Magnetosheath marginal stability: Hybrid expanding box simulations

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ISSI

Instabilities Driven by Proton Temperature Anisotropy

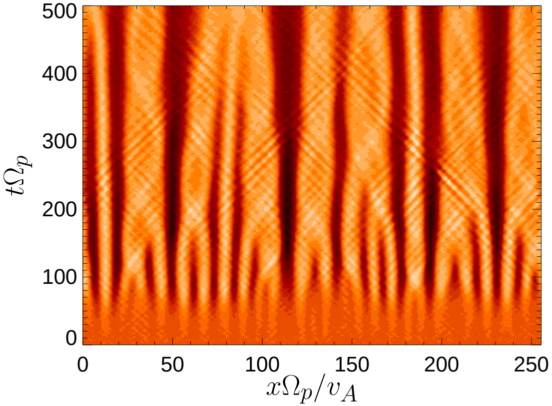
$T_{\perp p} > T_{\| p}$

- Ion cyclotron instability
  resonant, $\gamma_{\max}$ at parallel propagation
  quasilinear saturation

- Mirror instability
  $\omega = 0$, $\gamma_{\max}$ at oblique propagation
  special role of resonant particles ($v \sim 0$)

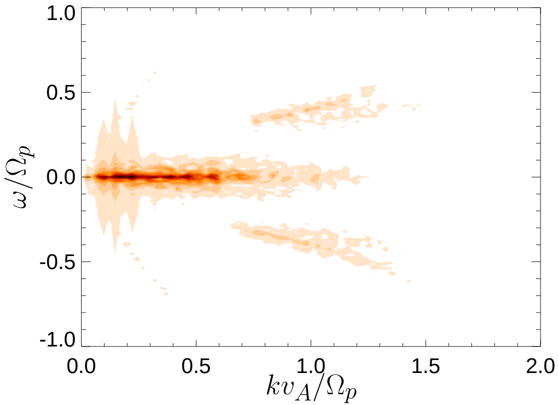
Wu et al., (2001): $\beta_{p\|} = 1$ and $\beta_{p\|} = 3$ for $\theta_{kB} = 70^{\circ}$

Evolution of B_y – mirror waves + ?



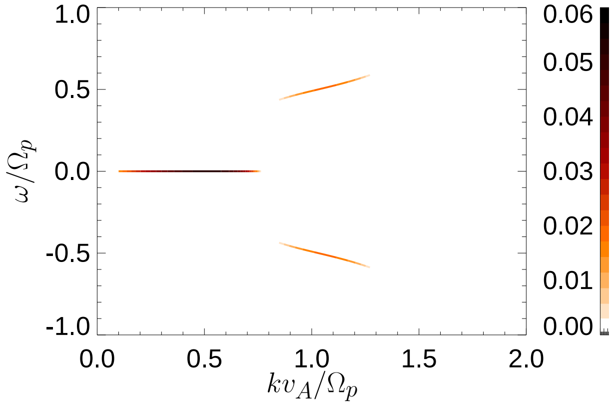
After Wu et al., (2001)

Spectrum B_y – Mirror & Alfvén waves



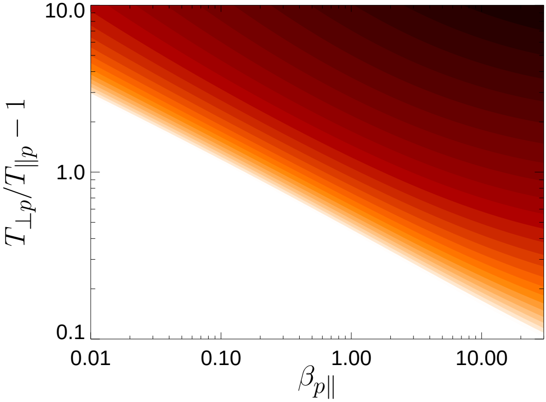
Linear theory

Explanation: Both instabilities are active!



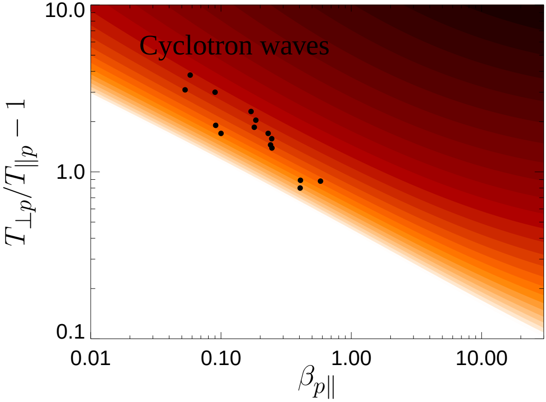
Observations: Magnetosheath Proton Anisotropy

Maximum growth rate of the ion cyclotron instability



Observations: Magnetosheath Marginal Stability

AMPTE: *Anderson and Fuselier* (1993) & *Gary et al.* (1993)



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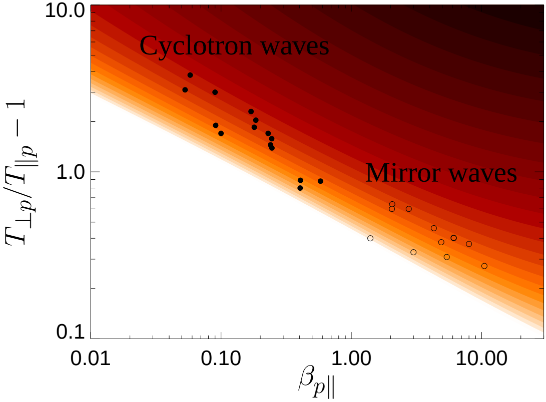
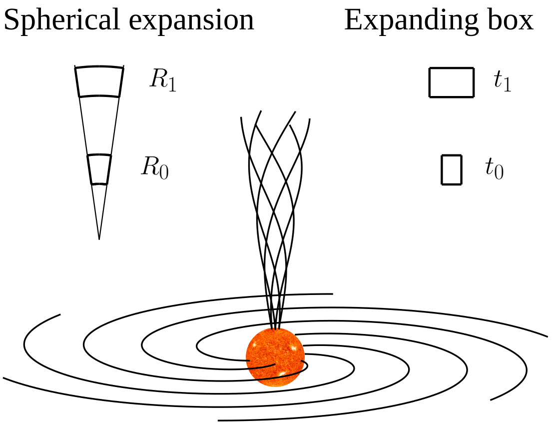


Expanding Solar Wind Plasma



Modified Vlasov Equation

Constant wind velocity U leads to the evolution:
Distance

$$R_1 = R_0 + U(t_1 - t_0)$$

Transverse sizes

$$x_\perp(t_1) = x_\perp(t_0)\frac{R_1}{R_0} = x_\perp(t_0)\left[1 + \frac{U}{R_0}(t_1 - t_0)\right]$$

$$x_\perp(t_1) = x_\perp(t_0)\left[1 + \frac{t_1 - t_0}{\tau}\right]$$

where τ is the characteristic time $\tau = R_0/U$.

Expanding box uses the co-moving coordinates $\xi = x_\perp(t_0)$

Generalization:

Let us suppose different characterictic times τ_i for each direction

$$x_i = (1 + t/\tau_i)\xi_i = L_{ii}\xi_i$$

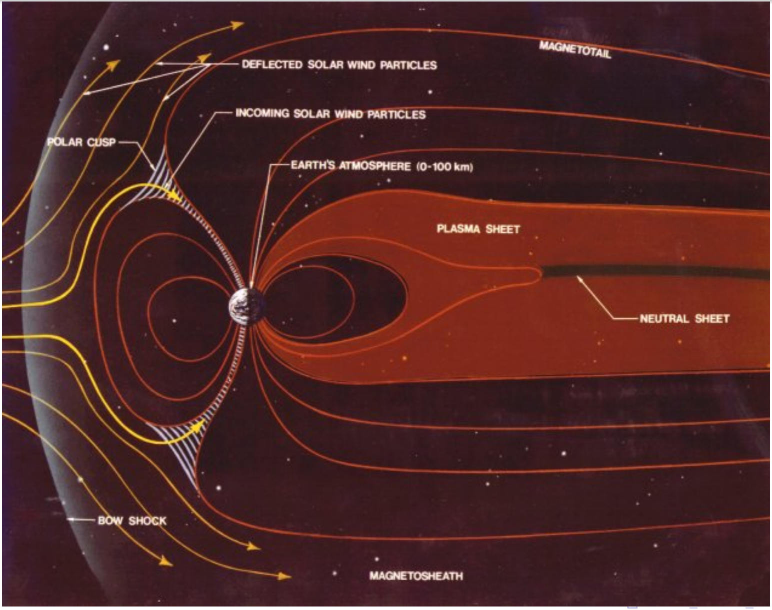
where $\mathbf{L} = \mathrm{diag}(L_{11}, L_{22}, L_{33})$

Vlasov equation in the co-moving coordinates $\boldsymbol{\xi}$ and $\boldsymbol{\nu} = d\boldsymbol{\xi}/dt$ may be given in a form

$$\frac{\partial f}{\partial t} + \boldsymbol{\nu} \cdot \frac{\partial f}{\partial \boldsymbol{\xi}} + \frac{q}{m}(\boldsymbol{\mathcal{E}} + \boldsymbol{\nu} \times \boldsymbol{\mathcal{B}}) \cdot \mathbf{L}^{-2} \cdot \frac{\partial f}{\partial \boldsymbol{\nu}} = 2\boldsymbol{\nu} \cdot \mathbf{V} \cdot \frac{\partial f}{\partial \boldsymbol{\nu}} \qquad (1)$$

where $\mathbf{V} = \mathbf{L}^{-1} \cdot d\mathbf{L}/dt$, and $\boldsymbol{\mathcal{B}} = (\det\mathbf{L})\mathbf{L}^{-1} \cdot \boldsymbol{B}$ and $\boldsymbol{\mathcal{E}} = \mathbf{L} \cdot \boldsymbol{E}$

Modified Vlasov equation (1) implemented in a hybrid code.


MAGNETOTAIL
DEFLECTED SOLAR WIND PARTICLES
INCOMING SOLAR WIND PARTICLES
POLAR CUSP
EARTH'S ATMOSPHERE (0-100 km)
PLASMA SHEET
NEUTRAL SHEET
BOW SHOCK
MAGNETOSHEATH

Magnetosheath plasma flow

Global magnetosheath plasma flow induces locally

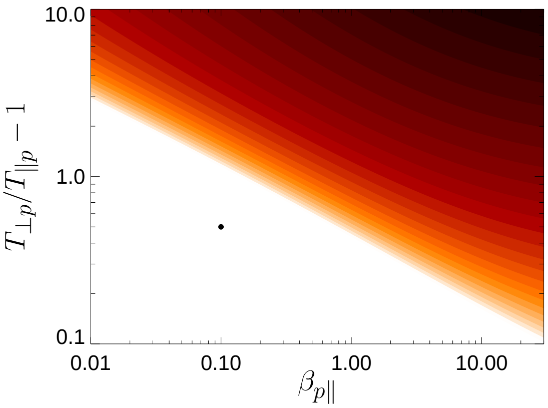
- plasma compression
- plasma expansion / field line stretching
- velocity shear, . . .
- temperature anisotropies $T_\perp > T_\parallel$

Compression: Expanding box model with a negative characteristic time.

$x_i = L_{ii}\xi_i = (1 - t/\tau_i)\xi_i$

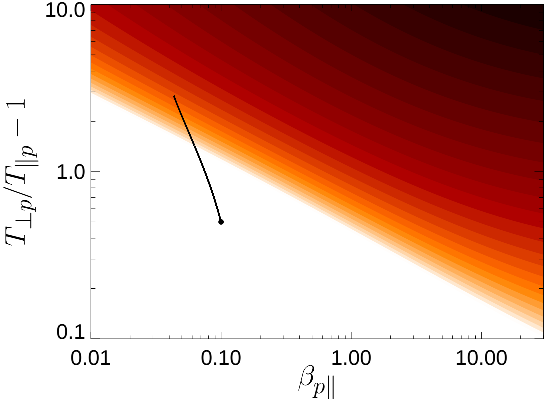
Compression process in the Magnetosheath

2D HEB simulations: Initial conditions



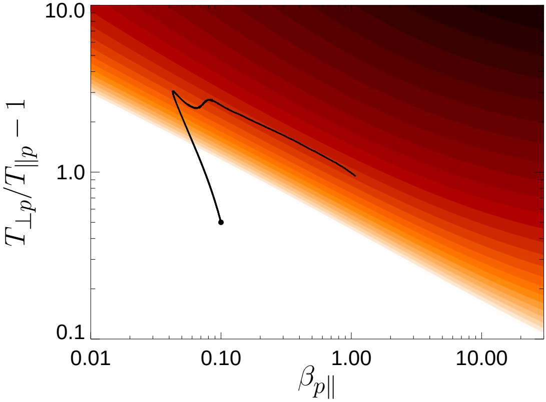
Compression Process in the Magnetosheath

2-D HEB simulations: CGL phase



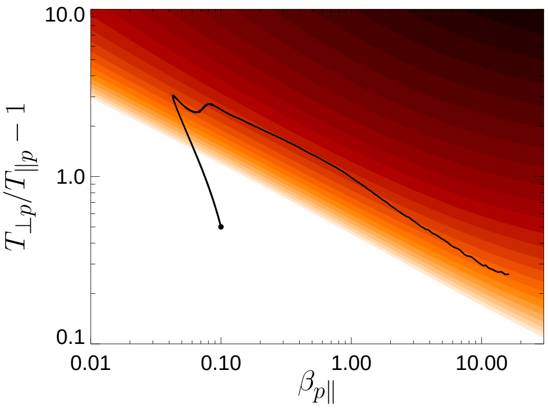
Compression Process in the Magnetosheath

2-D HEB simulations: ion cyclotron marginal stability path



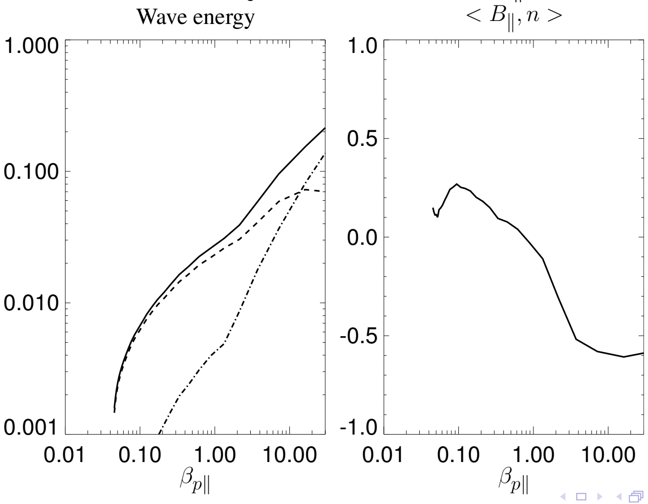
Compression Process in the Magnetosheath

2-D HEB simulations: Mirror waves



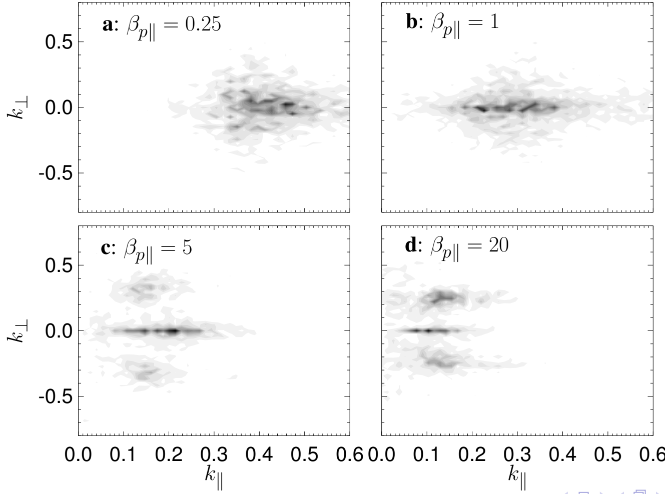
Compression Process in the Magnetosheath

Evolution of $\delta B^2/B_0^2$ and correlation $\langle \delta B_{\|}, n \rangle$



Compression Process in the Magnetosheath

Spectrum evolution



Magnetosheath Compression

HEB simulation of a slow compression

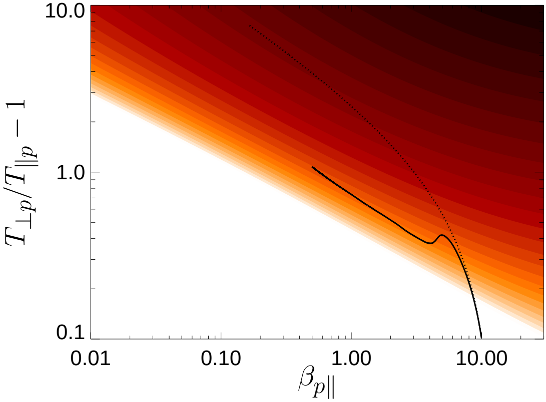
- ion cyclotron marginal stability path from low β to high β
- modified by mirror waves for high β

An opposite path, from high β to low β is often observed

The compression is not the only process.

Field Line Stretching

Marginal stability path in the opposite direction



Summary

- Investigation of plasma expansion or compression
- Insight to the role of wave-particle interactions
- Ion cyclotron marginal stability evolution
- Large amplitude mirror waves