

Preliminary Calculations of Alfvén Resonance Current Drive[†]



Goals

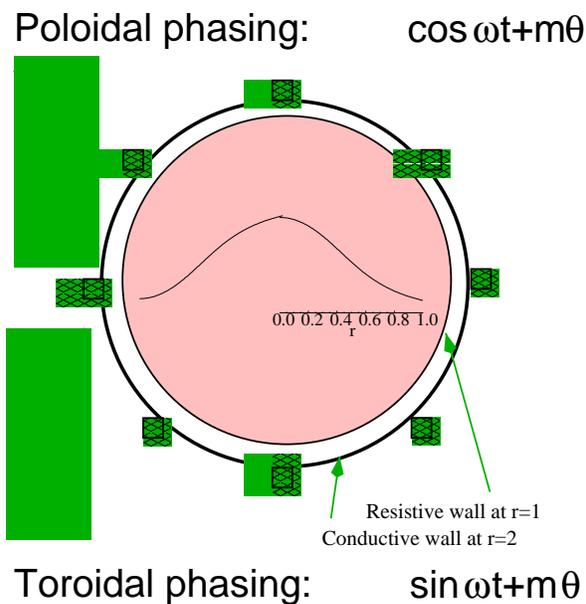
- ★ Verify and benchmark linear/monochromatic behavior
- ★ Study nonlinear propagation of Alfvén waves in a resistive plasma
- Study nonlinear interaction of spectrum of waves
- Explore the interaction of MHD turbulence with Alfvén waves, an Alfvén Dynamo effect.
- Look at current profile control

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Launching a Monochromatic Alfvén Wave



Cylindrical Geometry



- A poloidal array of coils are excited with poloidal and toroidal currents with a 90° relative phase
- The frequency is chosen to localize deposition according to resonance condition

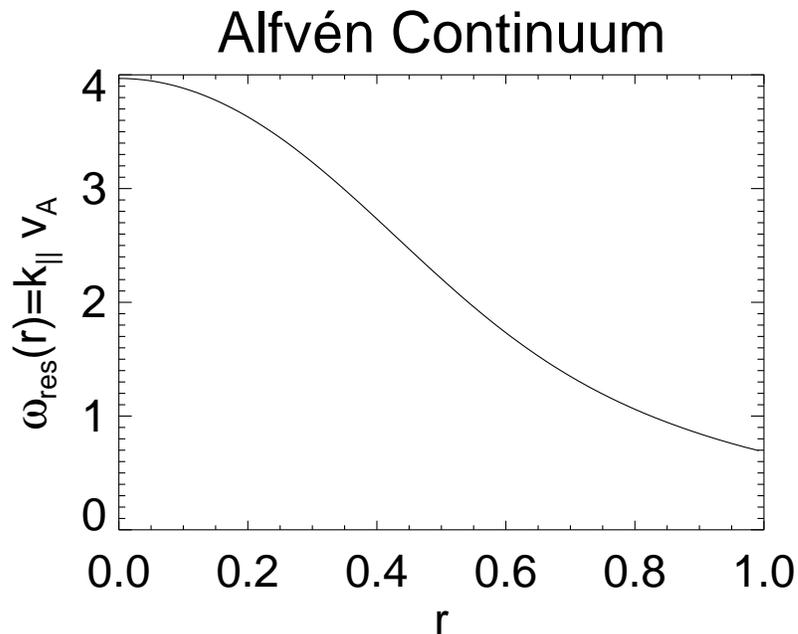
★ This is implemented in the `Debs` code as time dependant boundary conditions on the poloidal and toroidal electric fields.

Preview of Results



- ➊ Showed localization of resonance consistent with Alfvén continuum.
- ➋ Relative phasing determines whether helicity is injected and the strength of $E_f \equiv (\tilde{\mathbf{v}} \times \tilde{\mathbf{B}}) \cdot \hat{b}$
- ➌ Quasilinear E_f shows localization at resonance surface
- ➍ Nonlinear amplitudes with monochromatic spectrum do not differ from linear amplitudes, at least on an Alfvén timescale

Alfvén Continuum for Spatial Resolution of Resonance



- The Alfvén continuum is shown without the effects of density for an $m = 2, k = 0$ mode.
- The scale is in units of $\omega_A \equiv / (B / \sqrt{\rho})$.
- Waves can be damped, resonant, or freely propagating depending on frequency.

One Dimensional Screw Pinch Model for Benchmarking



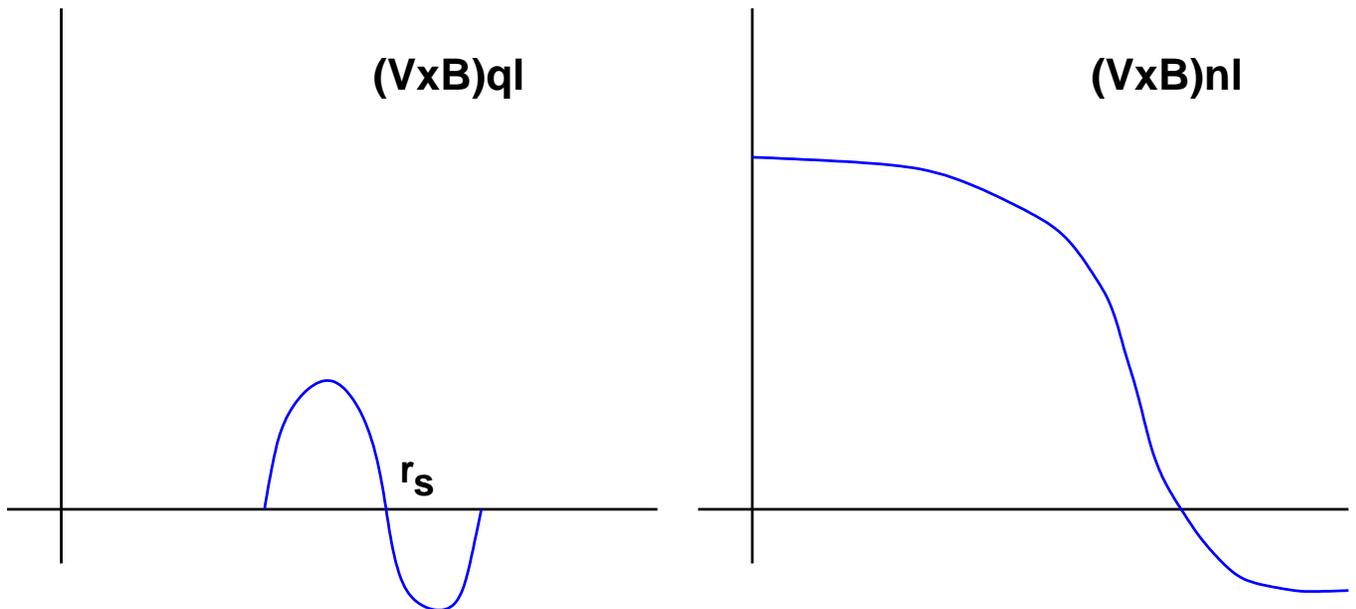
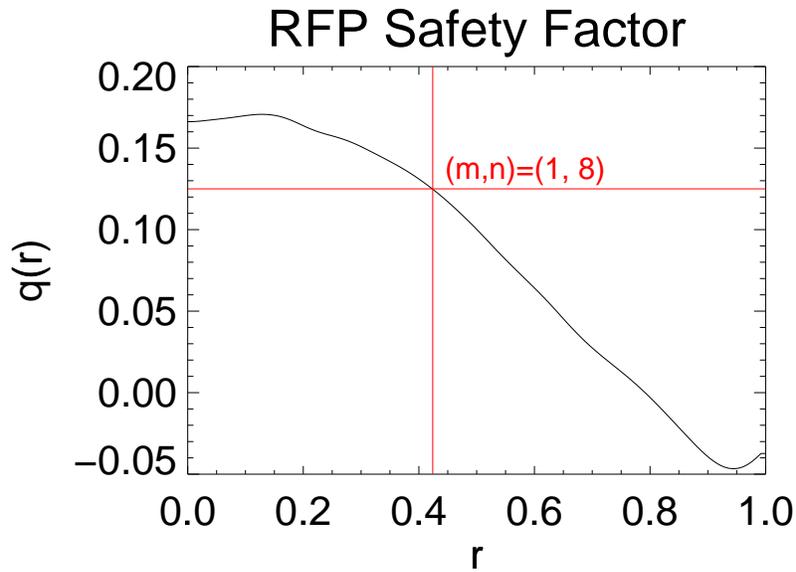
$$\frac{d}{dr} \left[A \frac{d}{dr} (r\xi) \right] - C(r\xi) = 0$$

$$A(r) \equiv \left[\frac{\rho(V_a^2 + V_s^2)}{r} \right] \frac{(\omega^2 - \omega_A^2)(\omega^2 - \omega_h^2)}{(\omega^2 - \omega_f^2)(\omega^2 - \omega_s^2)}$$

Where $A(r)$ is the Alfvén resonance term and ξ is the radial displacement.

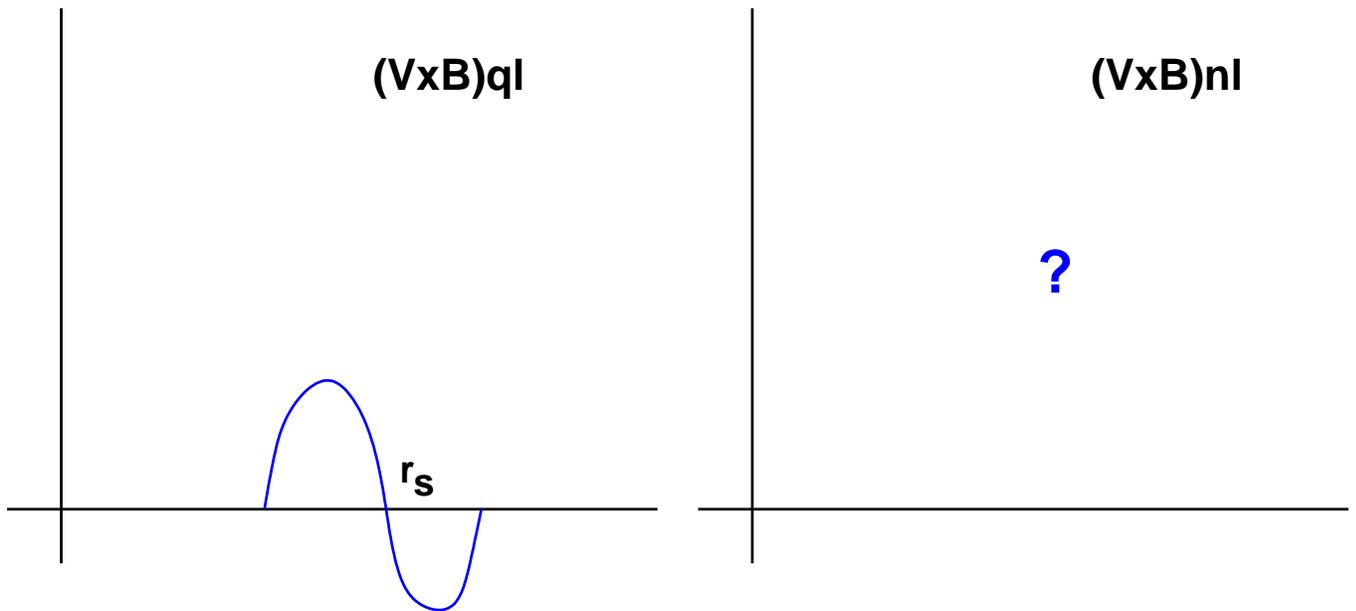
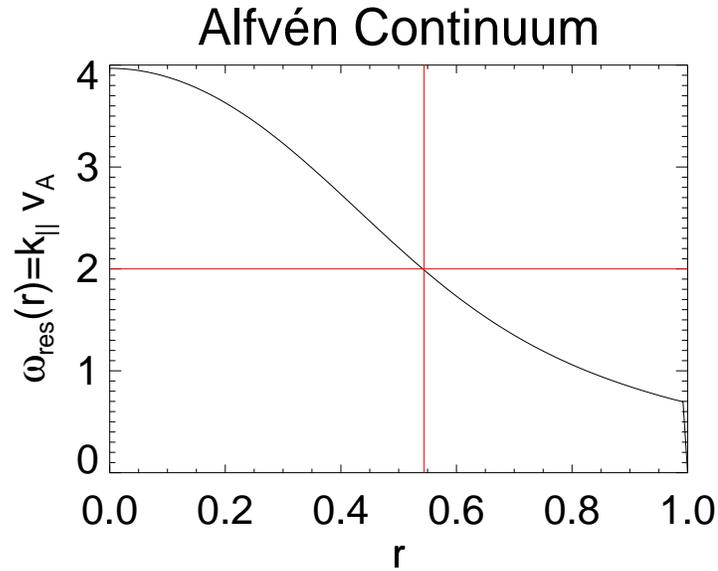
- The resonance occurs at $A = 0$, a mathematical singular point.
- The singularity is removed by finite resistivity.

Analogies to tearing mode and rational surfaces



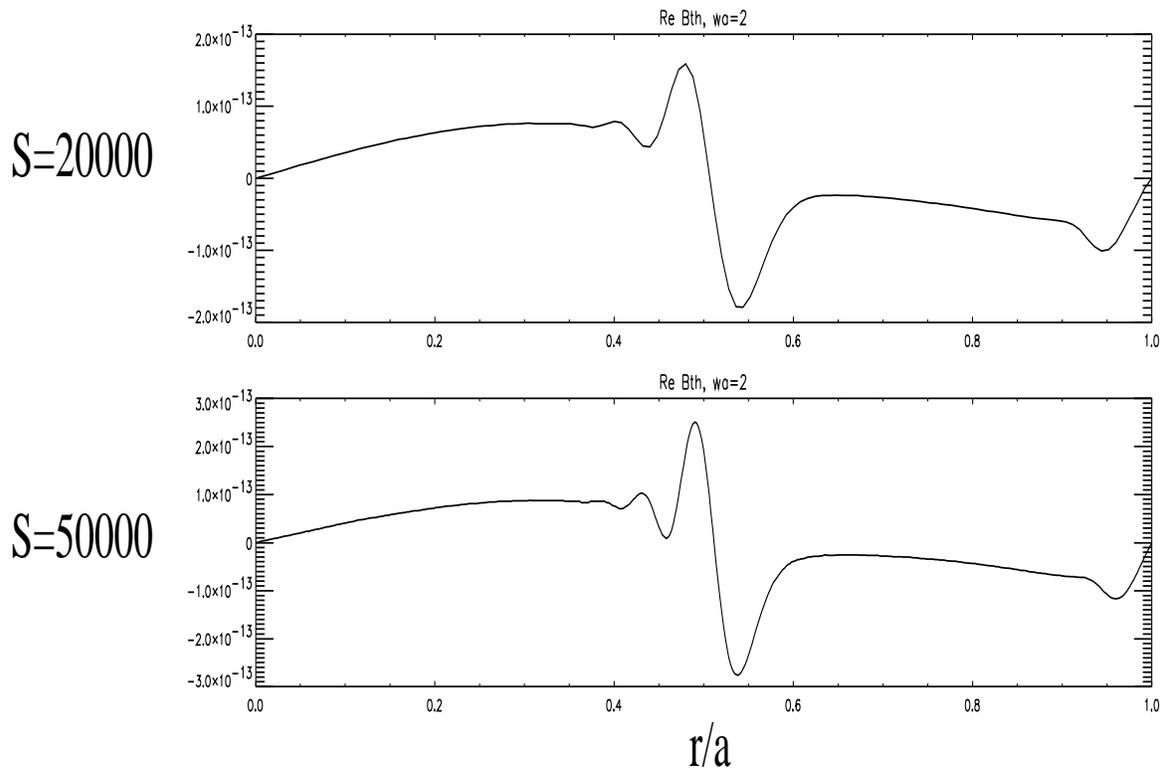
- $k_{||} = 0$ determines resonance.

Analogies to tearing mode and rational surfaces



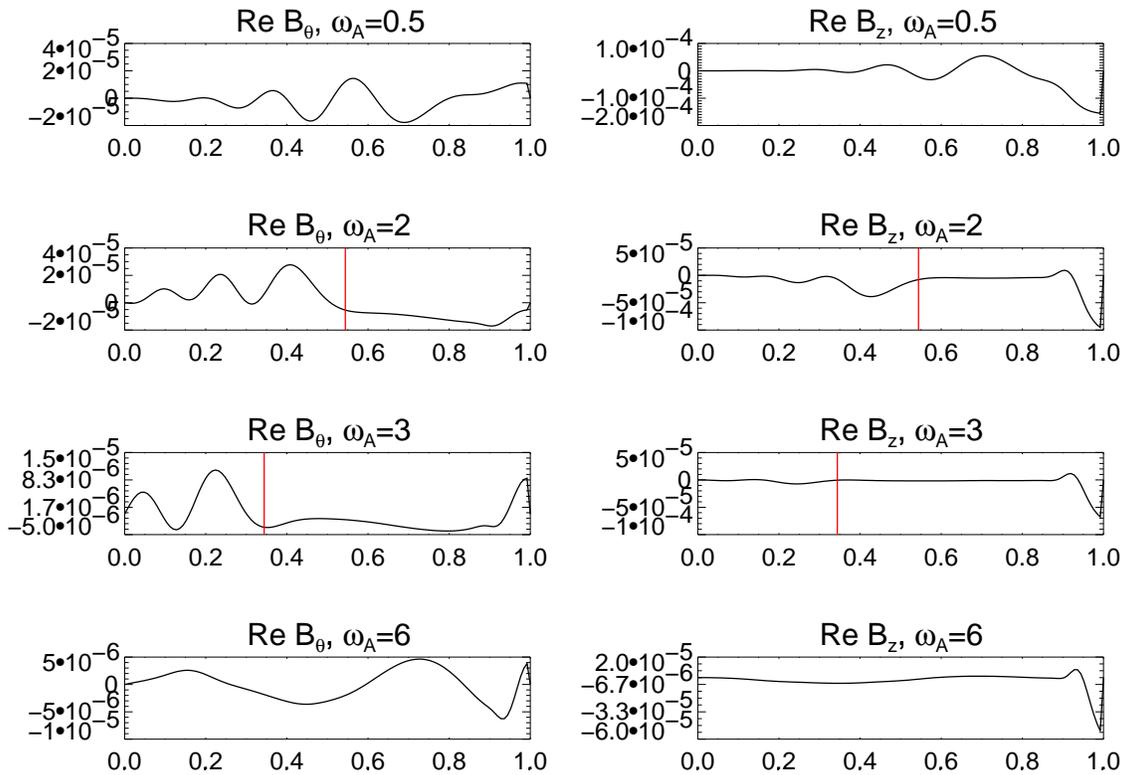
- $k_{\parallel} = \omega / v_A$ determines resonance.

S-scaling of resonance width



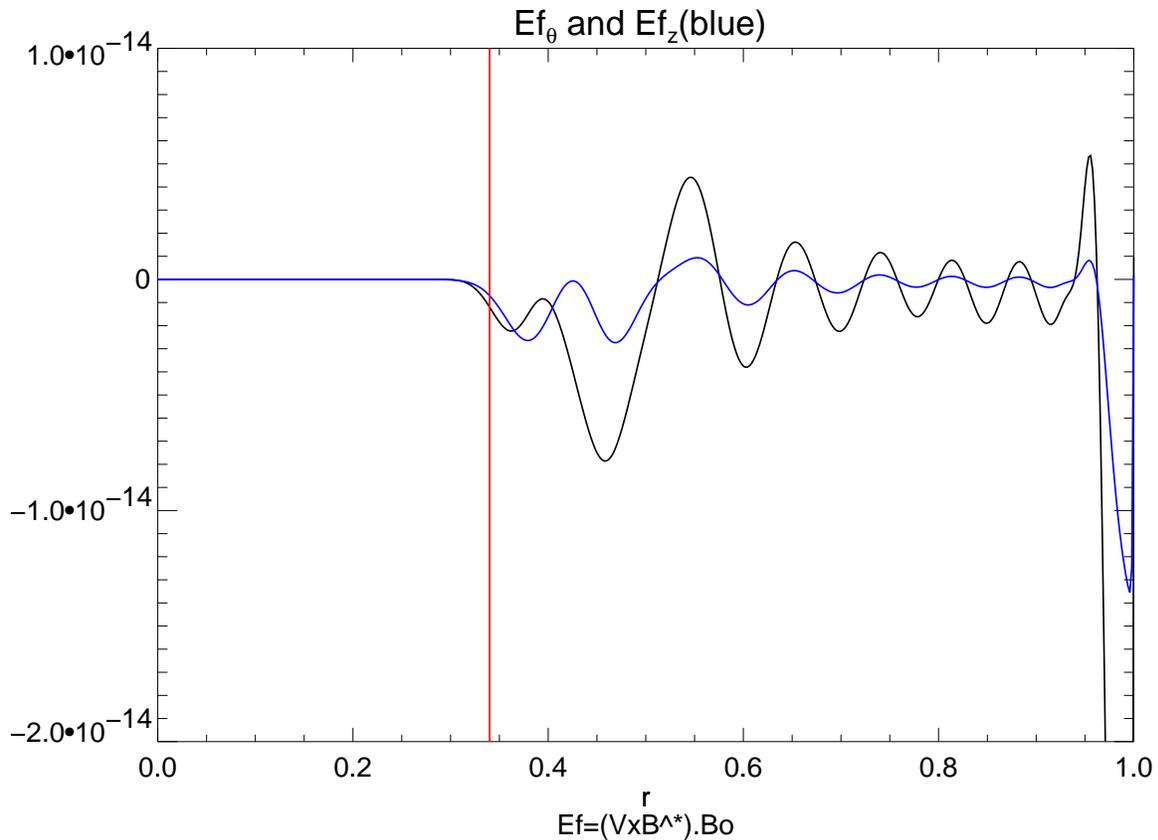
- Plots of B_θ for $m = 2$ for two values of S
- The resonance narrows with higher Lundquist number
- Scaling $\approx S^{-0.31}$, near the theoretical, $S^{-1/3}$ (Tataronis)

Three Dimensional Resistive Numerical Model



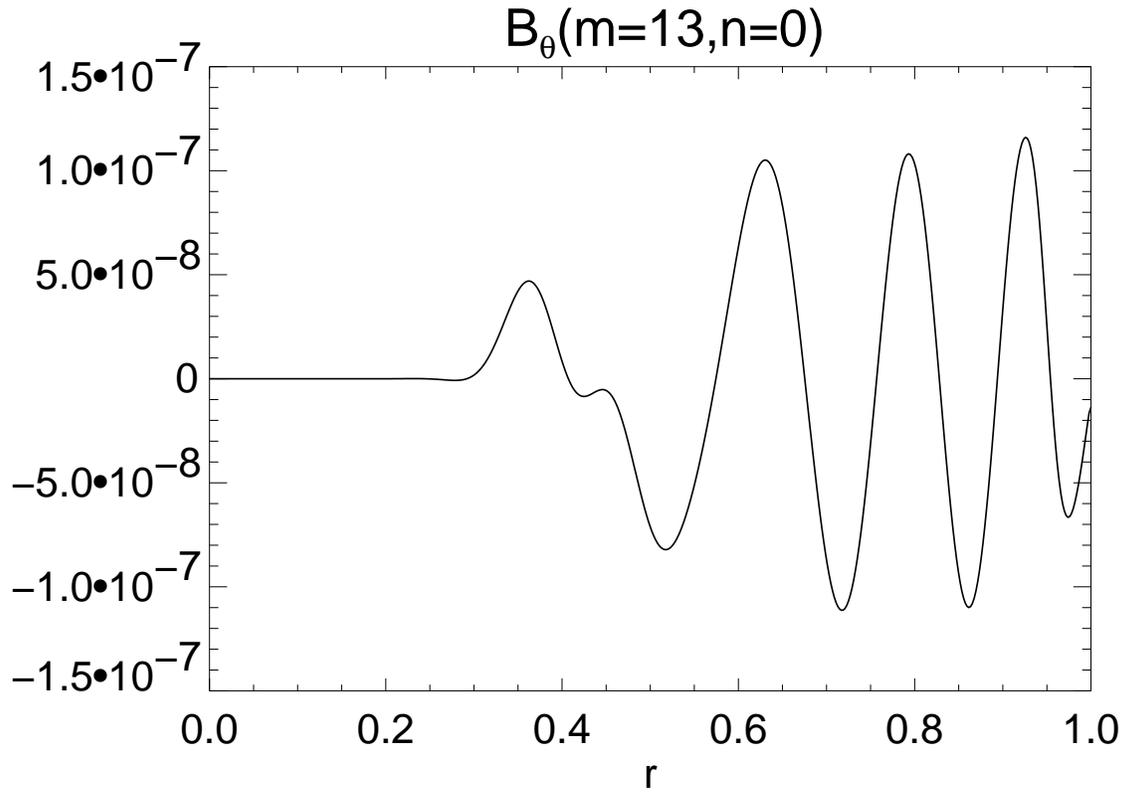
- Preliminary results at $S = 1000$
- Using $E_\theta(m = 2, k = 0)$ at the wall.
- This will create an $E_\theta \times B_z$
- However, no helicity is injected.

Linearly Polarized Wave

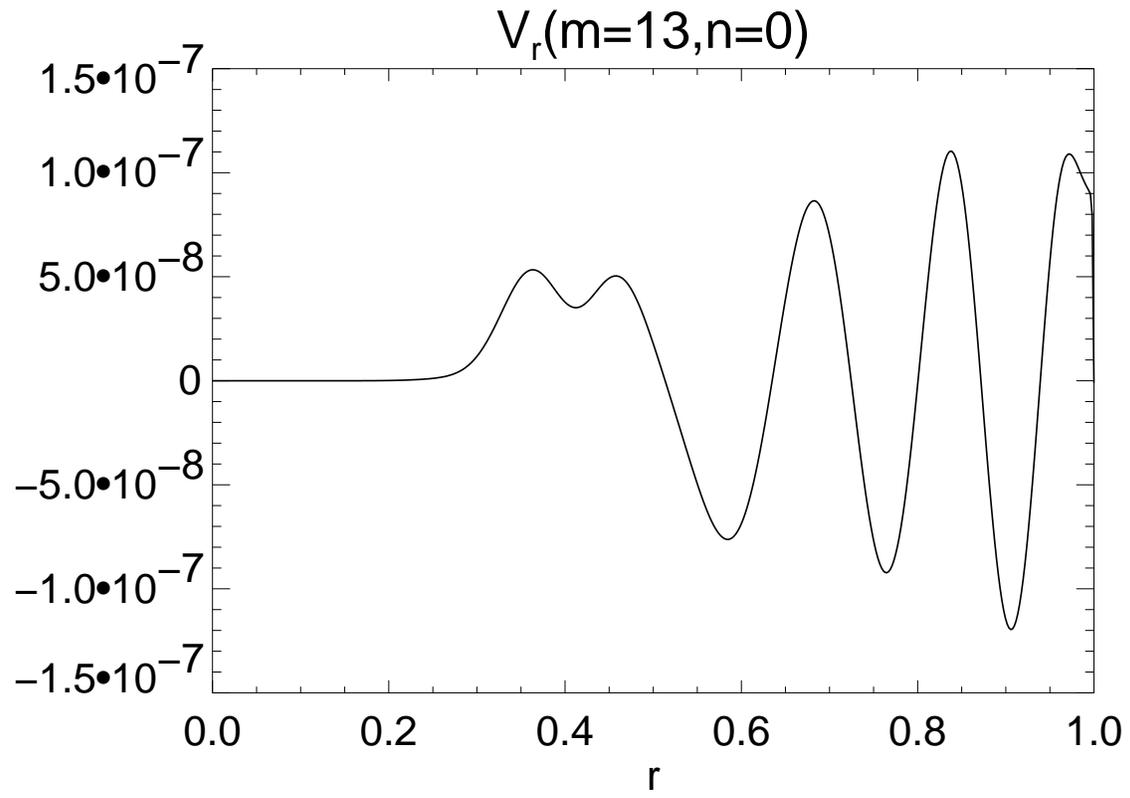


- No current is driven by a zero helicity wave.
- The amplitude of the parallel dynamo term is orders of magnitude less than the products of the V and B amplitudes.

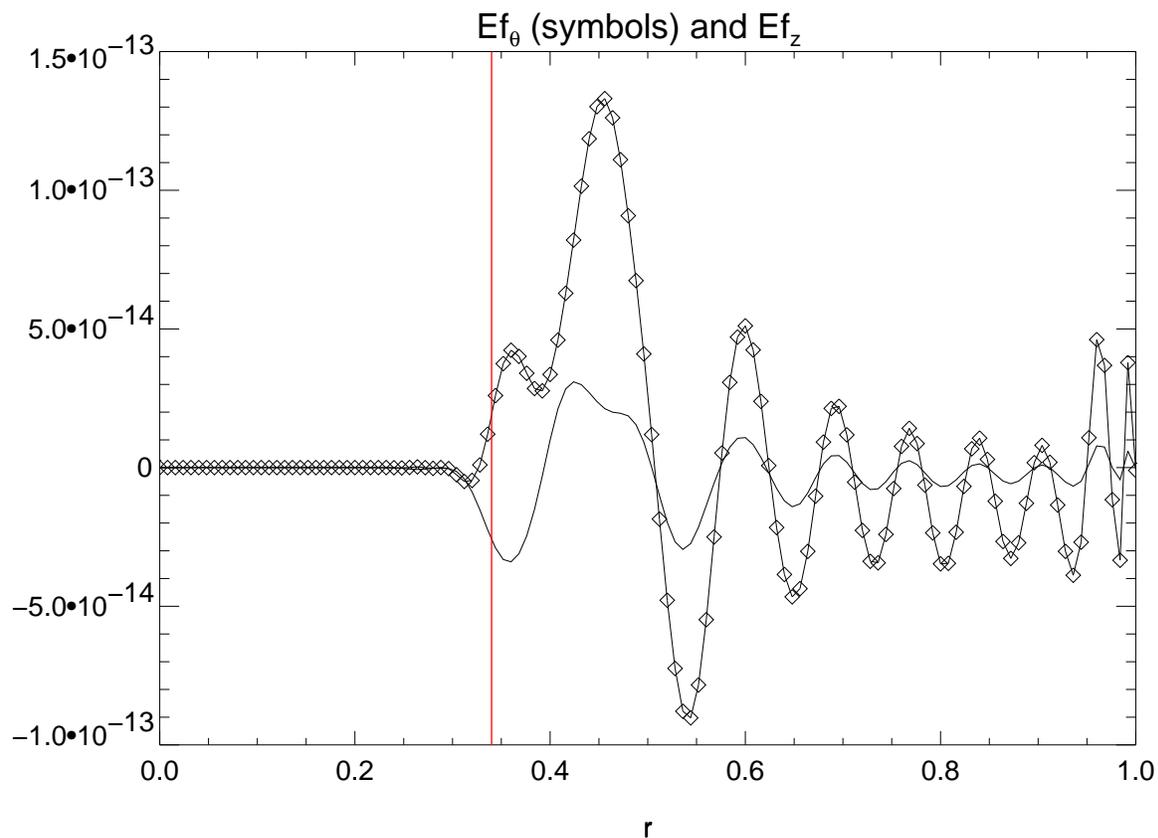
Linearly Polarized Wave



Linearly Polarized Wave

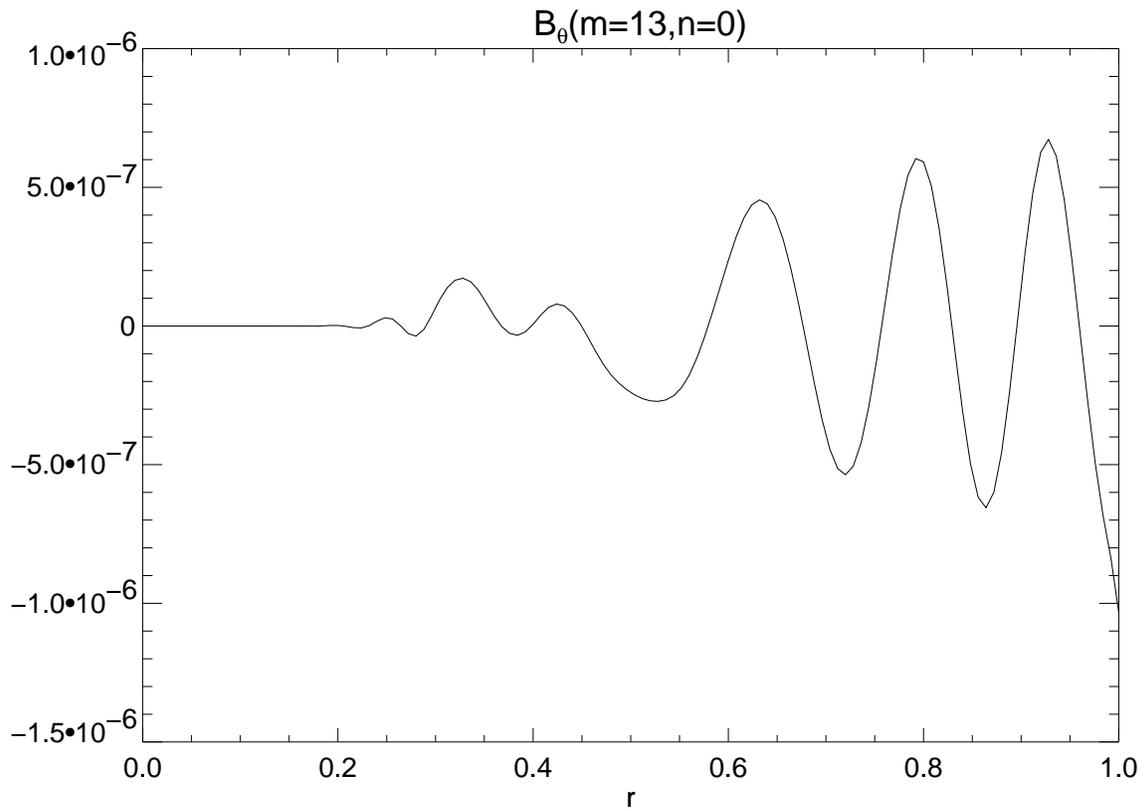


Circularly Polarized Wave

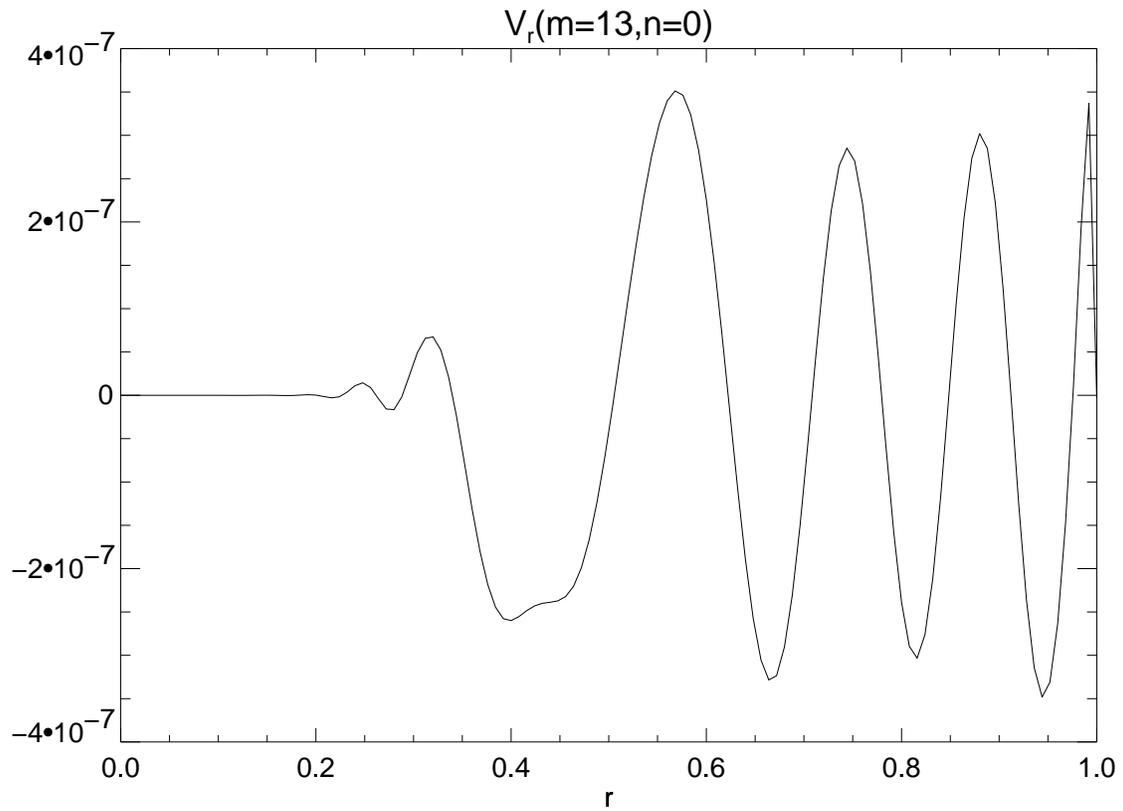


- \mathbf{V} and \mathbf{B} are in phase.
- $|E_f| \approx |\mathbf{V}||\mathbf{B}|$

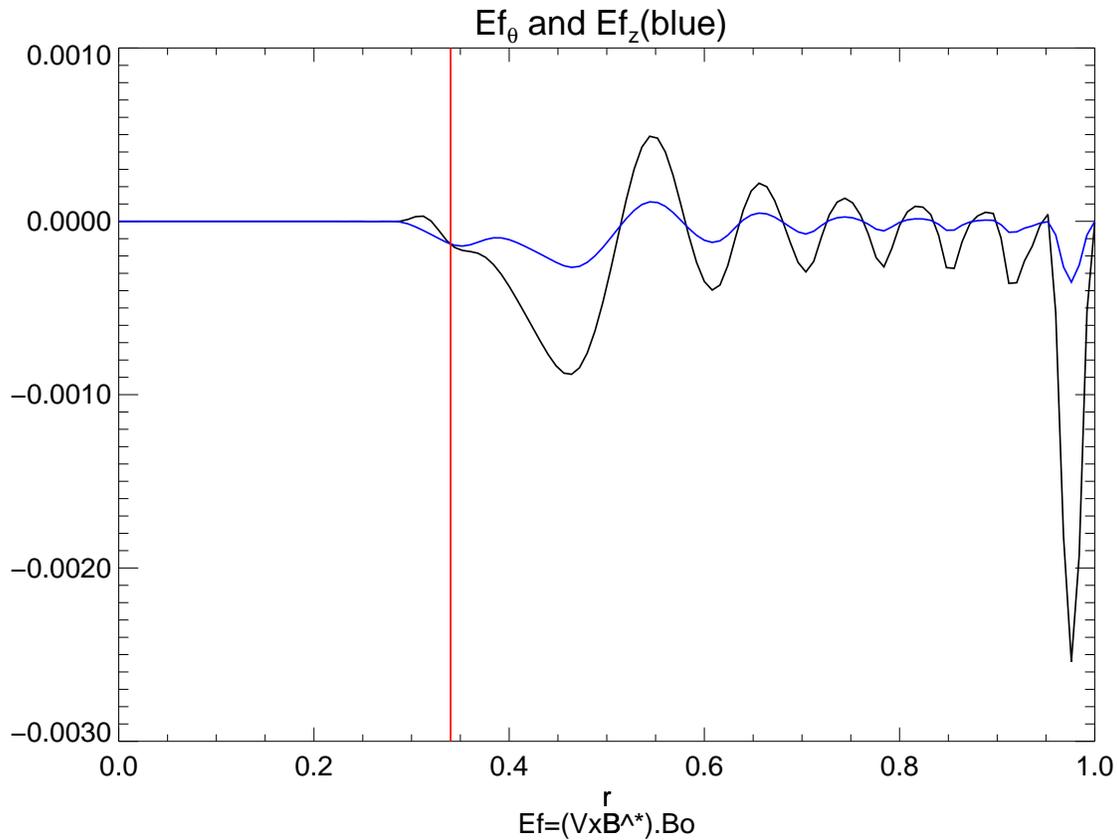
Circularly Polarized Wave



Circularly Polarized Wave

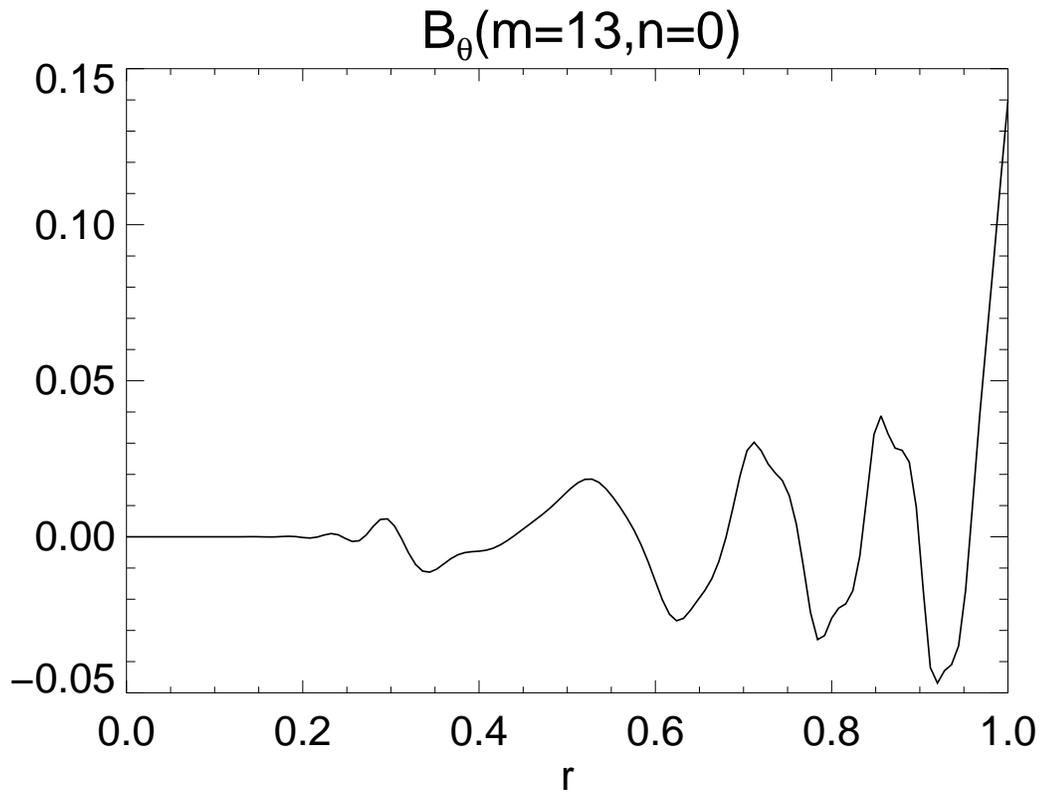


Circularly Polarized Wave, large amplitude

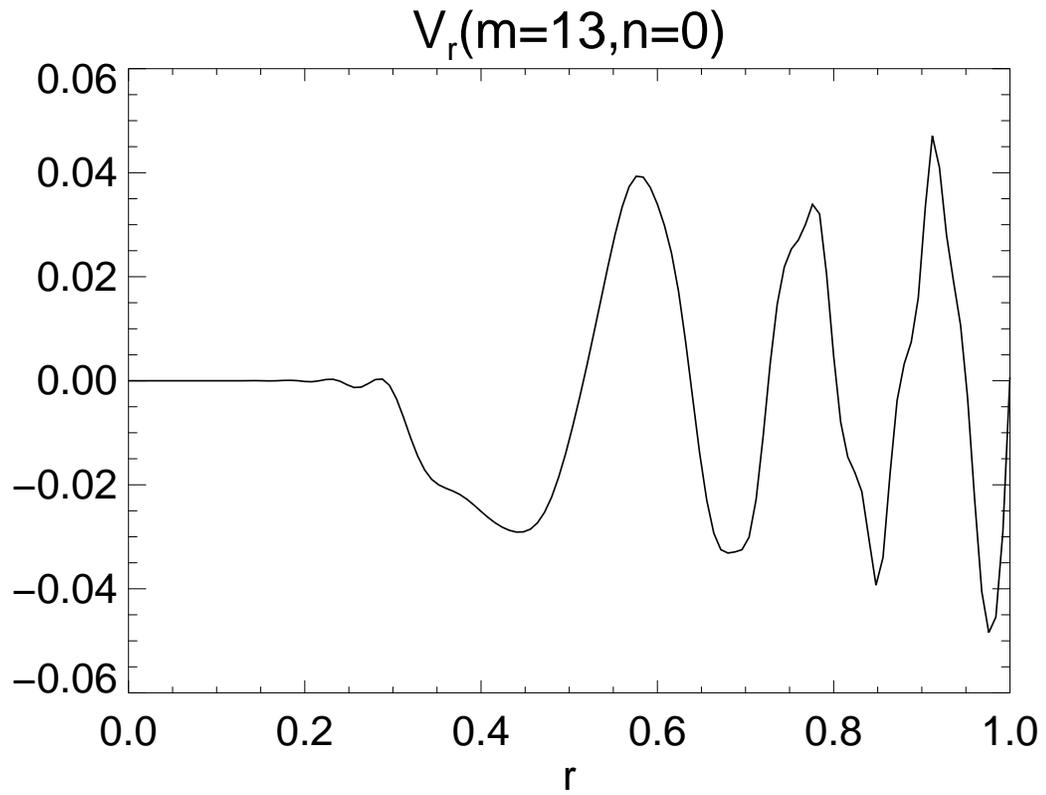


- Amplitudes are order 10% now.
- Because of monochromaticity, wave form looks the same.
- Long time evolution may show some feedback on equilibrium

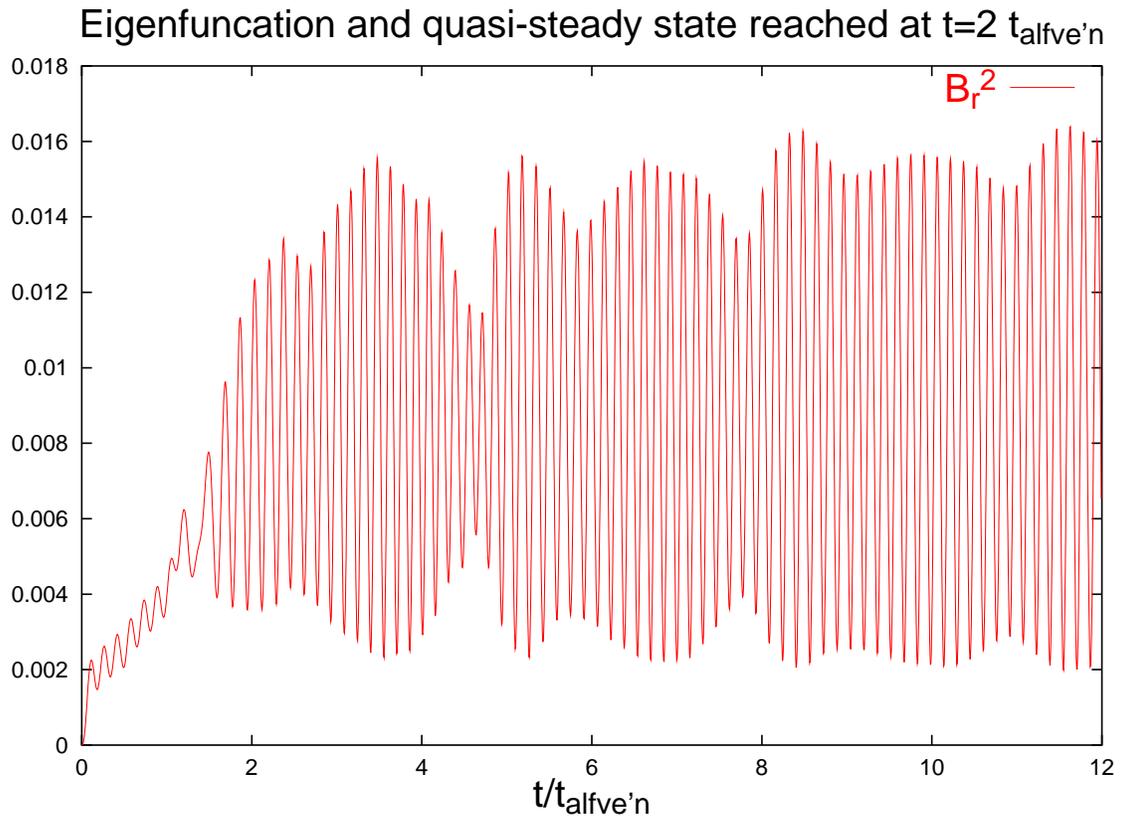
Circularly Polarized Wave, large amplitude



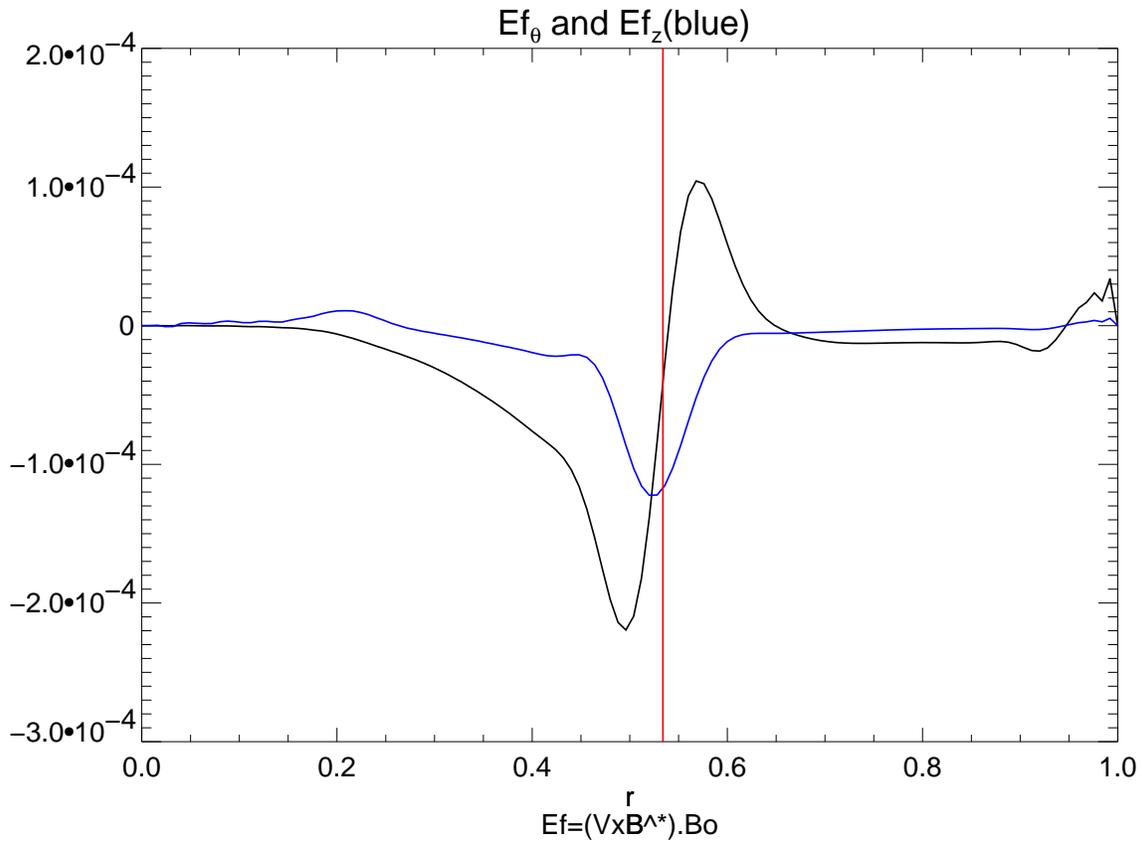
Circularly Polarized Wave, large amplitude



Power evolution



Low mode number shows resonance more clearly.



Future Plans



- Quantitative benchmarking of Debs with screwpinch eqn.
- Numeric stage done (antenna is built), start studying the physics.
- Optimize impedance matching at the plasma-vacuum interface, and look at effect of density on edge resonance.
- Calculate efficiency, $\eta \equiv J/P$
- Study nonlinear current from $\mathbf{V} \times \mathbf{B}$
- Multimode launch, long time interaction with turbulence.