Atmospheric evolution and past habitability of Venus: understanding the roles of ion escape

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Conclusions

- Current observations suggest that the loss of atmosphere to space played a key role in the evolution of Venus over time. Understanding the processes that drive upper atmospheric escape to space is thus crucial to understanding the evolutionary path of Venus as a whole.
- Observations at similar solar system bodies, that do not possess strong magnetic fields (e.g. comets, Mars, Titan, Pluto), have demonstrated that a wide and alluring range of escape processes exist. Hints of these processes have also been observed at Venus, but limitations of current datasets preclude a complete identification and understanding of these processes.
- **A dedicated, comprehensive upper atmosphere and ionosphere mission to Venus is required to identify and fully understand the processes that drive atmospheric evolution there.**

References

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Atmospheric evolution at Venus – from surface to space

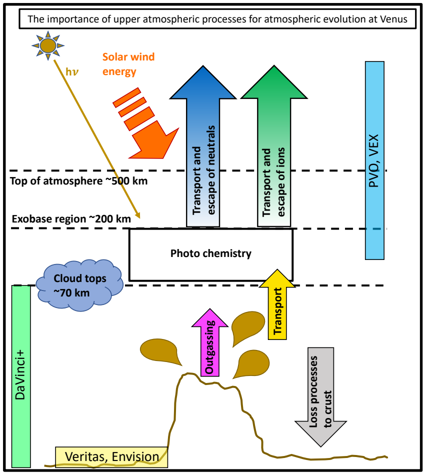

Figure 1: *Cartoon depiction of key processes associated with atmospheric evolution at Venus, along with regions observed by past and future missions.*

- In order to constrain Venus' evolutionary path to its current day dry state, knowledge of several parameters are required. These include the D/H ratio of any outgassing source, the D/H ratio at time = 0, and absolute loss rates of H and D [1, 2, 3 ,4].
- Observations near the surface can provide some of these; observations in the upper atmosphere are required to constrain absolute loss rates and the fractionation factor of H and D.
- PVO observations have provided insufficient constraints on H loss rates [e.g. 5, 6, 7].
- Atmospheric particles must obtain enough energy to overcome Venus' strong gravity in order to escape to space.
- Hot planetary H (i.e. energetic tail of distribution) can reach high altitudes, where it can charge exchange with solar wind protons and be lost to space [8, 9, 10].
- Contribution of ion loss to space must also be considered [e.g. 11].
- Cold planetary ions produced by photochemistry are in contrast energized via interactions with magnetic and electric fields [e.g. 12, 13, 14].
- VEX has provided constraints on ion loss rates [e.g. 15, 16], but much is still unknown about the underlying energization mechanisms and how they vary with e.g. solar conditions.
- Studies of other bodies that like Venus, do not posses strong magnetic fields, e.g. comets, Pluto, Titan, Mars, have highlighted the importance of atmospheric loss to space for their long term evolution [17, 18, 19, 20, 21]. A zoo of different magnetic and electric field processes exist: understanding their contributions and effectiveness at driving ion escape is necessary to understand this part of the Venus evolution puzzle.

Important escape mechanisms remain unresolved at Venus

- Recent work by [22] identified a specific mechanism to energize planetary ions at Mars via magnetic and electric fields. This particular process is known as "magnetic pumping", and has also been observed at Earth.
- The blue oval highlights "compressive waves" in the magnetic field: quasi-sinusoidal variations in strength that are a key component to magnetic pumping.
- The green oval highlights specific behavior of planetary electrons, that react in tandem with the compressive waves. This is another key component of magnetic pumping.

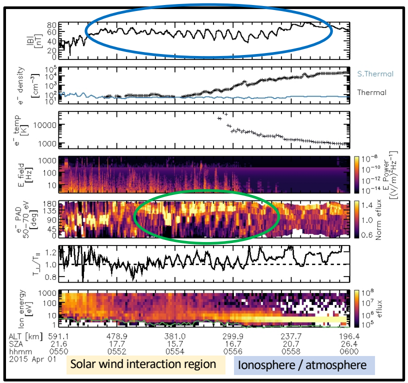

Figure 2: *MAVEN observations of magnetic pumping at Mars. Detailed ion and electron measurements allow us to conclusively identify this process.*

There is a compelling need for upper atmosphere measurements at Venus that can resolve various plasma energization processes. These measurements are crucial to understanding the evolution of Venus as a whole.

- Similar "compressive waves" are observed in PVO observations at Venus.
- Ion and electron measurements suggest that energy may be transferred to the planetary atmosphere/ionosphere, but measurements are not as comprehensive as at Mars and do not allow us to conclusively identify magnetic pumping.

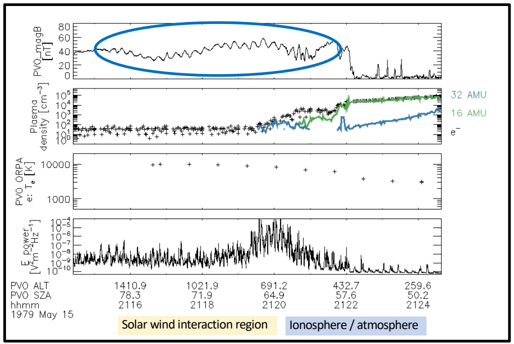

Figure 3: PVO observations of possible magnetic pumping at Venus. Ion and electron measurements allow us to postulate that this process is present, but not conclusively identify it.

- Similar "compressive waves" are observed in VEX observations at Venus.
- Electron measurements suggest that the planetary electrons react in tandem to these waves, but instrument limitations preclude a conclusive identification of magnetic pumping.

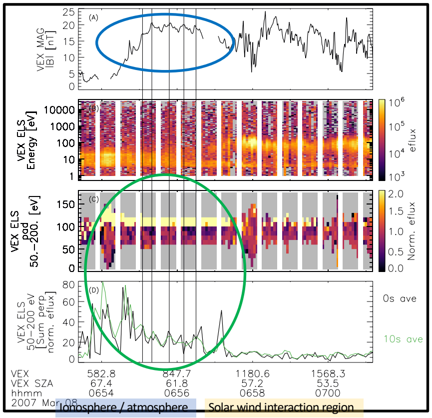

Figure 4: VEX observations of possible magnetic pumping at Venus. Electron observations provide more information than PVO, but instrument limitations preclude a conclusive identification of the process.

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