Final Report

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TITLE: Relative Abundance of Ices in the Disks of T Tauri Stars
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1 Results From Our 1992-1995 *Origins of Solar Systems* Program

Very little work has been carried out to determine whether or not large organic molecules similar to those observed on the surfaces of minor solar system bodies also reside in the mantles of icy grains located in dense molecular clouds or in the local environments of protostars and PMS stars. Ten years ago Lacy *et al.* (1984) first identified a broad absorption band near 4.62 μm, the C≡N stretch fundamental, in the spectra of two embedded protostars, W33A and NGC 7538 IRS 9. The only follow-up observational work to this study is that done by us under the sponsorship of *Origins of Solar Systems* under this grant.

2 Research Goals

During the years 1993-1995 we focused our research on answering two questions of importance to organic chemistry in the solar nebula:

- Are the X(C≡N) molecules seen toward young stars (embedded in molecular clouds) located in circumstellar material or foreground molecular cloud material?
- What is the dominant mechanism that transforms simple organic molecules into more complex organic molecules, such as X(C≡N). In particular, what is the source of ions or ultraviolet photons necessary to produce the X(C≡N) molecules?

In a series of conference abstracts and three papers (Tegler *et al.* 1993, 1995; Weintraub *et al.* 1994) we published as the products of our *Origins of Solar Systems* sponsored research, we reported

evidence strongly suggesting that X(C≡N) is associated with the local environments of protostars and PMS stars. In these publications we reported the detection of a broad absorption feature at 4.62 μm (2166 cm^{-1}) in the spectra of three low mass protostars and T Tauri stars, L1551 IRS 5, Elias 18 (both in in Taurus) and RNO 91. These sources are only the third, fourth and fifth known in the sky to show the broad 4.62 μm absorption feature and the first discovered since 1984 (the others are the protostars W33A and NGC 7583 IRS 9; Lacy *et al.* 1984). Of equal importance, this feature is not seen toward several other embedded sources in our survey, nor is it seen toward the source Elias 16, located behind the Taurus cloud. Whereas, the abundances of frozen CO and H_2O are strongly correlated with each other and with the visual extinction toward sources embedded within and behind the molecular cloud, we found a non-linear anticorrelation between the abundance of X(C≡N) and frozen CO in non-polar lattices and no correlation between the abundance of X(C≡N) and frozen CO in polar lattices (see Figure 8 of Tegler *et al.* 1995). Our results indicate that X(C≡N) molecules result from chemical processing of dust grains dominated by non-polar icy mantles in the local environments of PMS stars. Such processing of icy grains in the early solar system may be responsible for organic compounds observed in minor solar system bodies. The delivery of these organic compounds to the surface of the primitive Earth through comet impacts may have provided the raw materials for prebiotic chemistry.

3 Refereed Papers [Copies of papers attached]

Tegler, S.C., Weintraub, D.A., Allamandola, L.J., Sandford, S.A., Rettig, T.W. & Campins, H.C. 1993, "Detection of Frozen CO and X(C≡N) in the Spectrum of L1551 IRS 5," *Astrophysical Journal*, **411**, 260-265.

Tegler, S.C., Weintraub, D.A., Rettig, T.W., Pendleton, Y.J., Whittet, D.C.B. & Kulesa, C.A. 1995, "Evidence for Chemical Processing of Pre-Cometary Icy Grains In Circumstellar Environments of Pre-Main-Sequence Stars," *Astrophysical Journal*, **439**, 279-287.

Weintraub, D.A., Tegler, S.C., Kastner, J.H. & Rettig, T. 1994, "Infrared Spectroscopy and Imaging Polarimetry of the Disk Around the T Tauri Star RNO 91," *Astrophysical Journal*, **423**, 674-680.

4 Conference Abstracts

Tegler, S., Rettig, T., Weintraub, D., Pendleton, Y., Whittet, D. & Kulesa, C., 1994, "Evidence for Chemical Processing of Pre-Cometary Icy Grains Around Pre-Main-Sequence Stars," American Astronomical Society Division of Planetary Sciences meeting, *Bulletin of the American Astronomical Society.*

Tegler, S.C., Weintraub, D.A. & Rettig, T.W. 1993, "Icy Grains Toward T Tauri Stars," Gordon Research Conference on *Origins of Solar Systems.*

Tegler, S.C., Weintraub, D.A., Allamandola, L.J., Sandford, S.A. & Rettig, T.W. 1992, "Detection of Frozen CO and X(C≡N) in the Spectrum of the FU Orionis Star L1551 IRS 5," 180th American Astronomical Society meeting, Columbus, OH, *Bulletin of the American Astronomical Society*, **24**, 988.

Tegler, S.C., Weintraub, D.A., Kastner, J.H. & Rettig, T.W. 1992, "Near-IR Spectroscopy and Imaging Polarimetry of RNO 91: Detection of Frozen H_2O, CO, and X(C≡N) In A Circumstellar Disk," 181st American Astronomical Society meeting, Phoenix, *Bulletin of the American Astronomical Society*, **24**, 1301.

Tegler, S.C., Weintraub, D.A., Allamandola, L.J., Sandford, S.A. & Rettig, T.W. 1992, "Detection of Frozen CO and X(C≡N) in Disks Around T Tauri and FU Orionis Stars," American Astronomical Society Division of Planetary Sciences meeting, Munich, *Bulletin of the American Astronomical Society*, **24**, 988.

Tegler, S.C., Weintraub, D.A., Campins, H. & Rettig, T. 1991, "Relative Abundance of Ices in Disks Around T Tauri Stars: Implications for Comet Formation," American Astronomical Society Division of Planetary Sciences meeting, *Bulletin of the American Astronomical Society*, **23**, 1232.

Tegler, S.C., Weintraub, D.A. & Campins, H. 1991, "Relative Abundance of Ices in Disks Around T Tauri Stars: Implications for Comet Formation," Gordon Research Conference on *Origins of Solar Systems.*