Electric Current Systems Induced by Solar Wind Coupling with Venus

Robin Ramstad[1] and Josephine Johnson[1]

1. Laboratory for Atmospheric and Space Physics, University of Colorado Boulder

Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

Summary

We investigate solar wind coupling with Venus using Venus Express (VEX; 2006-2014) magnetic field measurements to study the electric currents induced in the electrodynamic interaction between the solar wind and the conductive Venusian ionosphere. Globally mapping the currents will enable quantifying the rate of energy transfer that limits solar wind-driven processes such as atmospheric escape. While the VEX measurements allow us to partially map the average state of the current system, single-orbit measurements from different parts of the solar cycle indicate that the interaction changes state in the highly ionizing conditions present during solar maximum. We argue that a future plasma-focused mission is needed to understand the Sun's effect on Venus' atmospheric evolution over geologic time.

1. Venus-solar wind coupling

Induced electric currents couple the Venusian upper atmosphere and ionosphere to the solar wind, driving heating and escape.

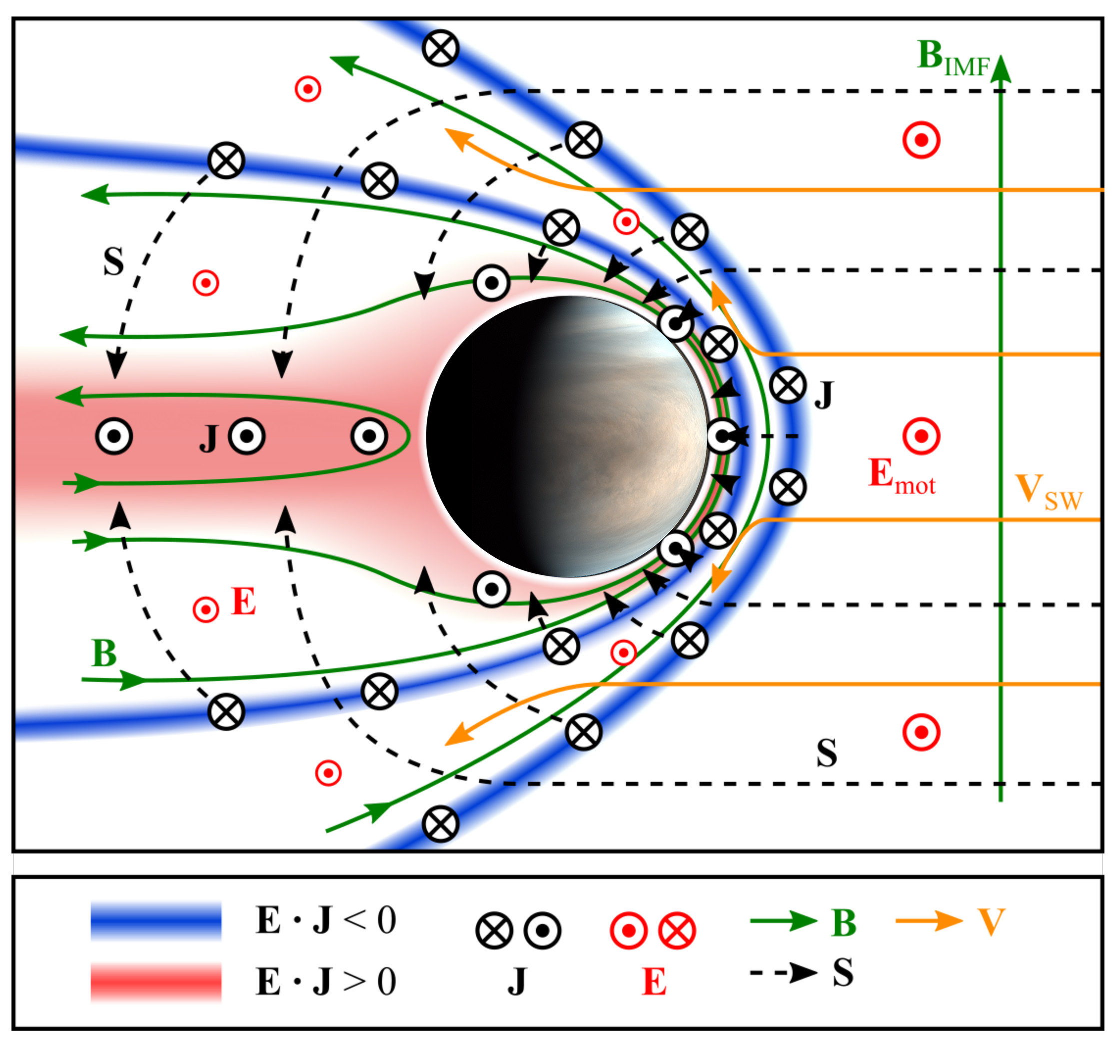

Figure 1: Illustration of electrodynamic energy transfer in an induced magnetosphere, showing dynamo regions (blue), load regions (red), magnetic (**B**) and electric fields (**E**), currents (**J**), and Poynting flux (**S**), and solar wind flow (**V**). Adapted from *Ramstad and Barabash* [2021], SSR.

2. Mapping electric current systems at Venus

We map the average global magnetic vector field structure at Venus using all available Venus Express magnetic field measurements. The average (DC) current can subsequently be derived using the Maxwell-Ampere law. In the time-avereage frame *d/dt* = 0, thus

$$\mathbf{J} = \frac{1}{\mu_0}(\nabla \times \mathbf{B}). \quad (1)$$

Slices in the resulting 3D-structure of the current systems are shown in Figure 2 below, revealing the regions that generate and deposite electromagnetic power in the solar wind interaction.

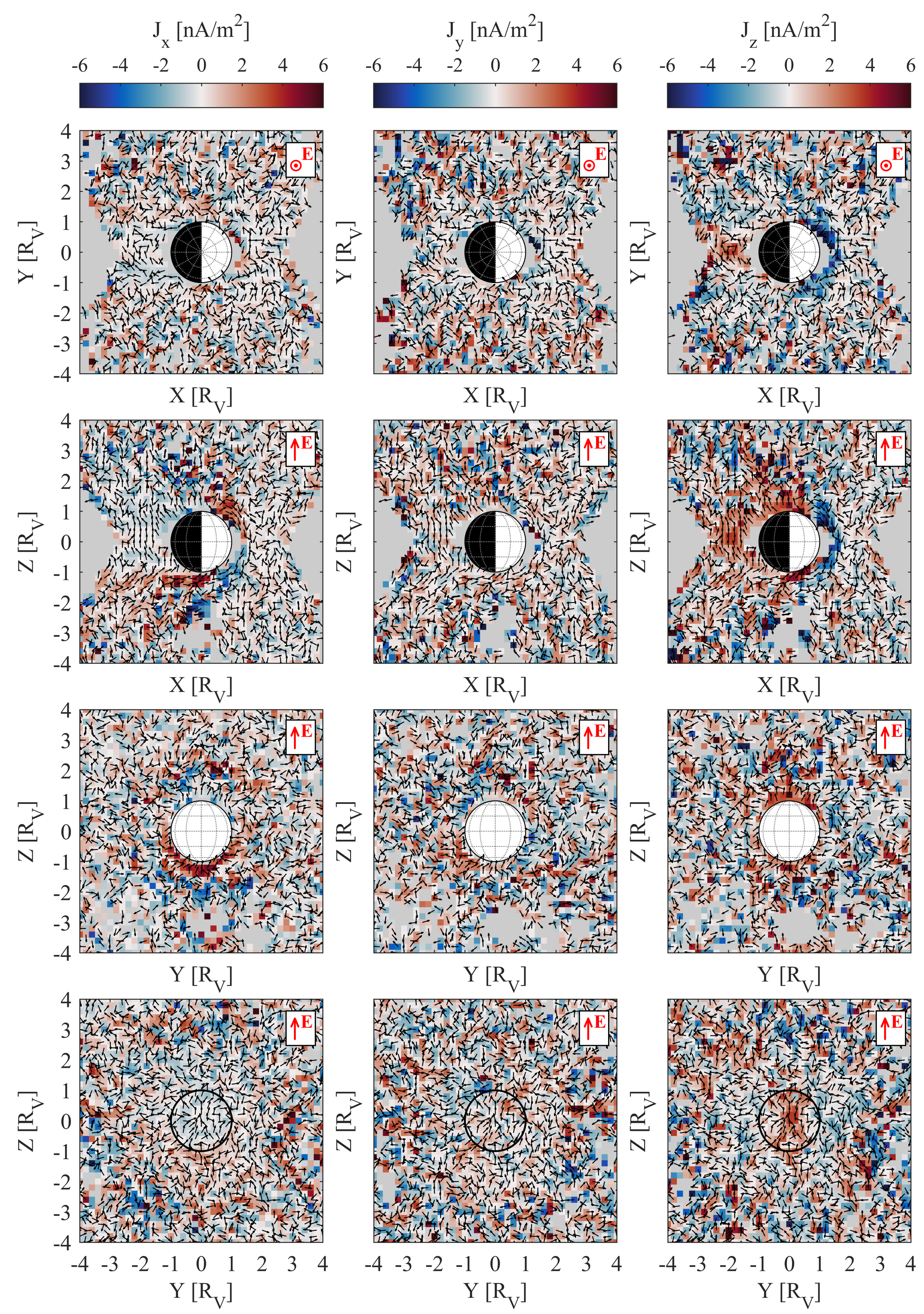

Figure 2: Electric current systems at Venus derived by mapping all available Venus Express magnetic field measurements and applying the Maxwell-Ampere law (equation 1). Columns show x,y,z-components and rows show different slice planes. The direction of the solar wind motional electric field ($\mathbf{E} = -\mathbf{v}_{sw} \times \mathbf{B}_{IMF}$) is indicated in the corner of each panel. The large-scale structure of the current systems is consistent with those recently found at Mars [*Ramstad et al.* 2020, Nat. Astron.]. Noise and gaps are largely due to the relative sparseness of the Venus Express measurements in combination with natural variability in the system and upstream solar wind

3. Solar cycle dependence

Comparing magnetic structure and plasma distributions between solar minimum and maximum shows that the solar cycle has a significant effect on solar wind coupling with the ionosphere and atmospheric escape.

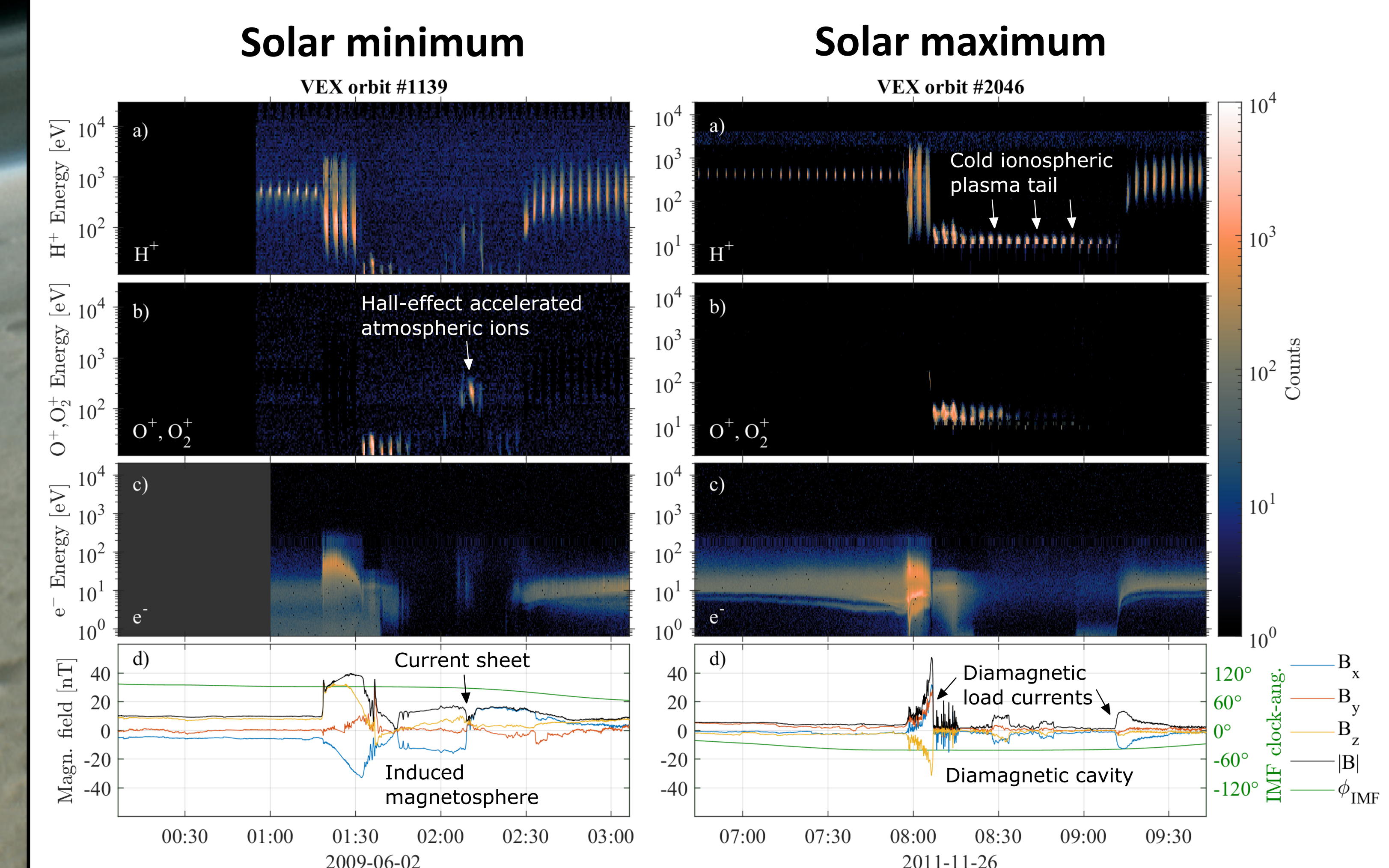

Figure 3: Plasma and magnetic field measurements from two similar Venus Express orbit paths, one during solar minimum (left) and one during solar maximum (right). The magnetosphere configuration changes from an induced magnetosphere to a diamagnetic cavity, affecting energization of ionospheric plasma and escape.

Conclusions

1. Venus Express magnetic field measurements show that electric current systems at Venus can be mapped statistically and that the average structure conforms to expectations.
2. Single-orbit comparisons show that the solar wind interaction changes qualitatively from solar minimum to solar maximum, greatly affecting solar wind coupling with the ionosphere and escape.
3. Understanding atmospheric escape over 4 Ga requires that we quantitatively understand the upstream dependencies of solar wind-ionosphere energy transfer at Venus. VEX measurements are sparse and do not provide sufficient covereage, future missions are required.

VEXAG 19, November 2021