3D simulation of the electron-Langmuir wave interaction in type III solar radio bursts

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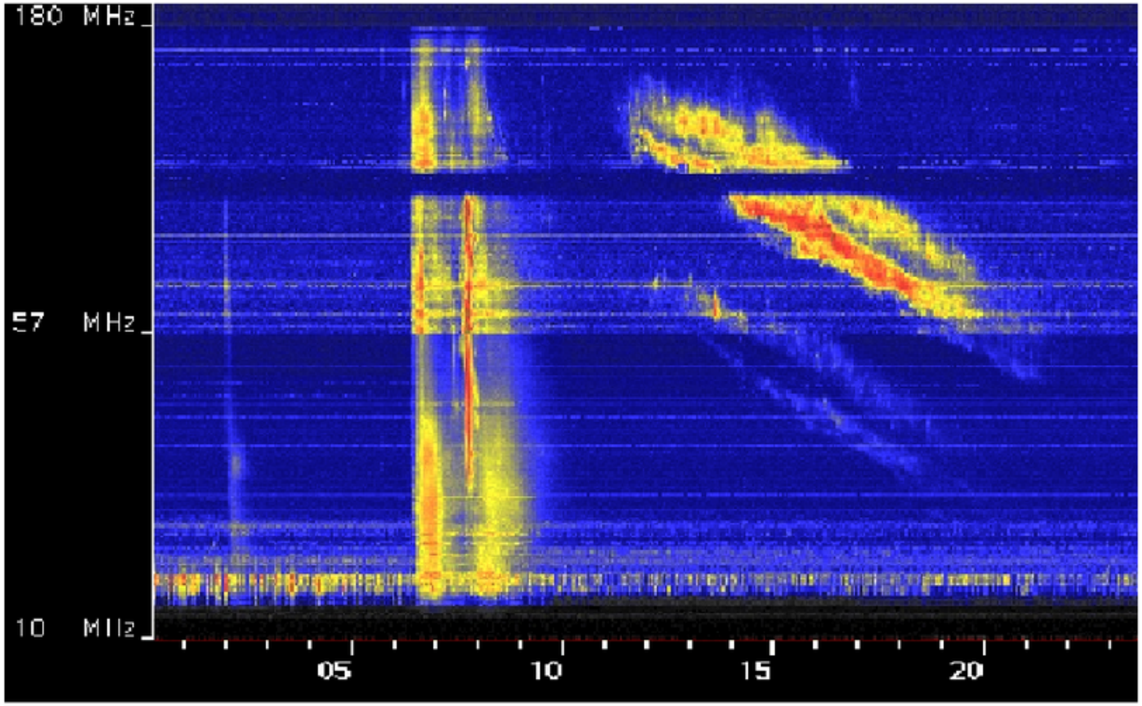
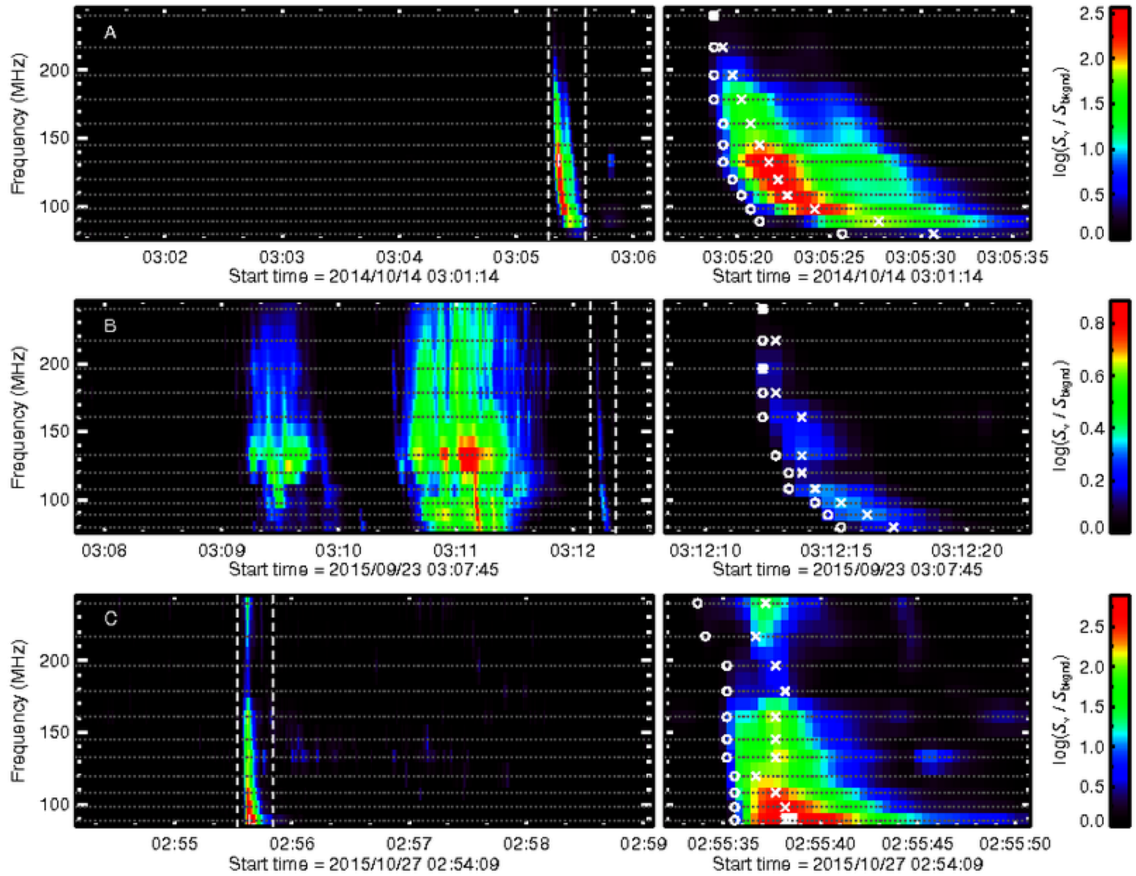
Type III radio bursts



Dulk et al 1985, Culgoora

- Most intense and frequent radio events from the Sun.
- Characterised by their fast frequency drift rate.
- Act as probes of the solar corona - emitted at ω_p and $2\omega_p$ - and signal energy releases.

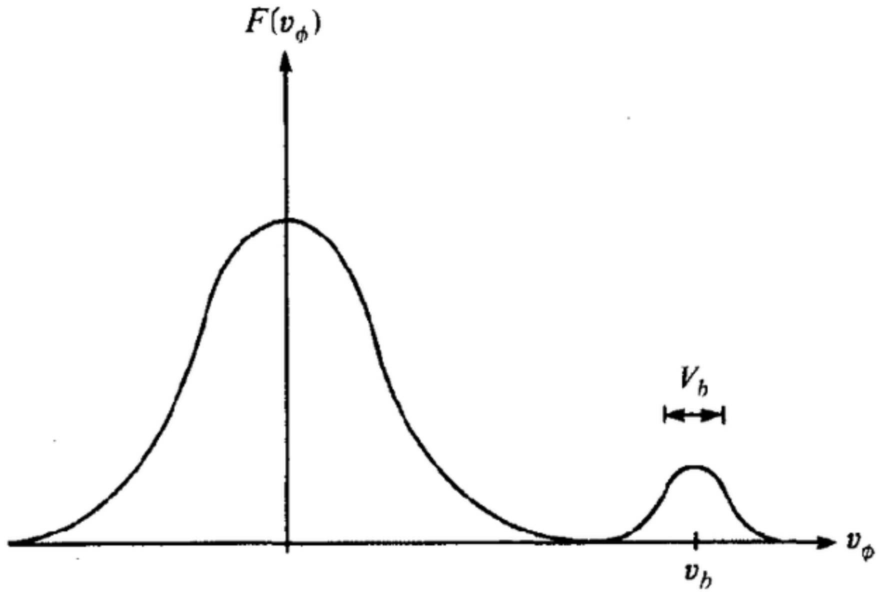
Type IIIs with MWA



P. McCauley et al 2018 (in prep)

- Dynamic spectrum - Frequency vs time, colour scheme corresponds to flux (background removed)

Bump on tail instability

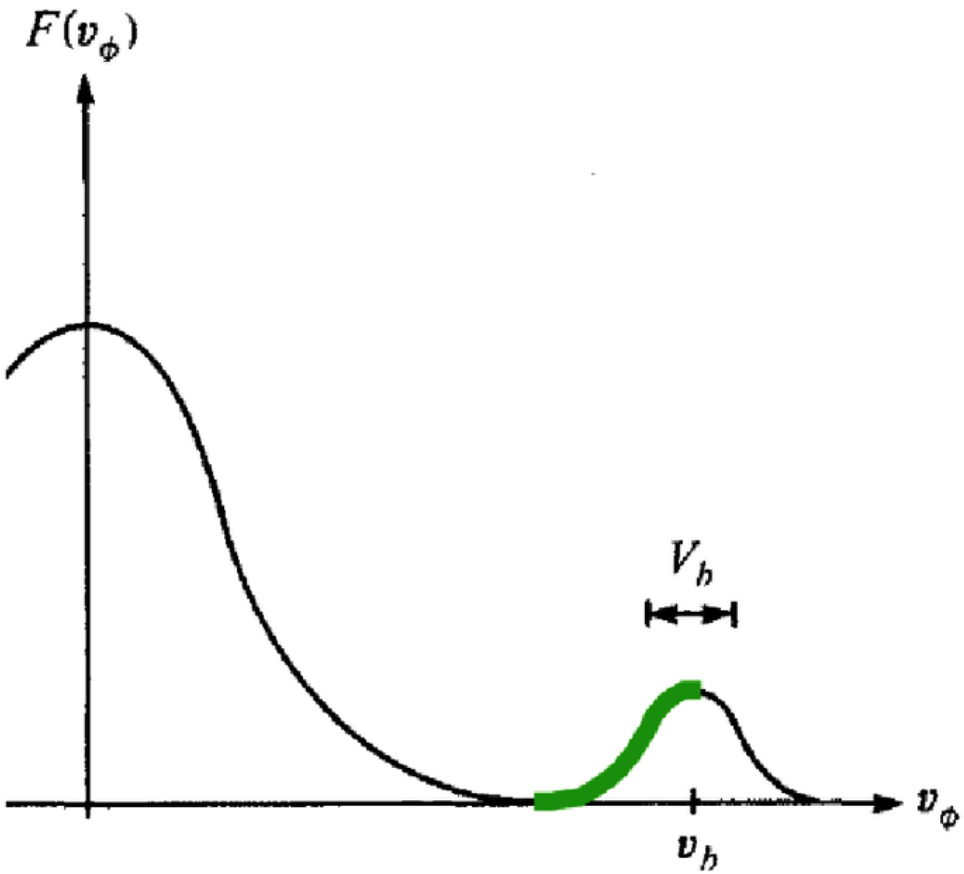


Grognard 1975

- Langmuir wave excitation/damping is prop to gradient of distribution in velocity space.

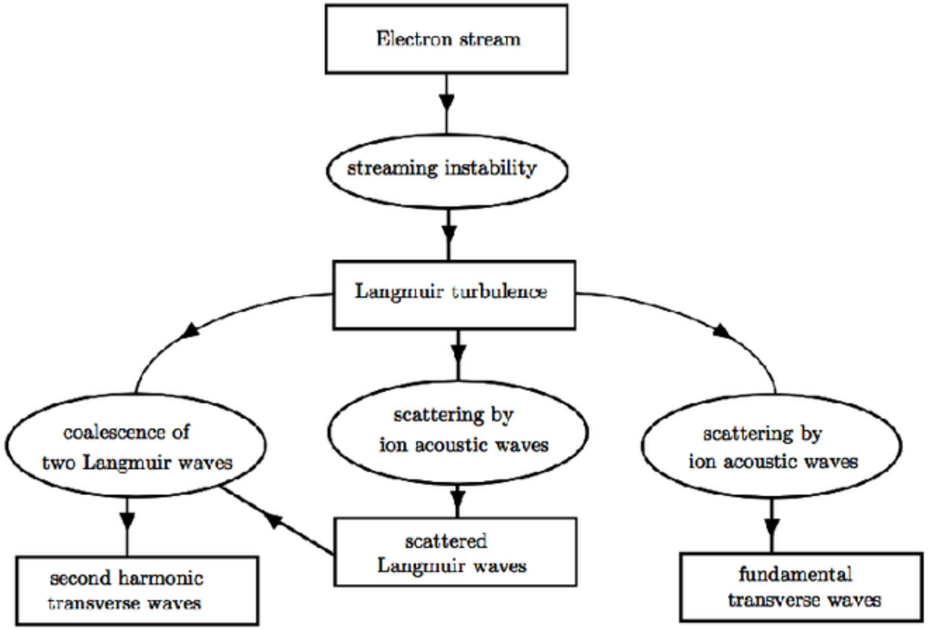
  A Maxwellian is a thermal state of the electron population - $\partial f / \partial v < 0$ always, so waves will not grow.

Bump on tail instability



- This part of the distribution will be unstable to the growth of Langmuir waves.

Type III emission mechanism



Melrose 2009

- Fast (0.2-0.6c) electron streams ejected from the Sun
- This beam generates Langmuir waves in background plasma
- Langmuir waves converted to radio waves via nonlinear processes.

The quasilinear equations

- A given electron distribution $f(\mathbf{p})$ interacts with the Langmuir wave population given by the occupation number $N_L(\mathbf{k})$.
- The evolution of the electron-Langmuir wave system is determined by the set of equations:

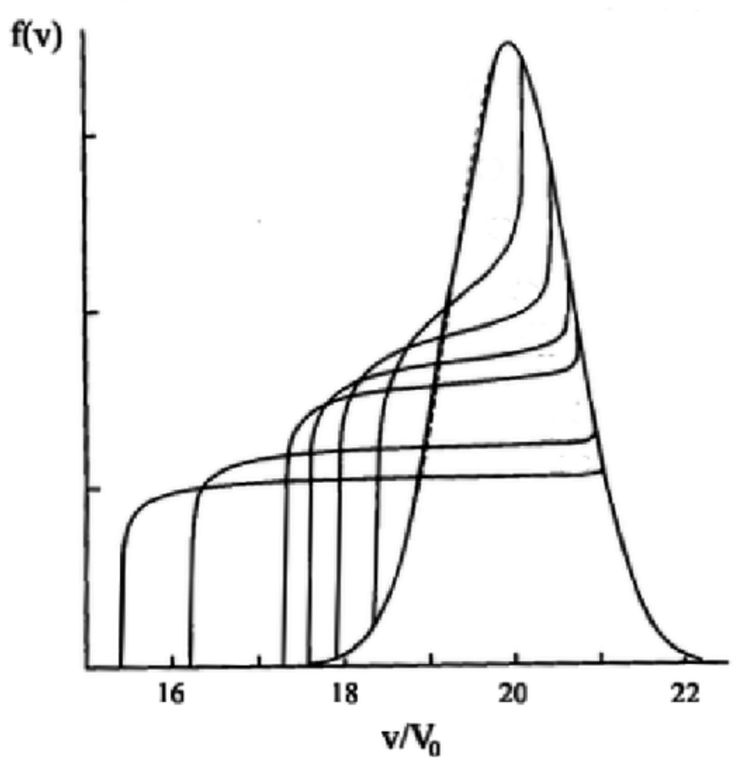
$$\frac{\partial N}{\partial t} + \mathbf{v_g} \cdot \frac{\partial N}{\partial \mathbf{x}} = \alpha_L(\mathbf{k}) - \gamma_L(\mathbf{k}) N(\mathbf{k})$$

$$\frac{\partial f}{\partial t} + \mathbf{v} \cdot \frac{\partial f}{\partial \mathbf{x}} = \frac{\partial}{\partial p_i}\left[A_i(\mathbf{p}) f(\mathbf{p})\right] + \frac{\partial}{\partial p_i}\left[D_{ij}(\mathbf{p}) \frac{\partial f(\mathbf{p})}{\partial p_j}\right]$$

- In particular, $\gamma_L \propto \partial f / \partial \mathbf{p}|_{v=v_\phi}$.

1D results - relaxation

- Energy flows from electron beam to the Langmuir waves
- The beam becomes more isotropic, tends towards a plateau distribution, where $\partial f/\partial v \approx 0$ - evolution stops.
- This plateau distribution is called marginally stable since $\gamma \approx 0$



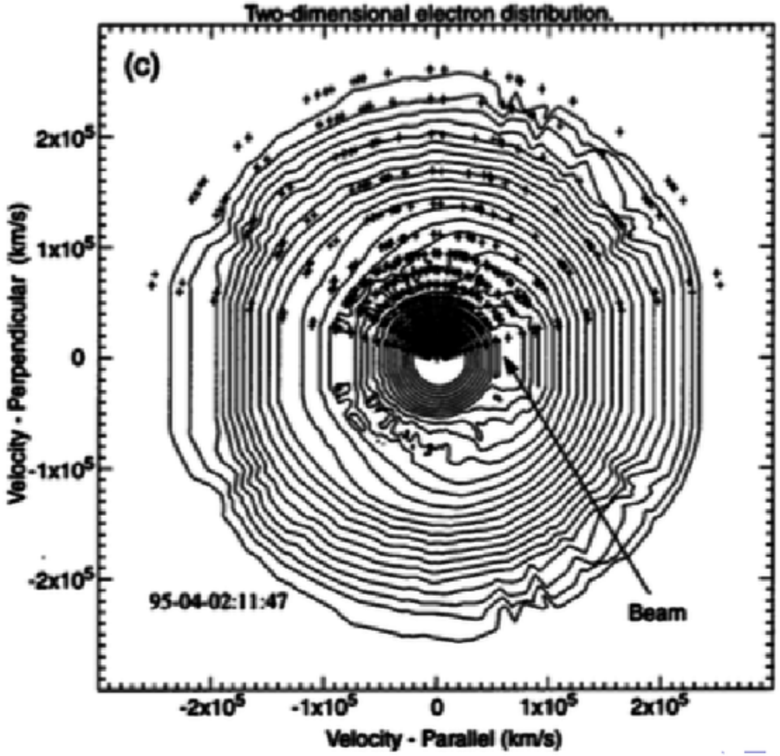
Grognard 1975

The state of QL research

- The physics of the 1D model has been fully explored.
- However, how important are 3D effects perpendicular to the magnetic field **B** in QL relaxation?
- The real world is 3D and type III electron beams are at least 20° wide $\perp$ to **B**.

Ergun et al 1998,

NASA WIND



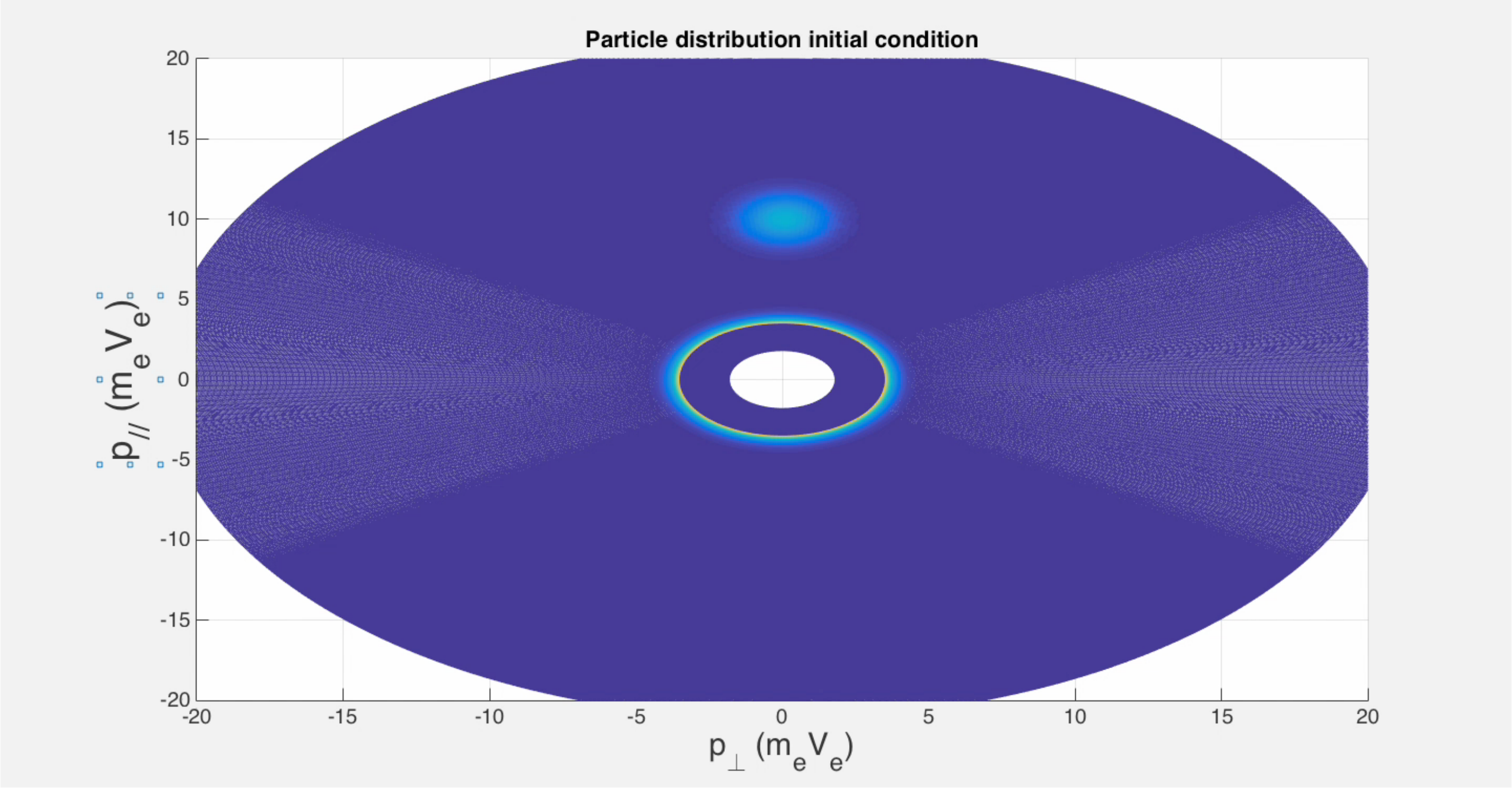
Merit of a 3D treatment

- Take intrinsically 3D effects like scattering into account
- More accurately simulate the QL physics of electron-Langmuir wave interactions
- Allow a definite quantitative analysis of the validity of the 1D approximation

New 3D code: Numerical method

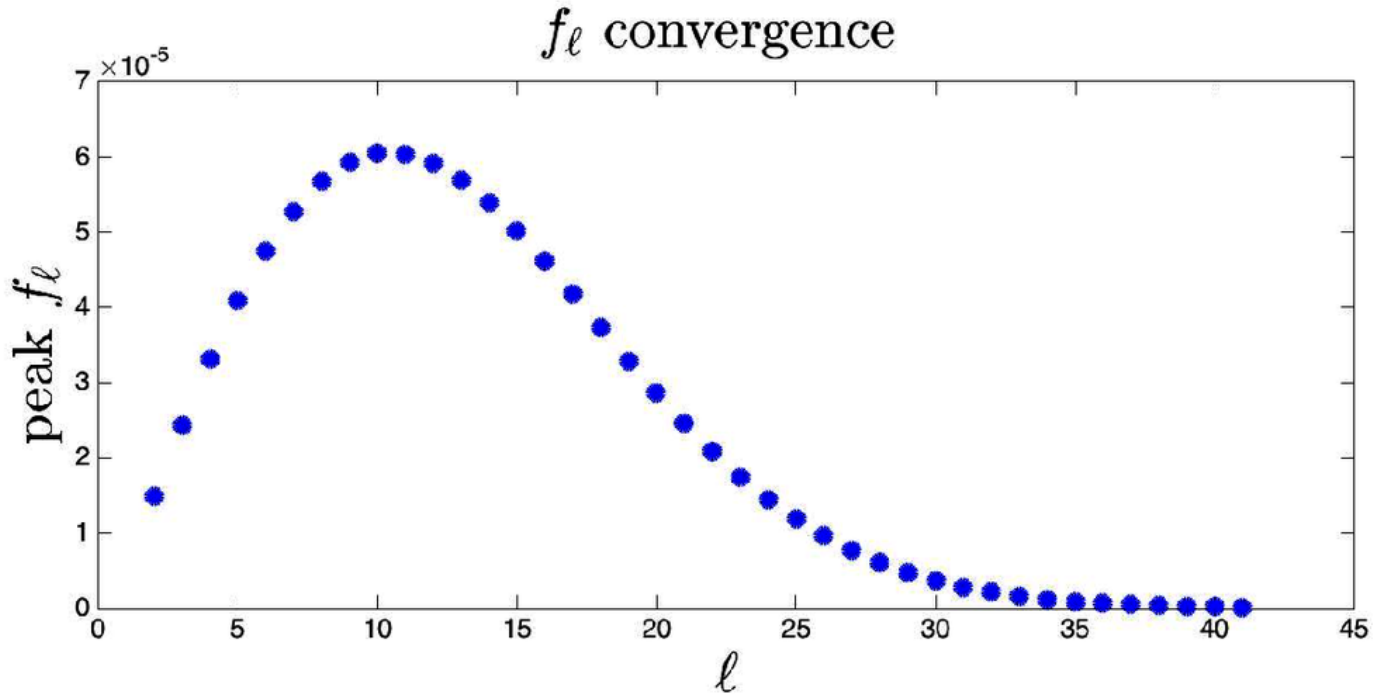
- Expansion in Legendre polynomials (axisymmetric special case of spherical harmonics).
- Coupling in the polynomials leads to a block-tridiagonal matrix equation.
- Very complex problem, multiple numerical processes in the simulation:
  - numerical integrations at each timestep n, momentum gridpoint j and Legendre expansion ℓ,
  - j_{max} inversions of matrices each of size ℓ_{max}, for each timestep.

3D-axisymmetric Maxwellian beam



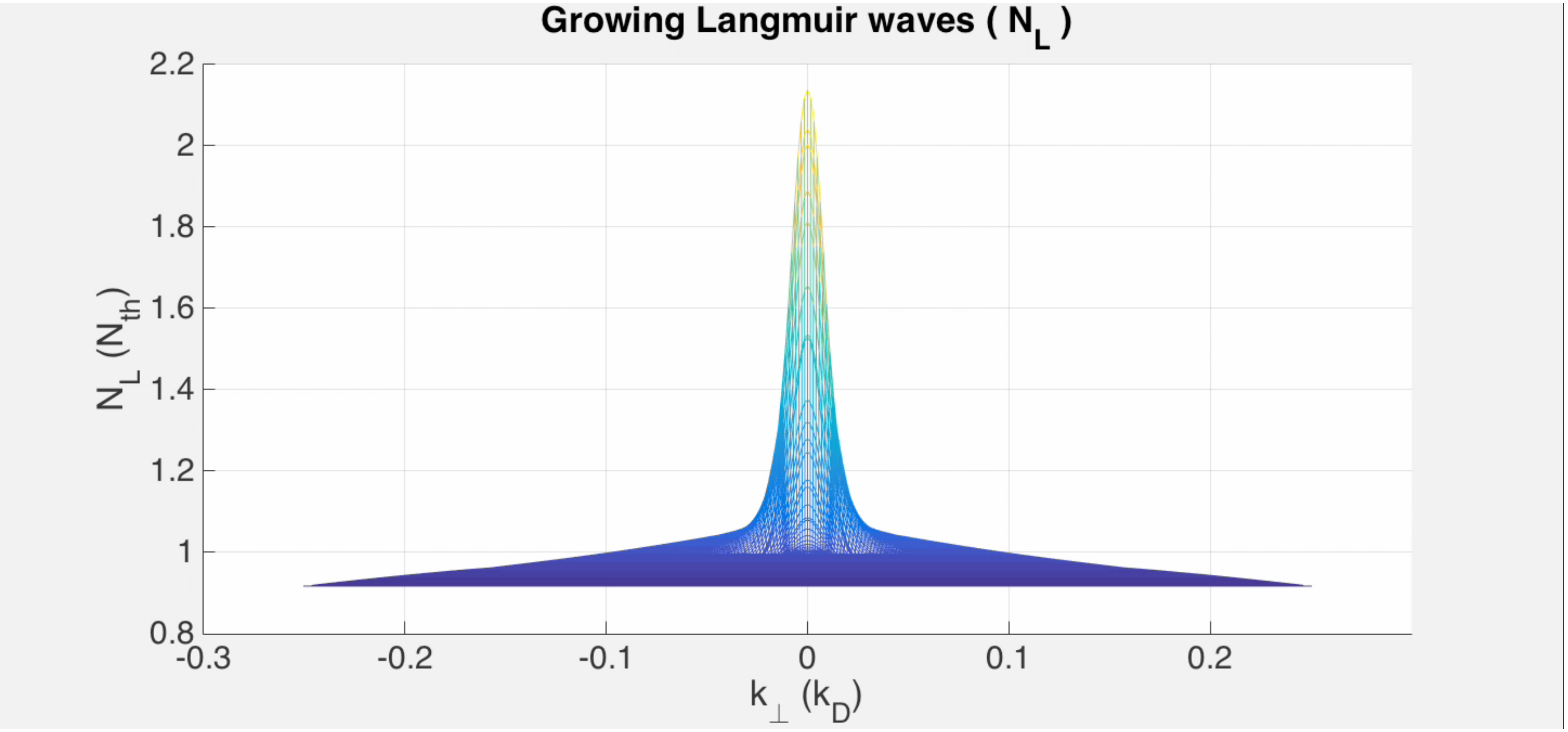
- Can model an electron beam as a maxwellian centred at a velocity $\mathbf{v_b}$..
- This beam has a speed of $v_b/V_e = 10$ and $n_b/n_0 = 10^{-3}$.
- In 1D the beam plateaus and the waves grow. The question for us is how does the plateau form in 3D?

Convergence



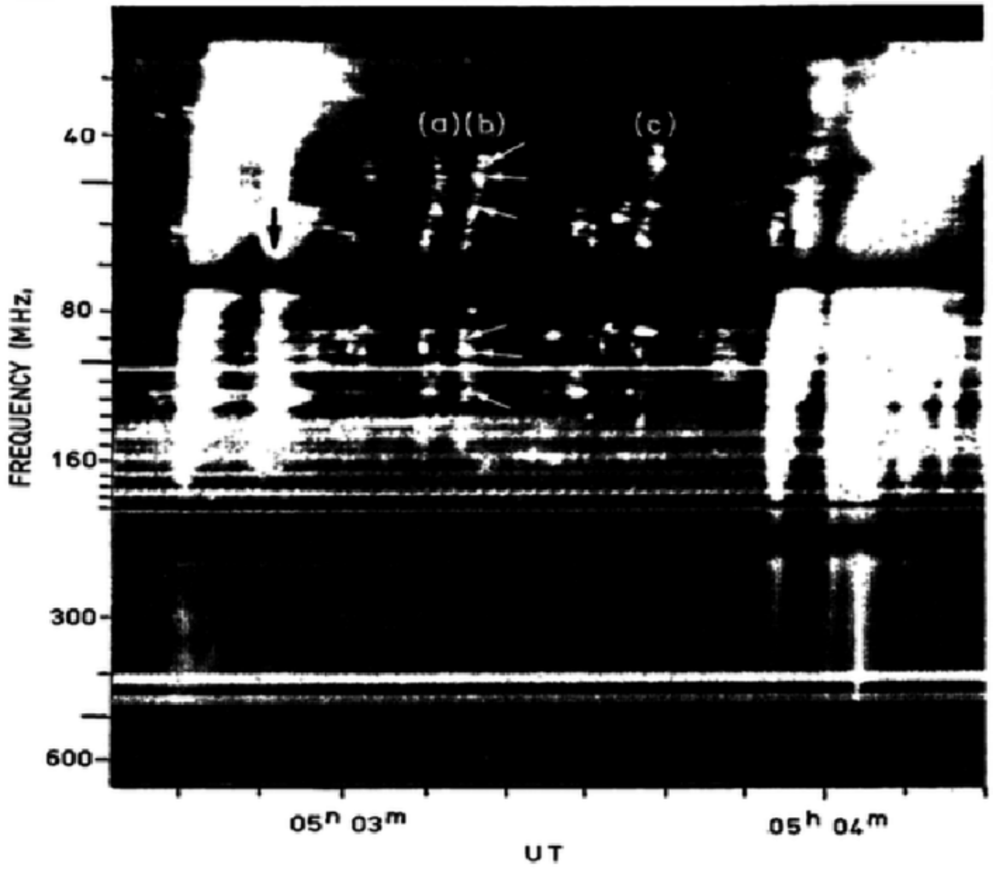
- Previous work (e.g. Hoyng et al 1979) suggest a smooth electron distribution would require < 10 Legendre polynomials
- For a Maxwellian beam (very reasonable) we find we need more

Growth of Waves



- Large peak at the expected **k**
- Analysis of the growth rate - consistent with the theoretical prediction to within 10%
- However, the particle response is proving more difficult. Results to come.

Future - fine structure

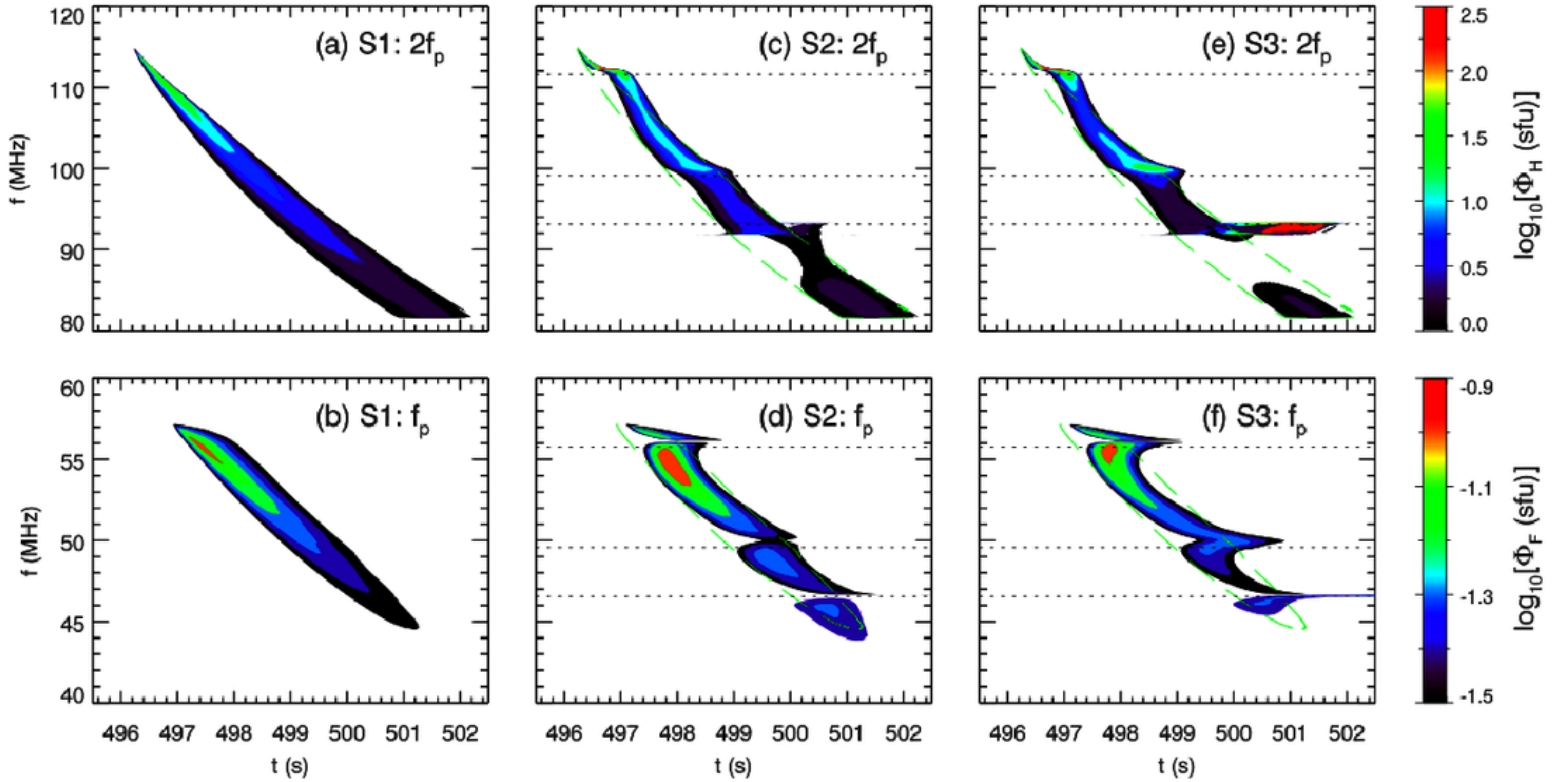


Takakura & Yousef 1974,

Culgoora radiospectrograph

- Fine structure and harmonic pairs seen at a), b) and c)

Future - fine structure



B. Li et al 2012

- Simulations using a 1D beam/wave model with density fluctuations

Conclusions

- We predict 3D effects will be significant to the evolution of exciter beams of type IIIs
- 3D relativistic and axisymmetric code will explore 3D effects and test validity of the 1D approximation - but problem is significantly more challenging than we or others predicted
- Working beam/wave code will feed into a type III dynamic spectrum simulation - comparison with MWA dynamic spectra, use for propagation models of the beam