



Opticks:

Optical Instruments from Ancient Times to the Present



Jan van Eyck
Arnolfini Wedding
1434



Session 2
Renaissance

OLLI at Illinois
Spring 2022

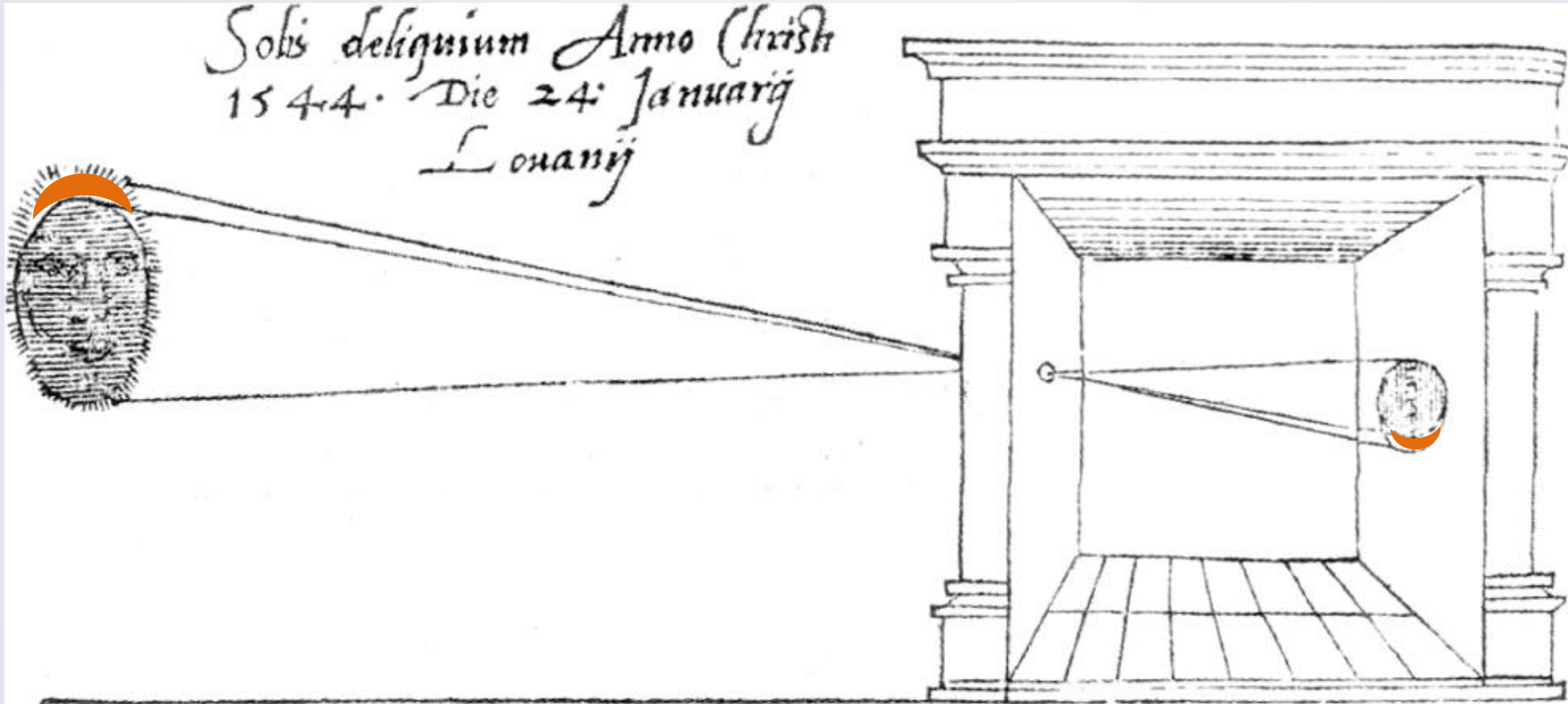
D. H. Tracy

Course Outline



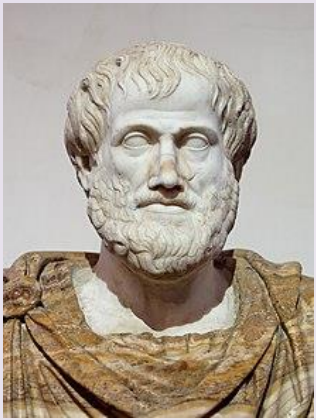
1. Beginnings: Optics in the Ancient World and the Middle Ages; Mirrors and Lenses
2. Renaissance and Pre-Renaissance developments. The eye. Early telescopes & microscopes. Art and Optics.
3. Newton's contributions leading to 18th and 19th Century developments in Optical instruments.
4. Modern Optics 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.

The Pinhole Camera: First published diagram



Frisius Gemma, Dutch Cartographer and Mathematician
De Radio Astronomica et Geometrico (1545)

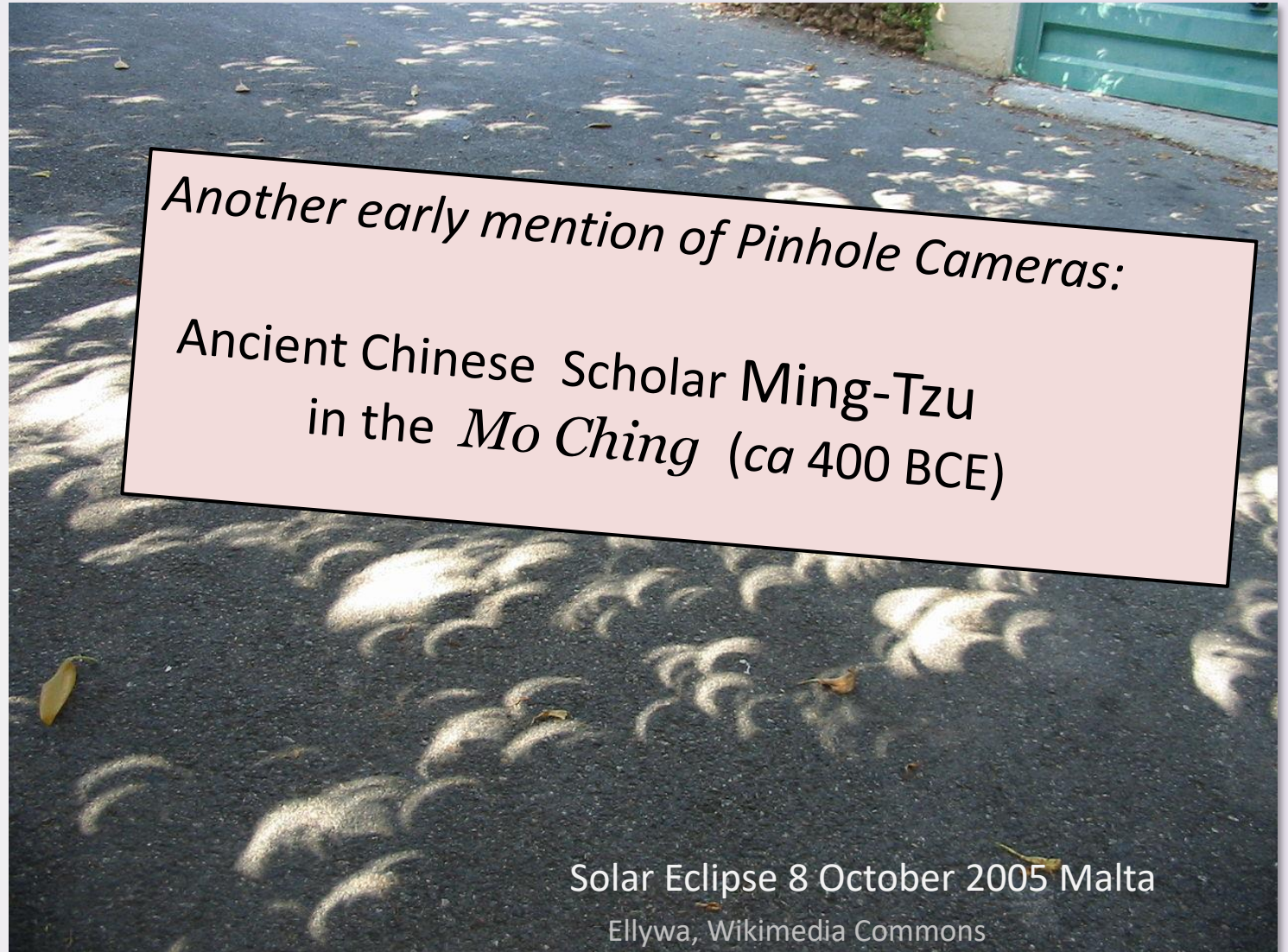




Aristotle
384-322 BCE

"Why is it that an eclipse of the sun, if one looks at it through a sieve or through leaves, such as a plane-tree or other broadleaved tree, or if one joins the fingers of one hand over the fingers of the other, the rays are crescent-shaped where they reach the earth?"

Problems –Book XV



Another early mention of Pinhole Cameras:

*Ancient Chinese Scholar Ming-Tzu
in the *Mo Ching* (ca 400 BCE)*

Solar Eclipse 8 October 2005 Malta

Ellywa, Wikimedia Commons



Early Timeline of Optical Science – Pinhole Cameras



Euclid
~ 330-280 BCE
Alexandria?

Optics
c 300 BCE



Ptolemy
100-170 CE
Alexandria

Optica
c 150 CE



Al-Kindi
c. 801-873 CE
Baghdad

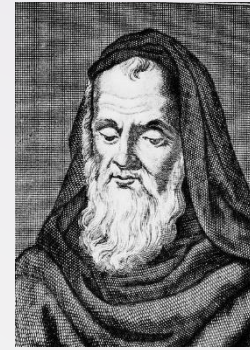
De Aspectibus
c 850 CE



“Father of Optics”

**Ibn al-Haytham
(Alhazen)**
c. 965-1040 CE
Cairo

Book of Optics
c 1020 CE
Latin Translation ~1200



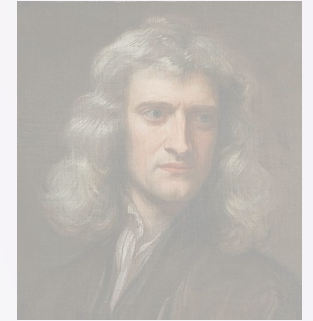
Roger Bacon
c. 1220-1292 CE
Oxford

*Science of
Perspective*
1267 CE



Johannes Kepler
1571-1630 CE
Prague

*Astronomiae
Pars Optica*
1604 CE



Isaac Newton
1643-1727 CE
Cambridge

Optiks
1704 CE

Explained
basic
Geometry



Explained
Inverted
Image

Used Pinhole
Camera for
Eclipse
Observation.

Described
Operation

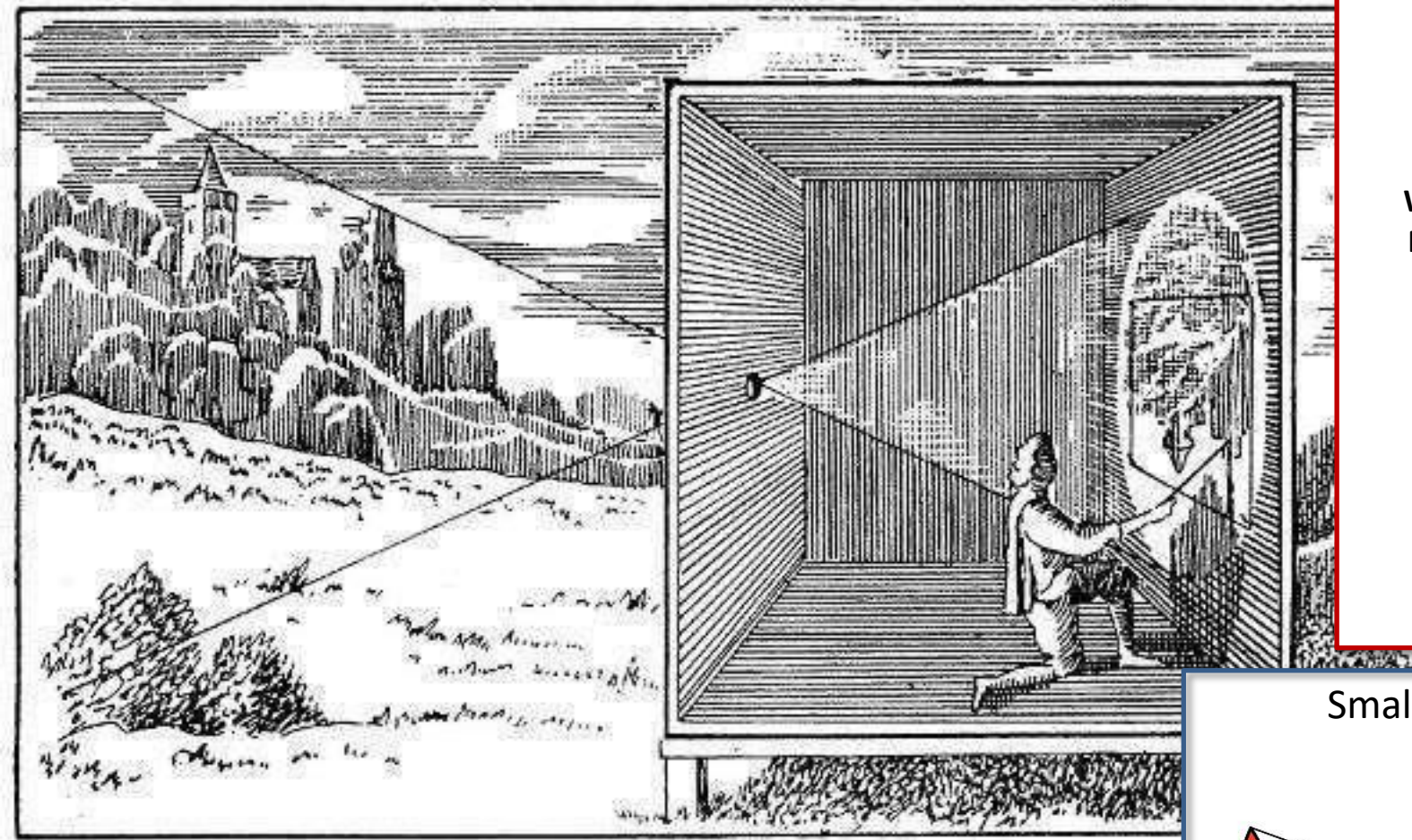
Opticks 2

Discussed,
recommended
use for Eclipse

Explained why
Hole shape
doesn't matter,
Renamed it

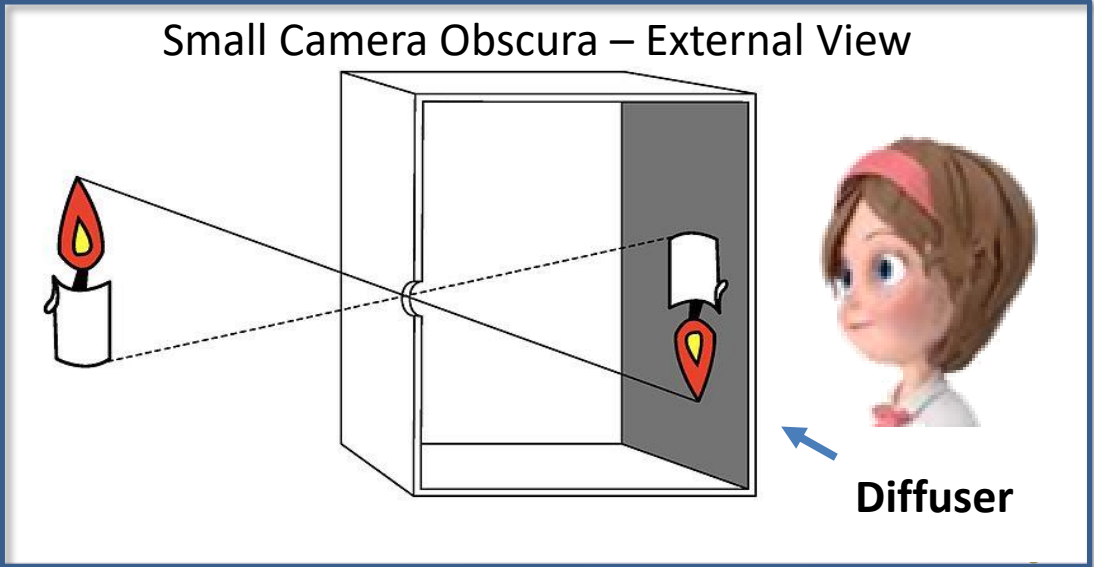
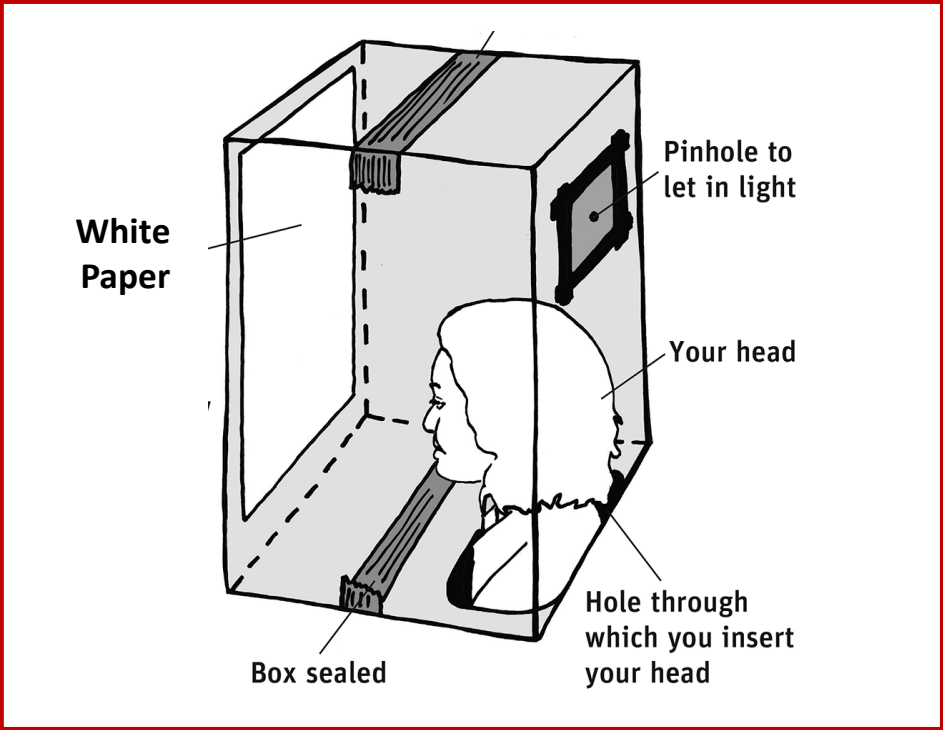
**Camera
Obscura**





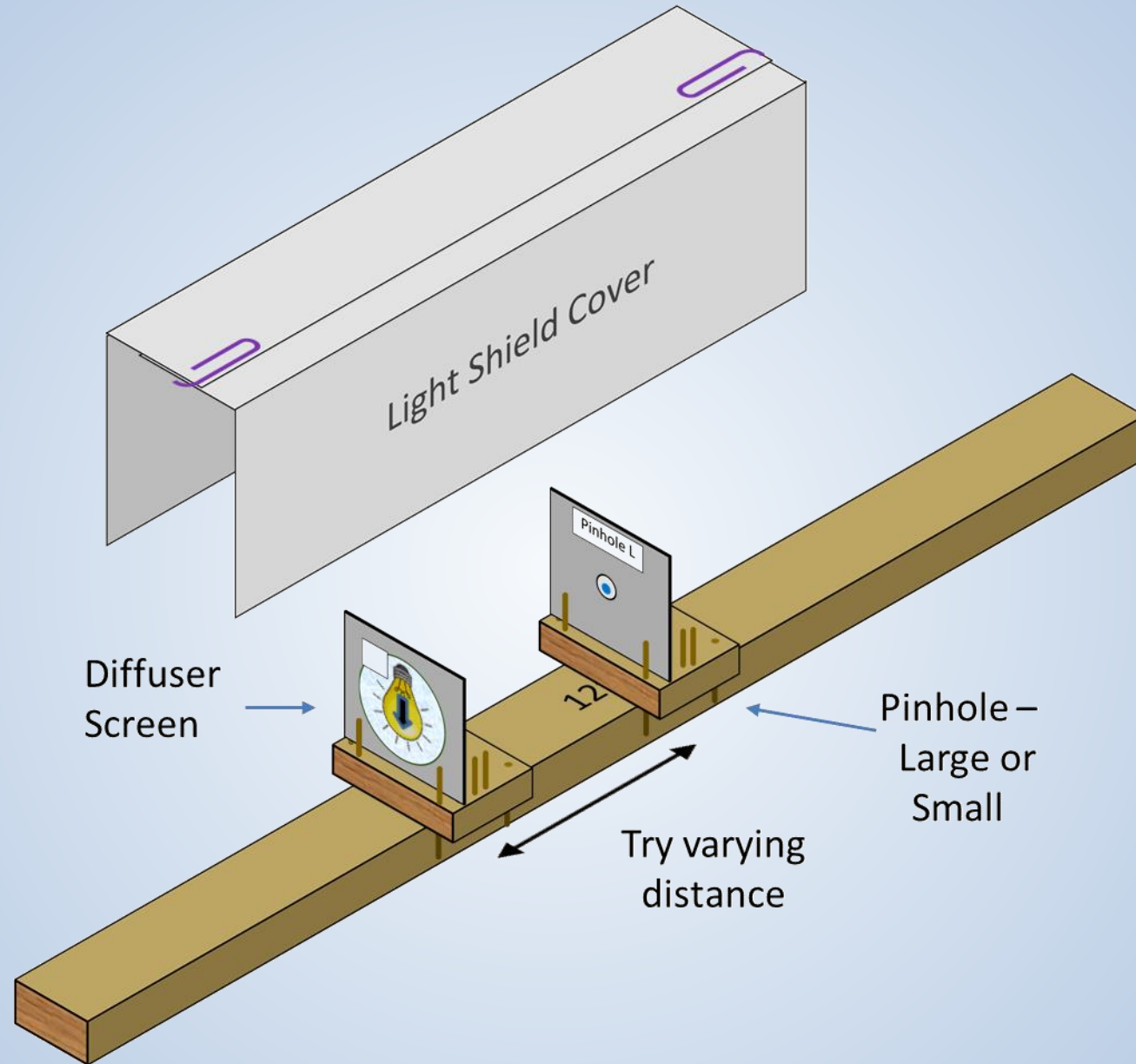
Portable Camera Obscura
Athanasius Kircher *Ars Magna Lucis Et Umbrae* (1645)

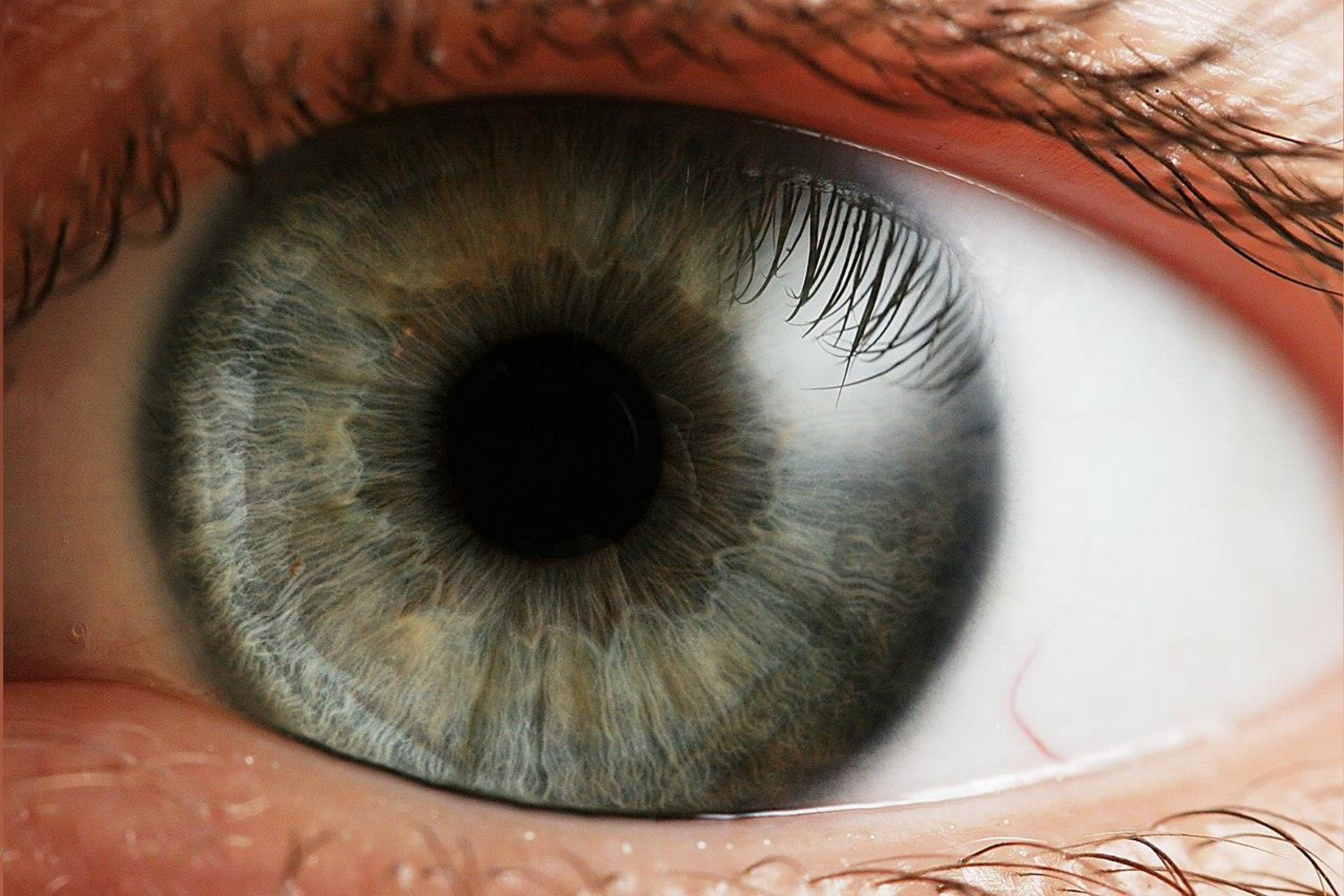
Problem: Dim or Blurry



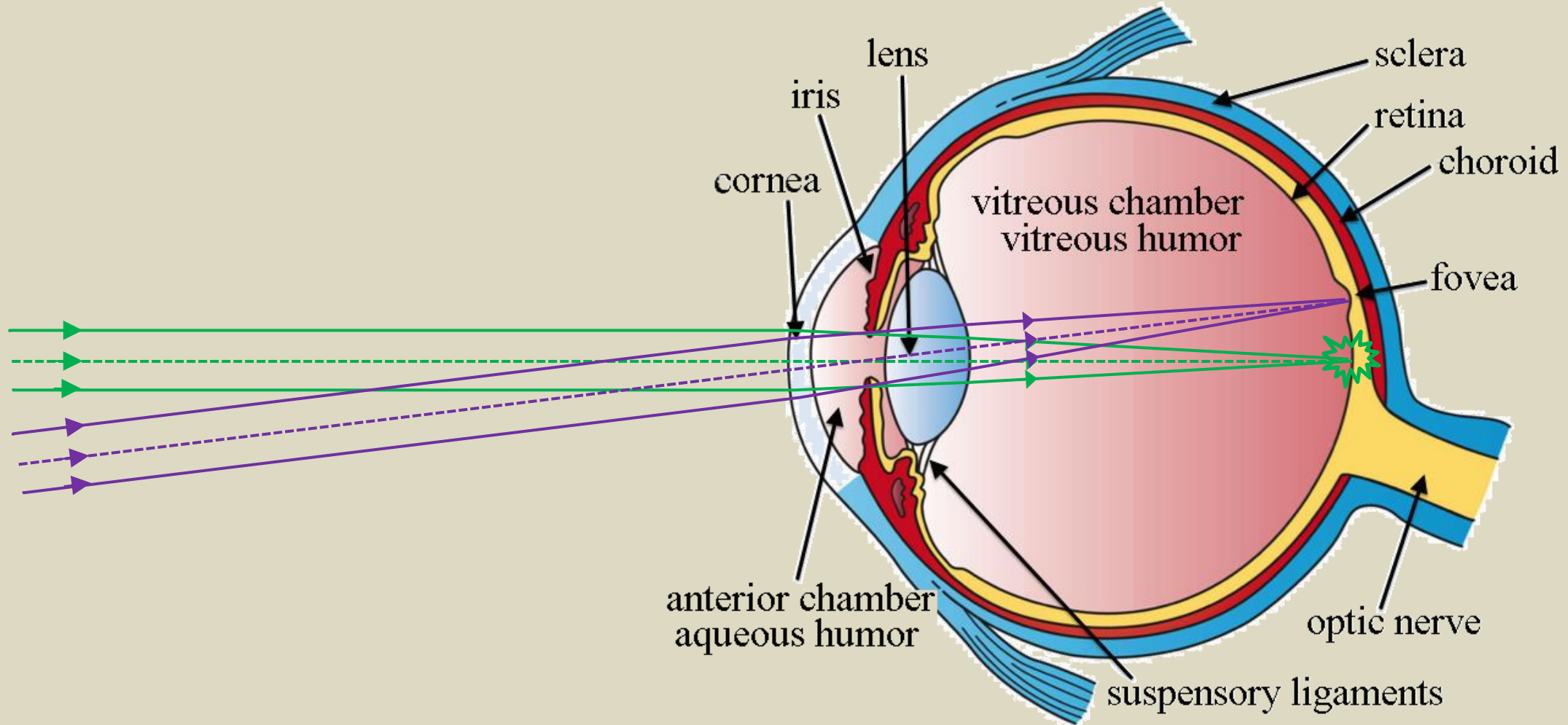
OLLI-OP

Camera Obscura (Pinhole Camera)





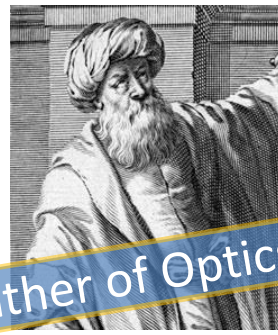
Modern Picture of the Human Eye



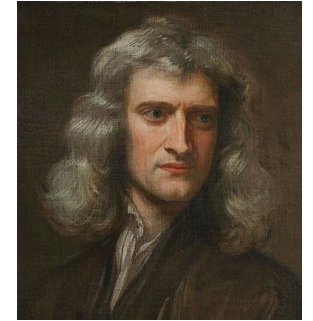
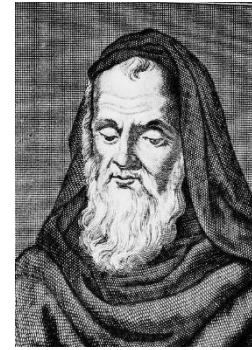
Wellcome Images



Early Timeline of Optical Science



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~ 330-280 BCE
Alexandria?

Ptolemy
100-170 CE
Alexandria

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c. 801-873 CE
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Optiks
1704 CE

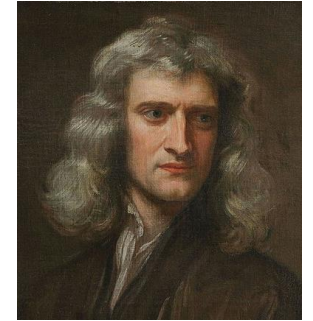
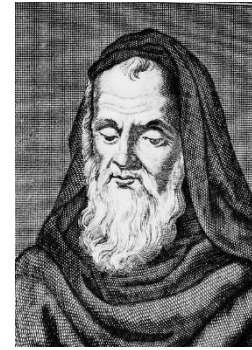
- Tried to understand Vision via Geometry
- Believed in *Extramission*



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1604 CE

Optiks
1704 CE

Galen's Anatomy of the Eye

- Tr and Vision try
- B amission

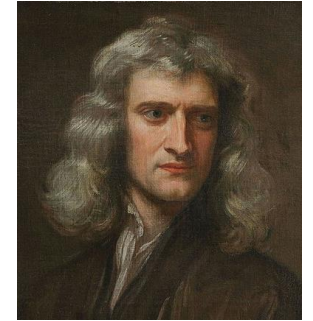
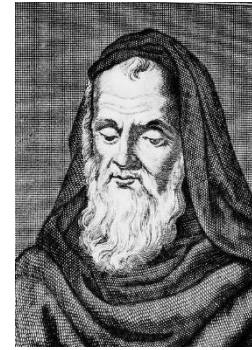
- Rejected *Extramission*
- Used Experimental Method
- Attempted Eye Model

Opticks 2

Early Timeline of Optical Science



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Optiks
1704 CE

Galen's Anatomy of the Eye

- Theory of Vision
- Theory of Extramission

- Rejected Extramission
- Used Experimental Method
- Attempted Eye Model

Opticks 2

Raised Awareness of Optics

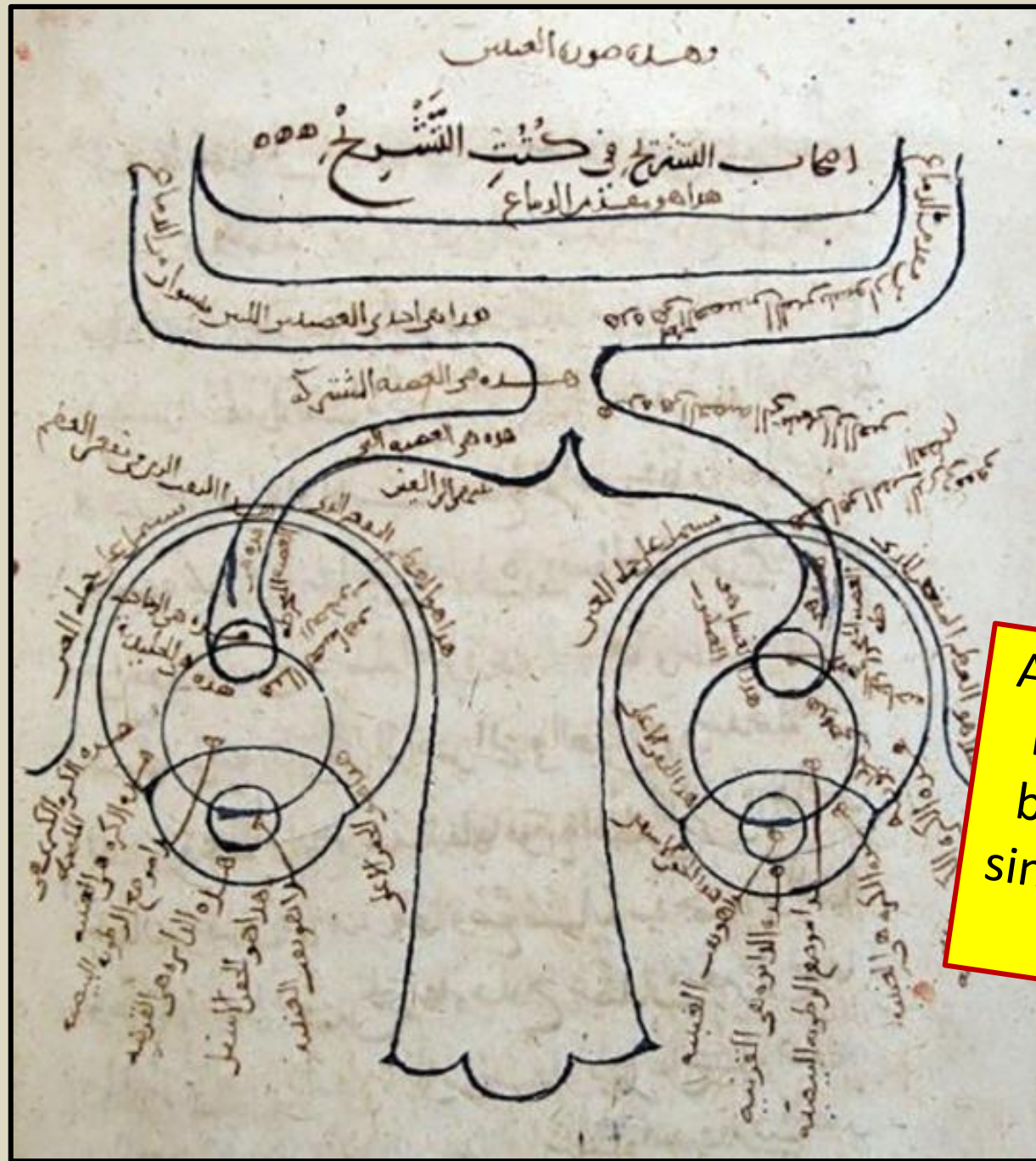
- Detailed theory of mirrors & lenses
- Correct Eye Model
- Refracting Telescope

- Consolidation
- Theory of Color
- Reflecting Telescope



Ibn al-Haytham
(Alhazen)
c. 965-1040 CE
Cairo
Book of Optics
c 1020 CE

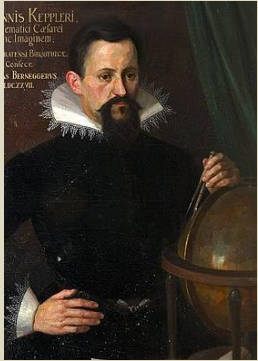
Late 11th Century copy of
the Kitab al-Mazir
Suleimaniye Mosque
Library, Istanbul



Somehow the
Optic Nerves
connect to the
Crystalline
Lenses, which
somehow “see”
the image.

Alhazen considered an
image on the **retina**,
but rejected the idea
since the image would
be **inverted!**

First Clear Proposal of Inverted Image on Retina



Johannes Kepler
1571-1630 CE
Prague

*Astronomiae
Pars Optica*
1604 CE

Theoretical, no experiments.

“I say that vision occurs when the image of the whole hemisphere of the world that is before the eye ... is fixed on the reddish white concave surface of the retina.”

“I tortured myself for a very long time...”

About Inverted Image

“How the image (*pictura*) is composed by the visual spirits that reside in the retina and the nerve, and whether it is made to appear before the soul or the tribunal of the visual faculty by a spirit within the hollows of the brain...
– this I leave to be disputed by the (physicians).”



Putting Kepler's Hypothesis to the Test --1619



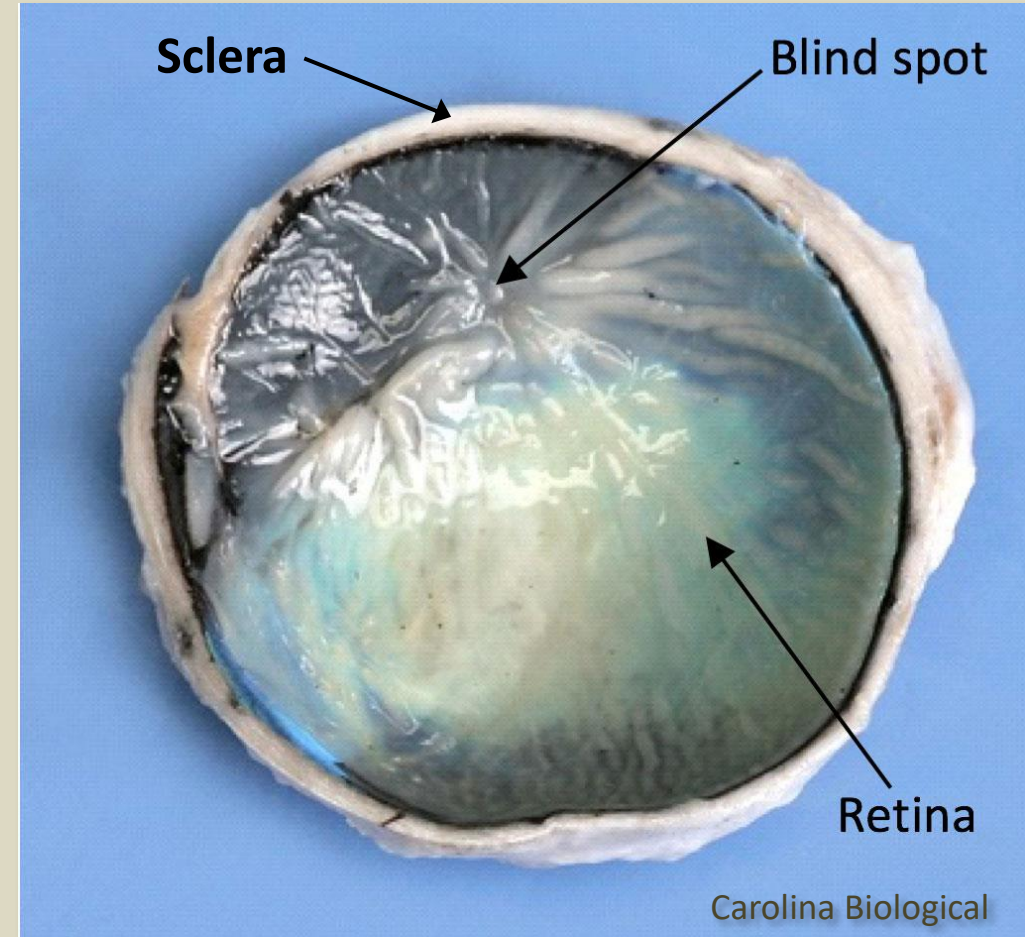
Christof Scheiner
1573-1650

Jesuit Astronomer/Physicist

*'Oculus hoc est:
fundamentum
opticum'* .
Innsbruck 1619



Cow's Eye



Putting Kepler's Hypothesis to the Test



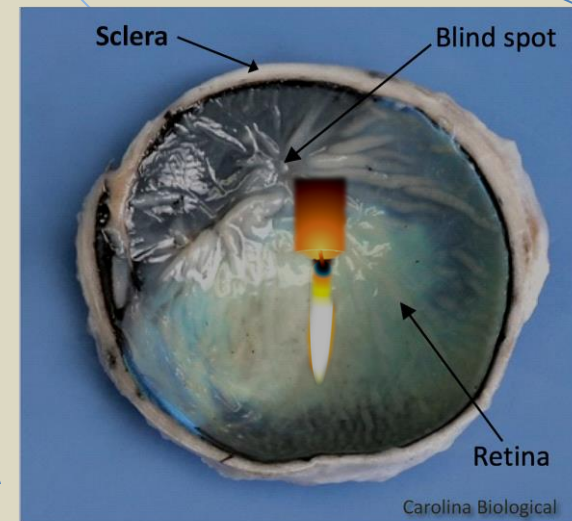
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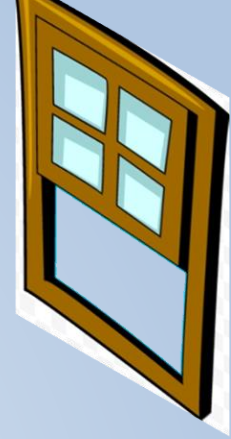
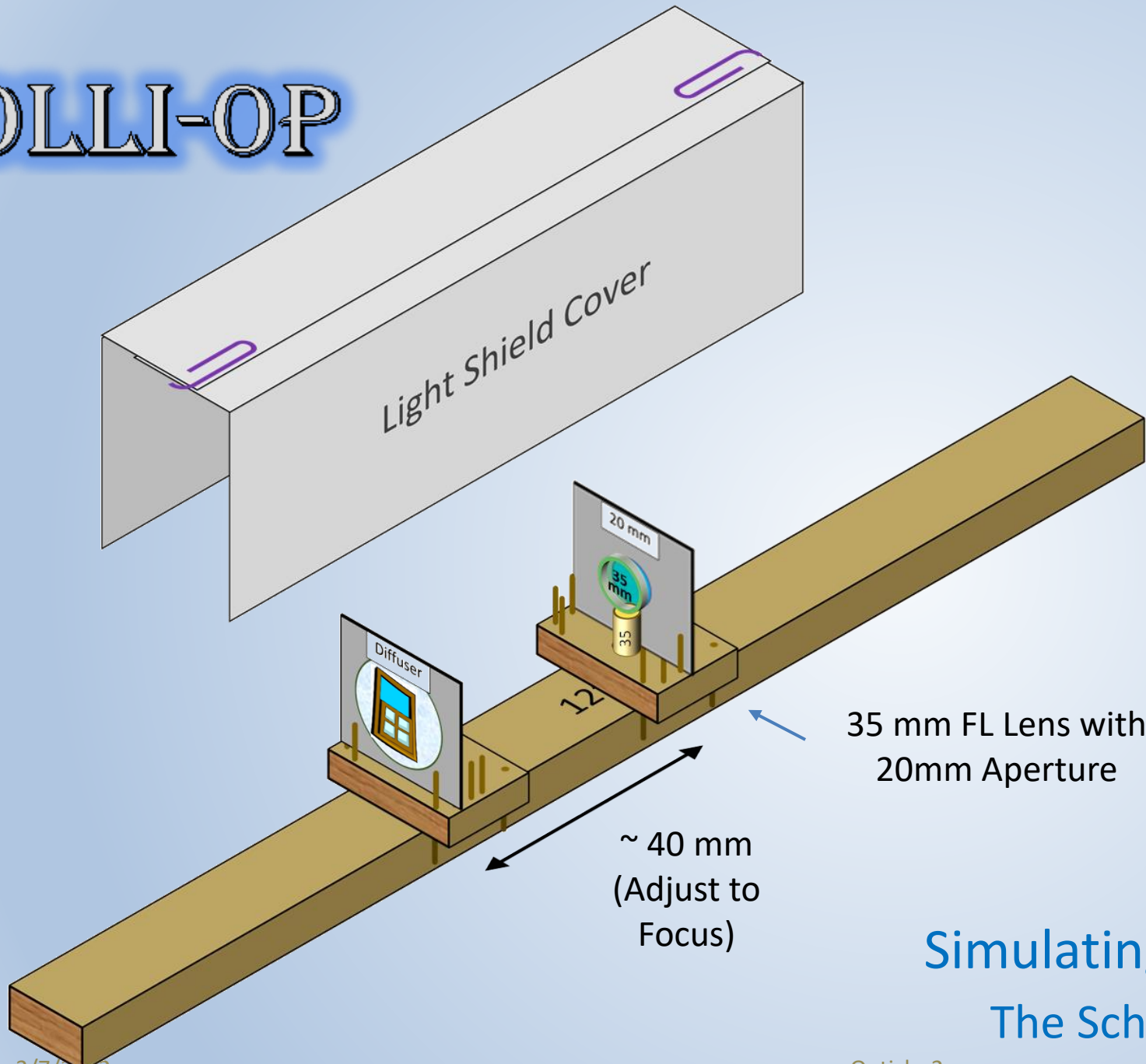
*'Oculus hoc est:
fundamentum
opticum'* .
Innsbruck 1619



Rene Descartes later
(1664) discussed the
retinal image, without
giving credit to
Scheiner's work.



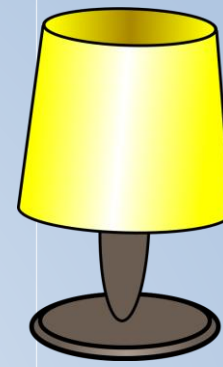
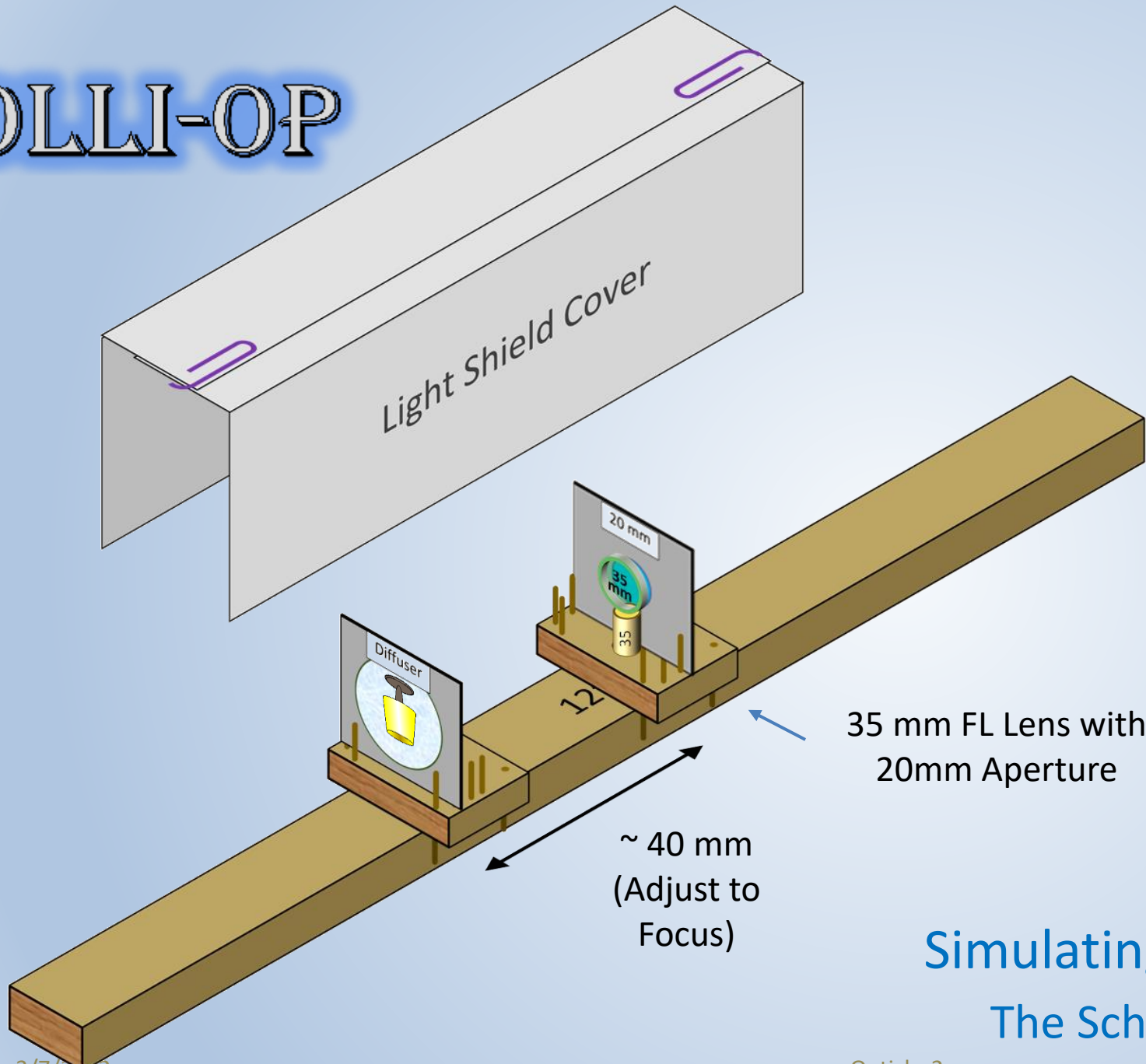
OLLI-OP



Simulating the Eye: The Scheiner Experiment



OLLI-OP

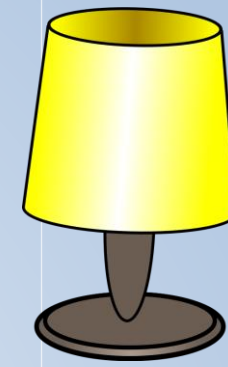
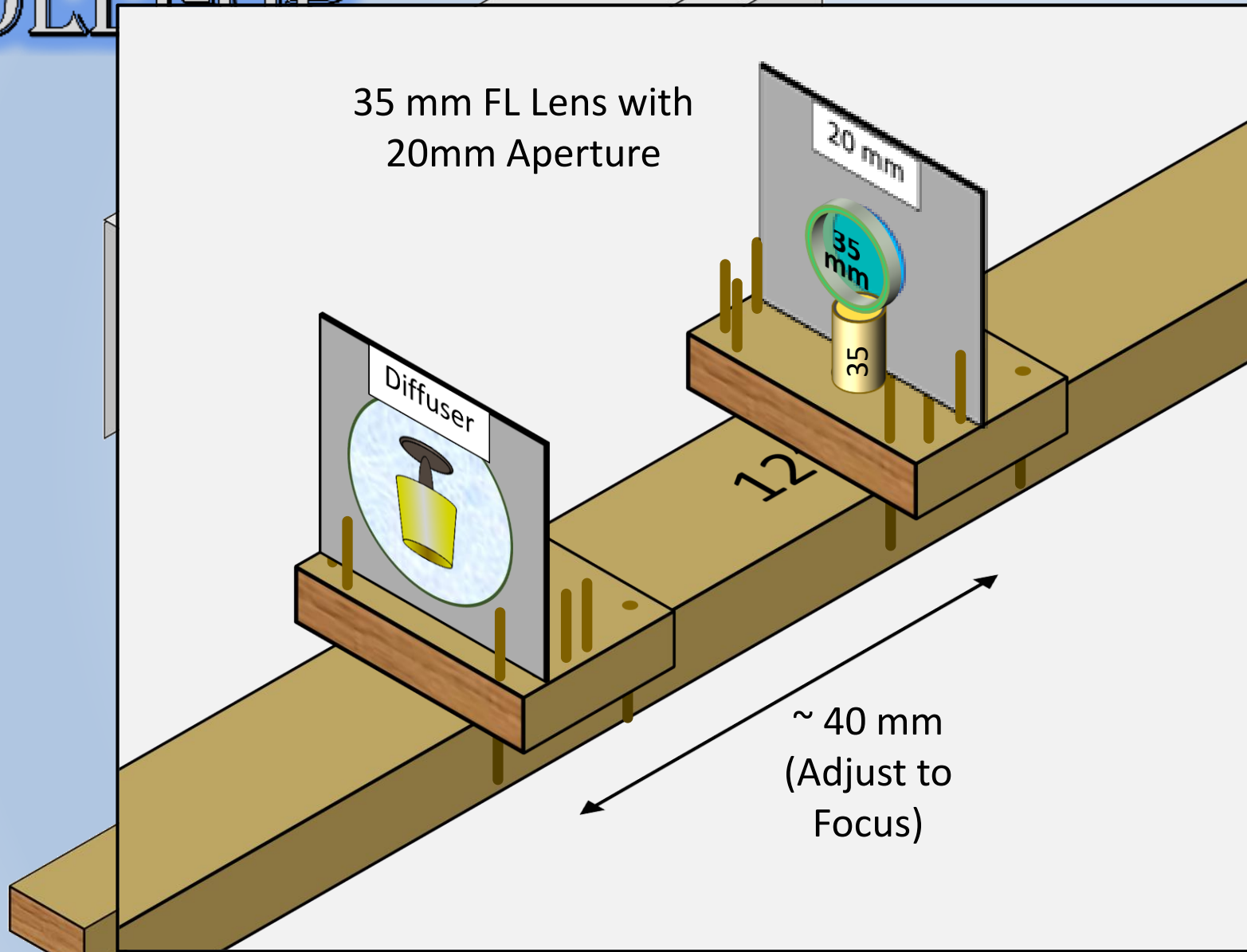


At night, a bright light fixture makes a good Object

Simulating the Eye: The Scheiner Experiment



OLL LOP



At night, a bright
light fixture
makes a good
Object

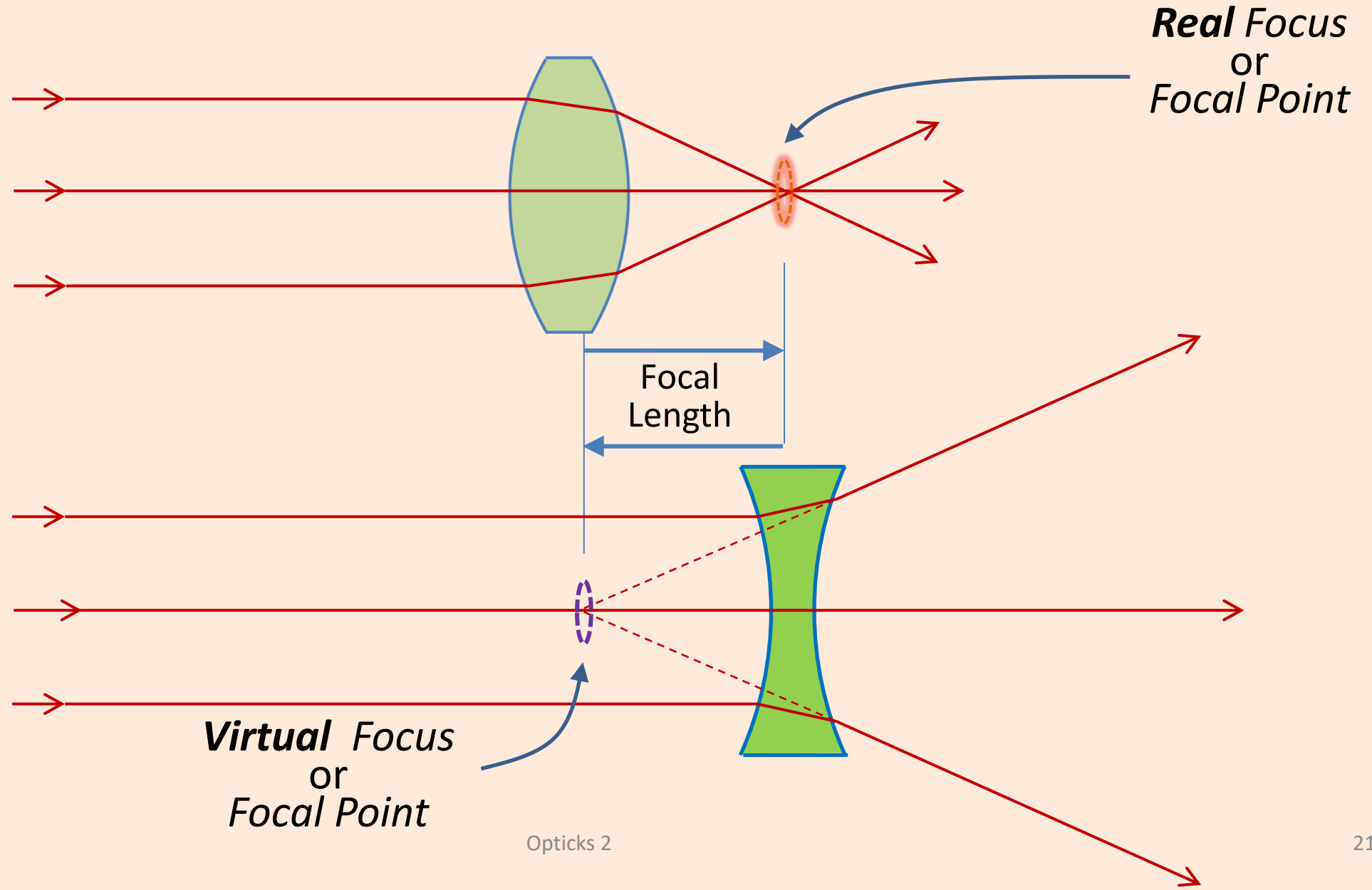
Simulating the Eye:
The Scheiner Experiment



Refractive Optics: Positive and Negative Lenses

- Convex
- Converging
- Positive

- Concave
- Diverging
- Negative

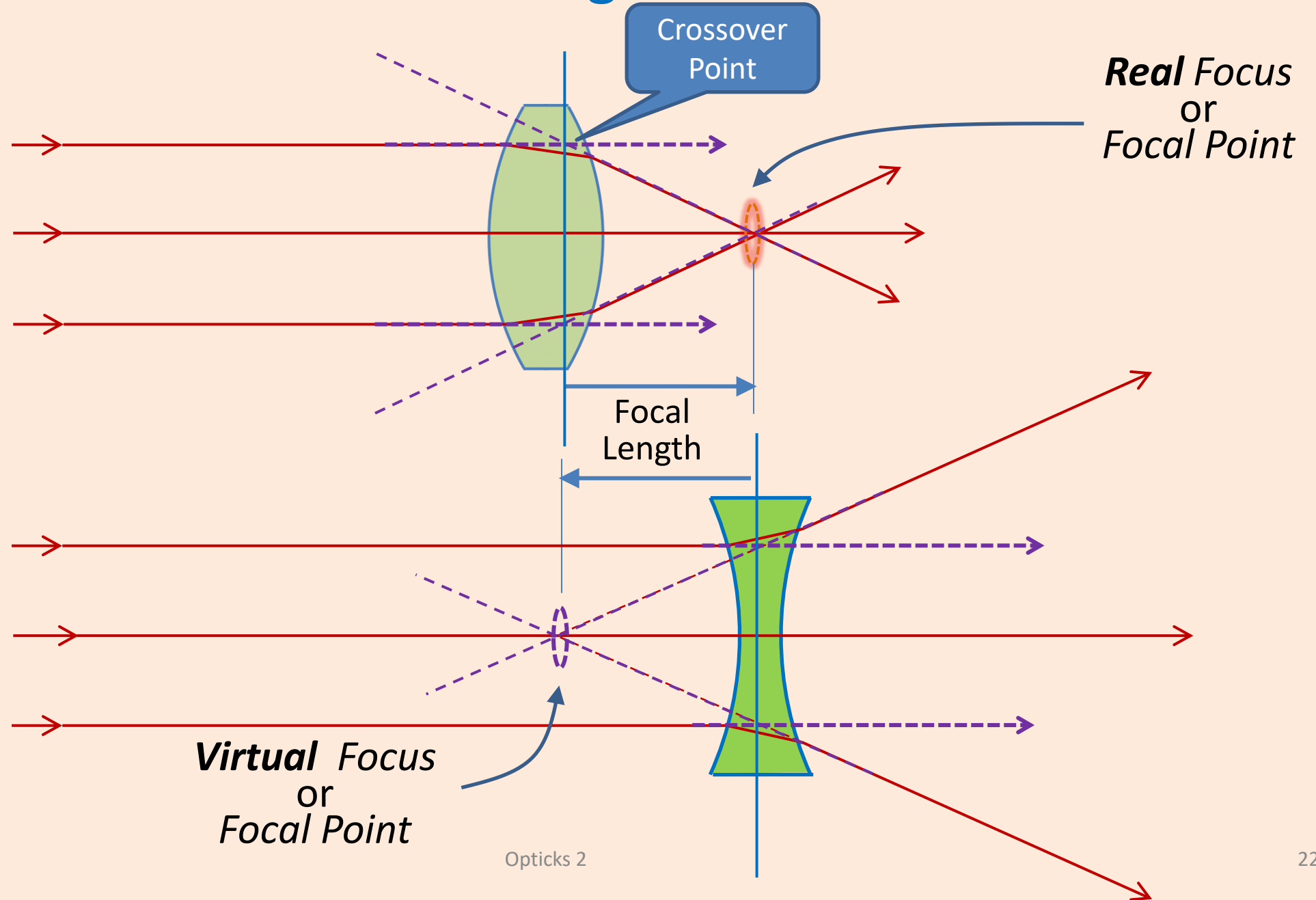




Where is the Focal Length Measured From?

- Convex
- Converging
- Positive

- Concave
- Diverging
- Negative





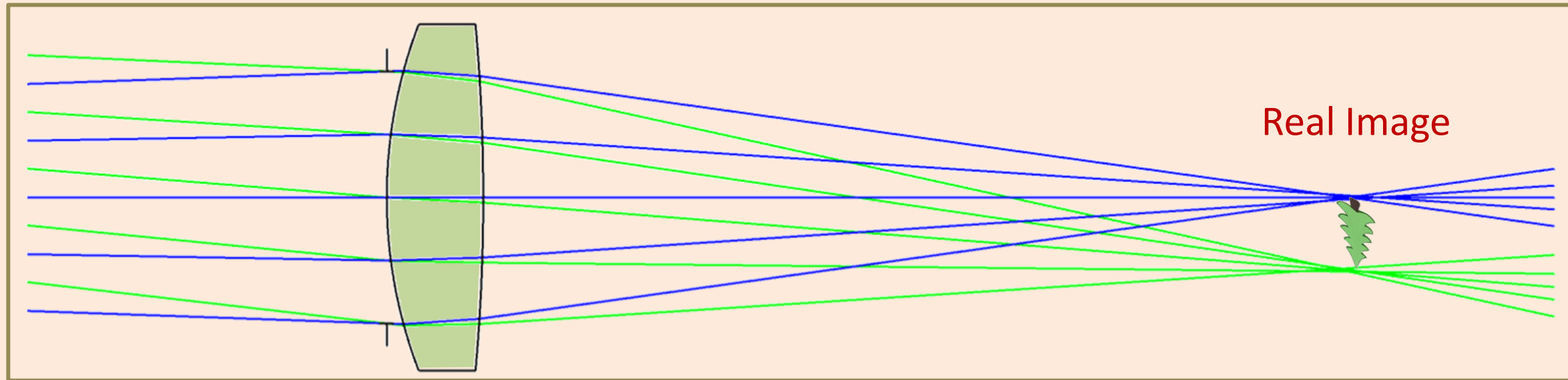
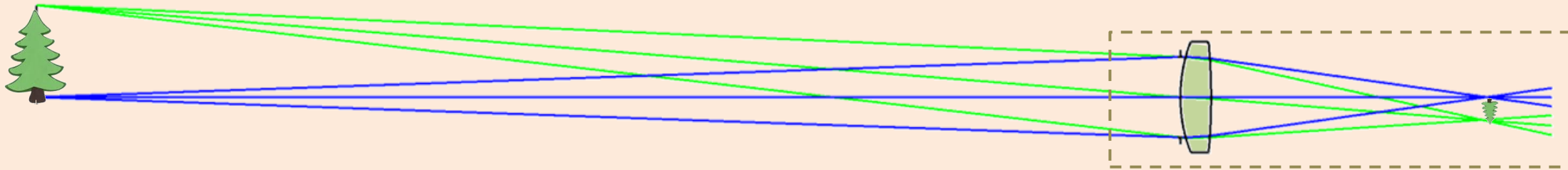
Port of Middelburg (1615)
Adriaen van de Venne

“Invention” of the Telescope

Middelberg, Zeeland (1608)



Vermeer 1641

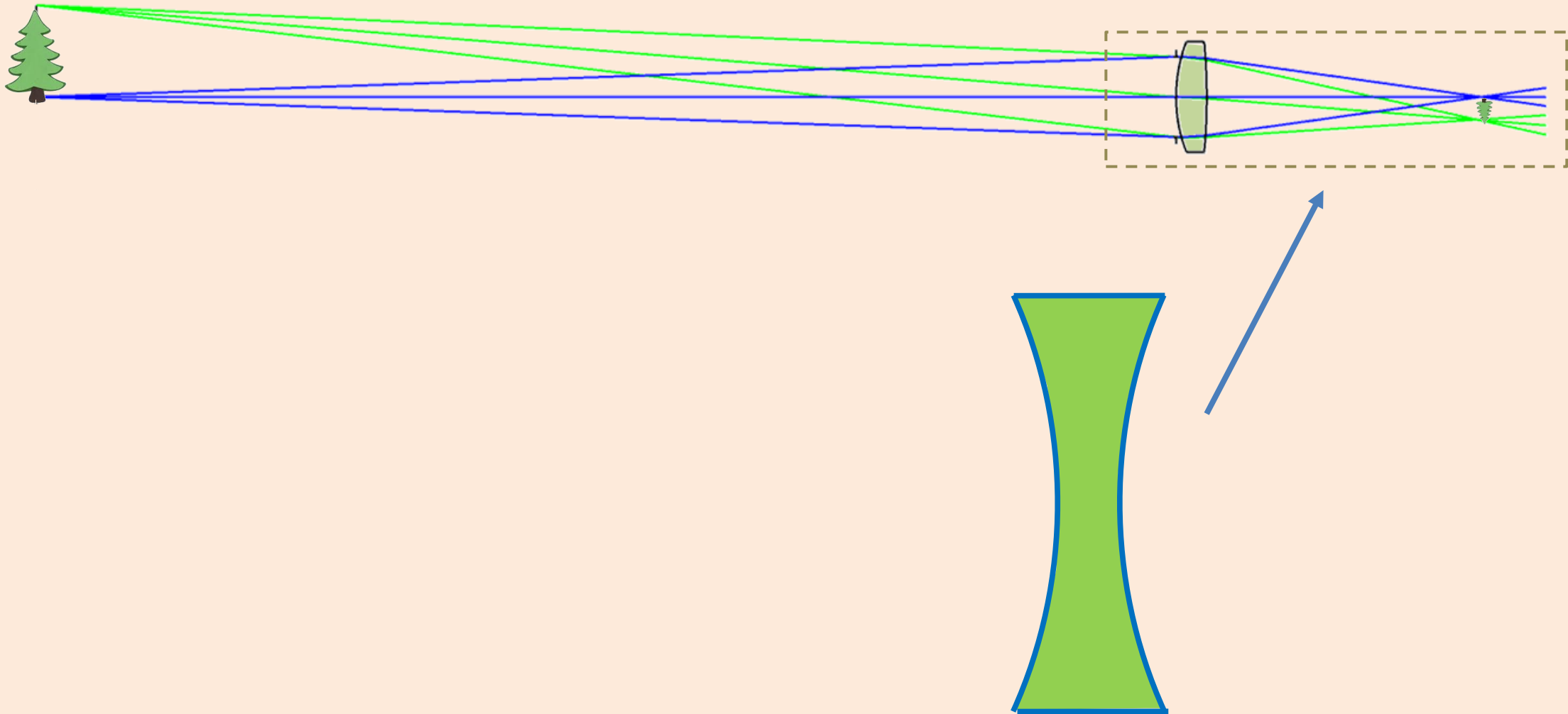


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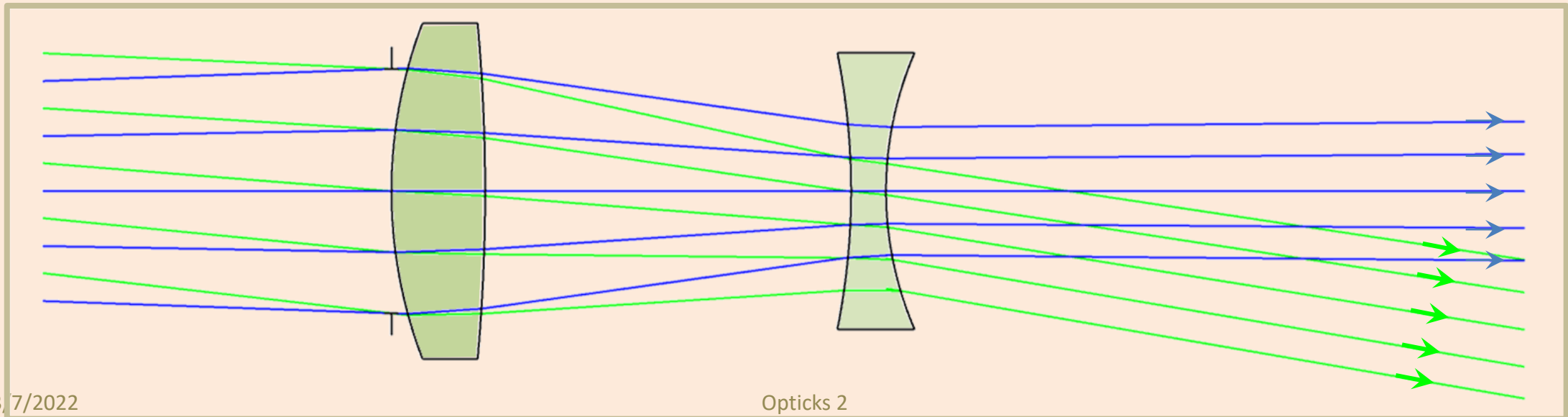
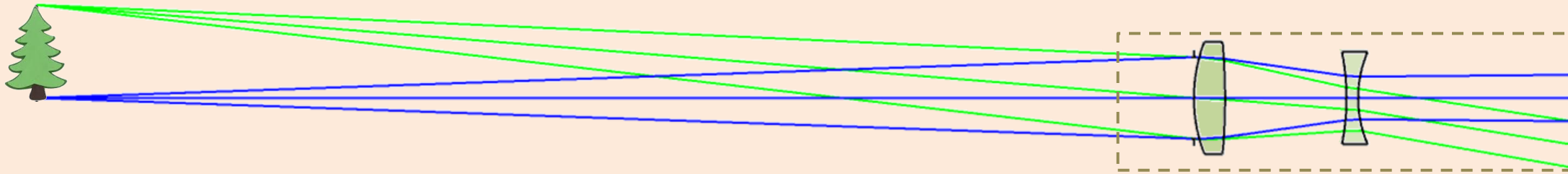
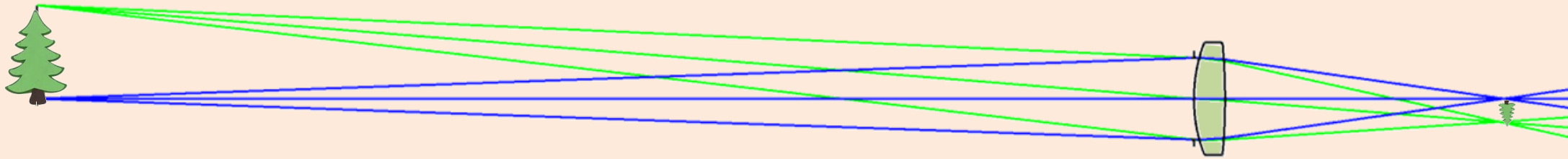


“Invention” of the Telescope

Middelberg, Zeeland (1608)

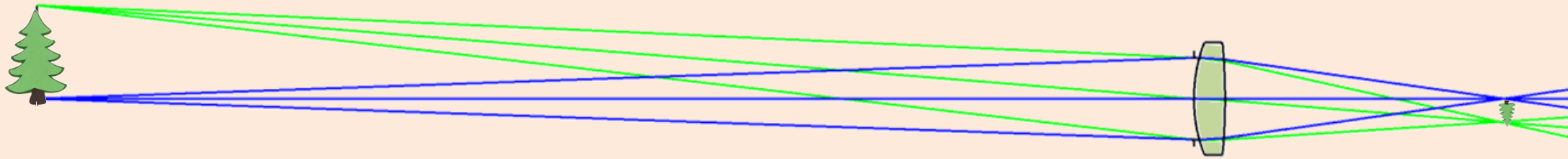


Vermeer 1641

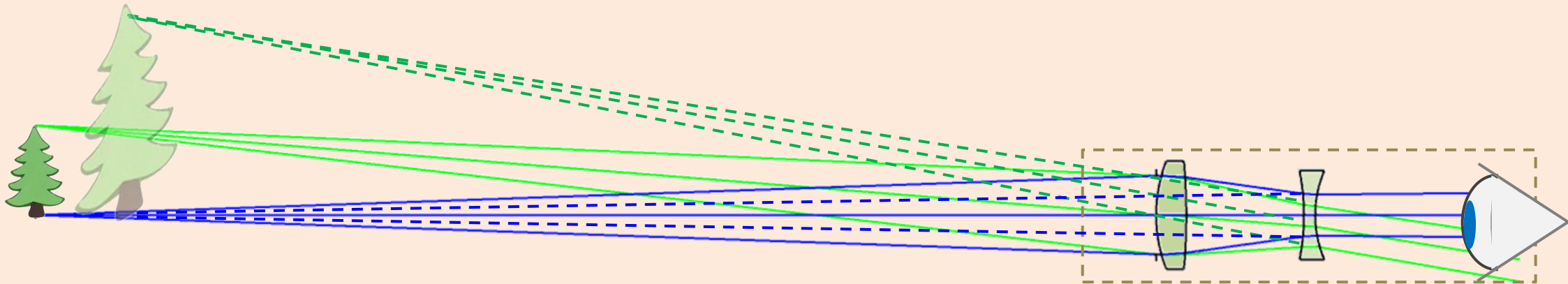


“Invention” of the Telescope

Middelberg, Zeeland (1608)



Erect
Enlarged **Virtual Image** of the
Tree at a long distance



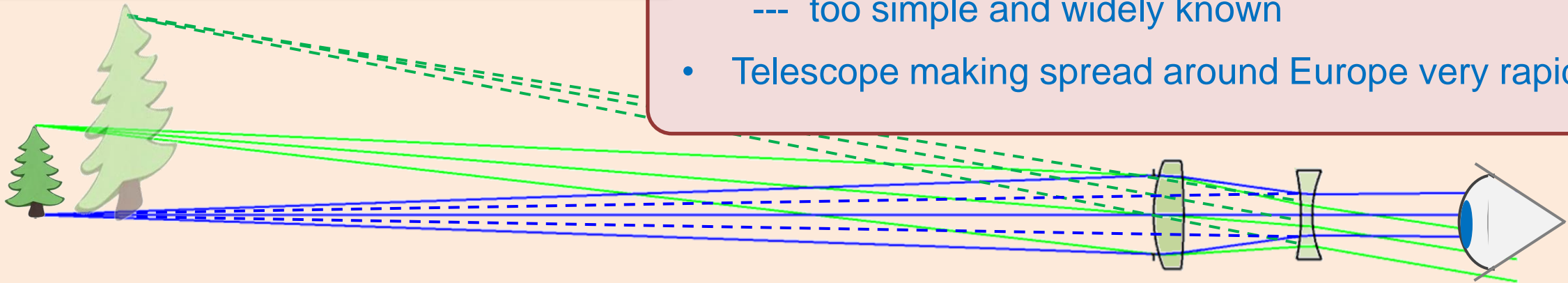
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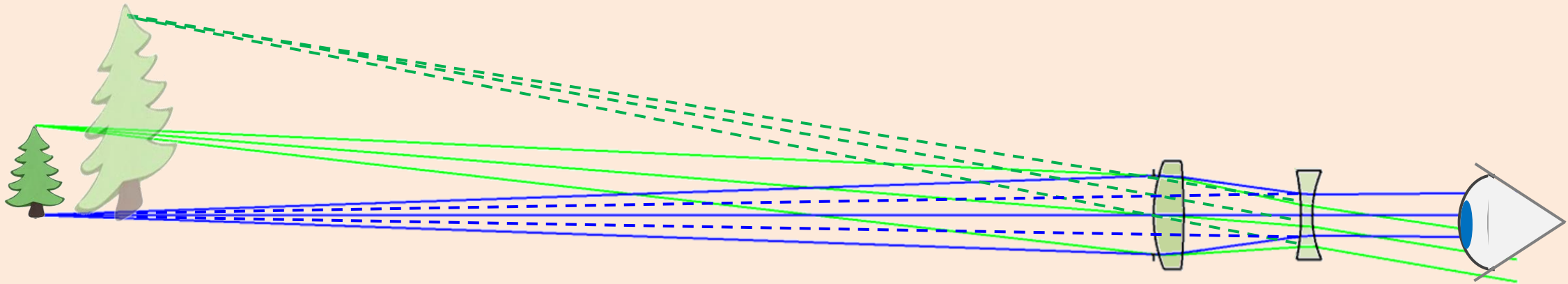
Engraving by Adriaen van de Venne
printed in Middelburg, 1624

- *Hans Lippershey*, a lens grinder and spectacle maker, filed a **patent application** on Oct 2, 1608 for a device *"for seeing things far away as if they were nearby"*
- But other patents were filed soon thereafter, and ultimately the Dutch authorities rejected all the claims --- too simple and widely known
- Telescope making spread around Europe very rapidly



Galileo Seizes the Moment

- May 1609:
Galileo hears about the “**Dutch Perspective Glass**”
- June 1609:
Galileo builds his own **3x telescope**.
- August 1609:
Presents an **8x telescope** to the Venetian Senate.
Immediately rewarded with tenure at University of Padua, and his *salary is doubled*.



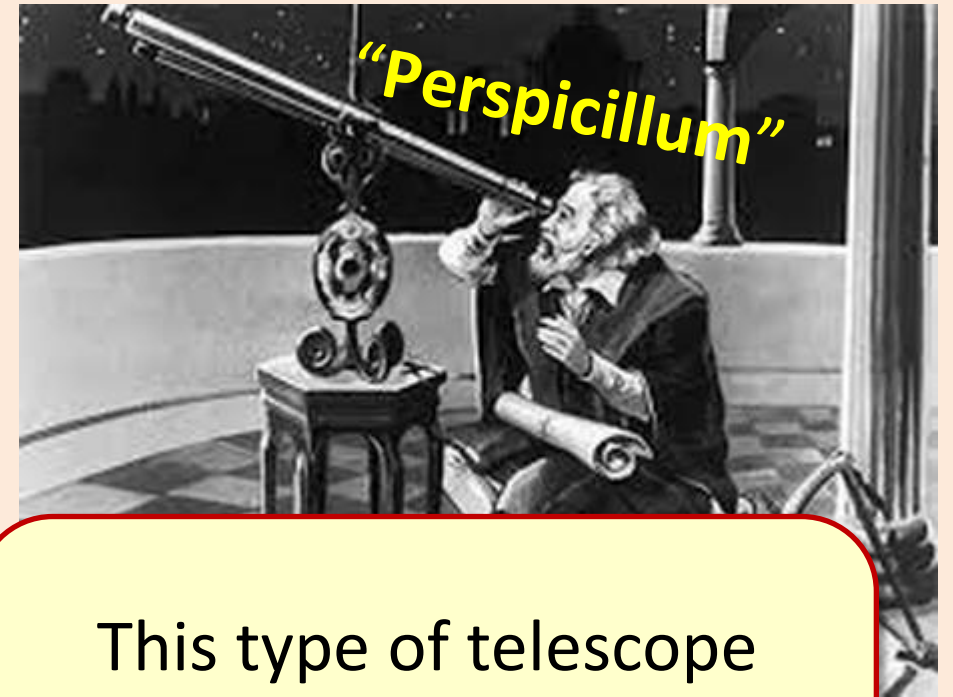
Galileo shows the
Doge and Senators
of Venice his
8x telescope
August 1609

Fresco in Florence,
photographed by
Alfredo Dagli Orti/The Art
Archive



Galileo Seizes the Moment

- May 1609:
Galileo hears about the “**Dutch Perspective Glass**”
- June 1609:
Galileo builds his own **3x telescope** in several days
- August 1609:
Presents an **8x telescope** to the Venetian Senate.
Immediately rewarded with tenure at University of Padua, and his salary is *doubled*
- November 1609:
Begins **astronomical observations** with a 23x telescope



This type of telescope
is called a
Galilean Telescope

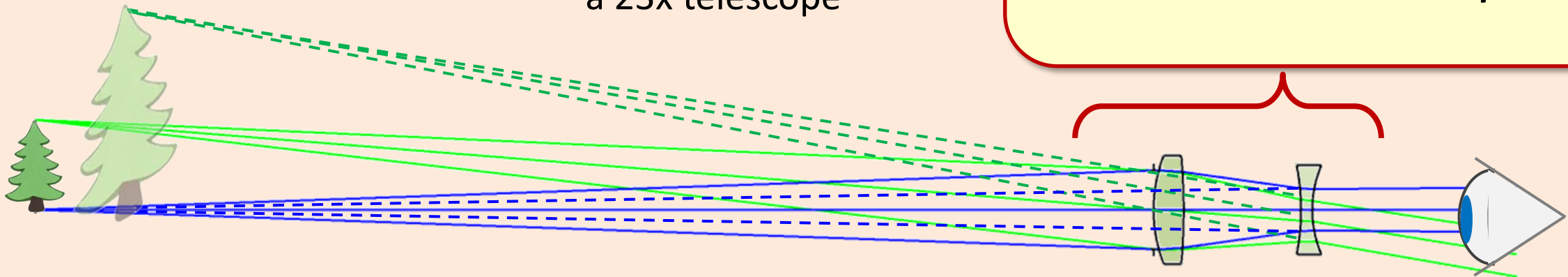




Photo: Susan Fourtané (Interesting Engineering)



On loan to Franklin Institute, Philadelphia (2009)

Two of Galileo's Telescopes survive

Museo Galileo
Florence



Museo Galileo



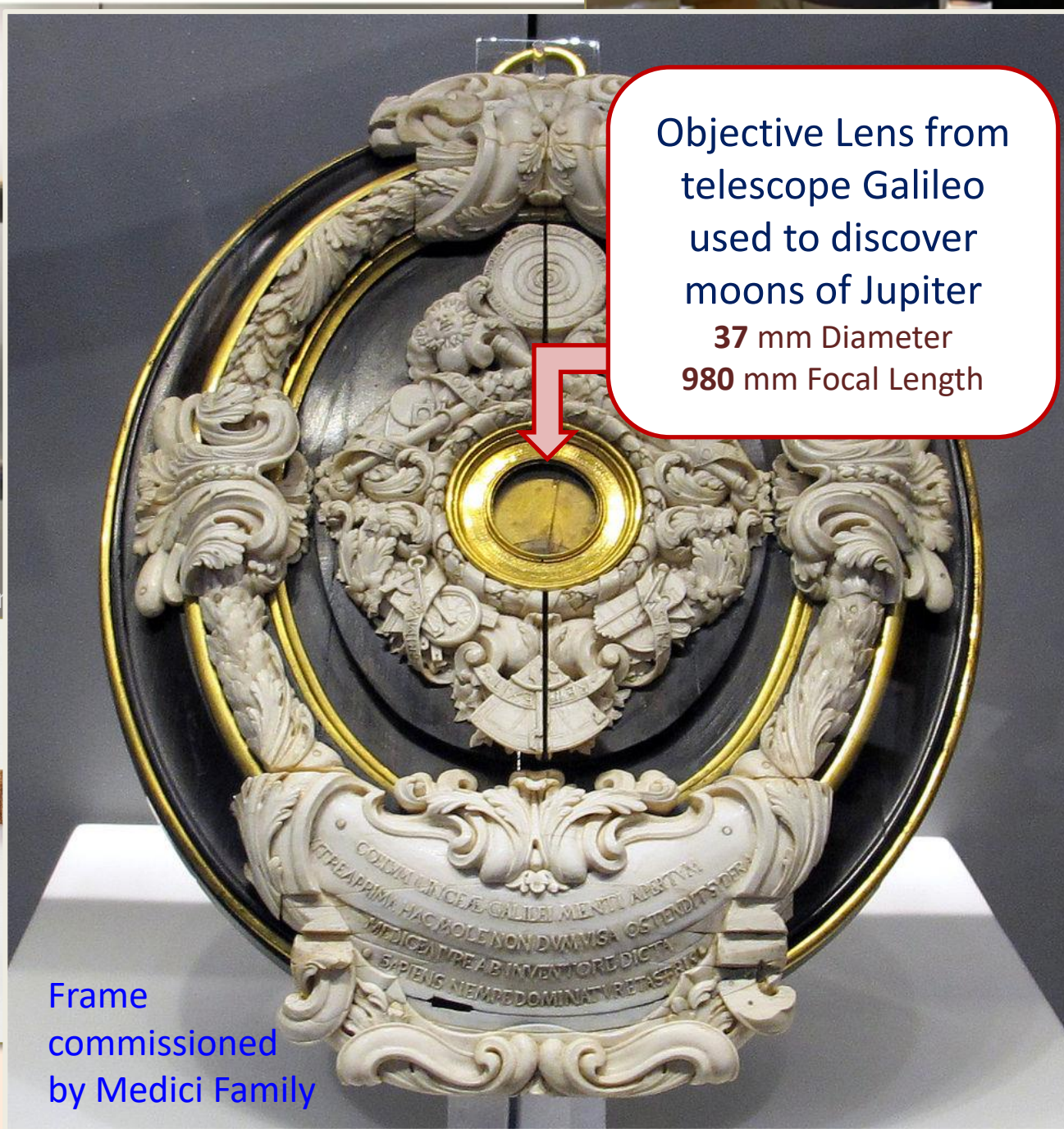


Photo: Susan Fourné (Interesting Engineering)

Two of Galileo's
Telescopes survive

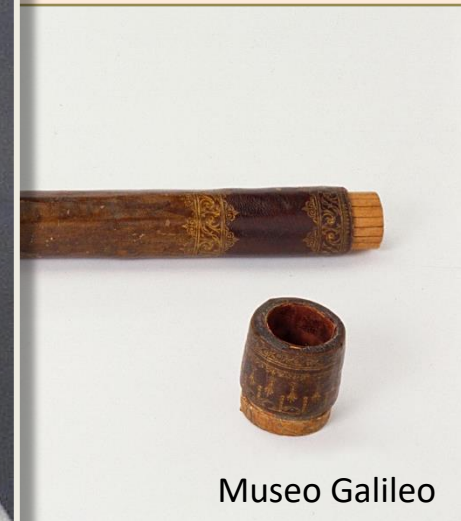
Museo Galileo
Florence

3/7/2022



Objective Lens from
telescope Galileo
used to discover
moons of Jupiter
37 mm Diameter
980 mm Focal Length

Frame
commissioned
by Medici Family

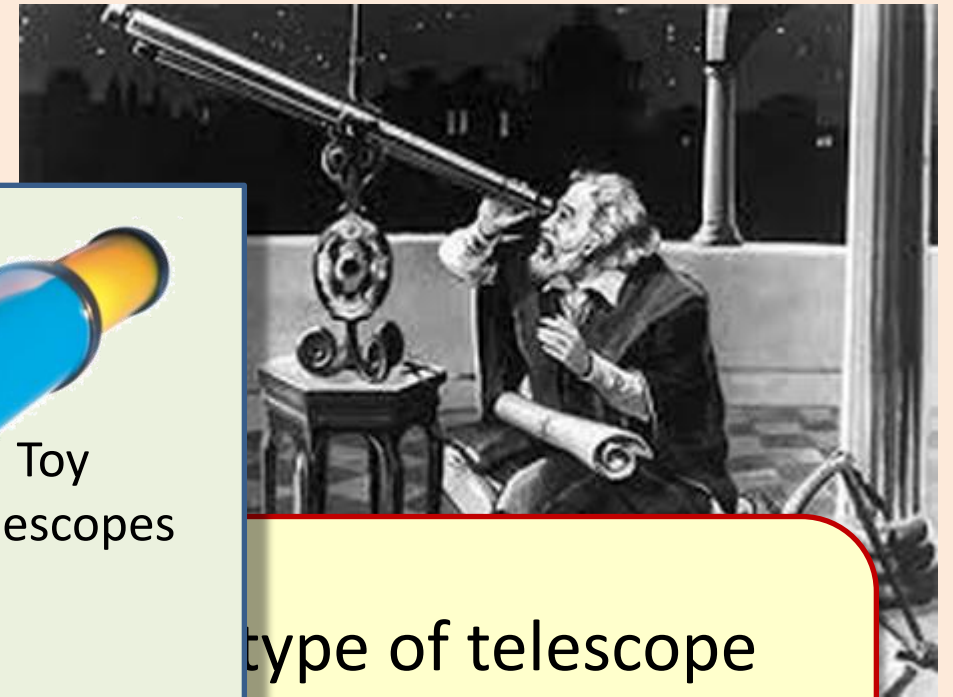
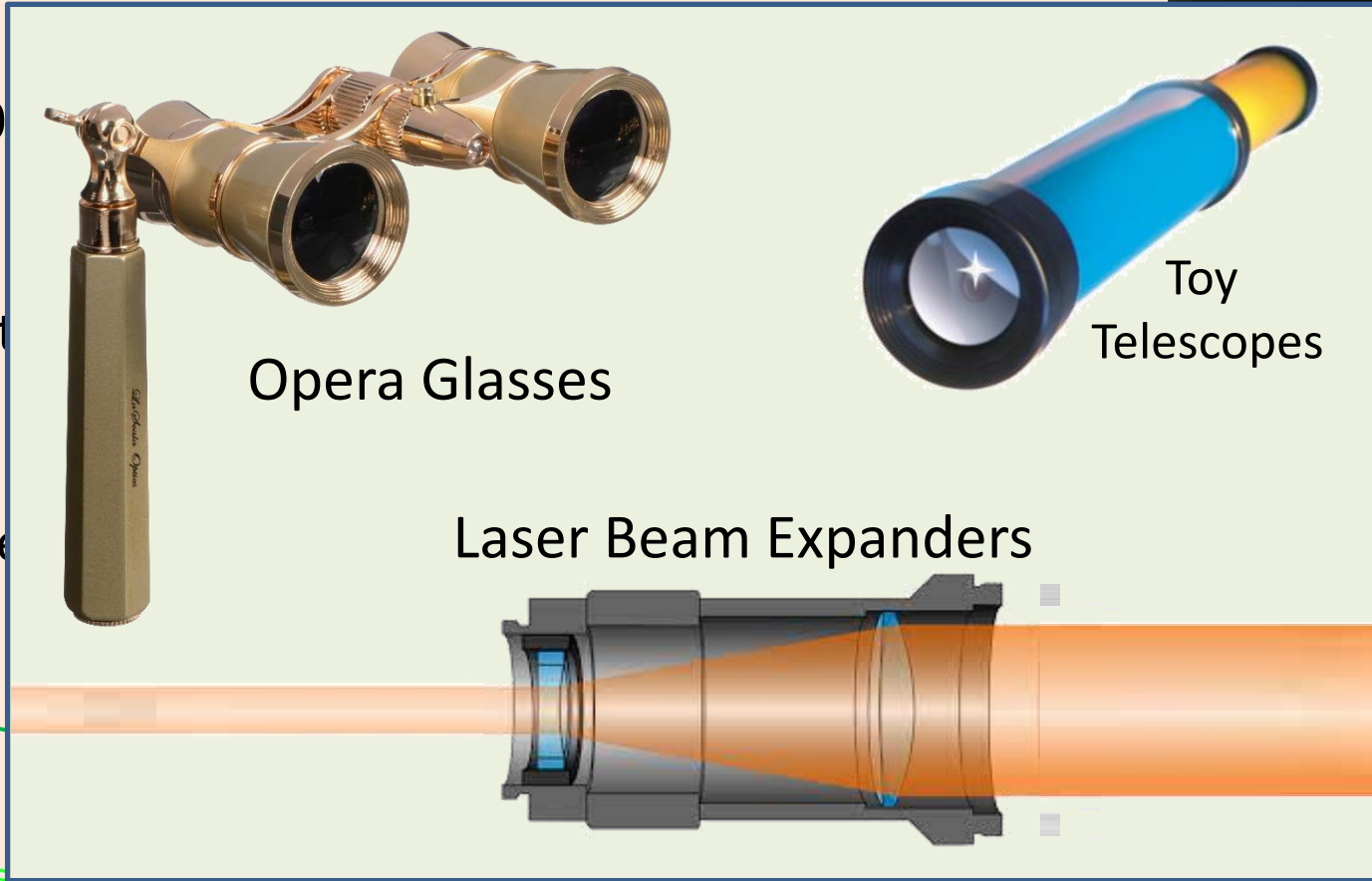


Museo Galileo

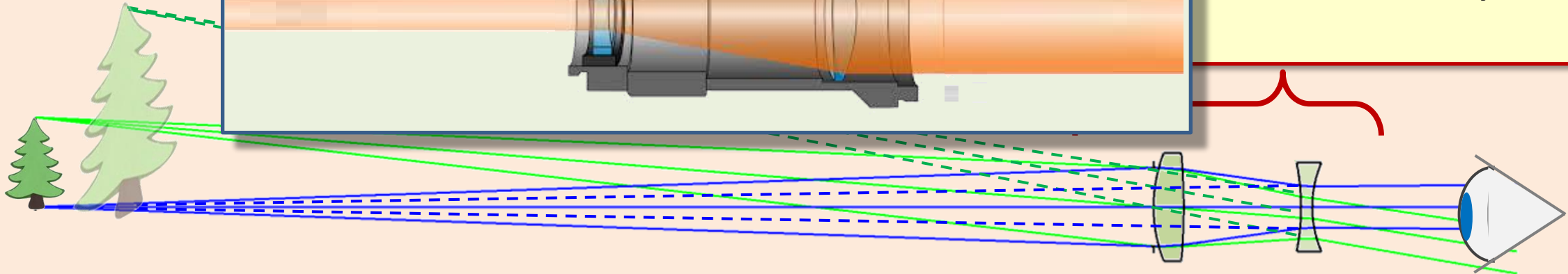


Galileo Seizes the Moment

- May 1609:
Galileo
- June 1609:
Galileo
- August 1609:
Presented to the
Imperial Academy of
Padua,
- November 1609:

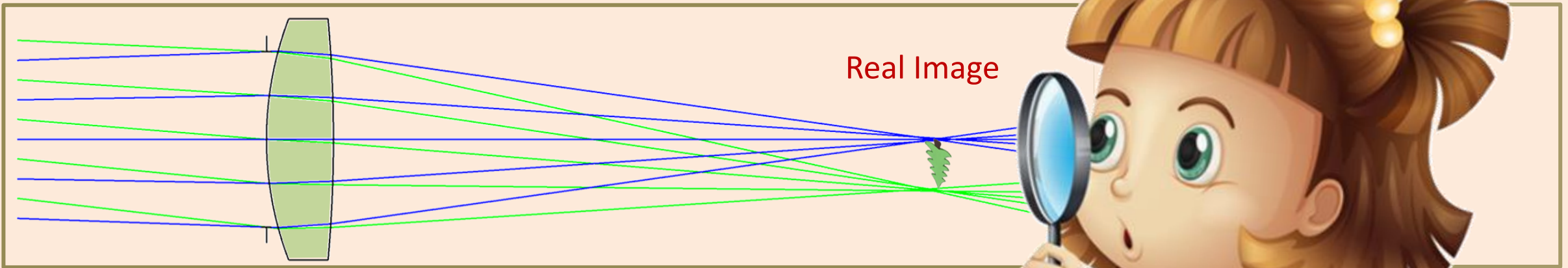
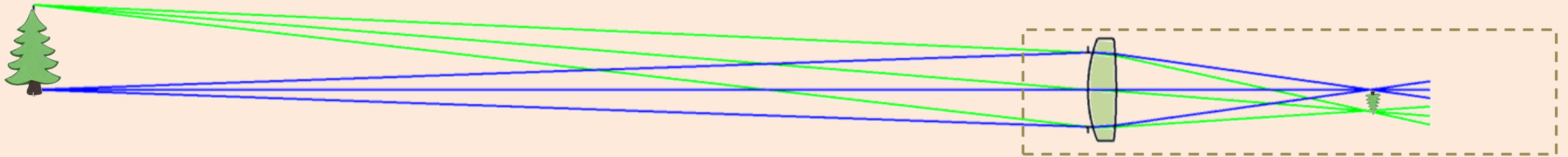


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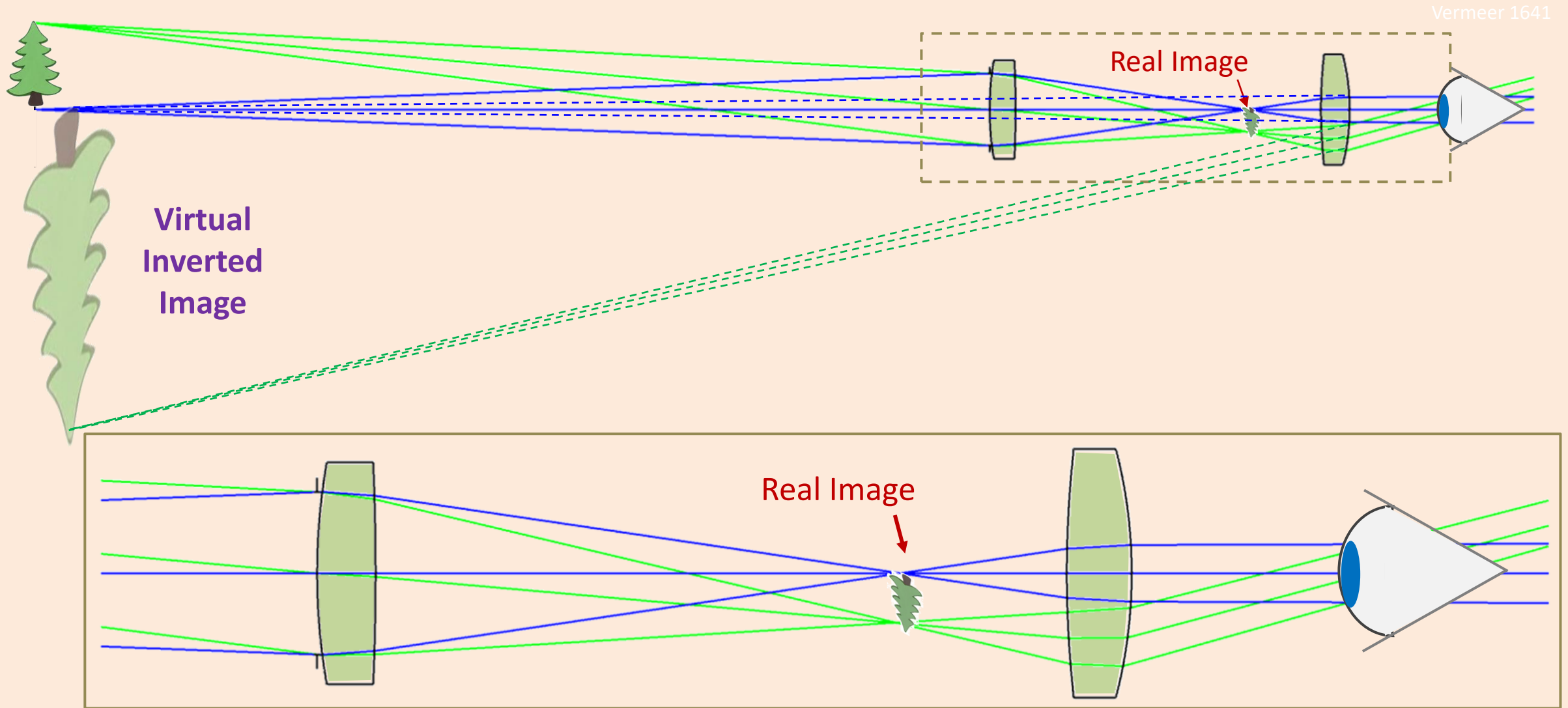


Another Kind of Telescope...

Vermeer 1641



Another Kind of Telescope: Two Convex Lenses



43
 Et quia imago rei visibilis est eversa per unam lentem: Lens vero propior non evertit denuo, quod accipit à Remotiori, sed sic ut accipit, ad oculum transmittit, ex supposito. Accipit autem respectu rei visibilis, imaginē eversam: Eversam igitur respectu rei visibilis ad oculum mittit.

Et quia imago ipsa eversa, prope punctum concursus, major apparet re ipsa, remotius aequalis; & adhuc remotius, minor, per XXCIV. imago igitur hac sic eversa, ubi fuerit ampliata per lentem propiorem, duobus primis casibus major omnino evadet re ipsa, ultimo casu vel major vel aequalis vel minor, prout fuerit lenti-um inter se proportio, qua est in arbitrio artificis: certè tamen major, quàm quantam lens, oculo proxima, eam acceperat à lente remotiori, per XXC.

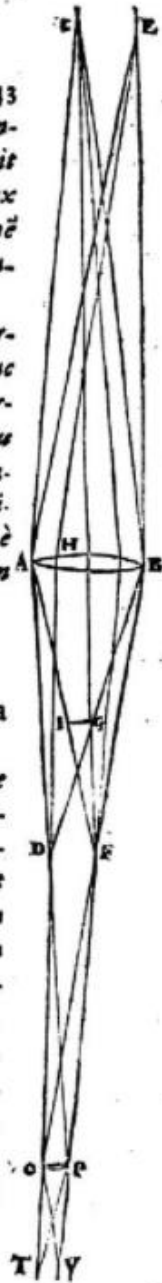
XXCVII PROBLEMA.

Duobus convexis distincta præstare visibilia & erecta, sed minora.

Hac duo convexa oportet in sufficienti discrimine esse convexitatum. Collocetur igitur oculus extra utriusq; puncta concursuum, alterius puncto distinctionis propior à reliqui puncto distinctionis remotior, ut ita neutro solitario eversa distinctè cernantur. Si enim fuerint lentes hoc situ cum oculo in eandem lineam composita, contraria vitia se mutuo tollent, & distinctio sequetur.

Vt autem & erecta sit imago, oportet eam bis everti. Et ut hoc fiat lentem propiorem oportet ipsam etiam esse remotam à remotiore ultra illius puncta concursus.

F 2 Sit



In *Dioptrice* (1611) Kepler analyzed the Galilean telescope, and proposed an alternative design with 2 convex lenses.

But he didn't build one...



Johannes Kepler

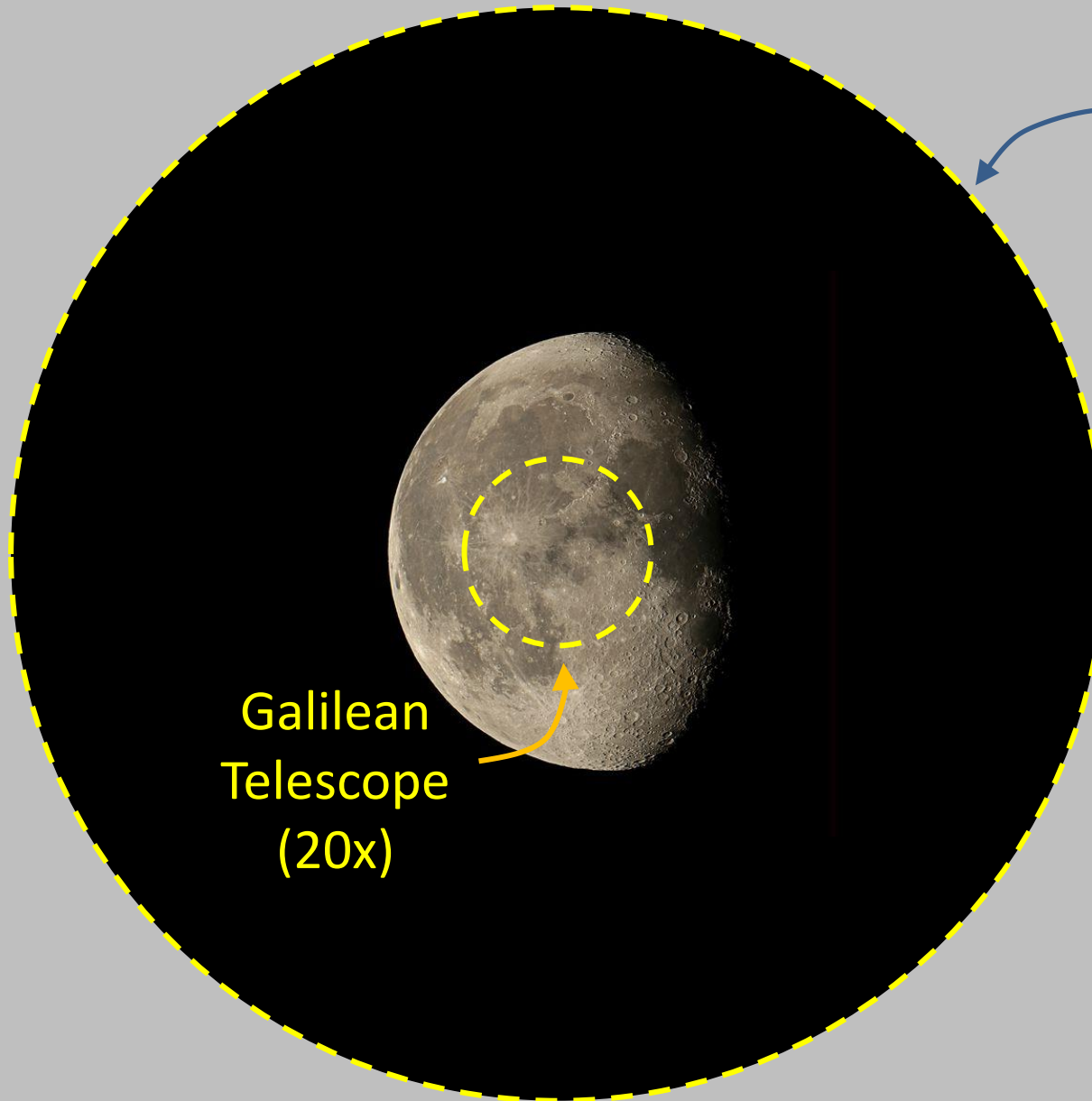
First implementation:
Christof Scheiner
 1613-1617

Not published until 1630



Christof Scheiner
 Jesuit Astronomer/Physicist

Field of View Comparison (approximate)



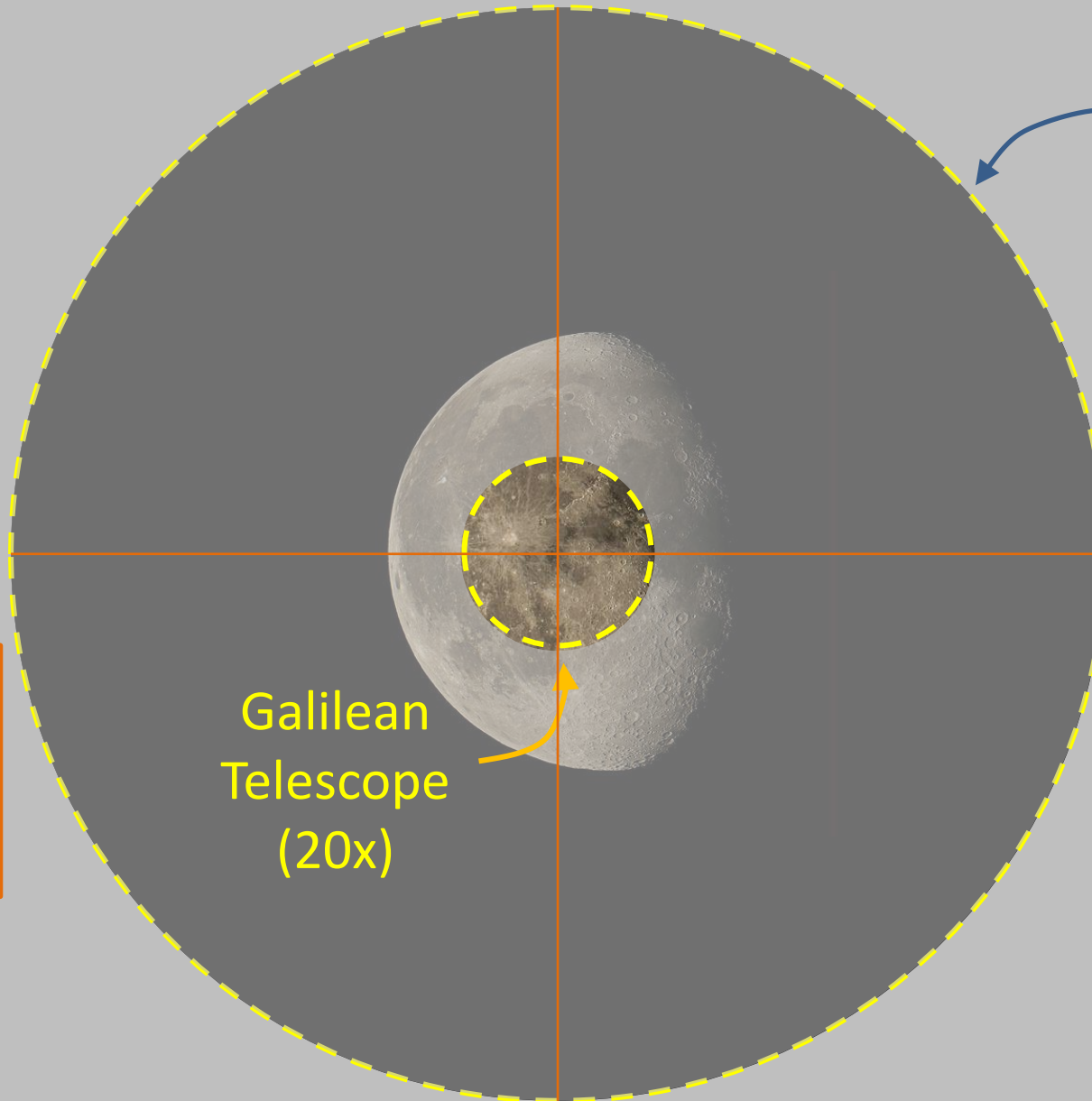
Keplerian
Telescope
(20x)

Galilean
Telescope
(20x)

Keplerian Refractive
Telescopes are also
called Astronomical
Telescopes



Field of View Comparison (approximate)



Keplerian
Telescope
(20x)

Galilean
Telescope
(20x)

Another advantage:
Kepler design
allowed **crosshairs**
in the image plane

Keplerian Refractive
Telescopes are also
called Astronomical
Telescopes



Telescope Race

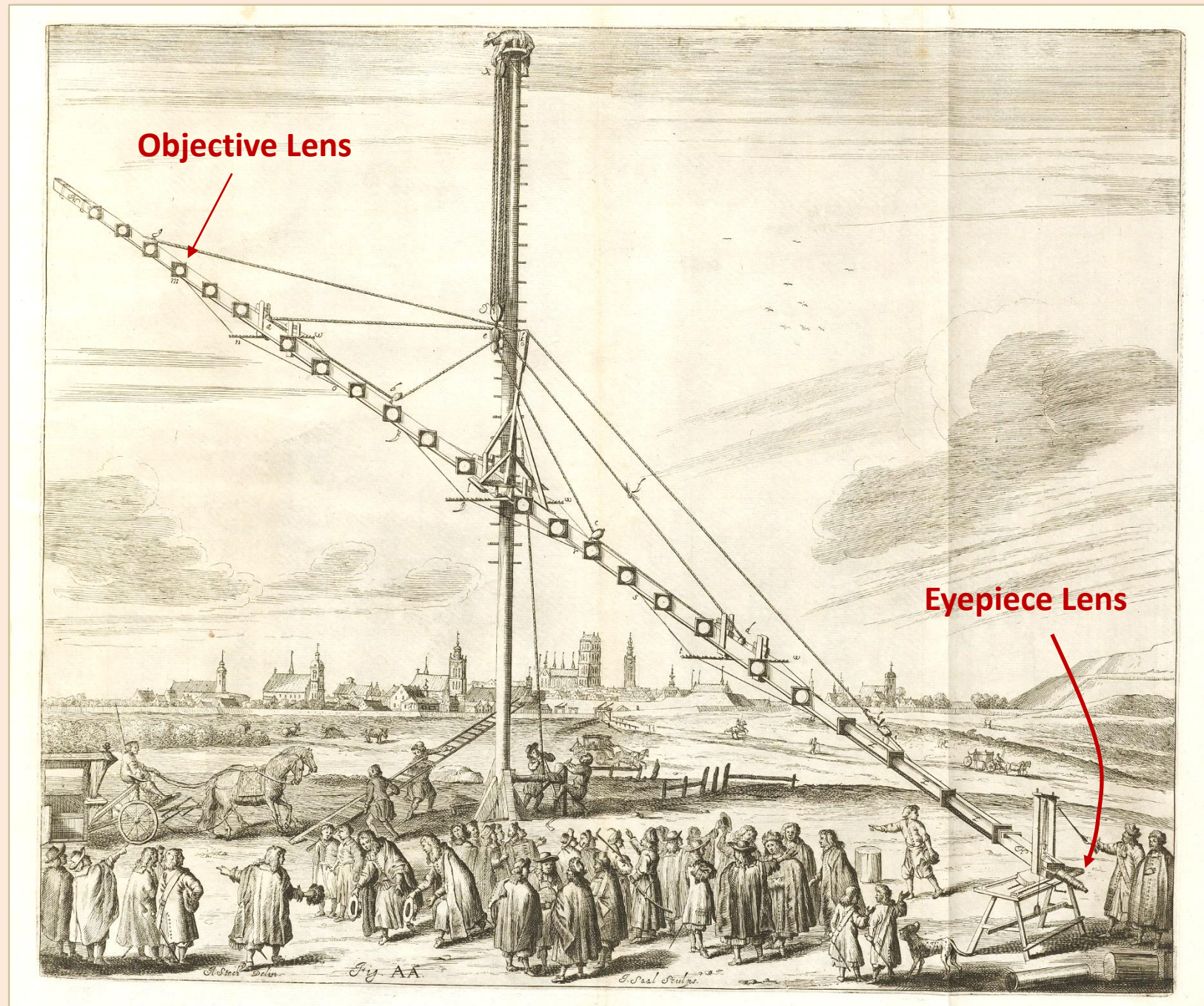
Mid 17th Century

148 ft Focal Length
Keplerian astronomical
refractor

Johannes Hevelius
Danzig, Poland

Machina Coelestis (1673)

Houghton Library, Harvard



Telescope Race

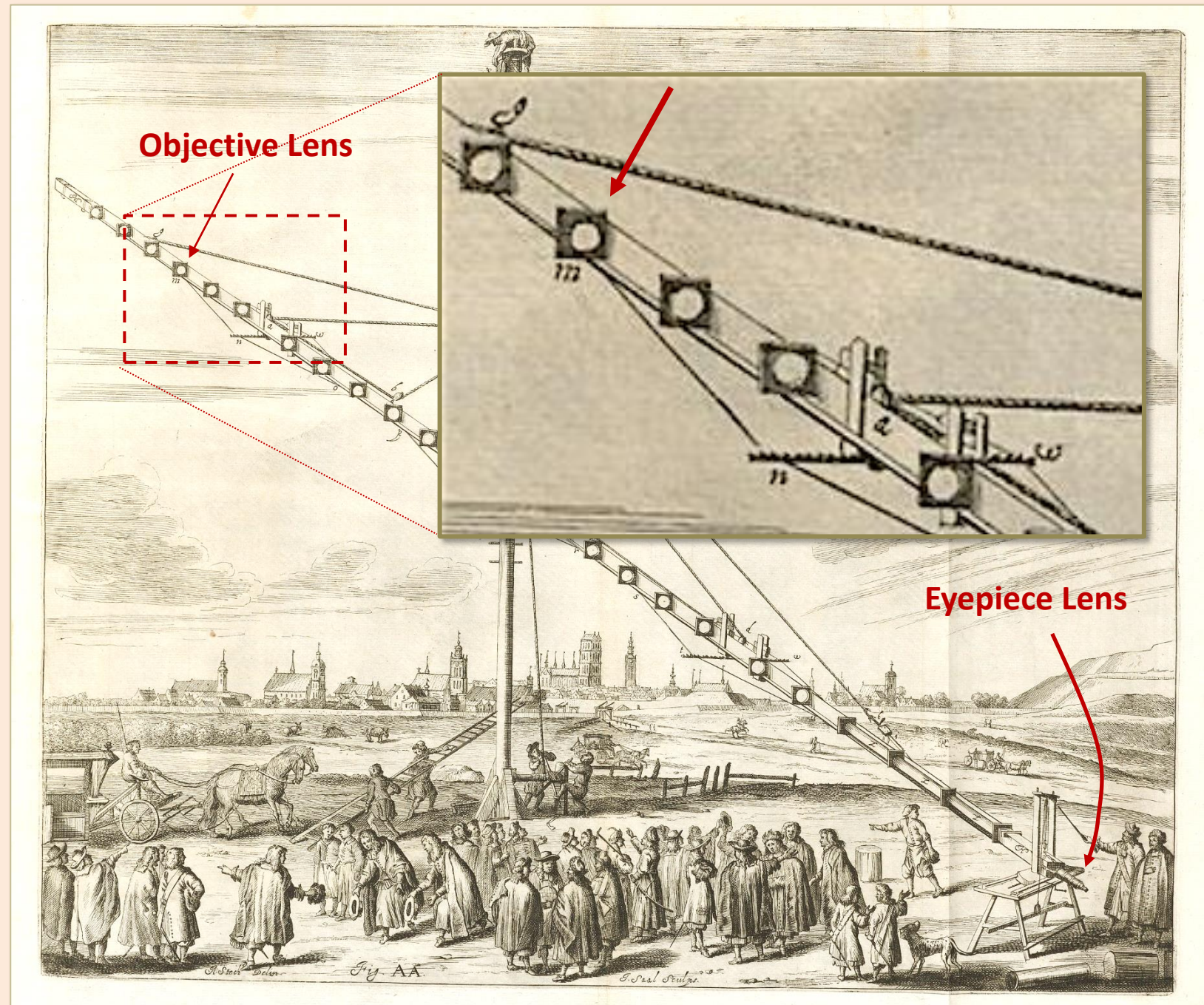
Mid 17th Century

148 ft Focal Length
Keplerian astronomical
refractor

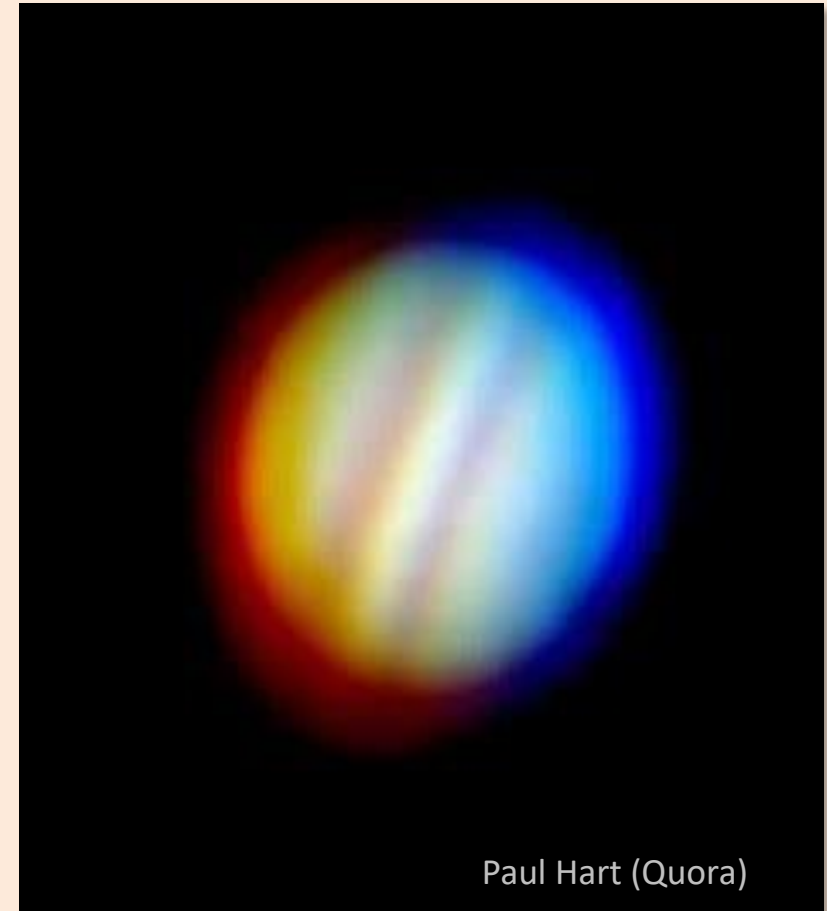
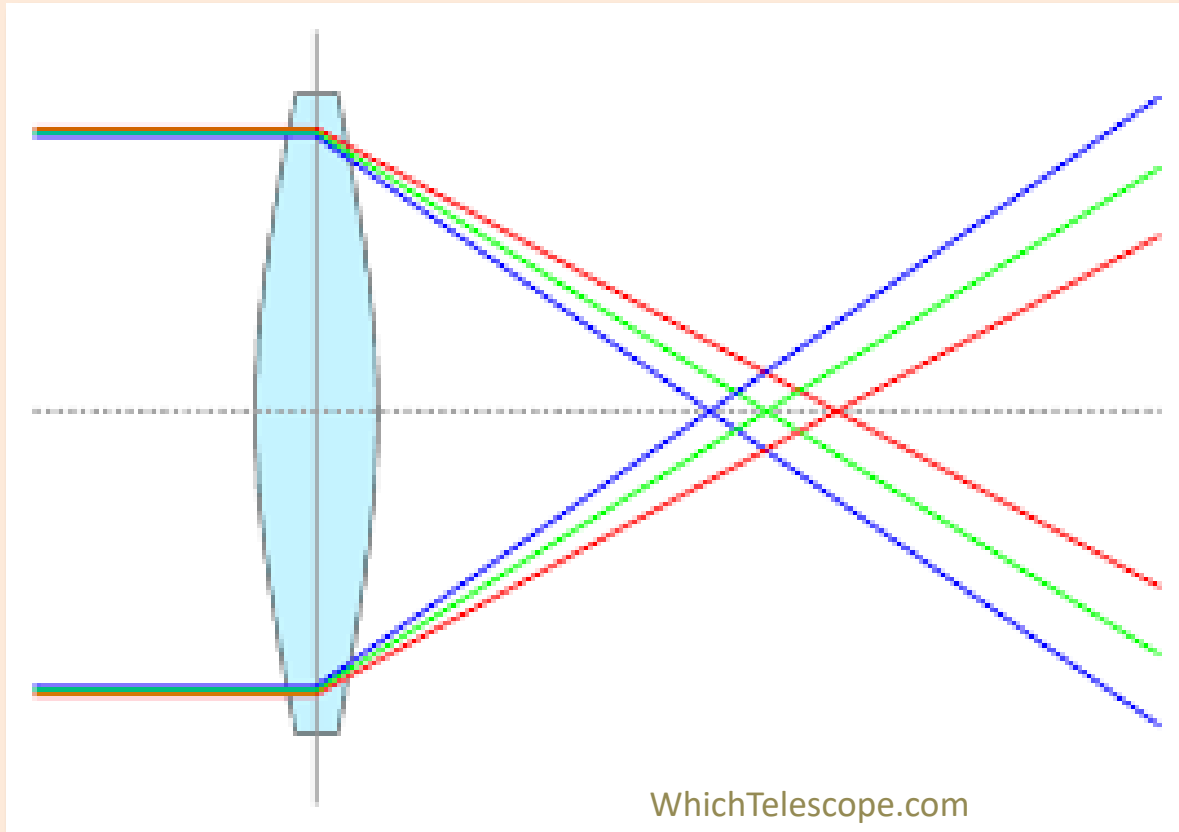
Johannes Hevelius
Danzig, Poland

Machina Coelestis (1673)

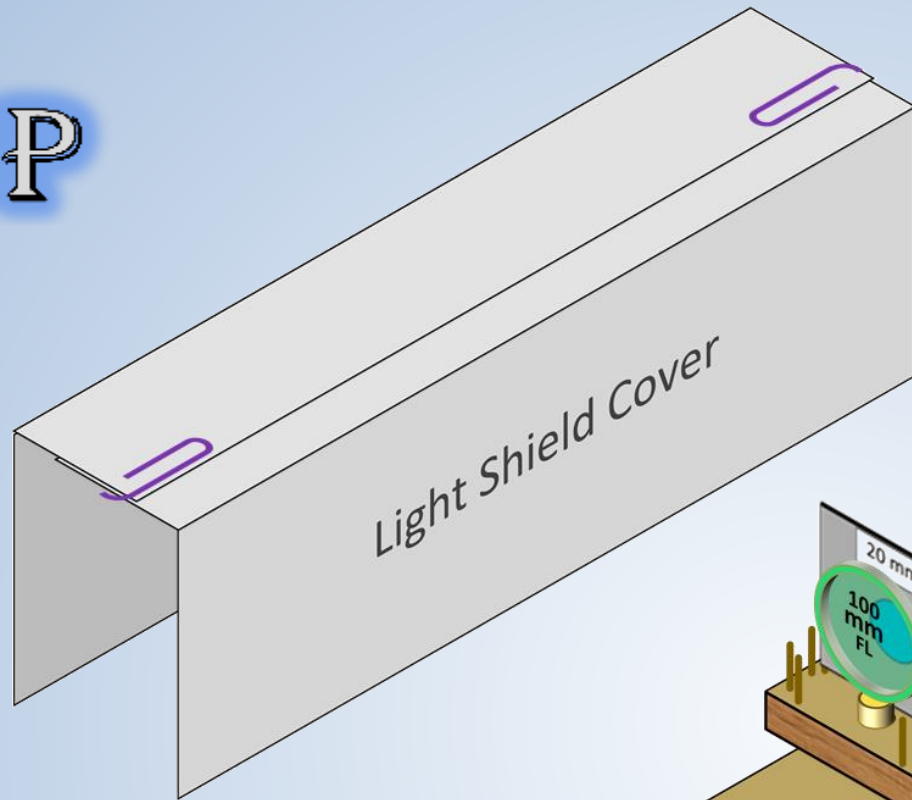
Houghton Library, Harvard



Achilles Heel of Refractors: Chromatic Aberration



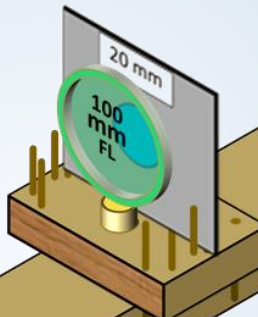
OLLI-OP



35 mm FL Eye Lens
with 12 mm
Aperture



12" RAIL



100 mm FL Objective
with 20mm Aperture

~ 175 mm
(Adjust to
Focus)

3x Keplerian Telescope



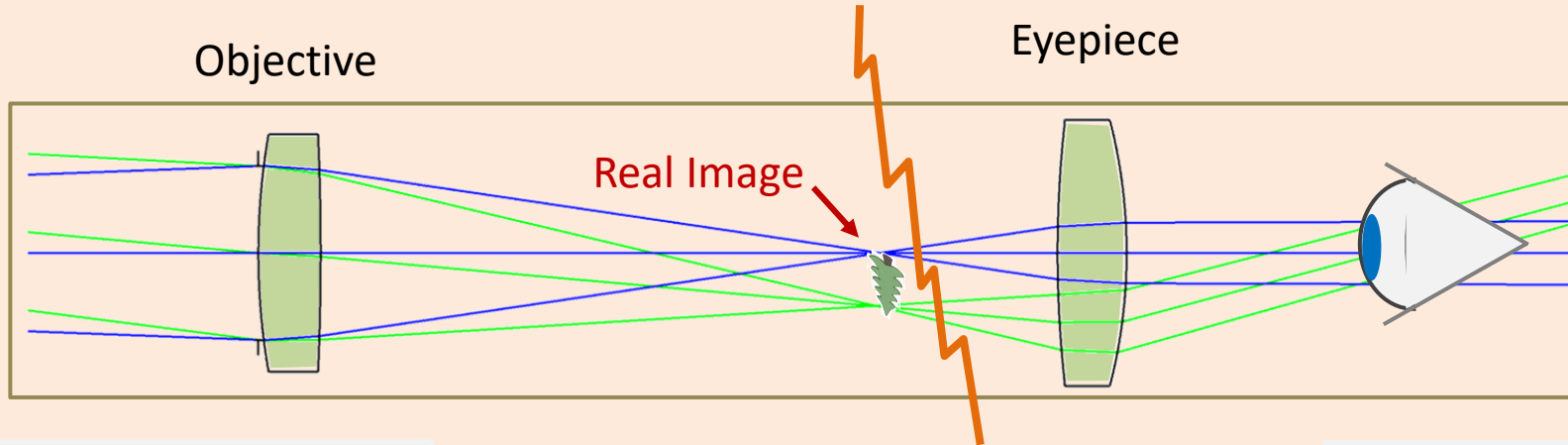
Slight Problem with
Keplerian Telescopes for
Everyday Use



Engraving by Adriaen van de Venne
printed in Middelburg, 1624



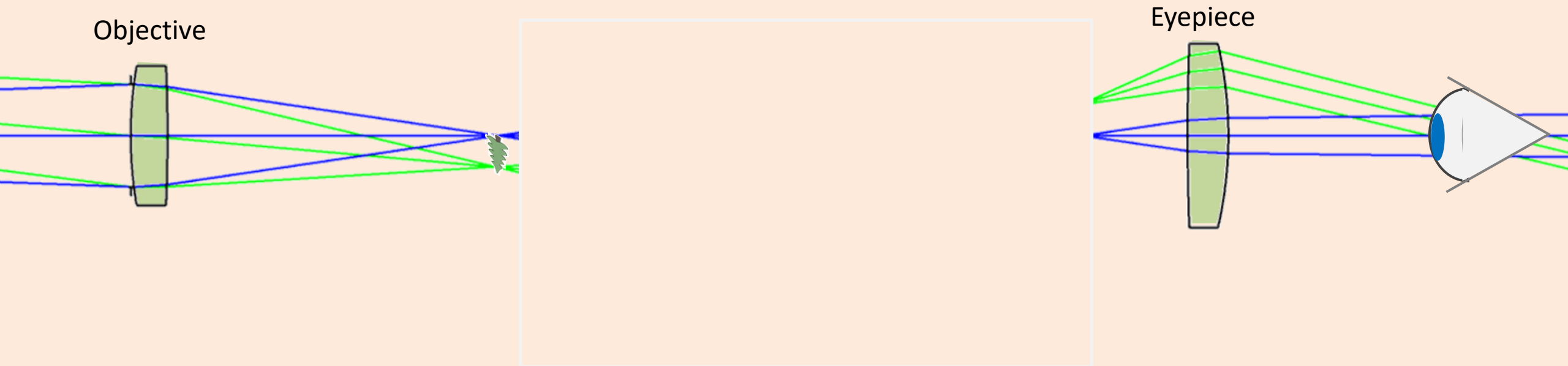
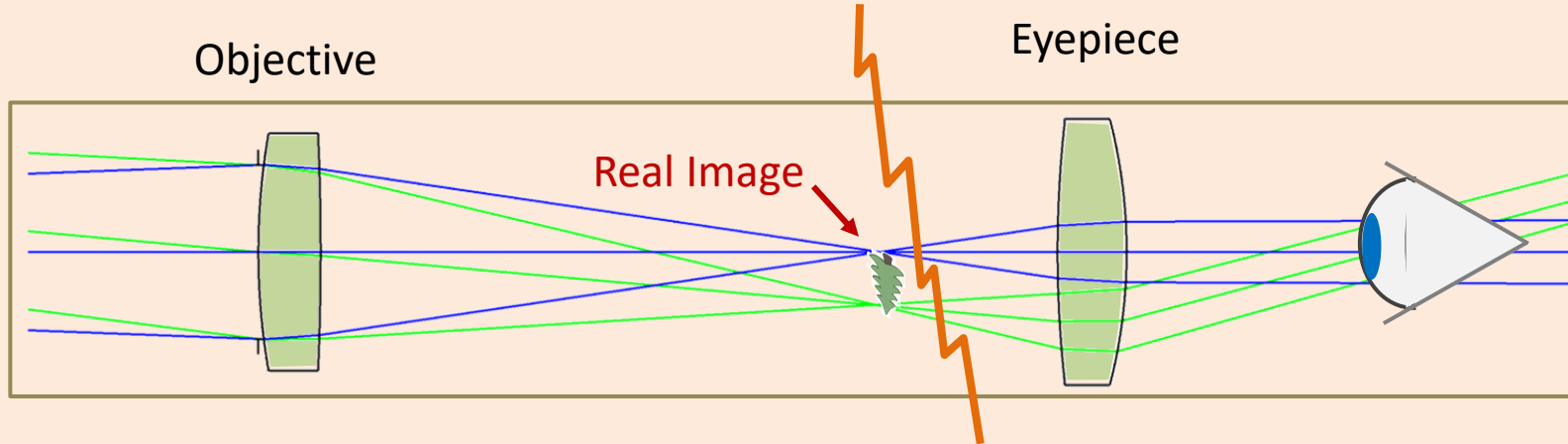
Building a Terrestrial (non-inverting) Telescope



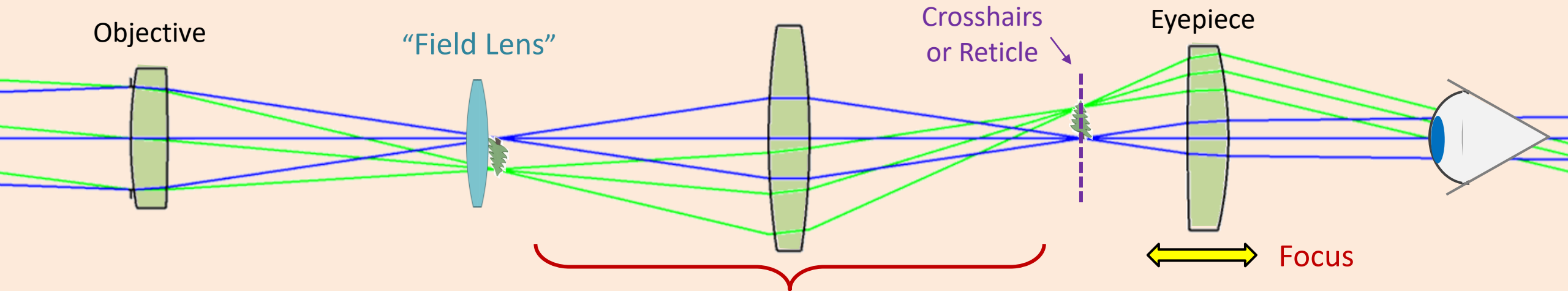
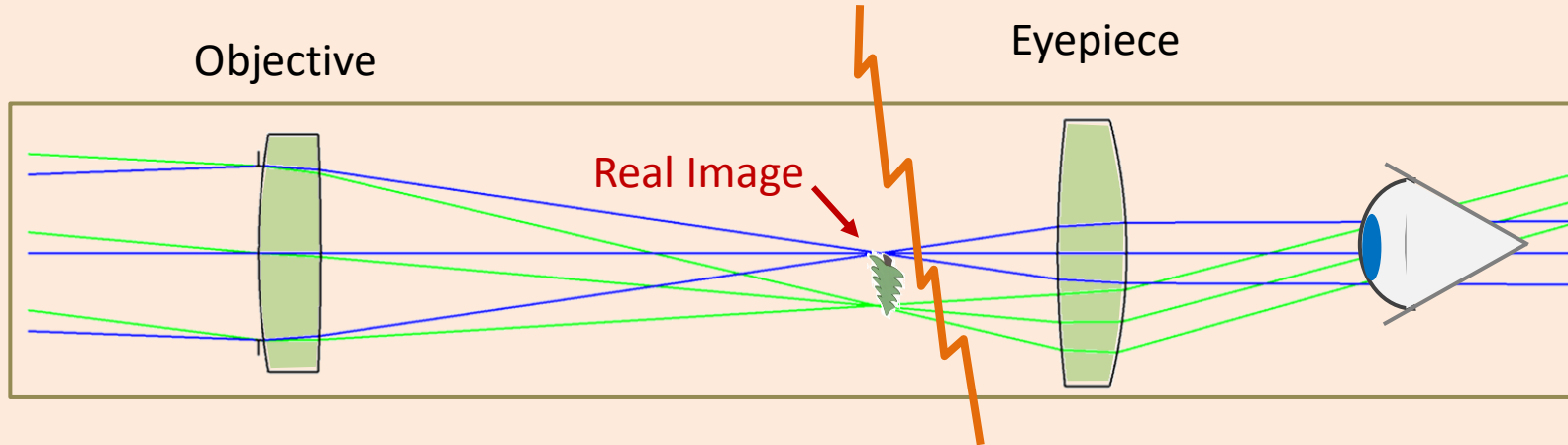
Cut Here



Building a Terrestrial (non-inverting) Telescope



Building a Terrestrial (non-inverting) Telescope



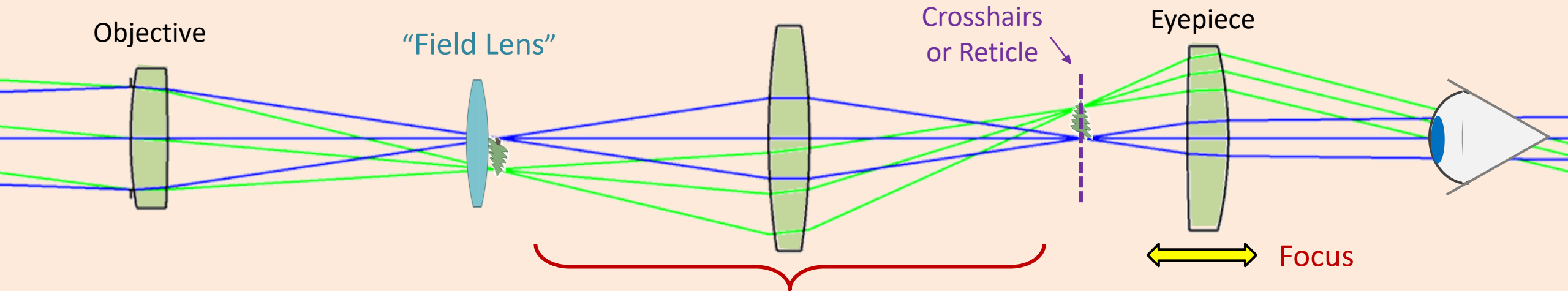
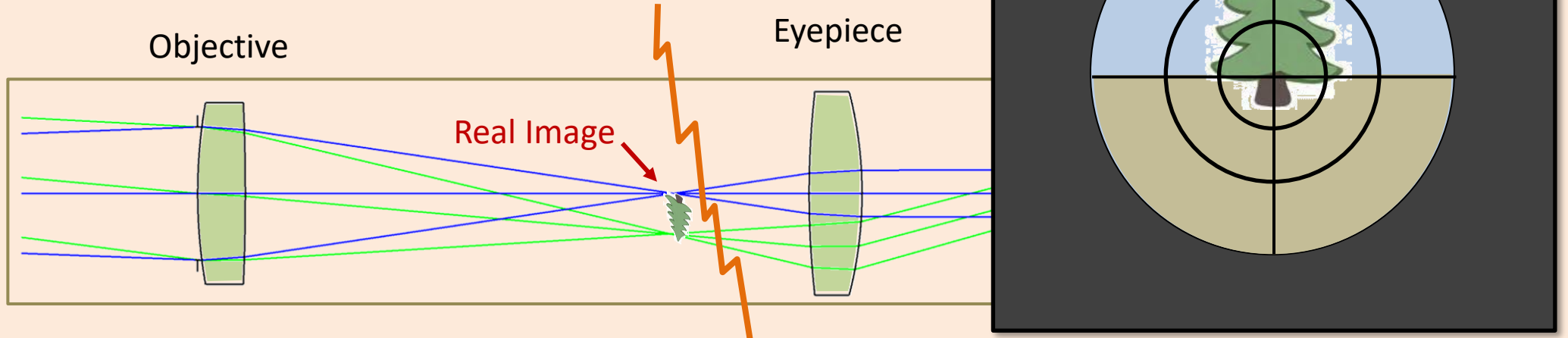
Insert Erector Lens

1:1 Relay

Terrestrial Refractor



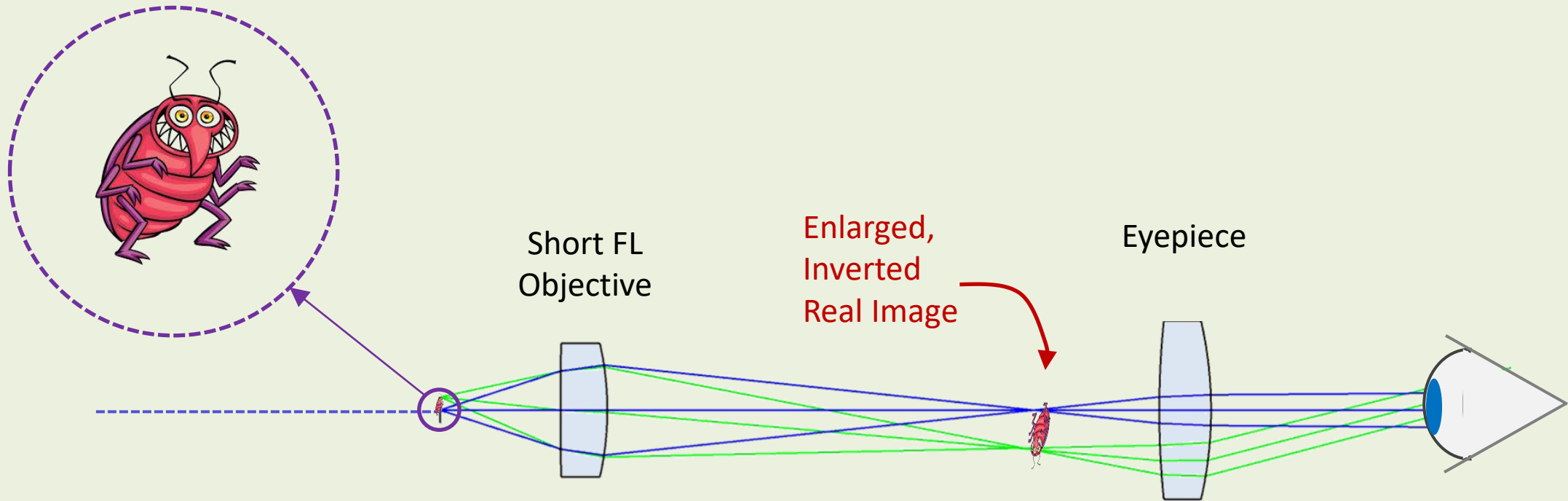
Building a Terrestrial (non-inverting) Telescope



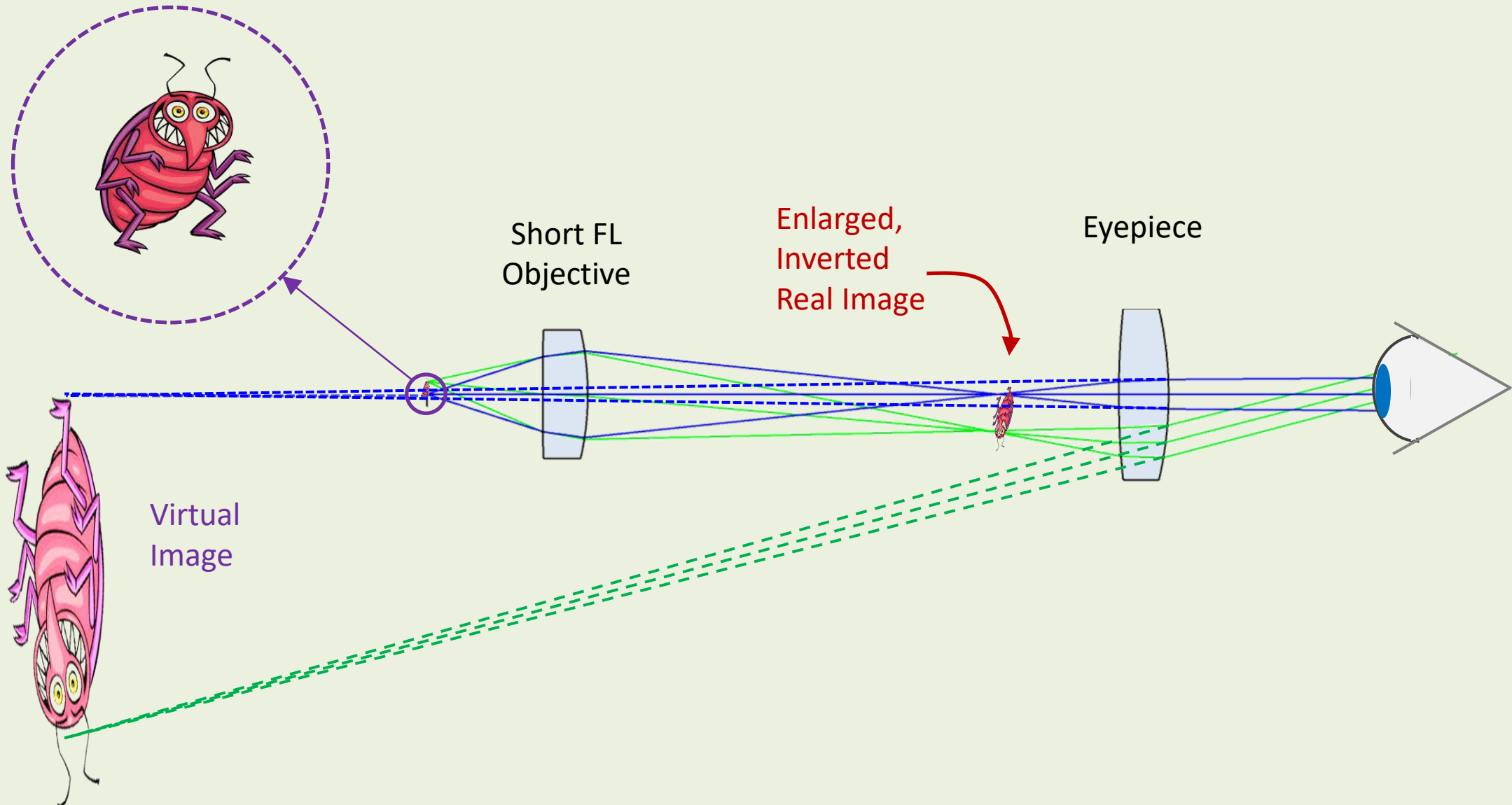
Terrestrial Refractor



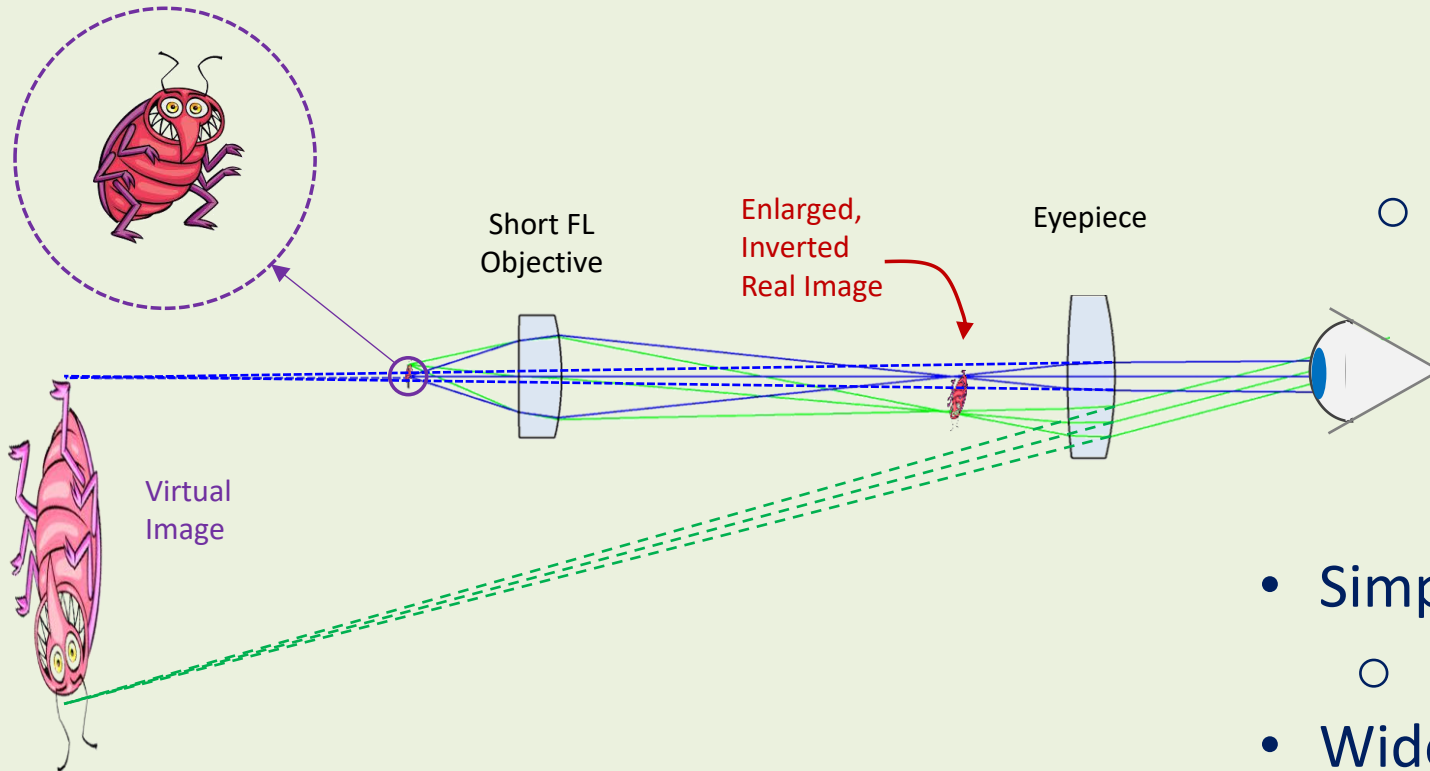
Compound Microscope



Compound Microscope



Compound Microscope



- Appeared in Mittelburg around the same time as Telescopes (~ 1608)
 - Same cast of characters
 - *Hans Lippershey*
 - *Hans & Zacharias Janssen*
 - Exact date unknown

Father & Son Team

- Simple to build, spread quickly
 - Poor performance, limited to ~ 30x
- Widely available by mid 1600's in Europe
- Initially, no "Killer Applications"





Robert Hooke

1635-1703

London

Polymath

Curator of Experiments at
Royal Society

Commissioned a
Microscope from
Christopher Cock,
a London Instrument
maker

3/7/2022



National Museum
of Health &
Medicine,
Bethesda MD

Opticks 2

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.



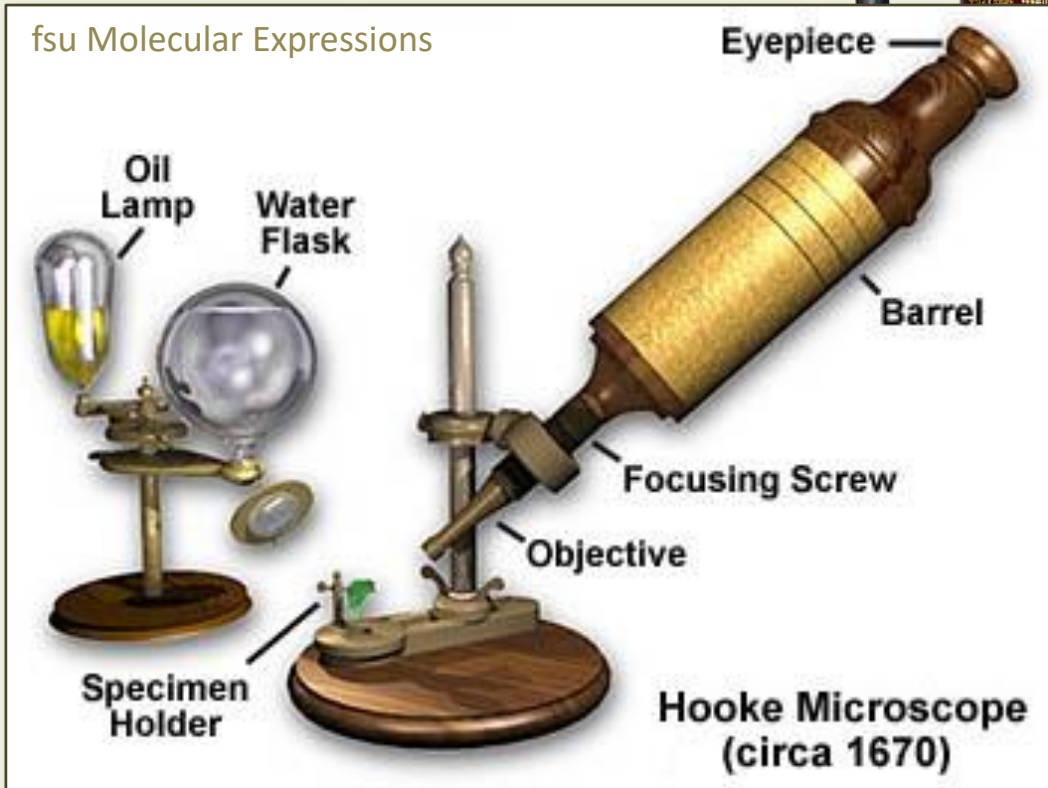
LONDON, Printed by *Jo. Martyn*, and *Ja. Allestry*, Printers to the
ROYAL SOCIETY, and are to be sold at their Shop at the *Bell* in
S. Paul's Church-yard. M DC LX V.

1665



Wikimedia

Robert Hooke

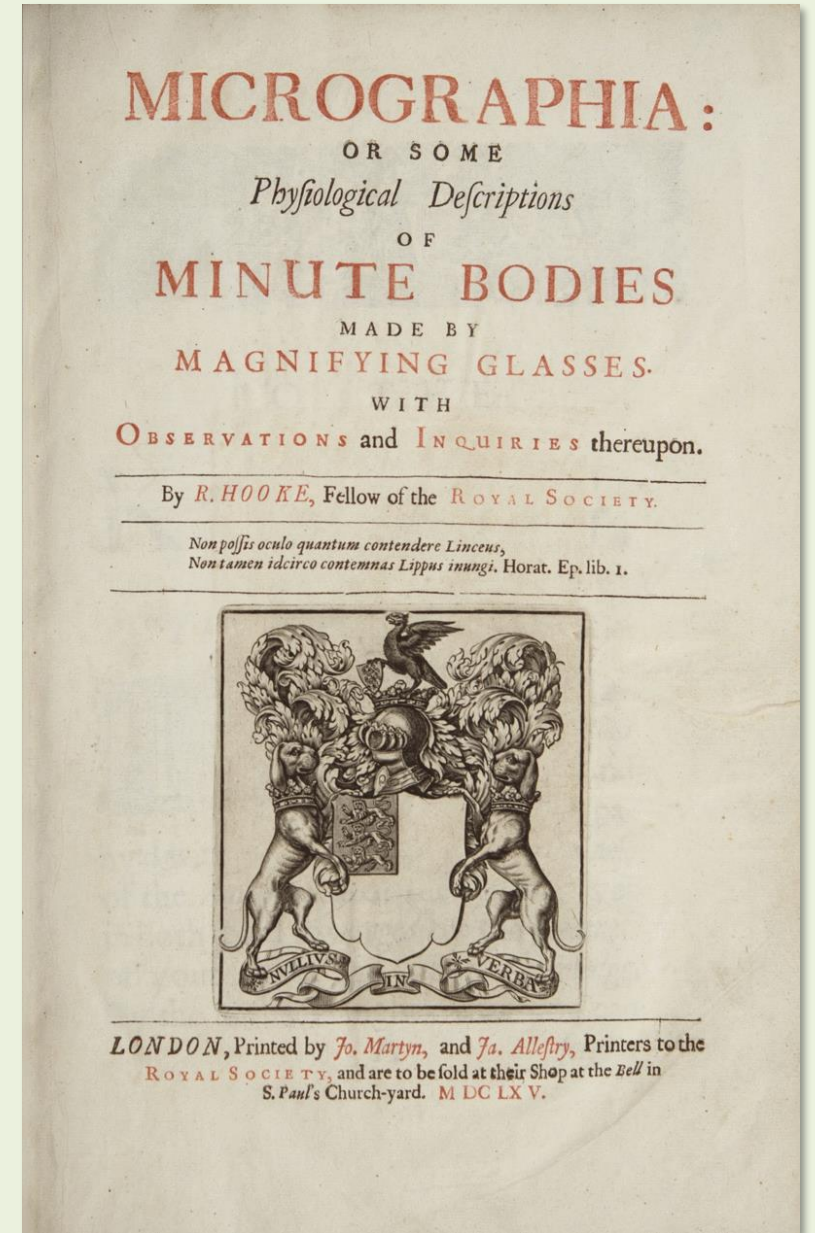


Hooke Microscope (circa 1670)



National Museum of Health & Medicine, Bethesda MD

Opticks 2





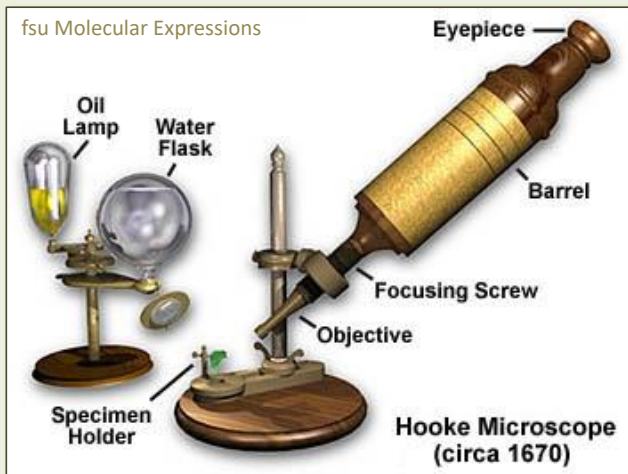
Robert Hooke

1635-1703

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National Museum
of Health &
Medicine,
Bethesda MD

Opticks 2

MICROGRAPHIA:
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1665



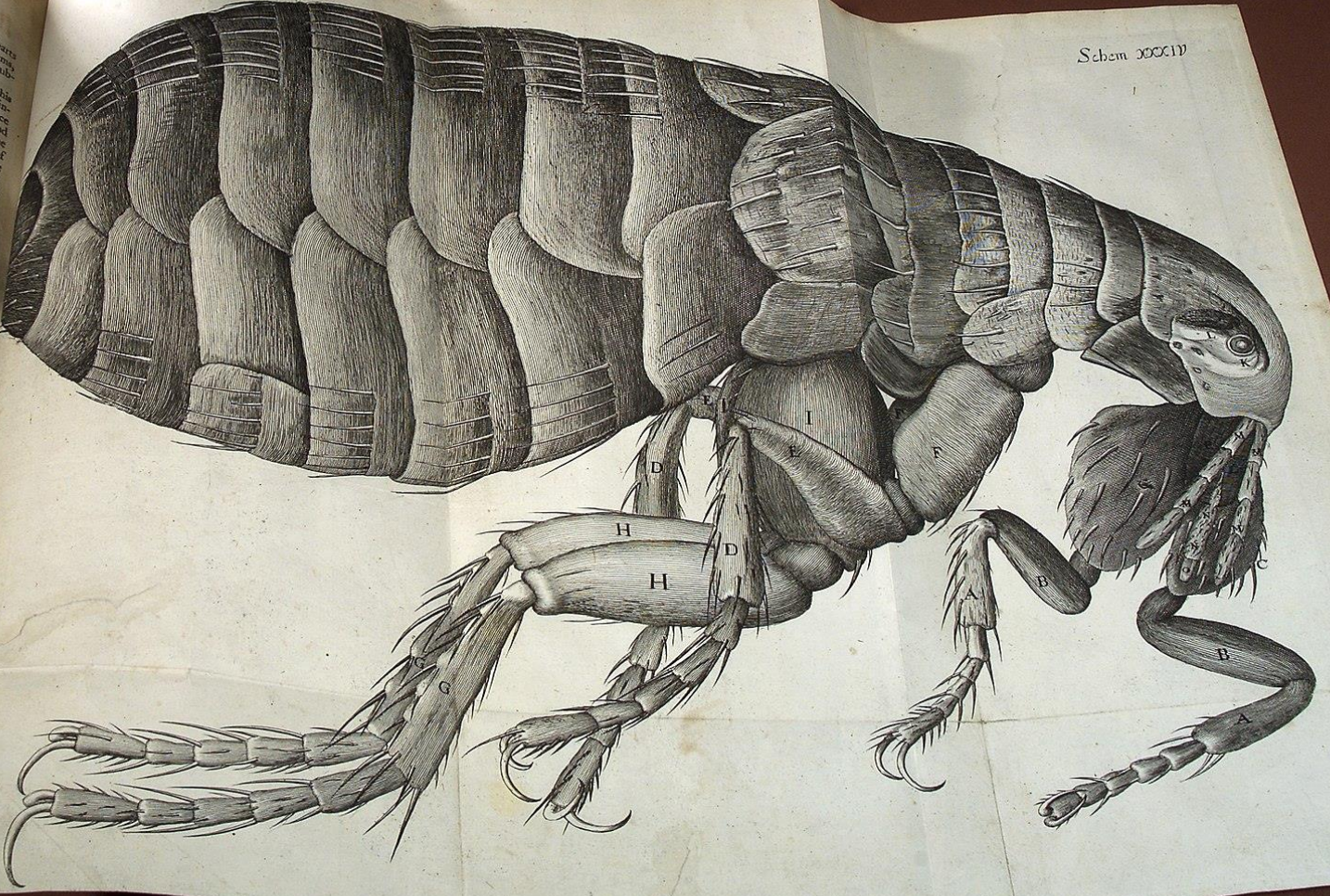
Example of lavish illustrations: The Flea

MICROGRAPHIA

through so many scourgings, washings, drestings and dryings, as the parts of old Paper must necessarily have suffered, the digestive faculty yet remains of their little creatures being able yet further to work upon those (sublim) bon parts, and reduce them into yet further to work upon those (sublim) little creature, when I consider what a heap of Saw-dust or chips this tale cannot quite but remember what a heap of Saw-dust or chips this of Nature, in placing in one of the reach of fire, to be conveyed by the beams of the materials convey'd into the stomach, and powdered by the animals, at to make the very spreading and waiving of that fire, to be instrumental to the procuring and collecting more materials to augment and cherish it self which indeed seems to be the principal end of all the contrivances observable in bruit Animals.

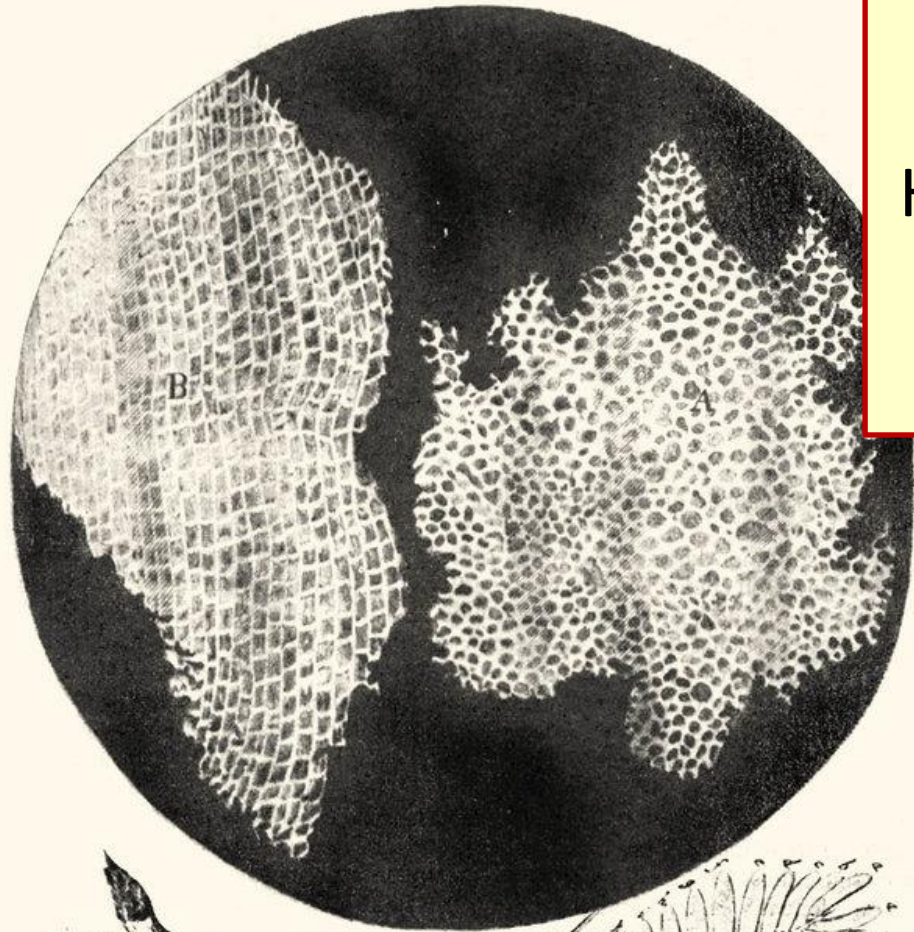
Observ. LIII. Of a Flea.
The strength and beauty of this small creature, had it no other relation at all to man, would deserve a description.
For its strength, the *Microscope* is able to make no greater discovery of it than the naked eye, but only the curious contrivance of its legs as no other creature, I have yet observed, has any thing like it; for that in another, and suddenly stretch them out to their whole length, and B within C, parallel to part J, of the 34. *Scheme*, lies within B, and the two next, lie quite contrary, that is, D without E, and E without F, but parallel also; but the parts of a double jointed Ruler, or like the foot, leg and thigh of a man; these six legs he clutches up as together, and when he leaps, springs them all out, and thereby exerts his whole strength at once.

But, as for the beauty of it, the *Microscope* manifests it to be all over adorn'd with a curiously polish'd suit of *scale*. Armour neatly jointed, and beset with multitude of sharp pins, slip'd almost like Porcupine's Quills, or bright conical Steel-bodkins; the head is on either side beset with a quick and round black eye K, behind each of which also appears a thin film cavity, L, in which he seems to move to and fro a certain thin film beset with many small transparent hairs, which probably may be his ears; in the forepart of his head, between the two fore-legs, he has two small long jointed feelers, or rather smellers, M, M, which have four joints, and are hairy, like those of several other creatures; between these, it has a small *proboscis*, or *probe*, N, N, that seems to consist of a tube,



Schem XXXIII

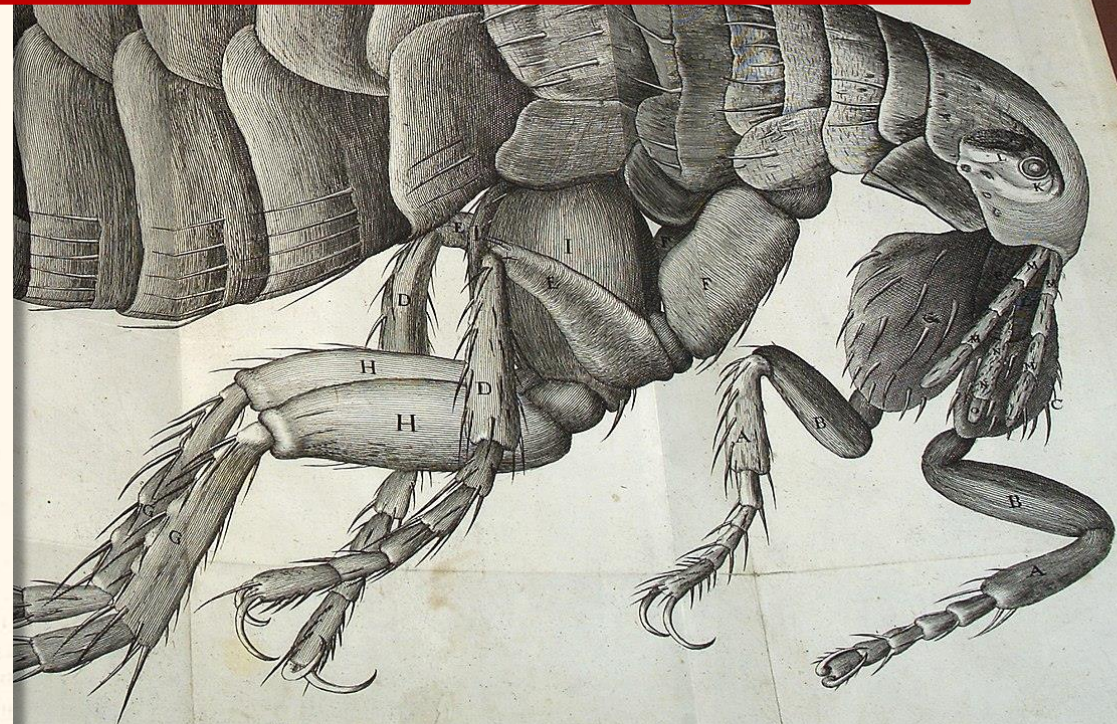
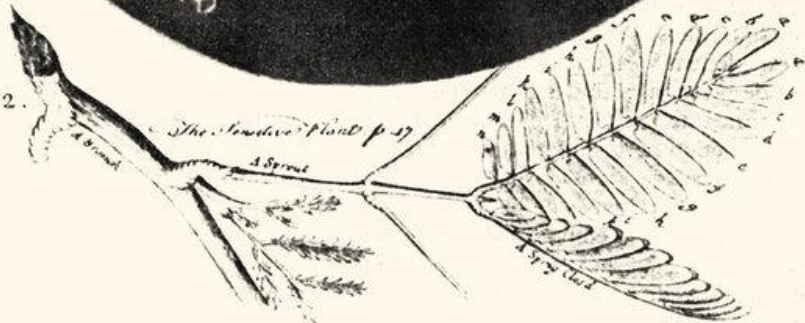
Fig: 1.



Drawing in *Micrographia* of thin sections of Cork, showing its Cellular nature.

Hooke famously coined the term '**Cell**' for these biological structures.

Fig: 2.





Antonie van Leeuwenhoek (1632-1723)
Delft Drapery Merchant,
Amateur Scientist

- Latecomer to Microscopy (1675)
- Built hundreds of simple microscopes
- Single lens, very short focal length
 - Basically powerful Magnifying Glasses
 - Up to 266x Magnification (*or higher*)
 - Ground his own lenses
- Discovered Microbial Life (*“Animalcules”*)
 - Protozoa
 - Bacteria
 - Red Blood Cells
 - Sperm
- Elected to Royal Society (1680)



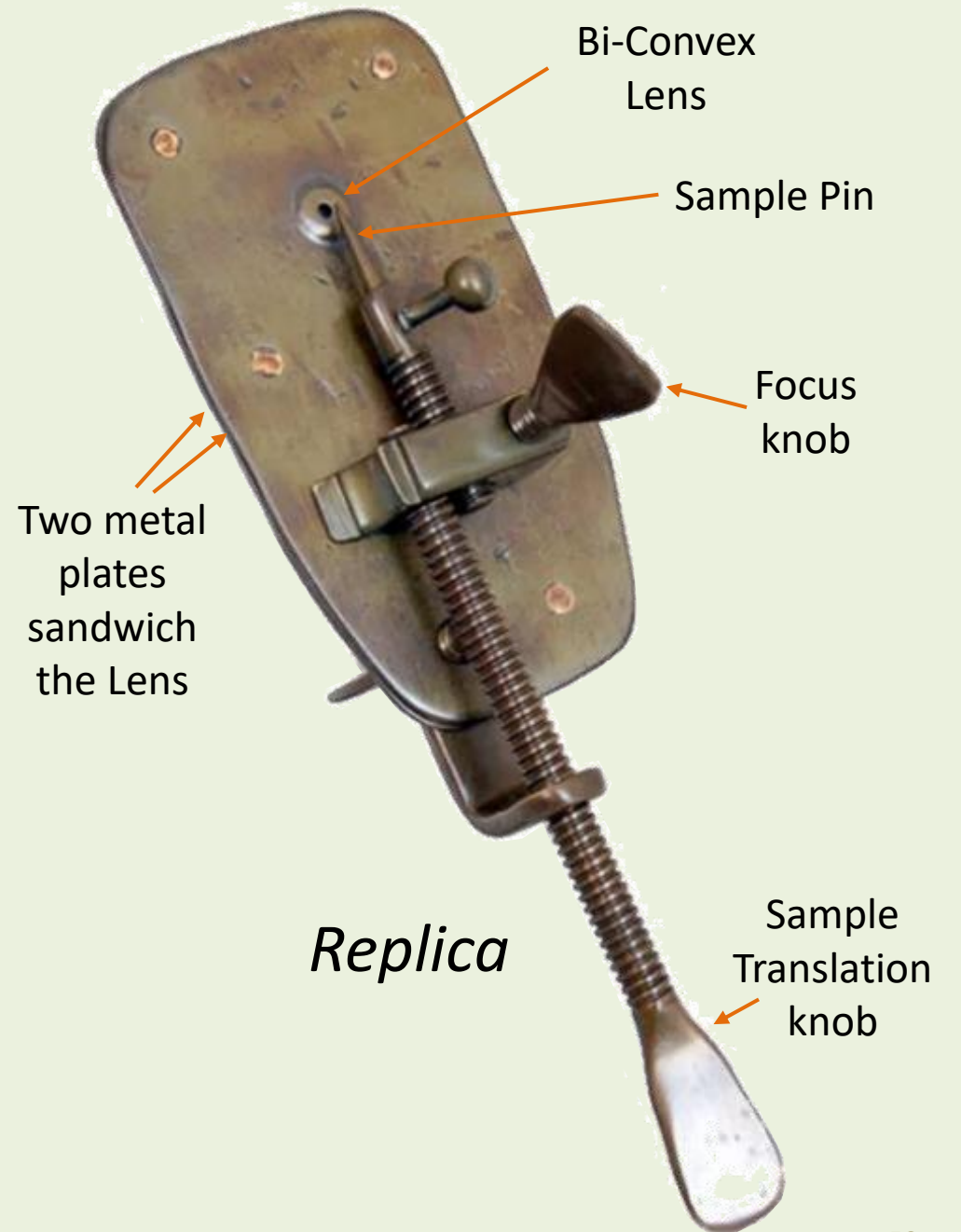
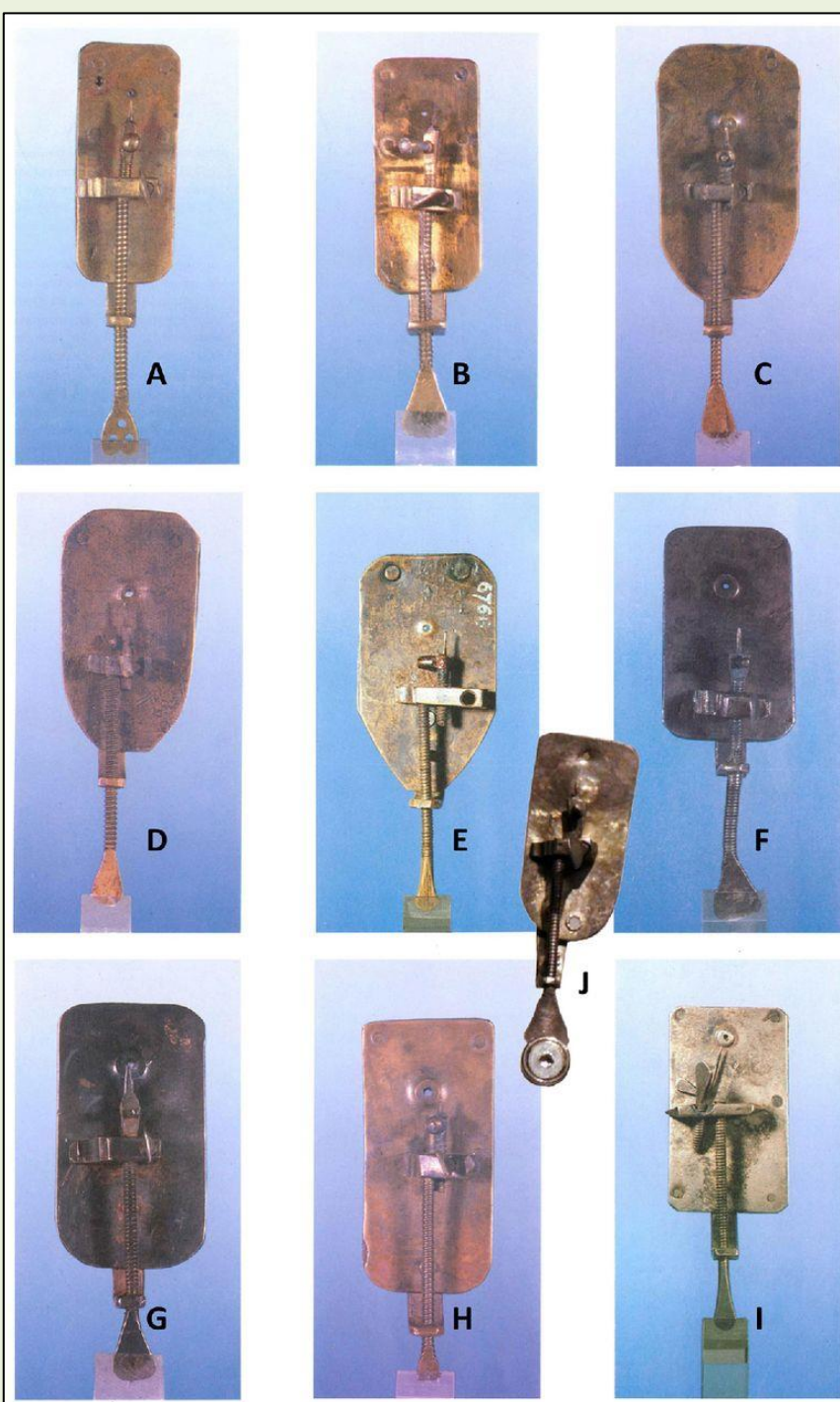
The 10 Possibly Authentic Surviving Leeuwenhoek microscopes

(of hundreds total?)

Focal Lengths
0.94 to 3.66 mm

FEMS Microbiol Lett,
Volume 362, Issue 9,
May 2015
[Museum Boerhaave,
Leiden]

3/7/2022

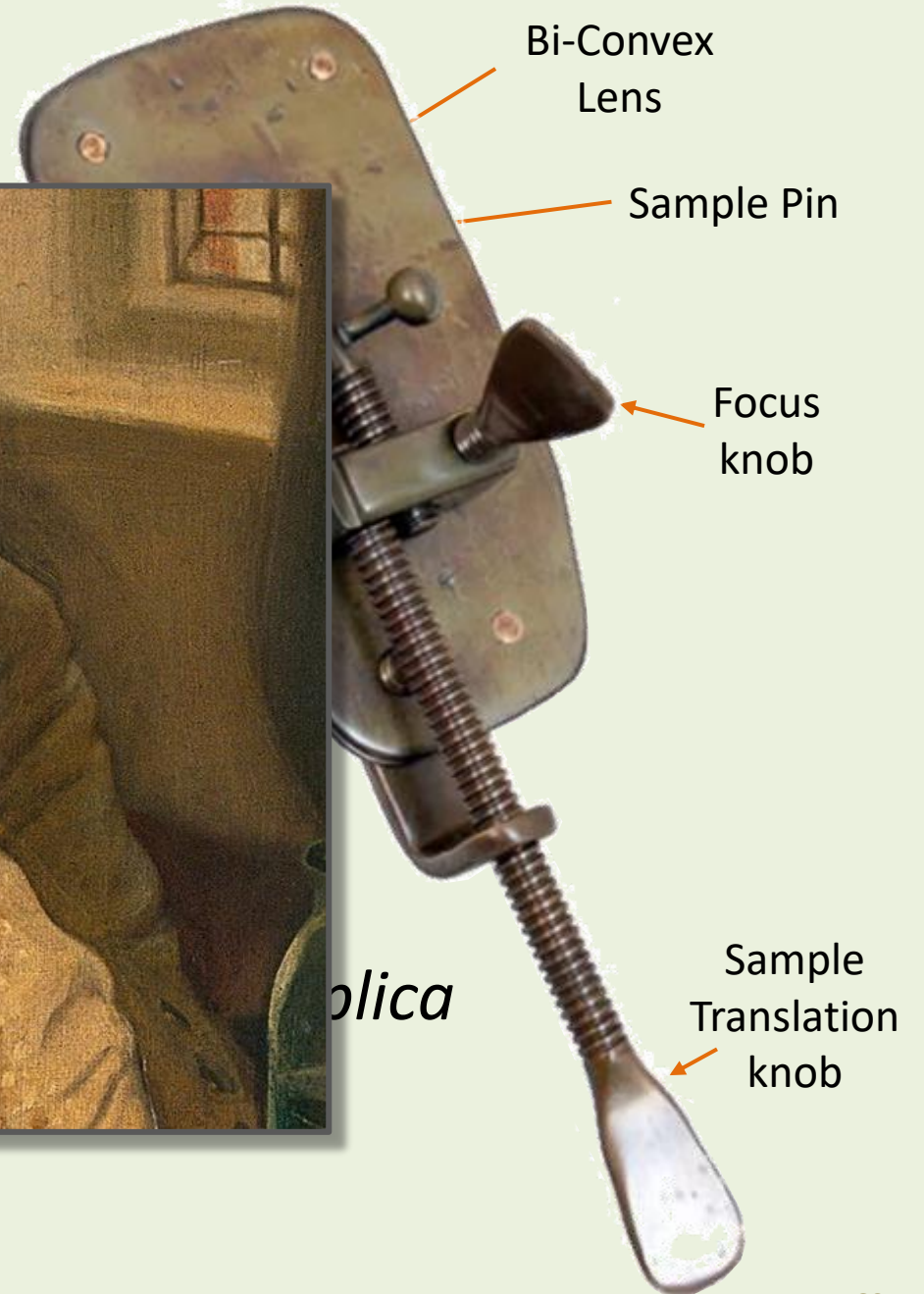
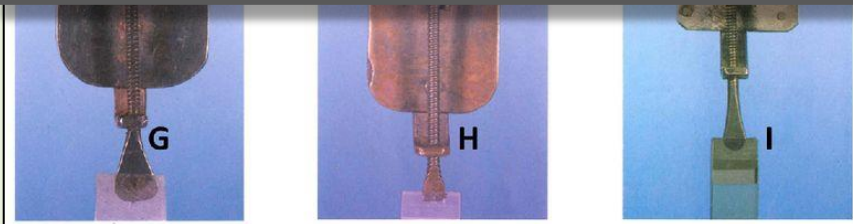


The 10 Possibly Authentic Surviving Leeuwenhoek microscopes (of ~ 500 total)

Focal Lengths 0.94 to 3.66 mm

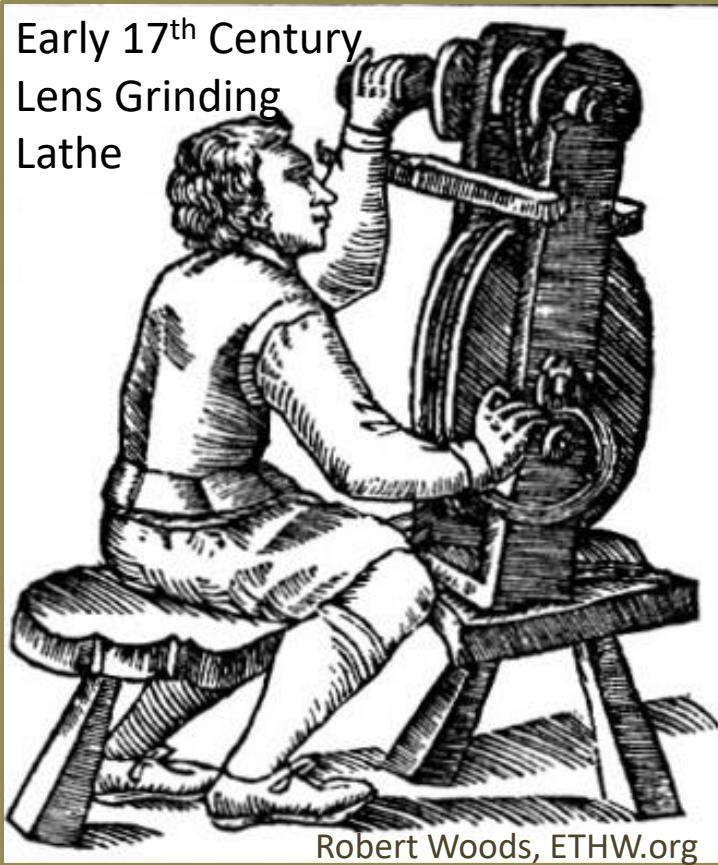
FEMS Microbiol Lett, Volume 362, Issue 9, May 2015

3/7/2022

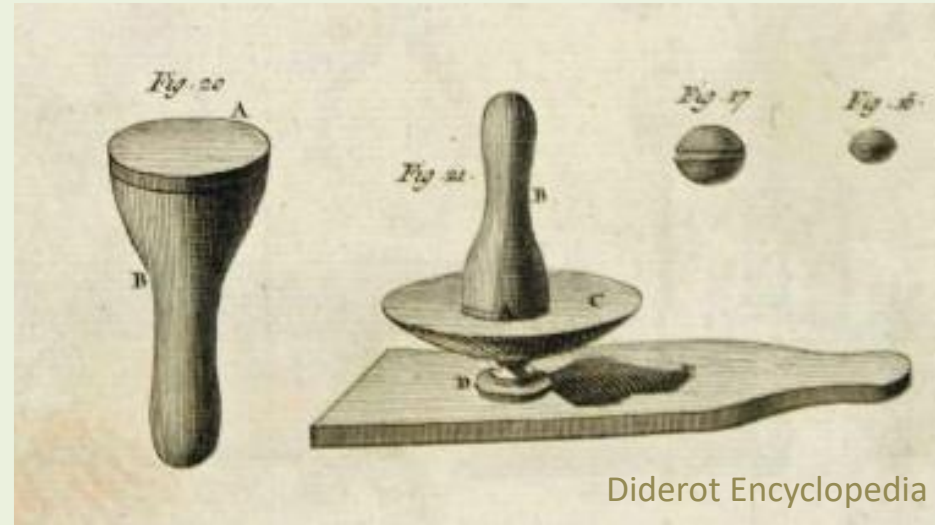


Early Lens Grinding

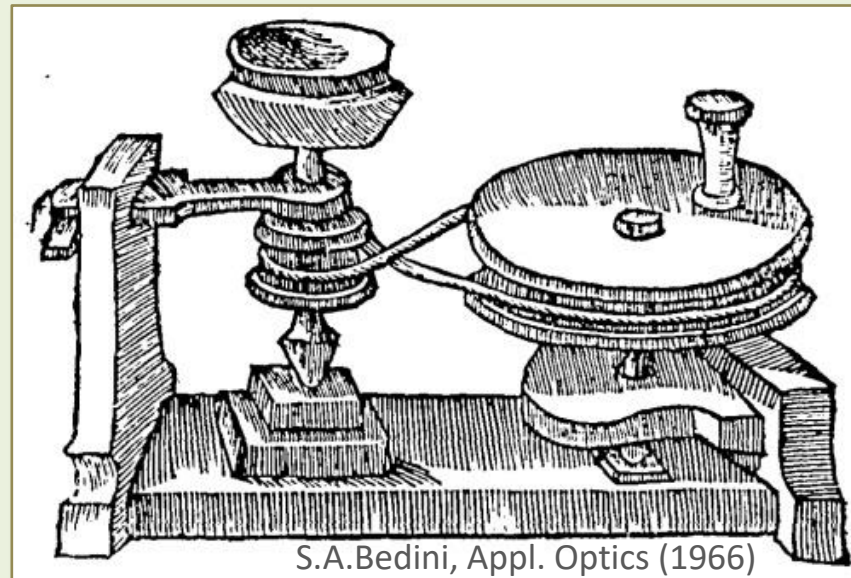
Early 17th Century
Lens Grinding
Lathe



Robert Woods, ETHW.org



Diderot Encyclopedia



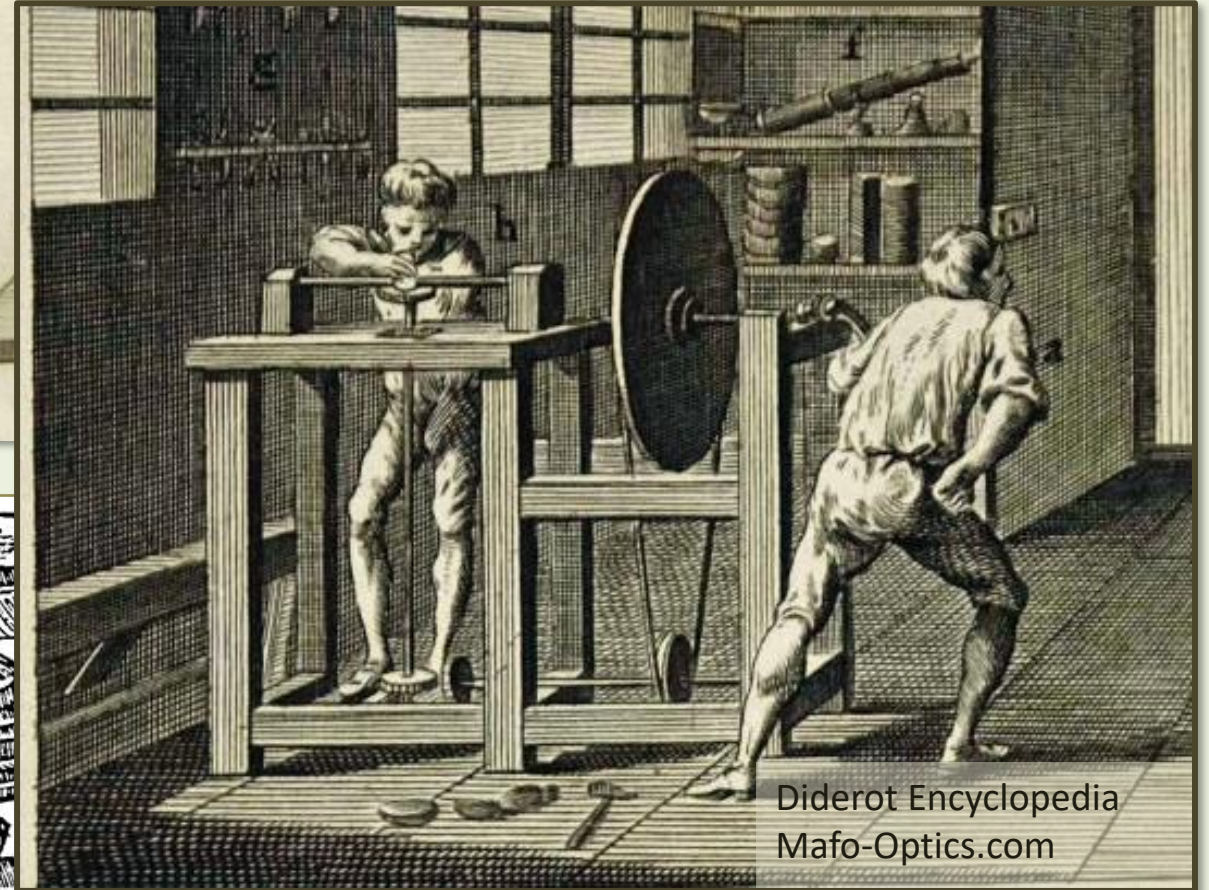
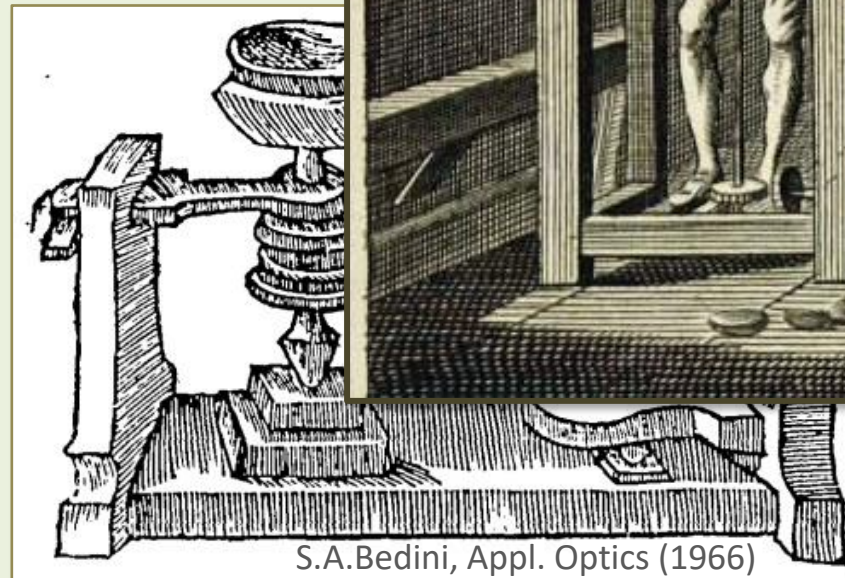
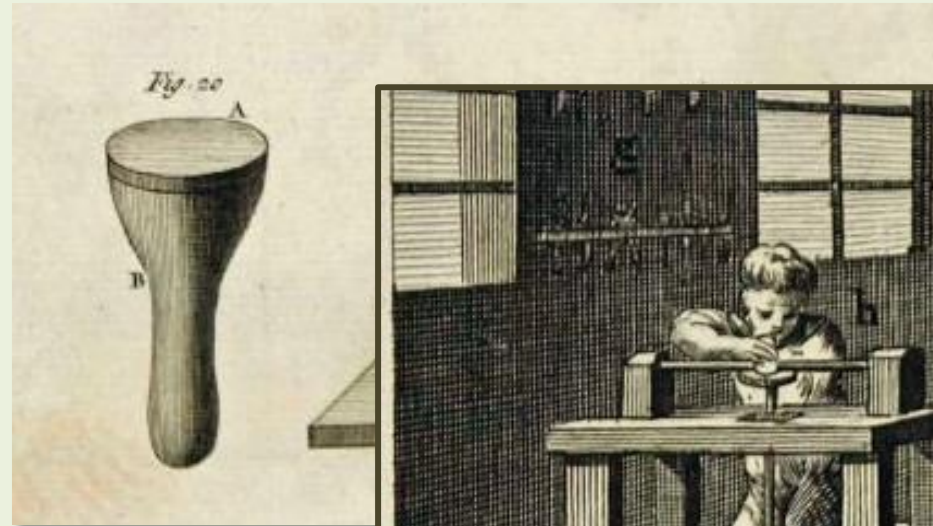
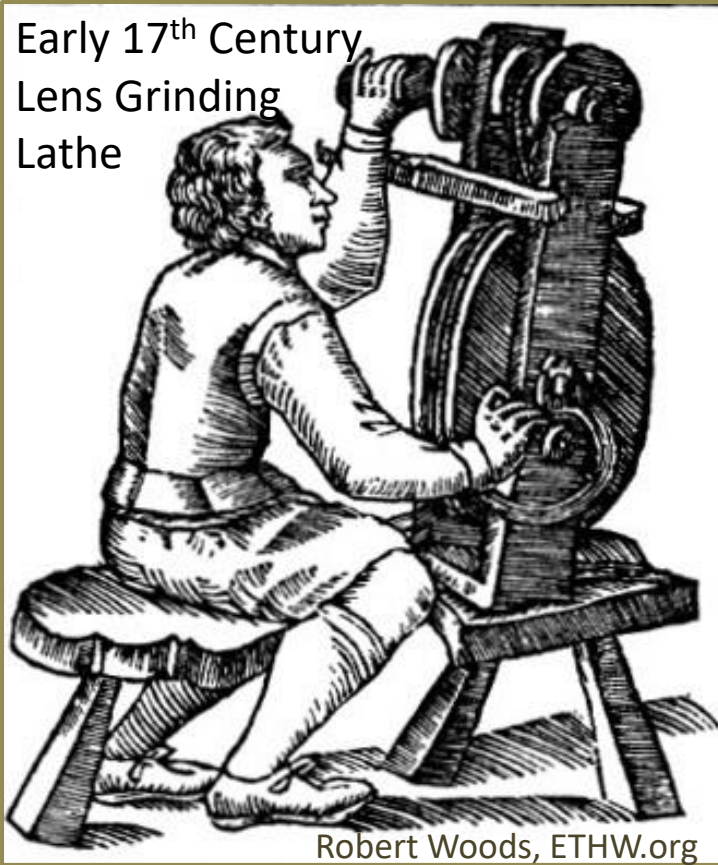
S.A. Bedini, Appl. Optics (1966)

Vertical Axis Grinder
Ippolito Francini
Florence
(1593-1653)



Early Lens Grinding

Early 17th Century
Lens Grinding
Lathe



Lens Making in the 1600s

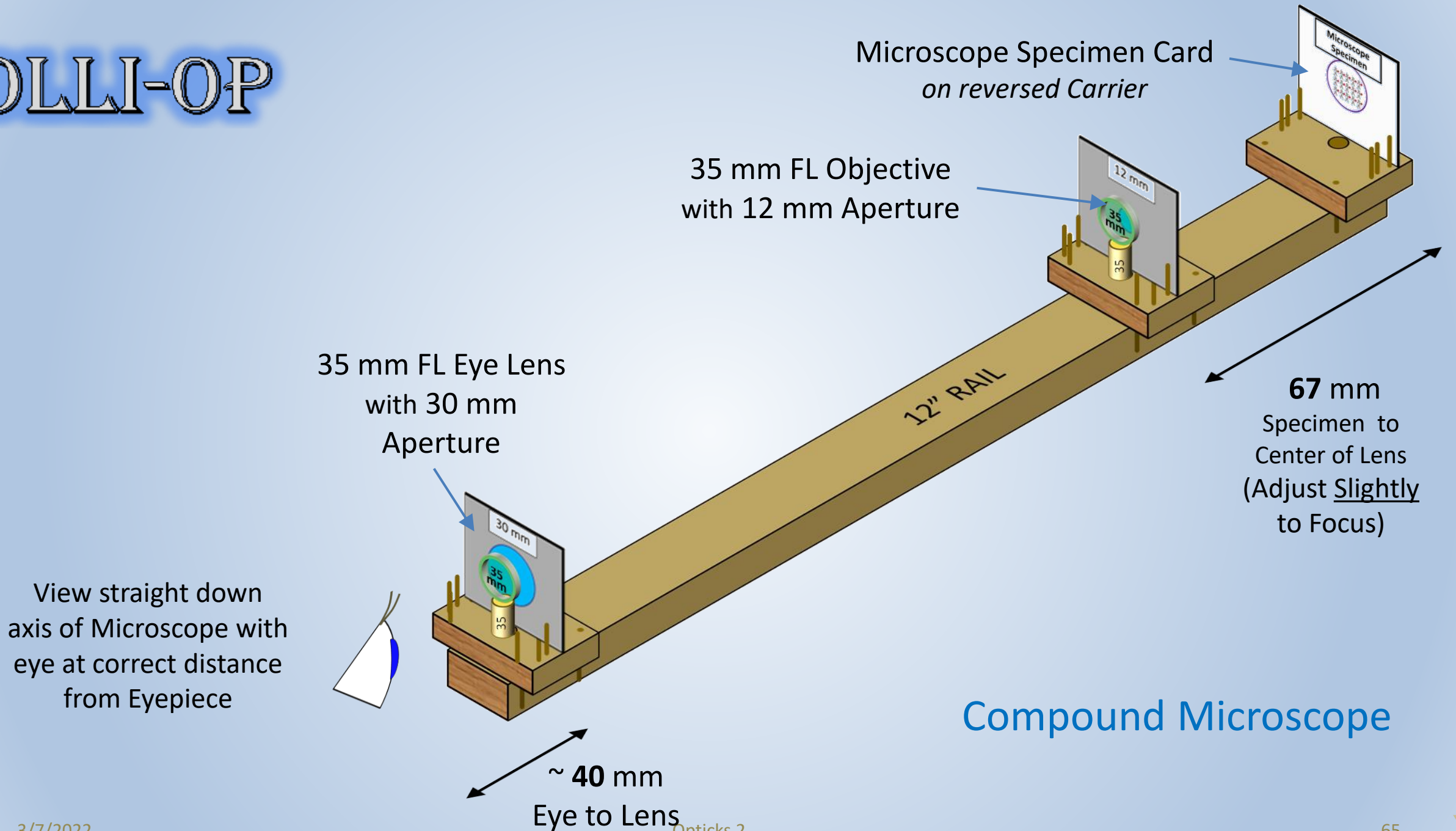
Corning Museum of Glass

<https://www.youtube.com/watch?v=2SJY0foypAo>



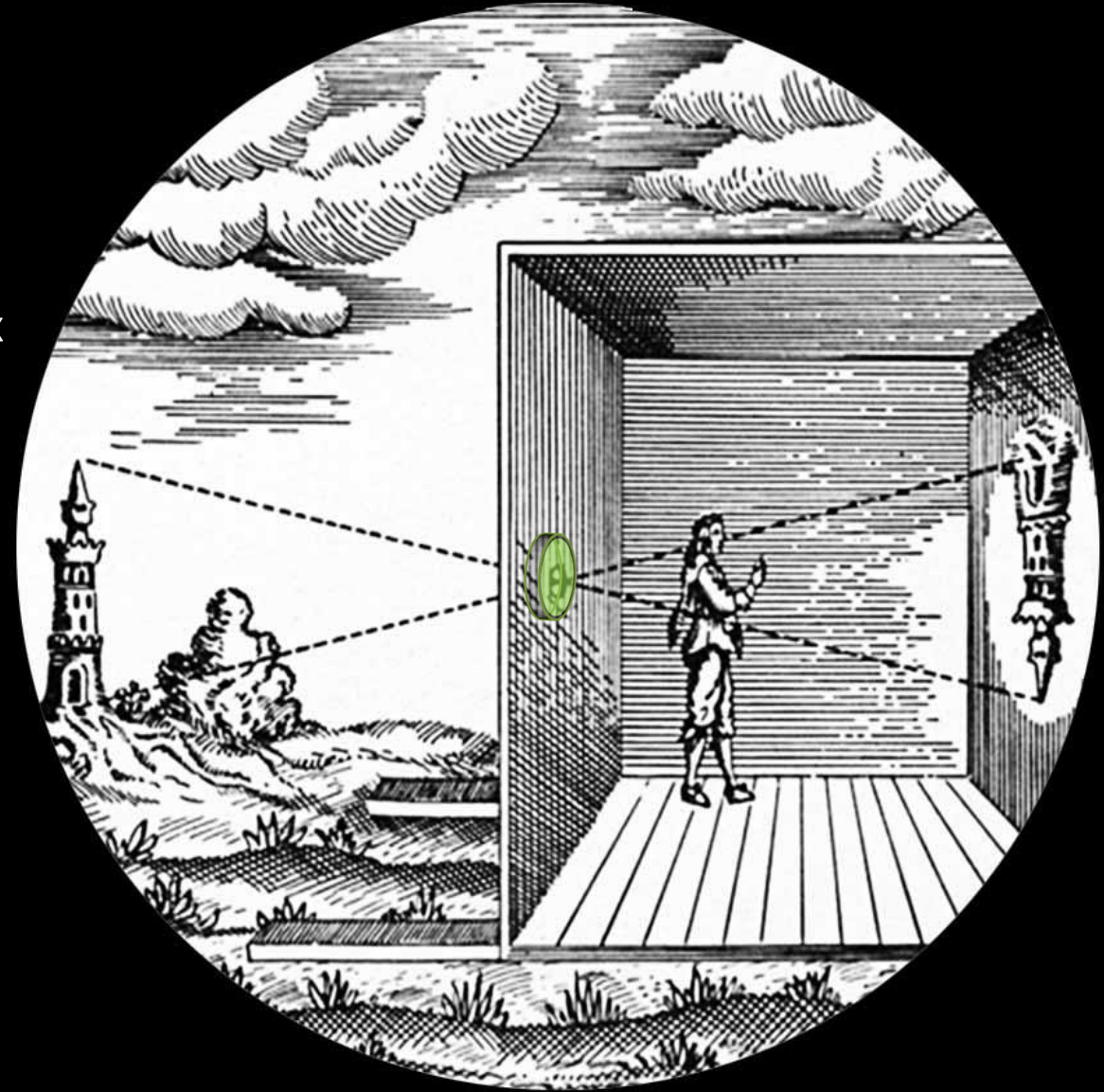
van Leeuwenhoek used. Sometimes just grinding was enough to produce a

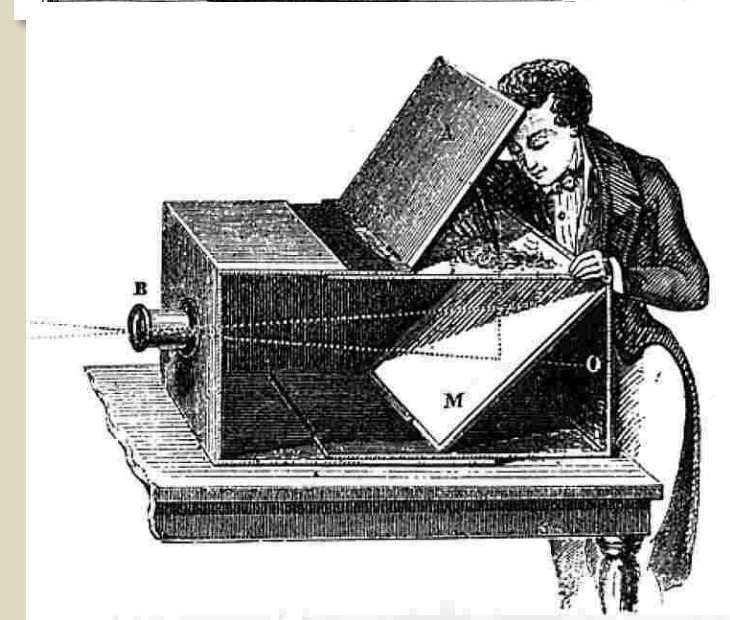
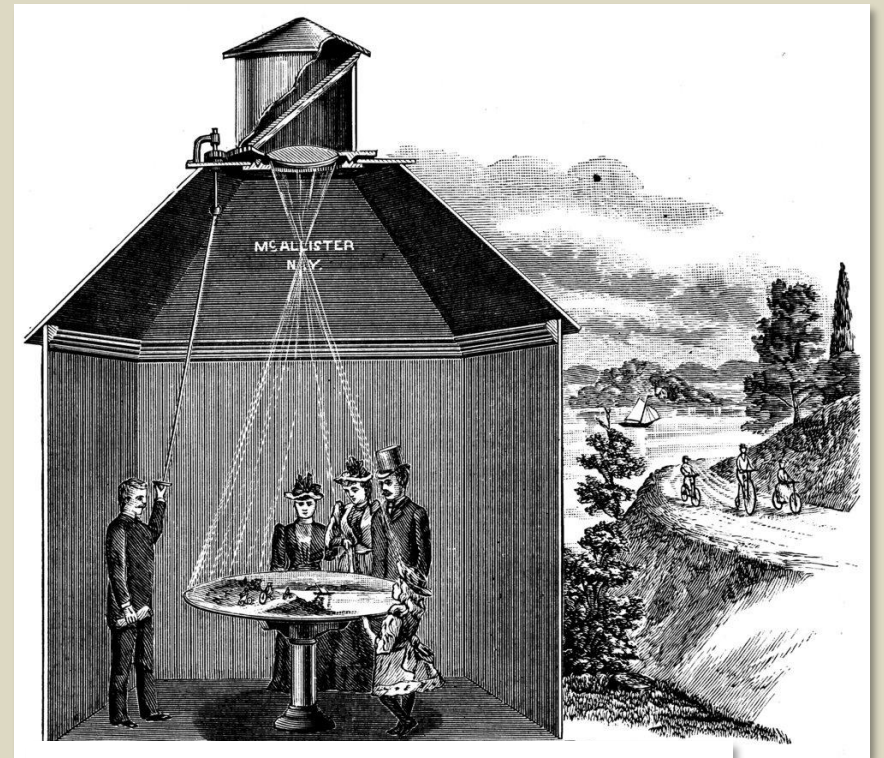
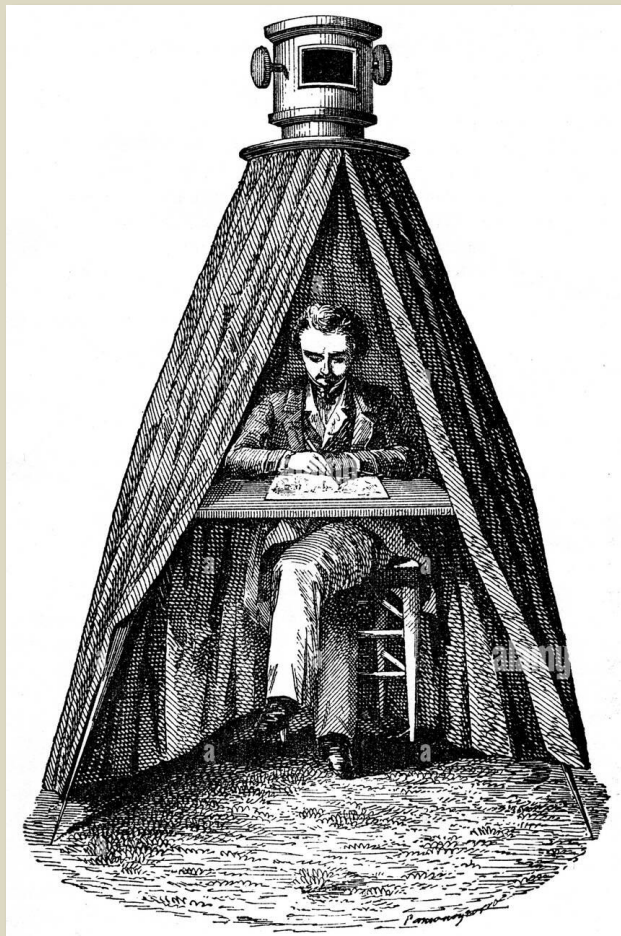
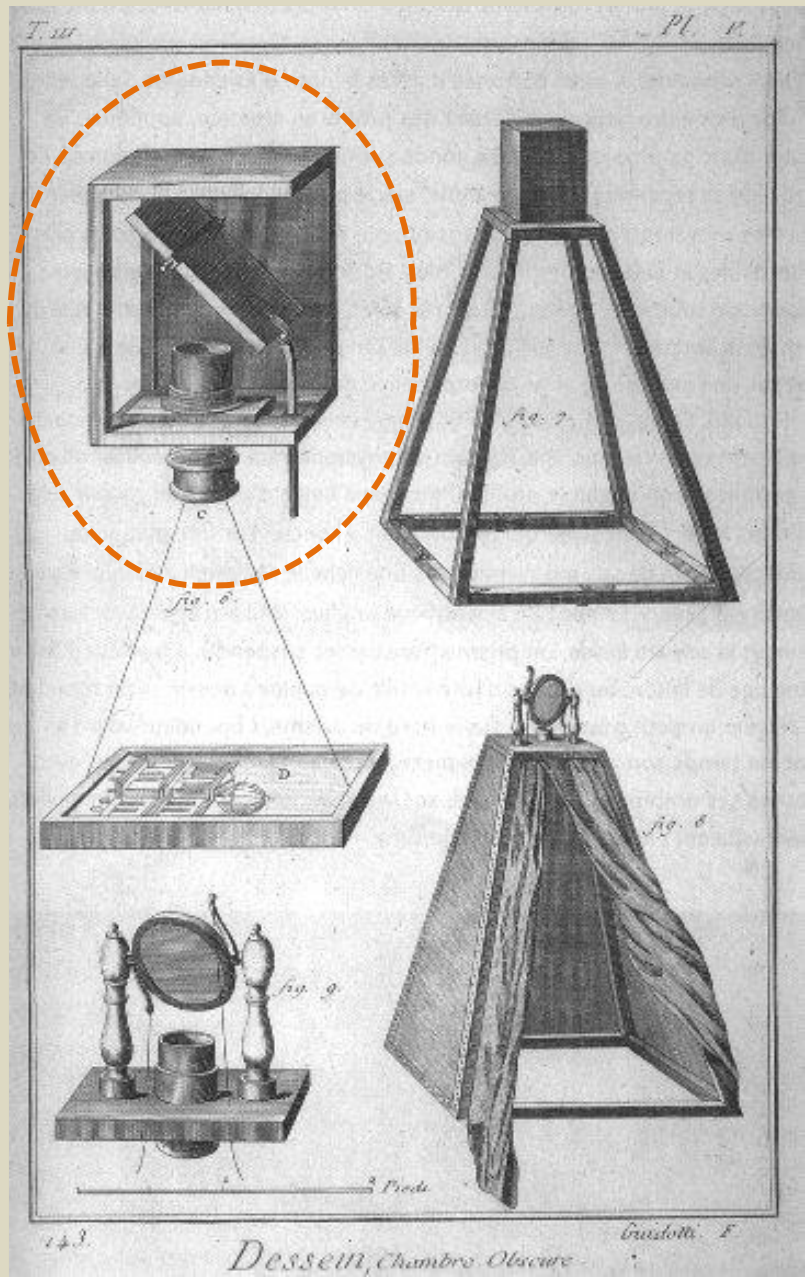
OLLI-OP



Improved Camera Obscura

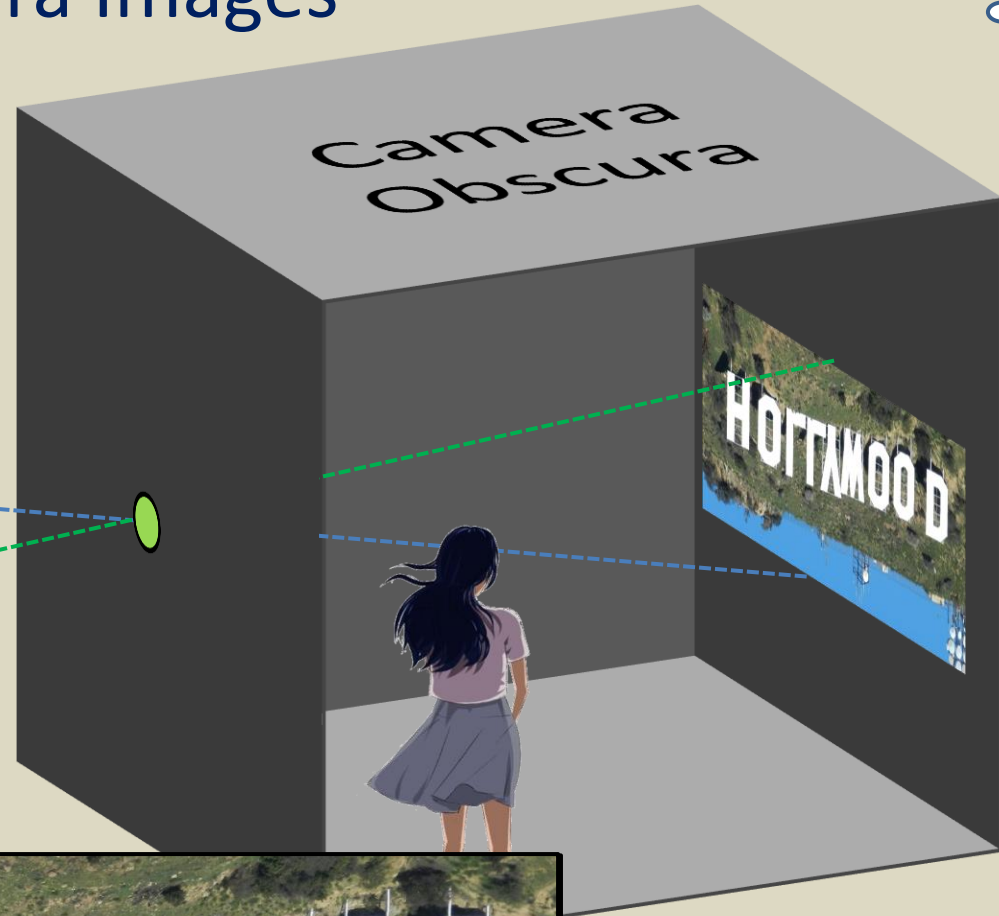
- **1550:** Gerolamo Cardano suggests putting Lens in pinhole (*De subtilitate Vol 1 Libri IV*)
- **1558:** Giambattista della Porta describes using Bi-Convex Lens to project image onto paper as a drawing aid
Magia Naturalis
- **1567:** Daniel Barbaro uses Camera Obscura with Bi-Convex Lens as drawing aid (*La Practica della Perspettiva*)
- **1589:** della Porta describes Camera Obscura with Bi-Convex Lens projecting scenes onto white sheets as entertainment/spectacle (*Magia Naturalis 2nd Edition*)
- *Spread rapidly in ensuing decades*



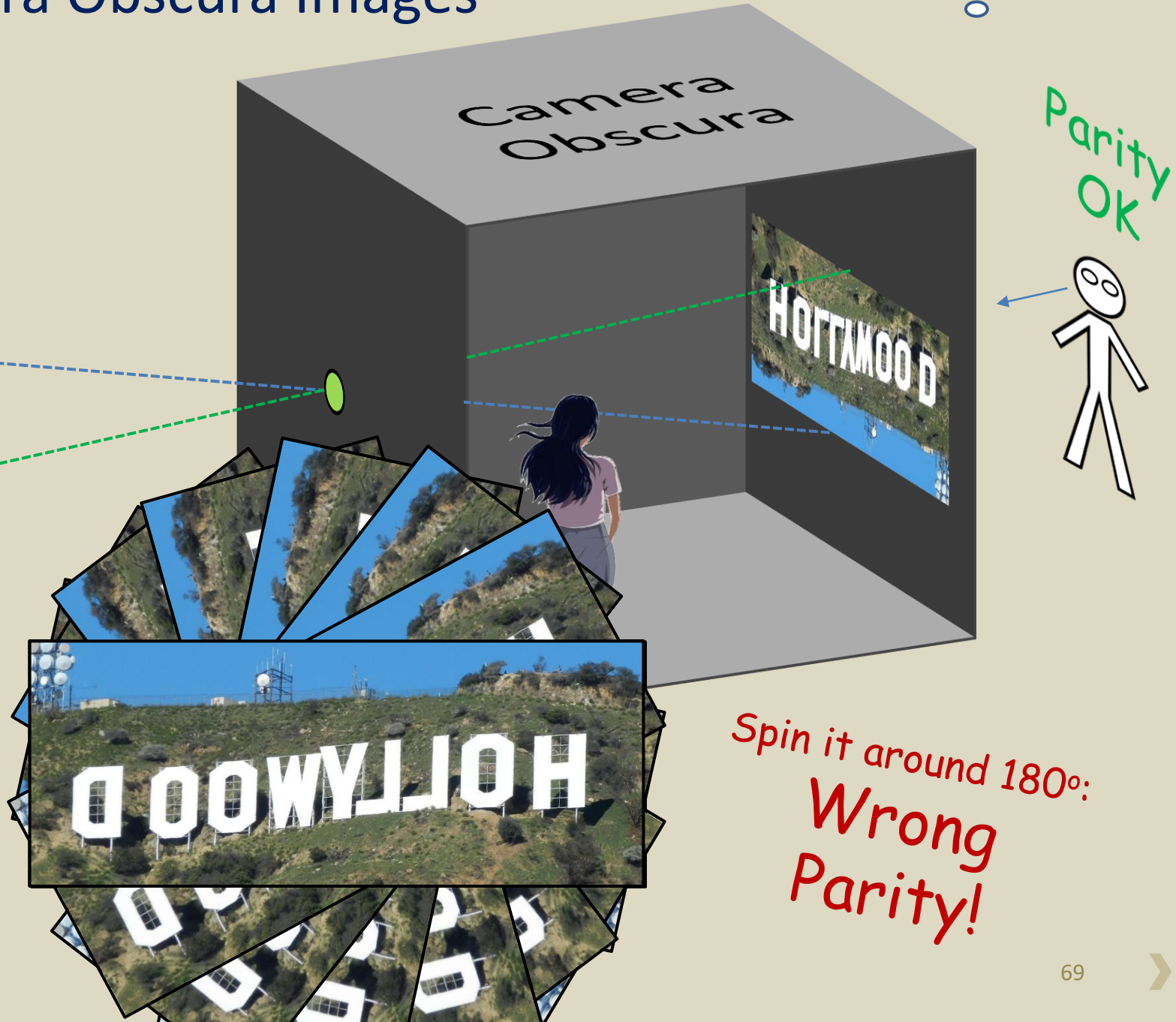


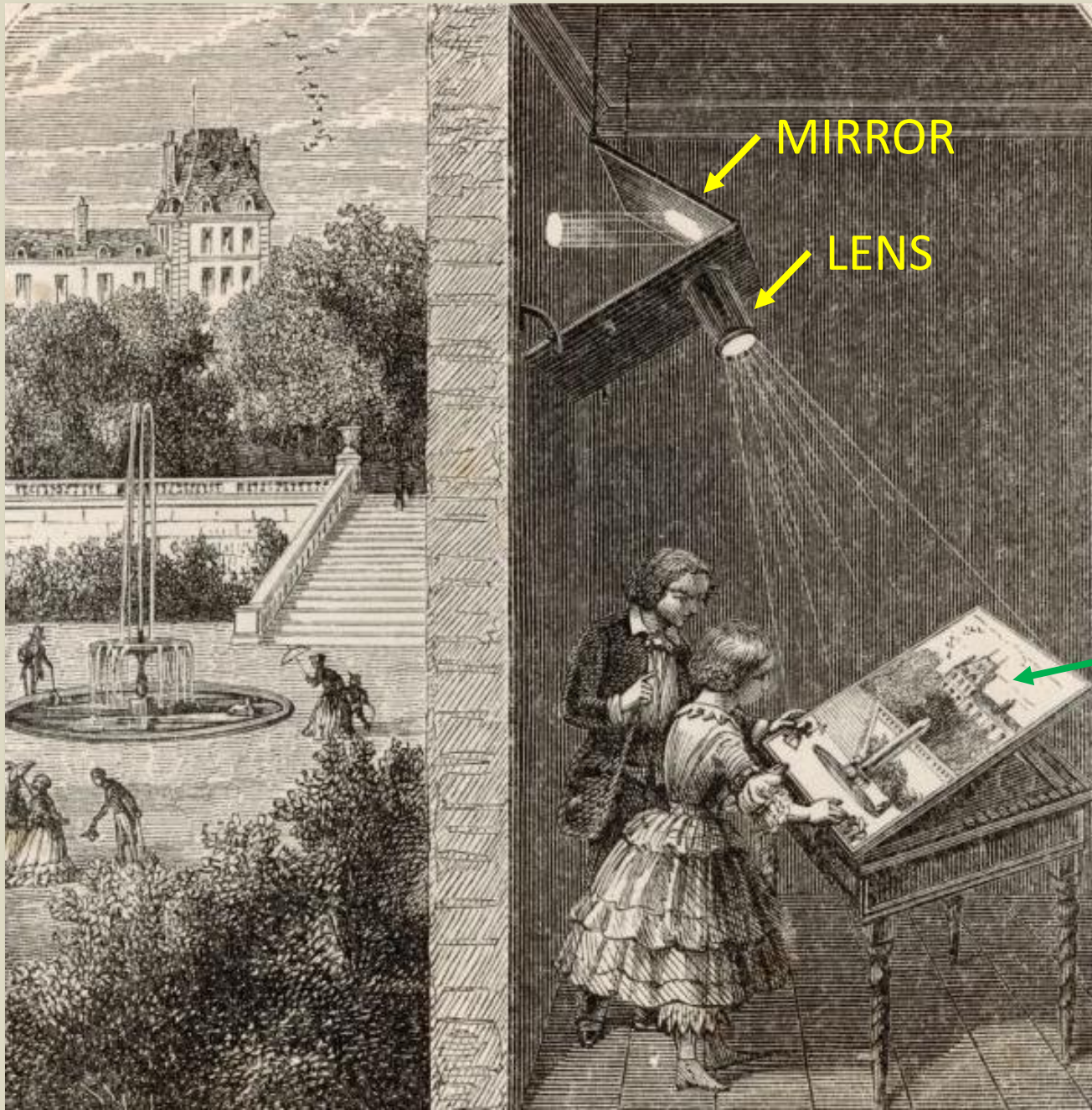
Camera Obscura
with Lenses

Parity of Simple Camera Obscura Images



Parity of Simple Camera Obscura Images





MIRROR

LENS

Parity is OK

Image is also erect



11th Century Alcázar of Jerez de la Frontera, Spain

'Atlas'
Camera Obscura



Public Cameras Obscura became very popular, especially in Victorian times.
There are still many around the world...



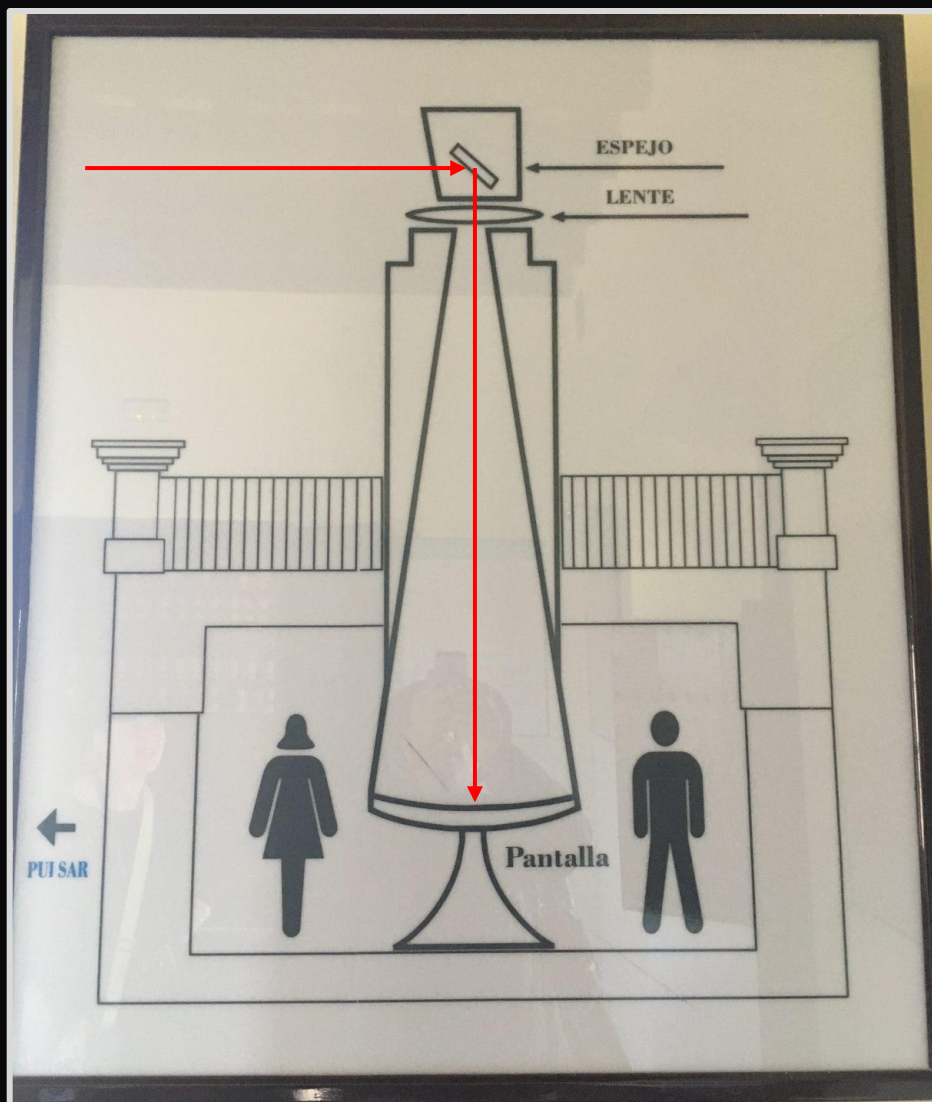
11th Century Alcázar of Jerez de la Frontera, Spain



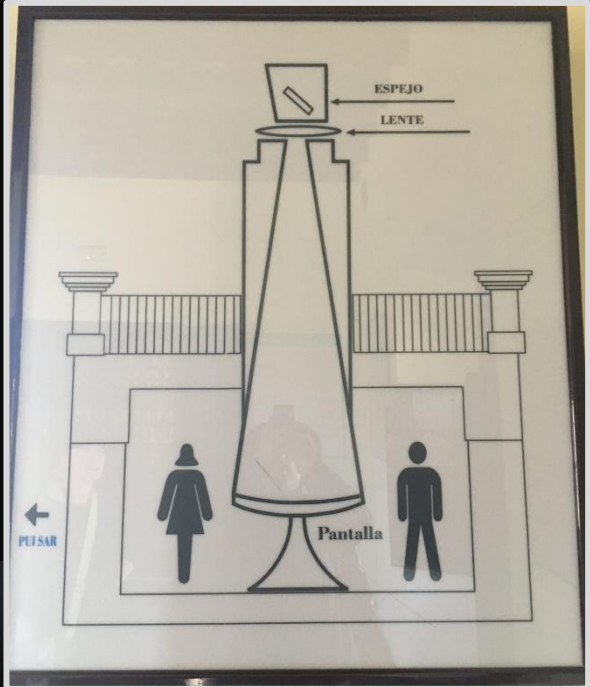
'Atlas'
Camera Obscura



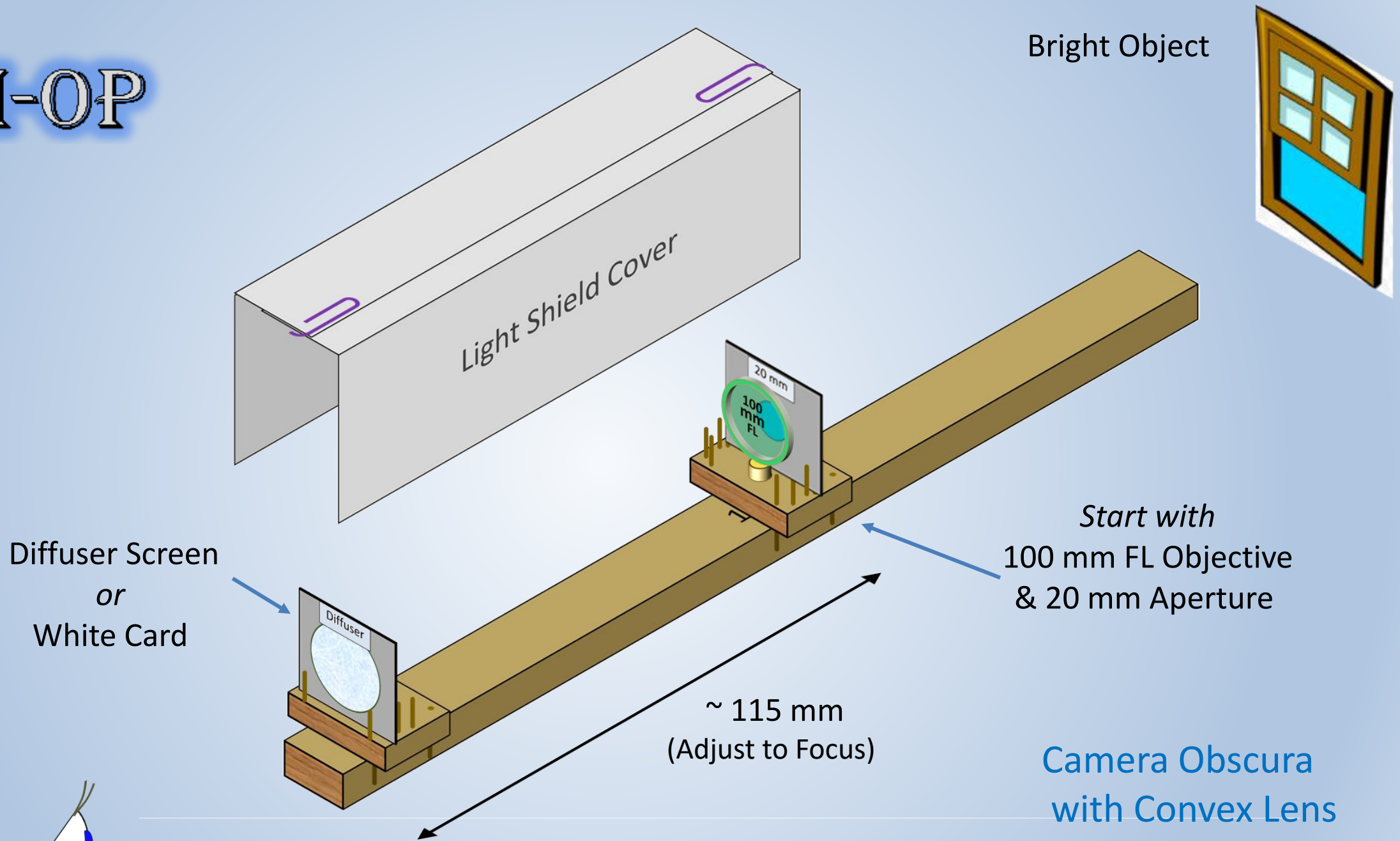
Atlas



Atlas



OLLI-OP



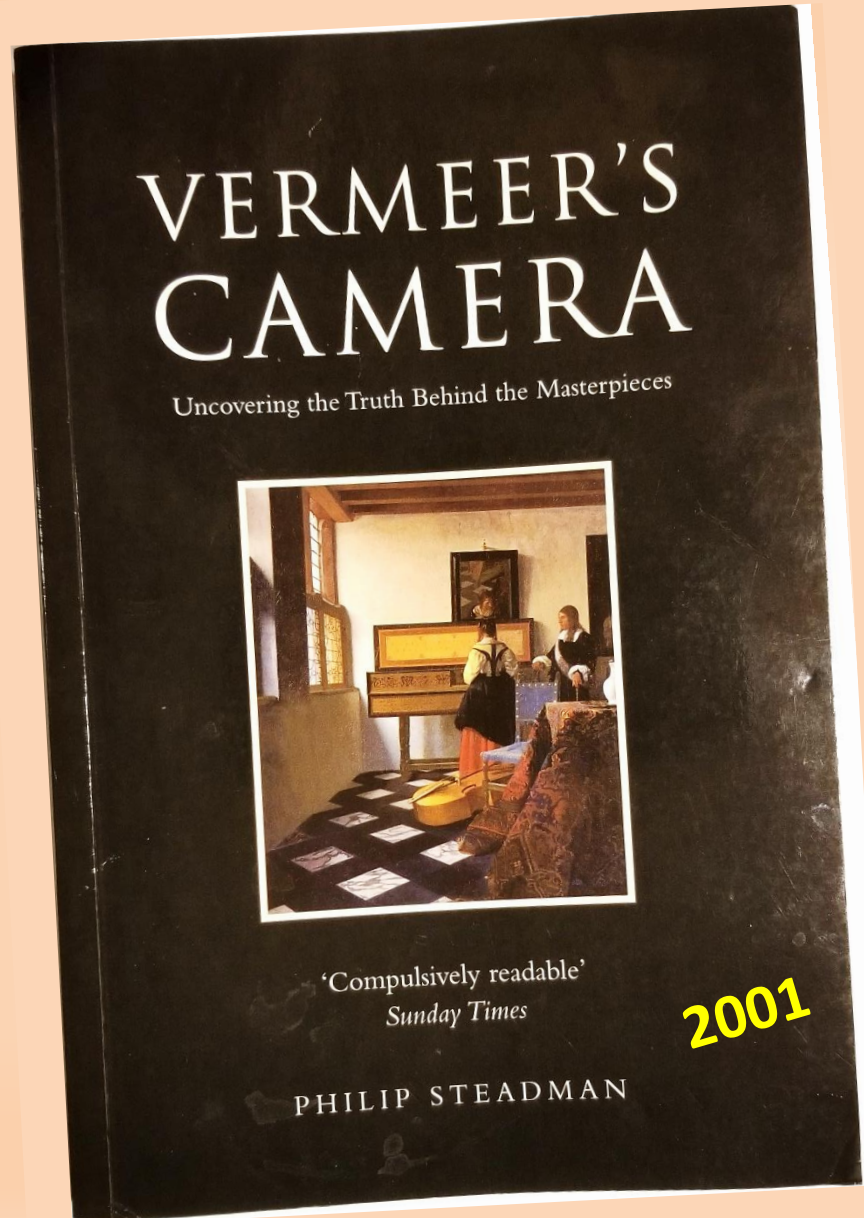
ART
ART

and

OPTICS



Phillip Steadman
Architect
London



Did Vermeer
use optics to
enable his
photo-realistic
masterpieces?



Johannes Vermeer
(1632-1675)
Delft, Holland
Only 35 known paintings



Vermeer's 'The Music Lesson'
ca 1662-1665

29" x 25"

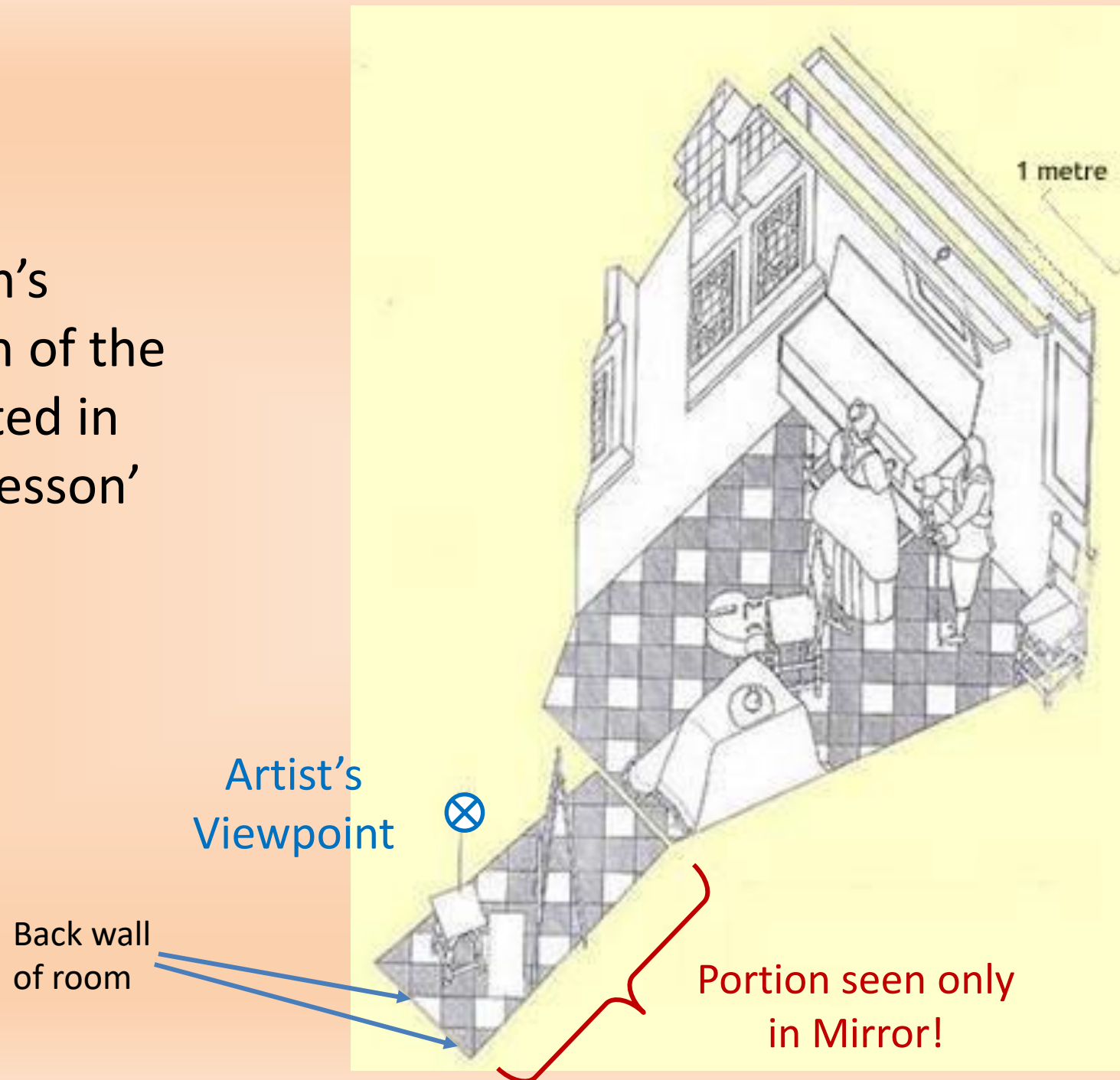
Buckingham Palace



Detail from
'The Music Lesson'



Steadman's Reconstruction of the Room depicted in 'The Music Lesson'



Vermeer's
'The Art of Painting'
ca 1666-1668

47" x 39"

Kunsthistorisches Museum
Vienna



Vermeer's
'The Wine Glass'
ca 1660-1661

25" x 30"

Gemäldegalerie
Berlin

All the floor tiles line up exactly,
even though some are twice the
size and were painted in
different color patterns!



Calculated Viewpoints of 6 Paintings

Plan View of Vermeer's Studio

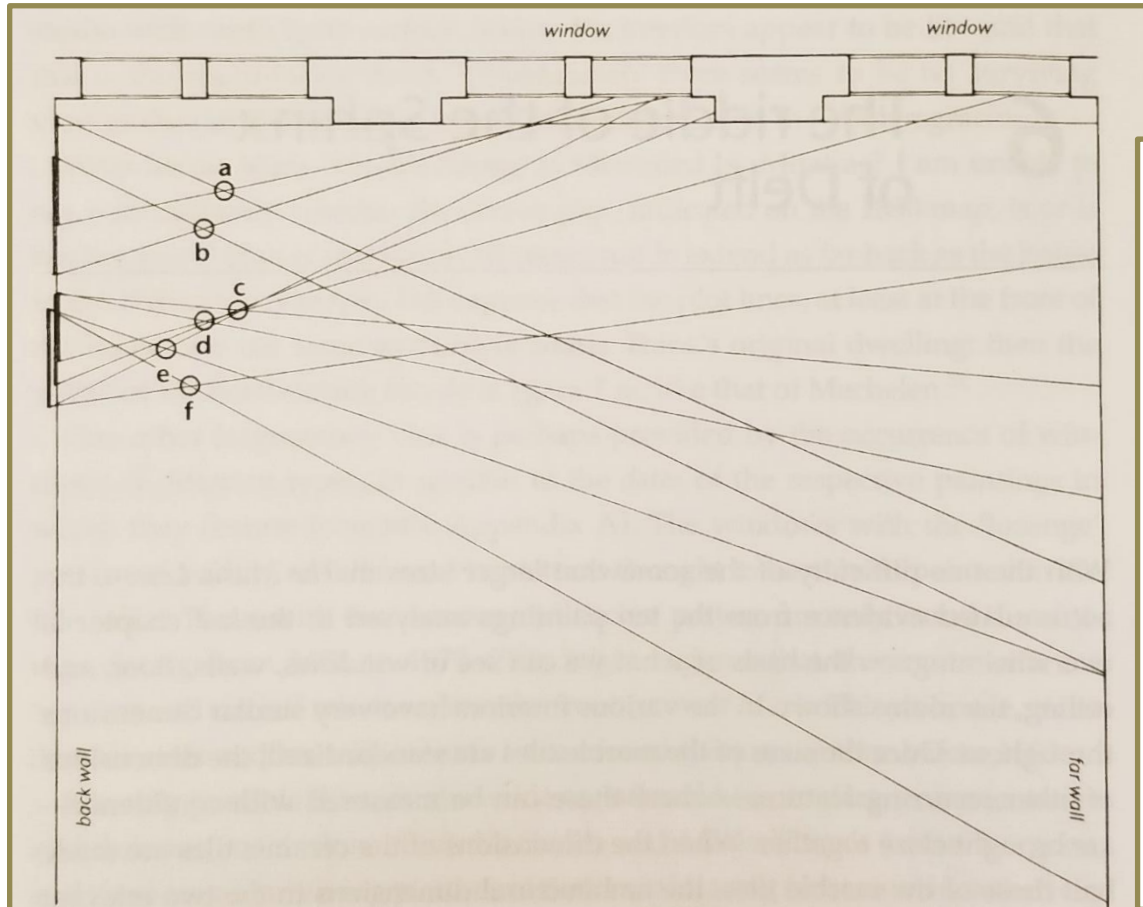
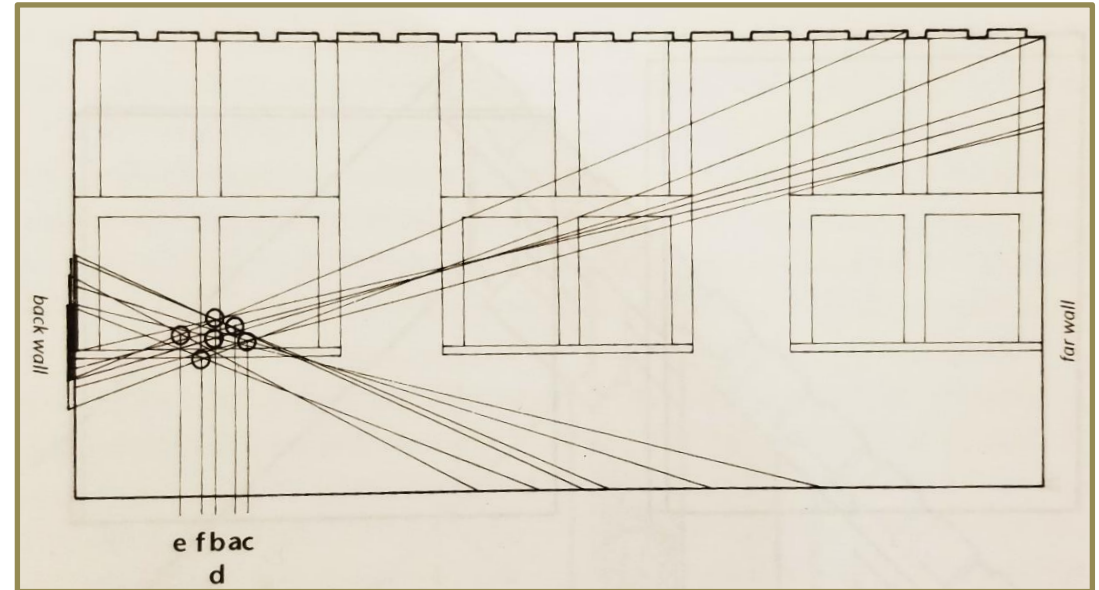


Figure 49 Plan of the room with viewpoints marked for six paintings: (a) *The Girl with a Wineglass*, (b) *The Glass of Wine*, (c) *Lady Writing a Letter, with her Maid*, (d) *Lady Standing at the Virginals*, (e) *The Music Lesson*, (f) *The Concert*. The diagonal lines mark the extent of what is visible in each picture. The third window is (still) hypothetical.

Side View of Vermeer's Studio



Figures from Phillip Steadman, *Vermeer's Camera* (2001)

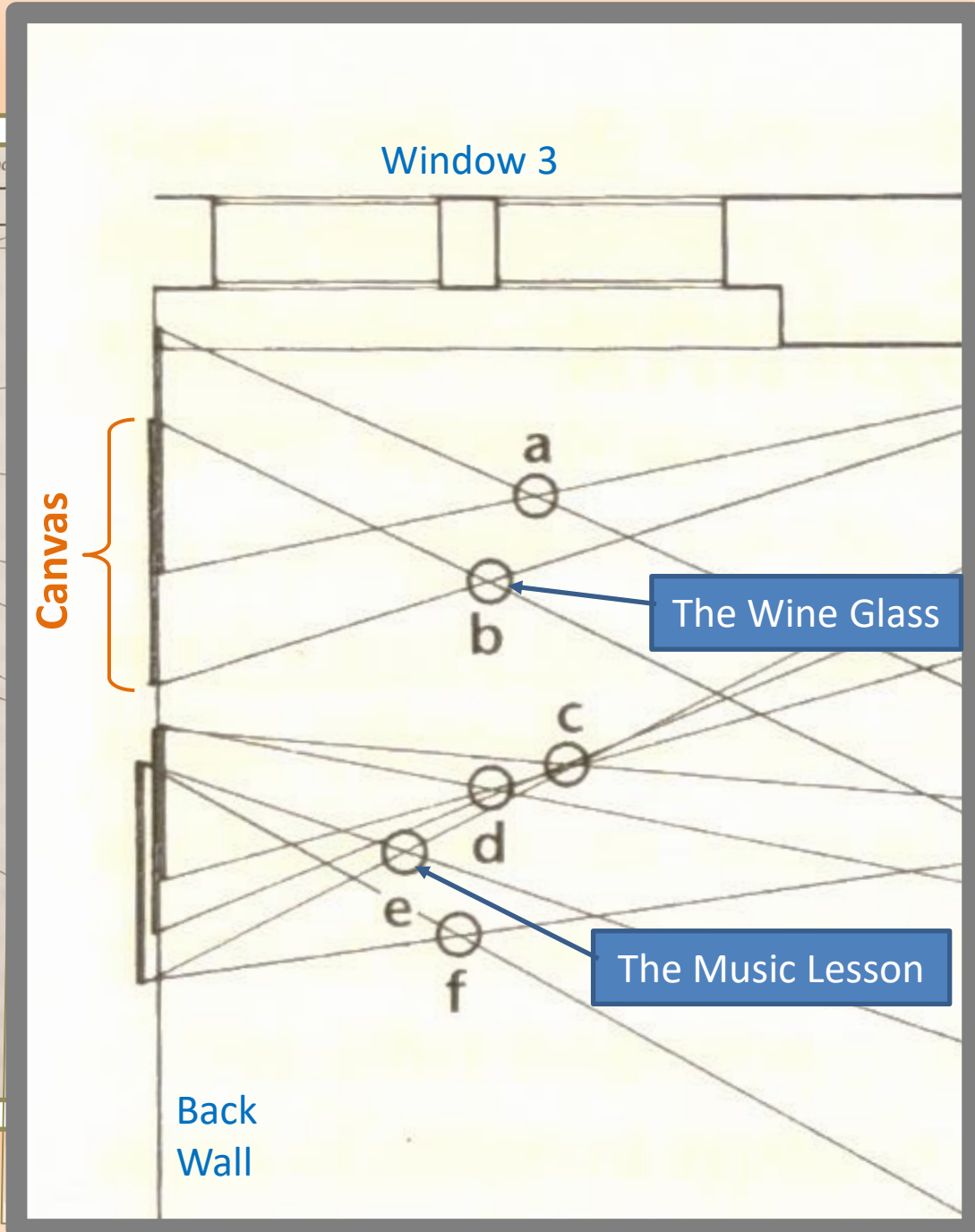
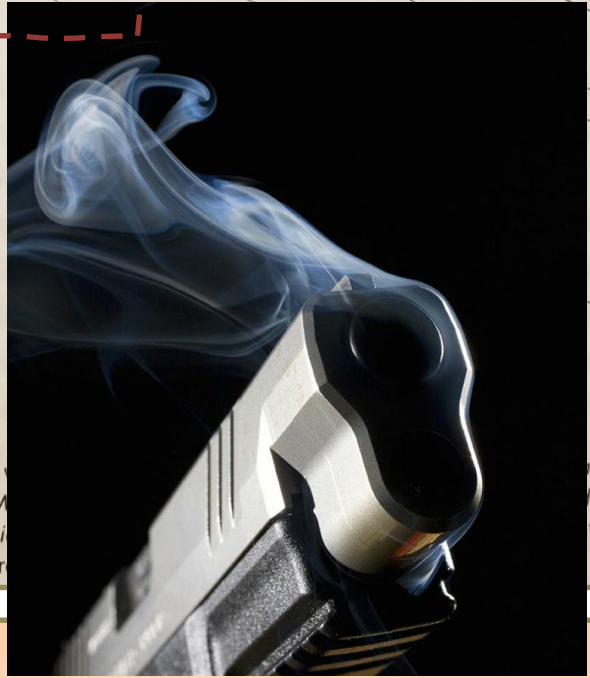
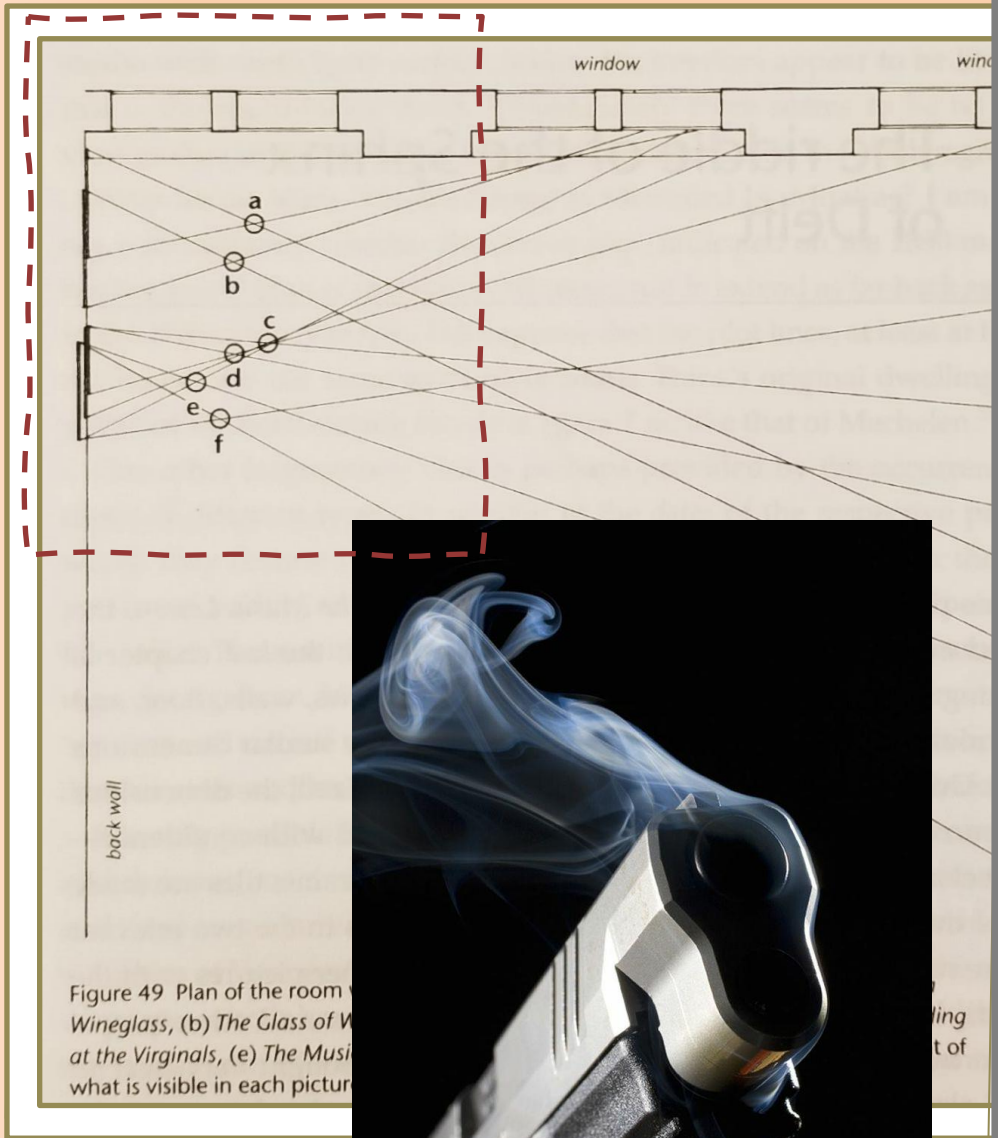


Studio



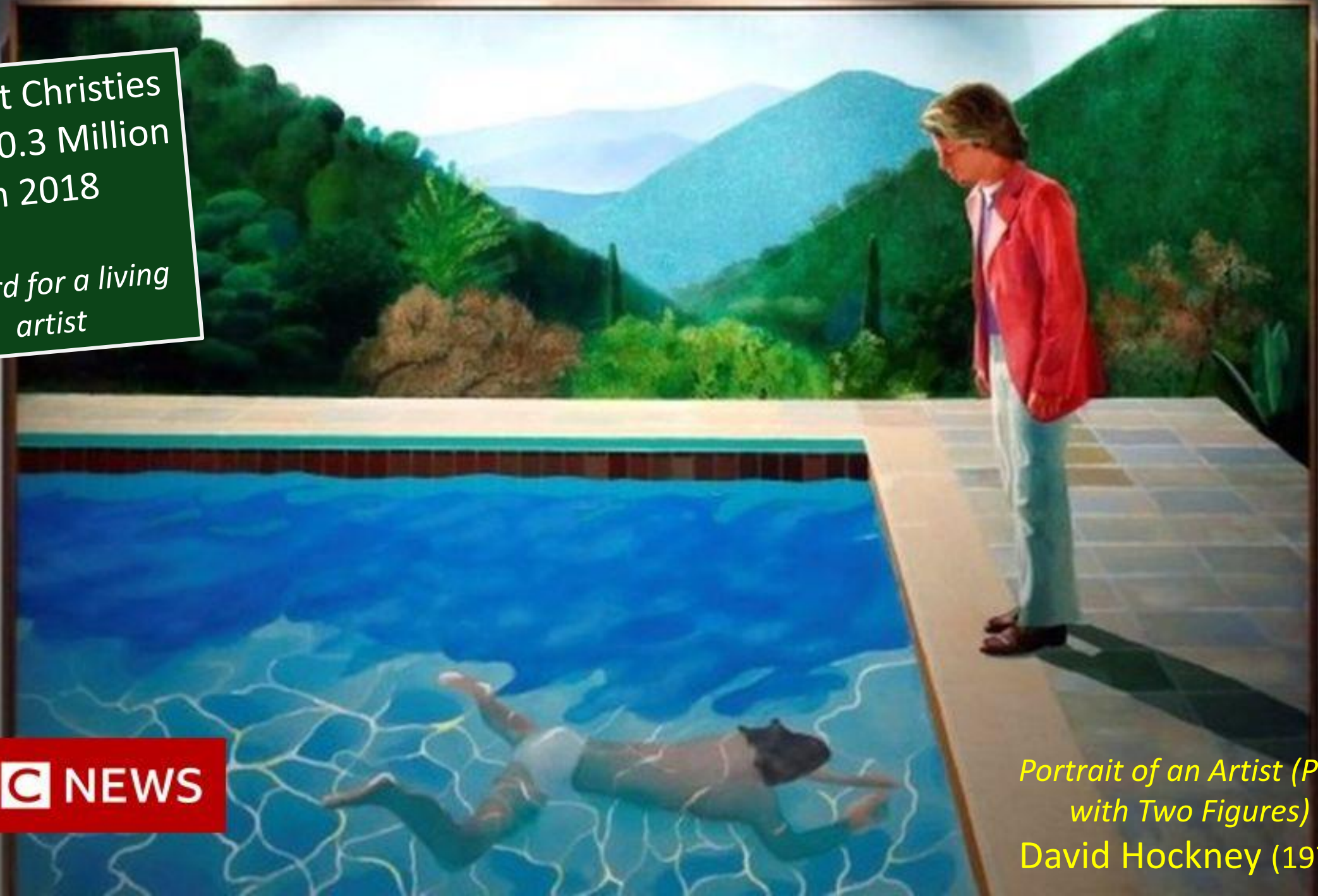
Vermeer's Camera (2001)

Plan View of Vermeer's Studio



Sold at Christies
for \$90.3 Million
in 2018

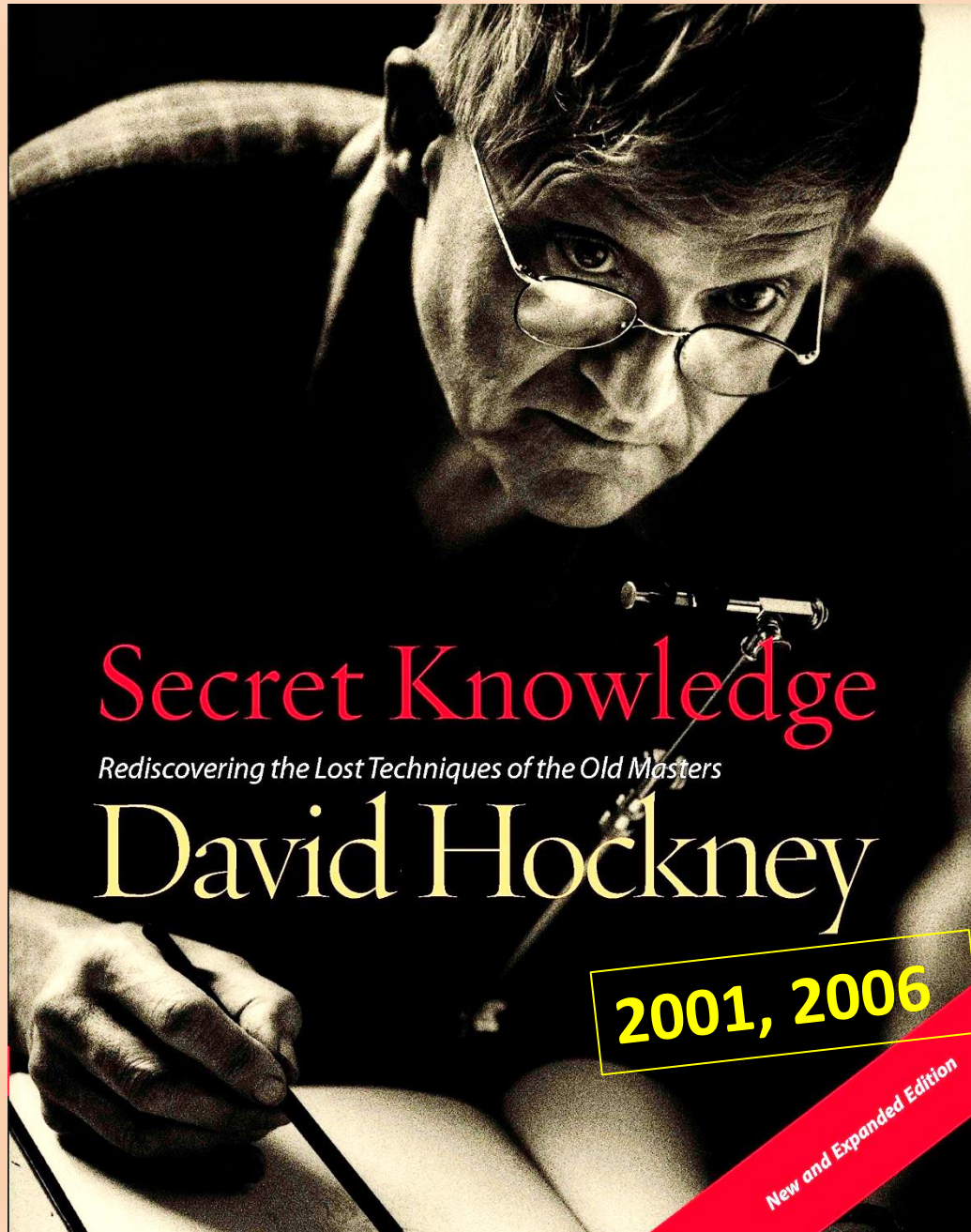
*Record for a living
artist*



BBC NEWS

*Portrait of an Artist (Pool
with Two Figures)*
David Hockney (1972)





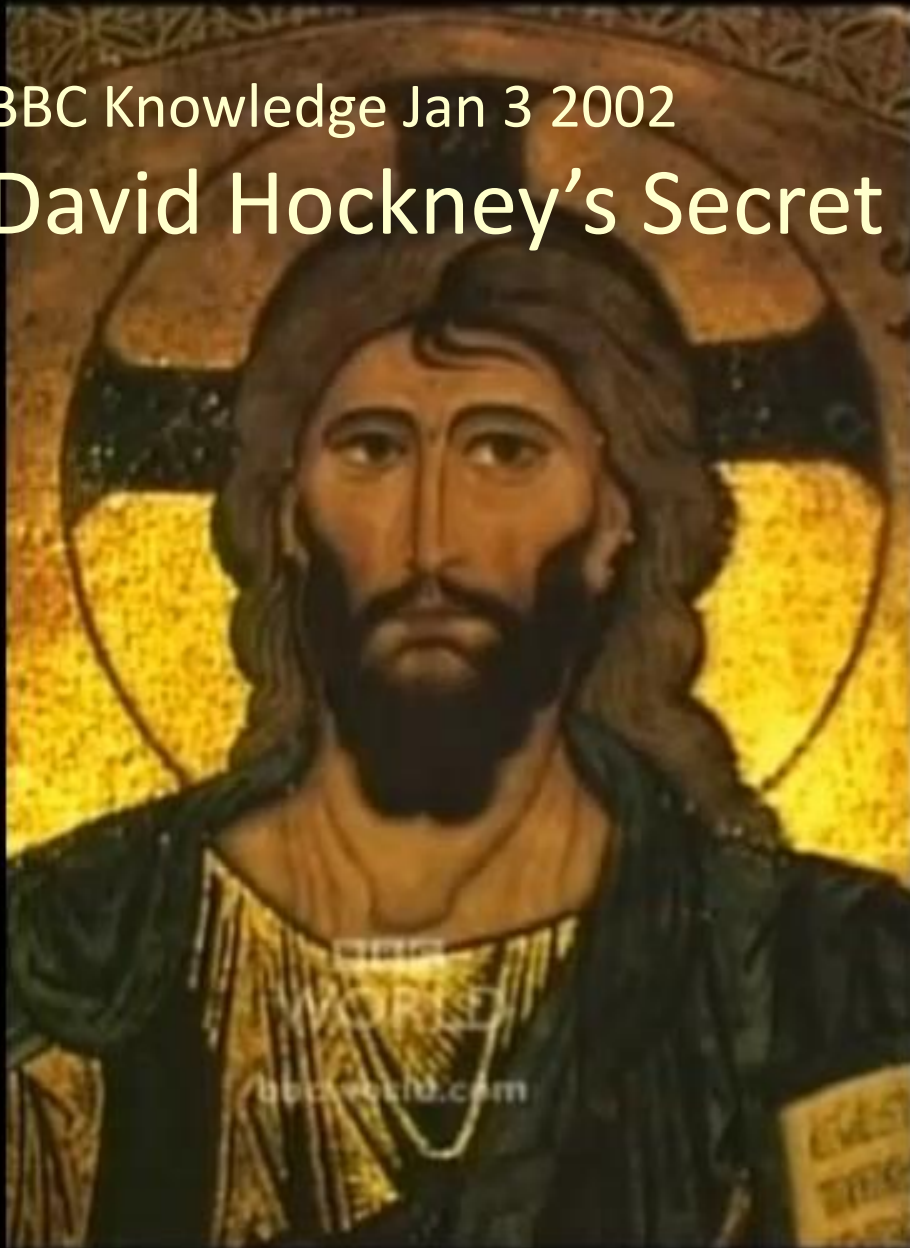
Collaborator:
Charles M. Falco
U. of Arizona
Optical Physicist

“Hockney-Falco
Thesis”



BBC Knowledge Jan 3 2002

David Hockney's Secret Knowledge



Jan van Eyck
Arnolfini Wedding
(or *Arnolfini Portrait*)
1434

National Gallery
London





Arnolfini detail (1434)





Arnolfini detail (1434)



Lorenzo Lotto
Husband and Wife
1523

*Hermitage,
St. Petersburg*



Arguments raged over distortions in rendering the table covering...



Detail from Lotto's *Husband and Wife*, 1523

Falco website, U of Arizona



Jan van Eyck

Portrait of Cardinal Albergati

1431-1435



Silverpoint Drawing 1431

~ 8" x 7'



Oil on Oak *ca* 1435

~ 13" x 11'

The Hockney-Falco Thesis Wars

2000 - now

- David Hockney
- Charles M. **Falco**
& Colleagues
- Phillip Steadman
- Tim Jenison (*Tim's Vermeer*)
- Many working artists

- Many Art Historians
- David G. **Stork**
& Colleagues
- Christopher Tyler
- *et al*

and the Winner is....



Renaissance

- Pinhole Camera
- The Eye
- Telescopes
 - Galilean
 - Keplerian
 - Terrestrial
- Microscopes
- Camera Obscura with lens
- Art & Optics

