Planetary Migration

- Normally – migrate inward; dynamical friction/drag on planet moving through disk
- See eqn 6.11 in your book
- $T \text{ (years)} = 10^5 \left( \frac{M_p}{M_\oplus} \right)^{-1} \left( \frac{M_*}{M_\odot} \right)^{-1/2} \left( \frac{a}{a_\oplus} \right)^{-1/2} \left( \frac{H}{H_\oplus} \right)^2 100$
  - Earth masses, g cm$^{-2}$,AU

→ Accounts for short period planets
Neptune Migration

- Neptune migrates from ~20AU to 30 AU
- Outer disk objects captured into resonances with Neptune during migration
- Objects in disk scattered by Neptune $\rightarrow$ “scattered disk” of KBOs
“Nice” Model  
Tsiganis et al. 2005, Gomes et al. 2005

- 4 giant planets between 5 AU – 14 AU
- Disk of planetesimals extends to 35 AU with total mass of 35 $M_E$
- Inner planetesimals $\rightarrow$ planet scattering orbits, planets migrate $\rightarrow$ J, S cross 1:2 resonances $\rightarrow$ excites eccentricities of planetesimals $\rightarrow$ drives up eccentricities of U, N $\rightarrow$ migrate outward disrupt outer disk $\rightarrow$ late heavy bombardment of terrestrial planets
Neptune migration

Neptune scatters planetesimals $\rightarrow$ increase in eccentricity $\rightarrow$ end up under the influence of J, S $\rightarrow$ scattered out of solar system $\rightarrow$ net effect is that N scatters material inward and migrates outward.

Fernandez & Ip 1986

Tsiganis et al. 2005

Multiple Planets (Wright 2009)
Udry et al. 2003 – limits of migration

- Lack of $M_p > 2M_j$ w/ $P < 100$ days
- Runaway migration?
- Large pl. form far out?
- Star/planet interaction?

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Spiegel et al. 2009