CHARACTERIZING METEORITE IMPACT VAPORIZATION AND OUTGASSING PROCESSES ON THE LUNAR SURFACE: A NEW METHODOLOGY AND OPPORTUNITY. Daniel E. Austin1, Ivan Miller1, Terik Daly2, Arlin Crotts3, Erik Syrstad4, William Brinckerhoff5, and Jani Radebaugh2, 1Dept. of Chemistry and Biochemistry and 2Dept. of Geological Sciences, Brigham Young University, Provo, UT, 84602, austin@chem.byu.edu. 3Dept. of Astronomy, Columbia University, New York, NY 10027. 4Space Dynamics Laboratory, Utah State University, Logan, UT 84341. 5Goddard Space Flight Center, Greenbelt, MD.

Introduction: Existing instrumentation for lunar exploration is unable to observe two important processes believed to occur on the lunar surface: outgassing of subsurface gases, and impacts of meteorites below the limits of seismic detection. Recently-outgassed species are obscured by the larger population of background atmosphere, and cannot be distinguished from background using atmospheric composition equipment such as a typical mass spectrometer. Impacts of meteorites in the mg to g range cannot be observed seismically or optically, and are too infrequent for observation on small (~m²) surfaces.[1-2] We are developing a novel instrument and method that would allow direct measurement of both of these processes. The device would further allow study of the chemical speciation that takes place during hypervelocity impacts of meteorites, a process difficult to study in the laboratory.

This abstract describes a simple, compact mass spectrometer and methodology for characterization of outgassing phenomena and impact-induced vaporization on the Moon. This instrument combines time-of-flight mass spectrometry with double-coincidence detection and an imaging detector, enabling analysis of the composition of gases. More importantly, however, the instrument uses a novel pattern analysis approach to separate neutrals emitted from brief outgassing events from the much larger population of background atmospheric neutrals [3-4] and species from the solar wind, etc. This approach also allows determination of distance and direction to the event using a single instrument—without the need for triangulation from multiple deployed instruments—and will further provide data on the temperature, magnitude, and duration of outgassing events.

Characterization of gases as they emerge [5-6] from the surface will provide information about the lunar interior, including possible subsurface resources for human lunar exploration. Correlation of outgassing with seismic activity will be possible. The instrument will also detect vapor produced from millimeter-sized and larger meteorites impacting over a very large area (roughly a million square kilometers), providing the first direct data on neutral speciation in hypervelocity impacts, data on meteorite flux [7], and data needed to better assess the impact hazards of human lunar activity. The instrument would detect lunar outgassing events down to a few milligrams at distances of several tens of kilometers, and larger events up to several hundred kilometers away, with better than unit mass resolution. The proposed instrument is sufficiently small (6 cm dia. x 14 cm) and low-power (6 W) that it would easily be integrated into various future missions.

Instrument Description: Figure 1 shows a schematic of the instrument. Neutrals enter the top of the device and are ionized by a continuous, focused electron beam. These ions then enter through the small aperture, traverse the imaging cone, and pass through the acceleration grid. Because there is no electric field in the ionization region or in the imaging cone, ions continue with the same momentum they had as neutrals (neglecting scatter from the electron beam). When an ion reaches the acceleration grid, its position is representative of the azimuthal and elevational angles it had as an incoming neutral. Ions reaching the accelerating grid are accelerated to 15 kV, pass through a thin (2 μg/cm²) carbon foil, and continue through the electron acceleration grid to a position-sensitive microchannel plate (MCP) detector. As an ion passes through the thin foil it releases a secondary electron, which is accelerated through 1 kV and also directed to the MCP detector. The ion is generally neutralized after passage through the foil. In an alternative design, ions are accelerated through curved trajectories before the carbon foil, improving

Figure 1. Mass spectrometer design
exclusion of UV photons.

The electron and ion reach nearly the same spot on the detector, separated in time by several microseconds (corresponding to the time-of-flight, and hence, the mass of the ion). The electron strikes the detector at the same location that the ion passed through the foil. The ion/neutral may scatter by several degrees by the foil, but will still reach the detector. The coincidence of two pulses at nearly the same location, appropriately spaced in time allow separation of real signal from noise. The position of the electron on the detector gives the azimuthal and elevational angles of the incoming neutral.

When multiple neutrals from a single, brief outgassing event are detected in this manner, a recognizable pattern is produced, as shown in Figure 2. In this case neutrals reach the detector at the same azimuthal angle, but differing elevational angles. The way these elevational angles change over time is a result of two factors: 1) the time distribution of the outgassing event itself, and 2) the kinetic energy and elevational angle of the neutral species. The time-variation of the elevational angle can be used to determine the distance to the event and also the energies of neutrals coming from that event. Data from many neutrals originating from the same event will follow a curve of the form:

\[ \frac{dt}{d\theta} = \frac{2v_0}{g} \cos \theta \]

which can be used to separate outgassing events from the much larger population of background species. The width of the fit to the above curve indicates the duration of the outgassing event. The variation of initial velocity, mass, and angle indicates the distance to the outgassing event. That combined with the azimuthal angle give the absolute event location.

This method relies on the fact that many neutrals will reach the instrument directly from the outgassing event, before their first bounce on the lunar surface. Upon first bounce and the resulting scatter, all trajectory information is lost, and the neutral becomes part of the atmospheric background.

**Performance Simulations:** Instrument performance was studied using SIMION ion trajectory software, and also using calculations that approximate gas populations, ionization cross sections, and scatter within the instrument (foil, electron beam, grids). For typical lunar conditions, outgassing events in the size range of 5-50 miligrams will be observable to a distance of at least 80 km, and larger events will be observable to over 200 km. Meteorite impacts will be observable from at least 800-1000 km away.

Figure 3 shows simulated data from a 20-mg, 5-second outgassing event and a 1-gram, 60-second outgassing event, both at a distance of 65 km from the instrument. Atoms from the event can be seen in spite of the large signal from background atoms.

**References:**