Development of a Linear Ion Trap for the Determination of the Presence of Biological Compounds in Aerosol Particles

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Overview

Ongoing development of an aerosol particle linear ion trap for astrobiological applications.

Using electrodes sourced from a commercial instrument, the setup in its current form is able to trap charged particles from an ESI. The integration of excitation source(s) and fluorescence detector(s) is planned to be performed.

Introduction

In 2005, the Cassini probe began studying Enceladus, a moon of Saturn where its Cosmic Dust Analyzer (CDA) detected dust sized particles near the South Pole. The probe flew directly through the plume in 2008 where the material was evaluated with its Ion Neutral Mass Spectrometer (INMS). This plume was found to contain water vapor along with organic materials, which could be indicative of life.[1] Others have suggested evidence of organics on the moon Titan in high altitude aerosols in the environment.[2] Many past and future space probes have relied or will rely on impact ionization with time-of-flight mass analysis to study chemical composition in situ.[3,4] Although the initial mass spectra have proven valuable, some of the more complicated organics analyzed are poorly characterized from the high speed impacts.

Such planetary bodies will increasingly become the focus of astrobiological investigation. Therefore, the need for new strategies which preserve and evaluate potential biological aerosols is necessary. Because most dust is believed to be already charged, softer approaches to the capture of charged particles may be exploited.

Herein, we outline the current developmental progress of an ion trap aimed at the nondestructive analysis of astrobiological aerosol particles. If employed, this device would rely on the collection of natively charged particles in the trap's potential well as it traverses a plume, atmosphere, or aerosol containing region. Plans to implement a bio-fluorescence detection system to the device would allow monitoring for the presence of amino acids, nucleic acids, coenzymes, and chlorophylls as the trap is filled or evacuated. This system could be combined online with a traditional MS for an even more powerful means to chemical speciation.

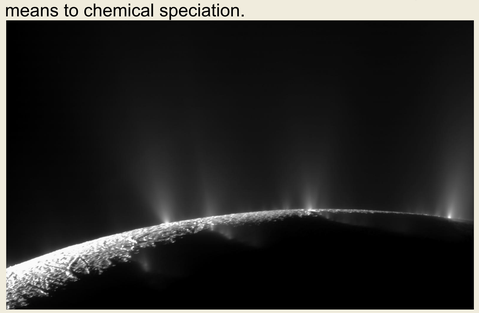

Figure 1. Photograph of the plumes of Enceladus taken from Cassini. Credit: NASA/JPL-Caltech/SSI

Method

- **Ion Trap:** The electrodes from a Thermo Fisher Scientific LTQ XL linear ion trap mass spectrometer are being used (shown in **Figure 2**). They are approximately 6.5 cm in length and 1.5 cm in both the x and y dimensions. This geometry possesses slits in both x electrodes allowing for ions to exit or to be used as an orthogonal viewing window. The outer hyperbolic electrode segments are electrically separated from the inner segments, where the trapping waveform is applied, and are electrically connected to each other and the endcap electrodes. The sample inlet holes in the center of the endcap electrodes have been widened to a diameter of 10mm and covered with a wire mesh to improve sample introduction and to help preserve the applied electric field respectively.

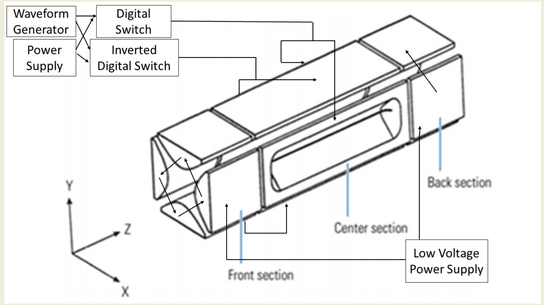

Figure 2. Geometry of LTQ electrodes and electrical connections.

- **Electronics:** The trapping waveforms are currently being generated by two GRX-1.5k-E high voltage pulsers that are capable of creating digital square waves with a peak to peak amplitude of up to 1500V. The gating waveforms to operate the pulsers are being generated by an SRS DS345 synthesized function generator. Outer hyperbolic electrode segments and endcap voltages are being supplied by a simple power supply.

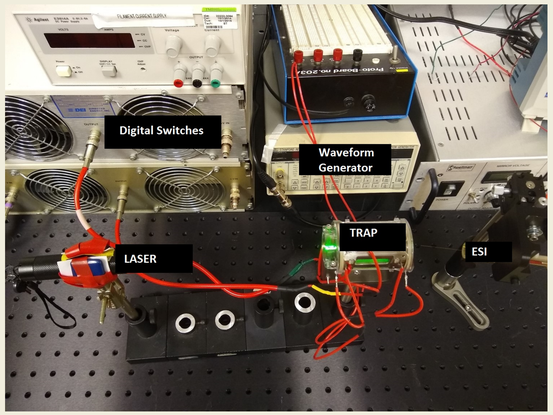

Figure 3. Current setup for trap, laser, ion source, and electronics.

Method

- **Samples:** lycopodium powder (moss spores) were prepared in an aqueous solution at 650ppm in 0.1% Dawn dish soap (Procter & Gamble, Cincinnati, OH). Polystyrene Latex Spheres (PSLs) obtained from Ted Pella, INC. (Redding, CA) in the sizes: 0.09, 0.30, and 0.49 µm nominal diameters at 0.1% *w/v* in water. PSLs obtained from LADD Research Industries (Williston, VT) possessed a 2.07 µm nominal diameter and were supplied at a concentration of 0.2% *w/v* in water. PSL solutions analyzed took equal parts of each of the 4 PSL solutions and was subsequently diluted 1:100 with water.

- **Sample detection method:** As a precursor to fluorescence detection, the observation of light scattering events from trapped particles with an axially oriented laser is used for trapping confirmation. If the trapped particles are large enough and the light source is bright enough, these events can be viewed with the naked eye. Currently, a green neodymium-doped yttrium orthovanadate (Nd:YVO4) laser pointer oriented along the central axis is being used as this visualization light source.

- **Sample Ionization/introduction:** Samples were ionized via ESI at a spray voltage of 2.5kV and were introduced into the trap from an approximate 45 degree angle from the trapping axis.

Preliminary Results

The ability of the system to trap particles was evaluated through the introduction of a lycopodium spore containing solution via ESI. Shown in **Figure 4**, particles were successfully trapped and are viewed through one of the exit slits in the electrodes. Particles from this solution were successfully trapped at 500Hz with amplitudes ranging from 200-800V.

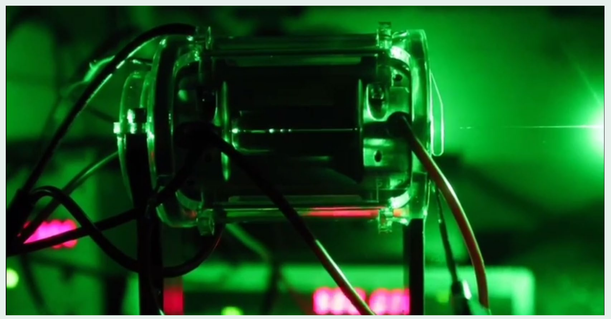

Figure 4. 3 trapped particles from lycopodium spore solution

Trapping times for the lycopodium spores ranged from a few seconds to over a minute. Existing in an unshielded atmospheric environment, it is likely that the air currents in the room have a deleterious effect on the trapping efficacy. When the PSL solution or a methanol blank is used, trapped particles can be observed for a few seconds at most, with little discernable difference between the two samples, for which optimized trap parameters have yet to be established.

Future Work

- Due to the fact that aerosol particles from a methanol only solution were trapped, it cannot be assumed that the particles trapped from the lycopodium spore or PSL solutions are completely desolvated. Determination of the mass and charge of the particles trapped will be beneficial to the characterization of the necessary trapping waveforms.

- The trapping of < 1µm particles is of interest. Particles of this diameter will be difficult to observe by light scattering, so a fluorescent characteristic will be required.

- The use of other aerosol generation devices has been considered. A surface acoustic waveform nebulization atmospheric pressure chemical ionization (SAWN-APCI) device has been shown by our group previously to generate submicron aerosol particles with a high ionization efficiency comparable to that of ESI.[5]

- The voltage potential walls of the endcap electrodes create an obstacle for the entry of charged particles into the trap. The addition of an aerodynamic lens has been considered to aid in the delivery of these particles to the trapping regions via an increase in transport efficiency.

- Implementation of a photomultiplier tube (PMT) orthogonal to the trapping axis will allow for a quantitative detection method for light scattering and fluorescent occurrences in the trap.

- In biological cells, amino acids, nucleic acids, some coenzymes, and chlorophylls are primarily responsible for the fluorescence. For amino acid based detection, excitation maxima can be found at 255 and 282nm for phenylalanine, at 275 and 303nm for tyrosine, and at 280 and 348nm tryptophan. Nicotinamide adenine dinucleotide (NADH) can be detected by illumination with 280nm by fluorescent emissions around 450nm. The excitation wavelengths required for these excitations could be generated with multiple lasers, multiple LEDs or a broadband excitation source with a monochrometer. Power, size, weight, and efficacy are of high concern in space applications.

Conclusion

- The particle trapping capabilities of the device was successfully confirmed but have yet to be optimized or fully characterized for the analytes evaluated.

- Implementation of this instrument in its final form could provide valuable information about higher order organic structures in astrobiological environments

References

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