Engineering, Operations & Technology
Boeing Research & Technology

Integration Assessment of Visiting Vehicle Induced Electrical Charging of The International Space Station

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Visiting Vehicle Electrical System Integration into ISS

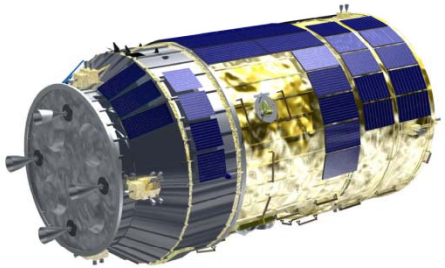
Visiting Vehicles are becoming a regular part of International Space Station operations.

When a visiting vehicle docks with ISS the electrical system grounds become bonded.

Since the plasma environment is electrically conducting…

… and the vehicles have variable solar array working potentials …

… it is necessary to perform an assessment of the electrical charging characteristics during mated operations.



JAXA/HTV

Spacecraft Charging Assessment Emerges as an ISS Integration Requirement

The Orion vehicle under development by the United States is the planned crew transport vehicle following the end of Space Shuttle missions in 2011…

…and … the electrical charge on the International Space Station affects its operation. There exists:

- probability of arcing of anodized coating.
- remote possibility EVA crew electric shock.

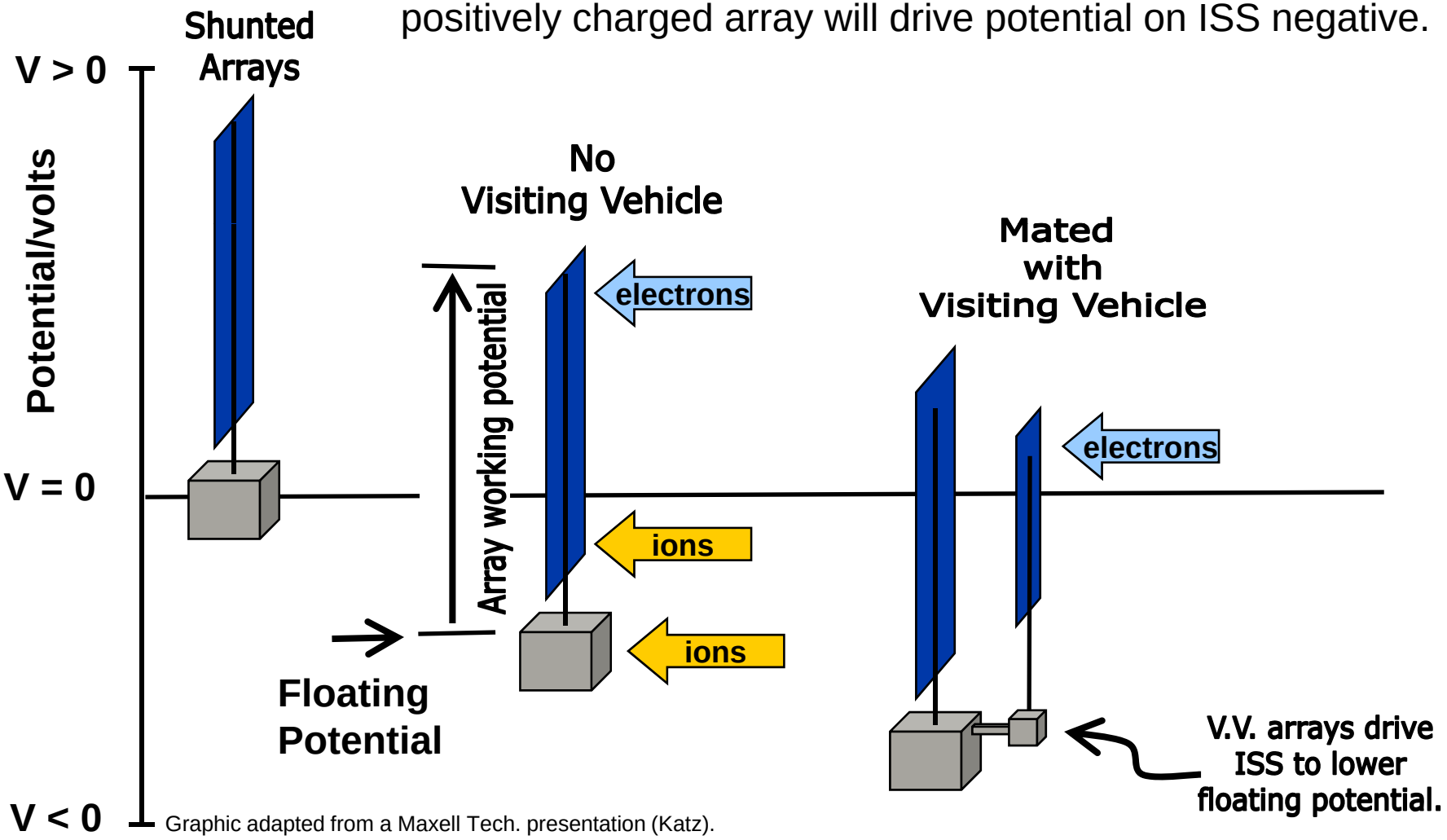
Therefore, a formal integration assessment of Orion has emerged as a requirement for safety and mission success.

Our approach:

- Augment existing theoretical model with additional electric current characterization of the Orion Solar Array.
- Perform trade analysis to discern an acceptable generic electric current limitation.

ISS Charging

Solar array electron collection at exposed conductors on positively charged array will drive potential on ISS negative.



Graphic adapted from a Maxell Tech. presentation (Katz).

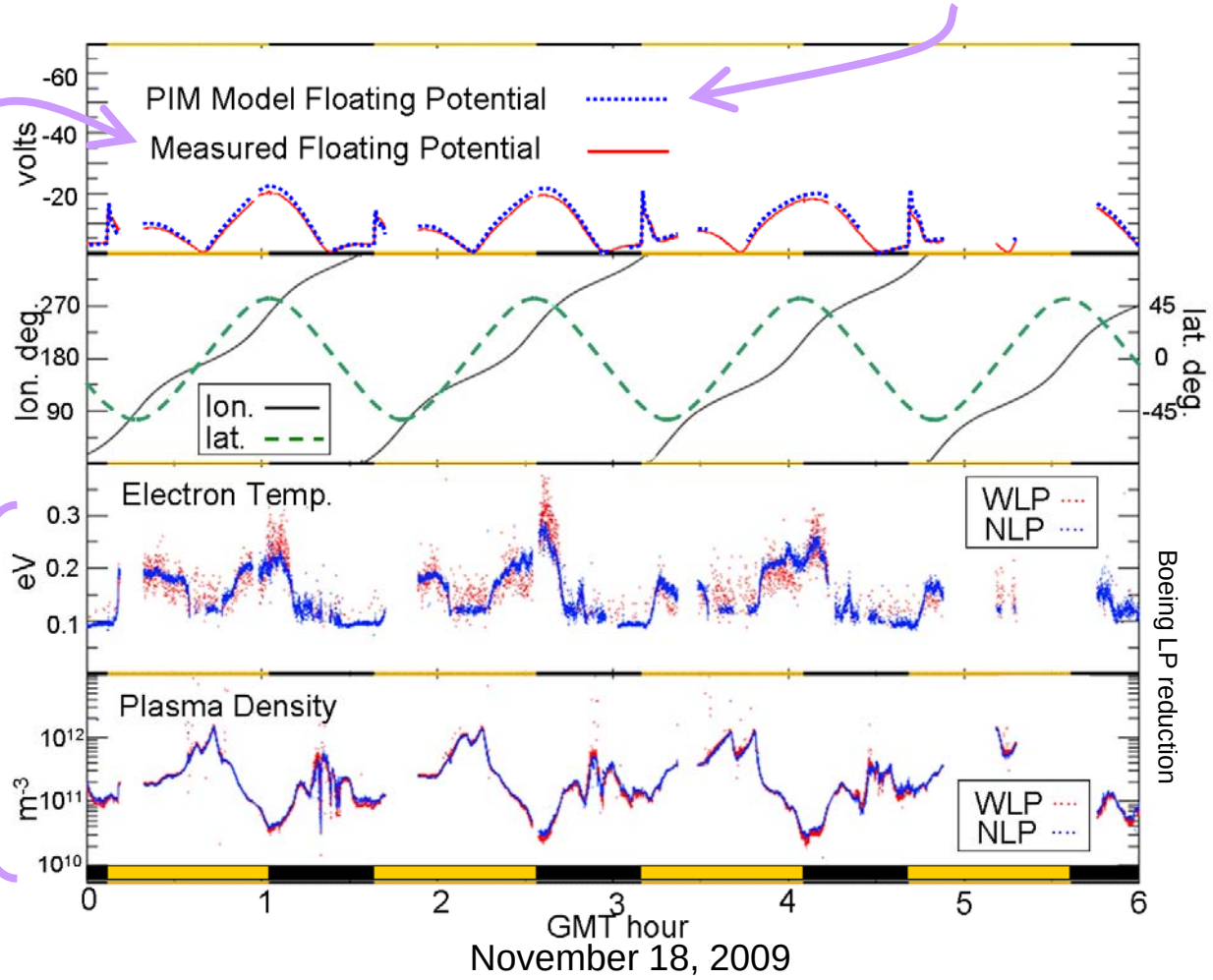
Floating Potential, Plasma State & Boeing Plasma Interaction Model.

Floating Potential Probe – measures potential of the bonded metal ISS structure relative to the plasma.

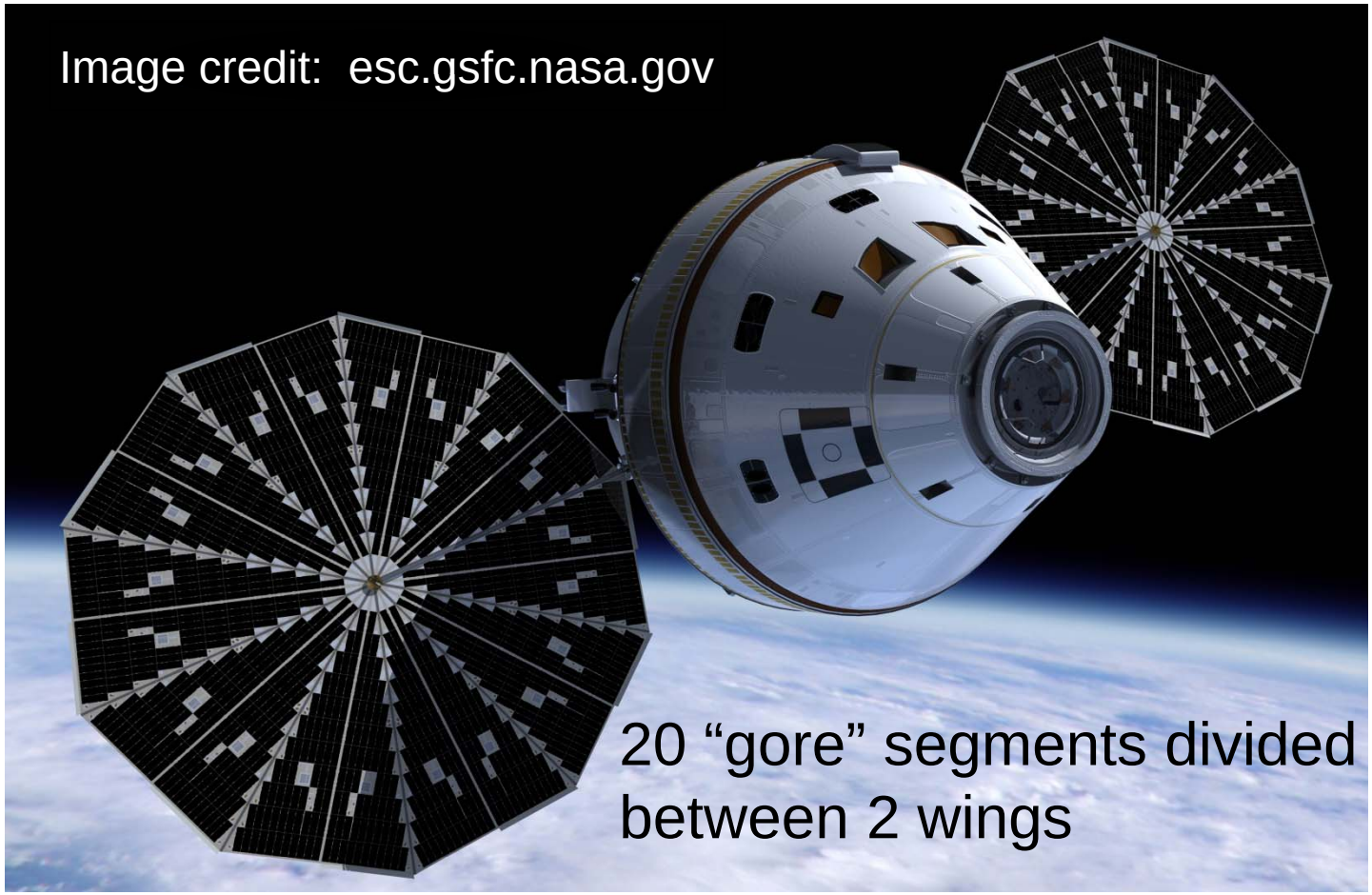
Plasma Interaction Model (PIM) – is a theoretical calculation based on 3 current contributions –

- Solar Arrays
- Array Masts
- Russian MLI

Langmuir probes are used to measure plasma density and electron temperature.

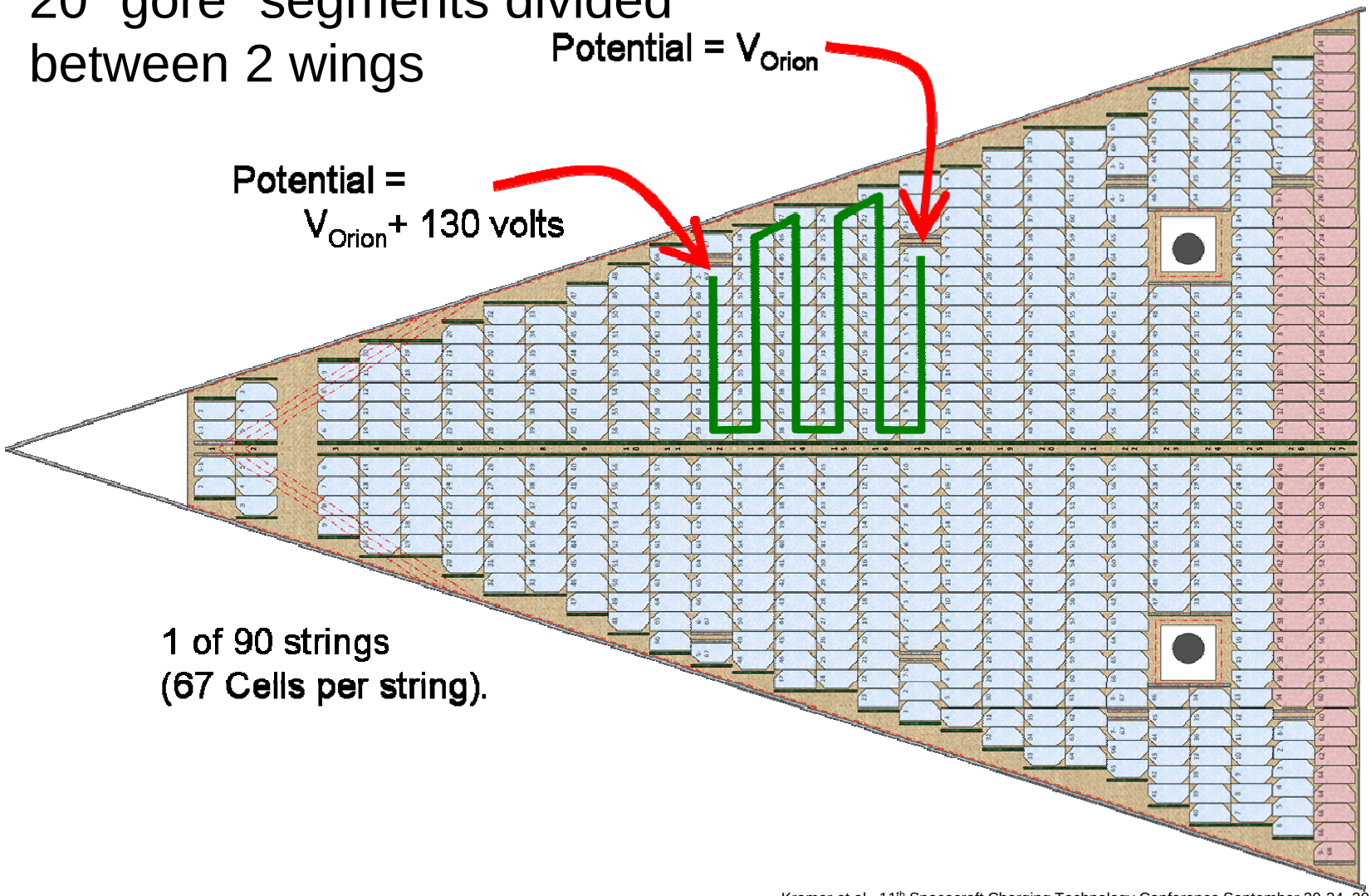


Solar Array Wings on Orion Vehicle



One “gore” Segment

20 “gore” segments divided between 2 wings

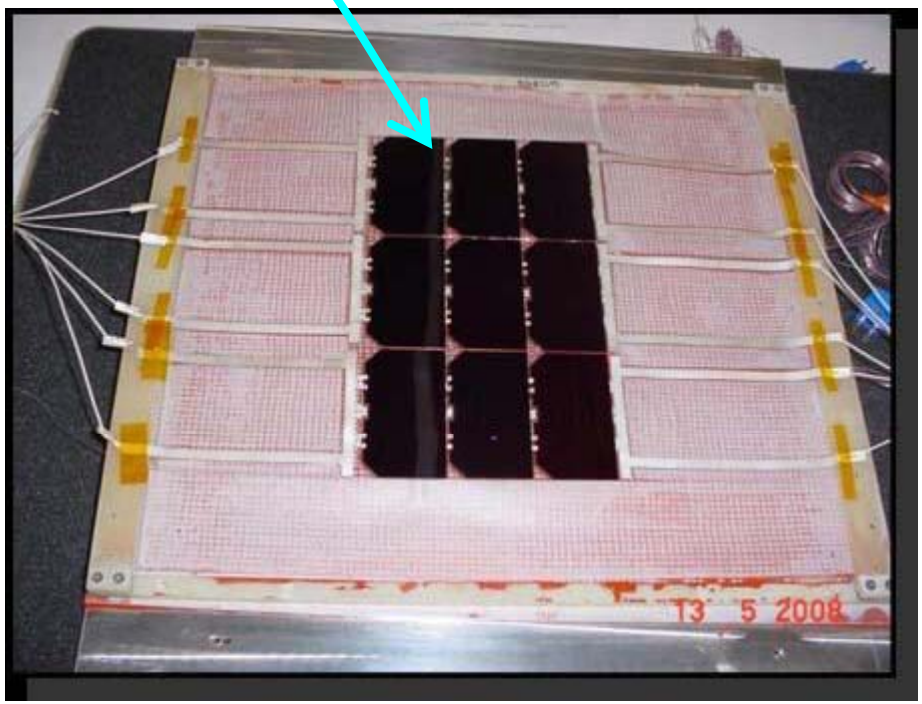


Exposed Conductors Collect Electrons

Cells are covered with glass but…

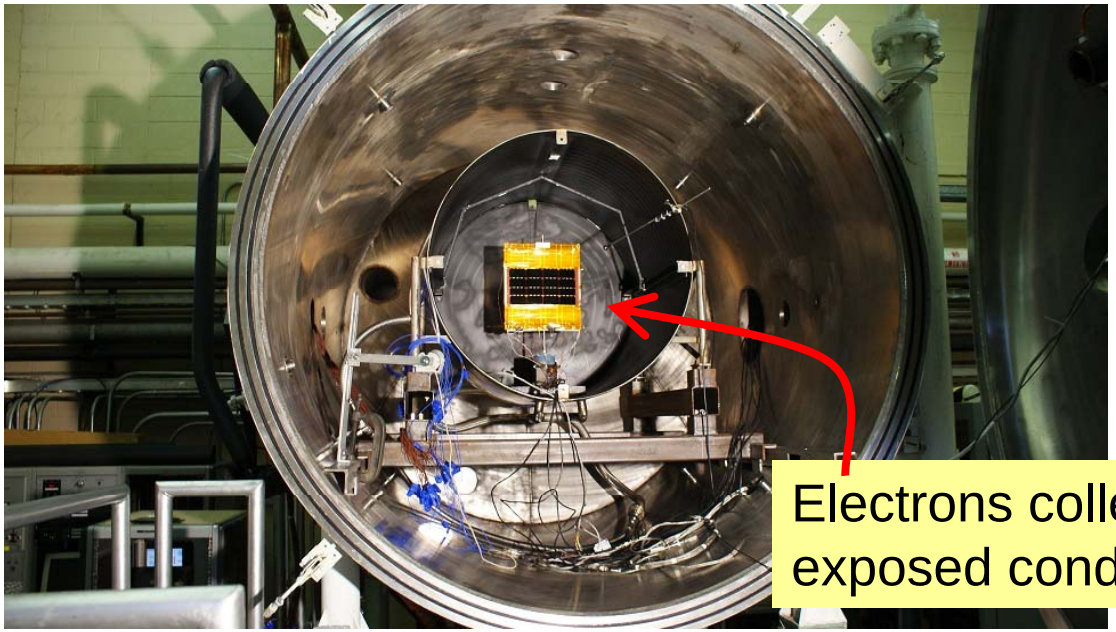
…with small amounts of exposed conductor…

... available to collect electrons when the string is biased positive relative to the plasma.



Cell Coupon in Plasma Chamber

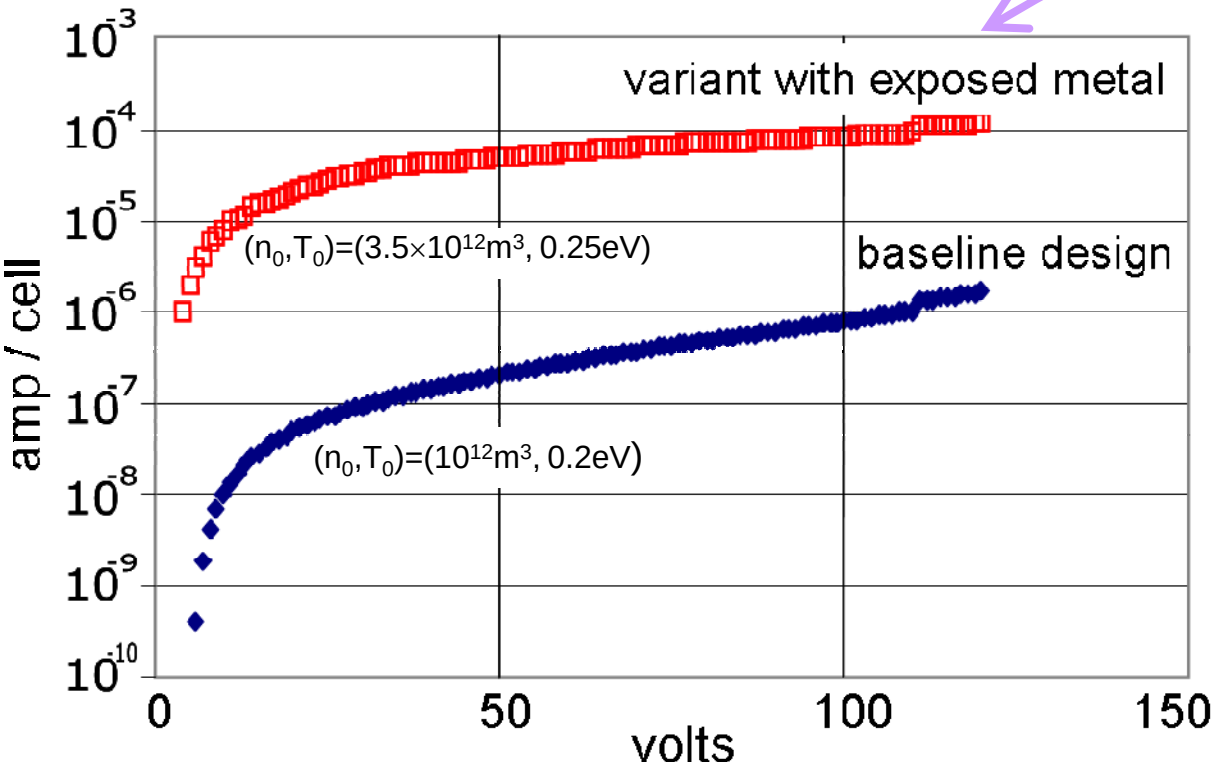
Positive and negative terminal are shorted together and biased externally.



Collected current is measured as bias is varied.

Laboratory Current – Voltage Sweep

The Baseline design described on previous charts was tested at ionospheric environment condition.



This variant has exposed metal end terminals and plasma state adjusted to higher density conditions.

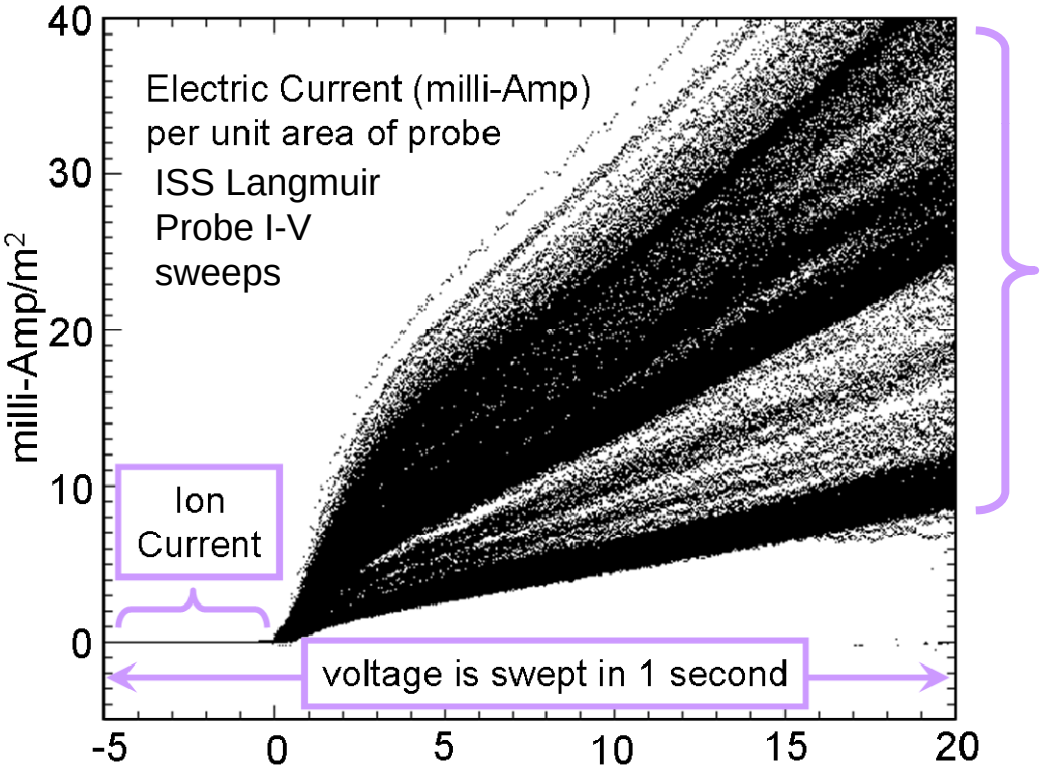
… the variant is an experimental control to illustrate the effectiveness of covering the conductors.

For the purpose of ISS integration it is essential that we relate collected current at chamber n_0 and T_0 to arbitrary n & T

Langmuir Probe Provides On-Orbit Physical Model

The probe is a metal element collecting current from the plasma.

Electrons collect on exposed conductor.



This spread results from variation in plasma state along ISS orbit.

Model of Visiting Vehicle in PIM

We derive a scaling relationship between I-V curve measured at chamber n_0 and T_0 to the I-V curve at arbitrary n and T.

Chamber Measured I-V curve

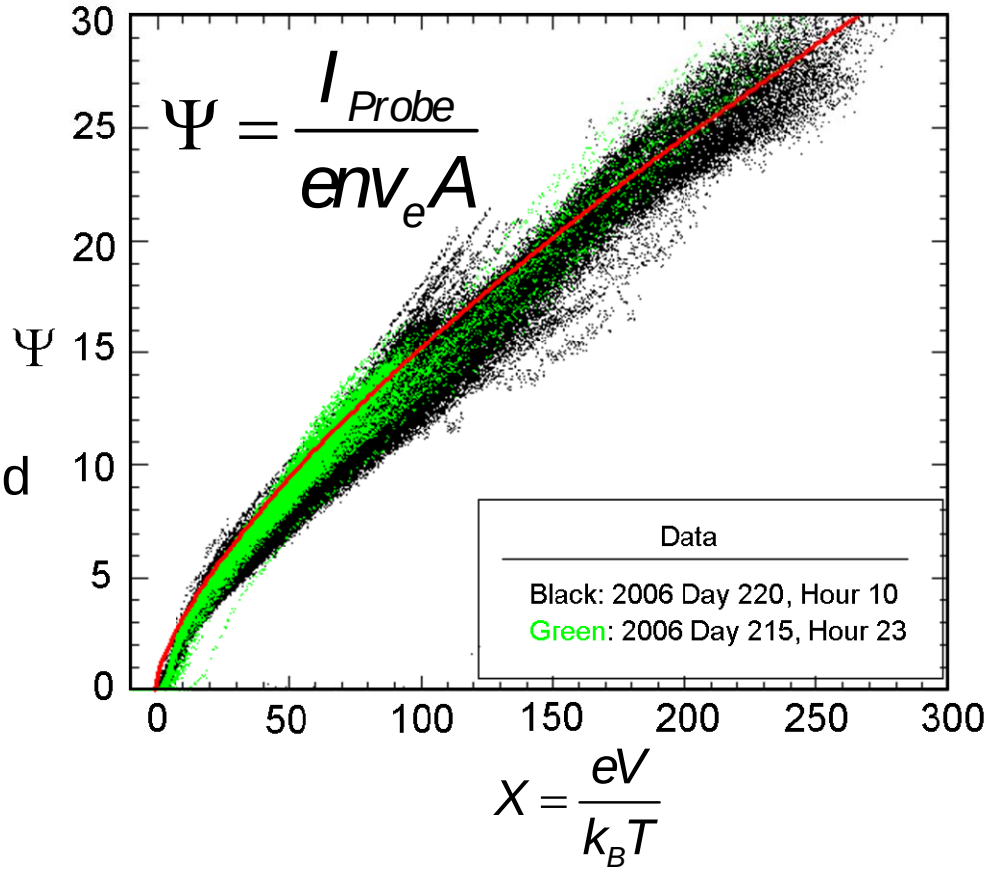
$$I(V,n,T) = I_M(V) \times \frac{n}{n_0}\sqrt{\frac{T}{T_0}} \times \left(\frac{1+\frac{V}{T}}{1+\frac{V}{T_0}}\right)^{0.7}$$

Scales directly with n…

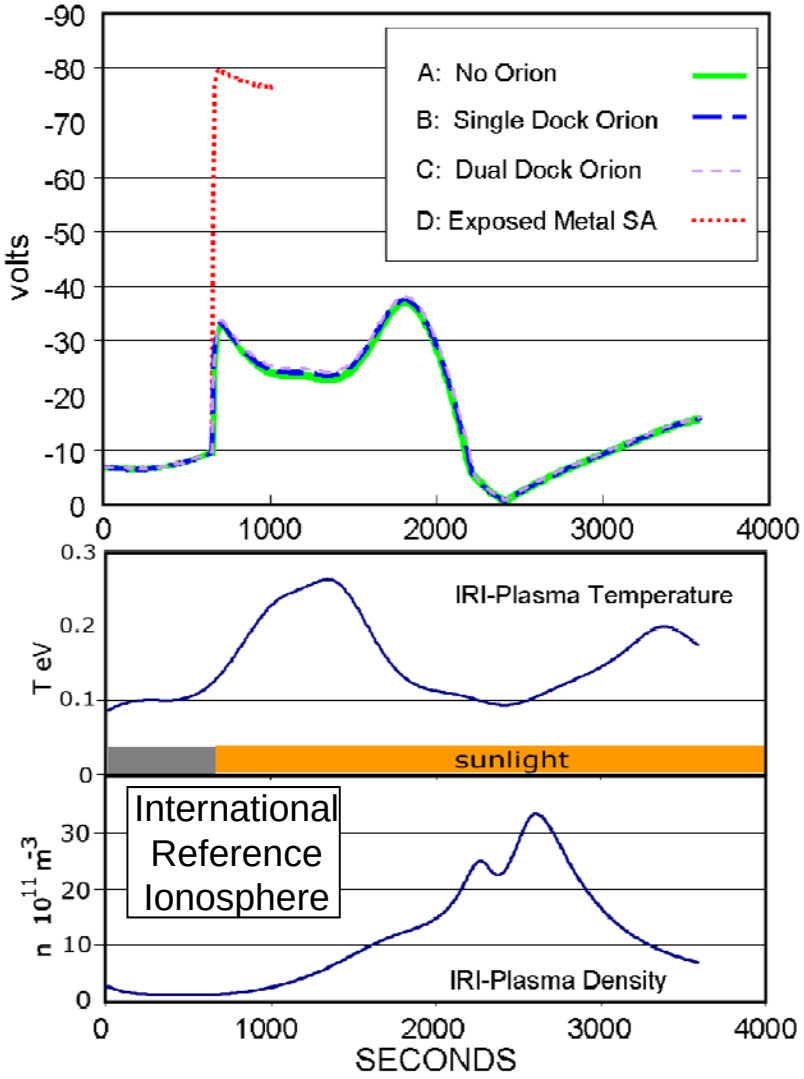
… has more complicated relationship to T

The equation is:

- our model of current collection.
- implemented as an additional current source in PIM.



ORION Charging of ISS



Four charging scenarios have been simulated.

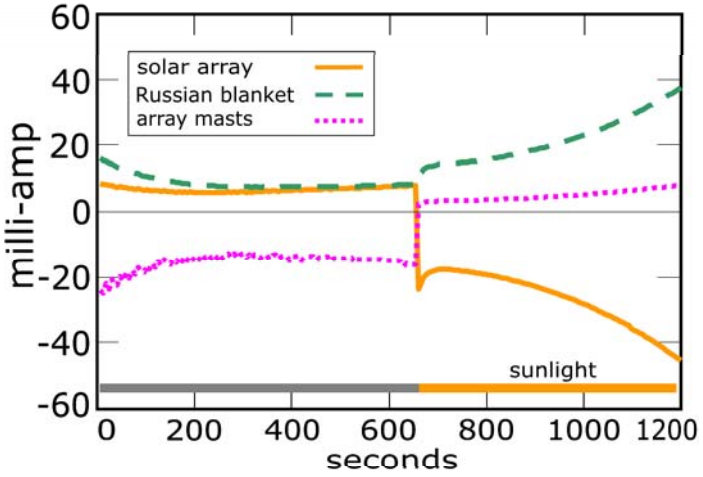
Eclipse exit is a worst case.

Single and Dual docked Orion simulations exhibit very benign charging characteristics.

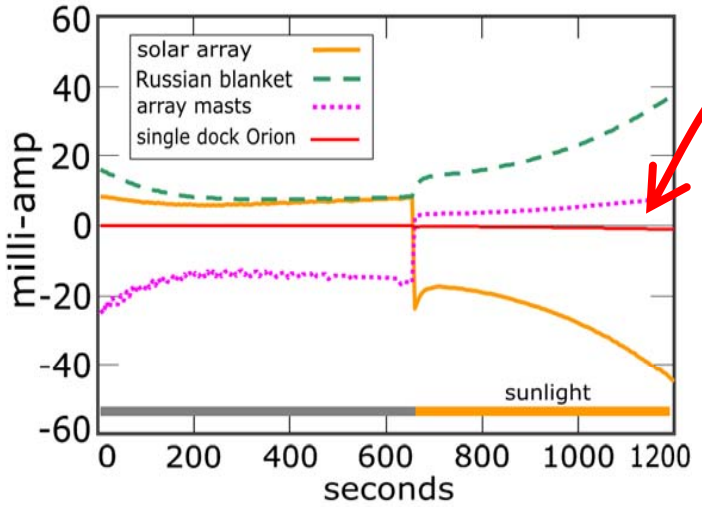
The exposed metal variant cell coupon with (case D) exhibits severe charging.

Theoretical Currents to ISS with Baseline Orion

Orion will contribute no adverse charging.



Nominal No-Orion Case



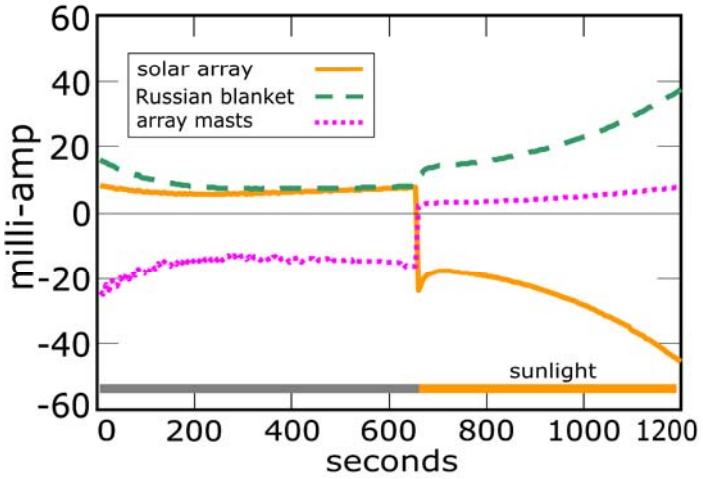
Currents are negligible compared to ISS solar arrays and other components.

Baseline: Single Docked Orion

Dual dock case (not shown) has similar benign charging contribution.

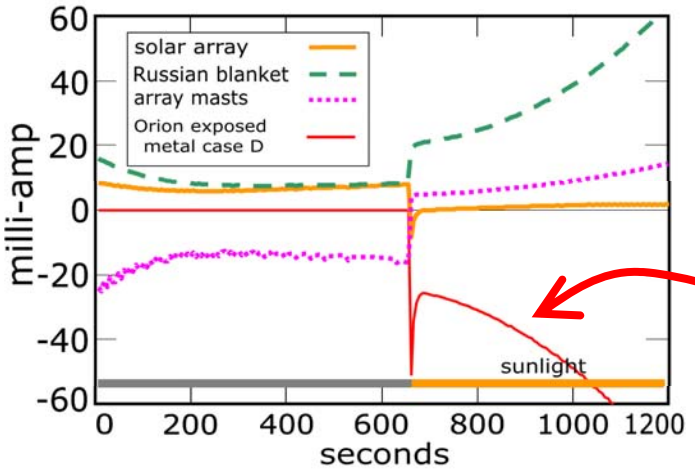
Theoretical Currents to ISS: Exposed Metal Variant

It is interesting to compare No-Orion with the exposed metal variant case.



Nominal No-Orion Case

Currents are negligible compared to solar arrays and other components.



Orion exposed metal variant.

~ 50 mA Orion current displace current from solar arrays & ISS FP approaches -80volts.

Trade Study

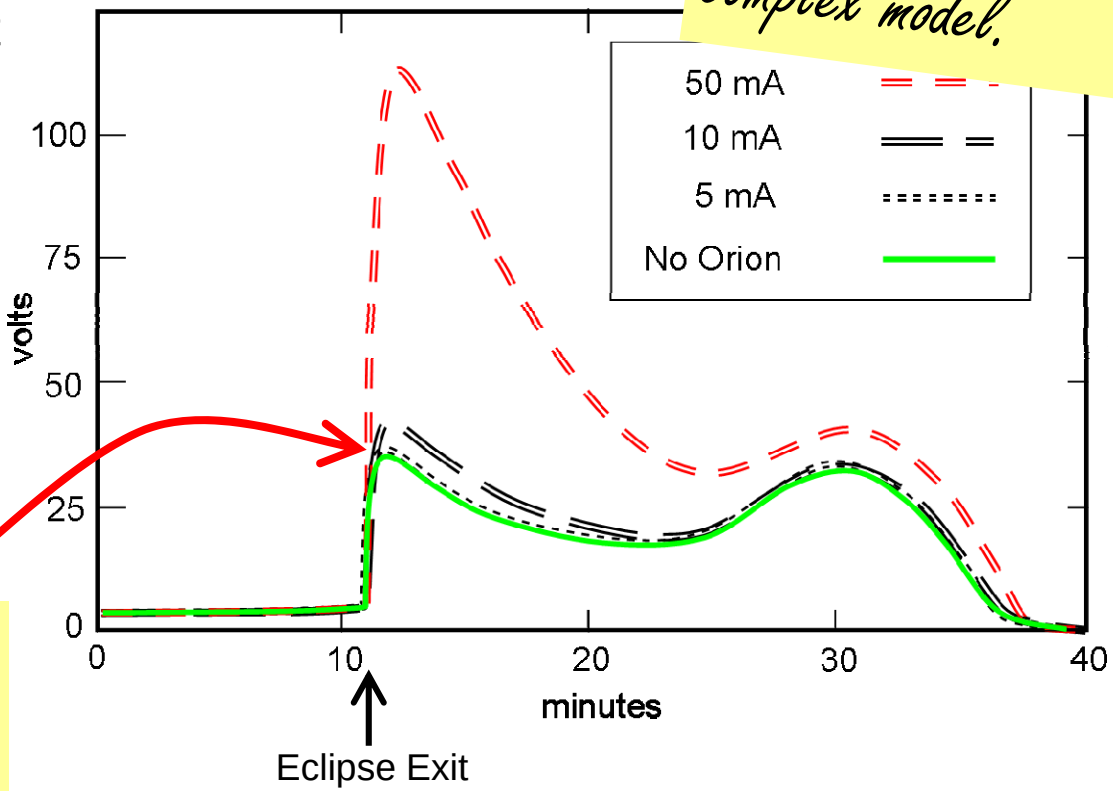
Orion model was modified to deliver a simple constant current (a parameter) when illuminated in sunlight -- zero current in eclipse. The parameter was varied among 5, 10 and 50 mA.

Establishes a simple visiting vehicle induced current limit that yields negligible impact to ISS-Visiting Vehicle integrated configuration.

Parametric current at 5 mA produces less than 2 volt excursion from nominal, No Orion charging.

5milli-amps appears to provide a satisfactory limit.

Discards the complex model.



Summary & Conclusion

- We measure the electric current collection characteristic from the Orion solar arrays.
- We also develop a theoretical scaling of the current incorporated into the Boeing Plasma Interaction Model.
- We find that currents supplied by the baseline Orion SA design impose less than 2 volt excursion from normal charging conditions -- baseline design imposes benign charging characteristics on ISS.
- Trade Study conducted provides objective criterion for a generic visiting vehicle current contribution to ISS:
  - Limiting combined visiting vehicle contribution to 5 milli-amps is found to mitigate adverse charging effects on ISS.
  - Remaining operational challenge to apportion 5 milli-amps among a fleet of several visiting vehicles.