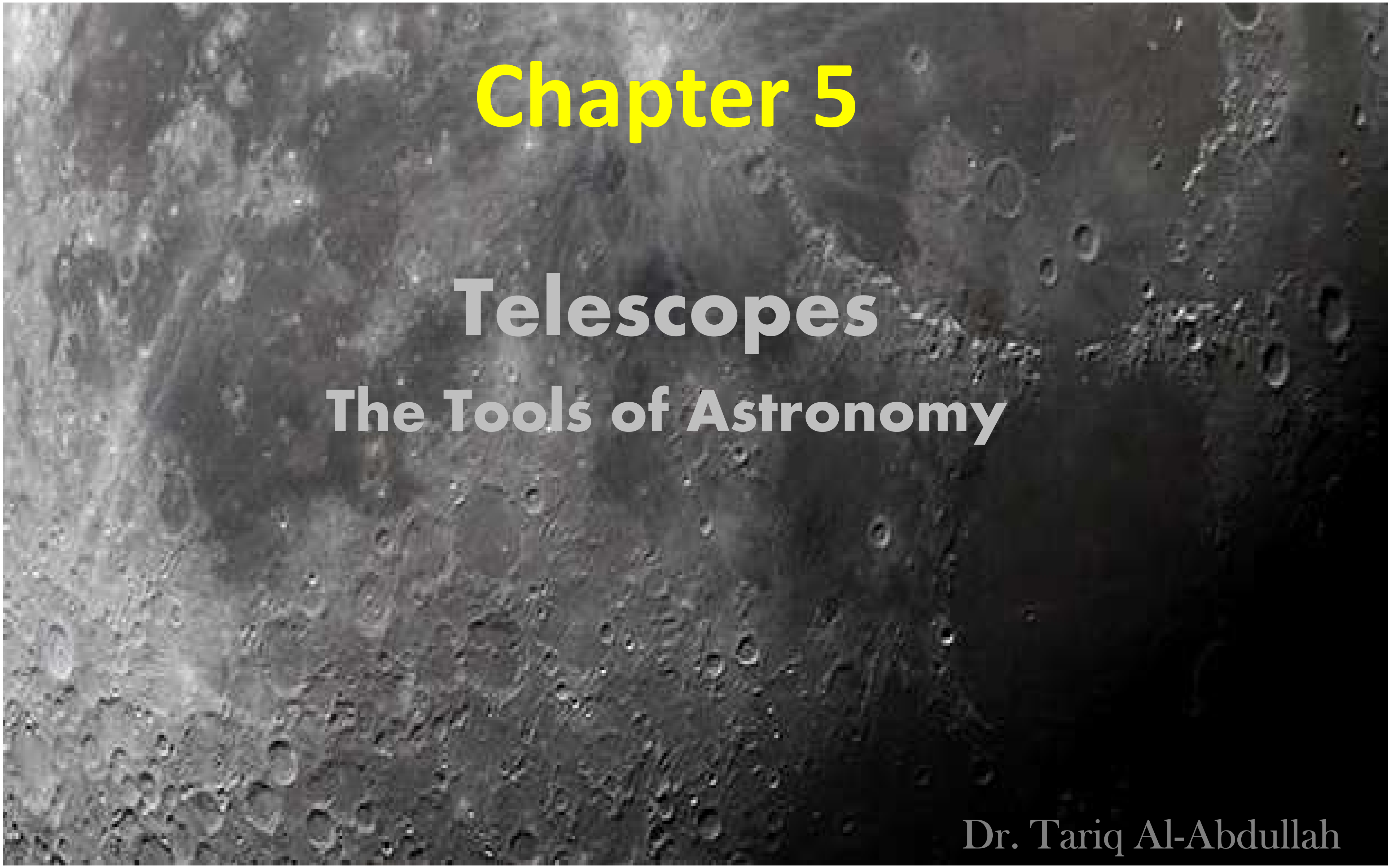


Chapter 5

Telescopes

The Tools of Astronomy

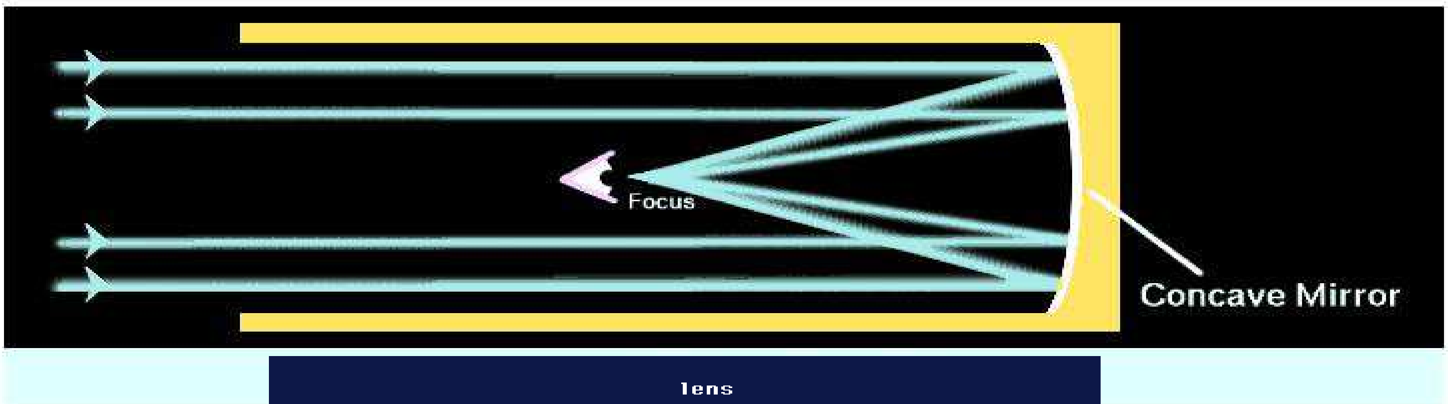
Dr. Tariq Al-Abdullah

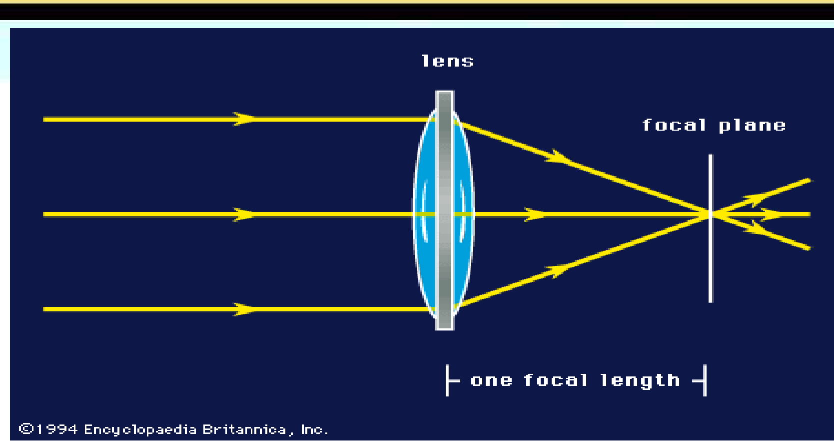
Learning Goals:

- 5.1 Optical Telescopes (The Hubble Space Telescope)
- 5.2 Telescope Size
- 5.3 Images and Detectors
- 5.4 High-Resolution Astronomy
- 5.5 Radio Astronomy
- 5.6 Interferometry
- 5.7 Space-Based Astronomy
- 5.8 Full-Spectrum Coverage

5.1 Optical Telescopes

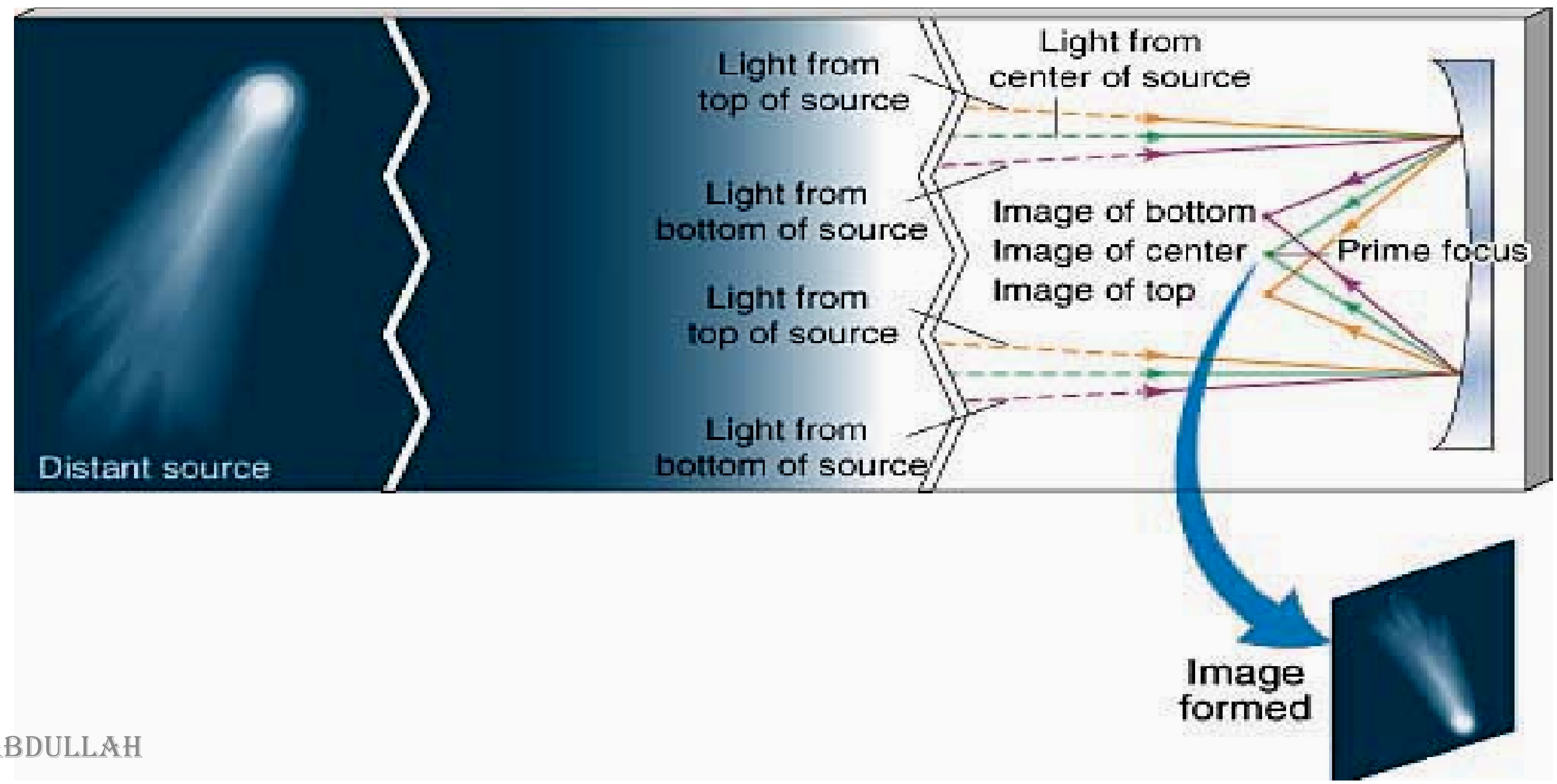
- ✓ **A Telescope:** a light bucket, capture many photons.
- ✓ Optical Telescope → Light visible to human eyes
- ✓ Reflecting & Refracting Telescopes.





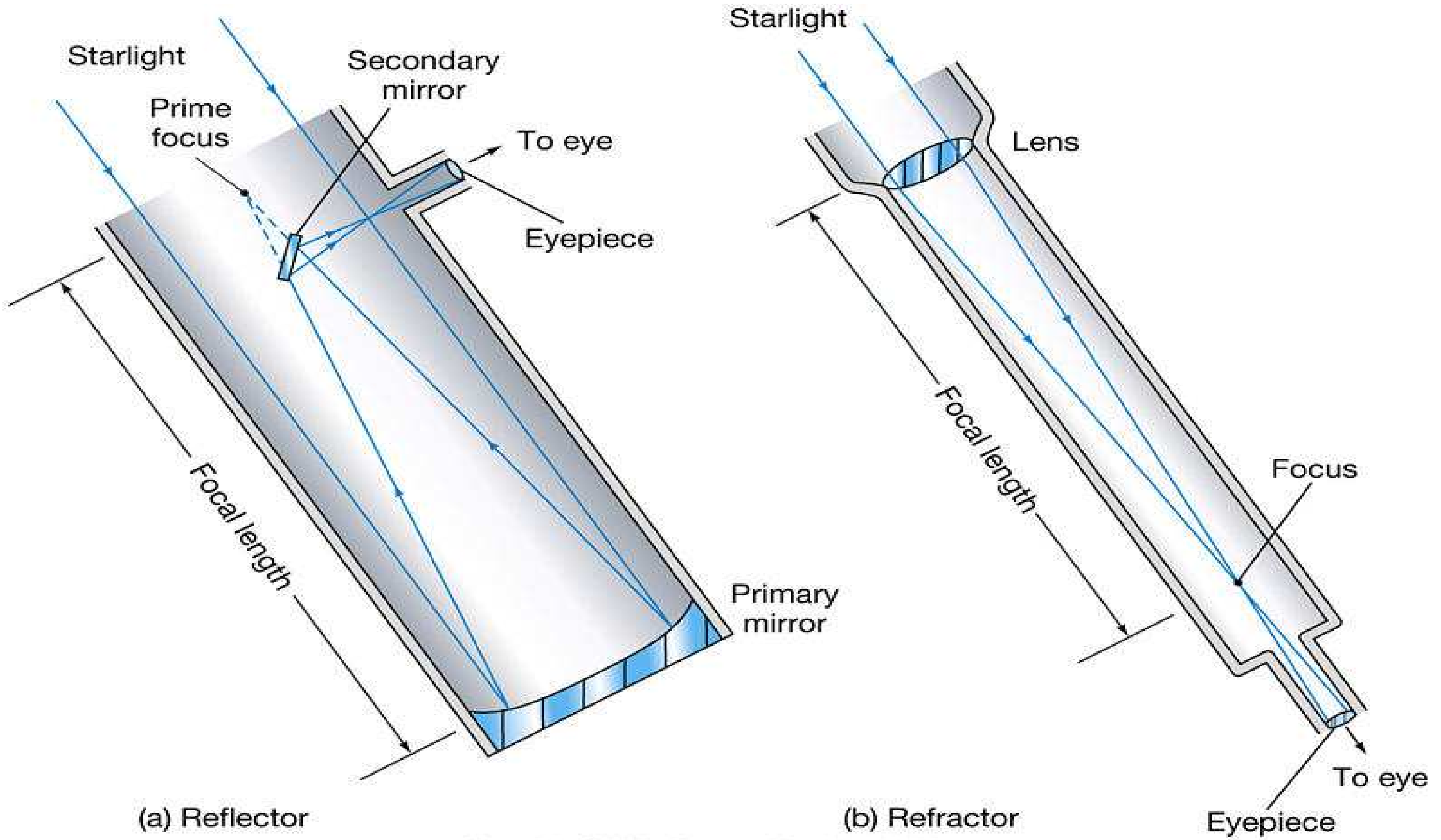
5.1 Optical Telescopes

- ✓ **The prime focus image is small 1 cm.**
- ✓ **Image magnified with a lens known as *eyepiece***
- ✓ **Angular diameter of the magnified image is much greater than the telescope's field view.**



5.1 Optical Telescopes

- ✓ **Comparing Refractors and Reflectors**

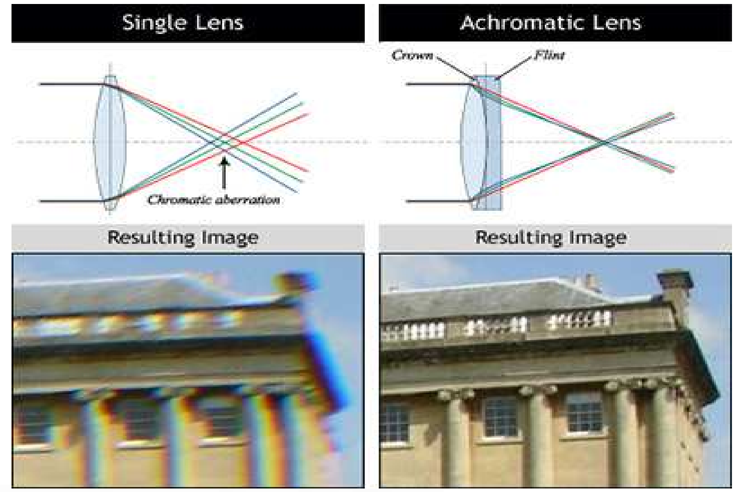


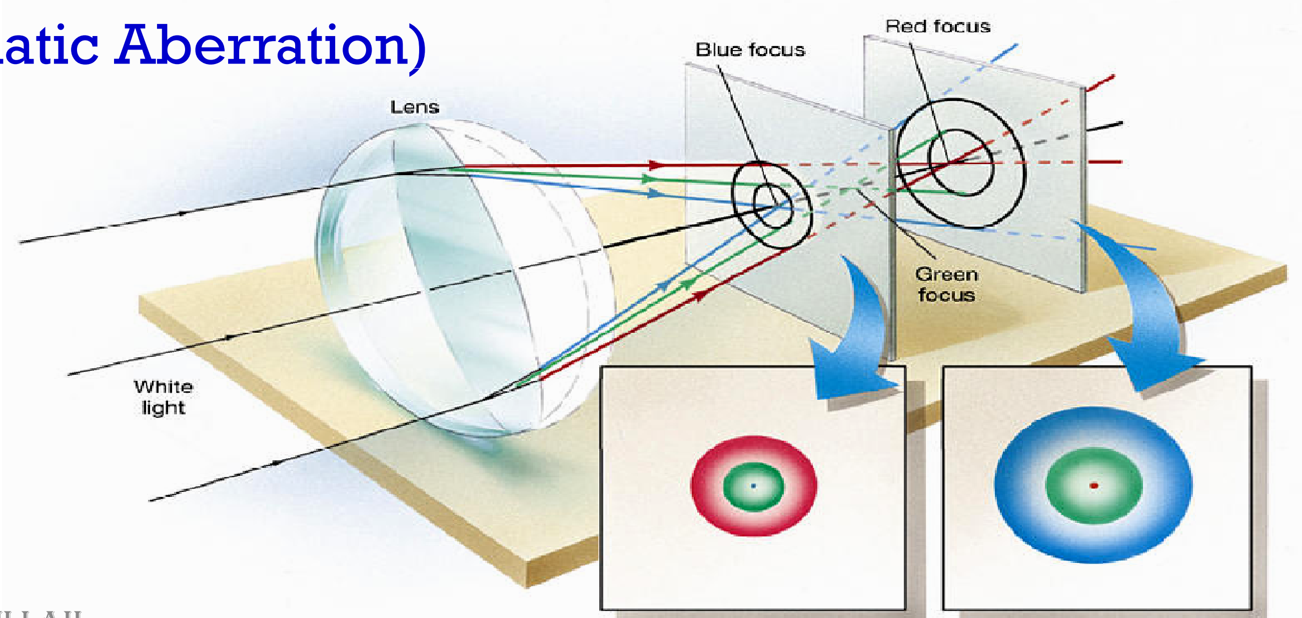
5.1 Optical Telescopes

- Why Reflecting Instrument is favored over Refractive one?

1- lenses disperses white light into its components. Each wavelength has its focus

(Chromatic Aberration)





5.1 Optical Telescopes

- Why Reflecting Instrument is favored over Refractive one?

2- lenses absorb part of the light, severe for IR light

(Chromatic Aberration)

3- A large lens is heavy→ deformation.

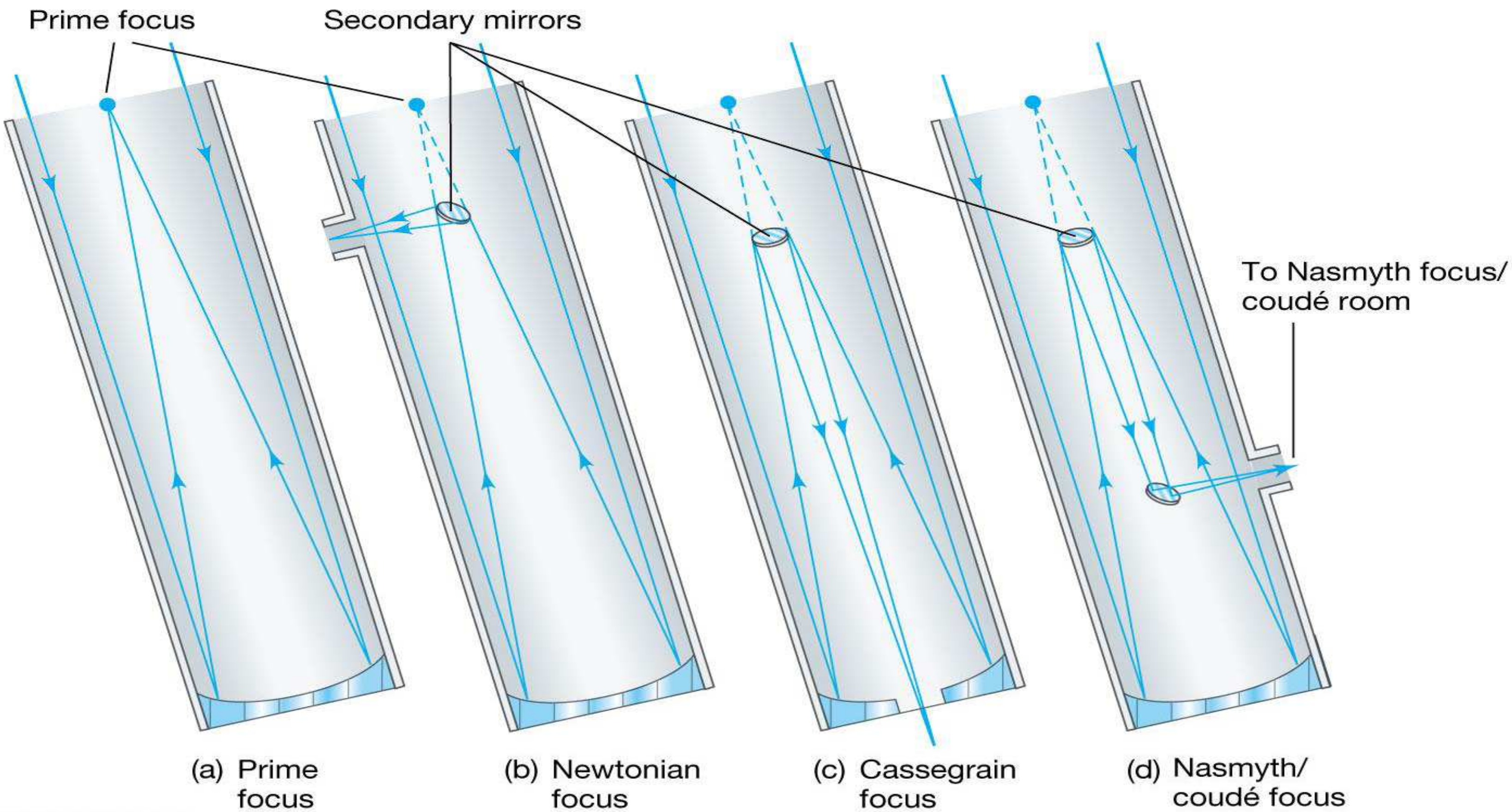
4- A lens has two surfaces that need cleaning and polishing.

Yerkes Observatory's 40-inch-diameter refractor (1897).

World Largest in Wisconsin, USA

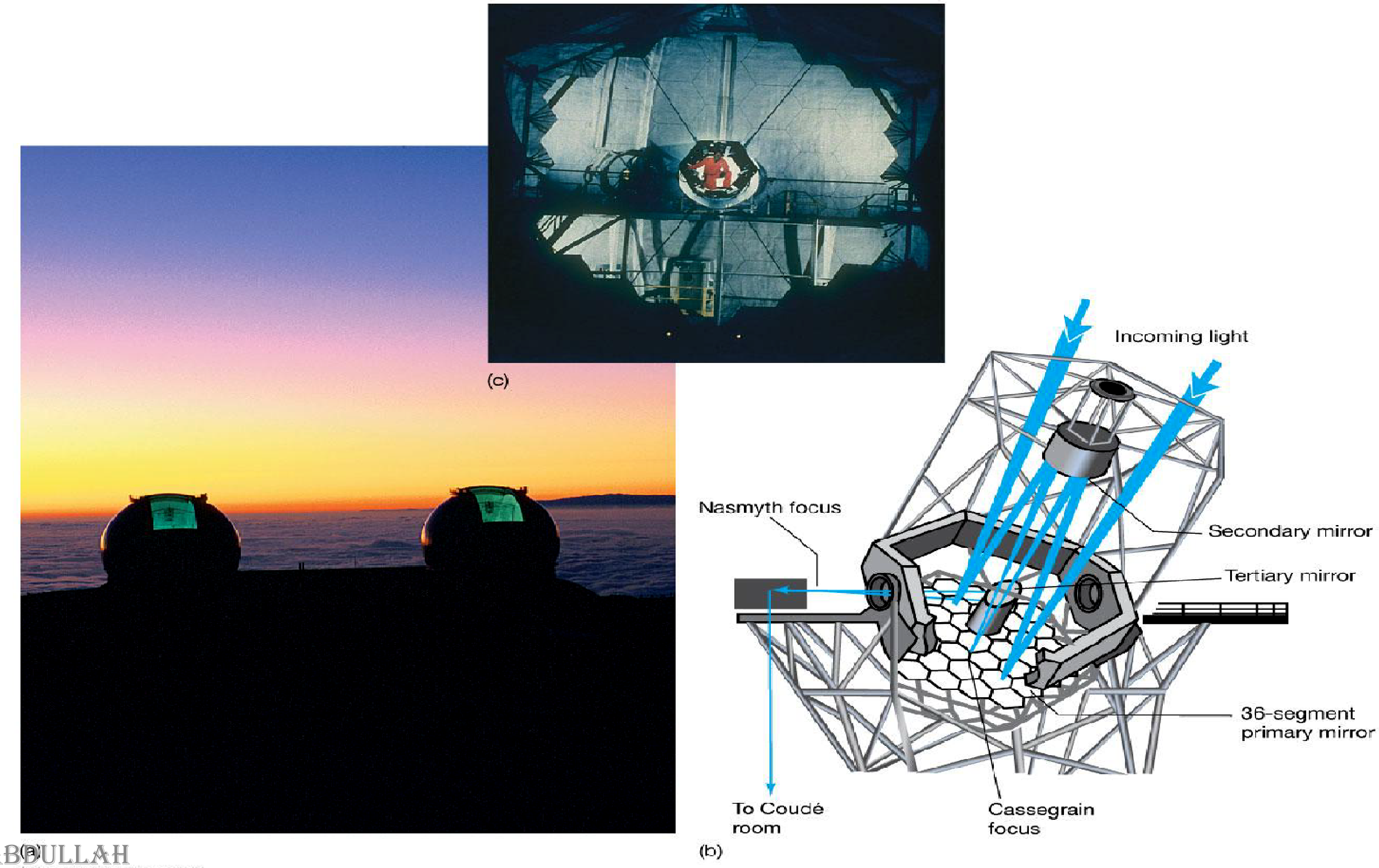
5.1 Optical Telescopes

✓ Types of Reflecting Telescope



5.1 Optical Telescopes

- ✓ **Modern Telescopes; 10–m Keck Observatory Hawaii**

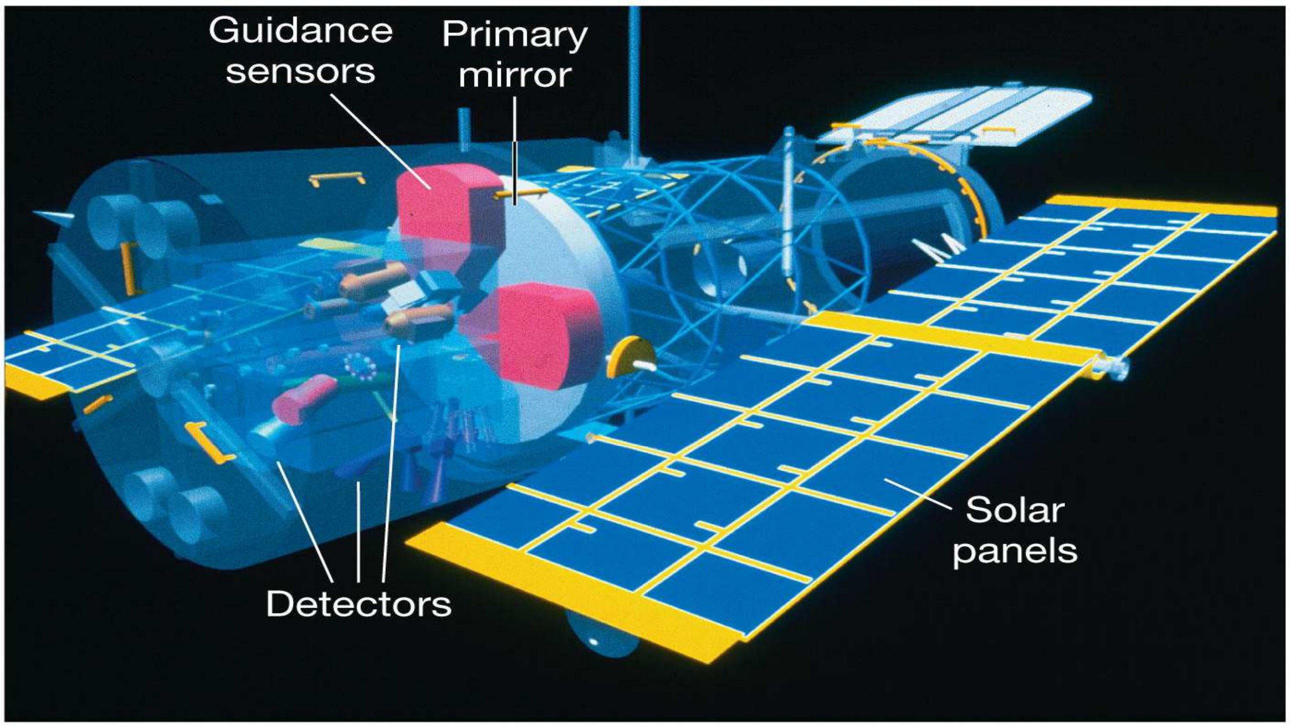


5.1 Optical Telescopes

* The Hubble Space Telescope 1990 – till now

It has a variety of detectors.

* The Hubble Space Telescope's main mirror is 2.4 m in diameter and is designed for visible, infrared, and ultraviolet radiation



Hubble Space Telescope

- it takes extremely high-resolution images with negligible background light.
- Here we compare the best ground-based image, on the left, with the Hubble image on the right

5.2 Telescope Size

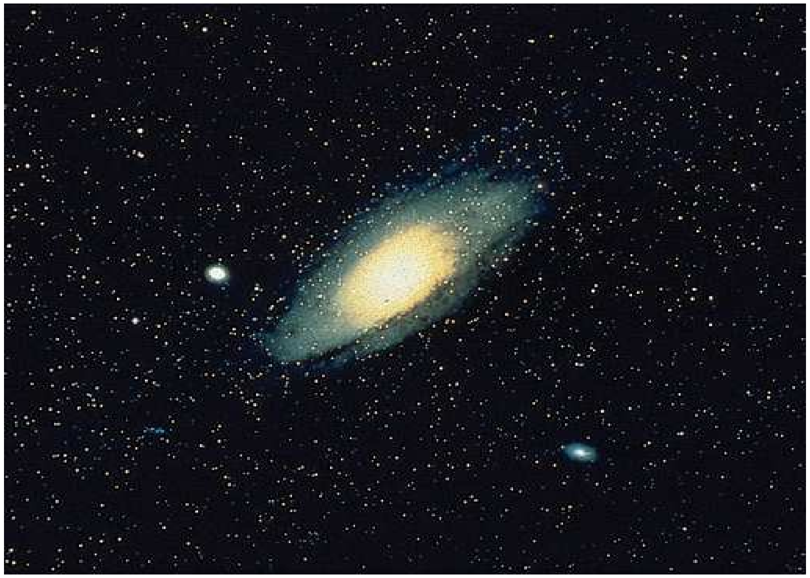
Their development over the years has seen a steady increase in *size,* for two

main reasons.

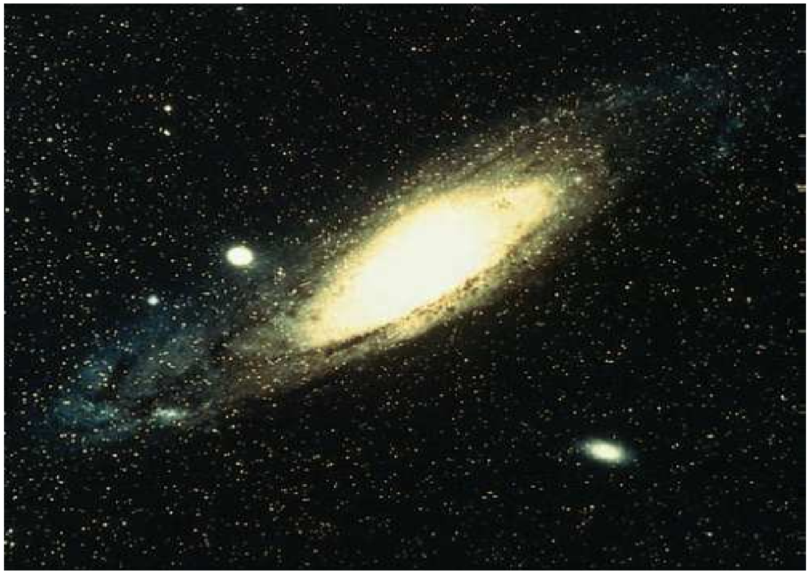
1- *light-gathering power*

2-the telescope's *resolving power*

Light-Gathering Power = Collecting Area



(a)



(b)

the Andromeda Galaxy

Both photographs had the same exposure time, but image (b) was taken with a telescope twice the size of that used to make image (a).

Brightness proportional to square of radius of mirror

Light-Gathering Power

- **Brightness**

  5-m mirror : 1-m mirror

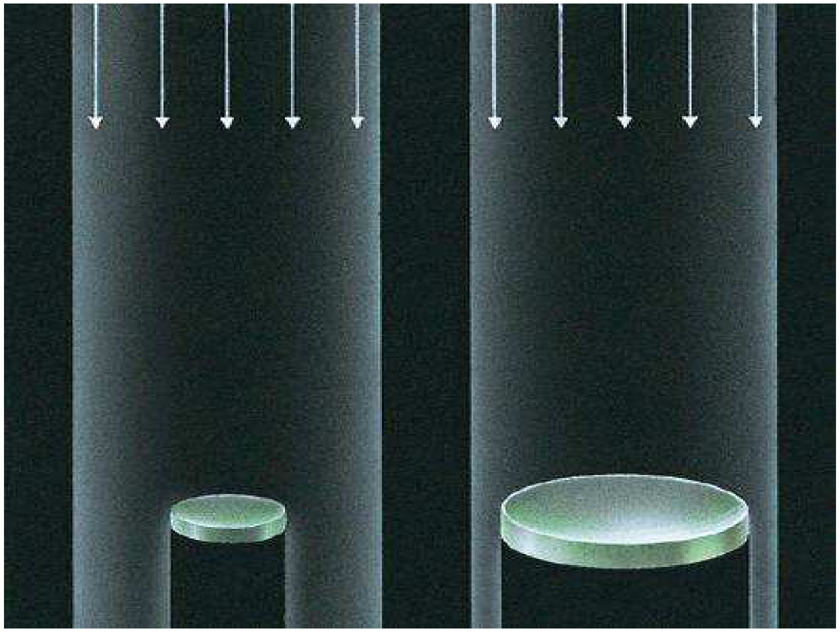
  25 : 1

- **Time**

  5-m mirror : 1-m mirror

  25 : 1

  2.4 min : 1-hour

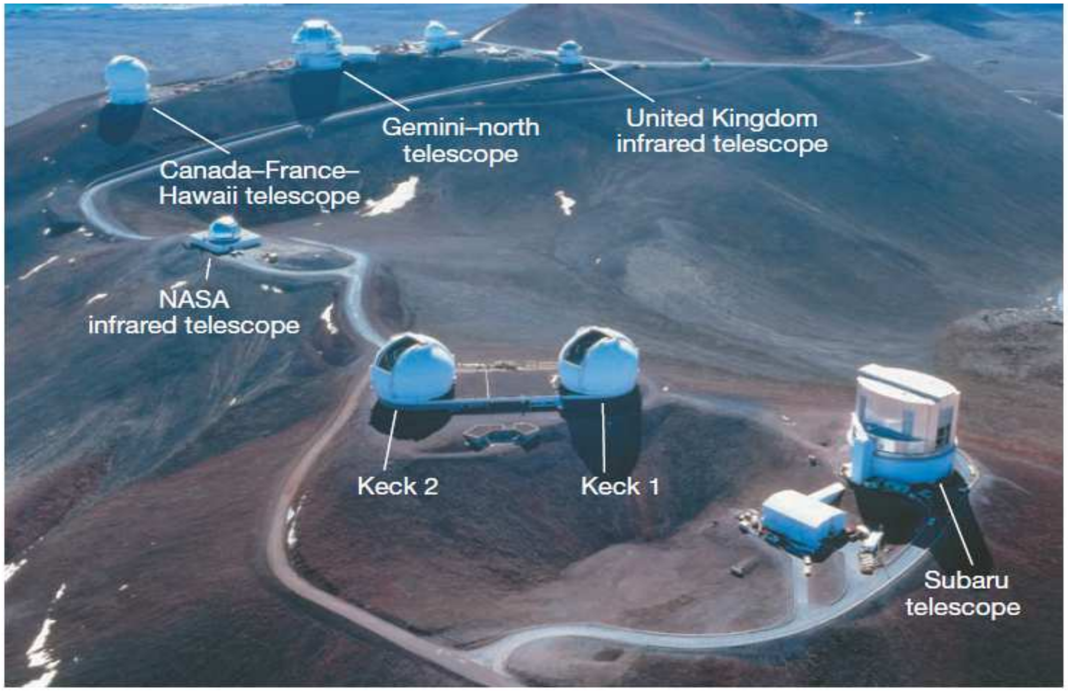


5.2 Telescopes Size

Modern Telescope are not expensive

Muna Kea Observatory 36hexagonal 1.8 m mirrors – 10.0 m reflector

VLT Observatory, four 8.2 m reflecting telescopes → 16.0 m single mirror

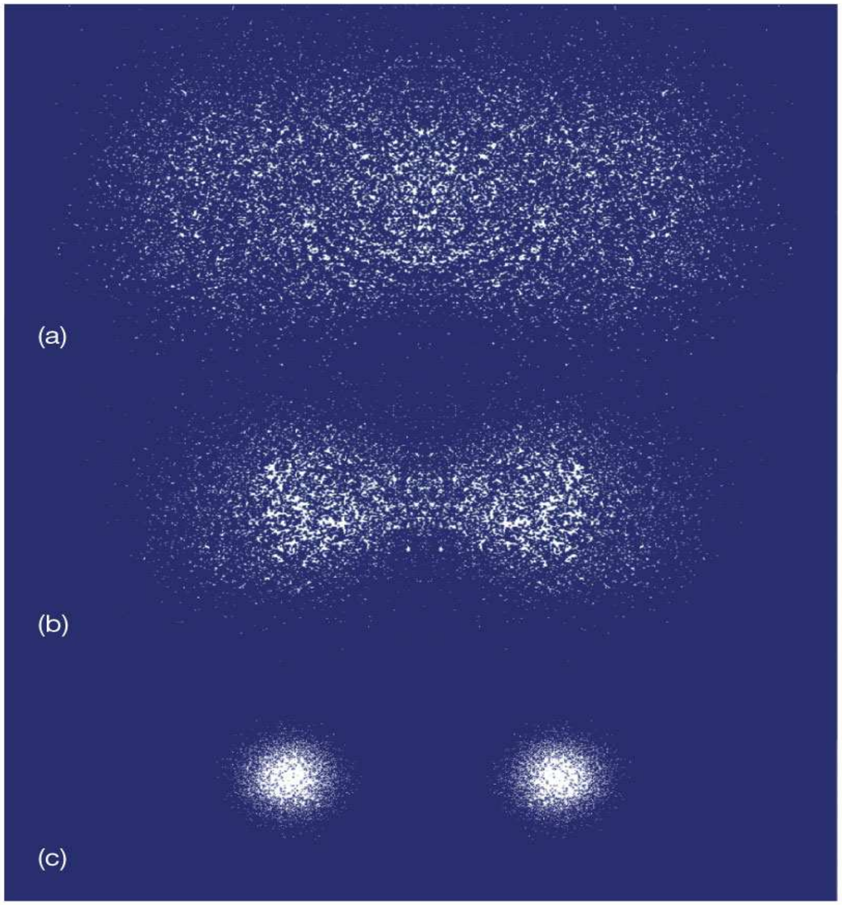


5.2 Telescopes Size

Resolving Power

A second advantage of large telescopes is their finer angular resolution.

In general, *resolution* refers to the ability of any device, such as a camera or telescope, to form distinct, separate images of objects lying close together in the field of view.



5.2 Telescopes Size

Effect of improving resolution:

- Detail becomes clearer in the Andromeda Galaxy as the angular resolution is improved some 600 times, from
    a) 10
    b) 1'
    c) 5“
    d) 1"

5.2 Telescopes Size

What limits a telescope's resolution? One important factor is *diffraction*, the tendency of light—and all other waves, for that matter—to bend around corners.

Because of diffraction, when a parallel beam of light enters a telescope, the rays spread out slightly, making it impossible to focus the beam to a sharp point, even with a perfectly constructed mirror.

5.2 Telescopes Size

The degree of fuzziness—the minimum angular separation that can be distinguished—determines the angular resolution of the telescope. The amount of diffraction is proportional to the wavelength of the radiation and inversely proportional to the diameter of the telescope mirror. For a circular mirror and otherwise perfect optics, we can write (in convenient units):

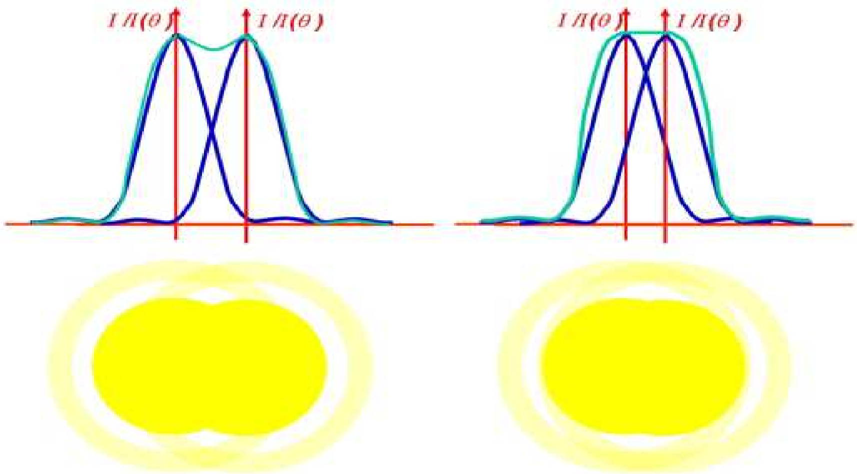
$$\text{angular resolution (arcsec)} = 0.25\,\frac{\text{wavelength }(\mu\text{m})}{\text{diameter (m)}},$$

Resolving Power

- **Large telescope ➔ Finer Angular resolution**
- **Close objects are separated by small angle on the sky.**
- ***Diffraction* limits the telescope's resolution (fuzziness).**

$$\text{Angular resolution (arc sec)} = 0.25\ \frac{\text{wavelength } (\mu\text{m})}{\text{mirror diameter (m)}}$$

- **Large telescope = less diffraction.**



Example 1 (large telescope)

diameter of telescope mirror = 1 meter = 100 cm
wavelength of light = 0.5 micron (visible)
ang. res. = 0.25 x 0.5 / 1 = 0.125 arc secs

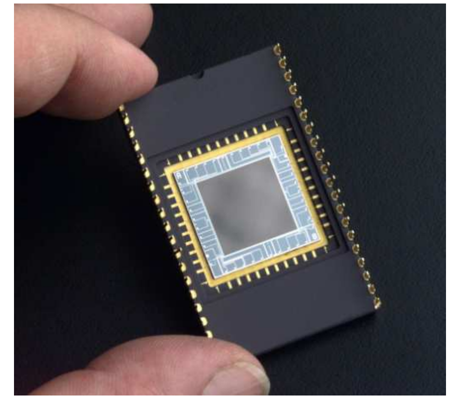
Example 2 (single radio-telescope dish)

diameter of radio-telescope = 25 meters
wavelength of radio-wave = 1 meter = 1 x 10^6 microns
ang. res. = 0.25 x (1 x 10^6) / 25 = 10,000 arc secs
Much worse than an optical telescope

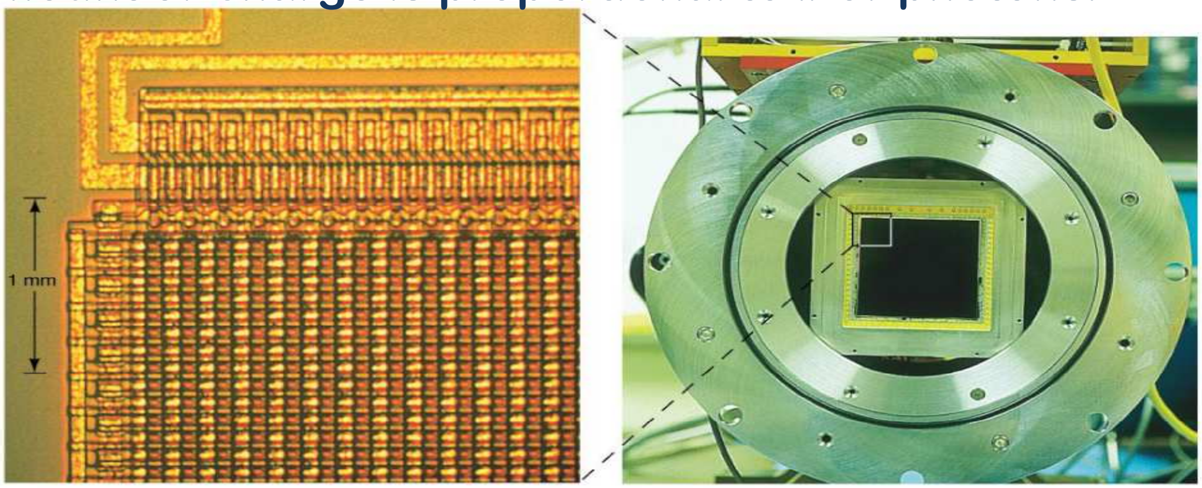
Example 3

diameter of radio-telescope = 25 kilometers = 25,000 meters
wavelength of radio-wave = 1 meter = 1 x 10 6 microns
ang. res. = 0.25 x (1 x 10 6) / 25,000 = 10 arc secs
Worse than an optical telescope, but not so bad

5.3 Images and Detectors



- **Telescopes gather and focus light to form an image**
- **Charged Coupled Devices (CCD)→Electronic Detector**
- **Silicon is divided into a 2D array of tiny elements (Pixels)**
- **Photon strikes a pixel ➔ Electric charge builds up on it.**
- **Amount of charge is proportional to # of photons.**



(a) (b)

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
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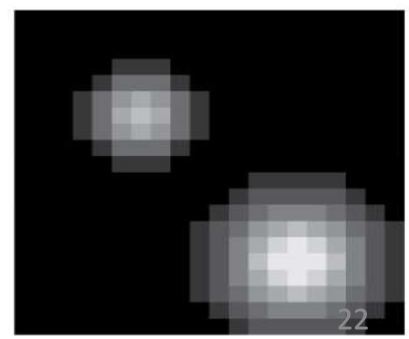
0	0	0	0	0	0	0	0	0	1	2	3	5	6	7	6	5	3	2	1
0	0	0	0	0	0	0	0	0	0	1	2	3	4	4	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	1	0	0

(c)



(d)

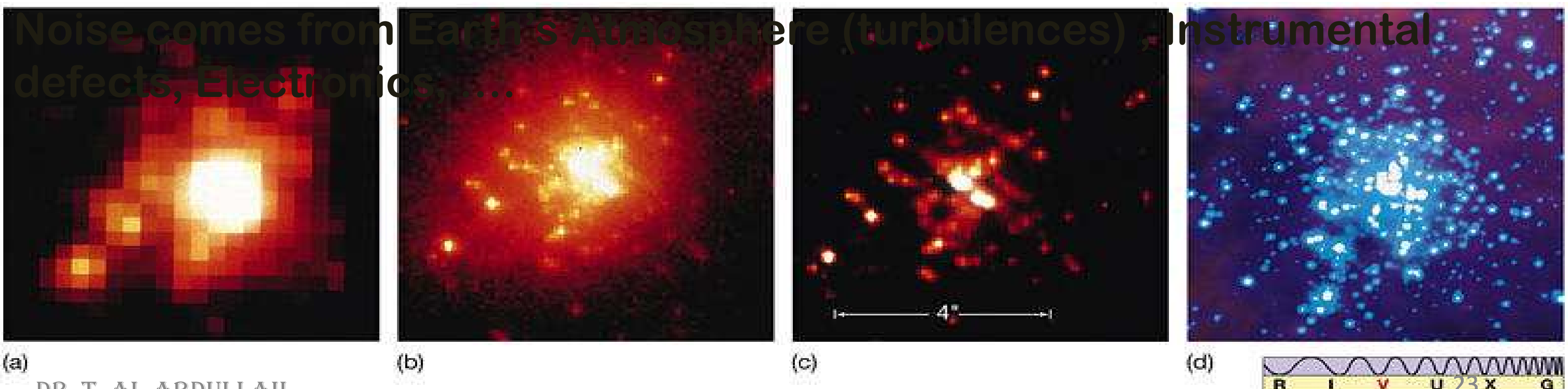
5.3 Images and Detectors

CCD in Astronomy vs Photographic plates

- **CCDs are efficient, records 90% of photons. 5% in photographic.**
- **Images 10-20 times fainter for the same exposure time.**
- **Less time (10%), fast recording.**
- **Easier to save and use.**

Computer Processing, remove background noise.

Noise comes from Earth's Atmosphere (turbulences), Instrumental defects, Electronics, ...



5.3 Images and Detectors

Photometry

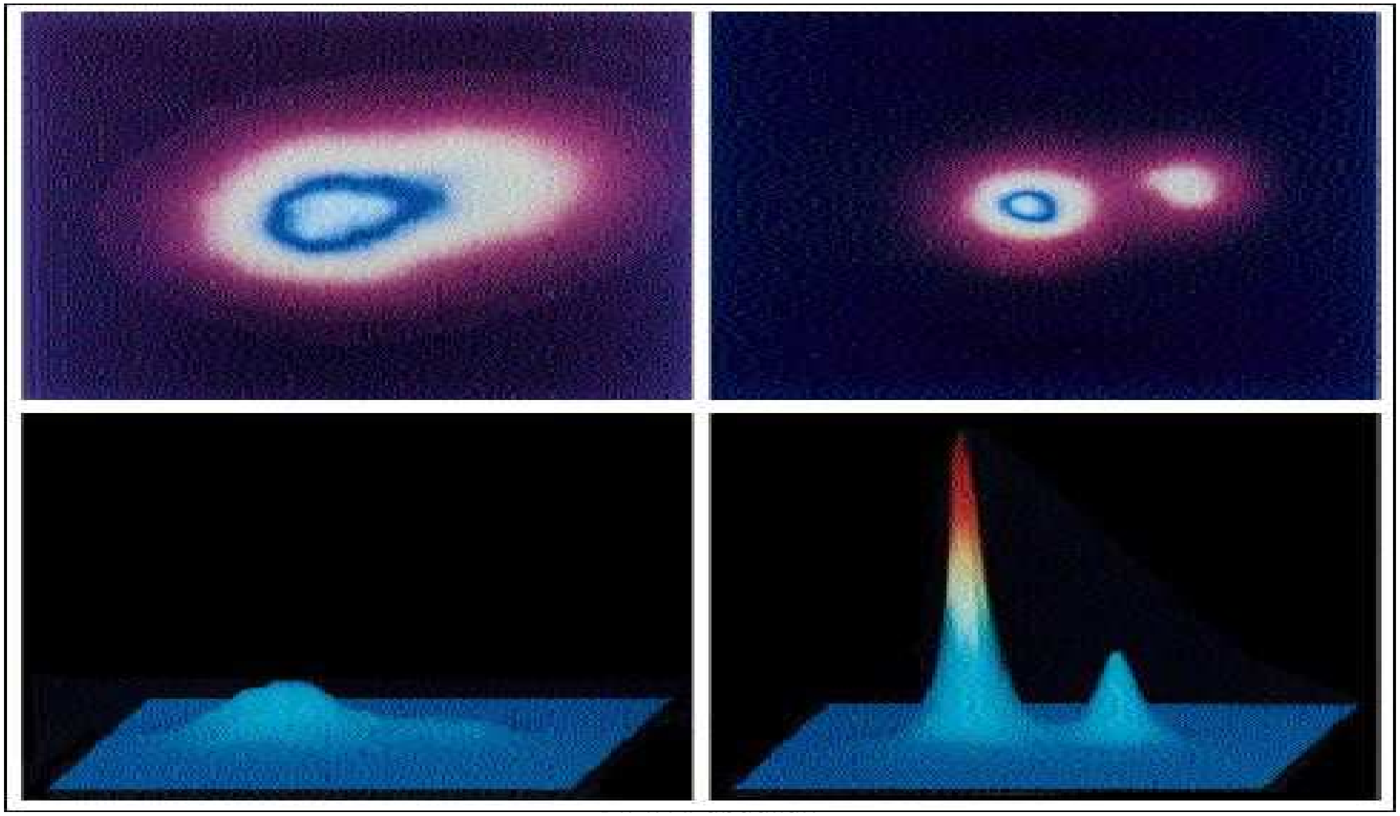
- Measuring the brightness of star by a detector.
- Astronomers combine photometric measurements with filters.
- HST construct visible images using red, green, and blue filters.
- Final image is an average over the entire exposure.

Spectroscopy

- Studying the spectrum of the incoming light.
- Light split into its component colors using a prism or diffraction grating.

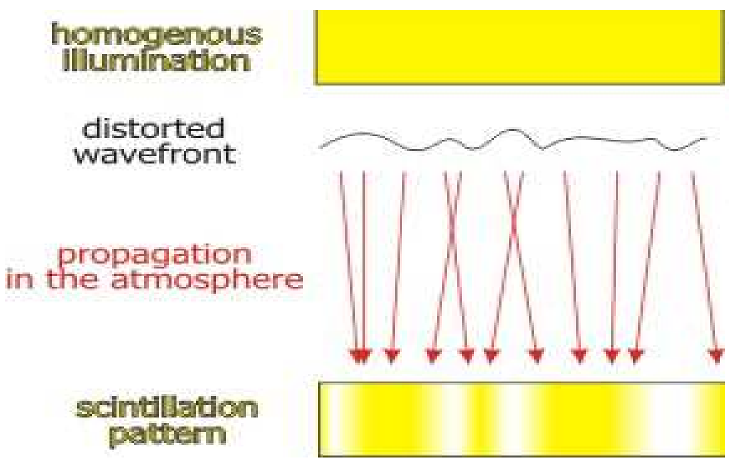
5.4 High Resolution Astronomy

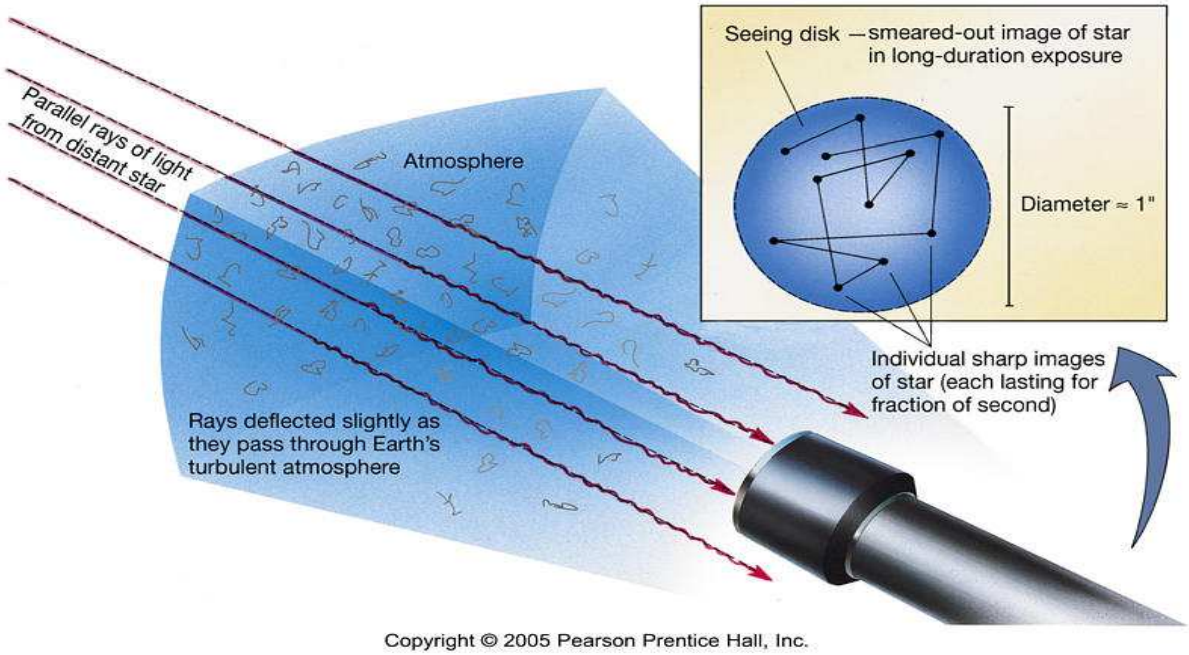
- Large Telescopes have limitations:
- 10-m Keck telescope should have 0.01” in blue light
- Reality not better than 1” because of noise



5.4 High—Resolution Astronomy

- The Earth Turbulent Atmosphere → twinkling of stars.
- "Seeing" describes the effects of atmospheric turbulence.
- Seeing disk: the circle over which a star's light is spread,
- Sighting positions are mountaintops, reducing light pollution.

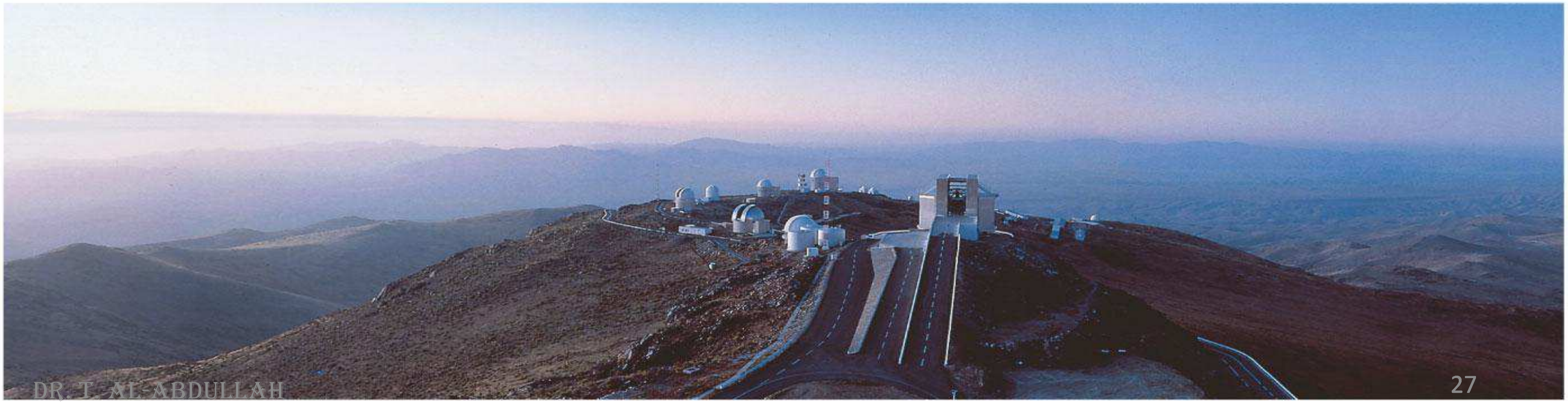




5.4 High—Resolution Astronomy

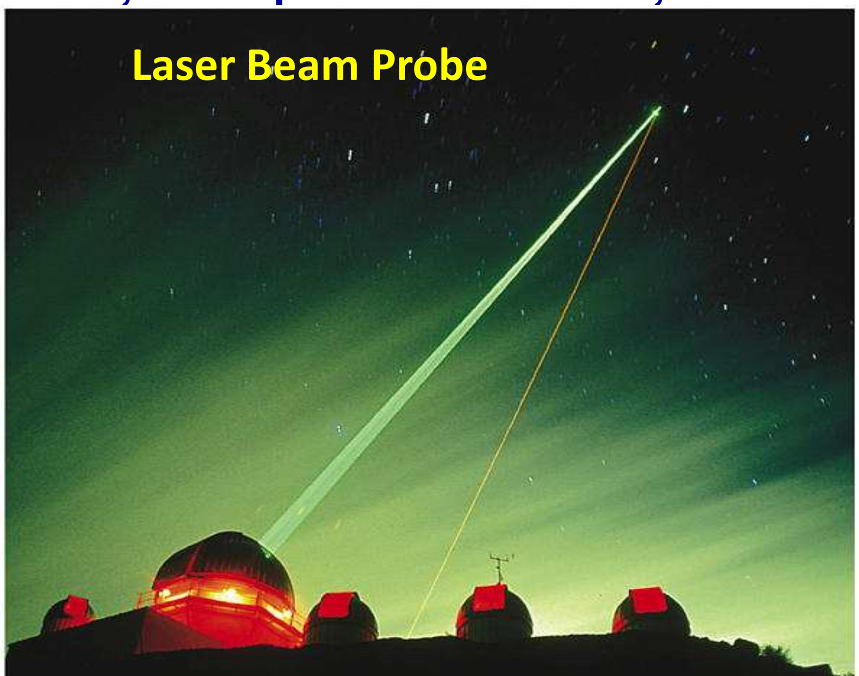
Solutions:

- **Put telescopes on mountaintops, especially in deserts**
- **Put telescopes in space**

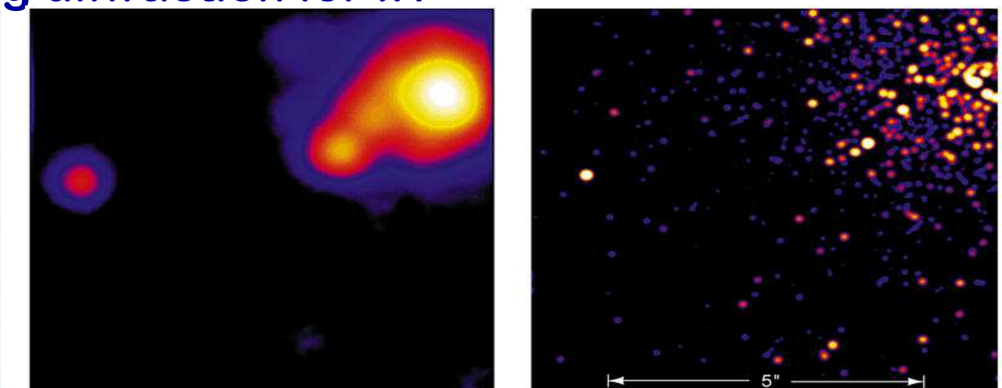


New Telescope Design

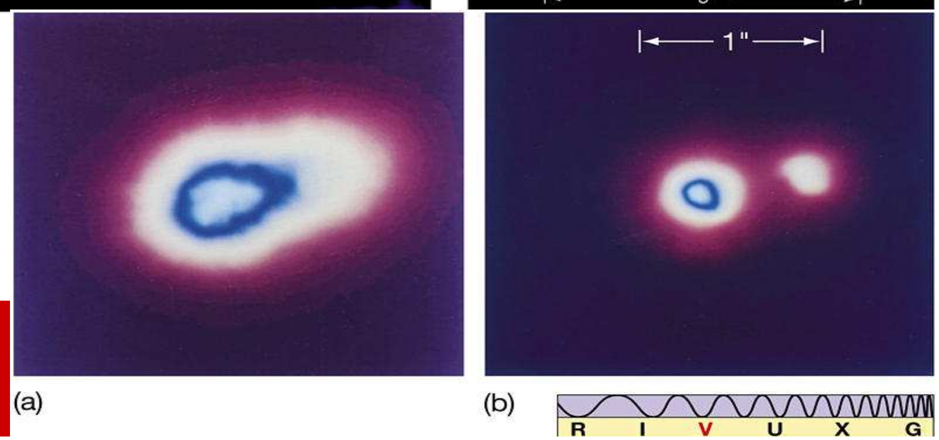
- Analyzing the image while light is still being collected.
- Controlling mirror defocusing & Temperatures, by using Active Optics.
- Adaptive Optics → Track atmospheric changes with laser; adjust mirrors in real time, Example IR with 0.06”, reducing diffraction for IR



allow corrections in the mirror surface thousands of times a second

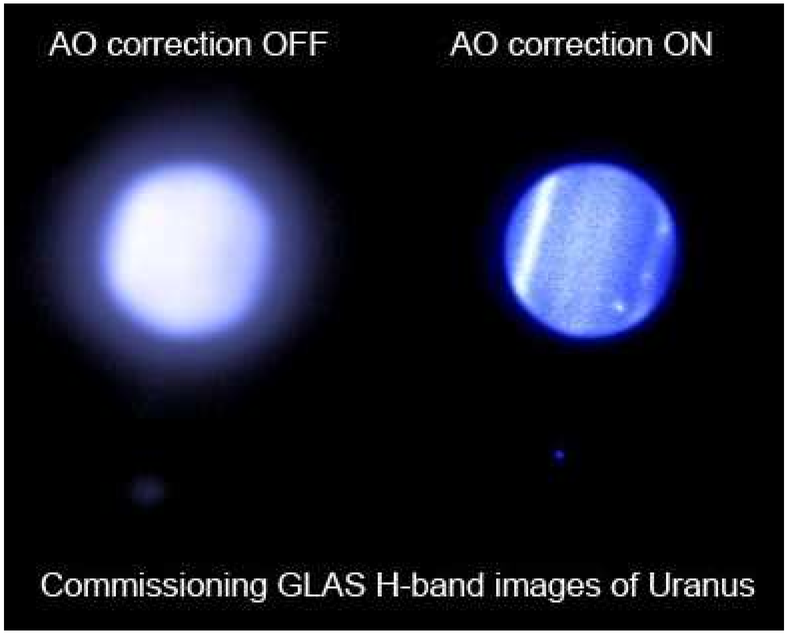


(a)



New Telescope Design

- New Technology Telescope (NTT) is the first one with active optics, 1989.
- 3.5 m NTT can achieve a resolution as sharp as 0.2”
- Adaptive Optics → real-time control



5.5 Radio Astronomy

Early Observatory

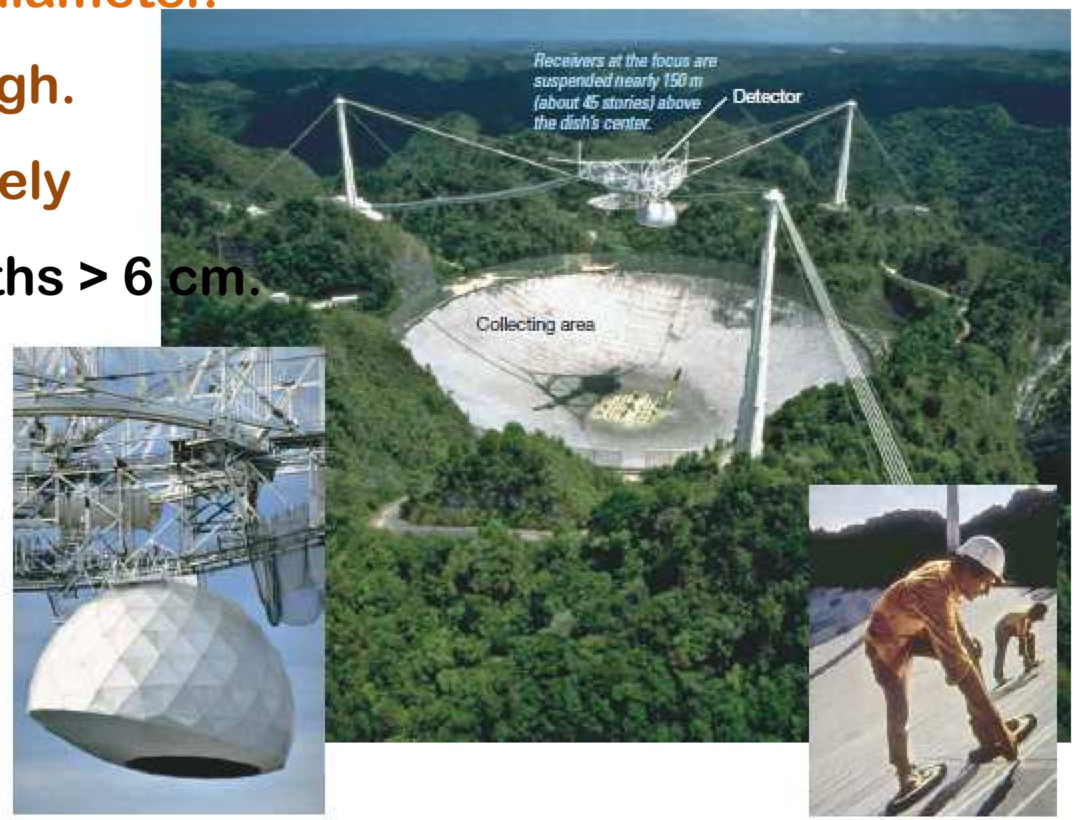
- Karl Jansky (1931) discovered a static “hiss” that had no apparent terrestrial source.
- The “hiss” peak occurred about 4 minutes earlier each day.
- He found the noise coming from the center of our Galaxy.

Essentials of Radio Telescopes

- 105-m-diameter and 150-m-tall, the National Radio Astronomy
- Detect a narrow band of wavelength at any time.
- Should be large cause the sources are faint.
- Total energy received is > 10^{-12} watt, where 10^{7} watt from a bright star.
- Resolution of 20” for 1 cm wavelength. 1’ for 3 cm.

5.5 Radio Astronomy

- Radio telescope is similar to the operation of Optical Reflectors.
- Register only narrow band of wavelengths at any time.
- Arecibo Observatory, 300-m-diameter.
- Reflecting surface can be rough.
- 1-cm waves reflected accurately
- Arecibo can detect wavelengths > 6 cm.
- Arecibo resolution is ~ 1`
- It covers 20^{o} angular range



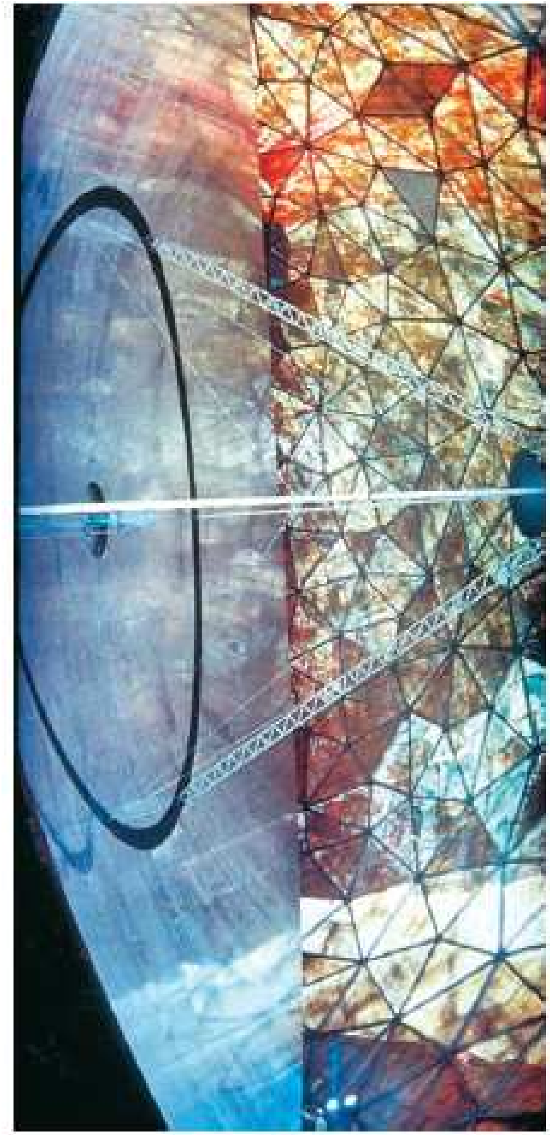
5.5 Radio Astronomy

- China largest telescope (FAST) 500-m
- Scan the heavens for signs of intelligent alien life, among other tasks.

5.5 Radio Astronomy

Haystack Observatory

- **36-m-diameter, polished aluminum**
- **Reflect and focus radio radiation with** $\lambda \approx$ few mm
- **contained with a protective shell.**

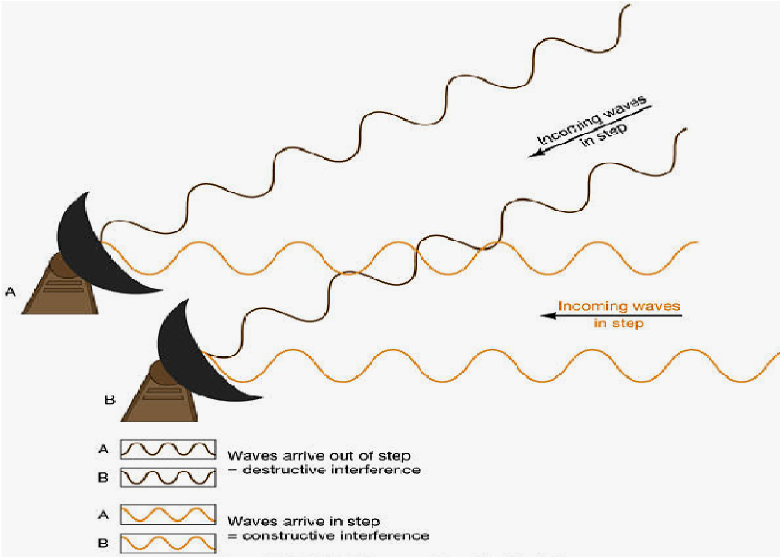


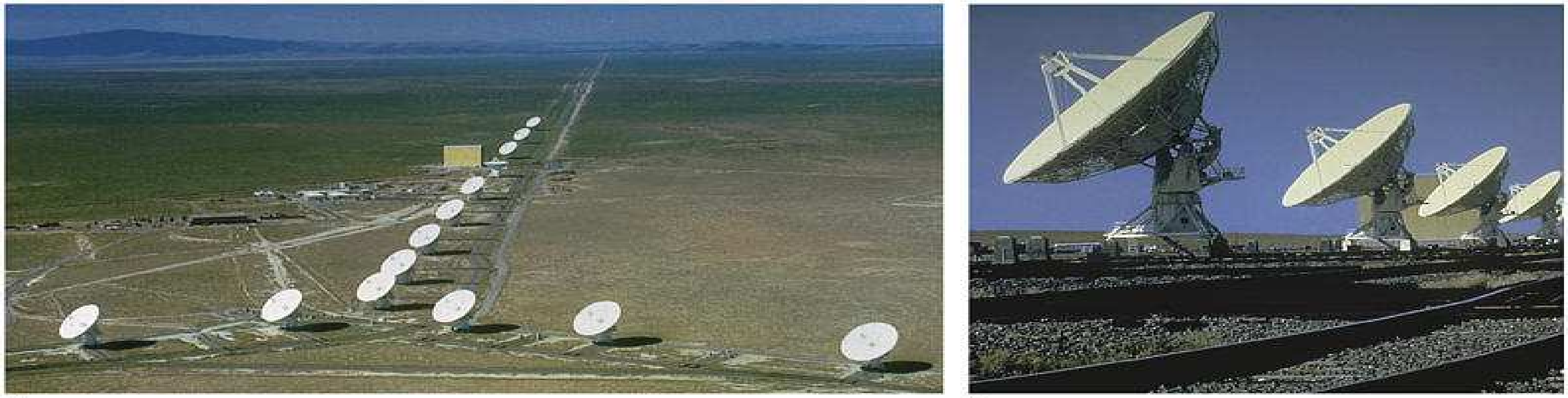
The Value of Radio Astronomy

- Radio telescope can observe 24 hours a day, the Sun is not a source.
- Observations can be made through cloudy skies, large λ.
- Opens up a new window on the universe:
    1- Visible sources weakly emits radio waves.
    2- Not absorbed by interstellar dust and material.
- Orion Nebula, 1500 l-y from the Earth.
- Series of contour lines connecting location of equal radio brightness.
- Inner contours represent stronger radio signals

5.6 Interferometry

- **Solving poor angular resolution in radio telescopes.**
- ***Many telescopes observed same λ from the same object at same time.***
- **Constructive Interference to produce sharp & strong signals.**
- **Out of phase signal are weakened by destructive interference.**
- **Better resolution ability.**




(a) (b)

5.6 Interferometry

• Resolution will be that of dish whose diameter = largest separation between dishes

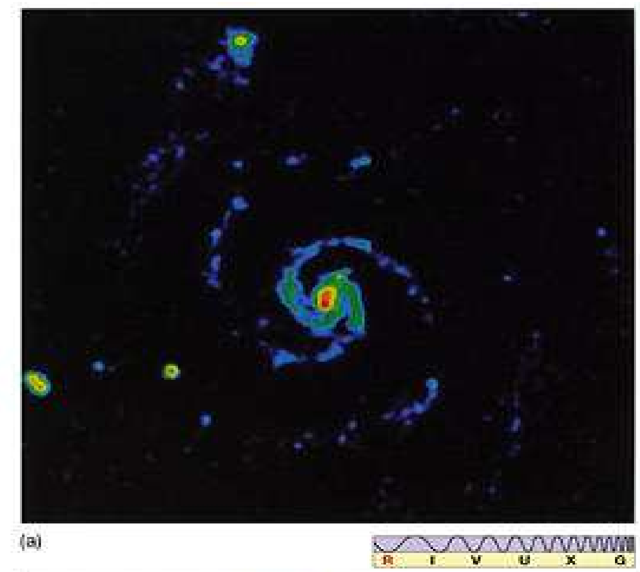
• Few arcseconds needs 5 km for 10cm wavelength, two small dishes 5 km apart do the job.

• Spanning to the size of Earth (VLBI), resolution of order 0.001``

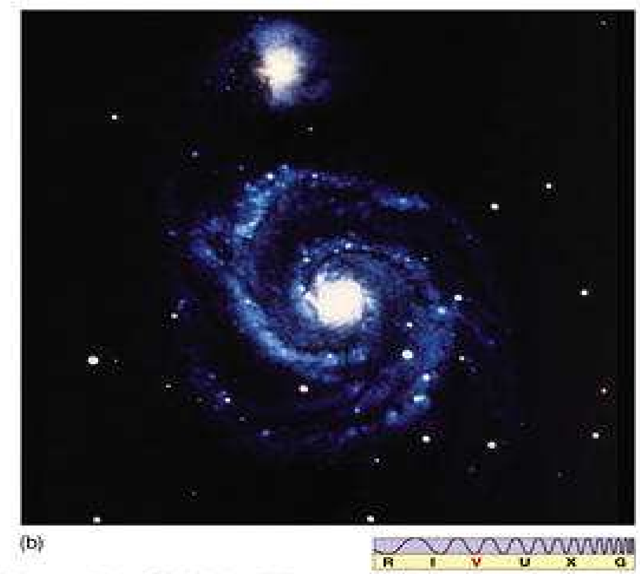
• Interferometry can also be done with visible light for high angular resolution, 300m 0.0002” ➔ size of stars

5.6 Interferometry

• VLA radio photograph of the spiral galaxy M51, observed at radio frequencies with an angular resolution of a few arc seconds.

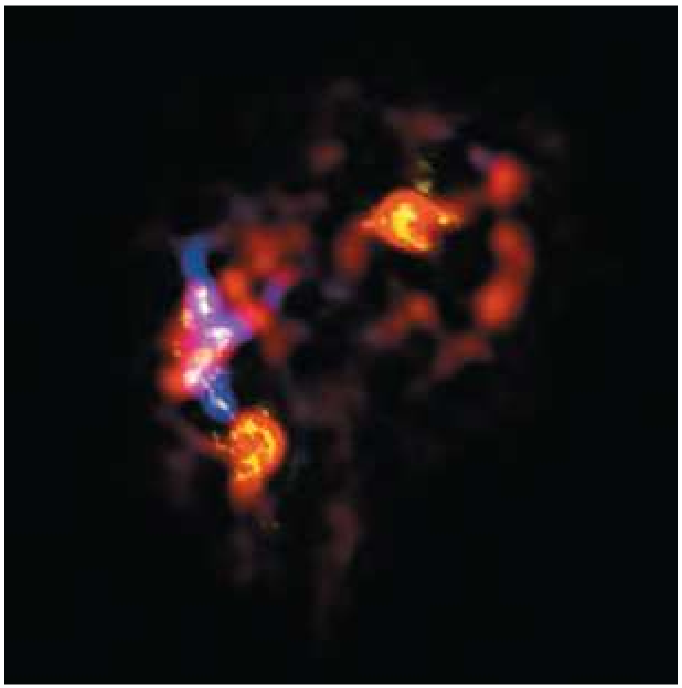


• An actual light photograph of the same galaxy made with 4-m optical telescope. **SAME DETAILS**

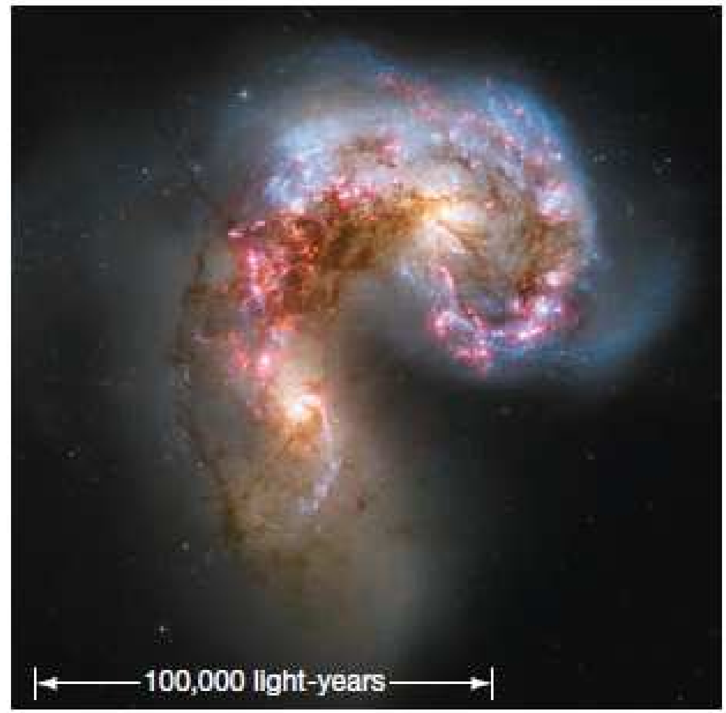


5.6 Interferometry

- A pair of colliding galaxies, 62 M-ly
- Interferometry gives comparable resolution with telescope.



Radio
vs
Optical



5.7 Spaced-Based Astronomy

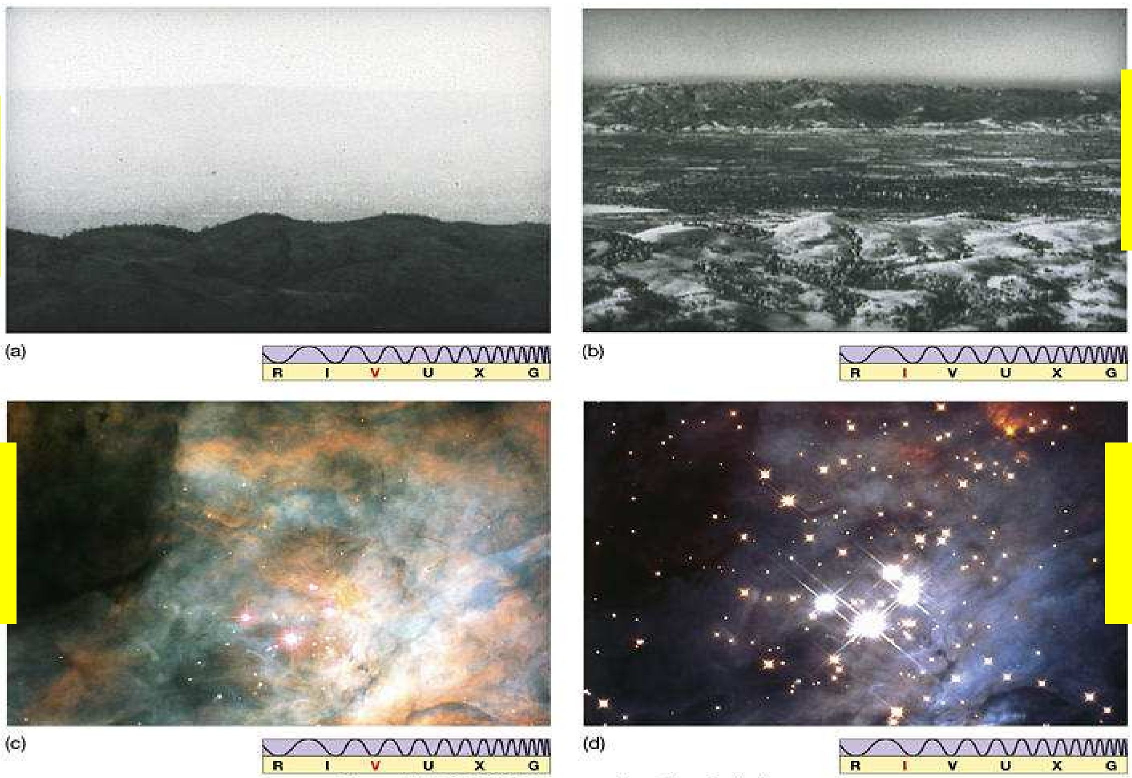
- **Full-spectrum Coverage, no atmospheric blurring.**
- See the whole picture more clearly.
- ***Infrared Telescopes*. Sensitive to longer wavelength radiations.**

S. Jose, optical

S. Jose, Infrared

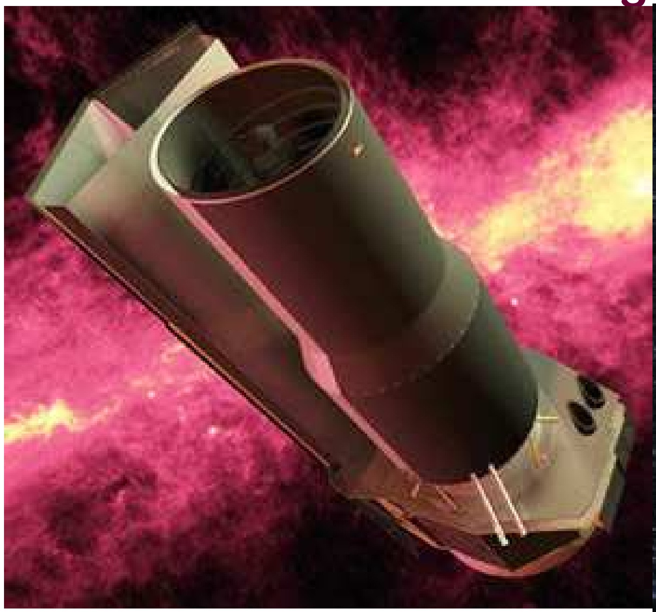
Orion nepula, optical

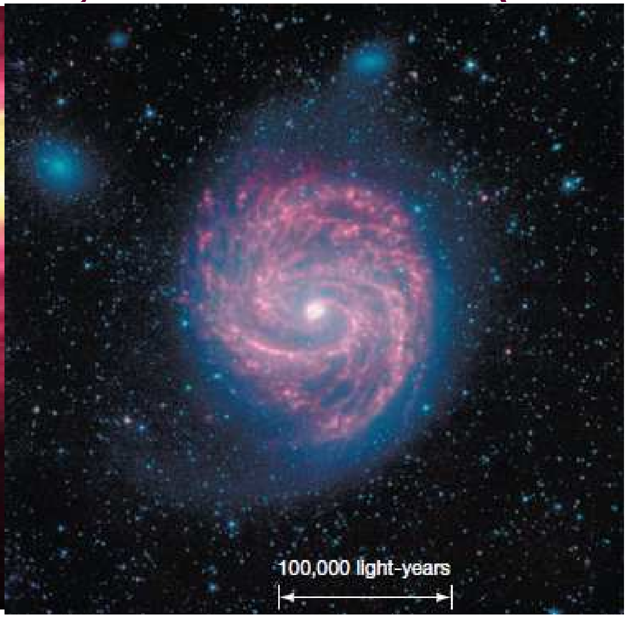
Orion nebula, Infrared

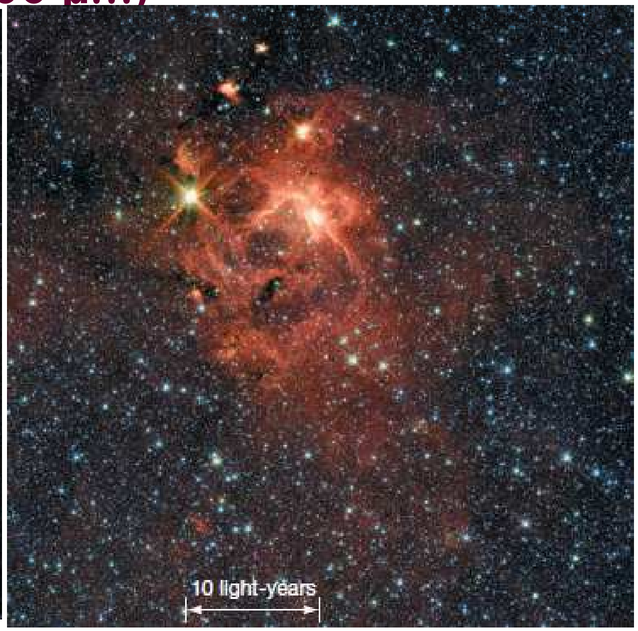


Infrared Astronomy

- **Perceive objects partially hidden from optical view.**
- **Penetrating properties of infrared.**
- Better observations in the space above the atmosphere
- **0.85-m Spitzer Space Telescope ➔ $\lambda \approx 3.6 – 160$ µm, resolution: 2.5 ”— 40 ”**
- **Follows the Earth around the Sun, delay 0.1 AU/year to decrease heating**
- **Cooled almost to zero degree, now around 30K ($\lambda \approx 100$ µm)**

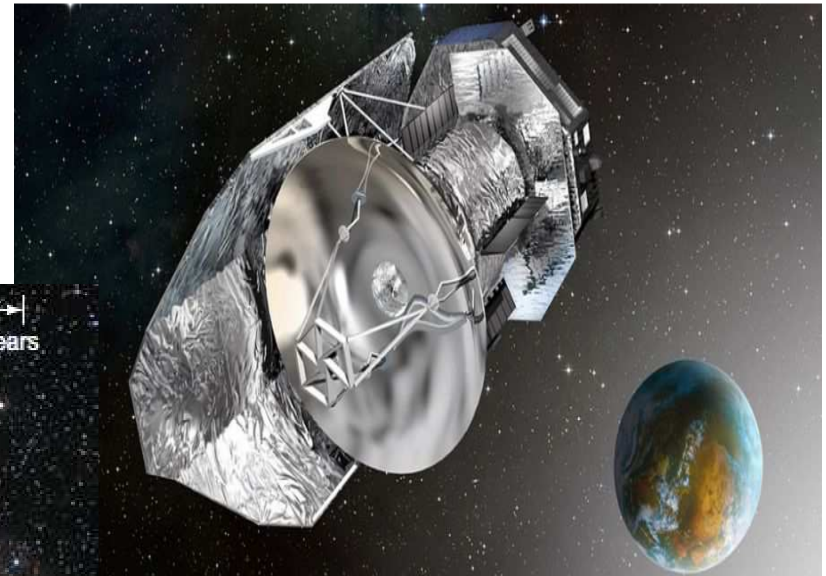






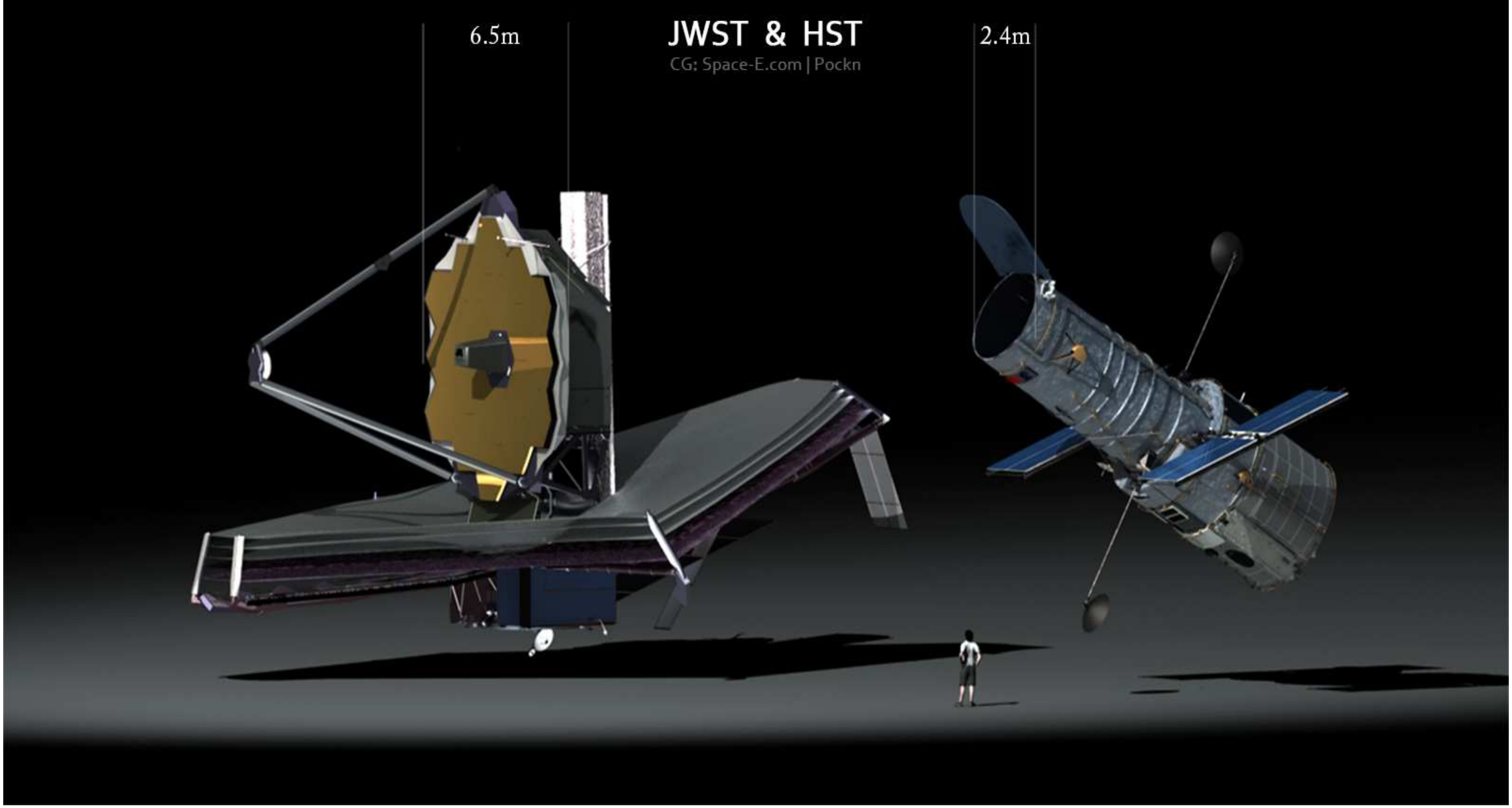
Infrared Astronomy

- Herschel Space Observatory, 2009 – 2013, 3.5-m
- 1.5 million km away from the Earth
- Far infrared: 50 – 700 μm
- Infrared vs visible



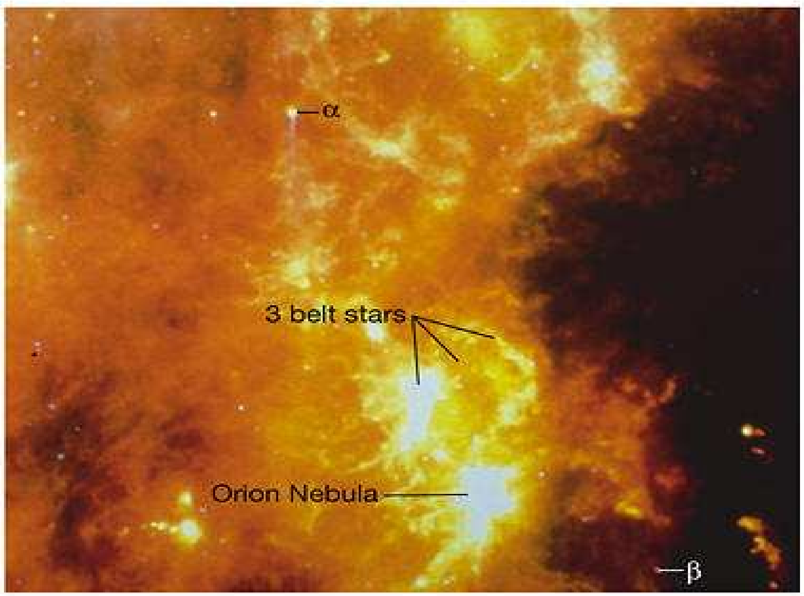
70µm, 160µm, 250µm

Infrared Astronomy



Infrared Astronomy

- **DISADVATAGES.**
- **False color; Wien's Law 30K gives 100μm radiation.**
- **colors denote diff. temp. descending from white, red, to black.**
- **Telescope radiate strongly in infrared, unless they are cooled.**



(a)

[infrared image of the Orion region]

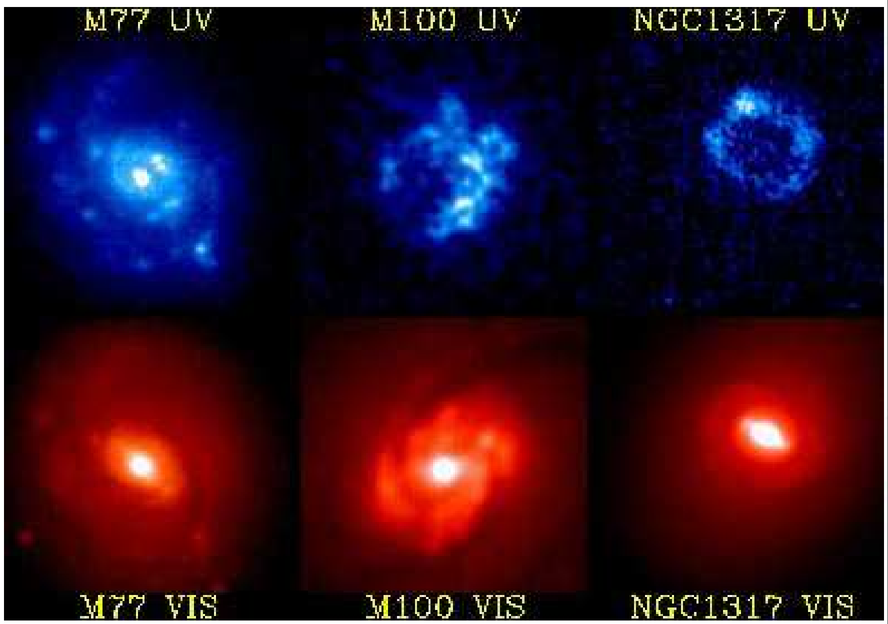
α: Betelgeuse (red) , β: Rigel (blue)

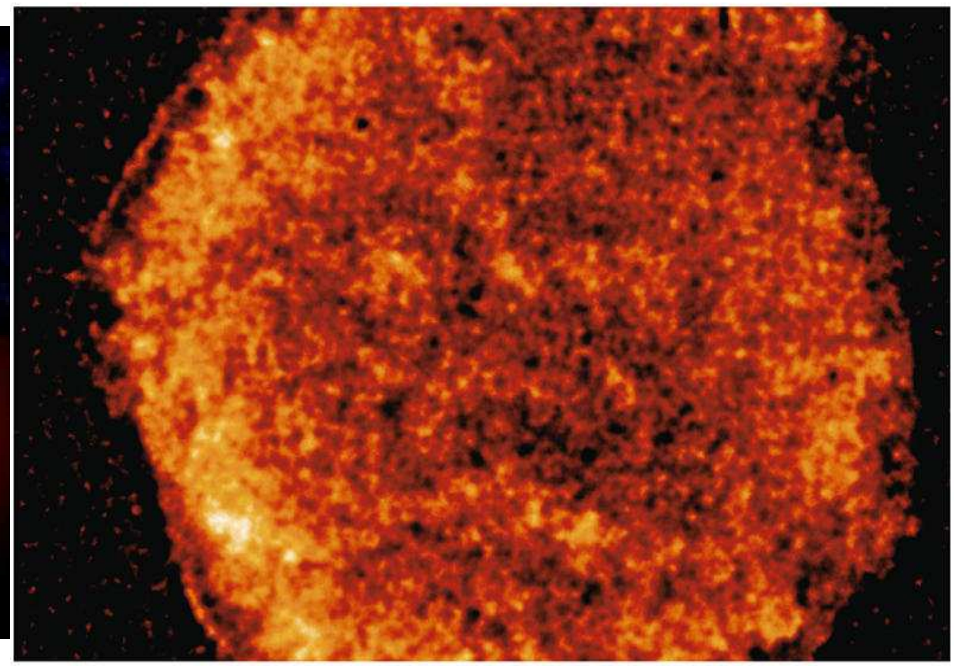
Ultraviolet Astronomy

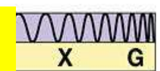
• Extended from 400 nm to few nm.

• Less than 300 nm is Completely opaque on the Earth because of the Ozone layer.

• very powerful tool to explore planets as well as stars.







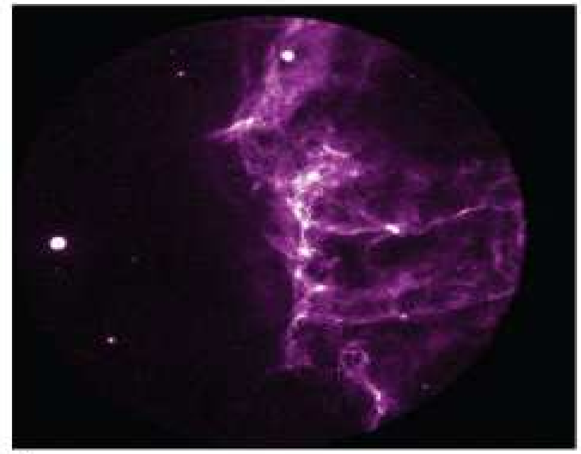
Visible versus UV

Tycho Supernova remnant

Dr.

5.7 Space-Based Astronomy

Ultraviolet observing must be done in space, as the atmosphere absorbs almost all ultraviolet rays.

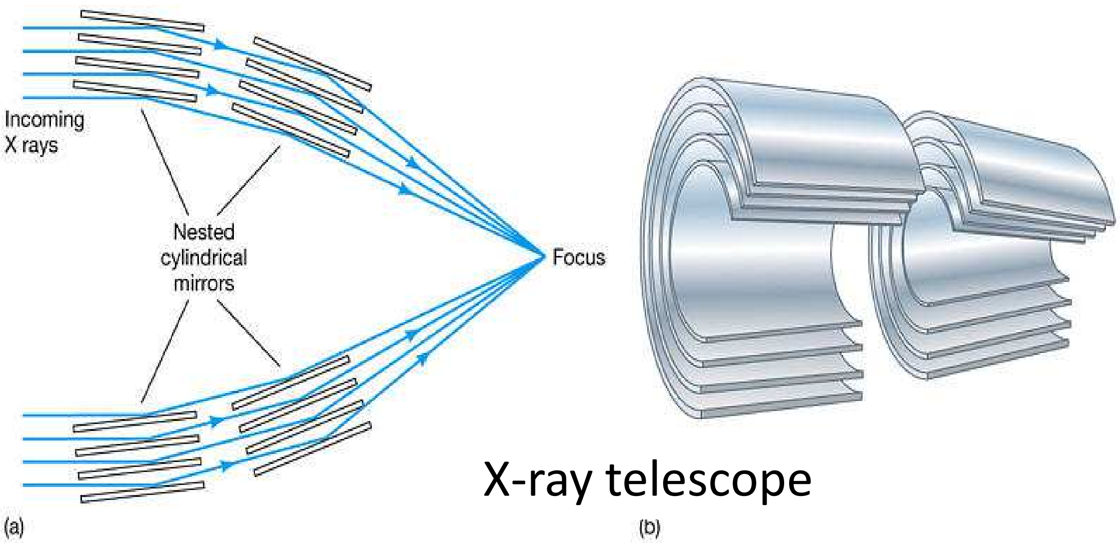


(a)

(b)

High-Energy Astronomy

- X-ray telescope and Gamma-ray detectors, can not be reflected easily.
- Must be captured above the Earth's atmosphere.
- X-rays reflected at grazing angles and focused to form an image.
- CCDs do not work well for hard X-rays and gamma rays.

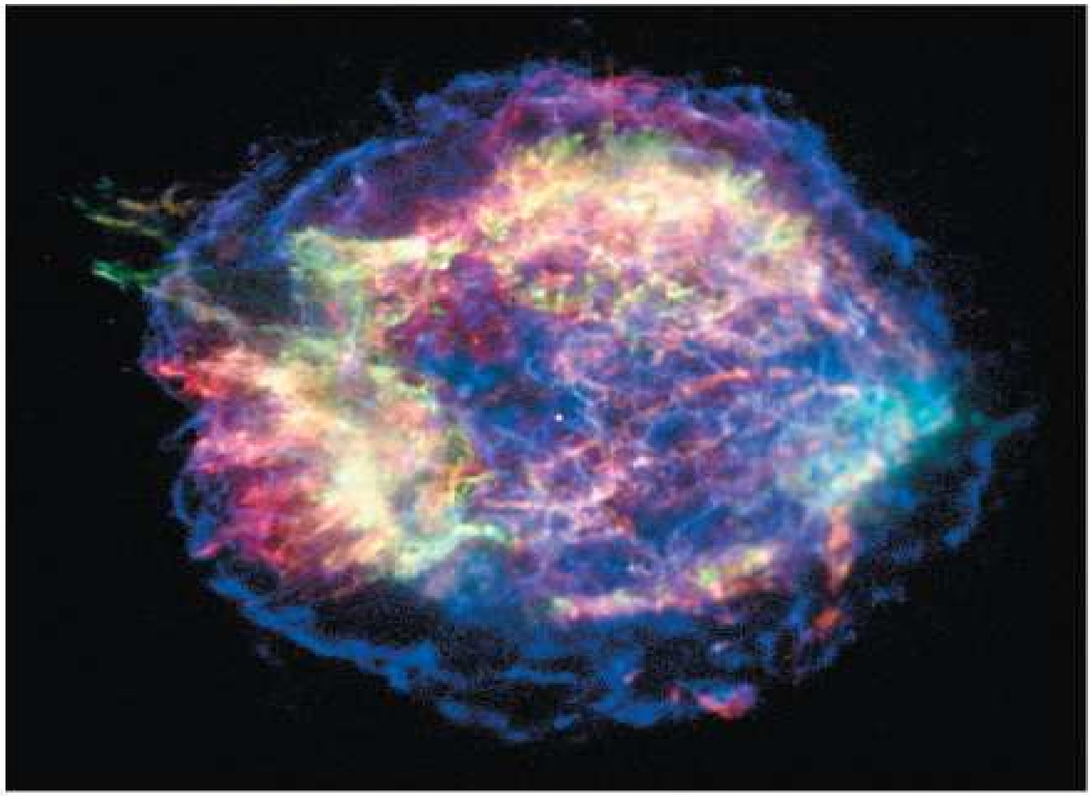


X-ray telescope

Chandra X-ray Observatory, 0.5"

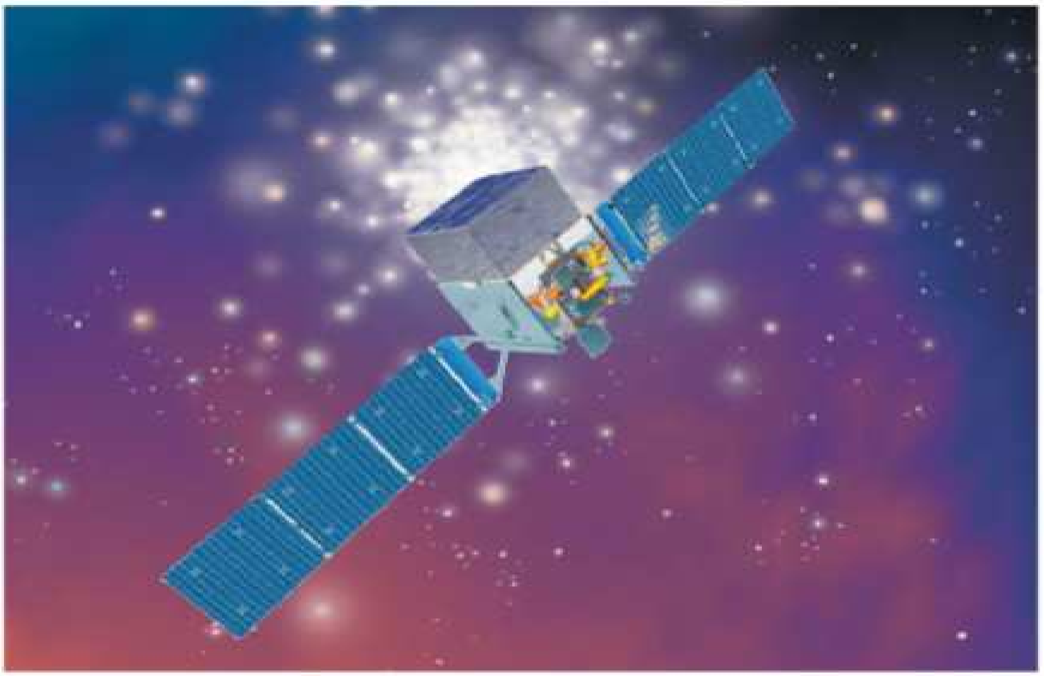
5.7 Space-Based Astronomy

X-ray image of supernova remnant

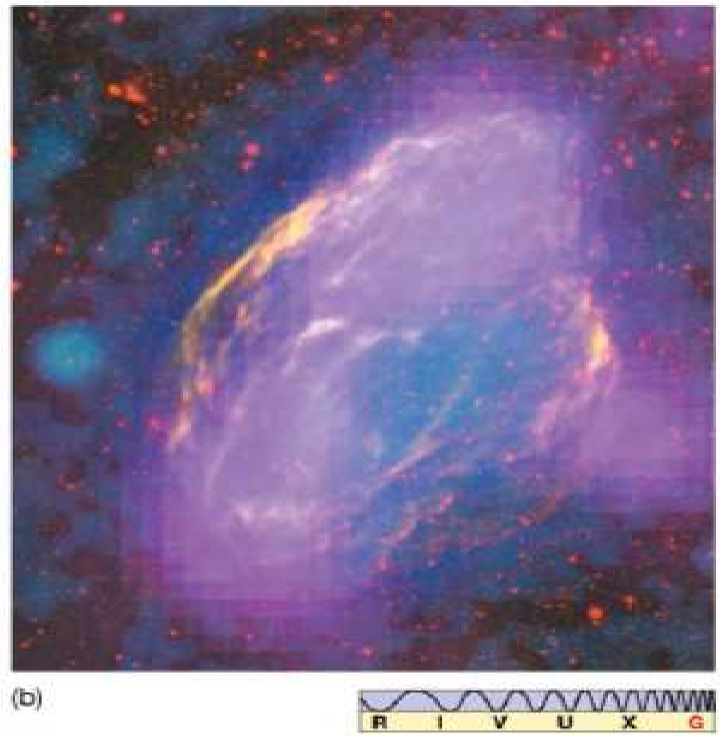


5.7 Space-Based Astronomy

Gamma rays cannot be focused at all; images are therefore coarse



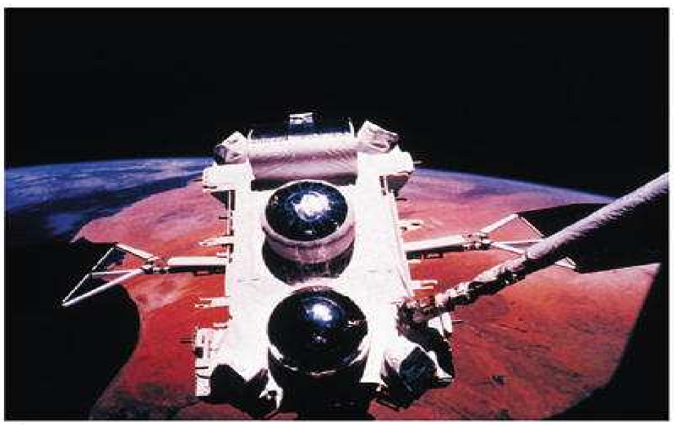
(a)



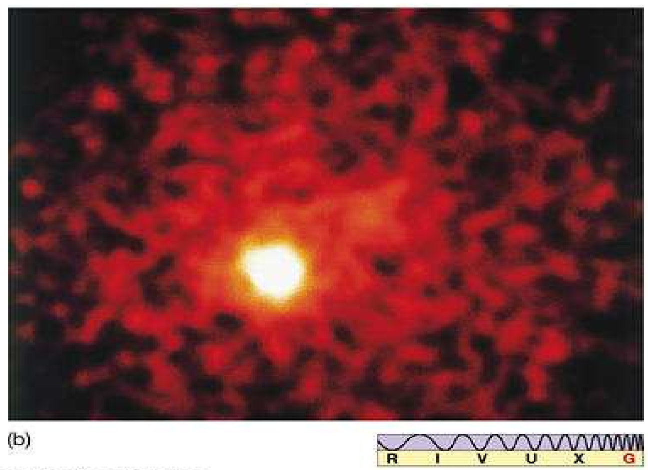
(b)

High-Energy Astronomy

- Individual photons are counted by electronic detectors on board, and results are transmitted to the Earth for processing & analysis.
- hours/days are needed for a single γ-ray photons to be detected.
- Gamma ray astronomy is the youngest. Resolution 1°
- Compton Gamma-Ray Observatory (CGRO), 1991, 17-tons.

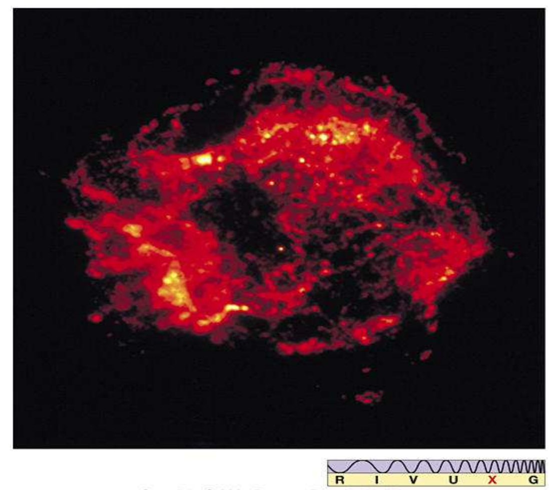


(a)



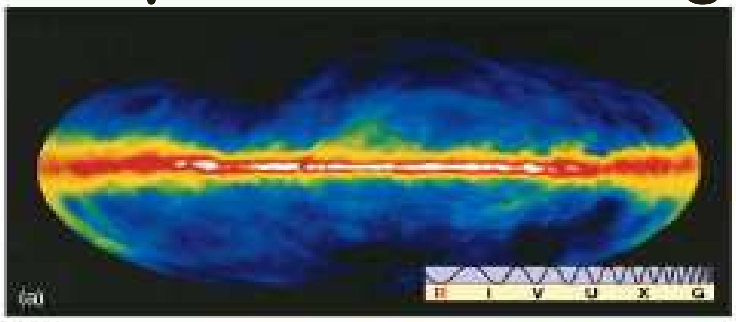
(b)

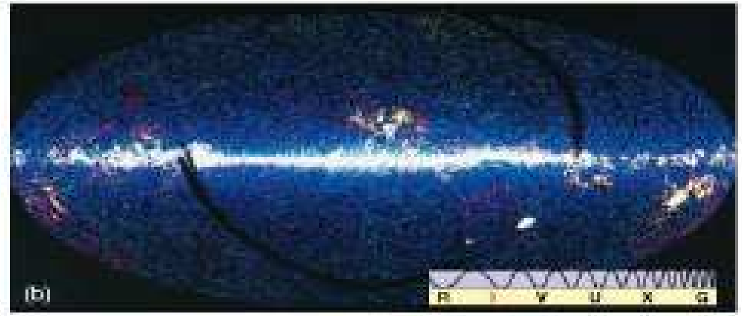
CGRO
Violent event in a distant galaxy
Highly energetic outburst in the nucleus

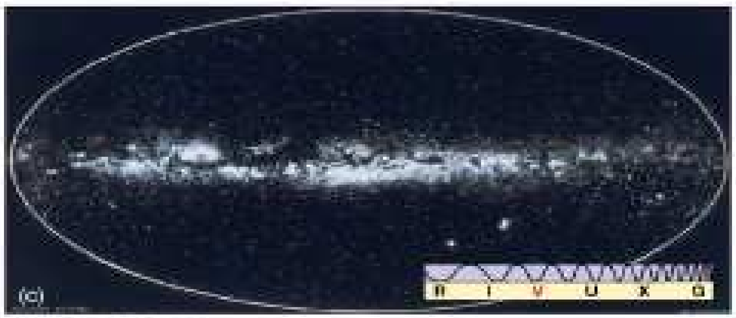


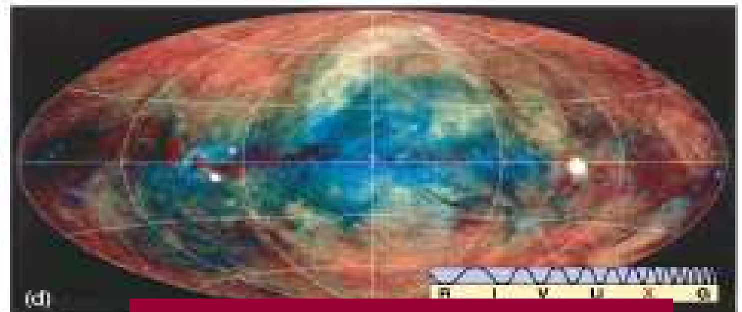
Supernova remnant
by Chandra

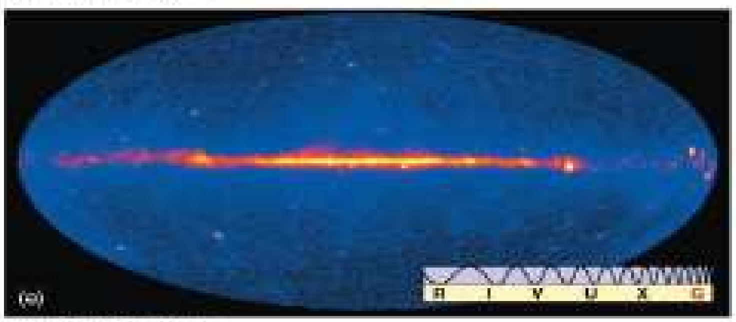
5.8 Full Spectrum Coverage











The Milky Way:
a) radio
b) Infrared
c) Visible
d) X-ray
e) Gamma-Ray


End Chapter 5