

Mass spectrograph for imaging low-energy neutral atoms

Arthur G. Ghielmetti

Edward G. Shelley

Stephen A. Fuselier

Lockheed Palo Alto Research Laboratory

D/91-20, B255

3251 Hanover Street

Palo Alto, California 94304

Peter Wurz

Peter Bochsler

University of Bern

Physikalisches Institut

3012 Bern, Switzerland

Federico A. Herrero

Mark F. Smith

NASA Goddard Space Flight Center

Laboratory for Extraterrestrial Physics

Greenbelt, Maryland 20771-0001

Thomas S. Stephen

University of Denver

Physics Department

Denver, Colorado 80208

Abstract. We describe an instrument concept for measuring low-energy neutral H and O atoms with kinetic energies ranging from about 10 eV to several hundred. The instrument makes use of a low work function surface to convert neutral atoms to negative ions. These ions are then accelerated away from the surface and brought to an intermediate focus by a large aperture lens. After deflection in a spherical electrostatic analyzer, the ions are postaccelerated to ~ 25 -keV final energy into a carbon-foil time-of-flight mass analyzer. Mass resolution is adequate to resolve H, D, He, and O. Energy and azimuth angle information is obtained by means of position imaging the secondary electrons produced at the carbon foil. A large geometric factor combined with simultaneous angle-energy-mass imaging that eliminates the need for duty cycles provide the necessary high sensitivity. From a spinning spacecraft this instrument is capable of producing a 2-D map of low-energy neutral atom fluxes.

Subject terms: magnetospheric imagery; atmospheric remote sensing; neutral atom imaging; ion optics; time-of-flight spectrometry; surface conversion.

Optical Engineering 33(2), 362–370 (February 1994).

1 Introduction

The objective of the inner magnetospheric imager mission presently under consideration by NASA is to obtain global maps of the distributions of plasmas in the Earth's ionosphere and magnetosphere. Fast neutral particles created from ions that undergo charge exchange on collision with neutral gas atoms of the upper ionosphere and geocorona offer the potential for imaging the original charged particle distributions. These neutrals are well suited for remote sensing because they are unaffected by the magnetic field and, thus, follow ballistic paths. Neutral atom imaging is a relatively new technique^{1,2} that requires significant improvements in detector and analyzer methods to make it suitable for sensing the typically low fluxes of neutral atoms. The High-Latitude Ion Transport and Energetics (HI-LITE) Explorer³ proposed to

investigate the global ion outflow from the high-latitude terrestrial ionosphere includes this type of novel neutral atom imaging instrument.

Conventional techniques for measuring neutral particle fluxes rely either on direct detection via the energy deposition in solid state detectors, or on ionization and subsequent analysis in charged particle instruments. The former technique has been successfully applied for imaging energetic (> 20 -keV) atoms originating in the terrestrial ring current.² However, these techniques cannot be applied efficiently to much lower energies.⁴ Because low-energy neutral atom fluxes in the planetary ionospheres and magnetospheres and in interplanetary space are generally many orders of magnitude lower than charged particle fluxes,¹ a highly efficient ionization process is called for. Neither electron nor field ionization with their low overall yield, nor photon ionization with its impractical demands on spacecraft resources (size, weight, and power), meet these requirements.

Transmission ionization employing thin carbon foils (C foils) provides reasonably high yields ($\sim 10\%$) down to

Paper MI-029 received April 25, 1993; revised manuscript received Aug. 25, 1993; accepted for publication Aug. 30, 1993.

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0091-3286/93/\$6.00.

energies as low as 1 keV/nucleon.⁵⁻⁷ Using ultrathin C foils in combination with highly sensitive analyzers, McComas et al.⁸ have reported good efficiencies for negative O production at energies as low as 1 keV. However, at energies below approximately 0.5 keV/nucleon, the yield of secondary electrons⁹ and of ions^{5,6} decreases rapidly. As a result, the very low energy regime of neutral particle fluxes remains thus far largely inaccessible to *in situ* measurements from spacecraft.

In recent years, new surface ionization techniques have been developed for laboratory applications that are capable of providing high ionization yields at energies below 1 keV.¹⁰⁻¹² These techniques make use of low work function surfaces for converting neutral particles to ions during surface impact and reflection. A similar system that relies on in-flight conversion surface regeneration is presently in operation on the Ulysses solar probe.¹³ Surface ionization introduces new demands on design that differ from conventional spaceflight instruments and requires the development of new analyzer elements with matched ion optical properties.

In this paper we describe the concepts for an instrument capable of imaging low-energy neutral H, O, and He atoms. Such an instrument would be suitable for imaging neutral atom fluxes from such diverse source regions as the cleft ion fountain and the interstellar neutral wind. An instrument based on the principles described here was proposed for flight on a NASA small explorer mission to image the charge-exchanged H and O neutrals from the high-latitude terrestrial ionosphere. Alternate concepts that combine conversion ionization techniques with a spectrograph have been described by Herrero and Smith¹⁴ and Gruntman.¹⁵

2 Instrument Description

2.1 Overview

The imaging low-energy neutral analyzer (ILENA) proposed here combines state-of-the-art laboratory technology with flight-proven space plasma analyzer technology. A schematic cross section of the sensor in a plane containing the axis of symmetry is shown in Fig. 1. The principal elements of the ILENA are an entrance collimation system, a conversion unit, an extraction lens, an electrostatic analyzer, and a C-foil time-of-flight (TOF) mass analyzer with position sensing. Neutral and charged particles enter the sensor via the external aperture B1 and are collimated in angle and area by the S1 entrance slit. An electrostatic deflector removes all ions with energies <100 keV, while a broom magnet deflects all electrons with energies <200 keV. The remaining neutral particles proceed to the conversion plate (C) where they impact at an oblique angle. At the conversion plate, some of the neutrals undergo charge exchange and become negative ions. These ions are accelerated away from the converter surface and are focused by a wide-aperture low-aberration lens (L) in the S2 slit plane. The conical slit S2 is set to transmit ions with initial energies within a passband of $\sim 10 < E < 300$ eV. Transmitted ions are subsequently imaged by a spherical electrostatic analyzer (EA) geometrically configured to be focusing in elevation angle in the image plane of the C foil. Before entering the TOF section, ions are postaccelerated to about 25 keV. On striking the C foil placed in the focal plane of the EA, the negative ions produce secondary electrons that provide the start pulse as well as the azimuth-radial position information.

The transmitted particles (ions and neutrals) proceed to the stop microchannel plate (MCP).

The entire instrument is rotationally symmetric about a vertical axis collocated with the S1 entrance slit. Ions that enter the analyzer through the S1 slit maintain their initial velocity direction except for nonspecular reflection at the conversion surface. These effects are minimized through a special ion optics design of the acceleration lens system. As a result, a direct correlation between the incident azimuth direction and the particles position in the plane of the C foil is achieved that enables one to deduce the original velocity direction of the neutral atom. In a similar manner, energy information is extracted from the radial impact position.

2.2 Collimator

All particles enter the instrument through aperture B1 and pass through a baffle system that prevents forward scattering of photons and particles through the use of serrated blackened (CuS) surfaces. A pair of horizontal deflection plates sweep out charged particles with energies per charge less than ~ 100 keV/e from the converter surface, and a small broom magnet deflects electrons with energies <200 keV. The required deflection plate voltages are ~ 5 kV. The collimator is fan shaped to provide the desired wide azimuth acceptance, while the elevation angle acceptance is defined by the heights of the B1 and S1 slits. A gas-tight shutter located behind S1 can be closed on command to protect the converter surface during launch and during the perigee portion of a low-earth orbit.

2.3 Conversion

Neutral atom fluxes are generally orders of magnitude lower than charged particle fluxes. In the case of the cleft ion fountain, for example, the expected peak fluxes of less than ~ 100 eV neutral atoms are between $\sim 10^3$ and $\sim 10^5$ (cm² sr s) at a distance of several thousand kilometers.¹⁶ Hence, a highly efficient ionization mechanism is required to obtain images of this source region on reasonably short time scales. The approach taken here is to use a low work function converter surface for converting atoms with positive electron affinity to negative ions. This type of charge exchange process works well for H and O atoms that have high electron affinities (0.75 and 1.46 eV). Particularly low work functions are obtained with monocrystalline tungsten W(110) substrates coated with a thin layer (~ 0.6 monolayer) of Cs (see Ref. 17). The Cs overlayer reduces the work function (to ~ 1.5 eV) and, in combination with the high-electron density of the W substrate, facilitates the electron transfer to the reflected particle.¹² Conversion studies, which have primarily focused on H and D because of their importance to fusion machines, have provided H⁻ yields of up to 67% under ideal laboratory conditions.¹¹ In contrast, only a few experimental measurements exist for the conversion efficiencies of O and He atoms. These have indicated high negative ion yields of 66% for O (see Ref. 18) and 14% for He (see Ref. 19), respectively. Because optimal control of the thickness of the Cs layer is probably more difficult to achieve in flight than in a laboratory environment, we prudently assume a somewhat lower conversion efficiency because of a thicker Cs coverage (Table 1). The results of model calculations for the conversion efficiency from a Cs/W(110) surface as a function

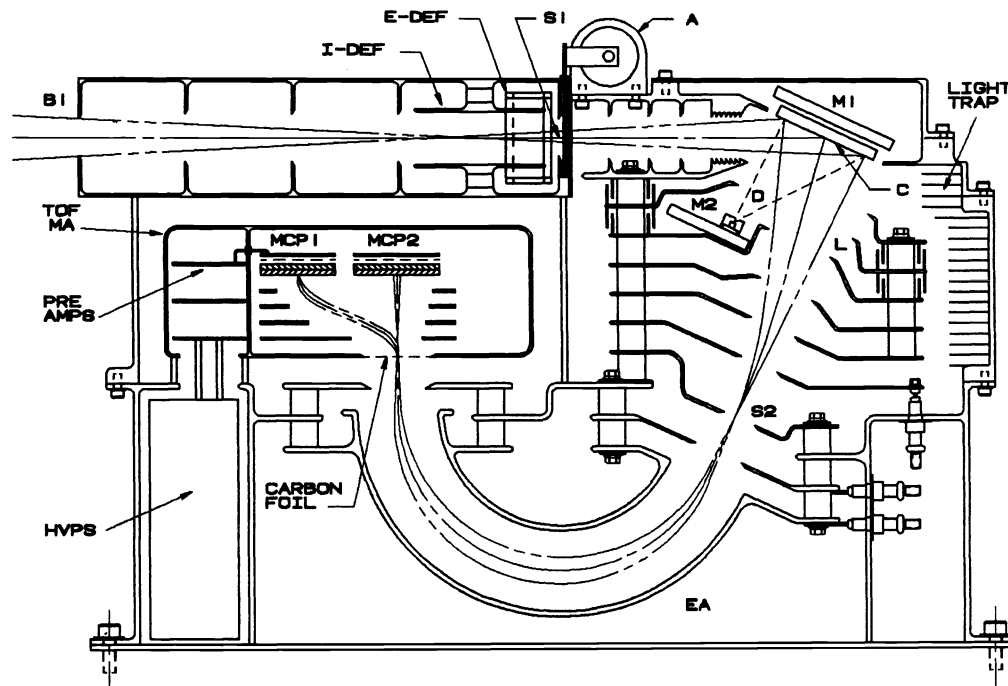


Fig. 1 Schematic drawing of the ILENA instrument with principal components. The entrance collimation system with elevation angle acceptance slits B1 and S1, ion and electron deflectors I-DEF and E-DEF, conversion surface C, cesium dispenser D, secondary electron guiding magnets M1 and M2, extraction lens L, energy limiting slit S2, spherical electrostatic analyzer EA, and the TOF mass analyzer MA.

Table 1 ILENA instrument summary for the HI-LITE mission.

Energy Range	: 10 eV to ~ 300 eV
Resolution	: ~ 5 steps
Mass Species	: H, O, He
Field of View	
Azimuth	: 8°
Elevation	: 90°
Angle Resolution	
Azimuth	: 10°
Elevation	: 10°
Conversion Efficiency	: 0.1
TOF efficiency ($\epsilon_e \cdot \epsilon_b \cdot T_d$)	: 0.4
Geometric Factor	: $2 \times 10^{-1} \text{ cm}^2\text{-sr}$

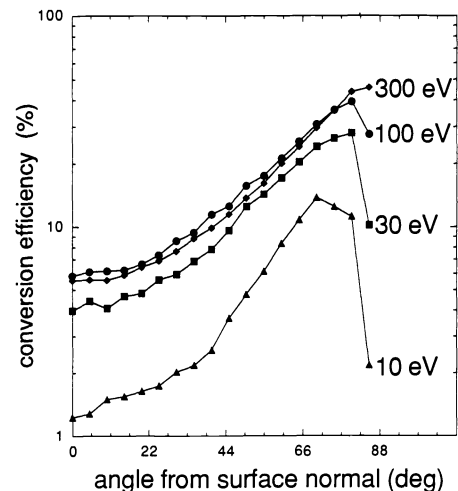


Fig. 2 Conversion efficiency for H reflected from a W(110) surface covered with 0.6 monolayer of Cs as a function of impact angle.

of impact angle are shown in Fig. 2 for the case of an optimal Cs coverage. A more detailed description of the derivation can be found in Ref. 20.

The conversion unit consists of individual azimuthal facets each aligned on a conical surface centered about the axis of rotational symmetry. The width of each facet is primarily driven by the azimuth angle resolution requirements. For the HI-LITE instrument,³ nine facets, each spanning 10 deg in azimuth, were considered. The optimal orientation of the converter surface represents a trade-off between the sensitivity and energy resolution requirements and the size and

weight constraints imposed by the mission. The impact angle of ~65 deg from the surface normal considered here provides a high conversion efficiency (Fig. 3) and high geometric factor with an acceptable converter size.²⁰ As discussed in Sec. 2.4, to achieve good energy resolution requires a narrow angular spread in the reflected ions and, thus, near-specular reflection. For an impact angle of ~80 deg, the expected full-width at half-maximum angular spread of the reflected ions is $< \pm 10$ deg (see Ref. 10) while the conversion efficiency remains high (Fig. 2). However, at this incidence angle the geometric factor is reduced by a factor of 2.5 compared to

an impact angle of 65 deg. The final choice for the impact angle is mission dependent and will be a compromise between the above parameters.

The converter unit includes a Cs dispenser (D) and a heater for baking the surface to remove undesired adsorbate contaminations. This allows for periodically reconditioning the converter surface during flight when needed. As discussed above, the ideal Cs-layer thickness is somewhat less than a monolayer. To verify the condition of the surface, we must measure its work function, because this is the determining parameter for the conversion efficiency. We accomplish this by illuminating individual azimuth segments with light from several (three) laser diodes at different wavelengths. The wavelengths of the laser diodes are strategically selected to obtain a relative measure of the work function at key points near the minimum of the work function curve.¹⁷ Photoelectrons emitted from the converter surface are collected on a positively biased anode with the aid of a guiding magnet (M1-M2). This current provides a measure for the conversion efficiency because the photon and negative ion production rates are both governed by the work function of the surface. During this operation the entrance slit shutter is closed to prevent interference by external EUV light.

The required regeneration frequency will depend on the rate of deterioration of the surface. Special care must be taken to prevent contamination of the converter surface at launch and from low-altitude exospheric gases. Diffusion of neutral spacecraft outgassing products into the sensor can be kept negligible compared to the internal sensor pressure through proper spacecraft mounting techniques.²¹ Generally, if the gas load to the converter surface is kept to less than one monolayer ($\sim 10^{15}$ atoms/cm²), the effects on conversion efficiency are expected to be small. For example, at altitudes of $\sim 1 R_e$ the expected average ram flux of H, the dominant constituent, is $< 10^8$ atoms/(cm² s), thus requiring more than 100 days for a monolayer of H to form (assuming perfect sticking). The entrance slit shutter will be closed during launch and during the low-altitude portion of a satellite orbit to protect the conversion surface. In the case of the proposed HI-LITE mission, we conservatively estimate that regeneration of the surface will not be necessary more frequently than every few days.

Because the primary gas load to the converter stems from the instrument internal residual gases, a clean ultra-high vacuum (UHV) must be maintained throughout the operational period of the sensor. For example, at an internal residual gas pressure of 10^{-9} Torr, and assuming a sticking probability of unity, a single monolayer would form in about 40 min. However, the surface degradation resulting from adsorbed gases depends to a large extent on the chemical properties of the molecules or atoms. Thus, materials that outgas electro-negative atoms and molecules, such as F and Cl, must be avoided. Hence, only metal and ceramic materials will be used in interior structures and surfaces. Standard space instrumentation techniques for maintaining a high degree of chemical cleanliness within the sensor will be used. These include thorough cleaning and vacuum bake out of individual components, assembly under dry nitrogen clean-hood conditions, and vacuum bake out of the entire instrument after assembly with a subsequent dry-N₂ purge until launch. The converter substrate itself will be subjected to a high-temperature bake out prior to installment into the sensor. A

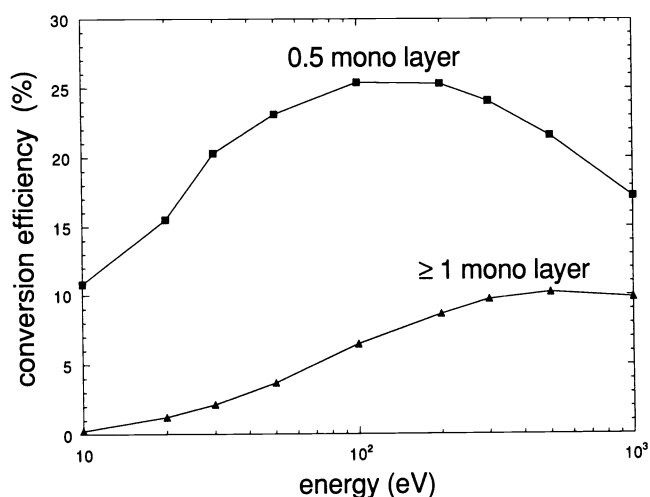


Fig. 3 Calculated conversion efficiency for hydrogen at an impact angle of 65 deg reflected from a W(110) surface covered with 0.6 monolayer or a thick layer (≥ 1 monolayer) of Cs taking into account the ionization efficiency and reflection probability.

separate bypass venting port will provide a tenfold-enhanced pumping speed to outer space. With these precautions, we expect that the final steady state pressure within the sensor can be kept significantly below 10^{-9} Torr throughout the operational phase of the orbit.

2.4 Extraction Optics

After acquiring a charge, the negative ions are accelerated away from the surface by a wide aperture lens system (L). The potential distribution of the lens (Fig. 4) was designed to efficiently collect the ions produced on C and to focus them in the plane of the S2 slit. Equipotentials are parabolically shaped over much of the interior region to minimize spherical aberrations. Figure 5 illustrates the energy dispersive properties of the acceleration lens; reflected ions are focused toward larger radii with increasing energy. To transmit the desired energy range from 10 to about 300 eV, the collimating slit S2 needs to be ~ 1 cm wide. Angle scattering about the specular reflection direction at the converter broadens the focal spot. As seen from Fig. 5, the broadening for ± 10 -deg scatter is much less than the energy dispersion. Hence, it is possible, in principle, to extract moderate energy information from the radial position, provided that angle scattering and energy straggling are sufficiently small. As discussed earlier, this requires near-grazing incidence impact angles.

To minimize the effects of nonspecular reflection on azimuth resolution (out of plane of Fig. 1), we must apply a high extraction field near the surface and have a high ratio of final-to-initial energy. A lens extraction voltage of about 10 kV represents a good compromise between the requirements for energy dispersion and azimuth angle resolution. With this voltage, the beam spread in the azimuthal direction is sufficiently small to allow for ~ 5 -deg azimuth resolution.

2.5 Energy Analyzer

Before entering the energy analyzer (EA) all ions are further accelerated to ~ 20 kV between the object slit S2 and the Herzog field limiting plate H1. The spherical analyzer is

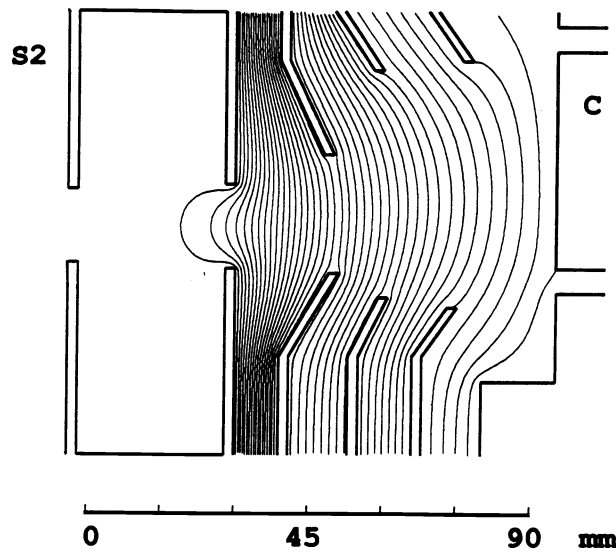


Fig. 4 Equipotential lines in extraction lens between converter surface C and exit slit S2.

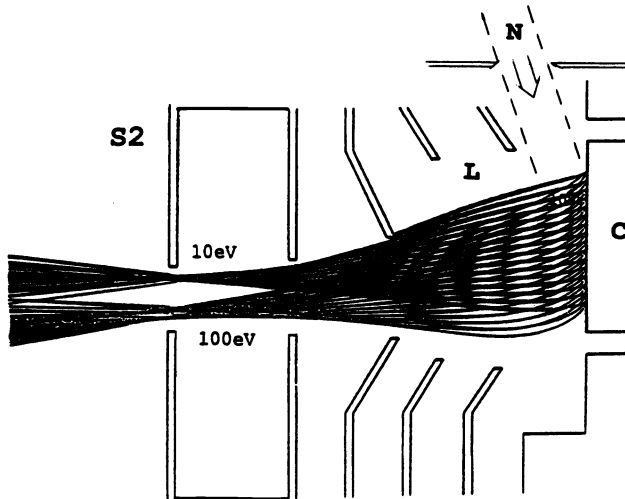


Fig. 5 Trajectories of ions originating at the converter surface with energies of 10 and 100 eV, respectively. Reflection angles are ± 10 deg from the specular direction (65 deg). Total acceleration potential to S2 is 10 kV.

geometrically configured to image the entire object slit S2 onto the C foil of the TOF mass analyzer. Because the image is inverted (magnification ~ 1), the more energetic ions are mapped to smaller radii. These elevation angle focusing and radial dispersion properties are illustrated in Fig. 6. To achieve this unity transmission requires an unusually wide plate separation for the spherical analyzer. Although this condition does not significantly affect the imaging properties of the analyzer, it does lead to a small analyzer constant (~ 1.2) and, consequently, high plate-to-plate voltages. However, since these voltages need not be scanned they can be directly derived via voltage dividers from the static TOF acceleration voltage. The analyzer further provides for the desired additional UV-light filtering by introducing multiple surface reflections and solid angle attenuation.

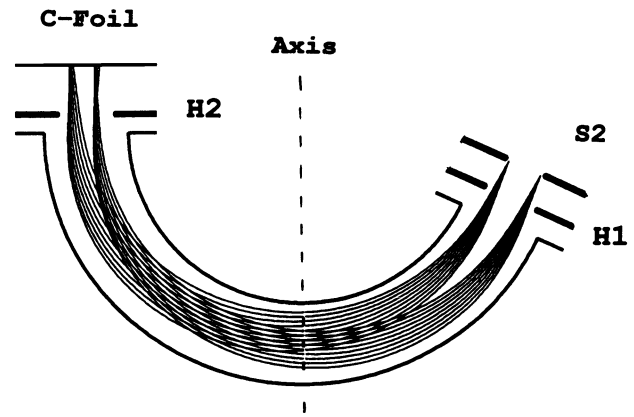


Fig. 6 Ray tracing of ions in the spherical electrostatic analyzer originating at the object slit S2 with angle and energy dispersion defined by the extraction lens. Geometric parameters are 62-mm center radius, 155-deg sector angle, and 24-mm plate separation.

2.6 Time-of-Flight Mass Analyzer

Following deflection in the EA, the ions are postaccelerated to the C foil at a potential of +25 kV. The mass analyzer is a TOF device using the conventional C-foil technique.²² The actual design is similar to the CODIF and TEAMS spectrometer²³ on the CLUSTER and FAST missions. The principal components of the TOF mass analyzer are the C foil, a drift path for the ions and neutral particles, a secondary electron extraction optics, and two MCP detector units. Secondary electrons produced on the back side of the C foils are accelerated and focused onto MCP1 (Fig. 1), producing both the start pulse for the TOF and providing radial and/or position information. The signal produced at MCP2 by the primary particle provides the stop pulse. The azimuthal position can be provided by either MCP1 or MCP2. Both the start and stop signals are obtained from low (50%) transmission grids placed behind the respective MCPs. The anode behind the MCP1 grid is divided into ~ 5 radial segments providing moderate energy resolution. Similarly, the anode behind the MCP2 grid is divided into nine sectors providing 10-deg azimuth angle resolution. The position and TOF electronics are contained within the high-voltage (HV) bubble. The encoded information is transmitted across the HV interface via fiber optics.

Because this instrument is sensitive to atoms with positive electron affinities, the TOF mass analyzer needs only to be able to separate H, D, He, and O in a single charge state. Figure 7 shows a simulated mass spectrum for a $2 \mu\text{g}/\text{cm}^2$ C foil and for the typical abundances expected in the upper ionosphere at $\sim 1000\text{-km}$ altitude. The expected mass resolution of the TOF mass analyzer for all ions of interest is given in Table 2.

3 Discussion

Early spaceflight instruments performed differential measurements of ion distributions and required scanning in multidimensional parameter space for obtaining distribution functions. While most newer instruments are imaging spectrographs,^{8,23,24} they still rely on plate voltage scans for covering the energy range. In the ILENA instrument we have carried the development one step further by simultaneously

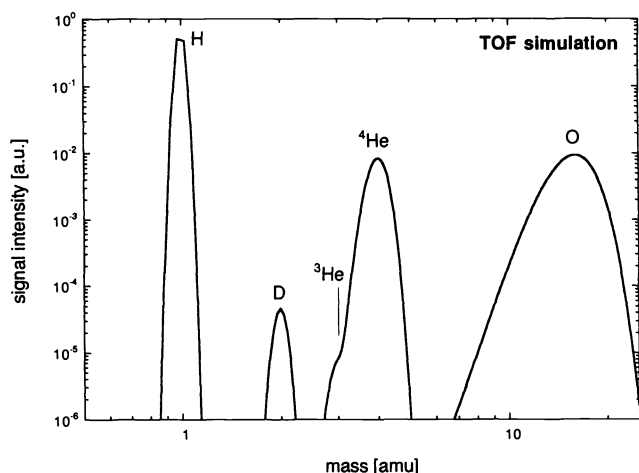


Fig. 7 Simulated mass spectrum for the TOF mass analyzer using ion abundances occurring at an altitude of 1000 km. The ion abundances and the mass resolution used for this simulation are given in Table 2.

Table 2 Mass resolution of the TOF mass analyzer at an ion energy of 25 keV for a C-foil thickness of approximately $2 \mu\text{g}/\text{cm}^2$. Relative abundances at an altitude of 1000 km are given. Resolution data is adapted from measurements reported in Ref. 22.

species	abundance [relative to H]	energy per nucleon [keV/nuc]	$\Delta\tau / \tau$	$m / \Delta m$
^1H	1	25	0.028	17.8
^2D	$1.8 \cdot 10^{-4}$	12.5	0.039	12.8
^3He	$5 \cdot 10^{-5}$	8.33	0.05	10.0
^4He	0.1	6.25	0.06	8.3
^{16}O	1	1.56	0.14	3.7

imaging over the three parameters azimuth angle, energy, and mass. This triple spectrographic imaging eliminates the need for a duty cycle, thus increasing sensitivity by the ratio of cycle period to accumulation time per cycle step. Compared to conventional energy scanning analyzers (16 energy steps), the ILENA provides a ~ 20 times higher sensitivity. The absence of fast high-voltage scanning provides the added benefit of simplified and lighter HV supply design.

The requirements on mass resolution on an instrument designed for imaging the high-latitude ionospheric acceleration regions are rather modest when compared with proven designs presently under development for spaceflight.²³ At the very least, a resolution of H and O at the 0.1% level is fully adequate for this type of investigation. For investigations of the interstellar neutral wind, we would ideally like to be able to additionally resolve D, ^3He and ^4He at their isotopic abundance levels (see Table 2). Despite its low-electron affinity (0 eV), the ionization efficiency reported for He is remarkably high.¹⁹ Although the He^- ion is unstable as it decays with a

mean life²⁵ of $> \sim 10 \mu\text{s}$, a large fraction ($> 97\%$) of the converted He is expected to arrive in the TOF section because its transit time from the converter to the C foil is only $\sim 0.25 \mu\text{s}$. While the proposed design easily separates D and He, its resolution is marginal for ^3He and ^4He . Further improvements in mass resolution can be achieved with thinner C foils and/or higher postacceleration voltages.

The rotational symmetry of this design makes it possible to obtain a wide field of view (FOV) in the azimuth direction coupled with simultaneous imaging of the incident azimuth angles. Although the azimuth acceptance of the present optics is geometrically limited to ~ 160 deg due to the flat FOV, such an instrument would nevertheless be able to cover more than 90% of the full 4π solid angle from a spinning spacecraft. Using a conical entrance FOV would permit us coverage twice per spin. For source regions of spatially limited extent, such as the auroral acceleration region, a 2π instantaneous FOV provides no further benefits in geometric factor. The azimuth resolution that can be achieved with this type of instrument is intrinsically limited by the width of the entrance slit S1, the radius of the conversion surface, and the magnitude of the lens extraction voltage. For a 1-cm^2 entrance slit area and a 10-cm radius, a resolution of ~ 5 deg is feasible in principle.

The ability to detect very low fluxes of neutral atoms relies on a low background from all sources. Although the TOF coincidence technique used here is inherently less sensitive to background, the large fluxes of EUV photons from the Sun, geocorona, and the Earth's limb would cause a serious background problem if not suppressed. In the proposed design, the required attenuation is achieved by a combination of efficient light traps,²⁶ multiple and diffuse surface reflections (three), and low reflectivity "black" surface coatings²¹ at critical places. The photon background rate at the detectors due to geocoronal EUV is estimated to be $< 10\text{s}^{-1}$. At this rate, the probability for chance coincidences from photons producing a secondary electron at the C foil and at the stop detector within the flight time window is negligibly small ($< 0.01\text{s}^{-1}$). Besides the photon background, the two other major potential sources of background are photoelectrons from the converter surface and negative ions produced by dissociative attachment of photoelectrons to residual gas molecules. Due to the low work function of the converter surface, photoelectrons will be produced in great quantities. These electrons would generate unacceptably high chance coincidence rates if allowed to reach the TOF system, even though individually they could be discriminated against due to their short flight times. To divert and trap these electrons, a weak magnetic field is applied between the pole faces of M1 and M2 (Fig. 1). As discussed in Sec. 2.3, the same trap serves as a collector for the photoelectrons during converter surface regeneration. The negative ion background is minimized by maintaining a low-residual gas pressure inside the instrument. Furthermore, by quickly accelerating the photoelectrons away from the sensitive region, the probability for electron attachment is further reduced because the cross section for this process is inversely proportional to the kinetic energy. For example, at a partial H_2O pressure of 1×10^{-9} Torr, the negative ion production rate is estimated to be about 1s^{-1} . Because these ions have very low energies (< 1 eV), they are tightly focused onto the low-radius part of the S2 collimator where they are efficiently eliminated.

Negative ions produced from the ambient neutral atmosphere in the ram direction have low energies and are blocked by the S2 collimator in the same way.

Sputtered negative ions, originating from energetic ion bombardment on the converter surface, also represent a potential source of contamination. Of primary concern are adsorbed gases because W or Cs ions have very low transmission efficiencies in the TOF section and can easily be recognized by their unique heavy mass. Because energetic ions are abundant in the Earth's orbit, it is essential to reduce their fluxes. In the present ILENA design, ions with energies up to 100 keV/e are rejected by an electrostatic deflector in the entrance collimation system.

A critical element of the ILENA instrument concept is the neutral to ion conversion technique. As discussed in Sec. 2.3, the optimum conversion efficiency is attained with a ~ 0.6 monolayer of Cs on a W(110) substrate, but reasonably high efficiencies are also obtained with somewhat thicker layers. The problem of maintaining a near-optimum layer thickness is facilitated because thicker layers evaporate quickly due to the high vapor pressure ($\sim 10^{-6}$ Torr) of Cs at room temperature, leaving behind a stable monolayer that has a vapor pressure several orders of magnitude lower.¹⁷ After reconditioning the surface for an estimated 10 to 100 times during a mission, the average contamination with Cs on internal surfaces of the sensor, other than the converter itself, is expected to be less than one monolayer. Because the vapor pressure of a Cs monolayer is very low, migration of Cs between different parts of the instrument is minimal. Nevertheless, special design precautions are taken to guard all internal high-voltage insulators (for example, individual guard baffles). No deterioration of the MCP detectors, which are well shielded behind the C foils, is expected at the estimated Cs evaporation levels.

While cesiated conversion surfaces have been thoroughly investigated in the laboratory environment, to our knowledge they have thus far not been applied to space plasma instrumentation. Our goal in our ongoing research effort is to develop this novel technology for use on spacecraft instrumentation. Because surface cleanliness is of particular concern for Cs-W surfaces, other candidate surfaces that provide low work functions but are less susceptible to degradation, such as, for example,^{27–28} Cs-O and Ba, are being investigated in parallel for this instrument.

4 Conclusions

We have developed the concept of a new type of mass spectrograph that is specifically designed for imaging low-energy neutral atom fluxes from space platforms. The instrument covers the energy range from about 10 to 300 eV, and the mass range from 1 to 20 amu with mass resolution sufficient to separate the major masses of interest H, D, He, and O. The instrument's large geometric factor and wide FOV combined with high conversion, transmission, and detection efficiencies (Table 1) and 100% duty cycle give it the necessary high sensitivity for imaging the low-energy outflow from the high-latitude ionospheric acceleration regions. Based on the model calculations reported in Ref. 20, we estimate count rates of ~ 1 to 10 Hz in a 10-deg azimuth pixel for the HI-LITE orbit, thus providing a well-defined image within about 5 min.

The energy range (10 to 300 eV) covered by the proposed new instrument is presently inaccessible to conventional C-foil transmission techniques proposed for measuring the more energetic > 1 keV/nucleon neutral atom (ENA) fluxes. This very low energy regime carries some of the highest neutral atom fluxes found in the magnetosphere. For example, the luminosity of the brightest areas of the high-latitude acceleration region¹⁶ substantially exceeds that of the ENA fluxes from the ring current.² Surface ionization is thus a new technology that ideally complements the energy range covered by the foil transmission technique, and that offers great potential benefits to future ionospheric, magnetospheric, planetary, and astrophysical investigations.¹⁵

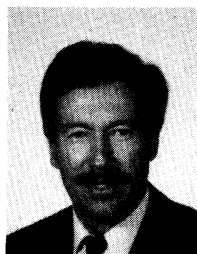
Acknowledgments

We acknowledge the technical and engineering support provided by T. Sanders. This research was supported by Lockheed Independent Research and by the Swiss National Science Foundation.

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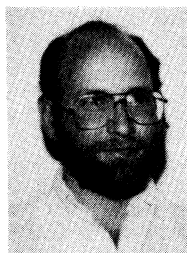
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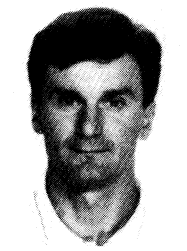
and space plasma research. He is the author of more than 35 papers on ion optics and space plasma research.



mission-definition teams. He has spent his entire professional career at the Lockheed Palo Alto Research Laboratory. He received his PhD in nuclear physics from Stanford University in 1967. He received an MS in physics from Stanford in 1962 and BS degrees in physics and mathematics from Oregon State University in 1959.



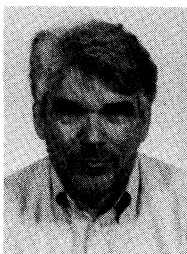
associate research scientist and was promoted to research scientist in 1989. He is the author of more than 60 publications in journals and conference proceedings. Fuselier is a member of the American Geophysical Union and has served on the Space Physics and Aeronomy Education Committee since 1990.



He has published papers in the fields of ion sputtering, electron-stimulated desorption, ion optics, physical chemistry, laser interaction with solids and particles, and extraterrestrial physics.



noble gases in terrestrial samples. Returning to the University of Bern, he continued his research on terrestrial samples and, simultaneously, he participated in the development and calibration of the ISEE-3 Ion Composition Instrument. After the successful launch of ISEE-3, he took an active role in the data analysis and interpretation with special emphasis on the abundances of minor elements in the solar wind, the isotopic composition of solar wind helium, and the dynamics of minor ions in the solar wind plasma. Presently, he is involved as a member of an international team in the development of the CELIAS experiment on the SOHO payload, and in collaboration with a team from the University of Maryland, in the development of the WIND-MASS and the WIND-SWICS experiments.



osphere Center, Arecibo Observatory. In 1981, he joined the scientific staff of the NASA/Goddard Space Flight Center. His current research interests are in upper-atmospheric and magnetospheric physics.

Stephen A. Fuselier is a research scientist at Lockheed Palo Alto Research Laboratory. His major areas of interest are solar wind magnetospheric coupling and bow shock/fore shock phenomena. He received a BS in 1981 from the University of Southern California and a MS in 1983 and a PhD in 1984 from the University of Iowa, all in physics. He held a two-year postdoctoral position at Los Alamos National Laboratory. He joined Lockheed in 1986 as an

Peter Wurz obtained an engineering degree in electronics and attended the Technical University of Vienna where he received a MS and PhD in physics. From 1990 to 1992 he performed postdoctoral work at Argonne National Laboratory, Chicago, Illinois, in the field of molecular mass spectroscopy of fullerenes, biomolecules, and polymers. Since 1992 he has held a position at the University of Berne, Switzerland, in the mass spectroscopy group.

Peter Bochsler is an associate professor of physics at the University of Bern, Switzerland. His main research interests include space physics, solar wind, and history of the Sun and of the solar system. He graduated from the University of Bern with a thesis on cosmic-ray-produced noble gas isotopes in meteorites. His PhD thesis dealt with 3H (tritium) in lunar soil. He spent two years at the Weizmann Institute of Science in Rehovot, Israel, investigating

Federico Herrero received the BS degree from Spring Hill College in 1965 and the MS and PhD degrees from the University of Florida in 1966 and 1968, respectively, all in physics. Following postdoctoral work at Johns Hopkins University, he joined the faculty at the University of Puerto Rico where he held the positions of professor and chairman of the Physics Department and performed thermospheric physics research at the National Astronomy and Ion-



Mark F. Smith is a space physicist at the Goddard Space Flight Center (GSFC), Maryland. His major areas of research are in the magnetopause, magnetospheric-ionospheric coupling, and space plasma instrumentation. He received a BSc (honors) in physics and astronomy in 1980 from University College London and a PhD in upper-atmospheric physics in 1984. He was a research assistant at Mullard Space Science Laboratory, United Kingdom, from 1984 to 1987. From 1987 to 1990, he was a senior research scientist at the Southwest Research Institute. He joined the Laboratory of Extraterrestrial Physics at NASA/GSFC in 1991. Smith has published more than 60 papers in various professional journals. He is a member of the American Geophysical Union.

Thomas S. Stephen: Biography and photograph not available.