**LABORATORY STUDIES OF CRYOGENIC OUTER SOLAR SYSTEM MATERIALS.** J. Hanley[1], W. Grundy[1], S. Tegler[2], R. Dillingham[2], D. Trilling[2], G. Lindberg[2], H. Roe[1], T. Stufflebeam[2] and collaborators. [1]Lowell Observatory, Flagstaff, AZ (jhanley@lowell.edu, w.grundy@lowell.edu), [2]Northern Arizona University, Flagstaff, AZ (stephen.tegler@nau.edu).

**Purpose:** The Physics and Astronomy Department at NAU hosts one of a handful of laboratories around the world devoted to studies of astrophysical ices [1, 2]. Simple molecules like $CH_4$, $H_2O$, $N_2$, CO, $CO_2$, $O_2$, $CH_3OH$, $C_2H_6$, and $NH_3$ are abundant throughout the universe and are important geological materials in the cold outer regions of the solar system. Their mobility and distinct material properties enable geological activity and produce a spectacular variety of exotic landforms, even at extremely low temperatures. But frustratingly little is known of the basic mechanical and optical properties of these volatile ices, and especially of their mixtures.

Their complexity is comparable to the silicates studied by petrologists, suggesting the term "cryopetrology" for our ice lab studies of these exotic cryogenic materials. Examples of these exotic ices and the landforms they can create are seen in Fig 1.

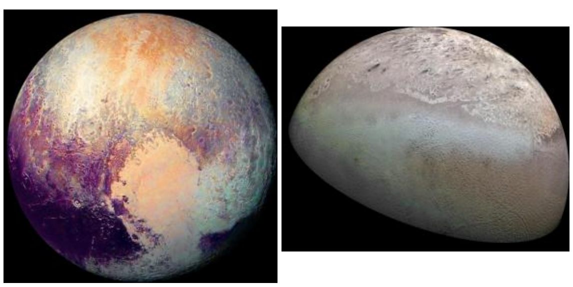

***Figure 1.*** *Enhanced color views of Pluto (left) and Triton (right), two outer solar system worlds with surfaces sculpted by cryogenic ices $N_2$, $CH_4$, and CO.*

**Current Hardware:** Within the laboratory setup (Fig 2A), volatile ices are condensed as thin ice films on a cold mirror (Fig 2B), or within an enclosed cell (Fig 2C). Cooling is provided by closed-cycle helium refrigerators, within vacuum chambers for insulation. Cryogenic ice samples are studied via various analytical techniques including visible and infrared transmission spectroscopy (Fig 2D) and photography (Fig 3). Mass spectrometers are capable of monitoring changes in composition.

**Results:** Changes in methane's infrared absorption bands enable remote sensing of whether it is dissolved in nitrogen ice, and the relative abundances of the two (Fig 4) [3]. These lab measurements of the optical properties are needed to interpret New Horizons infrared observations of Pluto.

The ices that can be created in the lab are useful to a variety of outer solar system bodies. For instance, mixtures of CO and $N_2$ are found on both Pluto and Triton, and spectral features acquired in the lab may aid in their identification [4].

The buoyancy of the ice formed from a nitrogen-methane liquid mixture depends on the composition of the mixture (Fig 5) [5]. Liquids with these ingredients can form rain, rivers, lakes, and aquifers on Titan.

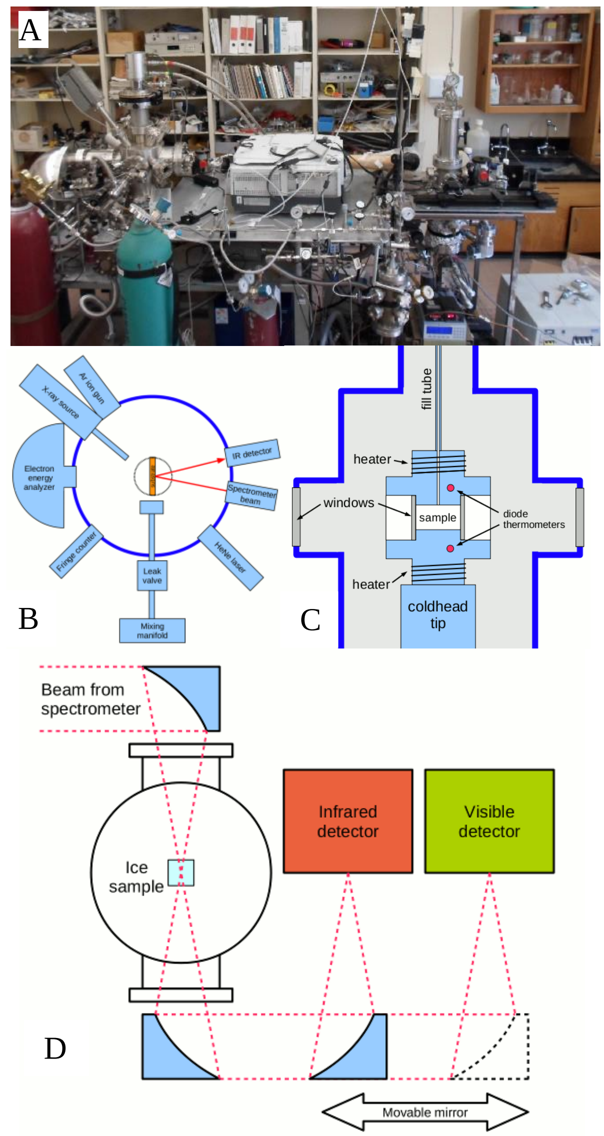


***Figure 2.*** *A) Photo of laboratory setup. B) Schematic of the thin-film side. C) Schematic of the cell side. D) Schematic of transmission spectroscopy path on cell side.*

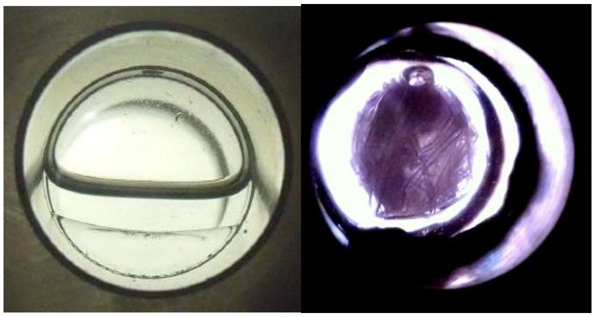

***Figure 3.*** *Left: Liquid methane ($CH_4$) starting to freeze into ice at 90.7K. Right: Liquid Nitrogen ($N_2$) mixed with CO frozen into ice at 50K.*

**Future Goals:** We would like to be able to study not only the spectroscopic properties of these materials at low temperatures, but the physical properties as well. These include density, viscosity, sound speed, vapor pressure, refractive index, compressibility, thermal and electrical conductivity, and diffusion rates.

One capability we are actively investigating is XRD to determine the structures of mixtures at cryogenic temperatures. This could be useful not only for the outer solar system, but Mars as well. We are also planning to add Raman spectroscopy capabilities. This would be very appropriate for future Europa, Titan, and other landers. We are eager to collaborate with other complementary facilities, as well as scientists who have a need for laboratory data to help with understanding mission and/or telescope data.

**References:** [1] Tegler, S.C., et al. (2012) *The Astrophysical Journal*, *751*, 76. [2] Grundy, W.M., et al. (2011) *Icarus*, *212*, 941-949. [3] Protopapa, S., et al. (2015) *Icarus*, *253*, 179-188. [4] Hanley, J., et al. (2016) *LPSC*, Abstract #2438. [5] Roe, H.G. and W.M. Grundy (2012) *Icarus*, *219*, 733-736.

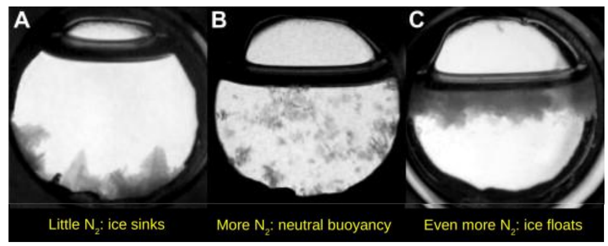


***Figure 5.*** *In each image the sample cell is filled with CH4 + N2 held at a constant temperature for long enough to allow the ice and liquid to fully equilibrate. At 86.6 K the ice crystals sank (A), while at 80.6 K the crystals floated (C). Between 83.8 K and 84.1 K we bracketed the neutral buoyancy point of the crystals (B). Figure and caption from [5].*

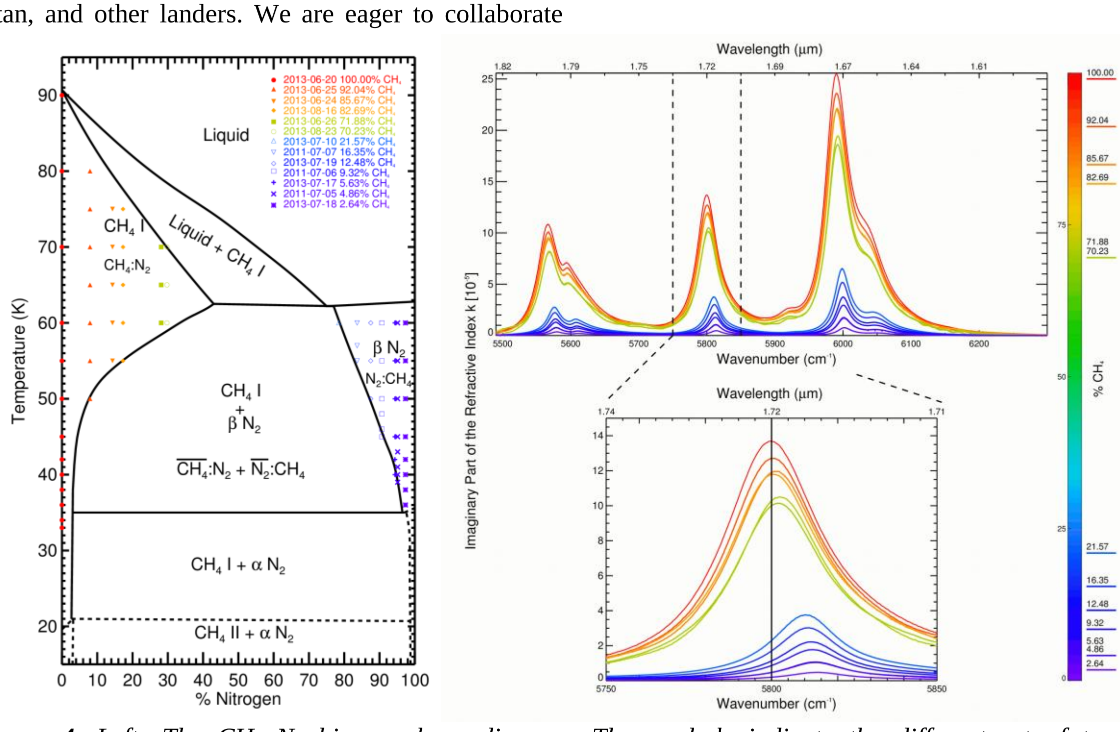


***Figure 4.*** *Left: The $CH_4$–$N_2$ binary phase diagram. The symbols indicate the different set of transmission measurements performed to conduct a systematic study of the changes in $CH_4$–$N_2$ solid mixtures spectral behavior with mixing ratio and temperature. Right, top panel: The imaginary part of the refractive index, k, of $CH_4$–$N_2$ ice mixtures at different mixing ratios at $T$ = 60 K over the range from 5490 to 6300 $cm^{-1}$. Bottom Panel: Expanded view of the $\nu_2$+$\nu_3$+$\nu_4$ band. Figures and captions from [3].*