

IN HOUSE-DEVELOPED GONIOMETER TO SUPPORT MEASUREMENTS OF THE BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION OF CO₂ ICE MADE IN AN ENVIRONMENTAL CHAMBER THAT SIMULATES MARTIAN POLAR CONDITIONS. J.A. Isen¹ and I.B. Smith², ¹York University Lassonde School of Engineering (jamieisen@gmail.com), ²Planetary Science Institute.

Introduction: Hyperspectral images recorded from planetary mission spectrometers provide various illumination and observation angles of planetary surfaces [1]. These instruments provide us with data that allows us to study their properties of surface materials. For the best interpretations of those data, these observations frequently need to be compared to laboratory measurements. One such measurement that has not been made before is the bidirectional reflectance distribution function (BRDF) [1] of CO₂ ice, an atmospheric constituent of Mars that seasonally covers latitudes from ~50° to the poles in each hemisphere. Additionally, Mars has a South Polar Residual Cap (SPRC) that persists throughout the warmest months on the planet.

At Mars, Remote-sensing spectrometers such as the Compact Reconnaissance Imaging Spectrometer (CRISM) flown on Mars Reconnaissance Orbiter (MRO) provides hyperspectral images of the seasonal cap and the SPRC.

At York University, we generate CO₂ ice in our environmental chamber that can control and maintain a stable pressure and temperature as low as 1 mbar and 140 K. This allows us to simulate the Martian polar conditions.

Under various pressure and temperature regimes, we can simulate environments that are analogous to the seasonal changes of Mars and then perform spectral measurements to compliment CRISM observations.

Experimental Setup: *Environmental chamber:* Our environmental chamber is 1-meter-long cylindrical stainless-steel vacuum chamber with an outer diameter of 71 cm. Inside the chamber, we have three cooling zones: a platen that acts as a base for all measurements, a cold plate where we make and control samples, and a shroud. To cool each zone, liquid N₂ (LN₂) is fed through the walls of the chamber at three ports (Fig 1).

Temperature regulation: The purpose of the shroud, that creates an interior diameter of 50 cm and is covered with space-black, high-emissivity paint, is to create a cold sky that does not emit radiation towards our sample, allowing it to behave more consistently with conditions on Mars. Further, the cold shroud supports cooling of the internal atmosphere to lower the surface temperature and the thermal gradient with samples that are primarily cooled from the bottom. The platen is cooled for the same reasons. The aluminum cold plate cools a 10x10 cm copper plate, painted black to reduce specular reflections, that acts as the sample stage.

There are seven thermocouples placed in the chamber to monitor several locations. Three are located on the shroud (two on the top one on the bottom). Two are placed on the cold plate at the front and back at opposite corners. One is placed on the platen, and another is placed in the ambient air. This provides references for when to start experiments and allows us to track the progress and control the temperature during experiments.

Pressure control: To control the pressure inside the chamber we use an Edwards nXDS10i dry scroll vacuum pump to lower the pressure below our setpoint and to cycle-purge the chamber prior running experiments. This acts to remove the humidity and terrestrial gases. During experiments, ice grows, reducing the internal pressure, so we have a port that allows us to feed CO₂ into the chamber from a tank outside with a constant pressure regulator set to 40 psi.

A Super Bee Pirani pressure gauge and a gas independent Kurt J. Lesker capacitance manometer, monitor the pressure level of the chamber. CO₂ gas flow is monitored and controlled with an Alicat mass flow controller.

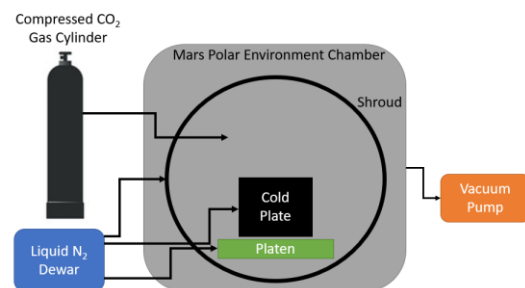


Figure 1. Simplified Mars Polar Environment Chamber Schematic

Control: We have LabVIEW code, written inhouse for our specific setup that allows us to monitor and control the temperature and pressure.

Pressure is controlled by a PID (Proportional, integral, derivative) setting, calibrated for our setup. Gas flow can be completely cut off or introduced at 20 liters per minute, or any value in between.

Temperature control is maintained by monitoring the thermocouples and by changing the flow rate of LN₂ with solenoids external to the chamber. Because the goal is to grow CO₂ ice only on the cold plate, the temperatures for the platen and shroud are set higher than the CO₂ frost point. This avoids an undesired

condition in which the cold zones with the largest area (and no sensors) condense ice in lieu of on the cold plate, where our sensors are trained. Using LN₂ flow to control temperature has a slow response rate. To have finer control at our sample, the cold plate is fitted with a separate, electric heater fed via electrical feedthroughs. This heater can adjust automatically in less than a second, giving fine control of the surface temperature of the cold plate, where our sample grows.

Pressure at both gauges and temperature at all seven thermocouples are recorded, monitored, timestamped, and plotted with LabVIEW.

Imagery: Two USB ports allow us to connect cameras and microscopes that we interchange depending on desired experiment. The chamber also has a 15-pin connector to allow us to wire motors, and sensors.

Goniometer: Our goniometer consists of two fiber optic cables on two separate robotic arms. One arm hosts the incidence light, and the other carries the detector with a collimating lens. The robotic arms are designed to vary the angles of each cable between $\pm 60^\circ$ from the 0° nadir position. The collimating lens has a focal distance of 4 cm that serves to redirect more light into the detector. The detector cable is linked to an Avantes Avaspec-NIR spectrometer that records NIR spectra between 1–2.5 μm with a minimum resolution of 12.9 nm. The illuminating source fiber optic cable is connected to an Avantes AVALIGHT-HAL-S-Mini source light with a wavelength range of 360–2500 nm. Figure 2 displays the prototype spectral goniometer.

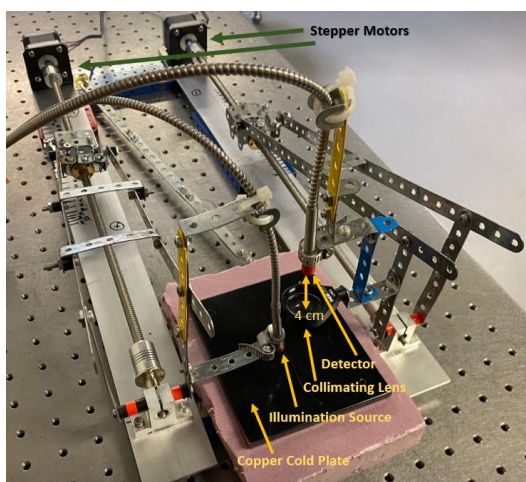


Figure 2. Prototype Goniometer

Reflectance calibration is performed with Spectralon® Diffuse Reflectance Standards. The standards consist of a variety of highly Lambertian pucks (reflectance is constant regardless of the view angle) that represent various percentages of reflectance.

We have measured each standard individually with our goniometer as a reference for our experiment. Figure 3 shows the result of each standard from 5–99%.

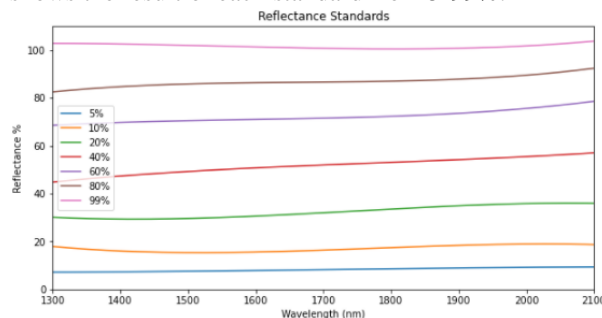


Figure 3. Spectralon® Diffuse Reflectance Standards Calibration Measurement.

Preliminary results and interpretation: In previous work we have successfully grown CO₂ ice under Martian conditions. We have measured the albedo using an infrared camera and reflectance of the ice with our spectrometer. We have also observed various CO₂ ice textures under various pressure and temperature changes. When CO₂ ice deposits on our cold plate it forms in one of two modes: transparent slab ice, or fine-grained frost [2]. These modes were expected as they resemble the CO₂ ice found at the SPRC of Mars [2]. When activating our heater, we observed fracturing and healing, potentially analogous to the formation of jets on the Cryptic Terrain found at the south pole of Mars.

In those previous experiments, however, spectral measurements were made with 0° phase because of our limited capability. With the new goniometer (Figure 2) we can vary both incidence and detector angles individually, giving us the phase information needed to make the BRDF measurements.

Future Work: Currently, experiments are being run to properly calibrate and finely adjust the goniometer design. We then plan on running a series of experiments to measure and model the BRDF under various Martian seasonal environments namely with fully transparent or highly reflective CO₂ ice.

To improve the removal of specular reflectance we plan to paint the copper plate with space grade black paint to ensure there is no chipping/flaking. There has been some consideration using analog Martian regolith on the cold plate. We are also considering adding a third motor to rotate the goniometer about the z-axis.

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References. [1] Brissaud O. et al. (2004). Applied Optics, 43(9), 1926–1937. [2] Karimova, R. LPSC 2021, No 2548, Id 1577.