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MOLECULAR CATASTROPHES AND THE FORMATION OF CIRCUMSTELLAR DUST

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Interstellar dust grains are presumed in part to have their origins in the outer atmospheres of red giant and supergiant stars because, despite the efficiency of shock destruction of grains in the ISM, meteoritic samples examined on Earth possess isotopic signatures that are consistent with nucleosynthetic origin in the interior of evolved stars (Clayton 1985). Among the four leading explanations for mass loss from such objects (thermally driven winds, magnetically driven winds, pulsation and radiation pressure on dust grains), there is ample evidence that once dust grains form near red giants and supergiants, radiation pressure is sufficient to drive them to infinity (Jura 1984). The problem of the formation of such dust is a classic one (Salpeter 1974) which requires understanding the combined roles of radiative transfer, gas dynamics and chemical reactions. Virtually all published studies have only attacked portions of the combined problem.

One key deficiency in previous efforts to understand the formation of circumstellar dust has been in using radiative equilibrium assumptions concerning the nature of the atmosphere underlying the circumstellar envelope (CSE). Contrary to the assertion of Jennings and Dyck (1972), based solely on optical Ca II K line emission, that chromospheres are 'quenched' in the presence of dust, recent ultraviolet and microwave analyses (Carpenter et al. 1985; Stencel et al. 1986; Hjellming and Newell 1983) have shown the chromospheres of dusty red supergiant stars to be persistent, and, unlike the solar chromosphere, can fill the entire volume out to the base of the CSE (several stellar radii). I suggest that this extended chromosphere is prone to instabilities which ultimately result in the formation of dust grains. Such instabilities are analogous to that known for the warm and cold phase of the ISM (cf. Lepp et al. 1985).

Compared to the ISM, the higher density atmospheres of stars (10^6 to 10^{12} cm^{-3}) occupy regions in a temperature-density plane for which molecular formation is required. Simple molecules like CO, SiO, H2O and OH are unique in that they have relatively high binding energies (11, 8, 5 and 4 eV), absorb well in the UV and radiate efficiently in the IR, and thus act as effective coolants. In high gravity stars like the Sun, the conditions in the upper photosphere tend to associate C and O. When this happens, the radiative cooling due to CO strongly cools the surroundings, leading to the formation of additional CO molecules which further enhance the cooling until complete CO saturation is achieved (a runaway process dubbed the "molecular catastrophe" by

Kneer 1983 and Muchmore 1986). In the Sun, there is a striking difference between the brightness temperatures in the 2.3 micron CO band, and atomic features of the upper photosphere. It is this strong temperature sensitivity of molecular opacity which I propose can operate to ultimately lead to the formation of dust at the base of CSE in red supergiant stars.

VLBI observations of the M4Ie supergiant VX Sgr by Chapman and Cohen (1986) and Lane (1984) are instructive in this context: the SiO masers lie closest to the stellar photosphere (at 1-2 radii), the OH and H2O masers occur farther out (tens and hundreds of radii). Localized CO catastrophes in the stellar photosphere give rise to pressure perturbations which result in SiO formation catastrophes in the extended chromosphere of the star. The formation of SiO in excited states prompts the observed maser emission, and subsequent chemistry anneals the SiO into clusters and associations like olivine (Mg,Fe)2SiO4 (Woolf and Nye 1969; Donn and Nuth 1985), which is removed from the star by radiation pressure. The OH and H2O masers result from their formation catastrophes at lower temperatures and densities in the outer chromosphere/CSE where conditions associated with their lower binding energy phase change take place.

The molecular catastrophe description for the conversion of chromospheric gas into molecular masers and circumstellar dust holds promise for a coherent expanation of the formation of these entities and the process of mass loss from cool, high luminosity objects. We will report elsewhere on quantitative simulations of this scenario, in collaboration with David Muchmore and Joseph Nuth, incorporating a full treatment of gas dynamics, radiative transfer and chemical reactions. This work has been supported by CASA at the University of Colorado, for which the author is grateful.

REFERENCES:

Carpenter, K., Brown, A. and Stencel, R. 1985 Ap.J. 289, 676.
Chapman, J. and Cohen, M. 1986 MNRAS in press.
Clayton, D. 1985 in Interrelationships Among Circumstellar, Interstellar and Interplanetary Dust, NASA Conf. Publ. 2403.
Donn, B. and Nuth, J. 1985 Ap.J. 288, 187.
Hjellming, R. and Newell, R. 1983 263, L85.
Jennings, M. and Dyck, H. 1972 Ap.J. 177, 427.
Jura, M. 1984 Ap.J. 286, 630.
Kneer, F. 1983 A&A 128, 311.
Lane, A. 1984 in VLBI and Compact Radio Sources, eds. Fanti et al. (Dordrecht; Reidel), p. 329.
Lepp, S., McCray, R., Shull, J.M., Woods, T. and Kallman, T. 1985 Ap.J. 288, 58.
Muchmore, D. 1986 A&A 155, 172.
Salpeter, E. 1974 Ap.J. 193, 585.
Stencel, R., Carpenter, K. and Hagen, W. 1986 Ap.J. 308 in press.
Woolf, N. and Ney, E. 1969 Ap.J. 155, L183.