Stars, Galaxies & Universe Lecture #5

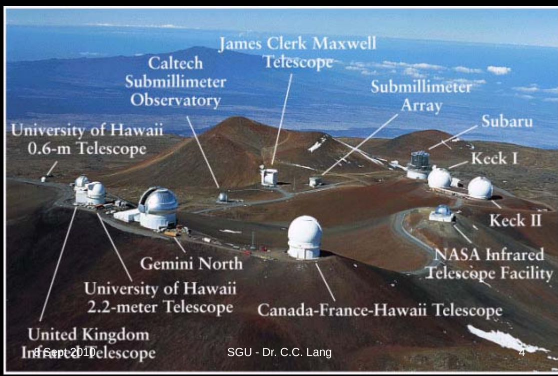
- Reading quiz on telescopes
- Telescopes
  - Ground-based telescopes (optical, radio)
  - Earth's atmosphere
  - Space-based telescopes

The Basics of Telescopes

Telescopes: Guiding Questions

1. How do reflecting and refracting telescopes work?
2. Why is it important that professional telescopes be large?
3. Why do most modern telescopes use mirrors rather than lenses?
4. Why are observatories in such remote locations?
5. Do astronomers use ordinary photographic film to take pictures of the sky? Do they actually look through large telescopes?
6. Why do astronomers need telescopes that detect radio waves and other non-visible forms of light?
7. Why is it useful to put telescopes in orbit?

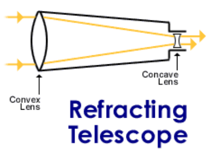
Telescopes on the Ground

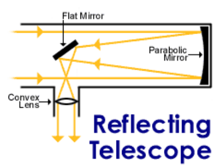


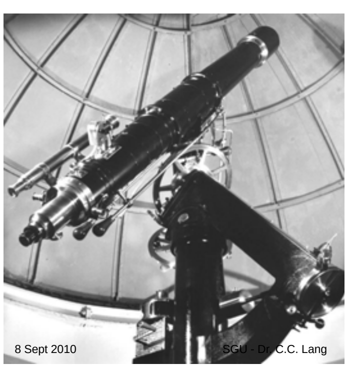
Two Basic Telescope Designs

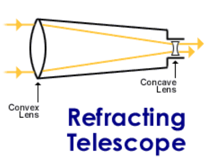
- Refractors
  - Use lenses to concentrate incoming light at a focus.
- Reflectors
  - Use mirrors to concentrate incoming light at a focus.

The goal is always the same – gather as much light as possible and concentrate it at a focus.









Refracting Telsecopes (Refractors)

- earliest telescopes were refracting
- need bigger lens to collect more light, but then you need a LONGER focal length!
- eventually got impractical

- famous refracting telescope
- tube is 64 feet long!
- lens diameter = 40 inches or ~ 1 m

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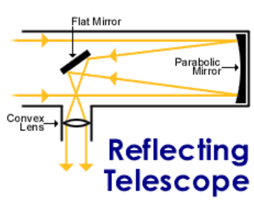
Yerkes Observatory near Chicago



The largest research telescopes in the world are ALL reflectors.

The Keck I telescope on Mauna Kea on the Big Island of Hawaii uses 36 hexagonal mirrors to make a total diameter of 10 m.

(N*ote the astronomers standing on either side of the platform.*)

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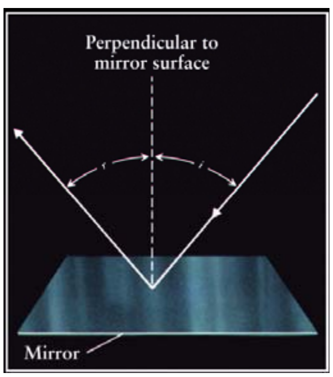
A reflecting telescope uses a mirror to concentrate incoming light at a focus.



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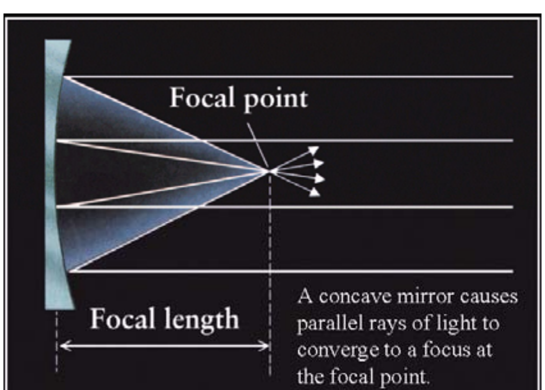
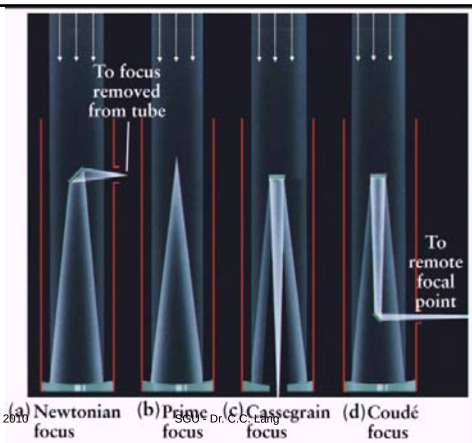
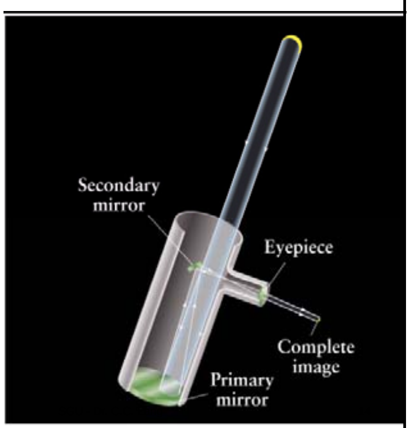




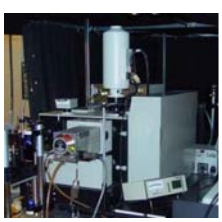
The secondary mirror in the tube does not cause a hole in the image.

It does however make it slightly dimmer because it reduces the total amount of light reaching the primary mirror.



Instruments are afixed to telescope

CCD camera chip



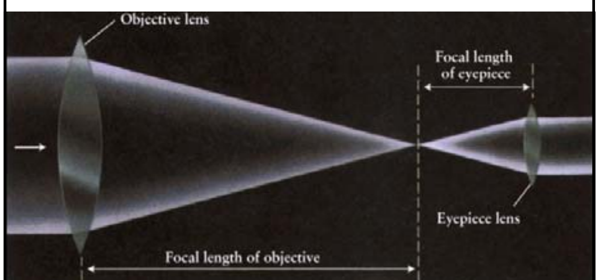
Spectrometer for measuring spectral lines (discrete parts of the EM spectrum)

Functions of a telescope

- Magnify

  magnification = (objective lens focal length / eyepiece lens focal length)

A refracting telescope actually uses two a lenses: an *objective* and an *eyepiece.*



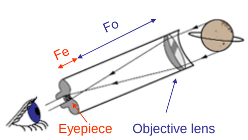
The two lenses are separated by the sum of their focal lengths.

M = power or magnification

$\mathbf{F_e}$ = focal length of the eyepiece

$\mathbf{F_o}$ = focal length of the objective

$$\mathbf{M} = \frac{\mathbf{F_o}}{\mathbf{F_e}}$$



Example:

F_O = 1 m (1000 mm)

F_E = 25 mm

Magnification = F_O/F_E = 1000 mm/25 mm = 40x

Functions of a telescope

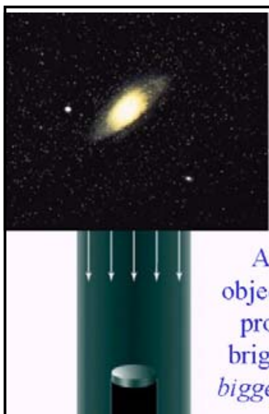
- Magnify

  magnification = (objective lens focal length / eyepiece lens focal length)

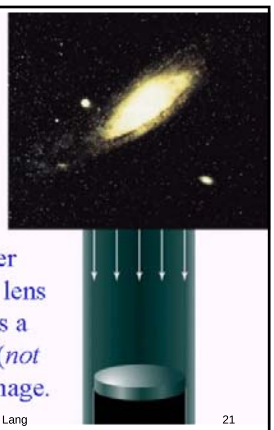
- Brighten

Light Gathering Power

is directly related to the diameter of the objective (πr^2).



A larger objective lens provides a brighter (*not bigger*) image.



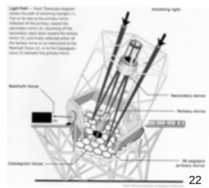
Light gathering power: Comparing two telescopes

- Effective collecting area ~ area (d = telescope diameter

$$A = \frac{\pi}{4} d^2$$

- Compare two telescopes: Hubble (d = 2.4m) and Keck (d = 10m)

$$\frac{A_{Keck}}{A_{HST}} = \frac{\frac{\pi}{4}10^2}{\frac{\pi}{4}2.4^2} = \left[\frac{10}{2.4}\right]^2 = 17.4x$$



Functions of a telescope

- Magnify

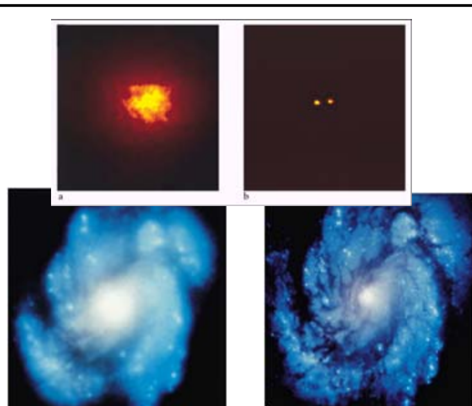
  magnification = (objective lens focal length / eyepiece lens focal length)
- Brighten

  called light gathering power

  Proportional to the diameter of the objective lens.
- Resolve fine detail

  called angular resolution

  Proportional to the size of the telescope (array).



Examples of how resolution depends on
wavelength and **telescope diameter**

Radio dish D = 64 meters
Wavelength = 20 cm = 0.02 m

Resolution ~ λ/D = 800" or 0.2 deg
(equation = 2.5 x 10^5 λ/D)

Optical telescope D = 10 meters
Wavelength = 500 nm = 5 x 10^{-7} m

Resolution = λ/D = 0."01 = 3 x 10^{-6} deg!

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Optical Observing from the Earth:

Must choose your location very carefully!

Challenges to observing from the Earth:

1. need a very dark spot (hard to find these days!)
2. absorption in the Earth's atmosphere
3. weather and air conditions, constituents

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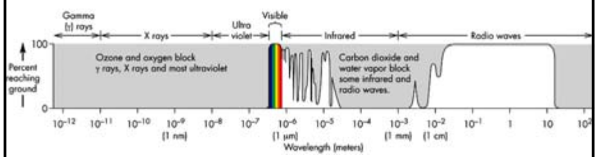
"Light Pollution" prevents skies from being dark
→ need to observe from a remote location

The Earth's atmosphere blocks much of the electromagnetic spectrum

→ *absorption of gamma and X-rays* **by ozone, oxygen**
→ **carbon dioxide, water vapor** *absorb IR and some radio waves*



Three "windows" from the ground
- optical/visible
- radio
- near-infrared (few μm)

The weather/air conditions are also important:

→ dust, particles in the air can absorb and scatter EM radiation

→ water vapor is a major absorber of EM radiation

→ distortion of waves by the atmosphere

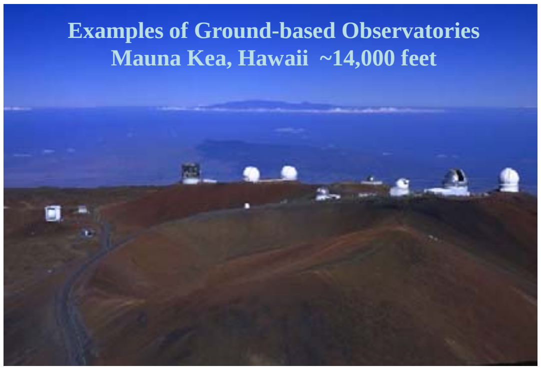
→ "seeing" is how well the atmosphere allows you to image details

"good seeing" conditions, "bad seeing"
seeing usually measured in arcseconds
Hubble has constant "seeing" of <1"
best telescopes on Earth can hope for ~0."5

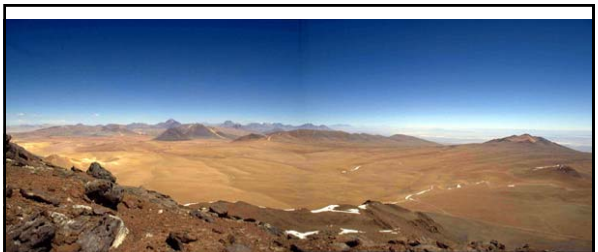
→ **bottom line: observing should be done at HIGH, DRY, REMOTE sites!**

University of Iowa's Rigel Telescope in Arizona

Examples of Ground-based Observatories
Mauna Kea, Hawaii ~14,000 feet

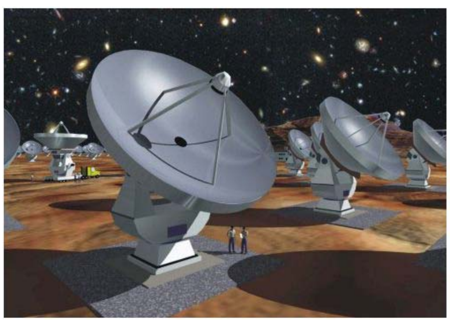


Keck I & II telescopes – optical telescopes
10-m mirror (made of smaller pieces)
Mauna Kea, Hawaii – elevation ~14,000 feet



Highest, driest telescope site: (~ 16,400 feet)
Atacama desert, Northern Chile

Future site of millimeter array telescope: ALMA



Artist's conception of ALMA telescope: 64 12-m telescopes!

Green Bank Telescope

Green Bank, WV

• 100-m across (more than 300 feet across!)

• 7300 tons of moving weight

One of the 27 VLA antennas

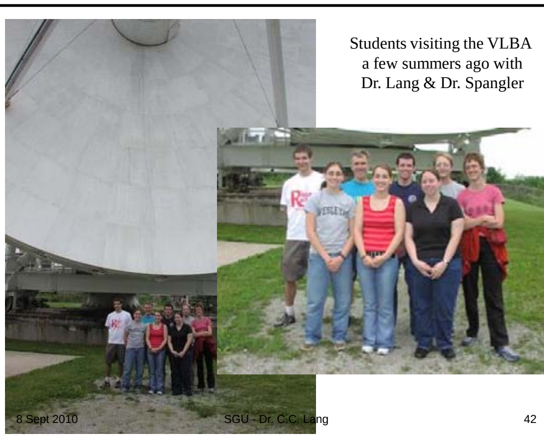
- 25 m (81 feet) across
- 230 tons each
- array simulates a 22-mile wide radio telescope!

Very Long Baseline Array (VLBA)

Very Long Baseline Array (VLBA)

What is the resolution of the VLBA?

North Liberty, Iowa VLBA Antenna

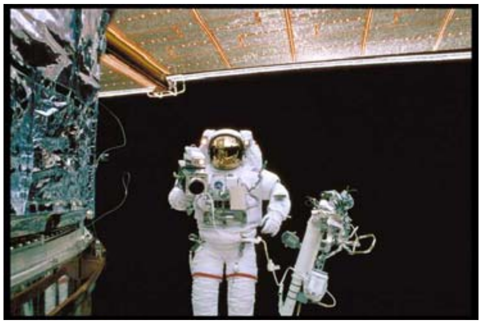


Students visiting the VLBA a few summers ago with Dr. Lang & Dr. Spangler

Hubble Space Telescope: "beat the atmosphere"

Hubble Space Telescope

- optical telescope
- 2.4-m mirror
- in "low-earth" orbit: 368 miles above Earth
- orbits every 90 minutes



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X-rays: Chandra X-ray Observatory

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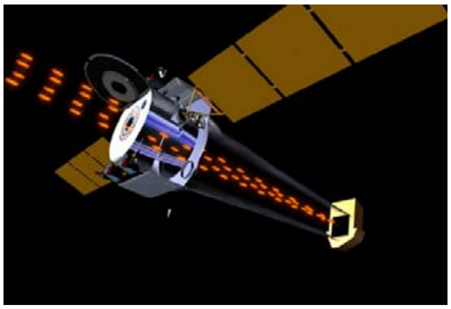
X-rays will pass through normal mirrors
to focus X-rays, use "grazing incidence"



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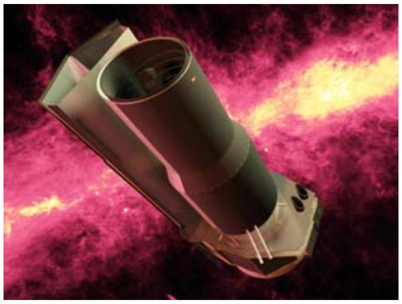

SPITZER: Space Infrared Observatory
(in earth orbit: an "infrared Hubble")

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SOFIA: Stratospheric Observatory for Infrared Astronomy
telescope implanted in a 747 aircraft, flies at 40,000 feet

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