***IN SITU* TEMPERATURE DEPENDENT LABORATORY SPECTROSCOPY FOR EXOPLANETARY ATMOSPHERIC CONDENSATES.** S. Marcum[1,2] and E. Kohler[1]. [1]NASA Goddard Space Flight Center, Astrochemistry Laboratory, Code 691, Greenbelt, MD 20771 [2]Southeastern Universities Research Association, Washington DC 20005.

Introduction: Significant effort is being made to characterize the atmospheres of recently discovered exoplanets. Observational photometry or spectra of large, gaseous planets are analyzed to help us understand characteristics of the observed planet including temperature, mass, atmospheric chemistry, and even provide hints about planetary evolutions. As we continue to improve our understanding of this new data, these new worlds are pushing our knowledge of planetary environments which have previously been limited to our own Solar System.

A white paper published in 2016 based on discussions of the National Aeronautics and Space Administration's (NASA) Nexus for Exoplanet System Science emphasized the importance of obtaining high quality spectroscopic data on the condensates expected to form clouds in exoplanet atmospheres [1]. Laboratory work to characterize the spectra of these condensates is crucial to understanding observations of exoplanet atmospheres and to serve as a diagnostic tool for future observations.

While laboratory spectral databases do exist, they are often limited to terrestrial temperatures. Many of the exoplanets being discovered have effective temperatures that are significantly higher, for which no such databases exist. At these higher temperatures not only will there be a temperature effect on the measured spectra, but also the molecular species could be unanticipated.

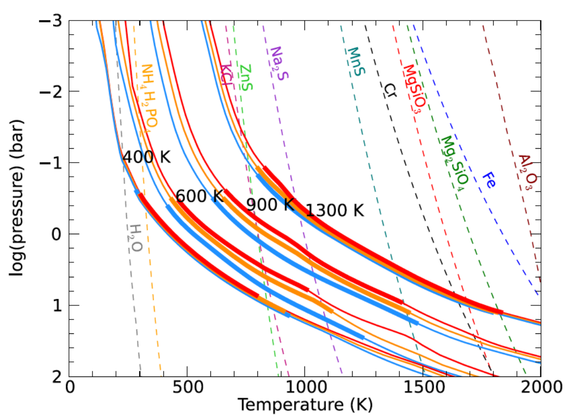

Figure 1. *Modeled P-T profiles of atmospheres with increasing effective temperatures, overlaid with condensation curves (dotted lines) of expected atmospheric constituents. Cloudless models in blue, and cloudy models (red) and (orange). Figure from [3].*

As seen in Figure 1, even a "low" temperature planet of approximately $T_{eff} = 500$ K could form a variety of species of refractory clouds deep in the atmosphere [2]. It is vitally important that laboratory spectral measurements, for a variety of hypothesized atmospheric constituents, are taken for better accuracy of exoplanet characterization endeavors.

Methods: Absorbance spectra was collected at NASA Goddard Space Flight Center using a Mattson RS-10000 Fourier Transform InfraRed (FTIR) spectrometer operating in the near and mid-IR regimes (2 μm – 17 μm). In order to allow data of the requisite temperatures and pressure to be collected *in situ*, the FTIR was retrofitted with an AABSPEC #2000-A multimode system (Figure 2), that houses samples and allows them to be heated up to temperatures of 1100 K under pressures of 133 bar – 10^{-11} bar.

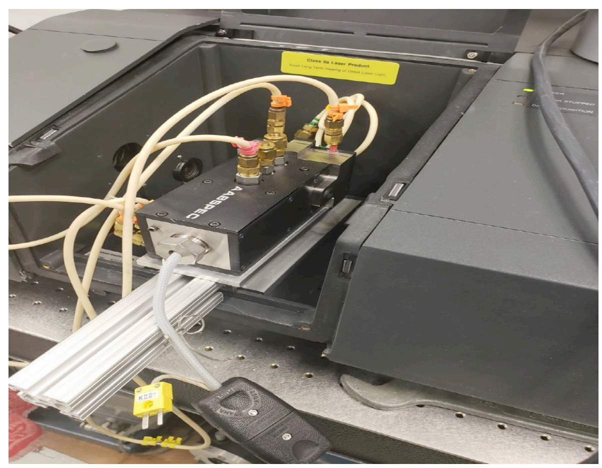

Figure 2. *Exterior view of the Aabspec cell used to obtain spectra for this investigation. Powered samples were loaded into the Aabspec cell and placed into the FT-IR spectrometer for measurements.*

For this investigation, a number of refractory materials hypothesized to be exoplanet atmospheric condensates were identified and the absorbance spectra was measured. Spectral data for forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$) has previously been collected with this apparatus and presented.

The samples used for this investigation were powdered and placed in the sample holder of the AABSPEC cell. The cell was pumped under vacuum to pressures of 9.3e^{-6} bar and initial spectral measurements were taken at 300 K. Subsequent measurements were taken in 50 K increments up to 1100 K. Each measurement consisted of 1000 scans with a resolution of 4 cm^{-1} to ensure high resolution data. The data for each sample was normalized and plotted to demonstrate the change in features with increasing temperature.

Results: The preliminary spectra for SiO_2 shows a steady shift in peak position and decrease in the peak height of the characteristic molecular spectral features as the temperature was increased. The data also shows that the full width half at half maxima (FWHM) increased as the temperatures increased, broadening the feature. This behavior is illustrated below in Figure 3.

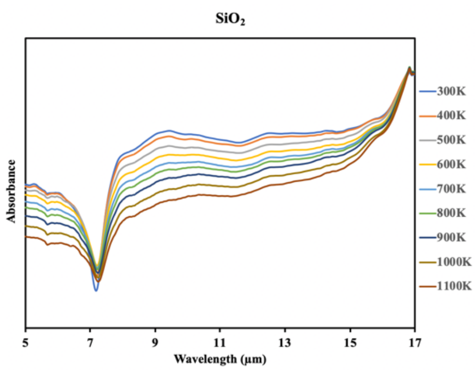

Figure 3. *Preliminary spectra of SiO_2 taken at temperatures ranging from 300 K to 1100 K.*

The temperature at which the sample is measured appears to have a significant effect on the characteristics of the observed spectral features. These trends in peak position, peak height, and FWHM are consistent with those observed in forsterite and enstatite during a previous investigation.

Conclusions: Observably significant changes in spectra with temperature demonstrate the need for further studies on other potential condensates. The compounds in this study will undergo further investigations to more accurately distinguish the effect that temperature has on spectra. Laboratory work to characterize the spectra of refractory cloud condensates is crucial to understanding observations of exoplanet atmospheres and to serve as a diagnostic tool for future observations. A comprehensive catalog of reference spectra will provide the needed laboratory data to help us better understand the atmospheres of these exoplanets.

References: [1] Fortney, J.J., et al., (2016) arXiv preprint arXiv:1602.06305. [2] Fortney, J. J. et al. (2008) Astrophysical Journal, v. 683.2, p.1104–1116. Crossref. Web. [3] Morley, C. J., et al., (2012) Astrophys. J., 756, 172. [4] Sing, D., et al. (2016) Nature, v. 529, p.59–62. [5] Wakeford, H.R., and Sing, D.K. (2014) Astronomy & Astrophysics, v. 573, A122