Formation Kuiper belt—1 Apr

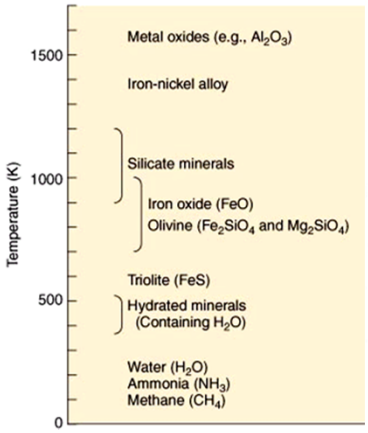
- Outline
  - Formation of Jupiter
  - Formation of the Jovian planets as a group
  - Formation of the Kuiper Belt
- Levinson, H. F., et al. 2008, "Origin of the structure of the Kuiper belt during a dynamical instability in the orbits of Uranus and Neptune," Icarus, 196, 258. This paper points out that there are clues to all of these topics in the orbits of the Kuiper Belt objects.

What a model for formation of Jupiter needs to consider

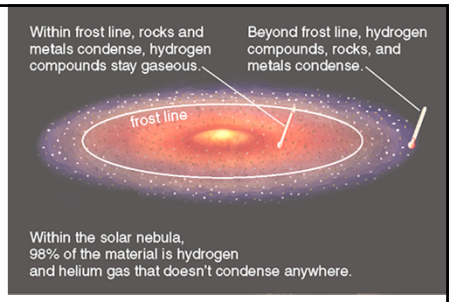
- 3-min question. What do we know about the formation of the solar system and the composition of Jupiter? Write one fact on paper. I will call on your group.

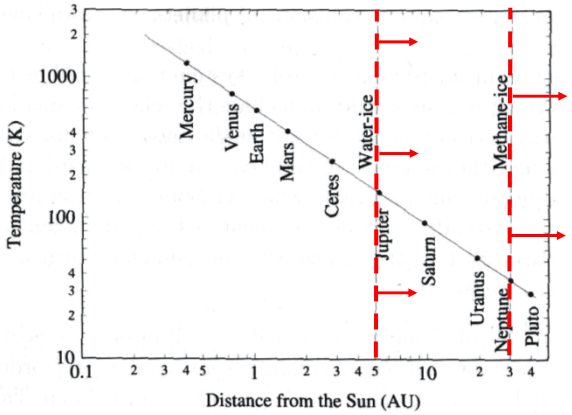
Thermal history of the Solar System

- Terrestrial vs. giant planets
- Asteroids vs. comets



Evaporation Temperatures





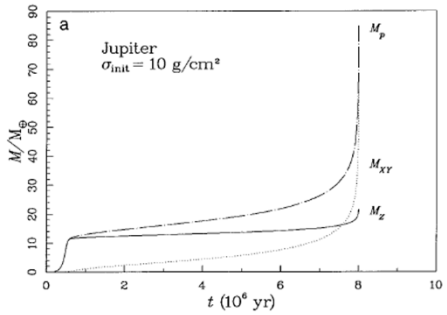
Model for formation of Jupiter

- 3-min question. You are making a computer model for the formation of Jupiter. What effects should you include? Write one effect on paper. I will call on your group.

Formation of Jupiter

- Model of Pollack, JB, et al, 1996, Icarus, 124, 62.
  - Gravity of planet seed
  - Model of gas envelope
    - A little star
  - Planetesimal can break apart when it runs into Jovian seed.
- Results
  - Phase 1
    - Jupiter accretes solids rapidly until they are exhausted.
    - Solids means rock and ices
  - Phase 2
    - Accrete solid slowly & gas
  - Phase 3: Runaway accretion
    - Size increases so that accretion rate becomes rapid

1. Runaway accretion occurs ___ for Saturn. We will discuss the reason later.
   A. Sooner
   B. Later
   C. At the same time



Rock & ice: M_Z
Gas: M_{XY}

Formation of the Jovian planets together

- 3-min question. You are making a computer model for the formation of 4 Jovian planets as a unit. What effects should you include? Write one effect on paper. I will call on your group.

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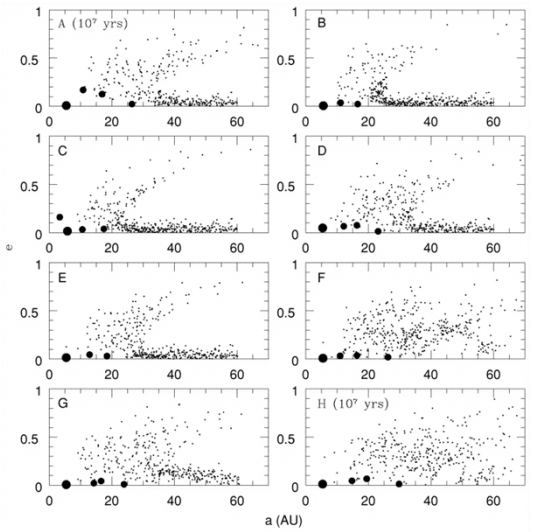
- Computer simulation
  - Thommes, E., Duncan, M., & Levinson, H., 2002, "The Formation of Uranus and Neptune among Jupiter and Saturn," AJ, 123, 2862.
- Put in by hand
  - 4 Jovian planets of $10M_E$.
  - Jupiter rapidly undergoes runaway accretion.
  - Many plantesimals of $0.2M_E$.
- Account for gravity of
  - Sun on Jovian planet & planetesimal
  - Jovian planet & Jovian planet
  - Jovian planet & planetesimal

- Semi-major axis and ellipticity for eight runs after 5Myr or 10Myr.
  - Biggest dot: "Jupiter"
  - Big dots: $10M_E$
  - Little dots: planetesimals

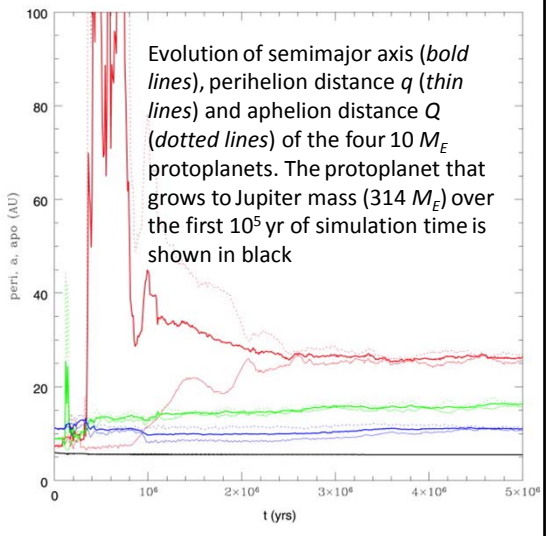


Formation of the Jovian planets

- Semi major axes
  - Jupiter 5.2AU $320M_E$
  - Saturn 9.5 95
  - Uranus 19.2 15
  - Neptune 30.1 17

1. Which line corresponds to Saturn?
   A. Black
   B. Blue
   C. Green
   D. Red

- 3min Q: What happens to Saturn, Jupiter, Neptune, & Uranus in this simulation?



Evolution of semimajor axis (*bold lines*), perihelion distance *q* (*thin lines*) and aphelion distance *Q* (*dotted lines*) of the four 10 M_E protoplanets. The protoplanet that grows to Jupiter mass (314 M_E) over the first 10^5 yr of simulation time is shown in black