Formation of the Kuiper Belt—9 Apr

- Homework 8 is due Fri, 15 Apr
- Levinson, H. F., et al. 2008, "Origin of the structure of the Kuiper belt during a dynamical instability in the orbits of Uranus and Neptune," Icarus, 196, 258.
  - Jupiter and Saturn's 1:2 resonance (done)
  - Late Heavy Bombardment (done)
  - Explanation of orbital elements of Kuiper Belt
  - Trapping planetesimals
  - Results
- Observations of planets outside the solar system.

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.
- U & N's orbits become eccentric when J & S reach the 1:2 resonance.
  - The semi-major axis changes quickly.
  - Orbit becomes more circular over millions of years

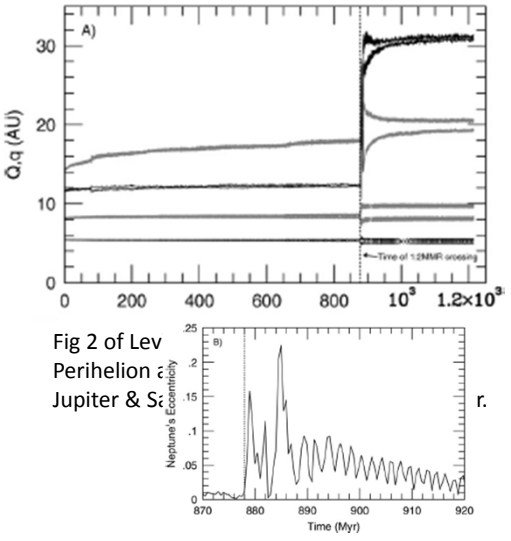


Fig 2 of Lev
Perihelion a
Jupiter & Sa
r.

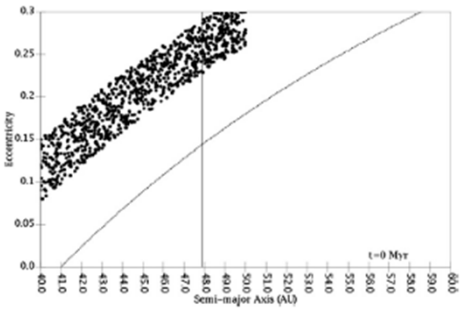
Trapping in Neptune's resonances

- At present time, Neptune's resonances are stable. Pluto's stays in the 3:2 resonance.
- How did a planetesimal get into a resonance?
- When Neptune's orbit was eccentric (0.3-4Myr), its resonances were not well defined. A planetesimal can go into a resonance and leave.
  - Orbital periods are 10^2 years. In 10^6yr, 10^4 orbits.

Calculation to illustrate trapping

- Start with planetesimals with eccentric orbits
  - Just after Jupiter & Saturn came into 1:2 resonance
- Neptune has a=34AU, e=0.2

1. 3-min Q: Why did Levenson et al. not give the planetesimals a low eccentricity?
2. Do these planetesimals get inside N's orbit?
   A. Y
   B. N
   C. Cannot determine

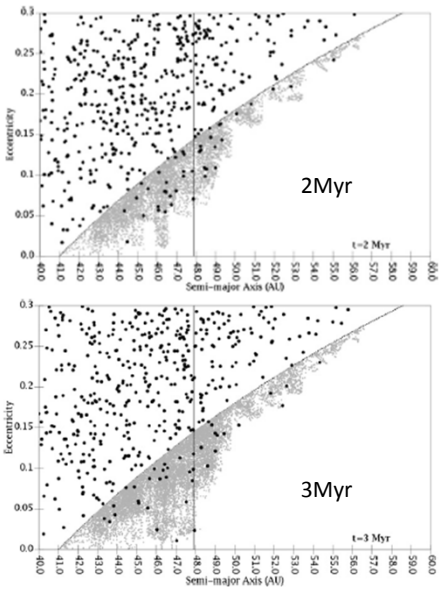


Line is perihelion = 42AU (Neptune's aphelion)
Vertical line: 1:2 resonance with Neptune.

- Orbit of a planetesimal changes.
- After 2Myr, some have had low eccentricity at some time.

1. Do planetesimals in gray region ever scatter off of Neptune?
   A. Y
   B. N
   C. Cannot tell

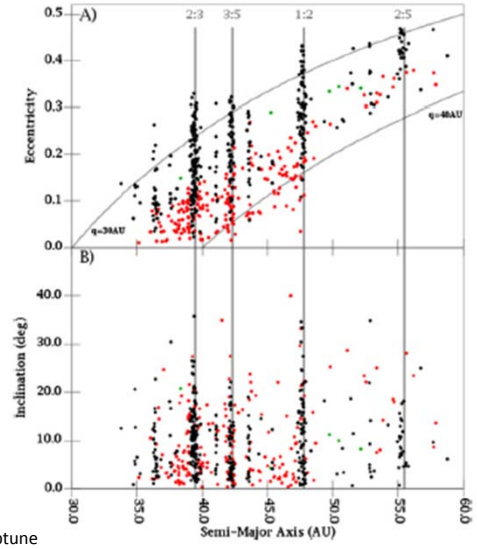
- When N's orbit becomes circular, some planetesimals that happen to have low eccentricity orbits become trapped there.
- Note: planetesimals rarely ever have orbits with low eccentricity beyond the 1:2 resonance.



Gray: at some time a planetesimal had this s-m axis and eccentricity.

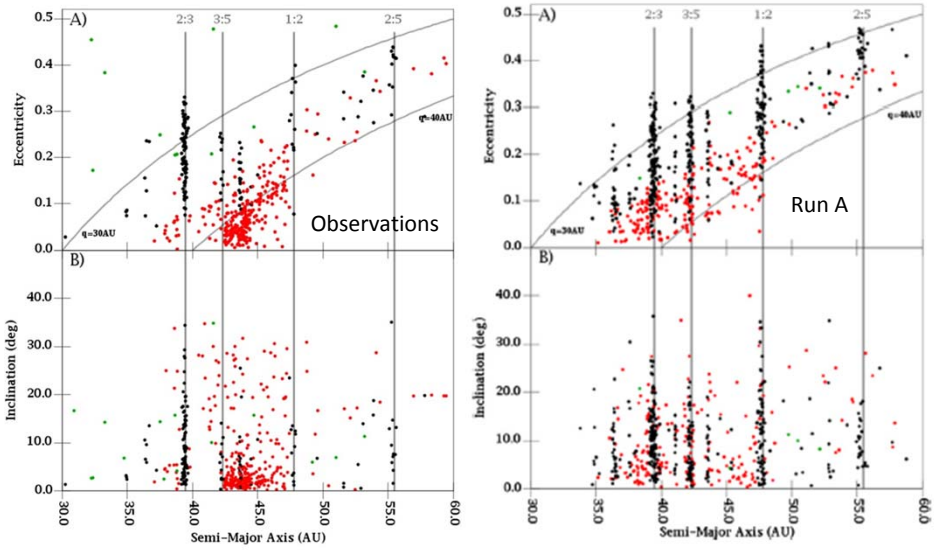
Results. Run A

1. Do planetesimals exist in Neptune's resonances? Do objects exist with orbits with low eccentricity?
   1. YY
   2. YN
   3. NY
   4. NN
2. Just after J&S became resonant, did planetesimals exist in Neptune's resonances? Did objects exist with orbits with low eccentricity?



Black: Resonant objects
Green: Unstable. Colliding with Neptune
Red: Stable, non resonant
Line shows constant perihelion q

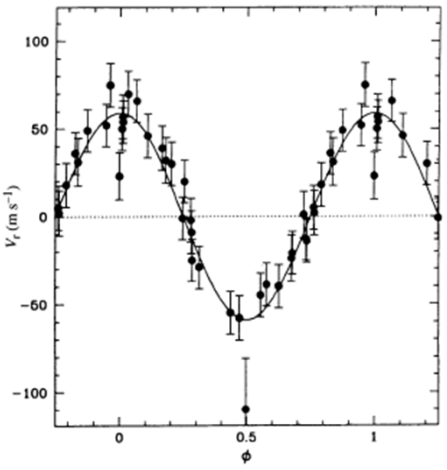
Observations & Run A



3-min Q: Describe the orbits of a population that the model of Run A does not produce.

Discovery of first extra-solar planet

- Michel Mayor & Didier Queloz, 1995, Nature, 378, 355, "A Jupiter-mass companion to a solar-type star"
- Doppler motion of 51 Peg
  - Only motion along the line of sight produces Doppler shift (proportional to v).
- 3-min Q: The earth moves at 30km/s. Why is 51 Peg moving so slowly (60m/s)?



Orbit of 51 Peg

- How big is the orbit?
- Speed is 60m/s. Period is 4day 5hr = 101 hr.
- Circumference is 60m/s*(3600s/hr)*101hr=22,000km
- Circumference of Earth is 40,000km
- Sun is 100 times bigger.
- Planet causes 51 Peg to move in a circle that is $1/200^{th}$ of its circumference.