A Dust Grain Photoemission Experiment

C.C. Venturini

Center for Space Plasma & Aeronomic Research

University of Alabama in Huntsville

J.F. Spann

Space Science Department

Marshall Space Flight Center

M.M. Abbas

Space Science Department

Marshall Space Flight Center

R.H. Comfort

Center for Space Plasma & Aeronomic Research

University of Alabama in Huntsville

Abstract

A laboratory experiment has been developed at Marshall Space Flight Center to study the interaction of micron-sized particles with plasmas and FUV radiation. The intent is to investigate the conditions under which particles of various compositions and sizes become charged, or discharged, while exposed to an electron beam and/or UV radiation. This experiment uses a unique laboratory technique where a single charged micron size particle is suspended in a quadrupole trap and then subjected to a controlled environment. Tests are performed using different materials and sizes, ranging from 10 microns to 1 micron, to determine the particle's charge while being exposed to an electron beam and /or UV radiation. The focus of this presentation will be on preliminary results from UV photoemission tests, but past results from electron beam, secondary electron emission tests will also be highlighted. A monochromator is used to spectrally resolve UV in the 120 nm to 300 nm range. This enables photoemission measurements as a function of wavelength. It has been observed that the photoemission rate decreases with increasing wavelength. Electron beam tests are conducted using energies between 100 eV to 3 KeV. It was found that for both positive and negative particles the potential tended toward neutrality over time with possible equilibrium potentials between -0.8 Volts and 0.8 Volts.

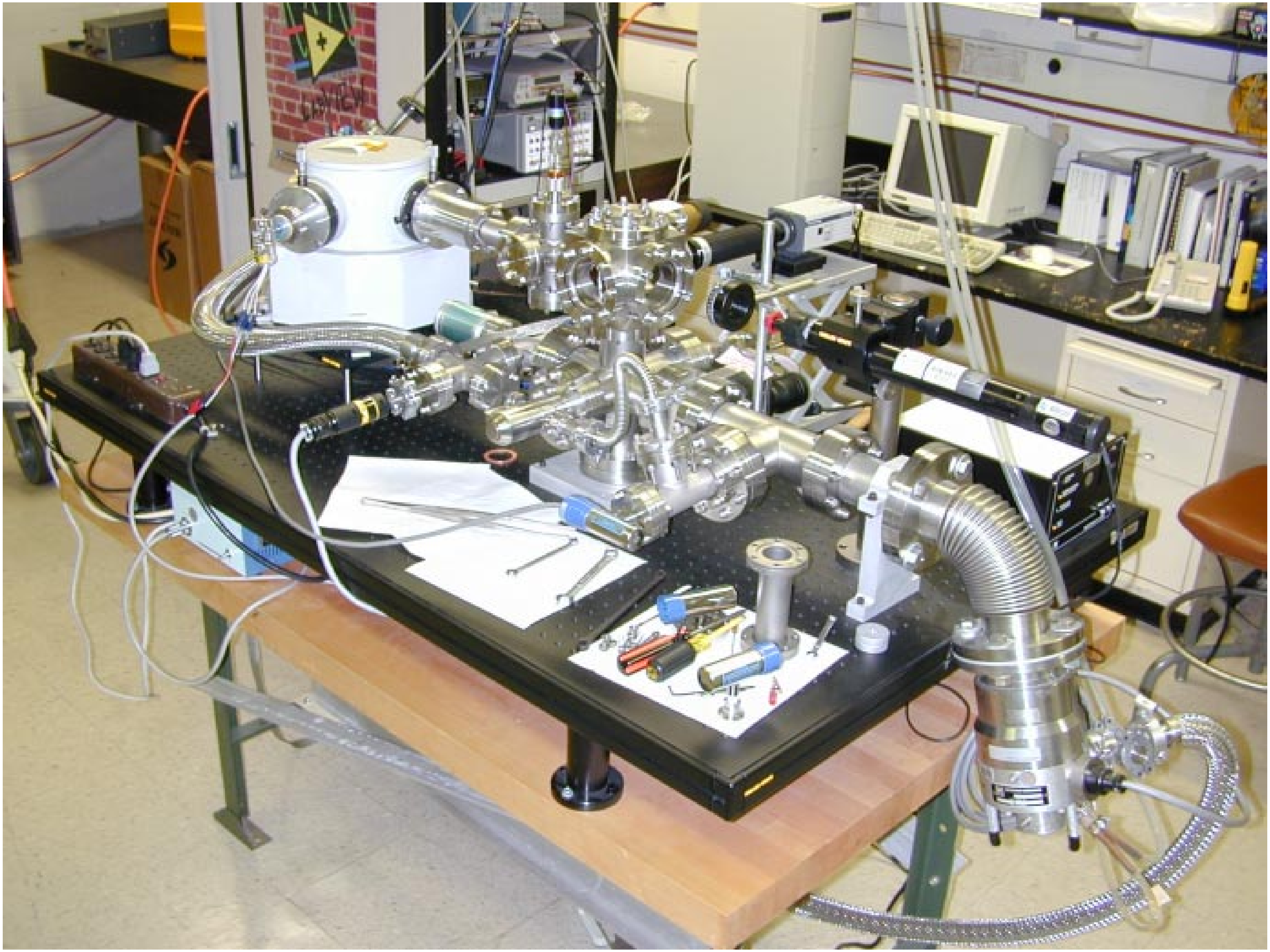
Purpose

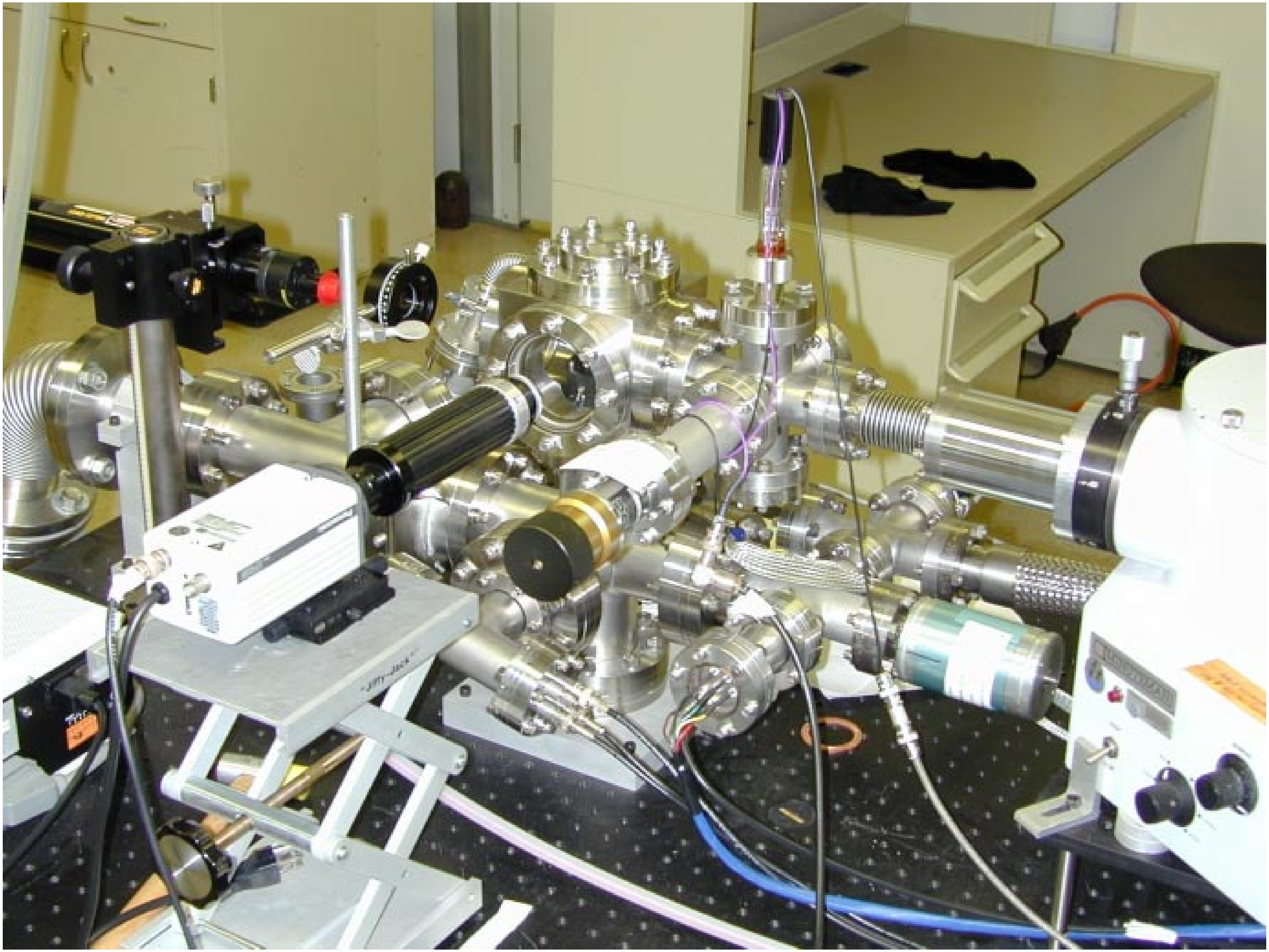
- Study the microphysics of a single charged dust particle.
  - Calculating and measuring properties such as diameter, charge, mass, and potential.
- Study the interaction of charged dust particles with FUV radiation.
  - Calculate photoemission rate.
  - Measure equilibrium potentials.

Theory

Major physical interactions relating to the experiment.

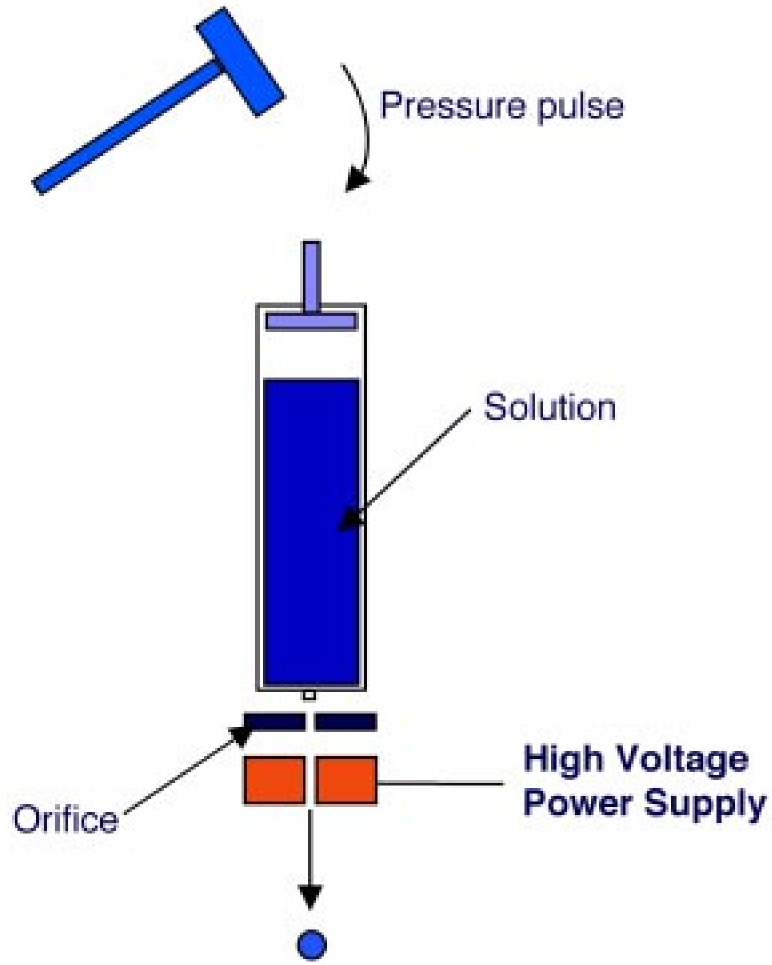
	Interaction	
Photoemission	Incident UV light causes electrons to be emitted from surface	Photoemission Yield $Y \propto$ Emitted electron current Incident photon current
Back-Scattering Electrons	Primary electrons experience elastic collisions with the solid lattice electrons and are reflected out with a lesser energy	Back-scattering coefficient $N \propto$ Primary electron beam energy Angle of incidence Atomic Number of material
Secondary Electron Emission	Primary electrons experience elastic collisions causing the solid lattice electrons to escape from the solid	Secondary electron yield $\delta_S \propto$ Incident primary electron current Secondary electron current
Electric Field Emission	Emission of electrons from the surface of the solid under the action of Electric Fields 10^9 V/m or higher	Field Emission Flux (Fowler-Nordheim formula) $G \propto$ Particle radius Particle potential Work Function Fermi Energy

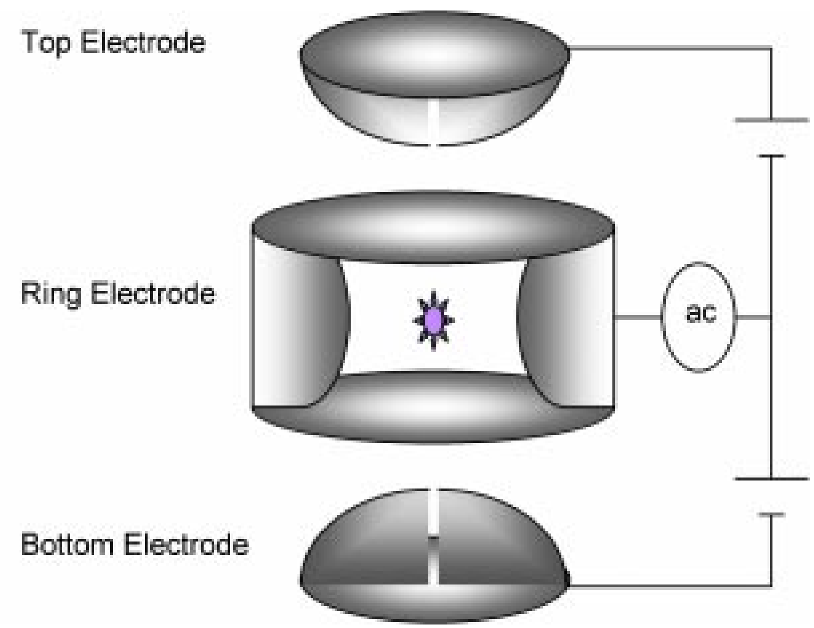




■ Particle Generation

A solution of distilled water and soluble or insoluble particles is sealed in a tube with a plunger at one end and a small orifice with diameter of fifteen microns at the other. A pressure pulse causes a stream of liquid droplets to be ejected. The droplets enter a static electric field produced by a potential difference between the orifice and charging plate with a DC voltage between 300 to 600 Volts. The liquid is then charged inductively and exits through a larger orifice. The water evaporates leaving the charged particle.





Electrodynamic Balance

Bihemispherical configuration consisting of a top/bottom electrode and center ring electrode. An alternating voltage is applied to the ring electrode and is analogous to a potential well where the point of lowest potential is at the geometrical center of the balance. The incoming charged particle finds the point of lowest potential and becomes suspended in the center of the balance. A DC voltage is applied to the top and bottom electrode to counter the effect of gravity.

Experimental Parameters

- 15 mW HeNe Laser (to illuminate particle)
- CCTV camera and monitor (to see the particle while in balance)
- Kimball Physics Electron Gun
  - Energy range of 100 eV to 3 KeV
  - Primary electron beam current was between 10^{-10} to 10^{-13} Amps
  - Discharge rate varied from 4 minutes to 6.3 hours
  - Dependent on the primary electron beam intensity
- Faraday cup
- Deuterium Lamp
  - MgF_2 window
  - 15 Watts
- Monochromator
  - Optics - 0.2 meter concave holographic vacuum UV
  - Spectral Resolution - Full width half max. of 8 nanometers
- PMT
  - CsI photocathode
  - MgF_2 window
  - $115nm<\lambda<119$ nm

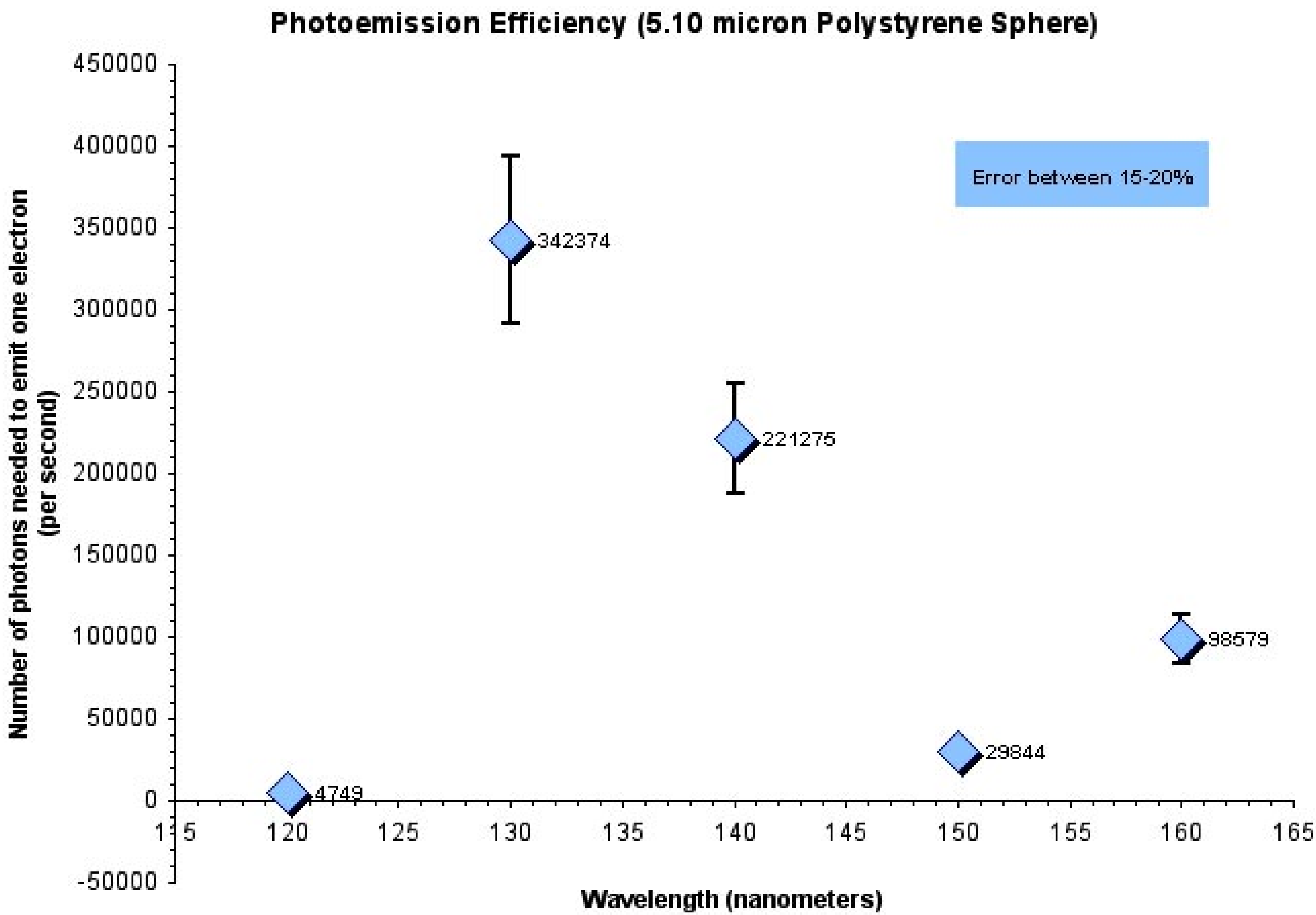
Interaction between FUV Radiation and Charged Particles

Test was conducted on a polystyrene sphere initially charged positive.

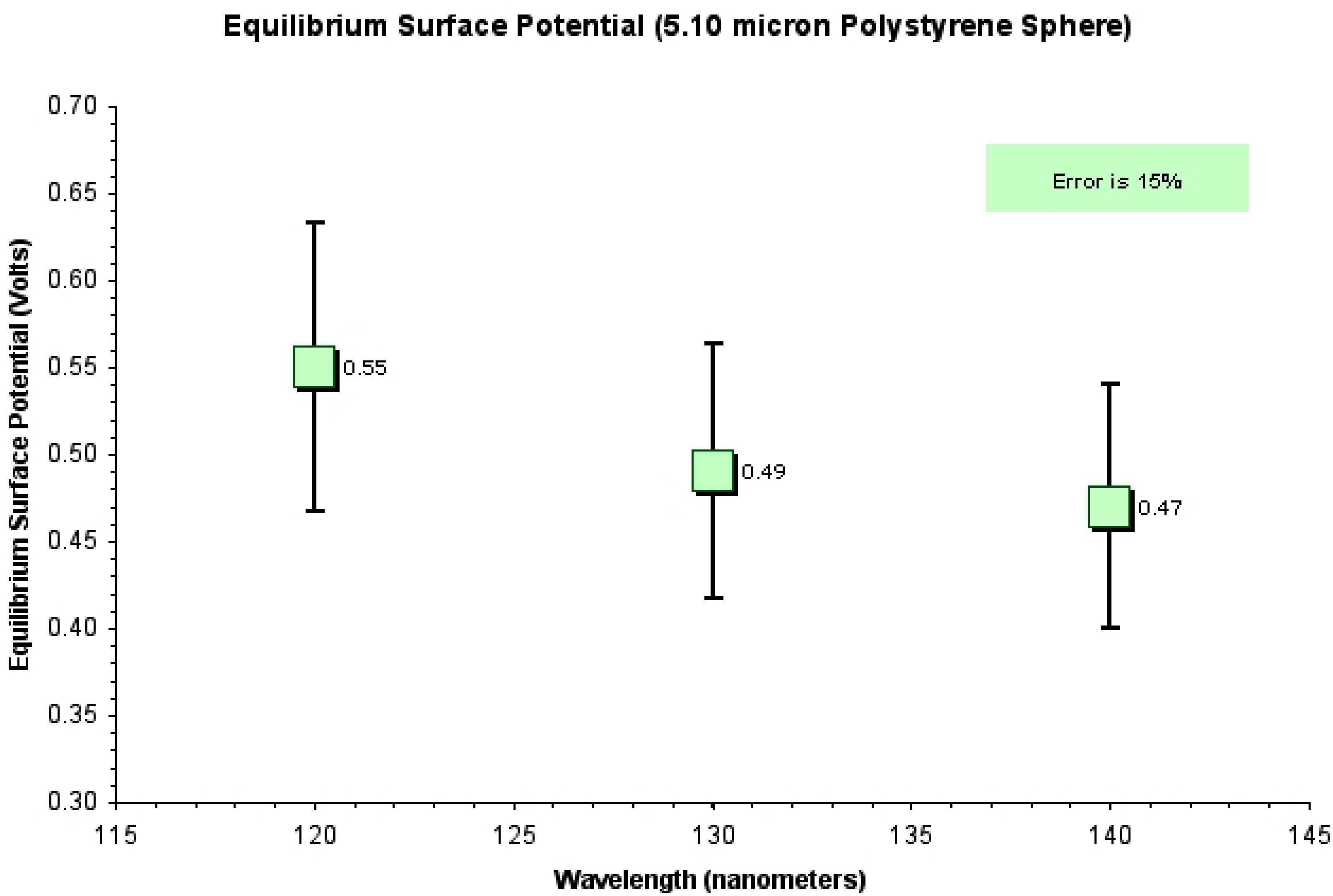
Density (g/cm^3)	Initial Charge/Mass (C/g)	Diameter (microns)	Mass (g)	Initial Surface Potential (Volts)	Number of electrons	Initial Charge (C)
1.062	$7.97 \times 10^{-5} \pm 14.5\%$	$5.10 \pm 1.4\%$	$7.36 \times 10^{-11} \pm 2.0\%$	$20.7 \pm 14.7\%$	$36688 \pm 15\%$	$5.87 \times 10^{-15} \pm 14.6\%$

Measurements include:

- Charge as a function of time
  - Manually adjusted the top/bottom electrode DC Voltage to keep particle at null point in balance.
- Incident photon current as a function of wavelength.



Photoemission Efficiency (5.10 micron Polystyrene Sphere)
Number of photons needed to emit one electron (per second)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
-50000
115
120
125
130
135
140
145
150
155
160
165
Wavelength (nanometers)
342374
221275
98579
29844
4749
Error between 15-20%



Equilibrium Surface Potential (5.10 micron Polystyrene Sphere)
Equilibrium Surface Potential (Volts)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
115
120
125
130
135
140
145
Wavelength (nanometers)
Error is 15%
0.55
0.49
0.47

Interaction between Electron Beam and Charged Particles

Tests were conducted on irregularly shaped Al_2O_3 particles, 1-3 microns in diameter (average values).

Number of particles	Density (g/cm^3)	Magnitude of the Initial Charge/Mass (C/g)	Diameter (microns)	Mass (g)	Magnitude of the Initial Surface Potential (Volts)	Magnitude of the Initial Charge (C)
72	3.965	1.17×10^{-4}	3.1	1.59×10^{-10}	25.8	5.08×10^{-15}
Standard deviation for a single particle: Charge/Mass 14%, Diameter 10%, Mass 17%, Charge 22%, Potential 24%						

Measurements include:

- **Charge as a function of time**
  - **Manually adjusted the top/bottom electrode DC Voltage to keep particle at null point in balance.**
- **Record the total electron beam current via the Faraday cup below balance.**

- **Summary of Results**
  - For both positive and negative particles, charge tended toward neutrality.
  - No true equilibrium potentials measured at this time.
    - Possibly between –0.8 Volts and 0.8 Volts
- **Considerations**
  - Irregularly shaped particles can have sharp edges or curves that can affect secondary electron emission and introduce field emission.

Future Plans

- Test both positive and negative polystyrene spheres as well as other materials including metals and other insulators.
- Calculate photoemission yield.
- Expose particles to electron beam and FUV radiation simultaneously.
- Compare data results to theoretical models.

Acknowledgements

Dusty Plasma Web Site

http://science.msfc.nasa.gov/ssl/pad/sppb/dusty

Contact Information (Email)

C.C. Venturini	venturinic@cspar.uah.edu
J.F. Spann	Jim.Spann@msfc.nasa.gov
M.M. Abbas	Mian.Abbas@msfc.nasa.gov
R.H. Comfort	comfortr@cspar.uah.edu

Funding for Ms. Venturini's research provided by the Alabama Space Grant Consortium NASA Training Grant NGT5-40018.