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Astrochemistry Results from the Spitzer c2d Project

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Abstract. The early results on astrochemistry from the Cores to Disks (c2d) Legacy program are summarized. The c2d program focuses on the formation of low-mass stars in nearby (within about 300 pc) clouds. Spectroscopy with IRS includes the following topics: ices seen against background stars, in protostellar envelopes, and in disks; grain growth and mineralogy, PAHs, and gas in circumstellar disks.

Keywords. dust — infrared: ISM — protoplanetary disks

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1. Introduction

The c2d Legacy Program (Evans *et al.* 2003) is using the instruments of the Spitzer Space Telescope to trace the evolution of molecular material from the prestellar, dense core stage through the formation of planet-forming disks. Five large clouds (covering a total of ∼20 sq. deg.) and about 90 smaller cores are being imaged with both IRAC (4 bands from 3.6 to 8 μm) and MIPS (3 bands from 70 to 160 μm). To study the timescale for disk dissipation, we are obtaining photometry on ∼190 weak-line T Tauri stars. The evolution of the physical and chemical state of the matter is being studied with spectroscopy of over 170 targets (down to sub-solar mass stars, as faint as a few mJy) with IRS. Finally, a large data base of complementary observations, from optical to millimeter wavelengths, is being assembled. Because the IRS observations bear most directly on astrochemistry, I will focus on them here.

2. Evolution of Ices

Spectroscopy of background stars can reveal the nature of the dust and ice in dense regions before any star has formed. The sensitivity of IRS on Spitzer allows study of lines of sight with very high extinction. Bergin *et al.* (2005) and Knez *et al.* (2005) have found large abundances of CO_2 ice, relative to H_2O ice, toward highly extincted background stars. The shape of the feature shows that the CO_2 is not crystallized, indicating its pristine nature. In addition, Knez *et al.* (2005) detect for the first time the 6.85 μm band toward background stars. Its strength is comparable to that previously observed toward embedded protostars, and thus its carrier (NH_4^+, tentatively) must have been formed early in the cloud history. Other, weaker features suggest the presence of HCOOH and NH_3, but these lie on the edge of stronger features and need confirmation.

Similar spectra of embedded protostars show features of solid CH_4, CH_3OH, CO, CO_2, H_2O, NH_4^+, and OCN^- (Boogert *et al.* 2004). Systematic trends in the shape of the CO and CO_2 bands indicative of increased temperatures leading to ice sublimation and changing ice structure can be seen in a range of objects, similar to what was seen toward more massive and luminous objects with ISO (*cf.* van Dishoeck 2004).

3. Evolution of Disks

Work with ISO observations also showed that disks around intermediate mass stars can have a range of profiles, ranging from flared, to self-shadowed, to disks with inner holes (van Dishoeck 2004). A similar range of SEDs is seen toward lower mass stars with Spitzer. Analysis of the silicate emission features at 10 and 20 μm shows evidence that the small end of the grain size distribution is increasing rapidly in disks (Kessler-Silacci *et al.* 2005). Considering models of rapid grain growth and settling, these observations may eventually shed light on processes such as vertical mixing and grain fragmentation.

PAH emission is detected toward at least 8% of the T Tauri stars, down to spectral type G8. The 11.3 micron feature strength suggests for some sources the presence of additional UV radiation beyond that provided by the star itself, perhaps associated with active accretion (Geers *et al.*, in preparation). Ionized PAHs around these cool stars could also be excited by visible or near-IR photons (Mattioda *et al.* 2005).

With special orientations, the disk can be probed by absorption spectroscopy. Ices in such a "grazing-incidence" disk were studied by Pontoppidan *et al.* (2005). Because the IRS instrument is not optimized for gas-phase features, the most surprising result so far is the discovery of gas-phase absorption bands of CO_2, HCN, and C_2H_2 toward one young star+disk, IRS46 in Ophiuchus (Lahuis *et al.* 2005). Large abundances of hot, dense, chemically-rich gas coming from a region less than about 10 AU in size suggest absorption in the inner regions of a disk. However, follow-up observations with high spectral resolution indicate a 25 km s^{-1} blueshift relative to the cloud velocity, raising the possibility of the footprint of a disk wind fortuitously located along the line of sight. Further observations are needed to decide between these two possible interpretations.

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