

## Planetary scattering and migration: lessons from Pluto

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Ever since Pluto was discovered, it was obvious that its orbit - highly elliptical, highly inclined - did not fit the general pattern of the major planets' orbits. Explanations for its unusual properties included speculations of catastrophic planetary collisions and scattering, involving Neptune and its moon Triton or other unspecified objects. Careful orbit analysis also revealed that Pluto was locked in a 3:2 orbital resonance with Neptune as well as other more delicate orbital resonances. This rendered catastrophic explanations less tenable. About 15 years ago, it was proposed that the peculiar properties of Pluto's orbit might be symptoms of a phase of systematic planetesimal scattering and planet migration associated with the formation of Uranus and Neptune (Malhotra 1993). A major prediction of this hypothesis was that the exterior orbital resonances of Neptune should be abundantly populated by minor planets. Subsequent discovery of hundreds of Kuiper belt objects locked in the 3:2 and other Neptune resonances has led to wide acceptance of the idea of planetary migration. It has also led to the recognition that Pluto is "just" one of the resonant Kuiper belt objects, albeit one of the largest ones. How far and how fast was the migration of the planets? Pluto and other Kuiper belt objects provide us with estimates. When did the migration occur? There are hints in our own neighborhood: the Moon had a large spike in the rate of meteoritic bombardment 3.9 gigayears ago; the projectiles were from the asteroid belt; the orbits of the remaining asteroids are imprinted with the effects of the migration of Jupiter and Saturn. If we push the idea to its limits, there is even the possibility that the giant planets went through a period of strongly chaotic scattering amongst themselves prior to a systematic migration phase. The idea of planetary migration and scattering has also gained support from discoveries of extra-solar planetary systems - the close-in "hot jupiters" have likely migrated inward from more distant orbits where they formed, and the orbital ellipticities of extra-solar planets may be a result of planet-planet scattering and resonant migration.

Suggested reading:

Malhotra, R., 1999, Migrating Planets, *Scientific American*, 281(3):56-63