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Plasma Instabilities Generated in the Ionosphere

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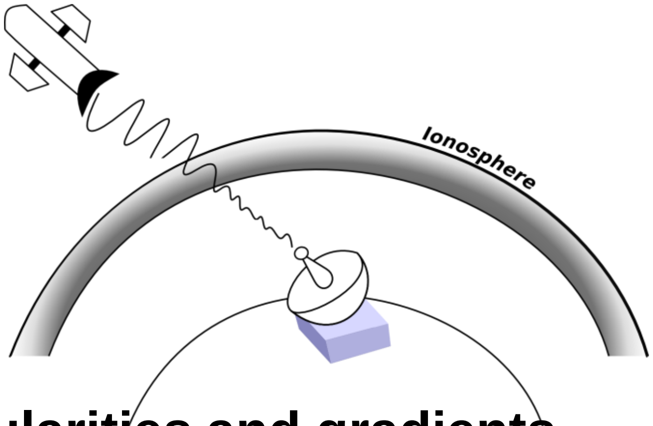
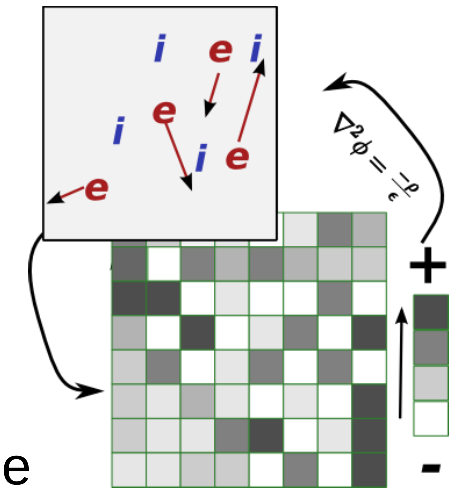
Motivation

- The ionosphere affects satellite to Earth communication through radio wave scintillations—by changing the phase or amplitude of the radio waves

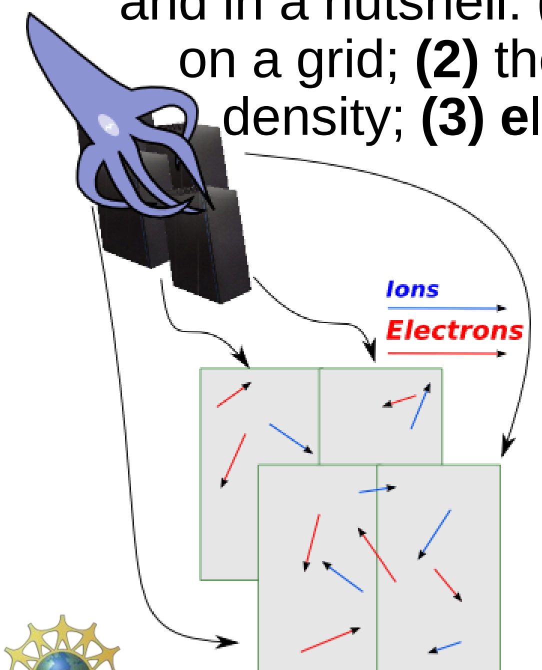


- This occurs when there are density irregularities and gradients in the ionosphere's plasma
- Plasma instabilities are cases when the amplitude of density irregularities grow, and this growth rate involves nonlinear and kinetic effects
- These local instabilities can lead to ion and electron heating, which affects important physical, large-scale properties of the Ionosphere—such as conductance.

Particle-in-Cell (PIC) and Kraken



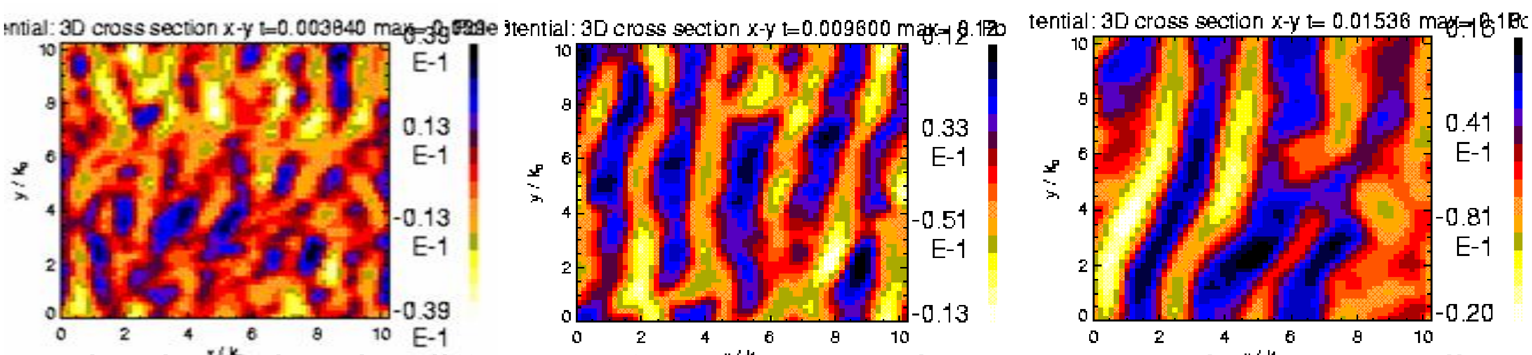
- Traditional CFD methods often lack detail such as nonlinear and kinetic effects, which are crucial to understanding the instability saturation mechanisms and subsequent energy dissipation
- **PIC** represents a plasma using macroparticles, and in a nutshell: **(1)** the charge density is summed on a grid; **(2)** the electric field is calculated from the density; **(3)** **e**lectric force moves the particles within the grid



- **Kraken** attacks the calculation through a decomposition of labor:
  - **Grid Domain Decomposition;** each processor gets a fraction of the total grid
  - **Particle Domain Decomposition;** each processor gets a fraction of the total particles

Farley-Buneman Instability in 3D

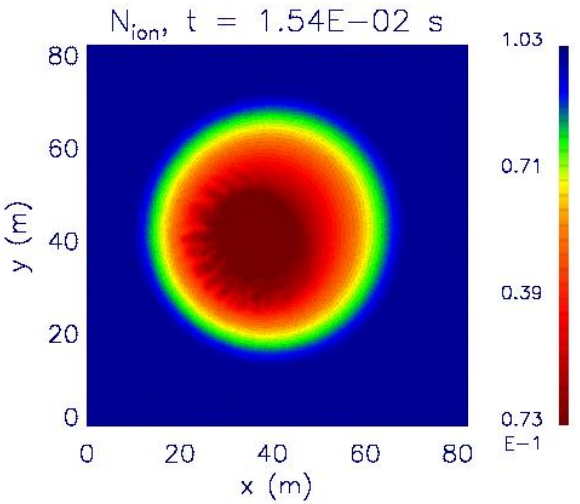
- **The Farley-Buneman Instability develops in the Ionospheric E-region due to electrons drifting rapidly perpendicular to ions.**
- **Recent 3D simulations of the Farley-Buneman instability confirm theoretical predictions that dynamics along the magnetic field leads increased heating when compared to 2D runs perpendicular to the magnetic field.**

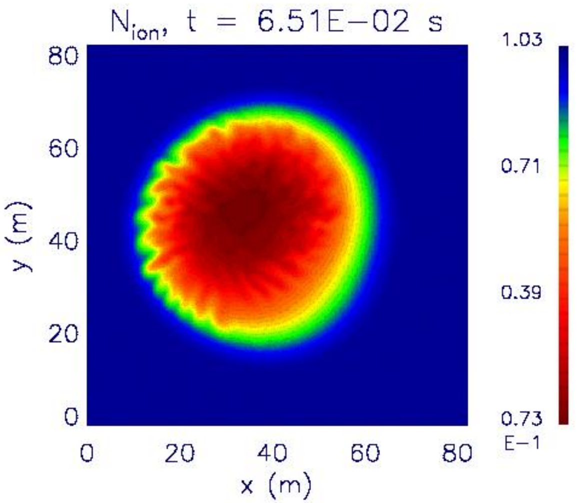


Normalized Ion density difference for 3 times and along a 2D slice, perpendicular to B, of a 3D simulation. The resulting waves grow to longer wavelengths with time, as is also seen in purely 2D simulations, but electron heating in this 3D simulation is 100% more.

Small Scale Plasma Bubbles

- Uplifting of low density "bubbles" create local density gradients; these drive short scale waves perpendicular to the gradient.
- Many studies have focused on the >100m scale physics involved; this is the only research addressing the <100m scale, which contributes to the dissipation of all larger scales.
- These simulations show that an external electric field can also interact with the gradient driven drift, enhancing the instability in some cases (left side of bubble) and weakening it in others (right side of bubble).





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Summary

- With Kraken resources, we have performed our largest 3D simulations ever. The simulations were large enough to confidently determine that the saturated state was not numerically determined, as was found for smaller 3D simulations.
- These 3D Farley-Buneman simulations confirm that dynamics along the magnetic field plays an essential role in heating electrons.
- Mechanisms used to characterize the development of large scale waves (>100 m) in the F-region predict that small scale waves should not exist. Our 2D bubbles show promise for explaining the existence of these small scale (<10 m) waves and the complicated dynamics the results from gradient driven flows.

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