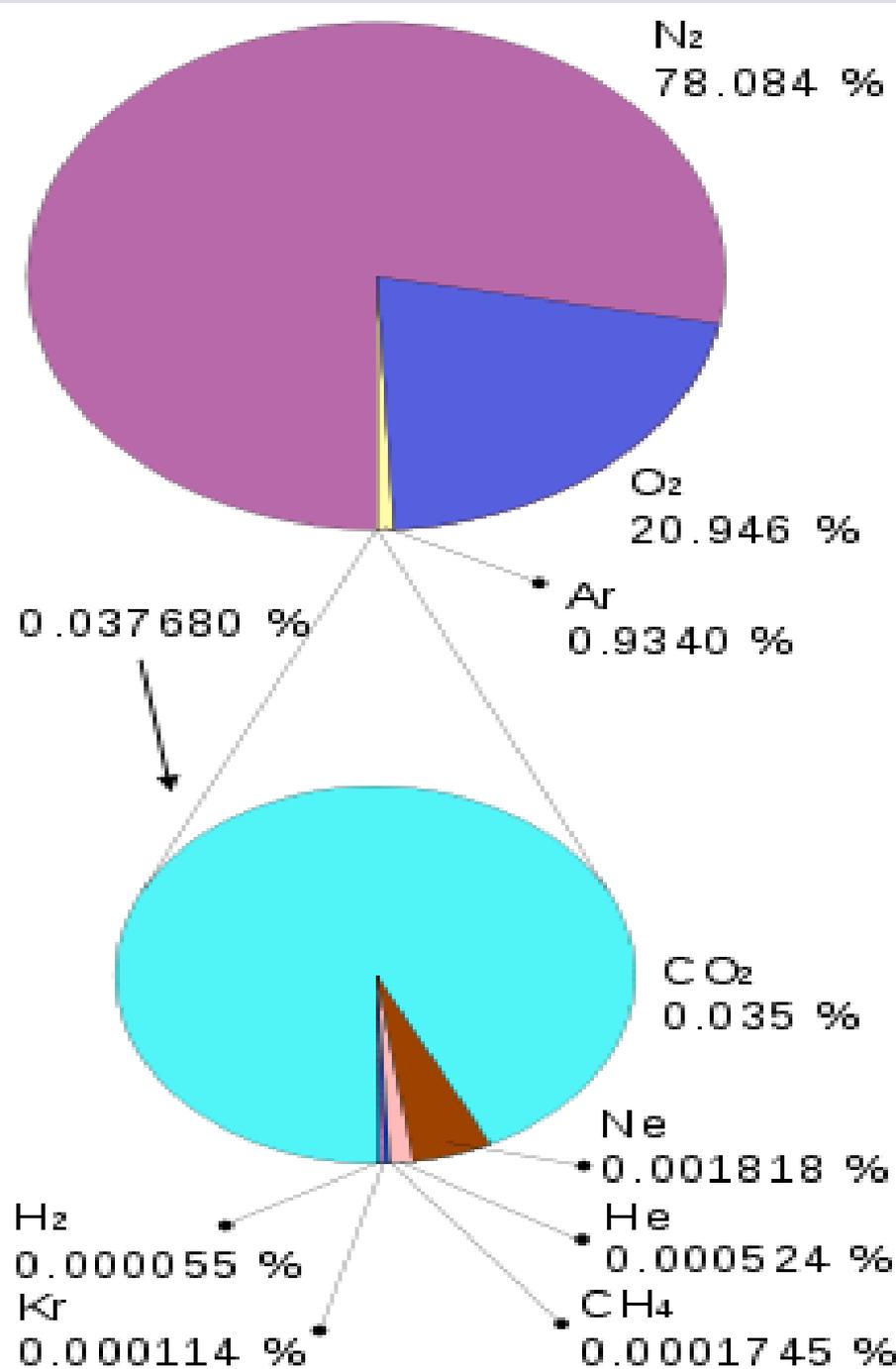


Atmosphere

# Introduction

- The **atmosphere of Earth** is a layer of gases surrounding the planet Earth that is retained by Earth's gravity.
- The atmosphere **protects life** on Earth by:
  - **absorbing ultraviolet solar radiation,**
  - **warming the surface through heat retention (greenhouse effect), and**
  - **reducing temperature extremes between day and night (the diurnal temperature variation).**

# COMPOSITION OF ATMOSPHERE



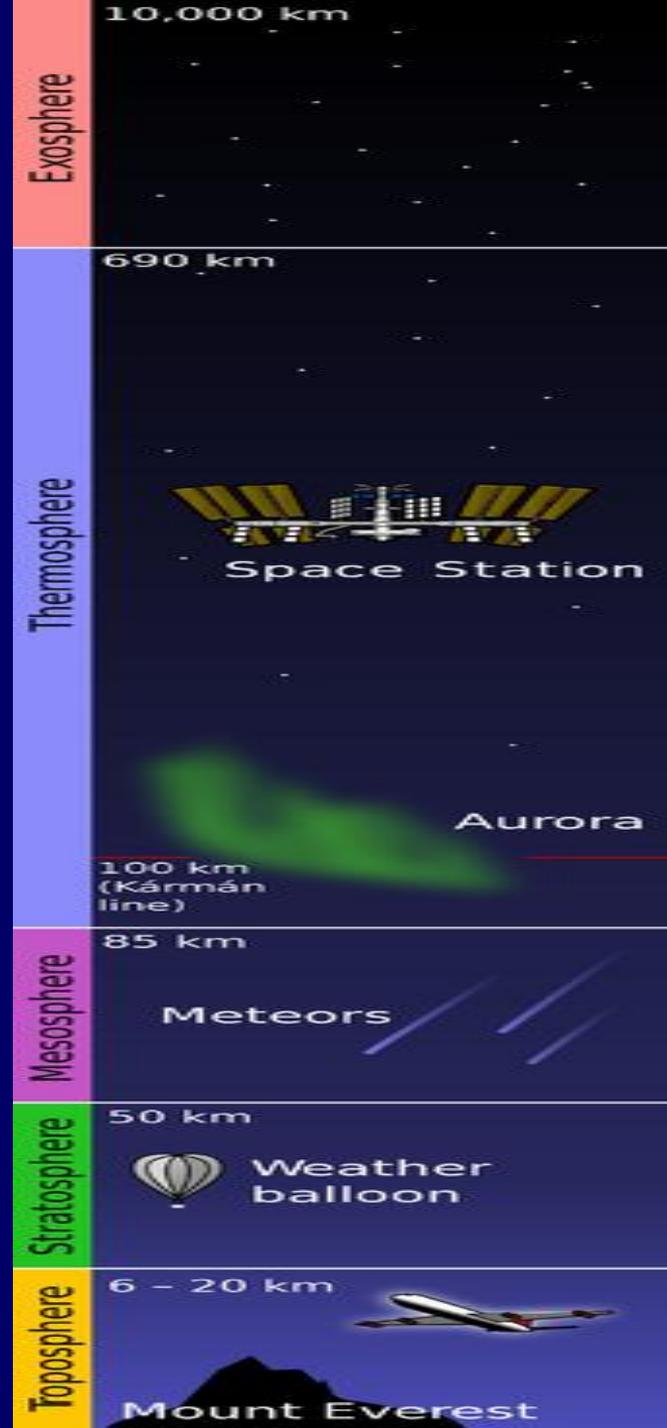
- The gaseous area surrounding the planet is divided into several **concentric strata or layers**.
- About **99%** of the total atmospheric mass is concentrated in the first 20 miles (**32 km**) above Earth's surface.
- Main two categories of layers in the atmosphere:
  - **THERMAL STRUCTURE**
  - **MAGNETO-ELECTRONIC STRUCTURE**

# Atmospheric stratification

- Atmospheric stratification describes the structure of the atmosphere, dividing it into distinct layers, each with specific characteristics such as **temperature or composition**.
- The atmosphere has a mass of about  $5 \times 10^{18}$  kg,
  - three quarters of which is within about **11 km** (6.8 mi; 36,000 ft) of the surface.
- The atmosphere becomes **thinner and thinner** with **increasing altitude**, with no definite boundary between the atmosphere and outer space.
- An altitude of **120 km (75 mi)** is where atmospheric effects become noticeable during atmospheric reentry of spacecraft.
- The **Kármán line**, at **100 km (62 mi)**, also is often regarded as the boundary between atmosphere and outer space.

- Temperature provides a useful metric to distinguish between atmospheric layers.
- In this way, Earth's atmosphere can be divided into **five** main layers. From **highest to lowest**, these layers are:

- **Exosphere**
- **Thermosphere**
- **Mesosphere**
- **Stratosphere**
- **Troposphere**
- **Other layers**
  - ozone layer
  - ionosphere,
  - The planetary boundary layer



# THERMAL STRUCTURE

- Exosphere
- Thermosphere
- Mesosphere
- Stratosphere
- Troposphere

# MAGNETO-ELECTRONIC STRUCTURE

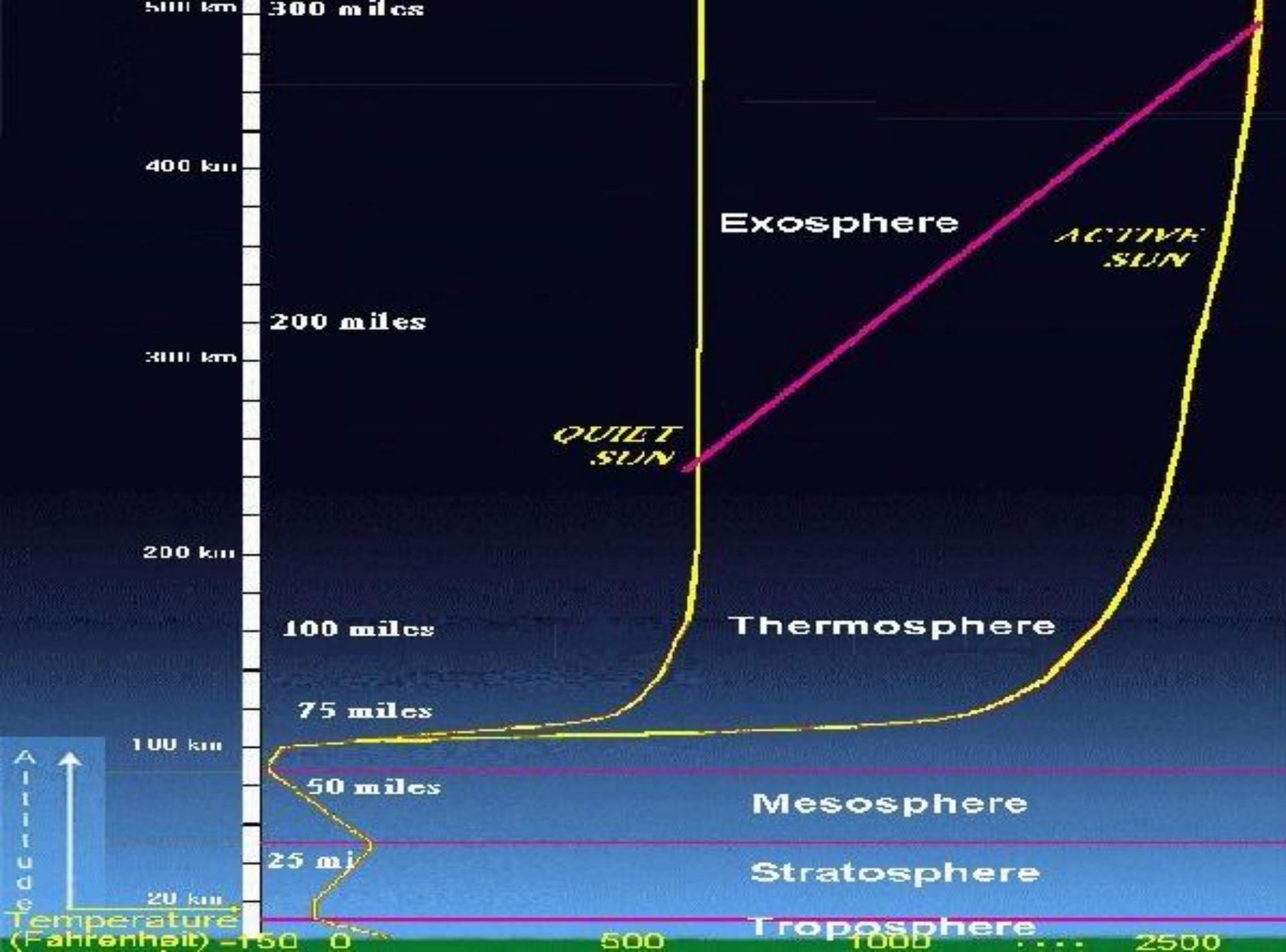
- The upper atmosphere is also divided into regions based on the behavior and number of free electrons and other charged particles.
  - **Ionosphere**
    - *D-region*
    - *E-region*
    - *F-region*
  - **Plasmasphere**
  - **Magnetosphere**

# Troposphere

- The heights of troposphere from earth surface:
  - At poles 9 km (30,000 ft)
  - At equator 17 km (56,000 ft) with some variation due to weather.
- Its height also varies with the seasons;
  - highest in the summer and
  - lowest in the winter.
- The troposphere is mostly heated by transfer of energy from the surface,
  - so on average the lowest part of the troposphere is warmest and
  - temperature decreases with altitude.

- This promotes **vertical mixing** (hence the origin of its name in the Greek word *trope*, meaning **turn or overturn**).
- The troposphere contains roughly **80%** of the **mass of the atmosphere**.
- The **tropopause** is the boundary between the troposphere and stratosphere.
- Temperature and water vapor content in the troposphere decrease rapidly with altitude.

- Water vapor plays a major role in regulating air temperature because it absorbs solar energy and thermal radiation from the planet's surface.
- The troposphere contains 99 % of the water vapor in the atmosphere.
- Water vapor concentrations vary with latitude.
- They are greatest above the tropics, where they may be as high as 3 %, and decrease toward the polar regions.



# Stratosphere

- The stratosphere is the second major strata of air in the atmosphere.
- The stratosphere extends from the **tropopause** to **about 51 km (32 mi; 170,000 ft)** above the planet's surface.
- The air temperature in the stratosphere remains relatively constant up to an altitude of 15 miles (25 km).
- Then it increases gradually to up to the *stratopause*.
- Temperature **increases with height** due to increased absorption of ultraviolet radiation by the ozone layer.
- Temperature may be **-60 °C (-76 °F; 210 K)** at the tropopause,
- The top of the stratosphere is much warmer, and may be **near freezing**

- The **stratopause**, which is the boundary between the stratosphere and mesosphere, typically is at 50 to 55 km (31 to 34 mi; 160,000 to 180,000 ft).
- The pressure here is **1/1000 sea level**.
- Ozone plays the major role in regulating the thermal regime of the stratosphere,
  - as **water vapor** content within the layer is **very low**.
  - **Temperature** increases with **ozone concentration**.
  - **Solar energy** is converted to **kinetic energy** when ozone molecules absorb ultraviolet radiation,
  - resulting in heating of the stratosphere.

- The *ozone layer* is centered at an altitude between **15-25 km**.
- Approximately **90 %** of the ozone in the atmosphere resides in the **stratosphere**.
- Ozone concentration in this region is about **10 parts per million by volume (ppmv)** as compared to **approximately 0.04 ppmv** in the troposphere.
- Ozone absorbs the bulk of solar ultraviolet radiation in wavelengths from **290 nm - 320 nm** (UV-B radiation).
- These wavelengths are harmful to life because they can be absorbed by the nucleic acid in cells and **triggers cancer**

# Mesosphere

- The mesosphere extends from the stratopause to **80-85 km** (50-53 mi; 260,000-280,000 ft) above the planet's surface.
- It is the layer where most **meteors** burn up upon entering the atmosphere.
- **Temperature decreases with height in the mesosphere.**
- The **mesopause**, the temperature minimum that marks the top of the mesosphere, is **the coldest place** on Earth and has an average temperature around **-85 °C (-120 °F; 190 K).**

- At the **mesopause**, temperatures may drop to **-100°C** (-150 °F; 170 K).
- Due to the cold temperature of the mesosphere, **water vapor is frozen**, forming **ice clouds** (or **Noctilucent clouds**).
- A type of lightning referred to as either **sprites** or **ELVES**, form many miles above thunderclouds in the troposphere.

- The mesosphere has sometimes jocularly been referred to as the "**ignorosphere**" because it had been probably the least studied of the atmospheric layers.
- The stratosphere and mesosphere together are sometimes referred to as the ***middle atmosphere***.

# Thermosphere

- Temperature increases with height in the thermosphere from the mesopause up to the thermopause, then is constant with height.
- Unlike in the stratosphere, where the inversion is caused by absorption of radiation by ozone, in the thermosphere the inversion is a result of the extremely low density of molecules.
- The temperature of this layer can rise to 1,500 °C (2,700 °F), depending on solar activity.

- The air is so rarefied that an individual molecule (of oxygen, for example) travels an average of 1 kilometer between collisions with other molecules.
- 
- The International Space Station orbits in this layer, between 320 and 380 km (200 and 240 mi).
- Because of the relative infrequency of molecular collisions, air above the mesopause is poorly mixed compared to air below.

- While the composition from the troposphere to the mesosphere is fairly constant, above a certain point, air is poorly mixed and becomes compositionally stratified.
- The point dividing these two regions is known as the **turbopause**.
- The **region below** is the **homosphere**, and the region above is the **heterosphere**.
- The top of the thermosphere is the bottom of the exosphere, called the **exobase**.
- Its **height varies with solar activity** and ranges from about 350-800 km (220-500 mi; 1,100,000-2,600,000 ft).

- This increase in temperature is due to the absorption of intense solar radiation by the limited amount of remaining molecular oxygen.
- Above 100 km (60 miles ) from Earth's surface the chemical composition of air becomes strongly dependent on altitude and the atmosphere becomes enriched with lighter gases (atomic oxygen, helium and hydrogen).

- Also at **100 km (60 miles )** altitude, Earth's atmosphere becomes too thin to support aircraft and vehicles need to travel at orbital velocities to stay aloft.
- This demarcation between aeronautics and astronautics is known as the Karman Line.
- Above about **160 km (100 miles )** altitude the major atmospheric component becomes **atomic oxygen**.
- At very high altitudes, the residual gases begin to stratify according to molecular mass, because of gravitational separation.

# Exosphere

- The outermost layer of Earth's atmosphere extends from the **exobase upward**.
- It is mainly composed of **hydrogen** and **helium**.
- The particles are so far apart that they can travel hundreds of kilometers without colliding with one another.

- Since the particles rarely collide, the atmosphere no longer behaves like a fluid.
- These free-moving particles follow ballistic trajectories and may migrate into and out of the magnetosphere or the solar wind.
- The exosphere is the **most distant atmospheric region** from Earth's surface.
- In the exosphere, an upward travelling molecule **can escape to space** (if it is moving fast enough) or be pulled back to Earth by gravity (if it isn't) with little probability of colliding with another molecule.

- The altitude of its lower boundary, known as the *thermopause* or *exobase*, ranges from about **250-500 km** (150 to 300 miles) depending on solar activity.
- The upper boundary can be defined theoretically by the altitude (about 120,000 miles, half the distance to the Moon) at which the influence of solar radiation pressure on atomic hydrogen velocities exceeds that of the Earth's gravitational pull.
- The exosphere observable from space as the geocorona is seen to extend to at least 60,000 miles from the surface of the Earth.
- The exosphere is a **transitional zone** between Earth's atmosphere and interplanetary space.

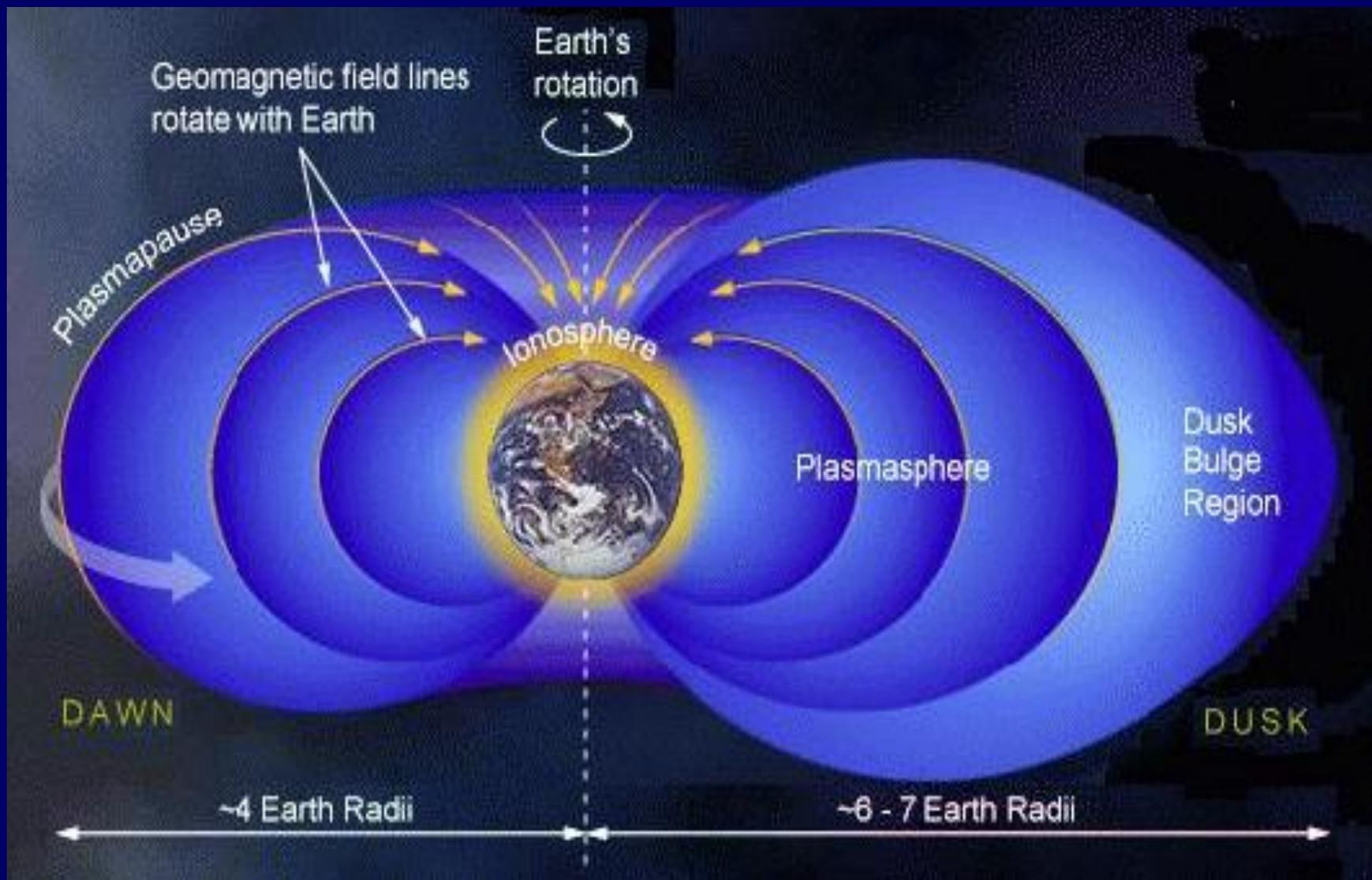
# Ionosphere

- The ionosphere is defined by atmospheric effects on **radiowave propagation** as a result of the presence and variation in concentration of free electrons in the atmosphere.
  - ***D-region***: 60 - 90 km (35 to 55 miles ) in altitude but disappears at night.
  - ***E-region***: 90 - 140 km (55 to 90 miles ) in altitude.

- *F-region* : above 140 km (90 miles ) in altitude. During the *day* it has two regions:
  - *F<sub>1</sub>-region* : 140 to 180 km (90 to 115 miles )
  - *F<sub>2</sub>-region* : around 250 to 500 km (150 to 300 miles ) in which the concentration of electrons peaks
- The ionosphere above the peak electron concentration is usually referred to as the *Topside Ionosphere*.

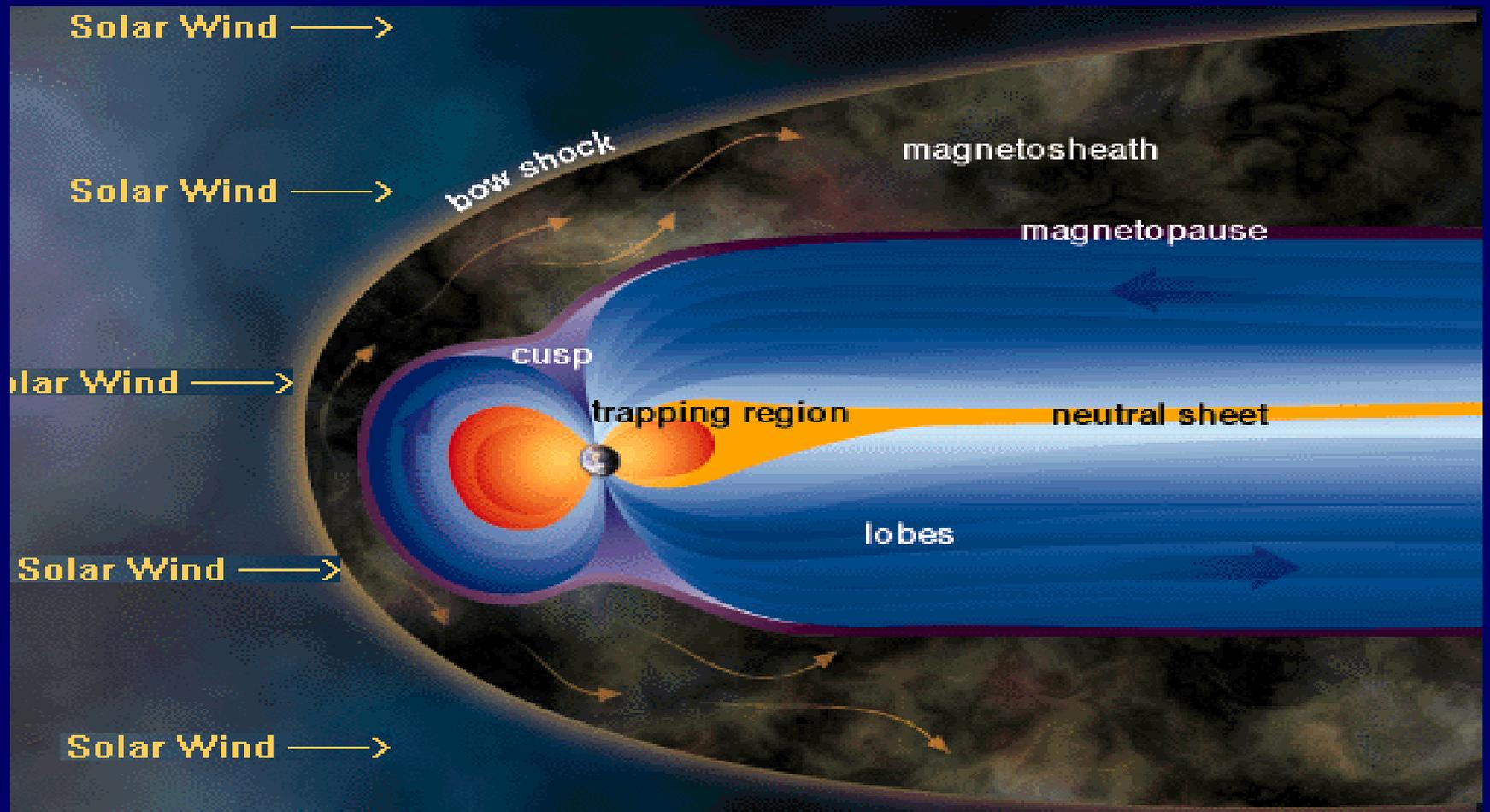
# Plasmasphere

- The plasmasphere is not really spherical but a doughnut-shaped region (a torus) with the hole aligned with Earth's magnetic axis.
- The Earth's plasmasphere is made of just that, a plasma, the fourth state of matter.
- This plasma is composed mostly of hydrogen ions (protons) and electrons.
- It has a very sharp edge called the *plasmopause*.
- The outer edge of this doughnut over the equator is usually some 4 to 6 Earth radii from the center of the Earth or **19,000-32,000 km** (12,000-20,000 miles) above the surface.
- Inside of the plasmopause, **geomagnetic field lines rotate with the Earth**.
- The inner edge of the plasmasphere is taken as the altitude at which **protons replace oxygen** as the dominant species in the ionospheric plasma which usually occurs at about 1000 km (600 miles ) altitude. The plasmasphere can also be considered to be a structure within the magnetosphere.



# Magnetosphere

- Outside the plasmapause, magnetic field lines are **unable to corotate** because they are influenced strongly by **electric fields of solar wind origin**.
- The magnetosphere is a cavity (also not spherical) in which the Earth's magnetic field is **constrained** by the **solar wind** and **interplanetary magnetic field (IMF)**.
- The **outer boundary** of the magnetosphere is called the **magnetopause**.
- The magnetosphere is shaped like an **elongated teardrop** (like a Christmas Tree ornament) with the **tail pointing away from the Sun**.



- The magnetopause is typically located at about 10 Earth radii or some **56,000 km** (about 35,000 miles ) above the Earth's surface on the day side and stretches into a long tail, the **magnetotail**, a few million miles long (about 1000 Earth radii), well past the orbit of the Moon (at around 60 Earth radii), on the night side of the Earth. However, the Moon itself is usually not within the magnetosphere except for a couple of days around the Full Moon.
- Beyond the magnetopause are the **magnetosheath** and **bow shock** which are regions in the solar wind disturbed by the presence of Earth and its magnetic field.
- **\*Mean earth radius is 6,371 km**