Modern Astronomy

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Call me Greg

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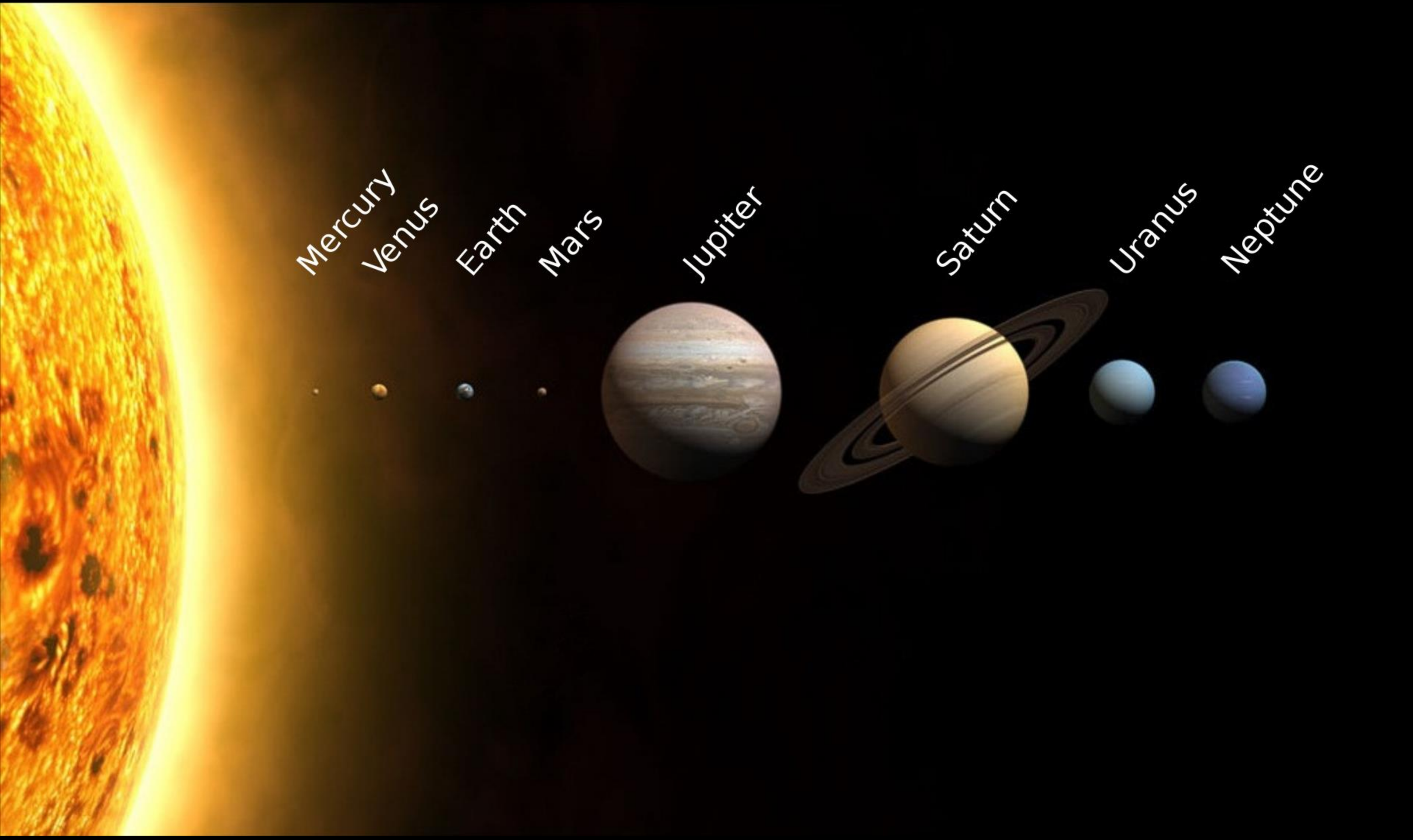
What will we cover?

- How do stars form? How do they die?
- The Big Bang, galaxy formation, and our future?
- Black Holes!
- Our own solar system! Other solar systems! Life!

Syllabus
https://gherczeg.github.io/modernastronomy/

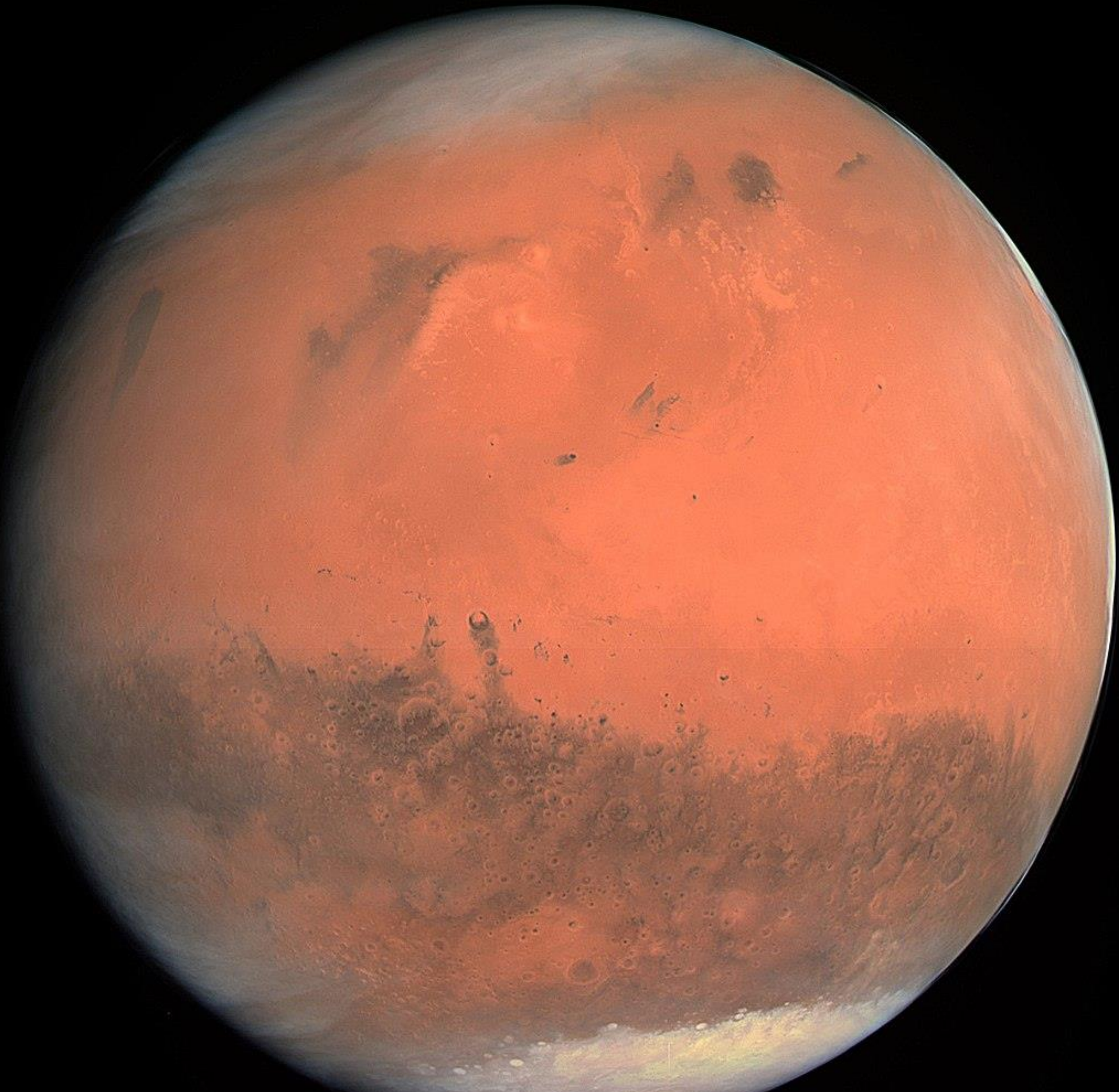
First homework (worth 0.5 homeworks)

- Introduce yourself to me
- Take a photo of yourself with your name
- Take a photo at least once per month of sunset from exact same location, pointing in same direction
  - sunrise also ok, if you prefer

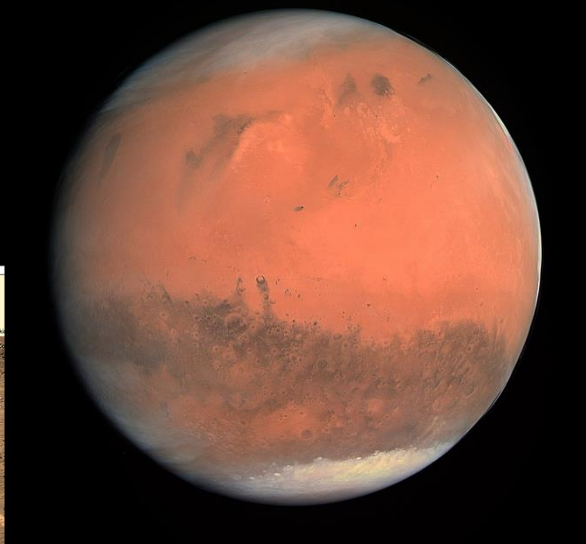

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune

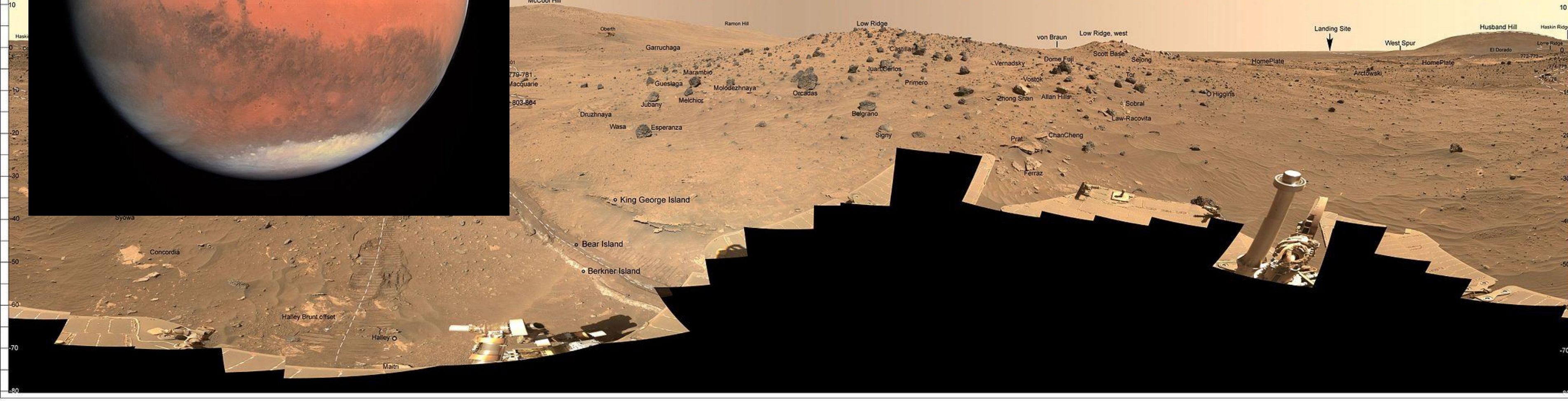
Earth from the Lunar Reconnaisance Orbiter

Earth from the Cassini Mission



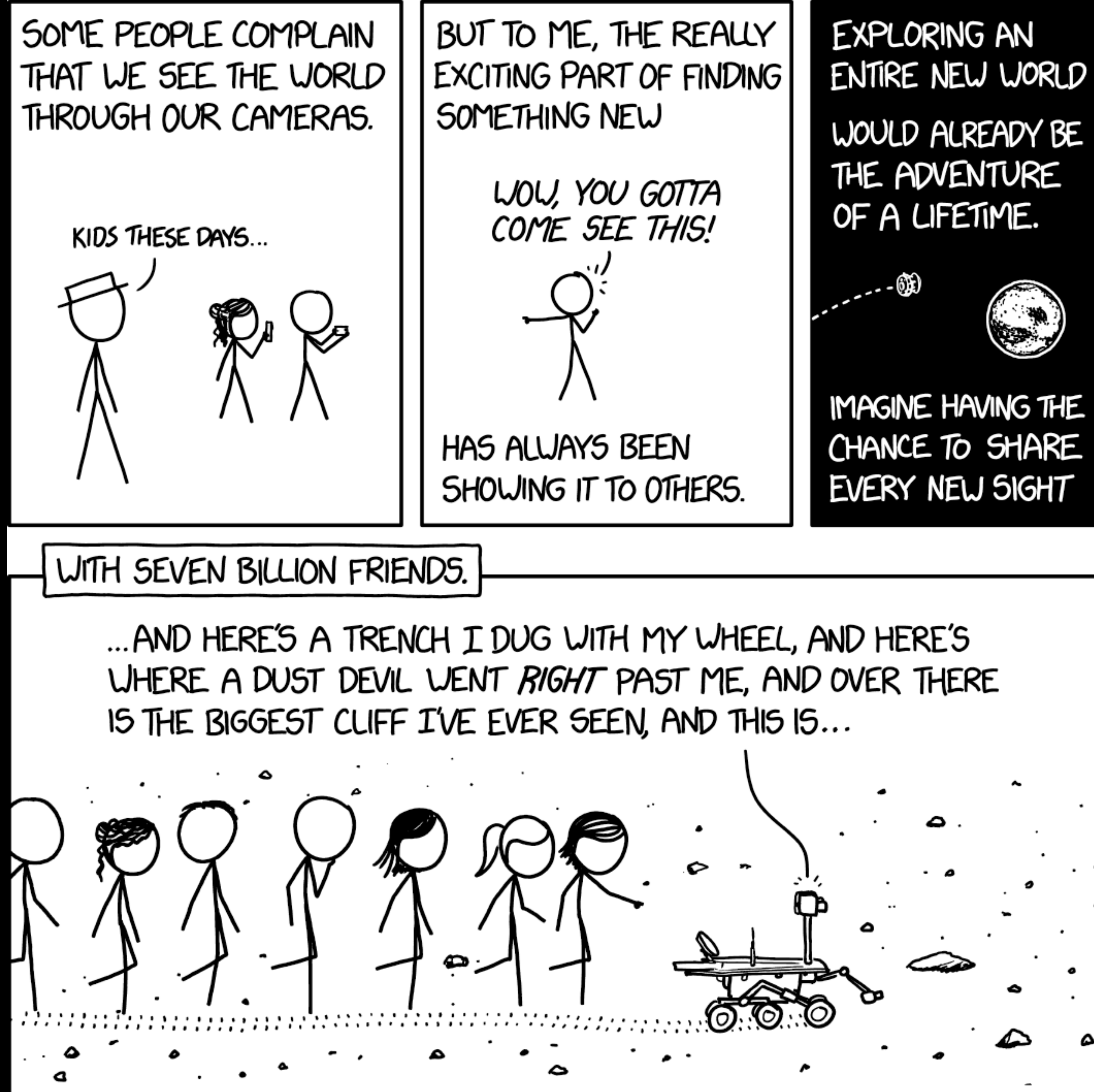
Mars

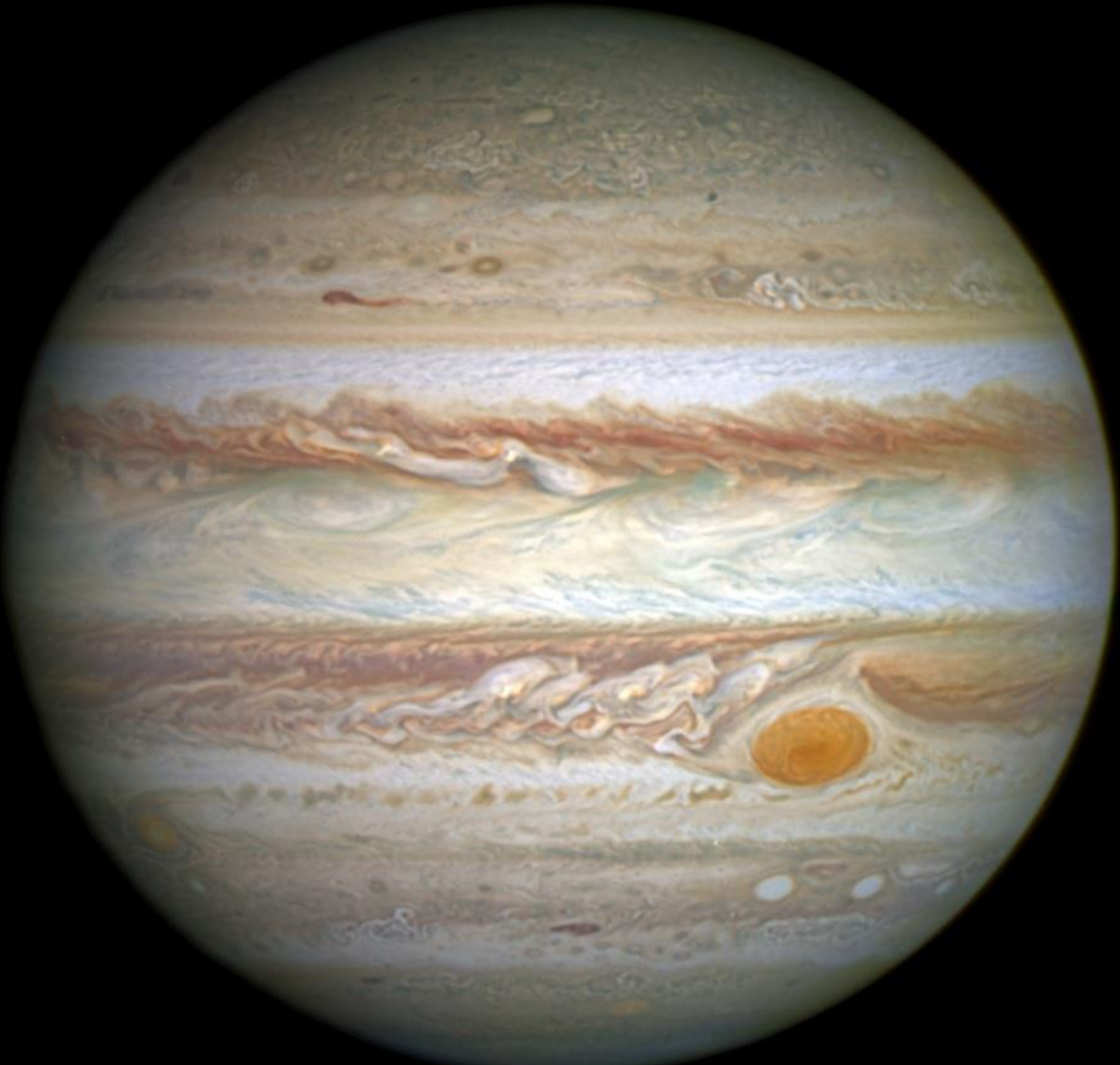




McCool Hill
Ramon Hill
Low Ridge
von Braun
Low Ridge, west
Landing Site
West Spur
Husband Hill
Haskin Ridge
Garruchaga
Marambio
Guesiaga
Molodezhnaya
Orcadas
Primero
Vernadsky
Dome Fuji
Scott Base
Sejong
Vostok
Zhong Shan
Allan Hills
Tor
Sobral
Higgins
Arctowski
HomePlate
HomePlate
Belgrano
Law-Racovita
Macquarie
Druzhnaya
Wasa
Esperanza
Jubany
Melchior
Signy
Prat
ChanCheng
Ferraz
King George Island
Bear Island
Berkner Island
Syowa
Concordia
Halley Brunt offset
Halley
Maitri

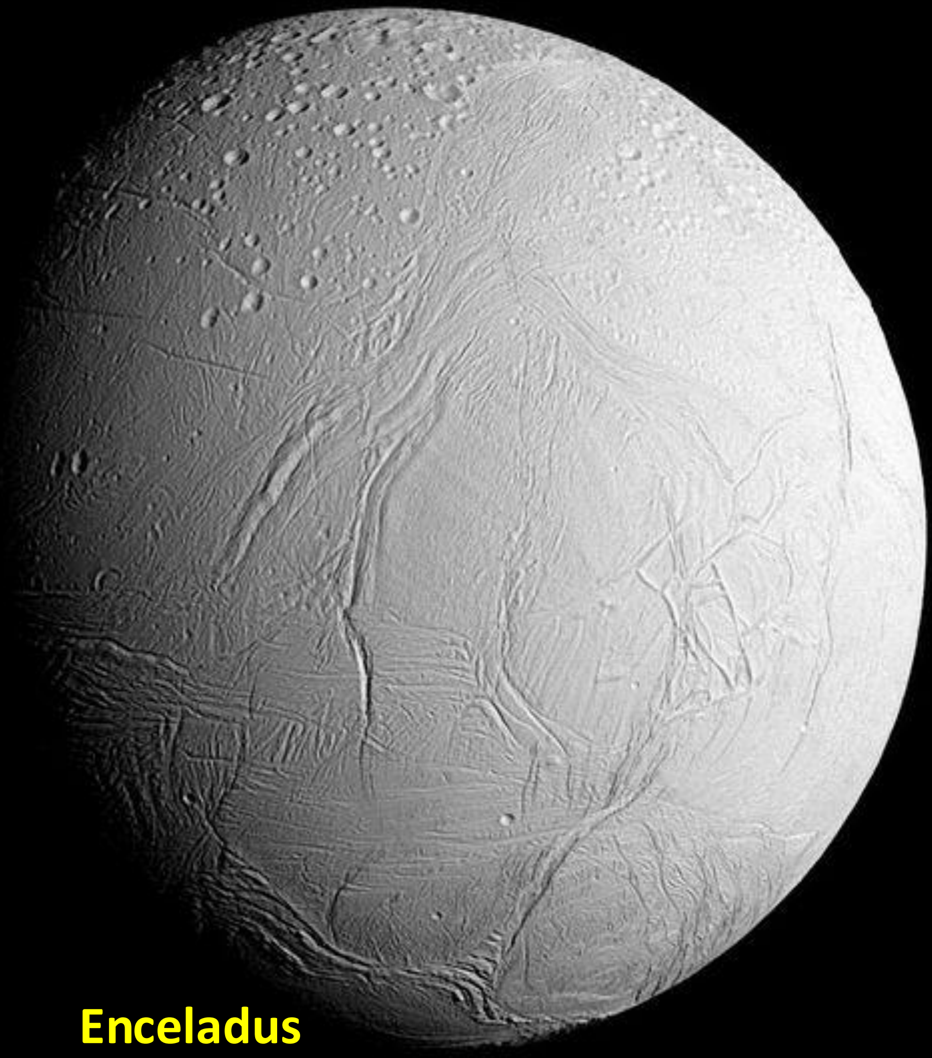
xkcd comic


SOME PEOPLE COMPLAIN THAT WE SEE THE WORLD THROUGH OUR CAMERAS.
KIDS THESE DAYS...
BUT TO ME, THE REALLY EXCITING PART OF FINDING SOMETHING NEW
WOW, YOU GOTTA COME SEE THIS!
HAS ALWAYS BEEN SHOWING IT TO OTHERS.
EXPLORING AN ENTIRE NEW WORLD
WOULD ALREADY BE THE ADVENTURE OF A LIFETIME.
IMAGINE HAVING THE CHANCE TO SHARE EVERY NEW SIGHT
WITH SEVEN BILLION FRIENDS.
...AND HERE'S A TRENCH I DUG WITH MY WHEEL, AND HERE'S WHERE A DUST DEVIL WENT RIGHT PAST ME, AND OVER THERE IS THE BIGGEST CLIFF I'VE EVER SEEN, AND THIS IS...



Jupiter from the Hubble Space Telescope

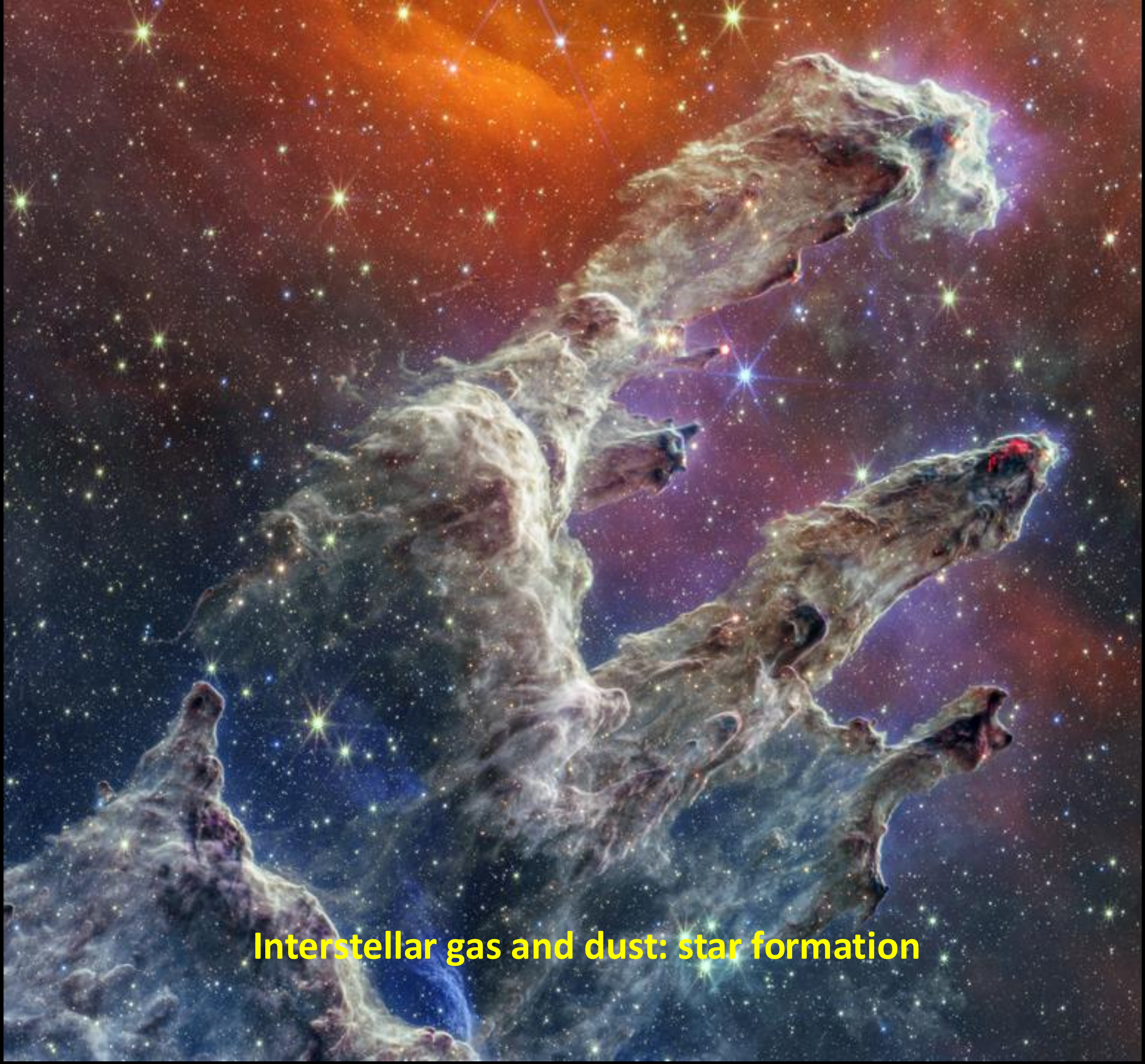

Jupiter from the Juno Mission



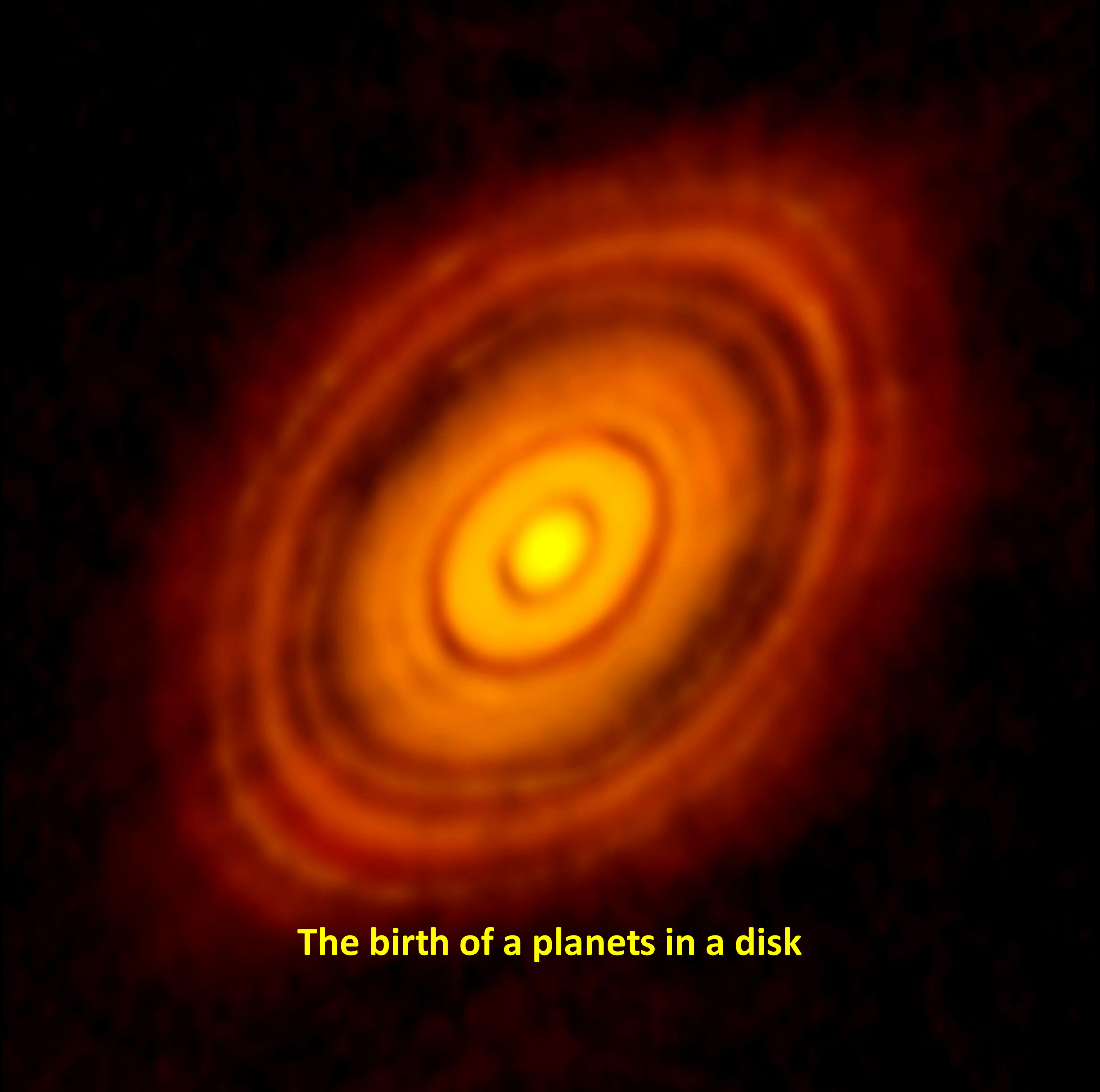
Enceladus

Enceladus: geysers seen from Cassini Mission

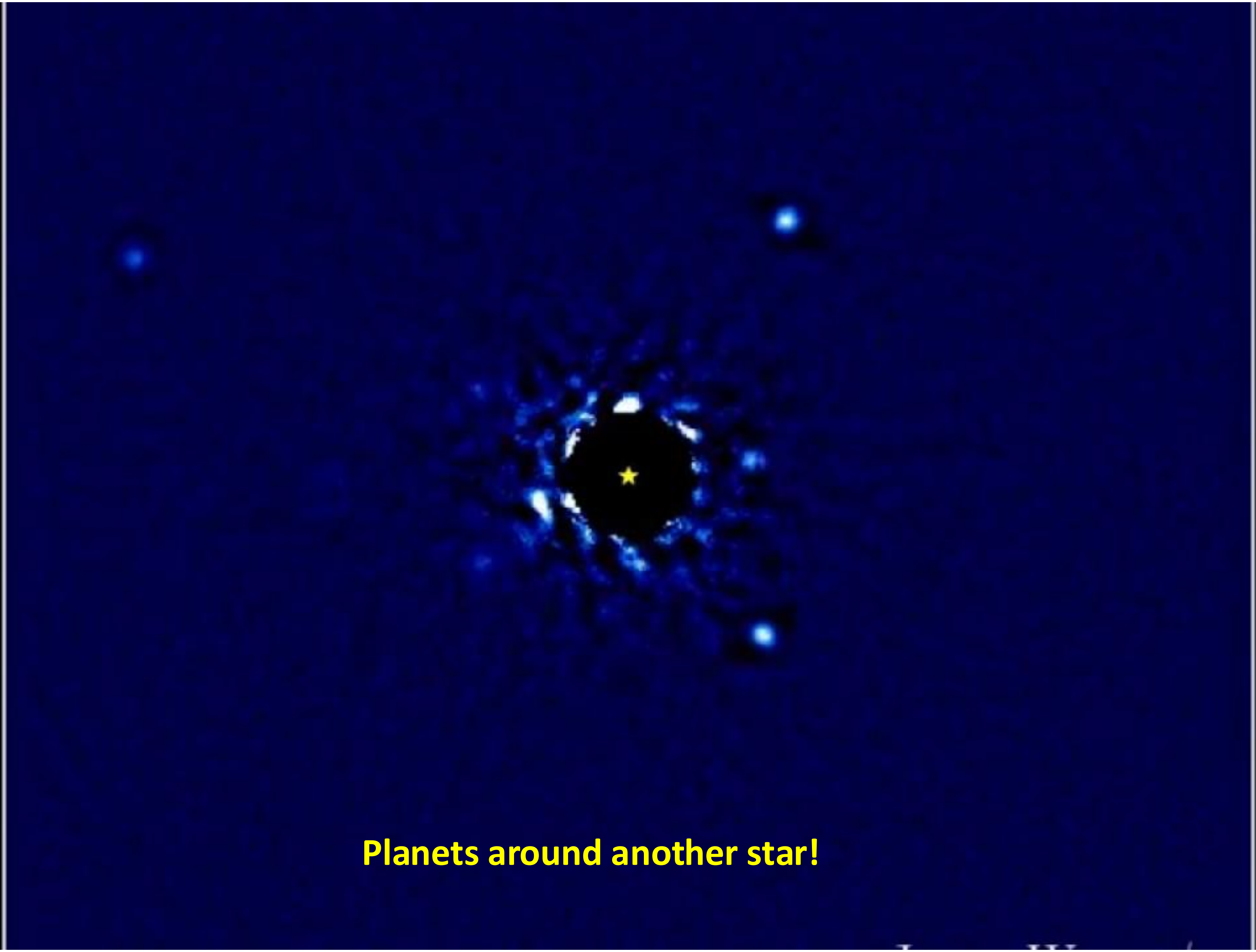

Globular cluster – millions of stars


Interstellar gas and dust: star formation


The birth of a young star

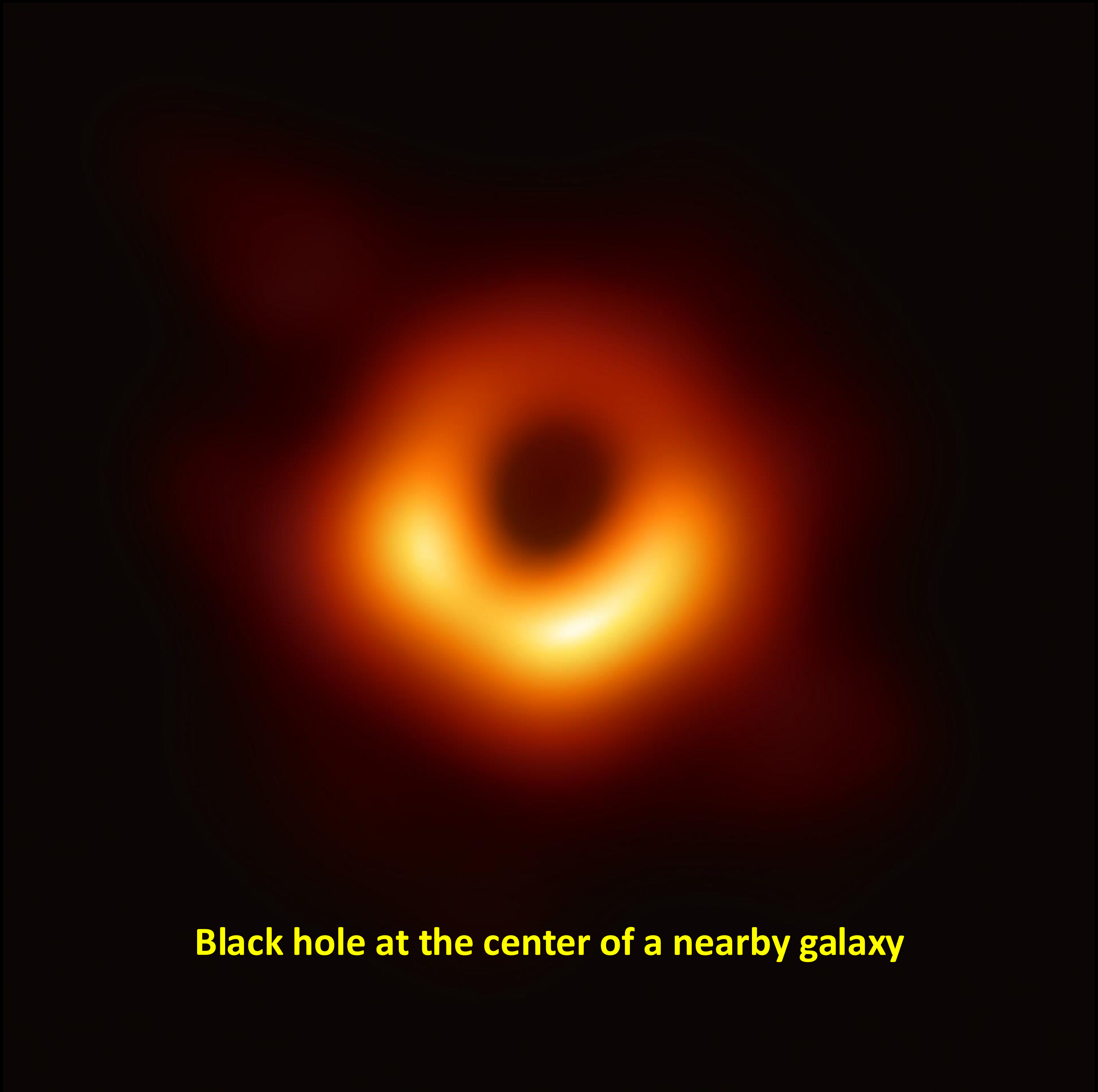


The birth of a planets in a disk


Planets around another star!

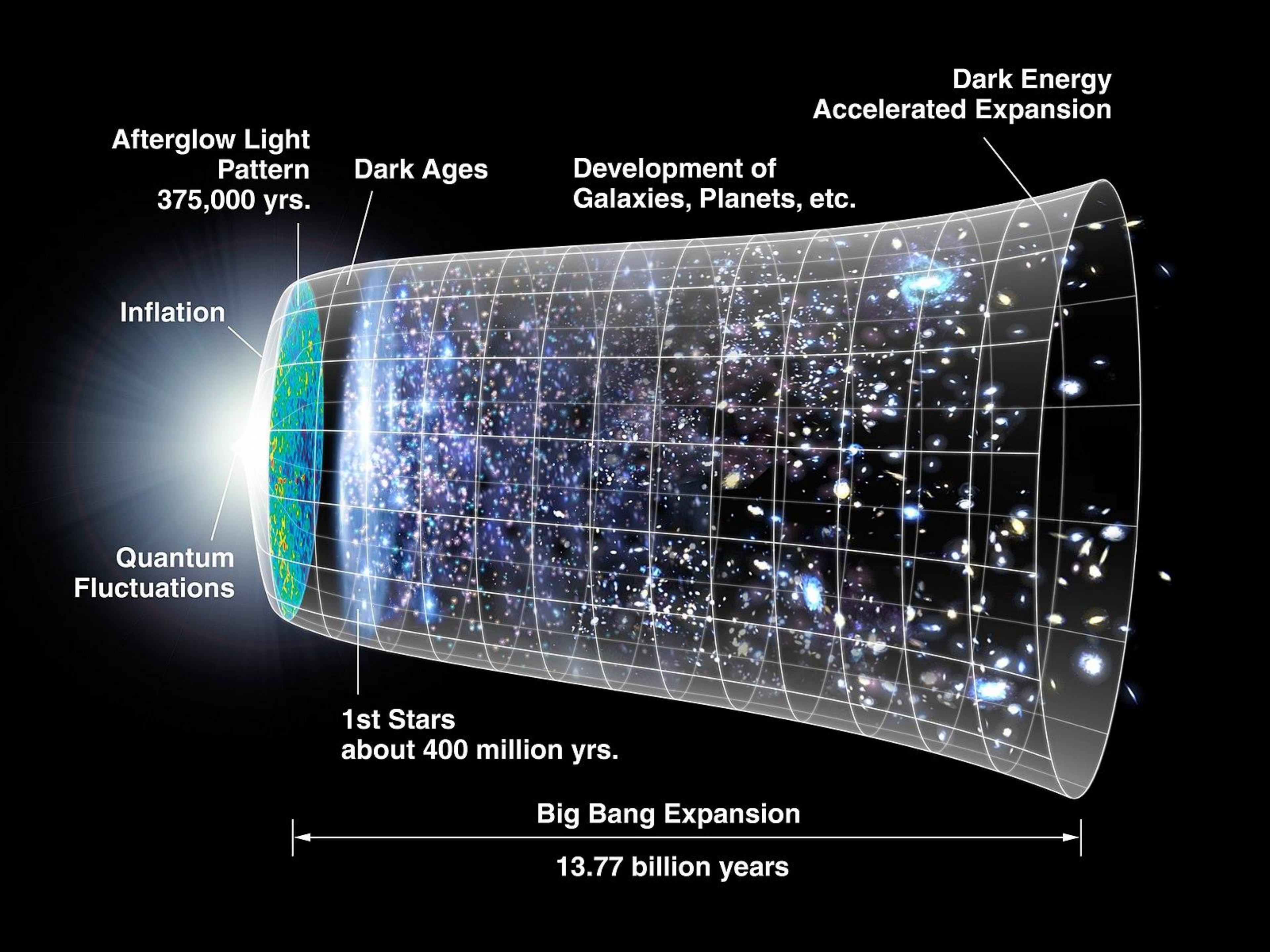
A spiral galaxy

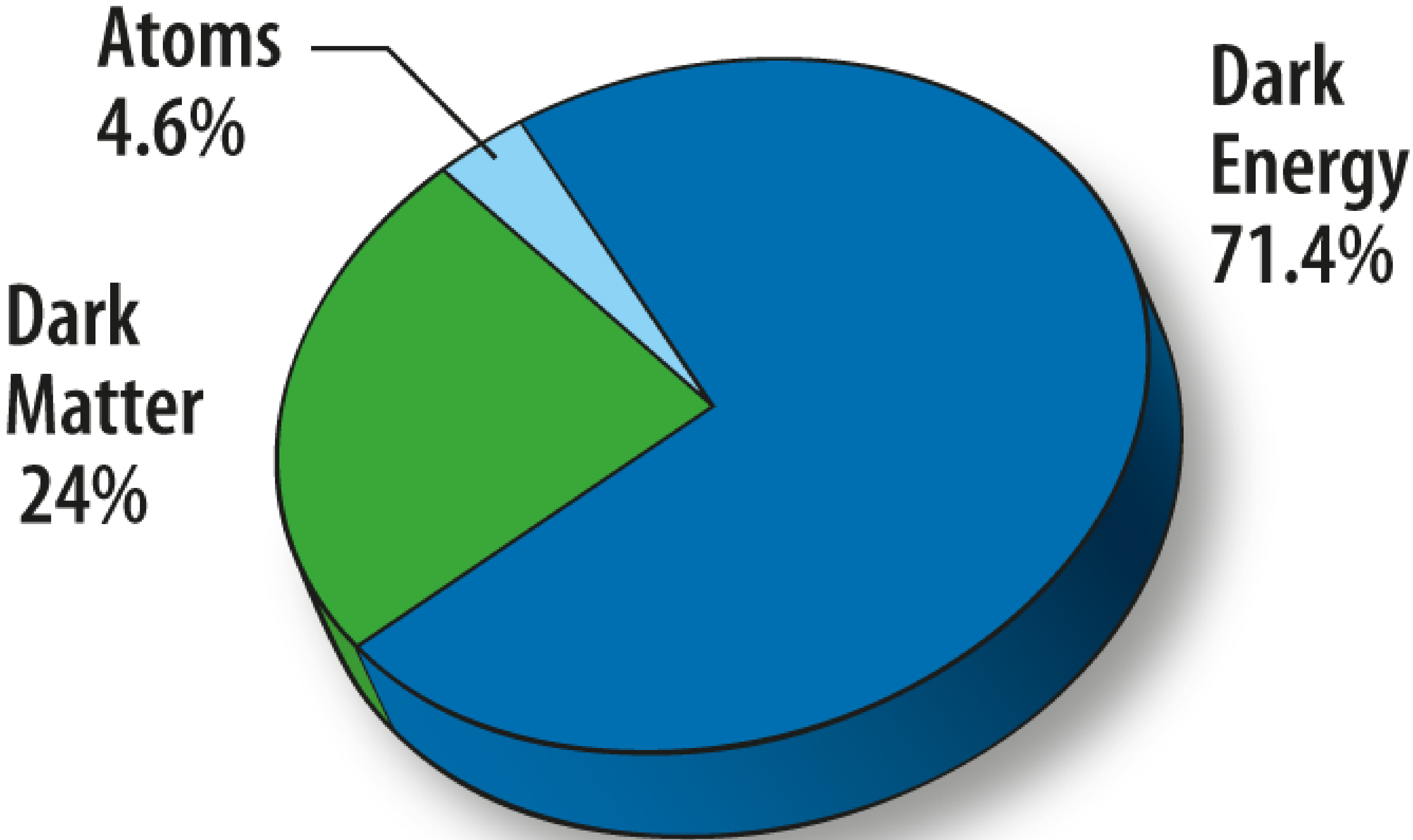
A map of the Milky Way



Black hole at the center of a nearby galaxy

JWST image of “blank” sky:
most distant object known (z=14, 300 million years after big bang)

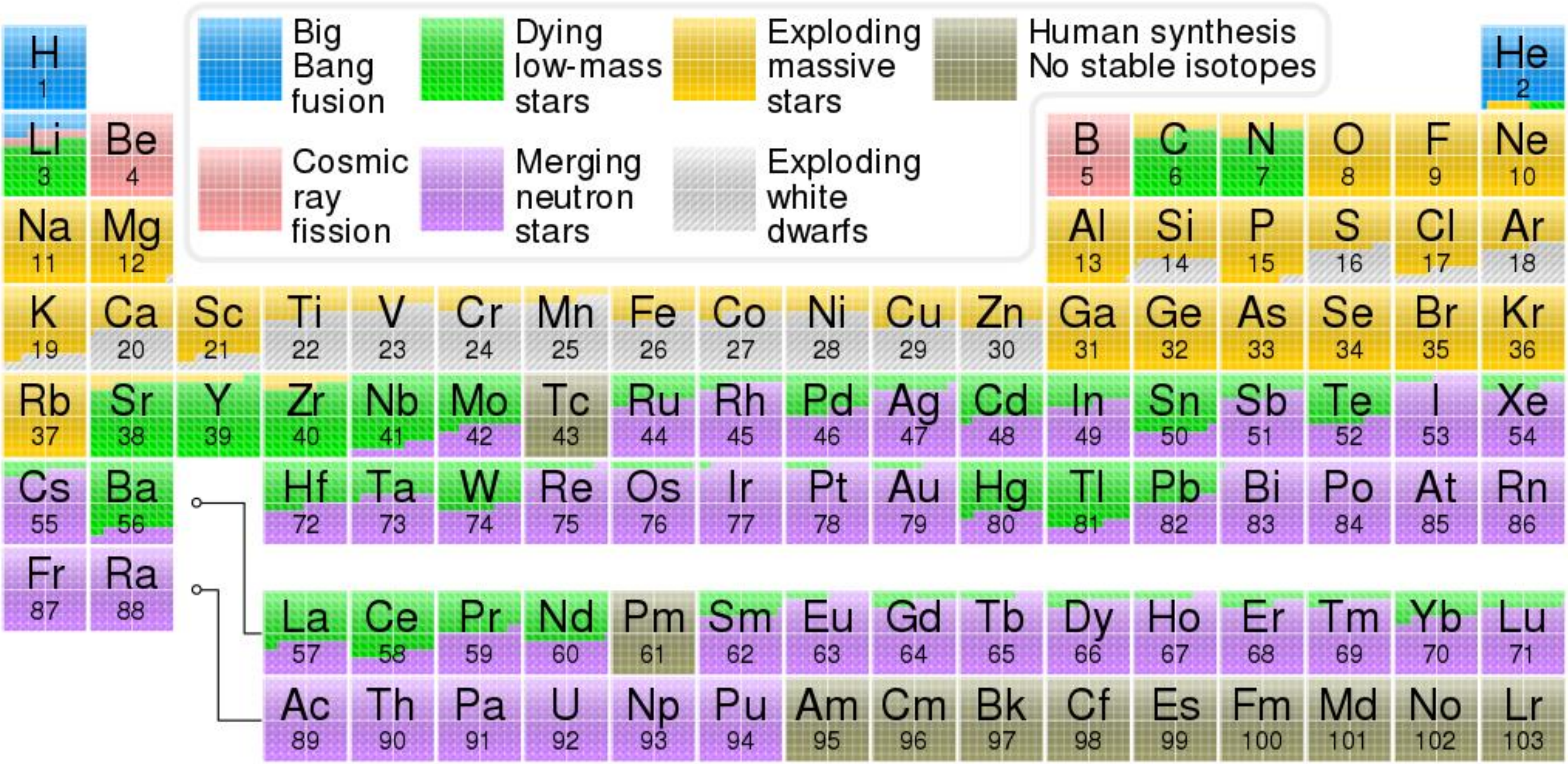

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years

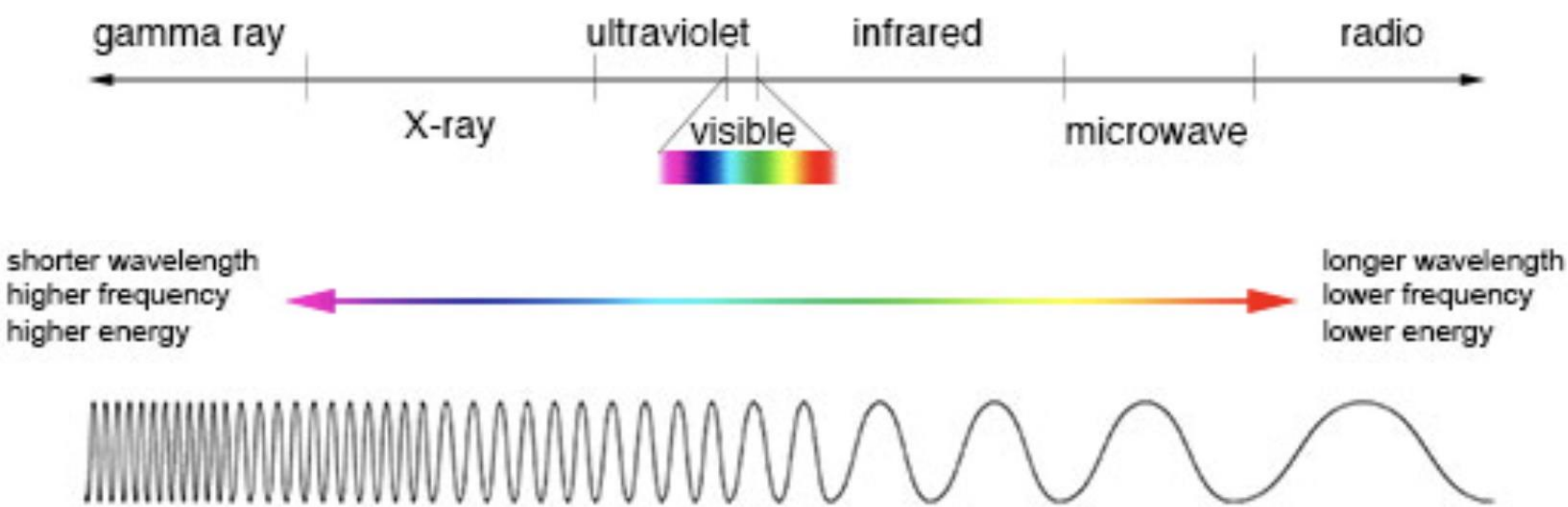


TODAY

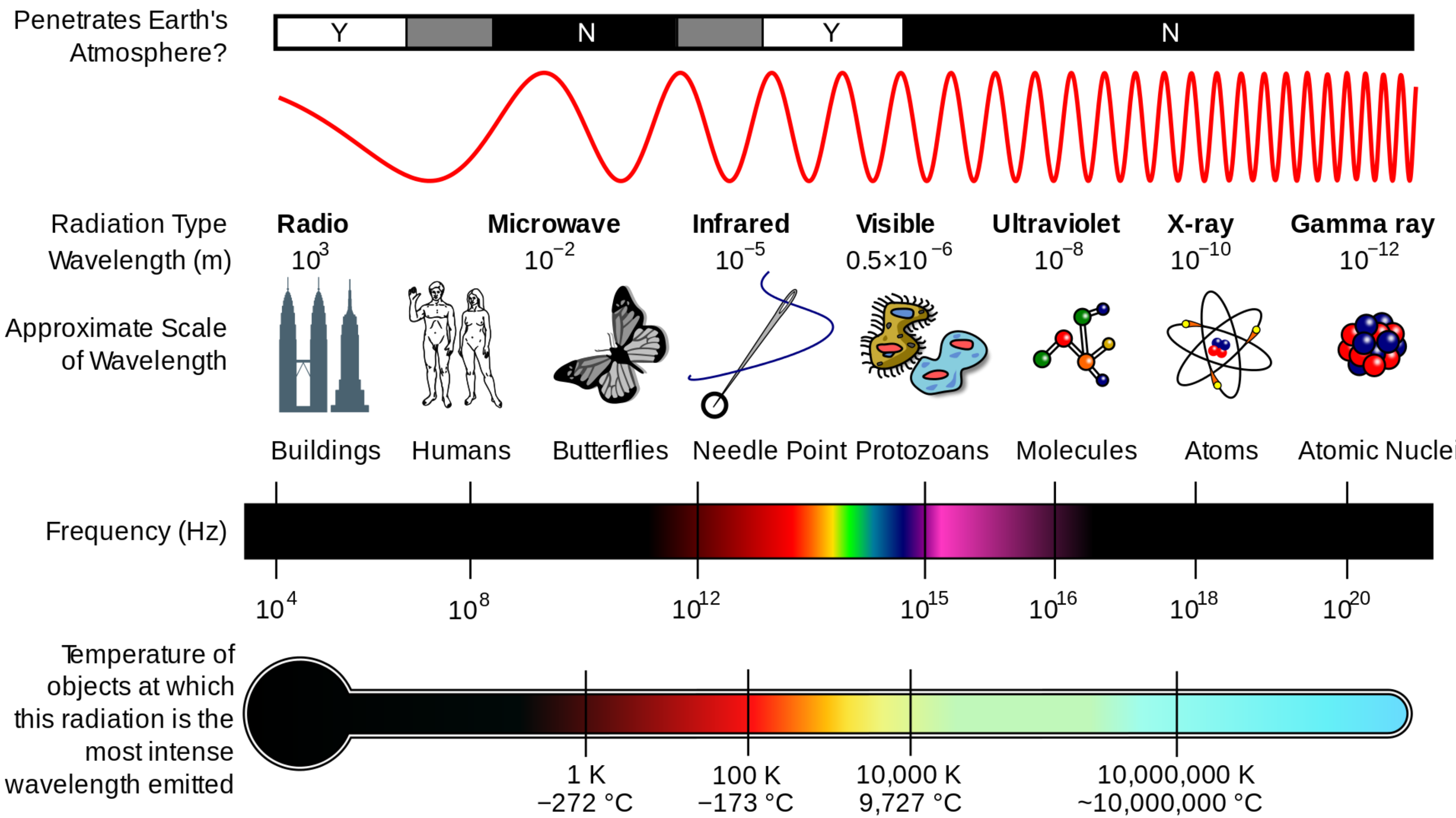
The Cosmically Abundant Elements

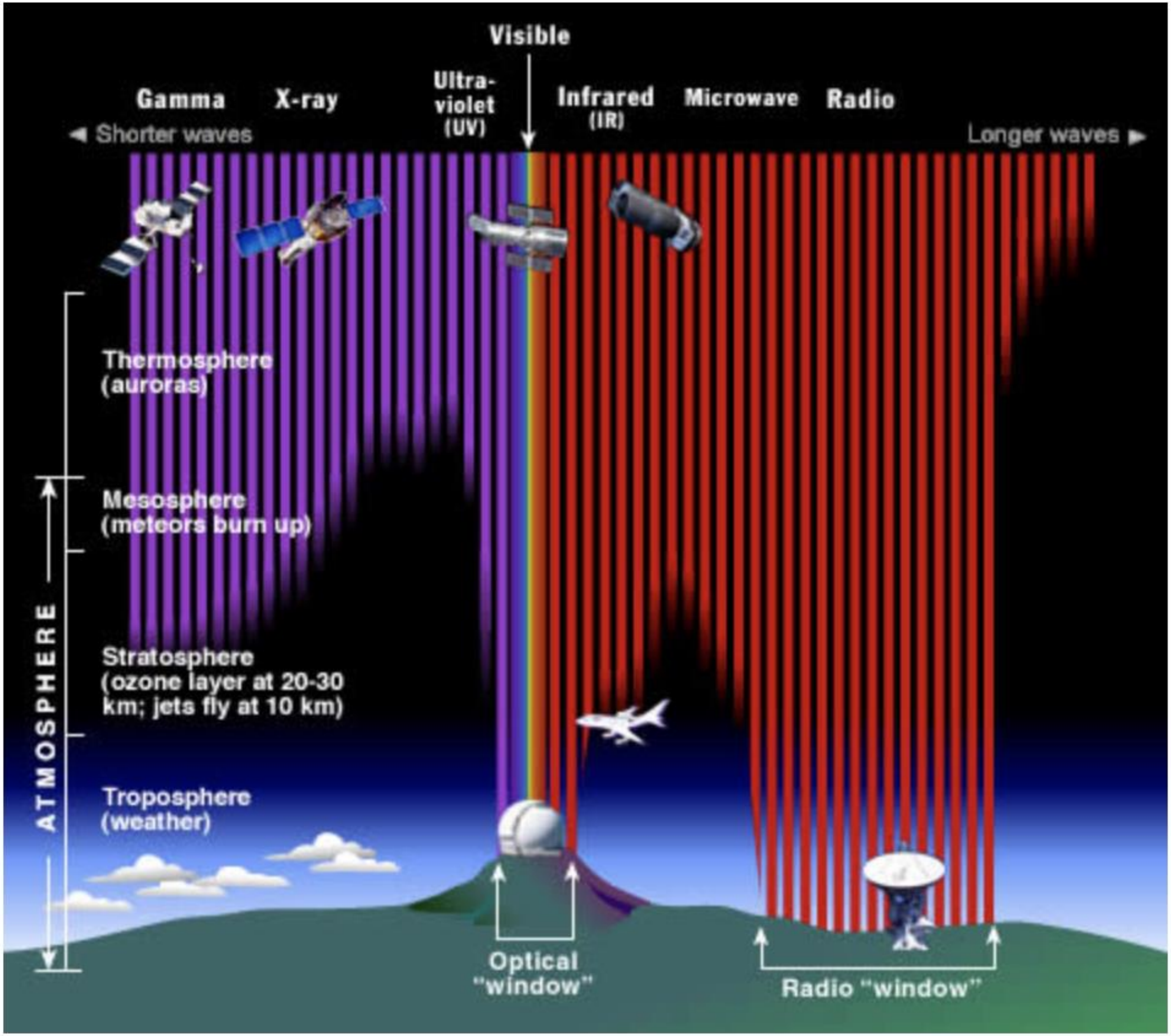
Element[1]	Symbol	Number of Atoms per Million Hydrogen Atoms
Hydrogen	H	1,000,000
Helium	He	80,000
Carbon	C	450
Nitrogen	N	92
Oxygen	O	740
Neon	Ne	130
Magnesium	Mg	40
Silicon	Si	37
Sulfur	S	19
Iron	Fe	32

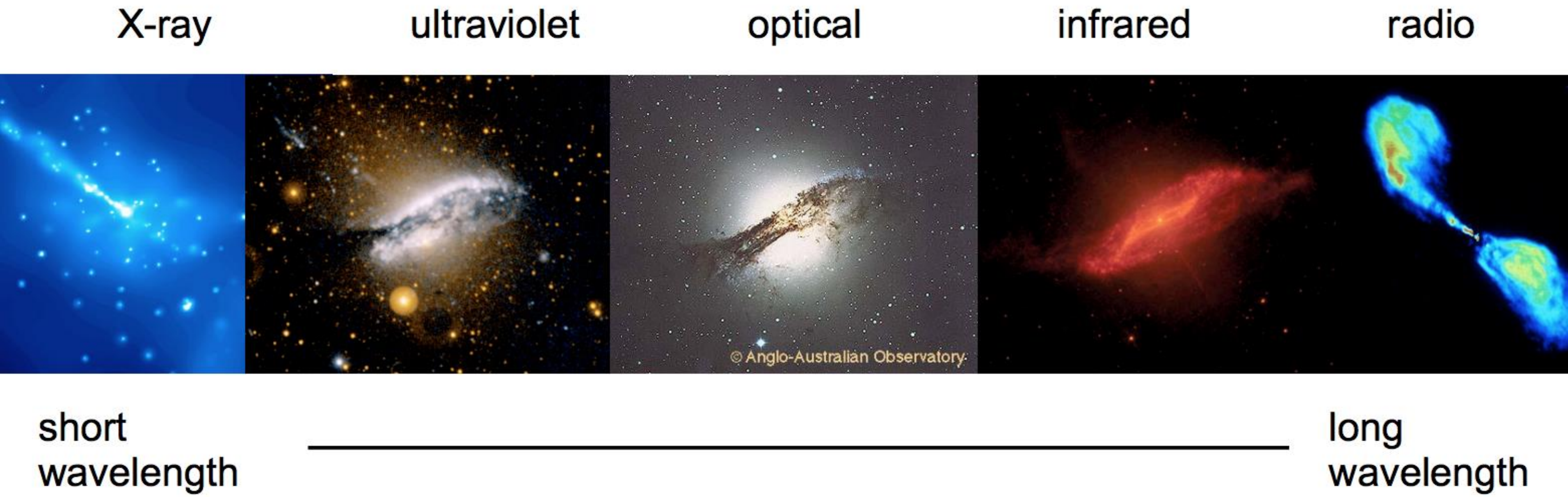

Big Bang fusion
Dying low-mass stars
Exploding massive stars
Human synthesis No stable isotopes
Cosmic ray fission
Merging neutron stars
Exploding white dwarfs
H 1
He 2
Li 3
Be 4
B 5
C 6
N 7
O 8
F 9
Ne 10
Na 11
Mg 12
Al 13
Si 14
P 15
S 16
Cl 17
Ar 18
K 19
Ca 20
Sc 21
Ti 22
V 23
Cr 24
Mn 25
Fe 26
Co 27
Ni 28
Cu 29
Zn 30
Ga 31
Ge 32
As 33
Se 34
Br 35
Kr 36
Rb 37
Sr 38
Y 39
Zr 40
Nb 41
Mo 42
Tc 43
Ru 44
Rh 45
Pd 46
Ag 47
Cd 48
In 49
Sn 50
Sb 51
Te 52
I 53
Xe 54
Cs 55
Ba 56
Hf 72
Ta 73
W 74
Re 75
Os 76
Ir 77
Pt 78
Au 79
Hg 80
Tl 81
Pb 82
Bi 83
Po 84
At 85
Rn 86
Fr 87
Ra 88
La 57
Ce 58
Pr 59
Nd 60
Pm 61
Sm 62
Eu 63
Gd 64
Tb 65
Dy 66
Ho 67
Er 68
Tm 69
Yb 70
Lu 71
Ac 89
Th 90
Pa 91
U 92
Np 93
Pu 94
Am 95
Cm 96
Bk 97
Cf 98
Es 99
Fm 100
Md 101
No 102
Lr 103

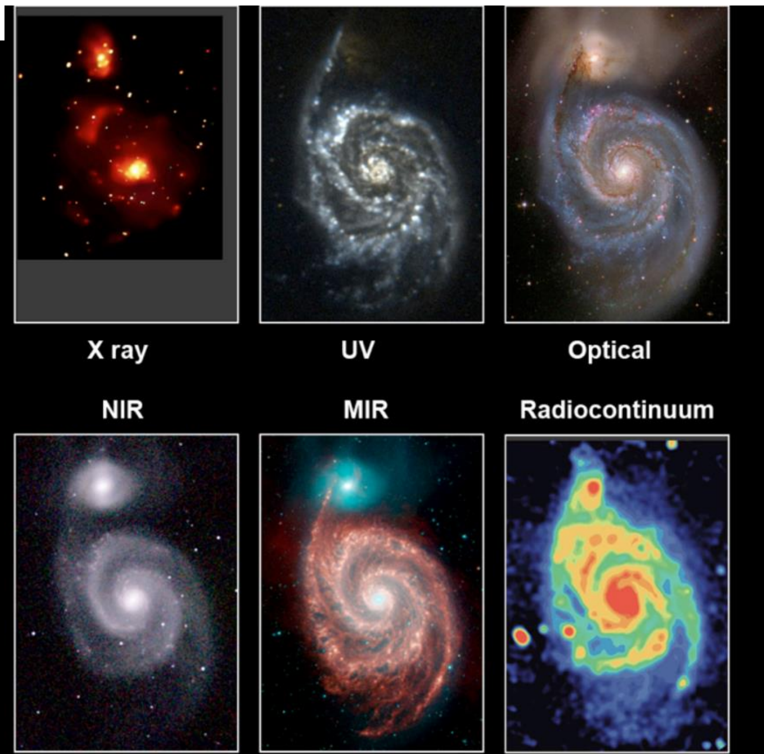


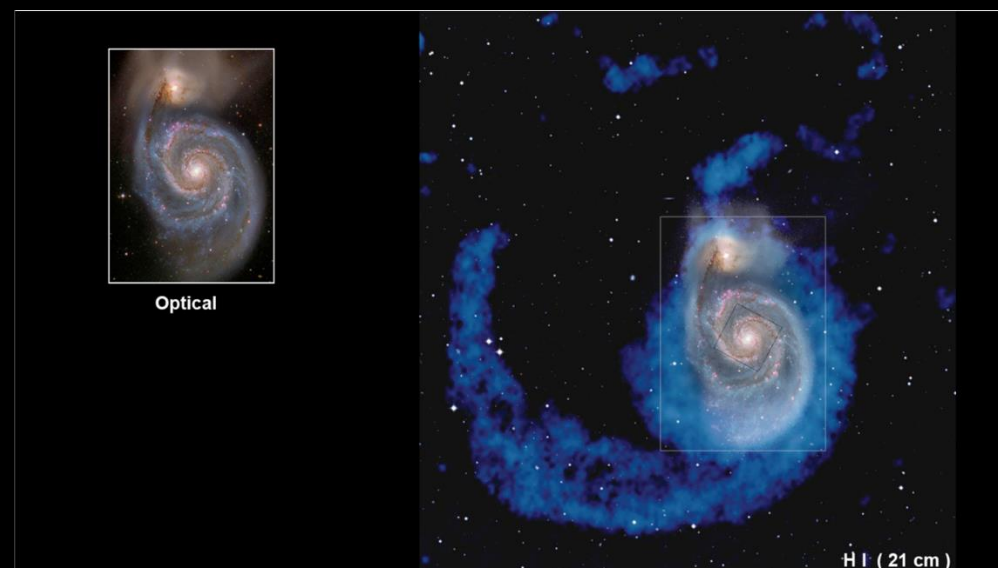
Comparison of wavelength, frequency and energy for the electromagnetic spectrum.
(Credit: NASA's Imagine the Universe)


Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength (m)
Radio
10^3
Microwave
10^−2
Infrared
10^−5
Visible
0.5×10^−6
Ultraviolet
10^−8
X-ray
10^−10
Gamma ray
10^−12
Approximate Scale of Wavelength
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

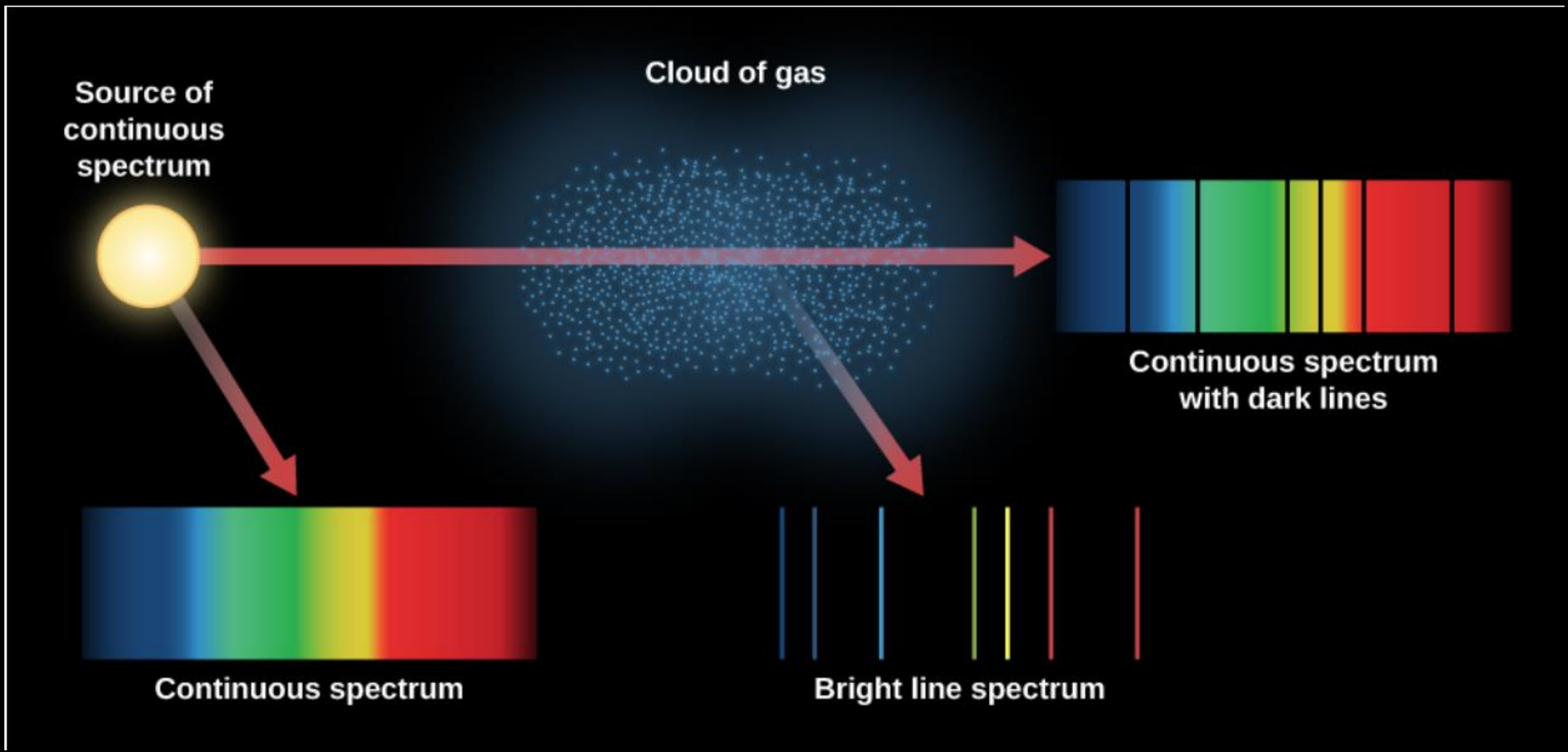

Visible
Gamma
X-ray
Ultra-
violet
(UV)
Infrared
(IR)
Microwave
Radio
◄ Shorter waves
Longer waves ►
Thermosphere
(auroras)
Mesosphere
(meteors burn up)
Stratosphere
(ozone layer at 20-30
km; jets fly at 10 km)
Troposphere
(weather)
ATMOSPHERE
Optical
"window"
Radio "window"



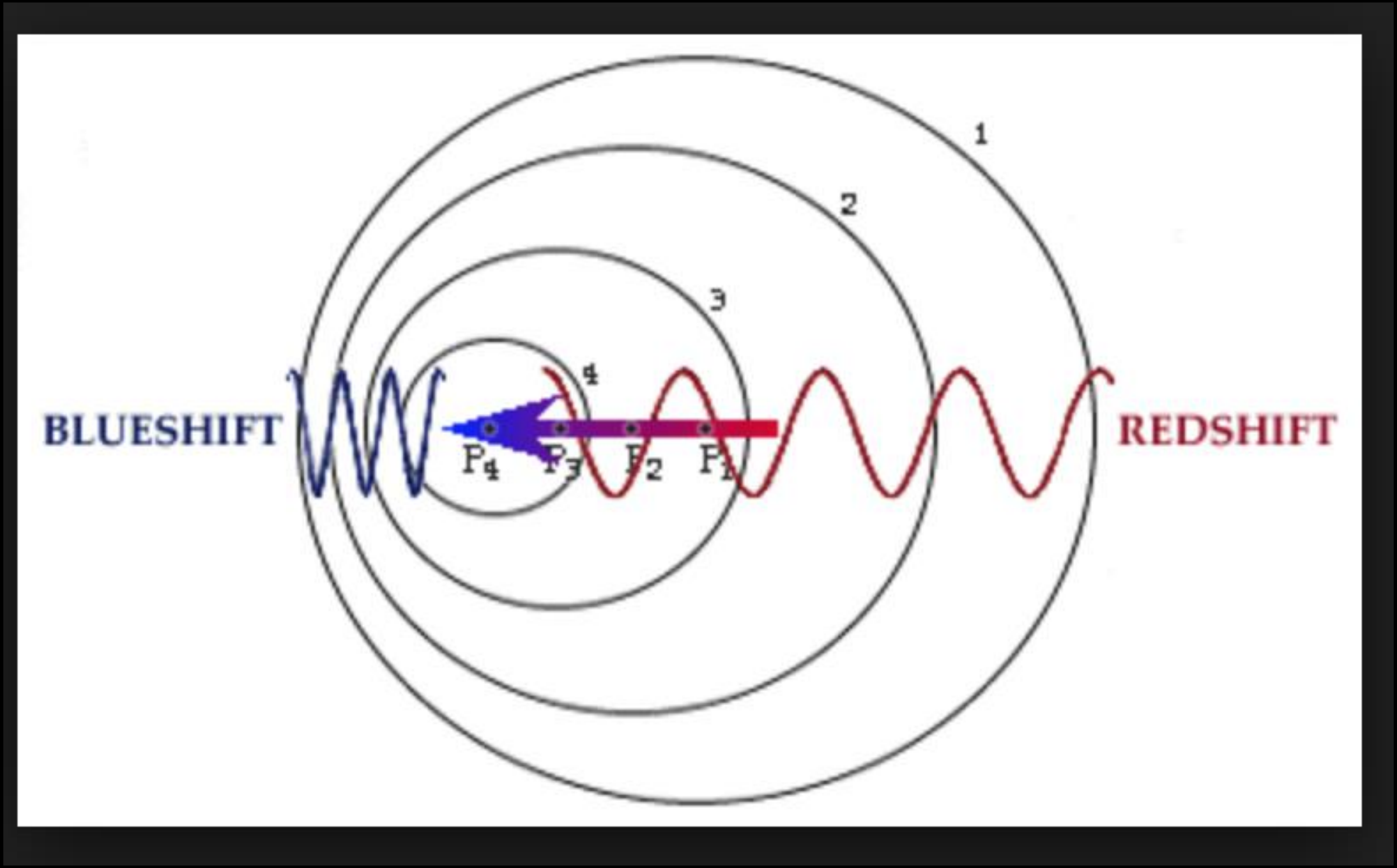




Different wavelengths of light



Emission and absorption in atomic spectral lines



Doppler effect: redshifts and blueshifts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The finite speed of light, combined with these enormous distances, means that when we look out into the universe, the light we see was emitted some time ago – a *long* time ago, if the object is very distant. When we look out into the Universe, we are looking back in time.

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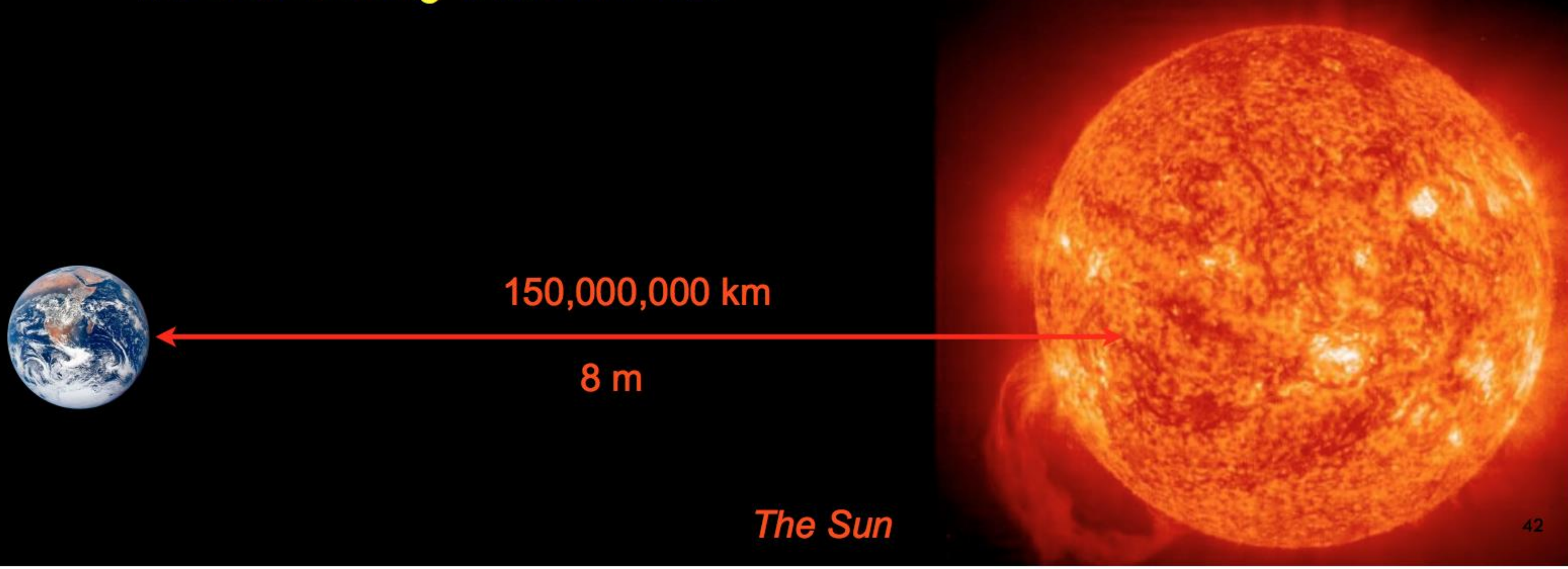

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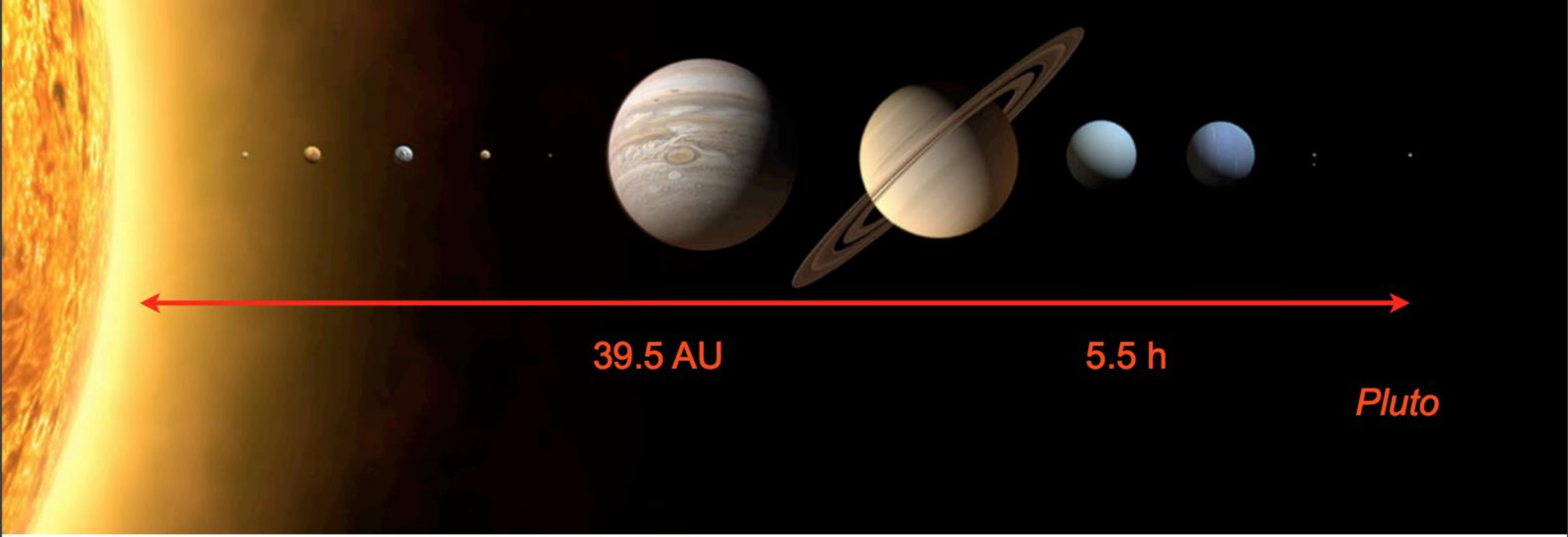

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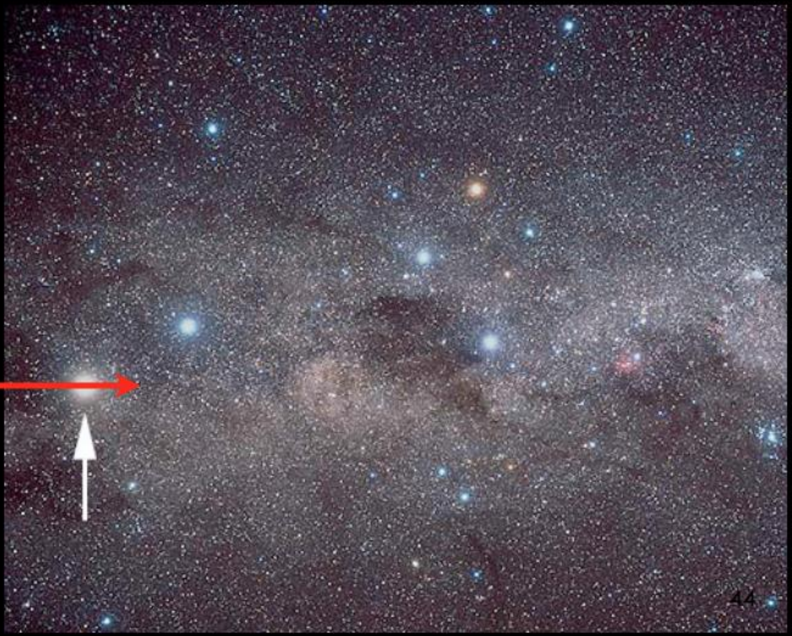

The nearest star, alpha Centauri

The finite speed of light, combined with these enormous distances, means that when we look out into the universe, the light we see was emitted some time ago – a *long* time ago, if the object is very distant. When we look out into the Universe, we are looking back in time.

The Andromeda galaxy

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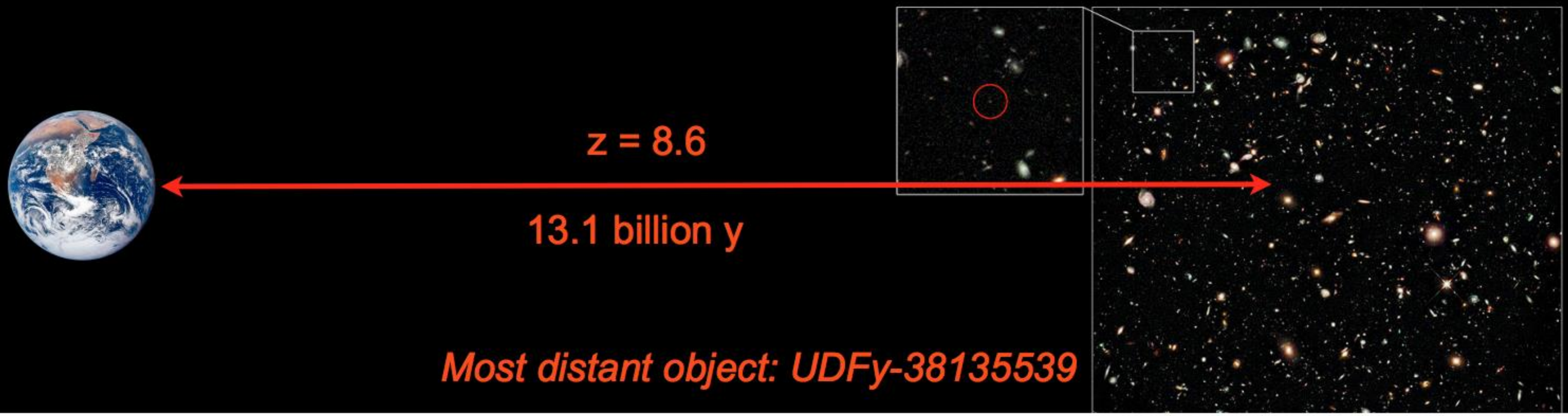
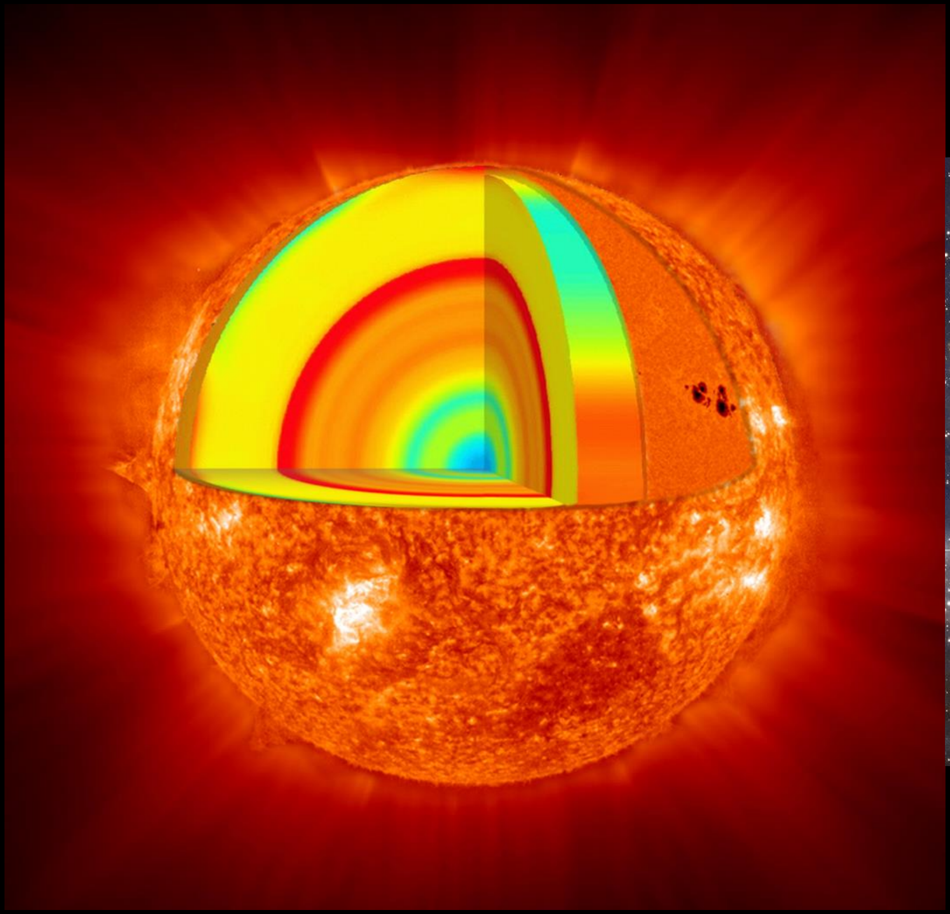
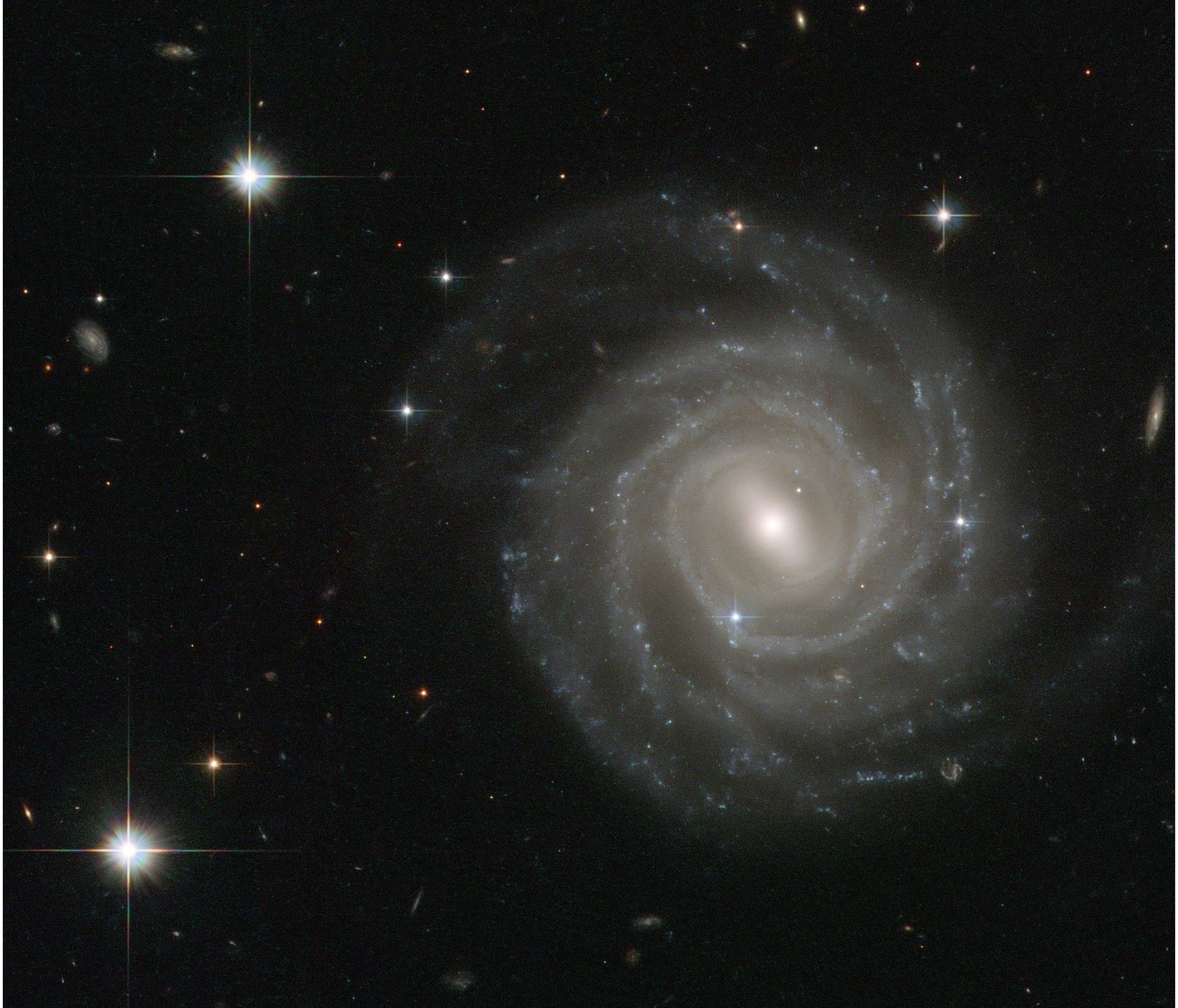


Stars: the Building Blocks of the Universe





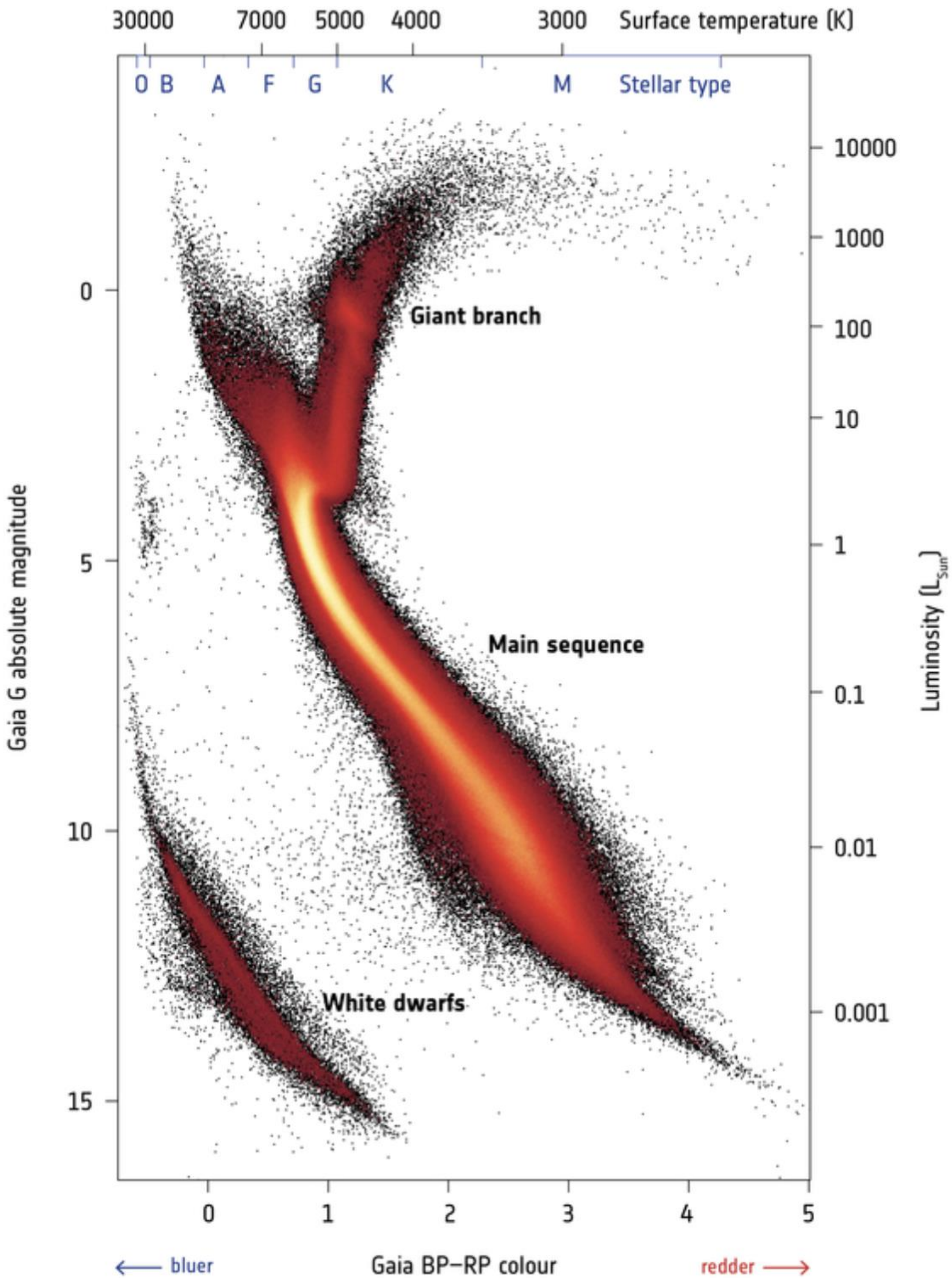
Important numbers

- Astronomical Unit (AU): 1.5×10^{13} cm
  - Sun to Earth
- Speed of light: 3×10^{5} km/s
- Light year: 10^{18} cm

What parameters of a star would you want to measure?

- Groups of 3-4 to discuss
- What would you want to know?
  - Do you think that is easy or hard to measure?

- Mass, age: fundamental quantities, hard to measure
- Temperature, luminosity: direct observables

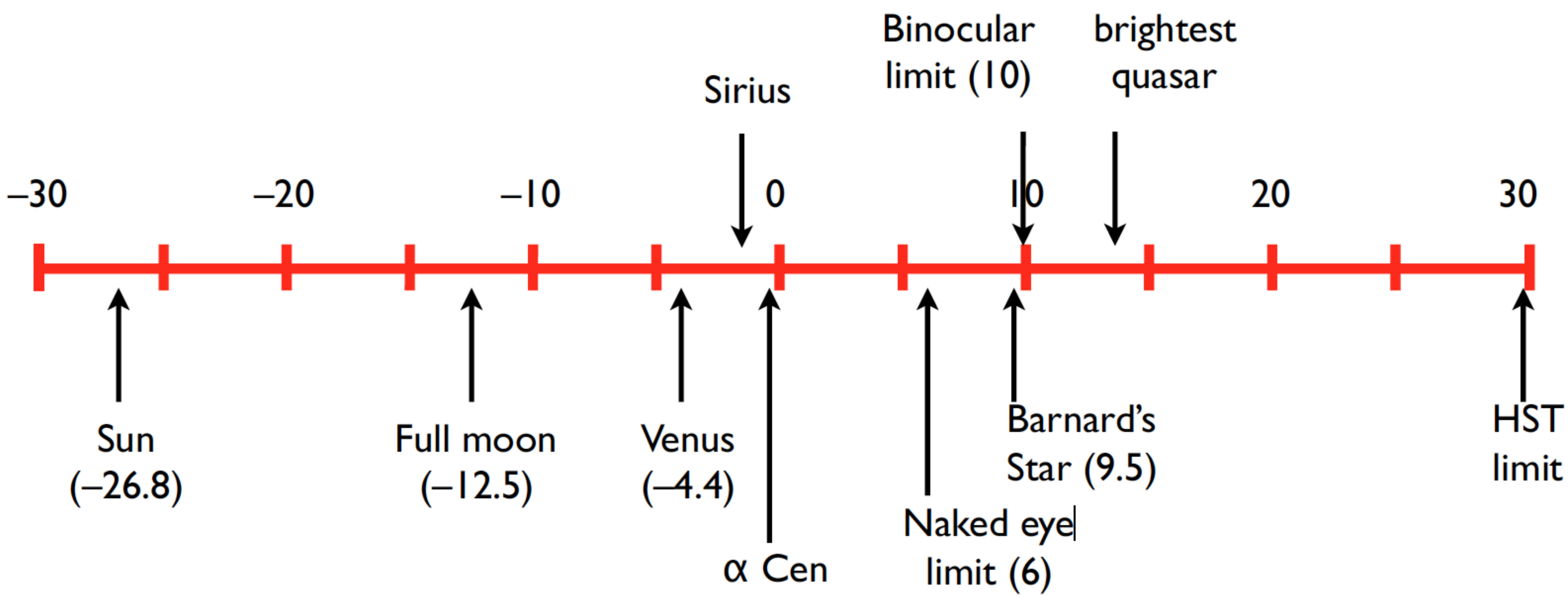


HR Diagram (Hertzsprung-Russell)

x-axis: Temperature (or color)

y-axis: luminosity (or brightness)

Magnitudes (how bright are stars)



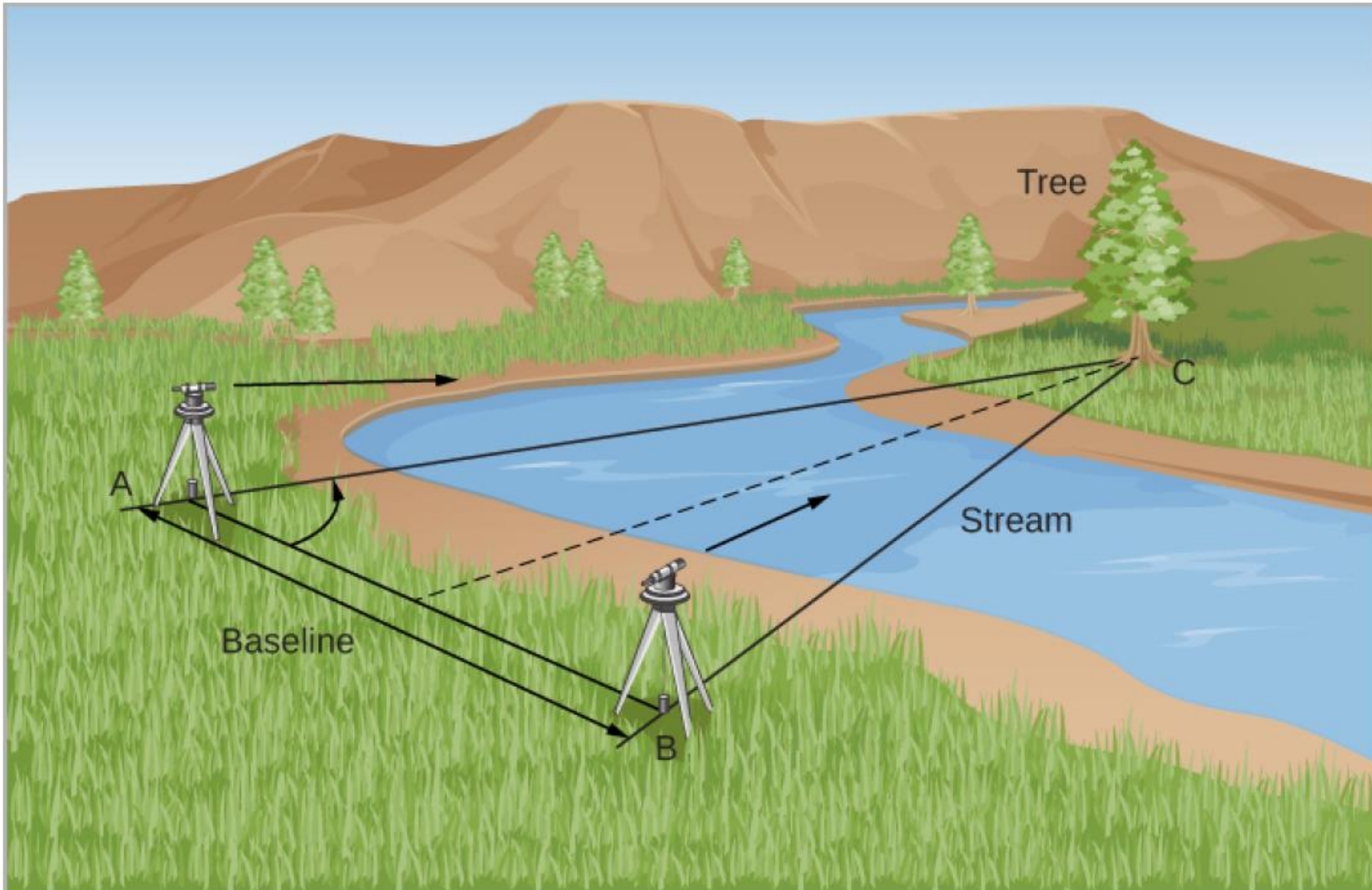
- Brightness: how bright are they at Earth
- Luminosity: how much energy are they emitting?

star	apparent mag
Sirius	–1.50
Canopus	–0.73
Alpha Centauri	+0.10
Vega	+0.04
Arcturus	0
Capella	+0.05
Rigel	+0.08
Procyon	+0.34
Betelgeuse	+0.41
Achernar	+0.47

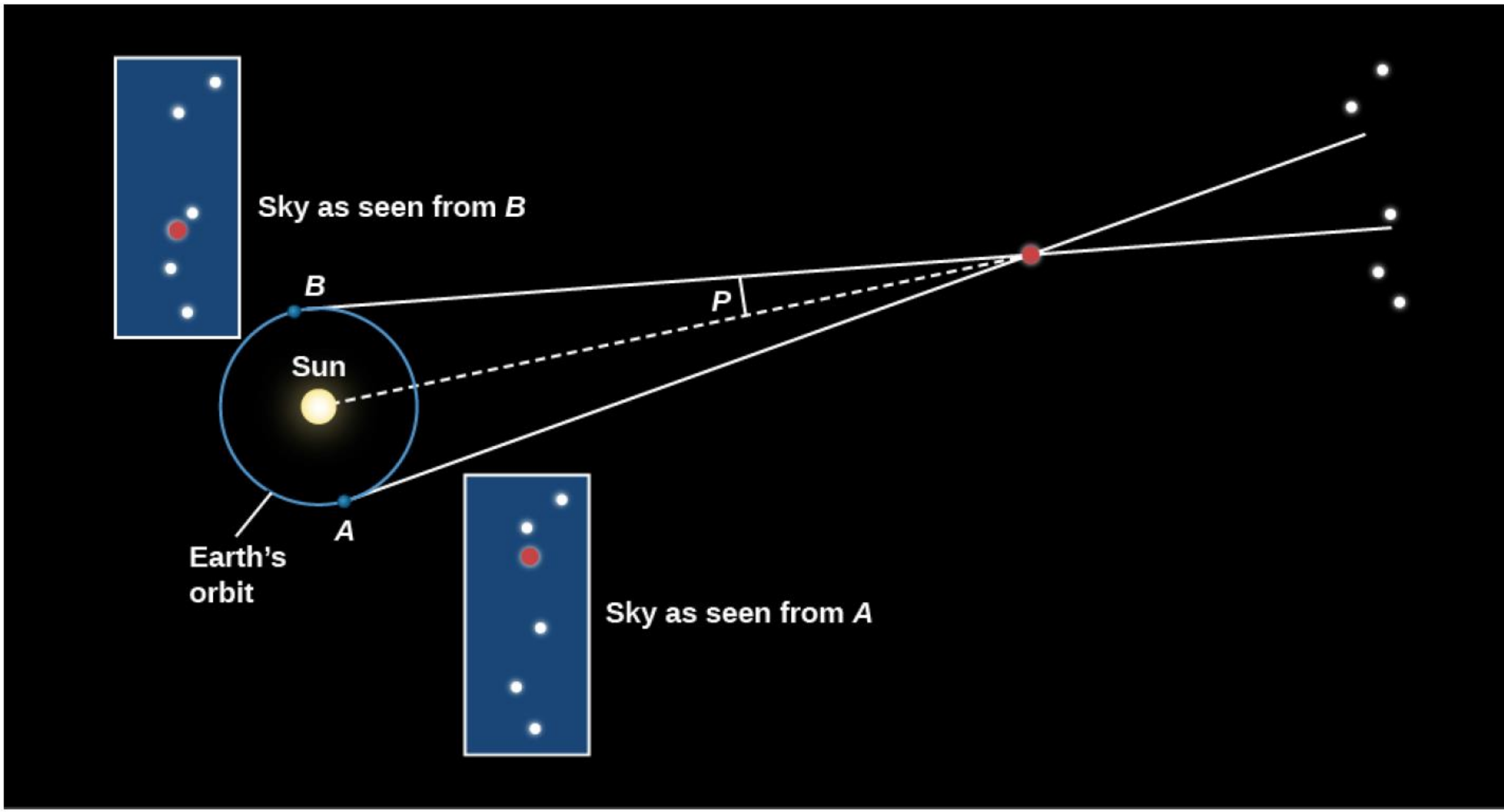
Sky is 2D!

Distance is usually uncertain

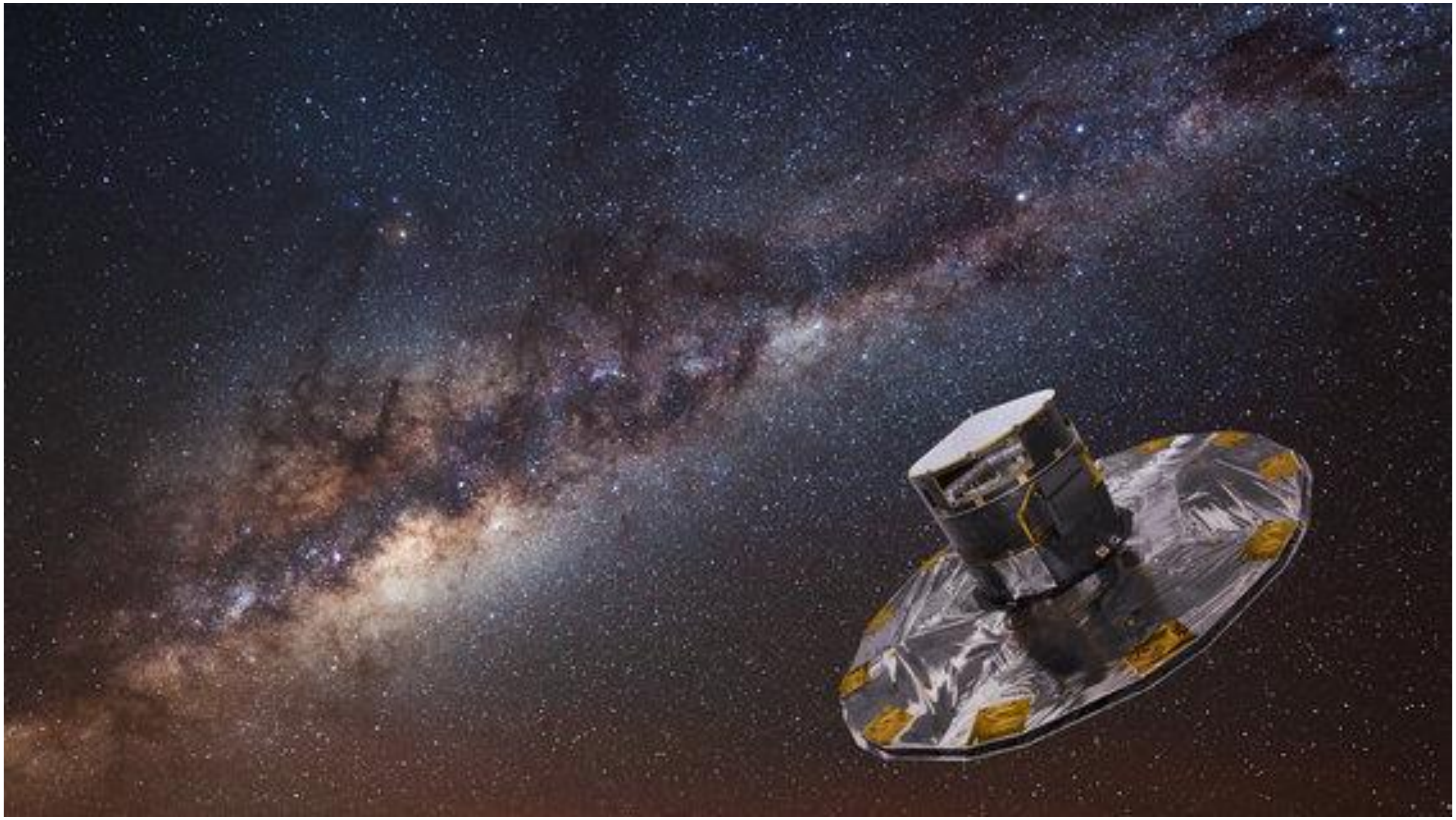
Distance: parallax



Distance: parallax



Gaia satellite:
distances to ~1 billion stars!



Blackbody emission: hotter objects emit at higher energies (=shorter wavelengths)

Peak of blackbody: $$\lambda_{\max} \cdot T = 0.288 \text{ cm} \cdot \text{K}$$