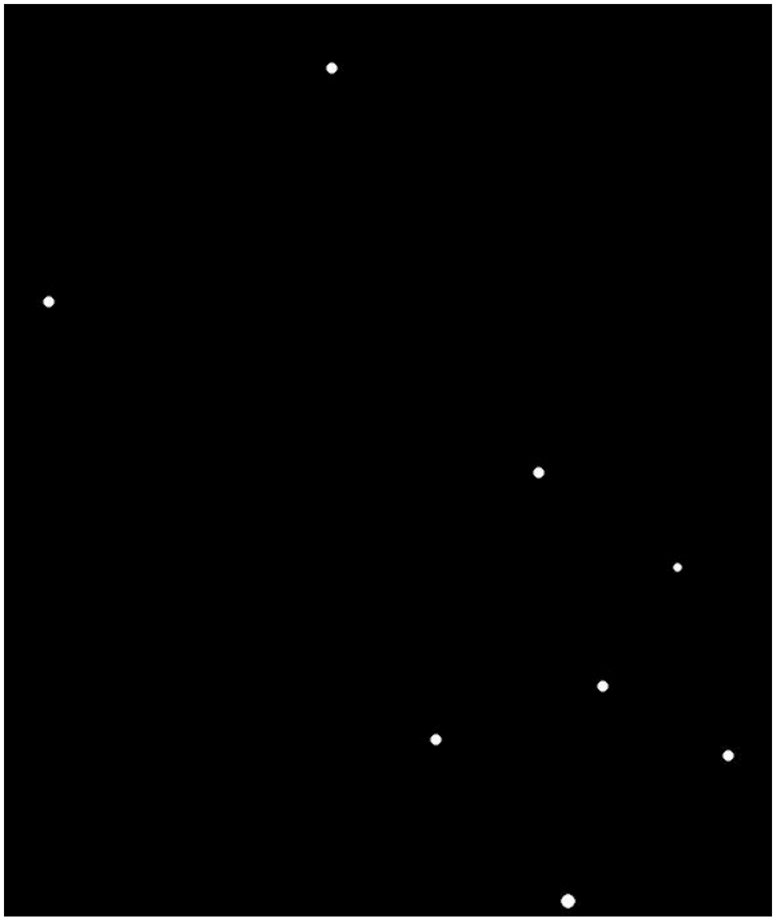
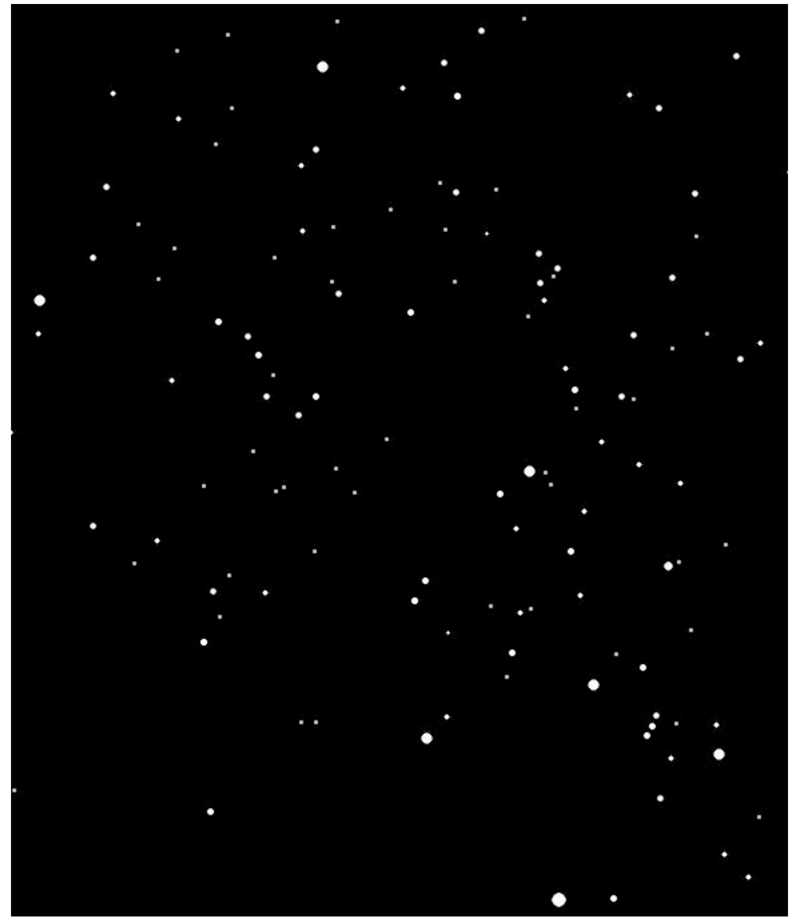
Telescopes

Purpose of a telescope

- Gather light from faint objects,
  - Light-gathering power depends on *area* of lens or mirror, so proportional to d^2. Why?
- Resolve small details
  - Smallest angular size that can be resolved is proportional to 1/d
- -> Bigger is better

Light Gathering Power



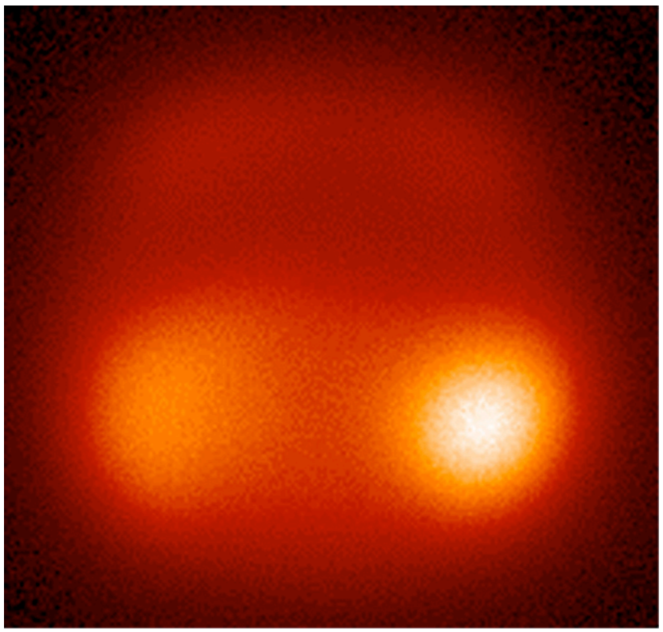


Little telescope Big telescope

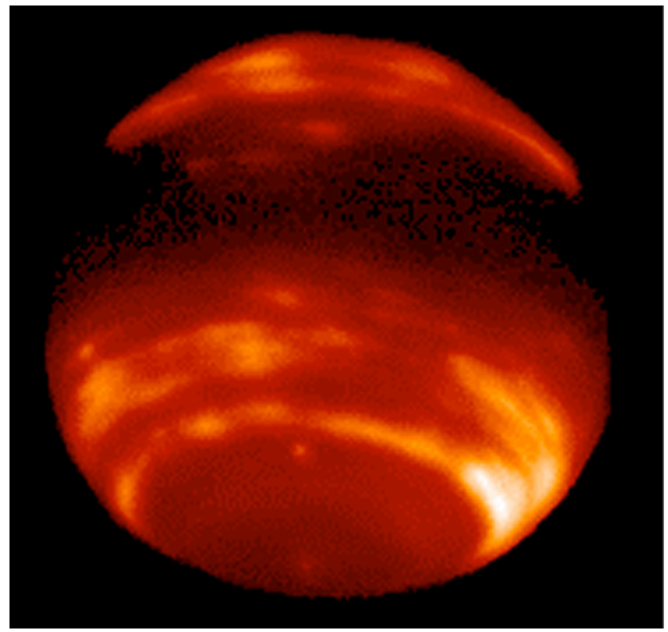
(same exposure time)

Resolving Power

- Neptune as seen in infrared from Earth



Small telescope

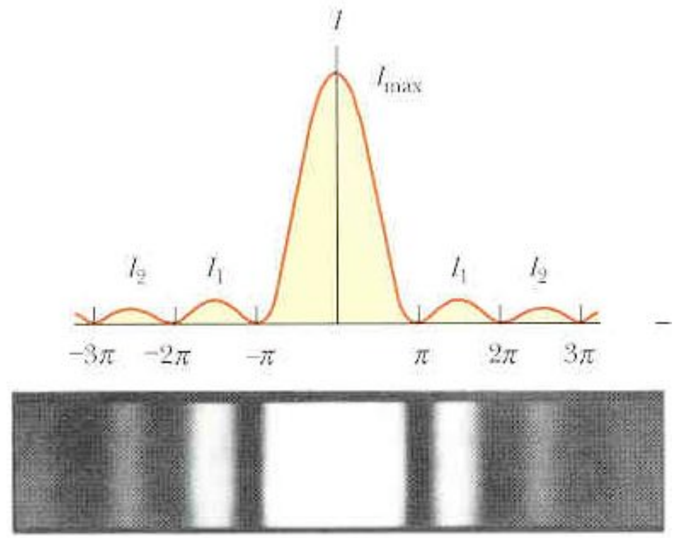


Big telescope

Limit to resolution set by diffraction

- Diffraction pattern of 1D slit, due to interference of waves from different parts of slit.
- Pattern is Fourier transform of slit (top-hat)
- Location of first null determines resolution

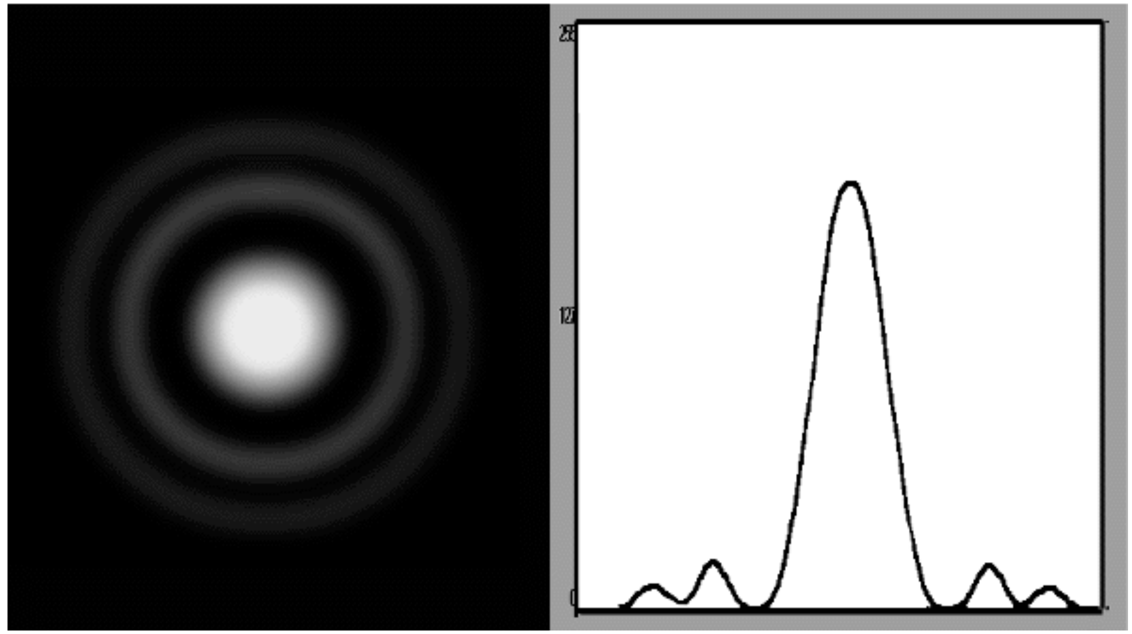
$$\theta_{null} = \lambda/d$$



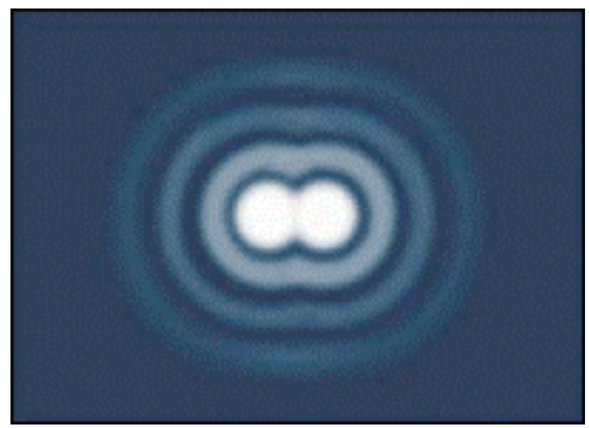
Limit to resolution set by diffraction

Diffraction pattern of 2D telescope mirror imaging point source = "Airy disk"

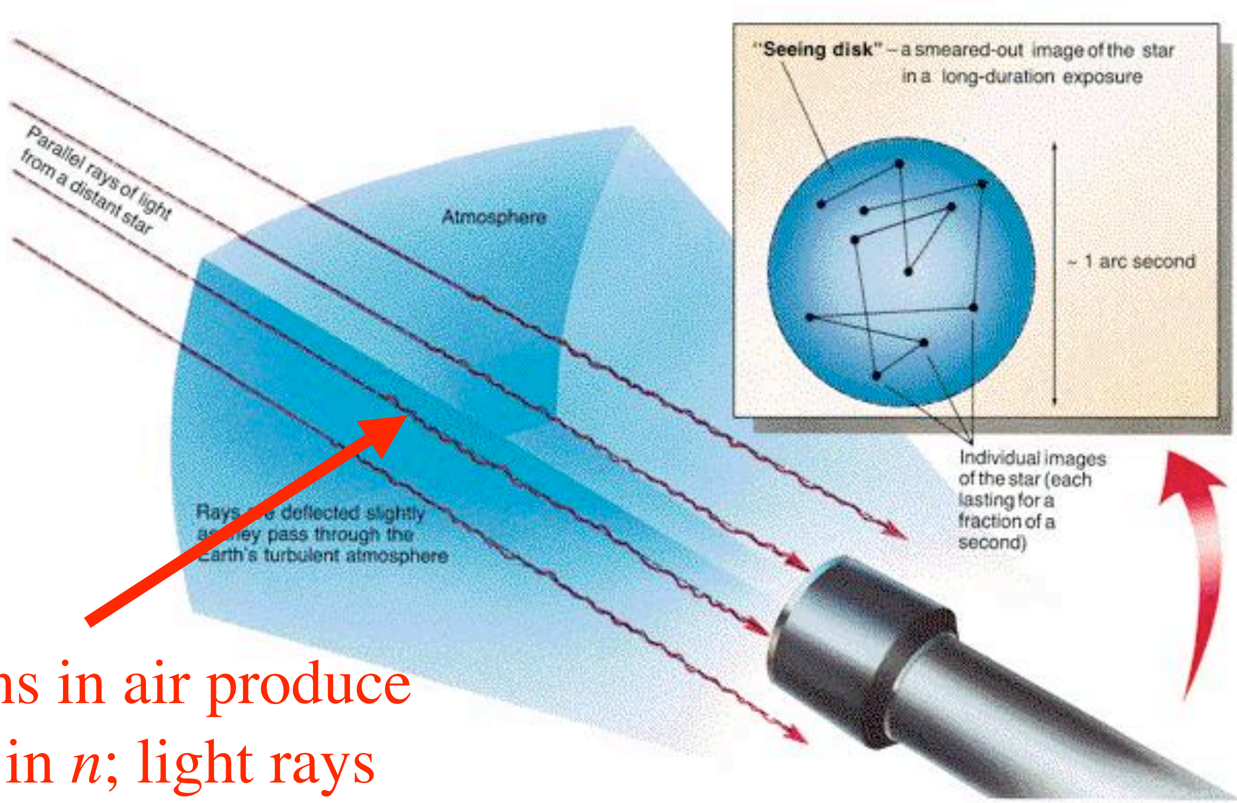
$$\theta_{null} = 1.22\lambda/d$$



Two point sources at limit of resolution



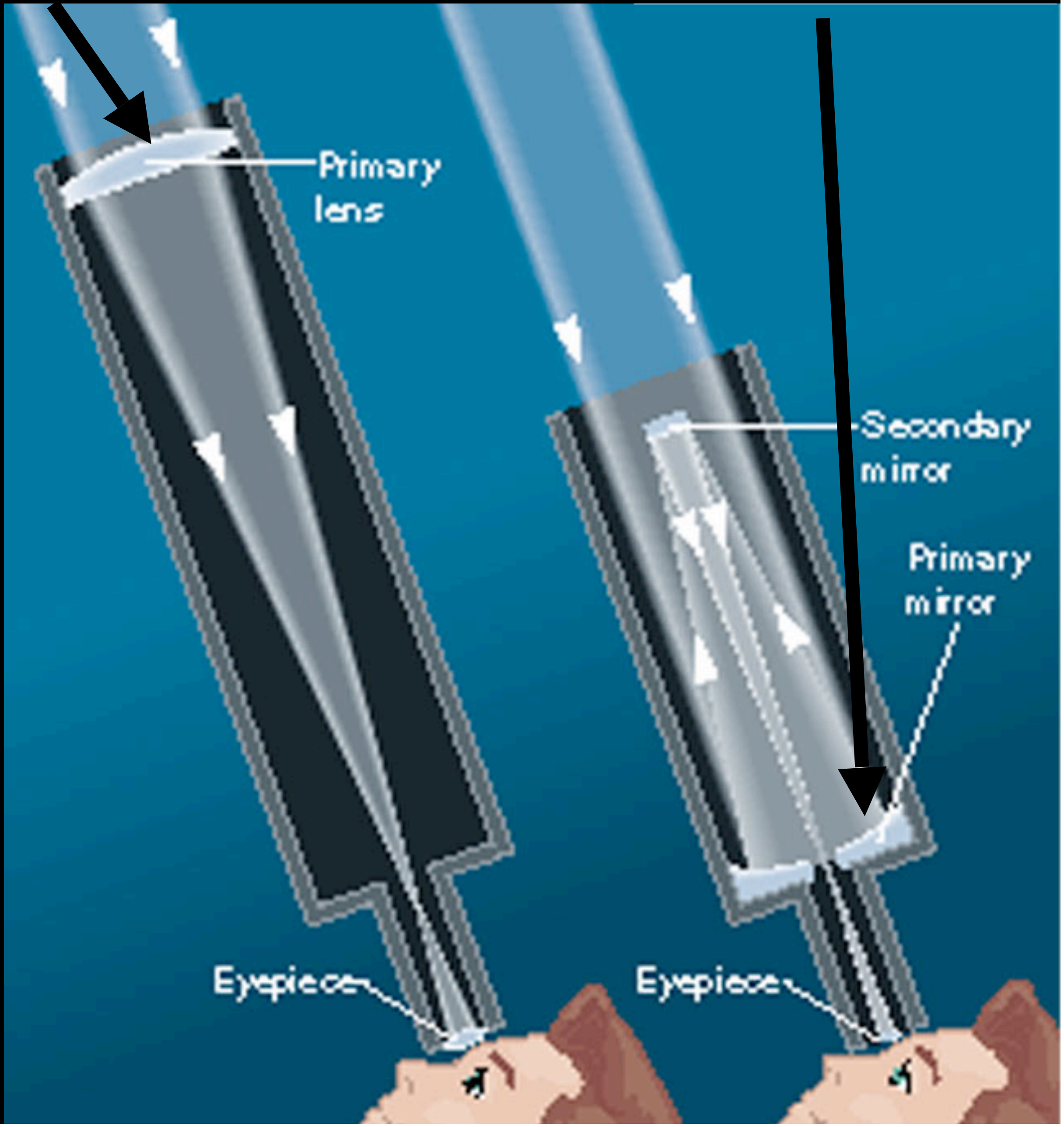
Resolving power also limited by "seeing"



ρ fluctuations in air produce fluctuations in *n*; light rays refracted

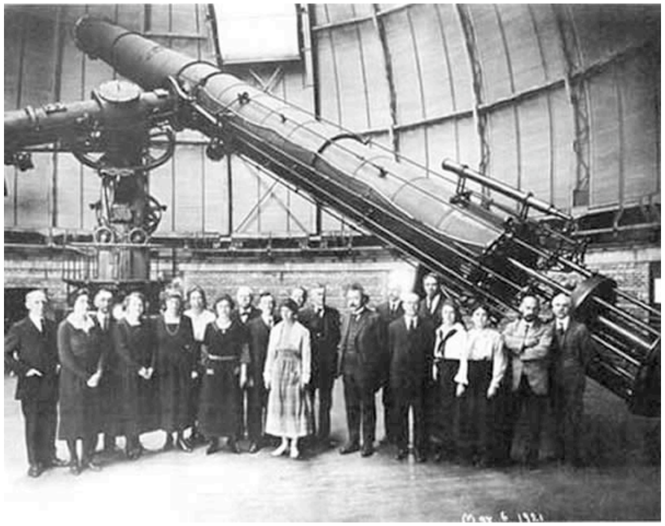
Corrected with adaptive optics - adjusting shape of mirror in real time to correct for distortions

Refractors (lens) & Reflectors (mirror)



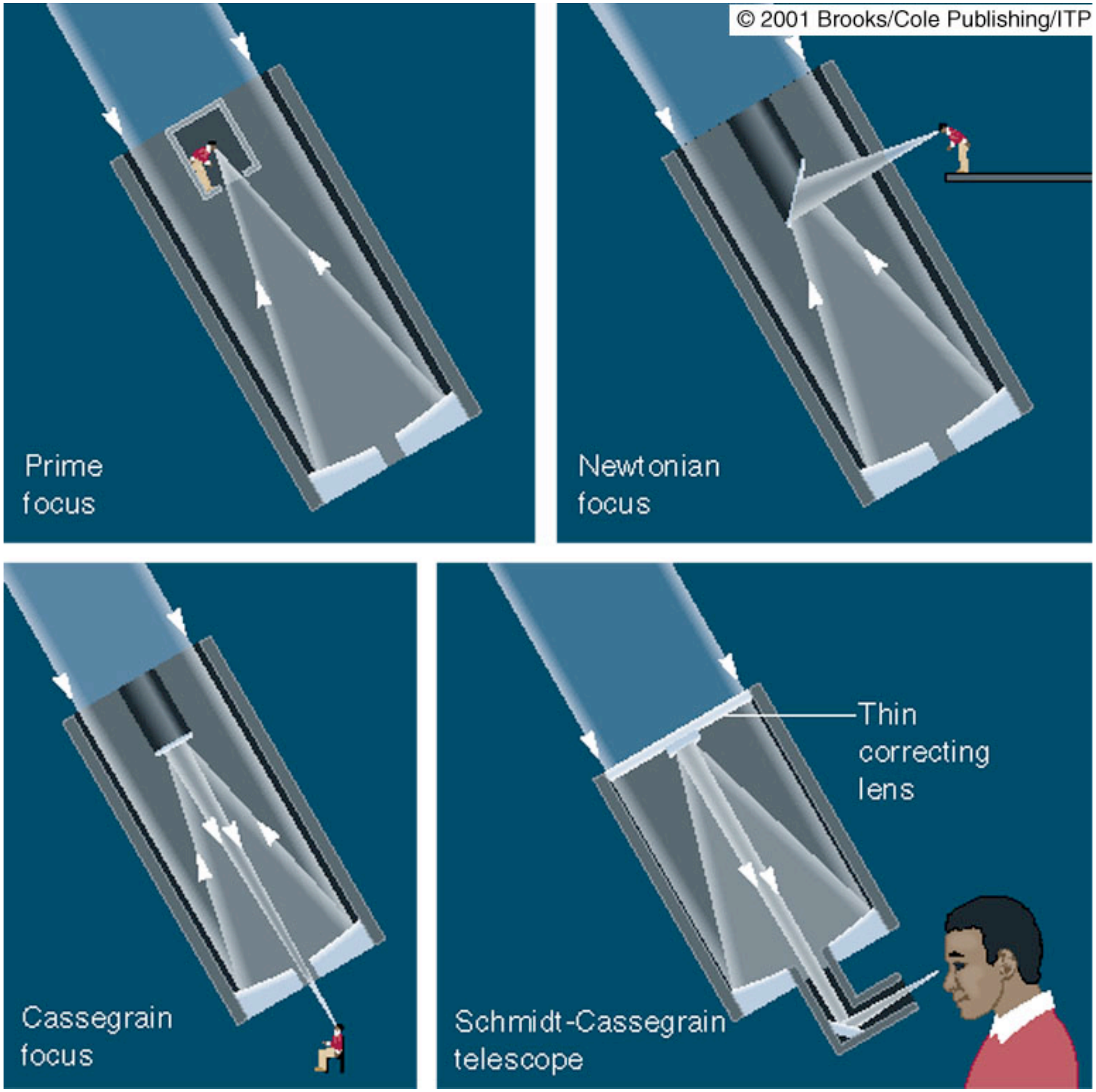
Disadvantages of Refractors

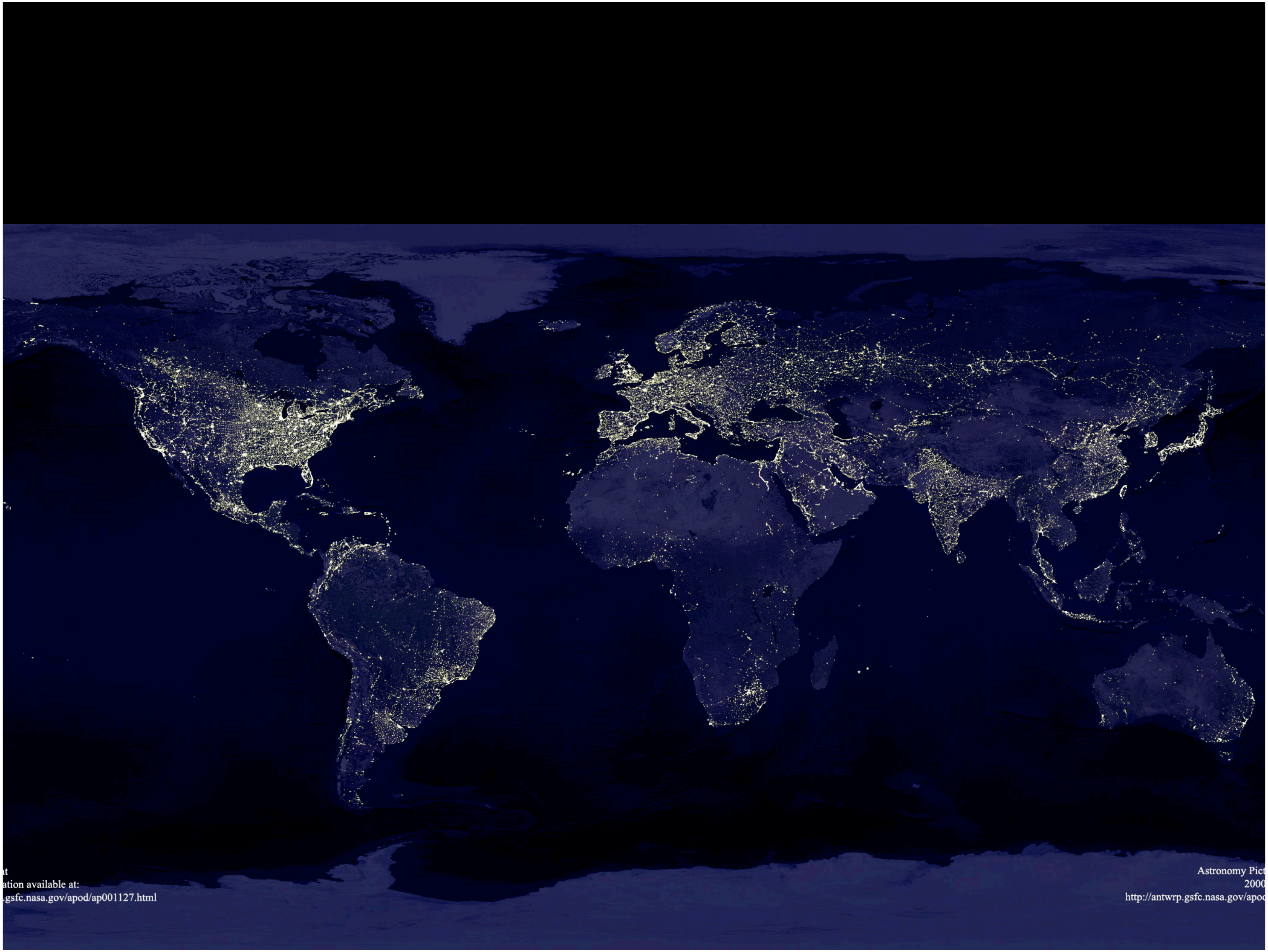
- Different colors have different focus, since index of refraction depends on λ – chromatic aberration
- Lens must be supported at edges → big, heavy lenses sag under own weight
  - Lens/mirror must kept to shape within $\lambda/4$
- Large lenses are prohibitively expensive
- Really long tubes for big focal lengths!
- As a result, all modern large telescopes are reflectors



Yerkes Obs. 40” refractor

Types of Reflecting Telescopes

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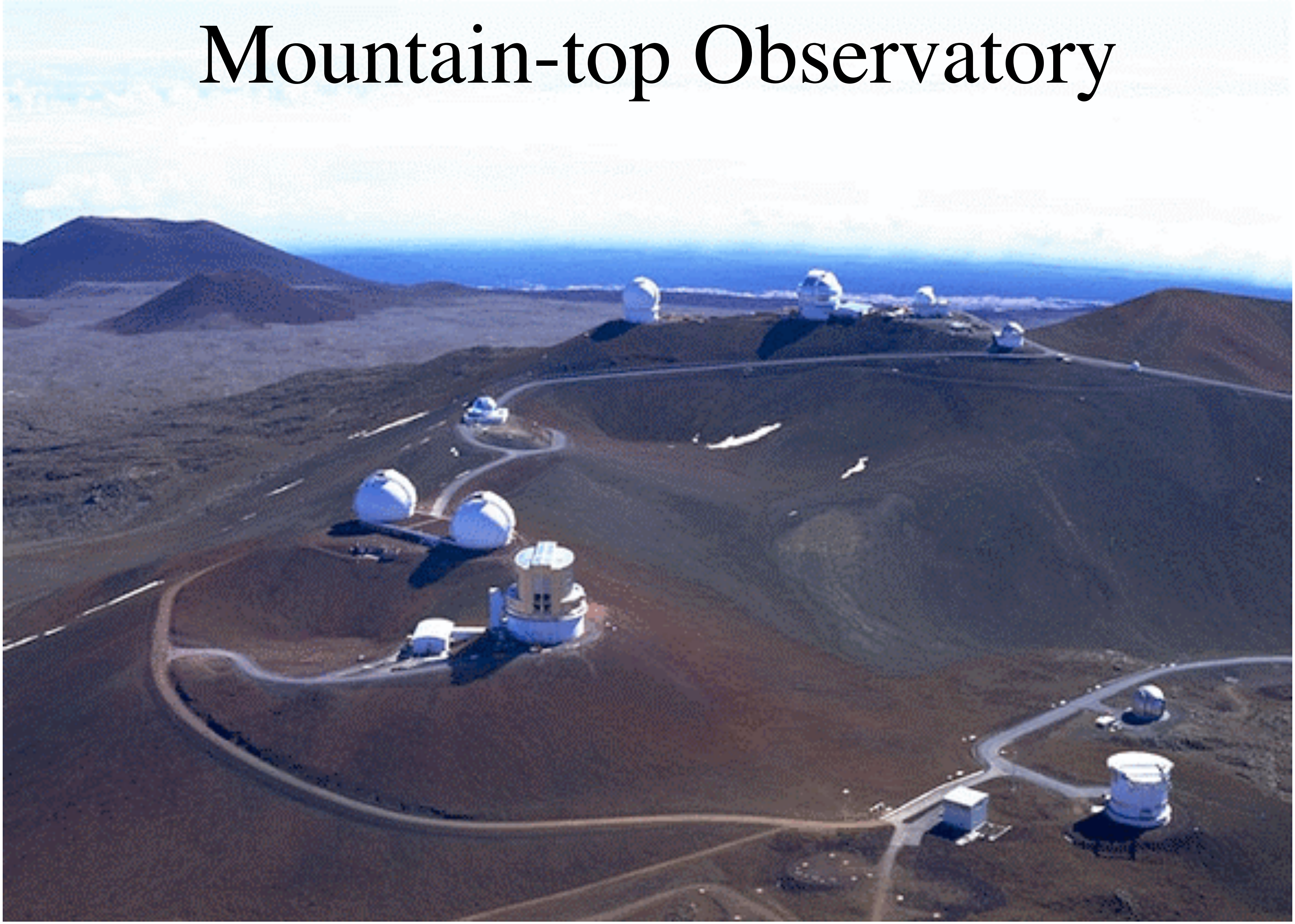
http://antwrp.gsfc.nasa.gov/apod

Ground Observatory Sites

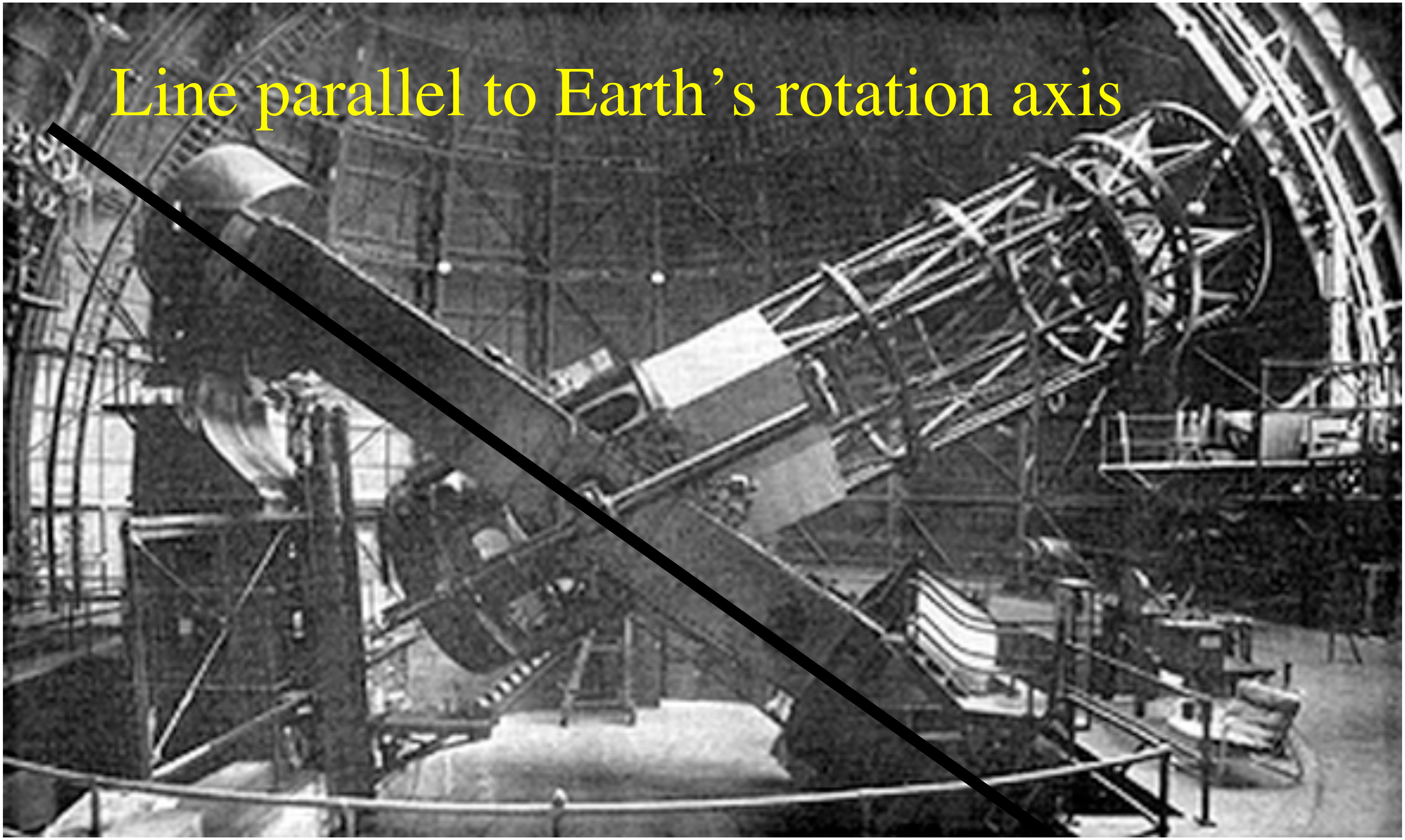
- Far from city lights
- Mountain top
  - Above water vapor, haze, fog, turbulent air
- Dry, clear location

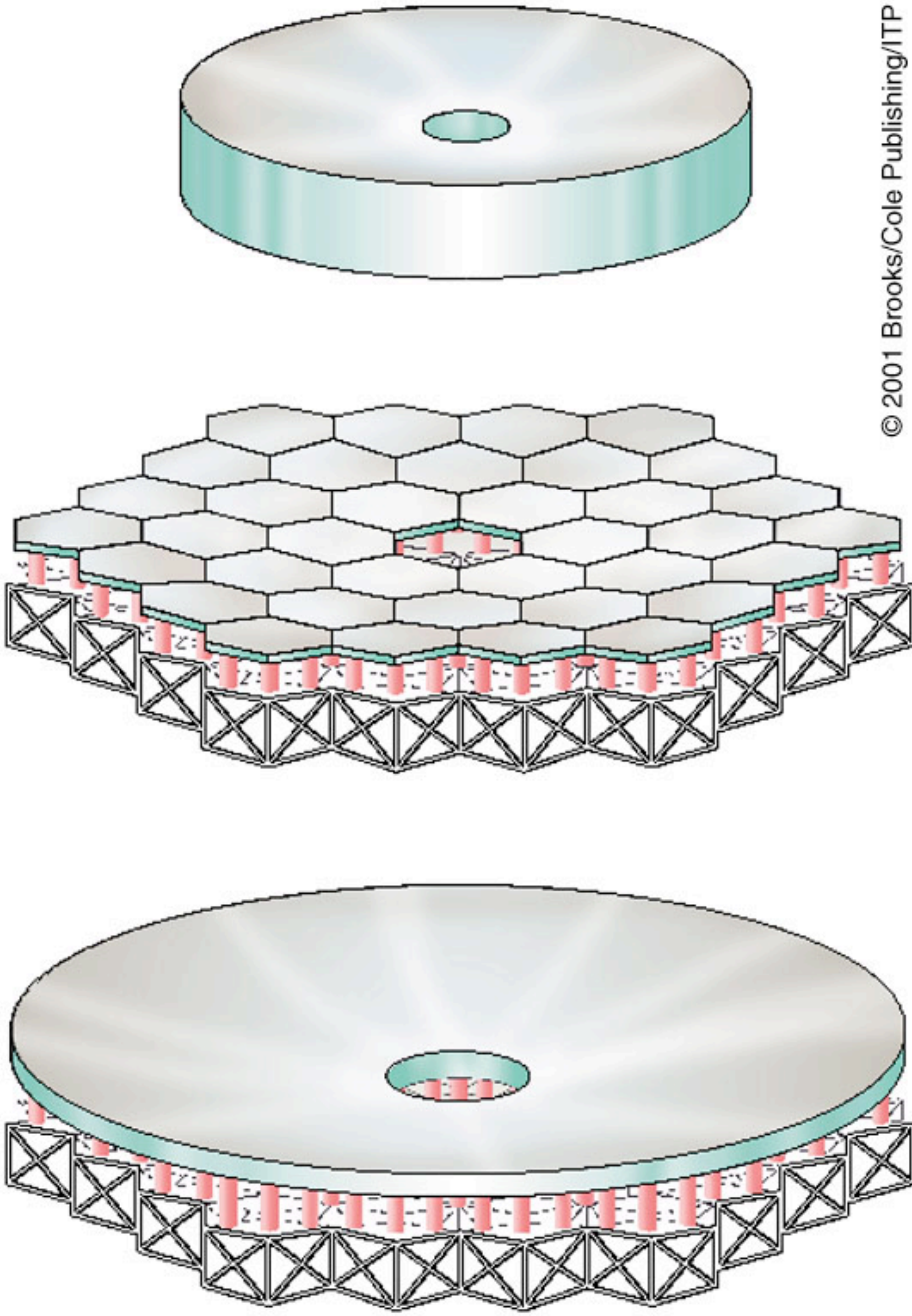
- Best locations:
  - Mountains in desert southwest (Arizona)
  - Hawaii (Mauna Kea at 14,000 feet)
  - Chilean Andes (6,000 to 18,000 feet)

Mountain-top Observatory



Telescope mounts: equatorial (below), altitude-azimuth

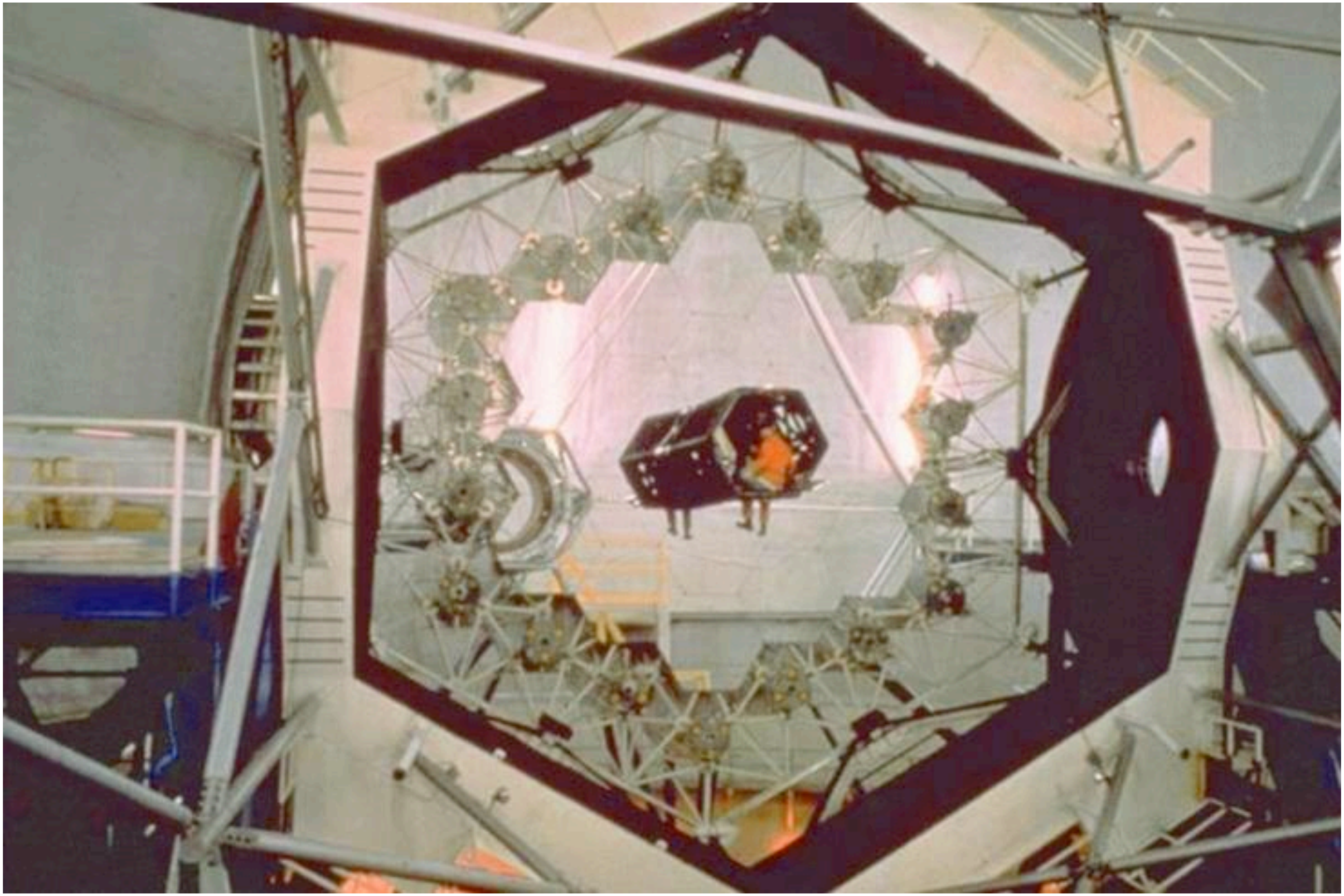




Monolithic mirrors - heavy, expensive

Segmented mirrors - cheap, more complicated to build

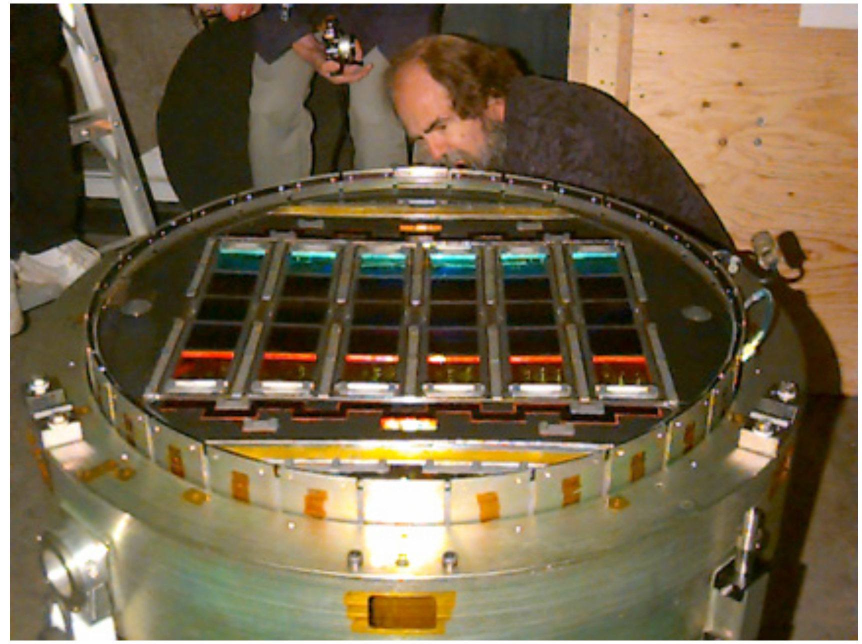
Thin mirrors - use computer controlled actuators to adjust shape = adaptive optics

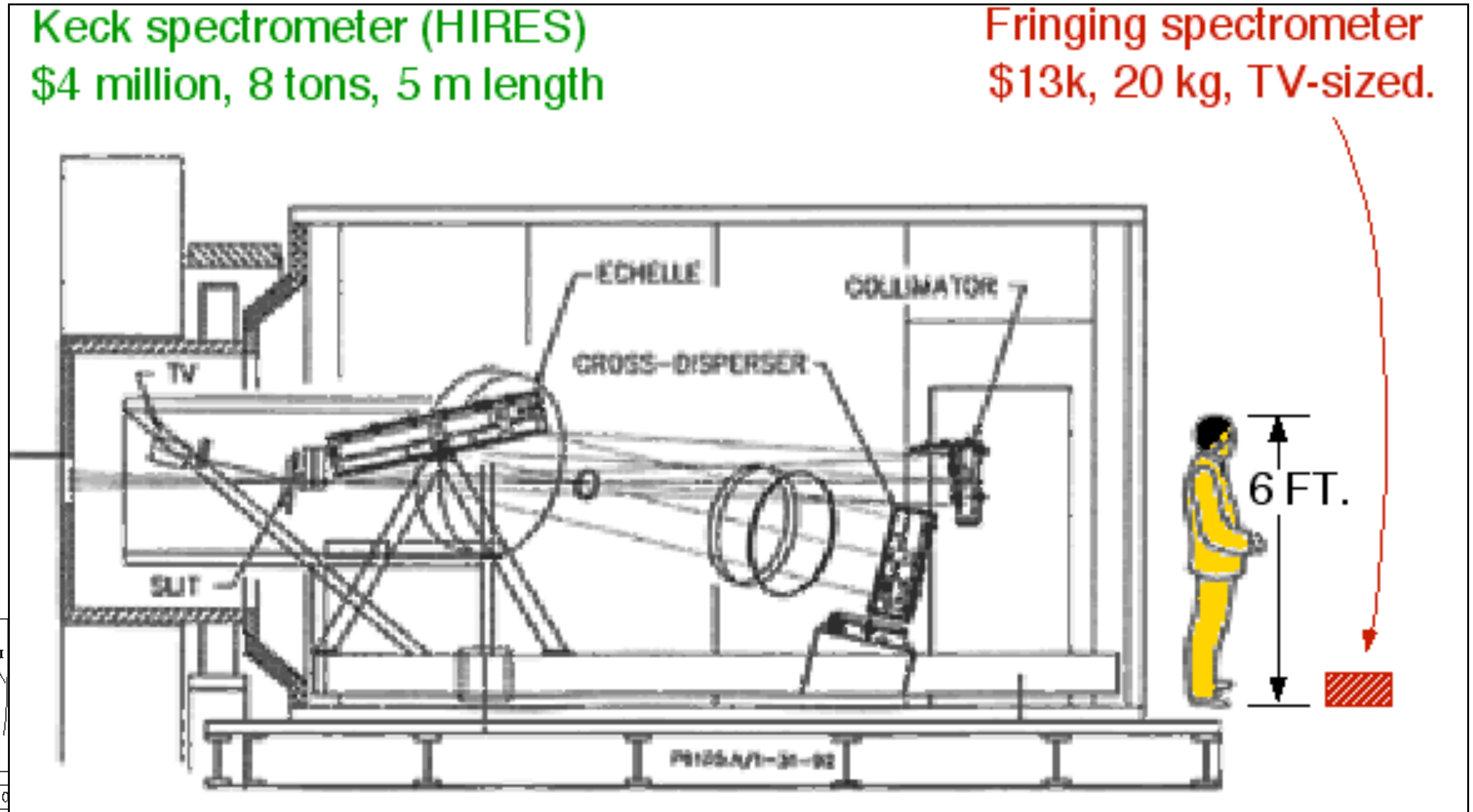


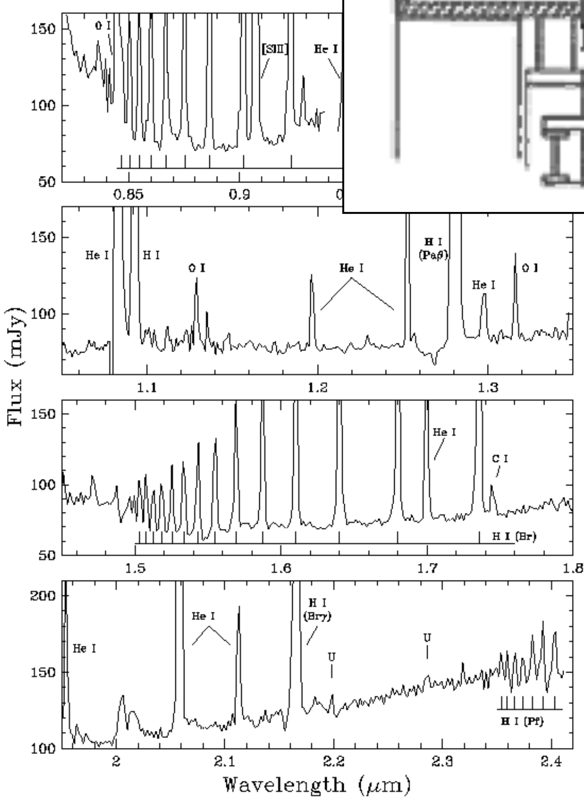
Detectors:

• Charged-coupled device (CCD), semiconductor detector, much more efficient than human eye, or photographic plate

• Used to detect both images and spectra





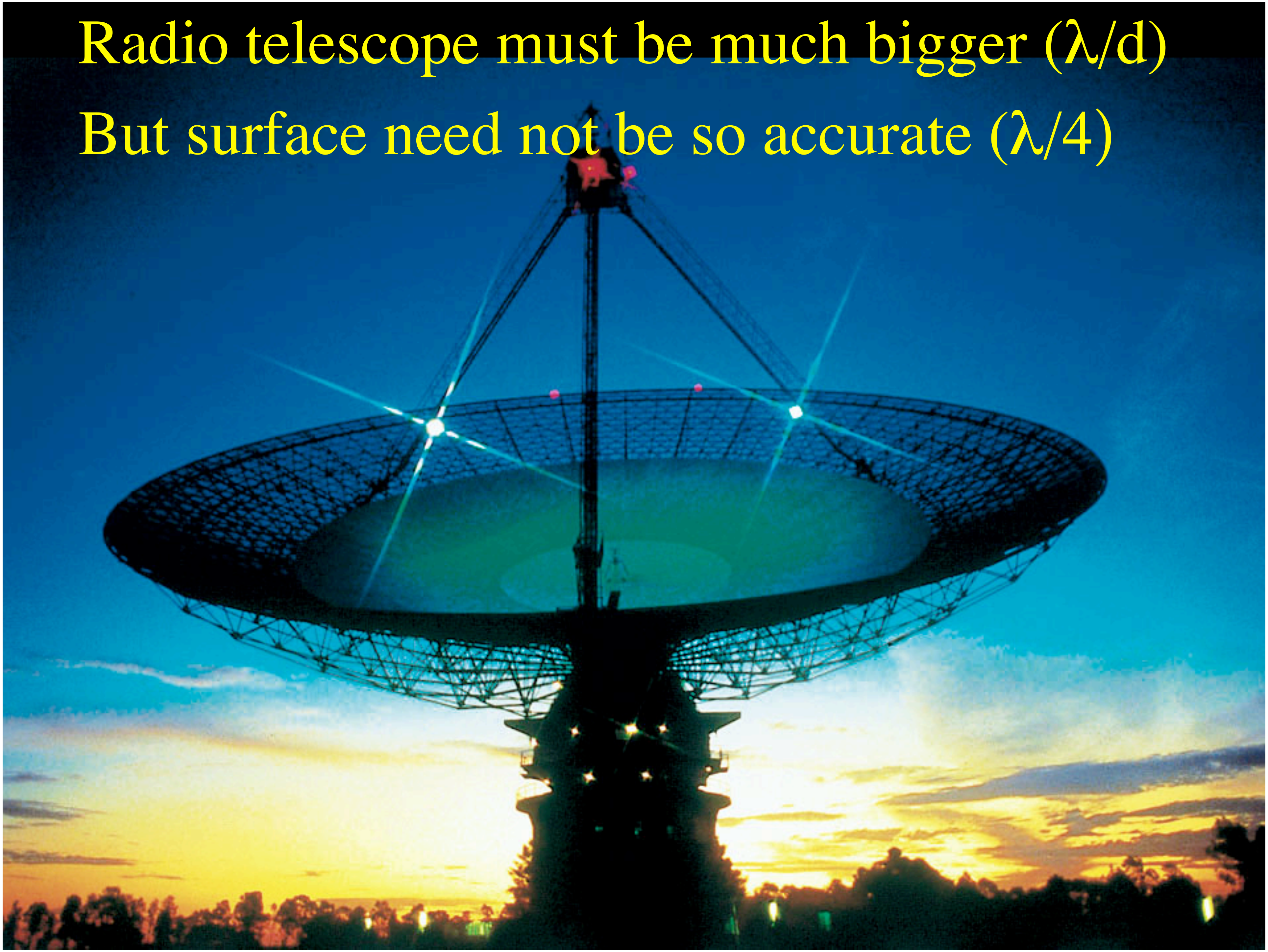


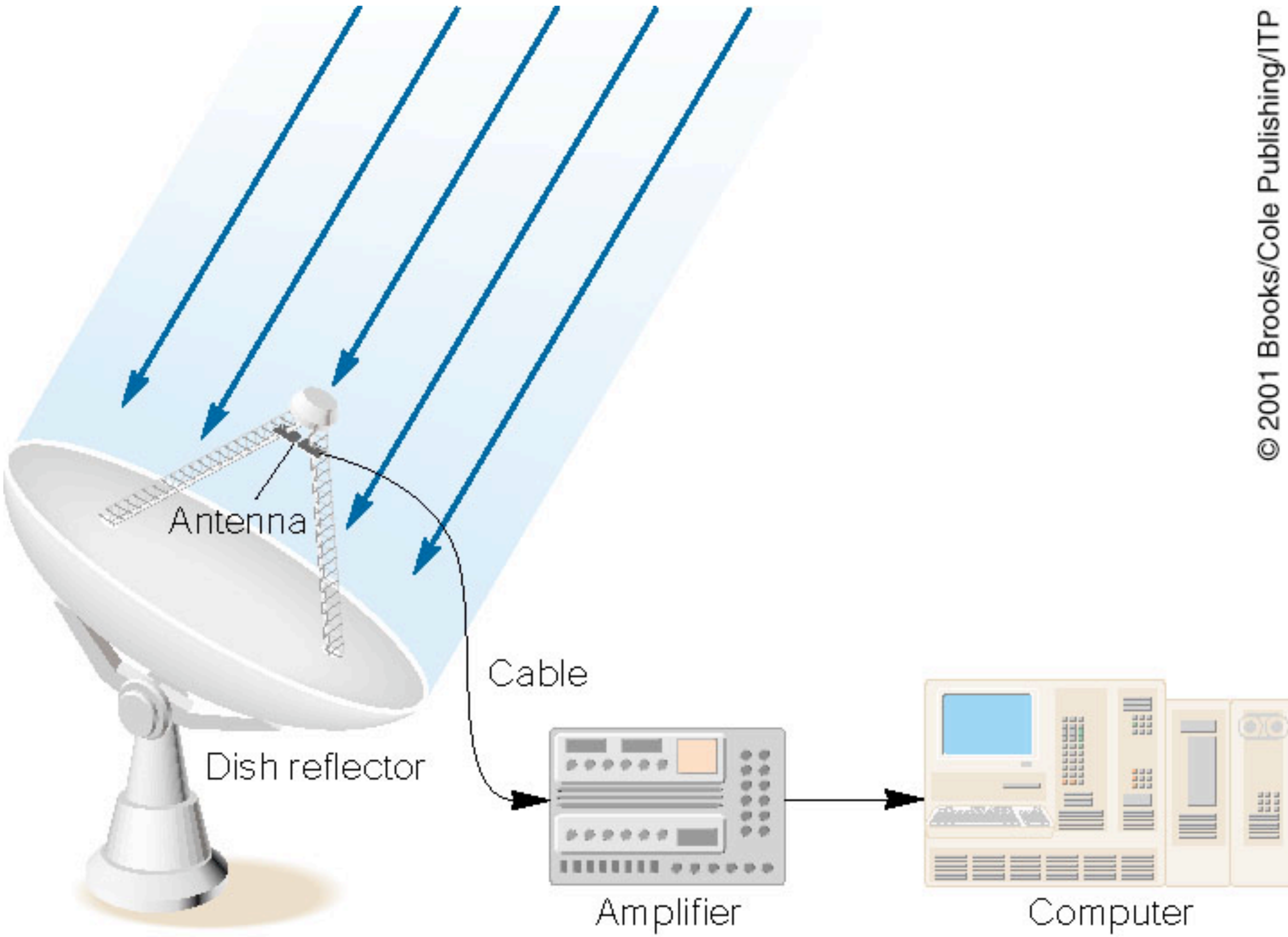
Spectrograph: uses diffraction grating to disperse light; CCD to record spectrum

Observing at a big telescope

Radio telescope must be much bigger (λ/d)

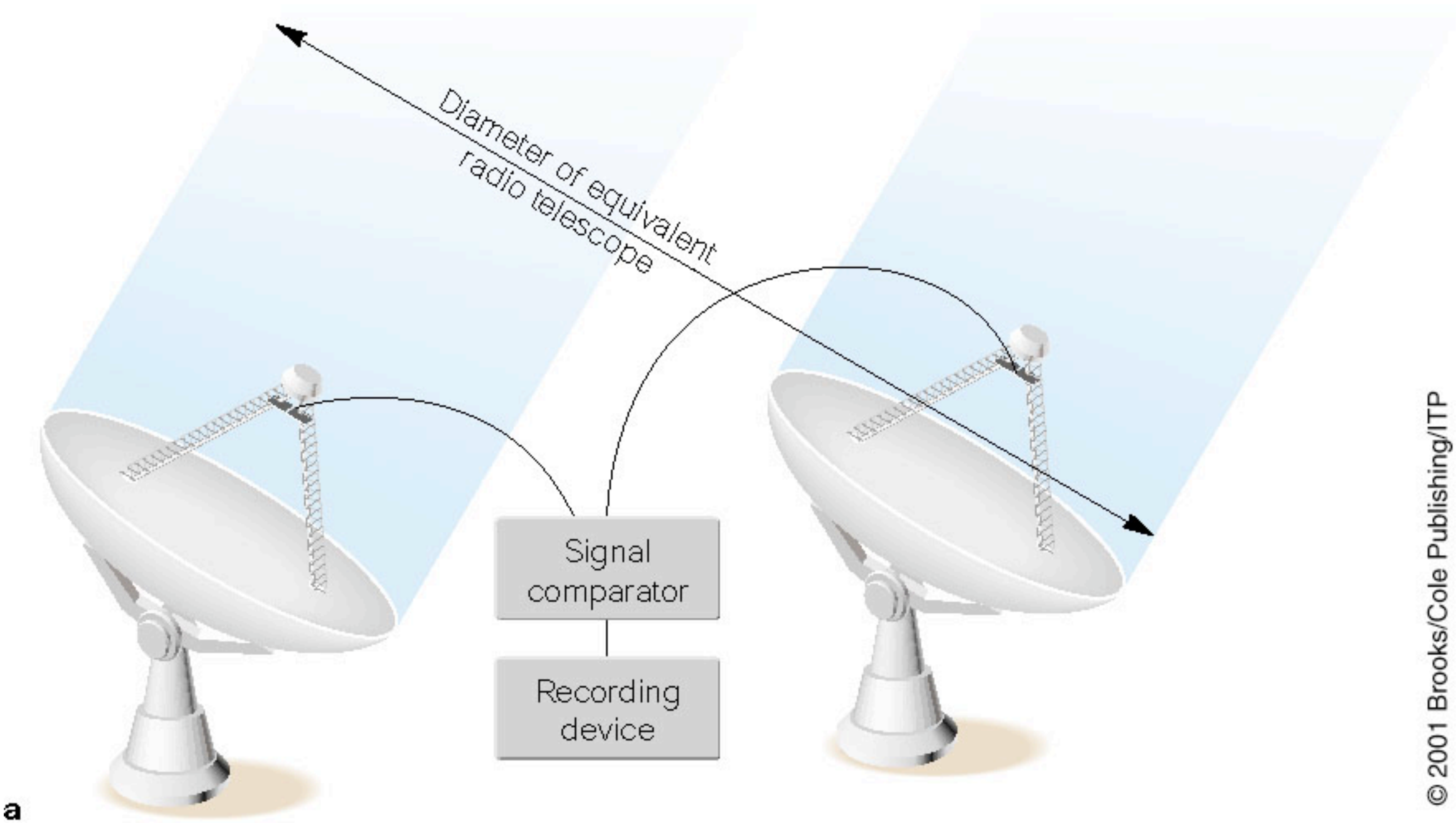
But surface need not be so accurate (λ/4)




Antenna
Cable
Dish reflector
Amplifier
Computer

Arecibo - world's largest radio telescope

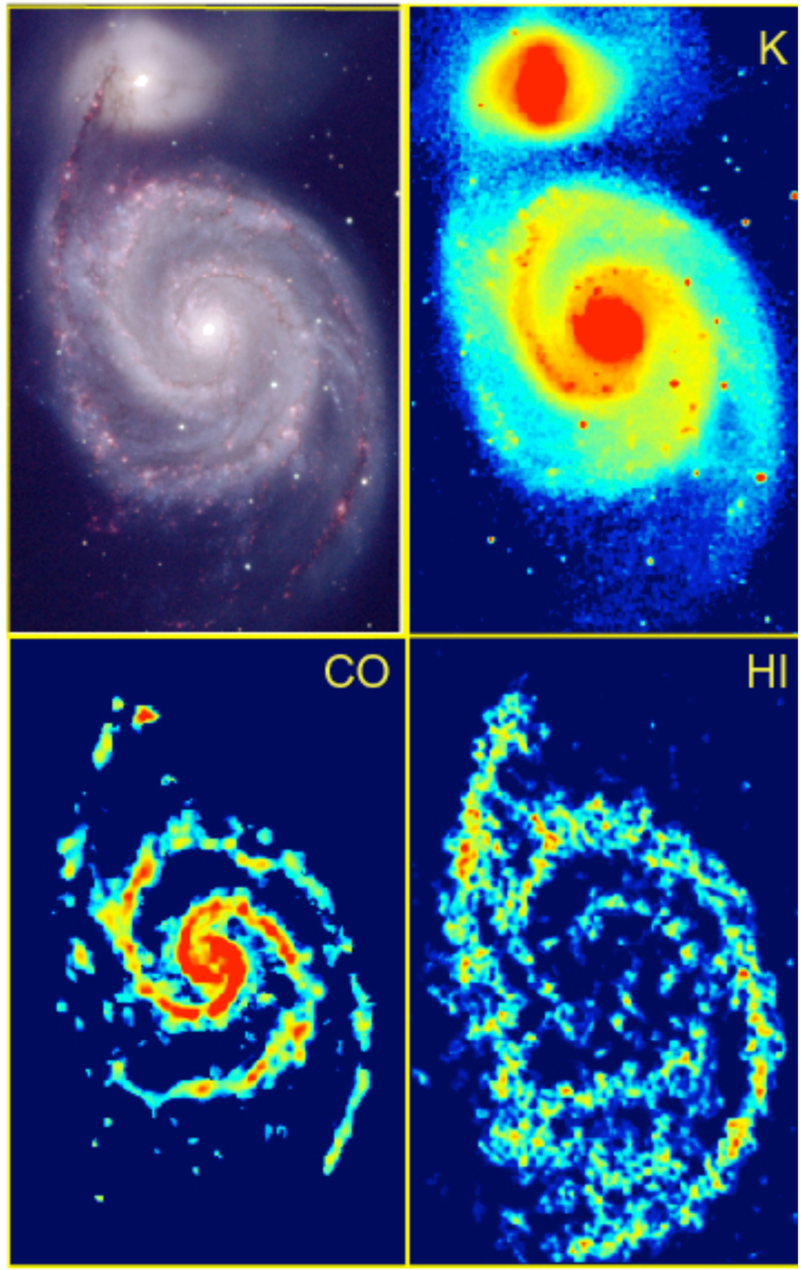
Interferometer combines signal from multiple dishes to give resolution equivalent to much larger telescope



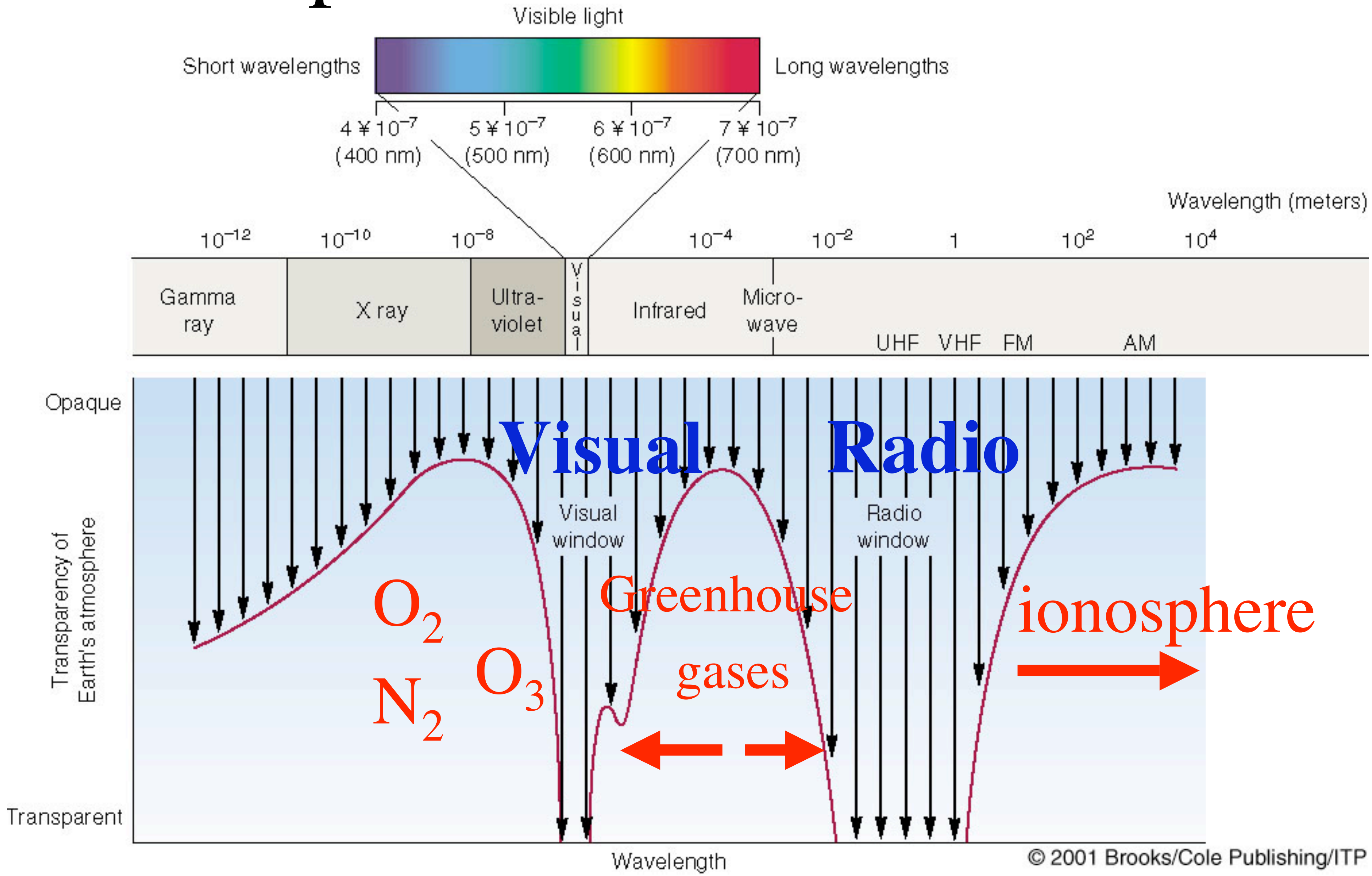
Very Large Array (VLA) in NM

- 27 radio telescopes, d=25 m, maximum separation 27 km

Whirlpool Galaxy at Different Wavelengths



Atmospheric windows to universe



Atmospheric Windows

- Atmosphere is transparent at *visible* and *radio* wavelengths
  - Ground-based observatories are OK
  - But space-based would give better seeing!
- Atmosphere is opaque at *gamma ray*, *x-ray*, and most of *ultraviolet* and *infrared* wavelengths
  - Space-based observatories are required

Strengths of HST (2.4 m mirror):

- works from UV to IR
- Free of atmospheric seeing - gives diffraction limited images (about 0.1”); lower background levels (no sky)

Globular Cluster NGC 6093

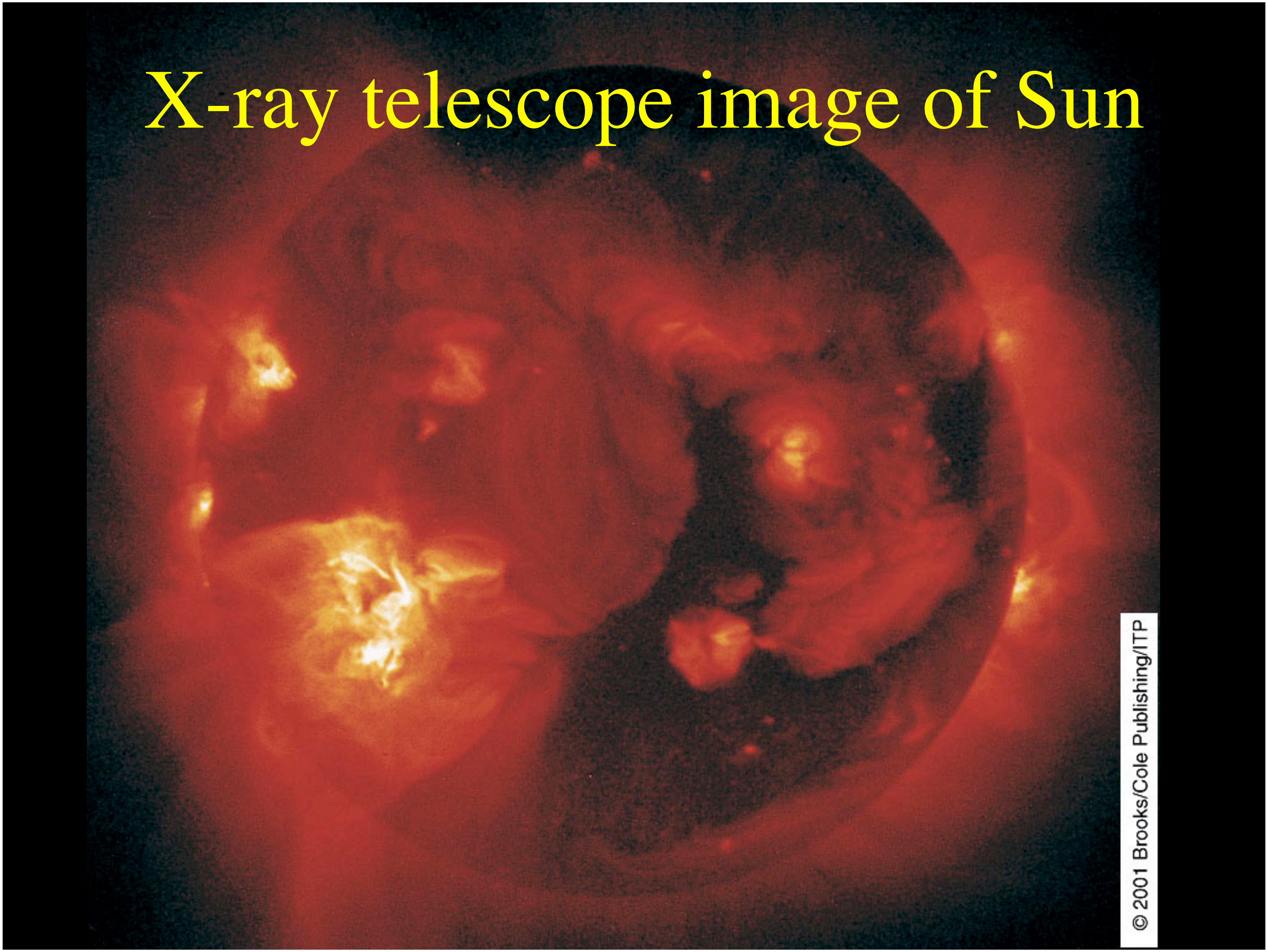
Hubble Heritage

PRC99-26 • Space Telescope Science Institute • Hubble Heritage Team (AURA/STScI/NASA)

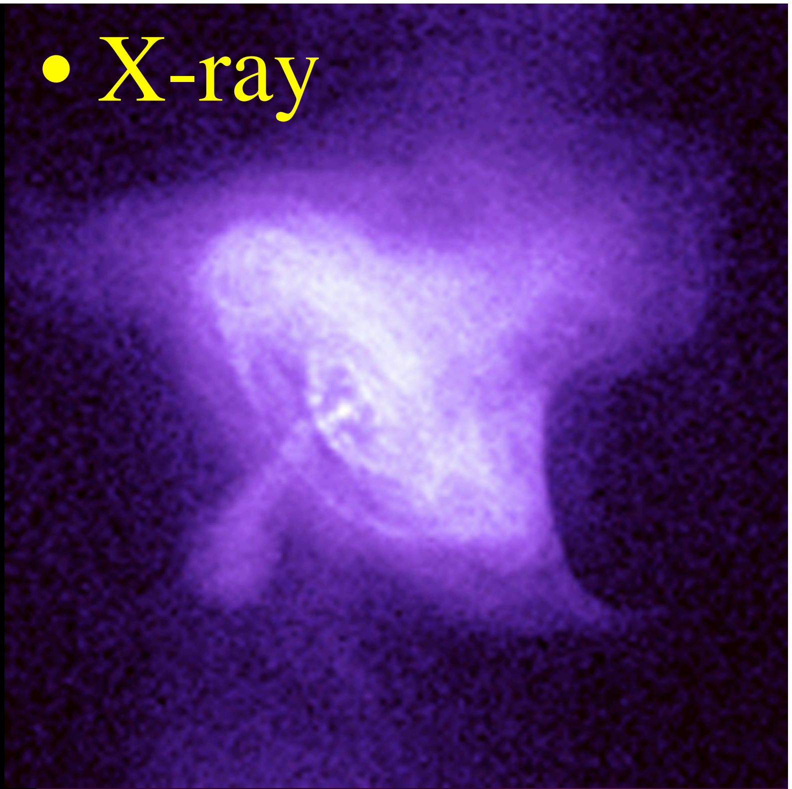
Planetary Nebula Mz 3

Chandra X-ray telescope:
uses grazing incidence mirrors, elliptical geocentric orbit

X-ray telescope image of Sun




• Visible light


• X-ray

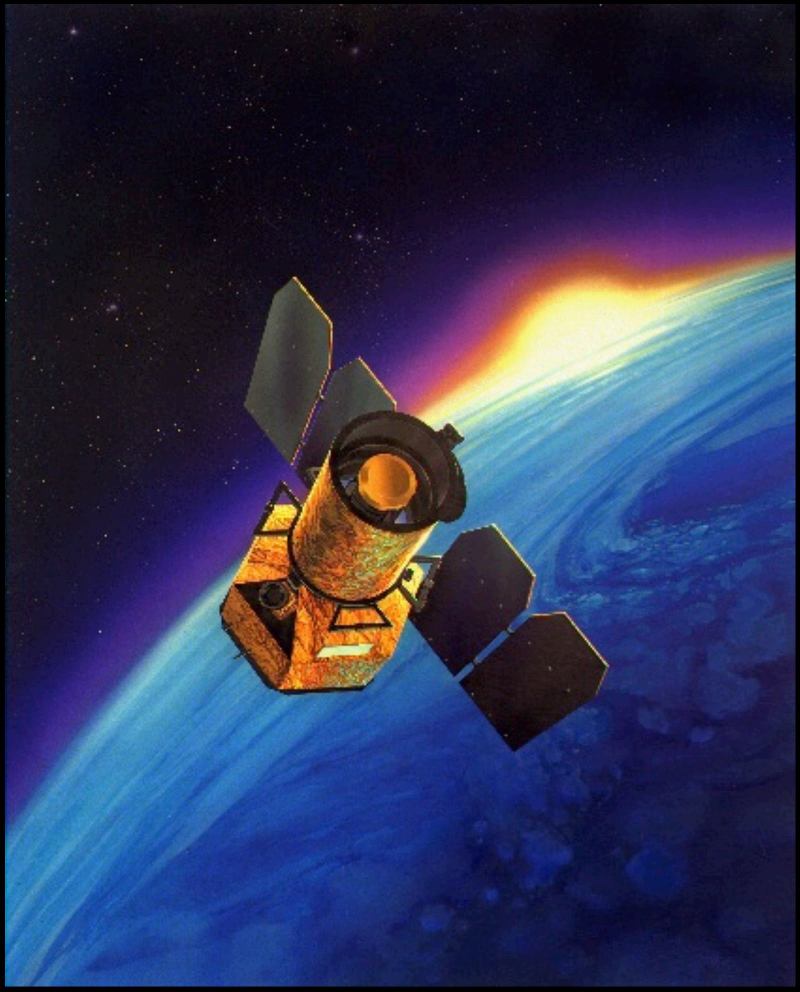

• radio

Spitzer Infrared Telescope

• 85 cm mirror (beryllium)

• heliocentric Earth-trailing orbit

GALEX UV Satellite



- 20” mirror
- 690 km orbit altitude

- 11” Schmidt-Cassegrain Reflector
- 40,000 object database
- Plop it down, and using GPS it finds stars and other astronomical objects
- “Only” $2999

Keck 10-meter telescopes