Fully kinetic simulations of radio emission from a propagating electron beam

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I. INTRO

- Type III radio bursts are produced as electrons accelerated by solar flares propagate out through the corona and into the solar wind.
- The standard theory for radio emission involves the conversion of Langmuir waves excited by electron beams via the bump-on-tail instability [1].
- An issue with this is that the wave coupling processes must not disrupt completely the beam propagation, since radio emissions are still observed at 1 AU [2].

II. METHODS

- A 2D PIC simulation was performed where a Maxwellian beam is injected between the white arrows (Fig. 2, panel C) and moves across the simulation box, which is long enough ($400d_e$) to observe propagation effects.
- Background parameters: $\omega_{pe}/\omega_{ce} = 20$, $T_e = 10\,T_i$, $v_{te} = 0.025c$.
- The injected beam has density $n_b/n_0 = 10^{-3}$ & drift speed $V_b = 8v_{te}$.

III. RESULTS

- Two different regions of excited Langmuir waves are created due to beam stabilization and time-of-flight effects (panel A). A quiet region separates the two where only Langmuir decay occurs.
- The bright red region has waves generated by the freshly injected and highly unstable beam. In the lighter red region are those excited from the initial transit by a more stable beam.
- Classic signatures of three-wave coupling conversion processes such as Langmuir decay and harmonic emissions are observed near the injection region (see Fig. 4), where electromagnetic emissions originate (see Fig. 1, panel C-D).
- Modulational instability exists only near the injection site (Fig. 4, panel D).

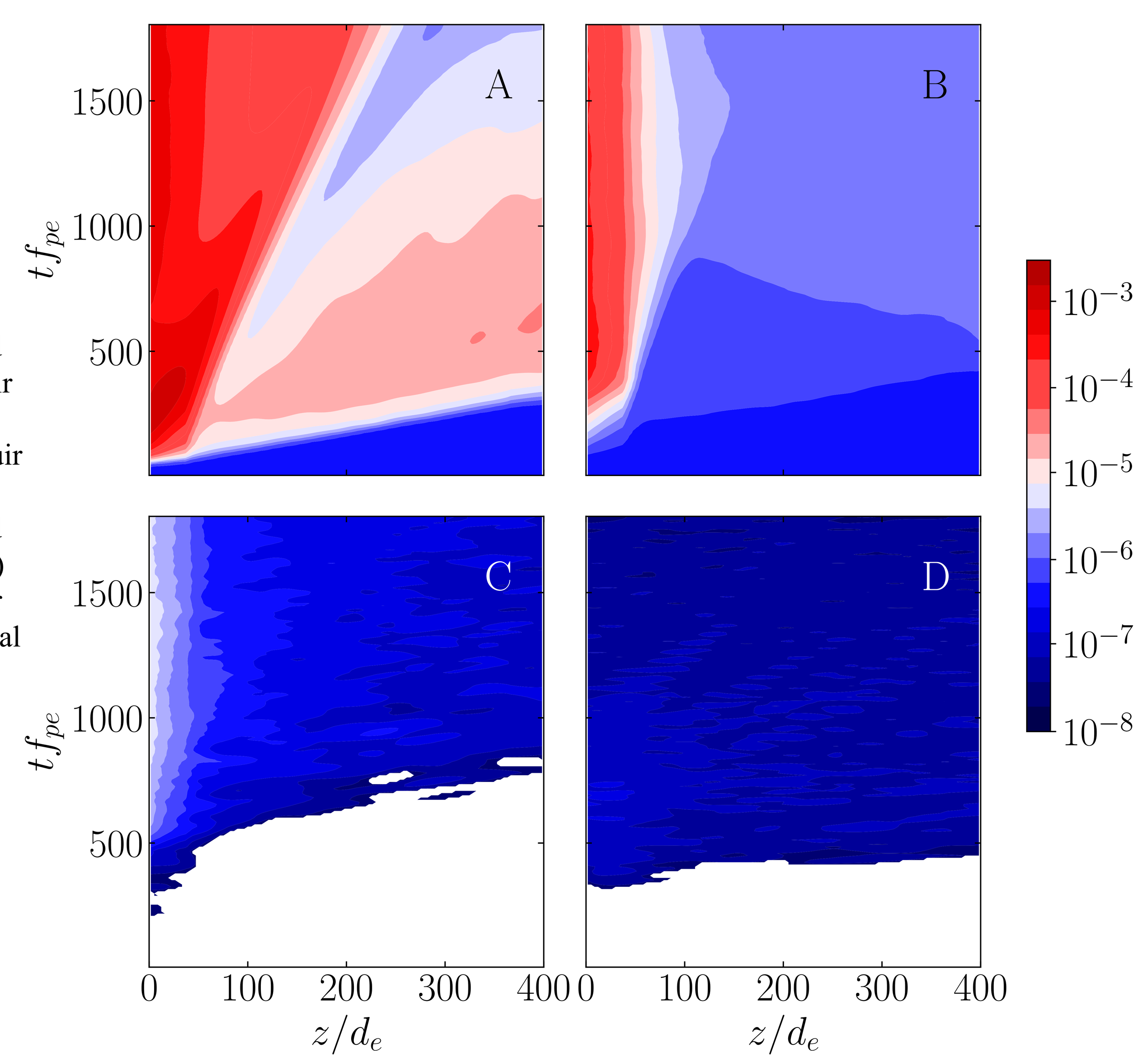

***Figure 1**.* Spatiotemporal evolution of forward propagating Langmuir waves (A), backscattered Langmuir waves (B), and fundamental (C) and second harmonic (D) emissions. The color shows the local spectral energy density.

- ***Fully kinetic, mesoscale PIC simulations*** *are used to investigate* ***propagation of flare accelerated electron beams*** *over long distances.*
- ***Only 15% of beam energy*** *is lost in the initial relaxation, after which the modified beam stabilizes,* ***enabling propagation to large distances****.*
- *Both* ***fundamental and second harmonic EM emissions*** *are observed.*
- ***Instabilities exist only in the front of the beam*** *unless background plasma changes downstream.*

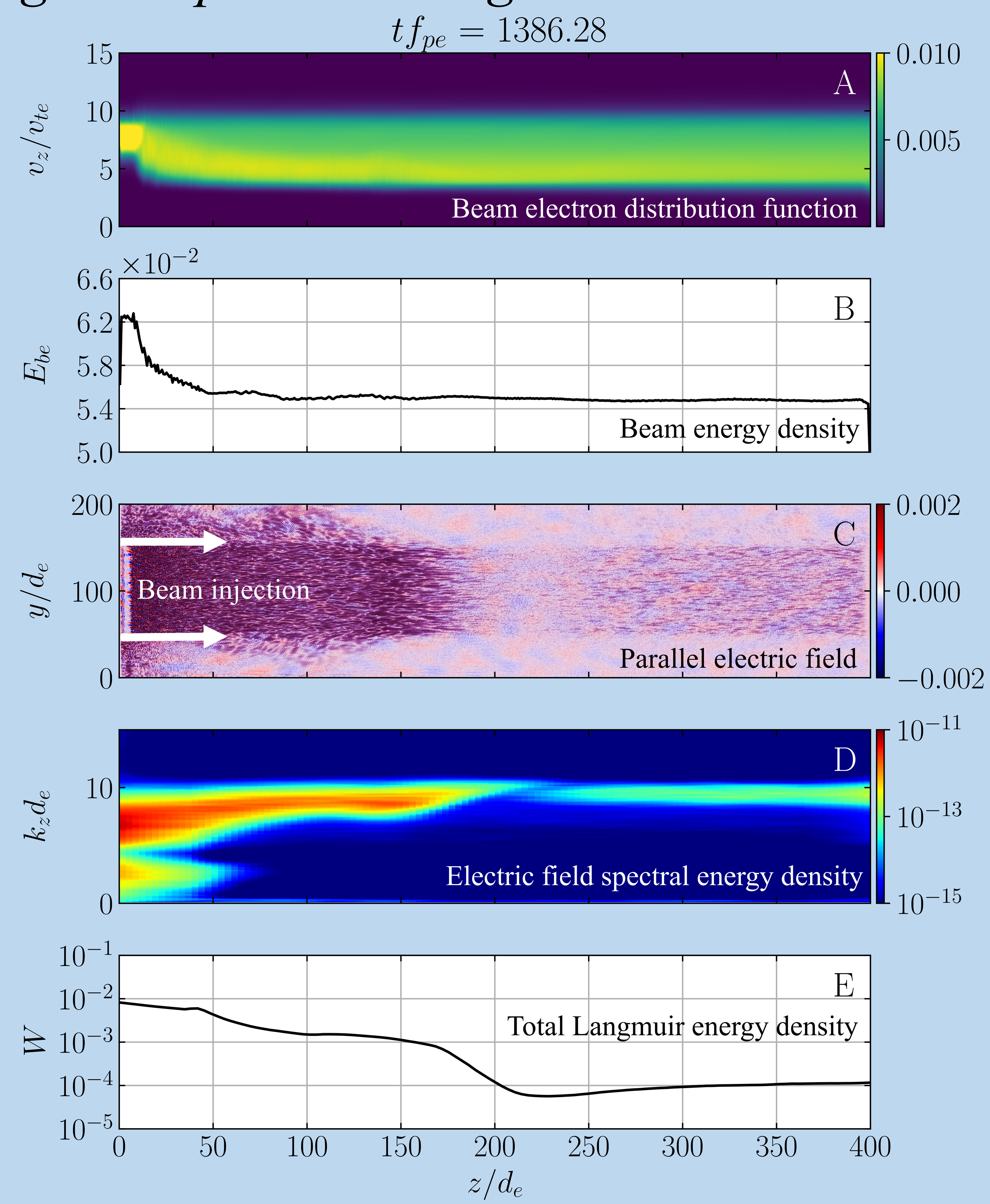

Figure 2. Overview of beam and wave evolution across the parallel dimension (z) of the box at t ~ 1400. A: velocity distribution function of beam electrons (without background electrons). B: energy density of the beam. C: parallel electric field. D: parallel electric field spectral energy density. E: total Langmuir (both forward and backward) energy density.

IV. DISCUSSIONS

- Most previous PIC studies of the conversion processes that generate type III emission used periodic boundary conditions, thus imposing a strong coupling between the beam and the excited waves [3,4].
- In our simulation, the beam escapes the region of strong wave activities with minimal energy loss. This escaping beam is stable and can propagate to longer distances.
- The stable beam can become unstable again due to background temperature and/or density variations at larger heliospheric distances where radiation can be observed.
- In the context of type III bursts, strong and weak plasma turbulence theories have been investigated with simulations [5,6,7]. Our model favors the quasilinear evolution of the downstream beam, which provides strong support for models of type III bursts that assume propagation near the state of marginal instability. However, signatures of turbulences are also observed due to the strong wave activities near the injection region.

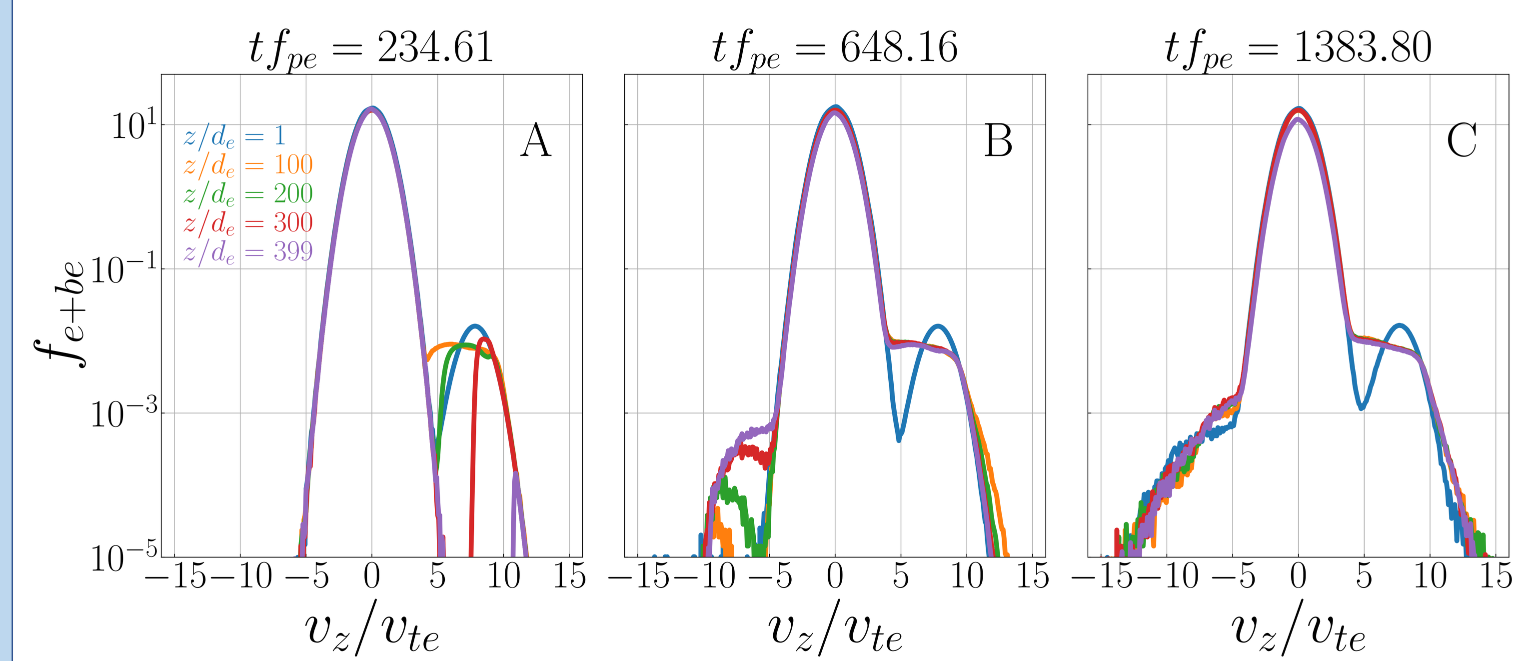

***Figure 3**.* Local electron distribution at 5 locations (colored) in the simulation box.
Note that panel A of Fig. 2 only shows the beam electron population, but this also shows the background electrons.

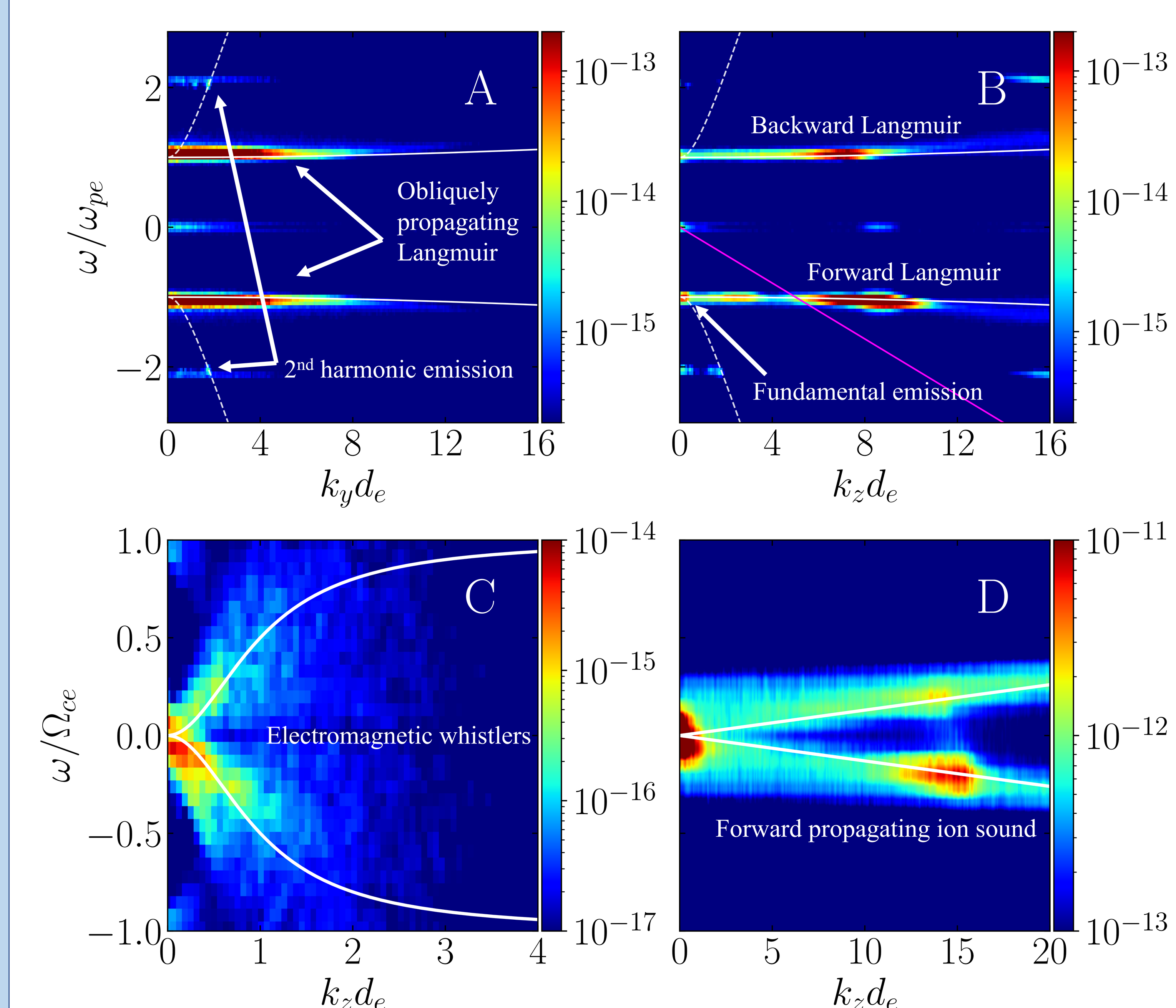

***Figure 4**.* Spectral energy density in perpendicular/parallel wavenumber (ky/kz) vs. frequency space.
Panel A-B: electromagnetic field spectrum. Panel C: low frequency magnetic field spectrum.
Panel D: ion density spectrum.

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