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Development of a Pluto Chamber for Surface Simulations

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Development of a Pluto Chamber for Surface Simulations

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by

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Abstract

In light of the exciting new discoveries being made by the New Horizons team, more data on Pluto is available than ever before. However, with the increase in recovered data, there is now a need for laboratory data to interpret it. Laboratory simulation of these conditions and subsequent testing of materials and samples therein is now possible and necessary to understand what has been observed. To do these simulations, a vessel that can achieve low temperatures and high vacuum is required. The scope of this work presented here was to design, build, and test a chamber that could perform these simulations of Pluto's surface.

Given the parameters of temperature and pressure, a chamber was constructed to simulate the conditions on the surface of Pluto. This chamber can reach and maintain the 30 K to 50 K temperatures of the surface. Pressure can be dropped to approximately ten microbars, which is equivalent to the pressure found on the surface. An atmosphere of dominantly nitrogen can be maintained and other gases can be introduced for testing. These gases can be condensed as ice and analyzed by Fourier Transform Infrared Spectroscopy. Custom gas mixtures are capable of being made. During experiments, images and video can be recorded.

These components and processes have been tested and performed over the course of experiments implemented in the Keck laboratory at the University of Arkansas. This chamber is versatile and can be modified using preexisting, open points of attachment to add new devices for other experimental purposes. Given its capabilities, it is an ideal vessel for use in experiments of surface conditions of Pluto and other Kuiper Belt Objects.

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I. Introduction

On July 14th 2015, New Horizons passed by Pluto on its closest approach and gave the world our first real glimpse of Pluto and its moon Charon. Using both remote sensing and in situ measurement, New Horizons discovered Pluto has diverse surface features of varying age in addition to variations in color, albedo, and composition (Stern 2015). Additionally, New Horizons was also able to obtain information on surface conditions, placing the temperature of the surface around 40 K and the pressure to be about 10 µbar (7.5 mTorr) (Stern 2015). If these conditions could be simulated, experiments could be run that are analogous to conditions on Pluto. Under simulated conditions, observations from Pluto can be recreated to better interpret the newly acquired data.

The objective of the project presented here is to design, build, and test a chamber to simulate the environmental conditions that occur on the surface of Pluto to help more fully interpret data from the New Horizons mission. To implement this objective, the first step was to design and plan a chamber to simulate the surface conditions observed on Pluto. Next, the physical construction of this planned chamber. Then finally, testing the completed chamber to insure that it met expectations.

The Keck Laboratory at the University of Arkansas is very experienced with simulation chambers. A simulation chamber in general is necessary because of the extreme cost and risk that would be associated with sending anything to an environment as far out and inhospitable as Pluto. The Keck Laboratory is home to four other simulation chambers in addition to this newly constructed one. Two are for various Martian simulations. One is for Venus studies. The fourth is a large simulation chamber designed for Titan (Wasiak 2012). In similar fashion, it would be unfeasible to physically visit and conduct experiments in each of those locations for the individual scientist.

At the University of Arkansas, I have constructed a Pluto simulation chamber, referred to as the Hyperion Chamber. This chamber can reach and maintain the conditions found on the surface of Pluto.

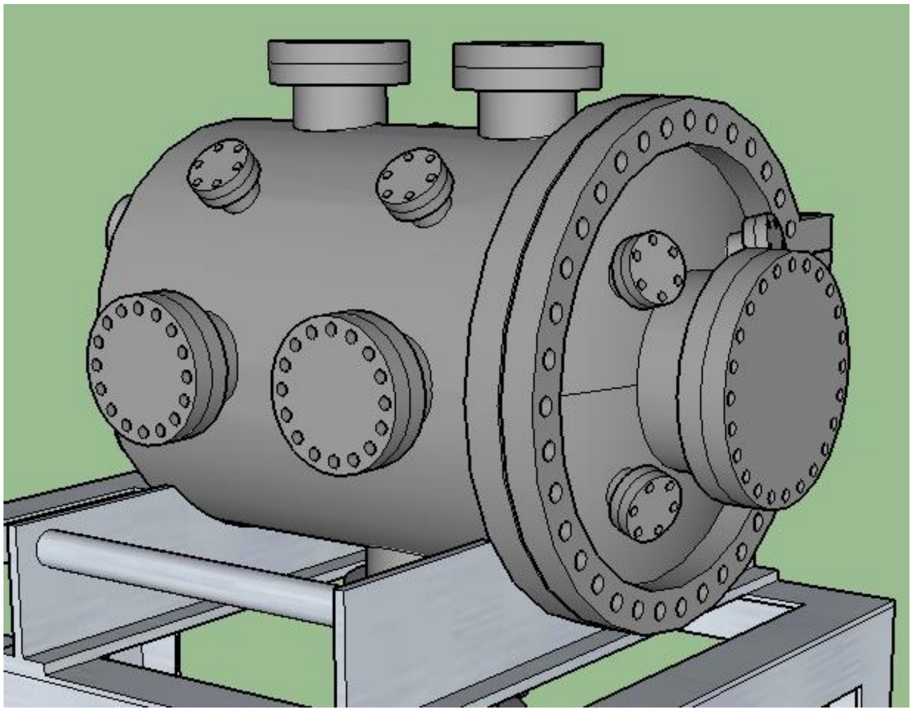

Figure 1. Schematic view of the chamber before any additional parts added.

Thanks to the recent mission to Pluto, a better knowledge of the conditions present on Pluto are available. Now, accurate simulations may be made. This chamber's intended use is to simulate the temperature, pressure, and atmospheric composition found on the surface of Pluto. With a simulation chamber of this sort, experiments can be performed which reflect how processes (such as ice mixtures, sublimation, melting, and flow patterns) would react under Pluto conditions. Using this chamber, we can deposit ices such as those observed by New Horizons and run experiments to understand Pluto's chemical interactions and dynamics (McMahon 2016).

II. Methods

A. Detailed Dimensions

The chamber is a stainless steel elongated cylinder with rounded ends, (Figure 1). The chamber is 22 inches (55.88 cm) long by 17 ¾ inches (45 cm) in diameter. The rounded ends extend an additional 1 to 2 inches out at their furthest. The chamber has twenty-one points of access in addition to a large lid that covers an entire side of the chamber. Twelve of these access ports are CF275 type flanges. Four of the flanges are located at the far end of the chamber, four on the lid, and the final four on the sides near the top. Seven of the access ports are CF600 type flanges. Two of these flanges are located on each side, two on the top, and one on the far end opposite the lid. There is one CF800 type flange located on the bottom. The chamber has been fitted with an adapter to CF275 to fit to the lines of the pressure system. There is one CF1000 type flange located on the door. The lid covers one entire end of the chamber and encompasses the 17 ¾ inch (45.085 cm) diameter opening of the chamber (McMahon 2016).

B. Parts

Pressure

The pressure on Pluto is approximately 10 µbar (7.5 mTorr) (Stern 2015).

To obtain desired pressures, an Alcatel Paschal series roughing pump is used. A vacuum of about 160 mTorr (213.32 µbar) can be obtained. Next, the cold head cryopumps the chamber down to about 13 mTorr (17.33 µbar). Sealing off the chamber from the roughing pump, the cold head can bring the chamber down to 9 mTorr (12 µbar).

Vacuum is measured using a Granville-Phillips Series 375 Convectron pressure indicator. In a nitrogen environment, this indicator can cover the range of pressure from our atmospheric conditions down to Pluto’s conditions. The Convectron gauge itself is installed in the door of the chamber, (Figure 2). Currently, data readings from the gauge are collected manually during experiments and recorded in an Excel spreadsheet.

Additionally, a Pirani gauge is also installed into the chamber, see Figure 2. However, it is not detailed enough to act as anything more than a double check on the Convectron gauge because the display only contains one decimal point measured in Torr.

Pressure is maintained by turning the roughing pump on or off, by unsealing or sealing the chamber, and by inserting gases.

Temperature

The average temperature on Pluto is 40 K (Stern 2015). Considering season changes, the average range of temperatures on Pluto is 30 K to 50 K (Grundy 2016).

Temperature is obtained using an Air Products DE-202 cold head connected to an Air Products HC-2 compressor. With no heating, the unit can reach about 11 K. It is installed in one of the top CF600 flange ports in the chamber with the cold stage hanging down, (Figure 2). Around the bottom end is a heat shield that further insulates the cold head and shields it from radiated heat. Additionally, the large vacuum of space between the cold head and the chamber walls enables the cold head to reach lower temperatures.

Data are collected manually during experiments from an Air Products Digital temperature Indicator/Controller. The readings are then recorded in an Excel spreadsheet. There is some error in the display of the indicator. To calibrate the temperature indicator/controller, first, the value displayed at room temperature was recorded. Then this value was compared to that of two other temperature indicators. Next, the thermocouple on the cold head was submerged in liquid nitrogen along with another thermocouple. This value was recorded and compared with the second temperature indicator and the boiling point of liquid nitrogen. Liquid nitrogen was chosen because it has a well-known boiling temperature of 77 K at 1 bar. Using these recorded points, a correction curve was created and that formula was used to adjust the values on the temperature indicator/controller to better reflect accurate values.

Temperature is controlled using the same Indicator/Controller instrument used for monitoring temperature. The controller aspect of the instrument allows for fine adjustments of cold head temperature. It has a set point control to define the temperature desired as well as a Vernier knob

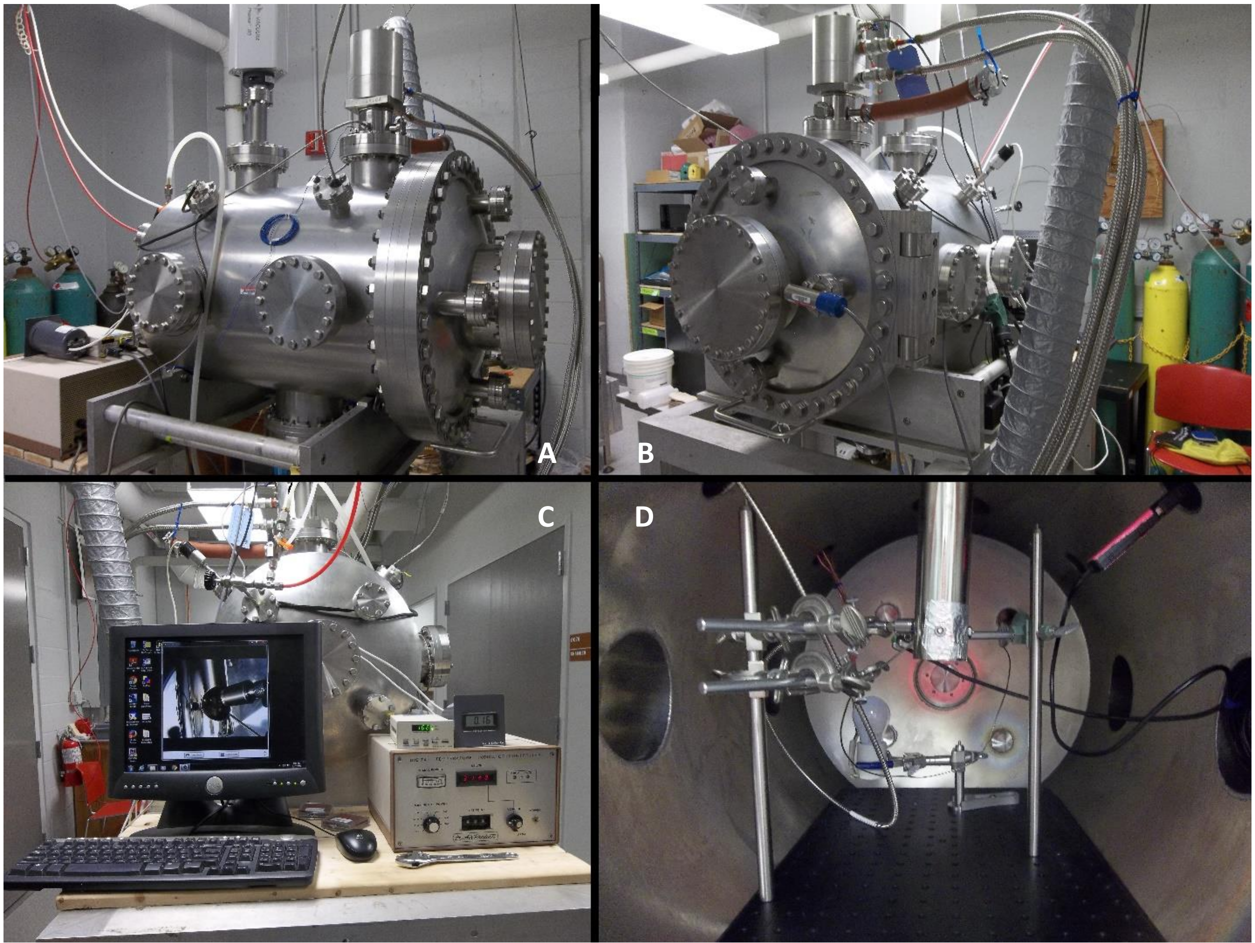

Figure 2. **A.** Side of the chamber, electrical and fiber feedthroughs visible along with the cold head and the Prisma mass spectrometer. **B.** Side view of chamber, USB feedthrough, Pirani gauge, Convectron gauge, and cold head visible. **C.** Back of the chamber, indicators/controllers visible in addition to the gas feedthrough. Image on the computer is the view from the interior camera. **D.** The interior of the chamber. Visible is the FTIR probe and the gas line, the camera is on the opposite side of the cold head.

for more precise adjustments. Also, it has a control for the amount of power, in watts, going to the heater line. Once these controls are set, it automatically adjusts the percentage of the power flowing through the heater line and adjusts as the actual temperature gets close to the desired temperature.

Atmosphere and Test Gases

The atmosphere on Pluto is predominantly nitrogen (N_2) with the next largest constituent being methane (CH_4) and then C_2H_X hydrocarbons (Stern 2015). Present on the surface of Pluto are ices of nitrogen, carbon monoxide, methane, and water (Grundy 2016).

In general, the chamber is kept filled with a nitrogen environment. This reduces the possibility of contaminants persisting in the chamber and interfering with experiments. Before each experiment, the chamber is purged with nitrogen gas to promote a clean environment.

Gasses are added to the chamber via a gas feedthrough, (Figures 2 & 3). The interior gas line is a 0.01 inch (0.254 mm) inner diameter by 1/16 inch (1.5875 mm) outer diameter, length of stainless steel tubing. The small line allows for gases to enter the chamber more slowly than a larger line. This design was chosen so that the vacuum in the chamber is not as heavily influenced when gases are added.

Exterior to the chamber is a mixing chamber that is used to make small amounts of custom mixtures. Composition of the mixtures is determined by observing the change in pressure in the mixing chamber as gas is added. Using the partial pressure, a mixture is made that is roughly accurate. To make these mixes, two cylinders of gas are used. On both cylinders, the outgoing flow is set to the same pressure. This is so the flow is the same from both cylinders. The set pressure is the final desired pressure of the mixing chamber. Both cylinders have lines going to the mixing chamber, on these lines are valves to control flow into the mixing chamber. On one gas cylinder, the valve is opened until a desired pressure of that gas within the mixing chamber is reached. This results in the mixing chamber becoming pressured to a lesser extent than the total desired pressure. Next, the flow from the second gas cylinder brings the total pressure in the mixing chamber up to what is desired.

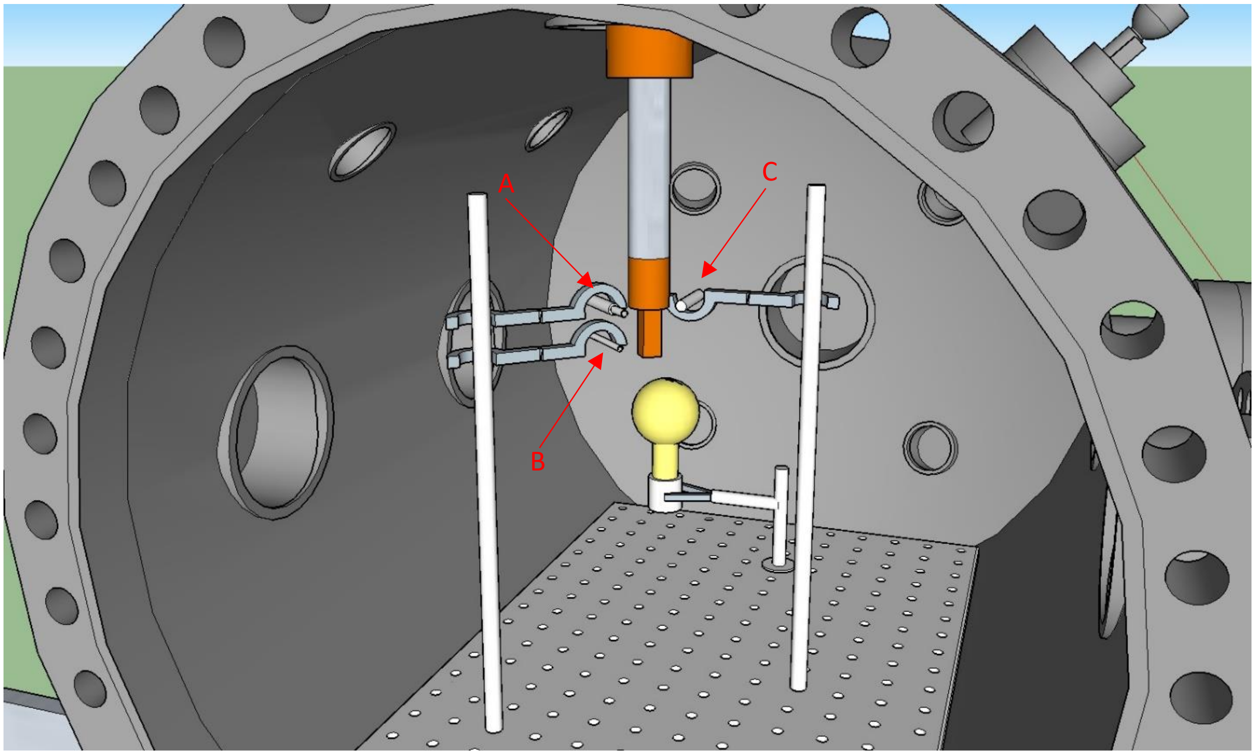

Figure 3. Schematic of the interior of the chamber. Shown are: **A.** Placement of FTIR probe. **B.** gas line. **C.** camera. Cables and cords not pictured.

Reflectance Spectroscopy

FTIR spectra of ices on the cold head are obtained through the use of a fiber probe mounted inside the chamber, (See Figure 2 & 3). On the end of the probe is a Thorlabs F240SMA-B lens that is used to focus the signal. The probe is connected through a feedthrough and a long extension fiber optic to a Thermo Nicolet 6700 FTIR Spectrometer. Within the spectrometer, a

CaF_2 beam splitter is used. Generally a TEC InGaAs detector is used but the option to use an In Sb detector is available.

For a background material, a piece of Spectralon was mounted on the cold head. After reaching a temperature and pressure of approximately 40 K and 160 mTorr (213 μbar), a background spectrum was taken and saved. Afterwards the Spectralon was removed and the saved background spectrum was used during the experiments.

Images

Pictures and video are obtained through the use of a small camera mounted inside the chamber, (Figure 3). A small lightbulb was placed in the back of the chamber to provide light for the camera. Electricity for the light is supplied through an electrical feedthrough. This feedthrough is fitted with extenders to facilitate the installation of devices. The light fills one of two possible connections on the feedthrough. The camera is a CrazyFire endoscope camera. Data from the camera is transmitted out of the chamber via a USB feedthrough into the computer associated with the chamber.

Table 1. Time Line of Pluto chamber construction

July 2015

- Project defined and started
- First set of parts (flanges and hardware) ordered

August 2015

- Removal of parts from a previous attempt at making a Pluto Chamber with this pressure vessel
- Roughing pump test – initial tests of chamber vacuum capability

September 2015

- Researched needed parts

October 2015

- Acquired HC-2 compressor unit and box of cold head associated hardware.
- Installed Prisma Quadrupole Mass Spectrometer
- Installed Pirani gauge

December 2015

- Acquired CF800 to CF275 adapter flange and FTIR fiber probe feedthrough

January 2016

- Cold head acquired
- Electrical feedthrough and light installed
- Redid roughing pump connection to chamber, added a valve to seal chamber off from pump.
- Pressure test of chamber and connecting lines.

February 2016

- Facility tour of NASA Ames Research Facility
- Worked on connecting the cold head to its compressor
- Pressure test of connecting hoses

March 2016

- Lunar and Planetary Science Conference
  - poster presentation of the Pluto Chamber
- Installed water lines
- Installed USB, gas, and FTIR fiber probe feedthroughs
- Reinstalled modified electrical feedthrough and light

April 2016

- Compressor began functioning
- Acquired mixing manifold
- FTIR fiber probe line checks
- Added internal components to the chamber
  - Breadboard
  - Gas line
  - Fiber probe
  - Camera
  - Lightbulb
- Cold head began functioning
- Cold head tests outside chamber

May 2016

- Integrated cold head
- Installed adapted FTIR fiber feedthrough and tested
- Calibration of indicator/controller
- First tests of fully built system

June 2016

- Condensation and freezing of test gases
- Running mixing experiments

C. Bench Tests

Pressure

Pressure was checked a multitude of times during the construction process. Pressure was first tested when there was no instruments or other parts attached to the chamber. This test was performed to see if the vessel itself could hold a vacuum. During this test, the chamber reached a minimum pressure of 2840 mTorr (3786 µbar). The pressure leveled off at 3070 mTorr (4093 µbar). At this point, the chamber was sealed and approximately 18 hours later, the pressure was 3140 mTorr (4186 µbar), which is about 500 times higher than the pressure on Pluto's surface.

After the whole system test, the two separate pieces (the chamber and connecting lines) were checked. First the chamber vessel itself was sealed from the roughing pump to determine how well it could hold a vacuum with no pump running (see above). Simultaneously, tests were run on the hoses and joints connected to the roughing pump. This was done to test those connections and to determine the quality of vacuum that could be reached there. In that test, the lowest pressure that the lines reached was 61.9 mTorr (82.5 µbar)

As each new part and feedthrough was installed on the chamber a similar test was run. After a part was installed, the chamber would be pulled down into as high a vacuum as it could go. If this was comparable to previous results and deemed acceptable then the chamber would be sealed off from the roughing pump to observe how it held a vacuum over time with the newest installation, typically overnight. Once these tests were passed, then the next part could be installed and the process repeated for all parts.

Finally, tests were done when all parts were installed and all internal components added. This was to check not only how low the chamber would go on a roughing pump or how well it could hold a vacuum, but also to see how much outgassing would be seen from the internal components. As the temperature was lowered in the chamber, observations were made of to what pressure level the cold head would cryopump the chamber. The average minimum pressure turned out to be about 11 mTorr (15 µbar) and this pressure could be held easily.

Temperature

Testing whether or not the cold head worked was a large part of the construction process. Many tests ended with seeing no cooling from the cold head. Finally, the correct modifications were made and the cold head began cooling as it was designed.

The first tests performed were outside the chamber in a vacuum shroud that came with the cold head. At this point, the temperature indicator/controller did not detect any change in temperature because of a bad connection. Until getting the temperature indicator to work correctly, these initial tests were conducted to observe whether or not the cold head would cool. When quantitative data was able to be collected, then tests to determine how low the temperature of the cold head could reach were performed. During these tests the cold head was subjected to a low vacuum of approximately 22 mTorr (29 µbar). The cold head cooled to approximately 152 K.

After the cold head was integrated into the chamber, it was subjected to a high vacuum with a large space around it. During these tests, the cold head was able to go much lower, down to 11.3 K. The first tests were performed to observe how low the cold head could go, with an approximate average minimum temperature of 11 K. Later tests incorporated the controller aspect of the temperature indicator/controller to manage the cold head temperature. The controller's set point was moved in increments and the temperature would follow. The ability of the controller to reach and maintain different temperatures was observed. In each case, the controller could reach and then maintain the temperatures that were programed into it. However, an error was discovered in the temperature indicator/controller, the value displayed differed from the actual temperature by about 26 K, possibly because of some malfunction in the sensor or somewhere within the device. This means the actual set point value does not match the temperature of the cold head. Therefore, a table was made from which an approximate desired temperature could be attained by using a specified set point value, see Table 3. These values were determined by systematic experimentation.

Atmosphere and Test gases

To test how different gases reacted in the chamber, various test gases were introduced and frozen on the cold head. These gases were nitrogen, argon, methane, and carbon monoxide, see Table 2. To introduce these gases into the chamber, a line was connected from their respective cylinders to the gas feedthrough. After this line was purged to eliminate potential contaminates, the gas was allowed to flow into the chamber.

Table 2

	N_2	Ar	CH_4	CO
Freezing Point	63 K	83.8 K	91.15 K	68.18 K

To test the mixing chamber, a mixture of 10 % CH_4 and 90% N_2 was made within the mixing chamber. This was chosen because a cylinder of this composition was already present in the lab. This way, the mixture made in the mixing chamber and the mixture made professionally, to within two tenths of a percent, by Airgas company, could be compared in order to test how the mixing chamber performed. Each mixture was introduced into the chamber and condensed as ice on the cold head. Then FTIR spectra were taken to verify that there was little to no difference in spectra between what was made in the mixing chamber and what was mixed professionally by Airgas company. This comparison was performed so that the mixing chamber could be reliably used as an alternative to repeatedly ordering large amounts of gases while only a small amount is actually used during experiments. Future tests of the mixing chamber should include multiple gases in order to further define the accuracy of the mixing chamber.

The mixture made in the mixing chamber was similar to the professional mixture that had been ordered, (See Figure 4). The overall form of the spectrum appeared as it should. The prominent bands at wavenumbers: 8600, 7500, and the three distinct bands between 6000 and 5500, were all visible in both spectrum. However the mixture made in the mixing chamber seemed to indicate the presence of more methane than the professional mixture, (See Figure 4). The peaks were larger and more defined in the spectrum of the mixture made in the mixing chamber. Additional peaks were visible at wavenumbers of 8800 and between 7500 and 7000. Therefore,

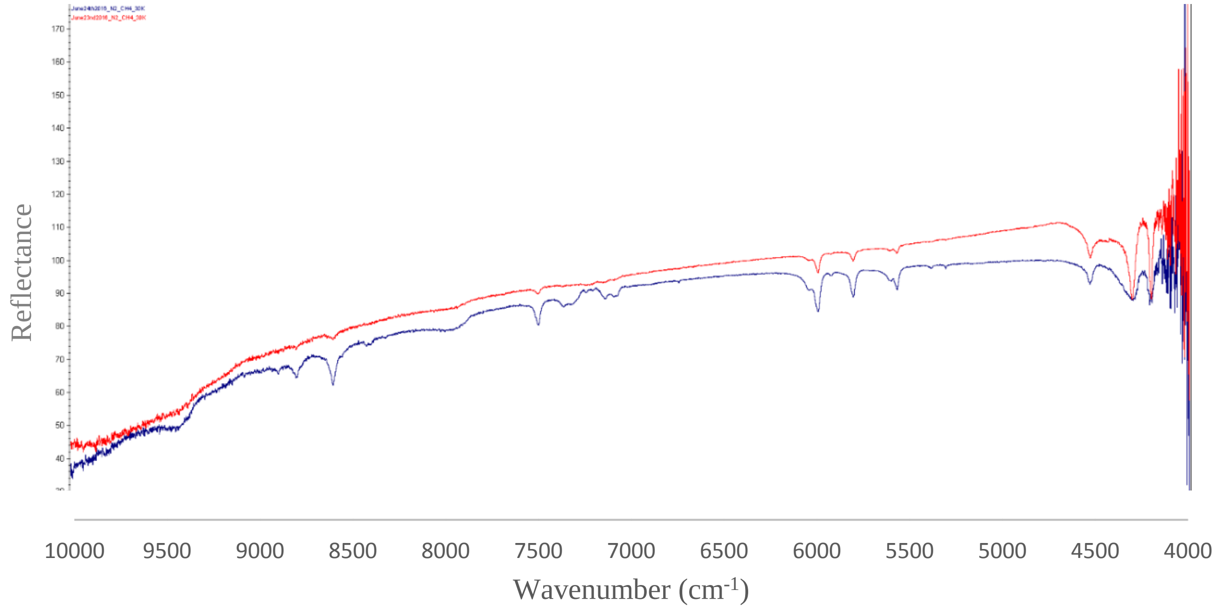

Figure 4. Comparison of a premade mixture and a custom one. Mixture of 90% N_2 and 10% CH_4. Red spectra is the premixed gas, blue spectra is the custom gas mixed in the mixing chamber.

as there are no drastic differences between the two mixtures, then rough if imperfect mixtures are attainable.

Reflectance Spectroscopy

To test the fiber feedthrough, a piece of Spectralon material was placed inside the chamber and then the chamber was resealed. Next, at ambient conditions, a background spectrum was taken as well as a regular spectrum from the Spectralon material. The regular spectrum was taken to check that nothing had changed since taking the background spectrum and that there was no issue with the feedthrough that would affect transmission. Assuming there were no issues with the feedthrough or lines, the regular spectrum should appear as a flat spectrum. When taken, the regular spectrum appeared as a flat spectrum, like expected, indicating no issues with the feedthrough or collection method. After that, the chamber was brought down to low temperature conditions of approximately 42 K and 15.4 mTorr (20.53 µbar) and the process was repeated. The two Spectralon spectra were expected to be identical in each set of conditions. For each measurement, a flat spectrum was anticipated because we normalized the spectrum of Spectralon to a background of Spectralon. Any peaks or slope would indicate that some part of the setup was aberrant.

The test results showed that the background spectra were both identical to each other. Both the regular spectra were flat as expected. The fiber feedthrough and associated connections and cables all worked as intended, at both ambient conditions and at Pluto’s conditions.

III. Results

A. Bench Tests

Pressure Tests

The lowest pressure achieved with just the roughing pump was 24 mTorr (31.997 µbar). This was after consecutive use consisting of purges and experiments and also leaving the roughing pump on for extended periods of time, typically thirteen hours. On average, when all the parts are attached to their respective flanges, a pressure of 163 mTorr (217.32 µbar) is achieved after about thirty minutes using only the roughing pump. From there, the pressure will slowly drop to somewhere between 24 mTorr (31.997 µbar) and 60 mTorr (80 µbar), however this second drop takes longer to get to that pressure. This is why it is good procedure with this chamber to activate the pump the night before an experiment is ran.

During the initial tests of the pressure hoses connected to the chamber, they were able to hold a vacuum of 61.9 mTorr (82.53 µbar) when sealed off from the chamber.

With the addition of the cold head to the chamber, most of the gas could be evacuated with the roughing pump and then the cold head would cryopump the chamber down to approximately 12 mTorr (16 µbar) as the remaining gas particles condensed on the cold head, (Figure 4). The lowest pressure achieved in the chamber has been 9.3 mTorr (12.4 µbar). This gas condensing on the cold head would be nitrogen, which is what is used to purge the chamber of potential contaminants before any experiments are run. This should not affect the results of experiments as nitrogen has a very weak spectral signature. However, if necessary, a background spectrum can be taken before the experiment is run that can substitute for the Spectralon background for that experiment.

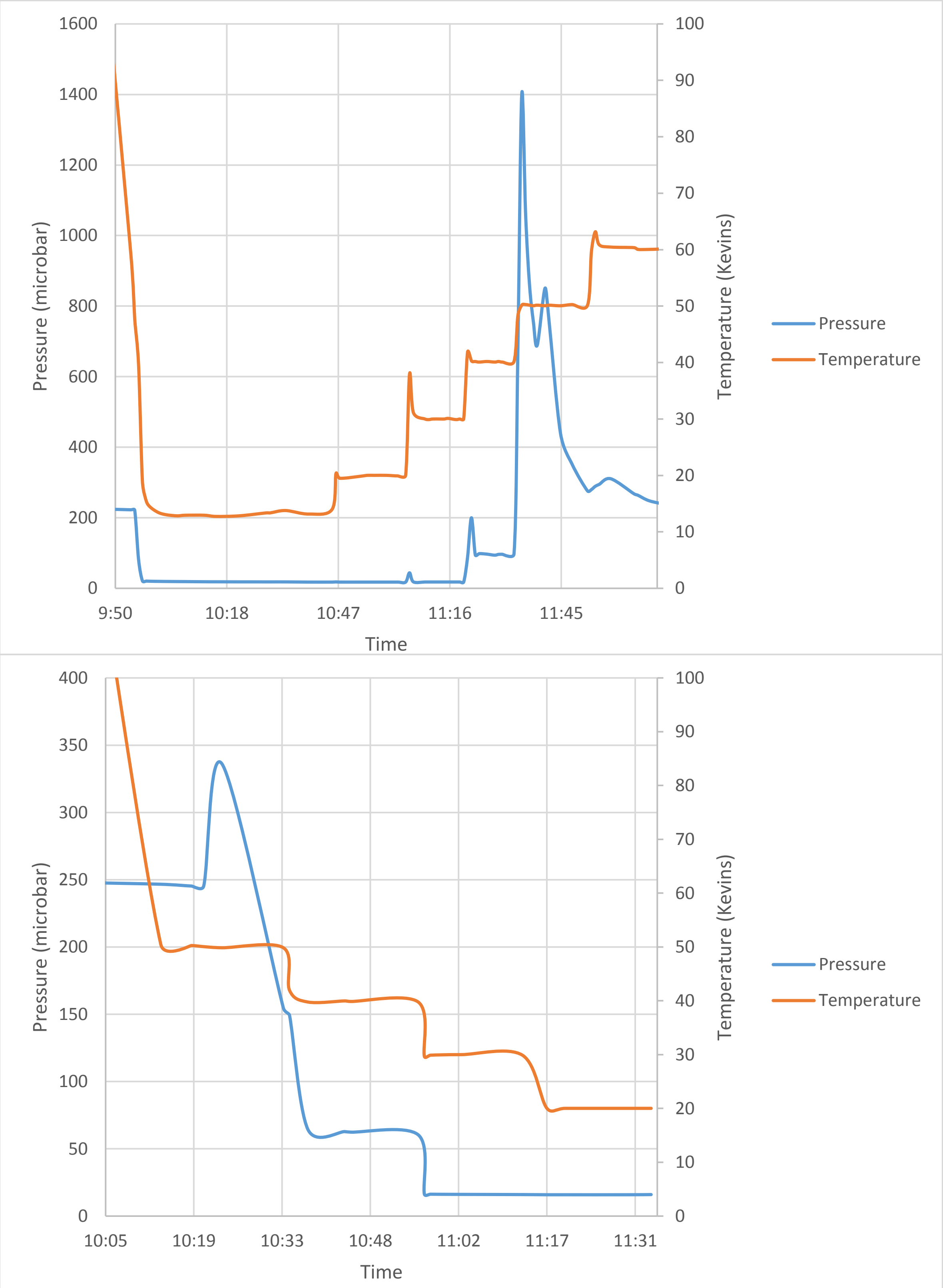

Figure 5. Graphs of temperature and pressure stability and control. **Top.** Temperature and pressure profile when starting from bottom limit and stepping incrementally upwards in temperature. **Bottom.** Temperature and pressure profile when starting at predefined upper value and stepping incrementally downward in temperature.

Temperature Tests

When the cold head was operated to determine the bottom limit, it was able to drop to and maintain a temperature of 11 K. It was able to hold this temperature, with little variation, as long as it was allowed. To check for variation, the cold head was left on overnight. The next day it had changed by only one or two Kelvin.

To provide more direct control over the temperature, a heater was connected to the temperature indicator/controller. With this controller a set point and a max wattage for the heater power can be defined. Once a set point is defined, the controller can quickly reach the corresponding temperature and maintain it as long as required. The set point can be changed as often as needed, (See Figure 4.)

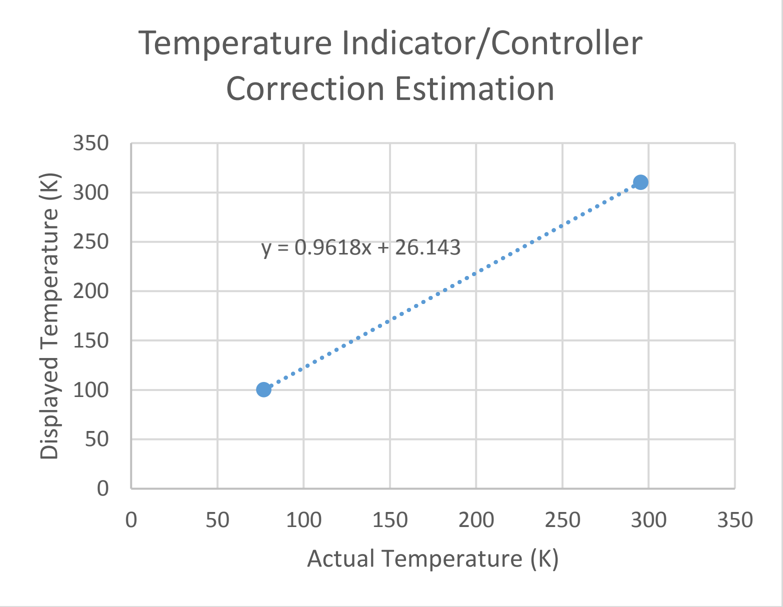

Figure 6. Correction estimation calculation for temperature readings from the indicator/controller.

In response to the error in the values displayed on the indicator/controller, two steps were taken. First, an estimate for a correction formula was formed from available points (See Figure 5). As mentioned previously, these data points were obtained from ambient conditions of 295.45 K and from immersing the associated thermocouple in liquid nitrogen. By plotting the points on a coordinate plane, a two points correction was determined. More points were desired, however, only these two were known to a degree of certainty. Having only two points, the formula ended up being a linear equation, see Figure 5. It is: $y = 0.9618x + 26.143$

The second step taken was to create a table of set point values in order to give an easy reference to what value needed to be input to reach common temperatures while using particular power levels, (See Table 3). The values in the table were found by experimentation, by inputting a value and then observing the corresponding temperature. Not all combinations have been determined yet. Typically, the same power setting is used during experiments. For values other than those listed in the table, formulas were determined to provide an approximate value to which the set point should be set in order to reach a specific temperature. This was done by plotting the determined values in the table and finding the equation of the line that goes through them for that power setting.

The reason for each temperature test and the table containing the values for 20 K to 50 K is because these values represent the seasonal ranges of temperature on Pluto. Therefore, efforts have been focused on this range of temperatures.

Table 3. Table of the set point value that needs to be entered to reach a desired temperature when using a set power.

Set Point	0.01 W	0.1 W	1 W	5 W	12 W	20 W
20 K				51	49.13	
30 K	As yet undetermined			61.05	59.14	
40 K				71.05	69.14	67
50 K				81	79.13	
60 K				91	89.03	

Atmosphere and Test Gases

Each of the gases introduced into the chamber (N_2, Ar, CH_4, and CO) produced relatively similar results. The gas was observed to freeze onto the cold head via the camera and its presence was confirmed by taking FTIR spectra, Figure 7.

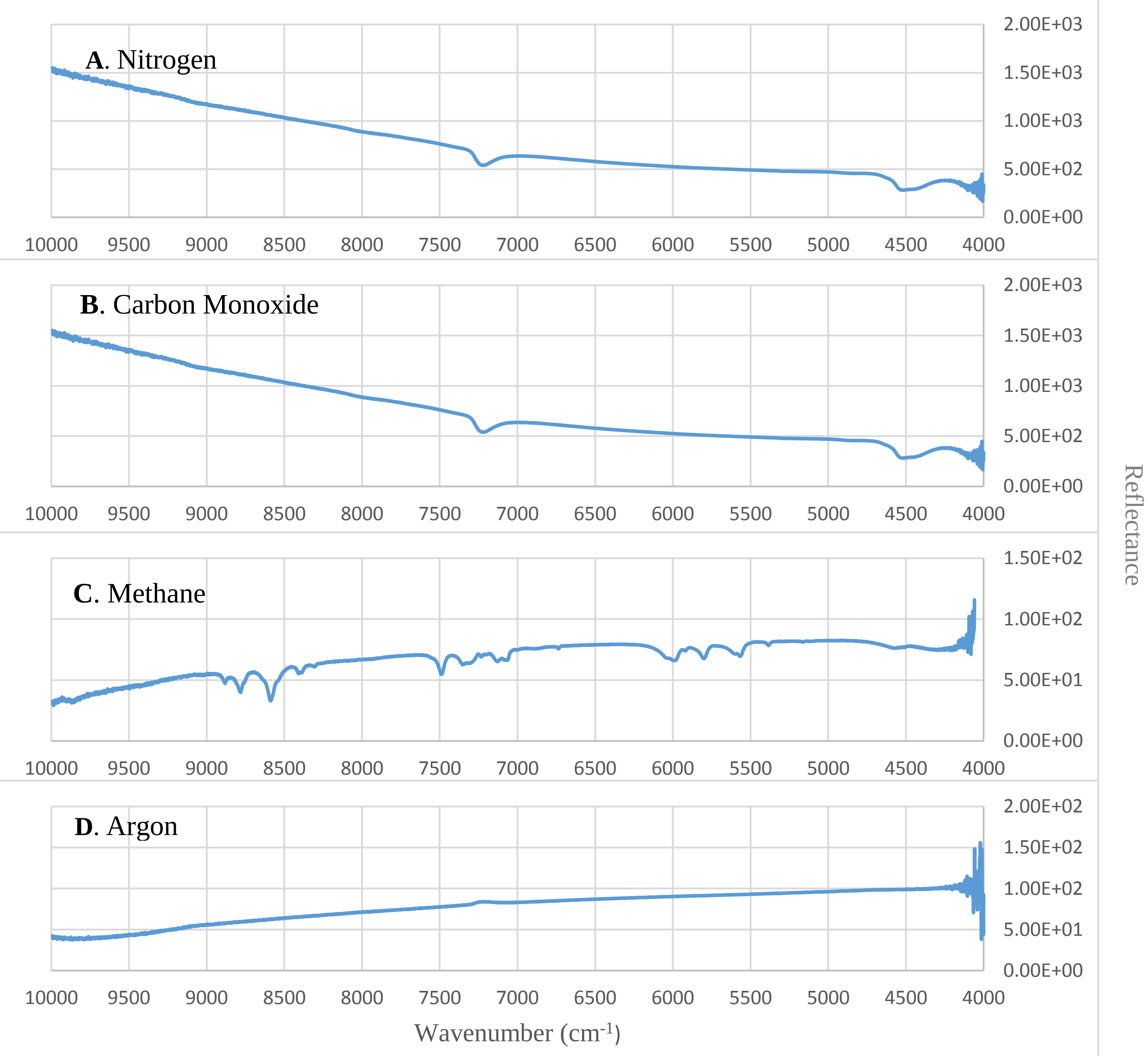

Figure 7. Spectra of pure gases that were tested and frozen inside the chamber. Spectra taken at 40 K **A.** Nitrogen. **B.** Carbon Monoxide. **C.** Methane. **D.** Argon

As mentioned previously, mixtures made in the mixing chamber are similar to ordered mixtures. These rough mixtures are not exact but they can be made easily and cheaply. These mixtures made in the mixing chamber should suffice for current applications of the simulation chamber.

B. Data Management

With this chamber, several types of data can be acquired. The data are stored on the chamber computer as well as in the cloud using Dropbox. The cloud is used because it makes it easier to access the data from multiple locations.

The saved data are sorted into folders by year, month, and then by day. Typically not more than one experiment is ran per day within the chamber. Therefore each experiment folder is designated by date. Then all the associated files for that experiment are included in that folder. In addition to using the date to denote files, a brief description of the experiment is also included in the title of the folder. This is so particular types of experiments can be found even if the date is unknown. For example, an experiment on the fourth of May, analyzing a particular mixture of 40% nitrogen and 60% methane would look like: May4th2016_40%N2_60%CH4. If necessary, additional description can be added as well.

Reflectance Spectroscopy

Spectral data are collected through a probe inside the chamber. A piece of Spectralon material fitted onto the cold head inside the chamber was used for the background. The data are collected using Omnic software. To archive it, the raw SPA files are converted into CSV files, which allow the data to be more accessible by various types of programs. Both the SPA files and the CSV files are saved within the folder of that day's experiment.

Pressure and temperature

Pressure and temperature data are displayed on their respective indicators and are manually inputted into Excel spreadsheets. The spreadsheets show the progression of the experiments. Comments within the spreadsheets act as the logbook for each particular experiment. Afterward, the spreadsheets are saved to the computer associated with the chamber as well as to the cloud via Dropbox.

Images

Using the camera inside the chamber, both pictures and video may be taken. Additionally, to view the spectra afterwards as one image without the Omnic software, the spectra from an experiment can be saved as a picture. This way it can be easily viewed later. All these images and videos, size permitting, are saved to the associated computer and uploaded to the cloud.

IV. Discussion

At its current state, this chamber can simulate Pluto for the purpose of performing experiments within the range of Pluto's conditions. The pressure, temperature, and atmospheric composition of the surface of Pluto can all be reproduced with this chamber. These conditions can be monitored, adjusted, and recorded. Experiments such as analyzing ice mixtures of varying composition by studying their spectral properties can be performed easily. With the introduction of an UV lamp, the interactions with atmospheric methane could be analyzed, particularly as it pertains to the formation of tholins and aerosols (Materese 2015). These tholins are the cause of the colors observed on Pluto (Stern 2015). They are formed by UV irradiation of methane-nitrogen mixtures in both gaseous and frozen states (Stern 2015). Similarly, the addition of an electron gun would allow simulation of cometary bodies. With some modification, the analysis of clathrates could be done.

While this chamber can reach and maintain the pressure evident on the surface of Pluto, it cannot go below that. This bottom pressure limit exist because of the capabilities of the pump that is on the chamber. With the addition of a turbomolecular pump, its use could be expanded to bodies that exist at higher levels of vacuum. The chamber does have the space available and a convenient attachment point for an additional pump. It is also worth noting that increases in temperature while running experiments may lead to pressure spikes because of the location of the heating element. This can be accounted for by waiting for gas to condensate again elsewhere on the cold head. An additional pump would also help with this occurrence.

While this chamber was designed to simulate Pluto, it could also be quite versatile. The majority of the ports are unused and the space inside the chamber is quite large. With the attachment of additional components, it could easily be modified to study other similar low temperature and pressure bodies. If an electron gun or ultraviolet light were added, it could potentially be used to study space weathering, the surface of the Moon (particularly the polar regions), comets, or asteroids.

Despite displaying an error in the measurements of temperature. The temperature indicator/controller performs well. The error is consistent and can therefore be accounted for in the data. The addition of more temperature sensors in the future will also help to correct in errors in temperature measurement.

In general, a multitude of tests were ran and will be run to insure that the chamber is in proper working conditions. Anytime something new is installed, a pressure and temperature check is essential to determine that whatever change was made does not affect the standard operation of the chamber. During construction, pressure checks were conducted regularly. The first pressure test set a standard baseline pressure to attain. As improvements were made and work progressed, that baseline was able to be lowered. Initial temperature tests of the cold head were not encouraging except to determine that the device operated. However, once the cold head was integrated with the rest of the chamber and had a large, insulating vacuum around it, it able to surpass expectations during temperature tests.

Outgassing within the chamber is a probable occurrence that should be considered. There are various objects within the chamber that can contribute to outgassing. By keeping the chamber closed, filled with nitrogen, and at some level of vacuum, it is hoped to reduce outgassing so that lower pressures can be achieved.

There are numerous planetary simulation chambers in existence. Each are designed to attain different sets of conditions and product different types of data. By analyzing some these that had been done before, an understanding of the possible limitations of different design parameters was gathered. Therefore, a determination of what could be possible, and what worked, with a simulation chamber was gained. Analysis of other completed simulation chambers provided necessary information to build the Hyperion chamber. A predominant source of information and experience came from work done concerning the Andromeda chamber, originally a chamber used to simulate the Martian surface (Sears 2000). The Andromeda Chamber was modified to accommodate a Titan module (Wasiak 2012). This module demonstrated methods of low temperature operation of assorted instruments (Wasiak 2012). This Pluto chamber needed a cost effective manner of cooling. Also, it was desired that this Pluto chamber remain versatile with its unused space, a model for this was a chamber built by Mateo-Marti et al. This chamber has a wide range of operating temperatures and pressures with an emphasis on astrobiology (Mateo-Marti 2006). It also uses a similar helium cooling system, this allows that only the sample area is cooled, preventing significant helium consumption (Mateo-Marti 2006).

Other similar planetary simulation chambers each perform their own designated task. However, a chamber can be modified later to adapt that task. The PELS facility is capable of running simulations that incorporate liquid and fluids, such as brines, at simulated conditions of Mars, Enceladus, or Europa (Martin and Cockell 2015). The MASC facility at VU University in Amsterdam was designed to run tests of instrumentation for future Mars missions (Motamedi 2015). The S.A.M. chamber at the University of Padua was designed to study bacteria at Mars conditions (Galletta et al. 2006). The MESCH chamber in University of Aarhus is a versatile system fitted with a load-lock system that allows for the exchange of samples without changing the chamber environment (Jensen et al. 2008). An analysis of these different chambers and their capabilities allows a grasp of what is feasible while designing a new chamber. Knowing what has worked before and what has been done helps to focus a project in what it should do and what direction it should take. This helps the design for a new project concentrate on what is achievable instead of spending too much time on trying to make something work that is unrealistic.

V. Conclusion

With the New Horizons successful flyby of the Pluto system, we now know more about Pluto than ever before. Even with the large amounts of fresh data, there are still questions that need answers. The construction of this chamber has made available a tool that can be used to help answer remaining questions about the chemical interactions and dynamics of the surface of Pluto. The Hyperion Chamber for Pluto simulations can reach and sustain the conditions found on the surface of Pluto. It can be used for various experiments to generate data. It can also be adapted to perform different types of experiments and could be adapted to investigate other heavenly bodies in the future. With the use of this tool, hopefully some existing questions may find answers.

VI. References

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