Astro 210
Lecture 19
March 4, 2011

Announcements

- HW5 due now
- Planetarium reports: due Monday
- HW6 available, due in 1 week
- Night Observing: last chance next week!
- first clear night next Mon-Fri will be *last* session
  report forms, info online

Last time:

- the dynamical Earth
- the origin of the seasons

Today: the Earth-Moon system

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 quickly 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: ~ 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:  online data -- pick a beach to visit!`

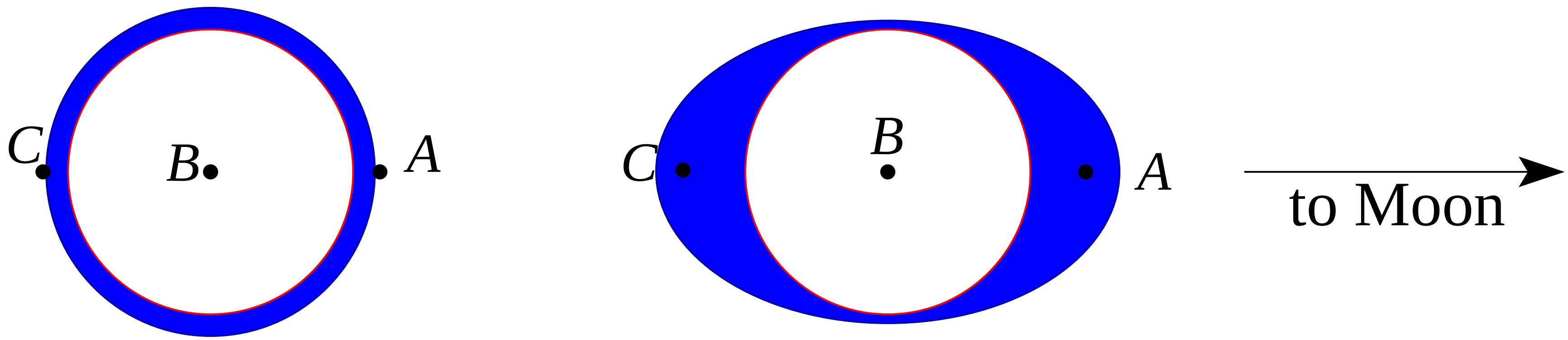
Q: what is tide period: high to high/low to low?

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

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

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!
"co-rotation"

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 $\omega_{\mathrm{spin}} = \omega_{\mathrm{orb}}$

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!

The Moon

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diagram: Earth-Moon to scale
$\rho_{\text{avg}} \sim 3000$ kg m^{-3}
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The Moon: Surface Features

⋆ **highlands**: lighter in color, heavily cratered

`www: Apollo 17 in highlands (mountains made by impacts)`

⋆ **maria** – "seas" (singular: mare): dark plains

`www: Mare Imbrium large scale`

`www: maria/highlands comparison`

smooth: fewer craters, made of volcanic rock *Q: how do we know?*

formed by lava flows

⋆ craters

cover surface

occur in all sizes, $>$ 20km to microscopic

`www: Mare Oriental`

`www: maria--overlapping craters`

Right After the One Small Step

(Garbled) the surface is fine and powdery. I can kick it up loosely with my toe. It does adhere in fine layers, like powdered charcoal, to the sole and sides of my boots. I only go in a small fraction of an inch, maybe an eighth of an inch, but I can see the footprints of my boots and the treads in the fine, sandy particles.

Niel A. Armstrong
July 20 1969
Mare Tranquillitatis–Sea of Tranquility

⋆ “soil” **regolith** = “rock blanket”

`www: footprint`

`www: Real Audio Armstrong--start at 3:35`

dust, rock fragments

accumulated debris from many impacts

⋆ other tips for tourists:

- no atmosphere → no UV, X-ray protection
- slow rotation → long “days”
  huge day/night temp diff: 370K vs 125 K
  Q: why?