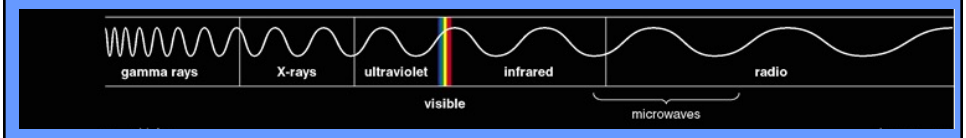
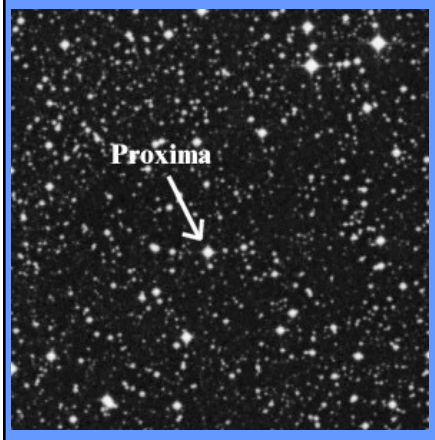
All the Light Our Eyes Cannot See:



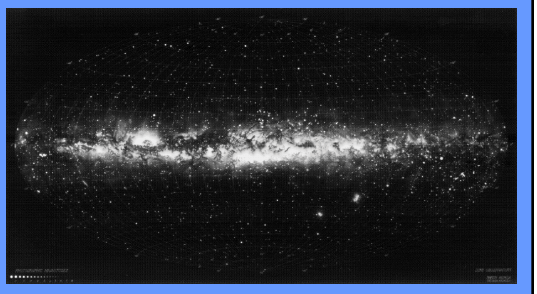
The Electromagnetic Spectrum and Telescopes, the Keys Astronomers Use to Unlock the Mysteries of the Universe

1

Distance to Proxima Centauri (the nearest star): 4.2 light years



Distance to the center of the Milky Way: 25,000 light years



How long will it take to travel to these locations in the fastest rocket ever launched?

2

2

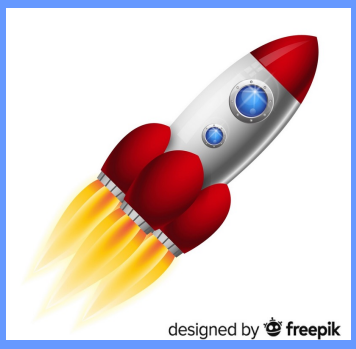
Fastest rocket ever launched from Earth:
New Horizons mission to Pluto
Launched: January 19, 2006
Arrived at Pluto: July 14, 2015
Fastest speed after escape from Earth: 16.26 km/s

Assume our "rocket speed" is
108,000 km/hr
(30 km/sec) !!!

3

3

Travel time to Proxima Centauri?
42,000 years



Travel time to the center of the Milky Way?
240 million years

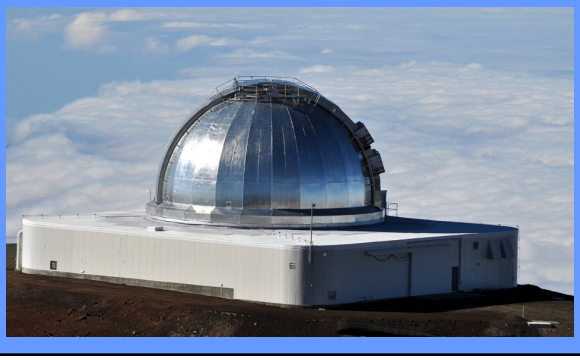
4

4

Experimental science

Credit: ORNL

Observational science



Credit: NASA IRTF

5

We take what the universe offers

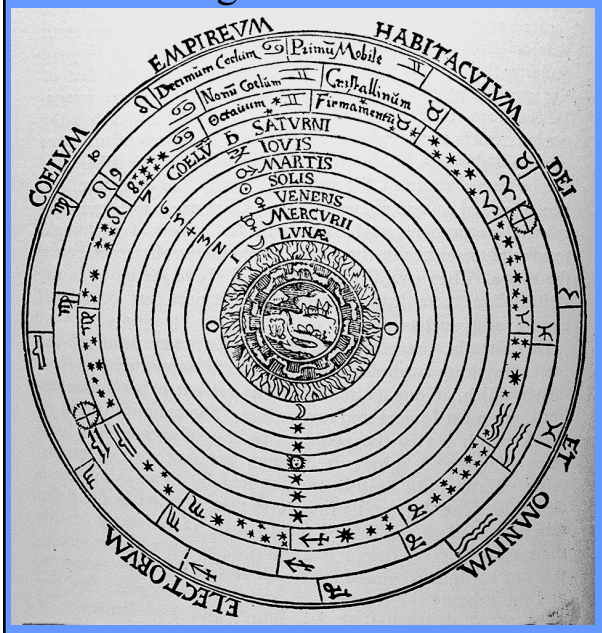
the universe gives us light

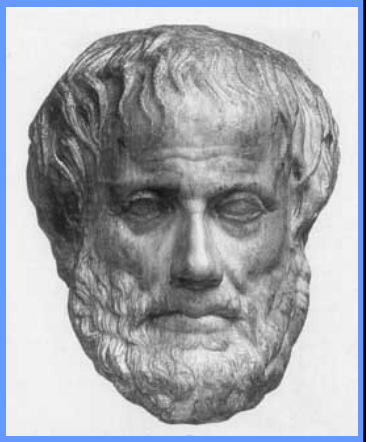
- in the future, astronomers may learn how to effeciently detect neutrinos and cosmic rays, but we are just learning how to do these things
- we are just now learning how to detect gravitational waves from distant, massive, colliding/coalescing objects

so astronomers must understand light

6

Aristotle's geocentric universe

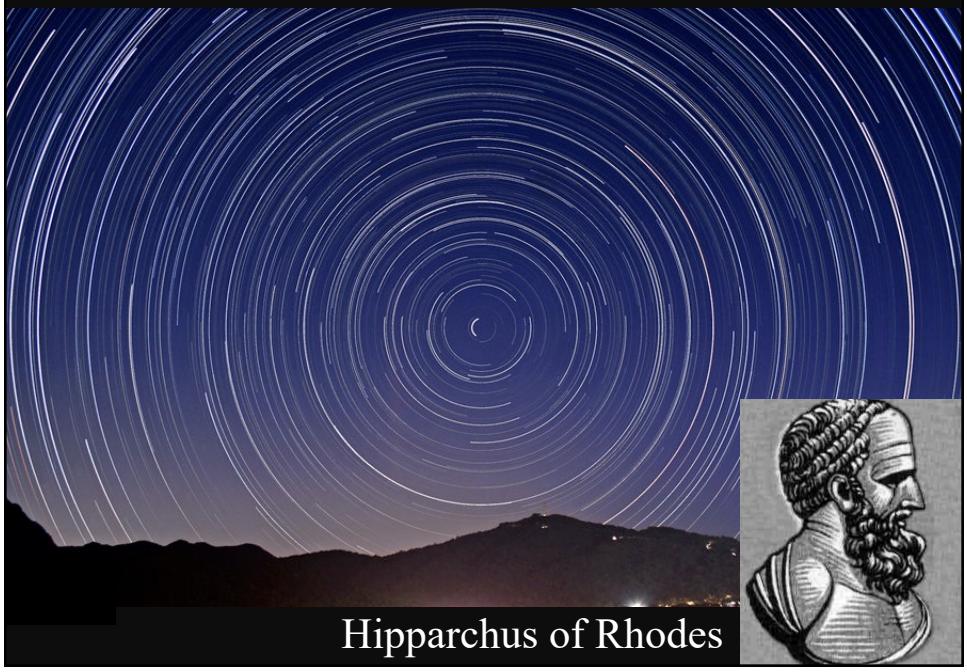




Aristotle
c. 350 BCE

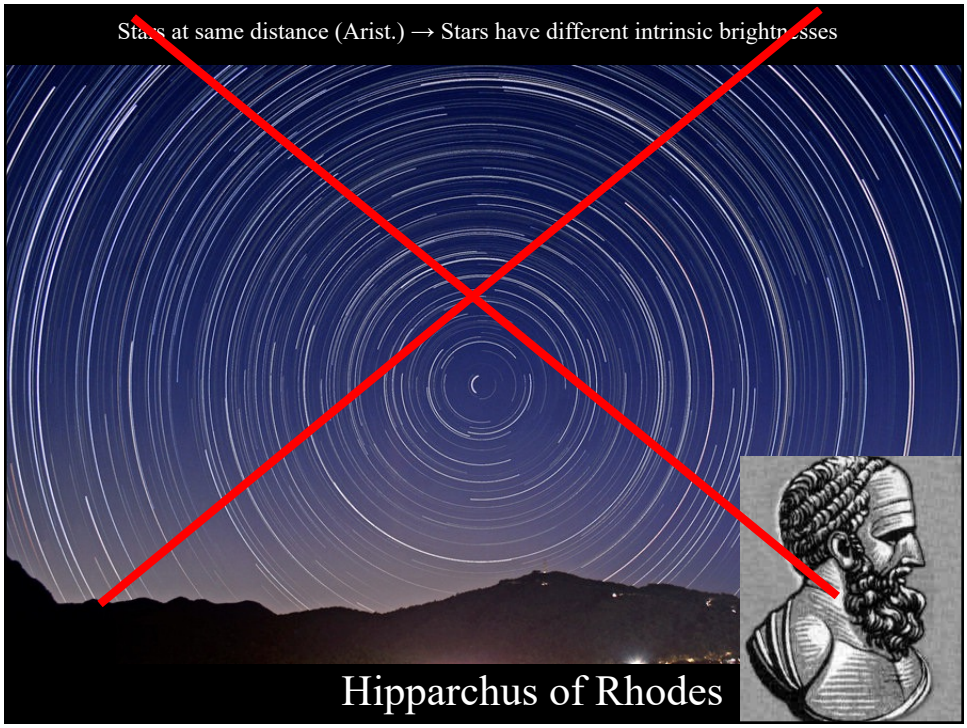
7

Stars at same distance (Arist.) → Stars have different intrinsic brightnesses

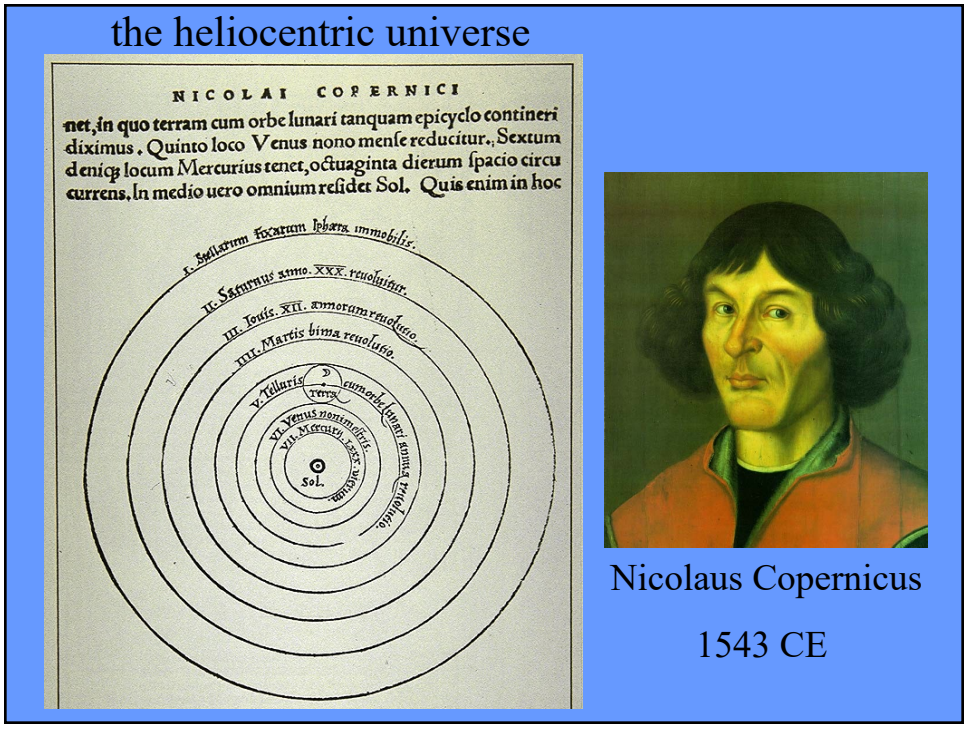


Hipparchus of Rhodes

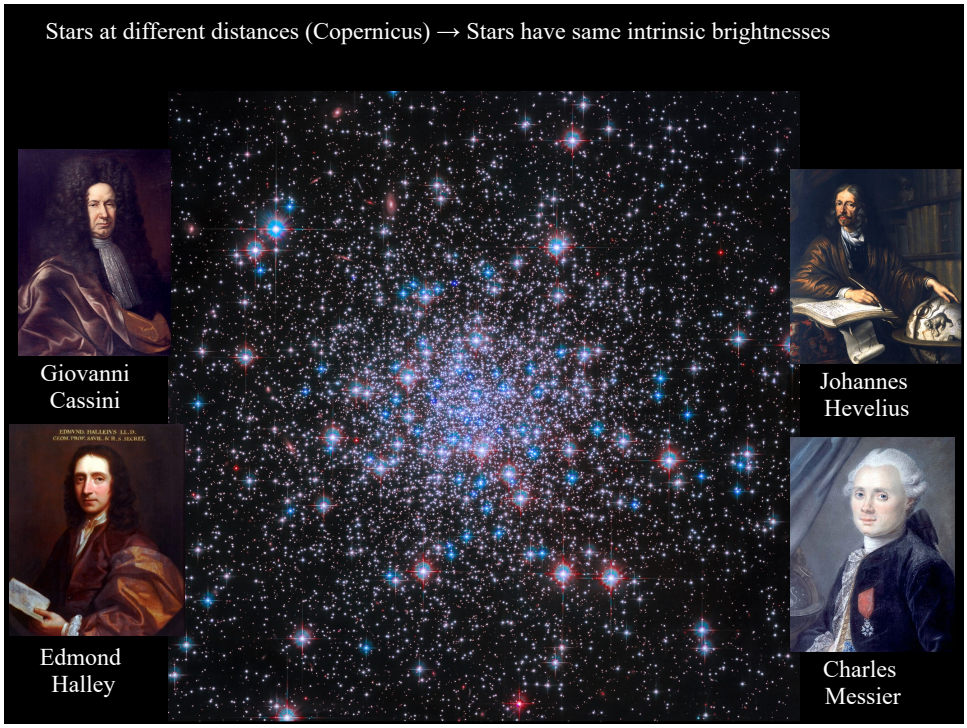
8


Stars at same distance (Arist.) → Stars have different intrinsic brightnesses
Hipparchus of Rhodes

9


the heliocentric universe
NICOLAI COPERNICI
net, in quo terram cum orbe lunari tanquam epicyclo contineri
diximus. Quinto loco Venus nono mense reducitur. Sextum
denique locum Mercurius tenet, octuaginta dierum spacio circu
currens. In medio uero omnium residet Sol. Quis enim in hoc
Nicolaus Copernicus
1543 CE

10


Stars at different distances (Copernicus) → Stars have same intrinsic brightnesses
Giovanni Cassini
Johannes Hevelius
Edmond Halley
Charles Messier

11


Stars at different distances (Copernicus) → Stars have same intrinsic brightnesses
Giovanni Cassini
Johannes Hevelius
Edmond Halley
Charles Messier

12

SCIENCE

- Use our senses to observe the world around us
- Discover the laws of physics that govern the behavior of objects in the universe
- Use rational thought to draw reasonable conclusions about the universe

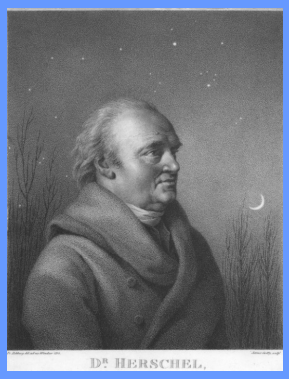
The key to scientific discovery?

- Ask a good question
- Come up with a good experiment to answer the question
- **Have the courage to question 'accepted wisdom' if the results of your experiment conflict yield a different answer**

13

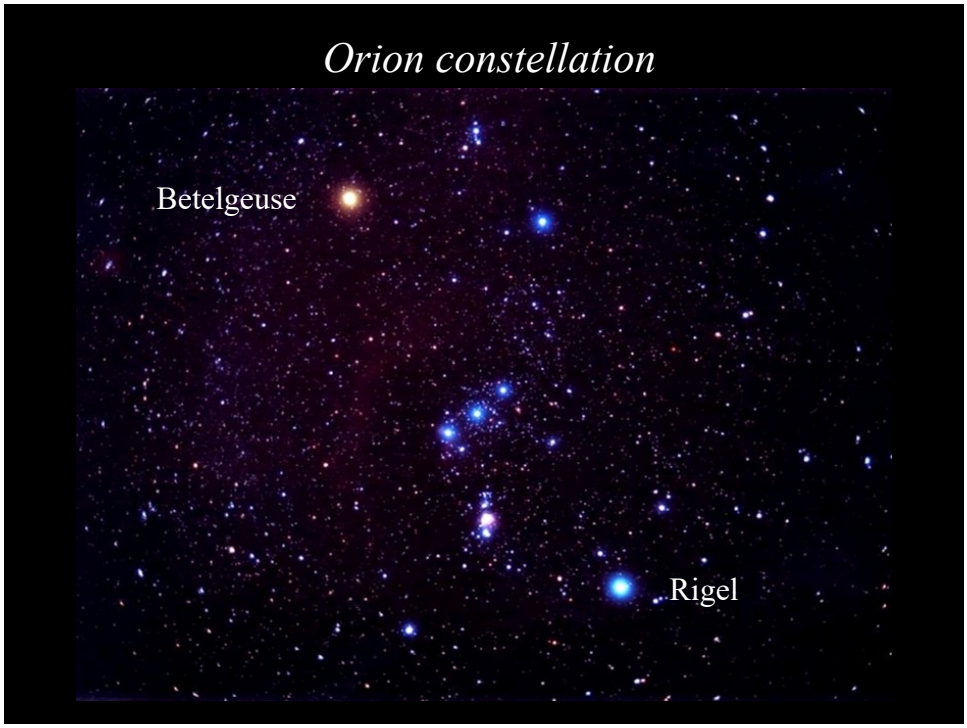
Are all stars alike?

Herschel's telescope

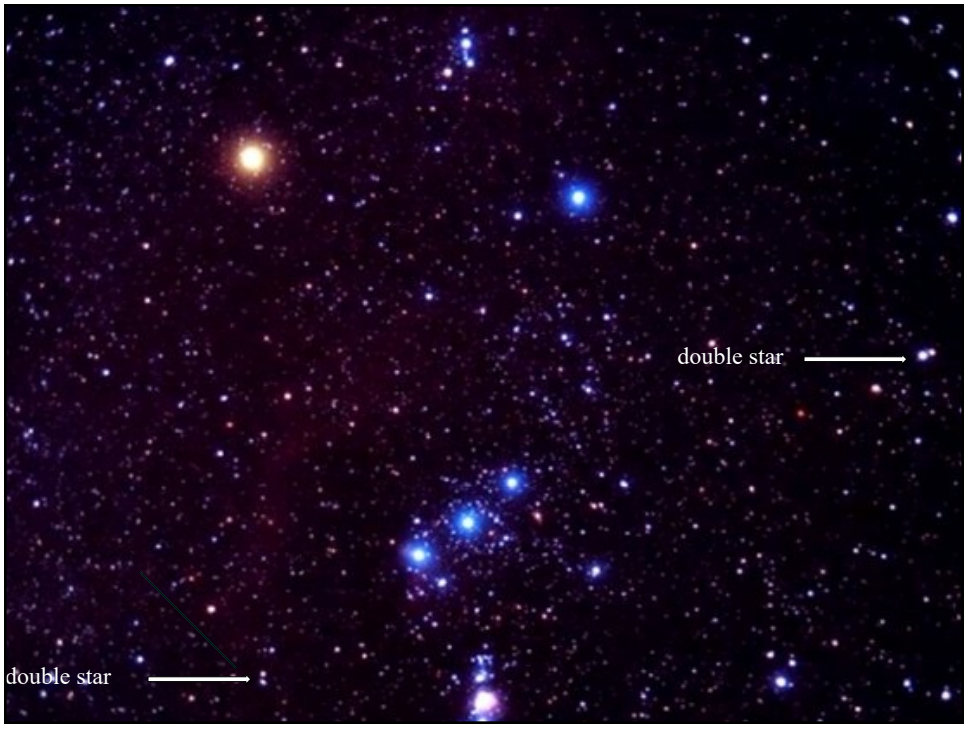


William Herschel
(1738-1822 CE)

14


Orion constellation
Betelgeuse
Rigel

15


double star
double star

16

‘double’ stars

‘accepted wisdom’

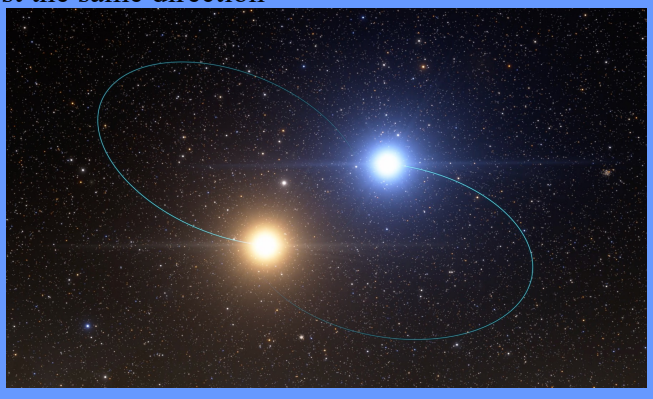
- brighter star in ‘double star’ is closer
- fainter star in ‘double star’ is more distant

Observations made:

- watched for motions both stars in doubles
- In 1802, **after 20 years**, he had his answer

17

- found some pairs in orbit around a common center
- they must be true **binary stars**, not just two stars seen in almost the same direction



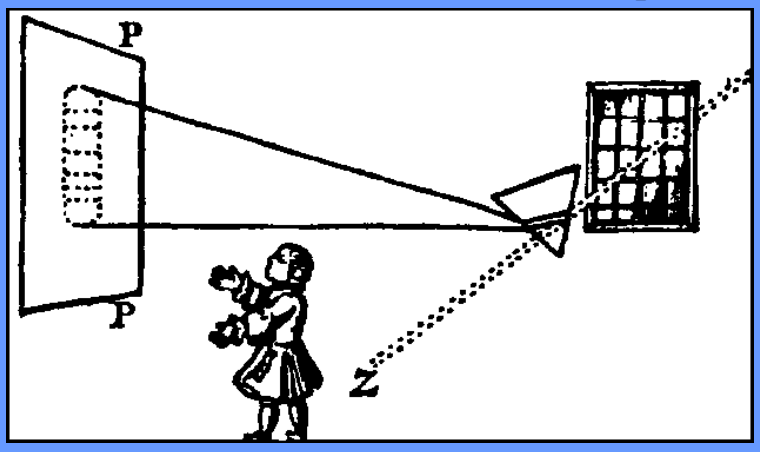
- one bright and one faint star in the pair **at same distance**
- **Stars are NOT all alike.**
  - **Their intrinsic brightnesses can differ.**
  - **Their colors can differ.**

Credit: ESO/spaceengine.org

18

What is light?

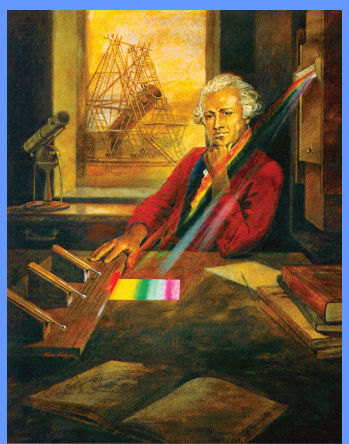
- In 1666, Isaac Newton put white light through a prism
- result: a rainbow of colors he called a **spectrum**



Newton's experimental arrangement is illustrated in Voltaire's *Eléments de la Philosophie de Newton,* (1738).

19

Does light produce heat?



Sir Frederick William Herschel

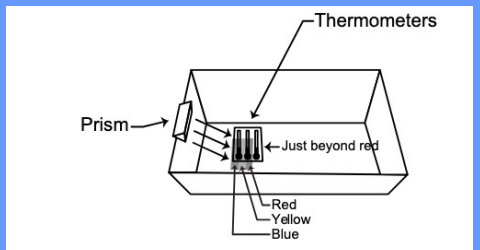
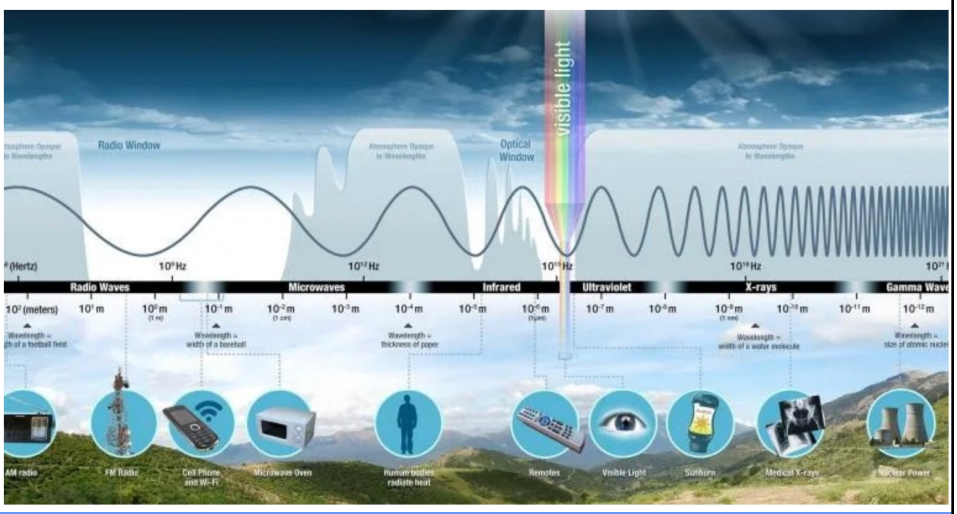


Figure 4. Herschel experiment.

- Light heats up the thermometers
- Something heats up a thermometer 'beyond the red'

Credit: https://spaceplace.nasa.gov › Herschel-ir-activity

20



Credit: https://science.nasa.gov/ems/01_intro/

21

What is light?

- energy carried through space
- something that carries energy through space

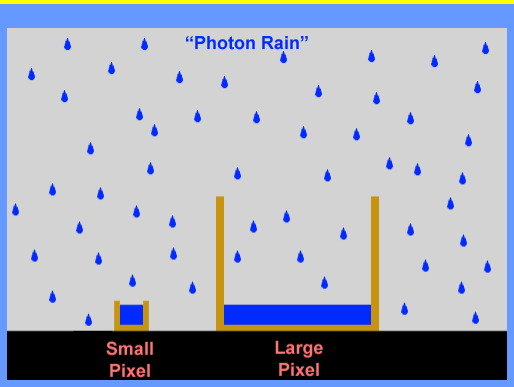
- a wave
- a particle

} a photon

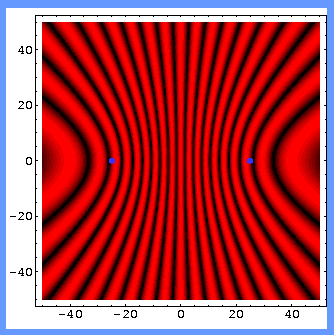
- light travels at speed of 300,000 km/sec

22

light acting as a particle



and as a wave



23

24

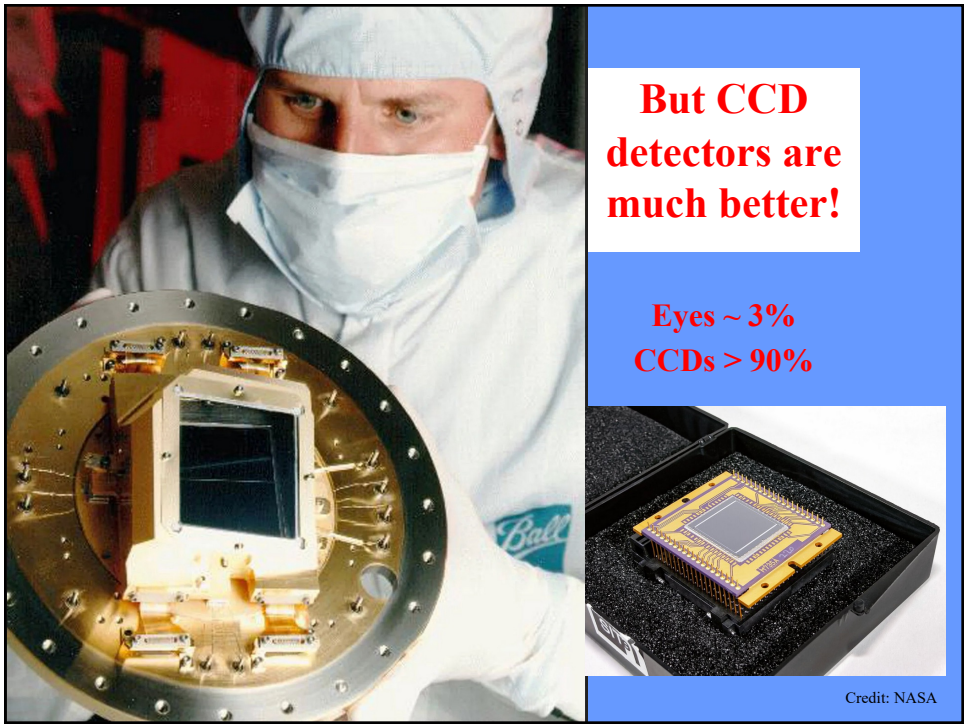
Your eyes are good at detecting visible (red, blue, yellow) light

25

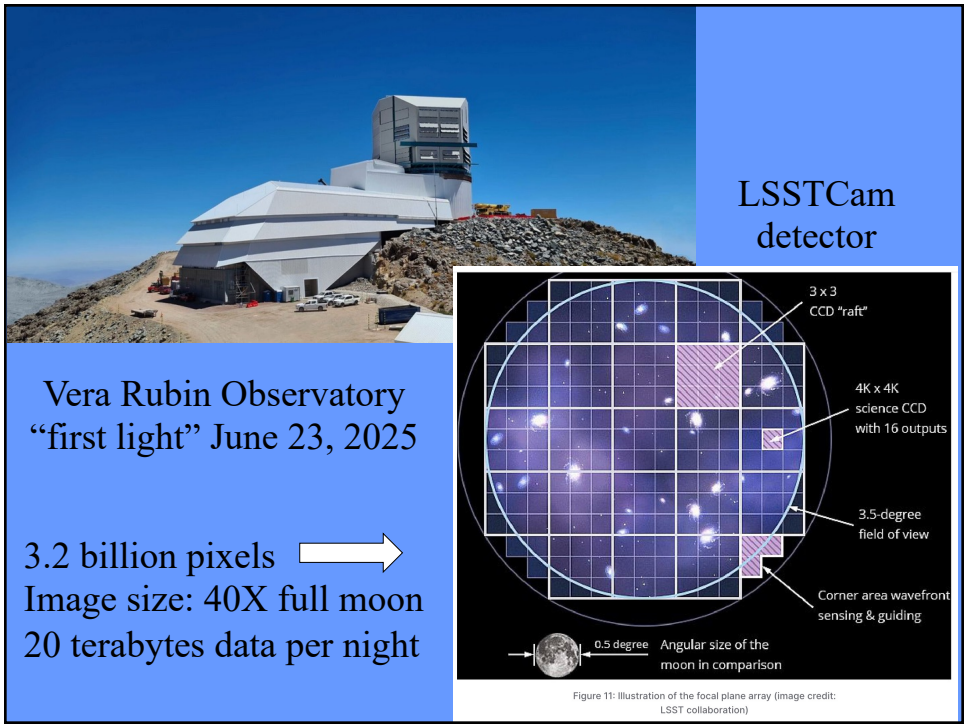
1880s: coated glass photographic plates

1950s: photomultiplier tube

26


But CCD detectors are much better!
Eyes ~ 3%
CCDs > 90%
Credit: NASA

27


LSSTCam detector
Vera Rubin Observatory "first light" June 23, 2025
3.2 billion pixels
Image size: 40X full moon
20 terabytes data per night
3 x 3 CCD "raft"
4K x 4K science CCD with 16 outputs
3.5-degree field of view
Corner area wavefront sensing & guiding
0.5 degree
Angular size of the moon in comparison
Figure 11: Illustration of the focal plane array (image credit: LSST collaboration)

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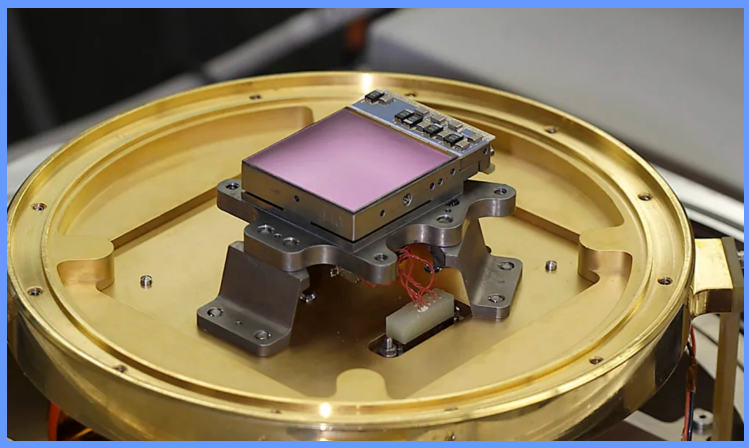
The water in your skin cells is good at detecting infrared light

29

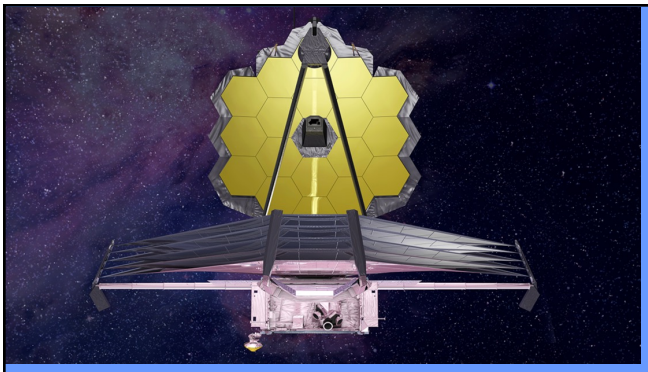
But specially designed silicon wafer detectors are much better!



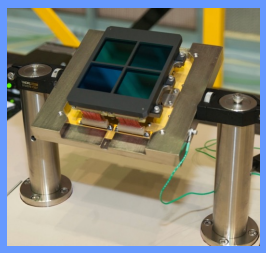
NIRCam detector in James Webb Space Telescope uses pixelated purple mercury-cadmium-telluride film

Credit: NASA

30

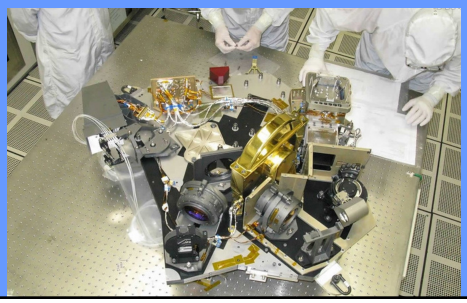


NIRCam detector



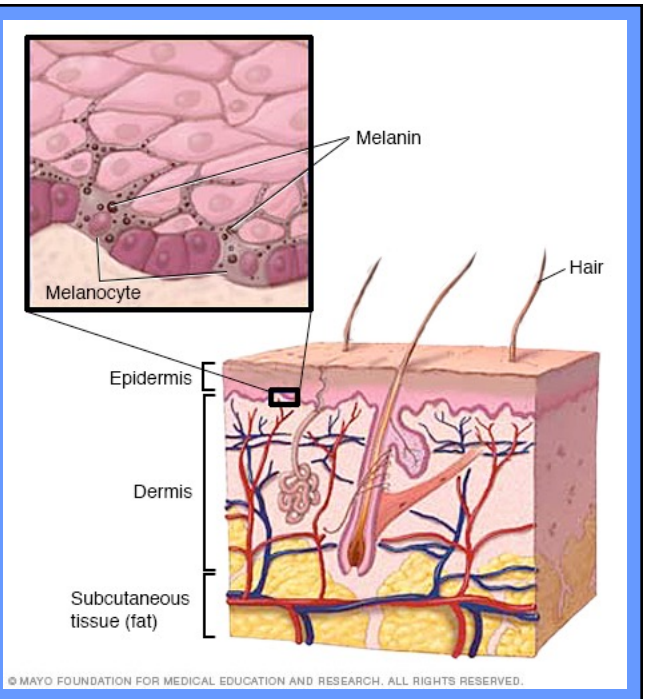
James Webb Space Telescope
launched Dec 25, 2021

NIRCam ⇨
4.2 million pixels
Image size:
1/620 full moon



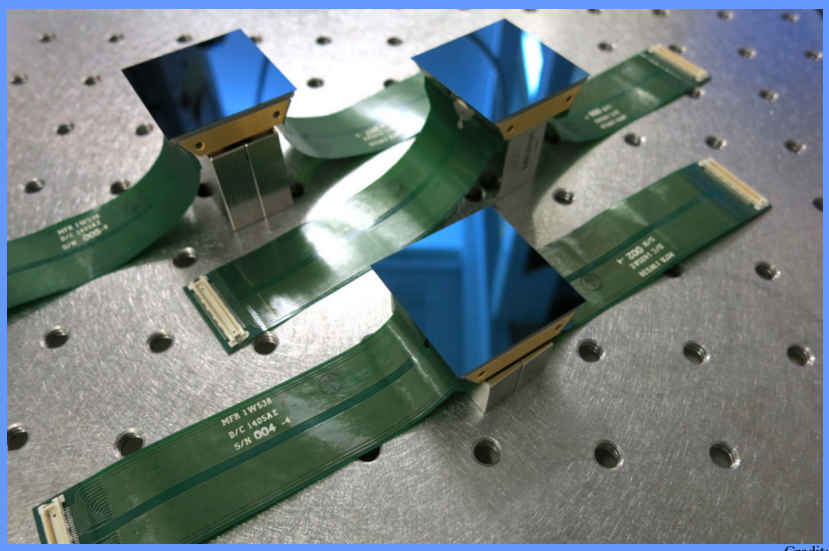
31

Melanin molecules in epidermis skin cells are good at detecting ultra-violet light



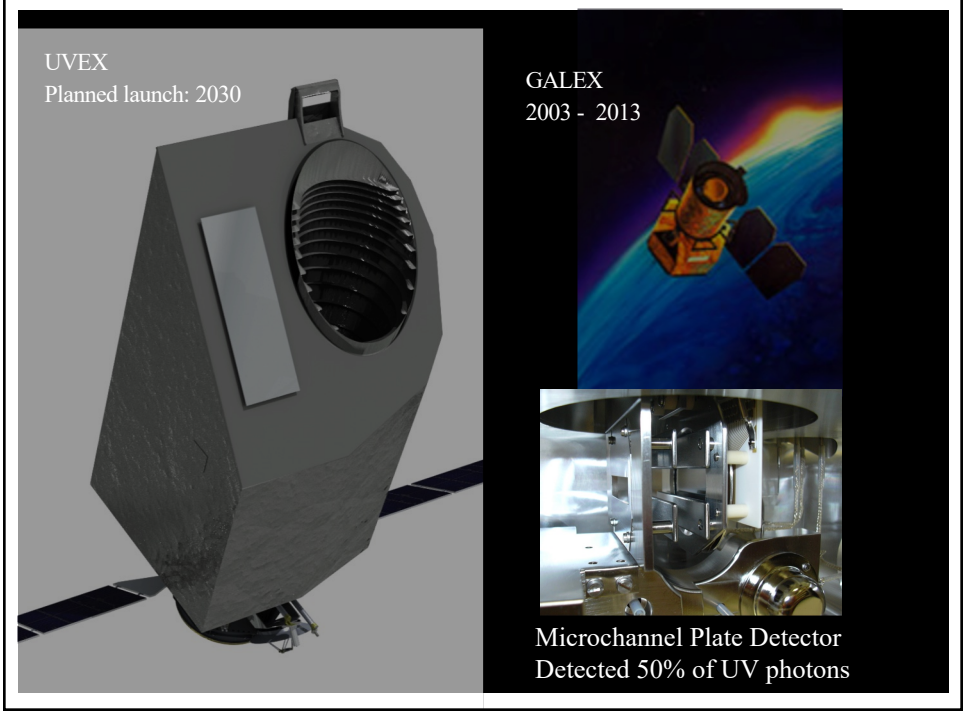
32

But these >80% efficient thin-film CCD arrays are better!



Credit: NASA

33

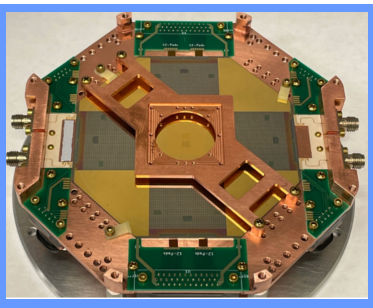


34

bone is good at detecting x-rays

35

But magnetic microcalorimeters are much better!



A magnetic microcalorimeter, with more than 100,000 pixels, cooled to temperature of - 469.6 F, might be used in future X-ray satellite telescopes

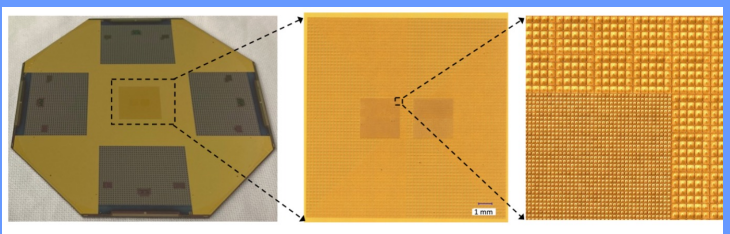


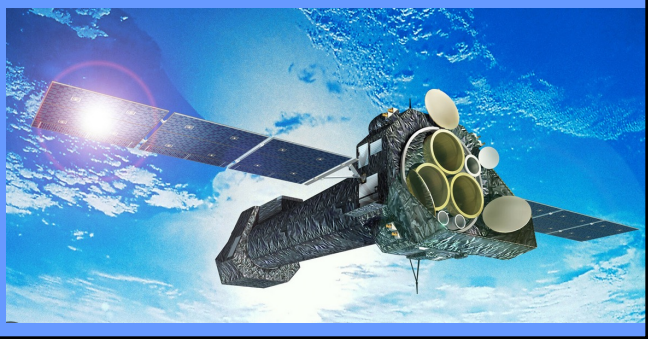
Figure 2: Zoom-in of prototype 100,000-pixel magnetic calorimeter array showing the three different pixel types in this array
Image credit: NASA GSFC

Credit: NASA

36

XMM Newton Telescope launched 1999 (ESA)

Chandra Space Telescope launched 1999 (NASA)



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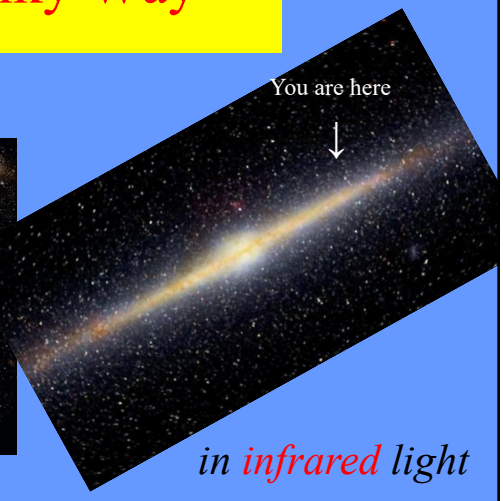
The Milky Way

in visible light

You are here



in infrared light

Serge Brunier: APOD 4 Oct 2005

COBE: APOD 30 Jan 2000

38


The Crab Nebula
X-rays: electrons spiral in disk and are ejected in polar jets; these trace the effects of the neutron star (pulsar) at the core
ultraviolet light: ions (charged nuclei) trace out outflowing winds of material ejected by the supernova explosion
infrared light: warm dust grains that form in the outflowing winds map out the magnetic field
radio light: atoms and molecules trace out the pulsar winds interacting with the supernova remnants

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