A MINIATURE MASS SPECTROMETER FOR HIGH-FLUX COSMIC DUST ANALYSIS.

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Introduction: An important component of cosmic dust research is composition analysis by mass spectrometers on spacecraft. At typical impact speeds of 10-100 km/s, the impacting dust grain and a portion of the surface it strikes are partially vaporized and ionized [1]. The ions can then extracted and analyzed using time-of-flight mass spectrometry. Several microparticle time-of-flight mass spectrometers have flown successfully through various dust environments in the solar system, and have been reviewed by Auer [2]. Reflectrons [3] are used in most instruments to compensate for distributions in initial kinetic energies of impact-generated ions [4]. Because of the need for a large active area to study sparse dust, such instruments have been in the range 16-17 kg and 0.02-0.03 m^3. Unfortunately, reducing the dimensions of time-of-flight mass spectrometers generally decreases mass resolution. Shortening the instrument can increase deviations from the paraxial approximation, and the resulting focused ions have greater spherical aberration. The difference in flight times between ions of different mass is smaller, so better ion focusing is needed to maintain sufficient resolution. Space-charge effects present greater complications, both because of the need for narrower arrival time distributions, and also because the physical dimensions of the instrument (and the spacing between ions) are reduced.

We have built and tested a smaller instrument design [5] that addresses these limitations. This instrument includes both a reflectron and a novel ring aperture system to compensate for ion velocity distributions in all three dimensions. The design also reduces the adverse effects of spherical aberration, grid scatter, and impact plate cratering. The small impact area in this design, however, limits its usefulness to operation in a region of space with a very high concentration of dust, such as a close flyby of a comet, a planetary ring, or an impact-generated dust plume.

Instrument Design: The cylindrically symmetric instrument, shown in Figure 1, is 28 cm long, 6 cm in diameter. Dust grains enter through the grid and aperture at the left of the diagram and strike the impact plate. Ions produced upon impact are extracted into the reflectron region by a potential of 3000 V. The reflectron compensates for the spread in the velocity components parallel to the instrument axis. In the reflectron region the ions spread out laterally due to space-charge and field inhomogeneties. As ions leave

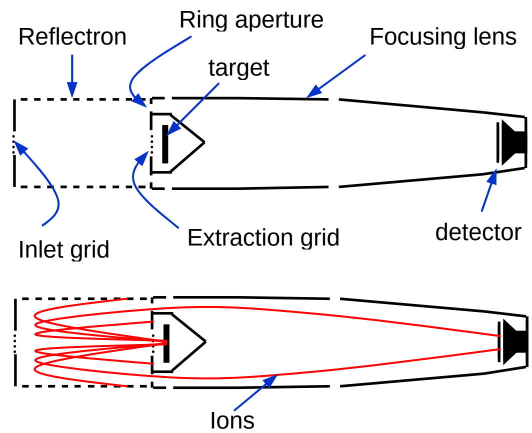

Figure 1. Schematic of time-of-flight mass spectrometer for high-flux cosmic dust analysis.

the reflectron, a ring aperture blocks the transmission of ions whose velocity components perpendicular to the instrument axis fall outside a given range. Thus only a "ring" of ions is permitted into the drift region, corresponding to a specific, narrow distribution of the radial component of kinetic energy. This ring aperture effectively reduces the spherical aberration of the ion beam to obtain the desired mass resolution. Signal attenuation accompanies a narrow ion window, but dust impacts typically produce sufficient ions that even low ion transmission will still yield strong signal [6-7]. By allowing only a ring of ions into the drift tube, space-charge effects are reduced, and a smaller detector can be used.

In the reflectron region the ions spread out radially due to space-charge repulsion, scatter from the extraction grid, inhomogeneities in the extraction and reflectron fields, and velocity components arising from initial thermal energies of the ions. In a region of space with a high dust concentration the impact plate quickly becomes cratered. As more micro-craters are produced by impacts, the ion extraction field becomes less homogeneous. In this instrument the ring aperture filters out lateral spread from any source, including field inhomogeneities and deterioration from cratering.

As can be seen in Figure 1, the acceptance angle of this instrument is only a few degrees. In a high flux environment the source of dust is presumably both known and localized, and the direction of dust flow is well defined. A narrow entrance can then be pointed in the direction of oncoming dust, while the small amounts of dust from other sources would not be accepted.

Experimental Validation: A prototype instrument was built for laboratory validation studies. Tantalum was used as the target material because of its high density. The prorotype instrument was tested using iron microparticles accelerated to velocities of 1-10 km/s using the van de Graaff dust accelerator at Concordia College [5]. The ion signals generated at the microchannel plate detector were digitized and recorded using a 150 MHz oscilloscope.

Figure 2 shows representative spectra from these high-velocity impact experiments. Detected species include iron, hydrogen, carbon, oxygen, sodium, and potassium. Hydrogen, oxygen, and carbon peaks are believed to arise from surface contaminants such as diffusion pump oil [8]. Sodium and potassium are also easily-ionized contaminants, common in surface ionization mass spectrometry. Tantalum was detected in some spectra, as well as tantalum oxide, but is not shown in Figure 2. A small peak at m/z = 27 could be $C_2H_3^+$, as suggested in other impact experiments [4], or could be aluminum.

Mass resolution ($m/\Delta m$ at FWHM) in the impact spectra from the dust analyzer is generally high compared with that of other cosmic dust composition instruments. In most spectra, mass resolution exceeds unit resolution for all species, including tantalum and tantalum oxide. In some spectra, the more intense peaks are broadened due to detector saturation. Mass resolution ranges from 300-500 for tantalum, 80-500 for iron, 30-300 for potassium and sodium, 30-200 for carbon, and 5-20 for hydrogen. The upper limit of resolution of lighter species (particularly hydrogen) is limited by the speed of the recording electronics.

Conclusion: Dust impact experiments demonstrate the high mass resolution possible under particle impact conditions using the prototype instrument. This instrument is ideally suited for particulate analysis in a fly-by through a planetary ring, near a comet, or through an impact-generated dust plume.

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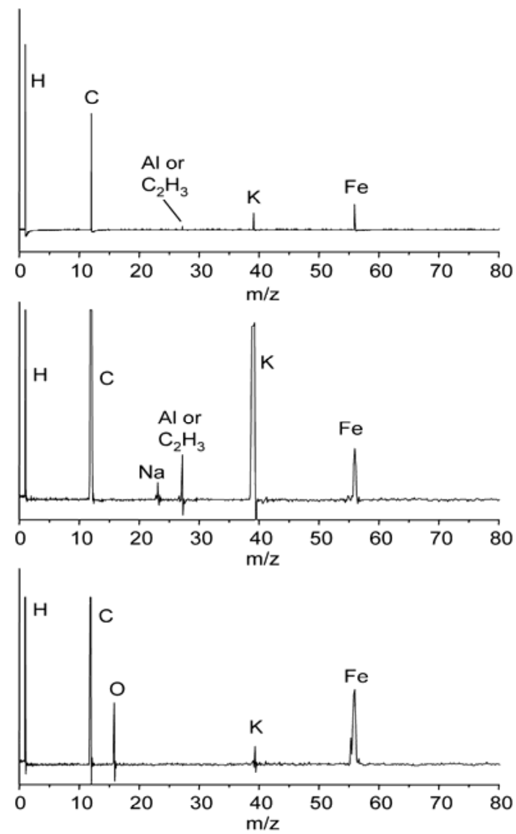

Figure 2. Spectra from impacts of accelerated iron particles on high-flux dust analyzer, from ref 5.