Astro 210

Lecture 18

February 28, 2018

Announcements

- **HW5 due online in PDF, Friday 5:00 pm**
- Office hours: instructor 2:00-3:00 pm today
- TA: 3:30-4:30 pm tomorrow (?)
- **Night Observing this week** – weather permitting
  Campus Observatory. Wed, Thur 7–9pm
  bring **report form** available on Moodle
  take and submit **selfie** while there

Craters

Craters caused by meteor/comet impact
$\longrightarrow$ explosion results
$\longrightarrow$ 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!

Mass extinction: dinosaurs died abruptly 65 Myr ago
ended Cretaceous era, began Tertiary that continues today

What killed the dinosaurs? Longstanding question

Alvarez+(1980): strong evidence for **meteor/comet impact**
global ~ 1 cm layer at Cretaceous/Tertiary boundary
`www: K/T boundary`
found to be (relatively) highly enriched in iridium
on Earth: most Ir is in core, binds to Fe
in space rocks: not differentiated, higher Ir

Q: what would be the definitive evidence?

T Rex and the Crater of Doom

large impact implies large **crater**

1990: buried crater found via gravity acceleration anomalies located off Yucatan peninsula, Mexico `www: topographical map of Yucatan--note bull's eye`

- diameter ~ 180 km – huge!

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

Q: how could a large impactor ruin your day?

K/T Mass Extinction

Lethal Effects

- explosion of impactor and surface material
  huge numbers of small particles launched into orbit
  rained down globally, delivering K/T layer but also **heat**
- **fire** for hours, heat flux $F_{\text{sky}} \approx 10 F_{\odot}$
  like pizza oven! global fires. species died if couldn't hide
- **brimstone** raining material sulfur rich $\longrightarrow$ acid rain
  and raised albedo A: skies darkened
- **floods** tusnamis launched

The Moon

Global Properties

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

$\rho_{\rm avg} \sim 3000$ kg m^{-3}
$\rightarrow$ not big metallic core, no magnetism

surface gravity acceleration

$$g_{\rm moon} = \frac{GM_{\rm Moon}}{R^2_{\rm Moon}} = 1.6 \text{ m/s}^2 \ \simeq \ \frac{1}{6}\ g_{\rm earth}$$

Giant steps are what you take
Walking on the Moon
– astrophysicists The Police (1979) *Reggatta de Blanc*

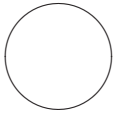
Tides

`www:  high/low comparison image`

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

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

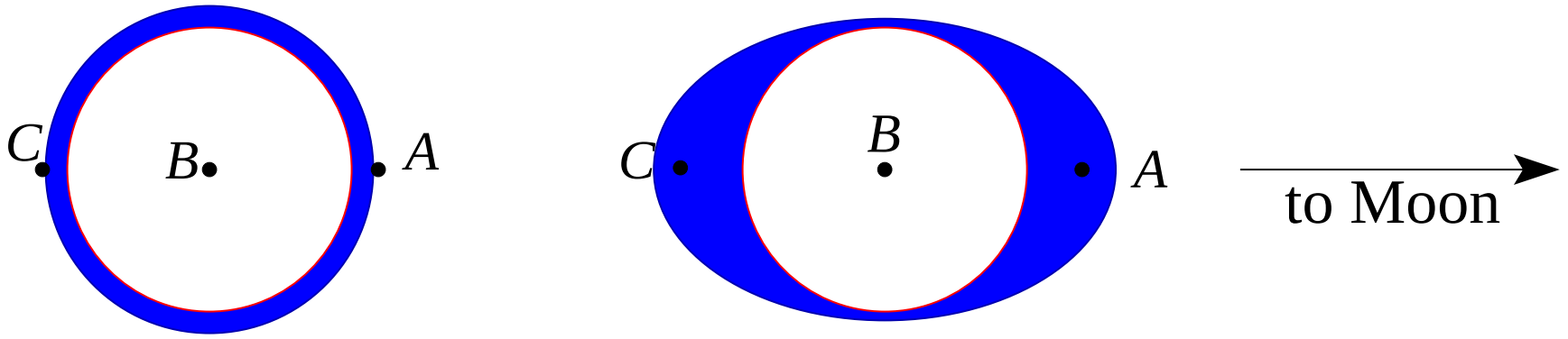
grav. force changes with distance $\rightarrow$ tidal forces
compare forces on mass m at different distances



$F_A = GMm/r^2 \quad F_B = GMm/(r+d)^2$
$F_A > F_B$ 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 $\omega_{\text{spin}} = \omega_{\text{orb}}$

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

Earth $\omega^E_{\text{spin}} > \omega_{\text{orb}}$

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: 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`

Apollo: 50th Anniversary

1950s-60s: Cold War "space race" to Moon – US vs USSR

- 1957: Sputnik 1 first artificial Earth satellite
- 1959: Luna 2 probe impacts Moon; Luna 3 orbits, sends images
- 1961: Yuri Gregarin first human in space

NASA Apollo

goal: land and return astronauts

approach: two spacecraft that dock and undock:

- Command & Service Module (CSM) orbits Moon, returns to Earth
- Lunar Module (LM="lem") lands on Moon, left in orbit

Apollo: 50th Anniversaries

Apollo 8 December 1968

- first humans out of low Earth orbit
- first humans to see Earth globally
- first humans out of Earth's gravity well
- first humans in another gravity well
- first humans to orbit Moon

Apollo 11 July 1969

humans walk on another world

Mare Tranqillitatis: Sea of Tranquility

Neil Armstrong (BS Aero Eng!), Buzz Aldrin, Michael Collins

`www: Apollo images and video`