Sigam a Energia

FOLLOW THE LIFE

- Solvent
- Biogenic elements
- ⇒ Source of Free Energy

searches for life within our solar system commonly retreat from a search for life to a search for “life as we know it,” meaning life based on liquid water, a suite of so-called “biogenic” elements (most famously carbon), and a usable source of free energy.

(Chyba & Hand, 2005, p. 34)

SIGA A VIDA

- Siga a água (Follow the water)
- Siga o carbono
- Siga o nitrogênio
- Siga o fósforo
- ⇒ Siga a energia
- Siga a entropia
- Siga a informação
- Siga o significado

How does life get the energy?

- Photosynthesis

A) Oxygenic:

$CO_2 + H_2O + h\nu$ (Energy) $\rightarrow CH_2O + O_2$

B) Anoxygenic

$CO_2 + 2H_2S + h\nu$ (Energy) $\rightarrow CH_2O + 2S + H_2O$

In reality:

$6CO_2 + 6H_2O + h\nu$ (Energy) $\rightarrow C_6H_{12}O_6 + 6O_2$

Glucose

How does life extract the energy?

- Respiration

$CH_2O + O_2 \rightarrow CO_2 + H_2O + \text{Energy}$

In reality:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$

- Fermentation

$C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_6O + \text{Energy}$

But there are ways to get energy without photosynthesis.

- Methanogenesis

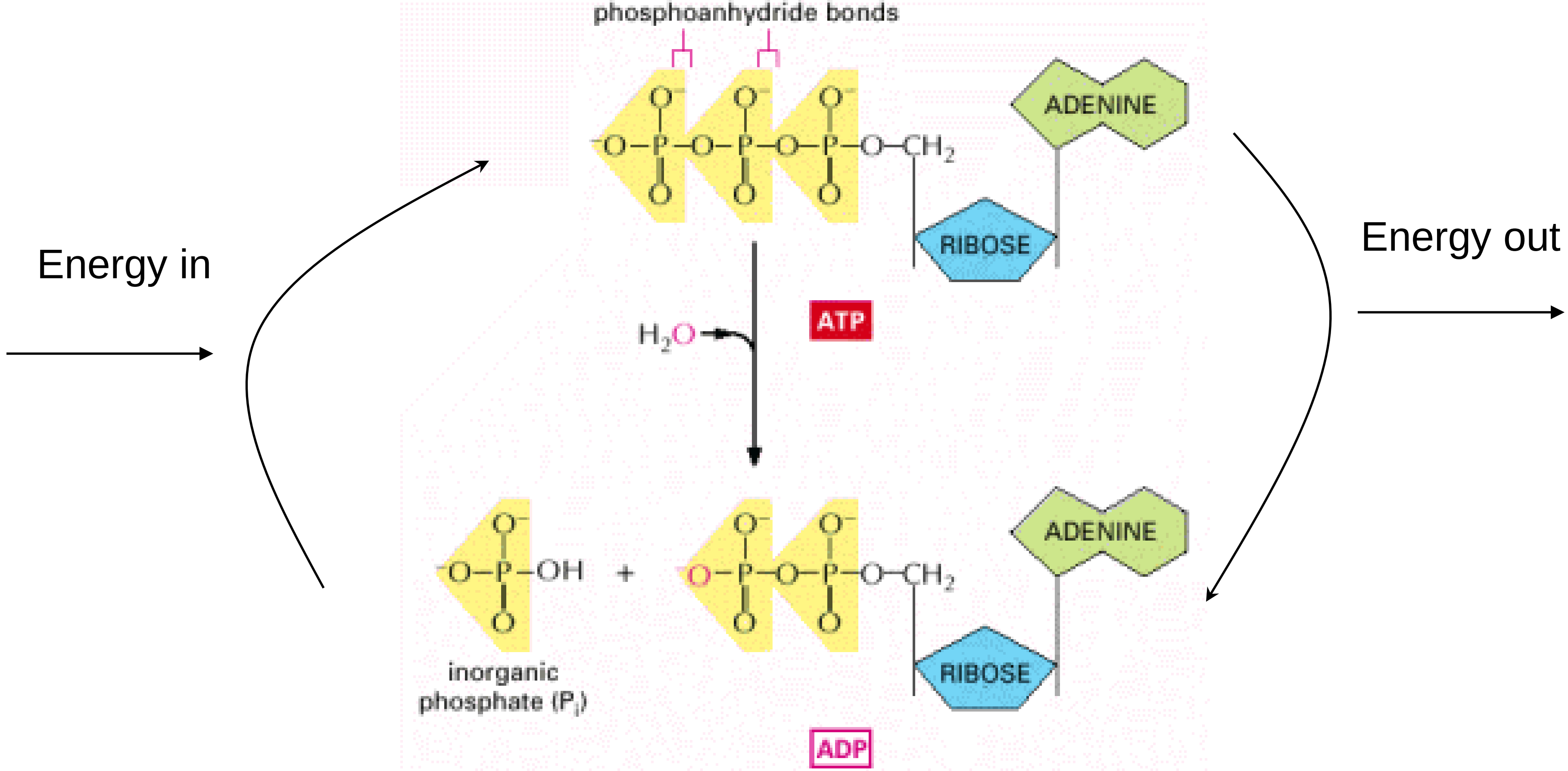
$CO_2 + 4\ H_2 \rightarrow CH_4 + 2H_2O + \text{Energy}$

- Sulfate reduction

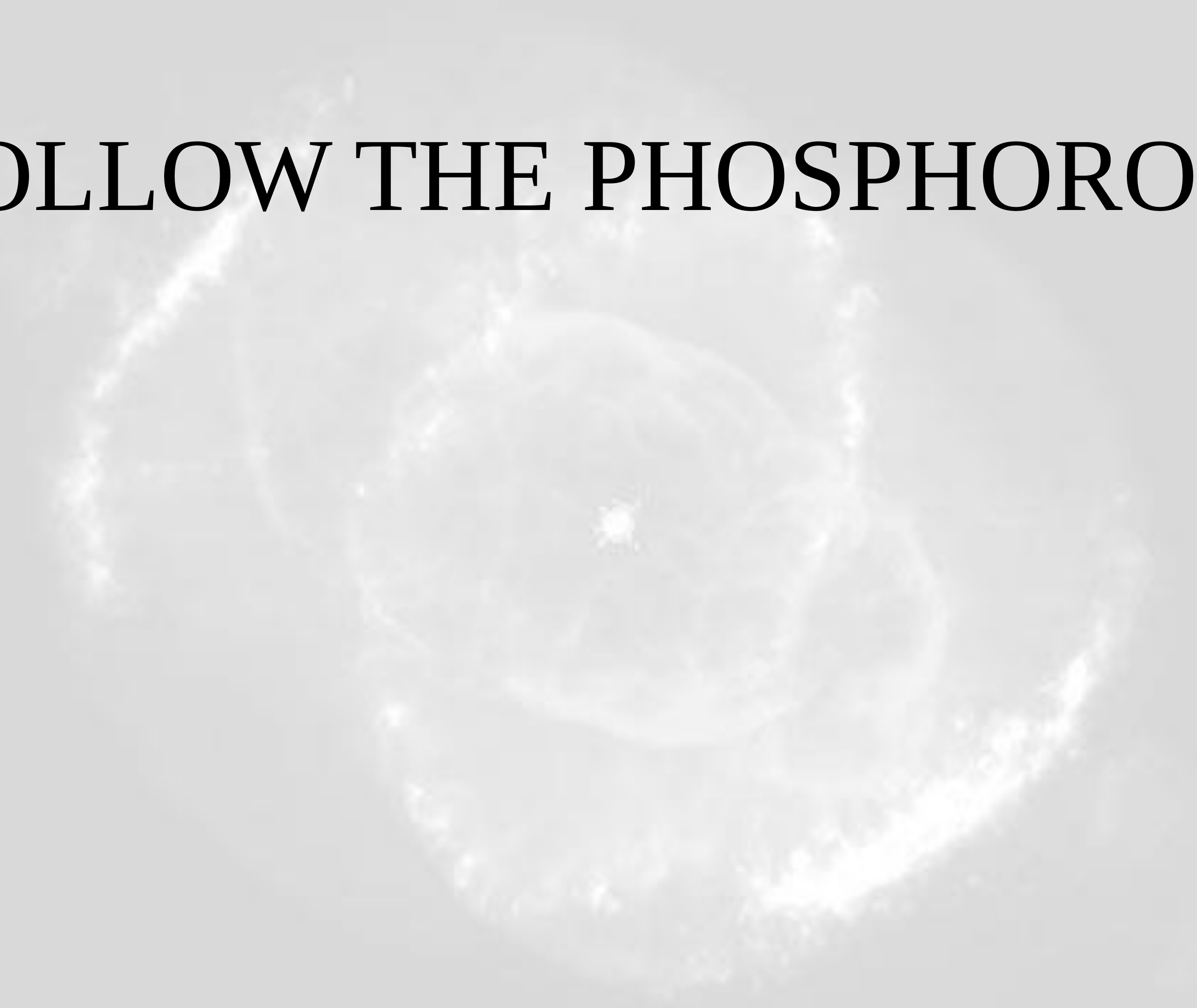
$4H_2 + SO_4^{2-} \rightarrow S^{2-} + 4H_2O + \text{Energy}$

ATP

- Every living cell uses ATP (adenosine triphosphate) to store and release energy



FOLLOW THE PHOSPHOROS?



FOLLOW THE LIFE

- Solvent
- ⇒ Biogenic elements
- Source of Free Energy

searches for life within our solar system commonly retreat from a search for life to a search for "life as we know it," meaning life based on liquid water, a suite of so-called "biogenic" elements (most famously carbon), and a usable source of free energy.

(Chyba & Hand, 2005, p. 34)

SIGA A VIDA

- Siga a água (Follow the water)
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- ⇒ *Siga o fósforo*
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Nucleotide

Each nucleotide:
1) Five-carbon sugar molecule
2) One or more phosphate groups ⇐
3) Nitrogen-containing compound – nitrogenous base

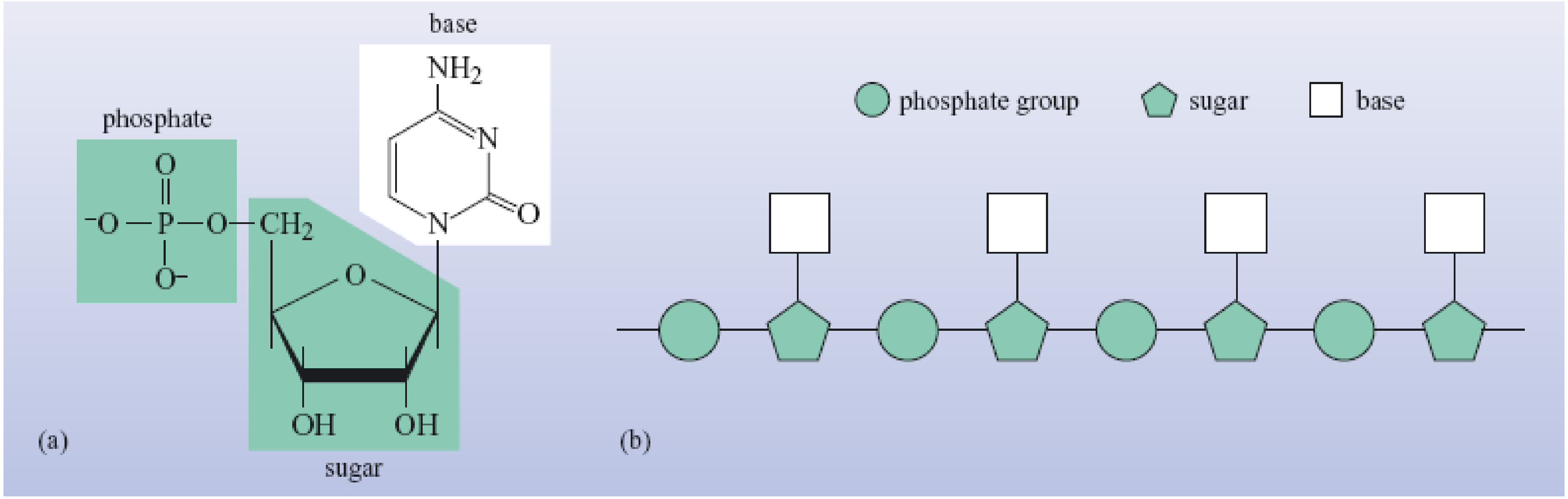


Figure 1.7 (a) The structure of a nucleotide consisting of a phosphate group, sugar molecule and nitrogenous base (cytosine in this instance). (b) Nucleotides polymerize by simple reactions that involve the loss of water to form nucleic acids. ((a) Zubay, 2000)

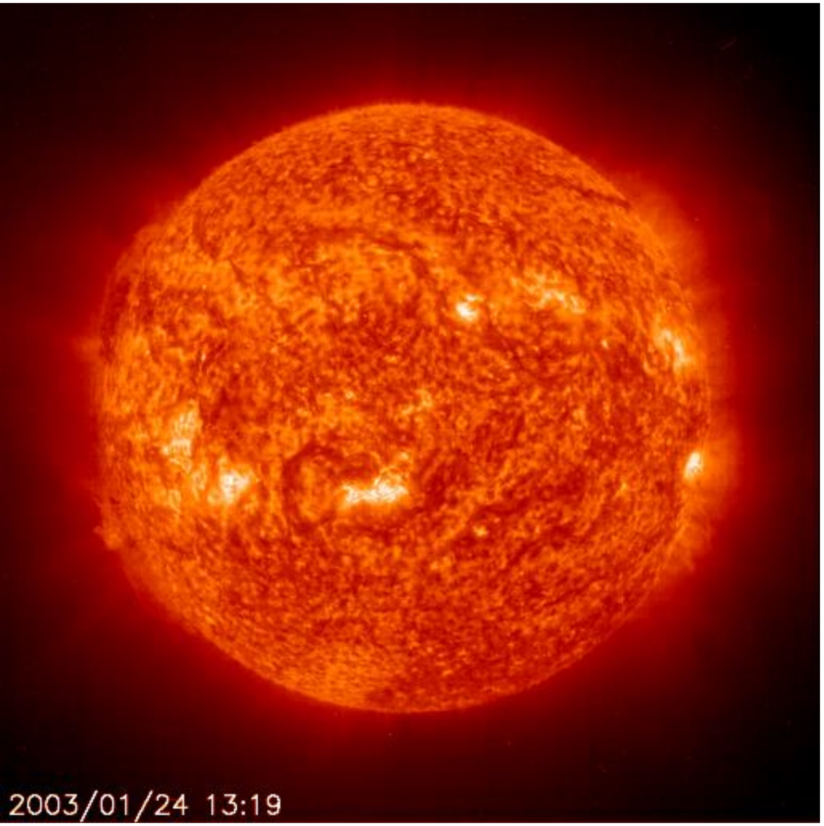
Classification of living organisms by carbon and energy sources

- Autotroph – organism gets carbon directly from the atmosphere (CO_2)
- Heterotroph – organism gets carbon by consuming preexisting organics
- “Photo” – energy to make ATP comes from light
- “Chemo” – energy to make ATP comes from chemical reactions (chemical disequilibrium)

Two primary sources of energy

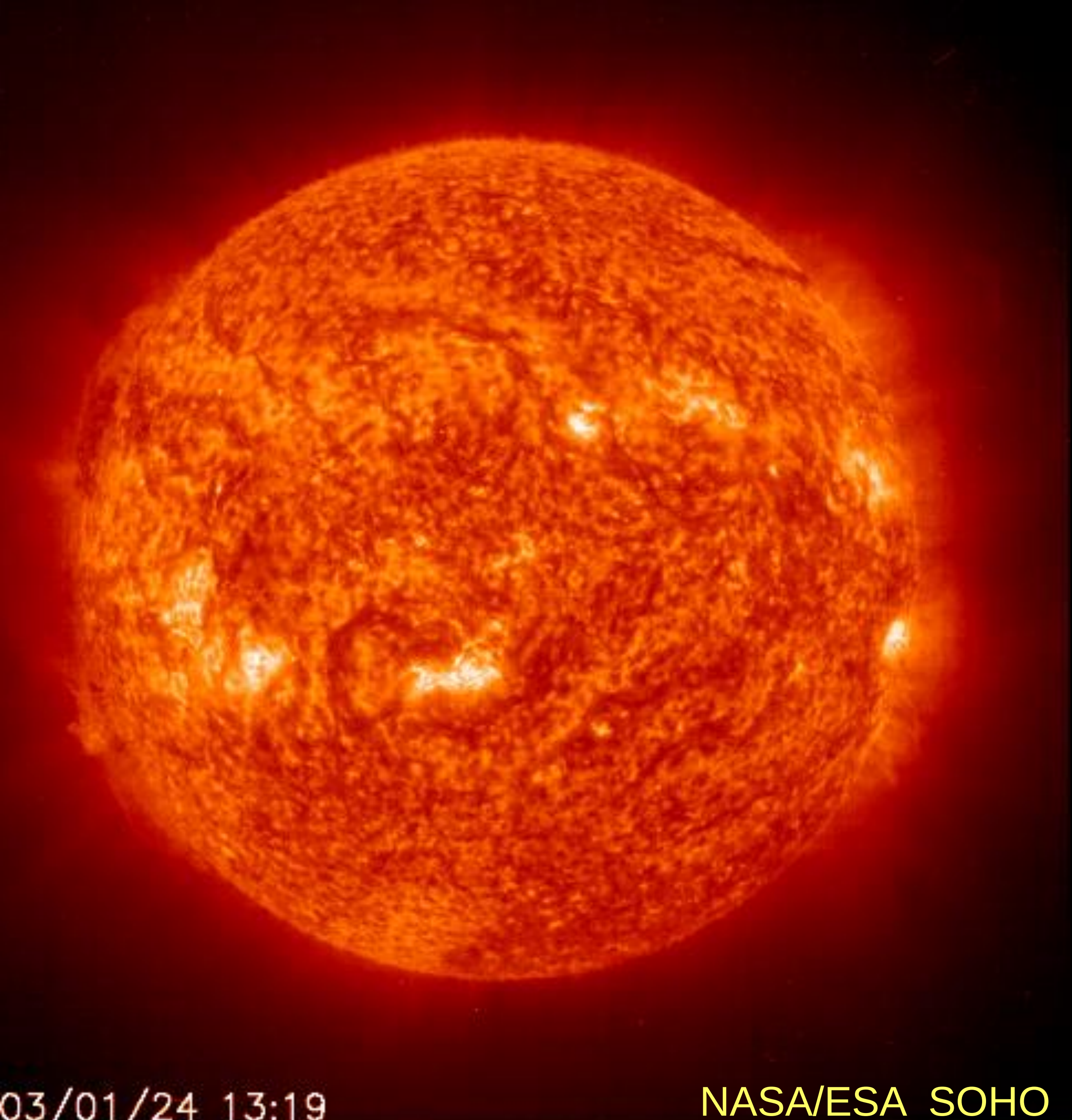
Sun

Earth's Interior



Solar Radiation:

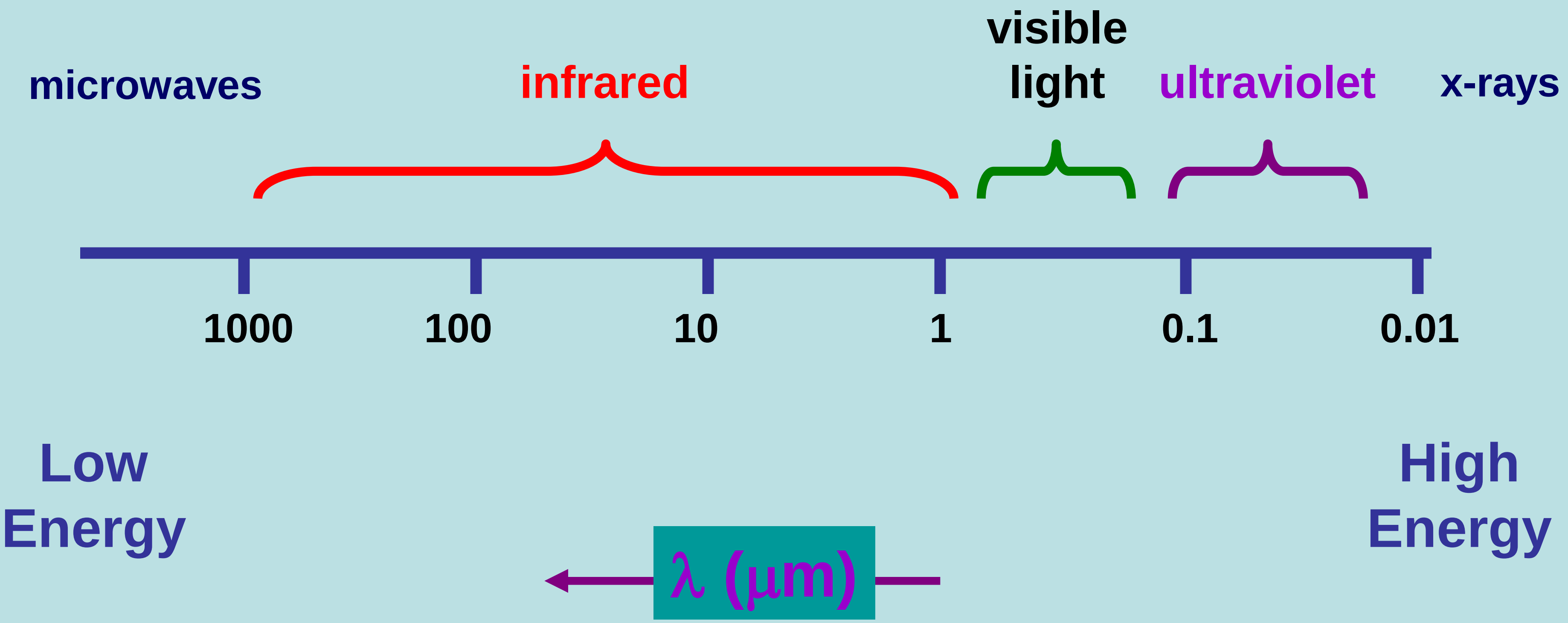
The source for 99.9% of Earth's energy



NASA/ESA SOHO

- Total luminosity of a star is determined by the temperature of the stellar surface.
  - The total amount of radiation received by a planet would depend on the position of a planet with respect to a star.
- The stellar surface temperature also determines the spectrum (the wavelengths at which the star mostly emits) of the received radiation by the planet
  - The atmospheric absorption alters the spectrum of the of the radiation at the surface of the planet

Electromagnetic Spectrum

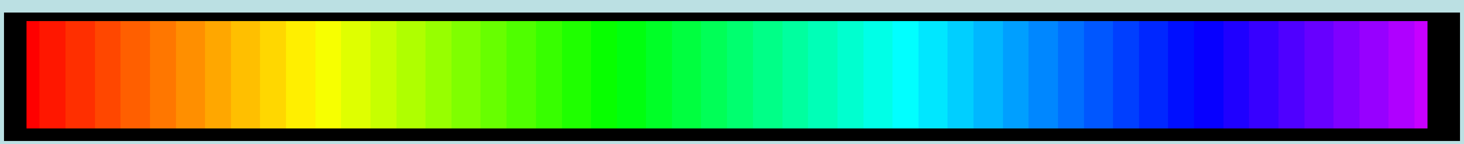


Visible Light (VIS)

0.7 to 0.4 μm

Our eyes are sensitive to this region of the spectrum

Red-Orange-Yellow-Green-Blue-Indigo-Violet

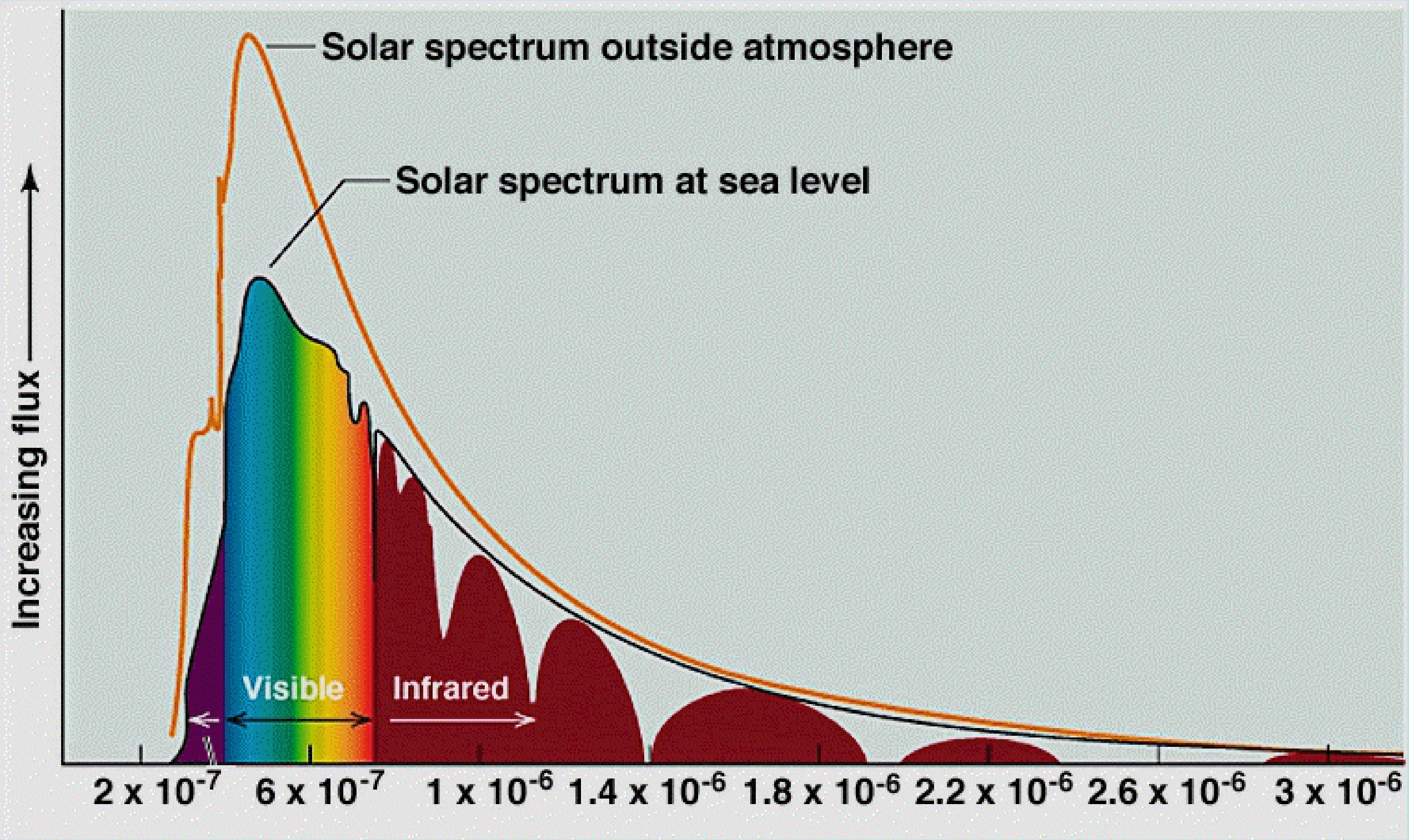


Solar Spectrum

The sun emits radiation at all wavelengths

Most of its energy is in the
IR-VIS-UV
portions of the spectrum

~50% of the energy is in the **visible** region
~40% in the **near-IR**
~10% in the **UV**



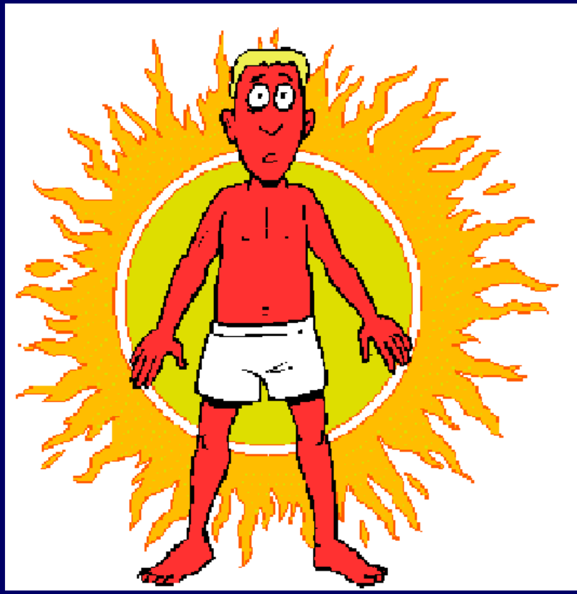
Wavelength (m)

Categories of UV Radiation

Name	Wavelength(s)	Biological Effect
UV-A	> 320 nm	Relatively harmless
UV-B	290-320 nm	Harmful
UV-C	< 290 nm	Very harmful, but blocked by O_3 and O_2

UV-B concern

- DNA and proteins absorb UV-B
- Animals: skin cancer, cataracts, suppressed immune system ….
- Plants: photosynthesis inhibition, leaf expansion, plant growth …



Stellar spectrum is important for life!

- Photosynthesis requires visible radiation (0.4-0.7 microns)
- Photosynthesis can be inhibited by UV radiation (UV-B)
- Organisms have to protect themselves from UV but have to be able to absorb visible radiation at the same time.

Radiação de Corpo Negro

Radiação de Corpo Negro

- Em 1792, Thomas Wedgewood observa em um forno que a temperatura está relacionado com a cor da luz emitida por um objeto aquecido.

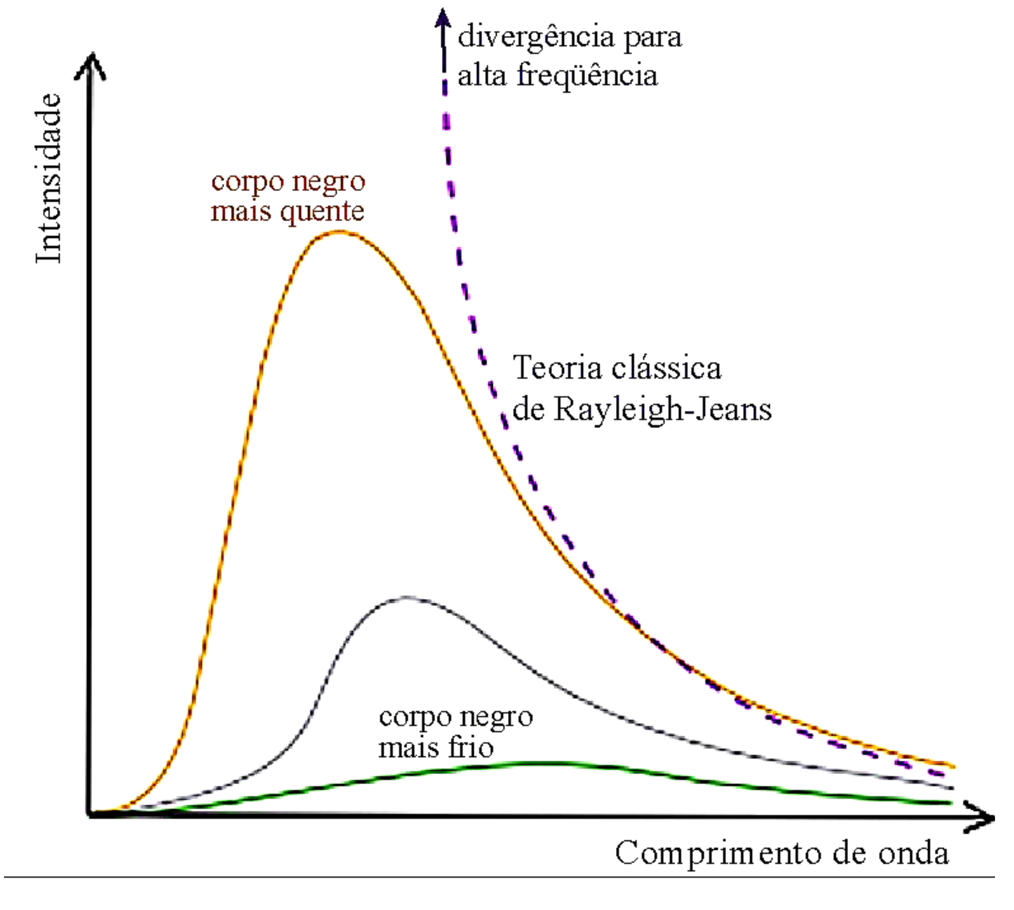
- No final do séc. XIX surge o conceito do corpo negro: um objeto (abstrato) que absorve toda a radiação e não emite nem reflete nada.
  - Na prática o objeto emite radiação e a distribuição desta radiação depende apenas da temperatura do objeto.

- Em 1898, Wilhelm Wien propôs uma lei de distribuição da intensidade da radiação de corpo negro para altas freqüências, mas que falha em comprimento de onda longo.

- Lord Rayleight e James Jeans obtêm uma lei válida para baixa freqüência, mas que leva à "catastrofe do ultravioleta" (diverge para pequenos comprimentos de onda).

Radiação de Corpo Negro

- A teoria clássica do final do século XIX não consegue explicar a radiação do corpo negro

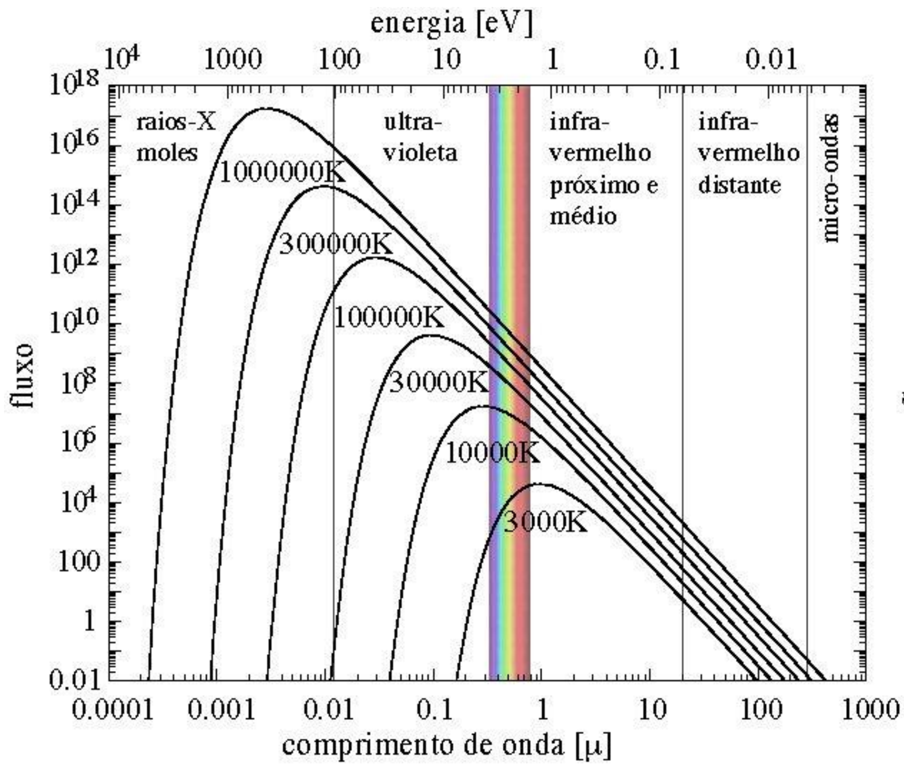


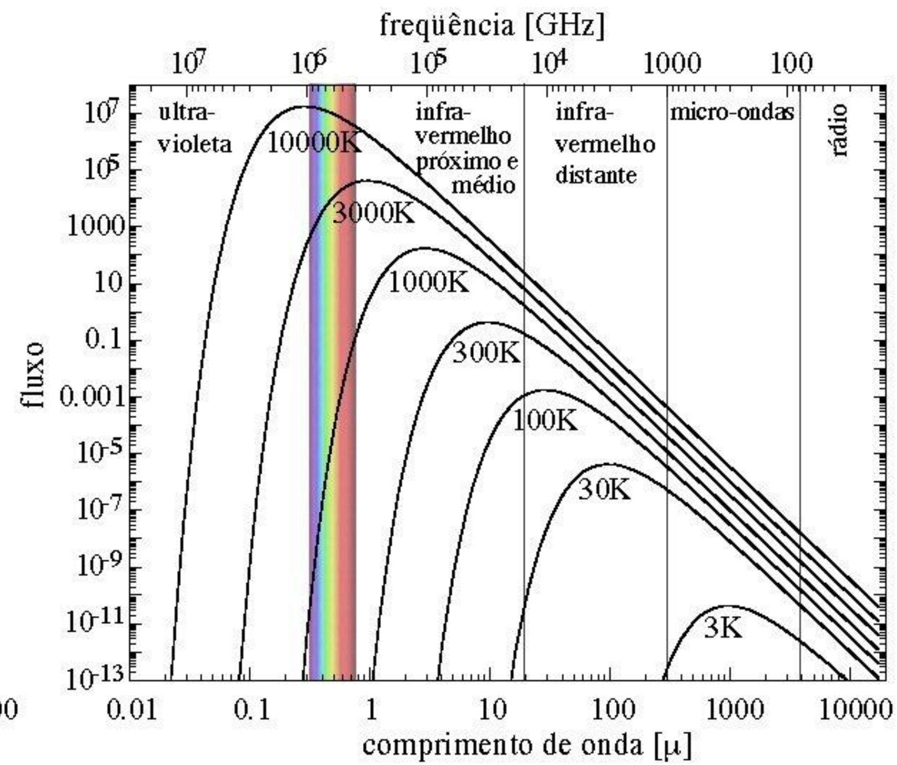
Radiação de Corpo Negro

- Em 1900, utilizando a <u>teoria quântica</u>, Max Plank descobre a distribuição de corpo negro, conhecida como <u>lei de Planck</u>.
- Intensidade, $I(\nu,T)$ corresponde ao <u>espectro de corpo negro</u> para uma dada temperatura.

$$I(\nu,T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}}-1}$$

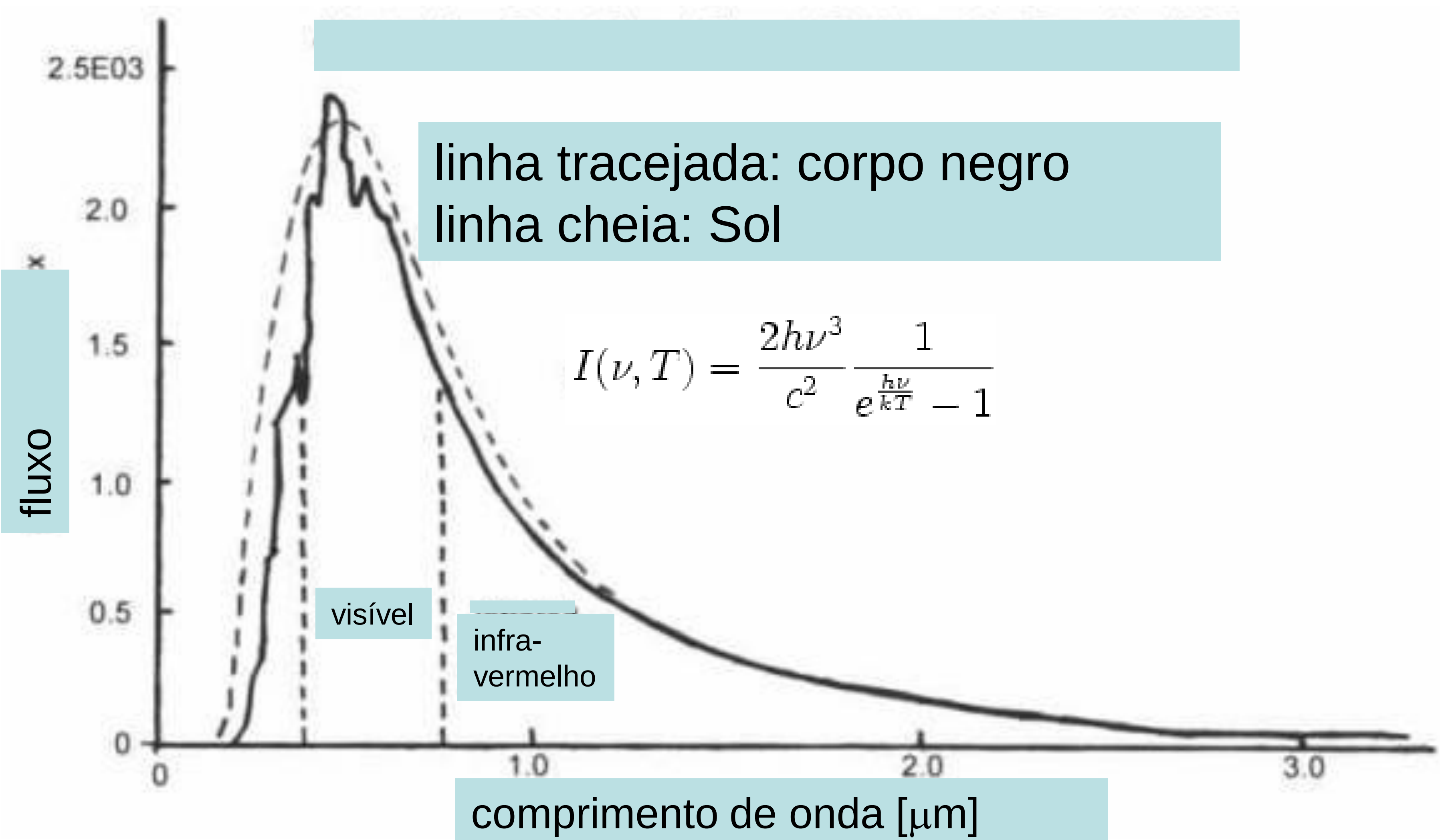
$$I_\lambda = \frac{2\pi hc^2}{\lambda^5(e^{hc/\lambda kt}-1)}$$





Radiação de Corpo Negro

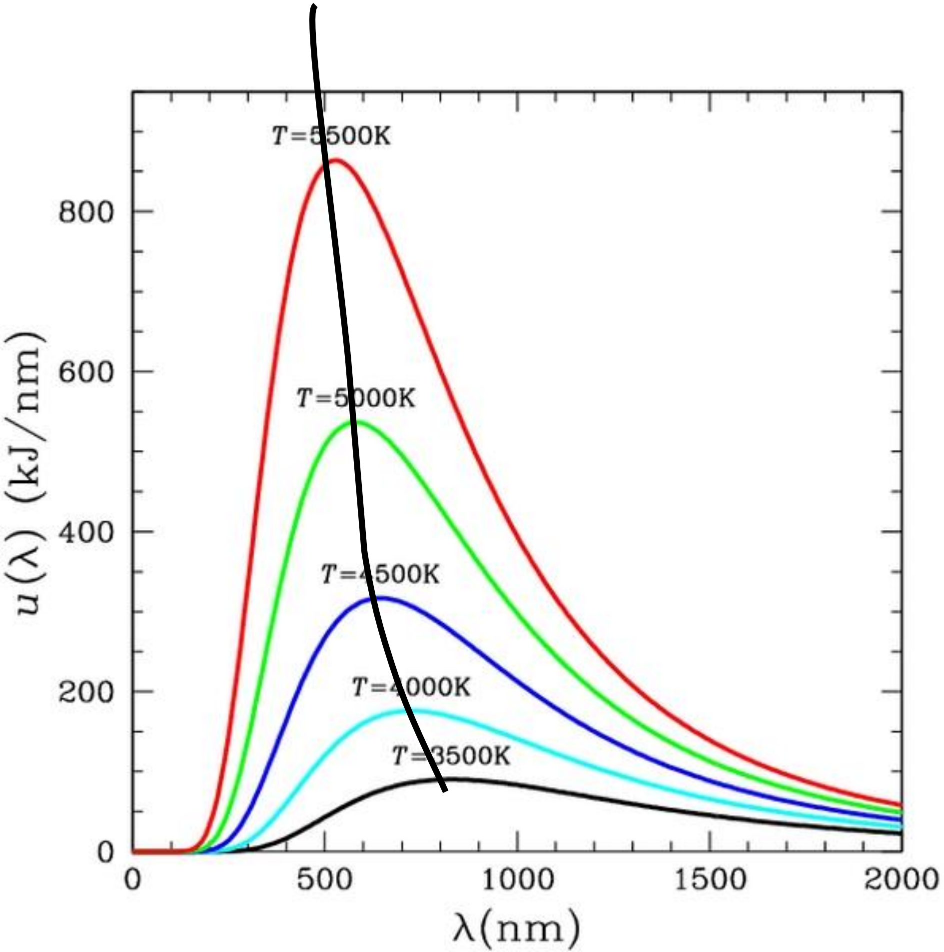
- Estrelas são exemplo de astros “quase corpos negros”.



Radiação de Corpo Negro

- Lei de Wien (descoberta em 1893): relação entre o comprimento de onde a emissão é máxima e a temperatura do corpo negro.

$$T \times \lambda_{max} = 0{,}2898 \ \ \mathrm{K} \times \mathrm{cm}$$



- Por exemplo:
  - T = 50000 K
    λ_{max} = 580 Å
  - T = 5800 K
    λ_{max} = 5000 Å
  - T = 310 K (37°C)
    λ_{max} = 9,3 μ
  - T = 2,7 K
    λ_{max} = 1,1 mm

Radiação de Corpo Negro

- Em 1879, Joseph Stefan descobre empiricamente a relação entre a energia emitida por um corpo negro e sua temperatura
- Em 1884, Ludwig Boltzmann demonstra esta lei.

- Lei de Stefan-Boltzmann: $\varepsilon = \sigma T^4$

ε é a energia emitida por unidade de tempo (potência) por unidade de superfície.

σ ➔ constante de Stefan-Boltzmann: $5{,}67 \times 10^{-8}$ watt m^{-2} K^{-4}

- Por exemplo:
  - T = 5800 K (Sol) ➔ ε = 6417 watt/cm^2 (corresponde p/ o Sol $3{,}9 \times 10^{26}$ watt)
  - T = 310 K (37°C) ➔ ε = 524 watt/metro^2
  - T = 2,7 K (radiação cósmica de fundo) ➔ ε = 3 watt/ km^2 ($6{,}7 \times 10^{48}$ watt p/ RCF)

Radiação de Corpo Negro

- Lei de Stefan-Boltzmann: $\varepsilon = \sigma T^4$

ε é a energia emitida (potência) por unidade de superfície.

σ ➔ constante de Stefan-Boltzmann
$= 5{,}67 \times 10^{-8}$ watt m^{-2} K^{-4}

- Luminosidade: $L = 4\pi R^2 \sigma T^4$

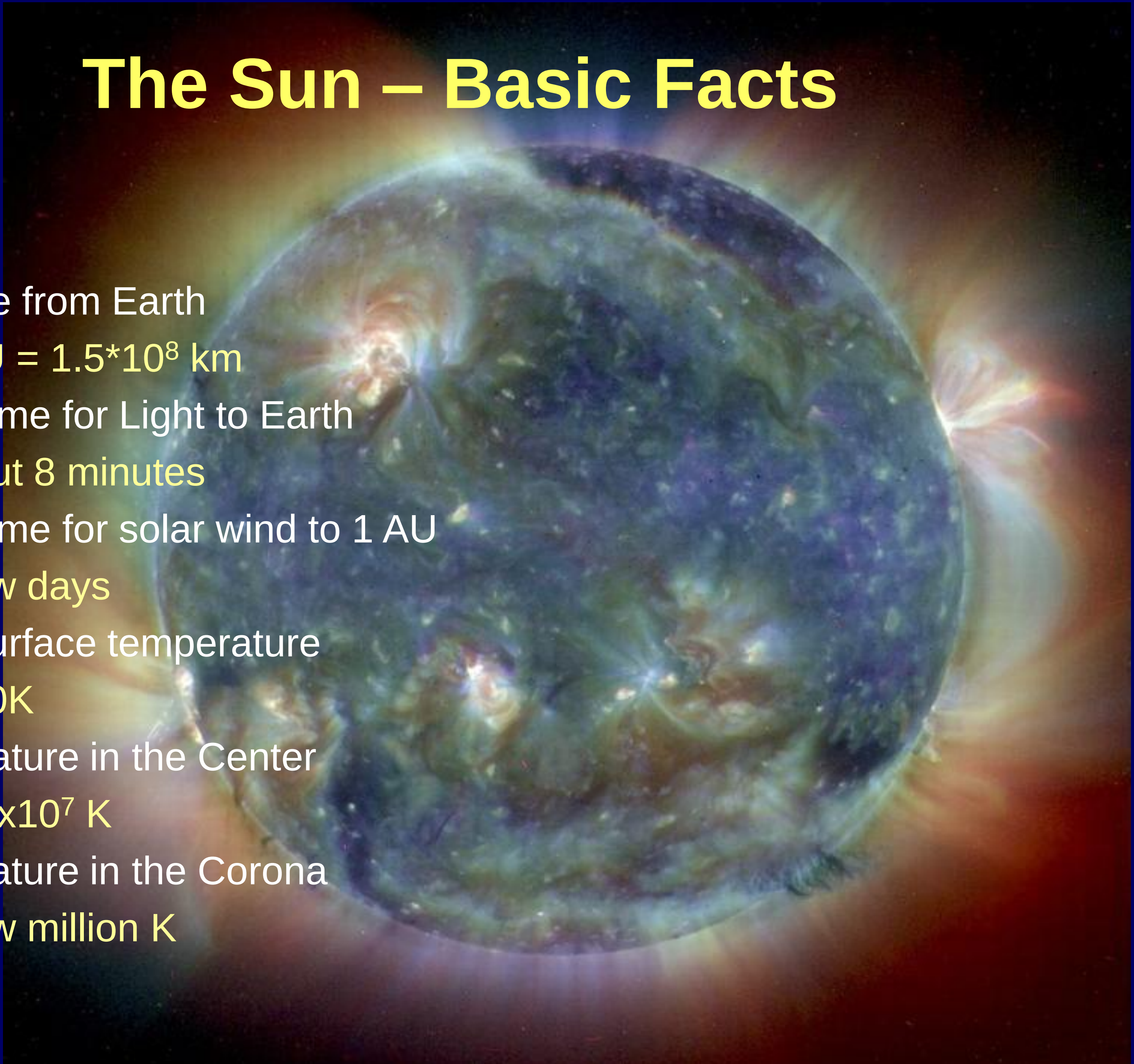
Temperatura efetiva do Sol: T=5.875 K

The Sun

- ~4.6 billion years old
- G2 class star (~8% of stars are G class) based on photospheric (stellar surface) temperature
- >100 million stars are of the same class in our galaxy
- Not only supports almost all life on Earth via photosynthesis but also drives the Earth's climate and weather

The Sun – Basic Facts

- Distance from Earth
  - 1 AU = $1.5*10^8$ km
- Travel time for Light to Earth
  - About 8 minutes
- Travel time for solar wind to 1 AU
  - A few days
- Mean surface temperature
  - 5800K
- Temperature in the Center
  - $1.55x10^7$ K
- Temperature in the Corona
  - A few million K



The Sun – Basic Facts

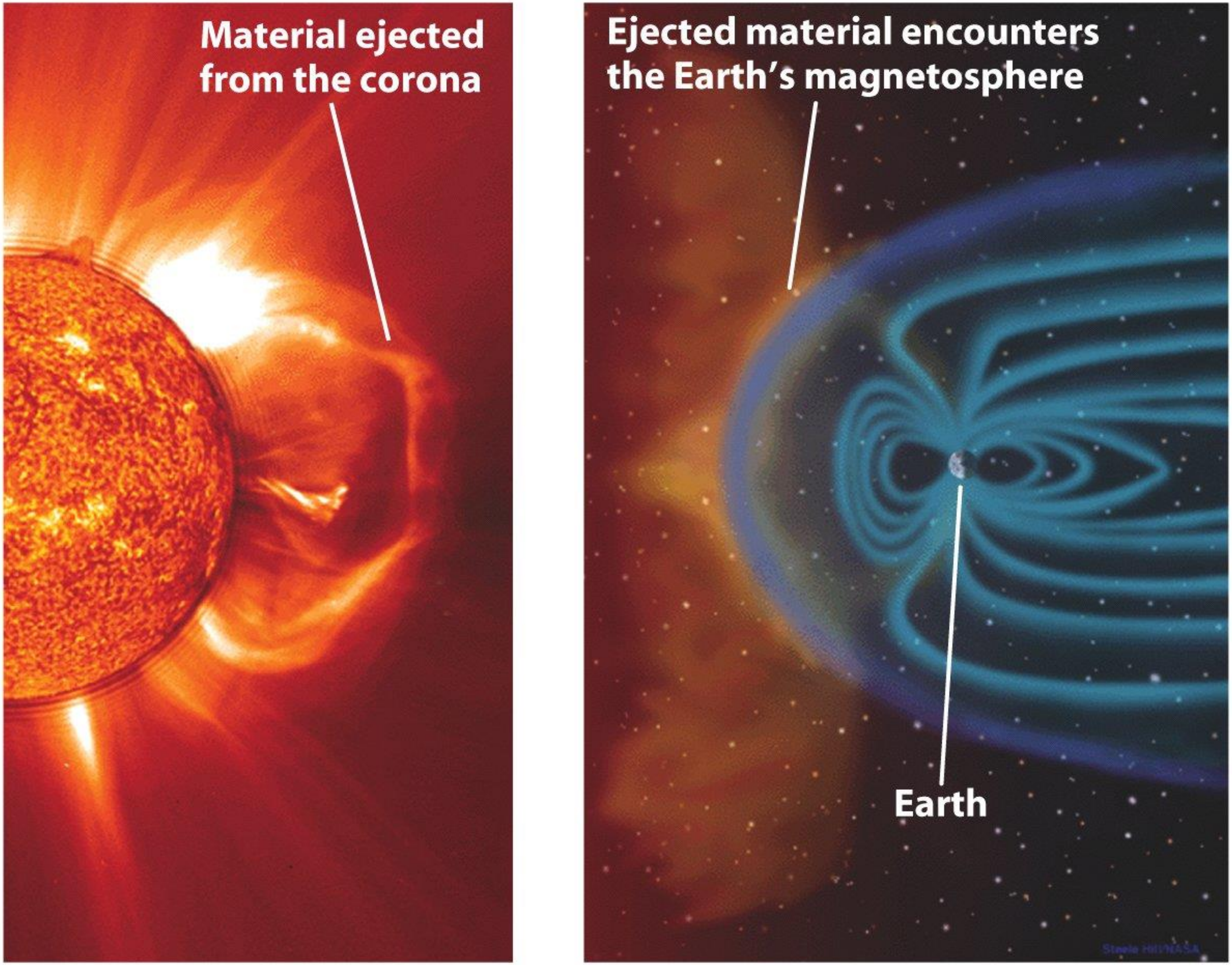
- Mass
  - 333,000 Earth Masses
  - 99% mass of the Solar system
- Diameter
  - 103 Earth Diameters
- Average Density
  - 1410 kg/m^3
- Composition (by mass)
  - 74% Hydrogen, 25% Helium, 1% other elements

How does the Sun Influence Earth?

- Provides the energy that creates life, warms the planet, drives the dynamic atmosphere and oceans. UV light can cause mutations.

- Geomagnetic storms
  - Aurora
  - Power-grid failures (Canada, 1989); Telecommunications failures

- High-energy solar particles
  - can destroy ozone
  - lethal radiation dosages to astronauts and passengers/pilots on polar air-travel routes

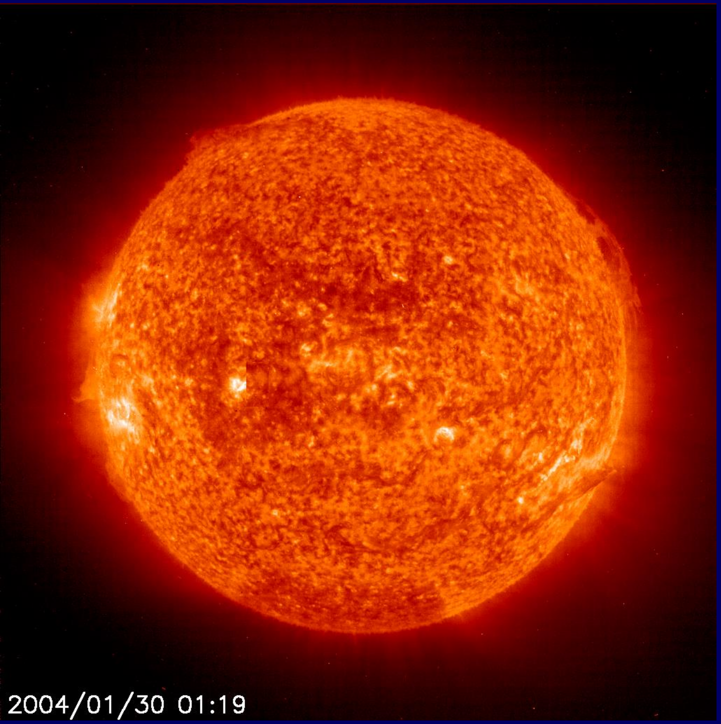


(a) A coronal mass ejection **(b)** Two to four days later

Solar energy
from hydrogen fusion

Solar Radiation

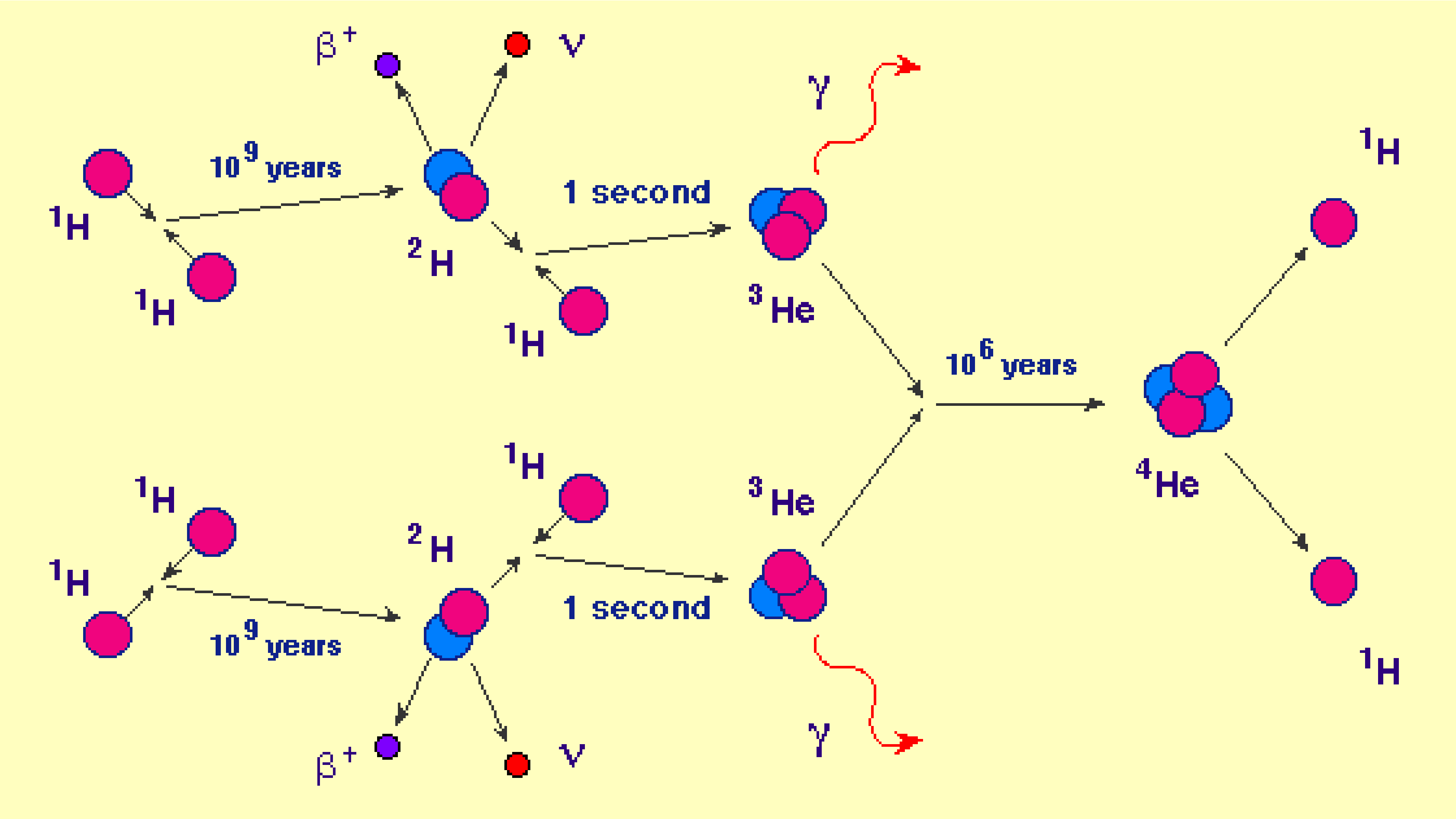
Photosynthesis



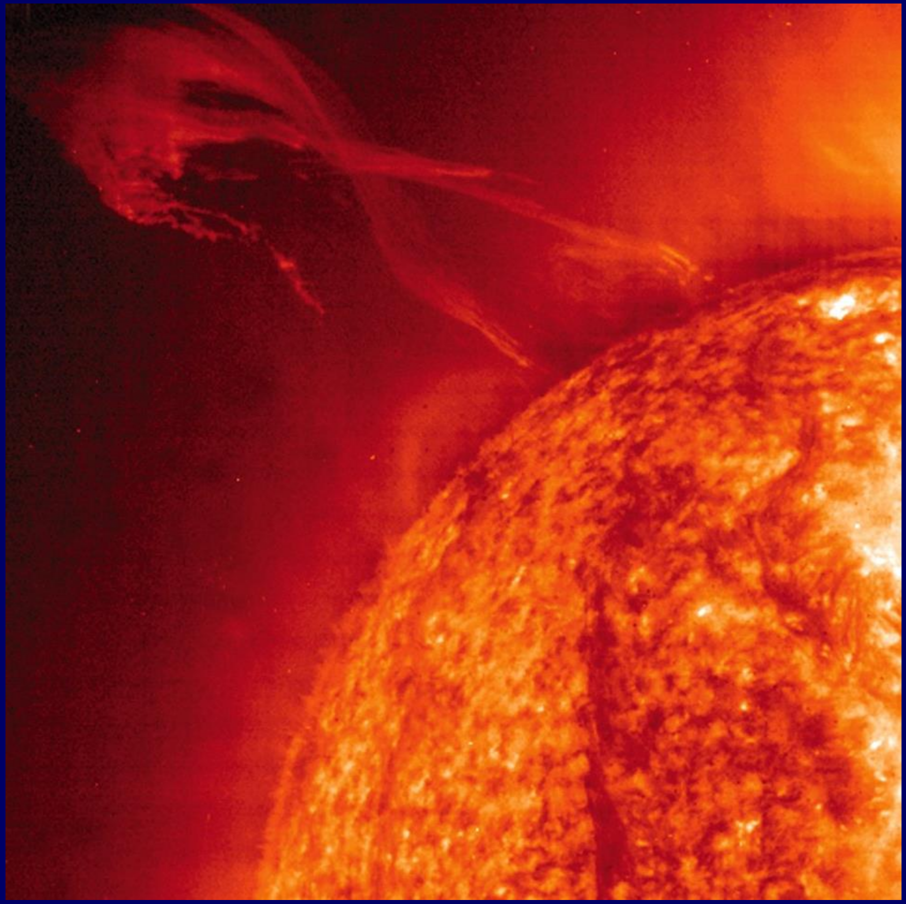
Climate

- Sun is in a hydrostatic balance – neither expands nor shrinks
- Gravitational force is balanced by the energy from thermonuclear fusion

Proton-Proton chain



The Sun's Energy Source is Thermonuclear Fusion in its Core

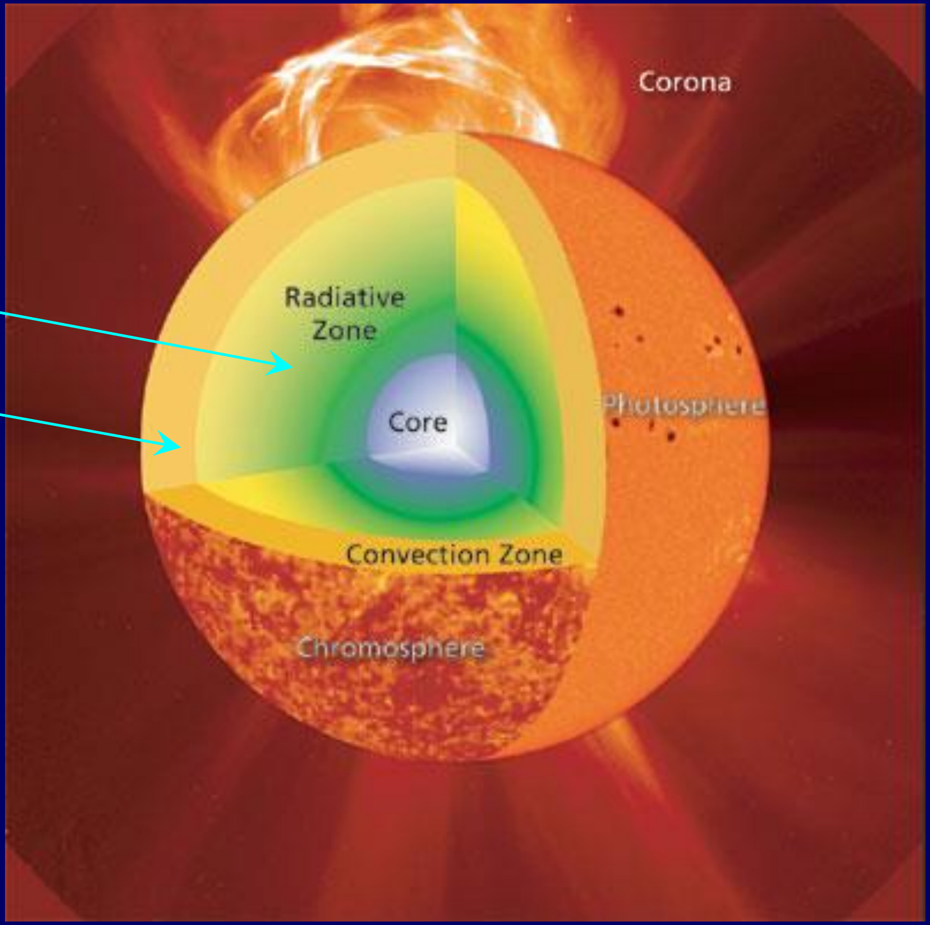


- Proton-proton chain
  - Four hydrogen nuclei "fuse" to form a single helium nucleus
- Thermonuclear fusion occurs only at the very high temperatures at the Sun's core
- Will continue to heat the Sun for another 5 billion years

The Structure of the Sun

- The Interior
  - Core (0.2 Solar radii)
  - Radiative zone
  (0.2-0.7 Solar radii)
  - Convection zone

- The Surface and Atmosphere
  - Photosphere
  - Chromosphere
  - corona



The Solar Constant

- Solar Luminosity
  - Total energy emitted by the Sun per second
  - L = 3.9 x 10^{26} W = 3.9 x 10^{26} Joules/sec

One Joule is the work done, or energy expended, by a force of one Newton (N) moving an object one meter along the direction of the force

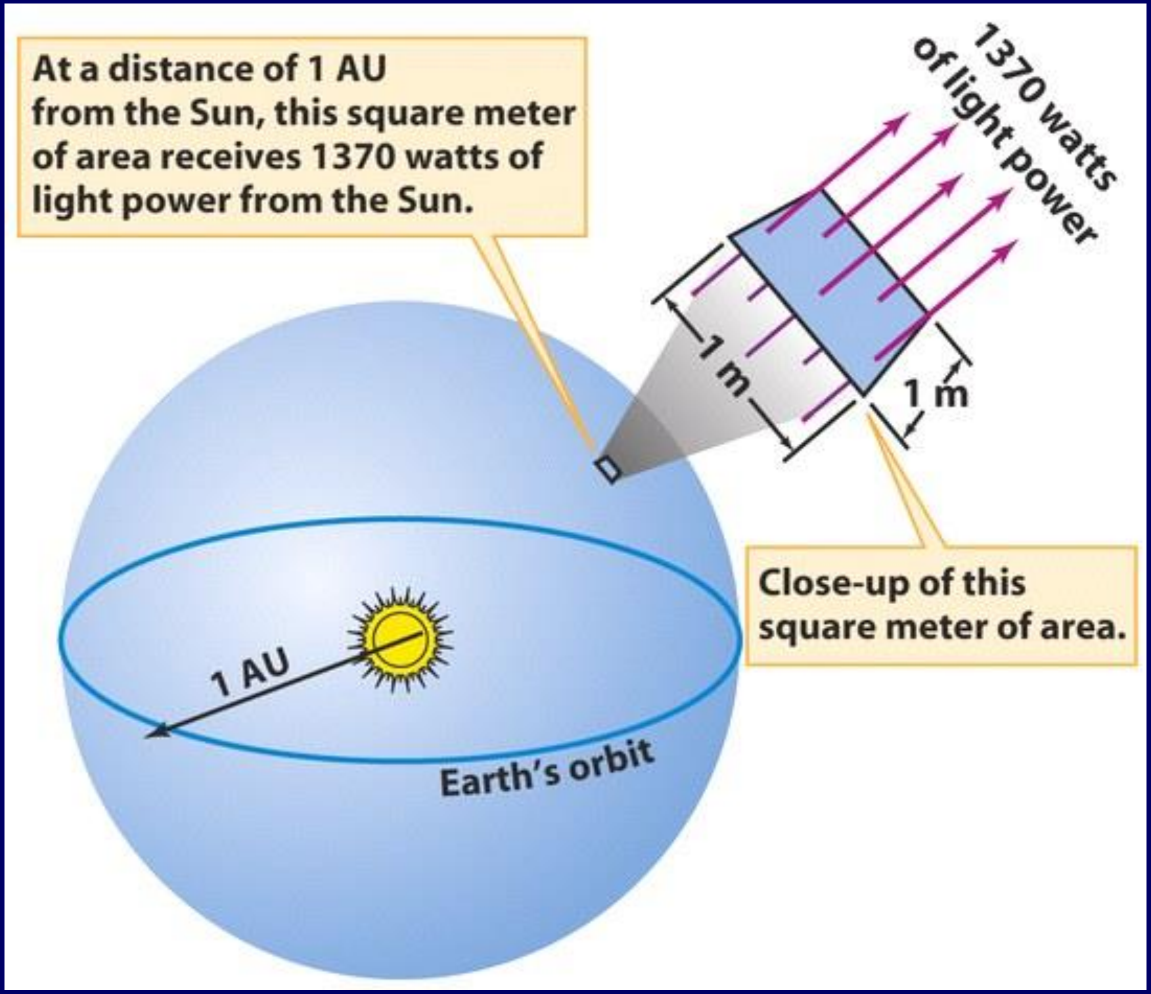
The force of Earth's gravity on a 100 kg human is about 1000 N

- 1 Calorie (1 cal) = 4,184 J
- 1 "Calorie" (food energy) = 1 kcal
- 1 gram TNT (trinitrotoluene) = 4184 J

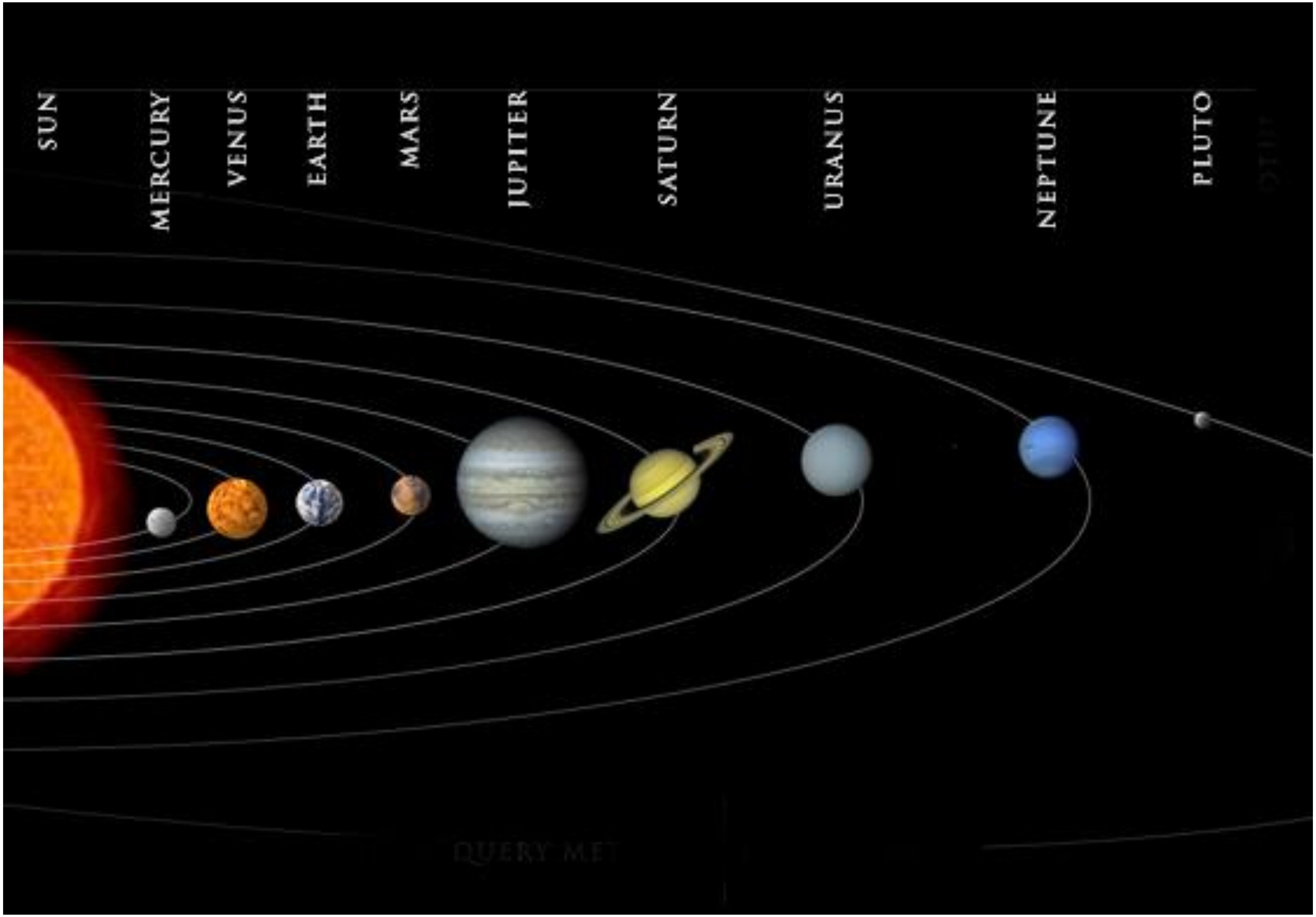
The solar constant

- Solar Flux
  - Luminosity divided by the area (the amount of energy per sec per area)
- Solar Constant
  - Solar Flux at the Earth's orbit $R_{earth\text{-}orbit} = 1.5 \times 10^8$ km
  - $L/(4\pi \times (R_{earth\text{-}orbit})^2) = \ldots.$

The solar constant

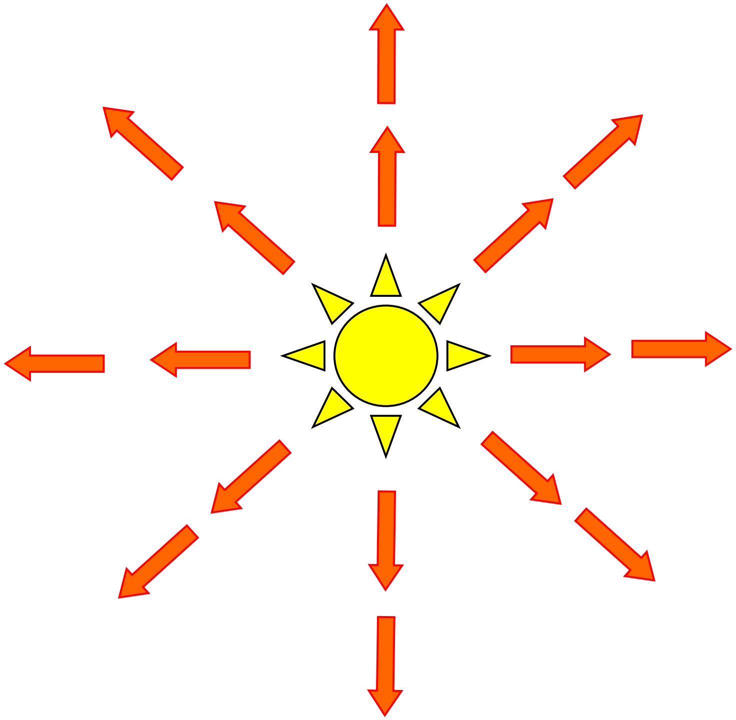


Each planet has its own solar constant…

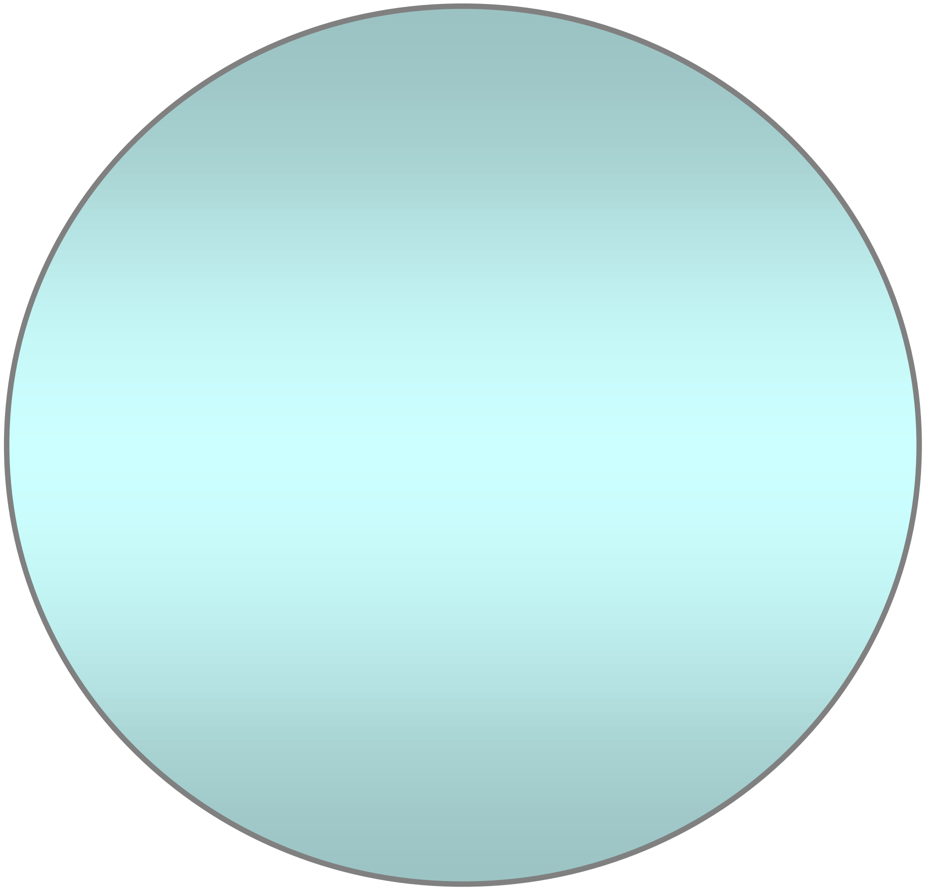


As energy moves away from the sun, it is spread over a greater and greater area.

➡ This is the Inverse Square Law

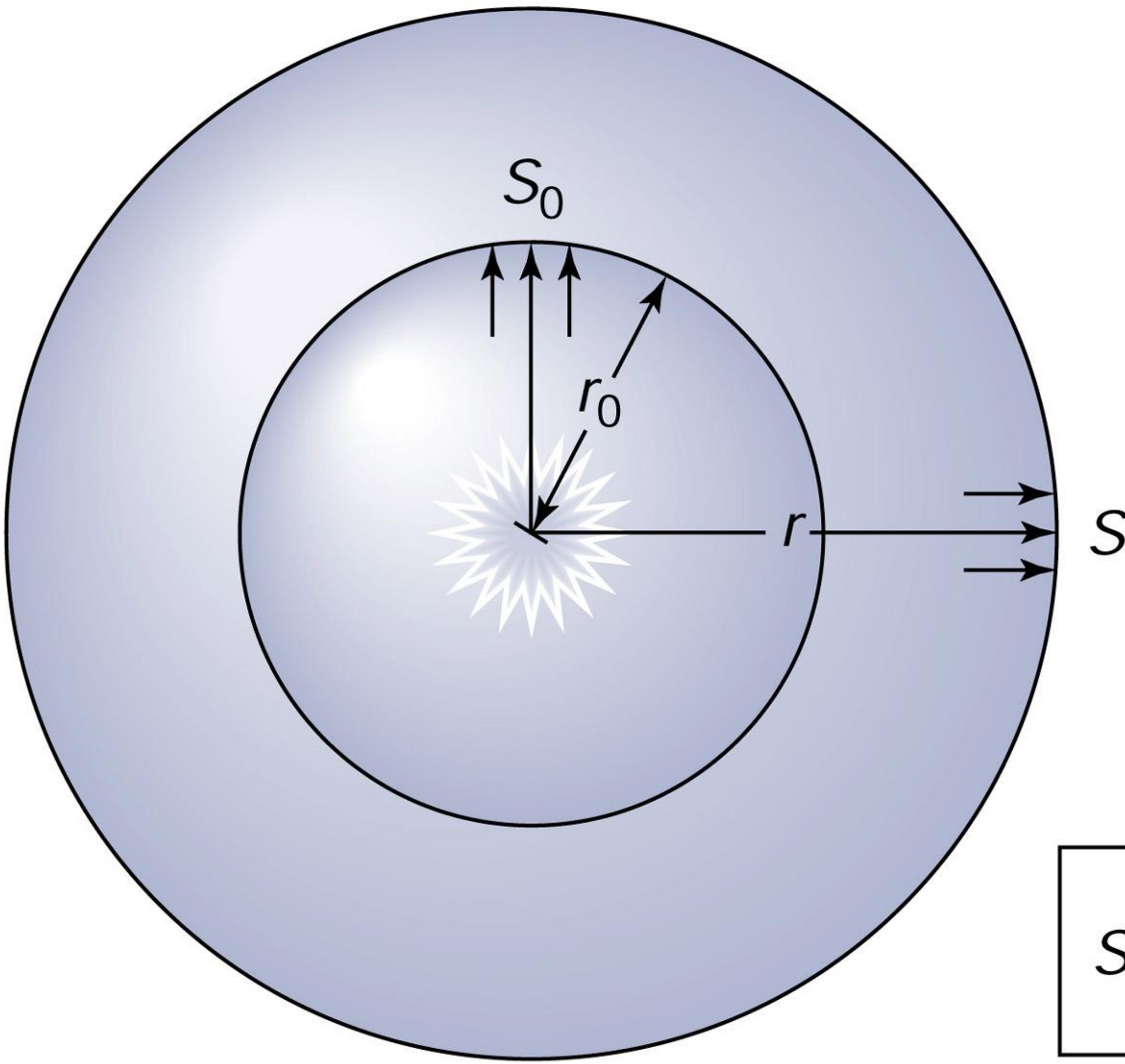


Some Basic Information:



Area of a circle = πr^2

Area of a sphere = $4 \pi r^2$



$$S = S_0\left(\frac{r_0}{r}\right)^2$$

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$S_{Earth} = S_0 = 1370\ W/m^2$

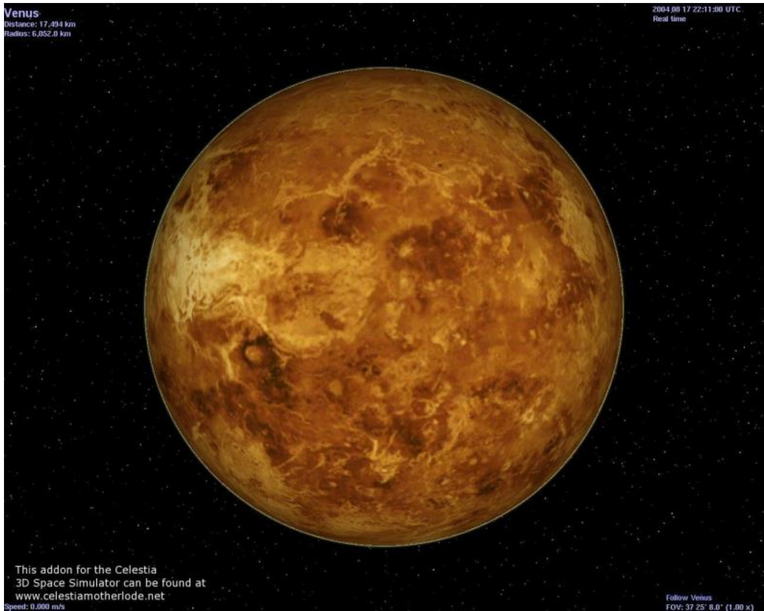
Mars

$S_{Mars} = ?$ $R_{Mars\ orbit} = 1.52\ AU$

$S_{Venus} = ?$ $R_{Venus\ orbit} = 0.72\ AU$

$S_{Jupiter} = ?$ $R_{Jupiter\ orbit} = 5.2\ AU$

Venus



$S_{Venus} = 2642.8 \text{ W/m}^2$ at Venus orbit

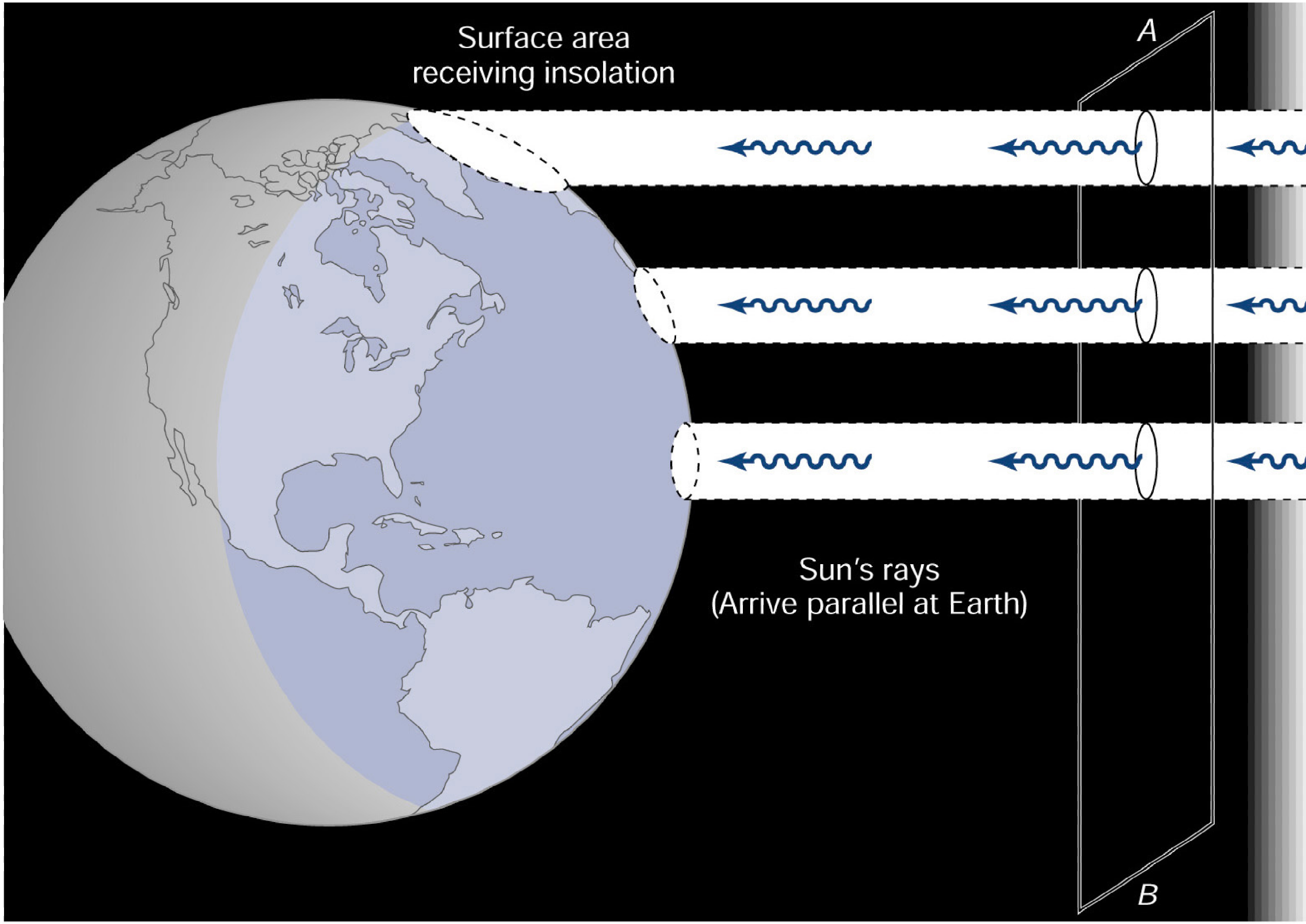
$S_{Earth} = 1370 \text{ W/m}^2$ at Earth orbit

$S_{Mars} = 593.0 \text{ W/m}^2$ at Mars orbit

$S_{Jupiter} = 50.7 \text{ W/m}^2$ at Jupiter orbit

Equator vs. Poles

- Earth is spherical
- The same solar beam would “cover” different areas in the equatorial and polar regions
- Polar regions would always get less solar flux than equatorial regions



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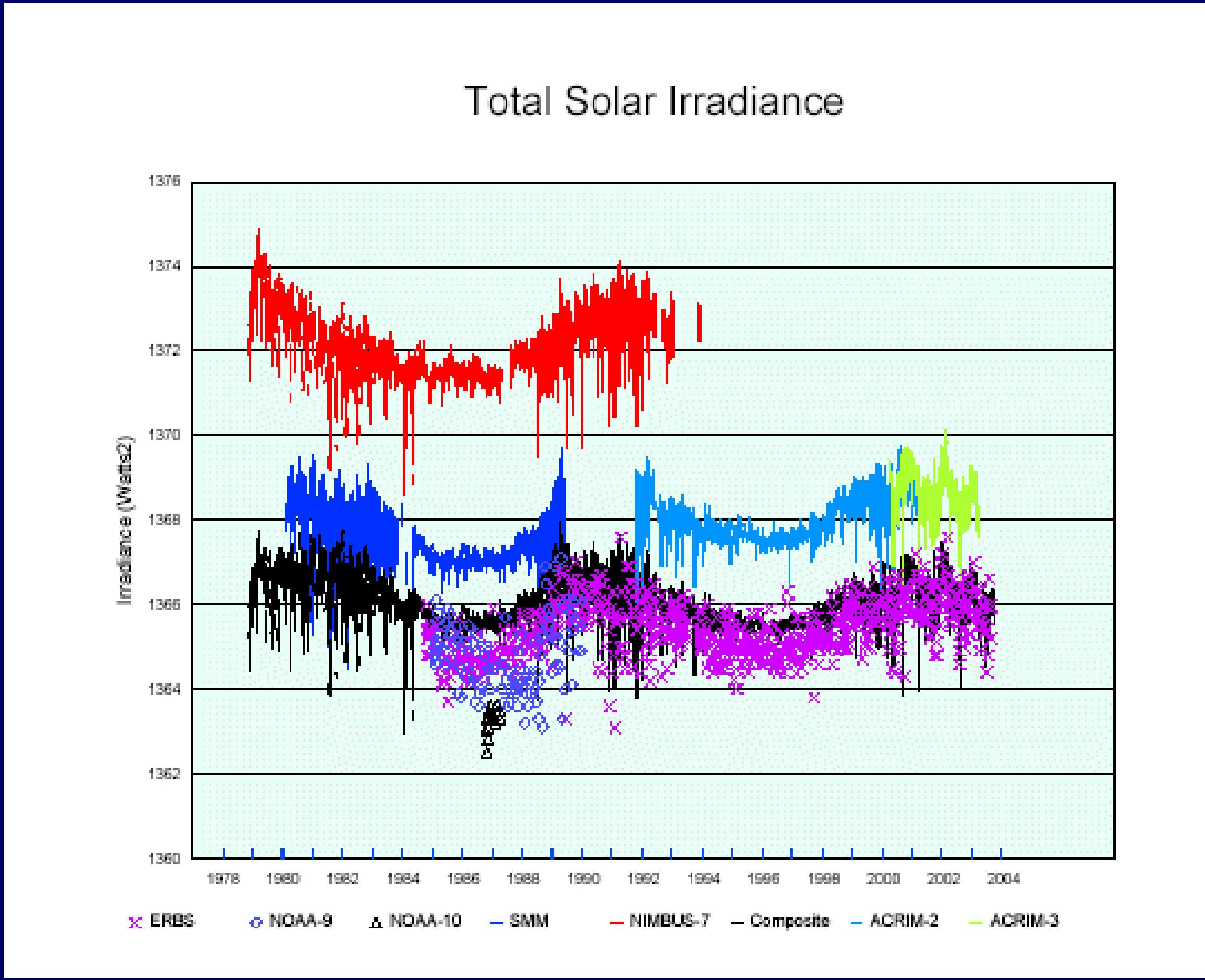
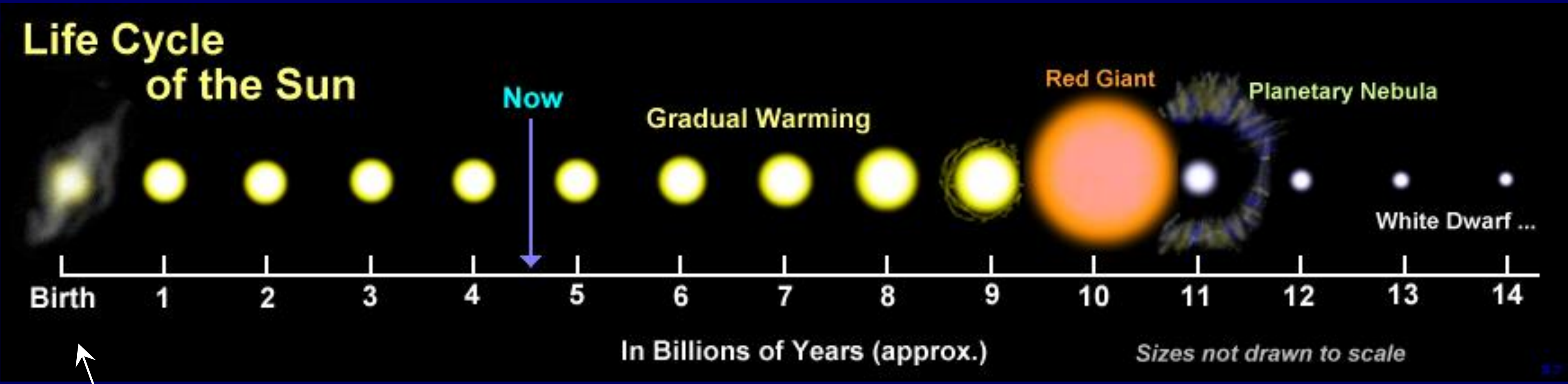
But the Sun is not really constant !

- Solar luminosity varies
- What causes this variability is an active area of research



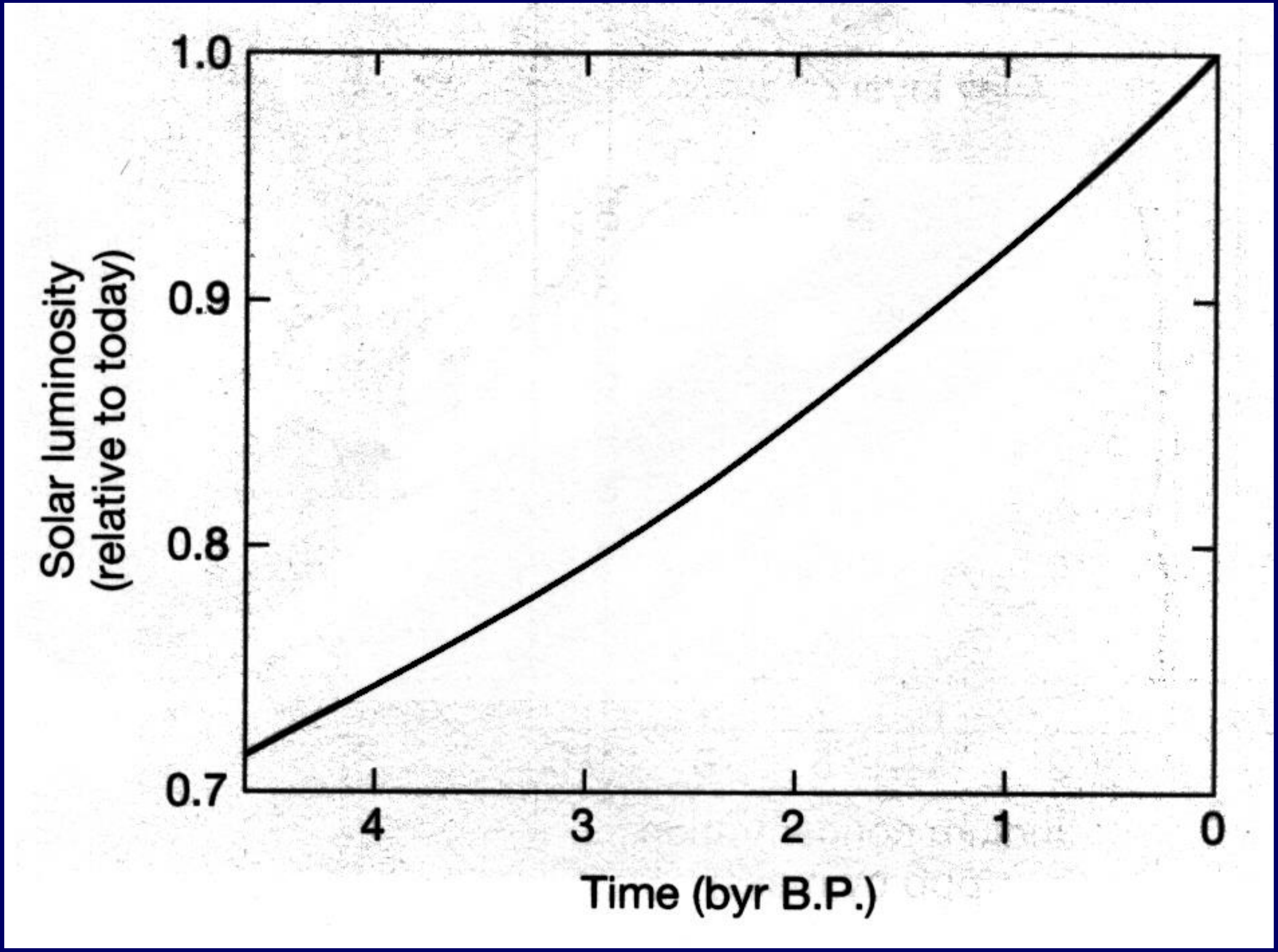
Solar Evolution



Collapse of the hydrogen molecular cloud

Earth will be likely destroyed

Solar Luminosity versus Time

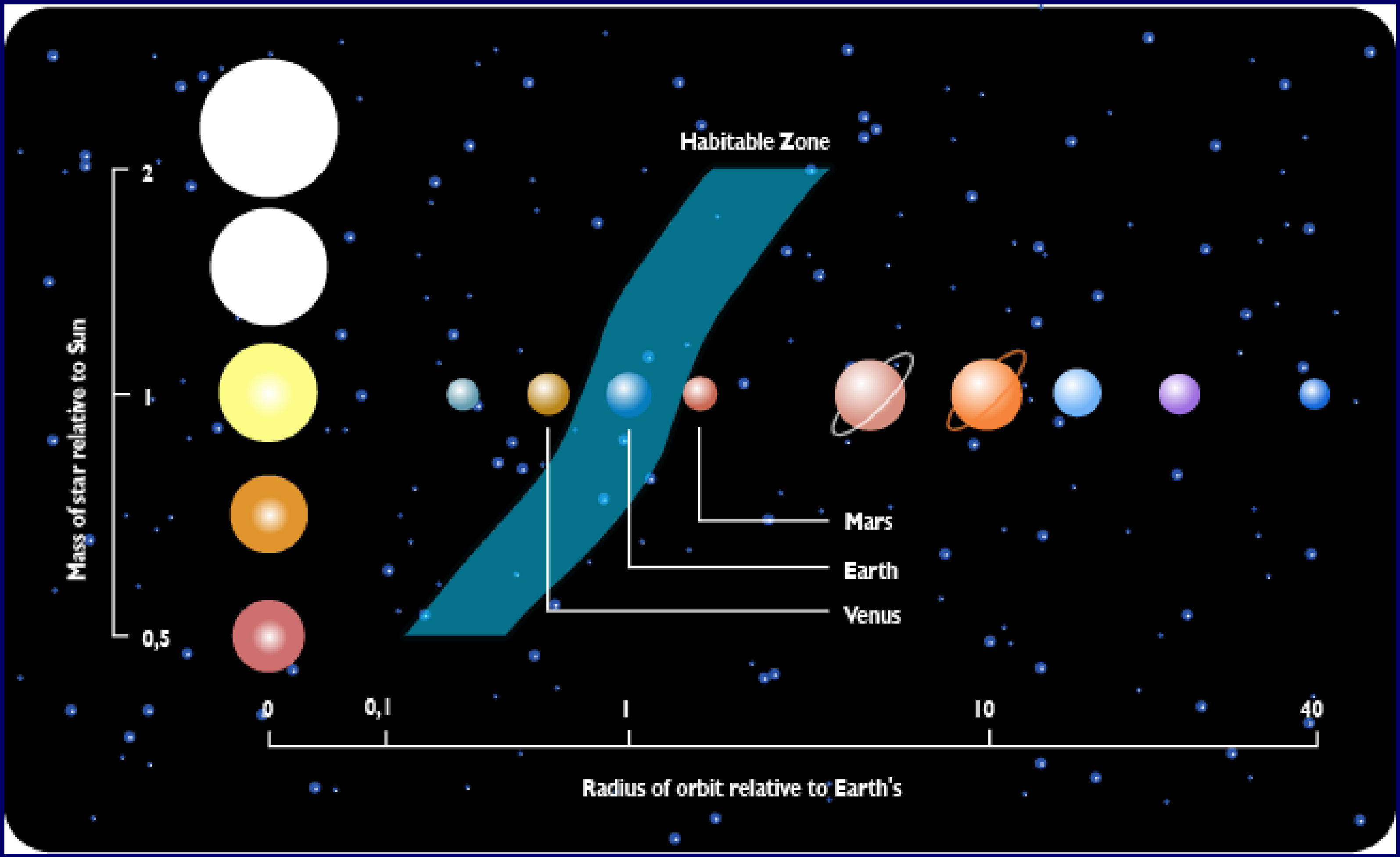


Faint Young Sun is important for climate. Not so critical for photosynthesis.

Why the Sun gets brighter with time.

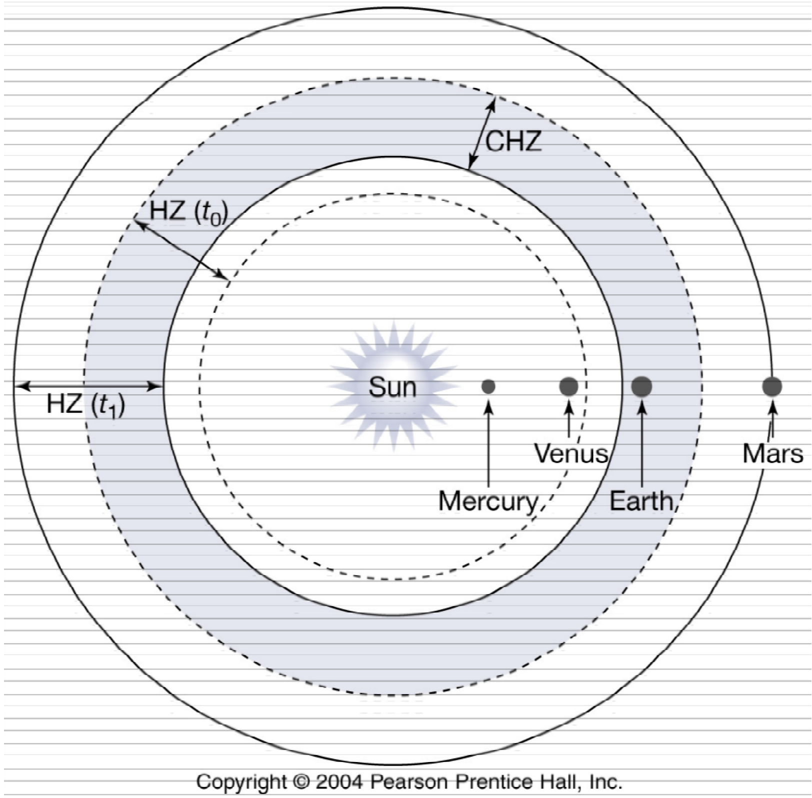
- H fuses to form He in the core
- Core becomes denser
- Core contracts and heats up
- Fusion reactions proceed faster
- More energy is produced $\Rightarrow$ more energy needs to be emitted

The boundaries of the Habitable Zone evolve with time



Continuous Habitable Zone (CHZ)

- A region, in which a planet may reside and maintain liquid water throughout most of a star's life.



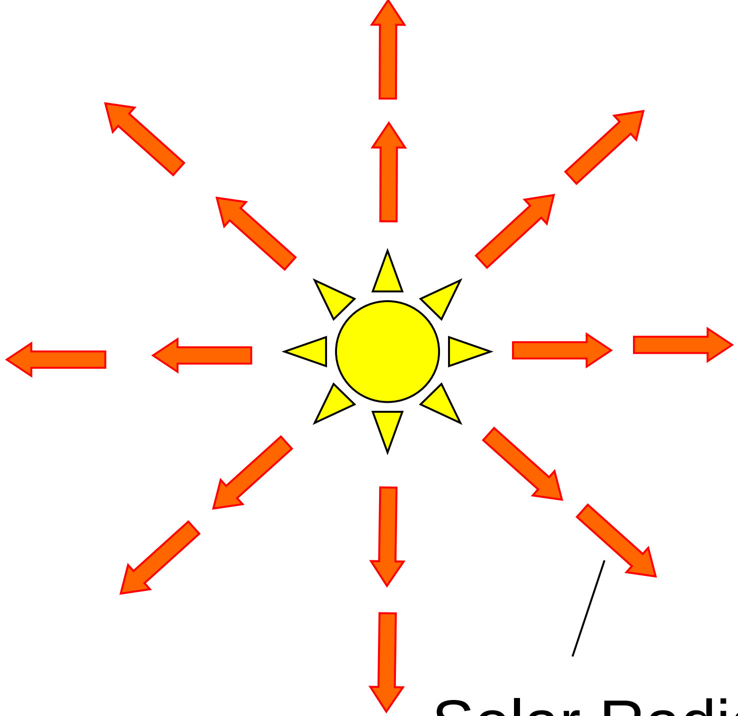
Sun as an energy source

- Sun is the main source of energy on the Earth’s surface
- Sun produces energy through thermonuclear fusion in the core
- The solar surface (photosphere) emits this energy in the form of electromagnetic waves (mostly at visible wavelengths)

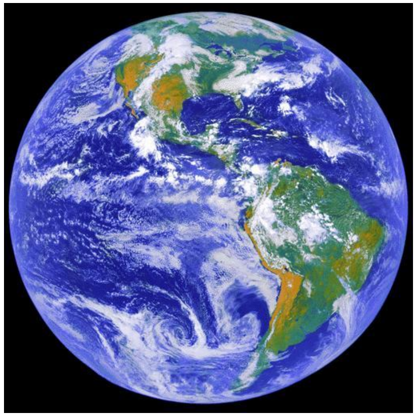
Sun as an energy source

- Solar flux decreases as radiation spreads out away from the Sun
- Planets are exposed to some small amount of the total solar radiation
- A small portion of that radiation can be used for photosynthesis
- Other biota can eat energy-rich organic molecules from photoautotrophs or each other.

Energy/food chain



Solar Radiation



Photosynthesis

Respiration

Other sources of energy.

- Earth is geologically active
- Earthquakes, Volcanoes and slow motion of the continents (plate tectonics) do not depend on the energy from the Sun
- There should internal heat source!
- The heat provides energy for chemosynthesis instead of photosynthesis

Storing of energy by life

- Photosynthesis

- Oxygenic:

$6CO_2 + 6H_2O + h\nu \text{ (Energy)} \rightarrow C_6H_{12}O_6 + 6O_2$

- Anoxygenic

$CO_2 + 2H_2S + h\nu \text{ (Energy)} \rightarrow CH_2O + 2S + H_2O$

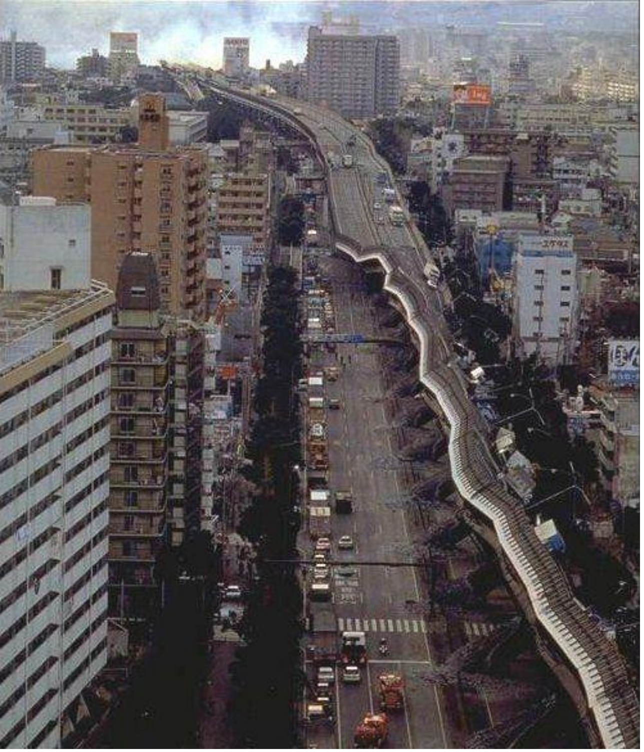
- Chemosynthesis

- Methanogenesis

$CO_2 + 4\ H_2 \rightarrow CH_4 + 2H_2O + \text{Energy}$

- Sulfate reduction

$4H_2 + SO_4^{2-} \rightarrow S^{2-} + 4H_2O + \text{Energy}$



Earquakes

Volcanoes

Source of energy in the Earth's interior?

- Nuclear heating
  - Radioactive decay (dominant)
- Gravitational Heating
  - Heat from accretion
  - Heat released from Earth's differentiation
  - Tidal heating (negligible for Earth)

Nuclear Energy

Radioactive decay

- **Radioactive decay** is the process in which an unstable *atomic nucleus* loses energy in the form of particles or electromagnetic waves and transforms towards a more stable *nucleus*.
- Example:
- $^{239}Pu \rightarrow {}^{235}U + {}^{4}He$

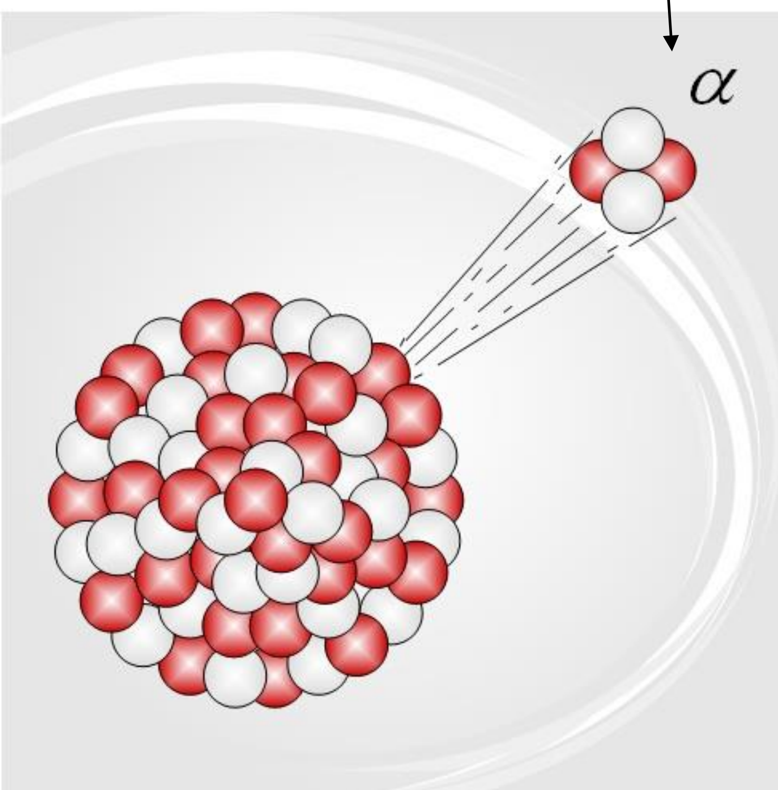
used in weapons

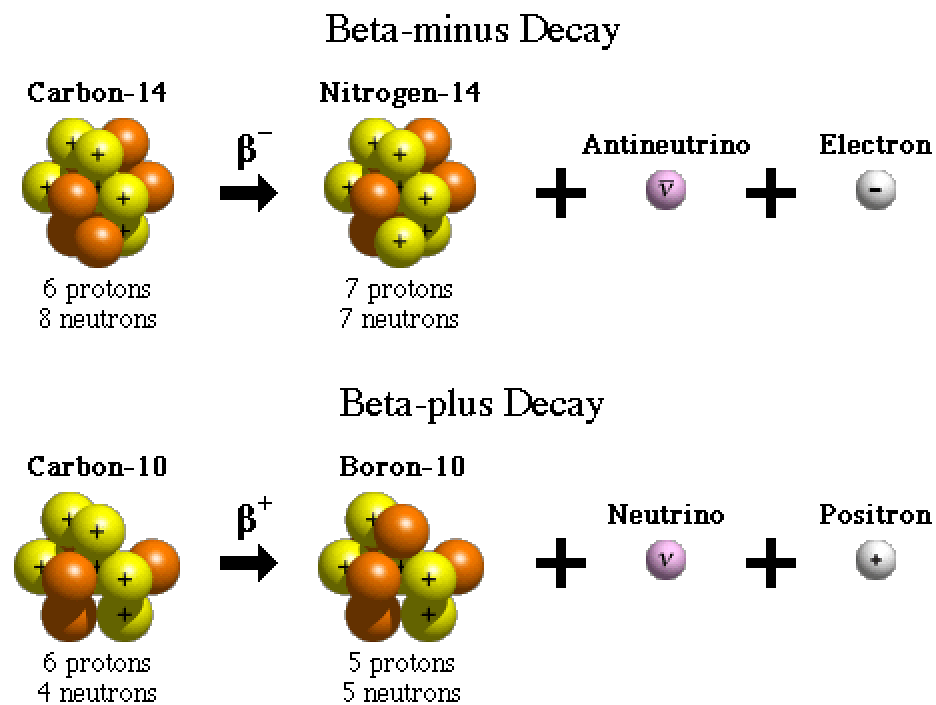
$$^{238}U \rightarrow {}^{234}Th + {}^{4}He$$

Very energetic!
Speed ~16,000 km/s

α-decay

β-decay

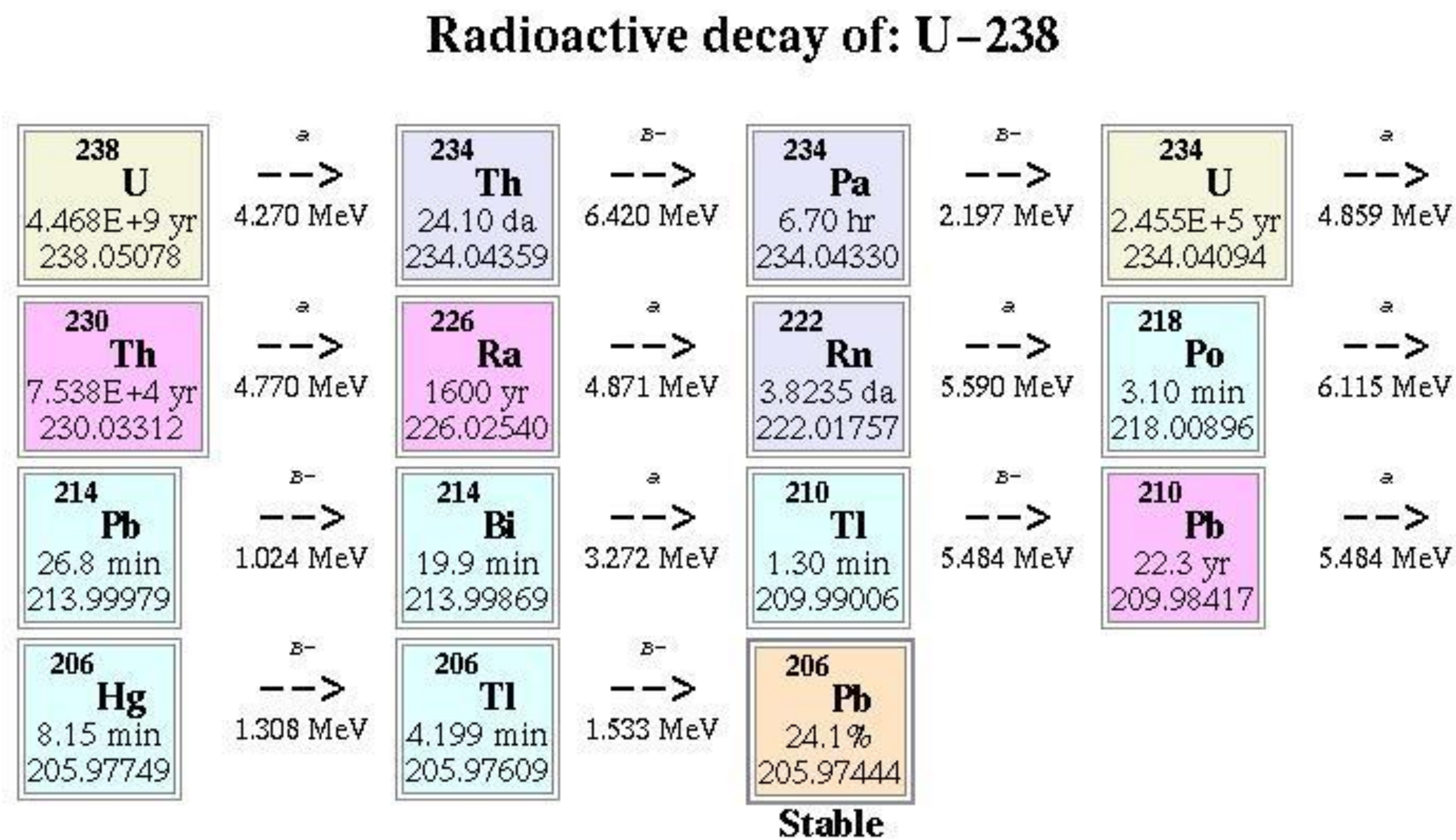




Radioactivity on Earth

- Earth rocks has some amount of Uranium (and other radioactive elements - potassium)
- Uranium can spontaneously decay to Thorium and eventually to Lead (stable)
- Energy is released during radioactive decay

In reality ^{238}U decay happens in a number of steps

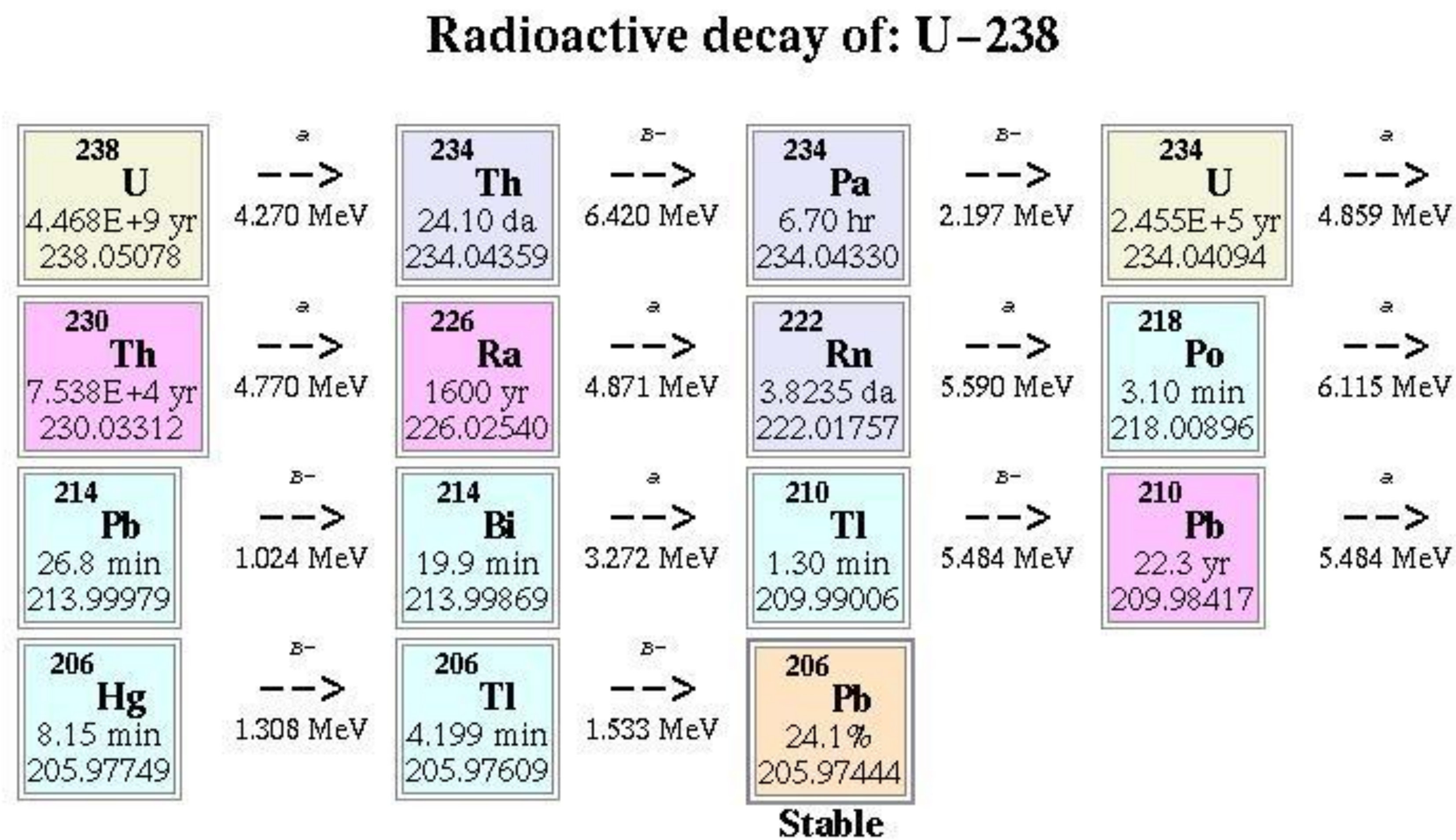


Decay of ^{238}U to ^{234}Th takes the longest period of time.
It takes 4.468 billion years to convert half of ^{238}U to ^{234}Th!

Present-day major heat-producing isotopes

Isotope	Heat release [W/kg isotope]	Half-life [years]	Mean mantle concentration [mass fraction]	Heat release [W/kg mantle]
^{238}U	9.46×10^{-5}	4.47×10^{9}	30.8×10^{-9}	2.91×10^{-12}
^{235}U	5.69×10^{-4}	7.04×10^{8}	0.22×10^{-9}	1.25×10^{-13}
^{232}Th	2.64×10^{-5}	1.40×10^{10}	124×10^{-9}	3.27×10^{-12}
^{40}K	2.92×10^{-5}	1.25×10^{9}	36.9×10^{-9}	1.08×10^{-12}

In reality ^{238}U decay happens in a number of steps



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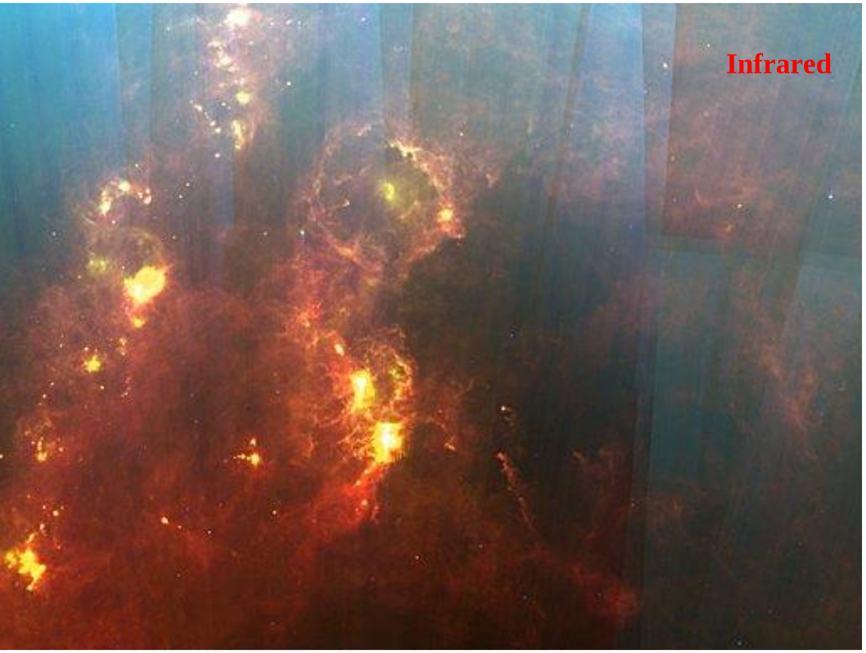
Gravitational Energy

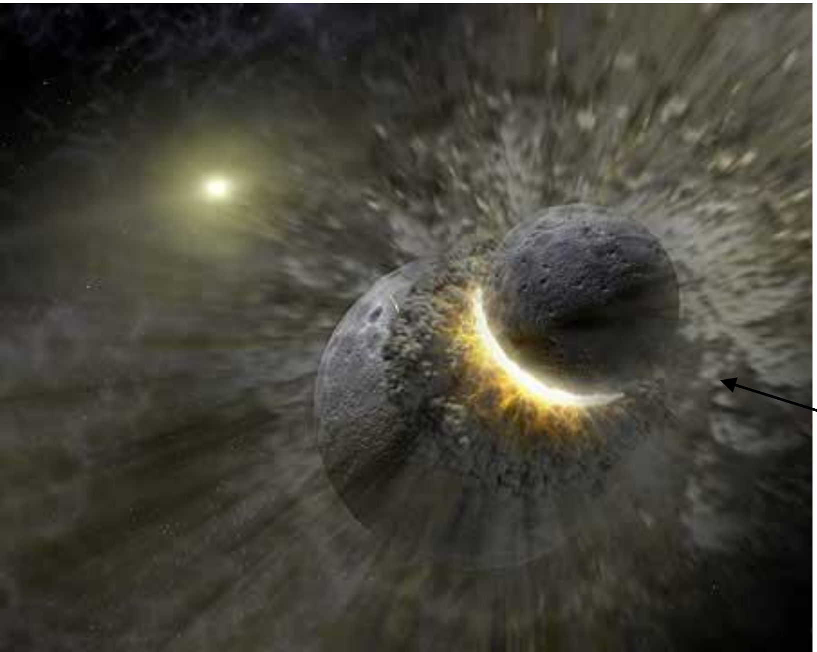
Internal heat from accretion.

- Nebular hypotheis: The solar system formed from a collapse of the giant molecular cloud
- Due to some trigger (supernova) a specific region of the cloud became denser
- Due to gravity that region started to attract more and more hydrogen
- Eventually in a specific region of the cloud the density of hydrogen became high enough to start thermonuclear reactions – Sun.



Giant Molecular Cloud

- Remaining dust and grains grew to clumps (diameter ~10 meters)
- Clumps grew into planetesimals (diameter ~5 km)
- Planetesimals grew into planets
- Tremendous amount of energy was released when planetesimals ran into each other – accretion



Accretion (continued)

- We still see the evidence of such collisions on the surface of the Moon
- There are a few craters on the Earth’s surface as well

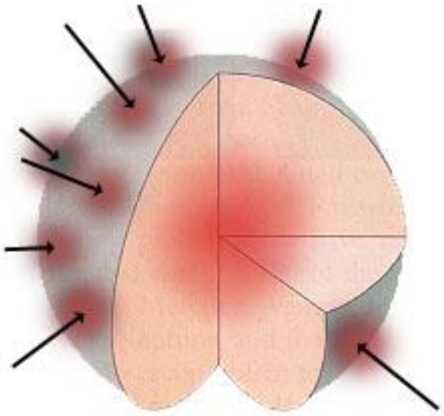
How much energy is in an impactor?

- Let’s consider an impactor with radius ~10 km which collides with Earth at 20 km/sec
- How much energy it will release?
- Density 3 g/cm^3 = 3000 kg/m^3
- M = Density* (4/3) *π*R^3
- E(Kinetic) = M*V^2/2
- Convert (J) to grams of TNT using

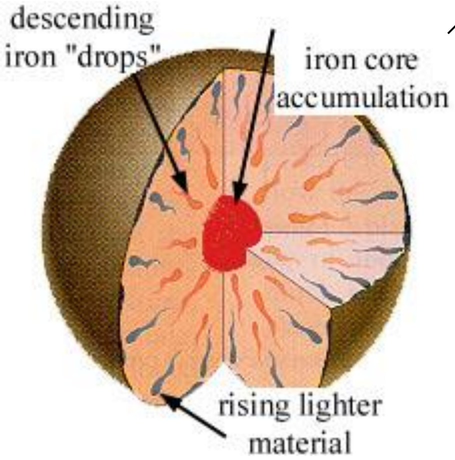
1 gram TNT (trinitrotoluene) = 4184 J

E (gram TNT) = …???

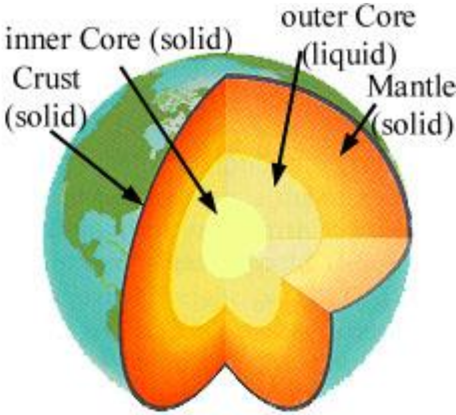
Internal energy from differentiation



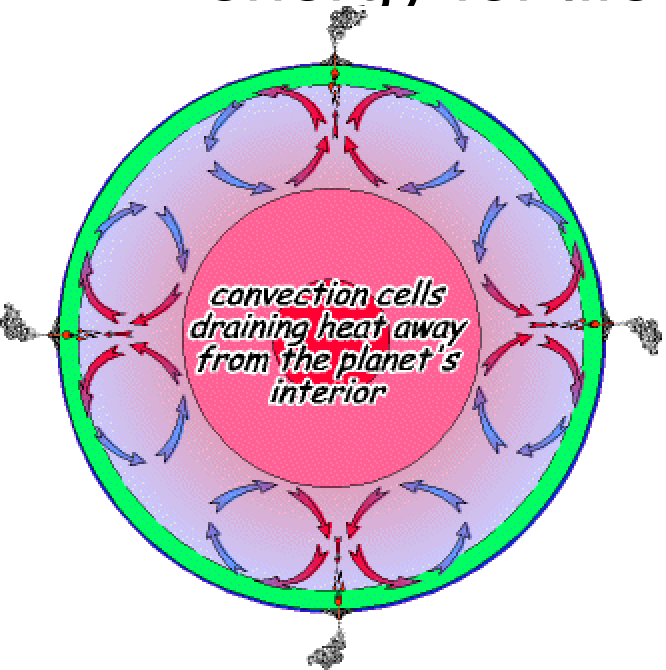
Early Earth heats up due to radio-
active decay and impacts. Over time the temperature of the planet interior rises towards the Fe-melting temperatures



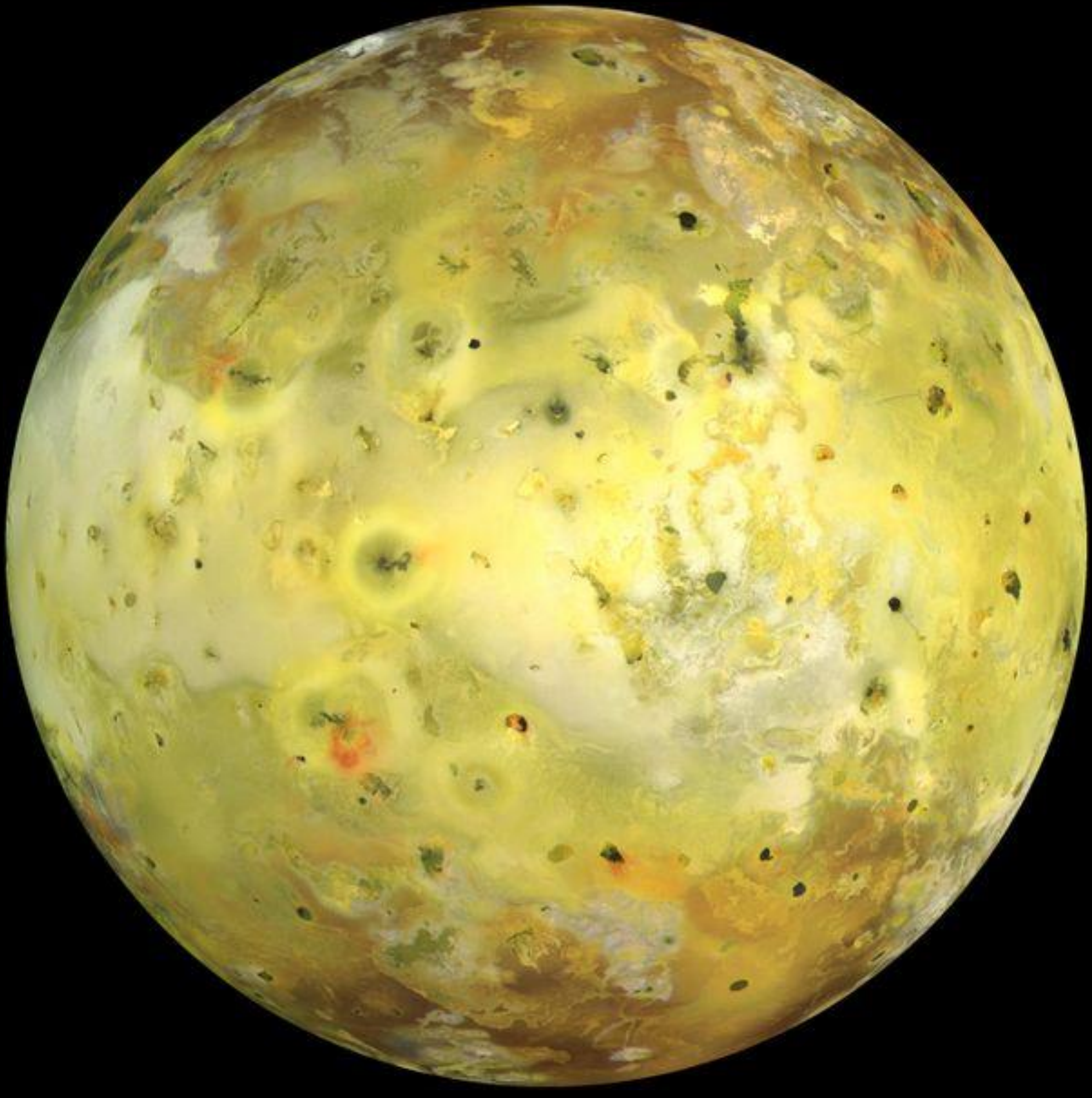
The iron "drops" follow gravity and accumulate towards the core. Lighter materials, such as silicate minerals, migrate upwards in exchange. Extra release of energy!



- Radioactive decay, accretion and sinking of heavy metals provide energy in the Earth's interior (Internal energy)
- Internal energy is the driver of volcanism, earthquakes and plate tectonics in general
- Tectonics constantly brings "fresh" rocks and volcanic gases to the surface where they can react with chemicals in the ocean releasing energy for life

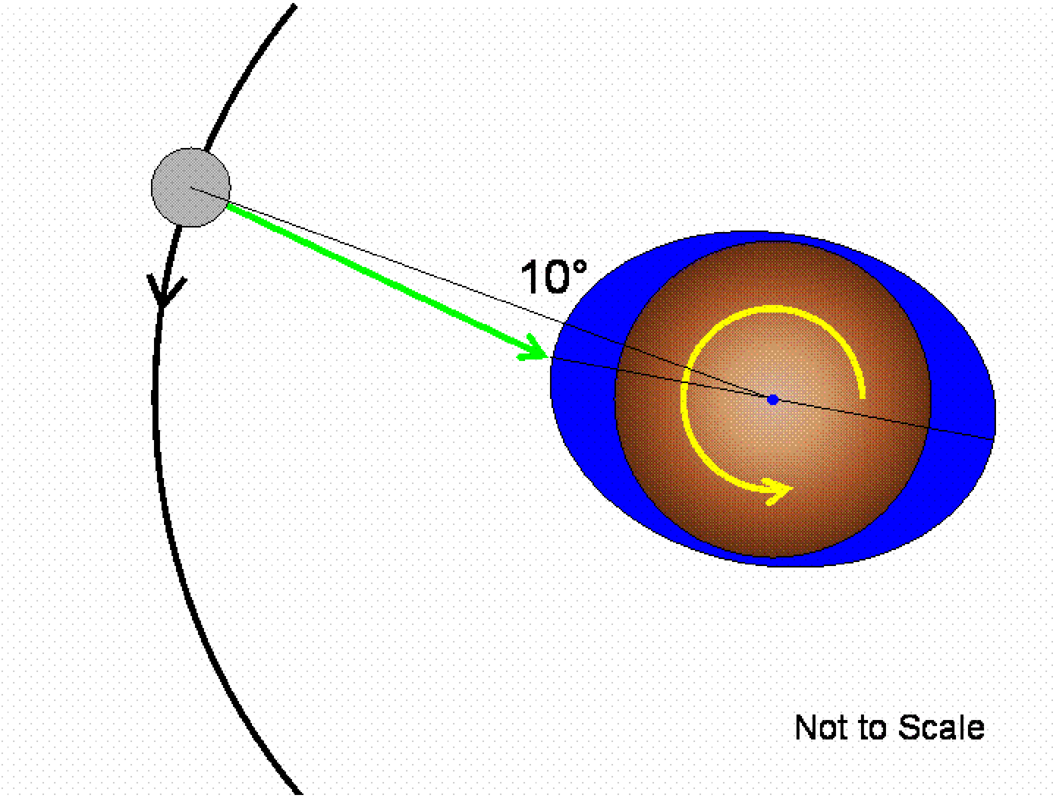


Tidal Heating



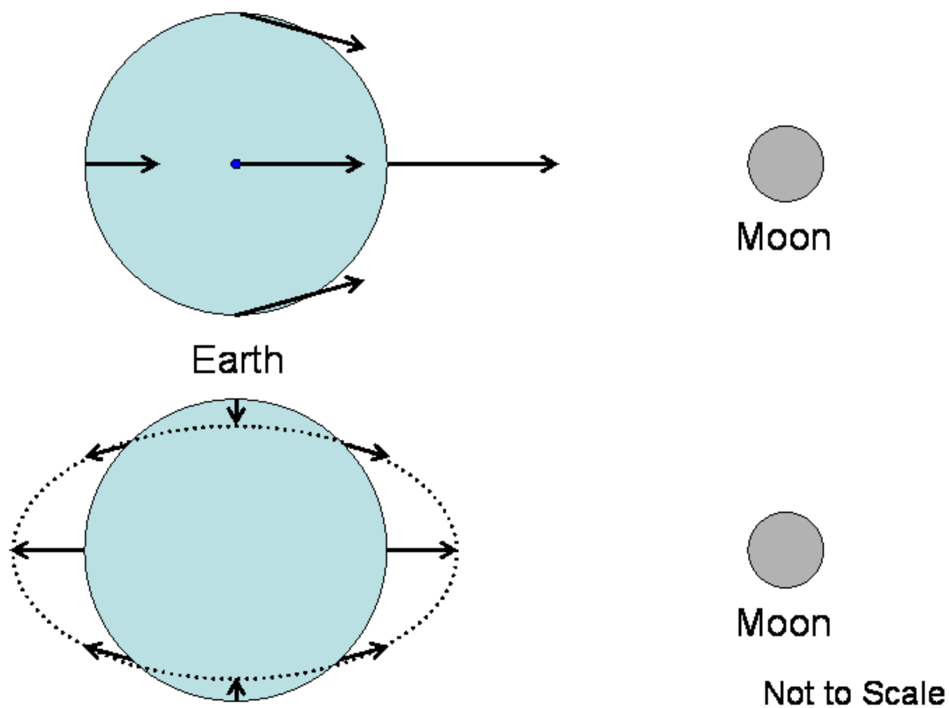
Tidal Friction

- The Earth's rotation tends to outrun the raising and lowering of the tides
- Moon's gravity exerts a small amount of drag – tidal friction due to torques
- This friction gradually slows the Earth's rotation

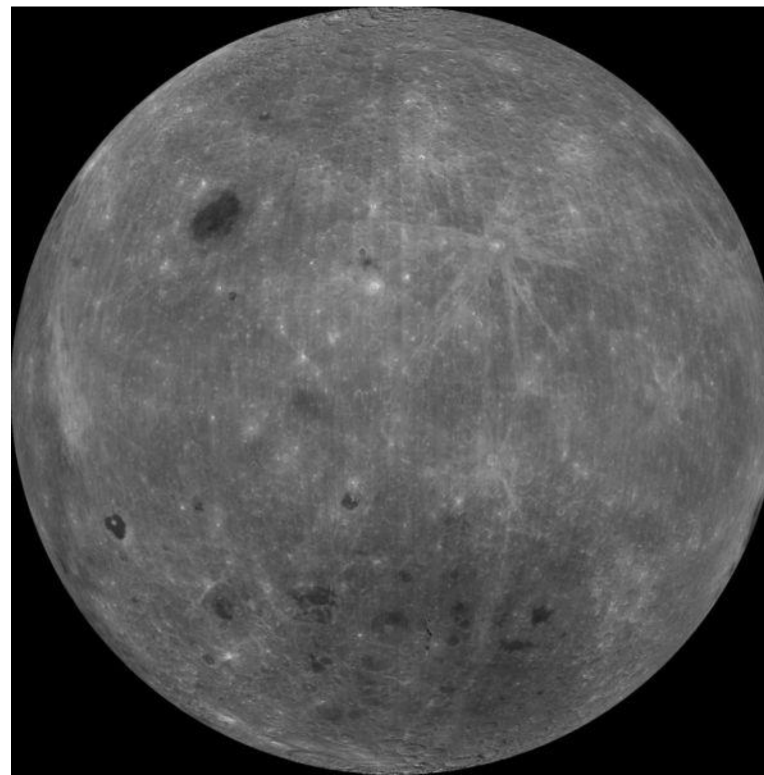


Synchronous rotation

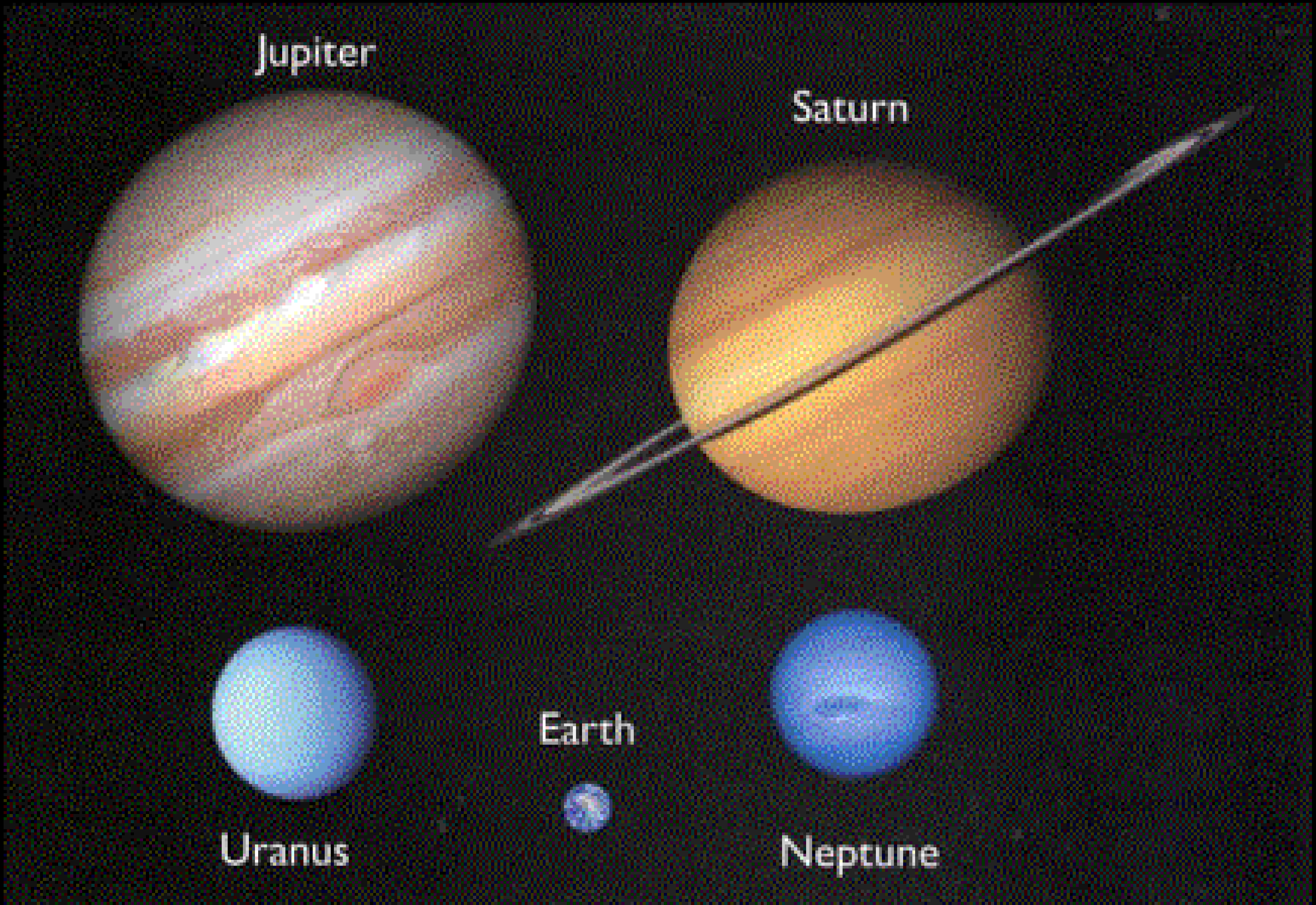
- The Moon always keep the same face turned toward the Earth – synchronous rotation.
- Synchronous rotation closely related to tides:



- Earth's gravity effects are much stronger on the Moon →Earth would raise much stronger tides on the Moon → tidal friction would be more severe → Moon would slow down its rotation much faster → synchronous rotation

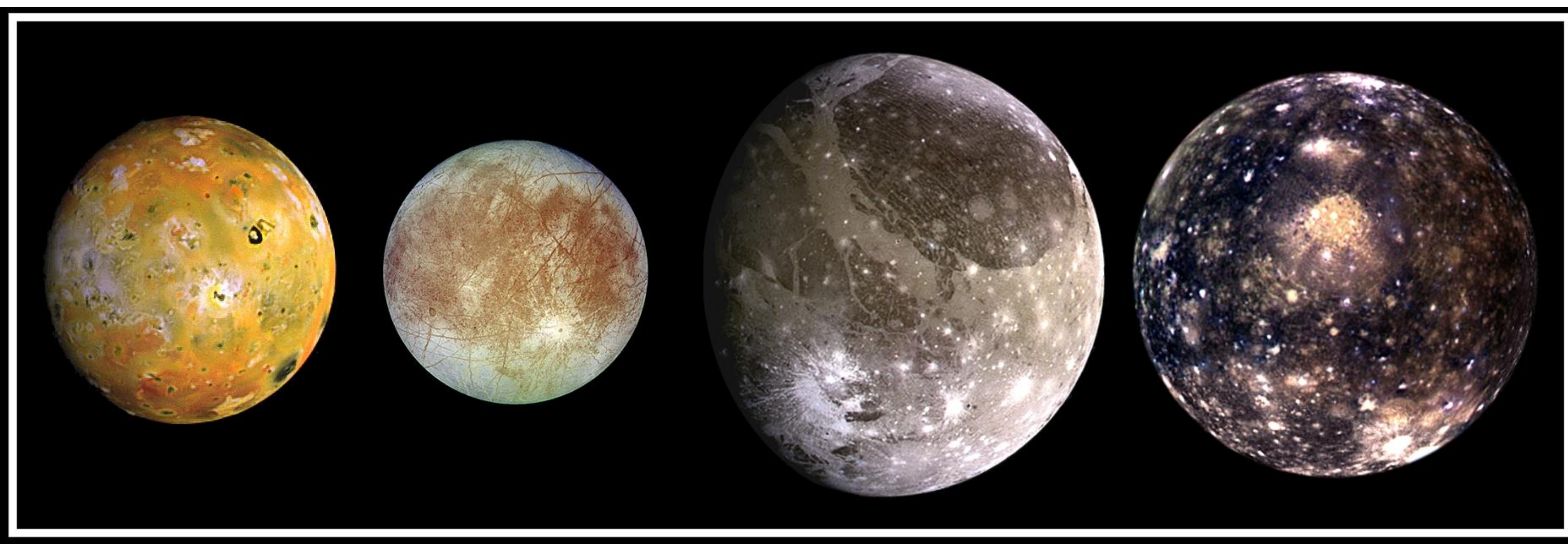


Tidal Friction is particularly severe for the moons of the Jovian planets



Jupiter’s satellites

- Galileo (1610) discovered four large satellites (moons) of Jupiter.
- Galilean moons: Io, Europa, Ganymede and Callisto



Relative characteristics

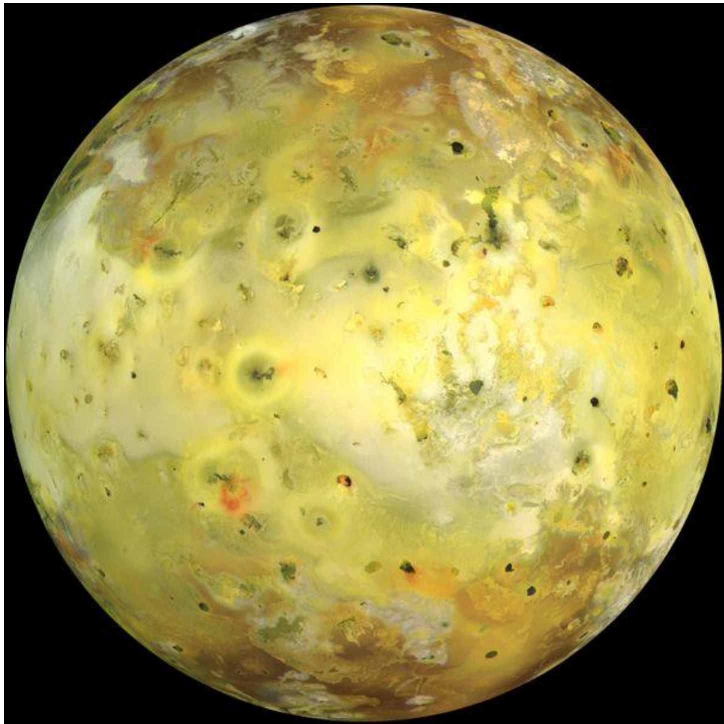
	Io	Europa	Ganymede	Callisto	Moon
Radius (km)	1822	1561	2631	2410	1738
Mean density (g/cm^3)	3.53	3.01	1.94	1.83	3.34
Average surface Temperature (K)	118	103	113	118	253
Period (days)	1.769	3.551	7.155	16.689	27.322

Water/ice density is ~ 1 g/cm^3

Tidal Heating

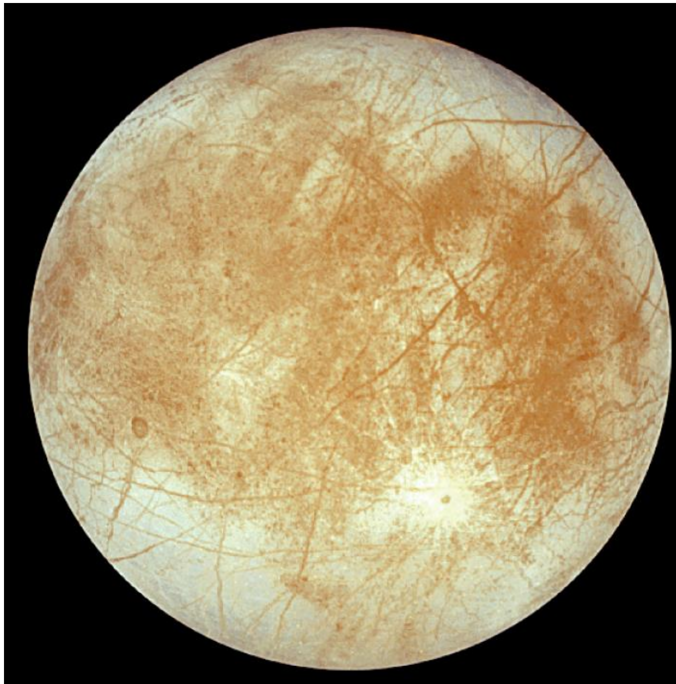
- Satellite orbits are non-circular →
- Jupiter raises tide bulges of different height because satellite's distance to Jupiter changes
- Oscillation of bulges produce extra tidal heating
- Orbital velocity is also not constant → additional tidal heating (libration)

- Tidal heating is the way to convert orbital rotational energy of the moon and parent planet into heat → very important for the Jovian moons because the solar energy flux is so weak. Io is more volcanically active than the Earth!



Europa

- Second closest to Jupiter and the smallest of the four Galilean moons. Spectroscopic observations indicate the presence of water ice on the surface.
- Very few impact craters – the surface has to be very young.
- But is the resurfacing caused by liquid water or by warm soft viscous ice?



- Tidal heating depends on the distance from the parent planet (Jupiter).
- Io is too close to Jupiter and has too much tidal heating. Callisto is too far and has to little heating – Callisto has very old heavily cratered surface.