THE LASER SPECTROMETER FOR ICES AND MINERALOGY.

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Introduction: The Laser Spectrometer for Ices and Mineralogy (LSIM) is a new class of rover- or lander-mounted "active spectrometer" that uses a supercontinuum laser (SCL), which emits coherent polychromatic light in the 450-2400 nm region to illuminate a target from broad range of distances. A fiber-fed NIR (900 – 2500 nm) point spectrometer measures the reflected light. The LSIM is designed to characterize the composition, lateral distribution, abundance, and grain size of ices, organics, hydrated species, and primary mafic igneous minerals in planetary regolith, independent of lighting conditions. Its ability to operate in shaded and dark environments (*e.g.*, permanently shaded regions of the moon, caves, lava tubes, night-time environments) as well as in daytime conditions makes it a uniquely versatile spectrometer. The use of the SCL as a light source allows the spectrometer to observe targets at distances of tens of meters.

The LSIM can be used as a point spectrometer with a 2° FOV to map the mineralogy of the surface at scales such as 3.5 cm at 1 meter, or 1.75 m at 50 m range. Given that the laser spot size is about 10x smaller than the spectrometer FOV, active mode can also be used in an illuminated scene to improve the spatial resolution by performing scene subtraction at the expense of decrease signal-to-noise ratio (SNR).

Instrument characteristics: LSIM is an active imaging spectrometer designed to be mounted onto a landed platform. The LSIM consists of 2 subsystems: the emitter stage (ES) and the receiver/ stage (RS) (**Figure 1**). In a landed mission, the receiver and transmitter foreoptics would be located on the remote sensing mast. The spectrometer, laser, and control electronics, would be located inside a thermal enclosure such as the rover or lander body. The optics are connected to their respective components via low-OH optical fibers, and communication between the control computer, ES, and RS is via USB and serial data links (RS-422).

Emitter Stage (ES): The emitter stage is a commercial off the shelf system (COTS), NKT Photonics SuperK Compact Supercontinuum Laser [1]. The NTK SuperK COMPACT is a pulsed ns-based supercontinuum source operating in the kHz range (>20 kHz). The laser output is fed via optical fiber to collimating optics, producing a beam with a diameter of 3 mm (at λ=2 μm) and a divergence of 0.2° (3.5 mrad) full angle. This results in a spot size of 6.5 mm at 1 meter distance and 17.5 cm at 50 meters.

Receiver Stage (RS): The RS consists of a NIR (900 - 2500 nm) grating spectrometer mated to a 3-inch foreoptic with a field of view of 2°. The spectrometer and foreoptics are a slight re-design of NIRSpec; a spectrometer developed during the preparation of a proposal of a passive NIR spectrometer and foreoptics for the Mars 2020 mission.

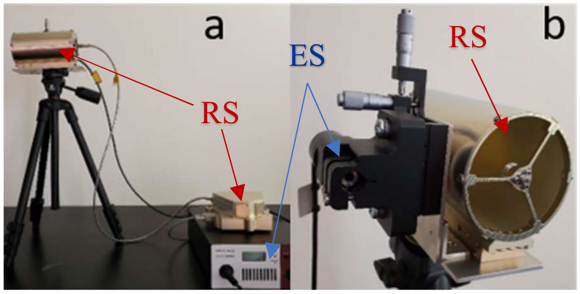


Figure 1. Multiple views of the SCL-Spec. (a) Integrated instrument, with the telescope and laser collimator mounted on the tripod, and the NIRSpec (bronze) sitting on top of the laser source. (b) Closeup view of the telescope and laser collimator with the collimator mounted on a targeting stage on the left. Components are labelled in blue for the ES and red for the RS.

Performance: We use the lidar link equation to develop a full forward model to predict the expected signal-to-noise (SNR) of the instrument as well as the detection limits of different volatiles. The lidar equation:

$$E_{rx} = E_{tx}\eta_r \frac{A_r}{R^2}\frac{r_s}{\pi} \qquad (1)$$

where E_{rx} is the received signal pulse energy, E_{tx} is the transmitted laser pulse energy, η_r is the receiver optics transmission, A_r is the receiver telescope aperture area, R is range distance to target, and r_s is the Lambert albedo of the target [2]. Of these, the transmission function is specific to the instrument and is unknown.

Given a knowledge of the received signal and detector characteristics (*e.g.*, quantum efficiency, read noise, dark current), we calculated the expected SNR via

$$SNR = S\,/\,\left(S_p + D_p + R\right)^{1/2} \qquad (2)$$

where S is the signal, S_p is the Poisson noise associated with the signal, D_p is the Poisson noise associated with the dark current, and R is the read noise.

Measurements: The Lunar PSRs are posited to contain a variety of ices, including water and carbon dioxide, among others. We measured CO_2 and H_2O ices, lunar simulant material (not shown), and a white reference material (Spectralon). CO_2 ice was store-purchased and intact pieces of this were measured. H_2O ice was

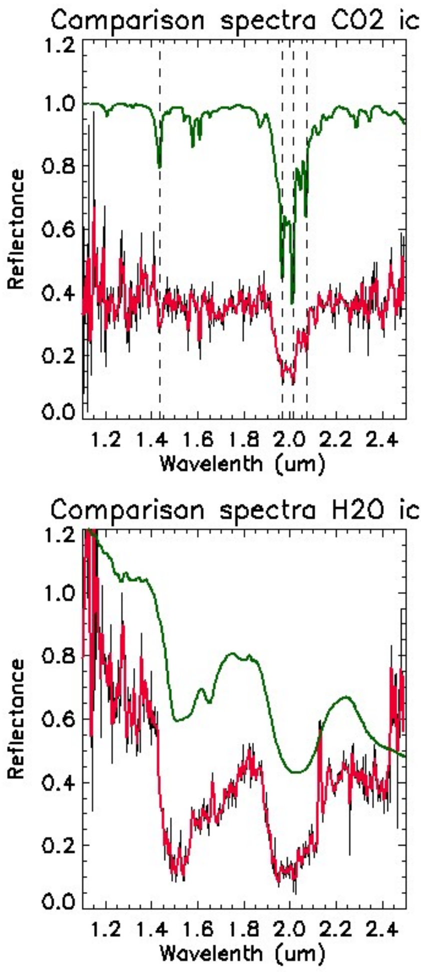


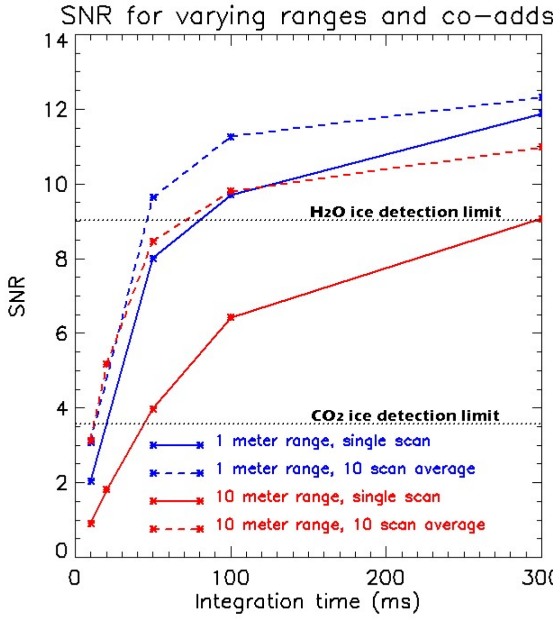
Figure 2. Proof-of-concept spectra of CO_2 (top) and H_2O (bottom) ice acquired with the NIRSpec from a range of 1 meter while being illuminated from the same distance by the SCL. Measured spectra (black) are smoothed with a 3-channel boxcar (red). Library spectra convolved to instrument's 10 nm resolution and 3 nm sampling are shown in green and shifted for clarity. Total integration time for each spectrum is 3 seconds. Multiple sharp features due to CO_2 start to become discernible (dashed lines).

measured as a frost, in granular form, and as solid pebble-sized pieces. Frost was grown on a cold substrate of CO_2 and on lunar sample simulant chilled with a CO_2 subsbtrate. Granular H_2O ice was prepared by crushing H_2O ice and sieving it to grain sizes < 160 mm (mortar, pestle, and sieves were cooled to CO_2 ice temperatures before use, and crushing/sieving were performed with the materials inside the cooled environment to prevent melting or sintering. H_2O pebbles were prepared in the process of crushing the H_2O ice, and mechanically separated from the granular material. H_2O ice and lunar simulant mixtures were prepared by mixing granular H_2O ice with similarly sieved simulant.

Results: Figure 2 shows laboratory and proof-of-concept spectra of H_2O and CO_2 ices acquired with LSIM. H_2O and CO_2 ices can be readily distinguished by broad absorptions around 1500 and 2000 nm, and by a sharp triplet superposed on a broad absorption in the 2000 nm region, respectively. The acquisitions were performed by averaging 10 spectra, each with an integration time of 300 ms. **Table 1** shows the calculated signal-to-noise based on measurements of spectralon. Detection limits in the plot, based on 1-σ detections, are consistent with our measurements.

Table 1. Measured SNR

Integration time per scan (ms)	# scans averaged	SNR at 1 meter	SNR at 10 meters
10	1	2.05	0.91
20	1	-	1.81
50	1	8.00	3.98
100	1	9.70	6.42
300	1	11.9	9.07
10	10	3.09	3.14
20	10	-	5.17
50	10	9.64	8.47
100	10	11.27	9.80
300	10	12.32	11.0



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References: **[1]** https://www.nktphotonics.com/lasers-fibers/product/superk-compact-supercontinuum-lasers/
[2] Sun, X. and G. A. Neumann (2015), *IEEE Trans. Geosci. Rem. Sens.*, 53(5), 2860–2874.