

The Pickup Ion Composition Spectrometer uses a large-gap electrostatic analyzer and position-sensitive time-of-flight to make improved measurements of the energy and velocity distributions of planetary and cometary pickup ions.

Pickup Ions

Newly ionized atoms from planetary sources that are picked up by the solar wind and carried into the heliosphere contain information on the plasma and dust compositions of their origin. These often singly charged pickup ions (PUIs) are collected by space-based plasma mass spectrometers and analyzed for their composition, fluxes, and distribution in both energy and velocity. There have been several successful PUI measurements from instruments designed for work in planetary environments, providing important insights into atmospheric compositions and loss mechanisms of planetary bodies [1], [2], [3]. These instruments have provided an exciting preview into the wealth of information contained in PUI data, and have laid the foundation for the next generation of PUI instruments.

Many PUI measurements, however, have come from accidental measurements by instruments that were designed to perform a different task [4], [5]. The first interstellar PUIs were measured by an instrument designed to analyze artificially released particles in Earth's magnetosphere [6], and the vast majority of heliospheric PUIs from all known sources (except in close proximity to comets and some planets) were discovered by instruments designed to measure the composition of the solar wind [7], [8].

These two challenges, the low duty cycle due to voltage stepping in the ESA, and low counting statistics due to sparse data collection, are addressed in the Pickup lon Composition Spectrometer (PICSpec). The ESA of PICSpec can increase the collecting power of 100x by increasing the geometrical factor (a metric of the collecting power). due to hardware design) as well as the amount of time that the instrument can spend at each voltage step [11]. The large-gap ESA of PICSpec is optimized for planetary and cometary missions; capable of allowing ions into the instrument over a large range of energies in a single voltage step. Ions of different E/q values are separated spatially, rather than temporally, which reduces the need for power-supply settling delays and increases the collecting power. For example, the PICSpec ESA can cover in 3 voltage steps the same E/q range that SWICS covers in 60 steps. Figures 3 and 4 show the PICSpec design in an ion optics simulation using SIMION software, and as a lab prototype, respectively. Ions enter the instrument from the left and pass through a carbon foil on the right, which will eject secondary electrons to trigger the beginning of a time-of-flight measurement. The ions will be collimated into a focal point that will also house a light trap, which can be seen by the straight photon trajectories in the simulation. Depending on their incident energy, the ions will be deflected within the ESA by differing amounts, reaching the carbon foil at energy-dependent positions. The use of a position-sensitive detector for the start signal electrons will allow a proxy mapping of the ion traversal locations on the carbon foil.



Measurements made using the PICSpec prototype have validated the E/q separation (Fig. 5). By using a position-sensitive detector in the time-of-flight section of the instrument, the ion impact location can be determined unambiguously. The E/q resolution of the ESA is between 2.9-6.7% over the E/q range. Ion composition instruments of the present generation have made pioneering measurements of PUIs, but are limited in their ability to fully characterize them. Instruments with high collecting power such as PICSpec, that are optimized for the complete characterization of PUIs, including their energy distribution, will enable the next generation of TOF-E telescopes.

Planetary Pickup Ion Composition Spectrometer (PICSpec)

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The groundbreaking instruments that made these "accidental" PUI discoveries were not designed specifically for the low-density, low-charge PUI plasma, so their sensitivity for detecting and resolving PUIs was limited. These instruments were primarily two-stage analyzers; an electrostatic analyzer (ESA) filters ions by their energy-per-charge (E/q), then their speed and energy are measured in a time-of-flight—Energy (TOF-E) telescope. While present instrumentation has made large strides in the measurement and identification of PUIs, there are still limitations that affect the data analysis. Due to the relatively low fluxes of PUIs, high-density solar wind ions with similar mass-per-charge (m/q) values can sometimes obscure the PUI signal. For example, pickup C²⁺ and solar wind Fe⁹⁺ have m/q of 6 and 6.22 amu/e, respectively, making them difficult to distinguish without an energy measurement, as shown in ACE-SWICS data of a January 2005 interplanetary coronal mass ejection (Fig. 1). This underscores the importance of a measurement of total energy in addition to the time-of-flight. In the magnetosphere of Mercury, where measurements are shielded from the bulk of the solar wind flow, the FIPS spectrometer on MESSENGER still measures only 0.5% of the incoming flux as planetary pickup ions; the rest is of solar origin [9]. To adequately identify the faint signal of pickup ions against the background of the solar wind, a larger sample size of ions must be collected by the instrument. In addition to the intrinsically low densities, low count rates in a sensor are due in part to the limited time it is able to spend analyzing each E/q step. For ¹⁰⁰ regimes in which the plasma characteristics change rapidly over time, high time resolution is 0⁸⁺-0⁶⁺0⁵⁺0⁴⁺0³⁺



critical. This can be achieved by rapid scans through the energy range of an instrument, accomplished by stepping through a cycle of pre-set voltages in the ESA. However, the settling time of high voltage power supplies combined with the total scan time may reduce the available collecting time of the instrument, providing poor PUI statistics. These E/qstepping, combined with the instrument's orientation with respect to the PUI trajectories at any given time, combine to form the duty cycle of the instrument: the fraction of measurement time devoted to a given ion species. For rare PUI species, the low flux combined with the duty cycle require long integration times to collect sufficient data, as illustrated in Fig. 2 by the ³He⁺ PUI measurements by Gloeckler and Geiss [10], which required a 40-month accumulation.

A Design Optimized for Pickup Ion Measurements



Present Instrument Limitations

1.6 < W < 2³He⁺ Avera ass/ch $5 10^{\circ}$ 2)

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