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Lunar Hydrospheric Explorer (HYDROX)

J. F. Cooper, N. Paschalidis, E. C. Sittler Jr., S. L. Jones (1), T. J. Stubbs (2), M. Sarantos (3), K. K. Khurana, V. Angelopoulos (4), A. P. Jordan and N. A. Schwadron (5)
(1) I Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA (john.f.cooper@nasa.gov / Phone: +1-301-286-4237) , (2) Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, (3) Goddard Planetary Heliophysics Institute, University of Maryland Baltimore County, Baltimore, Maryland, USA, (4) Institute of Geophysics and Planetary Physics, University of California Los Angeles, Los Angeles, California, USA, (5) EOS Space Science Center, University of New Hampshire, Durham, New Hampshire, USA

Abstract

The Lunar Hydrospheric Explorer (HYDROX) is a 6U CubeSat designed to further confirm the existence of lunar exospheric water, and to determine source processes and surface sites, through ion mass spectrometer measurements of water group (O^+, OH^+, H_2O^+) and related ions at energy/charge up to 2 keV/e. and mass/charge 1 – 40 amu/e. HYDROX would follow up on the now-concluded exospheric compositional measurements by the Neutral Mass Spectrometer on the NASA LADEE mission and on other remote sensing surface and exospheric measurements (LADEE, LRO, etc.).

1. Introduction

Long after the Apollo lander missions, the Moon had been assumed to be dry until later findings were reported on epithermal-neutron detection of hydrogen in polar regions, trace water content of lunar rocks, remote observations of H_2O and OH at the surface, and outgassing from the LCROSS satellite impact on Cabeus crater. The neutron measurements now suggest large deposits of ice-rich regolith in polar cold trap regions, equivalent in volume to many hours of peak water flow at Niagara Falls. Recent polar ice maps indicate that these deposits may have been present for billions of years after accumulation from global sources and exospheric transport to the poles. Final peer-reviewed reports from LADEE may confirm the presence of natural sources of exospheric water molecules in what could then be called the lunar hydrosphere. But the narrow field of view of the Neutral Mass Spectrometer (NMS) on LADEE samples only the cold exospheric neutrals and ions, not the hot pickup ion population accelerated in the local convective electric field. HYDROX would determine the full energy/charge and mass/charge spectra of both elemental and molecular ions, while also measuring the 3-D angular distributions providing information on source sites. HYDROX and WIMS are optimized for measurements of water group and related ions. HYDROX would be constructed, operated, and managed by NASA Goddard Space Flight Center.

2. Science Objectives

The three major science objectives of HYDROX are to (1) confirm exospheric water and measure molecular ion abundances, (2) follow spatial and temporal variations over at least six lunations (29.53 days) to determine source processes, and (3) determine surface source sites via numerical backtracking of ion beams resolved in energy/charge, incidence angle, and mass/charge at HYDROX. The principal sources are expected to be photo-stimulated desorption (PSD), meteoritic impact vaporization (MIV), and solar wind sputtering (SWS). Occasionally large energy fluxes of energetic particles could provide a fourth source via chemical radiolysis reactions and deep dielectric charging in the surface regolith. Fountain plumes from permanently shadowed regions of polar craters would also be detectable.

3. Implementation

HYDROX is 3-axis stabilized with solar electric propulsion to take it into 150 x 250 km polar orbit at the Moon after deployment into cis-lunar space from a NASA or other launch vehicle. The sole instrument is the Wide Field of View Ion Mass Spectrometer (WIMS) with high mass resolution M/dM ≥ 30 for elemental and molecular ions H+ - Ar+. The spacecraft and instrument are operated together as a closely coupled observational system to optimize detection of water group ions and to determine energy/charge-angle-mass/charge distributions as functions of spatial location and time.

Lunar pickup sons are detected at HYDROX after accumulation in the hydrosphere as neutrals from various potential sources, ionization by solar UV photons or hot plasma interactions, and subsequent acceleration on cycloidal trajectories to the spacecraft in the electric and magnetic field of the near-lunar solar wind. The angular resolution of the IMS and the 3-axis attitude maneuverability of the HYDROX CubeSat combine to allow maximum angular resolution of incident ions. With no other operational requirements than support of the IMS measurements, HYDROX is optimized for definitive determination of ion mass/charge abundances, source processes, and surface source sites. Although it carries no magnetic or electric field instruments, 3-D velocity and spatial distributions of lunar pickup ions would be used to estimate directions and magnitudes of these fields for ground-based computational modeling of lunar ion trajectories.

4. Supporting Measurements

Knowledge of the space weather environment around the Moon would be important to planning of HYDROX mission and science operations. Real-time upstream field, plasma, and energetic particle measurements would be available from the Advanced Composition Explorer (ACE) and DISCOVR spacecraft at L1. Although the composition and source process science objectives (see above) do not require precise knowledge of the local space weather environment, Daily cross-calibrations of magnetic-electric field and bulk plasma parameters with ARTEMIS P1 and P2 would be valuable for modeling of ion detection trajectories back to exospheric and surface source sites. If LRO were to continue, the CRaTER instrument would provide key local measurements of orbital radiation dosage rates that could be used to model surface radiolysis and deep dielectric charging as water ion contributors. Earth-based observations of meteoritic impacts and neutral cloud (Na, K) variations would also be useful for comparison to HYDROX observations.

Finally, HDROX is designed as a pathfinder for deployment of multiple-platform heliophysics and planetary instruments into lunar orbit. CubeSats have the advantage of highly focused operations in support of single instruments, or a highly complementary (e.g. field and plasma) suite of small instruments. Multiple CubeSats could be deployed at Explorer-level mission costs as lunar constellations to more fully survey the Moon and its space environment. Future science, exploration, and commercial operations at the Moon would most cost-effectively and efficiently be supported by constellations of small satellites. Although further exploration of the solar system would usually be led by single spacecraft missions, it may not be feasible to put these larger spacecraft into orbit around the bodies of interest, e.g. Europa and Enceladus, for highest resolution measurements of the interiors by gravity and magnetic field analysis. But this could alternatively be done by small subsats carried by the main mission spacecraft, such as Europa Clipper for Europa. Separation of field-plasma-particle from imaging and other remote-sensing instruments on different spacecraft would greatly simplify science operations planning and minimize mission cost. Flyby missions like Europa Clipper may be sufficient for global surface geologic and compositional coverage, but orbiters, however small, are needed for deep probing of interiors.

5. Summary and Impact

HYDROX would be the first lunar science mission to completely survey the composition, source processes, and surface source sites of lunar exospheric neutrals detected at the spacecraft as hot elemental and molecular pickup ions. It would significantly complement earlier cold exospheric neutral and ion measurements by LADEE. HYDROX would provide high-resolution hot ion mass spectrometry to any existing constellation (e.g., other CubeSats, ARTEMIS, LRO) of lunar-orbiting spacecraft to enable more comprehensive measurements of the lunar exosphere, surface, and remotely-probed interior. It would be a pathfinder to testing of the concept that constellations of small satellites, each with dedicated and highly complementary instruments, could be more efficient and cost effective than larger single satellites for exploration and survey of the Moon and other planetary bodies. Surface-based operations for science, exploration, eventual human habitation, infrastructure for Mars exploration, and commercial operations at Earth’s nearest neighbour would be highly dependent on in-situ resource utilization, for which water to be probed by HYDROX would be an essential material.

Development and operation of small satellites also offers hands-on education and training opportunities for young scientists, engineers, and project managers that would otherwise be difficult to obtain. HYDROX for planetary science at the Moon follows from the successful respective flights and development of the ExoCube and Dellingr CubeSats for heliophysics science in low Earth orbit. NASA Goddard Space Flight is supporting CubeSat development and operations for all these applications.