THE DYNAMIC SOLAR NEBULA.

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Introduction: Protoplanetary disks are dynamic objects, within which gas and solids are pushed and jostled due to magnetic fields and gravitational forces. The net motions of materials are inward, with much of the mass accreting onto the stars. as part of their last stages of pre-main sequence evolution, while some materials are pushed outward to conserve angular momentum. This evolution results in heating of the disk as gravitational energy is converted into thermal energy, and thinning of the disk as mass is redistributed over increasing radial distances.

Chondritic meteorites record a dynamic history of our own solar nebula, as they contain materials that formed and were processed in a variety of physical and chemical environments, yet are intimately mixed on fine-scales. Further, mineralogic and isotopic similarities between cometary grains and chondritic components suggest that a large-scale exchange of material took place during the early stages of solar nebula evolution, allowing grains that formed in the inner solar system to be carried outwards tens of astronomical units to be incorporated into the comets that formed there.

To date it is unclear how the dynamic evolution of a protoplanetary disk would give rise to the different physical and chemical environments recorded by primitive bodies in our solar system. I will highlight recent work that suggests that astrophysical models for protoplanetary disk evolution provide a context within which we can understand the properties of asteroids, comets, and the planets.

Disk Evolution: The mass accretion rates of protoplanetary disks have been successfully explained by assuming that a turbulent viscosity generates shear stresses within the differentially rotating gas [1]. The turbulence also serves to produce random motions within the disk, allowing gaseous and solid species to diffuse throughout the disk. When the vertical structure of the disk is accounted for in viscous disk models, it is found that the inward movement of mass in the disk largely occurs in the surface layers of the disk, with the outward transport of material due to angular momentum transport occurring at the disk midplane [2-4]. This flow structure and the diffusion that arises from turbulence can allow for the large-scale redistribution of primitive materials and gas, allowing the large-scale exchange of materials throughout the disk [e.g. 5,6].

Gas Drag Redistribution of Solids: The radial pressure gradient in a protoplanetary disk will generally cause the gas to orbit the central star at slightly sub-Keplerian rates. This results in solids losing energy and angular momentum to the gas as they orbit the star, causing them to migrate inwards with time relative to the gas. The rate of migration is size dependent with bodies centimeters to meters in size migrating inward most rapidly at nearly 1 AU/century [6,7].

This inward movement had previously been considered a challenge for planet formation models as the rapid inward movement of materials would cause them to be “lost to the sun.” However, other outcomes could occur which would be important for the chemical evolution of primitive materials. Among them is that volatile-rich solids can be heated and vaporized, leading the abundances of different species to evolve over time at different locations within a disk. In the case of water, this evolution may have played a role in forming the different reducing/oxidizing environments sampled by primitive materials as well as the evolution of oxygen isotope ratios among inner solar system solids [8,9].

Summary: Models for protoplanetary disk evolution and material transport are providing a context where we can understand how different environments can be recorded by chondritic components and how different materials are mixed into common meteorite parent bodies. Testing, constraining, and validating these models requires detailed comparisons between model predictions and the chemical, isotopic, and mineralogic properties of primitive materials.

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