SUBMILLIMETER SOLAR OBSERVATION LUNAR VOLATILES EXPERIMENT (SSOLVE).

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Introduction: The Submillimeter Solar Observation Lunar Volatiles Experiment (**SSOLVE**) is a pathfinder for lunar exploration, a small and simple instrument to resolve broad uncertainty in the abundance of lunar water and processes for its supply, removal, and relocation. Water observed in the lunar surface and polar cold traps could be delivered by solar wind or meteoroids or it could be indigenous, with powerful implications for the Moon's formation history and evolutionary processes The key to distinguishing the source of lunar water and present processes controlling it is the abundance of water in the atmosphere/exosphere and its diurnal variability. SSOLVE is designed to make these measurements, with high sensitivity and precision.

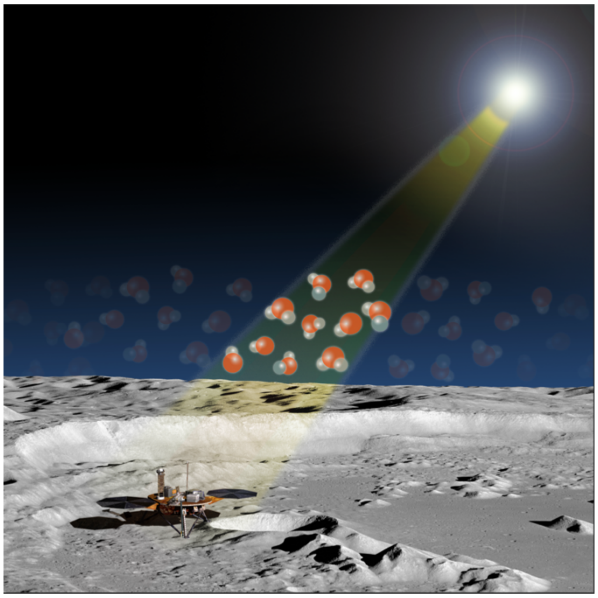

Fig. 1: SSOLVE will measure lunar water vapor against the bright Sun. SSOLVE will operate submillimeter spectrometers from a lander, using a heliostat to target the Sun to measure the column abundance of H_2O, OH, and HDO in the lunar atmosphere. H_2O and OH establish the chemical state of water and constrain current photolysis and loss rates, while HDO/H_2O constrains the history of hydrogen loss. Spectral absorption features can measure very small quantities of atmospheric water, $<10^{12}$ mol/cm^2 ($\sim10^5$ mol/cm^3 at surface). Vapor quantities inferred from diurnal variability of surface hydration, $>10^{14}$ mol/cm^2 ($\sim10^7$ mol/cm^3), could be detected in <10 min.

Technique: SSOLVE will use the Sun as a light source to illuminate the presence of water in the tenuous lunar atmosphere: its abundance, diurnal variability, chemical state (H_2O vs. OH), and the balance between sources and loss (Fig. 1). Water is critical to understanding lunar formation, the interaction between rocky bodies and space, and the potential for *in situ* resource utilization (ISRU) in lunar exploration and beyond. The SSOLVE design employs two bore-sighted heterodyne spectrometers: one spectrometer detects the 557 GHz transition of H_2O and the 509 GHz transition of HDO; the other spectrometer detects the 2510 GHz transition of OH. Doppler broadening in the absorption lines will measure the translational temperature of the gas to determine whether it is thermally accommodated to the local surface temperature as usually assumed. A sun-tracking scanner (heliostat) will acquire and track the Sun regardless of lander orientation, as well as enabling measurements on dark sky and on calibration targets. A radome and enclosure will shield the instrument from dust and visible-wavelength sunlight to enable staring at the Sun (Fig. 1).

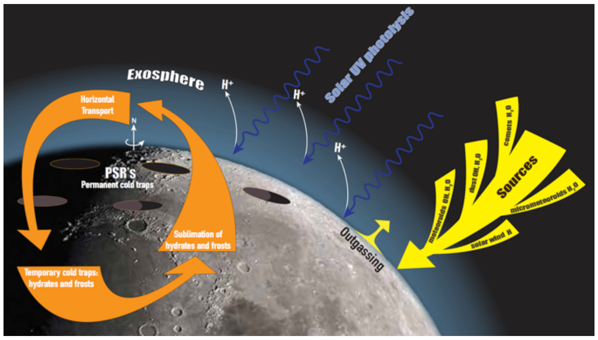

Fig. 2: SSOLVE will measure water vapor to learn which source(s) of water dominates the lunar atmosphere. The global inventory of water in the atmosphere/exosphere is in equilibrium between input sources (yellow) and losses to space and (potentially) permanent cold traps at the poles. Molecules migrate from the warm daylight surface across the terminator to be temporarily trapped on the cold night-time surface until the Moon's rotation brings the hydrated/frosted surface into daylight to thermally desorb the volatiles into the atmosphere, completing a hydration cycle (orange).

Measurement scenario: In a fourteen-day mission, SSOLVE will quantify the amount of water in the Moon's exosphere, retiring the controversy in the scientific community as to the amount of water and whether there is horizontal transport across the Moon's surface (Fig. 2.

The abundance of water in the tenuous atmosphere immediately above the daytime lunar surface has not been measured, although a wide range of estimates can be derived from measurements on orbit (Benna *et al.* 2018), remote sensing (Li and Milliken 2017; Livengood *et al.* 2015; Sunshine *et al.* 2009; Fig. 3), and equilibrium between assumed supply and loss rates (Table I). These estimates vary by orders of magnitude. The instruments that were deployed by the Apollo missions were unable to measure the neutral atmosphere in daylight due to instrument problems, so neither the total gas pressure nor the composition of volatiles at the surface are known with any certainty (Cook *et al.* 2013; Stern *et al.* 2013; Hoffman and Hodges 1975).

Water is challenging to investigate in small quantities due to its presence as a contaminant on instrument surfaces, in sample handling environments, and in rocket exhaust. SSOLVE is designed to overcome these problems by measuring the total column of H_2O and OH above the lunar surface, in comparison with calibration measurements that can eliminate local contributions to water vapor in the line of sight. SSOLVE will use high spectral resolution to identify transitions of H_2O, OH, and HDO with certainty, to measure abundance, and to characterize physics in the exosphere using Doppler linewidth from translational motion.

Table I: SSOLVE will determine the abundance of lunar water vapor – or confirm near-zero abundance

basis		column abundance, H_2O or OH	volume density
Maximum above exobase	collisionless atmosphere	3×10^{14} mol/cm^2	3×10^{7} mol/cm^3
LADEE mass spectrometer	4 km above surface	$\leq 10^{10}$ mol/cm^2	$\leq10^{3}$ mol/cm^3
comparable to or greater than [H_2]	[H_2] ~10^{9}–10^{10} mol/cm^2	10^{9}–10^{10} mol/cm^2	10^{2}–10^{3} mol/cm^3
micrometeoroid dominated	<100% H_2O	$<10^{12}$ mol/cm^2	$<10^{5}$ mol/cm^3
solar wind dominated	<100% efficiency	$<10^{13}$ mol/cm^2	$<10^{6}$ mol/cm^3
mineral hydrate concentrations	total surface reservoir ~10^{19} H_2O/cm^2	3×10^{16} mol/cm^2	3×10^{9} mol/cm^3

Gray shading indicates abundance less than the H_2O *detection threshold of* ~3×10^{11} *mol/cm*^{2}.

Mission concept: The SSOLVE instrument design and measurement goals assume a solar-powered lander outside the polar regions, within approximately ±60° latitude. The diurnal variability that SSOLVE will measure is diminished closer to the poles. Solar power restricts the mission to one lunar day, as surviving the lunar night cannot be assumed without power for survival heaters. We assume sufficient power for instrument operation in 12 days out of ~14 days of sunlight. The longest integration time that we consider assumes a duty cycle of ~16.7% to conserve average power, resulting in 48 hours' total integration time. Longer total survival or higher duty-cycle would reduce the minimum measurable column proportional to the square root of integration time.

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Abstract summary:

Submillimeter
is the clear choice, to measure
Moon's water vapor.
Rising from the ground, maybe;
how much, and what happens next?