AERO-VISTA
Plasma Impedance Impacts on AV Sensitivity

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Interference from Space Plasma

- Orbiting at an altitude between 450 and 600 km
- Frequency range of scientific interest is 400kHz-5MHz
- Space plasma expected to strongly interact with the VS **dipole & monopole** antennas
    - Electron plasma frequency
    - Electron cyclotron frequency
    - Upper hybrid frequencies

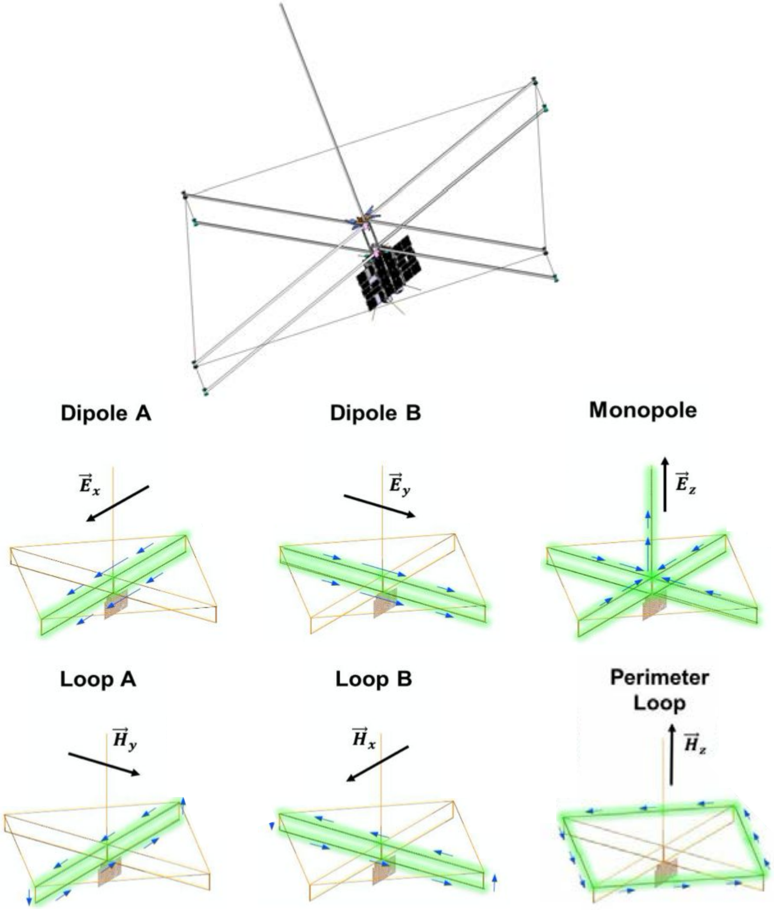

Fig. 1. AERO-VISTA 3D model with highlighted antenna structures in green. Blue arrows indicate direction of electrical current. *AERO-VISTA Project.*

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Expected Plasma Effects on the VS Antenna

- Plasma resonances and cutoffs:
  - Influence the response of the antenna to signals as a function of frequency
  - Modify the radiation resistance and reactance, i.e. the impedance
- Why does this variation in impedance matter?
  - Increased noise floor

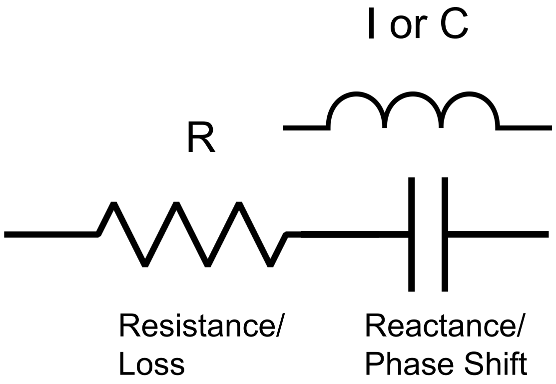
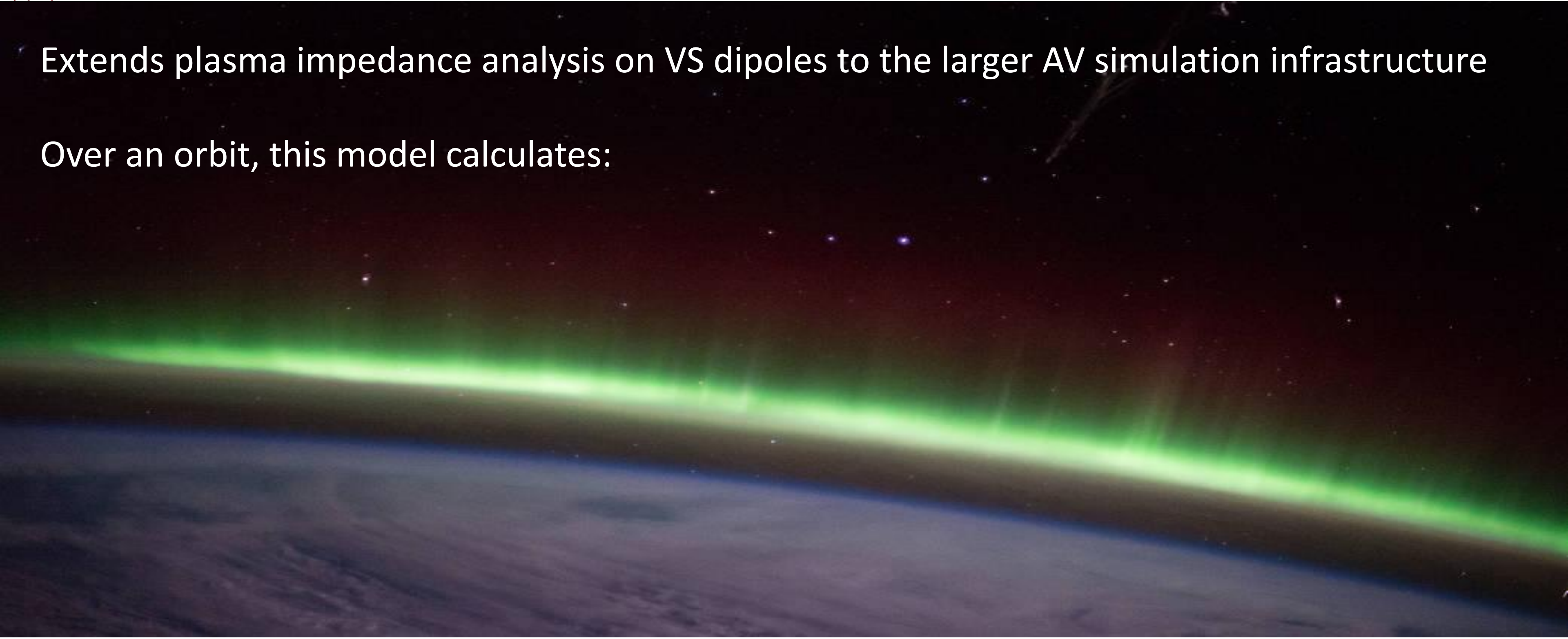


Fig. 2. Simple impedance visualization.

Plasma Impedance Model Overview



Extends plasma impedance analysis on VS dipoles to the larger AV simulation infrastructure

Over an orbit, this model calculates:

Fig. 3. Aurora borealis Earth observation from the ISS. *ESA, astronaut Samantha Cristoforetti.*

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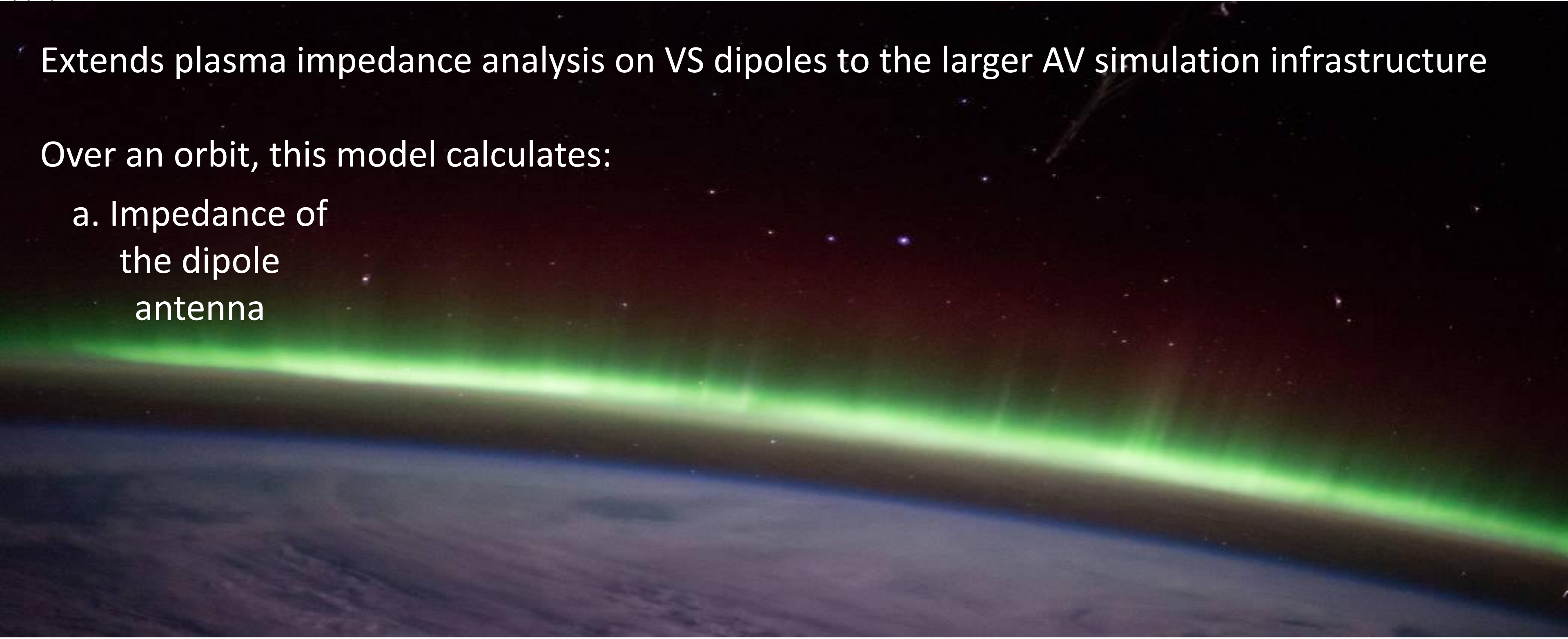

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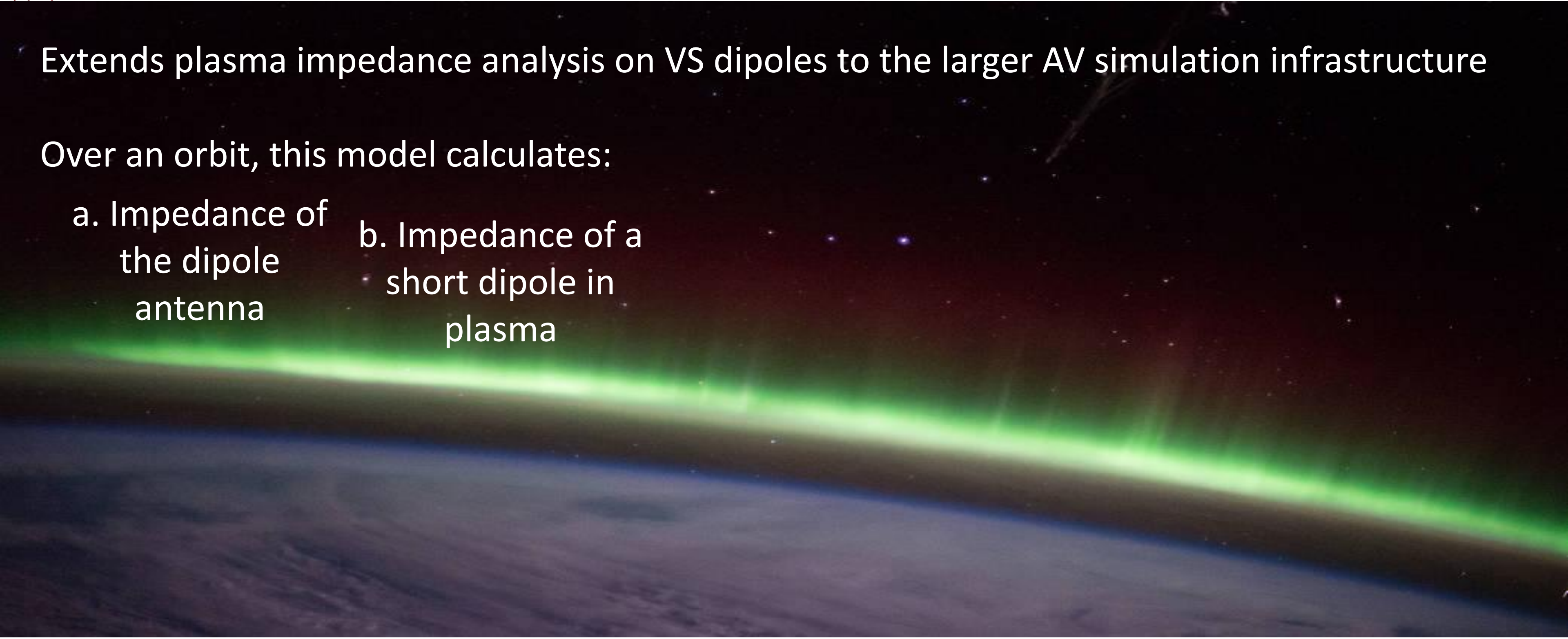

Extends plasma impedance analysis on VS dipoles to the larger AV simulation infrastructure

Over an orbit, this model calculates:

a. Impedance of the dipole antenna

b. Impedance of a short dipole in plasma

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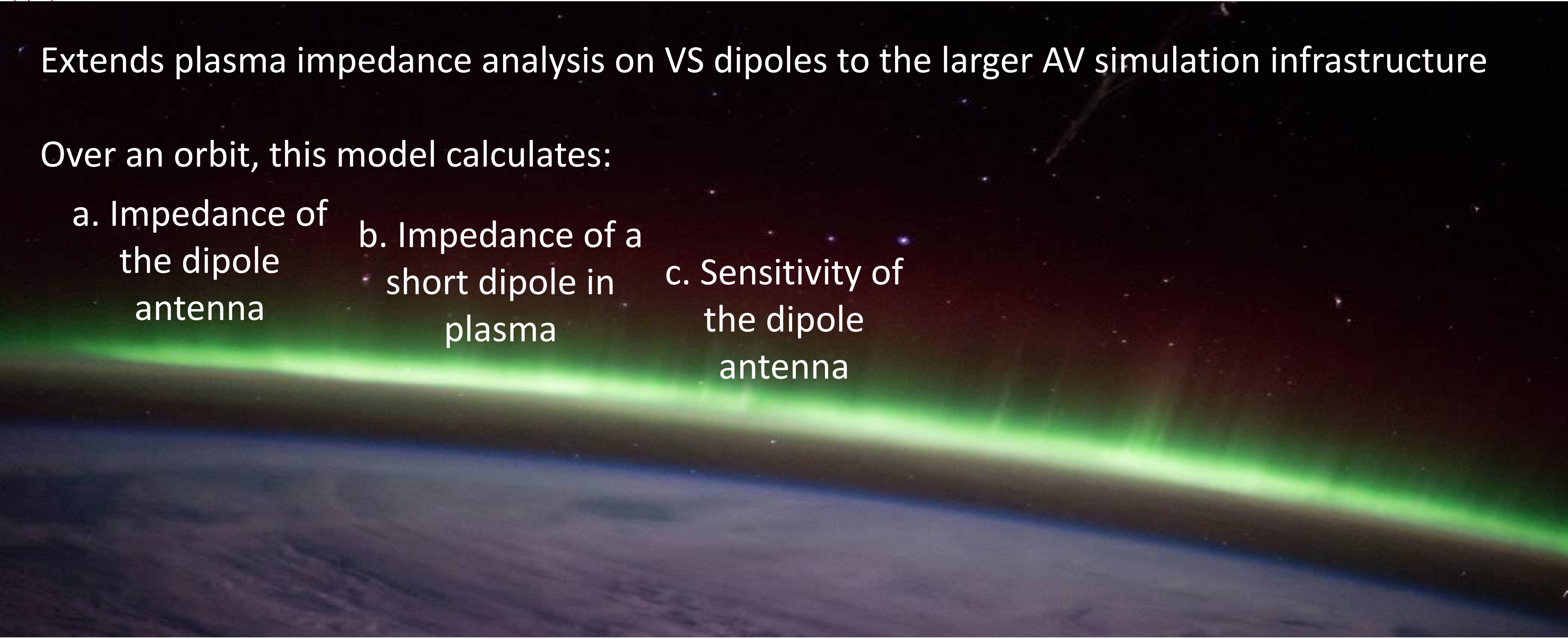

Extends plasma impedance analysis on VS dipoles to the larger AV simulation infrastructure

Over an orbit, this model calculates:

a. Impedance of the dipole antenna

b. Impedance of a short dipole in plasma

c. Sensitivity of the dipole antenna

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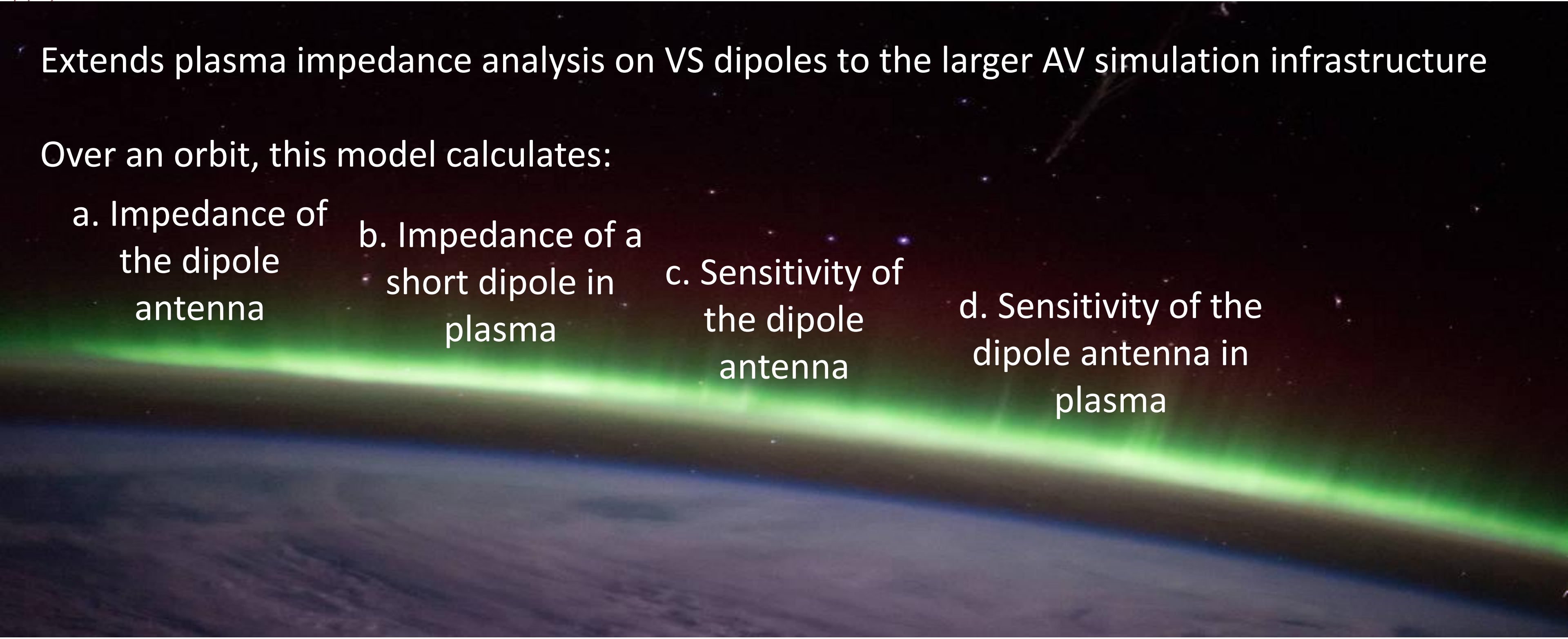

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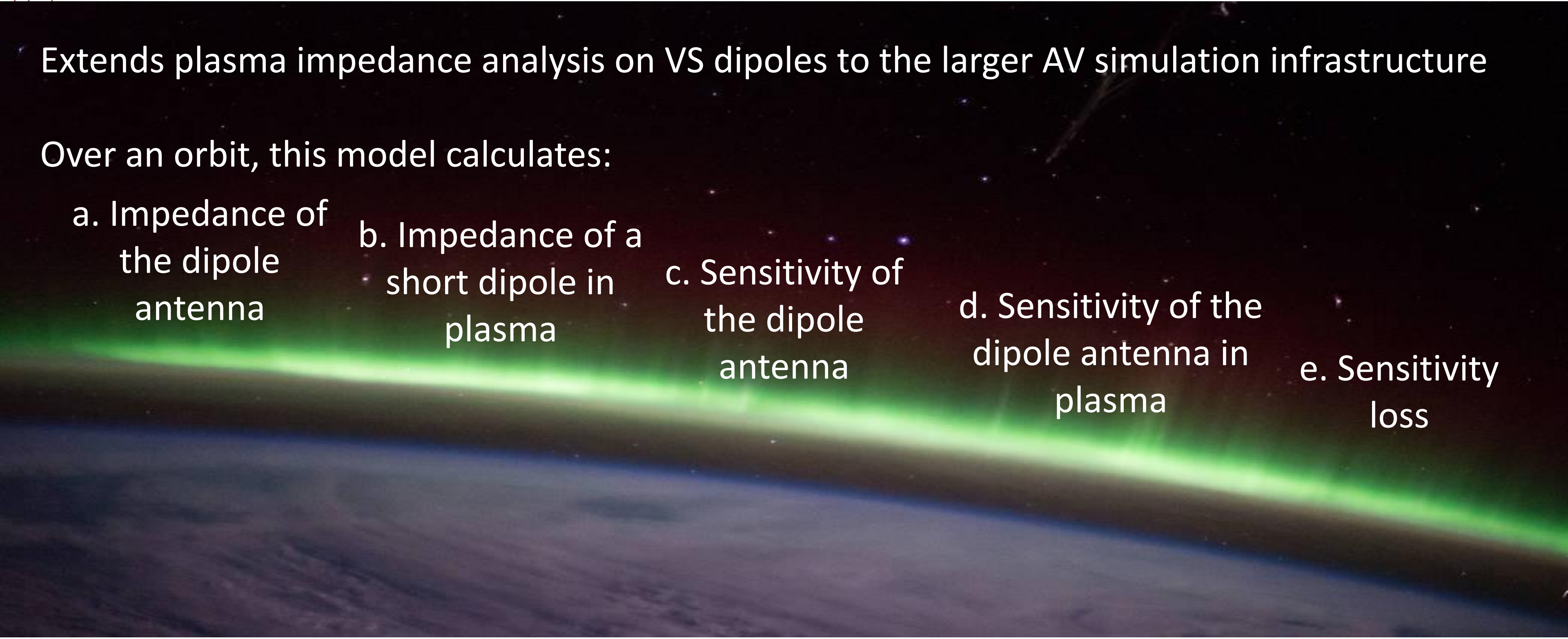
Plasma Impedance Model Overview



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d. Sensitivity of the dipole antenna in plasma

e. Sensitivity loss

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Three models (IRI, IGRF, and MSISE-00) are used to estimate environmental parameters at a specific time and space along the orbit

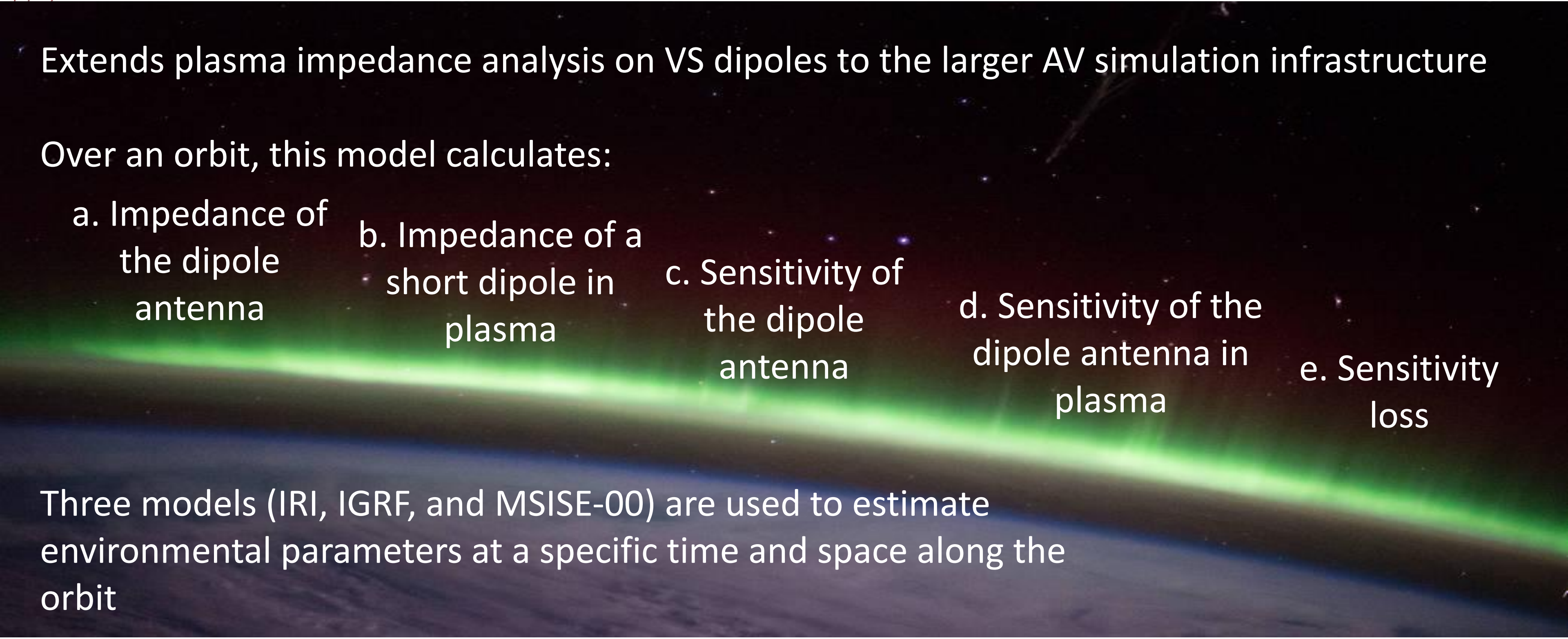

Fig. 3. Aurora borealis Earth observation from the ISS. *ESA, astronaut Samantha Cristoforetti.*

Impedance Calculation

$$Z_{\text{in}} = \frac{a}{j\omega 2\pi\epsilon_0 K' L F^{1/2}} \left[\ln \frac{L}{\rho} - 1 - \ln \frac{a + F^{1/2}}{2F} \right]$$

Fig. 4. Impedance formulation from *Balmain, “The Impedance of a Short Dipole Antenna in a Magnetoplasma”, 1964.*

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$$\mathbf{K} = \begin{bmatrix} K' & jK'' & 0 \\ -jK'' & K' & 0 \\ 0 & 0 & K_0 \end{bmatrix}$$

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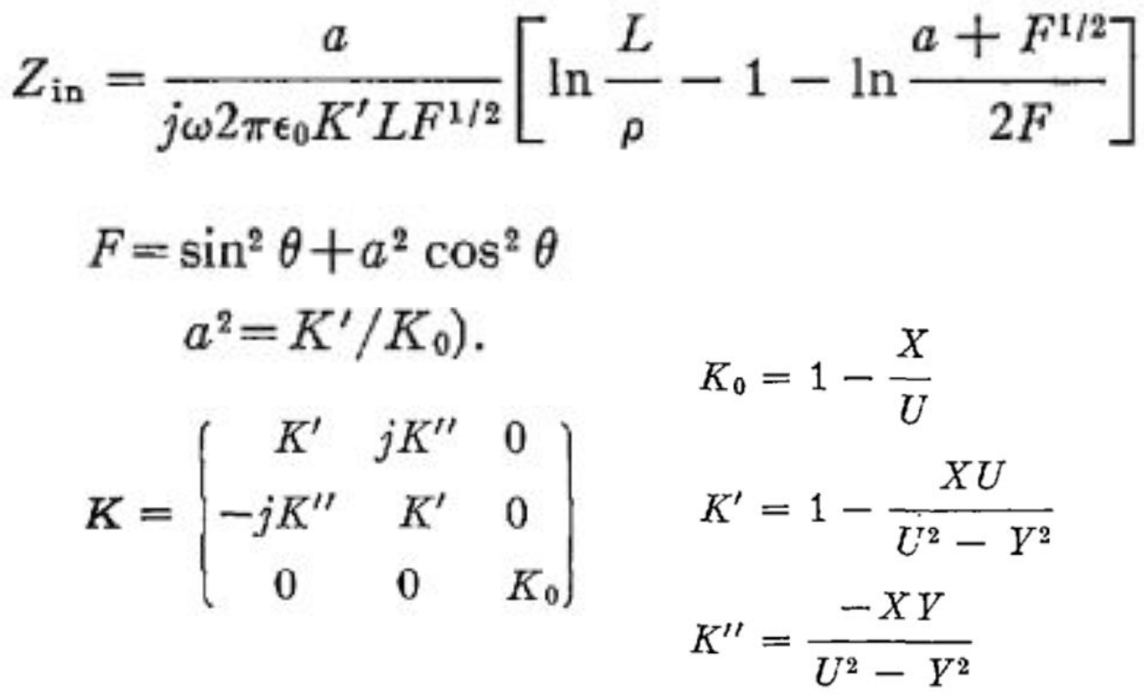

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$$K_0 = 1 - \frac{X}{U}$$

$$K' = 1 - \frac{XU}{U^2 - Y^2}$$

$$K'' = \frac{-XY}{U^2 - Y^2}$$

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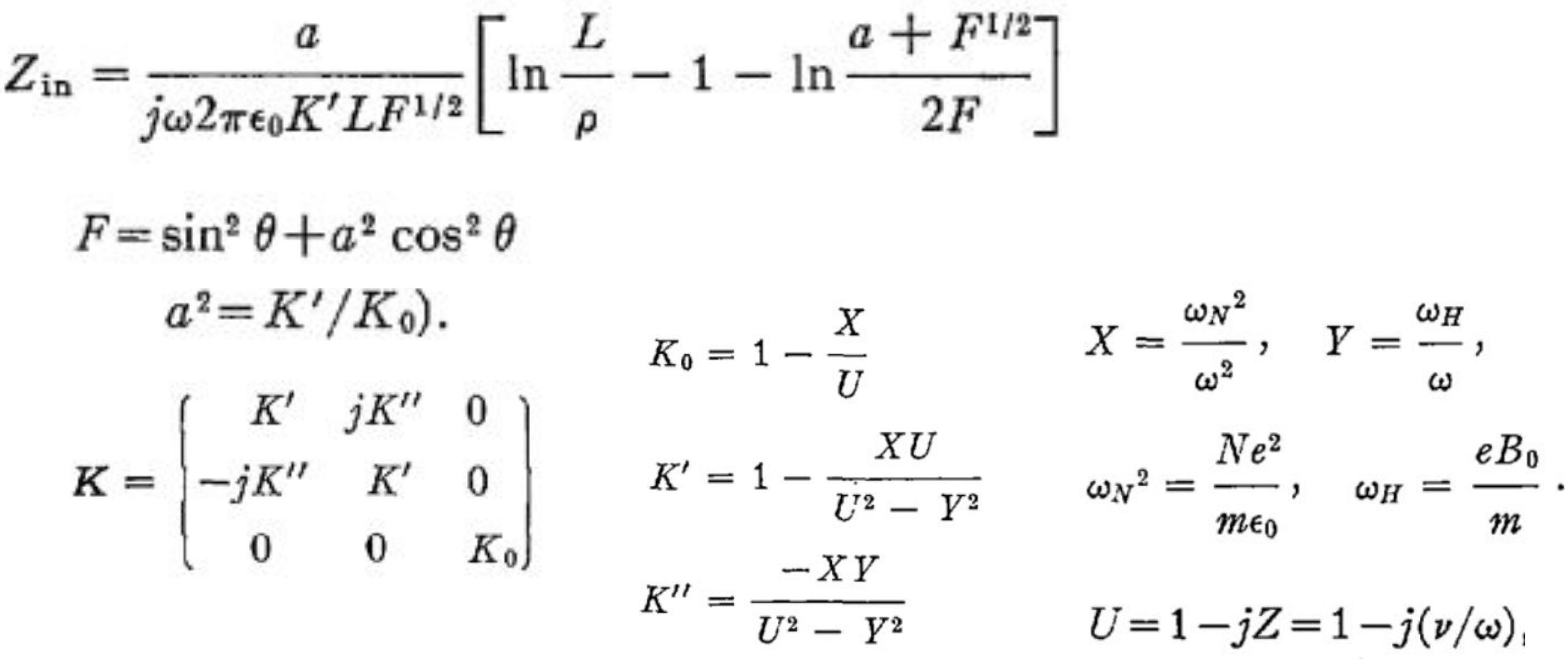

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$$X = \frac{{\omega_N}^2}{\omega^2}, \quad Y = \frac{\omega_H}{\omega},$$

$${\omega_N}^2 = \frac{Ne^2}{m\epsilon_0}, \quad \omega_H = \frac{eB_0}{m}.$$

$$U = 1 - jZ = 1 - j(\nu/\omega),$$

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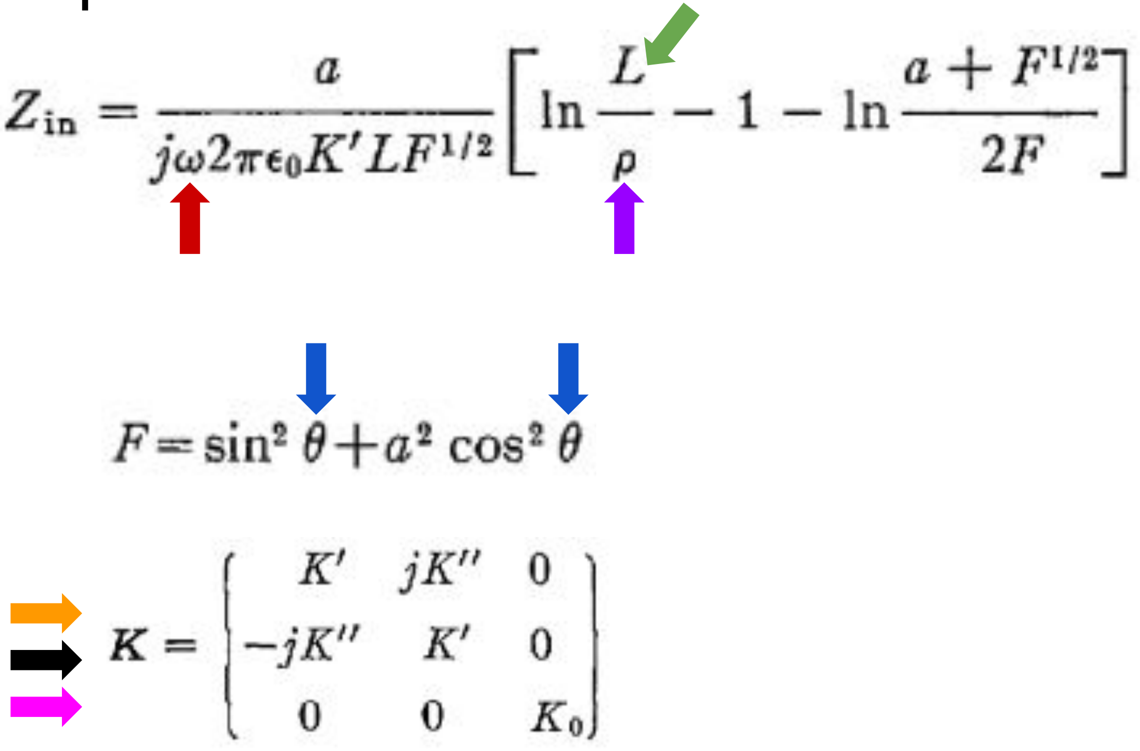

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$$K = \begin{pmatrix} K' & jK'' & 0 \\ -jK'' & K' & 0 \\ 0 & 0 & K_0 \end{pmatrix}$$

- Frequency
- Half length of the dipole antenna
- Radius of the dipole antenna
- Angle between dipole antenna and B-fld.
- Electron plasma freq.
- Electron cyclotron freq.
- Collision freq.

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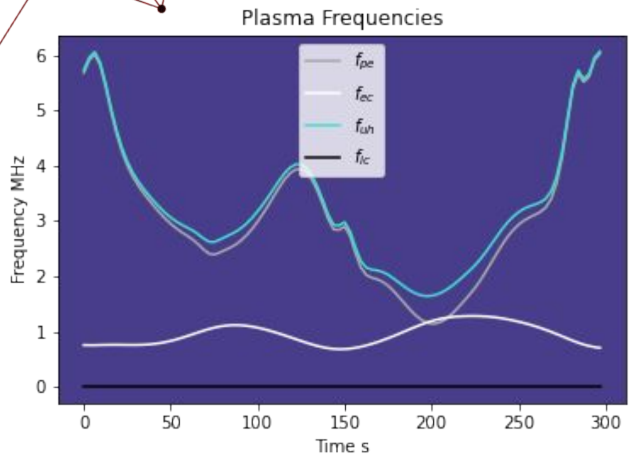
Impedance Plot



Electron plasma freq.
Electron cyclotron freq.
Upper hybrid freq.

Main takeaway:

- Changes in impedance occur during periods of plasma resonances

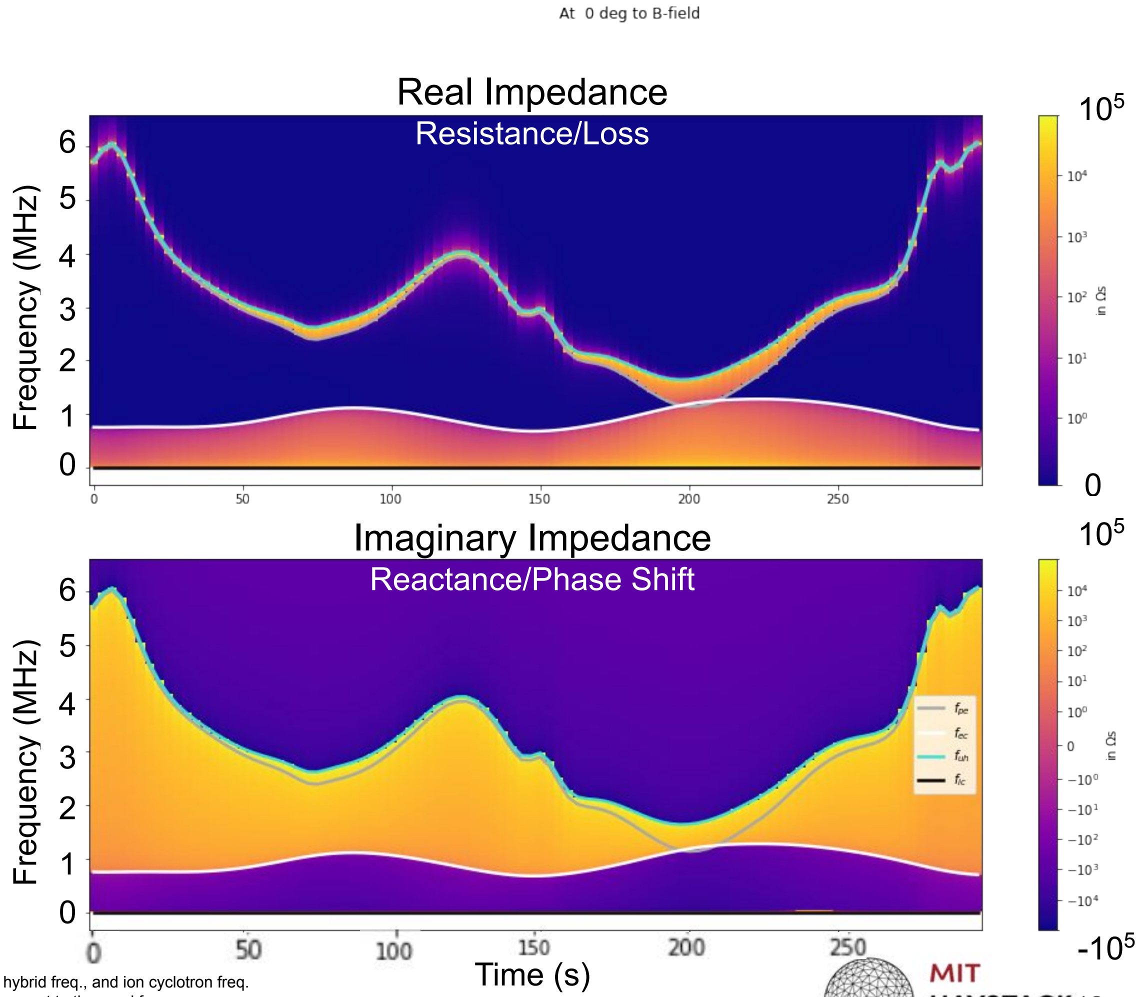


Fig. 5. (Top Left) Plot of plasma frequencies including electron plasma freq., electron cyclotron freq., upper hybrid freq., and ion cyclotron freq. (Top Right) Real impedance with respect to time and frequency. (Bottom Right) Imaginary Impedance with respect to time and frequency.

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Sensitivity Calculation

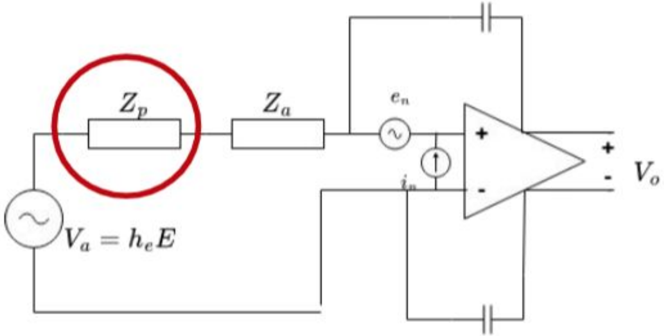


Fig. 6. Circuit including plasma impedance component circled in red. *AERO-VISTA project.*

- Antenna amplifier contains an inherent voltage and current noise
- Sensitivity we are calculating is the increase to the noise floor when plasma effects are added

$$S_v = \frac{\sqrt{|e_n|^2 + |i_n Z|^2}}{h_e} \text{ in } \frac{V}{m\sqrt{Hz}}$$

Fig. 7. Sensitivity equation.

- h_e = effective height of the antenna = 1.2 m
- e_n = voltage noise = 2 nV/sqrt(Hz)
- i_n = current noise = 2 pA/sqrt(Hz)
- Z = impedance

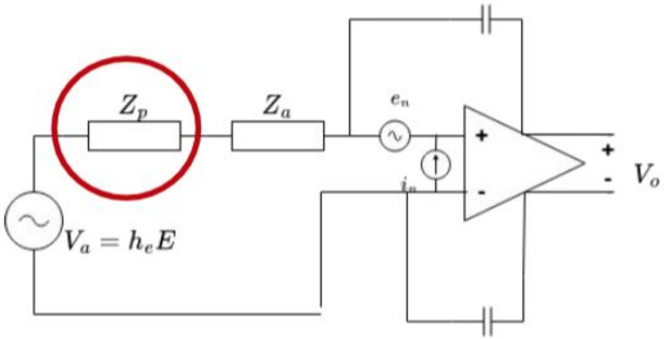
  = Z_capacitor + Z_plasma
  - Z_capacitor :

$$Z_C = -j\frac{1}{\omega C} \text{ in } \Omega$$

  - C = capacitance = 40pF

Sensitivity estimates are from Alexander Morris at LL.

Sensitivity Calculation



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Sensitivity Loss Plot

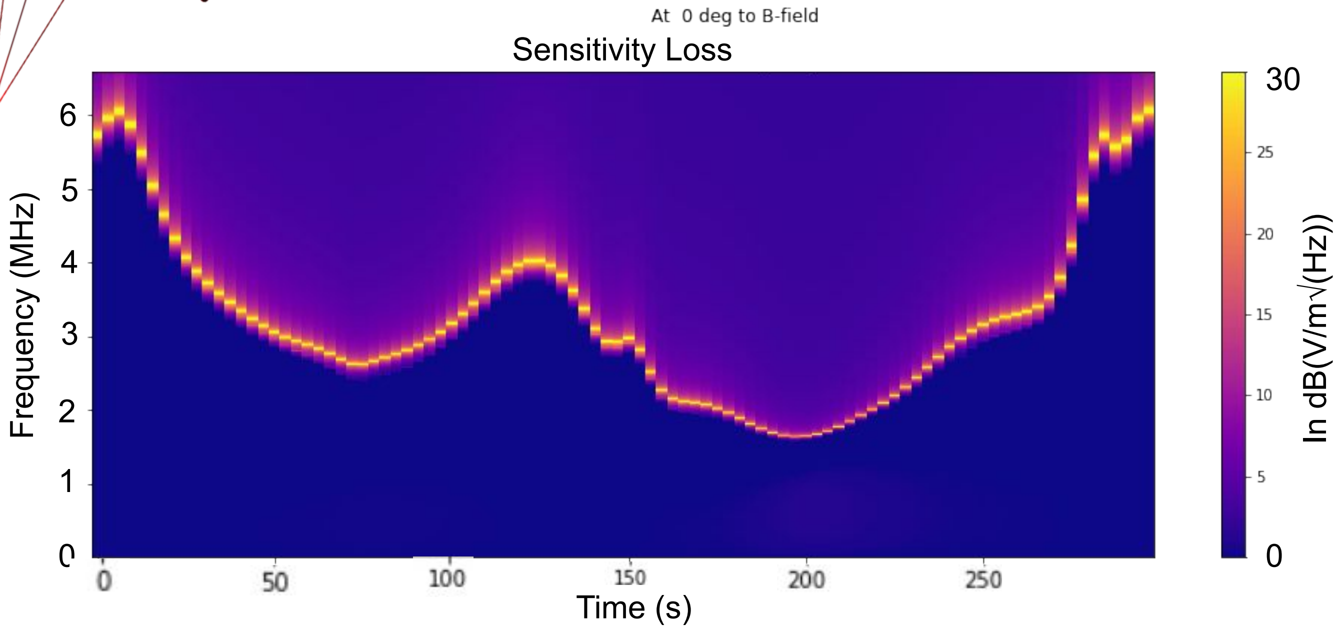


Fig. 8. Sensitivity loss plot at 0 degrees to B-fld.

Sensitivity Loss Calculation = S_p / S_og

- S_p = sensitivity w/ plasma effects
- S_og = original sensitivity w/o plasma effects (sensitivity of capacitor)

Main takeaway:

- Up to 30 dB in loss at some places

Note:

- Time sampling of ~3 s intervals resulted in the blotchy lines shown on the plot, there are not peaks of intensity in some areas.

AERO-VISTA Simulation Pipeline

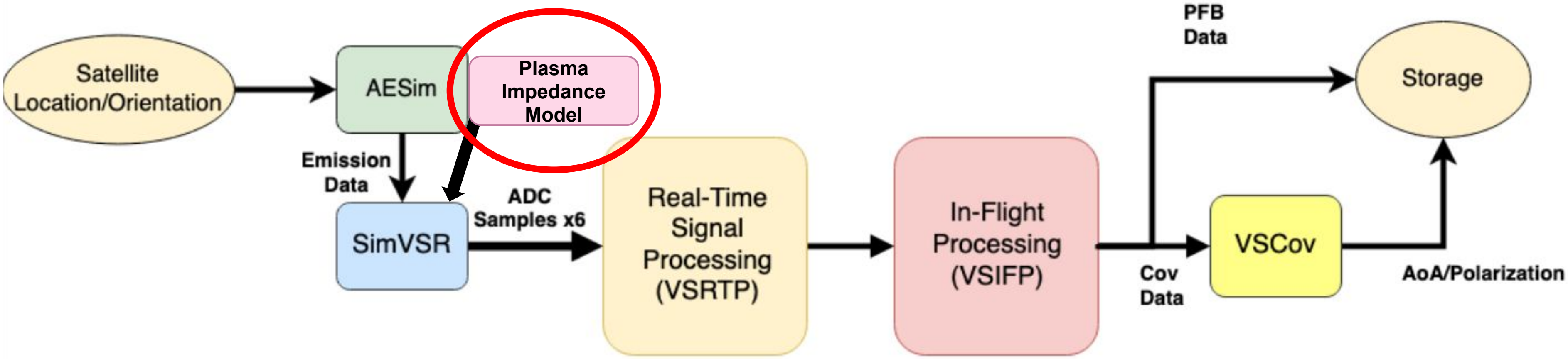
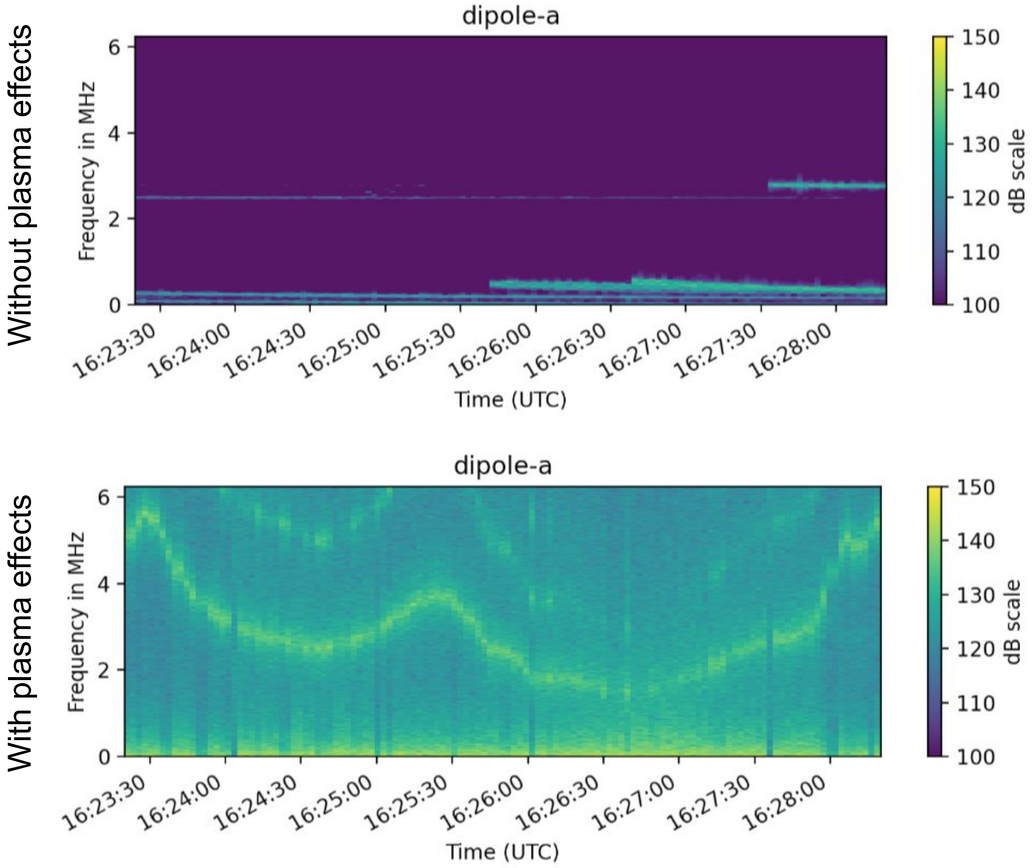


Fig. 9. AERO-VISTA simulation pipeline. *AERO-VISTA project.*

- Calculated sensitivity data is used as an input for SimVSR, the next step in the AV simulation pipeline

Preliminary SimVSR Spectrograms



Effects of the impedance have a greater impact than expected

- May be overestimating impedance effects
- Further work is needed to verify these results

Fig. 10. SimVSR spectrograms. (Top) Original SimVSR spectrograms without plasma effects. (Bottom) SimVSR spectrograms with plasma effects.

Summary & Future Work

- Using the Balmain impedance model, developed software that computes:
    - Sensitivity
    - Sensitivity loss
- This model will be used to extend the AV simulation pipeline
    - Kat Kononov's sensitivity calculations
- Further verification is needed to double check results due to the impedance effects being larger than expected

Fig. 11. AERO-VISTA logo. *AERO-VISTA project.*

Thank you! Questions?

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