Kinetic Simulations of the Rayleigh-Taylor Instability in Space Plasmas

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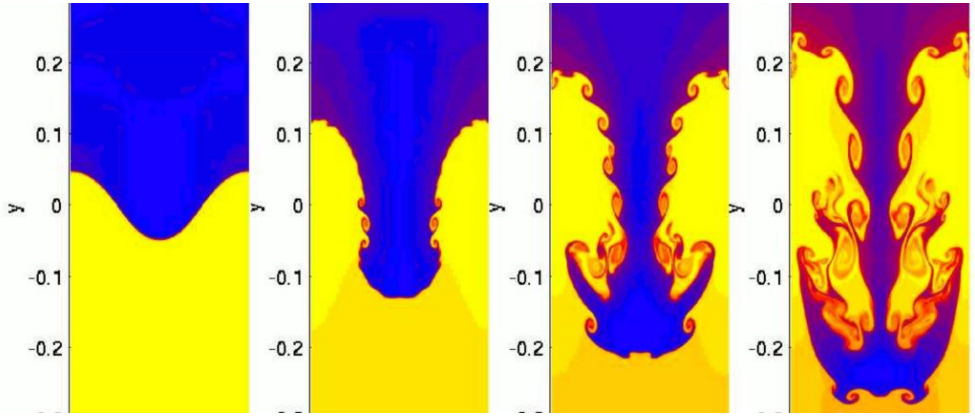
Plasma bubbles at the ionosphere degrade GNSS signals

Rayleigh-Taylor Instability (RTI):
Triggered when a denser fluid is supported by a less dense one against an effective acceleration.

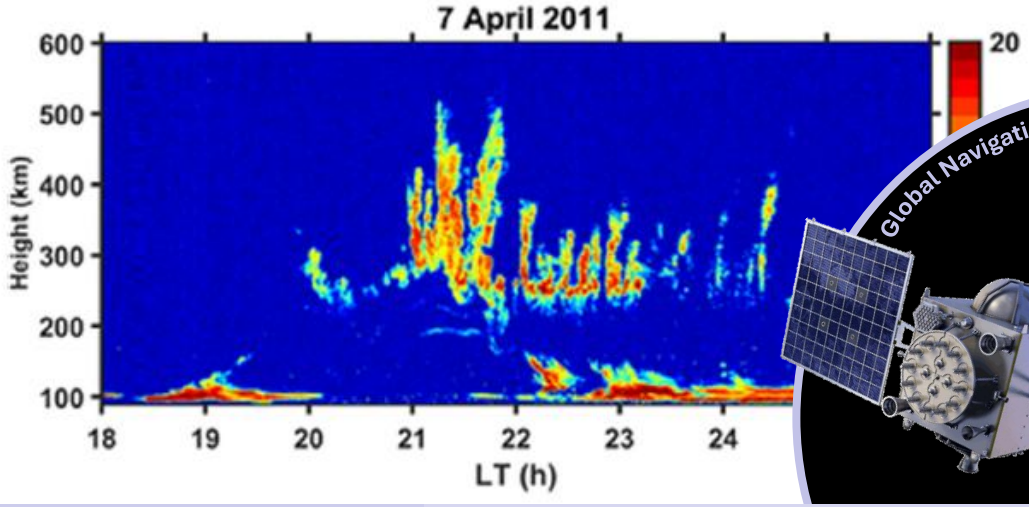
Equatorial Plasma Bubbles (EPBs):
RTI-driven plasma density depletions that form near Earth's magnetic equator.

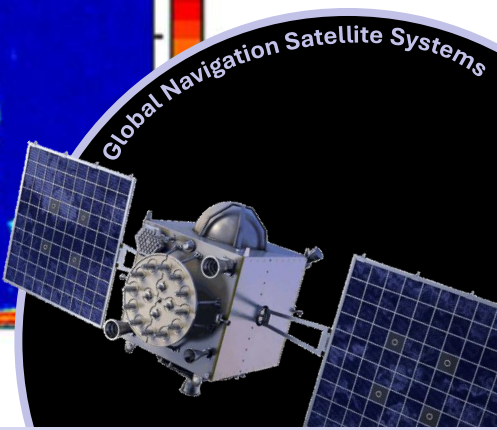
Economic impact (London Economics):
7-day GNSS outage: £7.64 billion loss.
1-day disruption: £1.42 billion loss.

RTI example



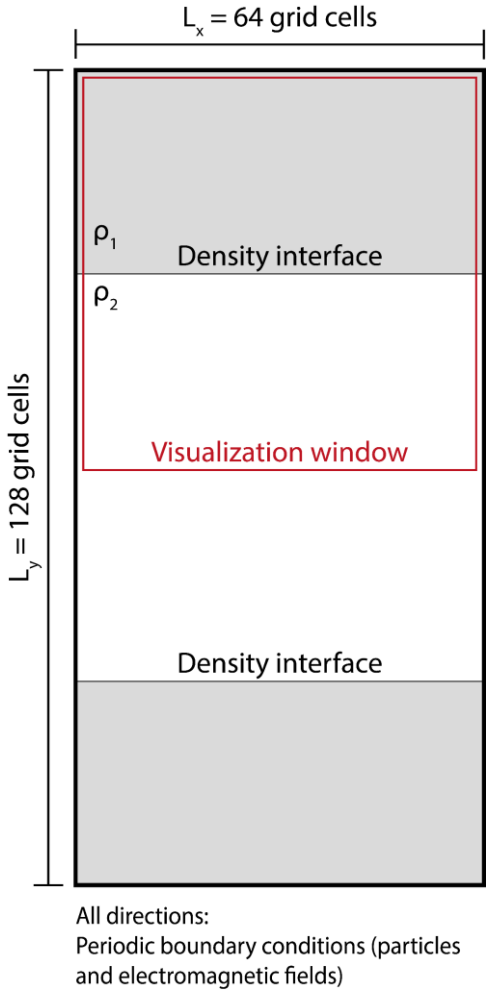
EPB radar detection



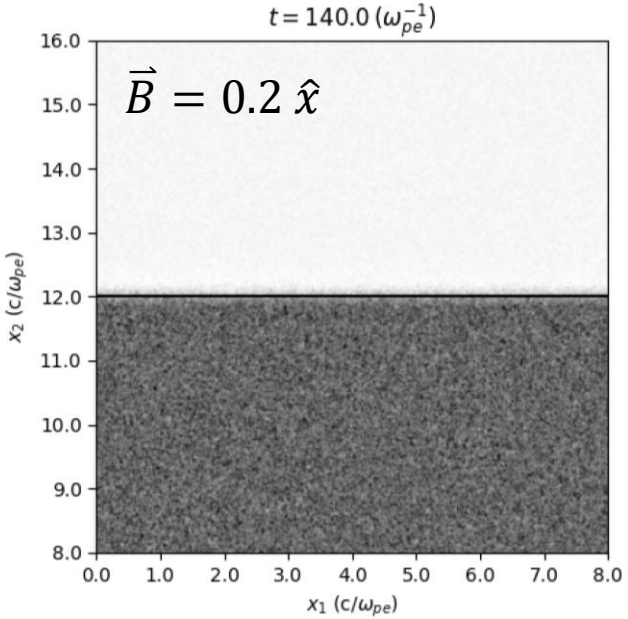


Simulating an RTI configuration without gravity: Equilibrium analysis

Simulation setup

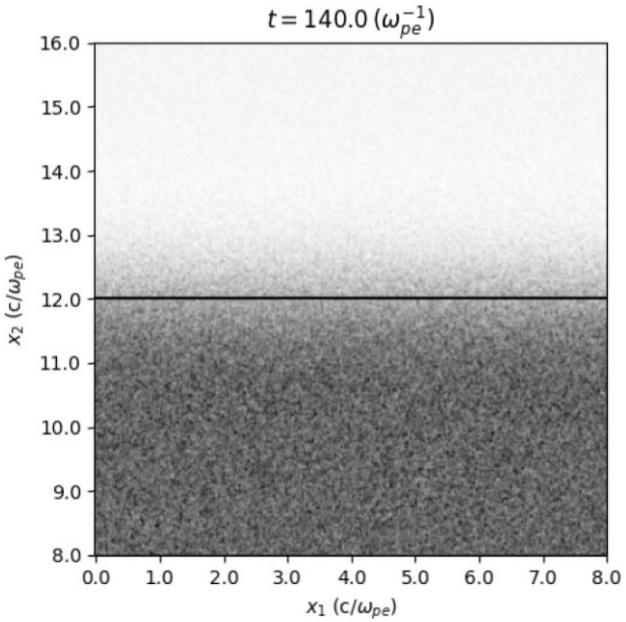


Density profiles



Magnetized case:

- Efficient magnetic containment;
- Sharp interface is preserved.

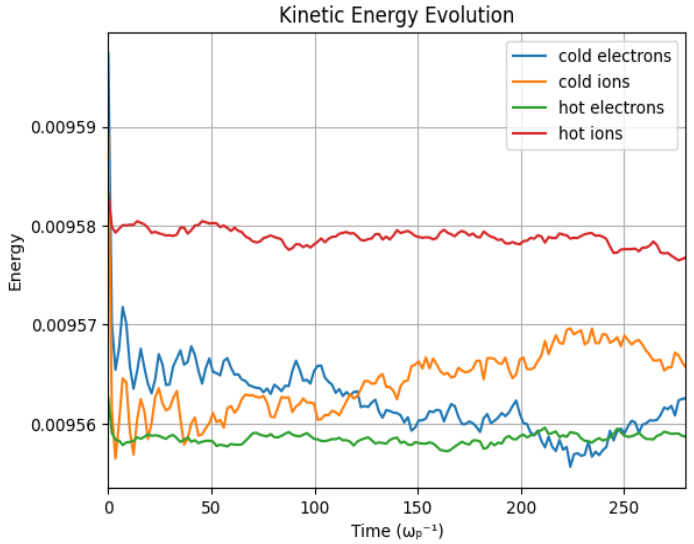


Unmagnetized case:

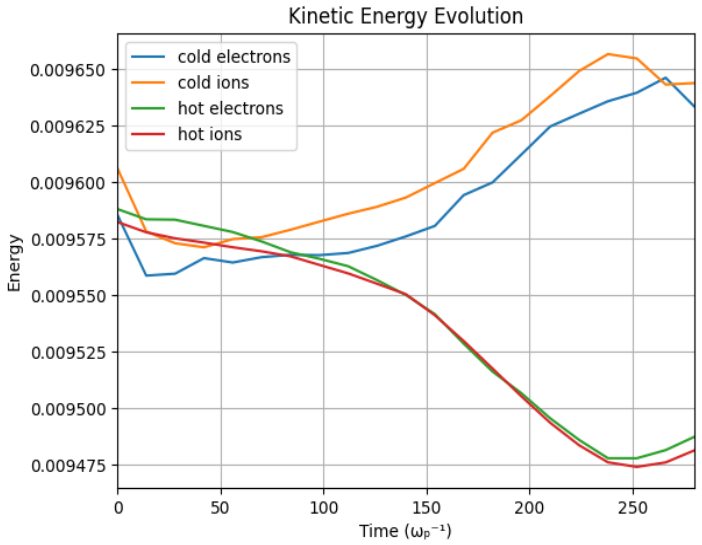
- Thermal expansion;
- Density gradient.

The unmagnetized system is not a kinetic equilibrium

Magnetized



Unmagnetized



Numerical heating will cause an increase in the Debye length of the plasma until the grid resolution is sufficient to resolve it.

$$\lambda_{D\,hot} > \lambda_{D\,cold}$$

Does kinetic energy stagnate with a noticeable time offset for the different plasmas (cold and hot)?

Yes → **Numerical heating signature**

No → **Rule out Numerical heating** ✓

A hydrodynamic equilibrium does not imply a kinetic equilibrium

What is the influence of the magnetic field in the system's equilibrium?

The presence of a magnetic field proved to play a crucial role in containment of the equilibrium state, in a fully kinetic treatment.

Hydrodynamic Equilibrium ≠ Kinetic Equilibrium

What's next?

- Add gravity to the simulation;
- Increase simulations' complexity towards a setup similar to the ionospheric bottom F-layer.