Timescales for Planetary Accretion and the Structure of the Protoplanetary Disk

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Models of planetary accretion which assume the mass of condensable matter in the protoplanetary disk was equal to that present in the planets today predict accretion timescales for the outer planets $\gtrsim 10^8$ years. Such timescales are inconsistant with observations of star forming regions, which suggest that most of the gas in disks around one solar mass stars is removed in a few x 10^6 years. This paper outlines a unified scenario for solar system formation consistent with astrophysical constraints. Jupiter's core could have grown by runaway accretion of planetesimals to a mass sufficient to initiate rapid accretion of gas in times of order of 5 x 10^5 - 10^6 years, provided the surface density of solids in its accretion zone was at least 5-10 times greater than that required by minimum mass models of the protoplanetary disk. The inner planets and the asteroids can be accounted for in this picture if the surface density of the solar nebula was relatively uniform (decreasing no more rapidly than $r^{-1/2}$) out to Jupiter's orbit. The total mass of the protoplanetary disk could have been less than one tenth of a solar mass provided the surface density dropped off more steeply than r^{-1} beyond the orbit of Saturn. The outer regions of the nebula would still have contained enough solid matter to explain the growth of Uranus and Neptune in 5 x 10^6 - 10^8 years, together with the coincident ejection of comets to the Oort cloud. The formation of such a protoplanetary disk requires significant transport of mass and angular momentum, and is consistent with viscous accretion disk models of the solar nebula.