The Ionospheric losses of Venus in the Solar Wind

Hania Azzam, Portsaid University

Supervised by : Prof. Dr. Waleed Moslem

OUTLINE

- History and Atmospheric Evolution
- Characteristics of Venus Atmosphere
- Solar Wind Interaction with Ionosphere
- Ionospheric Escape
- Suggested Solution, Hydrodynamic Approach proposed for Plasma Expansion and Self-Similar approach
- Numerical Results (Venus Express, Lundin) and Conclusion

HISTORY AND ATMORSPHERIC EVOLUTION

- Venus is one of the brightest objects in the night sky.

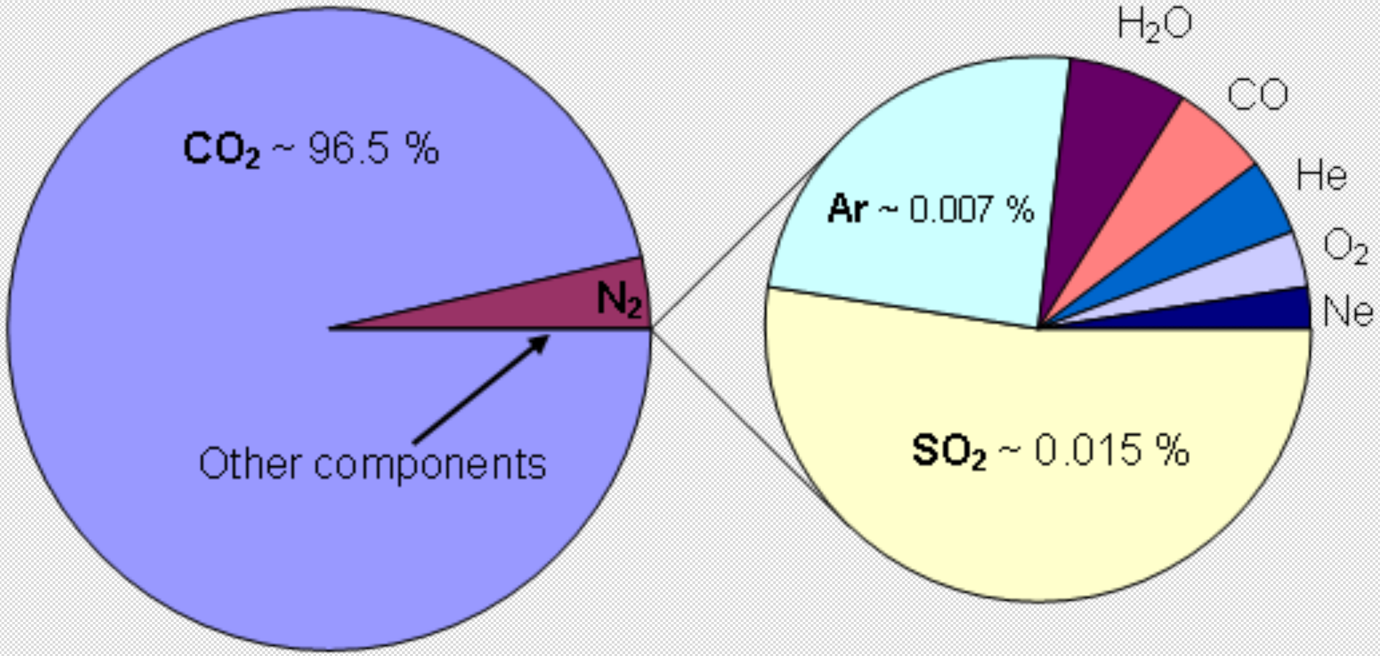
- Venus appears as a bright morning or evening star, and has been observed by humans through many early civilizations, the planet therefore acquired many different names.

HISTORY AND ATMOSPHERIC EVOLUTION

CHARACTERISTICS OF VENUS ATMOSPHERE

ATMOSPHERE OF VENUS

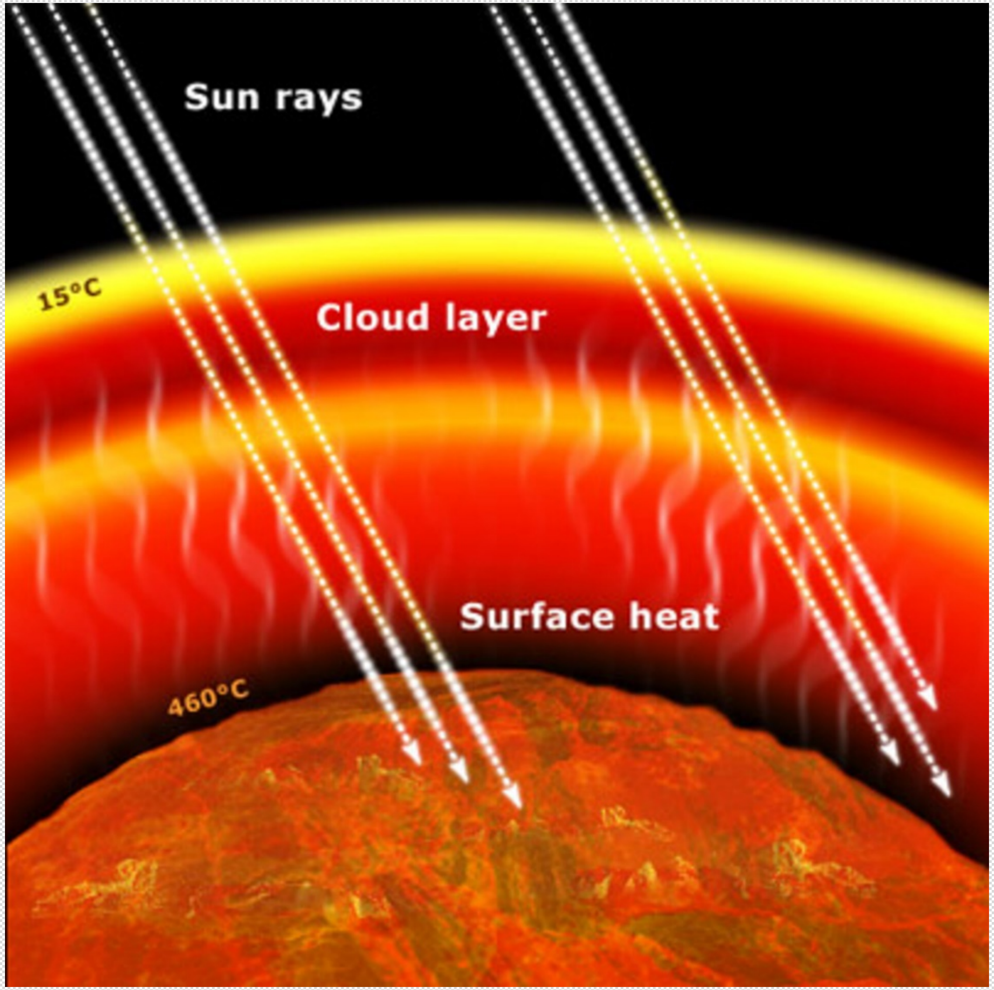
- The atmosphere of Venus is crushingly thick.
- Total mass 92 times that of Earth's atmosphere.



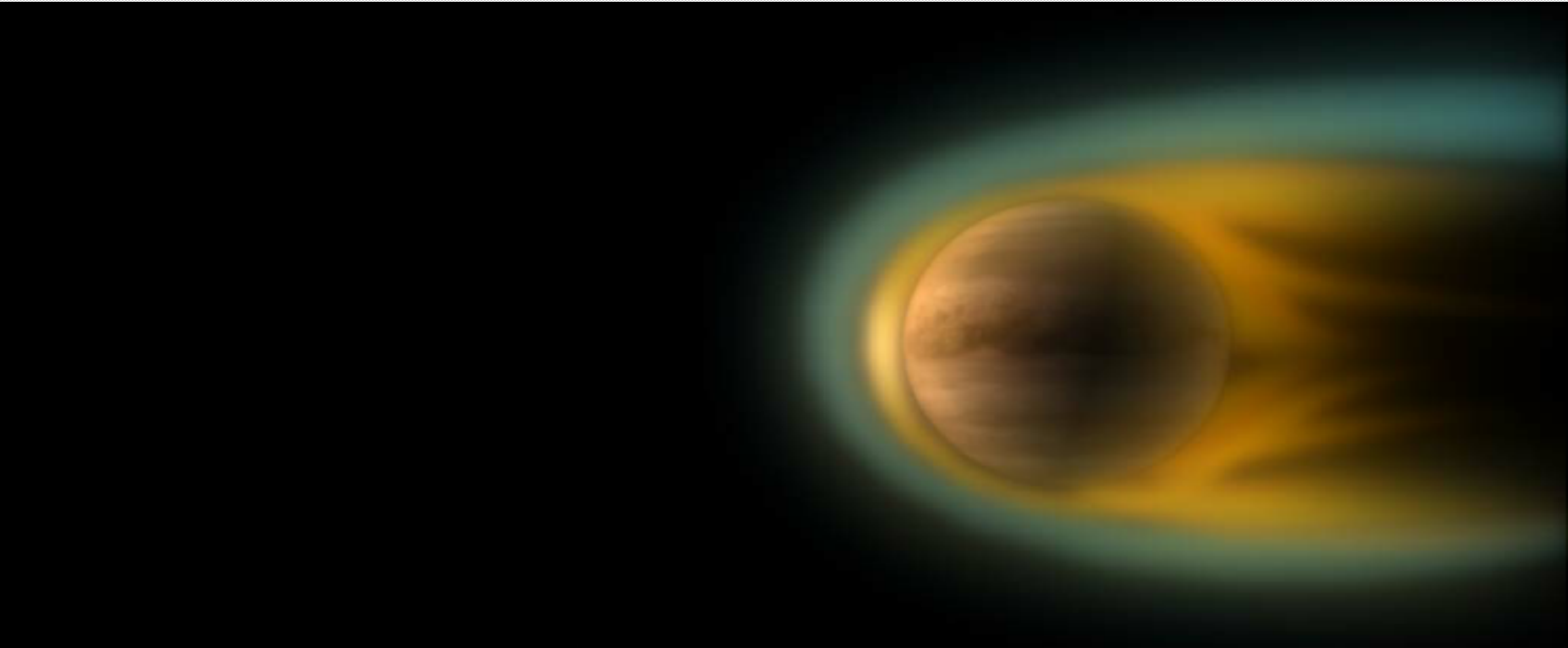
CHARACTERISTICS OF VENUS ATMOSPHERE

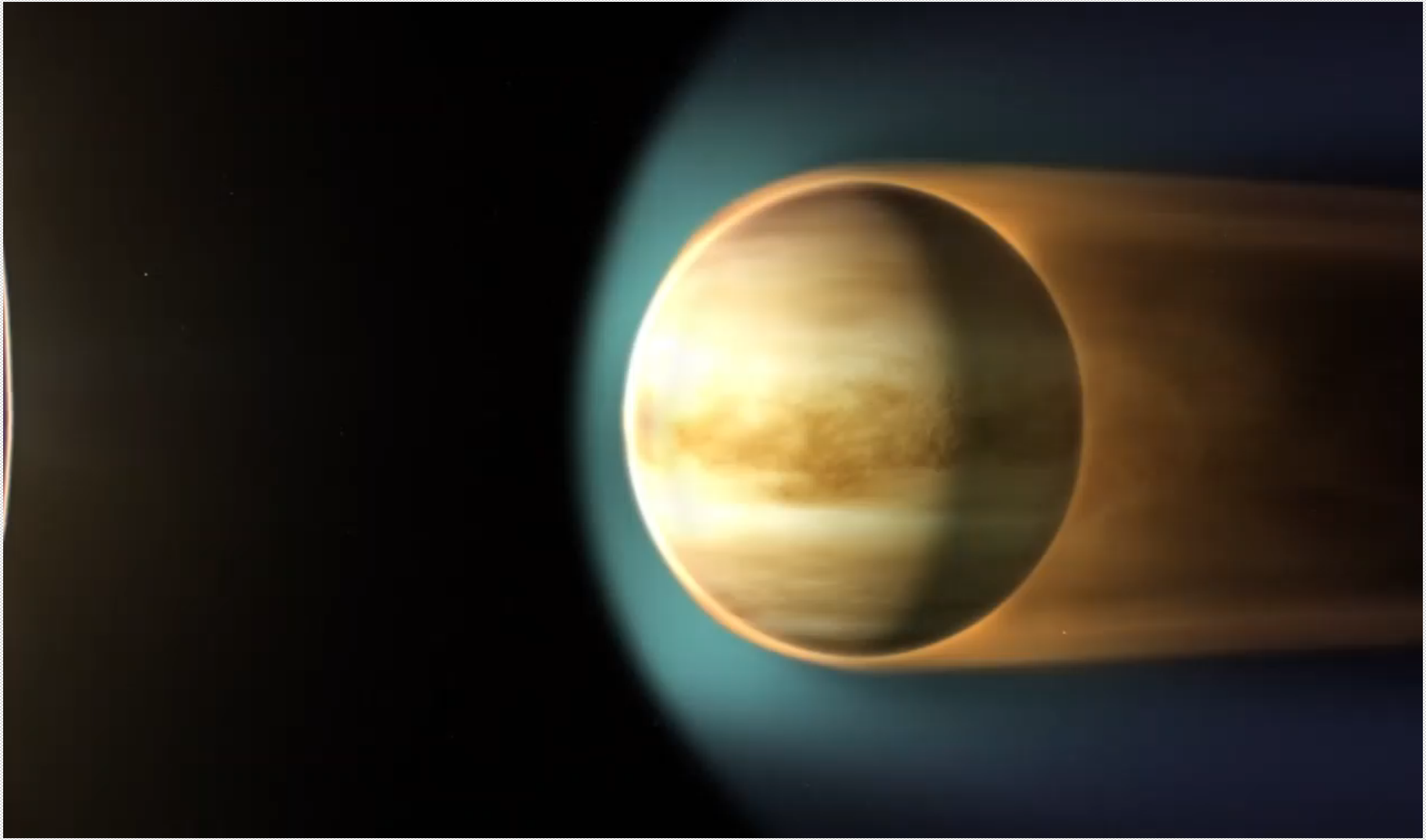
- The CO_2 acts as a greenhouse gas that causes the lower atmosphere of Venus to have a temperature of above 460 C.

- In the upper atmosphere the CO_2 acts in an opposite manner. Here, it emits radiation, effectively cooling the upper atmosphere (the exosphere). Not enough for thermal escape.

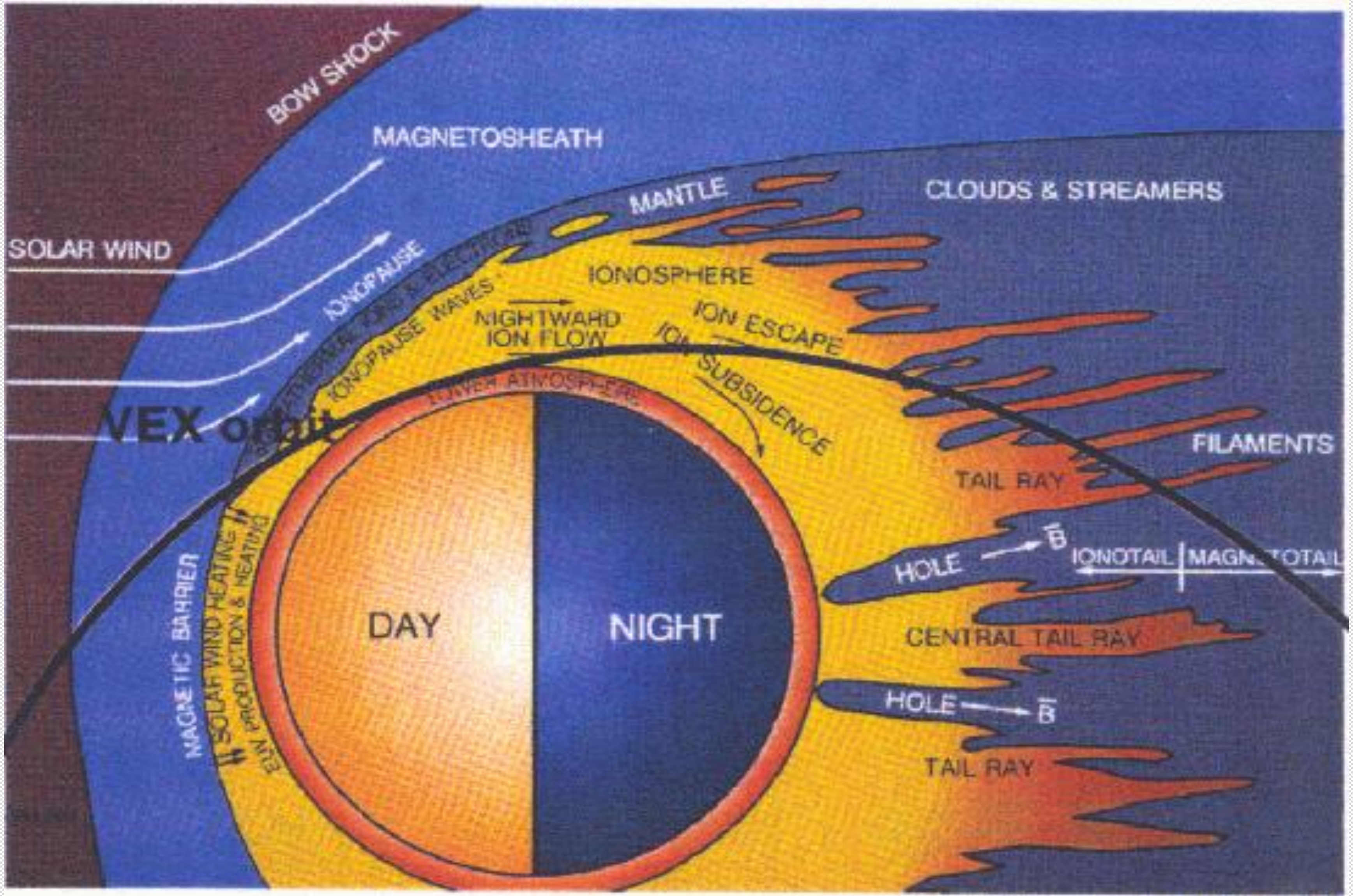


SOLAR WIND’S INTERACTIONS WITH IONOSPHERE



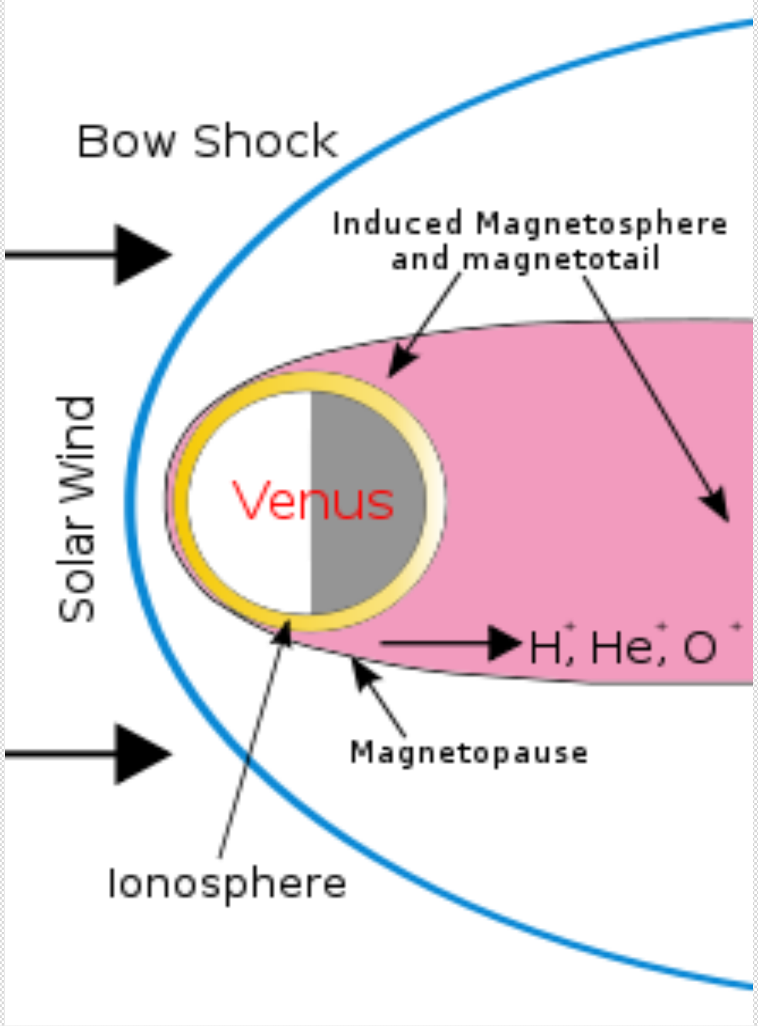


SOLAR WIND'S INTERACTION WITH IONOSPHERE



SOLAR WIND'S INTERACTIONS WITH IONOSPHERE

- Venus is unmagnetized.
- Lacks an intrinsic magnetic field.
- Thus, Its Ionosphere interacts with the solar wind directly, leading to outflows and acceleration of plasma particles.
- In the upper ionosphere of Venus the observations indicate a dominance of O+ and H+.



IONOSPHERIC ESCAPE

- The escape processes has, or had a significant impact on the Venusian atmospheric evolution.

- In order for a particle to escape to space, from a body with a gravity force,
it needs to reach above the escape velocity **Ves.**

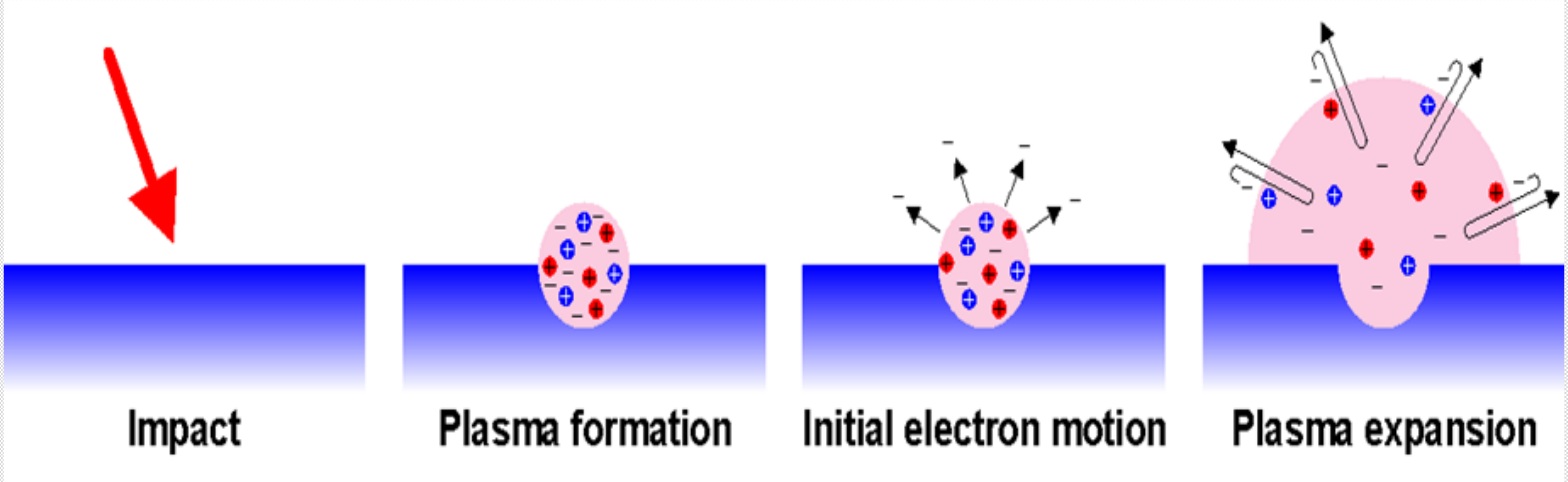
where m the mass of the escaping particle,
r is the distance from the center of mass of Venus,
G is the universal gravitational constant,
and M is the mass of Venus.

$$K + W = 0,$$

$$\frac{mv_{esc}^2}{2} - \frac{GMm}{r} = 0,$$

$$v_{esc} = \sqrt{\frac{2GMm}{r}},$$

CONCEPT OF PLASMA EXPANSION



- Decreasing the relative density of particles
- Increasing its freedom, i.e. Velocity

SELF-SIMILAR APPROACH

- Self-similar approach supposes that all independent variables (x , t)
- are combined together in one new variable ξ as $\xi = x/c\,t$.

$$C_s = \left(\frac{k_B T_e}{m1}\right)^{\frac{1}{2}}$$

$$\frac{\partial n_i}{\partial t} + \frac{\partial}{\partial x} n_i v_i = 0$$

$$\frac{\partial v_i}{\partial t} + v_i \frac{\partial v_i}{\partial x} = -\frac{e}{m_i}\frac{\partial \phi}{\partial x} - \frac{1}{m_i\, n_i}\frac{\partial P_i}{\partial x}$$

$$\frac{1}{n_e}\frac{\partial P_e}{\partial x} - e\frac{\partial \phi}{\partial x} = 0$$

$$\frac{1}{n_p}\frac{\partial P_p}{\partial x} + e\frac{\partial \phi}{\partial x} = 0$$

$$n_i + n_p - n_e = 0$$

self-similar variable $\xi = x/c_s t$

$$(V_i - \xi)\frac{dN_i}{d\xi} + N_i\frac{dV_i}{d\xi} = 0$$

$$(V_i - \xi)\frac{dV_i}{d\xi} + 3\,\sigma_i\, N_i\frac{dN_i}{d\xi} + \frac{d\Phi}{d\xi} = 0$$

$$\frac{d\Phi}{d\xi} - \frac{1}{N_e}\frac{dN_e}{d\xi} = 0$$

$$\frac{d\Phi}{d\xi} + \frac{\sigma_p}{N_p}\frac{dN_p}{d\xi} = 0$$

$$\alpha\frac{dN_i}{d\xi} + \beta\frac{dN_p}{d\xi} - \frac{dN_e}{d\xi} = 0$$

RESEARCH PLAN

Species of ions and electrons

setting model equations

normalization and self-similar transformation

PDE -> ODE

Coding Mathematica and solving the determinant of coefficients

Initial conditions and actual data values

Graphing and result discussion

Based on the observations of the upper ionosphere of Venus, our plasma model consists of two types of positive ions, namely H+ and O+ (indicated in the next with subscripts 1 and 2, respectively), and the neutralizing (very light and mobile) electrons (subscript e). These are the ionospheric populations interacting with the solar-wind electrons (se) and protons (sp).

$$\frac{\partial n_j}{\partial t} + \frac{\partial}{\partial x} n_j u_j = 0$$

$$m_j n_j \left(\frac{\partial}{\partial t} + u_j \frac{\partial}{\partial x}\right) u_j + Z_j e n_j \frac{\partial \varphi}{\partial x} + \frac{\partial P_j}{\partial x} = 0$$

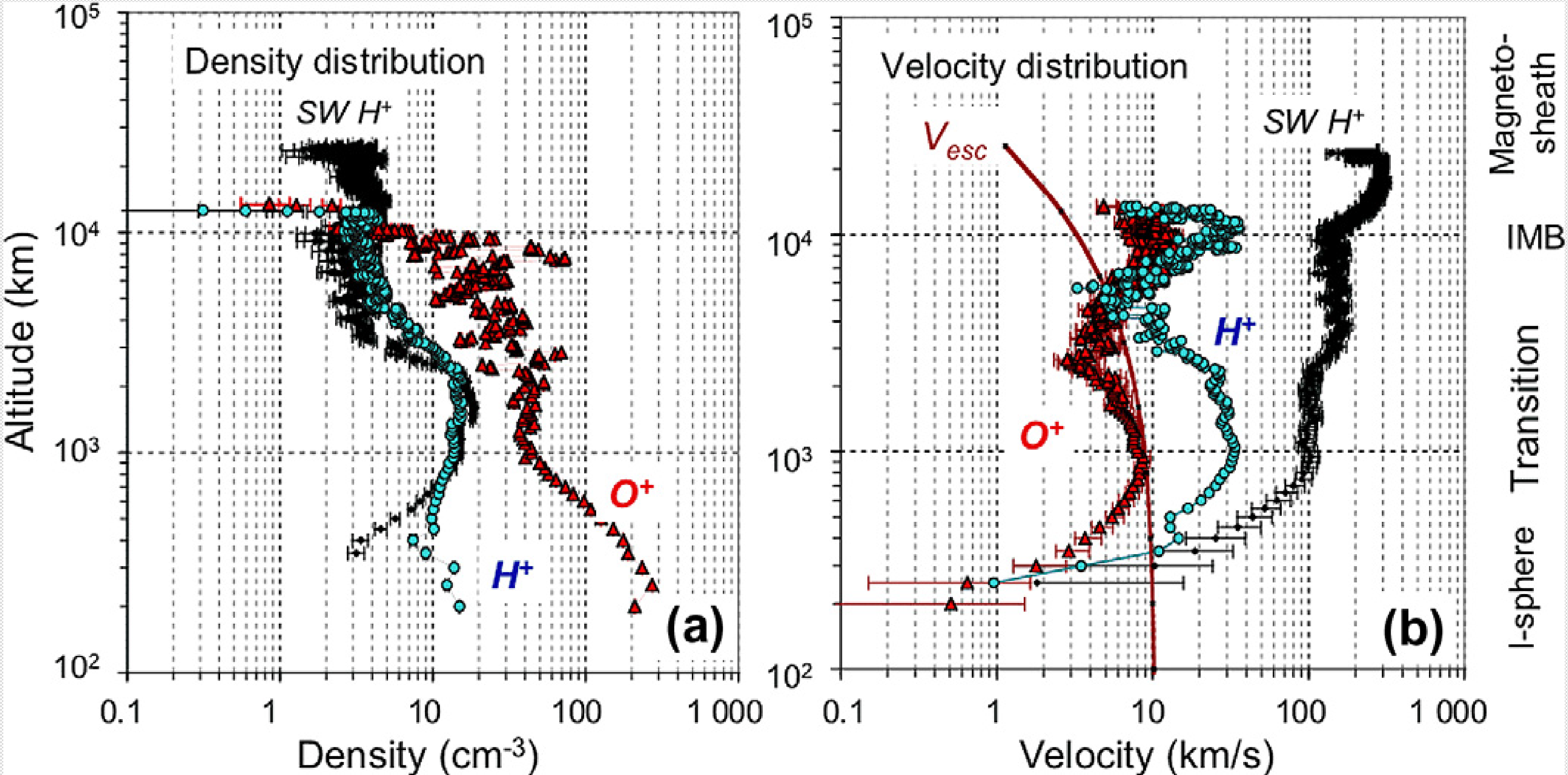
$$e n_k \frac{\partial \varphi}{\partial x} - \frac{\partial P_k}{\partial x} = 0$$

$$n_1 + n_2 - n_e - n_{se} + n_{sp} = 0$$

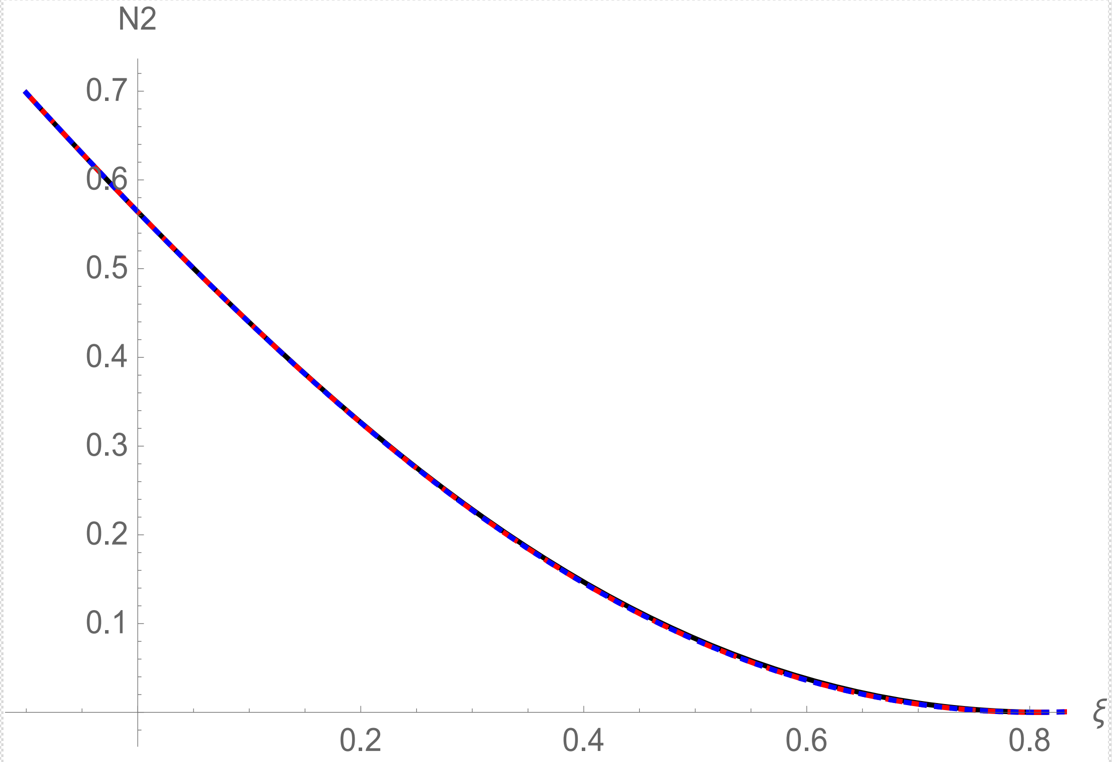
After normalization and using the self-similar transformation we get:

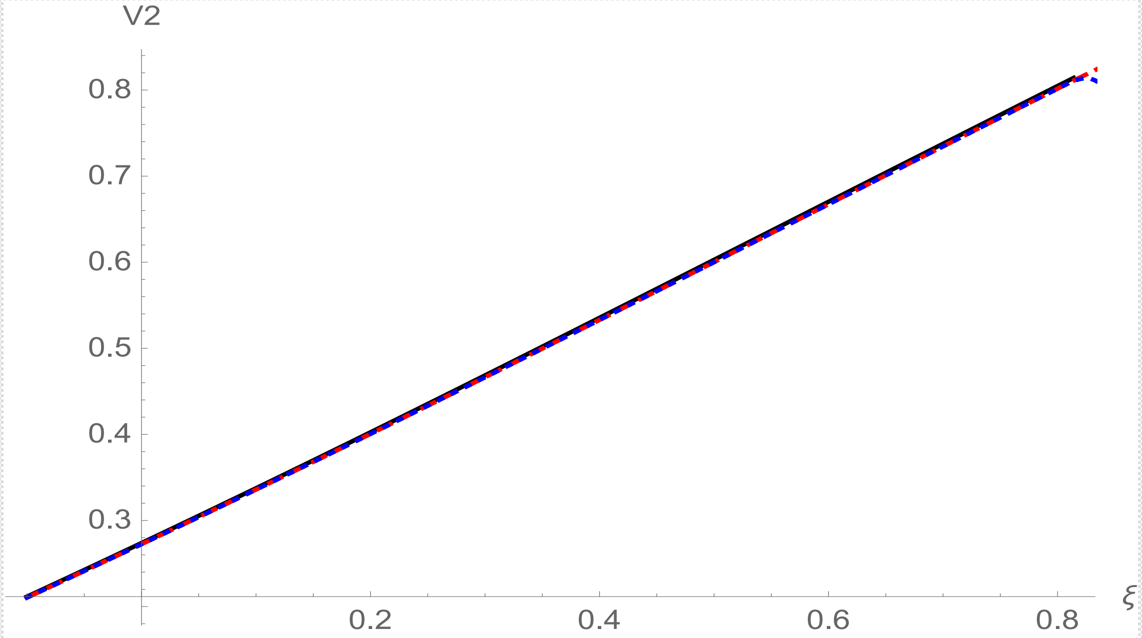
$$\begin{pmatrix} (V_1-\xi) & 0 & 0 & 0 & 0 & N_1 & 0 & 0 & 0 \\ 3\sigma_1 N_1 & 0 & 0 & 0 & 0 & (V_1-\xi) & 0 & 0 & 1 \\ 0 & (V_2-\xi) & 0 & 0 & 0 & 0 & N_2 & 0 & 0 \\ 0 & 3Q_2\sigma_2 N_2 & 0 & 0 & 0 & 0 & (V_2-\xi) & 0 & Q_2 \\ 0 & 0 & \left(\frac{-1}{N_e}\right) & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & \left(\frac{-\sigma_{se}}{N_{se}}\right) & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & (\widetilde{V}_{sp}-\xi) & 0 & 0 & N_{sp} & 0 \\ 0 & 0 & 0 & 0 & 3Q_{sp}\sigma_{sp}N_{sp} & 0 & 0 & (\widetilde{V}_{sp}-\xi) & Q_{sp} \\ \alpha & \beta & -1 & -\delta & \varepsilon & 0 & 0 & 0 & 0 \end{pmatrix} \times \begin{pmatrix} N_1' \\ N_2' \\ N_e' \\ N_{se}' \\ N_{sp}' \\ V_1' \\ V_2' \\ V_{sp}' \\ \phi' \end{pmatrix} = \mathbf{0}$$

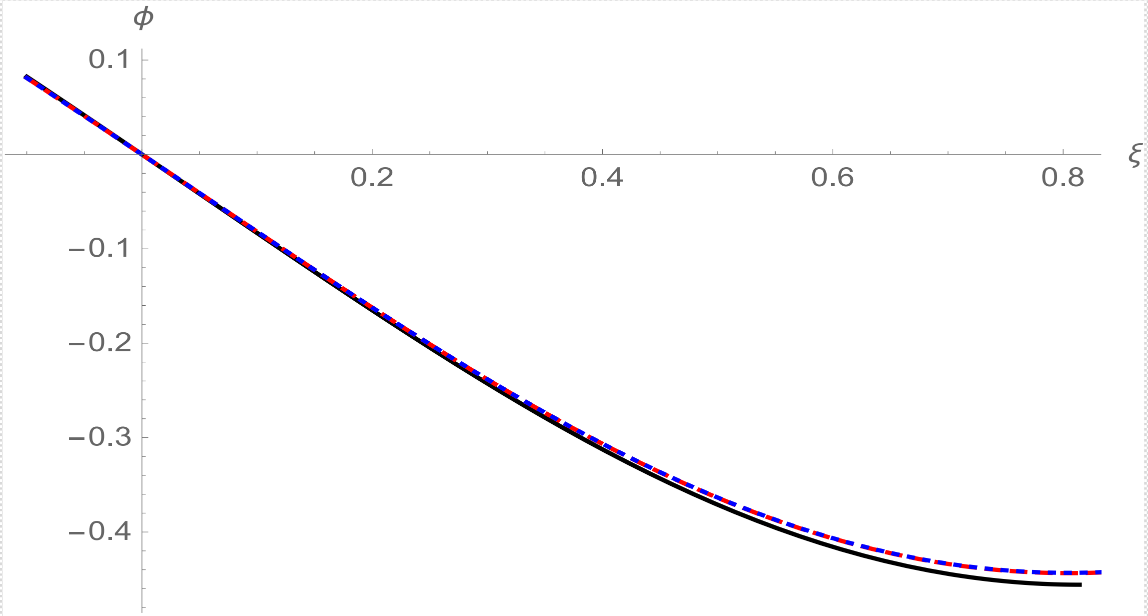
NUMERICAL RESULTS



(NOON-MIDNIGHT) O+ & H+ EXPANSION Vs20

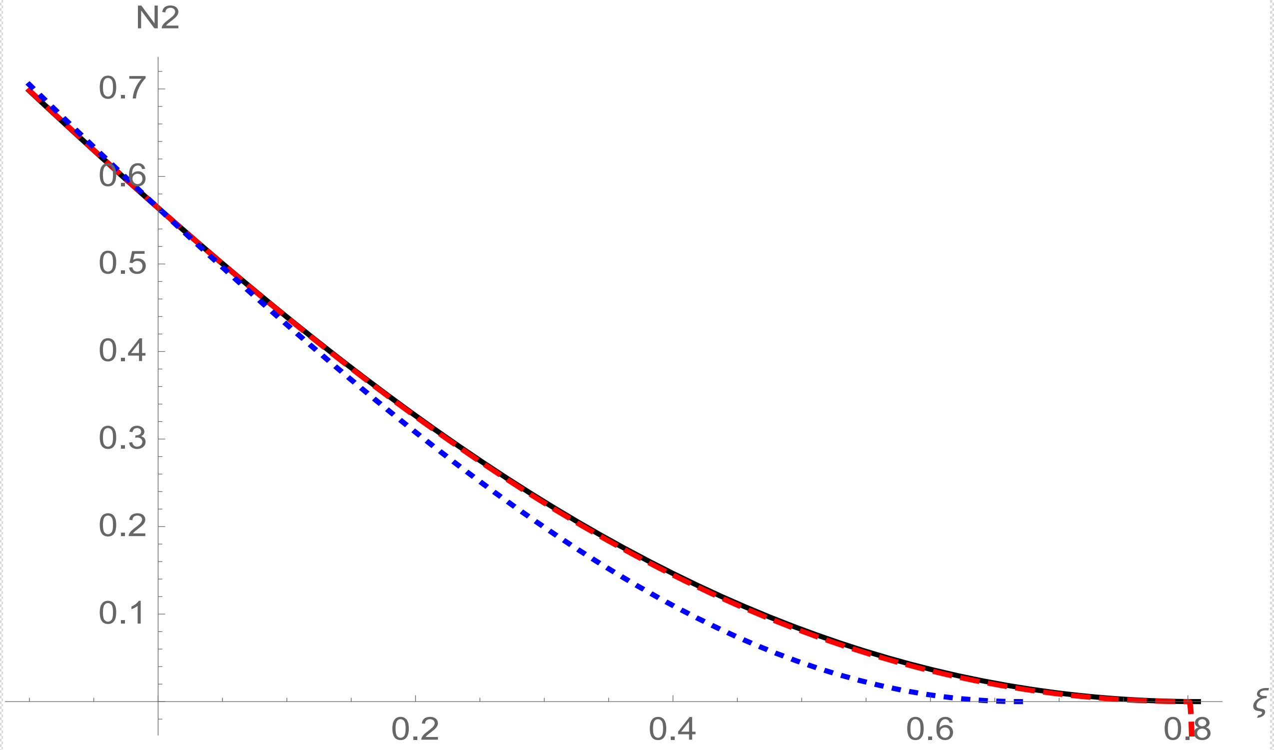


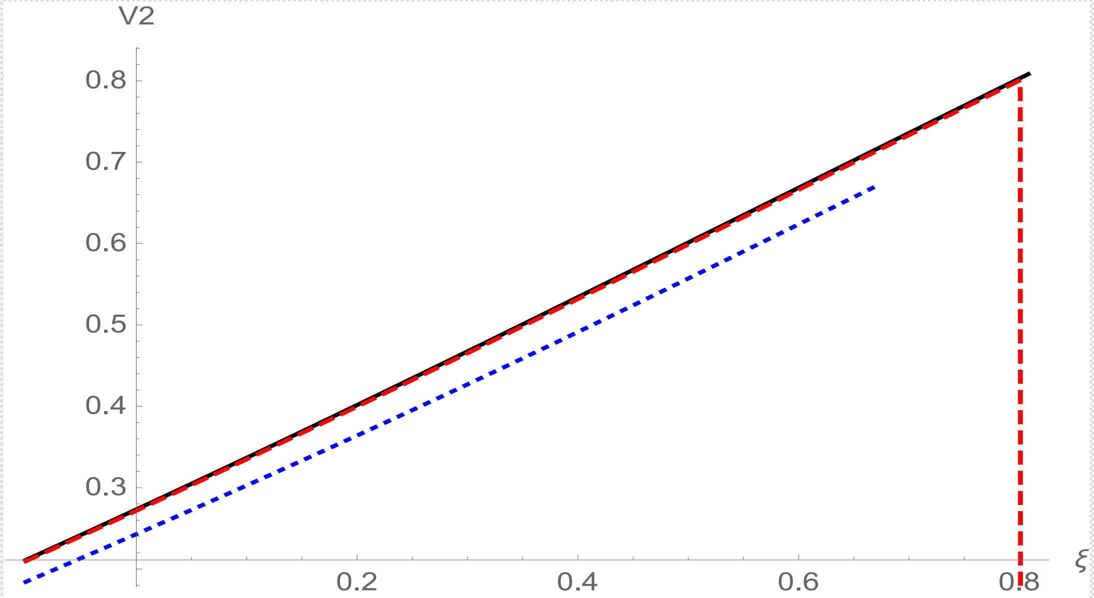


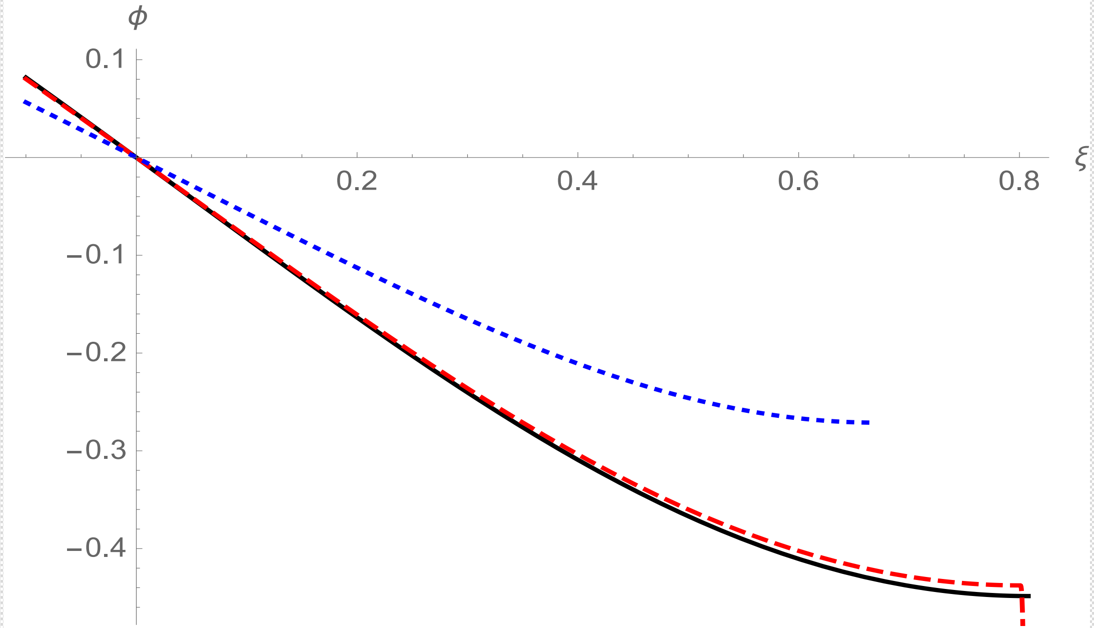


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $V_{s20} = 1$ (solid black), $V_{s20} = 10$ (dashed red),
and $V_{s20} = 50$ (dotted blue).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$, $\sigma_{s1} = \sigma_{s2} = 1$,
$\alpha = 0.335$, $\beta = 0.564$,
and $\delta = 0.235$.

(NOON-MIDNIGHT) O+ & H+ EXPANSION δ

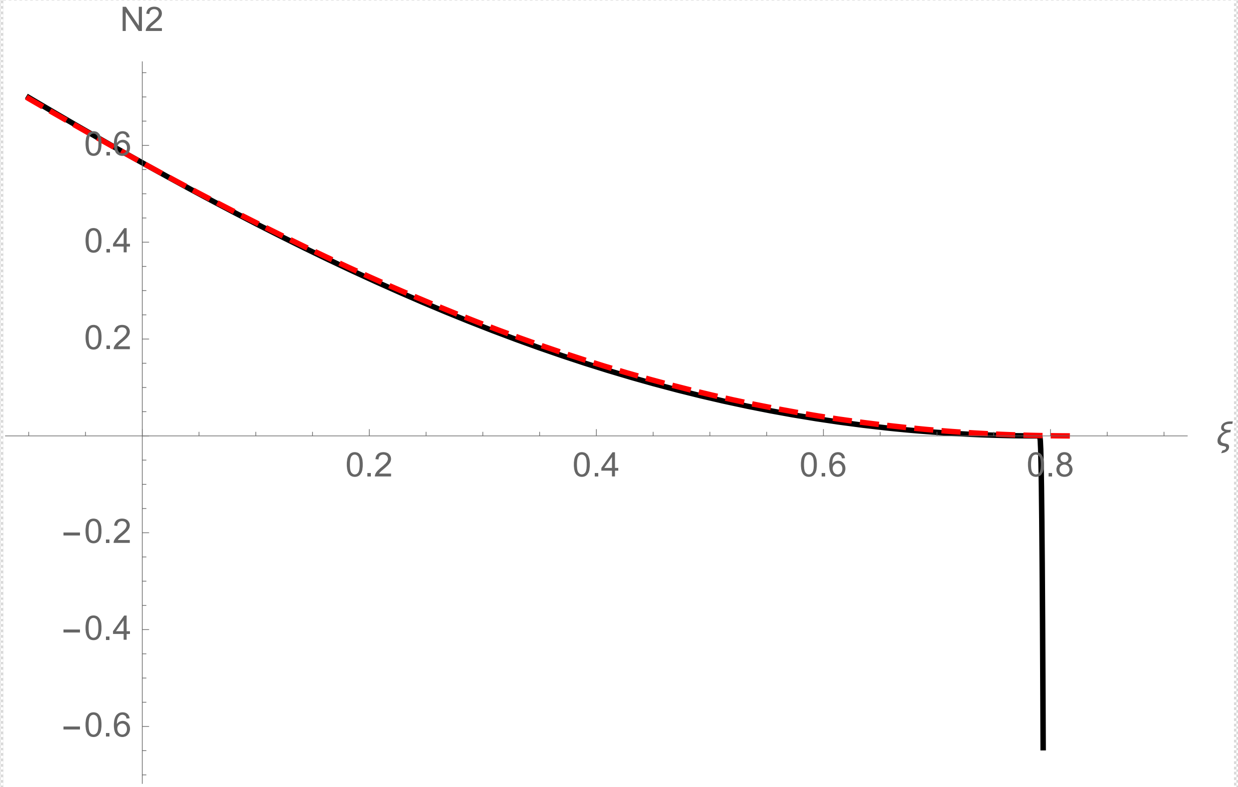


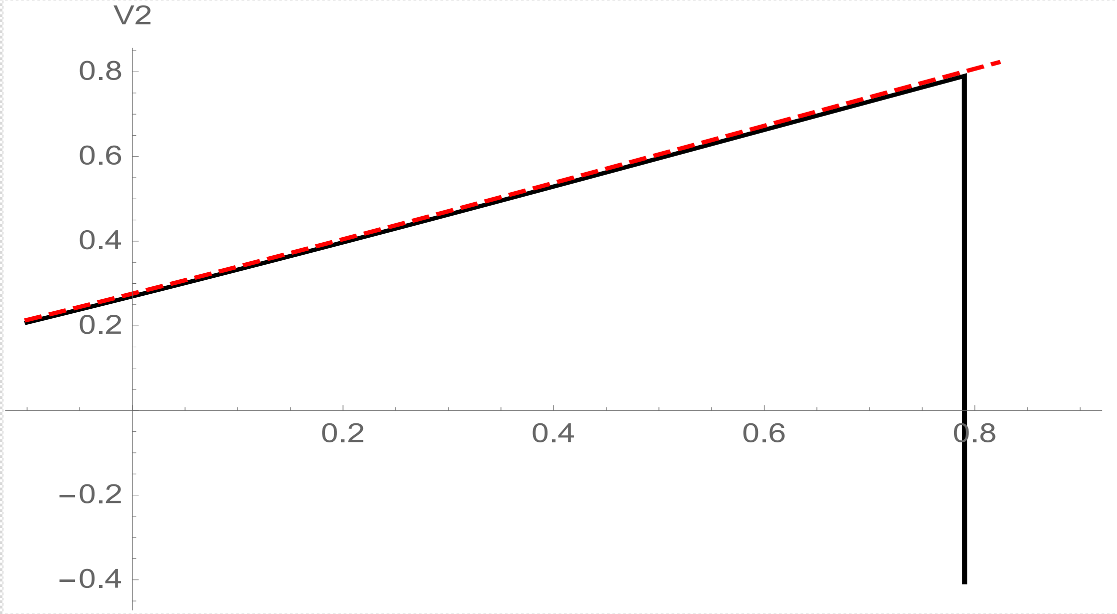


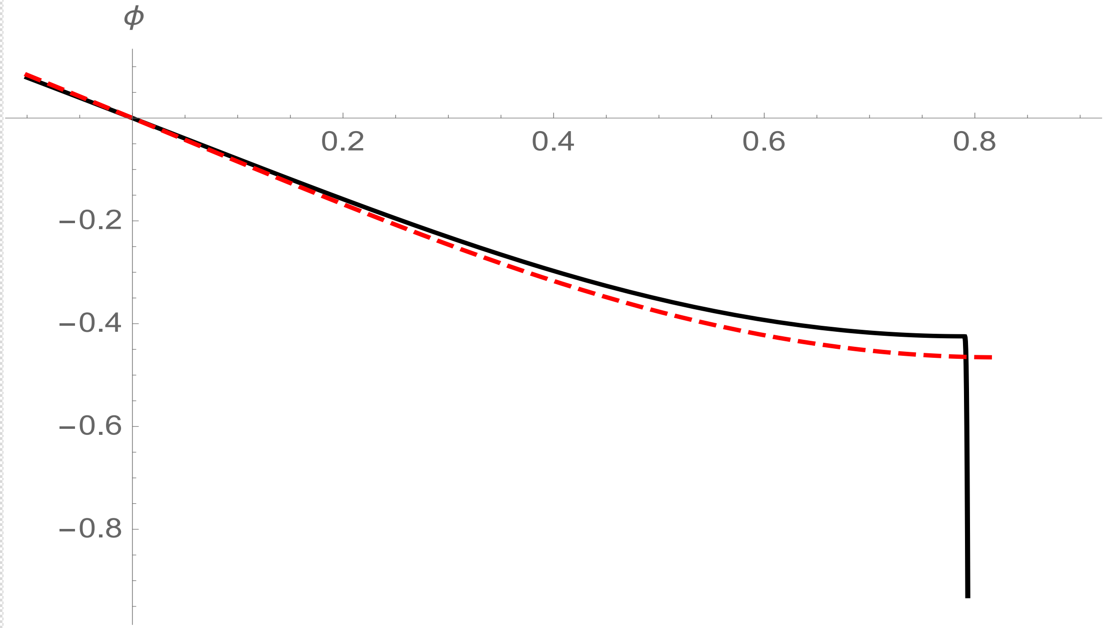


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $\delta = 0.2$ (solid black), $\delta = 0.27$ (dashed red)
and $\delta = 0.8$ (dotted blue).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$, $\sigma_{s1} = \sigma_{s2} = 1$,
$\alpha = 0.335$, $\beta = 0.564$, and $V_{s20} = 8$.

(NOON-MIDNIGHT) O+ & H+ EXPANSION α

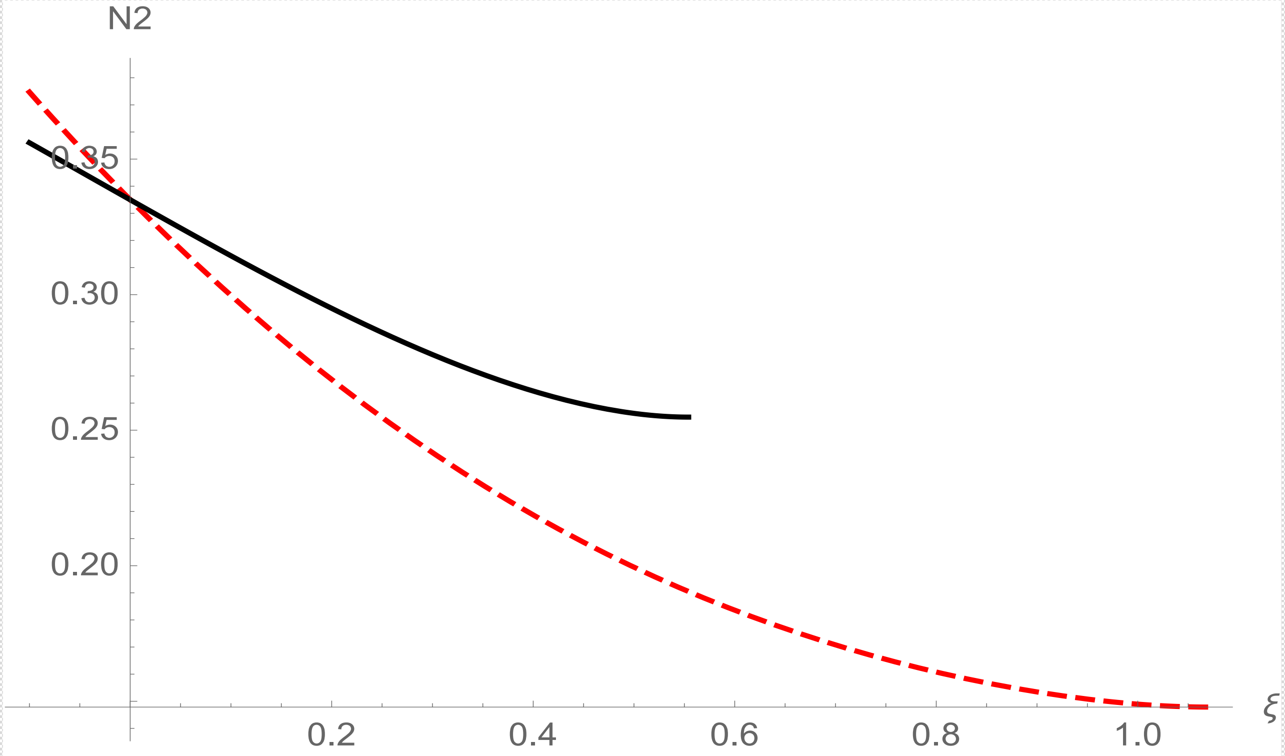


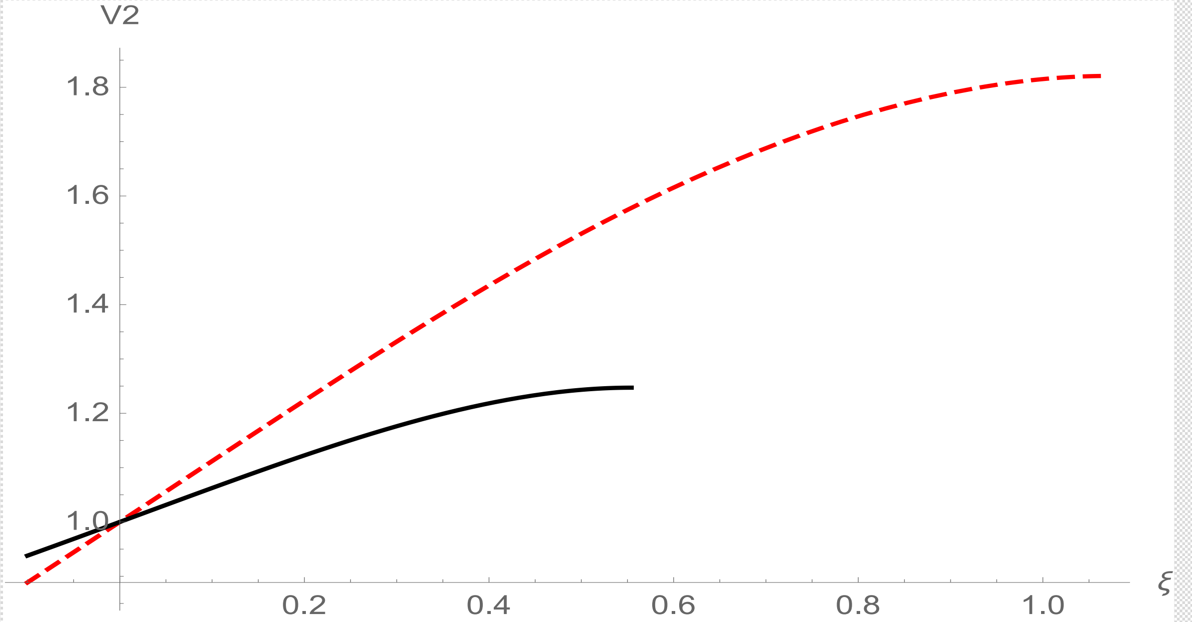


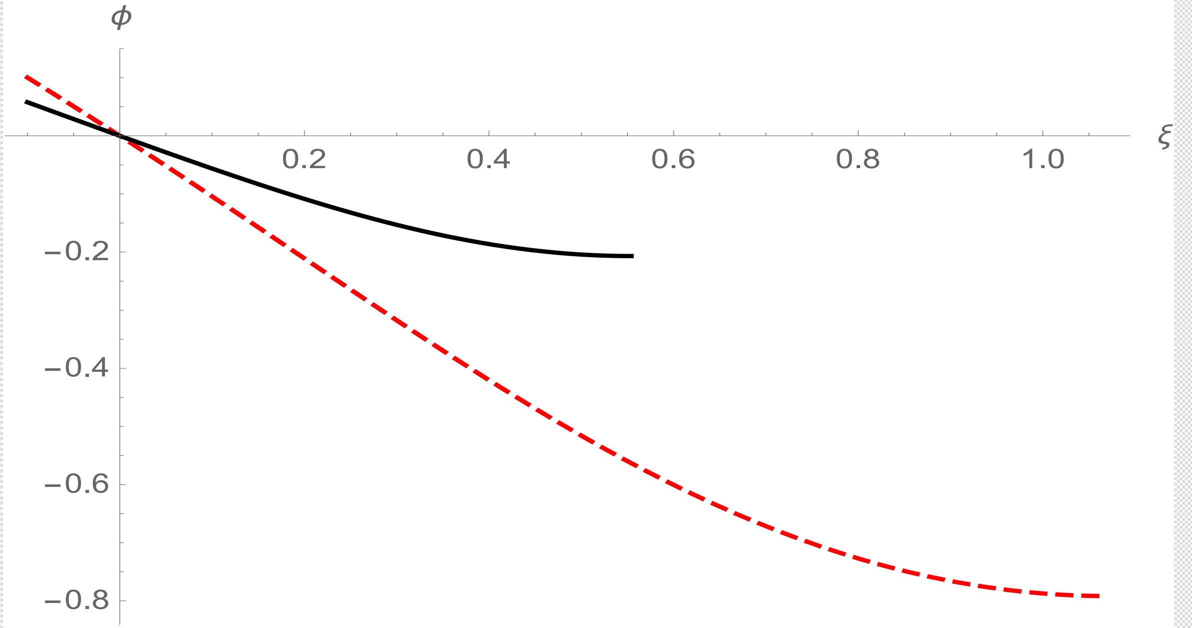


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $\alpha = 0.27$ (solid black) and $\alpha = 0.4$ (dashed red).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$,
$\sigma_{s1} = \sigma_{s2} = 1$, $\delta = 0.235$, $\beta = 0.564$, and $V_{s20} = 8$.

(NOON-MIDNIGHT) O+ & H+ EXPANSION β

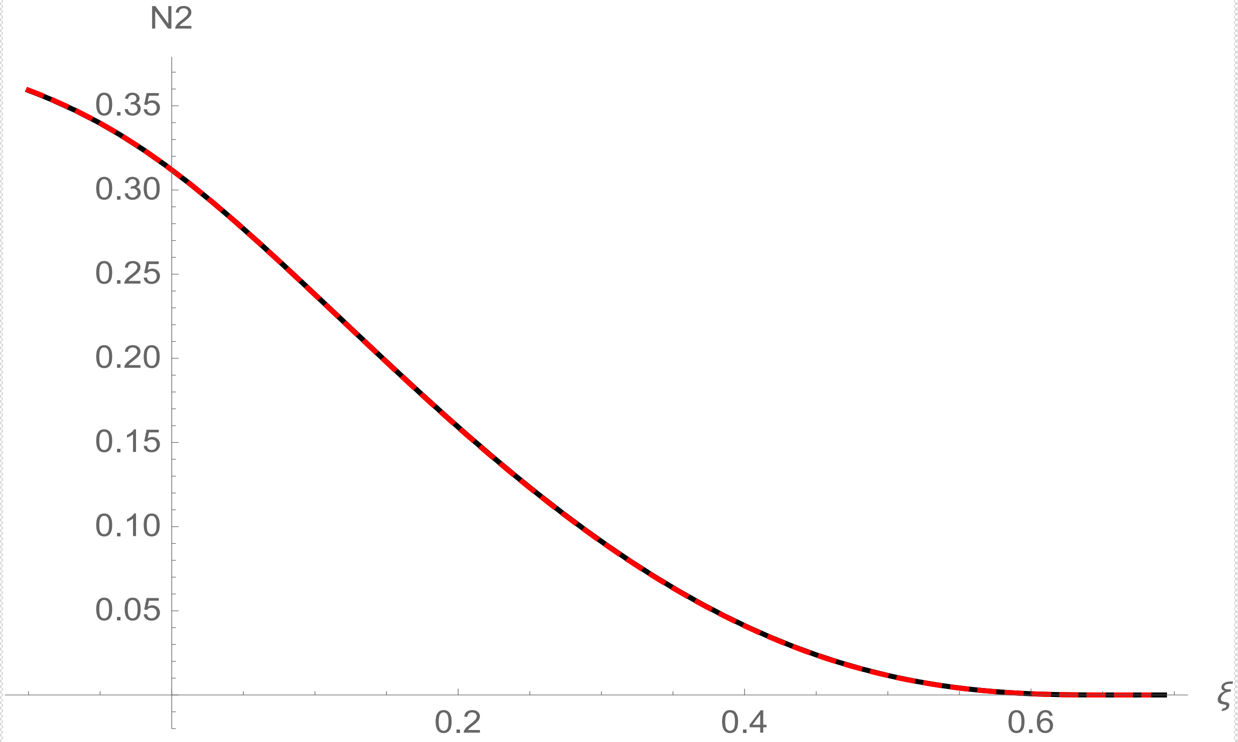


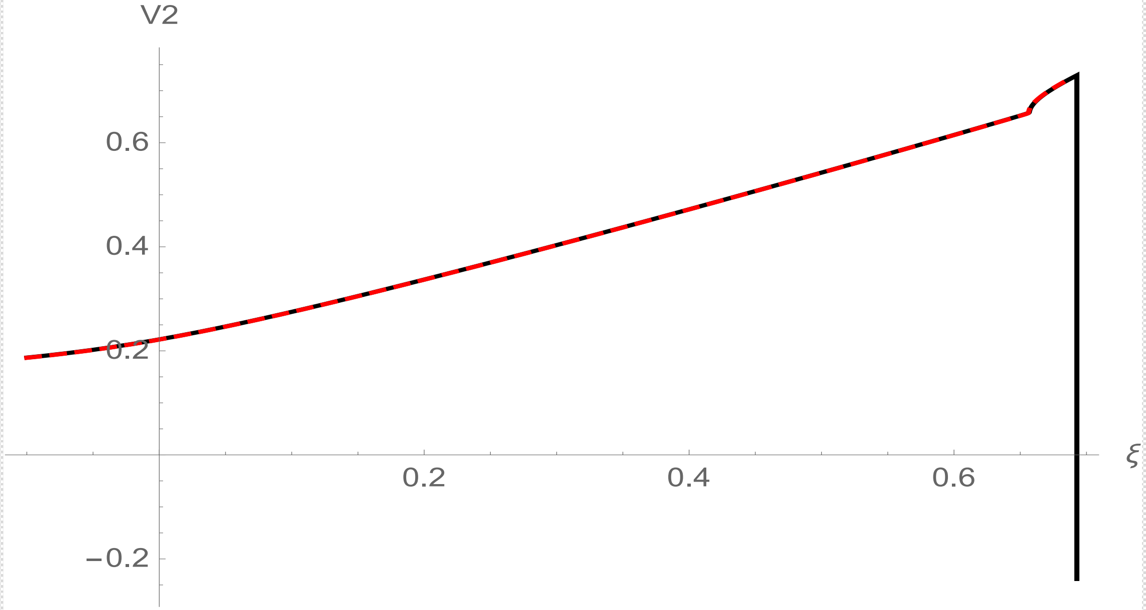


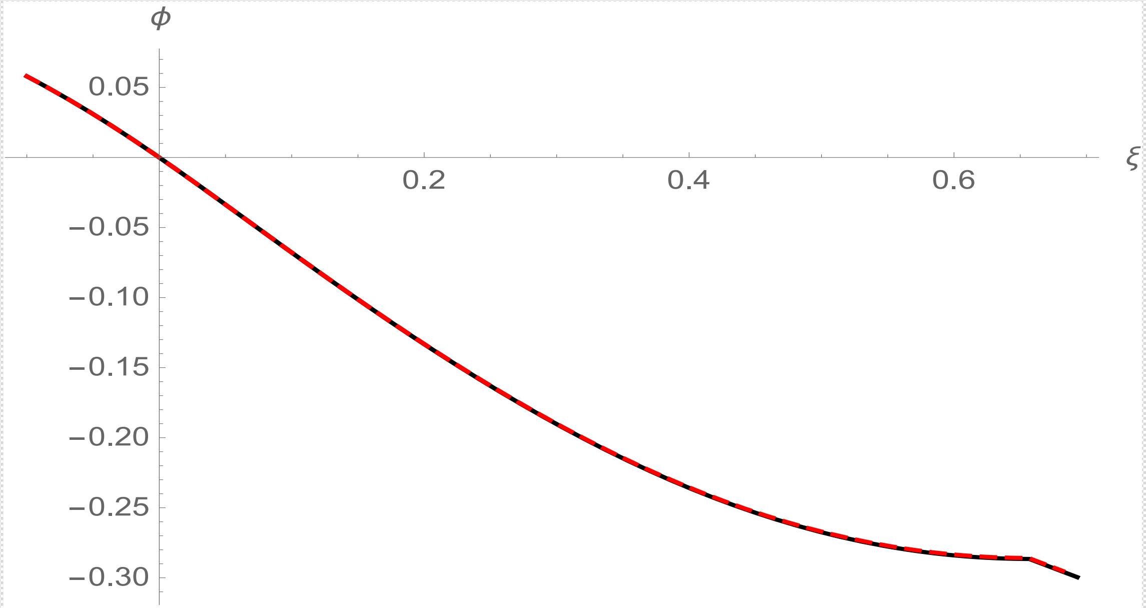


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $\beta = 0.4$ (solid black) and $\beta = 0.73$ (dashed red).
Here, $Q = 1 / 8$; $Q_{s2} = 1$,
$\sigma_1 = \sigma_2 = 0.25$, $\sigma_{s1} = \sigma_{s2} = 1$, $\delta = 0.235$,
$\alpha = 0.335$, and $V_{s20} = 8$.

(DAWN-DUSK) O+ & H+ EXPANSION Vs20 (1000-2000 Km)

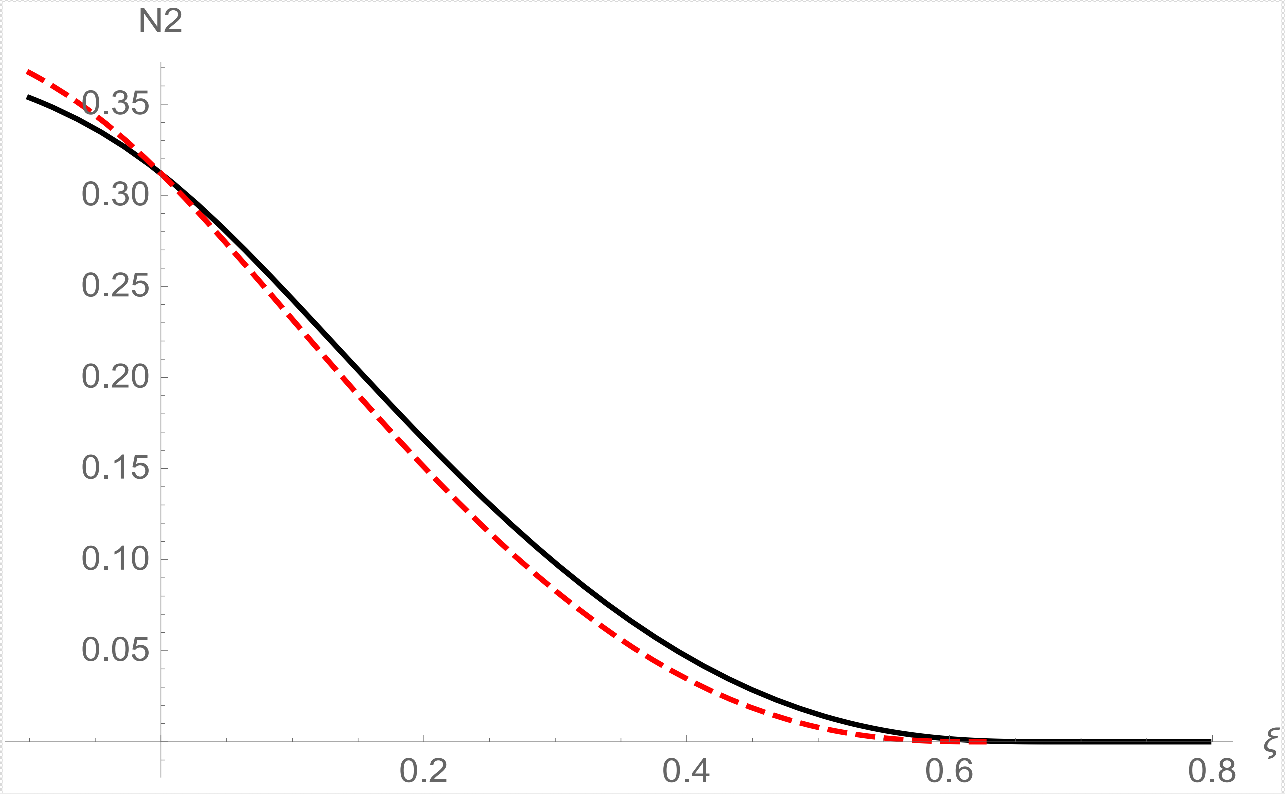


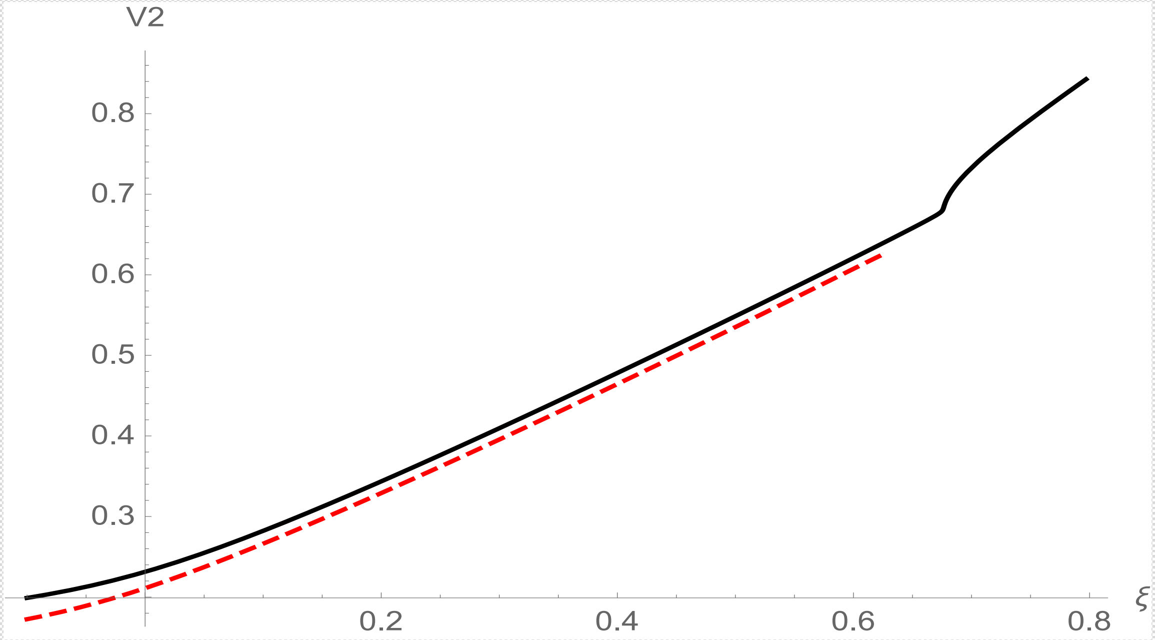


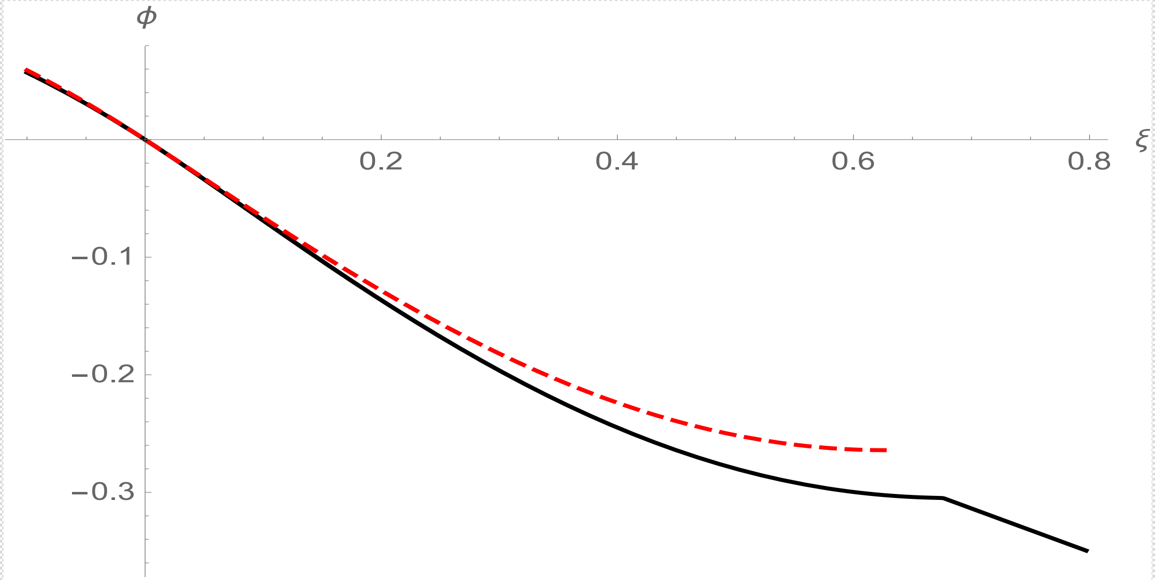


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $V_{s20} = 5$ (solid black) and $V_{s20} = 11$ (dashed red).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$,
$\sigma_{s1} = \sigma_{s2} = 1$, $\delta = 0.21$, $\alpha = 0.69$, and $\beta = 0.312$.

(DAWN-DUSK) O+ & H+ EXPANSION δ (1000-2000 Km)

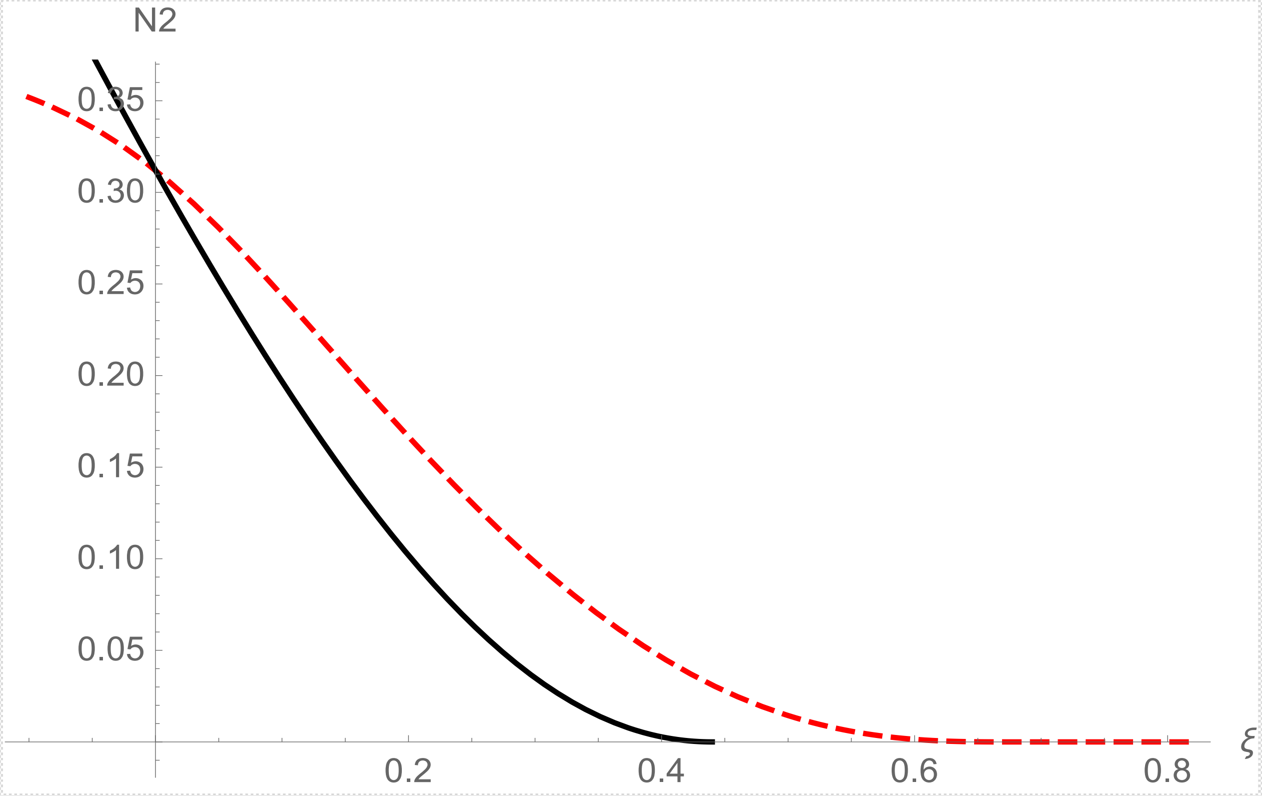


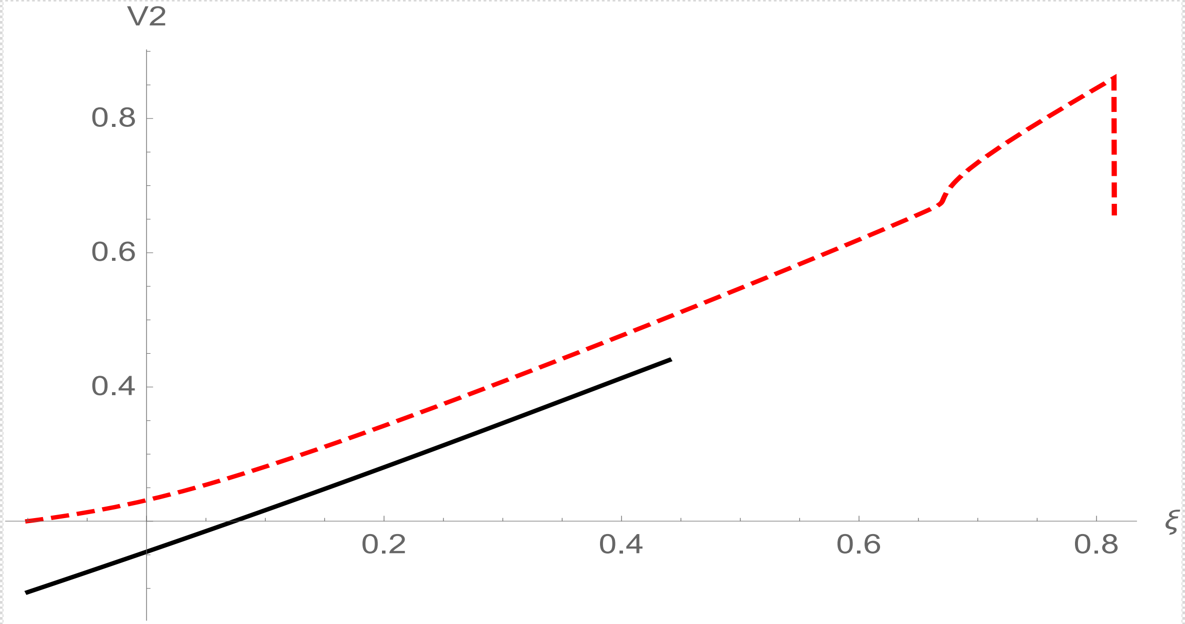


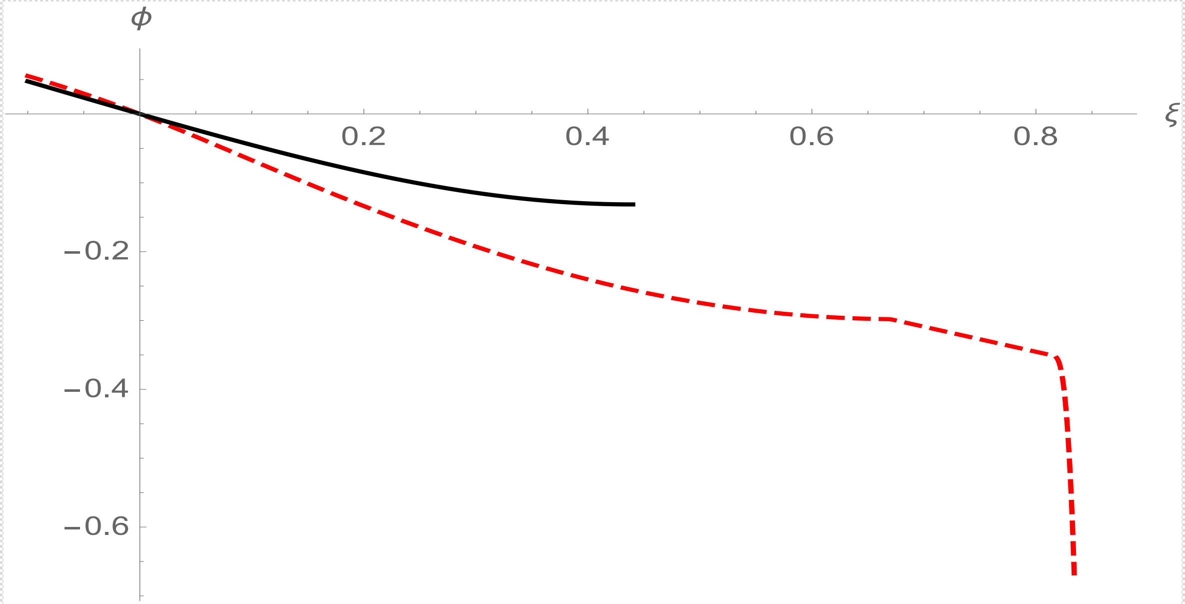


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $\delta = 0.12$ (solid black) and $\delta = 0.29$ (dashed red).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$,
$\sigma_{s1} = \sigma_{s2} = 1$, $\beta = 0.312$, $\alpha = 0.69$, and $V_{s20} = 8$.

(DAWN-DUSK) O+ & H+ EXPANSION α (1000-2000 Km)

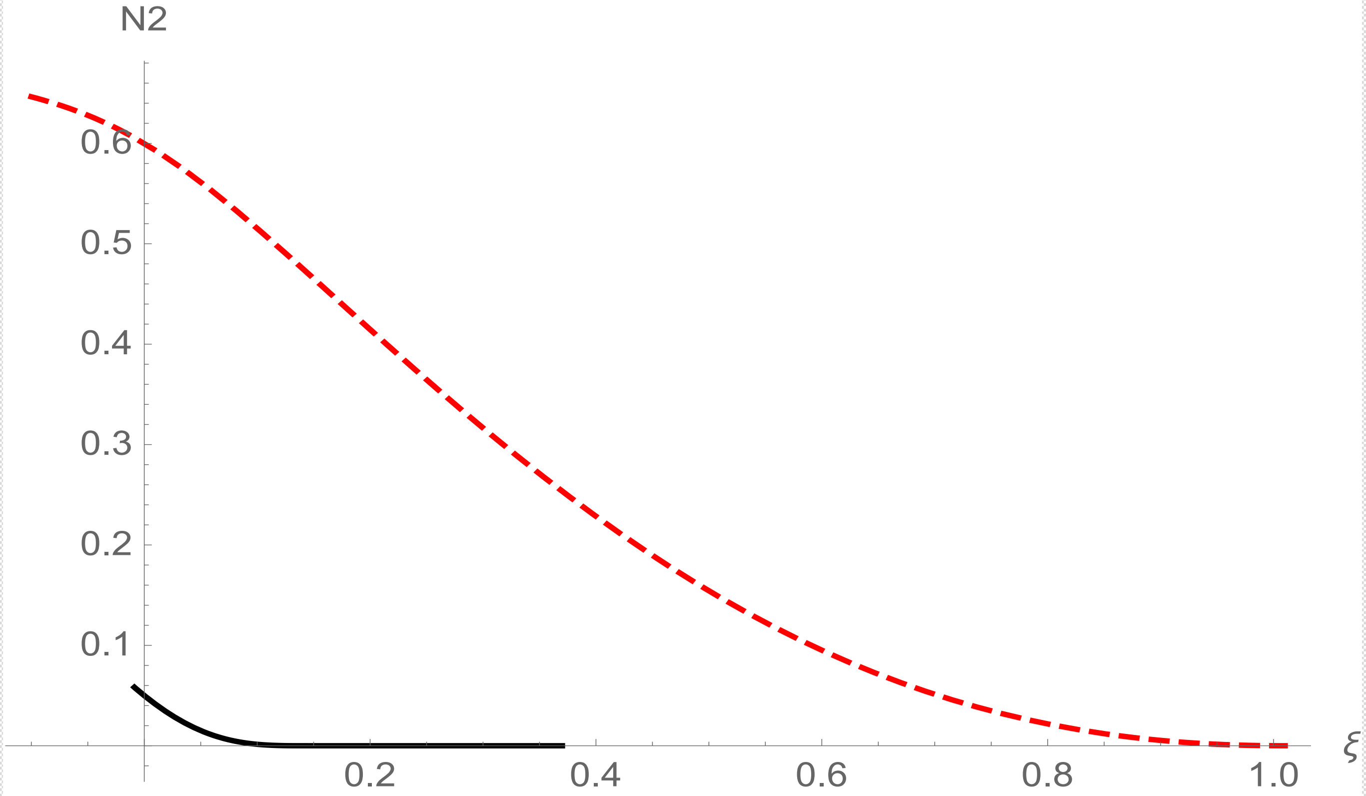


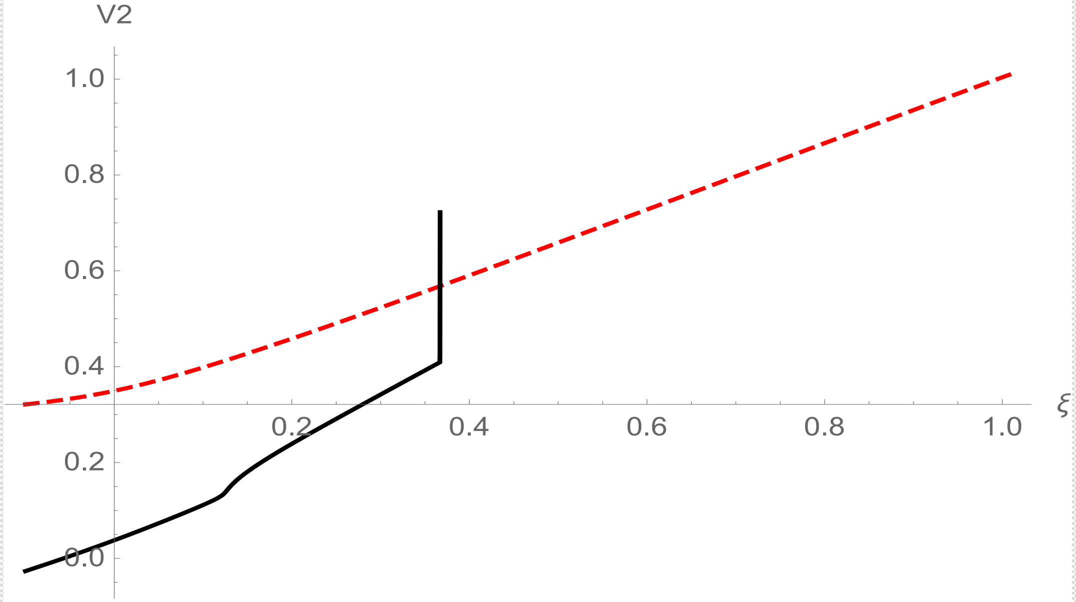


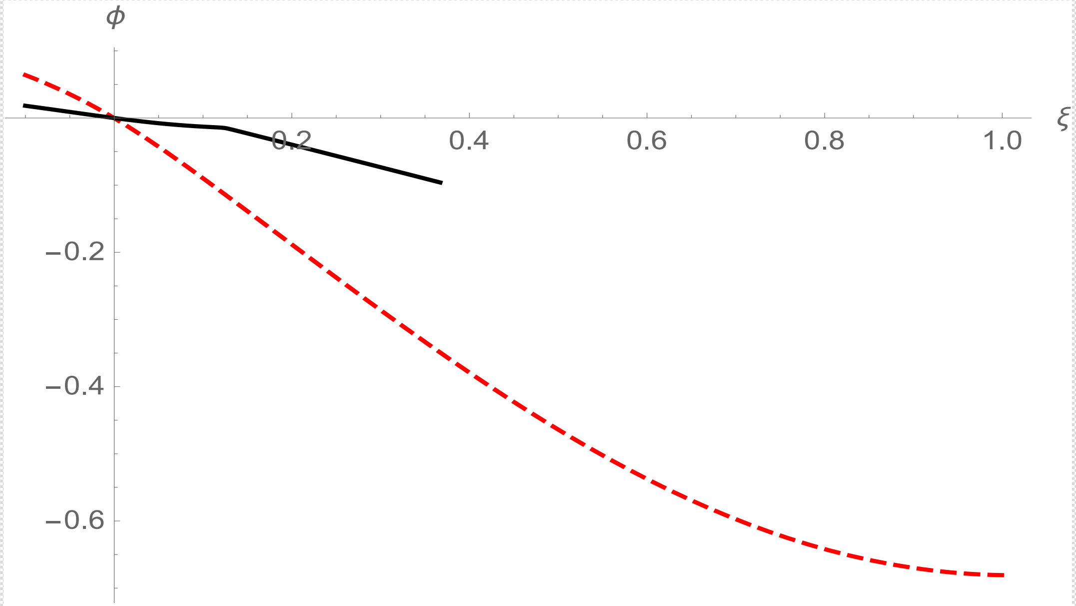


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $\alpha = 0.4$ (solid black) and $\alpha = 0.7$ (dashed red).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$,
$\sigma_{s1} = \sigma_{s2} = 1$, $\delta = 0.21$, $\beta = 0.312$, and $V_{s20} = 8$.

(DAWN-DUSK) O+ & H+ EXPANSION β (1000-2000 Km)

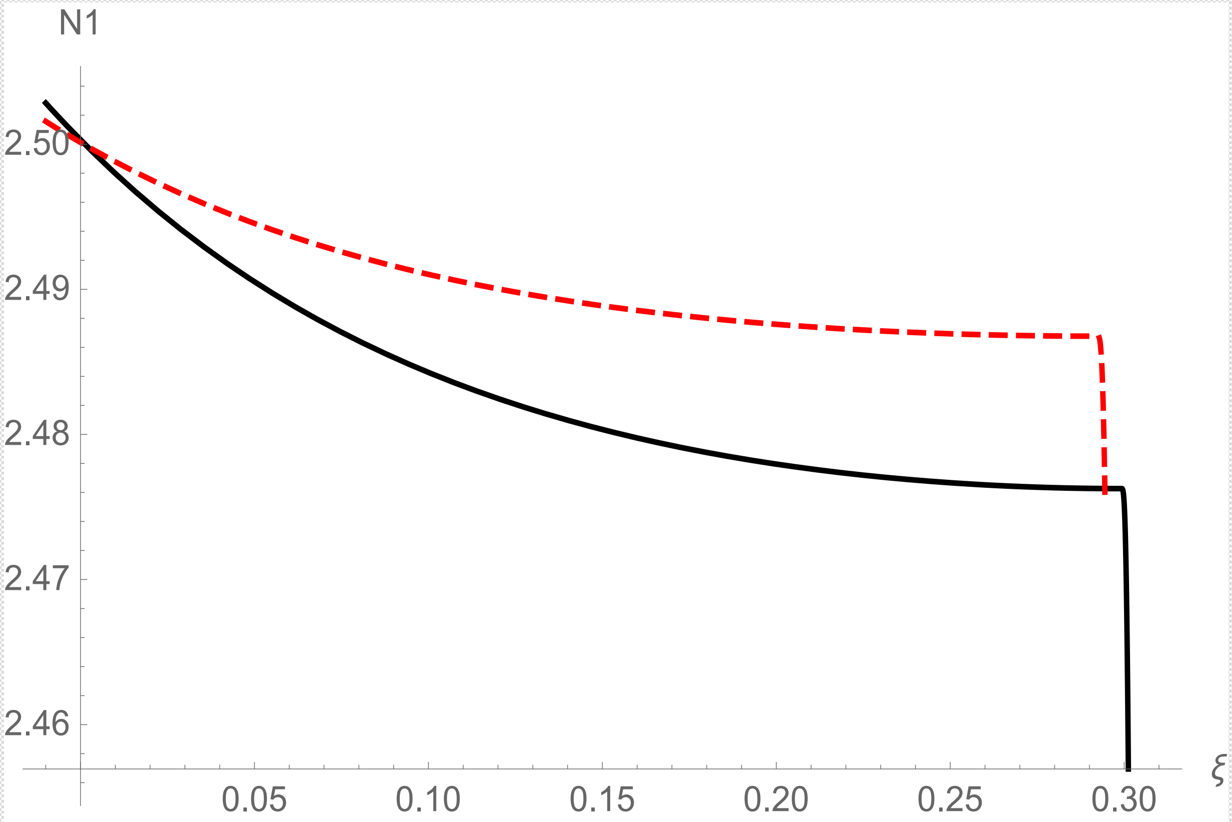


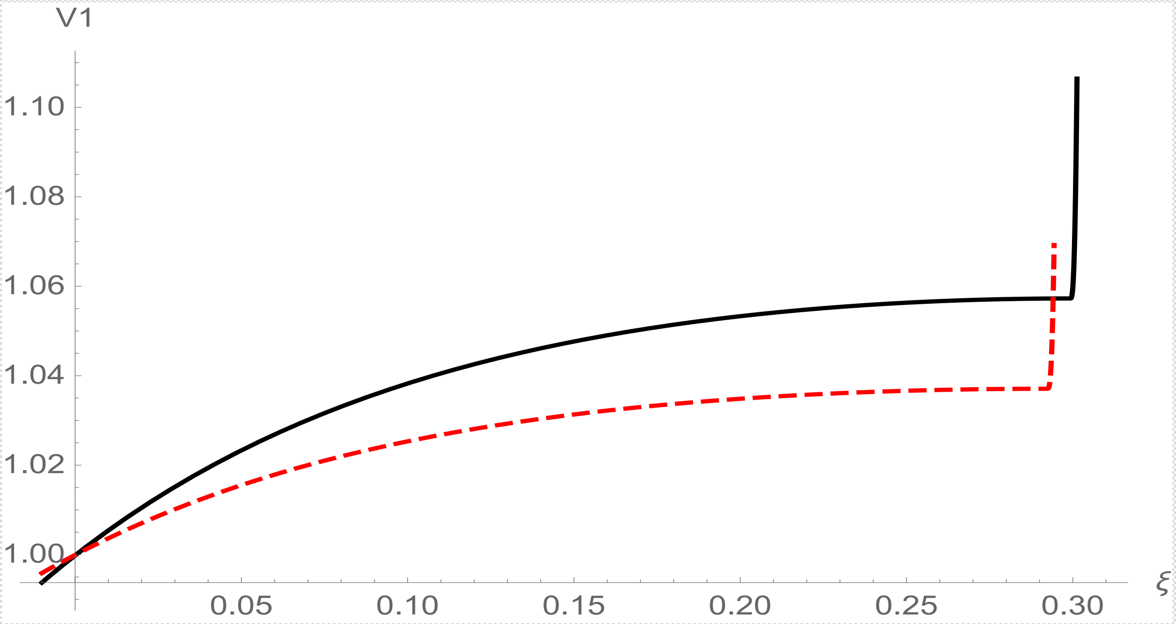


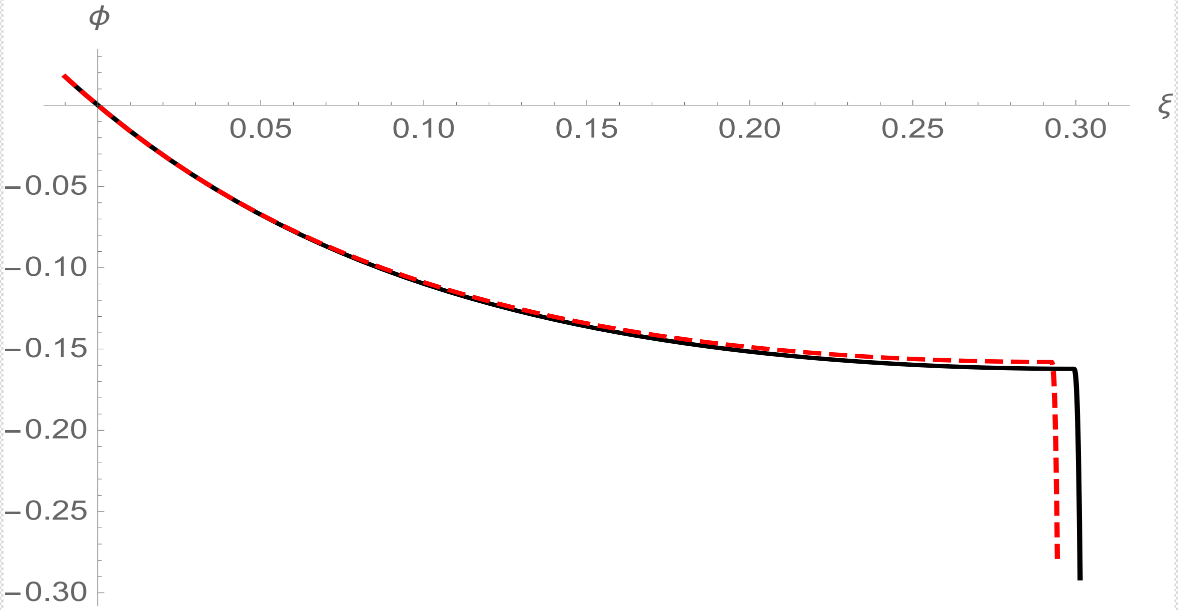


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $\beta = 0.05$ (solid black) and $\beta = 0.6$ (dashed red).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$,
$\sigma_{s1} = \sigma_{s2} = 1$, $\delta = 0.21$, $\alpha = 0.69$, and $V_{s20} = 8$.

(DAWN-DUSK) H+ EXPANSION Vs20 Alt>2000 Km

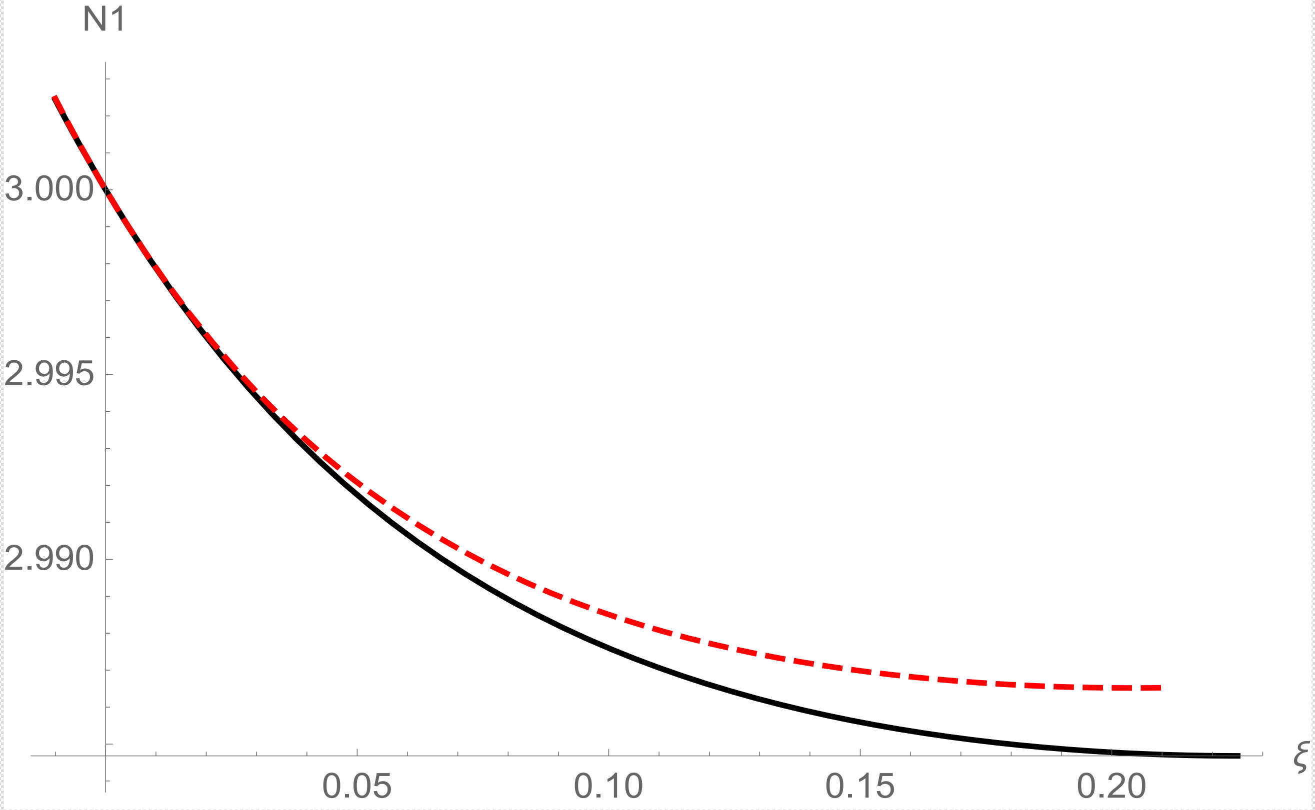


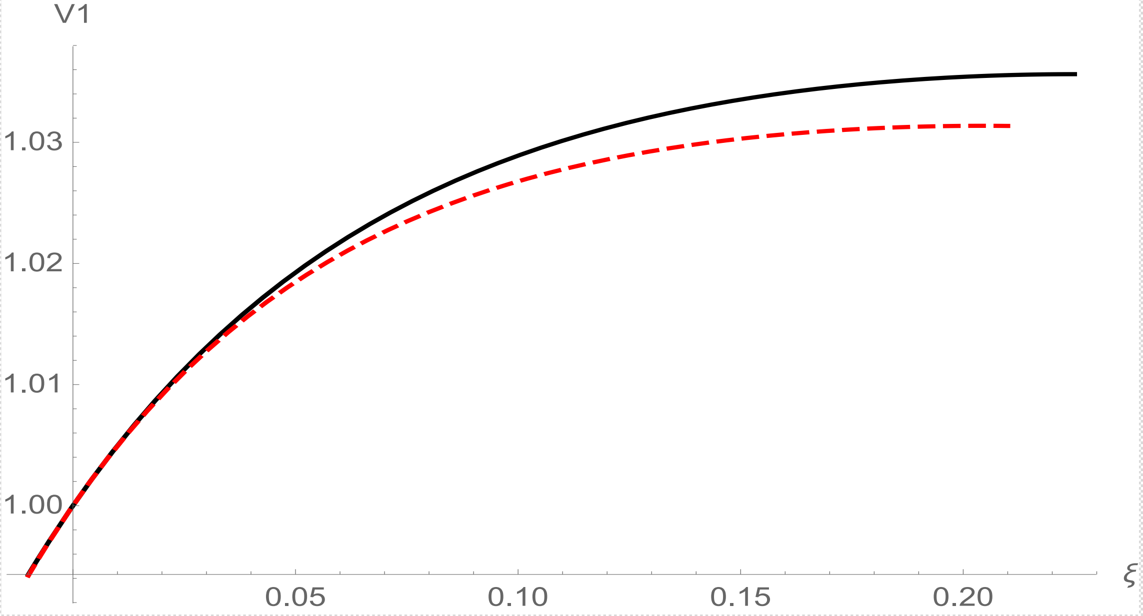


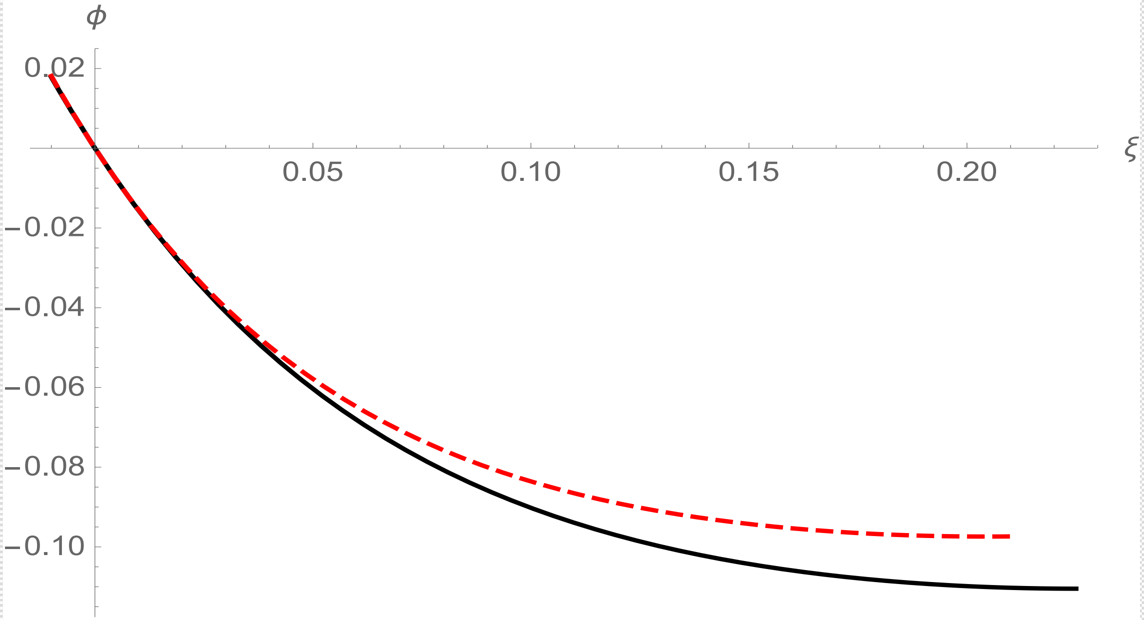


Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $V_{s20} = 5$ (solid black) and $V_{s20} = 6$ (dashed red).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$,
$\sigma_{s1} = \sigma_{s2} = 1$, $\delta = 2.5$, $\alpha = 1$, and $\beta = 0.312$.

(DAWN-DUSK) H+ EXPANSION δ Alt>2000 Km







Normalized positive ion density N_2,
Normalized positive ion velocity V_2,
Normalized electric potential ϕ
versus the self-similar variable ξ,
where $\delta = 3$ (solid black) and $\delta = 3.9$ (dashed red).
Here, $Q = 1 / 8$; $Q_{s2} = 1$, $\sigma_1 = \sigma_2 = 0.25$,
$\sigma_{s1} = \sigma_{s2} = 1$, $\beta = 0.312$, $\alpha = 0.69$, and $V_{s20} = 6$.

CONCLUSION

- Our present results suggest that for noon midnight sites the O+, the

relative density, i.e. $\delta = ns20/ne0$, may be the main factor to enhance the ionic loss.

- The other parameters like H+ density and solar wind density and velocity seem to have minor effects.
- For dawn-dusk region, the plasma species for lower altitudes (≈ 1000 – 2000 km) are composed of H+ and O+ as well as electrons, and all densities (i.e. O+, H+, and solar wind densities) may play an important role, either reducing or boosting the ionic loss.
- For higher altitudes (> 2000 km) only H+ and electrons are encountered and the impact of the solar wind density and velocity is to diminish the expansion of ionosphere.
- The streaming solar wind velocity still has no effect on the plasma escaping

THANK YOU!