Magnetic Topology at Venus: New Insights into the Venus Plasma Environment

Shaosui Xu[1](shaosui.xu@ssl.berkeley.edu), Rudy A. Frahm[2], Yingjuan Ma[3], Janet G. Luhmann[1], David L Mitchell[1]

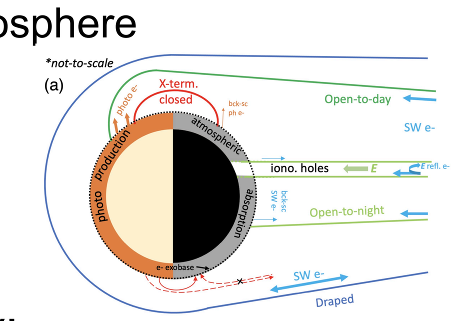
[1]Space Sciences Laboratory, University of California, Berkeley, CA, USA, [2]Southwest Research Institute, San Antonio, TX, USA, [3]Department of Earth Planetary and Space Sciences, University of California, Los Angeles, CA, USA

I: Abstract

This study provides the first characterization of magnetic topology (i.e., the magnetic connectivity to the collisional ionosphere) at Venus, which might give new insights into the Venusian space environment on topics such as the penetration of the interplanetary magnetic field (IMF) into the ionosphere, planetary ion outflow and inflow, and auroral emission. Magnetic topology is inferred from the electron and magnetic field measurements from Venus Express (VEx). We demonstrate through a few case studies that various types of magnetic topologies exist at Venus, including typical draped IMF, open magnetic fields connected to the nightside atmosphere or the dayside ionosphere, and unexpected cross-terminator closed field lines. We also provide a detailed characterization of an ionospheric hole event, where we find an open topology and a field-aligned potential of ~[−10, −20] V with respect to the collisional ionosphere, which has important implications for its formation mechanism. This study enhances our current understanding of Venus' magnetic configuration and lays the groundwork for a new powerful tool to help understand various topics of the near-Venus space environment. (*Geophysical Research Letters*, *48*, e2021GL095545)

II: Methodology and Motivation

- **WHAT** is magnetic topology
  - magnetic connectivity to collisional atmosphere
  - One end: open topology
  - Two ends: closed topology
  - None: draped topology

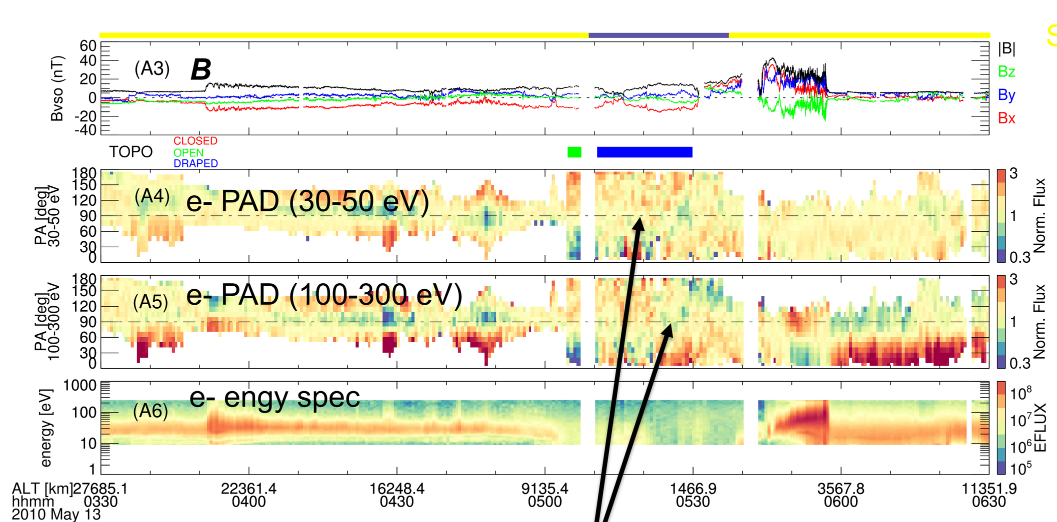


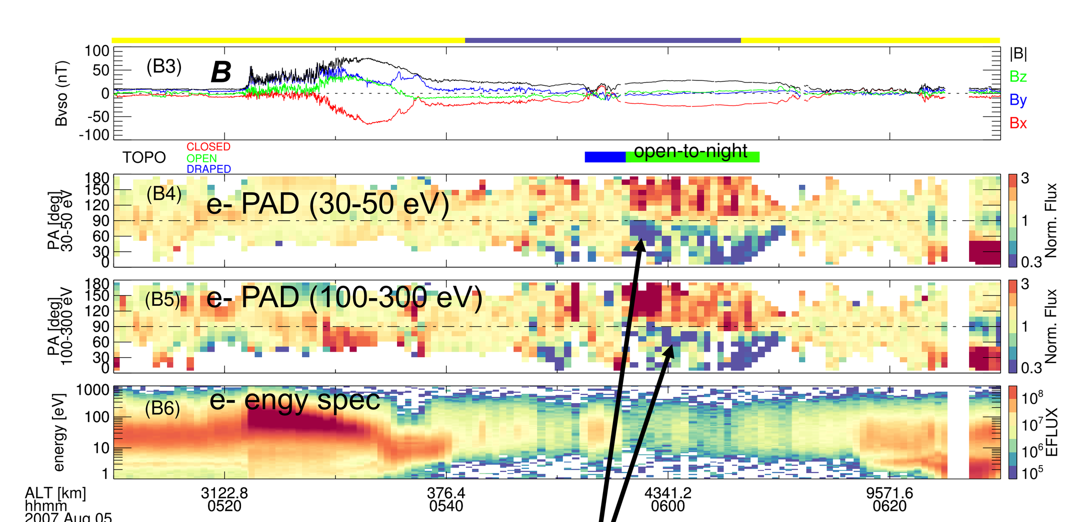
- **HOW** to determine magnetic topology:
  - Electron pitch angle distribution (PAD):
    - One-sided loss cone: intersecting atmosphere on one end, open
    - Double-sided loss cone: intersection on both ends, closed
  - Electron energy spectra for field-aligned directions:
    - Photo e- in one direction, solar wind electrons in another, open
    - Photo e- in both directions, closed
  - Solar wind electrons in both directions with no loss cone, draped

- **WHY** we study magnetic topology?
  - Magnetic topology at Mars used to understand various important topics, most of which applicable for Venus
  - Magnetospheric configuration, magnetic reconnection, magnetic flux ropes, ionospheric sources and structures, electron dynamics and wave-particle interactions, electrostatic fields and potentials, ion precipitation and escape

- This study provides ***first*** characterization of magnetic topology at Venus, new insights into
  - Planetary ion outflow and inflow and water loss, atmospheric evolution
  - e- precipitation, a source for ionosphere and aurorae
  - Formation mechanism of ionospheric hole structures
  - Comparative planetary study of Mars and Venus

III: Magnetic Topology at Venus: Draped and Open-to-Night

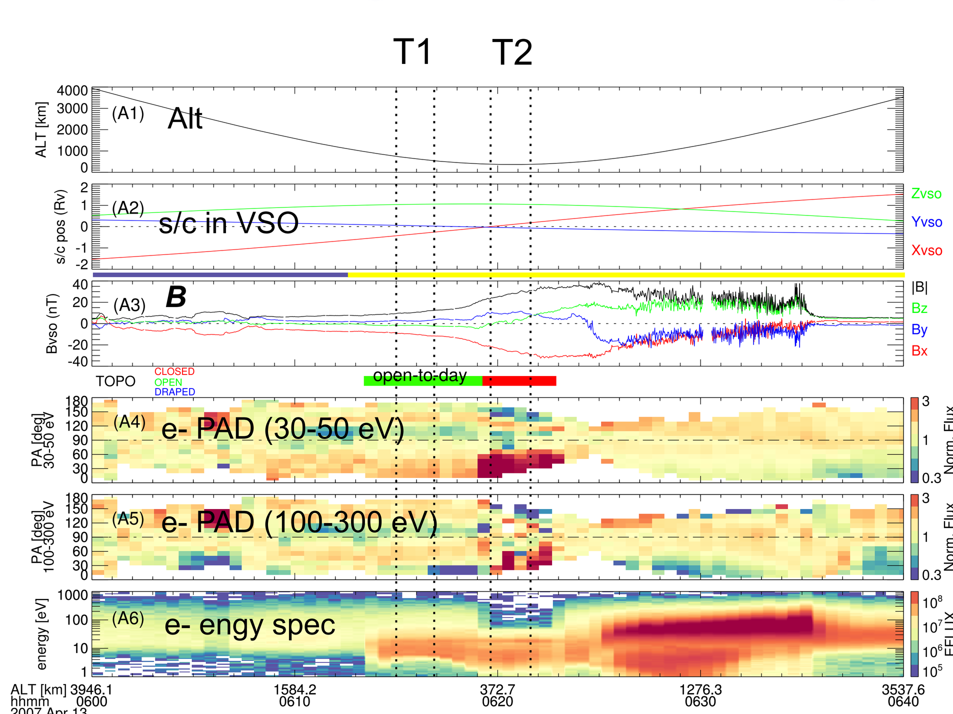


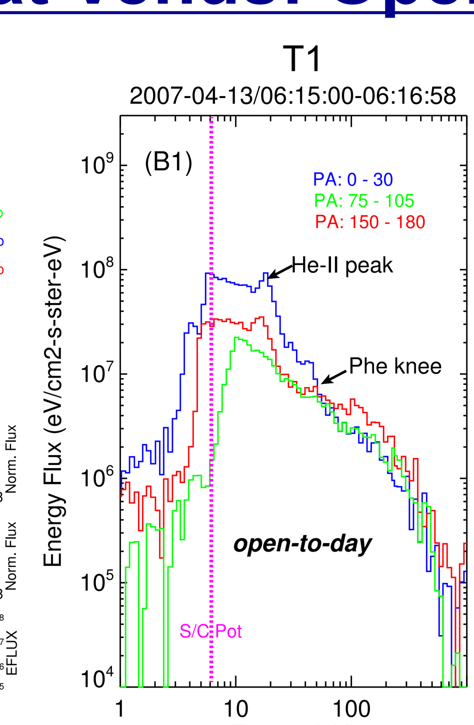


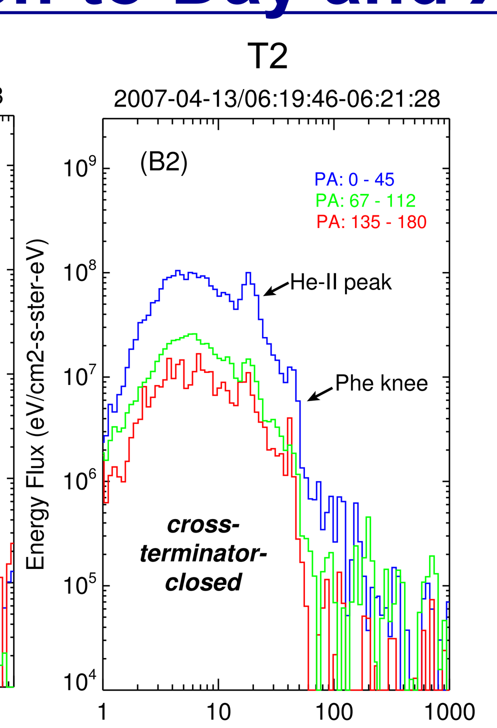
❖ **Draped: isotropic PAD, no loss cone**

❖ **Open-to-night: one-sided loss cone (nightside connectivity)**

IV: Magnetic Topology at Venus: Open-to-Day and X-Term. Closed

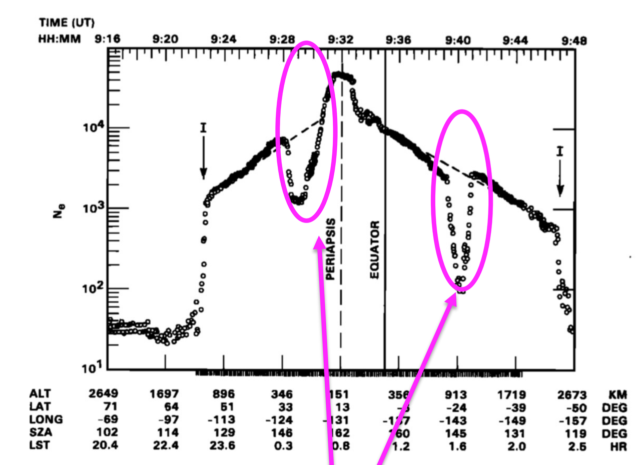


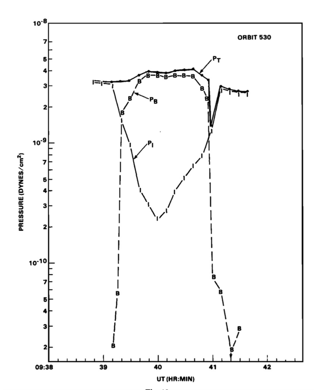




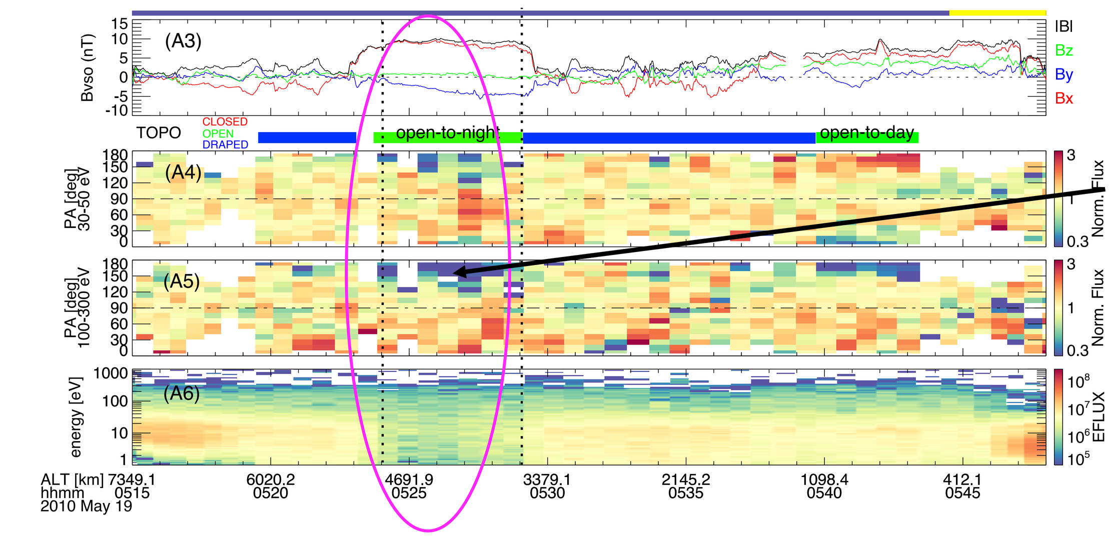
- T1:
  - // photo e- & anti// SW e-
  - ❖ **Open-to-day (dayside ionosphere connectivity)**
- T2
  - // photo e- & anti// backscattered photo e-
  - ❖ **Cross-terminator closed loop**
  - ❖ *An unexpected magnetic topology at Venus*

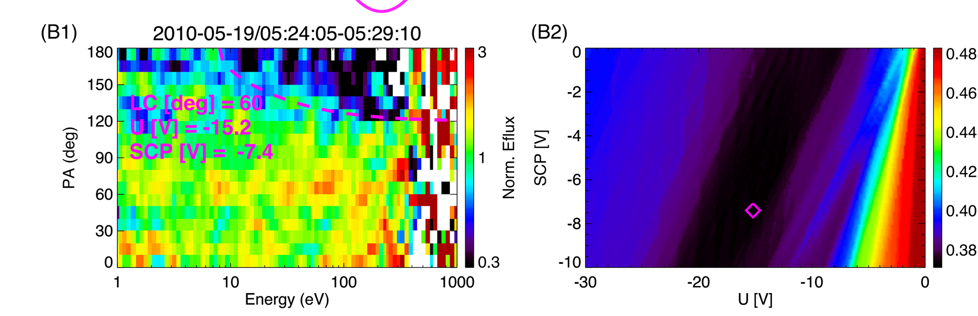
V: Ionospheric Hole and Parallel E Field





- **Iono. Holes:**
- Thermal e- density depletion
- Increased |B| (P_B) to maintain pressure balance

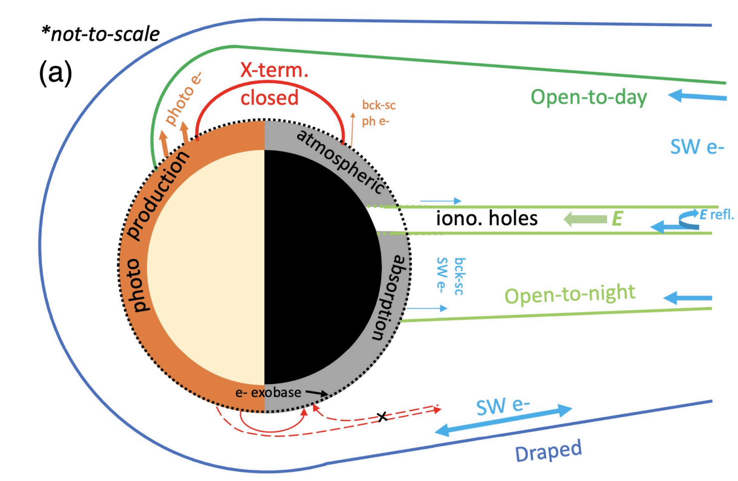


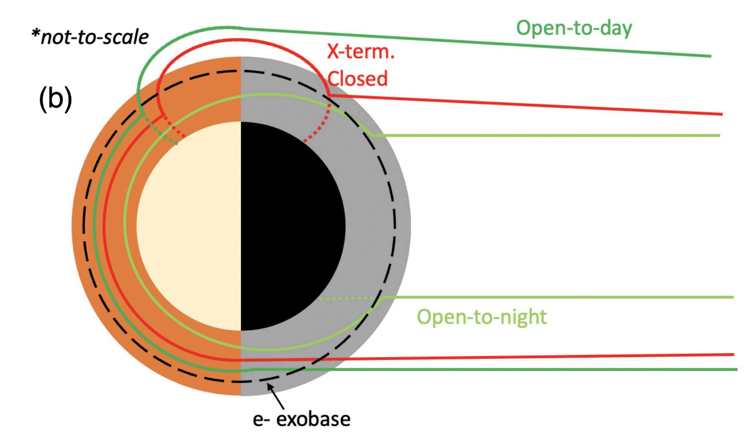


- A hole structure identified by Collinson et al. [JGRA, 2014]
- Loss cone in anti// e- (A4 & A5)
  - "Open" magnetic topology (nightside connectivity)
- Energy-dependent loss cone size (B1 & B2)
  - Loss cone fitting following Halekas et al. [JGRA, 2008]
  - Best fit: Usc ~ -7 V & Uv ~ -15 V
  - Usc = [-10, 0] V→ Uv = [-20, -10] V

❖ *Implication for hole formation:*
- *Radially inward parallel E field preventing ions flowing out*
- *Contradicting theories about outward E field*

VI: Discussion and Summary





❖ Key points
- various magnetic topologies inferred at Venus, including unexpected cross-terminator closed loops
- Ionospheric hole formation: open topology and radially inward parallel E field

❖ Connectivity below the collisional atmosphere (e- exobase):

1. IMF penetrating deeply into the ionosphere
2. Crustal magnetism (albeit weak)
3. Or, even the conductive metallic core

VII: Broad Impact

- Magnetic topology can be a new powerful tool to help better understand the near-Venus space environment
- Raise interesting questions related to important Venus science questions
  - History and current nature of its magnetism
  - How possible coupling from the ionosphere to the interior as a whole might affect its interaction with the solar wind, and/or the history/evolution of its atmosphere
  - Motivate future Venus orbiters coupled with sub-exobase magnetometer observations (on balloons or even on the surface)
- Enable Venus-Mars comparative study of their magnetic environments

VIII: Future Work

- Systematically catalog all types of magnetic topology at Venus with all VEx data
- Statistically analyze and map each type of topology and investigate its variation in response to solar drivers
- Search for more ionospheric hole events and field-aligned potential events and see if a robust relation exists

References:

- Collinson et al. (2014). The extension of ionospheric holes into the tail of Venus. *Journal of Geophysical Research: Space Physics*, *119*(8), 6940–6953.
- Halekas et al. (2008). Lunar Prospector observations of the electrostatic potential of the lunar surface and its response to incident currents. *Journal of Geophysical Research: Space Physics*, *113*(A9), A09102