IN SITU DETERMININATION OF SURFACE VOLATILE COMPOSITION AND ABUNDANCE WITH THE LASER ABSORPTION SPECTROMETER FOR VOLATILES AND EVOLVED GAS (LASVEGAS).

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Introduction: The Laser Absorption Spectrometer for Volatiles and Evolved Gas (LASVEGAS) is a laboratory-proven (TRL-4) infrared laser spectrometer that is undergoing maturation to TRL-6 for application to icy moons at Jupiter and beyond (e.g., Europa, Enceladus, etc.) under the NASA MatISSE Program, and was recently selected for adaptation development specific to the lunar environment under the NASA DALI Program. Lunar LASVEGAS is designed to meet high priority in situ measurement objectives for science and robotic and human exploration (Table 1). The flow down of the science Goals and Objectives to instrument performance are summarized in Table 2 with specific capabilities for some key gases shown in Table 3.

Table 1. Traceability of Lunar LASVEGAS Science

NASA Relevance	Science Goals	Science Objectives
NAS 2007: Science context for lunar exploration, Concepts 4 and 8 ASM-SAT Goal 4a and 8d Lunar Science for Landed Missions Workshop: A1, SKG1, Lunar Exploration Roadmap: Objective Sci-A-1, Sci-A-3, Sci-A-4, Sci-A-6, Sci-B-2, FF-C-1, GAP-SAT 1-C, 1-D Decadal Survey Cross-cutting Lunar Goals (Chapter 5).	1. Establish compositional state and distribution of lunar polar region/permanently shadowed volatiles.	1A. Measure the abundance of water ice in polar and permanently shadowed regions.
		1B. Measure the abundance and range of secondary volatiles and trapped gases within the lunar regolith and lunar ice (CO, CO_2, CH_4).
		1C. Search for and identify unknown volatiles, esp. high order organics.
	2. Constrain volatile release and transport processes.	2. Measure abundance of key transport process markers
	3. Determine abundance of material and suitability of location for ISRU.	3. Measure abundance of volatile molecules important for water, oxygen, and fuel production.

Table 2. Measurement Requirements and Instrument Performance

Sci. Obj.	Meas. Req.	Instr. Req.	Instr. Perf.
1A	Water to mass fraction of 1 ppm ± 0.1 ppm. Detect water to mass fraction of 1 ppb.	Spectral range containing water lines Better than0.02 cm^{-1} resolution Fractional absorption: $<10^{-3}$ for measurement; $<3x10^{-4}$ for detection.	3.5-11 µm range w/ numerous absorption lines 0.0033 cm^{-1} resolution fractional absorbance < 10^{-4} exceeds required measurement thresholds for all gases (Table 3). **Measurement to 1 ppb (by mass) or less is possible for most gases with fractional absorption < 10^{-4}.**
1B & 1C	Mass fraction of Table 3 gases to 1 ppm ± 0.1 ppm.	Spectral range containing relevant absorption lines Better than 0.02 cm^{-1} resolution Fractional absorption: $<10^{-3}$ for most gases; $<10^{-4}$ for H_2S, HO_2, and C_2H_6.	
2	Mass fraction to 10 ppm +/- 1 ppm H_2O, CO_2, CO, NH_3, CH_4, H_2S, SO_2, H_2O_2.	Spectral range containing relevant absorption lines Better than 0.02 cm^{-1} resolution Fractional absorption $<5x10^{-4}$	
	Mass fraction to 1 ppm +/- 1 ppm of D, ^{13}C, and ^{18}O in H_2O, CO_2, CO, and CH_4.		
3	Measure abundance of volatile molecules important for water, oxygen, and fuel production.	Same as Objective 1 requirements.	

Instrument Overview: The proposed baseline design of Lunar LASVEGAS is shown in Fig. 1. The measurement technique relies on the simple and time-tested direct laser absorption spectroscopy technique [1]. Either a sample of regolith or a gas is introduced into the instrument via the Sample Acceptance Subsystem (SAS). The SAS receives a crucible-filled sample from a mature (TRL-5/6) sample acquisition and delivery system developed by Honeybee Robotics [2]. Once in the SAS chamber, the regolith sample is heated to melt and/or vaporize volatiles and any trapped gases. No processing is required for a pure gas input.

Table 3. Example abundances (regolith mass fraction) of some gases that can be detected. Regolith density vis assumed to be 1.35 kg m^{-3} and regolith volume is 5 mL.

Molecule	**Mass Fraction**	**Molecule**	**Mass Fraction**
H_2O, HDO, $HO^{18}O$	3.6 x 10^{-12}	NH_3	2.0 x 10^{-12}
CH_4, CH_3D, $^{13}CH_4$	1.5 x 10^{-11}	SO_2	3.0 x 10^{-11}
CO_2, $^{13}CO_2$, $CO^{18}O$	3.9 x 10^{-13}	SO_3	6.3 x 10^{-9}
CO, ^{13}CO, $C^{18}O$	2.2 x 10^{-12}	HO_2	1.3 x 10^{-7}
NO	3.9 x 10^{-11}	H_2O_2	2.0 x 10^{-8}
N_2O	1.3 x 10^{-12}	HCl	3.6 x 10^{-9}
NO_2	8.3 x 10^{-12}	HBr	9.7 x 10^{-8}
OCS	7.8 x 10^{-9}	HOCl	5.7 x 10^{-8}
H_2CO	1.3 x 10^{-8}	C_2H_2	4.9 x 10^{-9}
HCN	1.6 x 10^{-8}	C_2H_6	4.2 x 10^{-7}
HCOOH	2.5 x 10^{-8}	C_4H_2	2.8 x 10^{-8}
C_2H_4	6.4 x 10^{-9}	CH_3OH	1.9 x 10^{-8}
CS	2.9 x 10^{-9}	H_2S	.5 x 10^{-7}

And many more gases with IR absorption are possible!

As the gases evolve from the regolith sample, they flow through a dust mitigation subsystem (DMS), also provided by Honeybee Robotics using mature (TRL-5/6) solutions. After dust mitigation, the gas flows into the optical cell measurement chamber where a bank of hypertunable infrared lasers are fired sequentially (not at the same time), with their beams directed into a multi-bounce optical cell [3]. The absorption signal is recorded on a detector, with a complete measurement taking ~2 min. The recorded signal is inverted on the ground to determine compositional abundance [e.g., 4].

Resource Requirements: The current best estimate (CBE) resource requirements for the baseline instrument is shown in Table 4. A threshold version of the instrument further reduces resource requirements by focusing only on H_2O/HDO, CO_2, CO, NH_3, and CH_4. Estimated development cost to TRL-6 is $3M and $18.3M additional for a flight investigation.

Accommodation: The small resource footprint of LASVEGAS makes it suitable for accommodation on the smallest of landers/rovers. It can also be easily carried by humans for rapid reconnaissance and prospecting. There is minimal set-up required. The packaging of the various subsystems is extremely flexible and can be reconfigured to minimize the impact on allocated payload volume.

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Table 4. Current Best Estimate (CBE) of Subsystems and Instrument Resources for a Nominal Measurement.

Subsystem	Mass (g)	Dimensions and/or Volume	Power (W)
Electronics	200	200 cm^2 total footprint	2
Laser Subsys.	171	5.0 cm x 4.9 cm x 7.1 cm	5.2
Alignment Mod.	78	2.5 cm x 7.4 cm x 0.5 cm	0.2
Detectors$^+$	10	2 cm^3	-
Optical Cell	103	10 cm x 5 cm O.D. Cylinder	-
SAS	25	3.5 cm (OD) x 4.7 cm	0.5
DMS	20	2.5 cm (OD) x 2 cm	-
Mechanical	485	7.5 cm x 9 cm x 19 cm	-
TOTAL	1092	1042.4 cm^3	7.9 (0.40 Whr)$^@$

*Based on numerous analog flight projects. $^+$Based on specs from parts catalog. $^\#$Based on direct calculation of material properties (Al). $^@$Based on 3 min total on time.

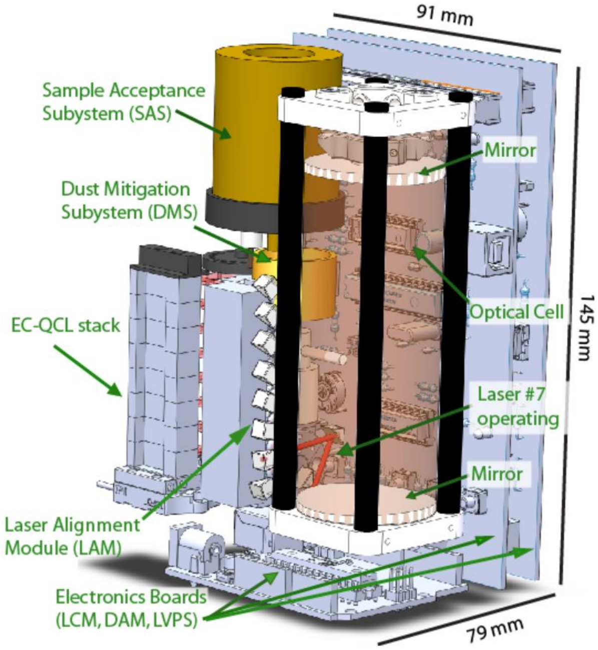

Figure 1. CAD model of the TRL-6 Lunar LASVEGAS instrument. The chassis and individually hermetically-sealed aluminum housings around the optical cell and laser systems have been removed for clarity.

References: [1] Demtröder, W. (2008), *Laser Spectroscopy*. [2] Zacny, K., et al. (2013) *J. Aerosp. Eng. doi: 10.1061/(ASCE)AS.1943-5525.0000212.* [3] Silver, J. (2005), *Appl. Opt., 44(31), 6545-6556.* [4] Norgaard, L. et al. (2000), *Applied Spectroscopy*, 54(3), pp.413-419.