SUBMILLIMETER SOLAR OBSERVATION LUNAR VOLATILES EXPERIMENT AT THE SOUTH POLE (SSOLVE@SP)

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Introduction: The Submillimeter Solar Observation Lunar Volatiles Experiment (**SSOLVE**) is a submillimeter spectrometer to measure the absolute abundance of water molecules (H_2O) on the line of sight to the Sun, as well as the photolysis product OH. **SSOLVE** can be packaged as a deployable instrument set apart from a crewed lander or delivered by a CLPS lander, in both cases operated remotely from Earth. The principal scientific goal for **SSOLVE** is to resolve broad uncertainty in the abundance of water vapor in the tenuous lunar atmosphere and to constrain processes for its supply, removal, and relocation.

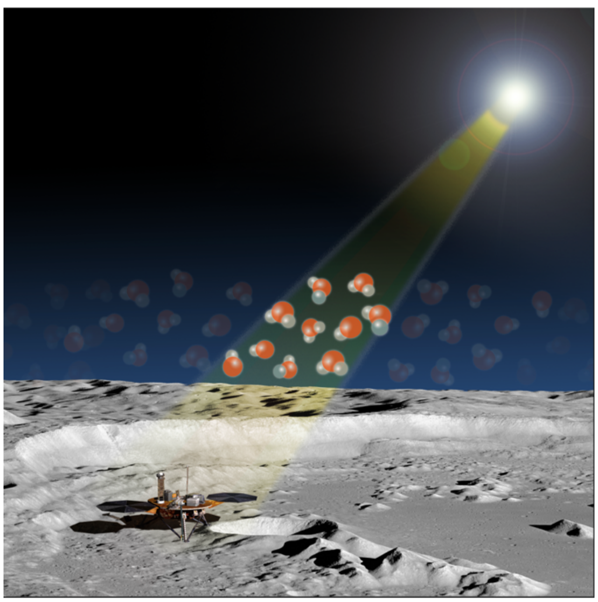

Fig. 1: SSOLVE will measure lunar water vapor against the bright Sun. SSOLVE will operate submillimeter spectrometers using a heliostat to target the Sun and measure the column abundance of H_2O, OH, and HDO in the lunar atmosphere. H_2O and OH establish the chemical state of water and constrain current 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, down to ~10^{12} mol/cm^2 (~10^5 mol/cm^3 at surface). Vapor of ~10^{14} mol/cm^2 or greater can be detected in <10 min.

The **SSOLVE** telescope is implemented in a commandable heliostat to target and track the Sun or to point to targets within 2π steradian. Volatile species abundance will be evaluated by high resolution (heterodyne) spectroscopy of spectral absorption features against a backlight source. Calibration measurements of the local atmosphere will target an internal source as well as nearby ground or human-made objects. To support human-crewed operations, **SSOLVE** will be able to point to the lander and astronauts to evaluate the release rate of water from these sources of site contamination and thereby constrain the effects of human landings on the lunar environment.

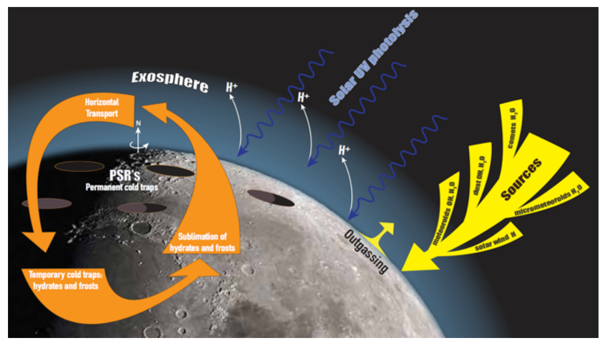

Fig. 2: SSOLVE will measure water vapor to learn which source(s) of water dominates the lunar atmosphere. The global inventory of water in the atmosphere/exosphere is in equilibrium between input sources (yellow) and losses to space and (potentially) permanent cold traps at the poles. Molecules migrate 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).

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).

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 an estimated H_2O detection threshold of ~3×10^{11} mol/cm^2 in a two week mission.

Measurement scenario: 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, in rocket exhaust, and in any human-occupied environment. **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.

Mission concept: In design, the reference **SSOLVE** mission has assumed a duty cycle of ~16.7% to conserve average power in a 14 day mission to estimate minimum detectable column abundance. Longer total survival or higher duty-cycle would reduce the minimum measurable column proportional to the square root of integration time. Relatively large quantities of water, such as would be shed in the immediate vicinity of a large lander and astronauts, could be measured in seconds against thermal emission from the astronauts' suits or the exterior of the lander. A relatively remote deployment would thus facilitate distinguishing indigenous water vapor from contamination, while enabling pointing directly to the vehicle and astronauts to estimate site contamination.

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