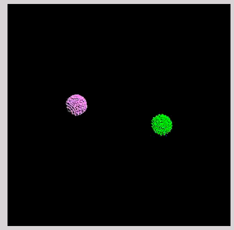
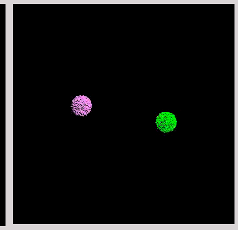
Terrestrial planet formation

In the inner Solar System, think dust (no ices) grew in size via collisions + sticking

Initial phases don't involve gravity - too weak for dust particles, cm and meter-sized bodies

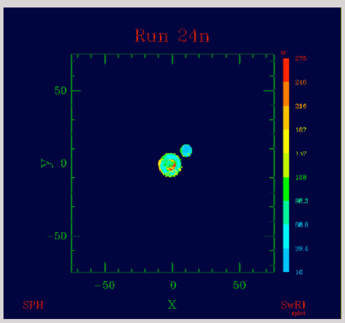
Form *planetesimals* with sizes of km and after that, gravity dominates the further growth

Movies: Derek Richardson

Rapid formation (< 1 million years) of large bodies - sometimes called planetary embryos (Moon to Mercury size)

Slower assembly of 50-100 embryos into final terrestrial planets. 10 - 100 million years.



One of the last giant impacts is thought to have formed the Moon (SwRI / Robin Canup simulation)

Formation of the giant planets

Most popular theory for giant planet formation: core accretion.

Cores of the giant planets (M ~ 10-20 Earth masses) form just as the terrestrial planets, but faster because of the additional surface density of icy materials beyond the snowline.

Cores then capture envelopes of gas from the disk before the gas is lost (within ~10 million years):

- several hundred Earth masses for Jupiter
- smaller envelopes for Saturn, Uranus and Neptune

Water on the Earth

Temperature in the protoplanetary disk at the location of the Earth was too high for water to condense

Meteorites from asteroids inside about 2.7 AU are very water-poor (0.1% by mass or less)

Possible delivery of water from:

- comets
- asteroids in the Main Belt

Constraint: composition of the Earth's oceans

2 **isotopes** of hydrogen:
- ordinary hydrogen (1 proton in atomic nucleus)
- deuterium (`heavy hydrogen') - 1 proton plus 1 neutron in the nucleus

The ratio of deuterium to hydrogen in the Earth is measured at ~150 parts per million (ppm)

Comets: D/H ratio of about 300ppm

Carbonaceous chondrites: meteorites thought to come from outer asteroid belt

D/H: 120-180 ppm

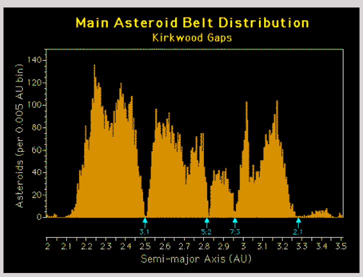
Seems most likely that the Earth's water came from the asteroid belt region rather than from comets

Total mass of water on the Earth is estimated at about 0.05% (5×10^{-4} Earth masses). If this was delivered by asteroids that are 10% water by mass, need:

$$\begin{aligned} M_{asteroids} &= 10 \times 5 \times 10^{-4} M_{Earth} \\ &= 5 \times 10^{-3} M_{Earth} \end{aligned}$$

…about 10 times the *current* mass of asteroids in the asteroid belt.

Suggestion: initial asteroid belt was much more massive, formation of Jupiter destabilized orbits and led to asteroids impacting the Earth



See the influence of Jupiter on the asteroids in the number of asteroids at different distances from the Sun

One way in which giant planets may be important for life

Giant planets also play a role in the outer Solar System:

- Jupiter ejects comets into the Oort cloud (protects Earth)
- Evolution of the outer planet orbits may have captured Pluto into its unusual, Neptune crossing orbit, and scattered debris into the inner Solar System

We can study all this in detail in the Solar System: how important are similar processes in other planetary systems?