Convective instabilities in the plasmasphere

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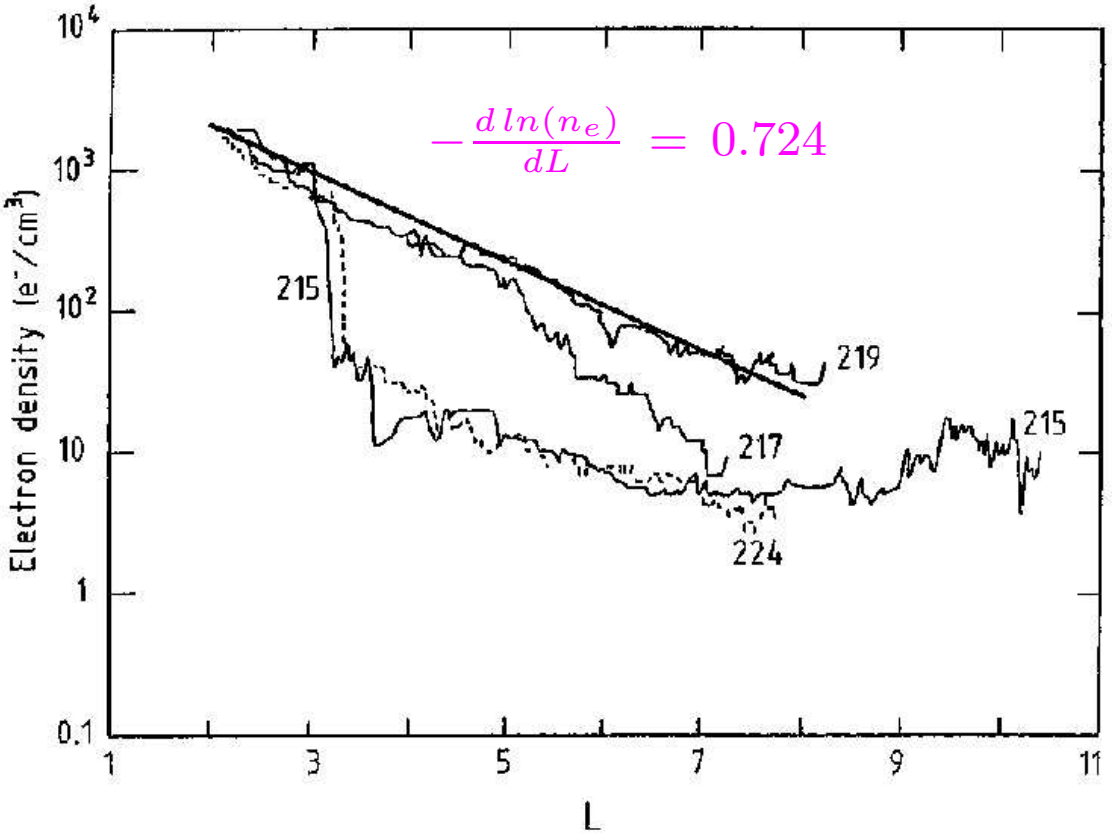
Workshop plasmasphere

The plasmasphere: a closed region in hydrostatic equilibrium ?



Carpenter and Anderson [1992]

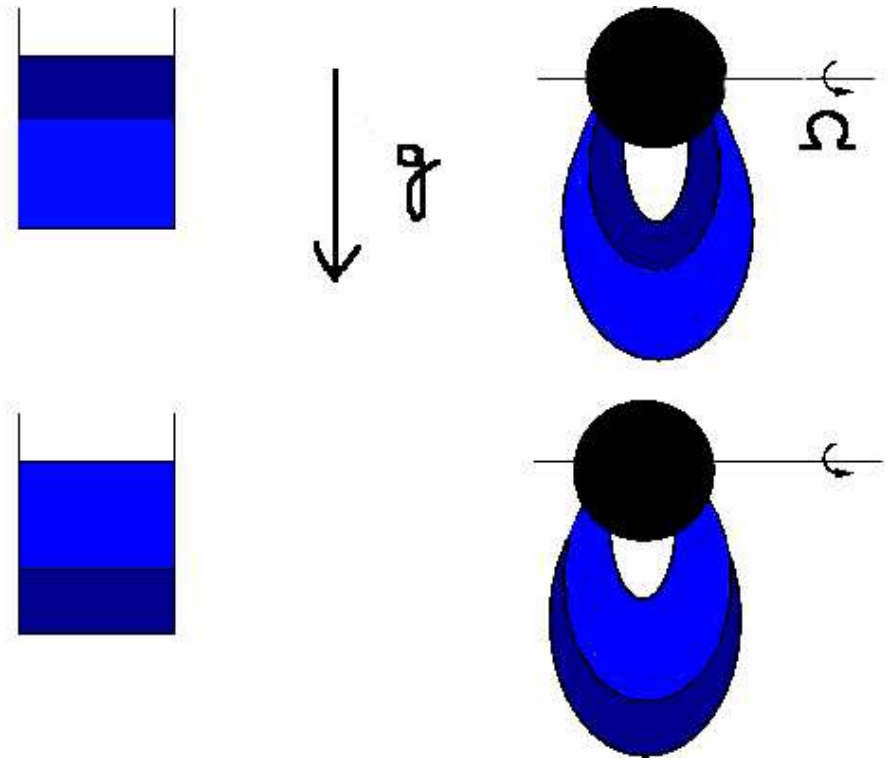
Refilling and saturation ?

Continuous plasmaspheric wind

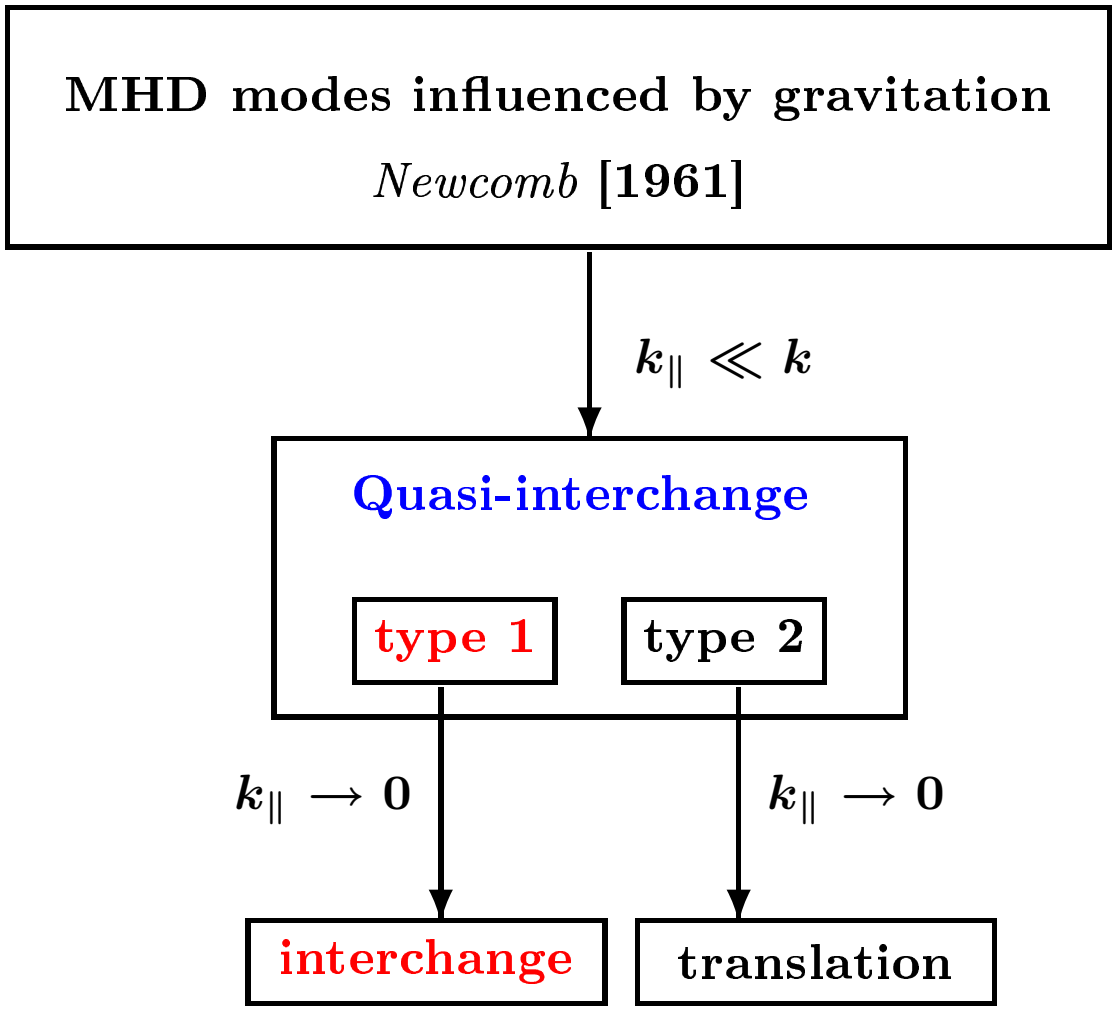
Lemaire and Schunk [1992, 1994]

OBSERVATIONAL CONTEXT

Rayleigh-Taylor type
Instability



Cross-L interchange motion
Field-aligned transport



Stability criteria

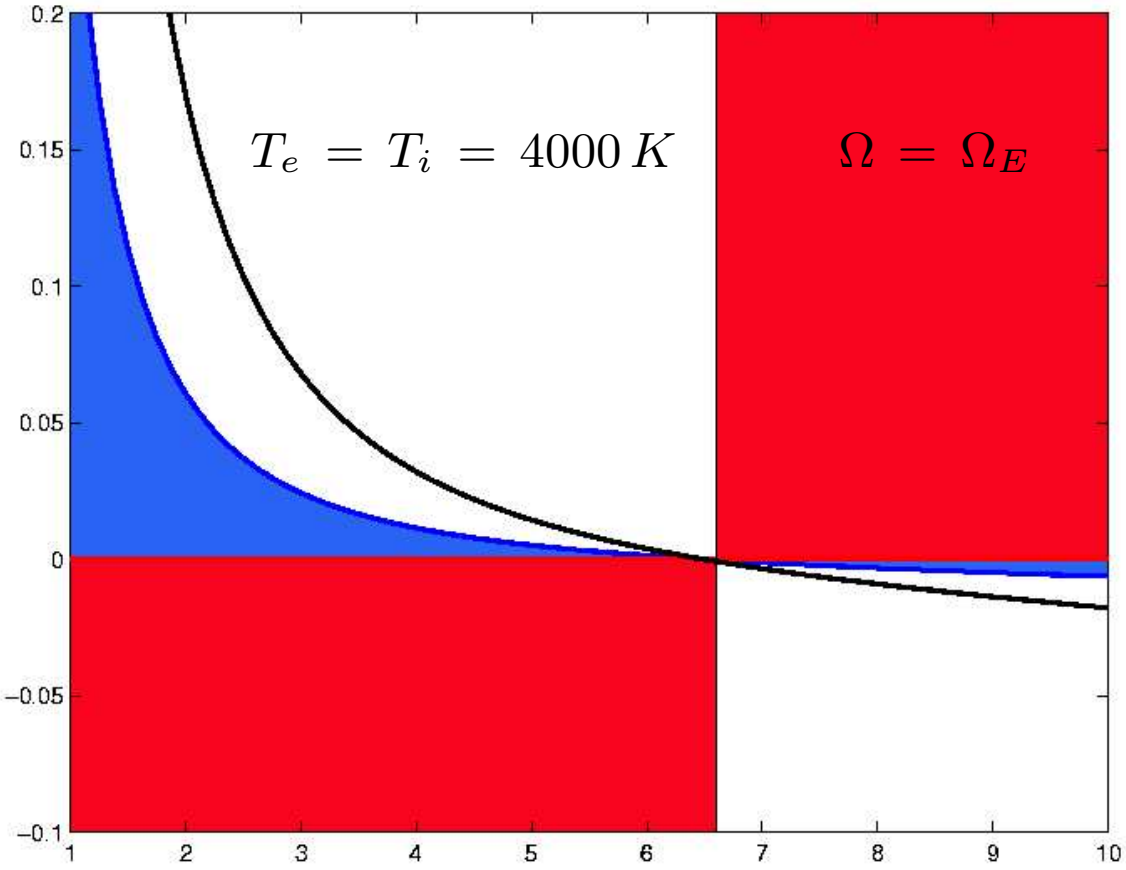
$$\text{stable} \iff \mathbf{g}\cdot\left(\frac{\nabla\rho_0}{\rho_0} - \frac{\mathbf{g}}{V_A^2 + C_s^2}\right) \geq 0$$

$$\text{stable} \iff \mathbf{g}\cdot\left(\frac{\nabla\rho_0}{\rho_0} - \frac{\mathbf{g}}{C_s^2}\right) \geq 0$$

GRAVITY ONLY $\quad \mathbf{g} \perp \mathbf{B}_0$

Isothermal hydrostatic equilibrium

$$-\frac{\boldsymbol{\nabla}\rho_0}{\boldsymbol{\rho_0}} \ (\frac{1}{R_E})$$



$\mathbf{L}\ (R_E)$

Stable $\forall$ L *Lemaire* [1999]

Unstable for $\mathrm{L} > 6.6\,R_E$

APPLICATION **g, Ω**

MHD modes influenced by stratification

Ferrière et al. **[2001]**

$k_{\parallel} \ll k$

Quasi-interchange

type 1 **type 2**

$k_{\parallel} \to 0$ $k_{\parallel} \to 0$

interchange **translation**

Stability criteria

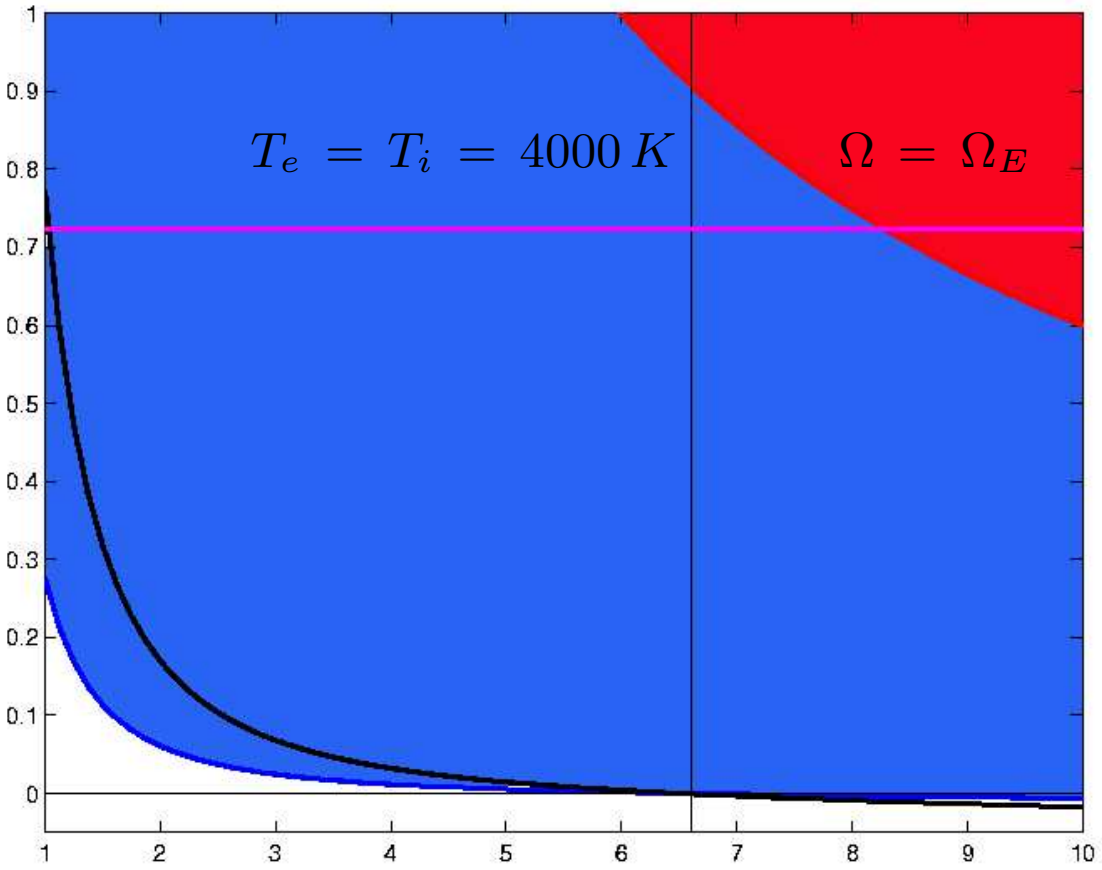
$$\left(\mathbf{g} - 2\,\mathbf{C_s^2}\,\mathbf{c_0}\right) \cdot \left(\frac{\boldsymbol{\nabla}\boldsymbol{\rho}}{\boldsymbol{\rho_0}} - \frac{\mathbf{g} + 2\,\mathbf{V_A^2}\,\mathbf{c_0}}{\mathbf{V_A^2} + \mathbf{C_s^2}}\right) \geq 0$$

$$\left(\mathbf{g} - 2\,\mathbf{C_s^2}\,\mathbf{c_0}\right) \cdot \left(\frac{\boldsymbol{\nabla}\boldsymbol{\rho}}{\boldsymbol{\rho_0}} - \frac{\mathbf{g}}{\mathbf{C_s^2}}\right) \geq 0$$

GRAVITY + CURVATURE

Isothermal hydrostatic equilibrium

$$-\frac{\boldsymbol{\nabla}\rho_0}{\boldsymbol{\rho_0}} \; (\frac{1}{R_E})$$



$\mathbf{L}\ (R_E)$

Unstable for $\mathrm{L} < 6.6\,R_E$
Unstable for $L > 1$ & $L > 8.3\,R_E$

APPLICATION $\mathbf{g}$, $\boldsymbol{\Omega}$, $\mathbf{c}_0$

Ferrière and André [2003]

Stability criterion
of all quasi-interchange modes $\forall k$

$$\underbrace{\mathcal{F} \geq 0 \quad \& \quad \mathcal{M} \geq 0}_{\text{homogeneous plasmas}} \quad \& \quad \underbrace{\varpi_0^2 \geq \frac{g_1^2}{\mathcal{M}}}_{\text{stratified plasmas}}$$

In particular, for the type 1 mode

	$\omega_0^2(\infty) \geq 0$	$\omega_0^2(\infty) < 0$
$\mathcal{F} \geq 0$	stable $\forall k_\parallel$	unstable $k_\parallel < k_\parallel^*$
$\mathcal{F} < 0$	stable $k_\parallel = 0$	unstable $\forall k_\parallel$

Key parameters

$$\omega_0^2(\infty) \geq 0 \equiv$$

$$\mathbf{g}\cdot\frac{\nabla\rho_0}{\rho_0}+\mathbf{c}_0\cdot\left[-\frac{\nabla P_{\perp 0}}{\rho_0}-\frac{\nabla P_{\parallel 0}}{\rho_0}+\left(\mathcal{F}+3C_\parallel^2\right)\mathbf{c}_0\right]$$

$$\geq \frac{\left[\mathbf{g}+\left(V_A^2-C_\parallel^2\right)\mathbf{c}_0\right]^2}{V_A^2+2\,C_\perp^2}$$

$$\varpi_0^2-\frac{g_1^2}{\mathcal{M}} \geq 0 \equiv$$

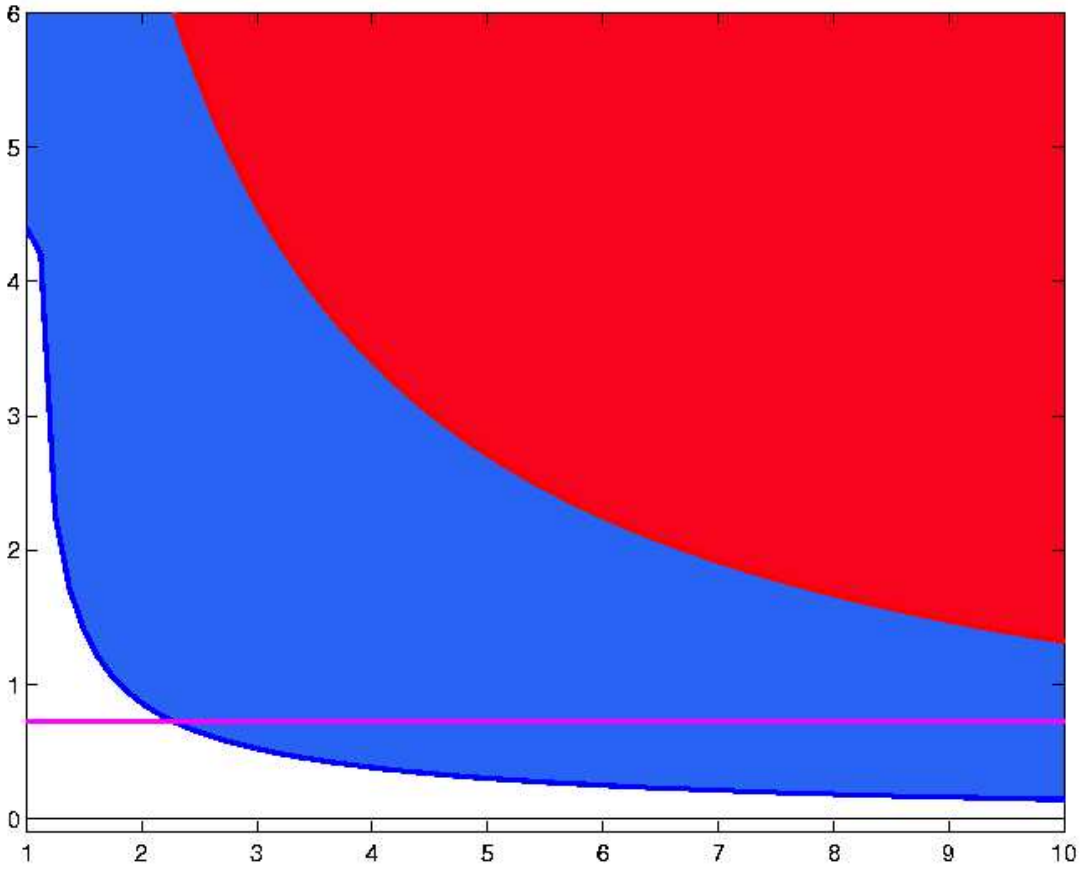
$$\mathbf{g}\cdot\left(\frac{\nabla\rho_0}{\rho_0}-\frac{\mathbf{g}}{C_\parallel^2}\right)+\mathbf{c}_0\cdot\left[-\frac{\nabla P_{\perp 0}}{\rho_0}-\frac{\nabla P_{\parallel 0}}{\rho_0}+2\mathbf{g}+\mathcal{F}\mathbf{c}_0\right]$$

$$\geq \frac{\left[\left(1-\frac{C_\perp^2}{C_\parallel^2}\right)\mathbf{g}+\mathcal{F}\,\mathbf{c}_0\right]^2}{\mathcal{M}}$$

η-exospheric model

Pierrard and Lemaire [2001]

$$-\frac{\boldsymbol{\nabla}\rho_0}{\boldsymbol{\rho_0}} \ \left(\frac{1}{R_E}\right)$$



$\mathbf{L}\ (R_E)$

Unstable for $\mathrm{L} > 2.3\,R_E$

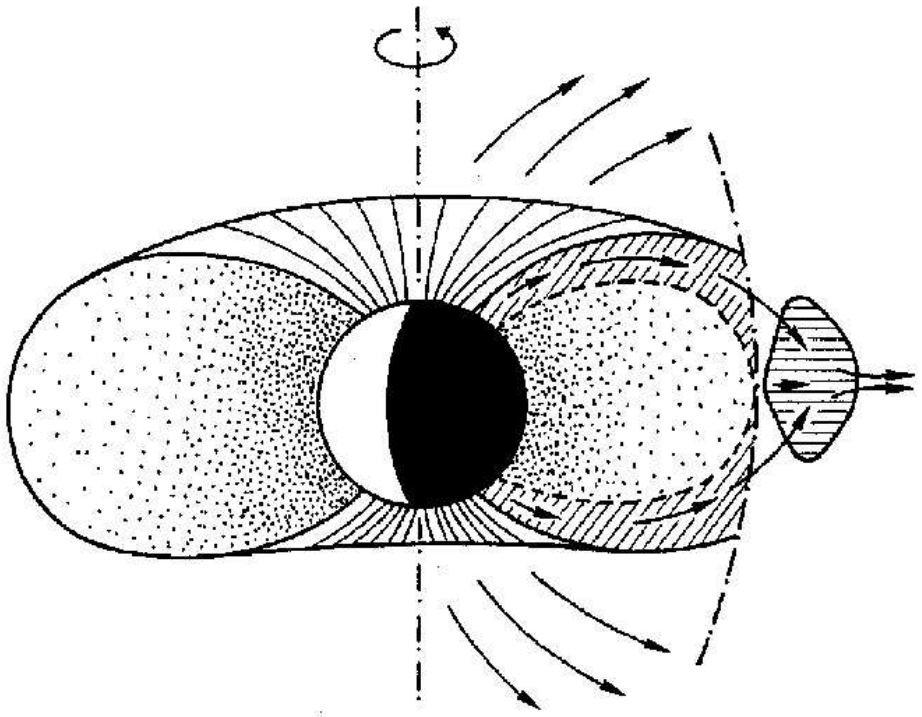
REALISTIC APPLICATION

Profiles stable against type 1 mode
but unstable against type 2 mode

⇒ Plasma flow along field lines !

Non-linear Scenario ?

⇒ Ballooning-type instability



⇒ Detached plasmoids

DISCUSSION