Reminder: Test #1 Sep 13

Topics:

- Fundamentals of Astronomy
- The Copernican Revolution and laws of motion
- Radiation and the Electromagnetic Spectrum
- Atoms and Spectroscopy
- Telescopes

Methods

- Conceptual Review and Practice Problems Intro-Chap 4
- Review lectures (on-line) and know answers to clicker questions
- Try practice quizzes on-line
- Review: Monday @ 4:00pm in RH103

Bring:

- Two Number 2 pencils
- Simple calculator (no electronic notes)

Reminder: There are NO make-up tests for this class

Test #1 Useful Equations

Kepler's laws, including: $P^2 \ \alpha \ a^3$ P=period, a=semi-major axis

Newton's laws, including: $F = ma$ m=mass, a=acceleration

Gravitation:

$$F = \frac{G\, m_1\, m_2}{R^2}$$

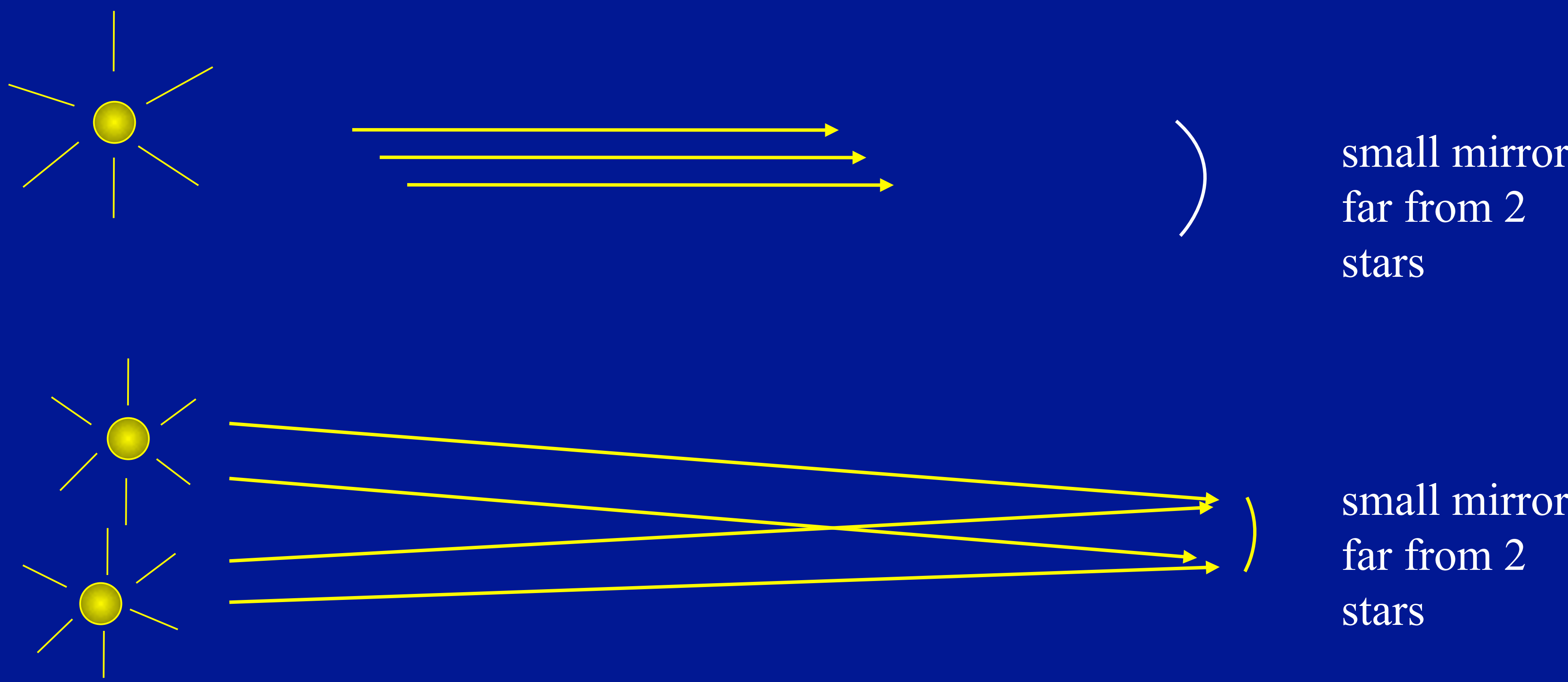
Speed of electromagnetic waves: $c = \lambda\, \nu$ Energy = $h\nu$

Wien's Law: $\lambda_{\text{max energy}} \ \alpha \ \frac{1}{T}$

Stefan's Law: $L = A\, T^4$ where the area $A = 4\pi r^2$ for a sphere

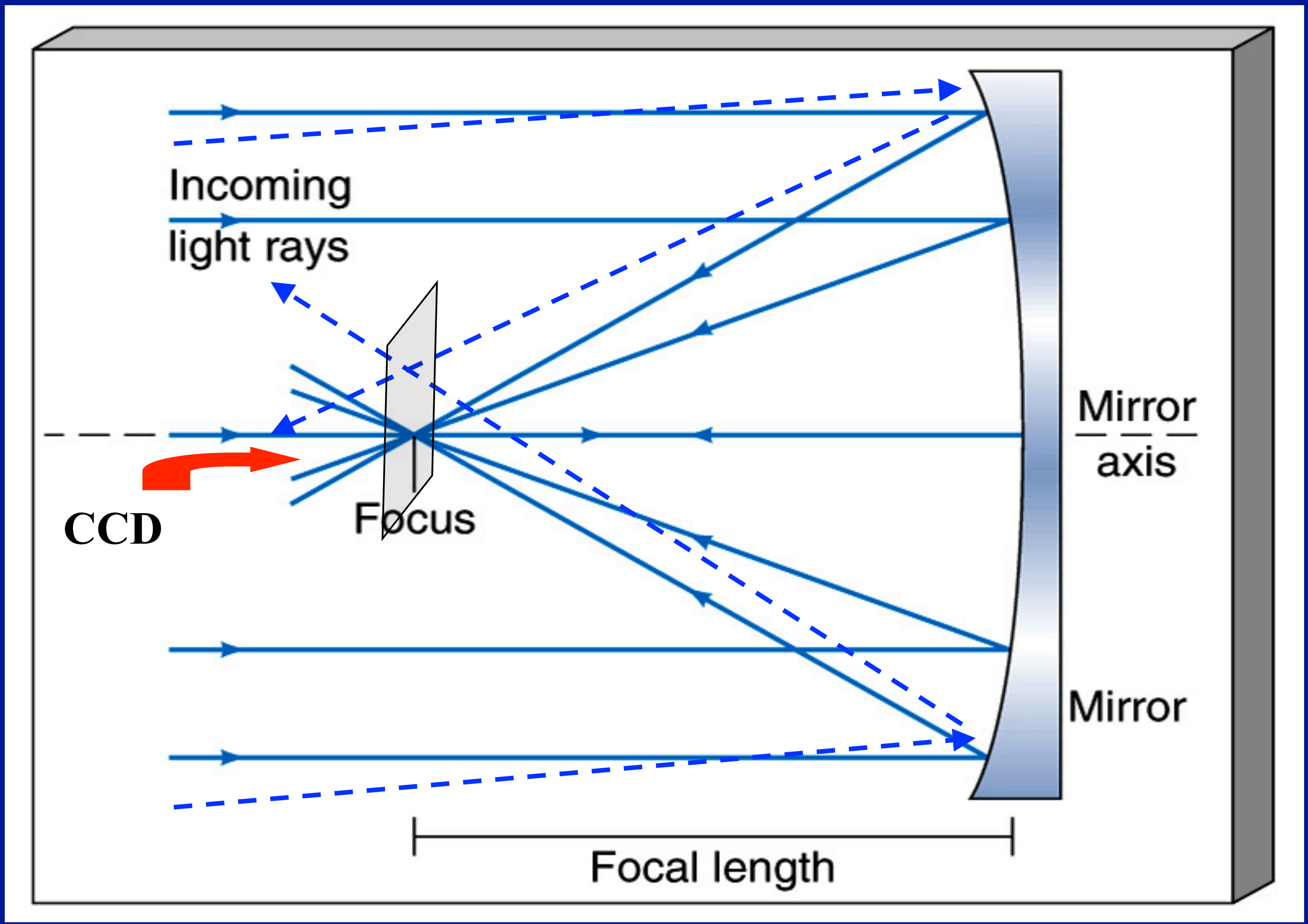
Telescopes

Light Hitting a Telescope Mirror



Light rays from any <u>single</u> point of light are essentially <u>parallel</u>. But the parallel rays from the <u>second</u> star come in at a <u>different angle.</u>

Light rays from a distant source, parallel to the "mirror axis" all meet at one point, the focus.

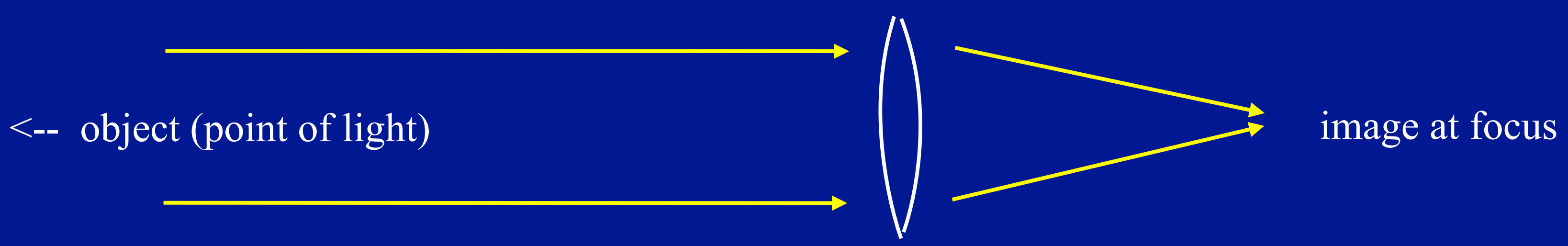


Parallel light rays at another angle meet at another point in same vertical plane, the "focal plane".

Optical Telescopes - Refracting vs. Reflecting

Refracting telescope

Focuses light with a lens (like a camera).



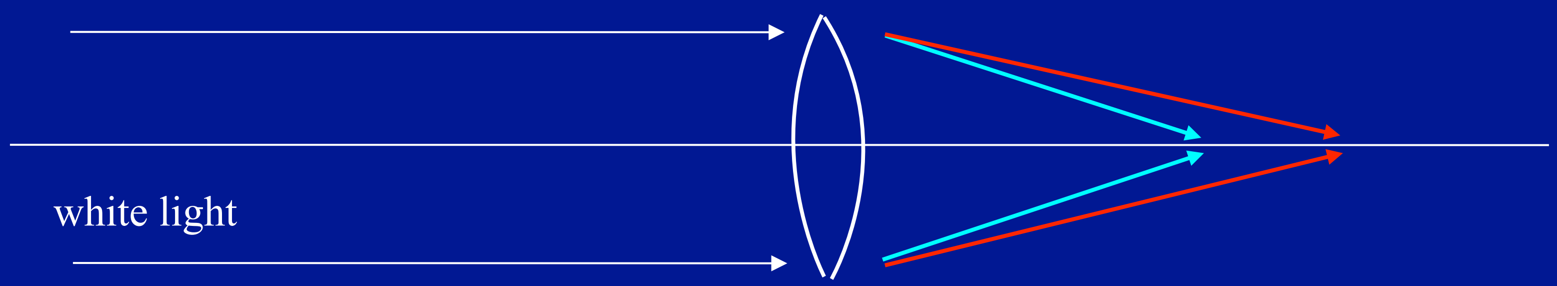
Problems:

- Lens can only be supported around edge.
- "Chromatic aberration".
- Some light absorbed in glass (especially UV, infrared).
- Air bubbles and imperfections affect image quality.

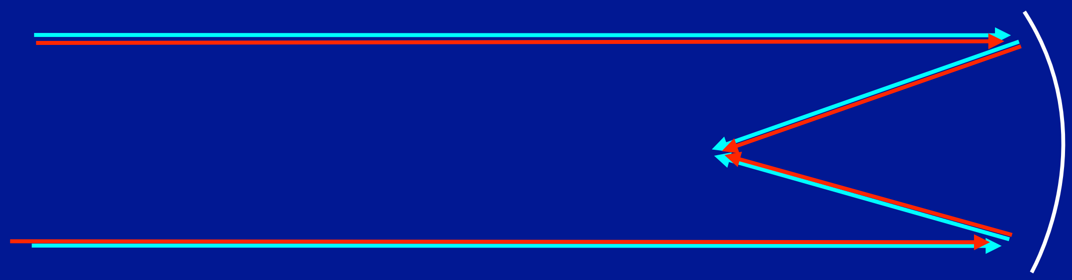
Chromatic Aberration

Lens - different colors focus at different places.

DEMO



Mirror - reflection angle doesn't depend on color.



Reflecting telescope

Focuses light with a curved mirror.

- Can make bigger mirrors since they are supported from behind.
- No chromatic aberration.
- Reflects all radiation with little loss by absorption.

Refracting Telescope

Yerkes 40-inch (about 1 m).
Largest refractor.

Reflecting Telescope

Cerro-Tololo 4 -m reflector.

Reflector Types

Prime focus

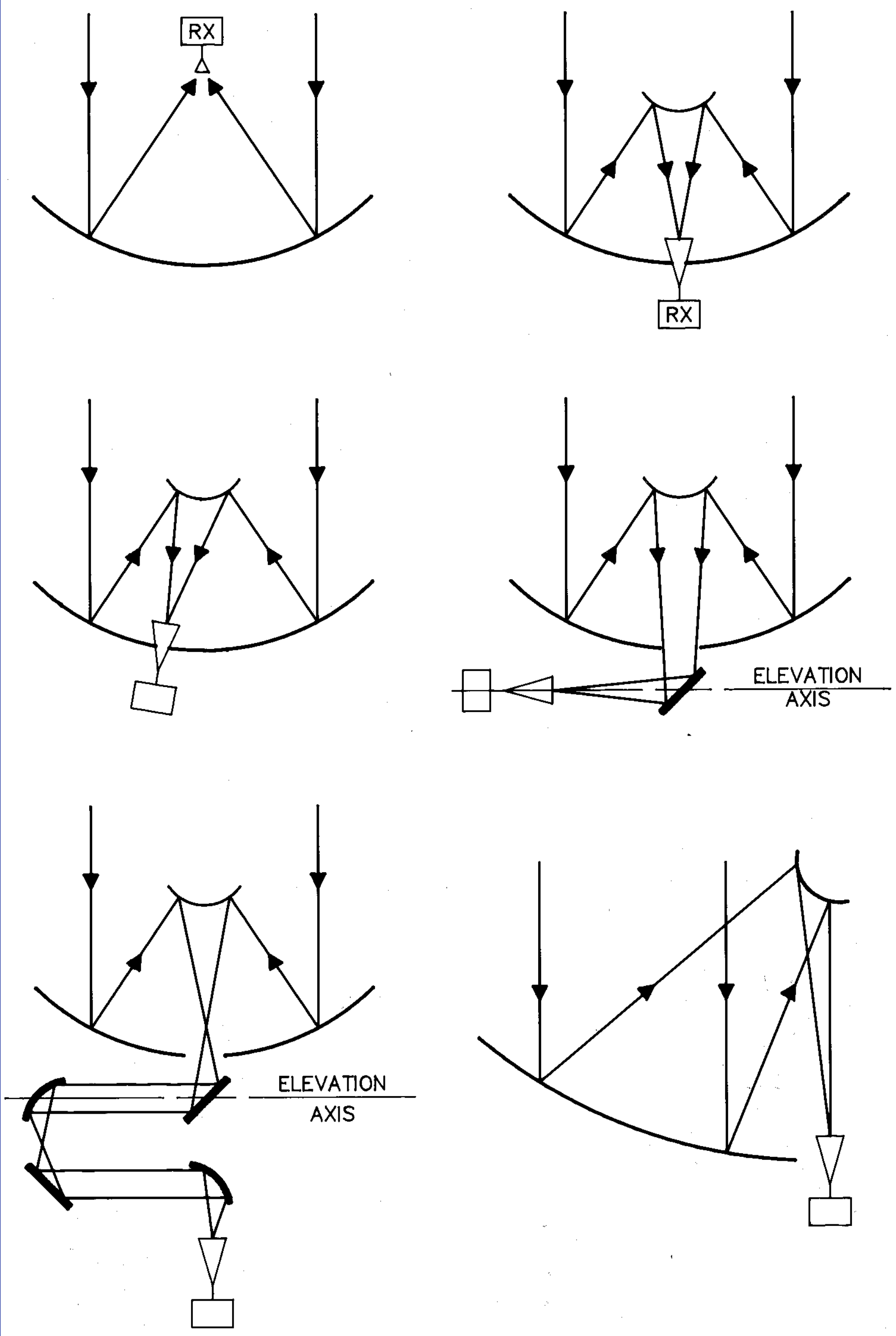
Cassegrain focus

Offset Cassegrain

Nasmyth

Beam Waveguide

Dual Offset



Reflector Types

Prime focus

(GMRT)

Cassegrain focus

(AT)

Offset Cassegrain

(VLA)

Nasmyth

(OVRO)

Beam Waveguide

(NRO)

Dual Offset

(ATA)

Clicker Question:

Compared to radio waves, gamma-rays travel:

A: faster

B: slower

C: at the same speed

Clicker Question:

An advantage of refracting telescopes over reflecting telescopes is:

A: Big lenses are lighter than big mirrors.

B: The focus is easy to get to.

C: They don’t suffer from chromatic aberration

D: They don’t suffer from altitude sickness

E: All of the above

Clicker Question:

Ground based telescopes work at what wavelengths?

A: Just the optical.

B: Just the radio.

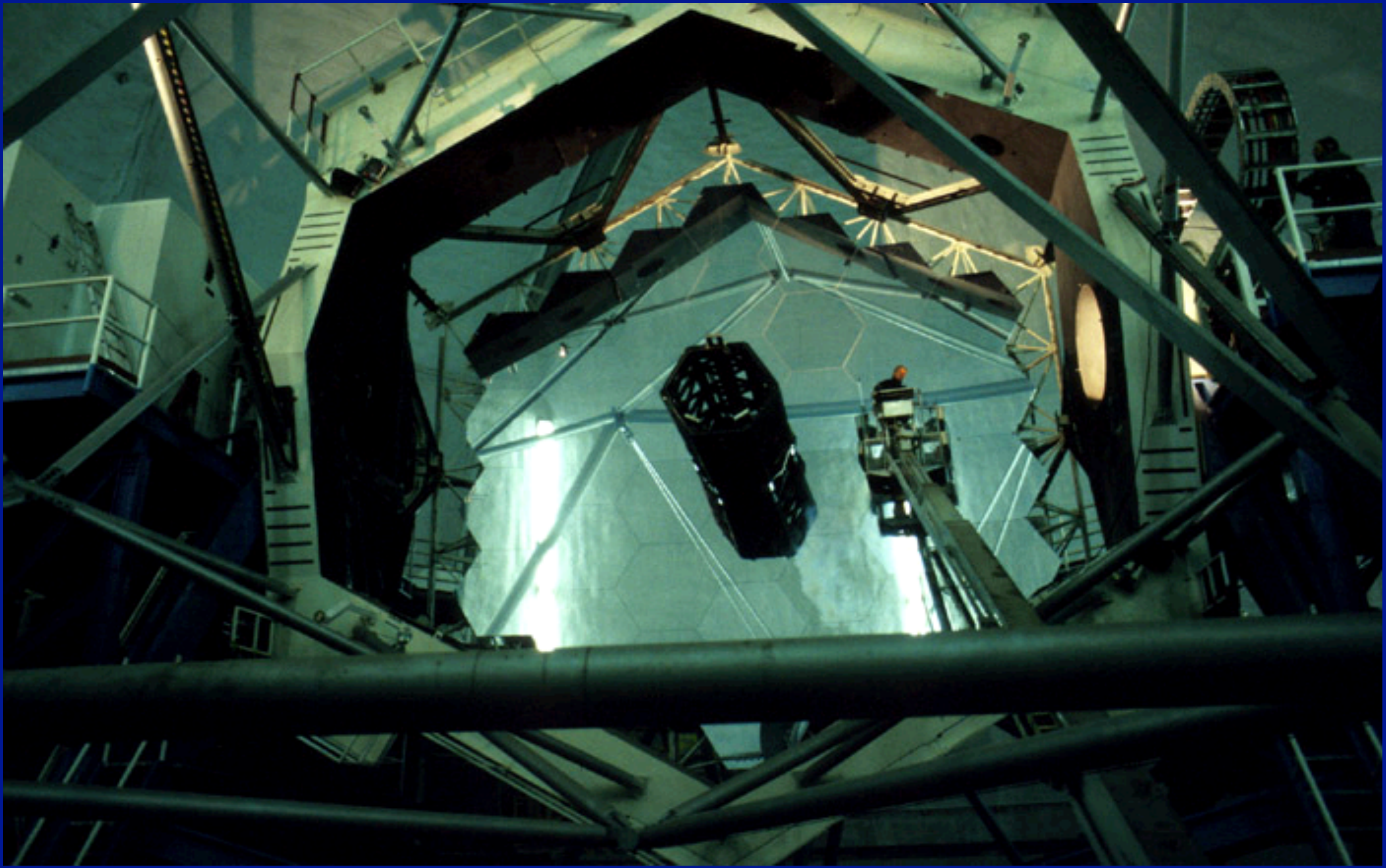
C: Just in X-rays.

D: Both in optical and radio wavelengths.

E: Both in optical, radio and X-ray wavelengths.

Mirror size

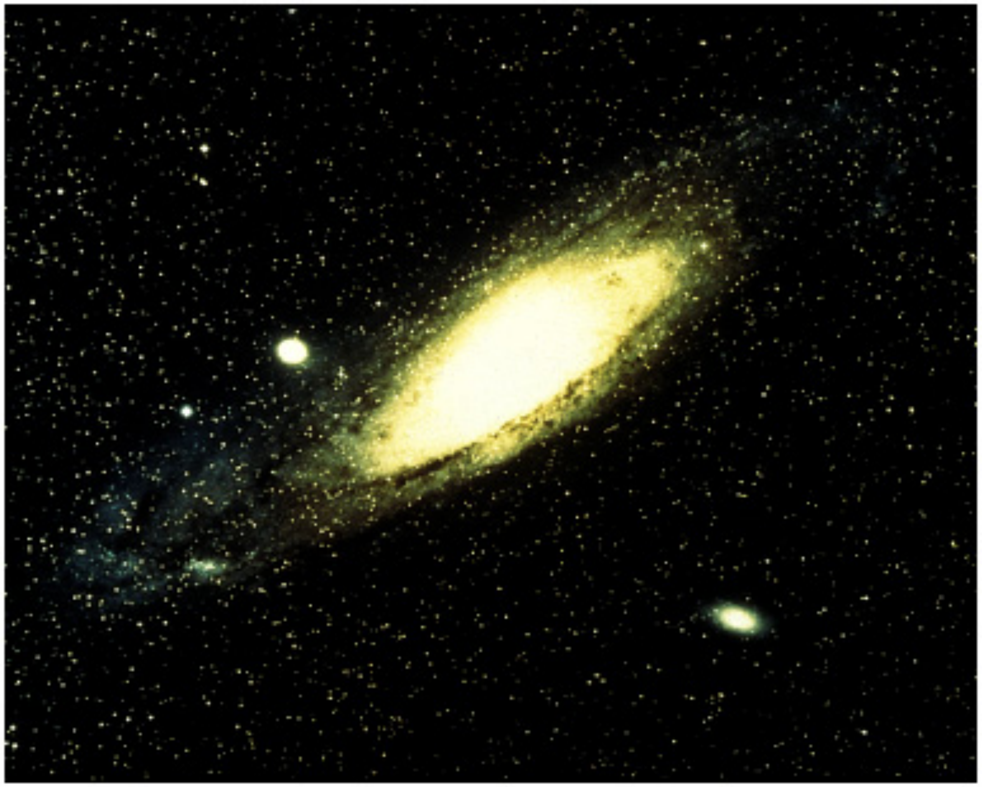
Mirror with larger area captures more light from a cosmic object. Can look at fainter objects with it.

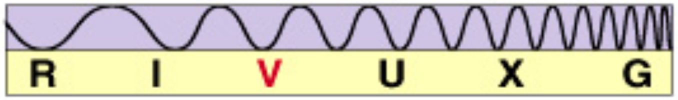


Keck 10-m optical telescope.
30 m optical telescopes are now under construction!

Image of Andromeda galaxy with optical telescope.

Image with telescope of twice the diameter, same exposure time.



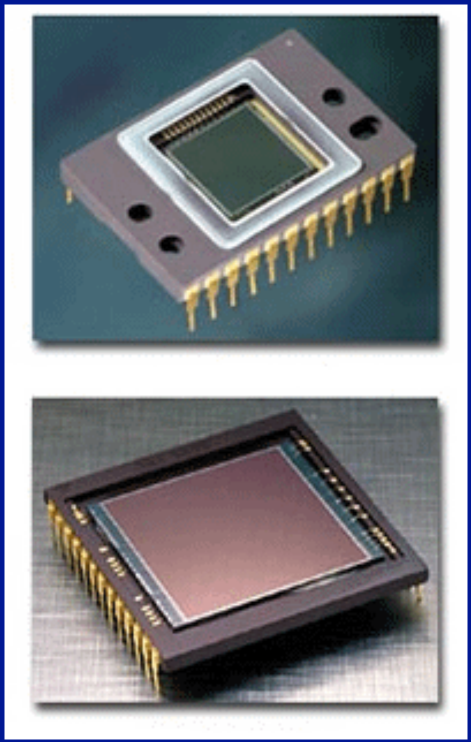


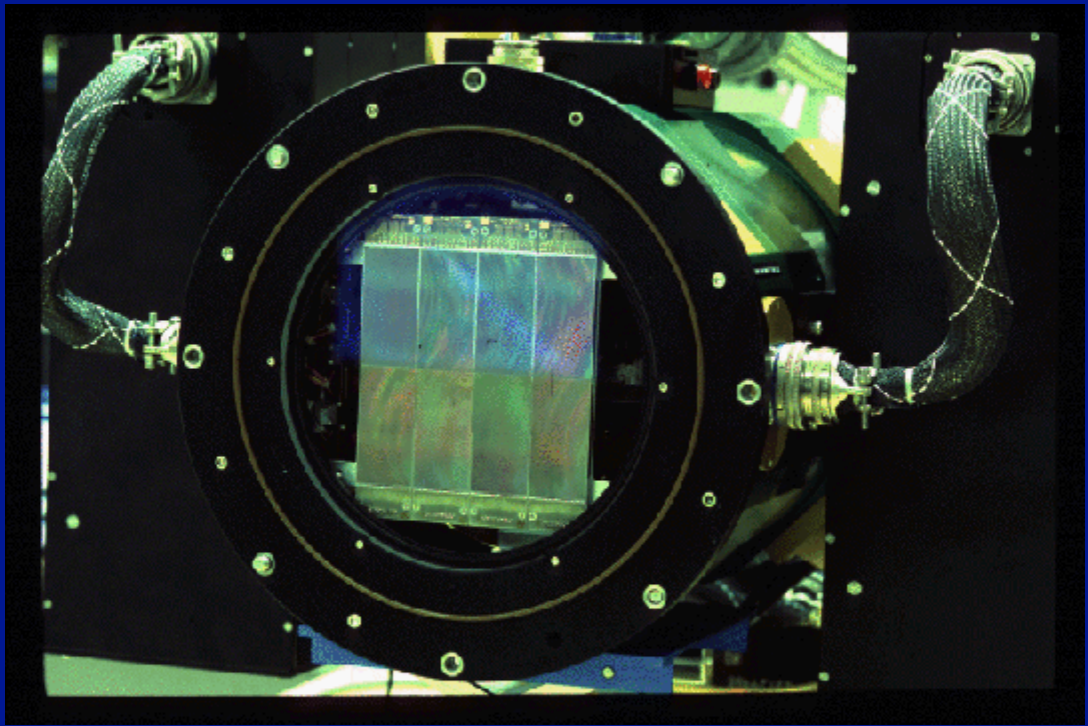
The Two Main Types of Observation

Imaging (recording pictures)

Spectroscopy (making a spectrum) usually using a diffraction grating

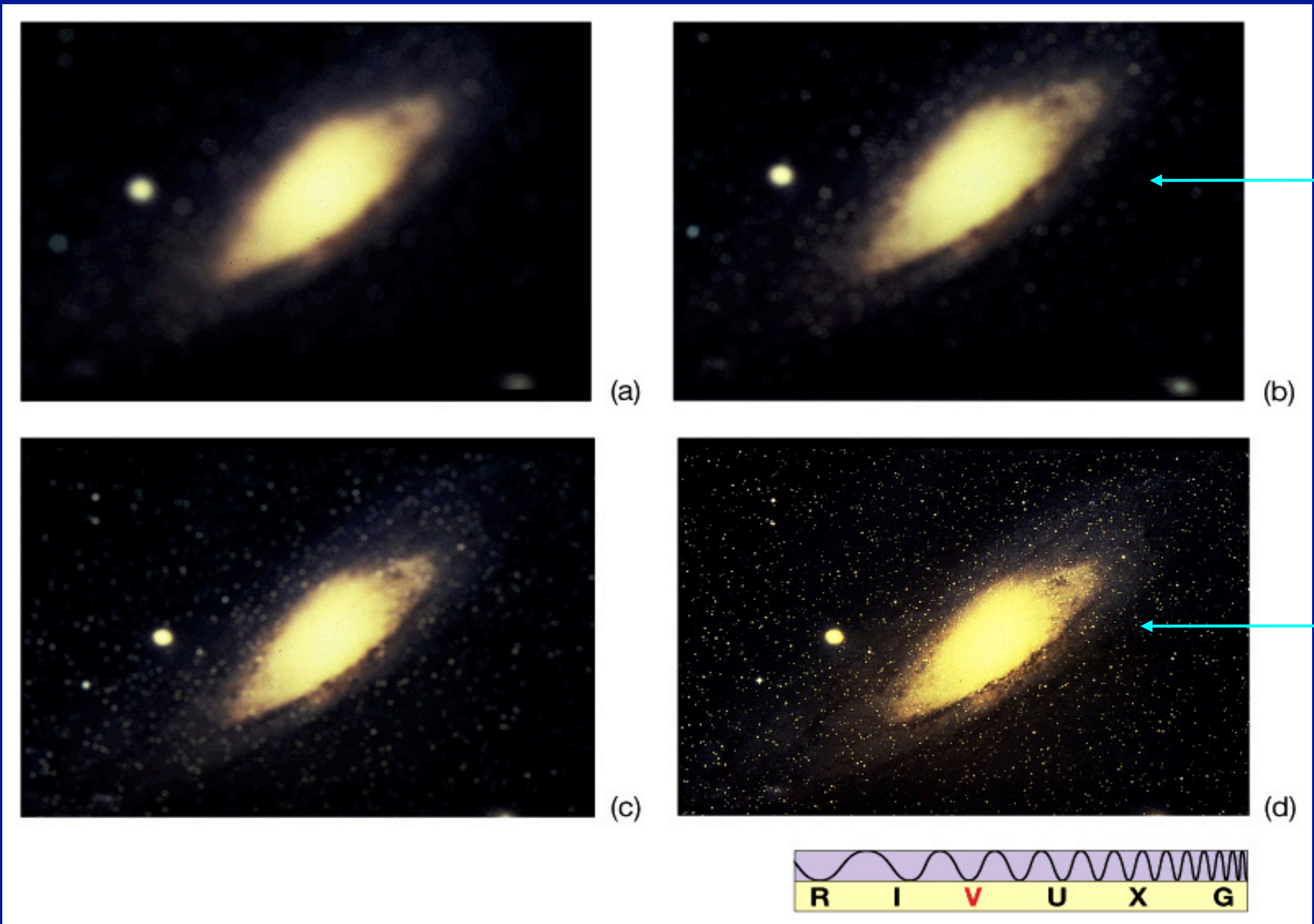
In both cases, image or spectrum usually recorded on a CCD ("charge-coupled device")





Resolving Power of a Mirror

(how much detail can you see?)



fuzziness you would see with your eye.

detail you can see with a telescope.

"Angular resolution" is the smallest angle by which two objects can be separated and still be distinguished.

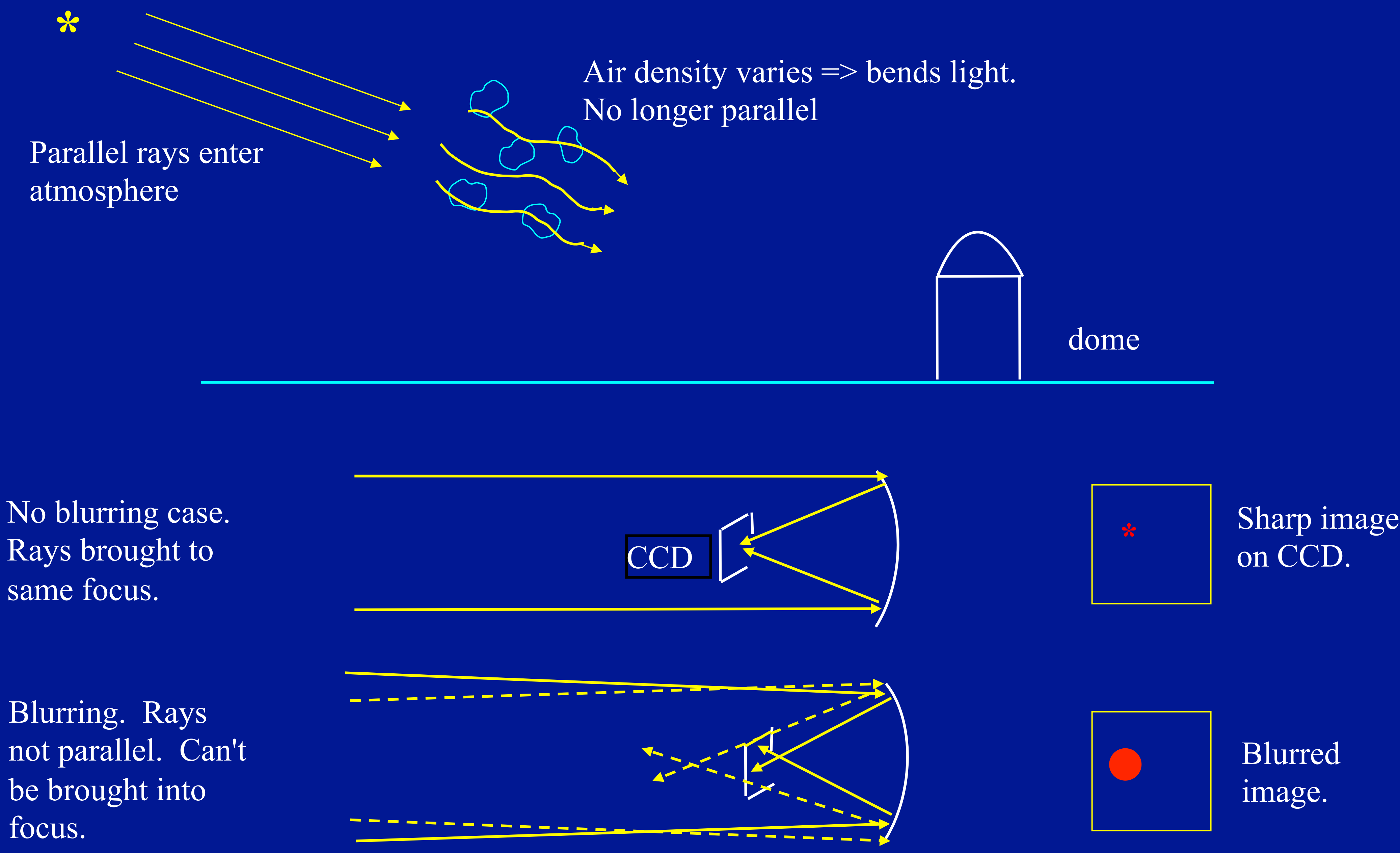
For the eye, this is 1' (1/60th of a degree). Looking at the Moon, you can distinguish features separated by > 100 km.

$$\text{angular resolution} \propto \frac{\text{wavelength}}{\text{mirror diameter}}$$

For a 2.5-m telescope observing light at 5000 Angstroms (greenish), resolution = 0.05".

<u>But</u>, blurring by atmosphere limits resolution to about 1" for <u>light</u>. This is called <u>seeing</u> (radio waves, for example, don't get blurred).

Seeing



Air density varies => bends light.
No longer parallel
Parallel rays enter atmosphere
dome
No blurring case. Rays brought to same focus.
CCD
Sharp image on CCD.
Blurring. Rays not parallel. Can't be brought into focus.
Blurred image.

Example: the Moon observed with a 2.5 m telescope

1" => 2 km

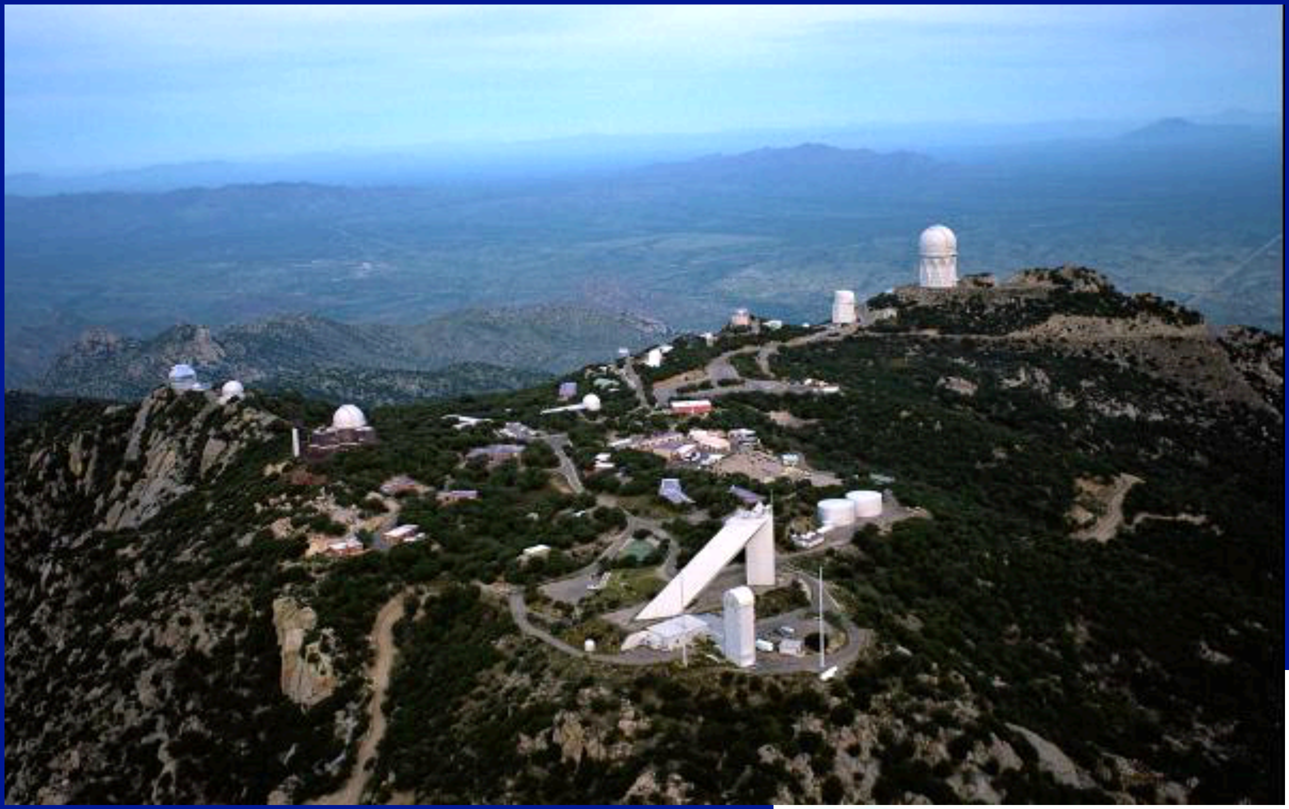
0.05" => 100 m

500 km

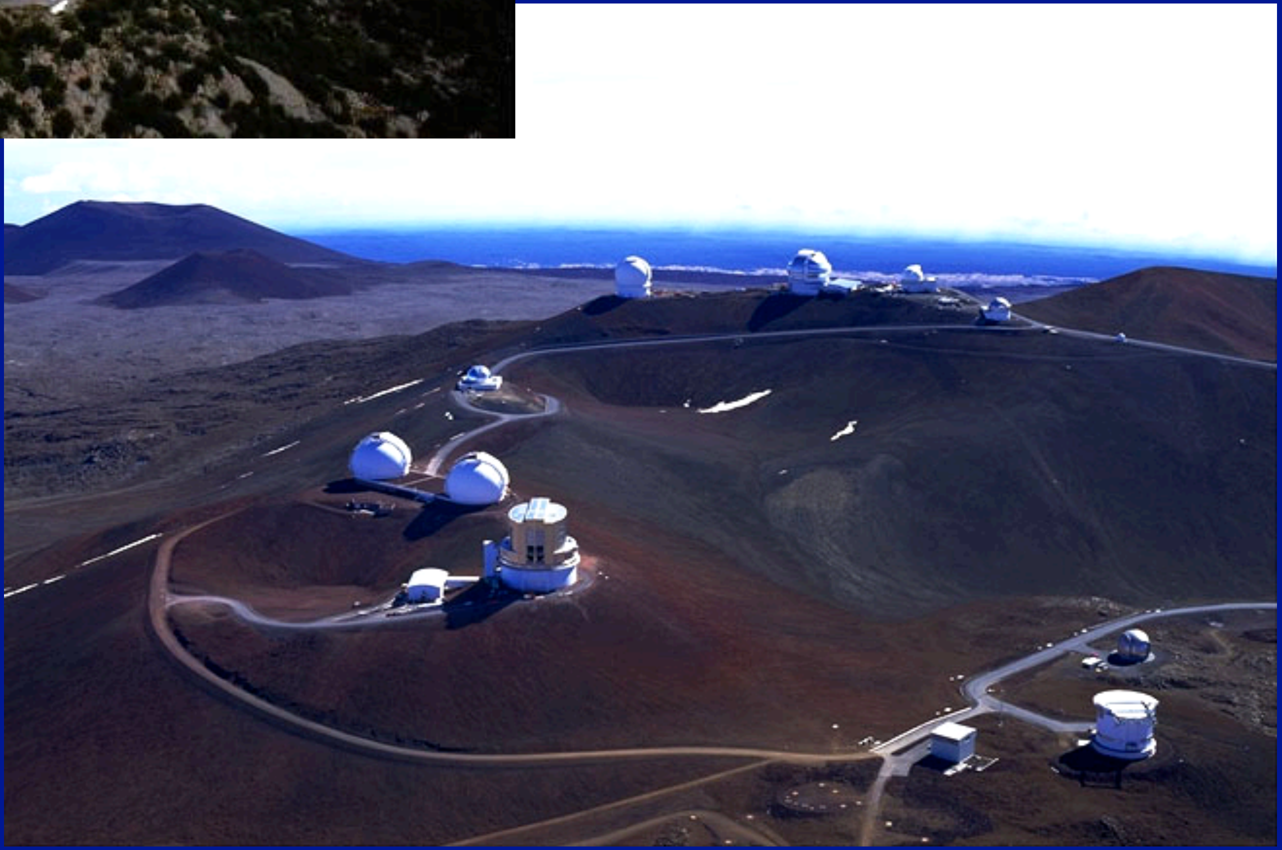
3400 km

North America at night

So where would you put a telescope?



Kitt Peak National Observatory, near Tucson

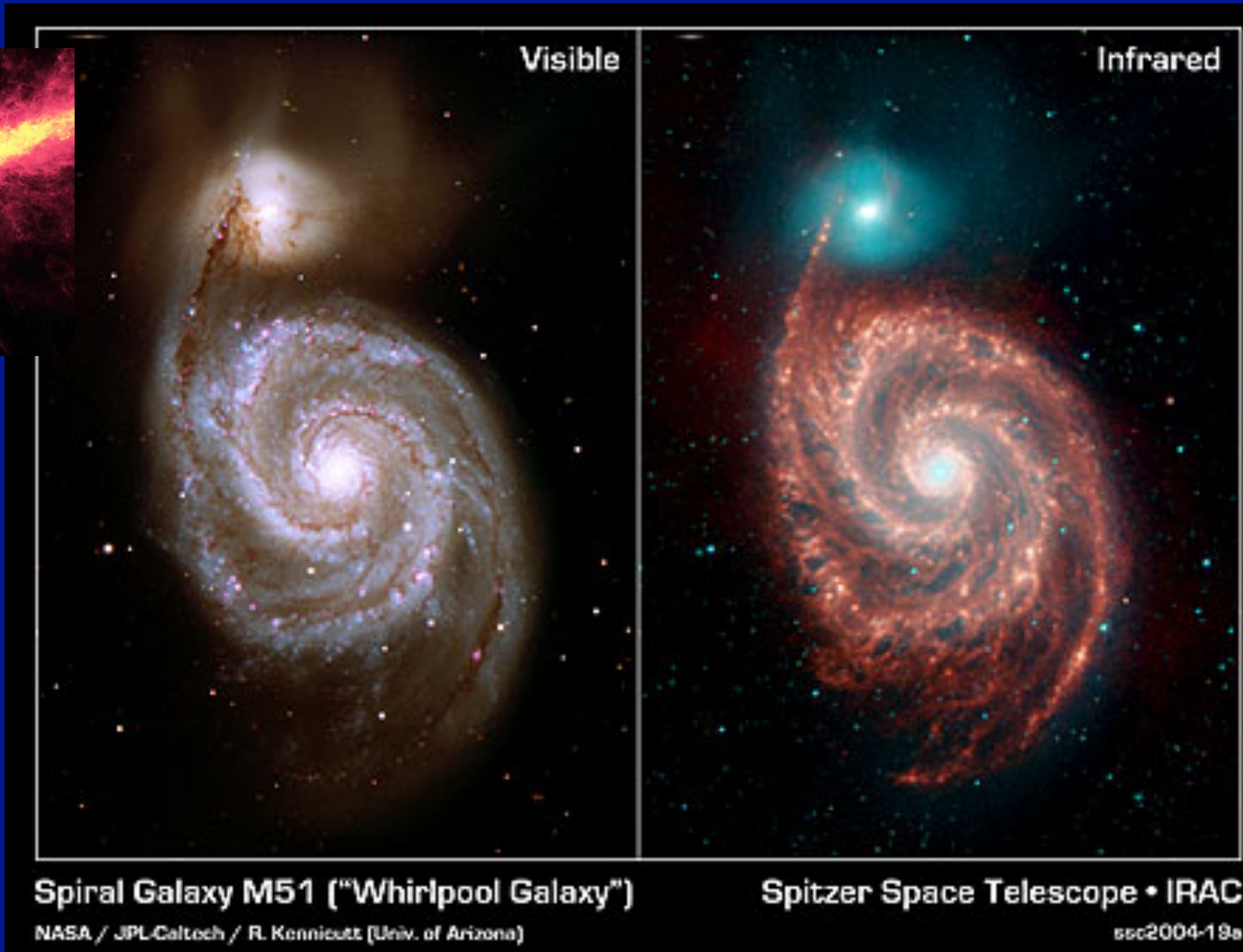


Mauna Kea Observatory, Hawaii

Astronomy at Yet Other Wavelengths

Telescopes also observe infrared, UV, X-rays and gamma rays.
Mostly done from space because of Earth's atmosphere.

Spitzer Space Telescope - infrared



Longer infrared wavelengths allow you to see radiation from warm dust in interstellar gas.

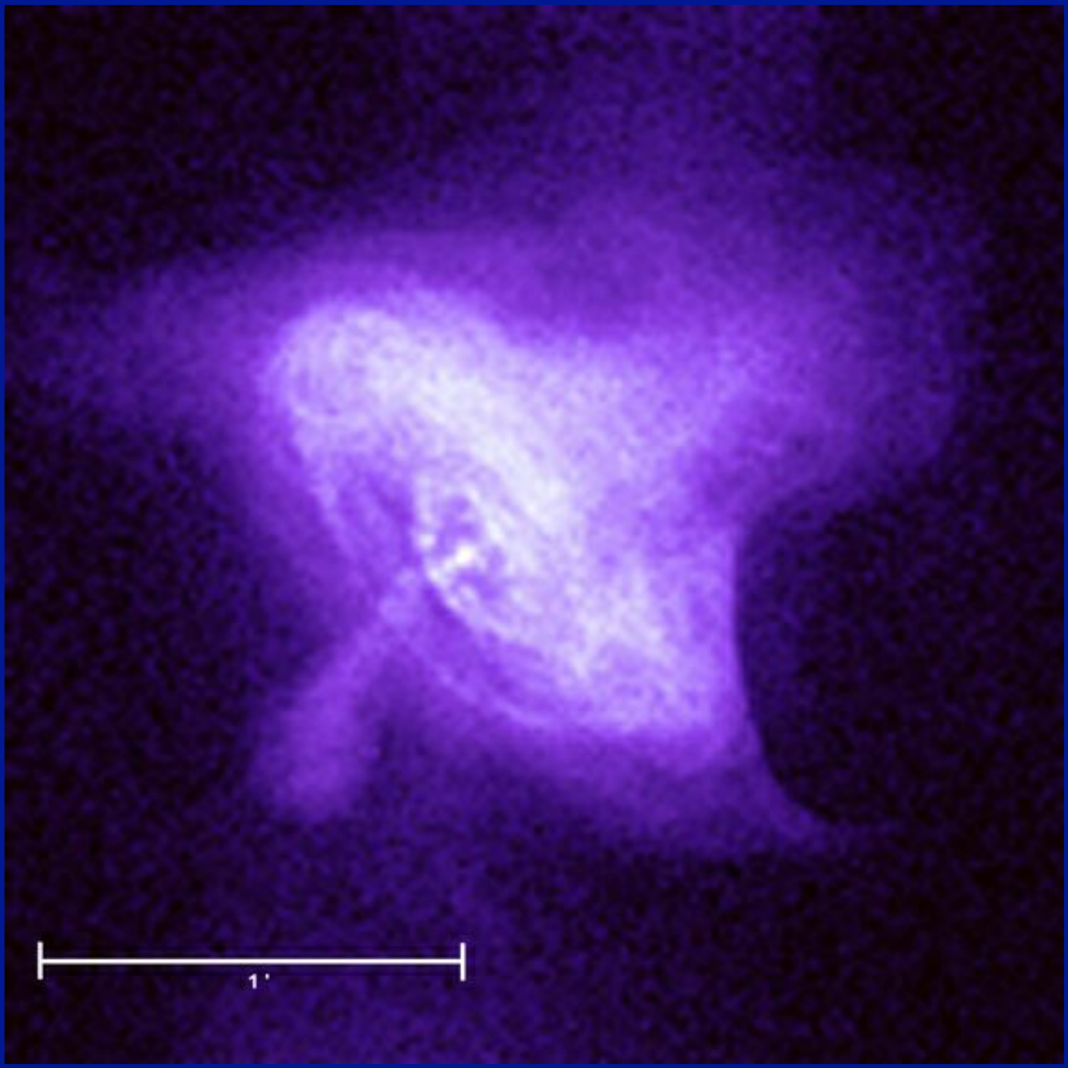
Shorter infrared wavelengths allows you to see stars through dust. Dust is good at blocking visible light but infrared gets through better.

Trifid nebula in visible light

Trifid nebula with Spitzer

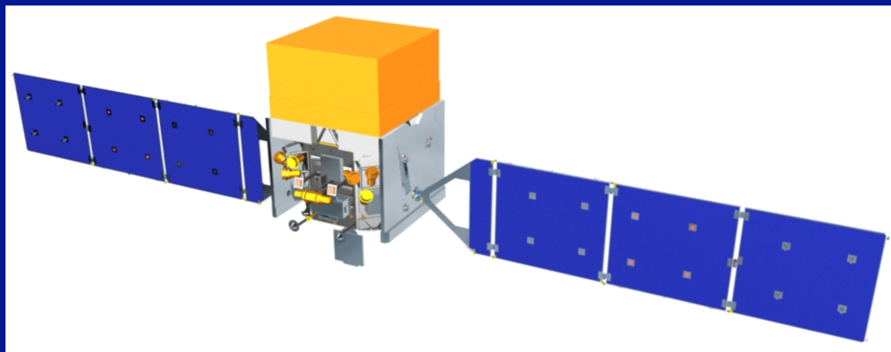
X-ray Astronomy

Chandra X-ray Observatory

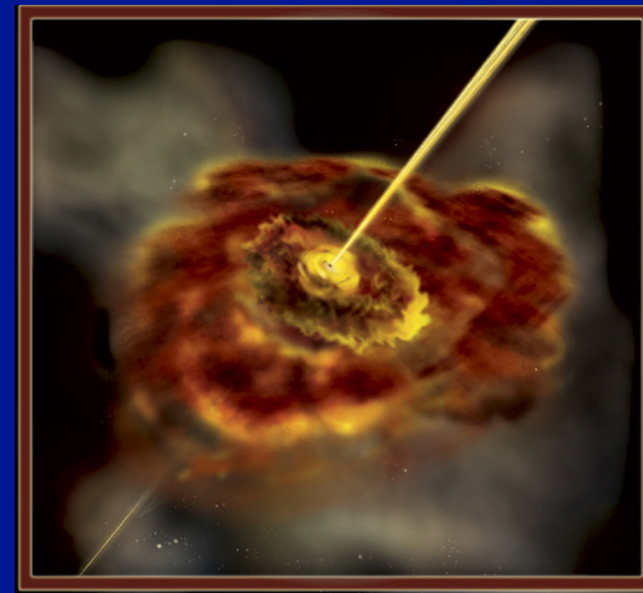


Crab pulsar and nebula in X-rays

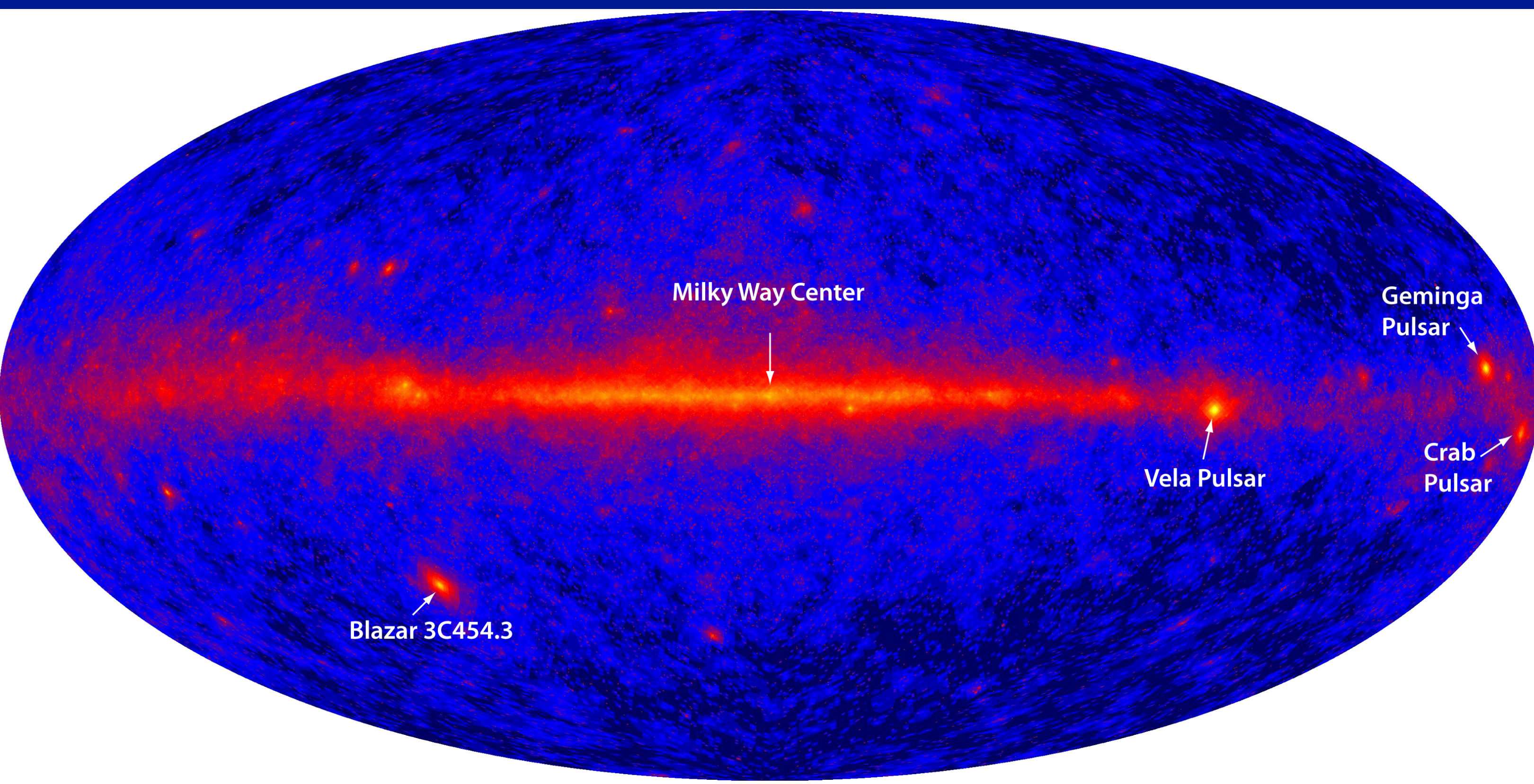
Gamma-ray Astronomy



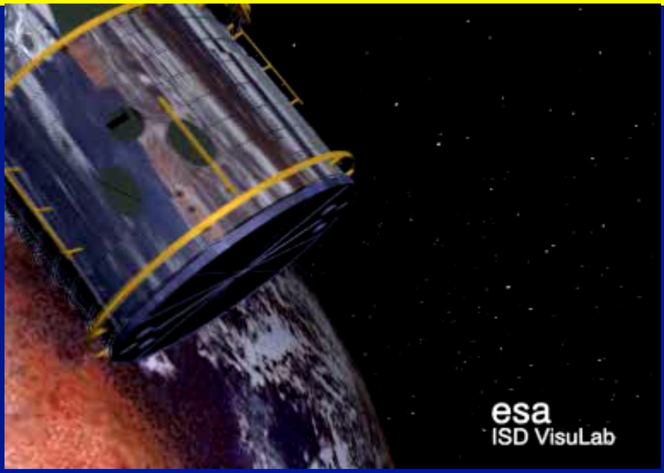
GLAST - Gamma-ray Large Area Space Telescope



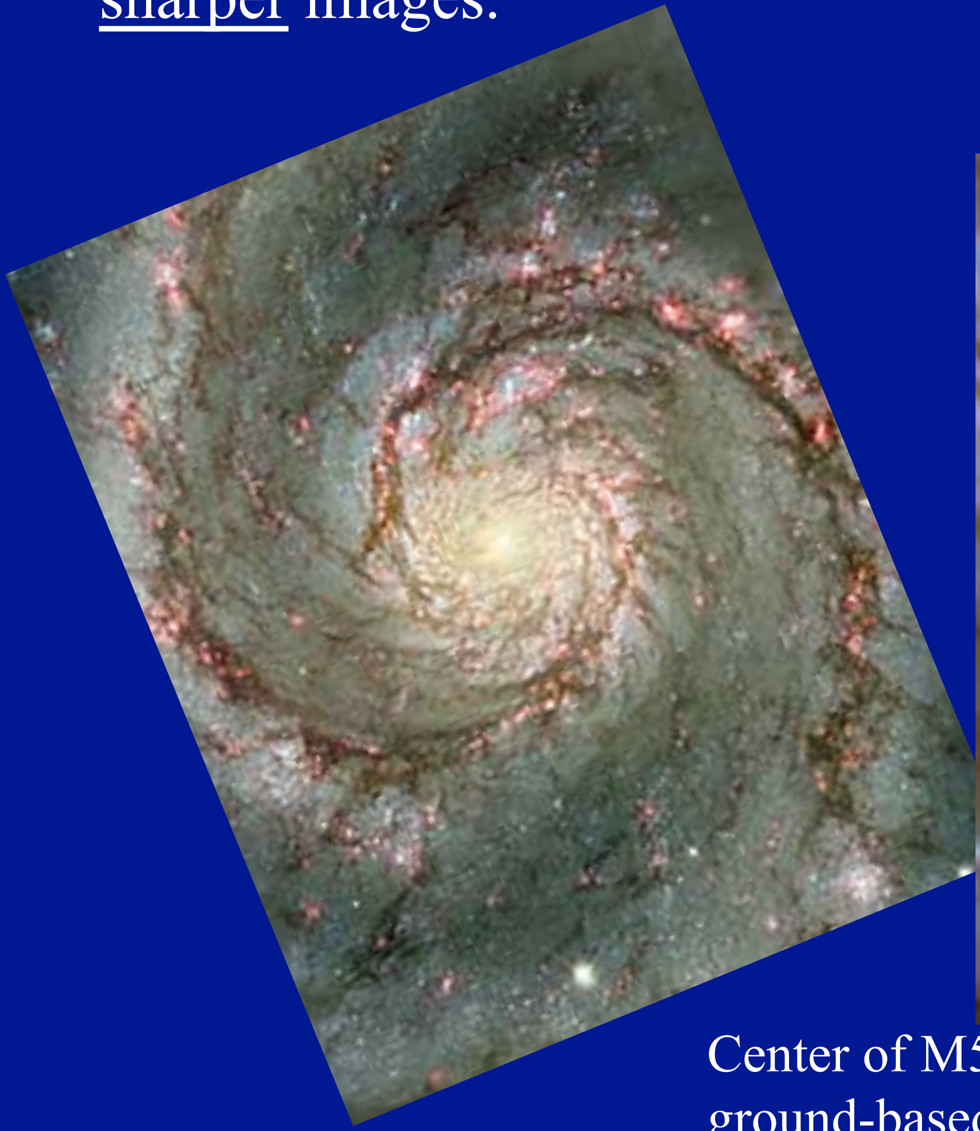
Artists conception of a jet from a blazar



Hubble Space Telescope and its successor-to-be: the James Webb Space Telescope



Advantage of space for optical astronomy: get above blurring atmosphere – much sharper images.



Center of M51: HST (left; 0.05” resolution) vs. ground-based (right; 1” resolution)

The JWST

Will have diameter 6.5 meters (vs. HST 2.5 meters) – much higher resolution and sensitivity. Will also observe infrared, whereas Hubble is best at visible light. Expected launch Oct. 2018

Radio Telescopes

Large metal dish acts as a mirror for radio waves. Radio receiver at focus.

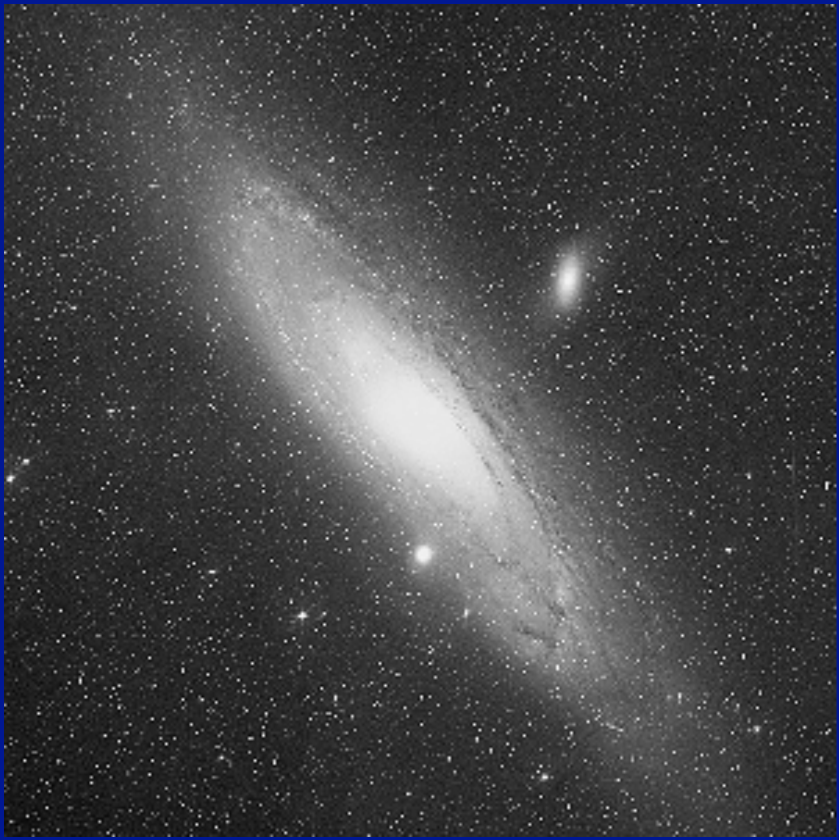
Surface accuracy not so important, so easy to make large one.

Jodrell Bank 76-m (England)

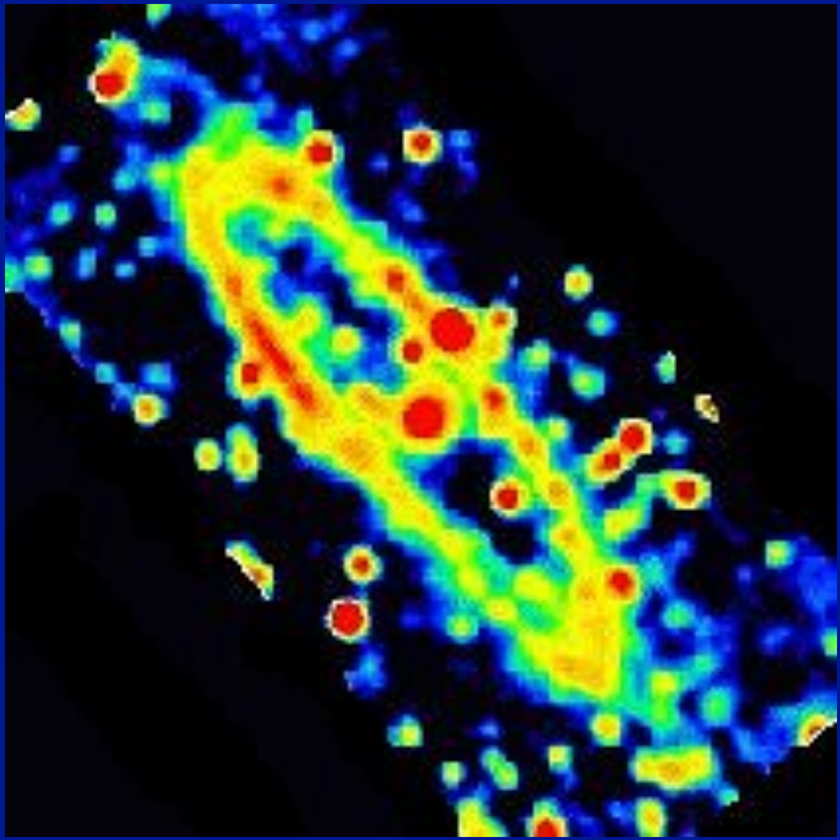
But angular resolution is poor. Remember:

$$\text{angular resolution} \propto \frac{\text{wavelength}}{\text{mirror diameter}}$$

D larger than optical case, but wavelength <u>much</u> larger (cm's to m's), e.g. for wavelength = 1 cm, diameter = 100 m, resolution = 20".



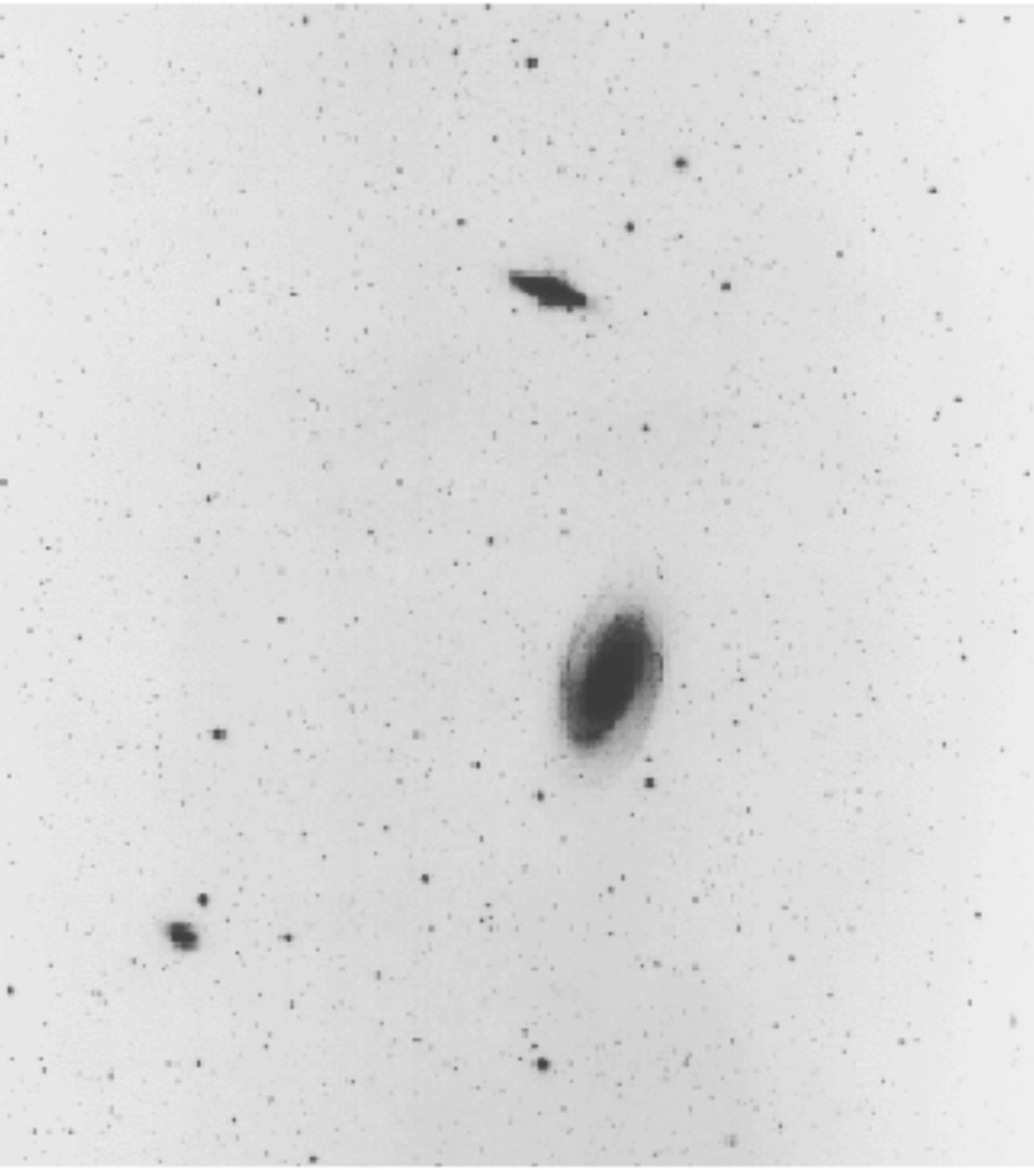
Andromeda galaxy –
optical



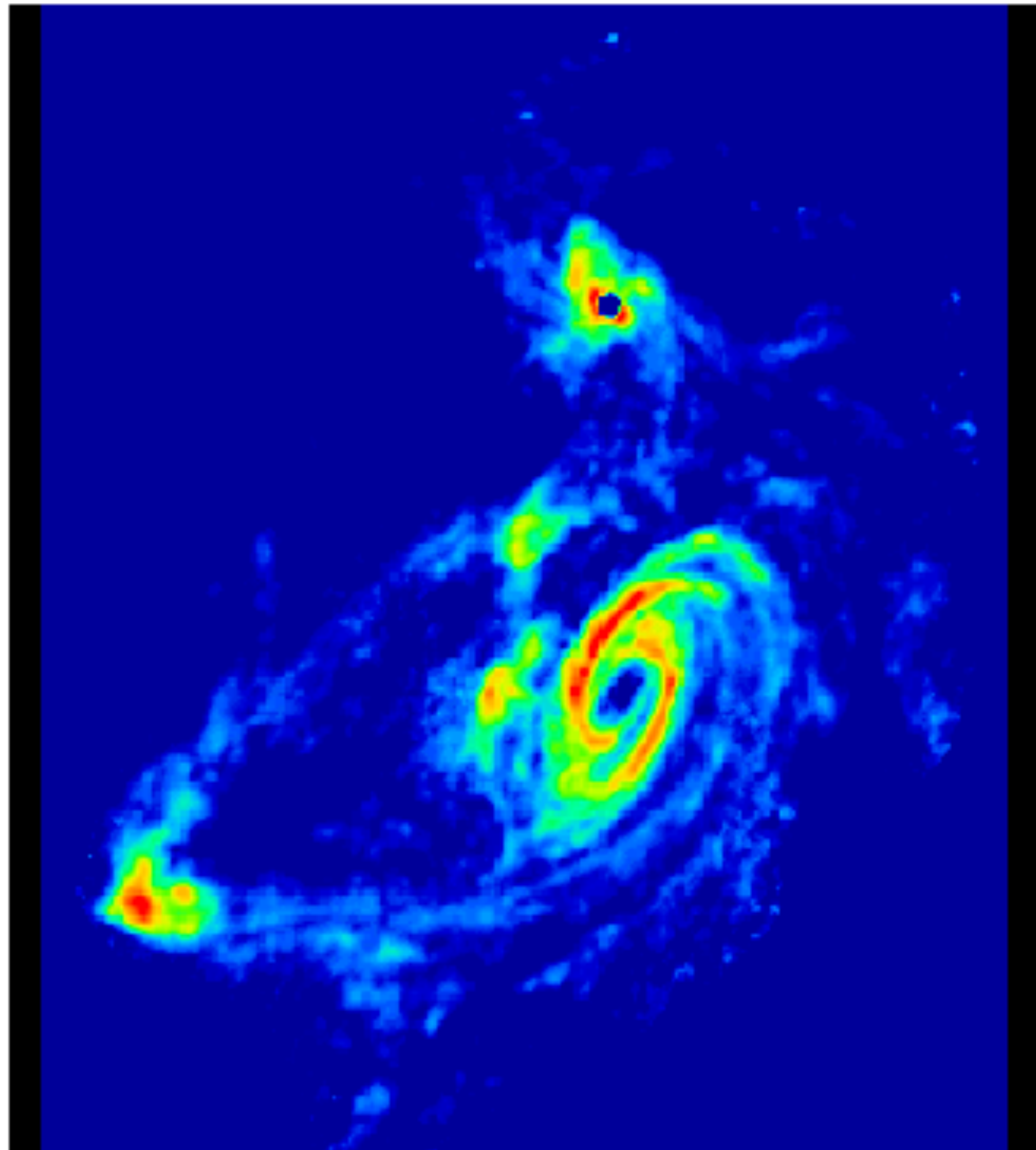
Andromeda radio map with
100m Effelsberg telescope

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution

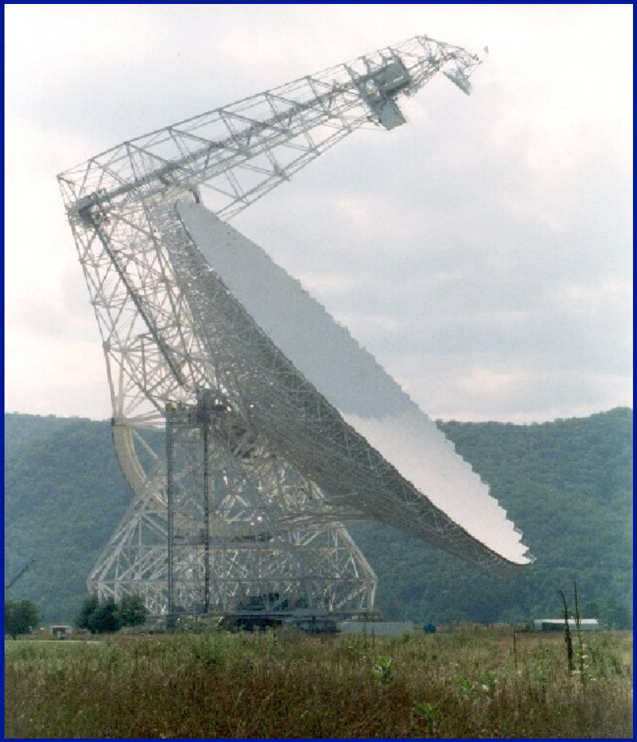


21cm HI Distribution



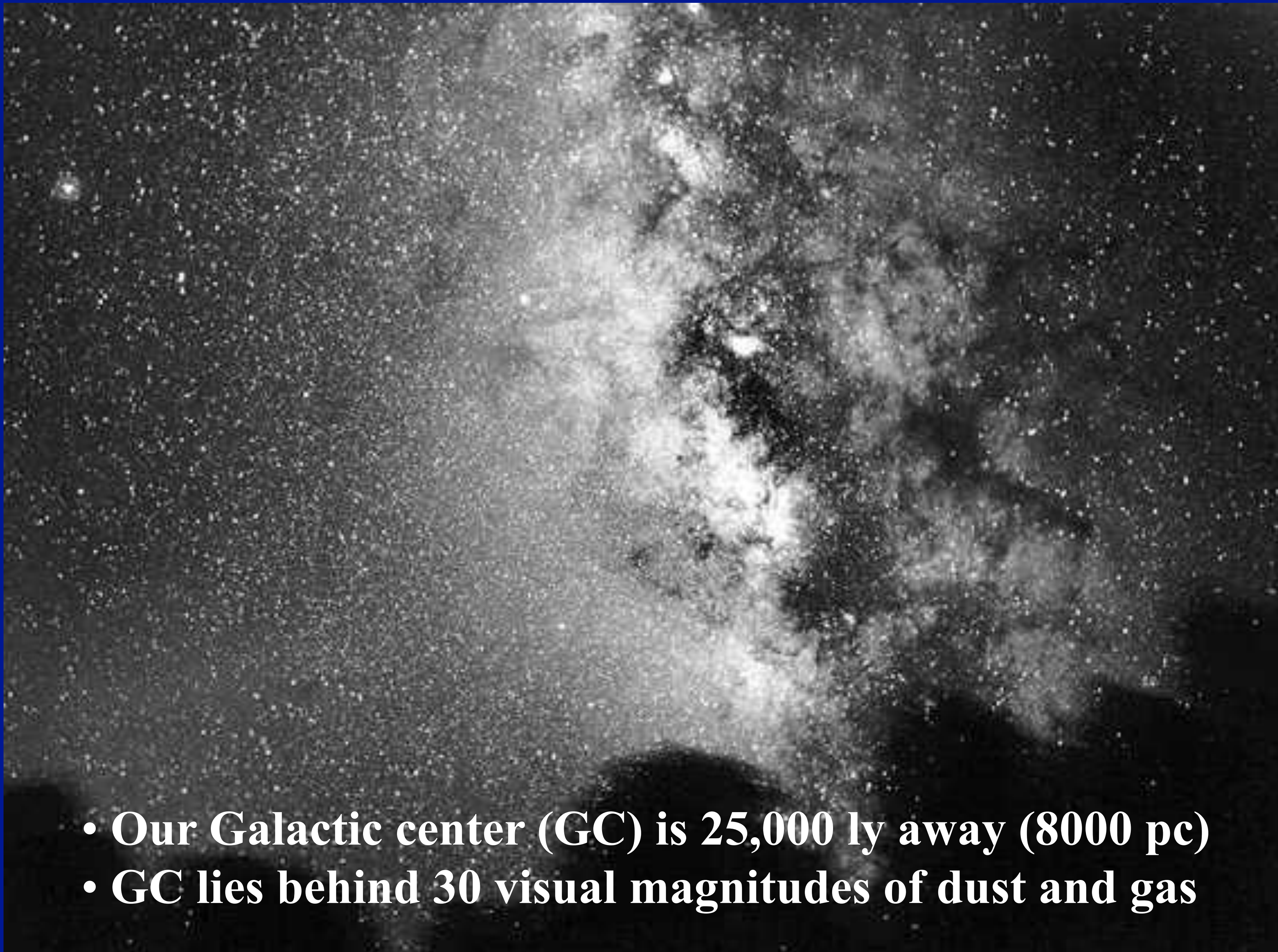
Parkes 64-m (Australia)

Effelsberg 100-m (Germany)



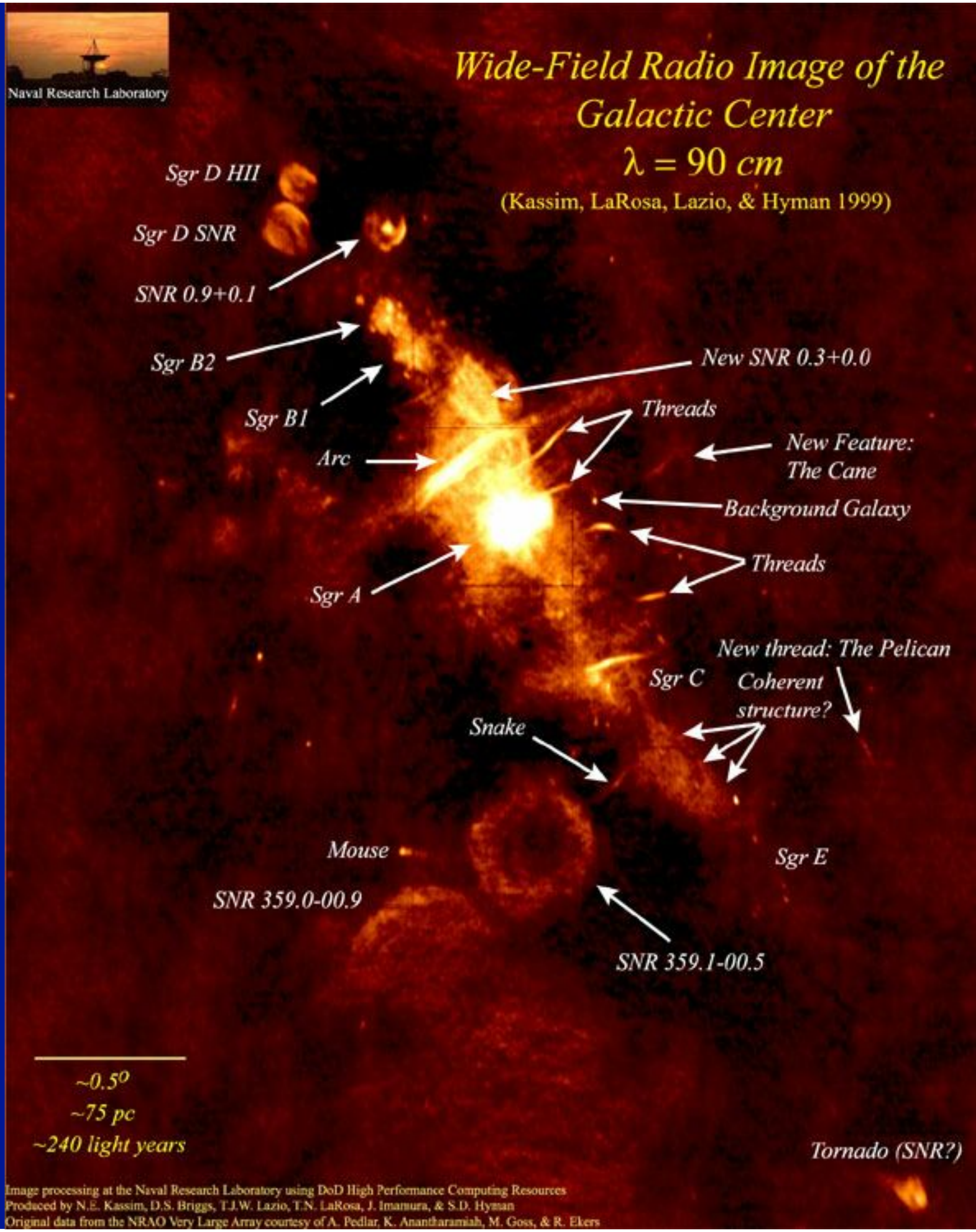
Green Bank 105-m telescope (WV)

Arecibo 300-m telescope (Puerto Rico)



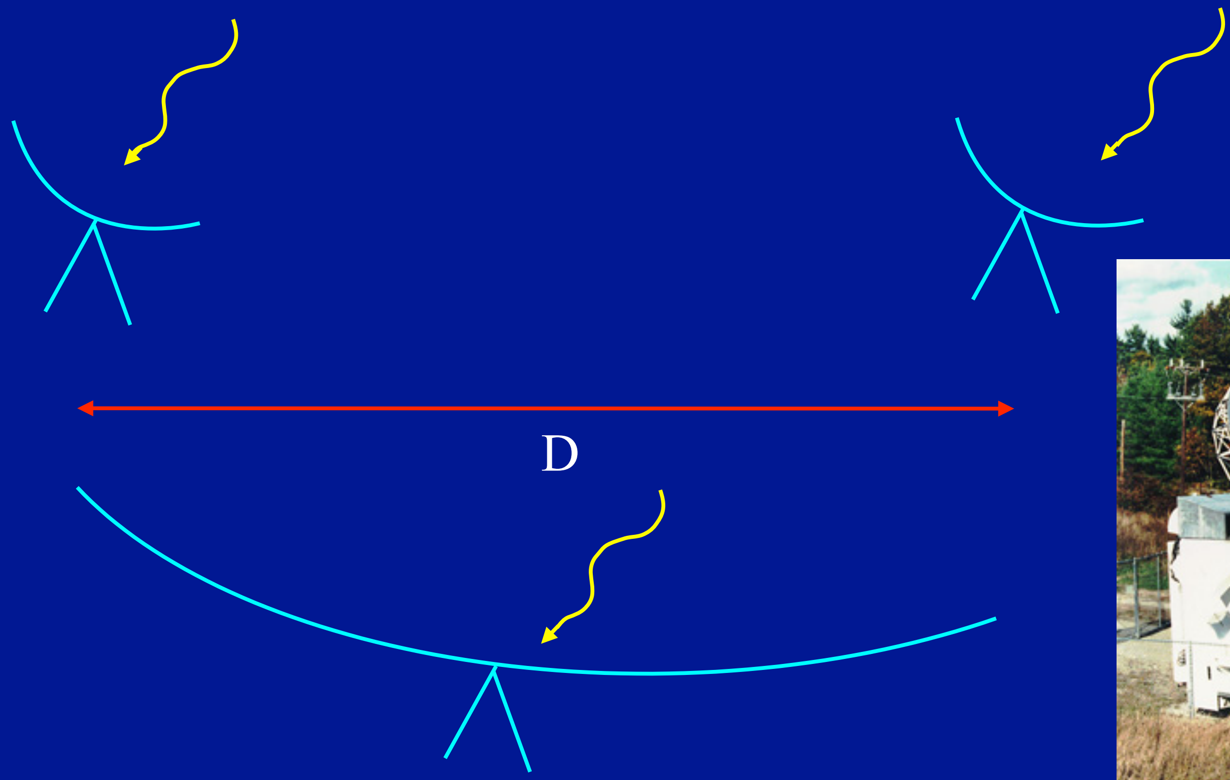
- Our Galactic center (GC) is 25,000 ly away (8000 pc)
- GC lies behind 30 visual magnitudes of dust and gas

VLA image at
λ=90 cm
~45” resolution
inner few degrees
of the Galaxy



Interferometry

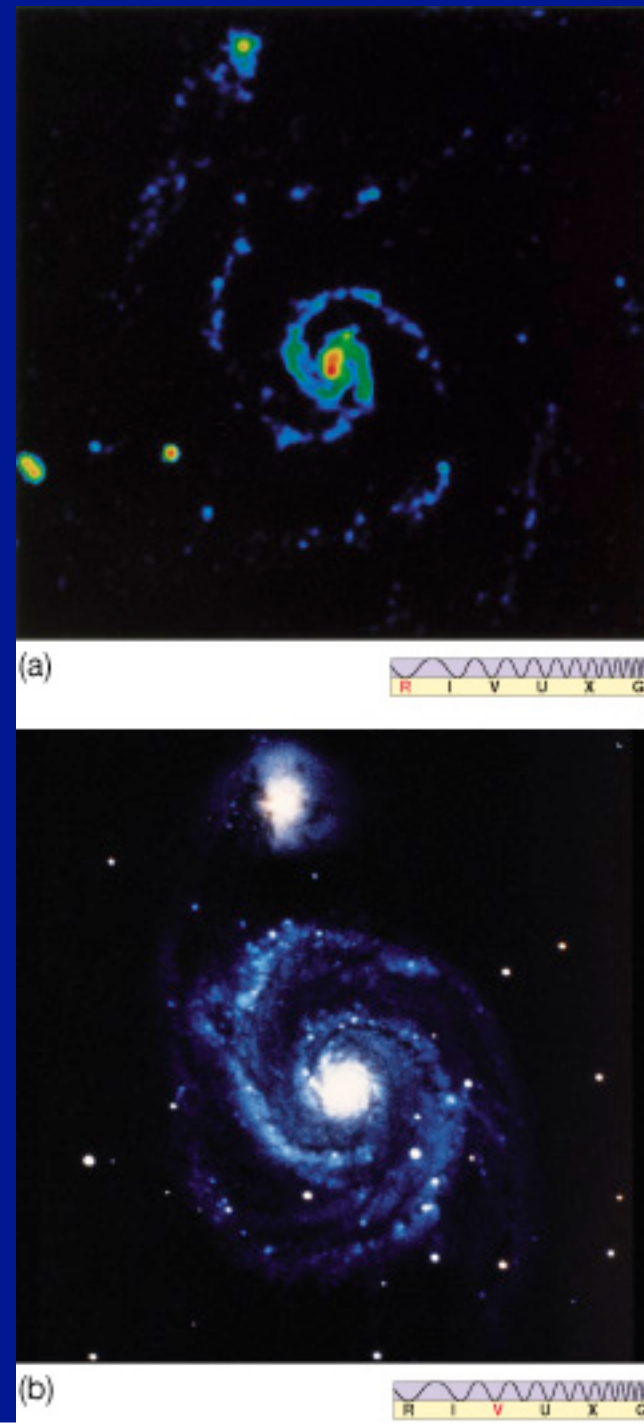
A technique to get improved angular resolution using an array of telescopes. Most common in radio, but also limited optical interferometry.



Consider two dishes with <u>separation</u> D vs. one dish of <u>diameter</u> D. By combining the radio waves from the two dishes, the achieved angular resolution is the same as the large dish.

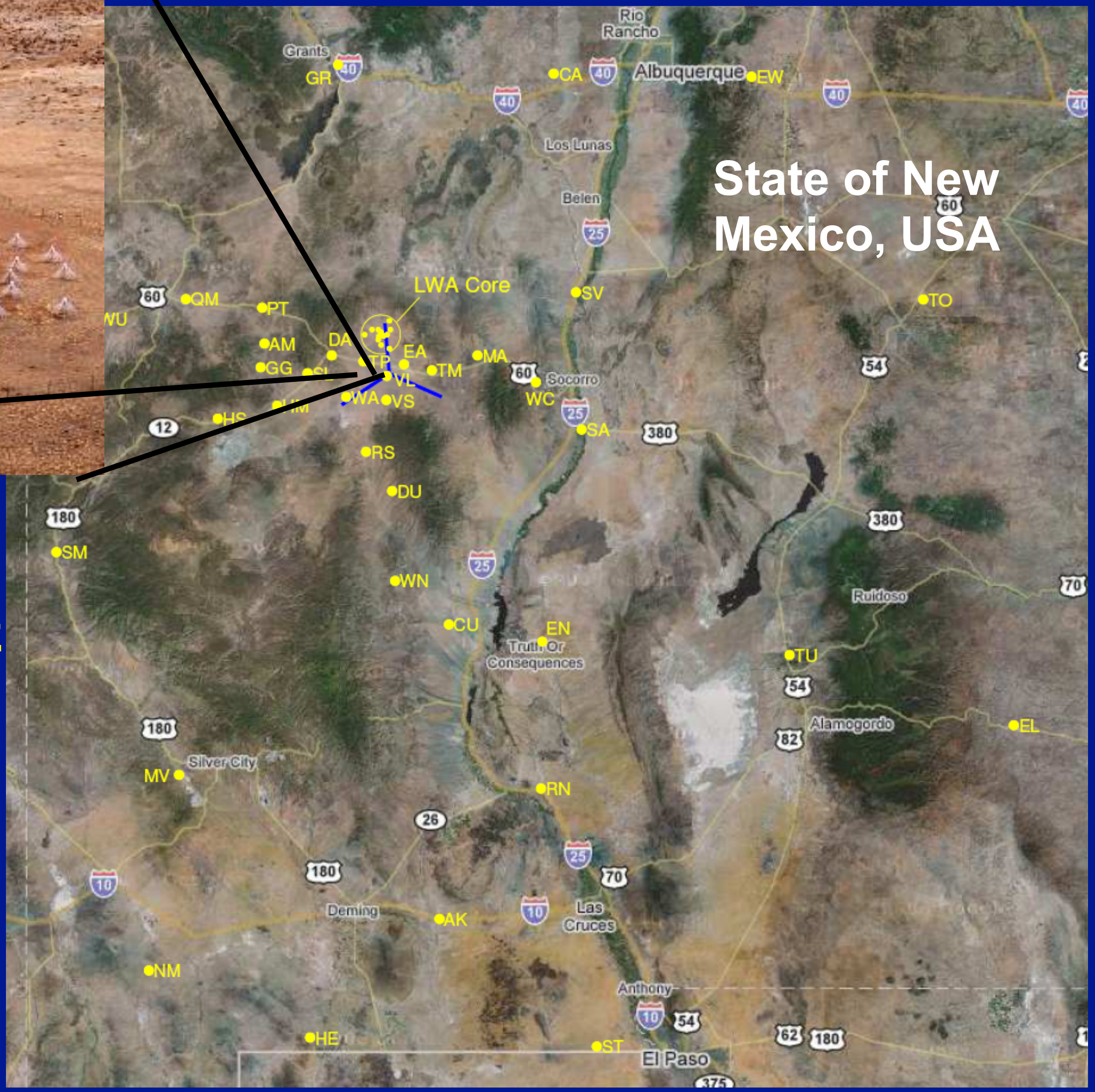
Example: wavelength = 5 cm, separation = 2 km, resolution = 5"

Very Large Array (NM). Maximum separation of dishes: 30 km



VLA and optical images of M51

Long Wavelength Array (LWA)



Frequency Range: 10-88 MHz
4 beams x 2 pol. x 2 tunings x 19 MHz
Also, 2 all-sky transient obs. modes

First station ("LWA-1") completed Jan 2011, LWA-SV almost finished.

Ultimately, 53 stations with baselines up to 400 km for resolution [8,2]" @ [20,80] MHz with mJy-class sensitivity

Clicker Question:

The biggest telescopes on Earth are:

A: Gamma-ray telescopes.

B: X-ray telescopes.

C: Optical telescopes

D: Radio telescopes

E: Infra-red telescopes

Clicker Question:

When multiple radio telescopes are used for interferometry, resolving power is most improved by *increasing*:

A: the distance between telescopes;

B: the number of telescopes in a given area;

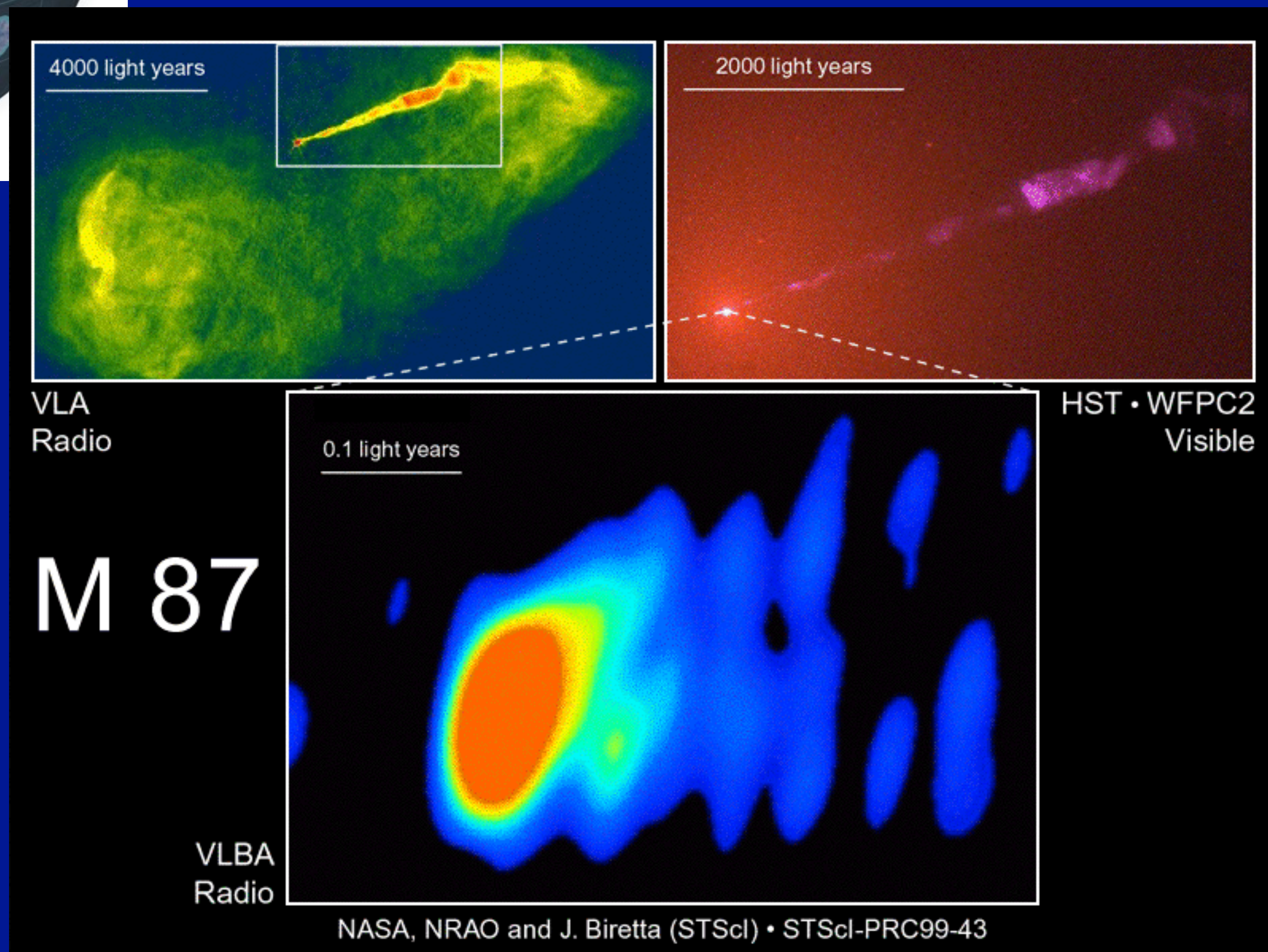
C: the diameter of each telescope;

D: the power supplied to each telescope

Very Long Baseline Array. Maximum separation 1000's of km

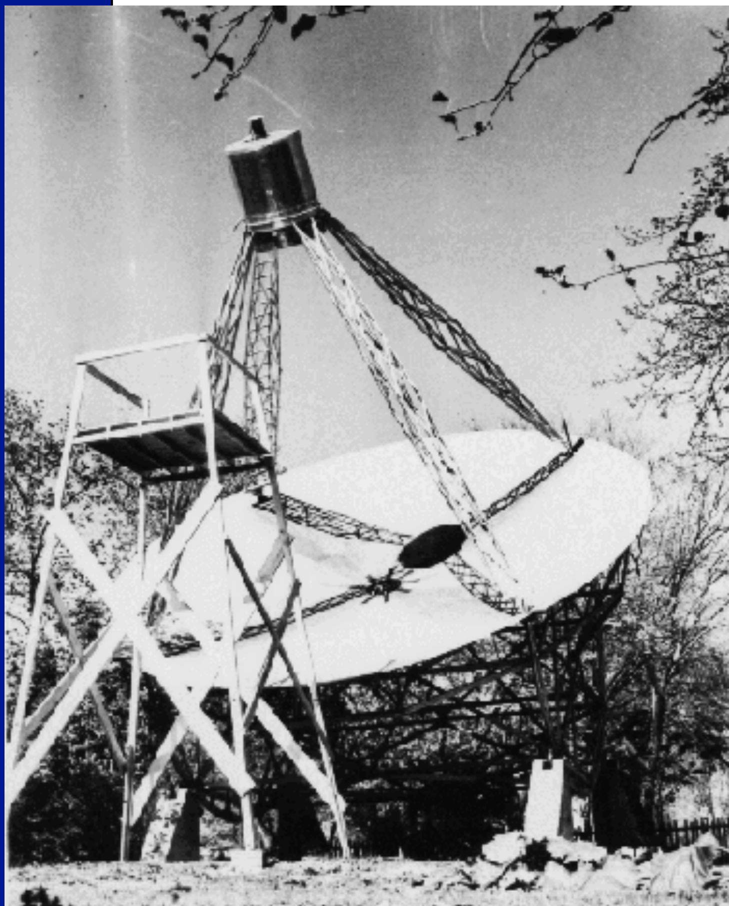
resolution: few arcsec

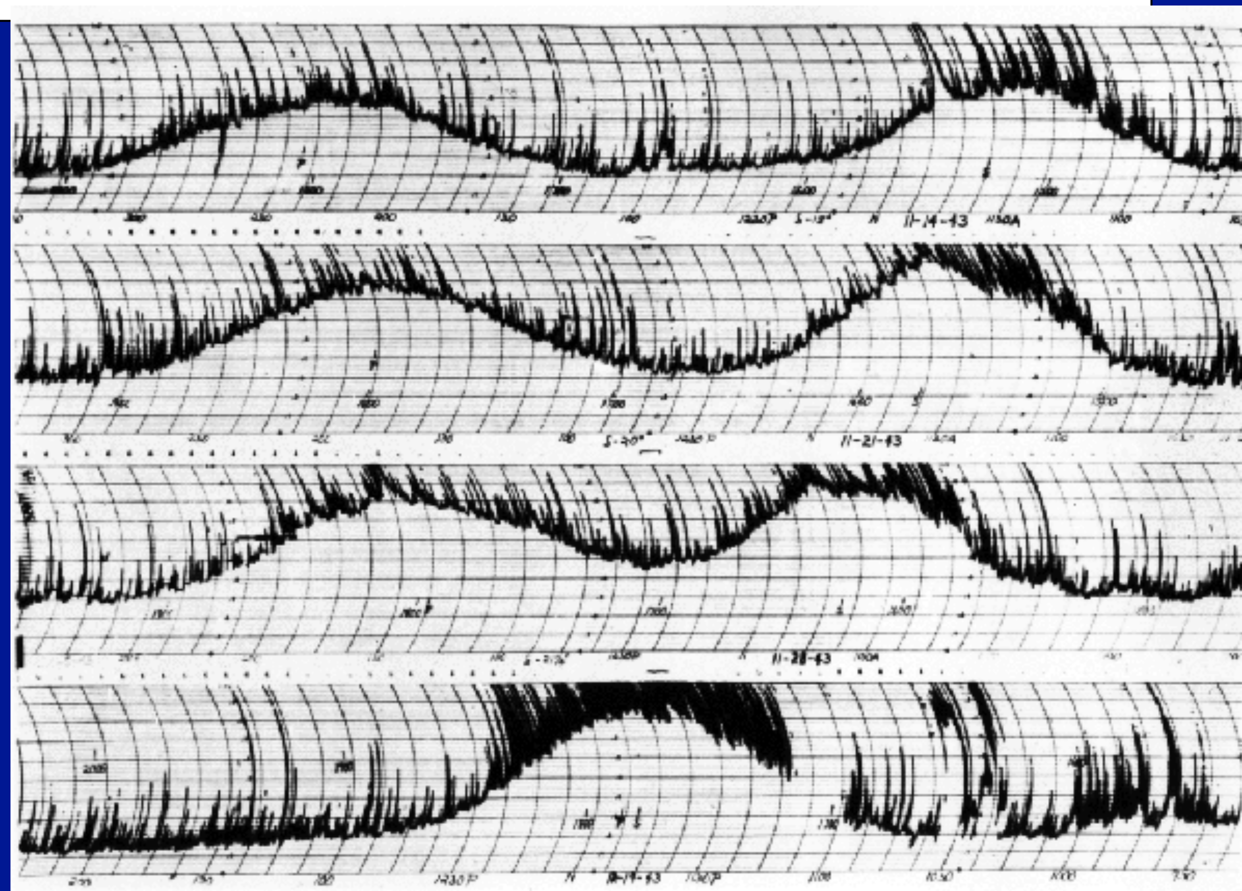
resolution: 0.05 arcsec



resolution: 0.001 arcsec!

Radio Frequency Interference





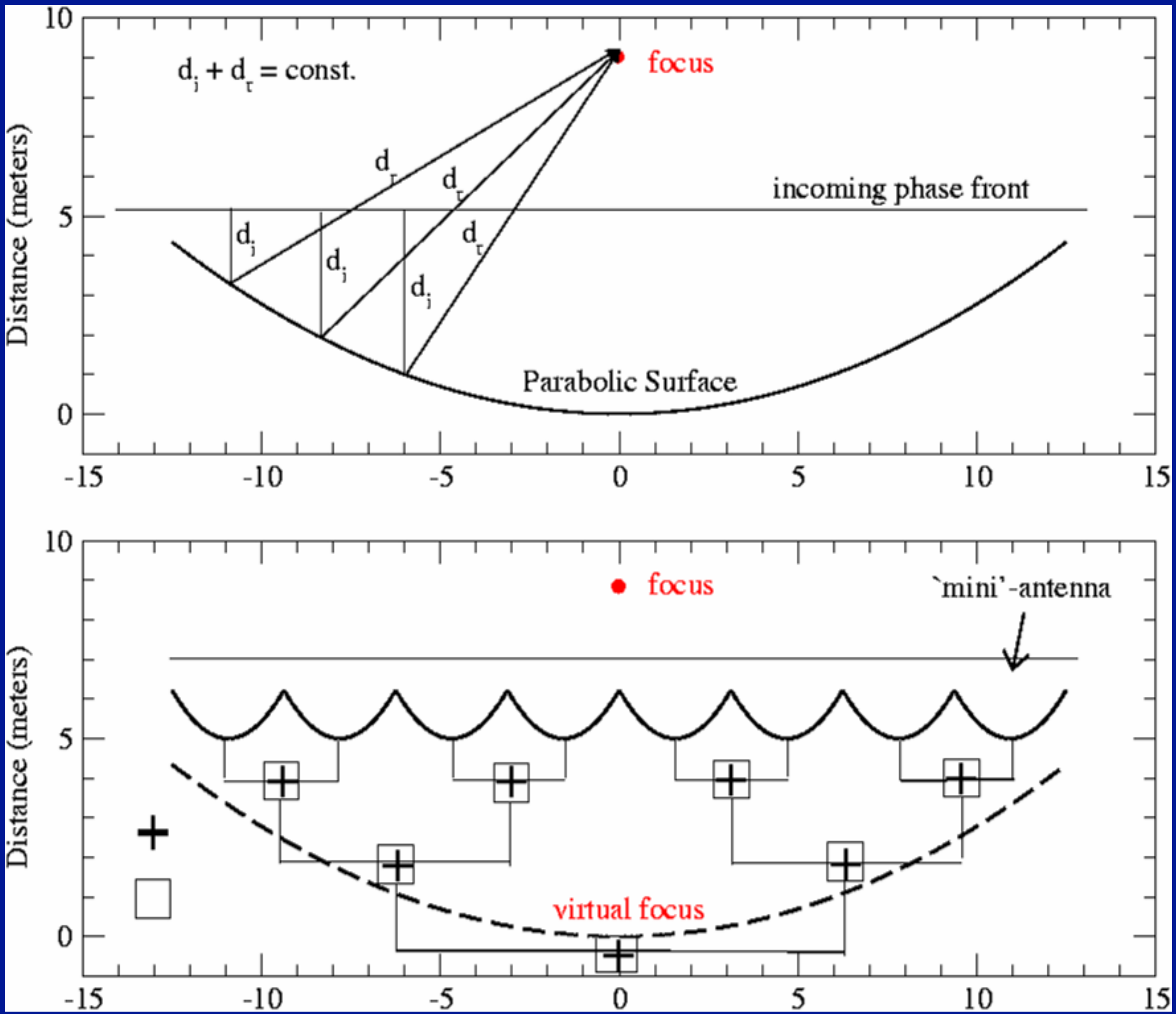
Grote Reber’s telescope and Radio Frequency Interference in 1938

Aperture Synthesis – Basic Concept

If the source emission is unchanging, there is no need to collect all of the incoming rays at one time.

One could imagine sequentially combining pairs of signals. If we break the aperture into N sub-apertures, there will be N(N−1)/2 pairs to combine.

This approach is the basis of aperture synthesis.



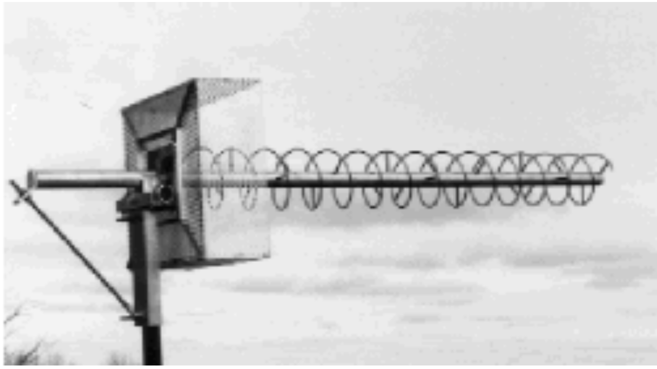
General Antenna Types

Wavelength > 1 m (approx)

Wire Antennas

Dipole

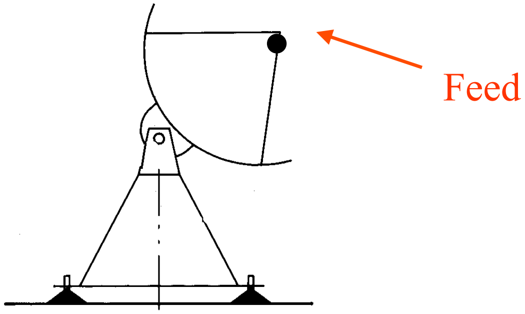
Yagi



Helix

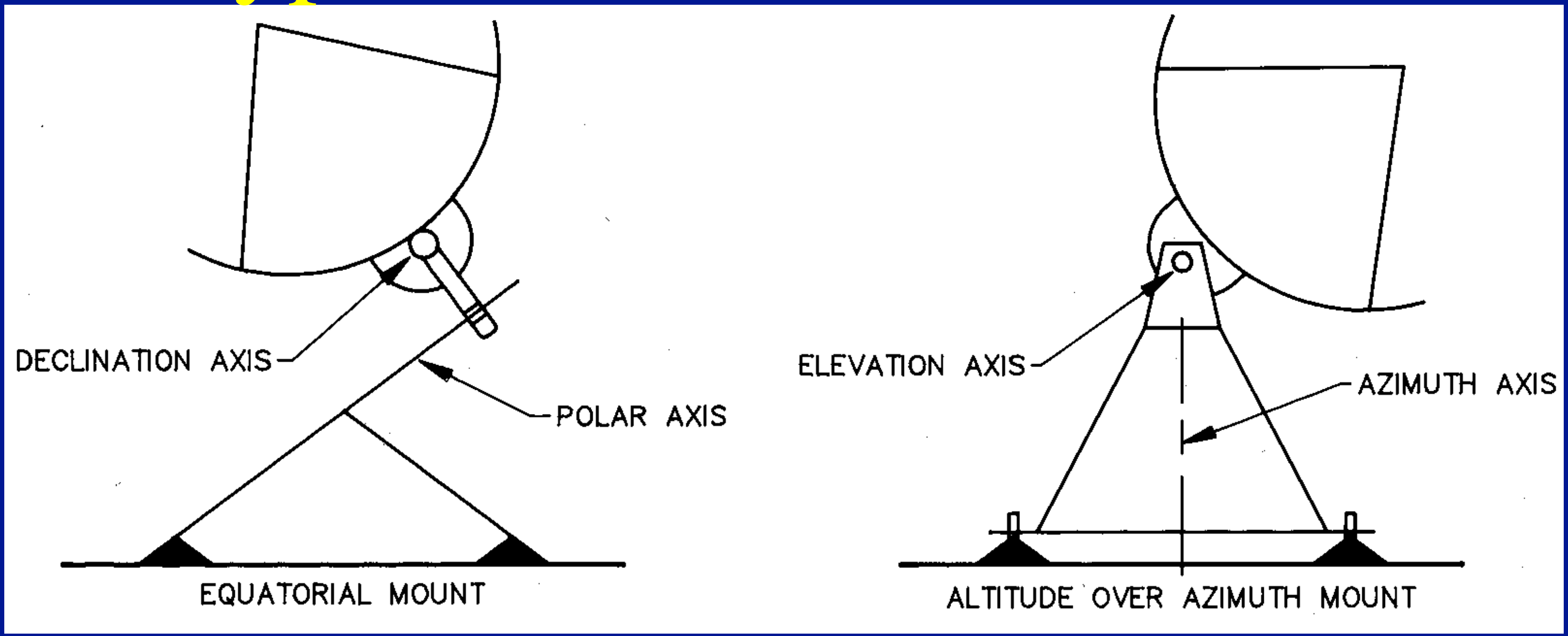
or arrays of these

Wavelength < 1 m (approx)



Reflector antennas

Types of Antenna Mount



+ Beam does not rotate
+ Better tracking accuracy
− Higher cost
− Poorer gravity performance

+ Lower cost
+ Better gravity performance
− Beam rotates on the sky