

Formation of the Oort Cloud—28 Mar

- Assignment for Fri
 - Reading
 - Section on “Origins” in http://en.wikipedia.org/wiki/Kuiper_belt
 - 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.
- Outline
 - Fernandez’s question & answer
 - Random walk
 - Perturbation by forces outside the solar system

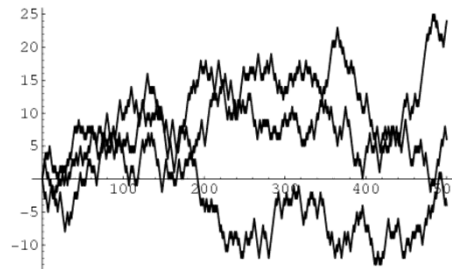
Fernandez’s question

- The perihelion distance is approximately constant compared with the semi-major axis. Therefore each orbit will go into the region of planets.
- The energy change in each passage is randomly positive or negative.
 1. Three-minute question: What happens to the comets in the Oort cloud after many orbits?
- Answer: Random walk.

Random walk

- A random walk is a process where a step is uncorrelated with the past. It occurs with equal probability in the positive and negative direction.
- After N steps of length L , the root-mean-square of the position is

$$L\sqrt{N}$$



Position vs number of steps for three trials.

<http://mathworld.wolfram.com/RandomWalk1-Dimensional.html>

Comet encounters: random walk in energy

- A comet with initial semi-major axis a_0 has initial energy

$$E_0 = -1/a_0$$

1. In this equation (1) of Fernandez, what has been left out?
 - A. G ,
 - B. M_{sun}
 - C. m_{comet}
 - D. A-C are all correct

Comet encounters: random walk in energy

- A comet with initial semi-major axis a_0 has initial energy

$$E_0 = -1/a_0$$

- The energy changes by ϵ for each encounter with a Jovian planet.
- After N encounters, the comet becomes unbound.
 - The new energy is zero

$$-\frac{1}{a_0} + \epsilon\sqrt{N} = 0$$

$$N = (a_0\epsilon)^2$$

Fernandez's answer

- For a comet to stay in the Oort Cloud, something must change its perihelion distance.
- Viable possibilities must be beyond the solar system.
 - Tidal force of the Milky Way Galaxy
 - Tidal force of giant molecular cloud
 - Other stars
 - Giant molecular cloud and stars were very different when the sun was born.

The sun's natal neighborhood

- Stars form in clouds of gas.
- Example: Orion nebula
- Gas cloud collapses.
- Stars form.
- Gas is blown away by light of hot stars.
 - Time is 0.1 Myr
 - Open cluster is revealed.
- Open cluster dissipates.
 - Time is 100Myr



Orion nebula



Visible

Infrared

Visible: NASA, C.R. O'Dell and S.K. Wong (Rice University)

Infrared: [NASA](#); K.L. Luhman (Harvard-Smithsonian Center for Astrophysics);

& G. Schneider, E. Young, G. Rieke, A. Cotera, H. Chen, M. Rieke, R. Thompson (Steward Observatory)

Pleiades, an open cluster



NASA, ESA, AURA/Caltech, Palomar Observatory

Effect of Sun's natal neighborhood

- Age of sun is 4500Myr
- If sun formed as part of an open cluster
 - There were many nearby stars for 100Myr, and then they left.
 - These star can affect comets in the Oort cloud by changing their perihelion distance so that they do not come close to the Jovian planets repeatedly.

Effect of perturbers outside solar system

- Why is the relative change in perihelion distance $\Delta q/q$ small for small a ?
- For a perturber to be effective, it must change the perihelion distance by $\Delta q/q > 1/2$.

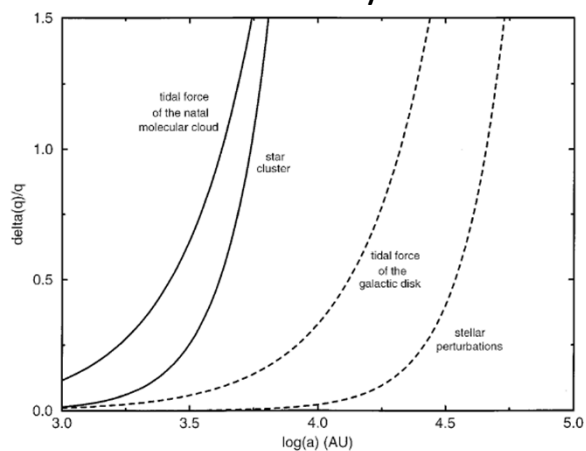


FIG. 2. Relative change in the perihelion distance of a comet as a function of its semi-major axis for different external perturbers. Dashed curves are for perturbers from the present galactic environment. Solid curves are for assumed perturbers in an early galactic environment.

Effect of perturbers outside solar system

- For a perturber to be effective, it must change the perihelion distance by $\Delta q/q > 1/2$.
1. What is the most likely reason comet Hale Bopp was injected into the inner solar system?
 - A. Molecular cloud
 - B. Star cluster
 - C. Tidal force of galactic disk
 - D. Encounter with a star

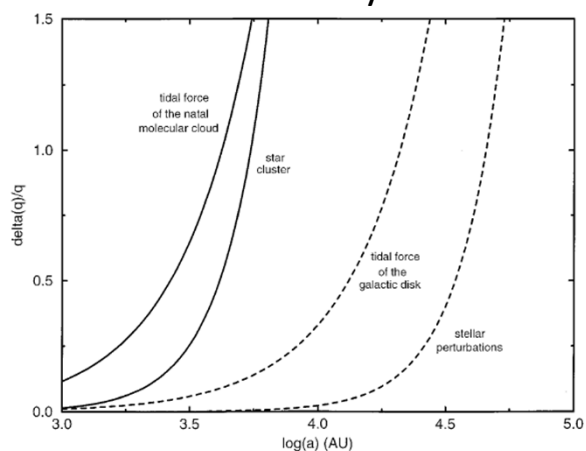


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Effect of perturbers outside solar system

1. What is the most likely reason comets kicked out of the region of the Jovian planets?

- A. Molecular cloud
- B. Star cluster
- C. Tidal force of galactic disk
- D. Encounter with a star

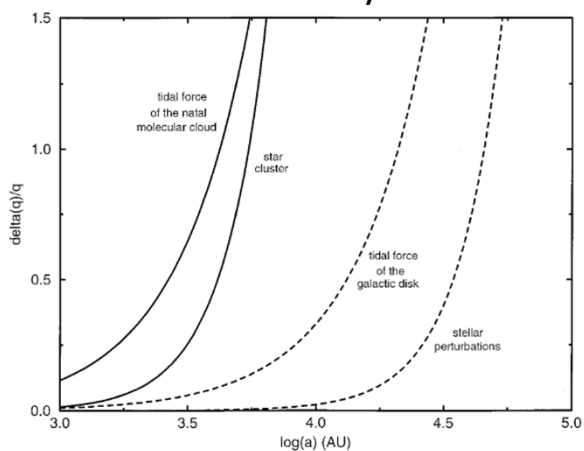


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Paper by Fernandez

1. Three-minute question: Fernandez asked, "How could the Oort Cloud exist in spite of xxx." What is xxx? Write your answer on paper and turn it in. I will call on groups to collect your answers.