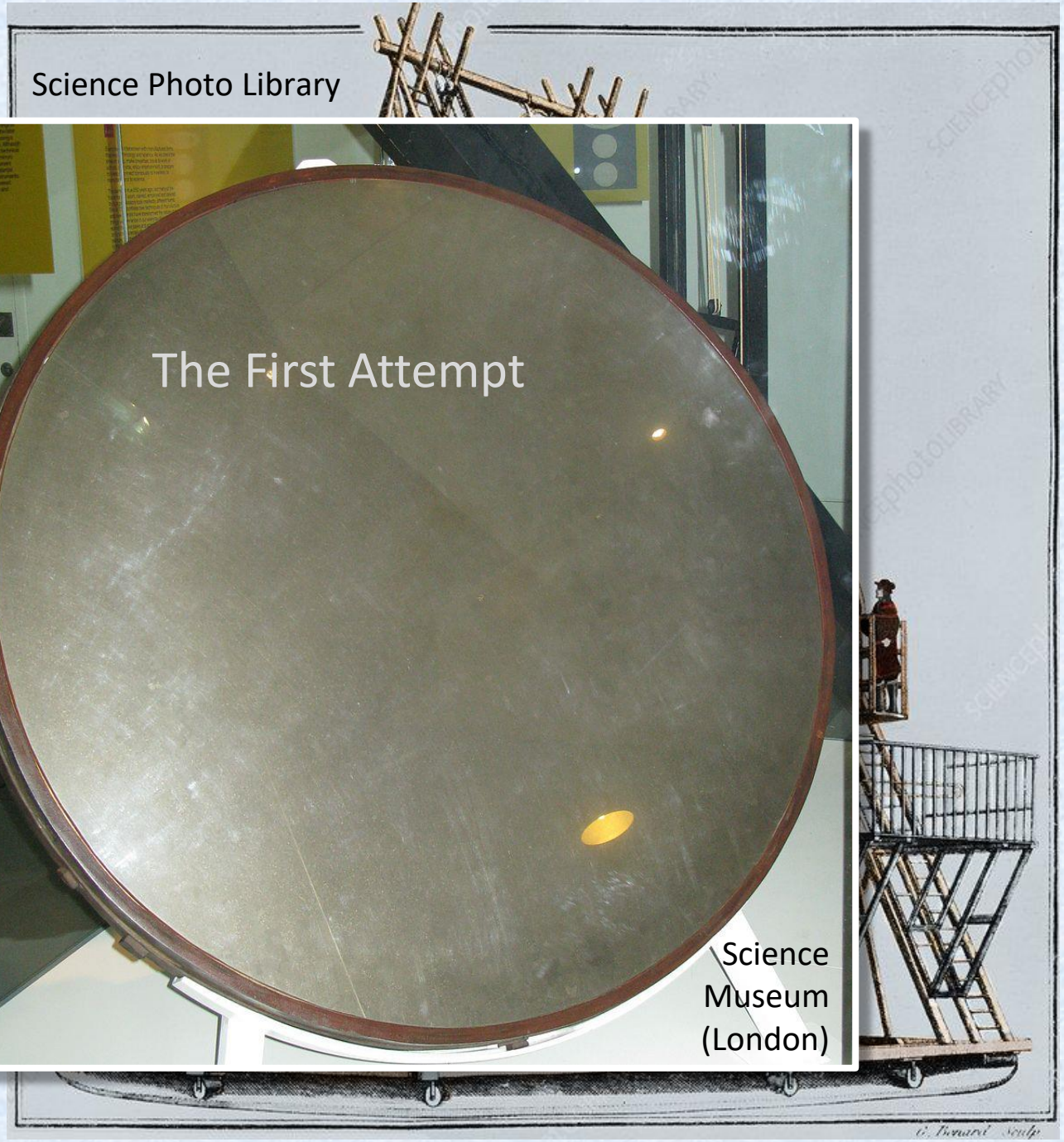
constructed from 1785-89 at the Herschels' Observatory in Slough, England

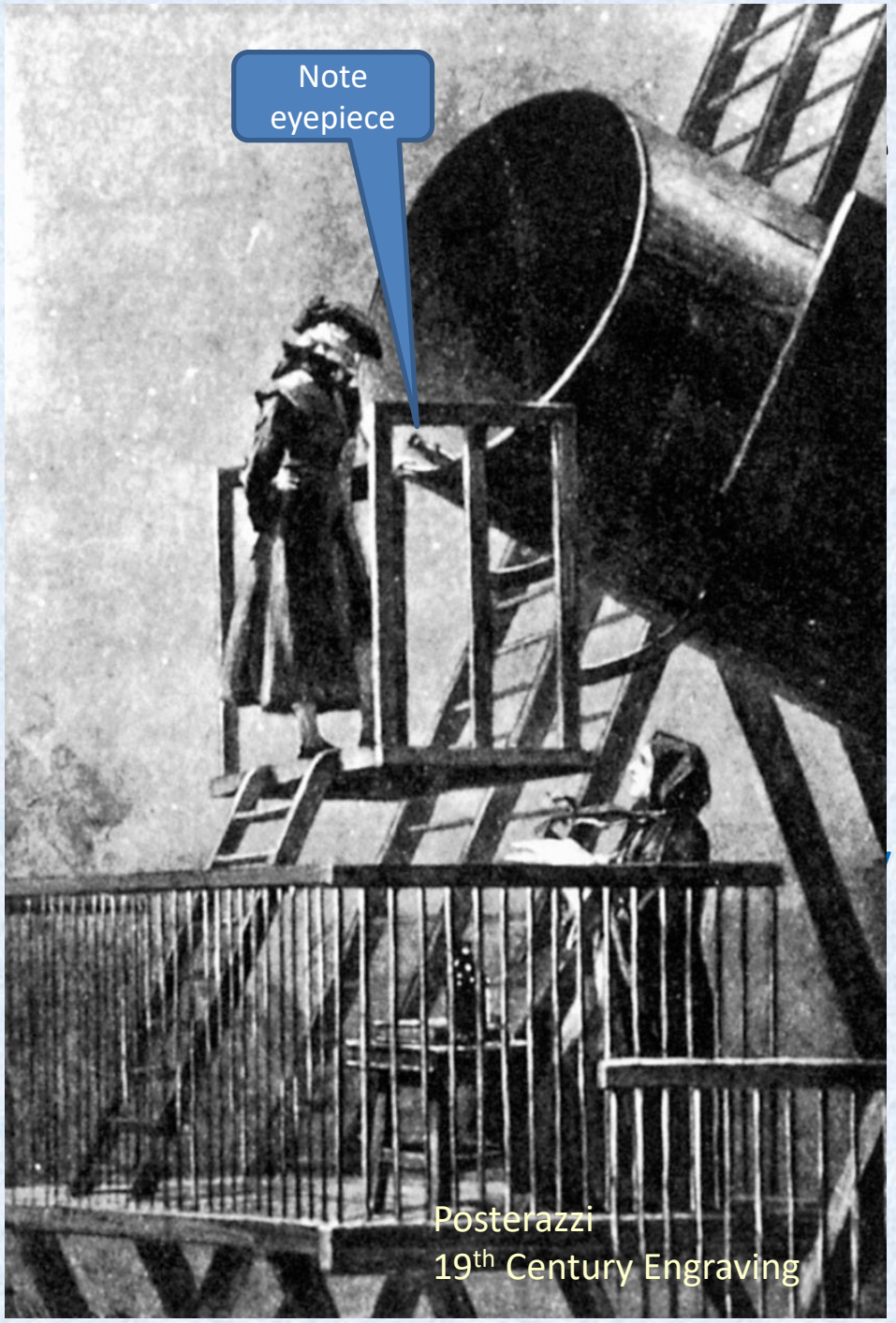
49 inch Speculum Mirror
Tin-Copper-Arsenic

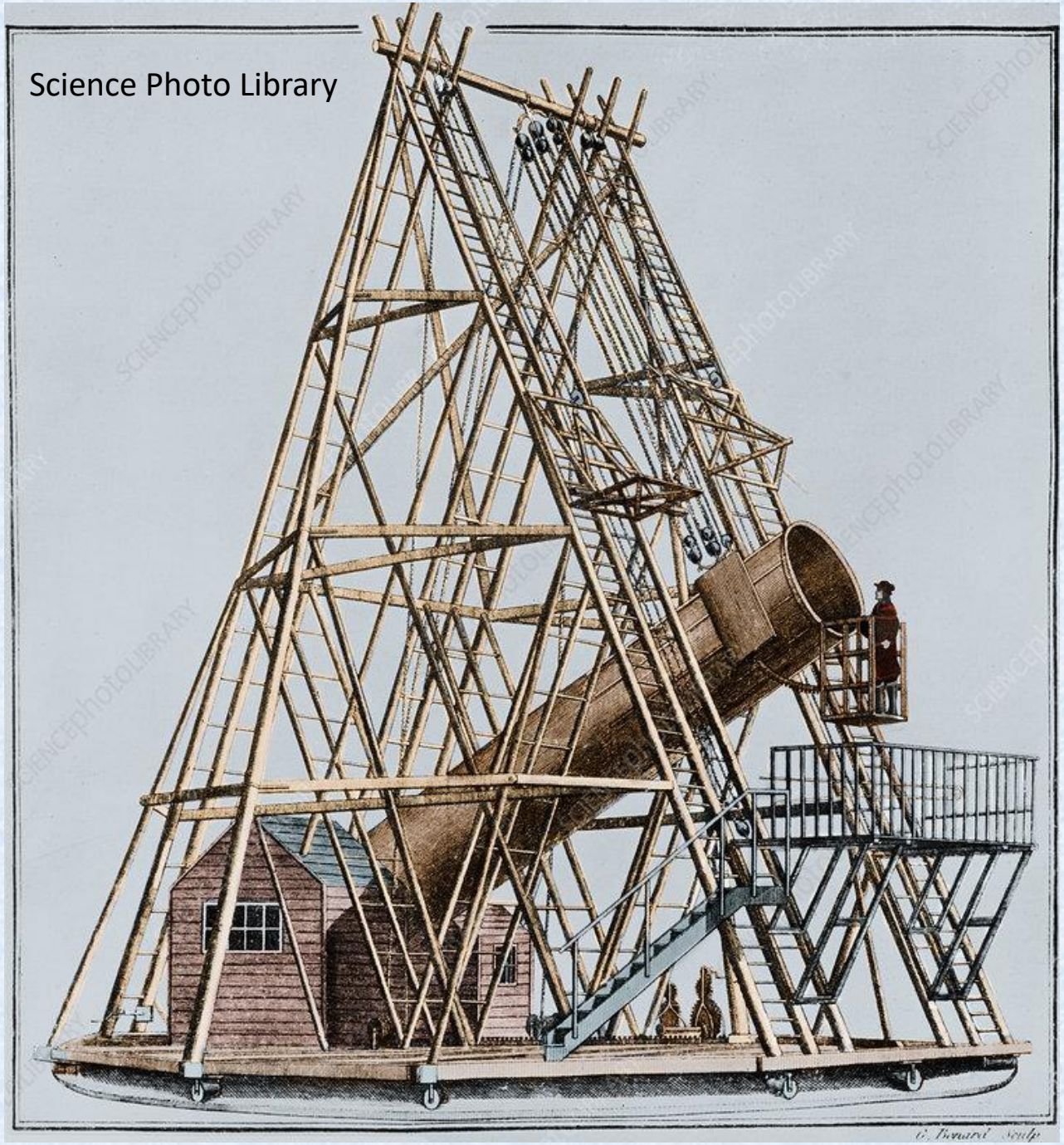
It was a public sensation….

…but not very useful for Astronomy

Their first 49" mirror was too thin and floppy, but was stored carefully and has survived.

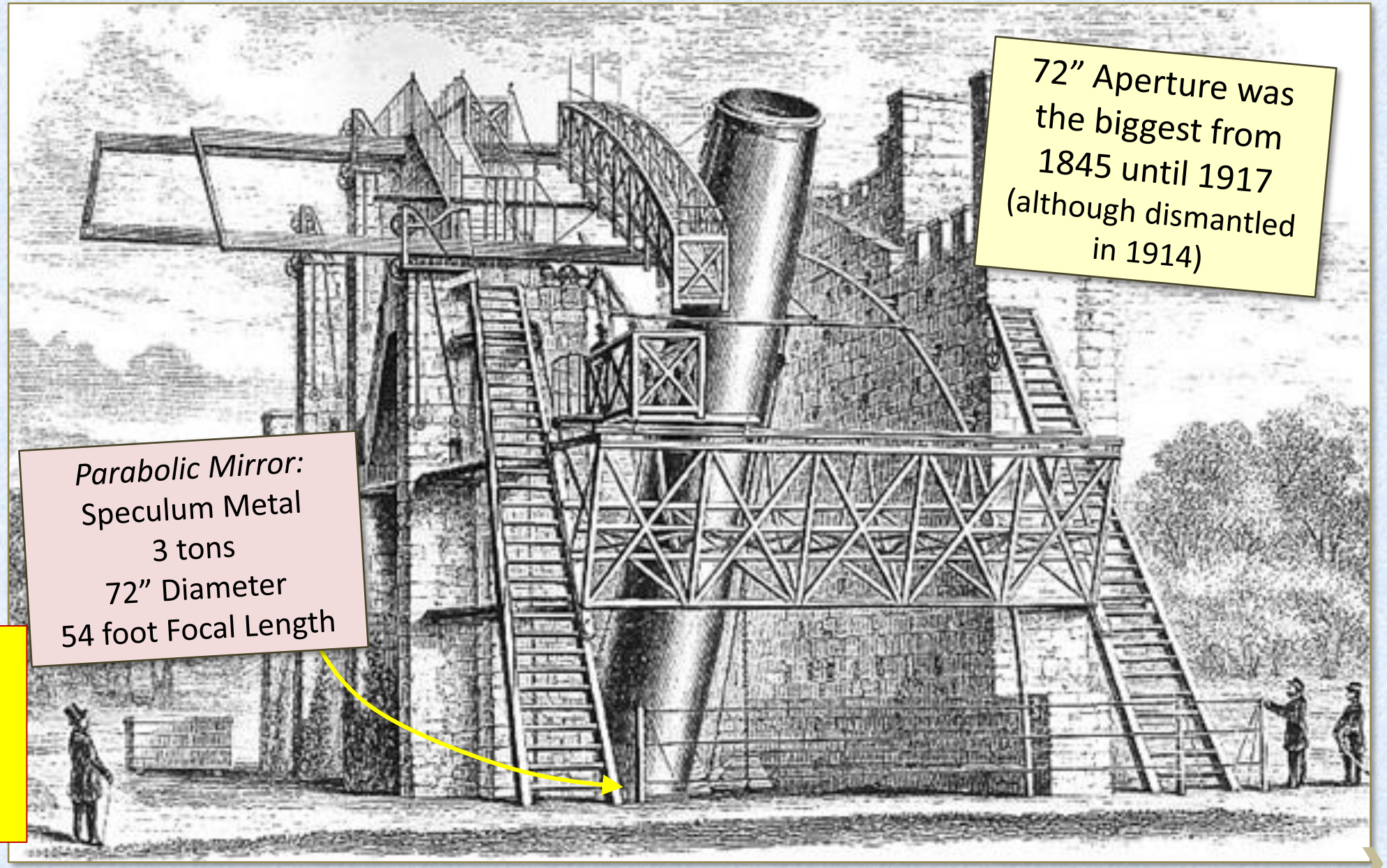



Note eyepiece
Posterazzi
19th Century Engraving


Science Photo Library

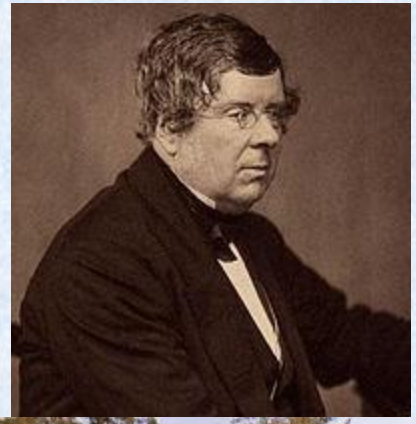
Leviathan of Parsonstown, Rosse 6 ft Telescope: 1845

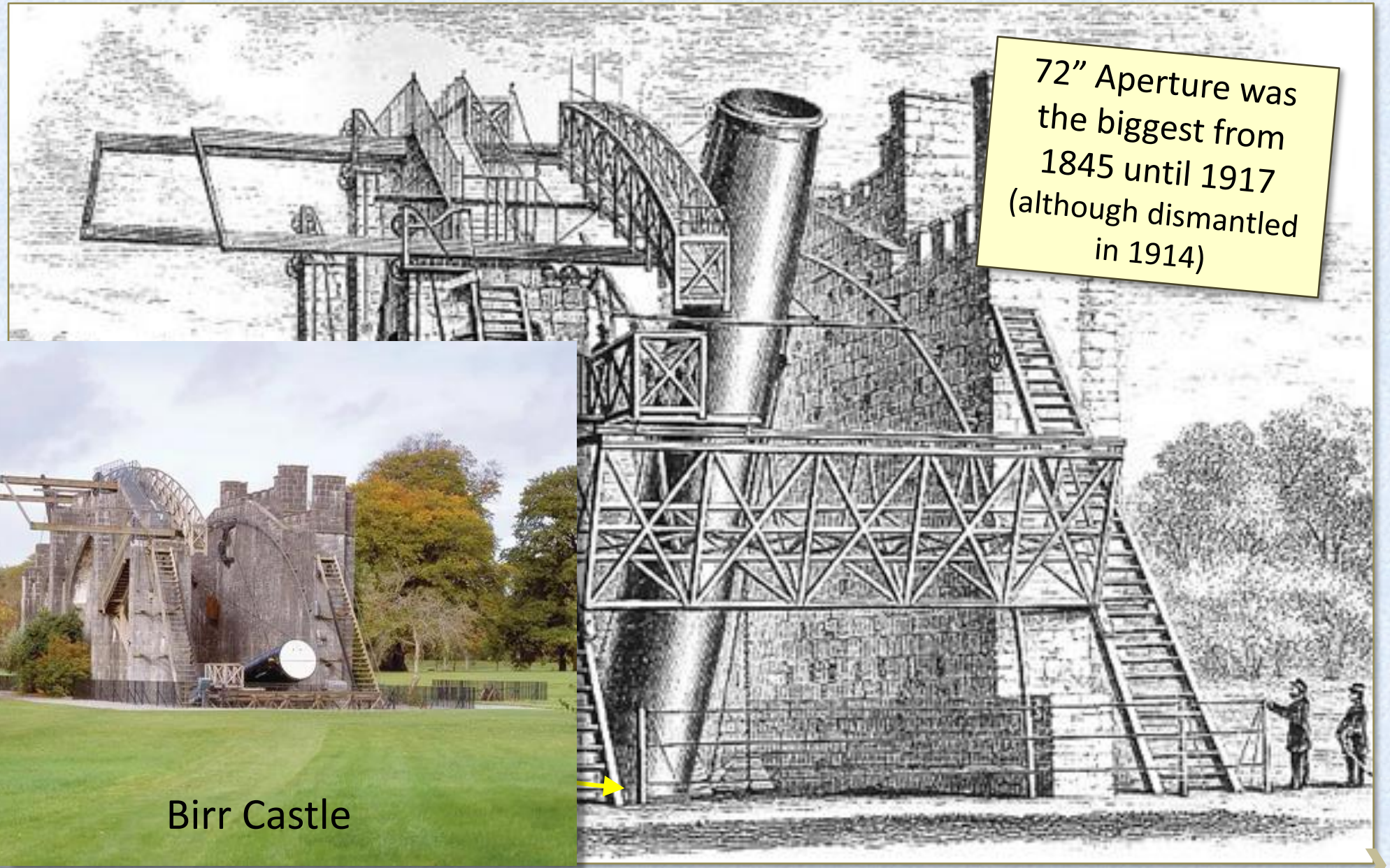
William Parsons
3rd Earl of Rosse
Birr Castle
County Offaly, Ireland



Used for serious astronomy, visited by astronomers worldwide. Could rotate East-West only slightly.

Leviathan of Parsonstown, the Rosse 6 ft Telescope: 1845





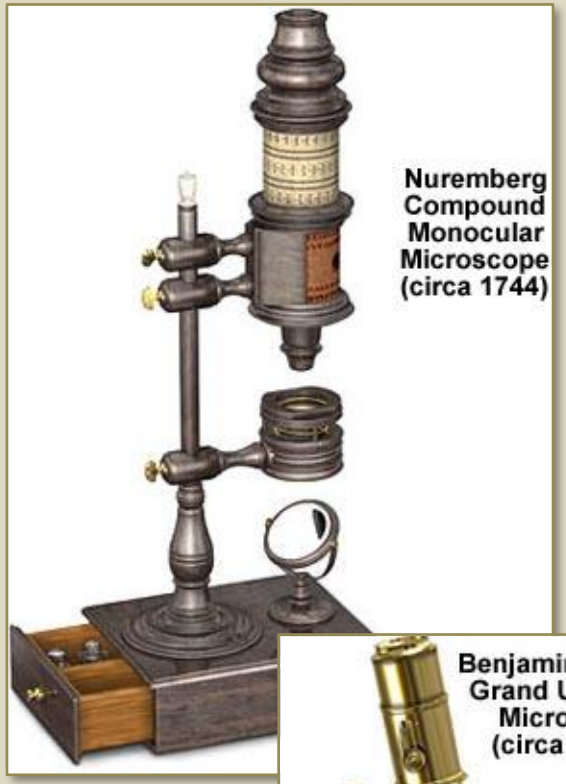
72” Aperture was the biggest from 1845 until 1917 (although dismantled in 1914)

Birr Castle

Late 17th Century Compound Microscopes

Primitive Optics

Figures from Molecular Expressions



18th Century Compound Microscopes

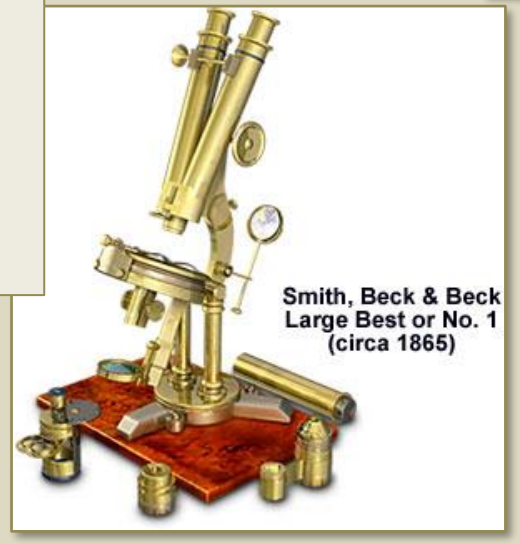
Little improvement in optics

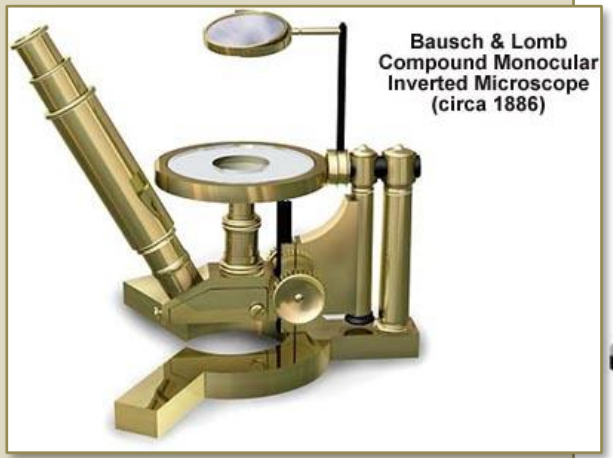
Figures from Molecular Expressions

19th Century Compound Microscopes

Major Optical Improvements

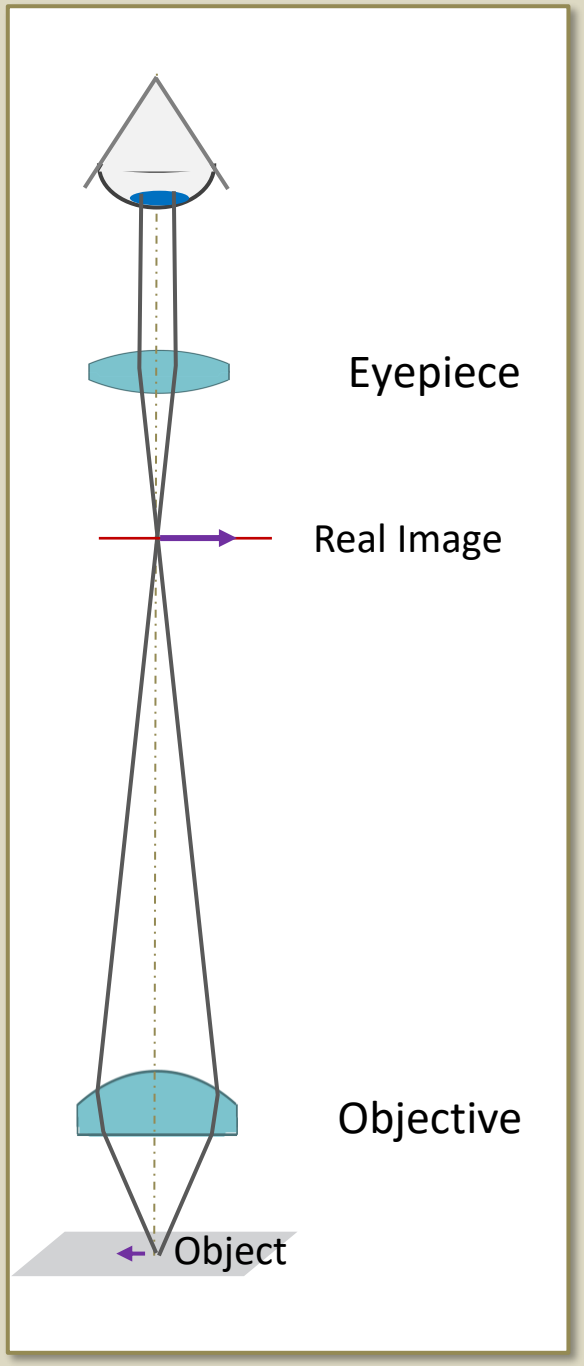
Lister Develops Achromatic Objective Theory (1826)

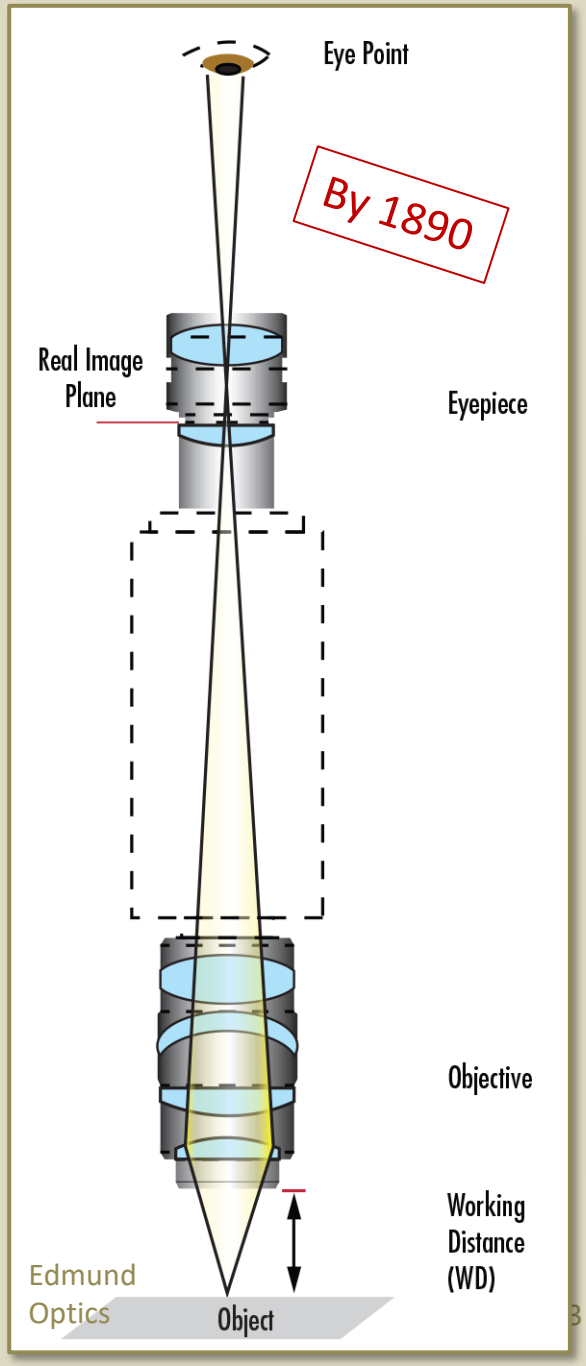




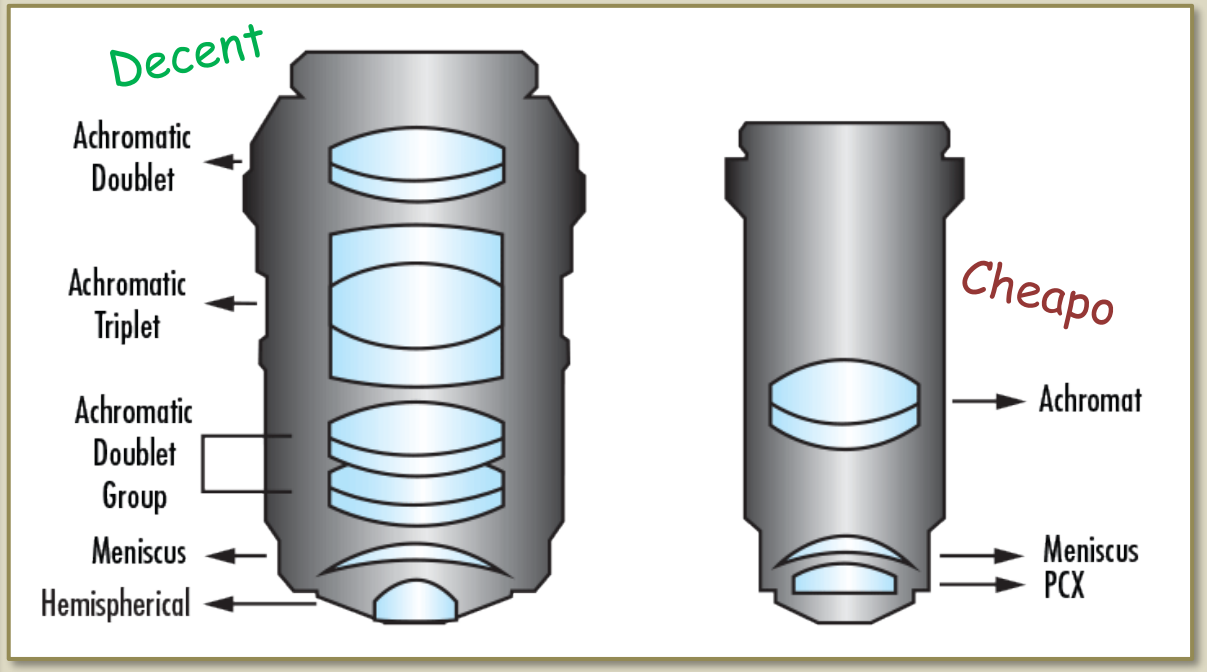
Figures from Molecular Expressions

Evolution of Compound Microscopes





By mid-20th Century



Opticks 3

- Laws of Reflection and Refraction
- Aberrations
- Newton
- Achromatic Lenses
- Fraunhofer
- Refractor Telescopes
- Toys
- Magic Lantern Projectors
- Reflector Telescopes
- Microscopes