Collisionless electron dynamics in the expanding solar wind

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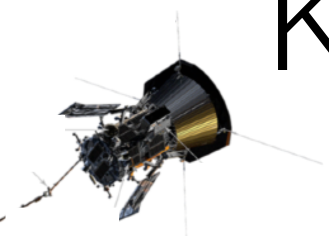
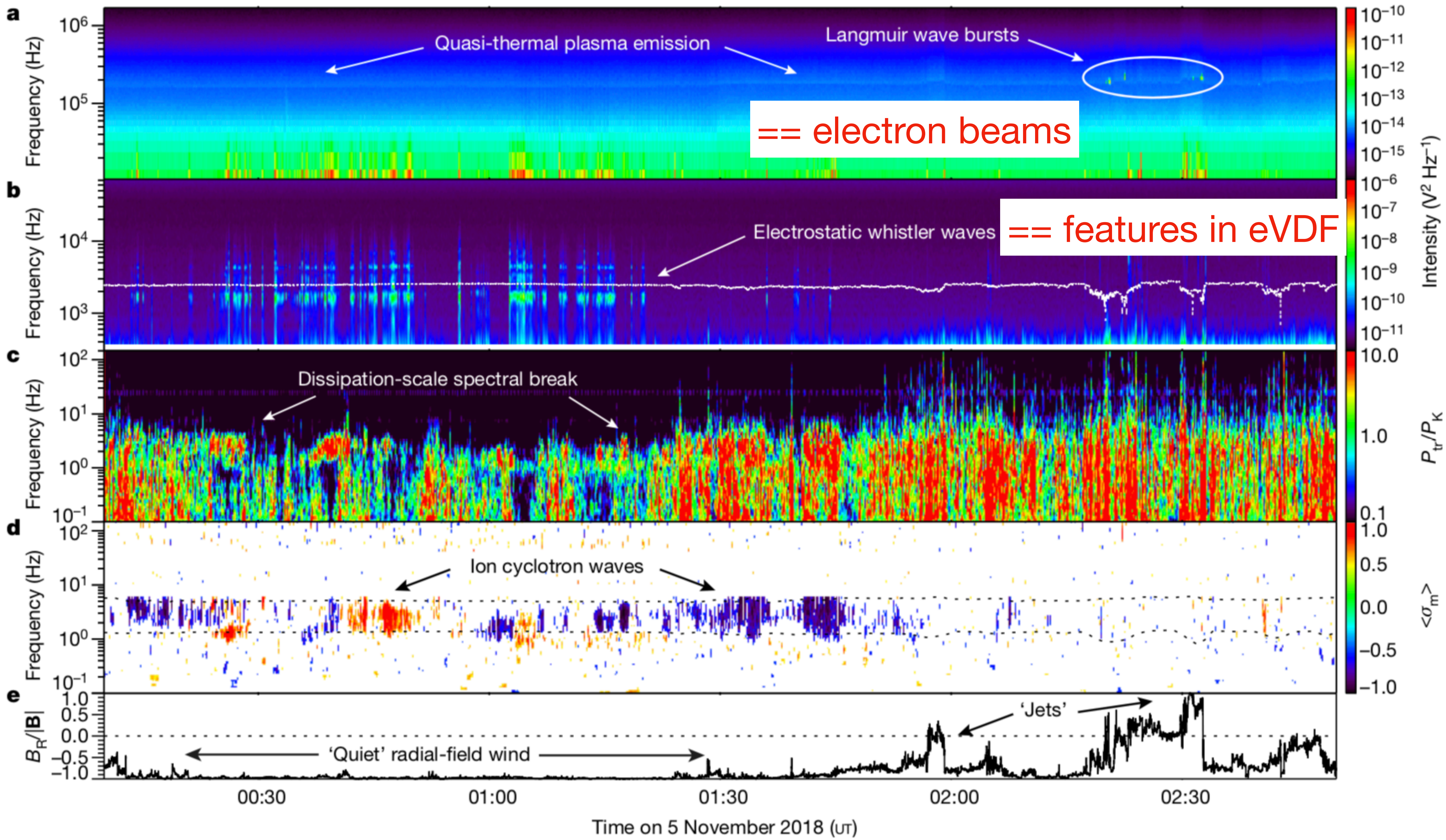
Kinetic physics in Parker Solar Probe





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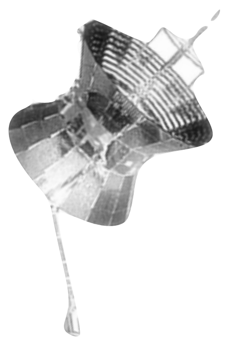
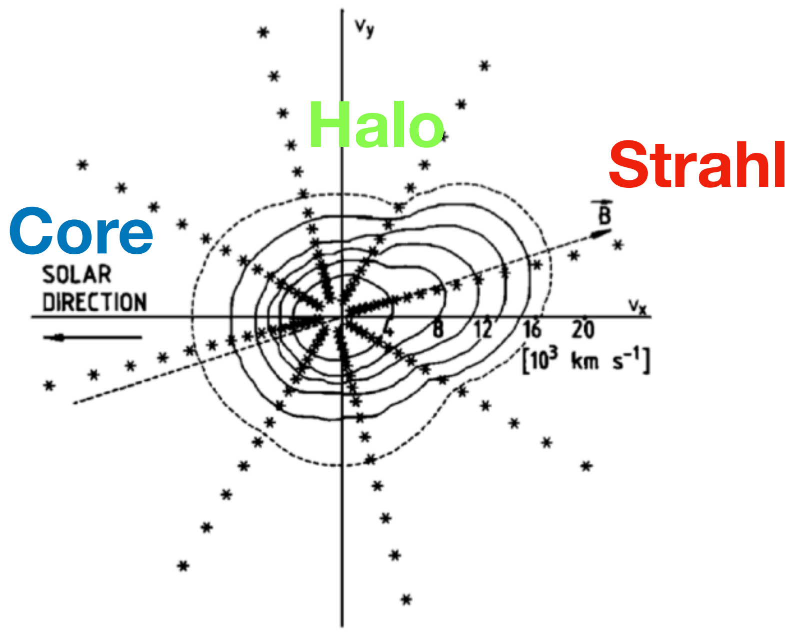
[Bale+ 2019]

Non-equilibrium velocity distribution functions

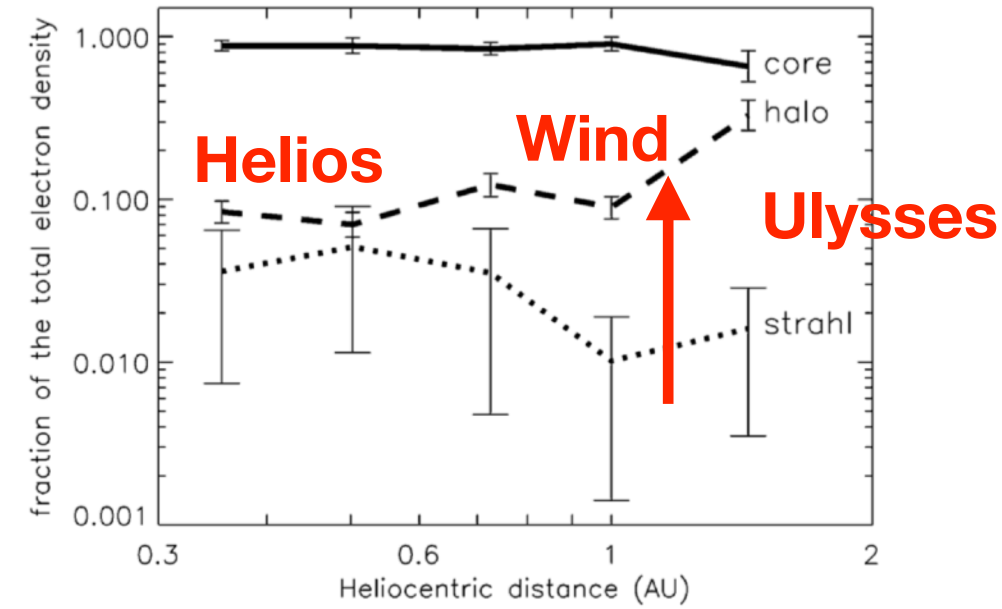
Electron (and ion) velocity distribution functions (VDF) exhibit non kinetic features which evolve with the heliocentric distance R



[Pilipp+ 1987]



[Maksimovic+2005]



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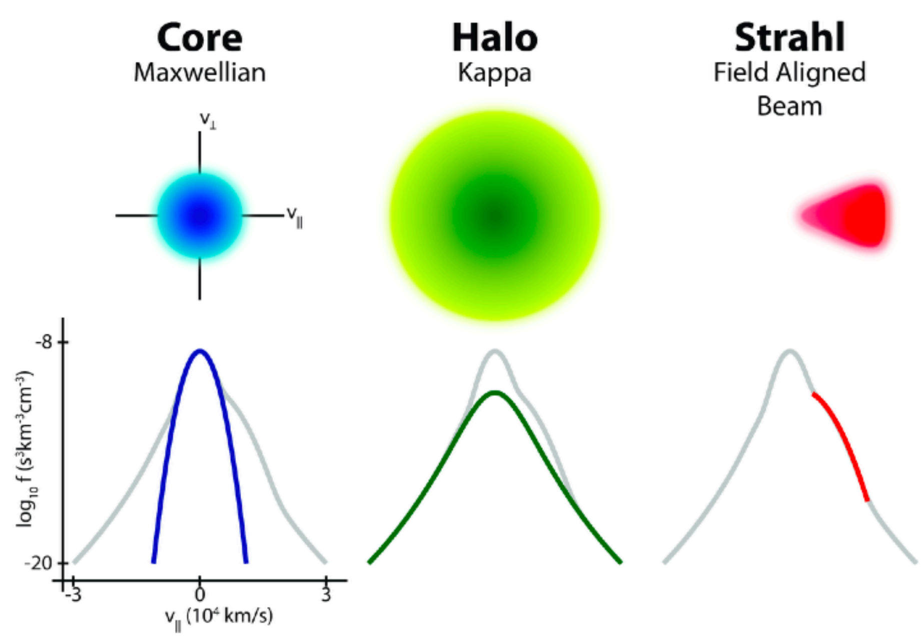
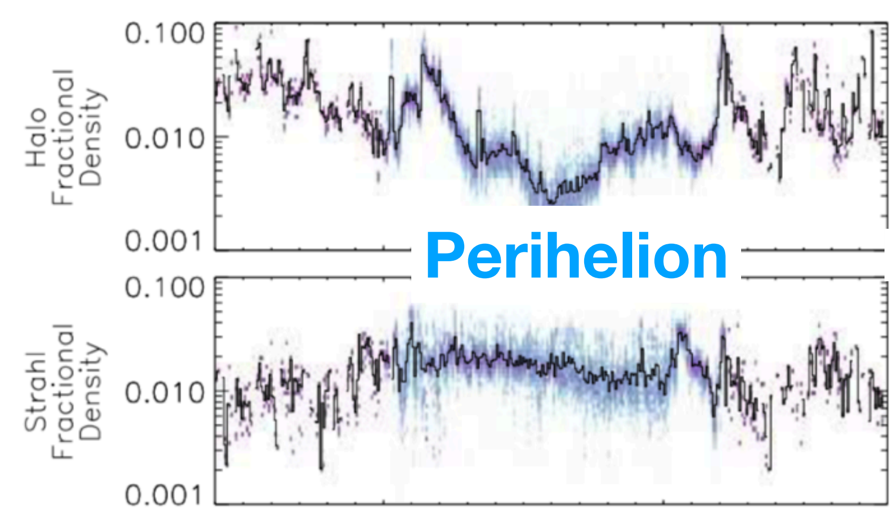
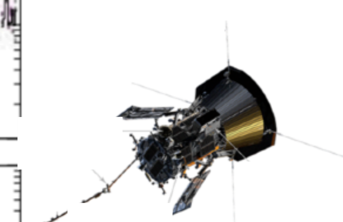


[Halekas+2019]





The eVDF evolution with heliocentric distance is possibly due to a combination of non linearities, kinetic instabilities, **expansion**

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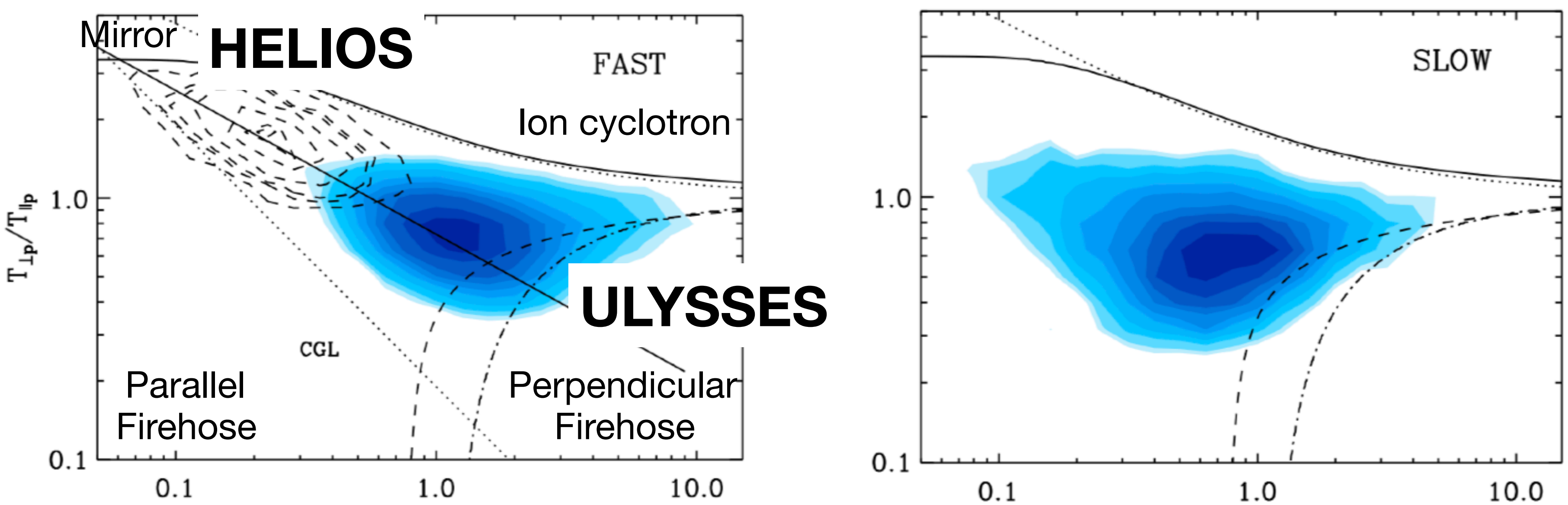
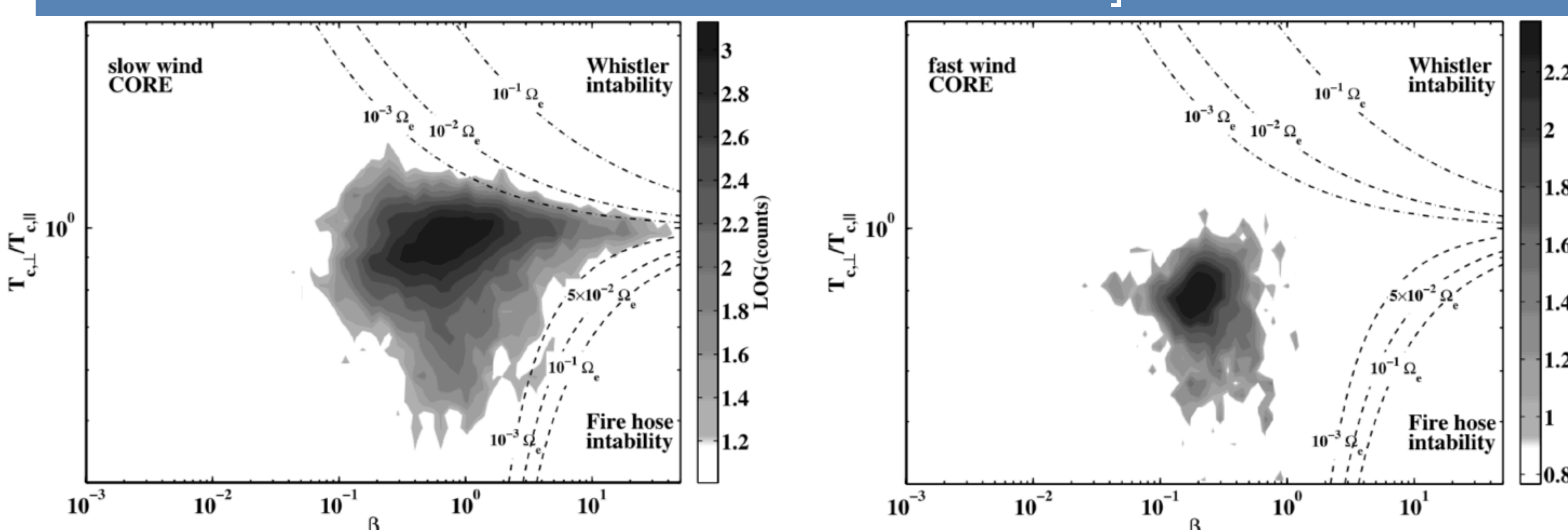
Kinetic processes constrain solar wind observations

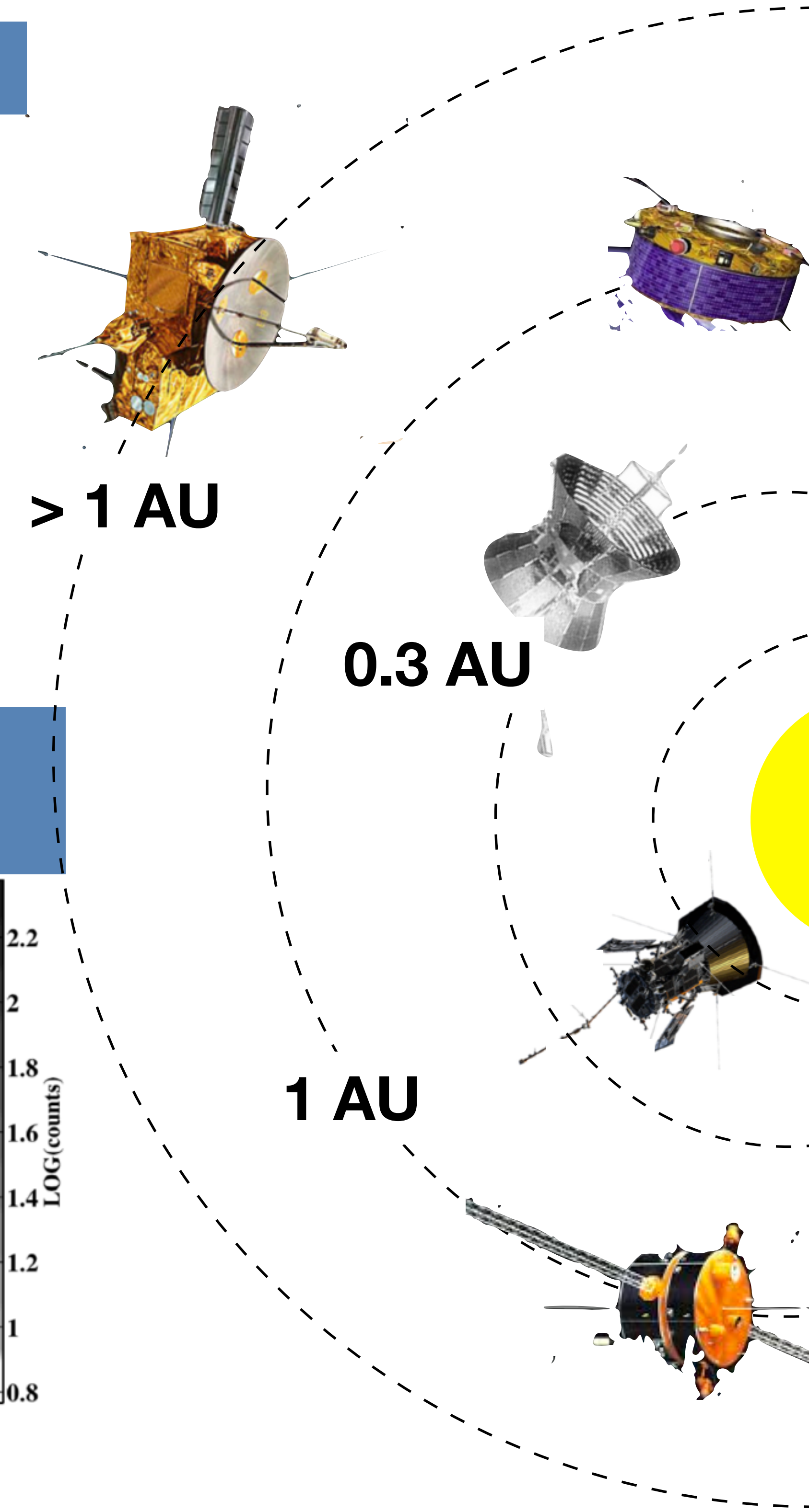
Marginal stability limits of kinetic instabilities appear to constrain solar wind ion and electron observations

IONS [Matteini+ 2013]



ELECTRONS [Stverak+ 2008, moderate R dependence is observed in Bercic+2019]





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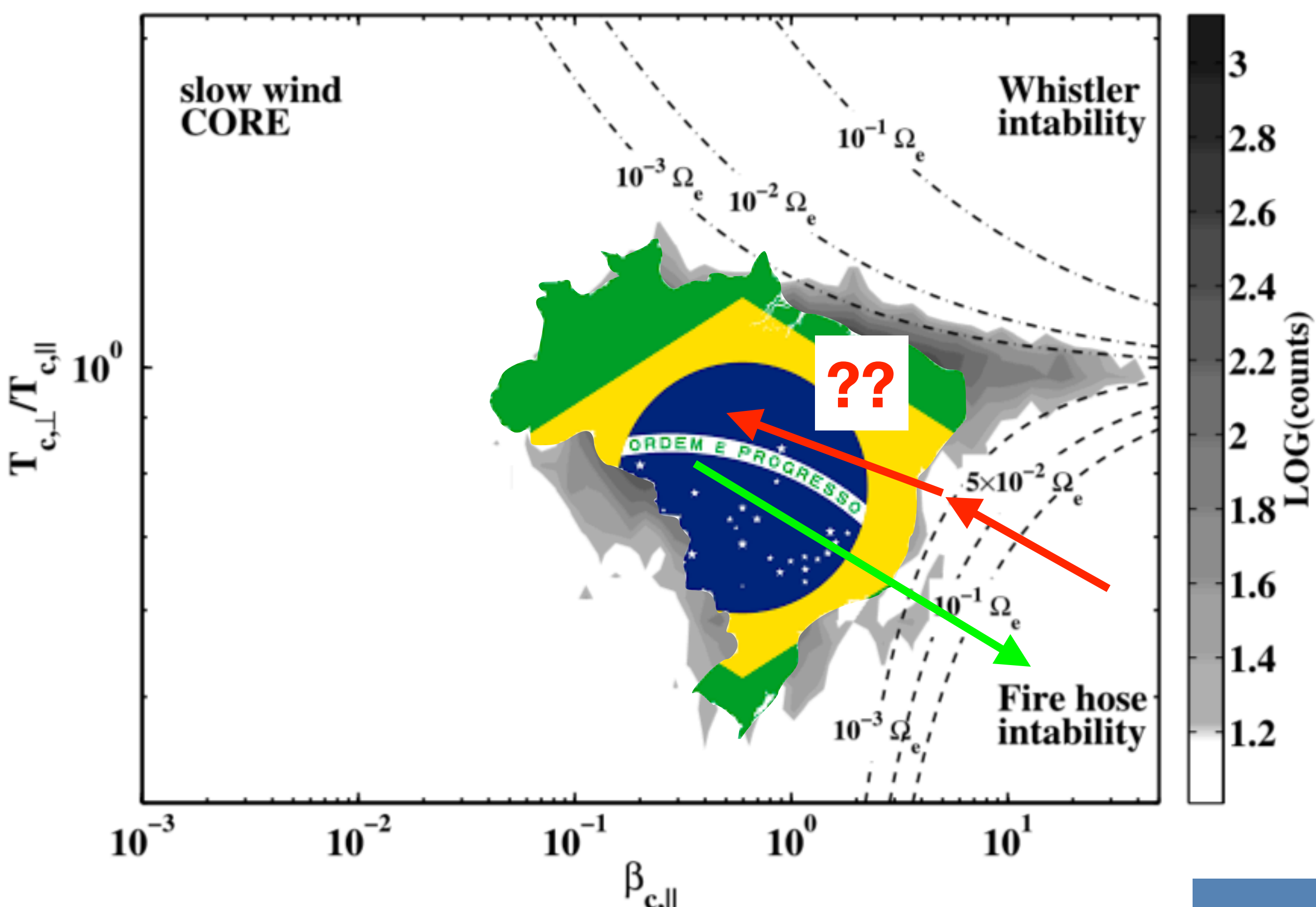

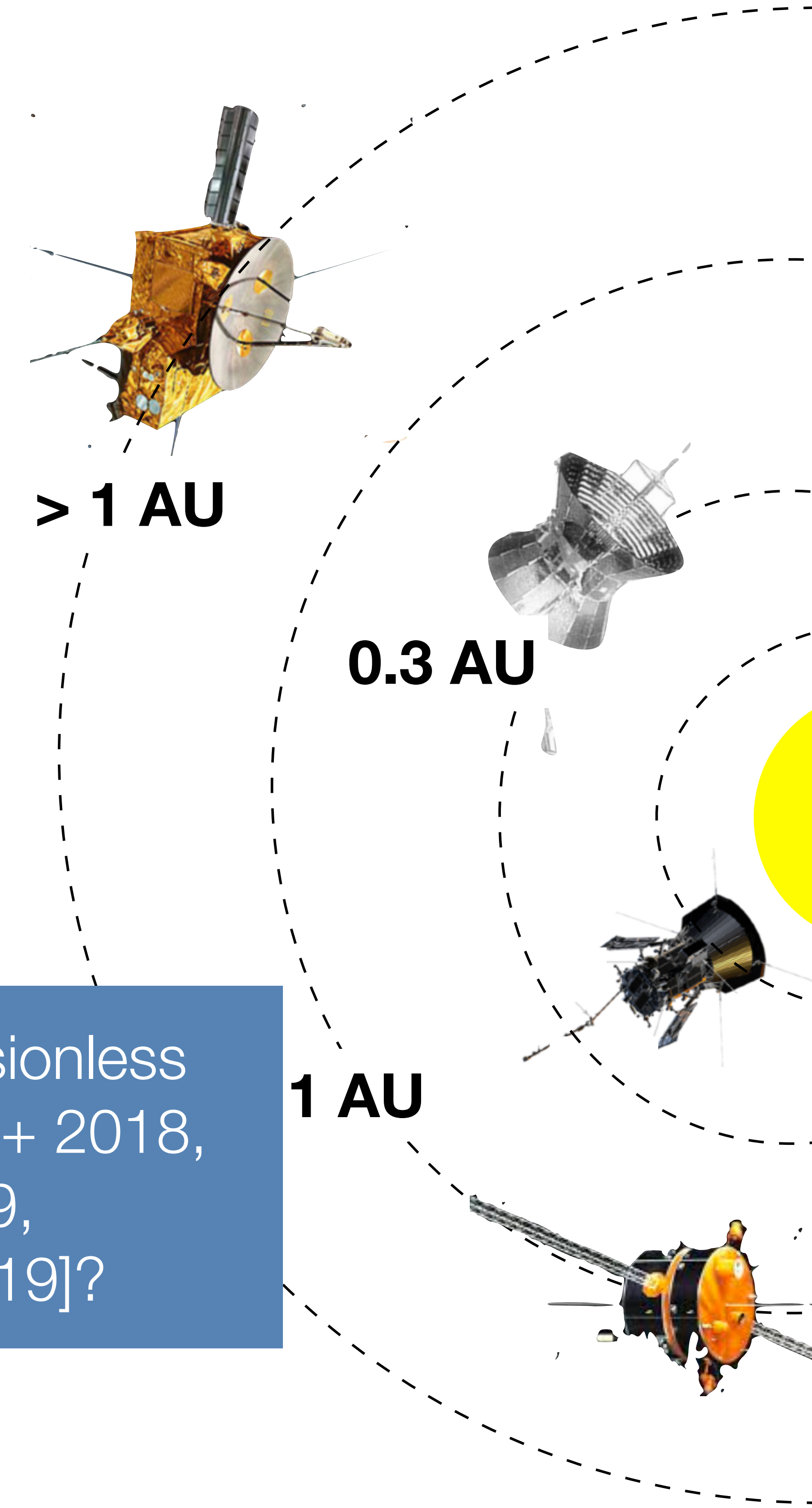

Expansion [Chew+ 1956] vs
Oblique Electron Firehose Instability
[Li+ 2000, Camporeale+ 2008]

Collisions or collisionless processes [Wilson+ 2018, Yoon+ 2019, McGinnis+ 2019]?

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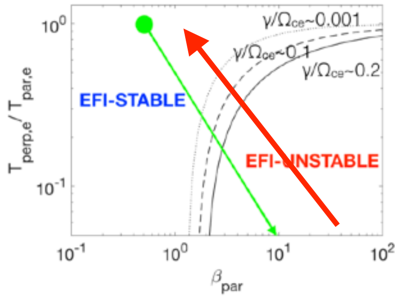
EB-iPic3D: a fully kinetic, semi-implicit Expanding Box Model code

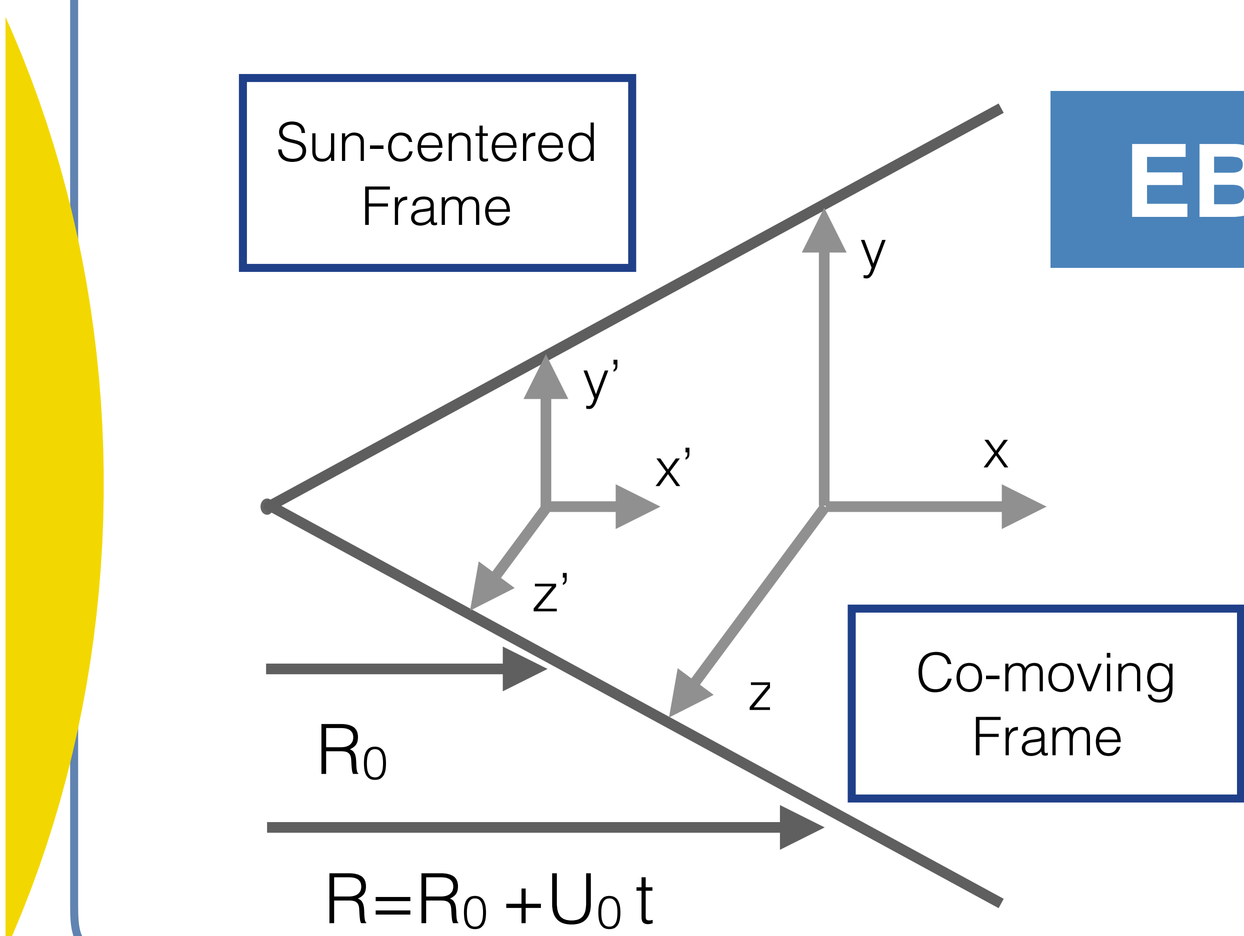


We need a numerical tool that combines

the capability of modeling
solar wind expansion

↓

Expanding Box Model
[Velli +1992, Grappin+ 1996, Liewer+ 2001, Tenerani+ 2017]

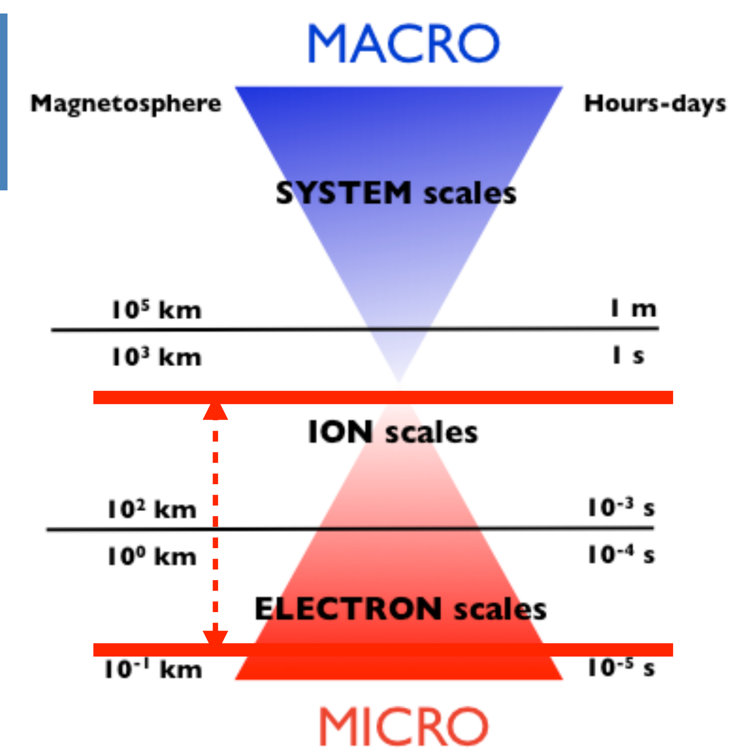


EB-iPic3D

a ***fully kinetic Particle In Cell approach***
(possibly able of dealing with large temporal and spatial scales)

↓

iPic3D (Implicit Moment Method Particle In Cell code)
[Brackbill+1982, Lapenta 2006, Markidis+ 2010]



Stability constraint: $\epsilon < v_{th,e}dt/dx < 1$

[Innocenti, Tenerani, Velli, Apj, 2019]

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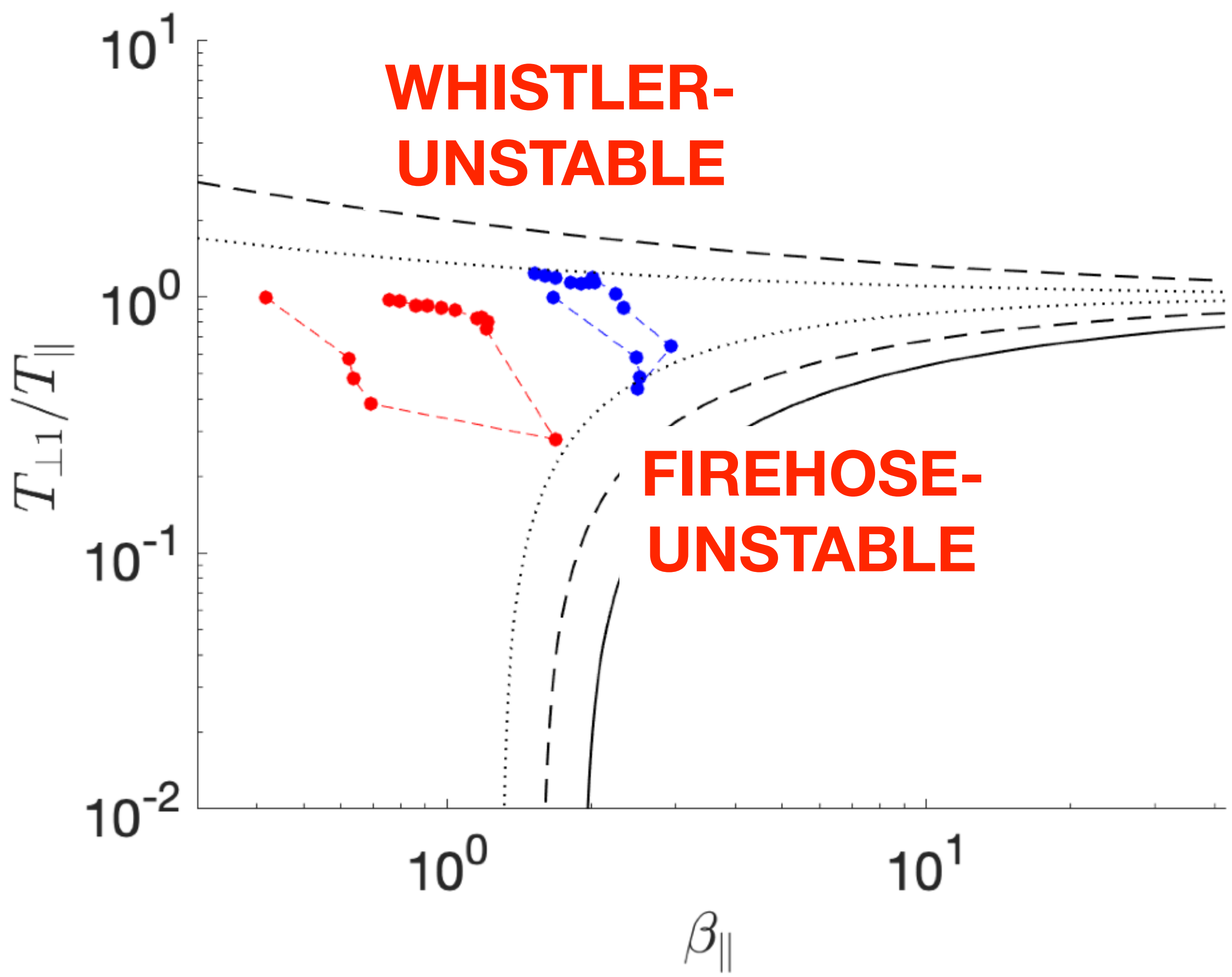
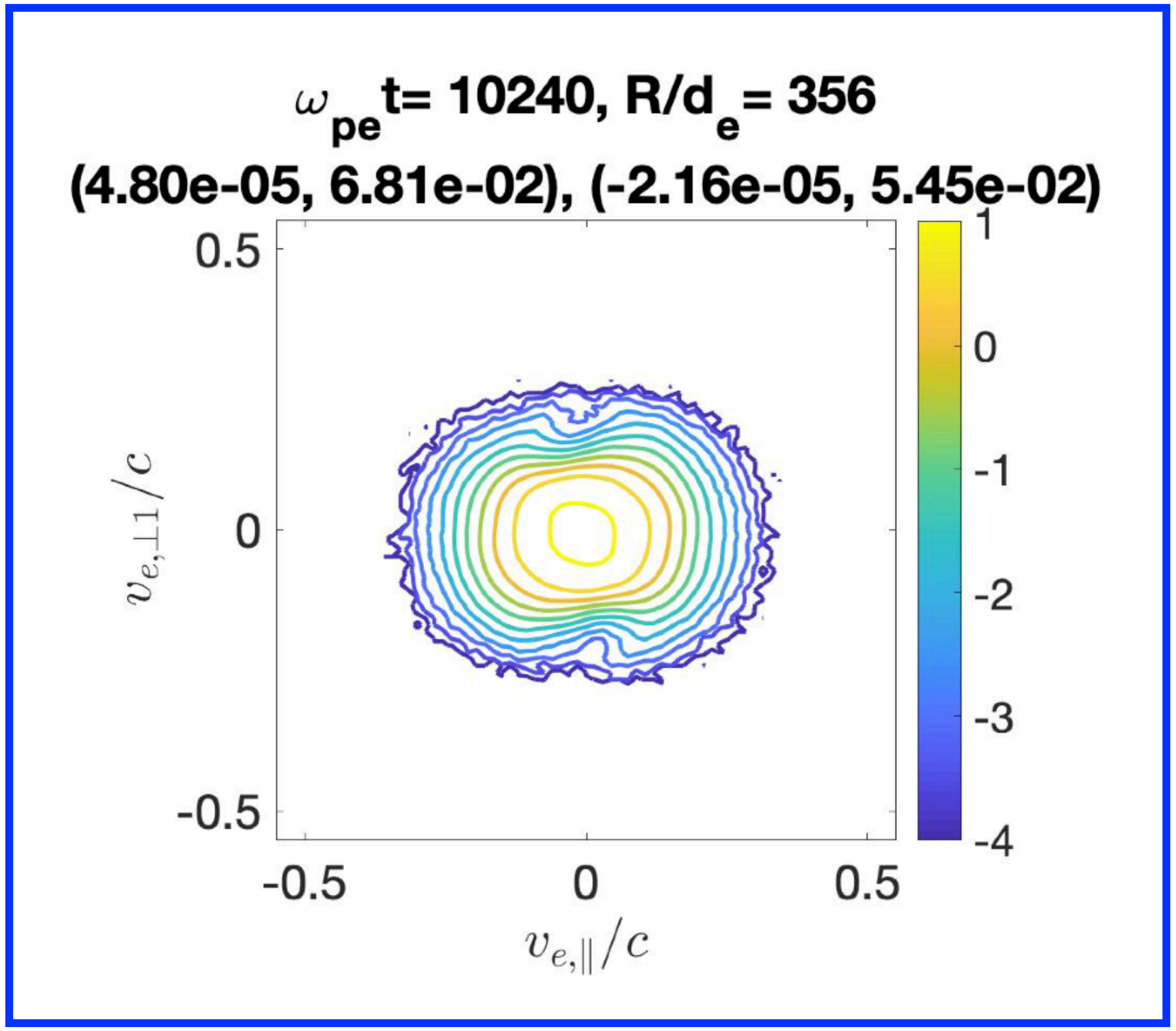
EBM Electron Firehose Instability simulations

Introducing a realistic initial magnetic field description (radial + transverse magnetic field component) and changing the simulation initial parameters, we can "populate" the β_{par} vs T_{perp}/T_{par} plane, to try to reproduce observations





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[Innocenti et al, in prep]

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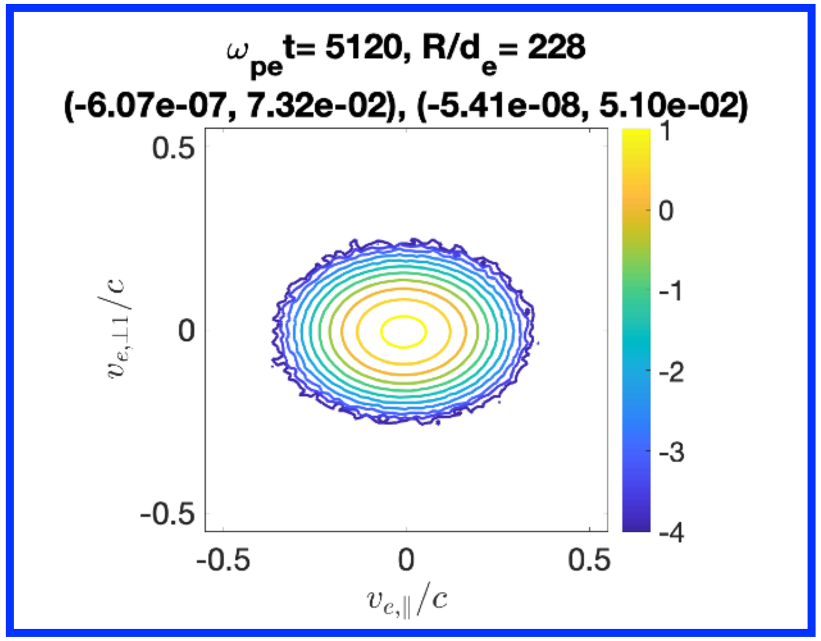

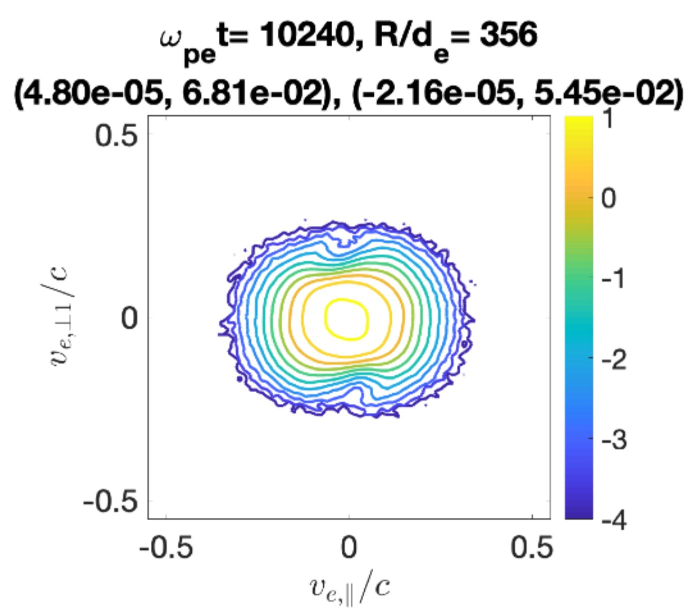

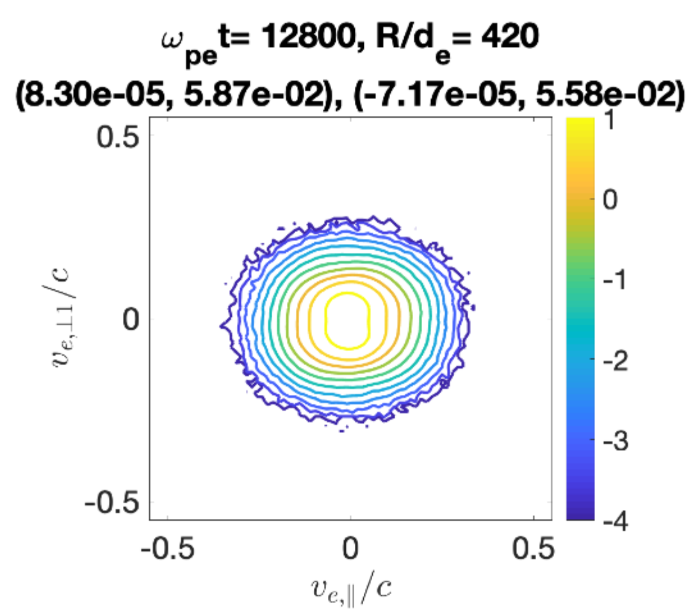

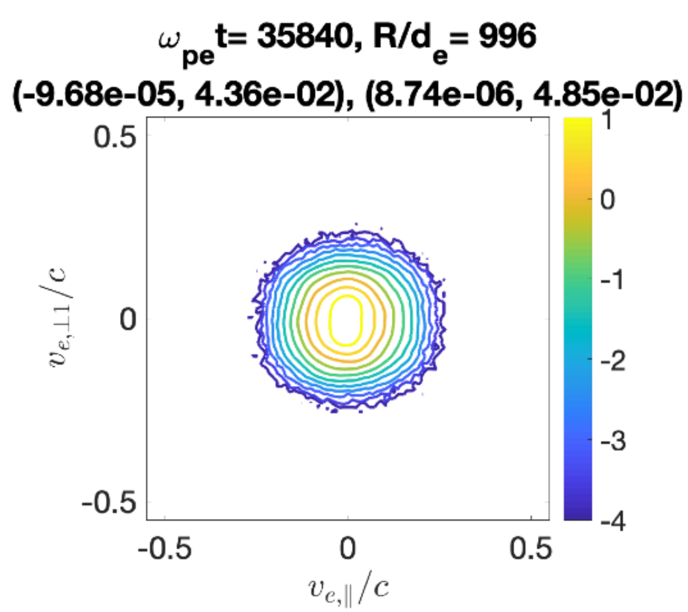

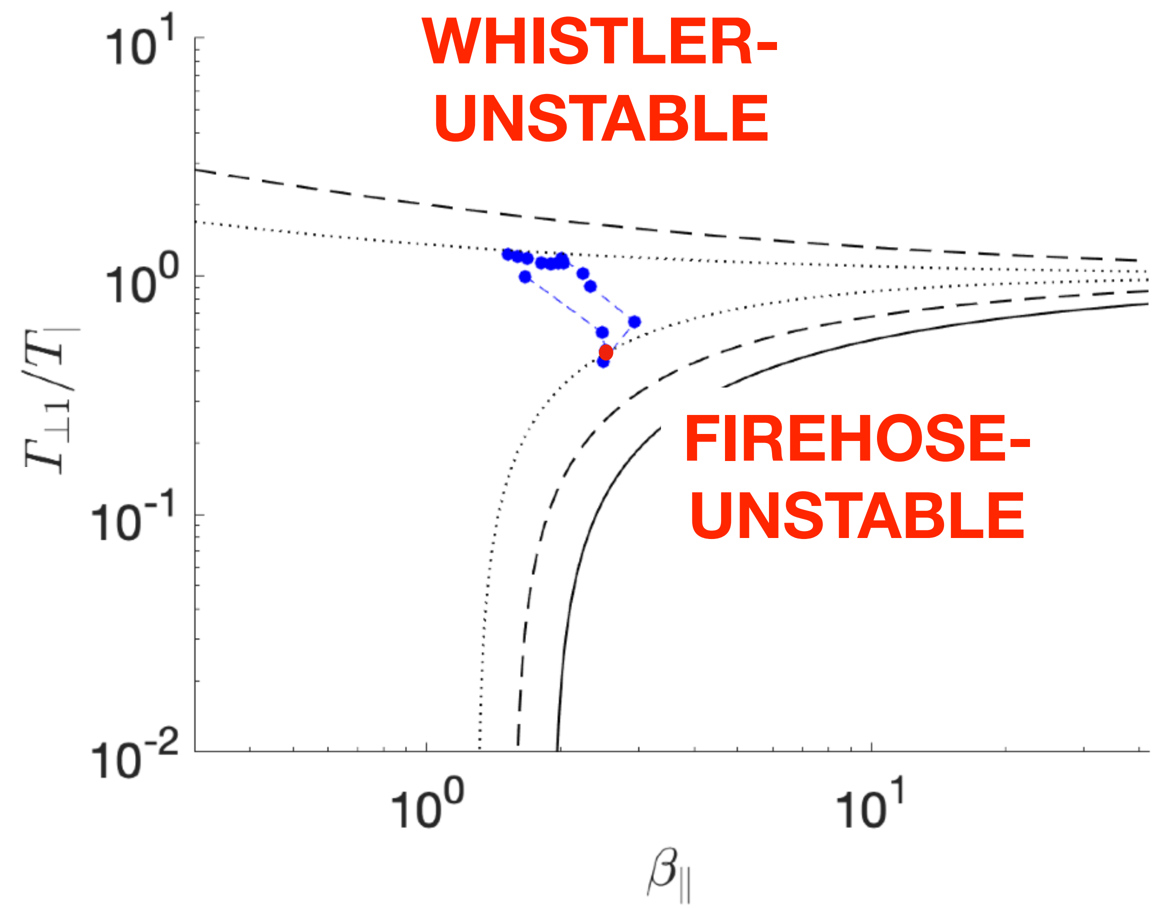

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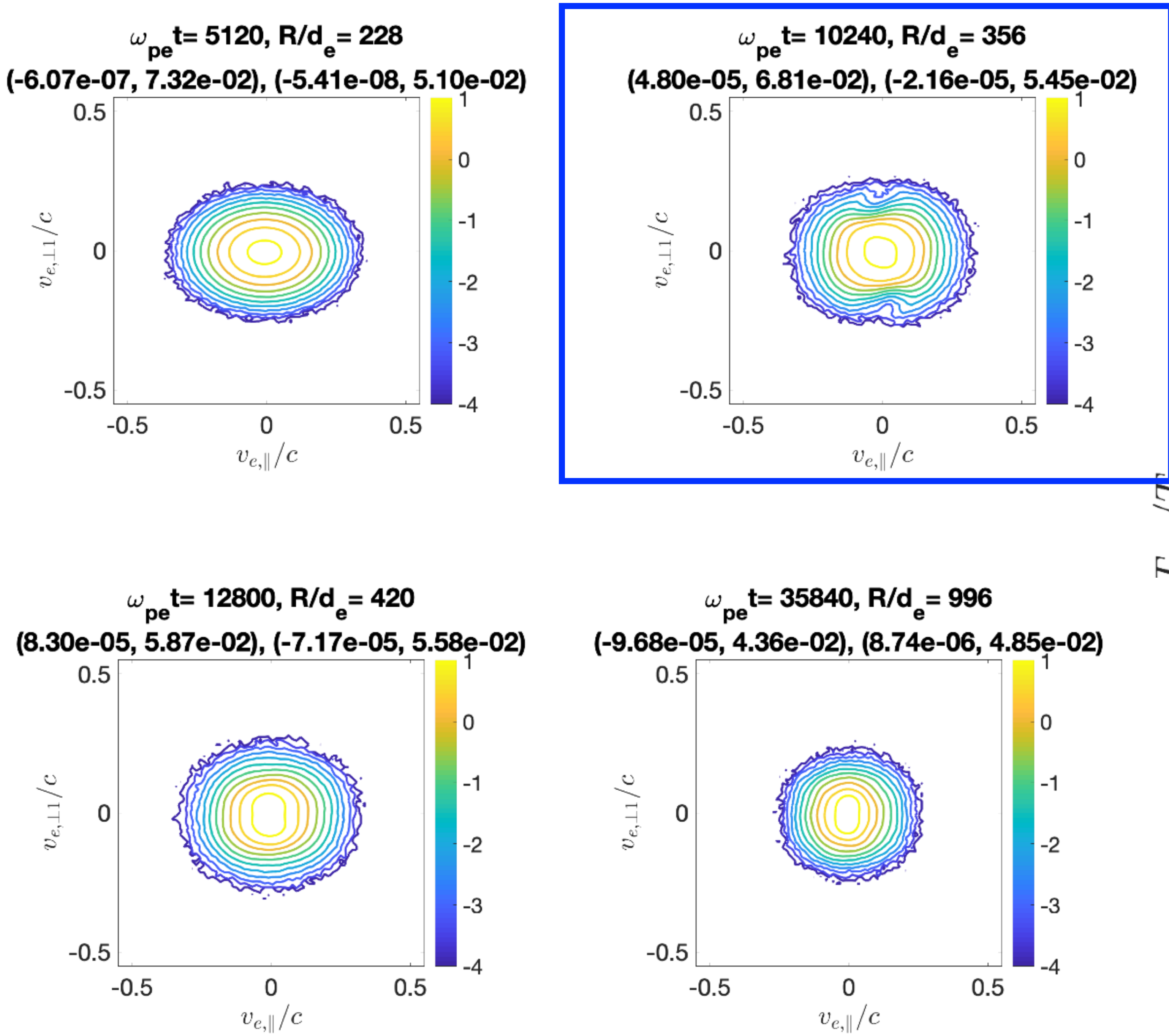

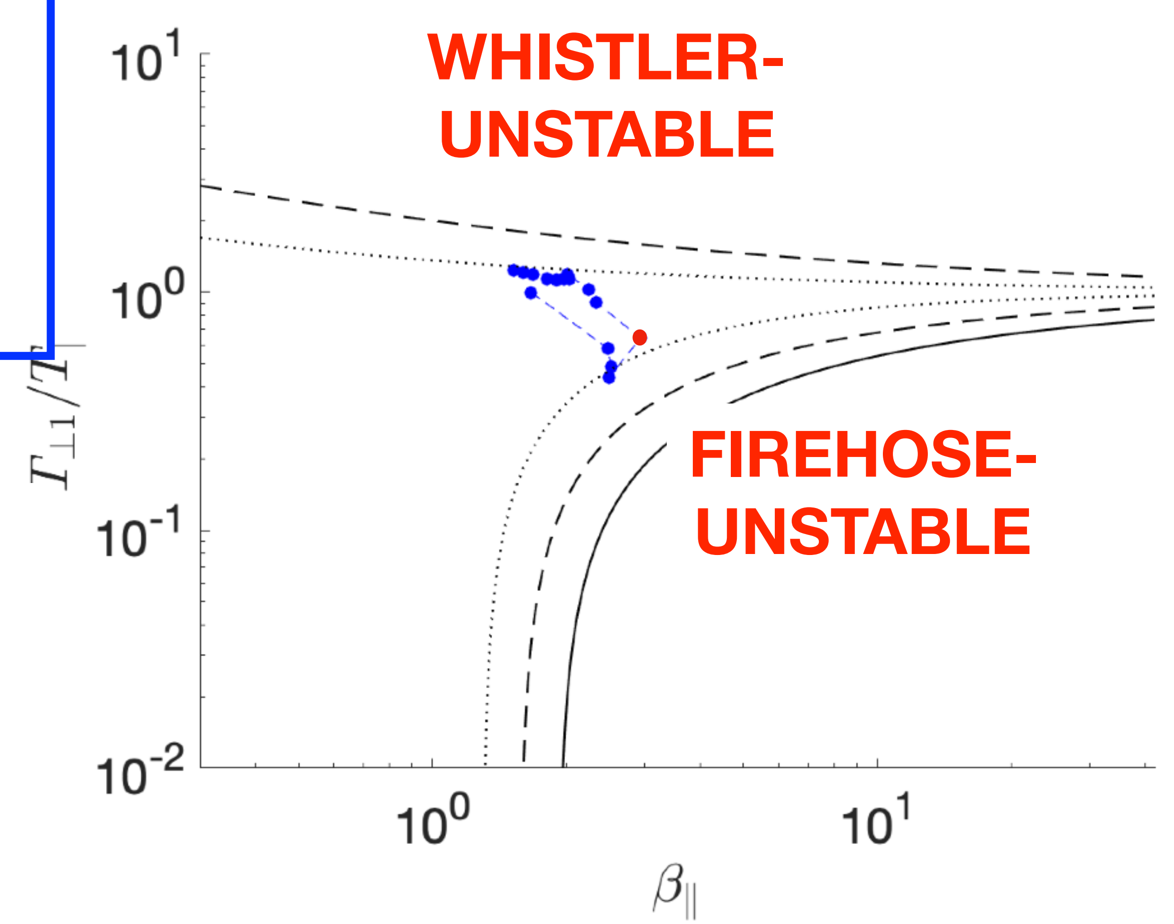

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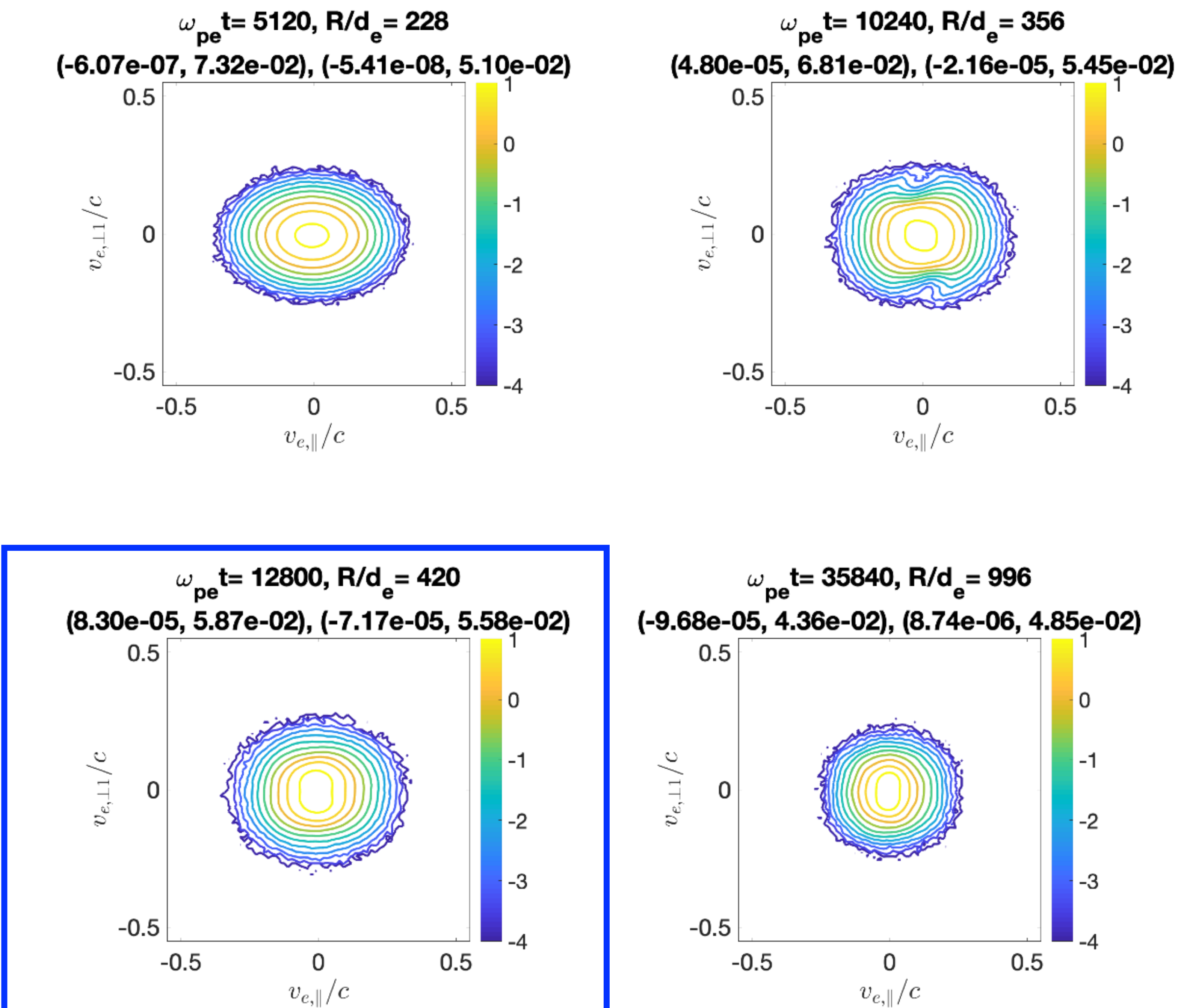

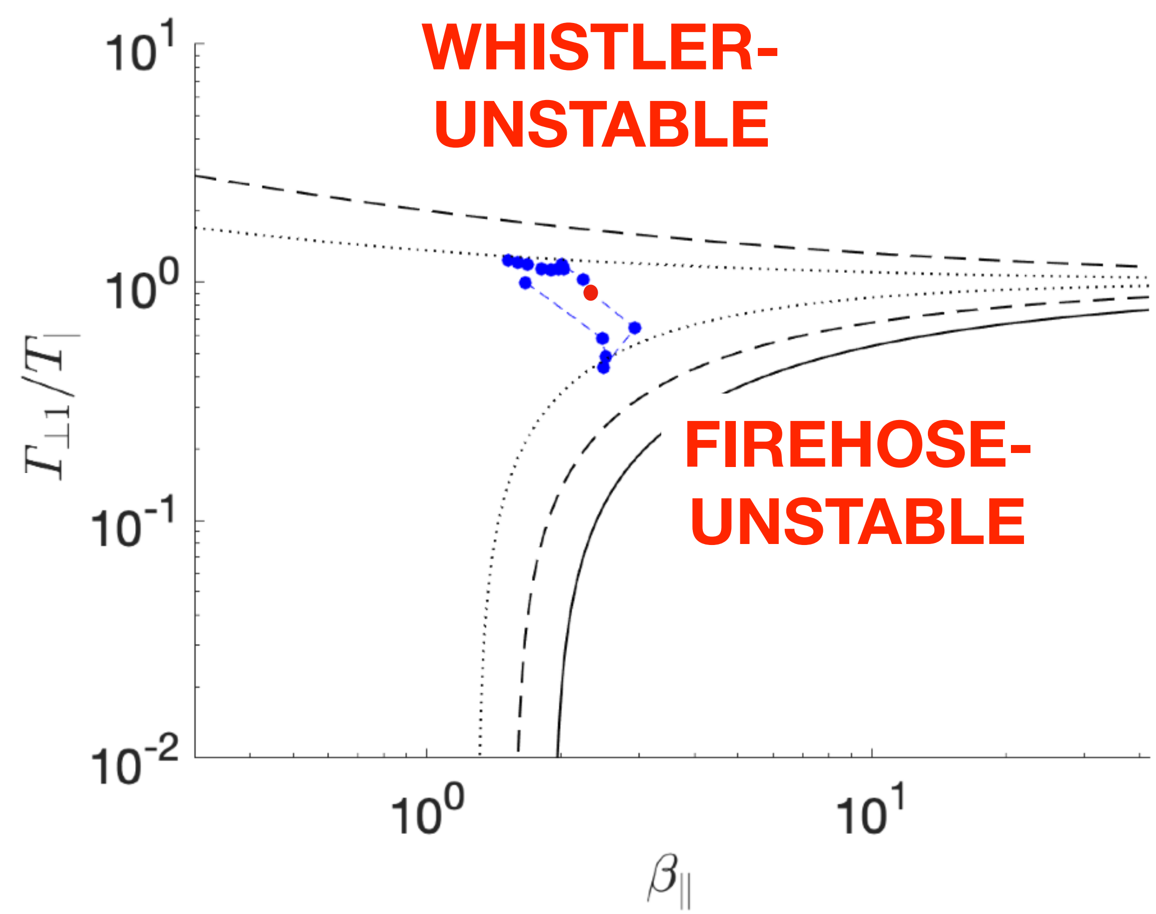

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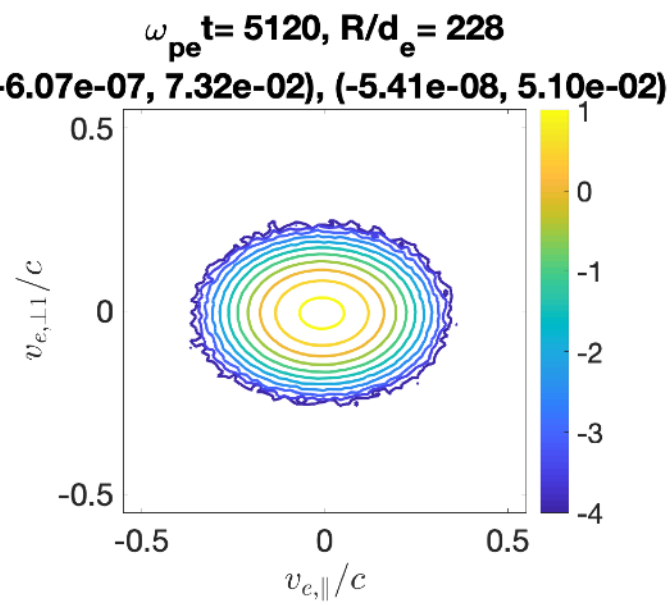

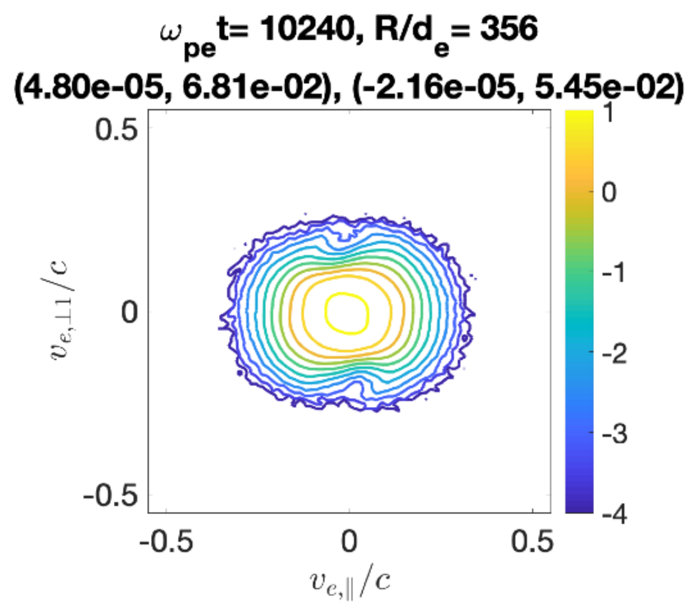

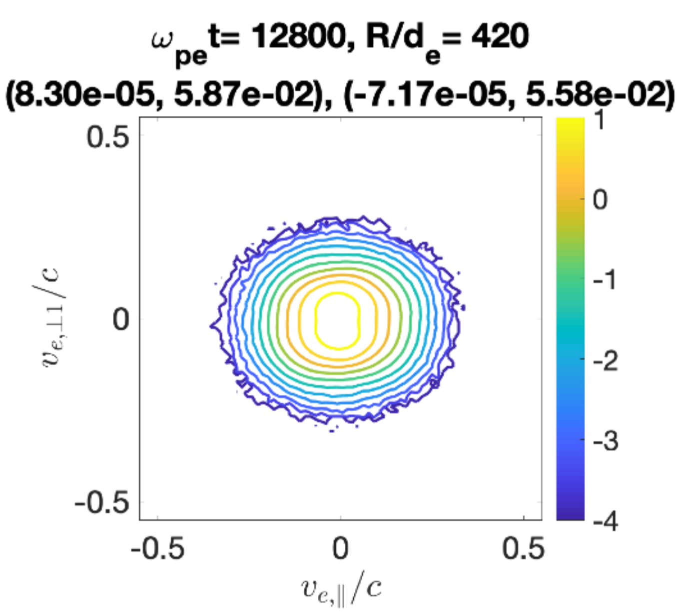

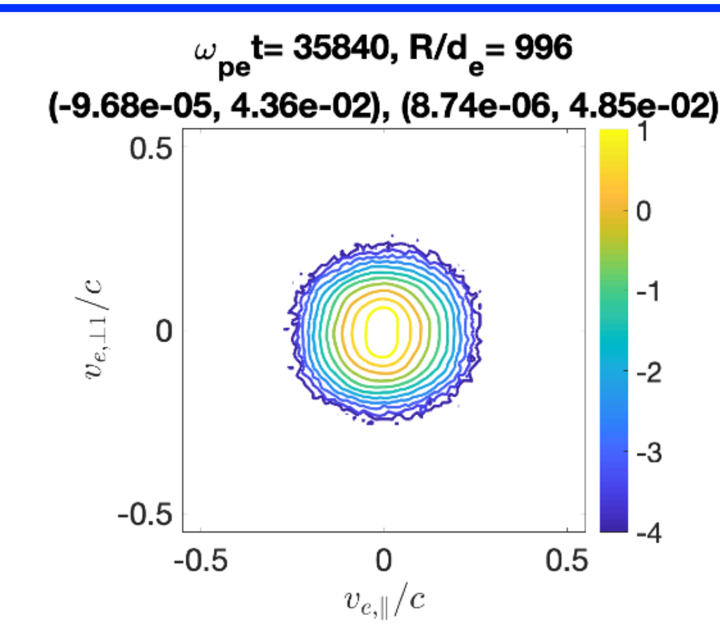

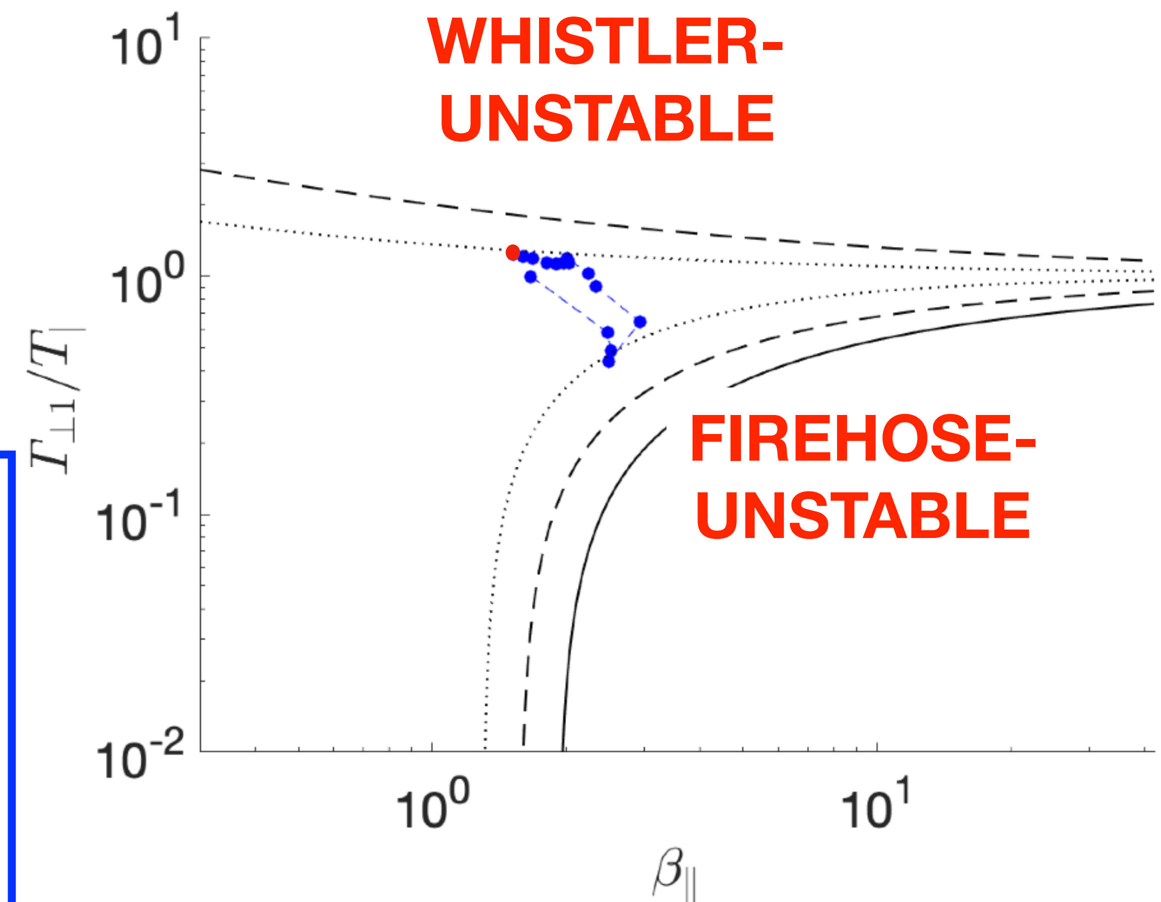

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[Innocenti et al, in prep]

Conclusions

- PSP has shown that electron beams and ion and electron micro instabilities are everywhere in the low-R solar wind: kinetic processes are of relevance in the nascent solar wind
- We have presented a method for the simulation of kinetic processes in the expanding solar wind, the fully kinetic EBM method, implemented in the **EB-iPic3D** code
- We have shown 2D3V EBM simulations, where the oblique firehose instability arises self-consistently after a phase of double-adiabatic-like expansion and moves the simulation trajectory in the β_{par} vs T_{perp}/T_{par} plane, compatibly with observations
- Through simulations with different initial parameters, we investigate the role of **purely collisionless processes** in shaping electron VDF evolution in the solar wind

Innocenti, M. E., Tenerani, A., & Velli, M. (2019). A Semi-implicit Particle-in-cell Expanding Box Model Code for Fully Kinetic Simulations of the Expanding Solar Wind Plasma. The Astrophysical Journal, 870(2), 66.
Innocenti, M. E., Tenerani, A., Boella, E., & Velli, M. (2019). Onset and Evolution of the Oblique, Resonant Electron Firehose Instability in the Expanding Solar Wind Plasma. The Astrophysical Journal, 883(2), 146.

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