Tides

Moon, Sun, Earth, Water

Tides are an artifact of gravity

- Gravitational Force looks like:

  $F = GMm/r^2$

- Since $F = ma$, $a = F/m$, so mass m accelerates with

  $a = GM/r^2$

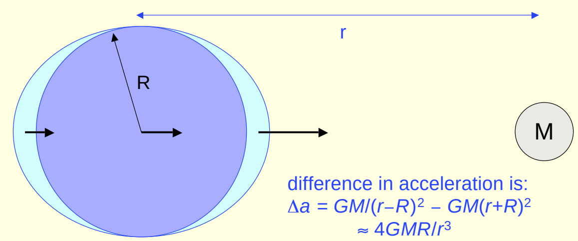
- Not all points on earth are equidistant to the moon
  - closest side accelerates faster toward moon than does center
  - farthest side accelerates slower toward moon than does center

Differential acceleration

- As earth free-falls toward moon…
  - …and why shouldn't it: the moon pulls on the earth, and nothing holds the earth from accelerating due to this force!
- The near side tries to accelerate faster
  - gets ahead of the rest of the earth
- The far side doesn't accelerate as fast
  - lags the rest of the earth
- Result is a bulge in front (eager), and a bulge behind (sluggish)

In picture form (exaggerated)

- Near side experiences greater acceleration toward moon
- Center acceleration is "just right" (just is what it is)
- Far side experiences lesser acceleration toward moon

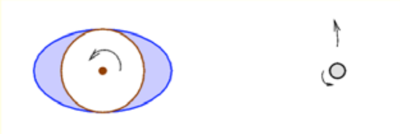


difference in acceleration is:
$\Delta a = GM/(r-R)^2 - GM(r+R)^2$
$\approx 4GMR/r^3$

So tidal influence on planet scales like M/r^3, where M is the mass of the tidal perturber

High Tide Twice Per Day

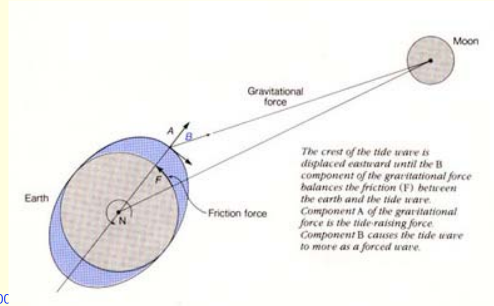
- As Earth rotates underneath the bulge (which stays pointing roughly toward the moon), a fixed point on earth experiences two high tides and two low tides per day



- Not only are oceans affected: the “solid” earth (not completely rigid) moves up and down about 0.4 meter peak-to-peak twice a day!

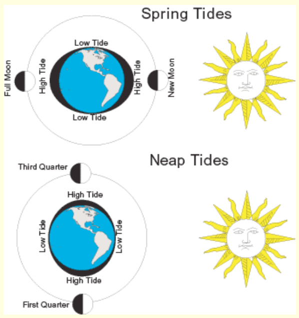
Tidal friction makes the moon’s orbit grow

- http://spiff.rit.edu/classes/phys235/no_moon/no_moon.html
- The bulge is carried forward by rotation (via friction), producing a gravitational “carrot” after which the moon races, gaining orbital energy and thus expanding the orbit by 3.8 cm per year

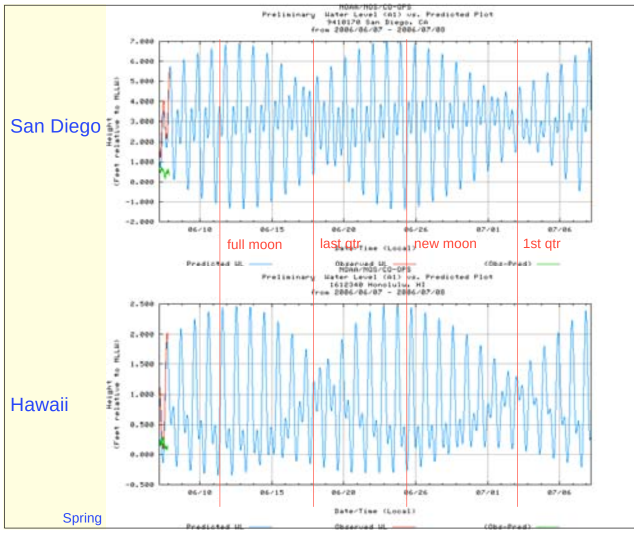


The Sun is a Player Too

- The M/r^3 ratio for the sun is 45% that of the moon
- When earth, moon, and sun are aligned (new moon, full moon), the tides add
  - called spring tides
- When 90° out of phase (first quarter, last quarter), they partly cancel
  - called neap tides
  - moon dominates, so high tide still along earth-moon direction



deceptive view: should be polar view of earth



UCSD: Physics 8; 2006

Tidal Resonance

- In Hawaii, the tides are less than a meter peak-to-peak
  - representing the natural size of the bulge
- On a continental shelf, can get greater amplitude due to “sloshing” behavior
  - 8 ft (2.5 m) peak-to-peak in San Diego
- Some inlets (Puget Sound, Bay of Fundy) experience resonance
  - if natural “slosh” time has a 12-hour period, can get substantial amplification
  - greater than 10 m peak-to-peak in some special locations

Spring 2006 9