A *Spitzer* Detection of Crystalline Silicates in a Protostar

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ABSTRACT

Recent surveys with the *Spitzer* Space Telescope have systematically identified protostars in nearby molecular clouds. The richest sample of protostars within 500 pc of the Sun is found in the Orion A molecular cloud, where we have observed 252 protostars with the Infrared Spectrograph (IRS) on board the *Spitzer* Space Telescope. Here, we present the IRS spectrum of the Orion A protostar 8385127-5141. The mid-infrared spectrum reveals the presence of various crystalline substructure in the amorphous silicate absorption features. Crystalline silicates are often observed as infrared emission features around the circumstellar disk of Herbig Ae/Be stars and T Tauri stars, but this is a very rare instance of crystalline features being detected in the envelope of a protostar, and it is to our knowledge, the first instance of these numerous absorption features being observed in a protostar with *Spitzer*.

INTRODUCTION

Crystalline silicates, the result of a relatively slow cooling of a material initially at high temperatures, are ubiquitously present in various astrophysical environments. In particular, they are often detected around the circumstellar environments of pre-main sequence stars (T Tauri stars and Herbig Ae/Be stars) and post-main sequence stars, and in primitive objects such as comets. For T Tauri stars, these optically thin emission features are expected to originate from small dust grains at the warm (~ 300 K) surface layer of inner (~ 3 AU) disk region.

Protostars are still surrounded by the in-falling envelope material from their parent cloud of gas and dust. They generally show smooth, featureless ~ 10 and 18 μm absorption profiles (Furlan et al. 2008); crystalline features are in almost all cases absent. In one protostar, Ciardi et al. (2005) show evidence for the presence of crystalline silicates in the form of forsterite emission near 11 μm; this emission appears to come from the hot inner region of the protostar suggesting that the dust was heated in the disk surrounding the central protostar. In these regions, thermal annealing or evaporation and re-condensation are the mechanisms that are generally thought to be responsible for the crystallization of silicates. Experimental studies indicate that such processes require temperatures of ~ 800-1200 K (Harker & Desch 2002) and >1200 K (Gail 2004), respectively. However, crystalline features in the cold envelope surrounding the protostar are not expected.

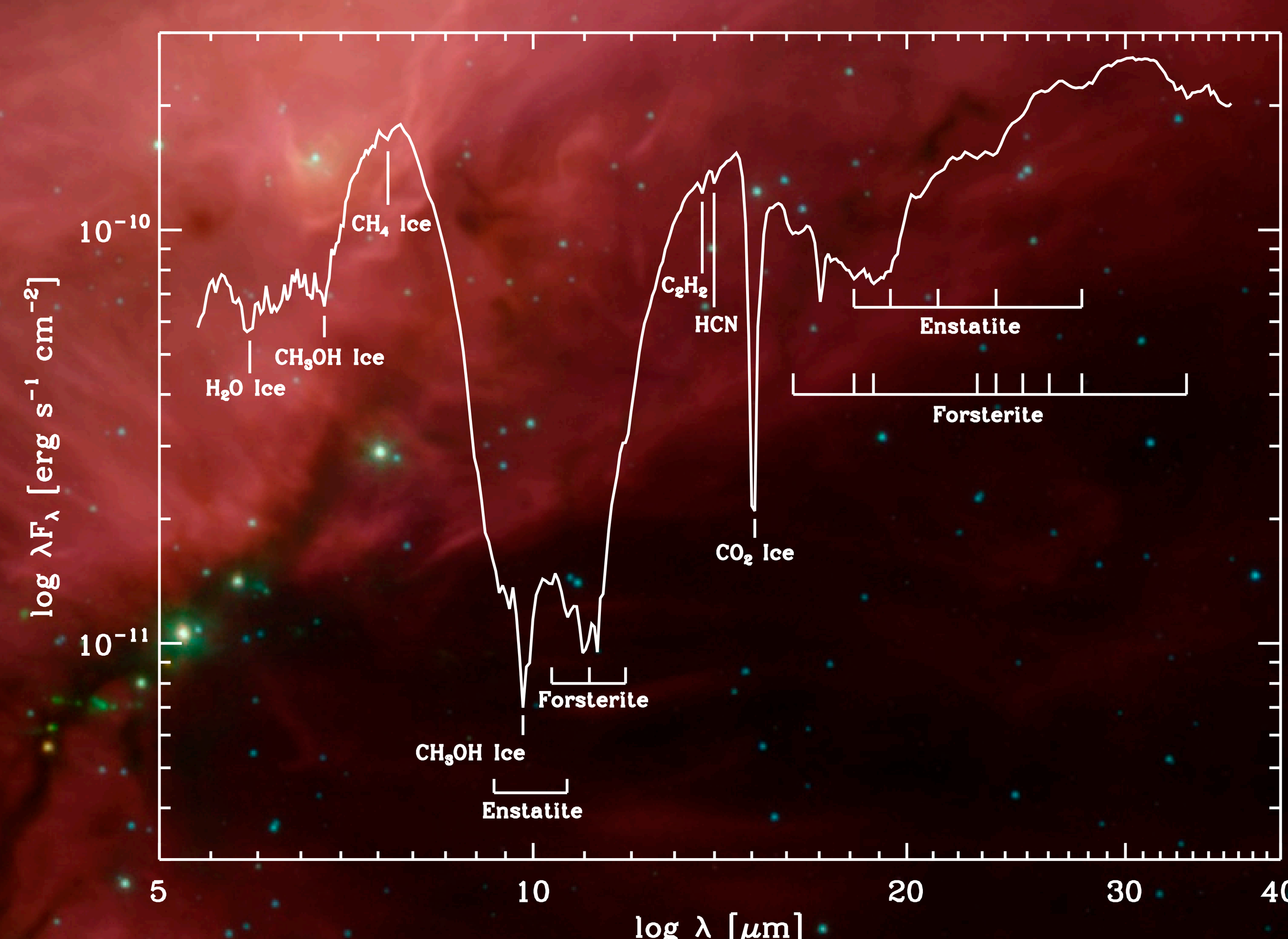

Figure 1. - IRS spectrum of the protostar 8385127-5141, with absorption features labeled. Note that the feature at ~ 17 μm is a sky-subtraction artifact, possibly arising from molecular hydrogen.

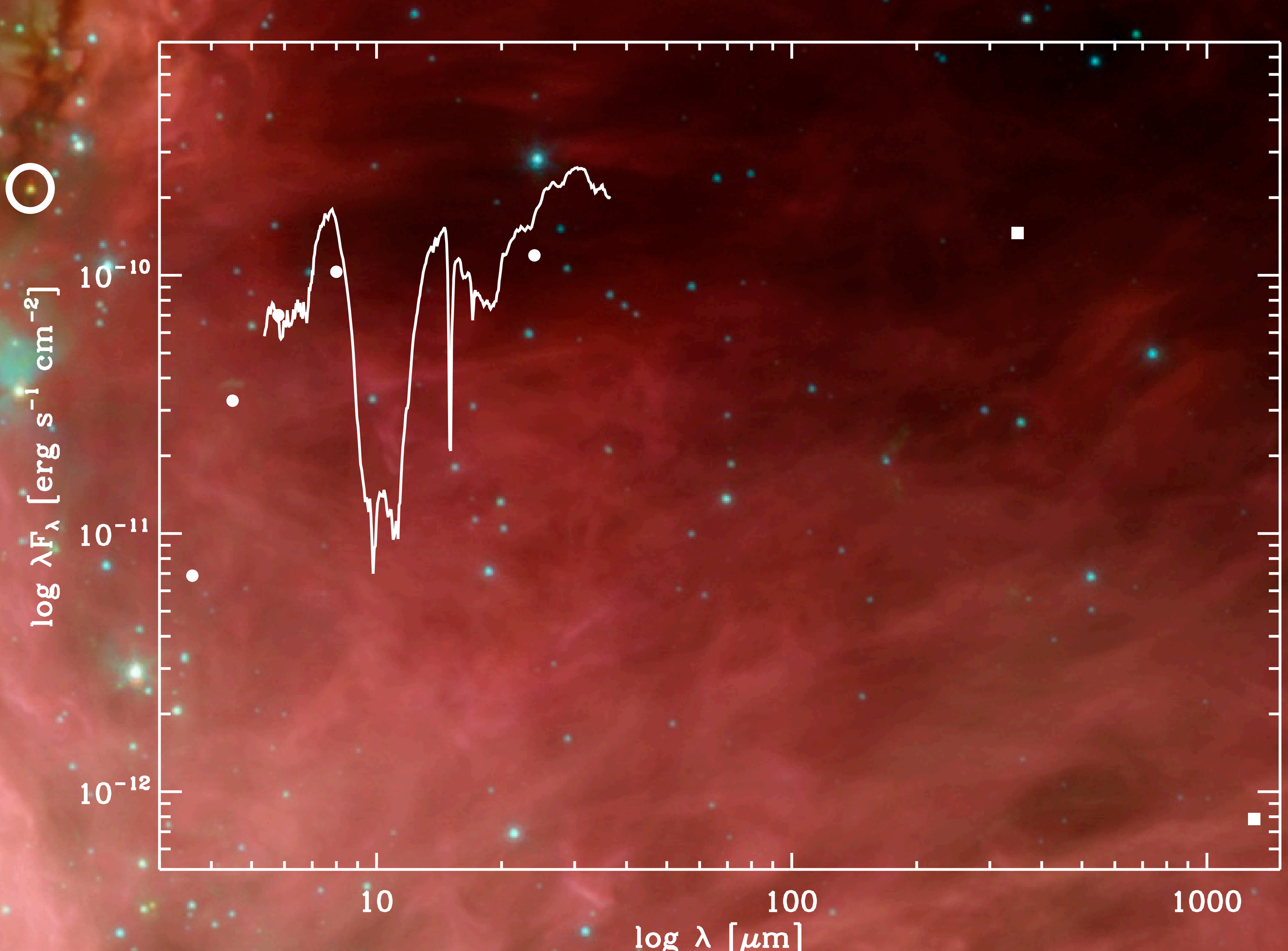

Figure 2. - SED of the protostar 8385127-5141. The IRAC and MIPS 3.6, 4.5, 5.8, 8.0, and 24.0 μm fluxes are shown as open filled circles, and the sub-mm and mm fluxes are indicated by the filled squares. The disagreement at 24.0 μm is possibly due to variability.

RESULTS

The protostar 8385127-5141, more commonly known as FIR 2, is a deeply embedded protostar located in the OMC-2 region of the Orion A molecular cloud (see circle near the center). A high-velocity bipolar CO outflow is thought to be associated with 8385127-5141 with near pole-on orientation (Williams et al. 2003; Takahashi et al. 2008). The protostar is not detected at near-infrared wavelengths.

Figure 2 shows the spectral energy distribution composed from the IRS spectrum with complementary IRAC and MIPS data from Megeath et al. (in prep.), as well as sub-mm data from taken from Lis et al. (1998) and Chini et al. (1997). The SED reveals that most of the power is emitted in the mid-to-far infrared, with a relatively flat slope over the IRS spectral range, indicating a pole-on orientation as also suggested from the CO outflow. ***The IRS mid-infrared spectrum reveals deep amorphous silicate absorption with numerous crystalline features that are coincident with the strongest absorptions features in enstatite and forsterite*** (see Figure 1). The spectrum also shows evidence for the presence of ices (H_2O, CH_3OH, CH_4, and CO_2) that are commonly found in the protostellar environment and a possible rare detection of two organic molecules (C_2H_2 and HCN). The detection of crystalline silicates as infrared absorption features suggest that they are located in the cooler, outer envelope. Such a location would presumably require a relatively large-scale mechanism to transport dust outward into the surrounding cold envelope, possibly by entraining the dust in an outflow.

Through radiative transfer modeling, we are currently investigating the nature of the central protostar and the structure of its envelope. This model will help us quantify the relative abundances of the crystalline silicates and will lead to a better understanding of their origin and implications.

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The support for this work is provided by NASA through contract number 1289605 issued by JPL/Caltech.