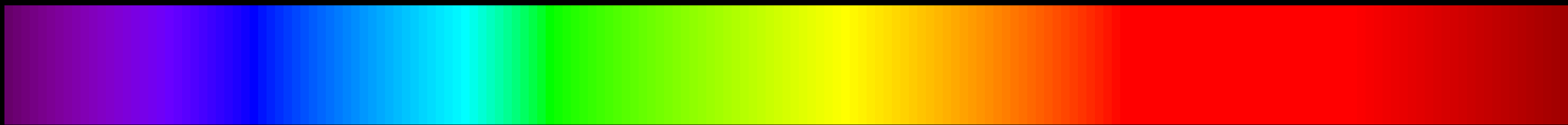
More About Light

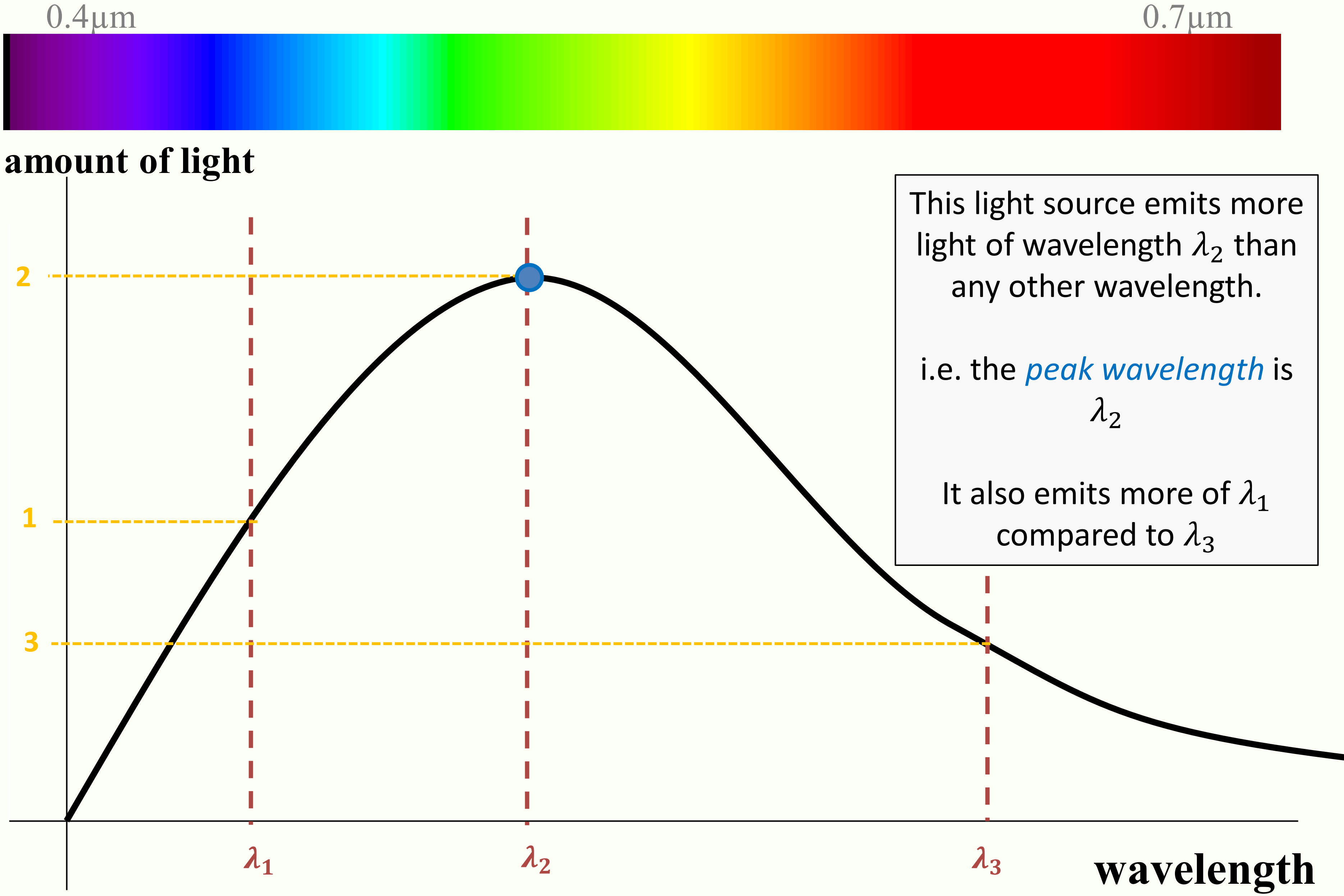
The sun emits a rainbow — a spectrum



How much light at each wavelength (color) depends on one thing:

the <u>TEMPERATURE</u> of the Sun

How much light at each wavelength?

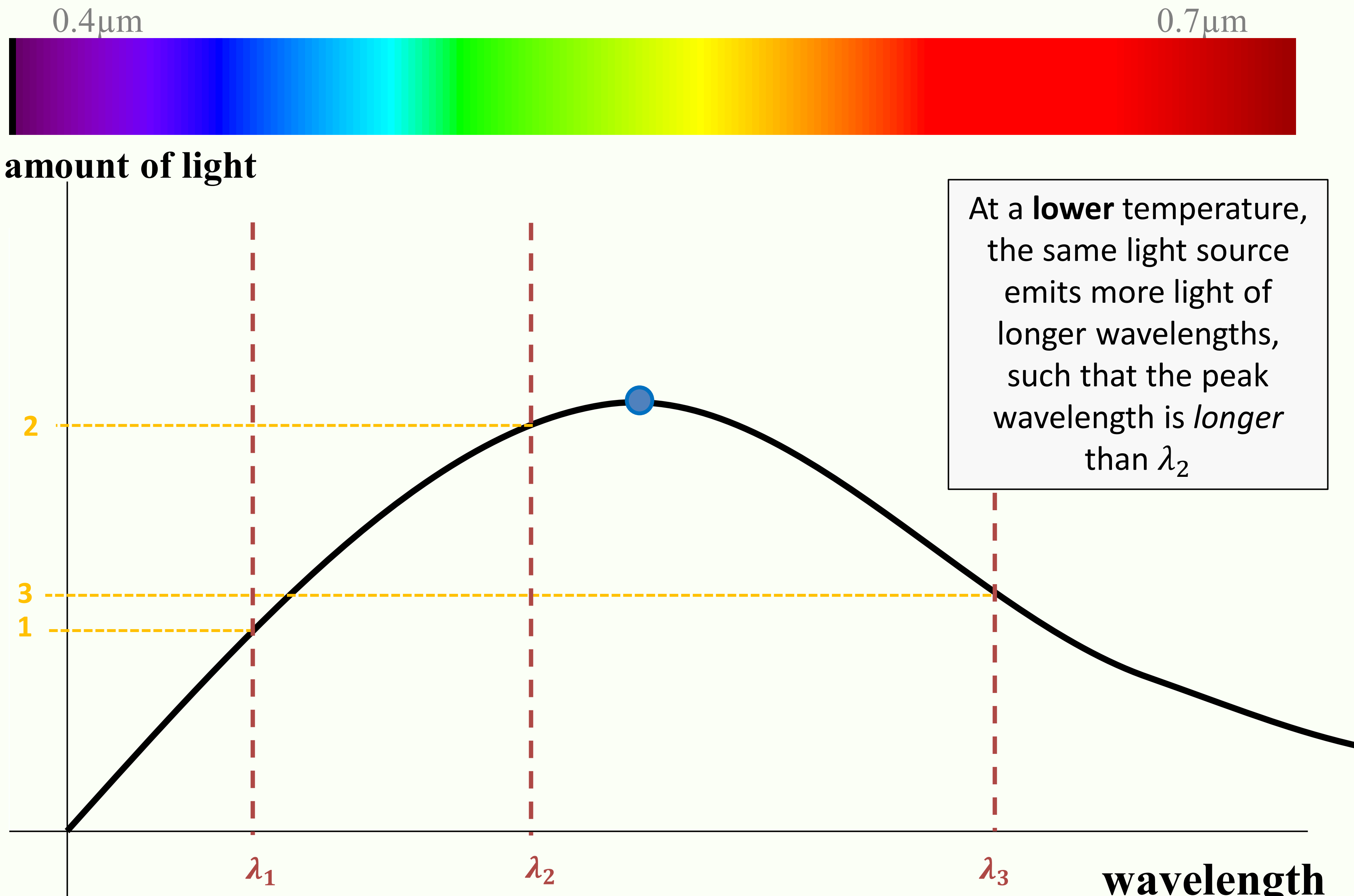


This light source emits more light of wavelength λ_2 than any other wavelength.

i.e. the *peak wavelength* is λ_2

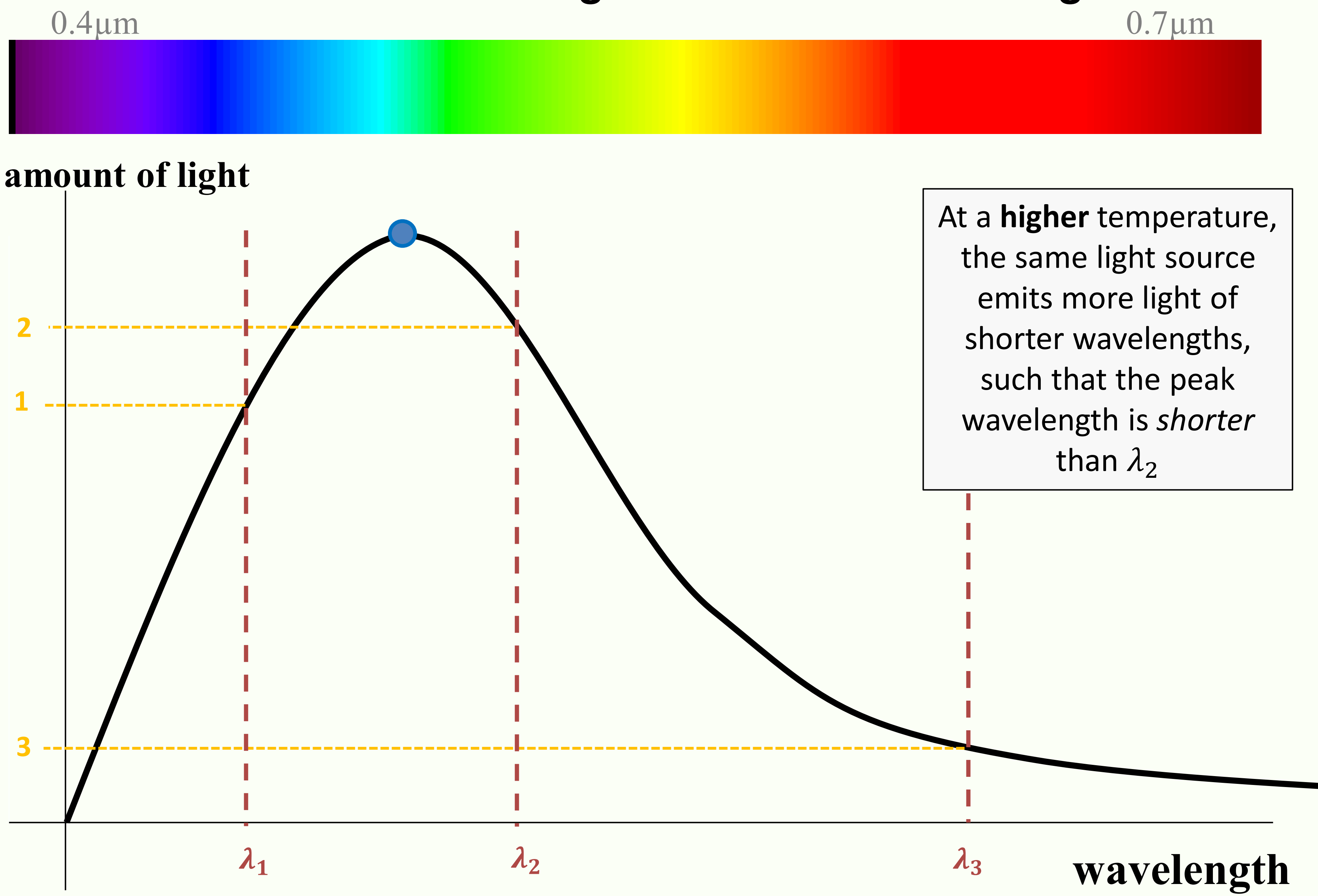
It also emits more of λ_1 compared to λ_3

COOL stars emit more light at longer wavelengths



At a **lower** temperature, the same light source emits more light of longer wavelengths, such that the peak wavelength is *longer* than λ_2

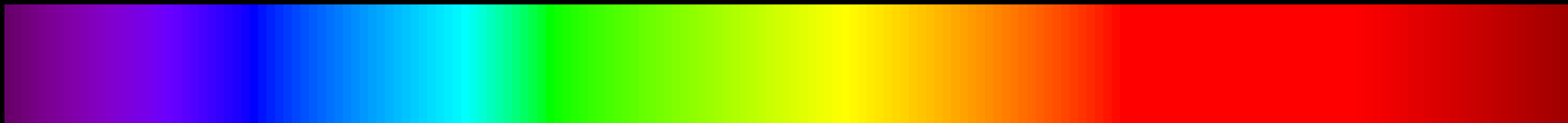
HOT stars emit more light at shorter wavelengths



All objects in the universe made out of charged particles emit light

How much light at each wavelength (color) depends on one thing:

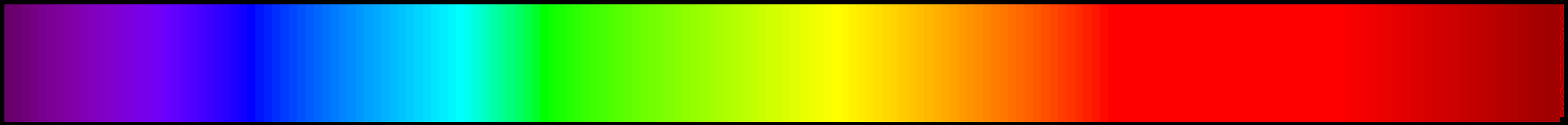
the TEMPERATURE of the object.



The color you see for the star is the color at which it puts out the most light.

The relation between color and peak wavelength is simple:

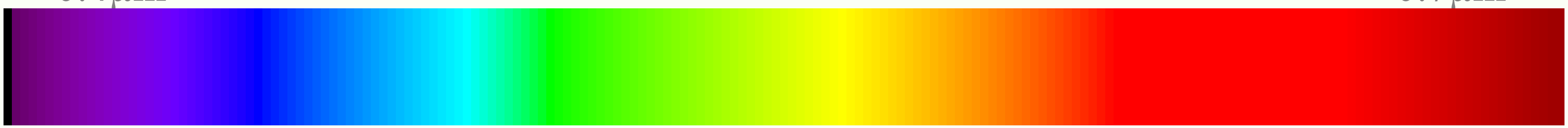
$$T = \frac{2900}{\lambda_{peak}}$$

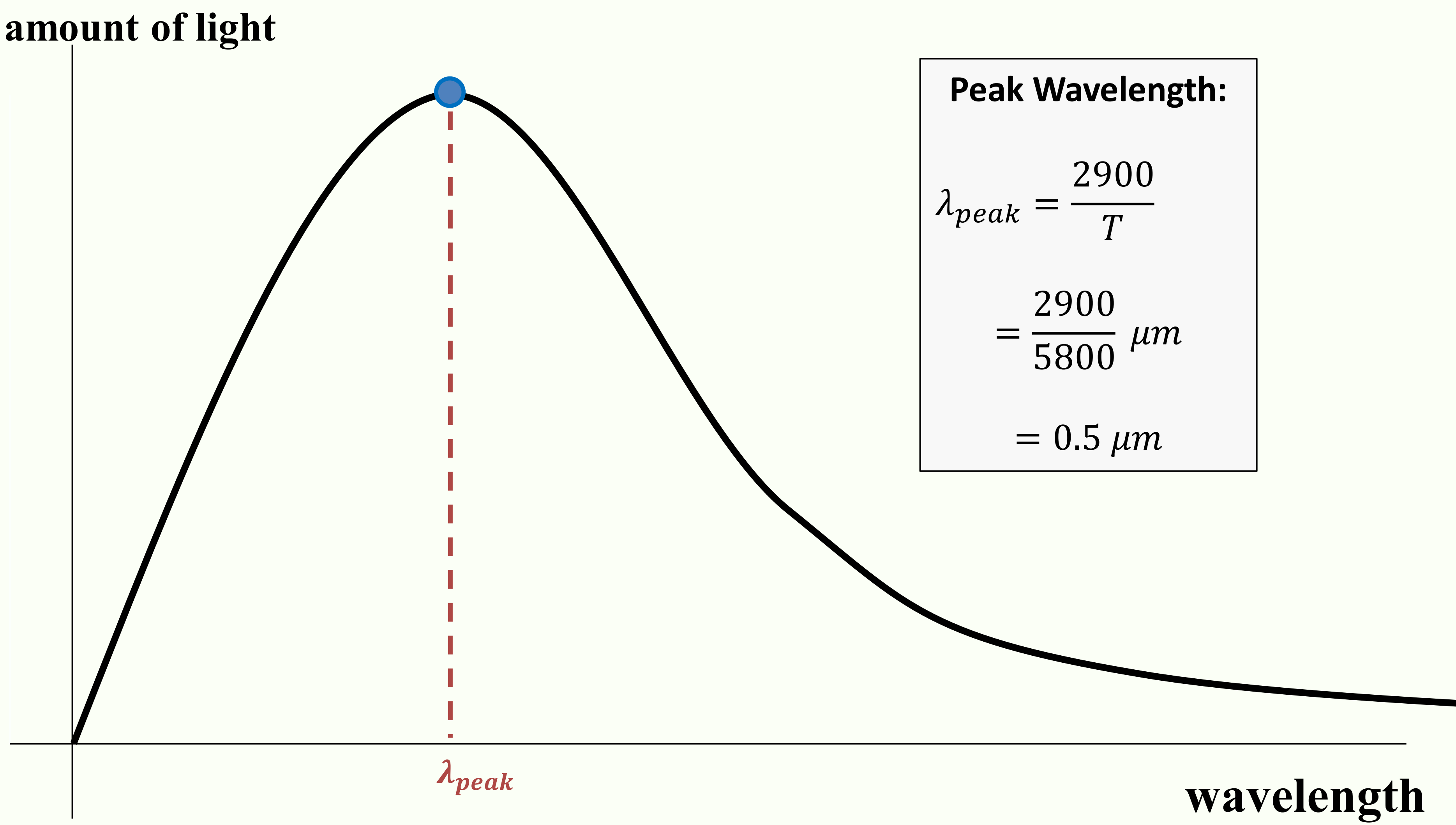


This means that the hotter the object, the bluer it appears, and the colder the object, the redder it appears

$$T = \frac{2900}{\lambda_{peak}}$$

So our Sun has a temperature of 5800 K





Peak Wavelength:

$$\lambda_{peak} = \frac{2900}{T}$$

$$= \frac{2900}{5800}\ \mu m$$

$$= 0.5\ \mu m$$

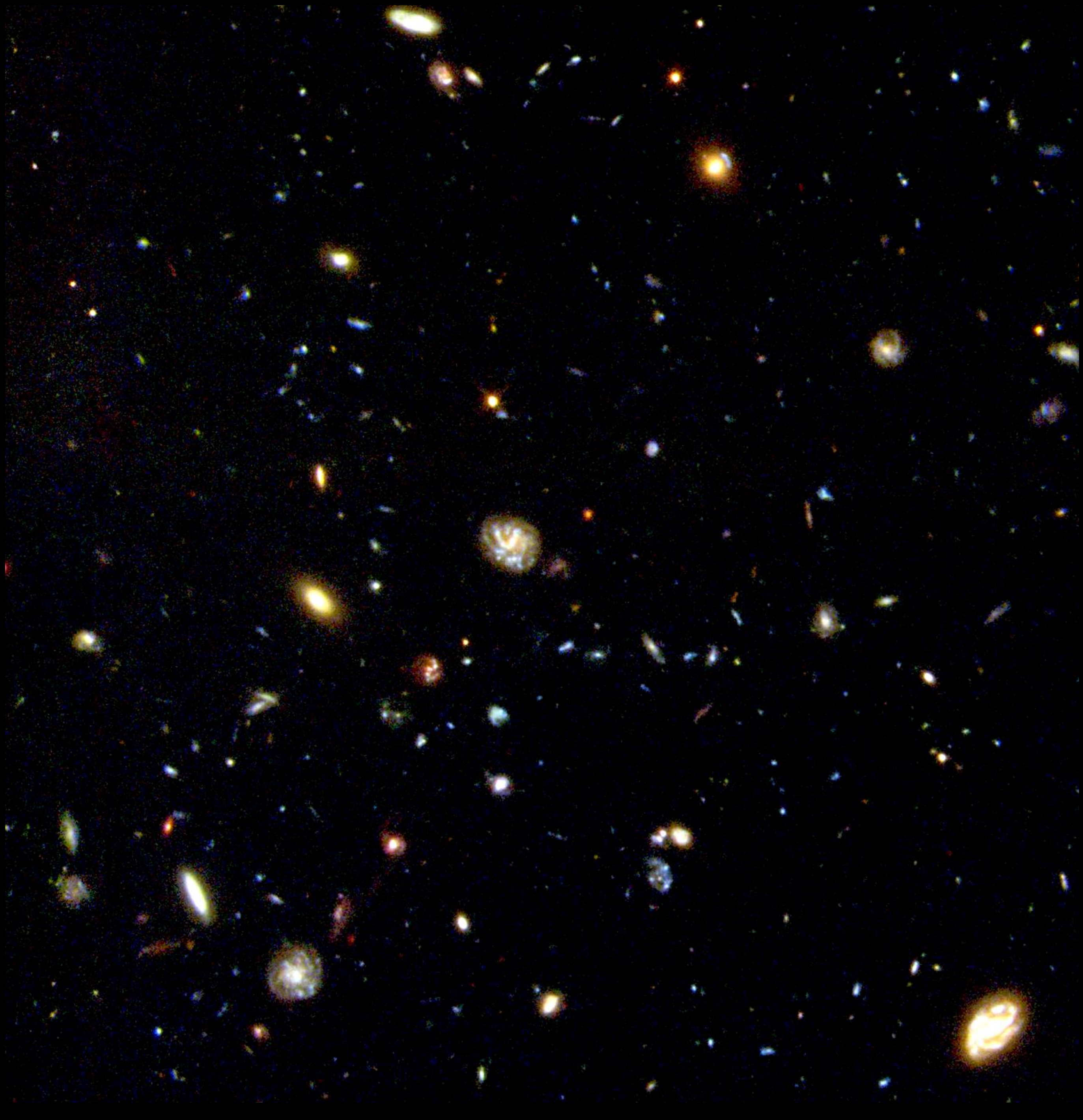
3,000 °K

5,800 °K

7,000 °K

10,000 °K

40,000 °K



IMAGES FROM TELESCOPES

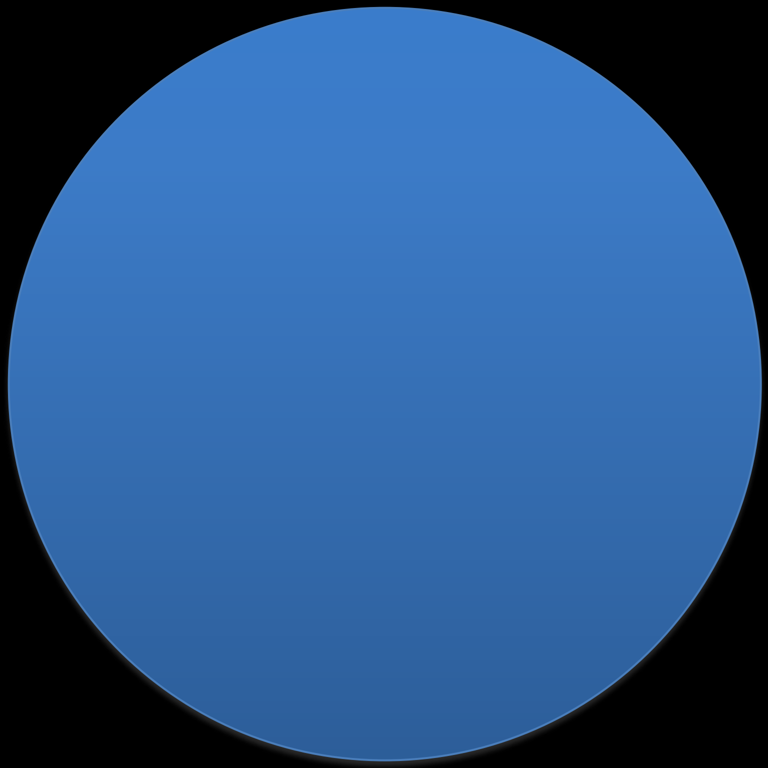
- Effects of Atmosphere
- Resolution
- Magnification

TELESCOPES in general:

- Refracting
- Reflecting

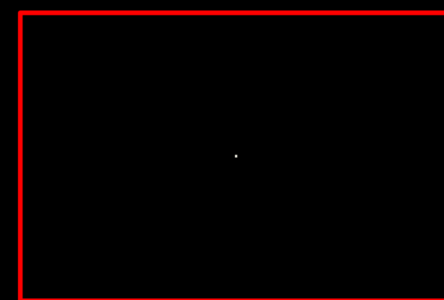
RESEARCH TELESCOPES (reflecting):

- Optical (visible light) Telescopes
- Radio Telescopes



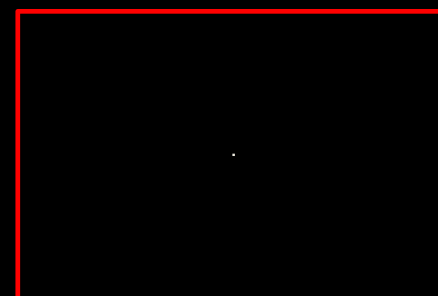
When light bends around (DIFFRACTS) the **edges** of the lens or mirror

Causing a diffraction pattern



star as a point source

image from
space telescope
with diffraction



star as a point
source

Diffraction due to light passing through the telescope smears the light out a little bit.

This is why we put telescope in Space

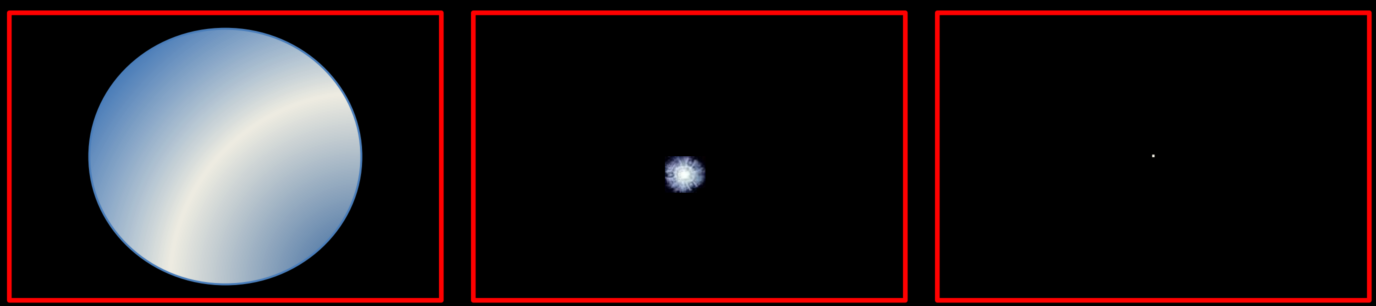
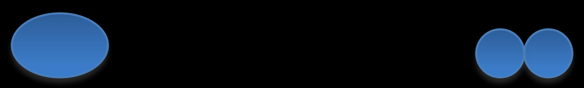


image from ground ← image from space with diffraction ← star as a point source

But refraction due to our atmosphere and the turbulent conditions of our atmosphere blur and distort the image.

RESOLUTION

Resolution is a measure of how much detail we can see in an image



Whether you can distinguish one blob or two — you see more detail on the right

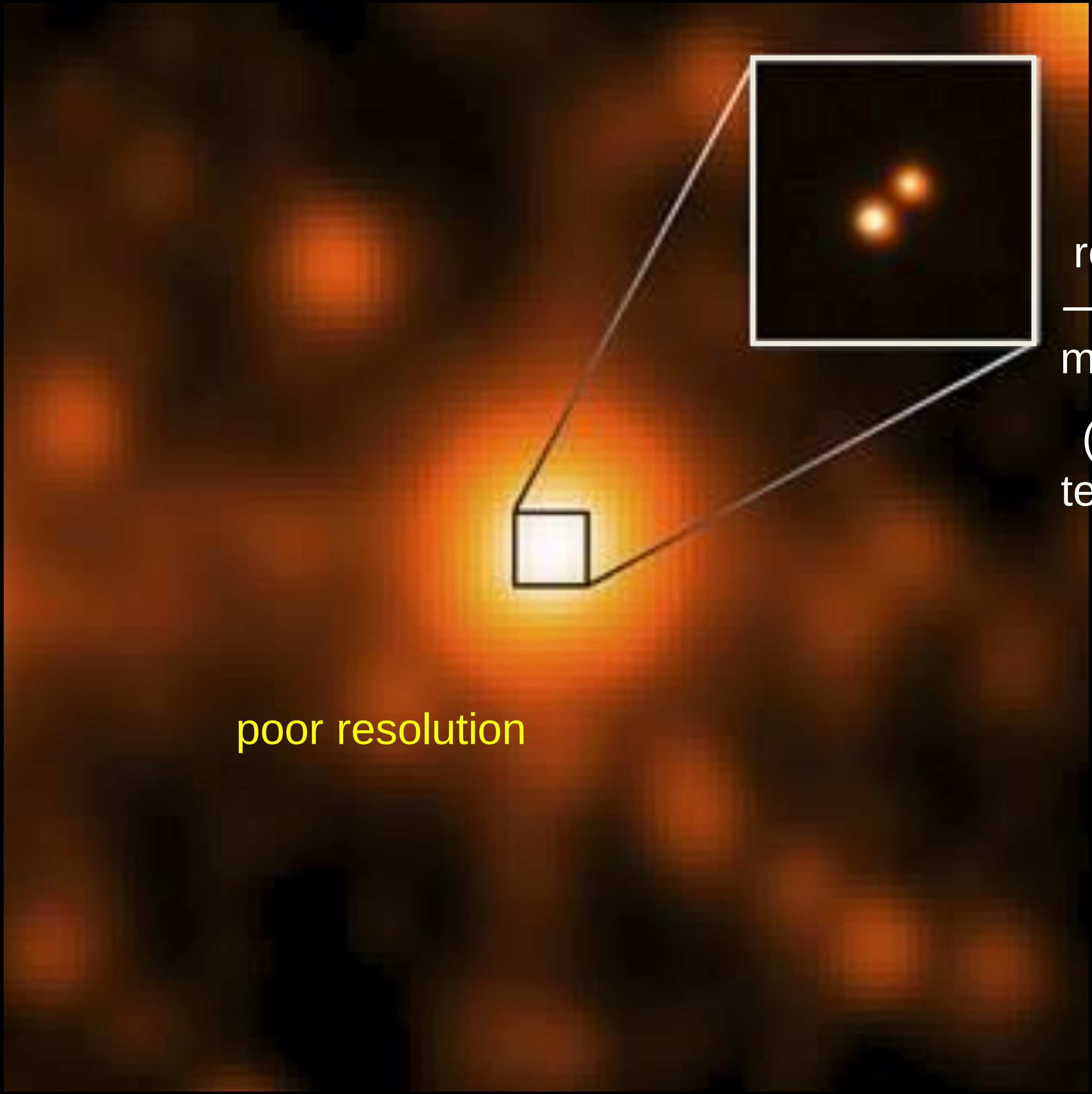
better RESOLUTION means more information

poor resolution

good resolution

poor resolution

good resolution



good resolution — can see more detail

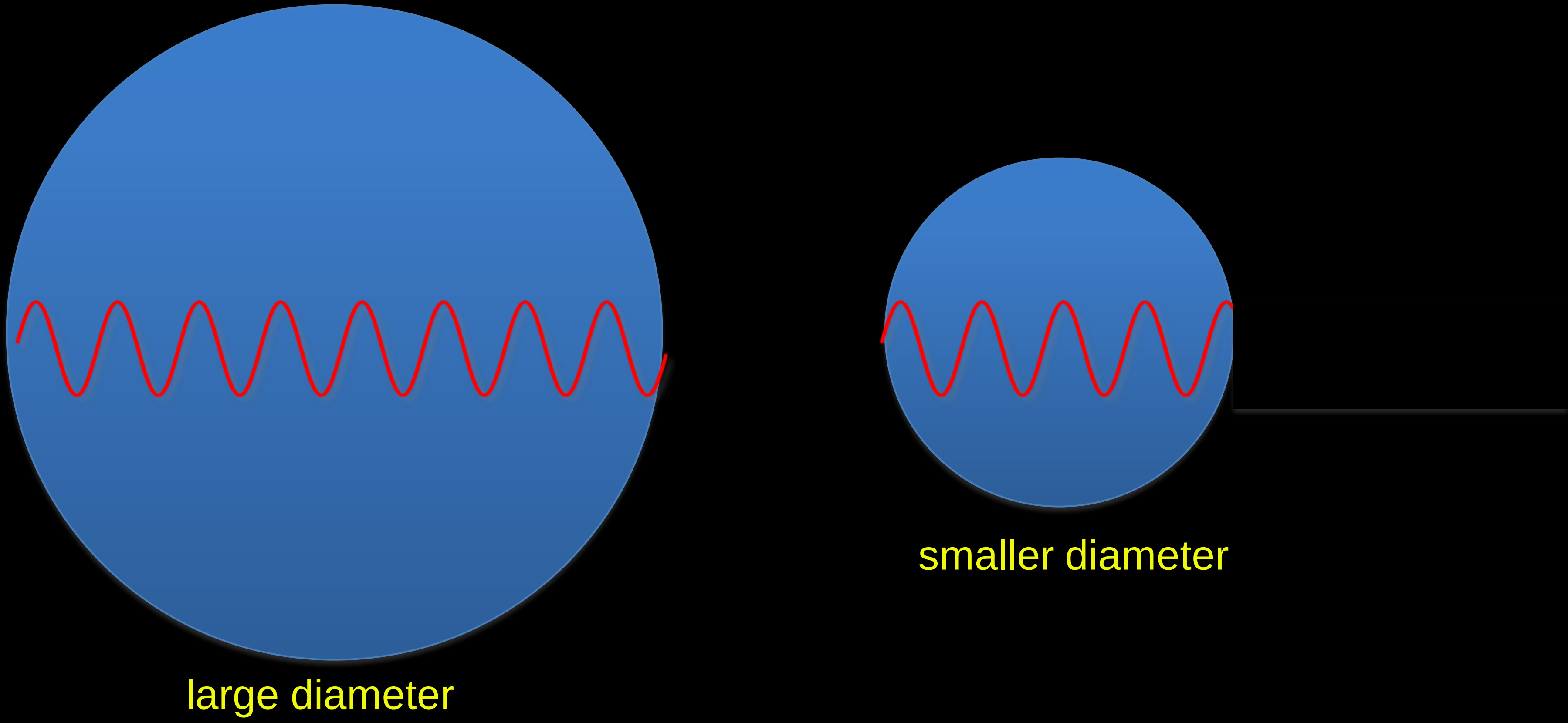
(different telescope!)

RESOLUTION

Resolution depends on the **diameter** of the telescope and the size of the **wavelength** observed

$$\text{Resolution} = \frac{\lambda}{\text{diameter of telescope}}$$

diameter of the telescope because the larger the surface, the more photons get captured.



The more photons, the more information, and so the better the resolution.

M82 — Cigar Galaxy

12 million l-y distant

small telescope

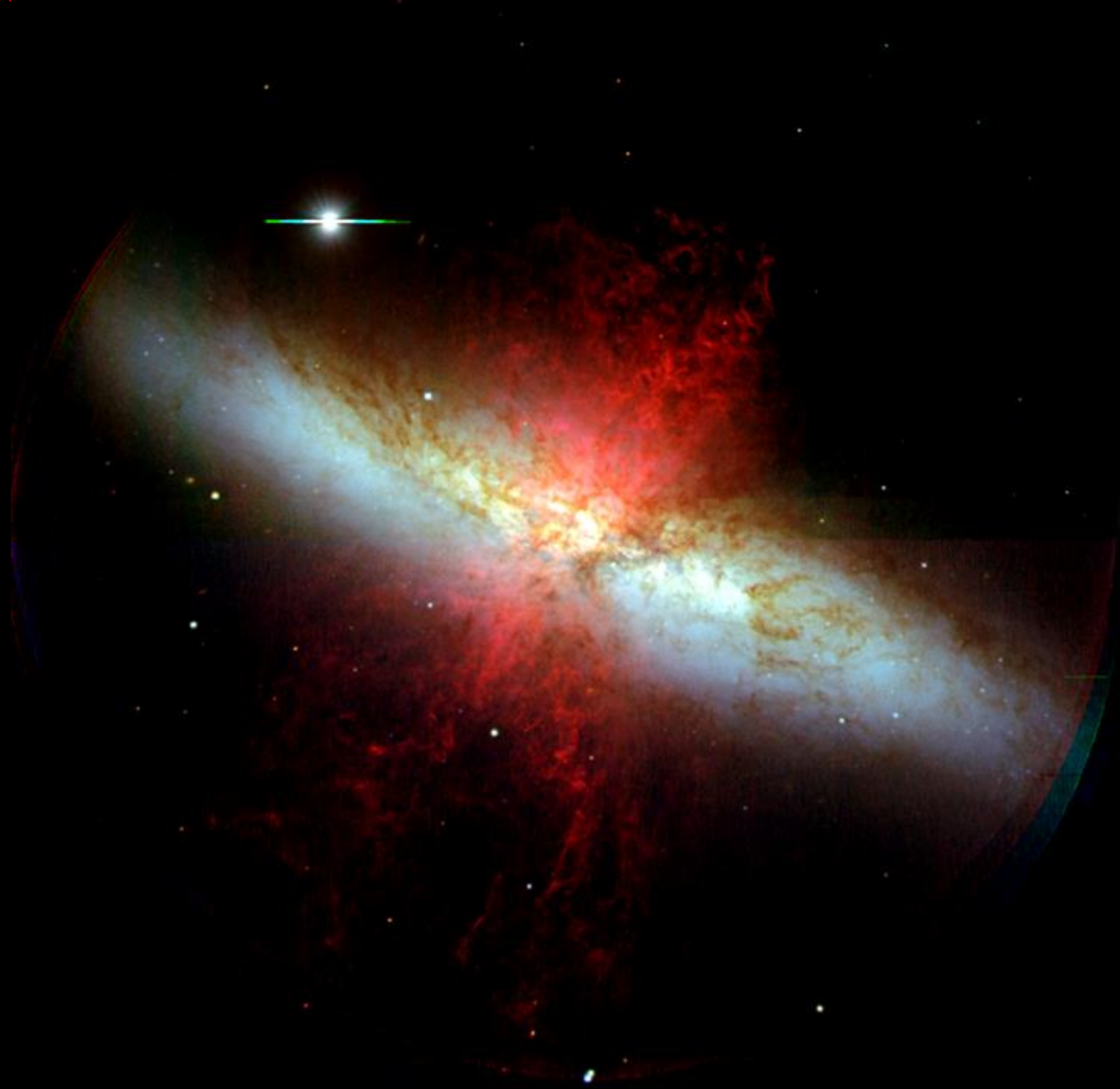
M82 — Cigar Galaxy

12 million l-y distant

medium telescope

M82 — Cigar Galaxy

12 million l-y distant



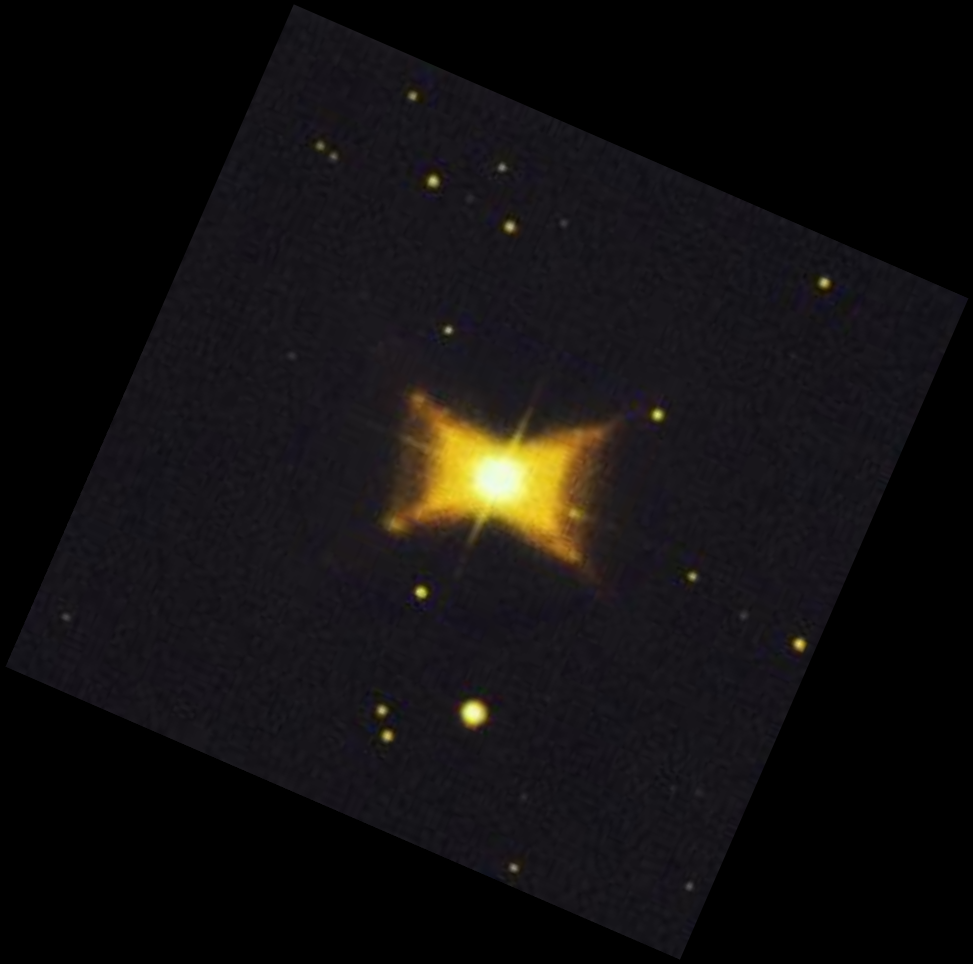
large telescope

Horsehead Nebula, small telescope

Horsehead Nebula, medium telescope

Horsehead Nebula, HST

RESOLUTION and MAGNIFICATION



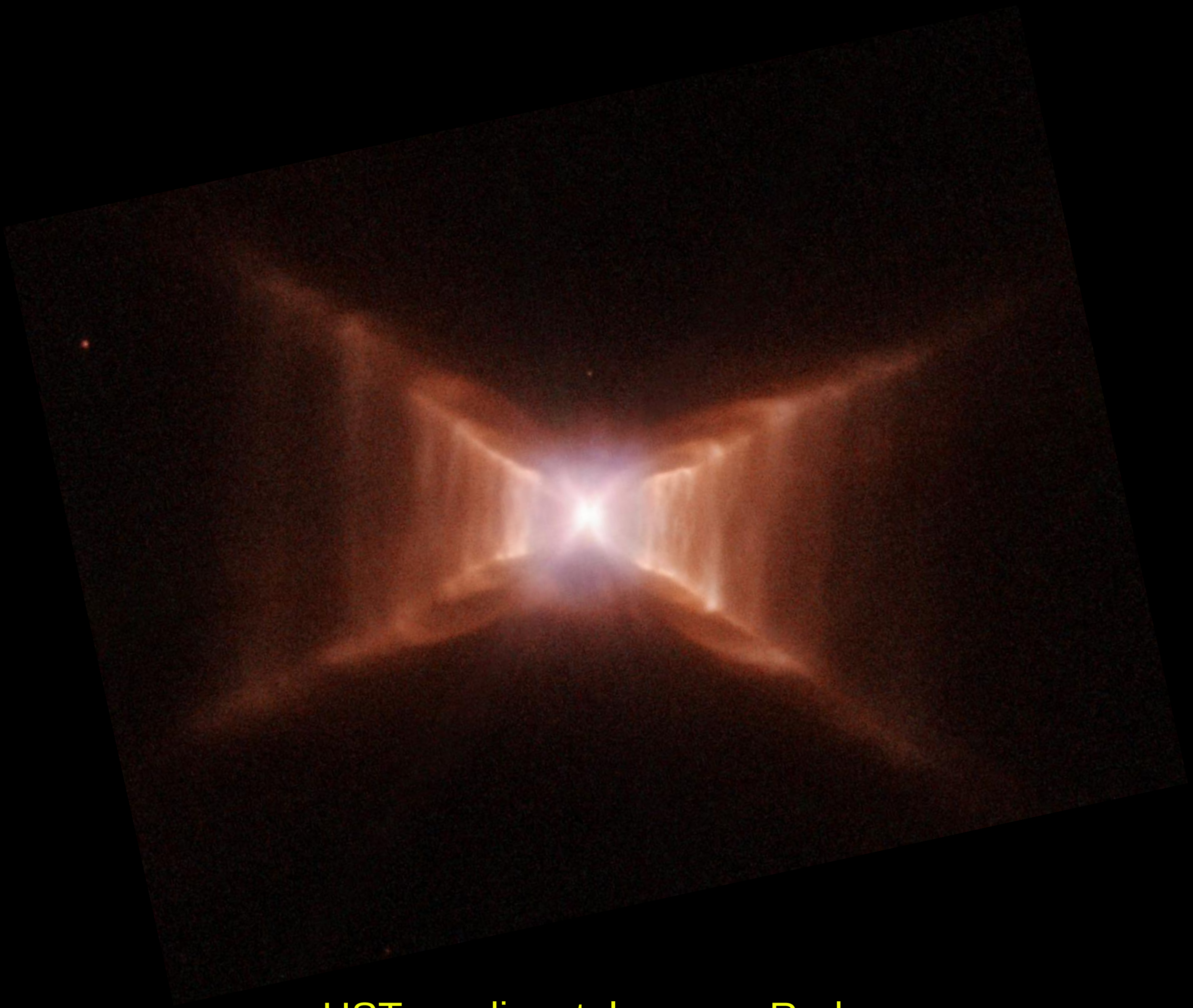
Ground based, small telescope,
Red Rectangle

RESOLUTION and MAGNIFICATION

if the RESOLUTION is poor,
MAGNIFICATION will not make it better

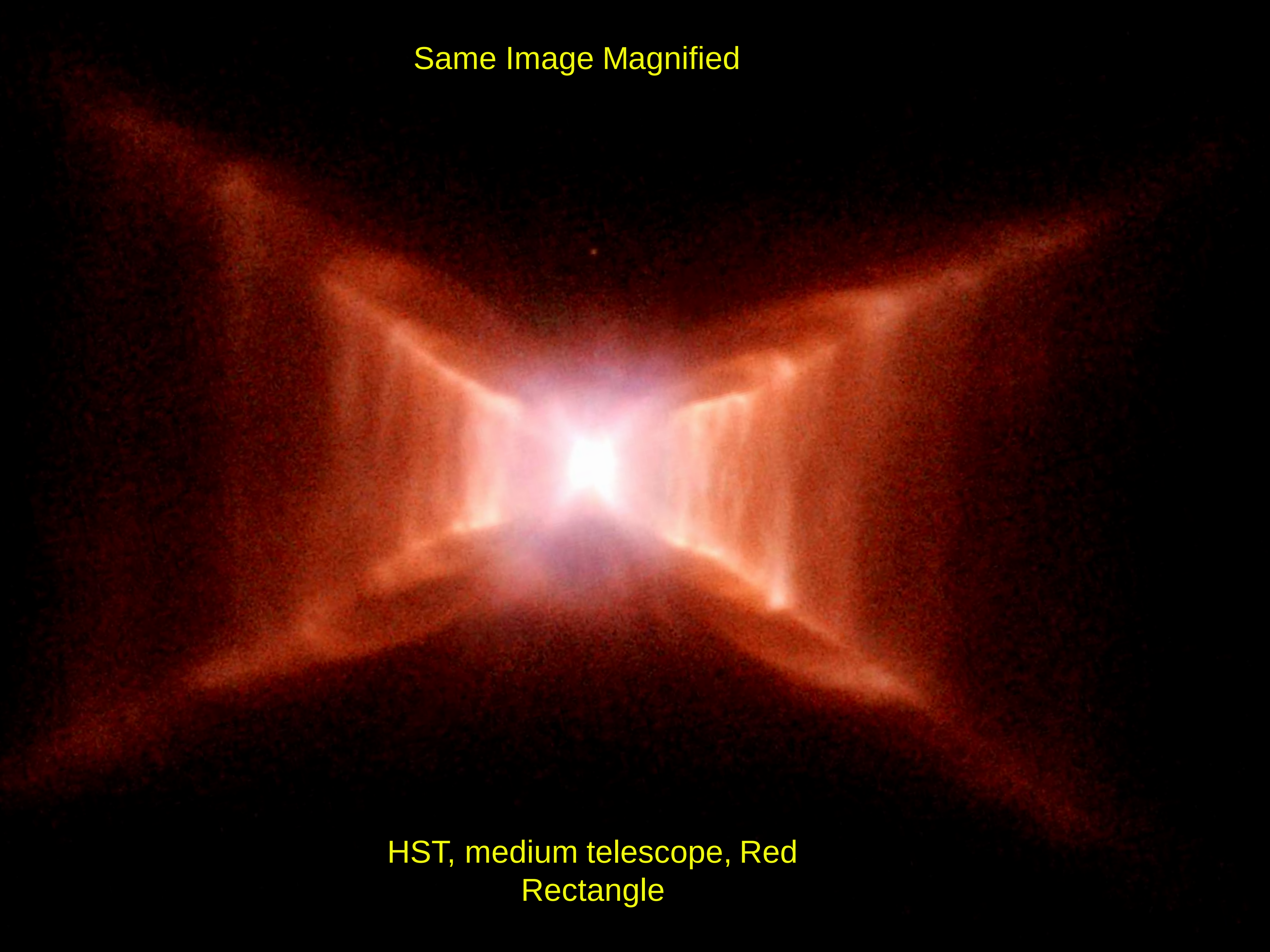
RESOLUTION and MAGNIFICATION

increase in MAGNIFICATION does not increase information

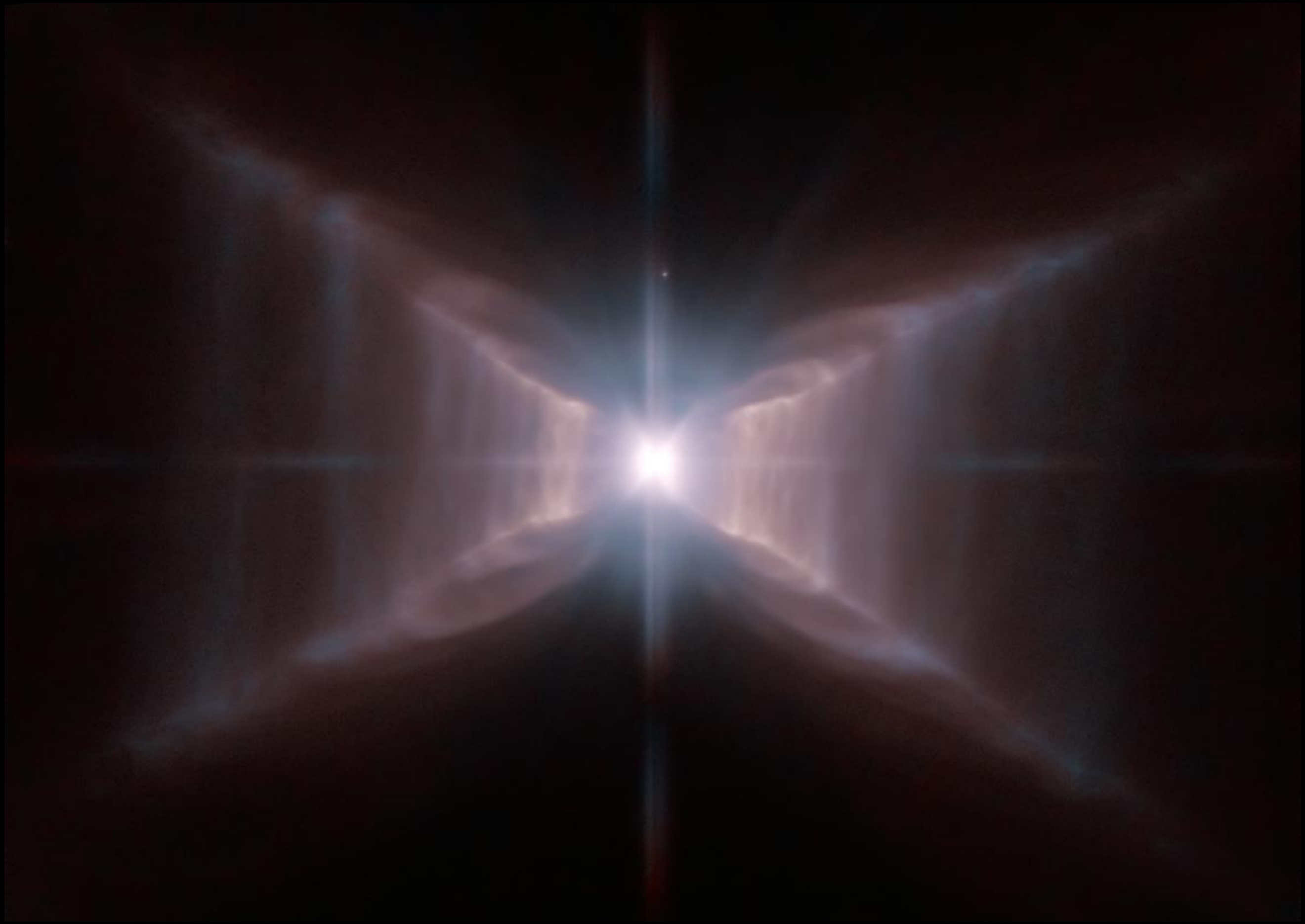


HST, medium telescope, Red Rectangle

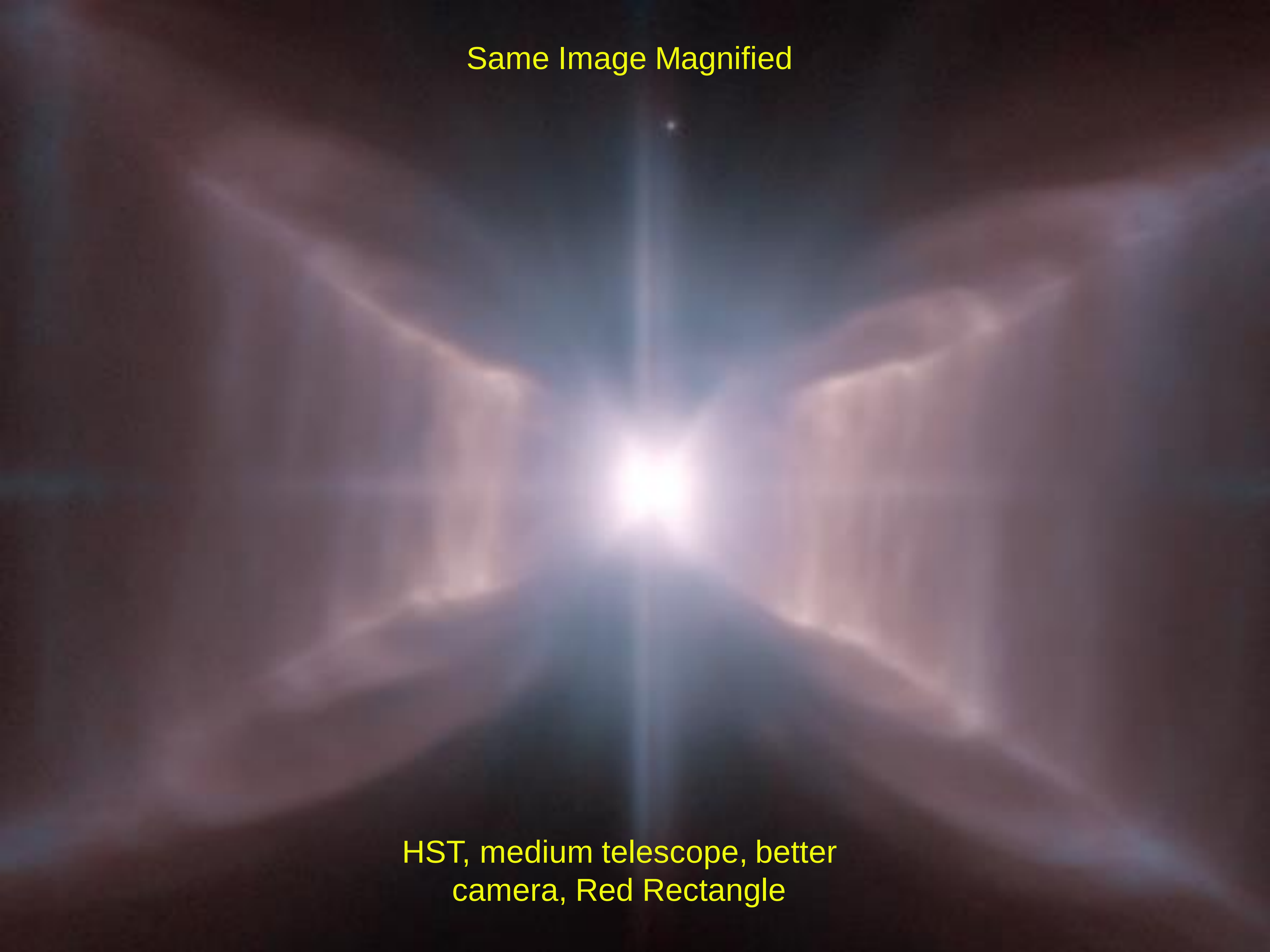
Same Image Magnified



HST, medium telescope, Red Rectangle



HST, medium telescope, better camera, Red Rectangle


Same Image Magnified
HST, medium telescope, better
camera, Red Rectangle

If the image has good RESOLUTION then you can MAGNIFY it and still see lots of detail

HST, medium telescope, better camera, Red Rectangle

Dumbbell Nebula, ground based,
medium telescope

Same Image Magnified

Dumbbell Nebula, ground based,
medium telescope, magnified view —
yuck — poor resolution

Dumbell Nebula, larger telescope

Same Image Magnified

Dumbbell Nebula,

M83 galaxy, small telescope

Same Image Magnified

M83 galaxy, small telescope

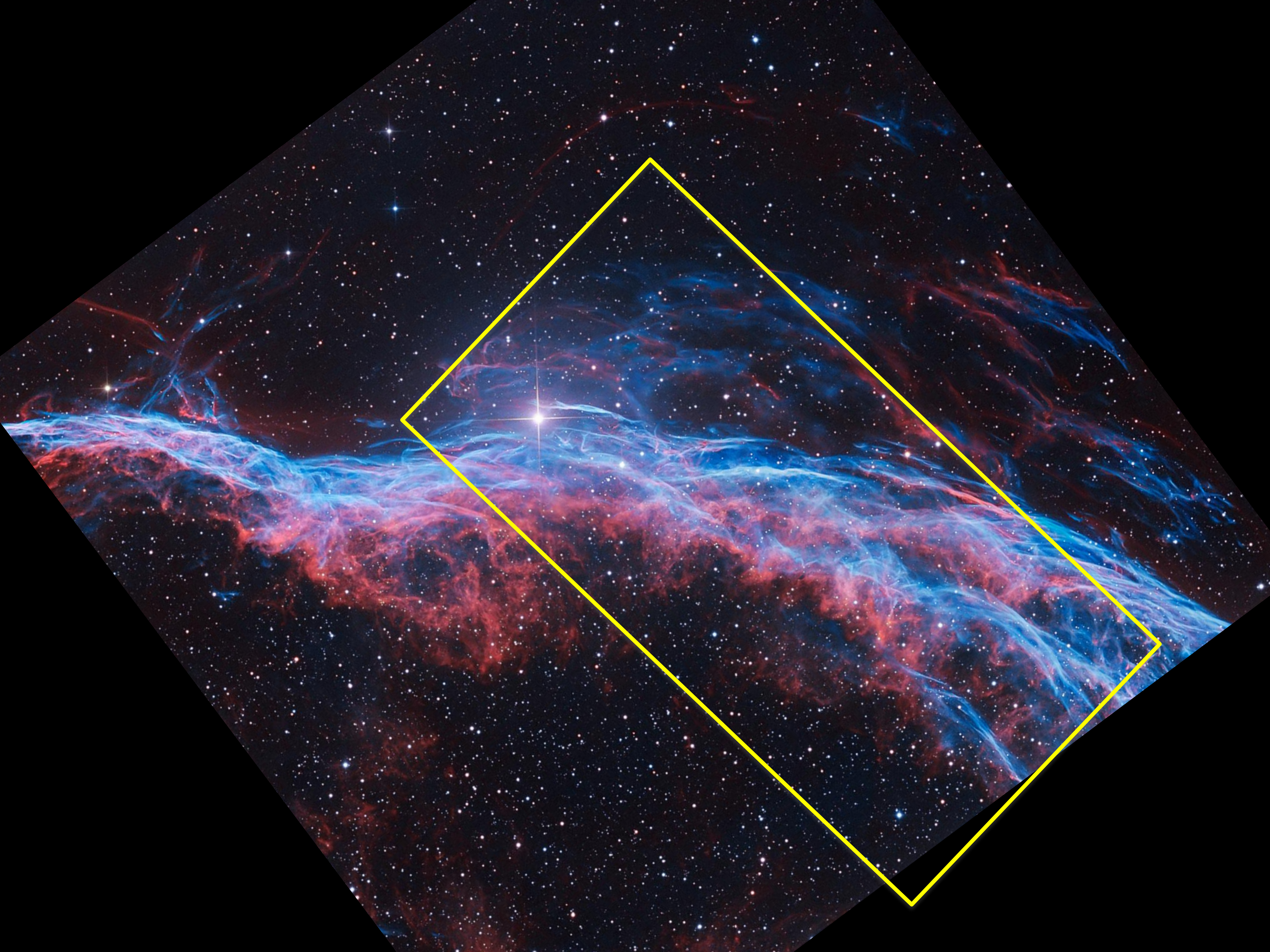
M83 galaxy, small telescope

M83 galaxy, larger telescope

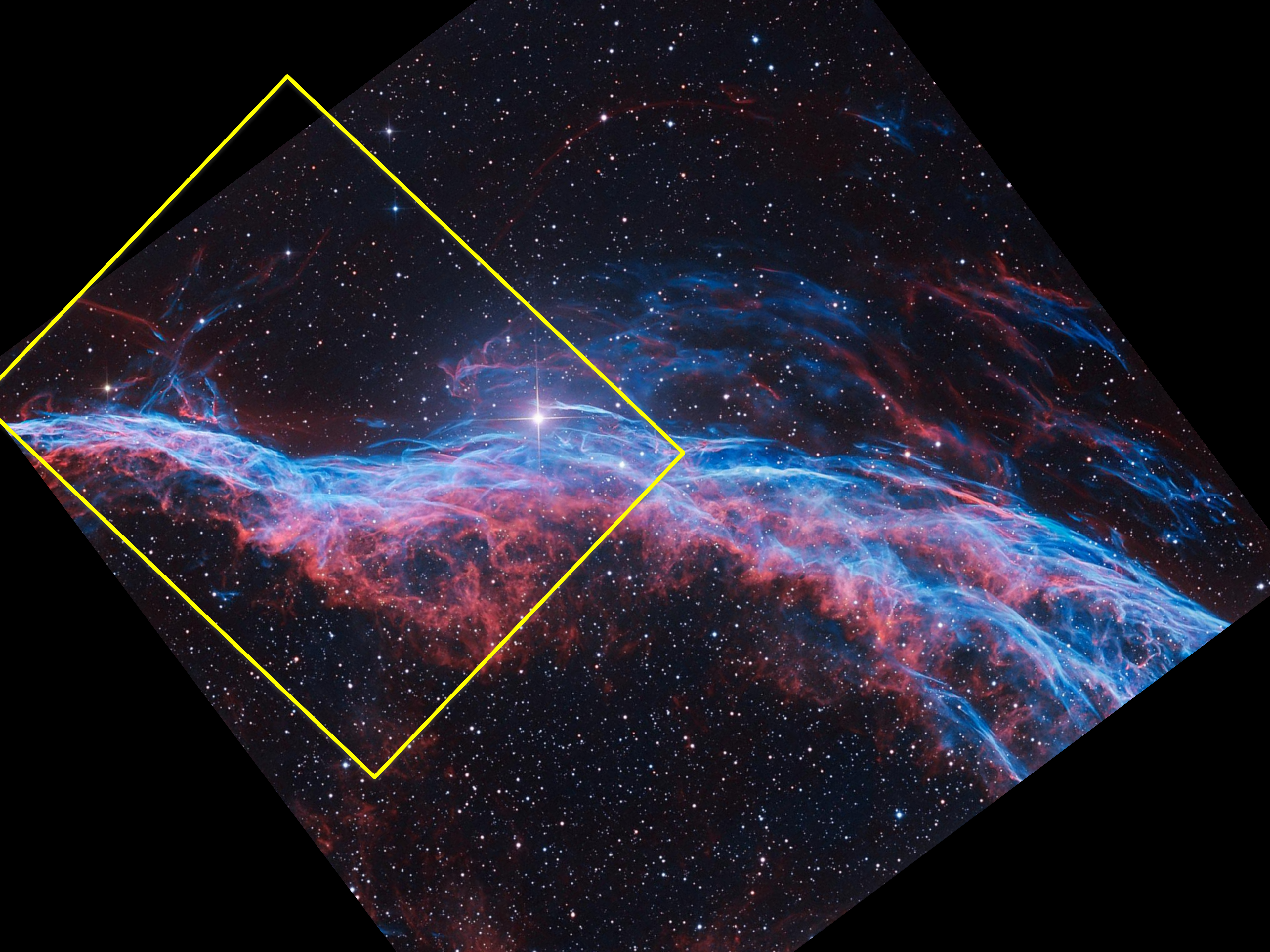
Same Image Magnified

M83 galaxy, larger telescope

good resolution image of Veil Nebula



Same Image Magnified

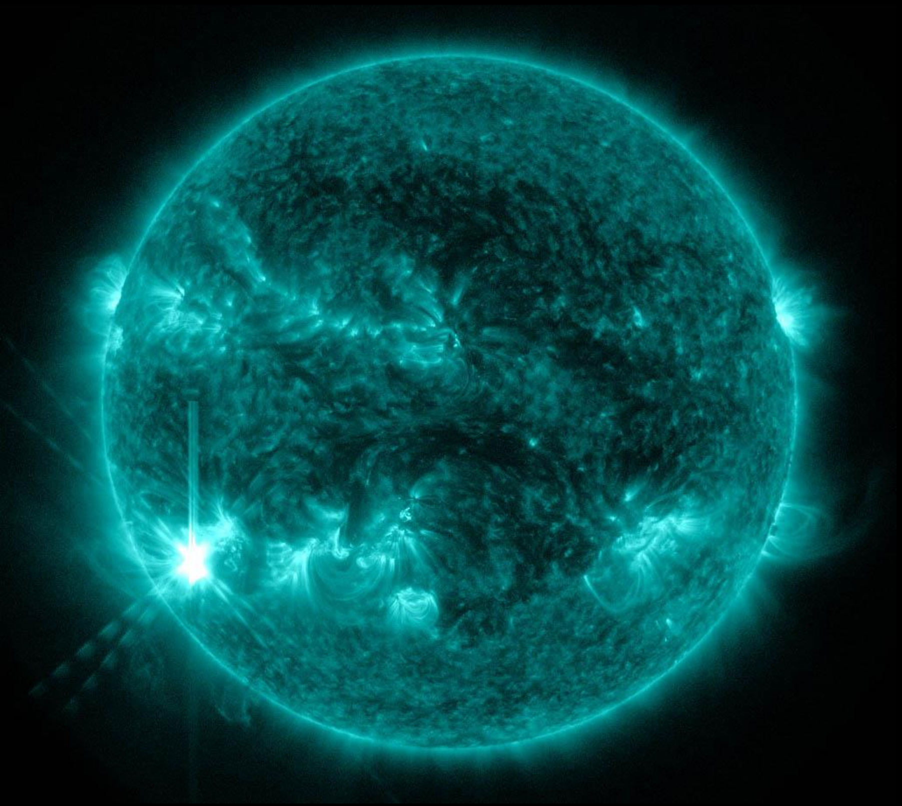


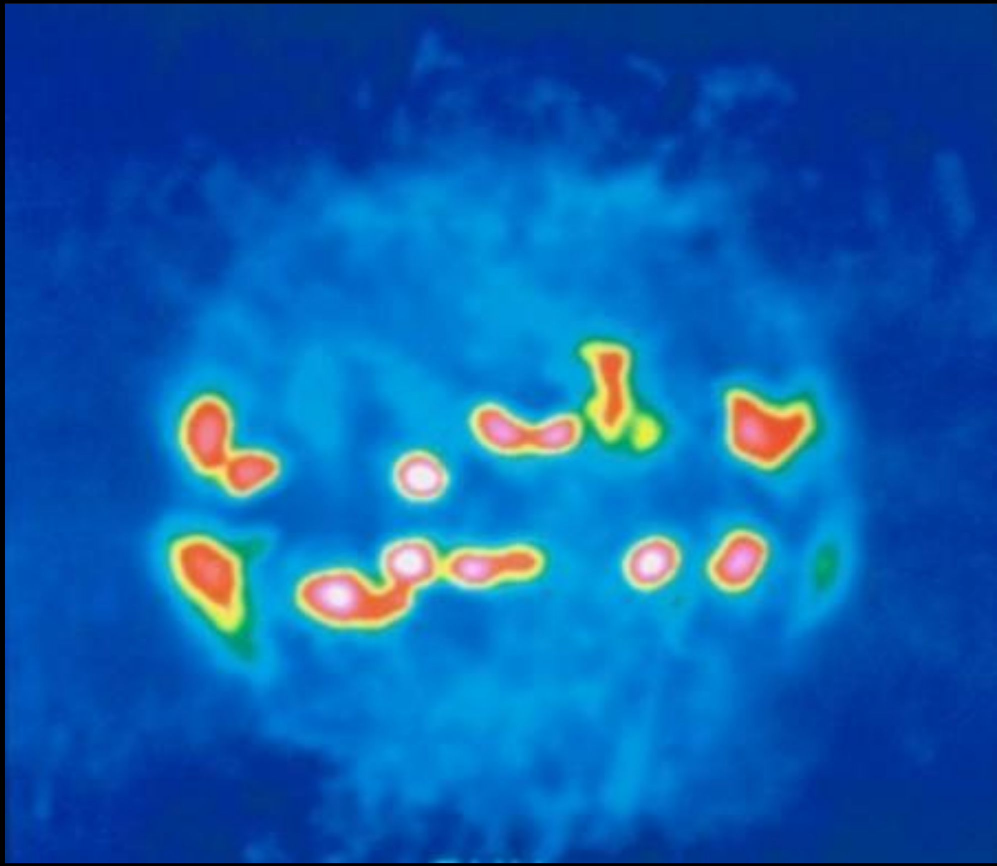
Same Image Magnified

IMPROVING RESOLUTION:

$$\text{Resolution} = \frac{\lambda}{\text{diameter of telescope}}$$

Since resolution depends on wavelength, using shorter wavelengths for detection will improve resolution





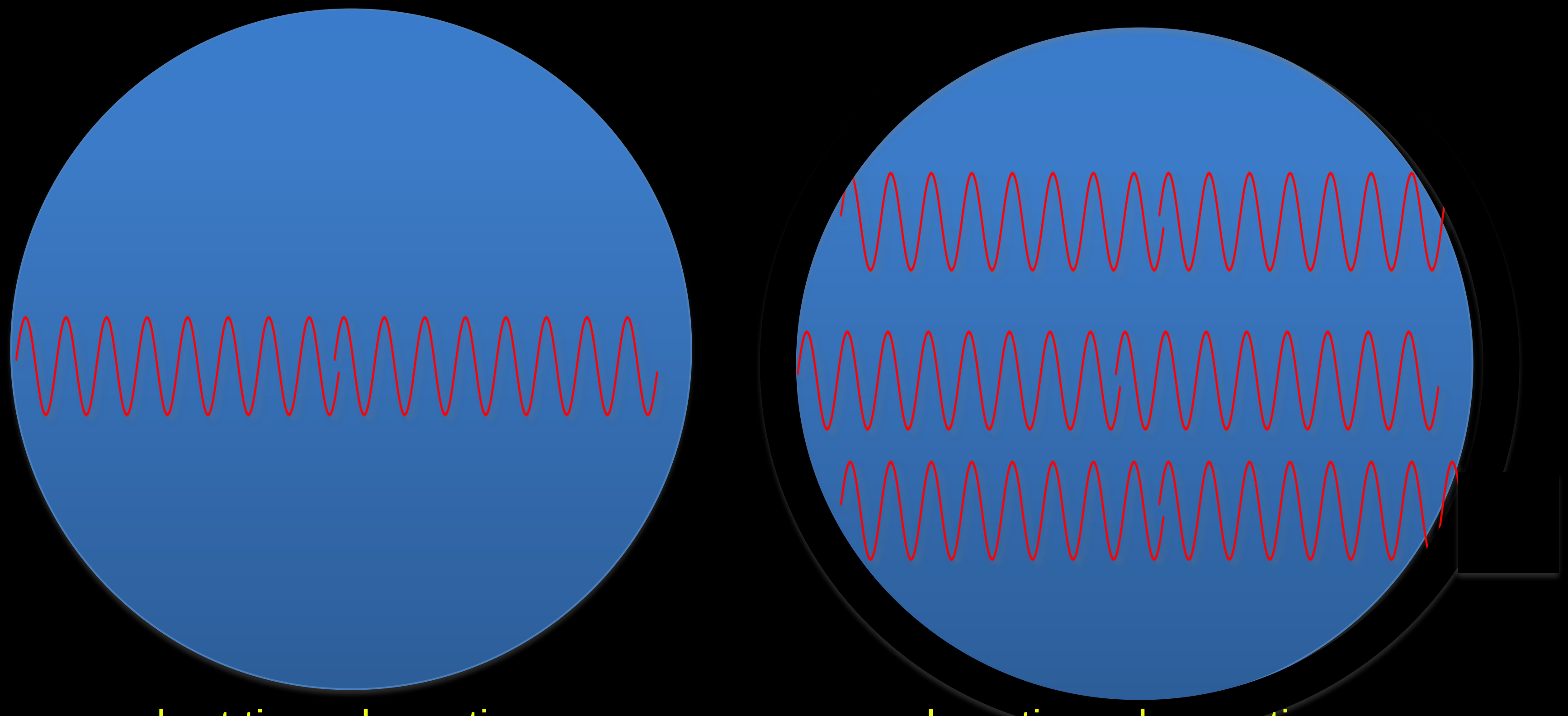
Sun in *short* x-ray wavelength

Sun in *long* radio wavelength

better resolution ⟷ poorer resolution

The more photons, the more information, and so the better the resolution.

There is another way to get better resolution with the same telescope observing the same wavelength

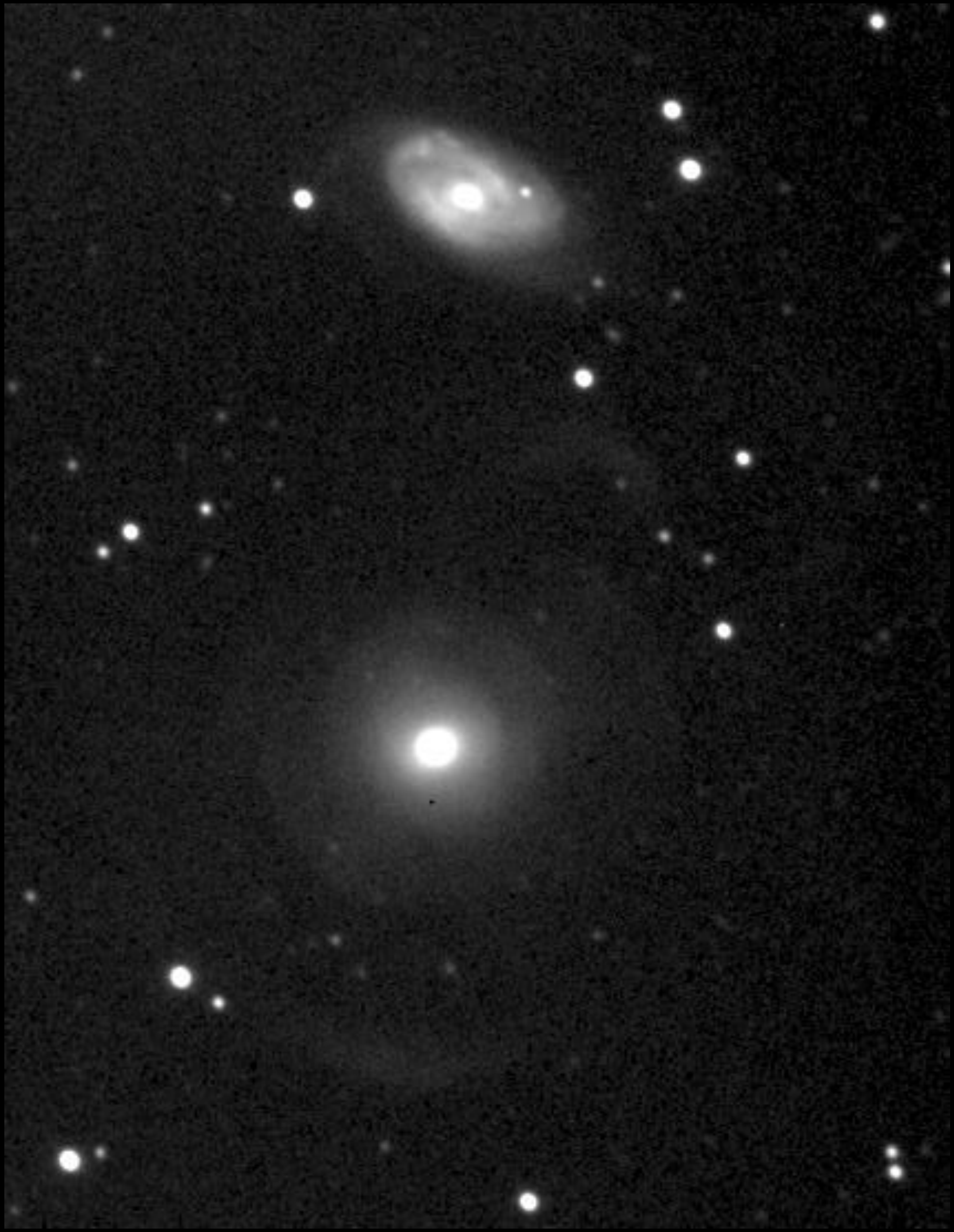


short time observtion

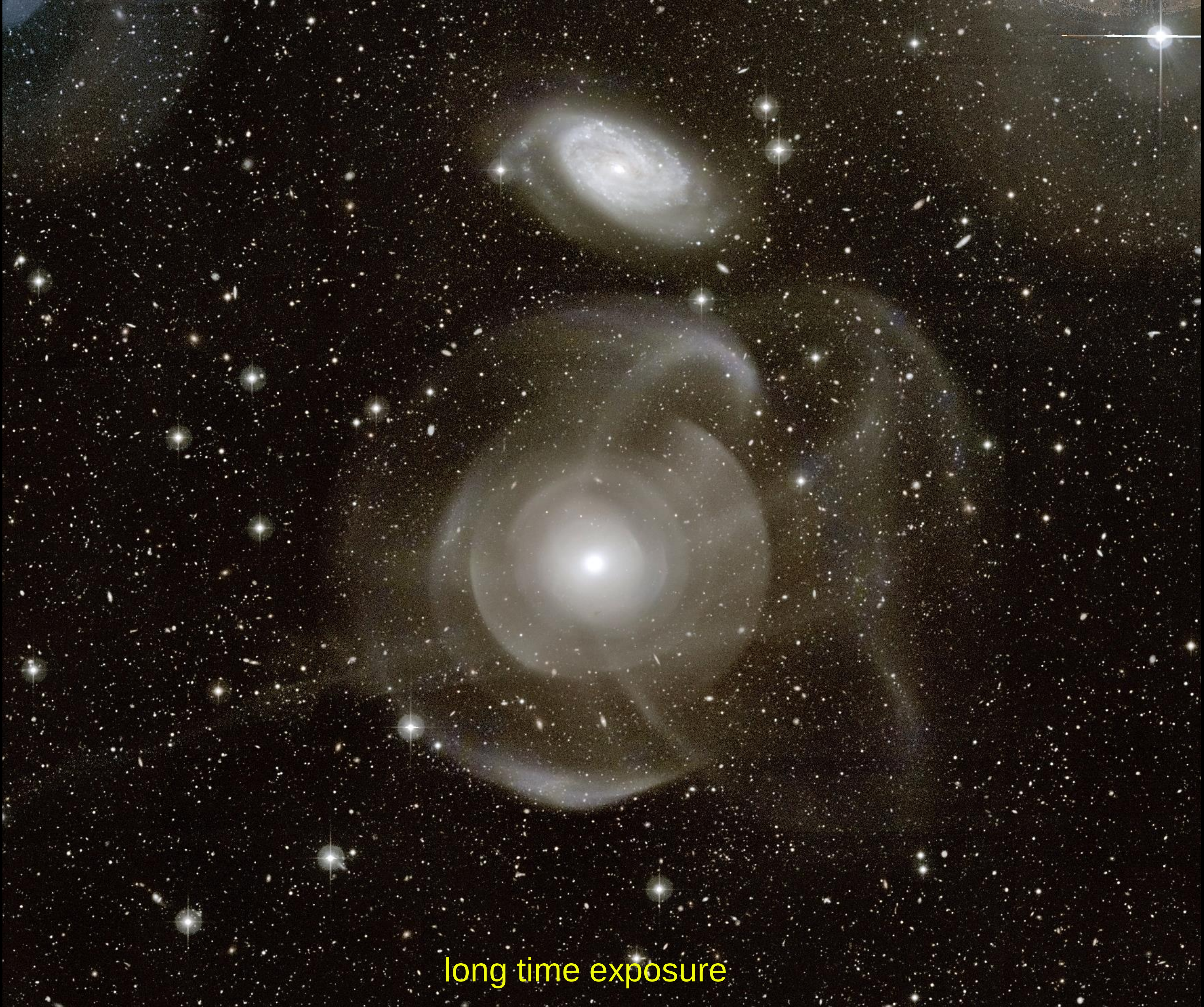
long time observation

INCREASE THE OBSERVING TIME

to get more photons



short time exposure


long time exposure

In SUMMARY:

Resolution depends on:

- diameter of telescpe
- λ observed

Resolution can be affected by

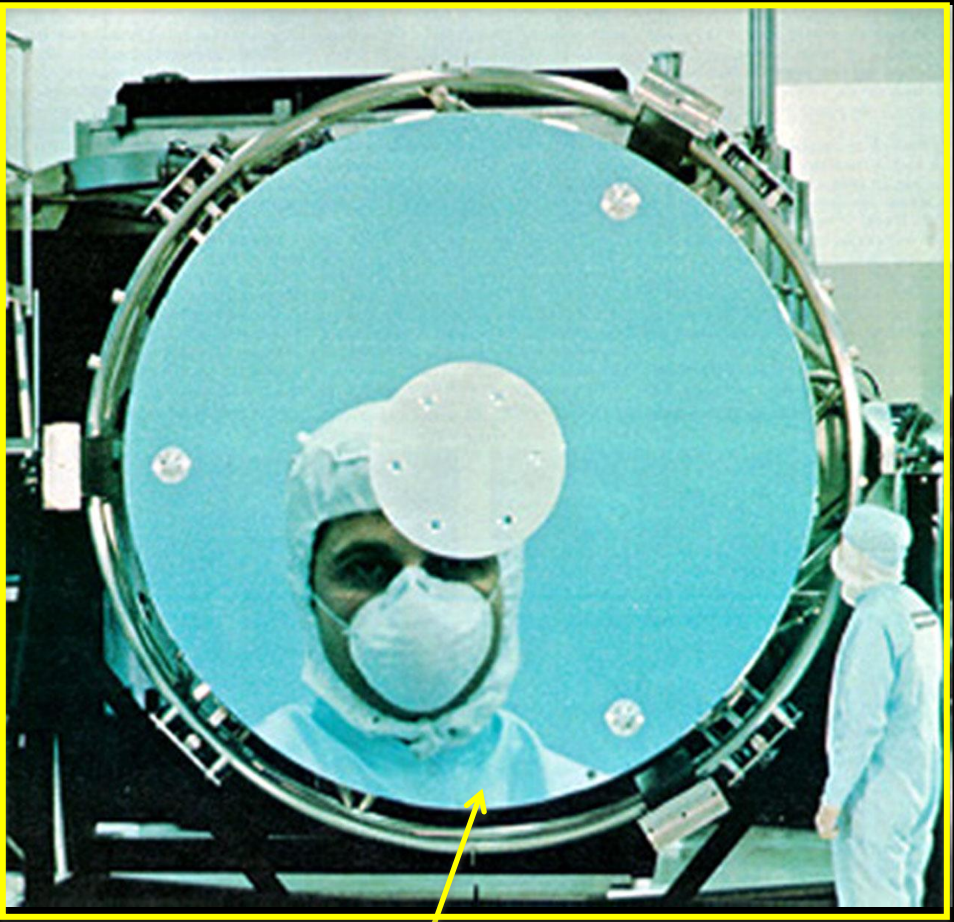
- atmosphere
- exposure time

Better RESOLUTION means more INFORMATION

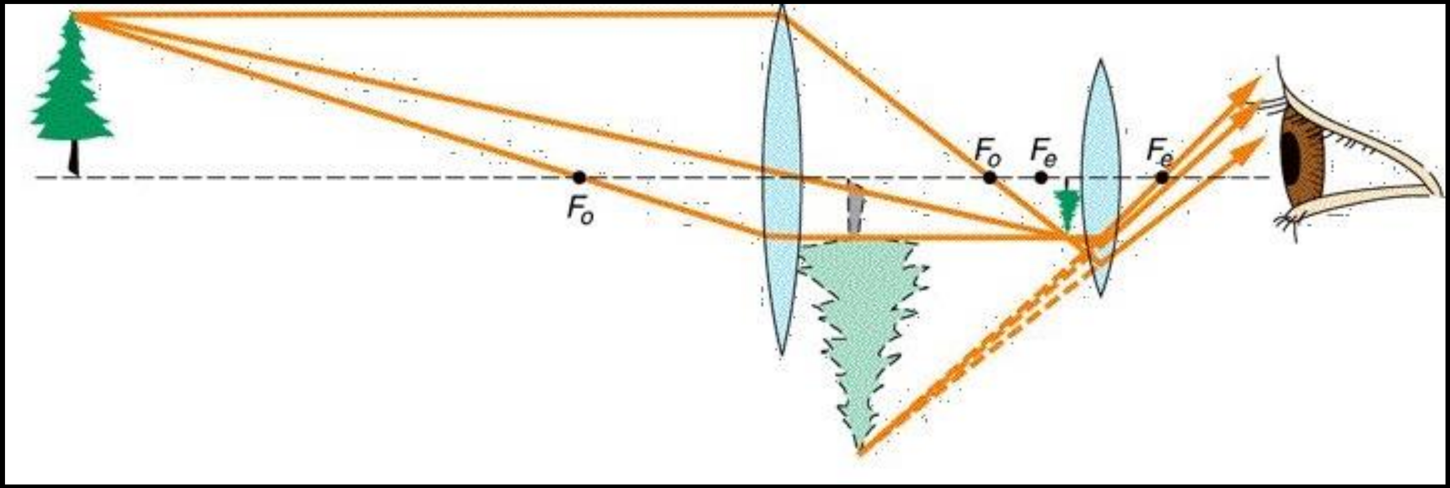
Higher Magnification does NOT increase INFORMATION

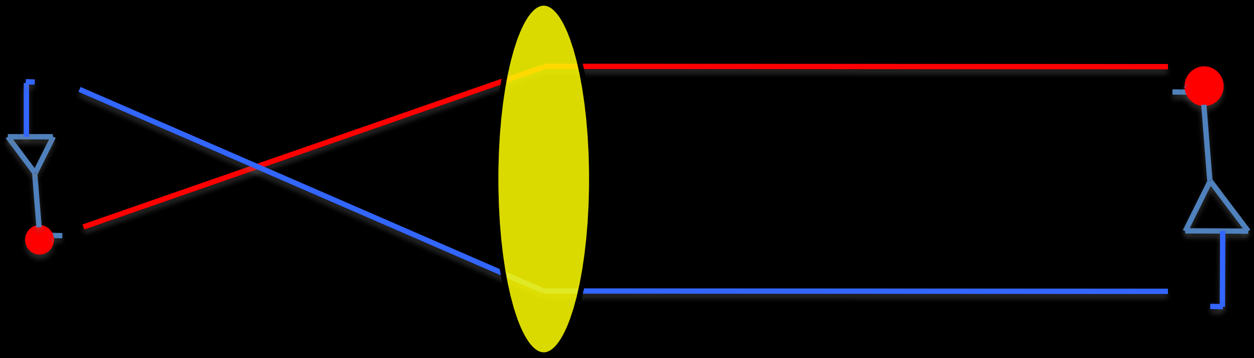
2 Basic kinds of Telescopes:
Refractor and Reflector

lens



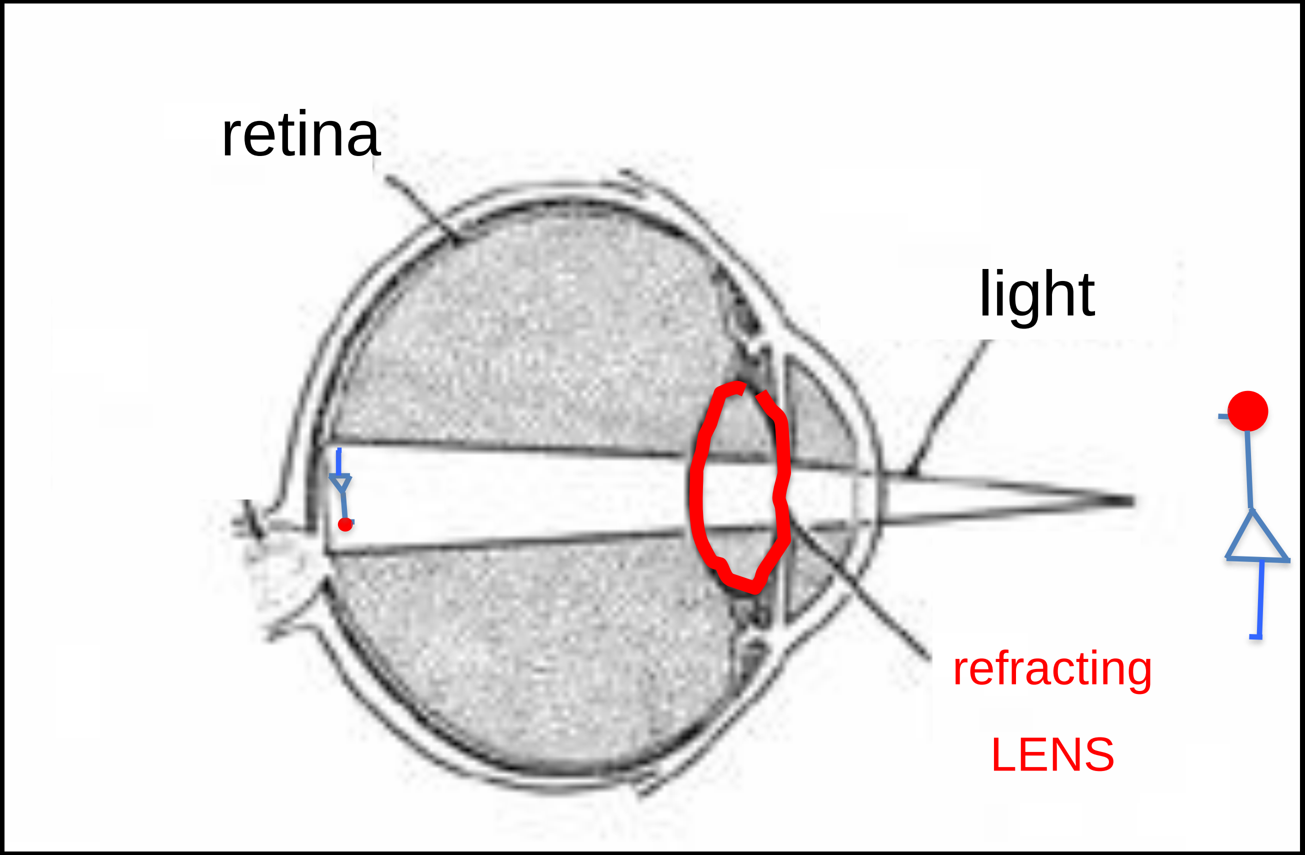
mirror





A lens from a REFRACTING telescope

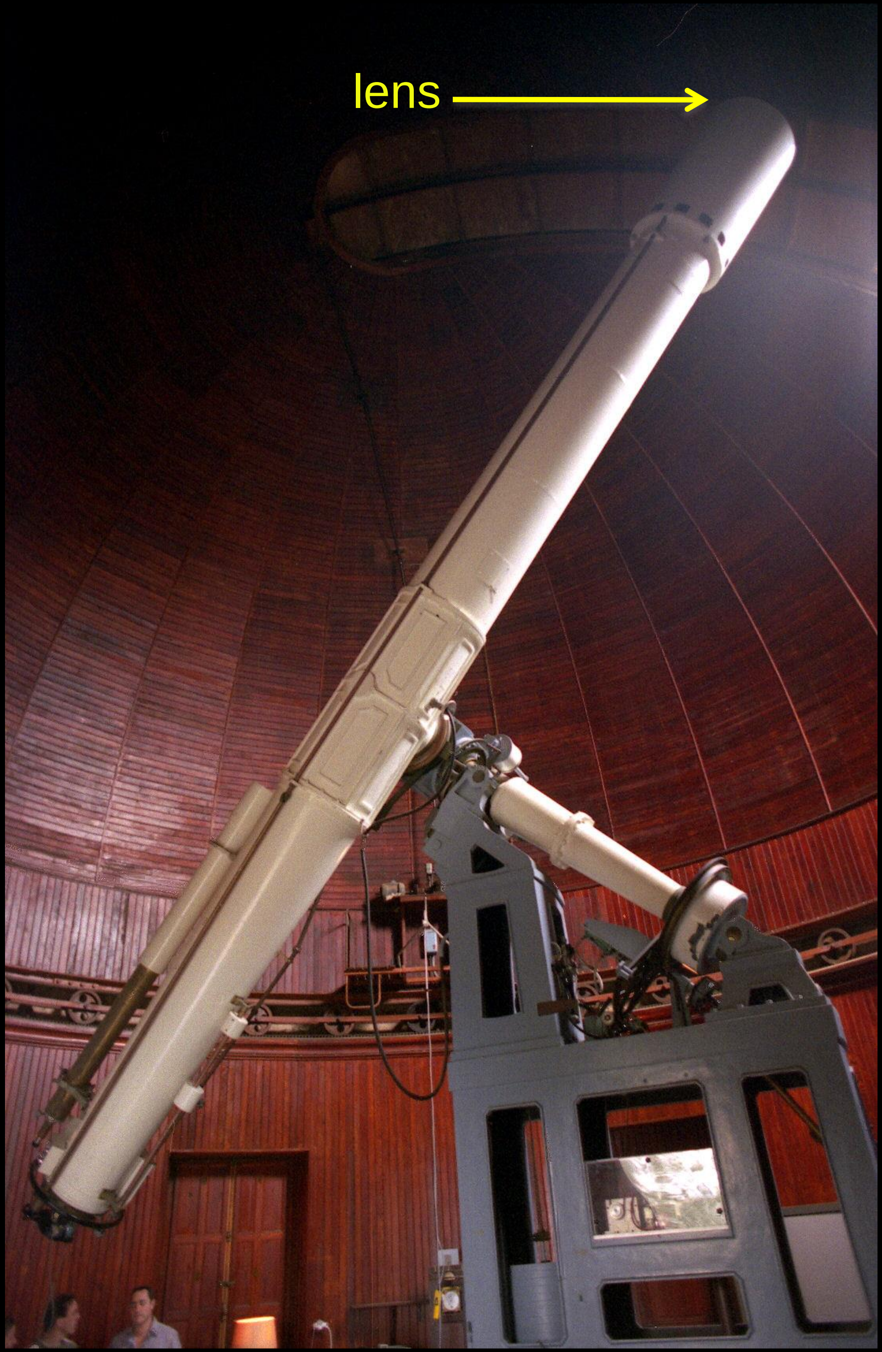
(note: not to scale)


retina
light
refracting
LENS

Lick Observatory 36" Refractor

lens

astronomer



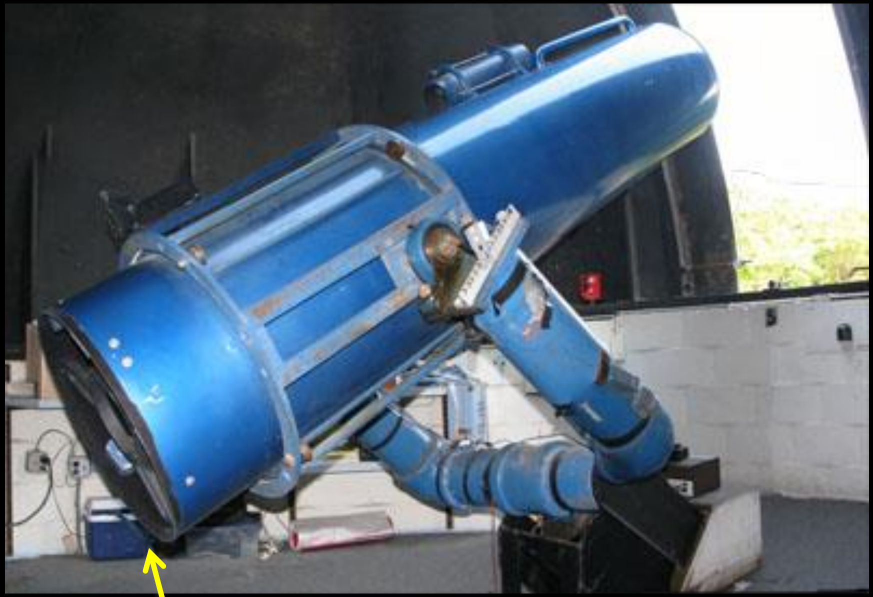
Problems with Refracting Telescopes:

- image distortion
- large lens warps
- bigger lens, longer tube

(Why do we want a large lens?)

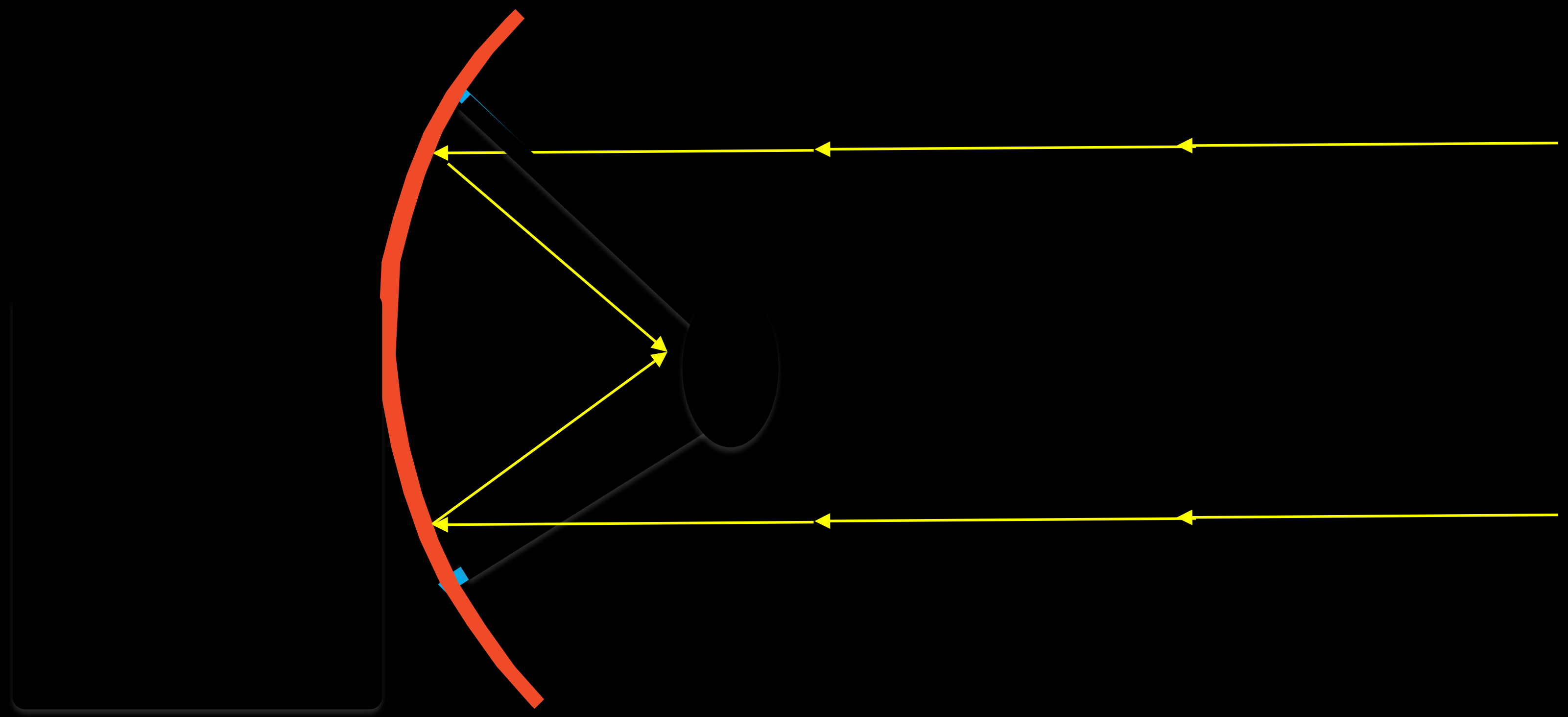
Advantages of Reflecting Telescopes:

- no distortion
- can make large mirror
- tube short



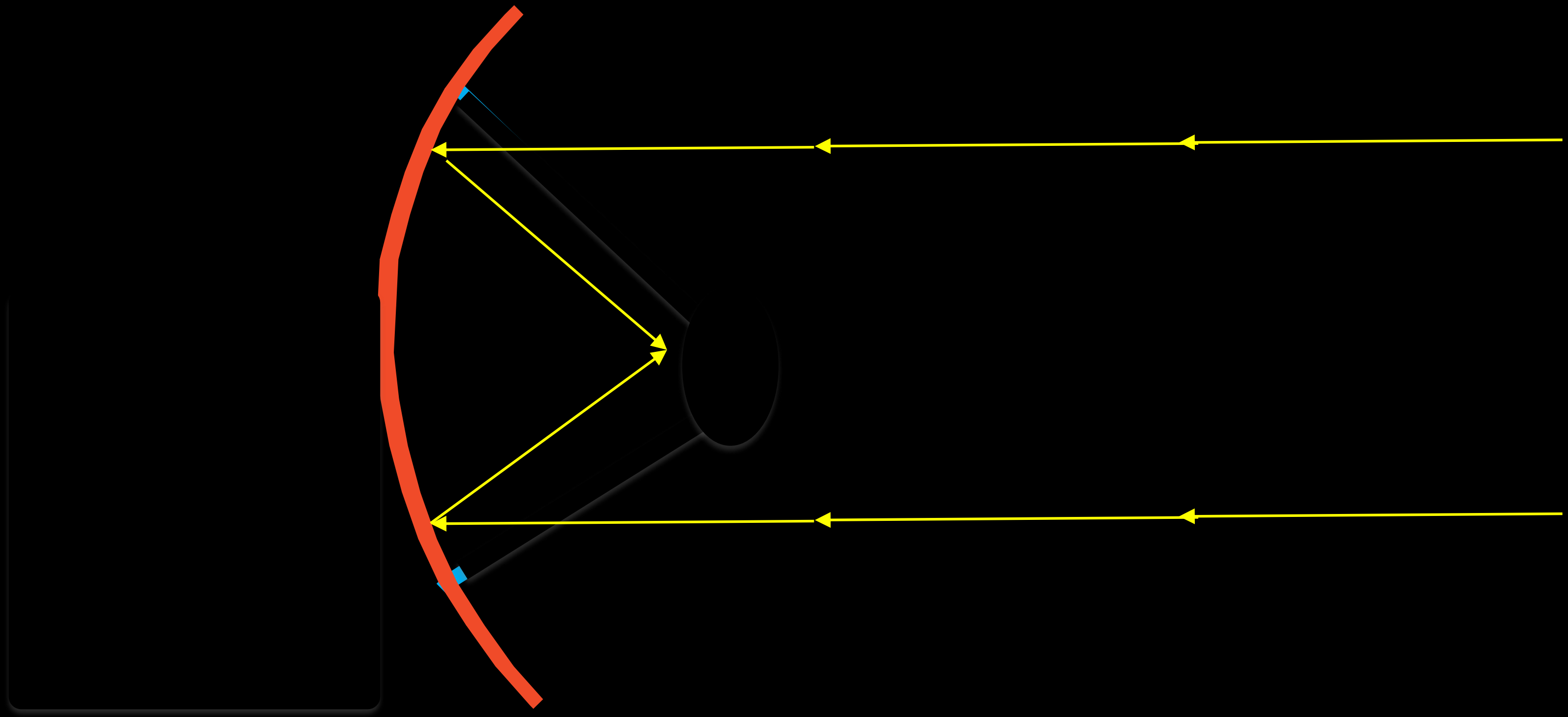
mirror

REFLECTING telescopes

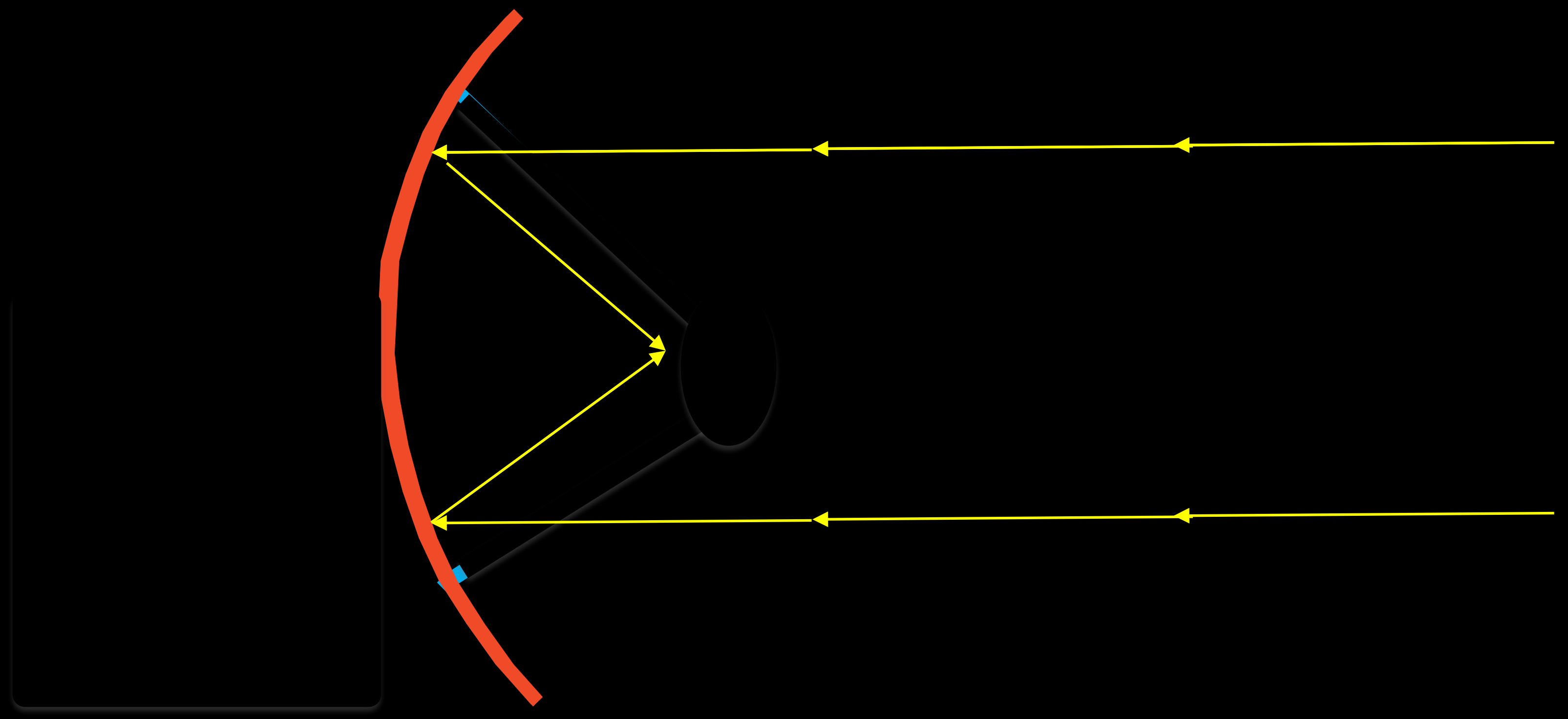


All modern research telescopes use MIRRORS —

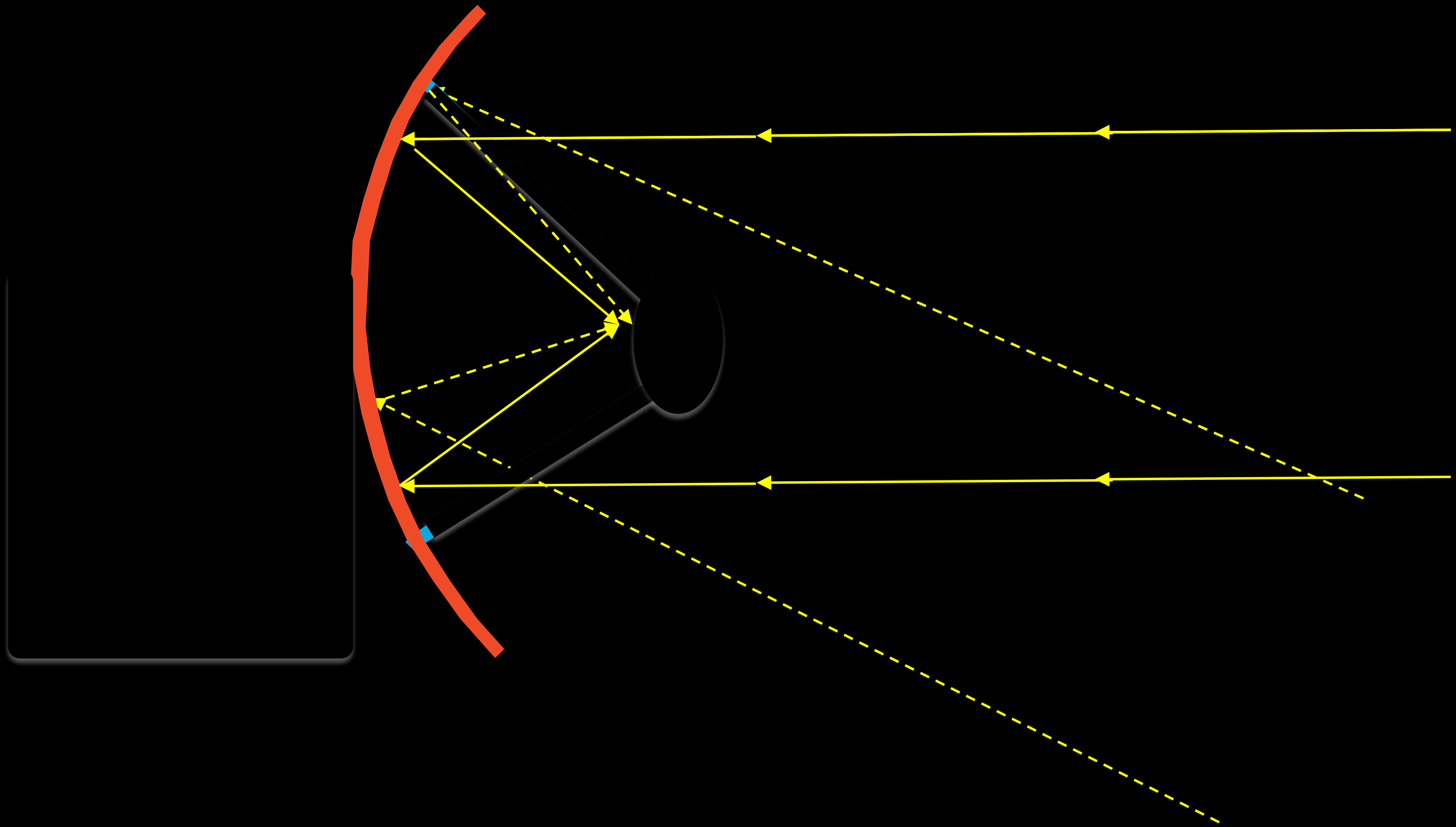
These are REFLECTING telescopes



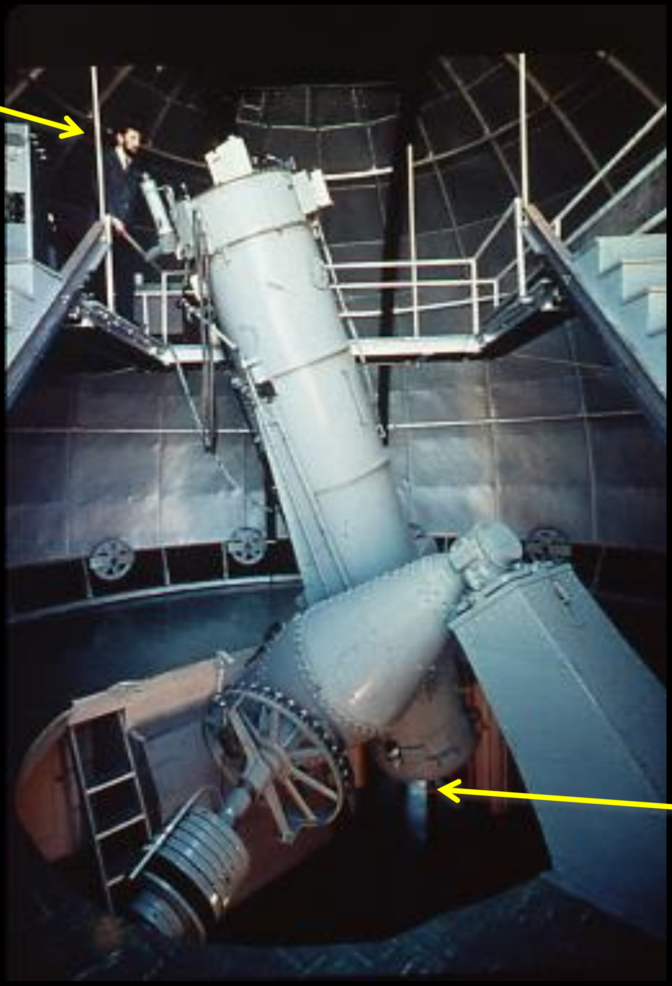
The parabolic shape of the mirror reflects light to one point.



…no matter where on the dish the light strikes.



astronomer



mirror

Lick Observatory — The Death Trap Telescope,

The 40” Crossley Reflecting Telescope

Lick Observatory — The Shane 120” Reflecting Telescope Dome

Lick Observatory — 120 inch Reflecting Telescope

mirror

control room door

person

Lick Observatory — The Shane 120” Reflecting Telescope Control room from the early 1980’s

More modern Control Room

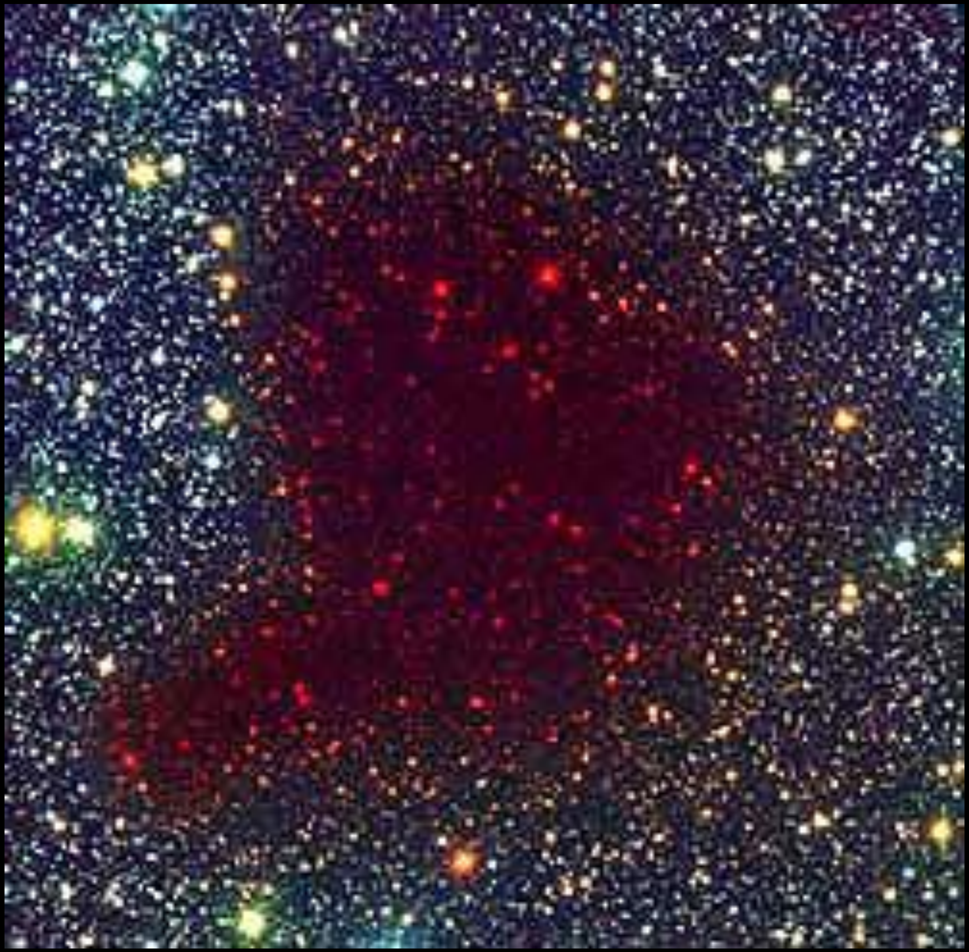
Kitt Peak Observatory — 4 meter telescope

We want to observe at other than visible wavelengths to see different physical processes

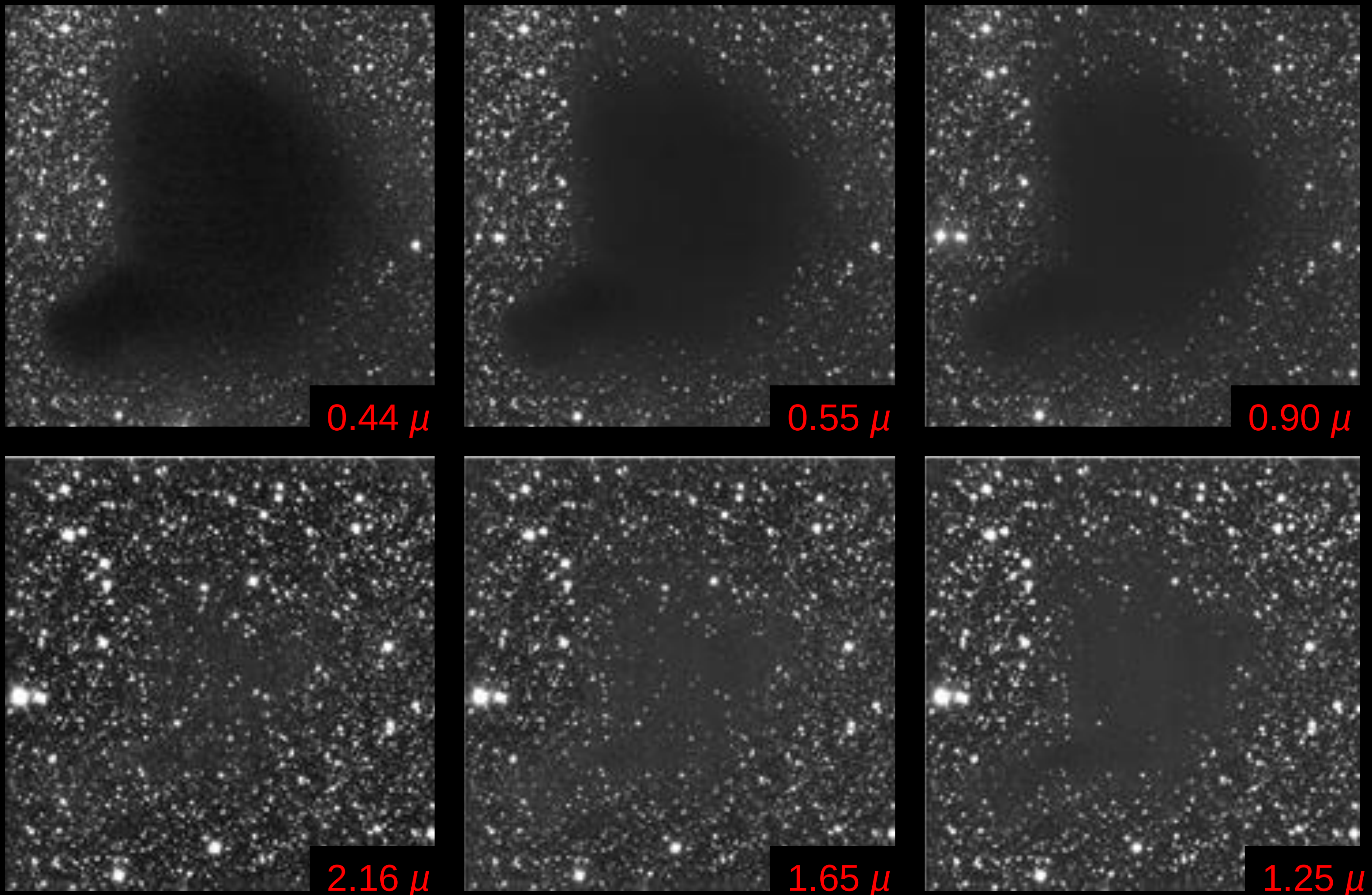
visible light image

infrared image

visible light

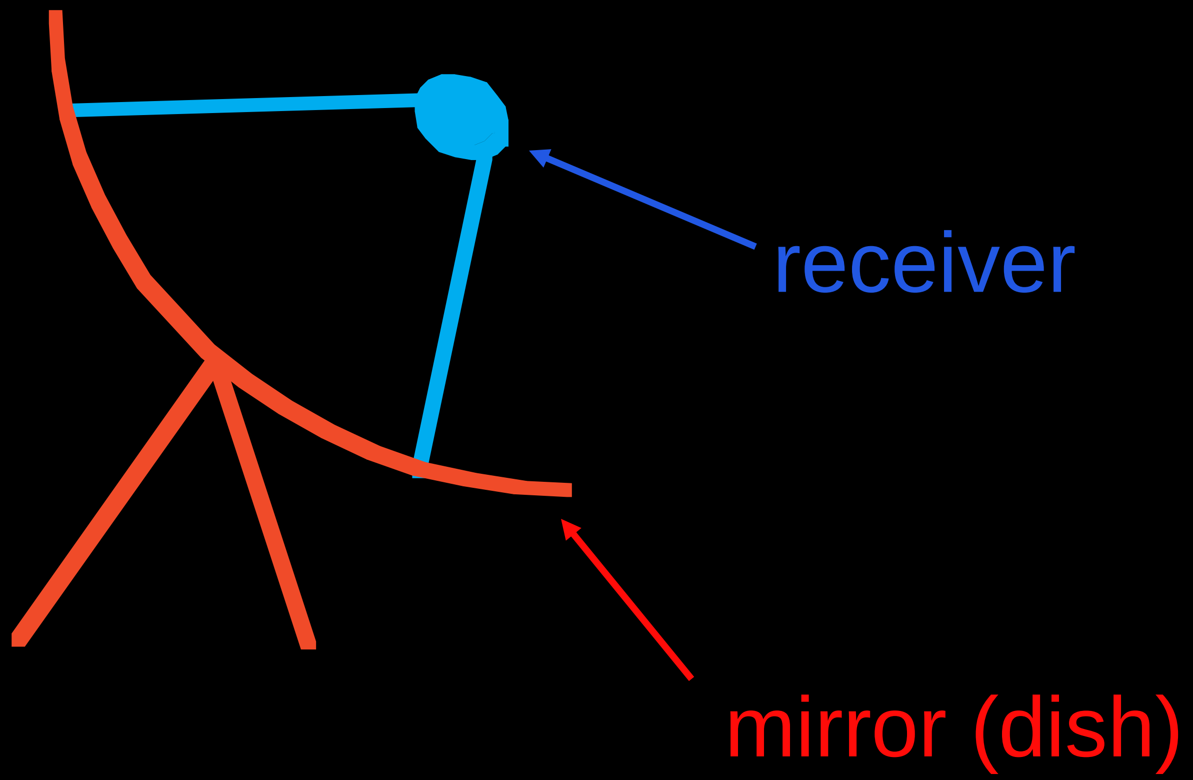


near-IR light, 0.9 μ

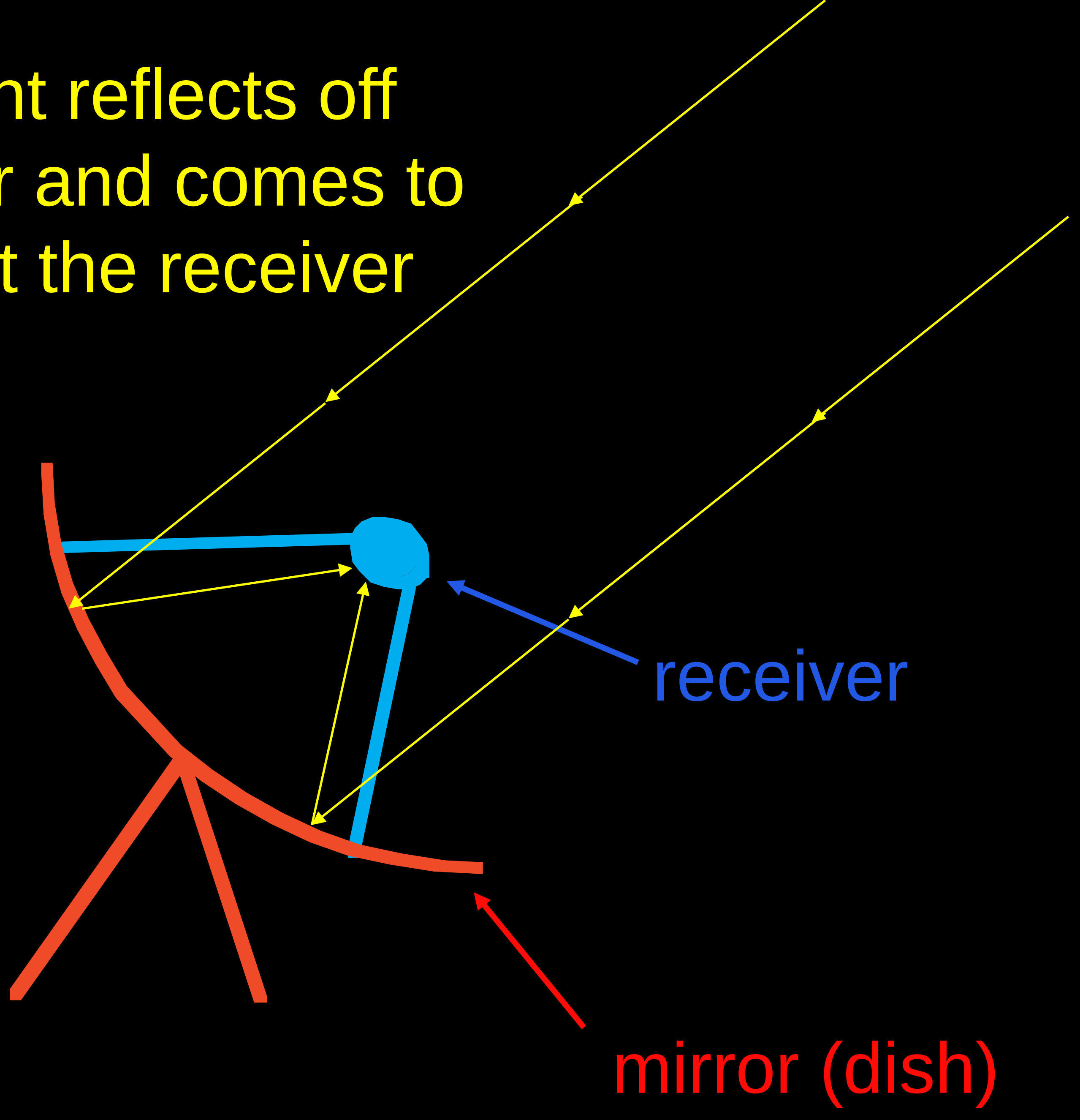


images at different wavelengths in this cloud tell us about dust grain size in the cloud

Radio Telescopes are mirrors

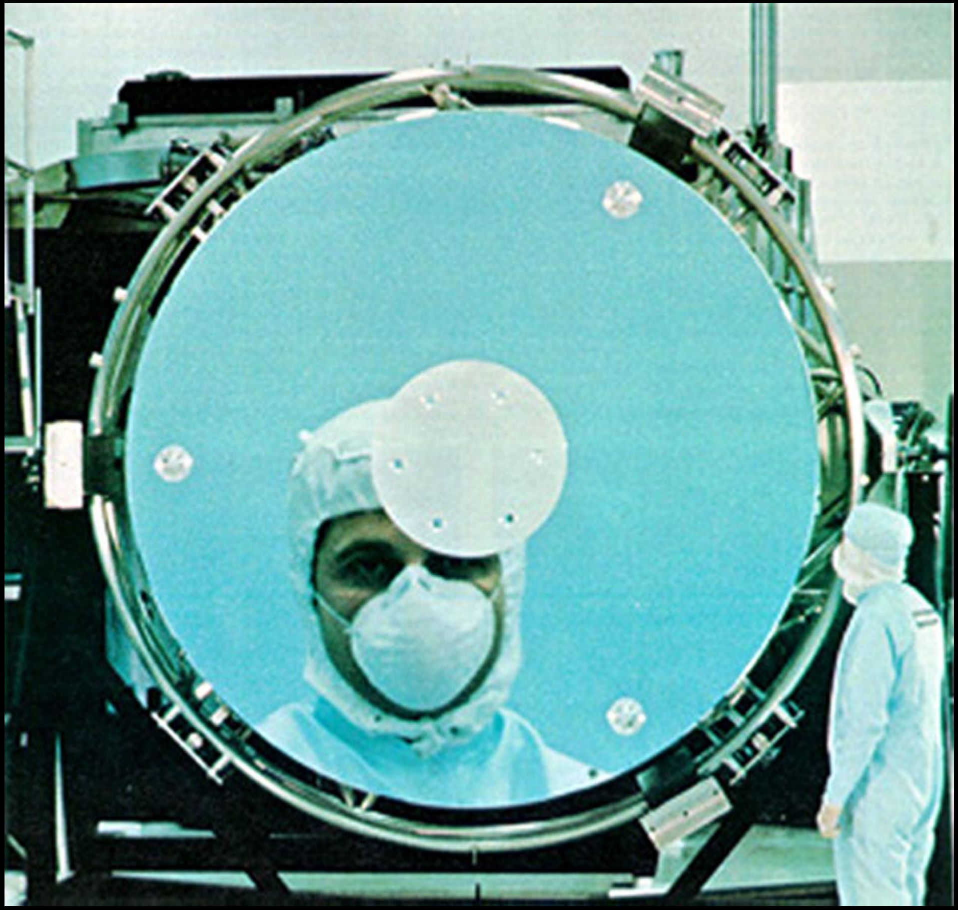


Radio light reflects off the mirror and comes to a focus at the receiver



Optical and Radio Telescopes are alike in that they are both mirrors.

So what makes a good mirror?
Why can't you see yourself in a radio telescope?



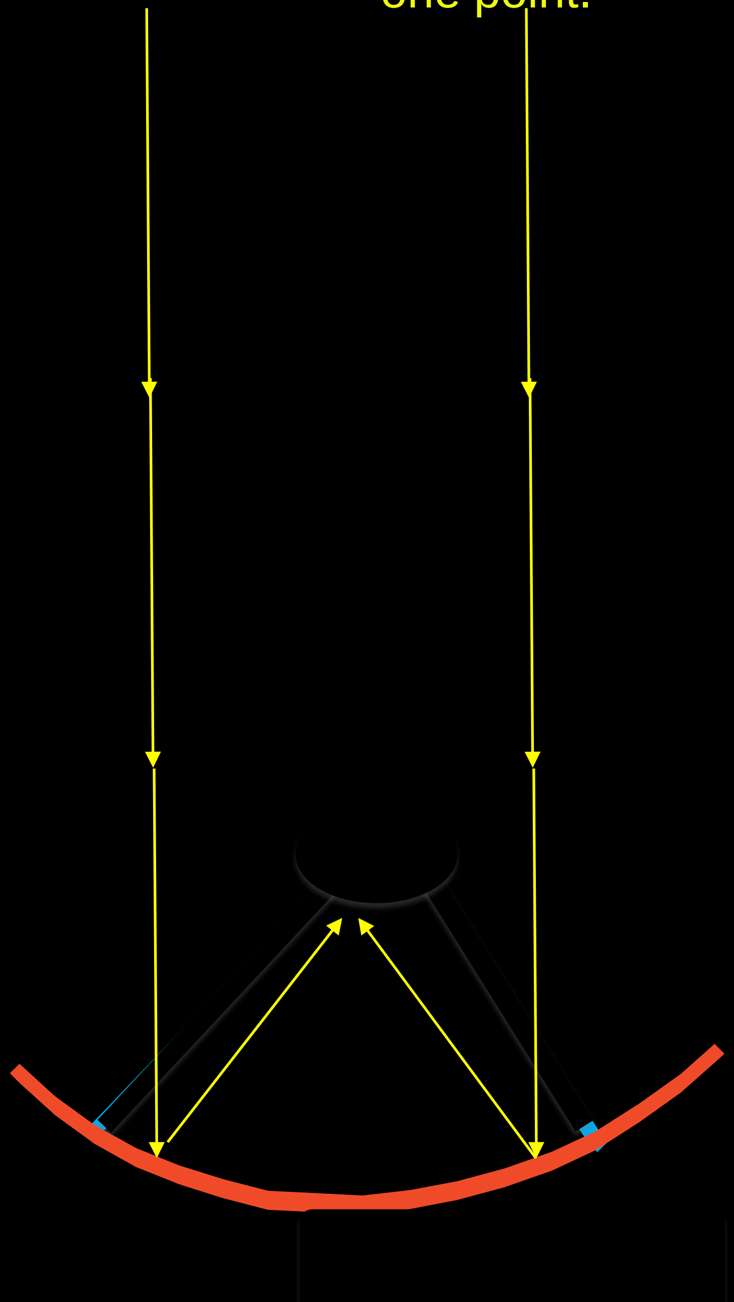
Optical and Radio Telescopes are alike in that they are both mirrors.

So what makes a good mirror?

- Parabolic
- Metal
- A smooth surface for the wavelength of light you want to observe

Radio Telescopes are Mirrors

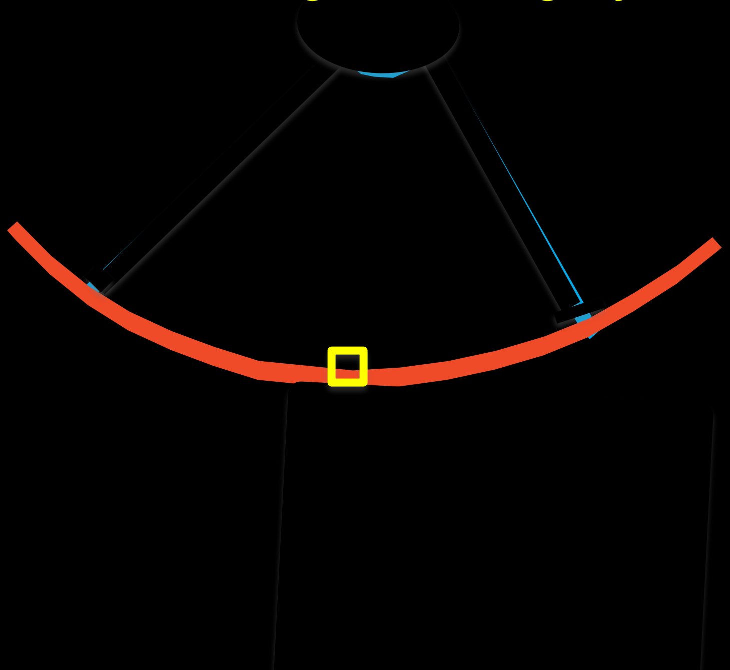
The parabolic shape of the mirror reflects light to one point.



Optical and Radio Telescopes are alike in that they are both mirrors.

So what makes a good mirror?

Smooth means having no bump on the mirror more than a tenth of the wavelength of the light you observe



Optical and Radio Telescopes are alike in that they are both mirrors.

So what makes a good mirror?

Smooth means having no bump on the mirror more than a *tenth* of the wavelength (0.1 x λ)

Optical and Radio Telescopes are alike in that they are both mirrors.

So what makes a good mirror?

For an optical telescope mirror: no bump > 0.05 μ (1/600 the width of a human hair)

Optical and Radio Telescopes are alike in that they are both mirrors.

So what makes a good mirror?

For a radio telescope mirror: no bump > 1 mm (for an observation at a wavelength of 1 cm)

Optical and Radio Telescopes are placed in different locations….

Kitt Peak Observatory

Optical telescopes are housed in domes on the top of high mountains…

Kitt Peak Observatory

Mauna Kea Observatory — Optical Telescopes on Mountain Tops

14,000 ft elevation

European Southern Observatory in Chile —
Optical Telescopes on Mountain Tops

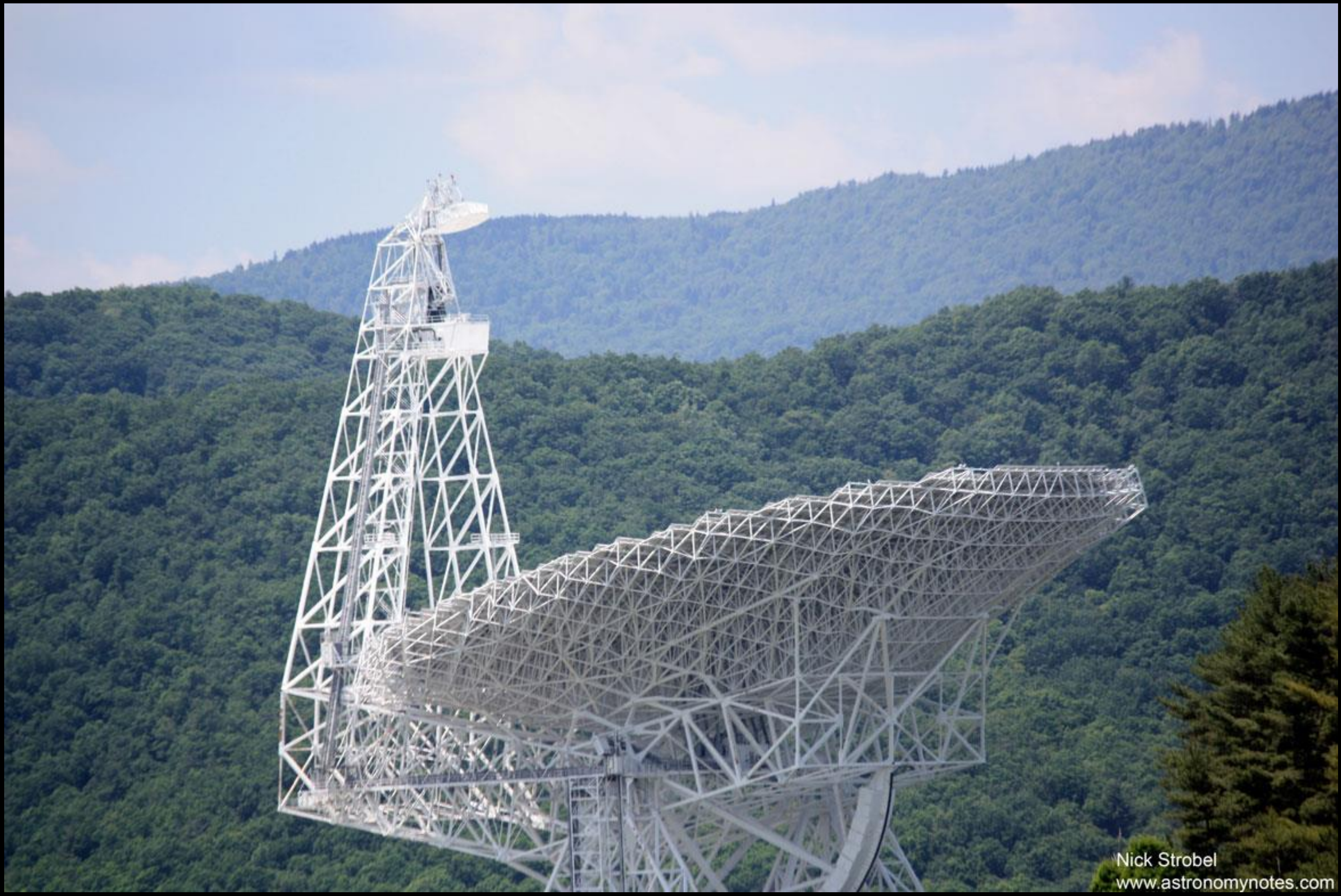
SOFIA — Airborne Observatory — INFRARED
Telescopes High in the Air

Hubble Space Telescope — Size of a School Bus

Hubble Space Telescope — Size of a School Bus

HST being repaired by the Space Shuttle

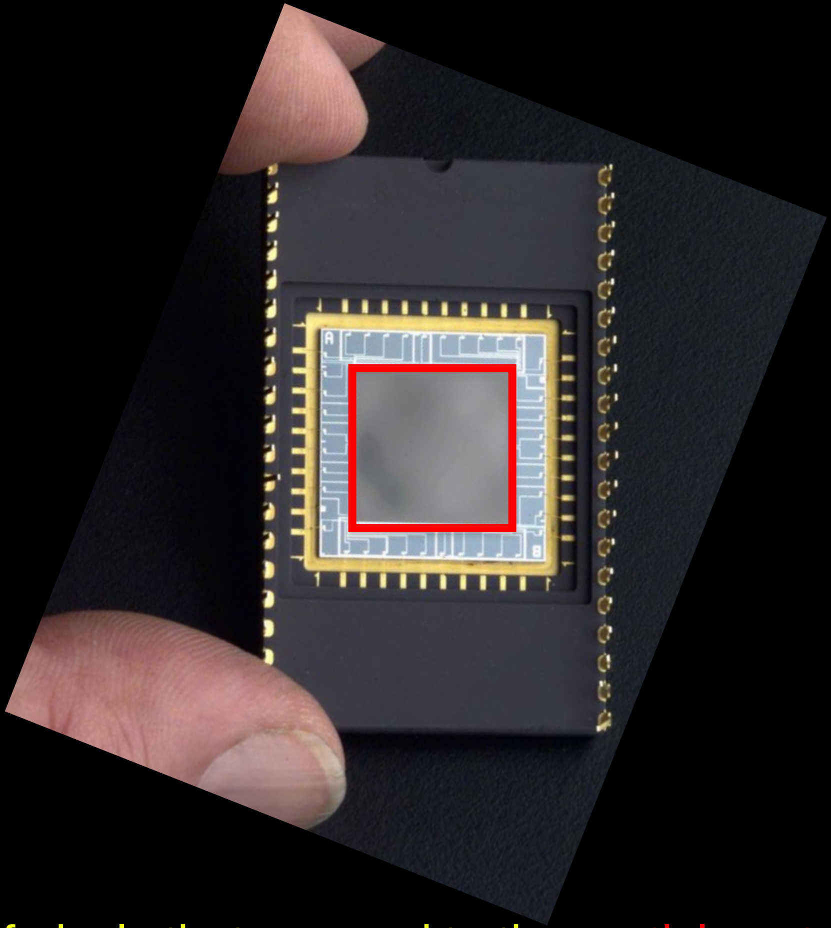
Green Bank Observatory



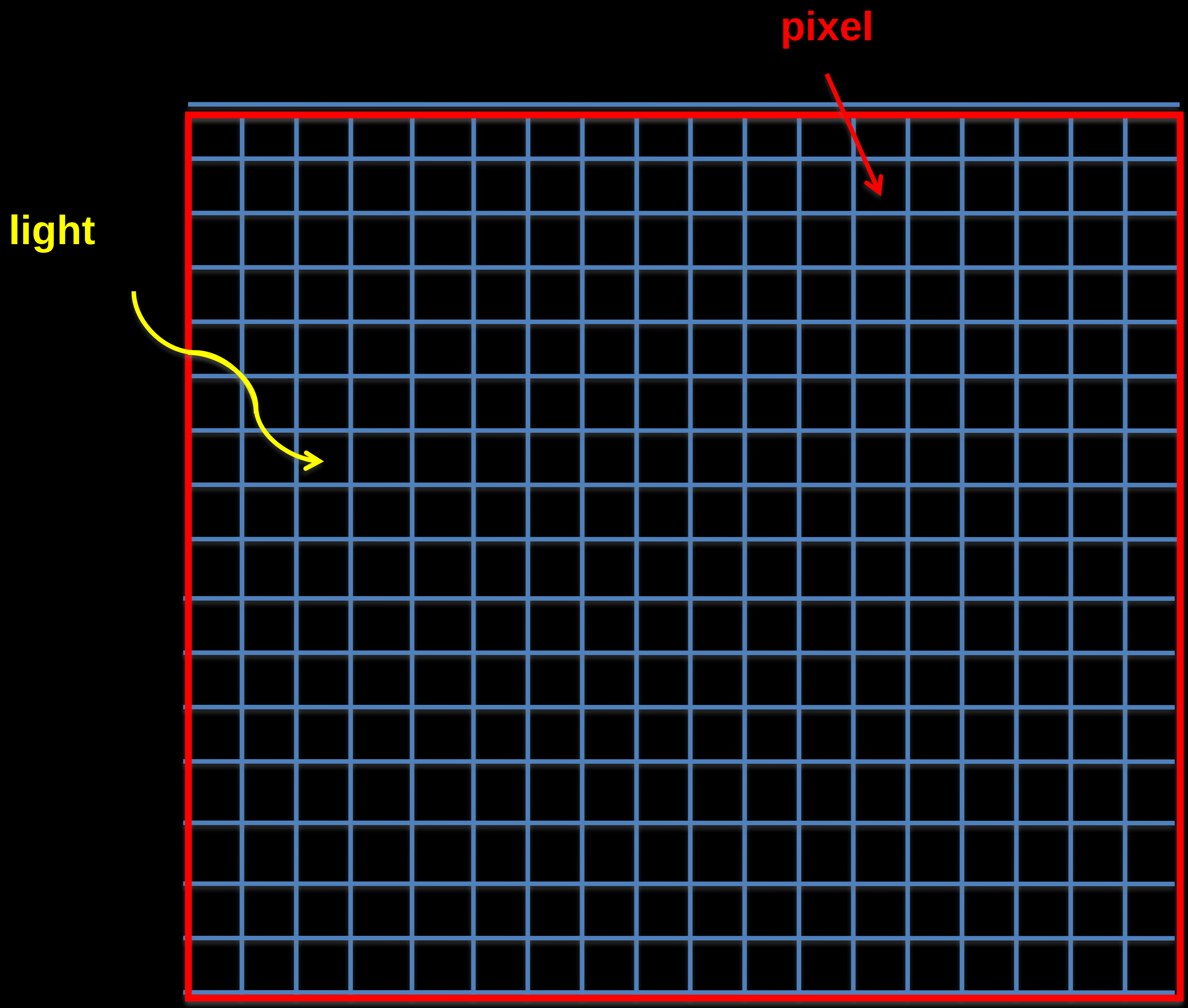
Radio telescopes are built in low valleys surrounded by mountains which protects against ground radio transmissions

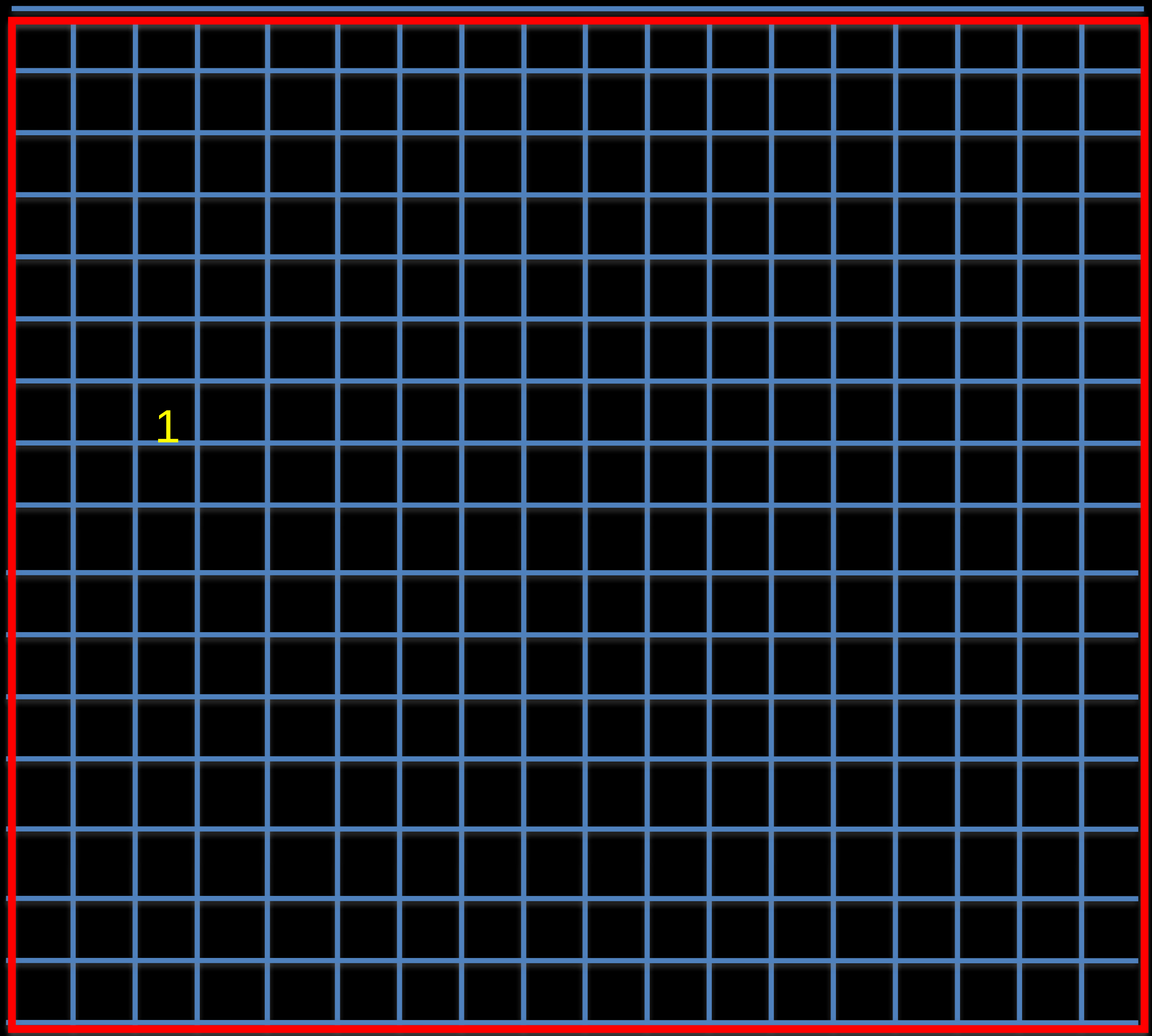
Optical and Radio Telescopes are different in that they use completely different systems to record the light.

Optical telescopes use a Charge Coupled Device (CCD)



It is an array of pixels that respond to the particle nature of light


pixel
light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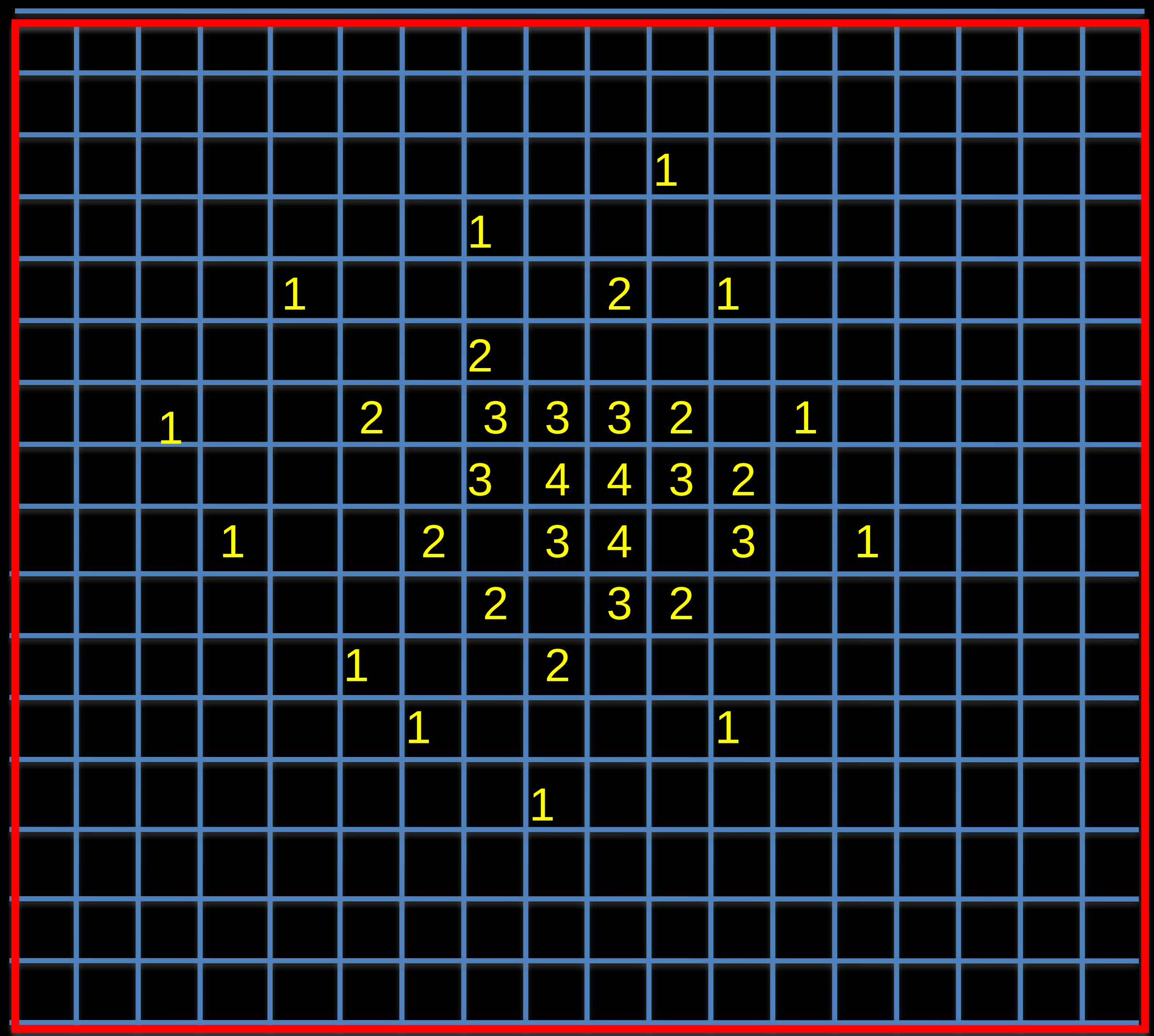
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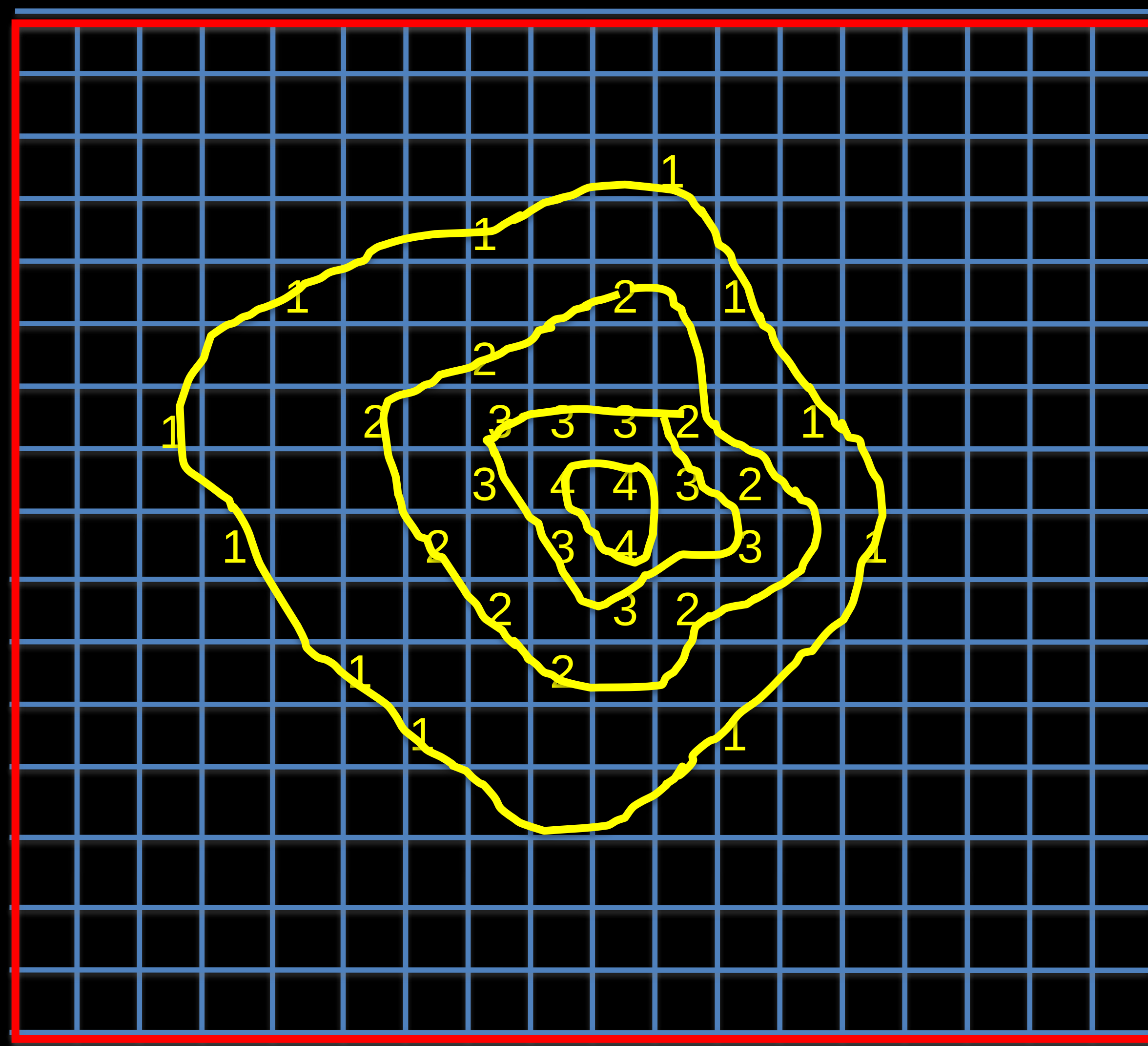
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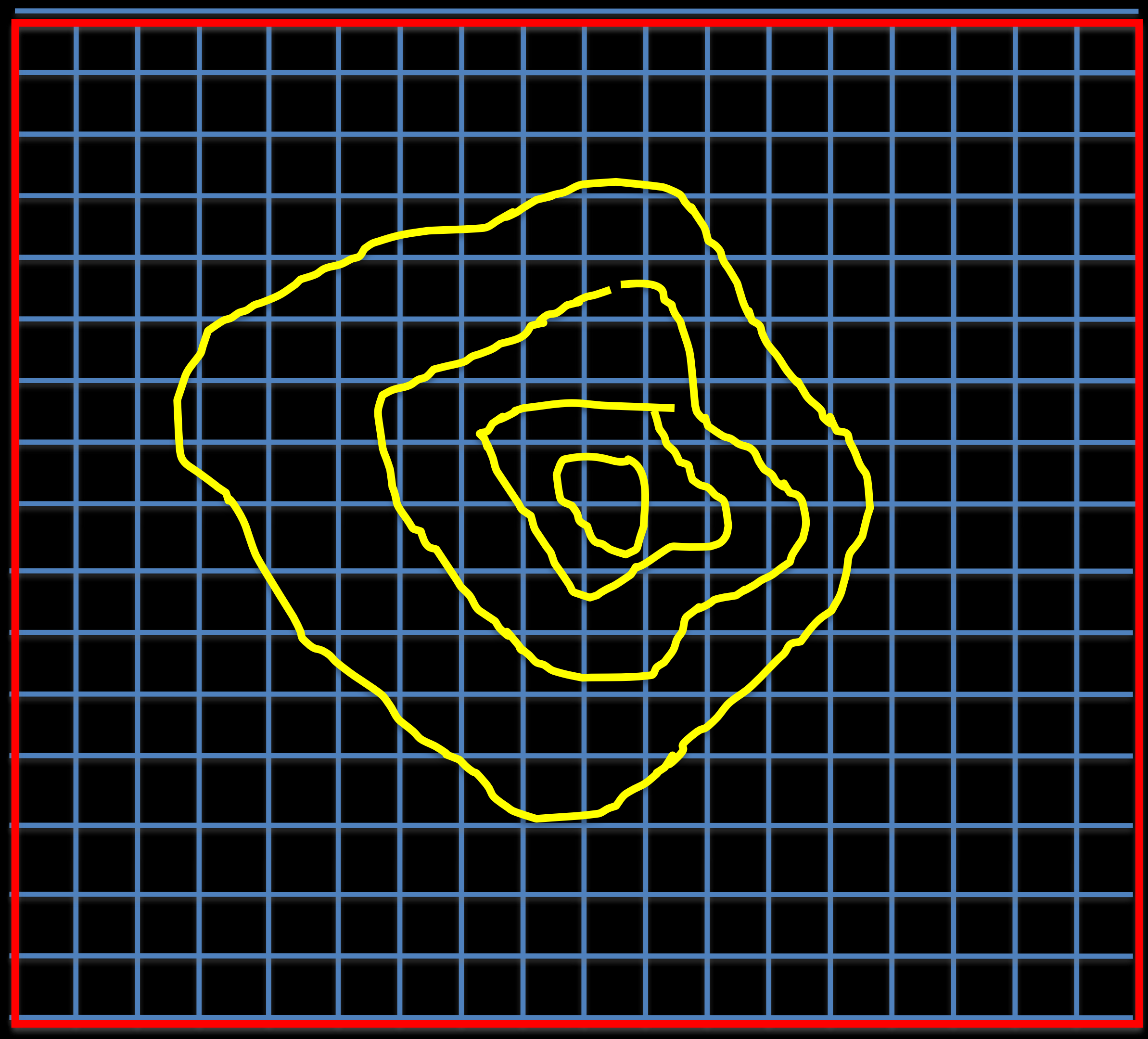
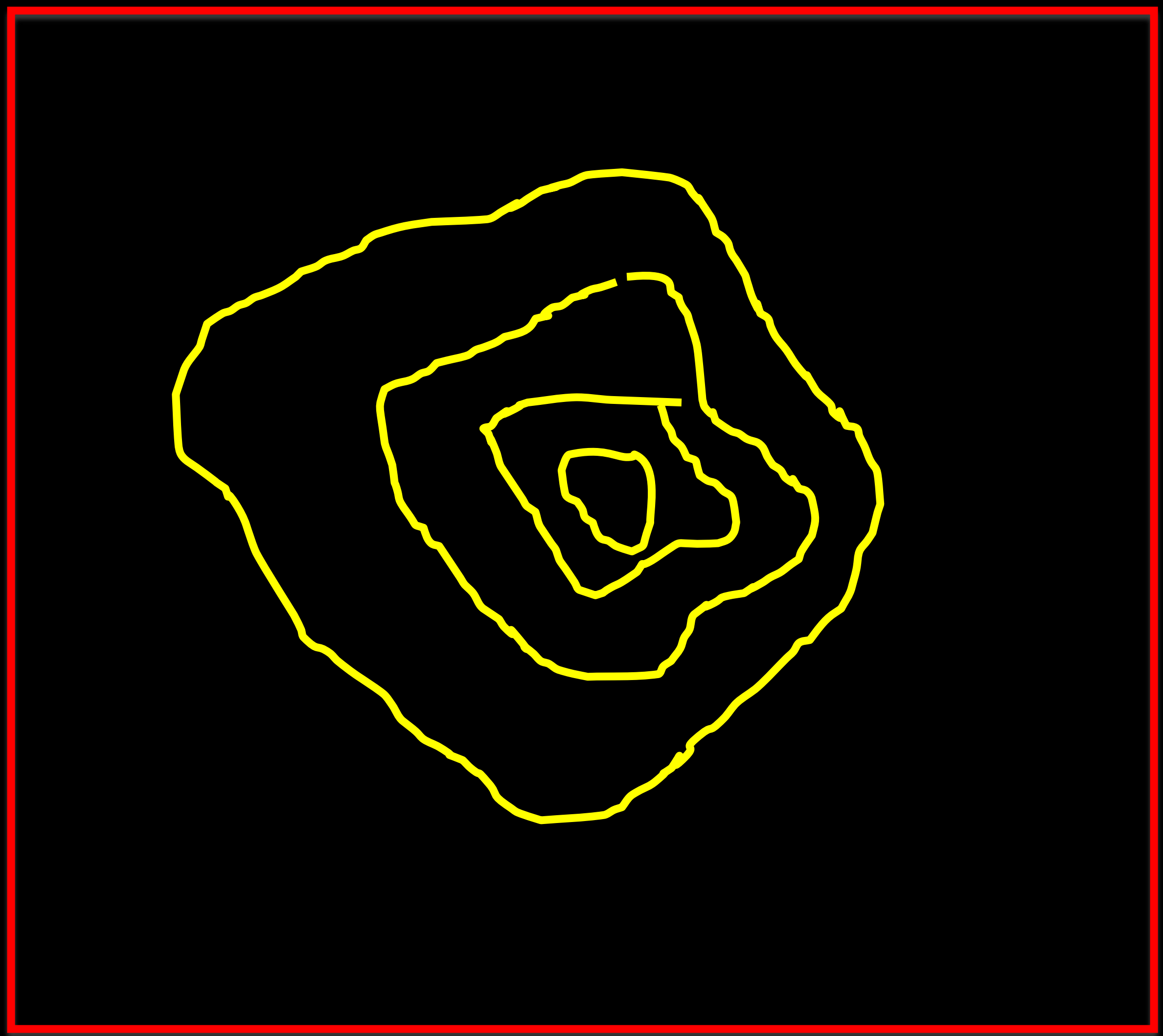
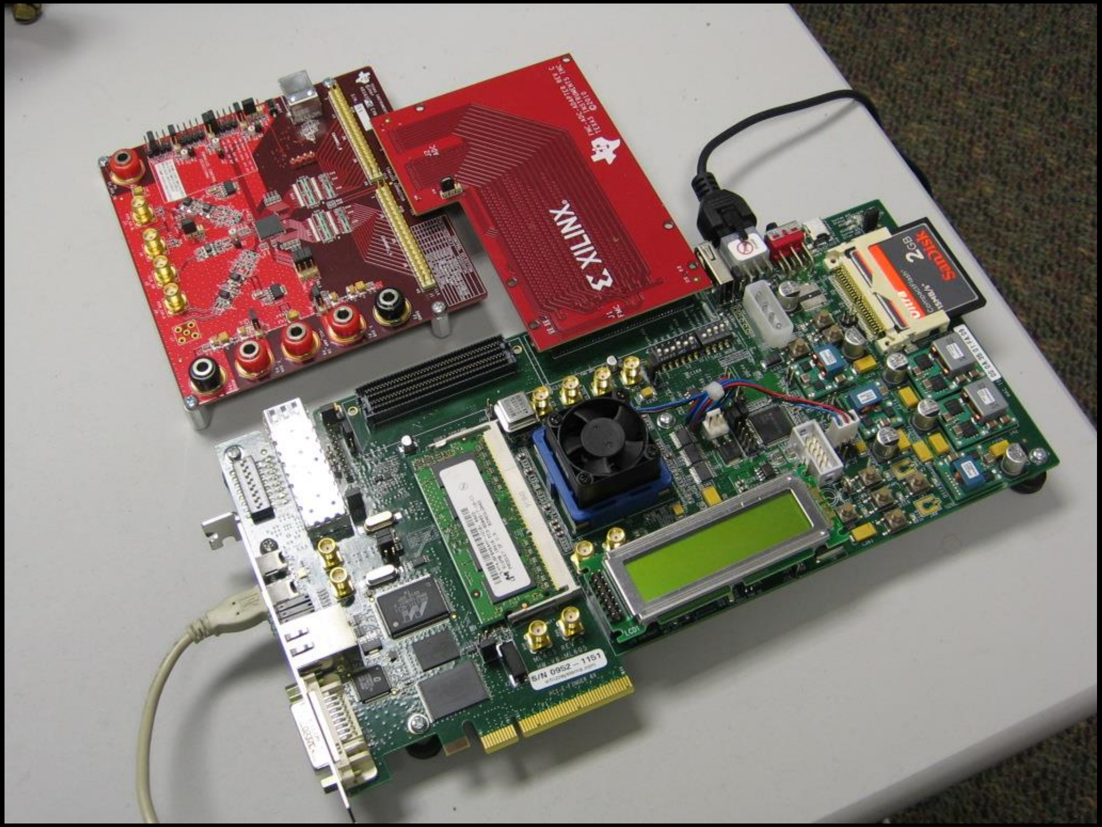


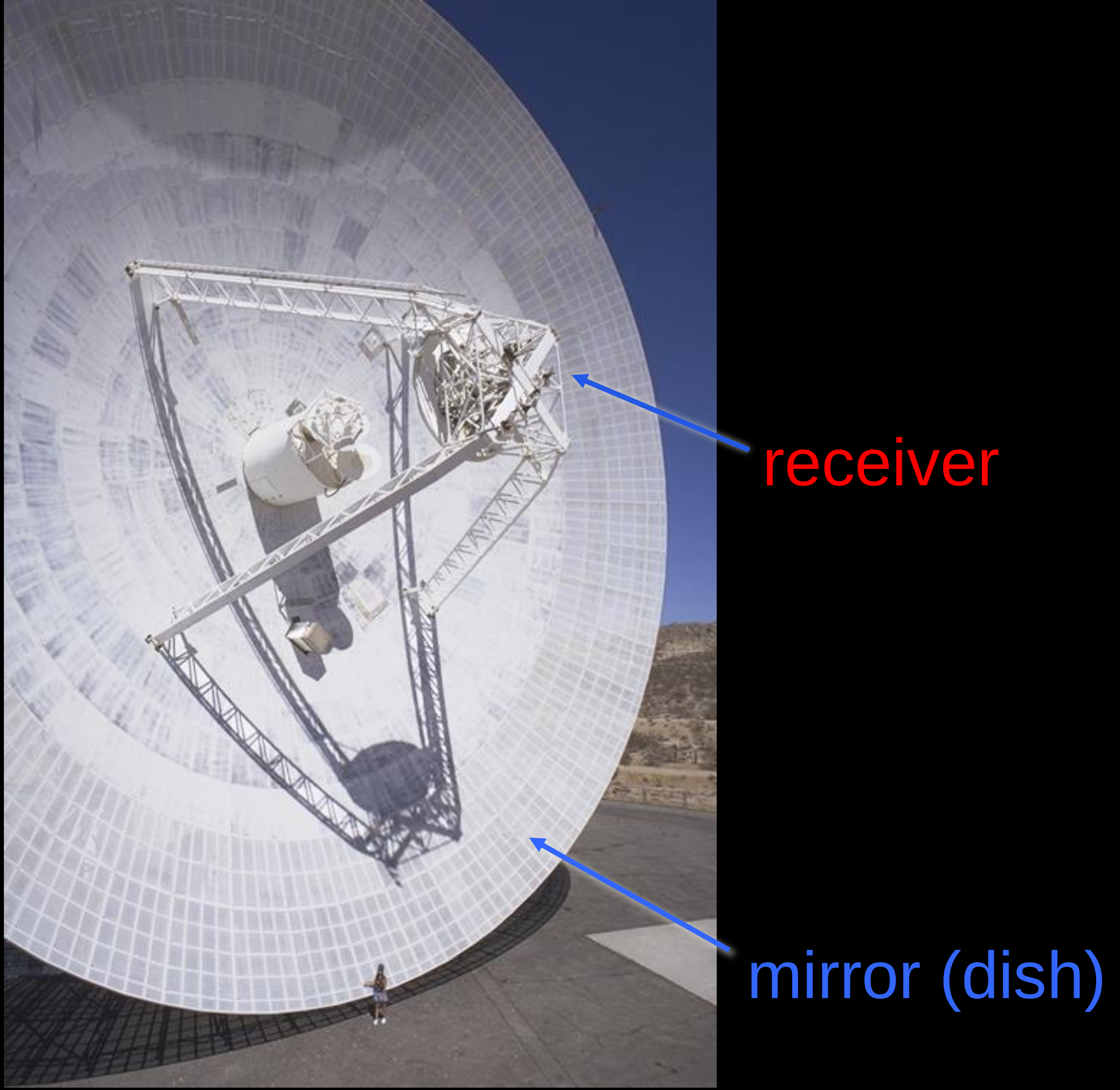


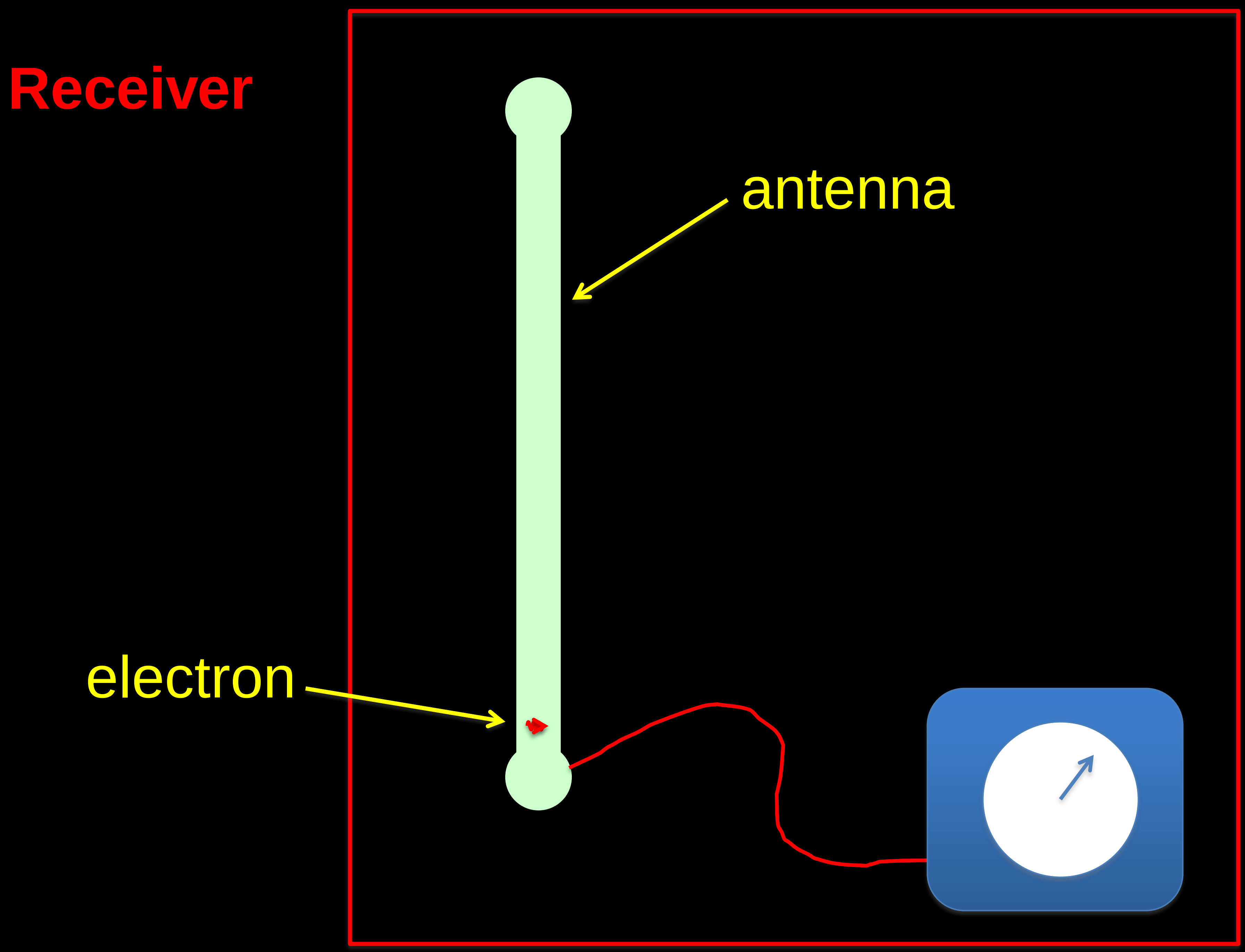
Optical and Radio Telescopes are different in that they use completely different systems to record the light.

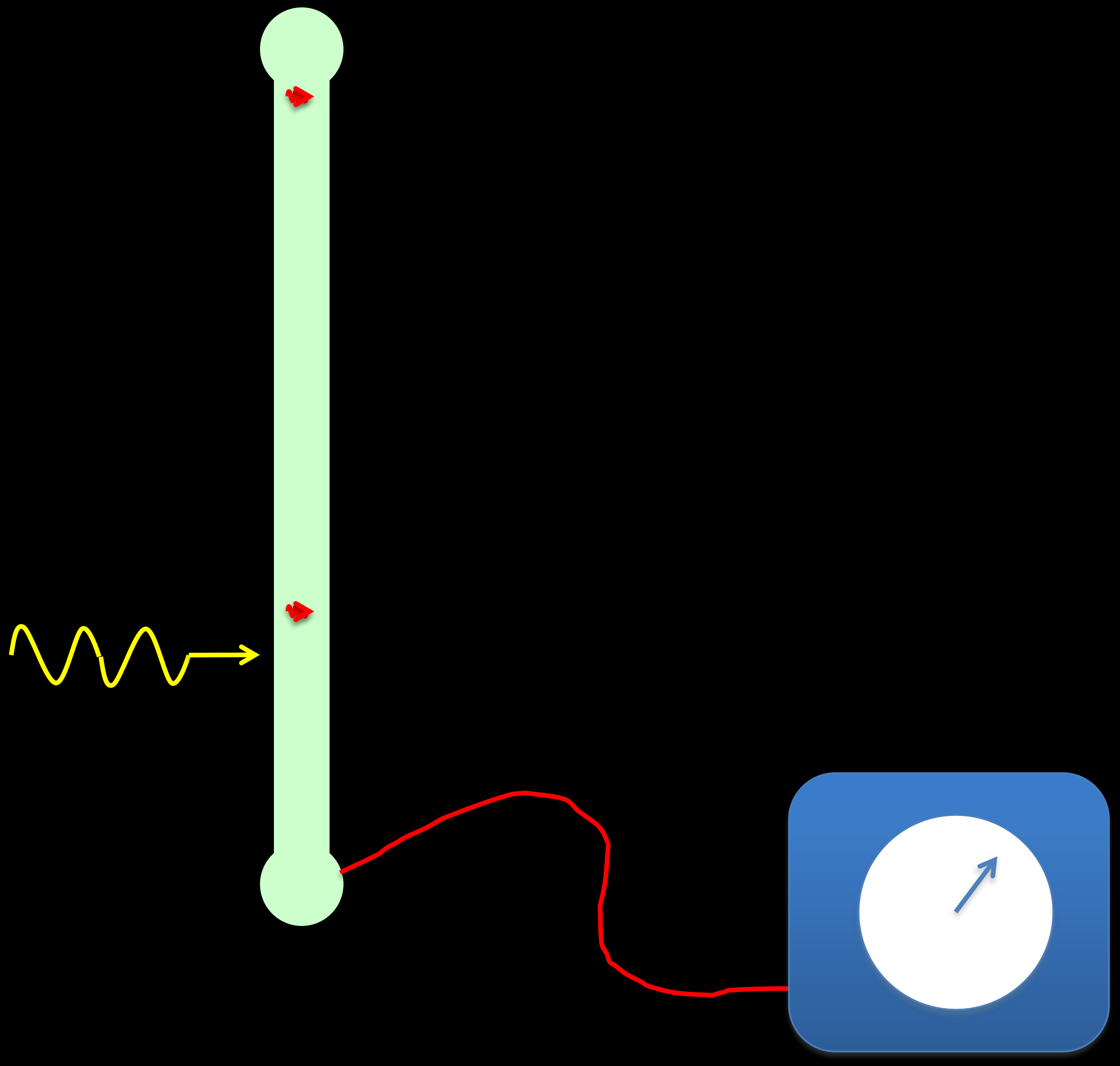
Radio telescopes use a Receiver



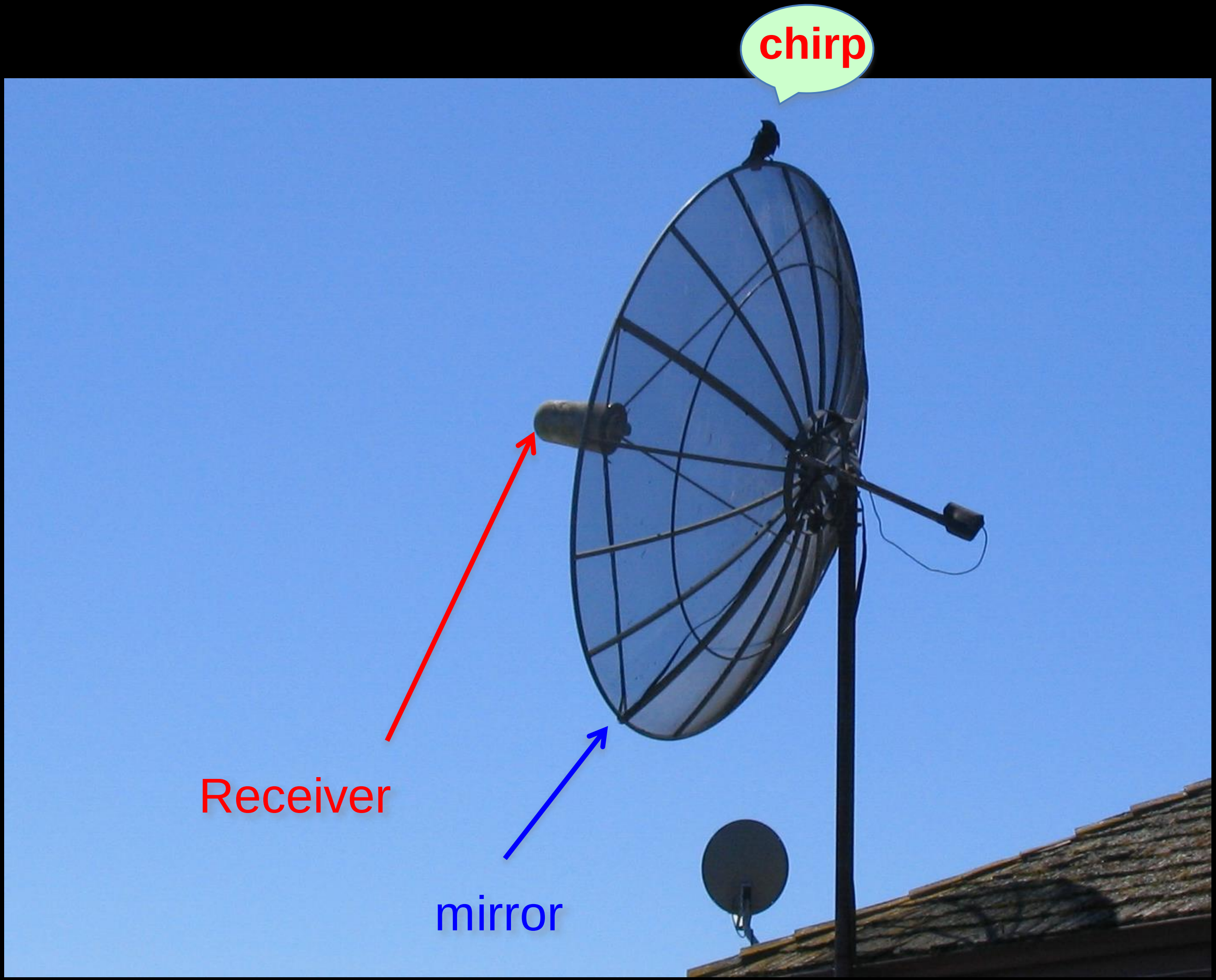
It measures the whole wave and exploits the wave nature of light


receiver
mirror (dish)


Receiver
antenna
electron



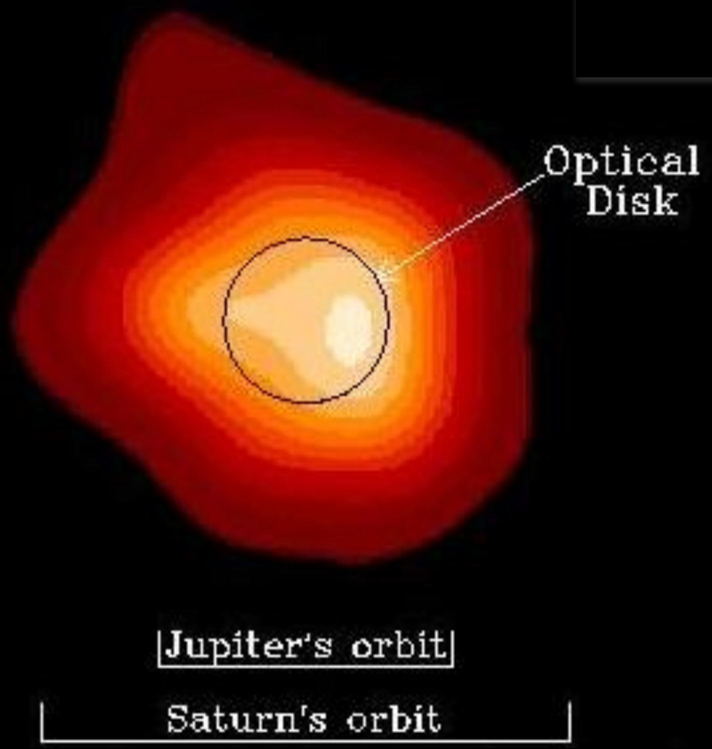
Remember the next time you see a satellite dish that it is just a small radio telescope!



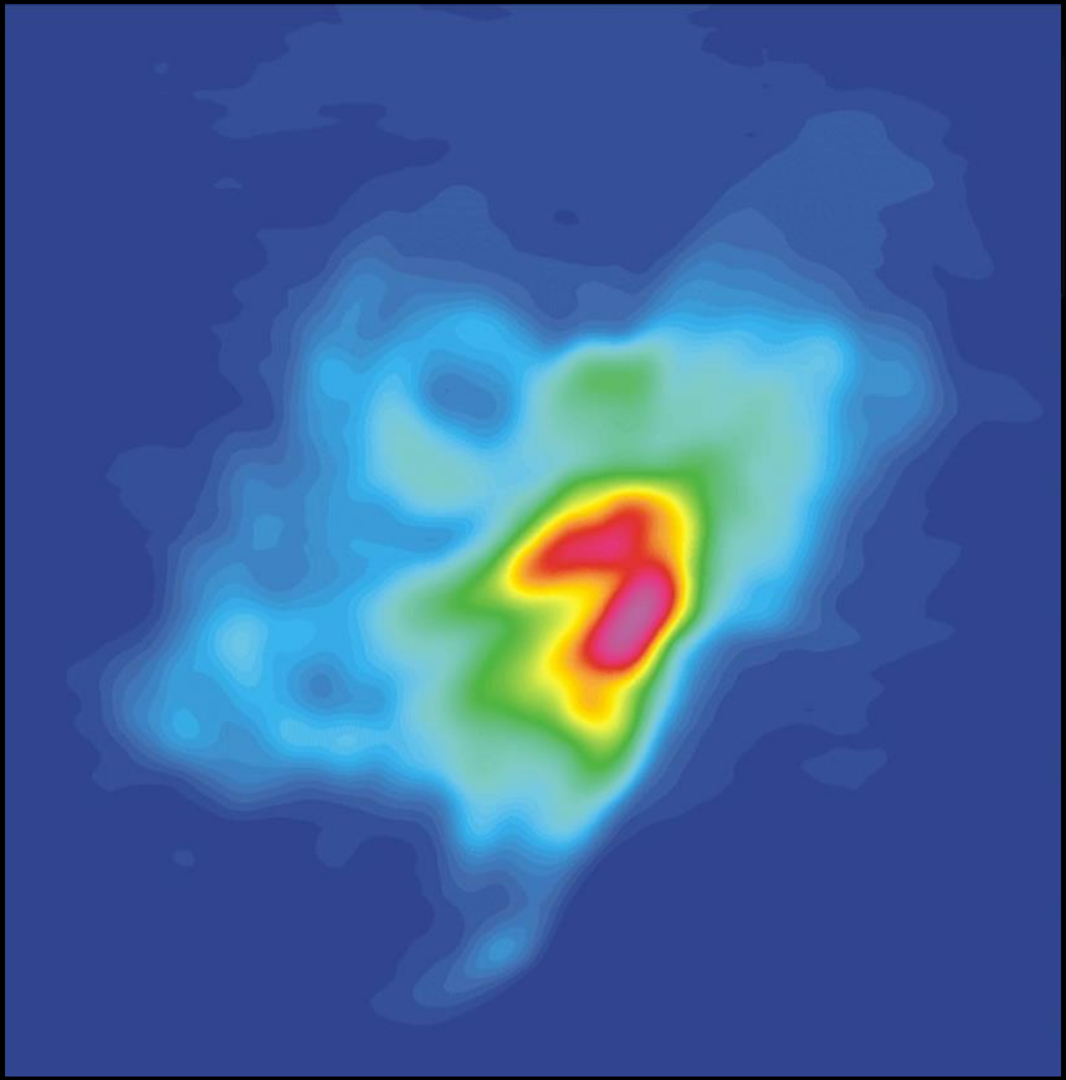
140 ft radio telescope at Green Bank

Max Planck Institute in Effelsberg, Germany — 300 ft Radio Telescope

1000 ft telescope at Arecibo, Puerto Rico



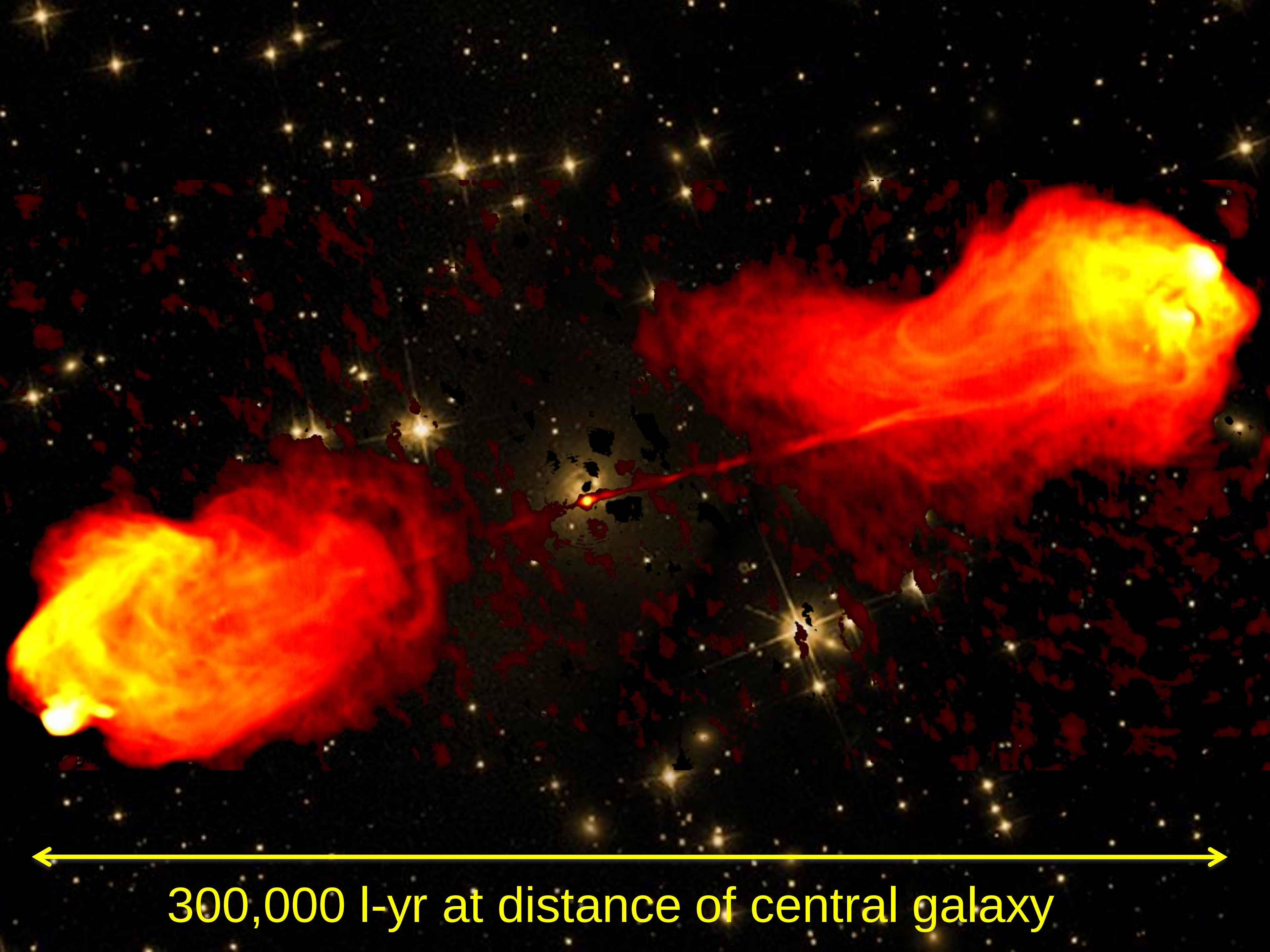
Betelgeuse



Orion Nebula

NRAO Very Large Array in Socorro, NM
Interferometry


300,000 l-yr at distance of central galaxy


300,000 l-yr at distance of central galaxy