Continuing our Roger Blandford abbreviations feast
$P, PP, B \ & (of\ course)\ M$

Maxim Lyutikov (Purdue)
Pulsars, Plasma Physics, Blandford & Magnetic fields
It’s an “interesting” problem...

Pulsars were discovered more than 40 years ago, yet we still do not understand how they produce high brightness radio emission.

Ω

Take a dipole
Spin it up

Sit back and see radiation coming out

Well, there are issues...
Pulsar radio emission: must be coherent

Intensity:
- Incoherent: \( I = \sum I_i \sim nI_i \)
- Coherent: \( I = (\sum A_i)^2 \sim n^2 I_i \)

Pulsars’ emission so bright: must be coherent
Two ways to achieve coherence: bunching and masing

- if $L < \lambda$ all particles emit in phase
- spontaneous, but in phase, Power $\sim q^2 \sim N^2 e^2$
- What created bunches?
- Radiation reaction will disperse the bunch

Maser:

population inversion: more particles ready to emit than to absorb

stimulated emission $\sim n_{ph}$
Coherent plasma emission

Binary collisions: too long

Plasma waves

Coherent plasma emission
Population inversion:
\[ \partial_{\epsilon} f > 0 \]
Best early hopes: coherent curvature emission

- Does not work: particle absorbs more than emits...

This is a roadblock in theories of pulsar radio emission.

- Twisting (your brain or the field line) may make it work...

Can next particle emit in phase?
A little magic: anomalous cyclotron resonance

Ginsburg 1965; Schwinger 1975
Cyclotron-Cherenkov emission

- A particle can emit a cyclotron photon even from the lowest Landau level, with no initial gyration
- Particle goes \textbf{up} in Landau levels and emits a photon (of negative energy in the center of gyration frame)
- “Maser” condition (more particles “want” to emit than absorb): more particles at low $p_{\text{perp}}$ (radiative decay times are short)
  \[ \frac{\partial p_{\perp}}{\partial t} f < 0 \]

\[ \omega - k_{\parallel} v_{\parallel} = -s \omega_B / \gamma, \ s = 1, 2, \ldots \]

- Need $n = k c / \omega > 1$ : Cherenkov-type emission (polarization shock-front)
- $\omega$ can be $<< \omega_B$
- Slow wave electron-cyclotron maser

May explain pulsar radio emission, (Lyutikov, Blandford, Machabeli, 1999a, b). There are issues...

- Machabeli & Usov, 1978
CRs moving with $v > v_A$ excite Alfven waves

$$\omega - k_{||} v_{||} = - \omega_B / \gamma,$$ $s=1,2,..$

$$\omega = k_{||} v_A \ll k_{||} v$$

$$k_{||} v = \omega_B / \gamma$$

$$\omega - \Omega_k = -\kappa / m$$: Inner Lindblad resonance: energy of Keplerian motion goes to excitation of epicyclic motion (=cyclotron rotation) and excitation of density waves (=emission of a photon)
- Observations of Crab giant pulses with sub-nanosecond (!) time resolution (Eilek & Hankins 2006).
- In the inter-pulse:
  - Narrow emission bands
  - No bands below ~ 4 GHz
  - Unequal spacing
  - Slightly drifting up in frequency
  - Seen in every IGP

Lyutikov 2007
Crab profile

1. Main pulse disappears @ 8 GHz
2. Interpulse disappears @ 2.6 GHz
   - new HFC components
   - Interpulse shifted by ~ 10°
3. “New” emission component at IP between 4 & 8 GHz,
4. may be composed entirely of GPs.
GPs from closed field lines: anomalous cyclotron resonance

\[ \omega(k) - k_{||} v_{||} = -s\omega_B / \gamma \]

- Need to fit plasma and beam properties: \( \omega_p, \gamma_{\text{plasma}}, \gamma_{\text{beam}}, \theta_{\text{obs}}, r/R_{NS} \):
  - \( r \sim R_{LC} \) (barely fits inside)
  - \( \gamma_{\text{plasma}} \sim 1 \) (not open field lines)
  - \( n/n_{GJ} \sim 10^5 \)
  - \( \gamma_{\text{beam}} \sim 10^7 \) (radiation-limited) - reconnection at Y-point
  - \( \theta_{\text{obs}} = 0.0023 \) (local B-field and line of sight)

NB: “normal” pulses are from open field lines

No emission below \( \omega_p \)!
How can this be?

Beam: Reconnection @ Y- point

- Fermi, VERITAS, MAGIC may see contemporaneous GeV signal
- Observations underway (GBT-VERITAS), the most wide-band simultaneous observations ever, 18 decades in energy
Conclusion

- Giant pulses come from closed field lines (only IGP!)
- Seen by chance, narrow emission window
- Closed field lines are not dead! Populated by plasma with $n >> n_{GJ}$
- Earth analogues (?): magnetospheric hiss, roars

- Radio emission generated high up in the magnetosphere
Roger, you know...
Congratulations!