Particle acceleration during collision of strong Alfven waves

Alexander Philippov (Princeton University)
Collaborators: Anatoly Spitkovsky, Kyle Parfrey

Outline

- Motivation: non-thermal emission from magnetars
- PIC simulations of Alfven wave collisions
- Application to magnetars

Non-thermal emission from magnetars

Magnetars:

highly magnetized neutron stars, 10^{15}G fields inferred

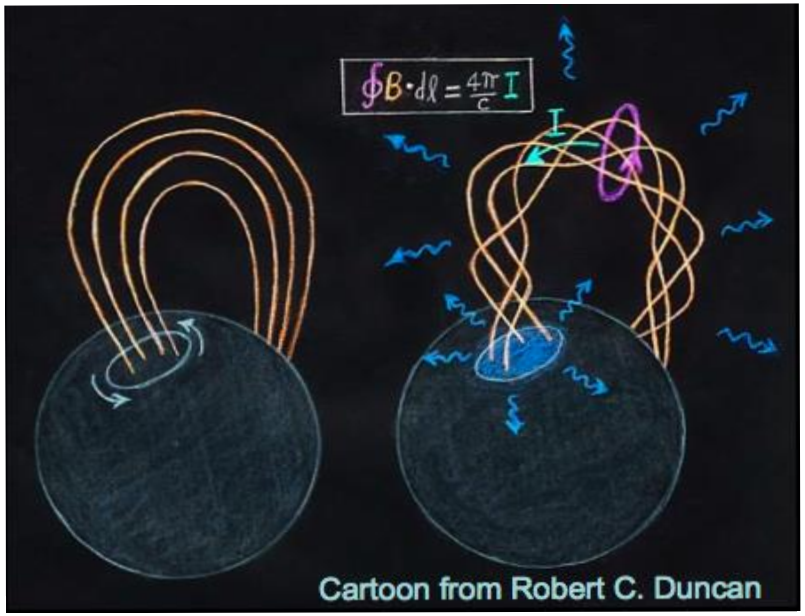
Slow spins: 3-10sec

X-ray emission > spin-down power

Emission is though to be powered by decay or unwinding of B field

Undergo giant flares, have bursty behavior -- catastrophic release of magnetic energy

Also, persistent emission



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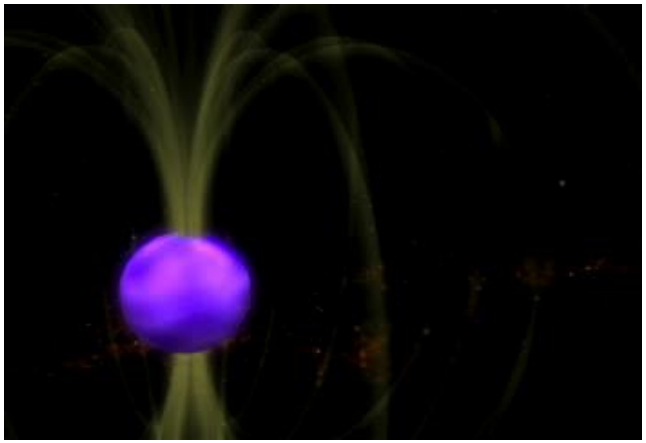

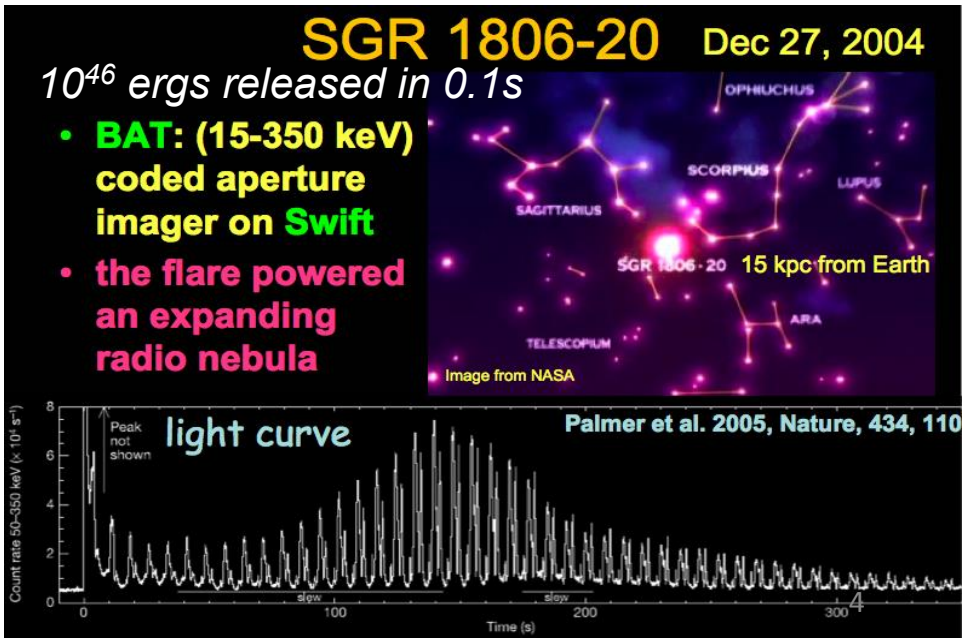

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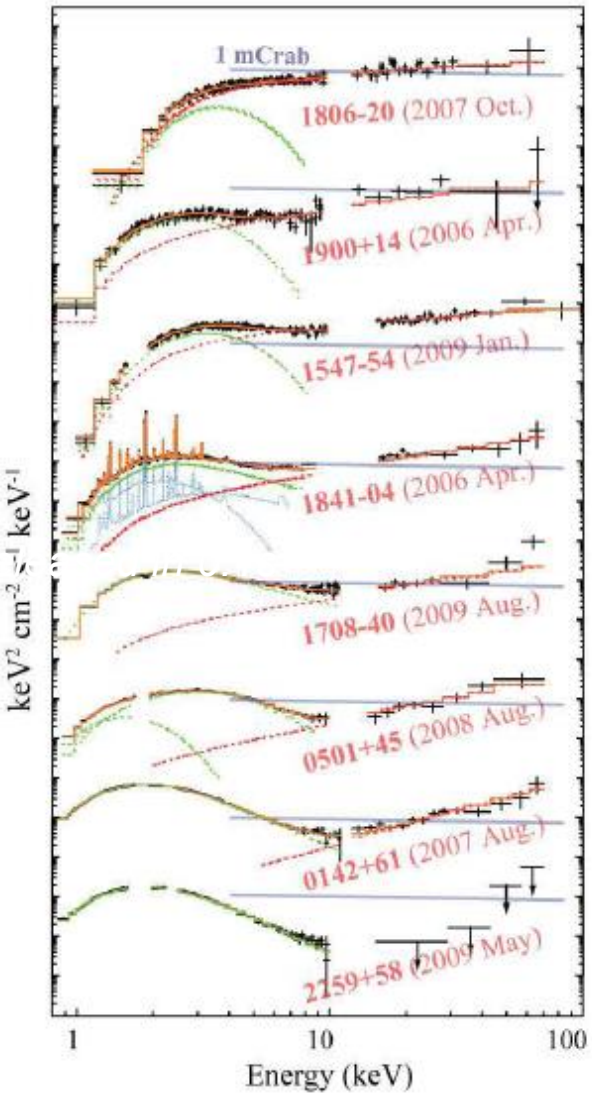
Also, persistent emission: thermal + rising tail in νF_ν. Non-thermal parts can be described in terms of cyclotron resonant scattering (Lyutikov 2006, Beloborodov 2013)

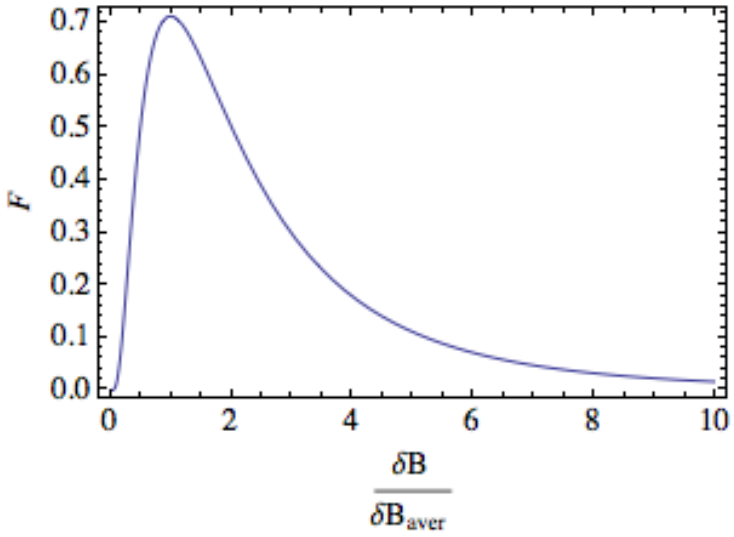
from Enoto et al., 2010

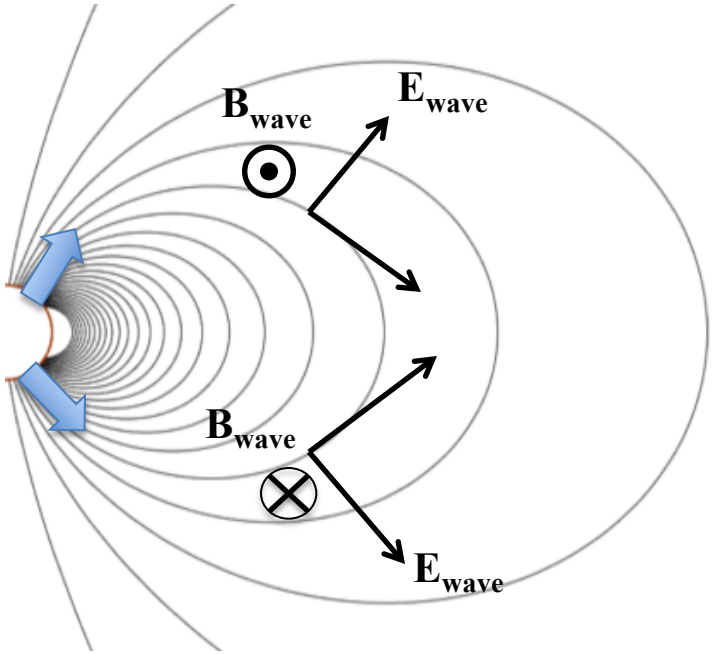


Non-thermal emission from magnetars

Idea:

Continuous shaking of field lines on the surface launches a spectrum of waves





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Yes, if E>B in the collision. Study this with PIC simulations.

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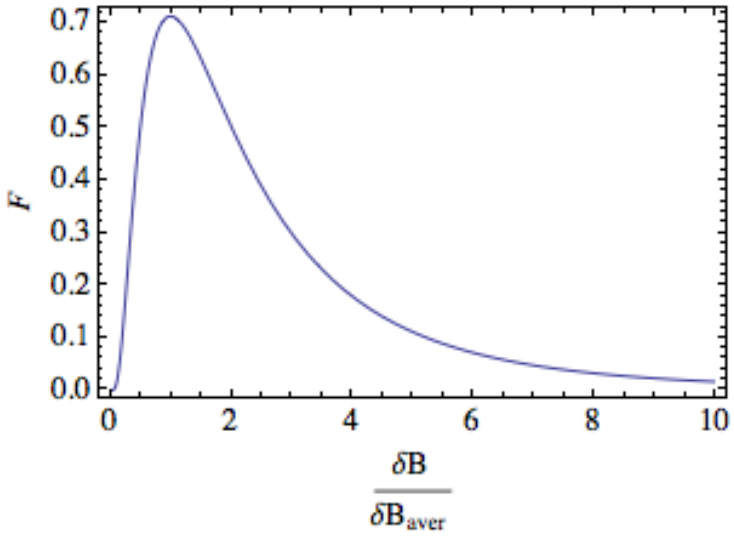

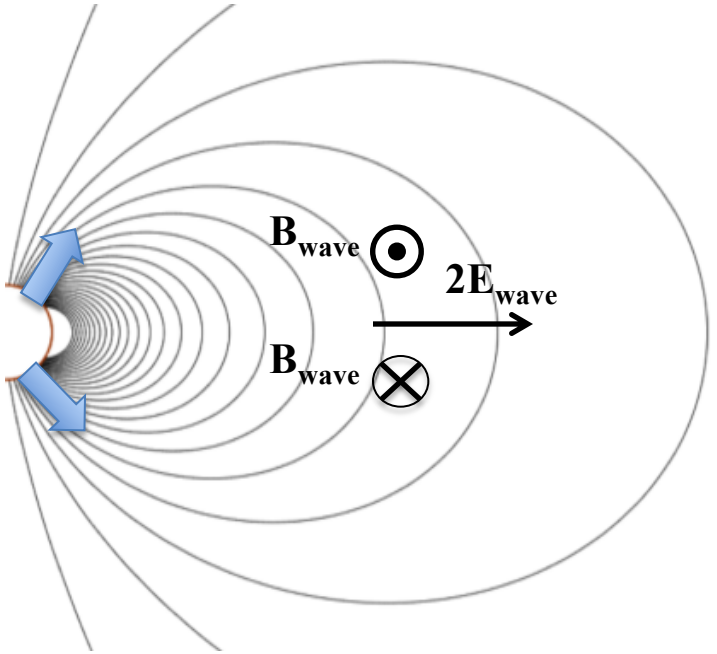

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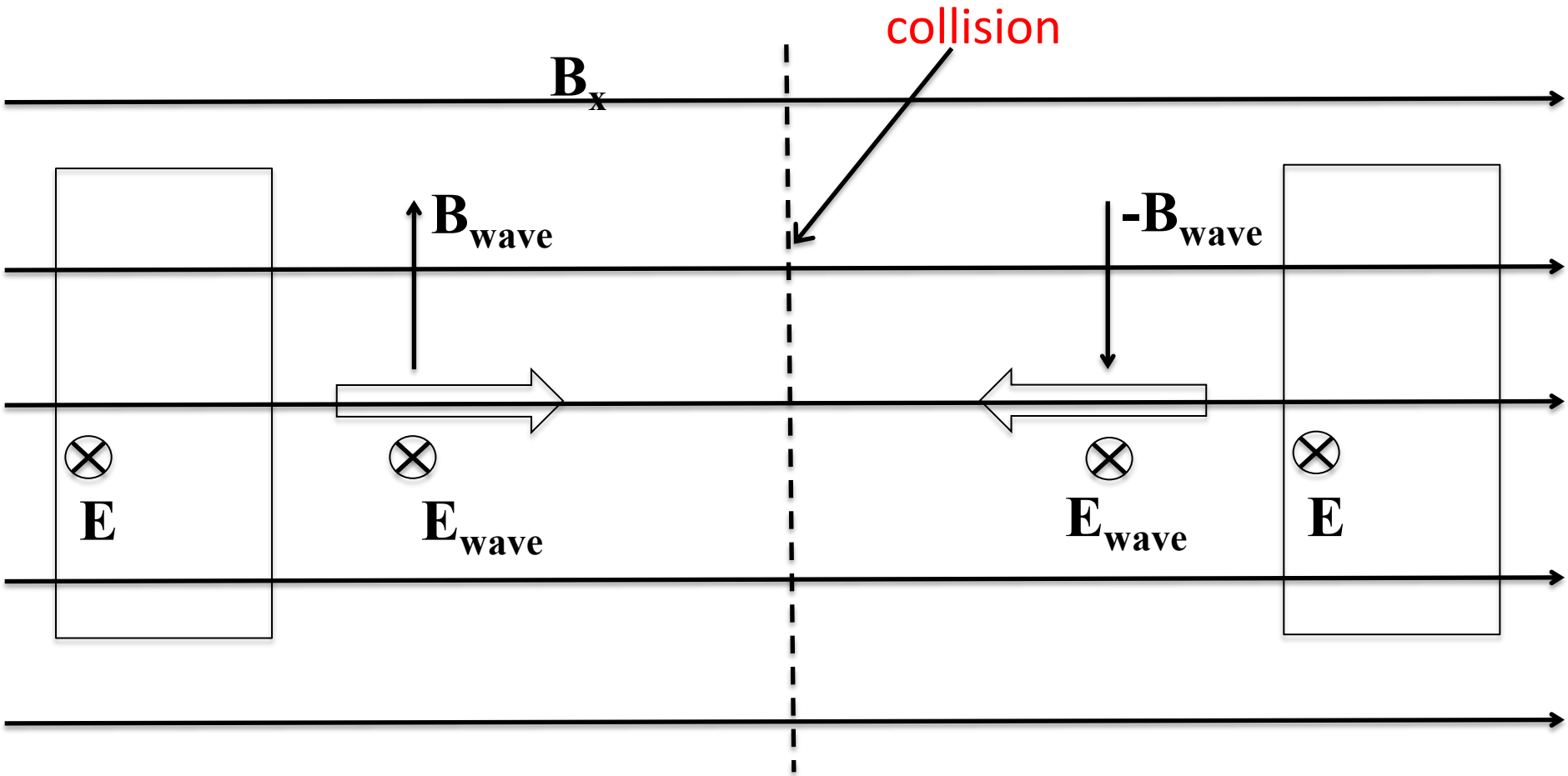
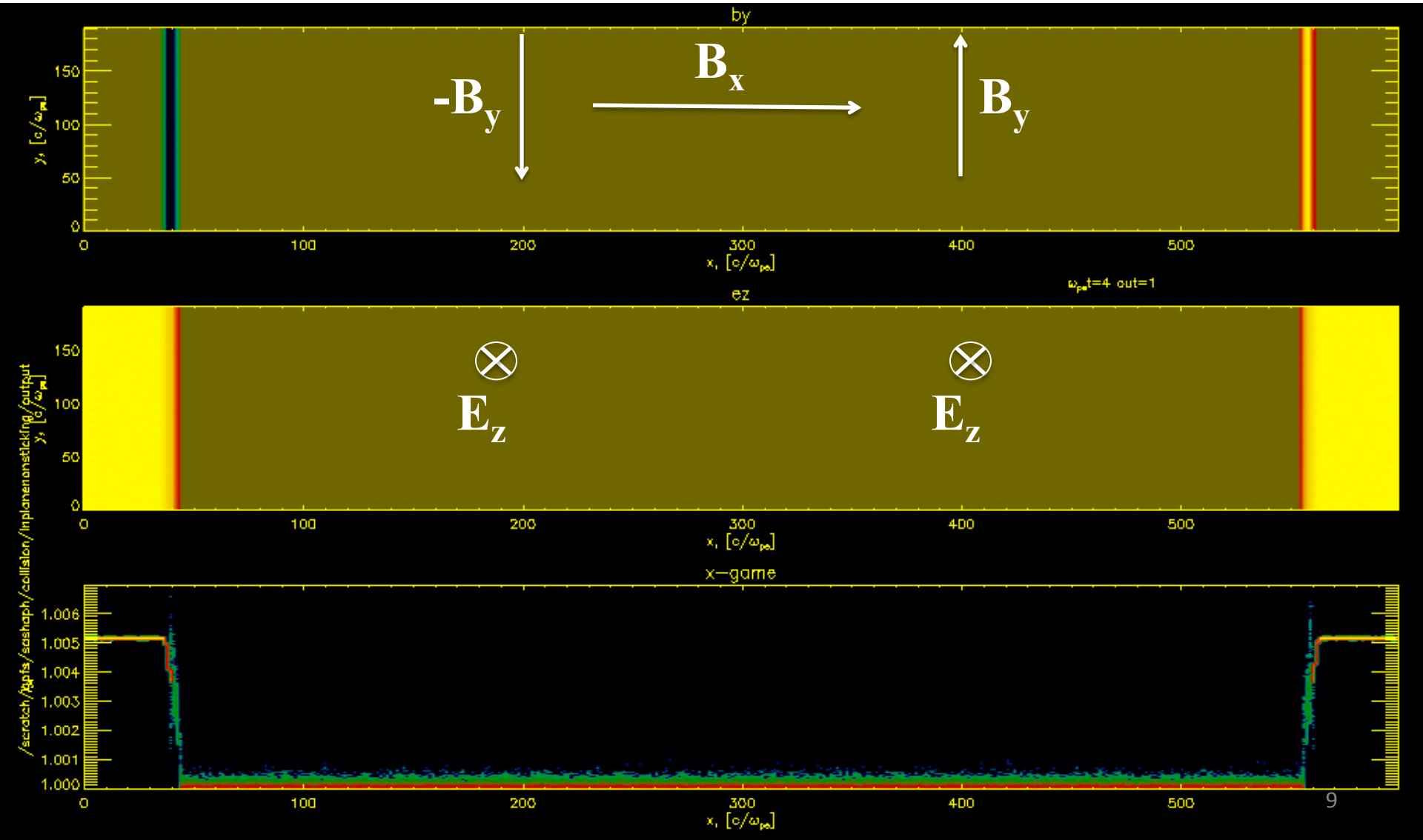
Simulation setup



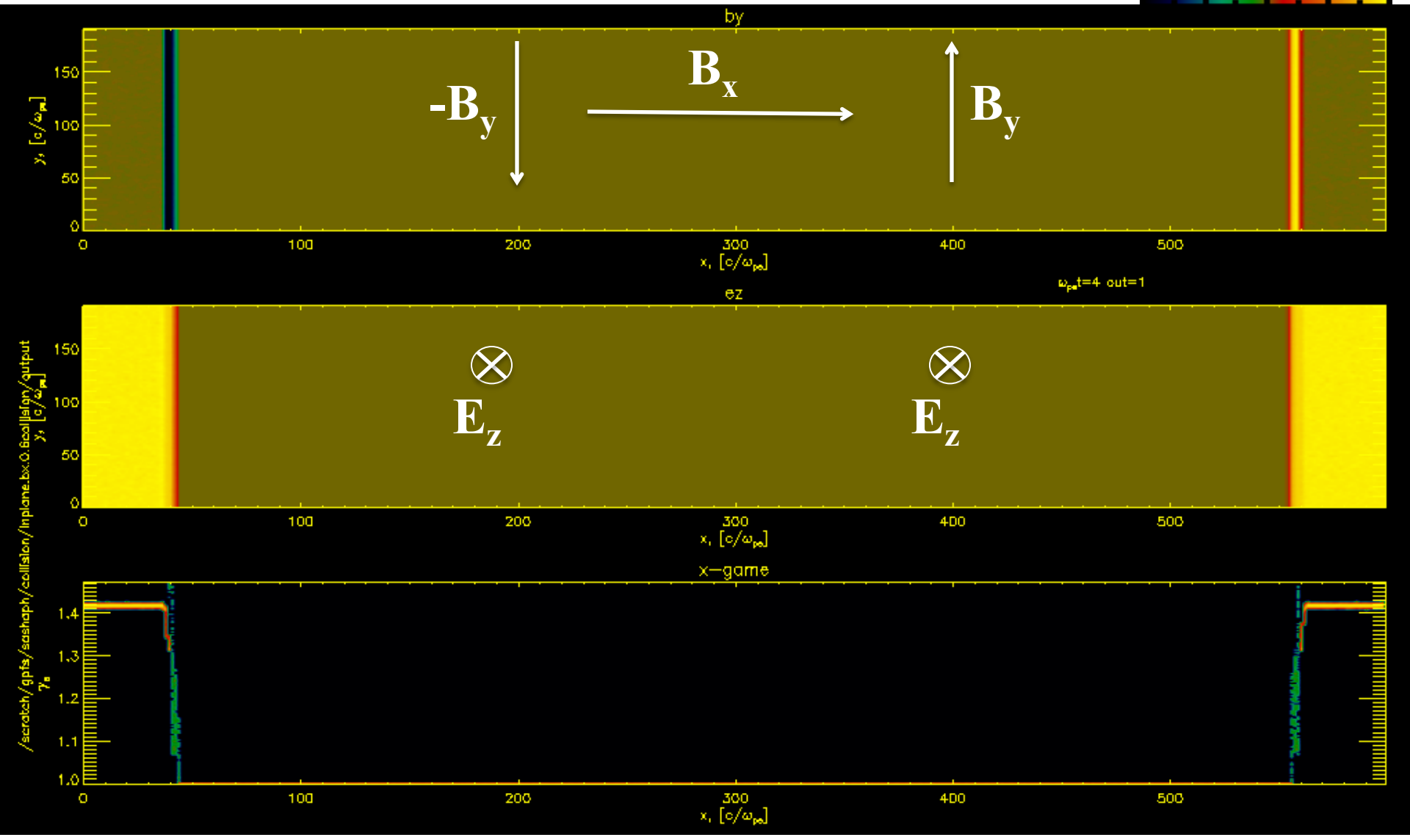
Electric fields sum up, magnetic cancel out.
What happens if E exceeds B?

Criterion: $2B_{wave} > B_x$

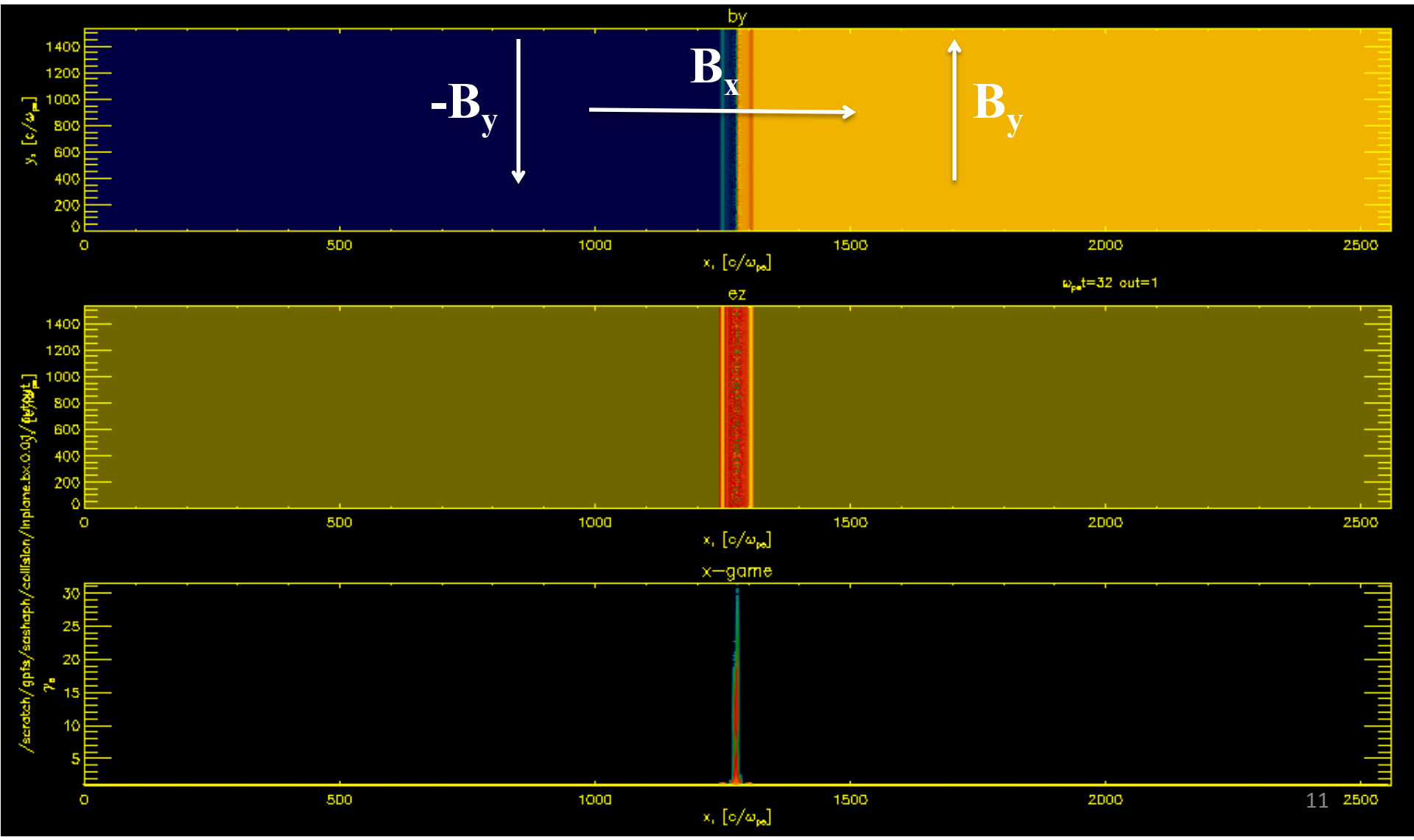
Collision of Alfven waves I: non-interacting case ($B_x/2B_y$ =0.7)



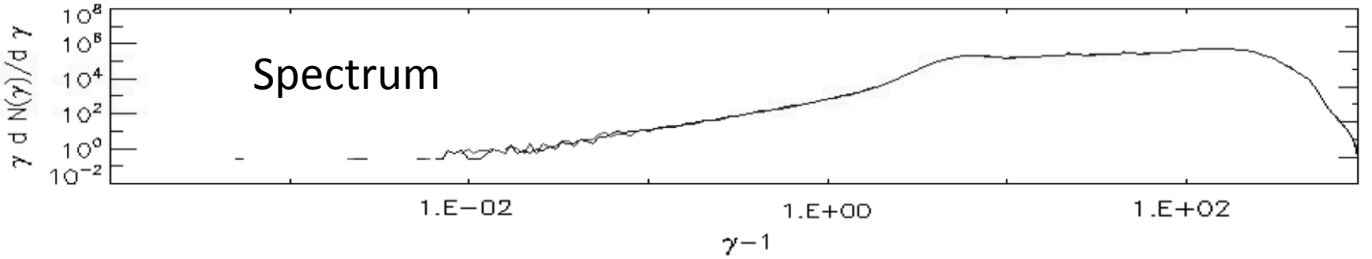
Collision of Alfven waves II: "sticking", higher wave amplitude ($B_x/2B_y = 0.7$)

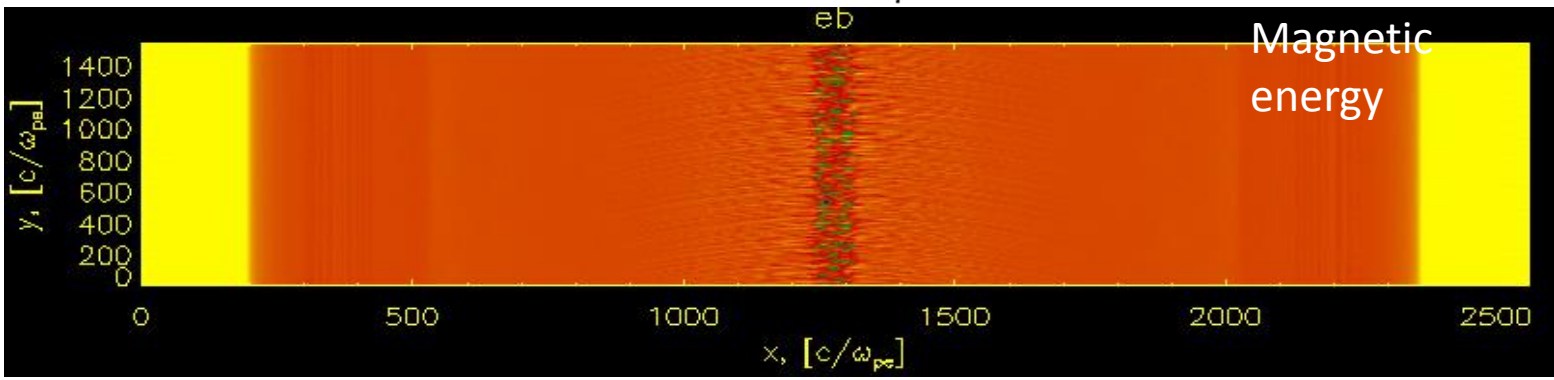


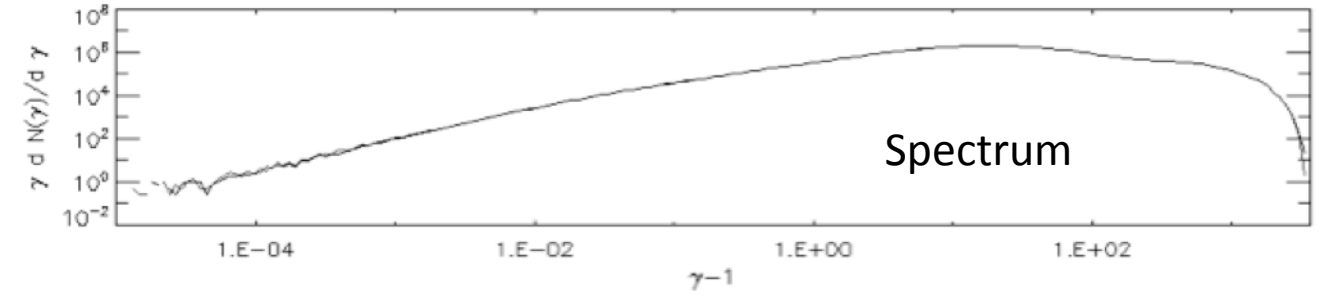
Collision of Alfven waves III: “sticking”, strong waves ($B_x/2B_y$ =0.05)

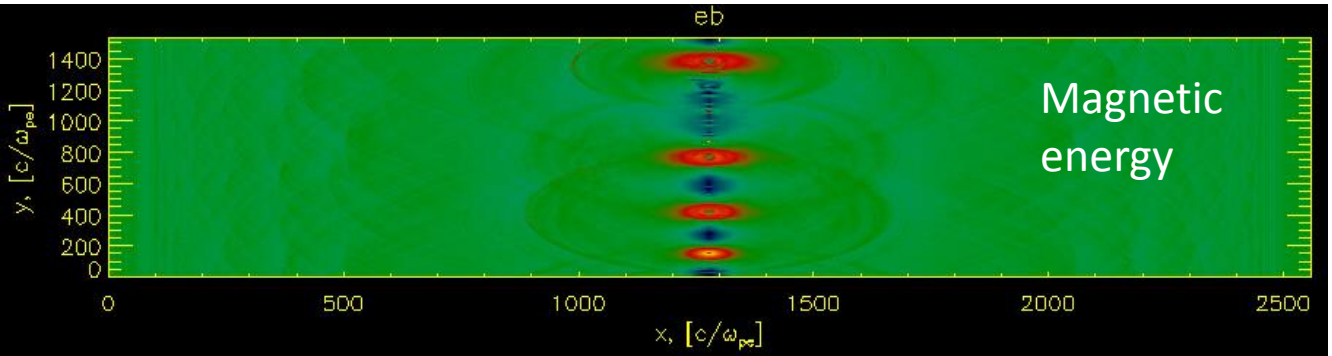


High guide field case





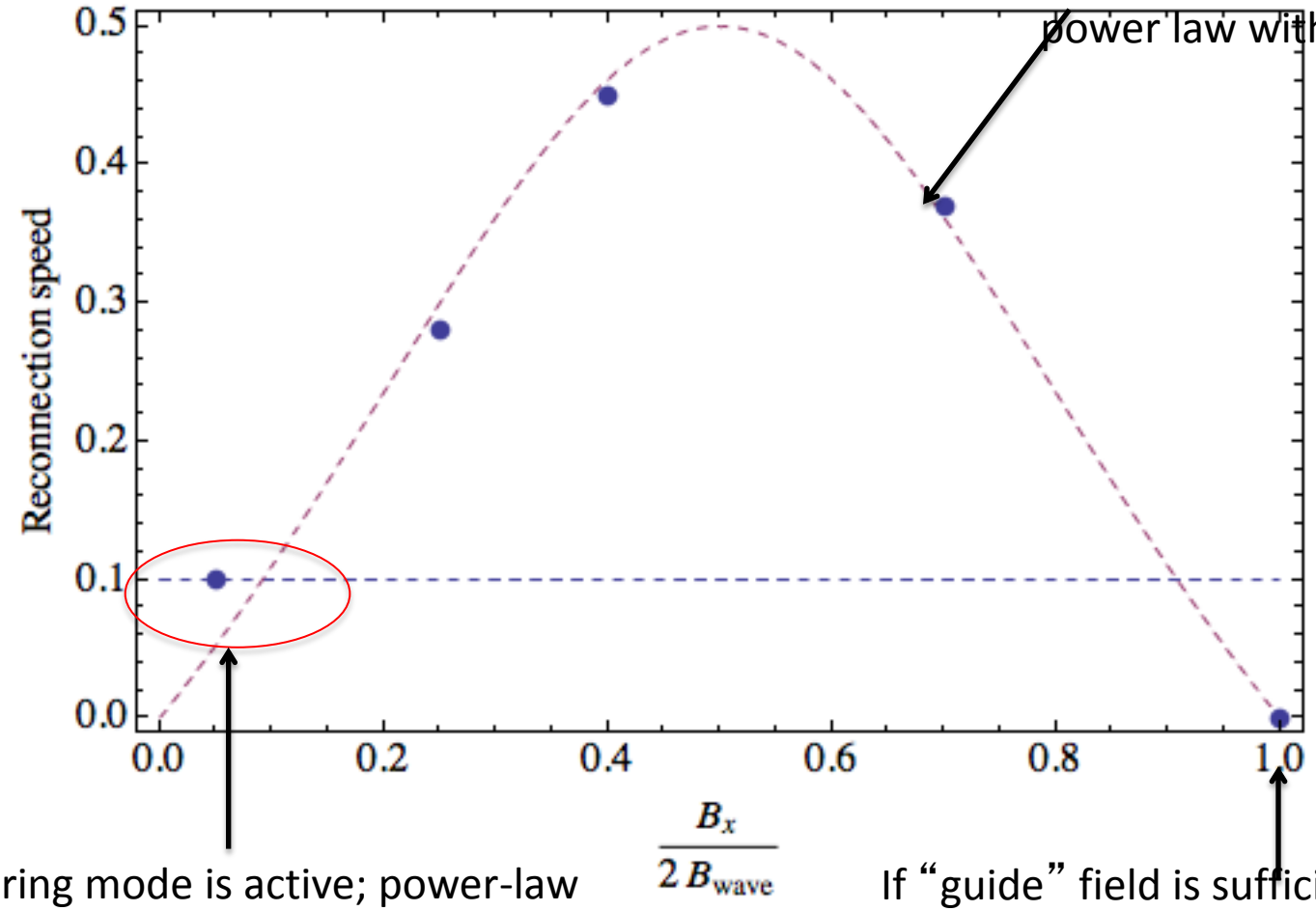




Low guide field case

Reconnection rate and particle spectrum

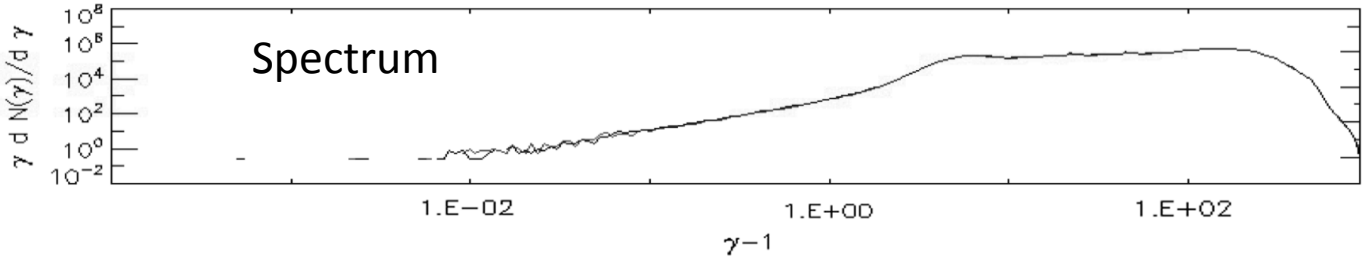
tearing mode is suppressed, E~B (at this point we measure the reconnection rate); transient power law with index ~1

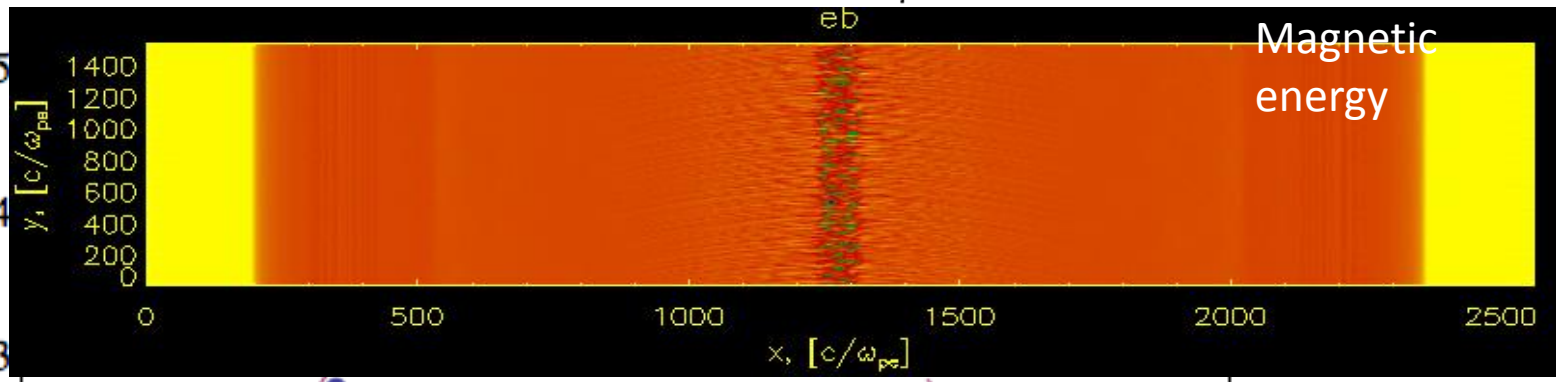


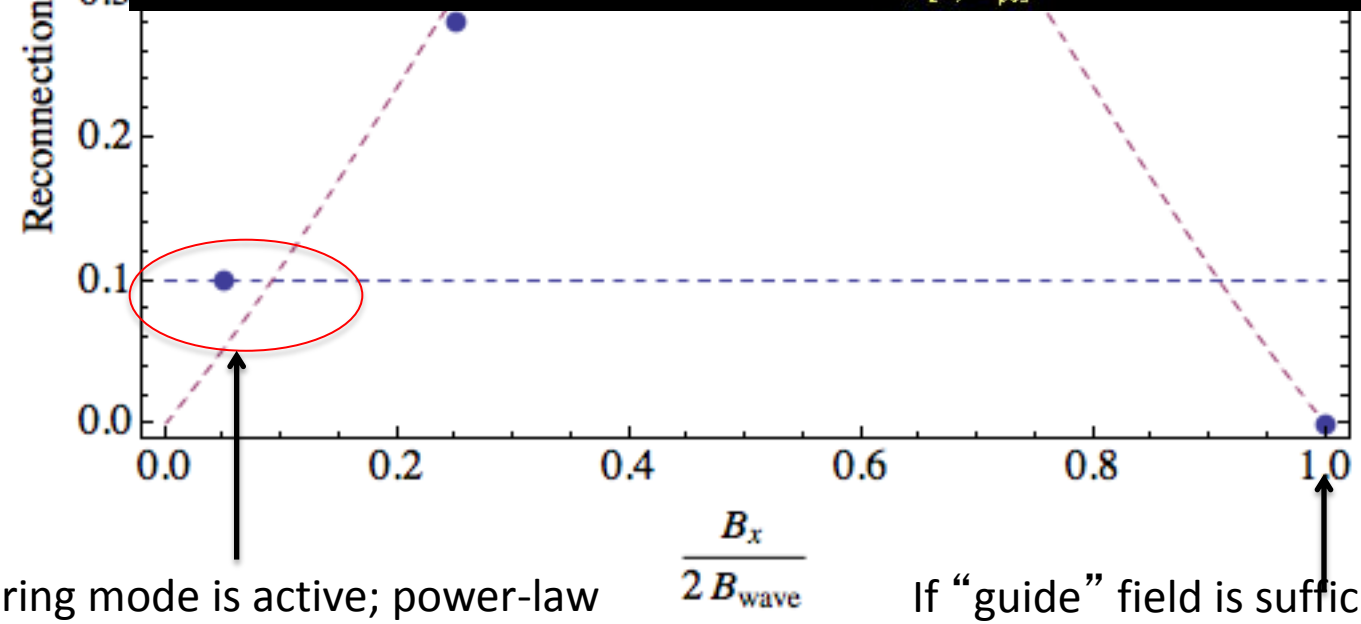
tearing mode is active; power-law accelerated particles with index ~2

If "guide" field is sufficiently strong no sticking happens

Reco







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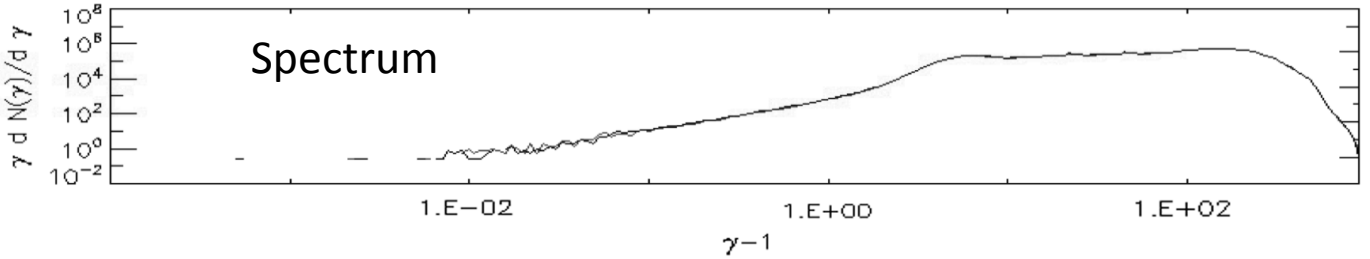
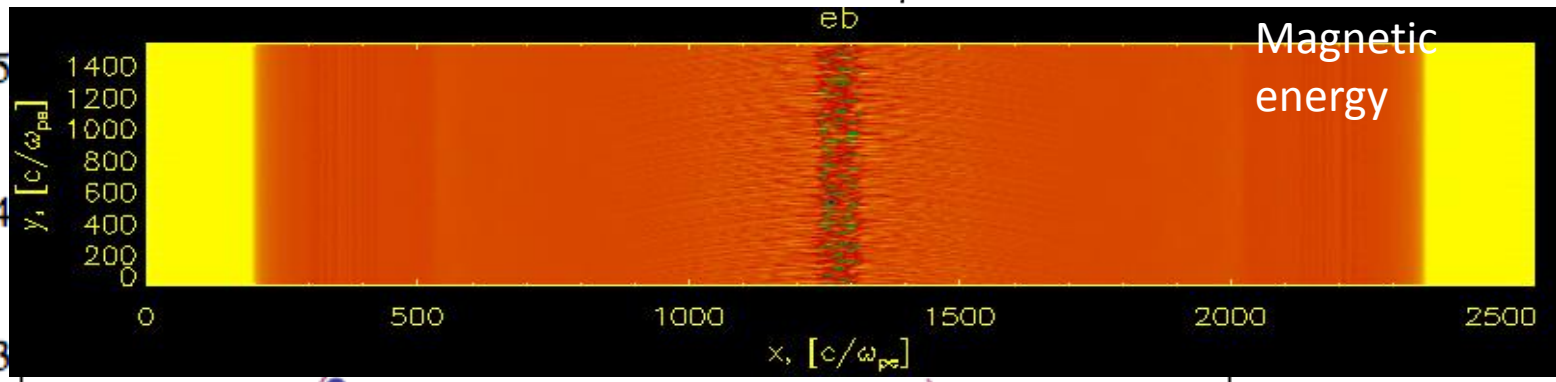
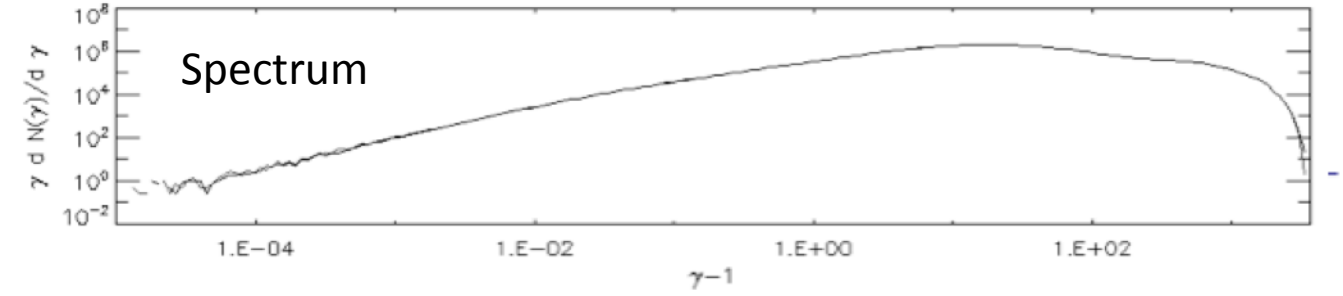
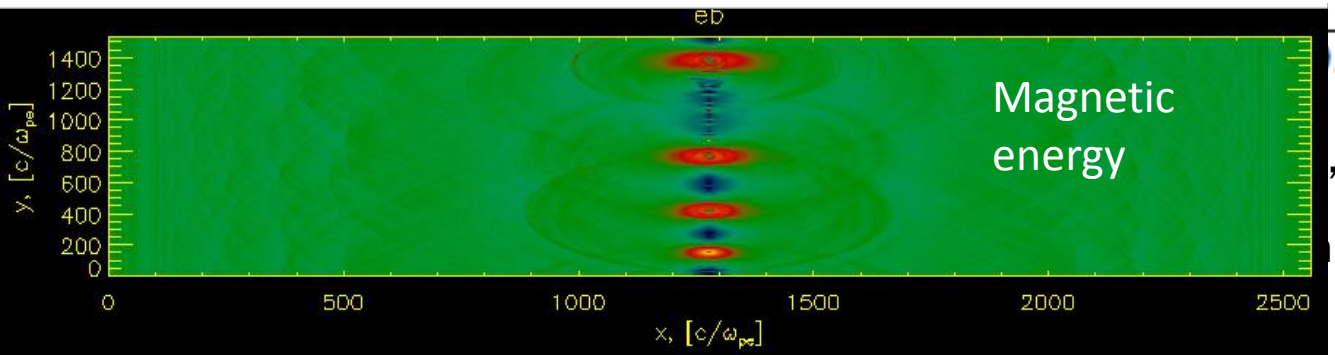








” field is sufficiently strong
o sticking happens

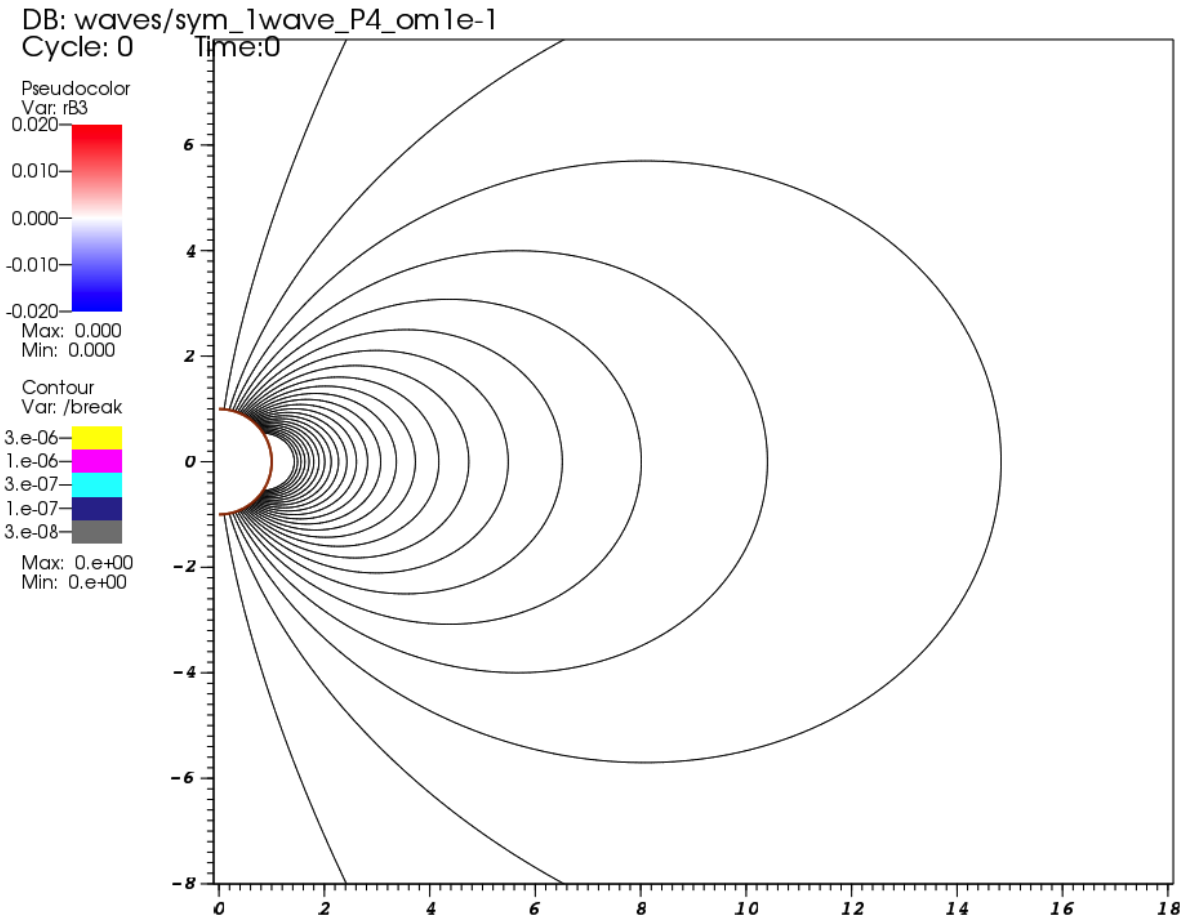
Collisions in dipole force-free magnetosphere

- There is an invariant on propagation along field lines

$$\frac{B_\phi^2}{B_p} = const$$

- Toroidal field in the wave (thus, electric field) can exceed background field in collisions

- For every fluctuation amplitude -- there is a critical radius of "sticking" and radiation.

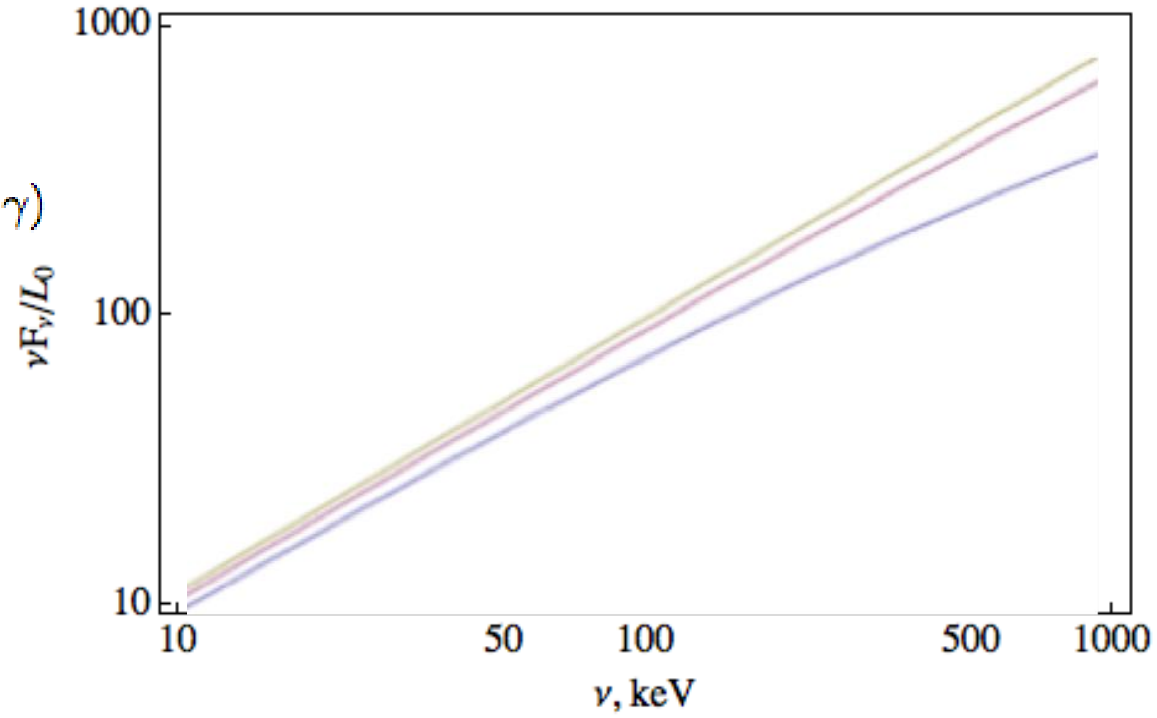


Force-free simulation with shaking of the field lines on the surface

What emission spectrum to expect?

Amplitude = 10^{-3}, 10^{-4}, 10^{-5}

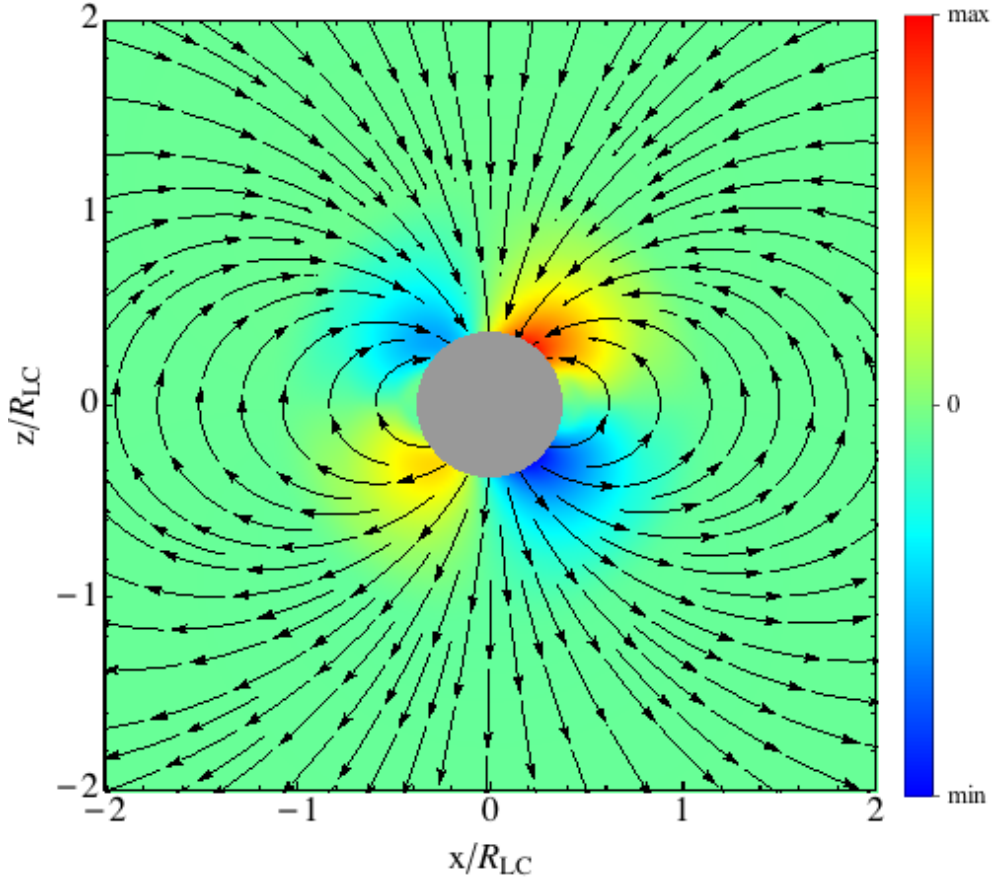
- Synchrotron radiation
- Assuming $N(E) = E^{-\delta}\theta(\sigma - \gamma)$ with index 1 and local magnetization, integrated over number of sticking waves at given radius



When integrated over the magnetosphere, this results in generally rising spectrum.

Application to pulsars (see my poster)

- Can now study pulsar magnetosphere from first principles!
- With sufficient plasma supply our PIC solution is close to force-free
- Produces a self-consistent current sheet



A. Philippov & A. Spitkovsky, in prep

Conclusions

Collisions of large amplitude Alfven waves can result in transient E>B regions.

This results in reconnection and “sticking” of the waves.

These sticking regions can be sites of efficient particle acceleration to flat power spectra.

When integrated over magnetosphere, this results in generally rising spectrum in νF_ν.