Signatures of Chemical Evolution in Protostellar Nebulae

Joseph A. Nuth III and Natasha M. Johnson
NASA's Goddard Space Flight Center
Solar System Exploration Division, Code 690
Greenbelt MD 20771 USA

A decade ago observers began to take serious notice of the presence of crystalline silicate grains in the dust flowing away from some comets. While crystallinity had been seen in such objects previously, starting with the recognitions by Campins and Ryan (1990) that the 10 micron feature of Comet Halley resembled that of the mineral forsterite, most such observations were either ignored or dismissed as no path to explain such crystalline grains was available in the literature. When it was first suggested that an outward flow must be present to carry annealed silicate grains from the innermost regions of the Solar Nebula out to the regions where comets could form (Nuth, 1999; 2001) this suggestion was also dismissed because no such transport mechanism was known at the time. Since then not only have new models of nebular dynamics demonstrated the reality of long distance outward transport (Ciesla, 2007; 2008; 2009) but examination of older models (Boss, 2004) showed that such transport had been present but had gone unrecognized for many years. The most unassailable evidence for outward nebular transport came with the return of the Stardust samples from Comet Wild2, a Kuiper-belt comet that contained micron-scale grains of high temperature minerals resembling the Calcium-Aluminum Inclusions found in primitive meteorites (Zolensky et al., 2006) that formed at T > 1400K.

Now that outward transport in protostellar nebulae has been firmly established, a re-examination of its consequences for nebular gas is in order that takes into account both the factors that regulate both the outward flow as well as those that likely control the chemical composition of the gas. Laboratory studies of surface catalyzed reactions suggest that a trend toward more highly reduced carbon and nitrogen compounds in the gas phase should be correlated with a general increase in the crystallinity of the dust (Nuth et al., 2000), but is such a trend actually observable? Unlike the Fischer-Tropsch or the Haber-Bosch reactions used in industry, the surface catalyzed reactions seen in our laboratory do not produce a simple product stream of methane or ammonia, respectively. Instead, such reactions produce a wide range of both aliphatic and aromatic hydrocarbons, as well as reduced nitrogen compounds such as ammonia, amines, amides and imides, as gas phase products together with a heavy, macromolecular, kerogen-like surface coating that remains on the grains. While CO and N_2 will certainly be depleted by conversion into more complex and less volatile species via reaction on grain surfaces, it may be very difficult to monitor such changes from outside the system.

References:

Boss, A.P. (2004) Astrophysical Journal, 616, 1265.
Campins, H. and Ryan , E.V.(1989) Astrophysical Journal, 341, 1059.
Ciesla, F. J. 2007, Science, 318, 613
Ciesla, F. J. 2008, Science, 319, 1488
Ciesla, F. J. 2009, Icarus, 200, 655
Nuth, (1999) Lunar Planet. Sci. Conf., 30, 1726.
Nuth, J.A. (2001) American Scientist 89, 230.
Nuth J. A., H. G. M. Hill & G. Kletetschka,(2000) Nature 406, 275.
Zolensky et al., (2006) Science, 314, 1735.