# Astronomy 405
# Solar System and ISM

## Lecture 4
## Physics of Planetary Atmospheres

January 23, 2013

# 13 Must See Stargazing Events in 2013

1) January 21 — Very Close Moon/Jupiter Conjunction
2) February 2-23 — Best Evening View of Mercury
3) March 10-24 — Comet PANSTARRS at its best
4) April 25 — Partial Lunar Eclipse
5) May 9 — Annular Eclipse of the Sun ("Ring of Fire" Eclipse)
6) May 24-30 — Dance of the Planets
7) June 23 — Biggest Full Moon of 2013
8) August 12 — Perseid Meteor Shower
9) October 18 — Penumbral Eclipse of the Moon
10) November 3 — Hybrid Eclipse of the Sun
11) Mid-November through December — Comet ISON
12) All of December — Dazzling Venus
13) December 13-14 — Geminid Meteor Shower

Please SHARE these experiences!

Roche limit:
when tidal force is greater than the gravitational force that holds the body together

$$\frac{G\,M_m}{R_m^{\;2}} < \frac{2\,G\,M_p\,R_m}{r^3}$$

$m$ : moon, $p$ : planet

$r$ : distance

$$r < f_R\,(\rho_p / \rho_m)^{1/3}\,R_p$$

where $f_R = 2^{1/3} = 1.3$

**Roche Limit**
$f_R = 2.456$

Saturn density = 0.71 g $cm^{-3}$

Moon density = 1.2 g $cm^{-3}$

Saturn radius = $6 \times 10^9$ cm

$r$ = $1.24 \times 10^{10}$ cm

All rings are within the Roche limit.

# Temperature of a planet

$$L = A\,\sigma\,T^4$$

A is the surface area

$\sigma$ is the Stefan-Boltzmann constant

$T$ is the temperature

$$L_\odot = 4\pi R_\odot^2\,\sigma\,T_\odot^4$$

$$L_\odot \frac{\pi R_p^2}{4\pi D^2}(1-a) = 4\pi R_p^2\,\sigma\,T_p^4$$

$$T_p = T_\odot (1-a)^{1/4}\sqrt{\frac{R_\odot}{2D}}$$

What assumptions are made? What if sychronous rotation?

$$T_p = T_\odot (1-a)^{1/4} \sqrt{\frac{R_\odot}{2D}}$$

The planet's temperature is independent of its size.
This equation applies to dust, asteroids, KBOs, etc.

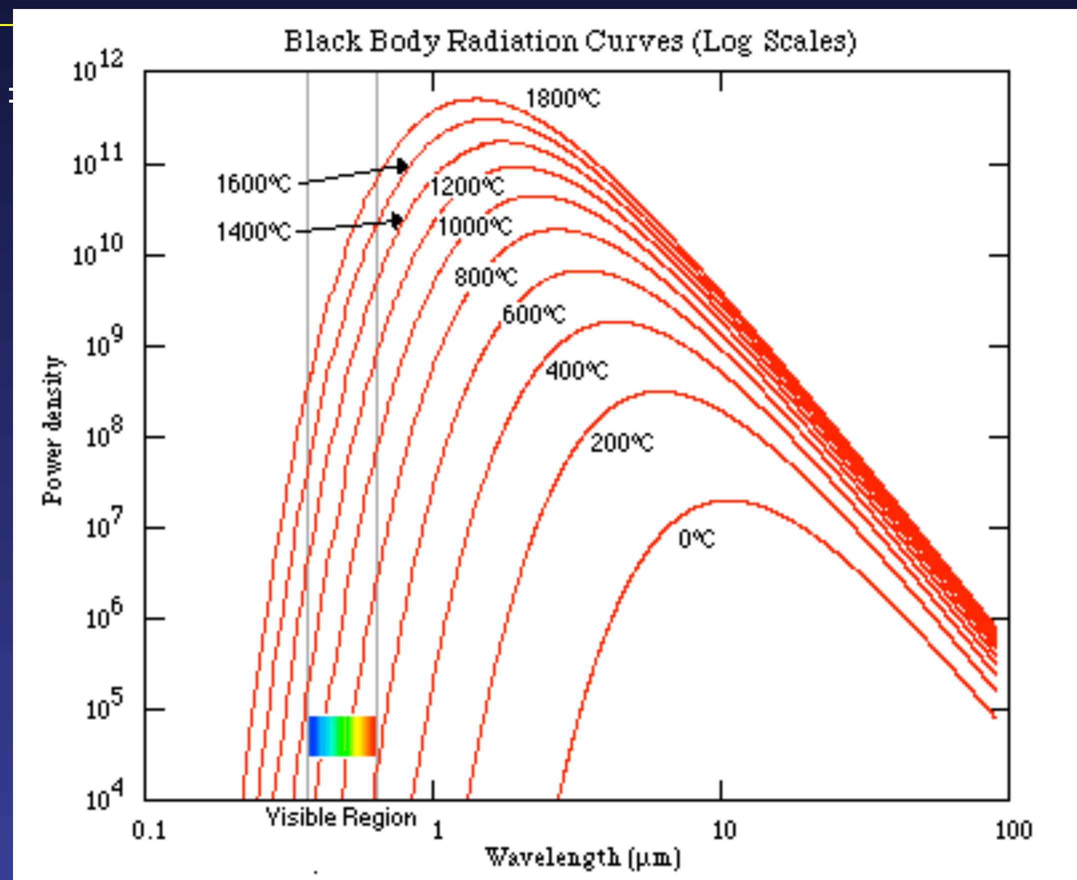
Earth $a = 0.3$, $T_\oplus =$

Clearly not correct.

Greenhouse effect:

Wien's law:

$\lambda_{max}\,T =$
0.002897 m K
2879 μm K



$$T_p = T_\odot (1-a)^{1/4} \sqrt{\frac{R_\odot}{2D}}$$

The planet's temperature is independent of its size.
This equation applies to dust, asteroids, KBOs, etc.

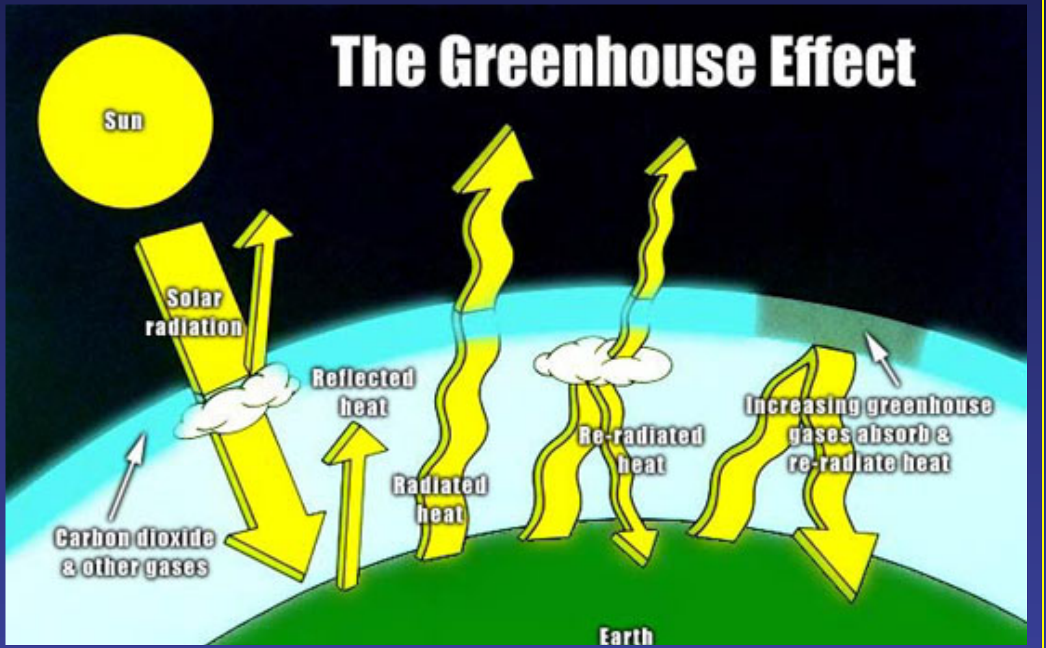
Earth $a = 0.3$, $T_\oplus = 255$ K = -19 C = -1 F
Clearly not correct.

Greenhouse effect:

Assume single layer

$T_{surf} = 2^{1/4} T_\oplus$

$\sim 300$ K



# Chemical Evolution of Planetary Atmospheres

The evolution and structure of a planetary atmosphere depends of *temperature, gravity, chemical composition*.

Primordial atmosphere is altered by:
- outgassing from rocks and volcanoes
- life on Earth
- comets and meteorites

The thermal motion of a particle may be large enough to escape.

The most critical component in the development of an atmosphere is the ability to keep it via gravity.

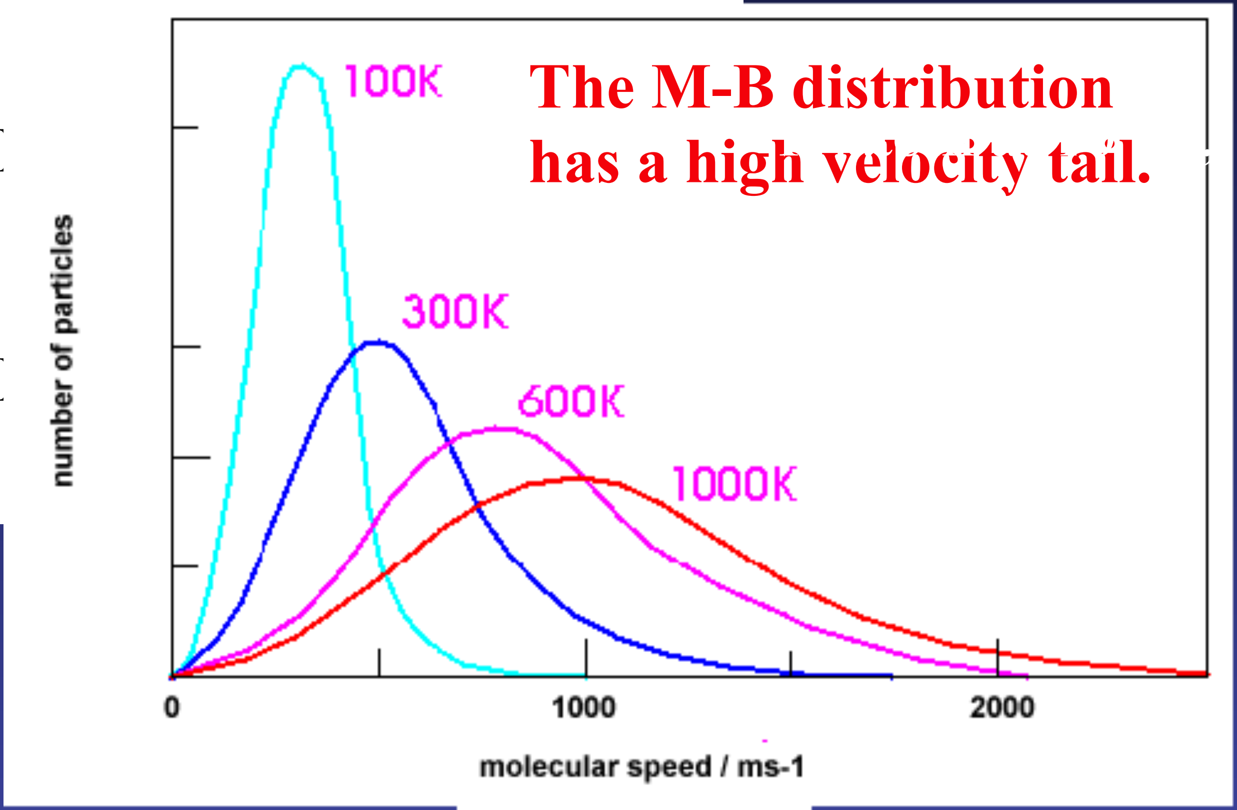
*n* particles with mass *m* and velocity between v and dv at temperature *T*

Maxwell-Boltzmann velocity distribution

$$n_v dv = n\left(\frac{m}{2\pi kT}\right)^{3/2} e^{-mv^2/2kT} 4\pi v^2 dv$$

$$v_{mp} = \sqrt{\frac{2kT}{m}}$$

$$v_{rms} = \sqrt{\frac{3kT}{m}}$$



Exosphere: The region in the atmosphere where the mean free path path of the particles become large enough to travel without collisions.

If $v > v_{esc}$ in the exosphere, it escapes.

$$v_{esc} = \sqrt{\frac{2GM}{r}} \quad \text{and} \quad v_{rms} = \sqrt{\frac{3kT}{m}}$$

If $v_{rms} > 1/6\ v_{esc}$, that component has escaped the planet's atmosphere.

$$T_{esc} > \frac{1}{54}\frac{G\ M_p\ m}{k\ R_p}$$

Example: The Earth atmosphere 78% $N_2$. $m$ of $N_2 = 4.7\text{x}10^{-26}$ kg

Earth: $M = 6\text{x}10^{24}$ kg, $R = 6.4\text{x}10^{6}$ m, $T_{esc} > 3900$ K, $T_{exo} \sim 1000$ K

Moon: $M = 7\text{x}10^{22}$ kg, $R = 1.7\text{x}10^{6}$ m, $T_{esc} > 180$ K, $T_{exo} \sim 274$ K

Number of particles moving vertically upward through the entire exosphere per second with speed between $v$ and $dv$: $(C_g \sim 1/16)$

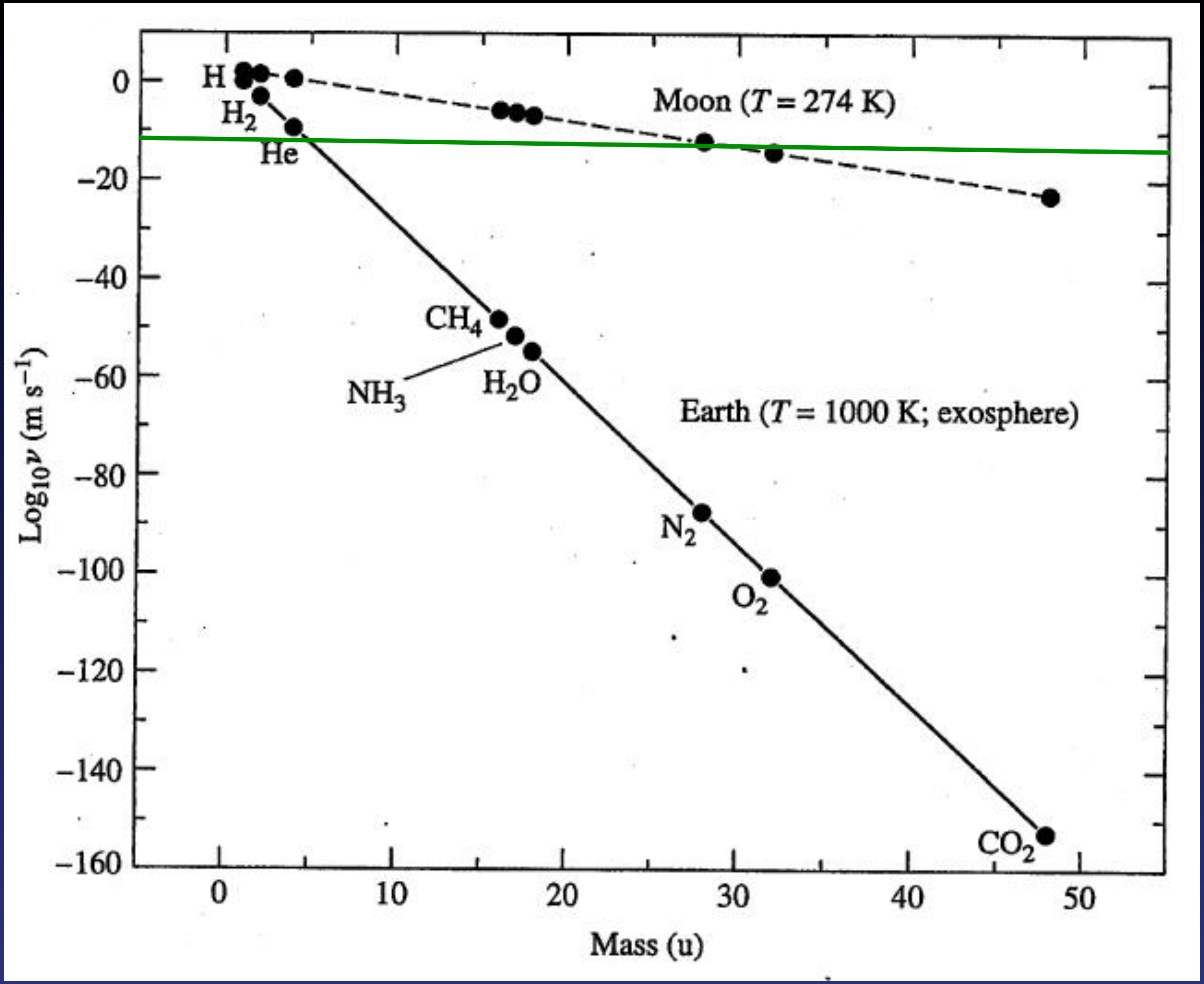
$$\dot{N}_v dv \equiv \frac{dN_v}{dt} dv = 4\pi R^2 C_g v n_v dv$$

$$\dot{N} = 4\pi R^2 \left(\frac{1}{16}\right) n \left(\frac{m}{2\pi kT}\right)^{3/2} \int_{v_{esc}}^{\infty} 4\pi v^3 e^{-mv^2/2kT} dv$$

$$\dot{N}(z) = 4\pi R^2 \nu n(z)$$

$$\nu = (1/8)\left(\frac{m}{2\pi kT}\right)^{1/2} (v_{esc}^2 + 2kT/m)\, e^{-mv_{esc}^2/2kT}$$

ν Is the atmospheric escape parameter (in units of m/s)




Earth

The atmospheric escape parameter, ν, is essentially the reduction rate of the effective thickness of the atmosphere of a certain species.

500 km / 4.6 billion years = $3 \times 10^{-12}$ m/s

If $\nu > 3 \times 10^{-12}$ m/s , that species is gone!