# Simulations of Secondary Farley-Buneman Instability

EQIT-05

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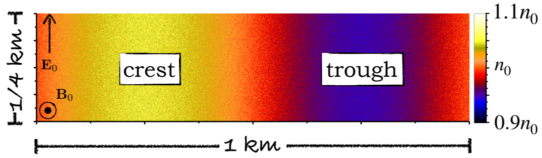
## Introduction

Radar observations of the equatorial E-region ionosphere have produced a variety of spectra of meter-scale plasma-density irregularities. Since the 1960s, researchers have attributed the observed spectra to two electrostatic instabilities: The Farley-Buneman instability (FBI) and the gradient drift instability (GDI). Both instabilities can occur self-consistently in a collisional plasma comprising magnetized electrons and demagnetized ions — the FBI requires that the total electric field exceed a threshold value while the GDI requires an ionization gradient parallel to the electric field. Echoes from vertically propagating meter-scale irregularities are particularly interesting because their occurrence is consistent with the passage of kilometer-scale structures, allowing them to trace out large-scale dynamics. While such irregularities may simply be the end result of a turbulent cascade, kilometer-scale structures can also directly drive meter-scale irregularities when their polarization electric fields exceed the threshold for FBI. This work presents hybrid numerical simulations of secondary FBI driven by a large-scale primary seed wave. Average turbulent electric fields are consistent with rocket data and 3-m wave spectra reproduce observed asymmetries.

## Parameters

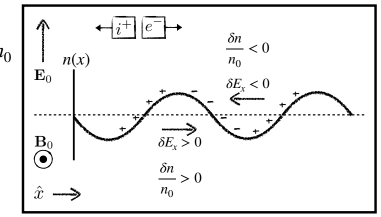
| Symbol | Value | unit | name |
|---|---|---|---|
| $m_i$ | $5.0\times10^{-26}$ | kg | ion mass |
| $m_e$ | $9.1\times10^{-31}$ | kg | electron mass |
| $m_n$ | $4.6\times10^{-26}$ | kg | neutral mass |
| $T$ | 220 | K | temperature |
| $n_0$ | $10^{10}$ | $m^{-3}$ | plasma density |
| $h$ | 102 | km | effective height (magnetic equator) |
| $\nu_i$ | 3350 | $s^{-1}$ | ion-neutral collision frequency |
| $\nu_e$ | $3.0\times10^{4}$ | $s^{-1}$ | electron-neutral collision frequency |
| $B_{y0}$ | $-2.5\times10^{-5}$ | T | magnetic field |
| $E_{z0}$ | 9.0 | mV/m | vertical electric field |
| $L_x$ | $\approx 1$ | km | zonal box length |
| $dx$ | 0.5 | m | zonal cell size |
| $L_z$ | $\approx 0.25$ | km | vertical box length |
| $dz$ | 0.5 | m | vertical cell size |
| $L_t$ | $\approx 0.3$ | s | real-time span |
| $dt$ | $10^{-5}$ | s | time step |

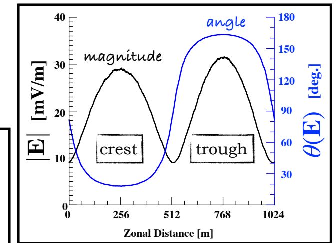
## Initial density and electric field




The simulation has periodic boundary conditions with a vertical background electric field and a background magnetic field out of the page.

In the wave frame, (magnetized) electrons drift ahead of (collisional) ions. That creates a polarization electric field in phase with the density perturbations.

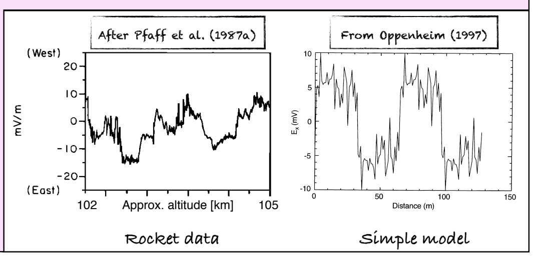



The initial total electric field magnitude is slightly asymmetric, with a peak in the density trough. The direction varies from 18° above west to 18° above east.

## Density and electric field: FBI turbulence creates flat-top fields

- **Figure 1**: Relative perturbed density (zoomed-in) and average zonal electric field after approximately 10 collisions, during wave growth, after wave-growth saturation, and at the end of the run.
- Meter-scale waves develop first and most strongly, and propagate at approximately ±45° of due west — upward in the troughs and downward in the crests.
- The electric field begins roughly sinusoidal, develops flattened tops coincident with FBI growth, and becomes distorted by the large-scale wave drift by the end of the run.
- Flat-top fields have appeared in rocket data (Pfaff et al., 1987a,b) and a simplified simulation (Oppenheim, 1997). They indicate field saturation due to a nonlinear, instability-driven current that transports plasma across magnetic field lines.




## 3-m wave spectra: Up-down/east-west asymmetries

**Figure 2a**: spectrum of 3-m waves as a function of phase velocity and angle from west. Up-going waves (negative Doppler) appear in a westward beam; down-going waves (positive Doppler) appear in an eastward beam.

**Figure 2b**: RMS of spectrum over angle. The asymmetry is consistent with previously reported up-down/east-west asymmetries (Patra et al., 2005, Choudhary et al., 2006, Hysell et al. 2007).

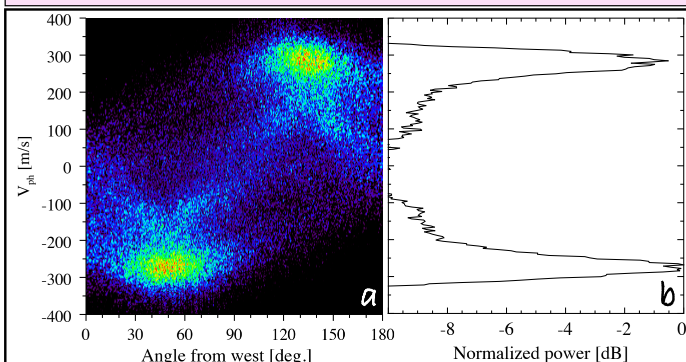
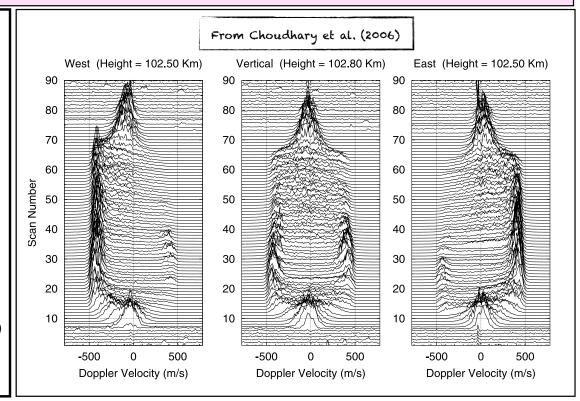



Figure 2



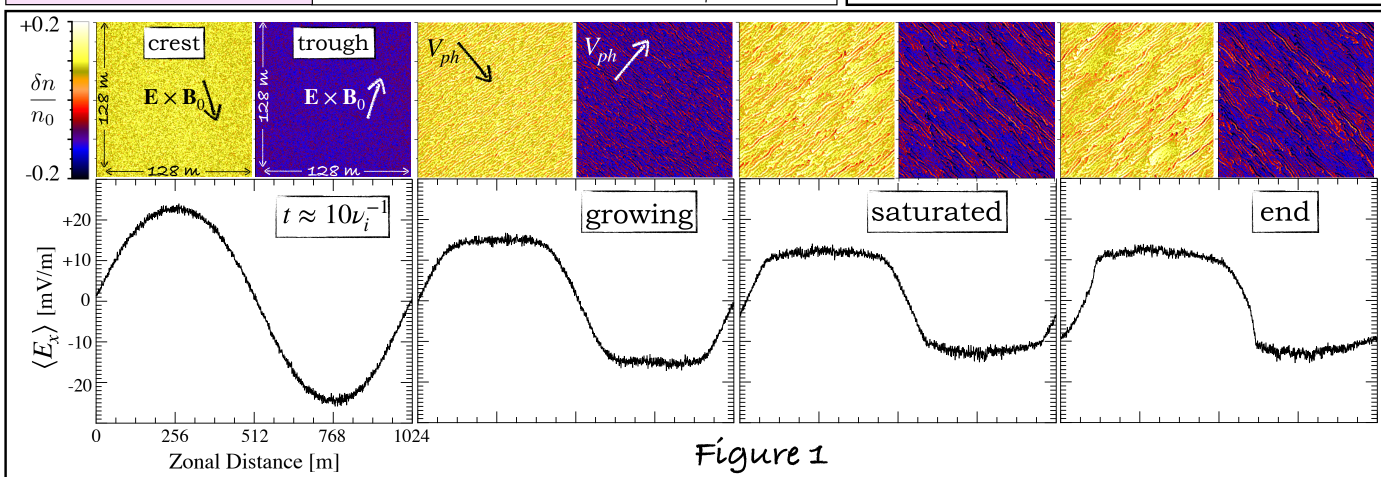




Figure 1

## Conclusions

- These are the first self-consistent kinetic simulations of the Farley-Buneman instability (FBI) driven by a large-scale wave (e.g., from the gradient drift instability) in the lower equatorial E-region ionosphere during daytime.
- FBI waves propagate upward and westward in the large-scale trough, and downward and westward in the large-scale crest.
- Average zonal electric field develops flattened tops in regions of FBI growth, indicating saturation due to nonlinear current. The nonlinear current transports plasma across the magnetic field.
- 3-m spectra show features consistent with previously reported up-down and east-west asymmetries in radar data.
- Results presented can extend to auroral density structures produced by convection, auroral precipitation, and ionospheric cavitation.