

## Formation of the Kuiper Belt—4 Apr

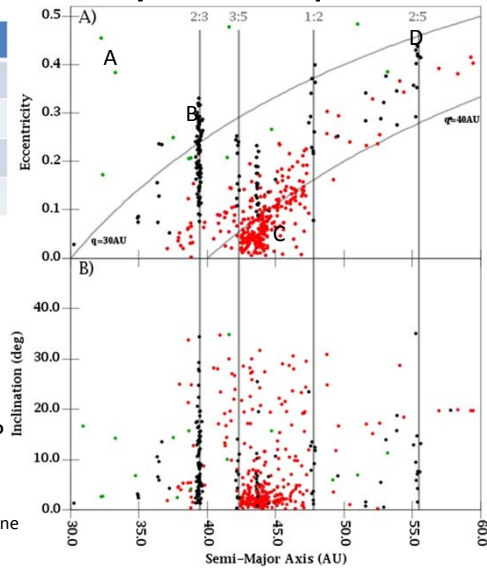
- Population of Kuiper Belt
- Nice model
  - Jupiter and Saturn's 1:2 resonance
  - Late Heavy Bombardment

## Population of objects beyond Neptune

	a [AU]	M [ $M_E$ ]	P [yr]
Jupiter	5.2	320	
Saturn	9.5	95	
Uranus	19.2	15	
Neptune	30.1	17	160

- Kuiper belt
    - $a > 30$  AU
    - Inclination is not high
  - Largest
    - Eris 2700km ( $e=.44, a=67\text{AU}, i=44^\circ$ )
    - Pluto 2300km
1. In Fig A, in which group is Pluto?

Kuiper Belt objects  
 Black: Resonant objects  
 Green: Unstable. Colliding with Neptune  
 Red: Stable, non resonant  
 Line shows constant perihelion  $q$   
 Levinson et al 2008, Icarus, 196, 258



## Nice model

- Start when gas in the disk disappeared.
- Jovian planets have circular orbits.
- Jovian planets are between 5.5 and 14AU.
  - Planets placed so that their orbits are not resonant.
  - Now 5.2 and 30AU.
- Disk of planetesimals from 1.5AU beyond outermost Jovian planet to 34AU.
- Planetesimals interact with Jovian planets over times greater than Myr.
- Time scale is long. Planets and planetesimals slowly exchange energy.

## What happens in the Nice Model?

- Planets and planetesimals slowly exchange energy.
- Orbits of Jupiter and Saturn change. Nothing interesting.
- 3-min Q: What happens that makes the gravitation interactions suddenly interesting?

## Jupiter-Saturn resonance

- Jupiter & Saturn's orbits change until they are in the 1:2 resonance.
- 1. Why does that make the interaction suddenly interesting?
  - A. Gravity becomes stronger.
  - B. The effects of gravity add up
  - C. Uranus & Neptune also become resonant.
- Saturn's orbit becomes more eccentric. It goes farther out to interact with U & N.

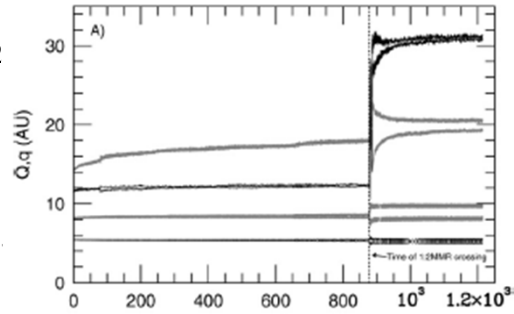


Fig 2 of Levinson et al.  
Perihelion and aphelion of Jovian planets.  
Jupiter & Saturn are in resonance at 880Myr.

## Jupiter-Saturn resonance

- Jupiter & Saturn's orbits change until they are in the 1:2 resonance.
- Saturn's orbit becomes more eccentric. It goes farther out to interact with U & N.
- 3-min Q. Describe U & N's orbits after J & S reach the 1:2 resonance.

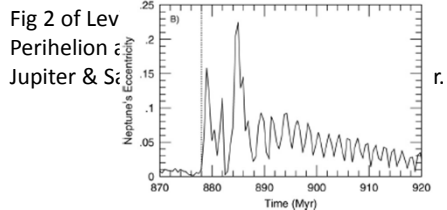
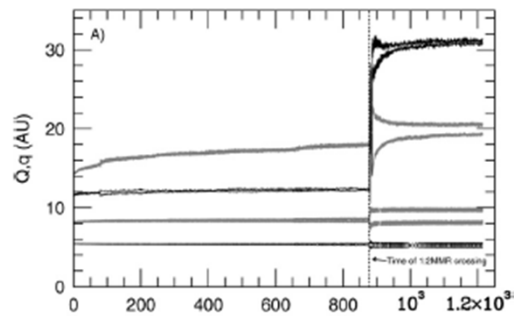
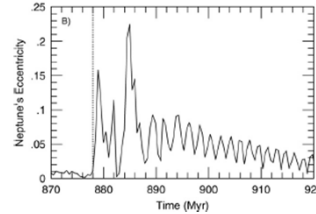


Fig 2 of Lev  
Perihelion &  
Jupiter & S

## Dynamical friction

- Dynamical friction
    - Planet pulls in planetesimals toward it.
    - Planetesimals move.
    - Motion is toward where the planet was.
    - Result is a denser cloud behind planet.
    - This slows down the planet.
  - Dynamical friction is stronger closer to sun where density of planetesimals is greater.
  - Effect is to slow down planet where it is going fastest. This makes orbit more circular.
1. How many orbits does it take for orbit to become circular?
    - A. A few
    - B. Thousands
    - C. Millions



## Late Heavy Bombardment

- Short period of bombardment found on Moon occurs at 3.9Byr (7600Myr after solar system forms.
  - Fouad Tera, D.A. Papanastassiou, G.J. Wasserburg, 1974, Isotopic evidence for a terminal lunar cataclysm, Earth and Planetary Science Letters, 22, 1
- Nice model accounts for this: Many planetesimals are scattered when Jupiter & Saturn cross the 1:2 resonance and cause Jovian planets to move.