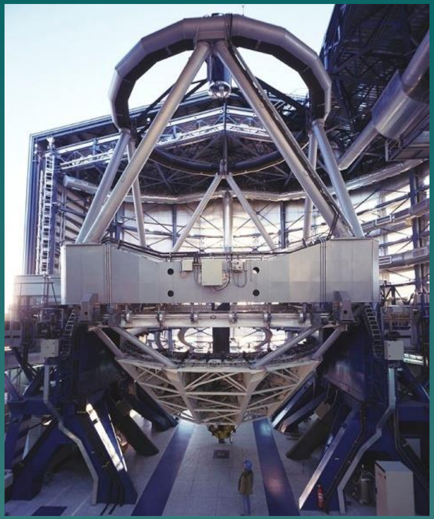
1600s



2000

Telescopes

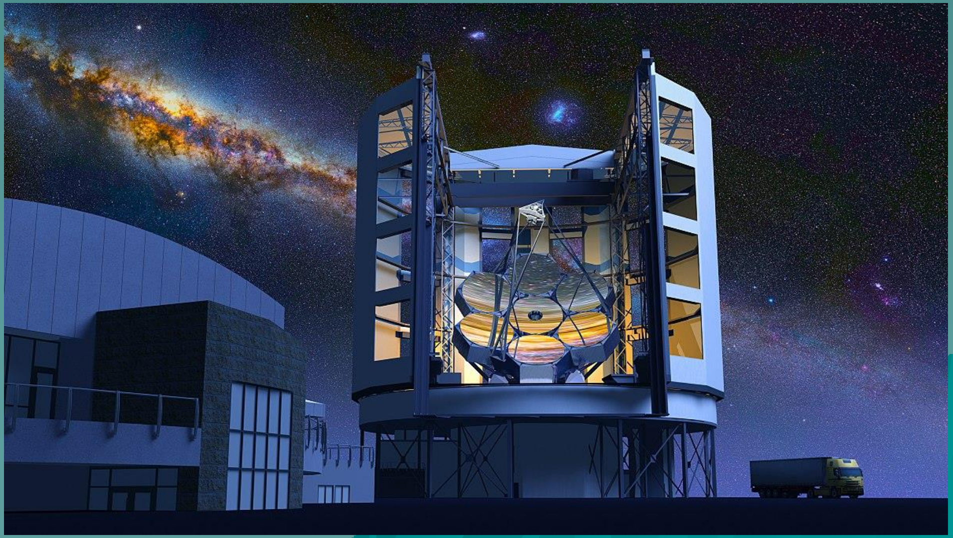
2020 – 30 meter telescope

General Properties

Telescopes - All Shapes and Sizes

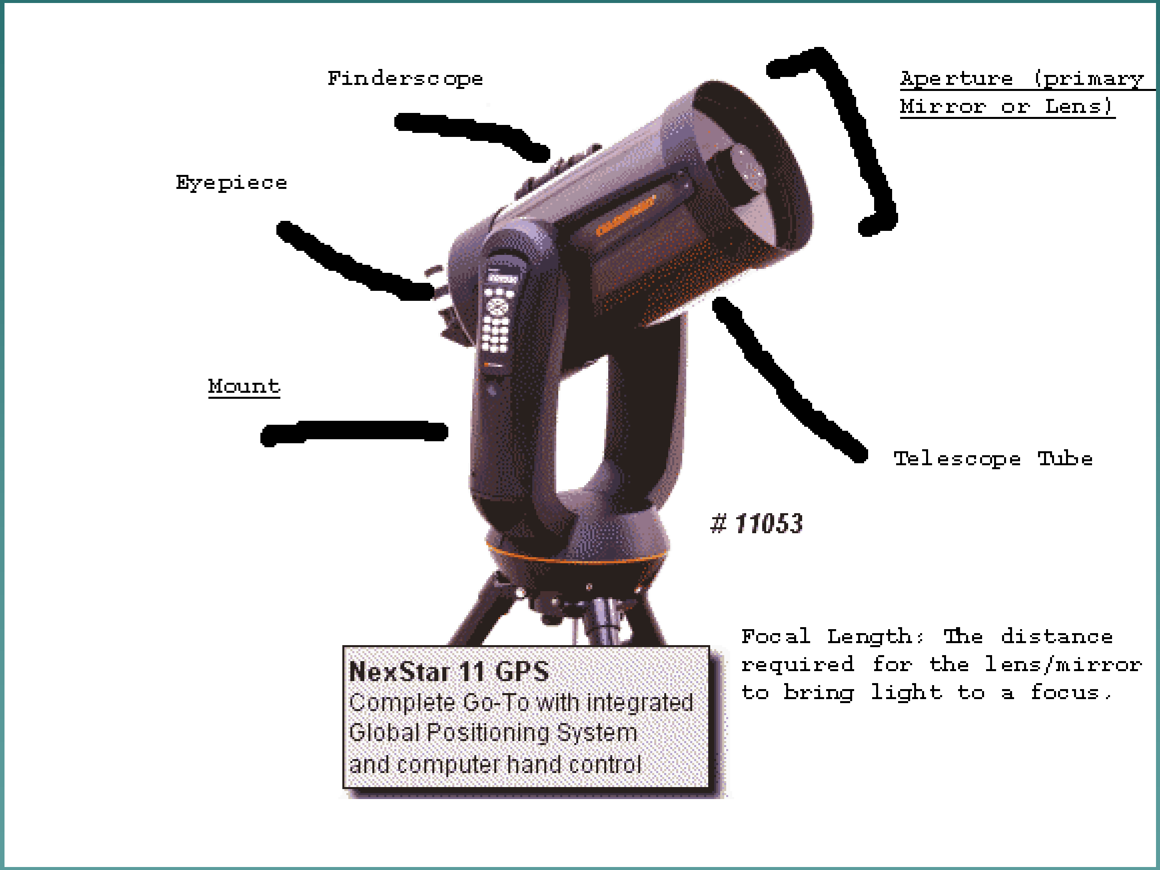
Personal Sizes

Current Scientific Observatory



Future

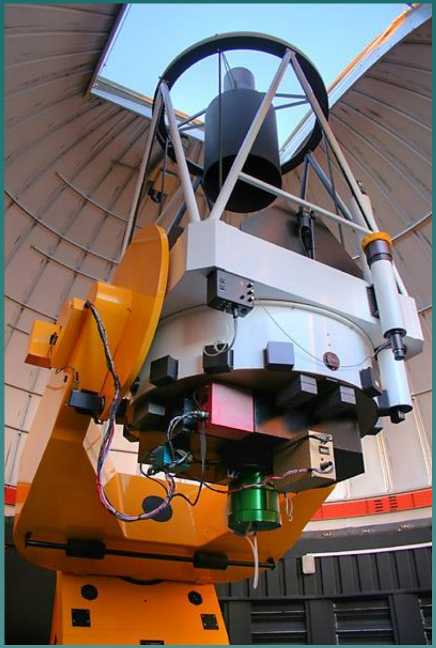
Basic Terminology



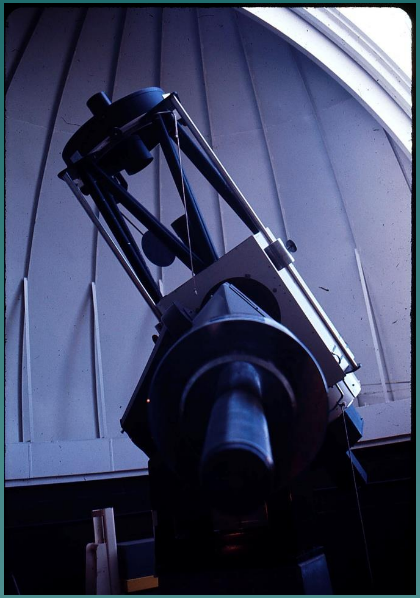
- Finderscope – small telescope mounted along larger one to assist in finding targets
- Aperture – diameter of mirror or lens
- Mount – support structure that holds telescope and allows for pointing and tracking stars
- Tube – open or closed varieties
- Eyepiece – optical assembly for visual viewing. Scientific telescopes normally do not have eyepieces.

Types of Telescope Mounts

Dobsonian
Alt-Azimuth



Fork mount



German Equatorial

Altitude-Azimuth mount (Alt-Az)

- Moves in altitude (up and down) and azimuth (left and right)
- Requires two motors to track
- Field of view rotates
- Has a blind spot at the zenith

Equatorial Mounts

- Aligned with earth's rotational axis.
- German Equitorial - Long arm with counterweights
- Moves east-west, north-south
- Requires one motor to track

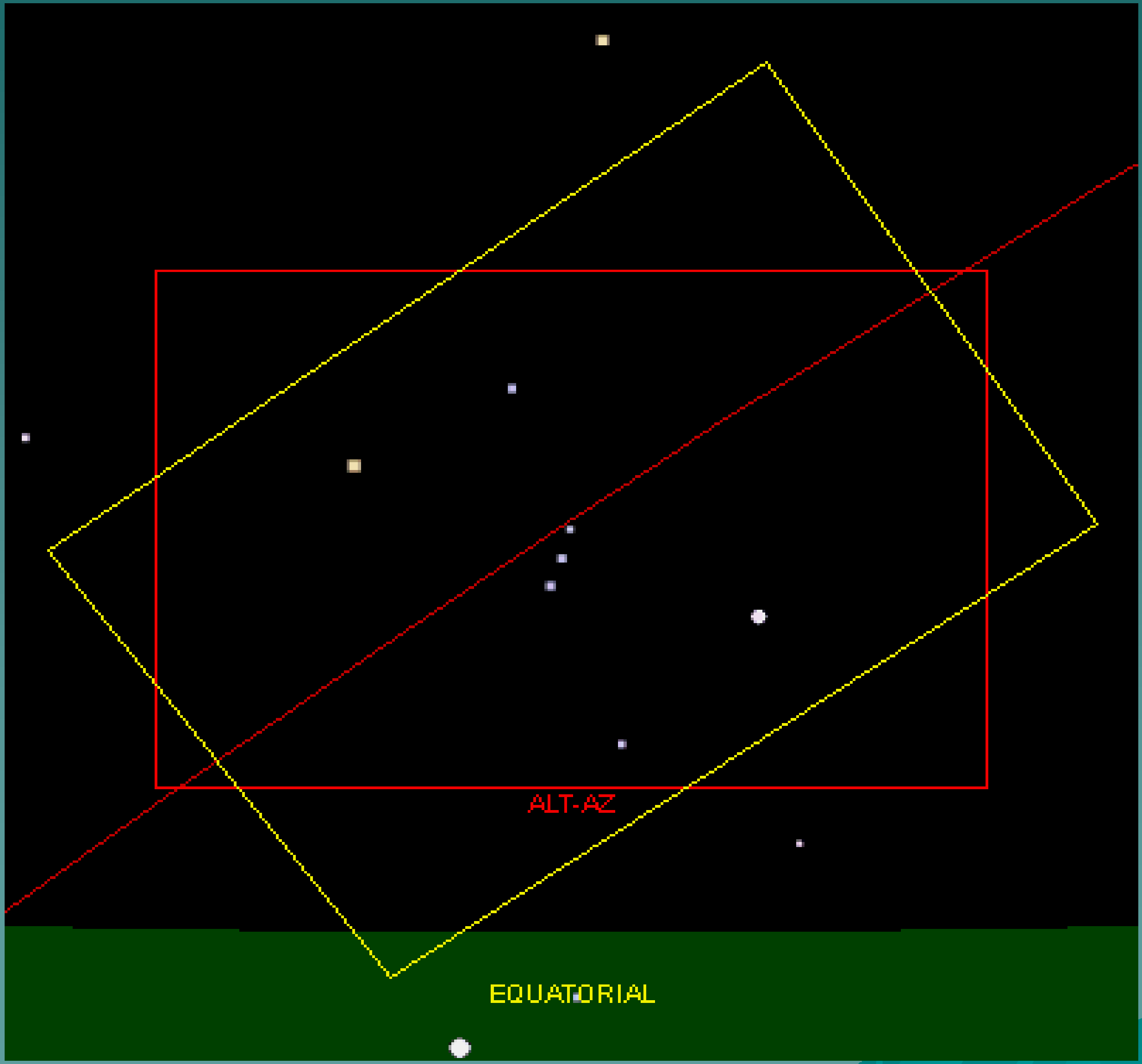
Field Rotation with Alt/Az telescopes

Orion rising in the East
19:15 hrs

Orion due South at midnight
00:00 hrs

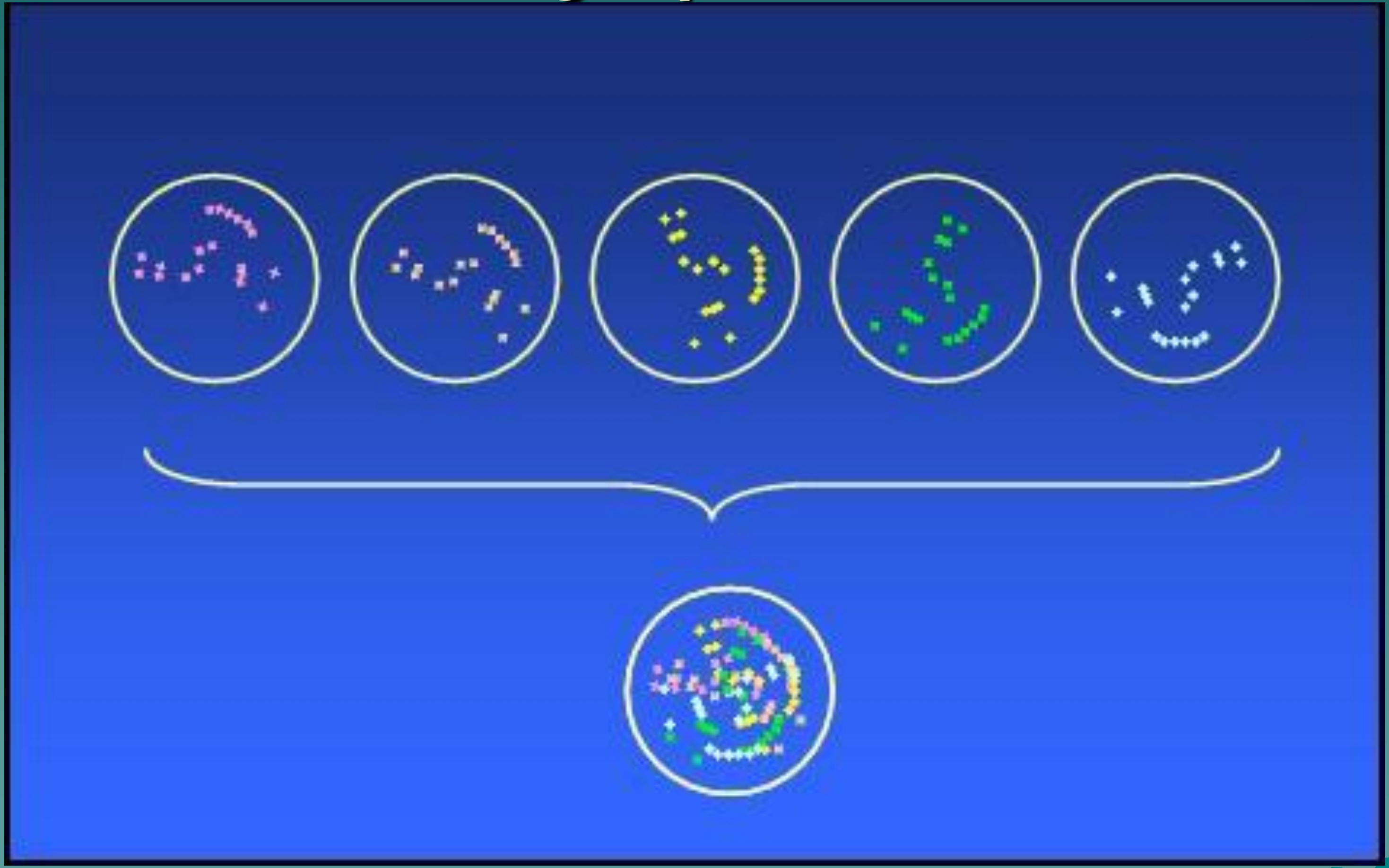
Orion setting in the West
04:36 hrs

Field Rotation over 24 Hours

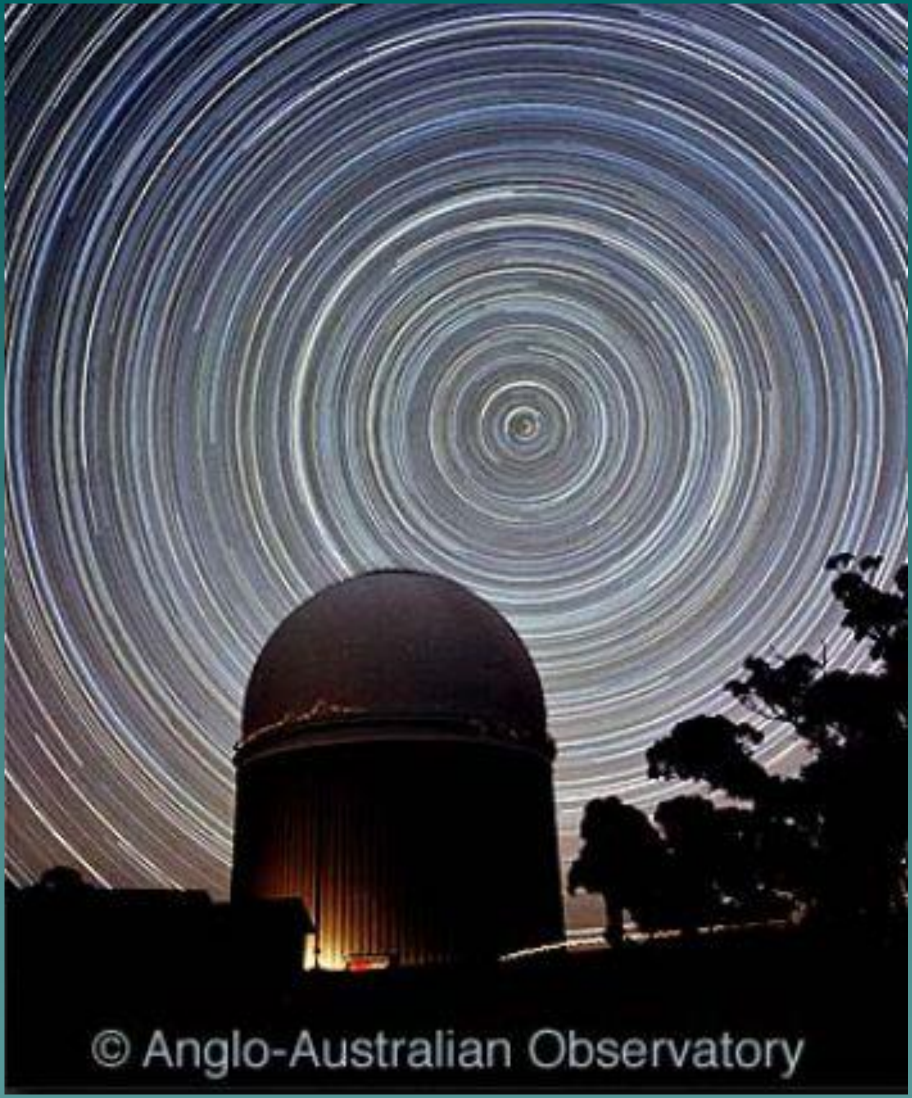


- Observer's latitude
- Right ascension and declination of object
- Earth's sidereal motion

Field Rotation – Looking in an Eyepiece

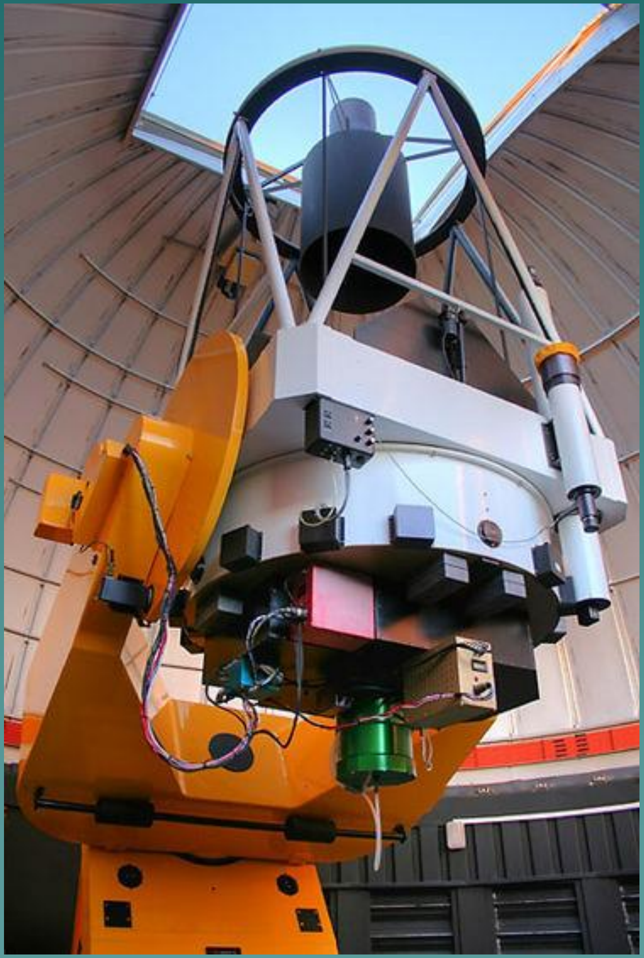


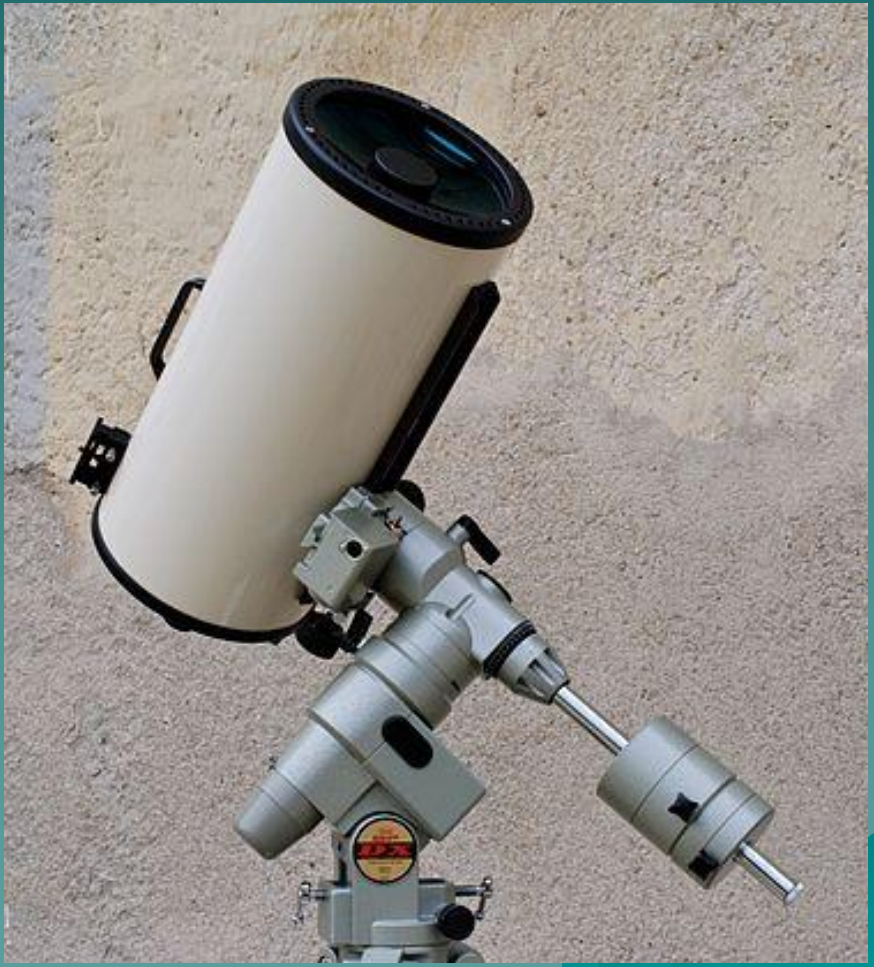
The star will be centered, but surrounding stars will rotate.



Effects of Earth's rotation

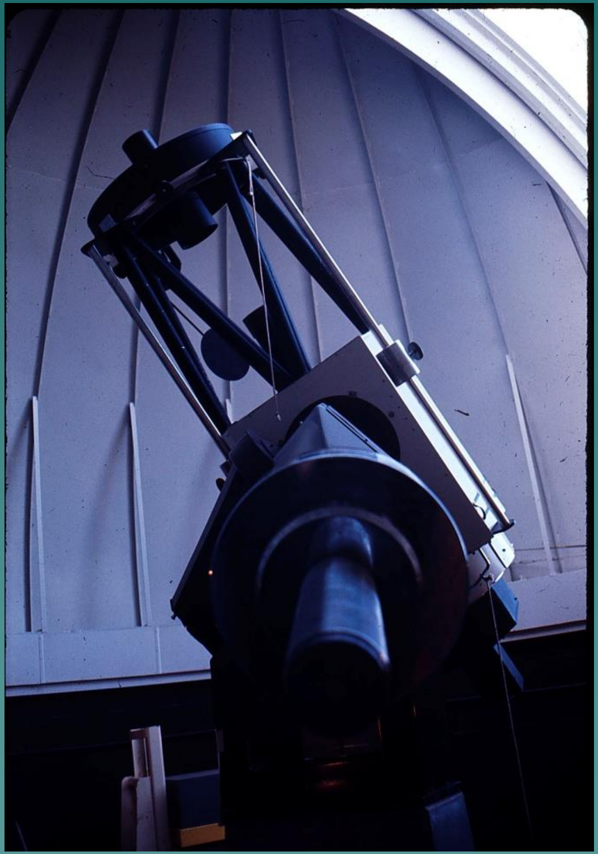
Equatorial Telescope Mounts





Telescope Tubes

Closed tube – generally bad because air is trapped inside



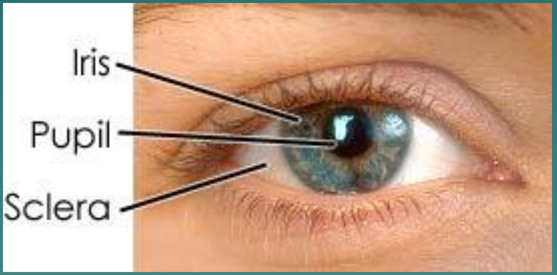
Open tube – allows air flow. Important consideration for science telescopes is that they be the same temperature as their surroundings to reduce air motion.

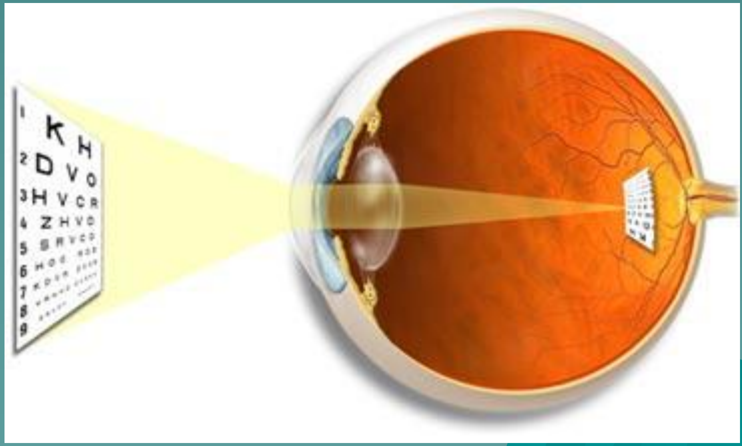
Telescope Magic Numbers

- Aperture - Diameter of lens or mirror
- Focal length – distance from mirror/lens to focal point
- Focal ratio = focal length/diameter
  - Low focal ratio = short focal length, wide field of view (for example f/3)
  - Long focal ratio = long focal length, small field of view (for example f/16)

The Job of a telescope

- To collect light!
  - Your eye is actually a small telescope
  - Light collecting power is controlled by the iris which varies from 2mm (daytime) to 8mm(0.4 inches) (nighttime)
  - Focus can also be changed w/o knob
  - This 8mm telescope reveals several thousand stars from a dark site!
- Increase angular resolution





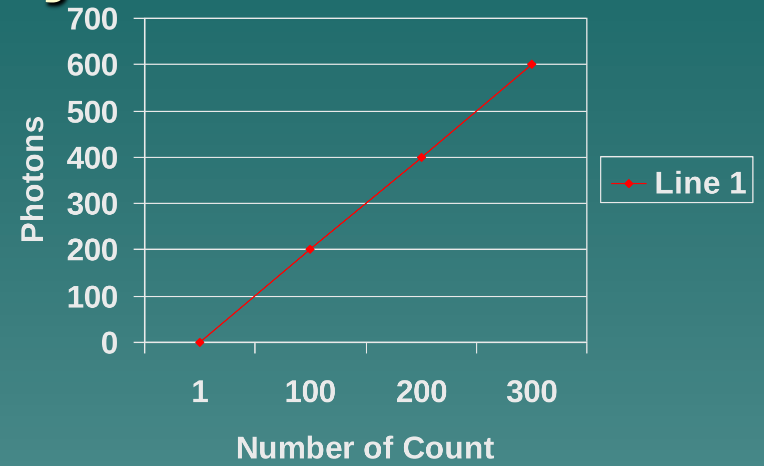
Key Property of all Telescopes

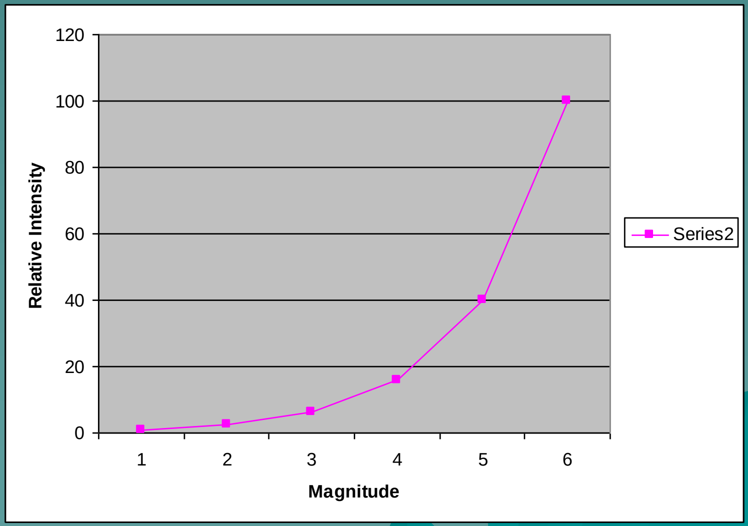
- Light gathering power
  - This is dependent on the area of the telescope lens/mirror.
  - Area = πr^2
- How much light is collected?
  - Comparing telescopes
    - $(\text{diameter telescope } 1)^2/(\text{diameter telescope } 2)^2$
  - Telescope with 2 times the diameter of another telescope has 4 times as much area
  - Telescope 10 times as large collects 100 times more light

How faint can different telescopes detect objects?

Astronomers classify brightness in terms of "magnitudes"

- It is not a linear system
- Relative system
  - Vega is designated magnitude = 0
- $m_1 - m_2 = -2.5 \log(f_1/f_2)$

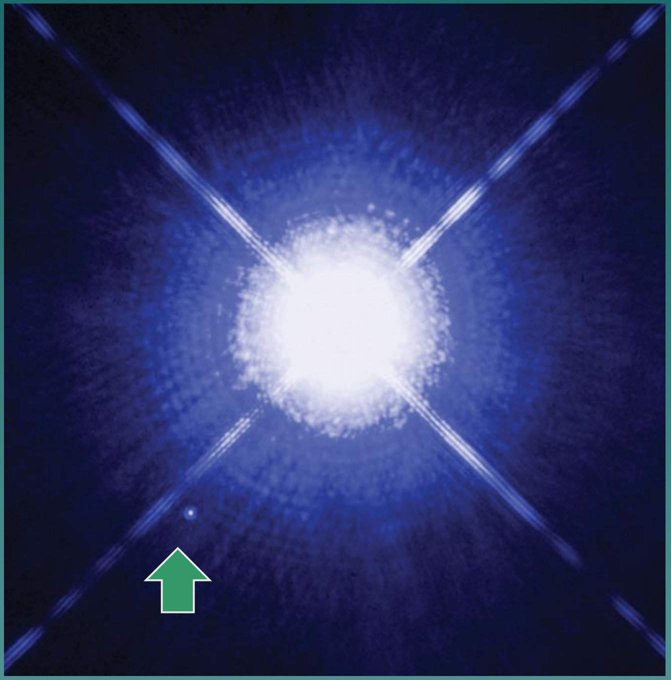




The Magnitude System

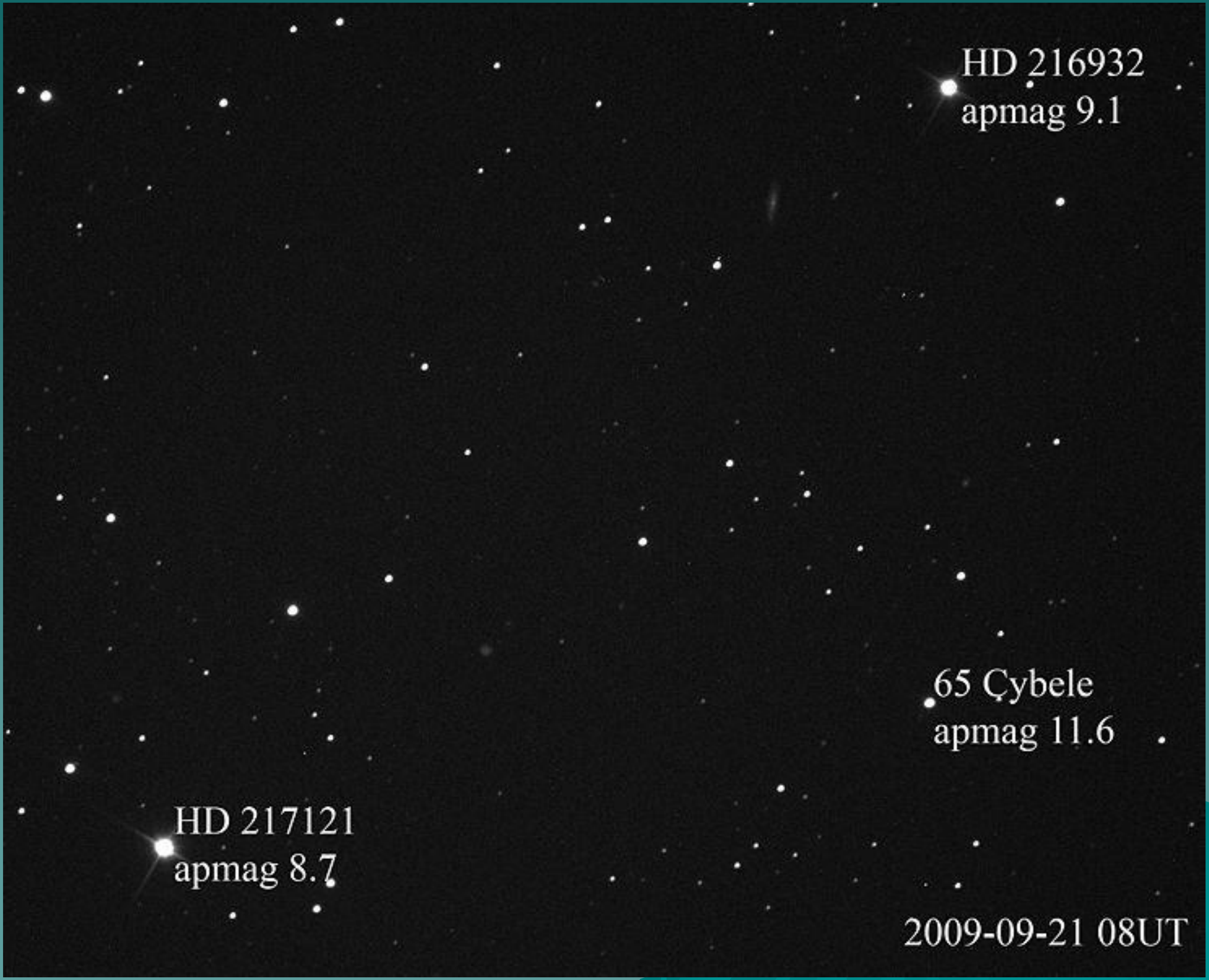
- History of Magnitudes
  - Earliest astronomical catalog created by Hipparcos in late 2nd century BC.
  - Divided visible stars into 6 classes by brightness
    - Brightest star seen by eye – 1st magnitude
    - Faintest star seen by eye– 6th magnitude – limit of human perception.
  - Telescope (1600s) revealed fainter stars – early system inadequate.
    - William Herschel started the revisions
    - Finished by Norman Pogson in 1856
    - Logarithmic scale in terms of intensity
    - Originally Polaris asssigned magnitude of 2, but Polaris is variable!
  - Modern fiddling- Switched to Vega → magitude =0
    - $m_1 - m_2 = -2.5 \log(f_1/f_2)$ f = flux or energy (units usually ergs cm^2 sec^{-1})
    - The magnitude scale is relative – always compare one star with another.
    - Bright objects have negative magnitudes → Sirius is m=-1.4
    - A fifth magnitude star is 2.5 times brighter than a 6th magnitude star
    - A change of 5 magnitudes = 100 times brightness
    - Magnitudes are wavelength dependent!
- There are two types of magnitudes:
  - Apparent magnitude – usually denoted with m
    - The brightness a star seems to be to us here on earth
  - Absolute magnitude – usually denoted with M
    - brightness that a star would have if it were placed 10 parsecs away.
- Magnitudes can be used to determine distance
  - $M - m = -2.5\log (D/10)^2$
  - Distance modulus
    - $M=m + 5 - 5 \log(D)$
  - If you can determine M (by theoretical means??) you can solve for D
  - Sun's absolute magnitude is 4.7
  - Sun's apparent magnitude is -26
  - Faintest star detected now is ~24TH magnitude
  - Sirius is the brightest star in our sky m=-1.46

Sirius



Sirius B

Sirius m = -1.46
Sirius B m=8.84


HD 216932
apmag 9.1
65 Cybele
apmag 11.6
HD 217121
apmag 8.7
2009-09-21 08UT

Area of Telescope Lens/Mirror and Limiting Magnitudes

- What does this mean in terms of magnitudes for visual telescopes?
- Area= πr^2
- Let's say the eye has a diameter of 0.5 inches
- Your eye can see stars to 6th magnitude
  - 2 inch telescope has 16 times the light gathering power as much as eye
    - Can see stars down to about 10th magnitude
  - 4 inch telescope has 64 times as much as your eye
    - Can see stars down to about 12th magnitude
  - 10 inch telescope has 400 times as much area
    - Can see stars down to about 14th magnitude
  - 8 meter (8.7 yrds) telescope can see stars 2,000,000 fainter than your eye can see
    - Can see stars down to about 21st magnitude

- Limiting magnitude

  $M_{limit} = 16.8 + 5\log(D*10)$

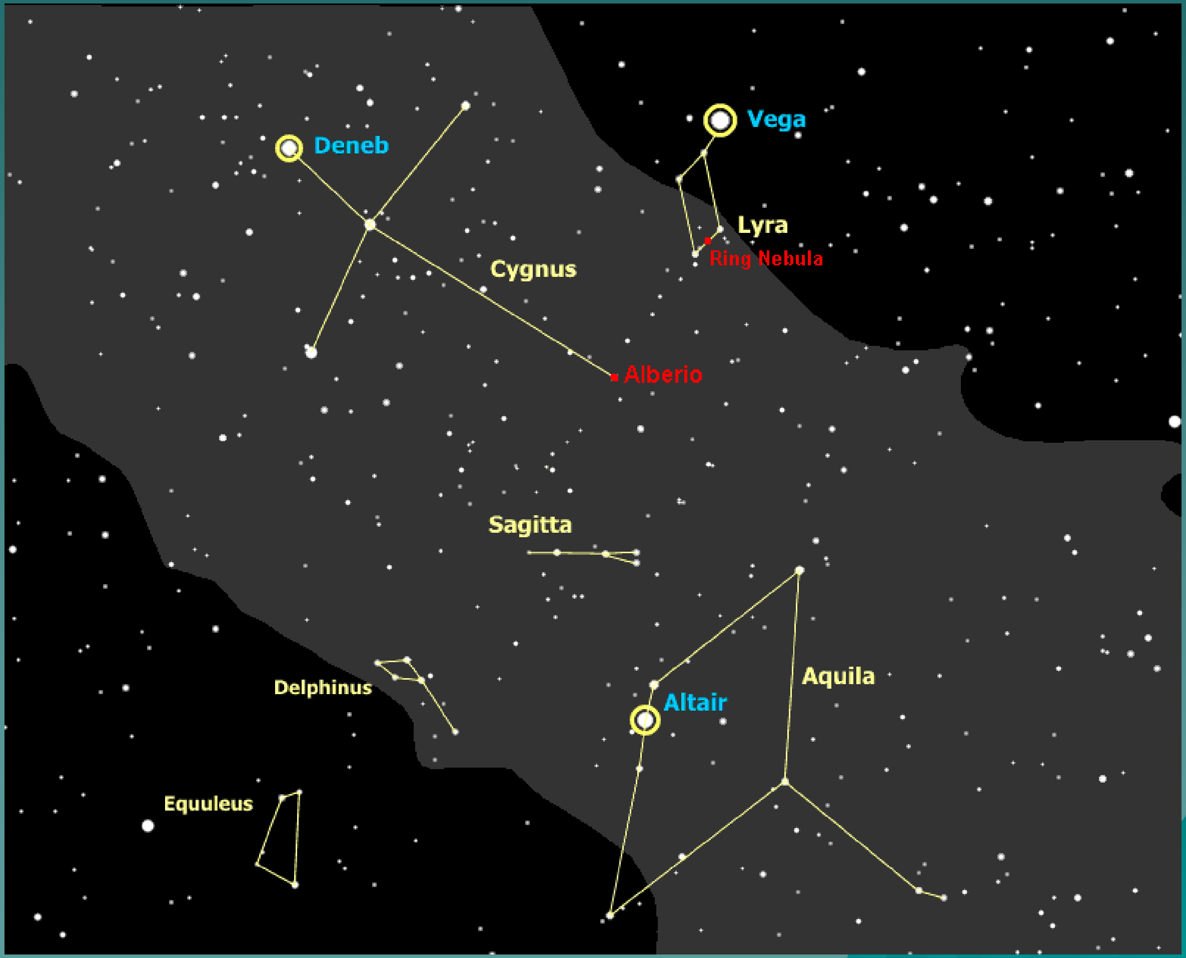
  D is telescope mirror diameter in meters

  Using a CCD instead of the eye will improve about 5 stellar magnitudes

Vega, Altair, Deneb

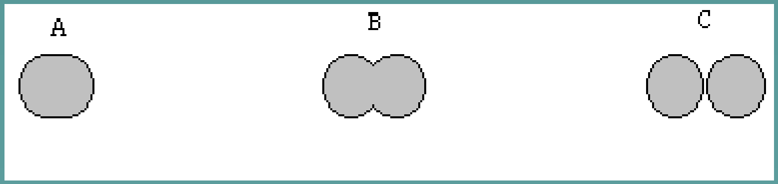
- Vega mag=0
- Distance= 25 lyrs
- Altair mag=0.77
- Distance = 17 lyrs
- Deneb mag=1.25
- Distance = 1500 lyrs

- Which star is putting out the most energy?

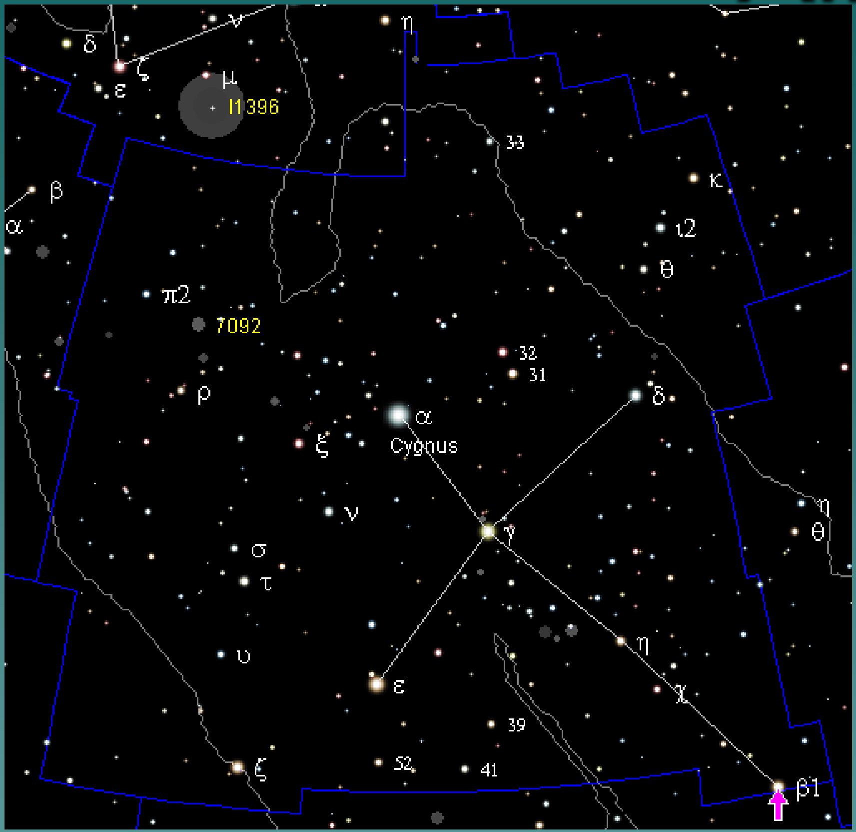


Resolution

- Resolution
  - The ability to separate the images of stars or other objects that are close together.
  - Diffraction - the bending/spreading of waves when they strike a barrier or pass through an aperture. Wavelength dependent.
  - $\Delta\Theta = (1.22)\lambda/D$ – for a circular aperture
    - 24 inch telescope – 0.2 arc seconds
    - Hubble Space telescope can resolve 0.05 seconds of arc
- To improve resolution, increase size of telescope



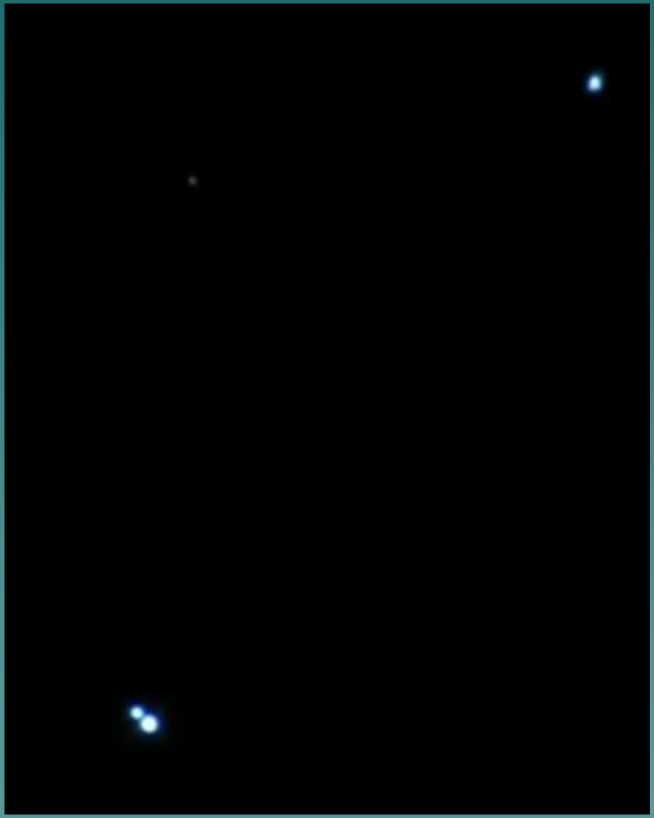
Alberio



Alberio to your eye

Alberio in small scope
380 light years away
Separated by 35 arcsec
Orbital period is at least 100000 years
Mag 3.1, 5.1

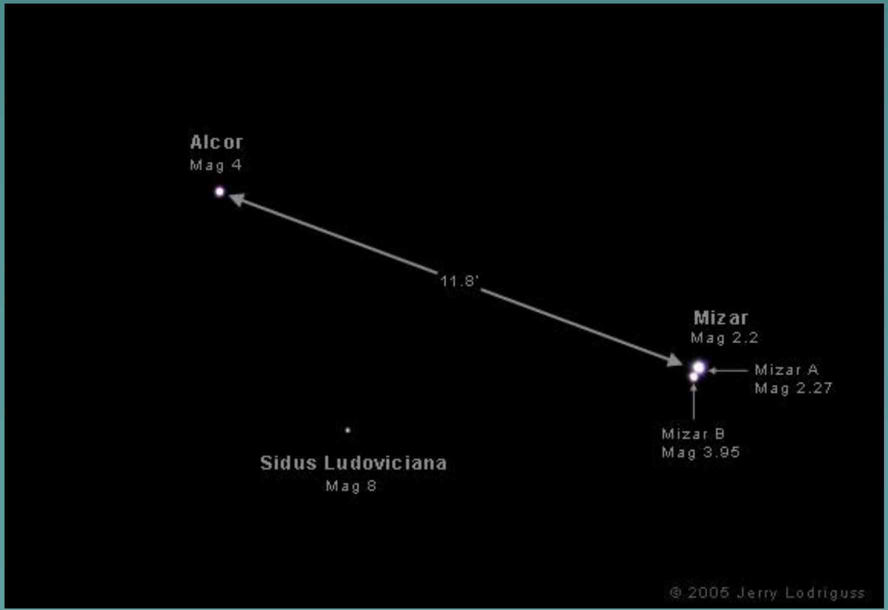
Ursa Major (Big Dipper) Test



Best estimate: Mizar and Alcor 1.1 lyr apart
83 lyrs away
Mizar mag=2.23, Alcor=3.99
Mizar A and B separated by 14 arcsec, corresponds to 340 AU

More about Resolution

- Telescopes are designed to form images as nearly perfect as the laws of physics allow.
- To form a sharp image, light waves from a distance source must meet at the focus of the telescope in phase. Need a good surface.
- Nothing is perfect, light waves arrive in almost perfect phase in a region surrounding the geometric point of focus
- Light appears as small spot called the "Airy disk".
- Best you can hope for is 84% total light inside disk, 16% in fringes.
- The pattern of light generated by a point source passing through a telescope is called the point spread function (PSF)



Airy = 2.44 λ/A (radians)

$Airy_{fwhm}$=1.02 λ/A (radians)

Diameter sets limits on what telescope can see

Matching Telescope Resolution and CCD Pixel Size

- Point Spread Function defines the smallest details to be seen in a telescope image.
- Sample size (pixel size) must be small enough to define the smallest details
- Nyquist theorem – sampling frequency must be at least two times the highest frequency present in the original signal
- Applied to image sampling, size of a pixel must be no larger than half the diameter of the PSF (diffraction disk).
- Images sampled with larger pixels are undersampled, some of details will be lost.
- Images samples with much more than two pixels across the core of the diffraction disk are oversampled
- $2d_{pixel}=d_{psf}$
- $F_{min}=Ad_{pixel}/0.51\lambda$

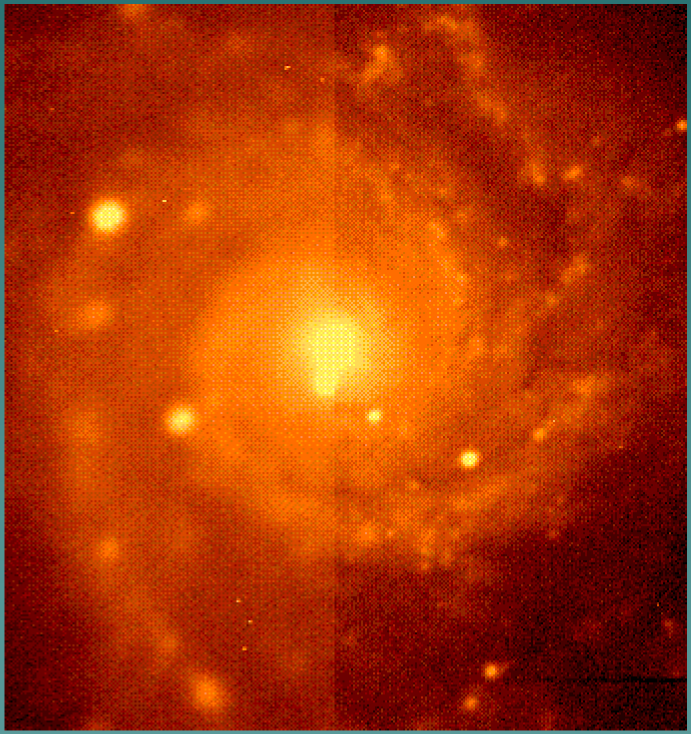
Magnification

- Frequently hailed by commercial telescope makers but not really important.
- Depends on the eyepiece used
- Magnification = (focal length of primary lens or mirror)/(focal length of eyepiece)
- Galileo's telescope magnified about 3 times
- Can make any telescope reach large magnifications, but do you get a useful image?
  - Magnification increases the apparent size of an image
  - Does not increase the total number of photons collected
- Minimum magnification = 4 x primary diameter (in inches)
- Maximum magnification = 50 x primary diameter (in inches)

Field of View

- Sky that can be seen through a telescope at any one time
- One degree is about twice the diameter of the moon.
- Field of view depends on the design of the optics and the detector.
- In general, telescopes with small focal ratios (f/3) have large fields of view. Large focal ratios mean small fields of view.
- Finder scopes have larger fields of view than the "main" telescope.
- Increasing magnification via eyepieces decreases field of view.
- The Alta CCD chip is 13.3x13.3 mm in size, and when attached to the 24 inch telescope at prime focus, gives a field of view of about half a degree (size of the moon).
- Finder scopes have larger field of view

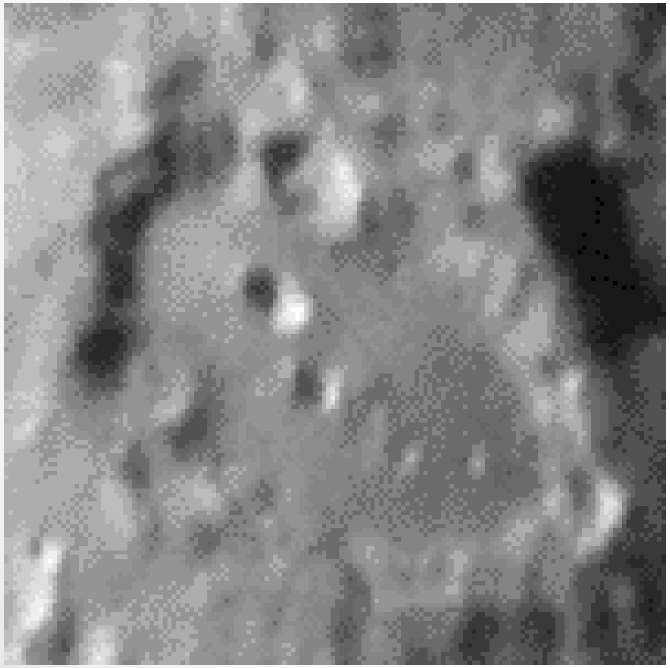
“Seeing”

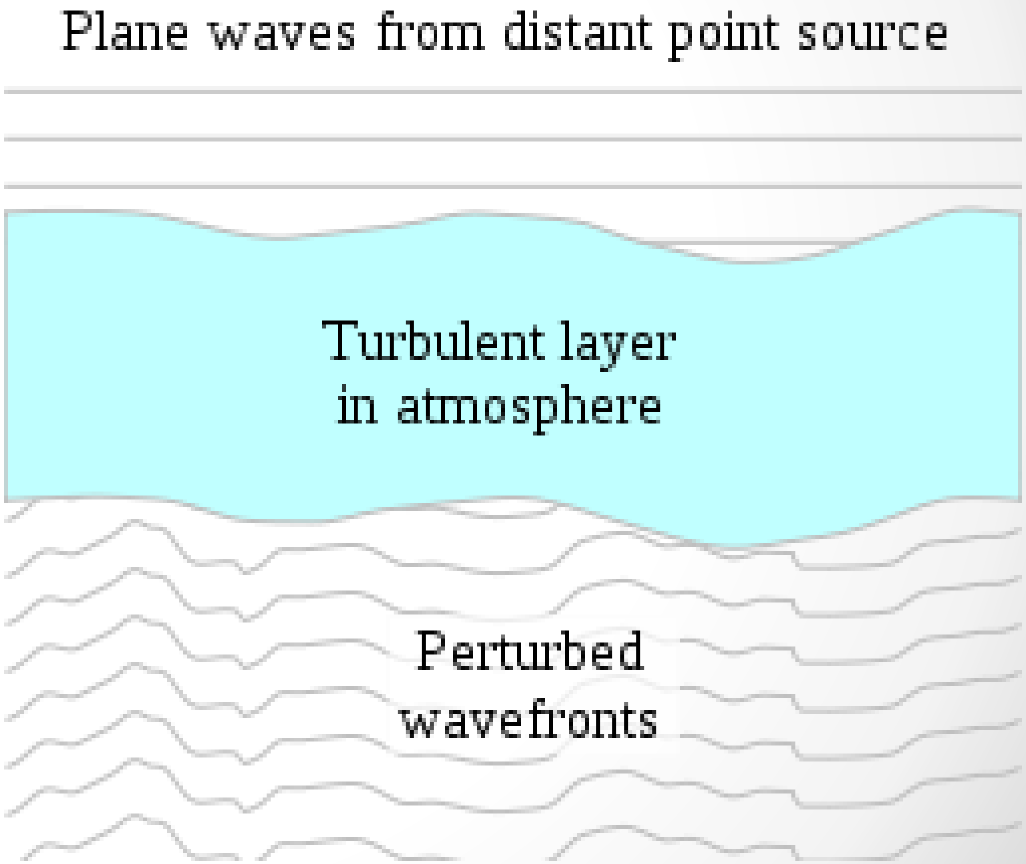


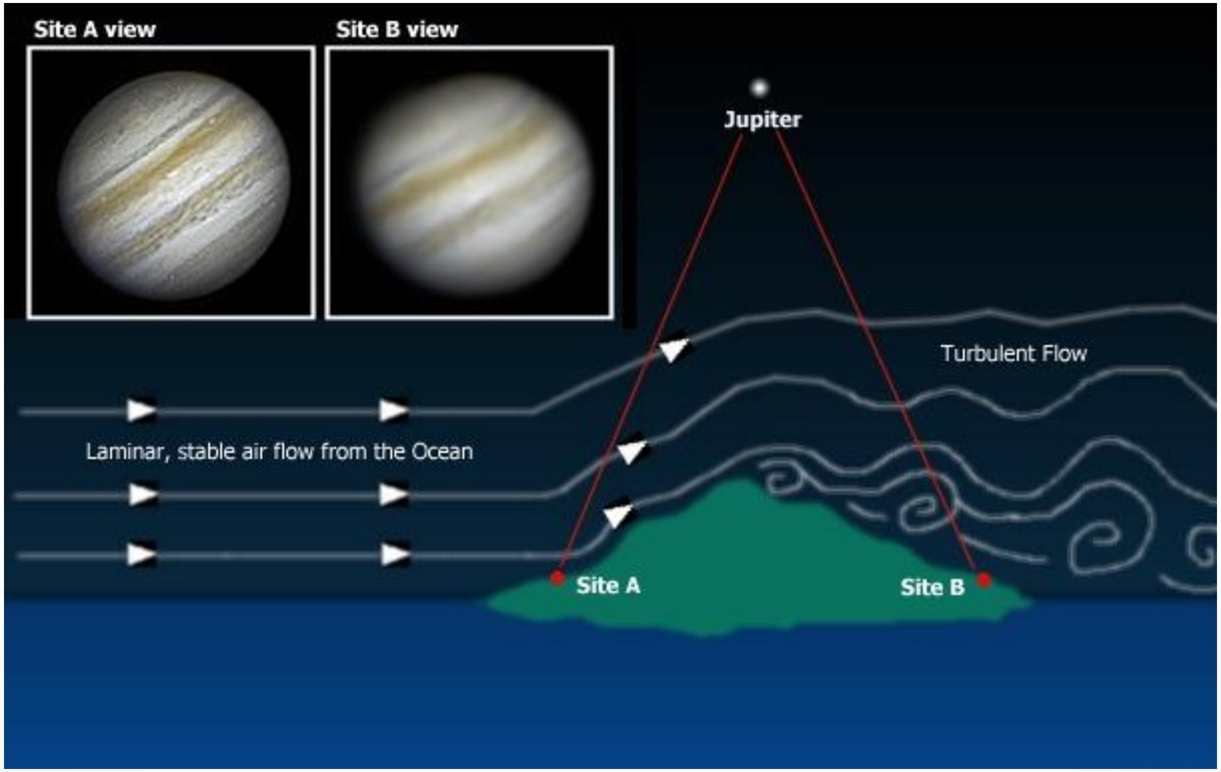
- Seeing is the quality of observing conditions induced by the earth’s atmosphere and the telescope’s environment
- Low altitude effects
  - Areas of different density radiate energy at different rates
  - Causes local convective currents.
  - Daily heating of the ground
  - Buildings
  - Telescope itself, if it is warmer than its environment.
- Mid- Altitude – topography. It is not a good idea to build downwind of anything big
- High Altitude – jet stream, etc.

Seeing and the Atmosphere

- Turbulence – short timescale variatons in atmosphere.






Site A view
Site B view
Jupiter
Turbulent Flow
Laminar, stable air flow from the Ocean
Site A
Site B

Where to put an observatory?

- Places with stable atmospheres, like mountaintops high enough to be over any temperature inversion layers. Islands surrounded by oceans, where the prevailing winds have crossed many miles of ocean (laminar flow off the ocean).
- Also a major factor is unvarying weather patterns, dominated by high pressure systems. Areas outside these large high-pressure systems have more variable weather, and hence a more variable state of atmospheric stability.
- Dry environment

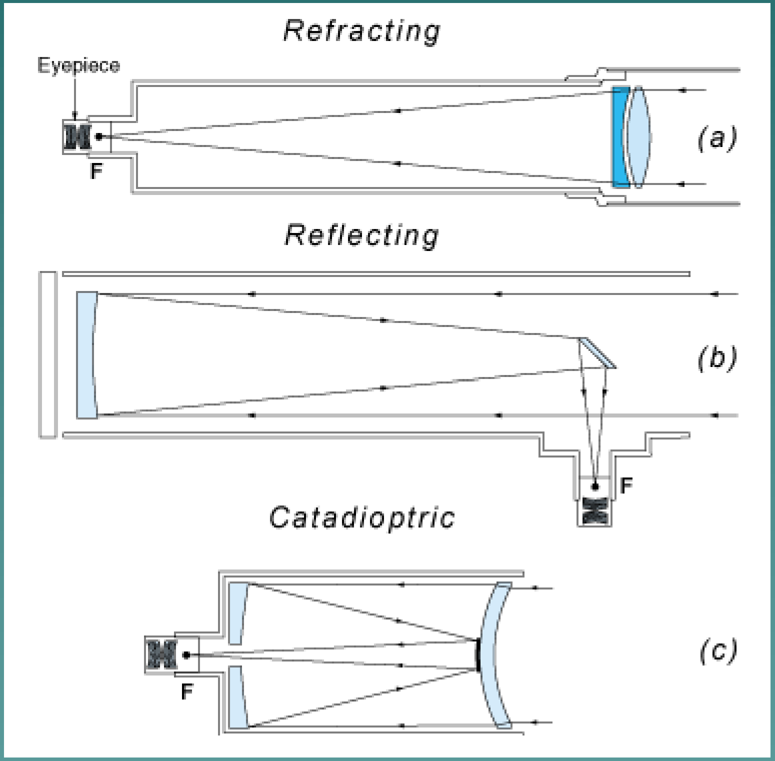
Review

- Light gathering power → area of lens/mirror.
  - magnitudes
- Resolution→ ability to separate close objects
- Actual resolution of a telescope is limited by "seeing"
- "Seeing" is the apparent size of a point source like a star
- "Seeing" is dictated by the atmospheric conditions
  - Altitude in the sky
  - Water vapor
  - Dust
  - Environment of the telescope
  - scintillation
  - At Mt. Cuba – about 3-10 arc seconds
  - Chile – 0.5-1 arc second
- Magnification
- Field of View

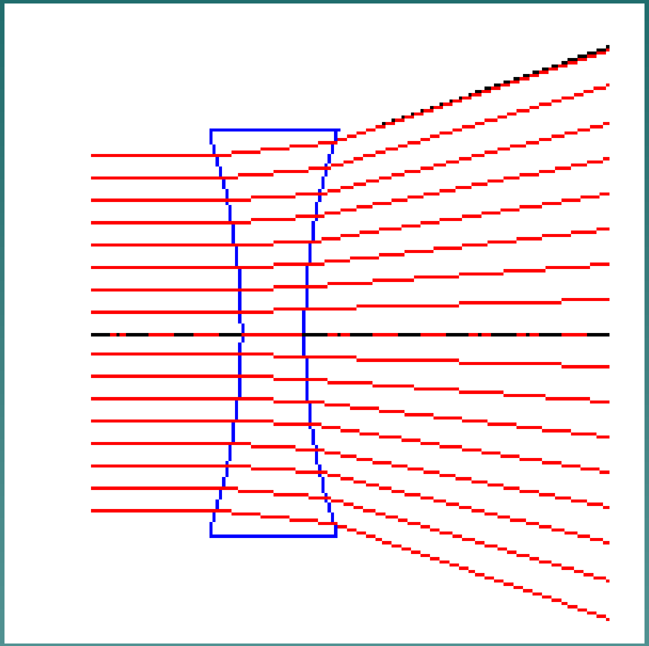
Types of Telescopes

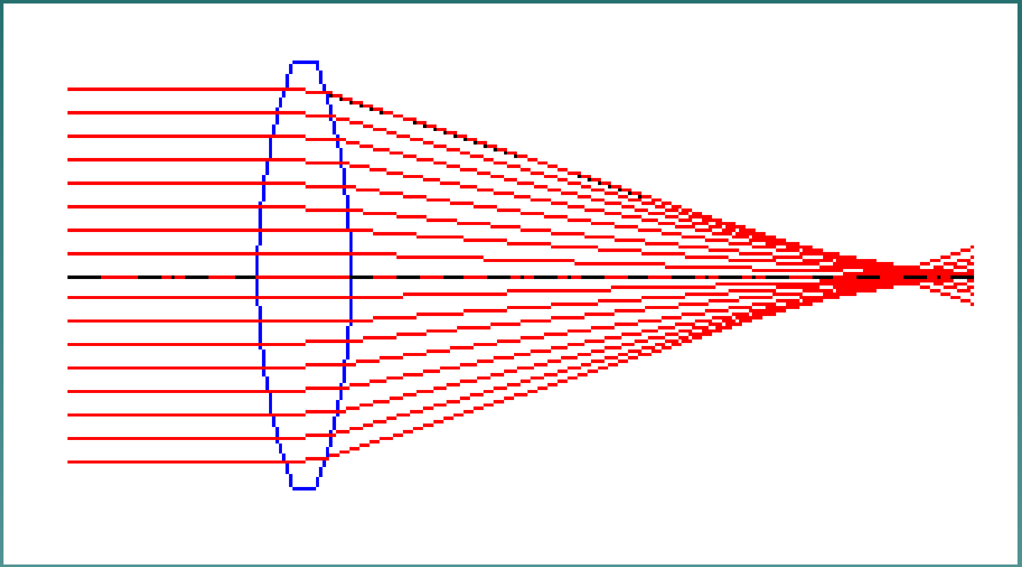
Three Types of Telescopes

- Refractor
- Reflector
- Catadioptric



Refraction



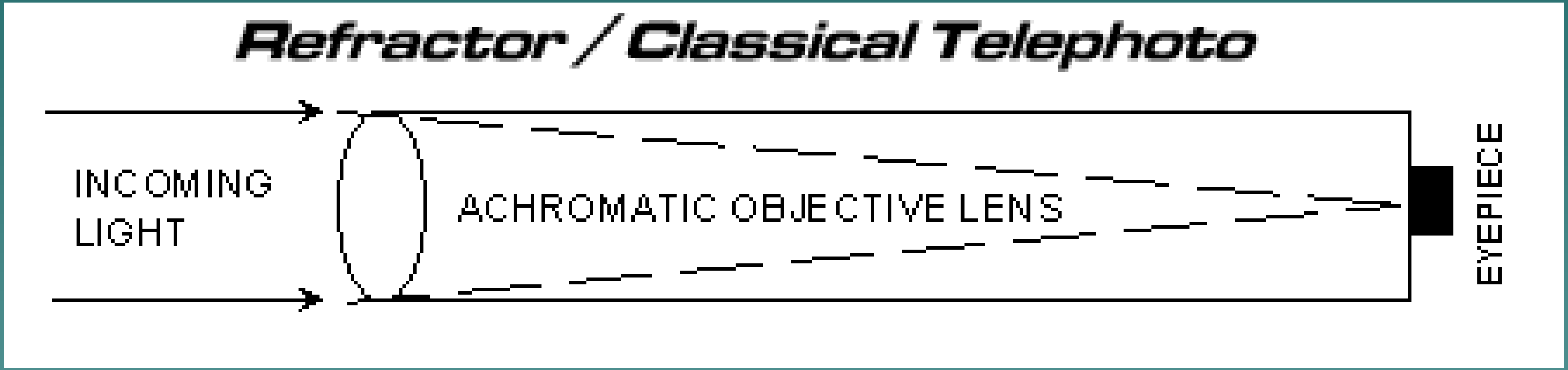


Diverging lens

Converging lens

Which would you use to construct a telescope?

Refracting Telescopes



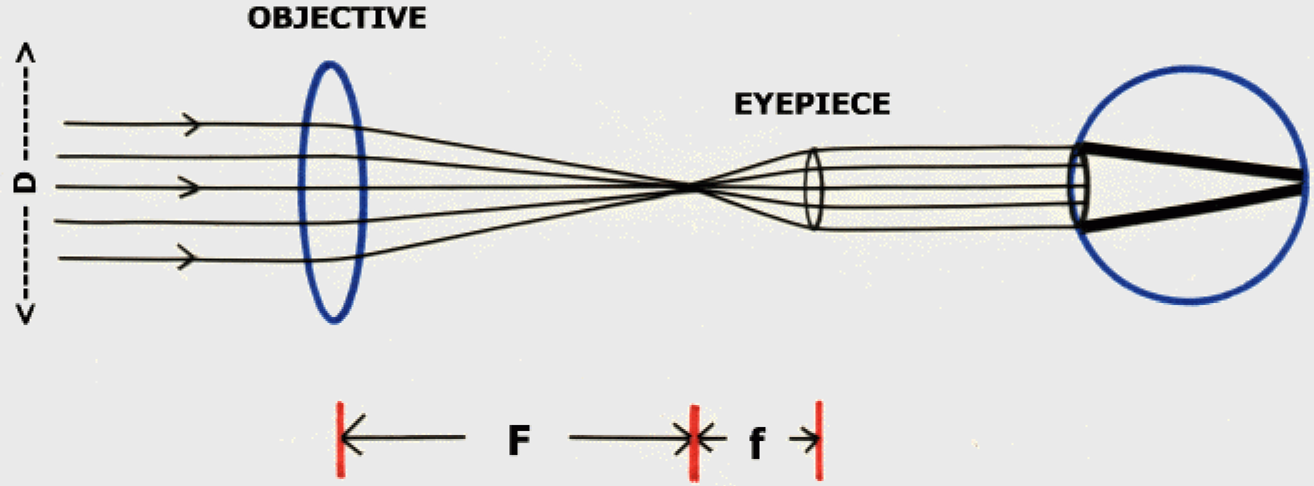
- Has a lens at one end of the telescope
- Light passes through the lens and is refracted
- Lens brings light to a focus at the eyepiece
- Galileo’s telescope was a refractor.

400th Anniversary

Light gathering power determined by D.

Magnification can be adjusted by changing eyepiece.

Magnification = F/f



Magnification = (focal length of primary lens or mirror)/(focal length of eyepiece)

History of Refractors

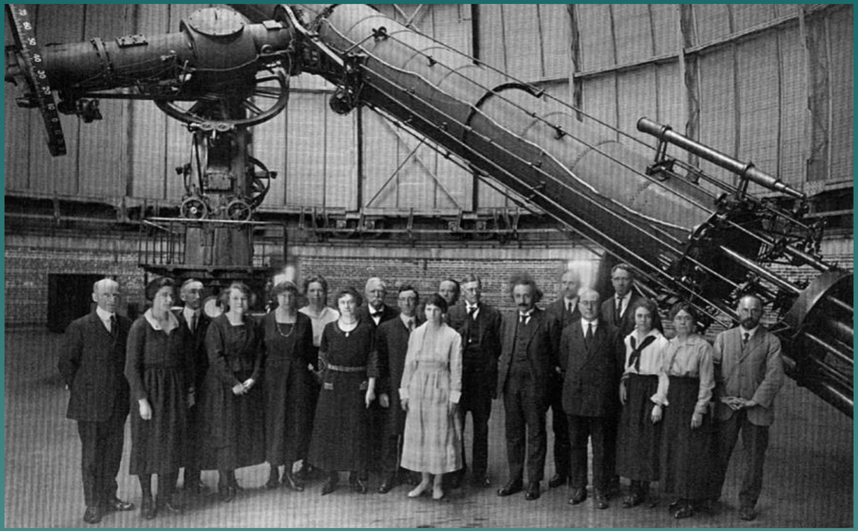
- Earliest telescopes - Galileo
- Premier telescopes of the 1800s
- Technology peaked in 1887 with 40 inch Yerkes refractor (outside Chicago)
  - Issues:
    - Absorbed too much of the light passing through
    - Massive piece of glass sagged under its own weight
-

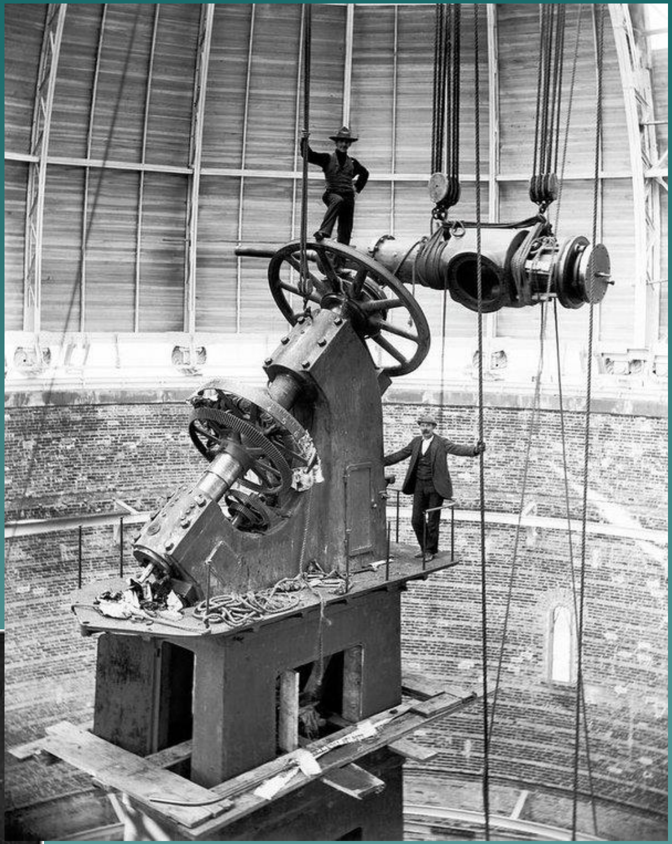
Galileo

Galileo's telescope: a 30mm handheld Refractor
Focused by sliding eyepiece in and out

Galileo Galilei
Born in 1564, died 1642
Famously denounced for his views on the earth's motion around the sun

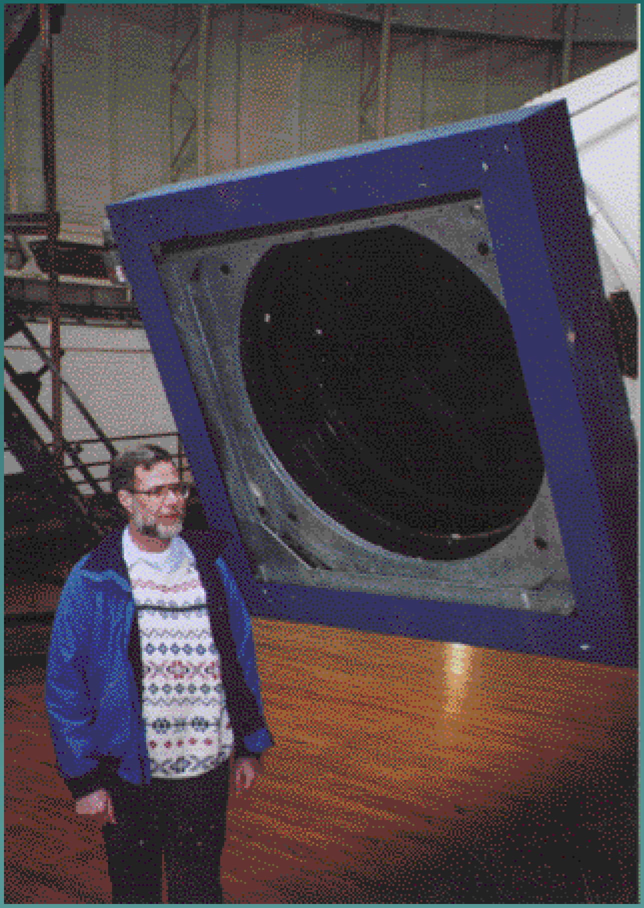
Yerkes Refractor





40 Inch diameter (102 cm)

40 inch lens



Tube is 60 feet long and weighs 6 tons

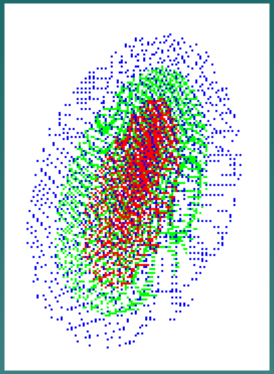
Disadvantages

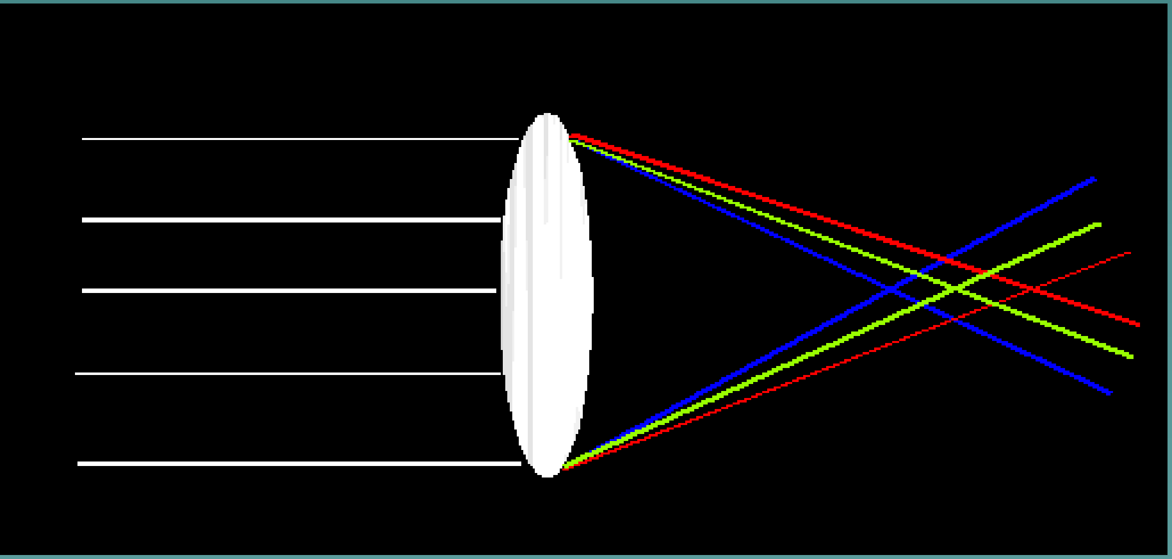
- Size
- This is about the largest solid glass body that can be supported on its edge without deforming under its own weight.
- The volume of the lens must be good.

40 inch refractor built in 1892

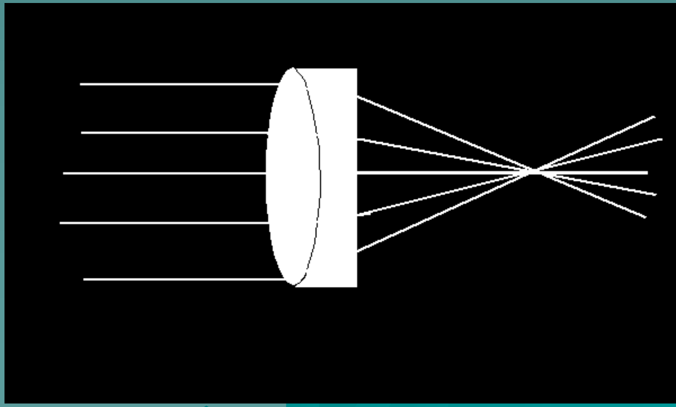
Disadvantages of Refractors

- Chromatic aberration – light of different wavelengths is bent differently by the lens!
- Different focuses for different colors!
- Your eye suffers from this problem, plus inverted image!



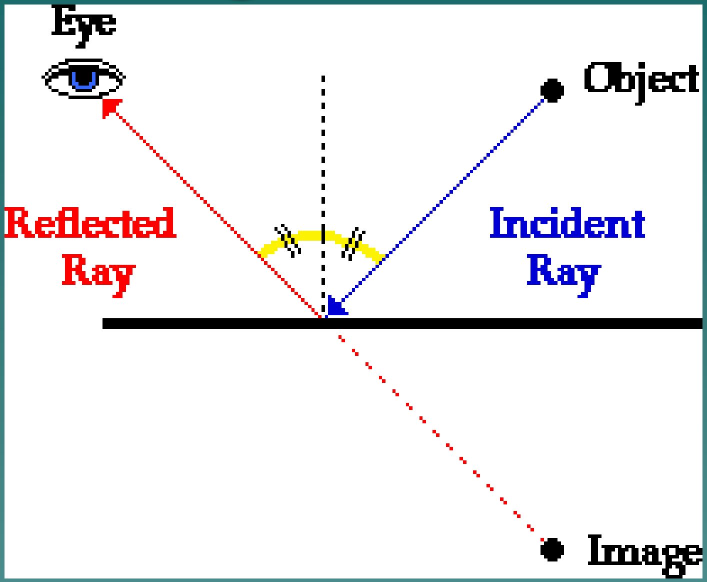


aberration

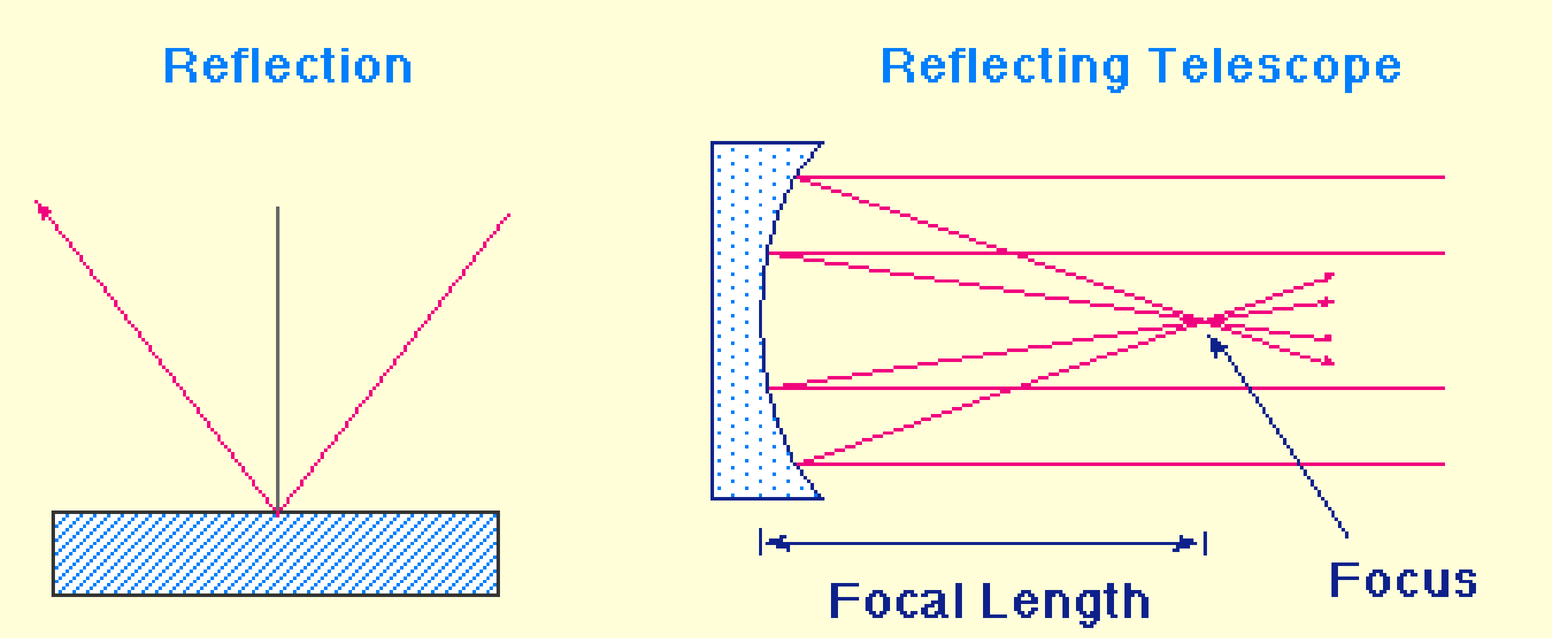


achromat

Reflecting Telescopes

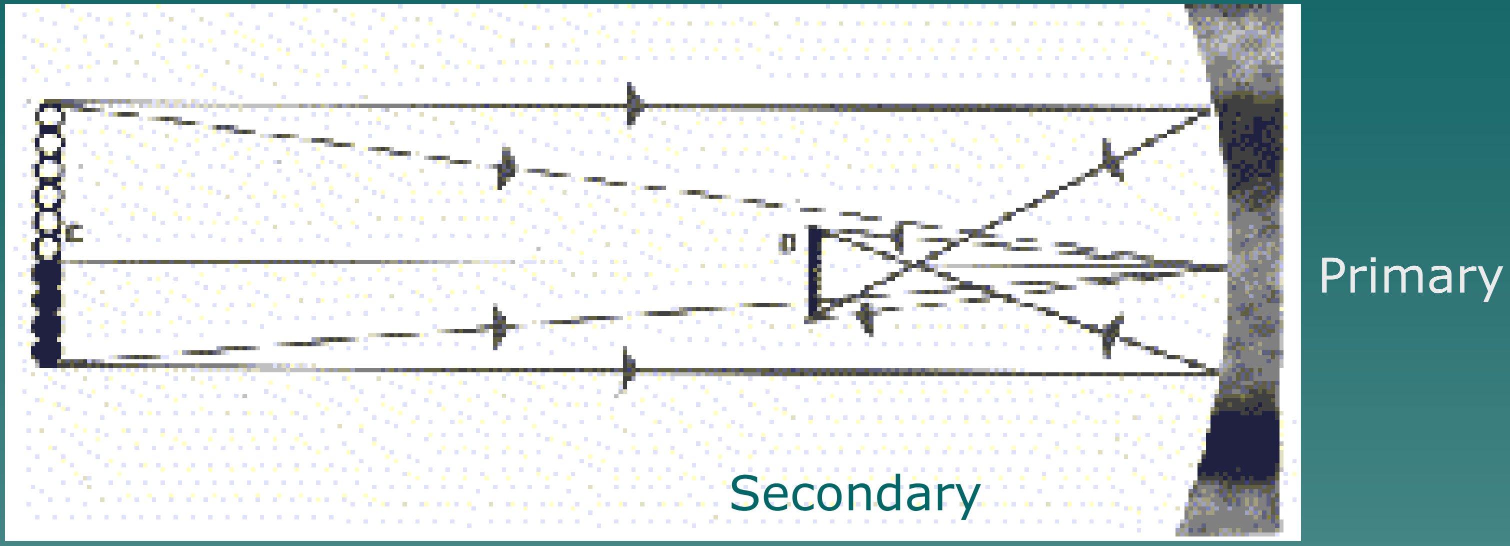


Reflecting Telescopes



Want to use mirror to collect and focus light – so can't use a plane mirror – use a curved mirror (concave)
Angle of incidence = angle of reflection
Center of curvature

Reflectors



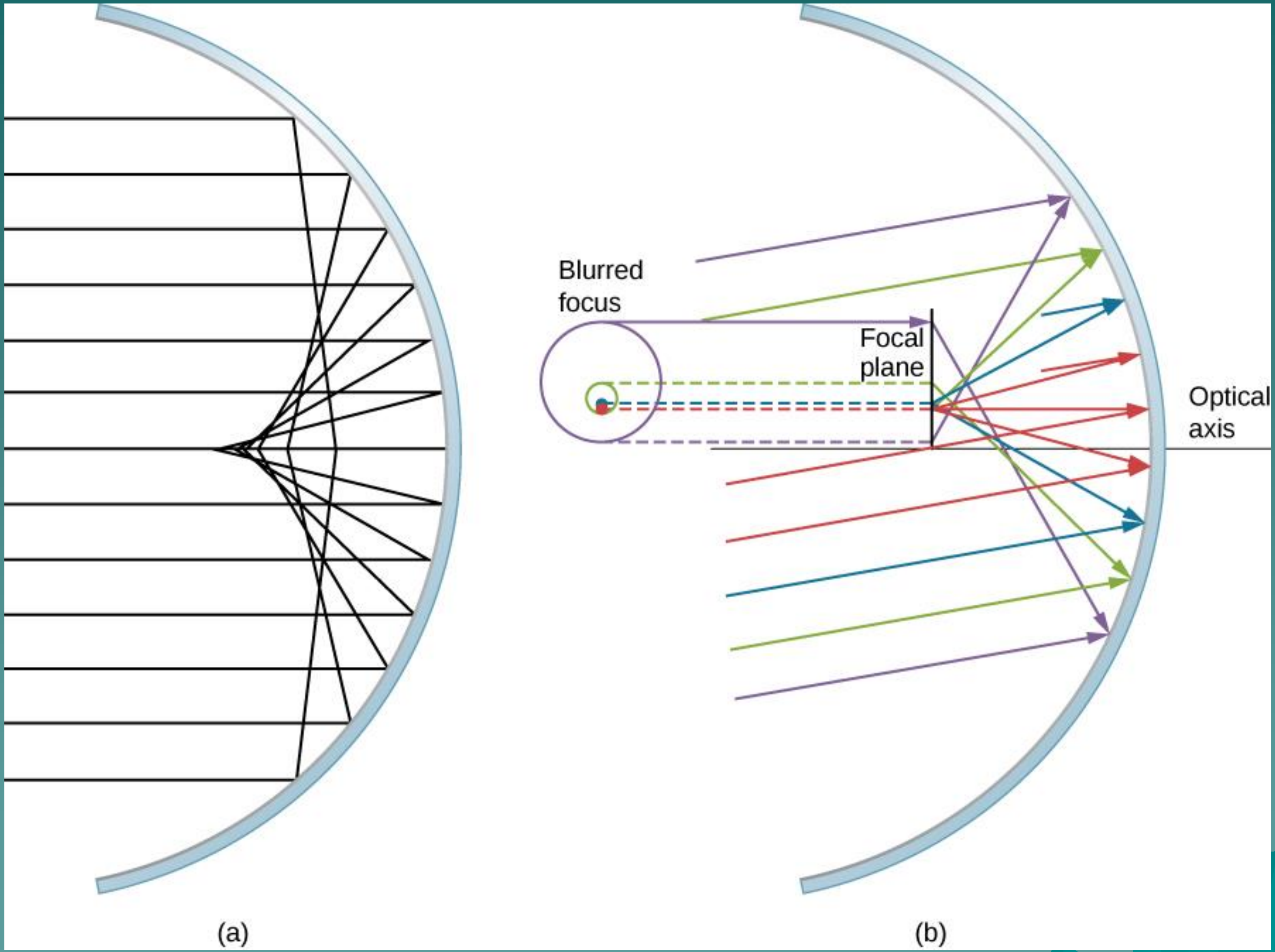
Use mirrors rather than lenses

- Mirrors are usually parabolic, not flat, to help bring the light to a focus.
- Mirrors have the advantage of being supported from behind.
- Light does not pass through mirrors, so no chromatic aberrations. mirrors began to replace lenses in larger telescopes.
- Use of second reflection can make tubes shorter.
- Early mirrors were metal – tarnished quickly, hard to polish because you changed the shape of the mirror. This is the reason the earliest telescopes were refractors. It was very hard to shape metal to the tolerances needed for reflecting telescopes.
- Later – started using glass with thin silver coating. Tarnished as well, but could be polished by replacing the silver
- Today use different kinds of high tech coatings and lens materials

Problems with Reflectors

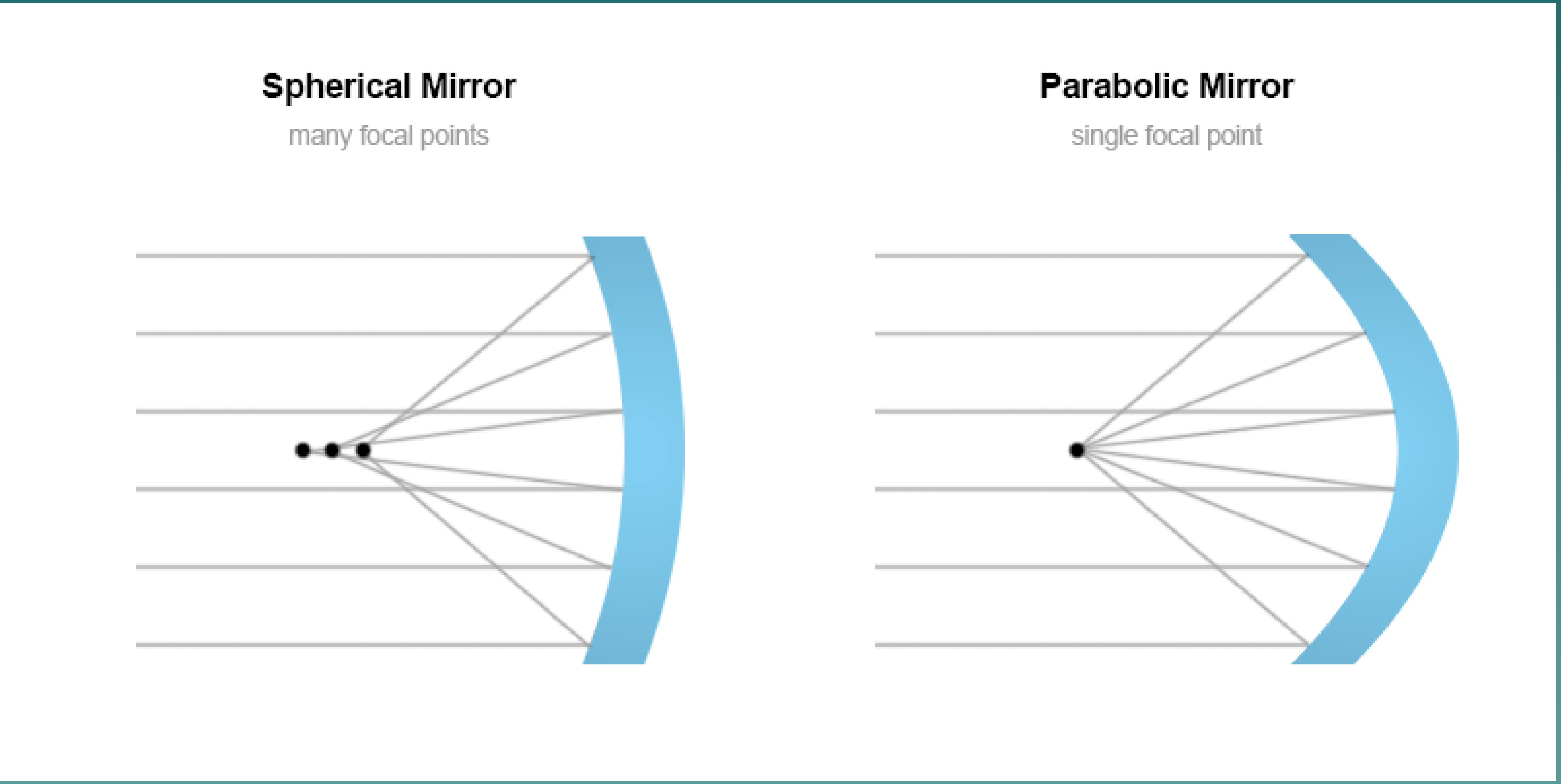
- Mirror maintenance
- Reflect light back in direction it came from
- Tarnish
- Optical problems
  - Spherical Aberration
  - Coma
  - Where do you look?

Spherical Aberration



Hubble Space Telescope is an example of this!

Spherical Aberration

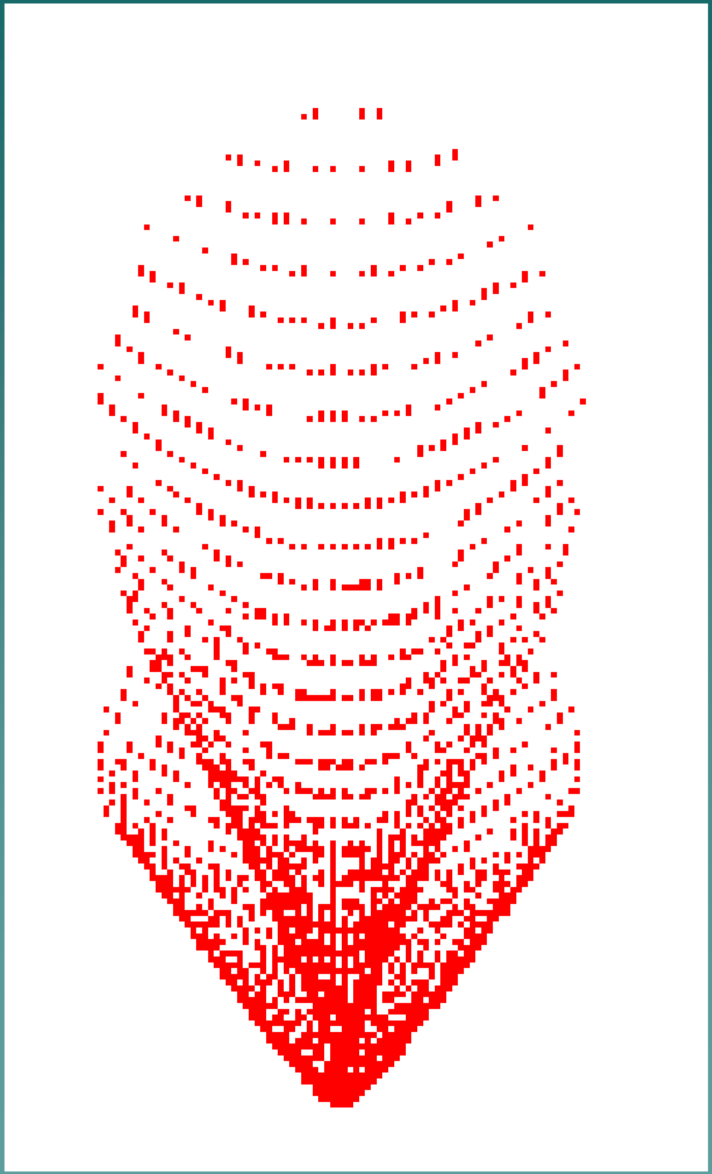


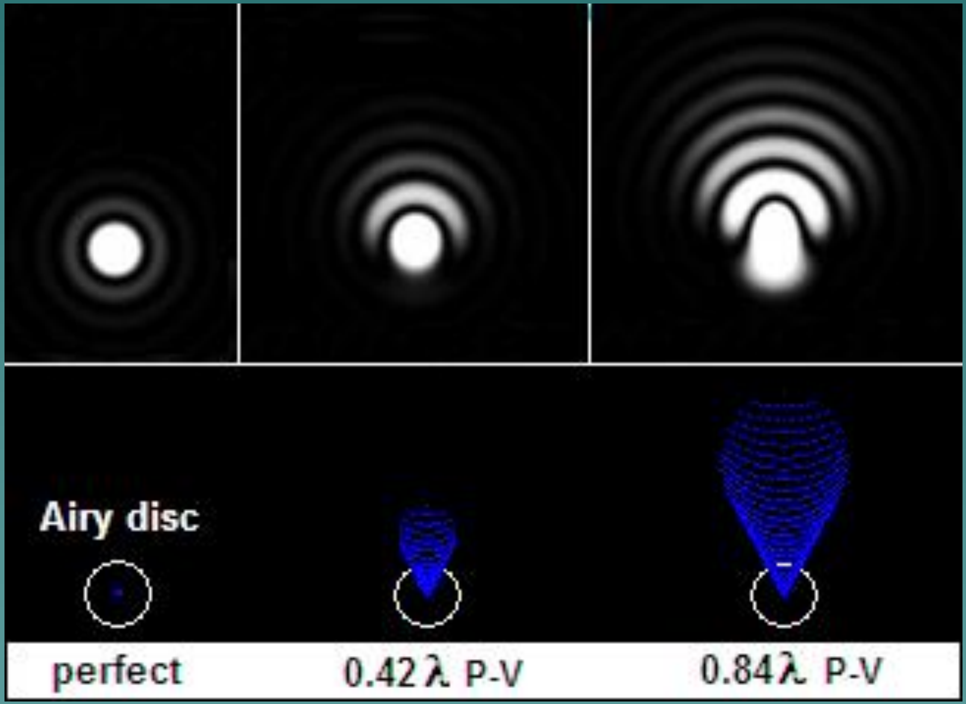
To correct spherical aberration, give your mirror a parabolic shape.

Spherical Aberration and Coma

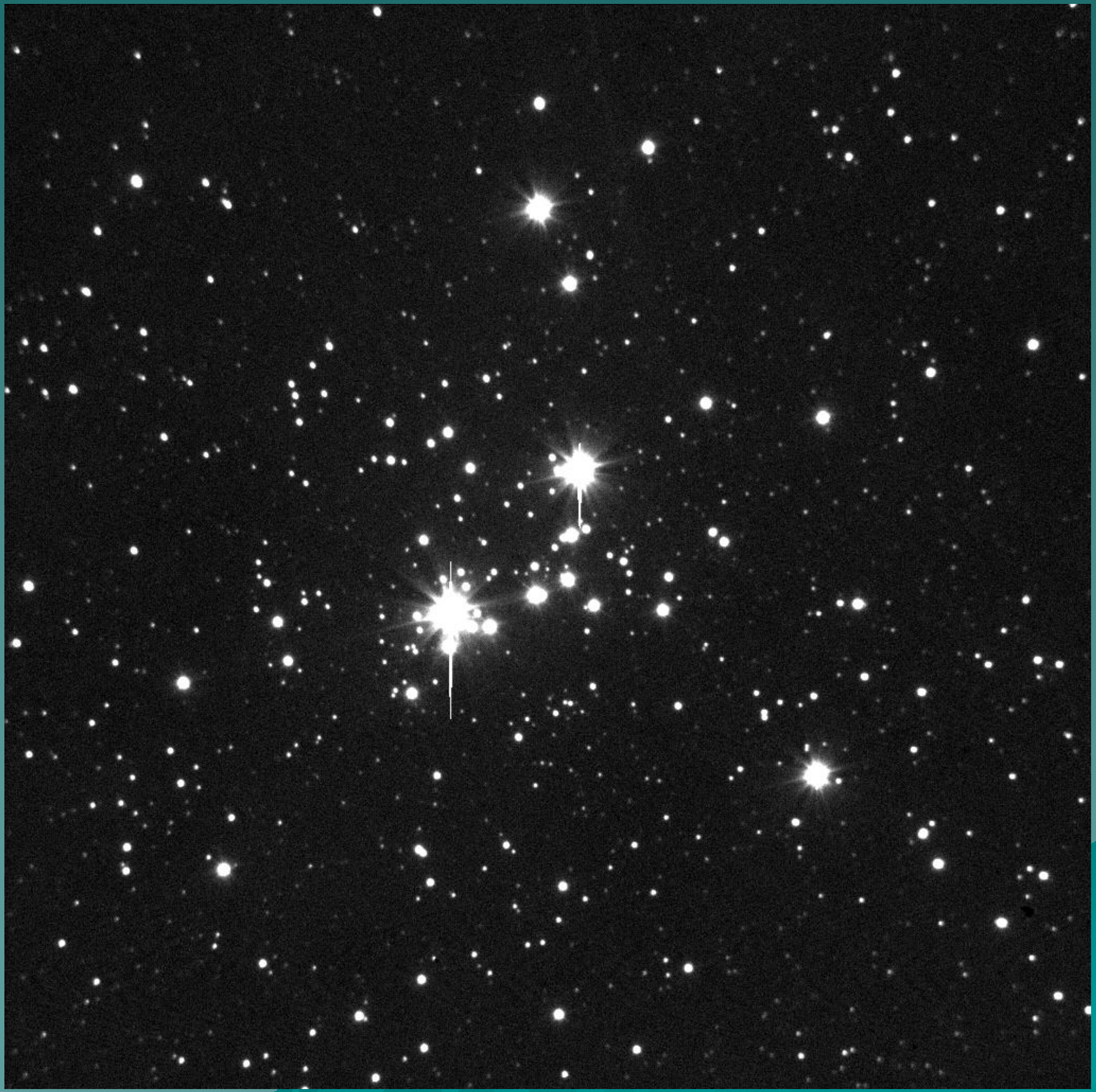
- Using a parabolic mirror introduces a new aberration called coma
- Coma affects objects away from the central optical axis (off axis).
- Caused by incoming photons that are not parallel to the parabolic axis.
- Severity is proportional to D^2 inversely proportional to focal ratio

Coma

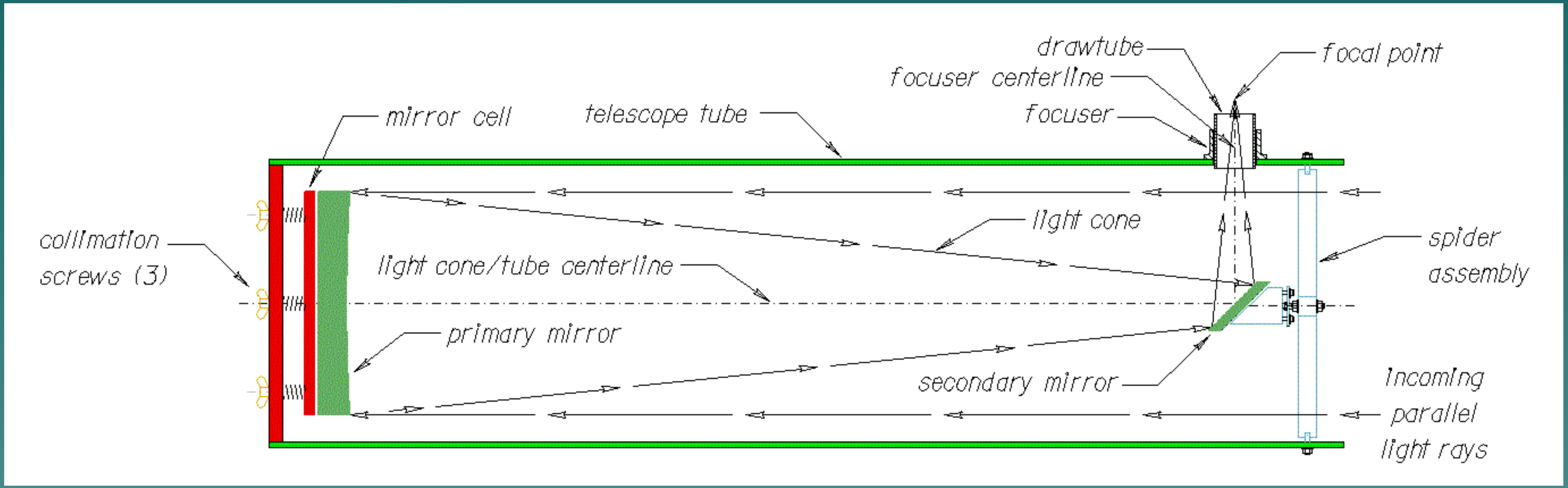




MCAO 24 inch coma



Types of Reflectors



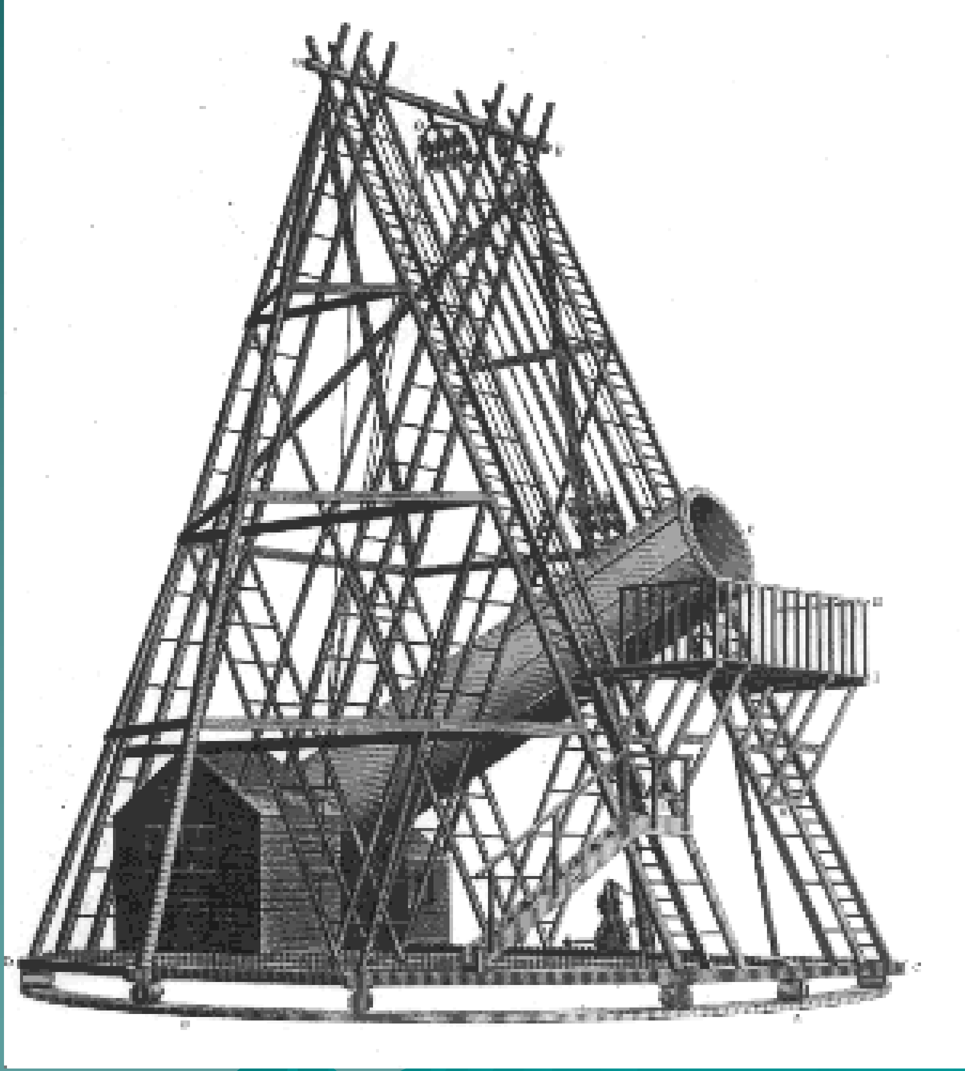
Newtonian Telescope - earliest design

- 1668 – Isaac Newton built the first one
- Mirror 1.3 inches, magnification 35 times
- Mirror from speculum metal –
    - an alloy of copper and tin –
    - Newton added arsenic for "whiteness"
- Reflected only 16% of light
- Tarnished easily

Newton's 1668 Telescope

Herschel 1.2 m reflector (1789)

- William Herschel was a musician with no astronomical training.
- Hershel's discovery of Uranus began serious quest for larger Telescopes
- Between 1773 and 1795
  - William Herschel made 430 mirrors – metal
- Largest 1.2 m
  - Was the largest telescope for 50 years.
  - Never lived up to potential
  - Mirror warped under weight
  - Two mirrors were cast
  - Took hours to cool down
  - Not a Newtonian – the primary mirror was tilted so you could see the image by while standing in front of the telescope.



Herschel's 1.2m (40") Telescope

- First Observation Feb 19, 1787
- "The apparatus for the 40-foot telescope was by this time so far completed that I could put the mirror into the tube and direct it to a celestial object; but having no eye-glass fixed, not being acquainted with the focal length which was to be tried, I went into the tube, and laying down near the mouth of it I held the eye-glass in my hand, and soon found the place of the focus. The object I viewed was the nebula in the belt of Orion, and I found the figure of the mirror, though far from perfect, better than I had expected. It showed four small stars in the nebula and many more. The nebula was extremely bright." Herschel, 1787

Herschel's Telescope

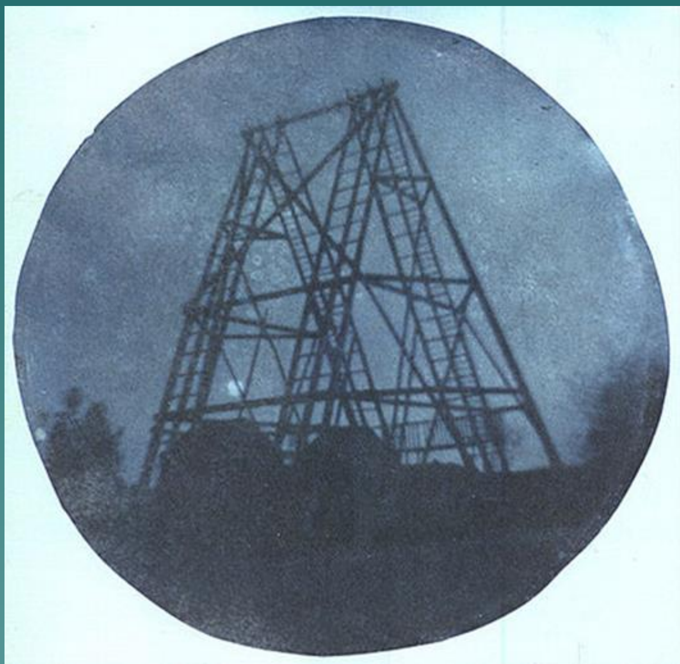


Image taken in 1839 by Herschel's son, John.

Telescope's first mirror on display in the Science Museum in London

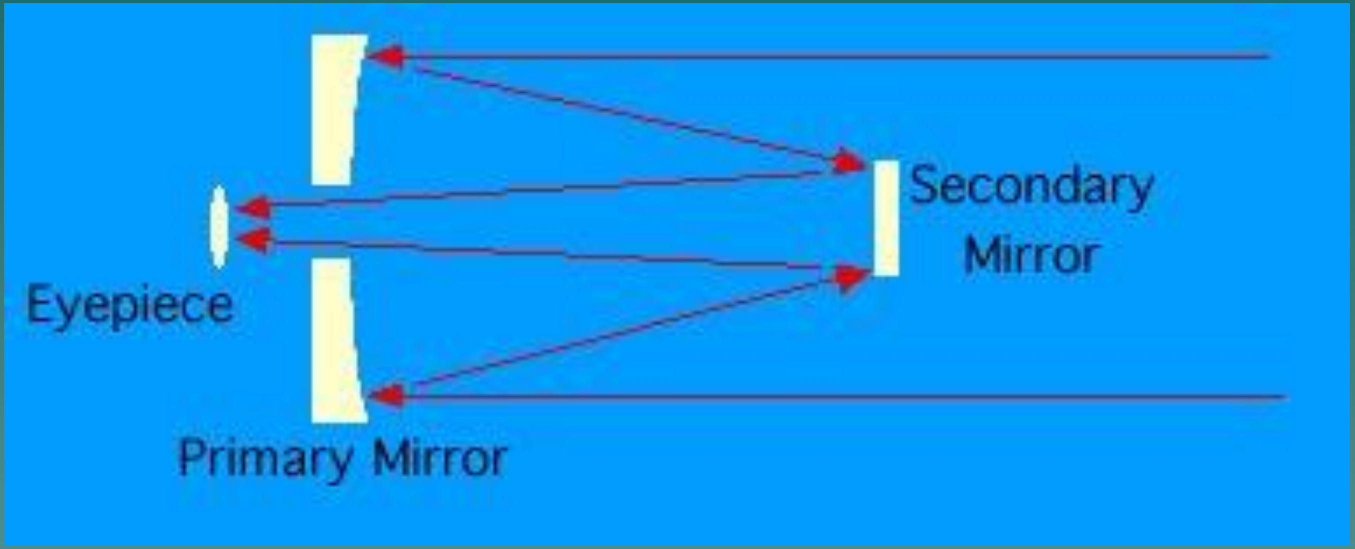
The Leviathan of Parsontown

- Built in 1842
  - 4 tons of molten metal
  - Took 16 weeks to cool
  - 1st attempt broke right before installation
- 72 inches
- First really good, large reflecting telescope
- Discovered Neptune's moon Triton
- Discovered Uranus's moons Ariel and Umbriel

The Leviathan

The Leviathan

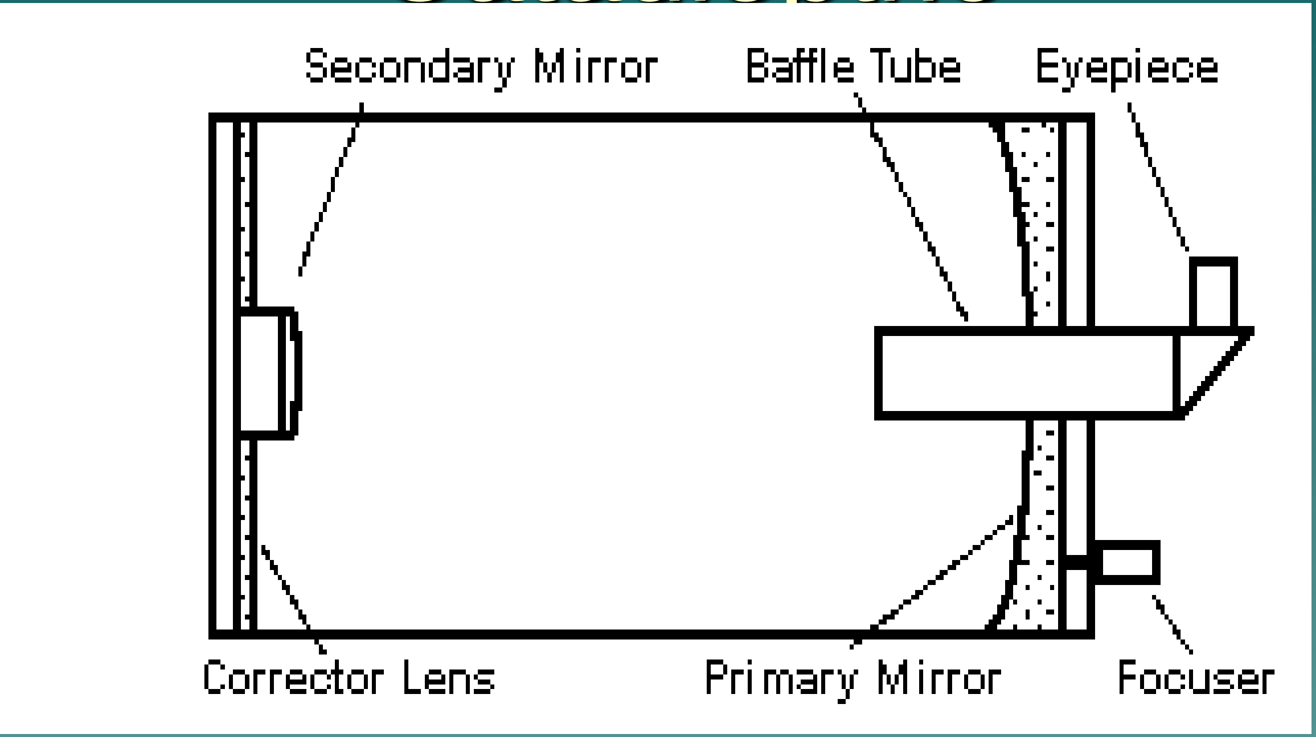
Cassegrain Reflector



24 inch telescope

- 1672 – Frenchman Guillaume Cassegrain produced the first

Catadioptric



Schmidt Cassegrain –
Uses both lenses and mirrors. Uses spherical mirror, with correcting lens at center of curvature.

Spheroidal

Parabolic

Telescopes today

- Refractors still used by amateurs
  - Simple design
  - Easy to use
  - Great for planets, the moon, and resolving binary stars.
  - No obstruction from a secondary mirror or diagonal.
  - Have evolved from small, manually pointed objects to sophisticated, computer controlled instrument.
- Reflectors are used in modern telescopes.
- Telescopes for all wavelengths of light!

Review of Telescopes/Properties

- Basic Terminology – aperture, focal length, focal ratio
- Properties dependent on size of the telescope
  - Light Gathering Ability
    - Magnitude system
  - Resolution
    - Seeing – atmospheric turbulence
- Other Properties
  - Field of View – f/ratio
  - Magnification – focal length/eyepiece focal length

Review of Telescopes

- Types of telescopes
  - Refractor – earliest
  - Reflector
    - Newtonian
    - Cassegrain
    - Earliest –metal mirrors (1750s)
    - Glass mirrors – 1850s
  - Catadioptric
- Optical problems
  - Chromatic aberration
  - Lens size/thickness
  - Spherical aberration
  - Coma
- Modern telescopes

Modern Astronomical Telescopes

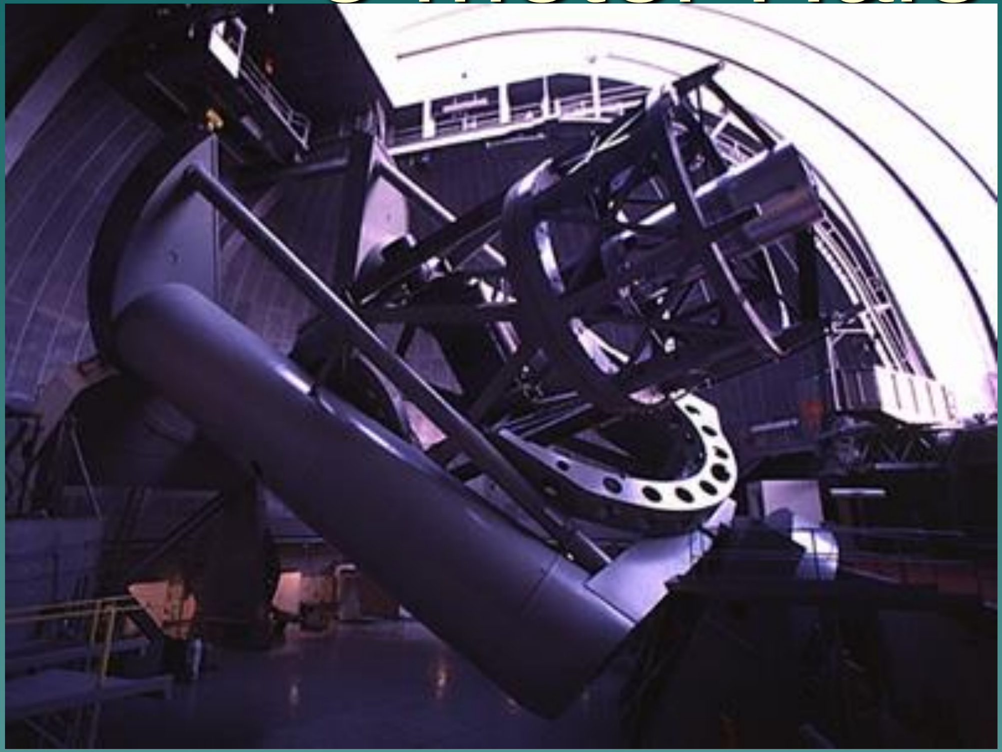
Major observatories: Hawaii, Chile, Texas, Canary Islands, Arizona, Australia, California, South Africa, China

Typical structure: Telescope housed inside large dome with slit that opens.

Silver Coated Mirrors

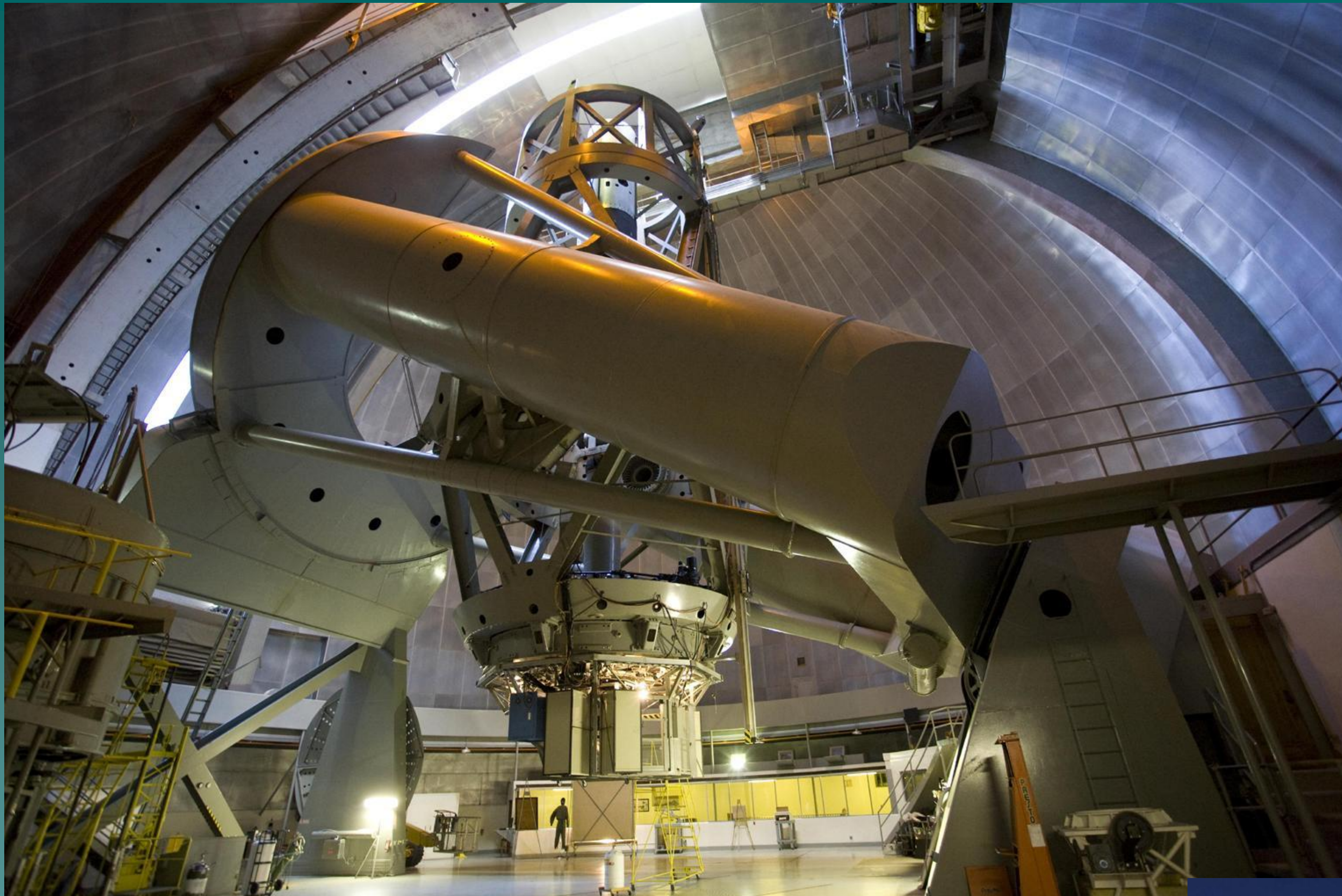
- 1856 – German chemist Justus von Liebig found he could use a mixture of silver nitrate, caustic potash, ammonia and sugar to deposit a reflective silver film onto a glass plate.
- Leon Foucault (Paris), Carl August von Steinheil (Munich) applied the process to create silvered glass telescope mirrors.
- Silvered glass advantages
  - Lighter
  - Less brittle
  - More reflective
  - Easier to make
  - Easier to maintain
- Henry Draper – 1864 – “On the Construction and Use of a Silvered Glass Telescope” was standard instruction book

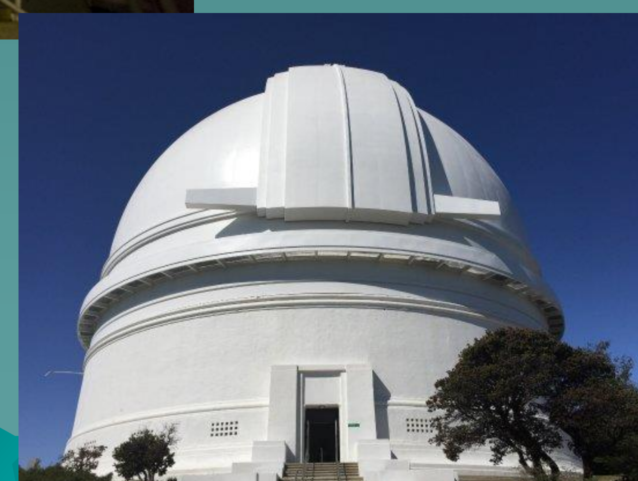
5 meter Hale telescope



The mount needed to support this monster is itself quite large. It is an equatorial mount, one axis is aligned with the rotation axis of the earth, like the telescopes upstairs.

- uses the largest single piece of glass possible to still have a good mirror. Monolithic. Anything larger will deform under its own weight.
  - 200 inch pyrex primary mirror. Weighs 14.5 tons (just the mirror). 20 tons total.
  - Pyrex was favored material until about 30 years ago – low thermal expansion
- The tube of the telescope is 60 ft. long.
- The telescope was built (1947) before the age of lightweight materials.
- The whole telescope weighs 500 tons.





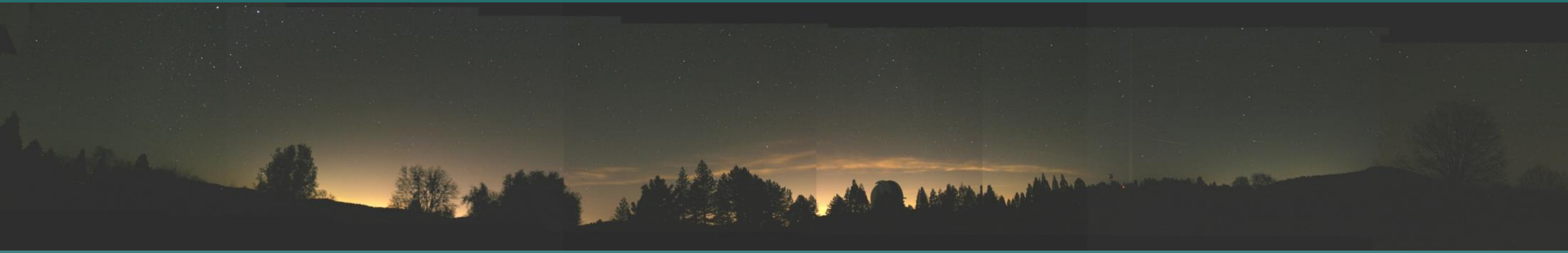
History of Palomar

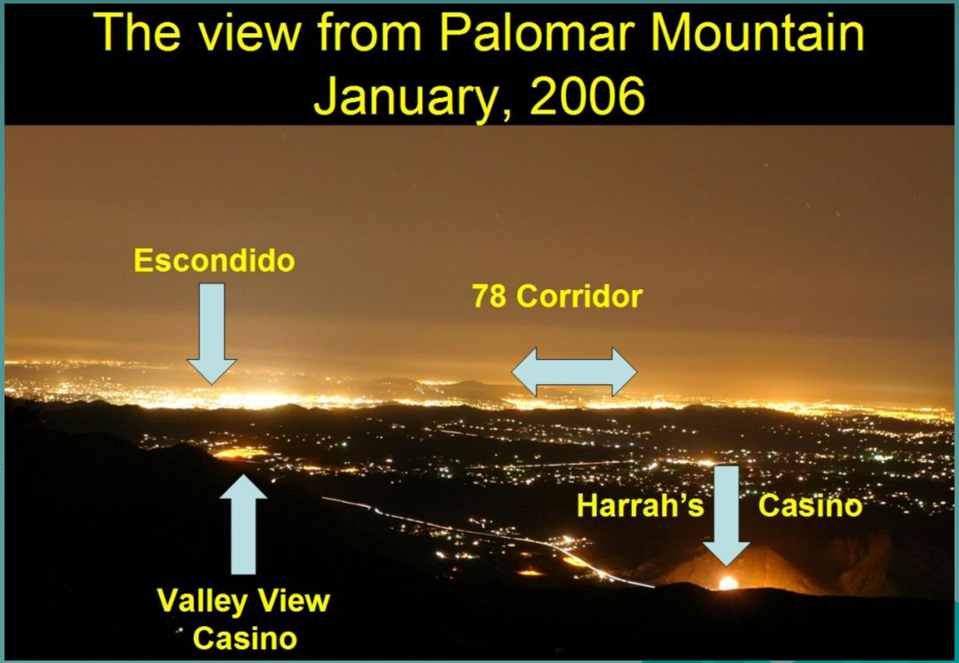
- George Ellery Hale – ardent proponent of the "new astrophysics"
- Faculty at University of Chicago 1892
- Secured money for 40 inch Yerkes refractor
- Secured funding for 60 inch and 100 inch telescopes at Mount Wilson in California (1908)
- All happened around the time that Edwin Hubble was measuring distance to galaxies for the first time. He wanted a bigger telescope.

Problems

- Hale telescope is about largest mirror that can be constructed from Pyrex and not deform under its own weight
  - Mechanical rigidity
- Thickness of mirror proportional to cube of the diameter
- Weight of a solid mirror proportional to D^5!
- Expensive and impractical
- Two approaches to reducing weight
  - Thin mirrors
  - Honeycomb mirrors

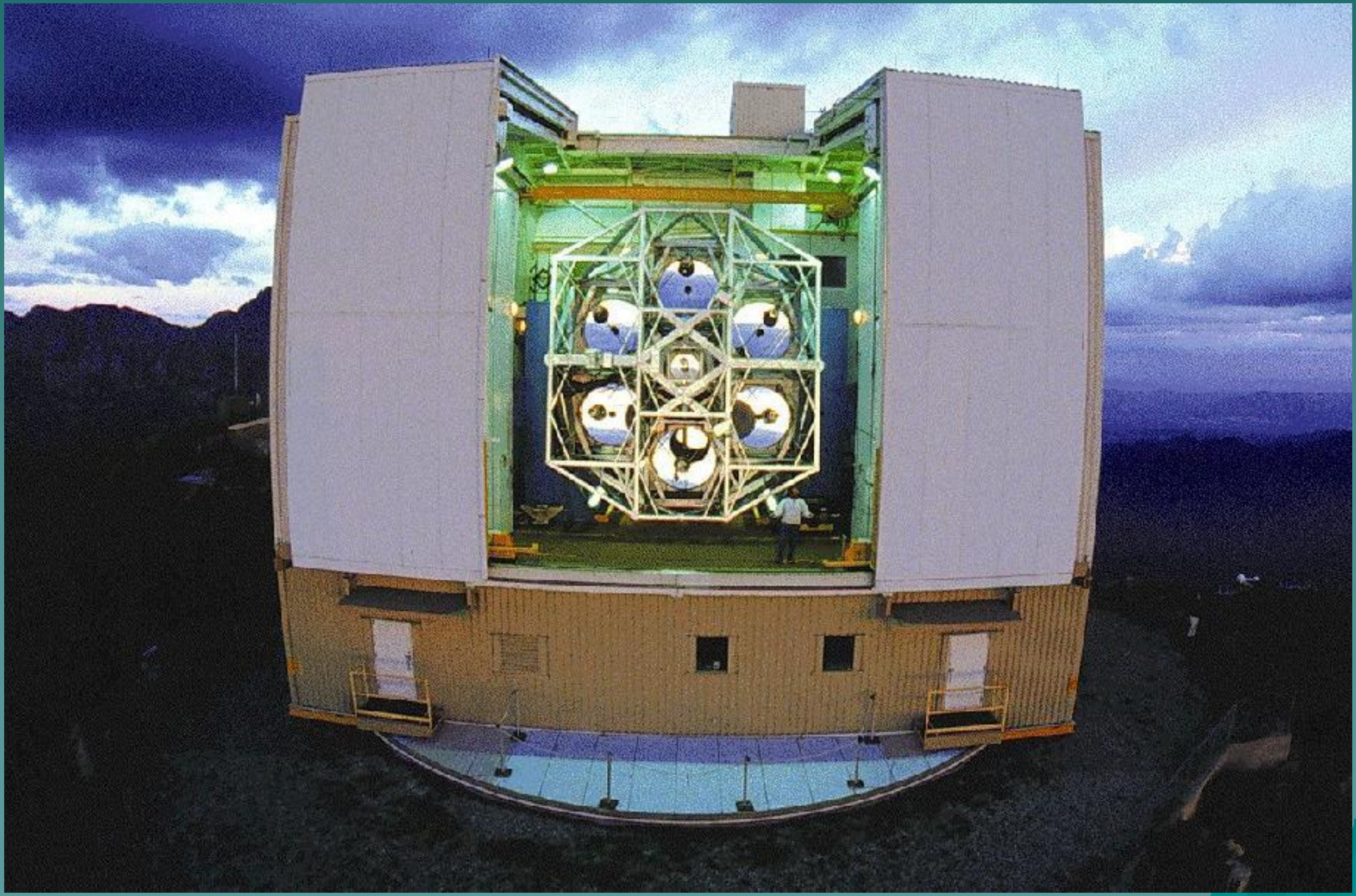
Palomar Today





The MMT

Multiple Mirror Telescope



Mt. Hopkins, 30miles south of Tucson, AZ

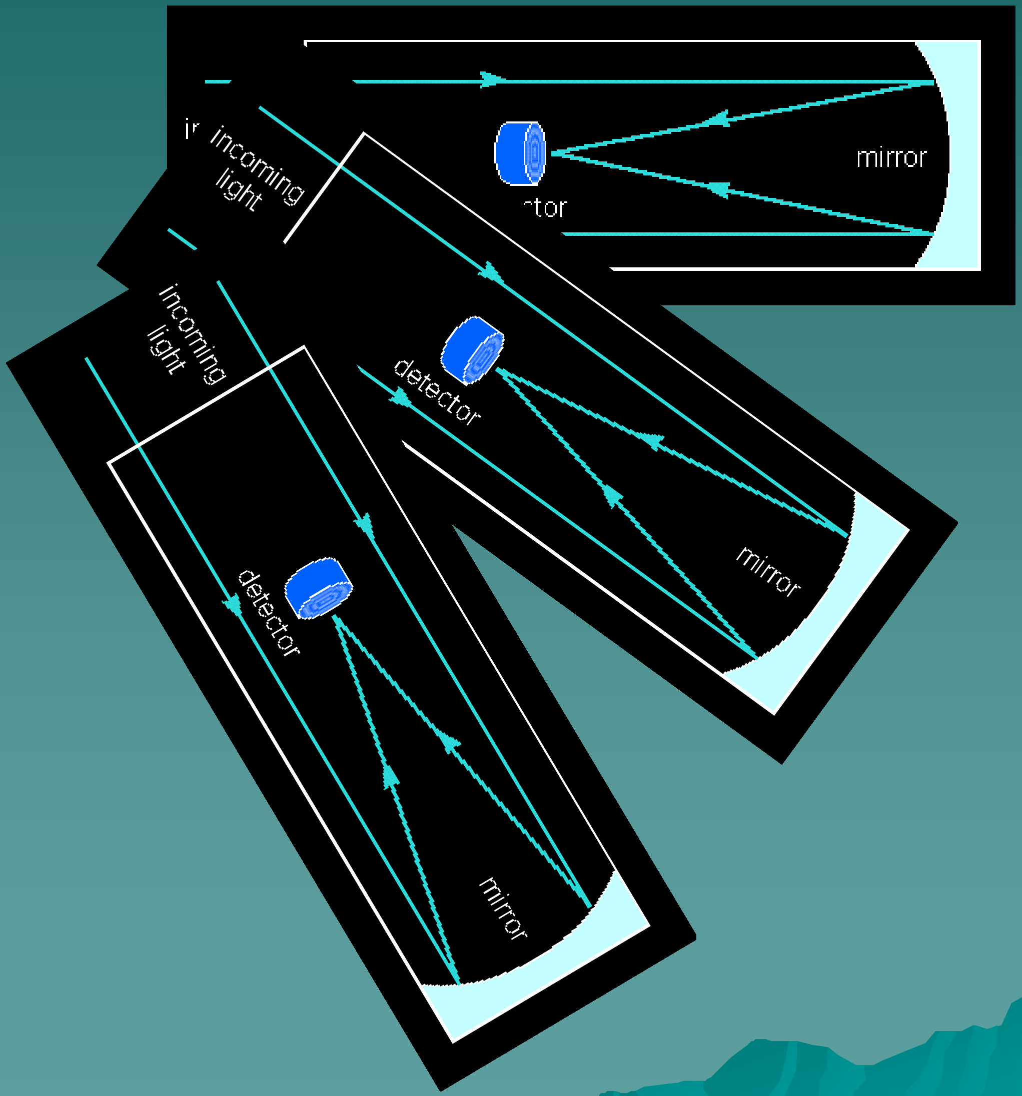
The MMT

The MMT was a telescope built before its time.

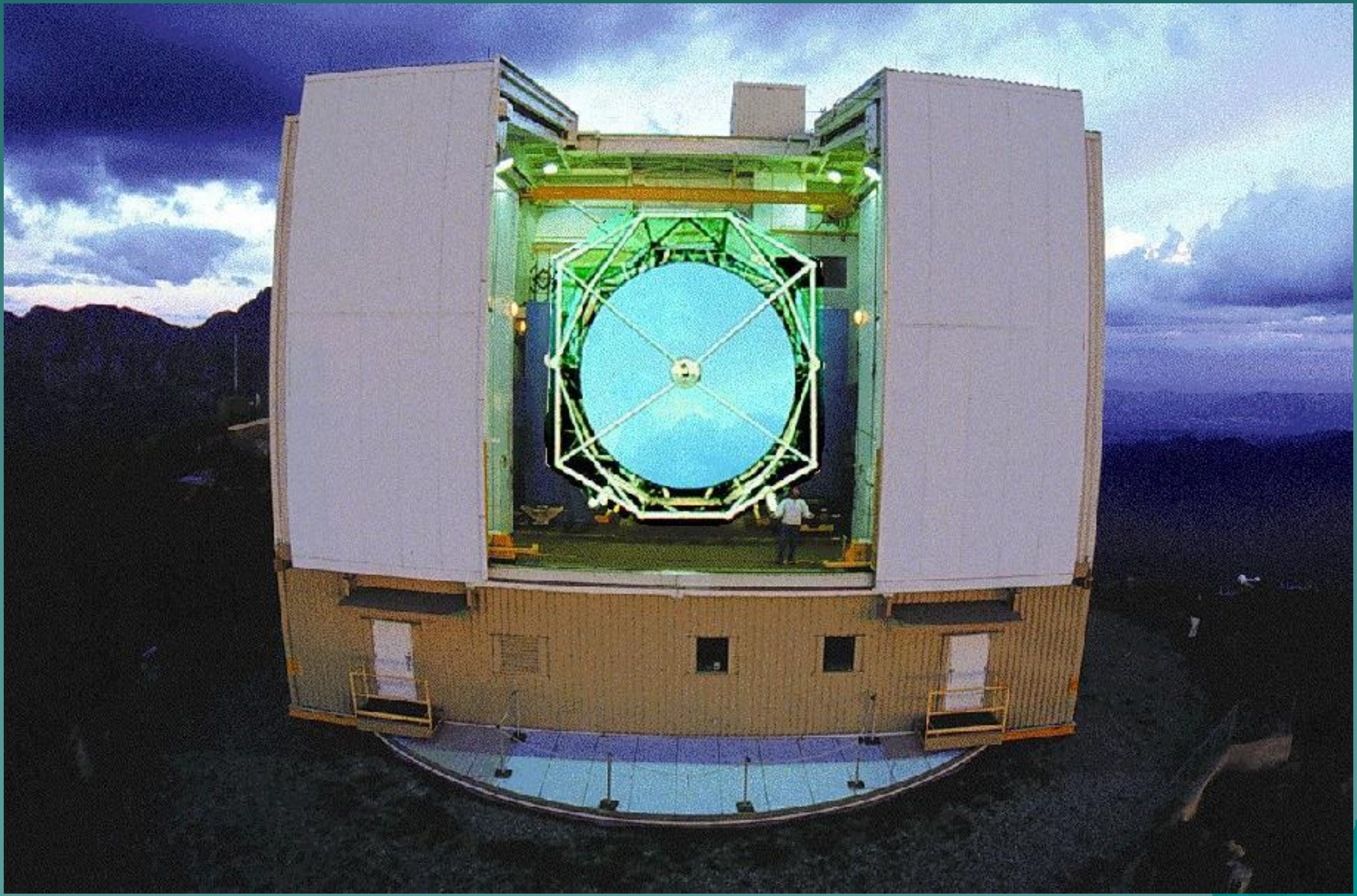
- Built in the 1980s.
- It revolutionized the idea of making telescopes.
- It was a 6 meter telescope, which means the primary mirror was 6 meters in diameter.
- But the mirror was not solid. It was constructed from 6 separate 1 meter mirrors. They were combined together to function as one mirror.
- Equivalent to 4.4m in area, but cost only 1/3 as much.
- It was ahead of its time because technology was not quite up to keeping the mirror segments aligned.

- Need precise alignment to maintain a good focus.
  - Wavelength of light ~5000 Å ($5x10^{-7}$ m)
- This is done by using "actuators", or small pistons, mounted behind each telescope mirror to push and pull on it.
- the MMT worked, but the not well.

Multiple Mirrors



MMT after

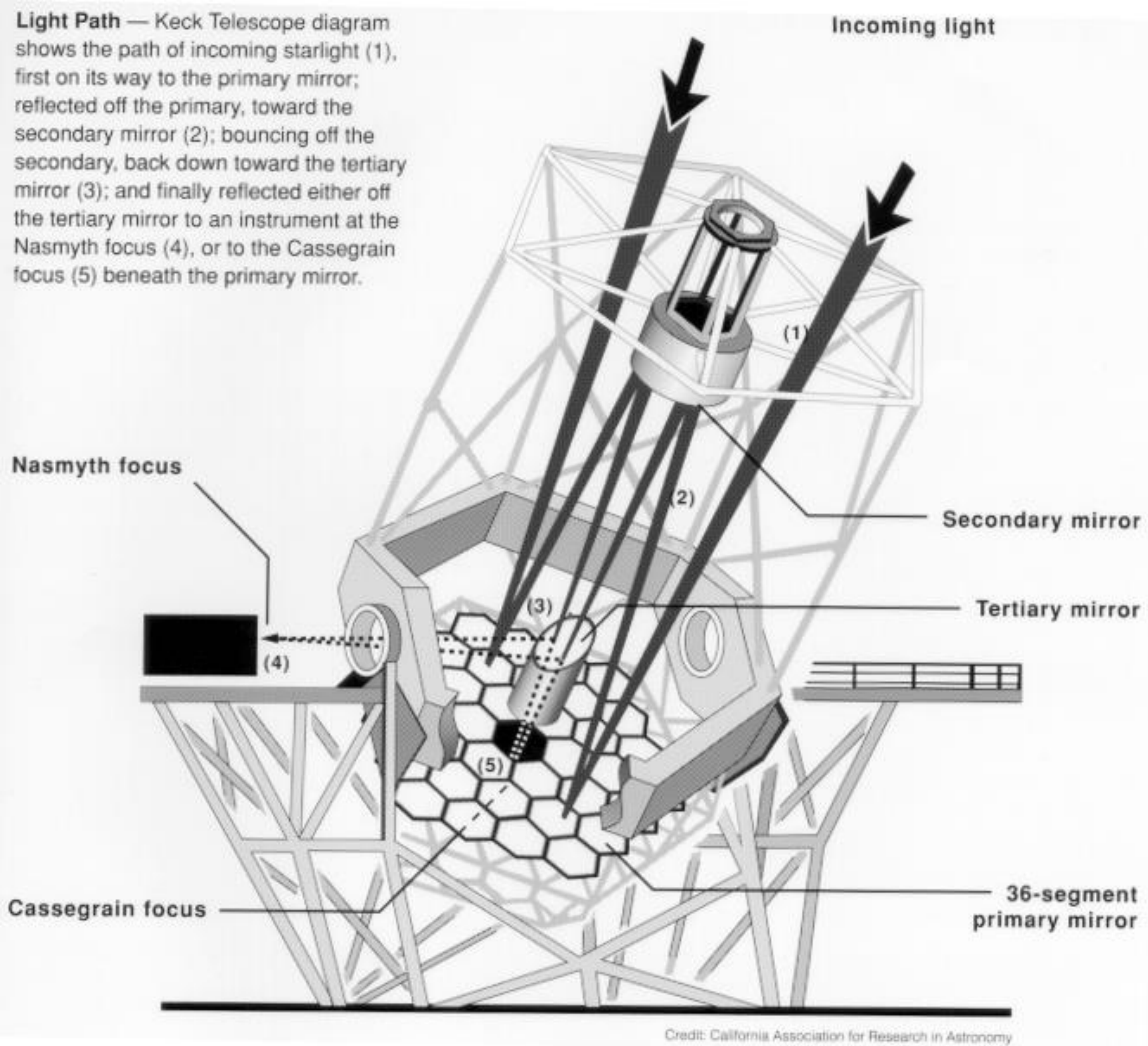


Refitted with a single 6.5 meter thin mirror - 2000

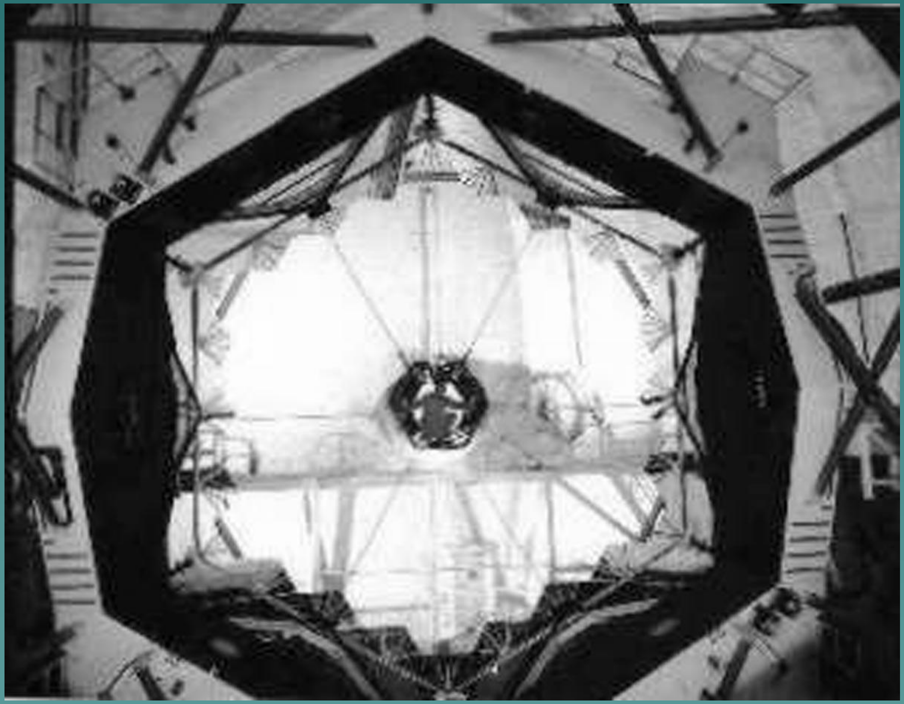

EXIT

The Keck Telescopes

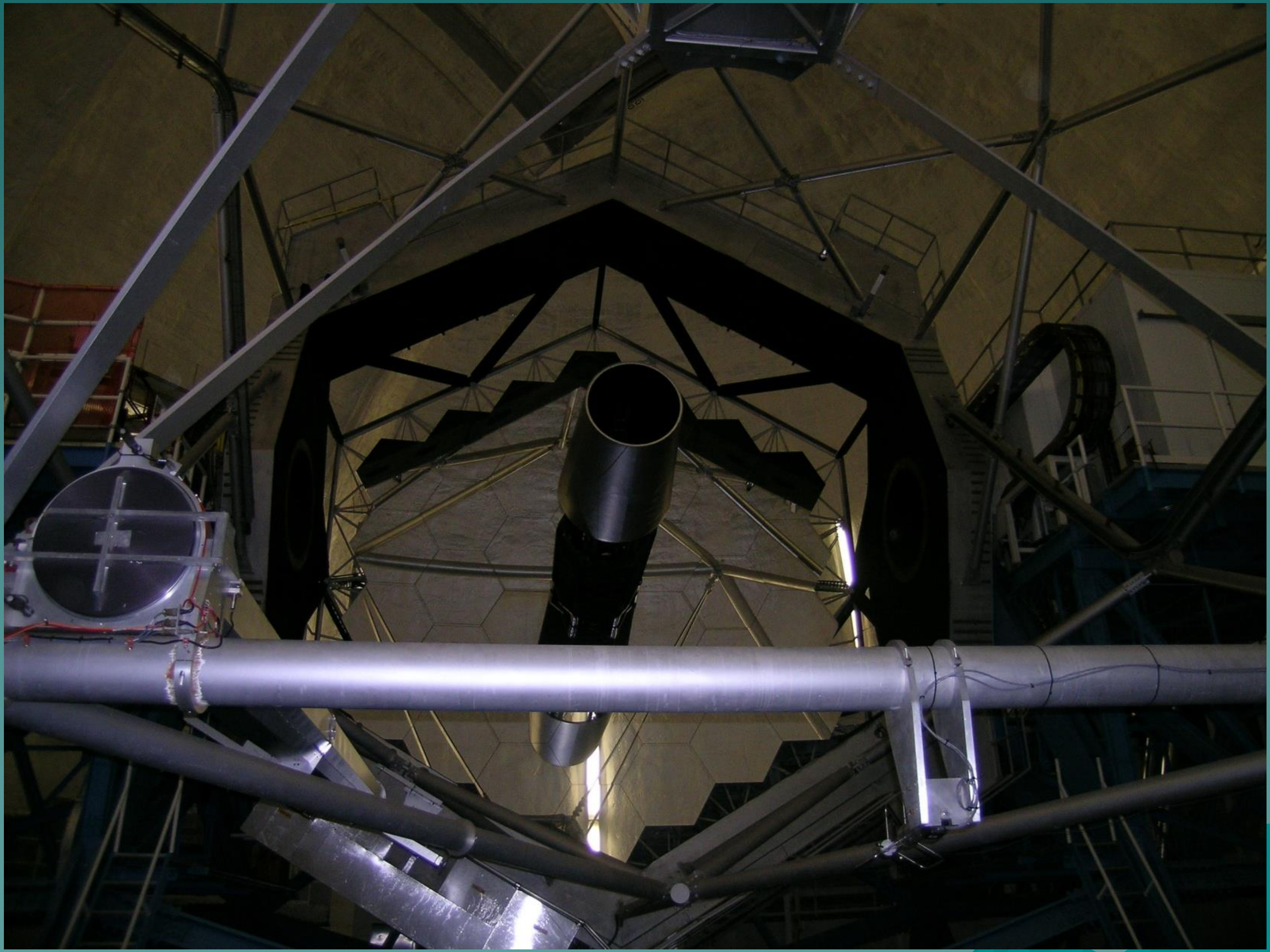
Primary mirror for each is
10 meters (33 ft) in diameter.


Light Path — Keck Telescope diagram shows the path of incoming starlight (1), first on its way to the primary mirror; reflected off the primary, toward the secondary mirror (2); bouncing off the secondary, back down toward the tertiary mirror (3); and finally reflected either off the tertiary mirror to an instrument at the Nasmyth focus (4), or to the Cassegrain focus (5) beneath the primary mirror.
Incoming light
(1)
(2)
Secondary mirror
Nasmyth focus
(3)
Tertiary mirror
(4)
(5)
Cassegrain focus
36-segment
primary mirror
Credit: California Association for Research in Astronomy

The Keck Mirrors



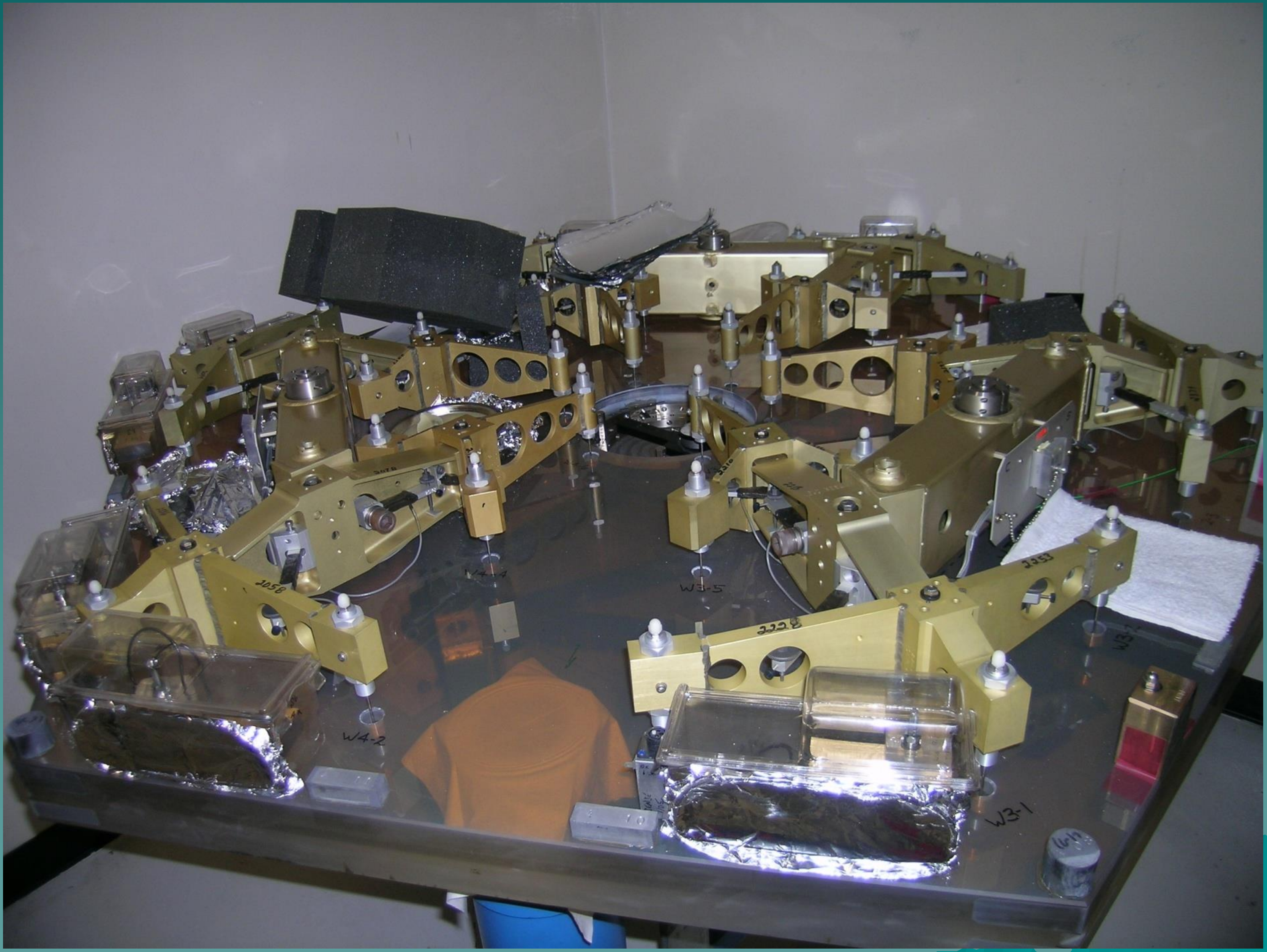
- Mirror is made of 36 individual lightweight segments.
  - Each segment is 1.8 m wide, 75 mm (3 inches) thick.
    Made of “Zerodur”, artificial material with low thermal expansion
    Ceramic material
  - Each segment is so smooth that if it were to the width of the earth, the highest mountain would be 3 feet high.
  - In other words, accurate to 1000th the width of human hair.
  - System of motors keep the mirrors aligned – active optics.


30
32
29
15
33

Mirror Support

168 electronic sensors mounted on the edges of the mirror segments.
3 actuators per segment
Sensors compare height difference between each segment.
Actuators move accordingly.
Aligned two times a second


W3-5
W4-2
W3-1

More facts about Keck

- Total mirror weight is just 14.4 tons.
- The mount is an alt/az mount, which means that it is not aligned with the rotational axis of the earth.
  - Mount weighs 270 tons.
  - Made of steel because it is important to be nonflexible.
  - Alt/Az mounts are cheaper to make the equatorial.
  - But are also more difficult to control.
- They go through some effort to maintain temperature equilibrium.
  - Important for seeing. If the telescope is hotter than the surroundings, it radiates energy, heats the surrounding air and makes the images seem to boil.
  - Chill the interior of both Keck domes.
    - Prevents temperature deformation of the mirror
    - Kept at or below freezing (not such a big deal at Mauna Kea).
  - Each dome has 700,000 cubic feet of air. The air is totally replaced every 5 minutes.

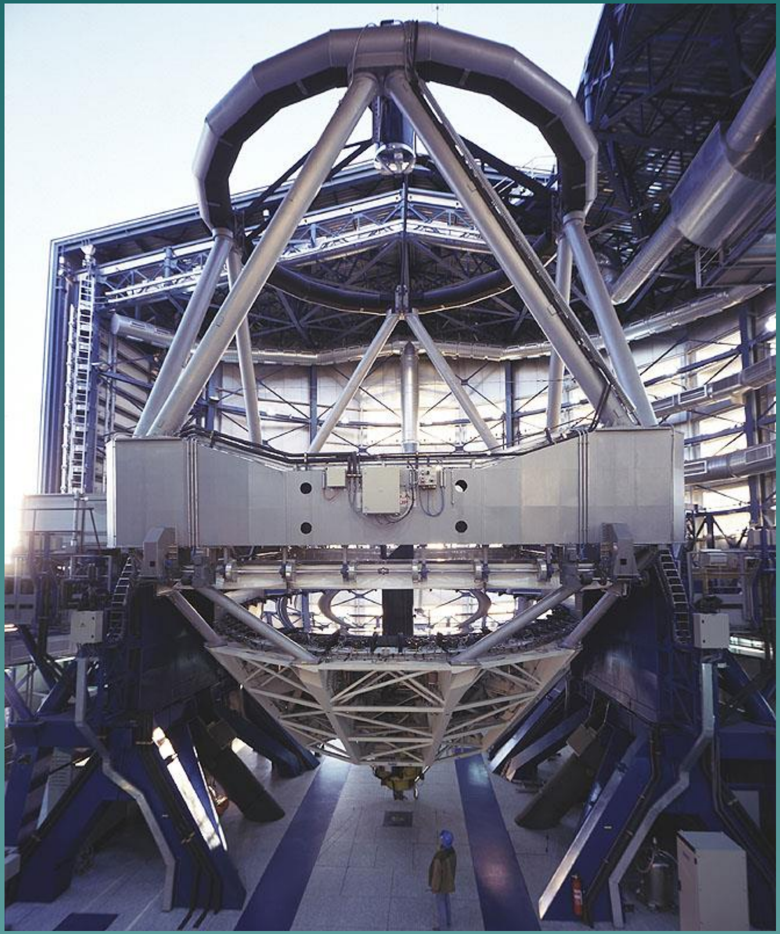

Telescope
Mirror
Guider
Dome
Rotator
LST 18:56:06
HORIZON STOW
KECK II
PRINCETON

The Very Large Telescope (VLT)

- Located in Chile, in the southern hemisphere
- Is actually a system of 4 telescopes that can work together

VLT Today

The VLT



•Four 8.2 meter telescopes
•Each telescope can be used separately or combined into one telescope (interferometry)

- Light-collecting ability which is proportional to its area.
- Mirror's ability to resolve detail. This is proportional to its diameter.

•If one removes pieces from a hypothetical 16 m mirror, one reduces its light collecting ability, but not necessarily its resolution.
•So if you use two telescopes separated by some distance, you can get the resolution of one big telescope.

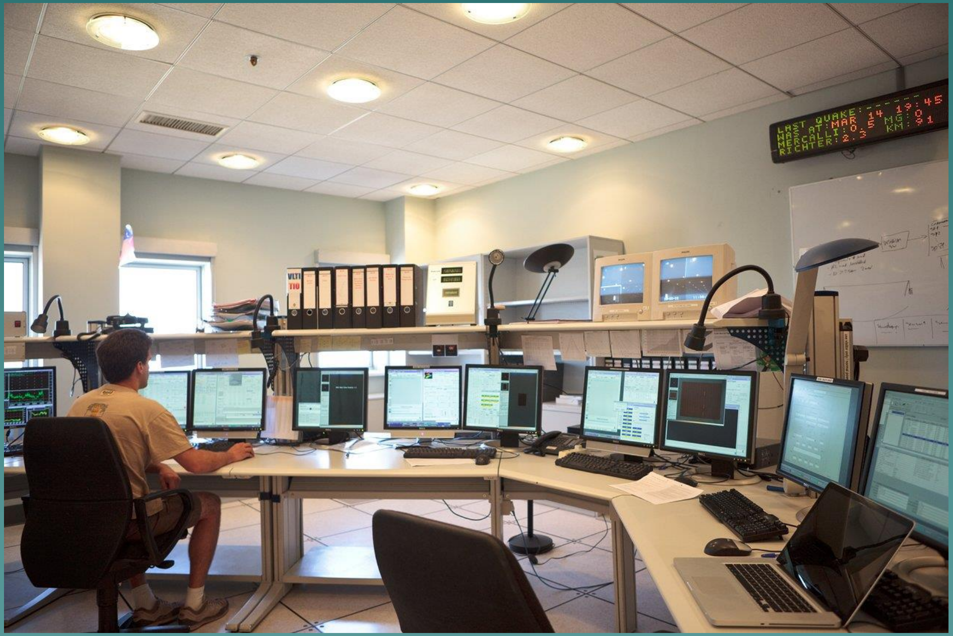
•Alt/Az mount as well (big telescopes are).
•Primary mirror is 8.2m (600 inches) wide and 80 mm thick. Made of Zerodur.
•Mirror weighs 50 tons
•Secondary mirror is 1.1 meters made of beryllium.
•Weigh 42 kg.


www.atacamaphoto.com

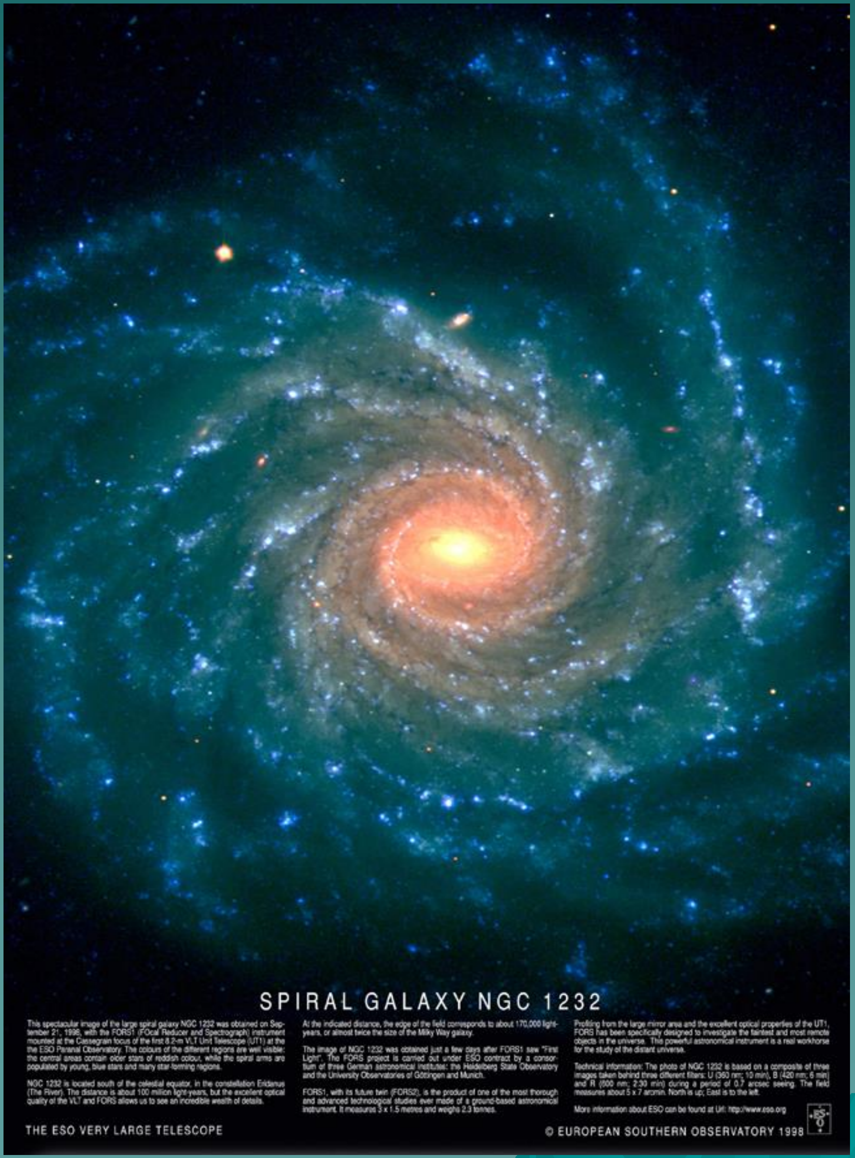

www.atacamaphoto.com


www.atacamaphoto.com

VLT Control Room

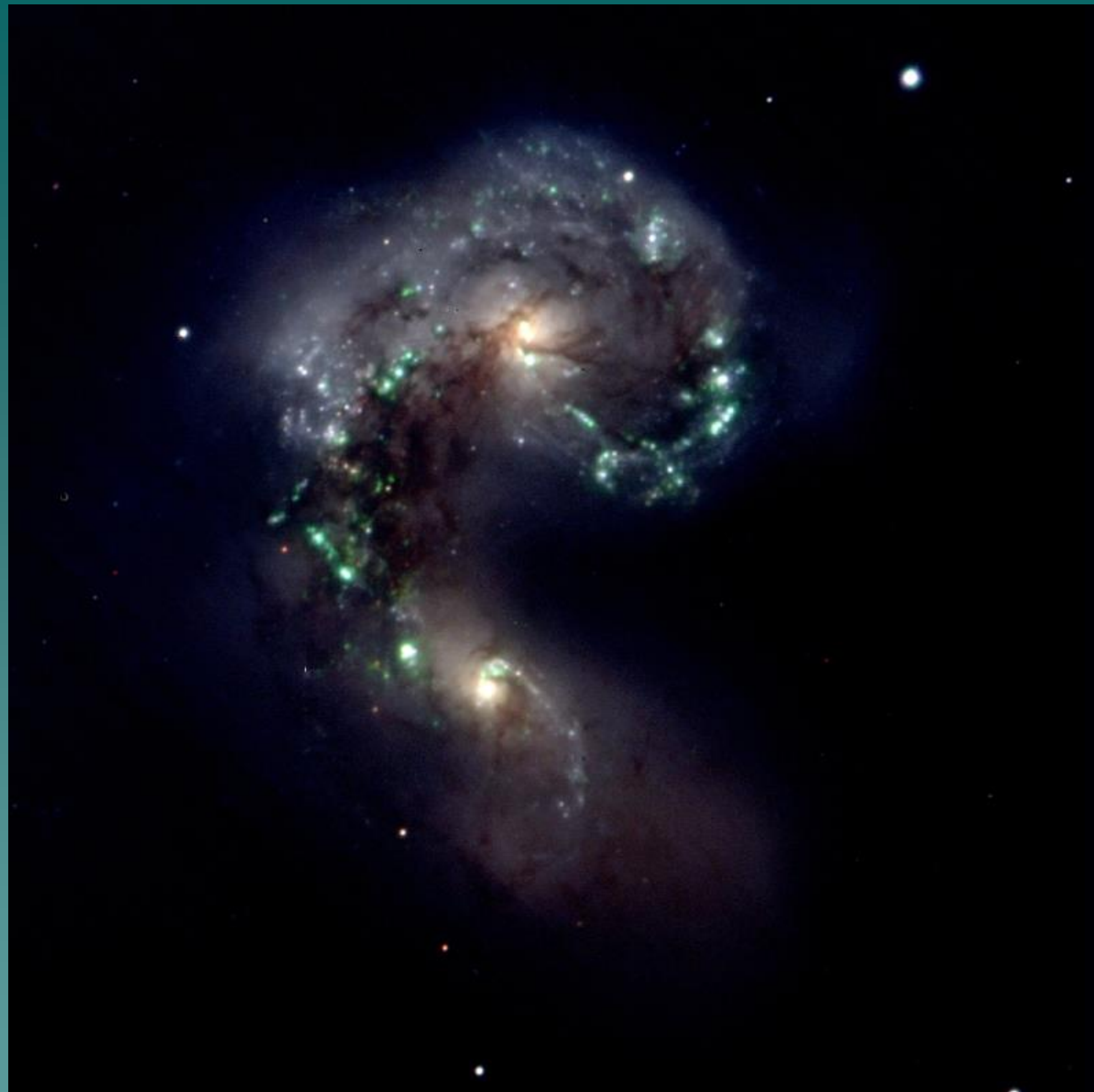


VLT Images


SPIRAL GALAXY NGC 1232
THE ESO VERY LARGE TELESCOPE
© EUROPEAN SOUTHERN OBSERVATORY 1998

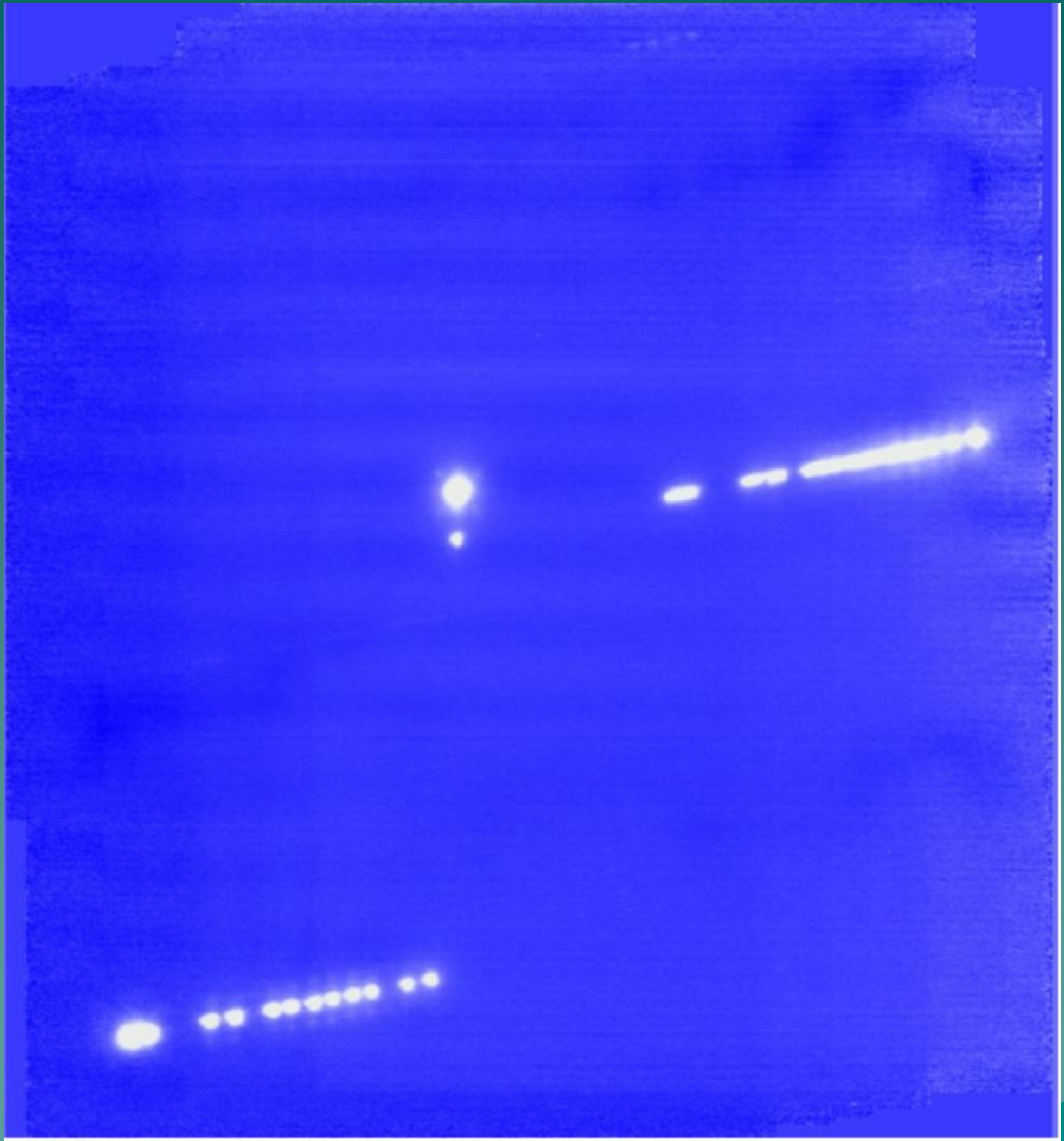
Spiral Galaxy Messier 83
(FORS / VLT)

ESO PR Photo 24b/05 (August 10, 2005)



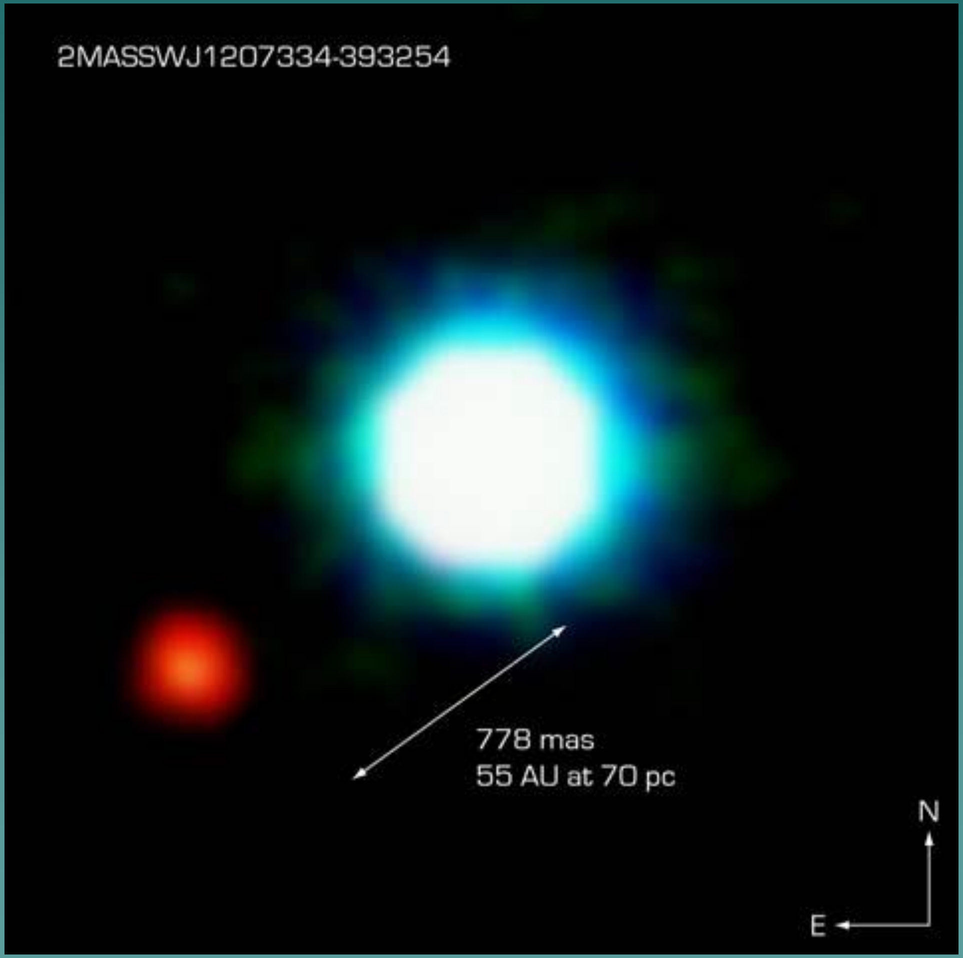
VIMOS Image of the Antennae Galaxies NGC 4038/39
(VLT MELIPAL + VIMOS)

ESO PR Photo 09a/02 (13 March 2002)



The Pluto-Charon System (NACO/VLT)

The First Image of an Extra Solar Planet?



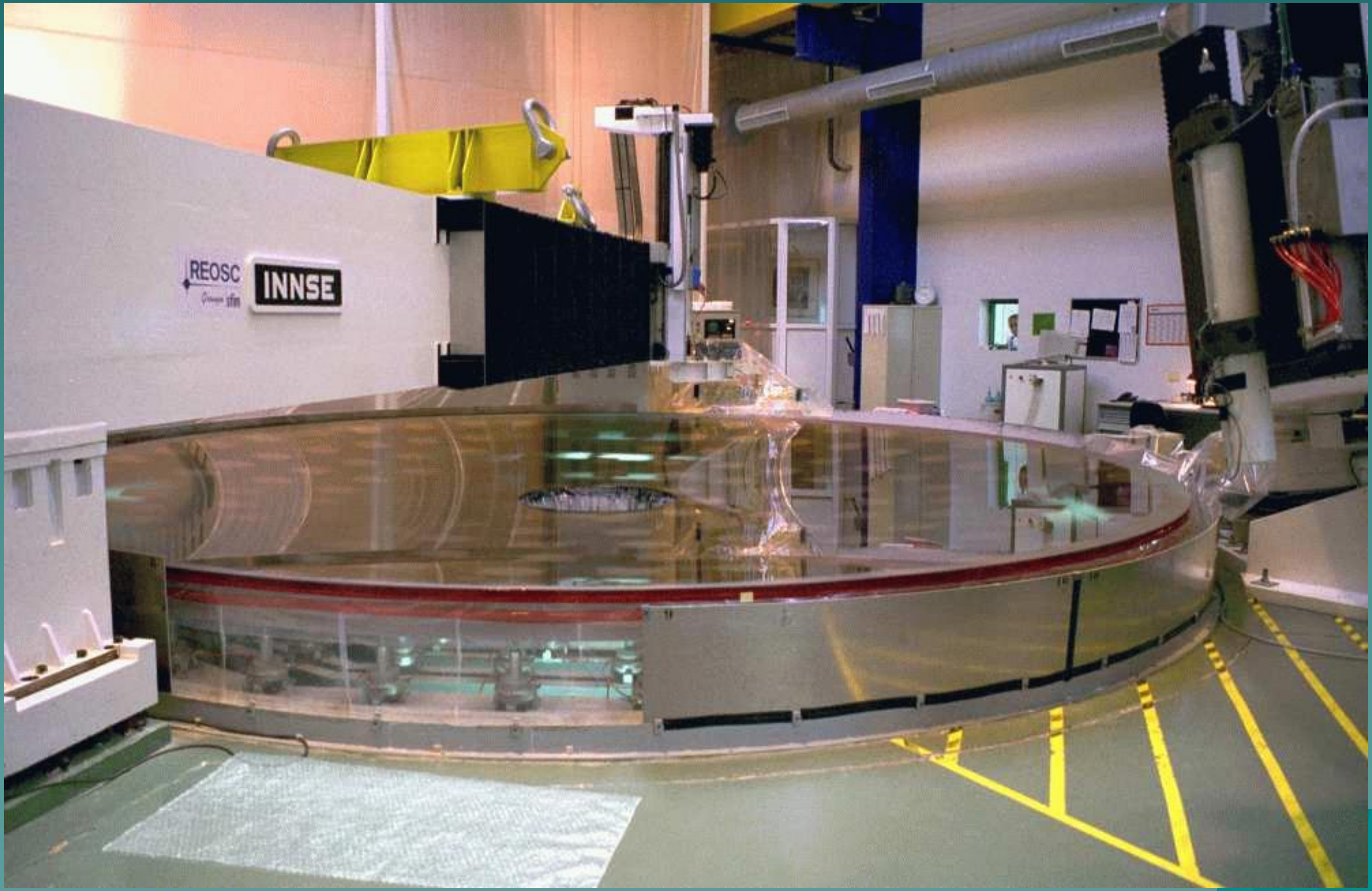
Gemini – The Twins

Gemini (the Twins)

- Another example of a large telescope is Gemini.
- 2 8.1 m telescopes, one in Hawaii and one in Chile.
- Main mirrors are single pieces of glass.
  - Honeycombed – material removed from behind
  - hexagonal blocks that have been fused in a special furnace – spin casting. The entire furnace, containing the mould, rotates so that the surface forms a parabola.
  - Keeps spinning as furnace cools.
  - 20 cm thick.
  - Very accurate polishing.
- Secondary mirrors formed same way
  - 1 meter
  - Supporting ribs 3mm wide
  - Weigh 50 kg
- Because the mirror is so thin, it is prone to deformation.
  - Complex mirror cell system of 120 actuators which push and pull parts of the mirror every few minutes.

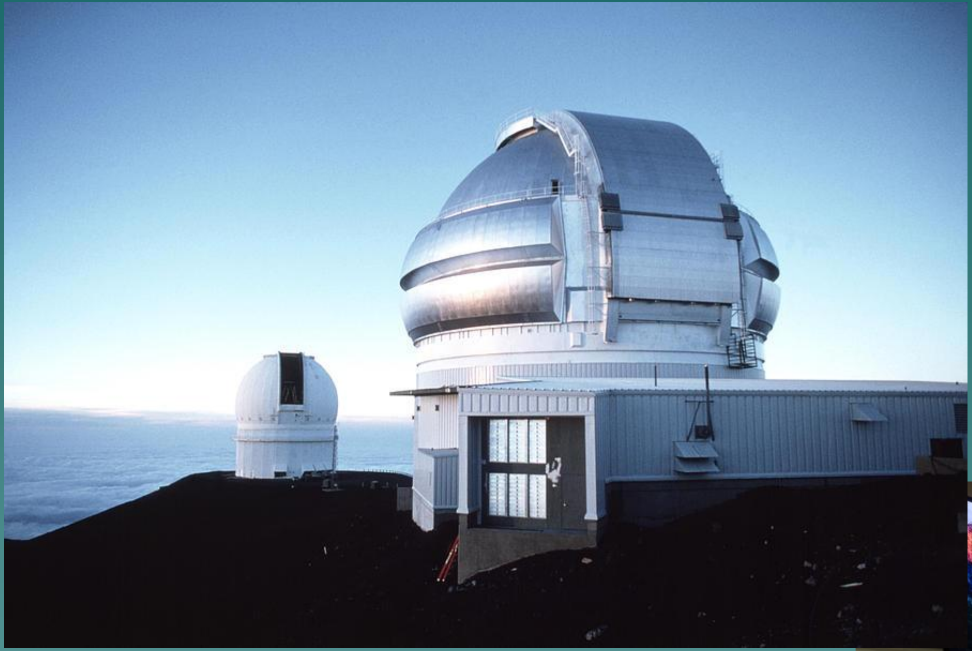
Gemini Mirror

Mirror Polishing



Housekeeping at Gemini

Gemini Dome

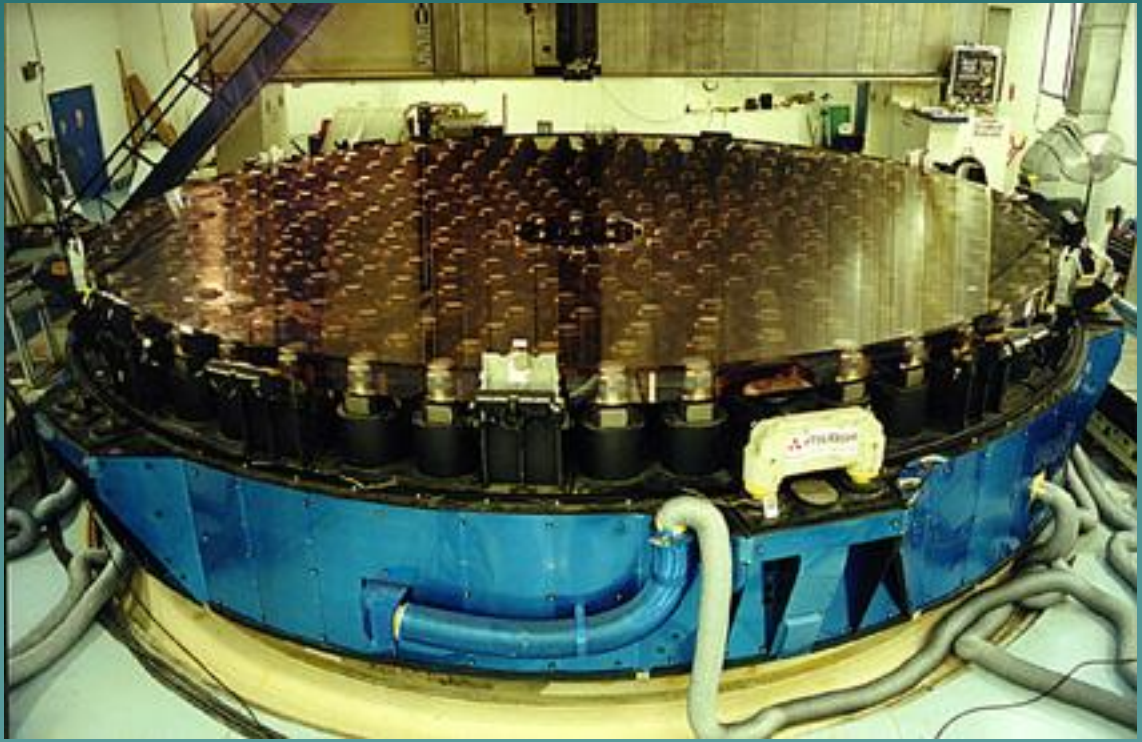


Gemini Images

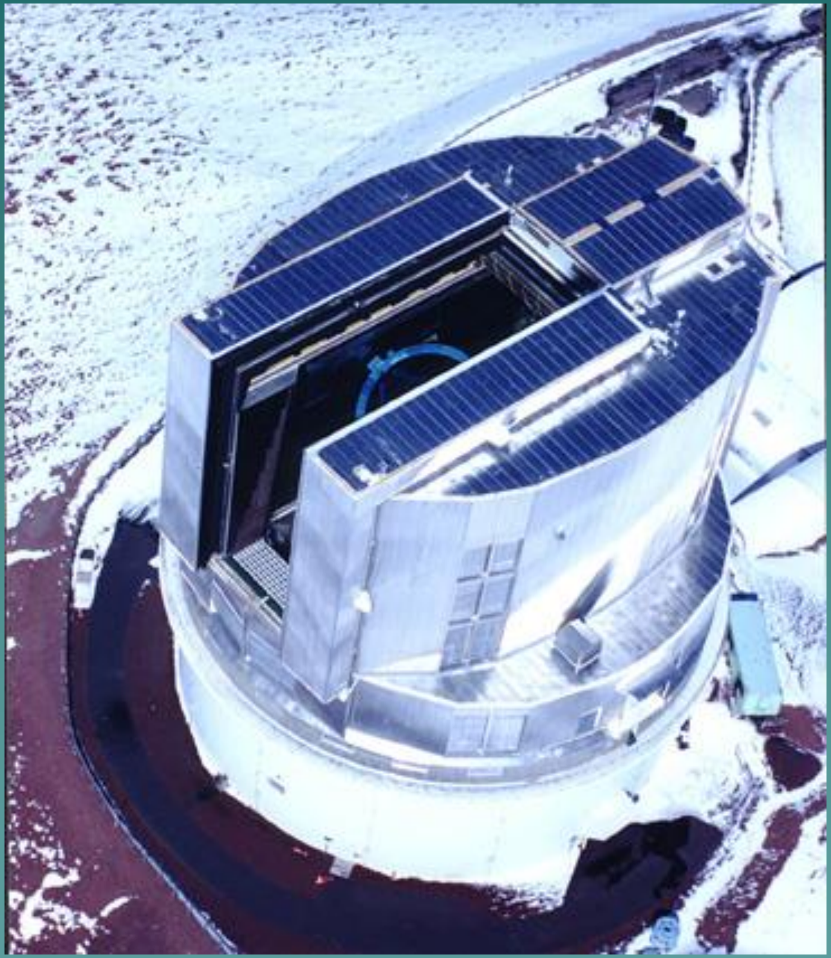
Subaru Telescope

- 8.2 meter telescope
- Main mirror is 30 cm thick.
- Took three years to produce the piece of glass this mirror came from and another 4 years to produce a finished mirror.
- Uses 261 actuators to maintain mirror shape
- One unique aspect – it has a magnetic drive. Most telescopes use a system of gears.
- Unique dome designed to reduce turbulence.
  - Cylinder rather than a hemisphere
  - Prevents warm/turbulent air from entering from the outside

Subaru Mirror



Subaru Dome



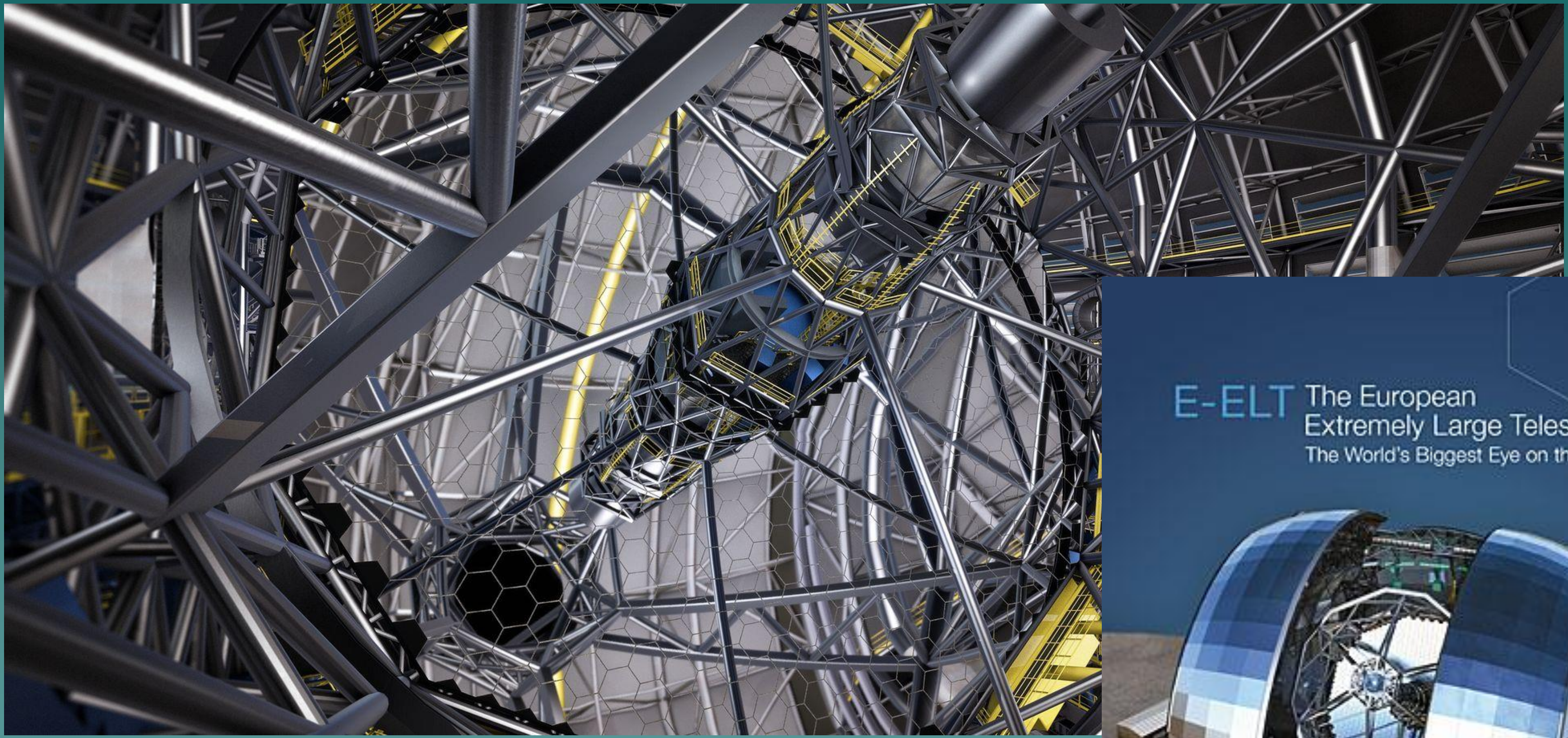
Telescopes of the Future

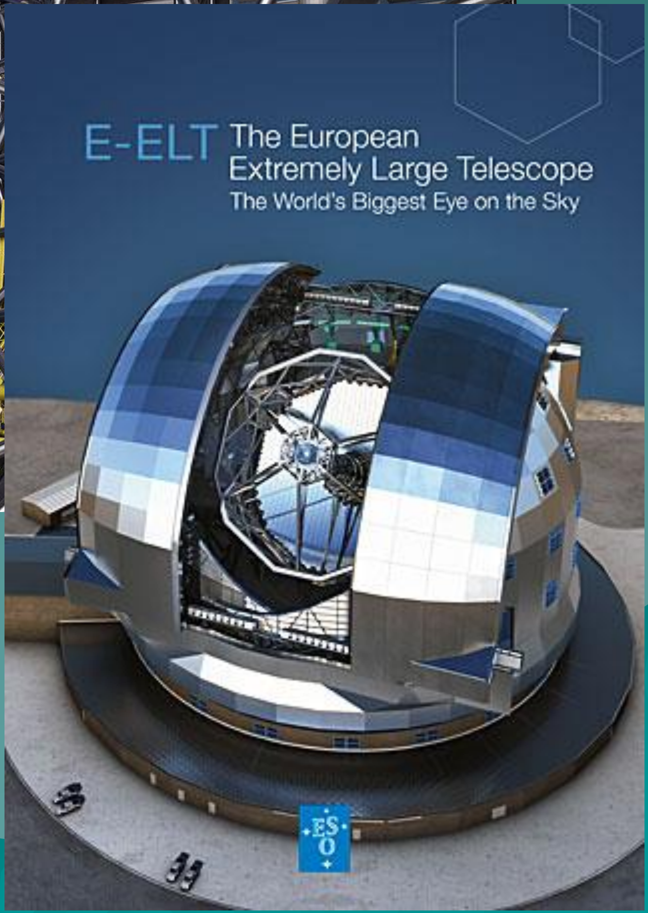
Thirty Meter Telescope - Hawaii

Giant Magellan Telescope - Chile

LSST - Chile

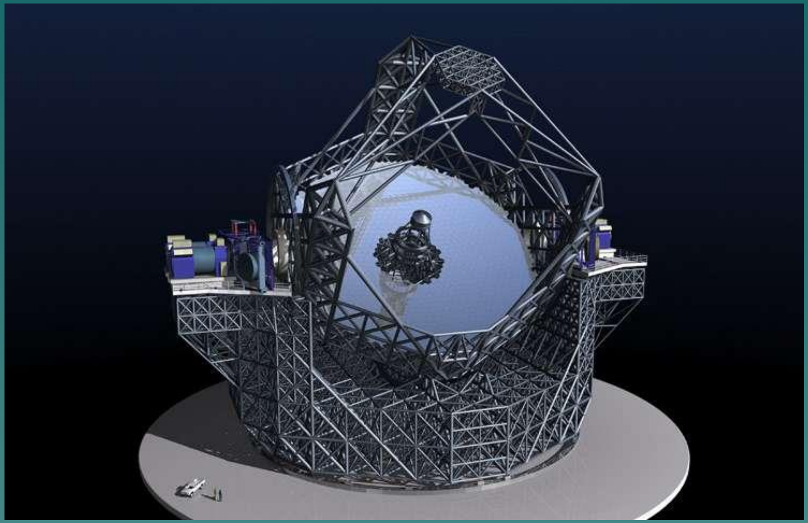
European ELT





- 39 meter (128 ft) telescope
- 798 segments in mirror
- Construction began in 2017 – finish 2024

Construction of ELT



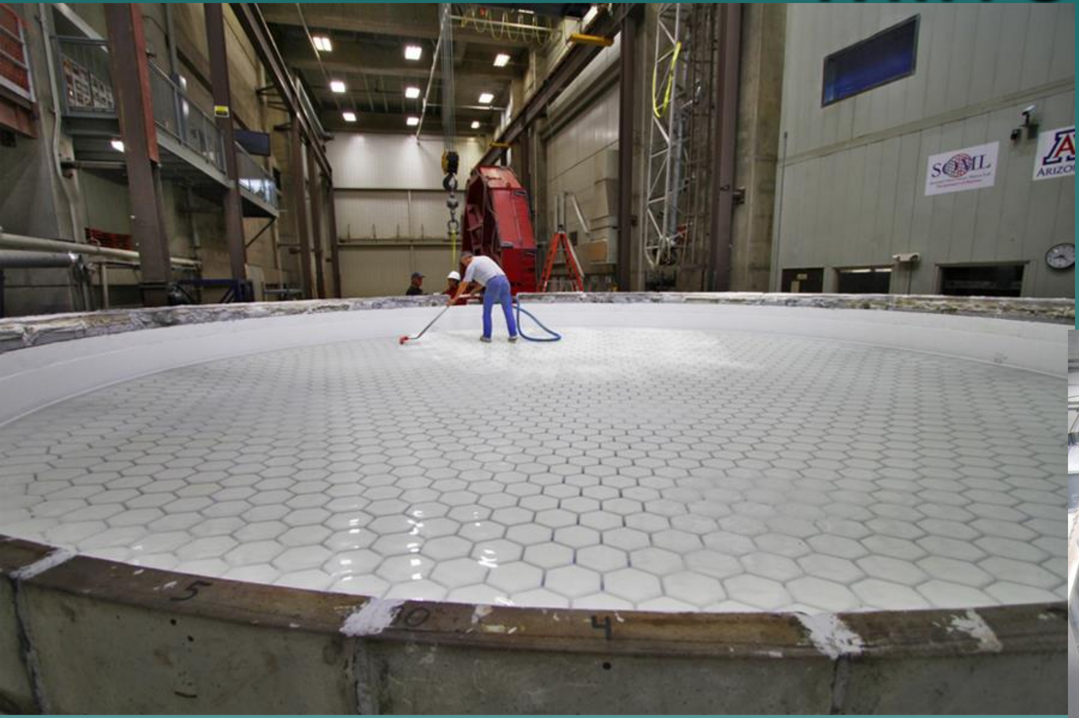
ELT Mirror

798 segments

The Giant Magellen Telescope

Construction Site

Giant Magellen Telescope Mirror



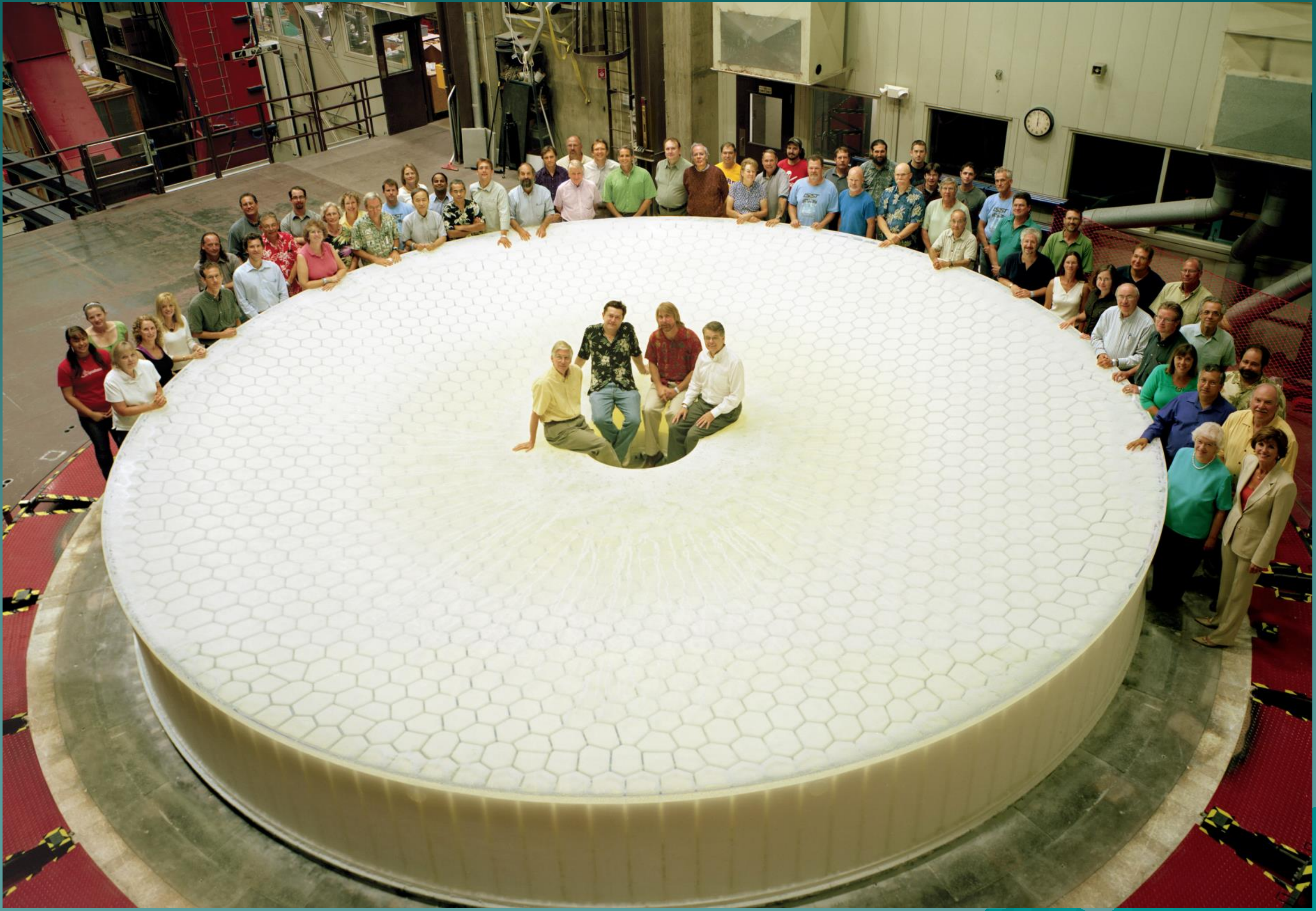
7 Mirror Segments – each 8.4m
combined for 25 m total aperture

The Finished Product

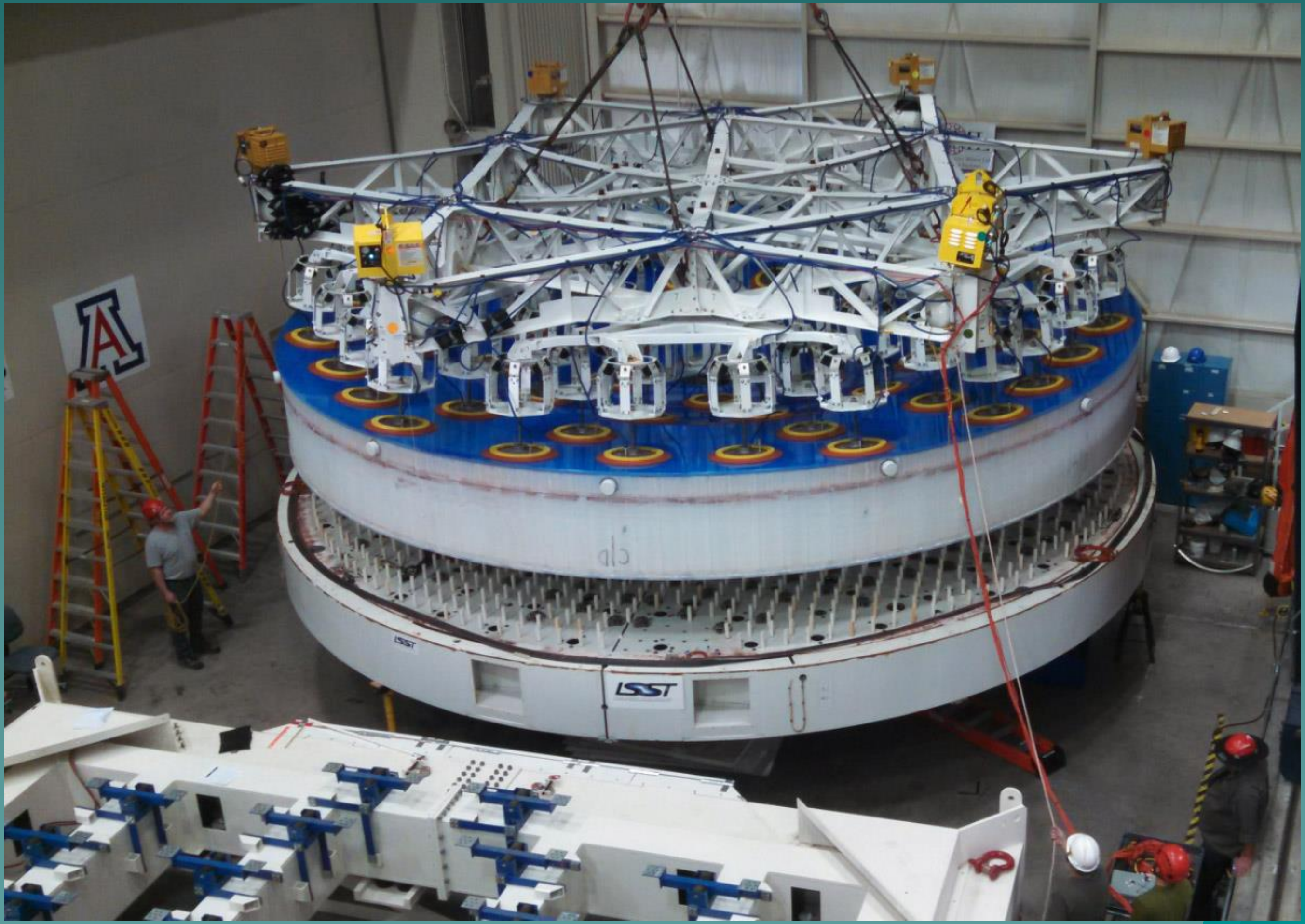
LSST

- 8.4 m mirror (27 ft)
- 3200 megapixel camera

Calibration telescope

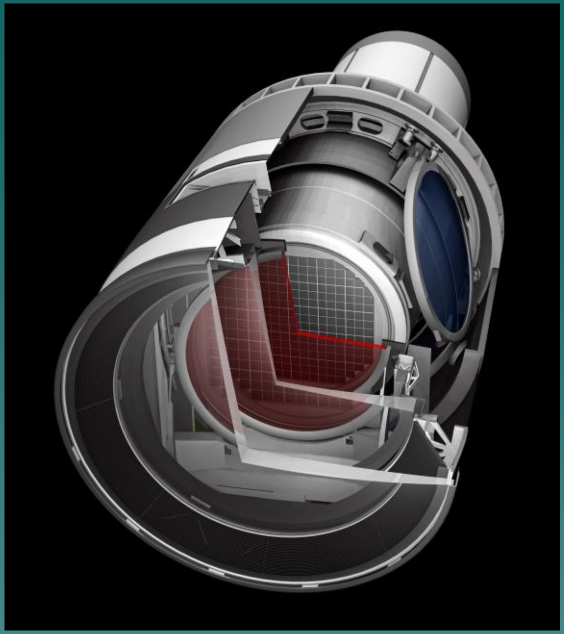


LSST Telescope

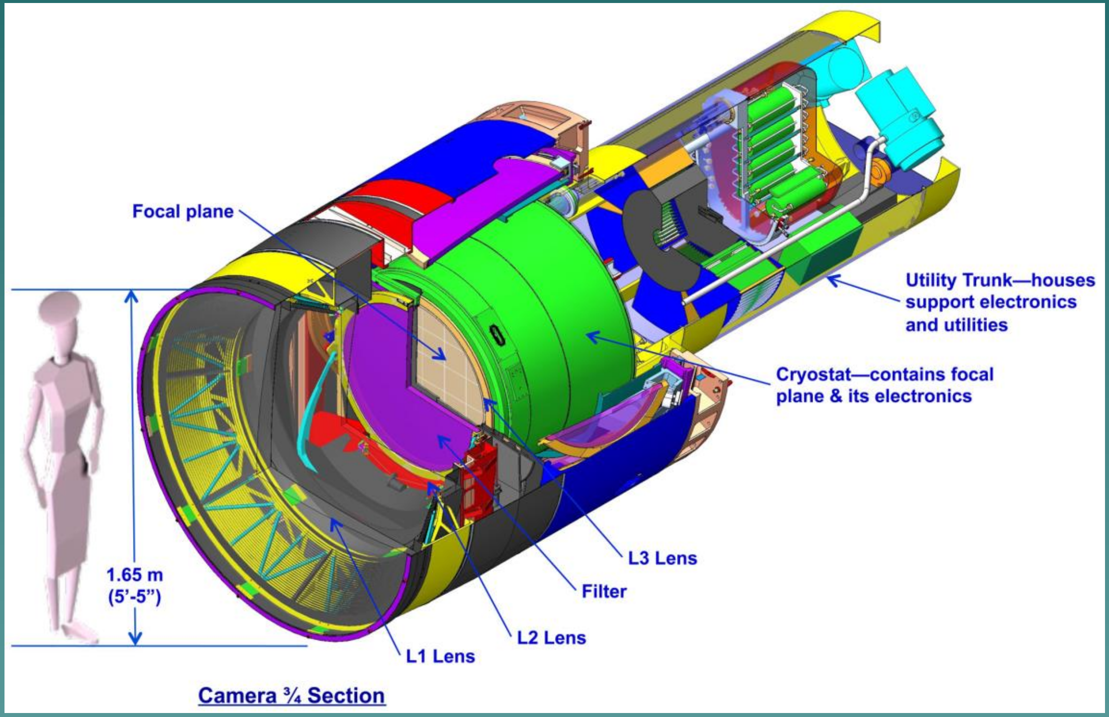



WWW.ASTURFEITO.COM
2018-04-12 CEST 12:00:02
LSST
Large Synoptic Survey Telescope
GHESA
asturfeito

The Camera

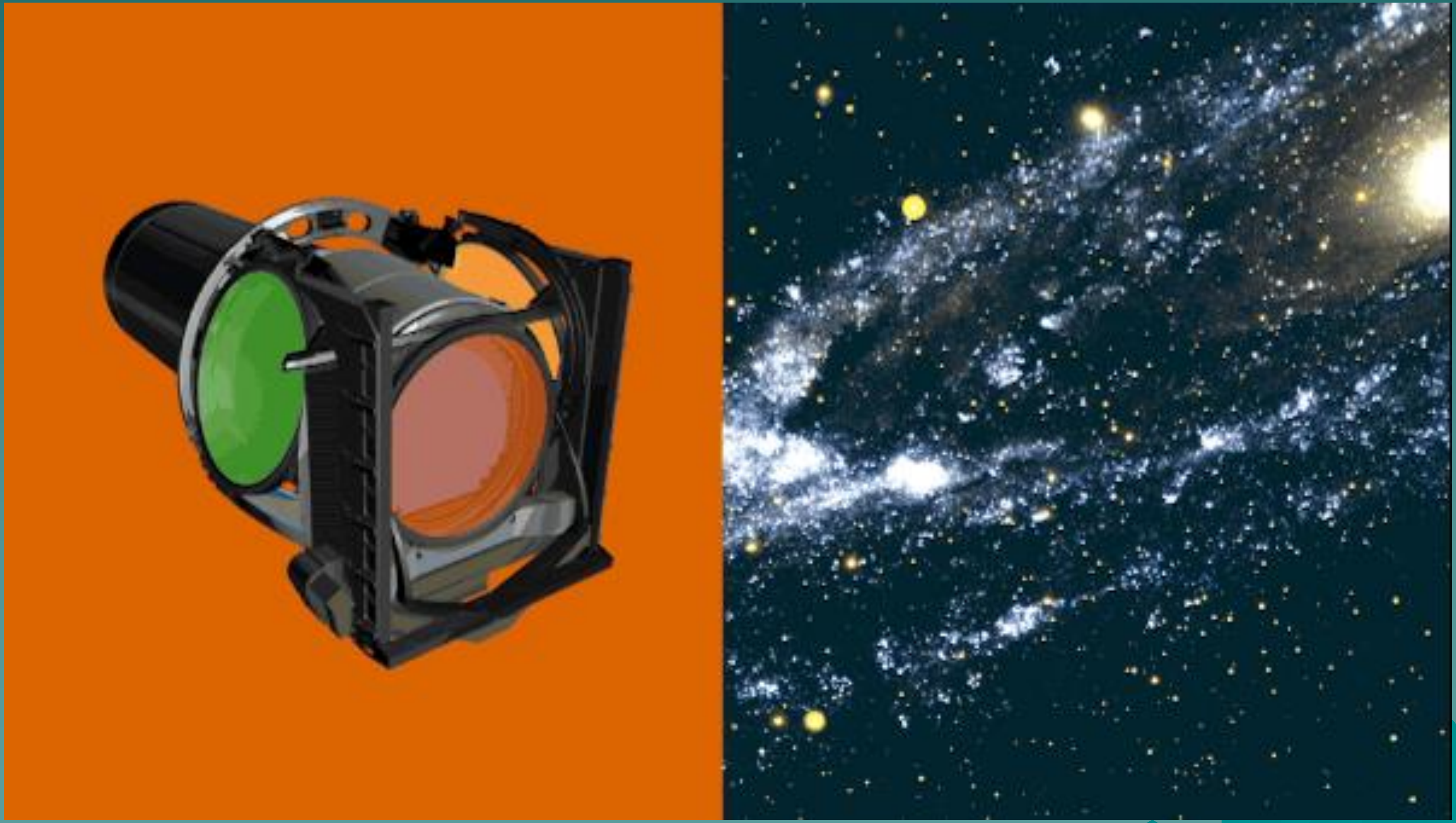


- Largest camera ever constructed (5.5x9.8ft)
- Weight 6200 lbs
- Sensitive 0.3 – 1 micron in wavelength
- Image surface is 25 inches
- 189 16 megapixel detectors
- 3.2 gigapixels
- Displaying one full sky image required 1500 HD TV displays



Detector Size

Filters

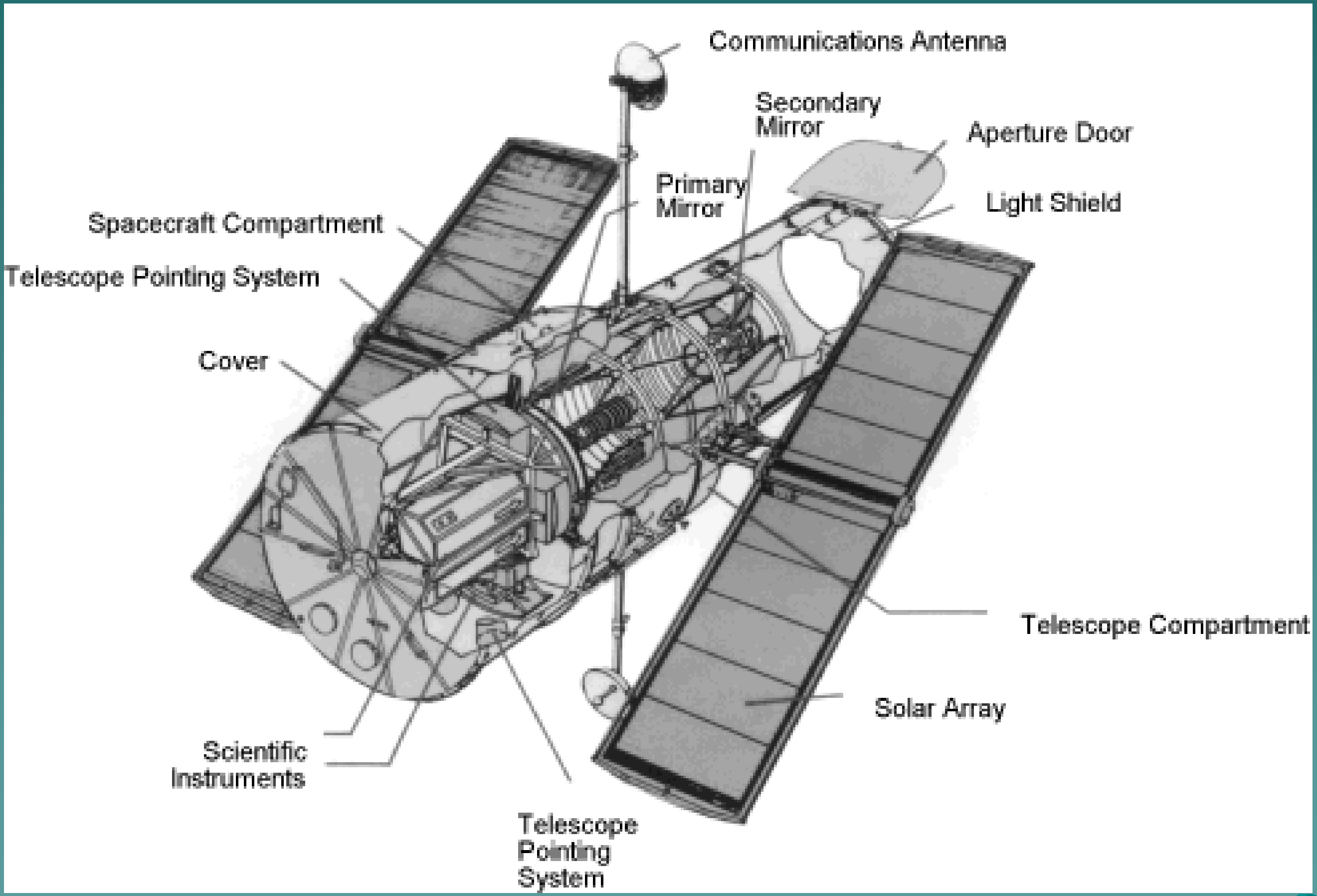


LSST Output

- 6 million gigabytes per year
- Equivalent to 800,000 images with a "normal" 8 megapixel camera.
- Final raw image archive – 60 Petabytes
- Bandwidth at the observatory – 600 gigabytes per second
- 10 million alerts per night (things that change)
- 11 official data releases
- 5.5 million total images
- First data release – 350 billion sources
- DR11 – 7 trillion sources

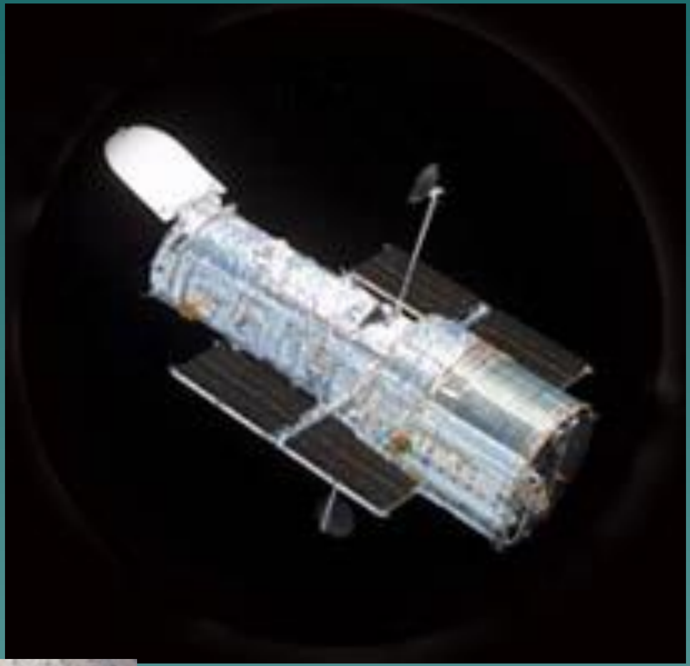
Telescopes in Space!

Hubble Space Telescope

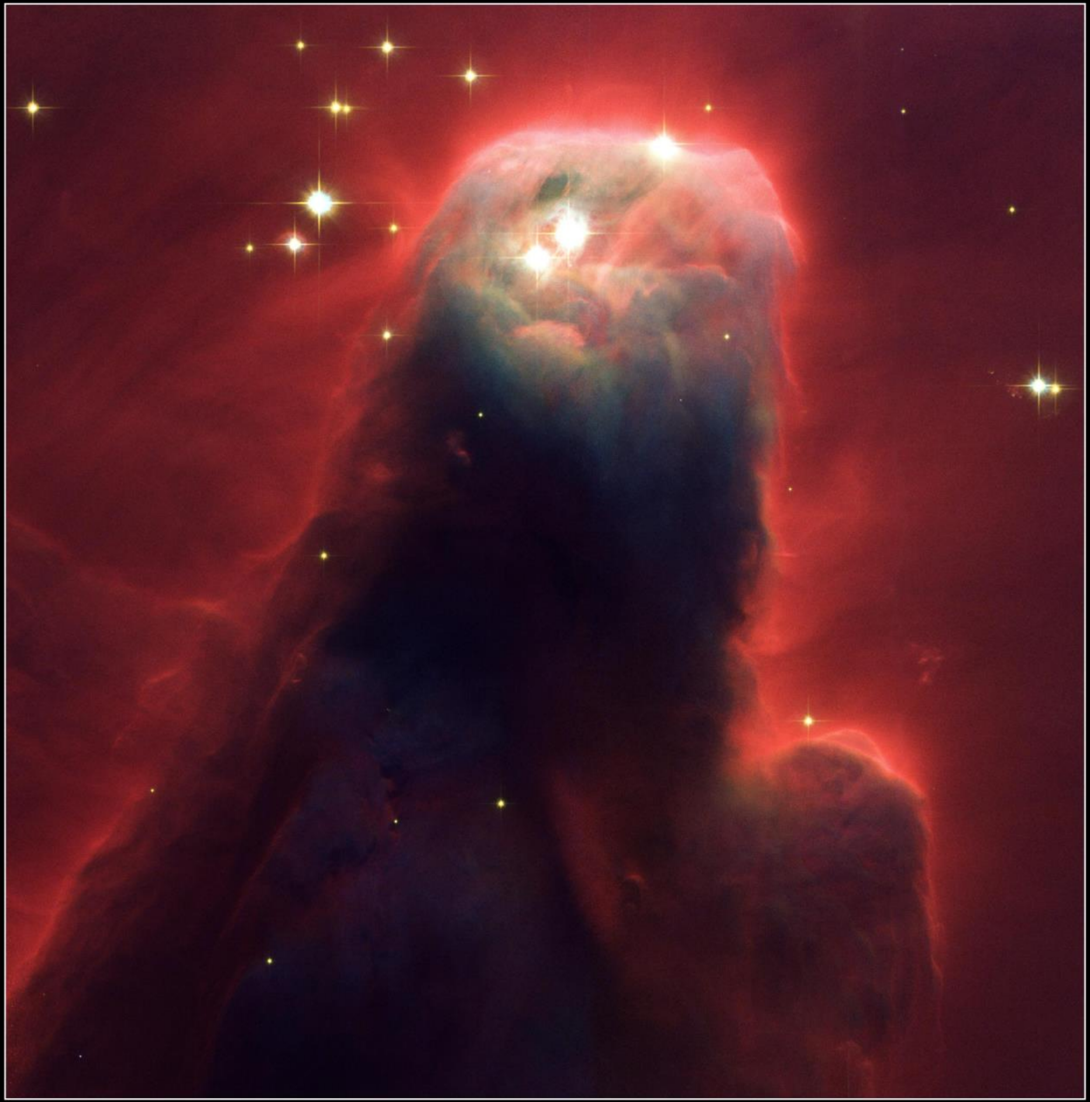


Hubble Space Telescope

- Actually a small telescope – 2.4 meters
- Big advantage – It is above the atmosphere! Excellent seeing!
- Disadvantage – very expensive




NASA



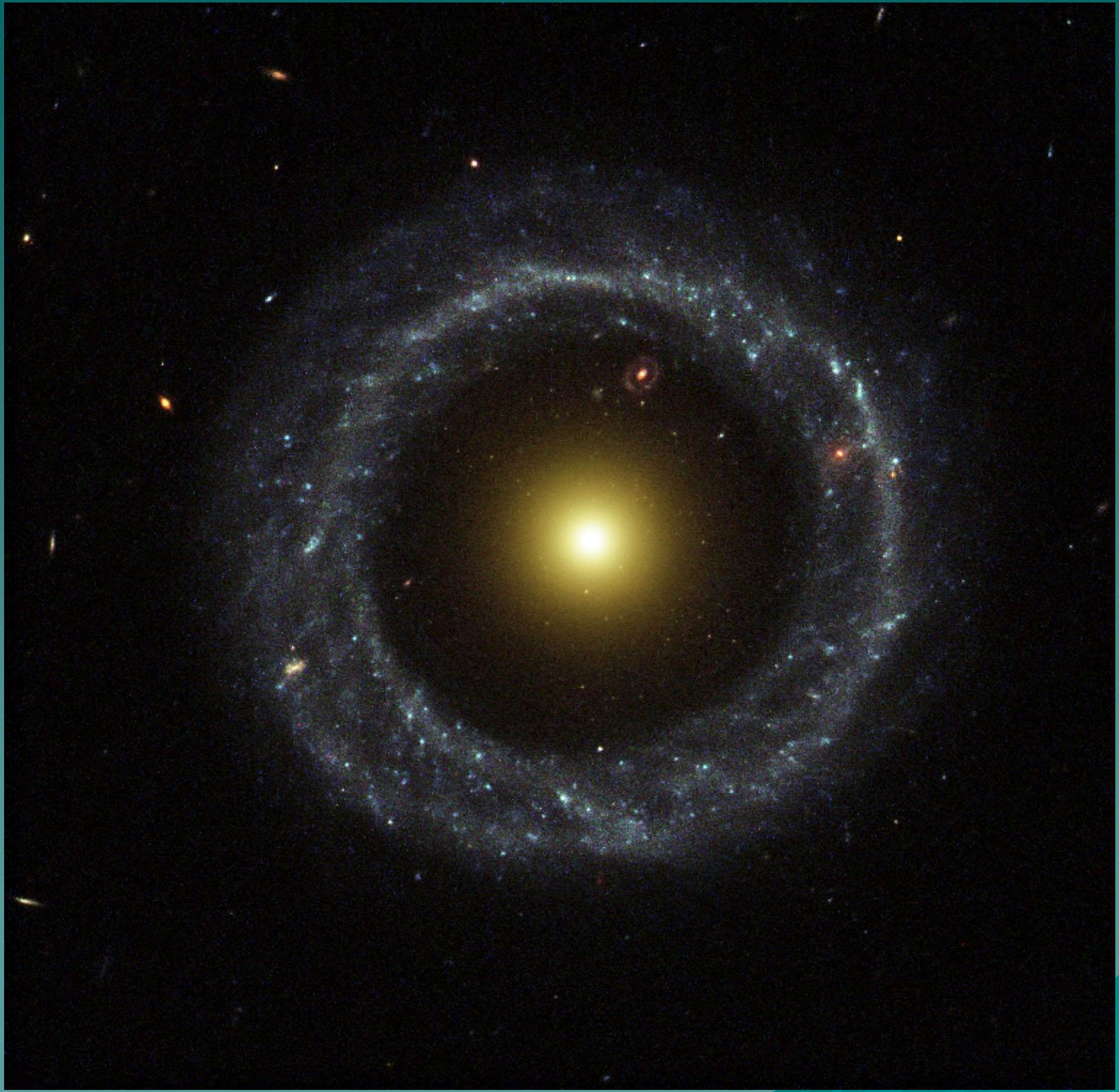
Cone Nebula

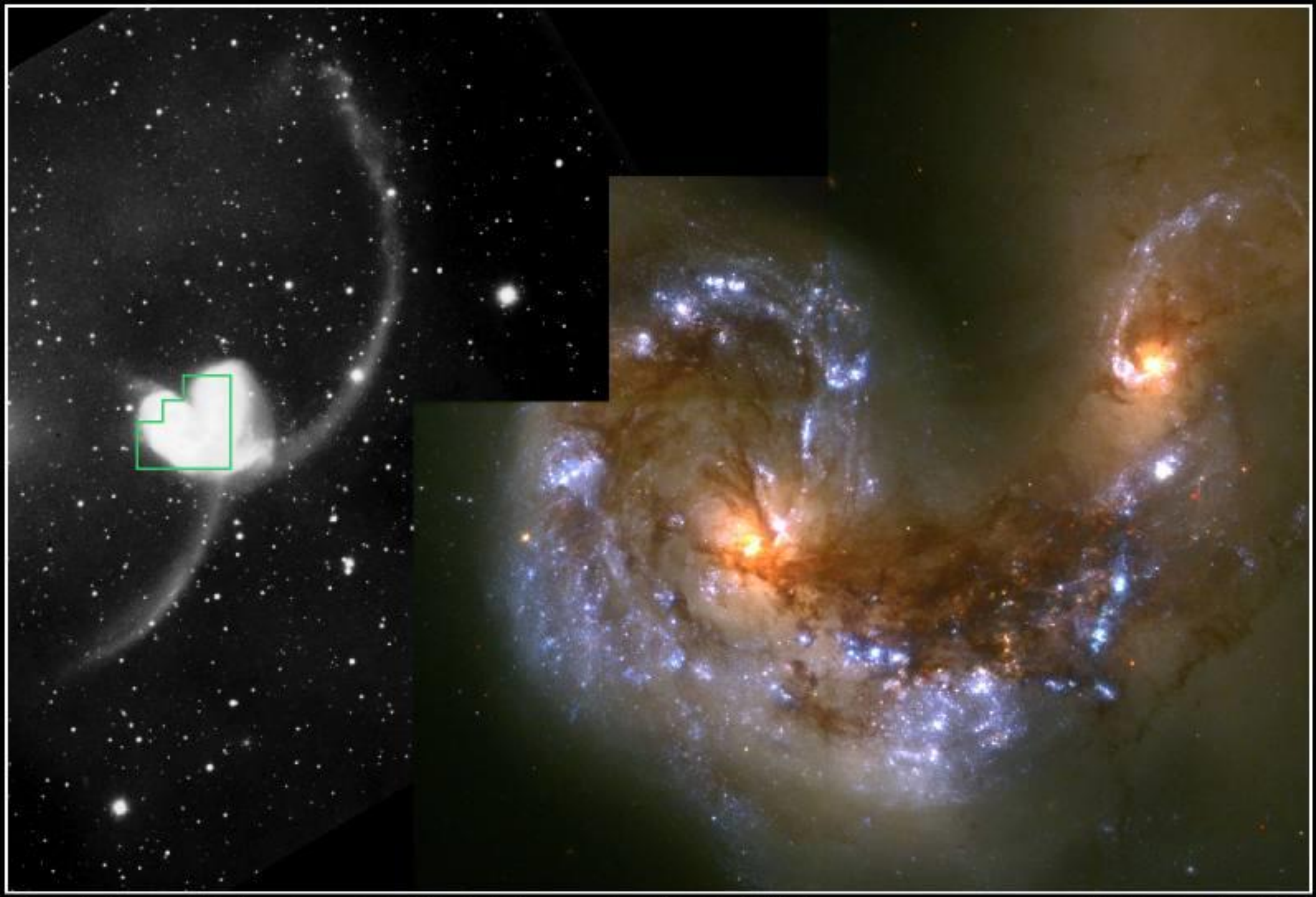
Hubble Space Telescope • Advanced Camera for Surveys

NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M. Clampin (STScI), G. Hartig (STScI), the ACS Science Team and ESA • STScI-PRC02-11b

Tadpole Galaxy • UGC 10214
Hubble Space Telescope • Advanced Camera for Surveys

NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M. Clampin (STScI), G. Hartig (STScI), the ACS Science Team and ESA • STScI-PRC02-11a

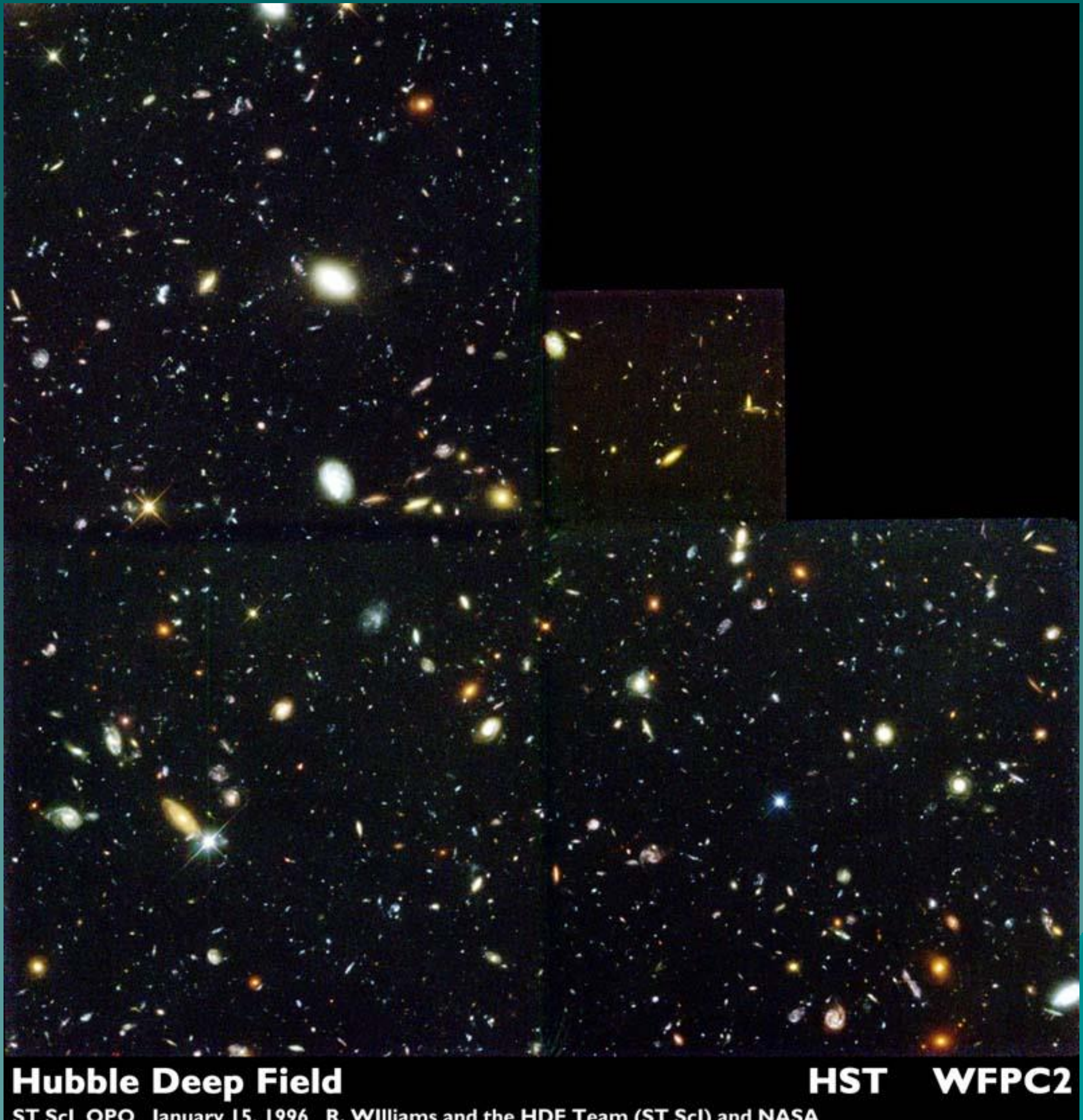


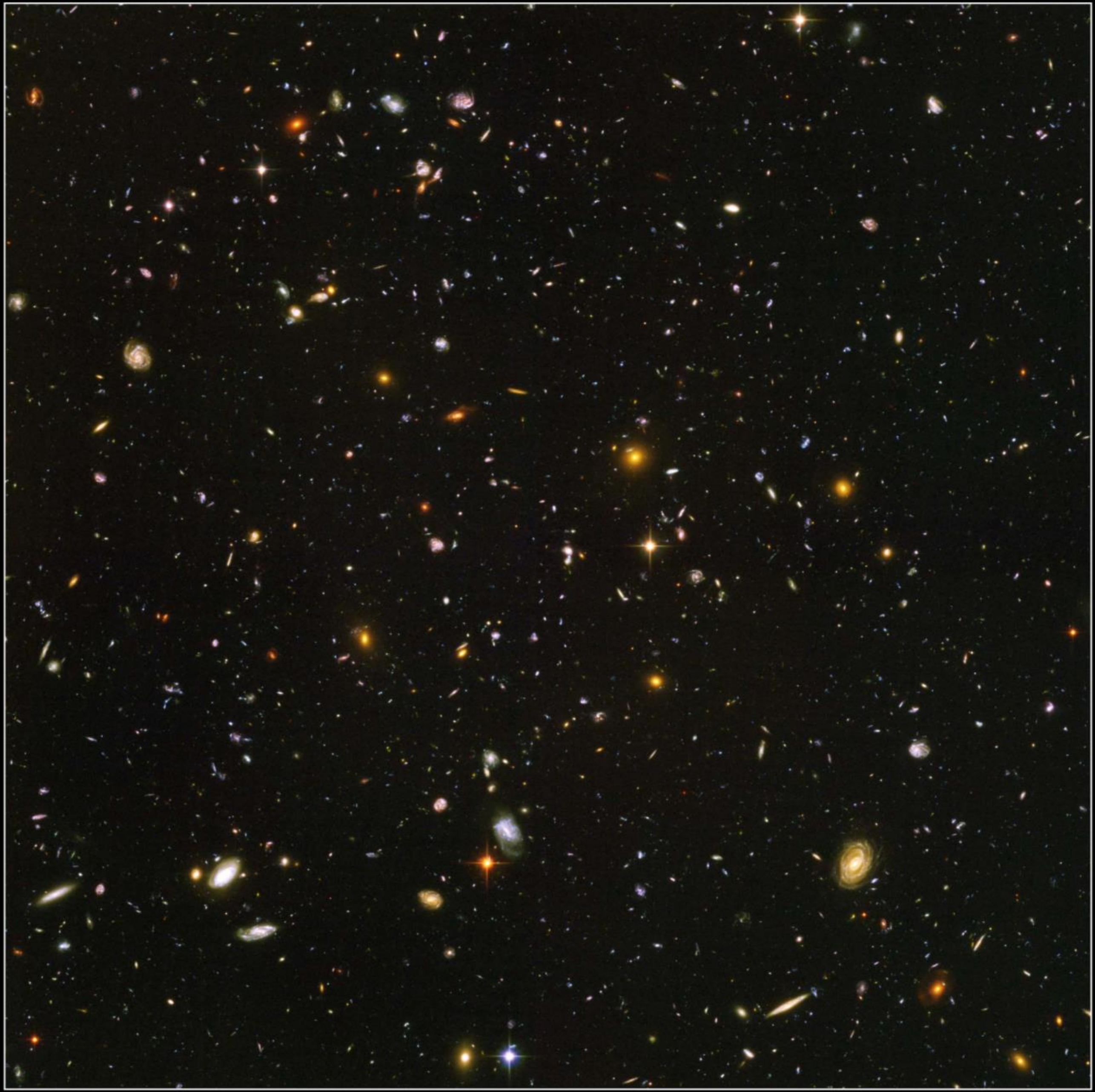


Colliding Galaxies NGC 4038 and NGC 4039 HST • WFPC2

PRC97-34a • ST ScI OPO • October 21, 1997 • B, Whitmore (ST ScI) and NASA

- 342 separate images
- 100 hrs total exposure



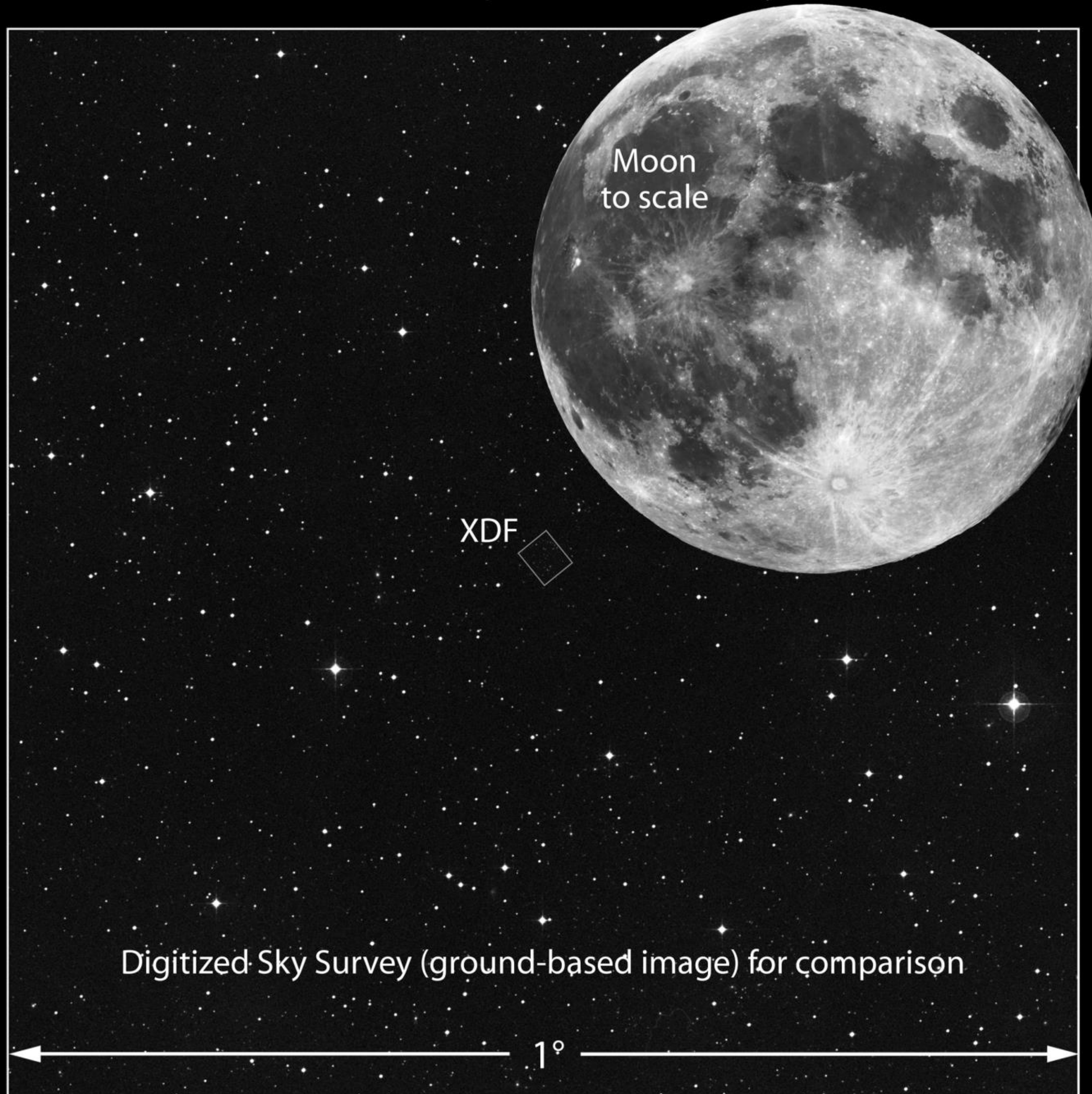


Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

Hubble extreme Deep Field

- Compiled 10 years of images taken 2003-2004
- Center of Hubble Ultra Deep Field
- Field of view is a tiny fraction of the size of the Moon.
- Contains about 5000 galaxies.

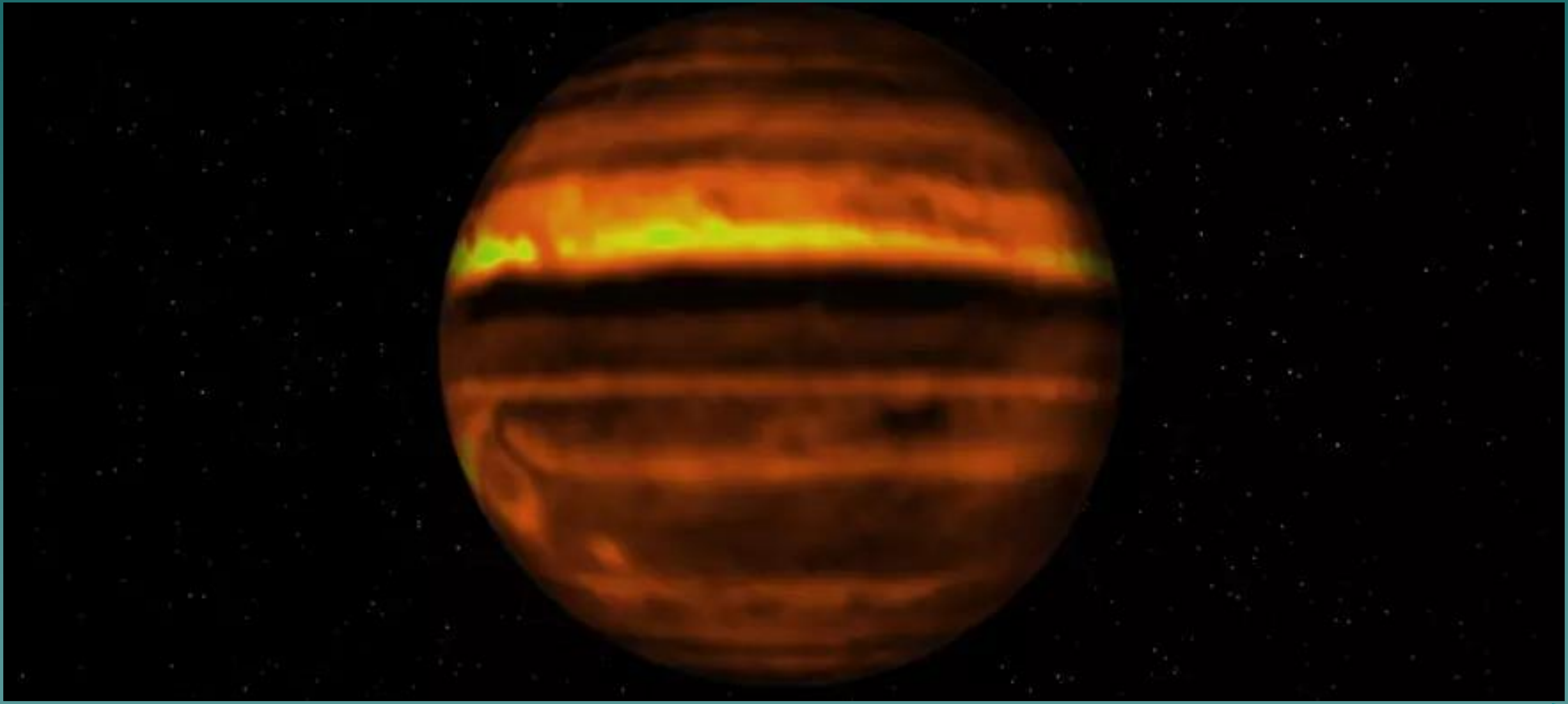
Size of Hubble eXtreme Deep Field on the Sky



ALMA

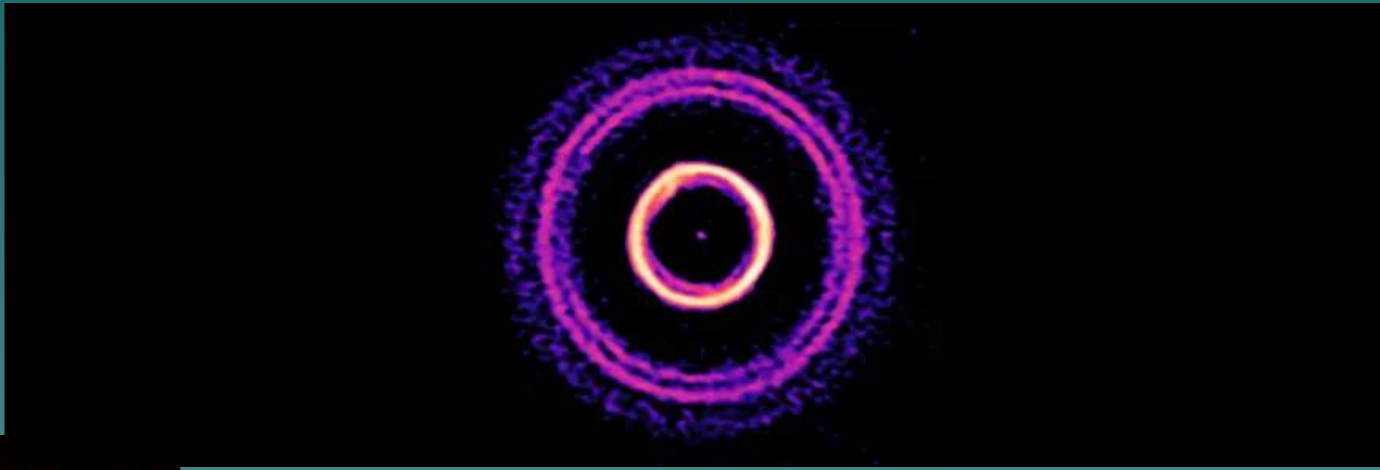
- Atacama Large Millimeter/Submillimeter array
    - Altitude is 16570 ft.
    - Atacama desert is one of the driest places on Earth.
- Most of the light comes from very cold objects like large clouds in space
- 66 high precision antennas
    - Main array is 50 antennas, each 12 m in diameter
- Telescopes act together as a single instrument
    - Can be arranged in different configurations
    - Can be spread over a distance as large as 16 kilometers

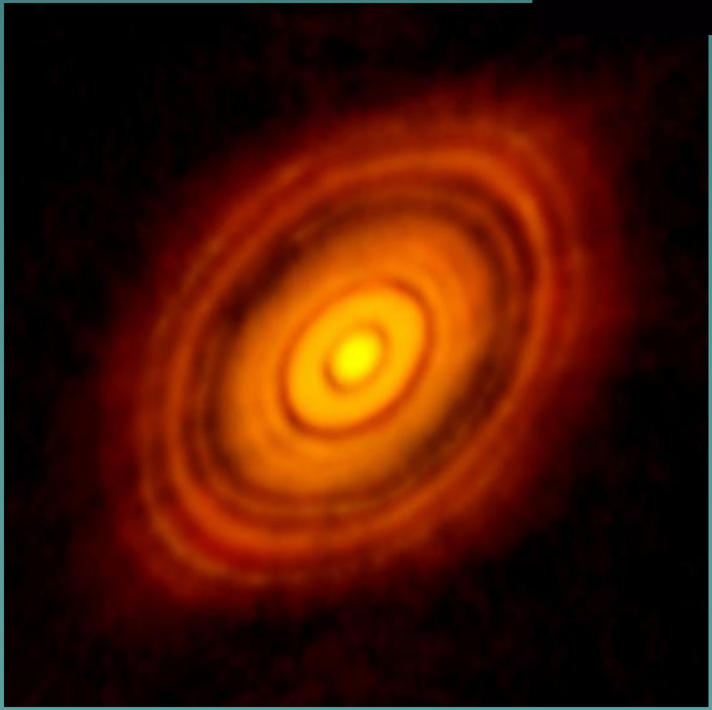
ALMA Observations of Jupiter



- ALMA peers 50 km below the visible cloud deck
- Bright regions show ammonia gas disruptions associated with visible storm in one of Jupiter's belts.

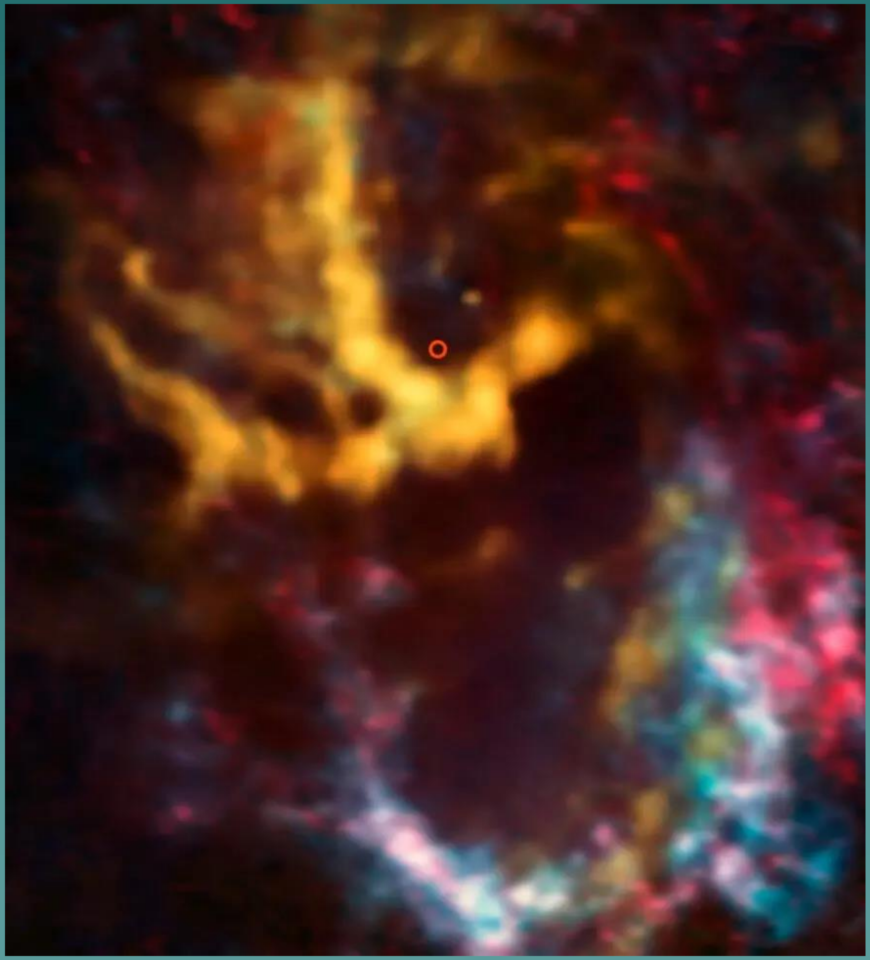
ALMA and Solar Systems





- HD 169142
- Interpreted as single 10x Earth mass planet that is migrating inward, disturbing the disk and creating multiple thin rings.

ALMA and the Center of the Milky Way



- Clouds of carbon monoxide
- 26,000 light years away
- Orbiting about 1 light year from the black hole (red circle)

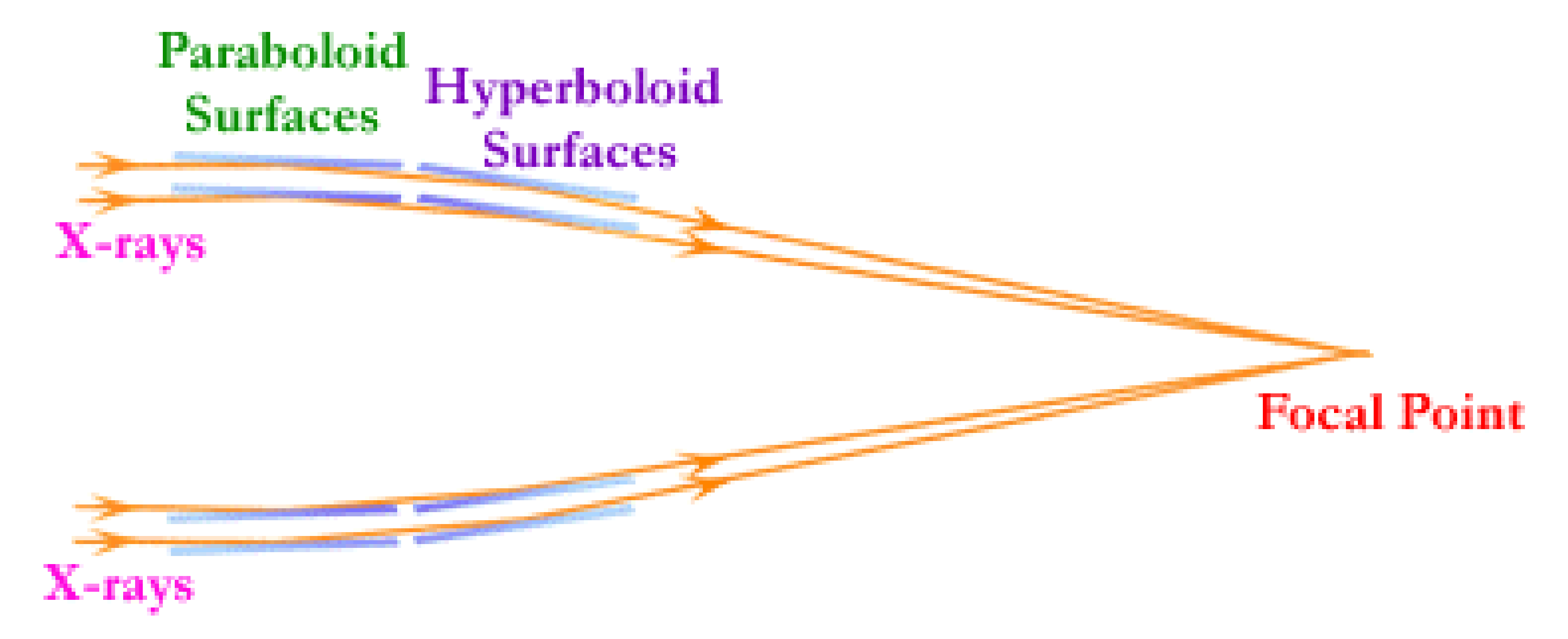
ALMA and Other Galaxies

- Center of galaxy NGC 5643
- Seyfert galaxy
  - Bright central regions
  - Black hole believed to be accreting
- This image shows energetic ionized gas flowing out from the center of the galaxy
- Image combines ALMA and VLT images
- Spiral rotating disk (red) of carbon monoxide
- Outflowing gas traced by ionized oxygen and hydrogen (orange and blue

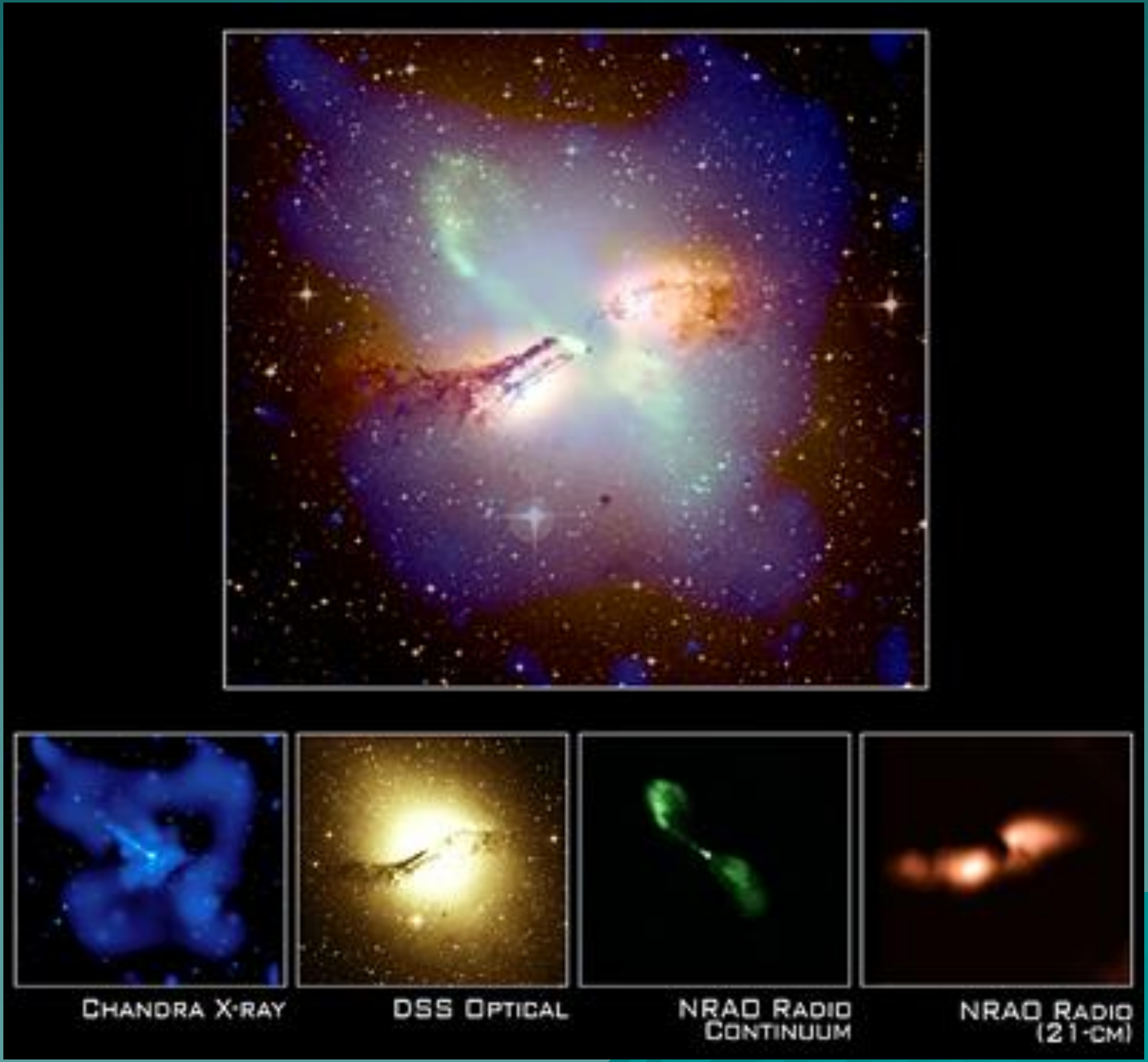
Chandra X-Ray Telescope

Visible Light

How an X-Ray telescope works

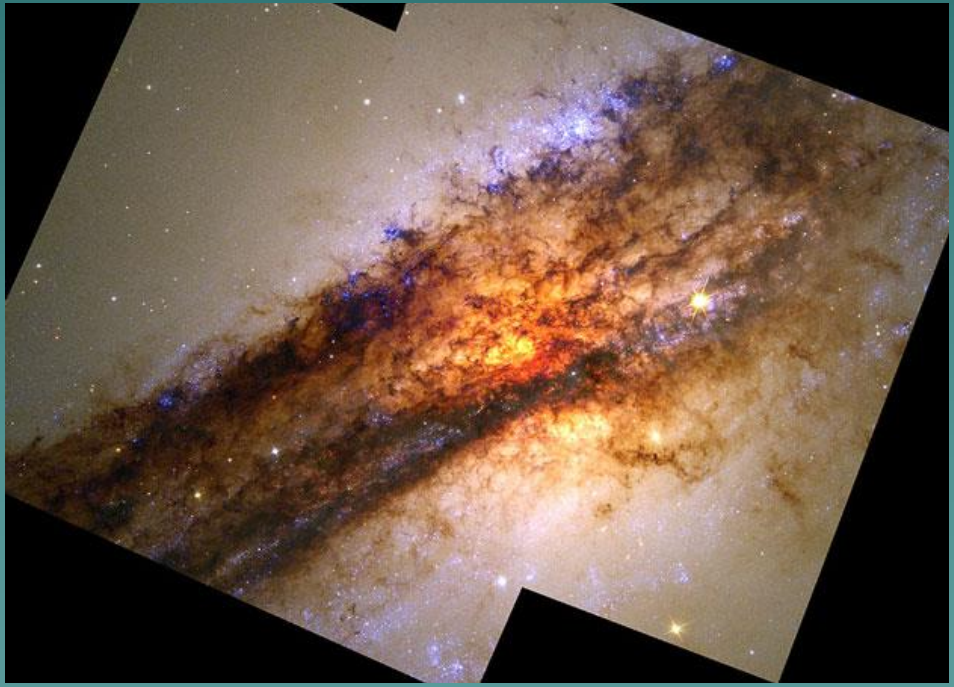


Centaurus A



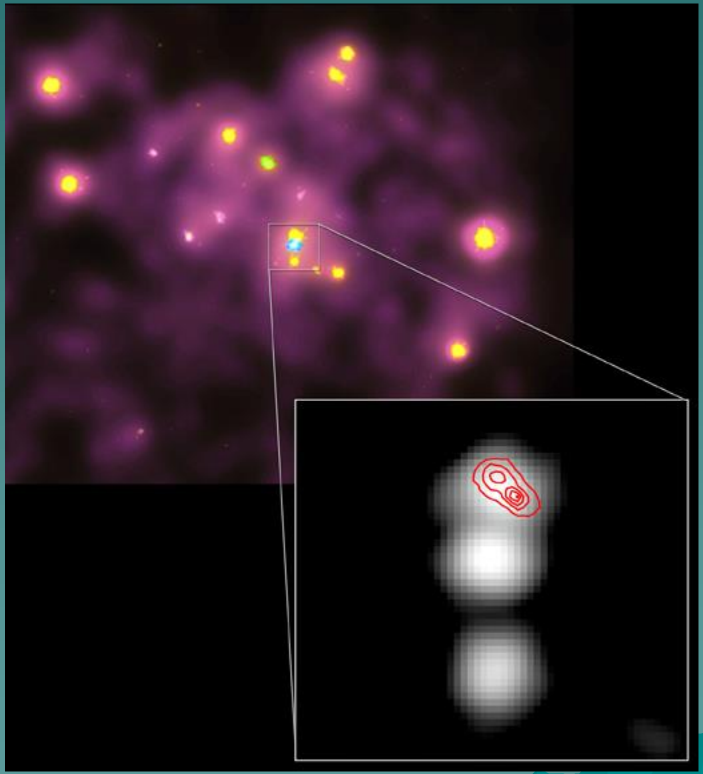
CHANDRA X-RAY
DSS OPTICAL
NRAO RADIO CONTINUUM
NRAO RADIO (21-CM)

More Centaurus A



M31 in X-Rays

X-Rays



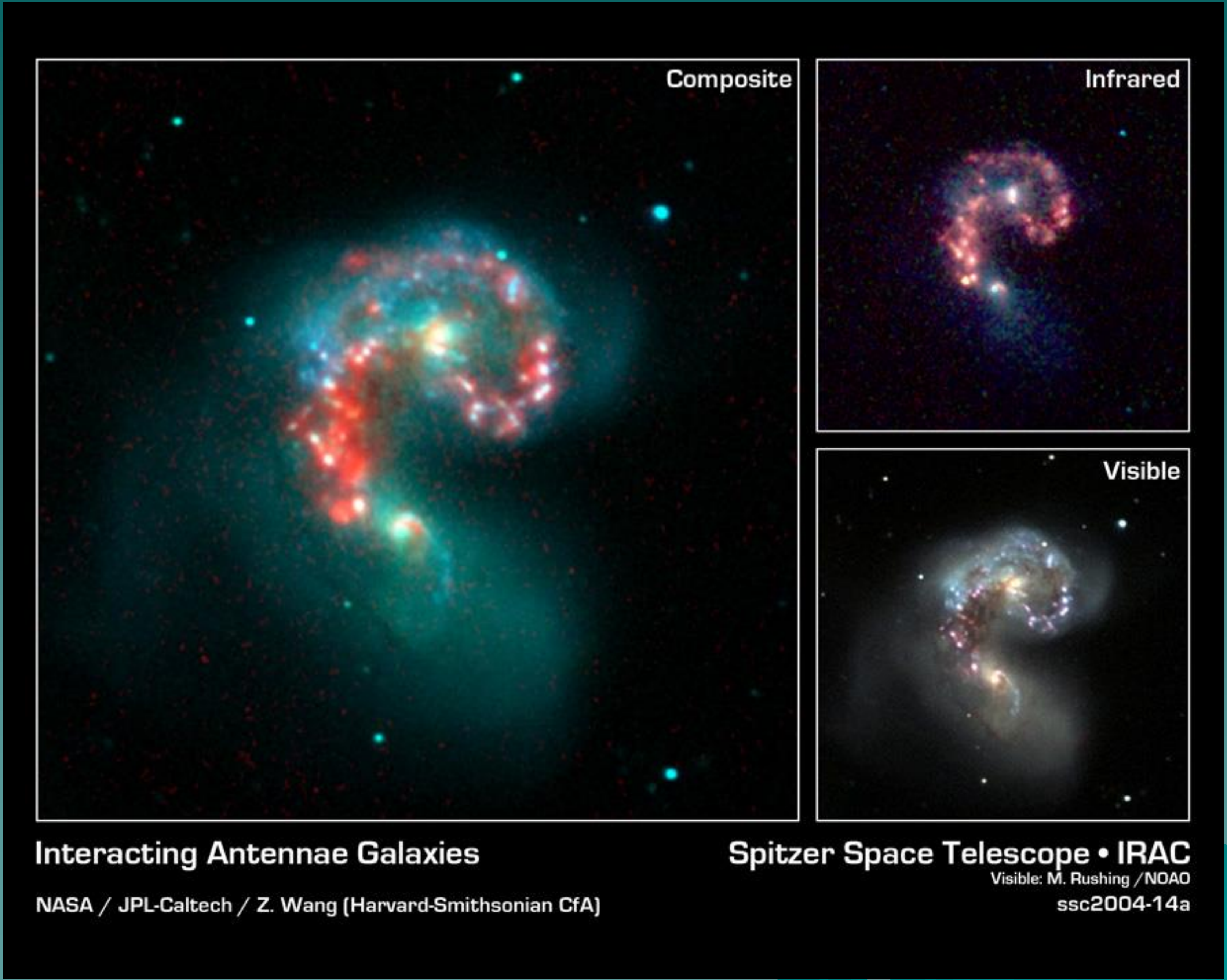
JWST

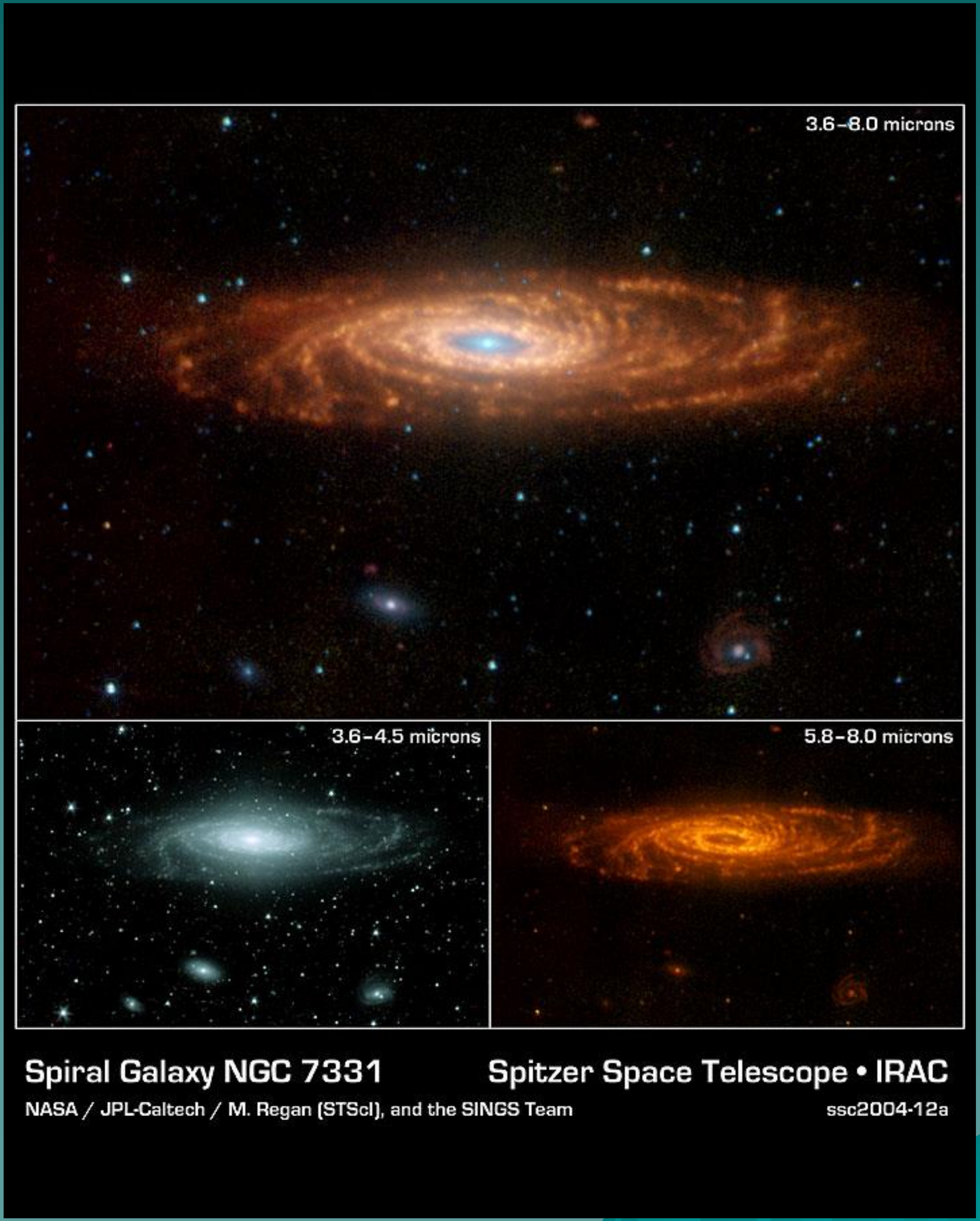
JWST deployment

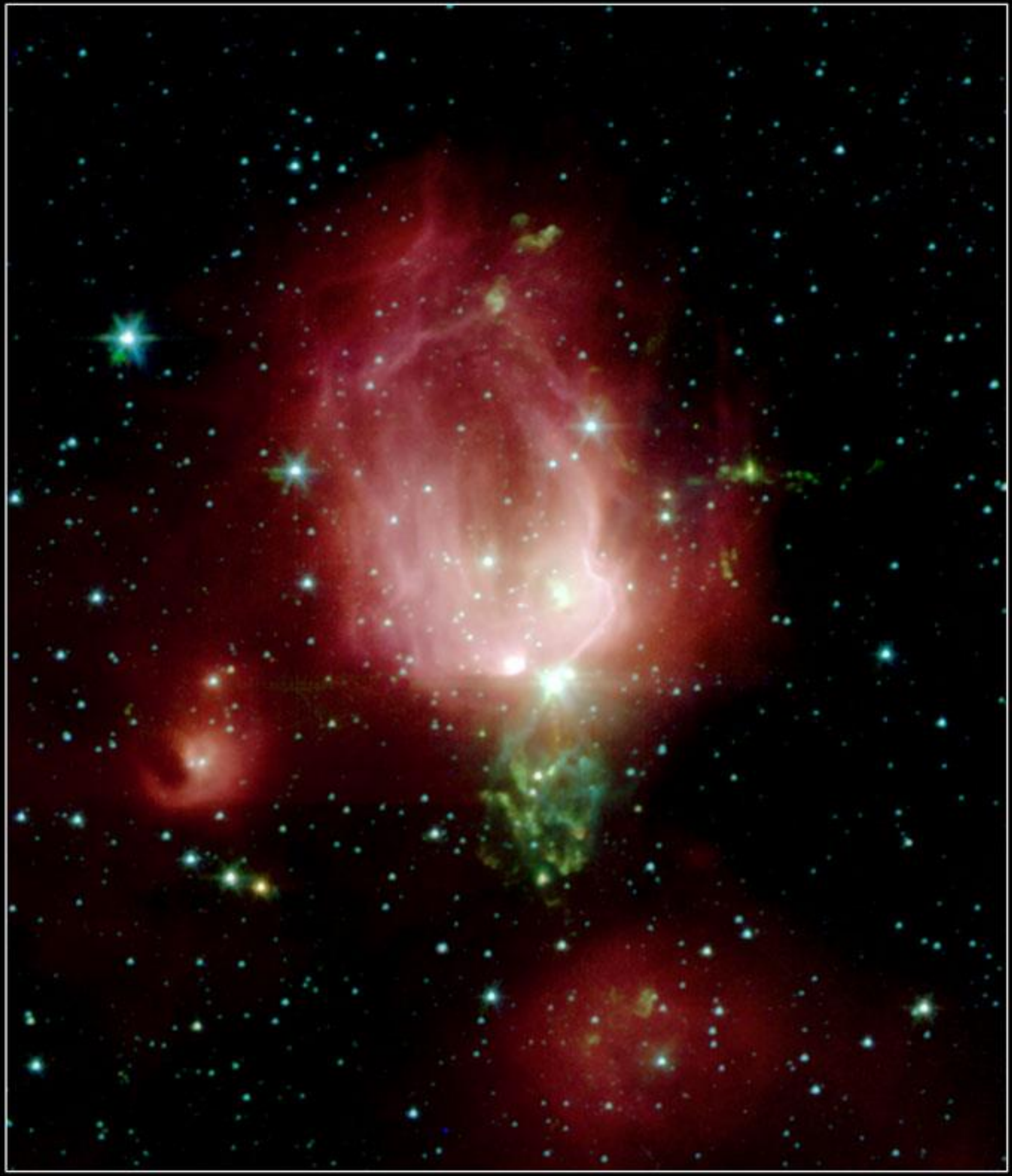
Telescopes in the Infrared

Interesting Factoids

- Launch Date:25 August 2003
- Launch Vehicle/Site:Delta 7920H ELV / Cape Canaveral,
- FloridaEstimated Lifetime:2.5 years (minimum); 5+ years
- Orbit:Earth-trailing, Heliocentric
- Wavelength Coverage:3 - 180 microns
- Telescope:85 cm diameter (33.5 Inches), f/12 lightweight Beryllium, cooled to less 5.5 K
- Diffraction Limit:6.5 microns
- Science Capabilities:Imaging / Photometry, 3-180 microns Spectroscopy, 5-40 microns
- Spectrophotometry, 50-100 microns
- Planetary Tracking:1 arcsec / sec
- Cryogen / Volume:Liquid Helium / 360 liters (95 Gallons)
- Launch Mass:950 kg (2094 lb) [Observatory: 851.5 kg, Cover: 6.0 kg, Helium: 50.4 kg, Nitrogen Propellant: 15.6 kg]


Composite
Infrared
Visible
Interacting Antennae Galaxies
NASA / JPL-Caltech / Z. Wang (Harvard-Smithsonian CfA)
Spitzer Space Telescope • IRAC
Visible: M. Rushing /NOAO
ssc2004-14a


3.6–8.0 microns
3.6–4.5 microns
5.8–8.0 microns
Spiral Galaxy NGC 7331
Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / M. Regan (STScI), and the SINGS Team
ssc2004-12a

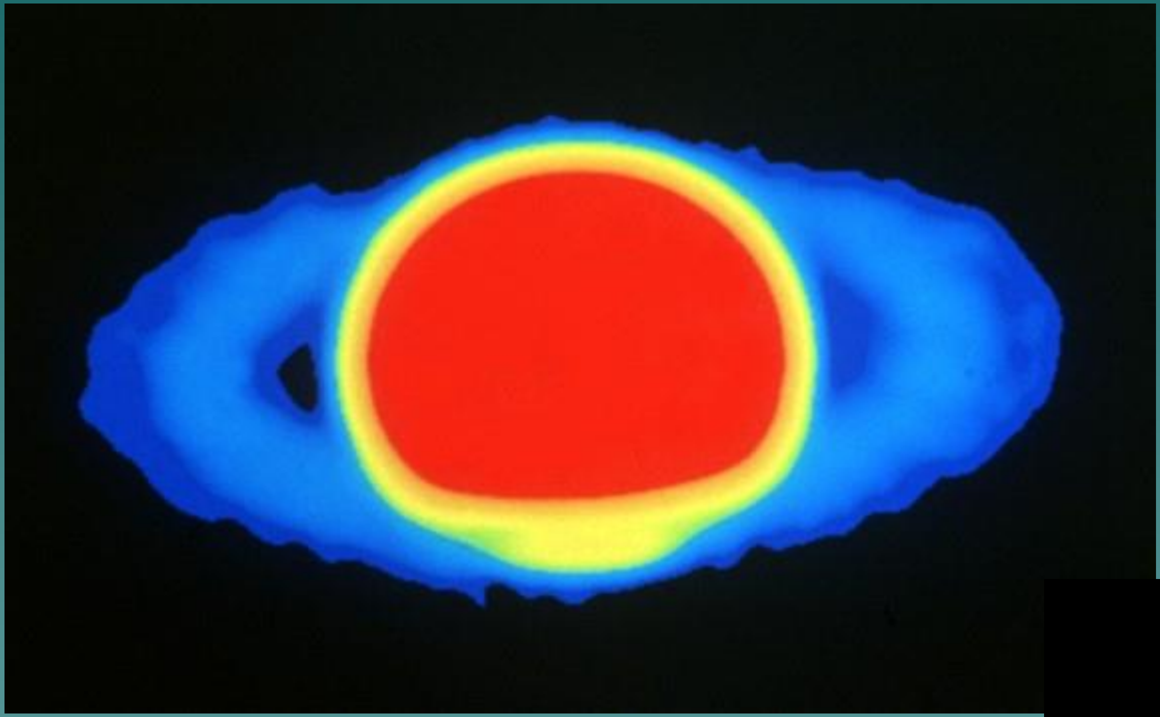


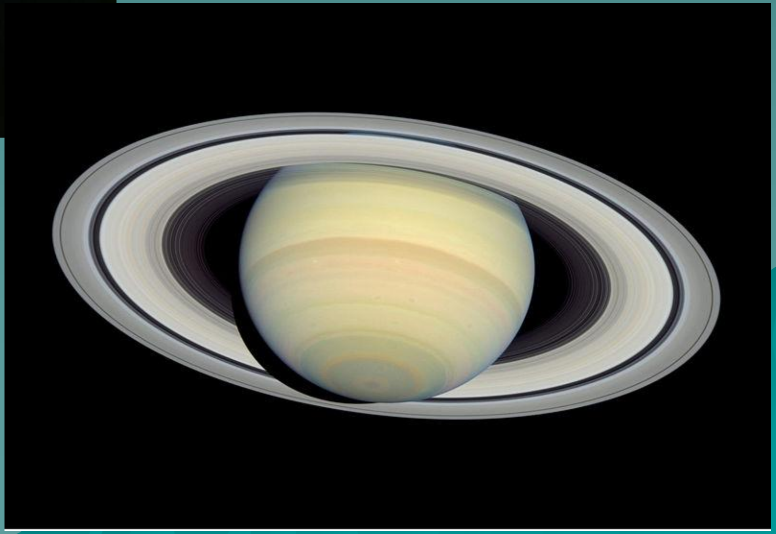
Reflection Nebula NGC 7129 Spitzer Space Telescope • IRAC

NASA / JPL-Caltech / S.T. Megeath (Harvard-Smithsonian CfA) ssc2004-02a

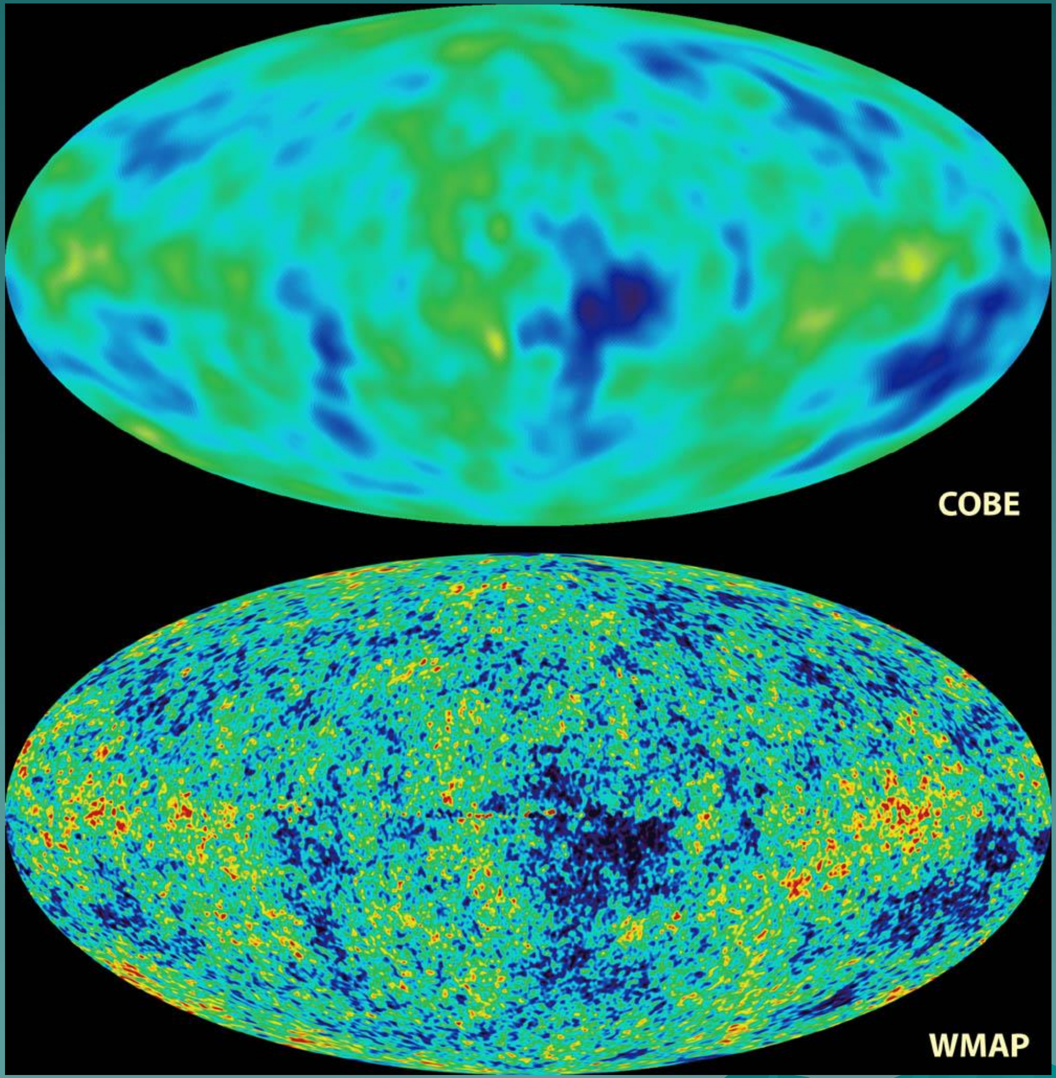
Telescopes in Radio

Saturn in Radio



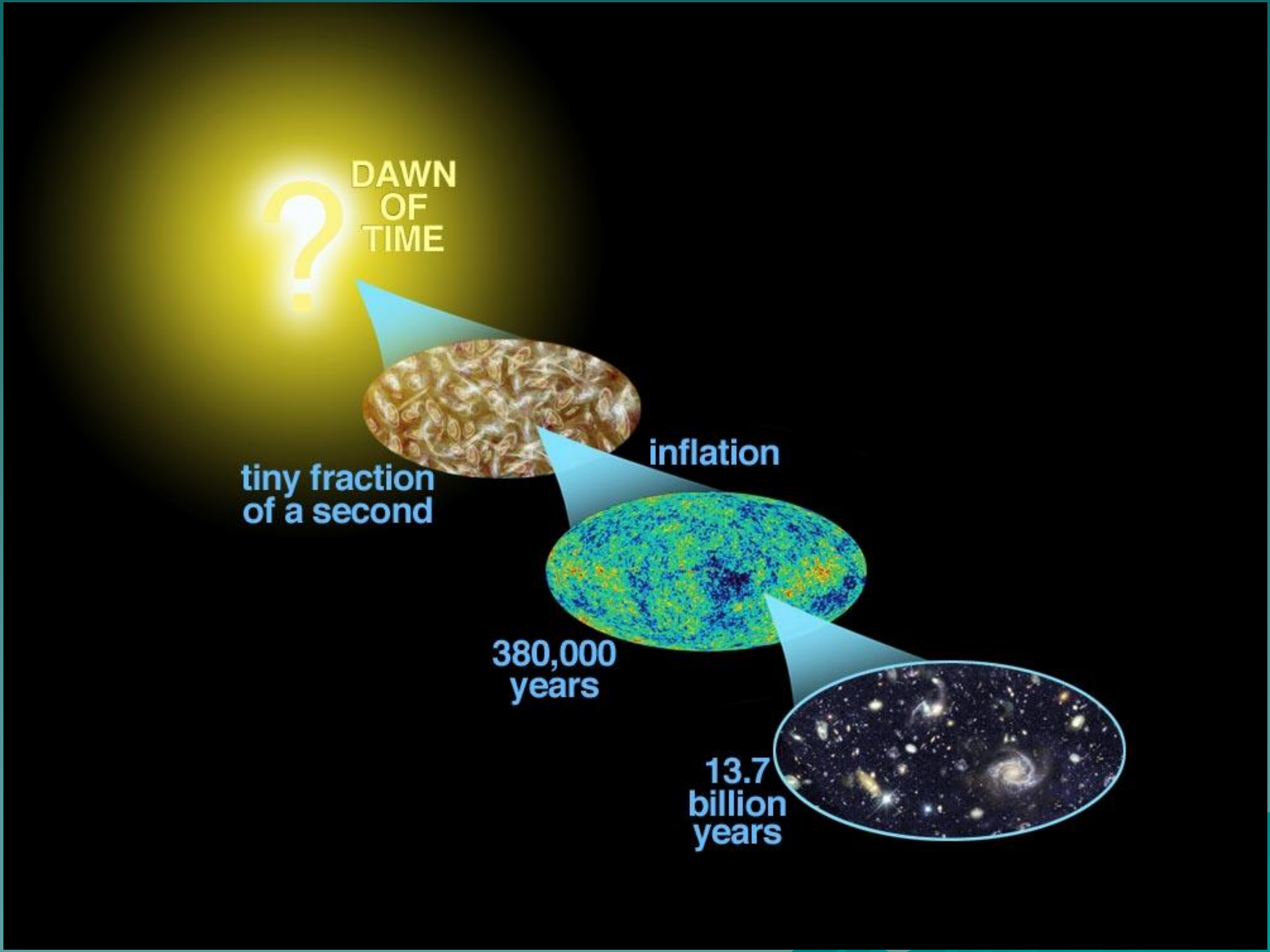


Wilkinson Microwave Observatory



What is the Background Radiation?

- Discoveredin 1964 Penzias and Wilson
  - Looking for source of noise from their radio telescope
  - 1% of static on television is due to background radiation
- Blackbody radiation
  - T=2.76 K
  - Isotropic
- Comes from the early universe, about 300000 yrs after Big Bang
  - Today radiation travels freely – universe is transparent
  - Earlier, universe was filled with radiation, and hydrogen plasma
  - Density was high enough so any radiation barely travelled any distance before being absorbed and reemitted.
  - Matter and radiation in thermal contact – temperatures were identical
  - Thermalization.
  - As universe expanded, density lessened and temperature dropped.
  - Universe became transparent.
  - Matter recombined – electrons and protons formed hydrogen atoms.
  - This happened at about 3000 K, background radiation was released at this point


DAWN OF TIME
inflation
tiny fraction of a second
380,000 years
13.7 billion years