

Convective instabilities in the plasmasphere

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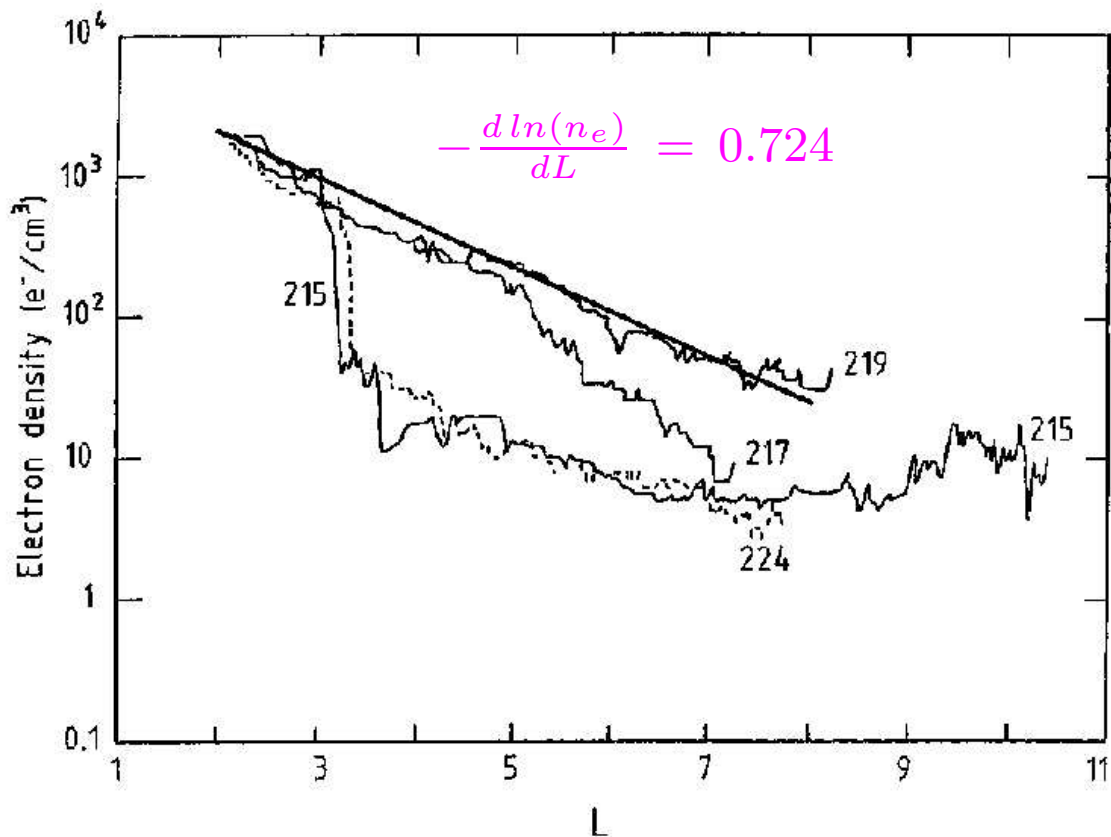
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Workshop plasmasphere

The plasmasphere: a closed region
in hydrostatic equilibrium ?



Carpenter and Anderson [1992]

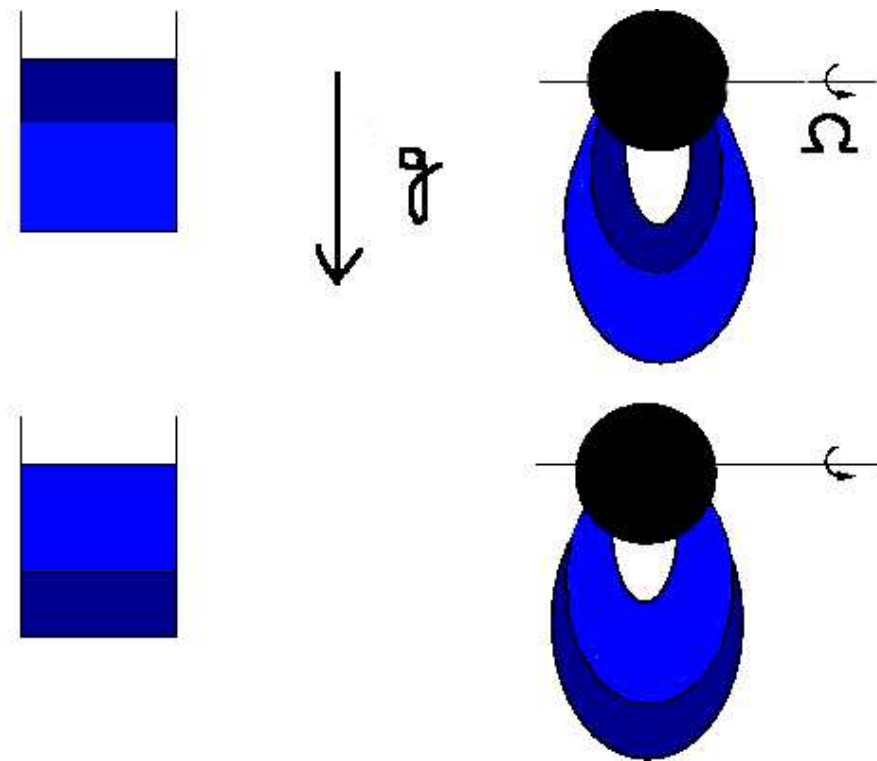
Refilling and saturation ?

Continuous plasmaspheric wind

Lemaire and Schunk [1992, 1994]

OBSERVATIONAL CONTEXT

Rayleigh-Taylor type Instability



Cross-L interchange motion
Field-aligned transport

MHD modes influenced by gravitation

Newcomb [1961]

$$k_{\parallel} \ll k$$

Quasi-interchange

type 1

type 2

$$k_{\parallel} \rightarrow 0$$

$$k_{\parallel} \rightarrow 0$$

interchange

translation

Stability criteria

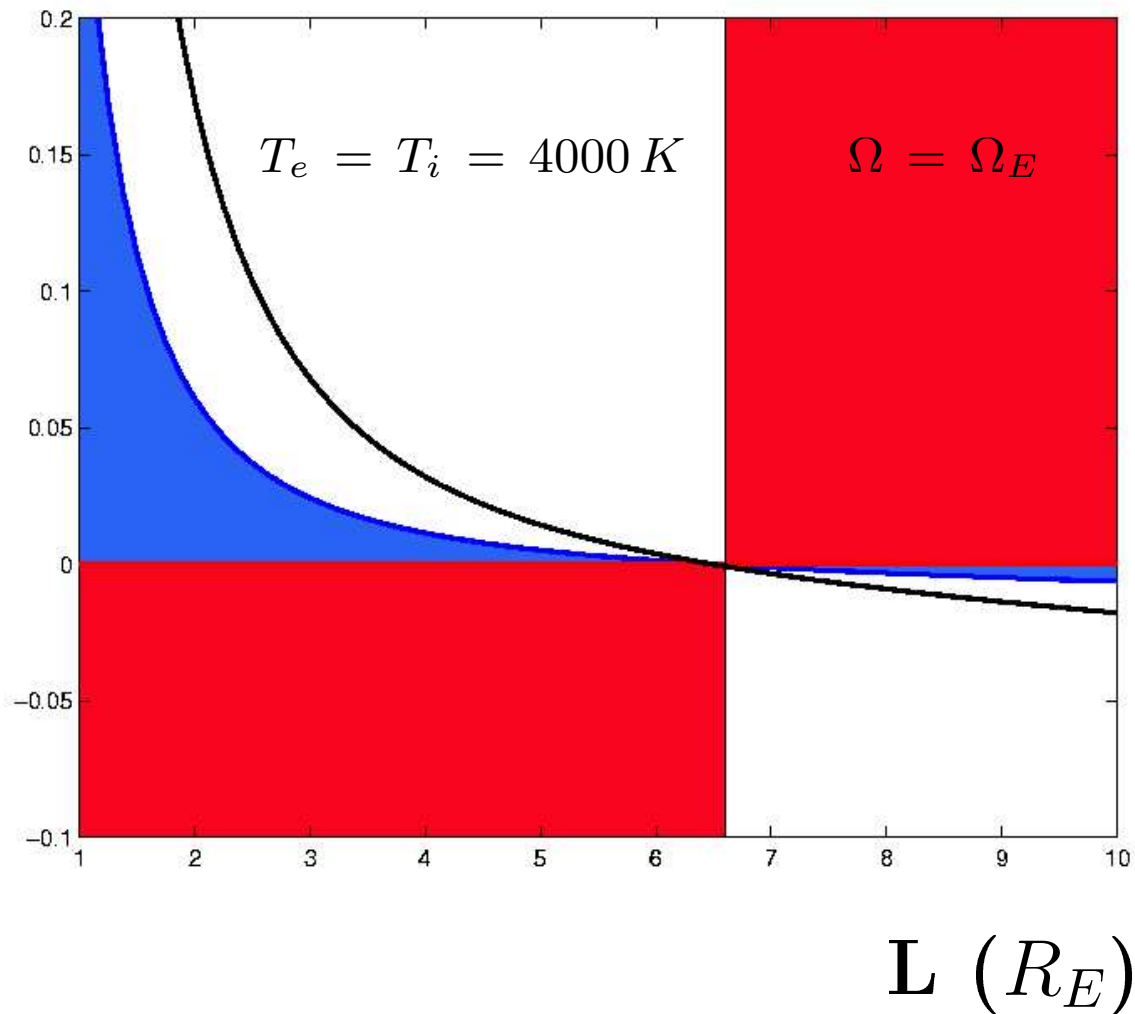
$$\text{stable} \iff \mathbf{g} \cdot \left(\frac{\nabla \rho_0}{\rho_0} - \frac{\mathbf{g}}{V_A^2 + C_s^2} \right) \geq 0$$

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

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

Isothermal hydrostatic equilibrium

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



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

Unstable for $L > 6.6 R_E$

APPLICATION

g, Ω

MHD modes influenced by stratification

Ferrière et al. [2001]

$k_{\parallel} \ll k$

Quasi-interchange

type 1

type 2

$k_{\parallel} \rightarrow 0$

$k_{\parallel} \rightarrow 0$

interchange

translation

Stability criteria

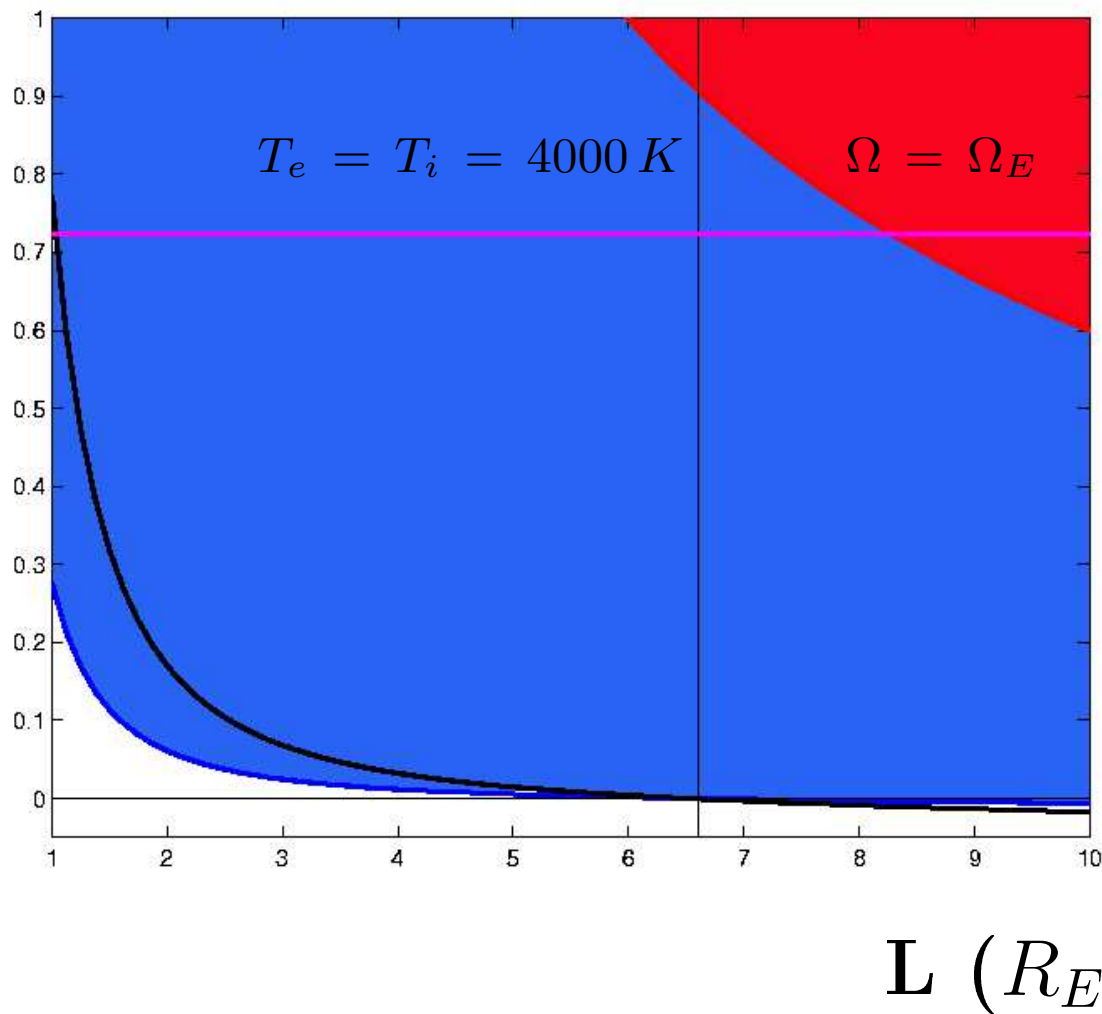
$$(g - 2 C_s^2 c_0) \cdot \left(\frac{\nabla \rho}{\rho_0} - \frac{g + 2 V_A^2 c_0}{V_A^2 + C_s^2} \right) \geq 0$$

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

GRAVITY + CURVATURE

Isothermal hydrostatic equilibrium

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



Unstable for $L < 6.6 R_E$

Unstable for $L > 1$ & $L > 8.3 R_E$

APPLICATION

g, Ω, c_0

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

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

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

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

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

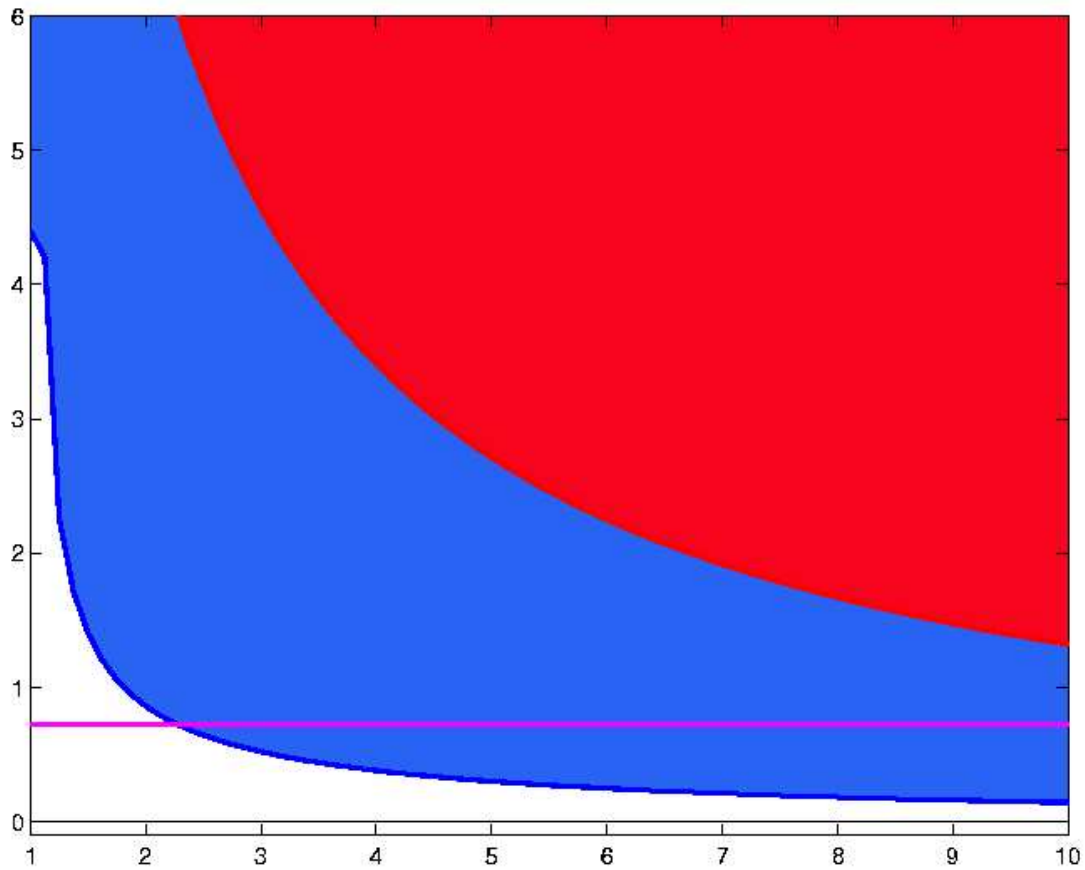
$$\mathbf{g} \cdot \left(\frac{\nabla \rho_0}{\rho_0} - \frac{\mathbf{g}}{C_{\parallel}^2} \right) + \mathbf{c}_0 \cdot \left[-\frac{\nabla P_{\perp 0}}{\rho_0} - \frac{\nabla P_{\parallel 0}}{\rho_0} + 2\mathbf{g} + \mathcal{F} \mathbf{c}_0 \right]$$

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

η -exospheric model

Pierrard and Lemaire [2001]

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



$L (R_E)$

Unstable for $L > 2.3 R_E$

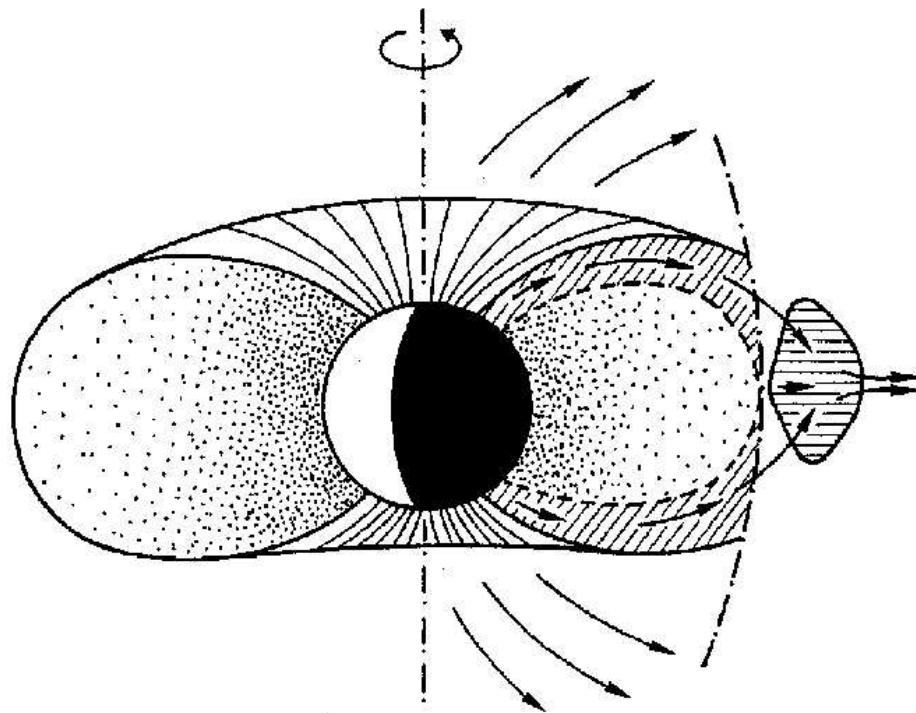
REALISTIC APPLICATION

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