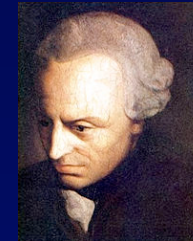
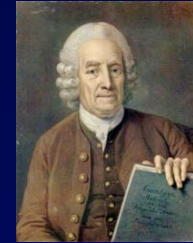


Protoplanetary discs

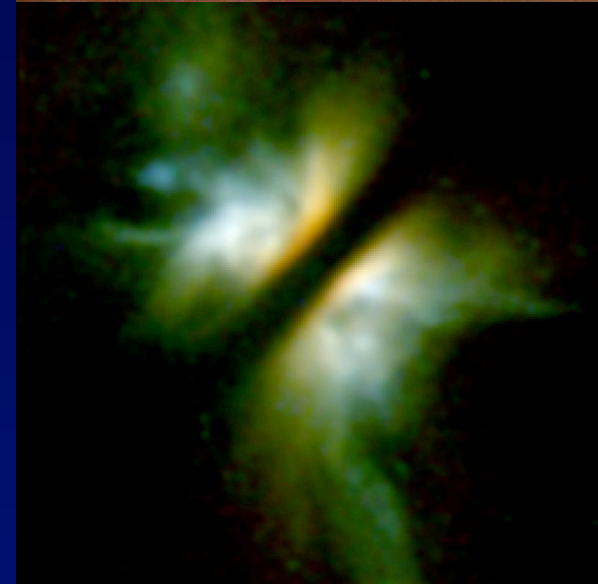
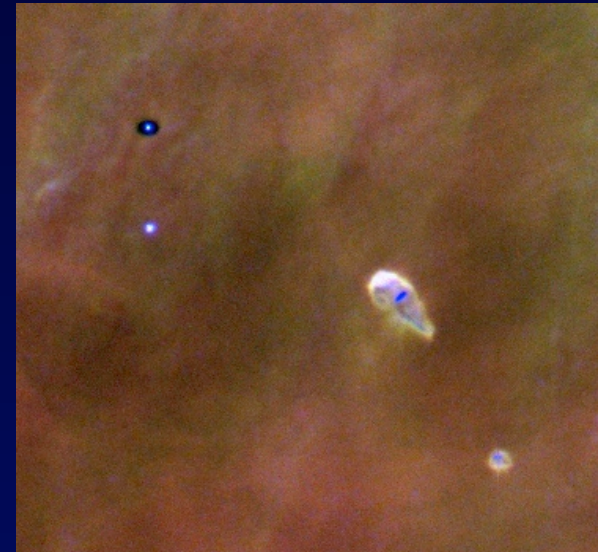
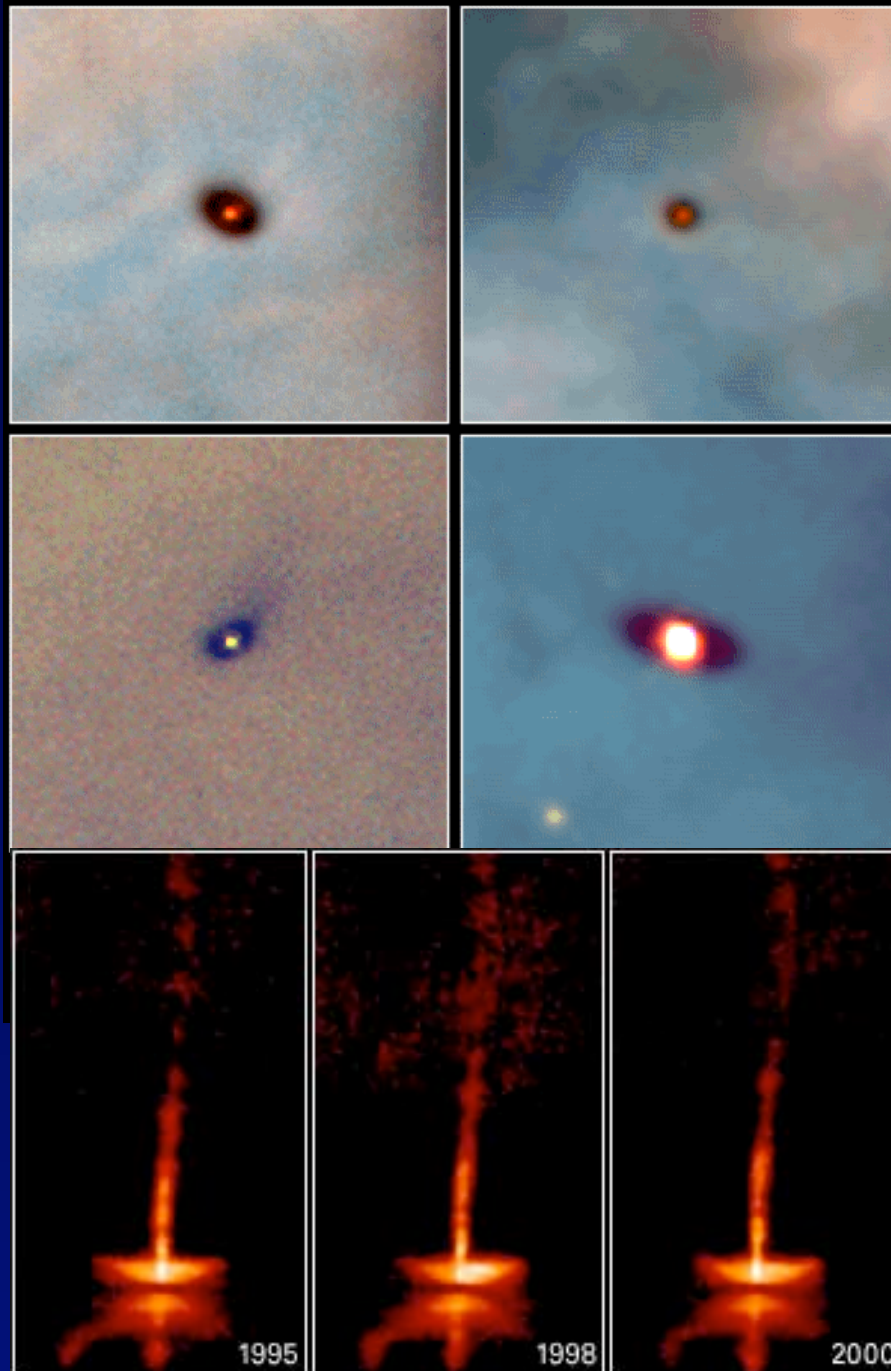
The **Nebula Hypothesis** for the formation of the Solar System was developed in the 18th century by Emanuel Swedenborg (1734), Immanuel Kant (1755) and Pierre-Simon Laplace (1796).

The Sun and planets formed from a rotating and flattened rotating cloud of gas and dust - the Solar Nebula



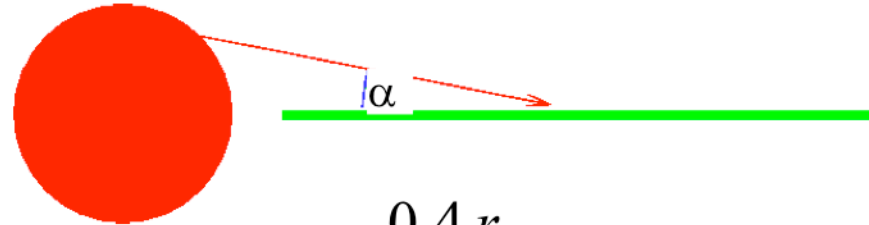


Observations of nearby star-forming regions reveal presence of...



... gaseous and dusty discs orbiting around young T Tauri stars (with outflows, and possibly being photoevaporated by UV photons from nearby high mass stars)

Flat irradiated disks



$$\alpha \cong \frac{0.4 r_*}{r}$$

Irradiation flux:

$$F_{\text{irr}} = \alpha \frac{L_*}{4\pi r^2}$$

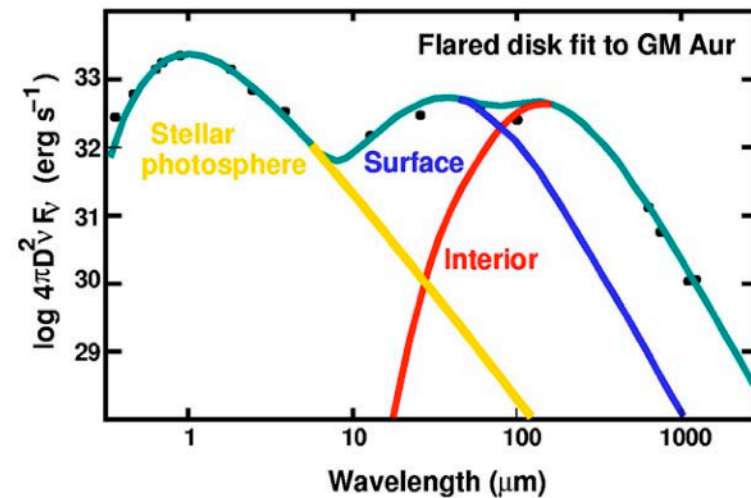
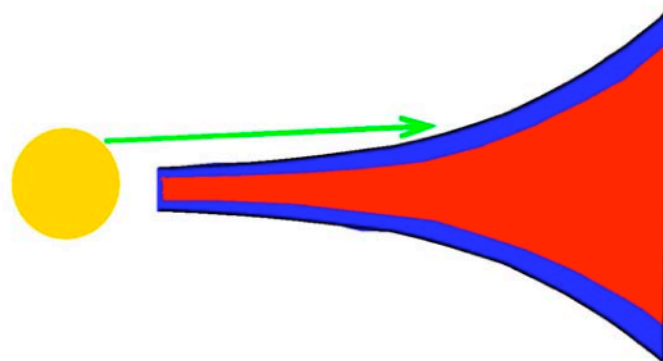
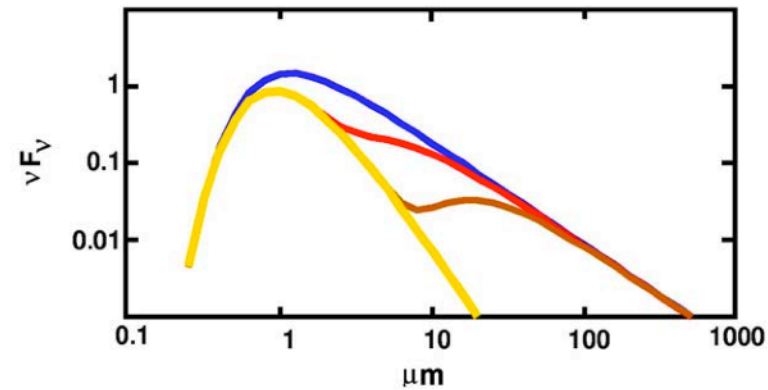
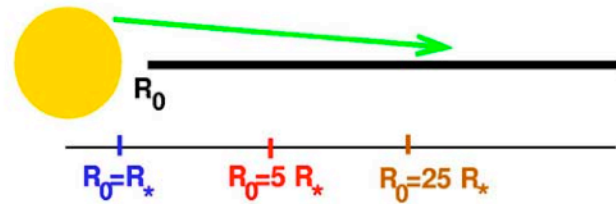
Cooling flux:

$$F_{\text{cool}} = \sigma T^4$$

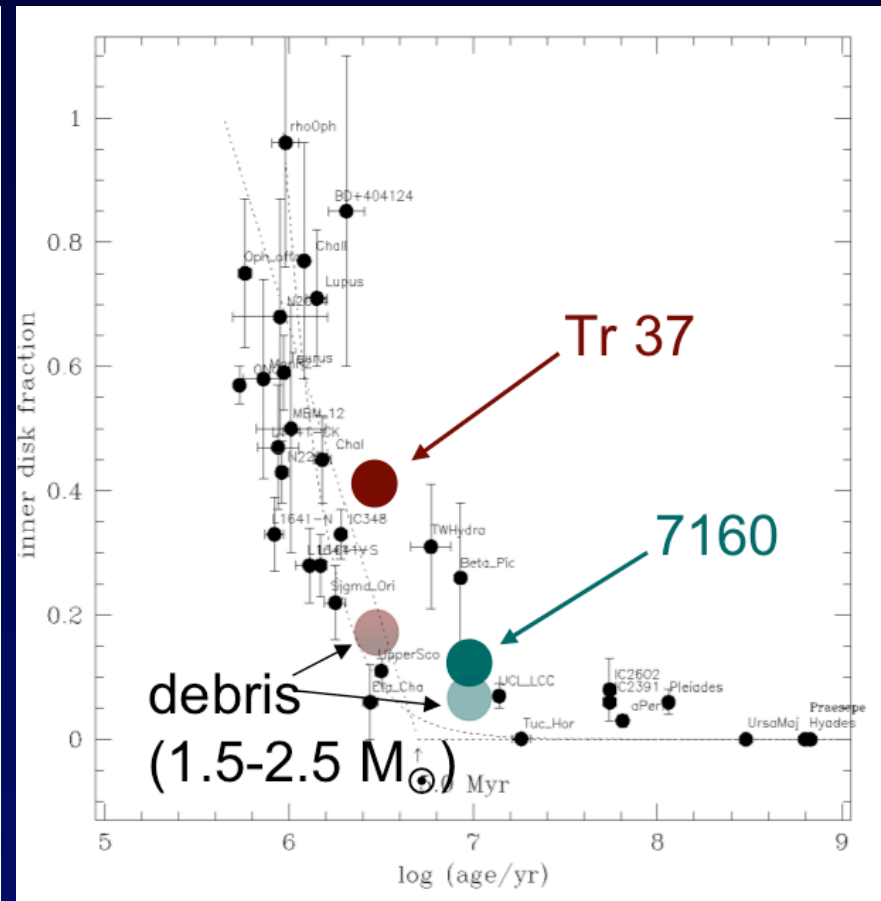
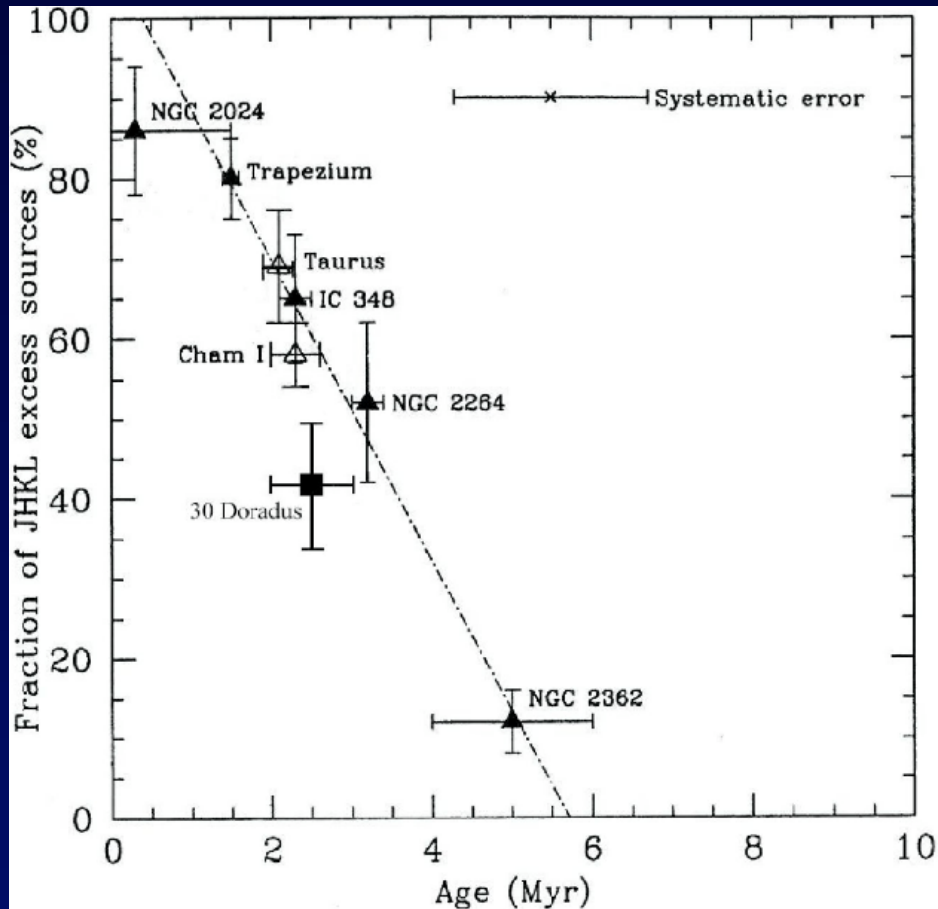
$$T = \left(\frac{0.4 r_* L_*}{4\pi\sigma r^3} \right)^{1/4}$$

$$T \propto r^{-3/4}$$

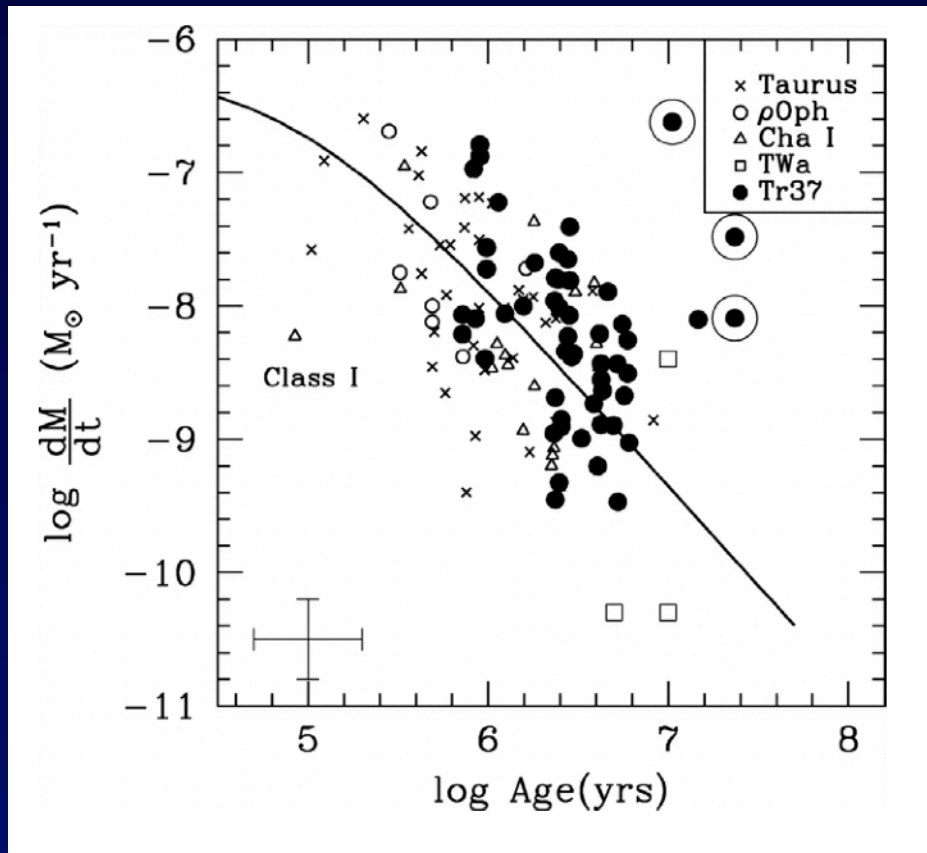
Radial temperature profile for a flat passive disc is the same as for a steady-state viscous disc !



But to fit the observed spectral energy distributions of T Tauri stars, flared disc models are required. These will have shallower temperature profiles as more radiation is intercepted at larger radii. Note that a disc absorbs radiation from a star at essentially all wavelengths, and mainly re-emits in the IR (because the effective temperature of the disc is such that the peak of the blackbody emission curve occurs in the IR). This gives rise to an IR excess (compared with the photosphere of the central star) which is used to diagnose the existence and physical state of the disc. A flared disc intercepts more radiation from the central star, and so produces a larger infrared excess.



Measurements of the fraction of stars in different stellar clusters with discs (detected through IR excess measurements) as a function of the age of the stars in the cluster (it is assumed that the ages of stars within a single cluster are approximately the same) show that discs have life times of a few million years (note that these measurements are detecting IR emission from dust in the disc, detecting the gas through emission lines is a more challenging observational problem).

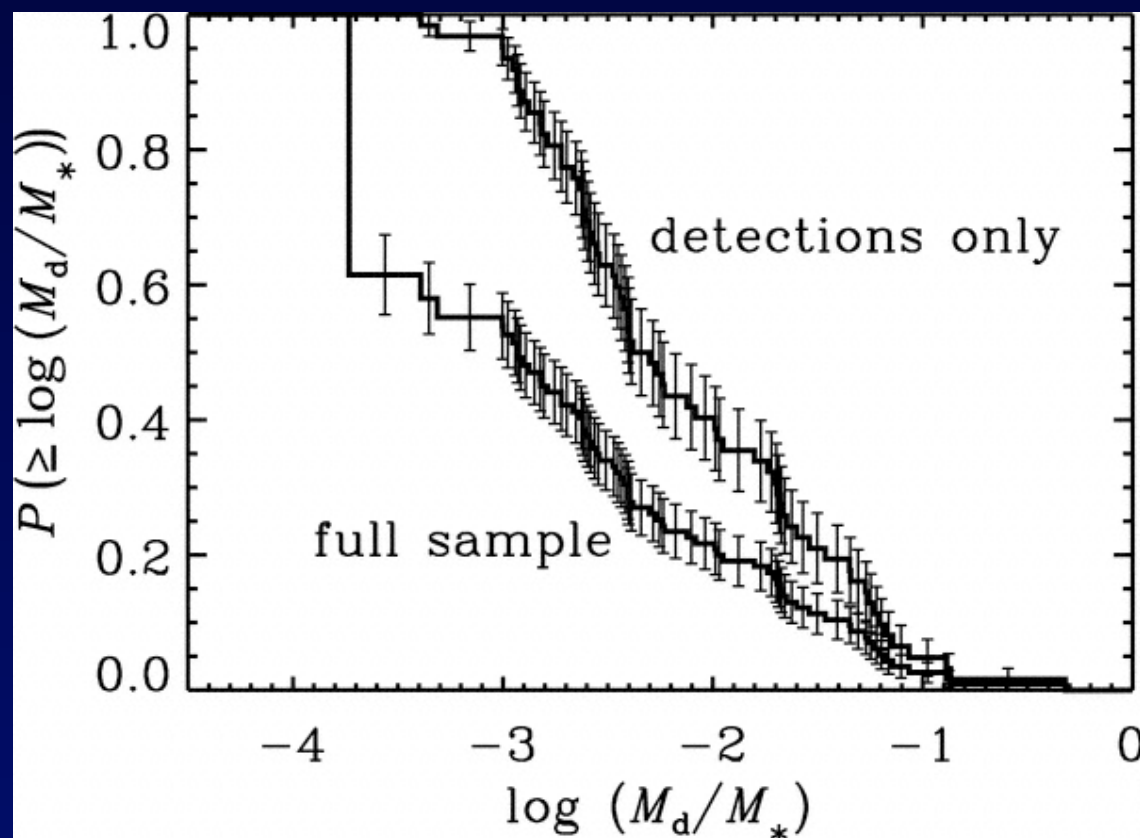


The accretion rate of gas onto the star is measured from the amount of $H\alpha$ emission. This is assumed to come from magnetically funneled accretion columns along which gas falls onto the surface of the central star. As the gas impacts onto the star and heats up, UV photons are emitted which act as a signature of accretion.

Gas accretion rates onto T Tauri stars also decrease on the same time scale of a few million years - both gas and dust are apparently dispersing from the disc on the same time scale.

Disc dispersal is thought to occur as a result of both viscous accretion onto the central star and photoevaporation due to the absorption of EUV radiation and/or X-rays from external stars (in a dense stellar cluster such as the trapezium cluster in Orion) or from the central star.

Protoplanetary disc masses



This diagram shows the cumulative probability of finding a disc with mass above a certain value. The maximum disc mass in the above diagram corresponds to being approximately equal to 10% of the central star's mass. Typical disc masses are between 0.001 and 0.01 stellar masses. These disc mass estimates are obtained from surveys which operate at mm and submm wavelengths, since the disc is optically thin at these longer wavelengths, allowing emission to be measured all the way through the vertical extent of the disc. The disc is optically thick to radiation emitted at shorter wavelengths (e.g. IR radiation), so the measured flux at such wavelengths only provides information about the disc surface layers, and not the mass interior to the surface.

Minimum mass solar nebula model

Take the planets of the Solar System.

Break them down into dust grains and atoms and spread into narrow annuli.

Augment the total amount of material in the disc with sufficient hydrogen and helium to create a disc with Solar abundance.

We then get a disc with surface density which falls off as $\Sigma \propto r^{-3/2}$. The surface density at 1 AU is $\sim 1700 \text{ g cm}^{-2}$ and at 5 AU is $\sim 150 \text{ g cm}^{-2}$.

This disc model is known as the **minimum mass solar nebula** model, and it forms the basis of most models of planetary formation. Note that this is the *minimum* mass required to form a planetary system like the Solar System.