Lunar Cube Sat Mass Spectrometer with Linear Energy Transfer Spectrometer Radiation Sensor. S. Madzunkov[1], J. Raines[2], P. McNally[2], J. Simcic[1], D. Nikolic[1], M. Darrach[1], and D. Fry[3]. [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr. Pasadena CA 91109, email: stojan.madzunkov@jpl.nasa.gov; [2]Space Physics Research Laboratory University of Michigan; [3]Johnson Space Flight Center, Space Radiation Analysis Group.

Introduction: We report on the flight-quality JPL Lunar CubeSat Mass Spectrometer (LCMS) integrated with the JSC Linear Energy Transfer Spectrometer (LETS) for multi-day lunar surface exospheric and radiation investigations. LCMS-LETS' primary science goals are to determine the density, composition, and time variation of the lunar volatiles and atmosphere, and correlate these with the local solar wind environment. LCMS-LETS will be ready for inclusion on NASA's small lunar lander missions in the 2022 timeframe, which seek low mass, low power instruments that can conduct high-value science investigations without requiring sample handing or mobility.

LCMS-LETS will be the first lunar instrument capable of **identifying and quantifying exosphere species with abundances ≥ 10 molecules/cm^3**. To achieve this performance, LCMS uses a Quadrupole Ion Trap Mass Spectrometer (QITMS) with an unsurpassed combination of low mass (7 kg), low power (max 30 W with heater bulb on), high sensitivity (0.003 counts/cm^3/sec), and ultra-high precision (0.5% for noble gas isotope ratios over 24 hours) that is 10× better than demonstrated by any previous ion trap mass spectrometer. Figure 1 shows the engineering model of the LCMS-LETS within a compact, 8U package. LCMS-LETS was selected for a 2020 DALI award.

LCMS is designed to mitigate spacecraft off gassing, an effect that has limited previous mass spectrometer investigations by designing the inlet to point away from the spacecraft with a sample inlet that has a limited 15° half-angle of the cone field-of-view (FOV) around pointing direction. As spacecraft off-gassing and dust intrusion are critical phenomenon that affect instrument performance, the compact size of LCMS enables astronauts to place it in various locations to minimize these effects. As well, these locations could be selected by the astronauts to study local phenomenon (e.g. off-gassing from geologic features and from solar radiation)

Understanding the lunar exosphere in detail is crucial to understanding the space environment of other airless bodies, which is perhaps the most common type of atmosphere in the solar system. On these bodies, the thin collision-free atmosphere extends to the surface ground as a "surface boundary exosphere" and species are free to follow arcing paths determined by the energy they received during liberation and by the gravitational pull. In addition to the Moon, Mercury, the larger asteroids, a number of the Moons of the giant planets and even some of the distant Kuiper belt objects out beyond the orbit of Neptune, all may have surface boundary exospheres. Despite how common this type of atmosphere is, we know very little about it. Having one right next door on our Moon provides us with an outstanding opportunity to improve our understanding. The LCMS-LETS instrument will address these questions and further our understanding of space-surface interaction and modeling water resources on airless bodies.

JPL's QITMS – the core of the LCMS-LETS instrument – provides a unique combination of ultra-

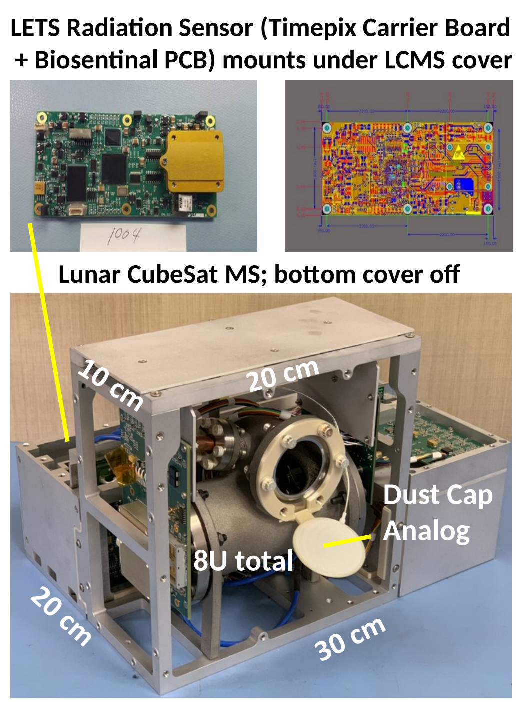

Figure 1: (Top) LETS is a TRL 6 flight spare built by JSC for the Biosentinel CubeSat. (Bottom) It mounts under the bottom cover of the TRL 5 Lunar CubeSat MS, built by JPL with internal strategic initiative funding.

sensitive, real-time particle analysis in a miniature, ruggedized package.

LCMS-LETS will provide the first one-to-one correspondence of released neutrals to a small area of the lunar surface and its local radiation environment, a result impossible from space-based measurements. These measurements will significantly advance our understanding of the interaction of the solar wind with the lunar regolith. By comparing these new measurements to existing surface composition maps we can relate the release of neutrals to surface composition and source mechanisms.

Ion sputtering (IS) and Electron-stimulated Desorption (ESD), two of five processes which supply the lunar exosphere, are particularly difficult to model because details of the processes are poorly understood. Filling in these details through observations will directly translate into model improvements. Two of the other three supply processes, thermal desorption and photon-stimulated desorption, are relatively straightforward to model since they depend on temperature and photon flux, which are easily computed. The remaining process, micrometeoroid vaporization, is reasonably well understood through modeling and orbital measurements. LCMS-LETS will improve this understanding through localized surface exosphere measurements. As a result, constraining the least understood IS and ESD processes will immediately improve our ability to estimate the

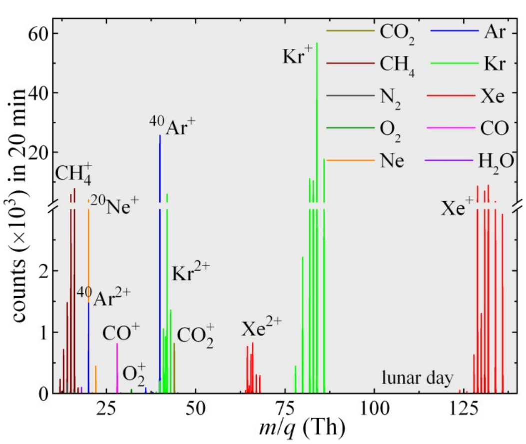

Figure 2: Modeled LCMS measurements of the lunar daytime surface exosphere show that it can make the first Kr and Xe abundance measurements to 4% accuracy on ^{78}Kr and 0.5% on ^{84}Kr within 20 minutes on the lunar surface. Its exceptional sensitivity also enables detection of CO_2, CH_4, N_2, O_2, CO, and H_2O, and other trace species that may be present.

relative contributions of each source term in lunar exosphere models, a result which has been elusive for many years

Performance and Results: Accurate in-situ measurements are needed to understand the formation and evolution of the lunar exosphere. The lowest abundances accurately measured (accuracy ≤ 10%) by the Apollo 17 Lunar Atmospheric Composition Experiment (LACE) and NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE), were approximately 1000 cm^{-3} and 100 cm^{-3}, respectively. This highlights the need for instruments that can quantify volatile concentrations as low as 10 cm^{-3}. For the noble gases, which have negligible off-gassing from the spacecraft and instrument, LCMS-LETS will acquire high-accuracy science measurements in < 1 hr on a short duration mission of less than a lunar day (Figure 2). For instance, Kr and Xe abundances (neither of which have been measured previously on the lunar surface) can be determined almost immediately after landing. If Xe is present at an abundance of 100 cm^{-3}, LCMS-LETS can determine this to 10% accuracy within 2 minutes. LCMS-LETS' ability to point its sample inlet anywhere between straight up and straight down, enables measurement of volatiles from above and below the sensor head to evaluate and account for the instrument outgassing.

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