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GRAIN MANTLES: THE IMPACT ON GRAIN EVOLUTION AND SELECTIVE EXTINCTION

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Depletion studies are used to infer the presence of mantles and to constrain grain evolutionary models in the diffuse interstellar medium. The presence of these mantles appears to be important in the evolution of the grains inside diffuse as well as dense clouds. In dense clouds where the element-to-element abundances sometimes differ from those found in diffuse clouds (Joseph *et al.* 1986), empirical relationships are starting to emerge between gas abundances and various types of peculiar selective extinction. These peculiar extinction curves may be the result of nonvolatile mantle formation on grain cores or may reflect chemical differences due to variations in the intrinsic metalicity from one cloud to another.

In a recent diffuse cloud study, using high-quality data found in the literature, Joseph (1988) inferred that the relative gas abundances of Fe, P, Mn, and Mg are probably set early in the lifetime of the grains and are not altered substantially thereafter, even though significant grain processing is likely to occur. A simple theoretical model (Figure 1) as well as the observational results (Figure 2) are reproduced from Joseph (1988). For a given level of overall depletion, the sightline-to-sightline rms variance in the depletion for each of these 4 elements was found to be significantly smaller than the element-to-element variance. Joseph discovered that the Fe, P, Mn, and Mg depletions in his sample, spanning approximately 1.0 (dex) in mean line-of-sight depletion, are linearly correlated with each other and have regression slopes near unity. Thus, his data suggest that the element-to-element abundances are remarkably similar, even though substantial differences in the overall level of depletion are observed from one line of sight to another. This result is at variance with many depletion models, which predict the element-to-element depletions as well as the overall level of depletion to be altered via dust-gas interactions inside diffuse clouds. Further, the results of Joseph (1988) are inconsistent with the grain destruction models of Seab and Shull (1983), probably indicating most grain-grain collisions in the aftermath of shocks result in grains that are shattered rather than vaporized.

Duley (1980) and Joseph (1988) both conclude that most of the iron in the diffuse interstellar medium exists preferentially in grain cores under substantial nonvolatile mantles that are chemically-distinct. These mantles appear to be consistent with a picture where the mantles are destroyed by shocks, but are replenished repeatedly between shocks in such a manner as to preserve the logarithmic element-to-element abundance differences. Occasionally, however, some clouds are severely shocked or are shocked a second time before the protective grain mantles can be established. In these few cases, the element-to-element abundances are changed. The formation of these mantles also helps to preserve the exceptionally large levels of depletion of certain elements such as calcium, despite the constant injection of small amounts of undepleted gas (Jura 1986).

While the selective extinction curve from one line of sight to another is remarkably similar in the diffuse interstellar medium, the number of sightlines with peculiar extinction rises dramatically for dense clouds. Over the past few years, peculiar extinction has been studied intensively in an effort to relate differences in the selective extinction of starlight to various other physical parameters (e.g. Massa, Savage, and Fitzpatrick 1983, Witt, Bohlin, and Stecher 1984). Both of these studies, which relied on broad-band optical photography to infer dense clouds, concluded that the far-UV extinction in dense clouds is generally lower than that found for diffuse clouds. In contrast, Joseph *et al.* (1986) used the presence of molecules as an indicator of density and they found enhanced far-UV extinction in lines of sight through dense clouds [as did Cardelli and Savage (1988)].

Following up earlier work, Joseph, Snow, and Seab (1988) discovered that dense clouds, which have a large CN/Fe I abundance ratio, have a shallow (~1.0 dex less than the Seaton (1979) average) 2200 Å extinction bump relative to the underlying extinction (see figure 3). The sightlines with a large CN/Fe I abundance ratio also exhibit enhanced far-UV extinction. While the CN/Fe I abundance ratio is sensitive to the wavelength dependence of extinction, preferential depletion of some elements or differences in the intrinsic element-to-element abundances must also be invoked to account for all of the observed abundance differences. Additional studies are already under way in an attempt to find other abundance ratios that could be used to predict various types of selective extinction as well as to predict the relative change in the abundances due to depletion.

Cardelli, J.A. and Savage, B.D.: 1988, Ap.J., 325, 864.

Duley, W.W.: 1980, Ap.J. (Letters), 240, L47.

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Joseph, C.L., Snow, T.P., Seab, C.G., and Crutcher, R.M.: 1986, Ap.J., 309, 771.

Jura, M.: 1986, in *Interstellar Processes,* D.J. Hollenbach and H.A. Thronson, eds.

Seab, C.G. and Shull, M.J.: 1983, Ap.J., 275, 652.

Seaton, M.J.: 1979, M.N.R.A.S., 187, 73P.

Witt, A.N., Bohlin, R. C. and Stecher, T.P.: 1984, Ap.J., 279, 698.

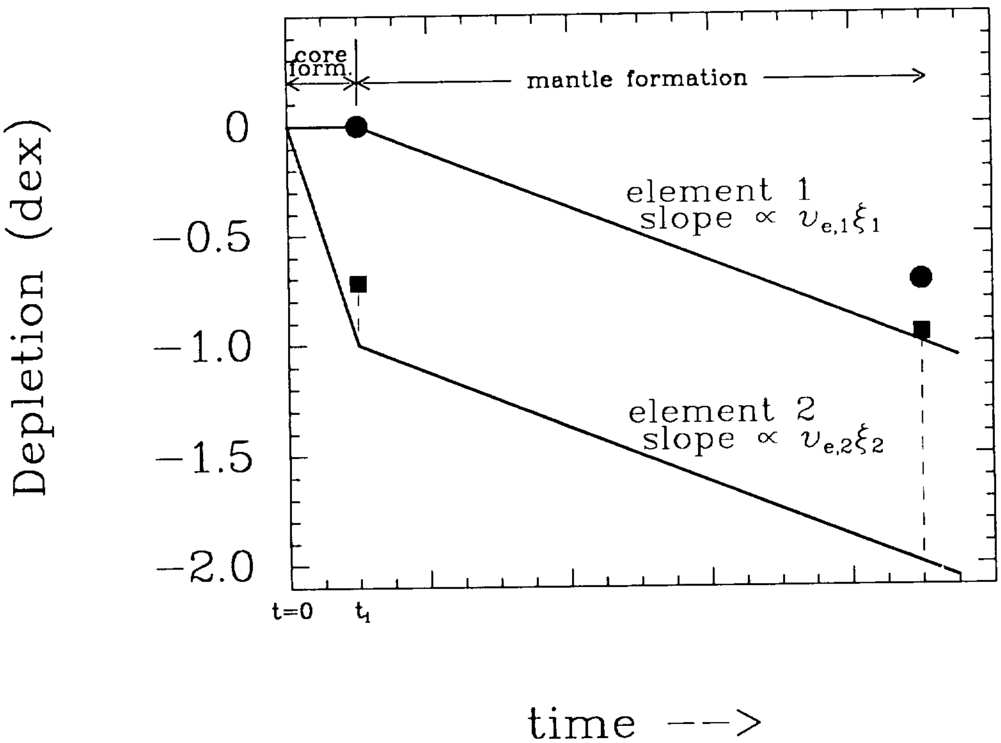

Figure 1 depicting a simple model of the time evolution of a parcel of gas and dust as observed by the depletions of two elements. At time, t=0, grains start to form in the outer atmospheres of late-type giants and grow until they are deposited into the diffuse interstellar medium at time, t_i. Much of the differences in the element-to-element depletions occur in this initial stage. Dust-gas interactions inside the interstellar medium take over for t > t_i with the gas going into mantles and depleting onto the grain cores according to the rate equation:

$$dn_i/dt = -n_i n_d <\sigma v> \xi_i$$

where n_i, n_d, $<\sigma v>$, and ξ_i are the density of element i, the particle density of the dust, the effective collisional coefficient, and the sticking probability, respectively.

A commonly held belief (contradicted by the observational results in Figure 2) is that depletion or sputtering processes in diffuse clouds usually result in line segments for $t > t_i$ that diverge (i.e. the element-to-element difference in depletion changes as the total overall level of depletion increases).

If elements 1 and 2 have comparable cosmic abundances, then the depletions represented above will form grains with a core-mantle structure. The solid circles and squares show approximately the resulting depletions of elements 1 and 2 if 10% of the grains are suddenly destroyed. This type of destruction (suggested by some shock models) is unlike sputtering, which normally only removes mantle material.

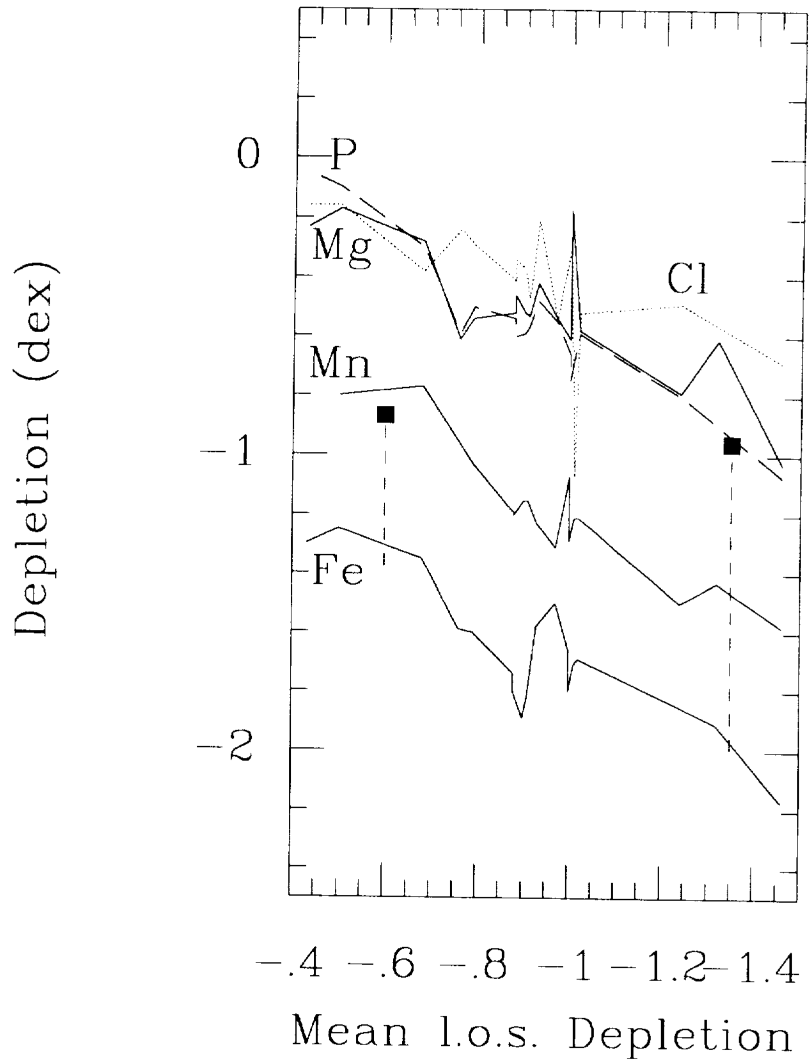

Figure 2 showing the observational results of Joseph (1988) that are based on measurements by Jenkins, Savage, and Spitzer (1986). The mean line-of-sight depletion, defined as the sum of the logarithmic depletions of the elements divided by the number of elements measured for the line of sight, is a general measure of the net amount of the available material deposited onto the grains. As is readily evident, none of these elements appears to deplete preferentially faster than any of the others. The two solid boxes show the approximate gaseous abundances of iron that would result if 10% of the grains in a line of sight with comparable depletion are suddenly destroyed.

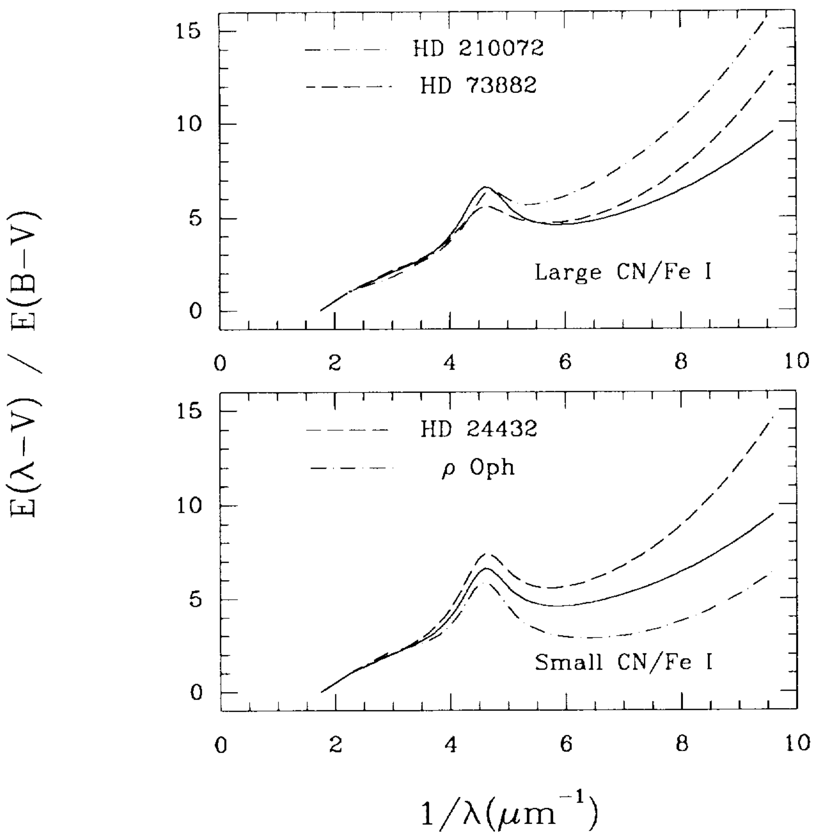

Figure 3 showing typical examples of the selective extinction curves for each of the 2 types of dense clouds in a study by Joseph *et al.* [1988, Ap.J. (Letters), submitted]. Joseph t, examined the molecular and neutral atomic abundances for 19 lines of sight through dense clouds known to have peculiar extinction curves. Lines of sight, which have a gaseous CN/Fe I abundance ratio greater than about 2 (0.3 dex), have a shallow $\sim$1.0 dex less than normal) 2200 Å bumps relative to the underlying extinction. The solid lines are the Seaton (1979) average for comparison.