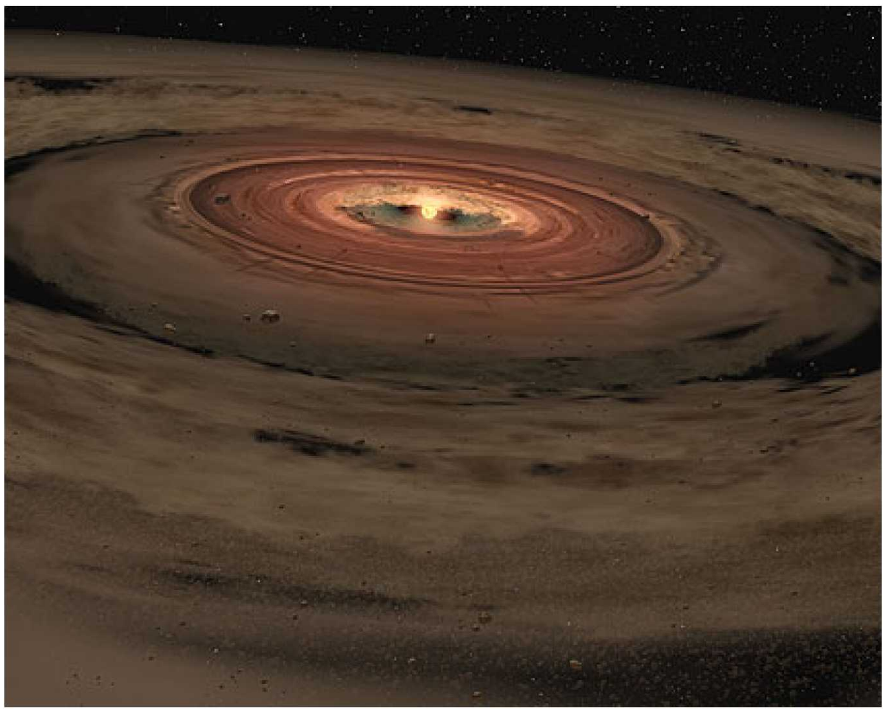
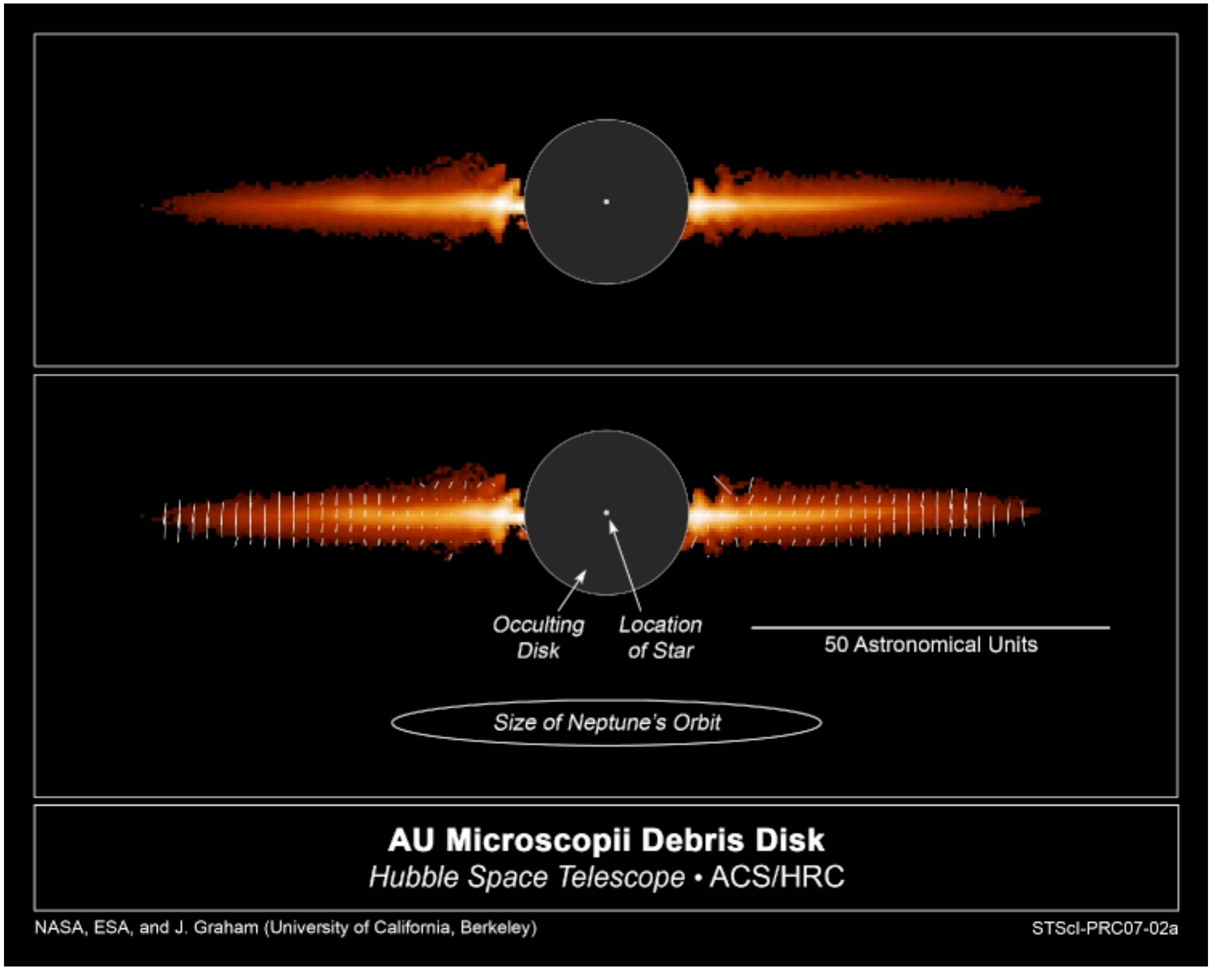
Planetismal hypothesis: solar system formation revisited



Artists impression of early solar nebula (NASA)

- Sun forms surrounded by protoplanetary disk, containing gas and dust grains: we observe such disks around young stars today

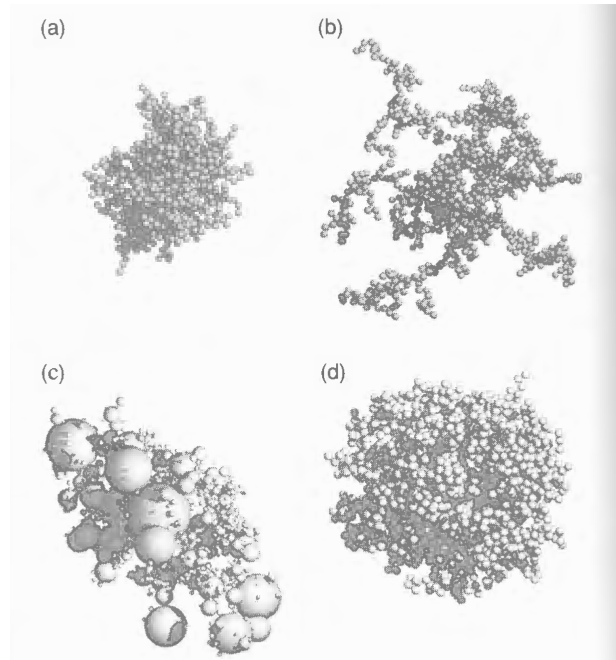


AU Mic is a nearby young M dwarf star

- Microscopic grains form

  Depending on the distance from the proto-Sun and thus the temperature of the nebula, the grains are made of silicates and Fe compounds (inner solar system, inside ice line) or water and other compounds (outer solar system)

- Microscopic grains aggregate to form small (cm-size) objects; fractal shapes
- They settle to the midplane and keep growing



Simulations of aggregations from different sizes of grains (Blum et al 1994)

- When grains are small in size they interact with the gas in ways that slow the grains down a little
- As planetismals become larger, the gas has little or no effect
- They grow further via 2-body collisions in which smaller objects tend to fragment and larger objects accrete and so grow to be even larger
- Eventually massive planetary embryos form at regular intervals in semi-major axis

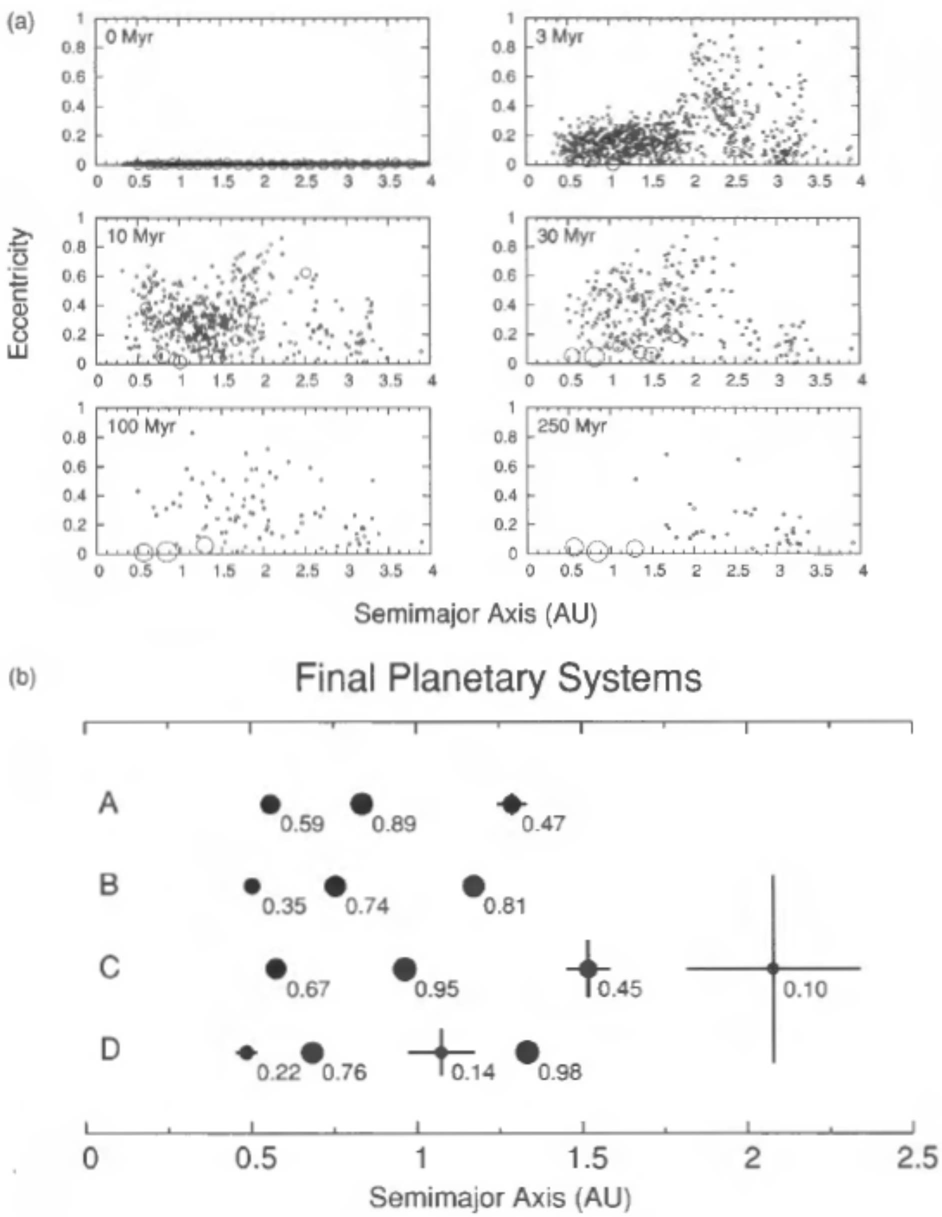
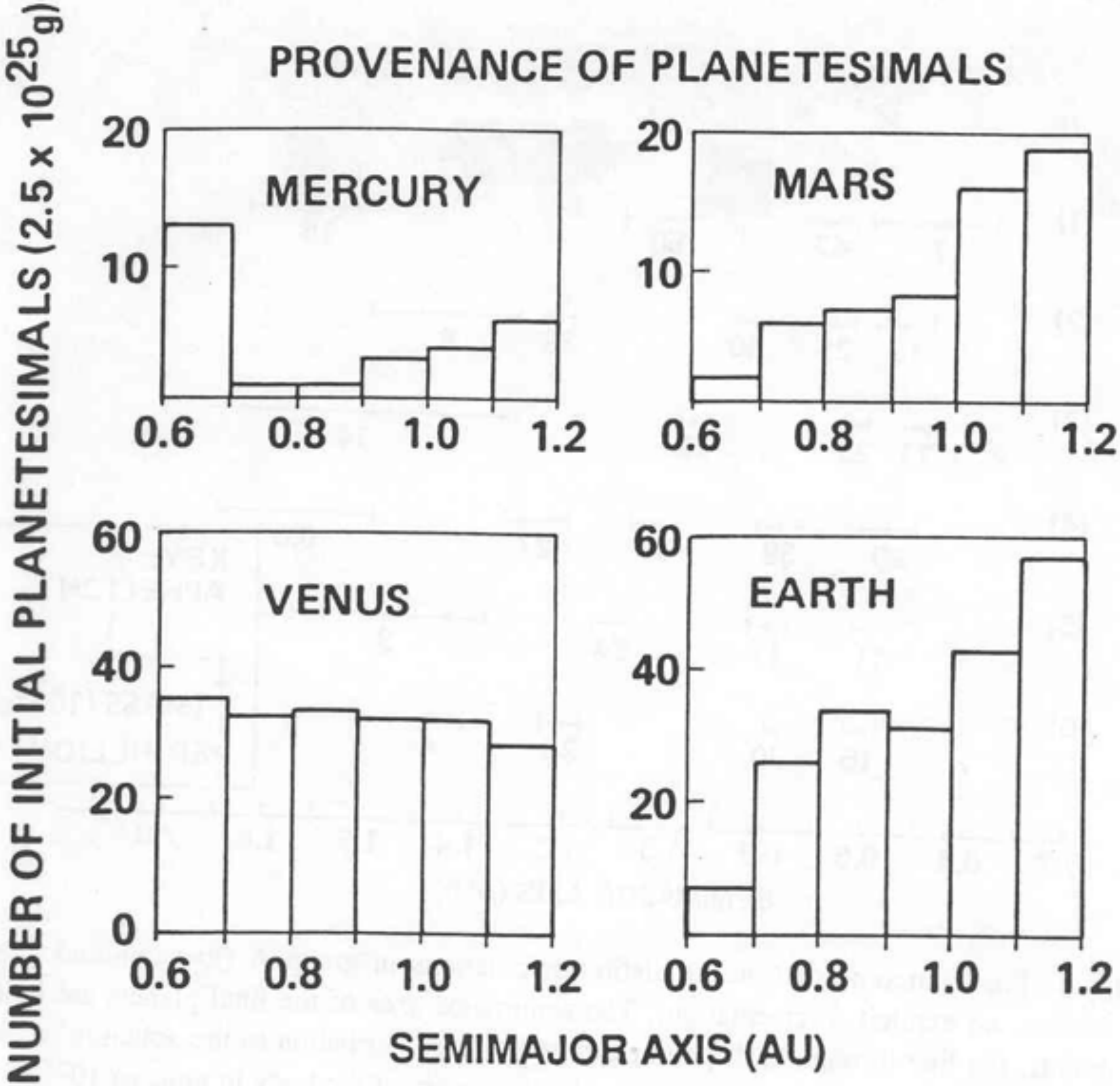


Figure 13.20 (a) Simulation of the final stages of terrestrial planet growth in our Solar System using an *N*-body code that assumes all physical collisions lead to mergers. The simulation begins with 25 planetary embryos as massive as Mars, ~1000 planetesimals each of mass 0.04 $M_{♂}$, and Jupiter and Saturn on their current orbits. The planetary embryos and planetesimals are represented as circles whose radii are proportional to the body's radius and whose locations are displayed in $a - e$ phase space at the times indicated. (b) Synthetic terrestrial planet systems produced by four different *N*-body simulations of the final stages of planetary accretion. The final planets are indicated by filled circles centered at the planet's semimajor axis. The horizontal line through each circle extends from the planet's perihelion to its aphelion; the length of the vertical line extending upward and downward from a planet's center represents its excursions perpendicular to the invariant plane at the same scale. The numbers to the lower right of each circle represent the planet's final mass in $M_{\oplus}$. For example, the outermost planet in simulation A has $a = 1.29$ AU, $e = 0.035$, $i = 1.55°$ and $M_p = 0.47$ $M_{\oplus}$. The results of the simulation shown in part (a) are presented in row A. The initial disks used for these four simulations are very similar, and the different outcomes arise from stochastic variations of accretion dynamics. See O'Brien *et al.* (2006) for particulars of the calculations. (Courtesy David O'Brien)

- Simulation shown on previous page starts with 25 objects as massive as Mars, 1000 planetismals 4% of Mars' mass and Jupiter and Saturn on current orbit.
- Gravitational perturbations induce orbits with wide range of eccentricity, so orbits cross (see 3 Myr panel)
- We then have a period of much chaos: close encounters and giant impacts
- Form a small number of terrestrial planets in of order 10^8 years: 4 different possible solar systems shown



6. Distribution of initial semimajor axes of the planetesimals that formed the final planets for
ase 1, group A.