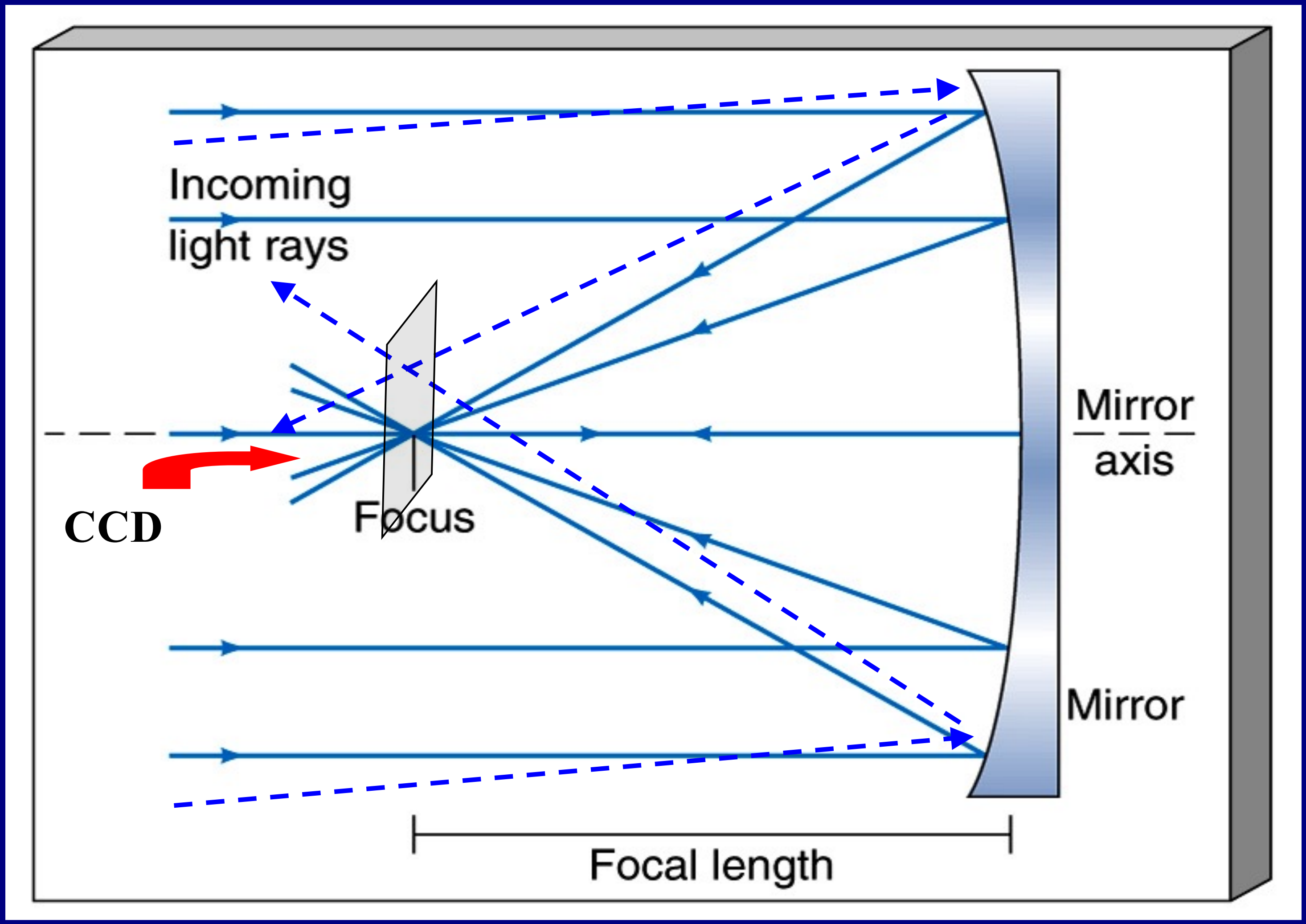
Telescopes

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

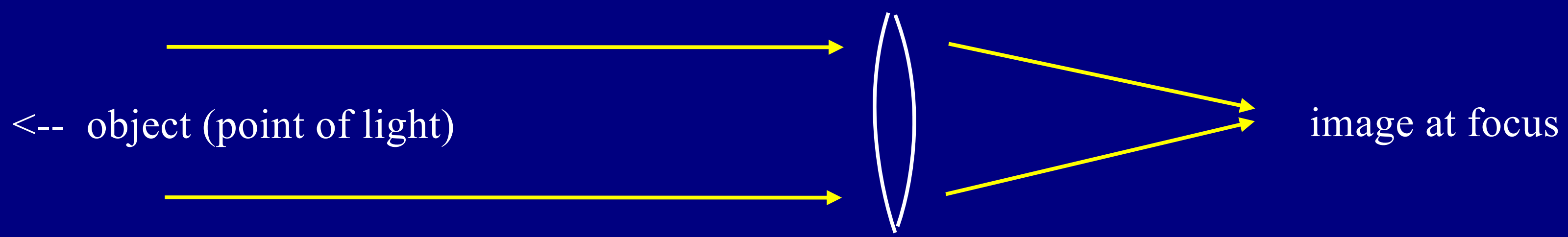


Parallel light rays at another angle meet at another point in same vertical plane, the “focal plane”.

Optical Telescopes - Refracting vs. Reflecting

Refracting telescope

Focuses light with a lens (like a camera).

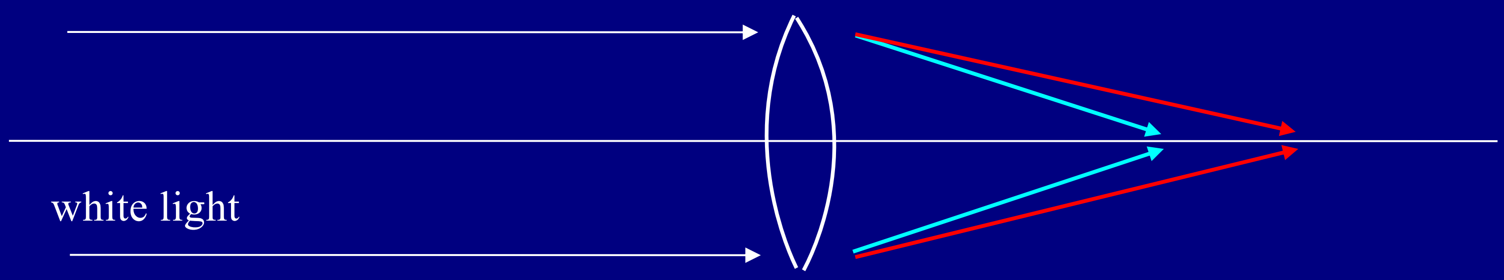


Problems:

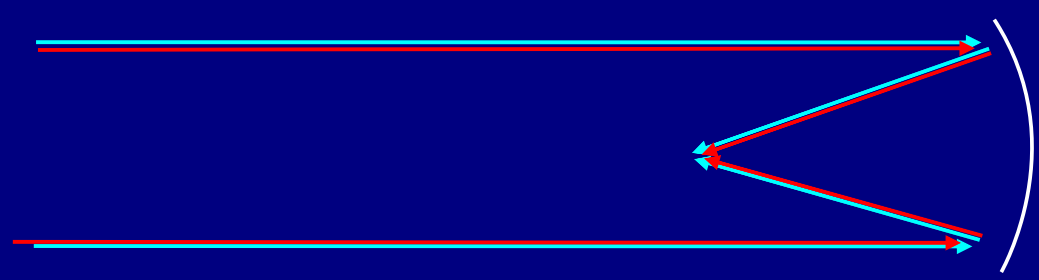
- Lens can only be supported around edge.
- "Chromatic aberration".
- Some light absorbed in glass (especially UV, infrared).
- Air bubbles and imperfections affect image quality.

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

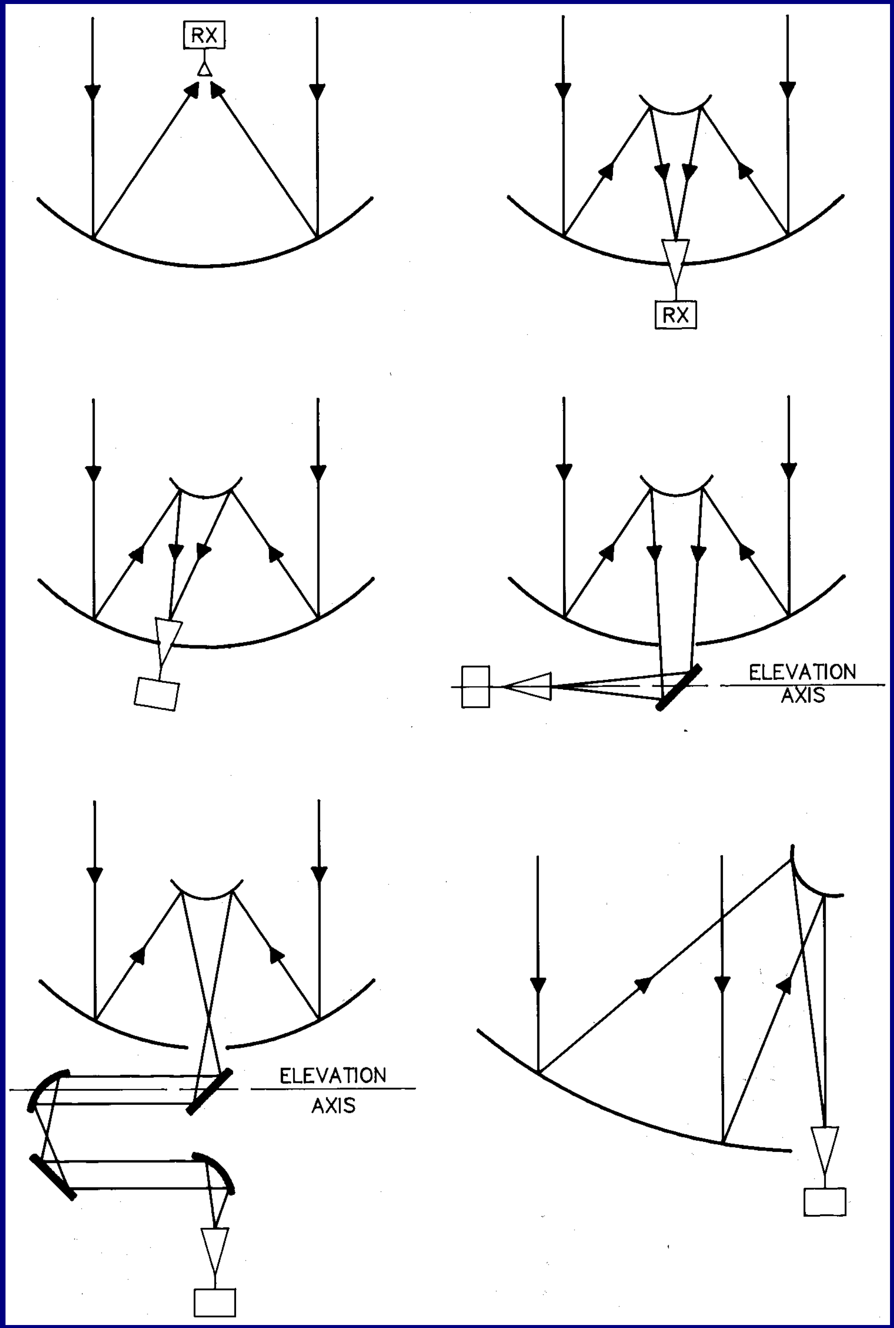
Cassegrain focus

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)

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.

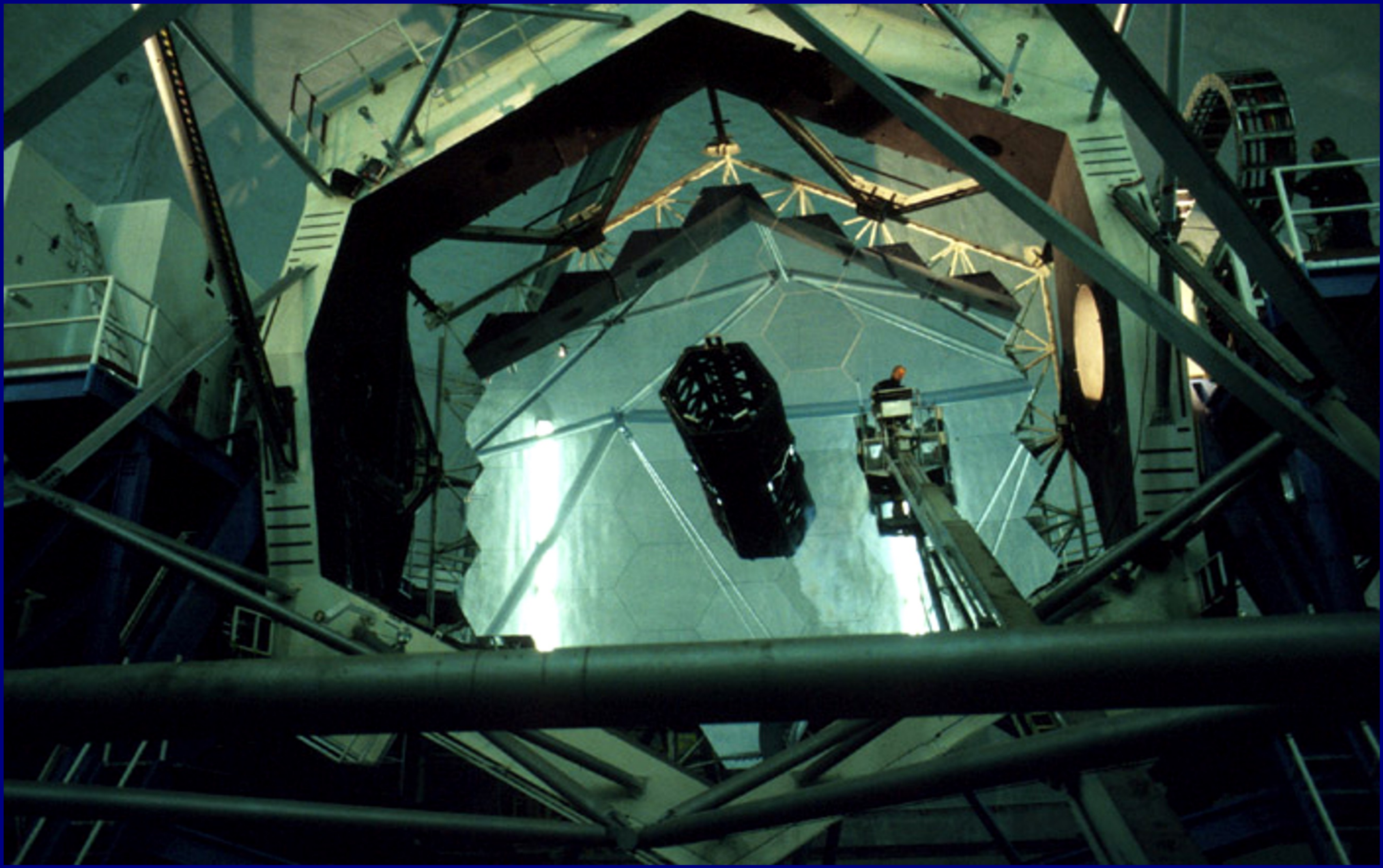
C: They don’t suffer from chromatic aberration

D: They don’t suffer from altitude sickness

E: All of the above

Mirror size

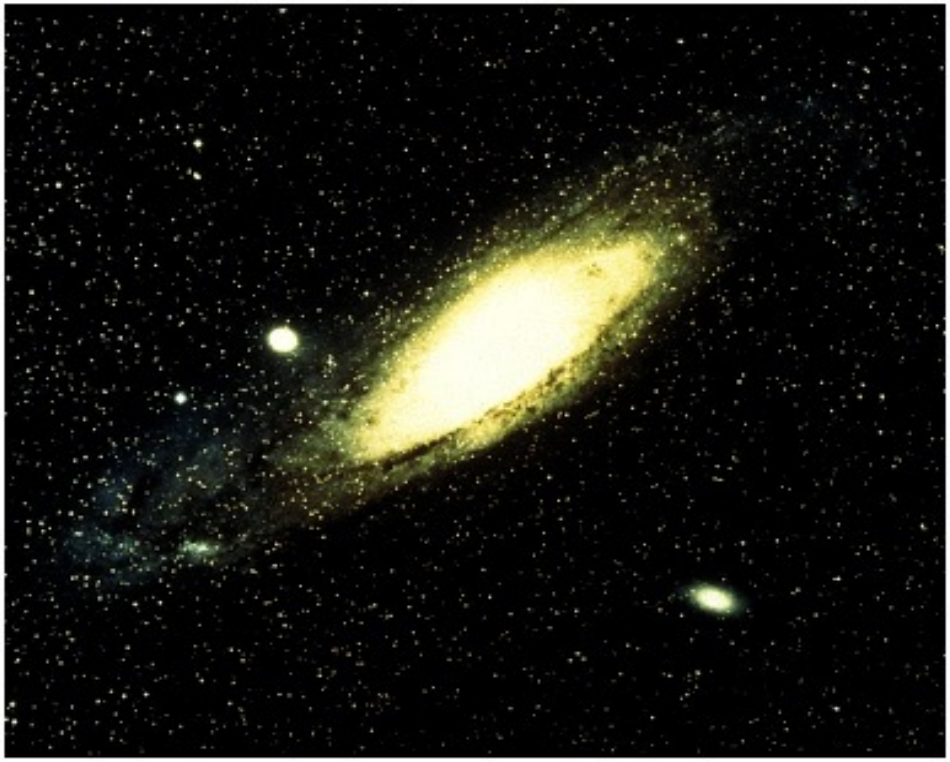
Mirror with larger area captures more light from a cosmic object. Can look at fainter objects with it.

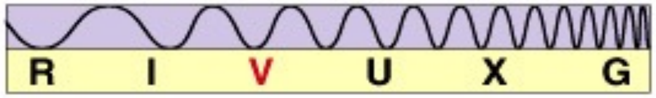


Keck 10-m optical telescope.
30 m optical telescopes are now under construction!

Image of Andromeda galaxy with optical telescope.

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



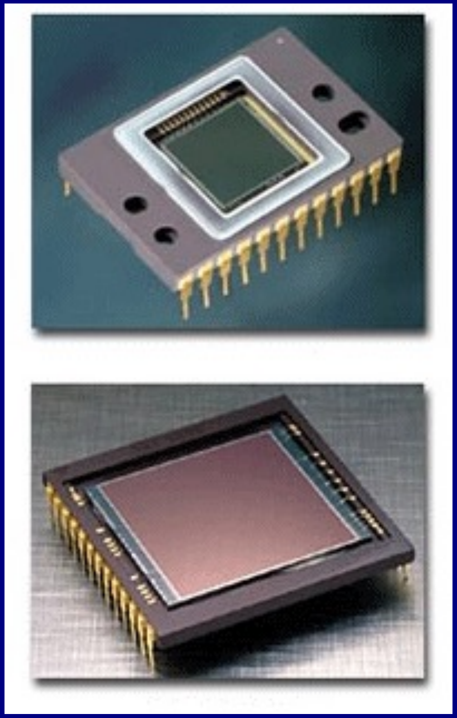


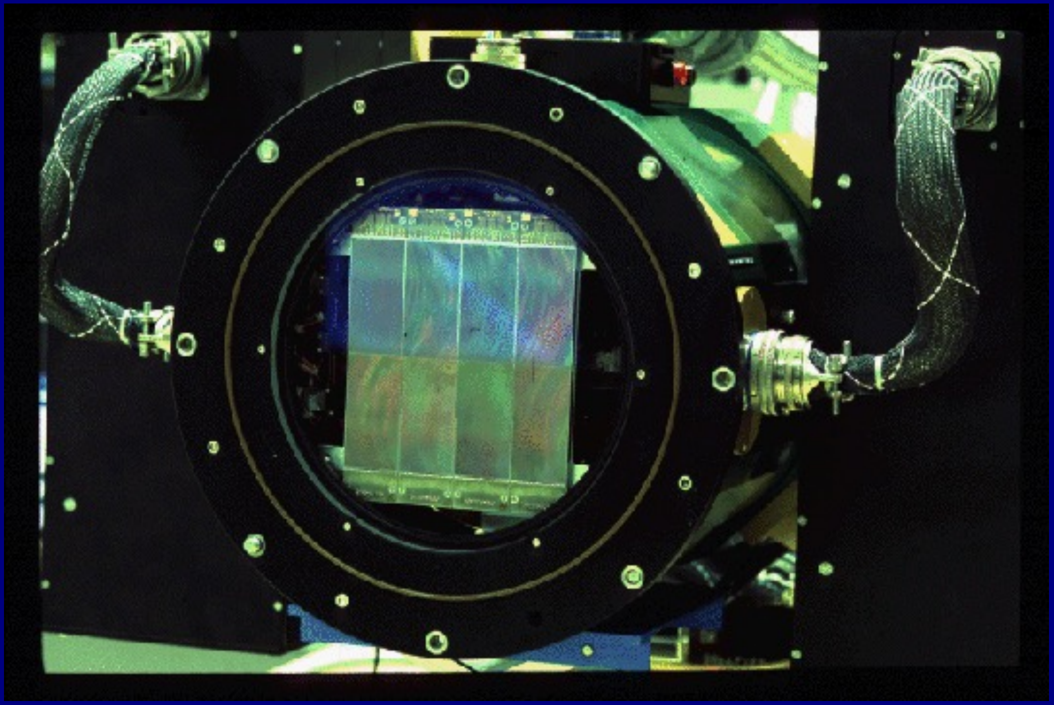
The Two Main Types of Observation

Imaging (recording pictures)

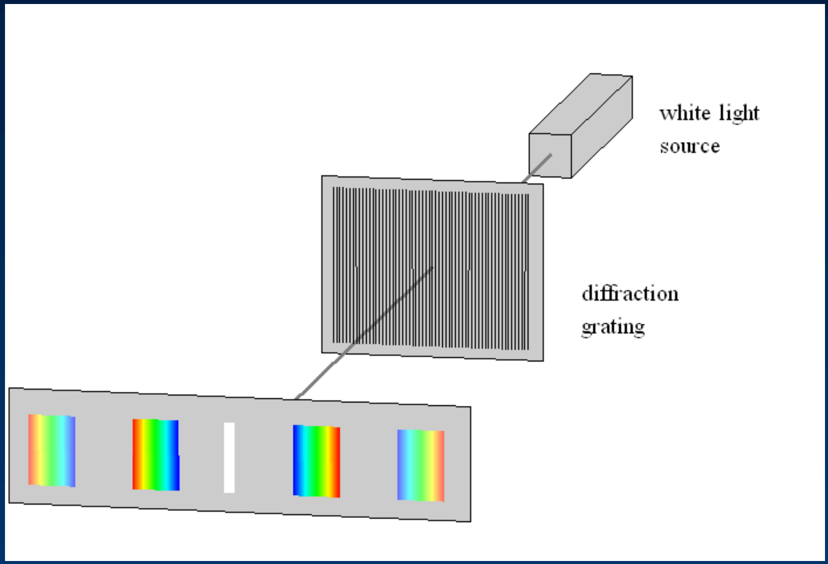
Spectroscopy (making a spectrum) usually using a diffraction grating

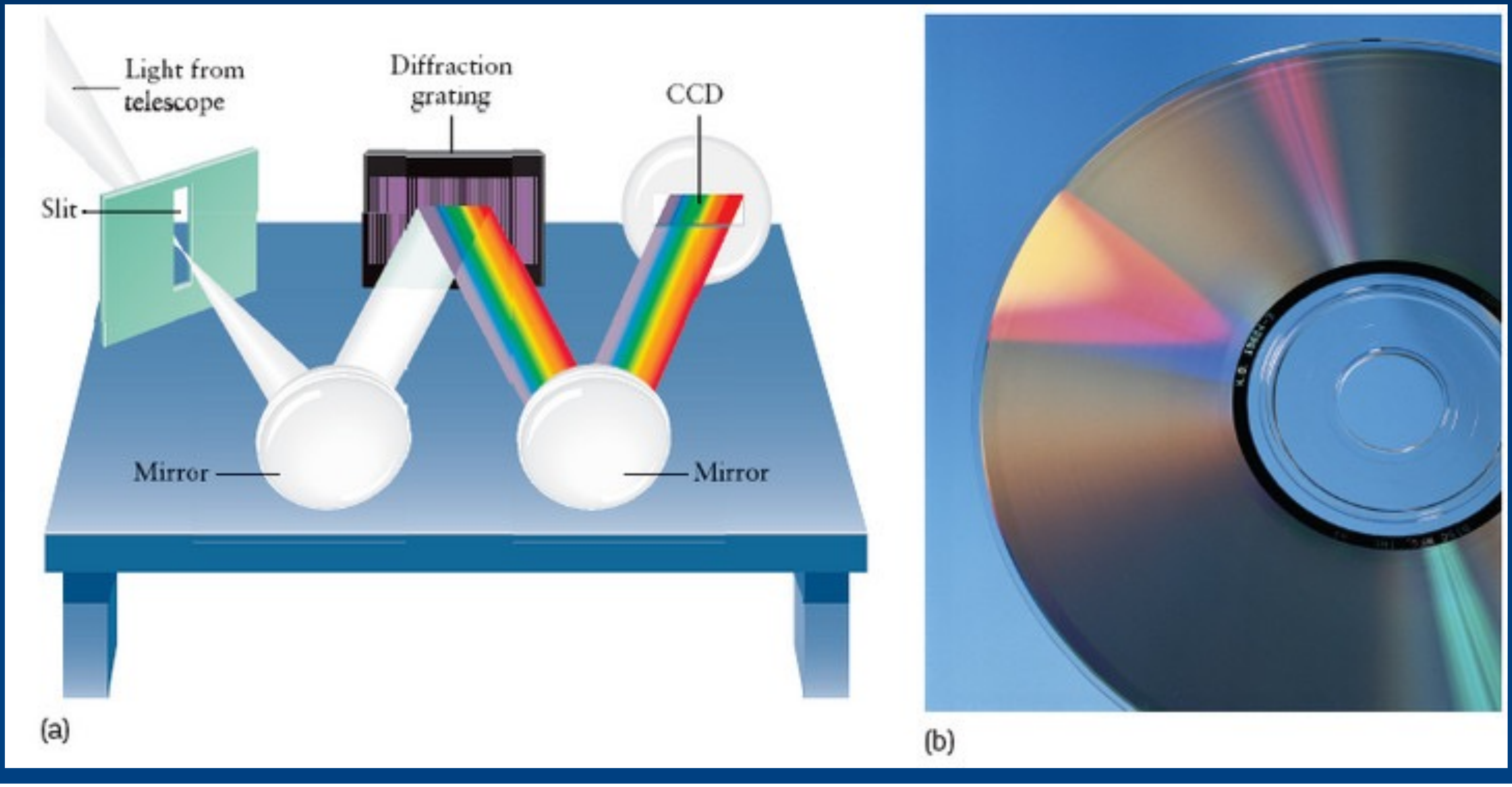
In both cases, image or spectrum usually recorded on a CCD ("charge-coupled device")

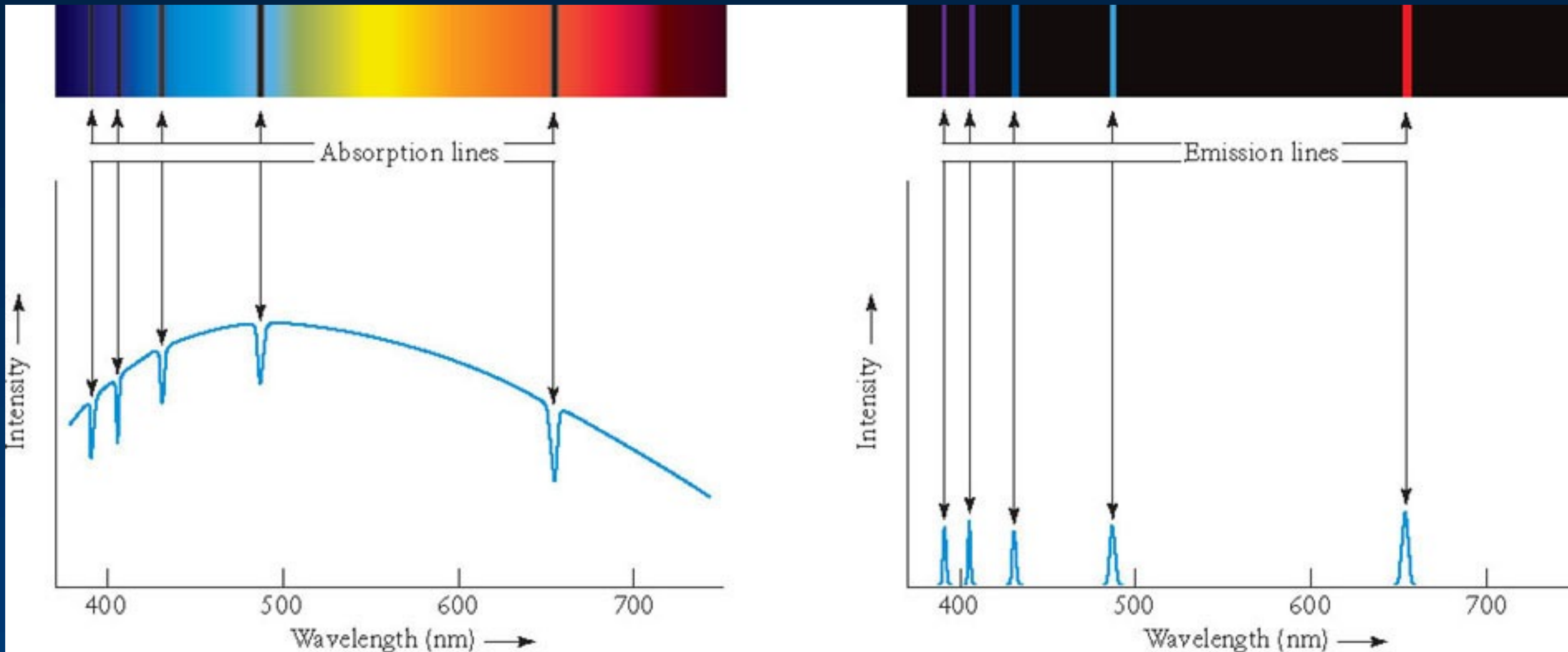




- Spectrographs: light spread out by wavelength, by prism or “diffraction grating”



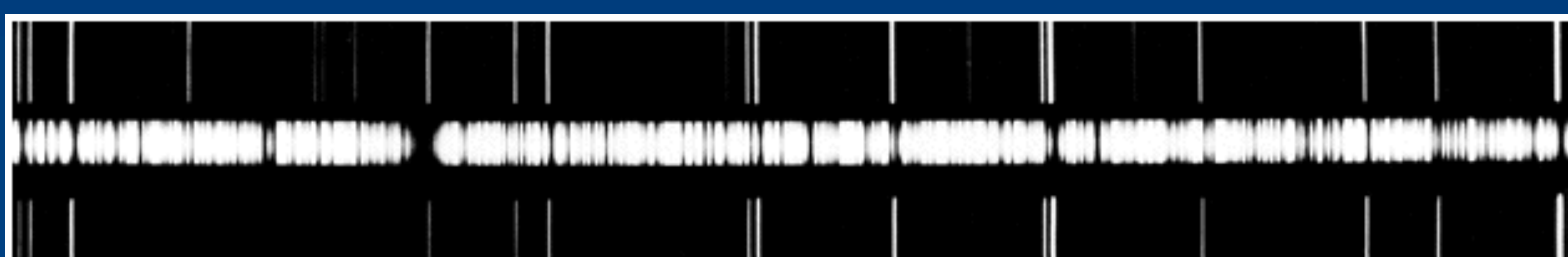




(a) Two representations of an absorption line spectrum

(b) Two representations of an emission line spectrum

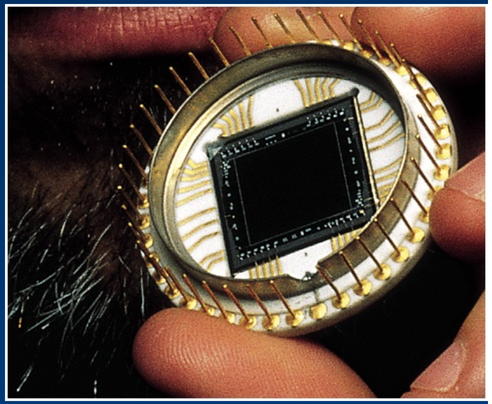
Photograph of astronomical spectrum, plus "comparison spectrum"

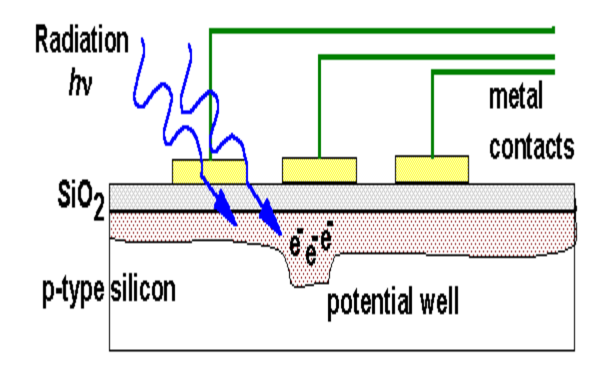


Detectors

Quantum Efficiency = how much light they respond to:

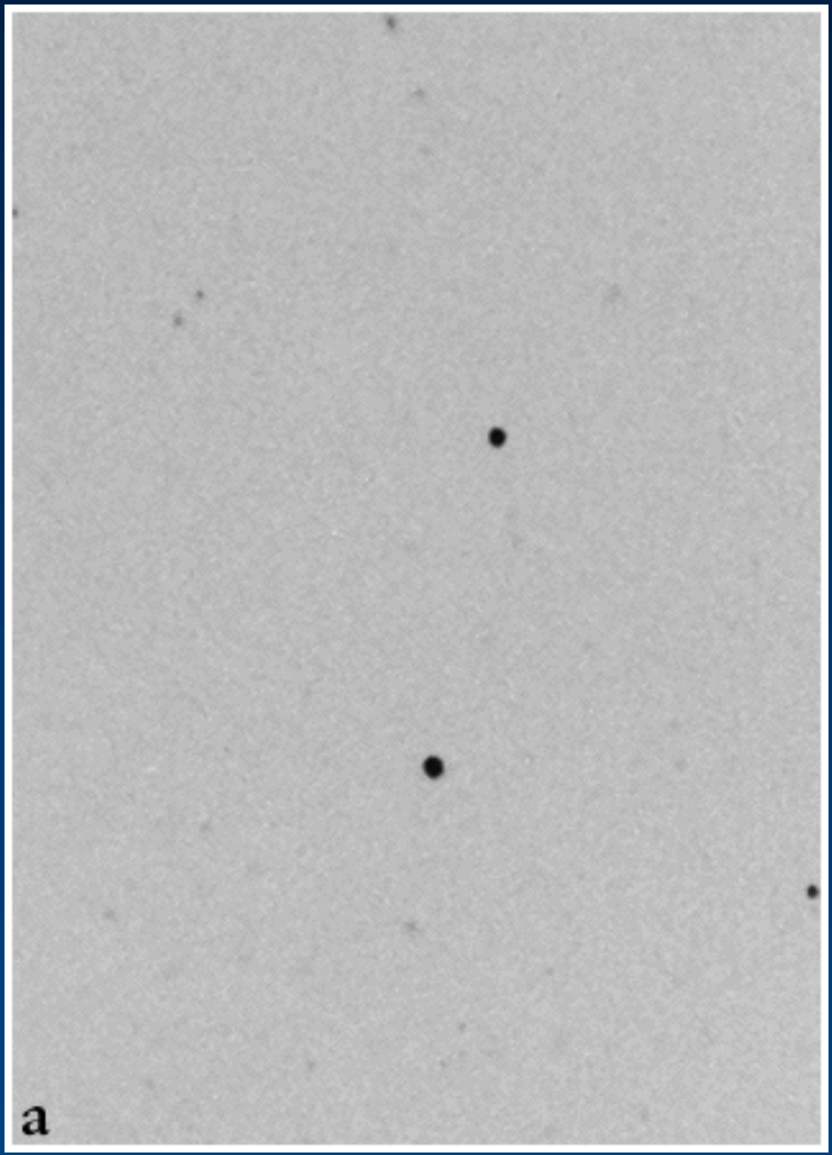
- Eye ≈ 2%
- Photographic emulsions ≈ 1-4%
- CCD (Charge coupled device) ≈ 80%
  - Can be used to obtain images or spectra
  - Also convenient because provide data in digital form, ready to process

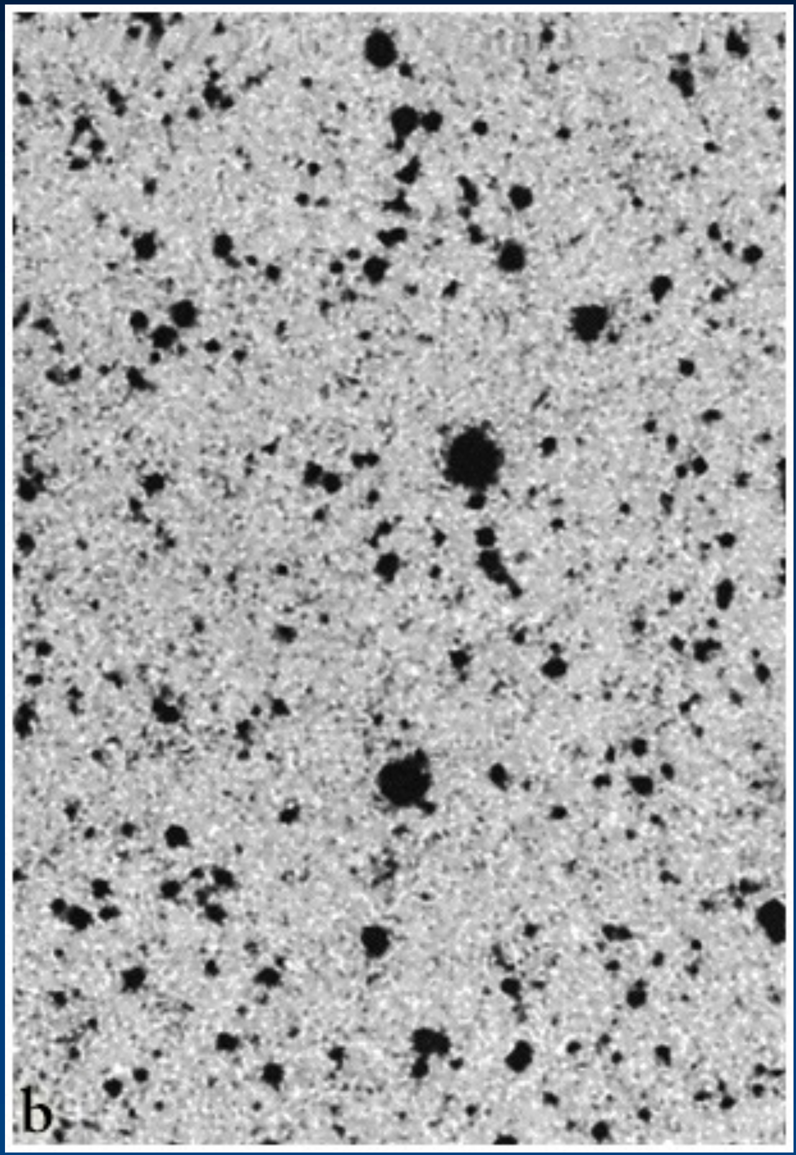




Photographic film

CCD

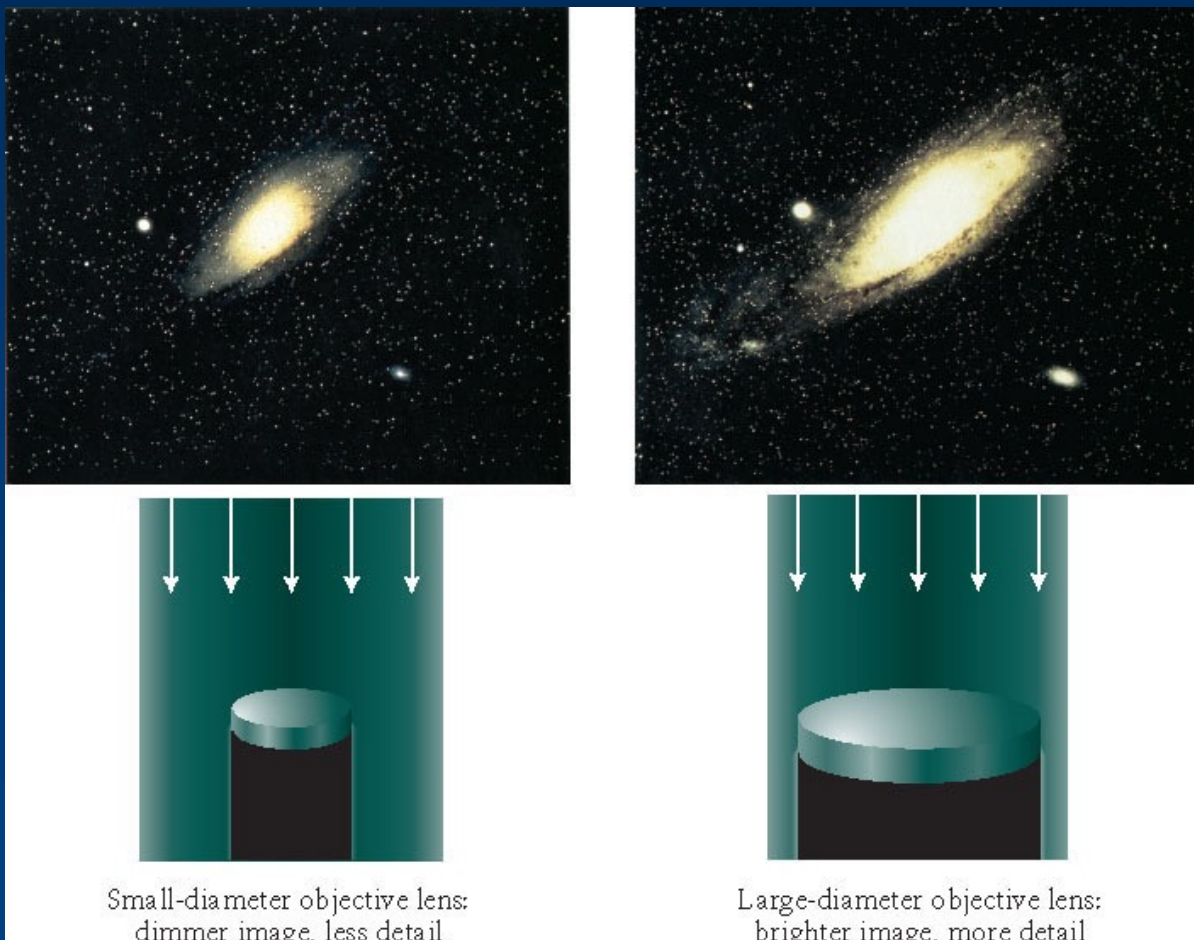




Same telescope, same exposure time!

Reasons for using telescopes

- **Light gathering power:** LGP $\propto$ area, or D^2
  Main reason for building large telescopes!



Two images of Andromeda galaxy, same exposure time, but right-hand image made with telescope with twice the objective diameter (true for lens or mirror)

Reasons for using telescopes, cont.

- **Field of View:** how much of sky can you see at once? Typically many arcminutes – few degrees

- **Resolution**: The ability to distinguish two objects very close together. Angular resolution:

$$\Theta = 1.22\ \lambda/D = 2.5 \times 10^5\ \lambda/D$$

where Θ is angular resolution of telescope in arcsec, λ is wavelength of light, D is diameter of telescope objective, in <u>same</u> distance units

Example, for D=2.5 m, λ=500 nm, Θ = 0.05"

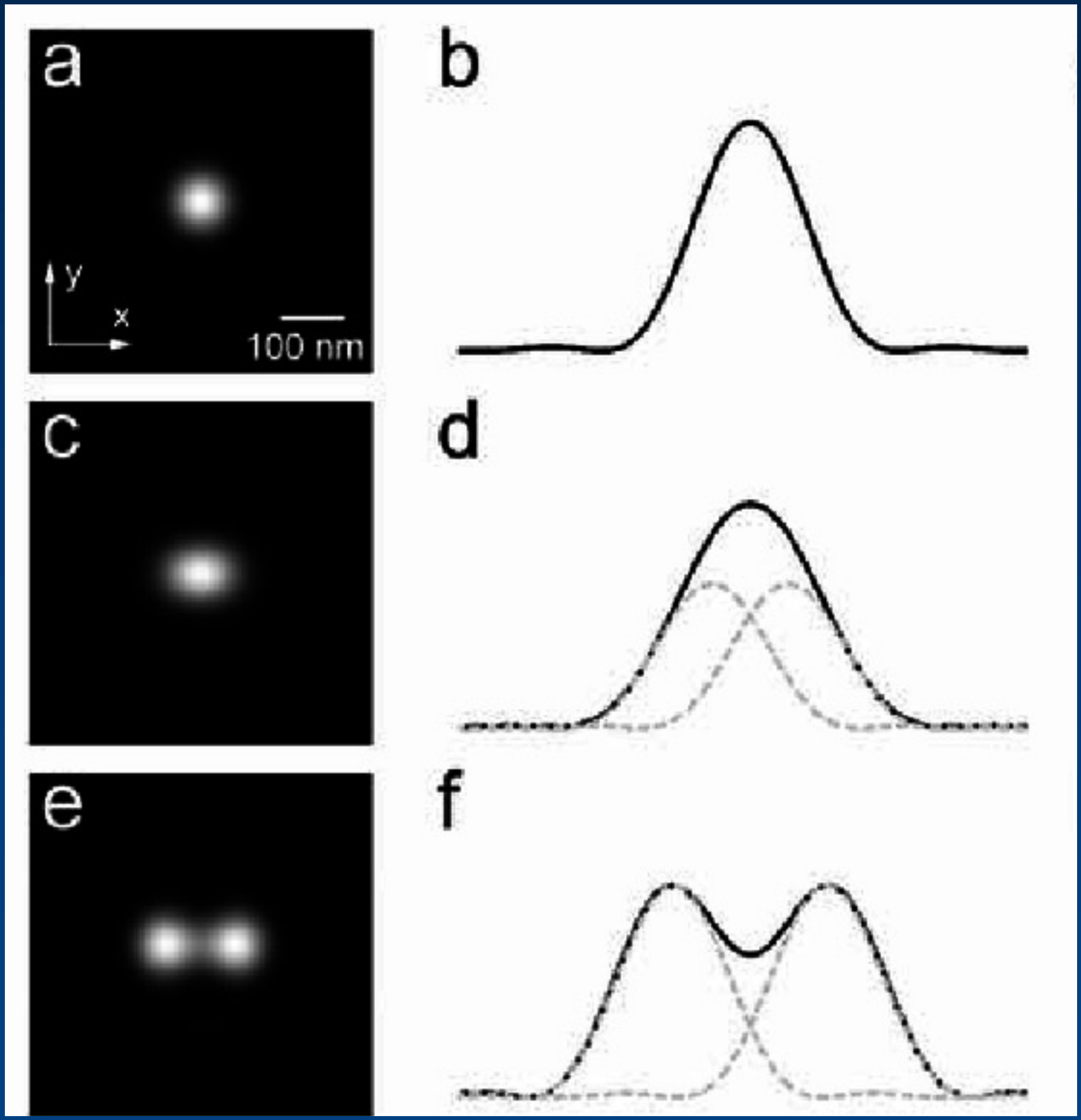
- Magnification: angular diameter as seen through telescope/angular diameter on sky
  - Typical magnifications 10 to 100 (depends on eyepiece)

THE QUEST FOR RESOLUTION

Diffraction limit:

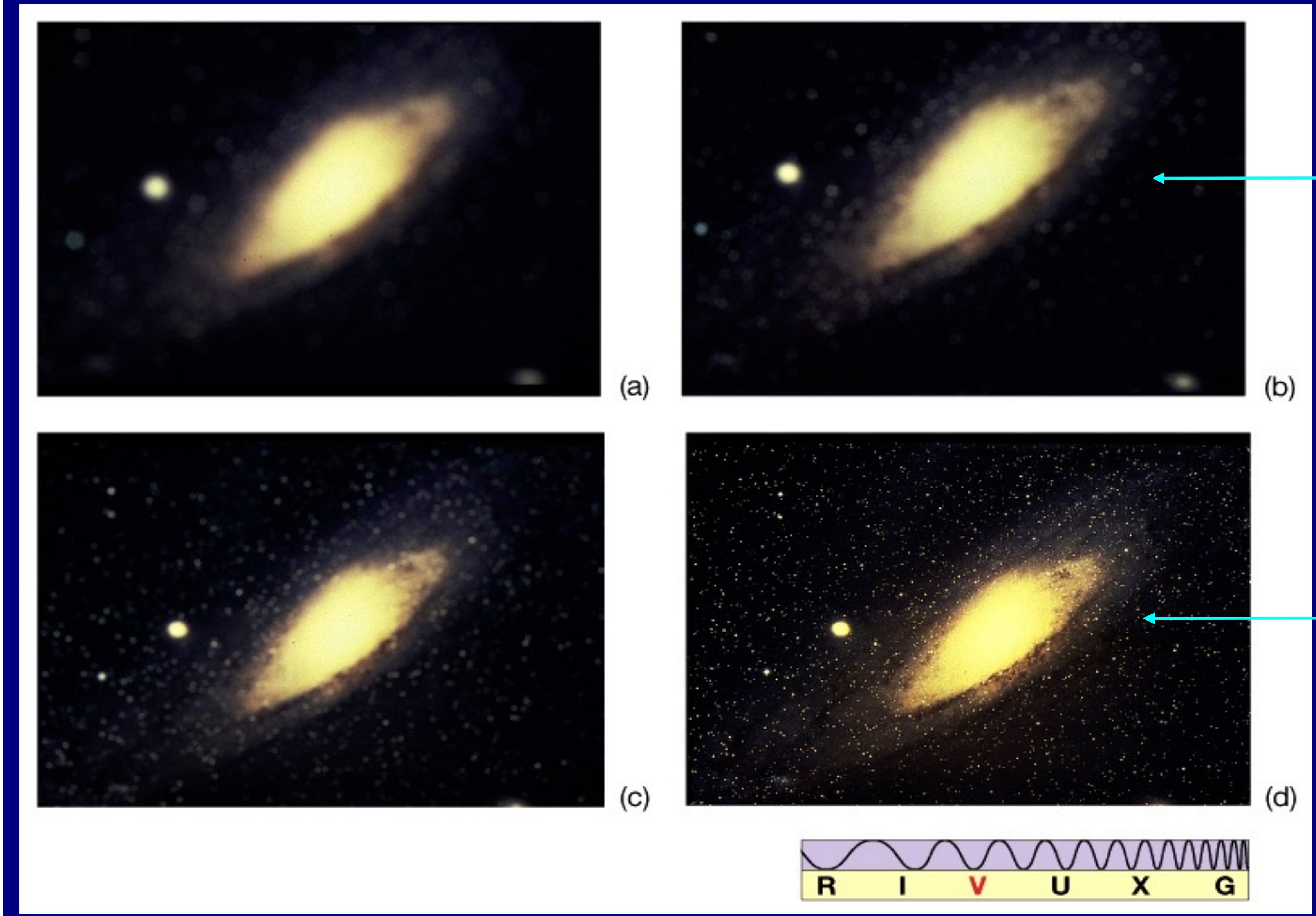
$\theta = 1.22\ \lambda/D$

θ = resolution
λ = wavelength
D = Diameter of telescope



Resolving Power

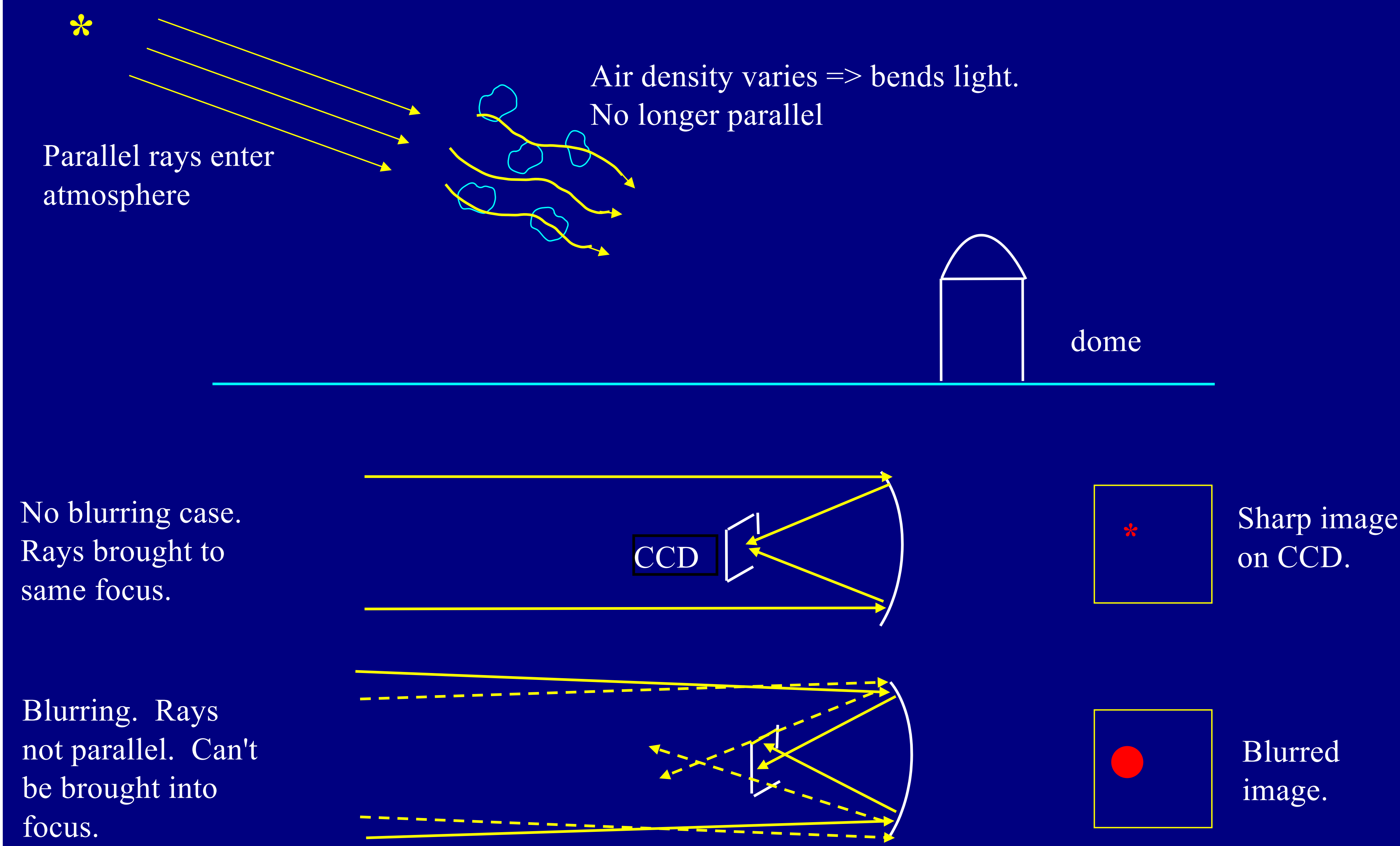
(how much detail can you see?)



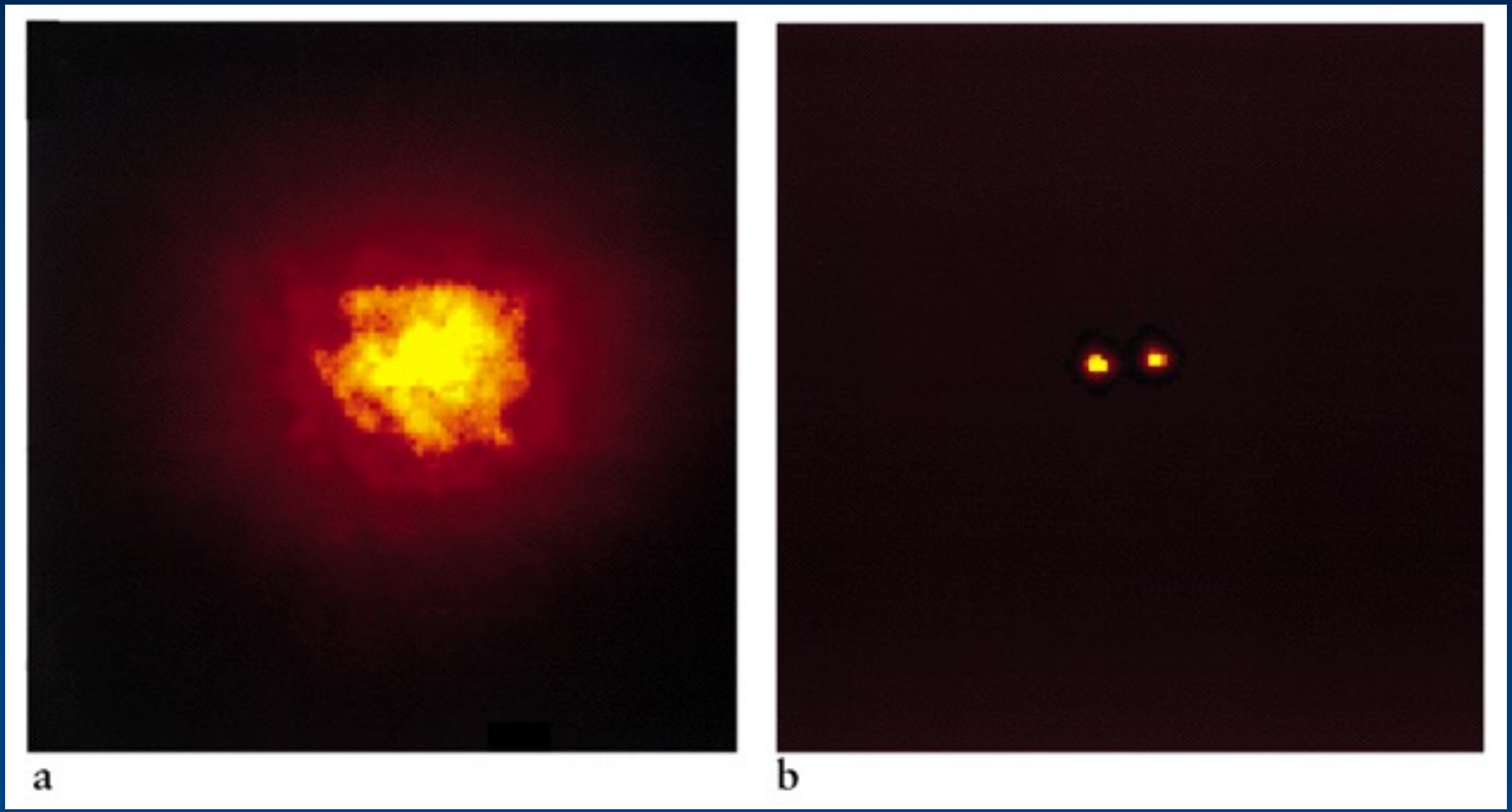
fuzziness you would see with your eye.

detail you can see with a telescope.

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.

- Adaptive Optics – use a wavefront sensor and a deformable mirror to compensate for deformations of incoming wave caused by the Earth's atmosphere.

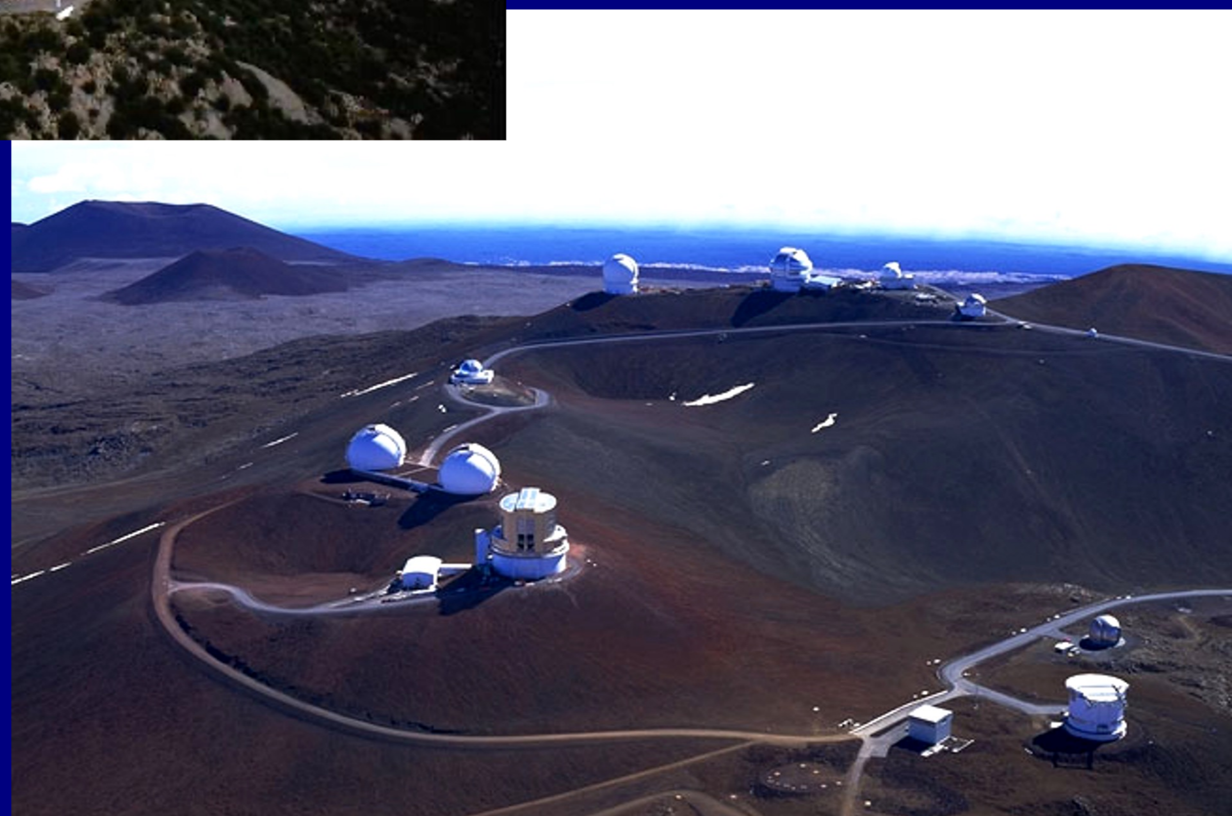


- Or, put telescopes in space (more later)

North America at night

So where would you put a telescope?

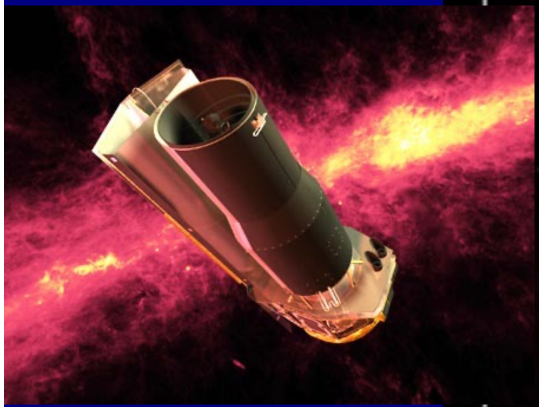
Kitt Peak National Observatory, near Tucson



Mauna Kea Observatory, Hawaii

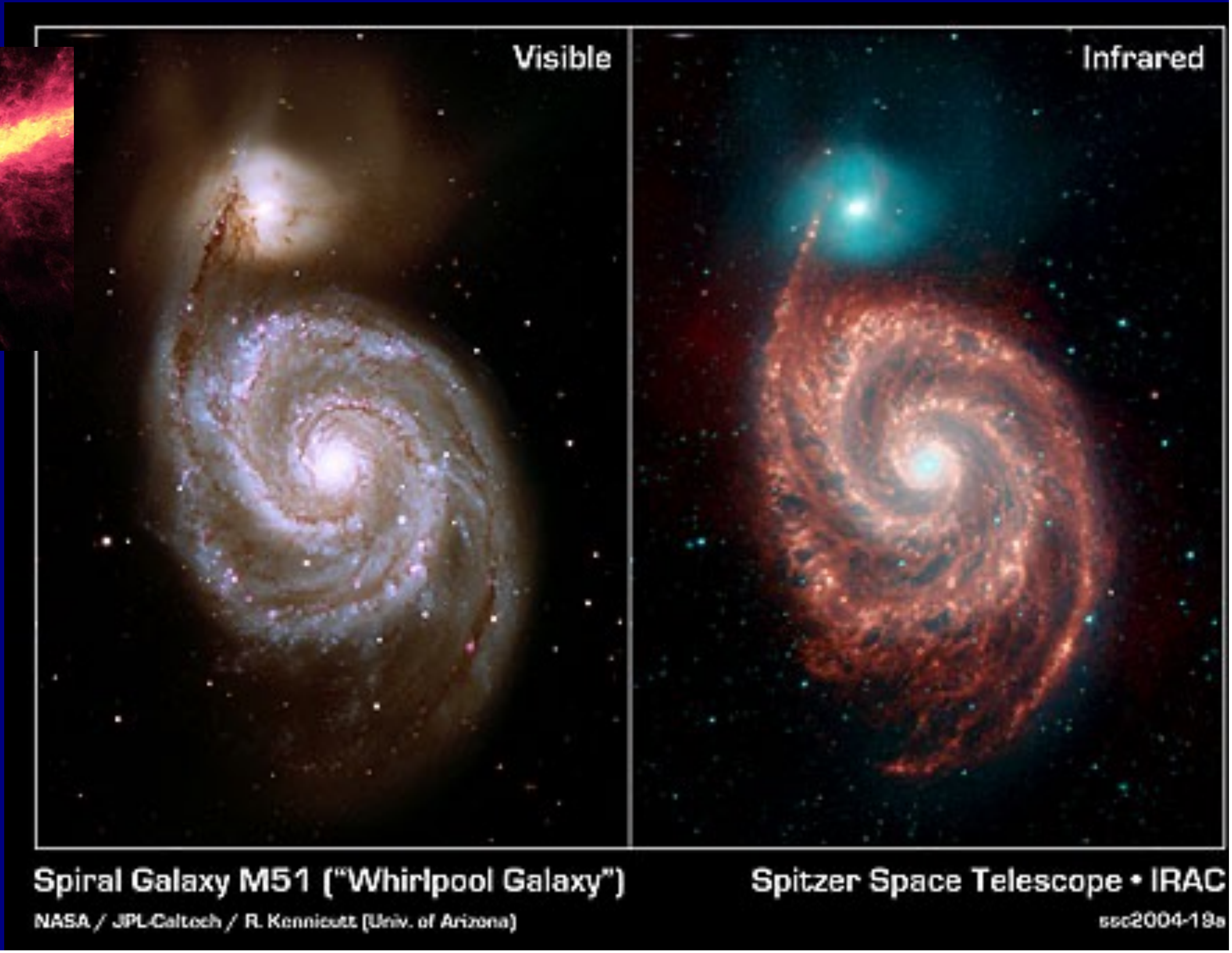
Astronomy at Other Wavelengths

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.



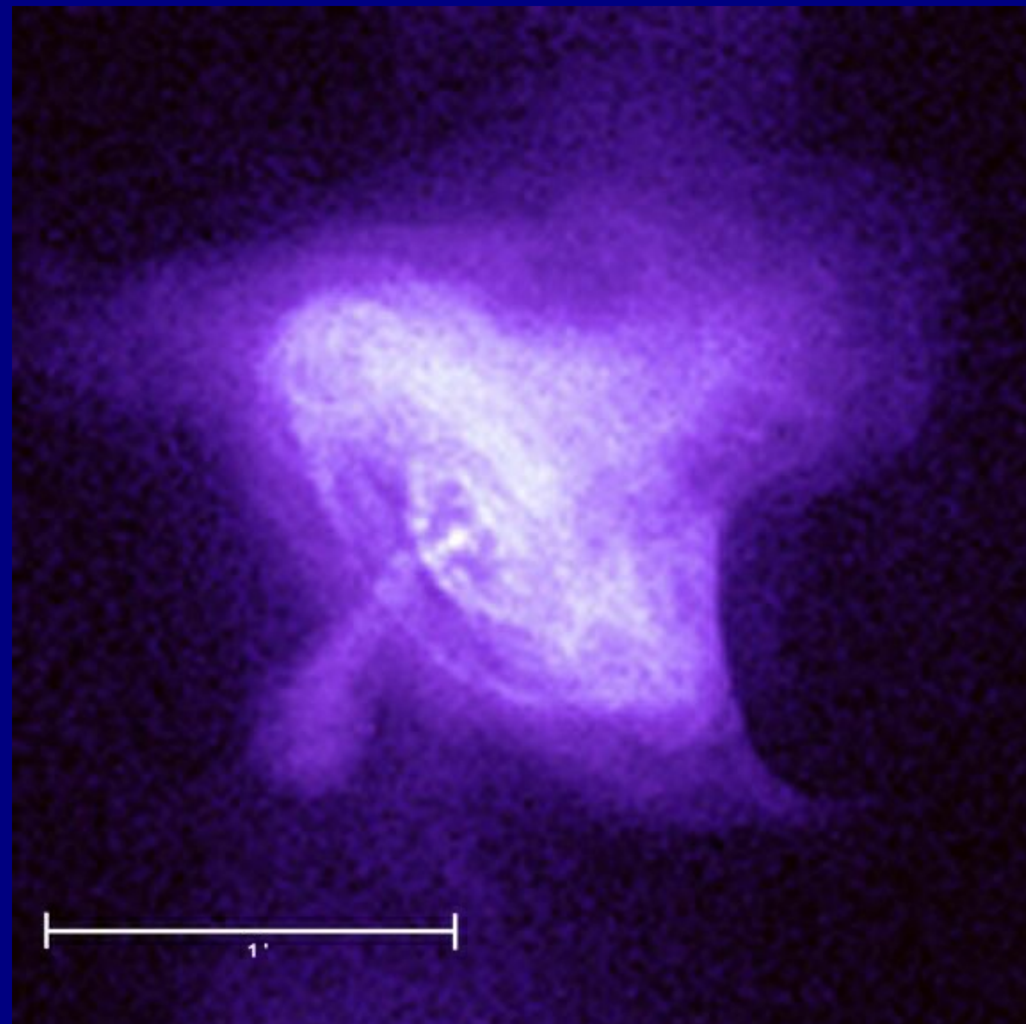
Shorter infrared wavelengths allows you to see stars through dust. Dust is good at blocking visible light but infrared gets through better.

Trifid nebula in visible light

Trifid nebula with Spitzer

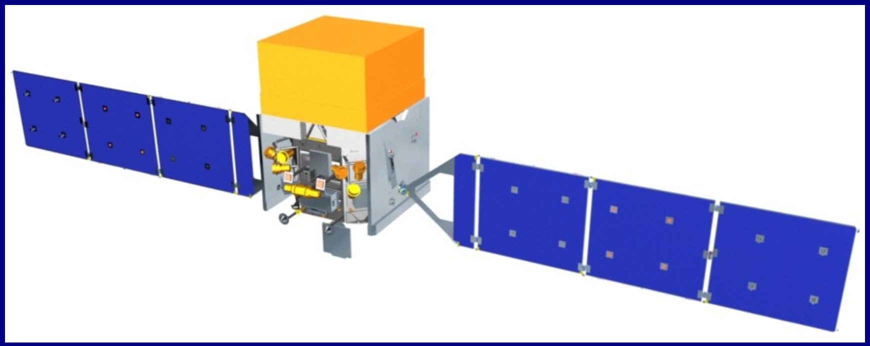
X-ray Astronomy

Chandra X-ray Observatory

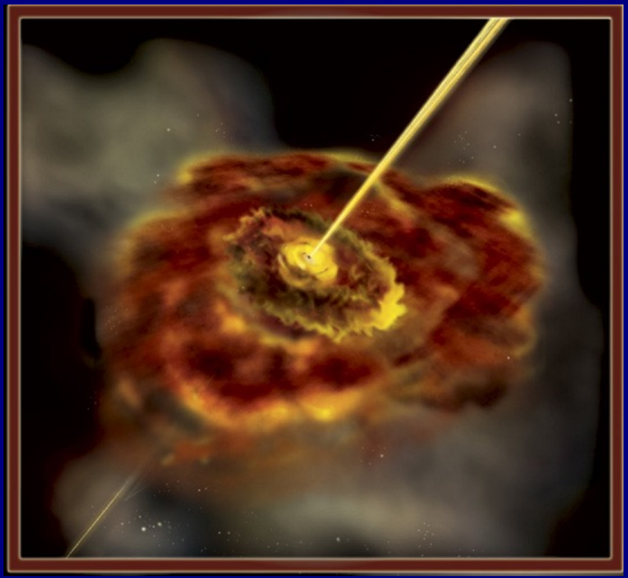


Crab pulsar and nebula in X-rays

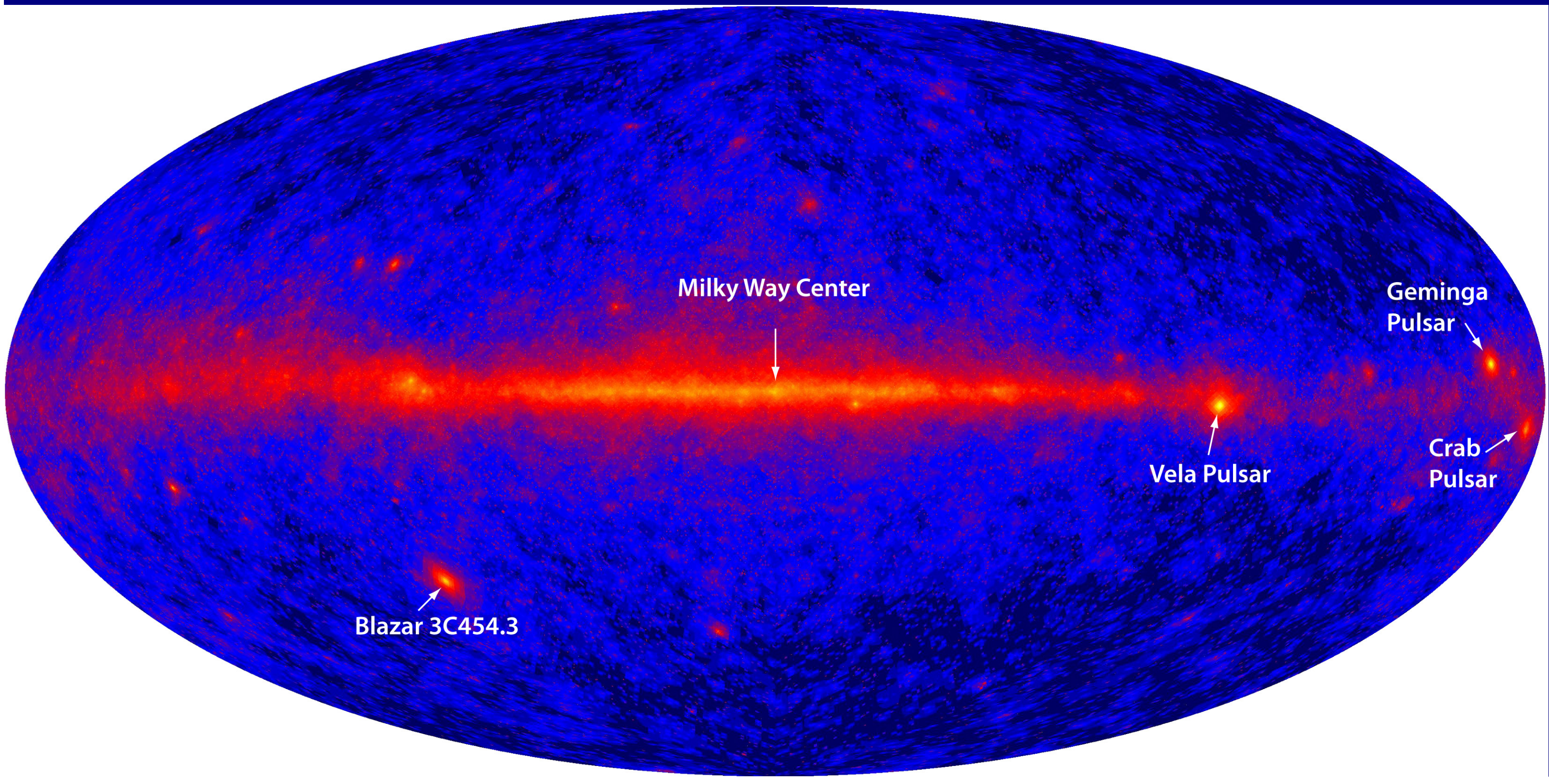
Gamma-ray Astronomy



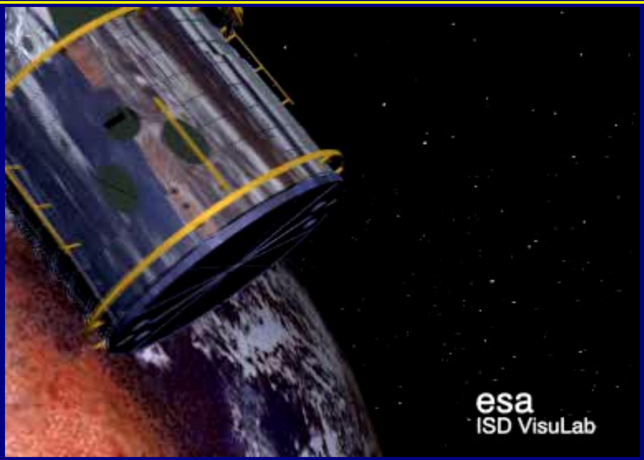
GLAST - Gamma-ray Large Area Space Telescope



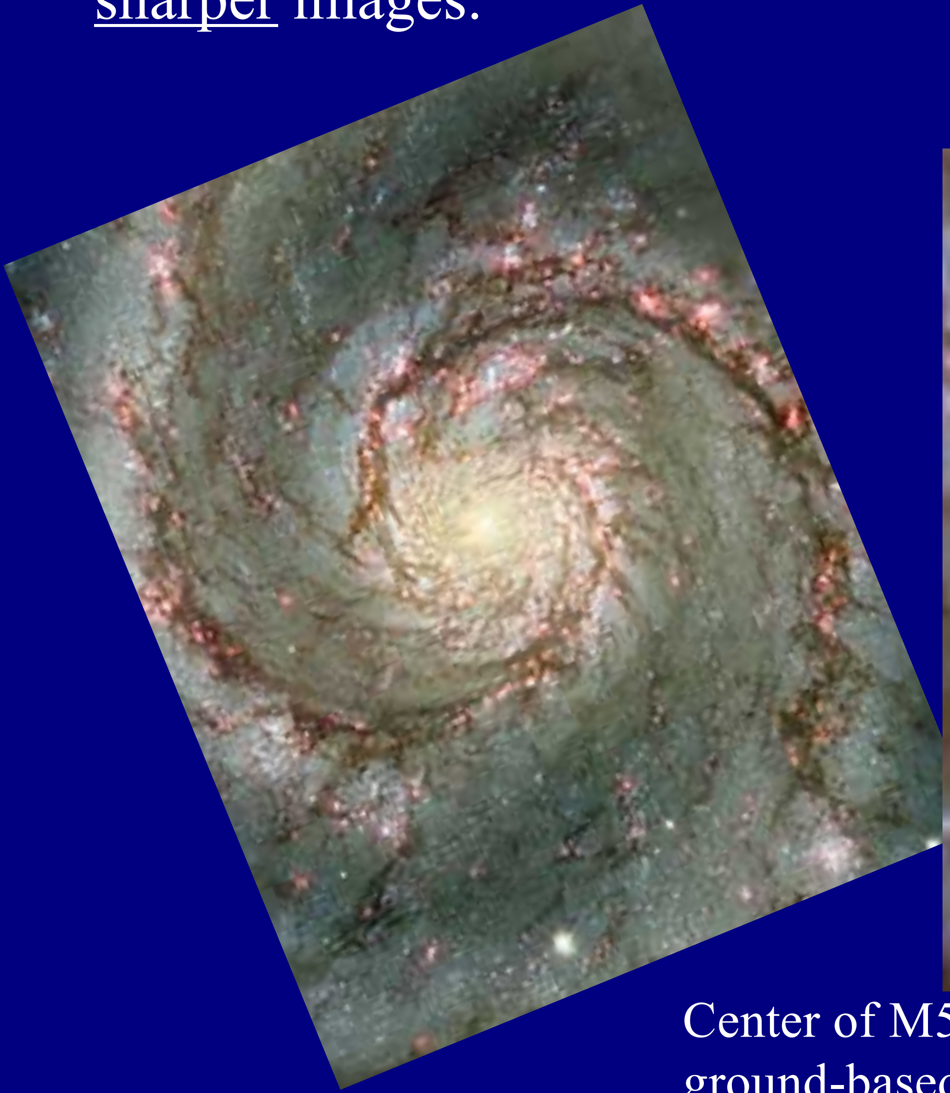
Artists conception of a jet from a blazar



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

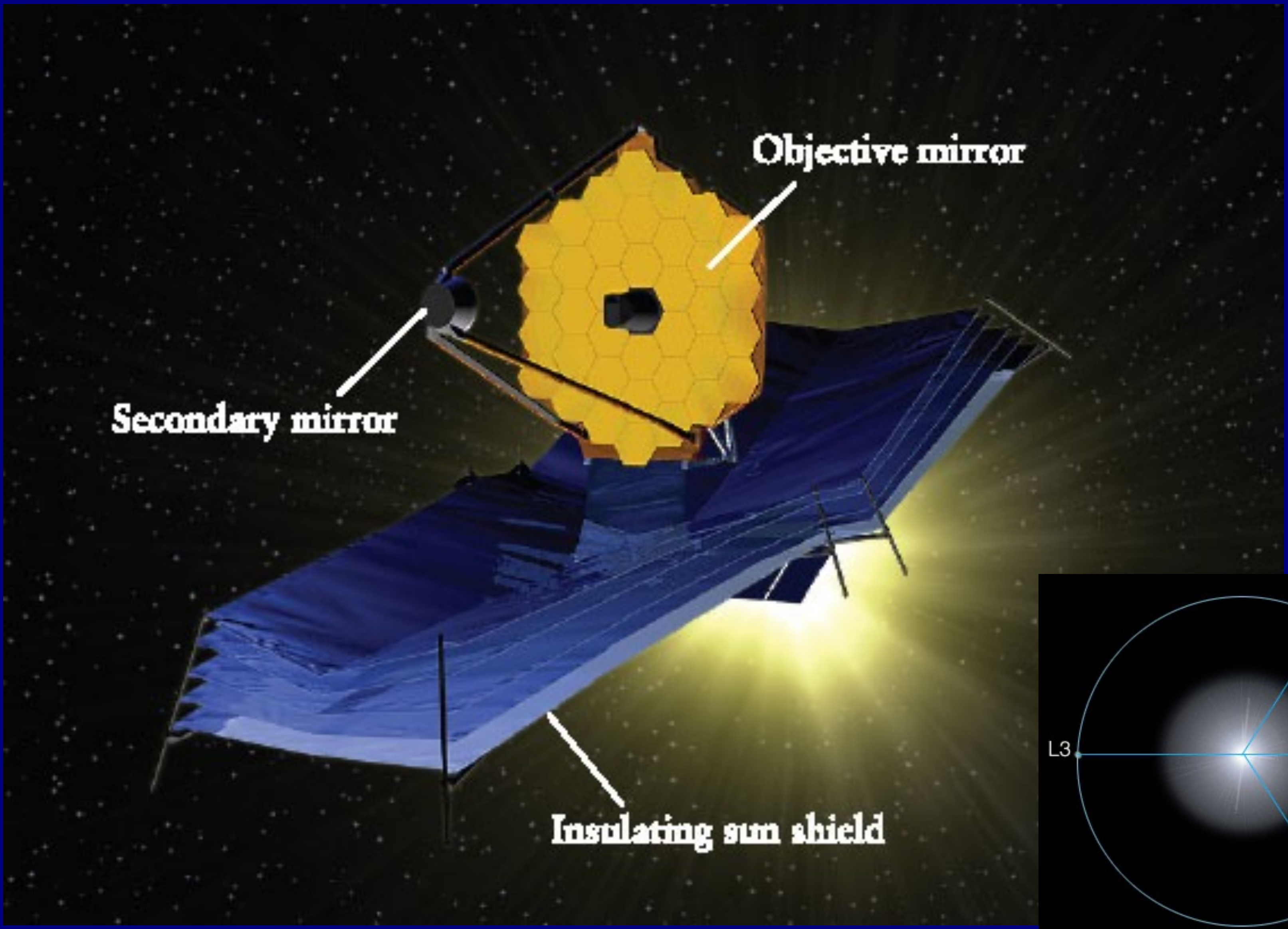


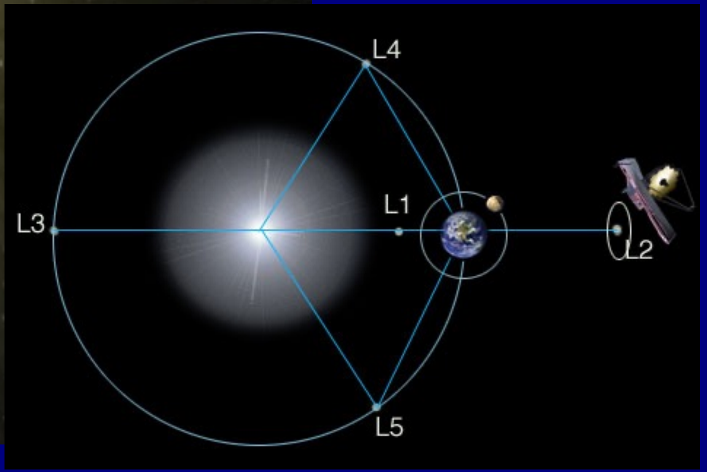
Advantage of space for optical astronomy: get above blurring atmosphere – much sharper images.



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

JWST


Objective mirror
Secondary mirror
Insulating sun shield


L4
L1
L3
L2
L5

Radio Telescopes

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

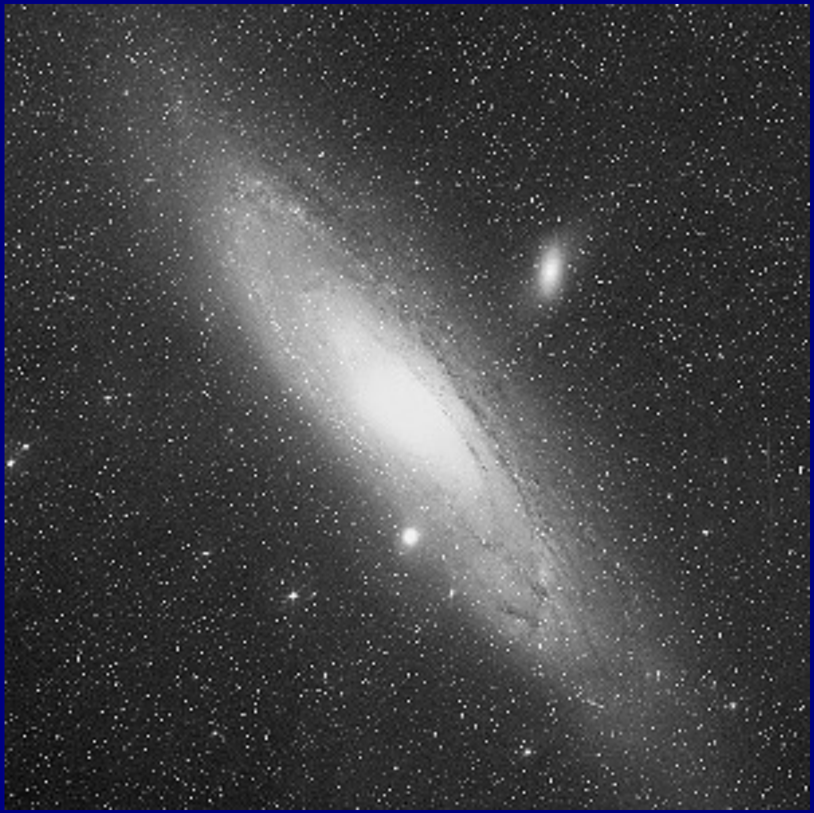
Surface accuracy not so important, so easy to make large one.

Jodrell Bank 76-m (England)

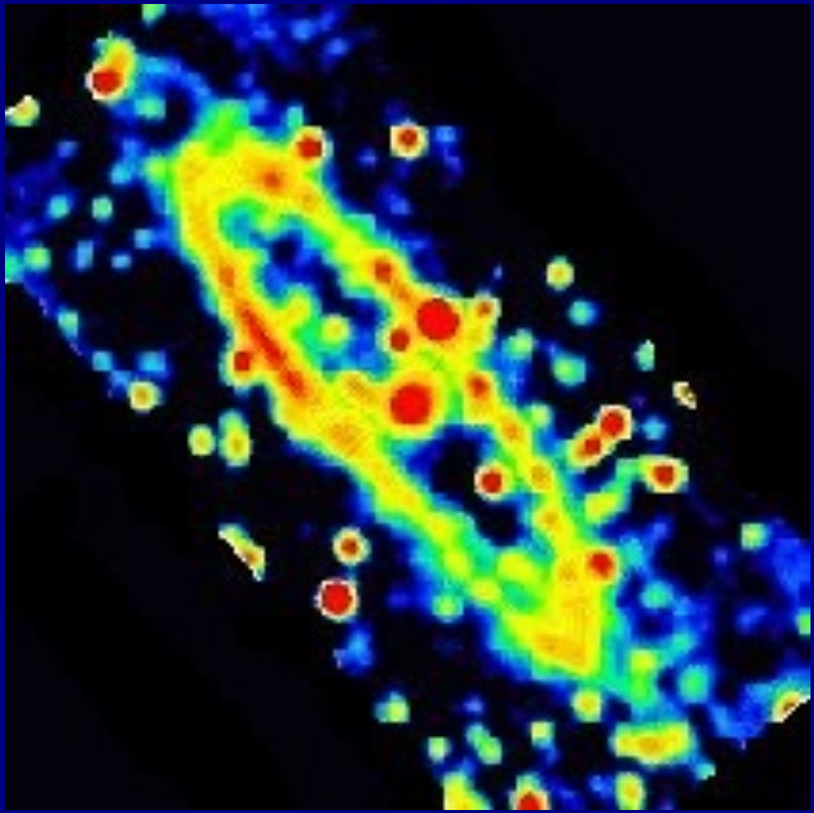
But angular resolution is poor. Remember:

$$\text{angular resolution} \;\alpha\; \frac{\text{wavelength}}{\text{mirror diameter}}$$

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".



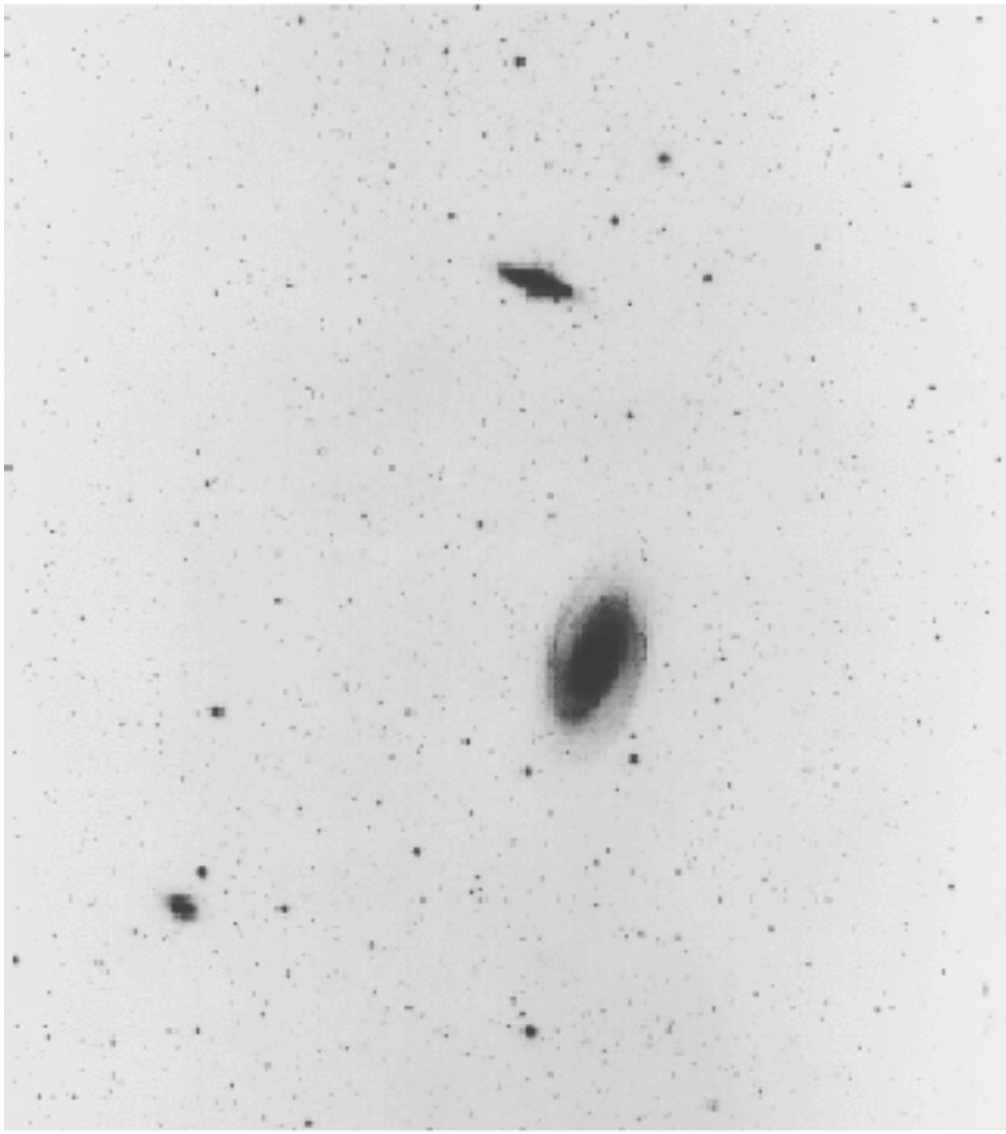
Andromeda galaxy – optical



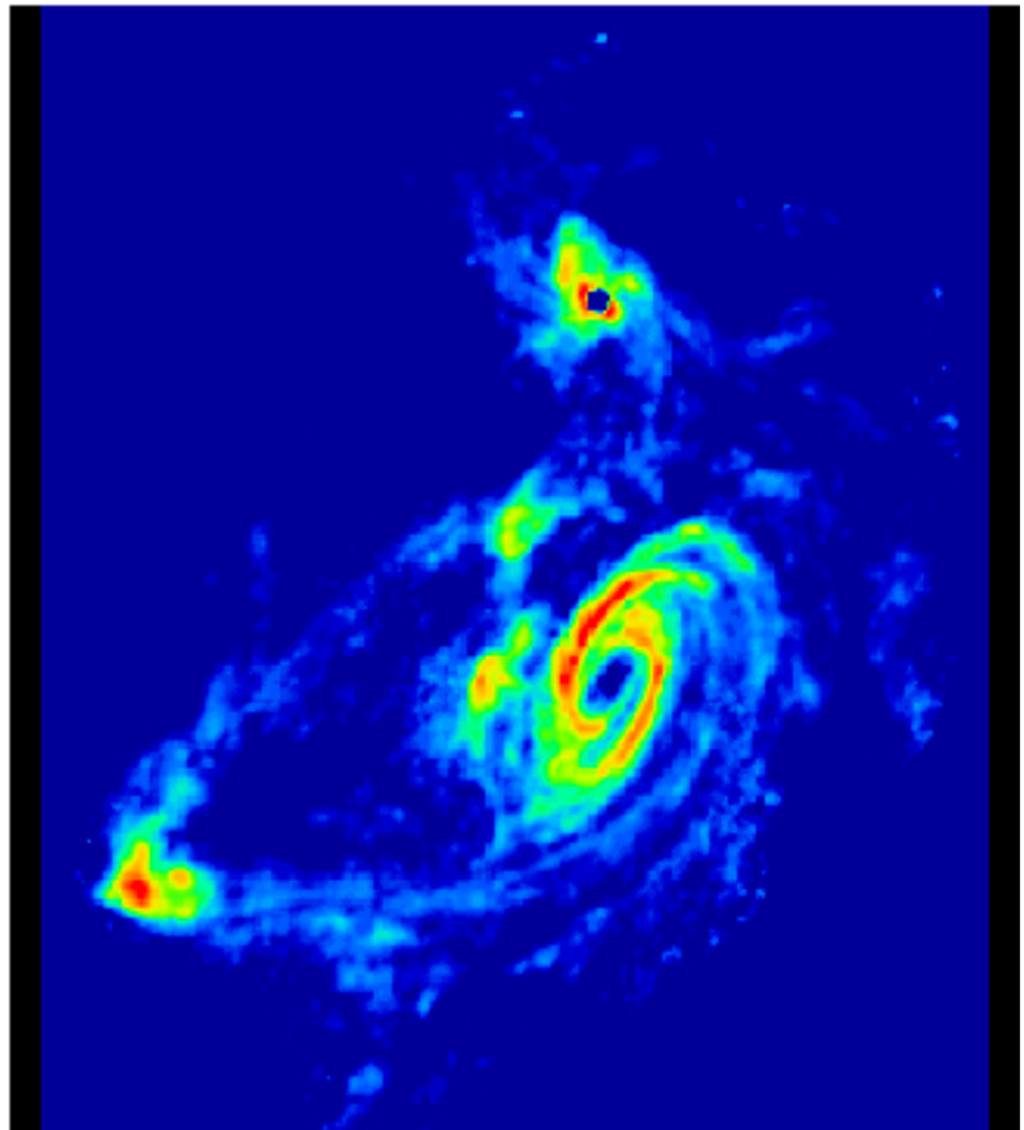
Andromeda radio map with 100m Effelsberg telescope

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution

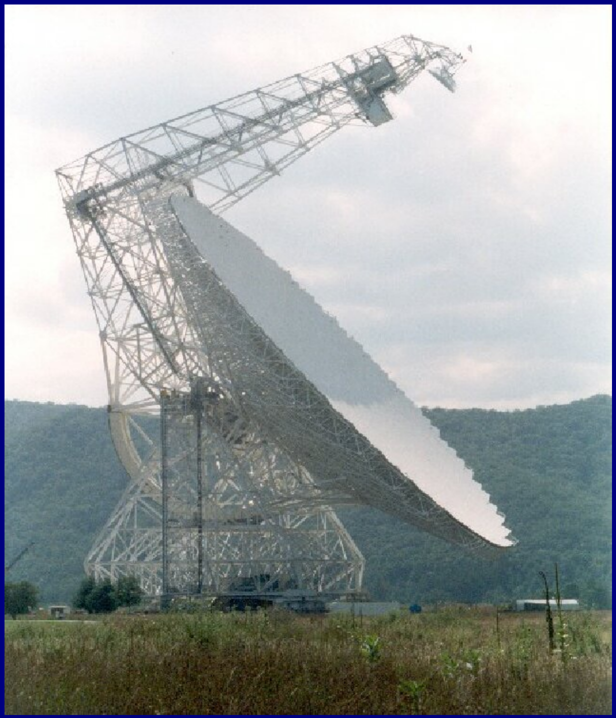


21cm HI Distribution



Parkes 64-m (Australia)

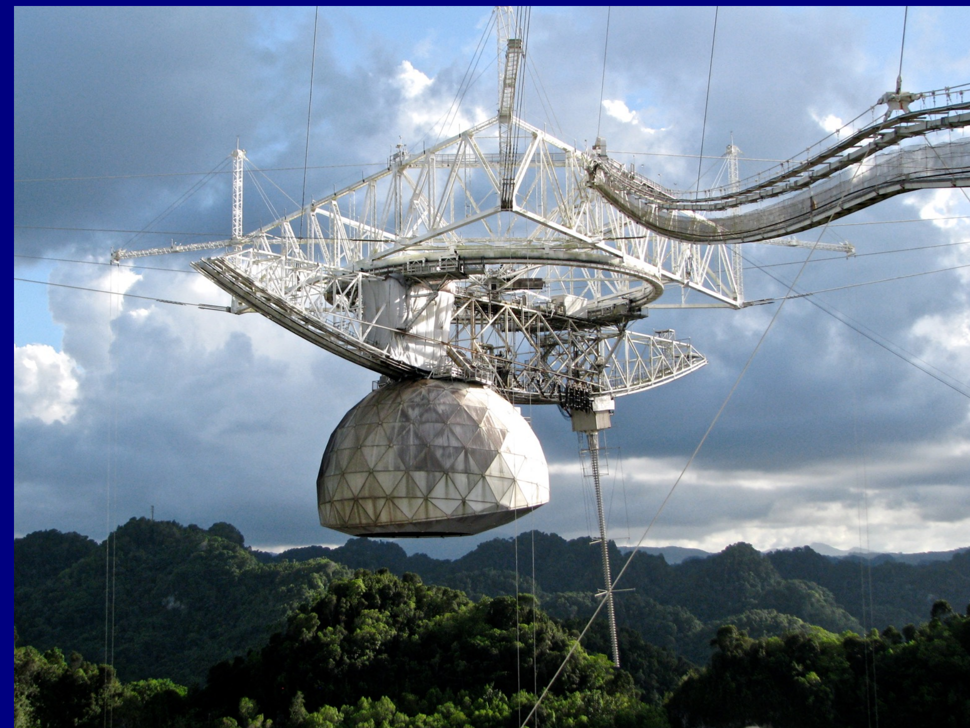
Effelsberg 100-m (Germany)



Green Bank 105-m telescope (WV)

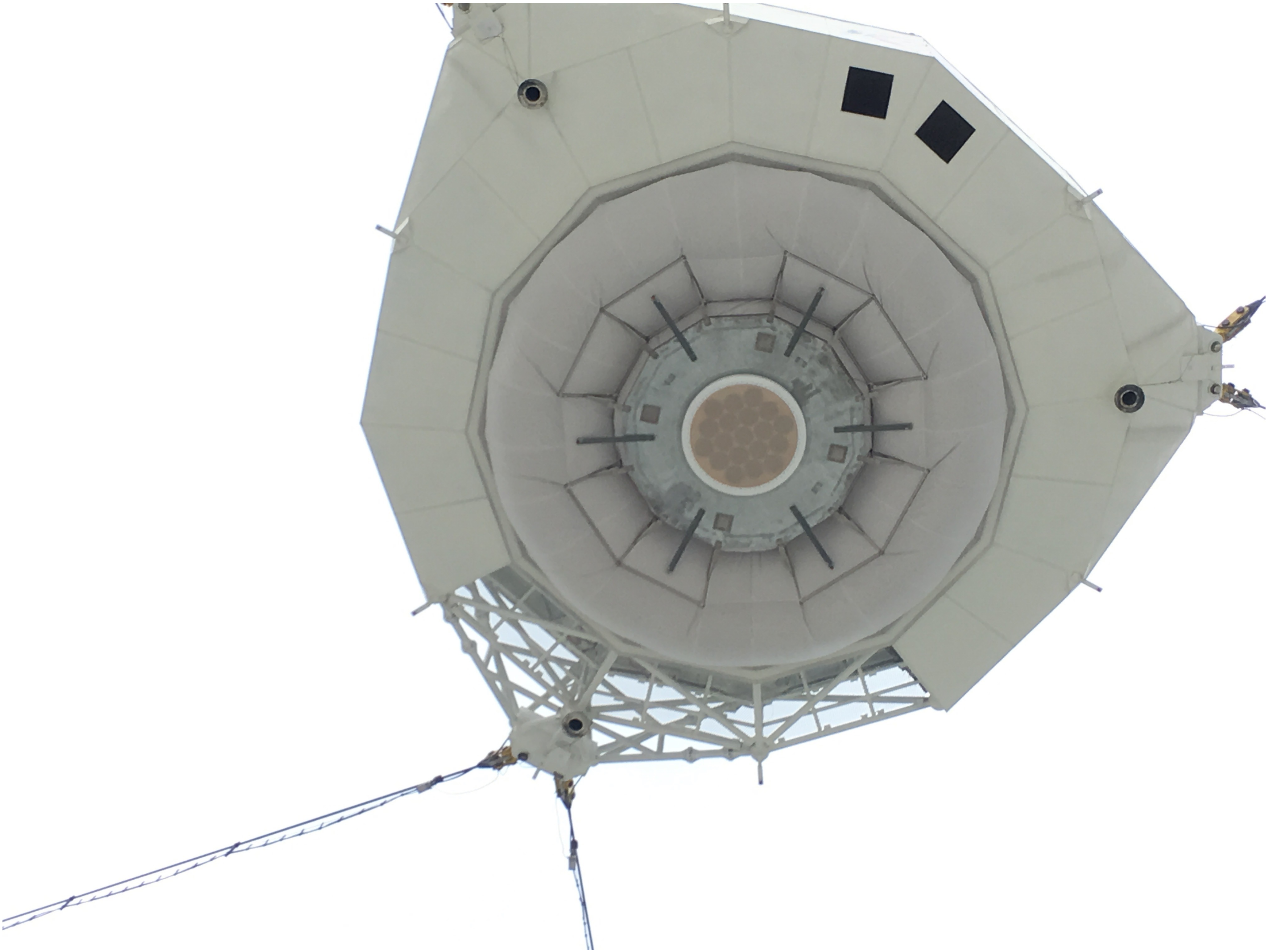
Arecibo 300-m telescope (Puerto Rico)

Arecibo 300-m telescope (Puerto Rico)

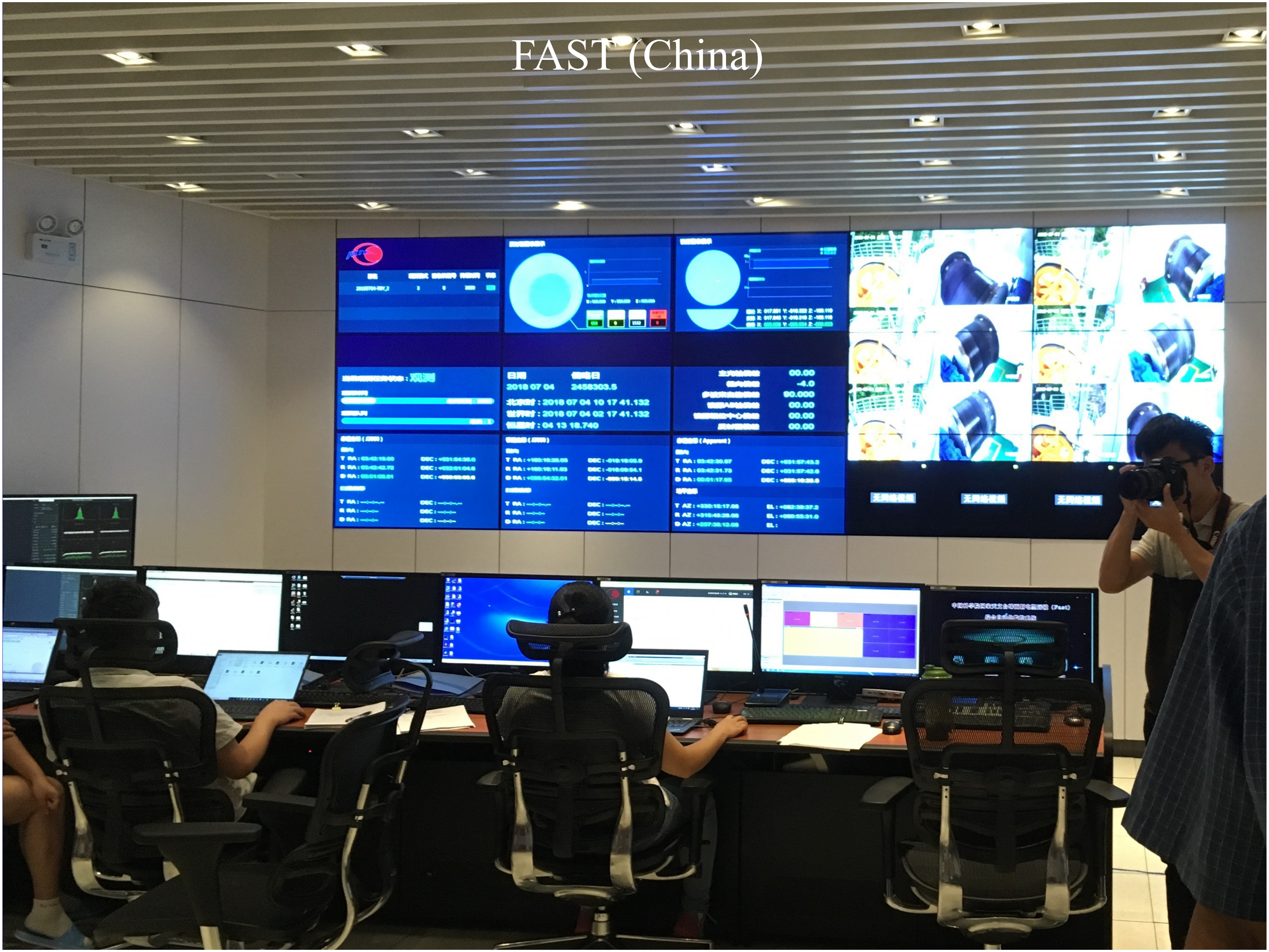


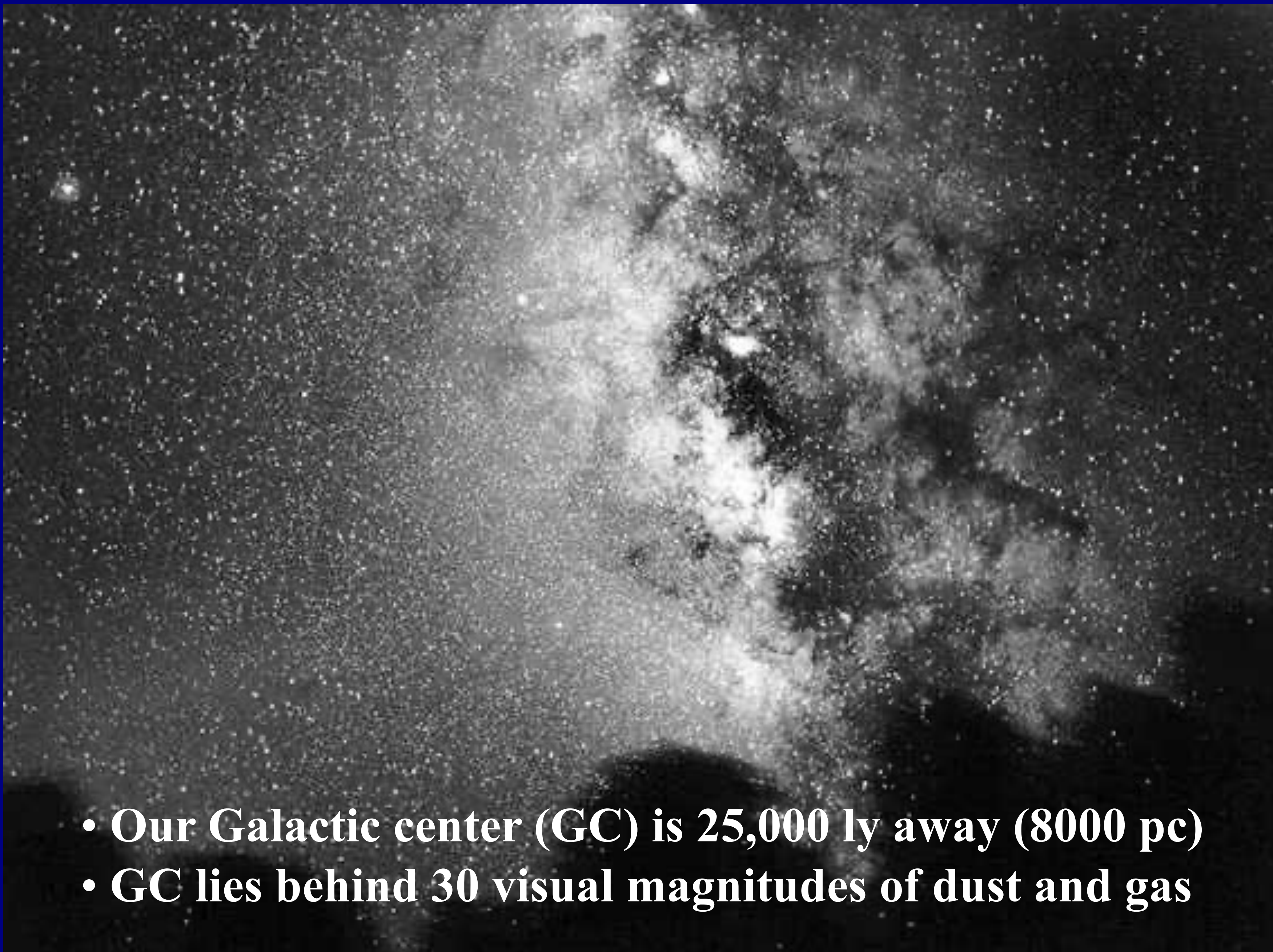
https://www.nature.com/articles/d41586-020-03421-y

FAST (China)



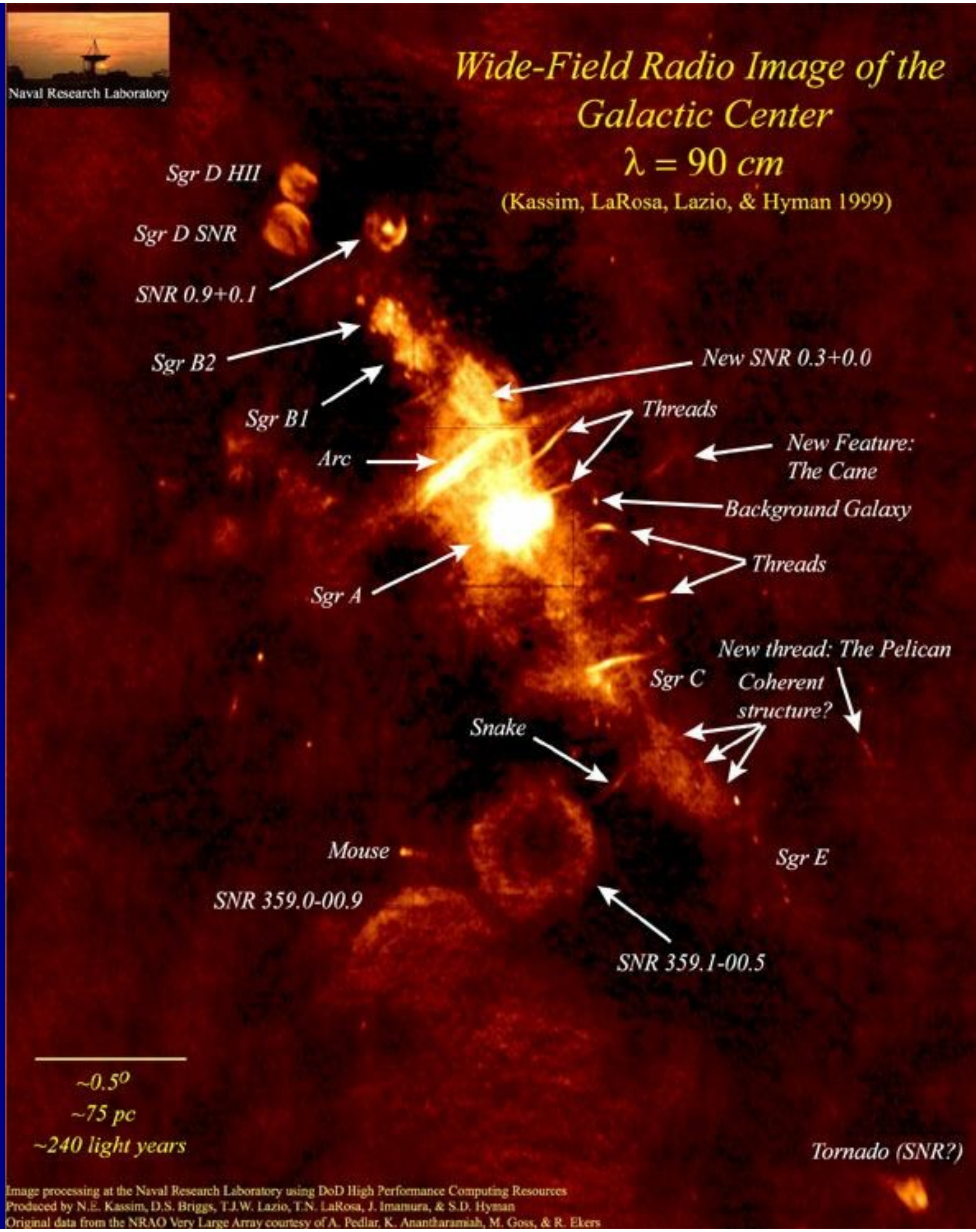
FAST (China)





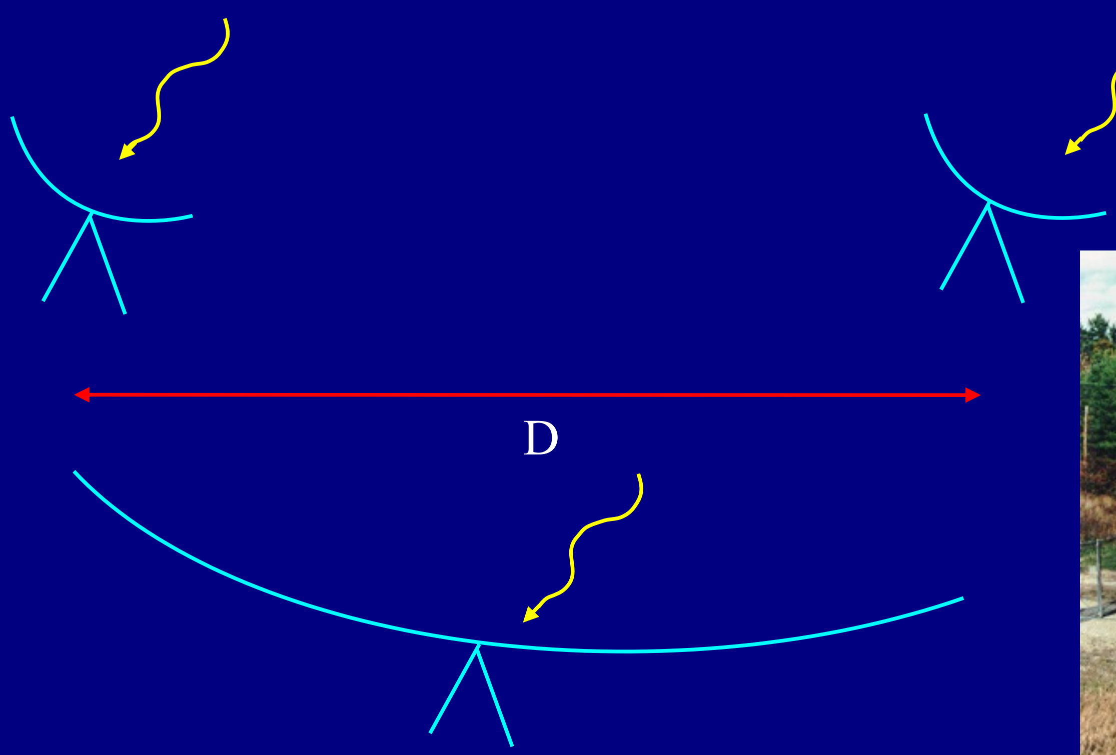
- Our Galactic center (GC) is 25,000 ly away (8000 pc)
- GC lies behind 30 visual magnitudes of dust and gas

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



Interferometry

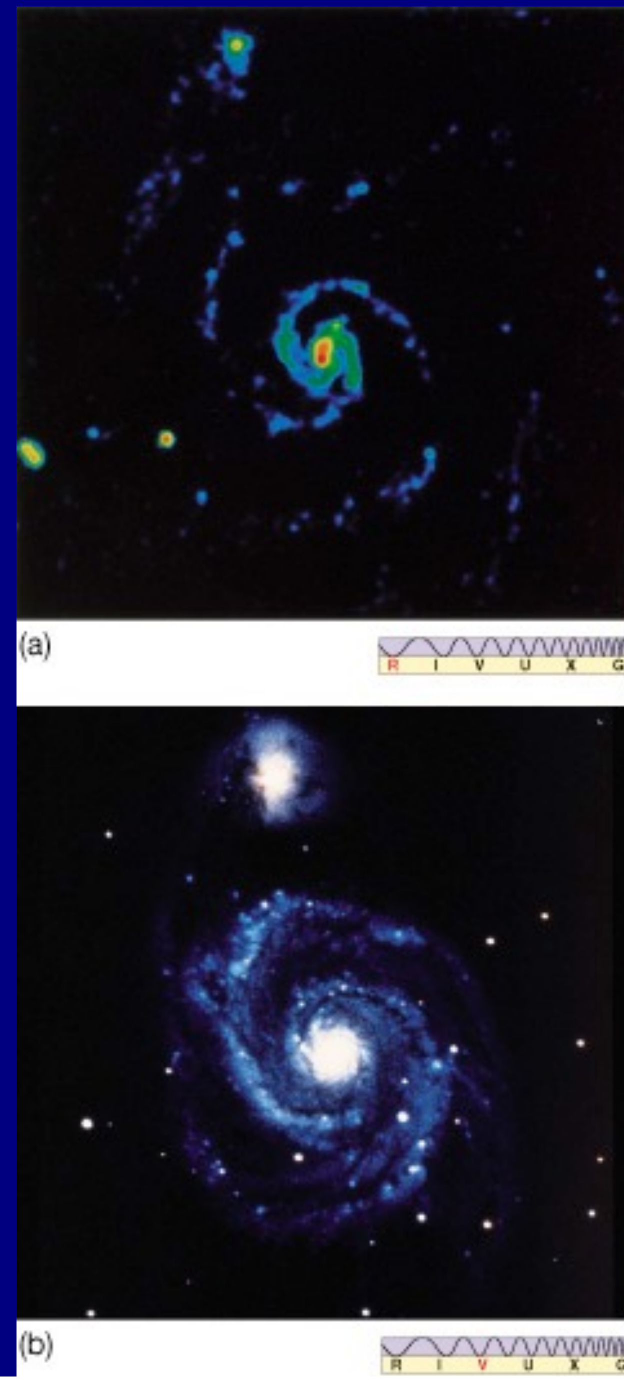
A technique to get improved angular resolution using an array of telescopes. Most common in radio, but also limited optical interferometry.



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

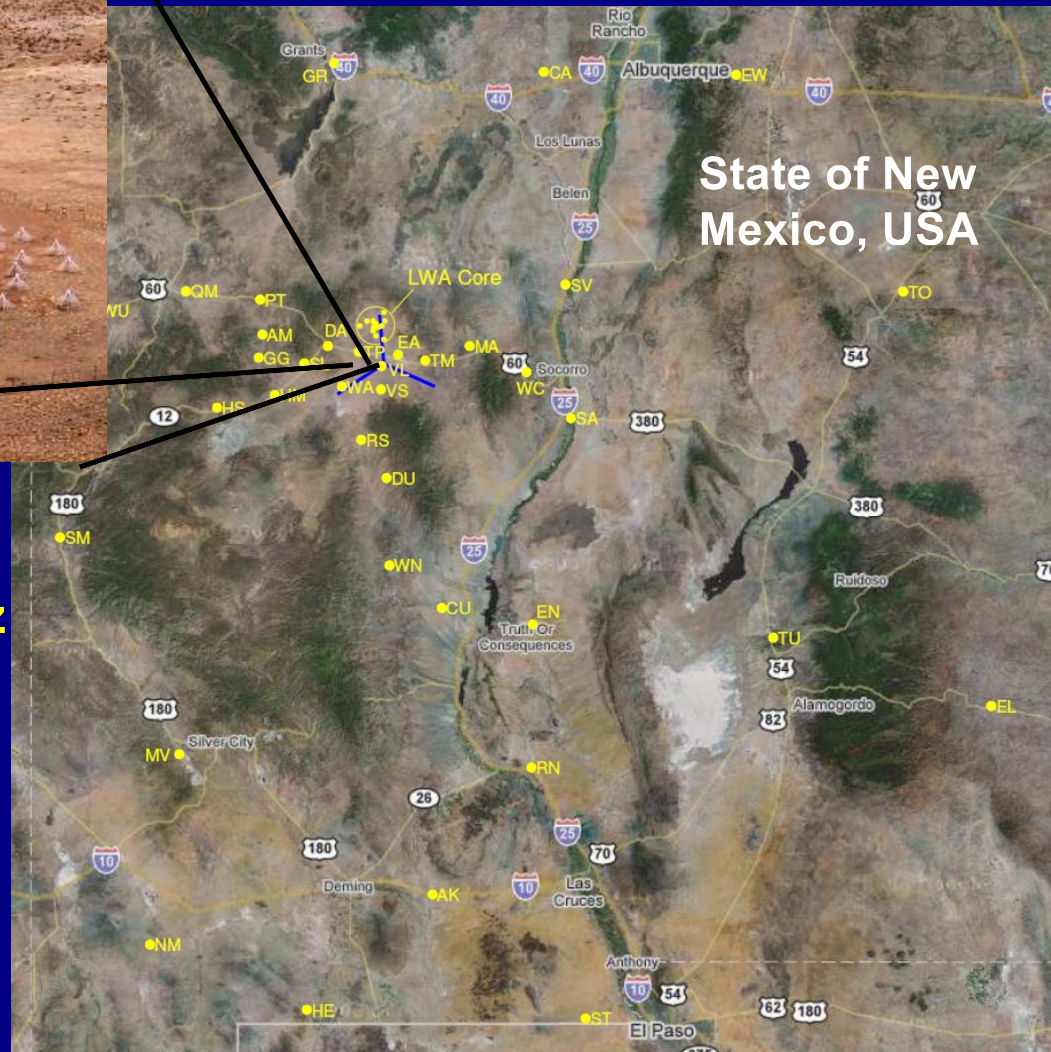
Example: wavelength = 5 cm, separation = 2 km, resolution = 5"

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") under construction, complete Jan 2011

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

Question:

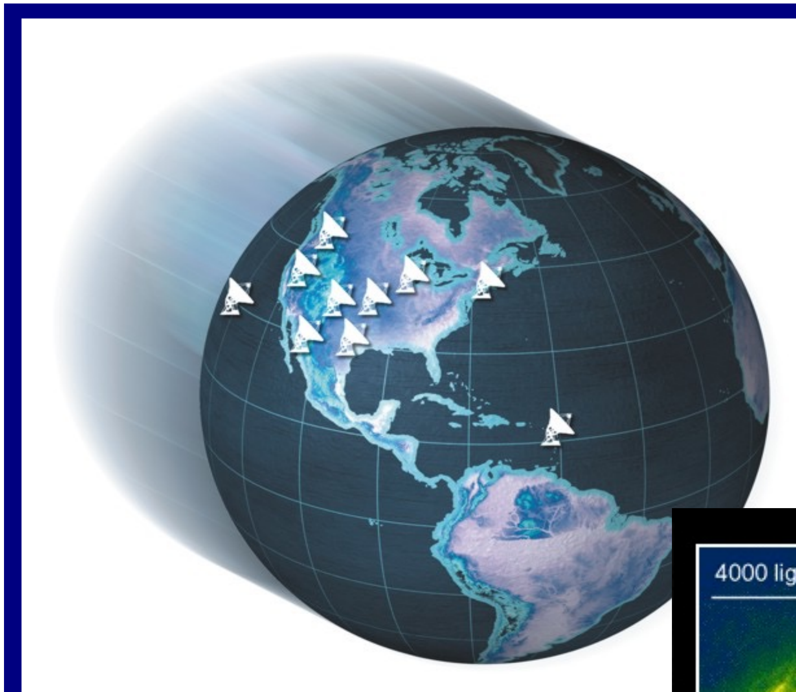
When multiple radio telescopes are used for interferometry, resolving power is most improved by *increasing*:

A: the distance between telescopes;

B: the number of telescopes in a given area;

C: the diameter of each telescope;

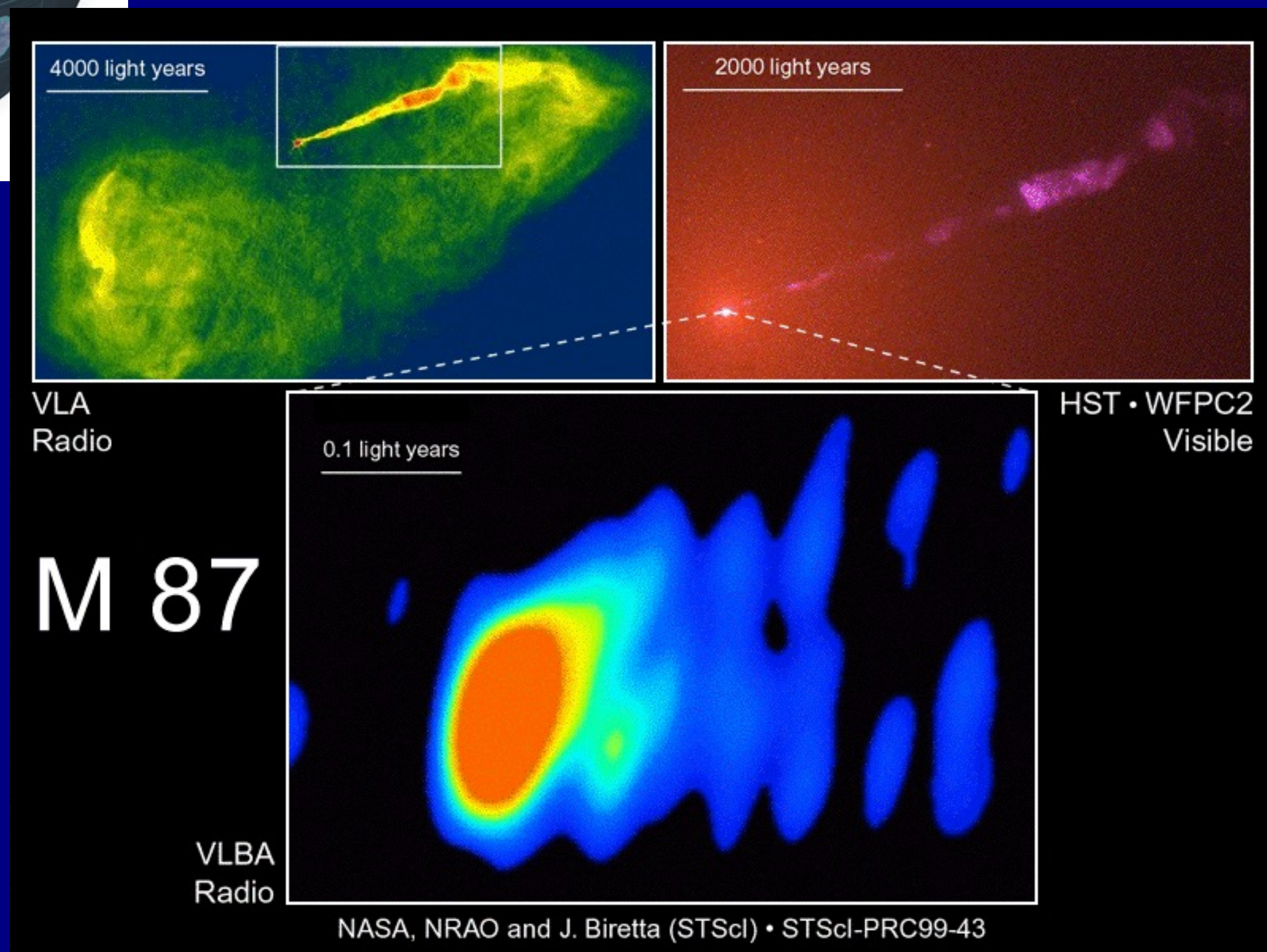
D: the power supplied to each telescope



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

resolution: few arcsec

resolution: 0.05 arcsec



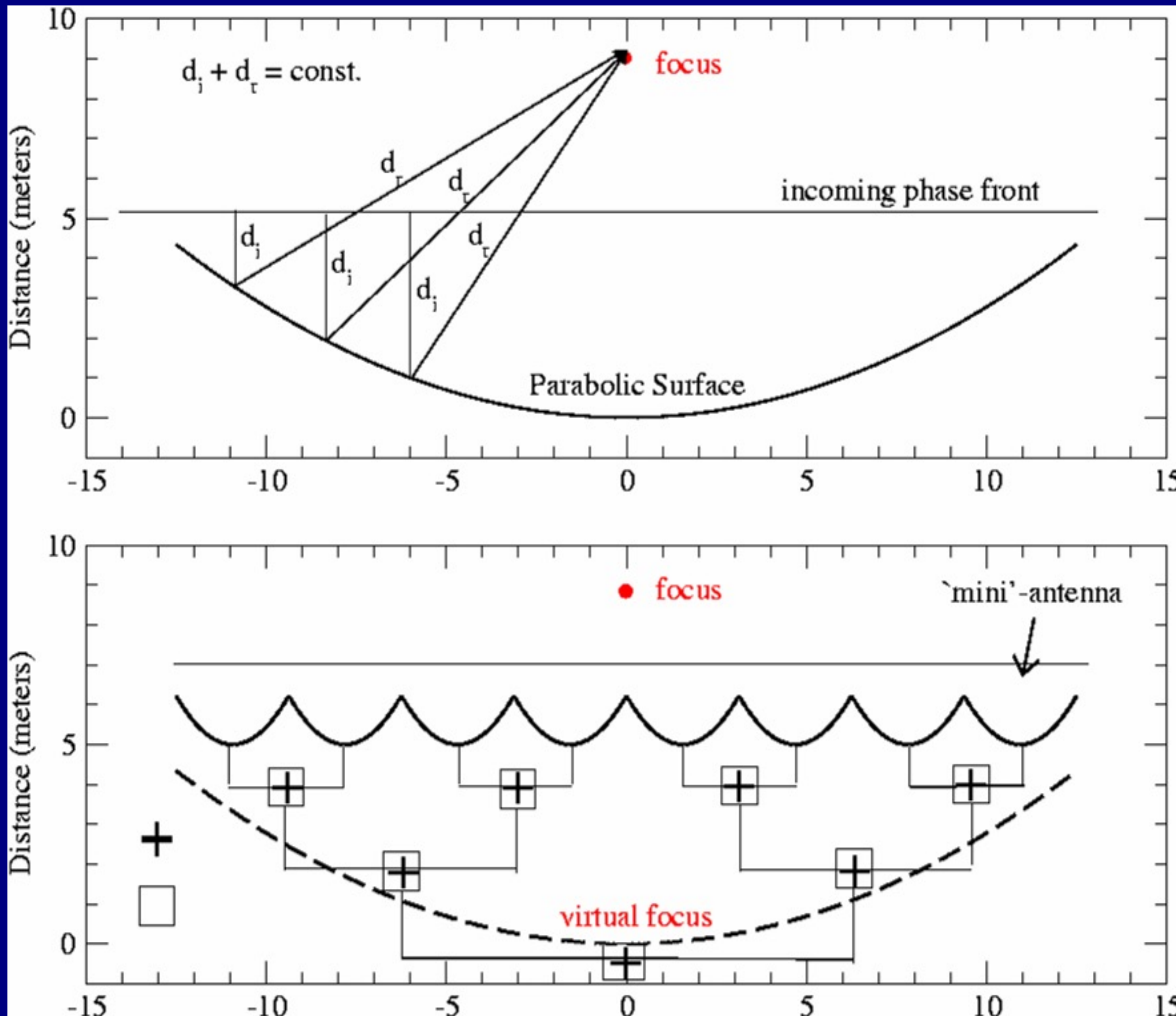
resolution: 0.001 arcsec!

Aperture Synthesis – Basic Concept

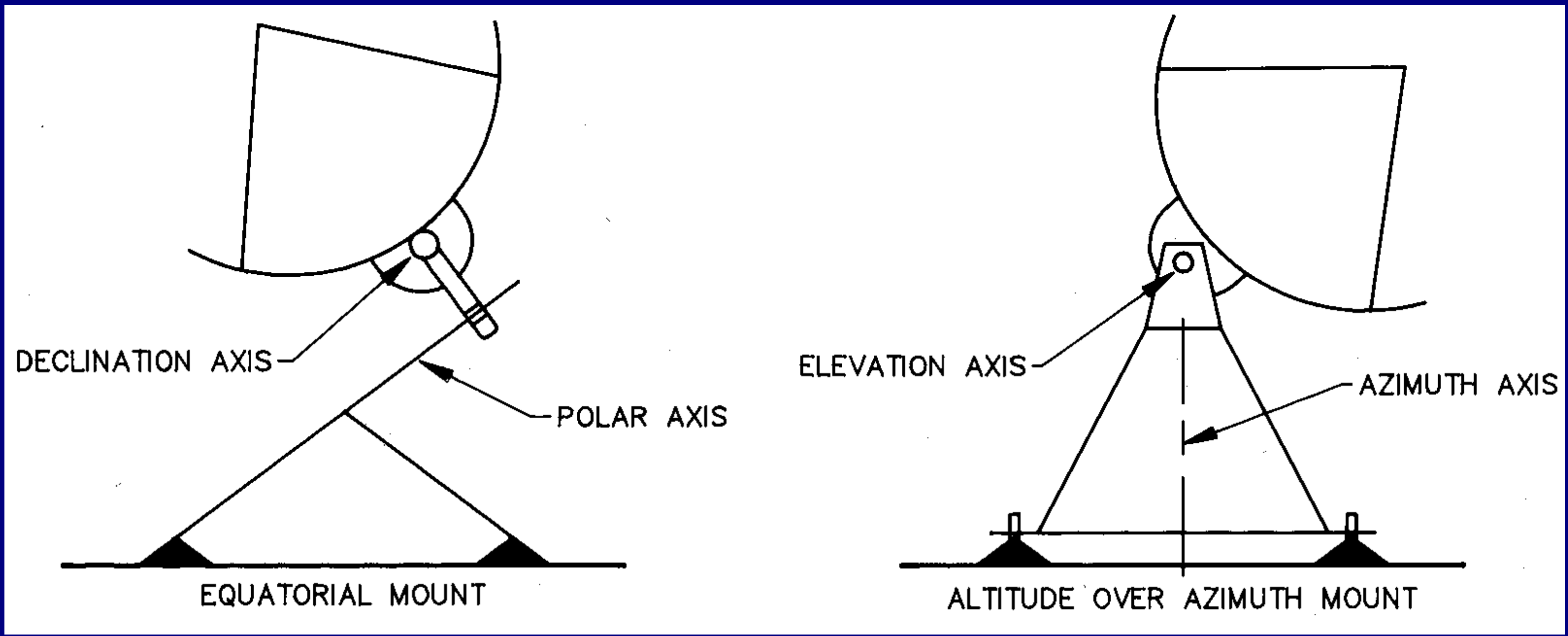
If the source emission is unchanging, there is no need to collect all of the incoming rays at one time.

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.



Types of Antenna Mount



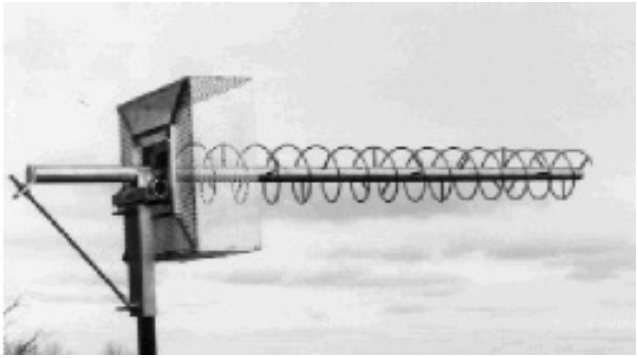
Equatorial mount	Altitude over azimuth mount
+ Beam does not rotate	+ Lower cost
+ Better tracking accuracy	+ Better gravity performance
– Higher cost	– Beam rotates on the sky
– Poorer gravity performance	

General Antenna Types

Wavelength > 1 m (approx)

Wire Antennas

Dipole

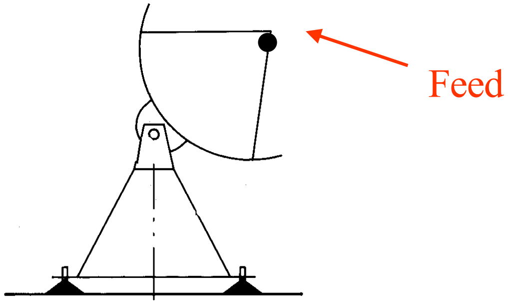


Yagi

Helix

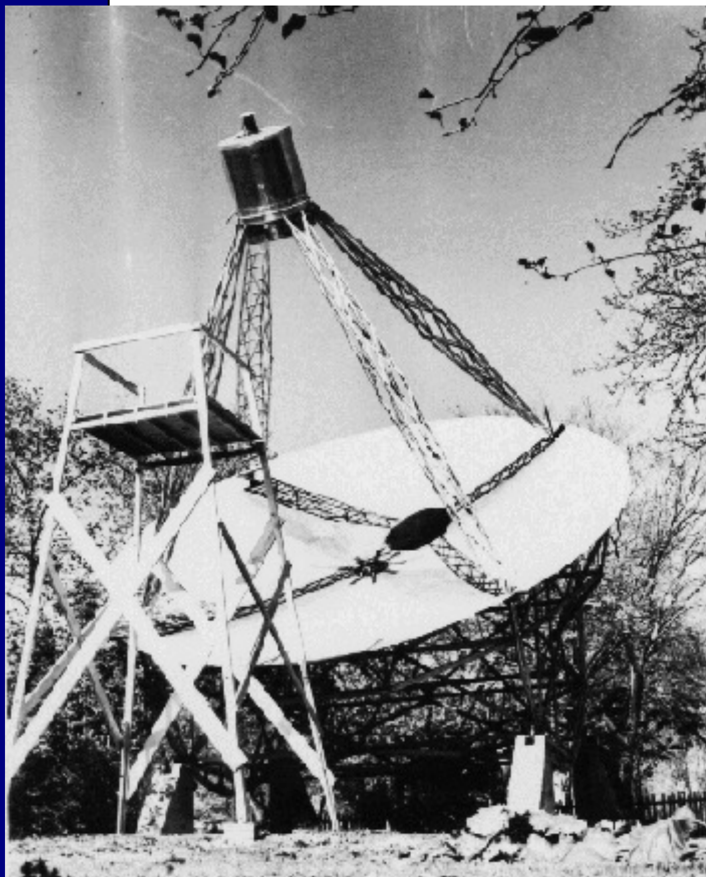
or arrays of these

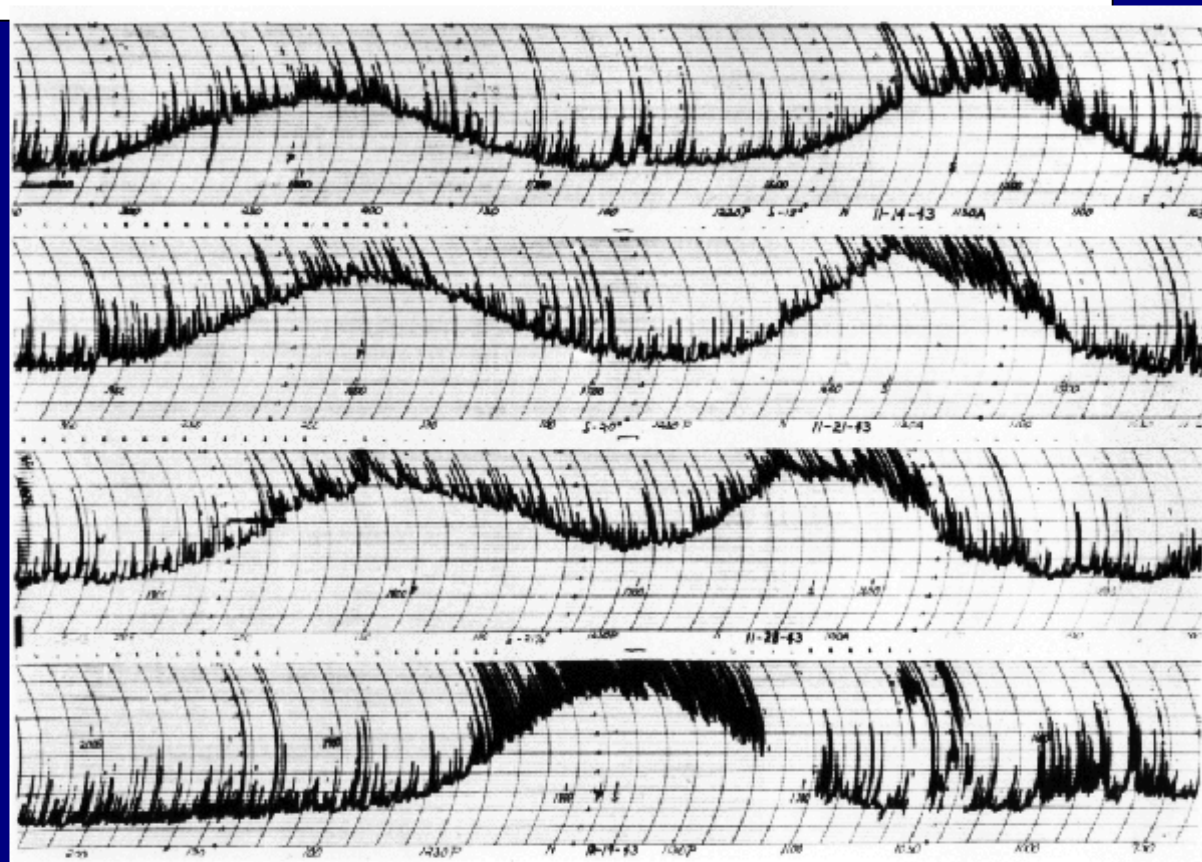
Wavelength < 1 m (approx)



Reflector antennas

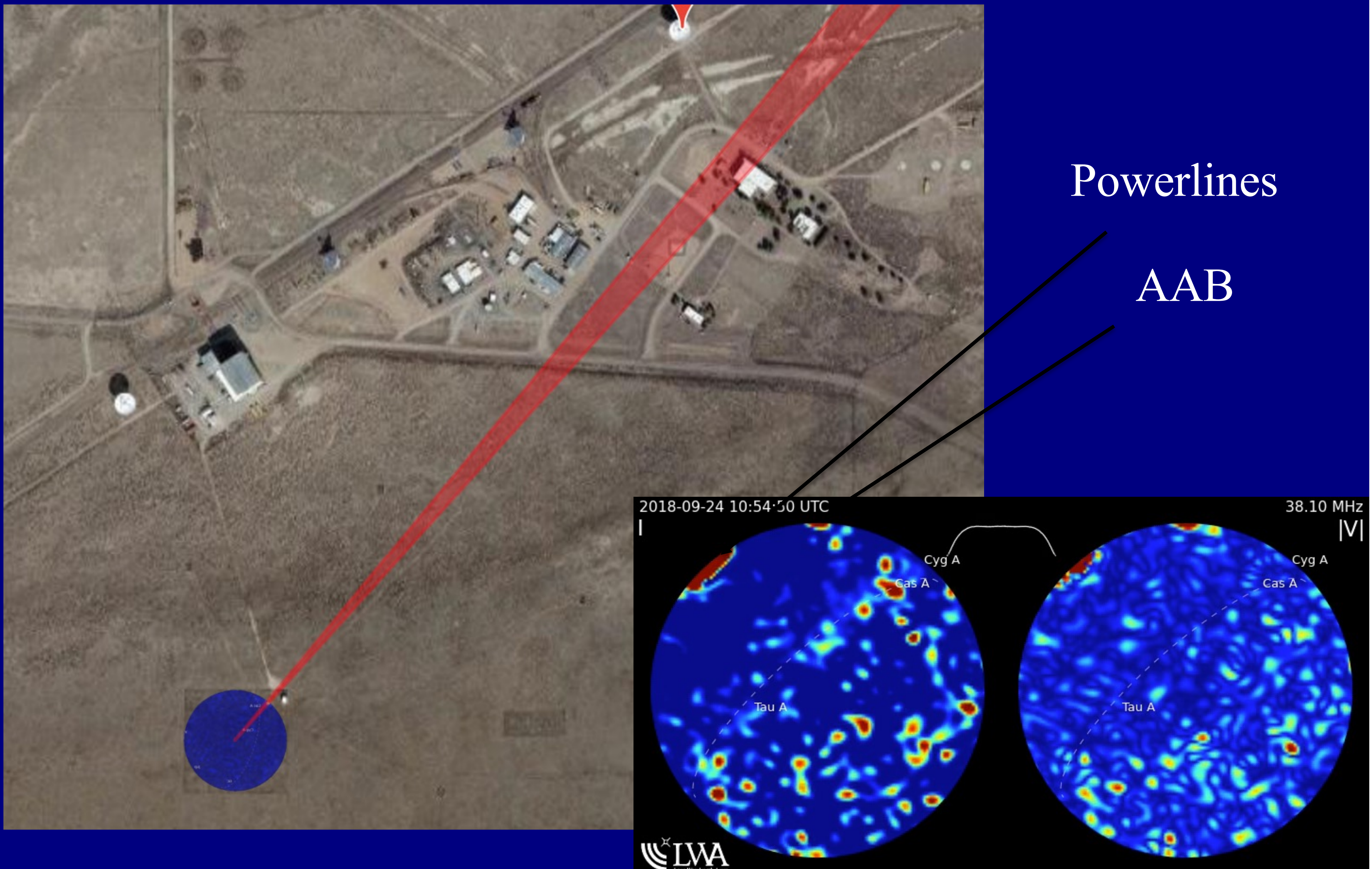
Radio Frequency Interference



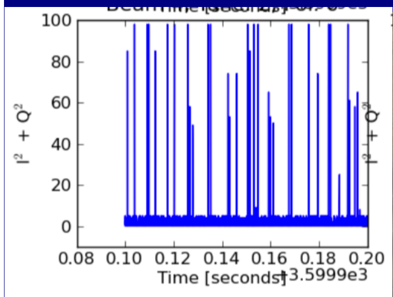


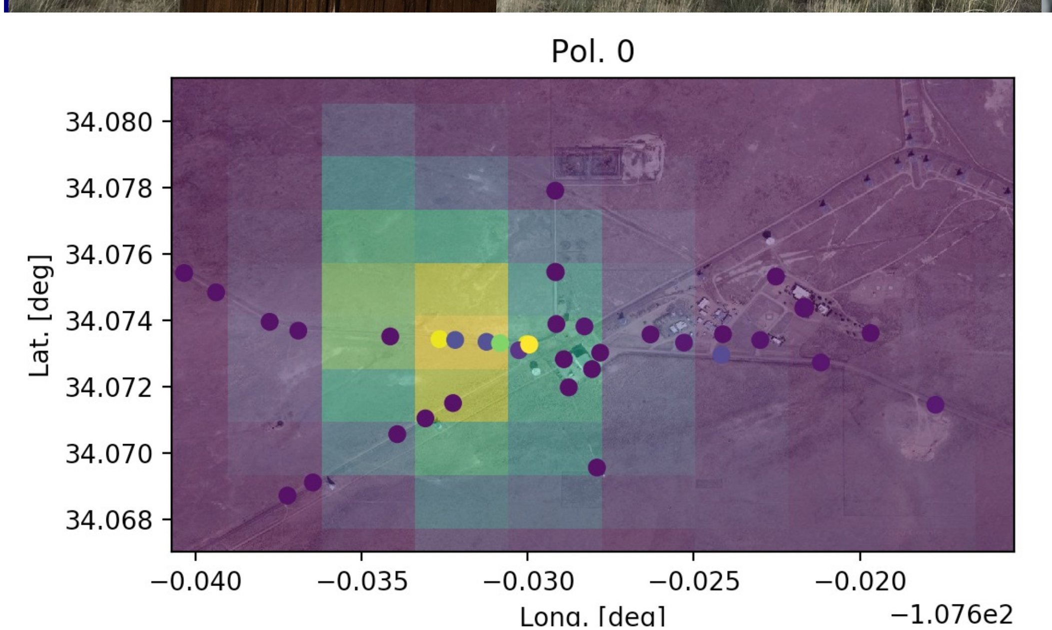
Grote Reber's telescope and Radio Frequency Interference in 1938

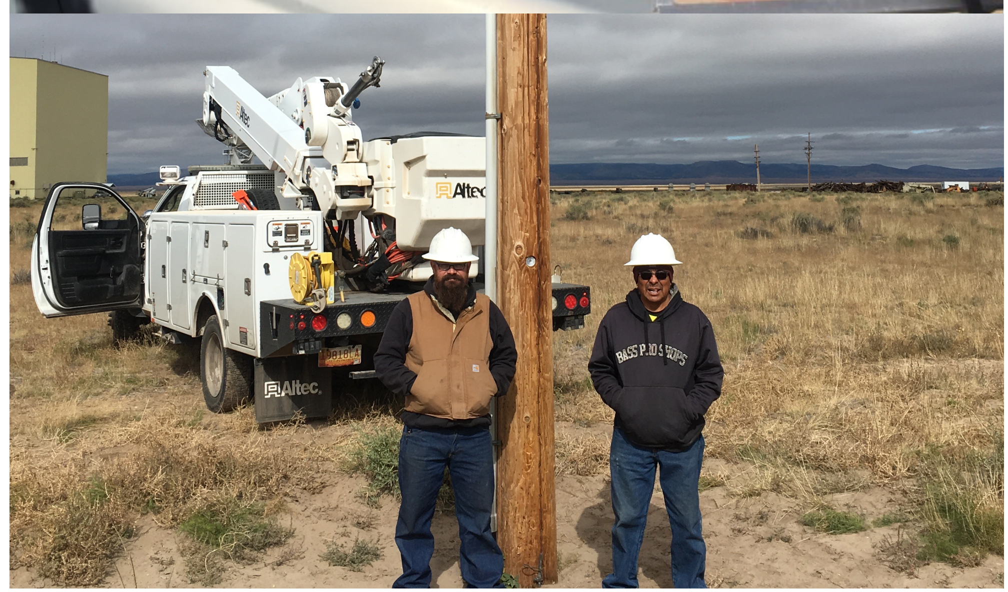
RFI - Powerlines



Detection and Mitigation of RFI from Powerlines

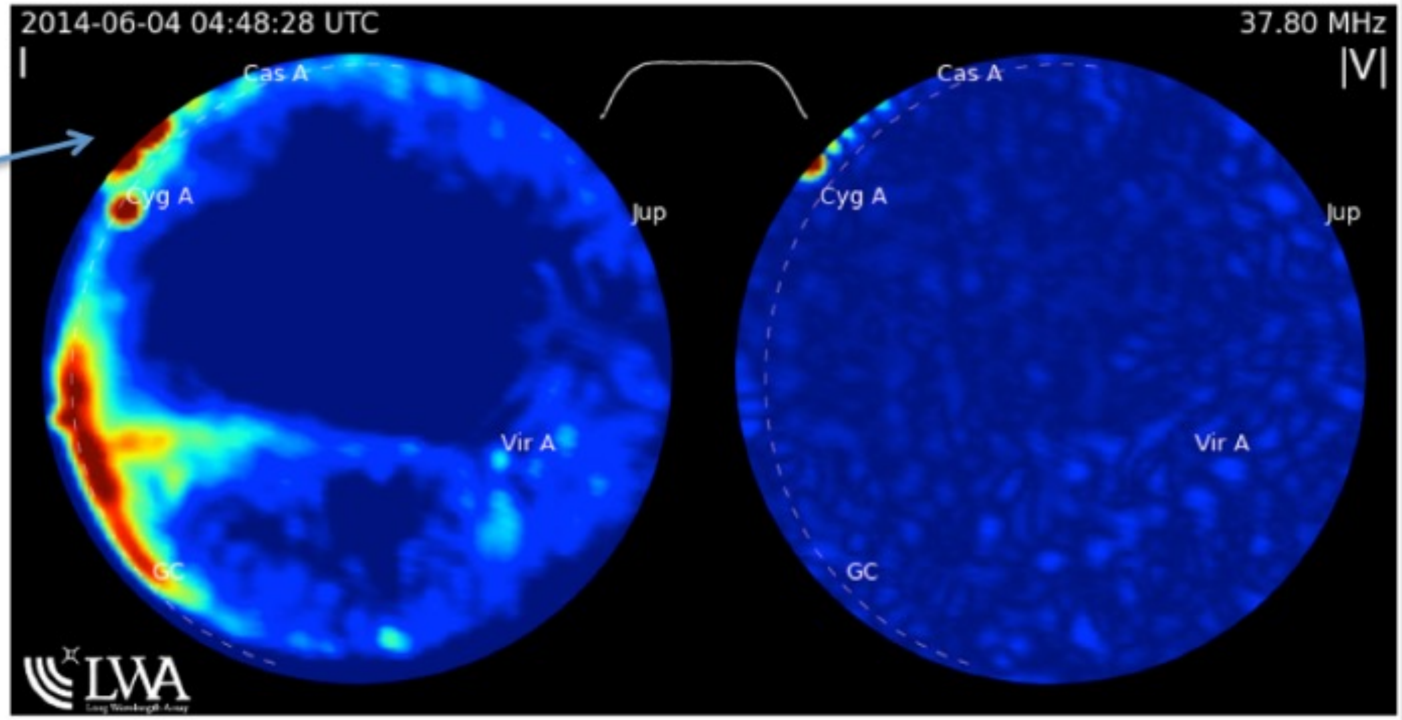






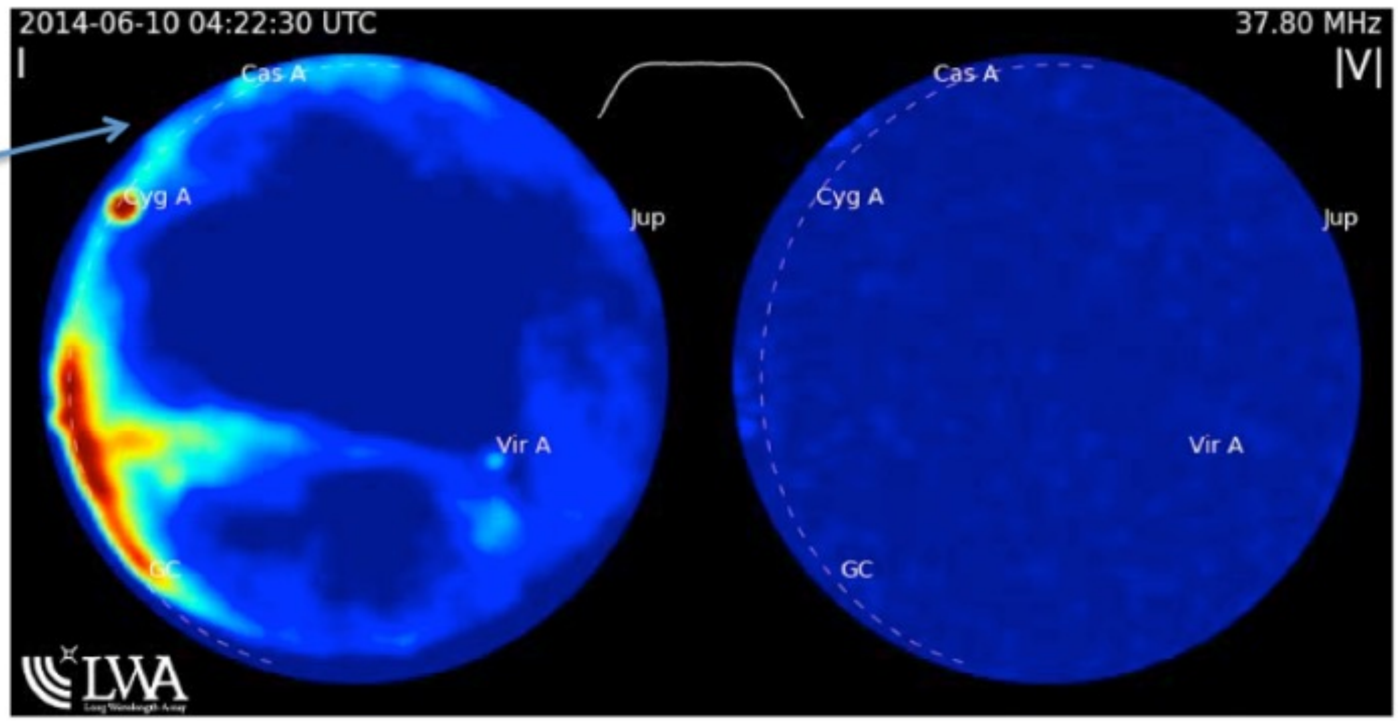
Before

Powerline noise

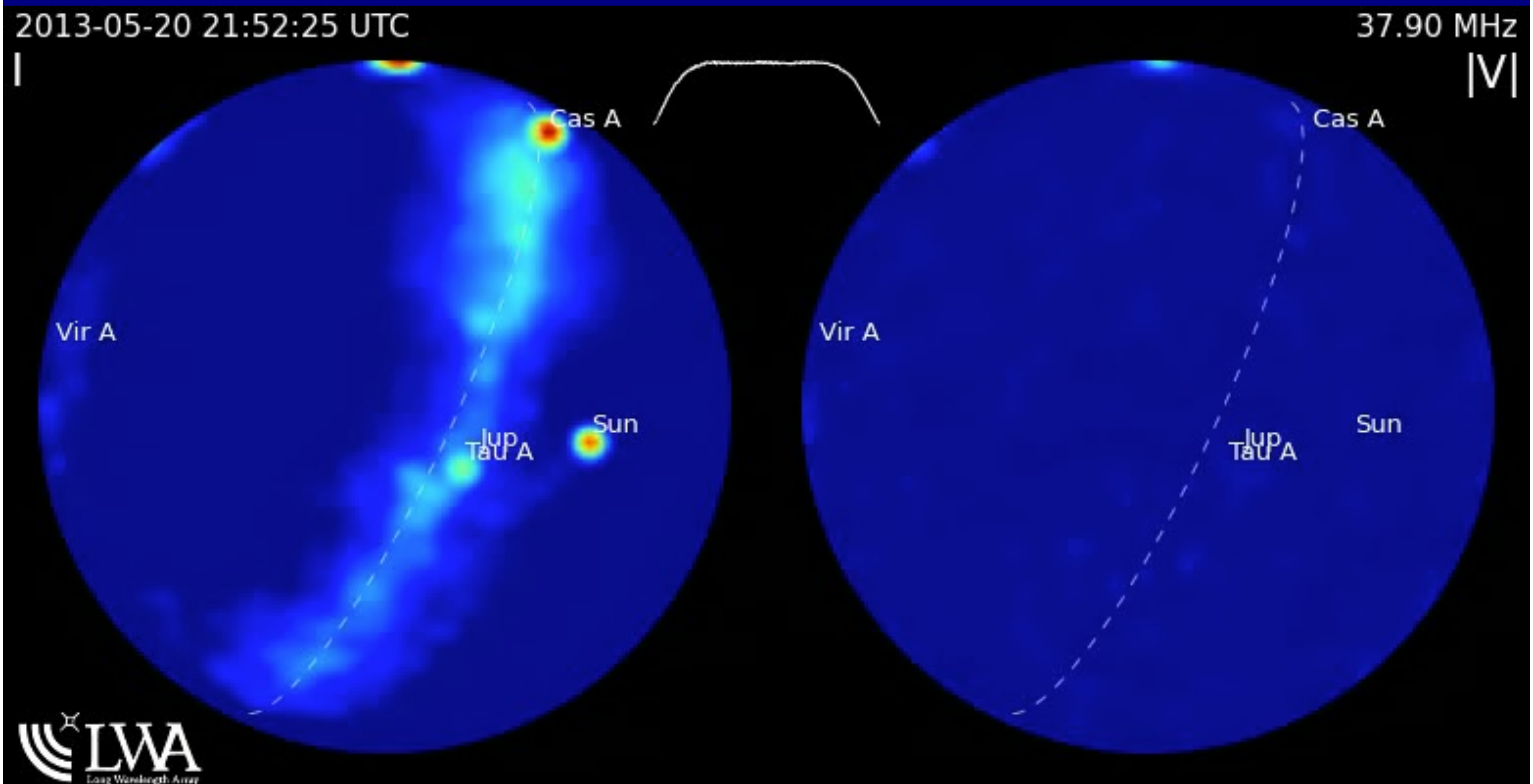


After

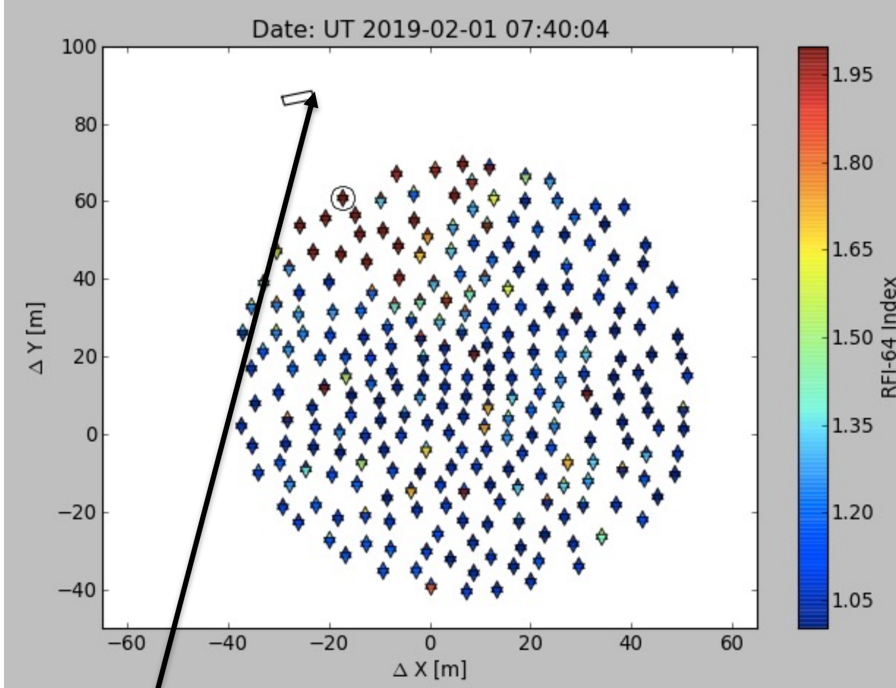
Clean
And overall
Image improved

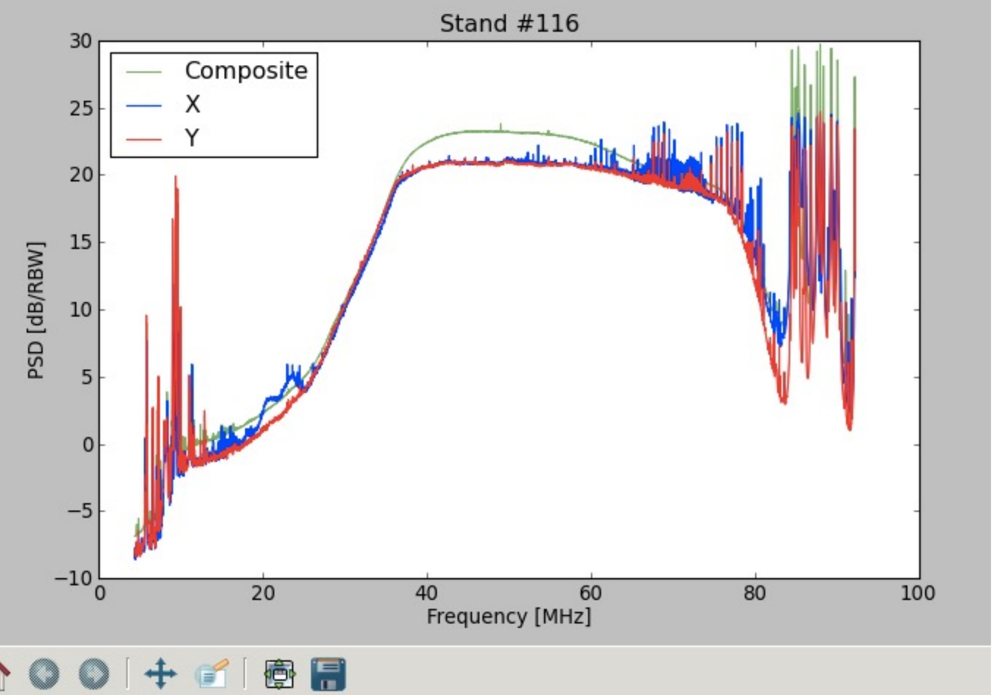


RFI – Lights in the AAB

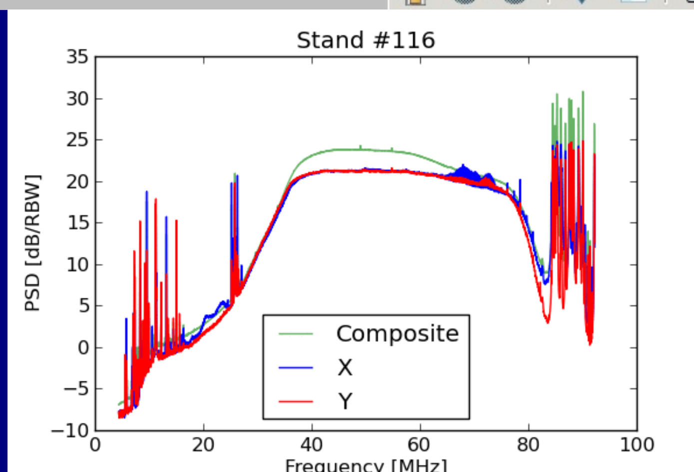


RFI – Cameras at LWA-SV





All-sky meteor camera



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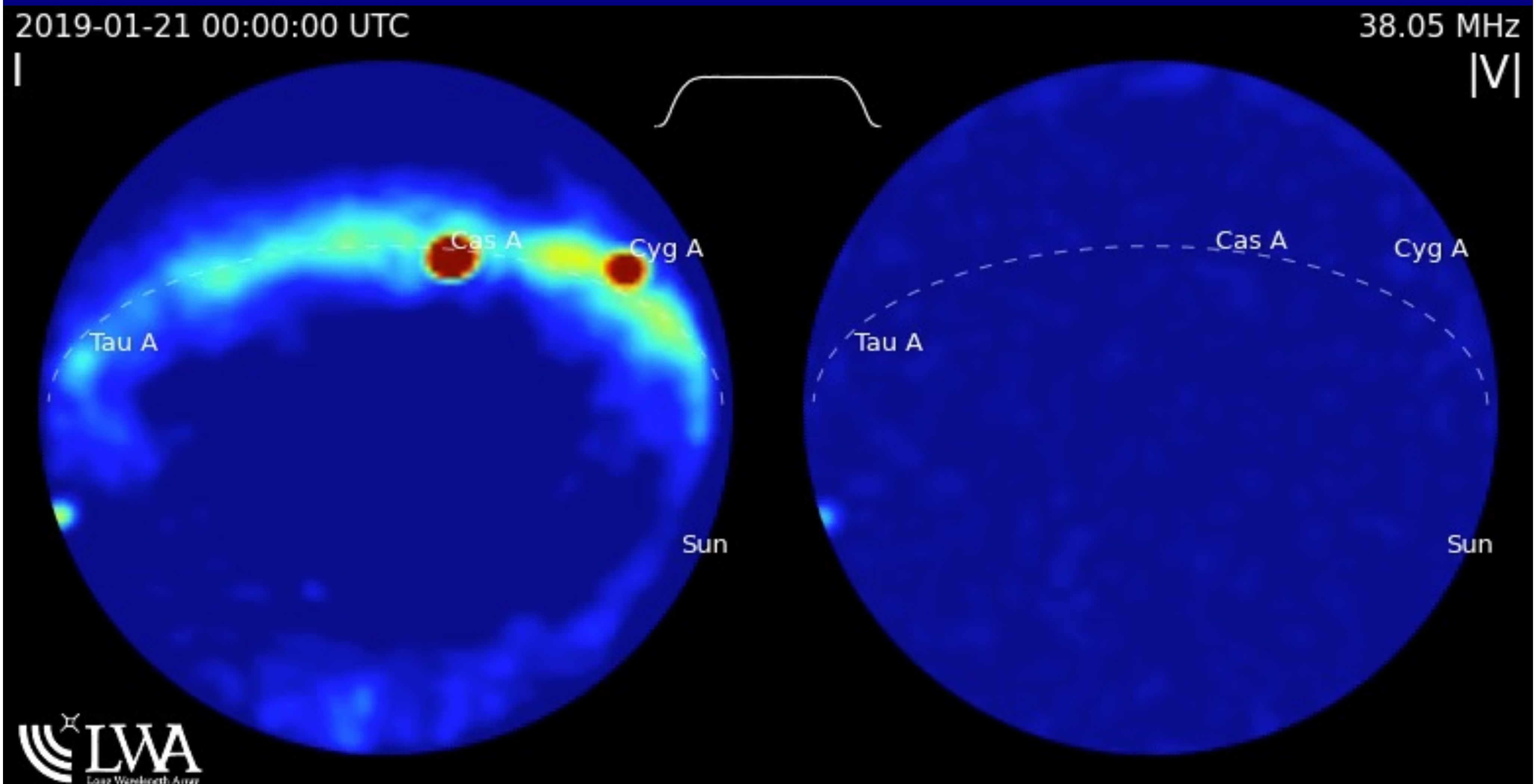
RFI - Planes



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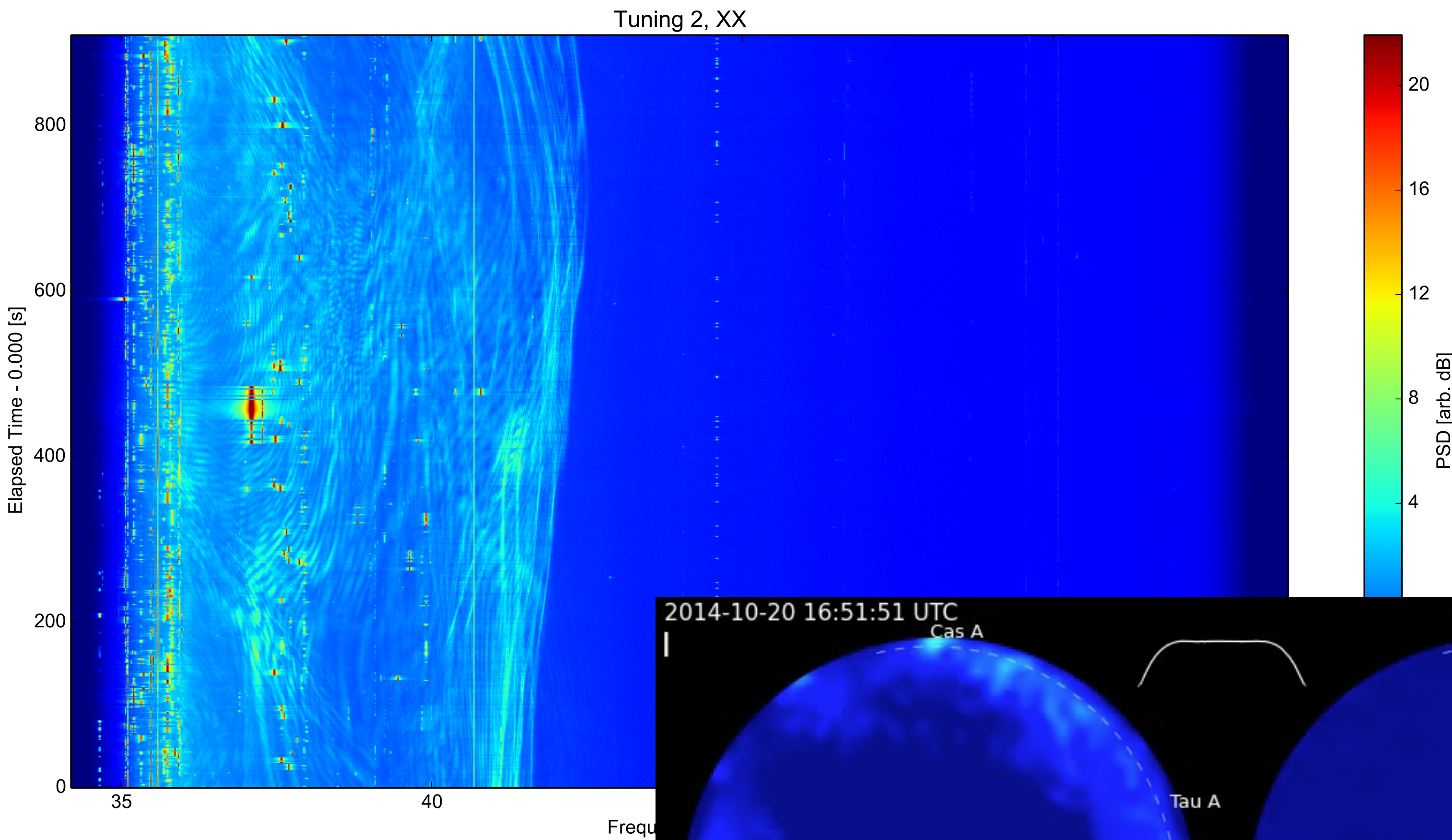
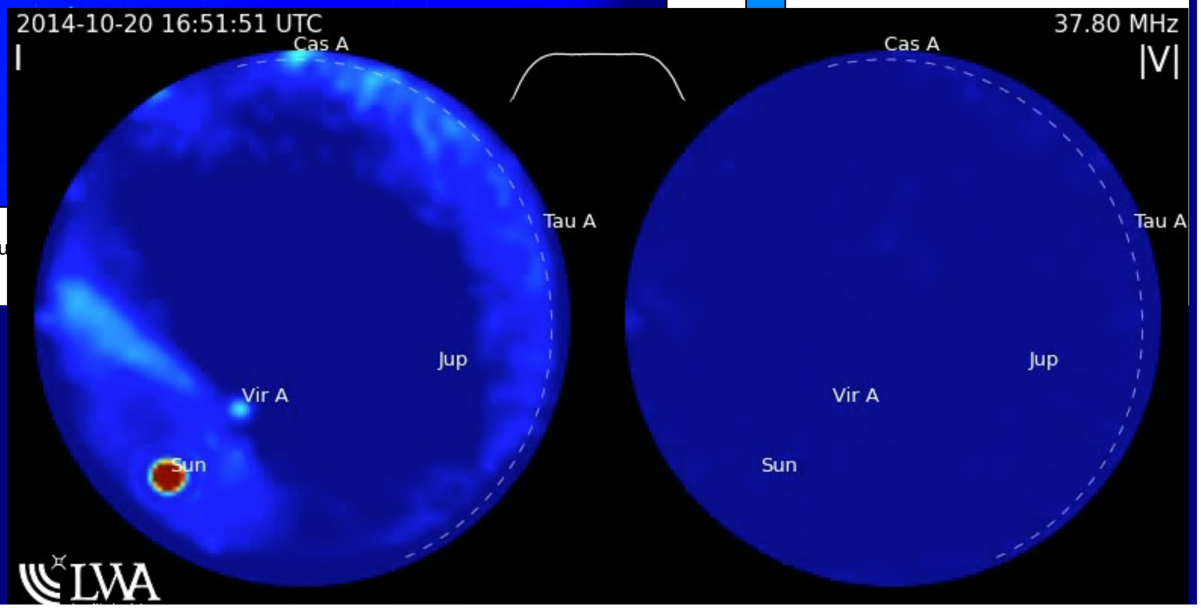
RFI - Strangeness





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