Life in the universe

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Life on Earth

Started very early (few 100Myr after formation) and “simple”

Stayed at the bacteria level until ~2 Byr ago

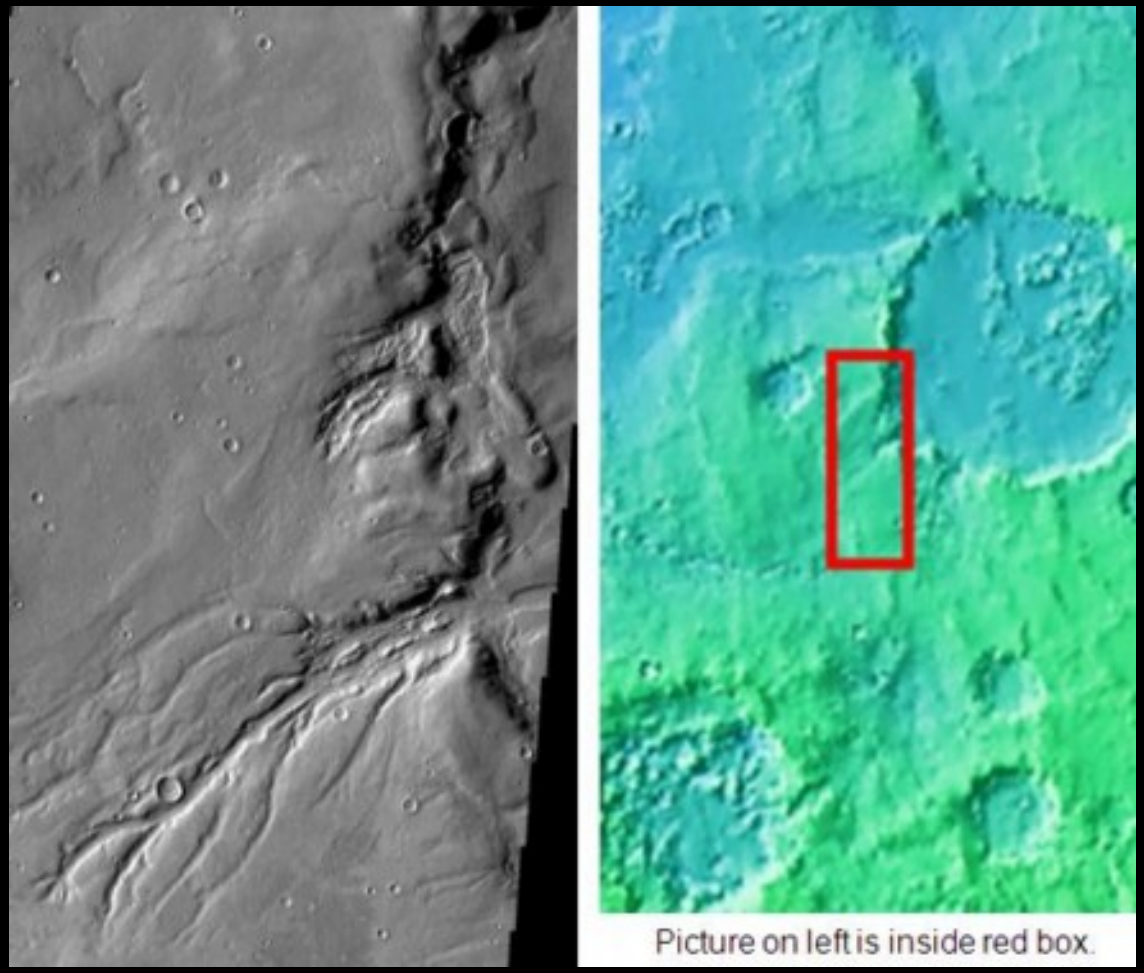
Is now very abundant

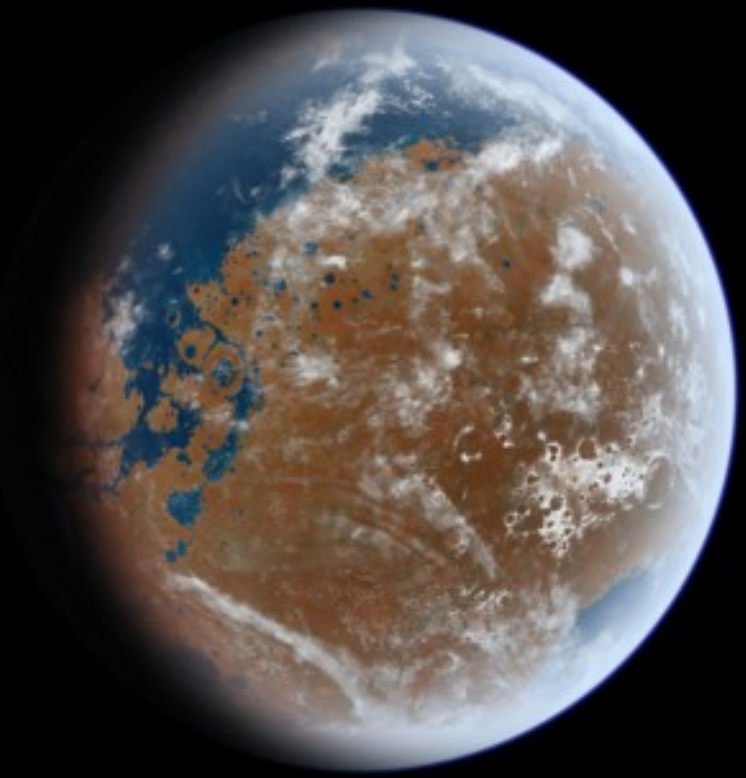
Will decline in few ~100Myr due to increase Sun luminosity

Mars

Mars is too cold, dry and its atmosphere too thin to support abundant complex life...
… but may still host bacteria

Mars





Ancient Mars ?

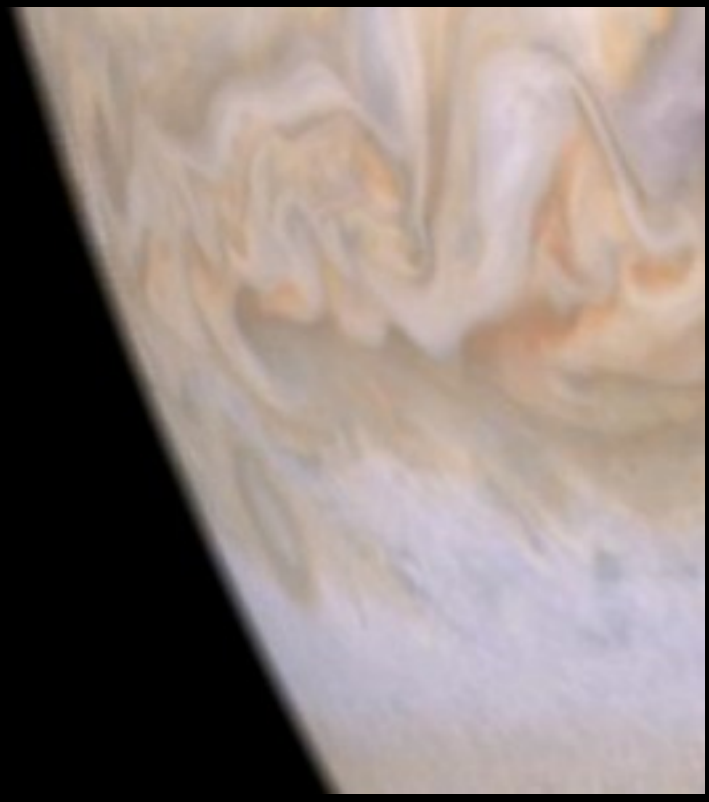
Mars had flowing water and more temperate atmosphere in the past

What makes planets habitable ?

Size matters: strong gravity = thick atmosphere

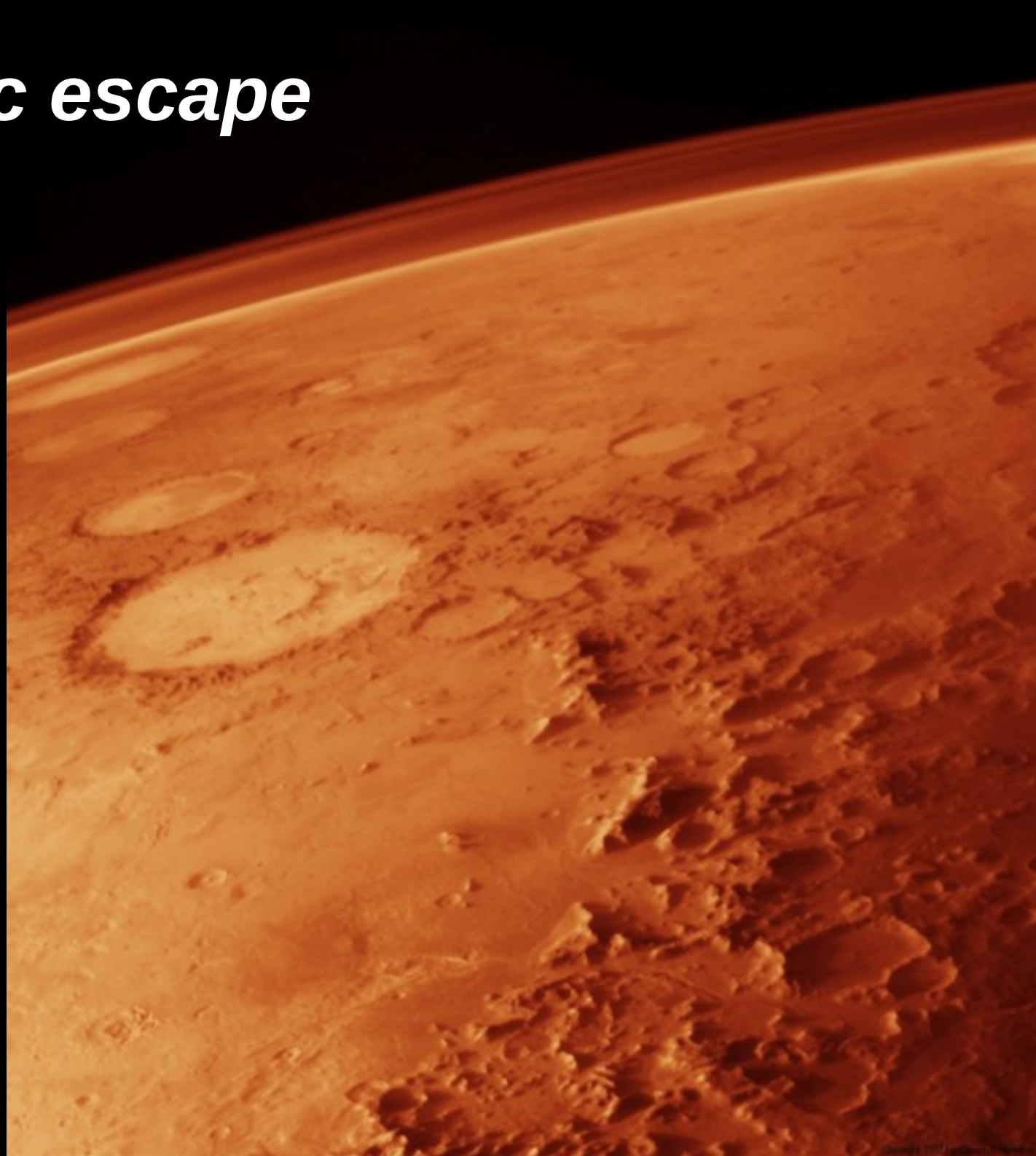
Moon: too small
No atmosphere

Earth



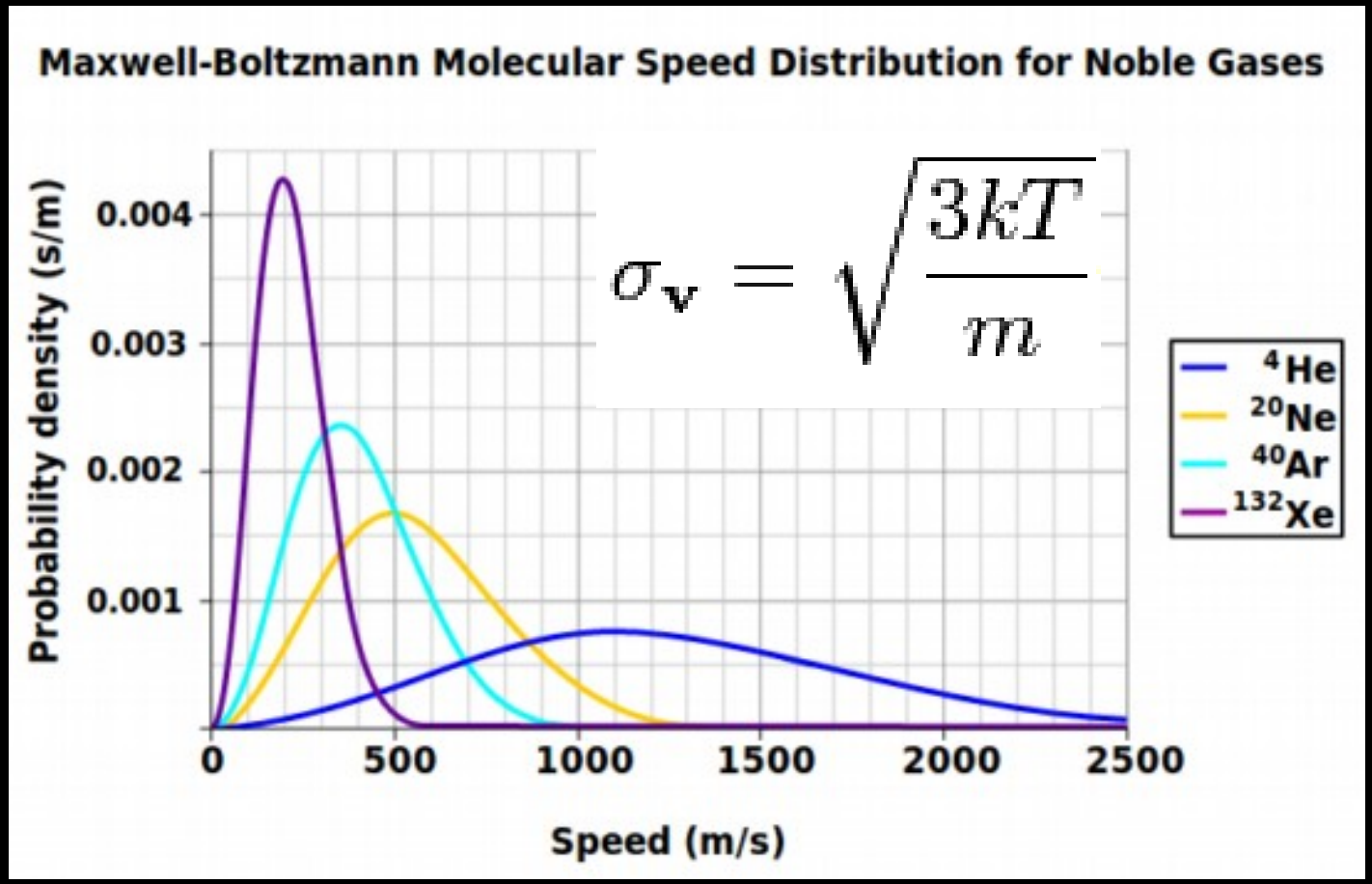
Jupiter: too big
Mostly gas

Atmospheric escape



Mars' thin atmosphere

Atmospheric escape



Escape velocity

$$v_e = \sqrt{\frac{2GM}{r}}$$

60 km/s for Jupiter
11 km/s for Earth
5 km/s for Mars
2.4 km/s for Moon

Gas temperature → molecules/atoms motion
Some molecules and gas will have speed > escape velocity, and will leave the planet

What makes planets habitable ?

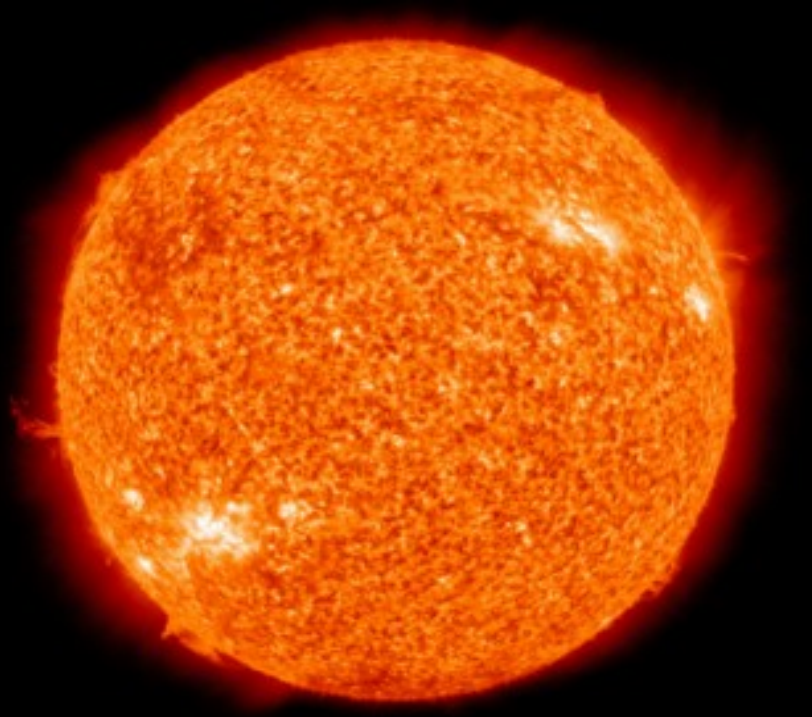
The planet must be in the **habitable zone** of its star: not be too close or too far

Venus: too close, too hot

Image credit: NASA/JPL-Caltech/MSSS

Mars: too far, too cold

Our Sun – a few facts



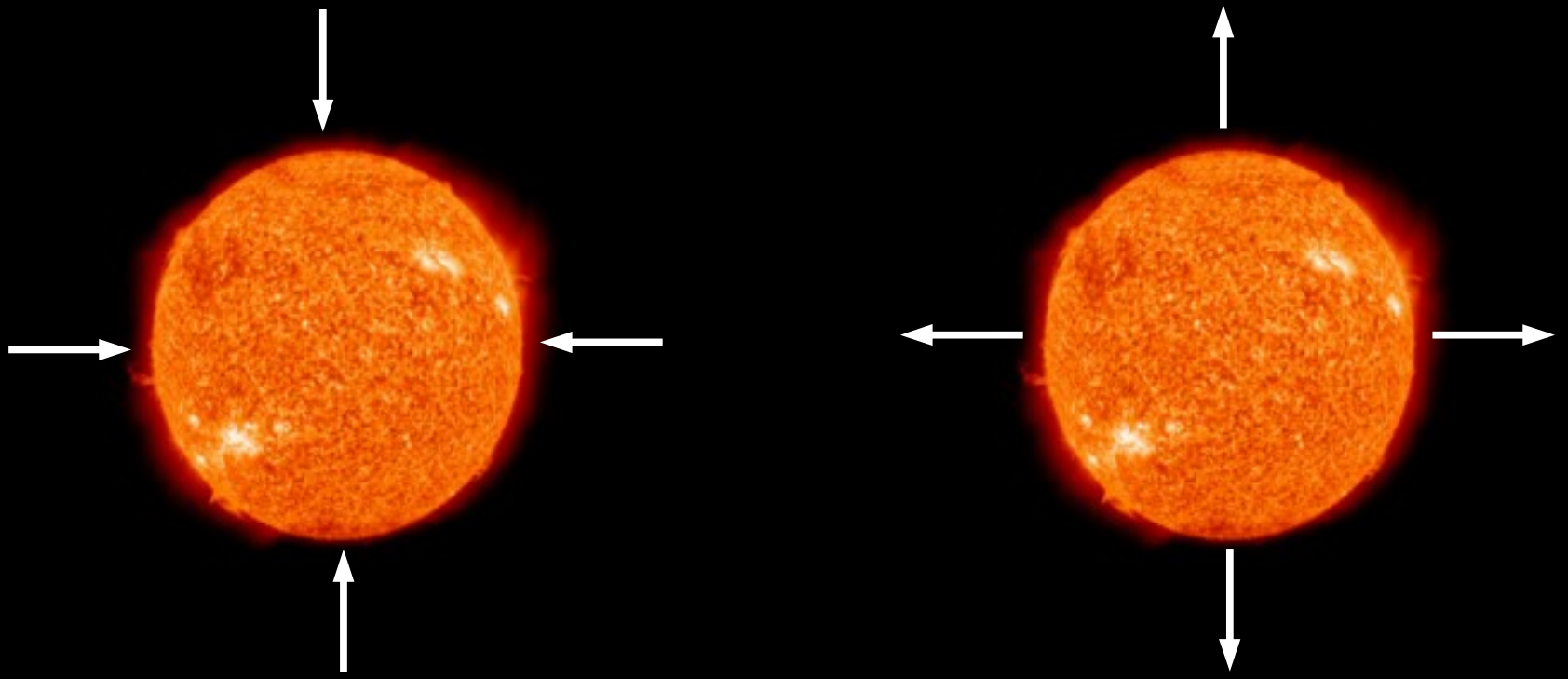
MASS
99.86% of the solar system mass
(this is why planets go around the Sun)

SIZE
1.4 million km diameter (~100x Earth)
Jet airplane would take few months to go around Sun

Mostly Hydrogen, a bit of Helium
Surface temperature: 5505 C

Earth receives ~1.4 kW of energy (in the form of light) per square meter from the Sun

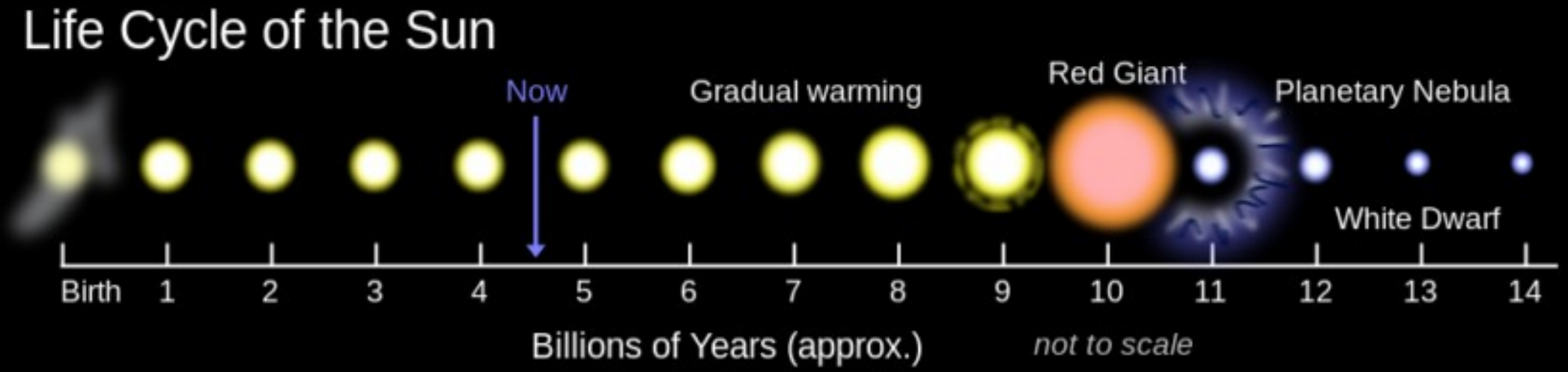
Gravity vs *Thermonuclear fusion*



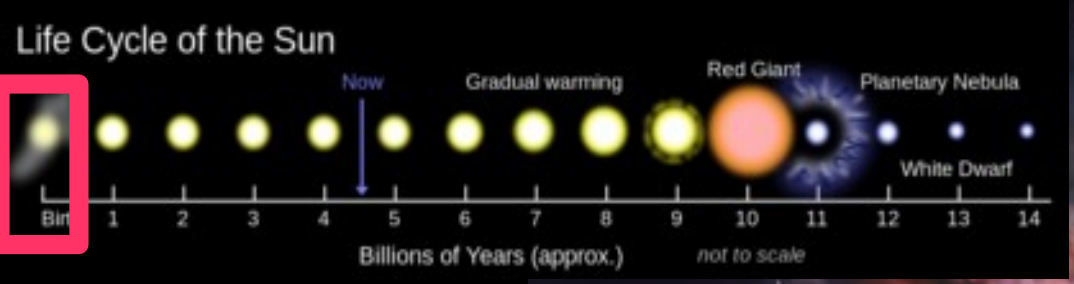
When gravity compresses the Sun core, pressure at center increases → thermonuclear fusion gets much more efficient → Currently in equilibrium: neither force can win

This equilibrium lasts for ~10 billion years for the Sun (this phase is called the "Main Sequence")

Sun life cycle



10 billion yrs of “stable life”


Life Cycle of the Sun
Now
Gradual warming
Red Giant
Planetary Nebula
White Dwarf
Bir
1
2
3
4
5
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8
9
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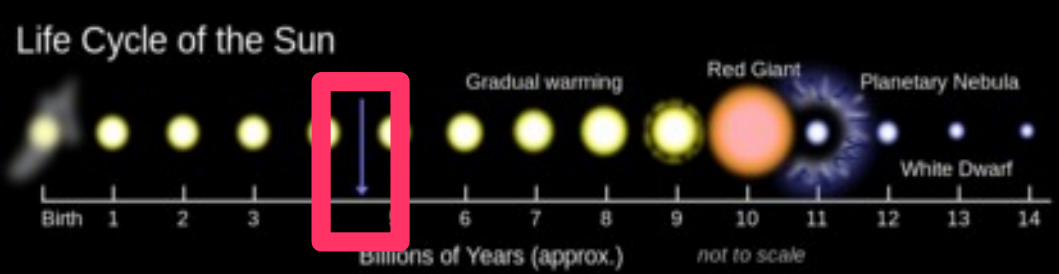
11
12
13
14
Billions of Years (approx.)
not to scale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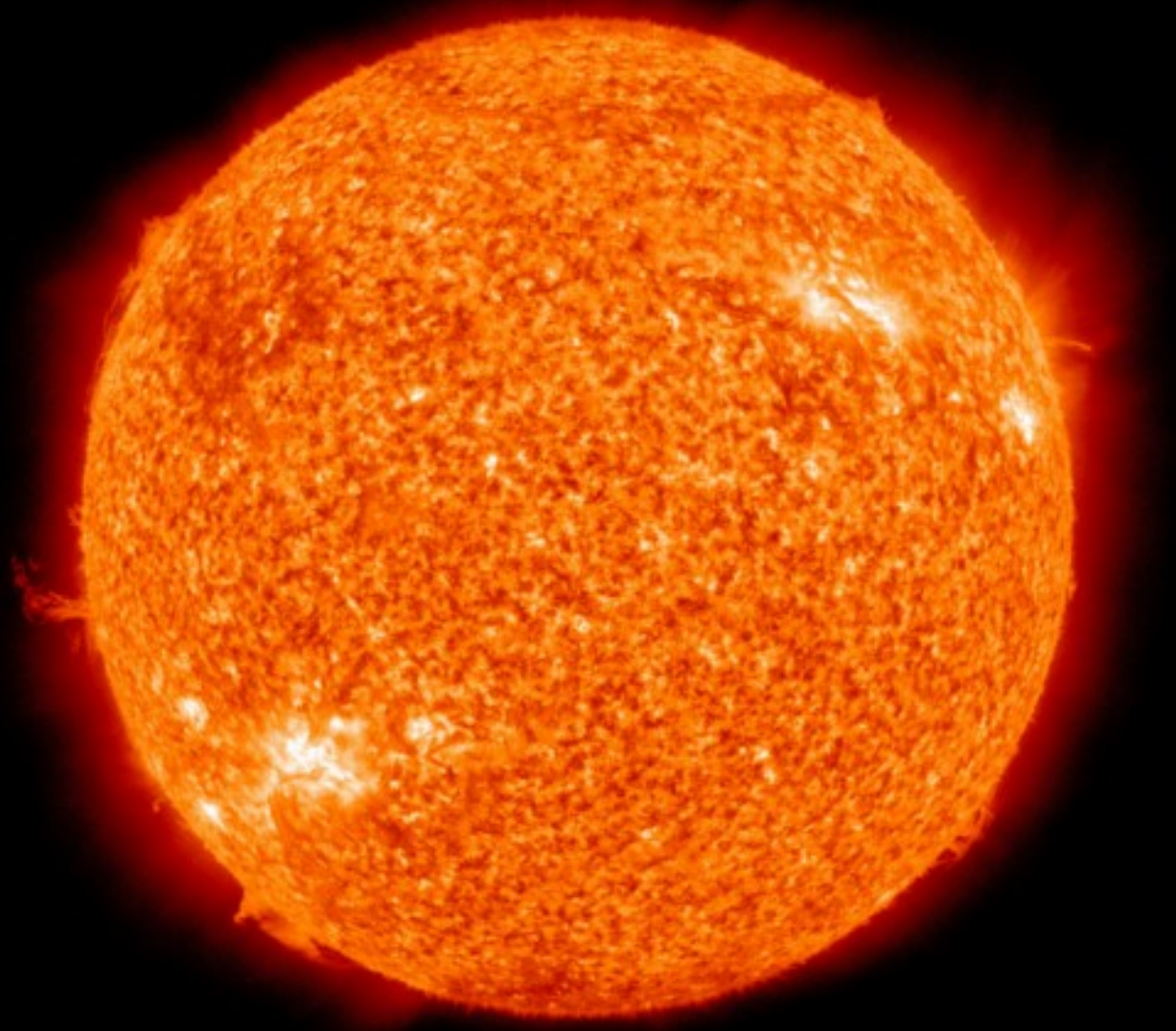

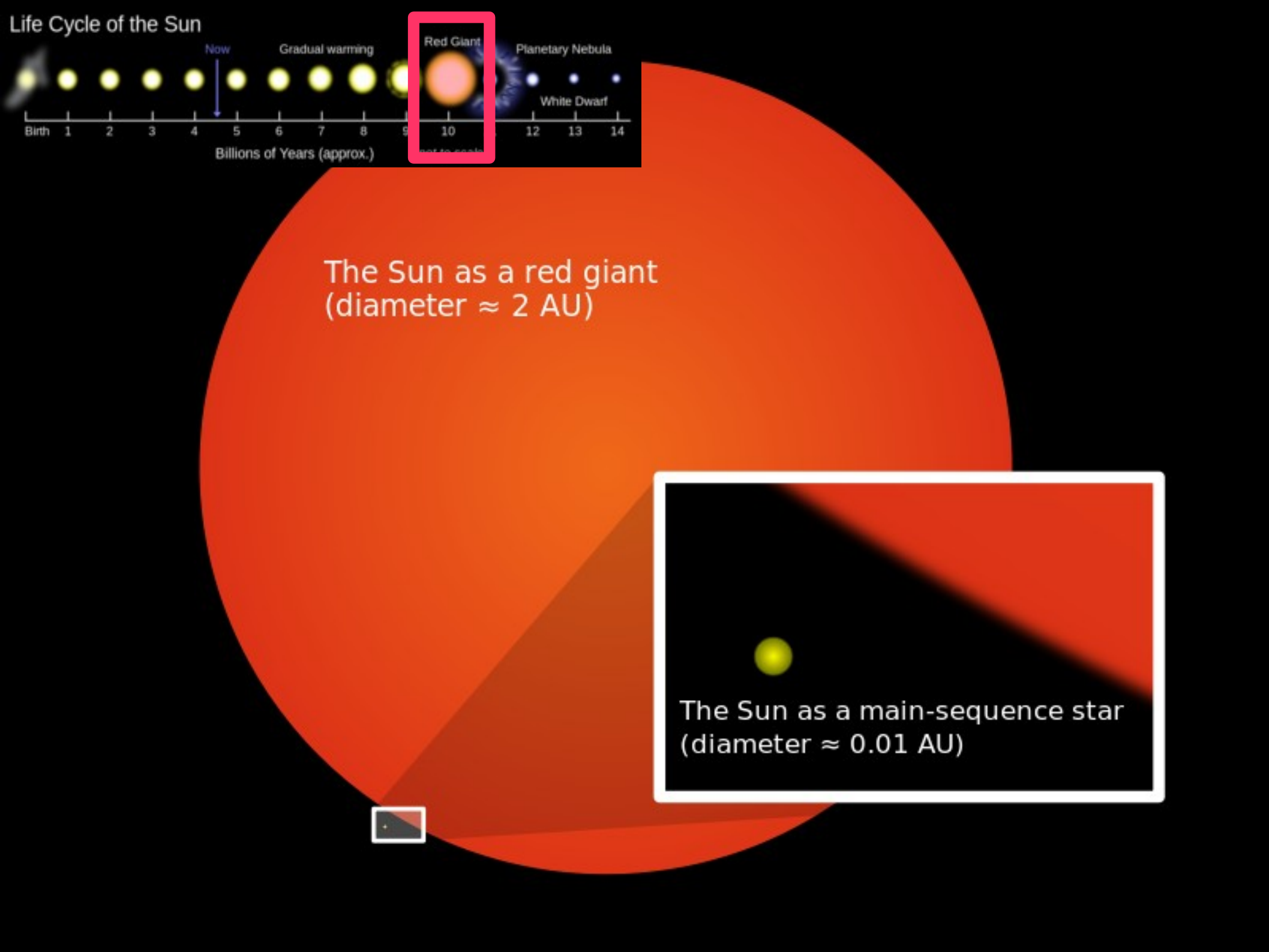
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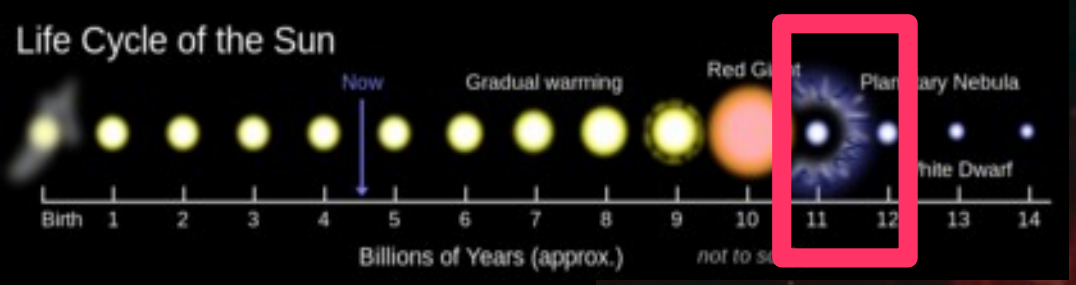
Billions of Years (approx.)
The Sun as a red giant
(diameter ≈ 2 AU)
The Sun as a main-sequence star
(diameter ≈ 0.01 AU)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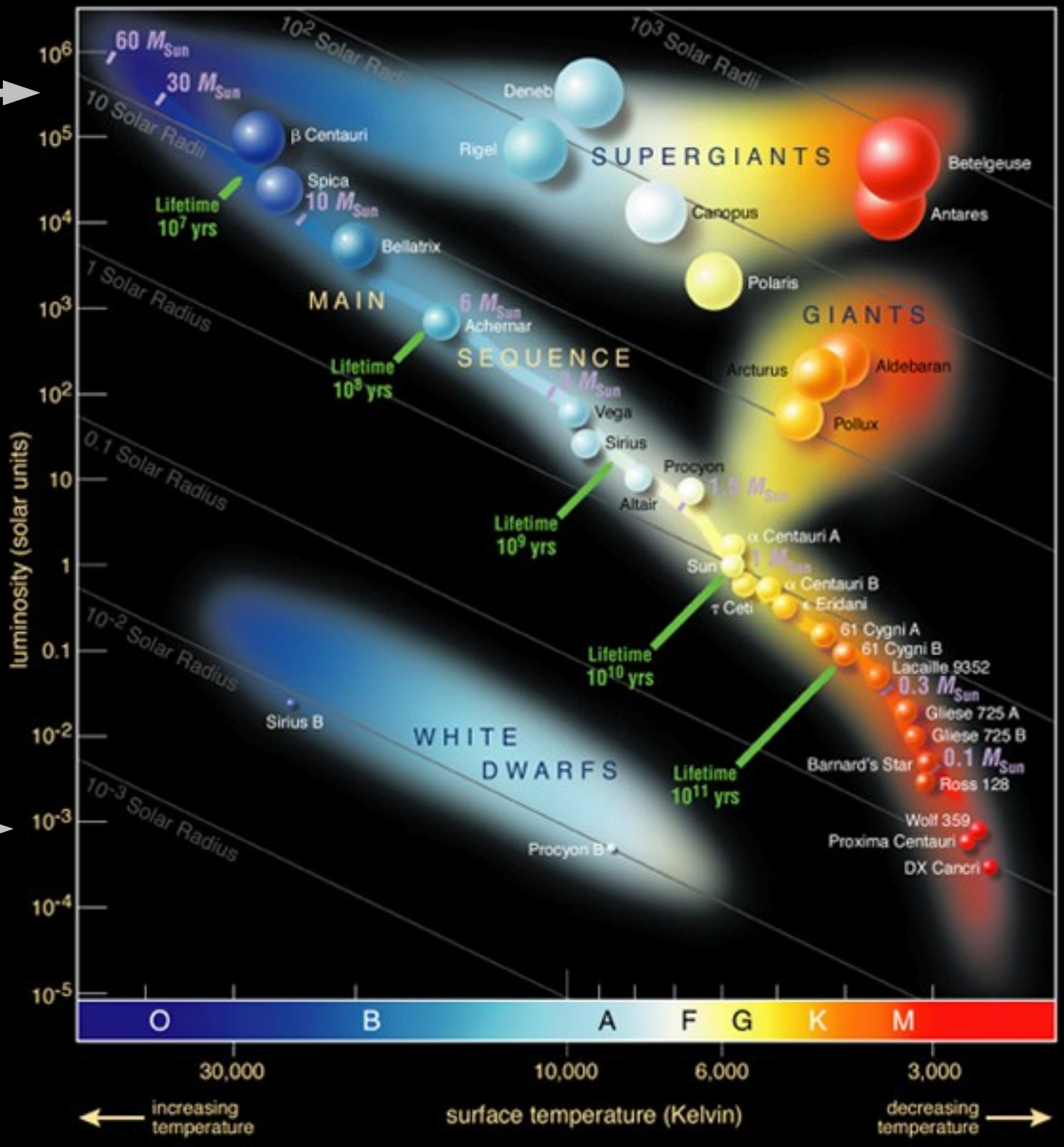
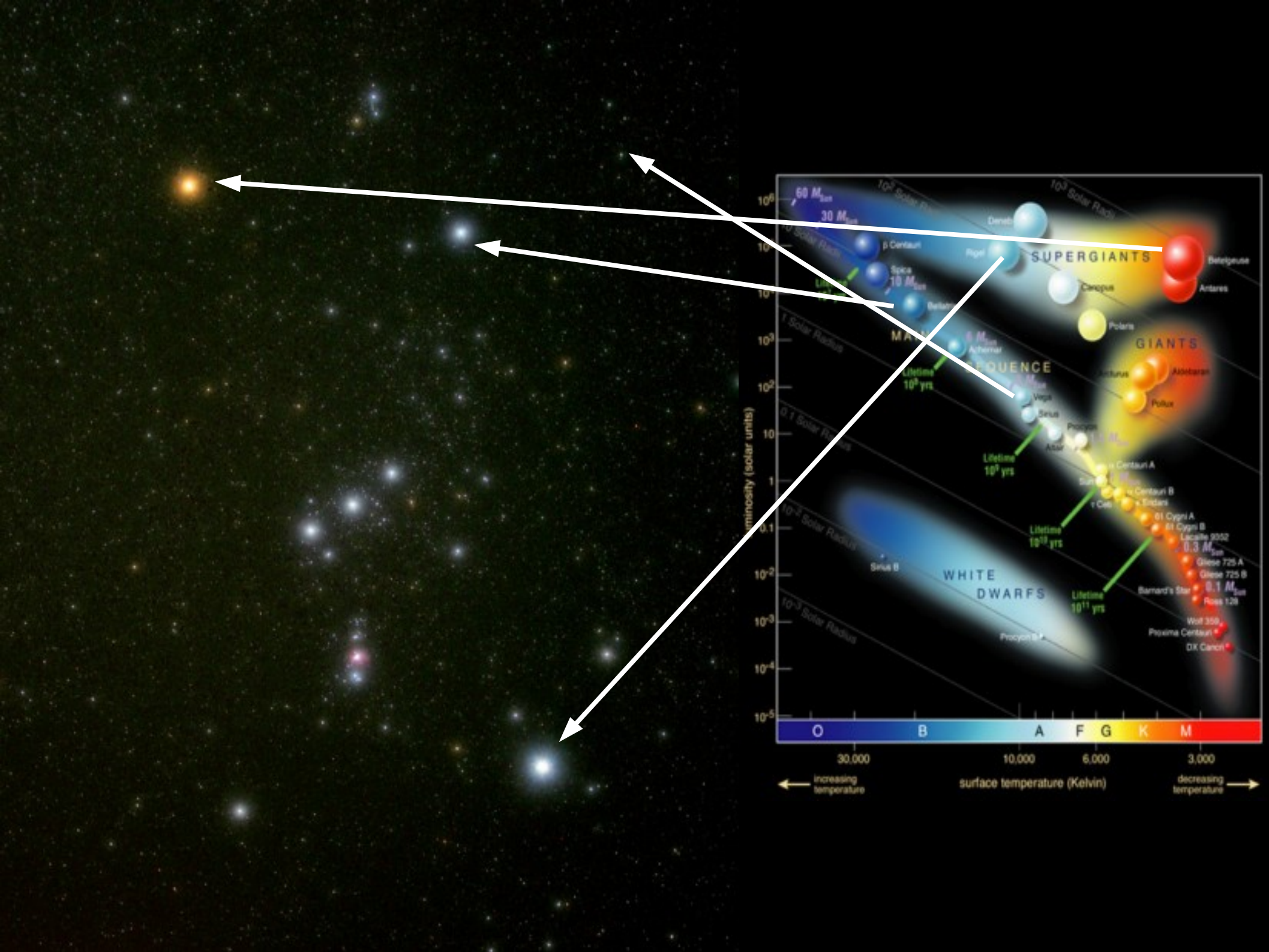
14
Billions of Years (approx.)

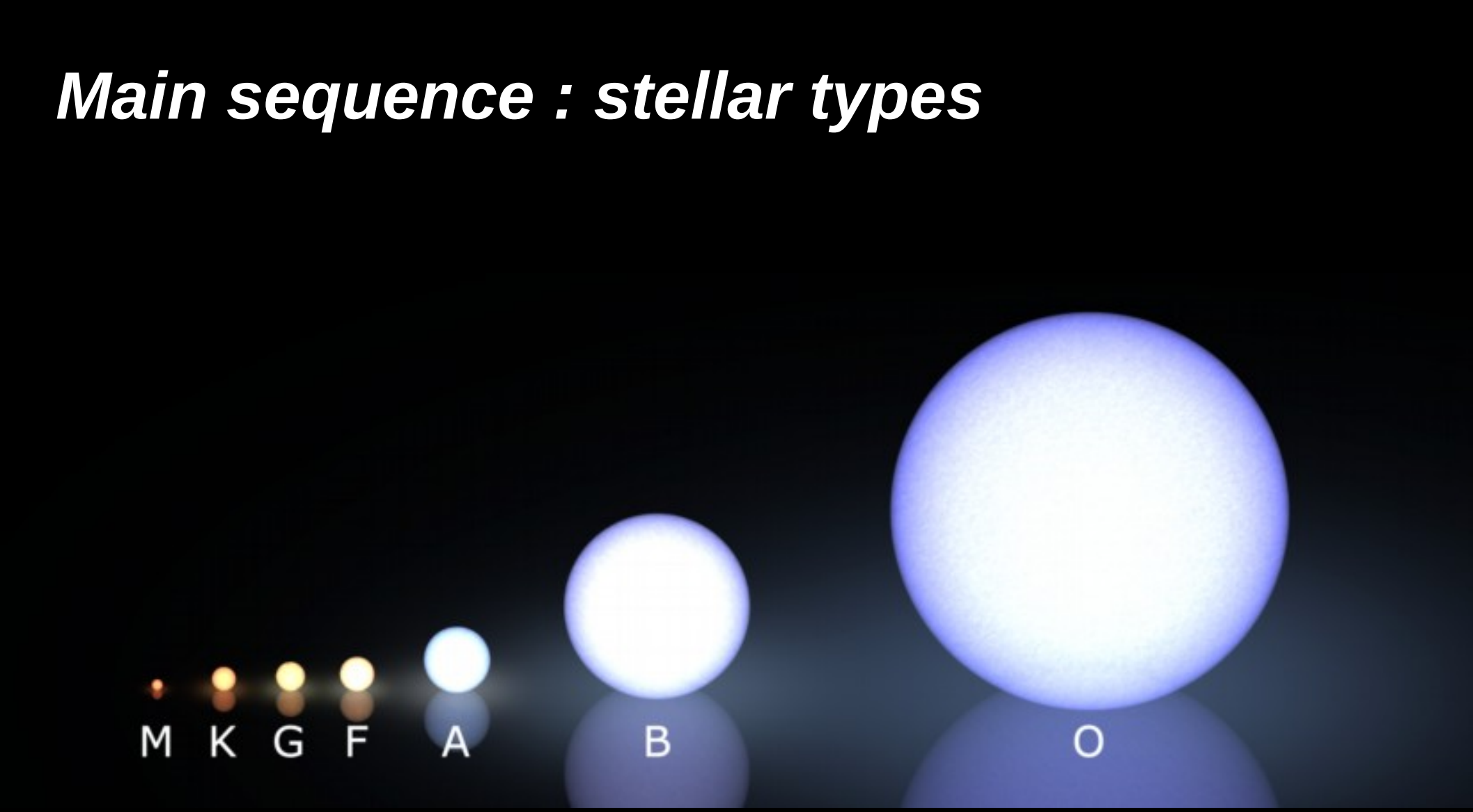
Brightest stars are 1 million times as bright as the Sun

Low mass stars are 0.1% as bright as the Sun, but live for much longer

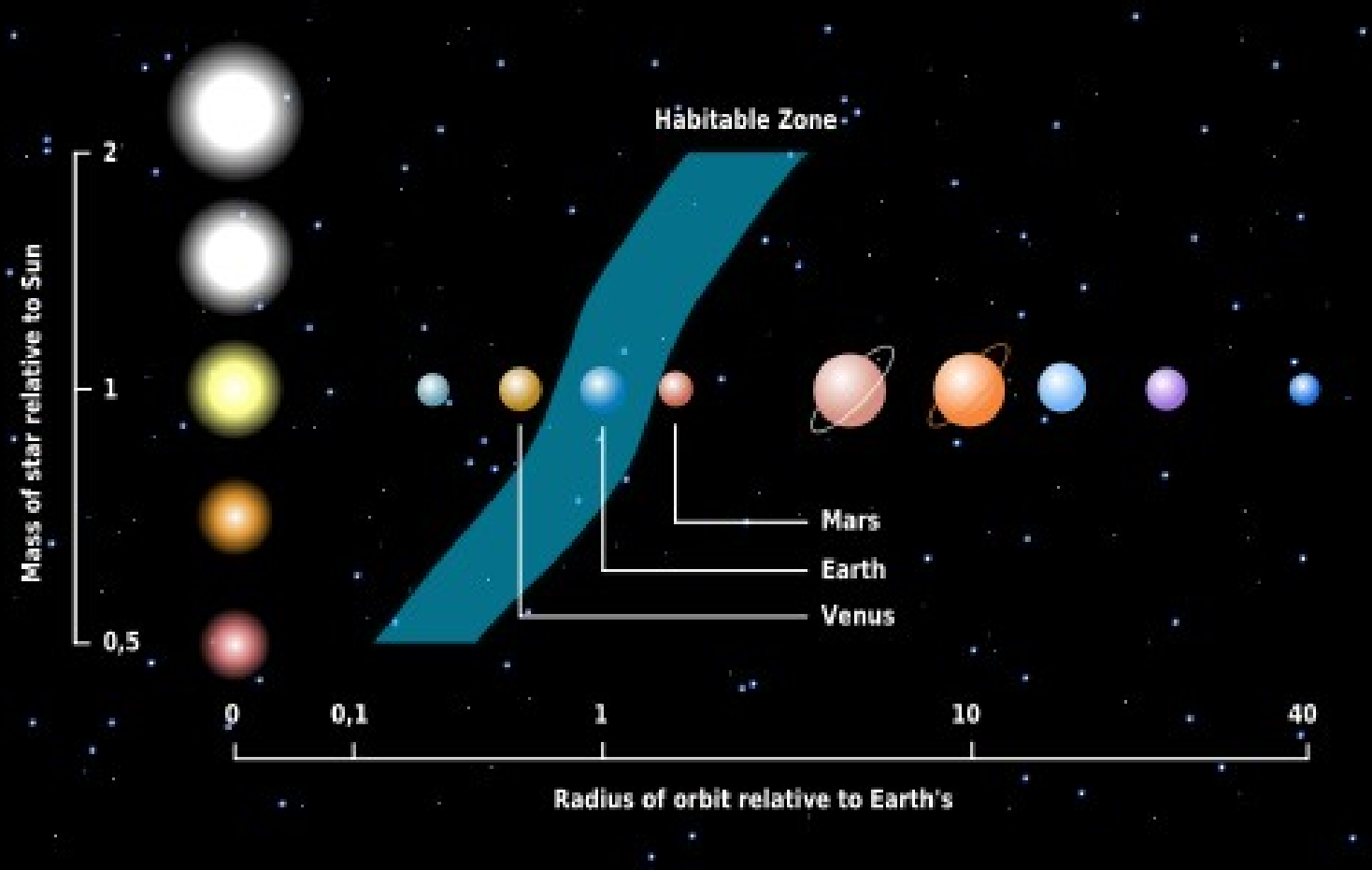



SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
Betelgeuse
Antares
Canopus
Polaris
Arcturus
Aldebaran
Pollux
Achernar
Vega
Sirius
Procyon
Altair
Sun
α Centauri A
α Centauri B
ε Eridani
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
Procyon B
β Centauri
Spica
Lifetime 10^9 yrs
Lifetime 10^8 yrs
Lifetime 10^10 yrs
Lifetime 10^11 yrs
60 M_Sun
30 M_Sun
18 M_Sun
8 M_Sun
2 M_Sun
1 M_Sun
0.3 M_Sun
0.1 M_Sun
10^2 Solar Radius
10 Solar Radius
1 Solar Radius
0.1 Solar Radius
10^-2 Solar Radius
10^-3 Solar Radius
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^-2
10^-3
10^-4
10^-5
O
B
A
F
G
K
M
30.000
10.000
6.000
3.000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

Main sequence : stellar types



Habitable zone of a star



Every star has a habitable zone

Life around... Theta1 Orionis C

Luminosity = 250,000x Sun

Distance = 1,500 light years

Age ~ 1.2 million yr

Mass = 40x Sun

Radius = 8x Sun

Surface temperature = 45,000 K
(Sun = 5,780 K)

Habitable zone =
Star apparent size from habitable zone =
Time in main sequence =

Life around... Theta1 Orionis C

Luminosity = 250,000x Sun

Distance = 1,500 light years

Age ~ 1.2 million yr

Mass = 40x Sun

Radius = 8x Sun

Surface temperature = 45,000 K
(Sun = 5,780 K)

Habitable zone = 500 AU
Star apparent size from habitable zone = 0.5 arcmin (60x smaller than Sun)
Time in main sequence = few million yrs

Life around... Proxima Centauri

Luminosity = 0.0017x Sun

Distance = 4.2 light years

Age ~ 4.85 billion yr

Mass = 0.123x Sun

Radius = 0.141x Sun

Surface temperature = 3,042 K
(Sun = 5,780 K)

Habitable zone =
Star apparent size from habitable zone =
Time in main sequence
Orbital period

Life around... Proxima Centauri

Luminosity = 0.0017x Sun

Distance = 4.2 light years

Age ~ 4.85 billion yr

Mass = 0.123x Sun

Radius = 0.141x Sun

Surface temperature = 3,042 K
(Sun = 5,780 K)

Habitable zone = 0.04 AU
Star apparent size from habitable zone = 1.5 deg (3x larger than Sun)
Time in main sequence > age of universe
Orbital period ~ 1 week → tidal locking

Other things that matter …

Ingredients: what is the planet made of ? How much water ?

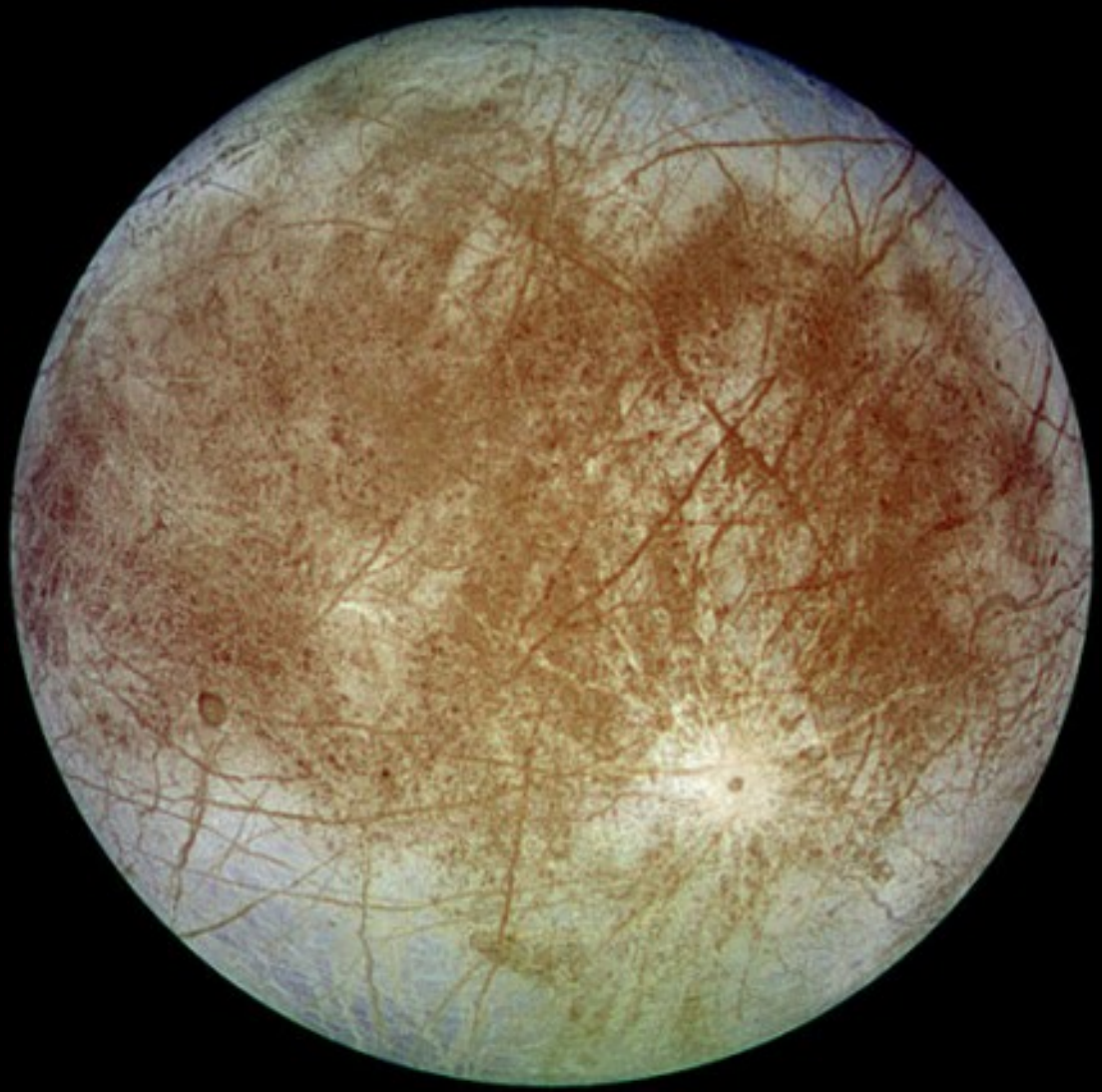
Carbon cycle on Earth regulates temperature

On Earth, carbon cycle enabled by plate tectonics, itself enabled by oceans & continents

Orbit stability (large climate shifts triggered by orbital instabilities)

Large impacts

Other possibilities ?



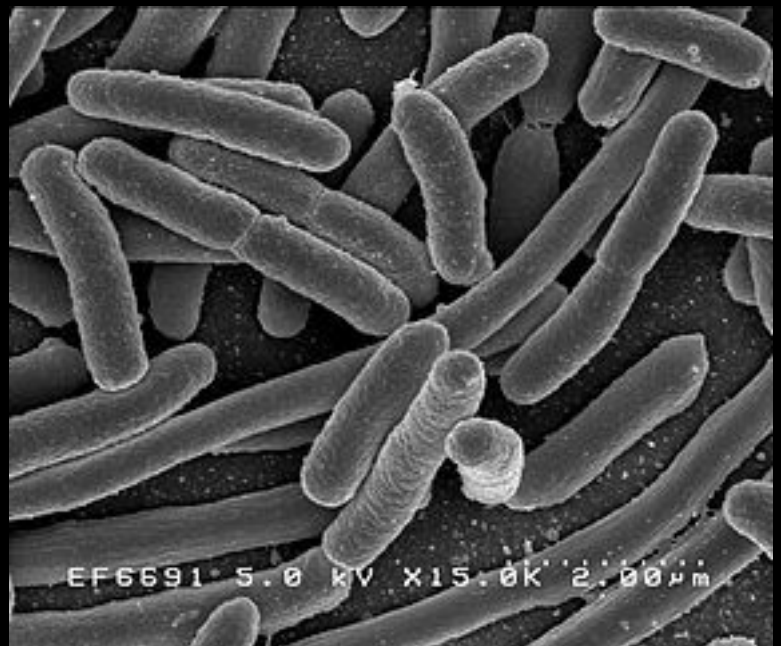
Europa (moon of Jupiter) may have liquid ocean under ice surface

What kind of life ?

“simple” bacteria, or “complex” intelligent life ?

On Earth, life did not evolve regularly

Large steps forward (from bacteria to multicellular organisms 2B yr ago, Cambrian explosion more recently) and also setbacks (snowball Earth episodes, mass extinctions)



Almost endless possibilities for life in the universe...

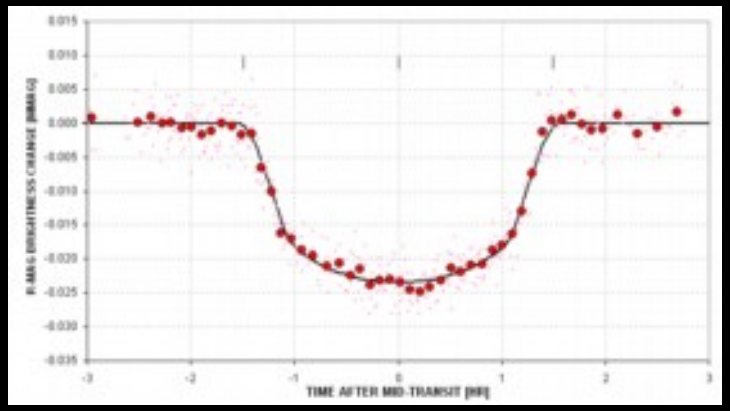
The universe has MANY galaxies, each composed of MANY stars with planets

Even if only 1 out of 10 stars has an habitable planet …

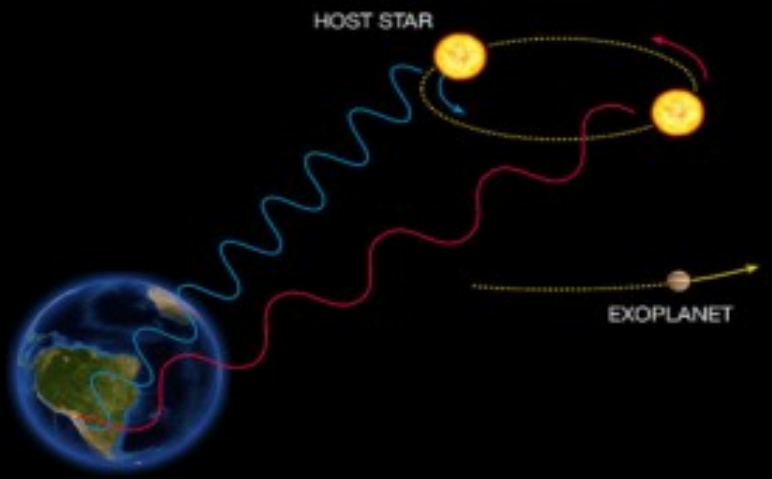
… If you could visit 1 habitable planet per second, it would take 600 years to visit all habitable planets in our galaxy alone

Almost all known planets are discovered indirectly (no image)

Transit
planet passes in front of star
→ star appears to dim



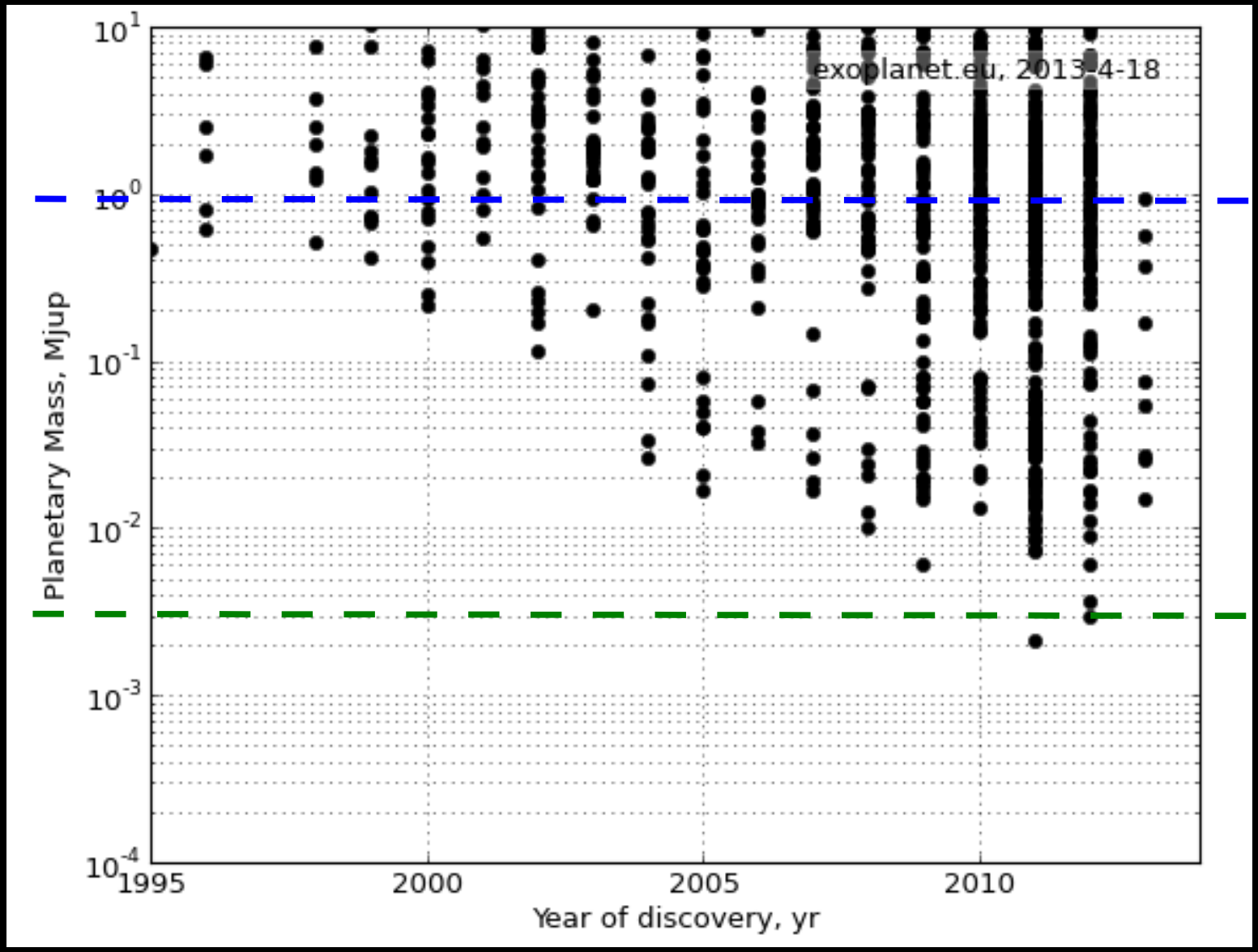
Radial velocity
planet pulls star in small periodic back and forth motion
→ detected thanks to Doppler shift, which makes light bluer as star moves toward us and redder as it moves away



The Radial Velocity Method

ESO Press Photo 22a/07 (25 April 2007)

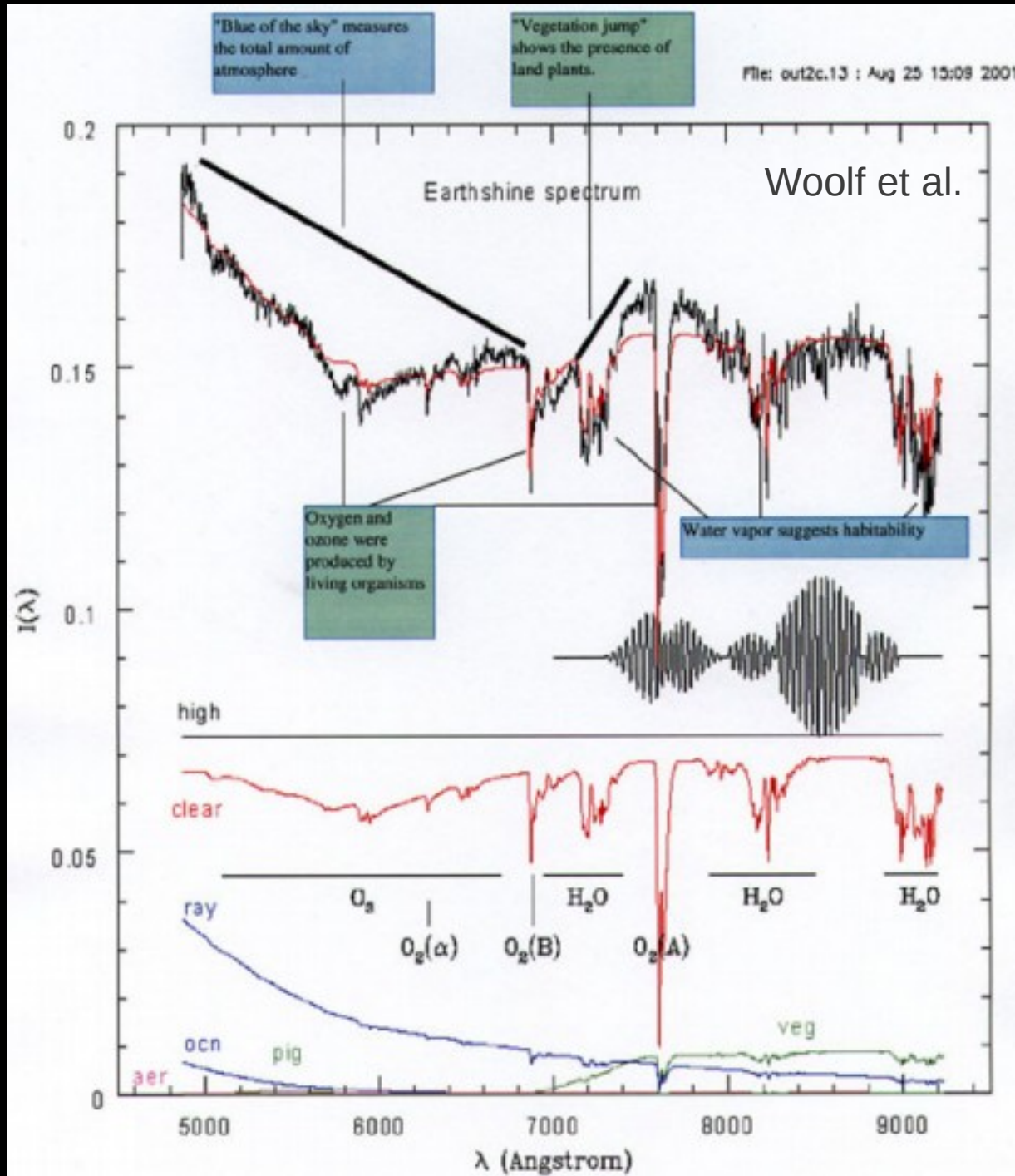
Planets identified – small planets are harder to find



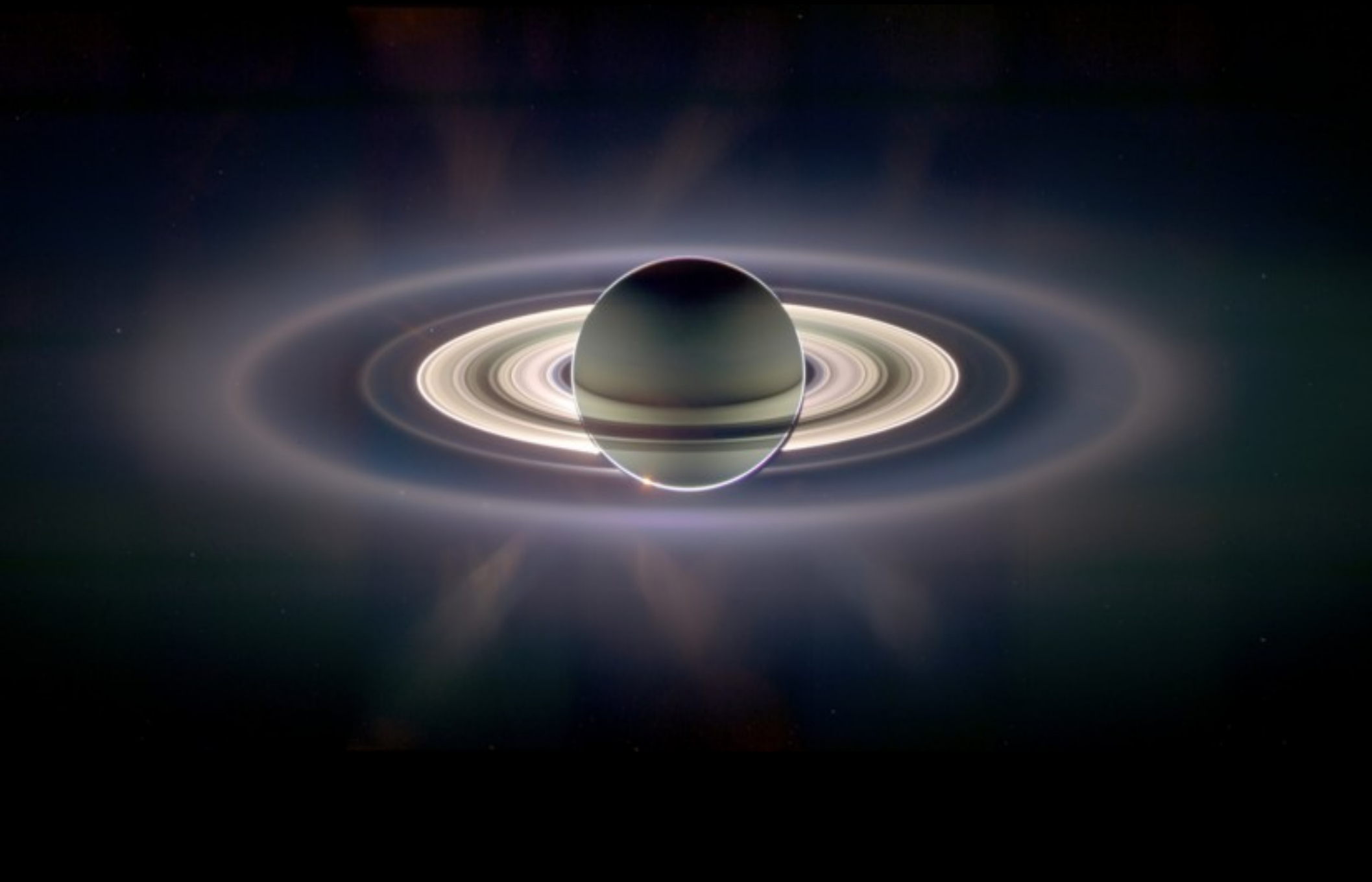
Directly imaging planet is necessary to find life

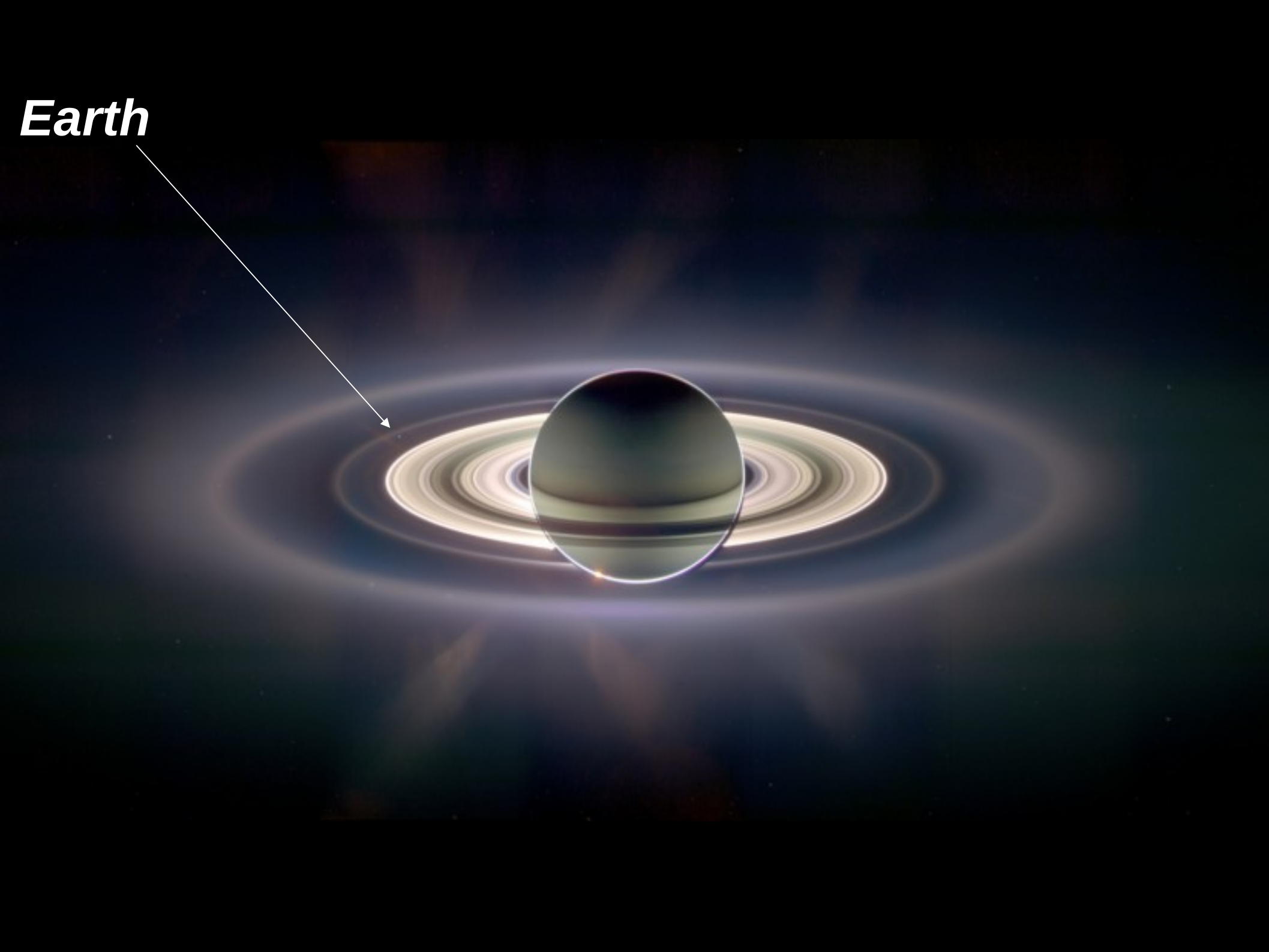
We need to take spectra of habitable planets

Spectra of Earth (taken by looking at Earthshine) shows evidence for life and plants



Taking images of exoplanets: Why is it hard ?




Earth