A MASS SPECTROMETER FOR COMPLETE CHARACTERIZATION OF VOLATILE OUTGASSING AND METEORITE IMPACT VAPORIZATION ON THE LUNAR SURFACE. Daniel E. Austin, Department of Chemistry and Biochemistry, Brigham Young University, Provo, UT, 84602, austin@chem.byu.edu.

Introduction: This abstract describes a simple, compact mass spectrometer designed to characterize outgassing phenomena and impact-induced vaporization on airless bodies in the solar system, in particular 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 [1,2] and species from the solar wind, etc. This approach also allows determination of distance and direction to the event using a single, compact 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 [3,4] from the surface will provide information about the lunar interior, including possible subsurface resources for manned 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 [5], and data needed to better assess the impact hazards of manned lunar activity. The instrument would provide valuable information on many other solar system bodies, most notably Europa, Enceladus, Mercury, and Io. On the Moon the instrument would detect outgassing events down to a few milligrams at distances of several tens of kilometers, and larger events up to several hundred kilometers away, with a mass resolution of at least 300 (m/Δm). The proposed instrument is sufficiently small (5 cm dia. x 14 cm) and low-power (8 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 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 loses 1 kV while traveling through this region, and also loses some kinetic energy while passing through the foil, but both of these effects are taken into account in the calibration of the mass spectrum.

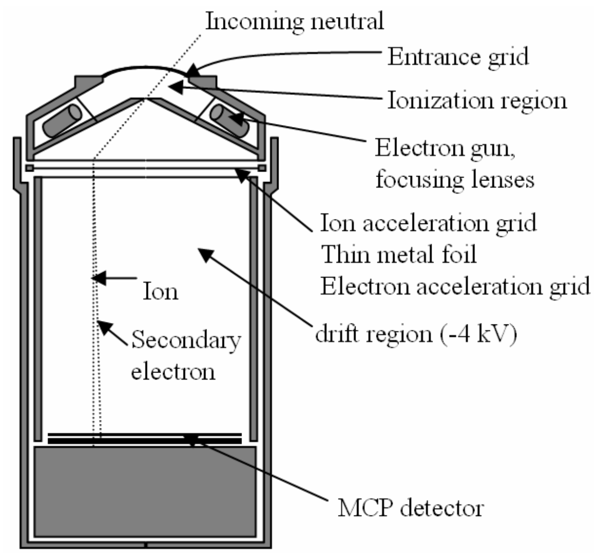

Figure 1. Mass spectrometer design.

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 coincidence of two pulses at the same location, appropriately spaced in time allow separation of real signal from detector noise caused by UV photons hitting the detector, UV photoelectrons from the foil, and dark current noise. The position of the ion 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

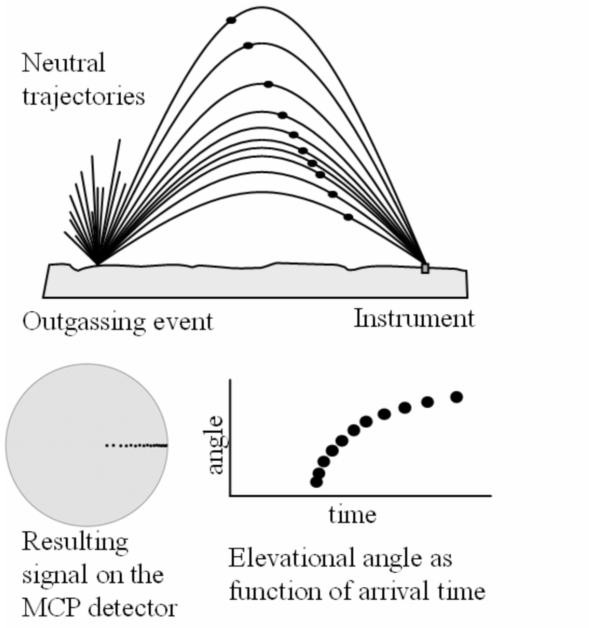

Figure 2. Detection of signal from outgassing event.

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.

UV photons are expected to create noise in this system, but the combination of a small aperture, the metal foil [6], and the double-coincidence criterion are sufficient to reduce the UV noise to acceptable levels.

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). Mass resolution, taking into account the variation in energy loss by ions passing through the foil, is estimated to be in the range of 300-600 ($m/\Delta m$).

For typical lunar conditions, outgassing events in the size range of 10-50 miligrams will be observable to a distance of at least 100 km, and larger events will be observable to 200 km. Meteorite impacts, with higher initial kinetic energies of neutrals, 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.

Conclusion: This instrument will enable direct measurement of two important, previously unobserved processes: (1) characterization of the sources and compositions of gases released from the regolith to the lunar atmosphere, and (2) characterization of the vapors produced in a high-velocity impact of a meteorite on the lunar surface. If outgassing occurs in discrete events with magnitude of at least 1-5 mg, such events can be identified in the presence of the solar wind and background atmosphere, providing information about the formation and interior of the Moon.

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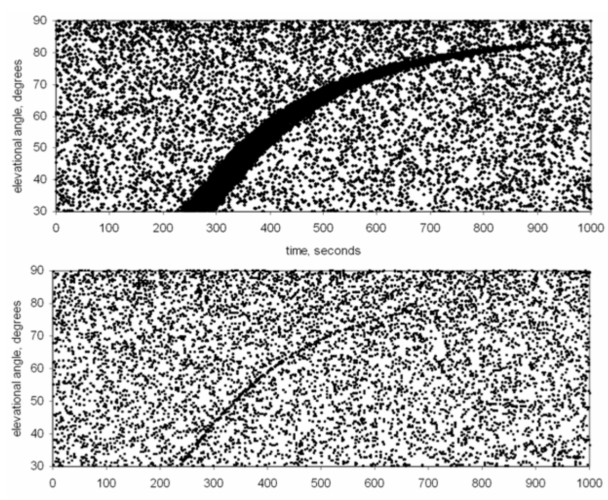

Figure 3. Simulated signal from 1) a 1-gram, 60-second outgassing event 65 km away, and 2) a 20 milligram, 5-second outgassing event 65 km away.