Past cusp researches: (potentially) missing facts

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(Potentially) missing facts

(1) cause of cusp-auroral electron ⇒ $\Delta V_{//} \approx 100-500$ eV

(2) Multiple entry points

(3) Full of escaping ionospheric ions ⇒ mass-loading

⇒ "Extra Open" of the cusp by mass-loading

⇒ consistent with cusp field-aligned currents
(1) Electron burst to produce red aurora

(Yamauchi et al. 2001)

e- by $\Delta V_{\|}$ rather than solar wind e-
(2) Acceleration region vs. cusp

(Woch and Lundin 1992)

(Kremser et al. 1995)

Viking Orbit 1104 10 Sept, 1986

aurora electron

LIA signature

westward
Acceleration both side of cusp

Viking orbit 1058 (860902)
Two types of injection

- Electron
- Pitch angle
- Ion (+)

Two injection sites

(Woch and Lundin 1992)
FTE vs cusp (both co-exist!)

FTE + cusp: breathing magnetosphere
Viking orbit 1082 (860906)

No heating = FTE?
Heating = cusp

(Yamauchi and Lundin 2001)
Many types of injections

We expect many different combinations of LIA signature and soft-X/UV signature
cf. Quick response to IMF

IMP-8 Solar Wind Parameters, 86-08-28
(GSM coordinates, linear scale)

- Angle (deg)
- V_th (km/s)
- n_sw (cm^-3)
- V_sw (km/s)
- |B| (nT)
- B_z (nT)
- B_y (nT)
- B_x (nT)
- UT

Viking Data, Orbit 1032, Date 86-08-28

YAMAUCHI ET AL.: HYBRID CUSP

IMF Bz<0
IMF Bz>0?

overlapping injections

Yamauchi et al. 1995

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cf. Ions from opposite cusp for large By

Cusp=10~11 MLT

Injection from southern cusp

Yamauchi et al., 2005
The "double entry point" for $B_z \geq 0$

How can it be possible?

$\Rightarrow$ mass-loading of escaping ions
(3) $O^+$ observation by Cluster/CIS

- **Magnetosheath**
- **Cusp and Mantle**
- **Plasma Mantle**
- **Plasma Sheet**
O+/H+ ratio ≈ 1% in the cusp and mantle

from Slapak et al., (2017)

\[ \sim 0.7 \times 10^{25} \text{ s}^{-1} \]

magnetosheath

\[ \sim 2 \times 10^{25} \text{ s}^{-1} \]

cusp and mantle

\[ F_{\text{loss}} \propto \exp(0.45 \times K_p) \]

O+ Loss Rate:

Mass-loading is substantial

(1) Momentum conservation:
momentum flux in the -x direction = \( \rho u^2 S \bigg|_{\text{before}} = (\rho + \Delta \rho)(u + \Delta u)^2 S \bigg|_{\text{after}} \)

(2) Mixing is inelastic mixing toward the common velocity:
kineIc energy flux \( K = \rho u^3 S/2 \bigg|_{\text{before}} > K + \Delta K = (\rho + \Delta \rho)(u + \Delta u)^3 S/2 \bigg|_{\text{after}} \)
or using (1), \( \Delta K/K = \int dK/K = \int du/u \approx - \int d\rho/2\rho \)
Mass-load = Inelastic mixing

using \( d\rho \) = "added mass over \( dx \) / volume in \( dx \)"

\[
= \frac{dF_{\text{load}}}{uS}
\]

\[
\Delta K/K_{\text{in}} = \frac{1}{2} \cdot \int d\rho(x) / \rho(x)
\]

\[
= \frac{1}{2} \cdot \int dF_{\text{load}}(x) u^2(x) / (\rho(x) u^3(x) S(x))
\]

\[
= \frac{1}{4K_{\text{in}}} \cdot \int dF_{\text{load}}(x) u^2(x)
\]

\[
\Rightarrow \Delta K \approx \frac{1}{4} u^2_{SW} \cdot F_{\text{load}}
\]

where \( K_{\text{in}} \) is the solar wind kinetic energy flux into the mass-loading area, \( F_{\text{load}} \) is total mass flux of escaping ions into the mass-loading area.

* Amount is substantial:

\[
n_{O^+}/n_{SW} \sim 0.01 \Rightarrow \frac{\rho_{O^+}}{\rho_{SW}} \sim 0.16
\]

\[
\Rightarrow \text{extract } 7\% \text{ of kinetic energy } E
\]

\[
\Rightarrow \Delta K \approx 10^9-10^{10} \text{ W into the ionosphere}
\]
Reconnection explains only
"extension of Region 1 current"

\[ \Delta K \approx 10^{9-10} \text{ W} \]

\[ \approx \text{cusp } J_// \]
Implications of $\Delta K \approx - u_{SW}^2 \cdot F_{load}/4$

Escape flux is a function of energy input: $F_{load} = F_{load}(\Delta K)$
where $\Delta K \propto F_{load} \cdot v_{SW}^2$ by mass-loading

$\Rightarrow$ Positive feedback !

Adding empirical relation: $F_{load} \propto \exp(0.45*Kp)$

$\Rightarrow$ Energy conversion is exponentially dependent to Kp
(stronger than reconnection)
end
Mass-load = Inelastic mixing

MHD dynamo during deceleration

without outflow

with outflow

exterior cusp

Solar Wind

proton

electron

$E$

$\Delta B$

$J_{//}$

Ionosphere

$B$

If $\sum P = \infty$, charges are canceled & $E = 0$

If $\sum P = 0$, charges cause $E = -UxB$

If $\sum P$ = finite, $E$ = finite & $I_p \cdot \sum P$ = finite $\propto \Delta E$

total O$^+$ mass flux: $F_{load} = \int x dF_{load}$

$L \cdot S$: mass-loading area
Aother questions (can be confirmed by obs.)

(1) Is the plasma mantle a downstream region of the cusp proper? Is the boundary cusp an upstream region of the cusp proper?

(2) How often do we observe a velocity-filtered cusp in different local times (mid-noon verses pre-noon/post-noon)?

(3) Do two (or more) types of injection (proper type and transient type) exist simultaneously? How many singularity exist around the cusp? One, two, or many?

(4) Is red aurora the signature of the cusp proper or boundary cusp or simply the wave acceleration?

(5) What is the cusp size, in both azimuthal and meridional extent, for different altitudes?

(6) What is the signature of opposite hemisphere's cusp?
Questions (for interpretation)

(7) How do we interpret the overlapping injections/meso-scale injections?
(8) How should we interpret the strong effects dynamic pressure?
(9) How should we interpret the seasonal dependence, by conductivity or geometry?
(10) Is the energy-pitch angle dispersion or the energy-latitude dispersion a measure of source distance?
(11) In MHD, a deceleration of convection across the background magnetic field means a pile-up of the magnetic field due to frozen-in, and hence the increase of the magnetic field strength. However, the magnetic field inside the cusp decreases in all observations. How should we interpret?
Questions (more general)

(12) Does cusp plasma follow linear drift paths (conserving adiabatic invariants) throughout the cusp?

(13) Is the ionosphere a passive sink, or does it play an active role (through escaping ions and conductivity) in determining the cusp location and morphology?

(14) Where do ionospheric cusps actually map in the magnetosphere according to observations?

(15) Optimum combination of the particle drift view, fluid view, and non-ideal view (e.g., ExB drift = frozen-in, magnetic drifts = non-frozen-in).

(16) Where is the dynamo of the strongest steady-state field-aligned current in the cusp region originate? What is the prime reason for its steady-state appearance and where is the generator?
(C) Lessons for research methodology

(1) Over-estimate of source-distance calculation

(2) Various morphology of the cusp means "case study" result can never be generalized because we can always find a case which agree with "your" personally favourate model.

(3) Danger of model-dependent analyses; e.g., \( V_z < 0, V_x < 0 \) and \( V_{\perp x} > 0 \) means that the plasma is flowing mainly downward and frozen-in field (if it is frozen) moves from mantle to the cusp proper.