



Origin of pulsar radio emission

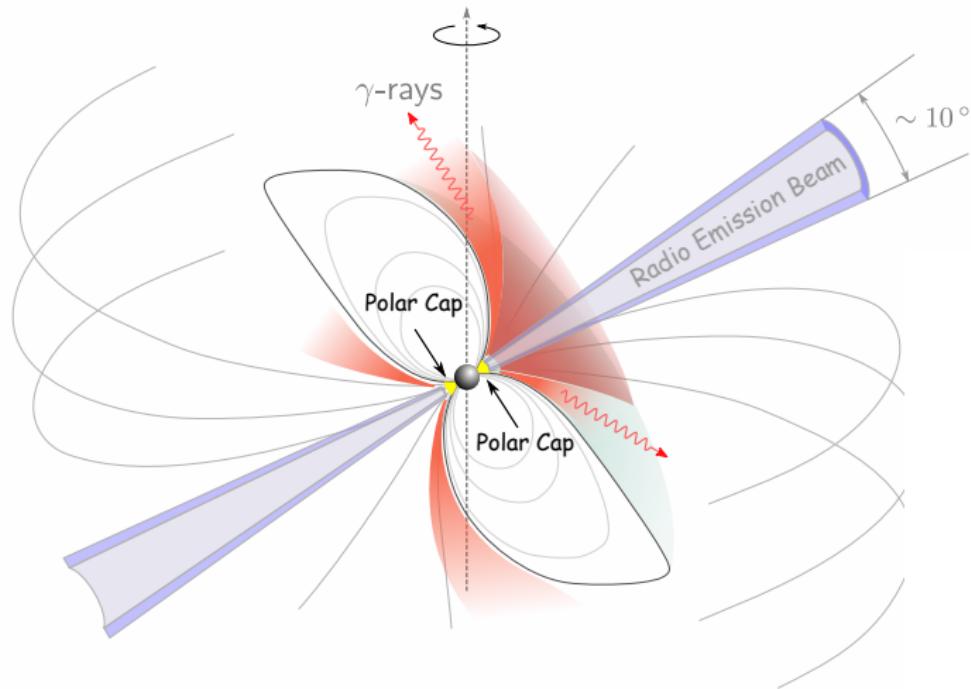
Andrey Timokhin
with A. Philippov (UMD) and E.Tolman (IAS)

University of Zielona Góra, Poland

Tenth International Fermi Symposium

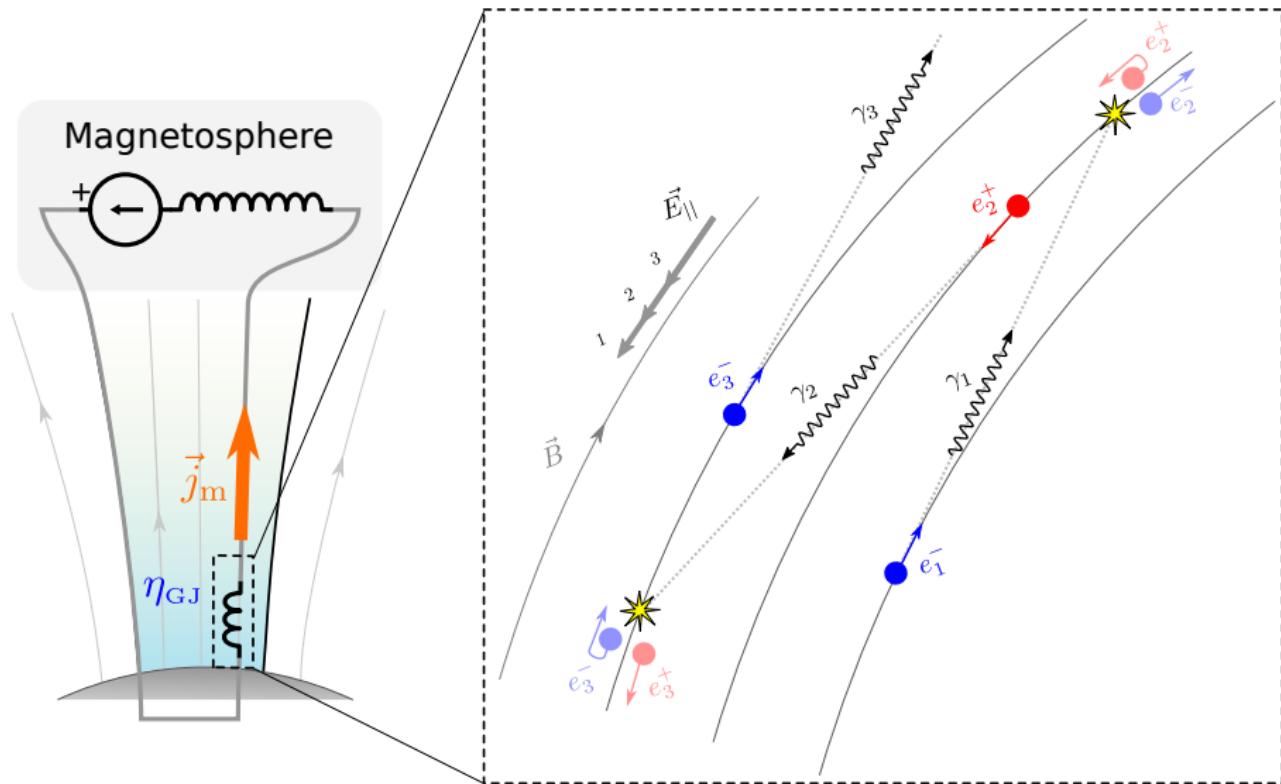
Pulsar: rapidly rotating magnet surrounded by plasma

“Electric lighthouse”

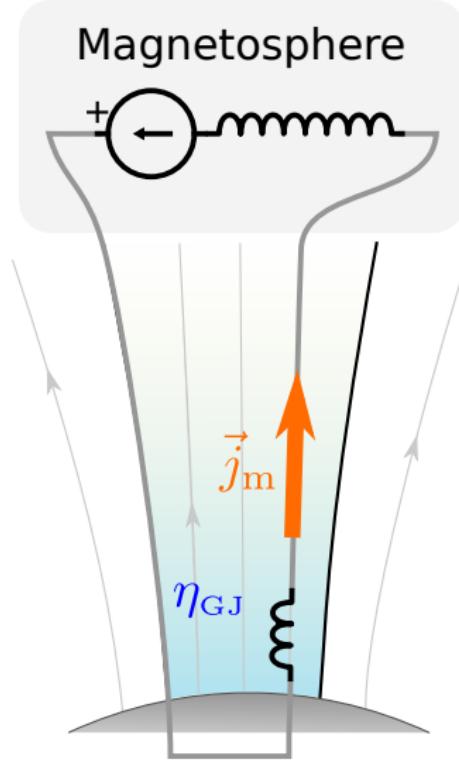


Plasma creation in the polar cap

Particle acceleration is regulated by pair production



Polar Cap Electrodynamics



- Rotation of the NS

$$\nabla \cdot \mathbf{E} = 4\pi(\eta - \eta_{GJ})$$

- Twist of magnetic field lines

$$\nabla \times \mathbf{B} = \frac{4\pi}{c} j + \frac{1}{c} \frac{\partial \mathbf{E}}{\partial t}$$

- $\mathbf{E} = 0$ if both

$$\eta = \eta_{GJ}$$

$$j = \vec{j}_m \equiv \frac{c \nabla \times \mathbf{B}}{4\pi}$$

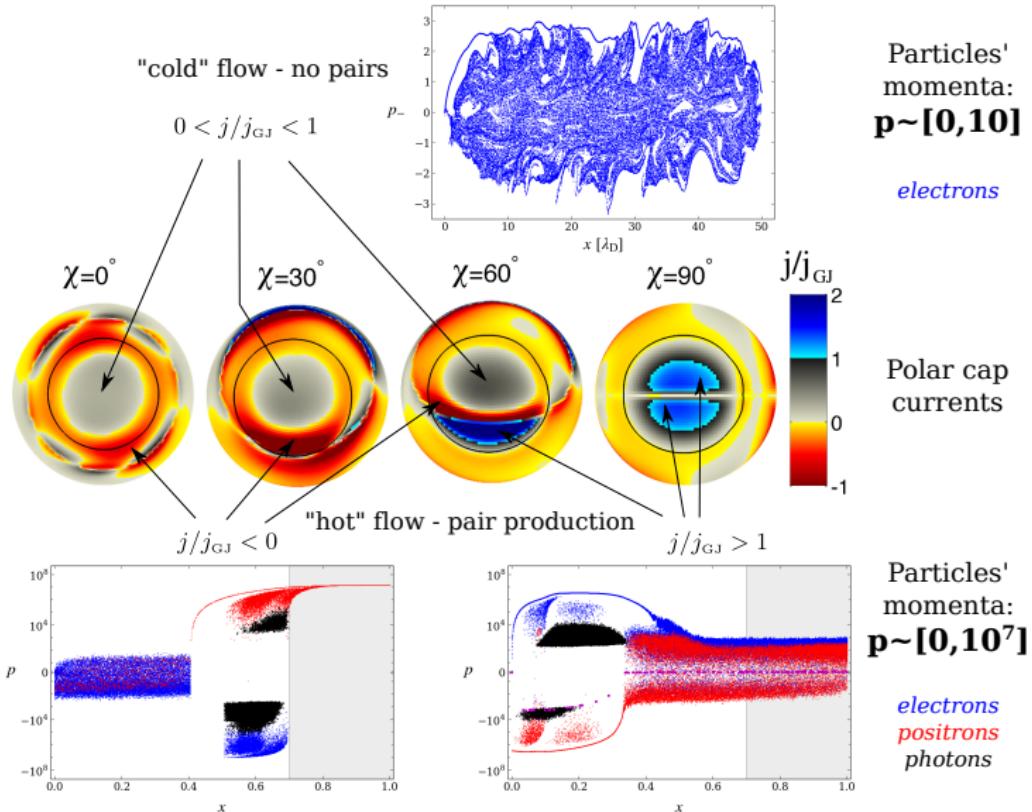
Pair creation is highly non-stationary

Limit cycle: series of discharges

Pair creation is non-uniform across the polar cap

Free particle extraction from the NS surface

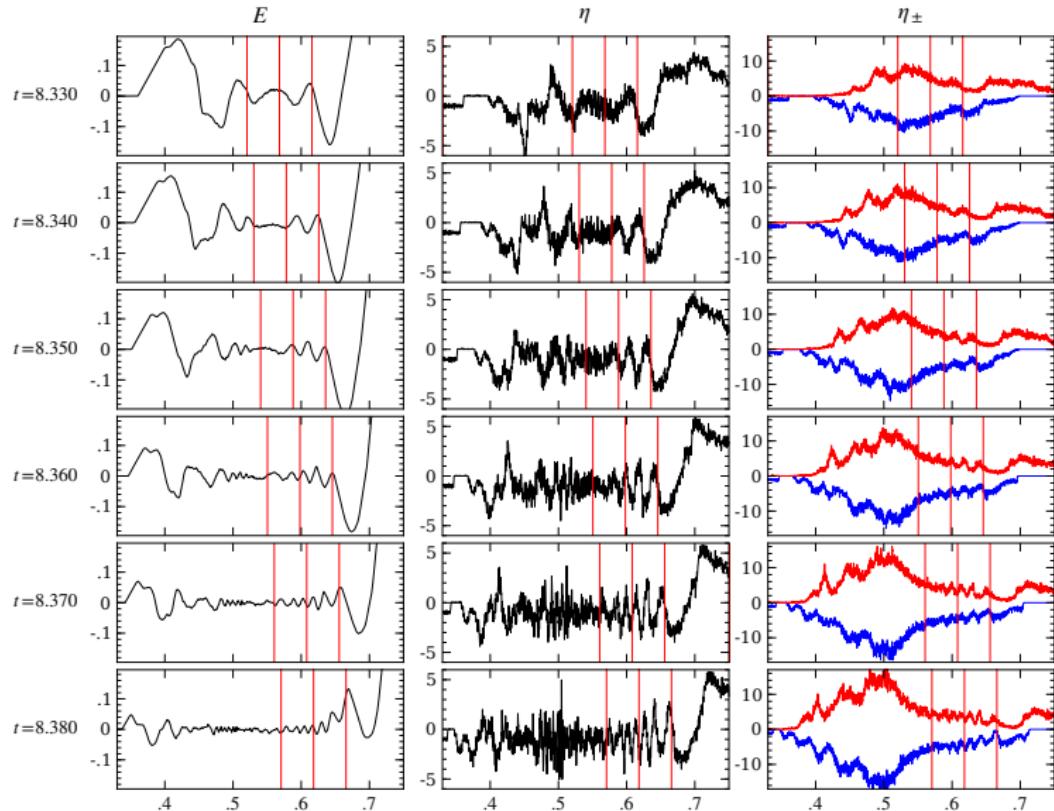
[AT & Arons'13]



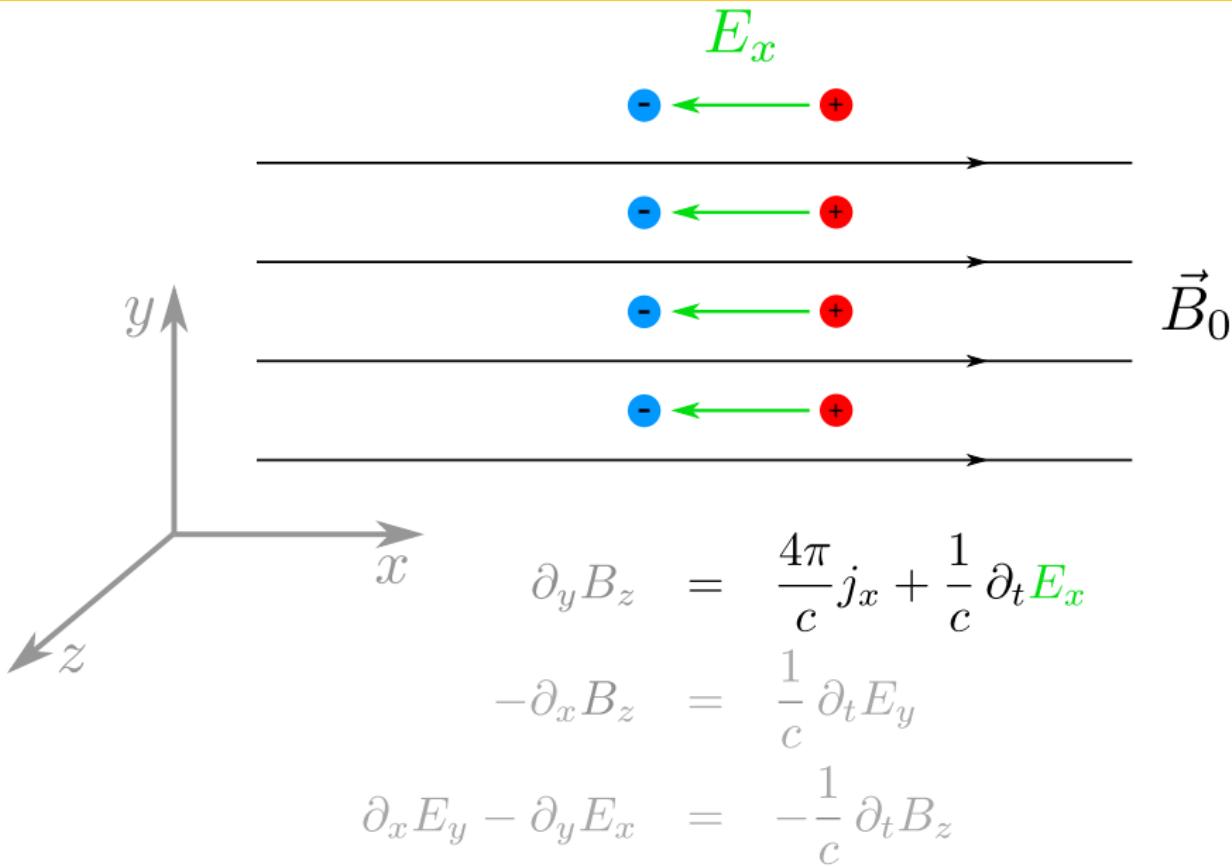
Waves during discharge: Coherent plasma motion (!)

In 1D only electrostatic Langmuir waves exist

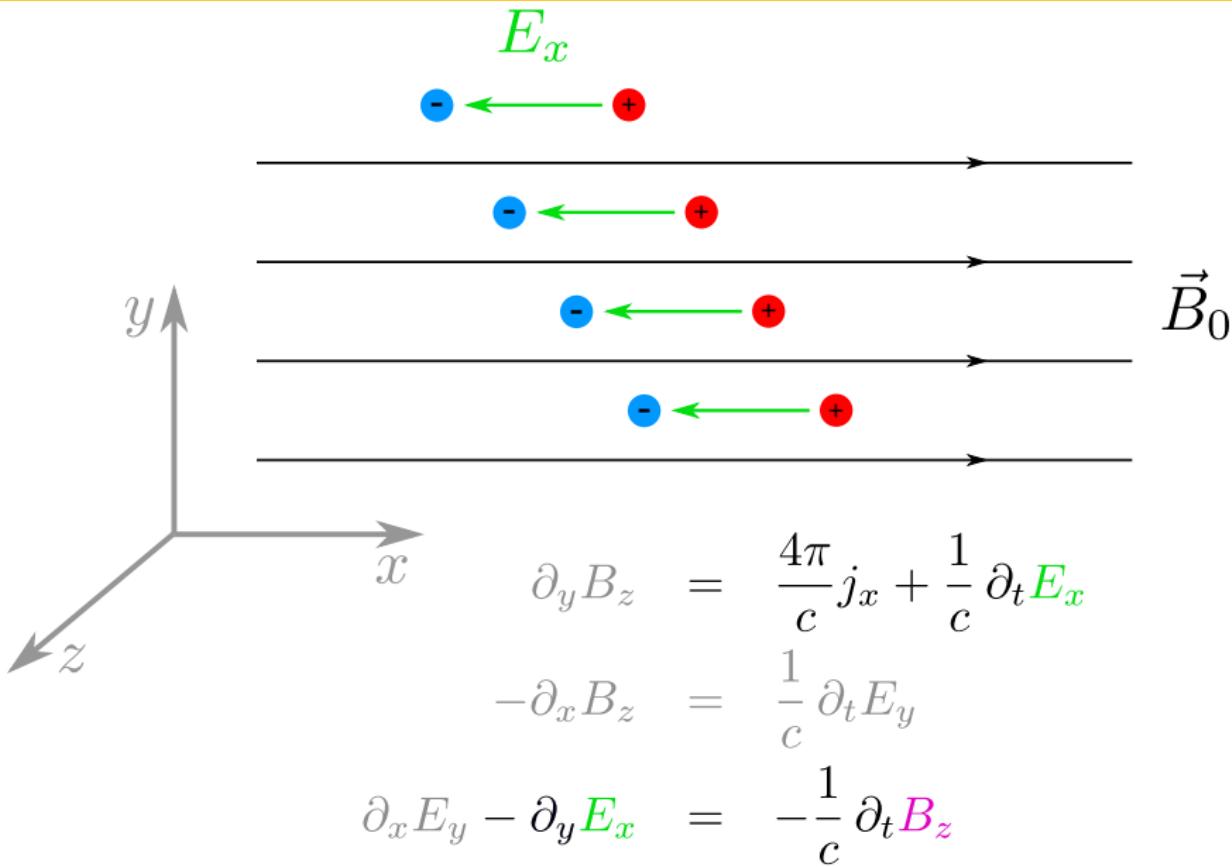
[AT & Arons '13]



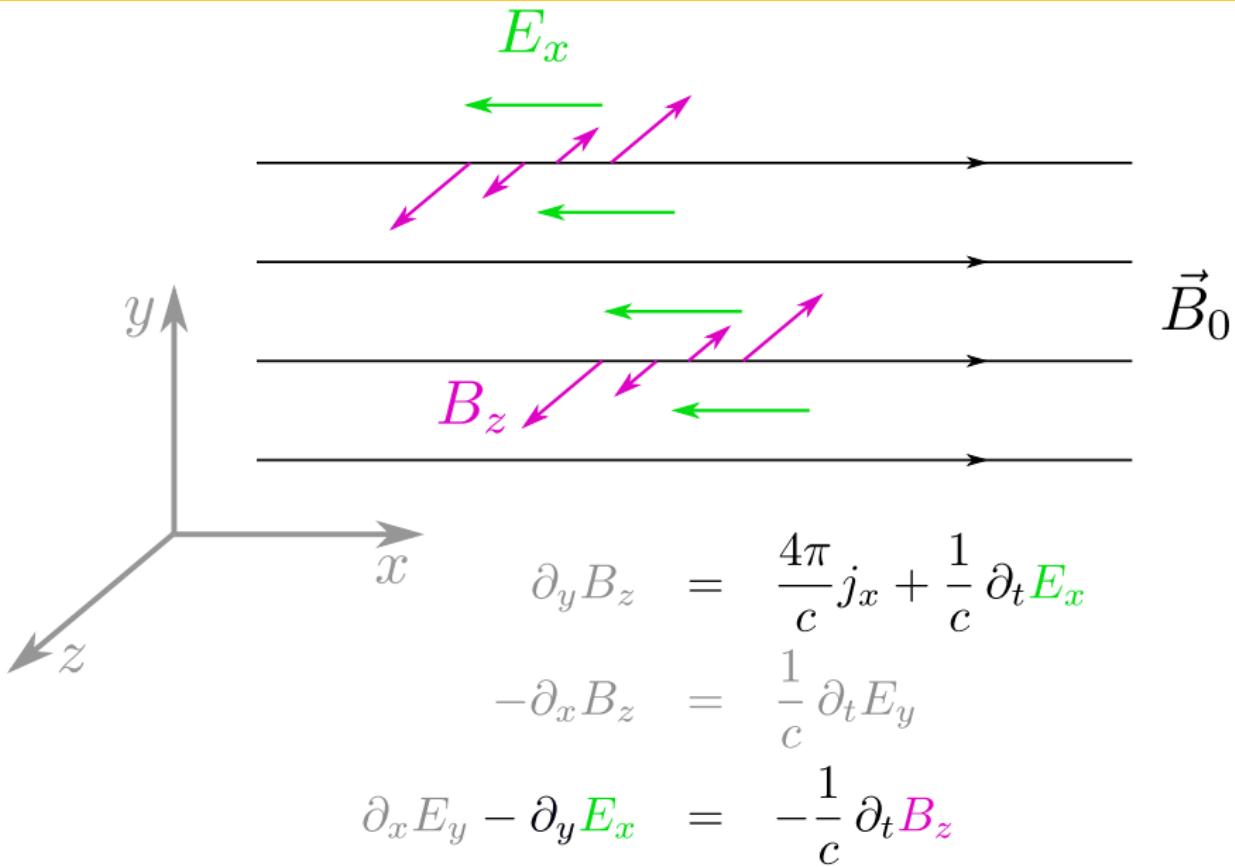
Pair formation uniform across $B_0 \rightarrow$ no EM mode



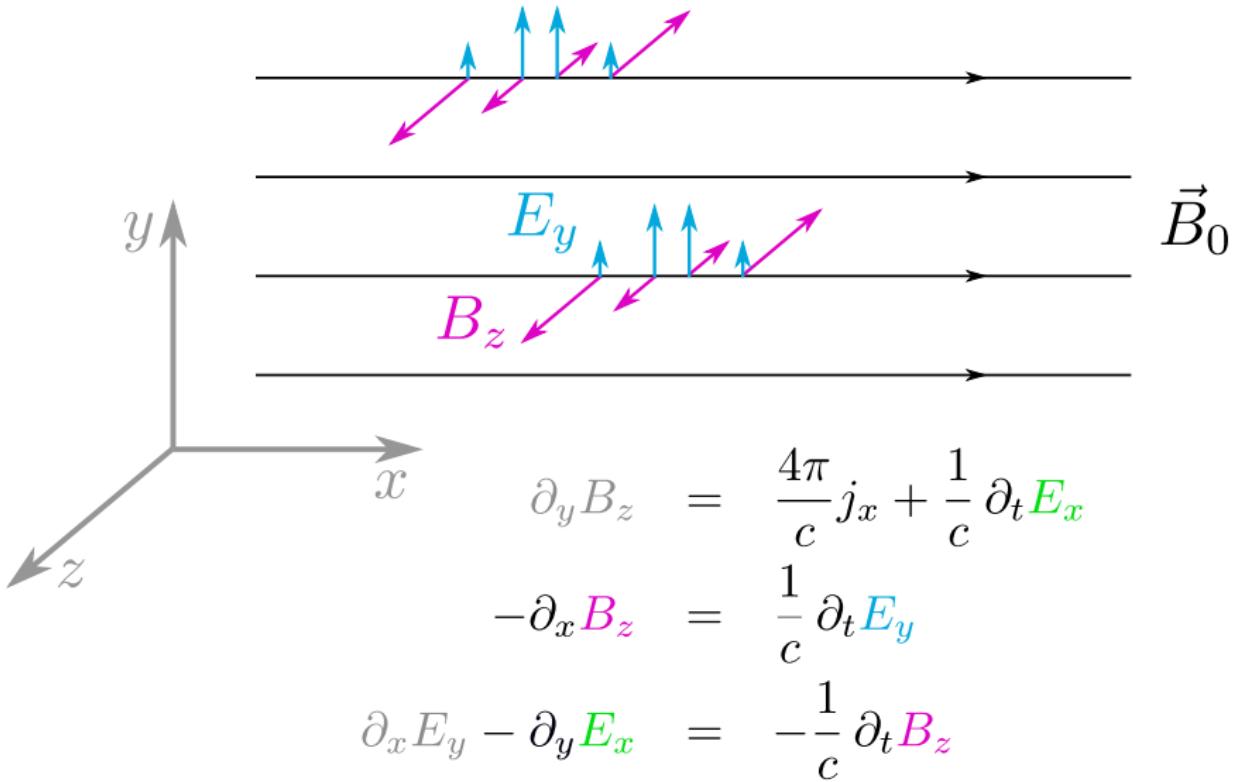
Inclined pair formation front: non-zero $\nabla \times \mathbf{E}$



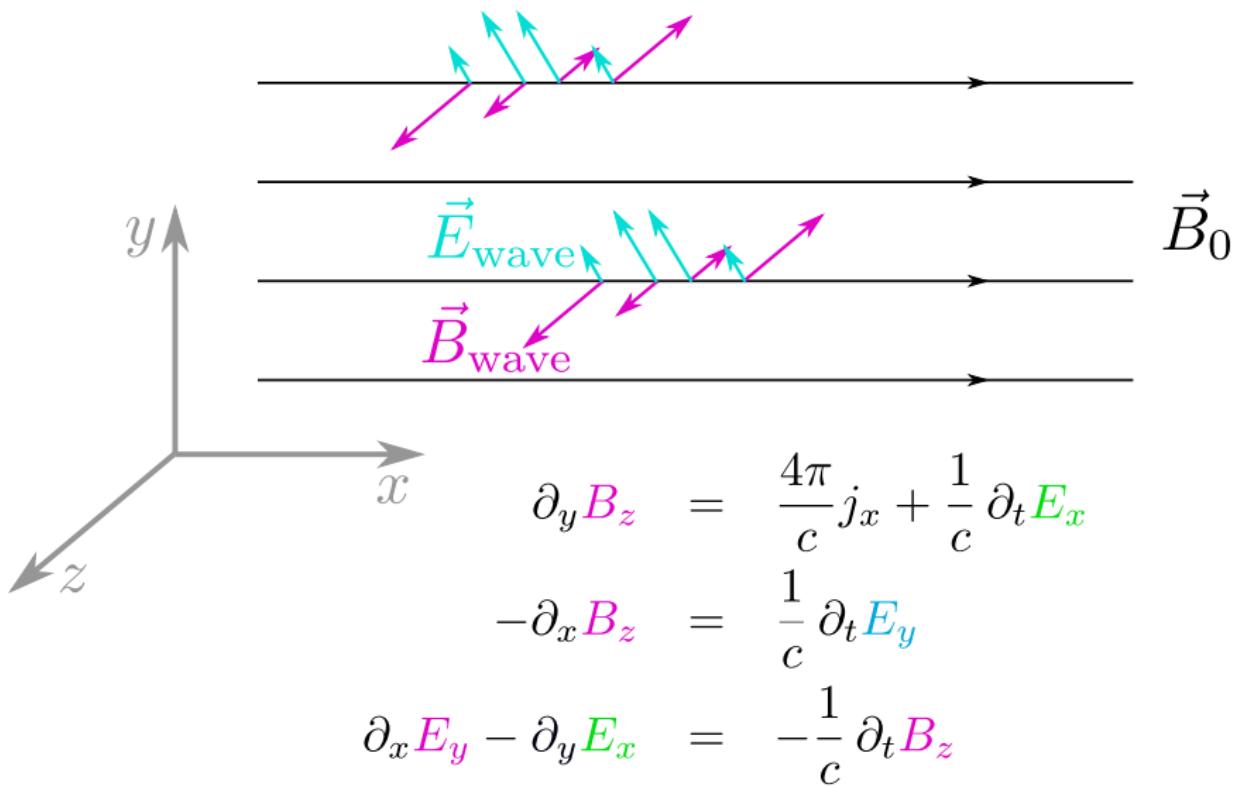
Inclined pair formation front: $\nabla \times \mathbf{E} \rightarrow B_z$



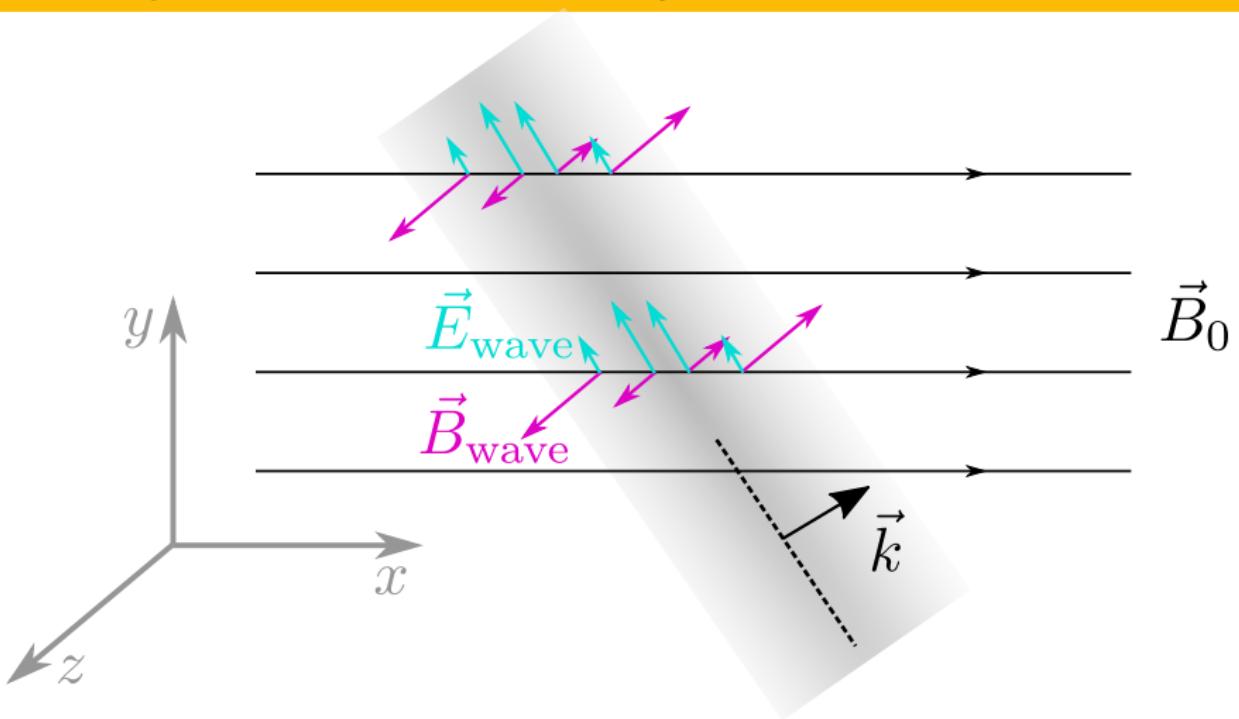
Non-uniform B_z in x direction: $\nabla \times \mathbf{B} \longrightarrow E_y$



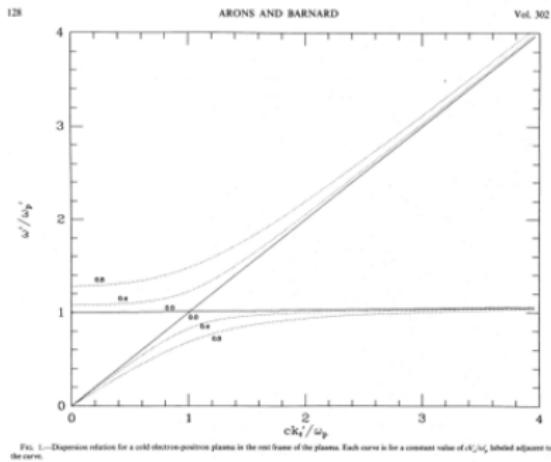
Electromagnetic mode: $\vec{B}_{\text{wave}} \perp \vec{E}_{\text{wave}}$



Ordinary mode: \mathbf{E} lies in the plane ($\mathbf{k} \cdot \mathbf{B}_0$)



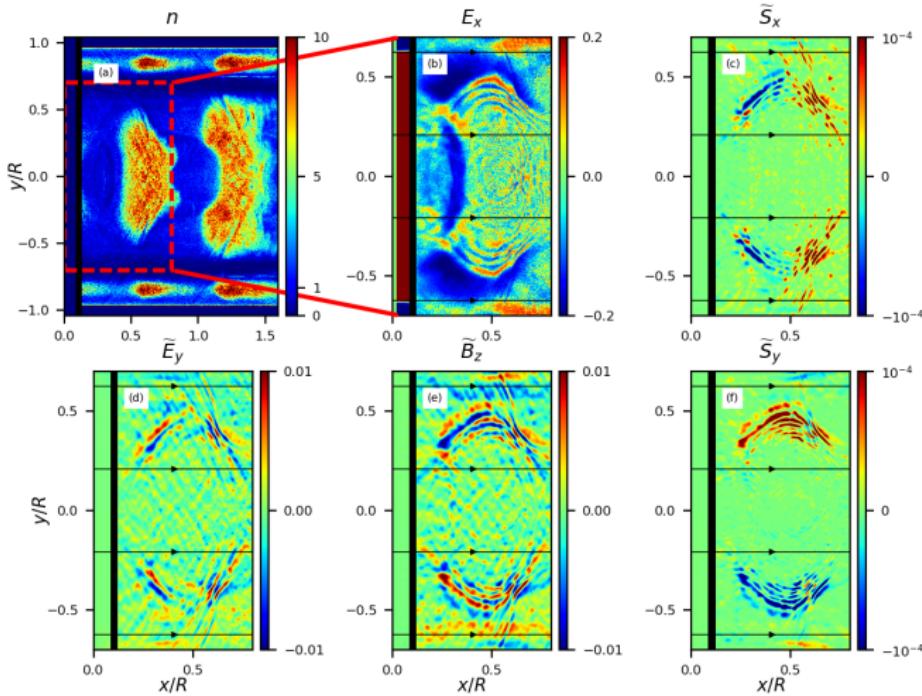
This mechanism generates the right kind of waves!



- Oblique discharge directly excites a superluminal O-mode with non-zero k_{\perp} , which has EM component.
- As plasma density drops, these waves should become vacuum EM.

Toy 2D PIC model of polar cap discharges

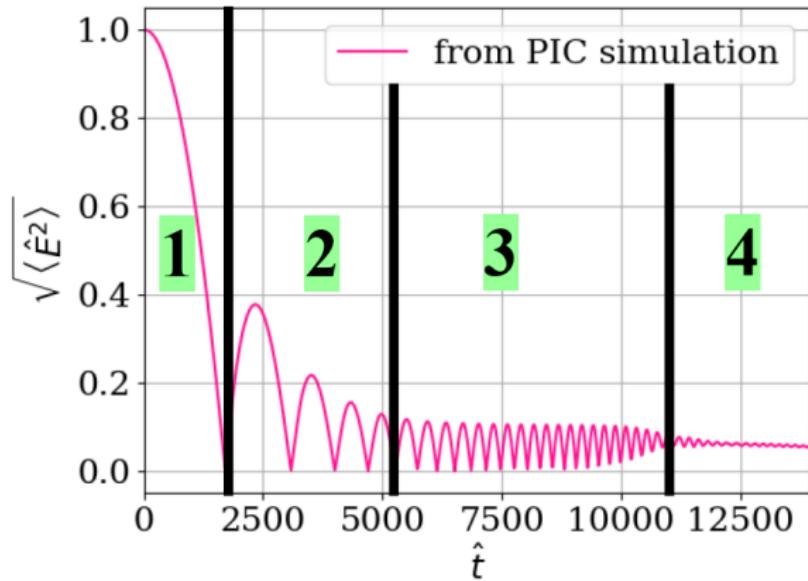
Pair formation threshold varies across parallel magnetic field lines



[Philippov, AT, Spitkovsky '20]

Damping of electrostatic wave becomes linear

Phases of electrostatic wave damping



- ① initial screening
- ② non-linear waves exponential damping
- ③ non-linear waves “frozen phase”
- ④ linear damping

[Tolman, Philippov, AT '22]

Conclusions

- Pulsars live when they produce e^\pm pairs in polar caps.
- Pair formation is non-stationary and non-uniform.
- Radio emission can be produced **directly** by the discharges
- The mechanism does not require any special conditions
(besides those already existing in polar caps)
- It generates the right kind of waves
- The waves seem to survive.