01/04/2025

Microscope & Telescope Fundamentals

Optical Engineering

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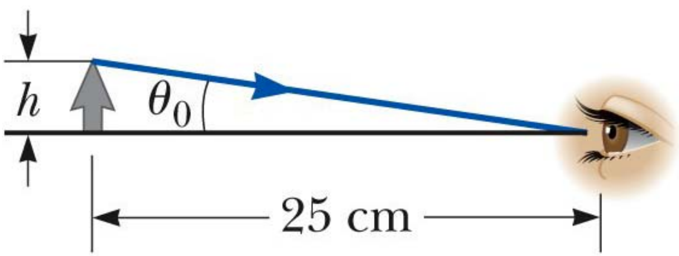
Magnifier

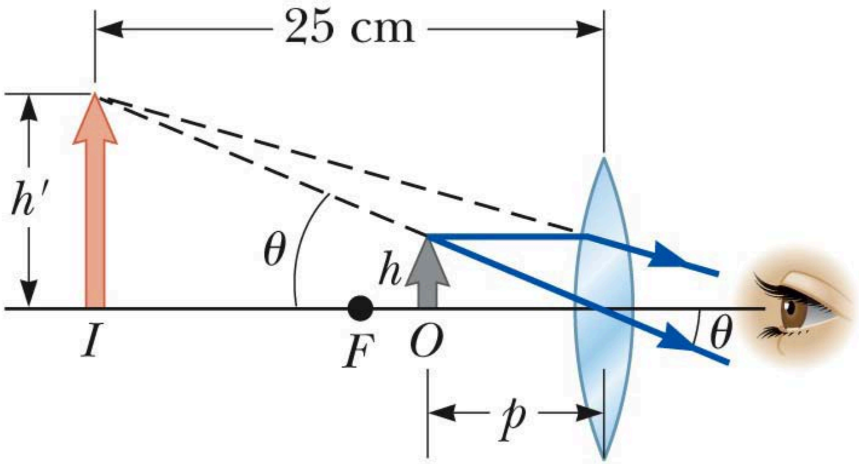
Un-aided vision

$$\theta_0 \simeq \frac{h}{25cm}$$

Magnifier-Aided vision

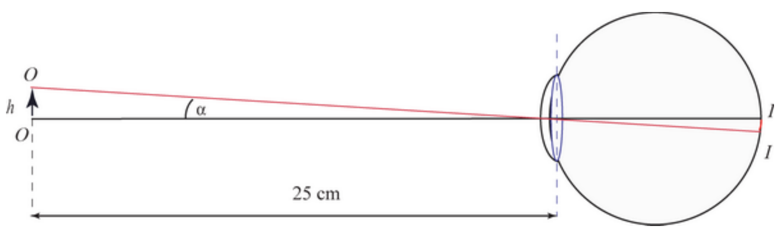
$$m = \frac{\theta}{\theta_0} \simeq \frac{h'}{h} = 1 + \frac{25cm}{f}$$

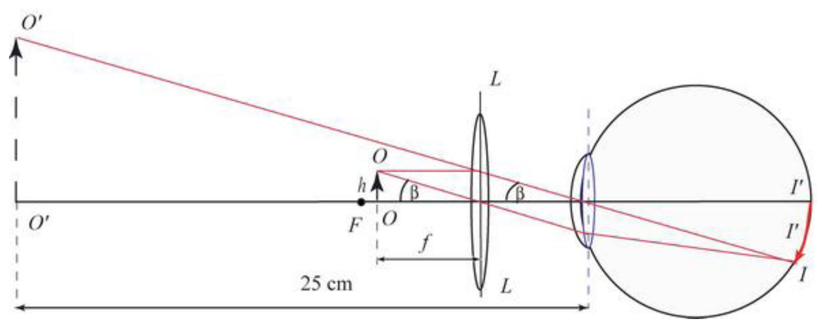




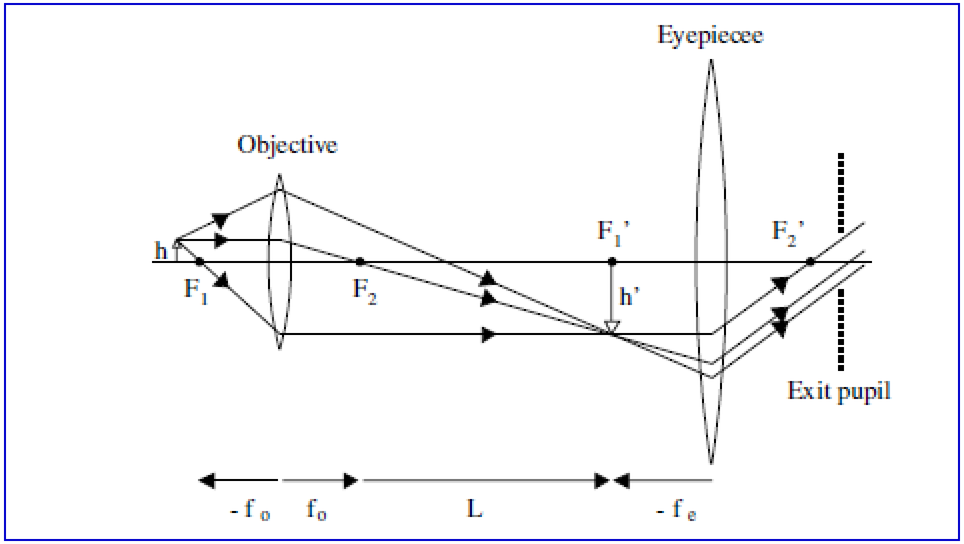
R. A. Serway and J. W. Jewett, “Physics for Scientists and Engineers”, Thomson Brooks/Cole, 6th Ed. 2004

http://www.soest.hawaii.edu/HIGP/Faculty/zinin/





Compound Microscope



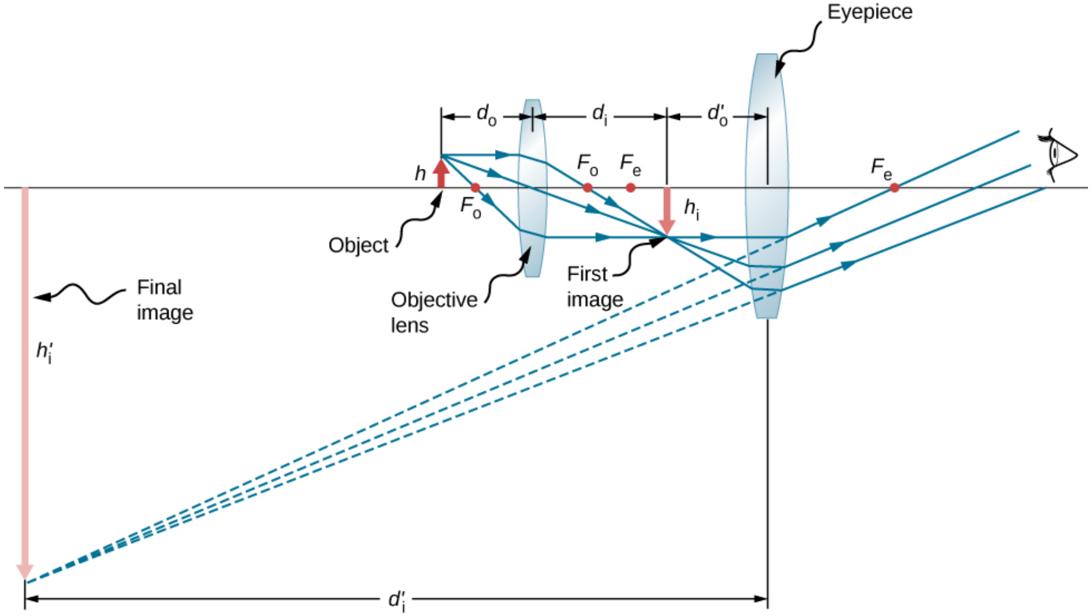
I. R. Kenyon, "The Light Fantastic," Oxford University Press, 2008

$$
\begin{aligned}
\theta &= \frac{h}{25\,cm} \\
\theta' &= \frac{h'}{f_e} \quad \Longrightarrow \\
\frac{\theta'}{\theta} &= \frac{h'}{h}\,\frac{25\,cm}{f_e} = -\frac{s'}{s}\,\frac{25\,cm}{f_e} \\
\frac{1}{s} + \frac{1}{s'} &= \frac{1}{f_o} \quad \Longrightarrow \\
\frac{1}{s} &= \frac{1}{f_o} - \frac{1}{f_o + L} = \frac{L}{f_o(f_o + L)} \quad \Longrightarrow \\
-\frac{s'}{s} &= -\frac{L}{f_o} \quad \Longrightarrow \\
\frac{\theta'}{\theta} &= -\frac{L}{f_o}\,\frac{25\,cm}{f_e}
\end{aligned}
$$

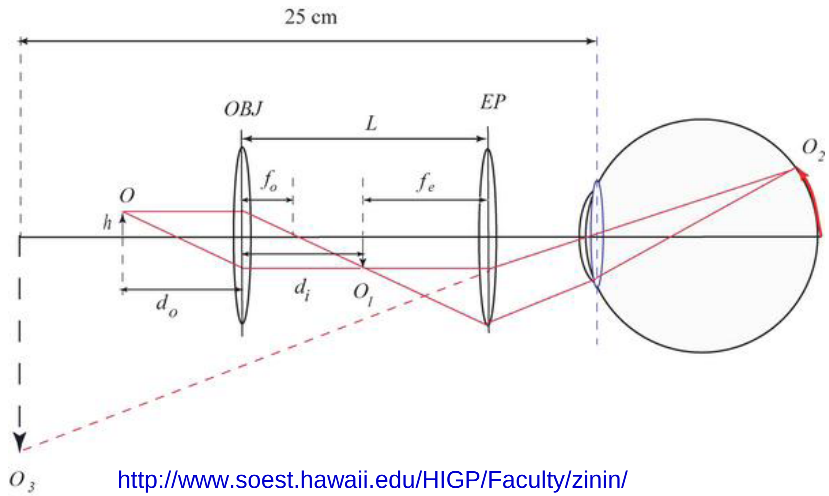
Angular Magnification

$$
\boxed{m = \frac{\theta}{\theta_0} \simeq \frac{h'/f_e}{h/25cm} = -\frac{L}{f_o}\,\frac{25cm}{f_e}}
$$

Compound Microscope

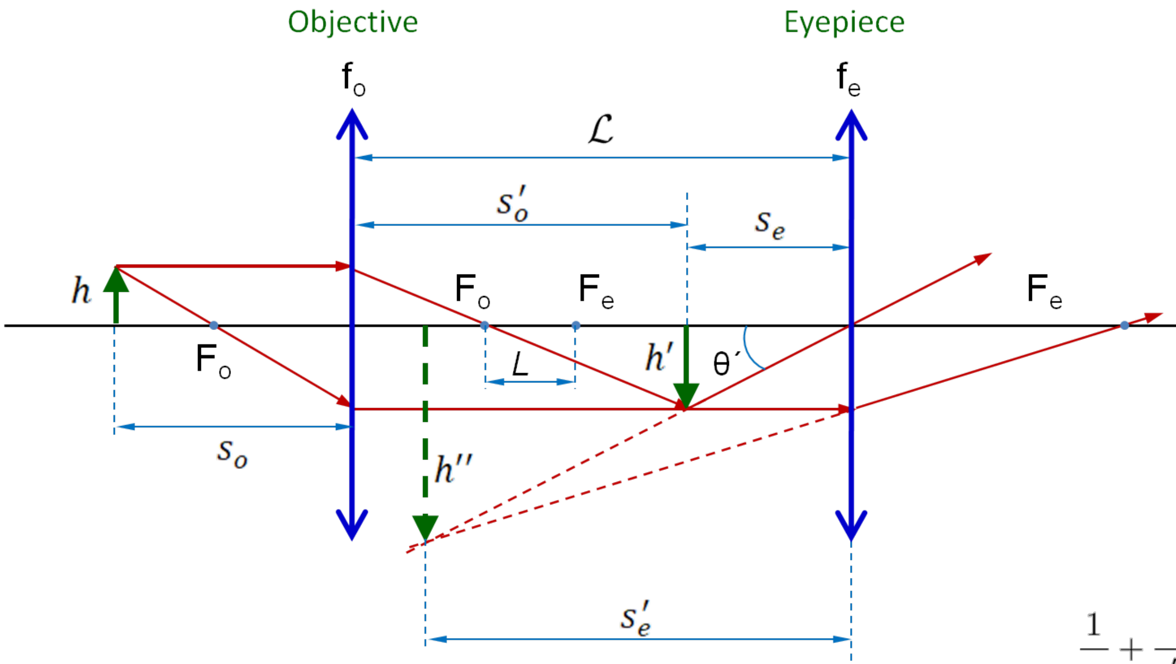


http://cnx.org/contents/DEwGvgGq@2/Microscopes-and-Telescopes



http://www.soest.hawaii.edu/HIGP/Faculty/zinin/

Compound Microscope



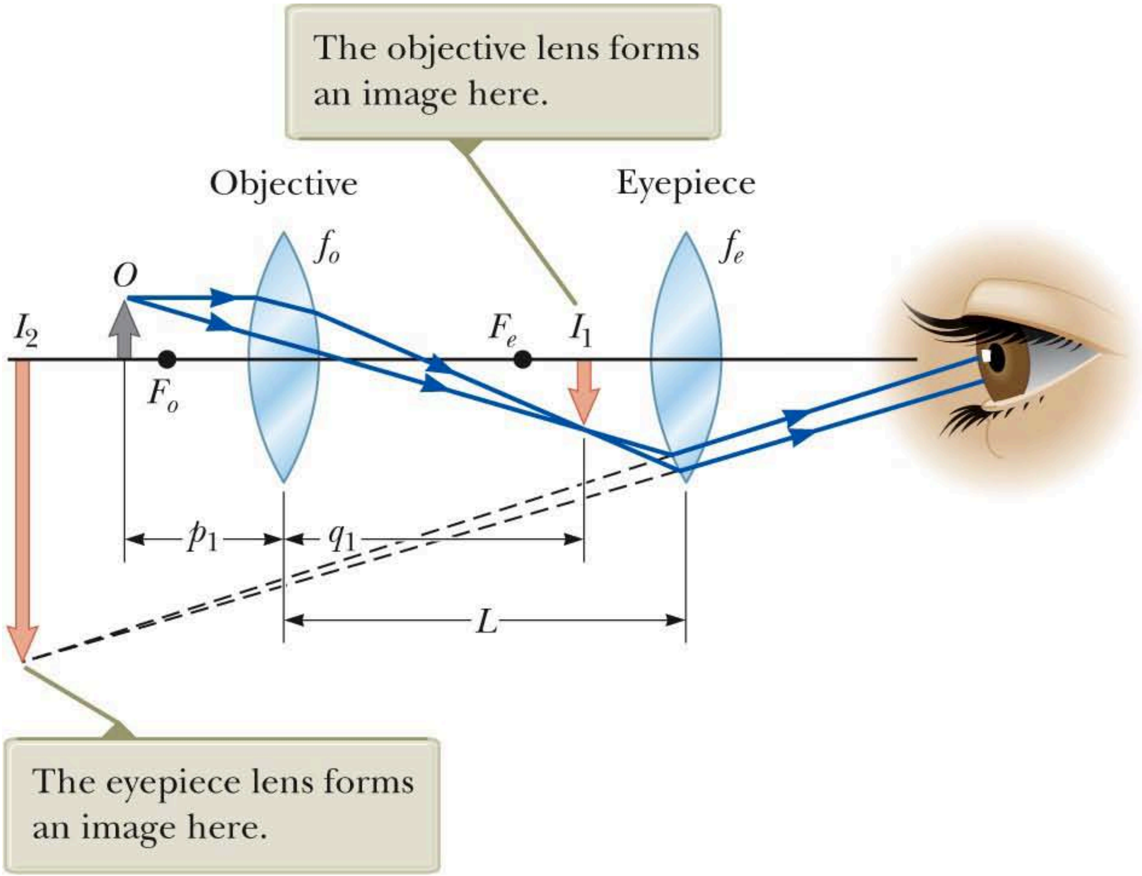
$$\theta = \frac{h}{25\,cm}$$
$$\theta' = \frac{h'}{s_e}$$

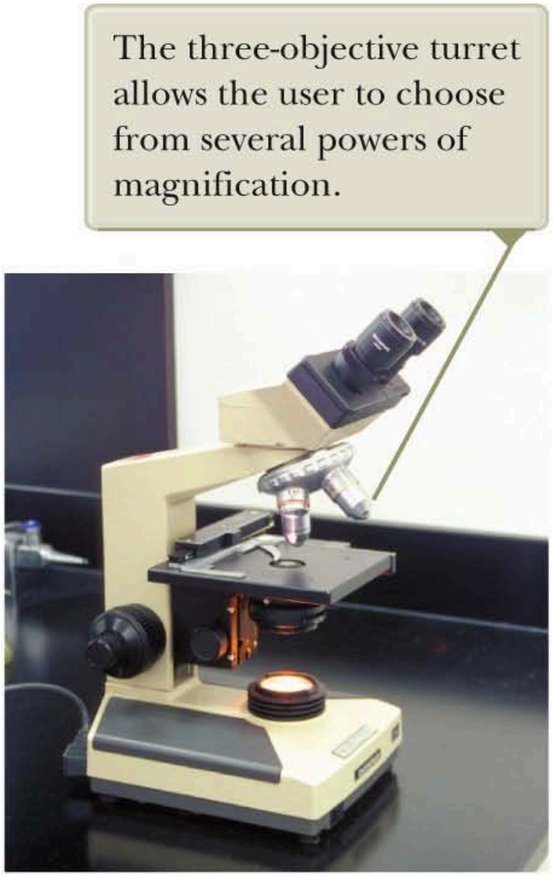
$$\frac{\theta'}{\theta} = \frac{h'}{h}\frac{25\,cm}{s_e} = -\frac{s_o'}{s_o}\frac{25\,cm}{s_e}$$
$$\frac{1}{s_o} + \frac{1}{s_o'} = \frac{1}{f_o} \quad \Longrightarrow$$
$$\frac{1}{s_o} = \frac{1}{f_o} - \frac{1}{\mathcal{L} - s_e} \quad \Longrightarrow$$
$$-\frac{s_o'}{s_o} = -\left(\frac{\mathcal{L} - s_e}{f_o} - 1\right)$$
$$\frac{1}{s_e} + \frac{1}{s_e' = -25\,cm} = \frac{1}{f_e} \quad \Longrightarrow$$
$$\frac{25\,cm}{s_e} = 1 + \frac{25\,cm}{f_e}$$
$$\frac{\theta'}{\theta} = -\left(\frac{\mathcal{L} - s_e}{f_o} - 1\right)\left(1 + \frac{25\,cm}{f_e}\right)$$

Angular Magnification

$$m = \frac{\theta'}{\theta} \simeq \frac{h'/s_e}{h/25cm} = -\left(\frac{\mathcal{L} - s_e}{f_o} - 1\right)\left(1 + \frac{25cm}{f_e}\right)$$
$$\mathcal{L} = s_o' + s_e = L + f_o + f_e, \qquad s_e' = -25\,cm$$

Compound Microscope

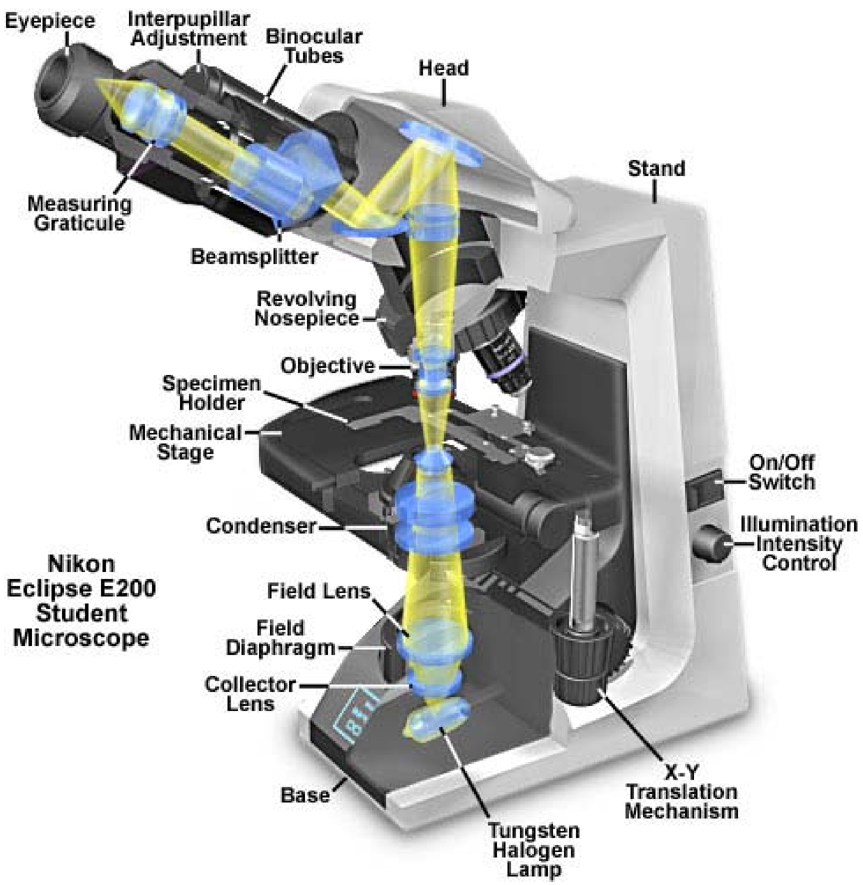




R. A. Serway and J. W. Jewett, "Physics for Scientists and Engineers", Thomson Brooks/Cole, 6th Ed. 2004

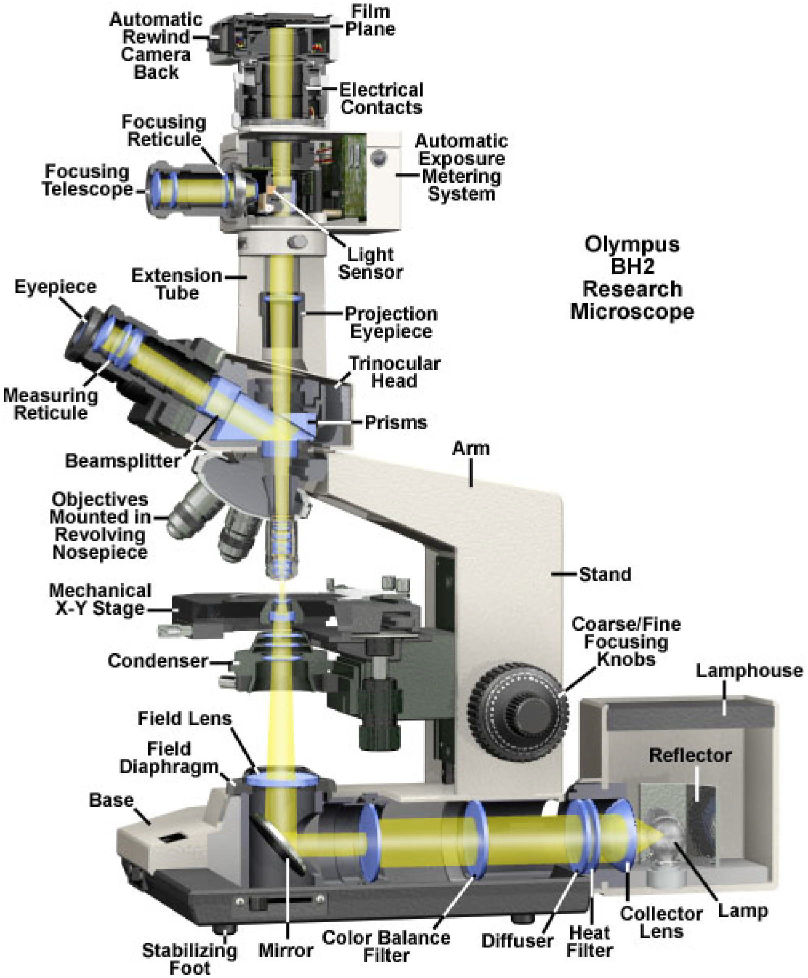
Compound Microscopes

Nikon Eclipse E200 Microscope Cutaway Diagram



https://micro.magnet.fsu.edu/primer/anatomy/nikone200cutaway.html

Olympus BH2 Research Microscope Cutaway Diagram



http://www.olympusmicro.com/primer/anatomy/bh2cutaway.html

Microscope Objective

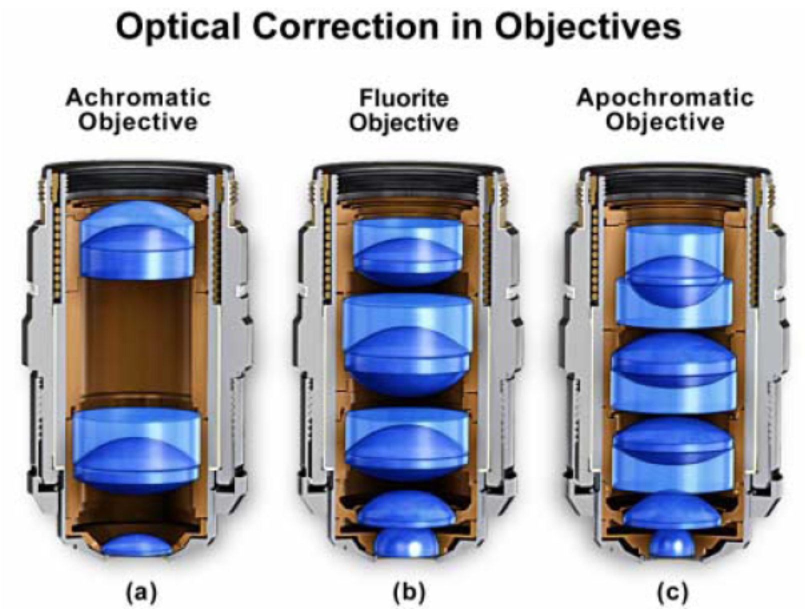


Figure 8. Levels of optical correction for aberration in commercial objectives. (a) Achromatic objectives, the lowest level of correction, contain two doublets and a single front lens; (b) Fluorites or semi-apochromatic objectives, a medium level of correction, contain three doublets, a meniscus lens, and a single front lens; and (c) Apochromatic objectives, the highest level of correction, contain a triplet, two doublets, a meniscus lens, and a single hemispherical front lens.

Davidson and Abramowitz, Optical Microscopy

Table 2 Objective Lens Types and Corrections [a]

	Corrections for Aberrations		
Type	**Spherical**	**Chromatic**	**Flatness Correction**
Achromat	* [b]	2 [c]	No
Plan Achromat	* [b]	2 [c]	Yes
Fluorite	3 [d]	< 3 [d]	No
Plan Fluorite	3 [d]	< 3 [d]	Yes
Plan Apochromat	4 [e]	> 4 [e]	Yes

[a] Source: Nikon Instrument Group
[b] Corrected for two wavelengths at two specific aperture angles.
[c] Corrected for blue and red - broad range of the visible spectrum.
[d] Corrected for blue, green and red - full range of the visible spectrum.
[e] Corrected for dark blue, blue, green and red.

http://www.olympusmicro.com/primer/microscopy.pdf
http://microscopy.fsu.edu

Microscope Objective

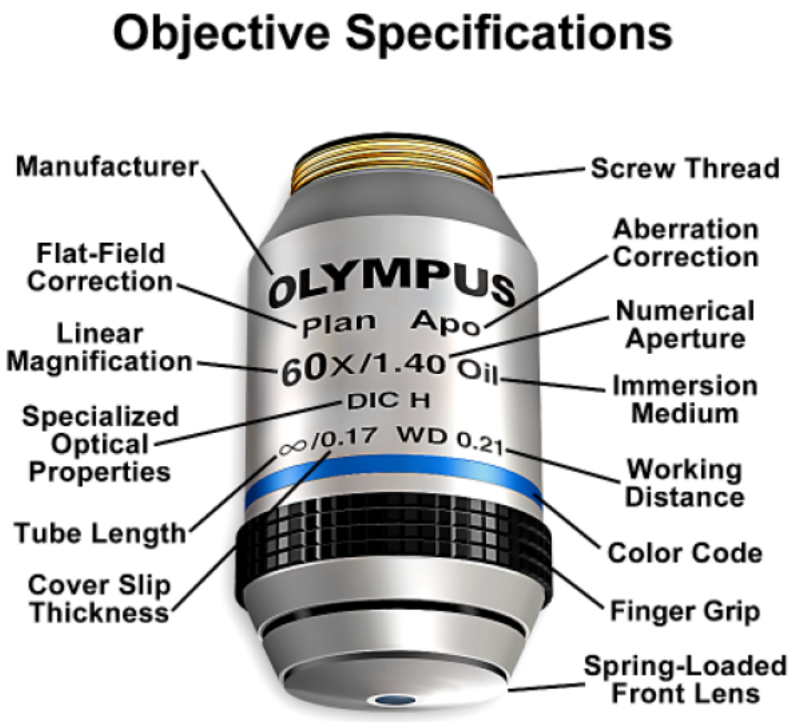


Figure 9. Specifications engraved on the barrel of a typical microscope objective. These include the manufacturer, correction levels, magnification, numerical aperture, immersion requirements, tube length, working distance, and specialized optical properties.

Davidson and Abramowitz, Optical Microscopy, 2002

Table 3 Color-Coded Rings on Microscope Objectives

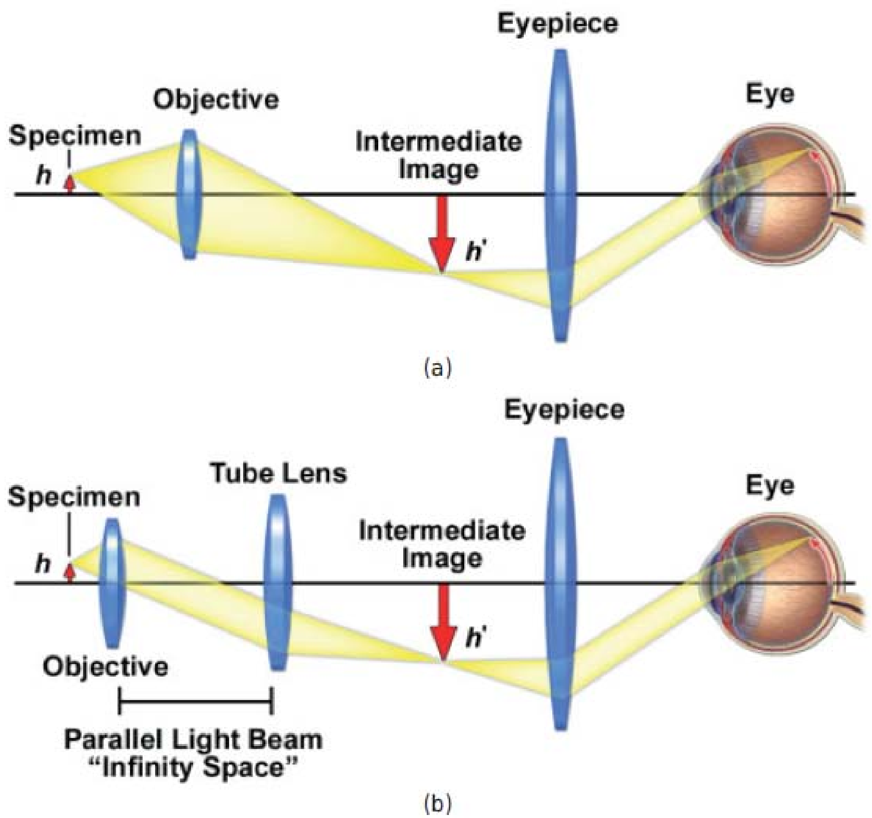
Immersion color code [a]	Immersion type
Black	Oil immersion
Orange	Glycerol immersion
White	Water immersion
Red	Special
Magnification color code [b]	**Magnification**
Black	1x, 1.25x
Brown	2x, 2.5x
Red	4x, 5x
Yellow	10x
Green	16x, 20x
Turquoise blue	25x, 32x
Light blue	40x, 50x
Cobalt (dark) blue	60x, 63x
White (cream)	100x

[a] Narrow colored ring located near the specimen end of objective.
[b] Narrow band located closer to the mounting thread than the immersion code.

http://www.olympusmicro.com/primer/microscopy.pdf

Compound Microscope Objective

Infinity Correction



Finite and infinity-corrected microscope optical configuration.

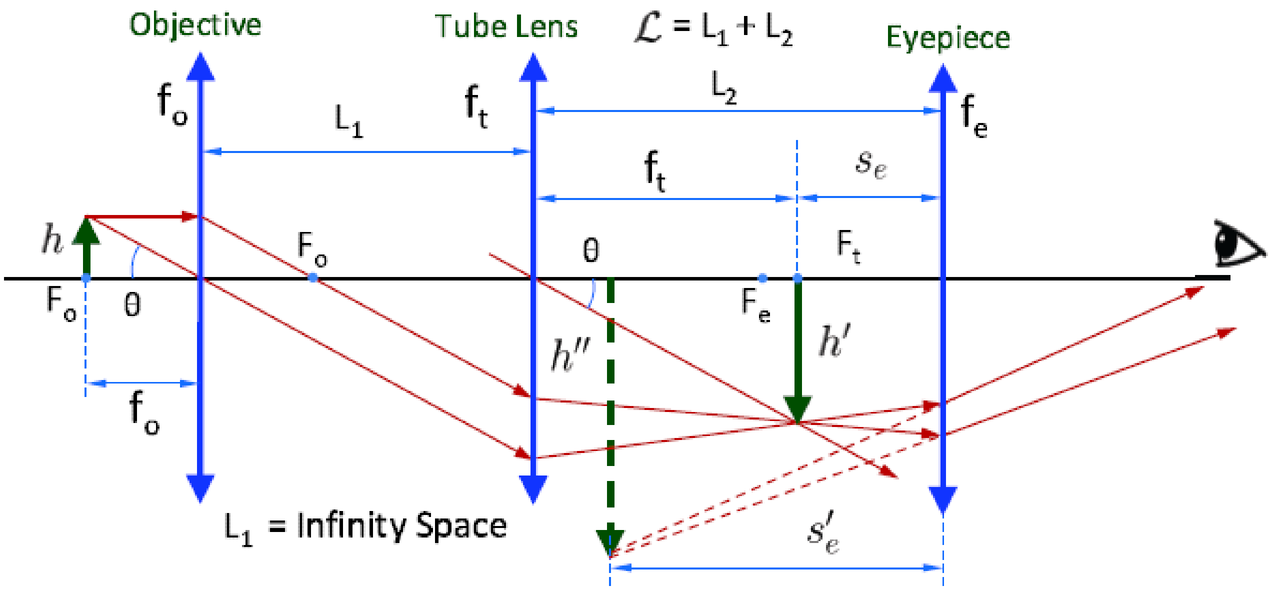
(a) Finite microscope optical train showing focused light rays from the objective at the intermediate image plane.

(b) Infinity-corrected microscope with a parallel light beam between the objective and tube lens.

D. B. Murphy and M. W. Davidson, "Fundamentals of Light Microscopy & Electronic Imaging ", Wiley –Blackwell, 2nd Ed. 2013

Compound Microscope Objective

Infinity Correction



$$\frac{1}{s_o = f_o} + \frac{1}{s'_o} = \frac{1}{f_o} \implies s'_o = \infty$$

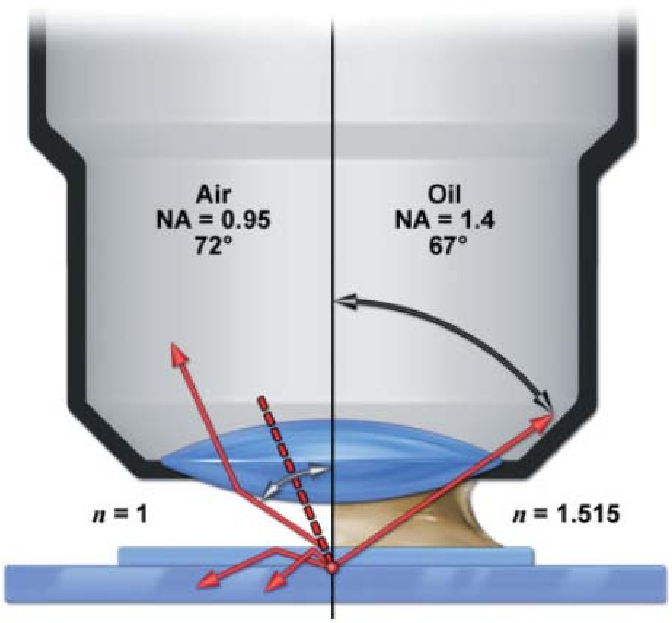
$$\frac{1}{s_t = -\infty} + \frac{1}{s'_t} = \frac{1}{f_t} \implies s'_t = f_t$$

$$\frac{1}{s_e = L_2 - f_t} + \frac{1}{s'_e} = \frac{1}{f_e} \implies s'_e = \frac{f_e(L_2 - f_t)}{L_2 - f_t - f_e}$$

$$m = \frac{h'}{h}\frac{h''}{h'} = -\frac{f_t}{f_o}\left(-\frac{s'_e}{L_2 - f_t}\right)$$

Microscope Objective

Numerical Aperture = NA = n sinθ

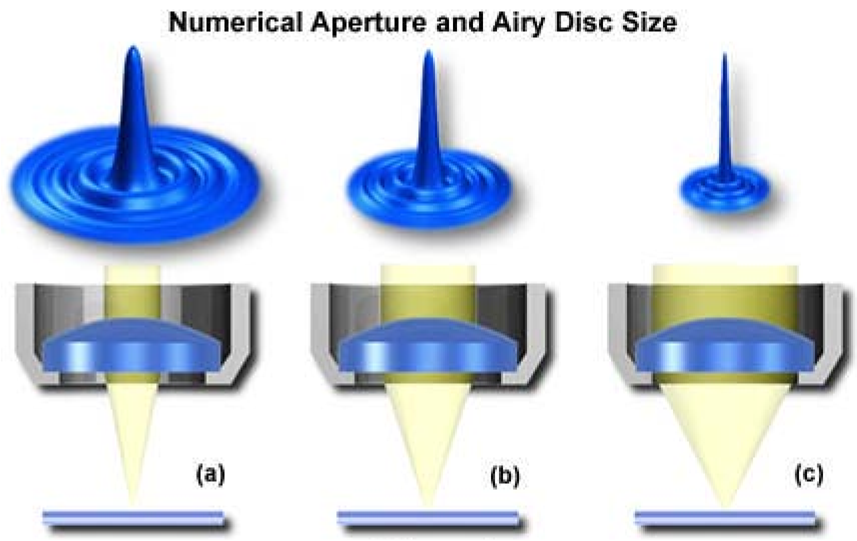


Objective Numerical Apertures Table

Magnification	Plan Achromat (NA)	Plan Fluorite (NA)	Plan Apochromat (NA)
0.5x	0.025	n/a	n/a
1x	0.04	n/a	n/a
2x	0.06	n/a	0.10
4x	0.10	0.13	0.20
10x	0.25	0.30	0.45
20x	0.40	0.50	0.75
40x	0.65	0.75	0.95
40x (oil)	n/a	1.30	1.00
60x	0.75	0.85	0.95
60x (oil)	n/a	n/a	1.40
100x (oil)	1.25	1.30	1.40
150x	n/a	n/a	0.90

D. B. Murphy and M. W. Davidson, "Fundamentals of Light Microscopy & Electronic Imaging ", Wiley –Blackwell, 2nd Ed. 2013

Microscope Objective
Resolution



Resolution Table

	Plan Achromat		Plan Fluorite		Plan Apochromat	
Magnification	**NA**	**Resolution (μm)**	**NA**	**Resolution (μm)**	**NA**	**Resolution (μm)**
4x	0.10	2.75	0.13	2.12	0.20	1.375
10x	0.25	1.10	0.30	0.92	0.45	0.61
20x	0.40	0.69	0.50	0.55	0.75	0.37
40x	0.65	0.42	0.75	0.37	0.95	0.29
60x	0.75	0.37	0.85	0.32	0.95	0.29
100x	1.25	0.22	1.30	0.21	1.40	0.20

D. B. Murphy and M. W. Davidson, "Fundamentals of Light Microscopy & Electronic Imaging ", Wiley –Blackwell, 2nd Ed. 2013

Microscope Objective/Eyepiece

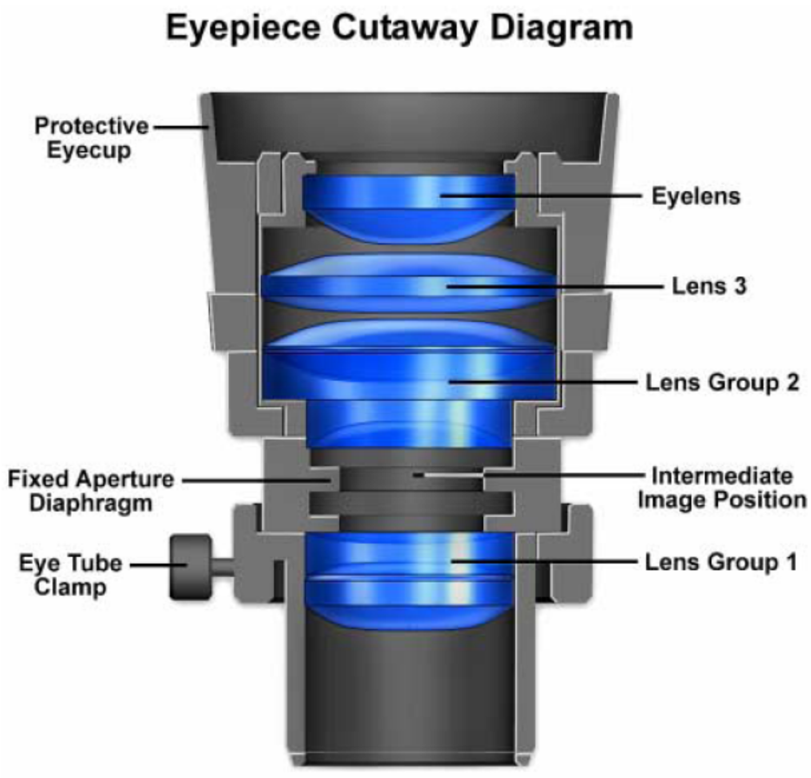


Figure 11. Cutaway diagram of a typical periplan eyepiece. The fixed aperture diaphragm is positioned between lens group 1 and lens group 2, where the intermediate image is formed. The eyepiece has a protective eyecup that makes viewing the specimen more comfortable for the microscopist.

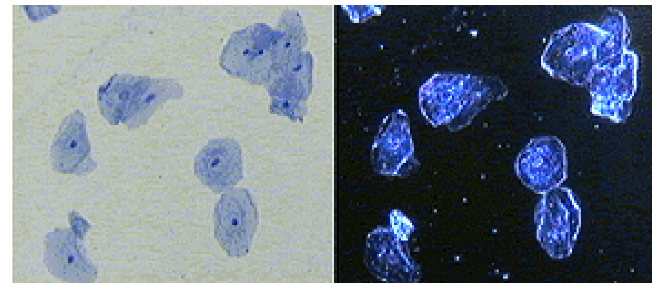
Davidson and Abramowitz, Optical Microscopy, 2002

Table 6 Range of Useful Magnification (500-1000 x NA of Objective)

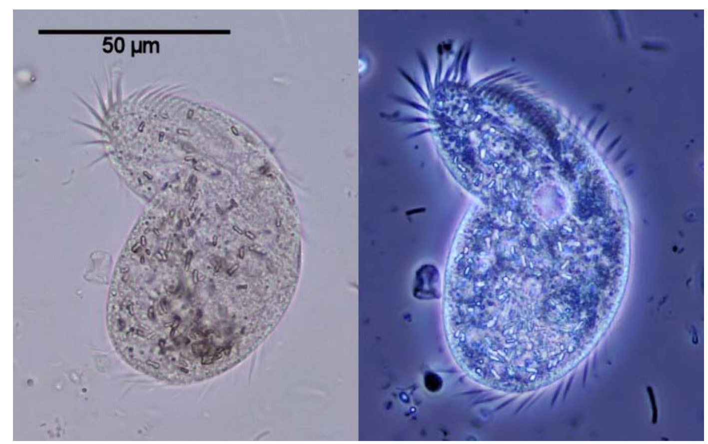
Objective (NA)	Eyepieces 10x	12.5x	15x	20x	25x
2.5x (0.08)	—	—	—	x	x
4x (0.12)	—	—	x	x	x
10x (0.35)	—	x	x	x	x
25x (0.55)	x	x	x	x	—
40x (0.70)	x	x	x	—	—
60x (0.95)	x	x	x	—	—
100x (1.42)	x	x	—	—	—

Types of Optical Microscopy

- Bright-Field Microscopy
- Dark-Field Microscopy
- Phase-Contrast Microscopy
- Fluorescence Microscopy
- Confocal Microscopy

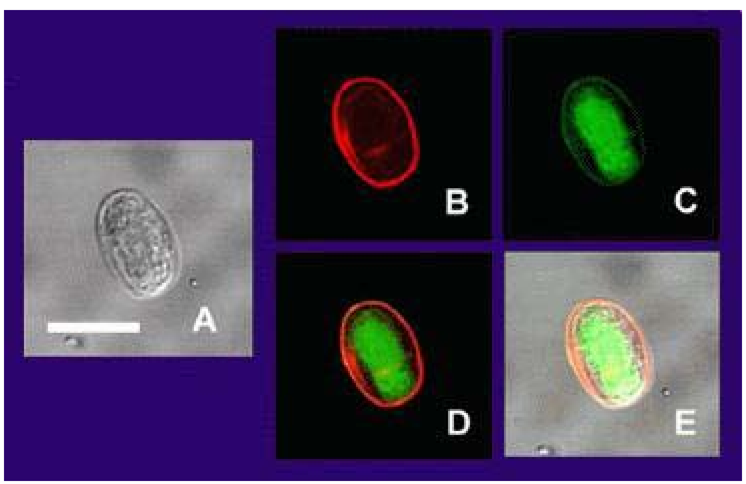


Bright-Field Image Dark-Field Image



Bright-Field Image Phase-Contrast Image

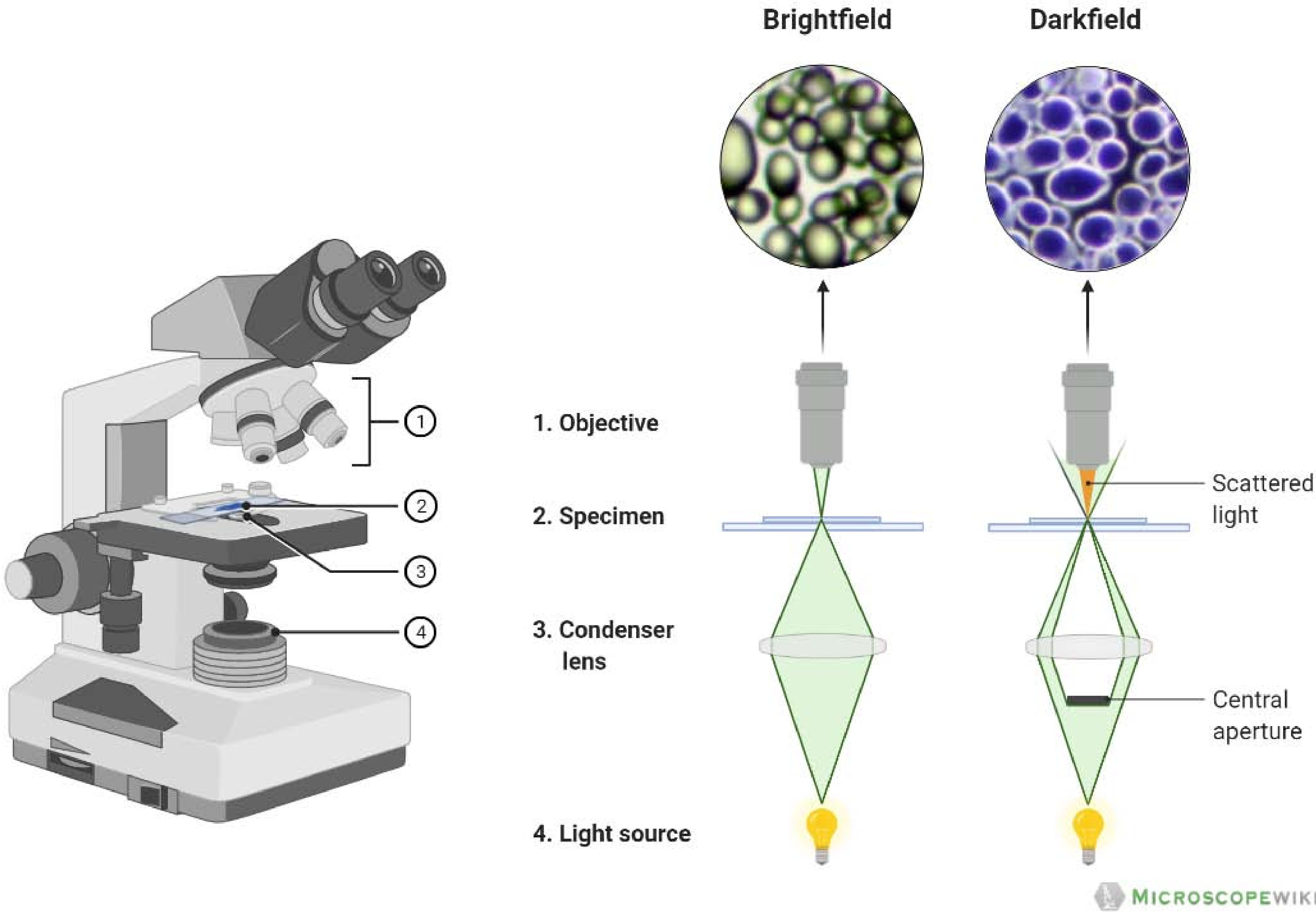
http://www.microscopy-uk.org.uk/mag/imgmar06/Cover2.jpg



Fluorescent Image

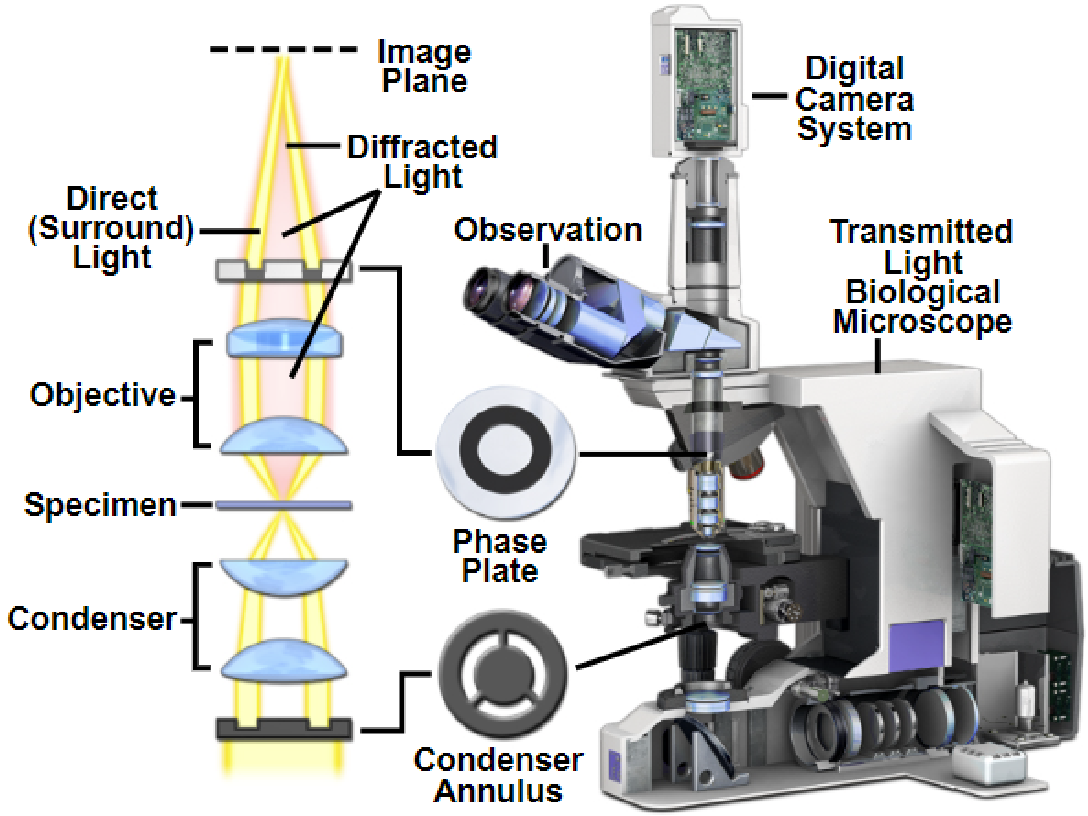
https://online.science.psu.edu/micrb106_wd/node/6078

Bright-Field and Dark-Field Microscopy



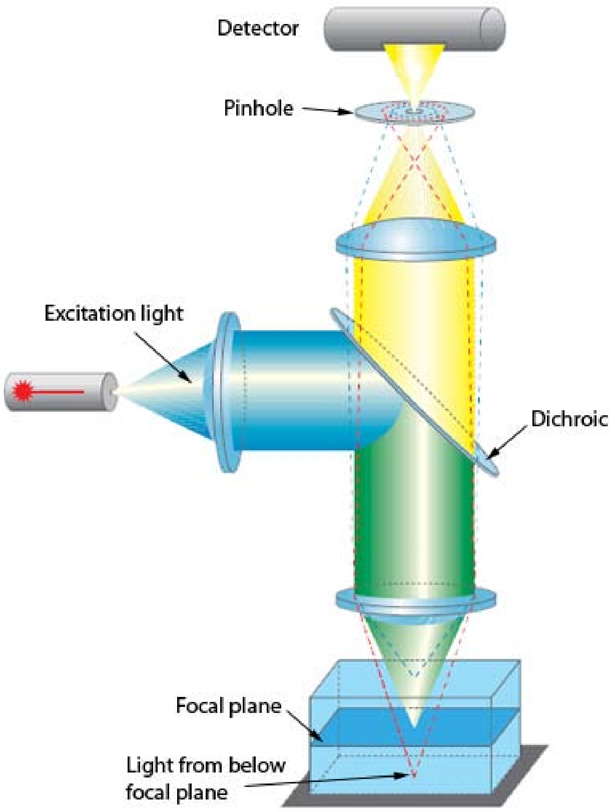
https://microscopewiki.com/brightfield-vs-darkfield-microscope/

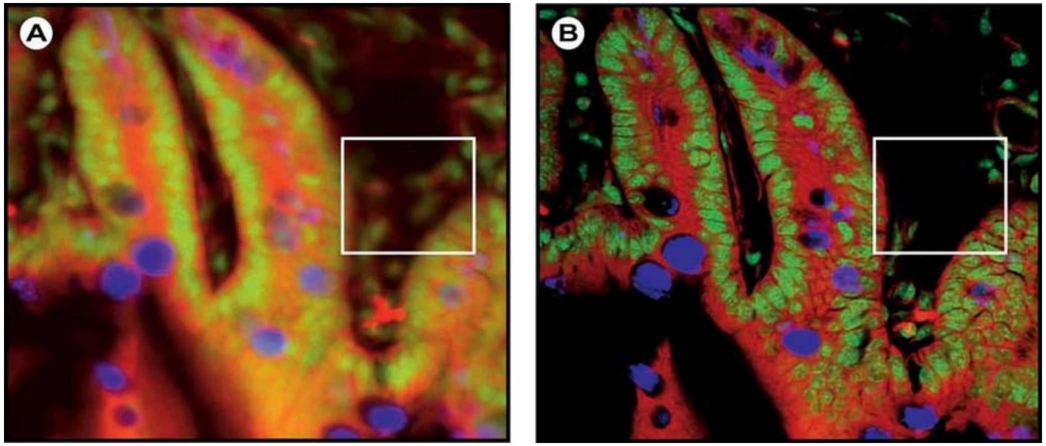
Phase-Contrast Microscopy



https://www.microscopyu.com/techniques/phase-contrast/introduction-to-phase-contrast-microscopy

Types of Optical Microscopy
Confocal Microscopy





Confocal versus wide field microscopy. Wide field (A) and confocal (B) image of a triple-labeled cell aggregate (mouse intestine section). In the wide field image, specimen planes outside the focal plane degrade the information of interest from the focal plane, and differently stained specimen details appear in mixed color. In the confocal image (B), specimen details blurred in wide field imaging become distinctly visible, and the image throughout is greatly improved in contrast. Notice that out of focus signals in the wide field image cause additional structures to appear (white box)

https://microscopy.duke.edu/sites/microscopy.duke.edu/files/site-images/confocalpinhole.jpg

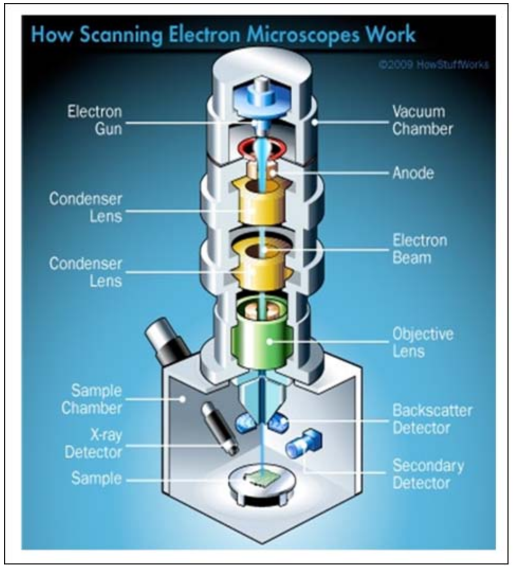
https://www.researchgate.net/profile/Hellen_Ishikawa-Ankerhold/publication/223982228/figure/fig6/AS:333477347119106@1456518603540/Confocal-versus-wide-field-microscopy-Wide-field-A-and-confocal-B-image-of-a.jpg

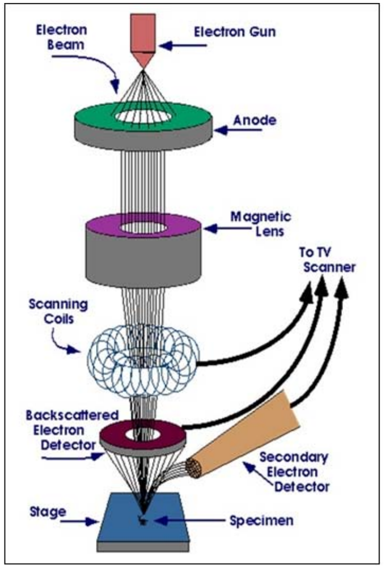
Types of Microscopy

Type	Probe	Technique	Best Resolution	Penetration	Uses and Constraints
Optical Microscopy	Visible Light	Detect reflected light (opaque samples) or transmitted light (transparent samples). Light focused using lenses.	~200 nm	Surface or volume (can probe through transparent materials)	
Near-Field Optical Microscopy (NSOM)	Visible Light	Detect reflected light (opaque samples) or transmitted light (transparent samples). Uses an aperture very close to the sample surface.	~10 nm	Surface or volume (can probe through transparent materials)	Biological samples.
X-Ray Microscopy (TXM, SXM, STXM)	X-Rays	Image derived from x-ray scattering or interference patterns. X-rays focused using a "zone plate" (Fresnel lens).	~20 nm	Surface or volume (x-rays can penetrate some materials)	Can be tuned to specific frequencies to provide element identification and mapping.
Scanning Electron Microscopy (SEM)	Electrons	Detect electrons back-scattered by the sample. Electrons focused using electromagnets.	~1 nm	Surface	Sample must be in a vacuum.
Transmission Electron Microscopy (TEM, STEM)	Electrons	Detect electrons scattered as they move through the sample. Electrons focused using electromagnets.	~0.05 nm	Volume	Samples must be <100 nm thick.
Focused Ion Beam (FIB)	Ions	Detect ions back-scattered by the sample. Ions focused using electromagnets.	~10 nm	Surface	Due to the large masses of the ions, this probe can be destructive to the surface of the sample. Therefore, it can also be used to etch the sample.
Scanning Tunneling Microscopy (STM)	Cantilever Tip	Detect the quantum tunneling current of electrons from the sample to the probe tip.	~0.1 nm	Surface	Sample must be conductive material and must be in a vacuum. Can be used to manipulate atoms on the sample surface.
Atomic Force Microscopy (AFM)	Cantilever Tip	Detect the electrostatic force between the sample and the probe tip.	~0.1 nm	Surface	Can be used to manipulate atoms on the sample surface.
Magnetic Force Microscopy (MFM)	Cantilever Tip	Detect the magnetic force between the sample and the probe tip.	~10 nm	Surface	Sample must be ferromagnetic or paramagnetic.

https://teachers.stanford.edu/links/TypesOfMicroscopy.ppt

Scanning Electron Microscopy





http://emicroscope.blogspot.com/2011/03/scanning-electron-microscope-sem-how-it.html

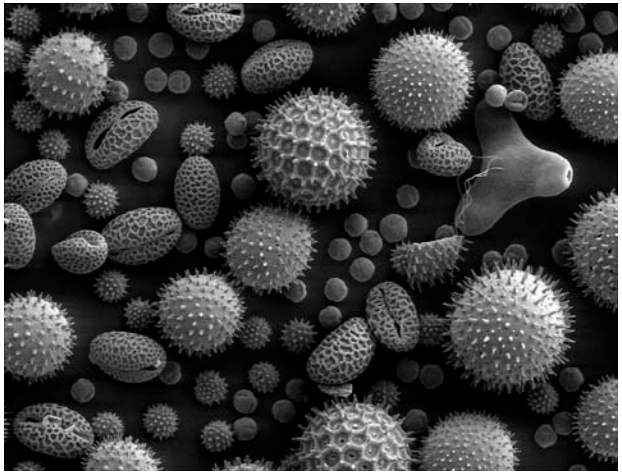
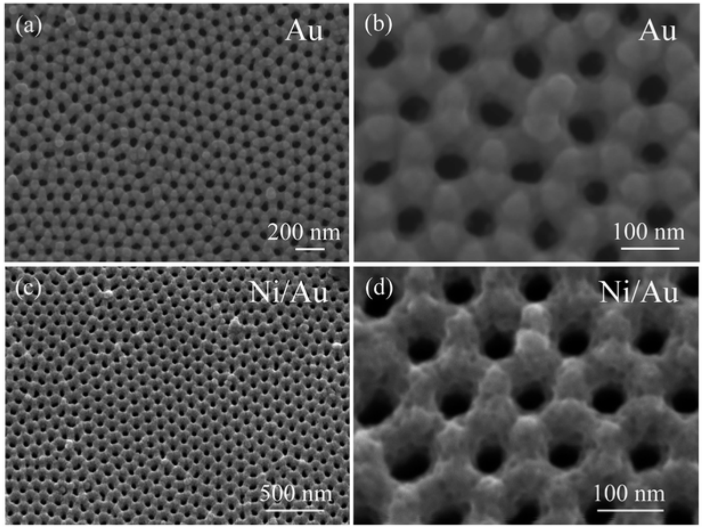


Image of pollen grains taken on an SEM shows the characteristic depth of field of SEM micrographs

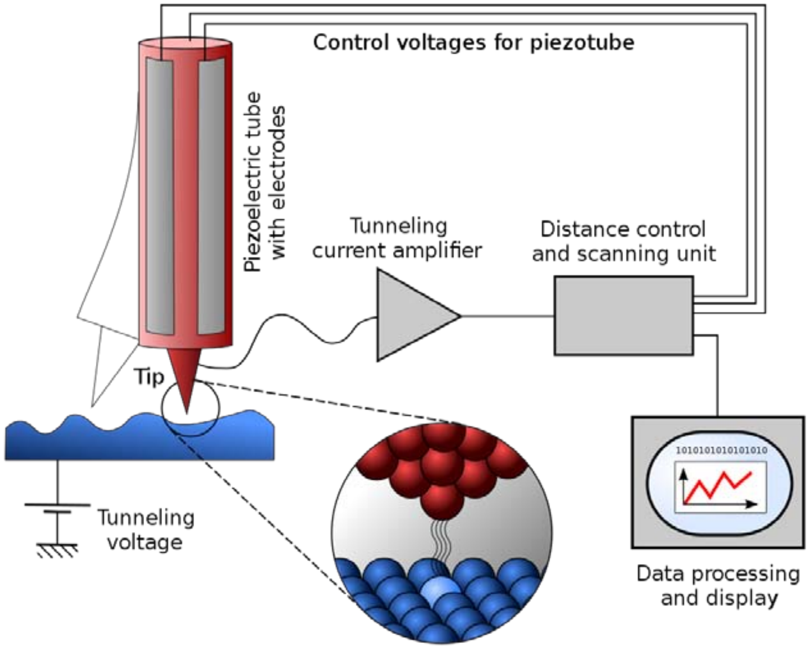
https://en.wikipedia.org/wiki/Scanning_electron_microscope



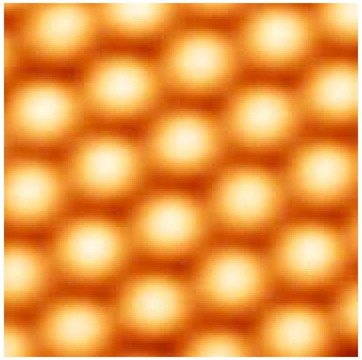
(a and b) SEM images in top view of the AAO (anodic aluminium oxide) template sputtered with Au layer, (c and d) the SEM images of the nanoporous Ni/Au film.

https://pubs.rsc.org/en/content/articlehtml/2020/ra/d0ra01224f

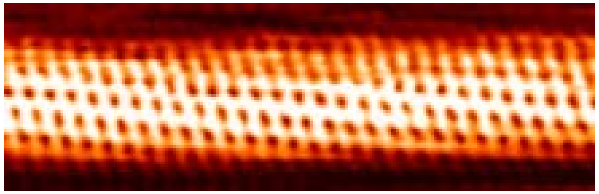
Scanning Tunneling Microscopy



https://en.wikipedia.org/wiki/Scanning_tunneling_microscope

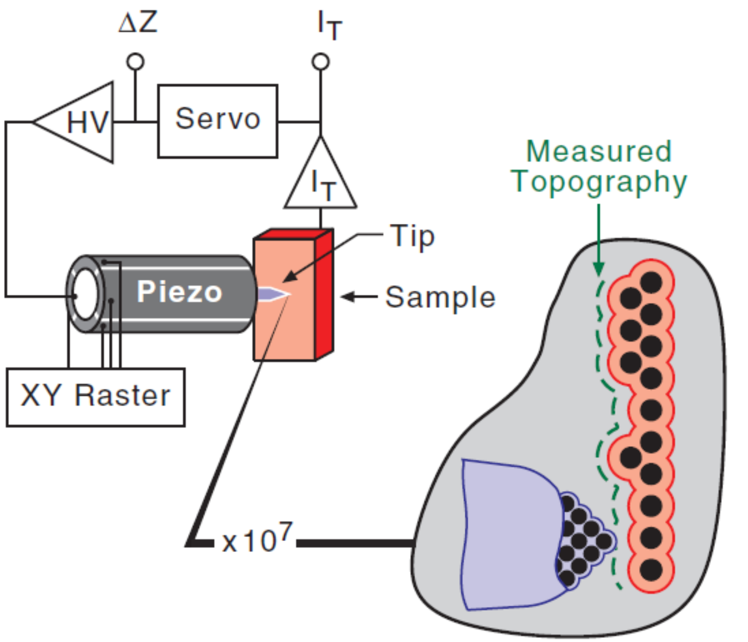


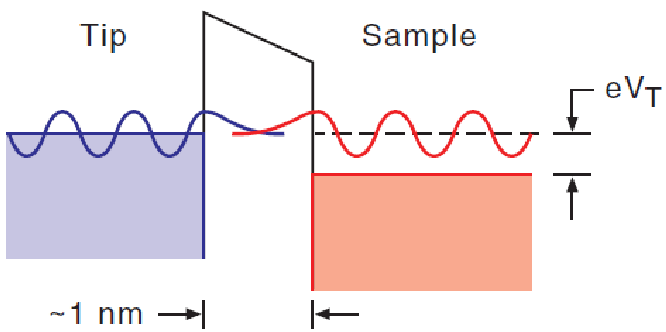
The silicon atoms on the surface of a crystal of silicon carbide (SiC). Image obtained using an STM.

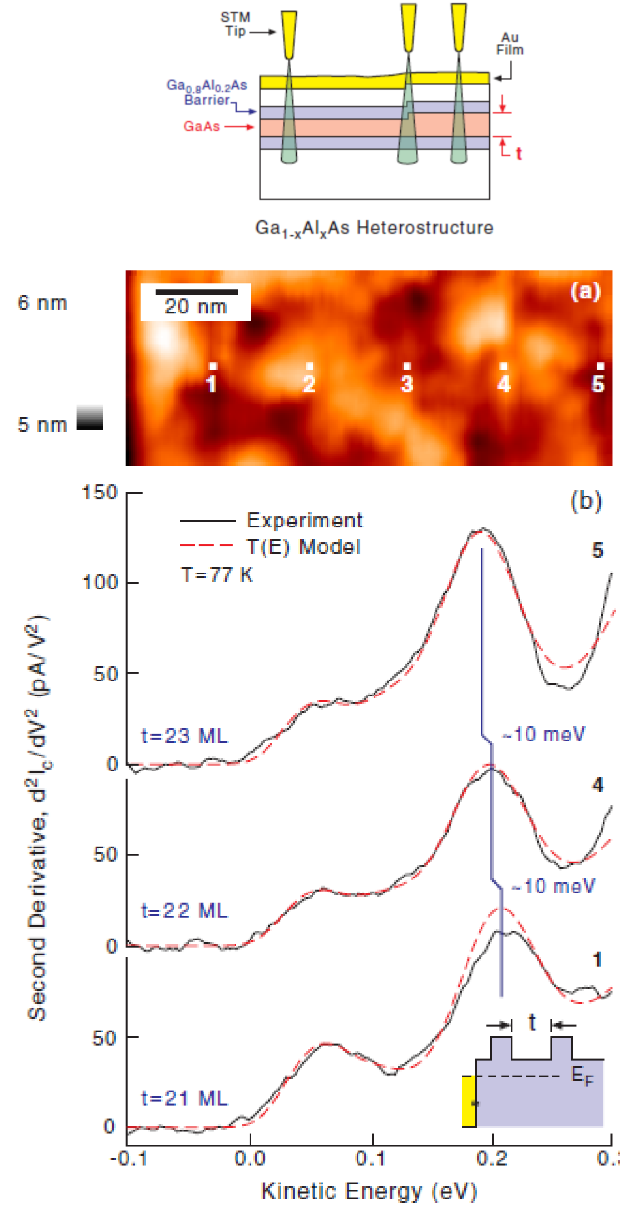


An STM image of a single-walled carbon nanotube

Scanning Tunneling Microscopy

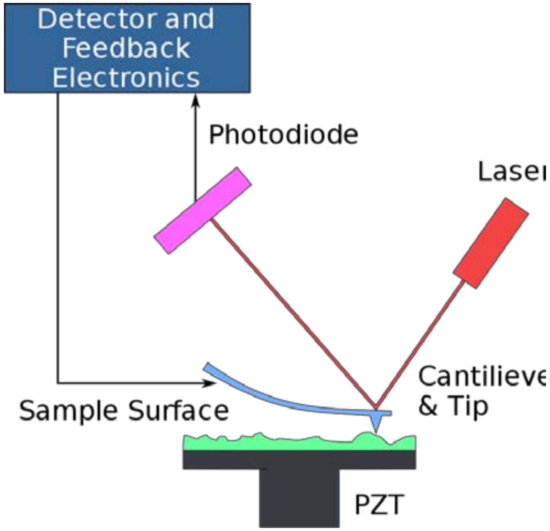


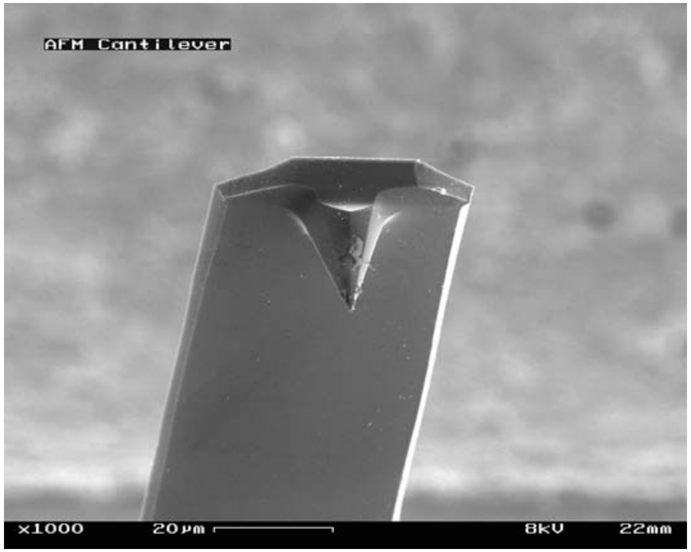




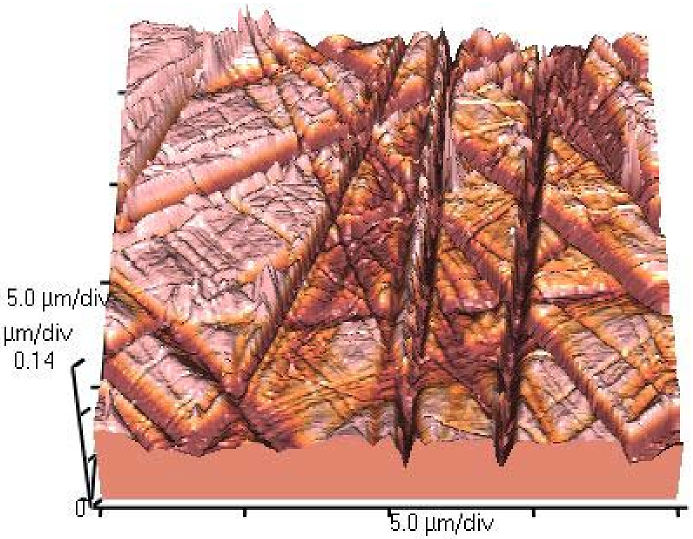
D. K. Guthrie, "Analysis of quantum semiconductor heterostructures by ballistic electron emission spectroscopy, Ph.D. Thesis, School of ECE, Georgia Tech, 1998

Atomic Force Microscopy





Electron micrograph of a used AFM cantilever. Image width ~100 micrometers



Atomic force microscope topographical scan of a glass surface. The micro and nano-scale features of the glass can be observed, portraying the roughness of the material. The image space is (x,y,z) = (20 μm × 20 μm × 420 nm).

https://en.wikipedia.org/wiki/Atomic_force_microscopy

Comparison between Microscopes in Terms of Magnification

- Optical and electron microscopes can easily generate two dimensional images of a sample surface, with a magnification as large as 1000X for an optical microscope, and a few hundreds thousands 100000X-300000X for an electron microscope.

- However, these microscopes cannot measure the vertical dimension (z-direction) of the sample, the height (e.g. particles) or depth (e.g. holes, pits) of the surface features.

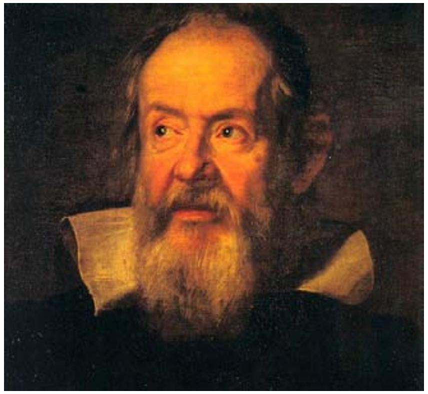
- AFM, which uses a sharp tip to probe the surface features by raster scanning, can image the surface topography with extremely high magnifications, up to 1000000X, comparable or even better than electronic microscopes.

- The measurement of an AFM is made in three dimensions, the horizontal X-Y plane and the vertical Z dimension. Resolution (magnification) at Z-direction is normally higher than X-Y.

https://my.eng.utah.edu/~lzang/images/Lecture_10_AFM.pdf

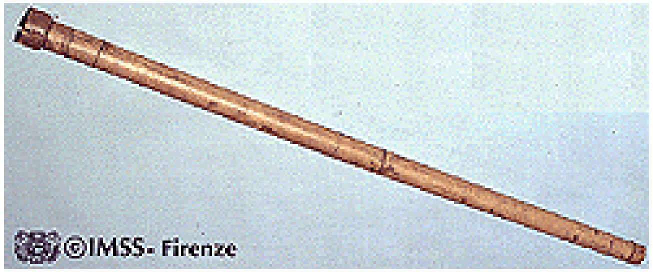
Telescope

Inventor
Hans Lippershey, 1608

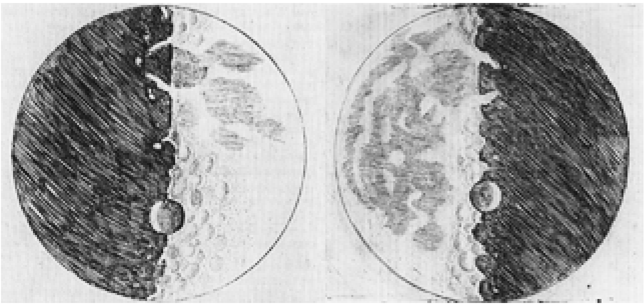


Galileo Galilei, 1609

https://www.space.com/21950-who-invented-the-telescope.html



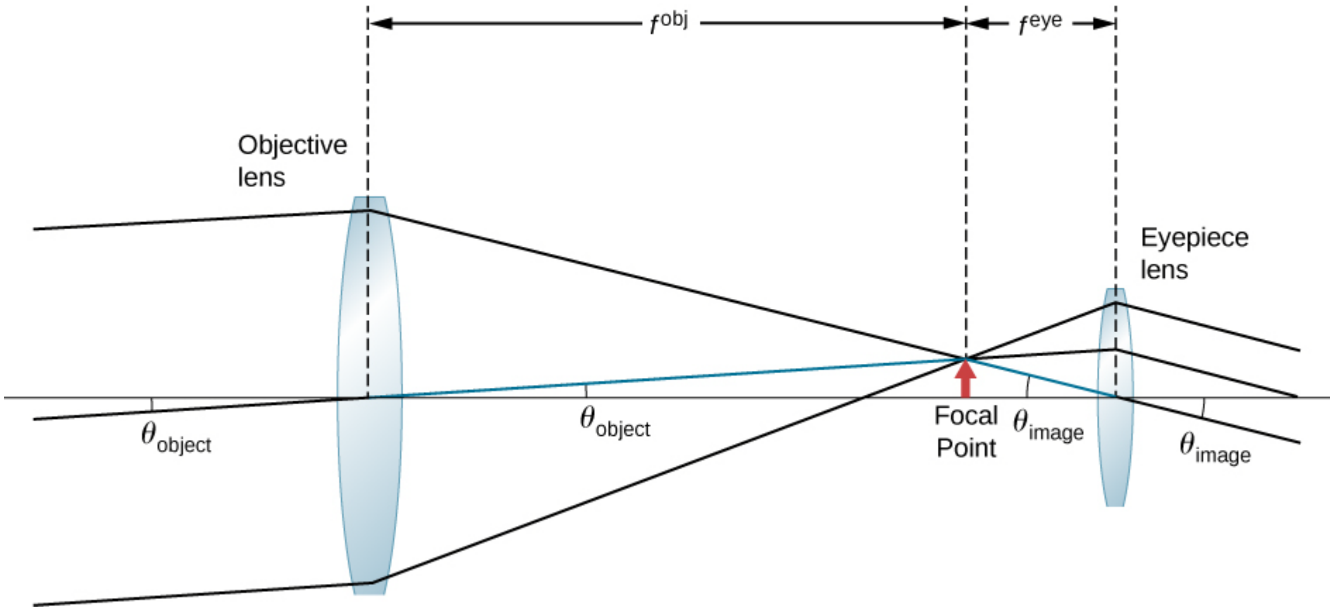
One of Galileo's telescopes. The focal length is 1330 mm with a 26 mm aperture, it magnifies 14x. It has an objective bi-convex lens and a plano-concave eyepiece.



Galileo's drawings of phases of the Moon.

https://www.atnf.csiro.au/outreach/education/senior/astrophysics/galileo.html

Telescope

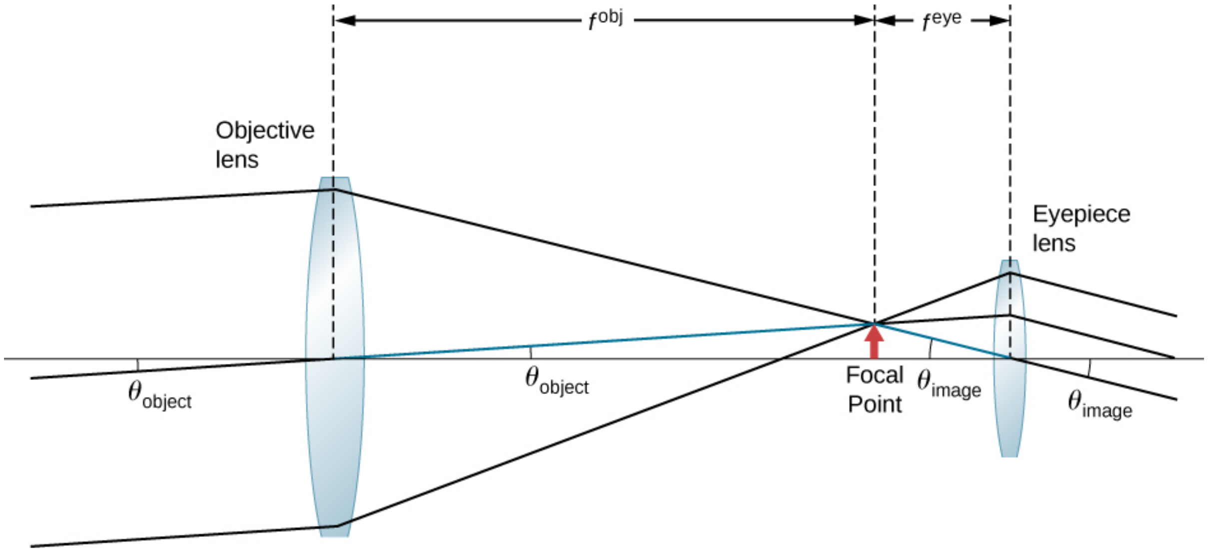


http://cnx.org/contents/DEwGvgGq@2/Microscopes-and-Telescopes

Angular Magnification

$$\boxed{m = \frac{\theta_{image}}{\theta_{object}} \simeq -\frac{f_{obj}}{f_{eye}} = -\frac{f_o}{f_e}}$$

Telescope



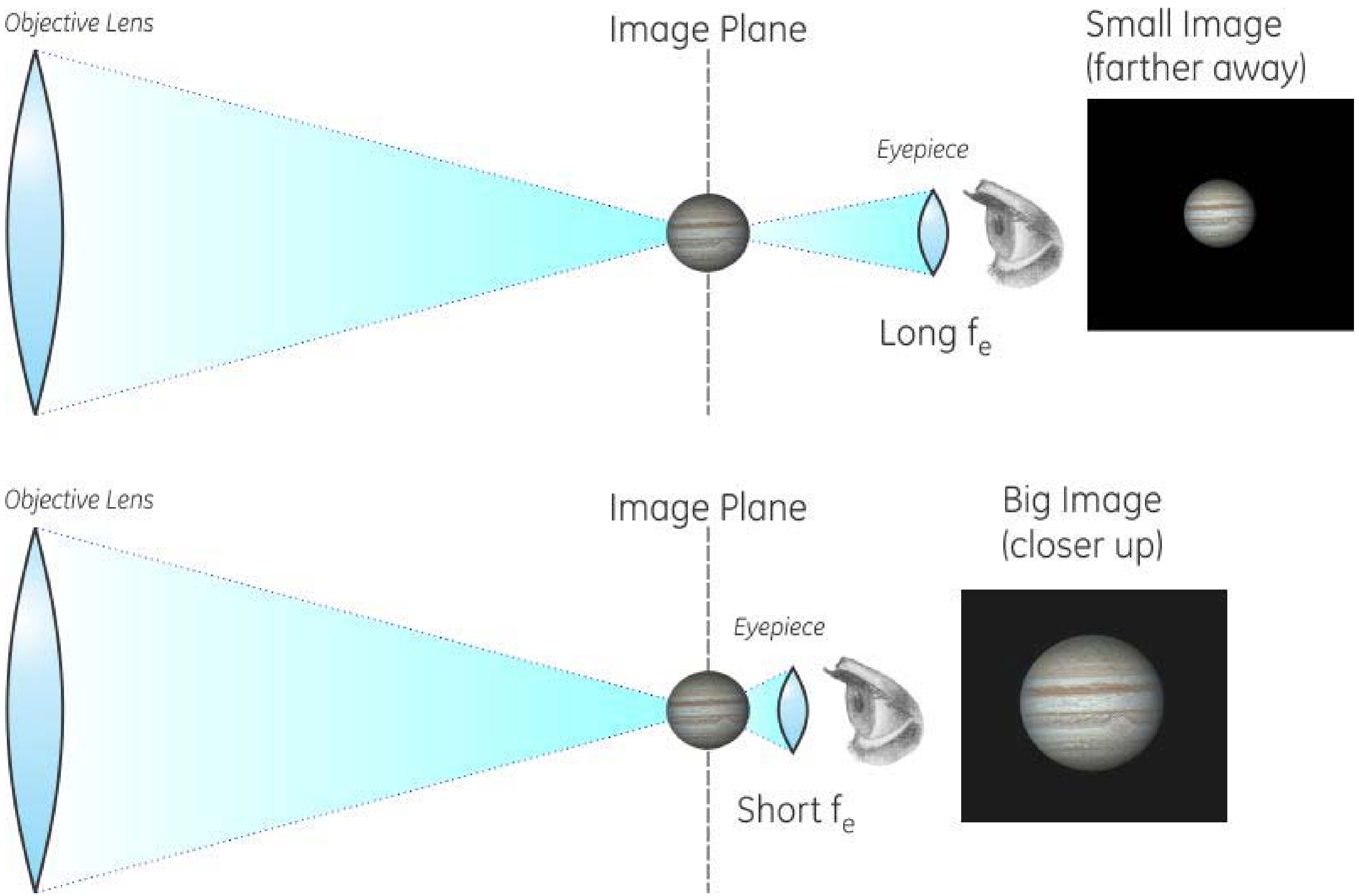
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/f_e & 1 \end{bmatrix} \begin{bmatrix} 1 & L \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f_o & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 - \dfrac{L}{f_o} & L \\ -\dfrac{1}{f_o} - \dfrac{1}{f_e} + \dfrac{L}{f_o f_e} & 1 - \dfrac{L}{f_e} \end{bmatrix}$$

$$C = 0 \implies L = f_o + f_e$$

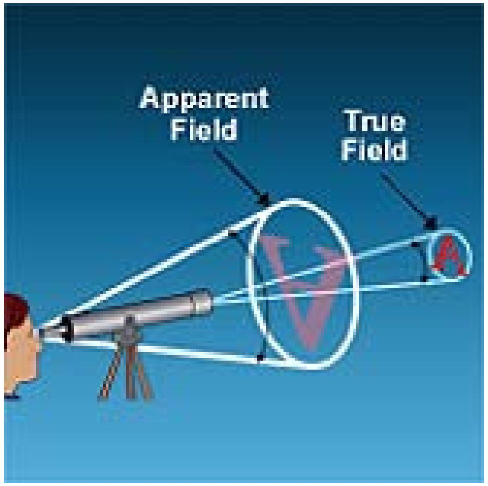
$$m = D \implies D = 1 - \frac{L}{f_e} = -\frac{f_o}{f_e}$$

Telescope



http://www.rocketmime.com/astronomy/Telescope/Magnification.html

Telescope

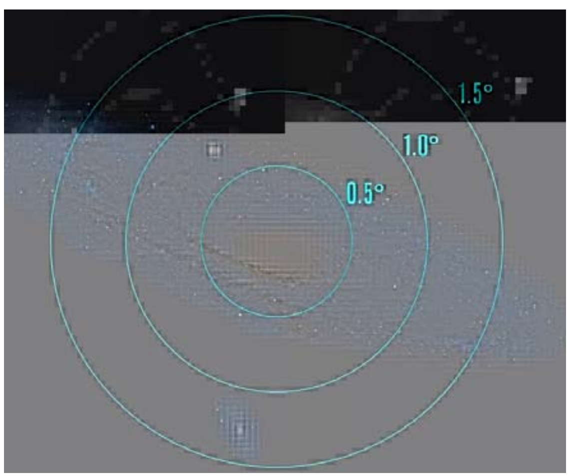


http://www.telescope.com/Articles/Equipment/Telescopes/Apparent-Field-vsTrue-Field/pc/9/c/192/sc/194/p/99822.uts

Apparent Field of View (AFOV): this is the width in degrees of the field as seen through the eyepiece alone.

$$FOV_{Telescope} = \frac{AFOV}{M(=\text{Magnification})}$$

Showing Andromeda Galaxy in 0.5°, 1.0° and 1.5° fields of view



Vendor	Model	Focal Length	Apparent FOV (°)	Actual FOV (°)	Magnifi-cation	Price
Orion	Optilux 2"	40	60	1.18	51	$140
Televue	Panoptic 2"	35	68	1.17	58	$370
Orion	FMC Plössl 2"	50	45	1.11	41	$120
Orion	DeepView 2"	42	52	1.07	48	$70
Edmund Optics	RKE Erfle 2"	32	68	1.07	64	$225
Meade	SWA 2"	32	67	1.06	64	$240
Orion	Optilux 2"	32	60	0.94	64	$140
Teleview	Panoptic 2"	27	68	0.90	75	$330
Teleview	Plössl 1.25"	40	43	0.85	51	$110
Celestron	Ultima 1.25"	35	49	0.84	58	$108

https://spacemath.gsfc.nasa.gov/weekly/10Page34.pdf

https://lovethenightsky.com/what-is-a-field-of-view-in-astronomy-and-why-is-it-useful/

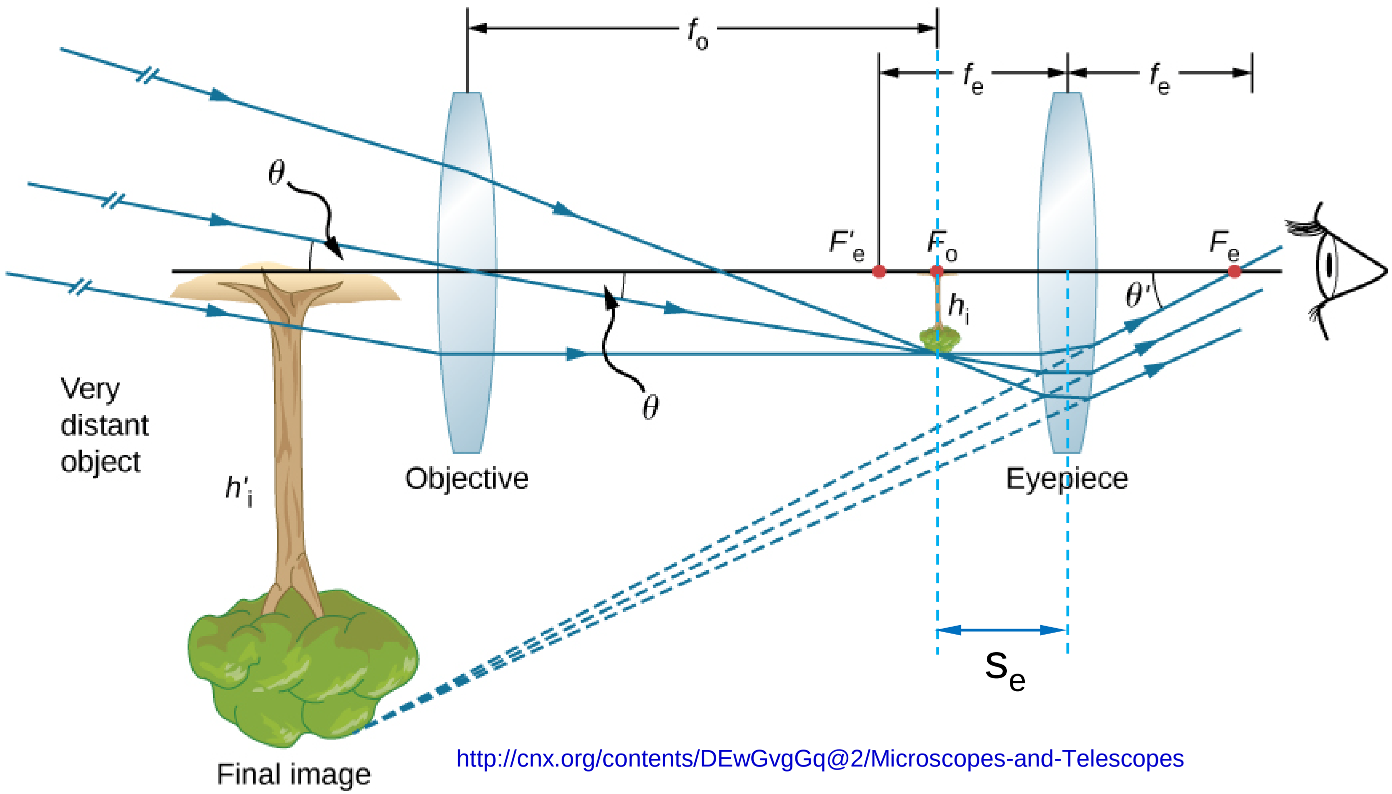
Telescope

Representative views of Saturn at low, high and excessive magnification.

http://www.rocketroberts.com/astro/eyepiece_basics.htm

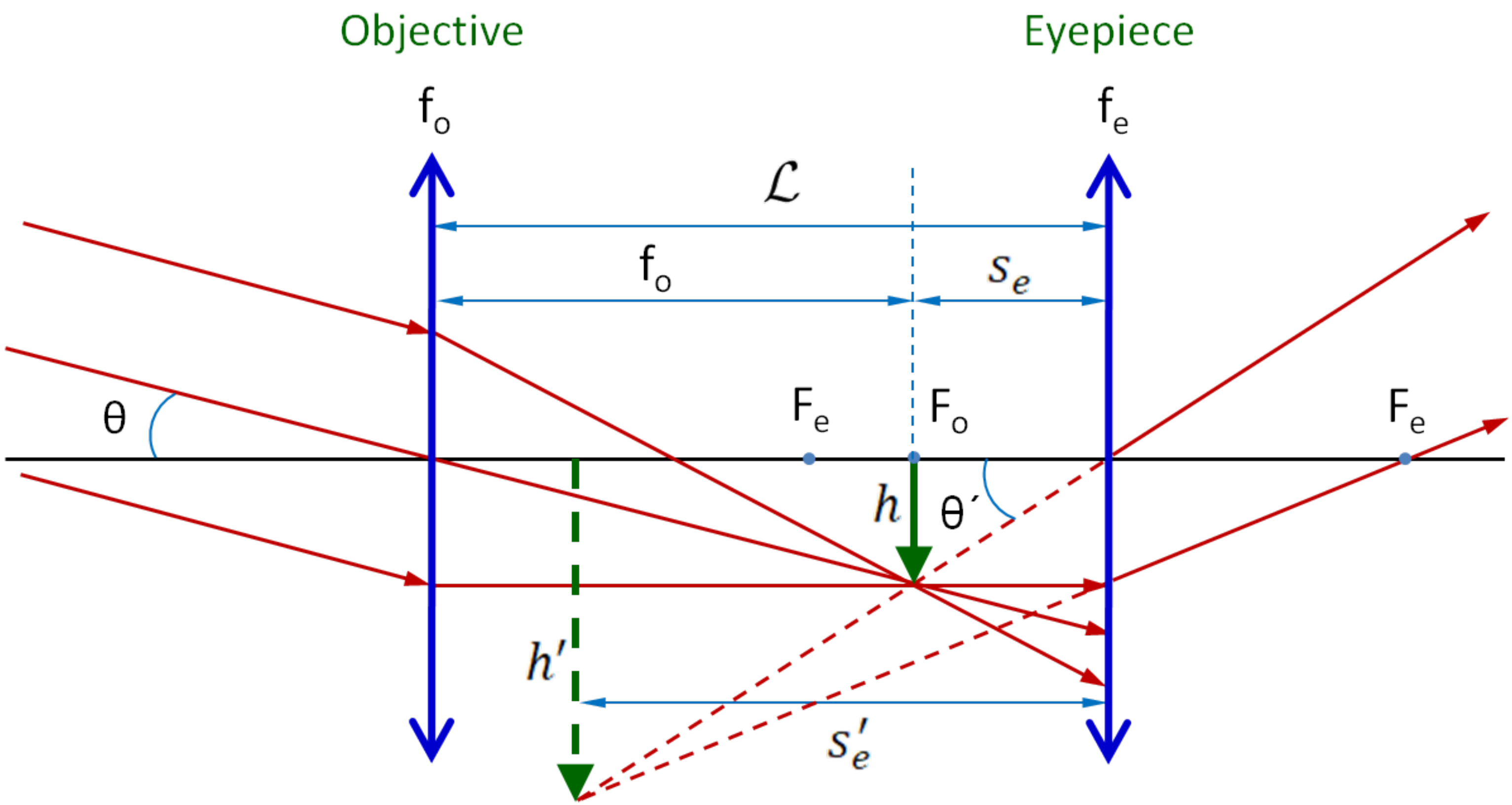
Practical Magnification = 50x per inch (2.54cm) of lens (or mirror) diameter

Refracting Telescope



http://cnx.org/contents/DEwGvgGq@2/Microscopes-and-Telescopes

Refracting Telescope

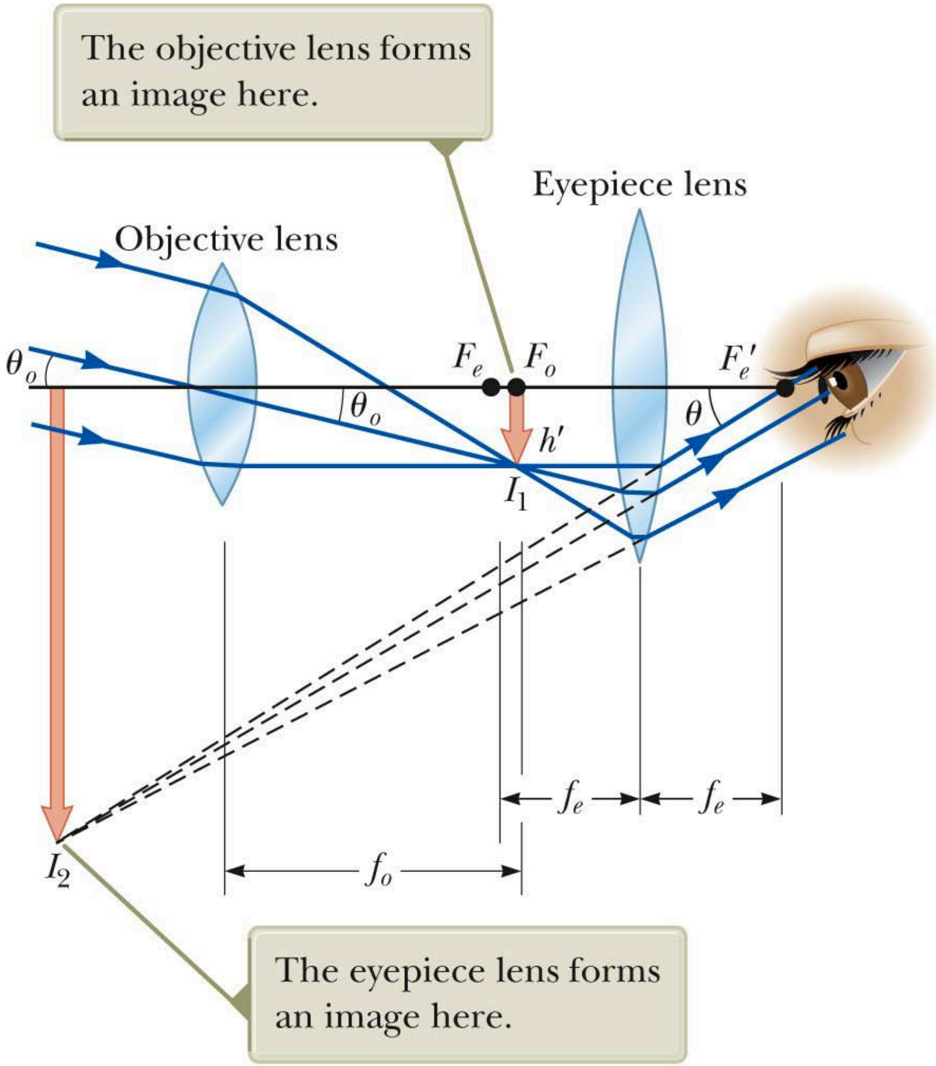


Angular Magnification

$$m = \frac{\theta'}{\theta} \simeq \frac{h'/s'_e}{h/f_o} = -\frac{f_o}{s_e} = -\frac{f_o}{\mathcal{L} - f_o}$$

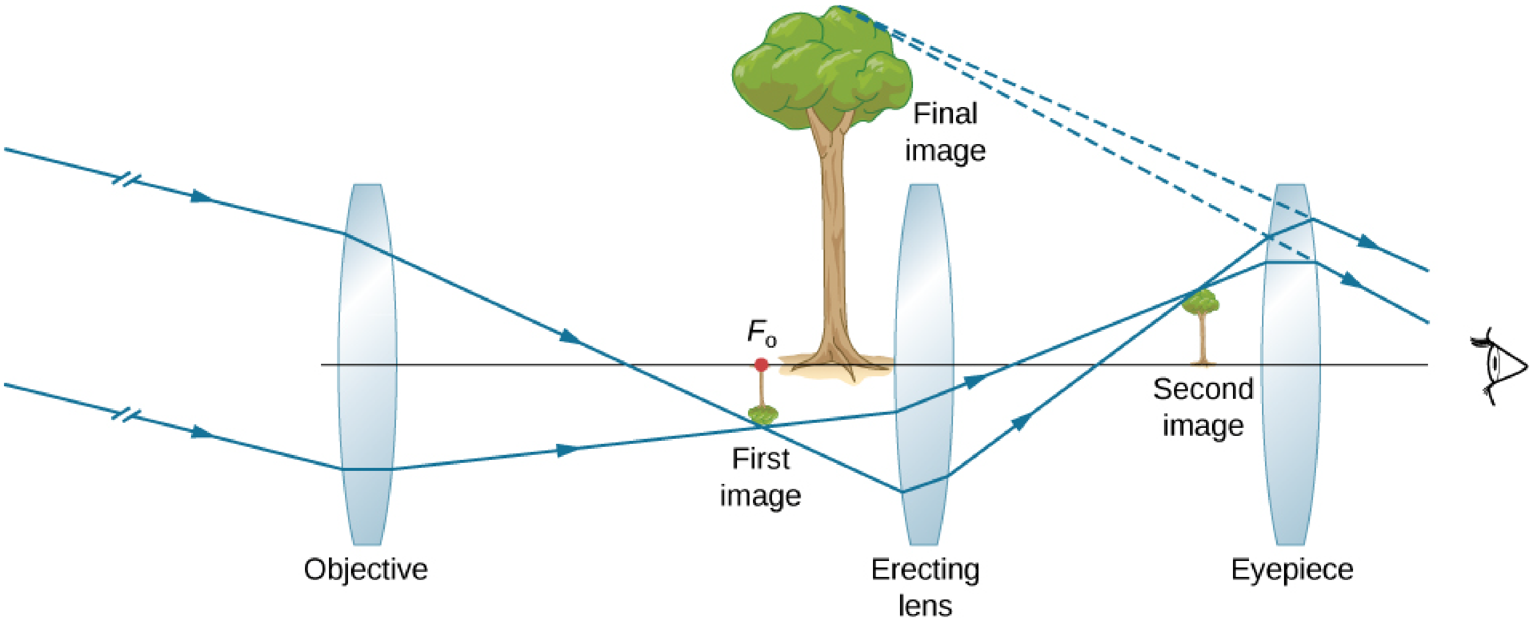
$$\mathcal{L} = f_o + s_e \leq f_o + f_e$$

Refracting Telescope



R. A. Serway and J. W. Jewett, "Physics for Scientists and Engineers", Thomson Brooks/Cole, 6th Ed. 2004

Erecting Refractive Telescope



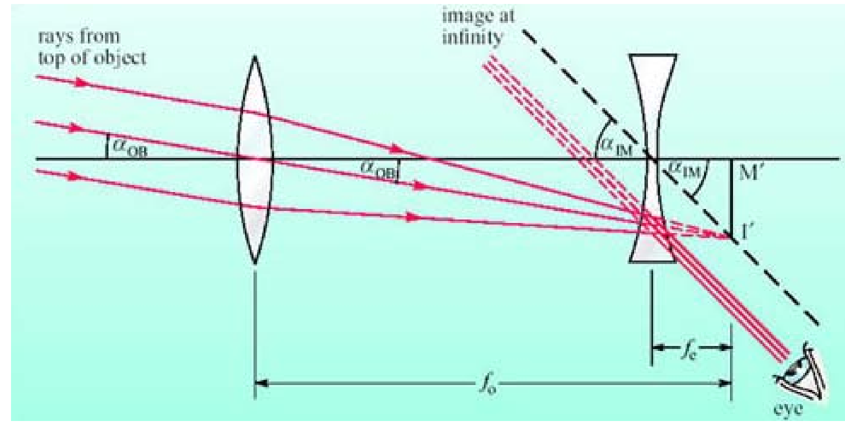
This arrangement of three lenses in a telescope produces an upright final image. The first two lenses are far enough apart that the second lens inverts the image of the first. The third lens acts as a magnifier and keeps the image upright and in a location that is easy to view.

http://cnx.org/contents/DEwGvgGq@2/Microscopes-and-Telescopes

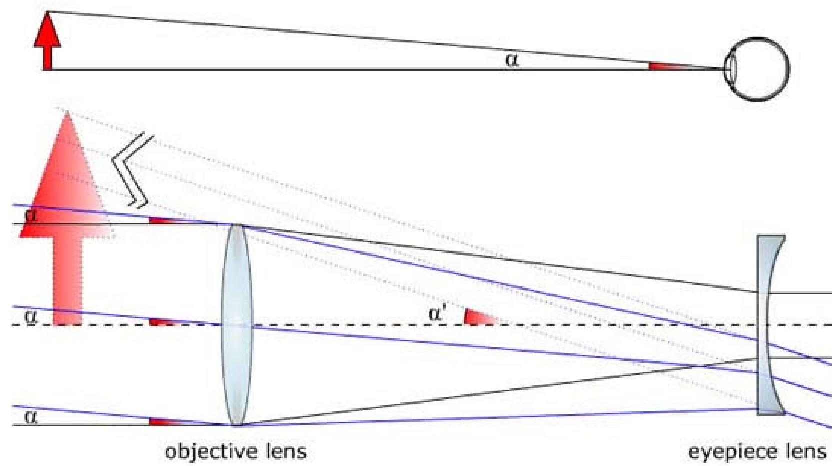
Galilean Telescope

Two of Galileo's first telescopes; in the Institute and Museum of the History of Science, Florence.

https://media1.britannica.com/eb-media/52/752-004-6FE60E05.jpg

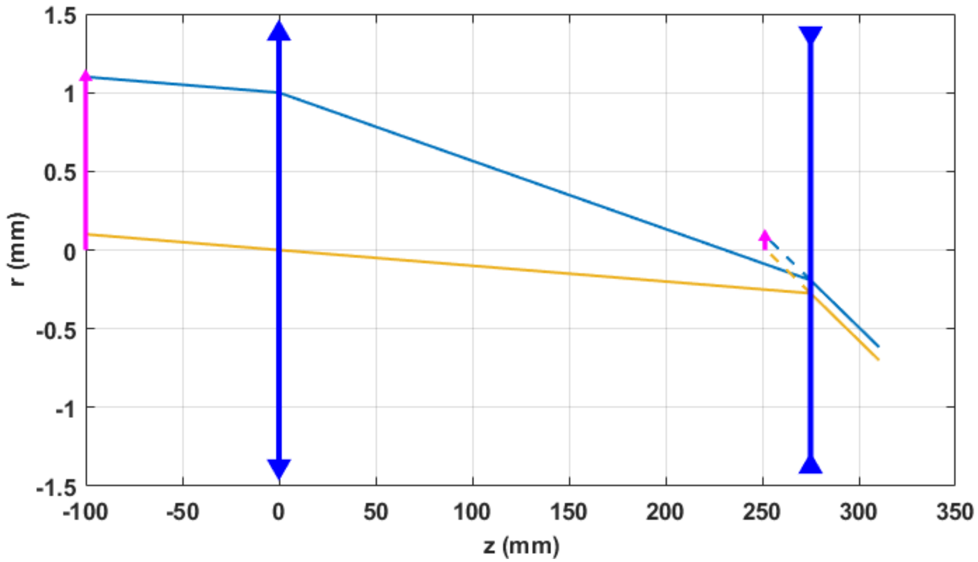


http://www.open.edu/openlearn/ocw/pluginfile.php/69922/mod_oucontent/oucontent/521/e2db4075/a05fd545/sxr208_1_002i.jpg

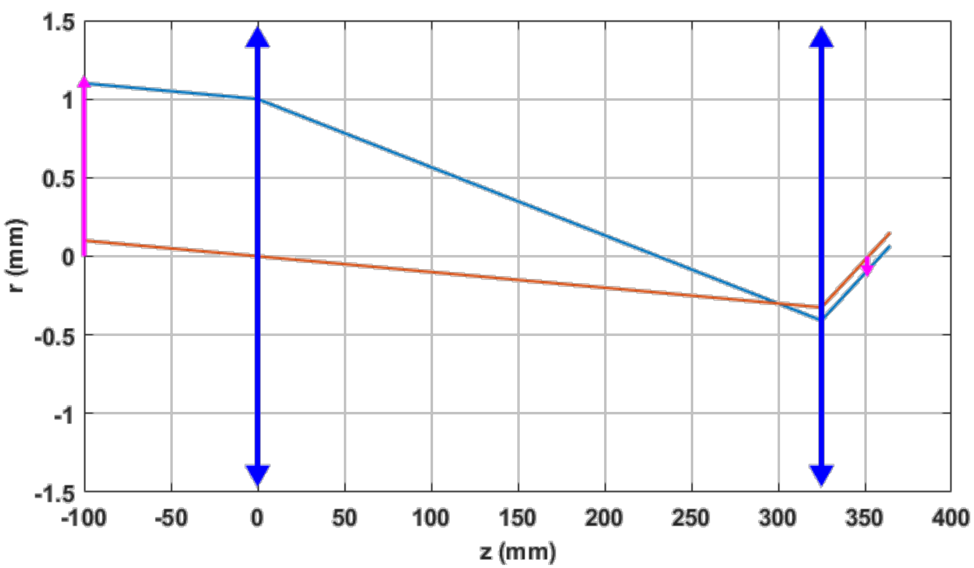


https://brunelleschi.imss.fi.it/esplora/cannocchiale/dswmedia/esplora/immagini/01_ing.jpg

Galilean versus *Keplerian* Telescope

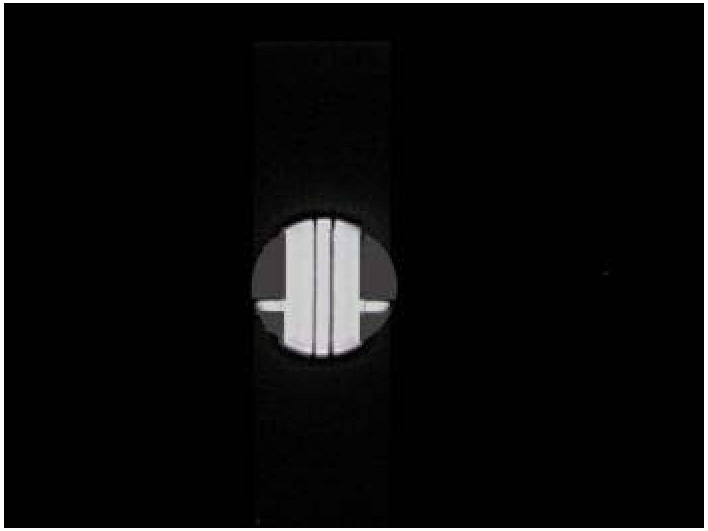


Galilean: f_o = 300mm, f_e = -25mm



Keplerian: f_o = 300mm, f_e = 25mm

Galilean versus *Keplerian* Telescope



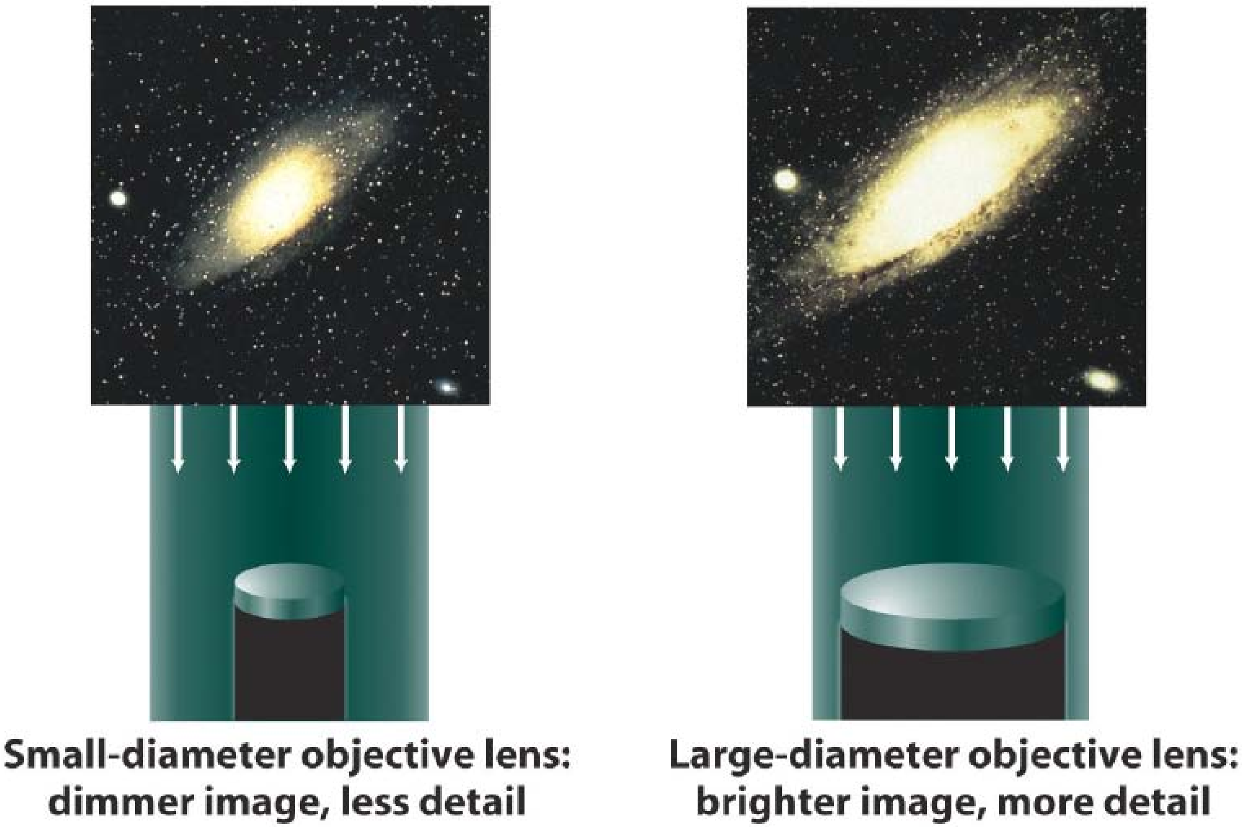
Above the field of object using a negative eyepiece -50 mm focal length and a 980mm focal length objective. The image is right side up and moves same way telescope moves. Even though the real field of view is smaller the observer can obtain a much larger virtual field of view by scanning their eye back and forth and up and down over the eye piece without moving the telescope. The observer automatically does this with time to get a larger field of view.

Above the field of view using a single lens positive eyepiece +50 mm focal length and a 980mm focal length objective. The image is upside down and moves opposite the direction of the movement of the telescope. At the higher powers requires a trained observer to manage the telescope.

http://www.scitechantiques.com/Galileo-Telescope-Anomalies-optics/

General Characteristics of Telescopes

Light-gathering-power: is directly proportional to the area of the objective lens/mirror, i.e., with the square of the lens/mirror diameter. It is important for seeing faint objects.



http://physics.gmu.edu/~hgeller/TeacherWorkshop/ch06a.pdf

Simple Telescopes

A typical 4" refractor

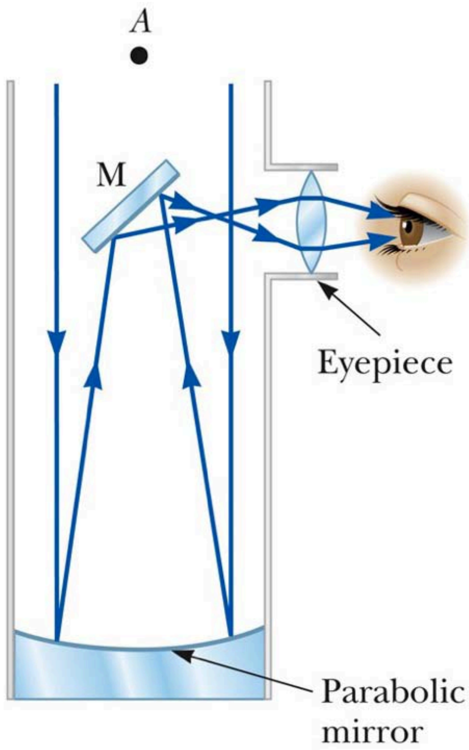
An 8" Newtonian Reflector

http://www.scopereviews.com/begin.html

Reflecting Telescope, Newtonian Focus

Isaac Newton's reflecting telescope (1668)

https://media.gettyimages.com/photos/isaac-newtons-reflecting-telescope-1668-isaac-newton-english-and-picture-id463903685



R. A. Serway and J. W. Jewett, "Physics for Scientists and Engineers", Thomson Brooks/Cole, 6th Ed. 2004

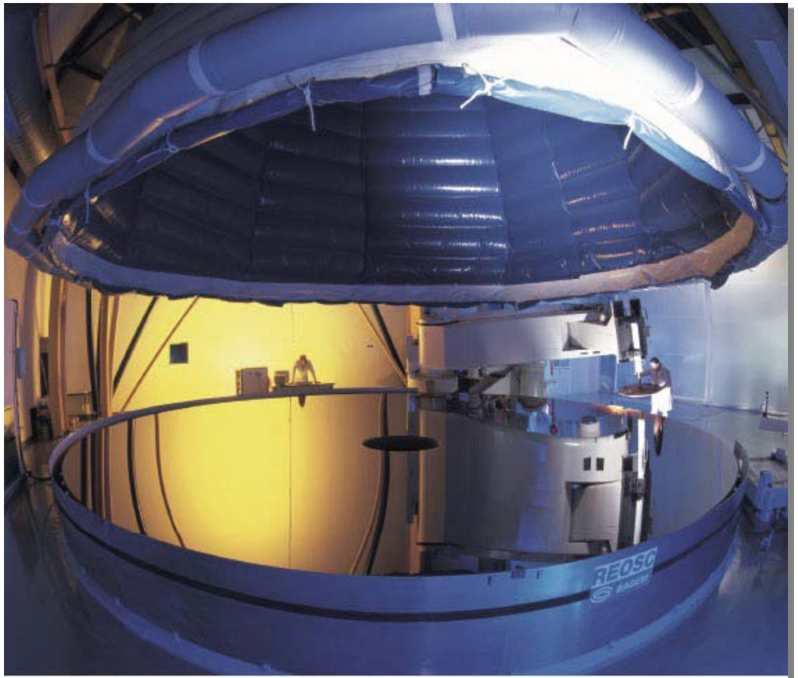
World's Largest Refractors: Yerkes 1 m

http://en.wikipedia.org/wiki/Alvan_Clark_%26_Sons

1897 picture

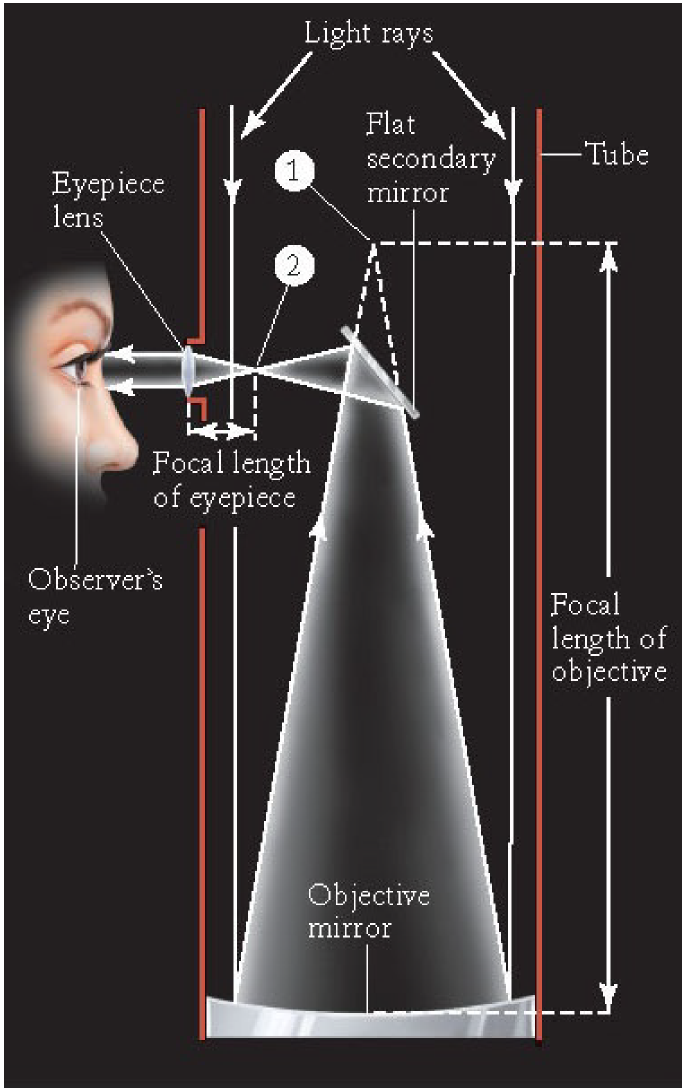
Reflecting Telescopes = Reflectors

A slab of glass is polished into a concave shape. The glass is then coated with a highly reflective substance (e.g., silver, aluminum).



(a) A large objective mirror

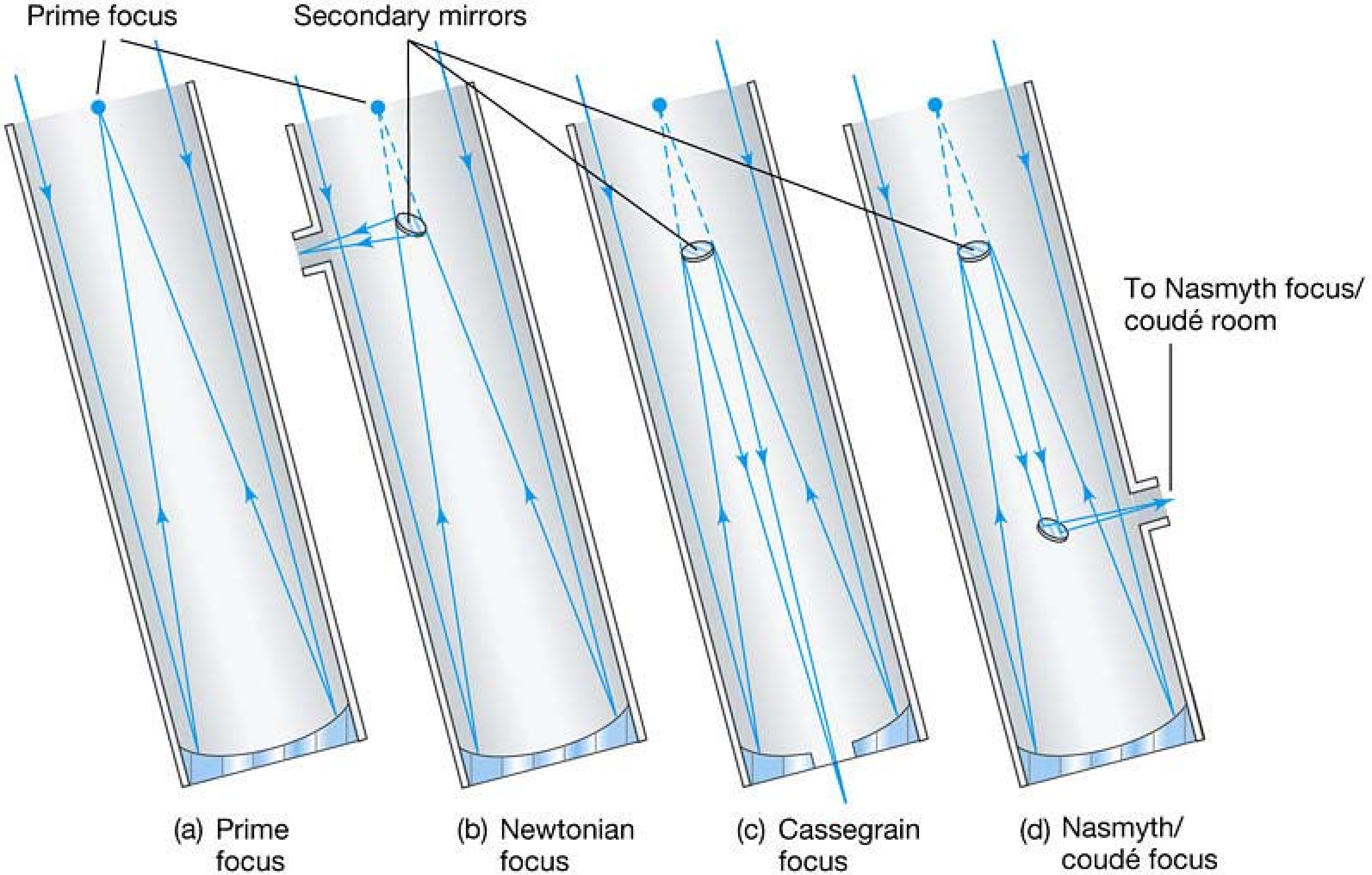
Reflecting Telescope Types



Newtonian reflector:

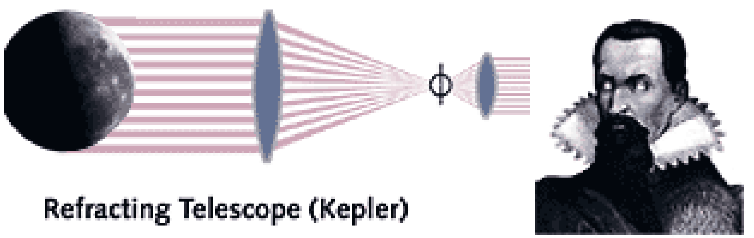
(small telescopes for amateur astronomers)

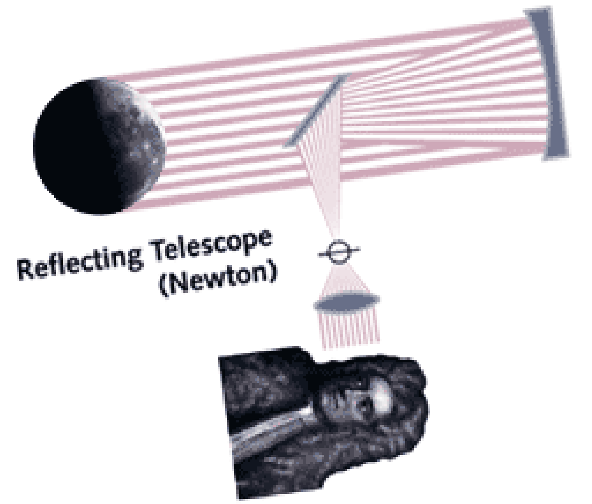
Reflecting Telescope Types

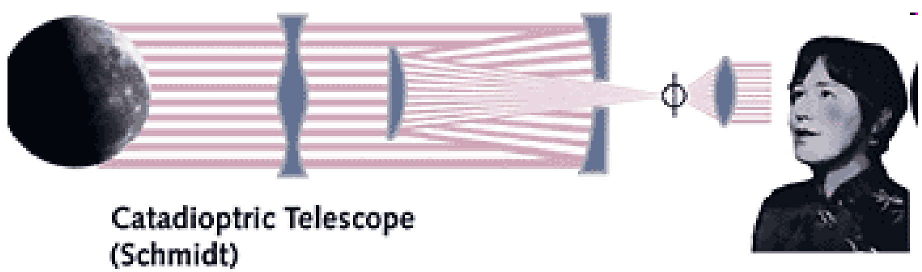


http://pages.uoregon.edu/jimbrau/BraulmNew/Chap05/FG05_06.jpg

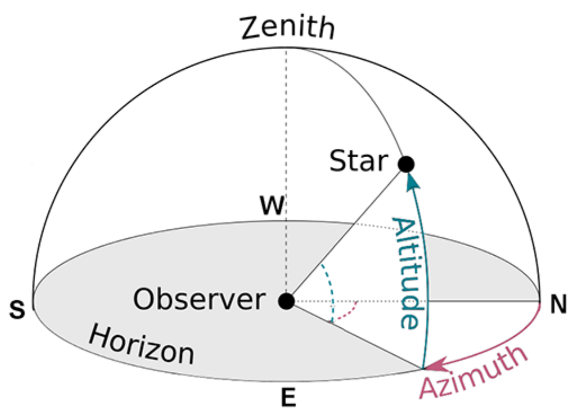
Main Telescope Types

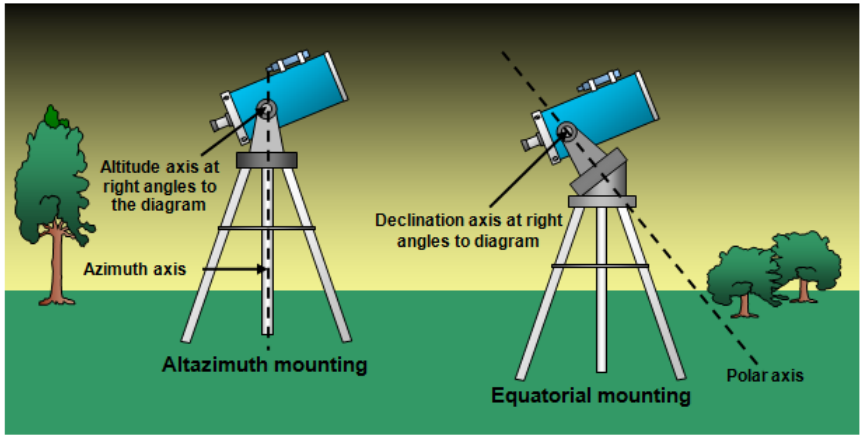






Main Telescope Mountings





Astronomical telescopes are usually mounted in one of two ways:

(a) **Altazimuth = altitude-azimuth** – one axis of the mounting vertical and the other horizontal

(b) **Equatorial** – one axis of the mounting in line with the axis of the Earth and the other at right angles to this

The two type of mounting have advantages and disadvantages:

(a) **Altazimuth = altitude-azimuth**

(i) advantages – a relatively cheap and simple type of mounting

(ii) disadvantages – The telescope must be moved about both the azimuth axis (left and right) as well as the altitude axis (up and down) to follow a star across the sky as the Earth rotates.

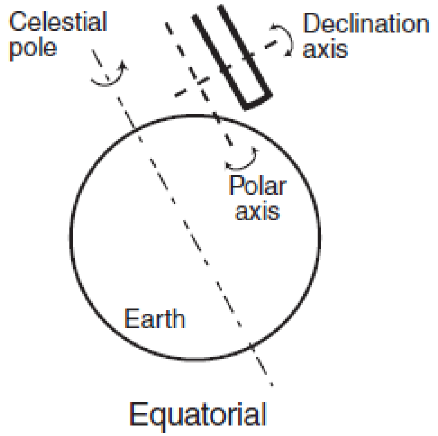
(b) **Equatorial**

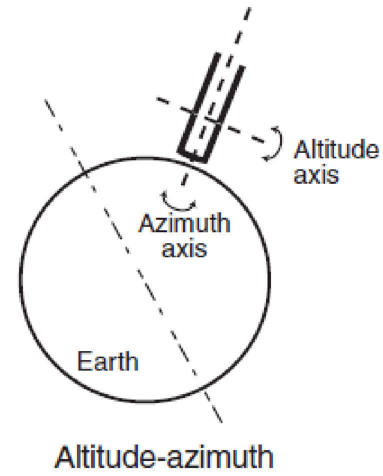
(i) advantages – because one axis (the polar axis) of the telescope is in line with the Earth's axis the telescope has only to move about this axis to follow a star across the sky. The declination of the telescope is fixed and then can remain unaltered if the telescope is set up properly.

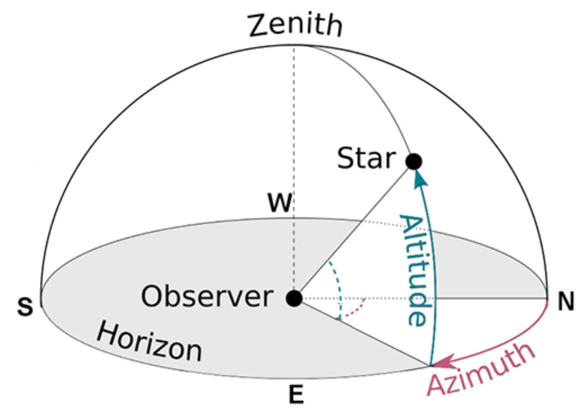
(ii) A more costly and sophisticated mounting but well worth it for the advantage in the ease with which it can follow a star

http://www.schoolphysics.co.uk/age14-16/Astronomy/text/Telescope_mountings/index.html

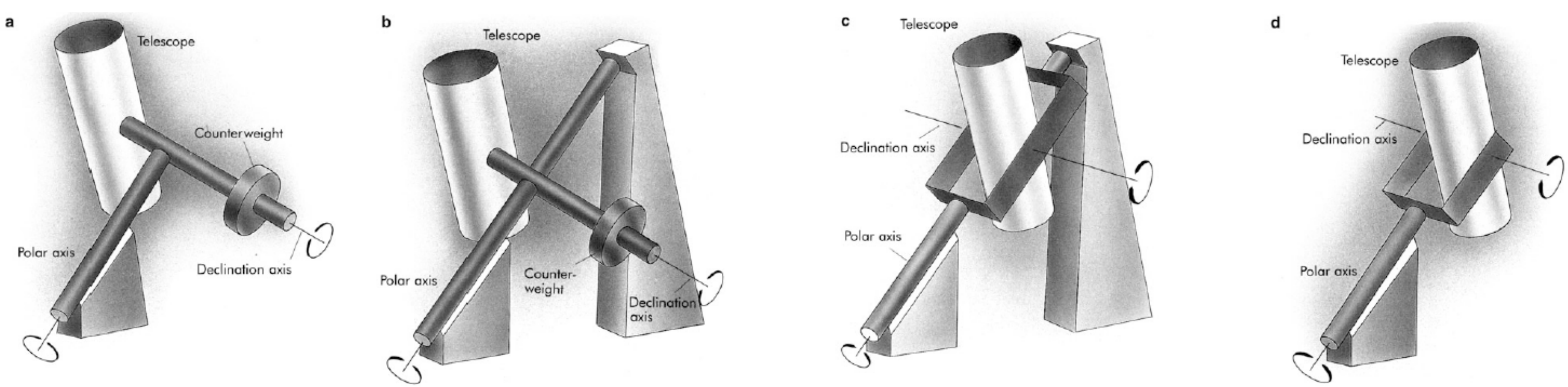
Main Telescope Mountings







P.Y. Bely, Ed. "The design and construction of large optical telescopes," Springer-Verlag 2003



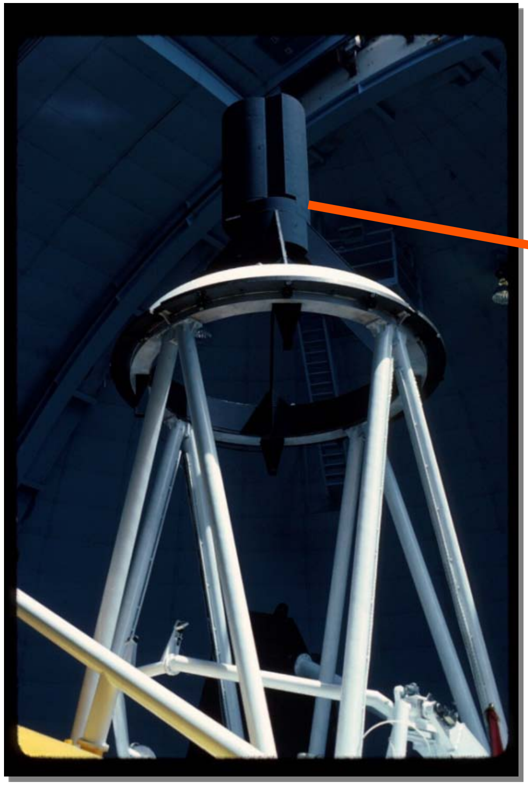
Variations on the equatorial mounting design: (a) German mounting, (b) modified English mounting, (c) English or yoke mounting, (d) fork mounting

C. R. Kitchin "Telescopes and techniques," 3rd ed., Springer-Verlag, 2013

Canada-France-Hawaii-Telescope 3.6 m - Hawaii, Mauna Kea

Cassegrain type

Prime Focus (used for big telescopes)



Inside the prime focus cage

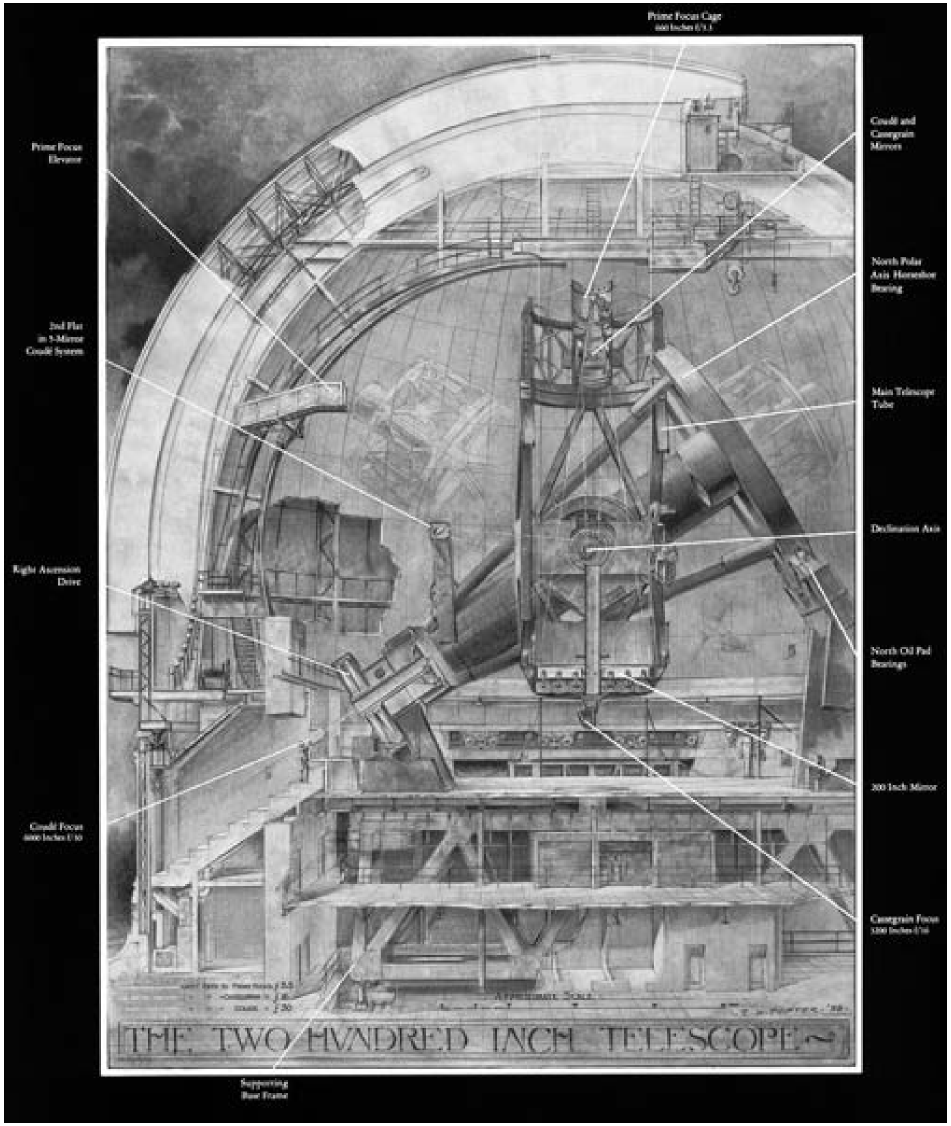
http://astro-canada.ca/_en/a2110.php

Hale 5m (200 inch) at Mt. Palomar

Cassegrain type

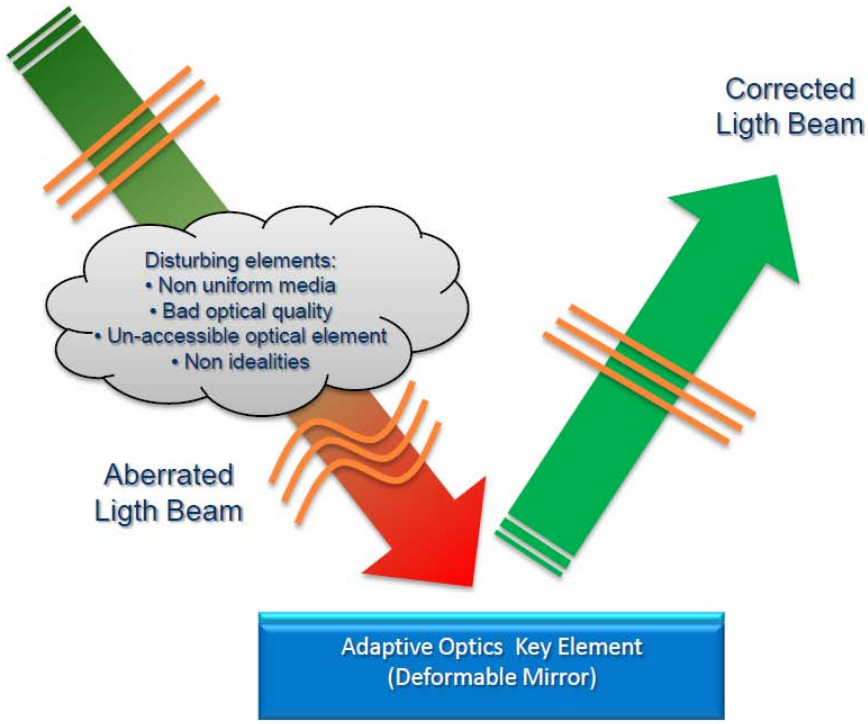
http://www.astro.caltech.edu/palomar/hale.html

Hale 5m (200 inch) at Mt. Palomar

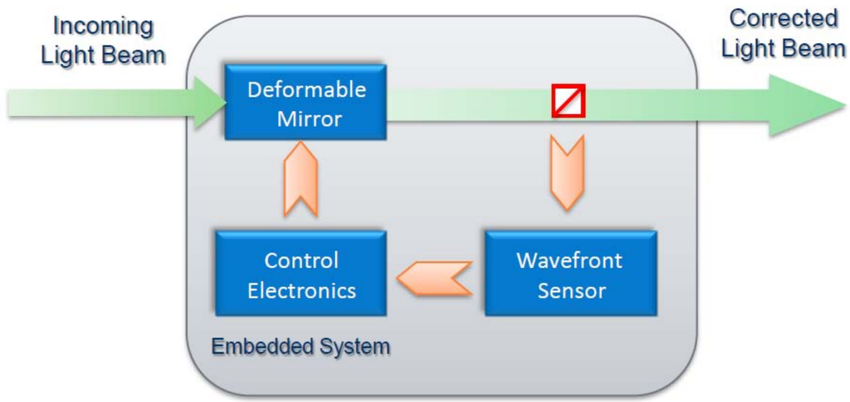


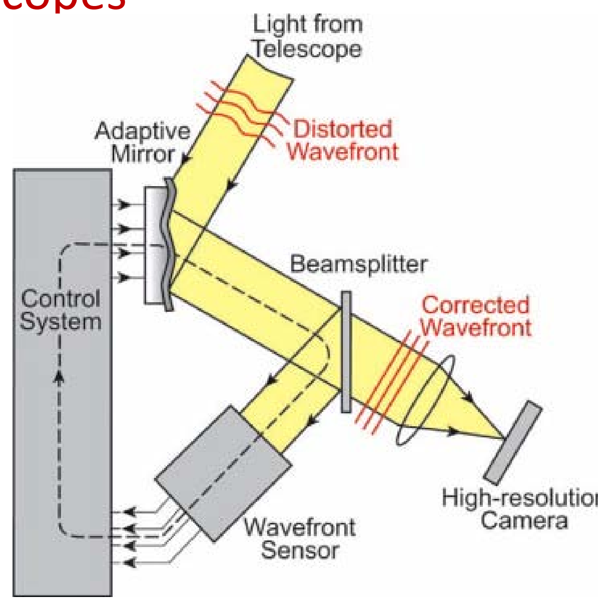
https://www.astro.caltech.edu/palomar/about/telescopes/hale.html

Adaptive Optics in Telescopes

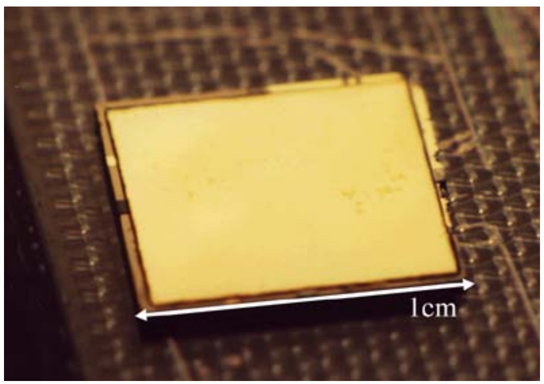


Adaptive Optics in Telescopes

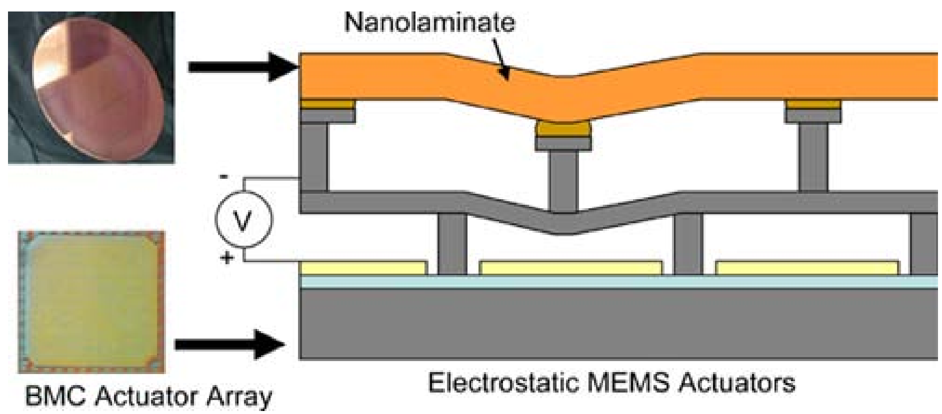




https://www.sciencedirect.com/topics/physics-and-astronomy/adaptive-optics



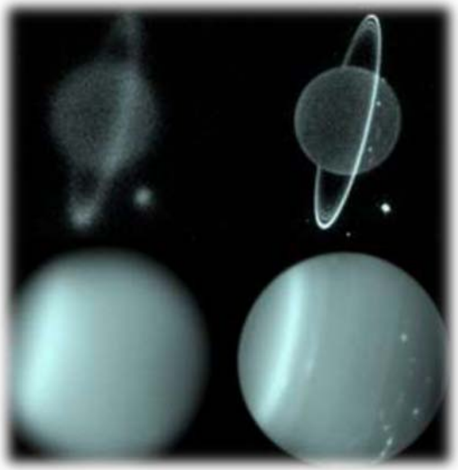
This large-scale nanolaminate deformable mirror has four pixels.



A deformable mirror is created by bonding a reflective nanolaminate foil onto a dense array of electrostatic MEMS actuators. BMC: Boston Micromachines Corp.

Adaptive Optics in Telescopes

ESO's Very Large Telescope (VLT)



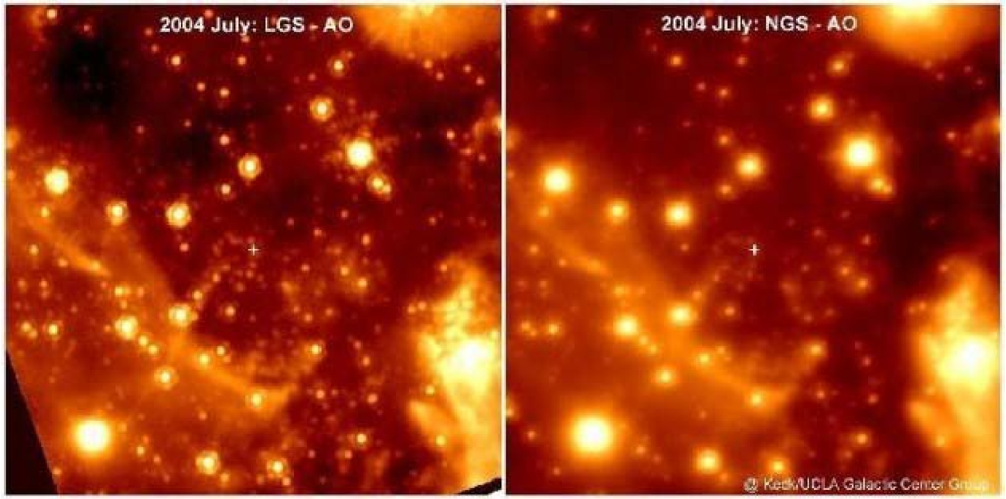
Uranus with the Keck Telescope:
Credits:Hammel, De Pater (Keck Obs.)

https://www.eso.org/public/images/eso1824b/

Keck Observatory

Galactic Center

With AO

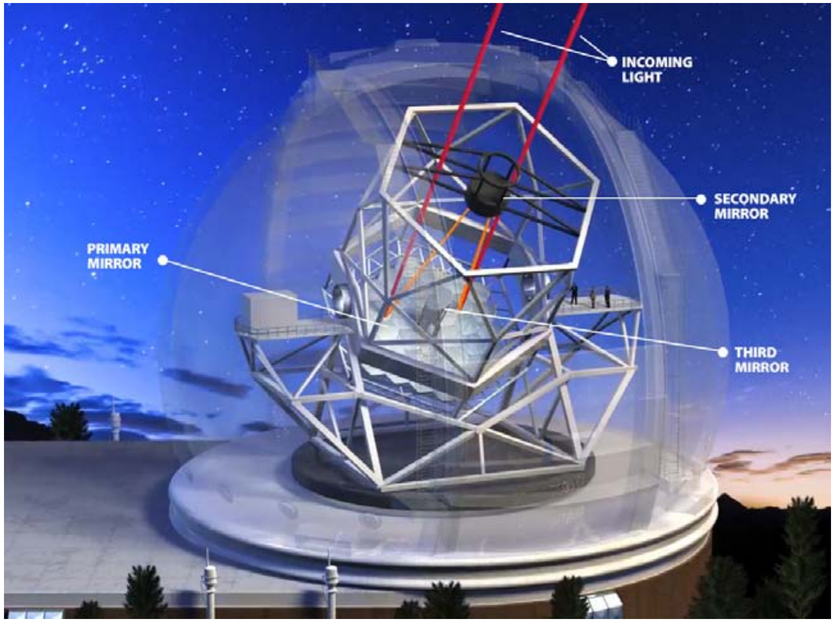


Without AO

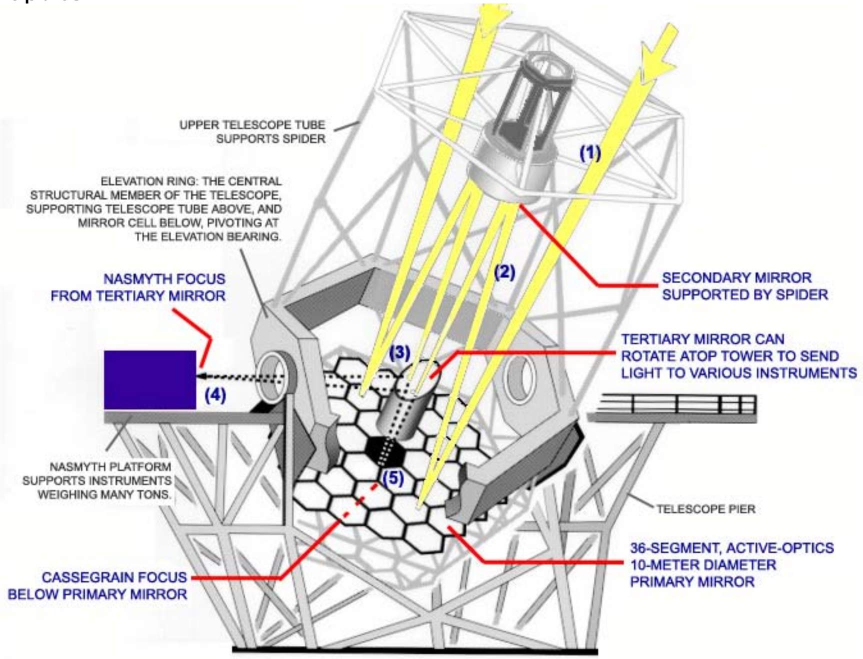
https://skyandtelescope.org/sky-and-telescope-magazine/adaptive-optics-before-and-after/

Keck Observatory 10m at Mt. Mauna Kea (Hawaii)

Left: The summit of Mauna Kea is considered one of the world's most important astronomical viewing sites. The twin Keck telescopes are among the largest optical/near-infrared instruments currently in use around the world.
Right: The night sky and Keck Observatory laser for adaptive optics.

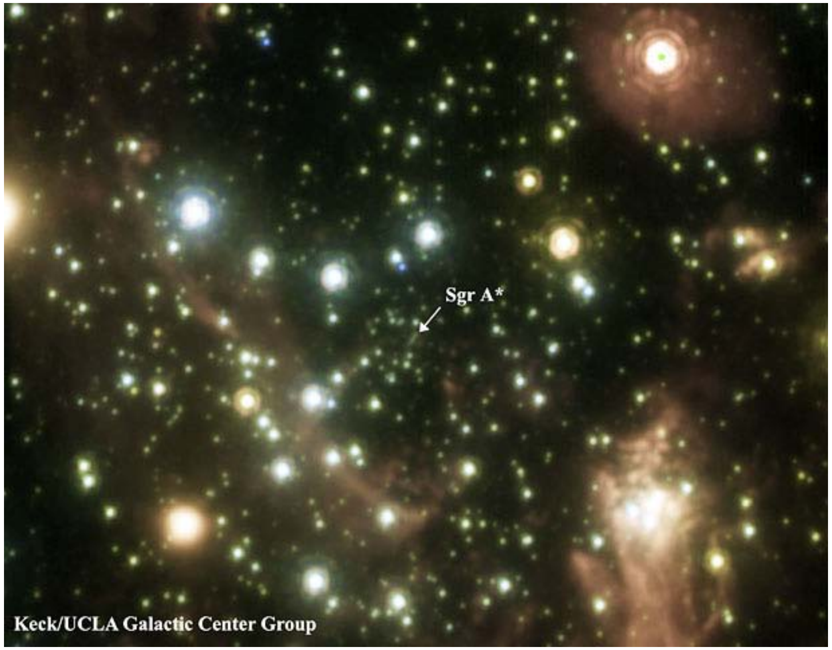


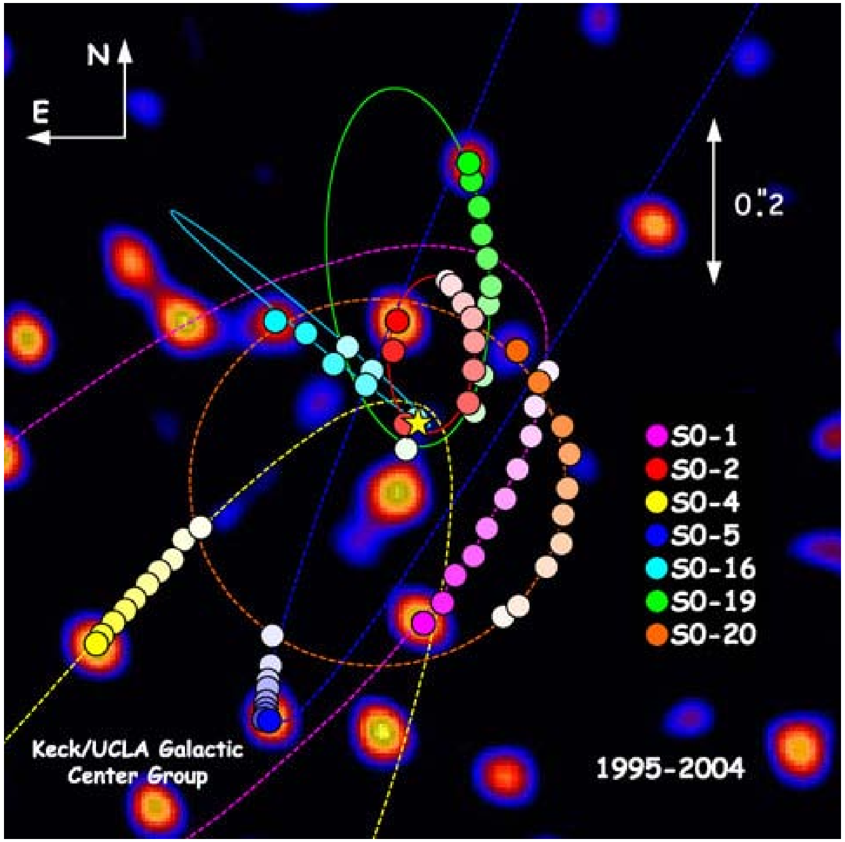
https://i.pinimg.com/originals/4d/b4/f1/4db4f1dec165188ad37f4429eaca5308.jpg



http://spacecraftkits.com/KFacts2.html

Keck Observatory 10m at Mt. Mauna Kea (Hawaii)





Few people know the center of the Milky Way—some 26,000 light-years from Earth—as intimately as Andrea Ghez, (Nobel Laureate Physics 2020) a professor of physics and astronomy at UCLA. Since the mid-1990s, Ghez has painstakingly measured the movement of stars at the galaxy's core, assembling evidence that it harbors a supermassive black hole with over three million times the mass of our sun.

Mt. Mauna Kea (Hawaii) Telescopes

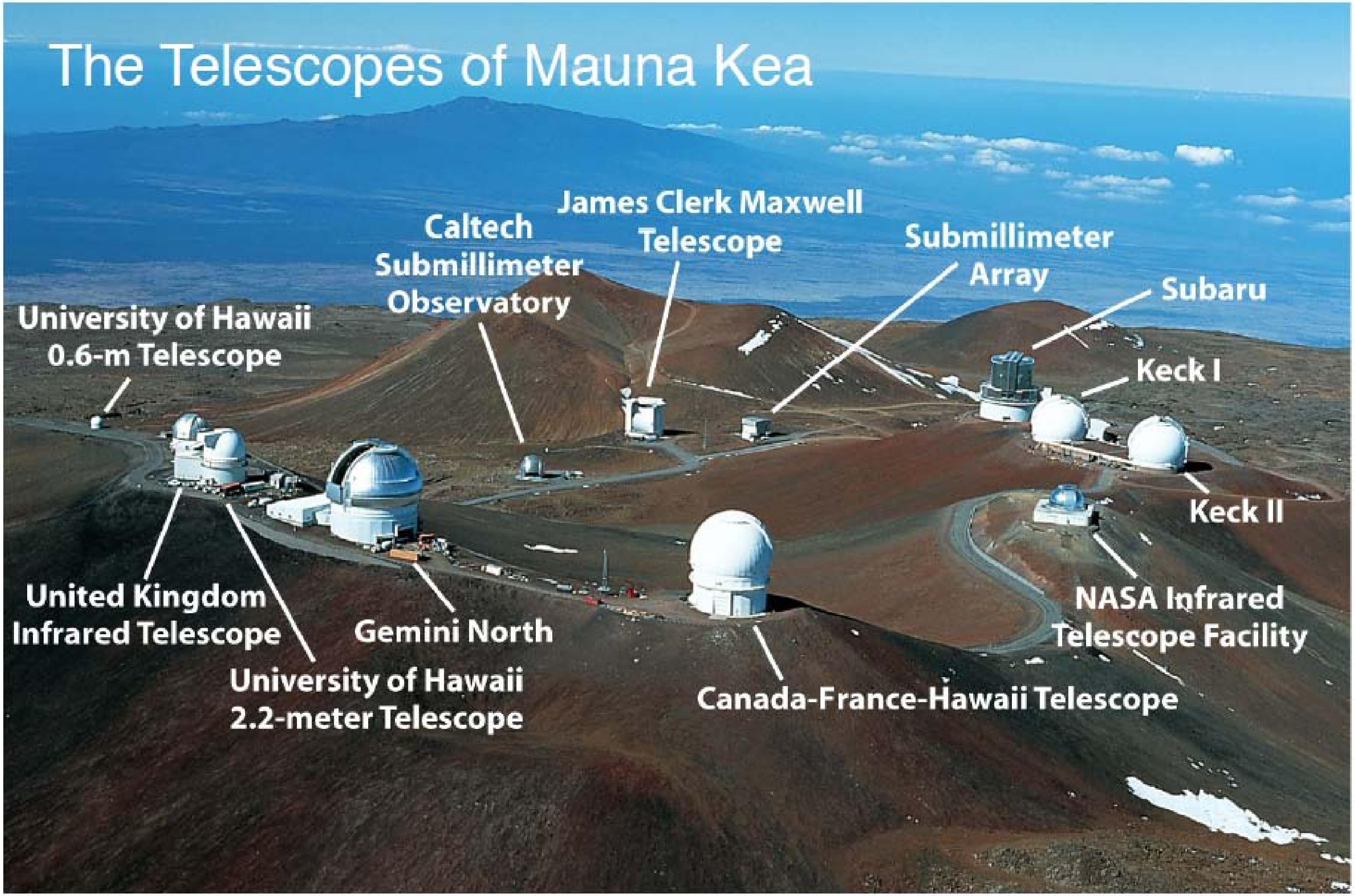


Figure 6-16
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