Continuing our Roger Blandford abbreviations feast

P,PP, B & (of course) M

Maxim Lyutikov (Purdue)

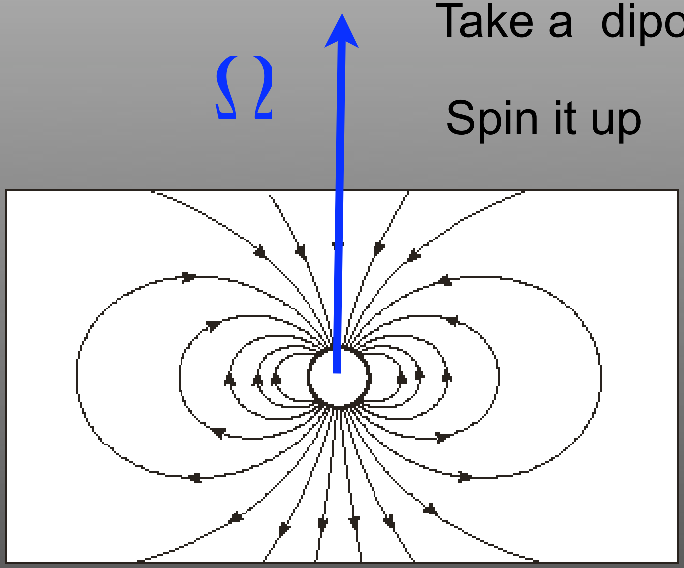
Pulsars, Plasma Physcs, Blandford & Magnetic fields

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.

Take a dipole

Spin it up



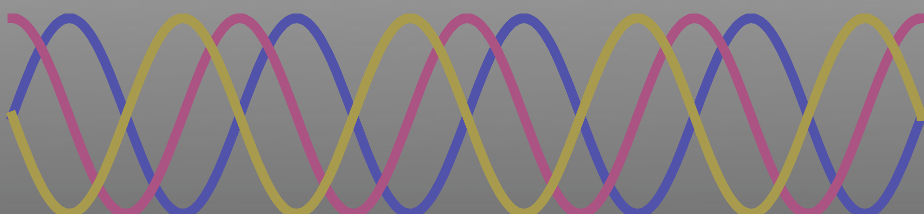
Sit back and see radiation coming out

Well, there are issues...

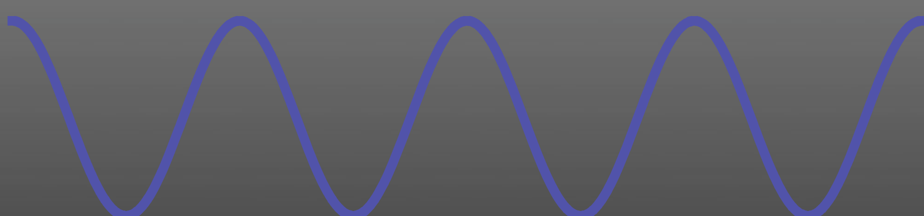
Pulsar radio emission: must be coherent

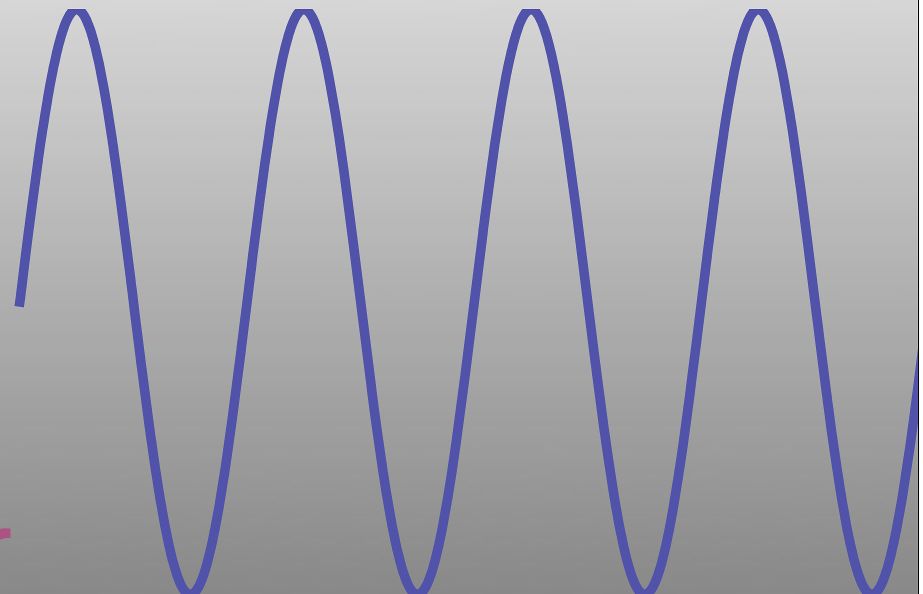
Intensity: $I = A^2$

- Incoherent : $I = \sum_i I_i \sim n I_i$
- Coherent: $I = (\sum_i A_i)^2 \sim n^2 I_i$



incoherent





coherent

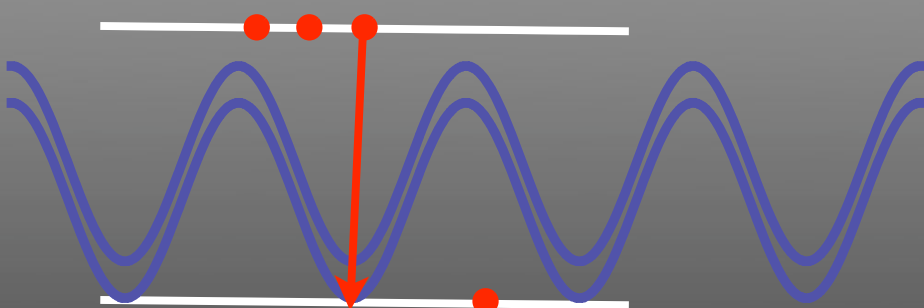
Pulsars' emission so bright: must be coherent

Two ways to achieve coherence: bunching and masing

if $L < \lambda$ all particles emit in phase

- spontaneous, but in phase,
Power ~ q^2 ~ N^2 e^2
- What created bunches?
- Radiation reaction will disperse the bunch

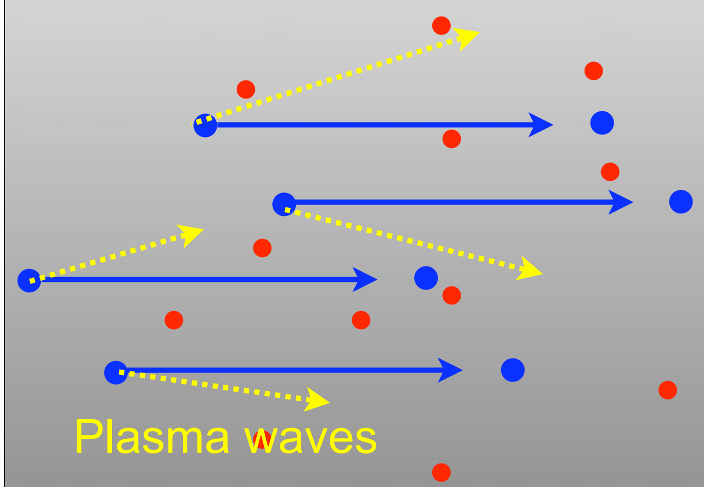
Maser:

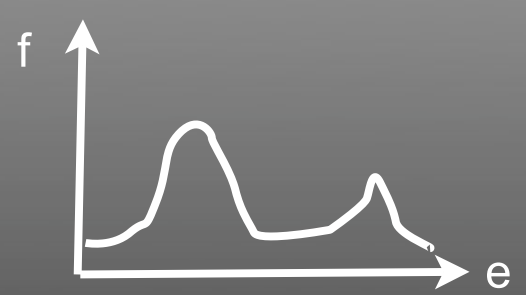


population inversion: more particles ready to emit than to absorb

stimulated emission ~ n_{ph}

Coherent plasma emission





Binary collisions: too long

Coherent plasma emission

Population inversion:

$$\partial_\epsilon f > 0$$

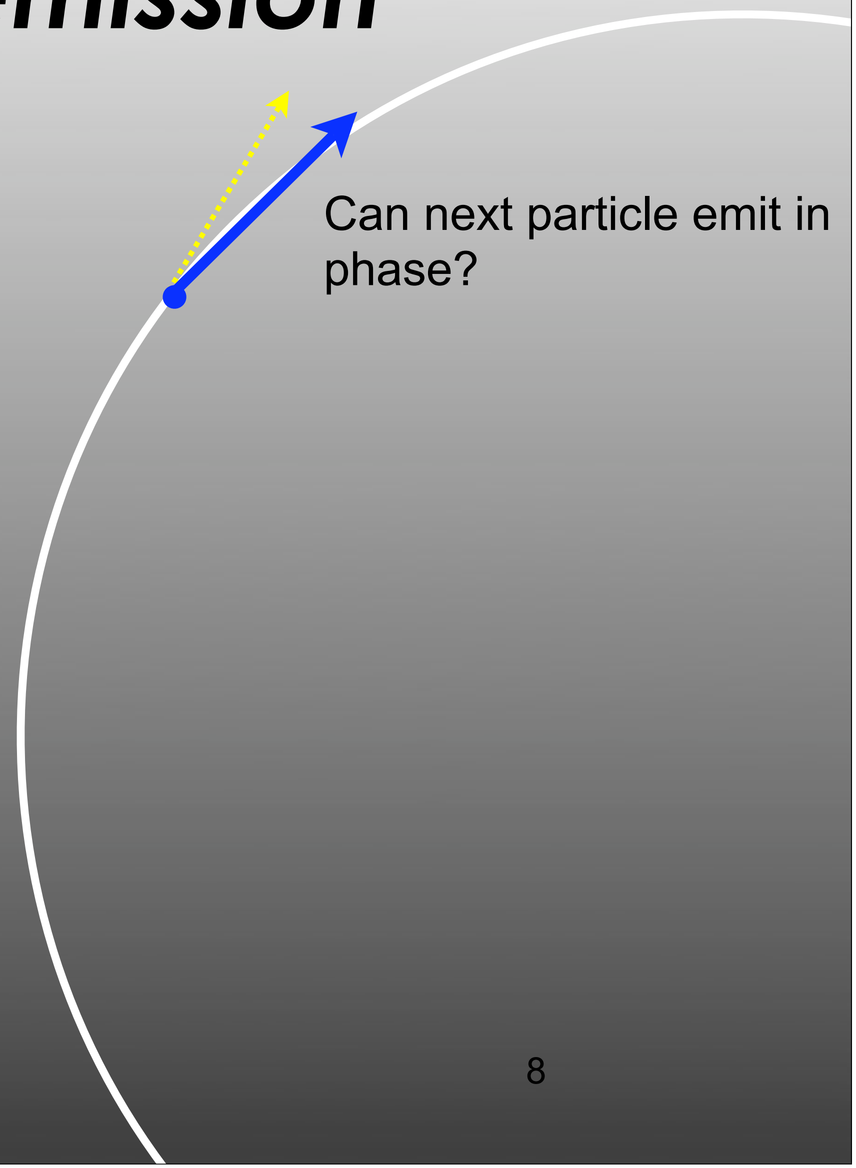
Best early hopes: coherent curvature emission

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

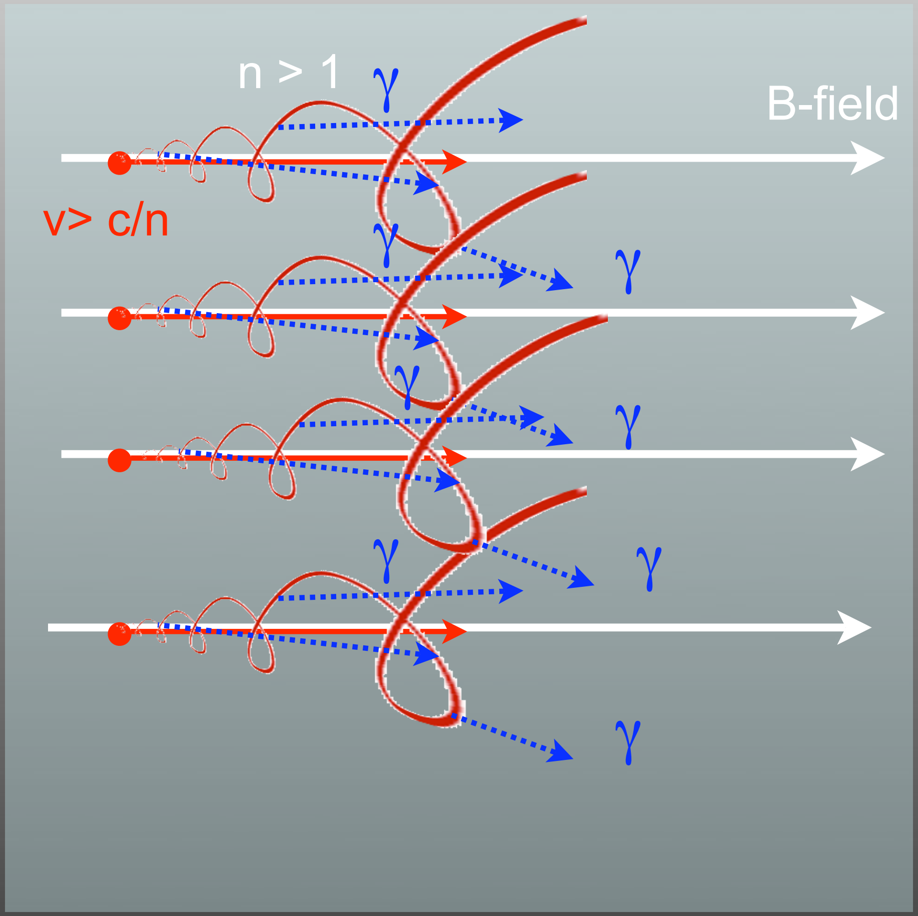
Blandford. MNRAS, 170, 1975, p. 551

This is a **roadblock** in theories of pulsar radio emission.

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



A little magic: anomalous cyclotron resonance

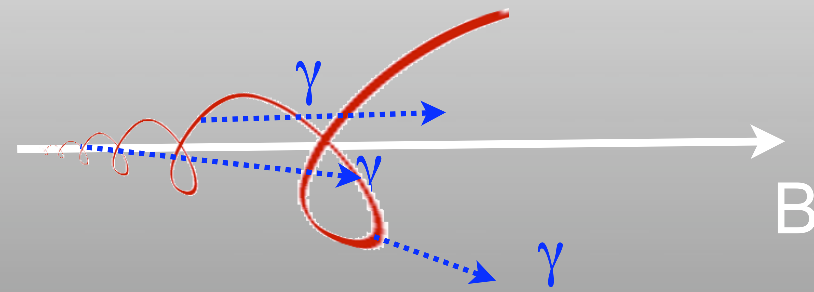


Ginsburg 1965;
Schwinger 1975

Cyclotron-Cherenkov emission

- A particle can emit a cyclotron photon even from the lowest Landau level, with no initial gyration
- Particle goes **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_{perp} (radiative decay times are short) $\partial_{p_\perp} f < 0$

- Machabeli & Usov, 1978



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

- $\omega - k_{\parallel} v_{\parallel} = - s\, \omega_B / \gamma$, s= 1,2,..
- Need $n = kc/\omega > 1$: Cherenkov-type emission (polarization shock-front)
- ω can be $<< \omega_B$
- Slow wave electron-cyclotron maser

You knew it all along

CRs moving with $v > v_A$ excite Alfven waves

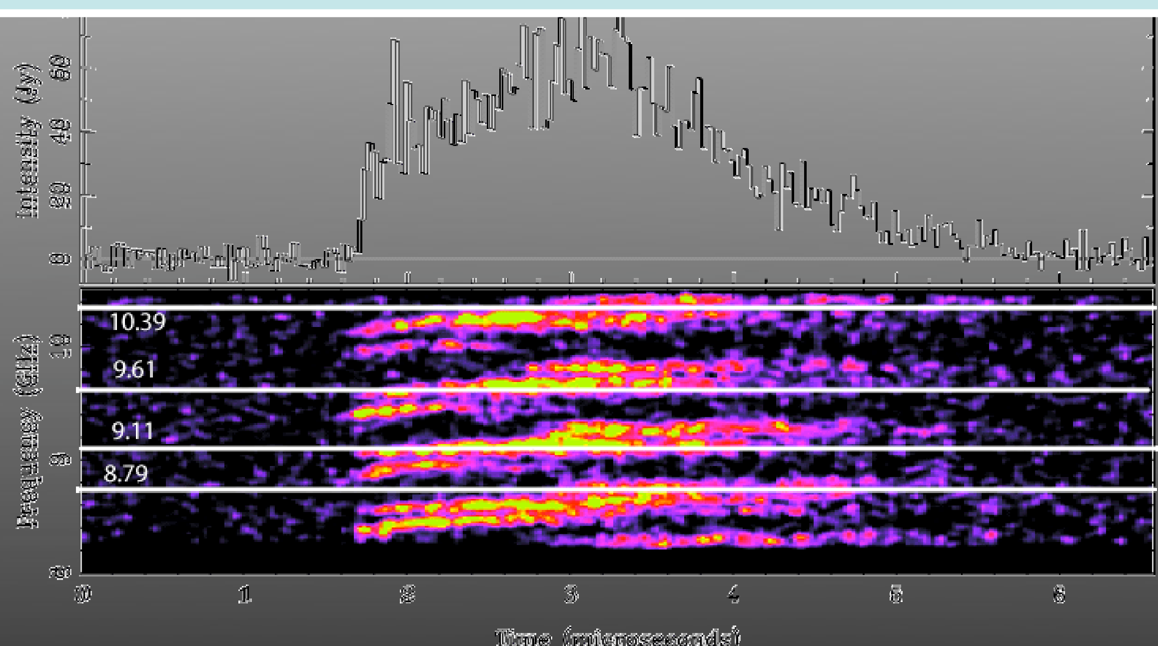
$\omega - k_{\|} v_{\|} = - s\, \omega_B / \gamma$, s= 1,2,..

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

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

$\omega - \Omega_k = -\kappa / m$: Inner Lindblad resonance: energy of Keplerian motion goes to excitation of epicyclic motion (=cyclotron rotation) and excitation of density waves (=emission of a photon)

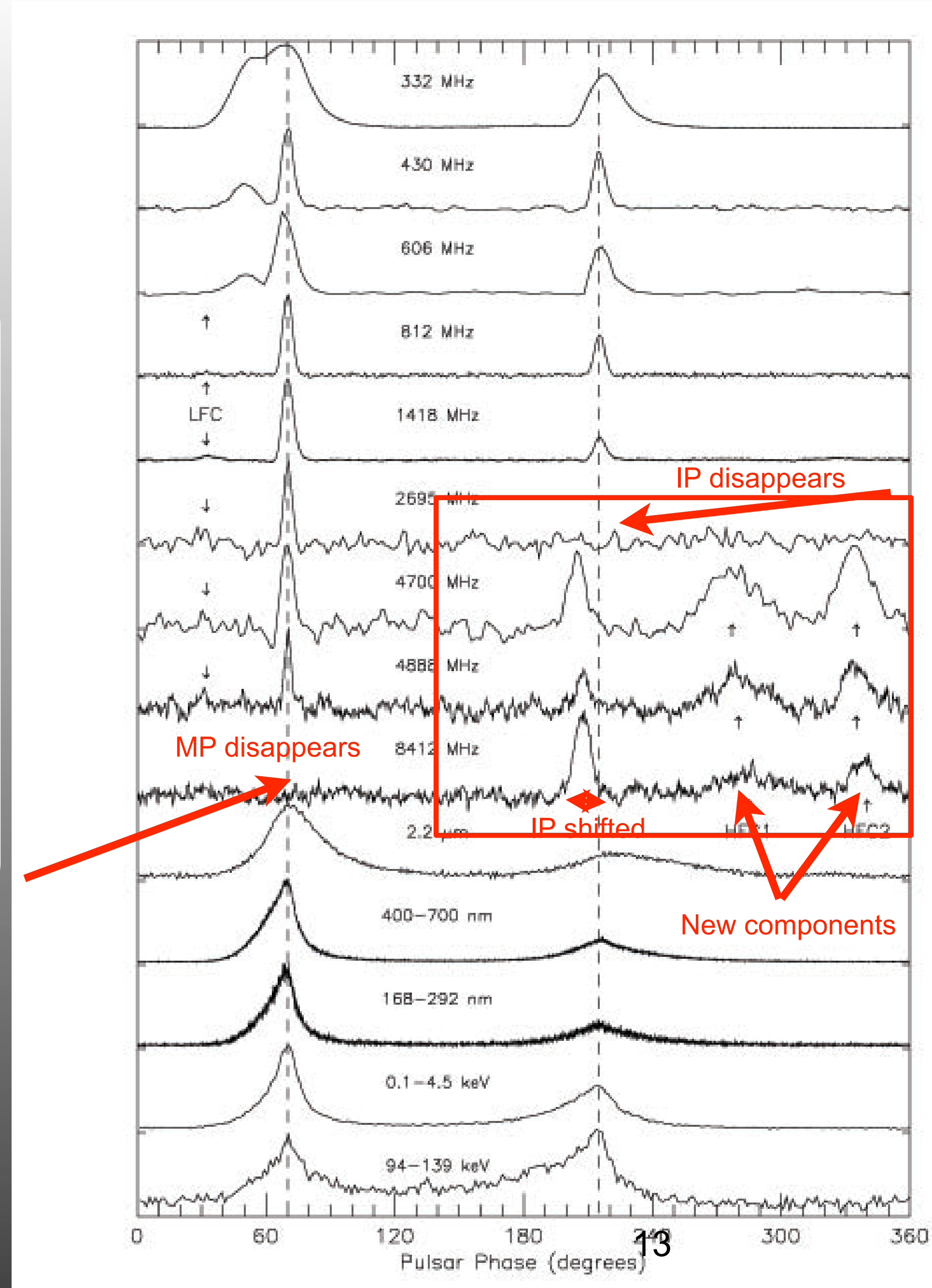
- Observations of Crab giant pulses with sub-nanosecond (!) time resolution (Eilek & Hankins 2006).
- In the inter-pulse:
  - Narrow emission bands
  - No bands below ~ 4 GHz
  - Unequal spacing
  - Slightly drifting up in frequency
  - Seen in every IGP



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.

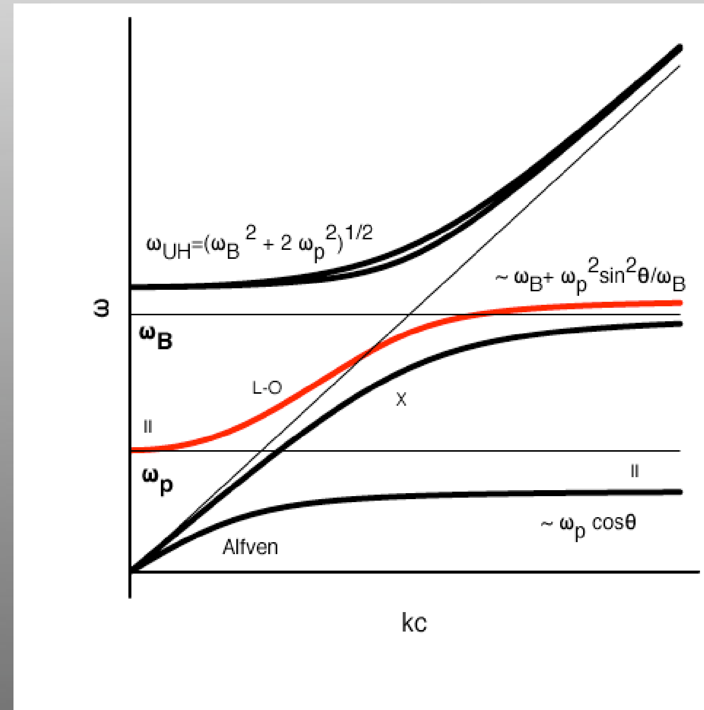


GPs from closed field lines: anomalous cyclotron resonance

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

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

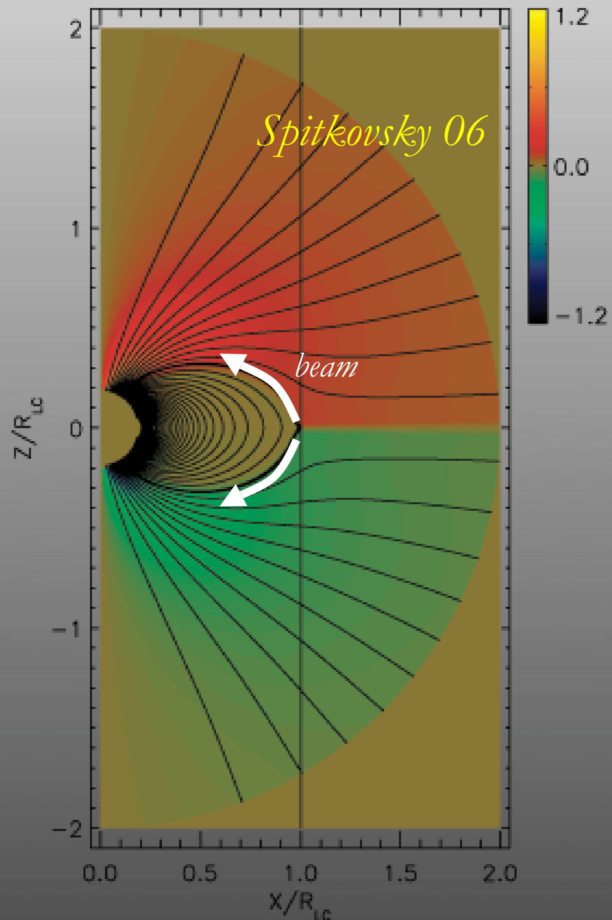
NB: “normal” pulses are from open field lines

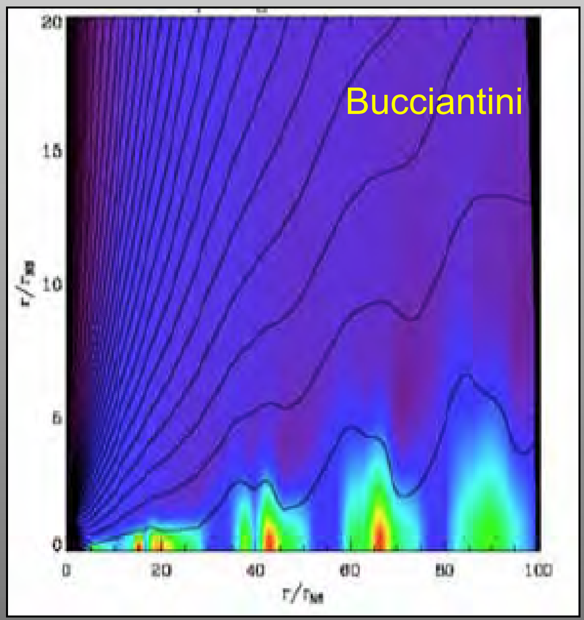


No emission below ω_p!

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!