Pulsar radio emission - oscillating model

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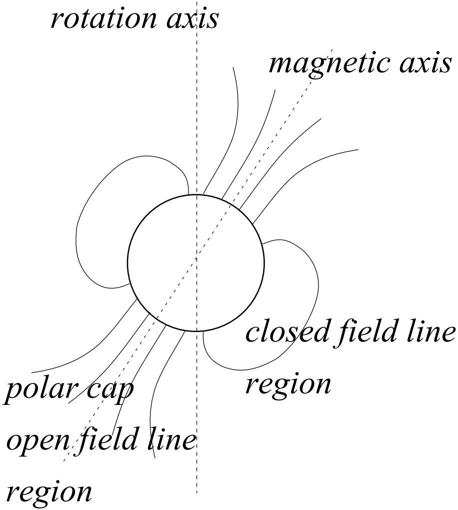
Outline

- Problems understanding pulsar radio emission
  - Magnetosphere model
  - Emission mechanisms
- Oscillating model
- Wave modes
  - Time-dependence
  - Coupling

What is a pulsar?



Emission models

- Production of emission is not well understood
- Must be a coherent process
- Variety of proposed mechanisms
- Most involve time-stationary magnetosphere

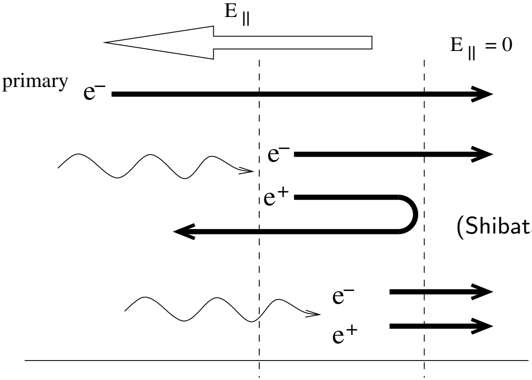
Pulsar fields

- Rotating magnetic field generates large electric field
- Particles pulled from pulsar, generate secondary particles
- Magnetosphere populated with plasma, corotates
- Goldreich-Julian density to enforce corotation (Goldreich & Julian, 1969)

Time-stationary models

- Pairs produced due to the extremely strong electric field, forming a charge layer to screen the parallel field

  (eg Ruderman & Sutherland 1975)



(Shibata et al, 2002)

- Steady plasma outflow above the PFF

Problems

- Very unlikely to have steady, time-stationary flow (Sturrock 1971)
- Initial parallel electric field is inductive, curl $\mathbf{E} \neq 0$; field from Goldreich-Julian density electrostatic, curl $\mathbf{E} = 0$
- Time-stationary models violently unstable (Levinson et al 2005)

Radiation mechanisms

- Three basic types (Ginzberg & Zheleznyakov, 1975)
- Coherent curvature emission N particles $\longrightarrow I \propto N^2$
- Emission is from 'bunches' of particles (or solitons), uses changing curvature of pulsar's magnetic field - localization in position and momentum space (Ruderman & Sutherland 1975, Melikidze, Gil, Pataraya 2000)
- Partially screened gap with columns of outflow
- Problems - bunch formation, back-reaction

Radiation mechanisms

- Plasma instabilities
- Masers - rapid wave growth in some mode due to negative absorption (population inversion)
- Reactive instabilities - intrinsic growth in a wave, eg two-stream instability (localization in momentum space)

Radiation mechanisms

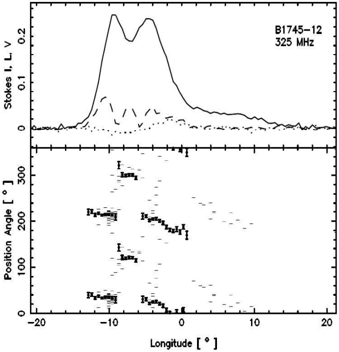
- Appealing to plasma instabilities works only with a high growth rate
- Most models use a thin beam through a background plasma
- Growth rate $\Gamma \propto (\frac{n_b}{n_p})^{1/2} \frac{1}{2\gamma_p^{1/2}\gamma_b^{3/2}}$ (Gedalin et al. 2002)
- Beams much less dense, very low growth rates - contrived solutions? (Usov 1987, Ursov & Usov 1988)

Wave growth

- Currently favoured theory uses plasma instability to generate waves
- Growth occurs with certain growth rate in each mode
- After long time expect radiation predominantly in the faster growing mode, single polarization

OPMs

- Observed that emission has (sometimes nearly equal) mixture of two orthogonal modes



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(Mitra, Sarala & Rankin)

- Polarization is often substantially elliptical

OPMs

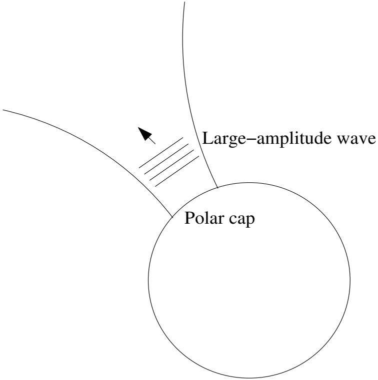
- Need coupling into two different modes
- Efficient coupling only near a point where polarization of the modes is changing rapidly
- Sufficient rapid change occurs only near cyclotron resonance
- Elliptical polarization also needs cyclotron resonance
- Waves generated near ω_p, orders of magnitude below Ω_c

Problems - summary

- Must be coherent, fast enough growth
- OPMs are hard to generate
- Time-stationary models unstable

Oscillating model

- Introduced as the result of perturbing the stationary model (Levinson et al., 2005)
- Oscillations as large-amplitude outward-propagating waves



(Luo & Melrose, 2008)

Oscillating model

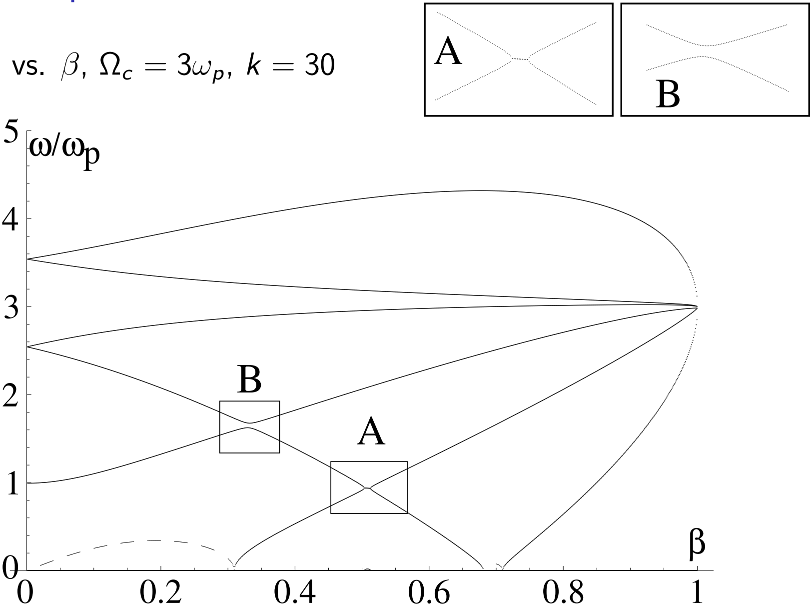
- Include displacement current, allow system to evolve
- Model has counterstreaming electrons and positrons in the magnetosphere
- Relative streaming Lorentz factor varies from $\gamma \sim 1$ to $\gamma \sim 10^6$
- Counterstreaming instabilities present
- Cyclotron frequency $\Omega_c \propto \frac{1}{\gamma}$ oscillates over wide range

Linear response

- Wave dispersion properties important for understanding generation of emission
- Model as a 1D pair plasma, treat in centre of momentum frame
- Calculate linear response and find available wave modes
- Plot ω as a function of β for some k

Wave dispersion

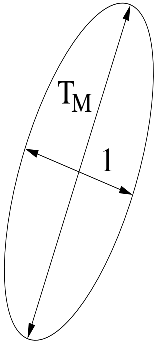
ω vs. β, $\Omega_c = 3\omega_p$, $k = 30$



Mode coupling

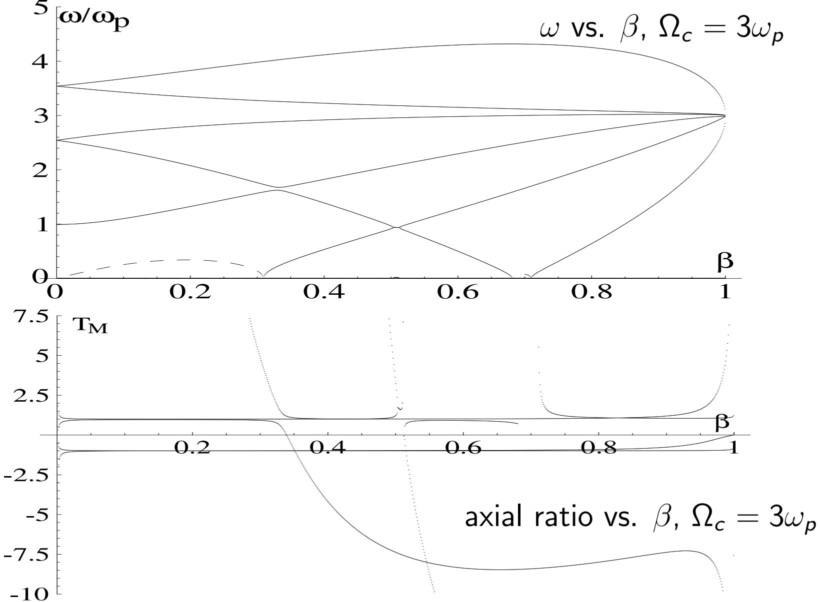
- Mode coupling is expected to occur when the polarization is changing most rapidly
- Look for polarization swings near mode crossings
- Mode coupling in intrinsically time-dependent medium is nontrivial

Polarization ellipse



- Mode coupling strong when polarization ellipse changes shape rapidly
- $T_M = \pm 1$ — circular, $T_M = 0, \infty$ — linear
- Can plot T_M as a function of k or β once the modes are identified
- Compare with shape of dispersion curves, position of resonances
- Cyclotron resonance at $\omega = \Omega_c / \gamma \pm \beta kc$

Polarization and dispersion as a function of β



What should we see?

- We expect backward emission, esp. at low frequency - model should produce emission in both directions
- Elliptical polarization can be explained
- Low frequency emission, at $\omega \leq \gamma^3 c/R_c$, dominated by curvature effects (we see emission from a short time)
- Models with high-γ outflow must be curvature dominated below this frequency; oscillating model has phases where γ much lower, perhaps coherent emission signatures at low frequency

Conclusion

- Pulsar radio emission not well understood
  - Magnetospheric models unstable
  - OPMs hard to explain
  - Efficient coupling requires cyclotron resonance
- Oscillating model provides some solutions
  - Including displacement current gives more realistic model
  - Allow interaction with cyclotron resonance
  - Rapid polarization change near resonance point, coupling
  - $\Omega_c \propto 1/\gamma$ can be below ω_p in phase where γ is maximum
  - Observational effects include expectation of backwards emission
  - Same emission should be observed at lower frequencies