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LOW ENERGY NEUTRAL ATOM IMAGING TECHNIQUES

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ABSTRACT

The potential scientific return from low energy neutral atom (LENA) imaging of the magnetosphere is extraordinary. The technical challenges of LENA detection include (1) removal of LENAs from the tremendous ambient UV without losing information of their incident trajectories, (2) quantification of their trajectories, and (3) obtaining high sensitivity measurements. Two techniques that have been proposed for this purpose are based on fundamentally different atomic interaction mechanisms between LENAs and a solid: LENA transmission through an ultrathin foil and LENA reflection from a solid surface. Both of these methods provide LENA ionization (for subsequent removal from the UV by electrostatic deflection) and secondary electron emission (for start pulse generation for time-of-flight and/or coincidence). We present a comparative study of the transmission and reflection techniques based on differences in atomic interactions with solids and surfaces. We show that transmission methods yield an order of magnitude greater secondary electron emission than reflection methods. Transmission methods are shown to be sufficient for LENA energies of approximately 1 keV to greater than 30 keV. Reflection methods using low work function surfaces could be employed for LENA ionization for energies less than several keV.

1. INTRODUCTION

Neutral atom imaging promises to be a revolutionary technique to view a variety of solar system plasmas, for example the structure and dynamics of the terrestrial magnetosphere,^{1,2} the Saturnian environment,^{3,4} coronal mass ejections⁵ (CMEs), and the heliosphere.^{6,7} Additionally, this technique can be used to observe the release of neutral material in space.⁸ Since the bulk of the solar system plasma is in the energy range of 0.5 to 10s of keV and the charge exchange cross sections for neutral atom creation decrease rapidly at energies above approximately 20-30 keV,⁹ low energy neutral atom (LENA) imaging is an important technique for investigation of solar system plasmas.^{2,10}

The first attempt to detect neutral atoms in space utilized a simple carbon foil to convert neutral atoms to ions and electrostatic deflection to remove them from the ambient UV.¹¹ Other techniques used for LENA detection include a slotted disk velocity analyzer¹² and secondary ion emission.¹³ Recently, LENA imaging techniques based on LENA reflection from a surface¹⁴ or transmission through an ultrathin foil^{2,10} have been proposed. Both of these novel techniques involve LENA ionization, electrostatic deflection, and time of flight/coincidence detection, although the mechanisms for LENA ionization and secondary electron emission are based on fundamentally different projectile solid interactions. In this paper, we compare the transmission and reflection techniques over the LENA energy range of 100 eV to 10s of keV.

The general approach for LENA imaging,² shown in Fig. 1, is related to the basic concepts of energetic neutral atom (ENA) imaging.^{15,16} First, incident ions must be rejected from entering the imager; this is typically performed by a collimator with alternately biased plates. Second, LENAs must be separated from the ambient UV; one possible technique^{2,14} involves LENA ionization and subsequent electrostatic deflection

Fig. 1. Basic approach to LENA Imaging.

into the detector section (although direct UV blocking techniques are an emerging technology for LENA detection¹⁷). Third, the approximate energy of the LENA is determined by electrostatic E/q analysis. Finally, in the detector section, trajectory information of the incident LENA is obtained and time-of-flight and coincidence schemes using secondary electron emission are utilized to measure LENA masses and reject penetrating radiation, respectively. For a spinning spacecraft, image resolution is determined by the azimuthal resolution, which is fixed by the collimator, and the polar resolution, which depends on both the trajectory aberrations induced by components in the LENA imager (e.g., angular scattering by LENA interactions with a foil of reflecting surface) and the intrinsic position resolution of the detector.

Two steps in the general LENA imaging approach described above affect the LENA trajectories between the collimator and the detector: LENA ionization for removal from the UV by electrostatic deflection and secondary electron emission employed for time-of-flight and/or coincidence. In this paper, we examine LENA ionization and secondary emission resulting from LENA transmission through ultrathin foils and LENA reflection from surfaces. Since the goal of LENA imagers is high detection efficiency and accurate measurement of the incident LENA trajectory, high-efficiency techniques must be employed for LENA ionization and secondary electron emission with minimal disturbance of their trajectories.

2. LENA IONIZATION

The primary technical challenge of detecting neutral atoms is their separation from the ambient UV (primarily Ly- α) to which neutral atom detectors (e.g., microchannel plate (MCP) detectors and channel electron multipliers) are sensitive. LENA imagers typically employ thick composite foils to block the UV,^{1,18} although at low energies associated with LENAs a thick foil induces significant angular scattering, energy straggling, and even complete LENA stopping. As described above, a better technique to remove LENAs from the ambient UV is LENA ionization and subsequent electrostatic deflection into the detector section of the instrument. Maximization of LENA ionization is critical since the geometric factor of a LENA imager is directly proportional to the ionization probability.¹⁰ LENA ionization has been proposed using either transmission through an ultrathin stripping foil^{2,10} or reflection from a Mo surface.¹⁴

2.1 Ionization via LENA Transmission through ultrathin carbon foils

In the LENA energy regime (approximately 100 eV to > 30 keV), projectiles that enter a solid rapidly undergo electron loss and capture interactions so that charge state equilibrium of a projectile beam occurs within several Angstroms of penetration into the solid.¹⁹ Therefore, the exit charge state distribution of projectiles transiting an ultrathin foil is independent of their incident charge state.²⁰ The probability P^+ that a projectile exiting an ultrathin foil is in charge state $q = +1$ shown in Fig. 2 for H, He, and O. For each species, P^+ increases with increasing incident energy. For H, P^+ ranges from approximately 5% at 1 keV to 42% at 30 keV, whereas for both He and O, P^+ ranges from 1-2% at 7.5 keV to 8-9% at 30 keV.

Previous studies¹⁹ of exit charge state distributions of H and O transiting $0.5 \mu\text{g cm}^{-2}$ carbon foils have shown that the probability of hydrogen exiting an ultrathin foil as H^+ is greater than probability of exiting as H^- , whereas the probability of oxygen exiting as O^+ is less than the probability of exiting as O^- . Since the instrument geometric factor is directly proportional to the conversion efficiency,¹⁰ an instrument for imaging hydrogen would focus on conversion of H LENAs to H^+ , whereas for imaging oxygen the emphasis might be on detection of O^- . However, imaging both positively and negatively ionized LENAs by periodically alternating the bias on the electrostatic deflectors may be impractical. Since H is the dominant component of solar system plasmas and no negative ions were observed in the He exit charge state distributions, a LENA imager using a conversion foil for LENA ionization should focus on detection of LENAs converted to positive ions.

2.2 Ionization via LENA Reflection from Surfaces

The charge state distribution of incident ions scattered from surface has been extensively.²¹⁻²³ At low energies ($< 5 \text{ keV}$), incident ions that are reflected from a point below the solid surface (i.e., that have penetrated the surface) have well-defined reflected charge state distributions indicating charge state equilibration.²³ The population of charge states in the resultant equilibrium charge state distribution is dependent on the electron capture and loss cross sections of the charge states in the beam, and several charge exchange interactions per beam projectile is required for a beam in initial charge state q to equilibrate. Alternately, incident ions that are reflected by surface atoms spend minimal time interacting with them, so a beam reflected from surface atoms does not have the opportunity to equilibrate. Consequently, the reflected charge state distribution will be have a disproportionate fraction of atoms in the incident ion charge state.²³ For example, an incident neutral beam reflected from surface atoms will be composed of more neutrals and fewer positive ions than an equilibrated reflected beam.

For LENA ionization from surface reflection, we are interested in the fraction of incident LENAs that are ionized. Although no detailed studies have been performed on neutral ionization via reflection, we can estimate the maximum probability of ionization of a reflected LENA. A neutral H beam incident on a surface will be driven from a charge state of $q = 0$ to some equilibrium charge state distribution. If the fraction of ions in charge state $q = +1$ are dependent only on the fraction in charge state $q = 0$ (i.e., double electron capture or loss in one collision cannot occur), then the *maximum* fraction of reflected atoms in $q = +1$ will correspond to its equilibrium value. Therefore, since the observed equilibrium charge state distributions of H^+ backscattered from carbon^{24,25} and H transmitted through carbon foils (Fig. 2) are almost identical, the maximum ionization probability of surface reflected H^0 should be equal to the probability of ionization for transmission shown in Fig. 2 (with minor variations due to different surface chemistry.^{24,25,26} We can therefore conclude that to LENA ionization probability (to charge state $q = +1$) via foil transmission is likely to be equal to or greater than that for surface reflection

Fig. 2. Probability of H, He, and O exiting a $0.5 \mu\text{g cm}^{-2}$ carbon foil as positive ions.

However, reducing the work function of the reflecting surface increases the probability that reflected projectiles with a positive electron affinity will leave the surface as negative ions. This technique has been examined for applications such as negative ion sources²⁷⁻²⁹ and neutral particle detectors.³⁰⁻³² Low work function surfaces used for conversion of low energy (< 2 keV) H^0 to H^- include ThO_2 which yields an negative ionization efficiency ϵ (number of scattered H^- per incident H^+) of 6% at 300 eV,³⁰ cesiated tungsten (Cs-W) with $\epsilon \approx 33\%$,^{33,34} CsO_2 ,³⁵ Cs with $\epsilon \approx 6\%$,³⁶ and Ba with $\epsilon \approx 4\%$.³⁷ These yields are relatively high and could result in efficient H and O ionization for LENA detection at energies less than a few keV.

Cesiated tungsten surfaces have been extensively investigated for incident beam angles corresponding to specular reflection.^{33,34} First, the ionization probability of scattered ions is dependent on the energy component normal to the surface, with a maximum at approximately 7 eV.³⁷ Consequently, at energies greater than approximately 1 keV, the probability of negative ionization and, therefore, ϵ decrease.^{37,38} Additionally, ϵ is highly sensitive to the fractional coverage of W by Cs.³⁴ These experiments were typically performed at UHV pressures (< 10^{-9} torr) since contamination of the reflecting surface can change its work function. Surface contamination is an acute concern in the spacecraft environment, so maintenance of the reflecting surface integrity is crucial.

3. ANGULAR SCATTERING

Angular scattering of LENAs arising from surface reflection or transmission through an ultrathin foil results in the loss of information about the trajectory of the incident LENA and degrades the resultant LENA image. Minimization of scattering is clearly a priority in LENA imager design. Angular scattering is a quasi-elastic phenomenon resulting from coulombic interactions between a projectile and atoms in the solid. Based on conservation of energy and momentum for a binary collision, the final energy of an incident atom of mass m_1 at an incident energy E scattering from an atom with mass m_2 ($\geq m_1$) initially at rest is

$$E_f = E \left(\frac{\cos \theta_s + (\mu^2 - \sin^2 \theta_s)^{1/2}}{1 + \mu} \right)^2 \quad (1)$$

where $\mu = m_2/m_1$ and θ_s is the laboratory scattering angle of m_1 . For an increase in μ , which can be controlled by proper selection of the solid material, the scattered projectile energy E_f approaches its incident energy E .

3.1 Scattering Resulting from Transmission Through Foils

Low energy atomic scattering in ultrathin foils can be treated theoretically as multiple small-angle scattering.³⁹ This approach, which has been experimentally verified,^{40,41} shows that for a particular projectile species and foil composition and thickness, the product of the angular halfwidth $\theta_{1/2}(E)$ and the projectile energy E is equal to a constant C . For a nominal $0.5 \mu\text{g cm}^{-2}$ carbon foil, $C \approx 12$ (deg keV) for incident H, and $C \approx 120$ (deg keV) for incident O. Figure 3(a) shows the scattering halfwidth of H incident on a nominal $0.5 \mu\text{g cm}^{-2}$ carbon foil, 502 Å and 983 Å Lexan foils, and a 502:451 Å composite Lexan:carbon foil. The angular scattering in the $0.5 \mu\text{g cm}^{-2}$ carbon foil is a factor of 7 to 9 less than scattering in the 983 Å Lexan ($C \approx 80$) and Lexan:carbon composite ($C \approx 105$) foils, respectively. The Lexan and composite foils are equivalent to the foil thickness used for UV blocking in LENA instruments and illustrate that imaging techniques employing thick foils are inappropriate for LENA imaging.

Fig. 3. (a) The angular scatter halfwidth $\theta_{1/2}$ is shown as a function of incident H energy for a variety of foils. (b) The polar resolution (Eq. 2) and H transmission through a 40 Å carbon foil are plotted vs. incident H energy.

As stated previously, degradation of a LENA's trajectory information as it transits the imager affects the polar resolution of the instrument. For a LENA imager with two $0.5 \mu\text{g cm}^{-2}$ foils¹⁰ and an intrinsic polar resolution δ_I (determined by the anode position resolution), the polar resolution δ of the imager is

$$\delta(E) = \sqrt{2 [\theta_{1/2}(E)]^2 + \delta_I^2} \quad (2)$$

where $\theta_{1/2}(E) = C/E$. Figure 3(b) depicts the polar resolution $\delta(E)$ for imaging low energy neutral hydrogen as a function of incident energy E for $0.5 \mu\text{g cm}^{-2}$ foils and an intrinsic polar resolution of $\delta_I = 2^\circ$ HWHM. The polar resolution $\delta(E)$ equals $\sim 2.5^\circ$ HWHM at $E = 10$ keV, $\sim 5^\circ$ HWHM at $E = 3$ keV, and $> 10^\circ$ HWHM for $E < 1$ keV. This is sufficient for imaging in an energy range of 1 keV to greater than 30 keV, although experiments are underway to use even thinner foils for less angular scattering.

Also shown in Fig. 3(b) is the transmission probability of H incident on a 40 Å carbon foil as a function of incident H energy. The data, which was computed using the TRIM computer code,⁴² shows that the transmission probability of H is approximately 89% at 0.5 keV, 97% at 1 keV, and nearly 100% at incident energies > 2 keV. Also, for small angle scattering, the energy of the transmitted projectile energy is well-preserved according to Eq. 1.

3.2 Specular Reflection from Surfaces

If we consider a collimated atomic beam incident on a lattice atom, the beam projectiles will be deflected by their coulombic interaction with the atom, forming a cone shaped region downstream of the lattice atom that is inaccessible to the projectiles^{43,45} (see Fig. 4(a)). If an adjacent lattice atom lies within the shadow cone (thick dashed line), it will not contribute to scattering of the incident parallel beam of particles. For an incident projectile of atomic number Z_I and energy E impacting on a lattice atom of atomic number Z_L , a universal expression for the shadow cone radius r as a function of distance d downstream from the lattice atom is⁴⁶

$$\begin{aligned}
r &= a \alpha (1 - 0.12 \alpha + 0.01 \alpha^2), & 0 \leq \alpha \leq 4.5 \\
&= a \alpha (0.924 - 0.182 \ln \alpha + 0.0008 \alpha), & 4.5 \leq \alpha \leq 100
\end{aligned} \tag{3}$$

where $\alpha = (2/a)(Z_1 Z_2 e^2 d/E)^{0.5}$. The Firsov screening length a in Å is⁴⁷

$$a = 0.468 (Z_1^{1/2} + Z_2^{1/2})^{-2/3}. \tag{4}$$

Using these equations, we can determine which surface atoms will contribute to beam scattering.

If the incident angle ψ of a projectile is less a critical angle ψ_c , the shadow cone of a surface atom will overlap with and prevent large-angle scattering from a neighboring surface atom (see Fig 4(b)). Based on the interaction geometry illustrated in Fig. 4(b) and knowledge of the nearest-neighbor distance l between adjacent surface atoms, ψ_c can be derived using Eq. 3. This theoretical approach, which has been experimentally verified,⁴⁸ shows that for a Mo surface ($l \approx 2.7$ Å) $\psi_c \approx 32^\circ$ at 200 eV and $\psi_c \approx 25^\circ$ at 1 keV, and for a Cs surface ($l \approx 5$ Å) $\psi_c \approx 20^\circ$ at 200 eV and $\psi_c \approx 14^\circ$ at 1 keV. Note also that with increasing energy, ψ_c decreases, r decreases, and incident projectiles can penetrate the surface so that fewer projectiles are scattered by surface atoms. At grazing incidence, reflection is analogous to planar channeling in the collective field of the shadowed surface atoms,⁴⁹ and, assuming the surface is atomically clean, the probability of reflection approaches unity. However, as the incident projectile energy increases, the screening parameter decreases, and the projectile is more likely to penetrate into the solid (i.e., the probability of specular scattering decreases).

For clean cesiated surfaces, the reflection coefficient is quite high.³⁴ Polar scattering (the angle between the surface and the surface normal) is approximately specular with a FWHM of the angular distribution relative to the surface normal of 9° and 18.5° for 400 eV incident beams of 85° and 75° relative to the surface normal, respectively.³⁴ Unfortunately, no experiments have been performed that study azimuthal scattering (around the surface normal) which defines the polar resolution δ of a LENA imager.

According to Eq. 1, a high mass atomic species should be used at the reflection surface to ensure minimal energy loss of the reflecting LENA. For example, the energy loss by H scattered from cesiated tungsten is less than 5%.³⁴ However, the energy loss by reflected low energy neutral oxygen would be

Fig. 4. (a) A shadow cone results from scattering of incident ions by a lattice atom. (b) Shadowing of neighboring surface atoms occurs for grazing angles less than a critical angle ψ_c , resulting in specular reflection.

substantial due to its large mass. Furthermore, scattering of LENAs from low mass contaminants on the reflecting surface results in significant energy loss of the LENA.

For angles of incidence less than ψ_c , all projectiles should reflect from aligned rows of surface atoms. The angular distribution of reflected projectiles depends on a variety of factors such as thermal vibrations of the surface atoms and multiple collisions by the projectile at the surface. Deviation from the surface order by surface defects, adsorbed species, or deposited residue can result in non-specular, large-angle scattering. In fact, low energy ion scattering is used to examine these phenomena,⁴³⁻⁴⁵ and the vacuum pressure must be less than approximately 10^{-9} torr to prevent surface contamination.⁴⁵ In the spacecraft environment, surface contamination can originate from a variety of sources, such as adsorption of outgassing species and deposition of sputtered spacecraft material. Consequently, the *in situ* conditioning of the reflecting surface is required.

4. SECONDARY ELECTRON EMISSION (SEE)

Secondary electron emission (SEE) is used for time-of-flight (TOF) and/or coincidence. Since H and O are expected to be the dominant LENA species and their masses vary by a factor of 16, TOF can be easily performed using windowing, i.e., H and O identification using two separate TOF regions. Coincidence measurements must be used to separate detection of LENAs from false detections induced by penetrating radiation. Both TOF and coincidence measurements utilize secondary electrons generated by the interaction of a LENA with a solid. SEE resulting from LENA transmission through an ultrathin foil and LENA reflection from a surface arise from different interaction mechanisms.

4.1 Characteristics of Secondary Electron Emission

SEE from the interaction of atomic projectiles with solids proceeds through two distinct processes. The dominant mechanism for secondary electron emission at velocities greater than approximately 40 eV/amu is kinetic electron emission (KEE) which is the result of direct and indirect (e.g., via recoils) inelastic energy transfer from the incident particle to atoms in the solid. The KEE yield γ_k (number of electrons per incident particle) is a function of the number and energy of free electrons created in the solid, the transport of secondary electrons in the solid, and their escape from the solid surface.⁵⁰

The general characteristics of KEE include: γ_k is dependent on the electronic energy loss of the projectile near the surface⁵¹⁻⁵³ (at LENA energies the electronic energy loss and, therefore, γ_k scale as the projectile velocity); γ_k is independent of the incident projectile charge state⁵⁴ because the depth of secondary electron emission is much greater than the pathlength associated with charge exchange interactions; the energy deposition by the projectile throughout the emission depth and, therefore, γ_k are proportional to the secant of the incident angle of the projectile relative to the surface normal;⁵⁵ and the secondary electron energy distribution is maximum at approximately 2.5 eV,^{52,56} so electron steering in a LENA instrument is relatively trivial.

Below the threshold for KEE at projectile velocities of ~ 40 eV/amu, potential electron emission (PEE) can be observed. PEE results from neutralization of a positively charged particle near the solid surface by Auger electron capture from the solid.^{57,58} The release of potential energy associated with this process results in secondary electron emission if the ion's ground state neutralization energy E_i (i.e., the ionization energy) exceeds twice the work function ϕ of the solid. The PEE yield γ_p can be approximately described using the semi empirical relationship⁵⁹

$$\gamma_P = 0.032 (0.78 E_i - 2 \phi) \quad (5)$$

A low work function surface results in a larger PEE yield; note that PEE through Auger neutralization will not occur for incident neutral particles in the ground state. Figure 5 depicts γ_P evaluated using Eq. 5 as a function of the work function ϕ of the solid for both incident H^+ and O^+ whose first ionization potentials are $E_i \approx 13.6$. For a low work function cesiated tungsten surface ($\phi = 1.5$ eV), the PEE yield γ_P equals 0.22; the expected PEE yield for surfaces of Cs ($\phi = 2.1$ eV), and W and Mo ($\phi \approx 4.5$ eV) are also shown. Note that γ_P is much less than γ_k for velocities greater than ~ 40 eV/amu. For conductive solids, PEE and KEE are additive so that the total secondary electron yield equals $\gamma_k + \gamma_P$.

4.2 SEE: Projectiles Transiting Foils

Since projectiles transiting foils penetrate the foil, secondary electron emission from both the entrance and exit surfaces of the foil includes contributions from both PEE and KEE, although KEE will dominate for projectiles with velocities greater than 40 eV/amu. SEE yields from carbon foils have been studied for projectile energies down to 25 keV,^{51,60} and the forward γ_k (secondary electron yield from the exit surface) has been observed to be greater than the backward γ_k (secondary electron yield from the entrance surface).⁶⁰ For 25 keV protons, the forward γ_k equals ~ 5 , the backward γ_k equals ~ 4 , and both forward and backward γ_k decrease with increasing energy.⁶⁰

Since γ_k is roughly proportional to the electronic stopping power of the projectile in a solid,^{52,61} we can approximate γ_k for projectile energies E less than 25 keV using the empirical data for $E \geq 25$ keV and computed stopping powers.⁴² The electronic stopping power of 1 keV H in carbon is approximately half of the electronic stopping power at 25 keV. Therefore, we estimate that the forward $\gamma_k \approx 2.5$ and the backward $\gamma_k \approx 2$ which are sufficient for TOF and coincidence measurements from either the entrance or exit surface.

4.3 SEE: Projectiles Reflected from Surfaces

For reflection of projectiles with velocities greater than the Bohr velocity (~ 25 keV/amu), electrons in both the projectile and target cannot react to the collision within the collision time. Consequently, the electrons of a grazing-incidence projectile will be detached by elastic scattering with surface valence electrons, resulting in a small γ_k peaked at a velocity corresponding to the incident projectile velocity.⁶² However, LENA velocities are below this regime, and since the projectile does not significantly penetrate the surface so that electronic energy loss is minimal, reflected projectiles will generate primarily PEE. Therefore, the total SEE yield from projectiles reflected from surface atoms corresponds to the values shown in Fig. 5.

The PEE yields for reflection may be underestimated since PEE could occur during the projectile's approach toward and departure from the

Fig. 5. Potential electron emission (PEE) yield γ_P based on Eq. 5 for H^+ and O^+ incident on various work function surfaces.

surface if the projectile is positively ionized for both its inbound and outbound trajectories. Alternatively, contamination of a low work function surface likely increases the work function and therefore decreases γ_p . Nevertheless, the total secondary electron yield resulting from surface reflection, which results in PEE, is approximately an order of magnitude less than the total secondary electron yield of projectiles transiting foils for which KEE dominates. Consequently, the maximum detection efficiency for TOF and/or coincidence schemes is derived using projectile transmission through foils.

5. DISCUSSION

Based on the preceding comparative study of transmission and reflection techniques, we can draw the following conclusions. First, scattering and exit charge state distributions have been quantified for H, He, and O transiting ultrathin foils; the polar resolution of a LENA imager is less than 3° HWHM above 8 keV, 5° HWHM at approximately 3 keV and increases with decreasing energy. Polar resolution of LENA imagers using reflection techniques cannot be evaluated due to lack of studies investigating angular scattering in the direction around the surface normal. Second, the (positive) ionization probability of LENAs transiting foils is equal to or greater than for LENA reflection from surfaces. Third, secondary electron emission from transmission through ultrathin carbon foils is approximately an order of magnitude greater than SEE from reflected projectiles. LENA imaging using foil transmission for LENA ionization and secondary electron emission is the optimal technique for the energy range of approximately 1 keV to greater than 30 keV.

Negative ionization techniques could be employed for ionization of very low energy neutral atoms (VLENAs) in the energy range of 5 eV to several keV where scattering of LENAs in a charge conversion foil degrades the polar resolution of the LENA imager. This technique is not likely applicable at incident H energies greater than several keV due to H loss by penetration into the solid and reduced negative ionization probability.^{37,38} A possible approach for VLENA imaging is similar to the approach by Gruntman for heliospheric neutral atom detection.³² VLENAs are incident at a glancing angle on a low work function surface that is biased to -5 keV. VLENAs are negatively ionized upon impact with the surface and accelerate into and pass through an electrostatic (E/q) analyzer. Then, they enter a detector section consisting of a carbon foil for secondary electron emission (coincidence) and two separate electron and ion detectors with wedge anodes to derive position information. Their polar trajectory is determined by measuring the VLENA trajectory between its point of transmission through the SEE foil (measured by the detected electron position) and the position of VLENA detection. Presently, no studies have been performed to examine either azimuthal scattering (around the surface-normal axis) which determines the VLENA polar angular resolution in a LENA imager or oxygen VLENA negative ion yields from a low work function material.

Unlike foils used in transmission techniques, reflection techniques require an atomically clean surface for spectral scattering and work function integrity. In the spacecraft environment, adsorbate from outgassing of spacecraft components and residue deposition of impurities^{63,64} can alter reflection kinematics, resulting in LENA loss by scattering into the reflecting surface and energy loss of reflected LENAs.⁶⁵ Furthermore, contamination can alter the work function of the reflecting surface resulting in an altered ionization probability. Surface maintenance is a special technical problem for control of cesiated surfaces which has a relatively high vapor pressure. Throughout the mission, maintenance of surface integrity by periodic deposition of fresh surface layers¹³ might be employed, although deposition statistics suggest that such a surface might be microscopically rough and, therefore, inadequate for specular scattering.

6. ACKNOWLEDGEMENTS

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