Interplay between Kelvin-Helmholtz and kinetic instabilities along Mercury's magnetopause

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Abstract: (1)

Boundary layers in space plasmas are always the locations of many phenomena allowing the mixing of plasma. But for a given boundary, different mechanisms can coexist and compete one with each others. In this work, we look with fully Particle-In-Cell simulations at velocity shear boundary layers with a gradient of density and magnetic field. We observe that in presence of a density gradient, kinetic instabilities (such as the lower hybrid drift instability) develops along the layer much quicker than the Kelvin-Helmholtz instability. In particular, we observe that one of those kinetic instabilities develops into forming large scale structures that compete (and even suppress) the Kelvin-Helmholtz instability, depending on the density gradient in the layer. Such a result can make us reconsider the main mixing mechanisms in plasma layers with strong density gradient, such as the magnetopause of Mercury.

Simulations: (2)

We made **4 simulations** of a magnetopause current layer with different asymmetries of magnetic field and density and different velocity shear.

Simulation code: **SMILEI** (fully kinetic Particle-In-Cell)

	Simulation 0	Simulation 1	Simulation 2	Simulation 3
B_1/B_2	0.5	0.5	0.5	0.5
n_1/n_2	10	10	5	1
$v_1 - v_2$	0	0.5	0.5	0.5

Where the subscripts:
1 —> magnetosheath
2 —> magnetosphere

Expected instabilities:

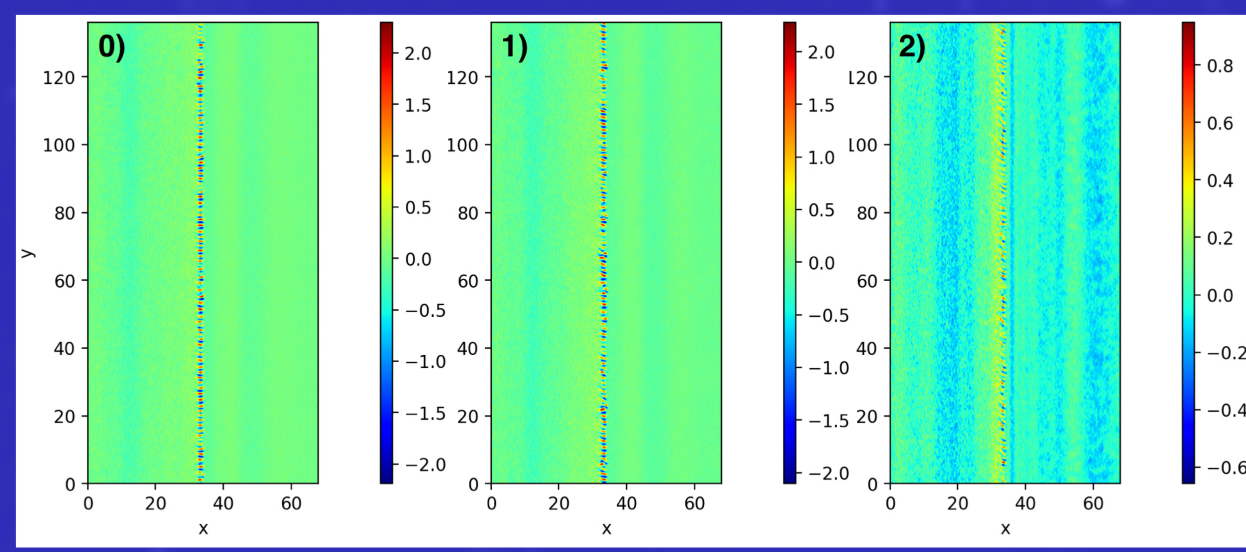
- Velocity shear —> Kelvin-Helmholtz instability (**KHI**)
- Density gradient —> Lower-Hybrid Drift instability (**LHDI**)

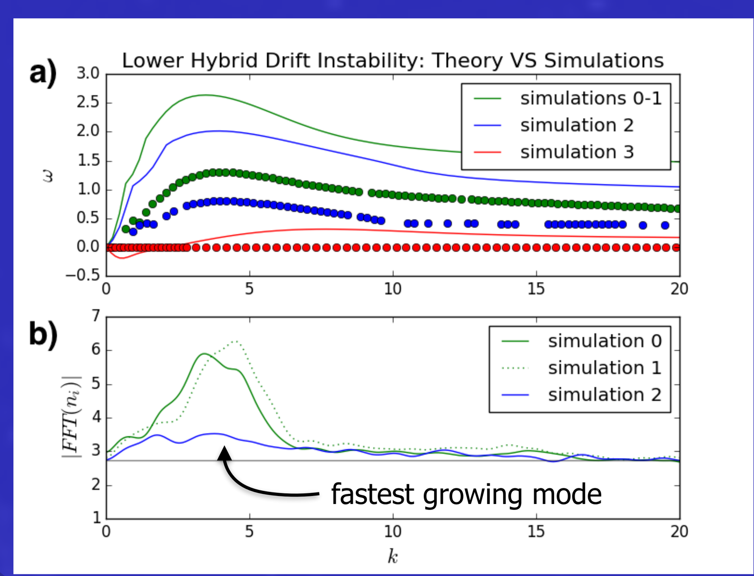
Note: Simulation 1 models a Mercury-like magnetopause

First phase: linear LHDI (3)

V_{ex}, t=7.5

The LHDI growth rate is much quicker than the KHI growth rate



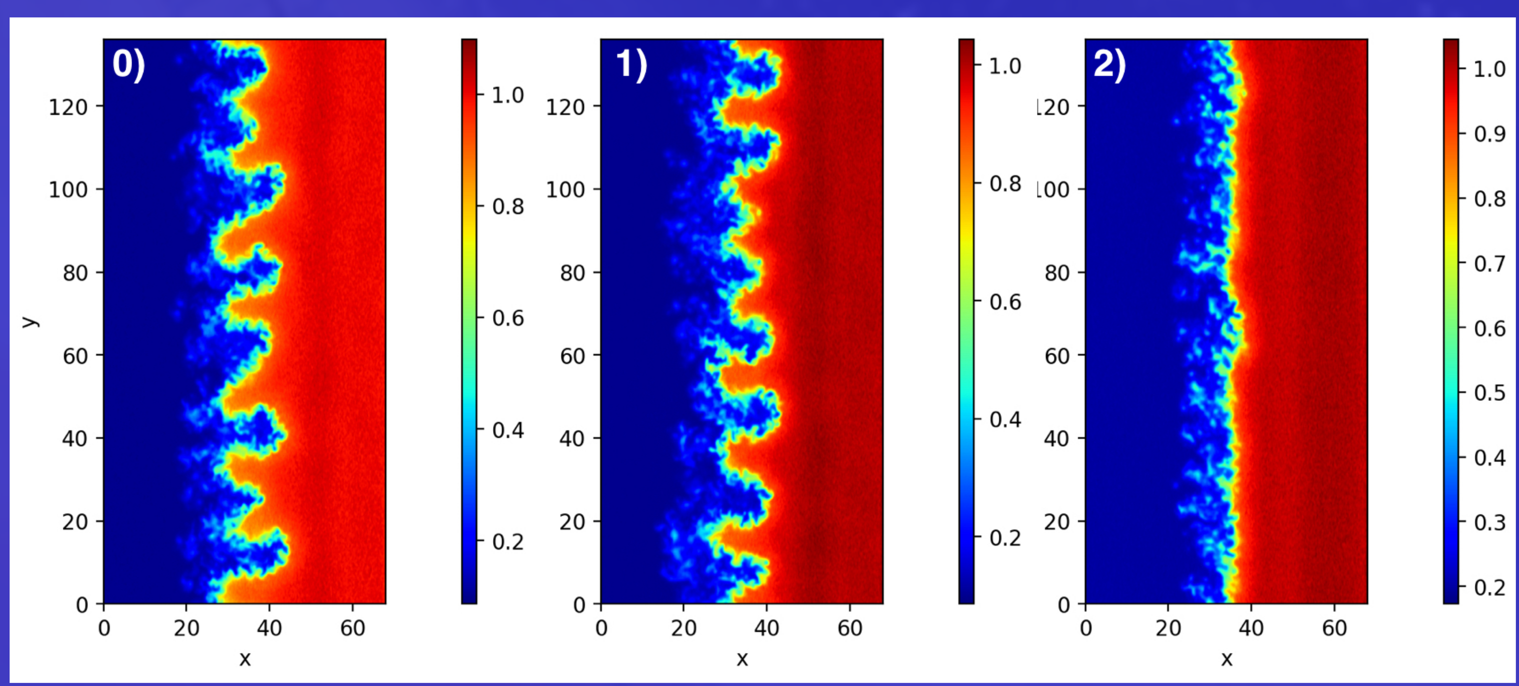


LHDI theory:

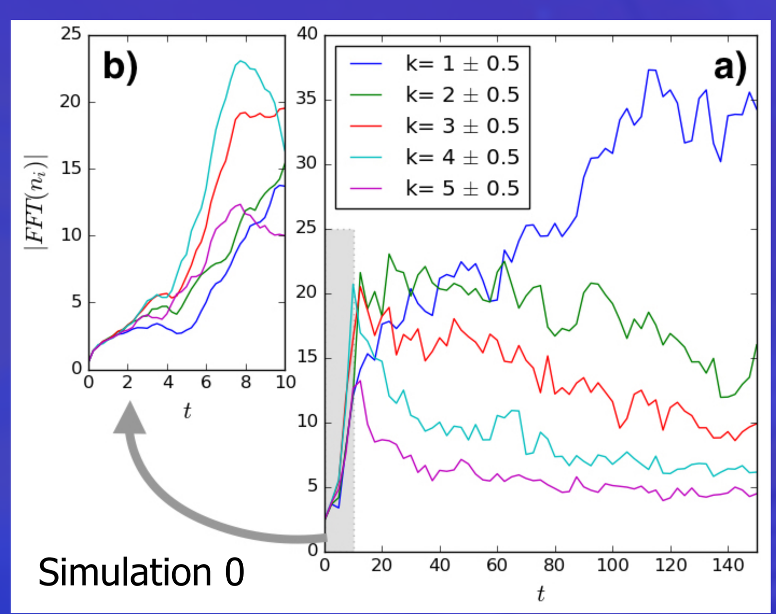
- straight line —> real frequency
- dotted line —> growth rate (imaginary frequency)

LHDI grows **quickly** but **at small scales**

Second phase: nonlinear LHDI (4)



N_i t=150



The linear LHDI saturates quickly.

An inverse cascade transfers energy **from small scales** (fastest growing modes, k~4) **to fluid scales** (k<1).

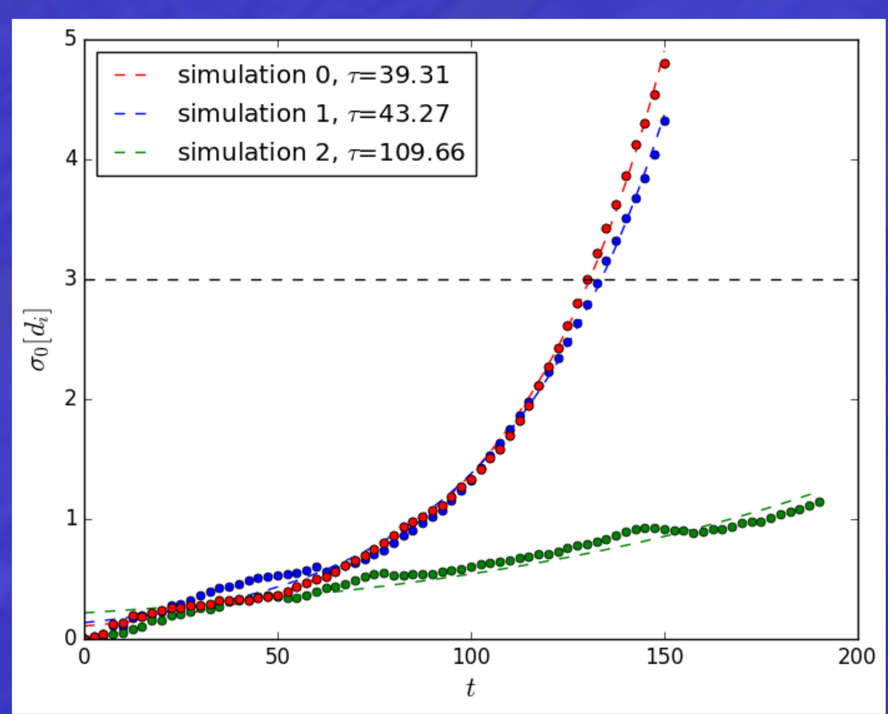
Another (kinetic) instability?

To measure the growth of the structures, we use the standard deviation of the layer's position in x:

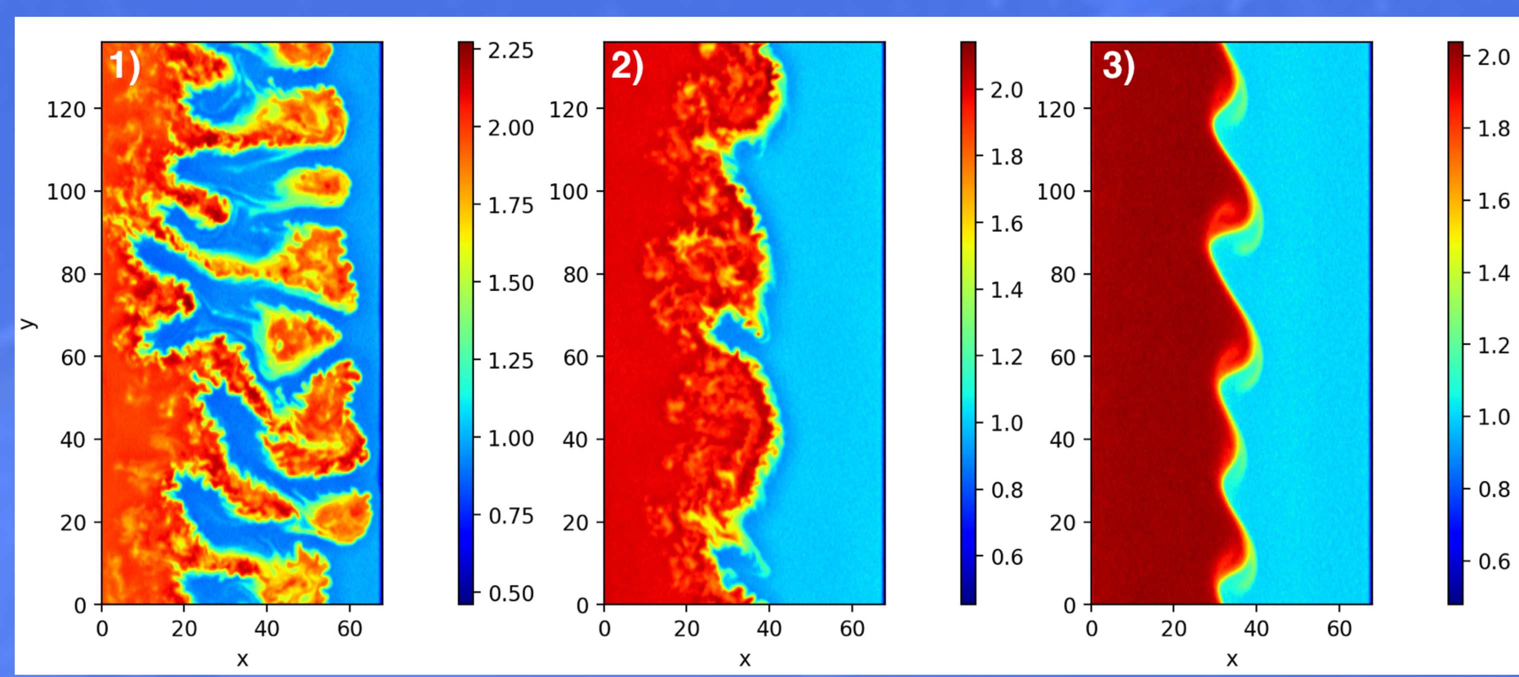
$$\sigma_0 = \sqrt{< x_0^2 >_y}$$

The evolution of this value can be fitted as:

$$\sigma_0(t) = Ae^{t/\tau}$$



Third phase: linear KHI and interactions (5)



B_z t=350

When applicable, the KHI grows, but on time scales much longer than the LHDI. If the structures of the second phase grow too fast, **they can block the growth of the KHI**. Thus we compare the characteristic growth time of both phenomena:

characteristic times	Simulation 0	Simulation 1	Simulation 2	Simulation 3
τ_{nl}	39	43	110	NA
τ_{KH}	NA	77	57	42

Where τ_{nl} is the characteristic time for the finger-like structures' growth and τ_{KH} for the KHI

Simulation 1:

$$\tau_{nl} < \tau_{KH}$$

The finger-like structures grow too fast —> **The KHI is suppressed**.

Simulation 2:

$$\tau_{nl} > \tau_{KH}$$

The finger-like structures grow slower that KHI —> **The KHI develops**, despite the initial instability.

Conclusions: (6)

- In its nonlinear phase of LHDI, we observe **another instability** (kinetic?) and a **cascade from kinetic scales to fluid scales**.
- The large-scales structures generated in the second phase by **the instability can suppress the KHI**.
- The relative importance of KHI and LHDI depends mainly on the **density asymmetry** and the **velocity shear.** Other parameters (ex: **layer width**) play a role.
- Published in Dargent et al. (2019, JPP)

Prospectives:

- **Characterization of the second phase instability** (Drift kink instability? Gradient instability?)
- Effect of the plasma composition (cold and/or heavy ions)
- Effect of the dawn-dusk asymmetry of the magnetopause on both instabilities.
- Comparison with future BepiColombo data

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