SPONTANEOUS WHISTLER-CYCLOTRON FLUCTUATIONS OF THERMAL AND NON-THERMAL ELECTRON DISTRIBUTIONS

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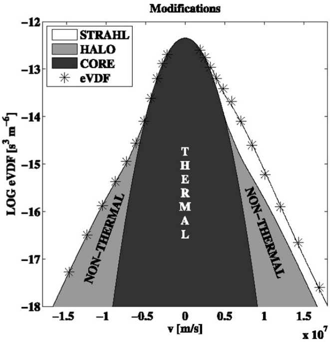
MOTIVATION

Observed electron VDFs in space environments exhibit various non-thermal features:

- Suprathermal tails
- Temperature anisotropies
- Differential Streaming
- Field-aligned beams



Two fundamental problems of laboratory and astrophysical plasmas

- Relaxation of collisionless nearly isotropic plasmas
  $\Rightarrow$ Fluctuation disipation theorem (FDT)
- Properties of the resultant quasi-steady state $\Rightarrow$ energy density equipartition with electromagnetic plasma turbulence.

Is it possible to obtain information about the VDF from electromagnetic turbulence characteristics?

Spontaneous Fluctuations

- Magnetic field fluctuations spectra from FDT theorem. Generalization of Sitenko's theory for multi-species anisotropic plasmas (Navarro et al., 2014; Viñas et al., 2015, Lazar et al., 2018)

$$\left\langle |\delta B_\perp|^2 \right\rangle_{(\omega,k_\parallel)} = \frac{\eta^2}{(1-\eta^2)} \frac{|\Omega_e|}{\omega} \mathrm{Tr}\left\{ \mathrm{Im}\left[\sum_s f(\kappa_e) \left(\bar{\beta}_{\parallel s}\, \chi_\perp^{(s)} \right) \Lambda_\perp^{-1} \right] \right\}$$

$\eta = ck_\parallel/\omega$, Λ : Dispersion tensor, $\chi^{(s)}$: Susceptibility tensor

Can we determine how non-thermal is the distribution looking at the spontaneous fluctuations?

Let's consider three different VDFs

Maxwellian

$$f_s(\mathbf{v}) = A_s \exp\left(-\frac{v^2}{\alpha_s^2} \right),$$

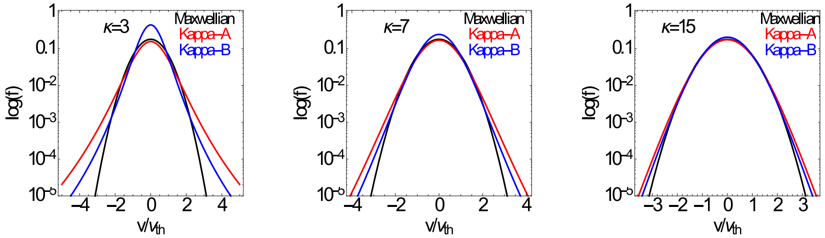
kappa A

$$f_s(\mathbf{v}) = A_{\kappa,s} \left(1 + \frac{v^2}{\kappa_s\, \theta_s^2} \right)^{-(\kappa_s+1)}$$

kappa B

$$f_s(\mathbf{v}) = B_{\kappa,s} \left(1 + \frac{v^2}{(\kappa_s - 3/2)\, \theta_s^2} \right)^{-(\kappa_s+1)}$$

- kappa A: Kinetic temperature depends on kappa. Enhanced tails.
- kappa B: Kinetic temperature independent of kappa. Enhanced core and tails.



WHISTLER FLUCTUATIONS. PIC SIMULATIONS

1.5-D full particle simulations. Magnetized electron-proton plasma.

Simulations parameters

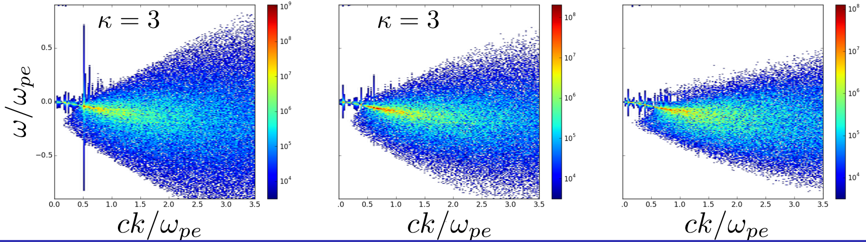
- $L = 256\lambda_e$, $N_x = 2048$, $dt = 0.08/\omega_{pe}$, $\omega_{pe}/\Omega_e = 5$.
- $m_p/m_e = 1836$, 10^3 part/species/cell.

Initial conditions:

Maxwellian, kappa-A, and kappa-B VDFs, with no temperature anisotropy at $t = 0$.
Different values for β_e and κ_e, including $\kappa_e = \infty$ (Maxwellian).

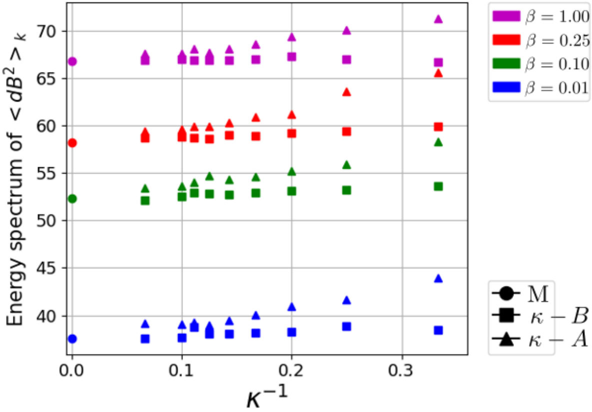
Transverse magnetic field power $(\beta = 0.1)$

kappa-B kappa-A Maxwellian



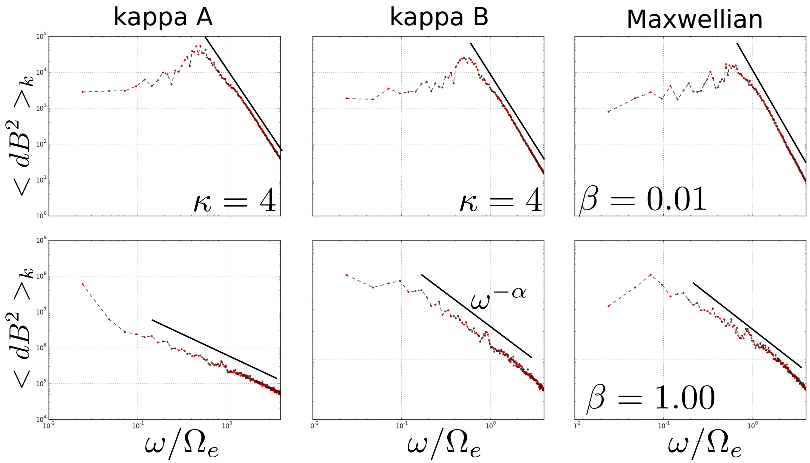
Total power of the fluctuations

Power between $-3 < \omega/\Omega_e < 3$, and $-3 < ck_{\|}/\omega_{pe} < 3$.



- Power $\sim \beta$.
- kappa-A: power increases with decreasing κ.
- kappa-B: for large beta, power even decreases with decreasing κ.

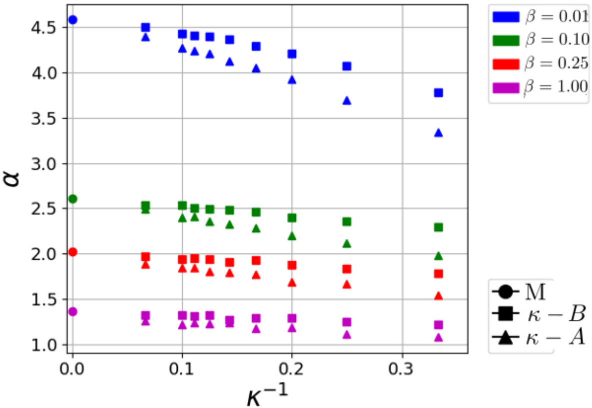
Reduced frequency spectrum. $B^2 \sim \omega^{-\alpha}$



- Power-law frequency spectra.
- Peak shifts to lower frequency with increasing β.

POWER SPECTRUM SLOPE

Power spectrum $B^2 \sim \omega^{-\alpha}$ exponent α as a function of κ.



- Slope steepens with increasing κ and decreasing β.
- Spectrum hardens with decreasing κ.
- These features do not depend on the kappa model.

(Moya et al., 2020, *in prep.*)

Conclusions

- We perform numerical PIC simulations to study whistler fluctuations using parameters relevant to space plasmas environments.
- We found a strong dependence between the shape of the velocity distribution function and the topological regions in the frequency-wave number plane in which the spontaneous fluctuations emerge.
- Power increases and fluctuations broaden with decreasing κ_e. Maximum power shifts to smaller k (smaller frequency).
- All frequency spectra correspond to power-law spectra. Slope steepens with increasing κ and spectrum hardens with decreasing κ.
- Independent of the kappa model, the presence of suprathermal tails produces clear changes in the magnetic field power spectrum.
- This feature may be used proxy to identify the nature of electron populations in space plasmas when high resolution particle instruments are not available.

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