UNIVERSITÀ DELLA CALABRIA

NONLINEAR WAVE-PARTICLE INTERACTION IN SOLAR WIND: HYBRID VLASOV NUMERICAL SIMULATIONS

*Denise Perrone**

in collaboration with

Francesco Valentini and Pierluigi Veltri**

** Dipartimento di Fisica, UNICAL*

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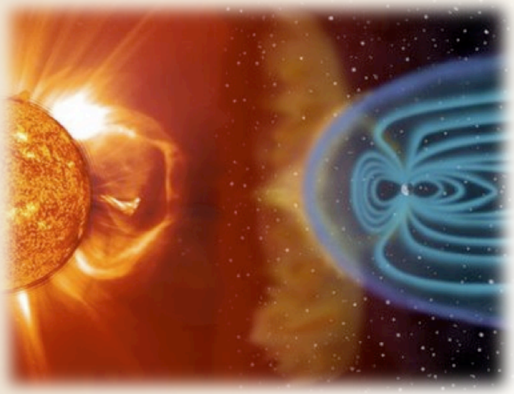
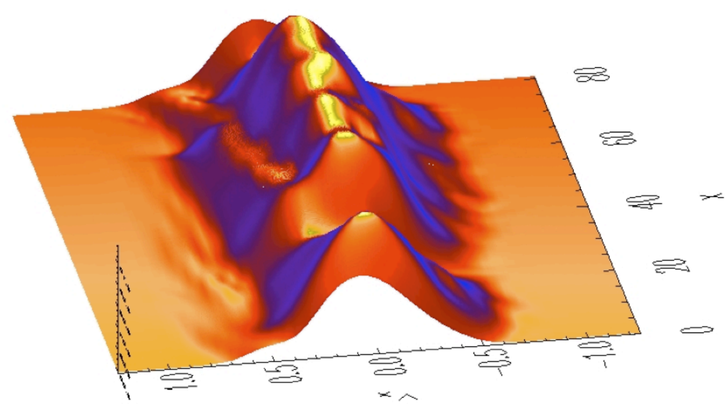
OUTLINE



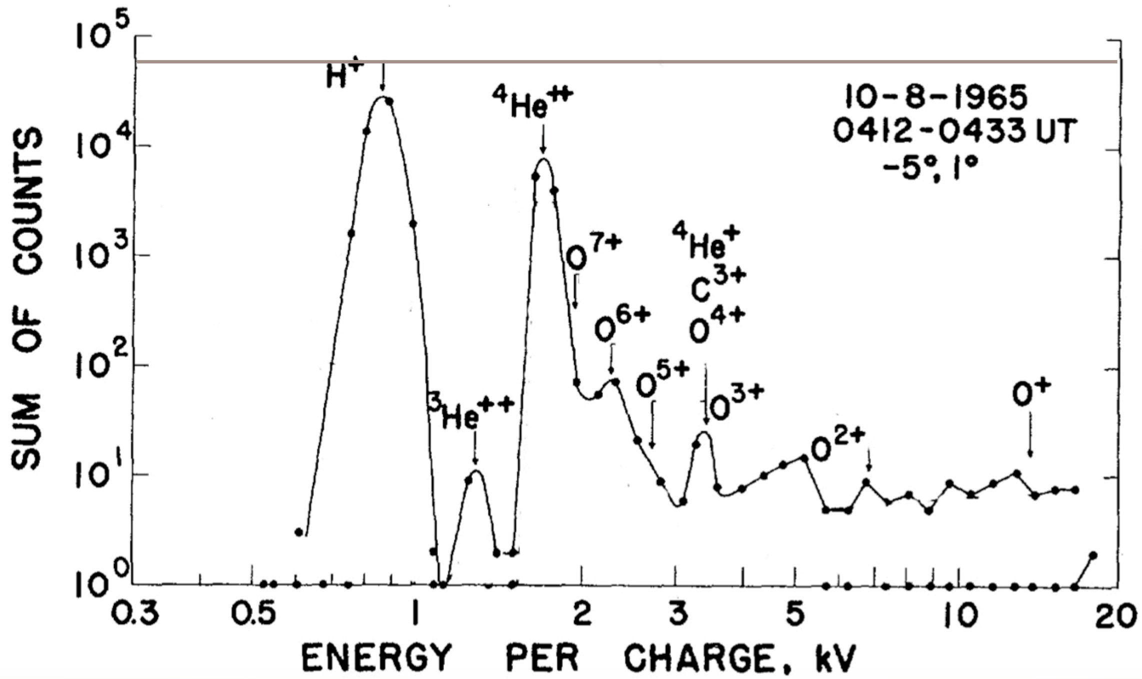
Solar Wind:
protons and alpha particles

Hybrid Vlasov numerical model and results



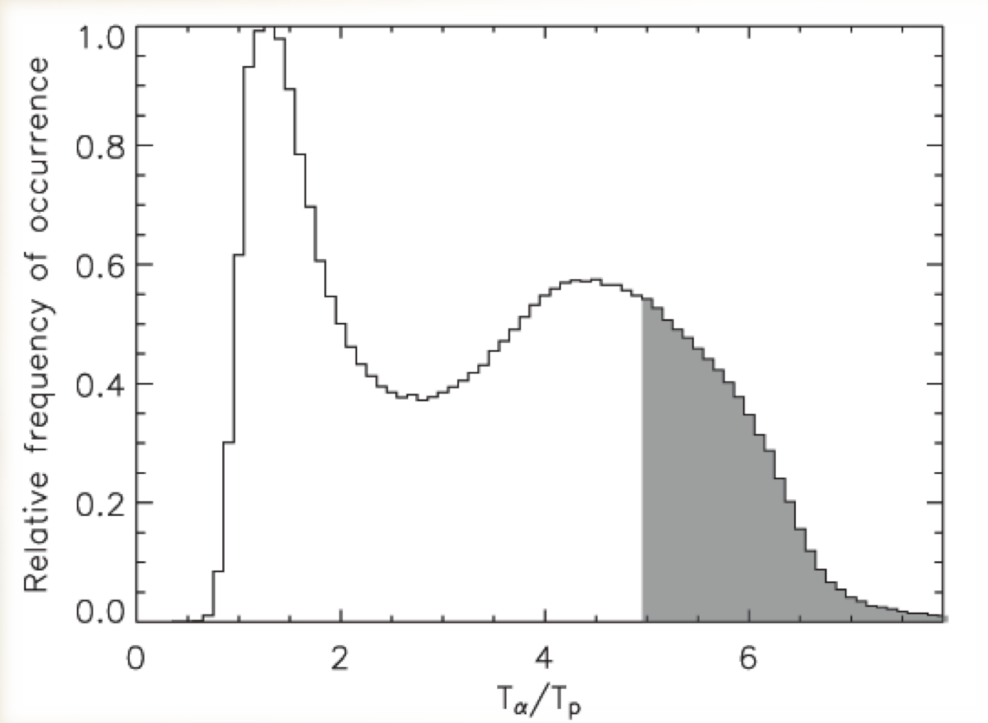
SOLAR WIND

The second most abundant ionic component is $^4He^{++}$ (≈ 5%)



Bame et al., Phys. Rev. Lett. 20, 393 (1968)

ALPHA PARTICLES



Kasper et al., Phys. Rev. Lett. 101, 261103 (2008)

ALPHA PARTICLES

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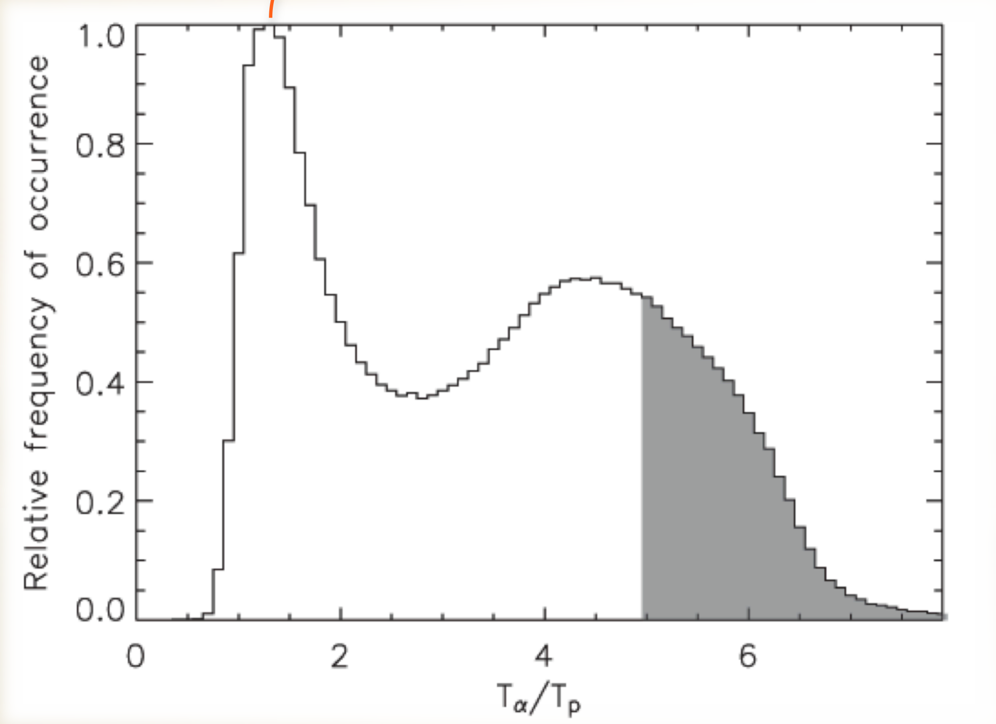

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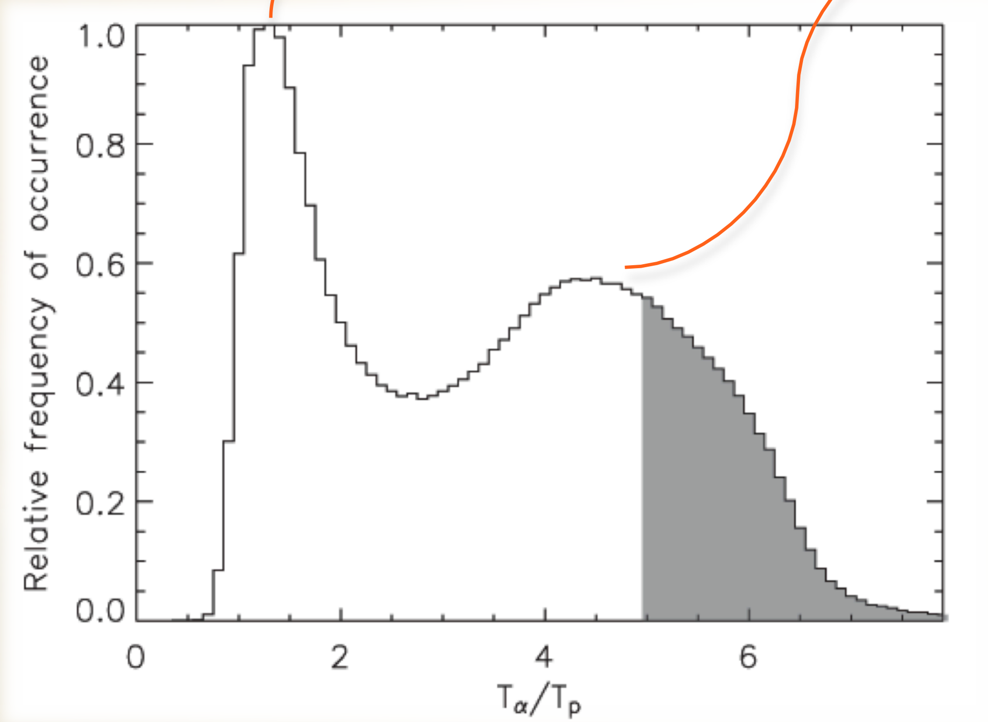

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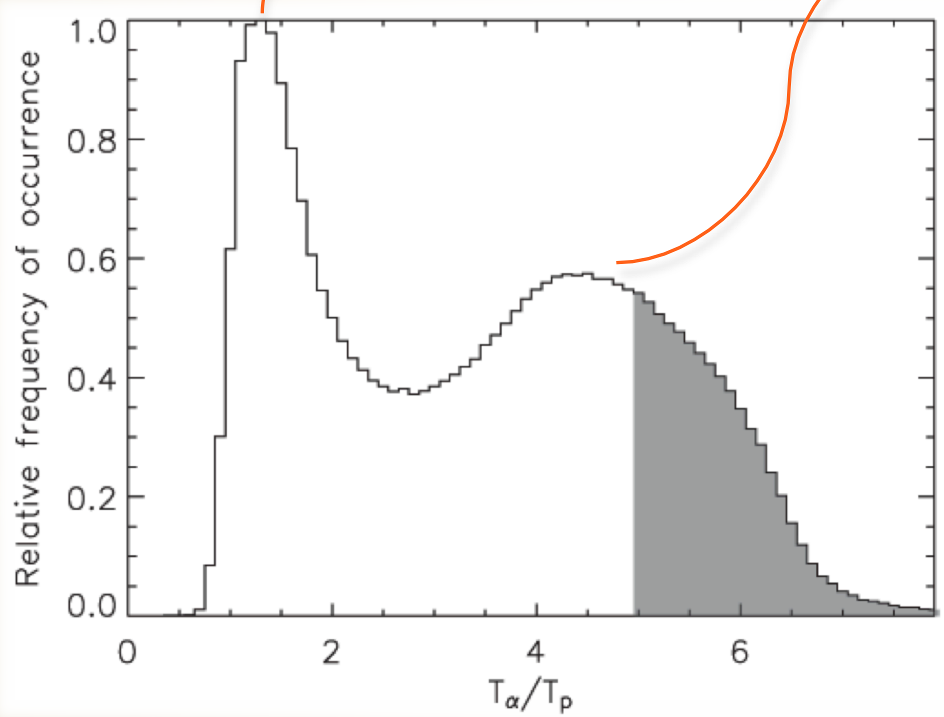
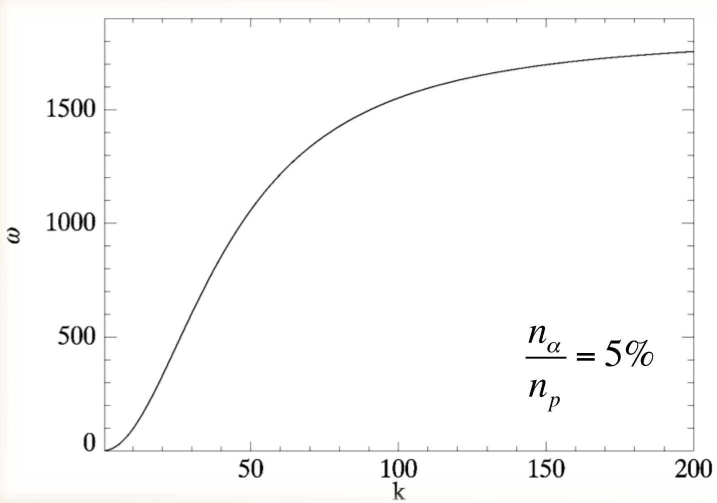


Alpha particles are heated and accelerated preferentially as compared to protons and electrons.

Kasper et al., Phys. Rev. Lett. 101, 261103 (2008)

ALPHA PARTICLES: linear theory

R-mode dispersion relation



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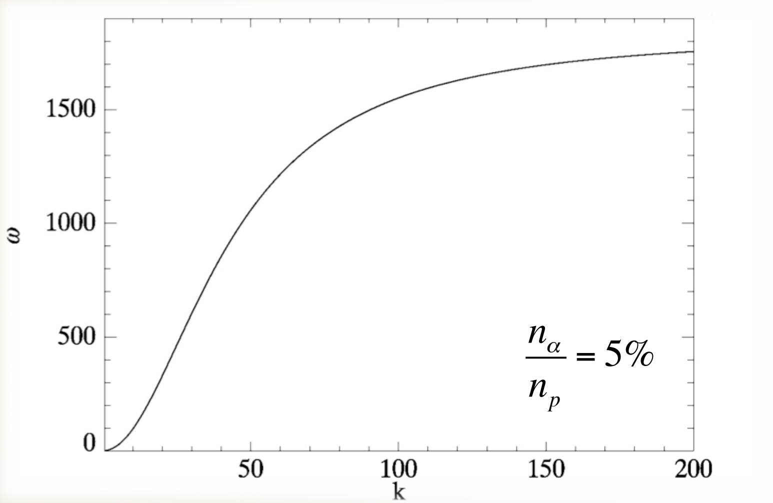
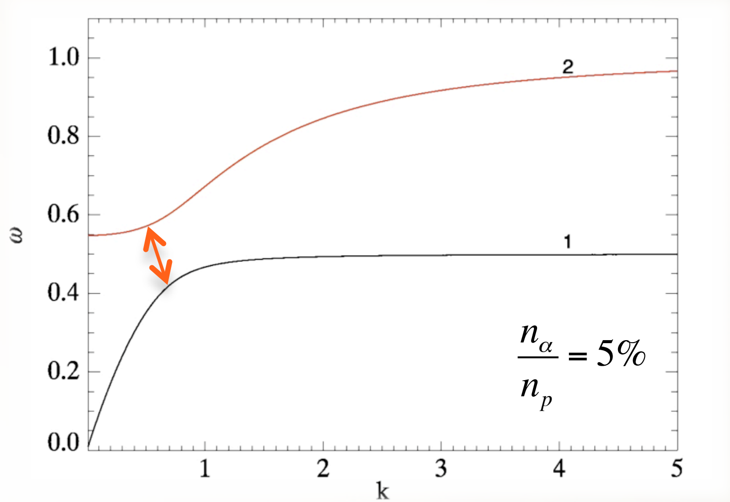


L-mode dispersion relation



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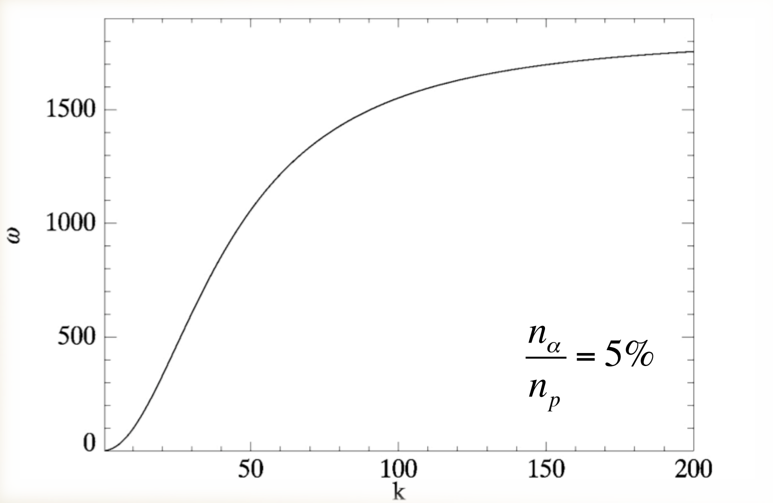

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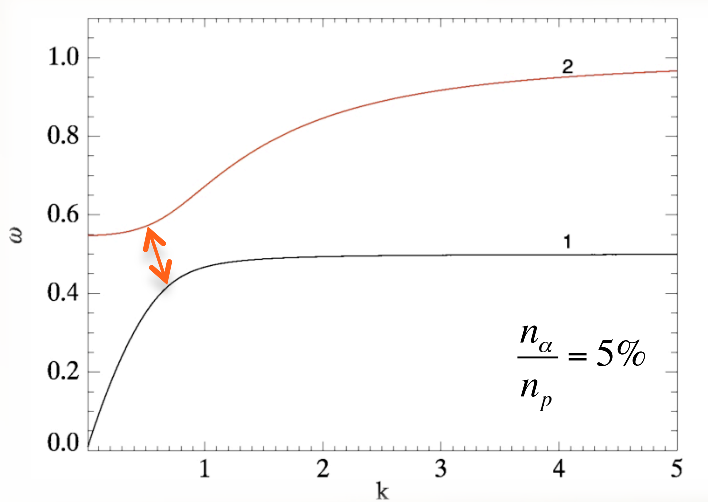

The presence of alpha particles changes the linear left-hand mode dispersion relation. The gap between the two branches depends on the alpha particle to proton density ratio.

NUMERICAL MODEL

In 1D-3V phase space configuration:

Vlasov equation

$$\frac{\partial f_i}{\partial t} + \mathbf{v} \cdot \nabla f_i + \left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right) \cdot \frac{\partial f_i}{\partial \mathbf{v}} = 0$$

$$\frac{\partial f_p}{\partial t} + \mathbf{v} \cdot \nabla f_p + \left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right) \cdot \frac{\partial f_p}{\partial \mathbf{v}} = 0$$

$$\frac{\partial f_\alpha}{\partial t} + \mathbf{v} \cdot \nabla f_\alpha + \left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right) \cdot \frac{\partial f_\alpha}{\partial \mathbf{v}} = 0$$

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Maxwell equations

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathrm{E}$$

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Quasi-neutrality condition

$$n_e \cong n_p + Z_\alpha n_\alpha$$

NUMERICAL MODEL

In 1D-3V phase space configuration:

Characteristic quantities

$$\bar{v} = V_A \quad \bar{\omega} = \Omega_{c,p} \quad \bar{l} = V_A / \Omega_{c,p} = d_p \quad \bar{n} = n_e$$

$$\bar{E} = m_p V_A \Omega_{c,p} / e \qquad \bar{B} = m_p c \Omega_{c,p} / e$$

Vlasov equation

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$$N_i = Z_i \frac{n_i}{n_e}$$

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$$N_i = Z_i \frac{n_i}{n_e} \qquad \frac{1}{M_i} = Z_i \frac{m_e}{m_i} \qquad P_e = \frac{\beta}{2} n_e \frac{T_e}{T_p}$$

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$$\mathbf{B}_0 = B_0 \hat{e}_x$$

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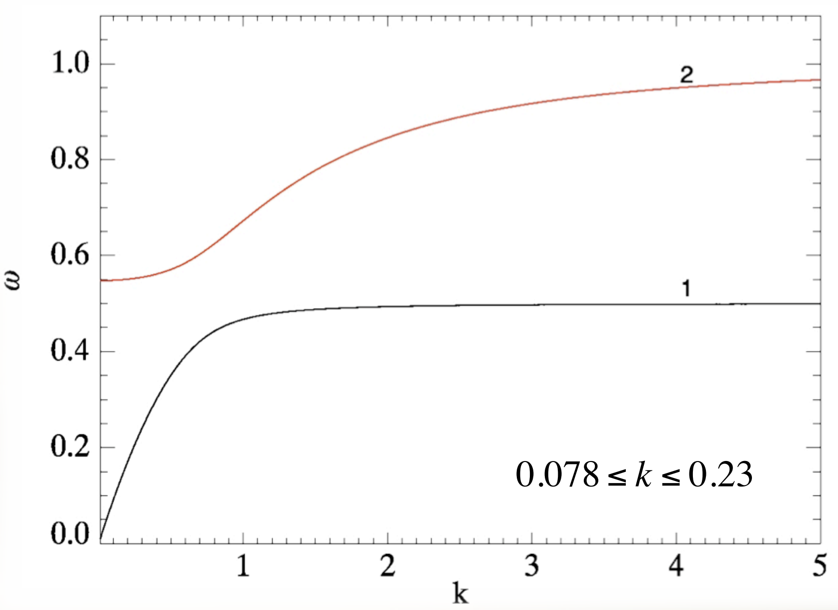

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$$\delta u_{y,p} = -\sum_n \varepsilon_n \frac{1}{\omega_n - 1}\cos(k_n x)$$

$$\delta u_{z,p} = -\sum_n \varepsilon_n \frac{1}{\omega_n - 1}\sin(k_n x)$$

$$\delta u_{y,\alpha} = -\sum_n \frac{Z_\alpha m_p}{m_\alpha}\varepsilon_n \frac{1}{\omega_n - Z_\alpha m_p / m_\alpha}\cos(k_n x)$$

$$\delta u_{z,\alpha} = -\sum_n \frac{Z_\alpha m_p}{m_\alpha}\varepsilon_n \frac{1}{\omega_n - Z_\alpha m_p / m_\alpha}\sin(k_n x)$$

$$\delta B_y = -\sum_n \varepsilon_n \frac{k}{\omega_n}\cos(k_n x)$$

$$\delta B_z = -\sum_n \varepsilon_n \frac{k}{\omega_n}\sin(k_n x)$$

SIMULATIONS

We analyze the kinetic dynamics of protons and alpha particles in terms of different values of the temperature ratios

$$\frac{T_e}{T_p} = 1, 5, 10$$

↔

$$\frac{T_\alpha}{T_p} = 1, 4$$

RESULTS

Independently on T_e/T_p or T_α/T_p:

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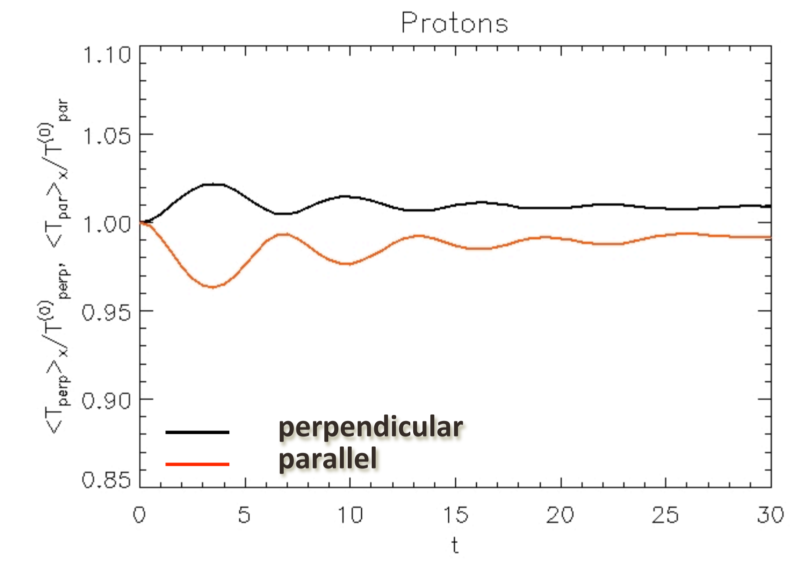

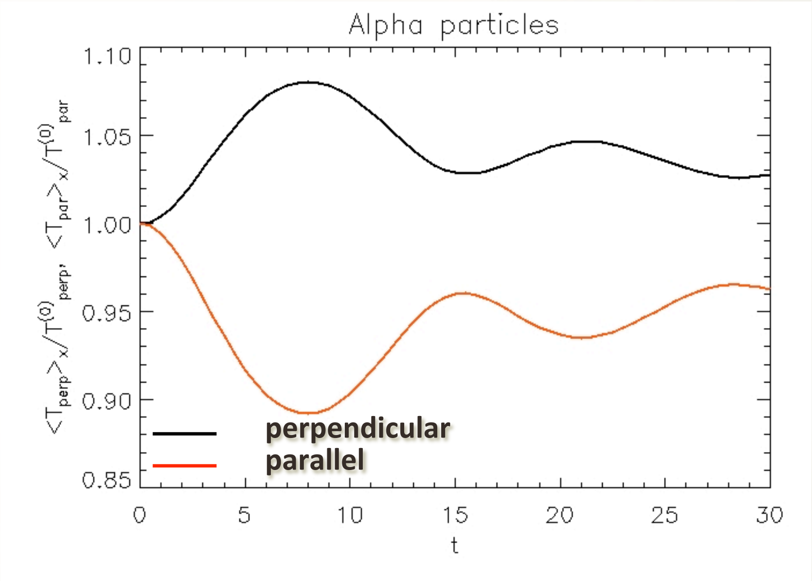

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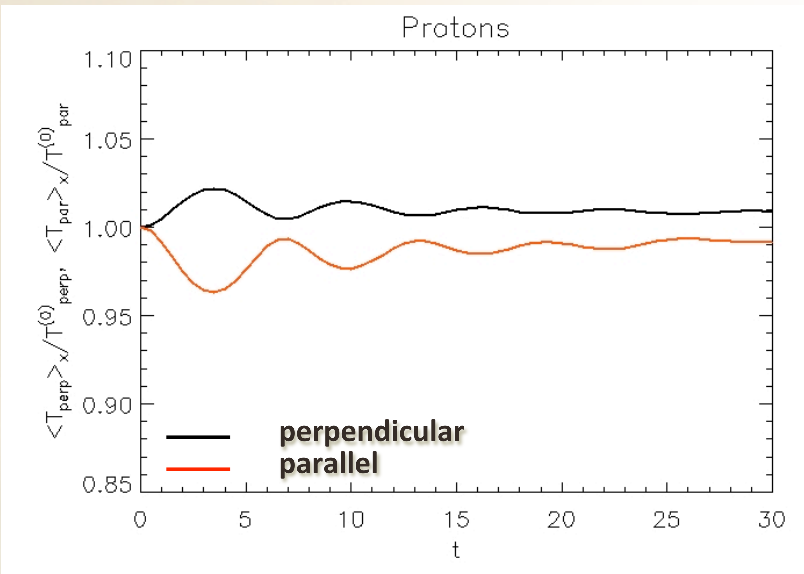

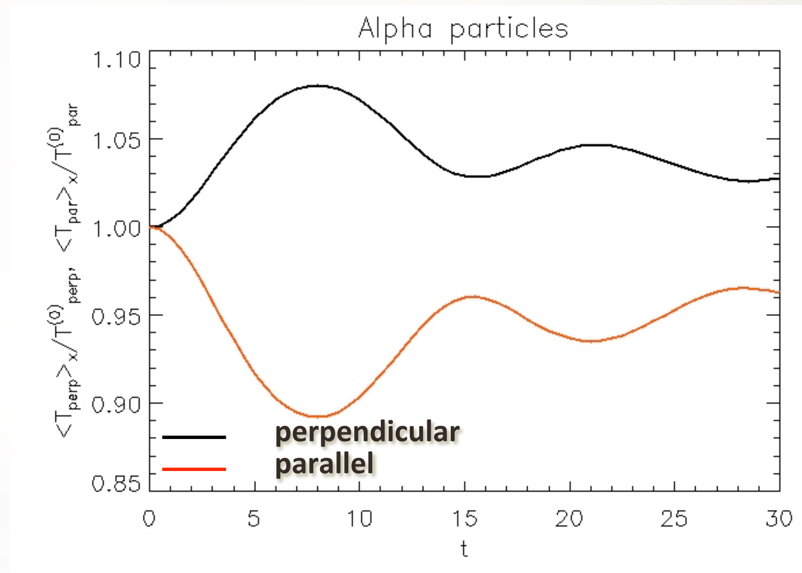

$$\xi = \frac{\langle T_\perp \rangle_x}{\langle T_{//} \rangle_x}$$

the maximum value of the anisotropy index

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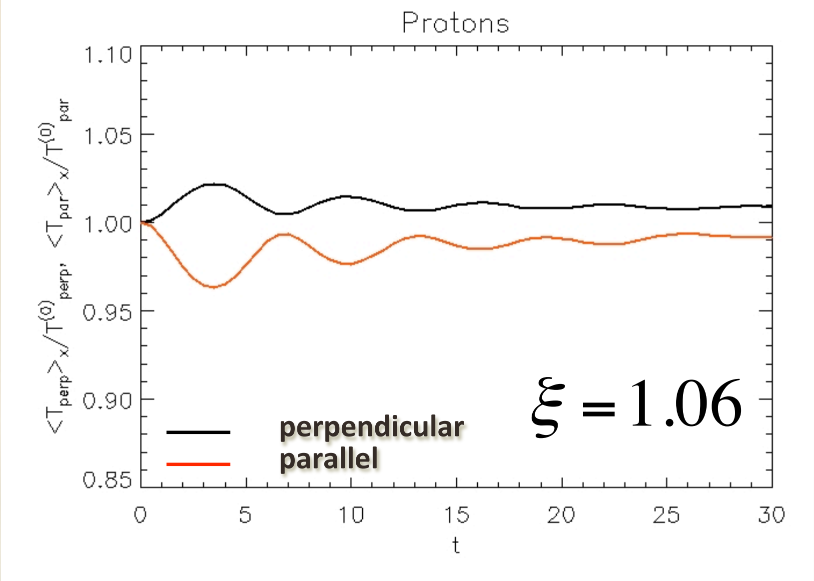

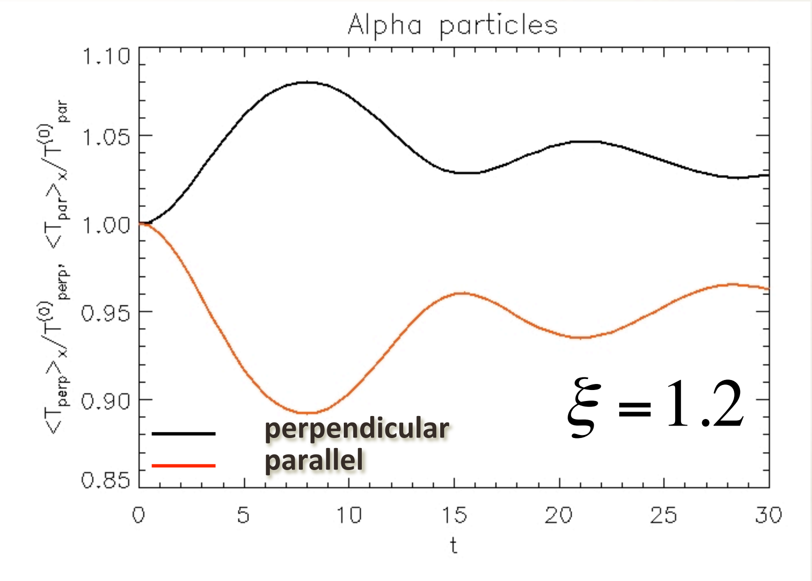

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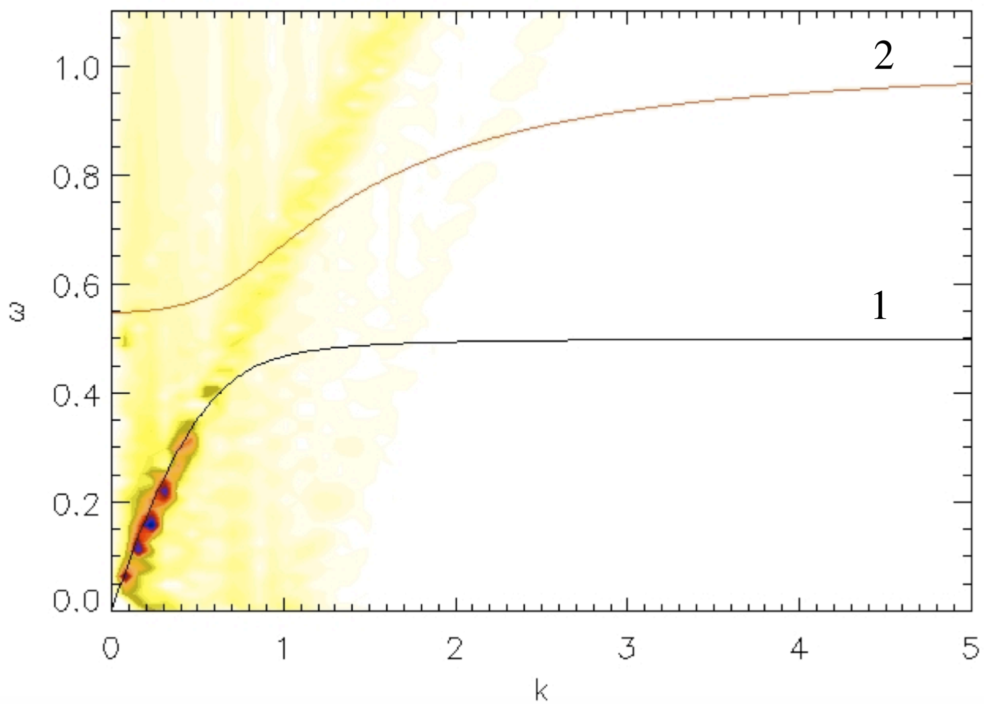
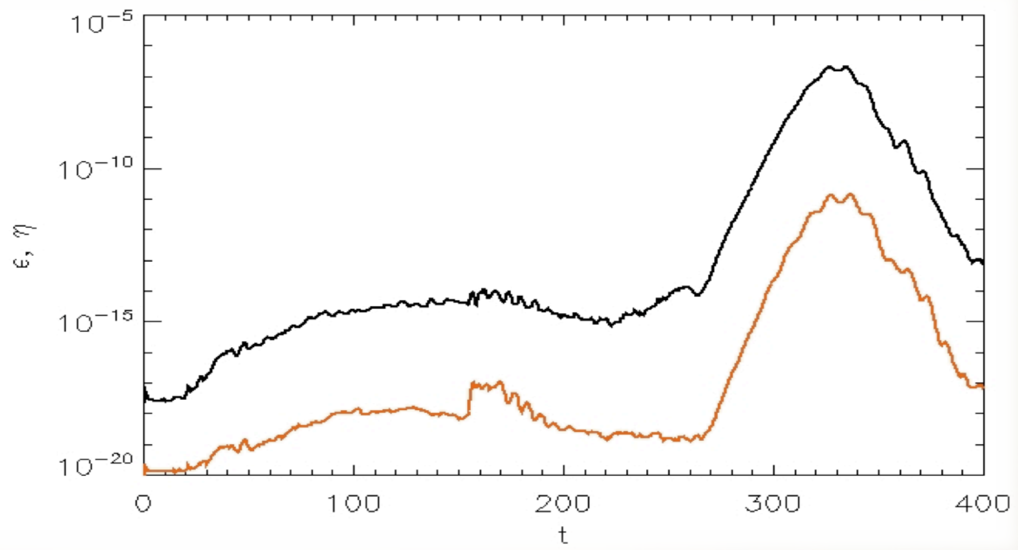


RESULTS: $T_e/T_p=1$

Independently on T_α/T_p

(black line) $$\varepsilon = \sum_{k>10} |E_k|^2$$

(red line) $$\eta = \sum_{k>10} |B_k|^2$$



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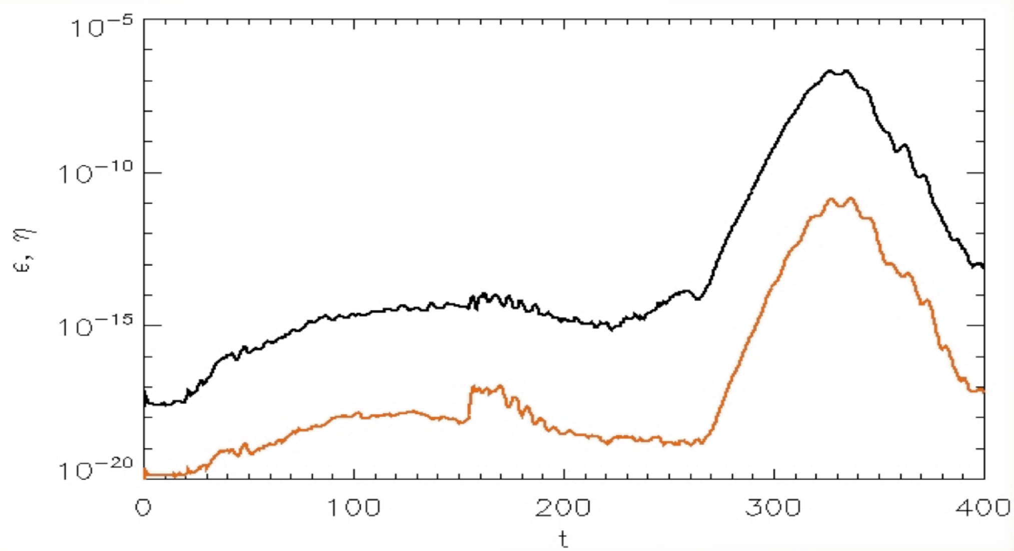

The tail at short wavelengths of the energy spectrum is dominated by electrostatic activity.

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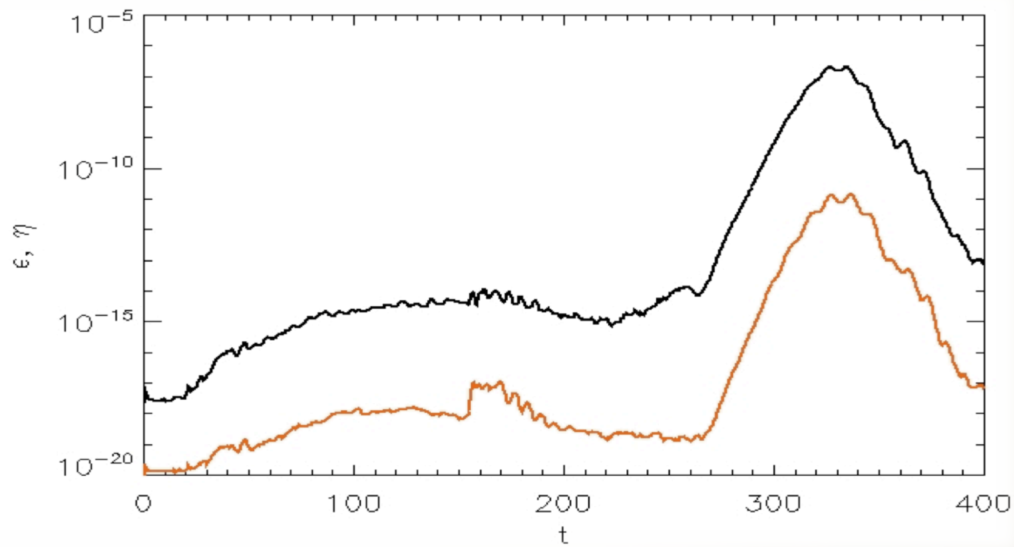

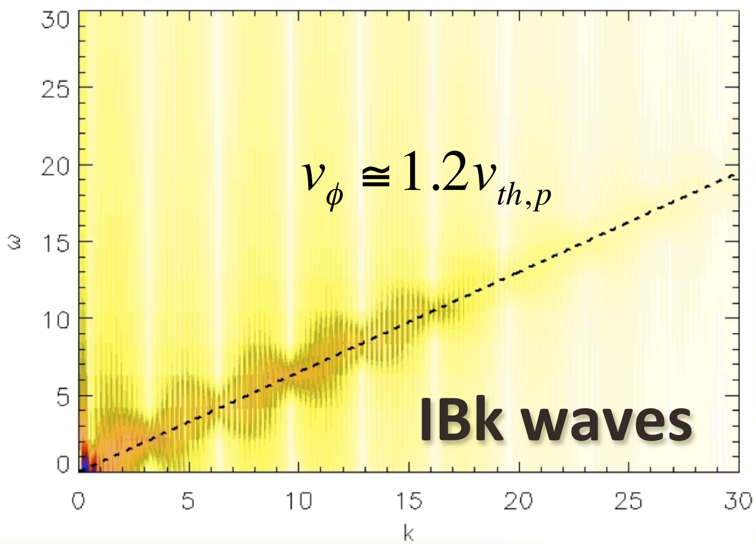

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Valentini et al., Phys. Rev. Lett. 101, 025006 (2008)
Valentini & Veltri, Phys. Rev. Lett. 102, 225001 (2009)

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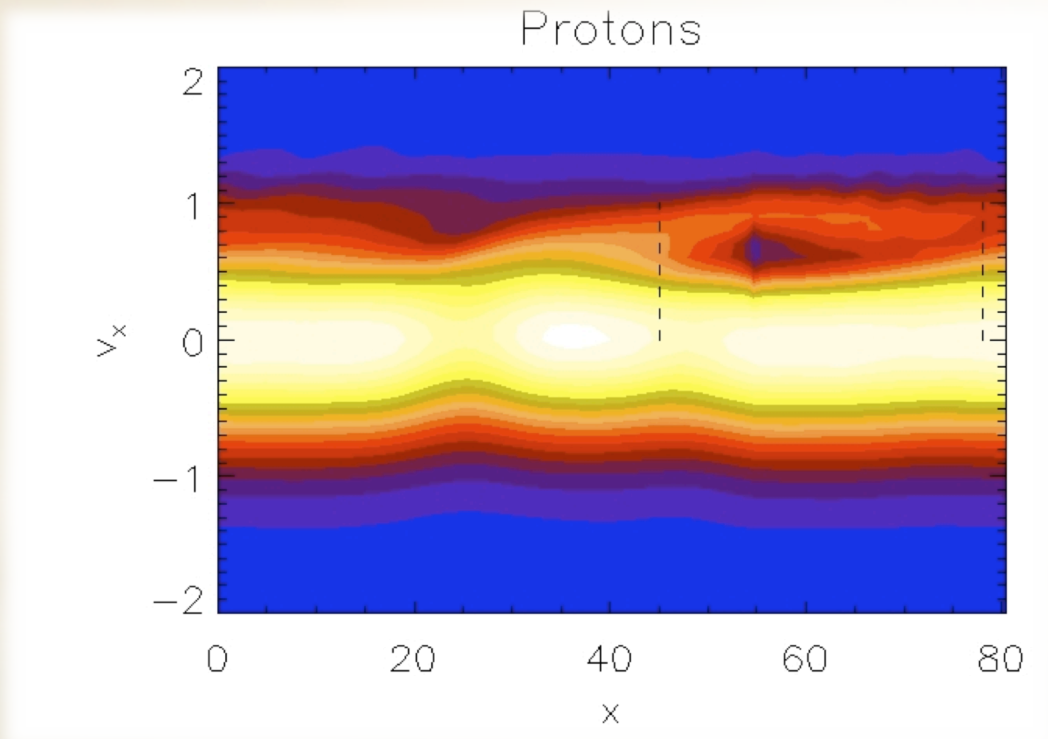
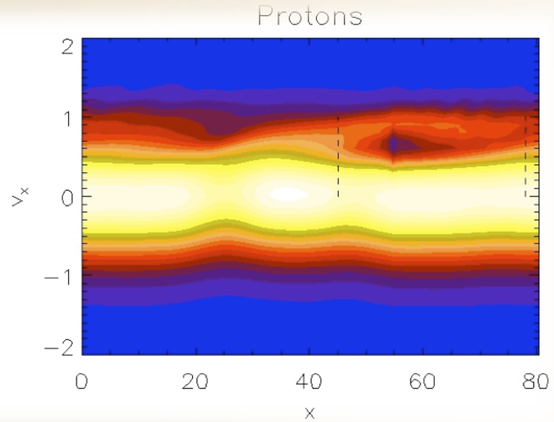


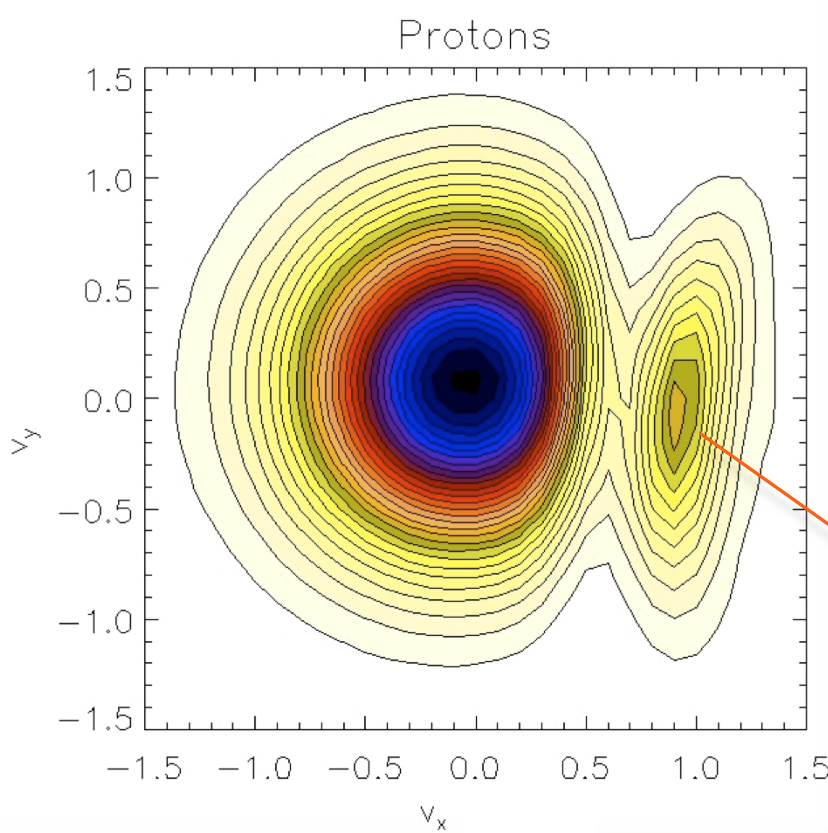
Generation of a localized trapped particle region

RESULTS: $T_e/T_p=1$

Independently on T_α/T_p



$$\hat{f}(v_x,v_y)=\frac{1}{x_2-x_1}\int_{x_1}^{x_2}dx\int_{-\infty}^{\infty}dv_z f(x,v_x,v_y,v_z)$$



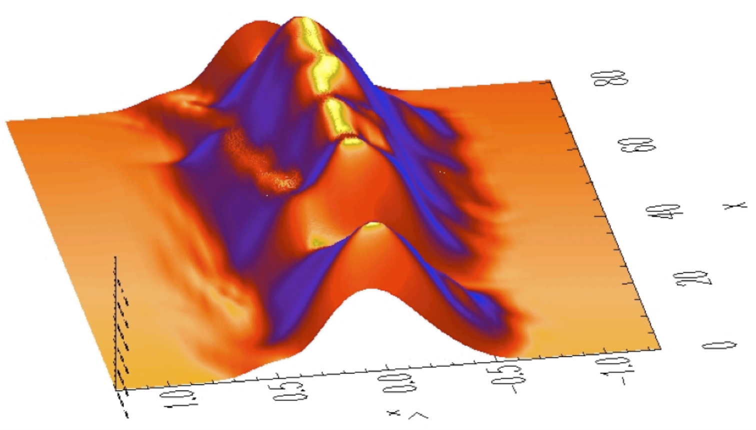
Generation of a well-defined field-aligned beam

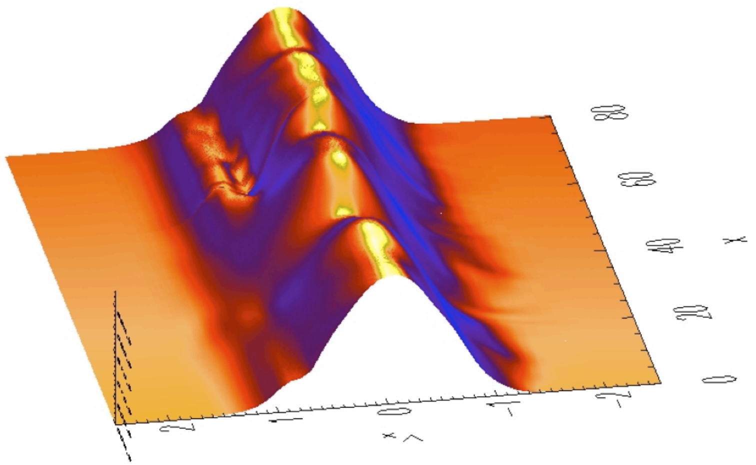
$\mathbf{B}_0$

RESULTS: T_e/T_p=1

$$\frac{T_\alpha}{T_p} = 1$$

$$\frac{T_\alpha}{T_p} = 4$$





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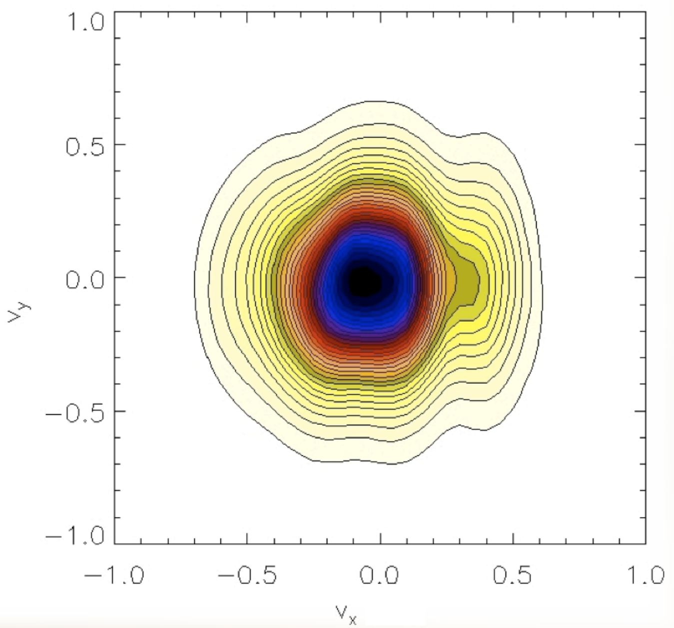

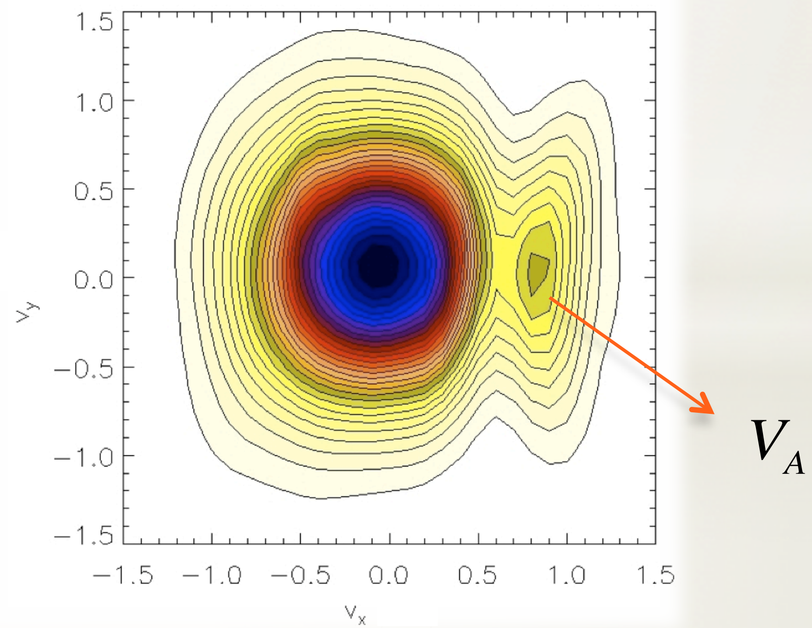

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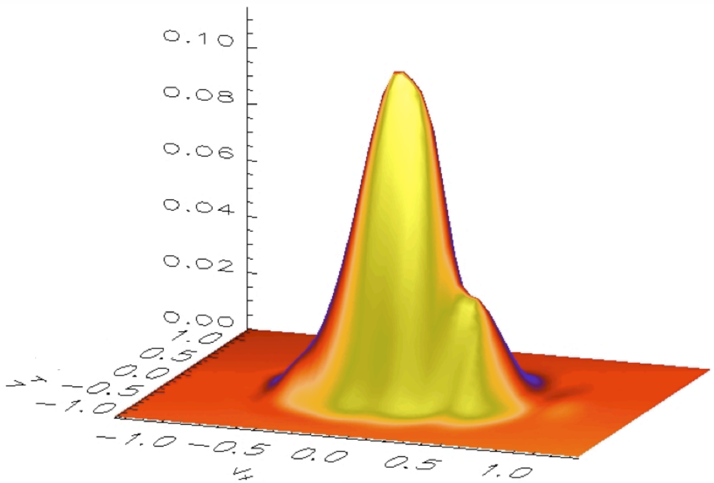
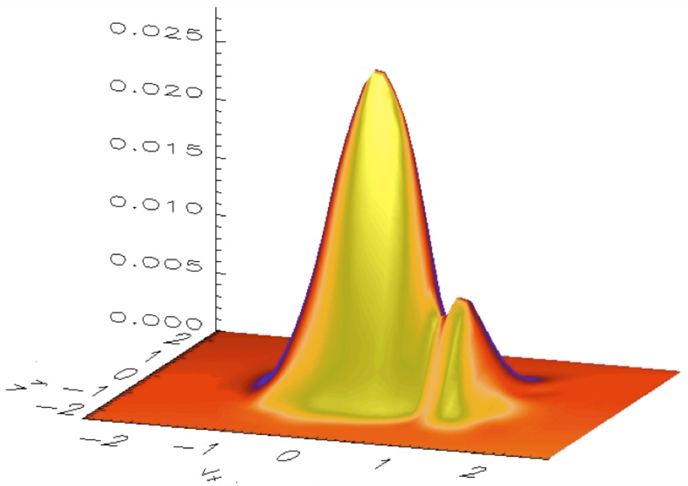
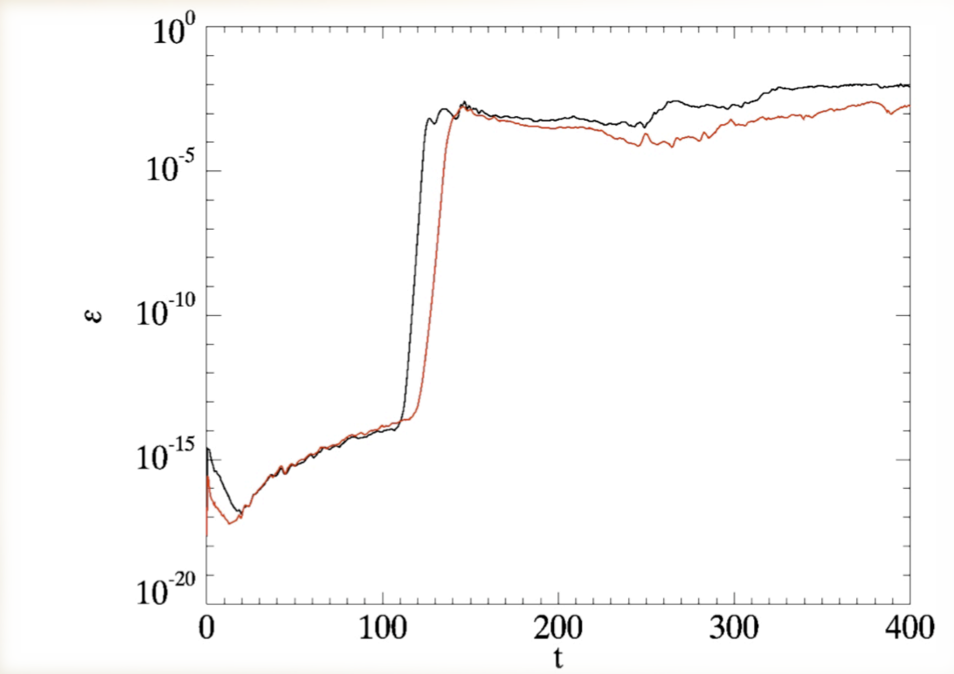




RESULTS: T_e/T_p=5,10

Independently on T_α/T_p



$$\varepsilon = \sum_{k>10} \left|E_k\right|^2$$

$$\frac{T_e}{T_p} = 10$$

$$\frac{T_e}{T_p} = 5$$

RESULTS: T_e/T_p=5,10

Independently on T_α/T_p

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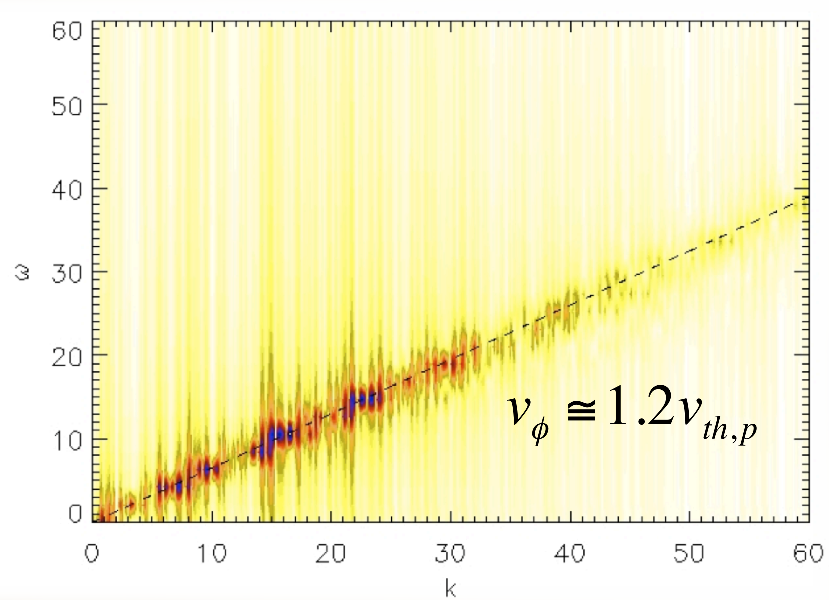

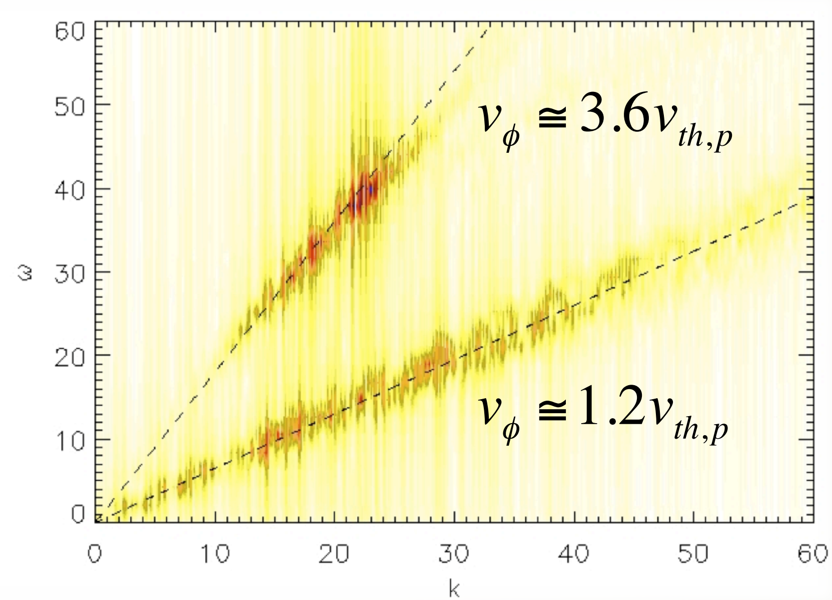

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The ion-acoustic branch is recovered only in the simulations with T_e/T_p=10, unrealistic for the solar wind.

THANKS FOR YOUR ATTENTION