A GUIDE TO THE USE OF THEORETICAL MODELS OF THE SOLAR NEBULA FOR THE INTERPRETATION OF THE METEORITIC RECORD

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Attempts to derive a theoretical framework for the interpretation of the meteoritic record have been frustrated by our incomplete understanding of the fundamental processes that controlled the evolution of the primitive solar nebula. Nevertheless, it is possible to develop qualitative models of the nebula that illuminate its dynamic character, as well as the roles of some key parameters. These models draw on the growing body of observational data on the properties of disks around young, solar-type stars, and are constructed by: (1) applying the results of known solutions of protostellar collapse problems; (2) making simple assumptions about the radial variations of nebular variables (e.g., that they are smooth on the large scale); and (3) imposing the integral constraints demanded by conservation of mass, angular momentum and energy. The models so constructed are heuristic, rather than predictive: they are intended to help us think about the nebula in realistic ways, but they cannot provide a definitive description of conditions in the nebula.

For instance, it is useful to know how such important physical quantities as the size of the nebula and its temperature and density depend on quantities associated with the initial conditions of star formation. It follows from the conservation of angular momentum that a disk's radius is proportional to $(J/f)^2$, where J is the angular momentum accumulated, and f is the fraction of accumulated mass retained in the disk. Neither of these quantities are well-constrained for the solar system. Current estimates of J (which cannot be determined by theoretical considerations alone) depend primarily on the amount of material believed to have been put into primordial comets. The determination of f is a major goal of dynamical theories; it is currently only weakly constrained by models of the structures of the outer planets and observations of T-Tauri star disks. For much of the nebula's lifetime, the temperature was determined by a balance between the rate at which energy was released as mass was transferred to the Sun and the rate at which energy was radiated from the nebula's surface. From this idea, and inferences drawn from the temperature distributions characteristic of T-Tauri star disks, it can be deduced that the temperature at any radius and time was proportional to (f/J). Corresponding dependencies on cloud collapse rate during the formation stage can be derived from similarly general considerations. In all cases, a sensitivity to poorly constrained parameters is revealed, which suggests that the expected range of initial conditions in the interstellar medium produces a rich variety of stellar outcomes. The derived relationships are useful for understanding evolutionary trends, generalizing the results of complex numerical simulations, focusing attention on the critical parameters, and delineating the predictive limits of current theoretical modeling.

Other results are not so sensitive to input parameters. The construction of simple models allows one to calculate the trajectories (defined as the radial positions as functions of time) of parcels of nebular gas. A general result is that much of the gas undergoes extensive radial excursions during the formation and post-accretion evolution the disk. Material that ultimately resides in the inner solar system might have previously spent considerable time in the cold outer regions. Moreover, gas from one part of the collapsing protostellar cloud is inevitably mixed with gas from other parts as it enters the nebula, even in the absence of turbulence. The degree of mixing is variable, but quantifiable in the context of the models. It may be that meteoritic evidence for the retention (on a macroscopic scale) of a degree of interstellar heterogeneity implies the rapid accumulation and decoupling of solids from nebular gas.