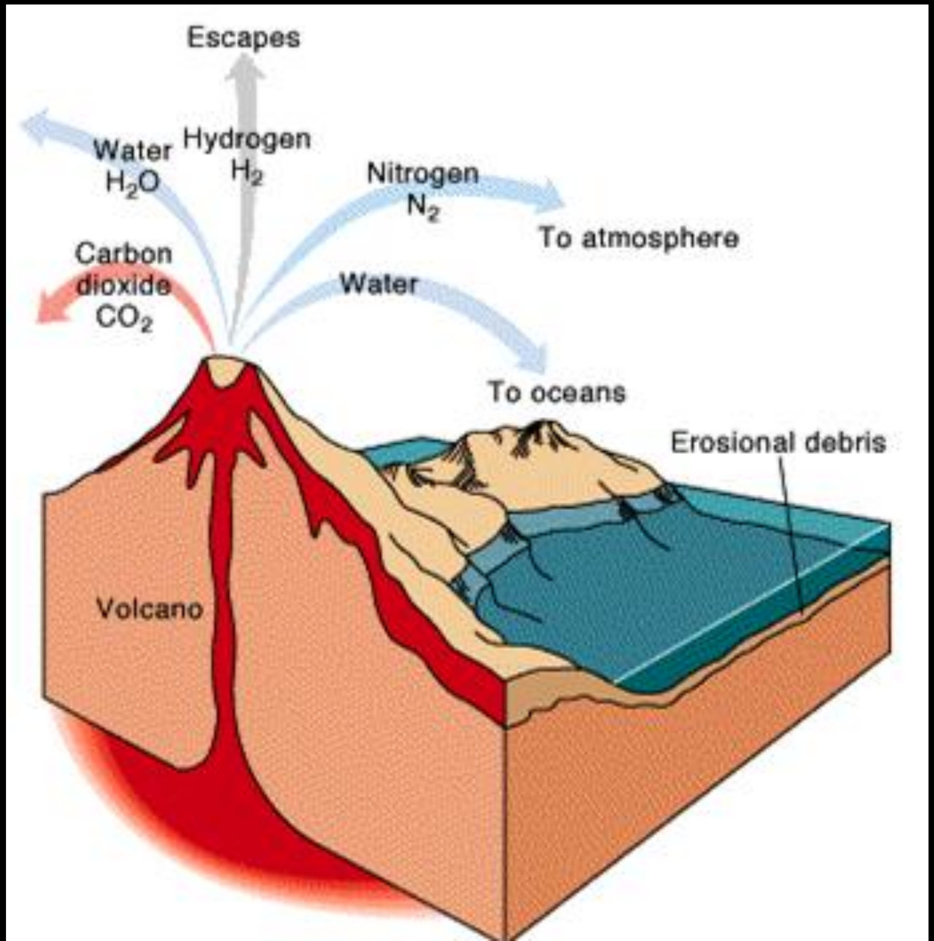
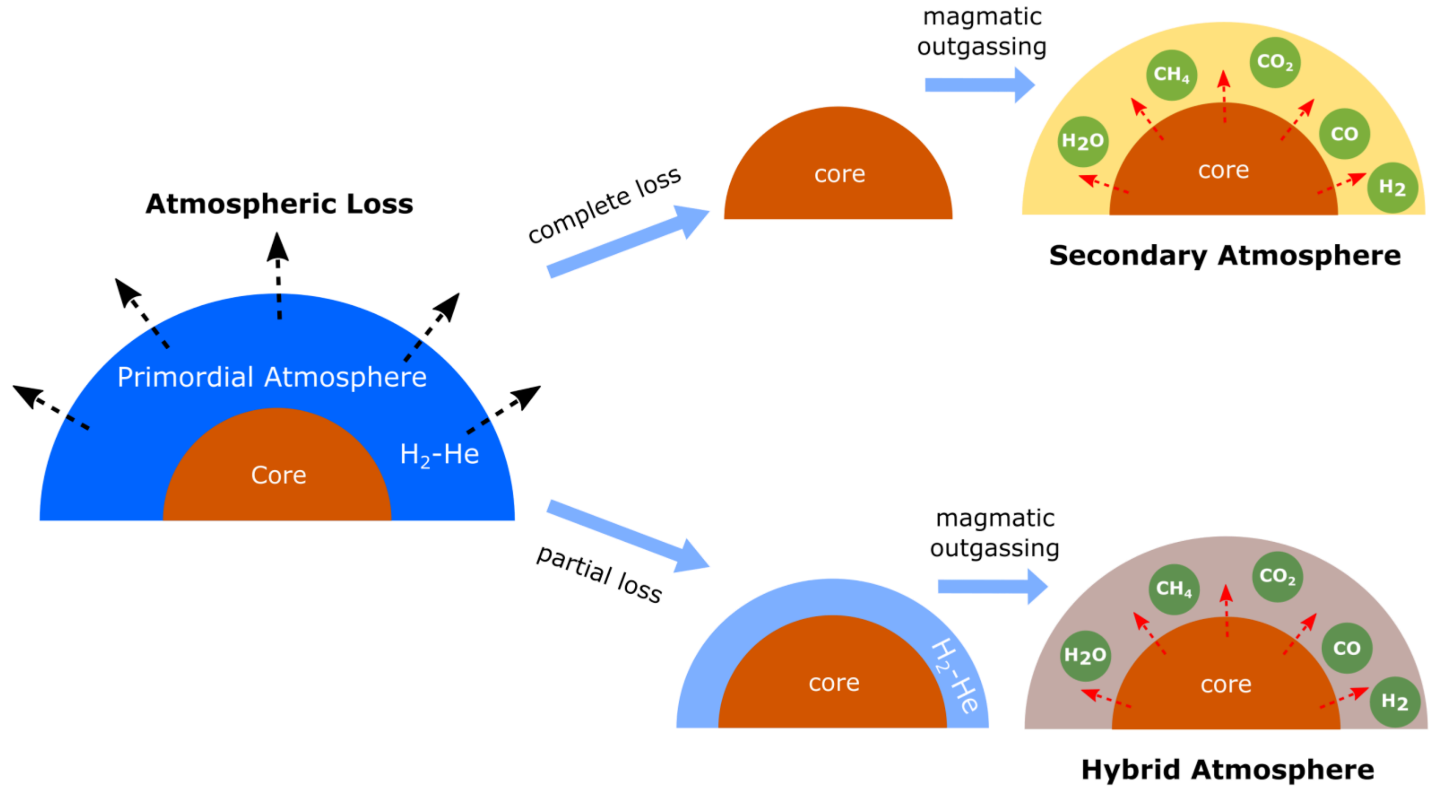
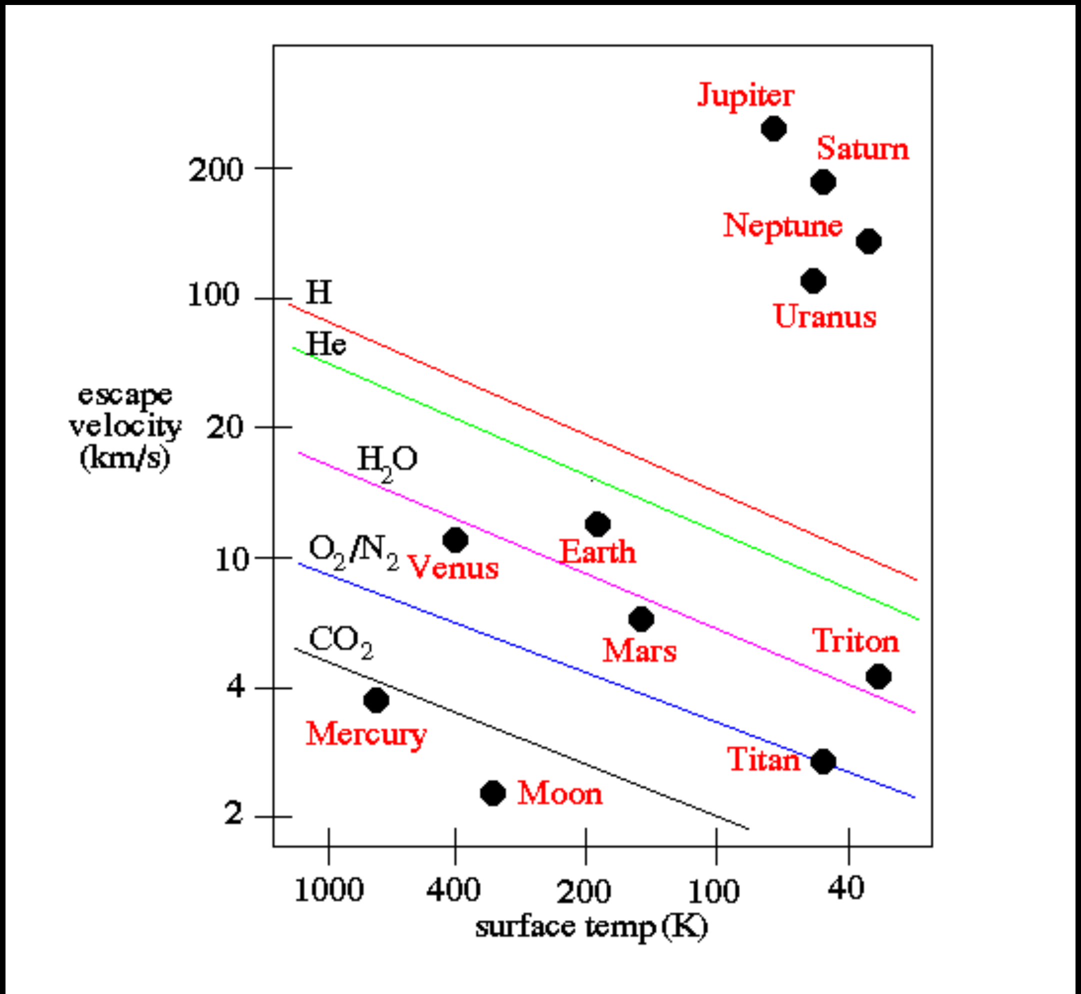

Escapes
Water
H_2O
Hydrogen
H_2
Nitrogen
N_2
To atmosphere
Carbon
dioxide
CO_2
Water
To oceans
Erosional debris
Volcano

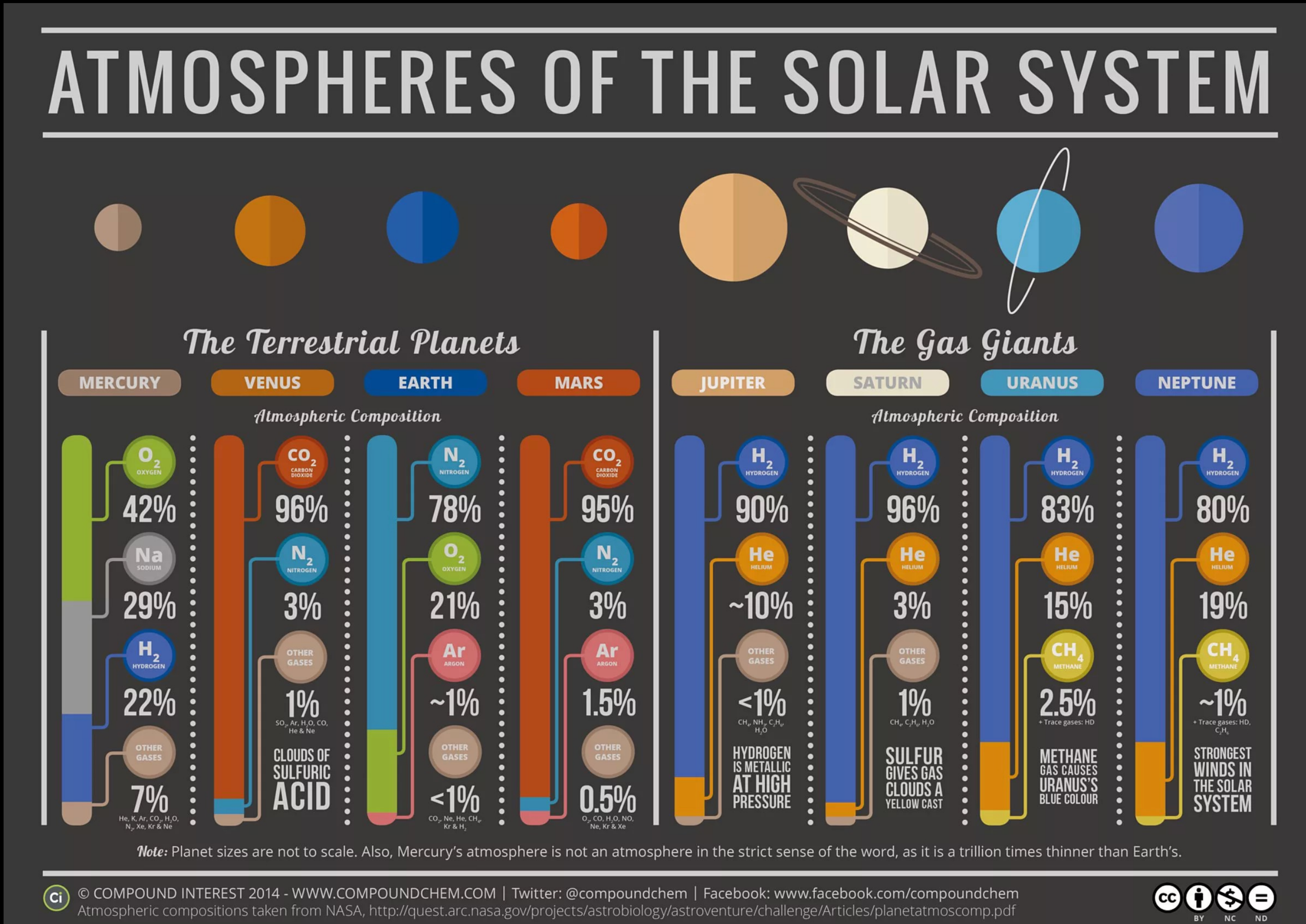


Atmospheric Loss
Primordial Atmosphere
Core
H_2-He
complete loss
core
magmatic outgassing
CH_4
CO_2
H_2O
CO
H_2
core
Secondary Atmosphere
partial loss
core
H_2-He
magmatic outgassing
CH_4
CO_2
H_2O
CO
H_2
core
Hybrid Atmosphere

The primary atmosphere for every terrestrial world was composed mostly of light gases that accreted during initial formation. These gases are similar to the primordial mixture of gases found in the Sun and Jupiter. That is 94.2% H, 5.7% He and everything else less that 0.1%.



However, this primary atmosphere was lost on the terrestrial planets. Why? a combination of surface temperature, mass of the atoms and escape velocity of the planet. What determines if a particular atom is retained by a planet's gravitational field? if the atom is moving less than the escape velocity for the planet, it stays. If it moves faster than escape velocity, it escapes into outer space.


ATMOSPHERES OF THE SOLAR SYSTEM
The Terrestrial Planets
MERCURY
VENUS
EARTH
MARS
Atmospheric Composition
O2 OXYGEN 42%
Na SODIUM 29%
H2 HYDROGEN 22%
OTHER GASES 7%
He, K, Ar, CO2, H2O, N2, Xe, Kr & Ne
CO2 CARBON DIOXIDE 96%
N2 NITROGEN 3%
OTHER GASES 1%
SO2, Ar, H2O, CO, He & Ne
CLOUDS OF SULFURIC ACID
N2 NITROGEN 78%
O2 OXYGEN 21%
Ar ARGON ~1%
OTHER GASES <1%
CO2, Ne, He, CH4, Kr & H2
CO2 CARBON DIOXIDE 95%
N2 NITROGEN 3%
Ar ARGON 1.5%
OTHER GASES 0.5%
O2, CO, H2O, NO, Ne, Kr & Xe
The Gas Giants
JUPITER
SATURN
URANUS
NEPTUNE
Atmospheric Composition
H2 HYDROGEN 90%
He HELIUM ~10%
OTHER GASES <1%
CH4, NH3, C2H6, H2O
HYDROGEN IS METALLIC AT HIGH PRESSURE
H2 HYDROGEN 96%
He HELIUM 3%
OTHER GASES 1%
CH4, C2H6, H2O
SULFUR GIVES GAS CLOUDS A YELLOW CAST
H2 HYDROGEN 83%
He HELIUM 15%
CH4 METHANE 2.5%
+ Trace gases: HD
METHANE GAS CAUSES URANUS'S BLUE COLOUR
H2 HYDROGEN 80%
He HELIUM 19%
CH4 METHANE ~1%
+ Trace gases: HD, C2H6
STRONGEST WINDS IN THE SOLAR SYSTEM
Note: Planet sizes are not to scale. Also, Mercury's atmosphere is not an atmosphere in the strict sense of the word, as it is a trillion times thinner than Earth's.
Ci
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Atmospheric compositions taken from NASA, http://quest.arc.nasa.gov/projects/astrobiology/astroventure/challenge/Articles/planetatmoscomp.pdf
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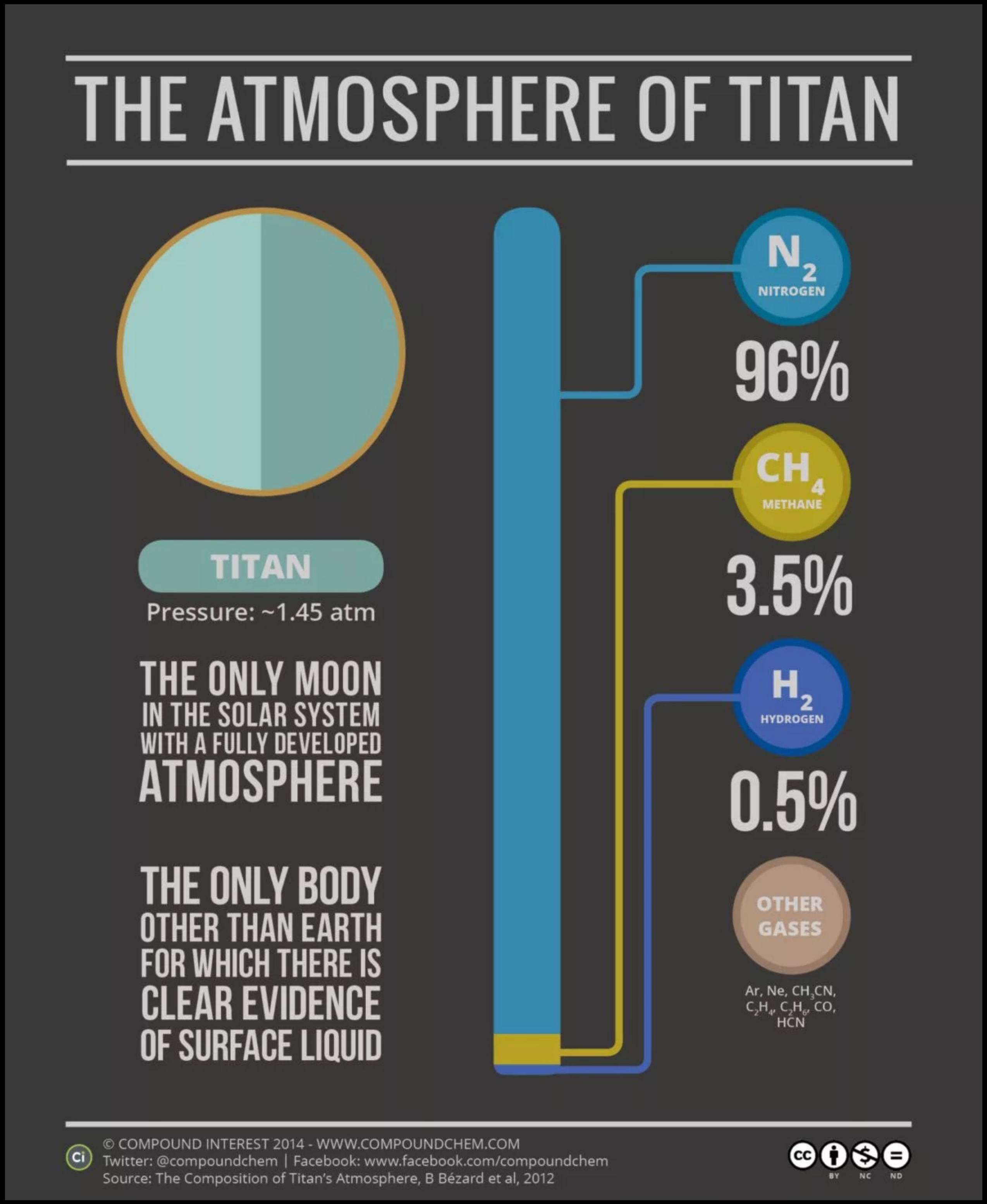
THE ATMOSPHERE OF TITAN
TITAN
Pressure: ~1.45 atm
THE ONLY MOON IN THE SOLAR SYSTEM WITH A FULLY DEVELOPED ATMOSPHERE
THE ONLY BODY OTHER THAN EARTH FOR WHICH THERE IS CLEAR EVIDENCE OF SURFACE LIQUID
N_2 NITROGEN
96%
CH_4 METHANE
3.5%
H_2 HYDROGEN
0.5%
OTHER GASES
Ar, Ne, CH_3CN, C_2H_4, C_2H_6, CO, HCN
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Source: The Composition of Titan's Atmosphere, B Bézard et al, 2012
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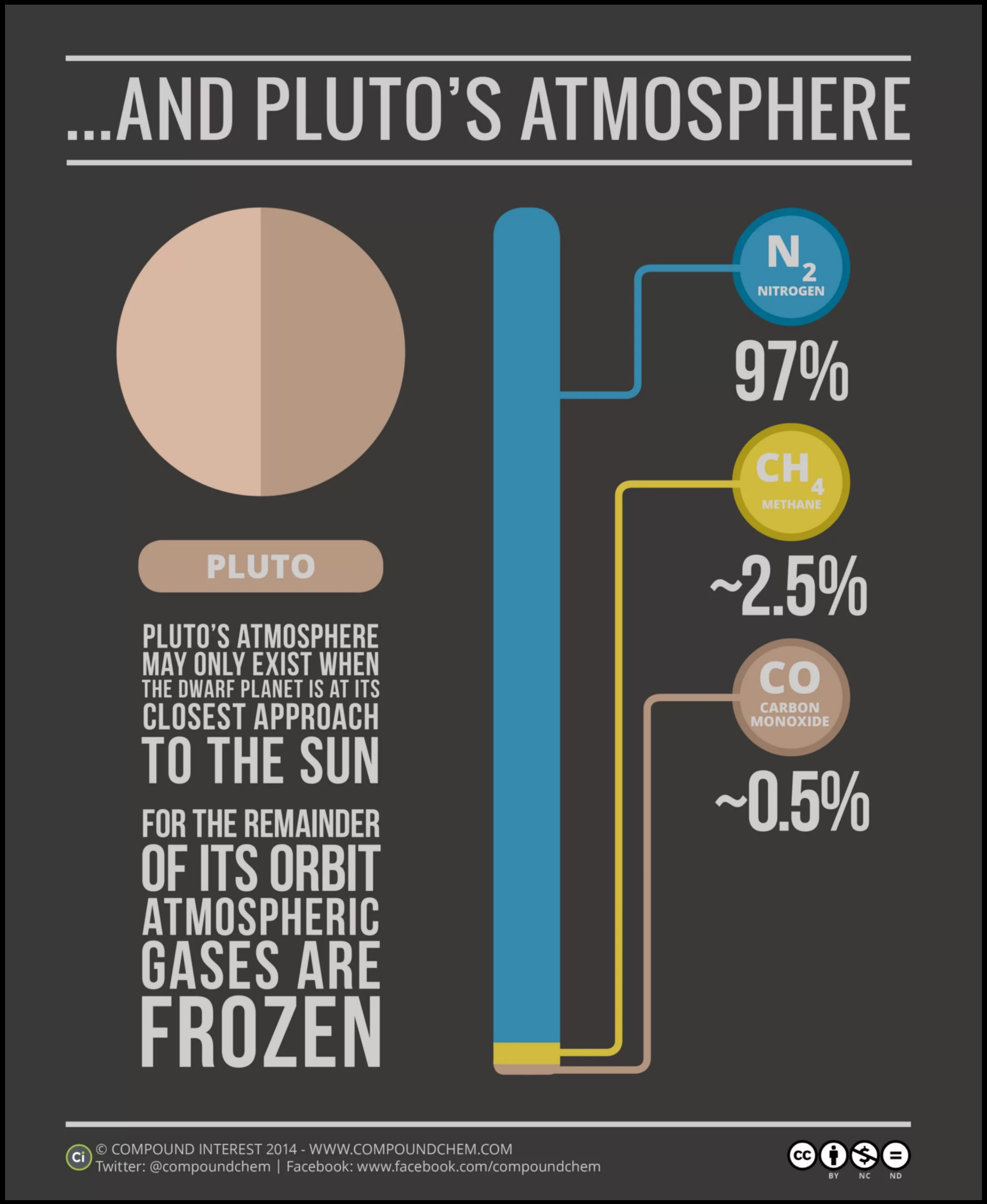
...AND PLUTO'S ATMOSPHERE
PLUTO
PLUTO'S ATMOSPHERE MAY ONLY EXIST WHEN THE DWARF PLANET IS AT ITS CLOSEST APPROACH TO THE SUN
FOR THE REMAINDER OF ITS ORBIT ATMOSPHERIC GASES ARE FROZEN
N_2 NITROGEN
97%
CH_4 METHANE
~2.5%
CO CARBON MONOXIDE
~0.5%
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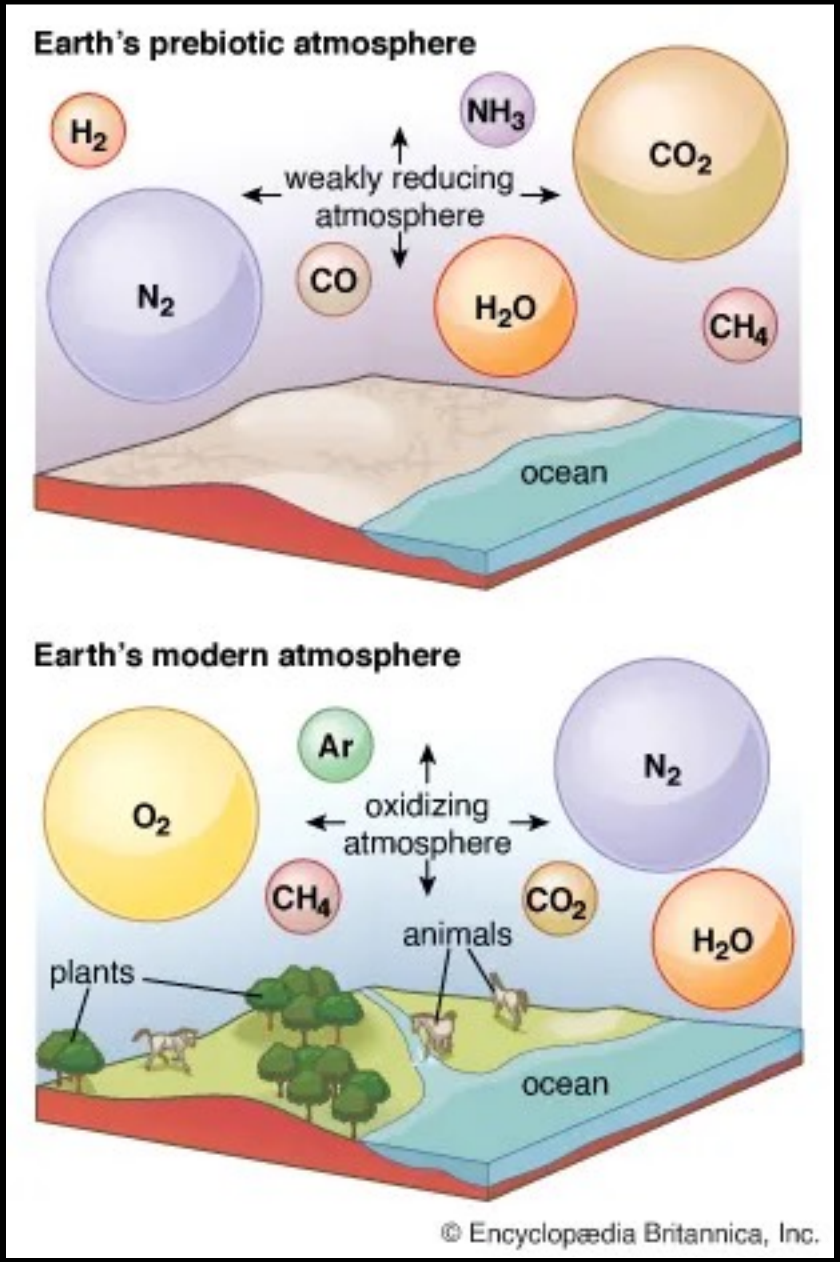
The composition of outgassing is similar for Venus, Earth and Mars and is composed of 58% H2O, 23% CO2, 13% SO2, 5% N2 and traces of noble gases (Ne, Ar, Kr). The latter evolution of this outgassing is driven primarily by the surface temperature and chemistry of the planet. Study this table closely, for all three planets had similar secondary atmospheres which evolved in very different ways.

Evolution of TP atmosphere from secondary outgassing

secondary atmosphere (outgassing)		Venus (hot)		Earth (warm)		Mars (cold)	
H_2O	58%	H_2, oxides	<0.1%	oceans	<1%	ice	<0.1%
CO_2	23%	—	97%	carbonite rock life photochemical	<1%	—	95%
SO_2	13%	sulfuric acid	<1%	sulfur rocks	<0.1%	sulfur rocks	<0.1%
N_2	5%	—	2%	—	78%	—	3%
noble gases	1%	—	0.5%	—	1%	—	2%
mass		thick		thick		thin	

Note that H2O is the key catalyst for the evolution of a secondary atmosphere. On the Earth, the temperature was just right for the formation of liquid water = oceans. The CO2 released by outgassing was dissolved in the liquid water to produce carbonate rocks. Thus, the Earth had a reducing atmosphere.



Earth's prebiotic atmosphere
H_2
NH_3
CO_2
weakly reducing atmosphere
N_2
CO
H_2O
CH_4
ocean
Earth's modern atmosphere
Ar
O_2
N_2
oxidizing atmosphere
CH_4
CO_2
H_2O
animals
plants
ocean
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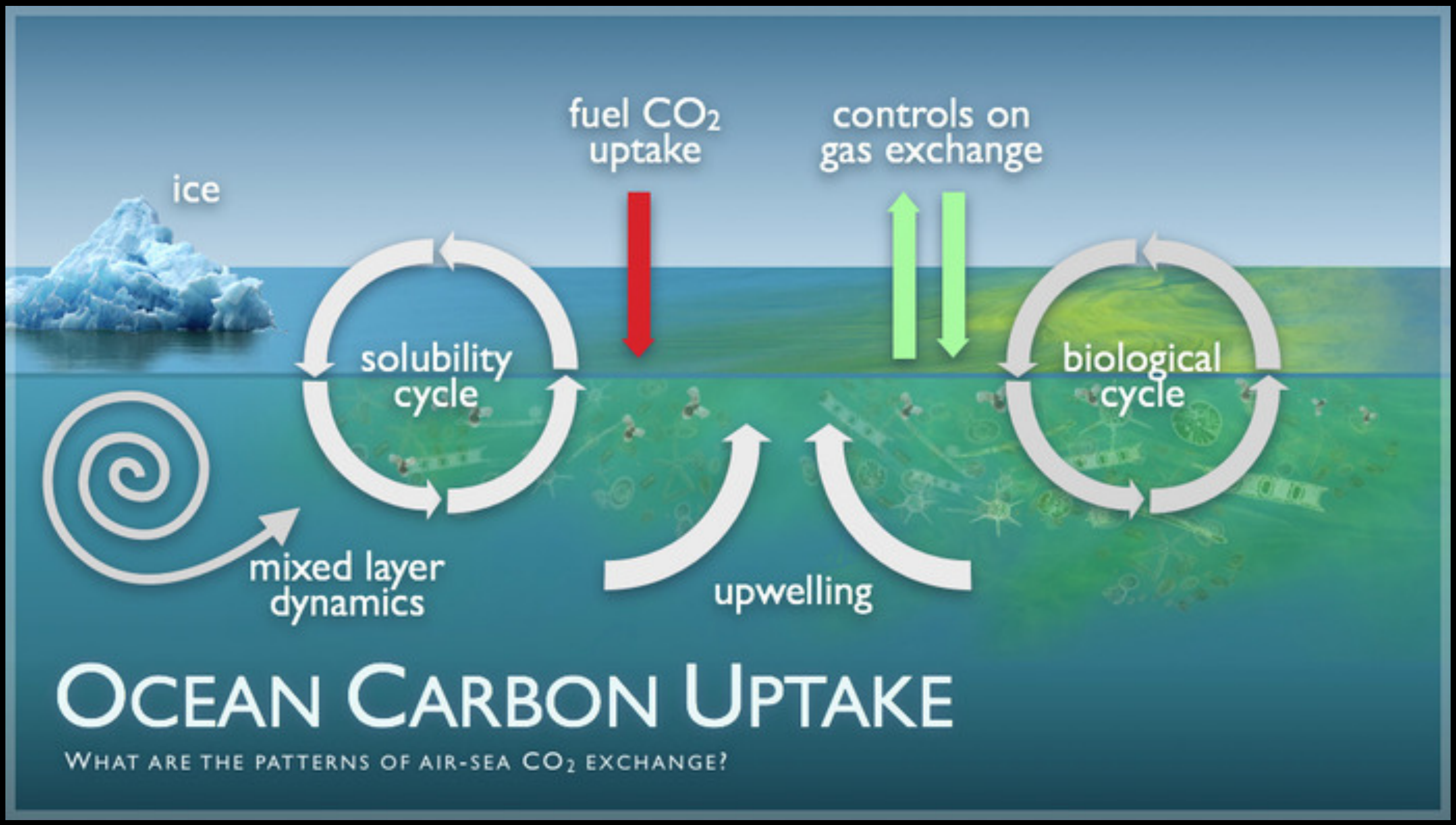
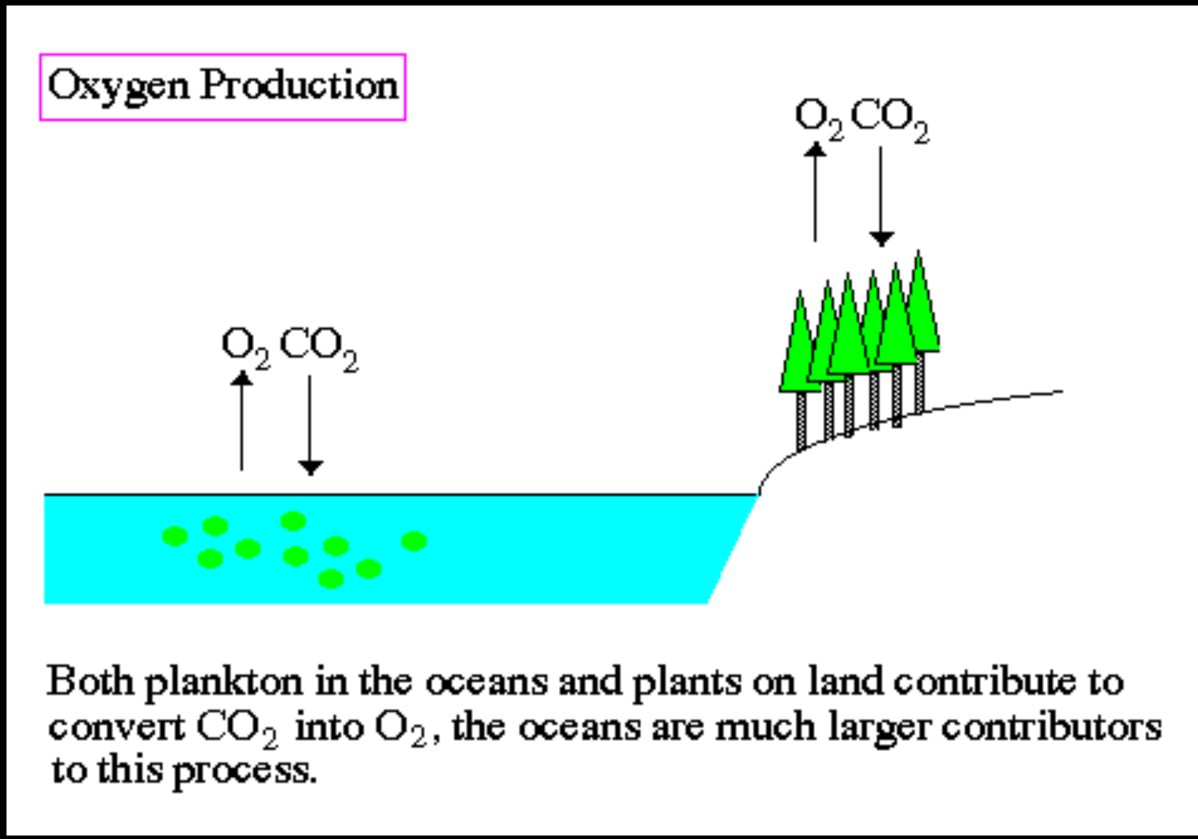
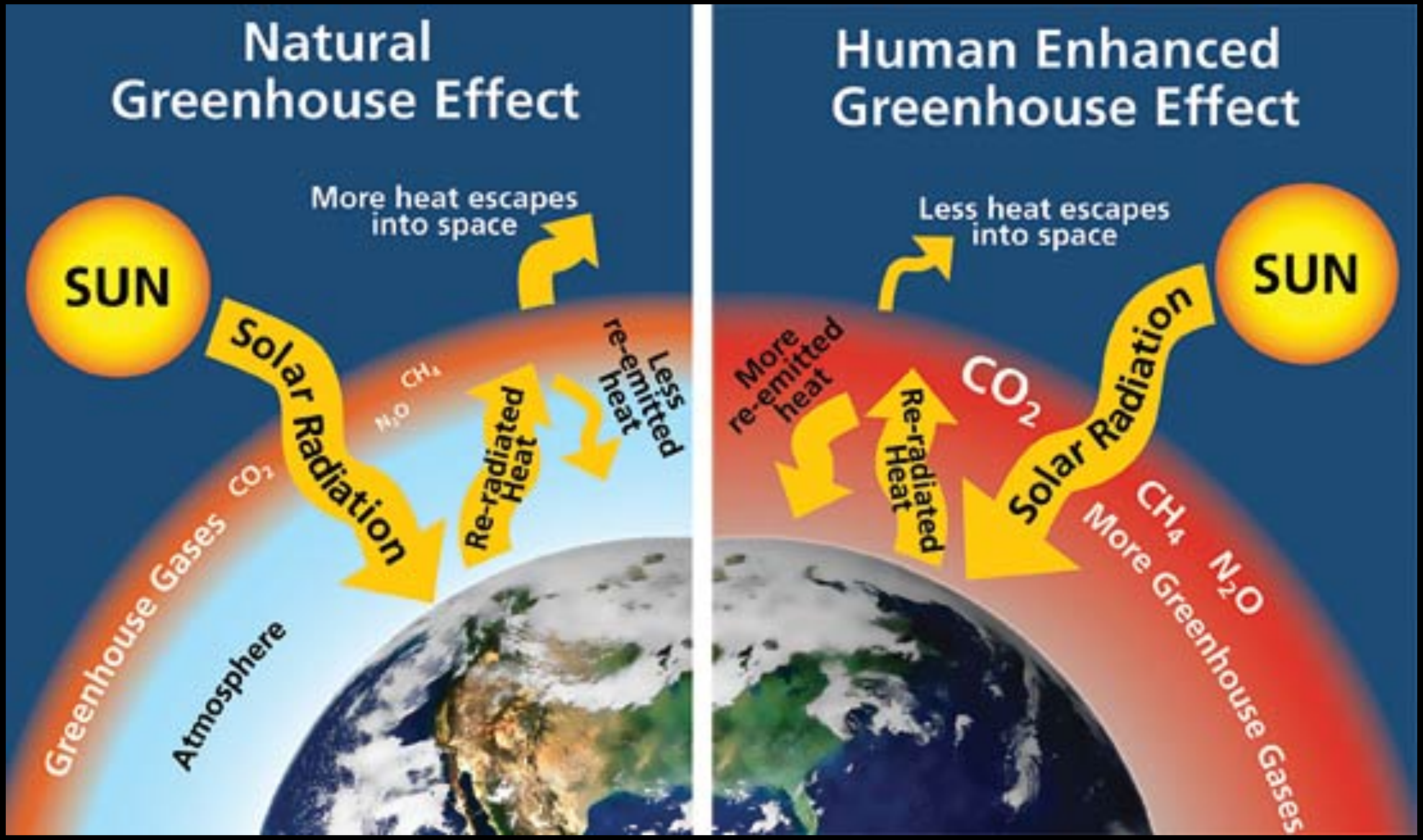




Note that most of the O2 released by outgassing is locked up in liquid H2O. Since O2 is highly reactive, it must constantly be replenished. Some is released by photodisintegration with H2O vapor in the upper atmosphere.

But most of the O2 in today's atmosphere is from the photosynthesis process associated with lifeforms. This occurred about 1 billion years after the Earth formed. The original secondary atmosphere of the Earth was lacking large amounts of O2 and was rich in N2 and CO2. Plants are needed to replenish O2, without plants all the oxygen would turn into rocks in a few 100 years.

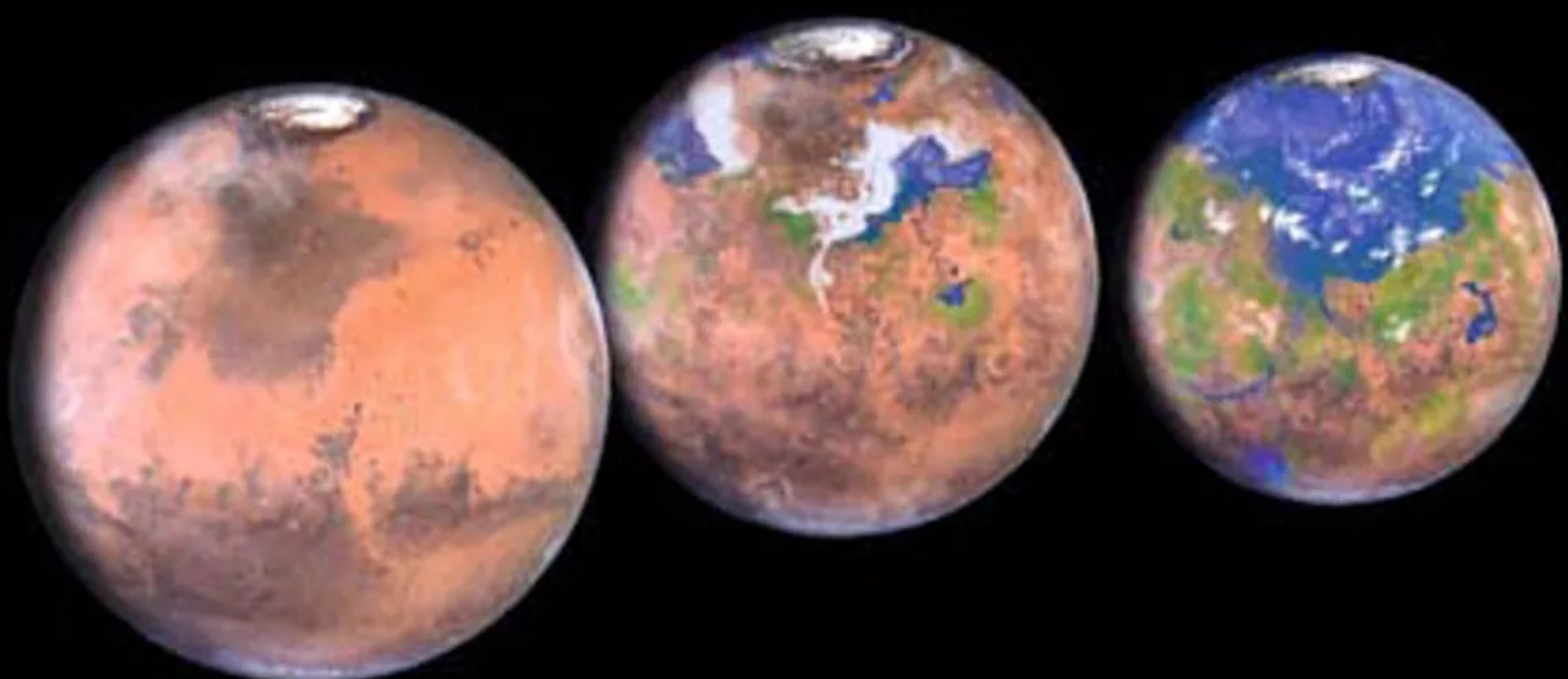
The greenhouse effect is controlled by the amount (by mass) of greenhouse gases in an atmosphere. These gases are primarily H2O, CO2, CH4, NH3. For secondary atmospheres on Venus, Earth and Mars, only CO2 has a major contribution to the greenhouse effect (although note that the amount of CH4 is increasing on the Earth due to the waste products of animals and agriculture).

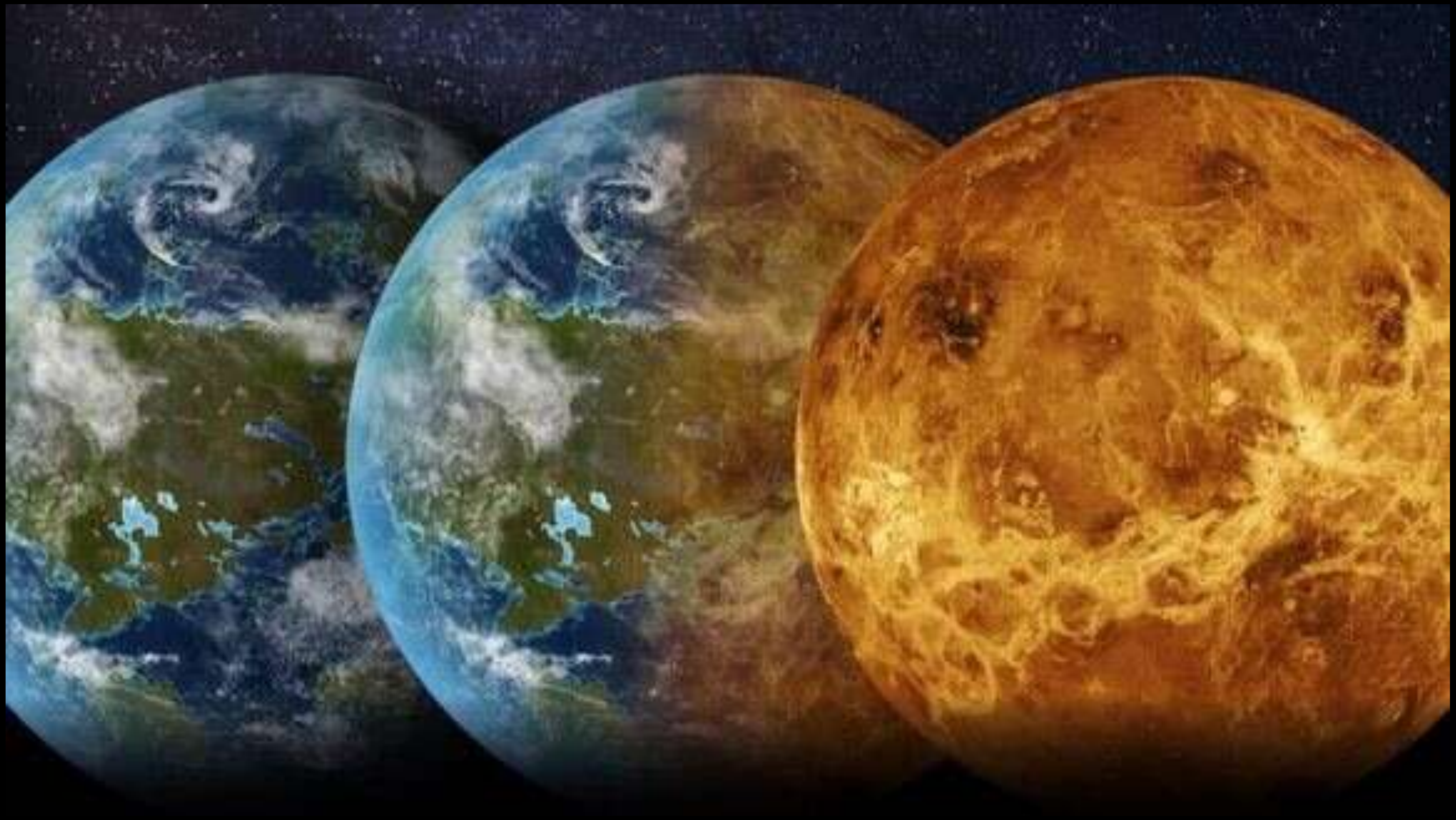


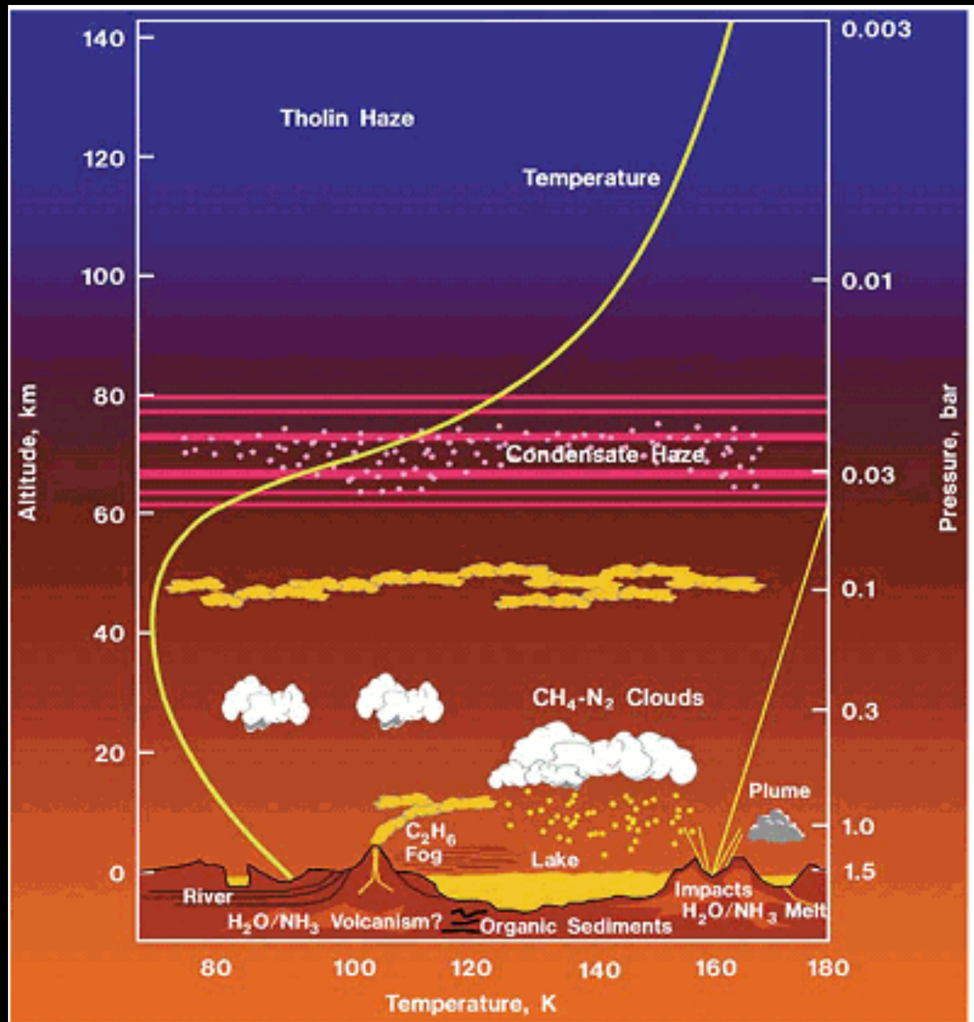
The greenhouse effect currently raises the temperature of Venus, Earth and Mars by the following amounts:

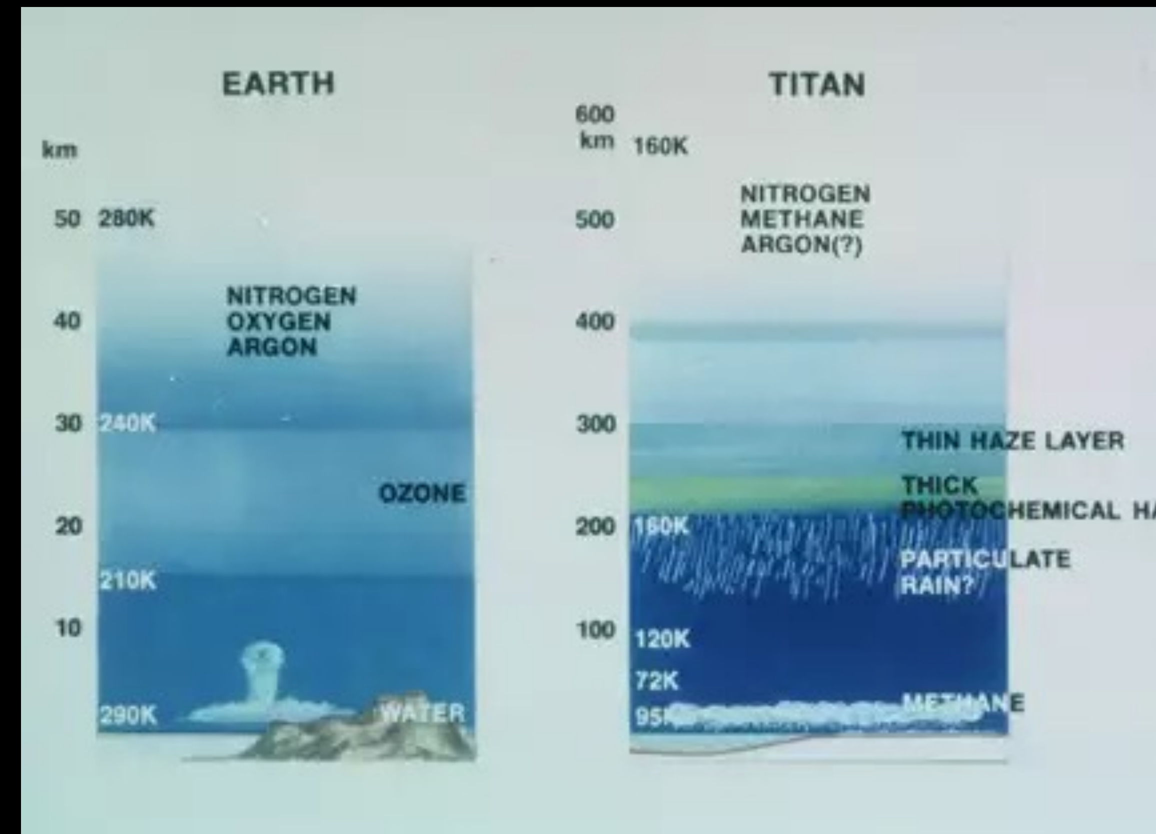
Mars -> +5 degrees
Earth -> +35 degrees
Venus -> +500 degrees

Note that the greenhouse effect for the Earth is just enough to keep us out of a perpetual Ice Age (a little greenhouse effect is good for you). Whereas for Venus, a severe runaway greenhouse effect makes it the hottest place in the Solar System.



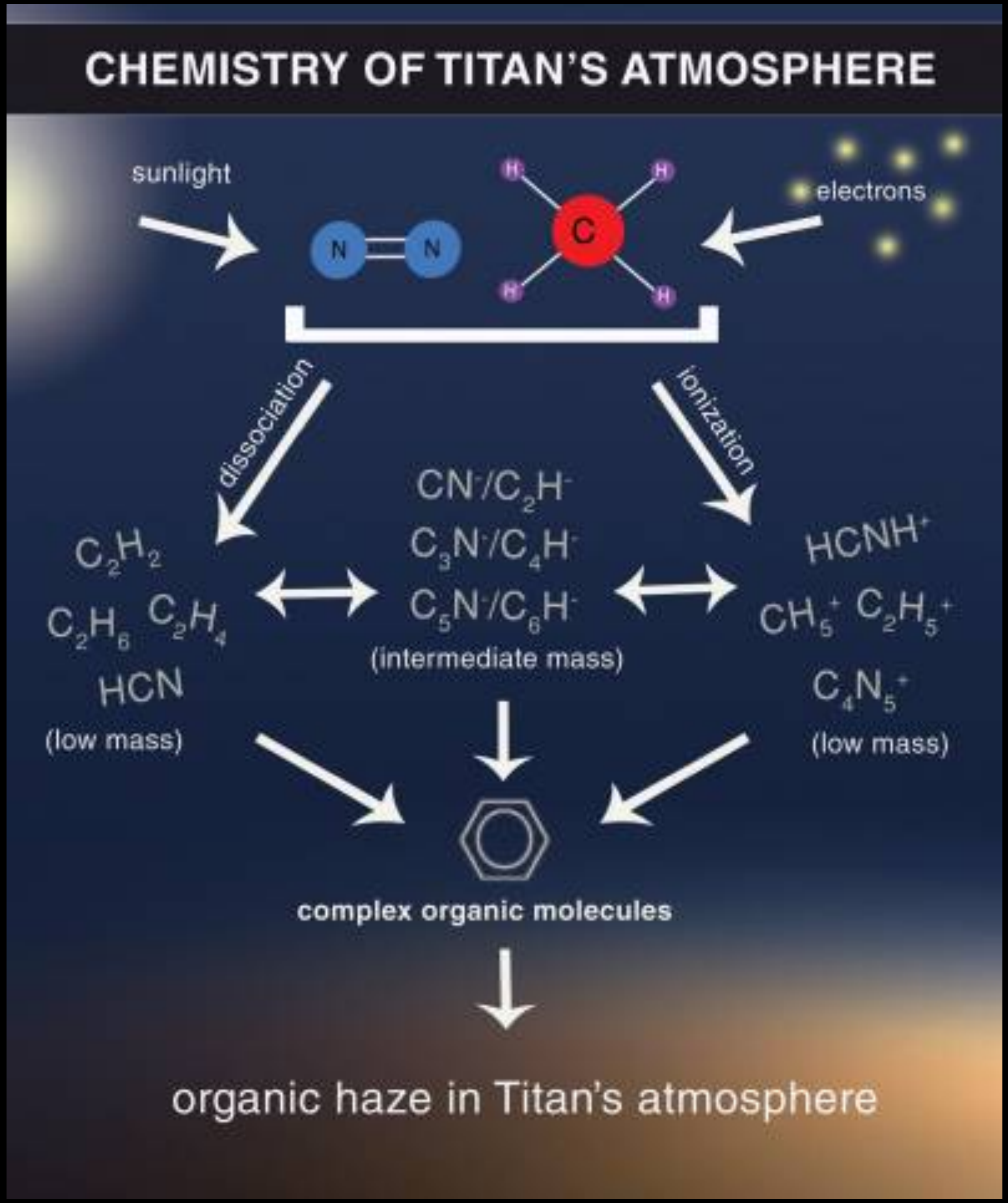






One of the thickest atmosphere's in the Solar System (2nd only to Venus) is Titan. Titan's current atmosphere is 90% N2 and 7% CH4 (methane). Since Titan formed in the outer Solar System where it is much cooler, and contains more icy materials such as NH3 (ammonia) and CH4. NH3 is easily separated into N2 and H2 by sunlight. The N2 is retained by Titan's gravity (see the chart above), but H2 escapes. Thus, over time, Titan has built up a N2 atmosphere like the Earth's from an original secondary atmosphere that was rich in NH3.

Note that the interaction of sunlight and CH4 induces chemical reactions that build hydrocarbons such as ethane, acetylene, propane; all of which have been detected in Titan's atmosphere.



Composition of a Secondary Atmosphere:

In summary, the composition of an atmosphere on a terrestrial planet will be determined by the following:

1) Distance from Sun (surface temperature of planet)

2)Mass and radius of planet = surface gravity = escape velocity

3) chemical reactions = different molecules are created and destroyed in various environments, higher temperatures mean faster reactions

4) geological activity = amount of outgassing, more activity = more outgassing = thicker atmosphere

5) living organisms = change the composition through their waste products

Why are Terrestrial Planets small and rocky? The primary atmosphere has boiled off leaving the rocky core. Why did this happen? Distance from the Sun for the primary worlds, distance from warm Jupiter or Saturn for the terrestrial moons.