Whistler Amplification and Stimulated Emission
NRL / Maryland collaboration

Personnel:

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Major accomplishments:

• HEMPIC code development (quasineutral + eliminates $c, \omega_p$ timescales $\Rightarrow$ very fast)

• Theory and simulation of ducting (with Anatoly Streltsov)

• Theory and simulation of whistler growth in homogeneous systems

• Nonlinear amplification of wave packets propagating along the earth's dipole field
  - Wave growth driven by resonant electrons propagating toward equator
  - Large frequency shifts (triggering of fallers)
  - Extensive simulation studies, theory in progress
HEMPIC SIMULATIONS OF WHISTLER INSTABILITY

- Realistic non-uniform geomagnetic field
- Single-frequency wave packet (bounded in space) initiated at t=0
- Fast electron distribution: ring distribution of constants of the motion \( v_2 \) and \( v_{\perp}^2 / B_0(z) \)
- Inflow of fresh electrons from the boundary of the simulation domain

**Electron distribution**

- **Cold electrons**
- **Fast electrons**
EVOLUTION OF WAVE AMPLITUDE $B_{\perp}$ and ELECTRON MOMENTUM $p_{\perp}$

$t = 0$  
$t = 0.014$ sec  
$t = 0.5$ sec
Dashed line indicates the angular frequency $\omega = 1200 \text{ sec}^{-1}$ that is initiated at $t=0$.
• For a ring distribution and a single frequency wave, electrons are resonant at two discrete locations, one on each side of the equator. Wave propagates to right, resonant electrons propagate (at a much larger velocity) to left.

• Wave initially grows at each of these resonant points.

• Resonant electrons are strongly phase-bunched at each resonant point. As these bunched electrons propagate to the left, they drive waves, at lower frequency than the initial triggering wave.

• Electrons propagating toward the equator lose energy and drive wave growth. Electrons propagating away from the equator gain energy and damp the waves.

• Resonant electrons remain resonant for a long time, because the wave frequency adjusts to the changing magnetic field, so as to maintain resonance. However very few electrons are phase trapped. The unstable waves are triggered by resonant untrapped electrons.

• We think we understand the main features and are working on a quantitative theory.
WHISTLER INSTABILITY STUDIES: NEXT STEPS

Physics:

• More realistic thermal, anisotropic and loss cone electron distributions

• Can a large-amplitude injected wave grossly modify the electron phase-space distribution so as to trigger rapid growth of new waves?

• Instability of obliquely-propagating waves and 2-D mode spectra

• Instability of ducted whistlers in 2-D

Code development:

• Will need to parallelize the HEMPIC code (very easy)

• Further code development may be necessary. Can use $\Delta t \gg 1/\Omega$ and $\Delta x \gg 1/\lambda$ by:
  
  - Expanding fields in linear normal modes. Very efficient if not too many modes needed.

  - For the particle kinetics, writing eqs for the deviation from unperturbed gyro motion. Using the mode expansion, these eqs can be integrated with long time steps.