Space & Atmospheric Physics

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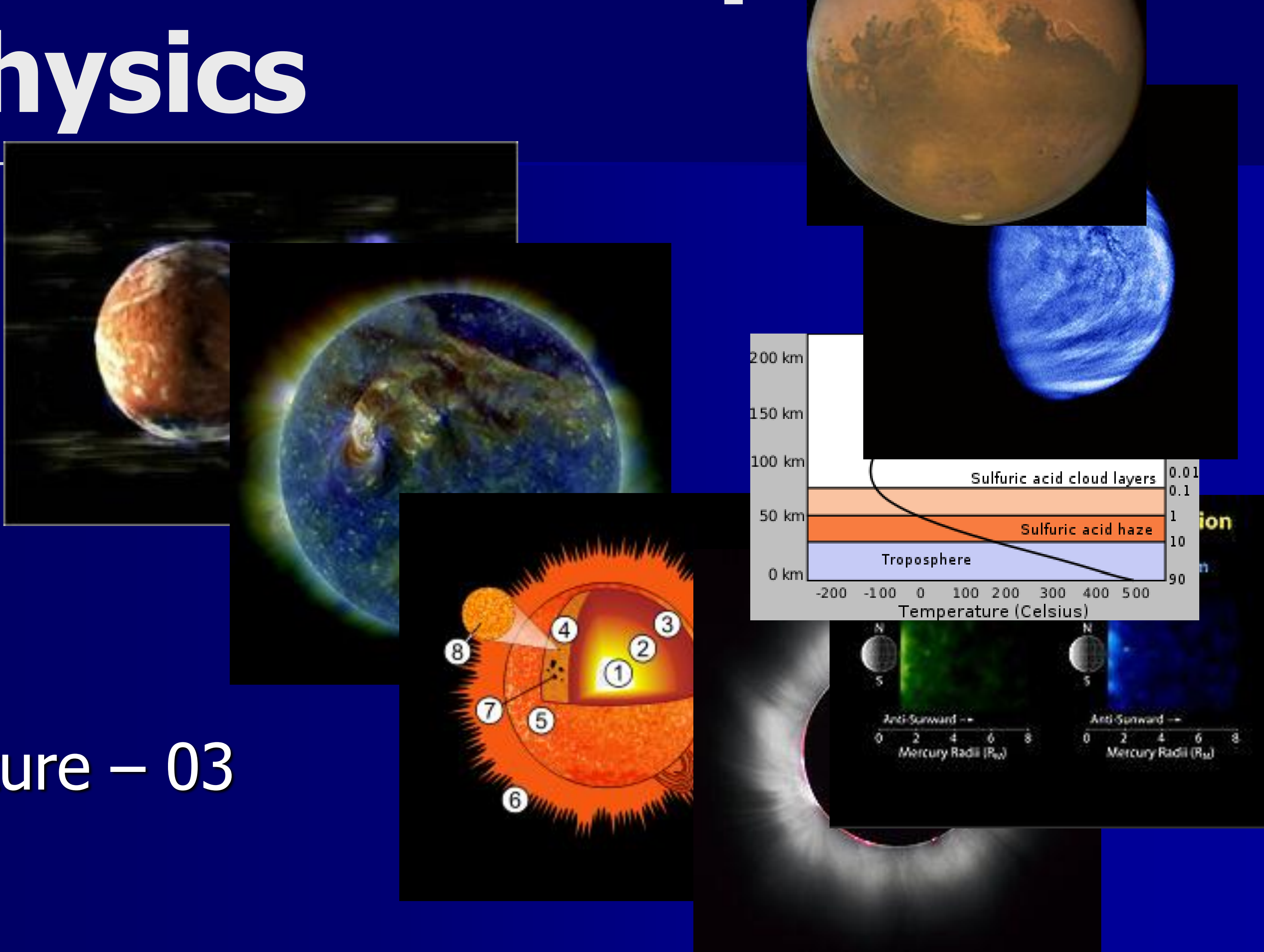


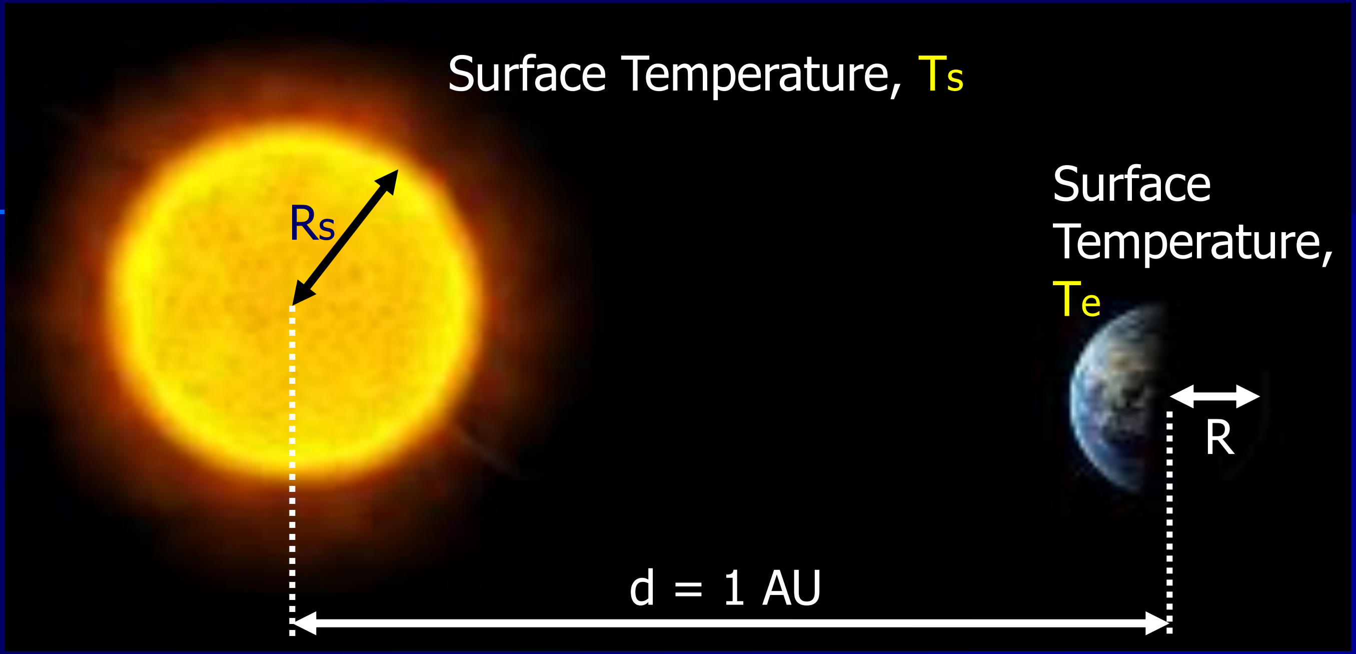
Lecture – 03

Planetary Atmospheres

Planetary Atmospheres

- Formation and Evolution of Planetary Atmospheres
- The Structure of the Terrestrial Atmosphere
- **The Temperature of the Neutral Atmosphere**
- The Escape of the Atmospheric Gases
- The Atmospheres of the Planets

The Temperature of the Neutral Atmosphere



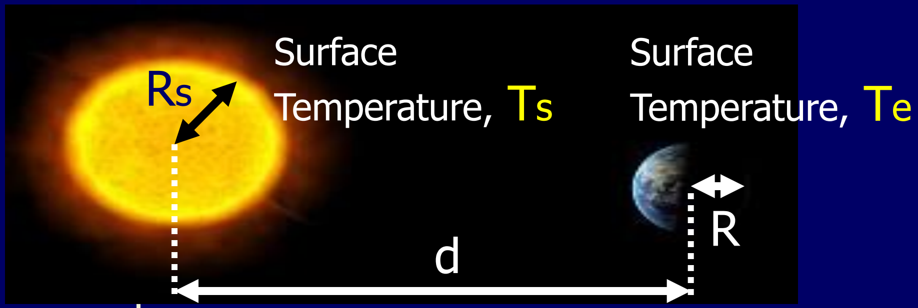
AL Method

$$\sigma = 5.67 \times 10^{-8} \, Js^{-1}m^{-2}K^{-4}$$

$$T_S = 5778\,K \quad (\sim 6000\,K)$$

$$R_S = 695500 \; km \quad (\sim 7 \times 10^5 \; km)$$

$$d = 149\,598\,000 \; km \quad (1\,AU)$$



Using Stephan's Law;

The **Energy** emitted per unit area, per second by the Sun =

$$E = \sigma T_S^{\ 4}$$

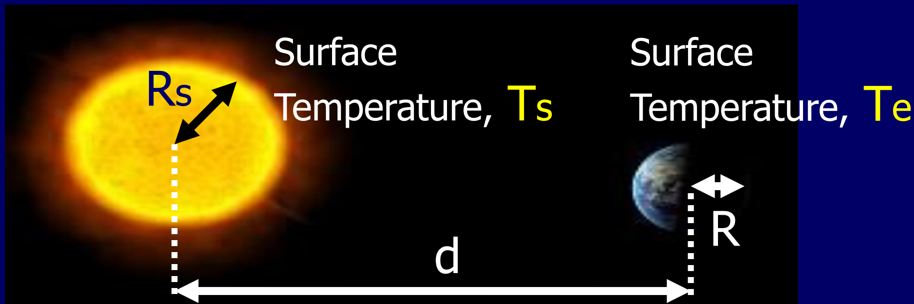
The **Total Energy** emitted per second by the Sun =

$$\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}$$

The Energy Density per second (Energy per unit area) at our orbit =

$$\frac{\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}}{4\pi d^2}$$

Where this ***d*** is distance from the Sun to the Earth's Orbit (1.0 AU)

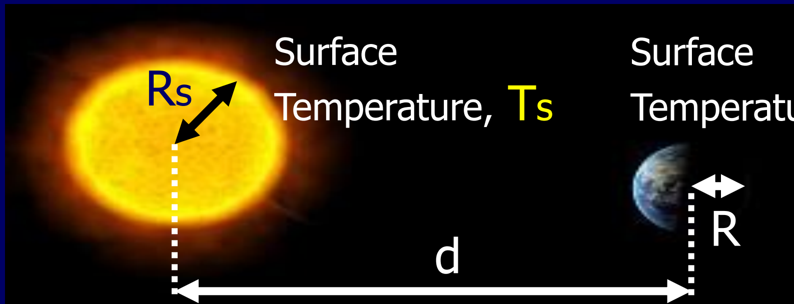


Using Stephan's Law

The Total Energy to the Earth = $\dfrac{\sigma T_S^{\;4} \times 4\pi R_S^{\;2}}{4\pi d^2} \times \pi R^2$ → 1

The Energy absorbed by the Earth = $e\sigma T_e^{\;4} \times 2\pi R^2$ → 2

Where this ***e*** is emissivity of the Earth (Factor per BB, for BB ; e=1)



Connect equation 1 & 2 ;

$$\frac{\sigma T_S^{\,4} \times 4\pi R_S^{\,2}}{4\pi d^2} \times \pi R^2 = e\,\sigma T_e^{\,4} \times 2\pi R^2$$

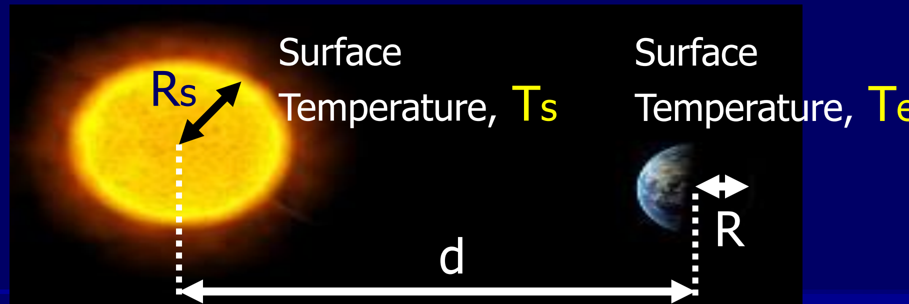
Where *e* should be [0 – 1]

$$T_e^{\,4} = \frac{\sigma T_S^{\,4} \times 4\pi R_S^{\,2} \times \pi R^2}{4\pi d^2 \times e\ \sigma \times 2\pi R^2}$$

$$T_e = \left(\frac{T_S^{\,4} \times R_S^{\,2}}{e\ d^2 \times 2} \right)^{1/4}$$

$$T_e = \{1047.62, 589.123, 393.97, 340.13, 332.121, 331.288\}\ C$$

???



Space Physics 01.nb * - Wolfram Mathematica 10.0

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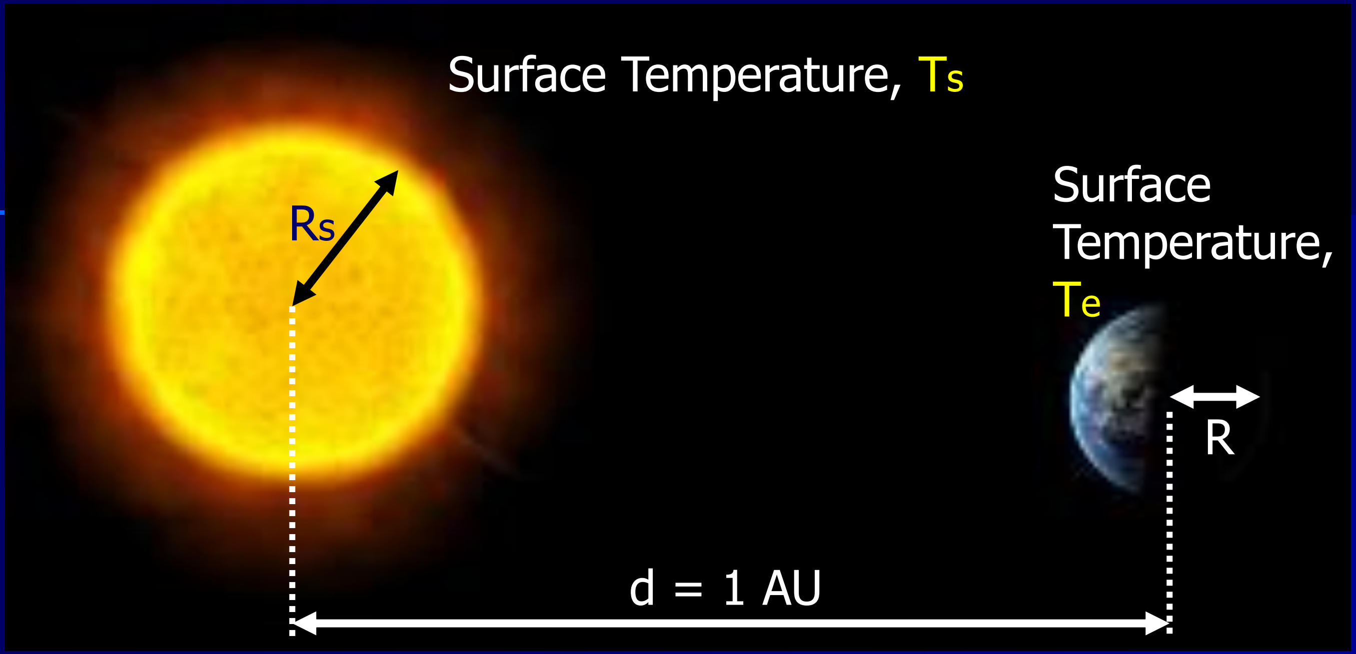
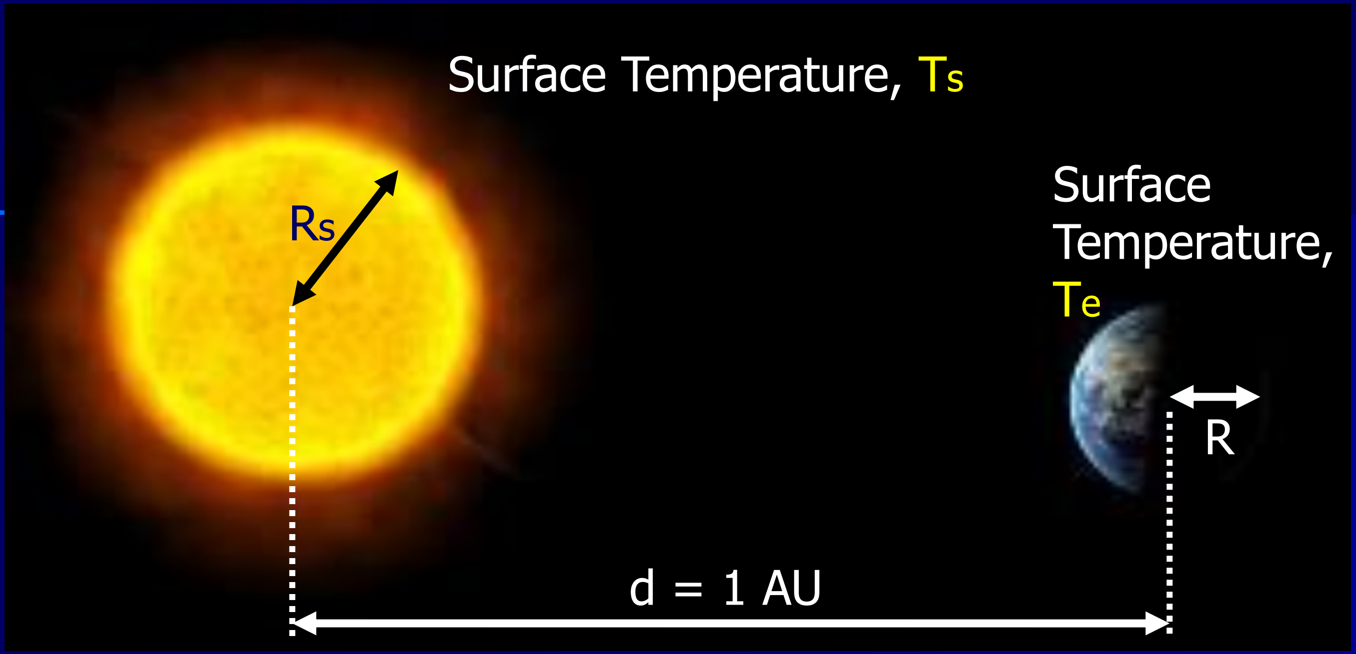
```
In[61]:= sig = 5.67 * (10 ^ (-8)); (* in J/s m^2 K^4 *)
ts = 5778; (* in K *)
rs = 695 500 * 1000; (* in m *)
re = 6400 * 1000; (* in m *)
d = 149 598 000 * 1000; (* in m *)
e = {0.01, 0.1, 0.5, 0.9, 0.99, 1.0} ; (* e in between 0 and 1 *)

te = (  ((ts ^ 4) * (rs ^ 2)) / (e * (d ^ 2) * 2)  ) ^ (1 / 4);
Print["Temperature on the Earth is : ", te - 273, " C"]

Temperature on the Earth is : {774.625, 316.123, 120.97, 67.1301, 59.1214, 58.288} C
```

The Temperature of the Neutral Atmosphere



Let us first consider the Earth as a rapidly rotating solid sphere of radius *R*. Let the reflectivity of this sphere be such that it reflects a fraction *A* (Albedo) and absorbs the remaining fraction (*1 – A*) of the incoming solar radiation. Let the sphere also radiate like a black body at an effective temperature *Te*.

The Temperature of the Neutral Atmosphere



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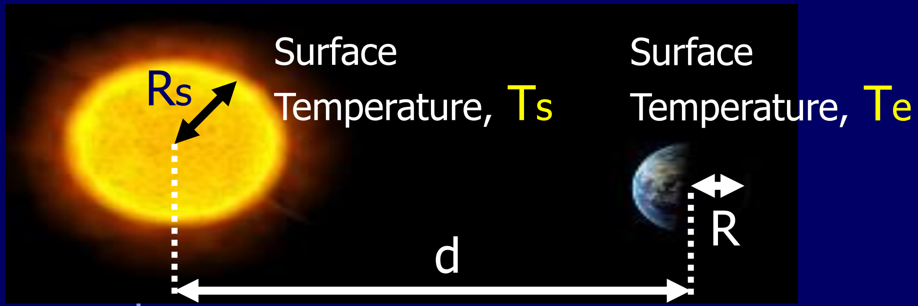
The Energy absorbed by the Earth = $\sigma T_e^4 \times 4\pi R^2$

Using Stephan's Law



The Energy emitted by the Earth = $(1-A)\times S_o \times \pi R^2$

Where So is the Solar Flux at 1AU.

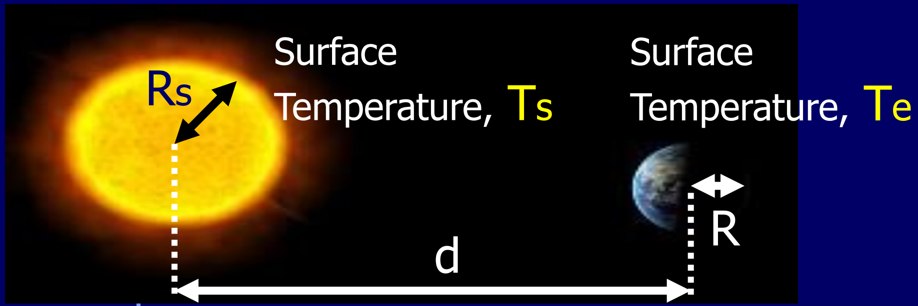
Under condition of thermal equilibrium;

The Energy absorbed by the Earth = The Energy emitted by by the Earth

$$\sigma T_e^{\,4}\times 4\pi R^2 = (1-A)\times S_o \times \pi R^2$$

$$4\sigma T_e^{\,4} = (1-A)S_o \longrightarrow 1$$

The Total Energy emitted per second by the Sun = $\sigma T_S^{\,4}\times 4\pi R_S^{\,2}$



The Total Energy emitted per second by the Sun =

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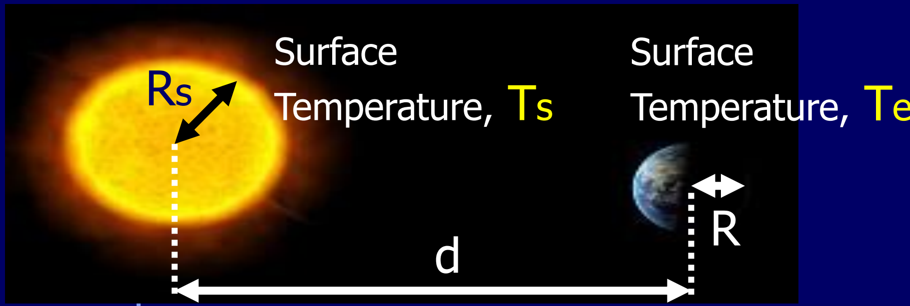
The Energy Density (Energy per unit area) at our orbit =

$$\frac{\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}}{4\pi d^2}$$

This is called Solar Flux, *So* at 1AU (at *d* or at our orbit)

$$\therefore \quad S_o = \sigma T_S^{\ 4} \left(\frac{R_S}{d} \right)^2 \longrightarrow 2$$



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This is called Solar Flux, *So* at 1AU (at *d* or at our orbit)

$$\therefore \quad S_o = \sigma T_S^{\,4}\left(\frac{R_S}{d}\right)^2 \longrightarrow 2$$

Connect equation 1 & 2 ;

$$\Rightarrow \quad 4\sigma T_e^{\,4} = (1-A)S_o \quad \Rightarrow \quad 4\sigma T_e^{\,4} = (1-A)\ \sigma T_S^{\,4}\left(\frac{R_S}{d}\right)^2$$

$$\Rightarrow \quad T_e^{\,4} = \frac{(1-A)}{4}\left(\frac{R_S}{d}\right)^2 T_S^{\,4} \quad \Rightarrow \quad T_e = \left(\frac{R_S}{d}\right)^{1/2}\left(\frac{1-A}{4}\right)^{1/4} T_S$$

Solar Flux at 1 AU

$$S_o = \sigma T_S^{\,4}\left(\frac{R_S}{d}\right)^2$$

Where,

$$\sigma = 5.67\times10^{-8}\ Js^{-1}m^{-2}K^{-4}$$

$$T_S = 5778\,K\ \ (\sim 6000\,K)$$

$$R_S = 695500\ km\ (\sim 7\times10^5\ km)$$

$$d = 149\,598\,000\,km\ \ (1AU)$$

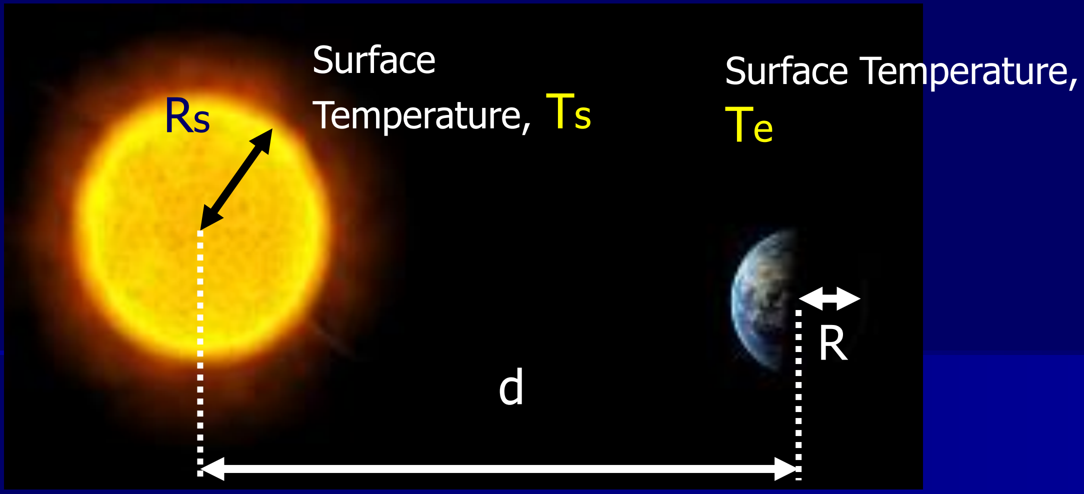
$$\Rightarrow\ S_o = 1365.95\ \ Jm^{-2}s^{-1}$$ in our orbit…

The value of the effective temperature of the Earth,

$$T_e = \left(\frac{R_S}{d}\right)^{1/2}\left(\frac{1-A}{4}\right)^{1/4} T_S$$

Where, $A = 0.4$ Albedo of the Earth…

$$\Rightarrow\ T_e = 245.181\,K$$



The value of the effective temperature of the Earth,

$$T_e = 245.181\,K$$

The value of Te is ~ 245 K. It is approximately 45 K lower than the average ground temperature, Tg (Tg = 290 K) of the Earth.

The difference is due to the Green House Effect of the terrestrial atmosphere which act as follows.

The incident Solar radiation has its maximum intensity in the visible portion of the spectrum and passes with practically no attenuation through the transparent atmosphere of the Earth. Thus, the (1 – A) fraction of the Solar radiation that is not reflect back, is absorbed by the ground and heats it up. The Earth radiates as a black body at a temperature Tg = 290 K , which is the average temperature of its surface. At Tg = 290 K most of the emitted energy is in the infra-red region.

The maximum intensity, according to Wien's Law, occures at a wavelength λm = 10^(-5) m.

$$\lambda_m T = {hc}/{6k} \approx 0.003\, mK$$

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$$\Rightarrow \lambda_m = {}^{0.003}\!/_{T}$$

$$\Rightarrow \lambda_m = {}^{0.003}\!/_{290}$$

$$\Rightarrow \lambda_m = 10^{-5}\, m$$

The infra-red spectrum is strongly absorbed by the tri-atomic molecules of the atmosphere, namely CO2, H2O and O3. The energy absorbed by these molecules is re-emitted in part toward the outer space and in part toward the ground, thus providing an additional heating source for the surface of the Earth.

The infra-red spectrum is strongly absorbed by the tri-atomic molecules of the atmosphere, namely CO_2, H_2O and O_3. The energy absorbed by these molecules is re-emitted in part toward the outer space and in part toward the ground, thus providing an additional heating source for the surface of the Earth.

Upward flux from the ground	=	Downward flux from the tri-atomic molecules of the atmosphere	+	flux of Solar radiation absorbed by the Earth

$$4\pi R^2 \sigma T_g^4 = 4\pi R^2 F_d + 4\pi R^2 \sigma T_e^4$$

Upward flux from the ground	=	Downward flux from the tri-atomic molecules of the atmosphere	+	flux of Solar radiation absorbed by the Earth

$$\sigma T_g^4 \quad = \quad F_d \quad + \quad \sigma T_e^4 \longrightarrow 4$$

The Equation of Radiative Transfer

Using Eddington Approximation (See Appendix I)

$$F_d = \pi I_d$$

and the intensity of the downward flowing radiation (Id)

$$I_d = \frac{F}{\pi}\left(\frac{3\tau}{4}\right)$$

Using Eddington Approximation $F_d = \pi I_d$

and the intensity of the downward flowing radiation (Id) $I_d = \frac{F}{\pi}\left(\frac{3\tau}{4}\right)$

(See Appendix I)

$\therefore$ $F_d = \pi I_d$ ➡ $F_d = \pi\left\{\frac{F}{\pi}\left(\frac{3\tau}{4}\right)\right\}$

➡ $F_d = F\frac{3\tau}{4}$ Where, $F = \sigma T_e^4$ and $\tau = \tau_o$

The opacity in the infra-red of the terrestrial atmosphere

$F = \sigma T_e^4$ and $\tau = \tau_o$ ⇒ $F_d = F \dfrac{3\tau}{4}$ ∴ $F_d = \sigma T_e^4 \dfrac{3\tau_o}{4}$

Using Eq 4:

$$\sigma T_g^4 = F_d + \sigma T_e^4$$

$$\sigma T_g^4 = \sigma T_e^4 \frac{3\tau_o}{4} + \sigma T_e^4$$

$$\sigma T_g^4 = \sigma T_e^4 \left(1 + \frac{3\tau_o}{4}\right)$$

$$T_g = T_e \left(1 + \frac{3\tau_o}{4}\right)^{1/4}$$

It has been observed that approximately 85% of the infra-red radiation is absorbed in the atmosphere and only 15% of the ground intensity (Ig) makes it through the Earth's atmosphere.

How to find τ_o :

$$I = I_g \, e^{-\tau_o} \Rightarrow \tau_o = -\ln\left(\frac{I}{I_g}\right)$$

Where,

$$\frac{I}{I_g} = \frac{15}{100} = 0.15$$

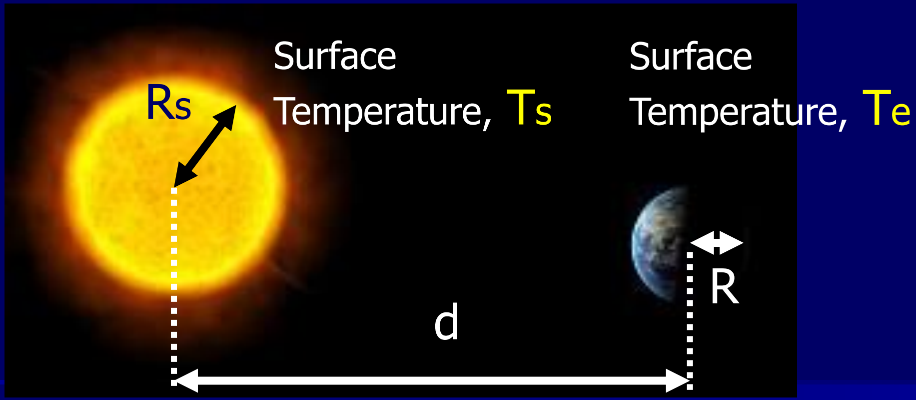
$$\Rightarrow \tau_o = -\ln(0.15)$$

$$\Rightarrow \tau_o = -(-1.89712)$$

$$\Rightarrow \tau_o = 1.89712 \approx 1.9$$

The value of ground temperature of the Earth,

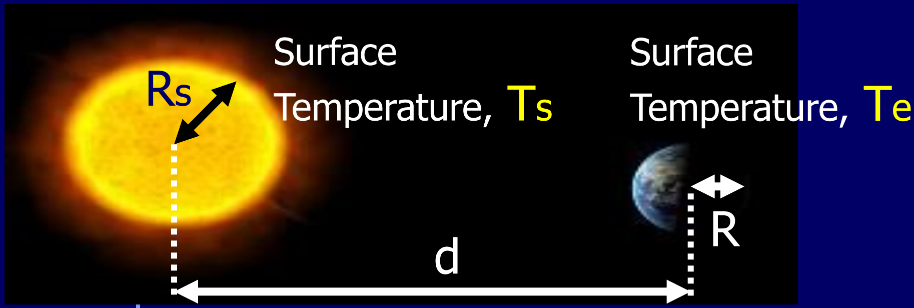
$$T_g = T_e\left(1 + \frac{3\tau_o}{4}\right)^{1/4} \Rightarrow T_g = 245\left(1 + \frac{3(1.9)}{4}\right)^{1/4} \Rightarrow T_g \approx 305\ K$$



The value of ground temperature of the Earth,

$$T_e = 305\,K$$

The temperature obtained in the above equation is somewhat higher than the average temperature on the surface on the Earth, but still it describes to a good approximation the Green House Effect. The small excess we have found in Tg occurs in part because we have neglected the convective transport of heat in the lower atmosphere, which would tend to cool down the surface of the Earth.



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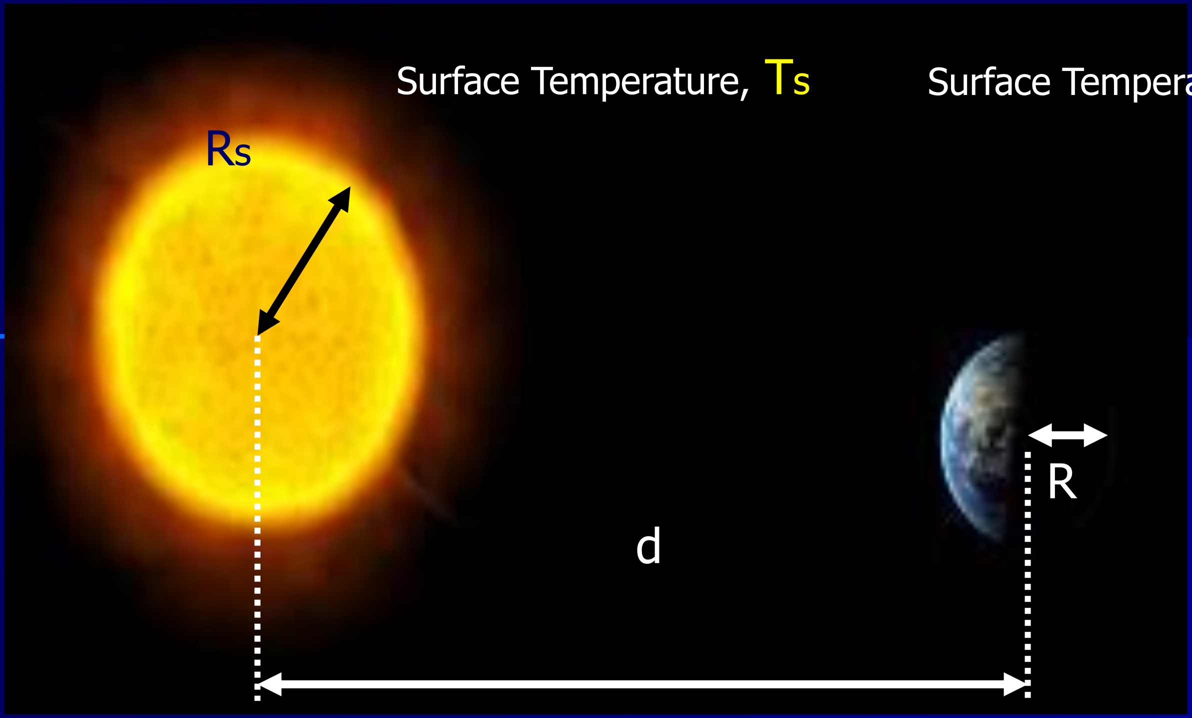
Note that the temperature of the air T_a near the ground is given by (A-30, appendix I), which yields a value for T_a lower than Tg.

$$T_a = T_e \left(\frac{1}{2} + \frac{3\tau_o}{4} \right)^{1/4}$$

$$T_a = 245 \left(\frac{1}{2} + \frac{3\,(1.9)}{4} \right)^{1/4}$$

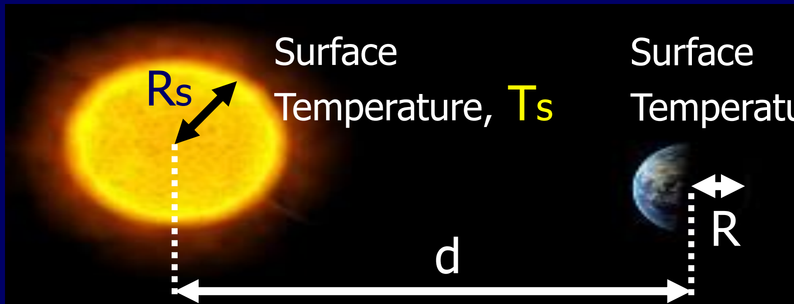
$$T_a = 288\,K$$



The temperature of the air T_a near the ground,

$$T_a = 288\,K$$

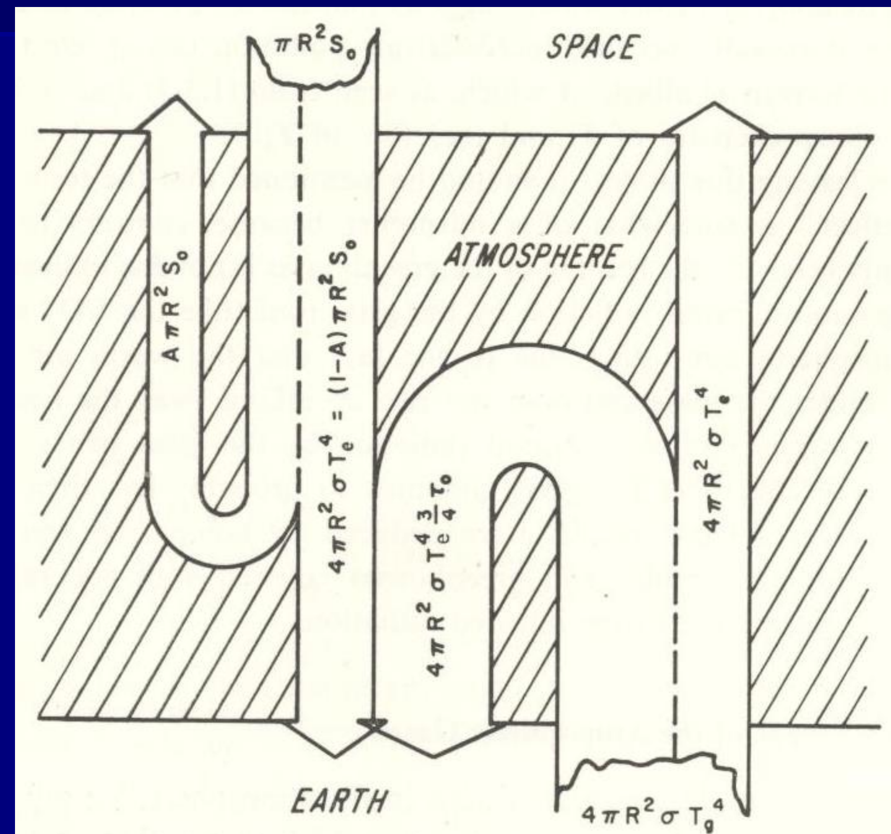
The discontinuity between T_g and T_a is in practice removed through conduction and convection and tends to lower the value of T_g obtained above.



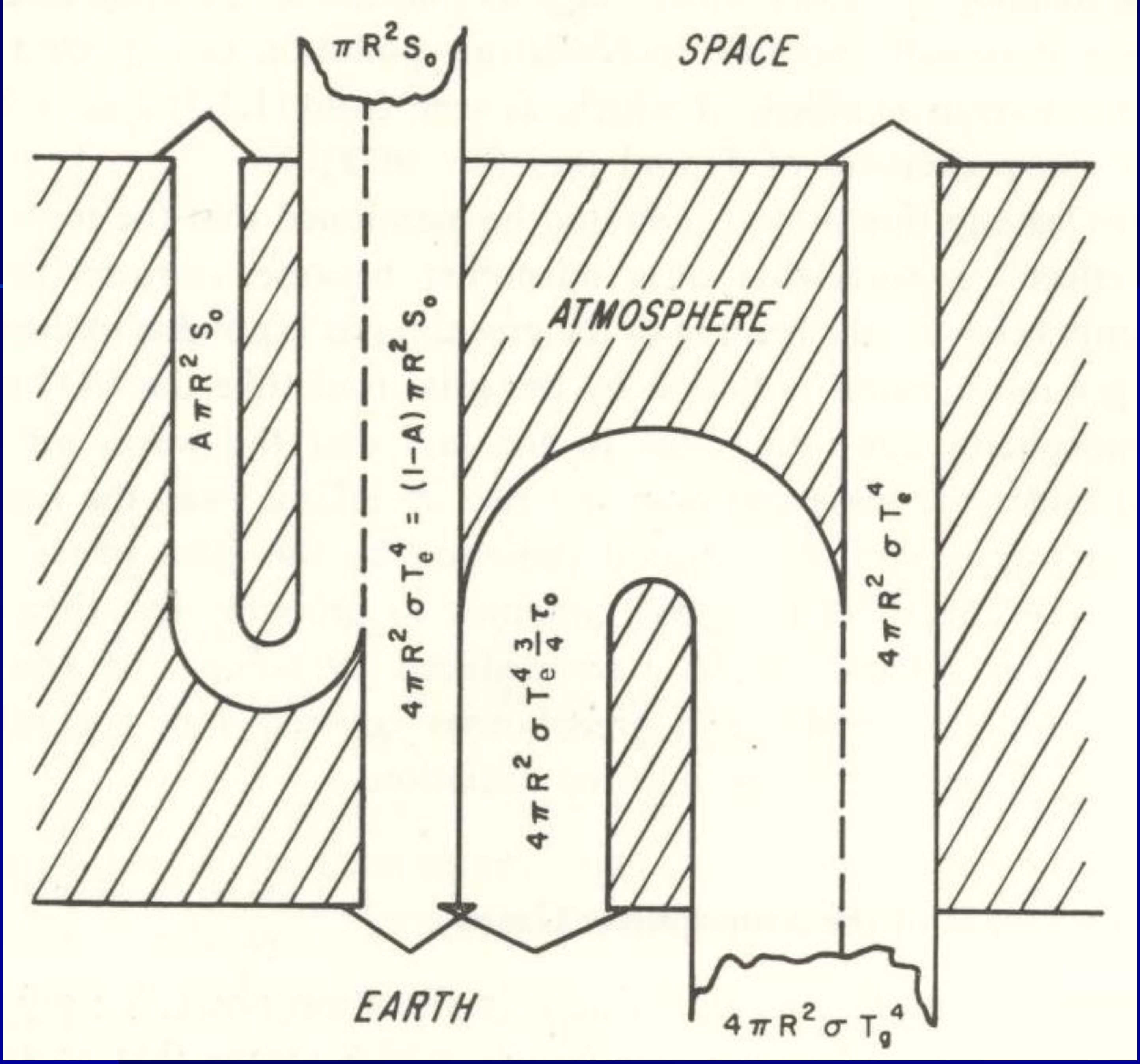
The temperature of the air T_a near the ground,

$$T_a = 288\,K$$

This figure describes the balance between the radiation received and the radiation emitted by the Earth, including the green house effect.



A diagram showing the balance of heat, including the G.H.E. in the atmosphere of the Earth.



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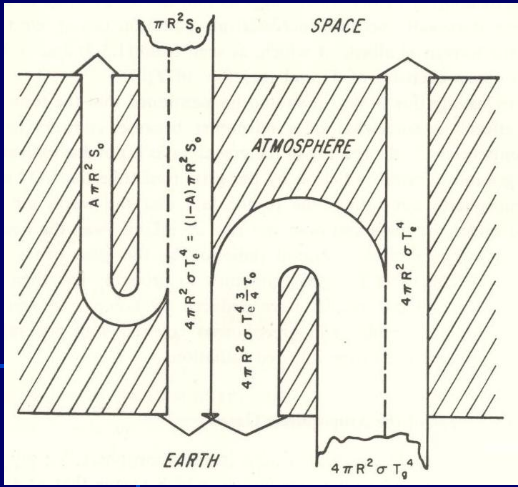

A diagram showing the balance of heat, including the G.H.E. in the atmosphere of the Earth.

It is significant to note that if the Earth did not have an atmosphere, or if the terrestrial atmosphere did not have any absorbing molecules such as CO2, H2O and O3, we would have $\tau_o=0$ and $T_g = T_e = 245$ K $= -28$ °C. This shows the importance of the green house effect, i.e. the trapping of the infra-red radiation emitted from the ground by the tri-atomic molecules of the atmosphere, and emphasizes the critical role of the minor atmospheric constituents.

Planetary Atmospheres

Planetary Atmospheres

Formation and Evolution of Planetary Atmospheres
The Structure of the Terrestrial Atmosphere
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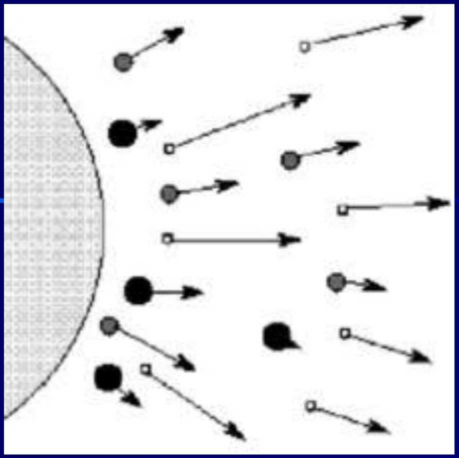
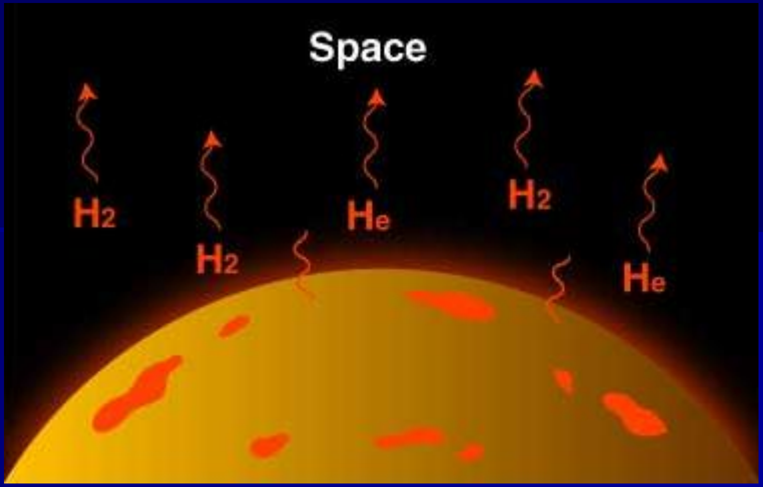
The Atmospheres of the Planets

The Escape of the Atmospheric Gases





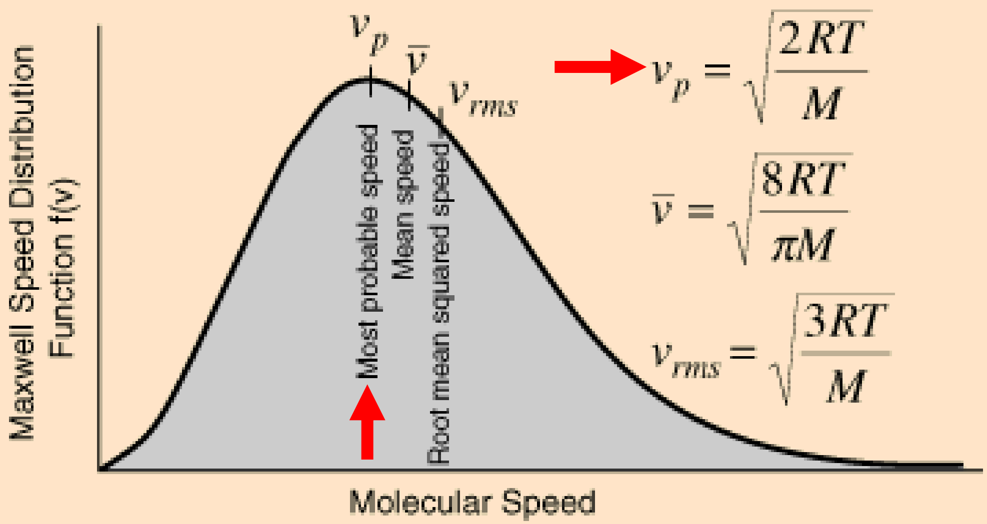
The kinetic theory of gasses shows that the particle velocities of a gas in a thermal equilibrium follow a Maxwellian Distribution, which in polar coordinates is given by the expression,

$$N\, f(V)\, dV\, d\Omega = 4\pi\, N \cdot \frac{e^{-\left(V/V_m\right)^2}}{\left(\pi V_m^2\right)^{3/2}} V^2 dV\, Sin\,\theta\, d\theta\, d\phi$$

Molecular Speed Calculation

The speed distribution for the molecules of an ideal gas is given by

$$f(v) = 4\pi\left[\frac{M}{2\pi RT}\right]^{\frac{3}{2}} v^2 \exp\left[\frac{-Mv^2}{2RT}\right]$$



$$v_p = \sqrt{\frac{2RT}{M}}$$

$$\bar{v} = \sqrt{\frac{8RT}{\pi M}}$$

$$v_{rms} = \sqrt{\frac{3RT}{M}}$$

The calculation of molecular speed depends upon the molecular mass and the temperature. For mass

m= 29 amu

M= 0.029 kg/mol

and temperature

T= 300 K

T= 26.850000 C

the three characteristic speeds may be calculated.

The nominal average molecular mass for dry air is 29 amu.

Most probable speed= v_p = 414.75819 m/s = 1493.1295 km/hr = 927.78766 mi/hr

Mean speed= $\bar{v}$ = 468.00451 m/s = 1684.8162 km/hr = 1046.8962 mi/hr

RMS speed= v_{rms} = 507.97297 m/s = 1828.7027 km/hr = 1136.3031 mi/hr

The Escape of the Atmospheric Gases

Maxwellian Distribution

$$f(V) = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} V^2 \cdot \exp\left(-MV^2/2RT\right)$$

The most probable speed (Vm)

The **most probable speed** is the speed associated with the highest point in the Maxwell distribution.

$$\frac{df(v)}{dv} = 0$$

$$\frac{d[f(V)]}{dV} = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} \frac{d}{dV}\left(V^2 \cdot \exp\left(-MV^2/2RT\right)\right) = 0$$

The Maximum/Minimum value is :

$$V = \left(\frac{2kT}{M}\right)^{1/2}$$

The Escape of the Atmospheric Gases

To find is it Maximum or Minimum : should be checked the second derivative of the **Maxwellian Distribution**

$$\frac{d^2[f(V)]}{dV^2} = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} \frac{d}{dV}\left(\frac{d}{dV}\left(V^2 \cdot \exp\left(-MV^2 / 2RT\right)\right)\right)$$

⋮

Then substitute $V = \left(\frac{2kT}{M}\right)^{1/2}$

$$\frac{d^2[f(V)]}{dV^2} = (-)ve$$

Then this V value should be the maximum value of the **Maxwellian Distribution**. This is called "The **most probable speed "**

$$V_m = \left(\frac{2kT}{M}\right)^{1/2}$$

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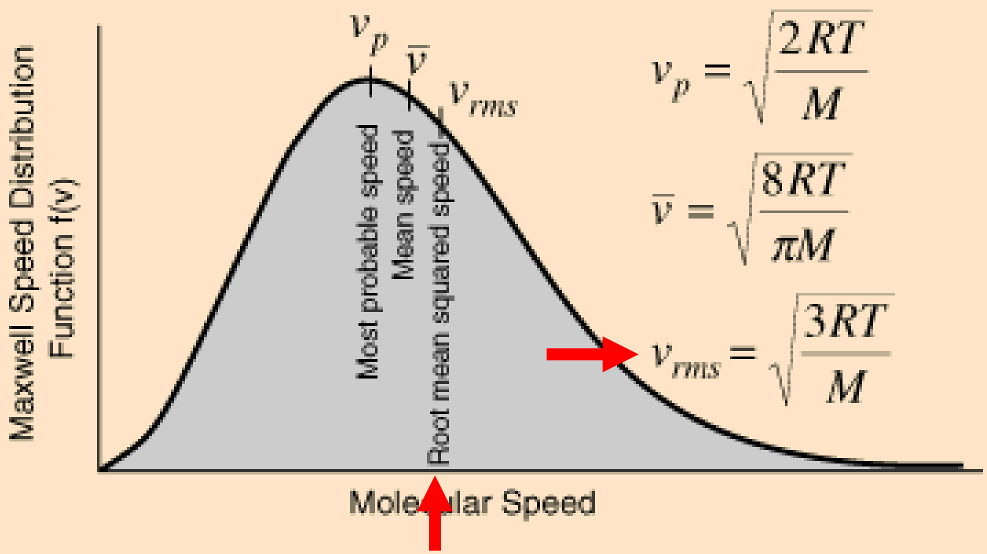

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R.M.S. Molecular Speed :

The Kinetic Energy of a atom in the Earth's atmosphere whose mass is m,

$$= \frac{1}{2} m V_{rms}^2$$

The Kinetic Energy of a atom in the Earth's atmosphere in the temperature T in Kelvin, (in 3D Form)

$$= \frac{3}{2} kT$$

Above two equations should be equal,

$$\frac{1}{2} m V_{rms}^2 = \frac{3}{2} kT$$

$$\therefore \quad V_{rms} = \left(\frac{3kT}{m} \right)^{1/2}$$

$$\therefore \quad V_{rms} = \left(\frac{3RT}{M} \right)^{1/2}$$

R.M.S. Molecular Speed :

$$\frac{1}{2} m V_{rms}^{2} = \frac{3}{2} kT$$

$\therefore \quad V_{rms} = \left(\frac{3kT}{m} \right)^{1/2}$ $\qquad\qquad$ $\therefore \quad V_{rms} = \left(\frac{3RT}{M} \right)^{1/2}$

When the Kinetic Energy of a particle exceeds the Potential Energy of the Gravitational Field of the Earth, this particle can in principle escape to the interplanetary space. The lowest velocity allowing the particle to escape is called the Escape Velocity Ve.

The Kinetic Energy of a particle in the Earth's atmosphere whose mass is m, $= \frac{1}{2} m V_e^2$

The Potential Energy of a particle on the surface of the Earth, $= -\frac{GMm}{R}$

where, M is the mass of the Earth and R is the Radius of the Earth.

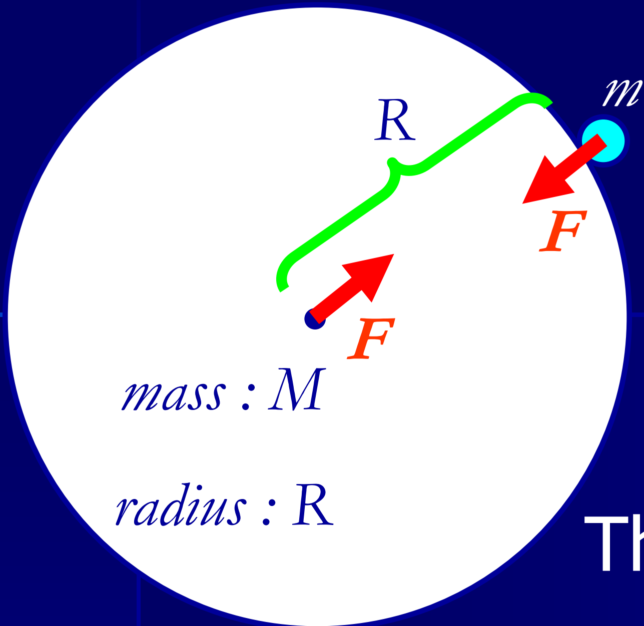
Kinetic Energy exceeds Potential Energy, the particle can escape ;

$$\frac{1}{2} m V_e^2 = \frac{GMm}{R}$$

$$\therefore \quad V_e = \left(\frac{2GM}{R} \right)^{1/2}$$

Where, $GM = gR^2$

Proof : P.T.O



Using the Newton's Gravitational Law :

$$F = G\frac{Mm}{R^2}$$

Using the definition of the Gravitational field intensity :

$$g = \frac{F}{m} \rightarrow F = mg$$

Therefore, $$G\frac{Mm}{R^2} = mg$$

$$\therefore \quad GM = gR^2$$

Therefore, the Escape Velocity of a planet:

$$V_e = \left(\frac{2GM}{R}\right)^{1/2}$$

$$V_e = \left(\frac{2gR^2}{R}\right)^{1/2}$$

$$V_e = (2gR)^{1/2}$$

- For the Earth

$$g = 10\,ms^{-2}$$

$$R = 6.4\times10^6\,m$$

$$v_e = (2gR)^{\frac{1}{2}}$$

$$\therefore \quad v_e = 11{,}200\,ms^{-1}$$

$$\therefore \frac{V_e}{V_m} = \frac{(2gR)^{1/2}}{\left(\frac{2kT}{m}\right)^{1/2}} = \left(\frac{R}{kT/mg}\right)^{1/2} = \left(\frac{R}{H}\right)^{1/2}$$

Where, $H = kT/mg$

The ratio of Ve : Vm

$$\frac{V_e}{V_m} = \left(\frac{R}{H}\right)^{1/2}$$

$$\frac{V_e}{V_m} = \left(\frac{6400\,km}{8.7\,km}\right)^{1/2}$$

$$\frac{V_e}{V_m} = 27.6 \approx 28$$

$$V_e \approx 28\,V_m$$

Escape Velocity *Most Probable Velocity*

- For the Earth $H = kT/mg$

$$H = \frac{(1.38\times10^{-23})(300)}{(4.8\times10-26)(9.81)}$$

$$H = 8.7\,km$$

As a result, particles in the atmosphere can not escape to the interplanetary space! (But this is not the only condition necessary for the particles to escape)

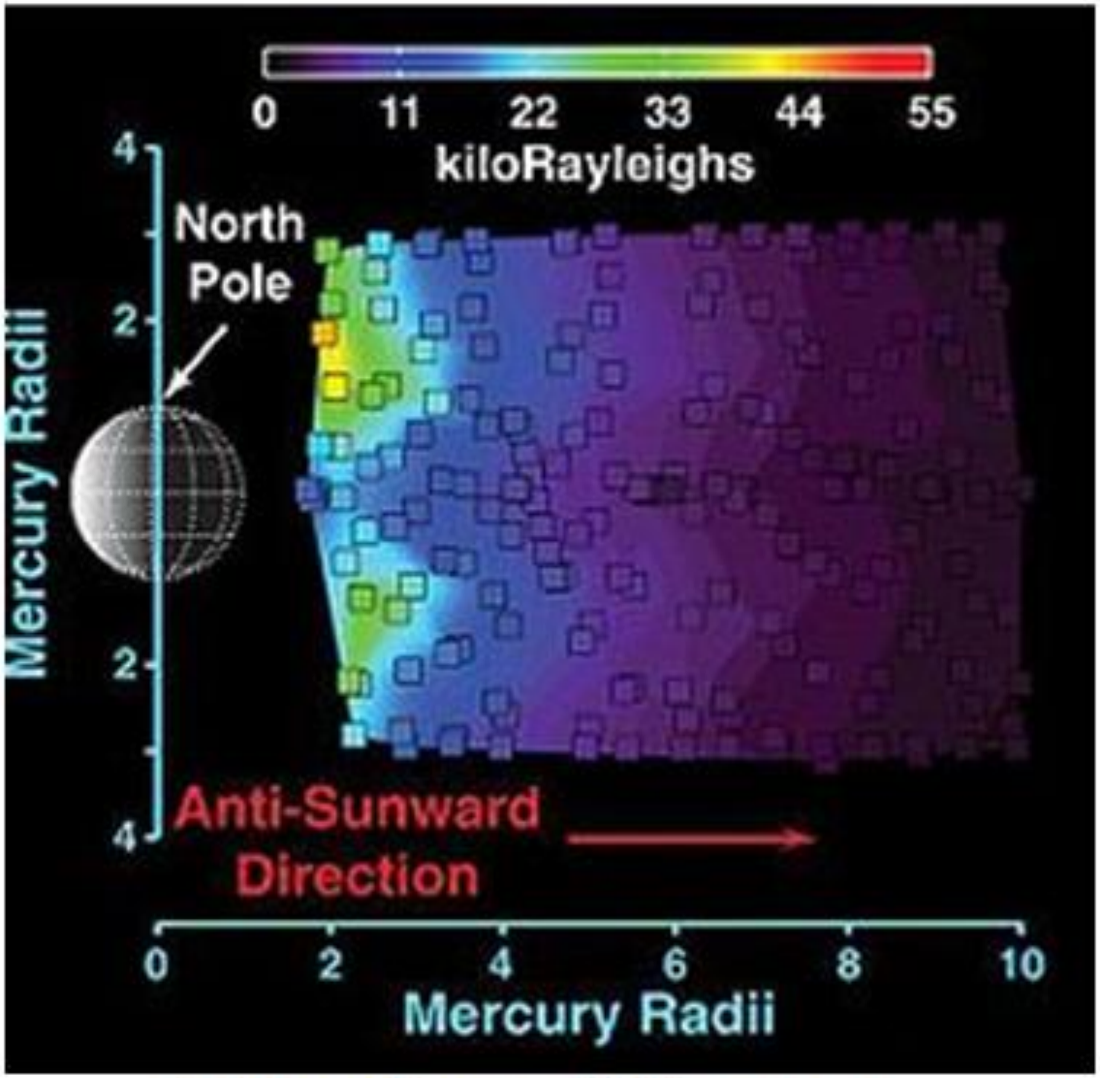
Planetary Atmospheres

Planetary Atmospheres

Formation and Evolution of Planetary Atmospheres
The Structure of the Terrestrial Atmosphere
The Temperature of the Neutral Atmosphere
The Escape of the Atmospheric Gases
The Atmospheres of the Planets

Atmosphere of Mercury

Atmosphere of Mercury



Atmosphere of Mercury

Atmosphere of Mercury

Species	CD,[n 1] cm^{-2}	SD,[n 2] cm^{-3}
Hydrogen (H)	$\sim 3 \times 10^{9}$	~ 250
Molecular hydrogen	$< 3 \times 10^{15}$	$< 1.4 \times 10^{7}$
Helium	$< 3 \times 10^{11}$	$\sim 6 \times 10^{3}$
Atomic oxygen	$< 3 \times 10^{11}$	$\sim 4 \times 10^{4}$
Molecular oxygen	$< 9 \times 10^{14}$	$< 2.5 \times 10^{7}$
Sodium	$\sim 2 \times 10^{11}$	$1.7\text{–}3.8 \times 10^{4}$
Potassium	$\sim 2 \times 10^{9}$	~ 400
Calcium	$\sim 1.1 \times 10^{8}$	~ 300
Magnesium	$\sim 4 \times 10^{10}$	$\sim 7.5 \times 10^{3}$
Argon	$\sim 1.3 \times 10^{9}$	$< 6.6 \times 10^{6}$
Water	$< 1 \times 10^{12}$	$< 1.5 \times 10^{7}$
Other	neon, silicon, sulfur, argon, iron, carbon dioxide, etc.	

1. ^ Column density
2. ^ Surface density

Atmosphere of Mercury

History

Mercury is the most difficult planet to observe due to its proximity to the Sun.

The viability of an atmosphere on Mercury had been debated before Mariner 10's 1974 flyby. **On the one hand proximity to the Sun would induce a high temperature.** On the other hand **the dark hemisphere would be very cold, causing many gases to freeze.**

By the 1960s **some evidence had accumulated indicating that Mercury might have a thin atmosphere.**

Atmosphere of Mercury

Properties

Mariner 10's UV observations have established an upper bound on the exospheric surface density at about 10^5 particles per cubic centimeter. This corresponds to a surface pressure of less than 10^(−14) bar (1 nPa).

For exospheric atomic hydrogen, the temperature appears to be about 420 K, a value obtained by both Mariner 10 and MESSENGER. The temperature for sodium is much higher, reaching 750–1500 K on the equator and 1,500–3,500 K at the poles. Some observations show that Mercury is surrounded by a hot corona of calcium atoms with temperature between 12,000 and 20,000 K.

Atmosphere of Mercury

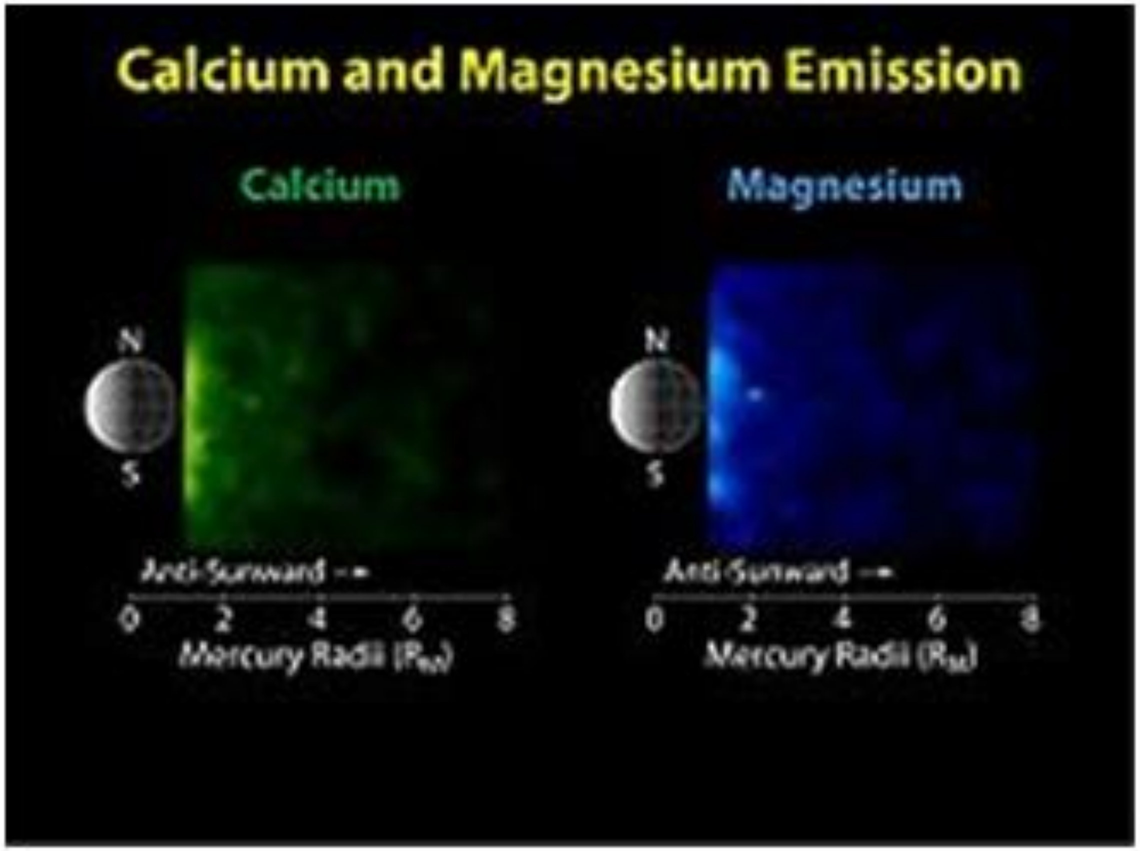
Tail

Because of Mercury's proximity to the Sun, the pressure of Solar light is much stronger than at Earth's location. Solar radiation pushes neutral atoms away from the Sun, creating a comet-like tail behind Mercury. The main component in the tail is sodium, which has been detected as far as 56,000 km (about 23 **R**M) from the planet. **This sodium tail expands rapidly to a diameter of about 20,000 km at a distance of 17,500 km**.

Atmosphere of Mercury

Mercury’s sodium tail

Atmosphere of Mercury



Ca and Mg in the tail

Atmosphere of Mercury

Origin

Mercury's exosphere is constantly escaping into space, implying that some process resupplies its constituents. The main source of hydrogen and helium is likely to be the Solar wind. Other atomic and molecular species are thought to originate from the **Herman** crust through three main processes:

Atmosphere of Mercury

- vaporization of surface material by meteoritic impacts,

- Sputtering by energetic charged particles from the Solar wind; and

- photo- and electron-induced desorption of alkali metal atoms.

Mercury's orbit has a significant eccentricity, which causes a strong variation in the Solar light and particle fluxes reaching the planet. Solar flares contribute additional variation.

Atmosphere of Venus

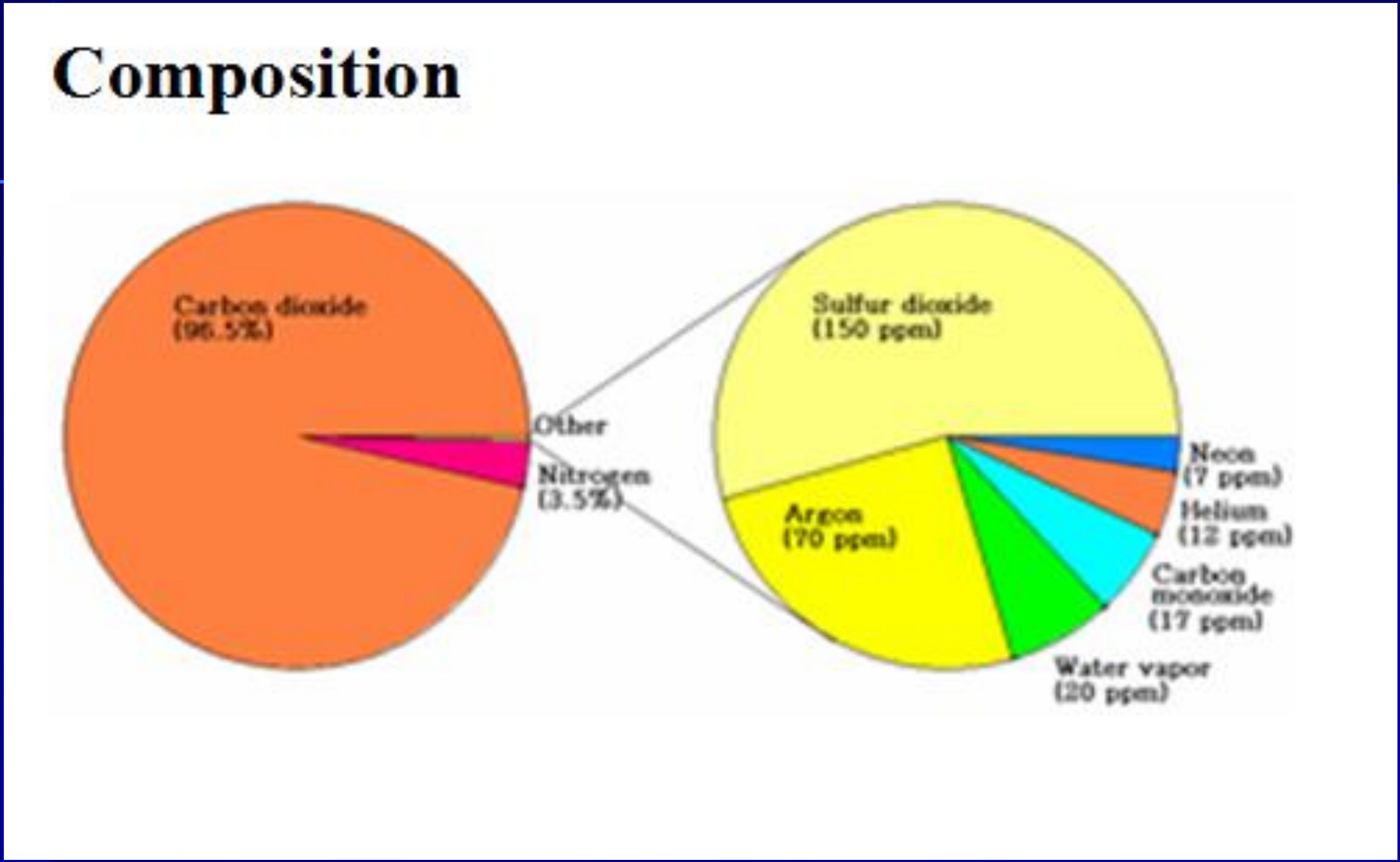
Atmosphere of Venus

Cloud structure in Venus' atmosphere in 1979, revealed by ultraviolet observations from Pioneer Venus Orbiter

Atmosphere of Venus

General information[1]	
Height	250 km
Average surface pressure	(92 bar or) 9.2 MPa
Mass	4.8×10^{20} kg
Composition[1][2]	
Carbon dioxide	96.5 %
Nitrogen	3.5 %
Sulfur dioxide	150 ppm
Argon	70 ppm
Water vapor	20 ppm
Carbon monoxide	17 ppm
Helium	12 ppm
Neon	7 ppm
Hydrogen chloride	0.1–0.6 ppm
Hydrogen fluoride	0.001–0.005 ppm

Atmosphere of Venus



Pie chart of the atmosphere of Venus. The chart on the right is an expanded view of the trace elements that all together do not even make up a tenth of a percent.

Atmosphere of Venus

Troposphere

The atmosphere is divided into a number of sections depending on altitude. The densest part of the atmosphere, the troposphere, begins at the surface and extends upwards to 65 km. At the furnace-like surface the winds are slow, but at the top of the troposphere the temperature and pressure reaches Earth-like levels and clouds pick up speed to 100 m/s.

The atmospheric pressure at the surface of Venus is about 92 times that of the Earth, similar to the pressure found 910 m below the surface of the ocean. The atmosphere has a mass of 4.8×10^20 kg, about 93 times the mass of the Earth's total atmosphere.

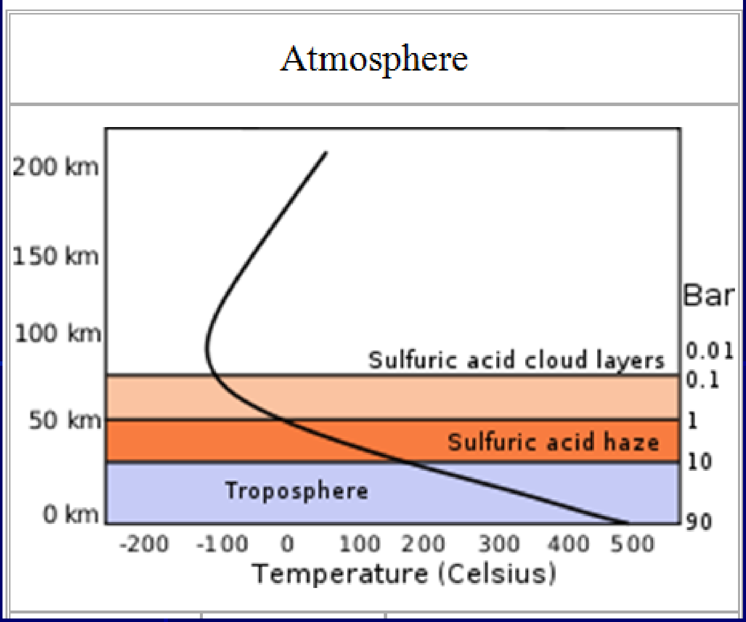
Atmosphere of Venus

Troposphere

The large amount of CO_2 in the atmosphere together with water vapor and sulfur dioxide create a strong Greenhouse Effect, trapping solar energy and raising the surface temperature to around 740 K (467°C), <u>hotter than any other planet in the solar system.</u>

The **average temperature on the surface** is above the melting points of Lead 600 K (327°C), Tin 505 K (232°C), and Zinc 693 K (420°C).

Atmosphere of Venus



The surface of Venus spends 58.3 days of darkness before the sun rises again behind the clouds.

Height (km)	Temp. (°C)	Atmospheric pressure (x Earth)
0	462	92.10
5	424	66.65
10	385	47.39
15	348	33.04
20	306	22.52
25	264	14.93
30	222	9.851
35	180	5.917
40	143	3.501
45	110	1.979
50	75	1.066
55	27	0.5314
60	−10	0.2357
65	−30	0.09765
70	−43	0.03690
80	−76	0.004760
90	−104	0.0003736
100	−112	0.00002660

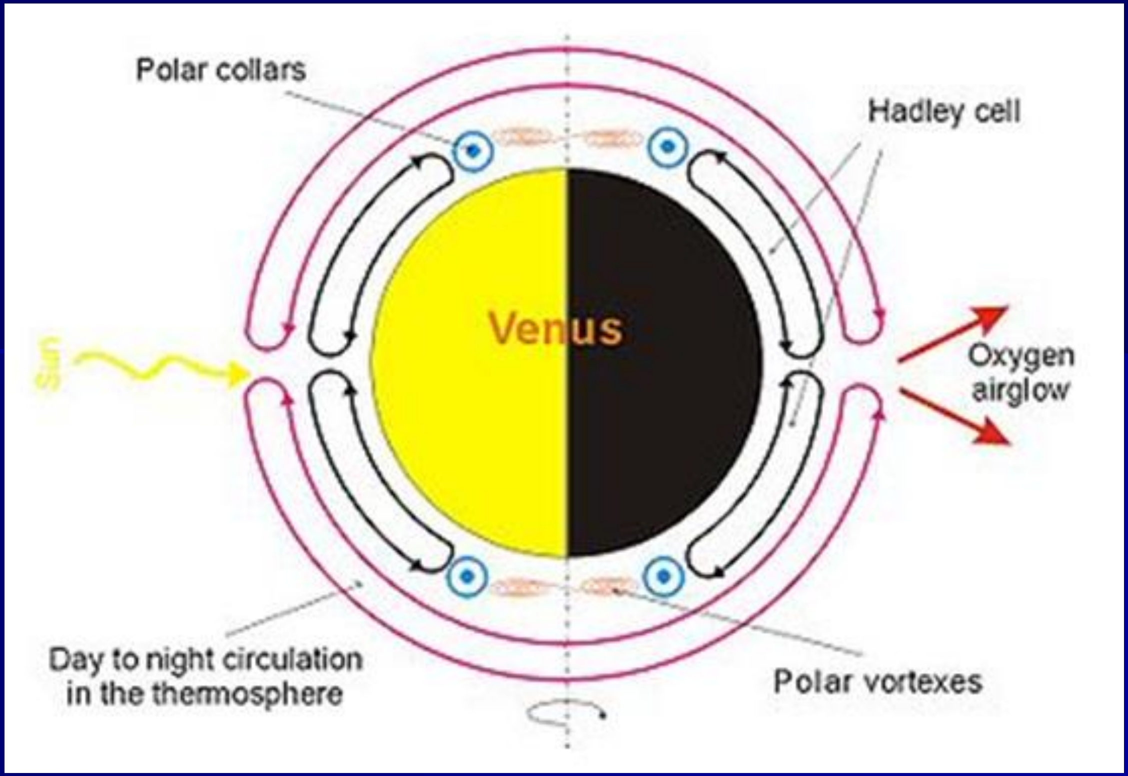
h	T
150	-25
200	50

Atmosphere of Venus

The troposphere on Venus contains 99% of the atmosphere by mass. Ninety percent of the atmosphere of Venus is within 28 km of the surface, by comparison, ninety percent of the atmosphere of Earth is within 10 km of the surface. At a height of 50 km the atmospheric pressure is approximately equal to that at the surface of Earth.

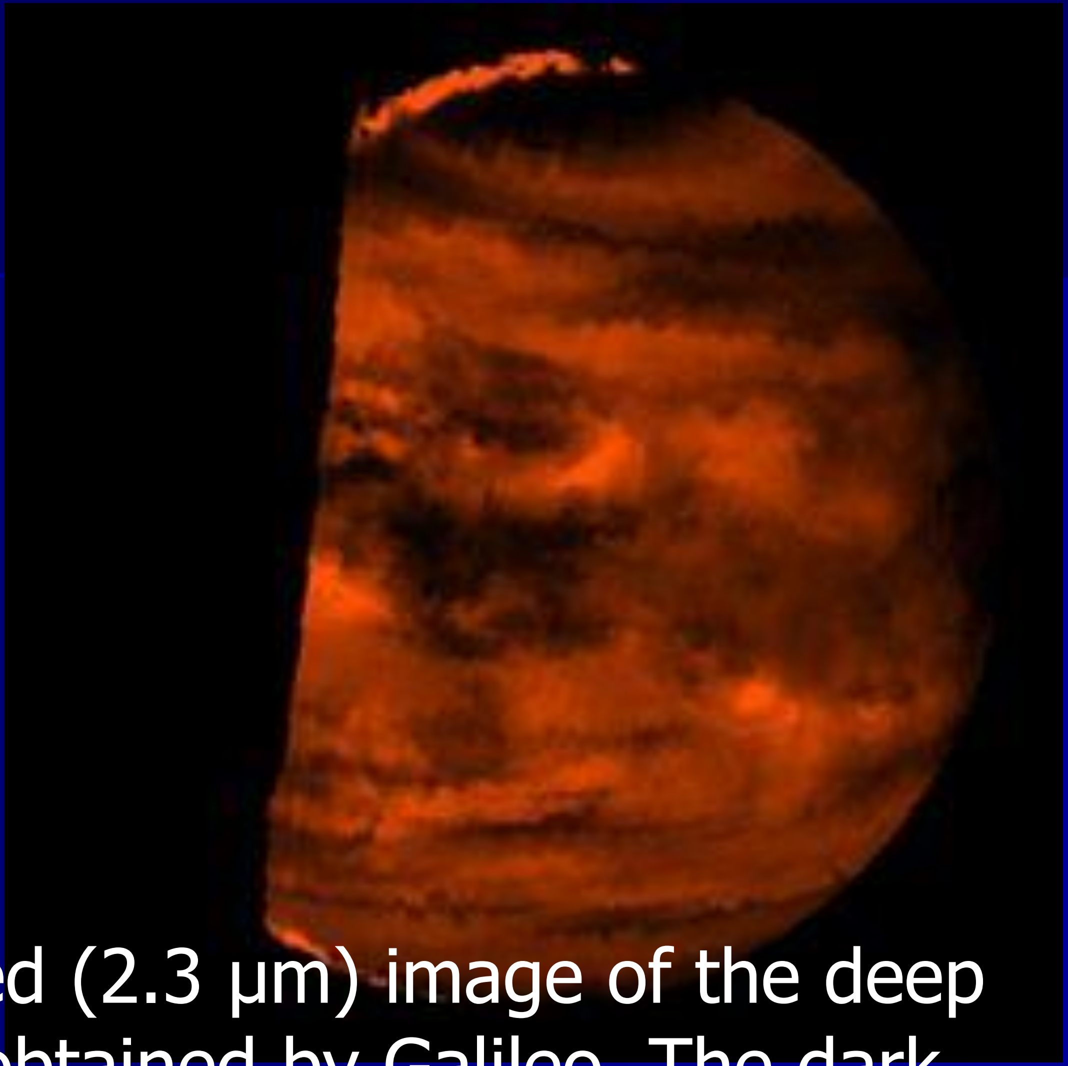
Atmosphere of Venus

Circulation



Meridional (north-south) component of the atmospheric circulation in the atmosphere of Venus. Note that the meridional circulation is much lower than the zonal circulation, which transports heat between the day and night sides of the planet

Atmosphere of Venus



False color near infrared (2.3 μm) image of the deep atmosphere of Venus obtained by Galileo. The dark spots are clouds silhouetted against the very hot lower atmosphere emitting thermal infrared radiation.

Atmosphere of Venus

Upper atmosphere and ionosphere

The mesosphere of Venus extends from 65 km to 120 km in height, and the thermosphere begins at around 120, eventually reaching the upper limit of the atmosphere (exosphere) at about 220 to 350 km. The exosphere is the altitude at which the atmosphere becomes collisionless.

The mesosphere of Venus can be divided into two layers:

the lower one between 62–73 km and the upper one between 73–95 km. In the first layer the temperature is nearly constant at 230 K (−43°C). This layer coincides with the upper cloud deck.

Atmosphere of Venus

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In the second layer temperature starts to decrease again reaching about 165 K (−108°C) at the altitude of 95 km, where mesopause begins. It is the coldest part of the Venusian dayside atmosphere.

In the dayside mesopause, which serves as a boundary between the mesosphere and thermosphere and is located between 95–120 km, temperature grows up to a constant—about 300–400 K (27–127°C)—value prevalent in the thermosphere.

Atmosphere of Venus

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In the dayside mesopause, which serves as a boundary between the mesosphere and thermosphere and is located between 95–120 km, temperature grows up to a constant—about 300–400 K (27–127°C)—value prevalent in the thermosphere. In contrast the nightside Venusian thermosphere is the coldest place on Venus with temperature as low as 100 K (−173°C). It is even called a cryosphere.

Atmosphere of Venus

Upper atmosphere and ionosphere …

Venus has an extended ionosphere located at altitudes 120–300 km. The ionosphere almost coincides with the thermosphere. The high levels of the ionization are maintained only over the dayside of the planet. Over the night-side the concentration of the electrons is almost zero.

The ionosphere of Venus consists of three layers:

v1 between 120–130 km,
v2 between 140–160 km and
v3 between 200–250 km.

Atmosphere of Venus

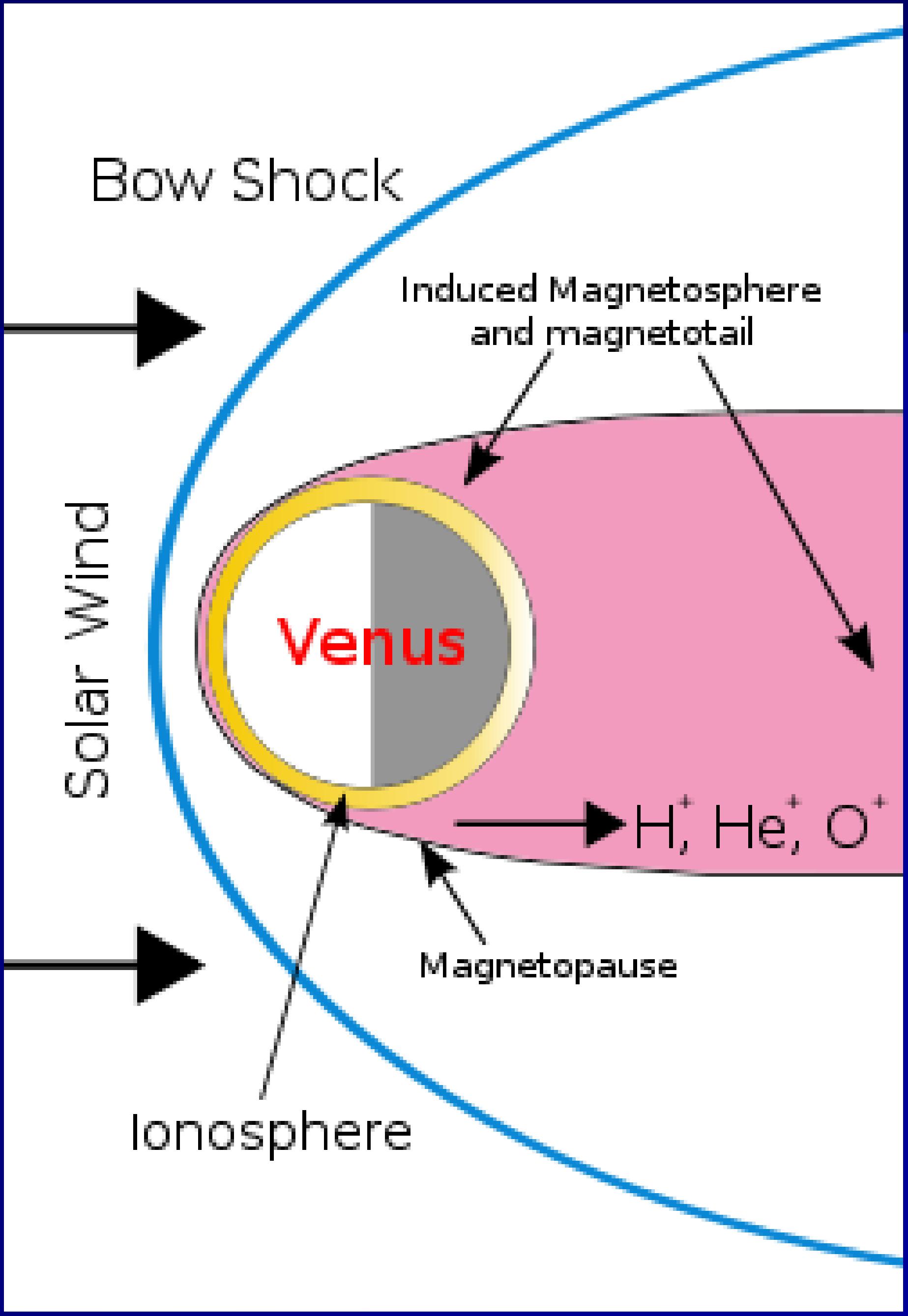
Upper atmosphere and ionosphere …

The ionosphere of Venus consists of three layers:
v1 between 120–130 km,
v2 between 140–160 km and
v3 between 200–250 km.

There may be an additional layer near 180 km. The maximum electron volume density 3×10^11 m−3 is reached in the v2 layer near the subsolar point. The upper boundary of the ionosphere—ionopause is located at altitudes 220–375 km and separates the plasma of the planetary origin from that of the induced magnetosphere.

Atmosphere of Venus

Induced magnetosphere



Venus interacts with the solar wind. Components of the induced magnetosphere are shown.

Atmosphere of Venus

Induced magnetosphere

Venus is known not to have a magnetic field. The reason for its absence is not clear, but is probably related to the planet's slow rotation or the lack of convection in the mantle. Venus only has an induced magnetosphere formed by the Sun's magnetic field carried by the solar wind.

Atmosphere of Venus

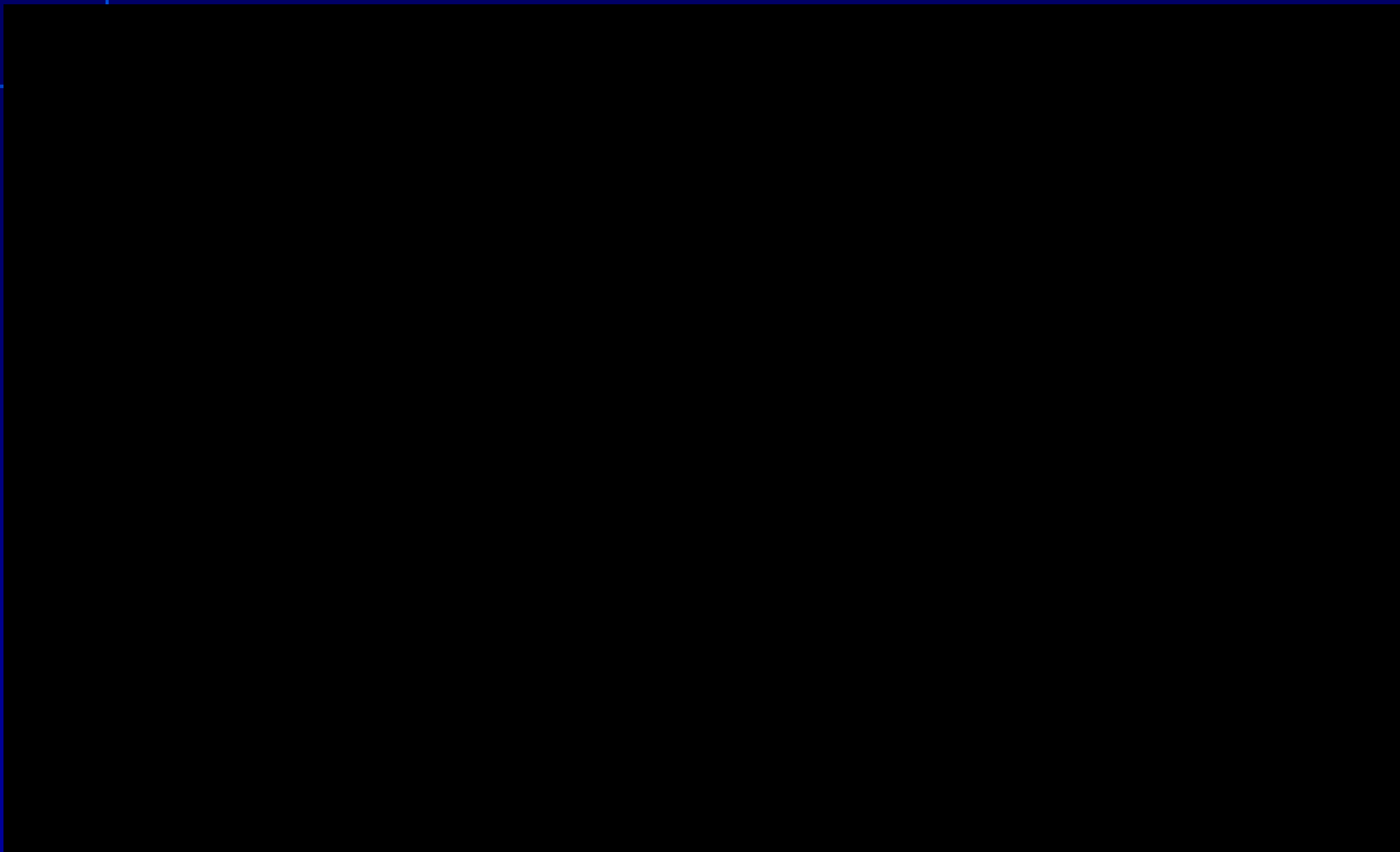
Clouds

Venusian clouds are thick and are composed of sulfur dioxide and droplets of sulfuric acid. These clouds reflect about 75% of the sunlight that falls on them, which is what obscures the surface of Venus from regular imaging.

The **cloud cover is such that very little sunlight can penetrate down to the surface,** and the light level is only around 5,000–10,000 lux with a visibility of three kilometers.

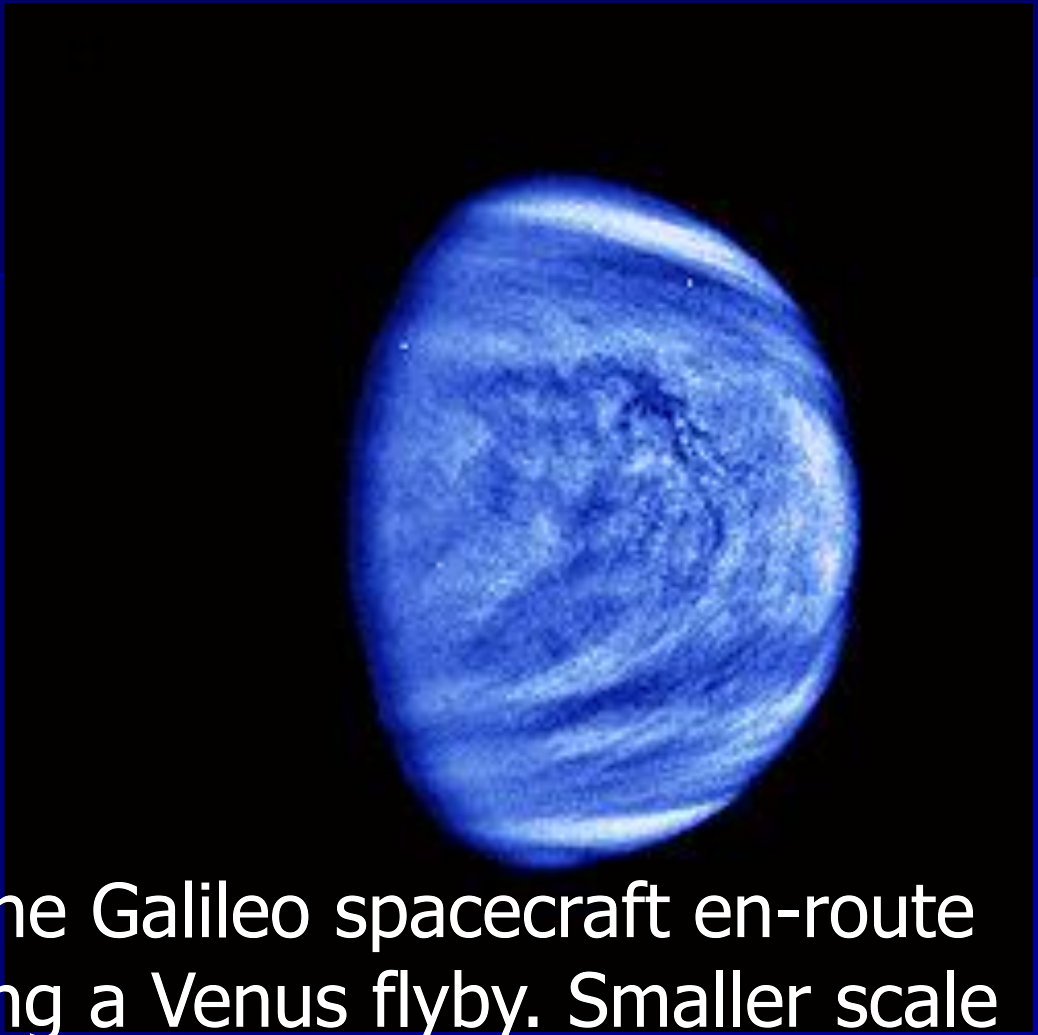
Atmosphere of Venus

Induced magnetosphere



Atmosphere of Venus

Clouds



Photograph taken by the Galileo spacecraft en-route to Jupiter in 1990 during a Venus flyby. Smaller scale cloud features have been emphasized and a bluish hue has been applied to show that it was taken through a violet filter.

Atmosphere of Venus

Sulfuric acid is produced in the upper atmosphere by the Sun's photochemical action on CO2, SO2, and water vapor. UV photons of wavelengths less than 169 nm can photodissociate CO2 into CO and atomic O. Atomic oxygen is highly reactive; when it reacts with sulfur dioxide, a trace component of the Venusian atmosphere, the result is SO3, which can combine with water vapor, another trace component of Venus's atmosphere, to yield sulfuric acid.

$$\mathrm{CO_2} \longrightarrow \mathrm{CO} + \mathrm{O}$$
$$\mathrm{SO_2} + \mathrm{O} \longrightarrow \mathrm{SO_3}$$
$$\mathrm{SO_3} + \mathrm{H_2O} \longrightarrow \mathrm{H_2SO_4}$$

Atmosphere of Venus

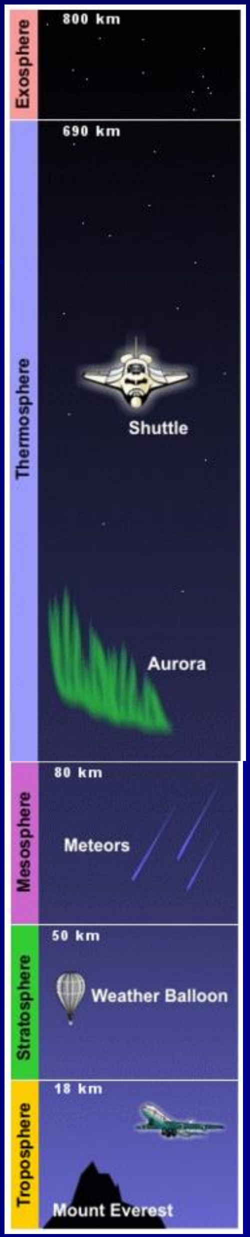
$$CO_2 \rightarrow CO + O$$
$$SO_2 + O \rightarrow SO_3$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

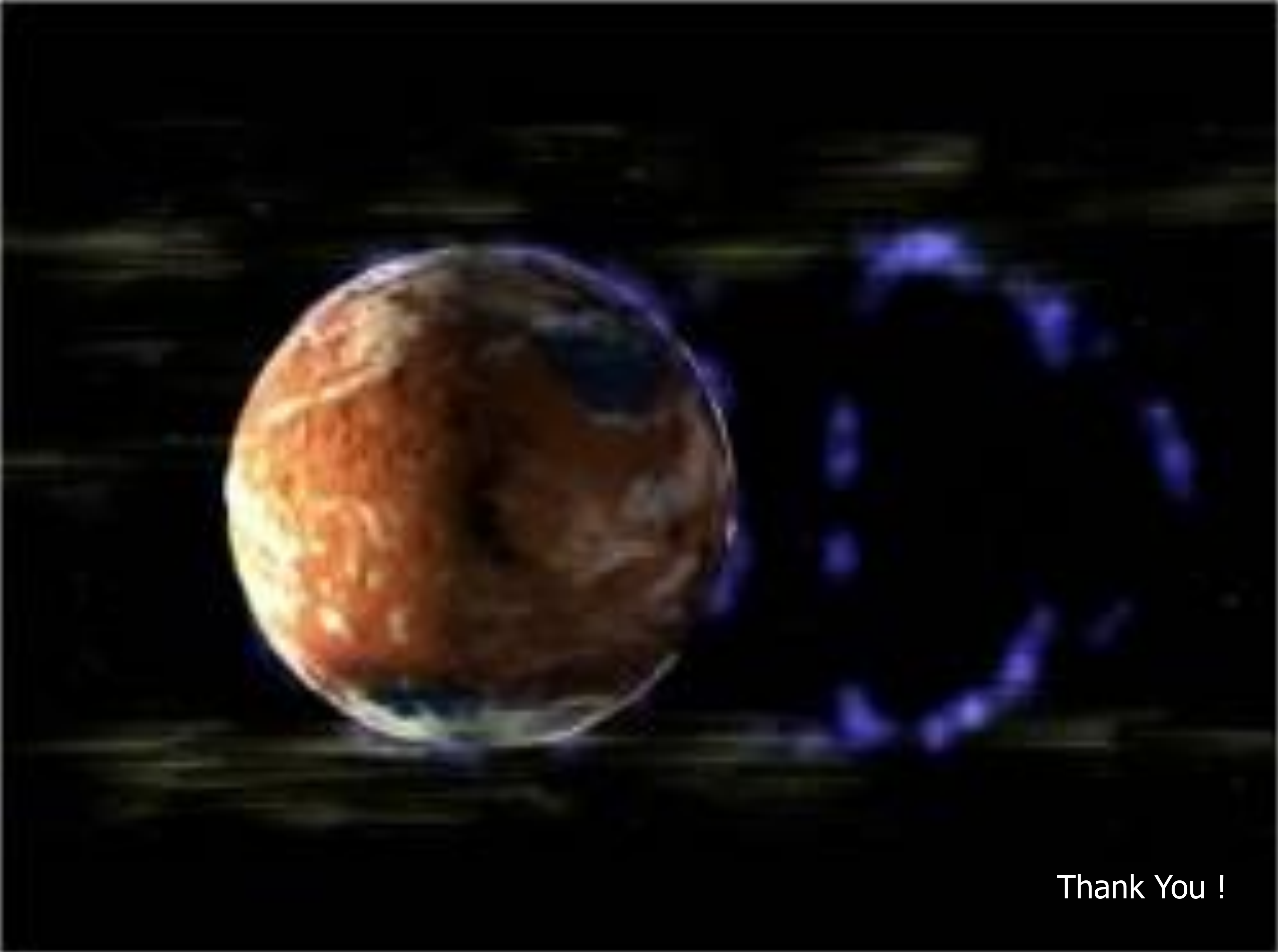
Venus's sulfuric acid rain never reaches the ground, but is evaporated by the heat before reaching the surface in a phenomenon known as virga.

The clouds of Venus are capable of producing lightning much like the clouds on Earth.

Atmosphere of Earth

Atmosphere of Earth




Thank You !