THE EDGE OF THE EARLY SOLAR SYSTEM: SOURCE REGION FOR ISOTOPIC ANOMALIES IN METEORITES?
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Increasing indications of the influence of a supernova in the origin of isotopic anomalies in meteorites [1-3] have emphasized the importance of dynamical studies of the supernova injection process [4-6]. Although the anomalous material can be produced in various ways [1,7-9], the distribution of that material must be consistent with the observed anomalies. In this regard, the constraints on overall mass of anomalous material (as inferred from anomalies in O [10]) and on injection times (as inferred from anomalies in Mg [11]) are particularly important. Detailed calculations [5] have modeled the motions of gas and dust at the edge of an interstellar cloud (such as might have been the progenitor of the solar system) during the interaction with a shell (such as might arise from the explosion of a supernova). The physics embodied in these calculations includes the effects of gas/grain drag, radiative cooling of the gas and Rayleigh-Taylor instabilities of the interface.

The often-cited picture of supernova injection of anomalies is included within the scope of these calculations. It has been found that 1) grains are more effective than gas at delivering the anomalous matter to the nebula and that 2) the bulk of the injected material remains near the edge of the nebula. The limitations on penetration are shown graphically in Figure 1. The curve marks the maximum column density penetrated by a spherical grain of radius a and mass \( m_g \) with initial velocity \( V \) (the scales are made dimensionless in terms of \( m_g / a^2 \) and the mean molecular velocity of the target gas). For small velocities, the penetration is proportional to velocity; as velocity increases, the penetration does not increase linearly, but is only logarithmic with respect to velocity. The column density is a model-independent way to gauge the penetration of injected material. The thermodynamic response of the nebular gas does not increase the penetration beyond the limits reported here. Thus, these calculations set an upper bound on the region affected by the encounter of a supernova blast wave with a solar system progenitor. The relative size of the affected region can be seen from Figure 2. A wide range of configurations is covered by the limits on mass and radius in Figure 2, with each configuration represented by a point. The line marked GRAINS (MARBLES) shows those configurations for which injected grains of radius \( 10^{-5} \) cm (inclusions of radius 1 cm) can penetrate to the center. Configurations lying to the left of the lines will develop a skin layer of anomalous material. Note that the configurations envisioned by Cameron and Fine [12], for example, lie within the incomplete penetration region. Thus, considerations of those processes which might occur at the edge of a solar nebula are in order.

One important process is the behavior of grains in the turbulent flows near the interface. The decay of \(^{26}\text{Al}\) into \(^{26}\text{Mg}\) sets the time scale for incorporation of the injected material into grains, and the question remains as to whether the turbu-
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Turbulence affects the condensation process. Furthermore, the occurrence of significant anomalies (~ few percent) in oxygen prompts one to ask whether the usual picture of turbulence is consistent with the preservation of anomalies at these levels. Recent studies [5,6] have shown that the "shrapnel" picture of injection is consistent with both sets of measurements because of the unusual interaction of grains and turbulent flows.

The calculations of Margolis [5] did not specifically include the effects of a possible magnetic field. There are strong indications [13] that grains bearing isotopic anomalies will be charged and thus subject to magnetic influences. Given the picture for supernova injection described by Schramm [1], it would not be too surprising to find any magnetic field attached to the nebular gas drawn around the edge of the configuration. The presence of a mean tangential field might lead one to speculate on the consequences of an astrophysical "mass spectrometer" operating on the anomalous grains. In any event, magnetic effects should be the next factor subjected to detailed study.

In conclusion, detailed studies of dynamical processes occurring in the early solar nebula represent a fertile field in which one might grow anomalous inclusions. This research has been supported by NASA grant NSG-7212 at the University of Chicago and by the NSF National Needs Postdoctoral Fellowships Program (SHM).

References
Figure 1

Figure 2