Using A Pulsed Electron Beam To Prevent Charging While Sensing Electric Potentials

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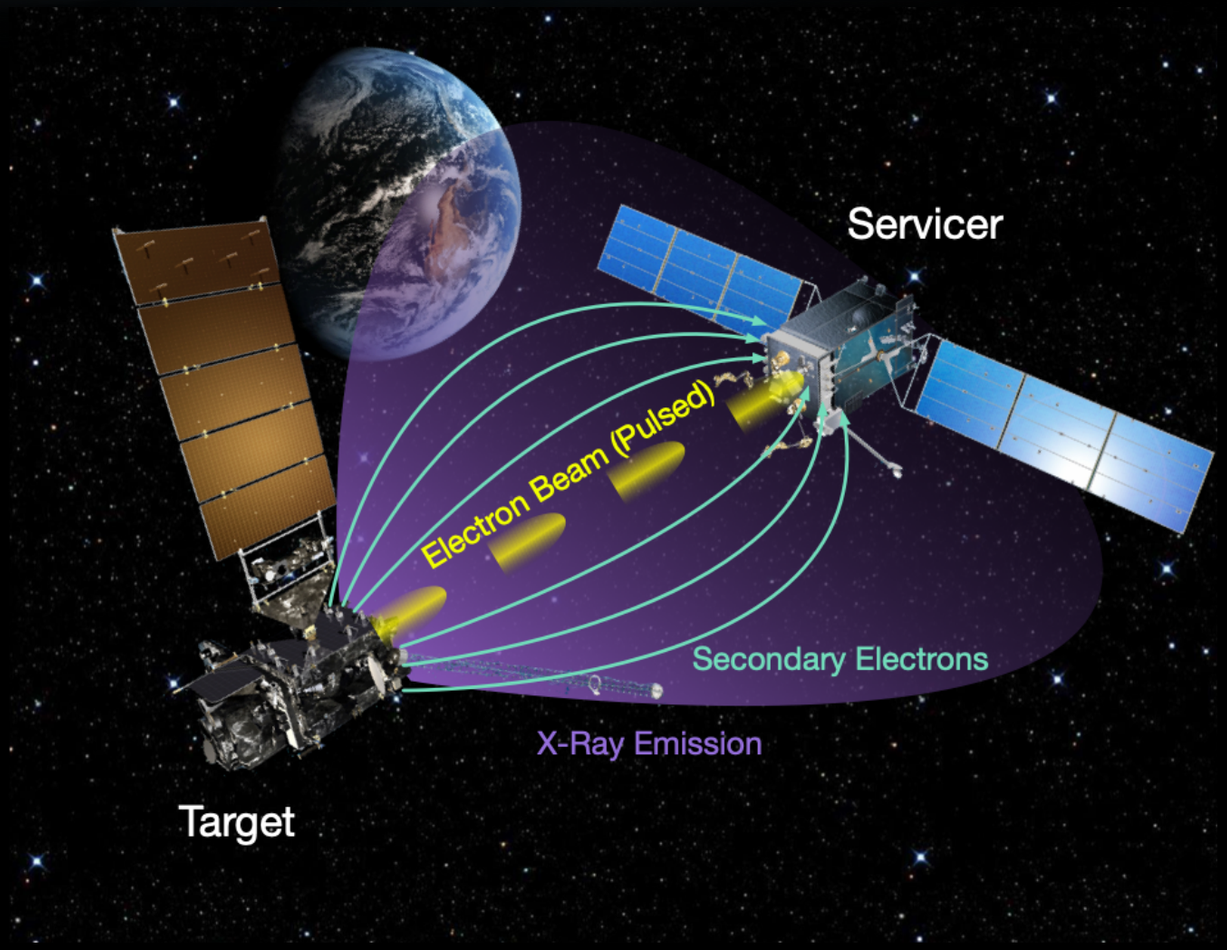
Remote Electric Potential Sensing Methods

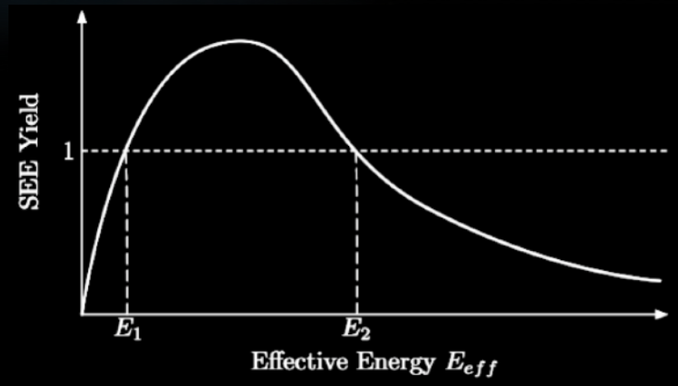
Electrons from servicer's electron gun hit target

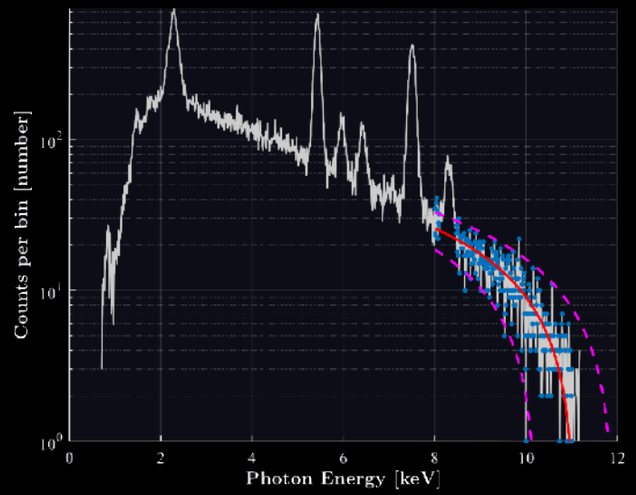
Emission of secondary electrons from target object	Emission of x-rays from target object
Retarding Potential Analyzer on servicer measures kinetic energy of secondary electrons	X-ray detector on servicer measures energy of incoming photons with various energies
Electron Method	**X-ray Method**



Remote Electric Potential Sensing Methods

- **<u>Issue</u>: Incoming electron beam could charge the target object**
  - We want to measure the “natural” electric potential of the target object, so this must be avoided
  - We could adjust the electron beam parameters (energy and current), but remote sensing methods pose limitations on how much we can change these parameters
- **Limitations on Electron Beam Parameters for Remote Sensing Methods:**
  - <u>Electron Method:</u> Low impact energy of electrons preferred to increase secondary electron yield
  - <u>X-Ray Method:</u> High impact energy of electrons preferred to increase x-ray spectrum energy range
  - <u>Both Methods:</u> High electron beam current benefits both sensing methods due to higher signal than for low current





Charging Model

- Photoelectron current

$$I_{ph}(\phi) = \begin{cases} j_{ph,0} A_\perp & \phi \leq 0 \\ j_{ph,0} A_\perp e^{-\phi/T_{ph}} & \phi > 0 \end{cases}$$

- Plasma currents (electron and ion)

$$I_e(\phi) = \begin{cases} -\frac{Aqn_e w_e}{4} e^{\phi/T_e} & \phi < 0 \\ -\frac{Aqn_e w_e}{4}\left(1 + \frac{\phi}{T_e}\right) & \phi \geq 0 \end{cases} \qquad I_i(\phi) = \begin{cases} \frac{Aqn_i w_i}{4}\left(1 - \frac{\phi}{T_i}\right) & \phi \leq 0 \\ \frac{Aqn_i w_i}{4} e^{-\phi/T_i} & \phi > 0 \end{cases} \qquad w = \sqrt{\frac{8T}{\pi m}}$$

- Electron Beam current

$$I_{beam}(\phi_T, \phi_S) = \begin{cases} -\alpha I_{EB} & \phi_S - \phi_T < E_{EB} \\ 0 & \phi_S - \phi_T \geq E_{EB} \end{cases}$$

- Secondary Electron Emission (SEE) current

$$I_{SEE}(\phi_T, \phi_S) = \begin{cases} 4Y_M I_{beam}(\phi_T, \phi_S)\kappa & \phi_T < 0 \\ 0 & \phi_T \geq 0 \end{cases} \qquad \kappa = \frac{E_{eff}/E_{max}}{(1 + E_{eff}/E_{max})^2} \qquad E_{eff} = E_{EB} - \phi_S + \phi_T$$

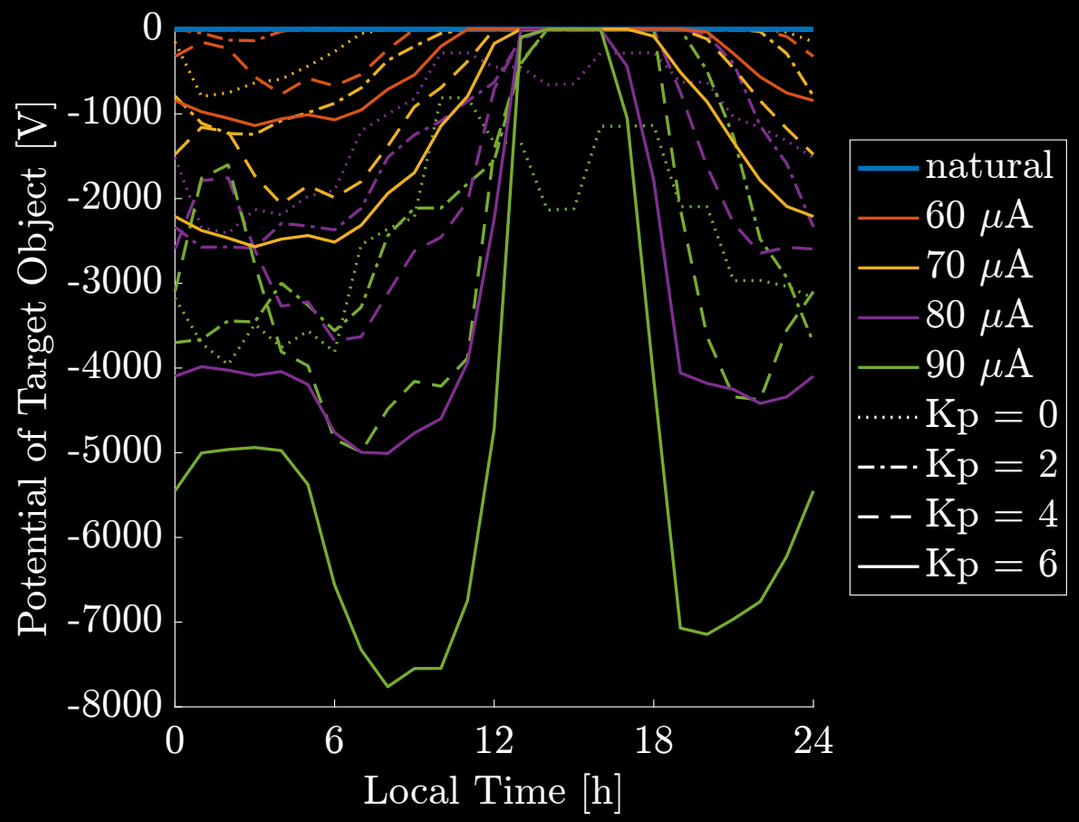
Effect of Continuous Electron Beam on Potential of Target Object

Continuous Beam: Effect of Local Time and Kp Index

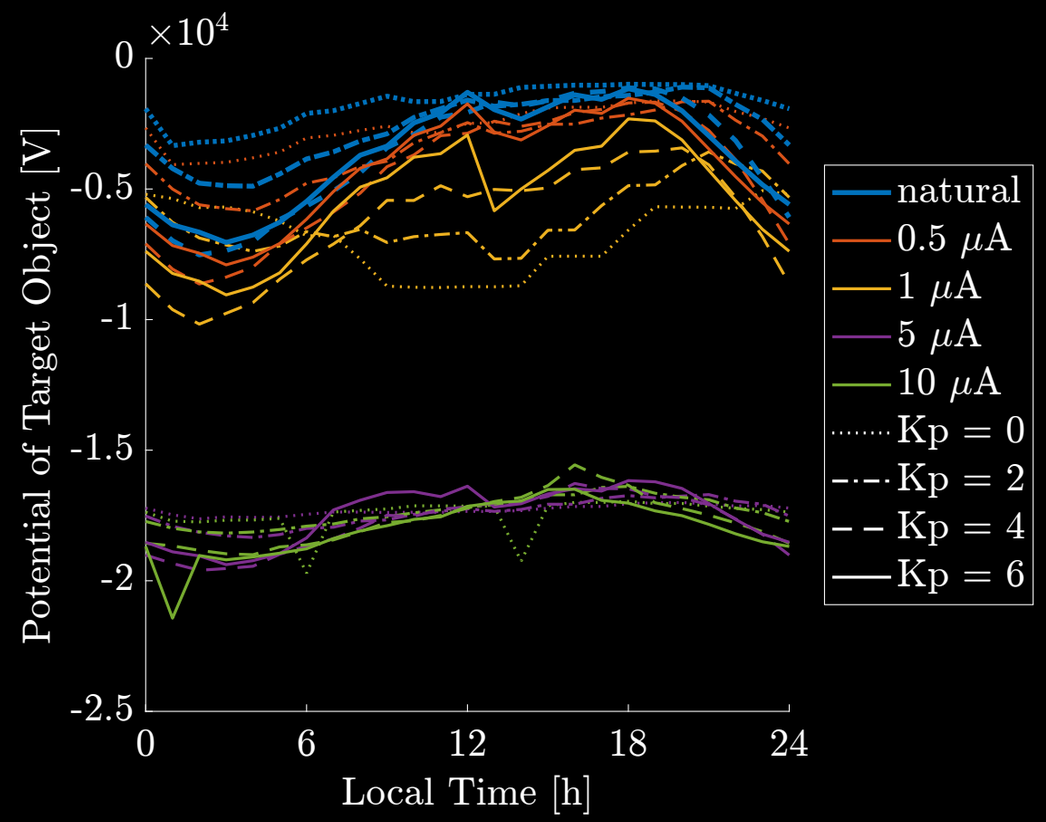
$R_T = 1$ m, $R_S = 1$ m, $E_{EB} = 20$ keV

- Equilibrium potential of target object for various locations around earth and space weather scenarios

In Sunlight



In Eclipse



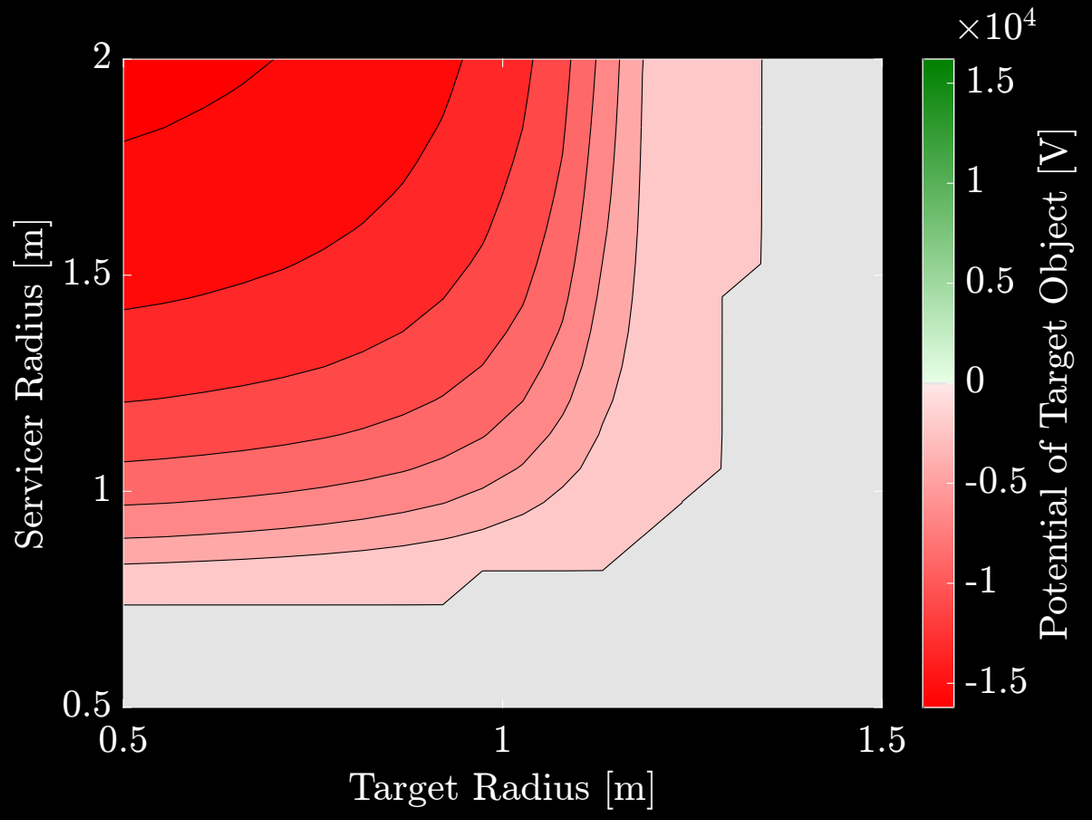
Plasma Data from: Denton, M. H. (2005). Bulk plasma properties at geosynchronous orbit. Journal of Geophysical Research, 110(A7), A07223.

Continuous Beam: Effect of Spacecraft Size

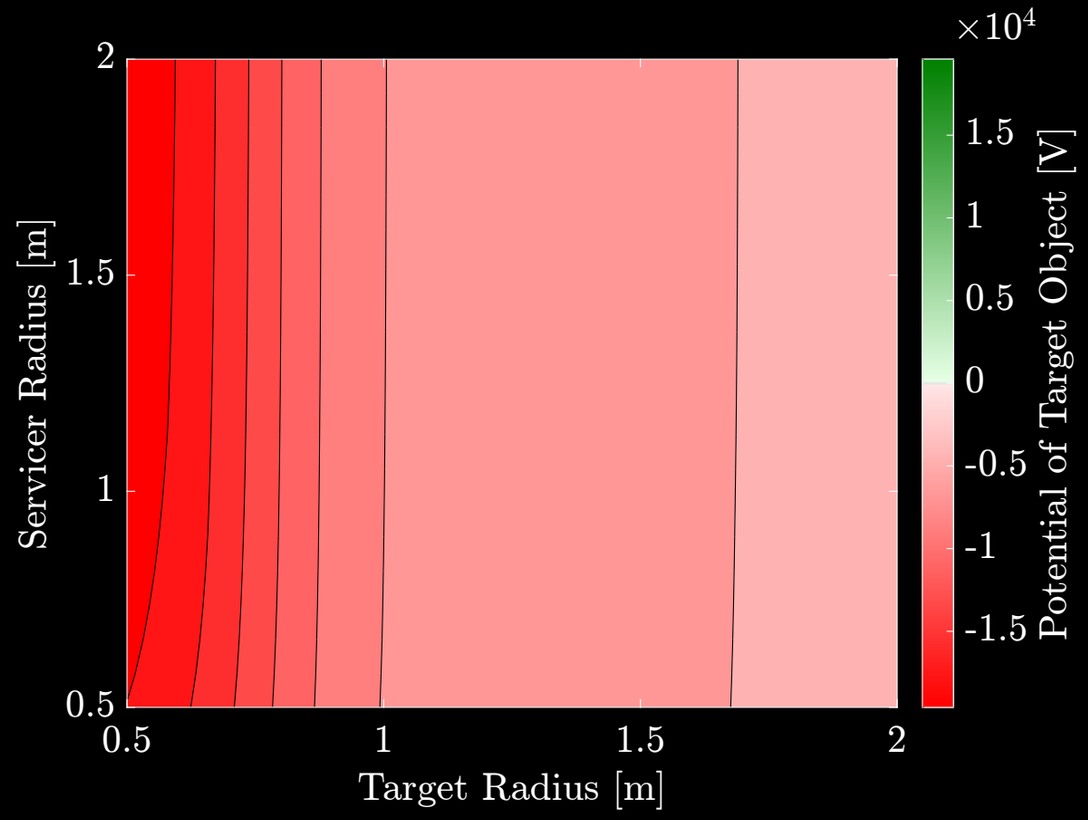
$LT = 6\ \mathrm{h}, \quad K_p = 2, \quad E_{EB} = 20\ \mathrm{keV}$

- How does the size of the spacecraft affect the equilibrium potential of the target object?

In Sunlight $\quad I_{EB} = 100\ \mu\mathrm{A}$



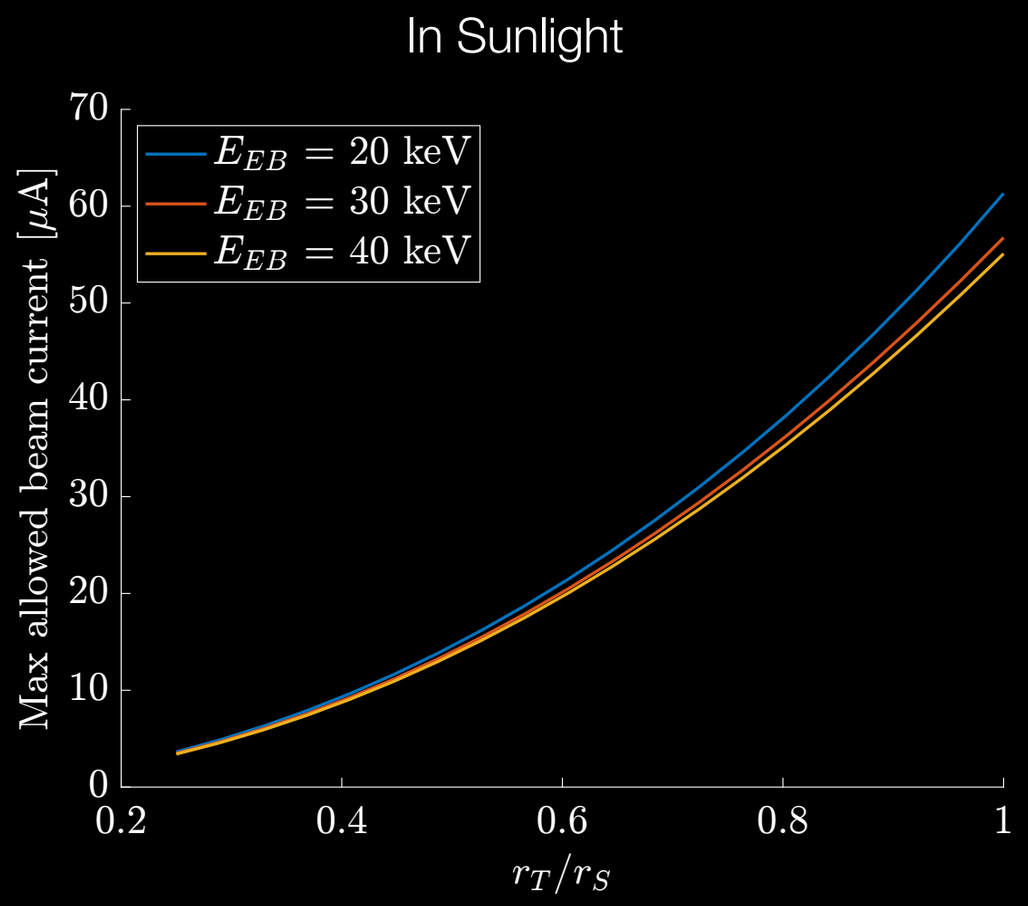
In Eclipse $\quad I_{EB} = 1\ \mu\mathrm{A}$

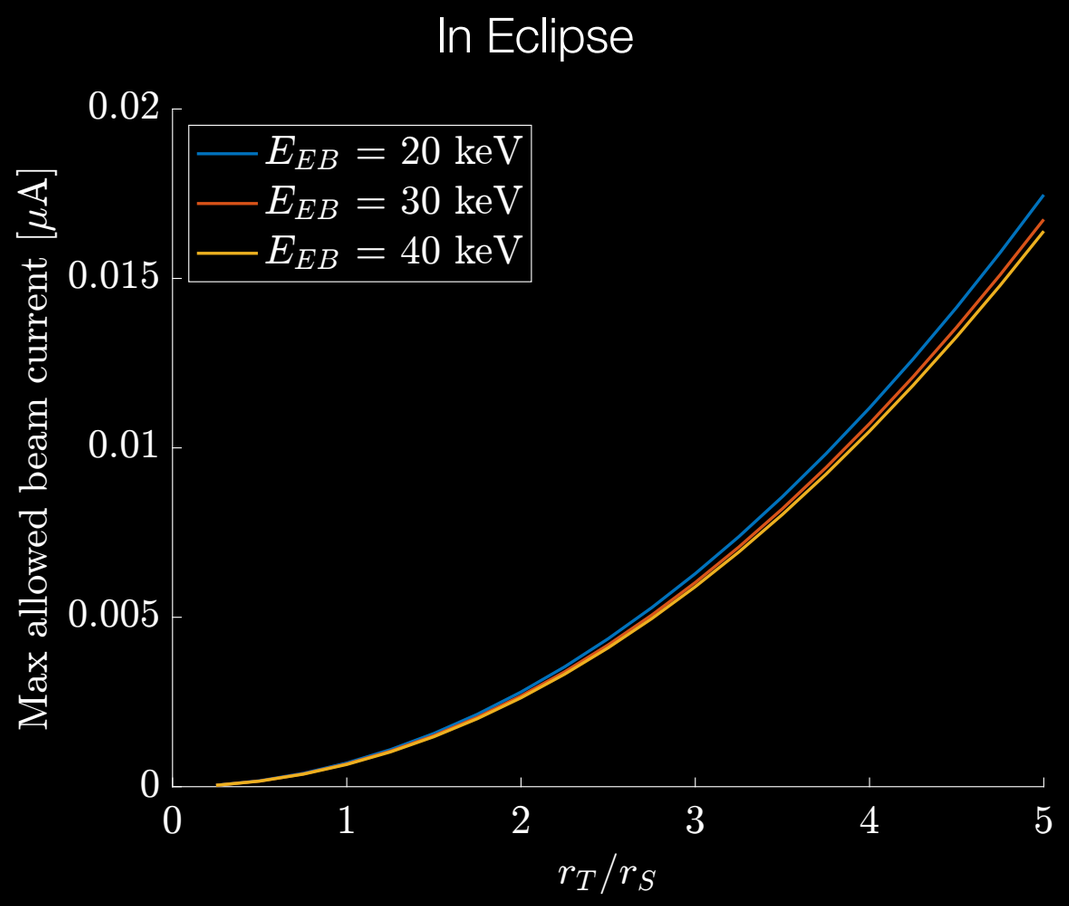


Maximum allowed current to prevent Charging

$LT = 6\ \mathrm{h}, \quad K_p = 2, \quad R_S = 1\ \mathrm{m}$

- What maximum electron beam current can we use with a continuous beam without charging the target object?

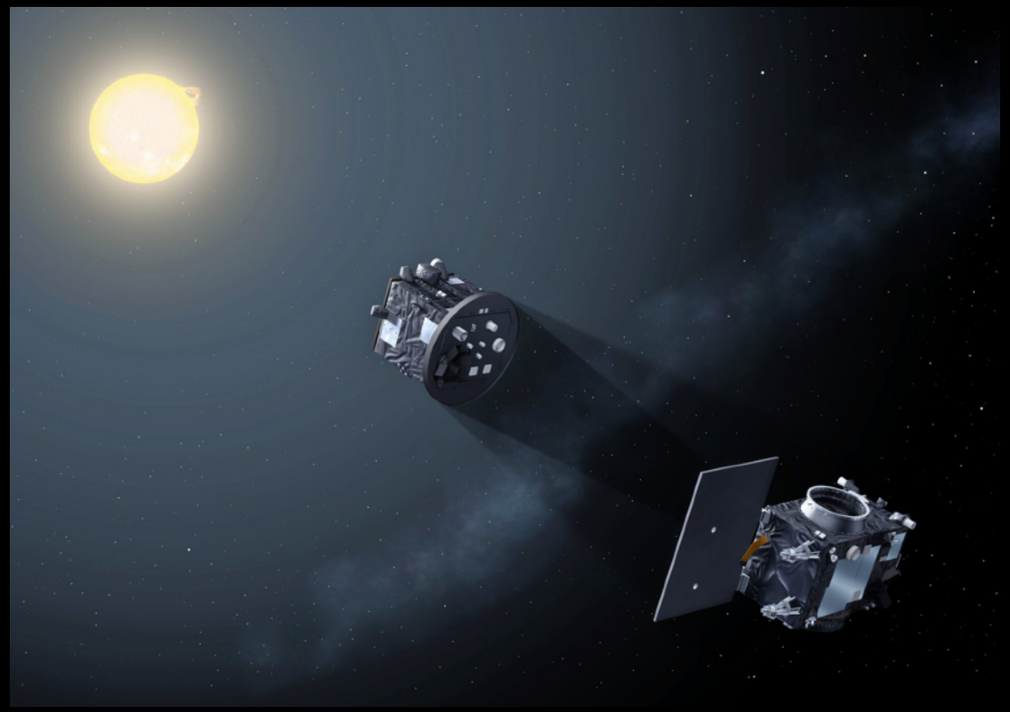




Conclusion for Continuous Beam Analysis

Charging of the target object while sensing its electric potential is especially a concern if the target object is eclipsed

The target object could be eclipsed by Earth (or Moon) but also by another spacecraft (e.g. the servicer)



ESA: Proba-3 satellites

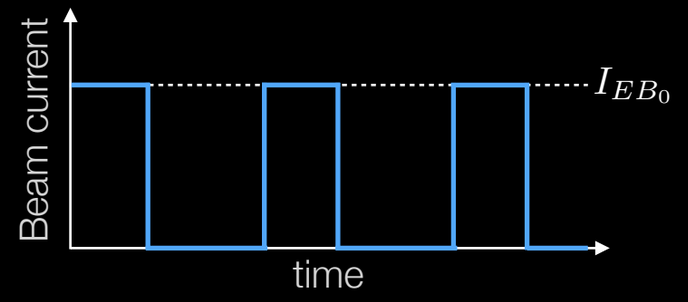
Pulsed Electron Beam

Overview of Pulsed Beam

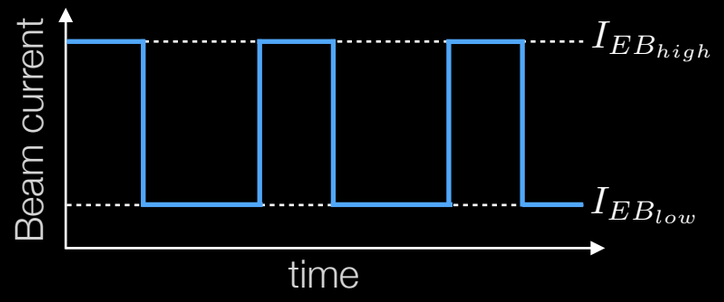
- **Three types of electron beam pulsing**
  - On-Off Pulsing: switch between 0 and nominal beam current
  - Current Pulsing: switch between low and high beam current
  - Energy Pulsing: switch between low and high beam energy
- **Control parameters of Pulsed Beam**
  - Repetition frequency f_{rep}
  - Duty Cycle d

Duty Cycle: $d = \frac{t_{on}}{t_{off}}$

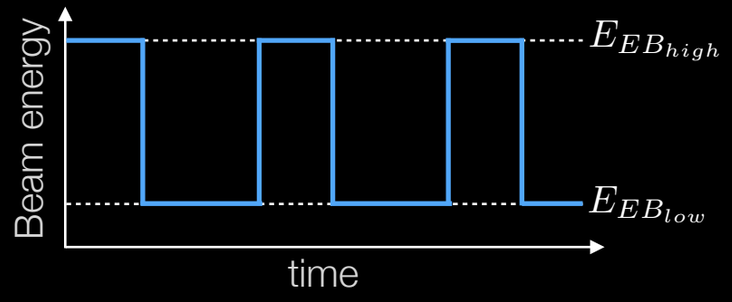
On-Off Pulsing



Current Pulsing



Energy Pulsing

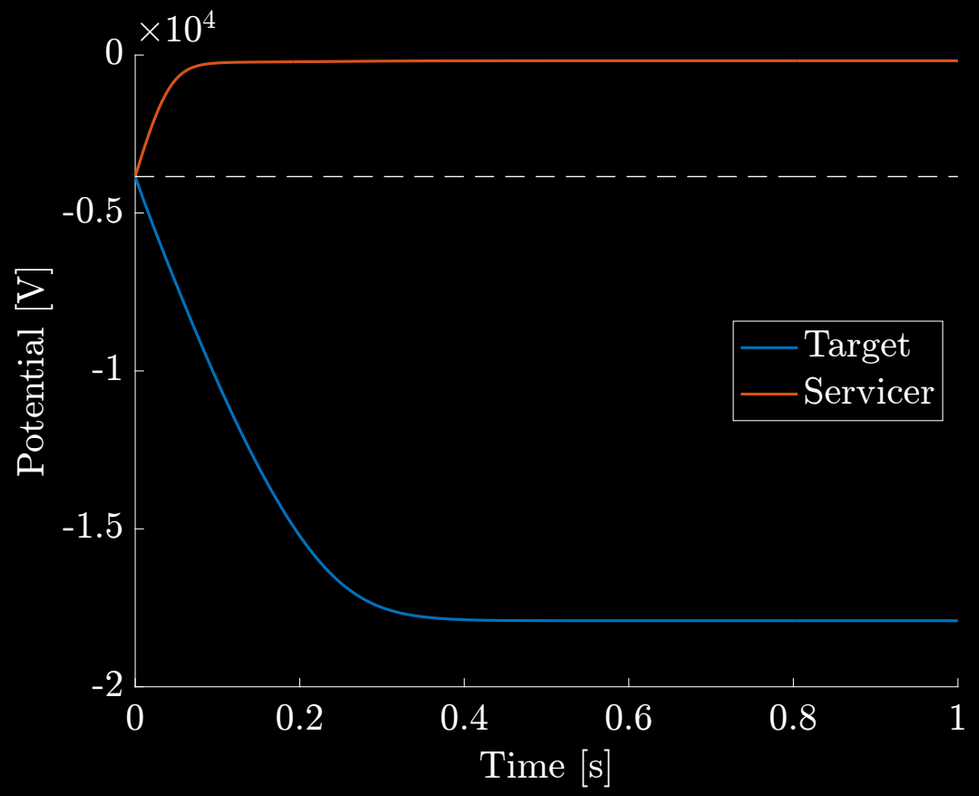


On-Off Pulsing Example

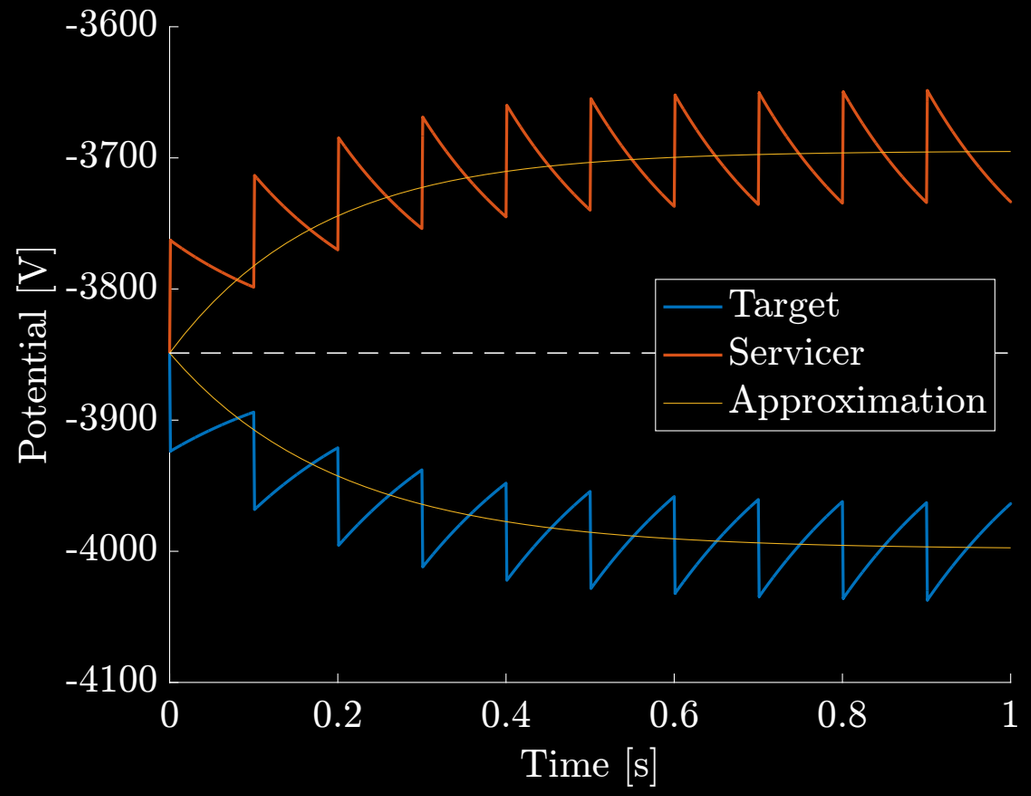
$$R_T = 1 \text{ m}, \quad R_S = 1 \text{ m}, \quad LT = 6 \text{ h}, \quad K_p = 2$$
$$E_{EB} = 20 \text{ keV}, \quad I_{EB_0} = 10\ \mu\text{A}, \quad f_{rep} = 10 \text{ Hz}, \quad d = 0.01$$

- Both spacecraft are eclipsed
- Comparison between continuous and pulsed electron beam

No Pulsing



On-Off Pulsing

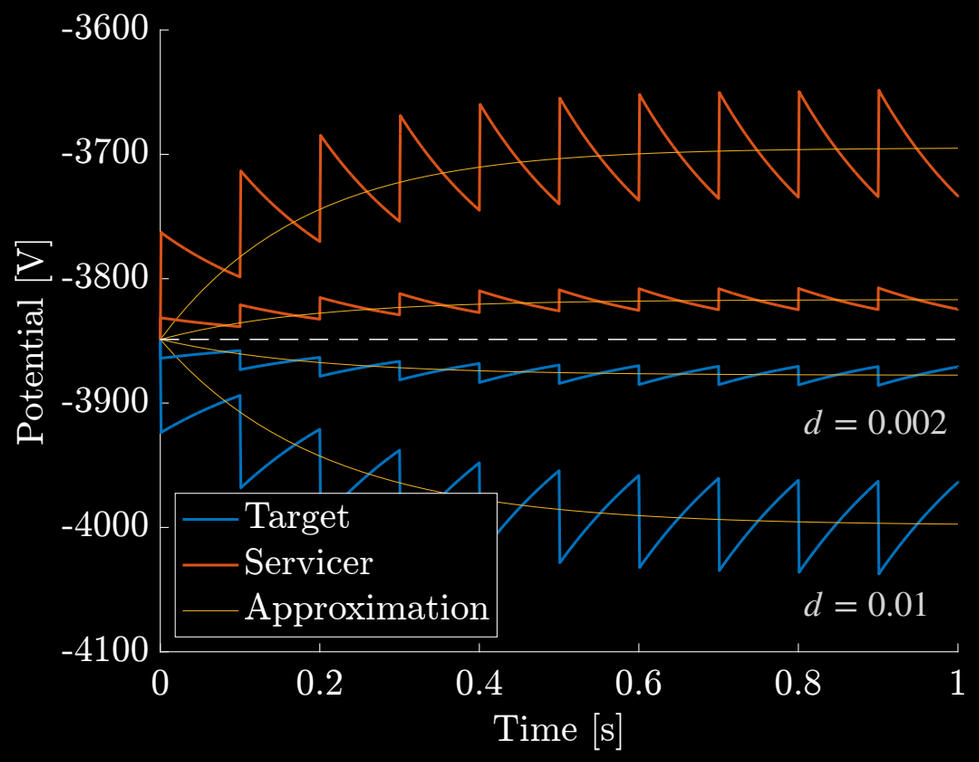


Duty Cycle vs. Repetition Frequency

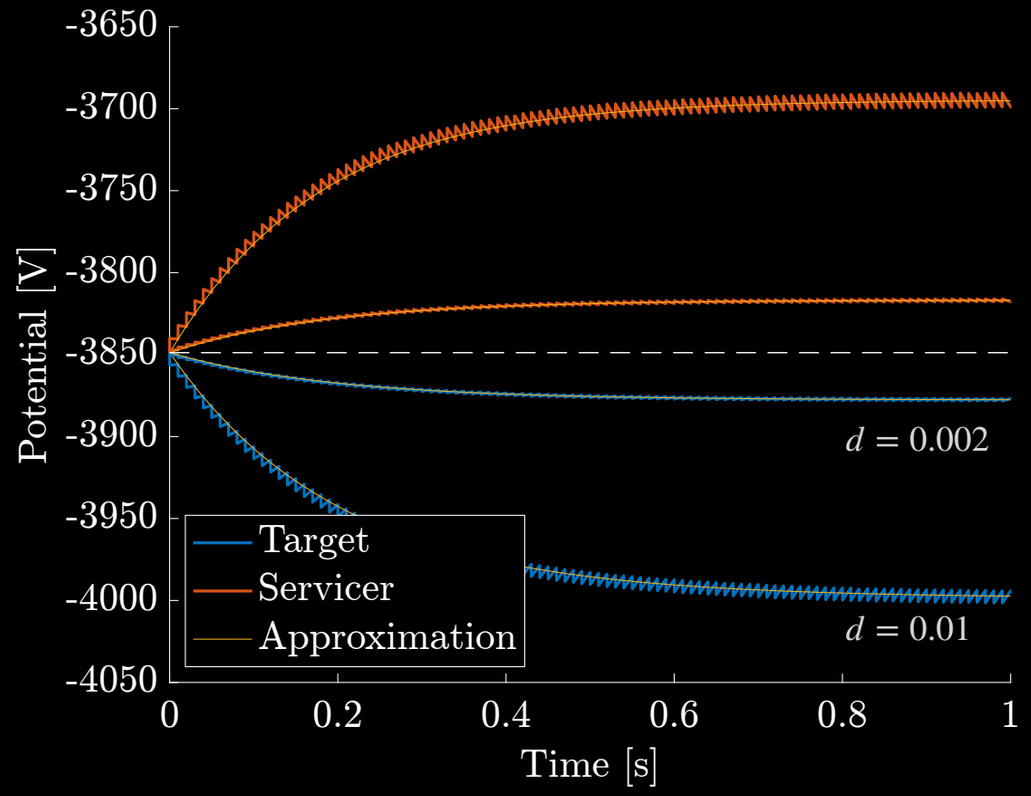
- Duty cycle affects change in potential
- Repetition frequency affects amplitude of oscillations

$$I_{EB_{eff}} = d \cdot I_{EB_0}$$

10 Hz



100 Hz



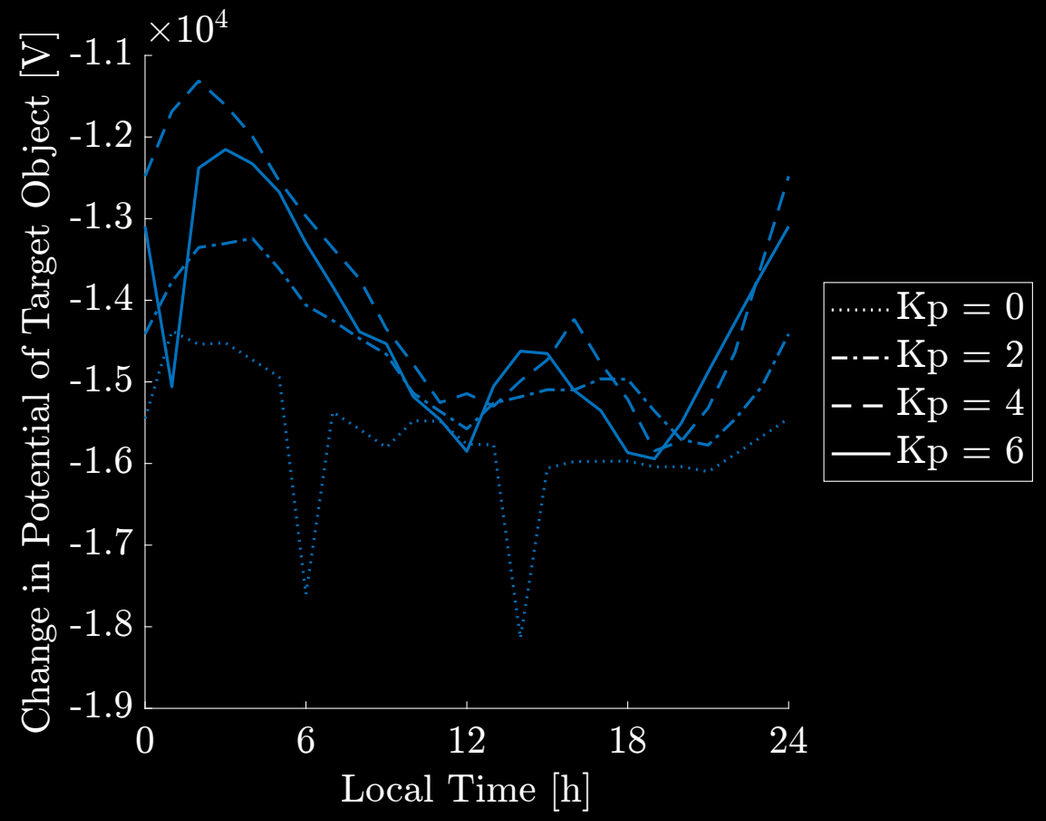
Pulsed Beam: Effect of Local Time and Kp Index

- Change in potential of target object for various locations around earth and space weather scenarios

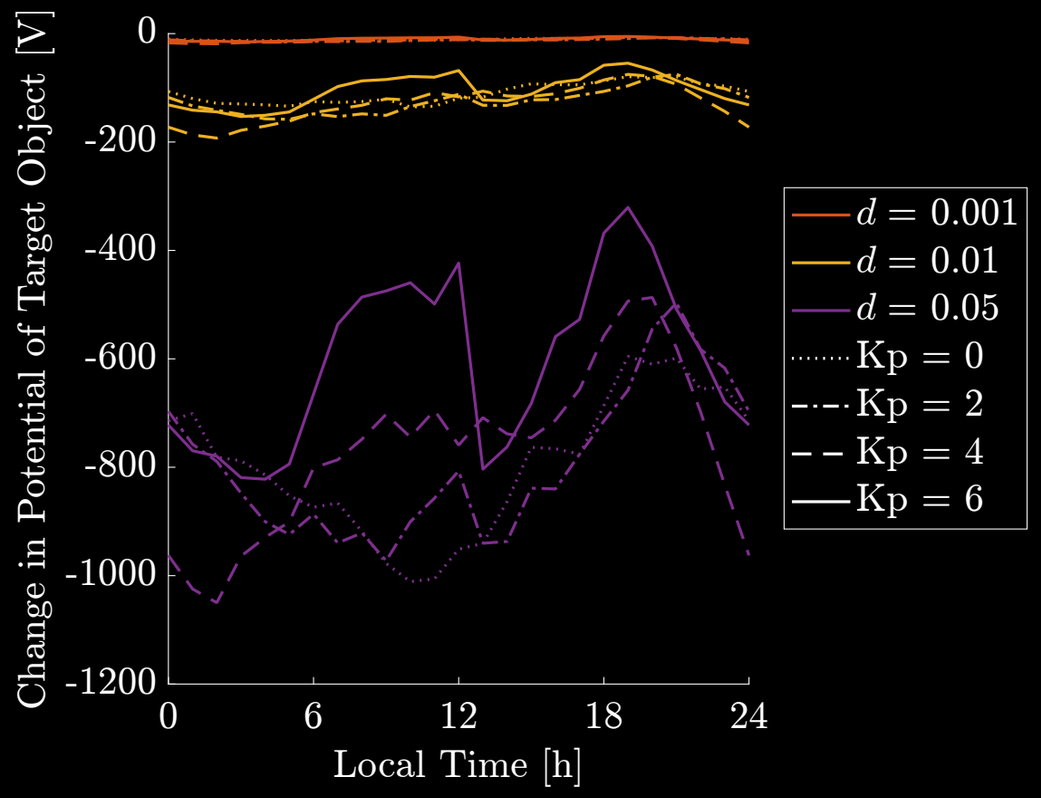
$R_T = 1$ m, $R_S = 1$ m

$E_{EB} = 20$ keV, $I_{EB_0} = 10\ \mu$A, $f_{rep} = 10$ Hz

No Pulsing



On-Off Pulsing

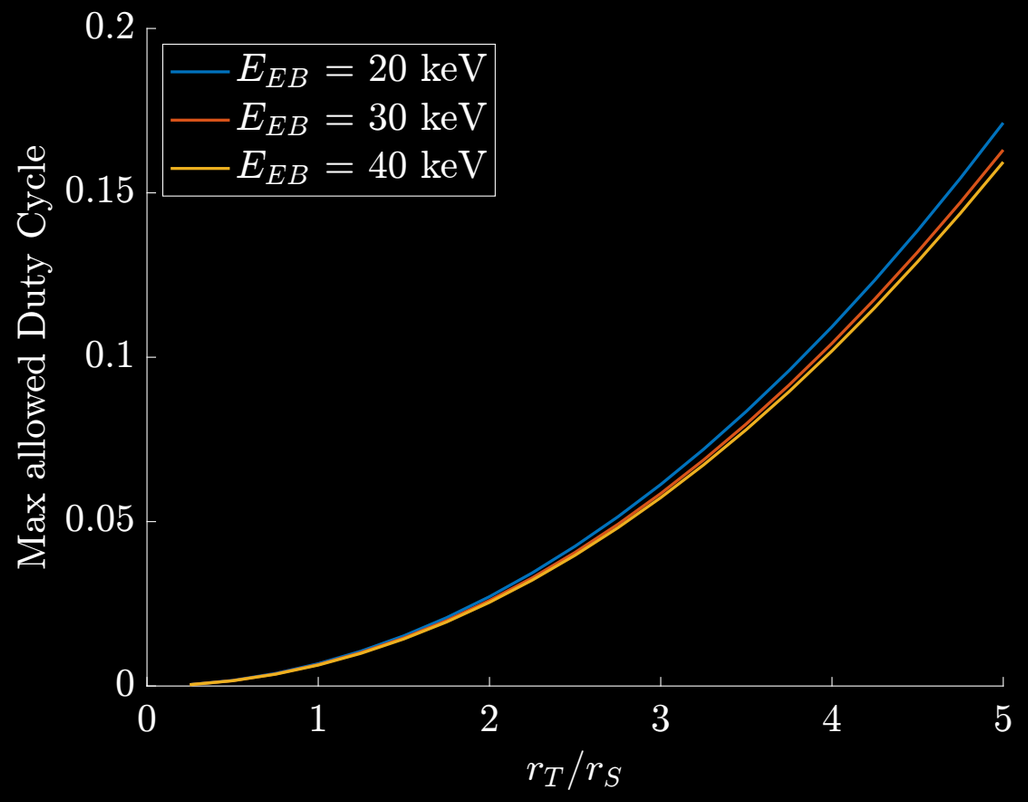


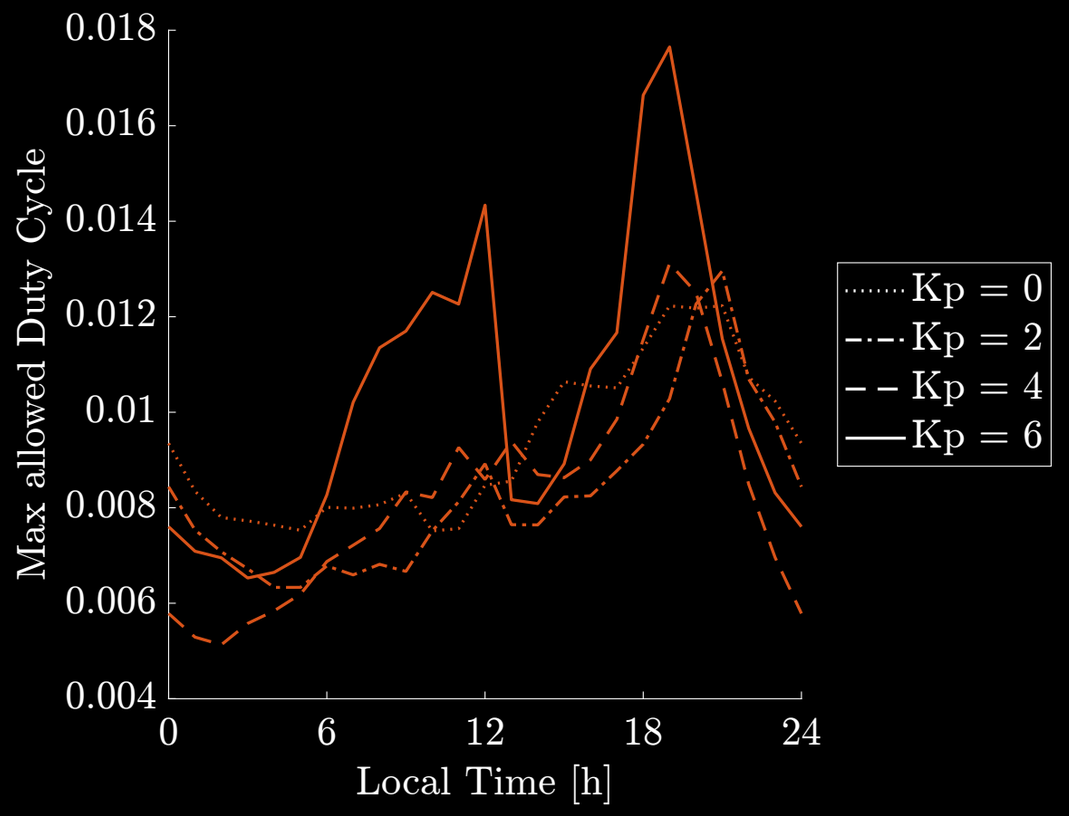
Plasma Data from: Denton, M. H. (2005). Bulk plasma properties at geosynchronous orbit. Journal of Geophysical Research, 110(A7), A07223.

Maximum allowed Duty Cycle to prevent Charging

- What maximum duty cycle can we use such that the change in potential is less than 100 V?

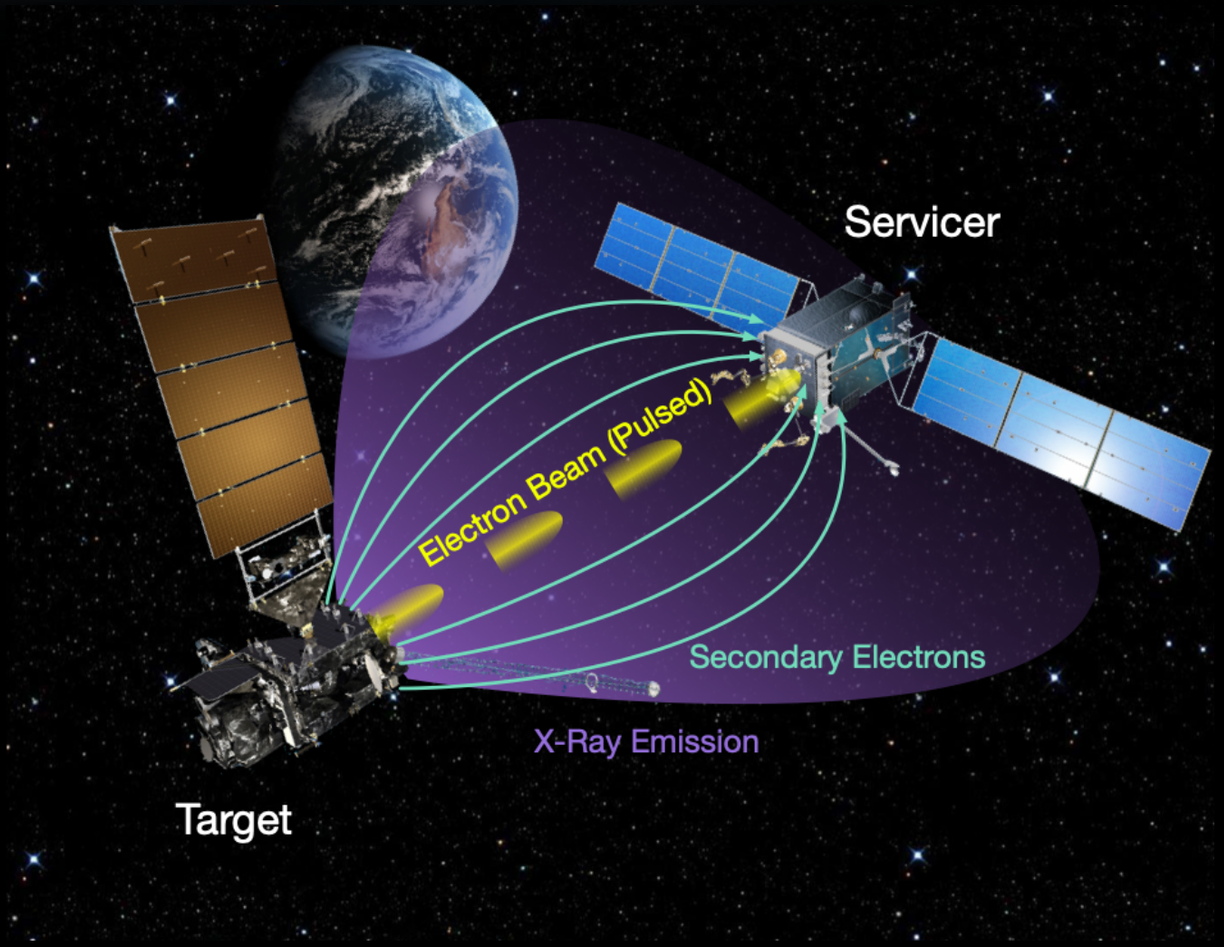
$$R_T = 1\ \mathrm{m}, \quad R_S = 1\ \mathrm{m}, \quad LT = 6\ \mathrm{h}, \quad K_p = 2$$
$$E_{EB} = 20\ \mathrm{keV}, \quad I_{EB_0} = 10\ \mu\mathrm{A}, \quad f_{rep} = 10\ \mathrm{Hz}$$





Conclusions

- The potential of the target object can change while the potential is being sensed with an electron beam
- The change in potential is drastic if the target object is eclipsed (by celestial body or another spacecraft)
- A pulsed electron beam can be used to reduce the average current and thus reduce charging



Questions?

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