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Particle-in-cell simulations of diffusion due to whistler - mode waves

NERC SCIENCE OF THE ENVIRONMENT

Rad-Sat

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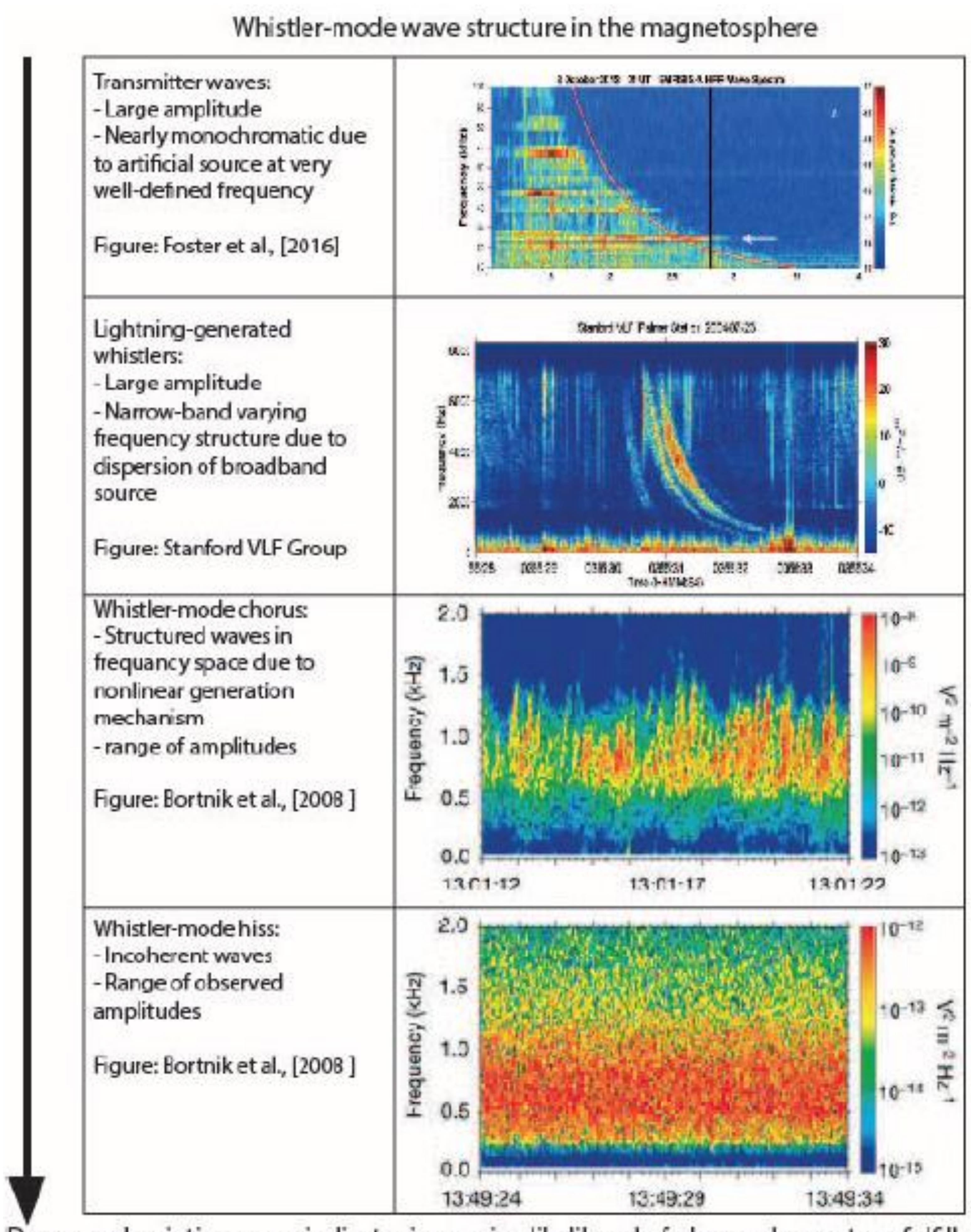
Introduction

Diffusion codes in Radiation Belt models (RBMs) are based on the quasilinear theory (QLT) of wave-particle interactions. Whistler-mode waves are included in RBMs, and contribute to local acceleration and loss of electrons. However, whistler-mode waves are unlikely to always satisfy the formal requirements of QLT. We use particle-in-cell (PIC) simulations to test this hypothesis.[1]

Whistler-mode waves

(A) 'Least like QLT'

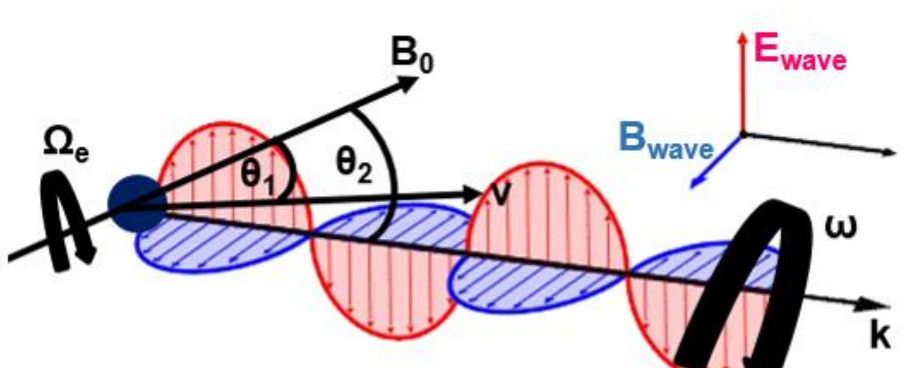


Downward pointing arrow indicates increasing likelihood of observed wave type fulfilling all the assumptions of quaslinear theory

Figure credit: C. E. J. Watt

(B) 'Most like QLT'

Quasilinear wave-particle interactions



$$\omega - k_{||} v_{||} = n\Omega_e$$

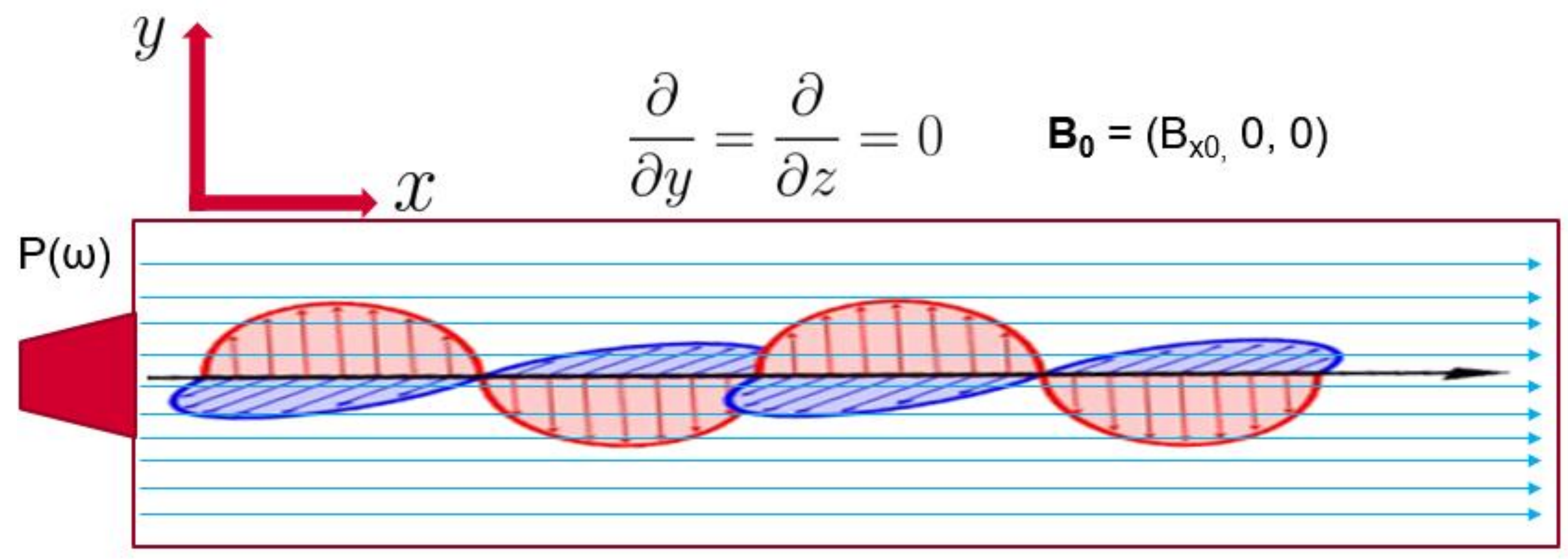
★ **Resonance condition** ★

Assumptions: a background B_0 with 'waves on top' such that:

- For every particle, there is a wave that is resonant
- Wave spectrum is broadband
- Wave phases are random
- Wave amplitudes are small
- *(Wave spectrum is time-independent: extra condition used in radiation belts)*

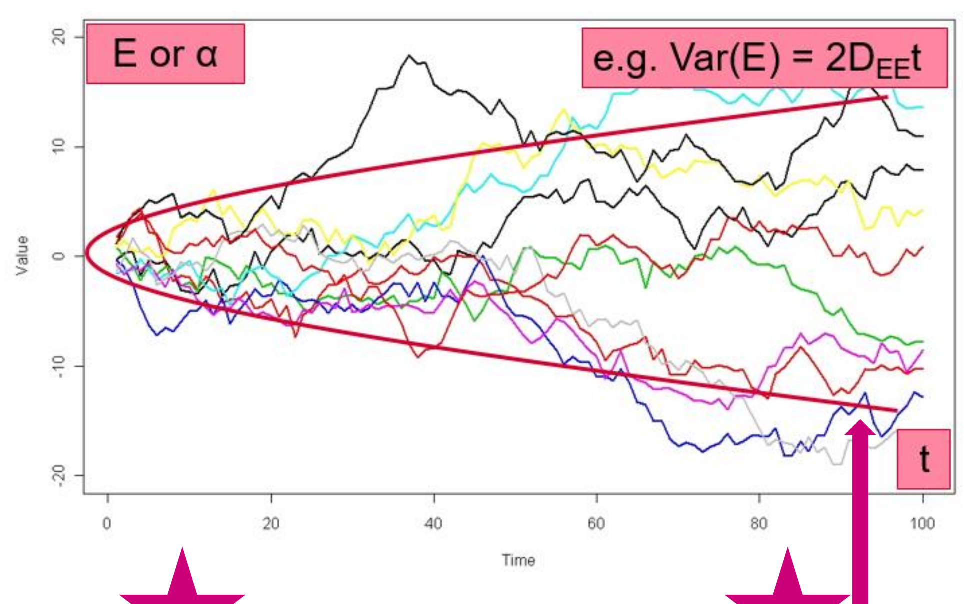
PIC simulations with EPOCH

- **Open-source**, explicit, relativistic and parallelised[2]
- **Easily customised** with a variety of BCs and ICs
- http://www.ccpp.ac.uk/epoch/epoch_user.pdf
- **Demonstrated utility** for the study of whistler-mode waves[3]



- **Initial experiments:** we simulate self-consistent wave-particle interactions for monochromatic transmitter waves and broadband hiss-like waves
- **Reasoning:** these two modes represent the two likely 'extremes' of the whistler-mode wave spectrum (A and B): nonlinear and quasilinear behaviour respectively.
- **Plasma:** 99.89% @ 1eV, 1% @ 10keV, 0.1% hot @ 100keV
- **Waves:** Transmitter waves driven as laser at LH boundary
  Hiss-type waves are naturally occurring above noise
- **Tracers**: non-interacting tracers embedded in the self-consistent PIC simulation. We track tracer particle energy, E, and pitch angle, α.

Analysis: Track diffusion with tracers



★ **Classical diffusion** ★

$$\frac{\partial f}{\partial t} = \sum_{i,j} \frac{\partial}{\partial J_i}\left[D_{ij}\frac{\partial f}{\partial J_j}\right] \quad D_{EE}(E,\alpha) = \frac{\langle(\Delta E)^2\rangle}{\Delta t}$$

Construct direct diffusion coefficients (if possible) from tracer statistics, evolving plasma through T=200t_{ce}:

- **QLT is based on Einsteinian diffusion**, e.g. variance of E, α behave as if under Brownian motion.
- **We test this assumption**, cf. similar works in **[4,5]** and **[6,7]** for test-particle and PIC respectively.

References

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