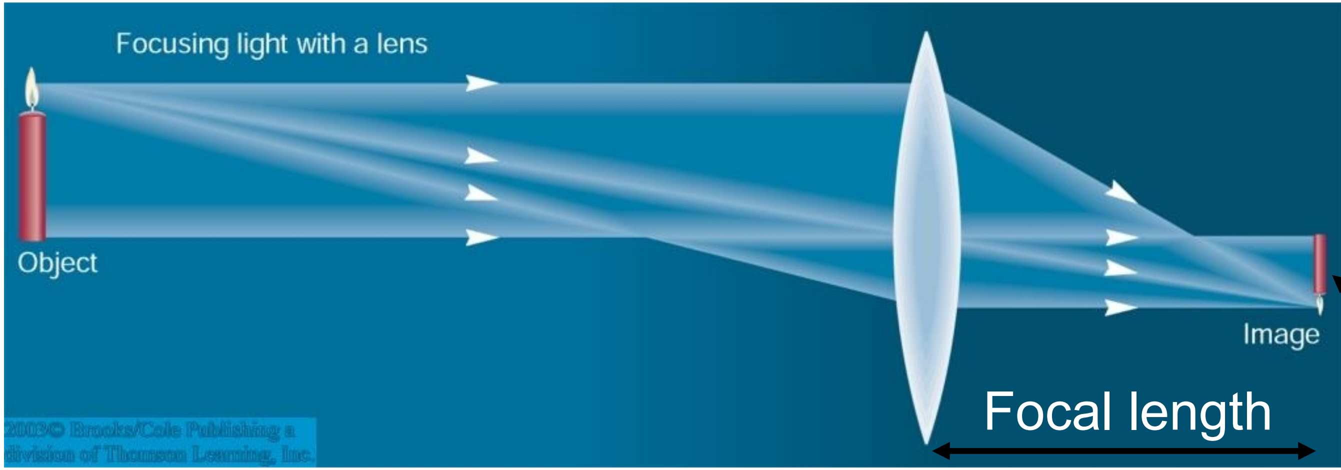
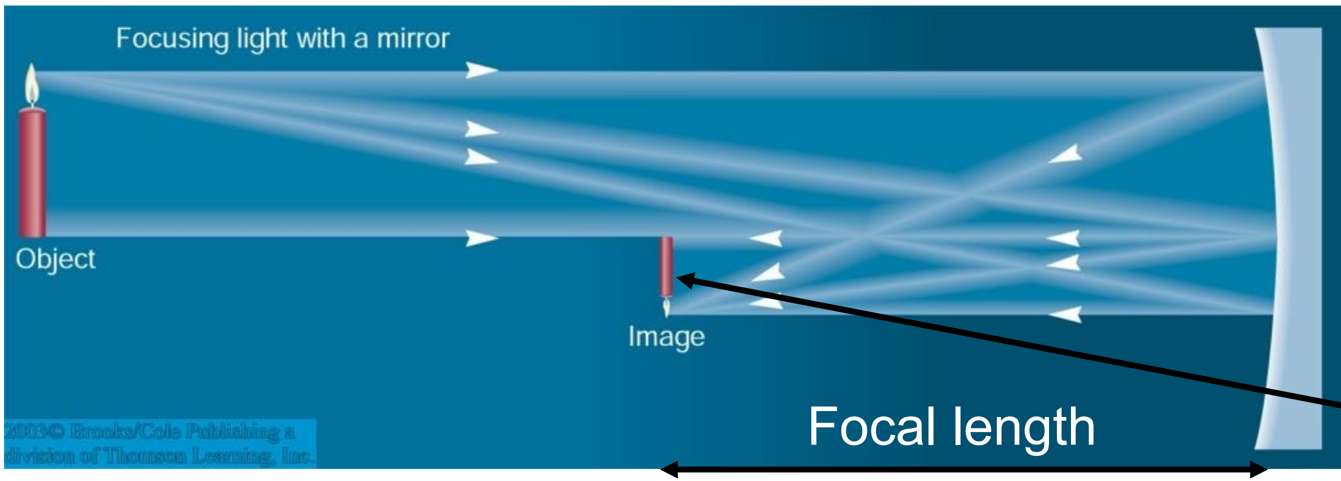
ASTR 2310: Chapter 6

- **<u>Astronomical Detection of Light</u>**
- The Telescope as a Camera
- Refraction and Reflection Telescopes
- Quality of Images
- Astronomical Instruments and Detectors
- Observations and Photon Counting
- Other Wavelengths
- Modern Telescopes

Refracting / Reflecting Telescopes



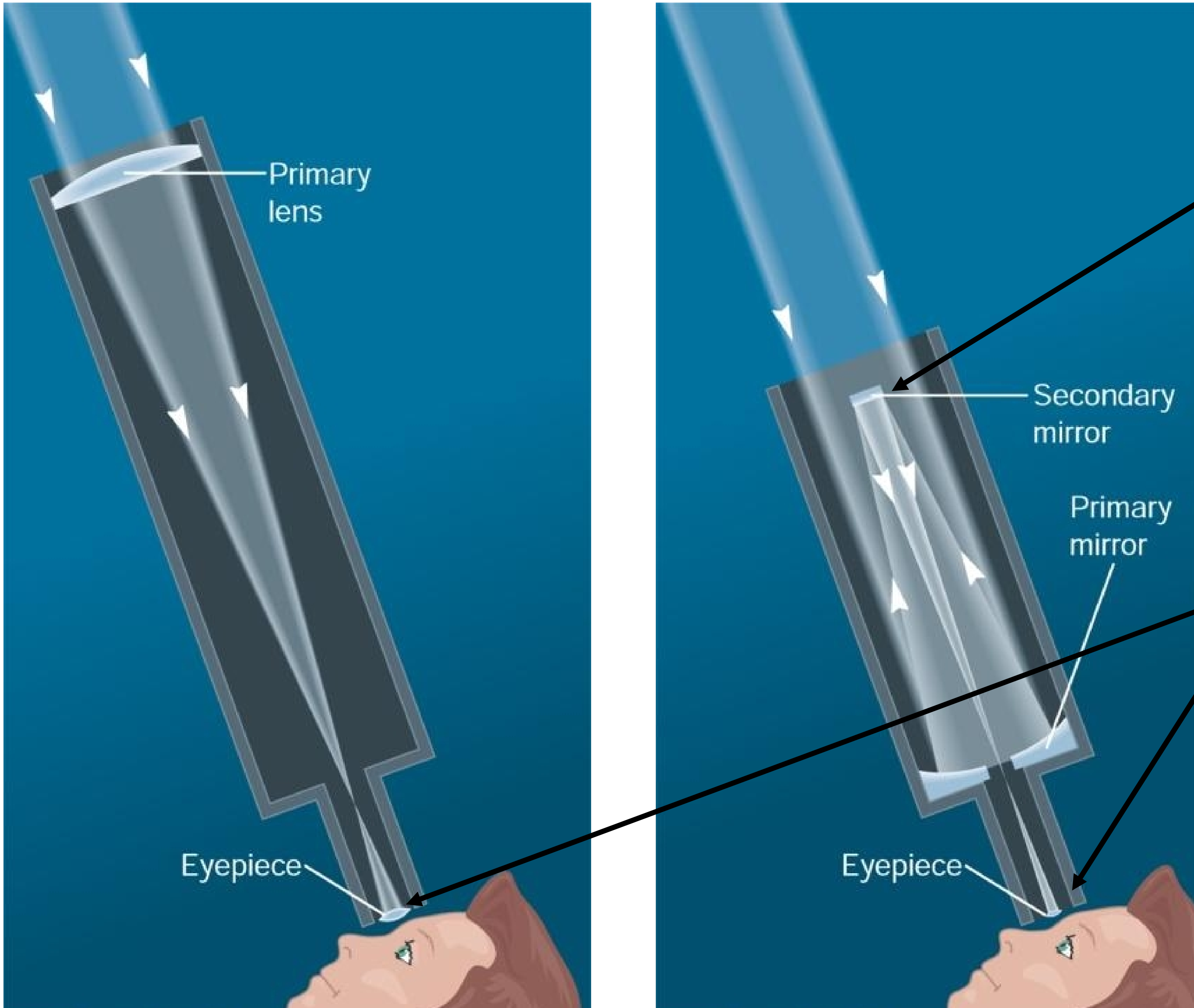
Refracting Telescope: Lens focuses light onto the focal plane



Reflecting Telescope: Concave Mirror focuses light onto the focal plane

Almost all modern telescopes are reflecting telescopes.

Secondary Optics



In reflecting telescopes: Secondary mirror, to re-direct light path towards back or side of incoming light path.

Eyepiece: To view and enlarge the small image produced in the focal plane of the primary optics.

Disadvantages of Refracting Telescopes

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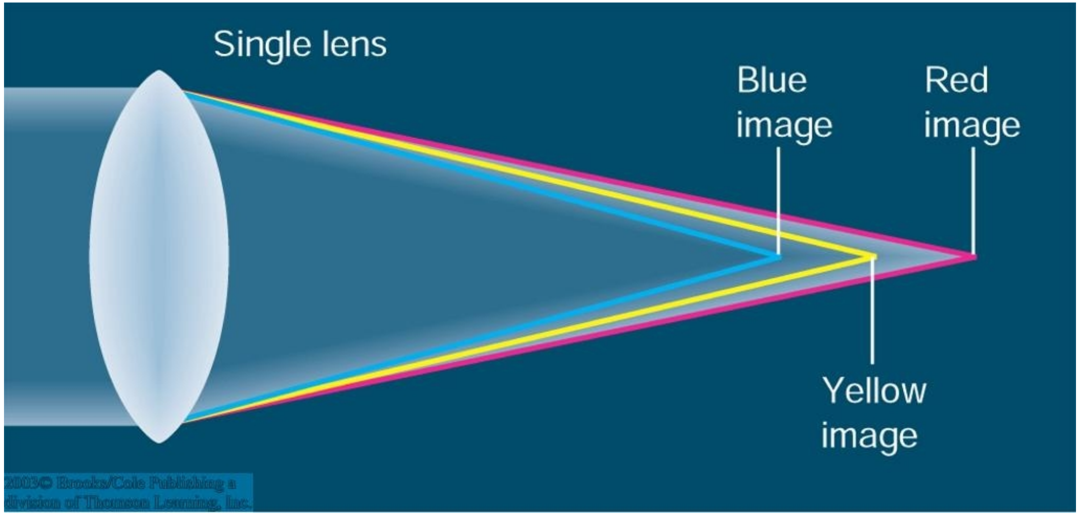
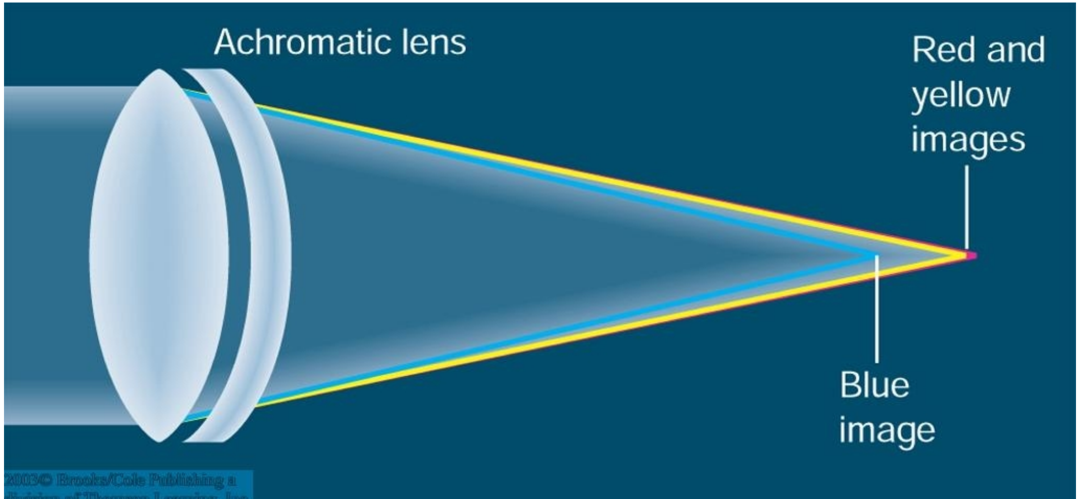


• Chromatic aberration: Different wavelengths are focused at different focal lengths (prism effect).

Can be corrected, but not eliminated by second lens out of different material.



• Difficult and expensive to produce: All surfaces must be perfectly shaped; glass must be flawless; lens can only be supported at the edges.

The Best Location for a Telescope

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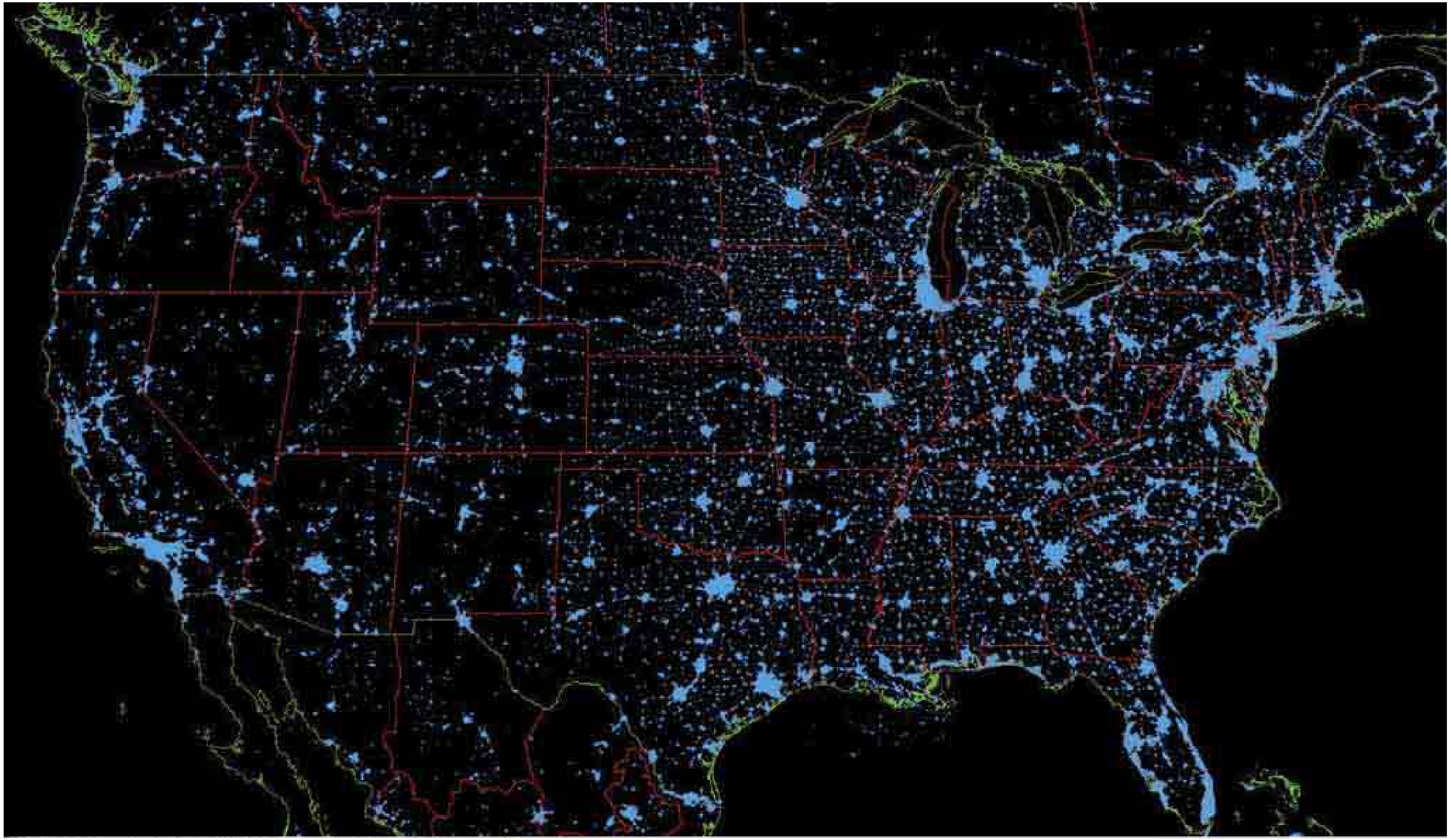

Far away from civilization – to avoid light pollution

The Best Location for a Telescope (II)

On high mountain-tops – to avoid atmospheric turbulence (seeing) and other weather effects

The Powers of a Telescope: Size does matter!

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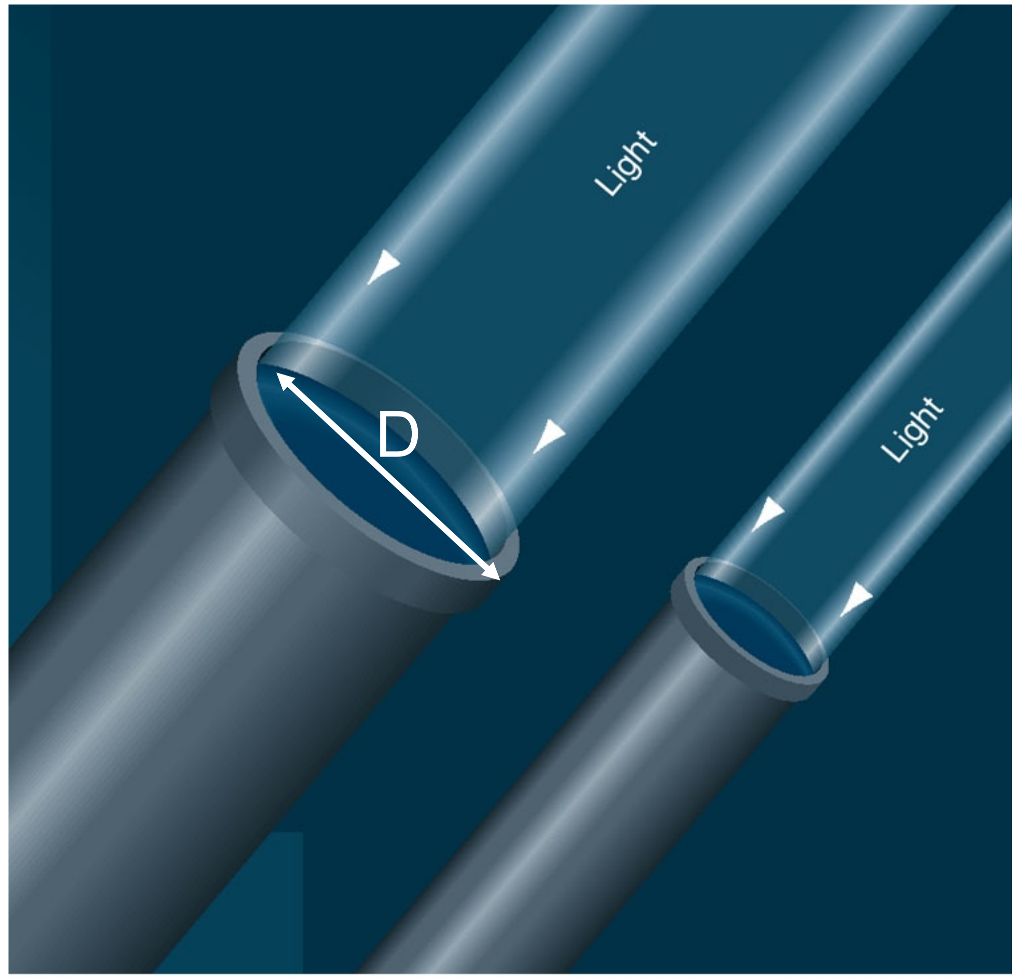
1. Light-gathering power: Depends on the surface area A of the primary lens / mirror, proportional to diameter squared:

$$A = \text{pi}\,(D/2)^2$$



The Powers of a Telescope (II)

2. Resolving power: Wave nature of light

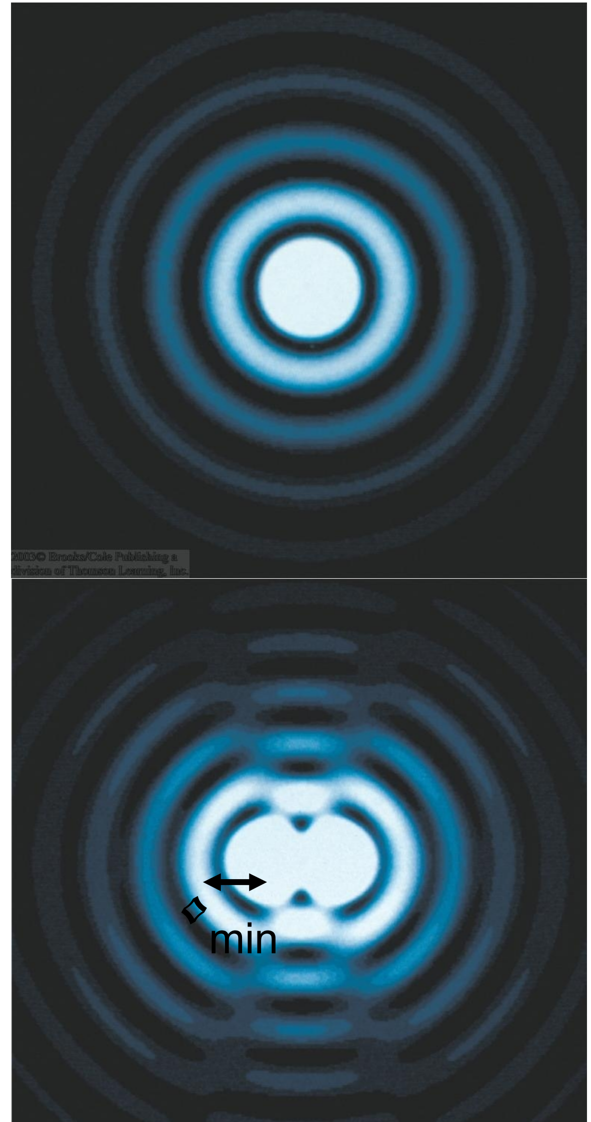
=> The telescope aperture produces fringe rings that set a limit to the resolution of the telescope.

Astronomers can’t eliminate these diffraction fringes, but the larger a telescope is in diameter, the smaller the diffraction fringes are. Thus the larger the telescope, the better its resolving power.

$$\theta_{min} = 1.22\ (\lambda/D)\ (\text{radians})$$

For optical wavelengths, this gives

$$\theta_{min} = 11.6\ \text{arcsec} / D[\text{cm}]$$



The Powers of a Telescope (III)

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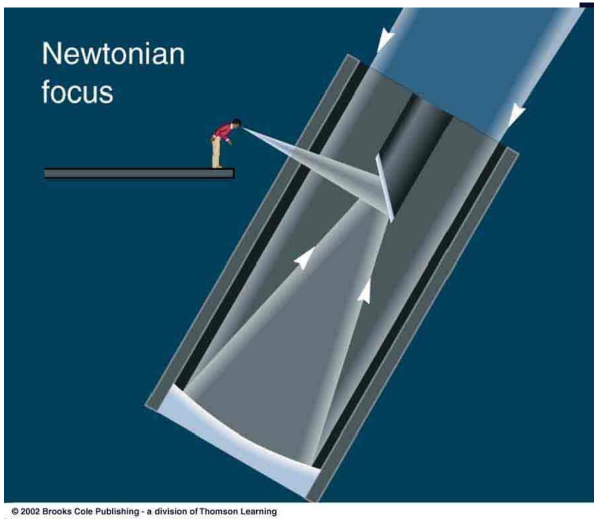
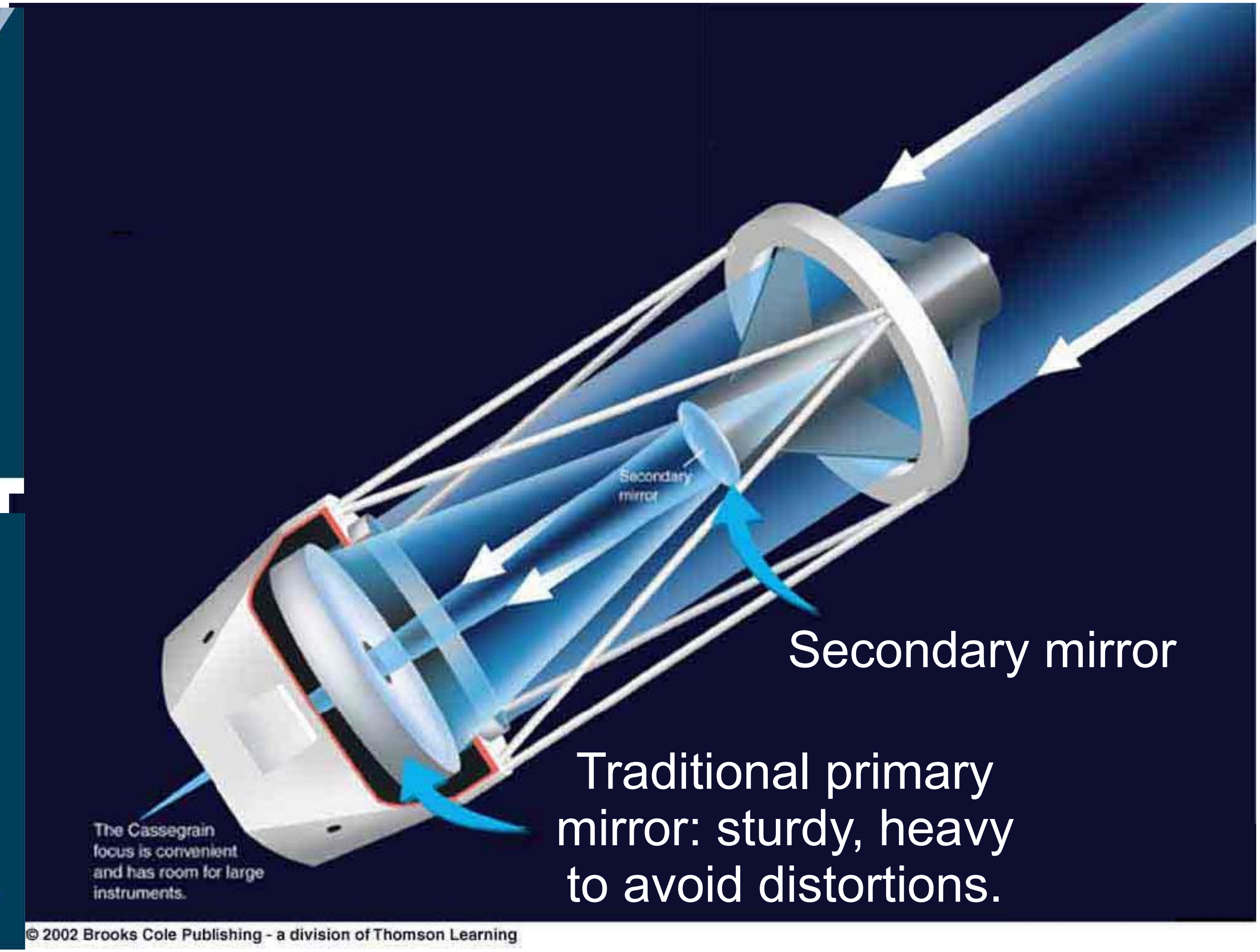
3. Magnifying Power = ability of the telescope to make the image appear bigger.

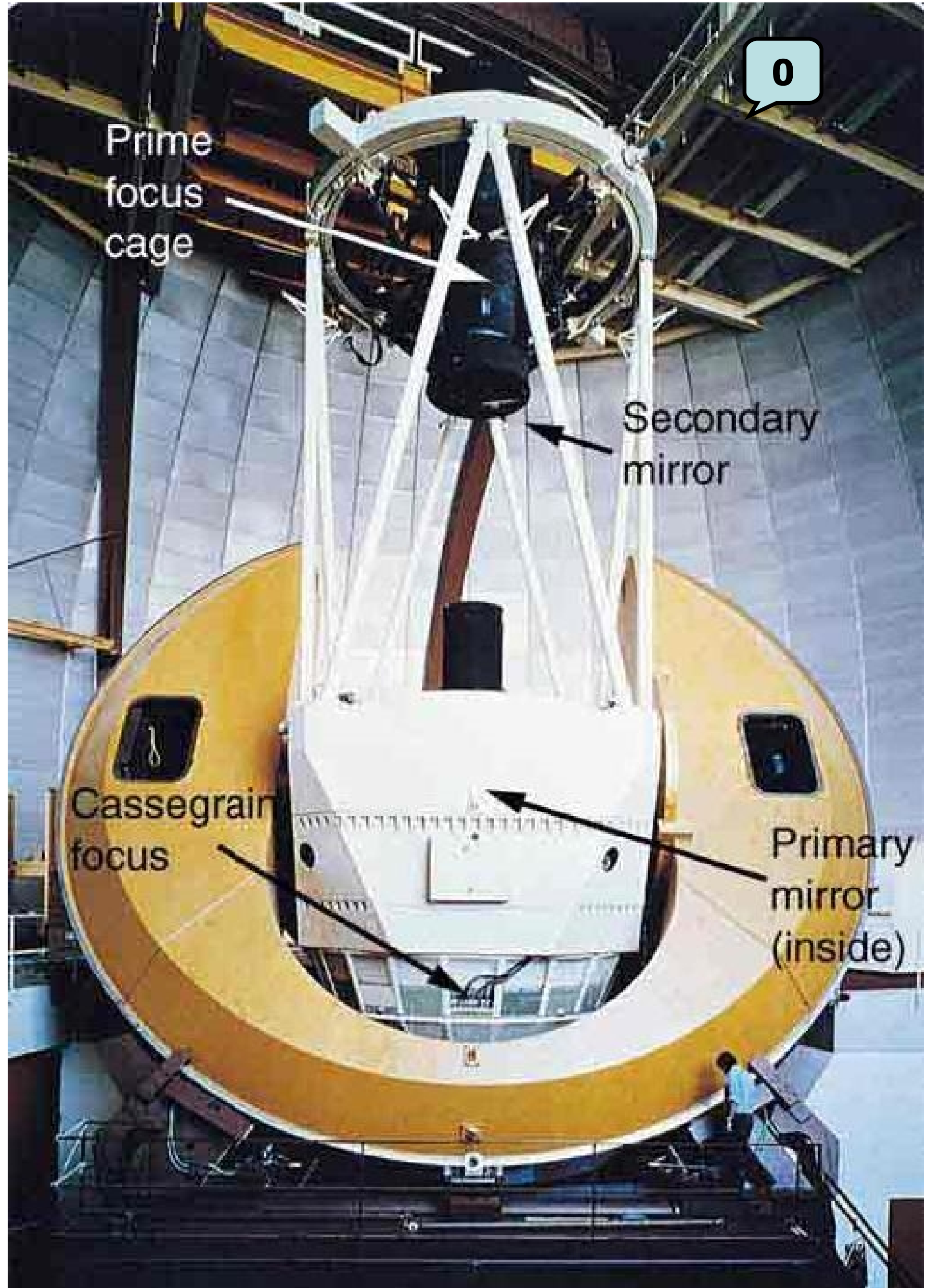
A larger magnification does not improve the resolving power of the telescope!

Traditional Telescopes (I)





Traditional Telescopes (II)



The 4-m Mayall Telescope at Kitt Peak National Observatory (Arizona)

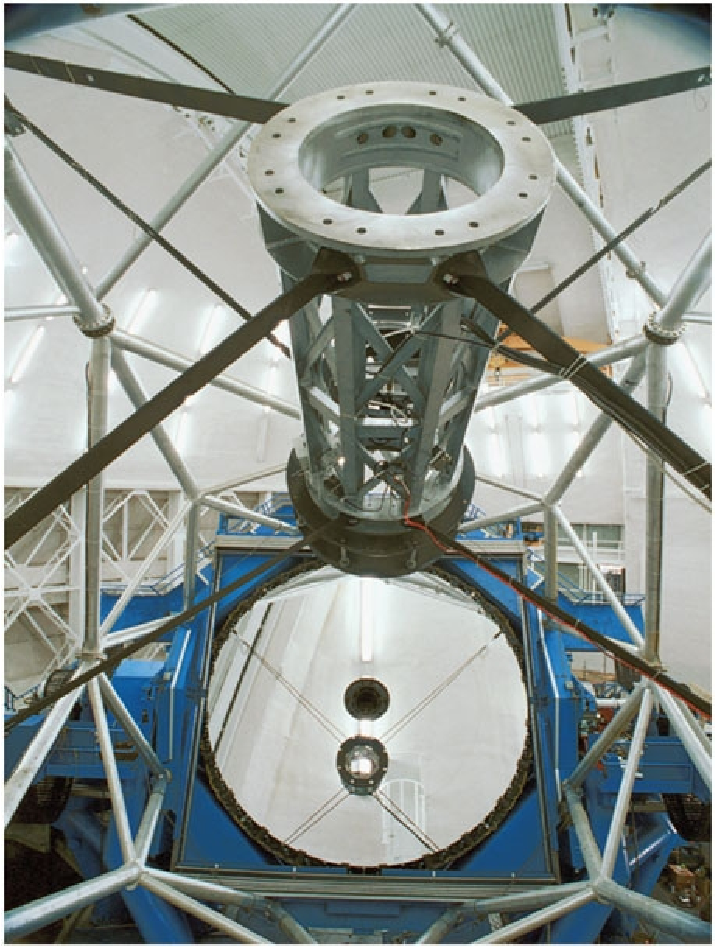
Astronomical Telescopes

Often very large to gather large amounts of light.

In order to observe forms of radiation other than visible light, very different telescope designs are needed.

The northern Gemini Telescope on Hawaii

Examples of Modern Telescope Design



The Very Large Telescope (VLT)

8.1-m mirror of the Gemini Telescopes

Seeing

Weather conditions and turbulence in the atmosphere set further limits to the quality of astronomical images

Advances in Modern Telescope Design

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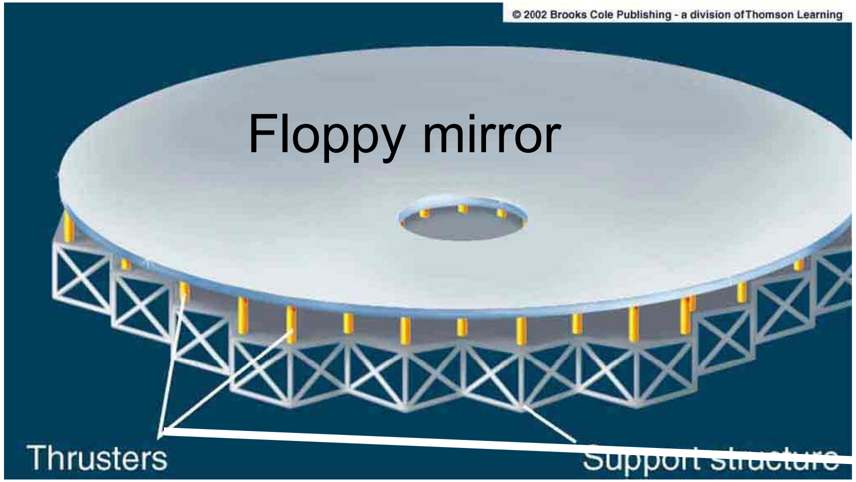
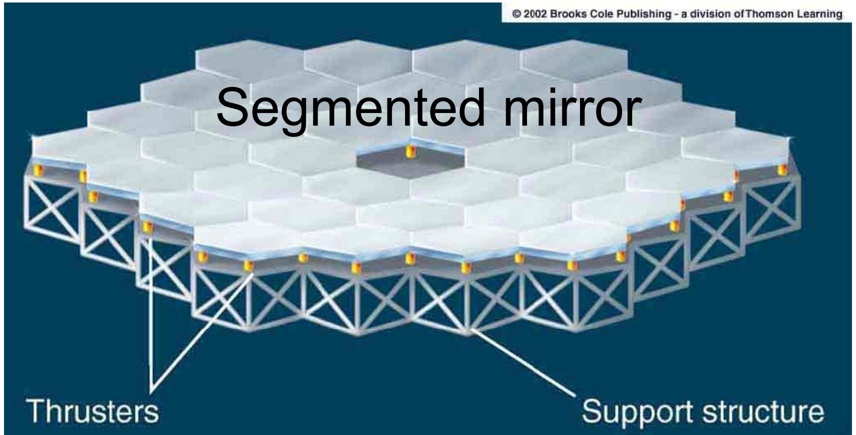
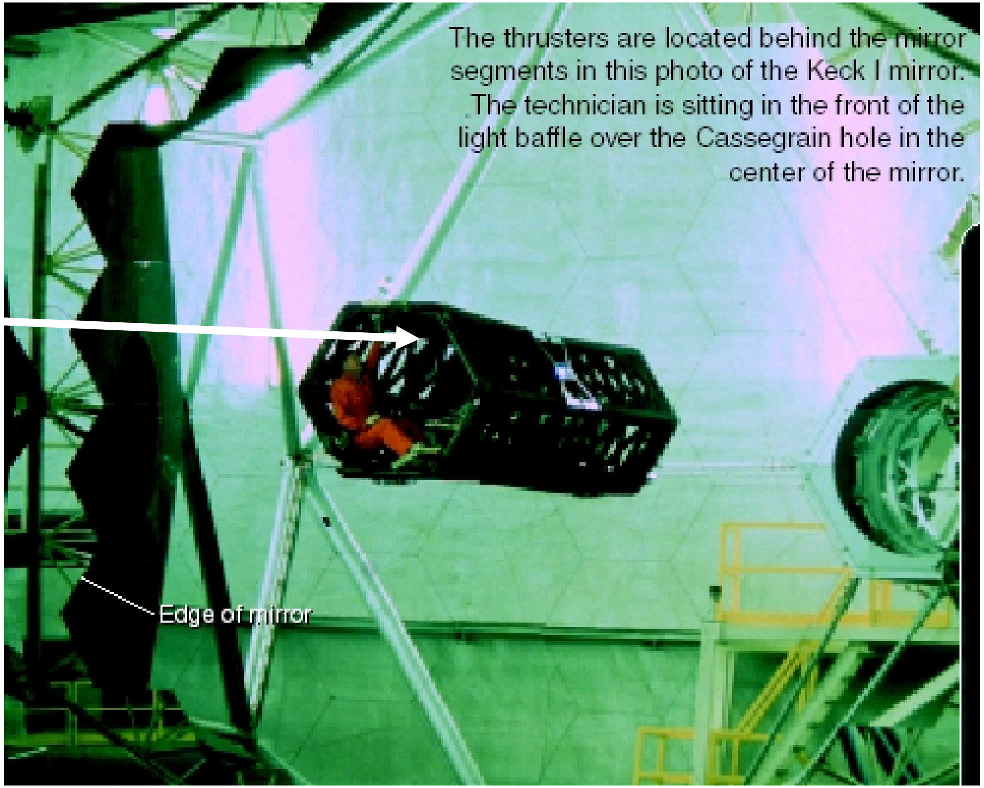
Lighter mirrors with lighter support structures,
to be controlled dynamically by computers

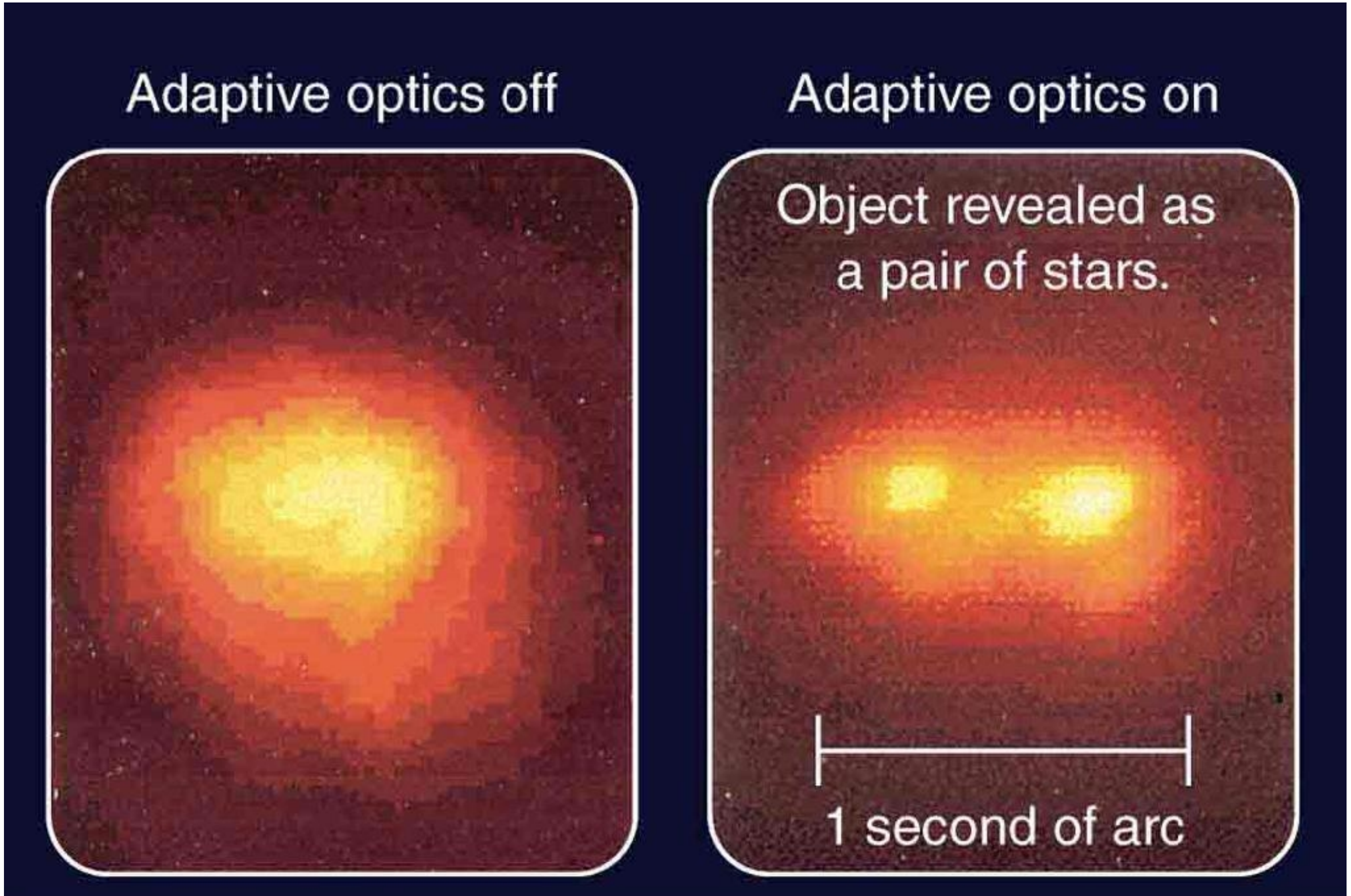






Adaptive Optics

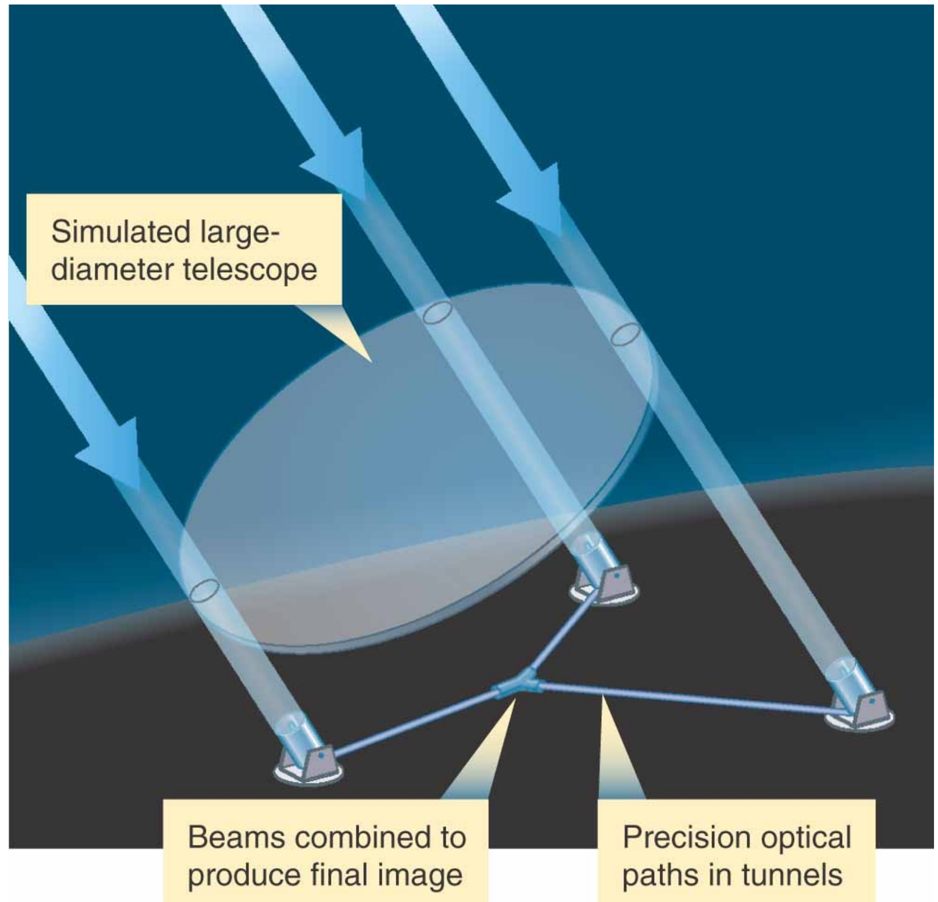
Computer-controlled mirror support adjusts the mirror surface (many times per second) to compensate for distortions by atmospheric turbulence



Interferometry

Recall: Resolving power of a telescope depends on diameter D.

🎭 Combine the signals from several smaller telescopes to simulate one big mirror 🎭 Interferometry



CCD Imaging

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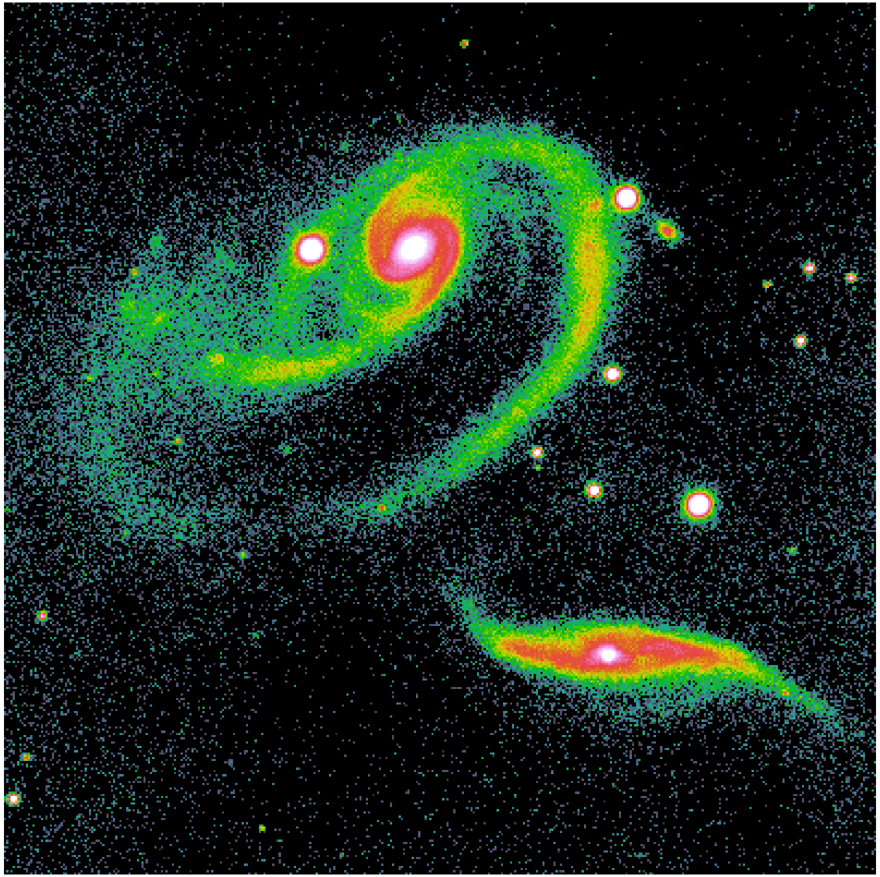
CCD = Charge-coupled device

- More sensitive than photographic plates

- Data can be read directly into computer memory, allowing easy electronic manipulations

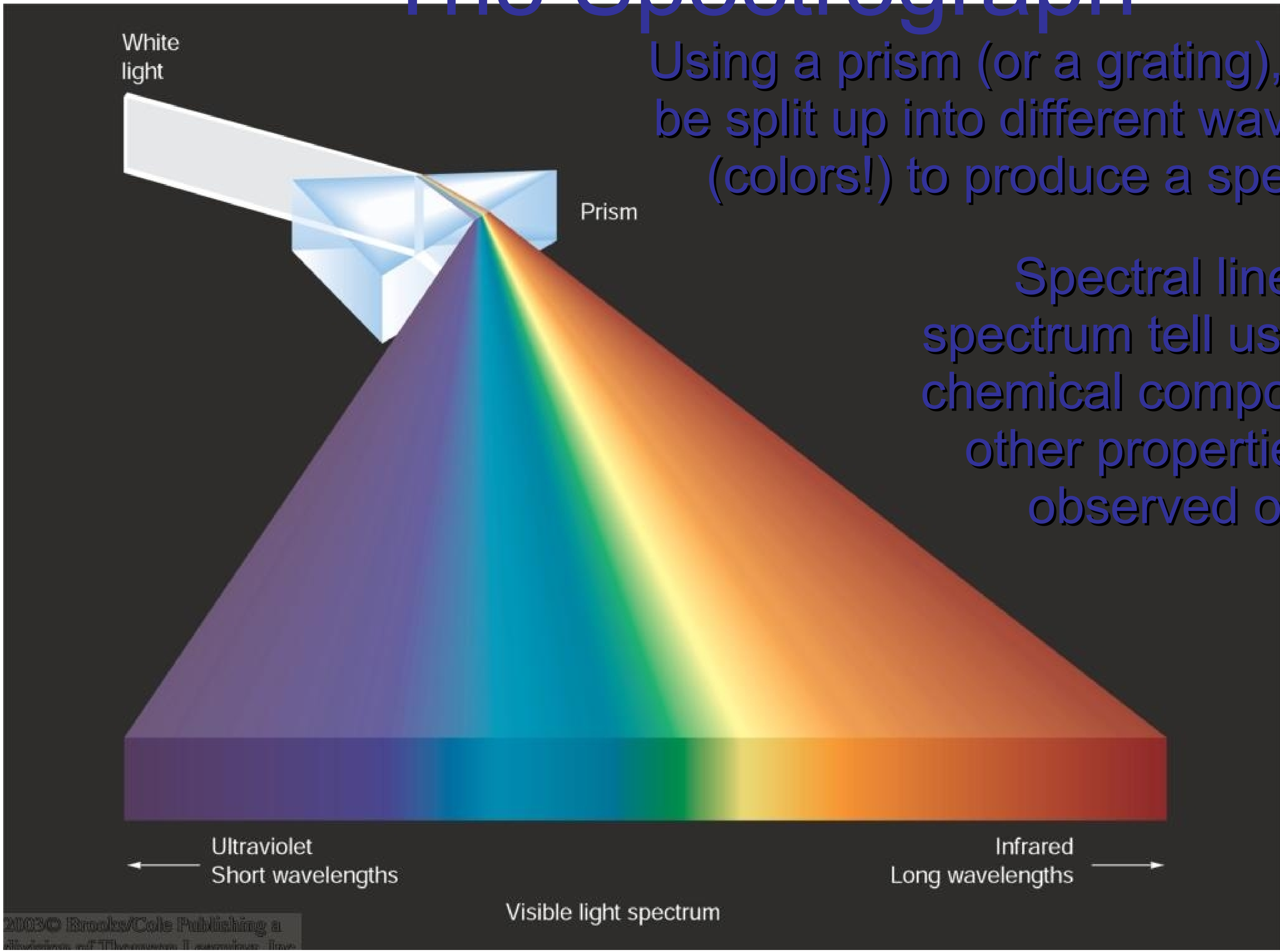


False-color image to visualize brightness contours

The Spectrograph

Using a prism (or a grating), light can be split up into different wavelengths (colors!) to produce a spectrum.

Spectral lines in a spectrum tell us about the chemical composition and other properties of the observed object



Radio Astronomy

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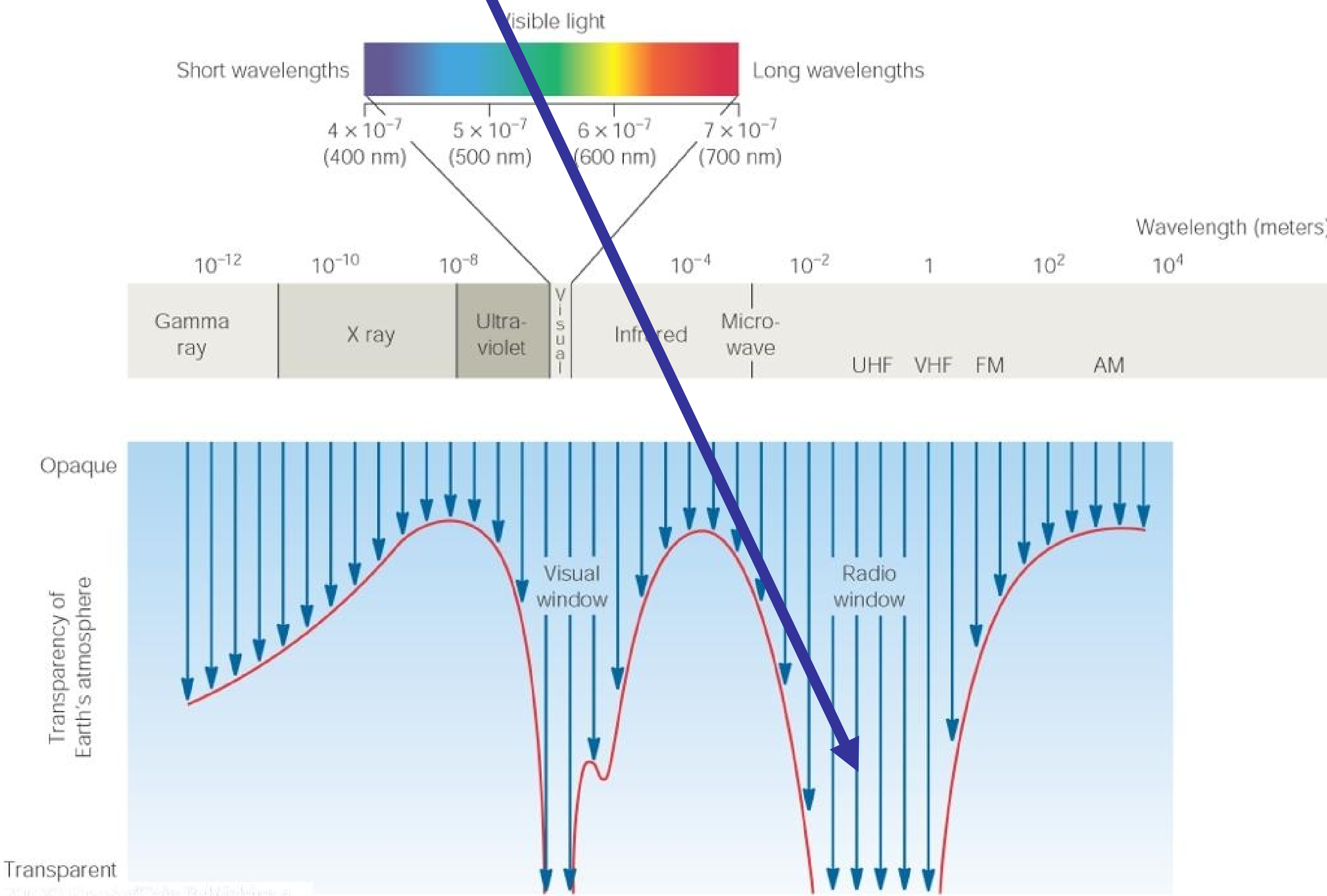
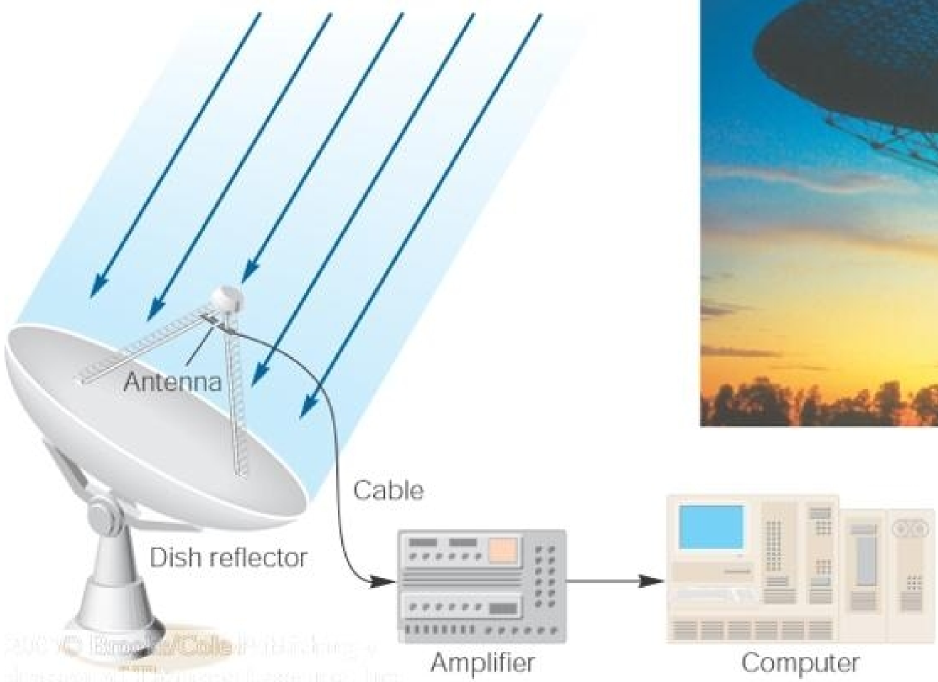
Recall: Radio waves of ~ 1 cm – 1 m also penetrate the Earth's atmosphere and can be observed from the ground.



Radio Telescopes

Large dish focuses the energy of radio waves onto a small receiver (antenna)



Amplified signals are stored in computers and converted into images, spectra, etc.

Radio Interferometry

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Just as for optical telescopes, the resolving power of a radio telescope depends on the diameter of the objective lens or mirror

$\theta_{min} = 1.22\ \lambda/D$.

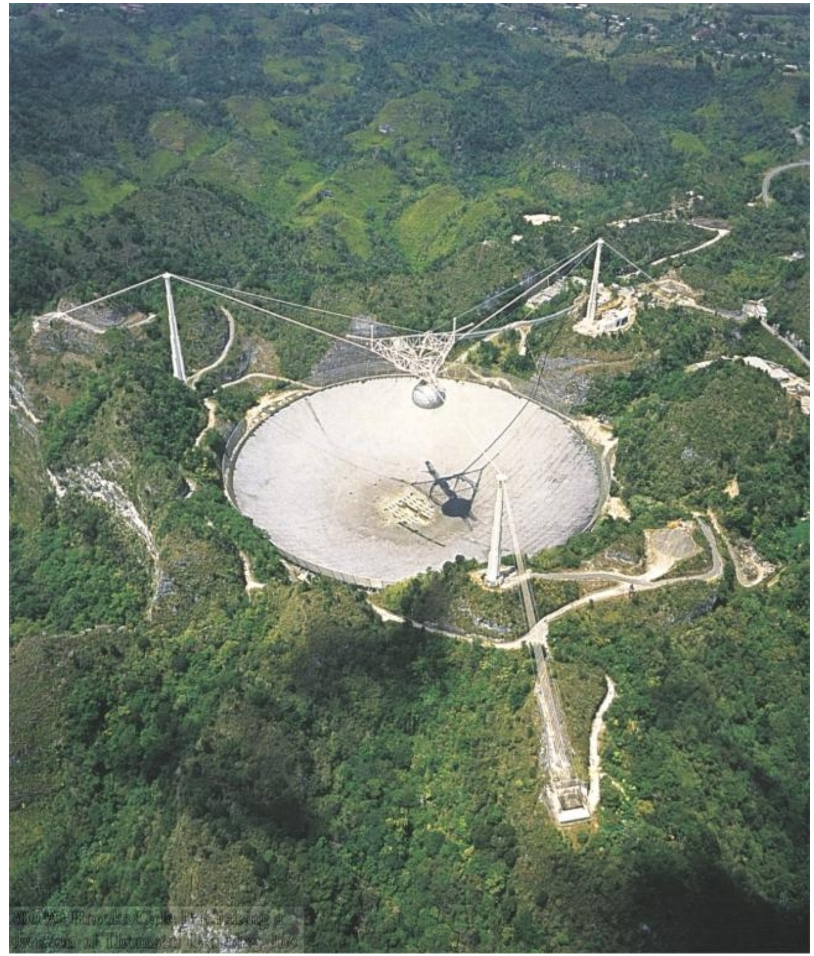
For radio telescopes, this is a big problem: Radio waves are much longer than visible light

Use interferometry to improve resolution!

The Very Large Array (VLA): 27 dishes are combined to simulate a large dish of 36 km in diameter.

The Largest Radio Telescopes

The 100-m Green Bank Telescope in Green Bank, West Virginia.



The 300-m telescope in Arecibo, Puerto Rico

Science of Radio Astronomy

Radio astronomy reveals several features, not visible at other wavelengths:

- Neutral hydrogen clouds (which don't emit any visible light), containing ~ 90 % of all the atoms in the universe.
- Molecules (often located in dense clouds, where visible light is completely absorbed).
- Radio waves penetrate gas and dust clouds, so we can observe regions from which visible light is heavily absorbed.

Infrared Astronomy

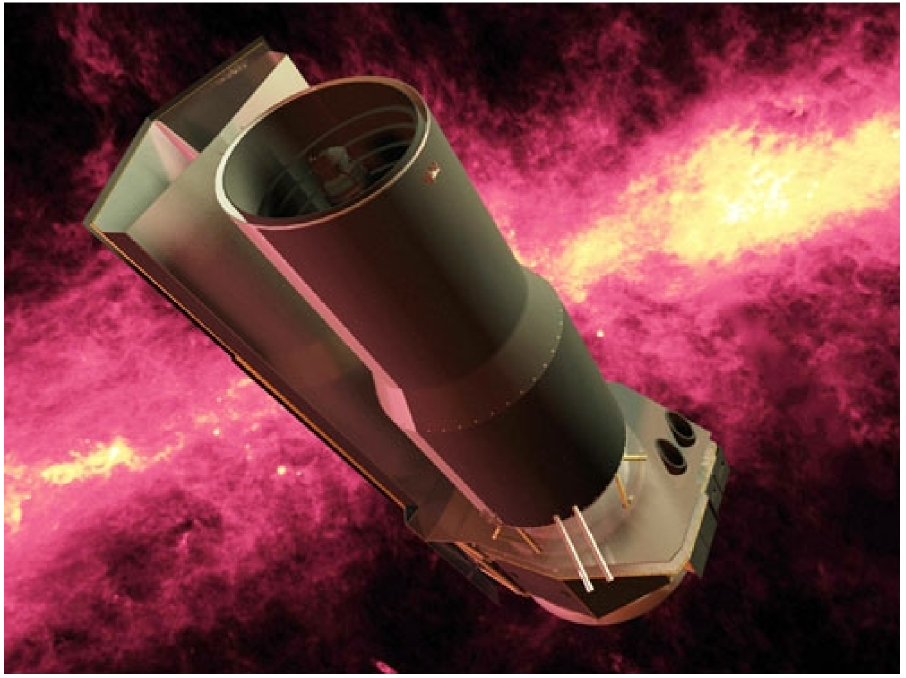
Most infrared radiation is absorbed in the lower atmosphere.

However, from high mountain tops or high-flying aircraft, some infrared radiation can still be observed.

NASA infrared telescope on Mauna Kea, Hawaii

Infrared Telescopes

WIRO 2.3m



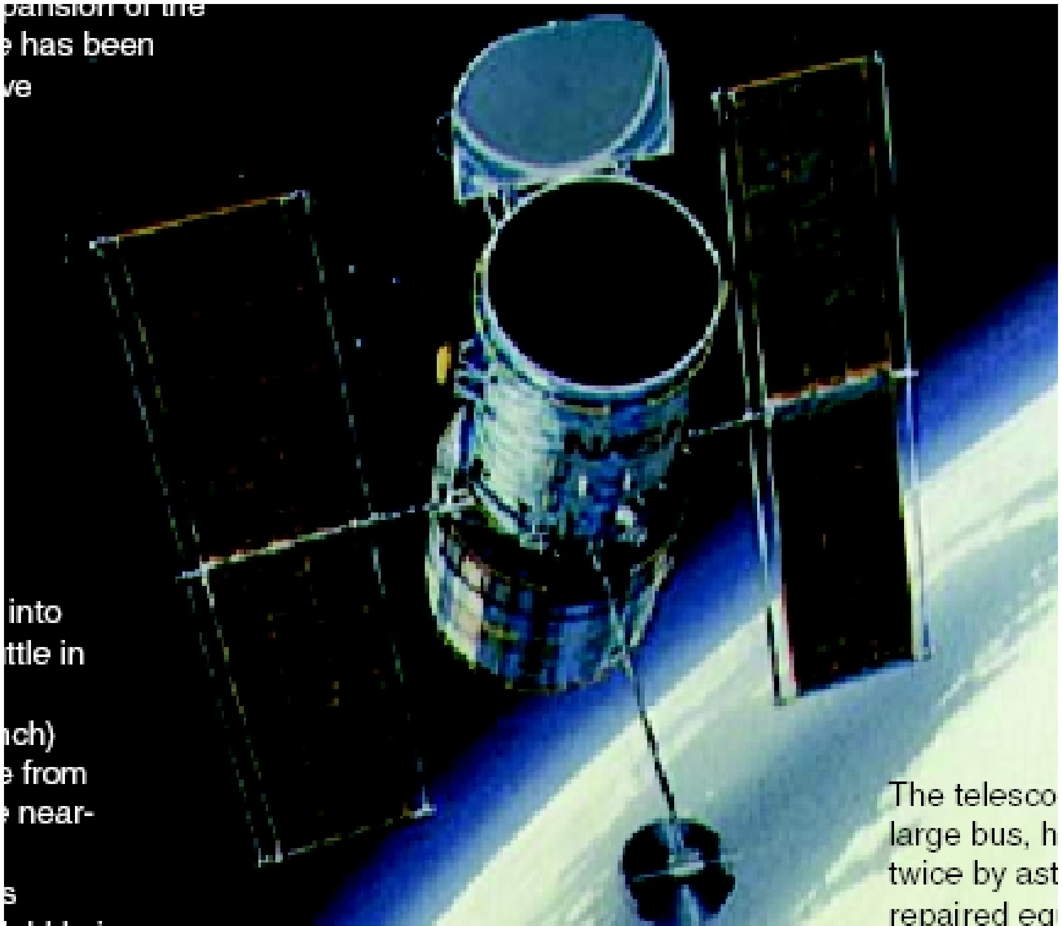
Spitzer Space Telescope

Ultraviolet Astronomy

- Ultraviolet radiation with $\lambda < 290$ nm is completely absorbed in the ozone layer of the atmosphere.
- Ultraviolet astronomy has to be done from satellites.
- Several successful ultraviolet astronomy satellites: IUE, EUVE, FUSE
- Ultraviolet radiation traces hot (tens of thousands of degrees), moderately ionized gas in the universe.

NASA's Great Observatories in Space (I)

The Hubble Space Telescope

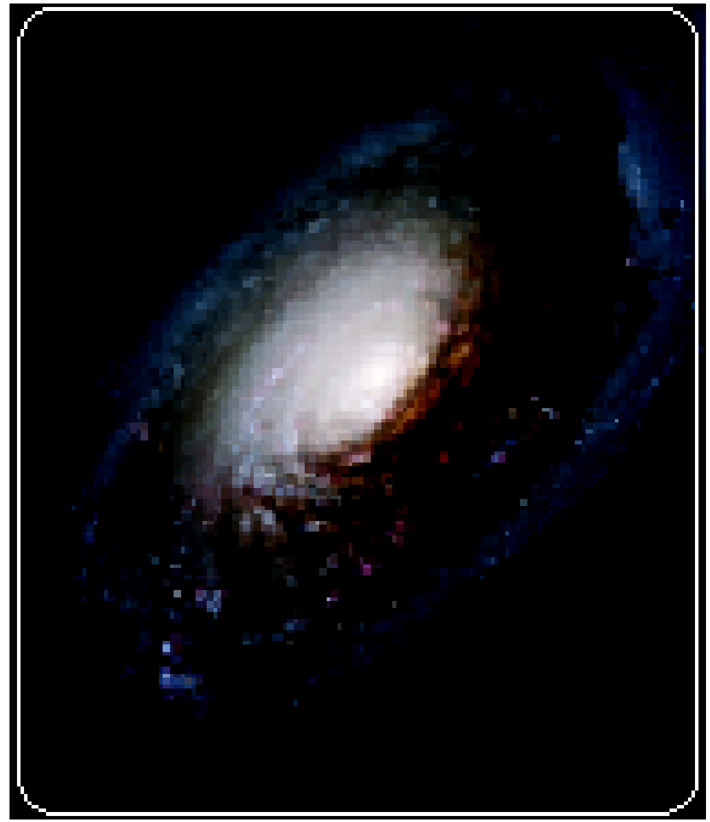


- Launched in 1990; maintained and upgraded by several space shuttle service missions throughout the 1990s and early 2000's
- Avoids turbulence in Earth's atmosphere
- Extends imaging and spectroscopy to (invisible) infrared and ultraviolet

Hubble Space Telescope Images

Mars with its polar ice cap

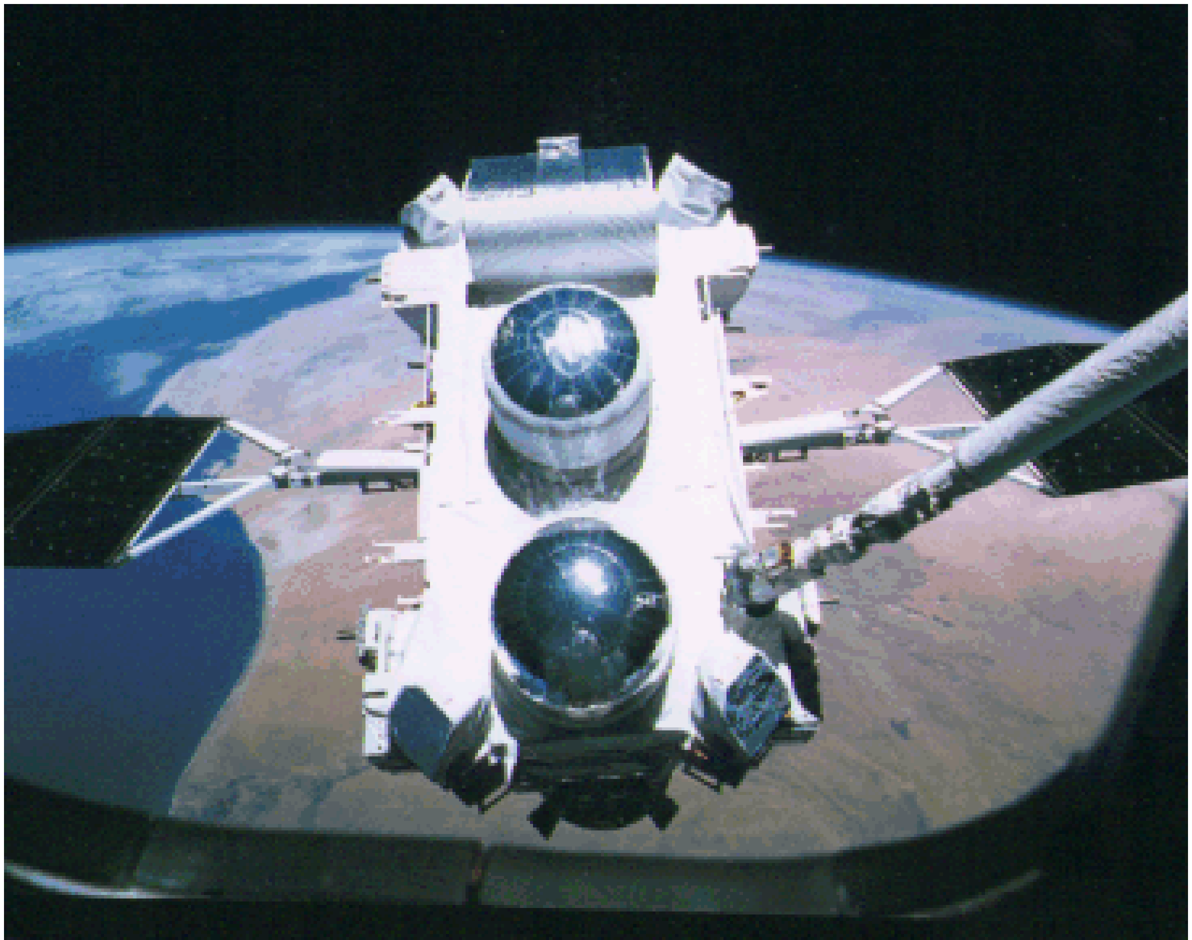
Nebula around an aging star



A dust-filled galaxy

NASA's Great Observatories in Space (II)

The Compton Gamma-Ray Observatory



Operated from 1991 to 2000

Observation of high-energy gamma-ray emission, tracing the most violent processes in the universe.

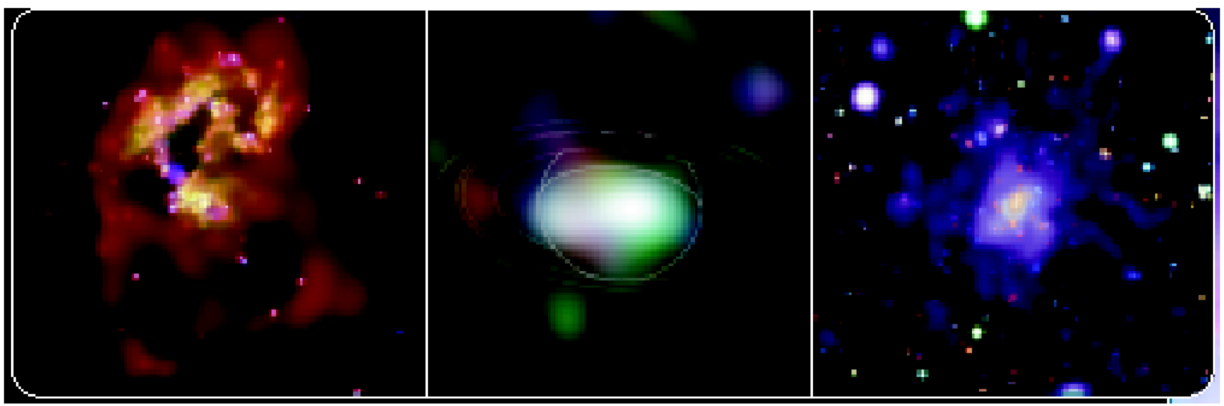
NASA's Great Observatories in Space (III)

The Chandra X-ray Telescope

Launched in 1999 into a highly eccentric orbit that takes it 1/3 of the way to the moon!

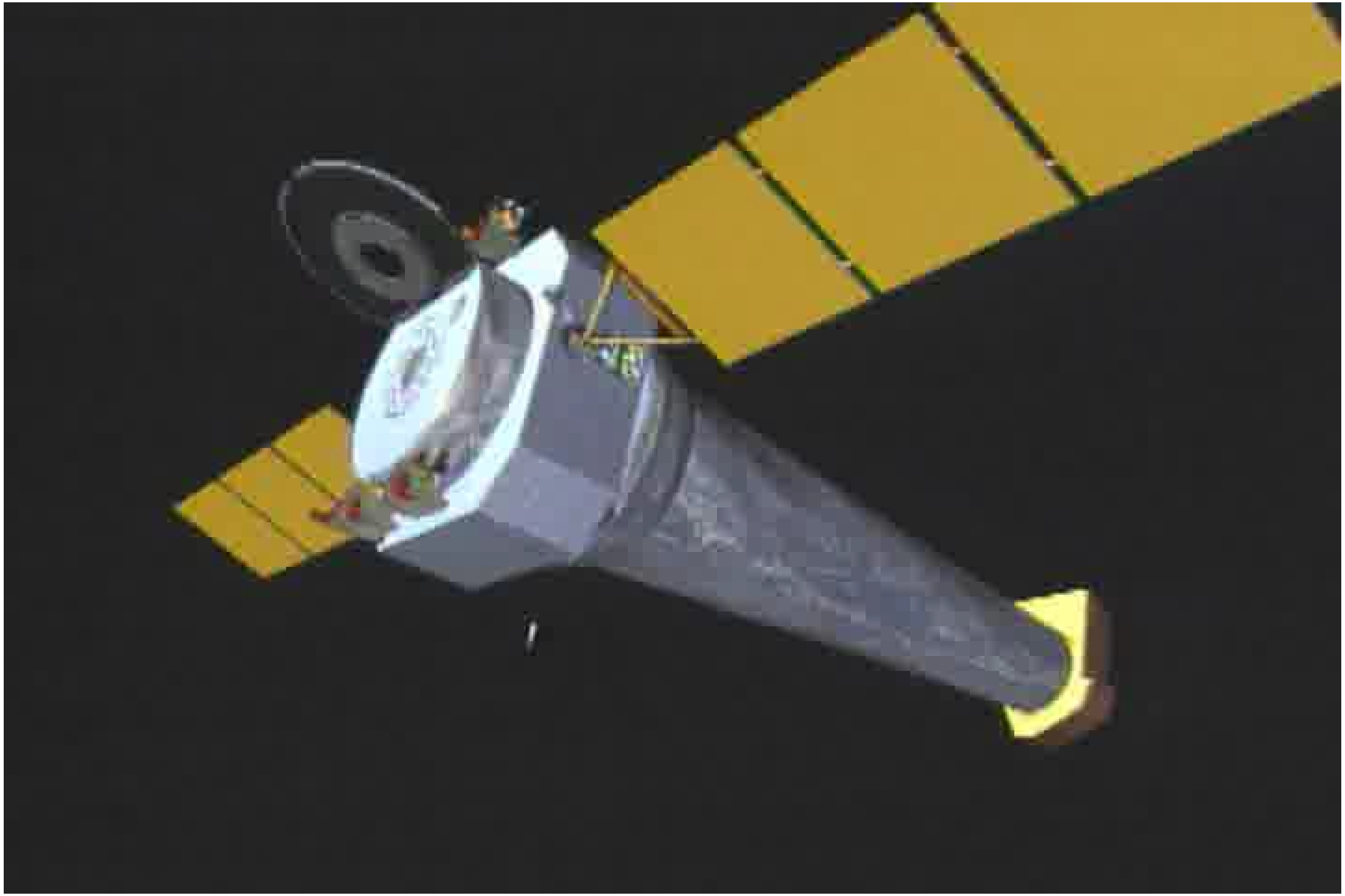
X-rays trace hot (million degrees), highly ionized gas in the universe.

Two colliding galaxies, triggering a burst of star formation



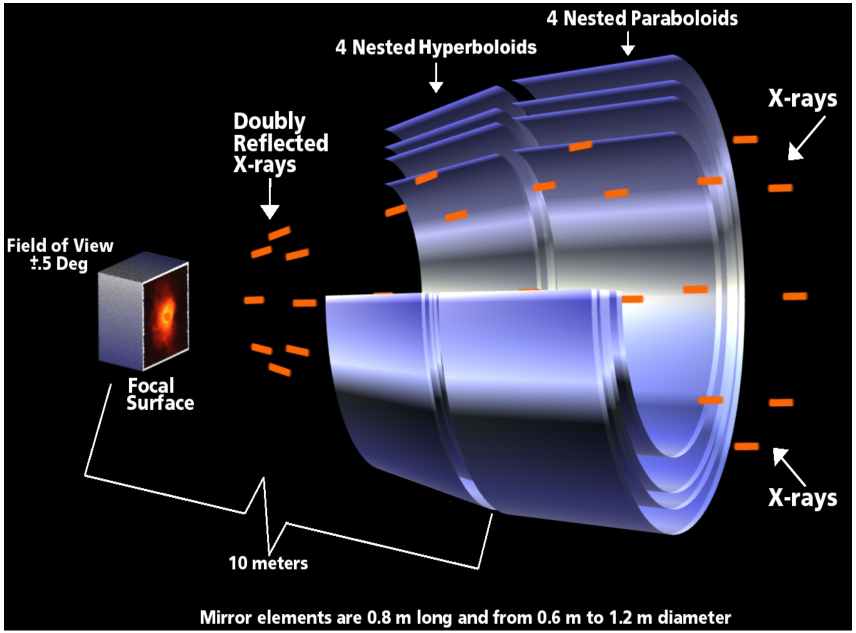
Very hot gas in a cluster of galaxies

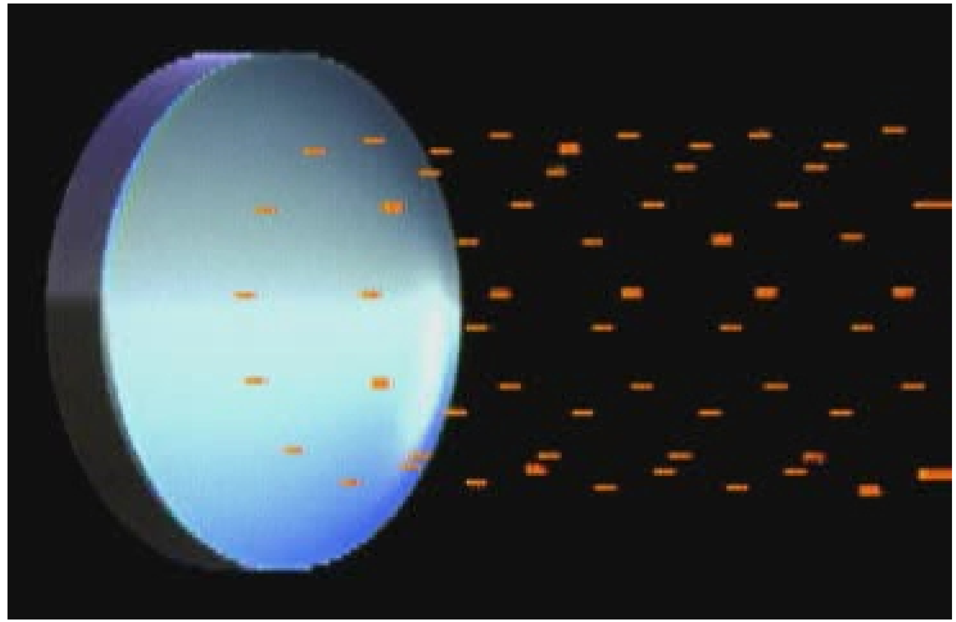
Chandra X-ray Observatory



Shuttle launched, highly eccentric orbit.

The Highest Tech Mirrors Ever!

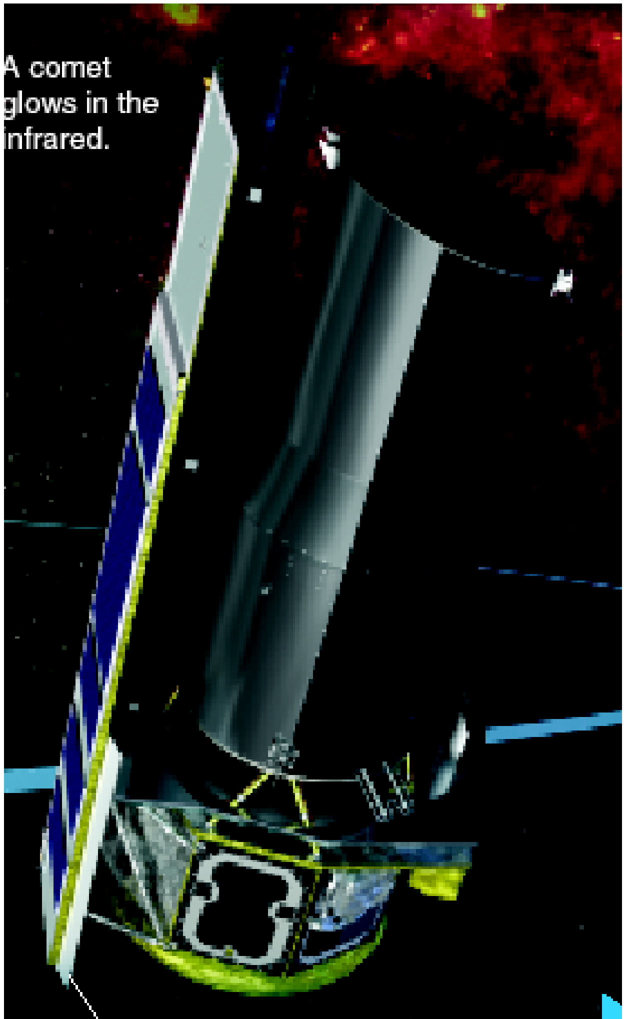




- **Chandra is the first X-ray telescope to have image as sharp as optical telescopes**

NASA’s Great Observatories in Space (IV)

The Spitzer Space Telescope



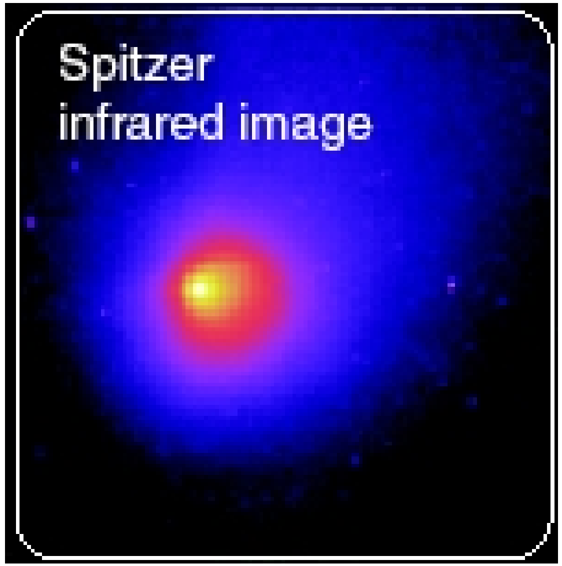
Launched in 2003

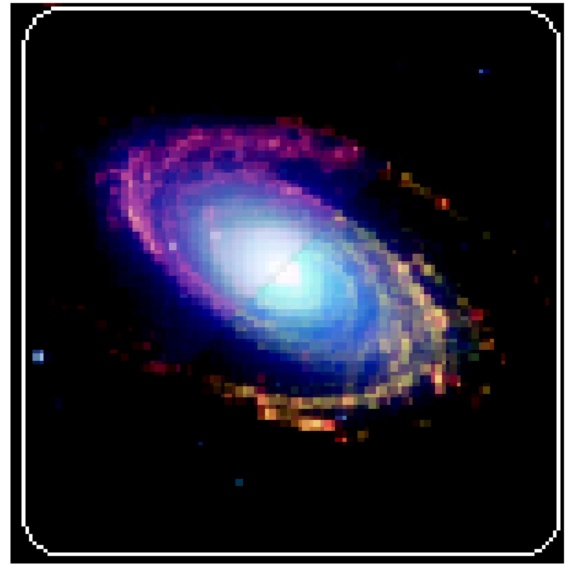
Infrared light traces warm dust in the universe.

The detector needs to be cooled to -273 ^{o}C (-459 ^{o}F).

Spitzer Space Telescope Images

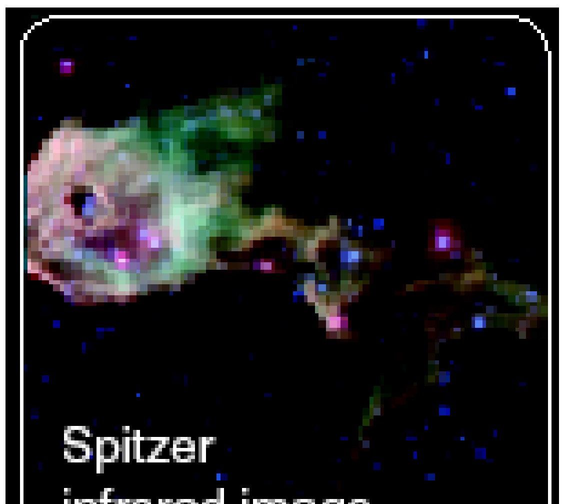
A Comet



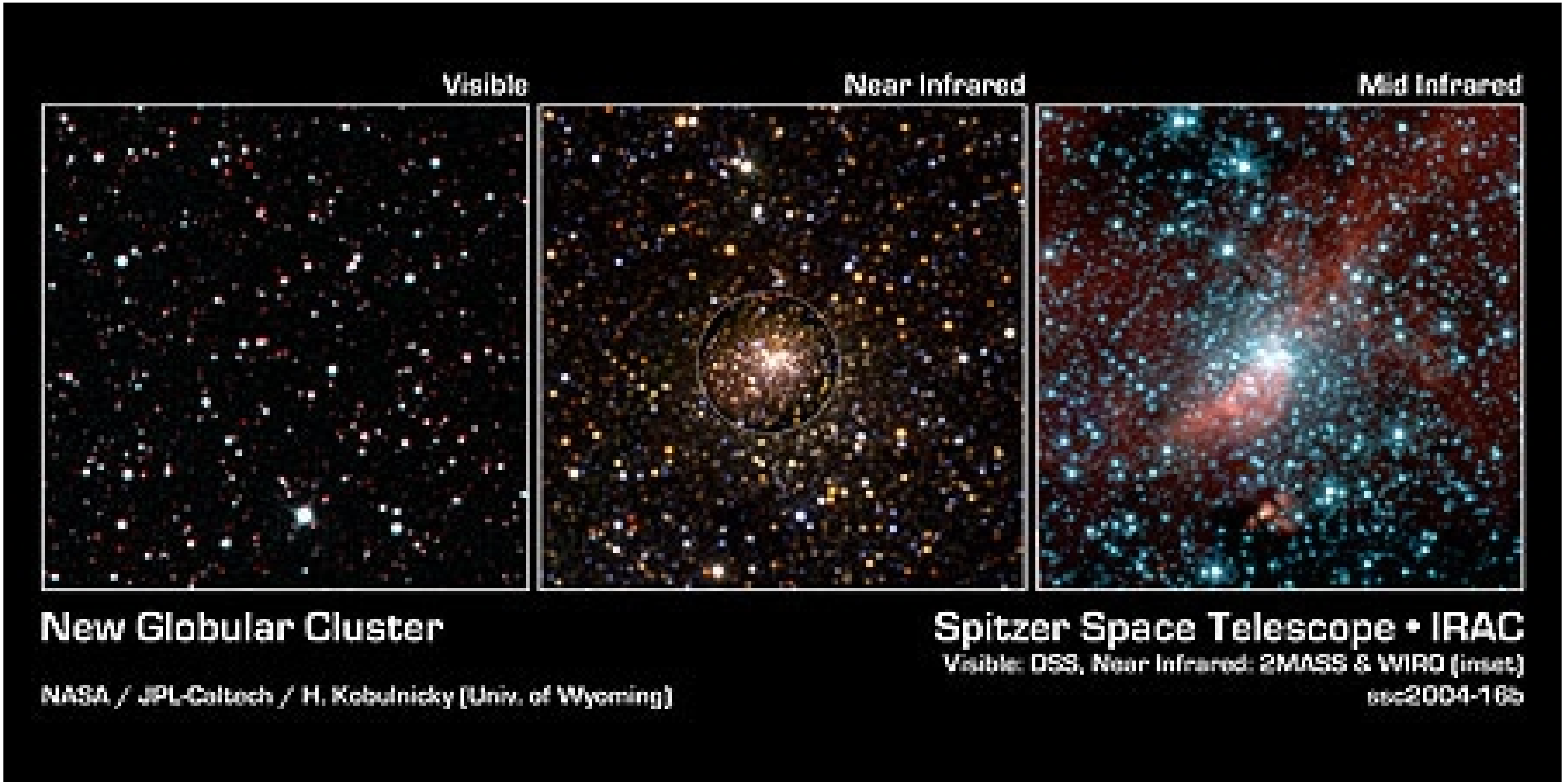


Warm dust in a young spiral galaxy

Newborn stars that would be hidden from our view in visible light

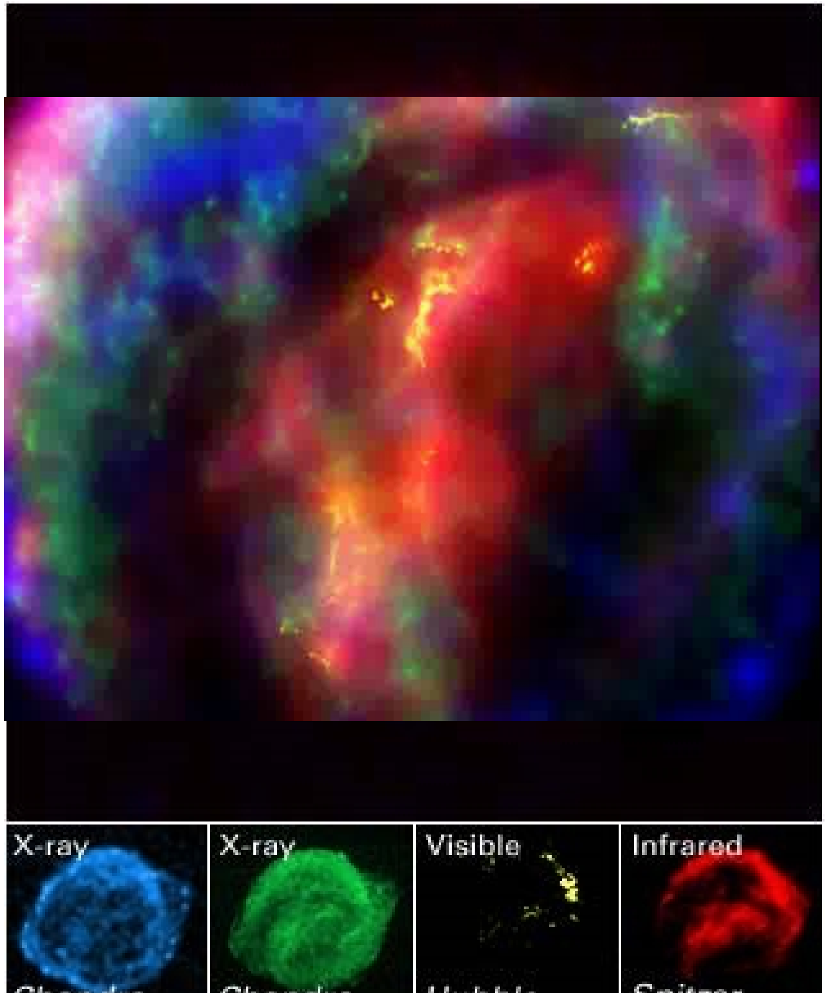


Spitzer Space Telescope



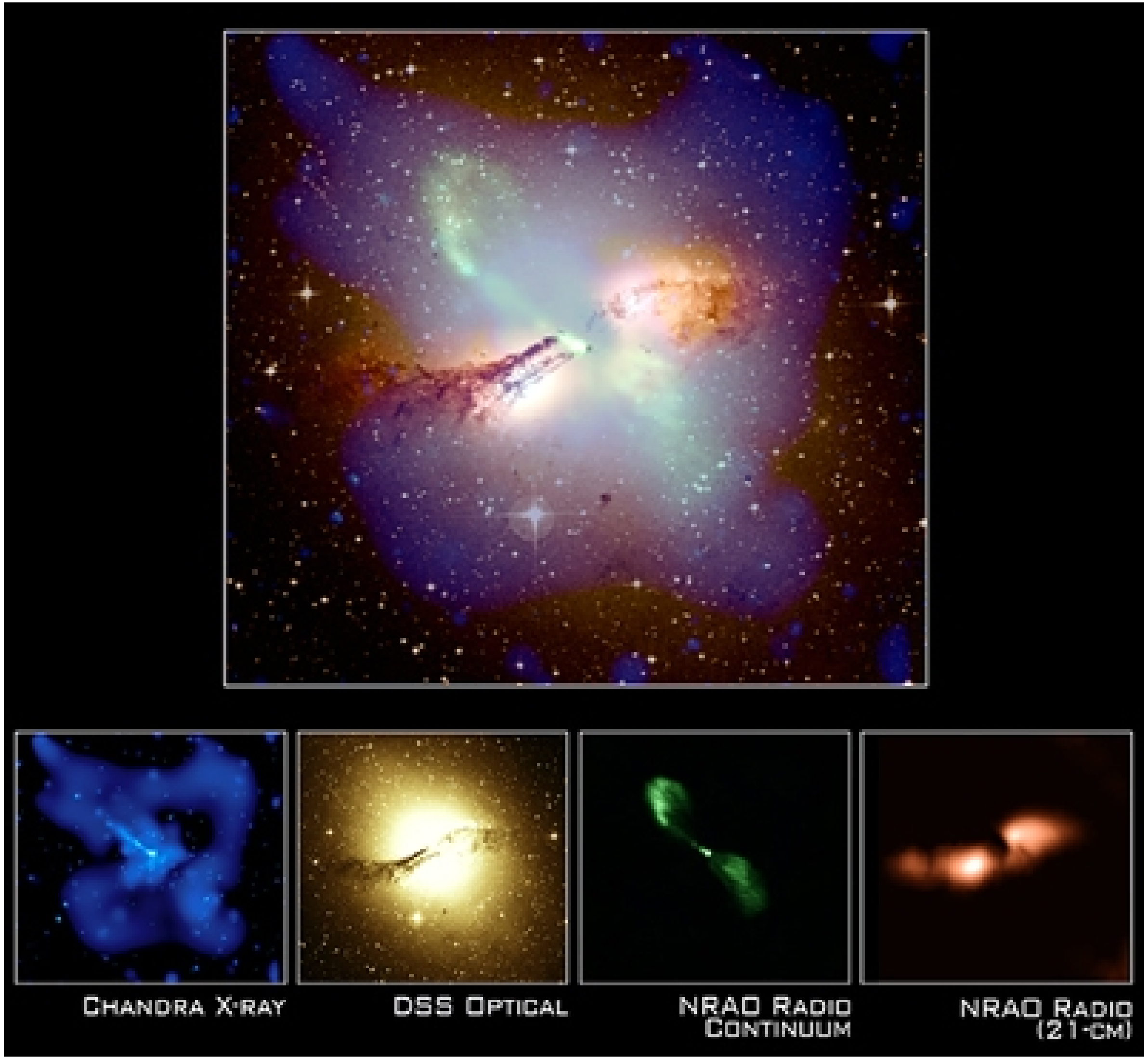
- Discovered by a Wyoming grad student and professor. The "Cowboy Cluster" – an overlooked

Kepler's Supernova with all three of NASA's Great Observatories



- Just 400 years ago: (Oct. 9, 1604)
- Then a bright, naked eye object (no telescopes)
- It's still blowing up – now 14 light years wide and expanding at 4 *million* mph.
- There's material there at MANY temperatures, so many wavelengths are

A Multiwavelength Look at Cygnus A



- A merger product, and powerful radio galaxy

NASA - Space Science - Missions - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://spacescience.nasa.gov/missions/

Firefox Help | Firefox Support | Plug-in FAQ

Under study	In development	Operating	Past missions
ANITA	AIM	ACE	Ended after 1989:
Constellation-X	Astro-E2	Cassini	ASCA
DUO	CINDI	Chandra	Astro-1 / Astro-2
EUSO	Dawn	CHIPS	BBXRT
GEC	Deep Impact	Cluster	Clementine
Geospace	GLAST	FAST	CGRO
IBEX	Herschel	FUSE	COBE
JIMO	Mars '05 Orbiter	GALEX	CONTOUR
JMEX	New Horizons (Pluto)	Genesis	CRRES
Juno	Planck	Geotail	DE-1
JWST (NGST)	SOFIA	Gravity Probe B	Deep Space 1
Kepler	Solar-B	HETE-2	Deep Space 2
LISA	Space Tech 5	Hubble (HST)	DXS
Mag Constellation	Space Tech 6	IMAGE	Equator-S
Mag Multiscale	Space Tech 7	INTEGRAL	EUVE
Mars 2009	STEREO	Mars '03 Rovers	Galileo
Mars - beyond 2009	Swift	Mars Express /	HALCA / VLBI
Moonrise	THEMIS	ASPERA-3	Hipparcos
NEXUS	TWINS	Mars Global Surv.	Hubble (past)
NuSTAR		Mars Odyssey	IEH-3
Phoenix		MESSENGER	ISEE-3/ICE
SDO		Polar	IMP-8
Sentinels		RHESSI	IRTS
SIM		Rosetta	ISO
Solar Probe		RXTE	IUE
TPF		SAMPEX	Kuiper (KAO)
WISE		SOHO	Leonid MAC
		Spitzer (SIRTF)	Lunar Prospector
preliminary concepts		Stardust	Magellan
		SWAS	Mars Clim. Orb.
		TIMED	Mars Observer
		TRACE	Mars Pathfinder
		Ulysses	Mars Polar Lander
		Voyager	NEAR
		Wind	ORFEUS

Done

The Future of Space-Based Optical/Infrared Astronomy:

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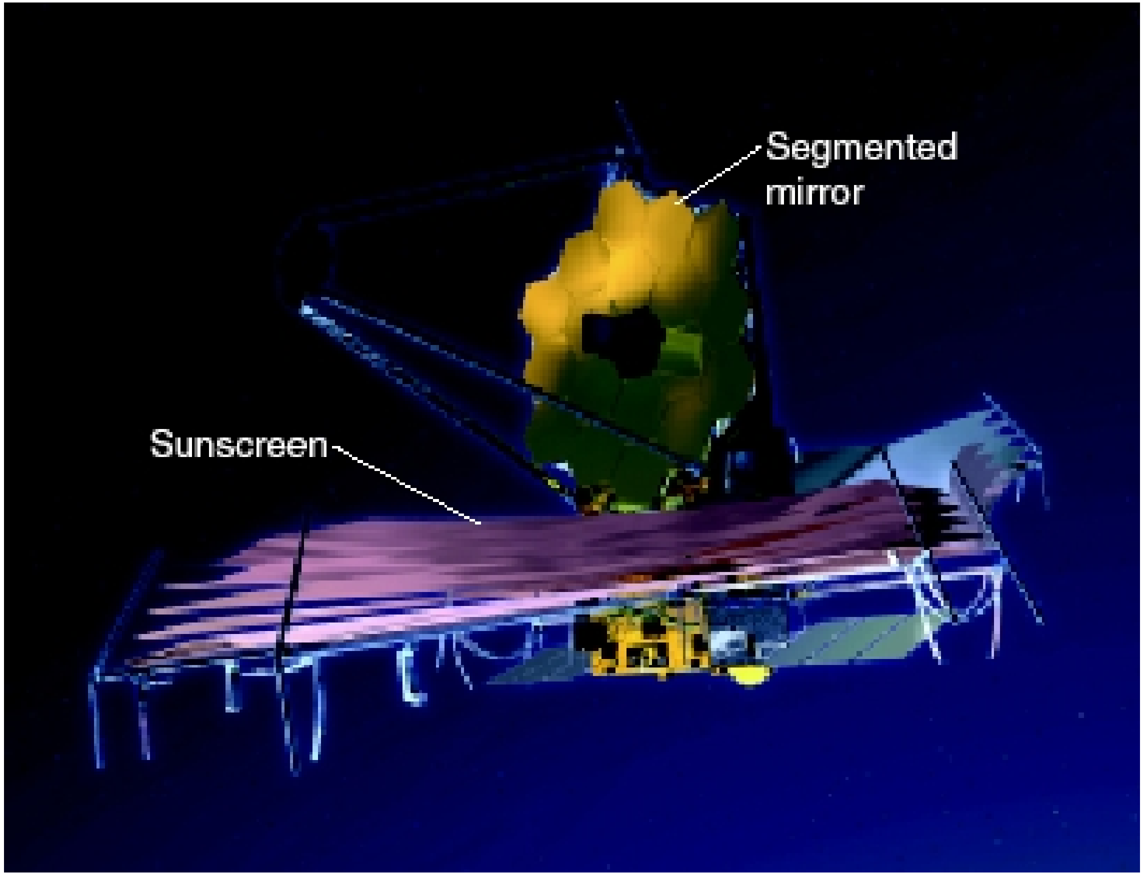

The James Webb Space Telescope