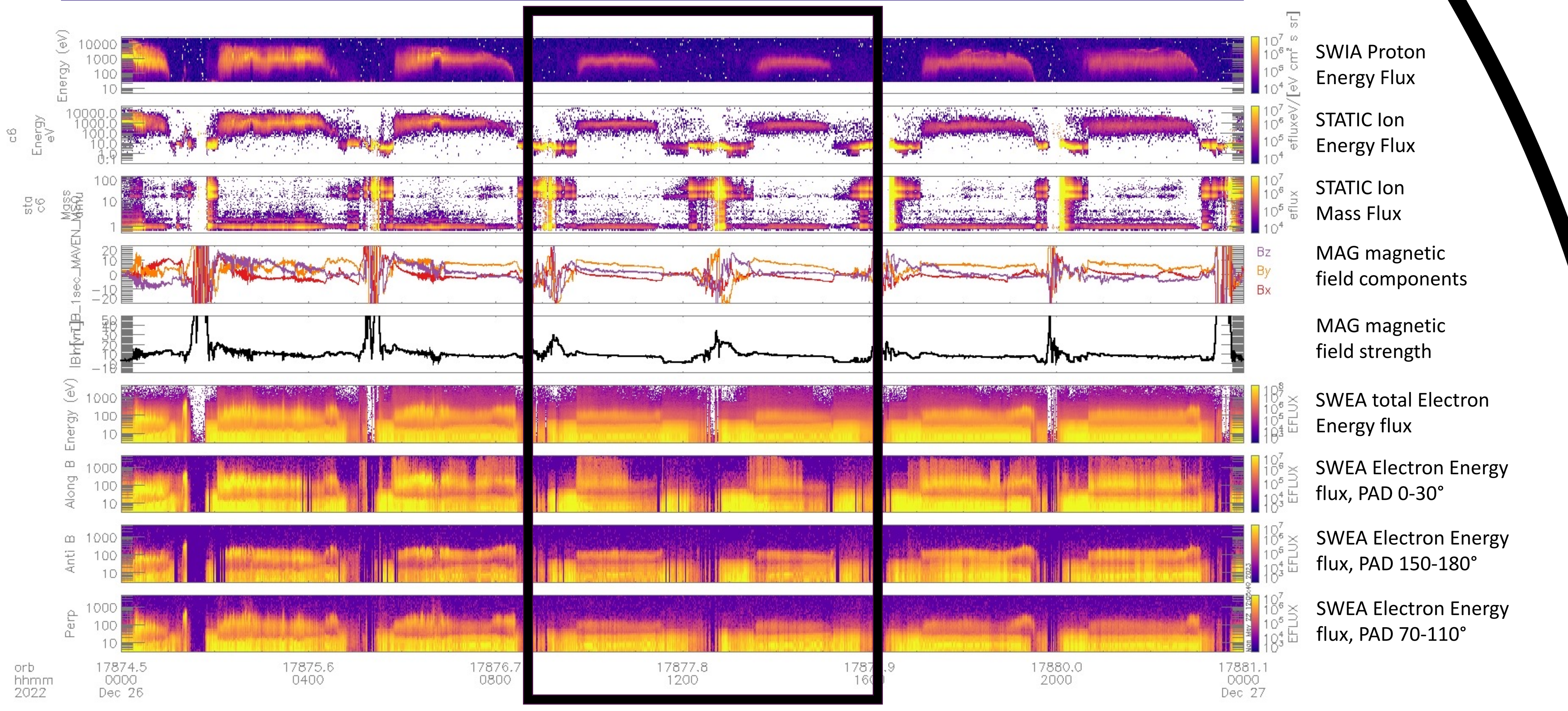
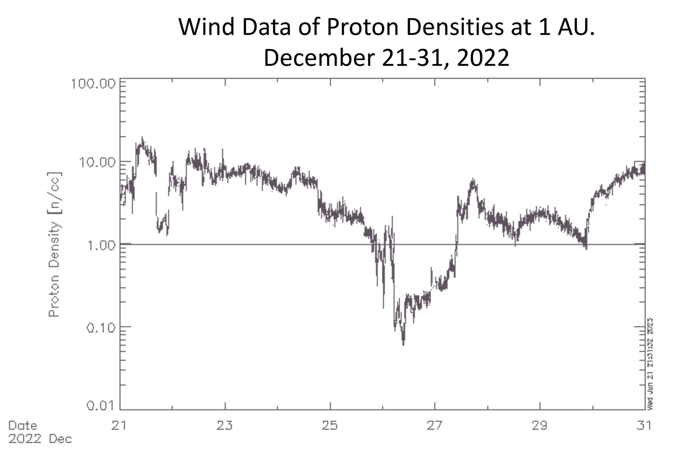
Solar Wind proton densities drop below 0.1 particles/cm³ during the December 2022 Disappearing Solar Wind (DSW) event.



Above: Overview of MAVEN data on December 26, 2022. Orbits during the minimum of the disappearing solar wind event are indicated by the black box

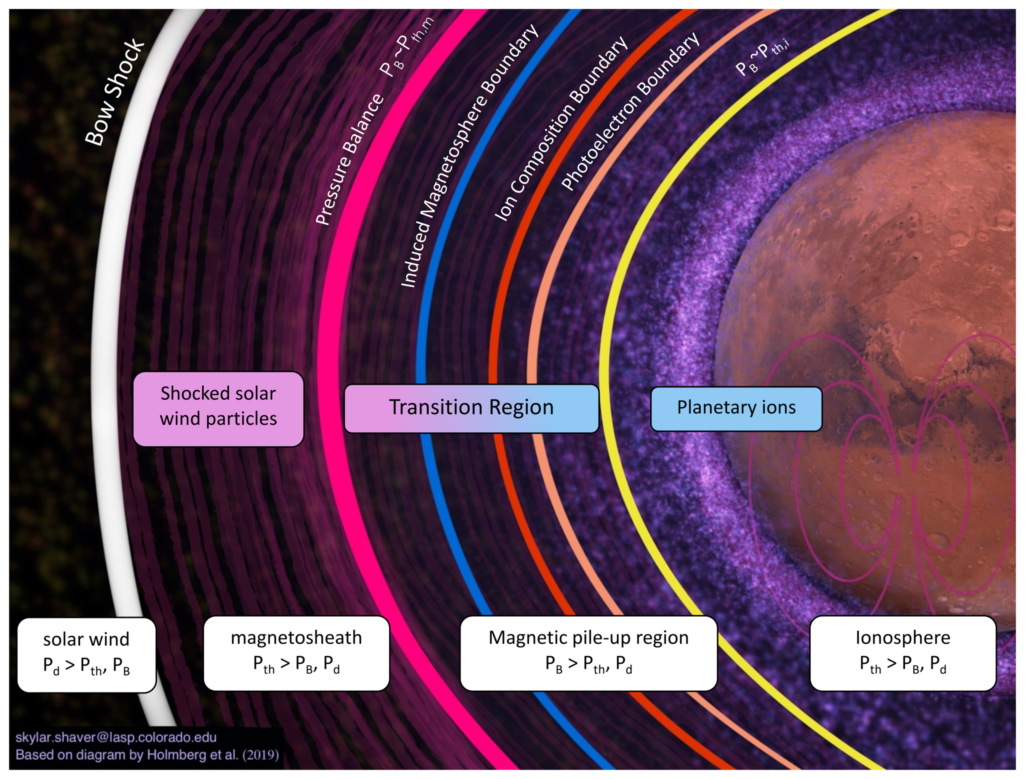
During the disappearing solar wind event, solar wind (SW) proton densities drop below 0.1 [/cm³], where typical values lie between 5-10 [/cm³]. Because the SW exerts less dynamic pressure on the system, the ionosphere can expand. We find that the ions and electrons expand differently and that SW electrons are able to get into the Martian ionosphere.

Right: This event is also observed at 1 AU with the Wind satellite on December 25, 2022. The shifted densities to Mars match what is seen upstream, along what could be the same parker spiral. The horizontal line marks a proton density of 1 particle/cm³.



Mars has a hybrid magnetosphere, with many different boundary regions between the solar wind and planetary ionosphere.

Mars does not have an intrinsic magnetic field, but it does have remnant crustal fields mainly in the southern hemisphere.



Boundary	Average Altitude [km]
Bow Shock	~1700
$P_{th,m}$ ~ P_B	910 - 1050
IMB	650 - 820
ICB	630 – 678
PEB	580 - 630
P_B ~ $P_{th,i}$	260 - 300

Left (Image): Depiction of the magnetosphere transition regions at Mars from solar wind to planetary plasma [1].

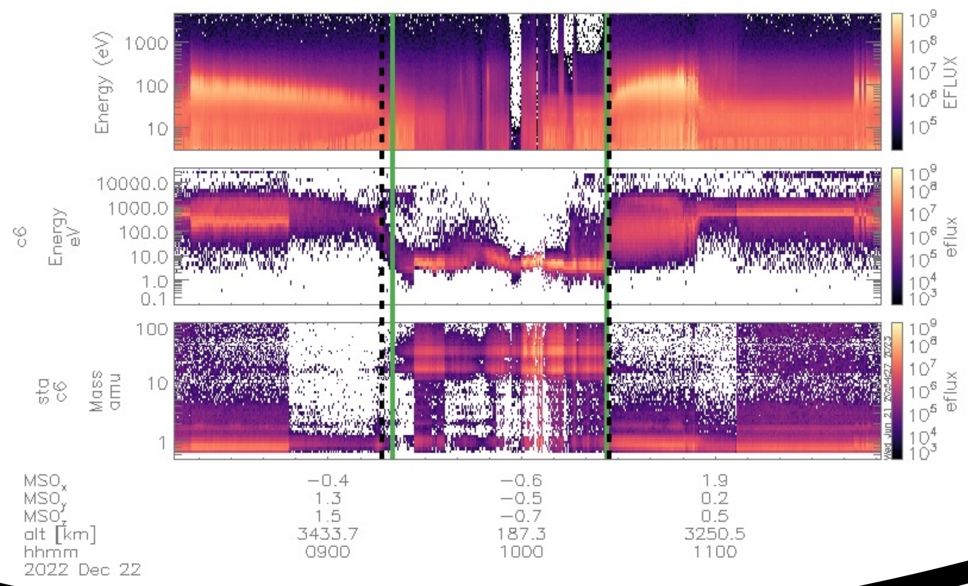
Left (Table): Average altitude of these transition regions [1].

Boundary regions are identified according to the spacecraft payload. These boundary regions are not static and can switch relative locations depending on driving conditions.

Bow Shock (BS):
The first point of information transfer indicating a planetary obstacle to the solar wind.

The Ion Composition Boundary (ICB):
The ICB marks the transition from light ion species to heavy ion species, from higher altitudes to lower altitudes. The ICB is defined using data from the Suprathermal and Thermal Ion Composition (STATIC) Instrument. This boundary indicates the transition from shocked solar wind plasma to ionospheric plasma through ion measurements.

The Induced Magnetosphere Boundary (IMB):
The IMB marks the location where sheath electrons with energies near 100 eV dissipate and cold plasma density increases from higher to lower altitudes. The IMB is defined using data from the Solar Wind Electron Analyzer (SWEA). This boundary indicates the transition from shocked solar wind plasma to ionospheric plasma through electron measurements.



Left: Example ICB and IMB on December 22, 2022. **ICB** marked by green solid vertical line. **IMB** by black dashed vertical line.
These are typical conditions.

Taking Up Space

Conclusion: Mars' Ionosphere expanded past the nominal bow shock location and keV electrons were permitted inside the ionosphere due to the extremely low proton densities during the Disappearing Solar Wind Event in December 2022.

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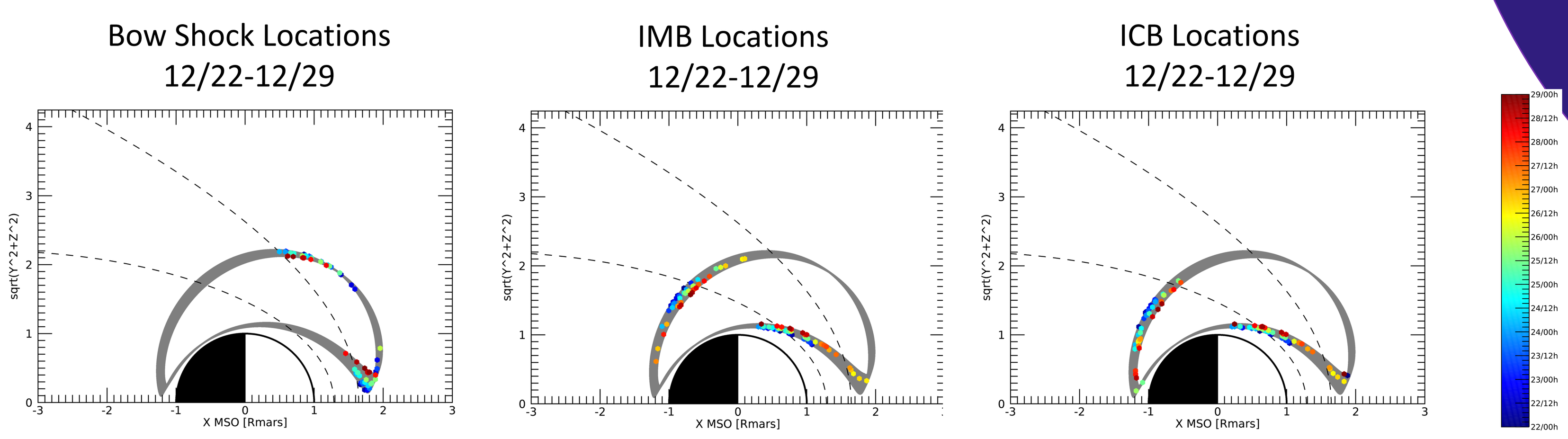
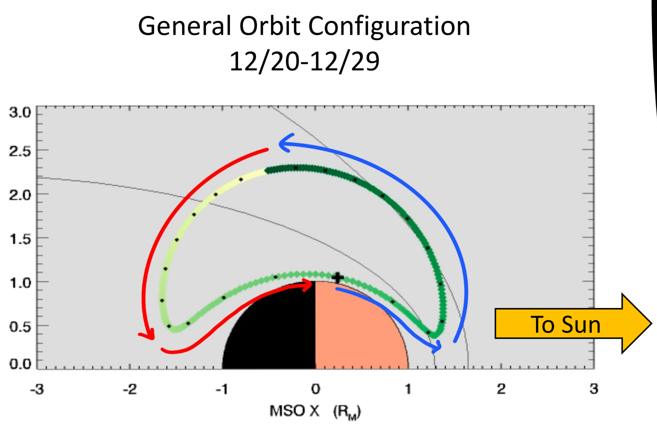
Martian ionosphere expands to altitudes >3000 km during the DSW event.

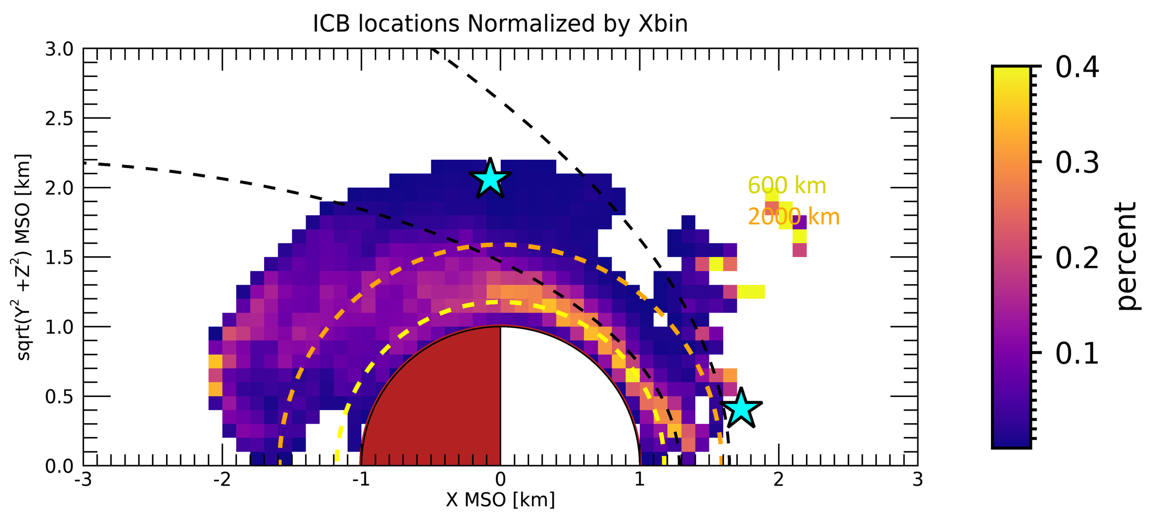


Above: The positions of Martian magnetosphere boundaries are marked along their respective orbits. The disappearing SW event is shown by yellow points. The BS is not observed during this time period.

Outbound (X_{MSO} > 0, dayside): The IMB and ICB are observed beyond the nominal location of the BS [2].

Inbound (X_{MSO} < 0, nightside): During the event, the ICB is observed at higher altitudes than normal and the IMB also expands outward. Just following the event, the IMB quickly moves to a lower altitude.



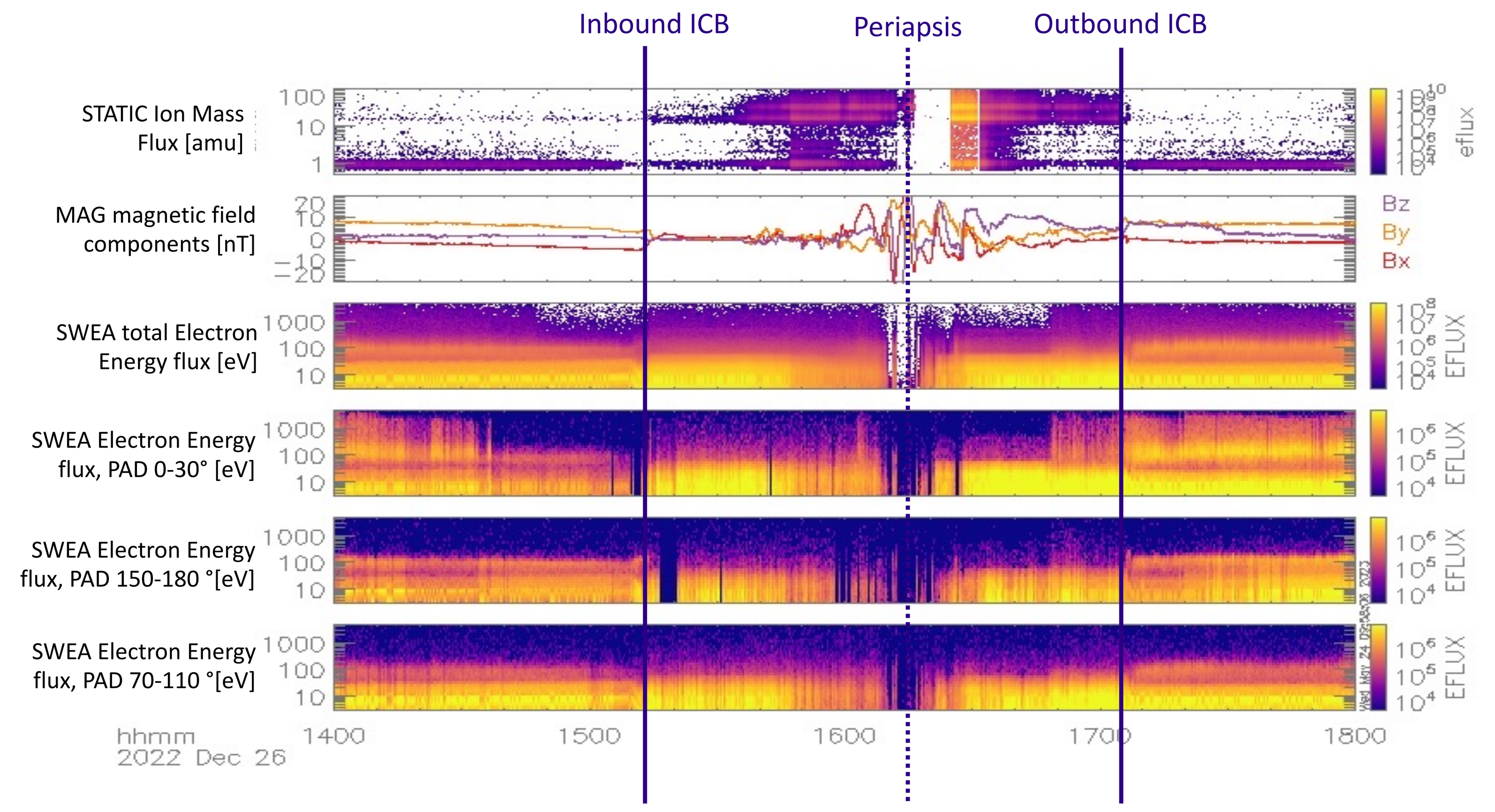


We have identified the ICB location for 7500+ orbits from 01/2015 to 01/2019 and compared those statistical locations with the ICB location during the event.

On the dayside, the ICB is normally observed near 600 km altitude with a cosine dependence with increasing SZA. During this event, the ICB is seen at an altitude >3000 km.

Above: 2D histogram of ICB locations normalized across X-MSO bins of 0.1 R_{mars}. The location of the ICB during the DisSW event minimum is marked by cyan stars. On the dayside, the ICB extends past the nominal bow shock location. The ICB is seen at the terminator on the inbound portion of the DisSW orbit. The average shape of the BS and IMB is marked by the outer and inner black dashed lines respectively. An altitude of 2000 km is indicated by the orange dashed line, and an altitude of 600 km is indicated by a yellow dashed line.

Electrons with keV energies are observed inside the Martian ionosphere during the DSW event.

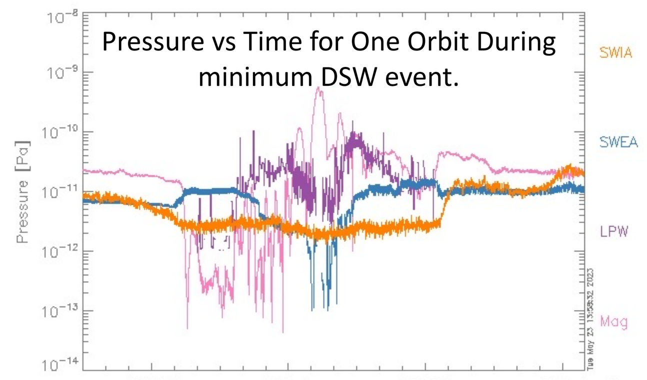


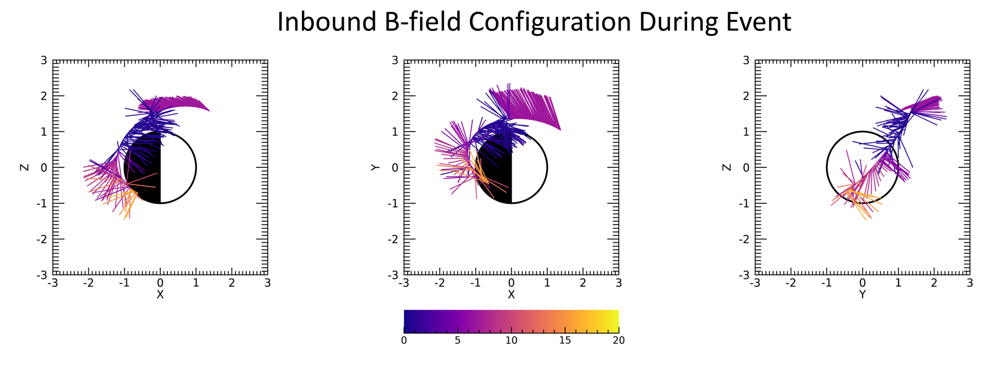
Right: STATIC, MAG, and SWEA data during one orbit of the DSW event. The ICB location is marked by a solid vertical bar. The spacecraft periapsis is marked by a vertical dashed line.

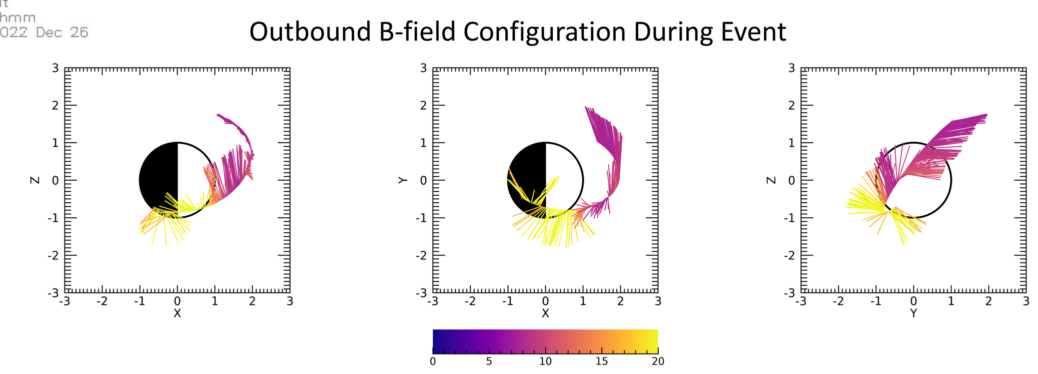
Inside the ionosphere, high energy (keV) electrons are observed in the direction along B. This is seen in both the minimum SW proton orbits from the DSW event.

Previous events with extremely low SW proton densities observed strahl electrons with above average energies due to less collisions along its parker spiral path [3].

Right: Pressure plots for thermal pressure of SWIA protons and SWEA electrons in the sheath region, MAG magnetic pressure, and LPW cold bulk thermal pressure in the ionosphere







Right: Magnetic field direction in MSO coordinates with color indicating B-field magnitude. On the dayside of the planet, the draped configuration of the IMF is visible. At the terminator in the MSO northern hemisphere, the magnetic field strength drops to ~1 nT and reverses direction.

Our hypothesis is that the interplanetary magnetic field is being carried by the electrons due to the low solar wind proton densities. This could explain why the strahl electrons on following the IMF are able to pass into the Martian ionosphere, past the ICB.

References:
1. Holmberg, M. K. G., et. Al.. 2019. *Journal of Geophysical Research, [Space Physics]* 124 (11): 8564–89.
2. Vignes, D., et. al. 2000. *Geophysical Research Letters*.
3. Lazarus, Alan J. 2000. "The Day the Solar Wind Almost Disappeared." *Science* 287 (5461): 2172–73.

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