Advances in Kinetic Modeling of the Solar Wind Magnetosphere Interaction: the Impulsive Penetration (IP) Mechanism

Prerequisites of the IP model

- plasma bulk velocity, $\boldsymbol{u}$, is approximated by the zero and first order drifts of electrons and ions (*Lemaire, 1985*)
- plasma is "slipping" with respect to the magnetic field at sharp boundaries
- collective effects: diamagnetism; boundary space charge layers; field aligned potential drops/weak double layers.

What is "impulsive" in the IP model

- localized (in space and time) excess of the flux of momentum density

$$nm < \boldsymbol{vv} >= nm\boldsymbol{uu} + nm\boldsymbol{ww}$$

$$\left(\boldsymbol{v} = \boldsymbol{u} + \boldsymbol{w}, \overline{\overline{p}} = \boldsymbol{ww}\right)$$

- rate of penetration $\Longleftarrow$ excess momentum, energy and plasma β;

- $low\ \beta$: no specific dependence on IMF orientation; $high\ \beta$: favored by Southward IMF.

Distribution of the electric field

- perpendicular component: polarization field due the to first order differential drifts of electrons and ions forming the plasma cloud - this is the **"driving force"** for the plasmoid's motion (*Lemaire, 1985*)

$$\boxed{\frac{d}{dt}\left(\frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2}\right)+\frac{\overline{\mu^+}+\overline{\mu^-}}{m^+}\boldsymbol{\nabla}\left|\boldsymbol{B}\right|\cong 0 \qquad (1)}$$

- parallel component: weak-double layers due to the velocity shear and/or inhomogeneities of the density and temperature at the interface discontinuity. (*Lemaire and Scherer, 1978; Raadu, 1988*)

Numerical simulations of the IP mechanism

- ideal MHD: simulate penetration only for strict alignment of $\overrightarrow{B}$ in 2D geometry (*Huba, 1996; Dai and Woodward, 1997*);

- resistive MHD: simulate penetration for a small cone angle ($< 6^0$) in 2D geometry (*Ma et al., 1991*)

- hybrid: simulate penetration only for strict alignment in 2D geometry (*Savoini and Scholer, 1994, 1996*);

- PIC: propagation of artificial injected plasma clouds by polarization electric field (*Livesey and Pritchett, 1989*)

(a complete review in Echim and Lemaire, *Space Science Reviews*, **92**, 565-601, 2000)

Density variation inside penetrating plasmoids

- Momentum conservation:

$$\frac{\partial}{\partial t}(nm\boldsymbol{u}) + \boldsymbol{\nabla}\cdot\left(nm\boldsymbol{u}\boldsymbol{u} + \overline{\overline{p}}\right) = n\left(\boldsymbol{F} + q\boldsymbol{u}\times\boldsymbol{B}\right)$$

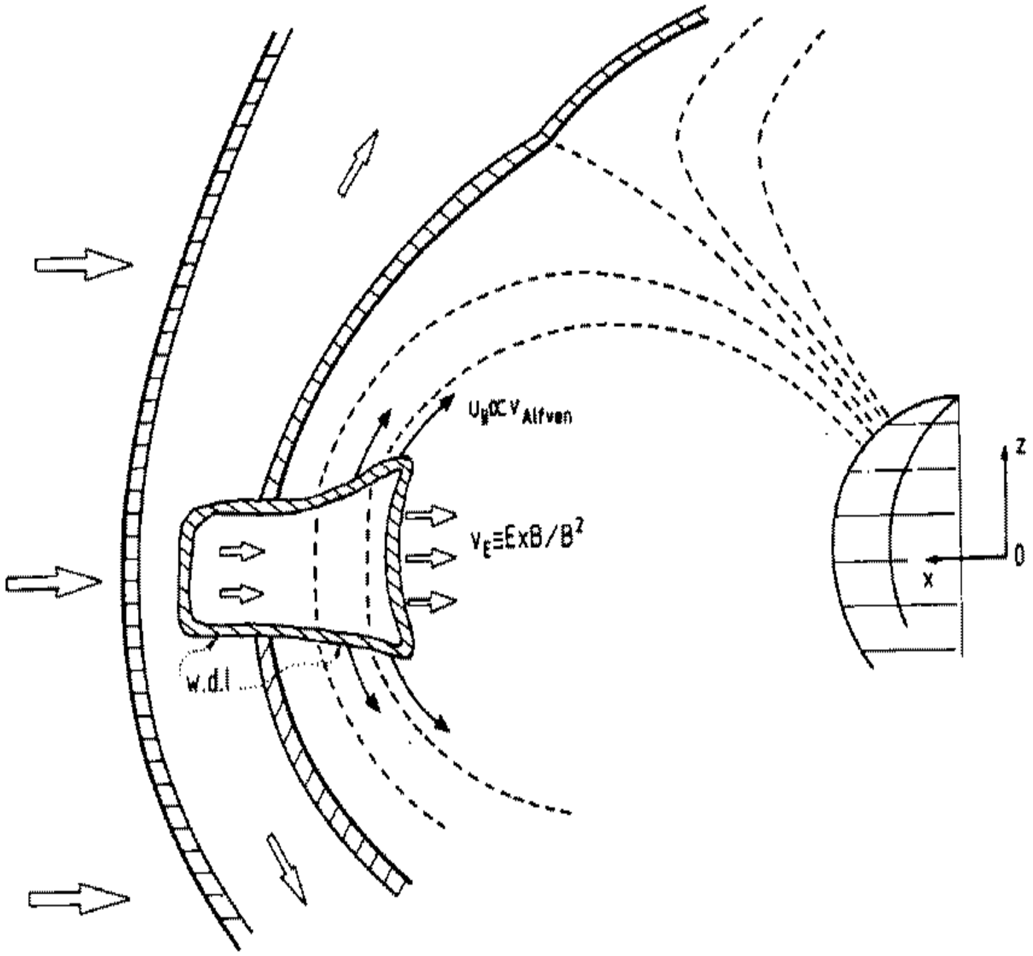
- propagation of weak-double-layers along $\boldsymbol{B}$-lines coupled to the Earth's ionosphere

$$V_{wdl} \leq V_A = \frac{B}{\sqrt{\mu_0 \rho_i}}$$

- local expansion of the volume + local decreasing of density

- density increases with radial distance inside the blob (positive gradient)

- experimental evidence: positive differences (*Sibeck et al., 2000*)

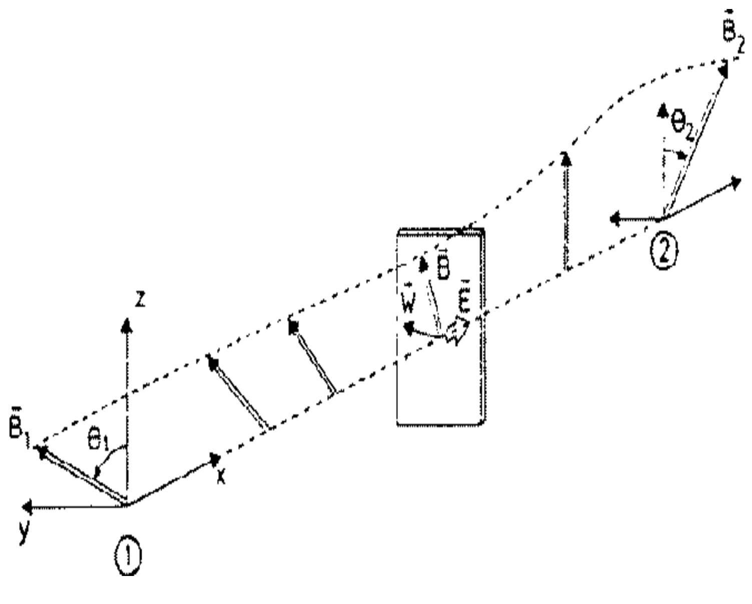

$U_{\parallel} \propto V_{Alfven}$
$V_E \equiv E \times B / B^2$
w.d.l
z
0
x

Distribution of the magnetic field

- high β plasmoids will produce a local time variation of $\vec{B}$ (*Heikkila, 1982*) and field line interconnection (*Lemaire and Roth, 1991*);

- a model magnetic field distribution of a TD is described by (*Lemaire and Burlaga, 1976; Roth et al., 1996*)

$$\boldsymbol{B}(x) = \frac{\boldsymbol{B}_1}{2} erfc\left(\frac{x}{L}\right) + \frac{\boldsymbol{B}_2}{2}\left[2 - erfc\left(\frac{x}{L}\right)\right]$$



Conclusions

- collective effects in solar wind and magnetosheath plasma set-up a distribution of the electric field which decouples the motion of plasma elements from the medium where they originate and drives them through non-uniform distributions of magnetic field.

- expansion of the volume of the plasmoids impulsively injected across B-field lines connected to the Earth's ionosphere produces a positive gradient of density.