UNIVERSIDAD DE SANTIAGO DE CHILE

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The combined effect of electron and proton firehose instabilities for the solar wind plasma conditions

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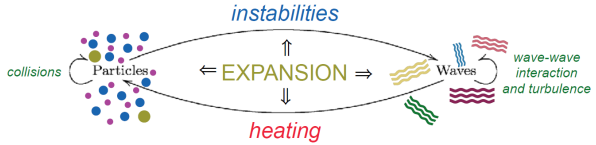
KU LEUVEN RUB

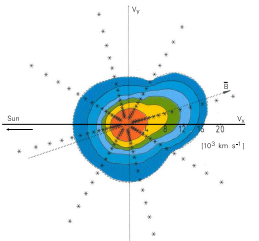
Introduction: Velocity distribution function

Observed electron and proton VDFs in the solar wind exhibit various non-thermal features:

- temperature anisotropies
- field aligned beams (e.g. strahl)
- differential streaming
- suprathermal tails

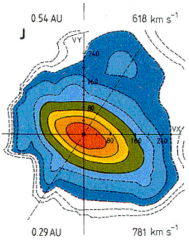


Electron VDF (Helios)



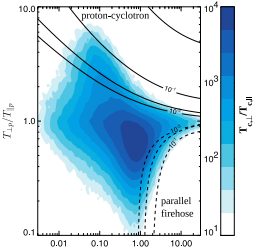
Philip *et al.*, JGR 1987

Proton VDF (Helios)

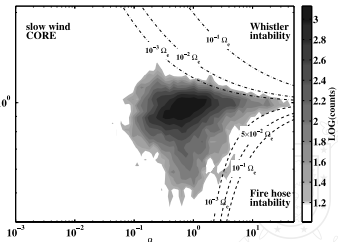


Marsch *et al.*, JGR 1982

(after Matteini et al. 2012)



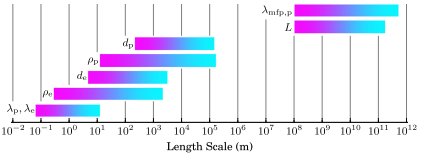
Hellinger *et al.*, GRL 2006

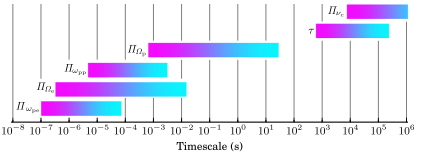


Štverák *et al.*, JGR 2008

Introduction: Multi-scale nature of the solar wind

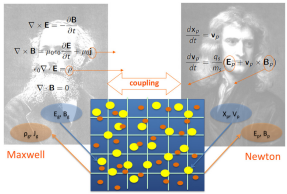
Simultaneous presence of different spatial and temporal scales.
Complete numerical simulations would need to resolve this entire range of scales.





Verscharen *et al.*, LRSP 2019.

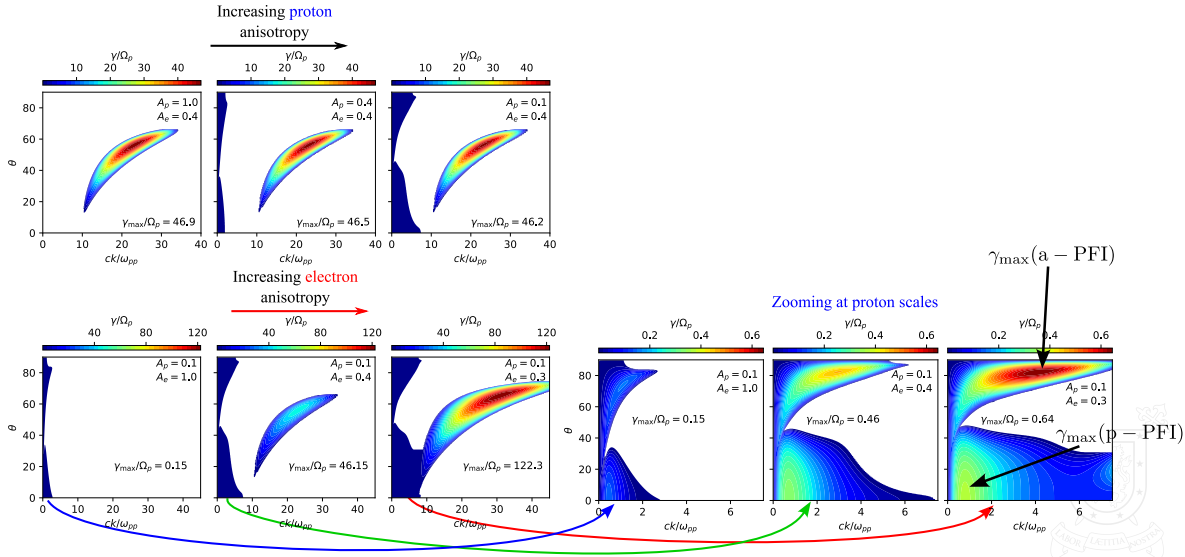
Markidis and Lapenta 2010.



Lapenta 2016.

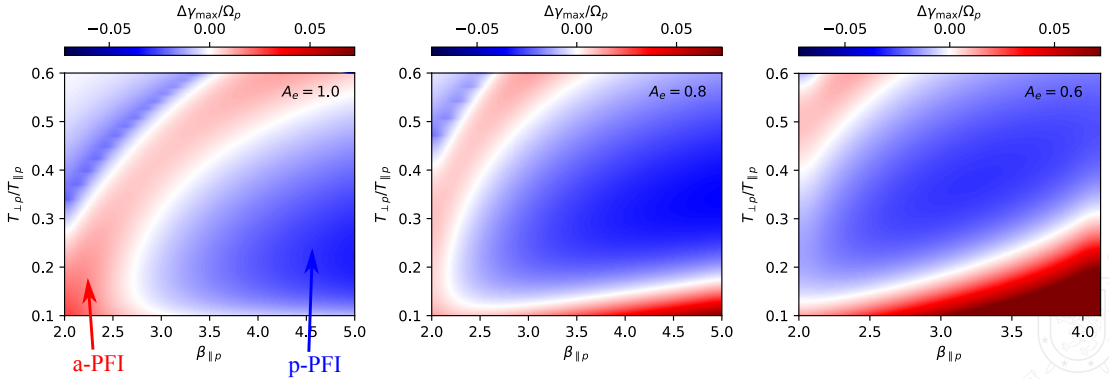
Semi-implicit PIC methods allow to resolve the multiple spatial and temporal scales.
Allow us to employ realistic parameters and retain a kinetic description of both protons and electrons

Oblique firehose instability



Periodic and aperiodic PFI thresholds are modified by electron anisotropy.

$$\Delta\gamma_{\max} = \gamma_{\max}(\text{a-PFI}) - \gamma_{\max}(\text{p-PFI})$$



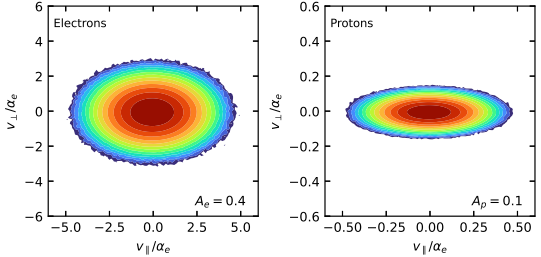
Particle-in-cell Simulation

We use a 2.5D implicit PIC code, **iPIC3D**.

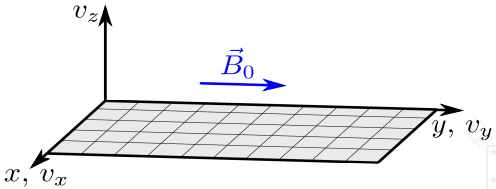
Initial eVFD → anisotropic electrons and anisotropic protons

Initial conditions favorable to the aperiodic firehose instability

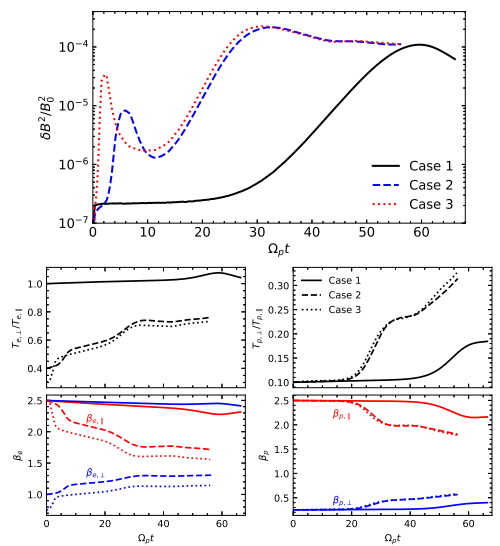
- Reduced mass ratio $m_p/m_e = 100$.
- Plasma-to-gyro frequency $\omega_{pe}/\Omega_{ce} = 20$.



- 608×608 cells and 1024 particles per cell per species.
- Time step $\Delta t = 0.2/\Omega_p$.



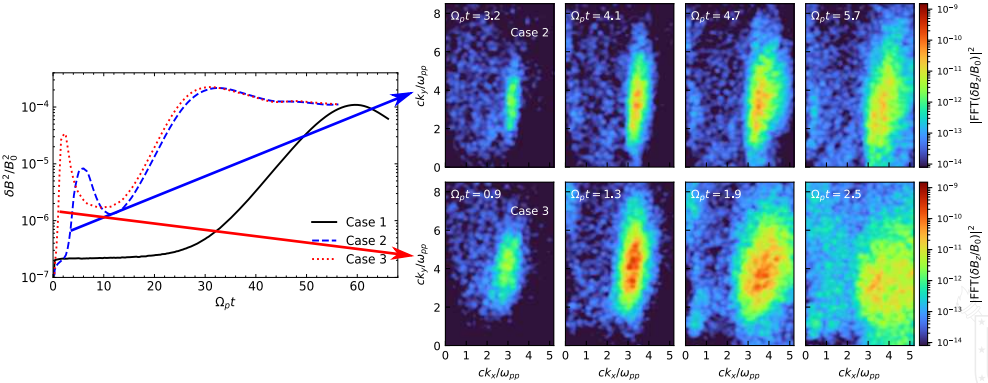
Oblique firehose instability



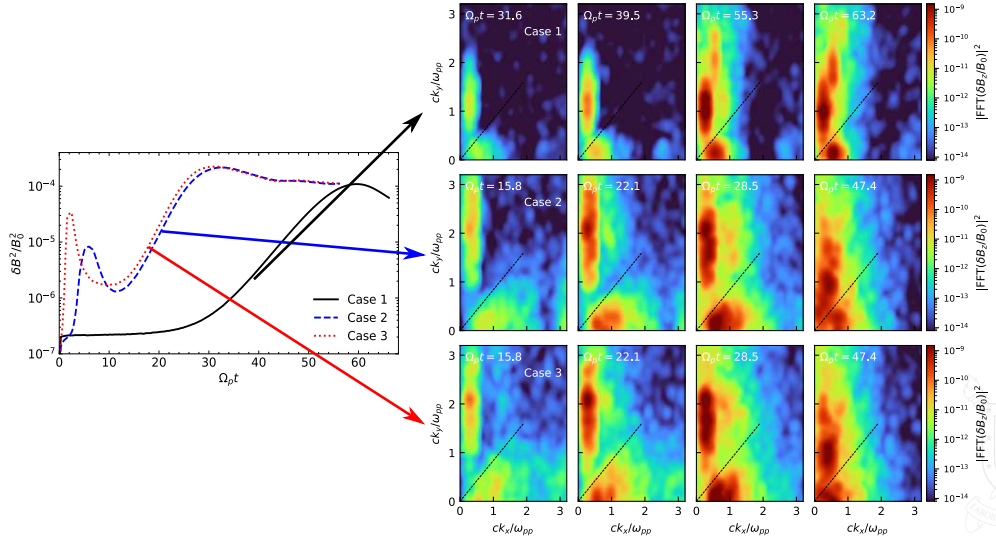
Case	Configuration	$\beta_{p,\parallel}$	$\beta_{e,\parallel}$	A_p	A_e
1	PFI	2.5	2.5	0.1	1.0
2	PFI + EFI	2.5	2.5	0.1	0.4
3	PFI + EFI	2.5	2.5	0.1	0.3

- The onset time for PFIs is shifted in the presence of anisotropic elelctrons.
- The interplay between PFIs and EFIs produce a more pronounce isotropization.

Oblique firehose instability



Oblique firehose instability



Summary

- We have performed a linear analysis of electron and proton firehose instabilities.
- Electron branches are almost not affected by anisotropy of protons, while proton branches are significantly influenced by electron anisotropies.
- 2D simulation shows that the presence of electron anisotropies modify the evolution of proton firehose instabilites.
- The interplay of PFIs and EFIs produce a more pronounce isotropization.

[1] R. A. López, A. Micera, M. Lazar, S. Poedts, G. Lapenta, A. N. Zhukov, E. Boella and S. M. Shaaban, ApJ **930**, 158 (2022).