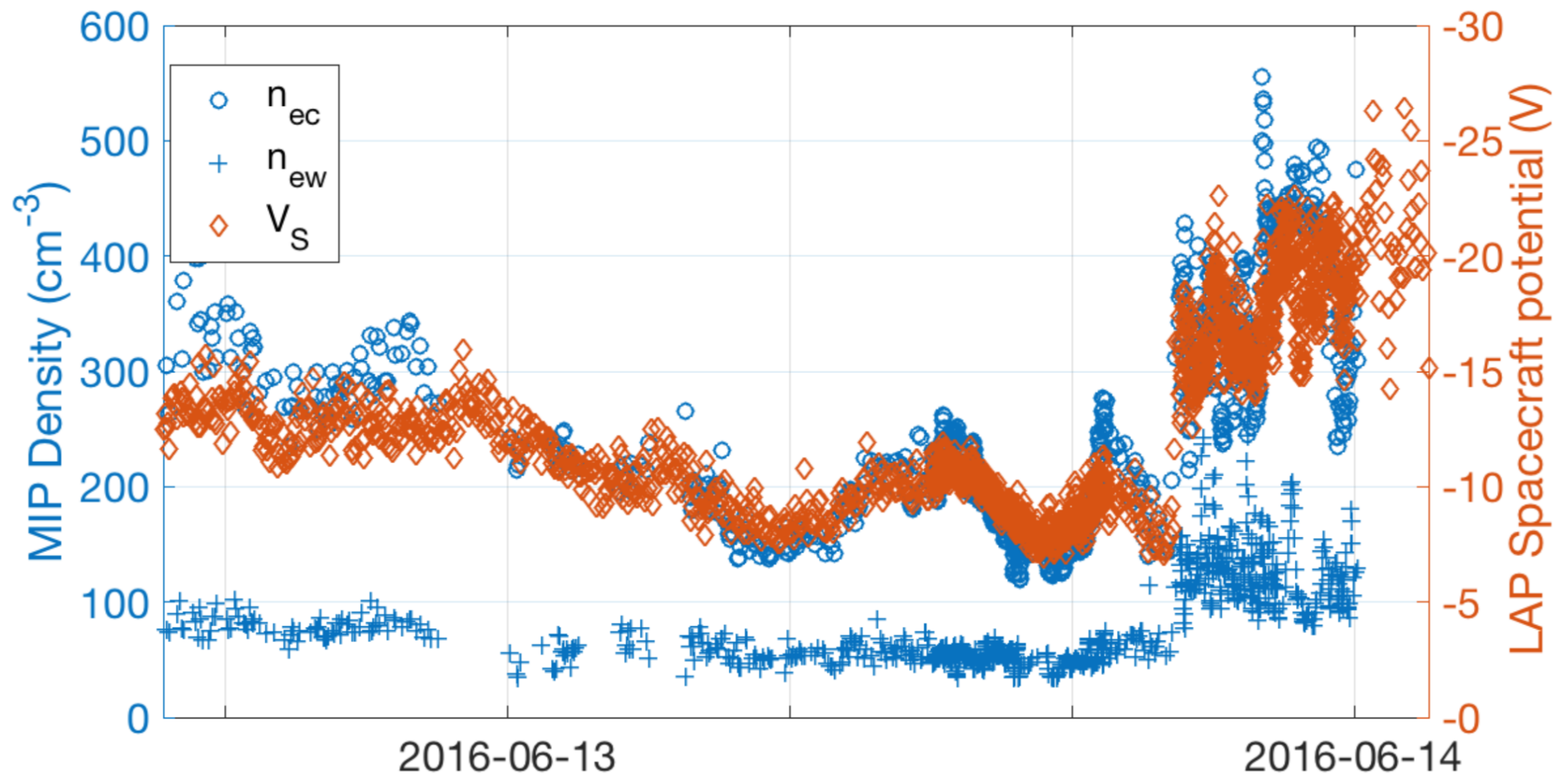


A Charging model for the Rosetta Spacecraft

F. L. Johansson et al
DOI:10.1051/0004-6361/202038592

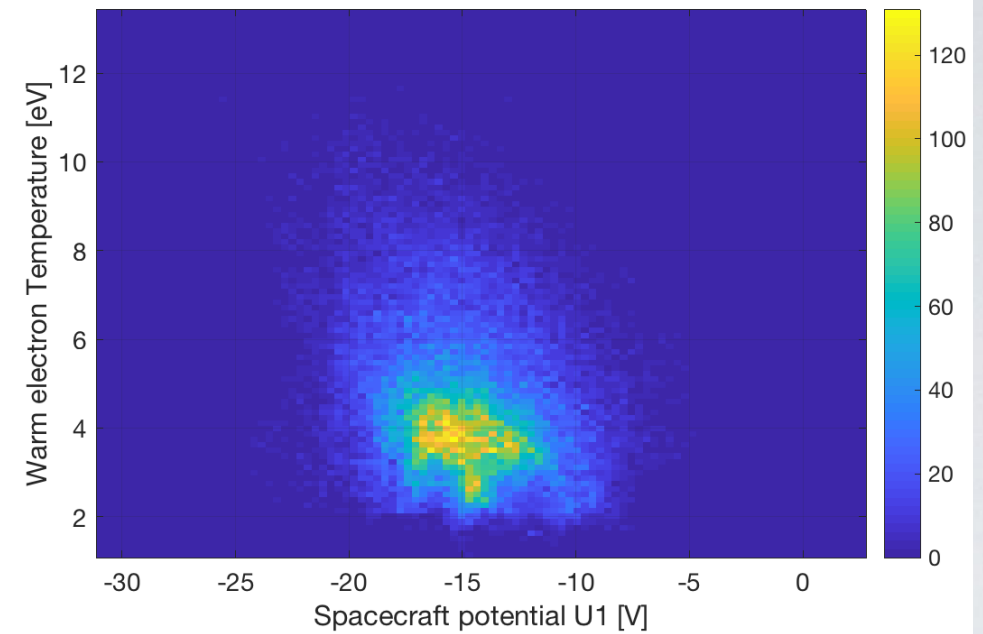
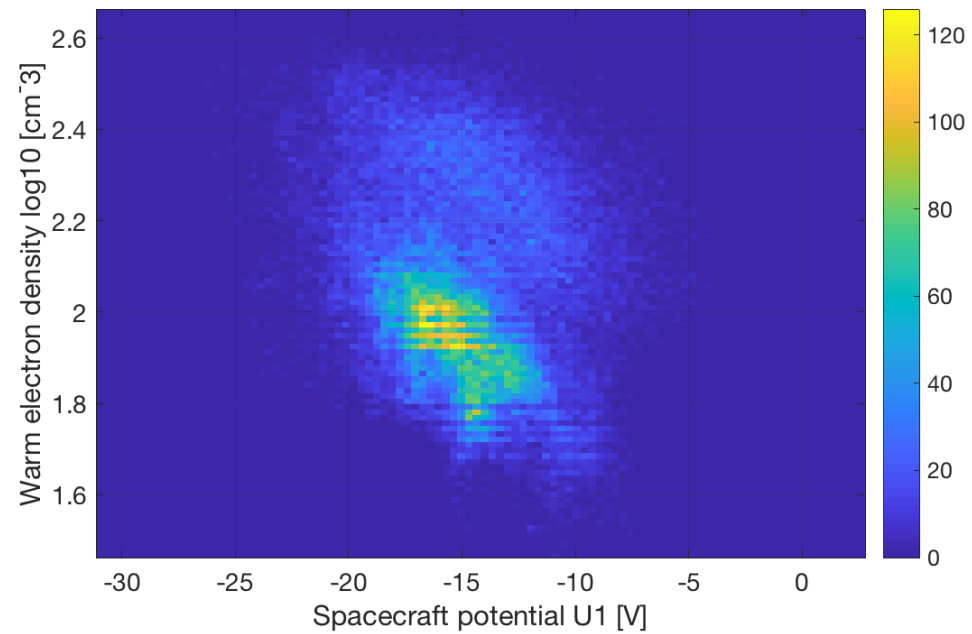
NEW RESULTS FROM 2019



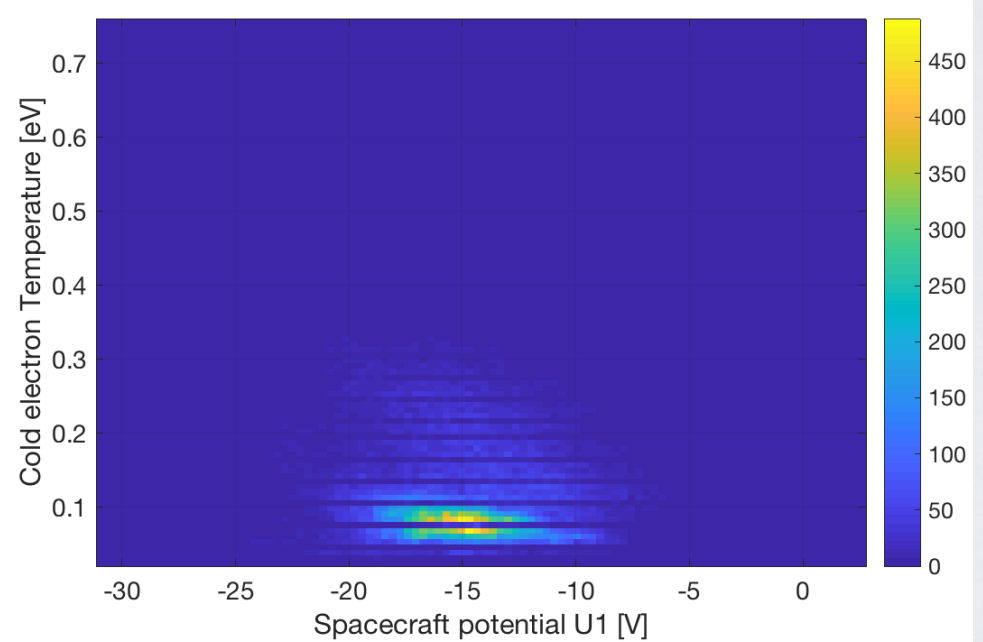
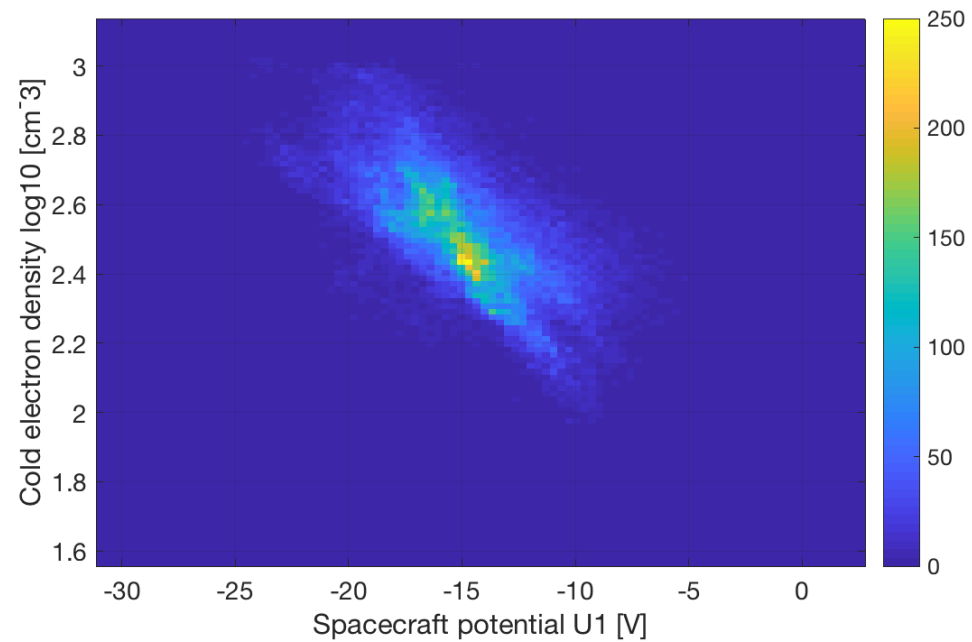
Spacecraft potential has a linear-log relationship with density, especially clear with the cold electron population (0.1 eV), even though 0.1 eV electrons cannot contribute a current to a uniformly charged -15 V body. How can this be

MOTIVATION -NEW RESULTS

Warm

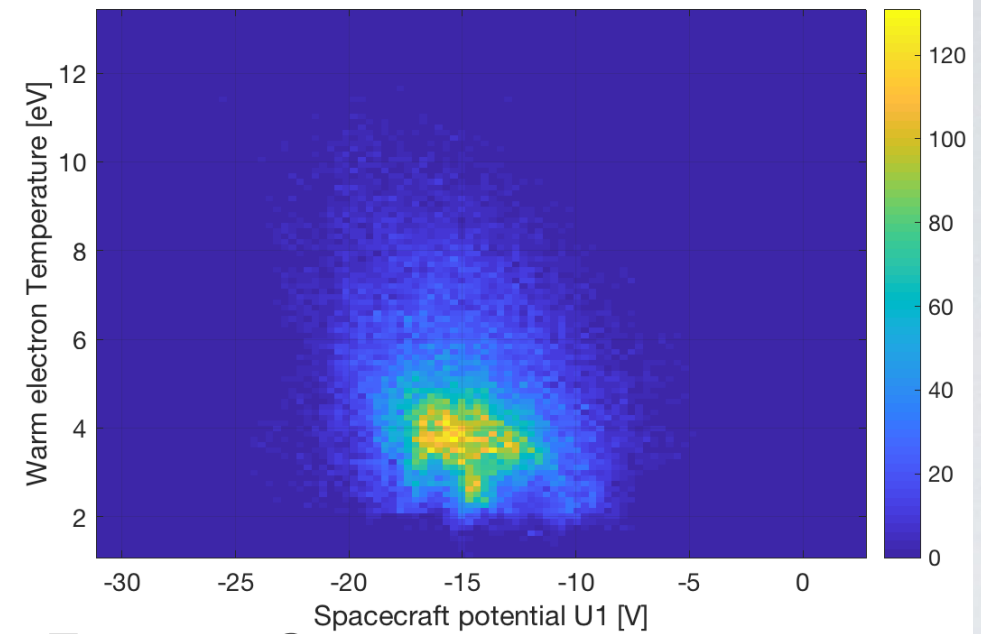
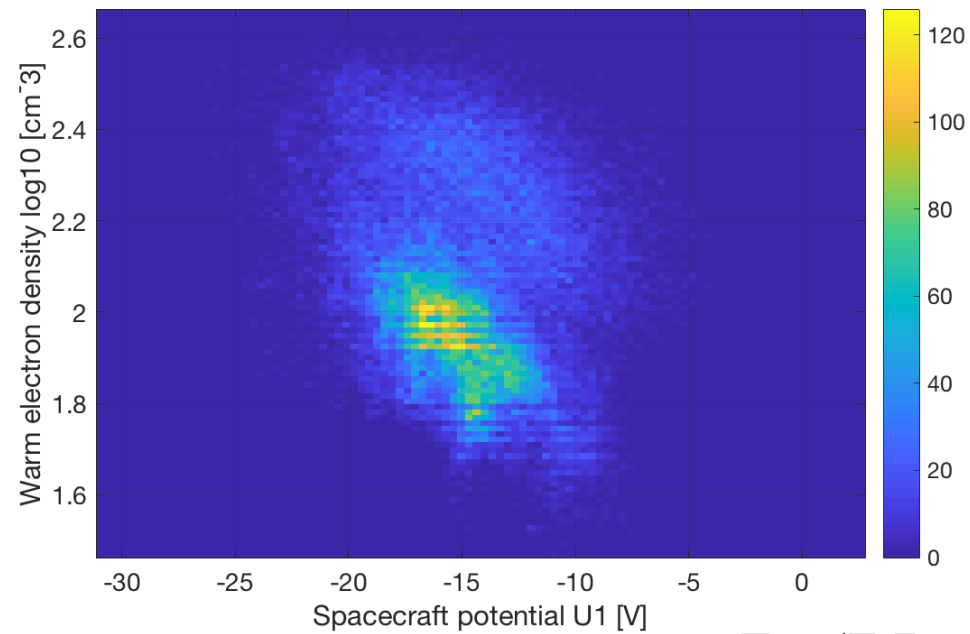


Cold



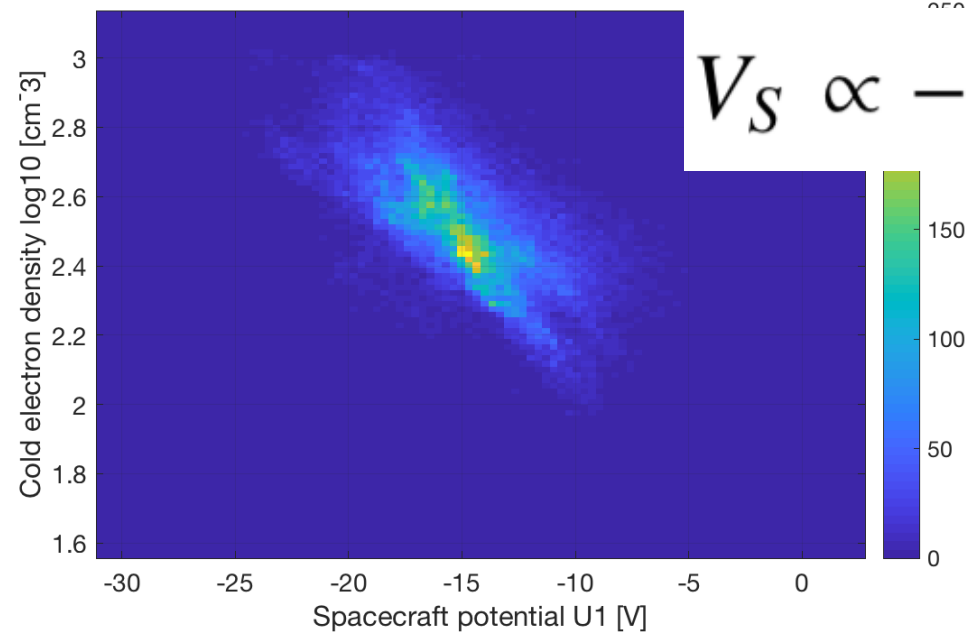
MOTIVATION -NEW RESULTS

Warm

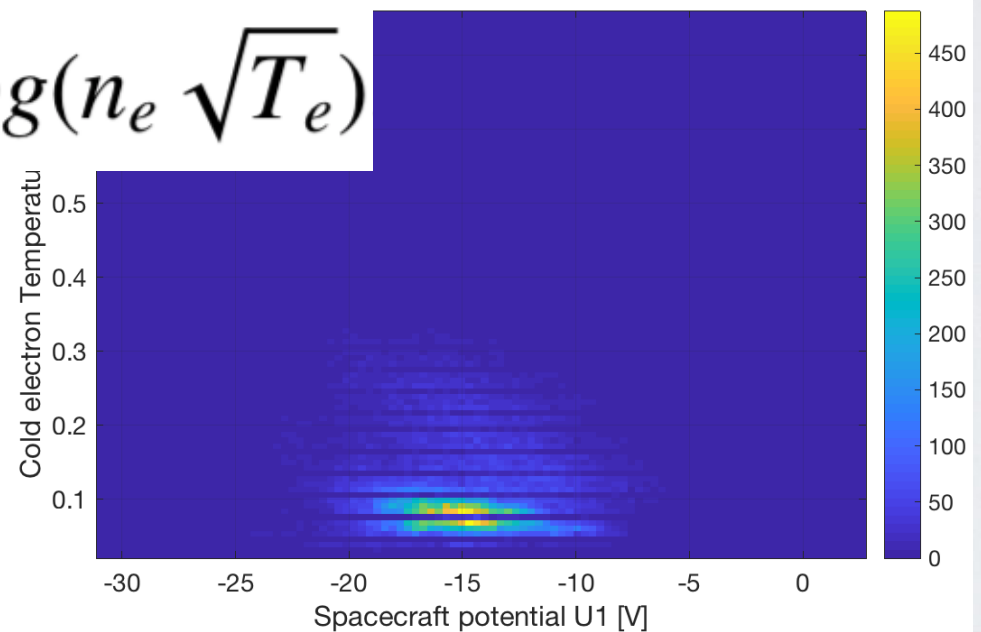


$$I_e (V_s < 0) + I_{ph0} \approx 0$$

Cold



$$V_s \propto -T_e \log(n_e \sqrt{T_e})$$



No temperature dependence?

SOLAR ARRAY DESIGN

In more detail than you ever thought you wanted to know

10 Solar panels × 25 strings, each consisting of 91 solar cells connected via **interconnects** terminating at a **+75V** and **0V** bus bar.

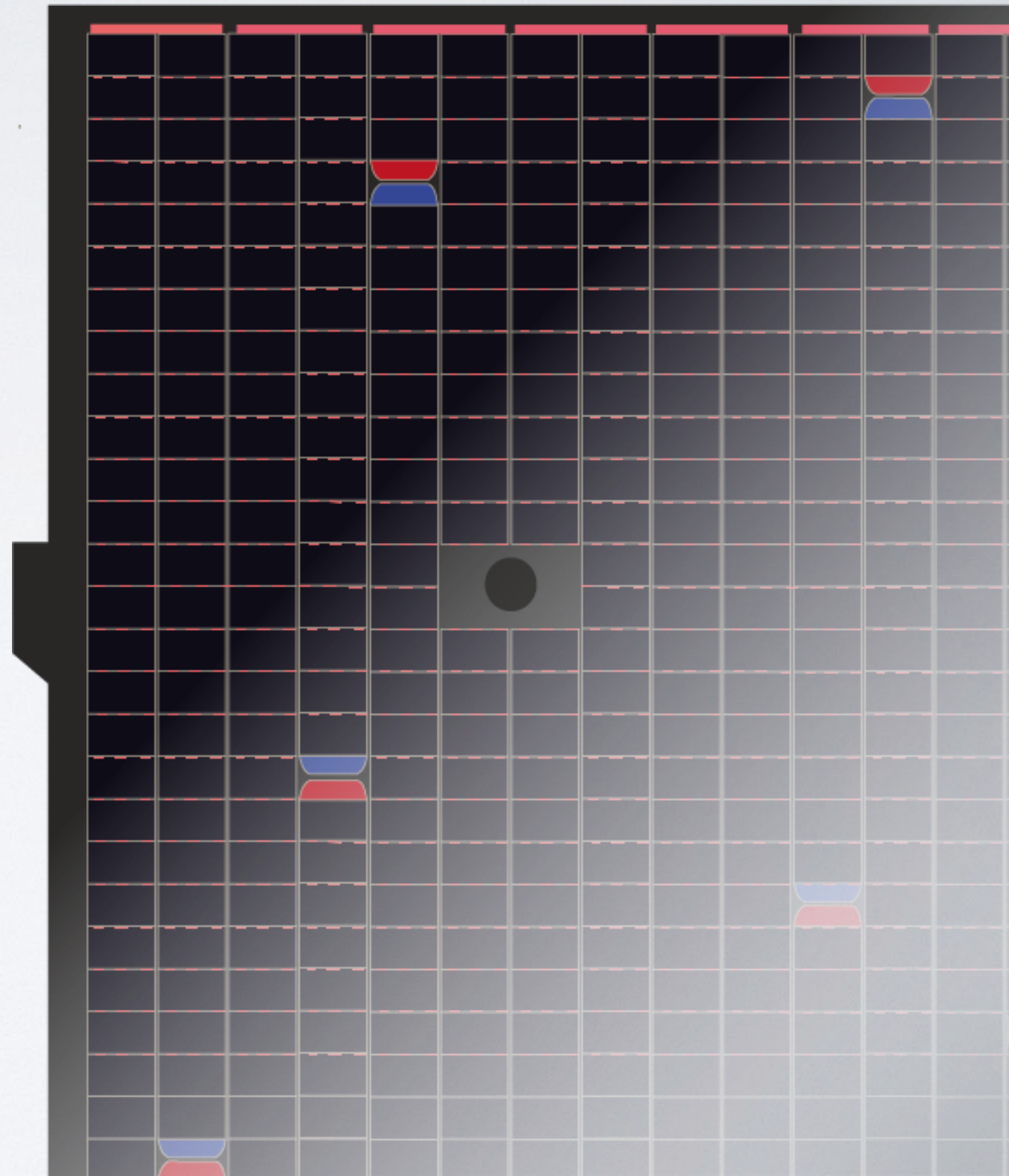
Each solar cell have grounded (0V) cover glass

Red and pink refers to positively biased conductors exposed to space.

The 23.000 interconnects are at potentials linearly increasing from 0.8V to 75V. On average \approx **+37.5V**

Long interconnects are found at top and bottom of each column of solar cell

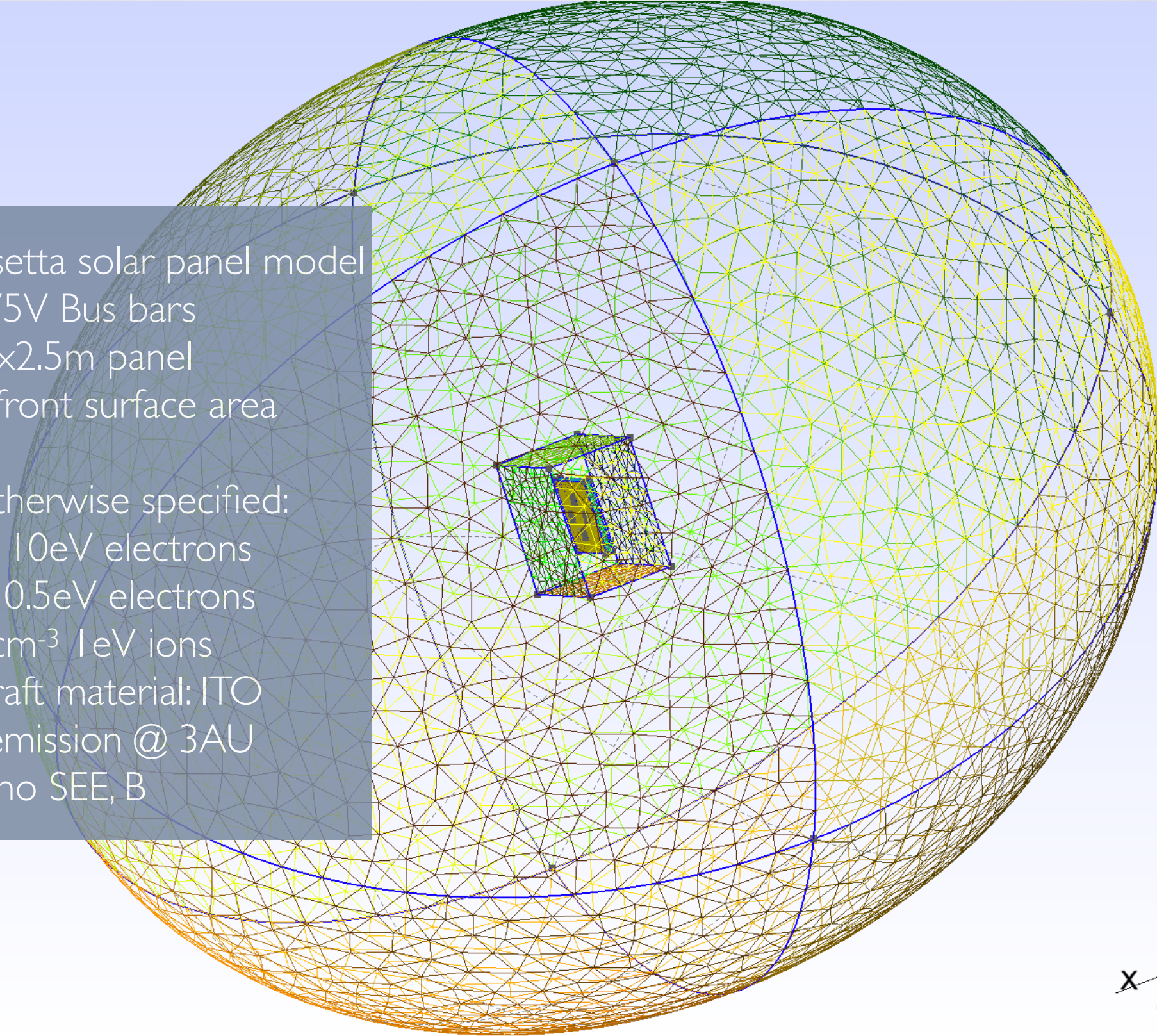
$$I_e \propto V/T_e$$

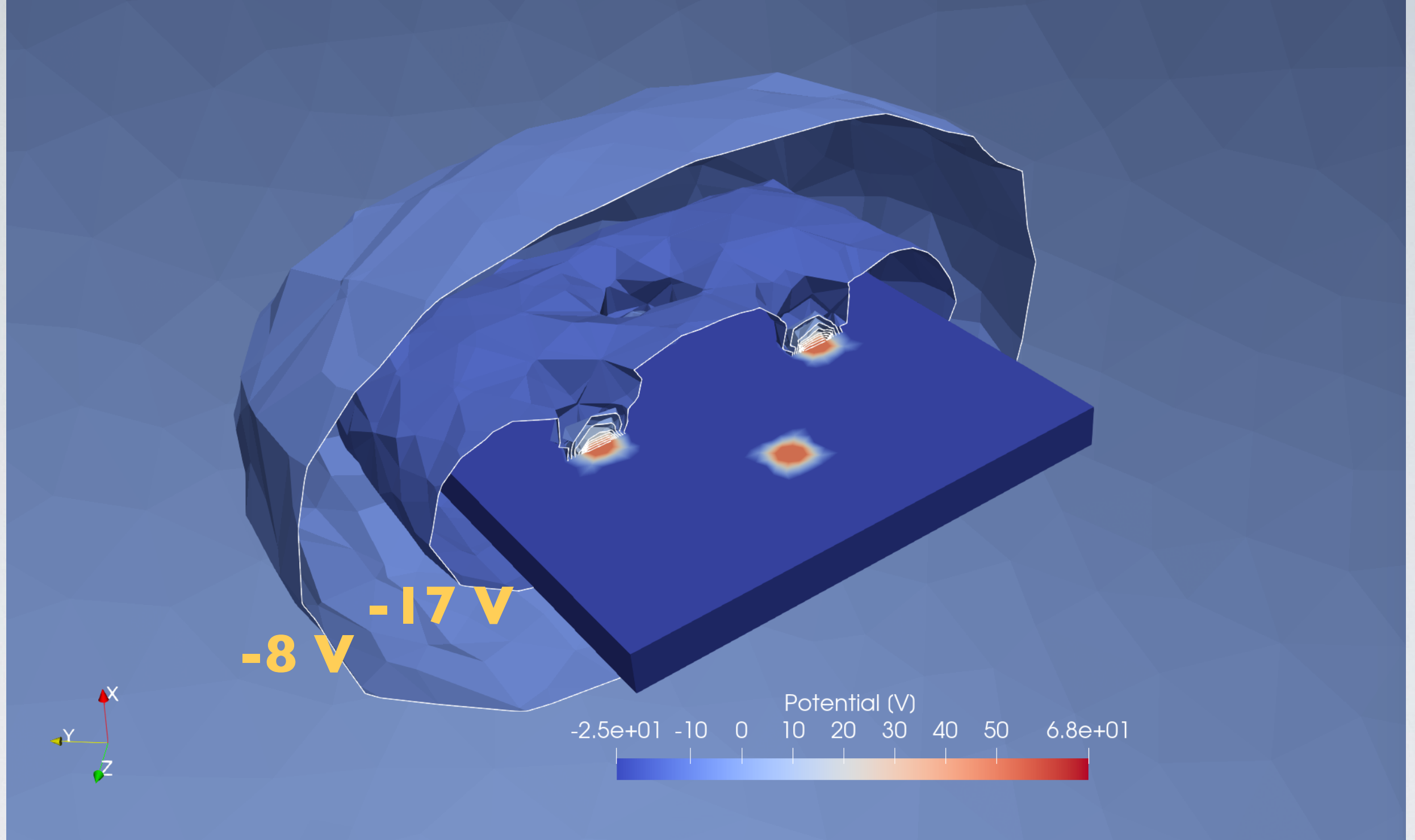


SIMULATION SETUP

Simplified Rosetta solar panel model
+75V Bus bars
2.5x2.5m panel
2.5% of front surface area

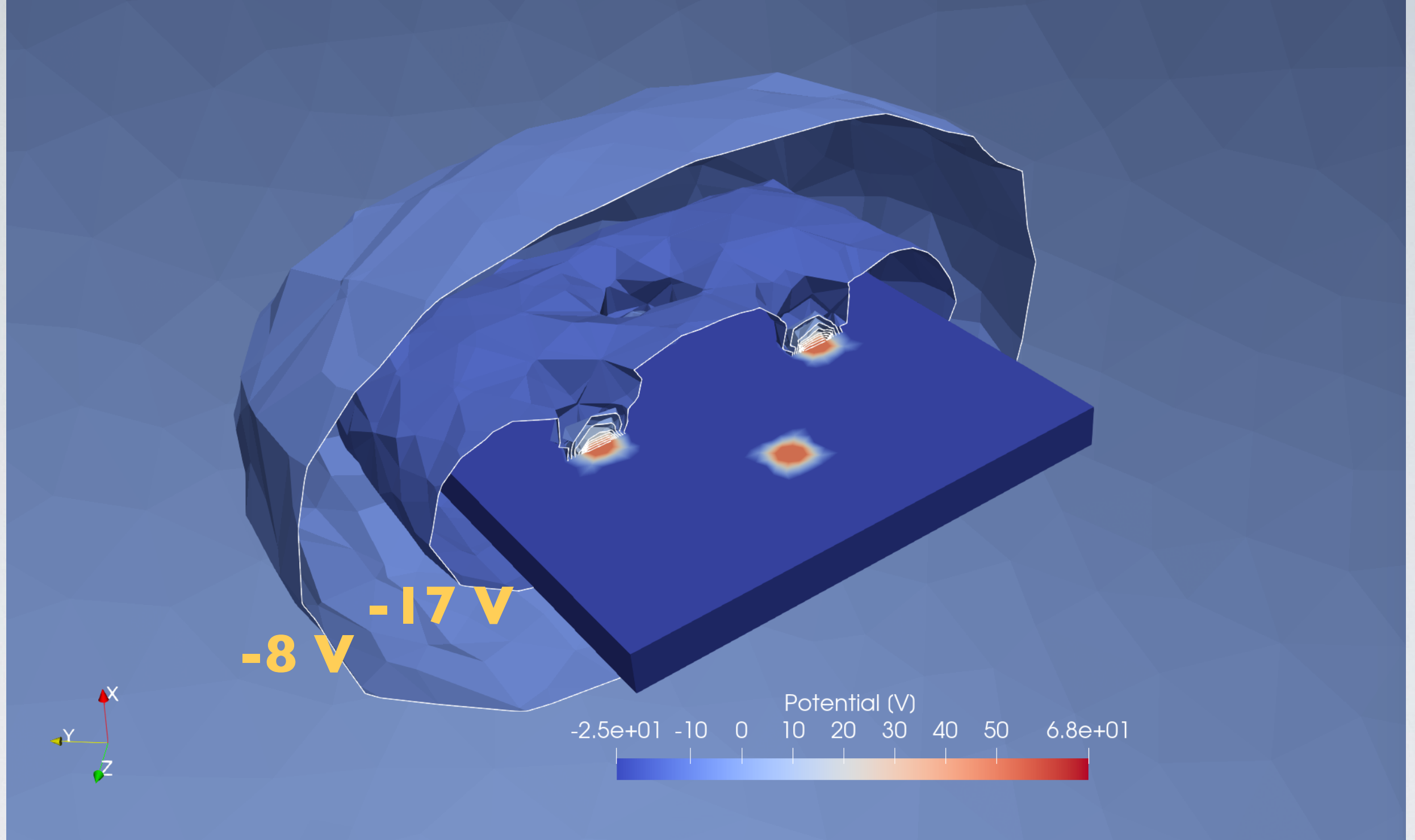
Unless otherwise specified:
50cm⁻³ 10eV electrons
50cm⁻³ 0.5eV electrons
100cm⁻³ 1eV ions
Spacecraft material: ITO
Photoemission @ 3AU
no SEE, B





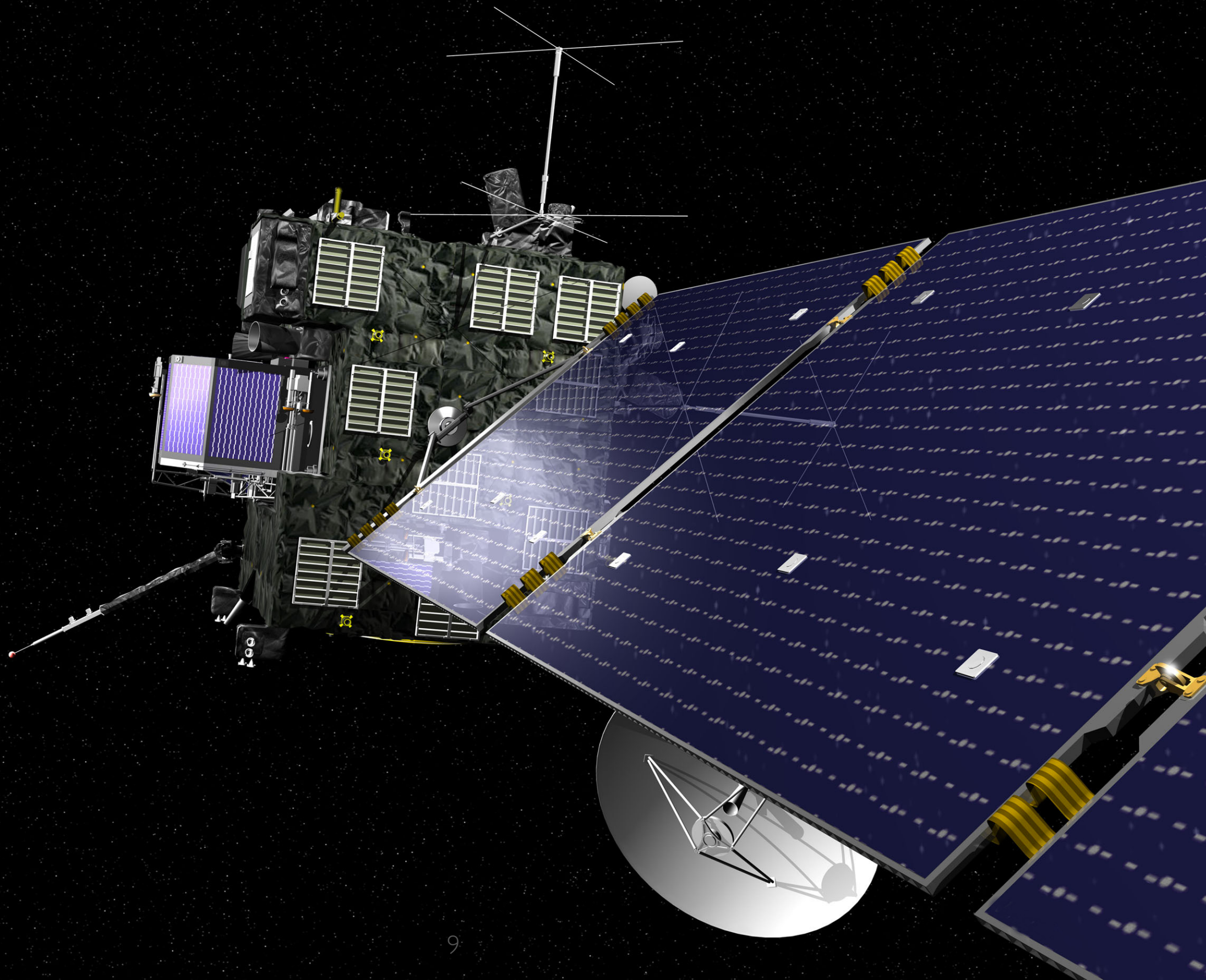
Model Merits

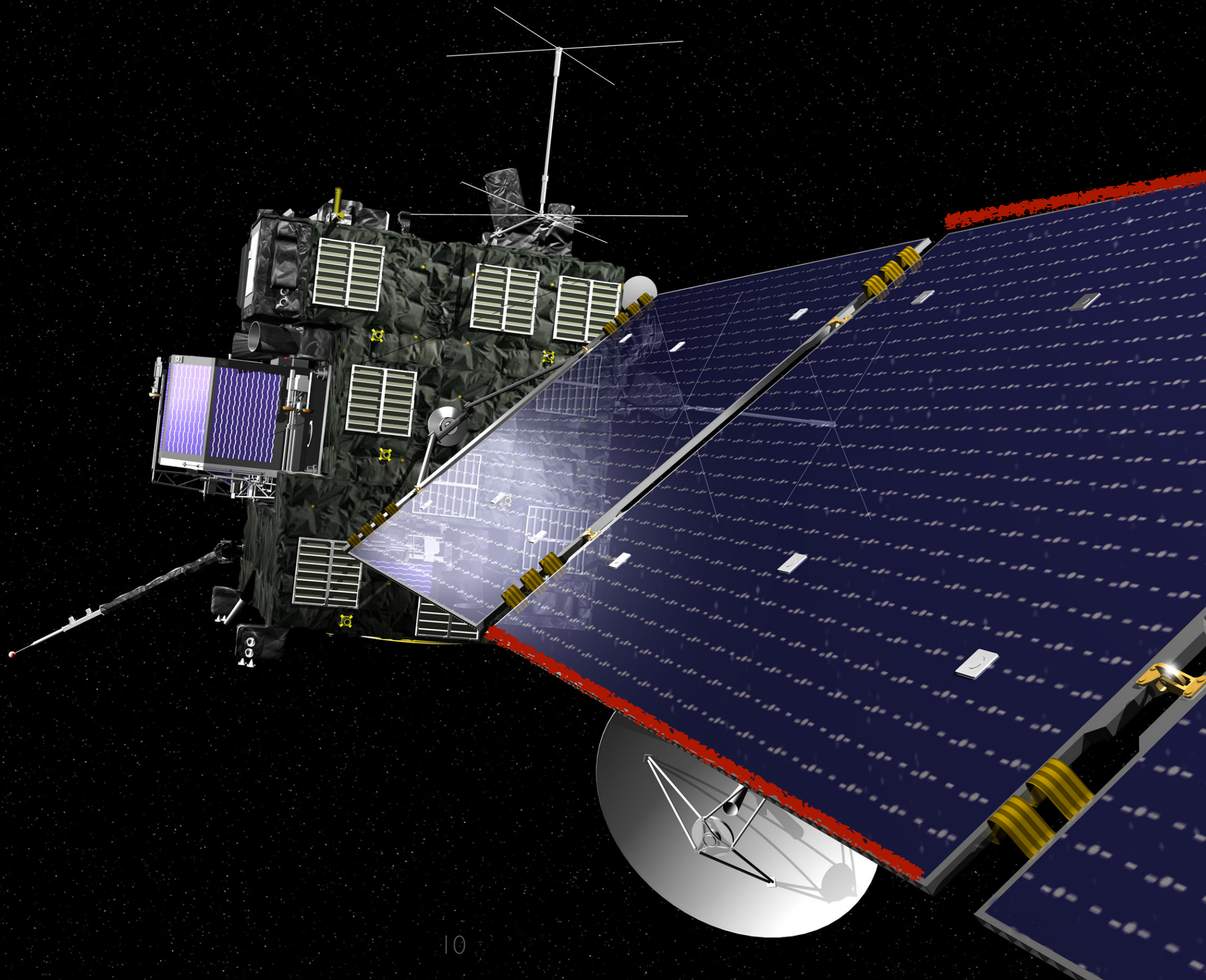
- Substantial negative charging when we add positively biased elements.
- Biased elements attracts locally produced (photo-) electrons. Effectively turns off the photoemission of an area 6 times as large on the spacecraft. This explains the magnitude of the spacecraft potential of Rosetta in cometary plasma, and the modest charging in the solar wind



Model Shortcomings

- The (Langmuir Probe theory) expectation of increased charging as we add a cold electron component never appears, in fact the opposite is true.
- Barrier potential shields entire spacecraft from cold electrons





Potential due to a Circular Double Disk

CHRISTOPHER SHERMAN

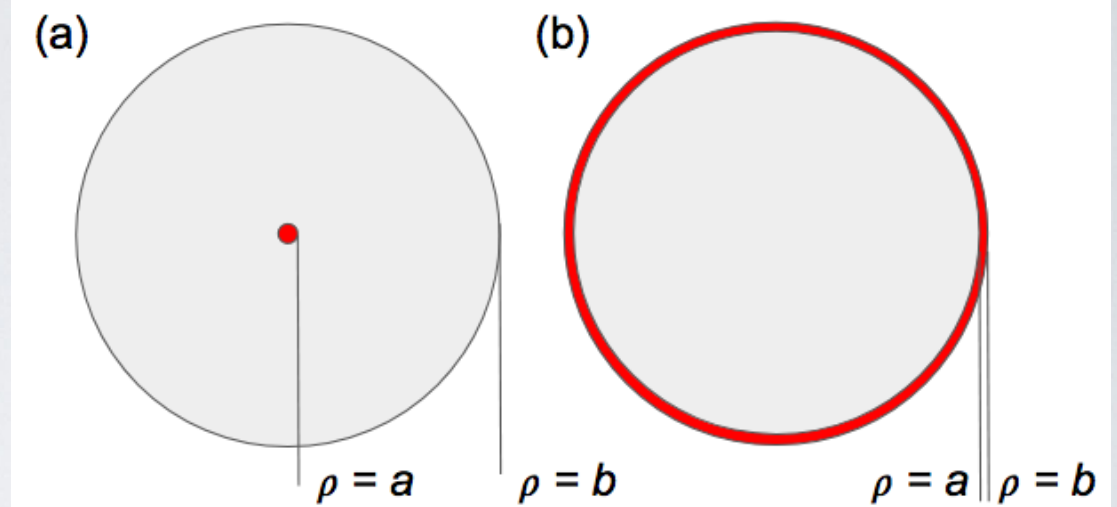
*Air Force Cambridge Research Laboratories, Laurence G. Hanscom Field
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AND

LEE W. PARKER

*Mount Auburn Research Associates, Incorporated,
Cambridge, Massachusetts 02139*

(Received 16 April 1970; in final form 8 September 1970)

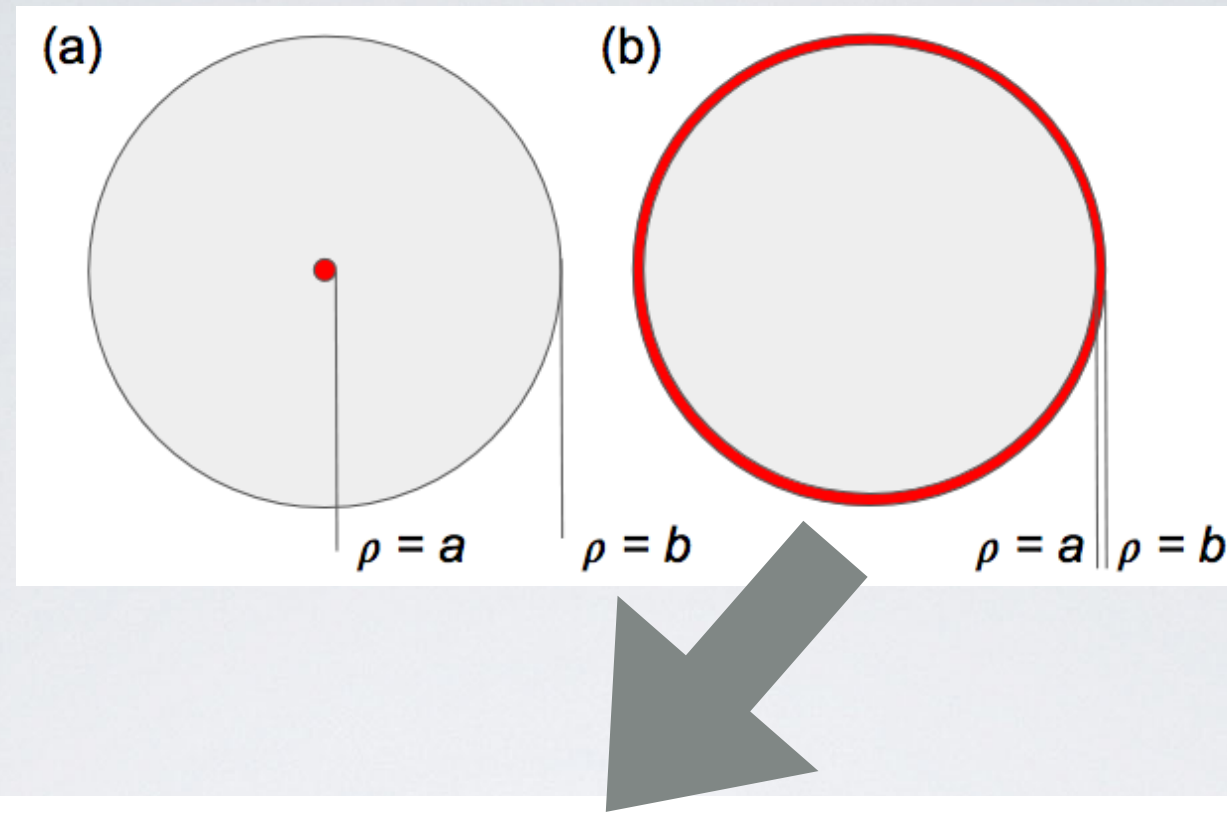


- Treat the solar panel as a double disk
- Far away the disks appears like a point with charge equal to their net charge, which must be either positive or negative

V_{out} . In cylinder coordinates (ρ, ϕ, z) where $z = 0$ defines the disc plane, Sherman & Parker (1971) found that the vacuum potential from this object is

$$\Phi(\rho, z) = V_{\text{in}} \frac{2}{\pi} \operatorname{atan} \left(\frac{b \sqrt{2}}{\sqrt{r^2 - b^2} + \sqrt{(r^2 - b^2)^2 + 4z^2 b^2}} \right) + (V_{\text{out}} - V_{\text{in}}) \frac{\sqrt{2}}{\pi} \cdot \int_a^b \sqrt{\frac{r^2 - s^2 + \sqrt{(r^2 - s^2)^2 + 4z^2 s^2}}{(r^2 - s^2)^2 + 4z^2 s^2}} \cdot \frac{s}{\sqrt{s^2 - a^2}} ds \quad (3)$$

where $r^2 = \rho^2 + z^2$. The integral can be analytically evaluated on the z axis and in the disk plane $z = 0$ to find that



1 V equipotentials, $a/b = 0.98$, $V_{\text{in}} = -10 \text{ V}$

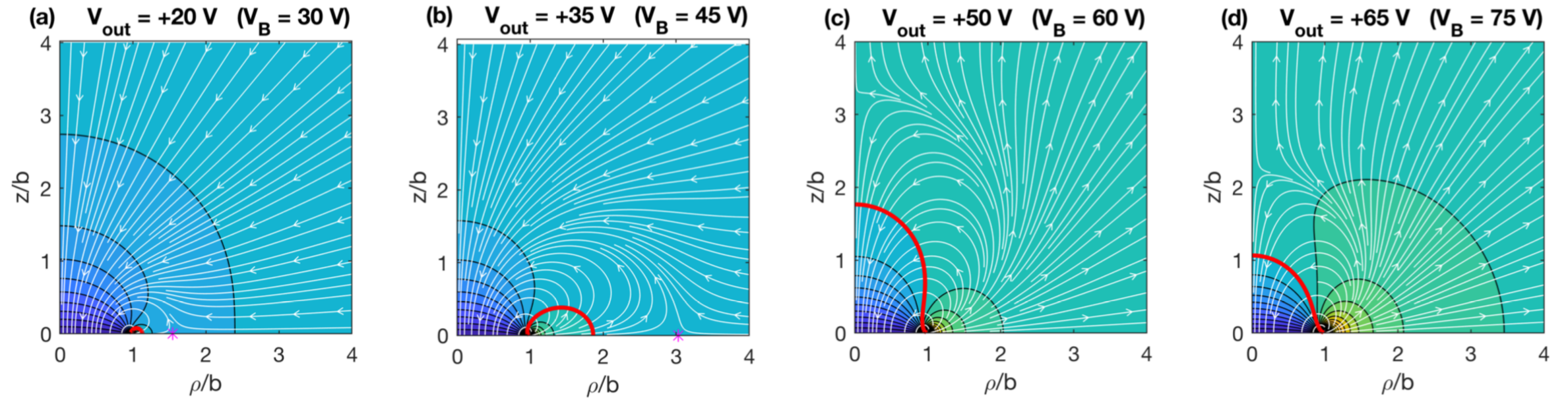


Fig. 8. Vacuum potential and electric field pattern in the $\rho - z$ plane around a thin circular disk of radius b as sketched in Figure 5(b). The disk potential inside $\rho = a$ is $V_{\text{in}} = -10 \text{ V}$ while the potential V_{out} in the annulus $a < \rho \leq b$ varies as stated above each panel. In all cases, $a = 0.98 b$. Numerically integrated electric field lines are plotted in white. The 0 V equipotential is shown in thick red; the potential is zero also at infinity. Black curves indicate equipotentials at every integer value (in volts), with the background colour further highlighting the potential. The magenta star indicates the location of minimum electron barrier height.

-2V Barrier potential at exact position
as analytical prediction

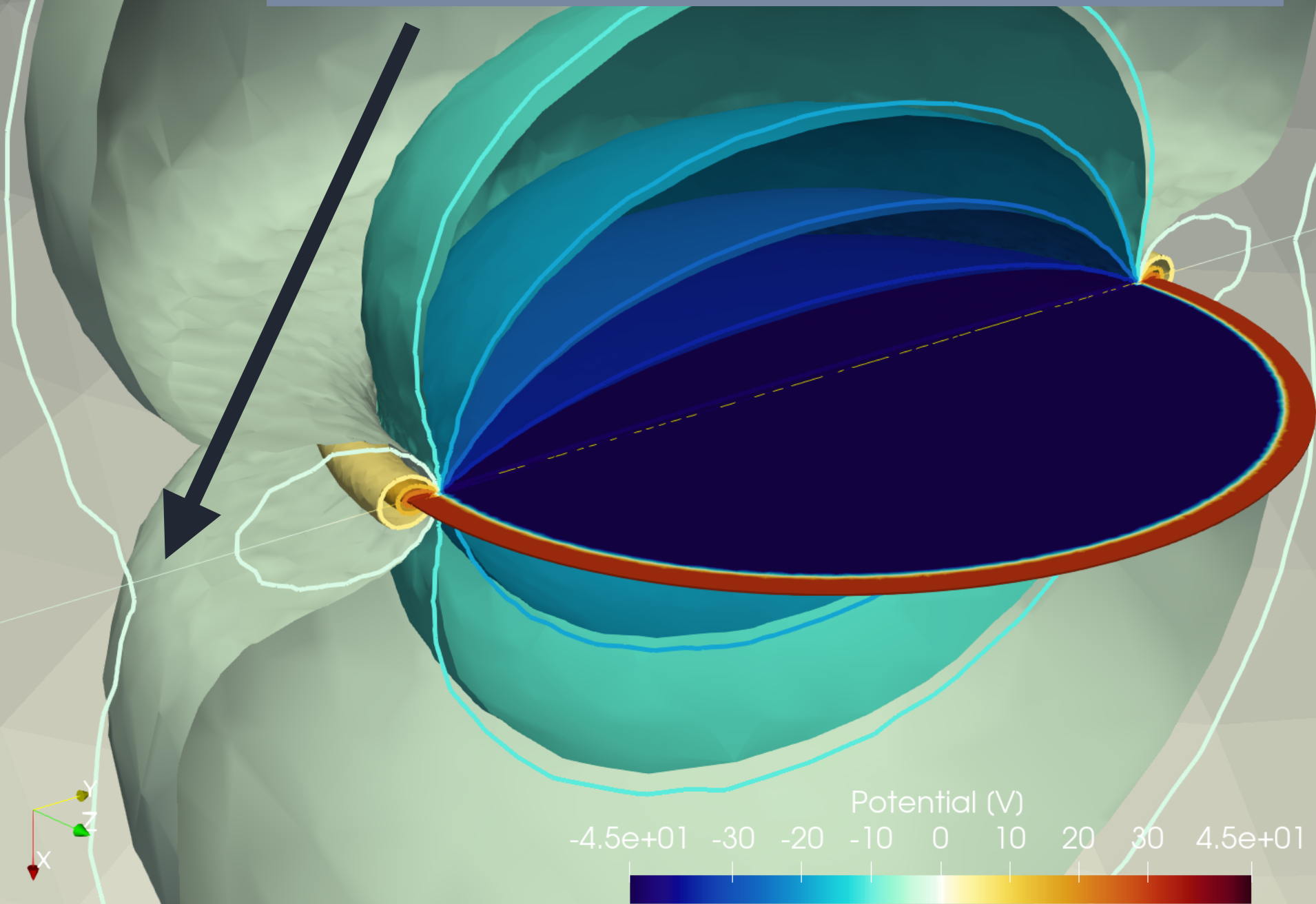
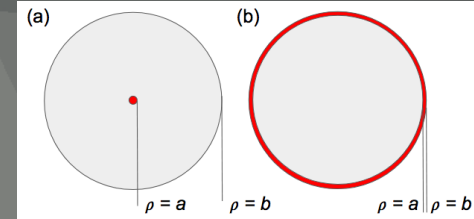
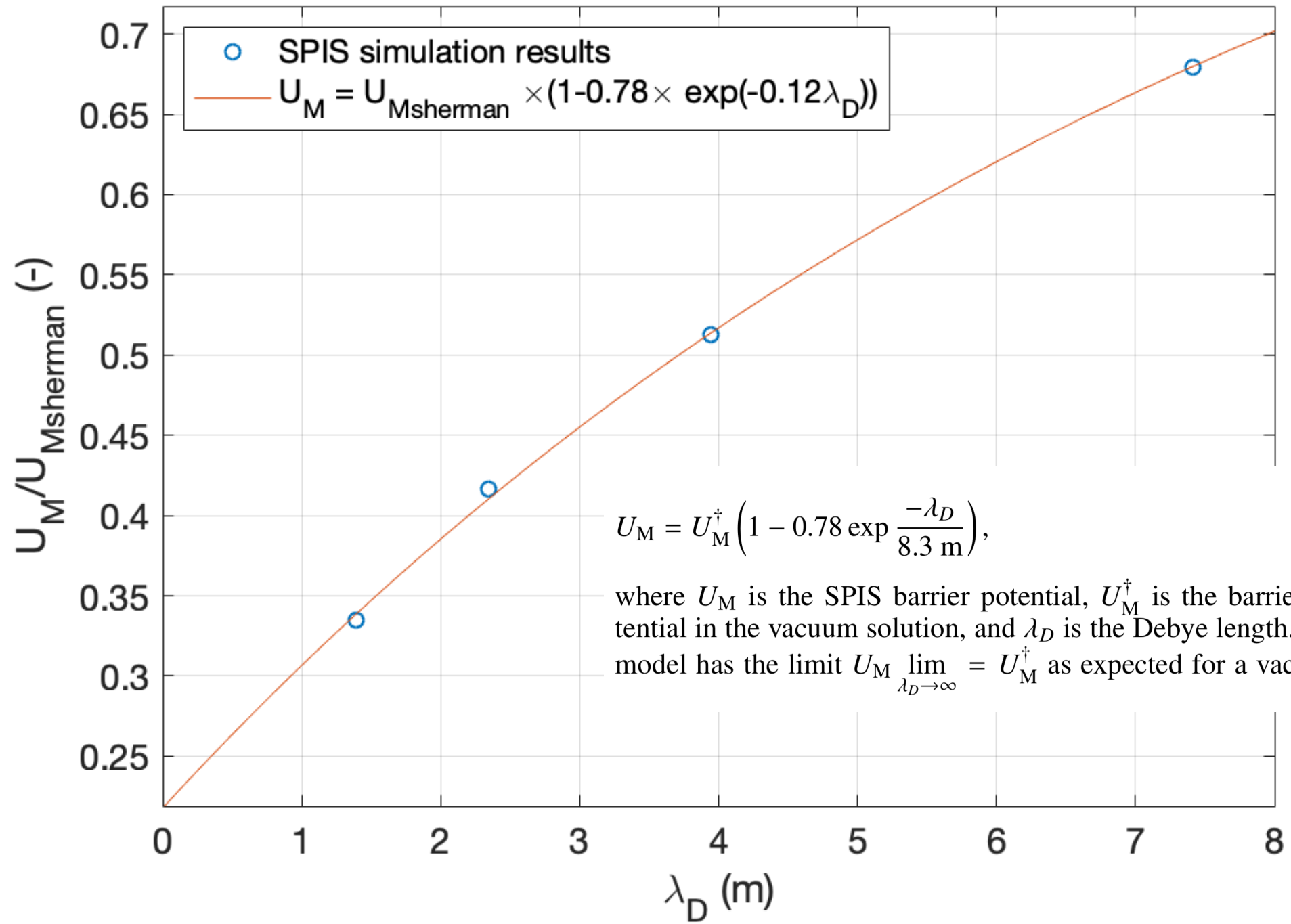
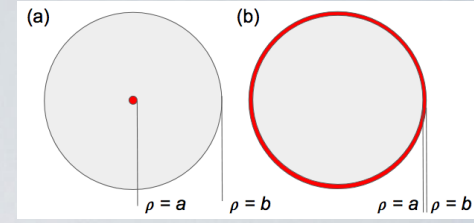
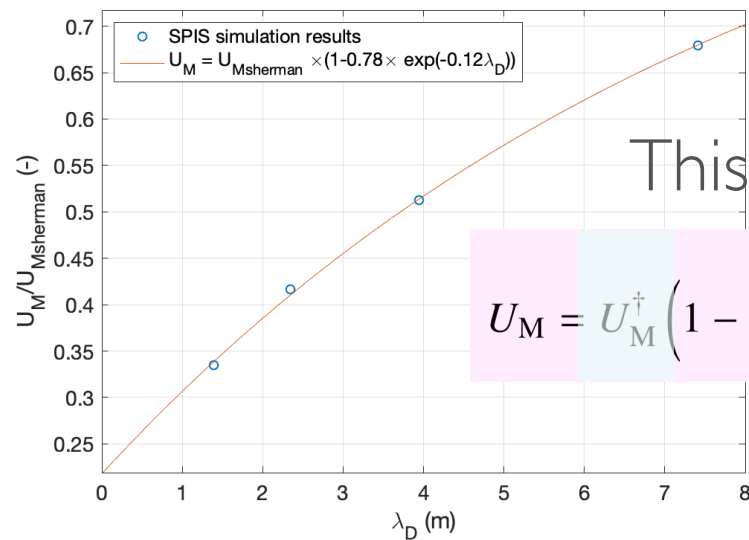


Fig. 10. 3-D Visualisation of electrostatic potential structure for the SPIS +75 V concentric disks ($a = 1.17$ m , $b = 1.25$ m) simulation, coloured by electrostatic potential. To illustrate the potential in the volume, we plot the potential along the X-Z plane, as well as 10 equipotential surfaces from -30 V to +25 V, cut in the X-Y plane.

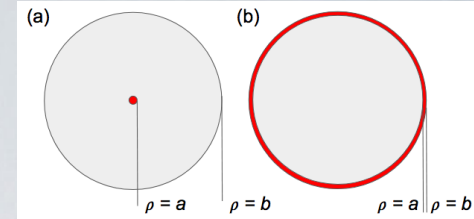




This work

$$U_M = U_M^\dagger \left(1 - 0.78 \exp \frac{-\lambda_D}{8.3 \text{ m}} \right),$$

Sherman+1971



$$\Phi(\rho, 0) = \frac{2}{\pi} \left[V_{\text{in}} \operatorname{atan} \frac{b}{\sqrt{\rho^2 - b^2}} + (V_{\text{out}} - V_{\text{in}}) \operatorname{atan} \sqrt{\frac{b^2 - a^2}{\rho^2 - b^2}} \right].$$

Olson+2010

Laframboise+1973

Sagalyn+1963

$$I_e = \begin{cases} -I_{e0} \exp \left(\frac{eU_M}{k_B T_e} \right) & \text{for } U > U_M \\ -I_{e0} \exp \left(\frac{eU}{k_B T_e} \right) & \text{for } U \leq U_M. \end{cases}$$

$$I_i = \begin{cases} -I_{i0} \left(1 - \frac{eU}{E_i} \right) & \text{for } U < E_i/e \\ 0 & \text{for } U > E_i/e, \end{cases}$$

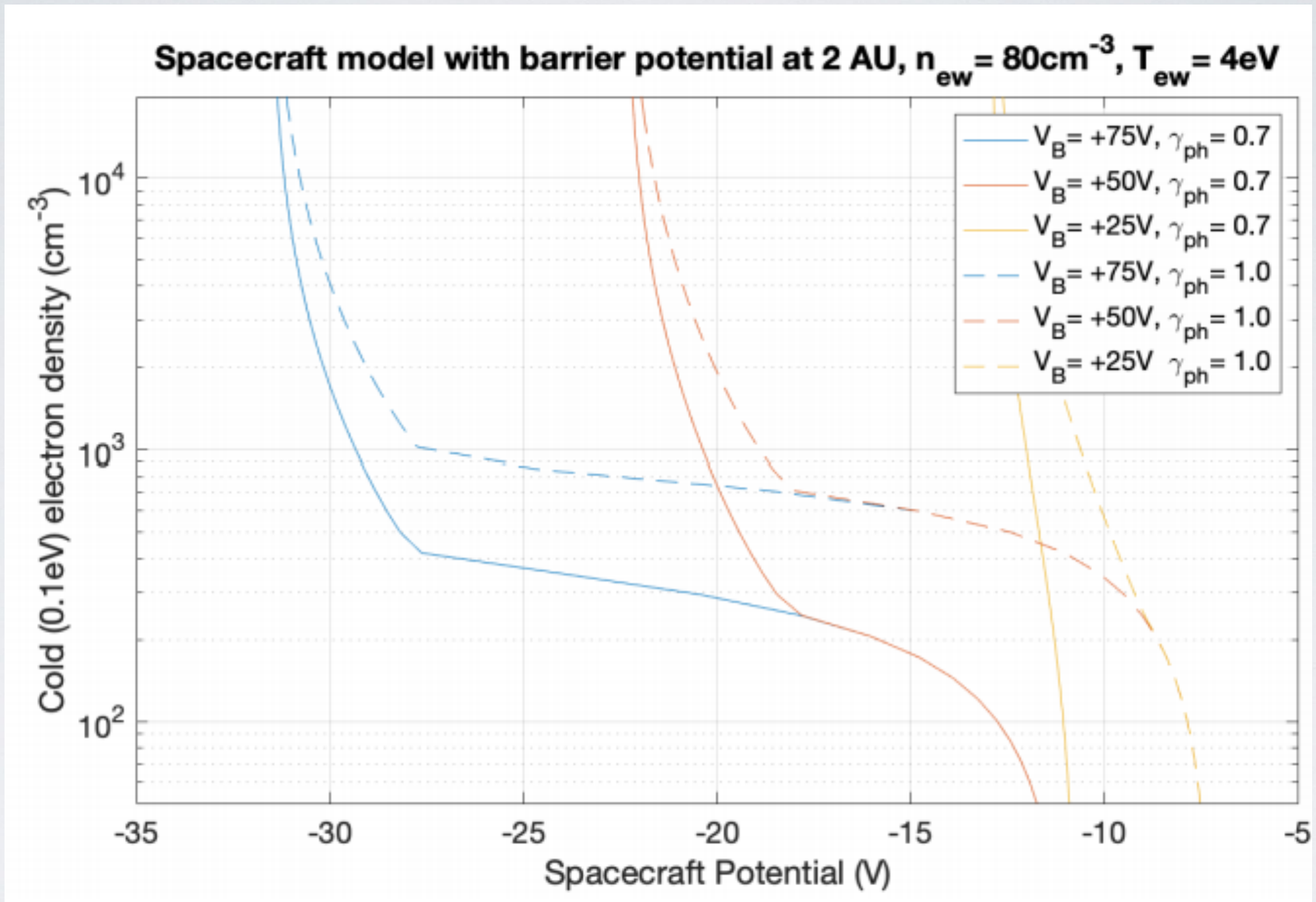
$$I_{\text{ph}}^{\text{tot}} = -\pi r_a^2 j_{\text{ph}0} \left(\frac{1}{d_{\text{AU}}^2} \right) \gamma_{\text{ph}},$$

Adapted from Grard+1973

$$V_S = \frac{k_B T_e}{e} \ln \left(\frac{-I_{\text{ph}} - I_i^a(V_S) - I_{\text{tot}}^b(V_S + V_B, U_M)}{I_{e0}^a} \right),$$

As the positive elements will reduce the net photoemission, we use a factor γ_{ph} to parameterise the reduced photoemitting area on the spacecraft

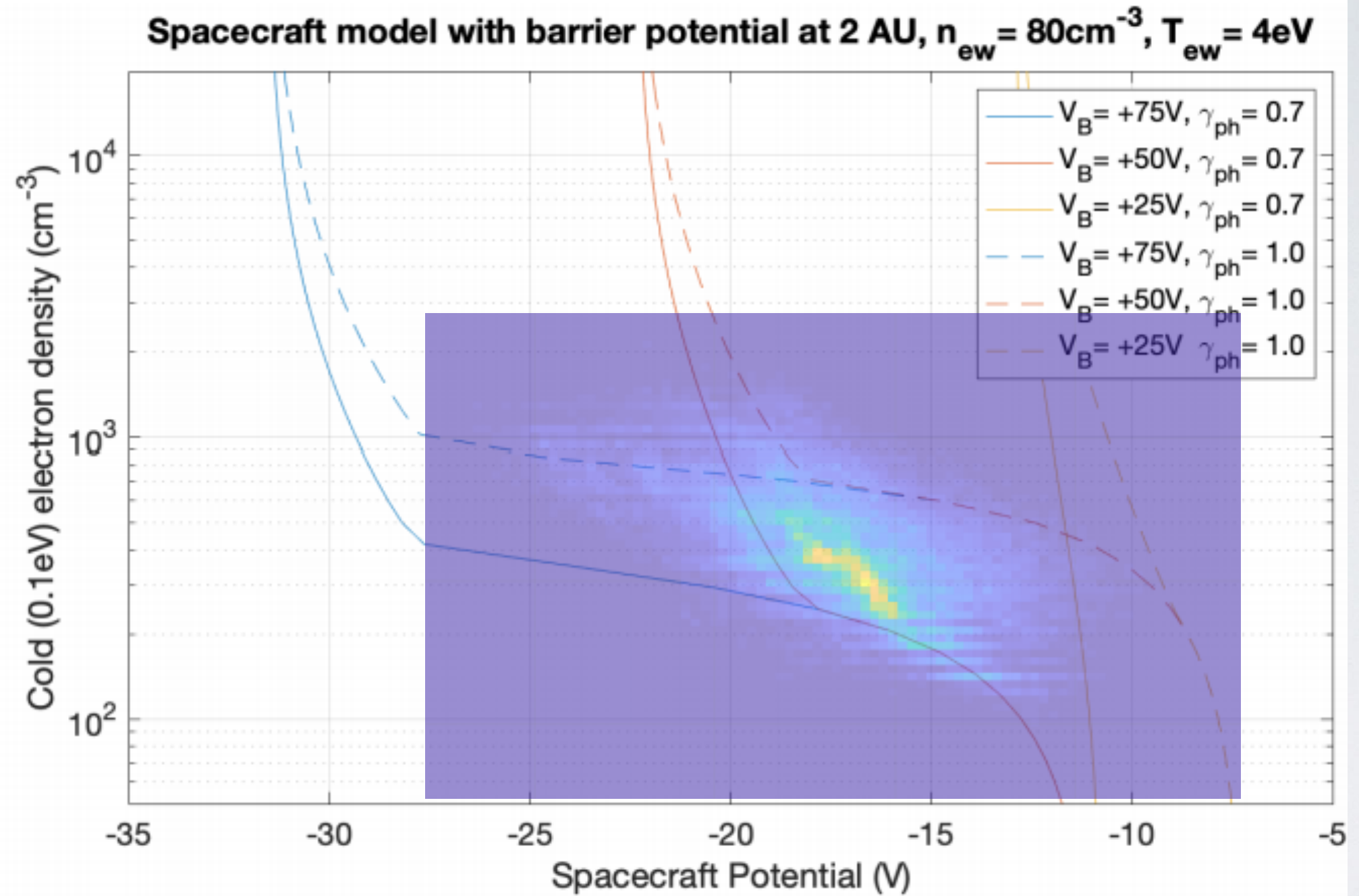
RESULTS



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$$V_S = \frac{k_B T_e}{e} \ln \left(\frac{-I_{ph} - I_i^a(V_S) - I_{tot}^b(V_S + V_B, U_M)}{I_{e0}^a} \right),$$

RESULTS



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$$V_S = \frac{k_B T_e}{e} \ln \left(\frac{-I_{ph} - I_i^a(V_S) - I_{tot}^b(V_S + V_B, U_M)}{I_{e0}^a} \right),$$

CONCLUSIONS

- V_{sc} strongly dependent on (cold) electron density
- Earlier work (Odelstad 2015, among others) proposes that a substantial warm (5-10 eV) electron population is omnipresent in the comet coma, responsible for the spacecraft charging.
- Many lessons learned for future planetary missions