The *Spitzer*-IRS Protostar Survey of the Orion Molecular Cloud Complex

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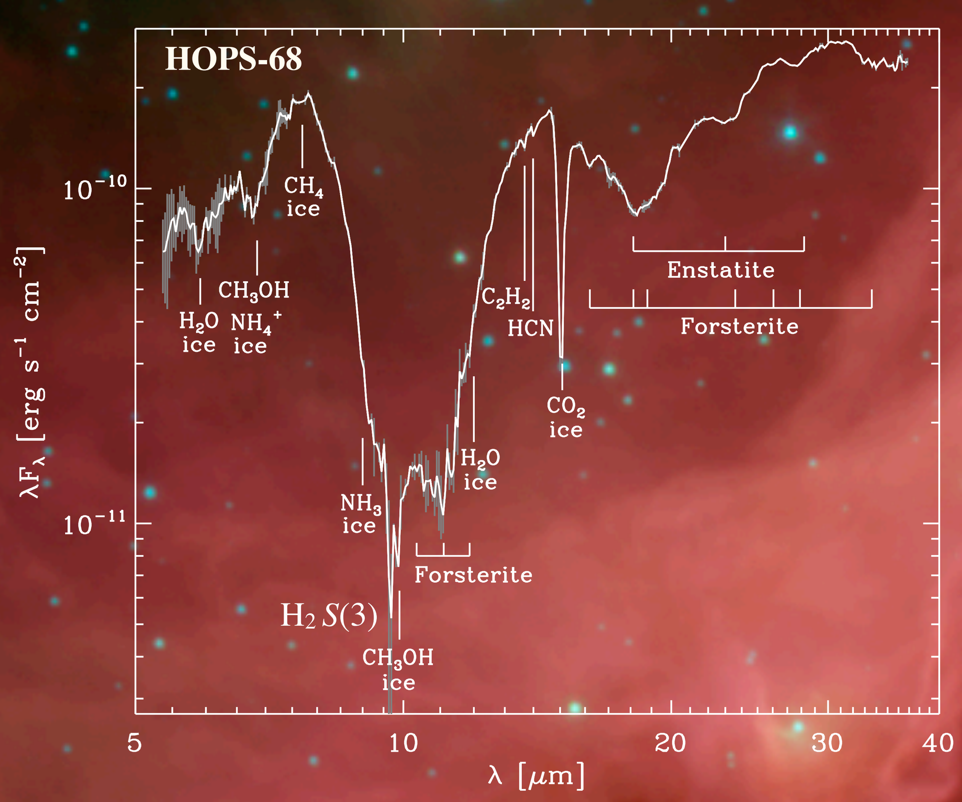
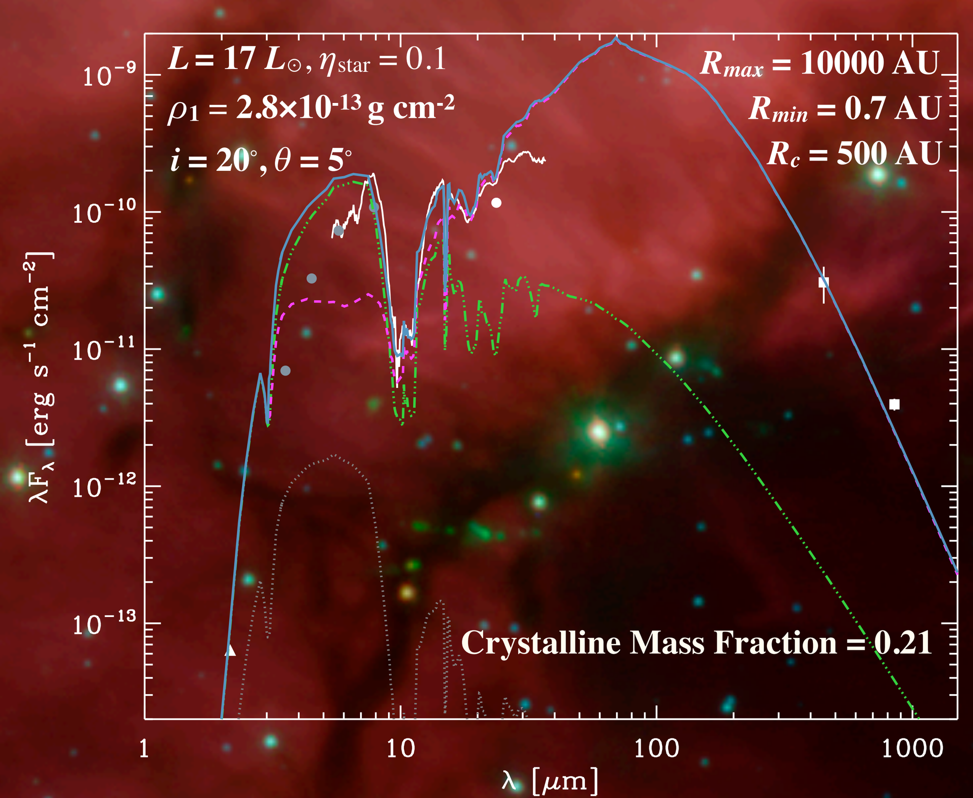
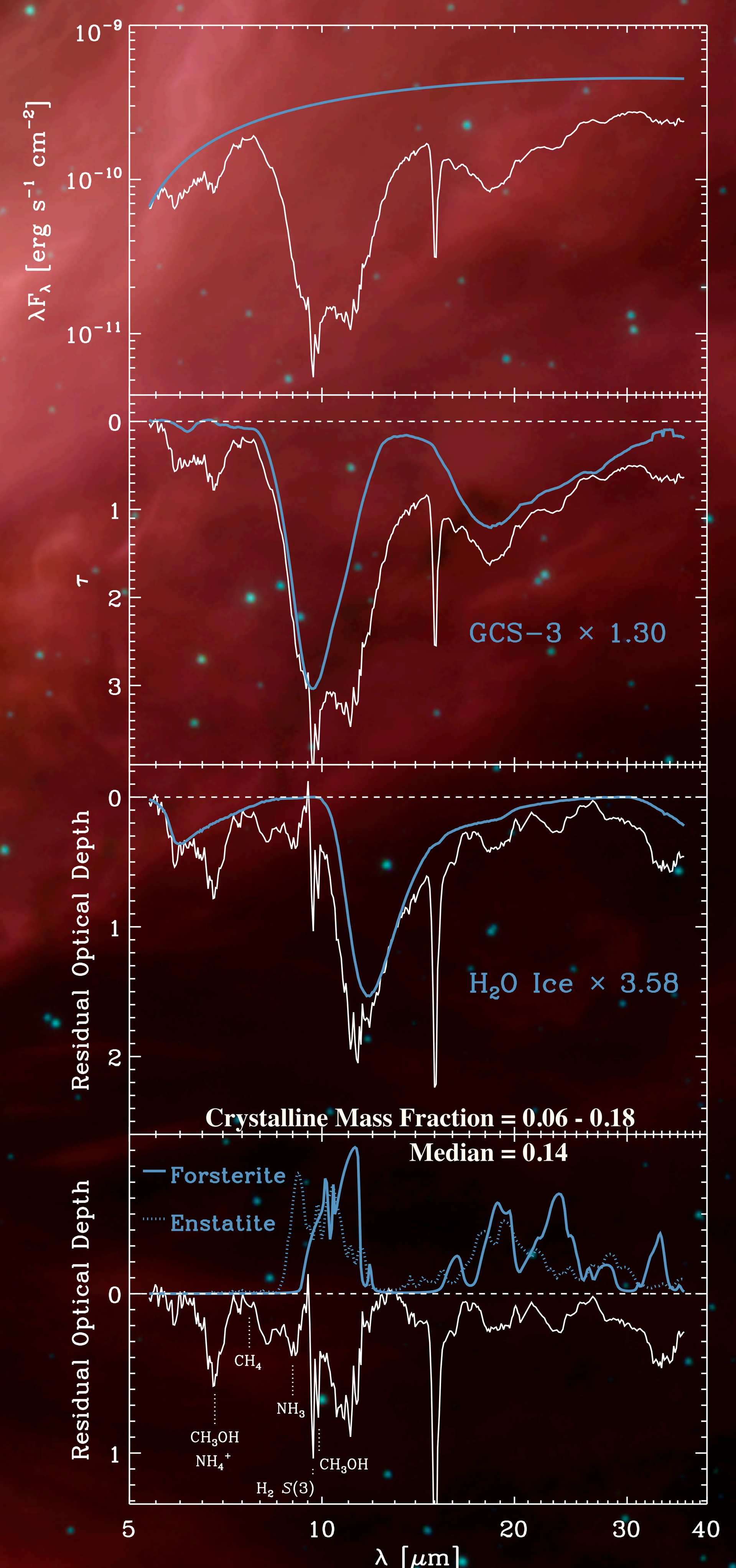
The Orion Molecular Cloud complex is the most active region of star formation within 500 pc of the Sun, where the *Spitzer Space Telescope* has identified over 400 protostellar candidates in a variety of environments, from dense clusters to isolation. With the *Spitzer* Infrared Spectrograph (IRS), we have obtained 5-36 μm follow-up spectroscopy of 349 protostellar candidates; these data are the first detailed mid-infrared spectroscopic survey of a large number of protostars in a single complex at a common distance. The spectra are being used in combination with the Herschel Orion Protostar Survey (HOPS) to determine the fundamental parameters of 278 protostars. We concentrate in this presentation on preliminary analyses of 110, high signal-to-noise, spectra. We present the first unambiguous detection of forsterite (Mg_2SiO_4) absorption at 11.1, 16.1, 18.8, 23.6, 27.9, and 33.6 μm from a cold protostellar envelope. We estimate the crystalline mass fraction along the line-of-sight by first assuming that the crystalline silicates are located in a cold absorbing screen and then by using radiative transfer models. The resulting crystalline mass fractions of 0.14 - 0.21 are significantly larger than the upper limit found in the interstellar medium (< 0.02 or ~ 0.03 - 0.05 in the presence of ice mantles; Kemper et al. 2005 and Li et al. 2007, respectively). We propose that the envelope, along the edge of the outflow cavity, has been contaminated by crystalline material that was: (1) annealed within the hot inner disk and/or envelope regions and subsequently transported by an outflow to the cold, outer envelope region (i.e., distances > 600 AU) or (2) annealed *in situ* by slow or oblique outflow-driven shocks. Such processes may concentrate crystalline material near the outflow cavity. If this is the case, then the detection of crystalline silicates would require an observed line-of-sight near the edge of the cavity; which we find of the case of HOPS-68. We also describe a new effort to reclassify the sources based on their mid-infrared spectra. We present several diagnostics based on synthetic colors and spectral indices, which are designed to measure the shape of the spectrum and depth of the spectral features. We describe current progress in distinguishing highly reddened disks and protostars based on these diagnostics.



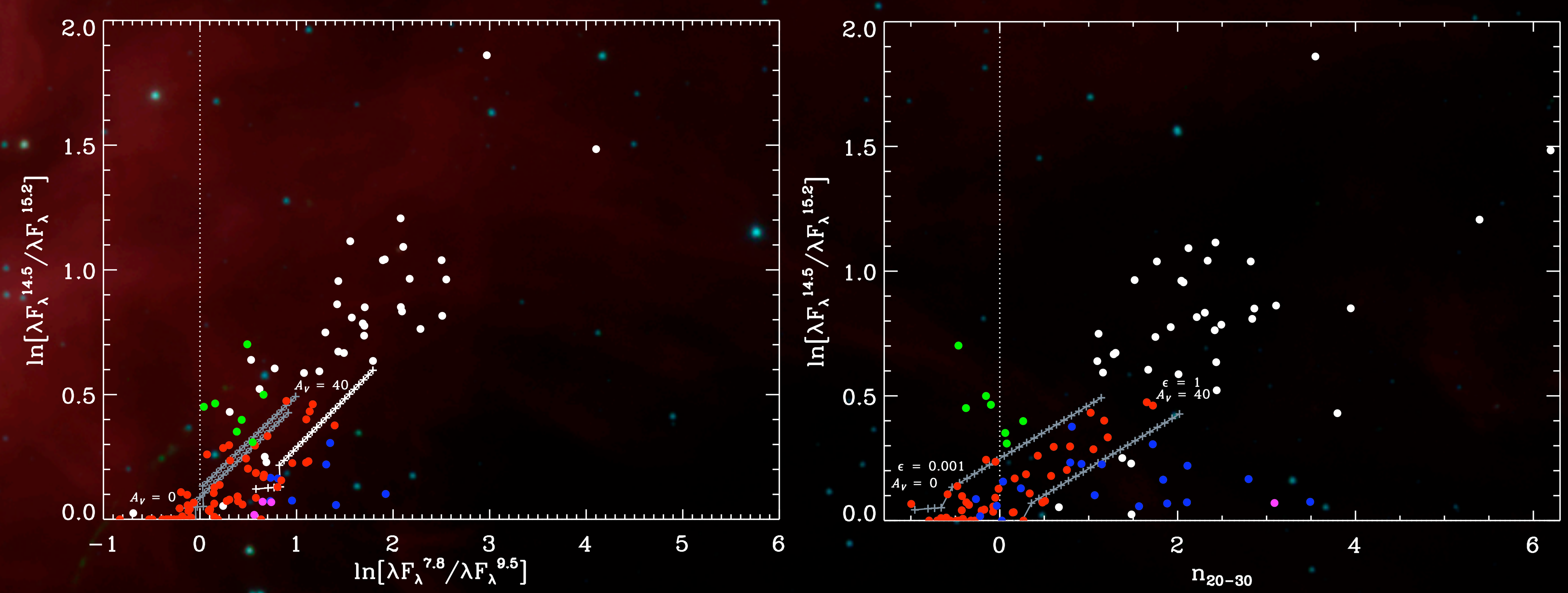
Spitzer-IRS 5 - 36 μm spectrum of the Orion OMC-2 protostar HOPS-68 (*see blue circle near the poster's lower left edge*), with uncertainties (*gray lines*) and feature identifications indicated.



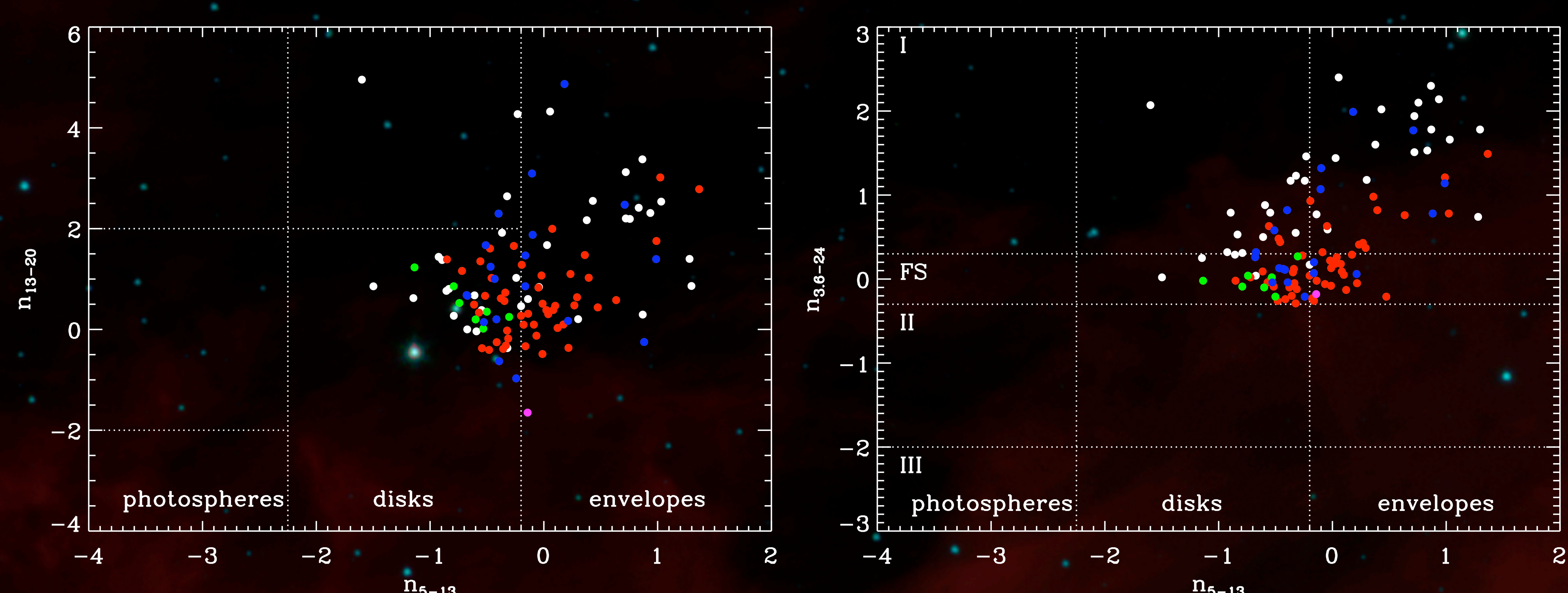
Best-fit model SED compared to the observed data of HOPS-68. The composite SED includes the *Spitzer*-IRS spectrum (*white line*), PANIC 2.16 μm flux, IRAC 3.6, 4.5, 5.8, and 8.0 μm fluxes, and MIPS 24 μm flux (S. T. Megeath et al., in preparation; *gray circles* and *white circle*, respectively). Also included are 450 and 850 μm SCUBA fluxes (*squares*) from the Johnstone & Bally (1999) continuum emission maps. The model SED (*blue line*) includes contributions from the central protostar (*gray line*), the disk (*green line*), both extinguished by the envelope, and the envelope (*magenta line*). Since the contribution of the envelope is a factor of ten greater than the attenuated disk component, an absorption feature in the disk would require an unphysical depth to produce an observed depth of 20 % in the combined SED, and thus, it is highly unlikely that the observed absorption arises in the disk.



The isolation of crystalline silicate features in the spectrum of HOPS-68. *Top panel*: The *Spitzer*-IRS spectrum with adopted second-order polynomial unabsorbed continuum (*blue line*). *Second panel*: The derived optical depth spectrum compared to the amorphous silicate profile of GCS-3 (*blue line*; Chiar & Tielens 2006). *Third panel*: The residual optical depth spectrum compared to small spherical grains of pure crystalline H_2O ice at T = 140 K (*blue line*; A. C. A. Boogert, private communication). *Bottom panel*: The residual optical depth spectrum (after subtracting the scaled H_2O ice profile) compared to arbitrarily scaled mass absorption coefficients for forsterite (*solid blue line*) and enstatite (*dotted blue line*).



Left panel: A comparison of synthetic colors that measures the approximate optical depths of the 9.7 μm silicate and 15.2 μm CO_2 ice absorption features. The 9.7 and 15.2 μm line depths predicted from the interstellar extinction law of McClure (2009) are shown, and includes both silicates and CO_2 ice for extinctions greater than A_V = 3. We show the effect of extinction (A_V = 0 - 40) on a pure photosphere (*white line*) and on two IRS spectra of pre-main sequence stars with disks (*gray lines*). Note that the depth of the silicate feature for stars with disks is less than that of a pure photosphere; this is due to the presence of silicate emission in the unattenuated disk spectrum. We show sources that have CO_2 ice features with depths less than that predicted with the extinction law (*blue circles*). Contaminating galaxies are also shown (*magenta circles*). *Right panel*: Approximate CO_2 line optical depth vs. the 20 - 30 μm spectral index; the spectral index is used to measure the slope of thermal emission resulting from the envelope. We compare these colors to those of synthetically reddened IRS disk spectra (*gray lines*), which exhibit various levels of dust settling (ε = 0.001 - 1.0). Sources lying on and between the indicated extinction lines are potentially reddened disks (*red circles*). Sources with approximately no silicate absorption and relatively deep CO_2 ice absorption (*green circles*) are likely to be pre-main sequence stars with disks, where the extinction has cancelled out the silicate emission from the disk. The (*blue circles*) are sources which appear deficient in CO_2 ice absorption (see left panel) and the (*magenta circles*) are galaxy contamination. The (*white circles*) are the most reliable candidates we have for protostars.



Left panel: Source classification scheme using the extinction-free 5 - 13 and 12 - 20 μm spectral indices from McClure et al. (2010). The classification of photospheres, disks, and envelopes are defined from McClure et al. (2010) for Taurus: sources with a 12 - 20 μm spectral index less than -0.2 are classified as disks. The colors scheme is the same as the above figures. *Right panel*: Comparison of 110 Orion sources using two classification techniques: 3.6 - 24 and 5 - 13 μm spectral indices from McClure et al. (2010). The 3.6 - 24 μm spectral index selection criteria is the same used from Wilking & Lada (1983), Wilking et al. (1989), and Greene et al. (1994), except we have excluded the 2.2 μm flux to reduce the sensitivity of the index on extinction. In total, our diagnostics suggest that there may be a substantial fraction of sources that are highly reddened pre-main sequence stars with disks and no infalling envelope, particularly for the class of "Flat-spectrum" sources. However, the different diagnostics are not entirely consistent as to which sources should be considered reddened stars with disks. With the addition of the 70 and 160 μm data from *Herschel*, we should be able to further distinguish between the reddened stars with disks and protostars with infalling envelopes.

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