*Origins: From the Protosun to the First Steps of Life*
*Proceedings IAU Symposium No. 345, 2018*
*B. G. Elmegreen, L. Viktor Tóth & M. Güdel, eds.*

doi:10.1017/S174392131900214X

# Infrared Spectroscopic Studies of Gases in the Circumstellar Environments of Young Stellar Objects

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**Abstract.** The building blocks of planets in planet-forming ("protoplanetary") disks are assembled early in the lifetime of a young star. The gas disks are relatively short-lived, with a half-life of about 3 million years, as chemical reactions modify the reservoir of material from the natal molecular cloud. *Spitzer Space Telescope* Infrared Spectrograph (IRS) spectra of protoplanetary disks around T Tauri stars show emission from $H_2O$ and absorption from other gases, sometimes consistent with formaldehyde, $H_2CO$, and other times consistent with formic acid, HCOOH, in the 5-7.5 $\mu$m region. SOFIA-EXES spectra of YSOs that follow up on these *Spitzer*-IRS studies are presented. How the gaseous features observed between 5-7.5 $\mu$m relate to those at other wavelengths is discussed. This work suggests that water and organic molecules, which are crucial for life as we know it, are present in the habitable zones of stars at a very early age [of 1-3 million years].

**Keywords.** infrared: stars

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Though many previous studies found evidence for water from *Spitzer*-IRS high resolution (R $\sim$ 600) spectra (e.g., Carr & Najita 2008), we find that *Spitzer*-IRS low resolution (R $\sim$ 90) spectra can identify water emission as well (note Pascucci *et al.* 2009 and Teske *et al.* 2011 identified HCN and $C_2H_2$ in *Spitzer*-IRS low resolution spectra). Models of low resolution *Spitzer*-IRS spectra of protoplanetary disks around young stars suggest the presence of $H_2O$, $H_2CO$, and HCOOH in these protoplanetary disks (Sargent *et al.* 2014). We are seeking high resolution infrared spectroscopic confirmation of the presence of these molecules (e.g., Roueff *et al.* 2006 found absorption at 3.6 $\mu$m in the spectrum of protostar W33A from $H_2CO$).

For the SOFIA-EXES medium resolution (Richter *et al.* 2018) spectrum of the young stellar object (YSO) IRAS 04278+2253, the spectral model shown in Figure 1 (at *left*) assumes a cool (300K) cloud of $H_2O$ in front of a warm blackbody, where the $H_2O$ has sufficient column density so that the absorption features at 5.782, 5.789, 5.802, 5.809, 5.818, 5.823, and 5.826 $\mu$m are clearly visible in the plot. The SOFIA-EXES spectra of IRAS 04278+2253 (not telluric-corrected) can largely be explained by telluric absorption and the $H_2O$ model. There are features not explained by telluric absorption or the $H_2O$ model, but it is not clear what their carrier is. The SOFIA-EXES low-resolution spectrum of DL Tau (Figure 1, *right*) is plagued by fringing. We have attempted to remove the fringes with a simple sine wave, following Cami *et al.* (2000), but this was not successful. A more sophisticated means of removing fringes is needed.

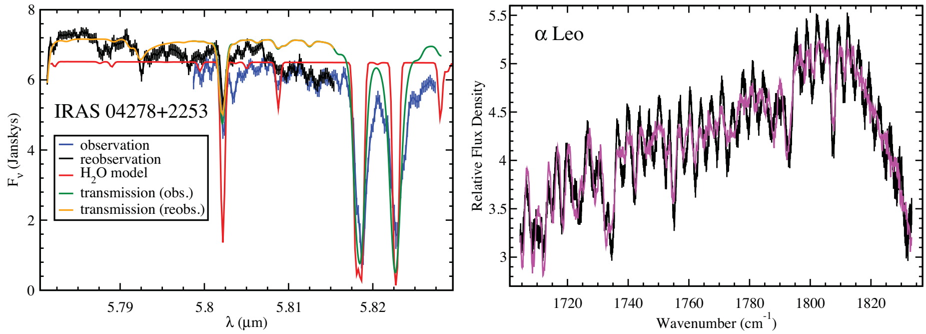


**Figure 1. Left**, SOFIA-EXES medium-resolution spectra of IRAS 04278+2253 from program 04_0180, with the original (March 2016) spectrum in blue; the re-observation (January 2017) in black; 300K HITEMP (Rothman *et al.* 2010) $H_2O$ model in red; and the transmission curves for Earth's atmosphere in green and orange. **Right**, SOFIA-EXES low-resolution spectrum of $\alpha$ Leo, the telluric calibrator for the DL Tau observation (program 04_0188). The signal from the observation is in black, and an attempt at removing the fringes with a simple sine wave (following Cami *et al.* 2000) is in magenta.

Initial reductions of archival Keck-NIRSPEC 2-4 $\mu$m spectra of a few of our stars do not reveal any $H_2CO$ lines at 3.6 $\mu$m; however, the lines may be variable, or the $H_2CO$ may be located in the disks such that absorption is seen at 5.7 $\mu$m but not at 3.6 $\mu$m. An interesting future project would be to measure and model the emission and absorption from gases in a larger sample of *Spitzer*-IRS spectra of T Tauri stars.

This work is based in part on observations made with the *Spitzer Space Telescope*, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under NASA contract 1407. This work is also based [in part] on observations made with the NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA). SOFIA is jointly operated by the Universities Space Research Association, Inc. (USRA), under NASA contract NAS2-97001, and the Deutsches SOFIA Institut (DSI) under DLR contract 50 OK 0901 to the University of Stuttgart. B.A.S. acknowledges SOFIA funding from subcontract SOF 04-0180 Sargent and subcontract SOF 04-0188 Sargent of prime contract NAS2-97001.

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