Hydrogen Albedo Lunar Observations from the Surface (HALOS) M. R. Collier[1], W.M. Farrell[1], J. W. Keller[1 ‡], O. J. Tucker[1], T.J. Stubbs[1], J. S Halekas[2], S. Ruhunusiri[2], P.E. Clark[3], J. L. McLain[1,4], [1]NASA/Goddard Space Flight Center, Greenbelt MD, 20771, [2]Dept. of Physics and Astronomy, University of Iowa, 414 Van Allen, Iowa City, IA 52242, [3]Jet Propulsion Laboratory, Pasadena, CA 91101, [4]CRESST, University of Maryland, College Park MD, 20742, [‡]Presenting author.

Introduction: The lunar surface breathes hydrogen. Solar wind protons continually bombard the top 100 nanometers or so of the oxide-rich regolith, and the surface constantly re-emits this hydrogen in various forms back into the exosphere. At low energies, the implanted protons convert to neutral hydrogen, and these atoms can diffuse within the surface to find an H partner to then exit the surface as thermal molecular hydrogen [Starukhina, 2006]. In fact, copious amounts of molecular hydrogen have been observed by LRO/LAMP in the exosphere [Stern et al, 2013; Hurley et al., 2017]. Some of these hydrogen atoms may also leave the surface directly to form a thermal H corona about the Moon. While possibly substantial, this enigmatic thermal H component has yet to be measured [Hodges, 2011]. In non-magnetic regions on the Moon, about 0.1-1% of the incident solar wind protons are immediately backscattered as H^+ at energies just slightly below the incident solar wind energy [Saito et al., 2008]. Besides protons, energetic neutral atomic hydrogen, H, is also immediately backscattered from the surface with energies ranging from a few 10's of eV to near 1 keV [McComas et al., 2009; Wieser et al., 2009; Futaana et al., 2012].

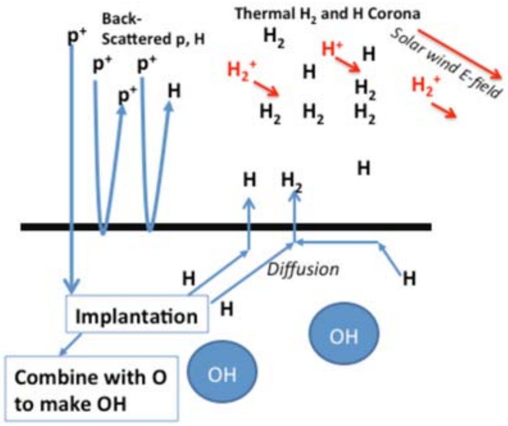


Figure 1 HALOS will, for the first time, quantify the lunar hydrogen pathways shown here.

Instrument Suite: The package to be delivered is a dual-instrument system: (1) An ion spectrometer (IS) to detect the incoming solar wind, photo-ionized component of the thermal H and H_2 exosphere, and to sense the back-scattered energetic protons that have been reported to originate from the surface [Saito et al., 2008]. (2) An energetic neutral atom (ENA) sensing system capable of detecting the backscattered energetic neutral hydrogen atoms between <30- ~1000 eV. Previous studies indicate that 7-35% of the initial solar wind proton influx may be immediately converted to this fast component [Futaana et al., 2012].

HALOS Implementation HALOS Element #1: Ion spectrometer. An Electrostatic Analyzer (ESA) to measure ion distributions. The targeted H products are the incoming solar wind (~1 keV protons), energetic backscattered hydrogen ions (~0.7 keV), and the medium energy exo-ions (~10-100 eV) from the thermal H and H_2 exosphere, H^+ and H_2^+. Regarding thermal H_2, LAMP UV observations of the H_2 exosphere suggest near-surface concentrations of ~5000/cm^3 [Stern et al., 2013; Hurley et al., 2017]. Given an H_2 photo-ionization rate of ~6 x 10^{-8}/s [Huebner et al., 1992], the local exo-ion production of H_2^+ is 300/m^3-s. These local newborn ions will be accelerated by the solar wind E-field. For IS sensors looking laterally at the horizon or looking up, the accelerated H_2^+ influx over ~10 km viewing distance is >10^6 H_2^+/m^2-s, a flux easily sensed in the IS. Inverting this argument, the IS flux measurements can then be used to infer changes in the thermal H_2 concentration in the region. The same analytical flow-down applies to the thermal H population, only using the H photoionization rate to convert from exo-ions to neutral concentrations. ALSEP/SIDE surface ion observations demonstrated that the local surface is ion-rich, which

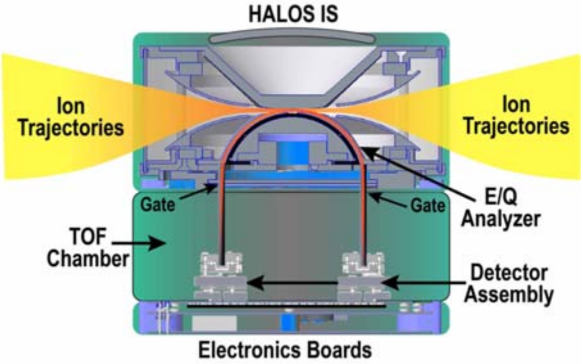


Figure 2 The HALOS IS design features flight-proven electrostatic frontend optics and electronics and a laboratory-prototyped gated tof system.

can be exploited to garner new understandings of the local space environment [Collier et al., 2011; 2017]. The polar regions provide significant contrast to the previous Apollo low latitude environment where the ALSEP/SIDE experiments took place.

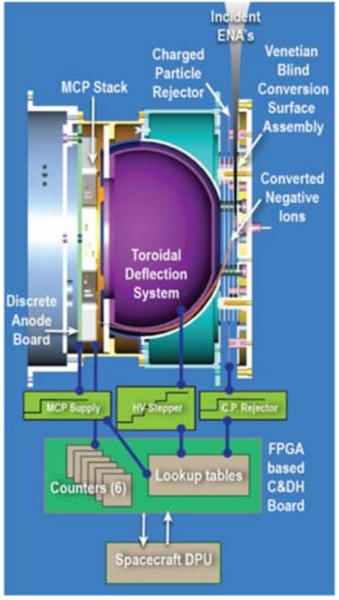


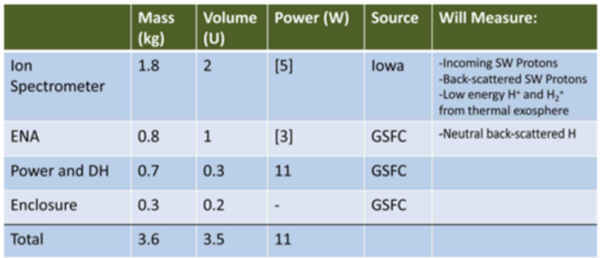
Figure 3 The HALOS ENA instrument is flight proven

The ion ESA provides high time resolution measurements while retaining wide energy and angular coverage. This is crucial for accurate determination of the form and variability of the ion distributions in the lunar environment. The basic design of the ESA analyzer is nearly identical to instruments that have been developed and successfully flown by the authors on several sounding rocket flights

HALOS Element #2: Energetic Neutral Atom spectrometer. Somewhere in the range 7-35% of the incoming solar wind is backscattered as energetic neutral hydrogen The HALOS energetic neutral atom (ENA) system sensing this component is based on a design first flown on the Fast Affordable Science and Technology Satellite (FASTSAT-HSV01) as part of the Space Test Program mission STP-S26 launched from Kodiak Launch Complex in Alaska in November 2010 [Rowland et al., 2010]. The instrument performed nominally in a 650 km altitude circular 72° inclination orbit during the entire mission, about two years. Two years later, in 2012, two more copies of this energetic neutral atom imager design were flown on the VISualizing Ion Outflow via Neutral atom imaging during a Substorm (VISIONS) sounding rocket out of Poker Flat, Alaska [Collier et al., 2015], and most recently, in December 2018, two more copies of this instrument flew on one of the VISIONS-2 sounding rockets launched from Ny Alesund. All four of these instruments performed nominally during the rocket flights.

CONOPS: The concept of HALOS operations is easy: Turn it on and take measurements. The low data rate - less than 2 kbps (Table 3.3) – can be easily injected into the lander data stream. Operations are only required if there is an anomaly. HALOS is relatively immune to electromagnetic interference (EMI) and can operate while other systems are on. HALOS can be included as an attached payload on a rover or lander, or as an astronaut-emplaced experimental package remote from the landing site.

Instrument Volume and Mass: We present in Table 1 of estimated volume and mass. The marriage of the ENA to IS represents an enhanced measurement capability to derive the primary volatile hydrogen species released from the lunar surface. Miniaturization of the IS and ENA results in both a reduced in mass and volume. The MAVEN SWIA ion spectrometer is 2.6 kg and about 4900 cm^{-3} and the proposed HALOS IS reduction to 1.8 kg and 2000 cm^{-3} represents a >30% decrease in mass and ~60% reduction in volume. The Chandrayaan-1 SARA/CENA neutral atom system is 2 kg and the proposed HALO ENA mass of 0.8 kg represents a 60% reduction in mass. (3) Further reduction in mass, volume, and power is achieved by using a shared P&DH system. Rather than each element having their own DPU and power conditioning, they now share that system.



	Mass (kg)	Volume (U)	Power (W)	Source	Will Measure:
Ion Spectrometer	1.8	2	[5]	Iowa	-Incoming SW Protons -Back-scattered SW Protons -Low energy H^+ and H_2^+ from thermal exosphere
ENA	0.8	1	[3]	GSFC	-Neutral back-scattered H
Power and DH	0.7	0.3	11	GSFC	
Enclosure	0.3	0.2	-	GSFC	
Total	3.6	3.5	11		

Table 1 HALOS features low mass, low power, and low volume. The total power used by the P&DH is 11 W with 5W going to the IS and 3W going to ENA on the other side of the converter

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