Comparative Planetary Foreshocks: Results from recent studies

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Outline

• Motivation
• Bow shock curvature
• New results from MAVEN
• Venus’ similarity with Earth
• Quasi-parallel structures
• Conclusion
The Foreshock

- Ion foreshock
- Electron foreshock
- Shock wave
- Magnetosheath
- Solar wind
- Earth
- Magnetosphere
Motivation

- Availability of critical data collection from various planets presenting different physical contexts
- In depth understanding of foreshock formation
- Insights on shocks

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<th>Number</th>
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## Bow shock scale & Particle orbit

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<th>Planet</th>
<th>$R_p/R_E$</th>
<th>Standoff/Scale H.</th>
<th>IMF $B/B_E$</th>
<th>Parker IMF $\theta_{Bx}$</th>
<th>Radius Curvature/$\rho_i$</th>
<th>Drift Length $\eta_{90}$</th>
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<td>Venus</td>
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<td><strong>1.6</strong></td>
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<td>Saturn</td>
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<td>0.04</td>
<td>84°</td>
<td>224</td>
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**Venus & Mars: Bow shock inside H–exosphere**

**Guiding center approximation (for ions) NOT valid in case of Mars**
Bow shock scale

[Slavin et al., 1985]
Maximum Particle Energization

Electric field tangent to the shock
\[ \mathcal{E}_t = BV \sin \theta_{RX} \]

Particle energization while drifting for a distance \( l \)
\[ \Delta E = q\mathcal{E}_t l = qBVl \sin \theta_{RX} \]

For a nearly perpendicular drift
\[ l \sim L \sqrt{1 + \frac{X_0}{L}}, \quad L = \text{semilatus}, \; X_0 = \text{conic section focus} \]

Comparison with Earth bow shock
\[ \eta_{90} = \frac{(\Delta E)_{\text{Planet}}}{(\Delta E)_{\text{Earth}}} \sim \left[ \frac{B \sin \theta_{RX} L \sqrt{1 + 2X_0/L}}{B \sin \theta_{RX} L \sqrt{1 + 2X_0/L}} \right]_{\text{Planet}} \times \frac{R_P}{R_E} \]
The terrestrial foreshock prototype

Electrons Spikes up to ~ 100 keV

ULF Wave Boundary

Except for FABs, One-to-One Association Backstreaming ions - ULF Waves

[Skadron & Lee, 1988]
[Le & Russell, 1992]
[Meziane et al., 2004]
Ions as a proxy for magnetic connection
For the terrestrial foreshock
Two Foreshock Electron Populations

Meziane et al., 2017

Monotonically decreasing fluxes from $Q_\parallel$ to $Q_\perp$
Ring beam distributions indicate a coherent reflection of solar wind electrons

02/Jcn/2015 17:00:16.325
Foreshock ions

Solar wind direct interaction with the Martian exosphere.
Newly-ionized neutrals are picked up by the IMF → Energy source for PCWs
Pickup ions as “seed population” for a coherent acceleration (SDA and/or shock surfing)
MAVEN Foreshock Ions

Do ions escape upstream?
Shock geometry & nature of distribution functions?
Is there any association with ULF waves?

Solar Wind

Upstream Ions

Shock

$\rho_p$

$Q_\parallel$

$Q_\perp$

$Q_\parallel$

$Q_\perp$

$B_\parallel$

$B_\perp$

$B_\parallel$

$B_\perp$

$B_\parallel$

$B_\perp$

$B_\parallel$

$B_\perp$

$B_\parallel$

$B_\perp$

$B_\parallel$

$B_\perp$

$B_\parallel$

$B_\perp$
MAVEN Foreshock Ions

Solar Wind

Reflected? Pickup ions?
Pickup ions & Reflected?

In the solar wind Frame of reference

\[ E \sim E_{SW} \]
\[ \text{Pitch-Angle} \sim \theta_{BV} \]

Pitch-angle \sim \theta_{Bn}
Do not escape Upstream
Martian foreshock

- **Electrons**
  - Entire shock as a source of backstreaming electrons
  - Two populations
    - Spikes at $\theta_{Bn} \sim 90^\circ$ [similar to Earth]
    - Broad source
  - Spikes maximum energy $E \sim \eta_{90} \times 100 \text{ keV} \sim 2 \text{ keV}$
  - Contribute to the pickup ion production

- **Ions**
  - An assessment (velocity distribution, shock geometry, maximum acceleration, ...) and a comprehensive understanding [no planer kinetic analysis] are needed.
  - Association with ULF waves?
  - Shock Pickup ion acceleration
  - The impact of the shock foot (no longer microscopic)
### Venus

[Futanaa et al., 2017]

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Electron Foreshock

Strong similarity with the Terrestrial foreshock.

Pioneer Venus Orbiter
[Crawford et al., 1993]
Plasma waves emission produced by electron beam propagation.

A natural laboratory for nonlinear processes (structures at various spatio-temporal scales).

Galileo flyby, 1990 Feb. 10

[Hospodarsky et al., 1994]
Ubiquitous energetic ions?

Galileo flyby, 1990 Feb. 10

Antisolar hemisphere 120-280 keV ions during a quite time (SW)

Coming from Venus-foreshock direction with $\theta_{Bn} > 45^\circ$

Power law spectrum $\rightarrow$ SDA rather than Fermi (exponential spectrum)

Pickup ions as only possible seed

Energetic ions must be ubiquitous?

[Williams et al., 1991]
Quasi-monochromatic ULF waves at Venus

- The periods of the waves shown are 18.1±1 s, while the local proton cyclotron periods is 12.1 s.
- The transverse part always dominates the power spectrum.
- Wave propagation direction is nearly along x_{VSO} (Venus-Sun line) and B.
- This waves present left-handed polarization with respect to background field.
- Backstreaming foreshock ions are associated with the waves.
Backstreaming Populations & ULF Waves

Isotropic ions?

FABs [Yamauchi et al., 2011]

18/Jun/2006
Venus’ similarity with Earth: The existence of the ULF wave foreshock boundary

[Lican et al., 2018]

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<th>ULF-Wave boundary slope</th>
<th>Ion Vel. Along boundary (VSW)</th>
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<tr>
<td>Earth</td>
<td>45°</td>
<td>78°</td>
<td>1.68</td>
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<tr>
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<td>77°</td>
<td>1.23</td>
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Specularly reflected

Source of Field-Aligned Beams?

1 Larmor radius?
Venusian Foreshock

• Similarities
  – Electron foreshock
  – ULF Boundary

• Investigations, quantitative in nature remain to be addressed
  – Ion velocity & shock geometry
  – Associations with ULF waves
  – Populations assessment

• Pickup ions as an ubiquitous seed for coherent particle-shock interaction (SDA , Surfing)
FORESHOCK STRUCTURES

[Collinson et al., 2015]

THEMIS

MAVEN