News and Reminders

Homework 5 - due now

Homework 6 - posted tonight or tomorrow

Next quiz - Wednesday (Nov. 20), ch 13.5 - 13.7 and FEEPS Ch. III

End of semester proposal due dates:

- Proposal due: Monday, Dec. 2

Download Wolfram CDF player in preparation for Monday's guest lecture:
http://www.wolfram.com/cdf-player/

Planetesimal Formation

Gravitational instability planetesimal formation:

- if dust settles in very thin disk that is also nearly perfectly free of turbulence, then dust disk may fragment into clumps that collapse under own gravity;
- problem: turbulence prohibits these circumstances from being reached.

Streaming instability:

- bodies drift in (from loss of angular momentum), encounter another one and accumulate into a cluster
  - *local* gas is sped up a little by cluster and rotates closer to Keplerian speed
  - headwind on cluster is reduced, and drifts more slowly toward the star
- slower drifting clusters are overtaken and joined by isolated particles from further away, increasing the local density and further reducing radial drift
- -> exponential growth of the clusters

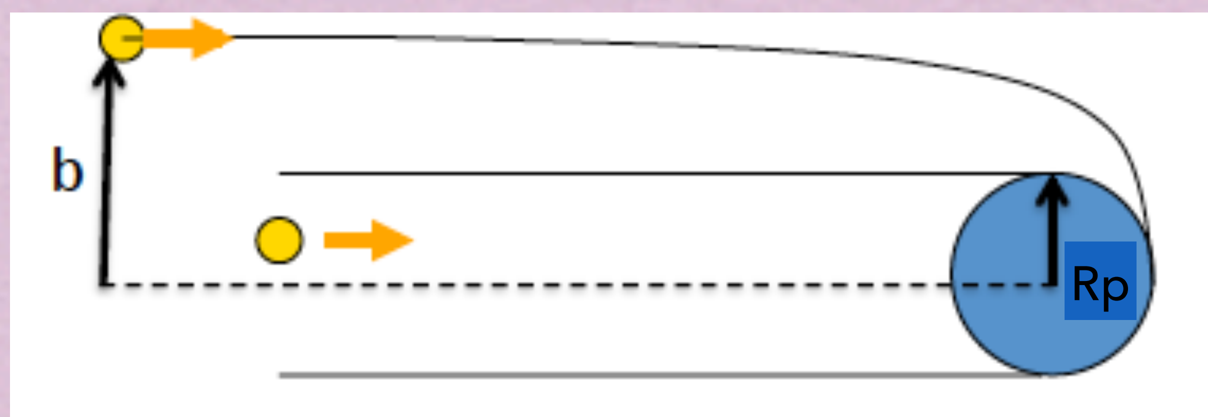
From Planetesimals to Planetary Embryos

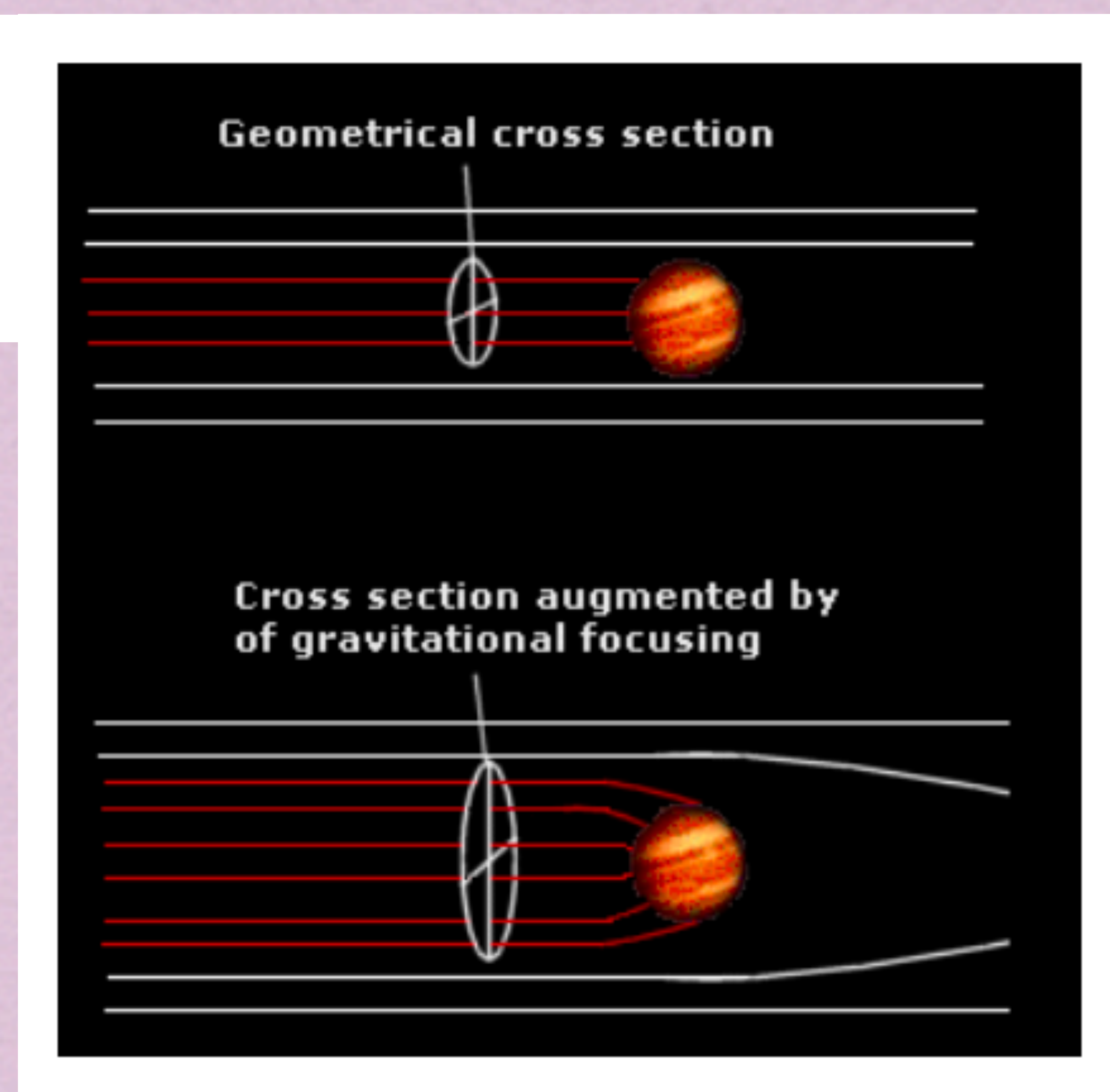
Lots of planetesimals floating around.
These **O(1 km)**-sized bodies feel much less headwind from the gas.

Collisions abound:

- can be mostly inelastic -> accretion
- elastic -> fragmentation
- elastic -> rebound
    - “semi”-Keplerian orbits are changed to random motions

Gravitational Focusing





Without gravitational focusing:

$\Gamma = \pi \; R_p^2$

With gravitational focusing:

$\Gamma = \pi \; b^2 = \pi \, (R_c^2 + 4R_cGm/v^2)$

Growth rate:

$$\frac{dM}{dt} = \rho_{sw} V_{rms} \Gamma$$

where ρ_s is the density of the planetesimal swarm and V_{rms} is the dispersion velocity

$$= \rho_{sw} V_{rms} \pi R_s^2 F_g \propto M^{2/3}$$

R_s can be approximated ~~in~~ as the radius of the embryo, if incoming planetesimals have $R \ll R_s$

Plugging in some reasonable numbers for F_g and ρ_{sw} (expressed as the surface mass density in the book):

$$F_g = 7 \quad \text{and} \quad \sigma_p = 10 \text{ g/cm}^2$$

(take $\rho_{sw} V_{rms} = \sigma_p n \sqrt{\frac{3}{\pi}}$) also $n = 2 \times 10^{-7}$ rad/s

For $R_s = 1000$ Km $= 10^8$ cm ; 442 Myr

For $R_s = 3000$ Km $= 3 \times 10^8$ cm ; 49 Myr

$\Rightarrow$ pretty long

Now let's make the cores of Jupiter and Neptune.

How does F_g and σ_p change with increasing distance from the Sun?

F_g is larger in outer regions, but σ_p drops to 3 g/cm^2 @ Jupiter's orbital separation, and is even smaller beyond.

Take F_g 4x larger @ Jupiter a:

for a 15 $M_\oplus$ core, need 600 Myr.

For Neptune, it would take many times the age of the Solar System.

So at large distances, $v \ll v_{esc}$ and $F_g \gg 1$

$$\Rightarrow F_g \approx \frac{v_{esc}^2}{v^2} \qquad \text{but } v_{esc}^2 \propto \frac{M}{R_s}$$

$$\text{so } \frac{dM}{dt} \propto M^{2/3} \cdot \frac{M}{R_s}$$

$$\text{but } R_s \propto M^{1/3}$$

$$\text{so } \boxed{\frac{dM}{dt} \propto M^{4/3}}$$

runaway growth