METR/ENVS 113

Lecture 1: Atmospheric Structure & Composition

SJSU Fall Semester 2020

Module 1: The Natural, Unpolluted Atmosphere

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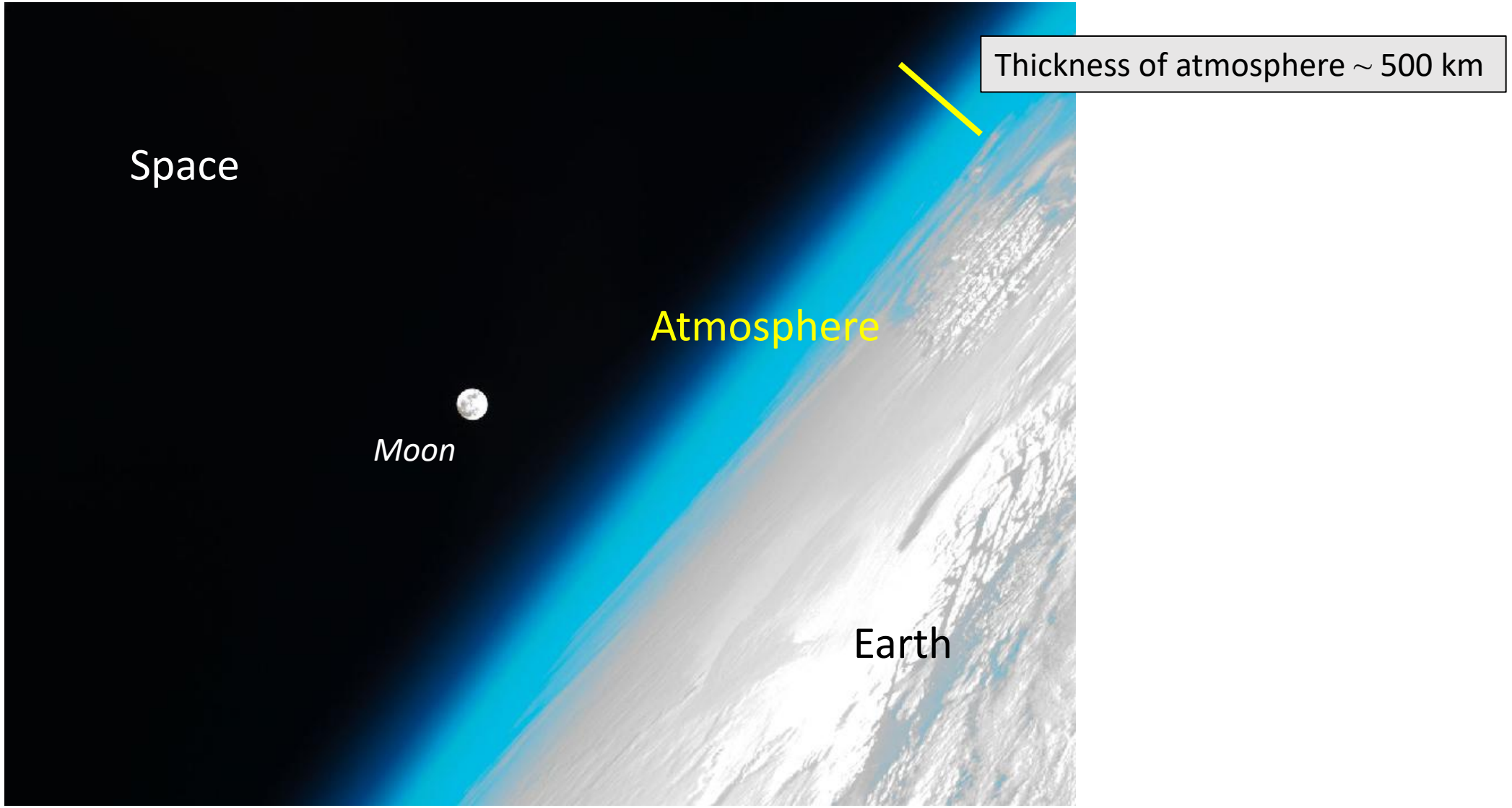
Outline

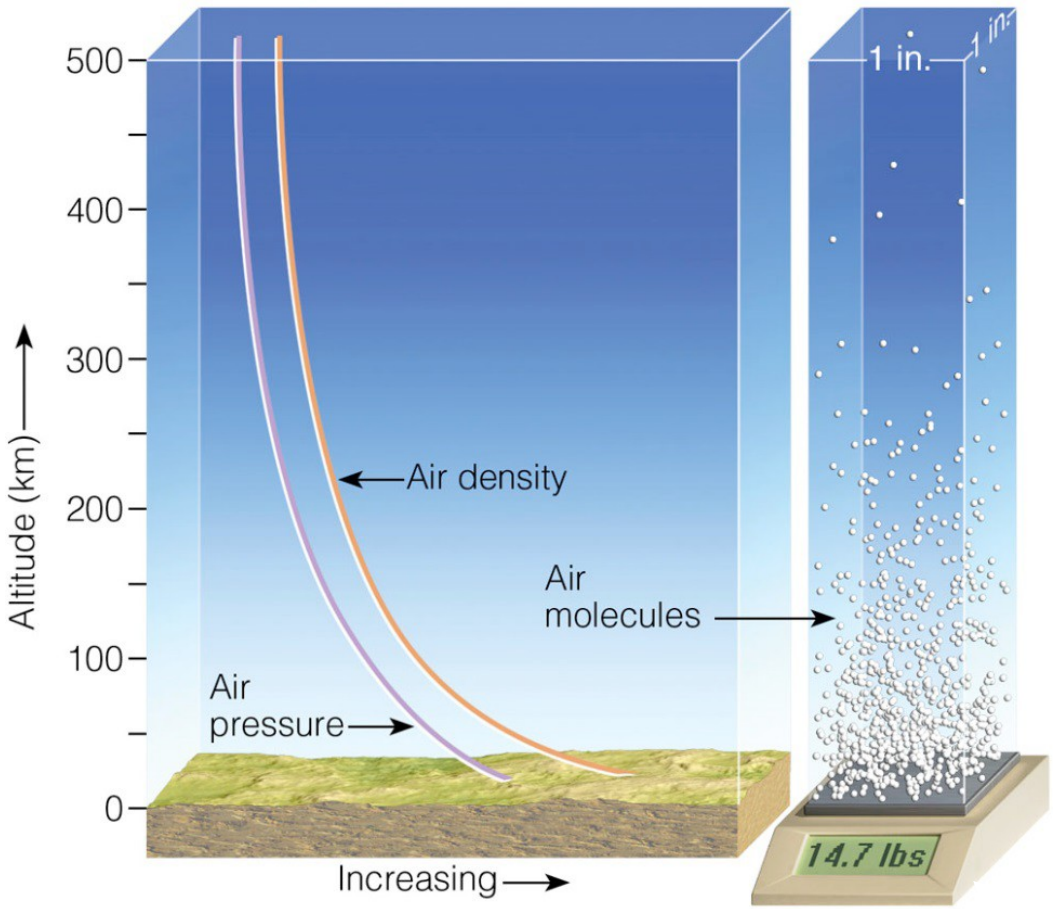
- Atmospheric Structure
  - Pressure, Density and Temperature
  - Atmospheric Layers
- Atmospheric Composition
  - Gases in the Earth's Atmosphere by Percent
- Related Topics
  - The Earth's Atmosphere vs. Other Planets
  - The Upper Atmosphere: Auroras
  - The Life Cycle
  - Human Respiration

Atmospheric Structure

The Atmosphere Viewed from Space



Density and Pressure



KEY POINTS

• Air density: the mass of air per volume. At the surface, air density ~ 1.2 kg/m^3.

• Air pressure: the weight of the overlying atmosphere per surface area. At the surface, air pressure ~ 14.7 lbs/in^2.

• Density and pressure are highest in the lower atmosphere, and decrease rapidly with height through the upper atmosphere.

• About 50% of mass in lowest 5 km (10%) of atmosphere.

14.7 pounds per square-inch of air pressure (typical value at the surface)

Temperature

KEY POINTS

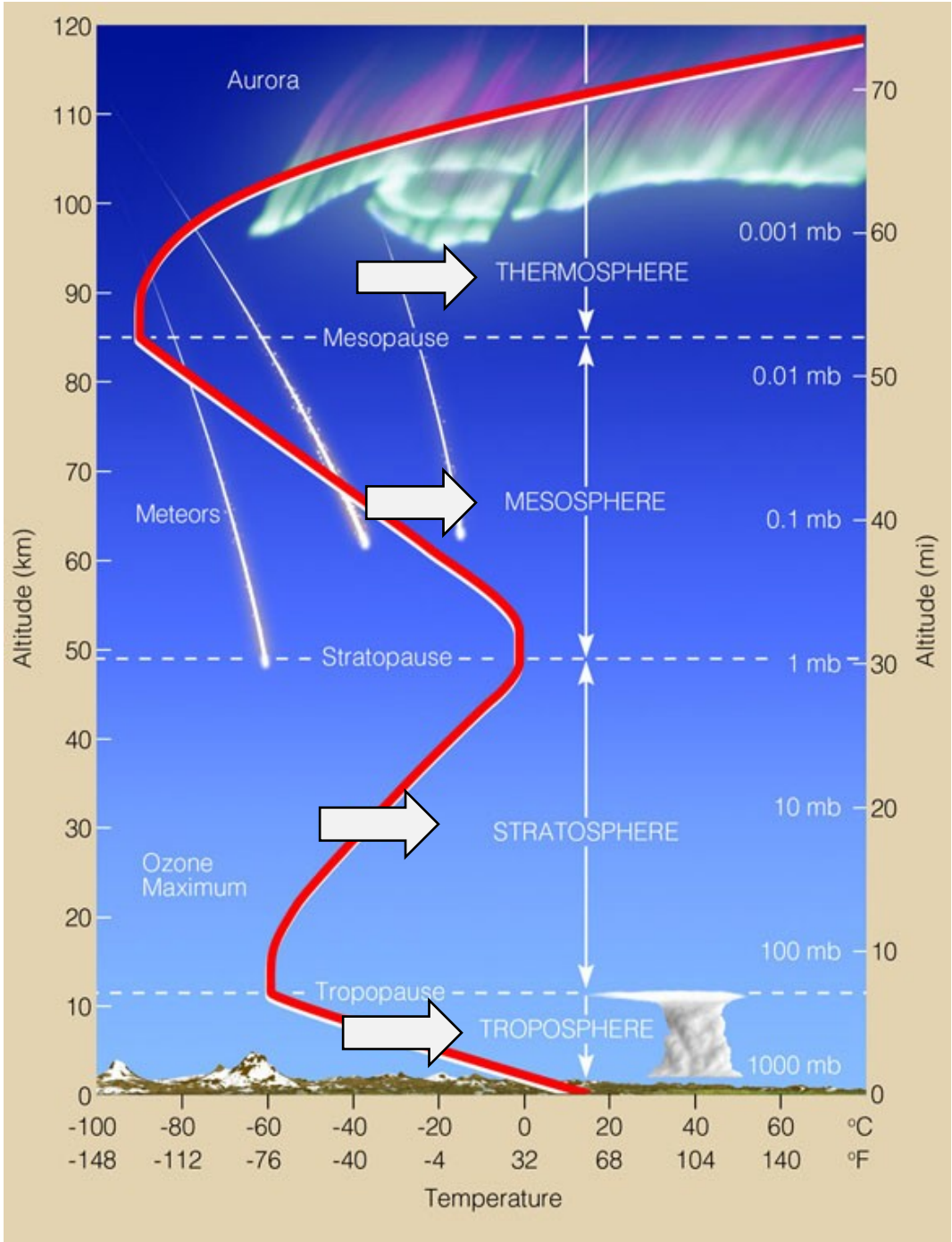
- Air temperature is the measure of the amount of kinetic energy or how fast air molecules or particles are moving around.
- Units =Celsius, Fahrenheit, Kelvin
- Kelvin is the absolute unit (zero molecular motion at 0 deg K)

Atmospheric Layers

MESOSPHERE AND THERMOSPHERE
(“upper atmosphere”)
- Not much air pollution importance
- Interesting phenomena: auroras, meteors

STRATOSPHERE
- Temperature increases with height (“temperature inversion”)
- where “ozone layer” is

TROPOSPHERE
- Temperature decreases with height
- Where weather and climate patterns exist.
- Focus of air pollution topics in this class

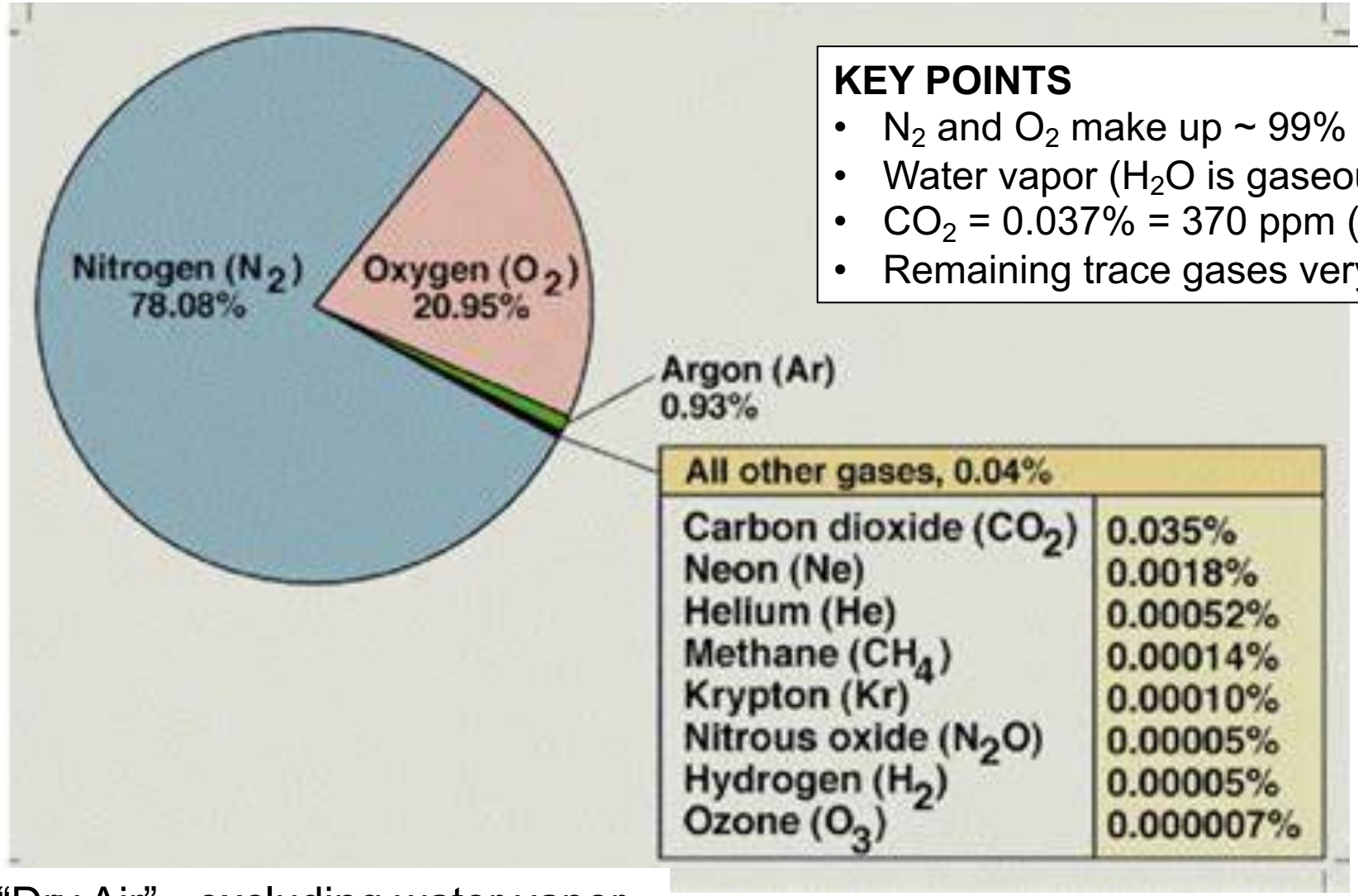


Atmospheric Composition

What is atmosphere comprised of?

- **Gases**
  - Chemical compounds in gaseous phase
  - Atmosphere is a mixture of various gases
  - Includes water vapor
- **Hydrometeors**
  - Water in liquid or solid phase
  - Clouds (ice and liquid), haze, rain, snow, hail
- **Aerosols**
  - Suspended solid particles, liquid or solid.
  - Dust, smoke & various other species
  - Very small in size.

Composition of Atmosphere: Gases, Dry Air*



All other gases, 0.04%	
Carbon dioxide (CO_2)	0.035%
Neon (Ne)	0.0018%
Helium (He)	0.00052%
Methane (CH_4)	0.00014%
Krypton (Kr)	0.00010%
Nitrous oxide (N_2O)	0.00005%
Hydrogen (H_2)	0.00005%
Ozone (O_3)	0.000007%

KEY POINTS

- N_2 and O_2 make up ~ 99% of dry air
- Water vapor (H_2O is gaseous phase) varies from 1 – 4%
- CO_2 = 0.037% = 370 ppm (ppm, parts per million)
- Remaining trace gases very, very low percentages.

* “Dry Air” - excluding water vapor.

Composition of Atmosphere: Further Details

Chemical Species	Concentration	Source
N_2	78.08%	volcanic, biogenic
O_2	20.95%	biogenic
H_2O (gas)	up to 4% (avg ~2.5%)	volcanic, evaporation
Ar	0.93%	radiogenic
CO_2	0.037% (370 ppm_v)	volcanic, biogenic, anthropogenic
Ne	18 ppm_v	volcanic (possibly)
He	5.2 ppm_v	radiogenic
Kr	1 ppm_v	radiogenic
CO	50 – 200 ppm_v	biogenic, anthropogenic, photochemical
CH_4	1.7 ppm_v	biogenic, anthropogenic
NMHC	5 – 20 ppb_v	biogenic, anthropogenic, photochemical
CH_2O	0.1 ppb_v	photochemical
N_2O	310 ppb_v	biogenic, anthropogenic
NH_3	0 – 0.5 ppb_v	biogenic, anthropogenic
NO_x	0 – 0.5 ppb_v	biogenic, anthropogenic, lightning
OCS	0.5 ppb_v	volcanic, biogenic, anthropogenic
H_2S	0 – 0.5 ppb_v	biogenic, anthropogenic
SO_2	0.01 – 1 ppb_v	volcanic, anthropogenic, photochemical
DMS	0.01 – 0.1 ppb_v	biogenic

Nitrogen (N_2) and Oxygen (O_2): 99% of Dry Atmosphere
Water Vapor (H_2O): 1 – 4%

Carbon Dioxide (CO_2) – Greenhouse Gas (GHG)

Ar, Ne, He, Kr – "Inert Gases" (non-reactive)

Carbon Monoxide (CO) – From combustion, air pollutant

Methane (CH_4) – Strong GHG

"Non-Methane" Hydrocarbons (NMHC); a class of air pollutants

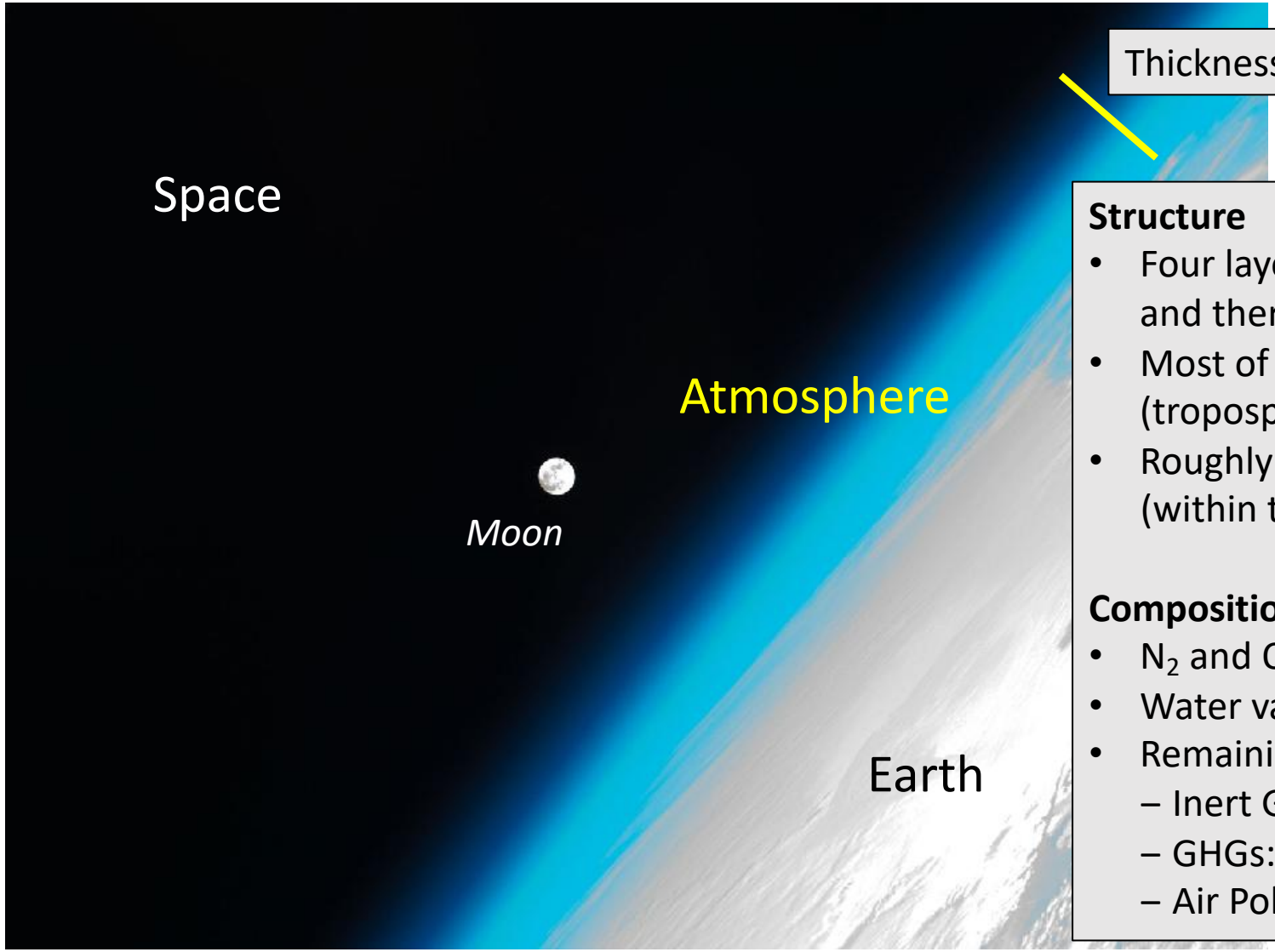
Ammonia (NH_3) – An air pollutant, industry & agriculture

Nitrogen Oxides (NO_x) – From combustion, an air pollutant

Hydrogen Sulfide (H_2S) – An air pollutant, rotten egg smell

Sulfur Dioxide (SO_2) – From coal combustion, an air pollutant

Summary



Thickness of atmosphere ~ 500 km

Structure

- Four layers: troposphere, stratosphere, mesosphere and thermosphere.
- Most of the mass is within the lowest 20 km (troposphere and stratosphere)
- Roughly half within lowest 5 km (within the “troposphere”)

Composition

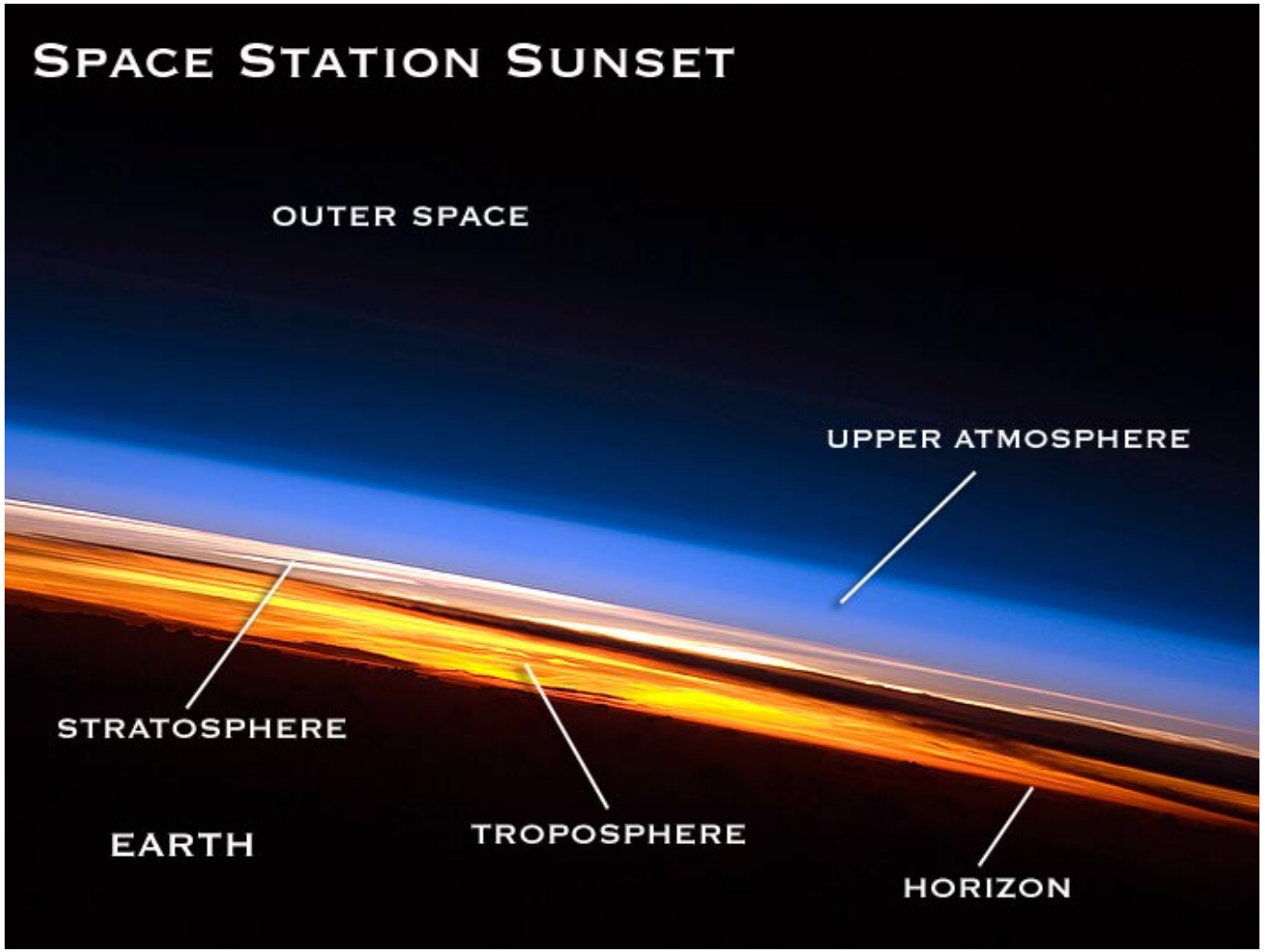
- N_2 and O_2: ~ 99% of dry gaseous composition
- Water vapor ~ 1 – 4%
- Remaining: “Trace Gases”
  - Inert Gases (e.g. Ar, Ne, Kr)
  - GHGs: Carbon Dioxide (CO_2) & Methane (CH_4)
  - Air Pollutants: e.g. SO_2, NO_x, CO, NH_3

Further Reading …

- https://www.space.com/17683-earth-atmosphere.html
- https://globalchange.umich.edu/globalchange1/current/lectures/Perry_Samson_lectures/evolution_atm/

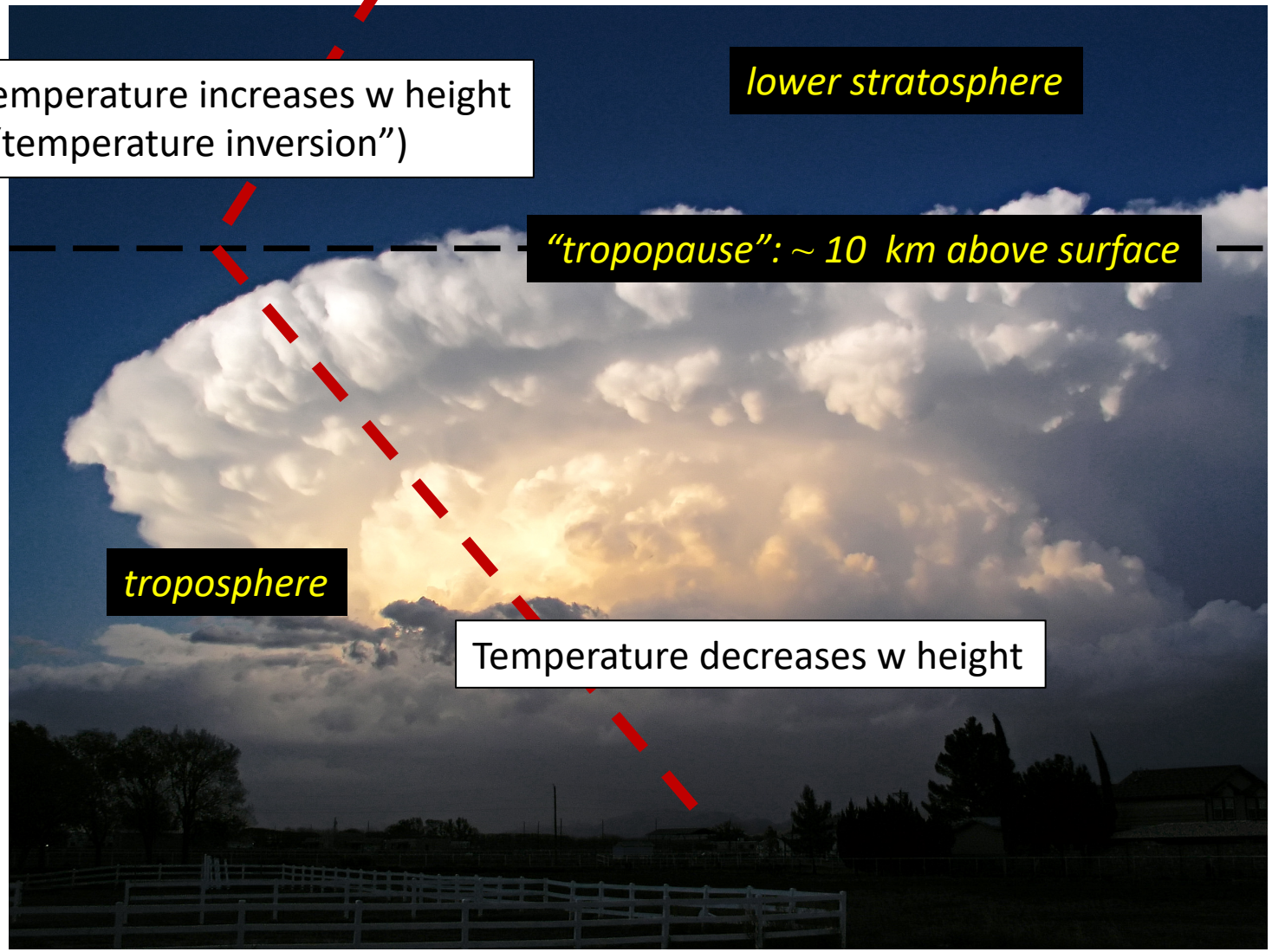
Related Topics

Atmospheric Layers: Viewed from Space at Sunset



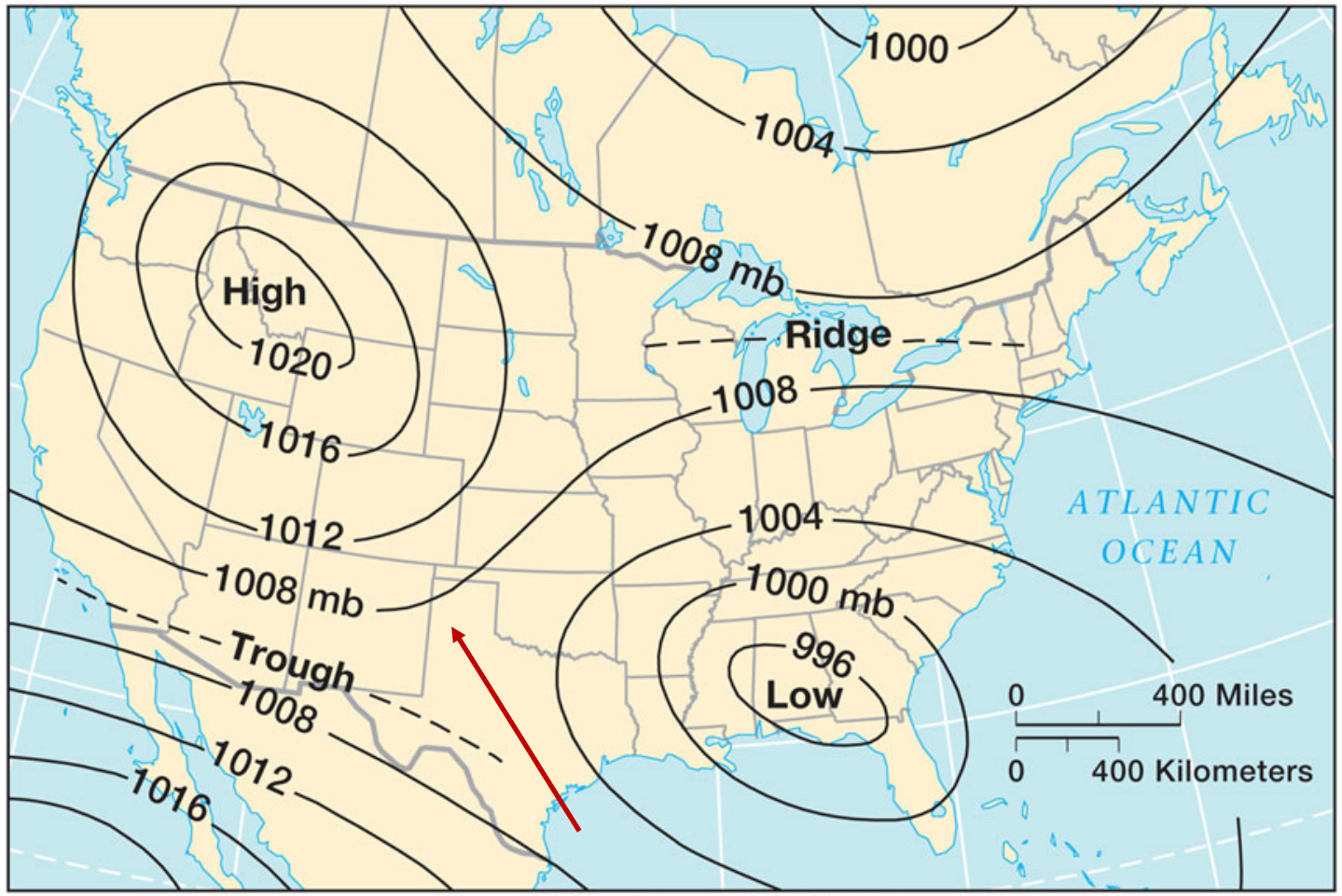
https://earthobservatory.nasa.gov/images/44267/sunset-from-the-international-space-station

The Troposphere



cumulus nimbus cloud
(thunderstorm)

Atmospheric Pressure: Weather Maps

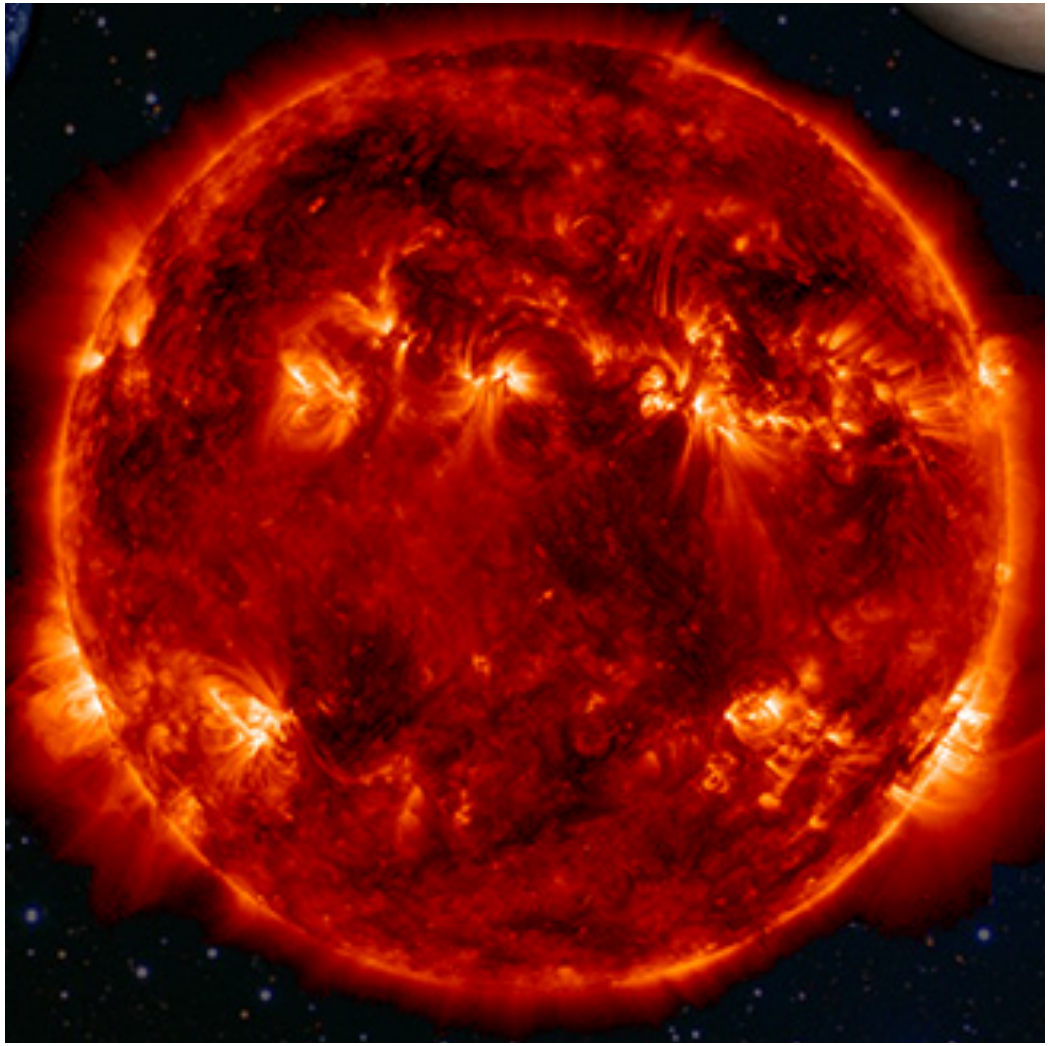


Isobars

- Lines of equal surface air pressure
- Helps identify weather systems.
- Low Pressure: Stormy weather
- High Pressure: Clear, non-stormy
- Air pollution episodes often associated with high pressure systems

(Example) 1008 mb isobar: everywhere along this line surface pressure equals 1008 millibars (mb)

The Sun: Composition



Element	Abundance (percentage of total number of atoms)	Abundance (percentage of total mass)
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.078	0.97
Carbon	0.043	0.40
Nitrogen	0.0088	0.096
Silicon	0.0045	0.099
Magnesium	0.0038	0.076
Neon	0.0035	0.058
Iron	0.0030	0.14
Sulfur	0.0015	0.040

https://solarsystem.nasa.gov/solar-system/sun/in-depth/

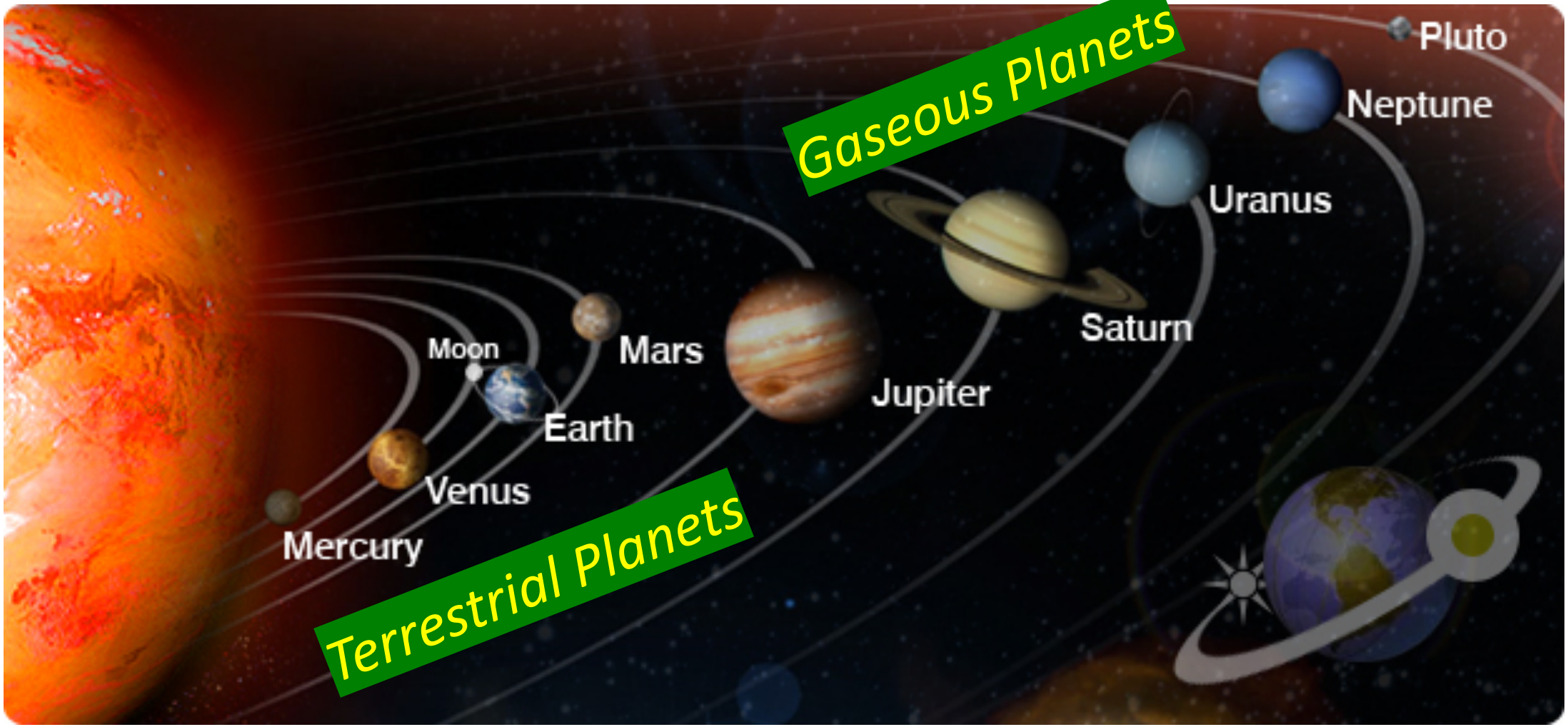
Auroras

(Absorption of charged particles from “solar wind” by N_2 and O_2 in Upper Atmosphere)
(Occur at high latitudes, produces stunning visuals called “auroras”)

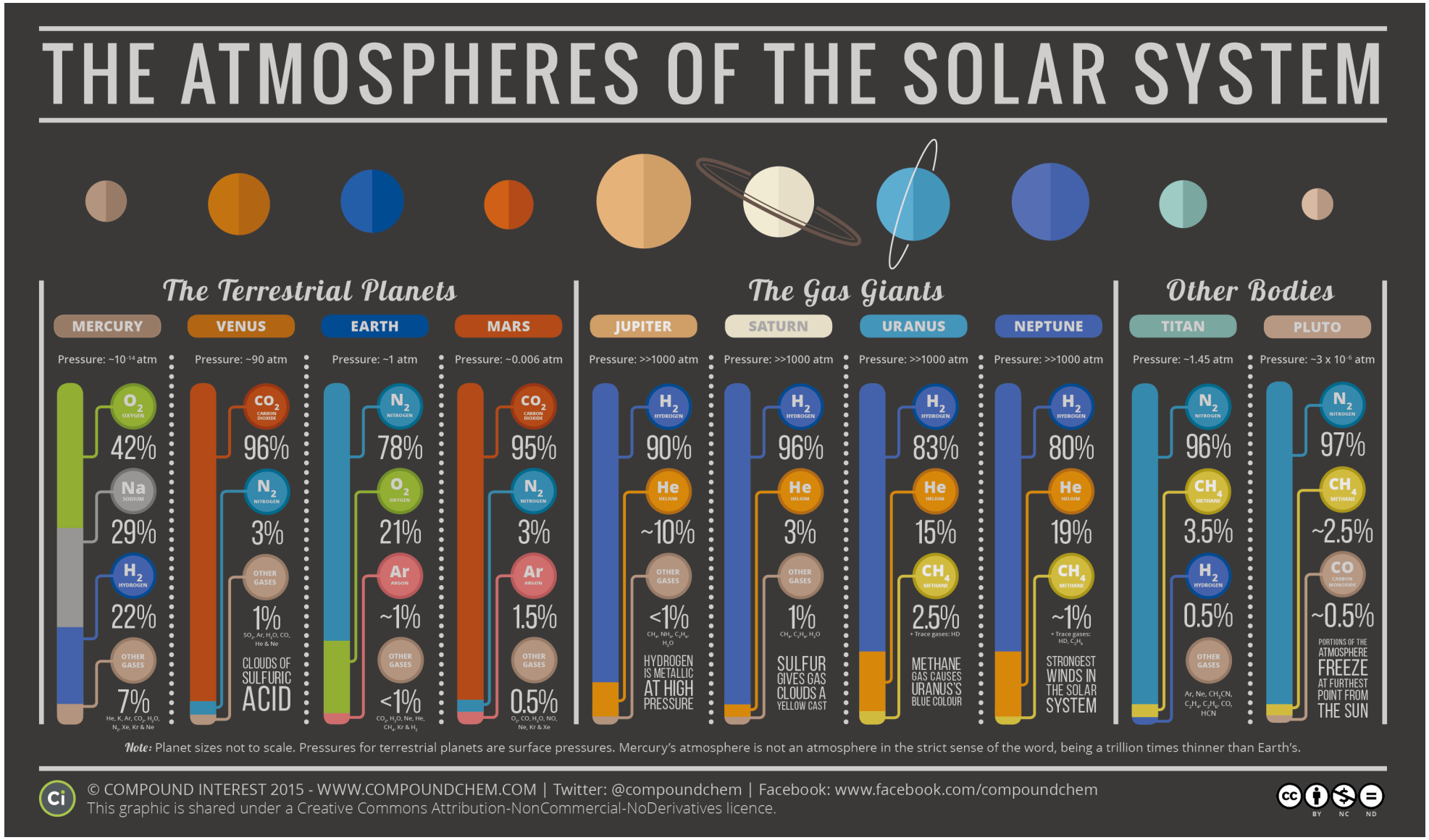
Aurora Borealis: Northern Hemisphere (“northern lights”)
Aurora Australis: Southern Hemisphere

https://www.nasa.gov/mission_pages/sunearth/aurora-news-stories/index.html

Atmospheres of Solar System Planets

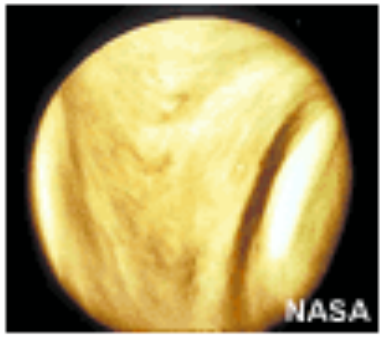


https://solarsystem.nasa.gov/news/436/10-things-planetary-atmospheres/

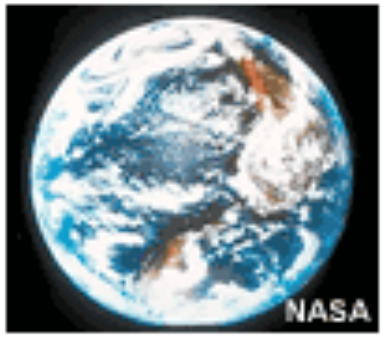


https://www.planetary.org/multimedia/space-images/charts/the-atmospheres-of-the-solar-system.html

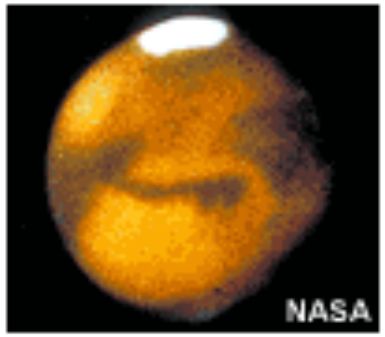
Our Nearest Neighbors: Venus, Mars vs. Earth



Venus



Earth



Mars

Carbon Dioxide (CO_2)	96.5%	0.03%	95%
Nitrogen (N_2)	3.5%	78%	2.7%
Oxygen (O_2)	Trace	21%	0.13%
Argon (Ar)	0.007%	0.9%	1.6%
Methane (CH_4)	0	0.002%	0

KEY POINTS

- Earth unique in that it has abundant oxygen (O_2)
- Venus and Mars are mostly carbon dioxide (CO_2)

Further Details: Venus, Mars vs. Earth

Planet	 Venus	 Earth	 Mars
T_{obs}, K (°C)	735 (462)	288 (15)	215 (-58)
Atmosphere: Pressure, kPa composition [trace gases]	9300 CO_2(0.965), N_2(0.035), [SO_2, Ar]	101 N_2(0.78), O_2(0.21), Ar(0.009), [CO_2, H_2O]	0.64 CO_2(0.95), N_2(0.03), Ar(0.02), [O_2, CO]

VENUS

- High pressure, thick CO_2 atmosphere
- Pressure ~ 90 times higher than on earth
- Very intense greenhouse effect (warms planet)
- High temperature (462 deg Celsius)

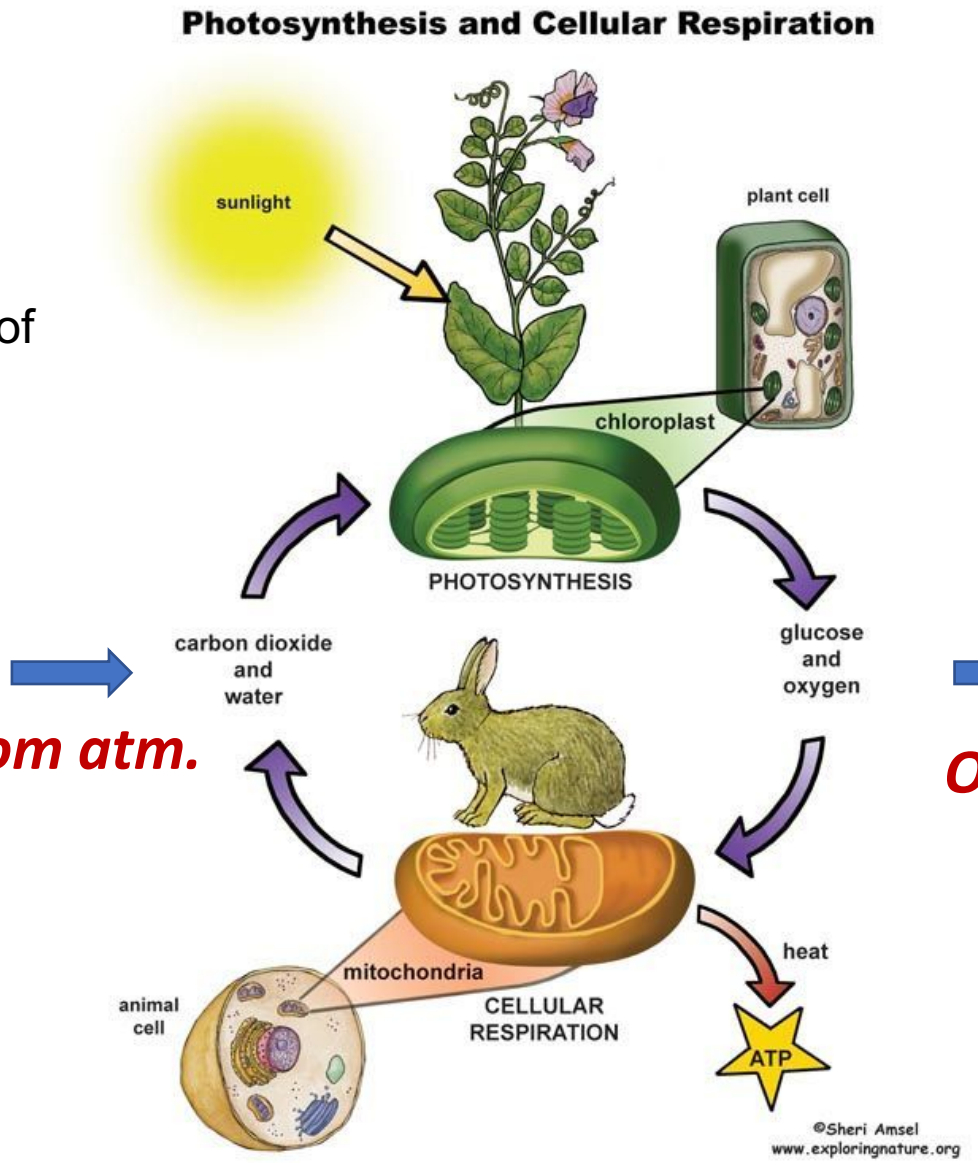
MARS

- Low pressure, thin atmosphere
- Pressure ~ 100 times lower than on earth
- Mostly CO_2, however little greenhouse effect since atmosphere thin
- Low temperature (-58 deg Celsius)

Earth's Life Cycle

Key Points

- Plant life evolved on earth, in during this period much of the CO_2 from early pre-life atmosphere on earth removed by photosynthesis. Oxygen outgassed to atmosphere.
- Source of O_2 in Earth's Atmosphere
- Requires water in liquid phase to occur.

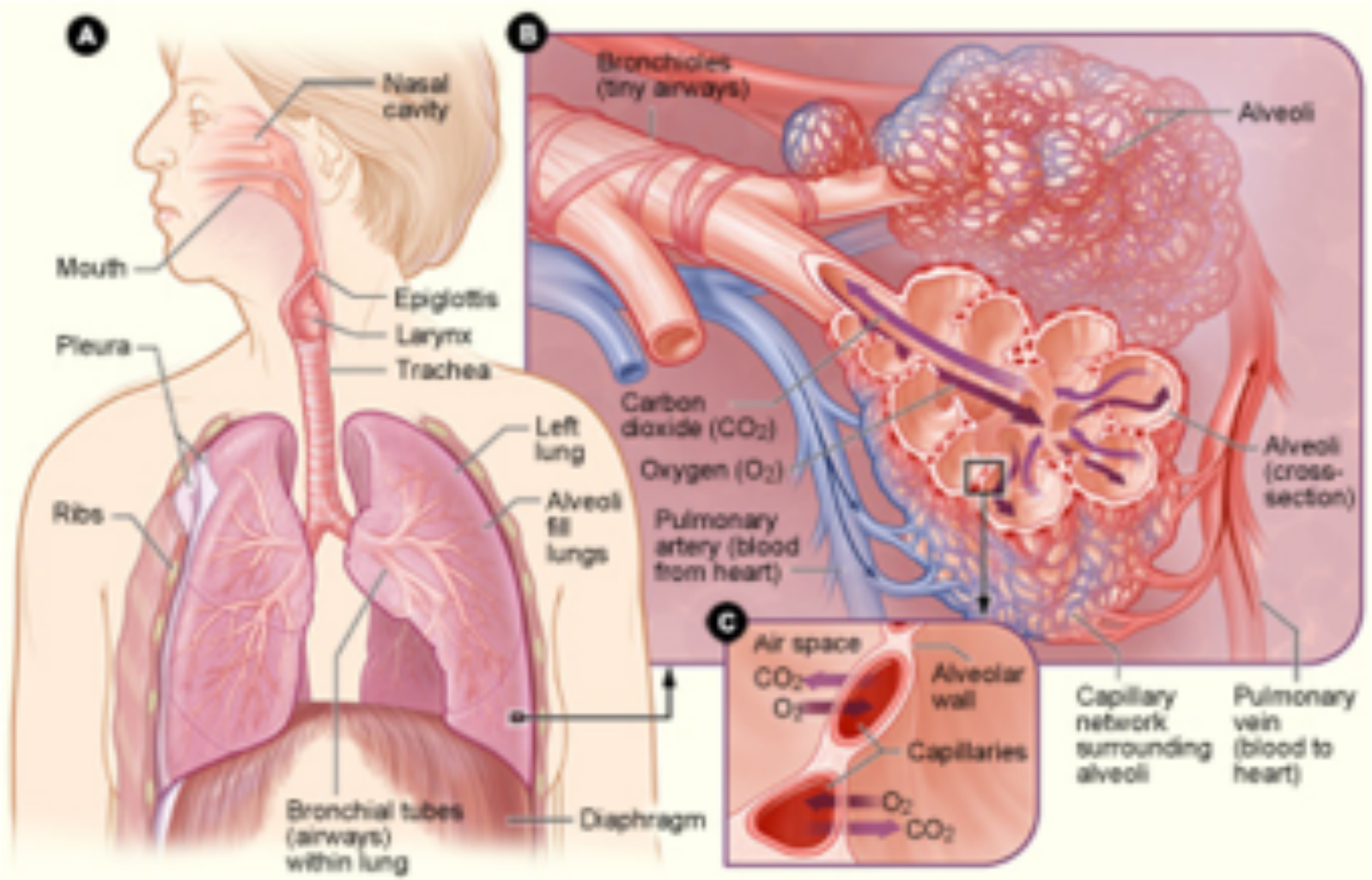


CO_2 from atm.

O_2 to atm.

https://en.wikipedia.org/wiki/Geological_history_of_oxygen

Human Respiratory System



A. **Air from mouth passes to lungs through Bronchioles, which terminate at alveoli**
B. **CO_2 / O_2 exchange during breathing occurs between capillaries and alveoli**
C. **Capillaries surround alveoli**

Too little O_2: Asphyxiation

- 19.5 – 23.5% O_2 in air optimal for human breathing
- As percentages reduce, increasing risks
  - 14 – 16% light-headed/ nausea
  - 10 – 14% fainting
  - < 10% risk of death
- Inert gases (Ar, Ne, He, Kr) often associated w asphyxiation since they are not detectible by human senses (non-odorous, do not directly impact health) and can displace oxygen at high concentrations.
- https://sciencing.com/minimum-oxygen-concentration-human-breathing-15546.html
- https://www.analoxsensortechnology.com/blog/2016/02/02/what-is-an-oxygen-depletion-sensor/

Rust: Example of corrosive effect of oxygen on ferrous metals*

Ferrous: containing iron