Extreme Space Weather Events and Charging Hazard Assessments in Lunar Environments

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Introduction

- **Space systems on lunar surface or in lunar orbit exposed variety of plasma environments including**
  - Solar wind
  - Magnetosheath
  - Magnetosphere

- **Surface potentials in these environments have been determine theoretically, experimentally to be on the order of [*Manka*, 1973; *Whipple*, 1981; *Halekas et al*., 2002; *Halekas et al*., 2005a,b]**
  - Day ~10's volts positive
  - Night ~10's to 100's volts negative, extremes to ~kV values

- **Charging environments at night in lunar orbit or on the lunar surface may contain charging risks similar to geostationary orbit during extreme space weather events**

- **Today's presentation is preliminary results from an investigation to:**
  - Examine free field plasma environments relevant to lunar orbit to determine range of mean and extreme conditions
  - Scale free field environments to lunar wake
  - Screen data set for extreme wake charging environments intended for use as input to quantitative 3-D spacecraft charging codes

Surface Charging Current Balance

- Time dependent current balance

$$\frac{dQ}{dt} = \frac{d\sigma}{dt}A = C\frac{dV}{dt} = \sum_k I_k = 0$$ at equilibrium

- Currents

$$\frac{dQ}{dt} = \sum_k I_k =$$

$+I_i(V)$ **incident ions**

$-I_e(V)$ **incident electrons**

$+I_{bs,e}(V)$ **backscattered electrons**

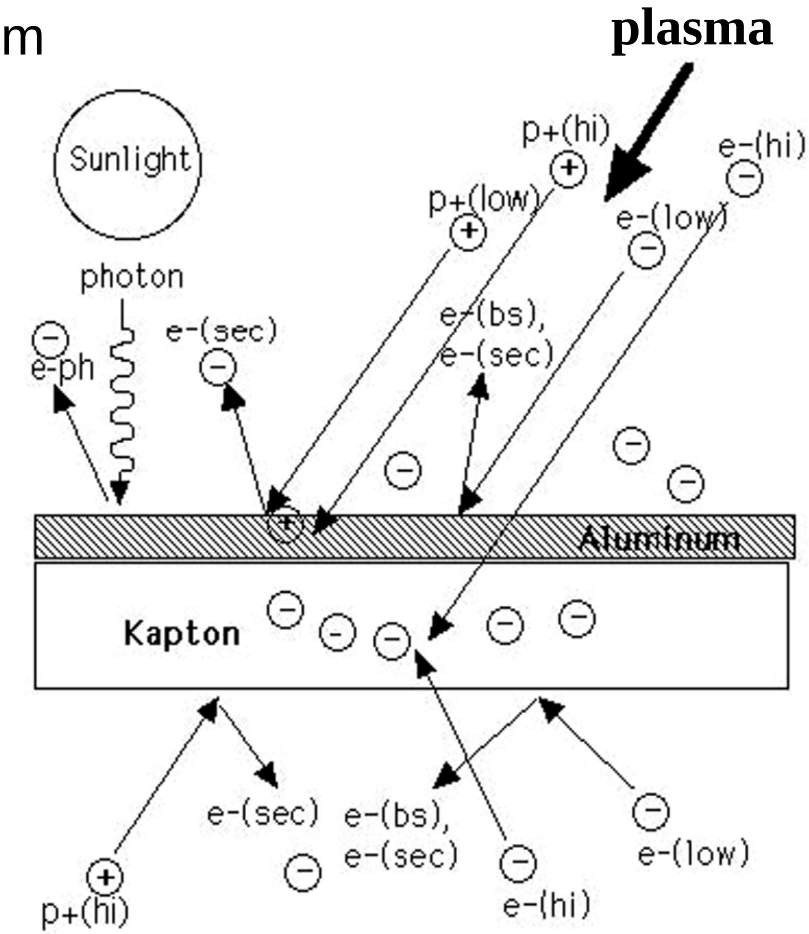
$+I_c(V)$ **conduction currents**

$+I_{se}(V)$ **secondary electrons due to I_e**

$+I_{si}(V)$ **secondary electrons due to I_i**

$+I_{ph,e}(V)$ **photoelectrons**

$+I_b(V)$ **active current sources (beams, thrusters)**



(*Garrett and Minow*, 2004)

Surface Potential

- Potential at equilibrium approximately

$$\phi = -\frac{kT_e}{e} \ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$

$$\sim -\frac{kT_e}{e} 3.74$$ with $T_e \sim T_i$, $n_e \sim n_i$, and $m_i / m_e \sim 1800$

- Neglects
  - Secondary electron emission (best for high energy electrons)
  - Photoemission (absent in lunar wake)
  - Ram flux (only interested in wake environments)

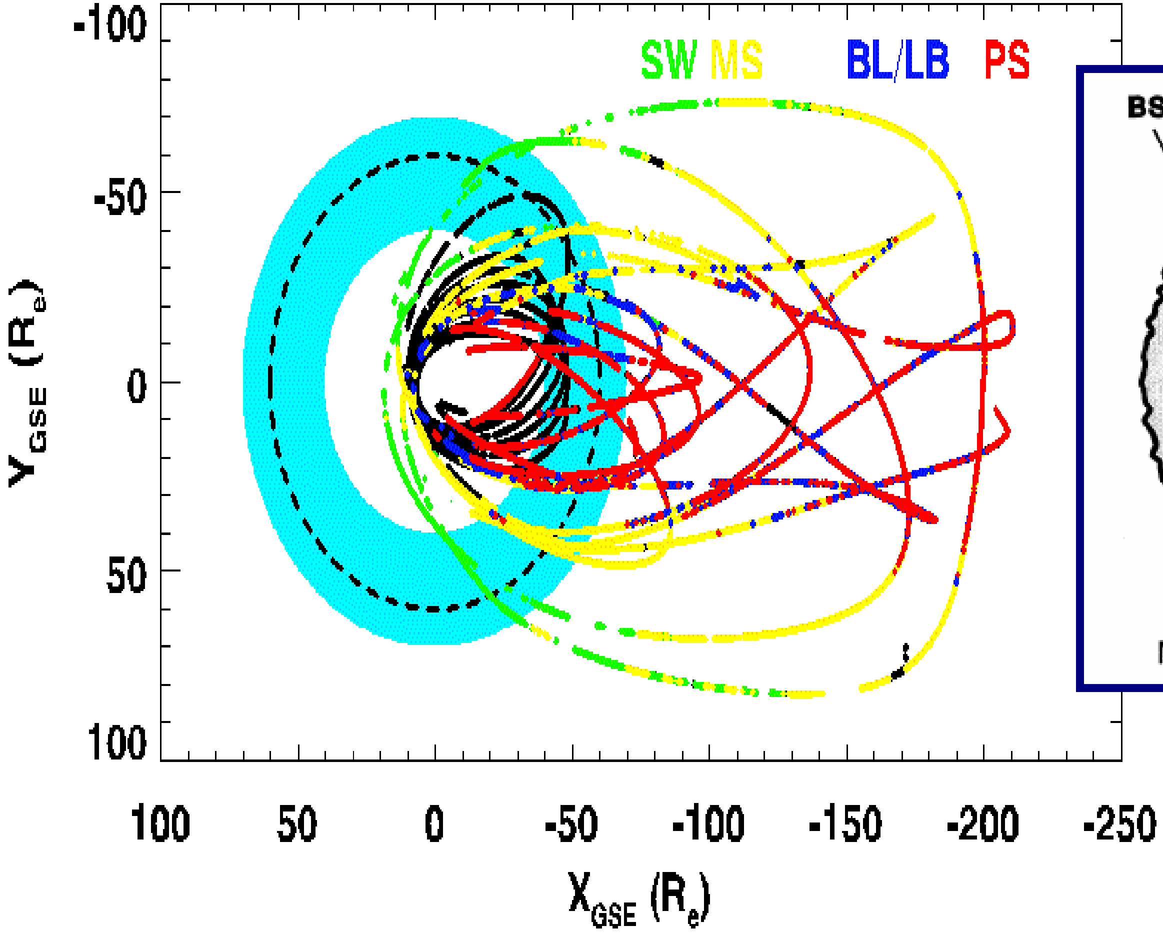
- Closed form potential solution provides convenient technique for rapid screening of large sets of plasma moments
  - Preserves N-T correlations
  - Not intended to provide quantitative computation of spacecraft potential

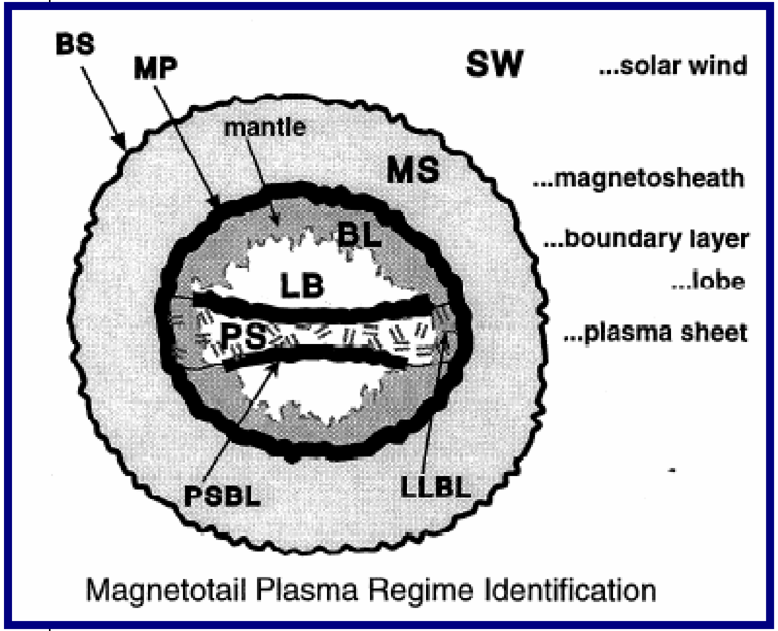
Data Set

Geotail: 10 Re x 210 Re, near ecliptic

--Comprehensive Plasma Instrument/ Hot Plasma Analyzer (CPI/HPA) **University of Iowa**

--Geotail plasma regime identification **EPIC Science Team, JHU/APL**

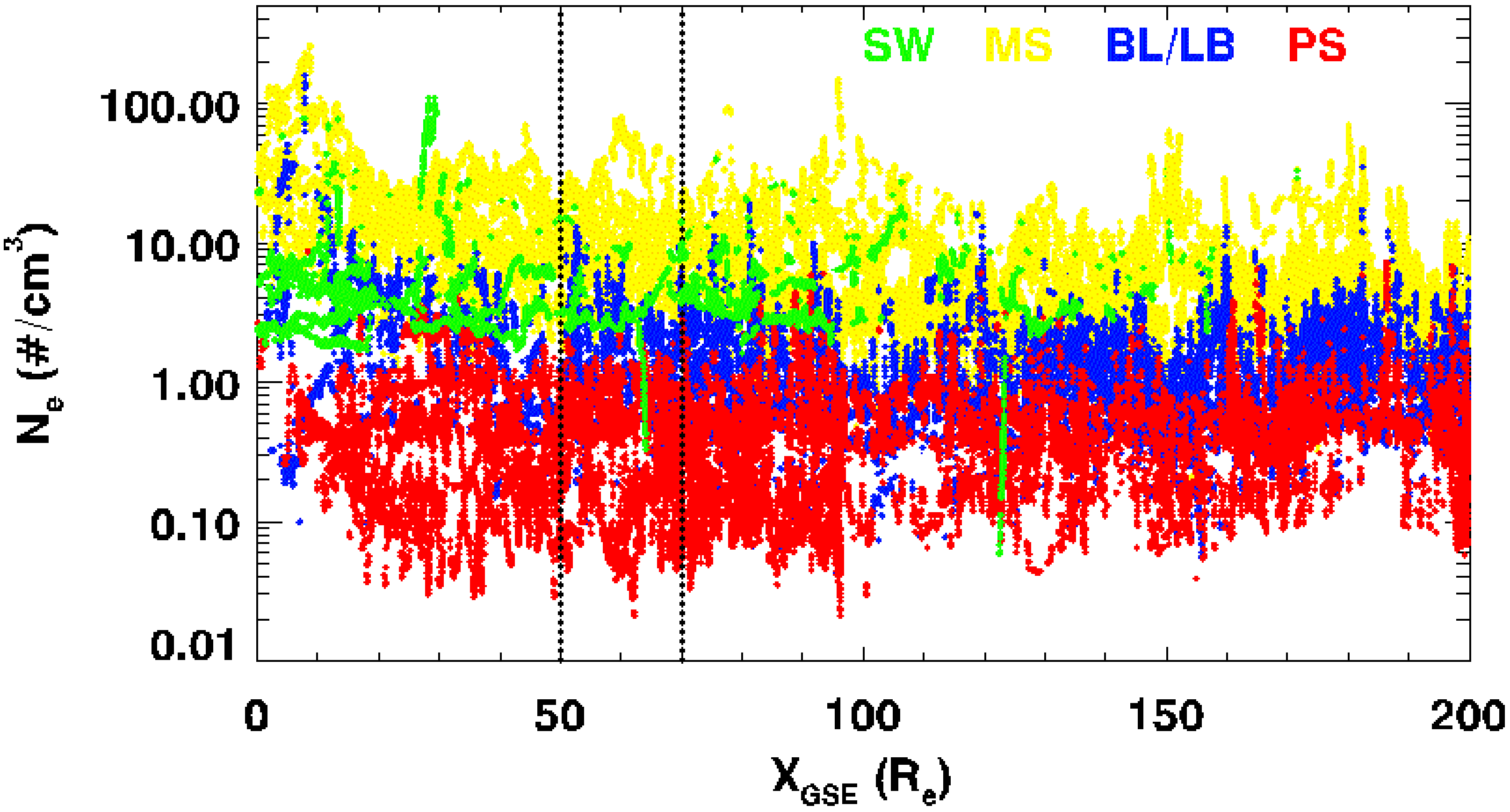




Magnetotail Plasma Regime Identification

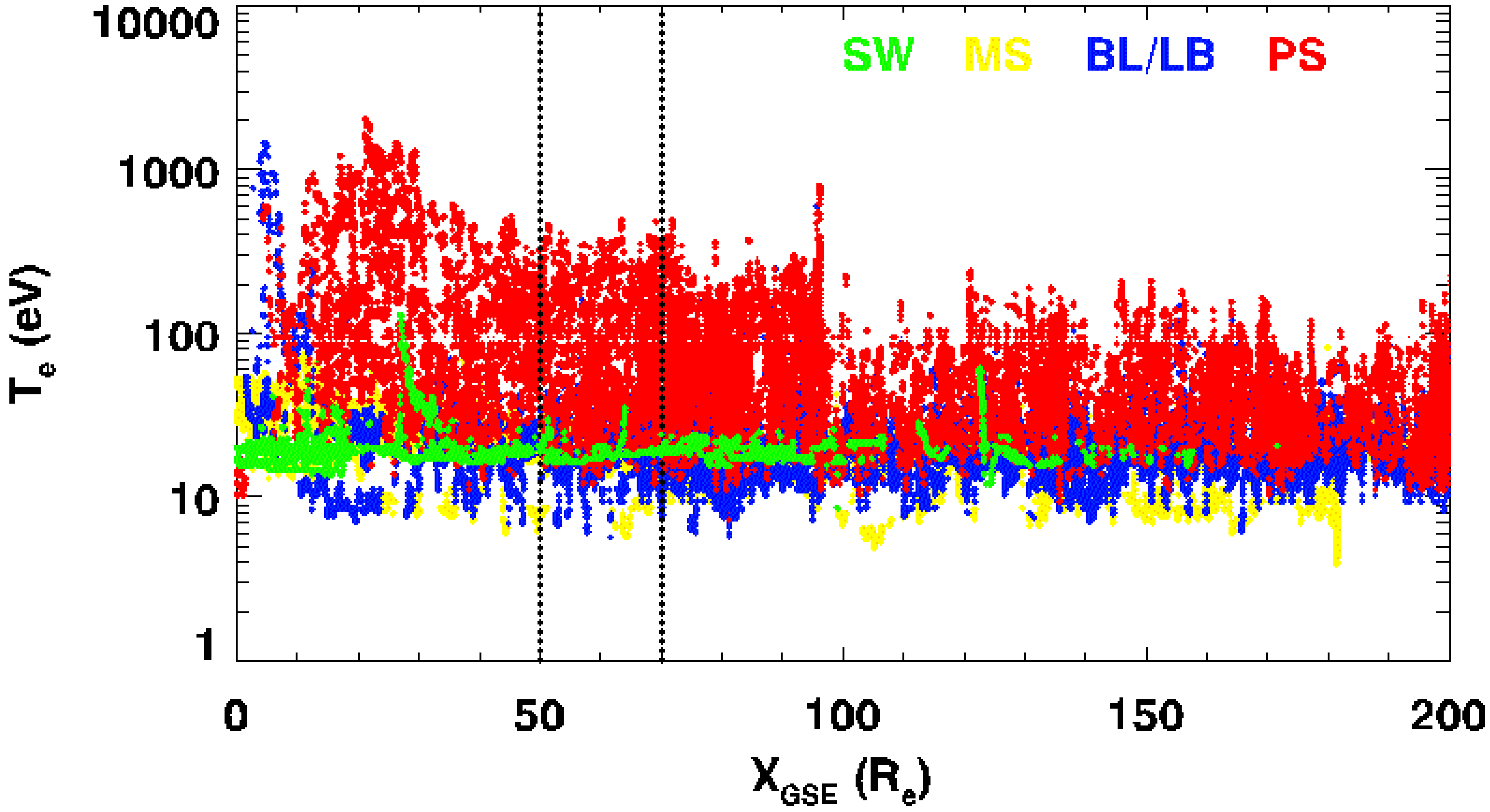
[*Christon et al*. 1998; *Eastman et al*., 1998]

N_e versus Radial Distance



~15 point median filter

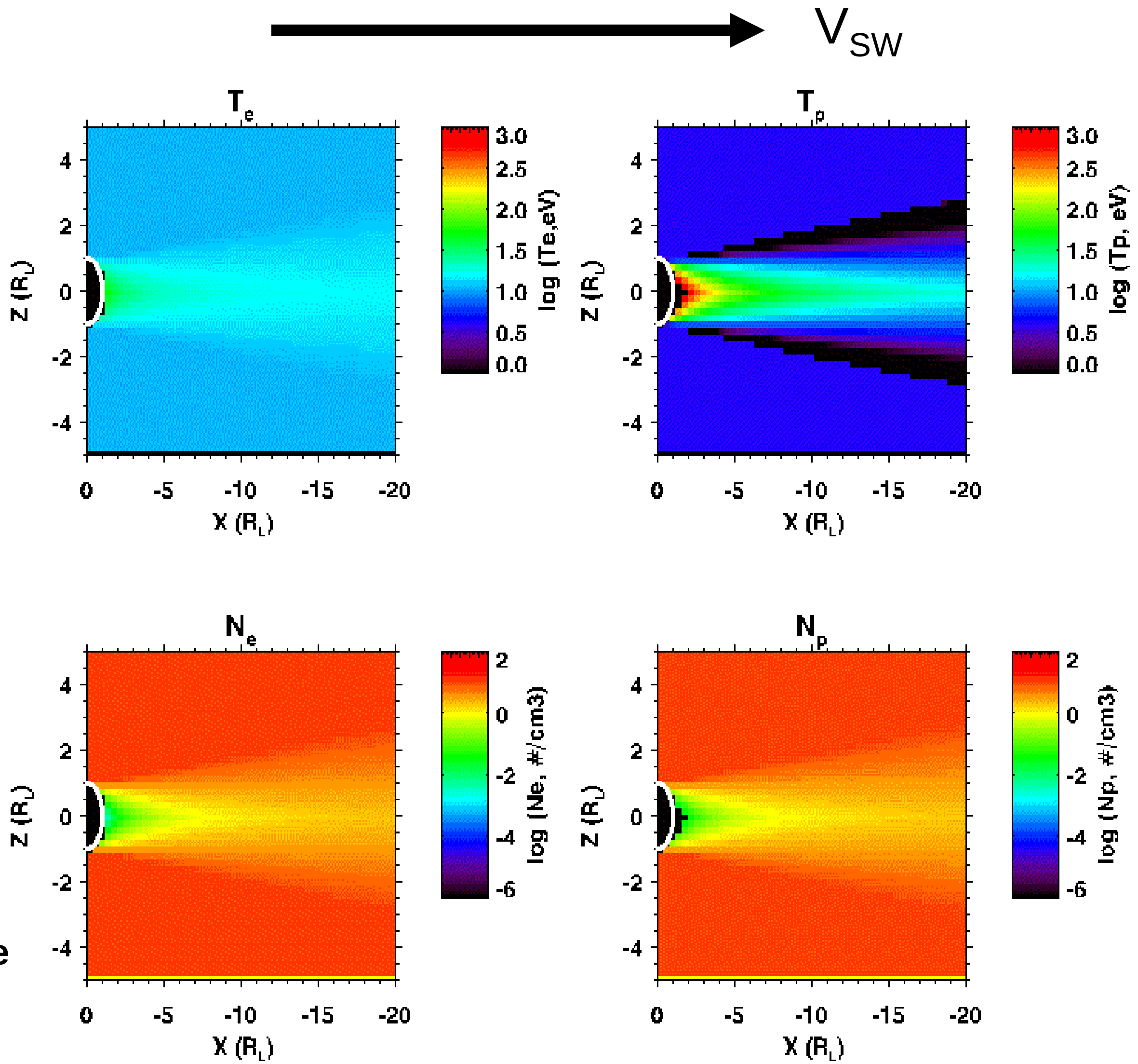
T_e versus Radial Distance



15 point median filter

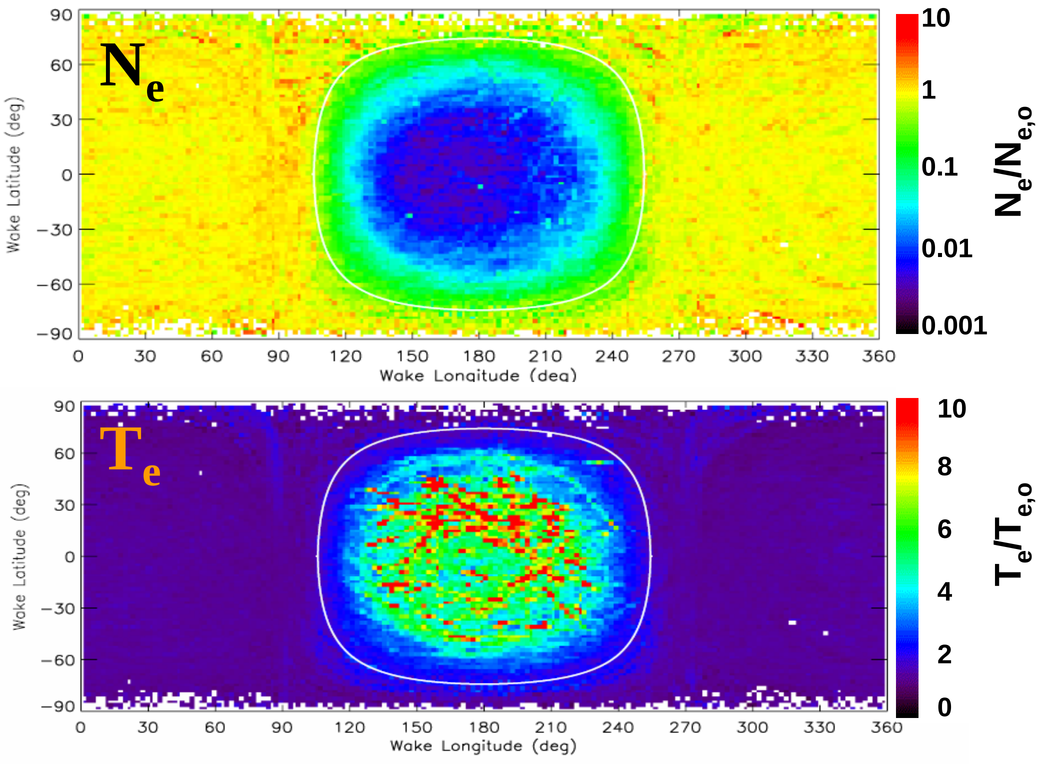
Lunar Wake Model

- **First order estimate for wake plasma environments from analytical wake models**
  - **Electrons [*Halekas et al*., 2005]**
  - **Ions [*Samir et al*., 1983]**
- **Model applicable to plasma expansion region into wake, distant lunar wake regions**
- **Deep wake near Moon requires further analysis**
  - **Wake model overestimates plasma density compared to in-situ measurements**
  - **Models inadequate to establish charging design environments which must be traceable to measurements**



Lunar Prospector Observations

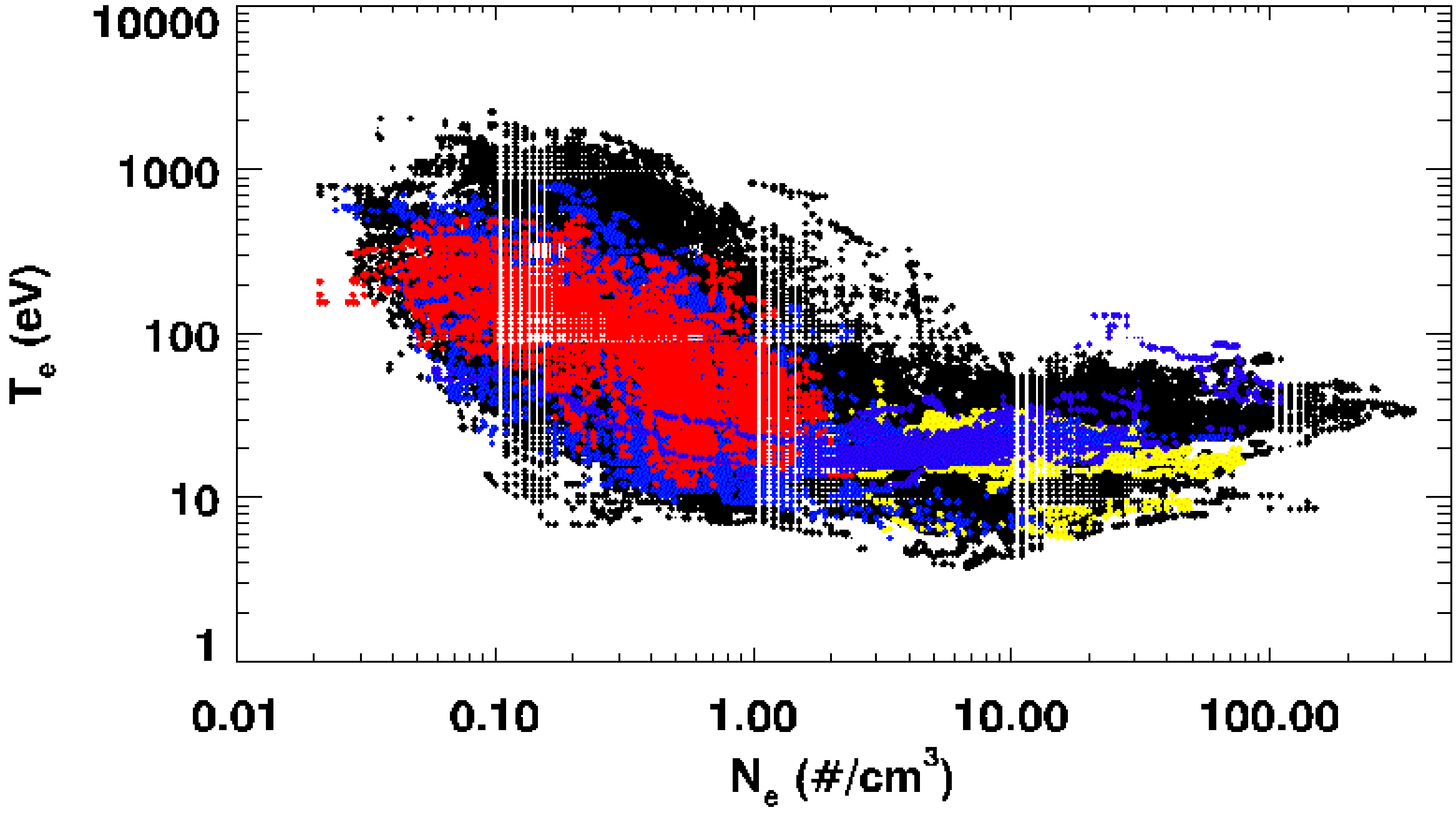
- **Most extreme charging environments (high electron temperature) in lunar system occur in lunar wake**
- **Photoemission is absent and plasma currents dominate charging process**
- **Lunar Prospector electron measurements establish wake parameters relative to free field environment [*Halekas et al.*, 2005]**
- **Geotail environments scaled to wake conditions using**
  - **N_e / $N_{e,o}$**
  - **T_e / $T_{e,o}$**
  - **Assume $N_i \sim N_e$**
    $T_i \sim T_e$



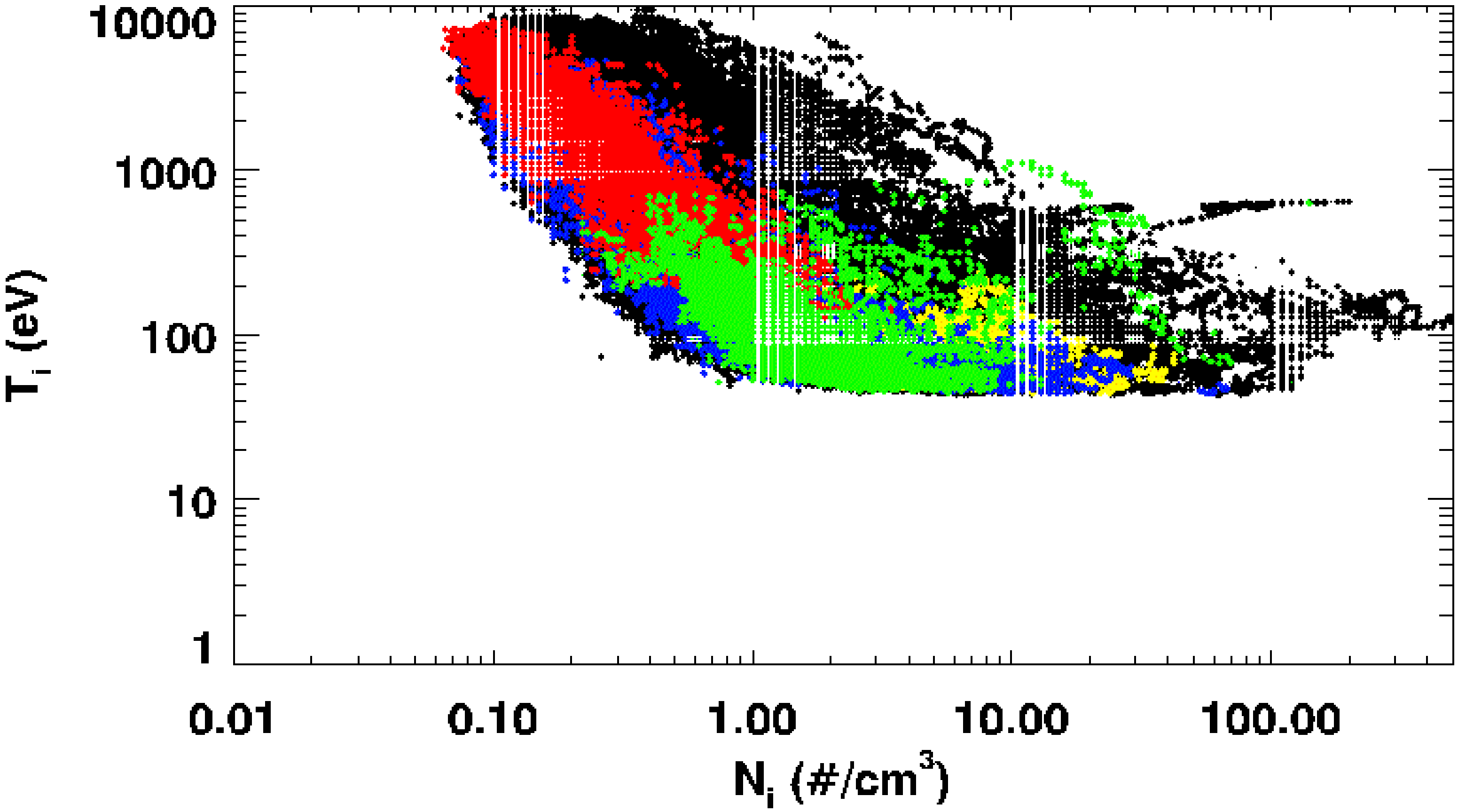
[*Halekas et al*. 2005b]

Environment	$N_e/N_{e,o}$	$T_e/T_{e,o}$
Free field	**1**	**1**
Wake 150º	**0.005**	**7.6**
Wake 180º	**0.003**	**4.5**

Free Field Ne-Te Correlations



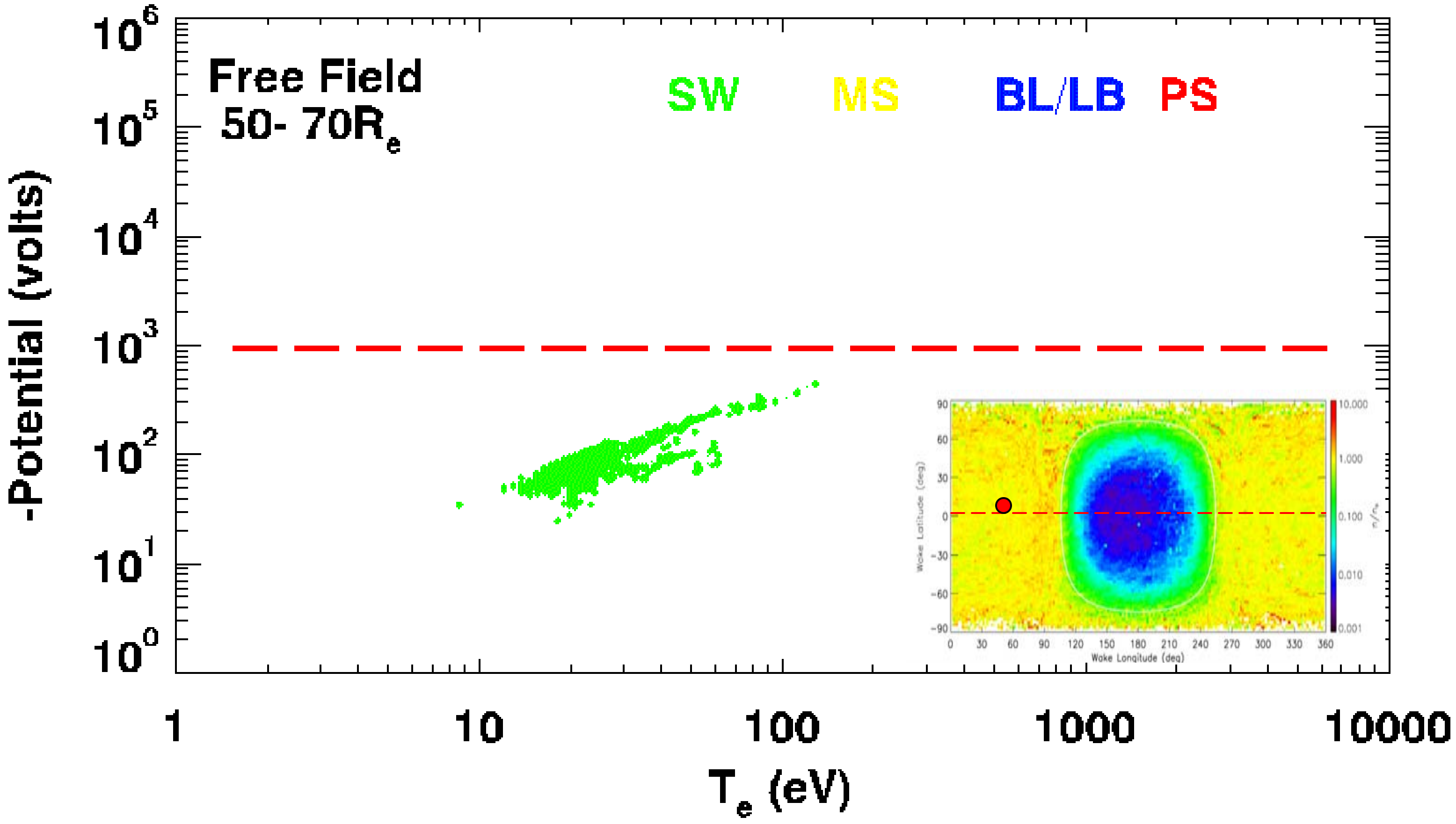
Free Field Ni-Ti Correlations



Free Field “Eclipse” Potentials

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\,\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



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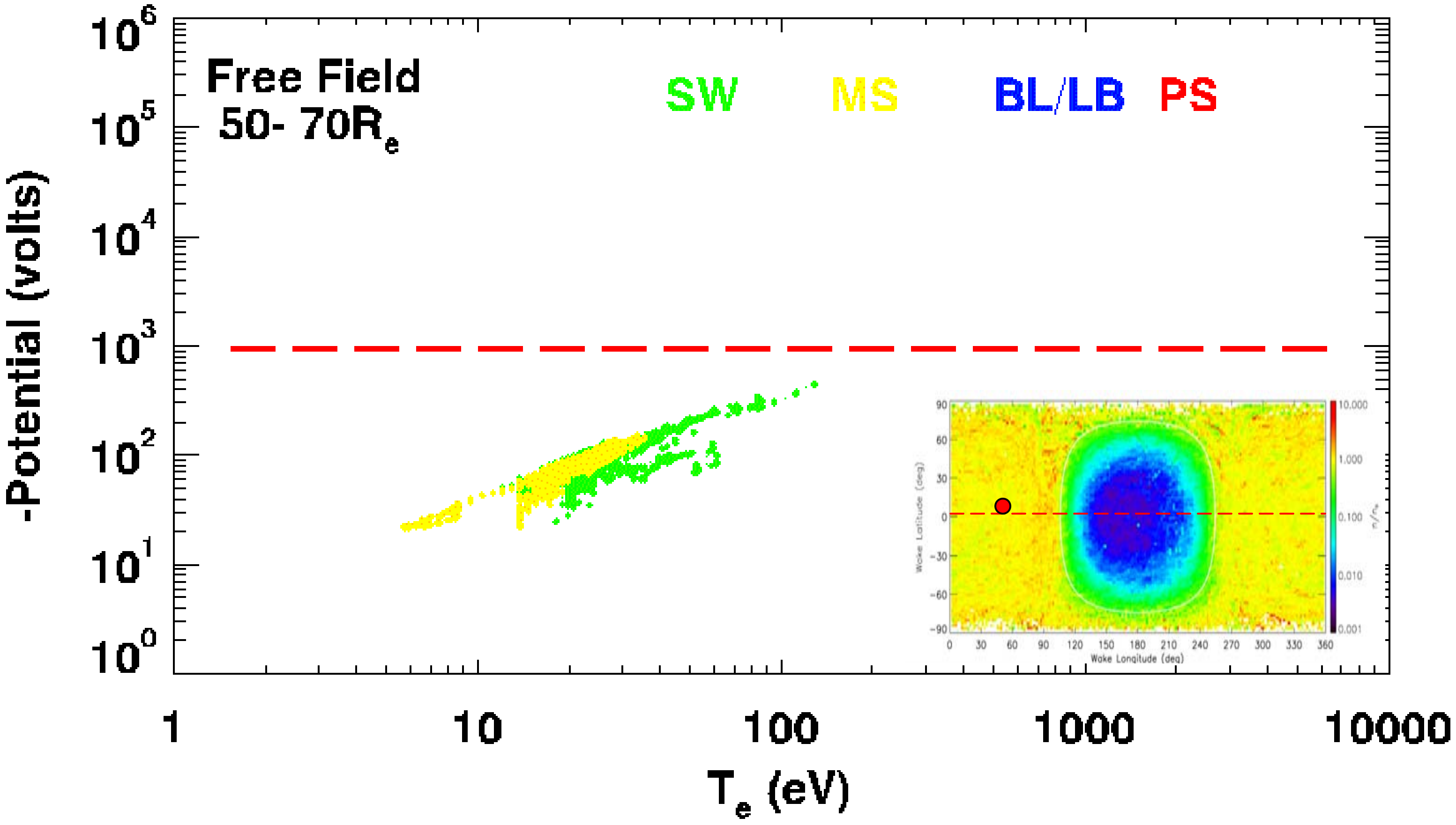

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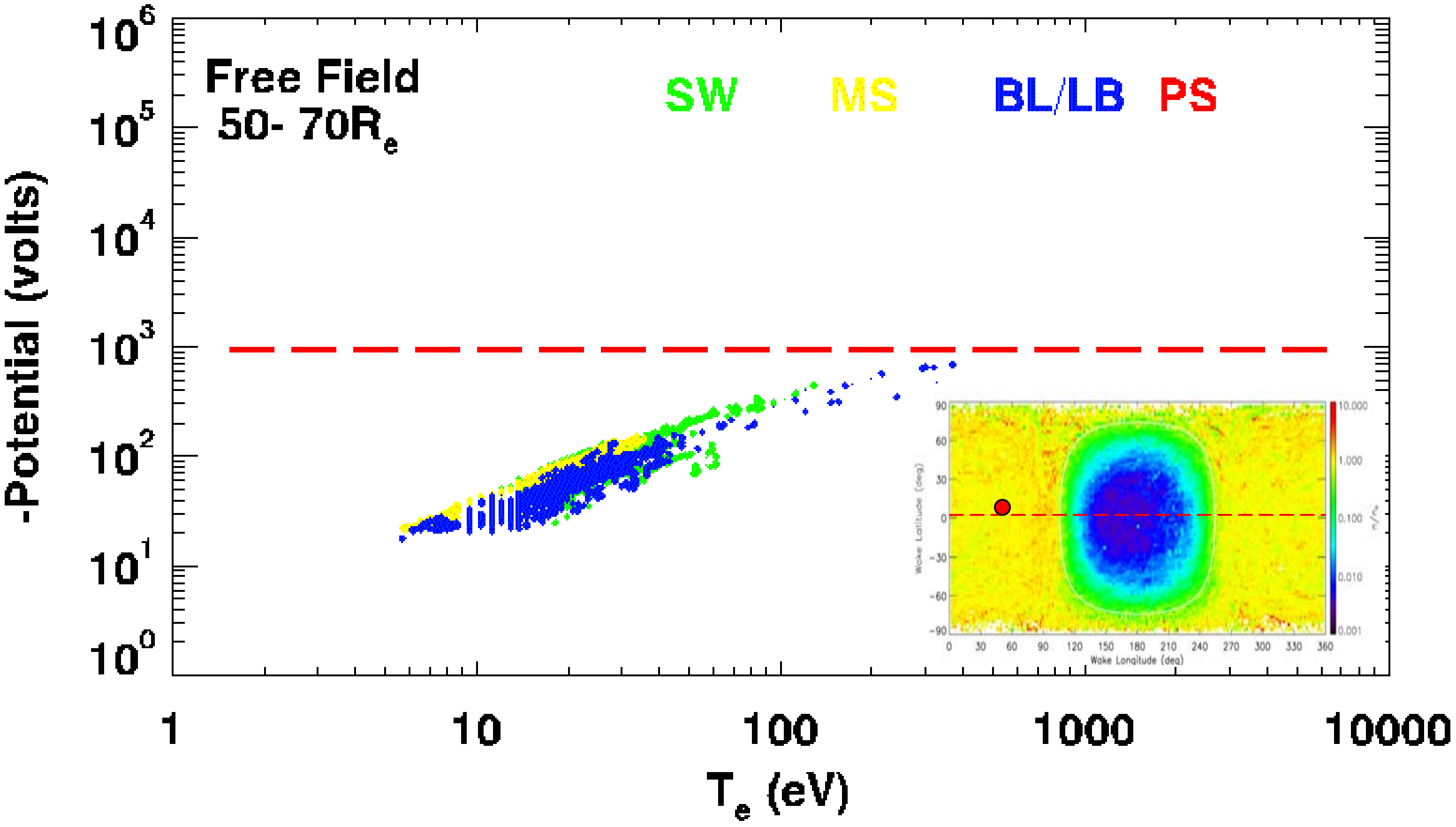

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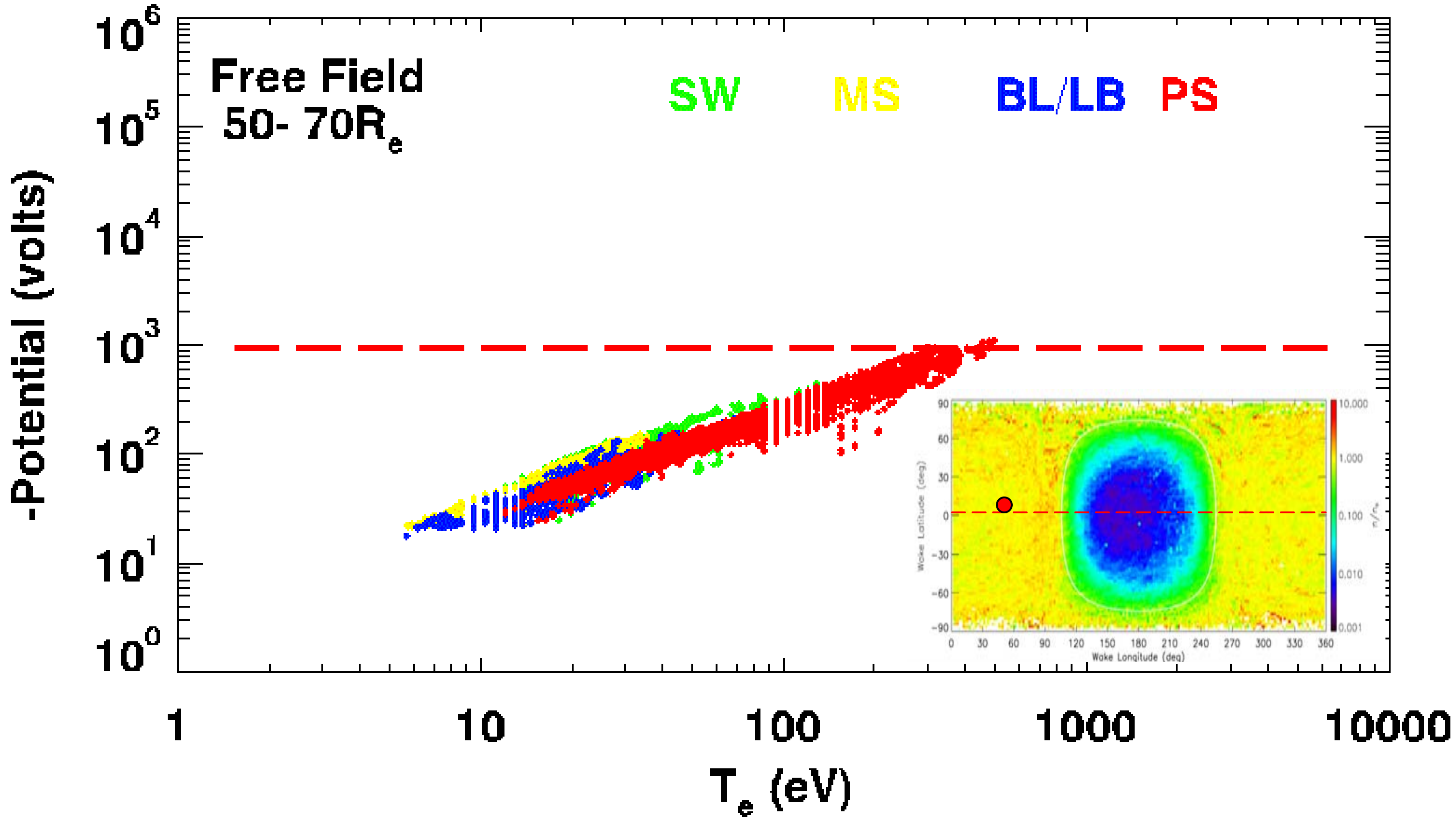
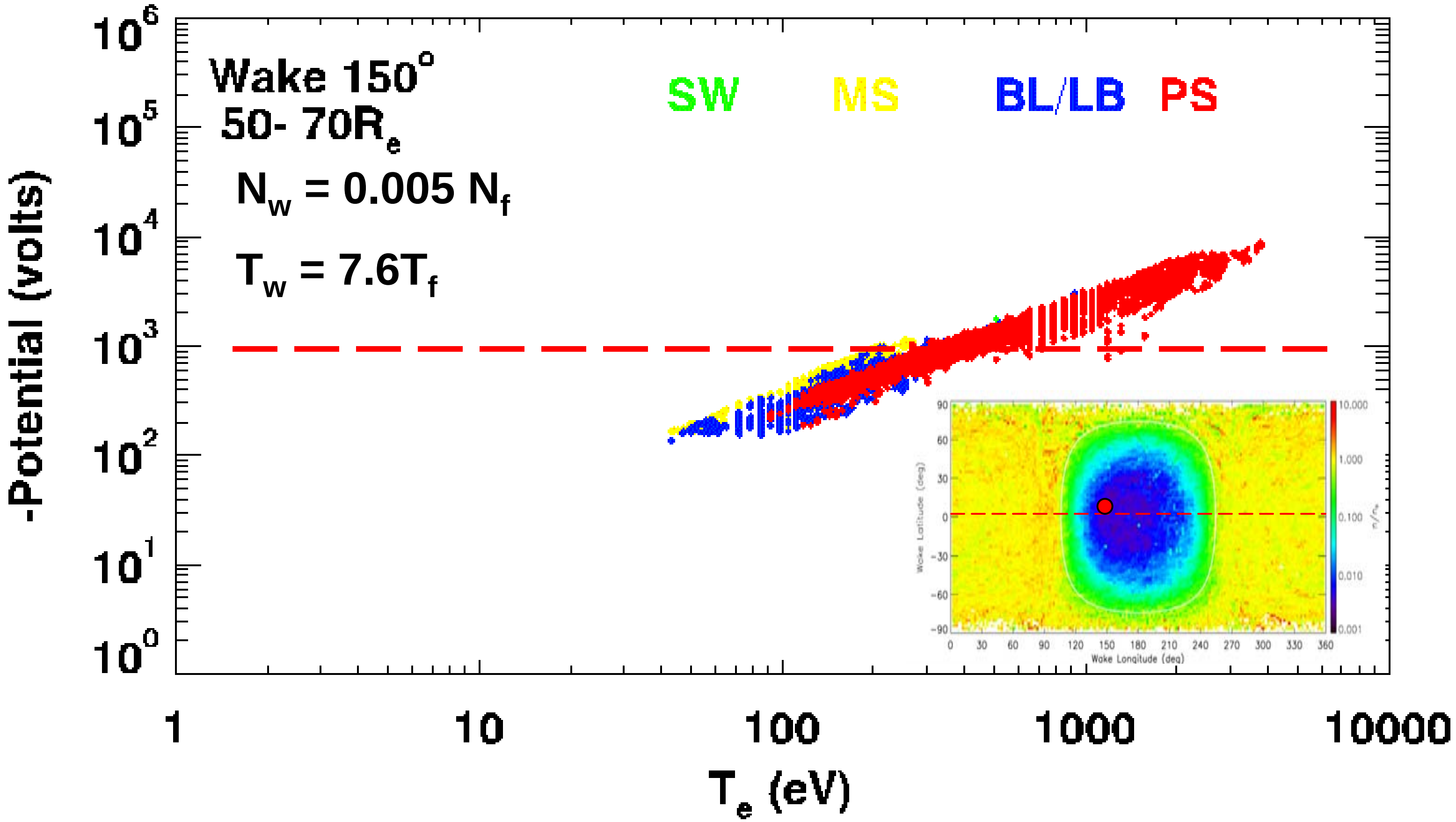


Wake Potentials: 150º

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



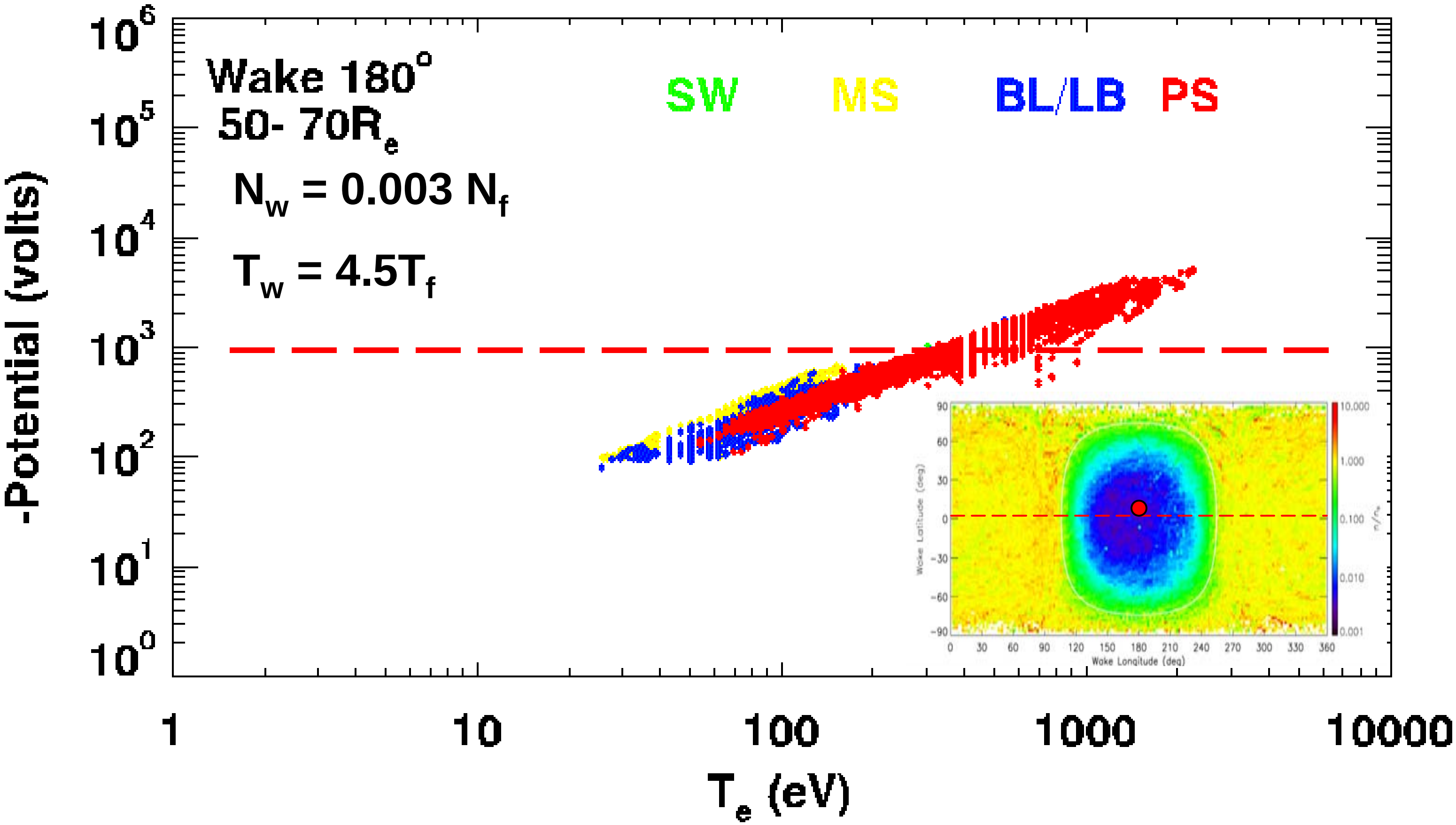
Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Wake Potentials: 180º

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



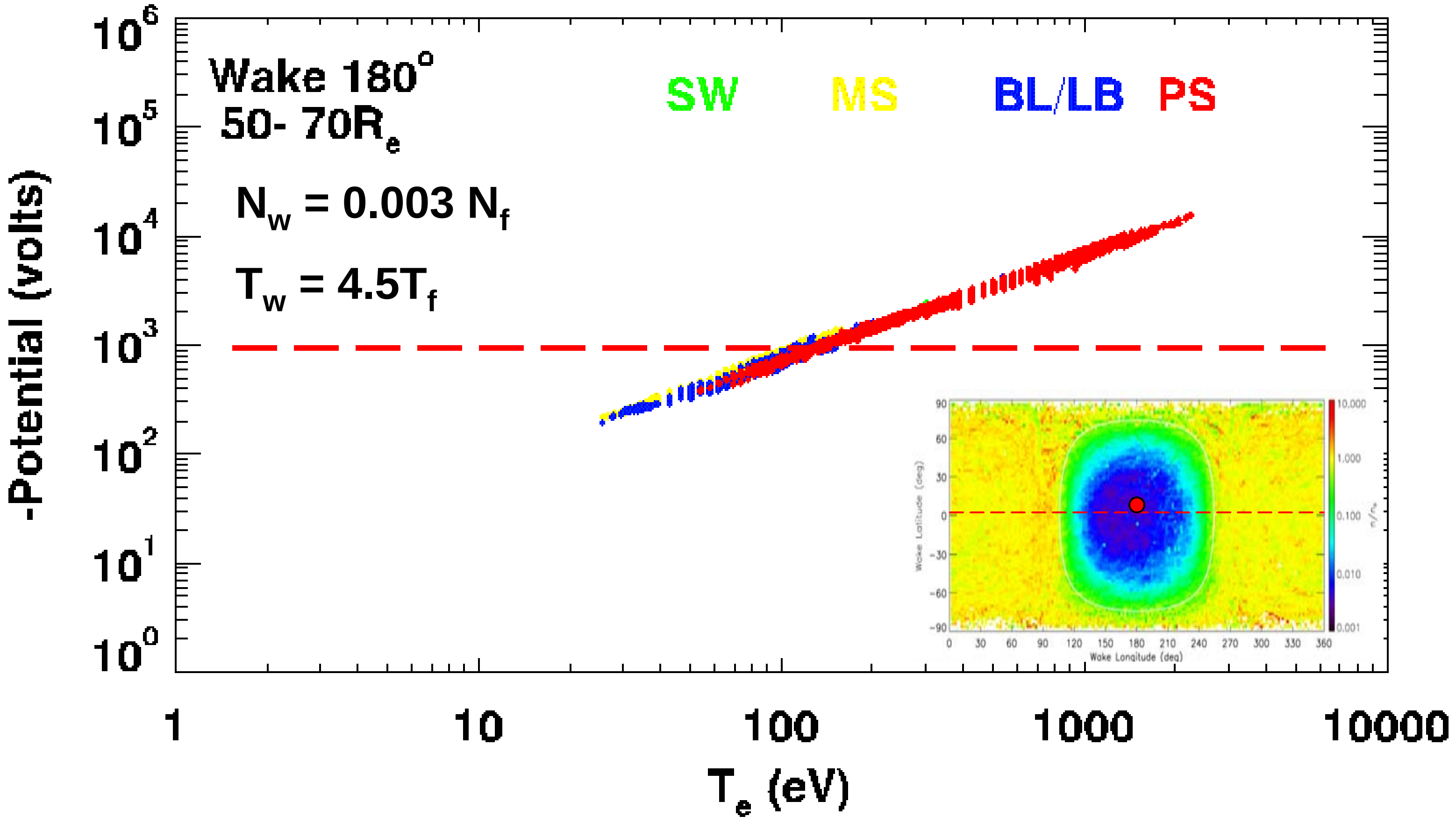
Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Wake Potentials: 180º

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\,\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



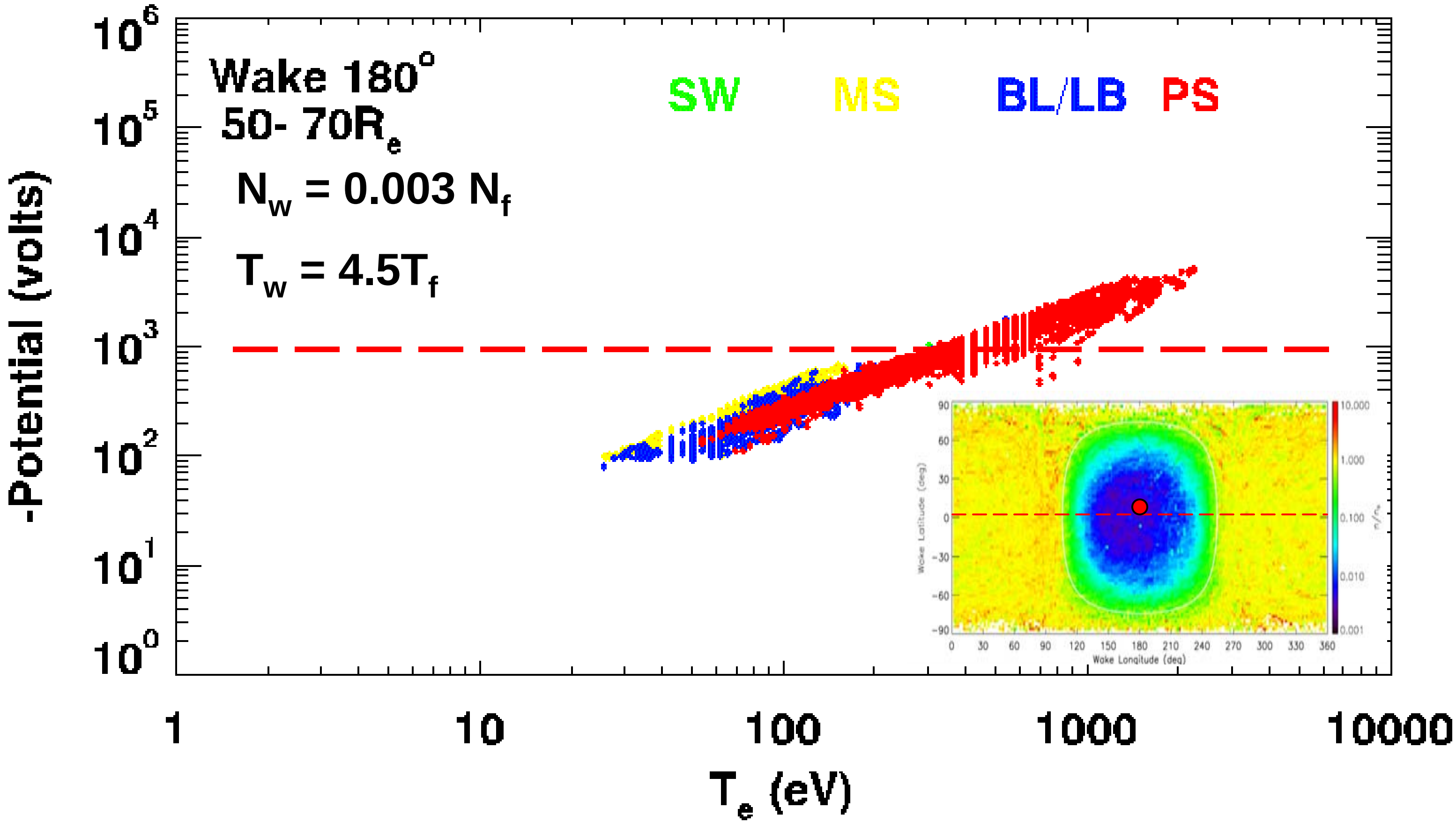
Assumes: $N_i \sim 0.1N_e$

$T_i \sim 0.01T_e$

Wake Potentials: 180º

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



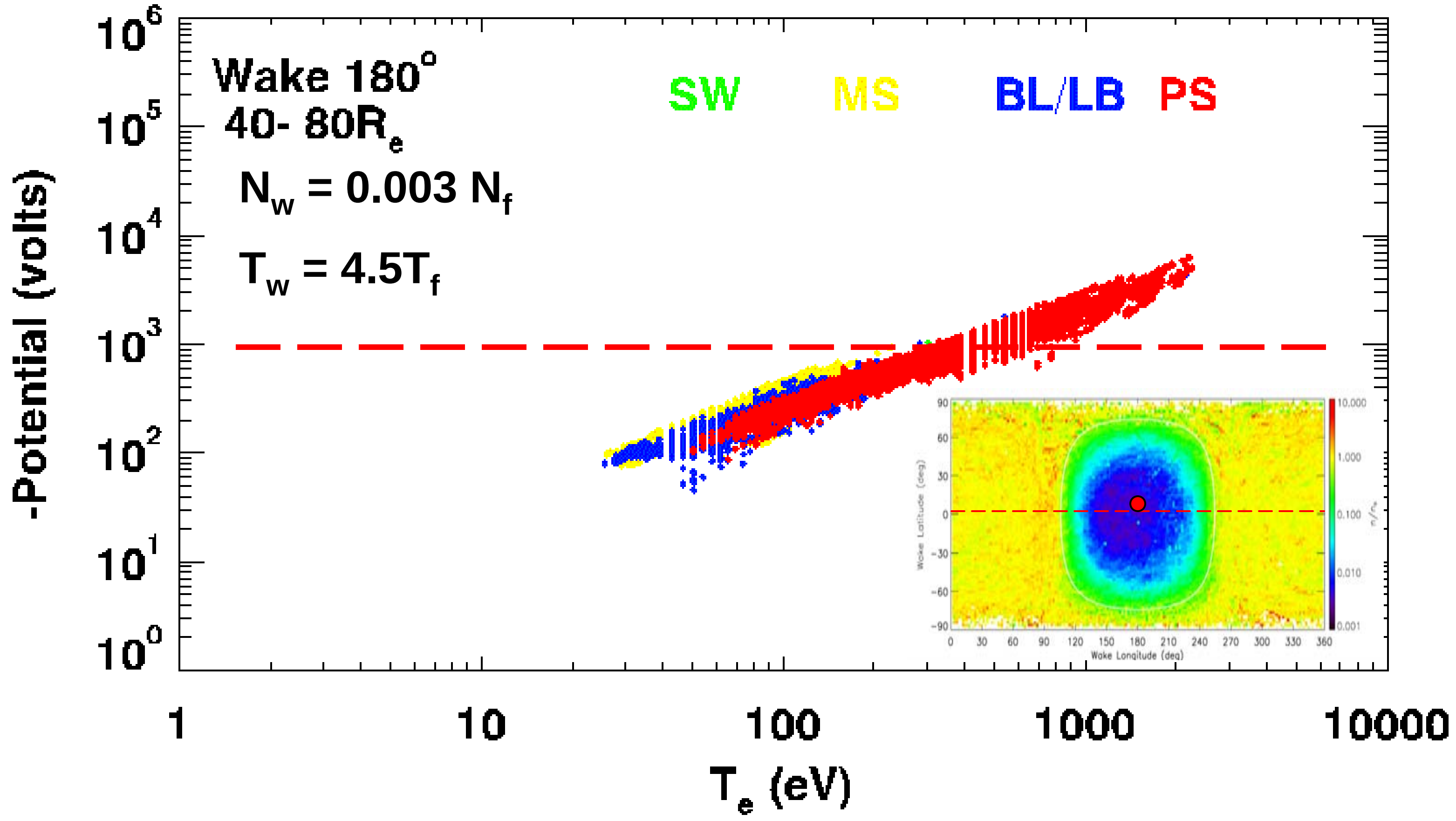
Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Wake Potentials: 180º

40-80 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



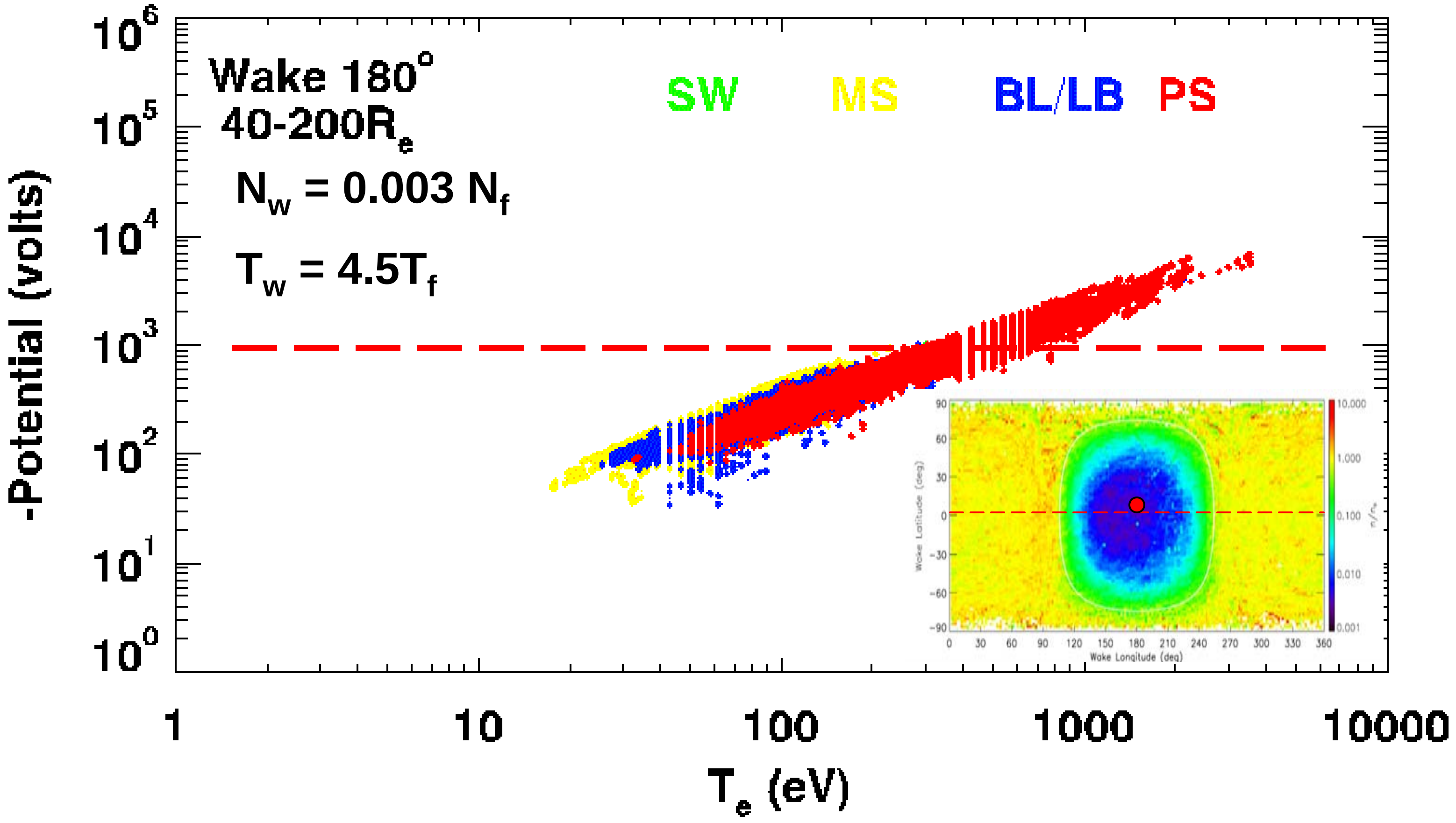
Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Wake Potentials: 180º

40-200 R_e

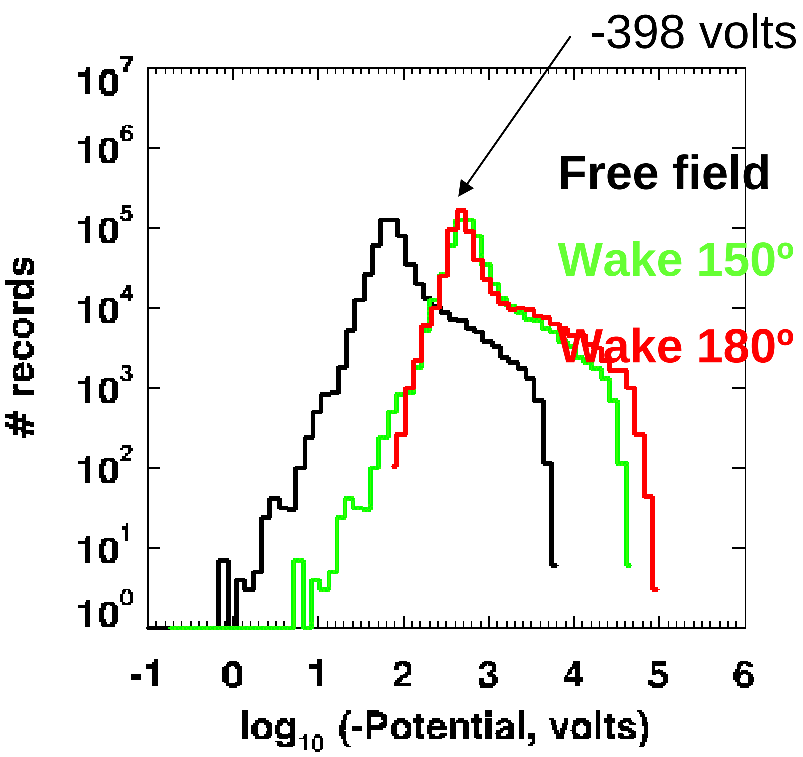
$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\,\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$

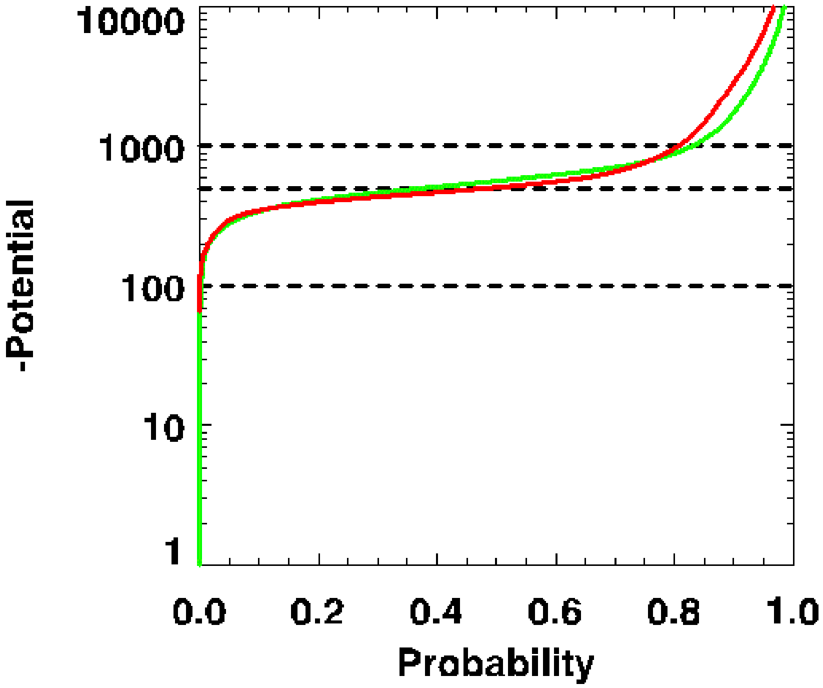


Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Surface Potential Distributions


Potential distributions


Cumulative Probability

All lunar relevant environments combined

~50% ≤ -500 volts

~15% ≤ -1000 volts

Lunar Surface Charging Observations

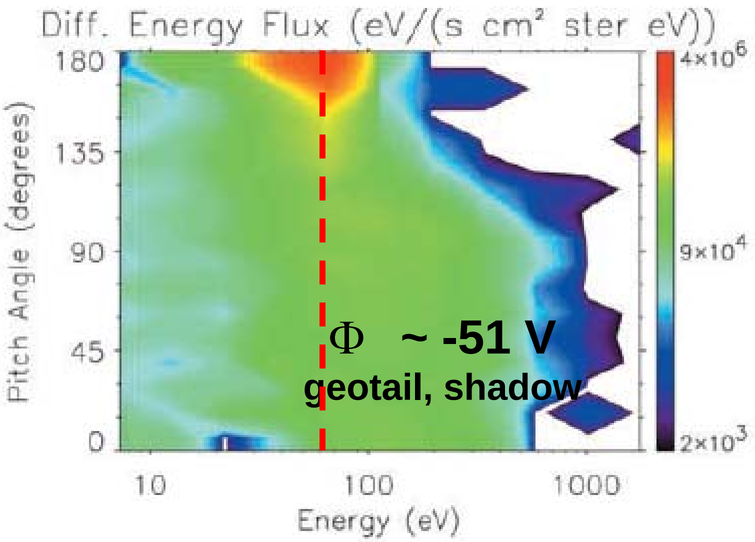
Lunar Prospector

20-115 km

Spacecraft potentials

day +10 V to +50V

night -100 V to -400 V

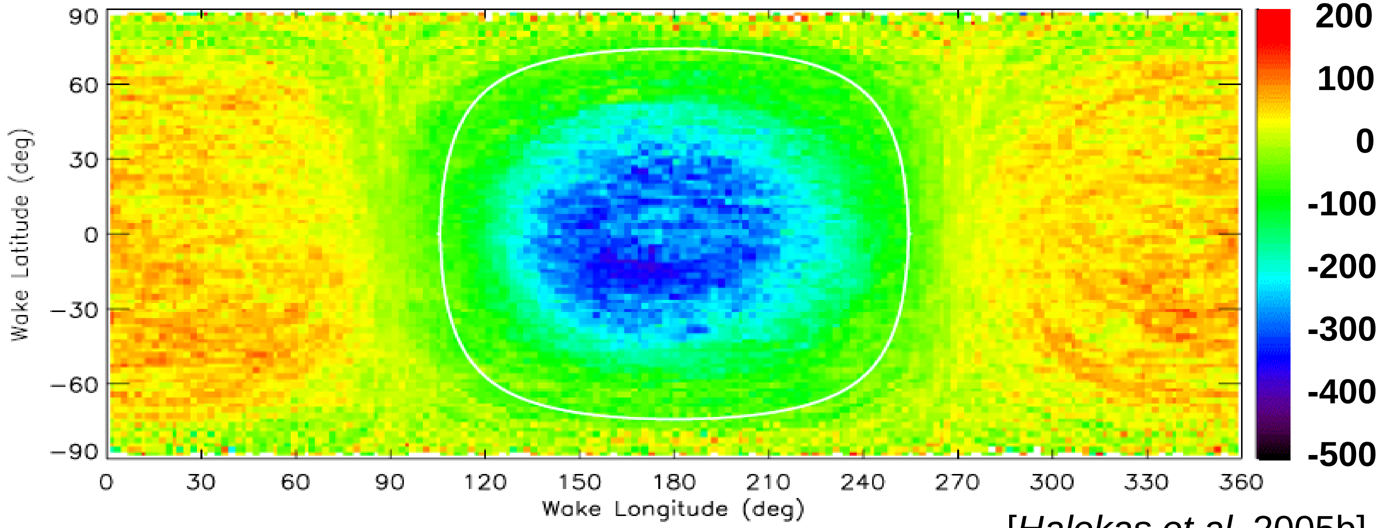


Φ ~ -51 V

geotail, shadow

[*Halekas et al.*, 2002]

Φ_{surface}



-398 volts

[*Halekas et al*. 2005b]

Summary

- Results from preliminary evaluation of extreme charging environments show:
  - Potentials of objects exposed to lunar plasma environments at lunar distances charge negative (in darkness) to values of
  - Mean ~ 100's volts negative ~50% ≤ -500 volts
  - Extremes ~1000's volts ~15% ≤ -1000 volts

Kilovolt potentials occur sufficiently frequently to be of interest to lunar system design

- Future work
  - Expand database
  - Evaluate charging for candidate spacecraft using 3-D surface charging models including secondary electron emission effects