Collisionless electron dynamics in the expanding solar wind

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Kinetic physics in Parker Solar Probe

== electron beams

== features in eVDF
Non-equilibrium velocity distribution functions

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

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

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We need a numerical tool that combines the capability of modeling solar wind expansion.

**Expanding Box Model**

**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)*

Stability constraint: \( \varepsilon < v_{th,e} dt/dx < 1 \)

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**EB-iPic3D**
A fully kinetic, semi-implicit Expanding Box Model code

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Introducing a realistic initial magnetic field description (radial + transverse magnetic field component) and changing the simulation initial parameters, we can “populate” the $\beta_{\text{par}}$ vs $T_{\text{perp}}/T_{\text{par}}$ plane, to try to reproduce observations.
EBM Electron Firehose Instability simulations

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[M.E.Innocenti, mariaelena.innocenti@gmail.com] [Innocenti et al, in prep]
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\[
\omega_{pe} t = 5120, \ R/d_e = 228 \\
(-6.07e-07, 7.32e-02), (-5.41e-08, 5.10e-02)
\]

\[
\omega_{pe} t = 10240, \ R/d_e = 356 \\
(4.80e-05, 6.81e-02), (-2.16e-05, 5.45e-02)
\]

\[
\omega_{pe} t = 12800, \ R/d_e = 420 \\
(8.30e-05, 5.87e-02), (-7.17e-05, 5.58e-02)
\]

\[
\omega_{pe} t = 35840, \ R/d_e = 996 \\
(-9.68e-05, 4.36e-02), (8.74e-06, 4.85e-02)
\]
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 $\beta_{\text{par}}$ vs $T_{\text{perp}}/T_{\text{par}}$ 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


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