Astro 210

Lecture 18

October 6, 2010

Announcements

★ Guest Instructor again! Prof. Athol Kemball

- HW5 due next time
  TA office hours tomorrow 10:30-11:30
- **required** Night Observing continues
  check online for schedule and weather info
  download & bring question sheet

Last time: Solar System Tour begins at home

Geodynamics: theory of plate tectonics

Q: what are plates? connection with volcanos? earthquakes?

Earth's Atmosphere

Composition of Our Atmosphere

Percentage by Volume

N_2	77%
O_2	21%
H_2O	1%
Ar	1%
CO_2, Ne	traces

atm density ρ, pressure varies w/ height h
$\rightarrow$ airplanes are pressurized "for your comfort & convenience"
we can understand why!

assume

- ideal gas $PV = NkT \rightarrow P = NkT/V = \rho kT/m$
  m=mass of gas molecule
- T = const (isothermal)

iClicker Poll: Forces on a Blob of Atmospheric Gas

Consider a blob of air in Earth's atmosphere, **at rest**
i.e., wind not blowing up, down, or sideways

How many forces are acting on this blob?

A zero

B only one

C more than one

consider: column of air at rest

column area A

sketch

slab of height dh has mass

$dM = \rho dV = \rho A dh$

slab weight $F_{\mathrm{w}} = -g dM = -g \rho A dh$:

downward force, but doesn't fall!?

Q: why? gas has weight–why not all at our feet?

upward force

pressure: on bottom $P(h)$, on top $P(h + dh)$

sketch

net force

$$F_{\mathrm{p}} = \Delta P \times A = [P(h + dh) - P(h)]A = A\,\frac{dP}{dh}\,dh$$
$$= A\,kT/m\,\frac{d\rho}{dh}\,dh$$

hydrostatic equilibrium: $F_{\mathrm{weight}} = F_{\mathrm{pressure}}$

★ air pressure on you is weight of column of air above you!

$\Rightarrow -g\rho A dh = A\,kT\,d\rho/dh\;dh$

$\Rightarrow d\rho/\rho = -mg\;dh/kT$

$\Rightarrow \boxed{\rho(h) = \rho_0 e^{-h/H}}$

exponentially decreases!

Q: so how high is the atmosphere?

"How high" is the atmosphere?

since the real atmosphere roughly obeys $\rho(h) = \rho_0 e^{-h/H}$,

- no sharp cutoff, but smooth decline in density
- strictly, in exponential atm, $\rho(h) > 0$ for all h

but a natural scale exists where ρ becomes small:
"scale height" $H = kT/mg$
as surface, $H \simeq 8$ km, $\rho_0 \simeq 1$ kg/m^3
$H \ll R_\oplus \rightarrow$ atm is thin layer `www: atm`
also: $P = \rho kT/m = \rho g H \propto \rho$, so

$$P(h) = P_0 e^{-h/H}$$

$P_0 = 1$ atm $\simeq 10^5$ N/m^2
note: $H \propto 1/m \rightarrow$ lighter particles higher

Craters

Craters caused by meteor/comet impact
→ explosion results
→ large energy release

Resulting features:
- circular "bowl" cleared out
- in larger craters, central peak ("rebound" of underlying rock)

`www: the Moon`

⌐ *Q: Why Moon's surface heavily cratered but Earth's not?*

Why Moon's surface heavily cratered but Earth's not?

▷ small meteors burn in E's atmosphere

▷ erosion

▷ oceans hide some

▷ tectonic activity

▷ volcanos hide some

Some large objects do survive fall

impact on surface

but erosion, geological activity quicly erases evidence

`www:  Manicouagan, Canada crater`

`www:  Clearwater lakes, also Canada`

`www:  Tunguska, Siberia 1929; exploded in air 1908`

∞ `www:  Meteor Crater, AZ`

Cosmic Calamity!

What killed the dinosaurs?

Meteor/comet impact

`www: topographical map of Yucatan--note bull's eye`

Yucatan crater: $\sim$ 180 km

age (from radioactive ^{40}K dating): 65 Myrs: when dinos died!

caused tidal wave

ignited fires

$\star$ stirred up dust – most important

$\rightarrow$ raised albedo A $\rightarrow$ less sunlight absorbed

$\rightarrow$ earth cooled

$\Rightarrow$ plants, animals died

The Moon

Global Properties

$M = 7.3 \times 10^{22}$ kg
$R = 1738$ km $\sim 1/4\ R_{\text{earth}}$
$d_{\text{EM}} = 3.8 \times 10^{5}$ km $\sim 60 R_E$

$\rho_{\text{avg}} \sim 3000$ kg m^{-3}
$\rightarrow$ not big metallic core

$g_{\text{moon}} = GM/R^2 = 1.6$ m/s$^2 \simeq 1/6\ g_{\text{earth}}$

Tides

`www: high/low comparison image`

`www: oneline data -- pick a beach to visit!`

Q: what is tide period: high to high/low to low?

grav. force changes with distance $\rightarrow$ tidal forces

compare forces on mass m at different distances

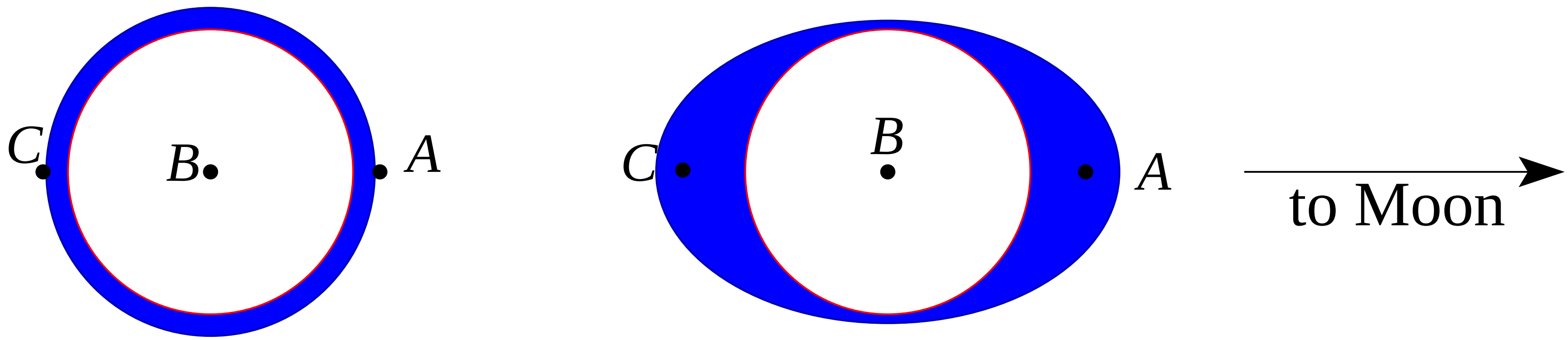
$F_A = GMm/r^2 \quad F_B = GMm/(r+d)^2$

$F_A > F_B$ force tries to pull A and B apart

$\rightarrow$ tidal force

$$\begin{aligned} F_{\text{tide}} &= F_A - F_B && (1) \\ &= GMm\left(\frac{1}{r^2} - \frac{1}{(r+d)^2}\right) && (2) \\ &= GMm\frac{(r+d)^2 - r^2}{r^2(r+d)^2} && (3) \\ &= GMm\frac{d(2r+d)}{r^2(r+d)^2} && (4) \end{aligned}$$

if $d \ll r \Rightarrow$ $\boxed{F_{\text{tide}} = 2GMm\frac{d}{r^3}}$



Earth in isolation   Earth in field of Moon

A feels *strongest* attraction

B feels average attraction

C feels *weakest* attraction

so: gravity acclerations $g_C < g_B < g_A$

relative to average $\Delta g = g - g_B$:

$\Delta g_C < 0 < \Delta g_A$

The Moon: Orbit

`www: lunation animation: always same face!`

`www: far side`

Always same side faces us!

demo: lunar globe

iClicker Poll: The Moon & Spin

The Moon always keeps the same face to us

What is the Moon's spin period?

A zero! no spin!

B nonzero! spin period $<$ orbit period

C nonzero! spin period $=$ orbit period

D nonzero! spin period $>$ orbit period

Moon has $\omega_{\text{orb}} = \omega_{\text{spin}}$ exactly!
"corotation"

Why? Tidal interaction and friction

ex: ball rolling in bowl $F_f \neq 0$
after time: stopped $F_f = 0$
$\Rightarrow$ friction drives a system to a state in which frictional forces are no longer active

Earth & Moon deformed by tidal forces
sketch
imagine $\omega_{\text{spin}} > \omega_{\text{orb}}$
Q: What is effect on Moon's surface?
Q: How will this change the spin & orbit over time?

Tidal stresses on Moon $\rightarrow$ Moon surface constantly deformed
Deformed Moon non-spherical: tidal bulges
Earth gravity on bulges $\rightarrow$ torque
increases Moon orbital angular momentum

repeated stretching/compression $\rightarrow$ friction, heating
dissipation $\rightarrow$ evolve to frictionless state:
reduces Moon spin angular momentum
until $\omega_{\rm spin} = \omega_{\rm orb}$

Note: may take long time!
complete for Moon, not for earth!

Earth $\omega_{\text{spin}}^{E} > \omega_{\text{orb}}$

sketch

Earth drags along tidal bulges

$F_N > F_F$

Two effects

1. slows earth spin (reduces ang. mom.)
   $dP_{\text{spin}}/dt \sim 1.6 \times 10^{-5}$ s/yr = 16 s/Myr
2. adds orbital ang. momentum to moon, (still circular)
   ($v_c = \sqrt{GM/R}$ or $\omega_{\text{orb}} = v_c/R = \sqrt{GM/R^3}$)
   net effect: earth-moon distance *increases*!
   $dR/dt \sim 2.3$ cm/yr

confirmed by laser ranging measurements! `www: laser to Moon`

Thus:

- moon recedes!
- Moon closer in past!