
Ab initio pulsar magnetosphere:
PIC epoch
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Thanks to John Arons and Vasily Beskin

The key question: magnetospheric shape

- How to model? Depends on plasma supply:
  - Vacuum model (A. Deutsch, 1955)
  - MHD (or force-free)
  - Kinetic models

What can not be done with MHD?

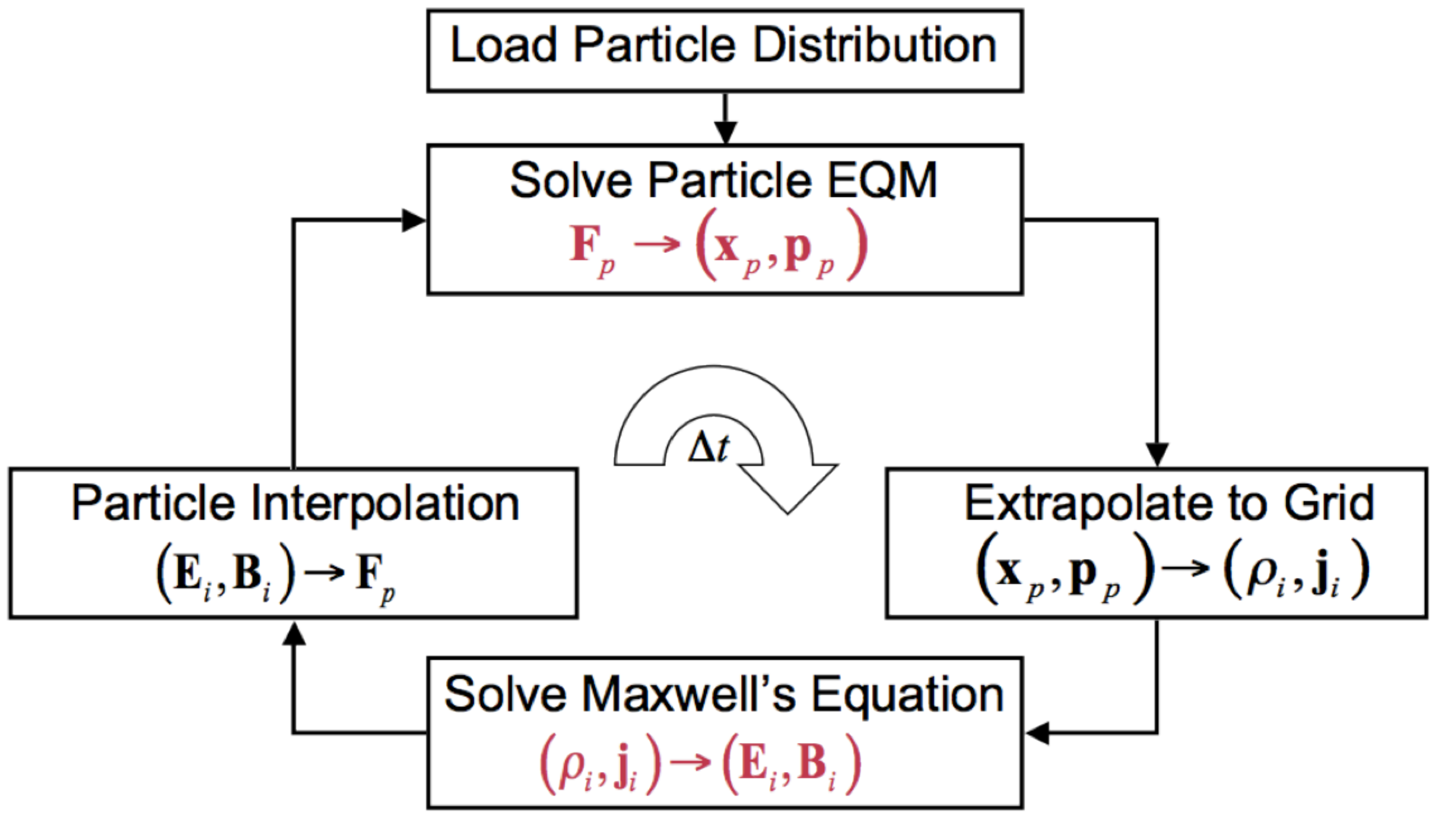
- E>B can not happen, difficult to accelerate particles (gamma emission). Not enough physics for reconnection study.
- How the necessary current is provided (e-/e+ motion)? Are there any plasma instabilities? (radio emission)

ρ_c	$\mathbf{j}$	ρ_m	T	Non-thermal particles	Plasma instabilities
✓	✓	✓	✓	✗	✗

PIC method

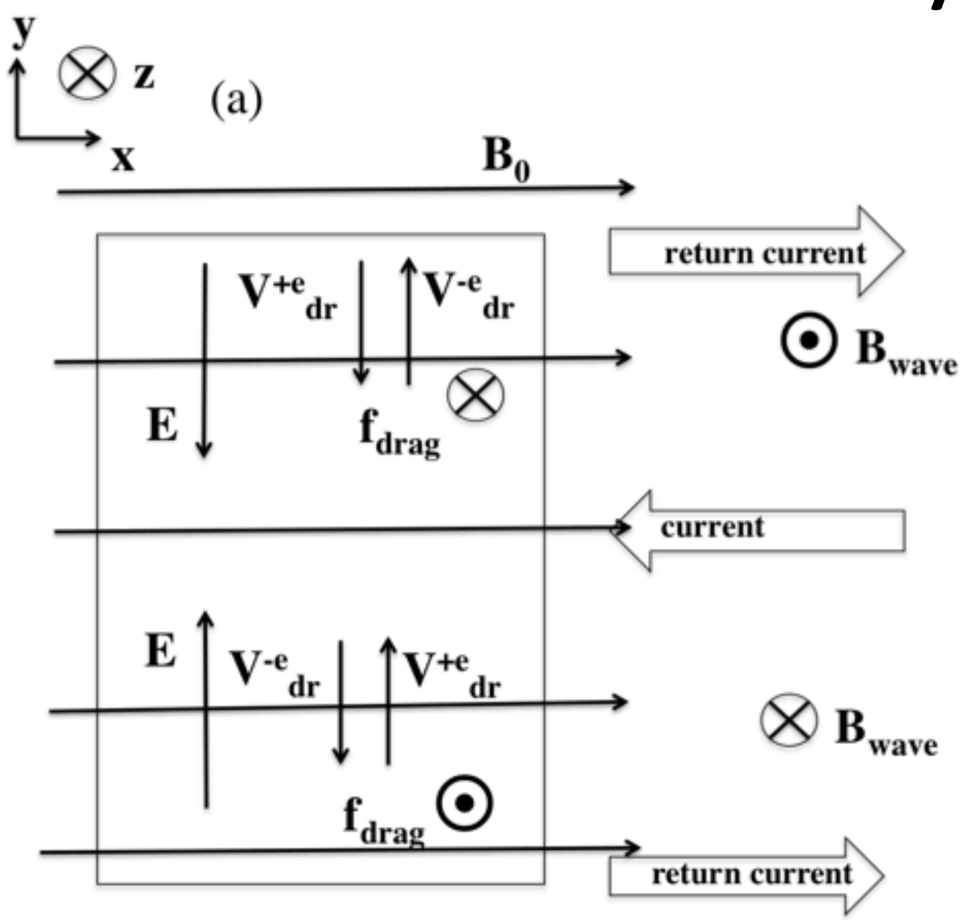
$$\partial E/\partial t = c(\nabla \times B) - 4\pi J\,, \qquad \nabla \cdot E = 4\pi\varrho\,, \quad \nabla \cdot B = 0$$

$$\partial B/\partial t = -c(\nabla \times E)\,, \qquad \frac{d}{dt}\gamma m\mathbf{v} = q(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B})$$



Relativistic version TRISTAN, Spitkovsky (2003): when charge is conserved, do not need to solve Poisson

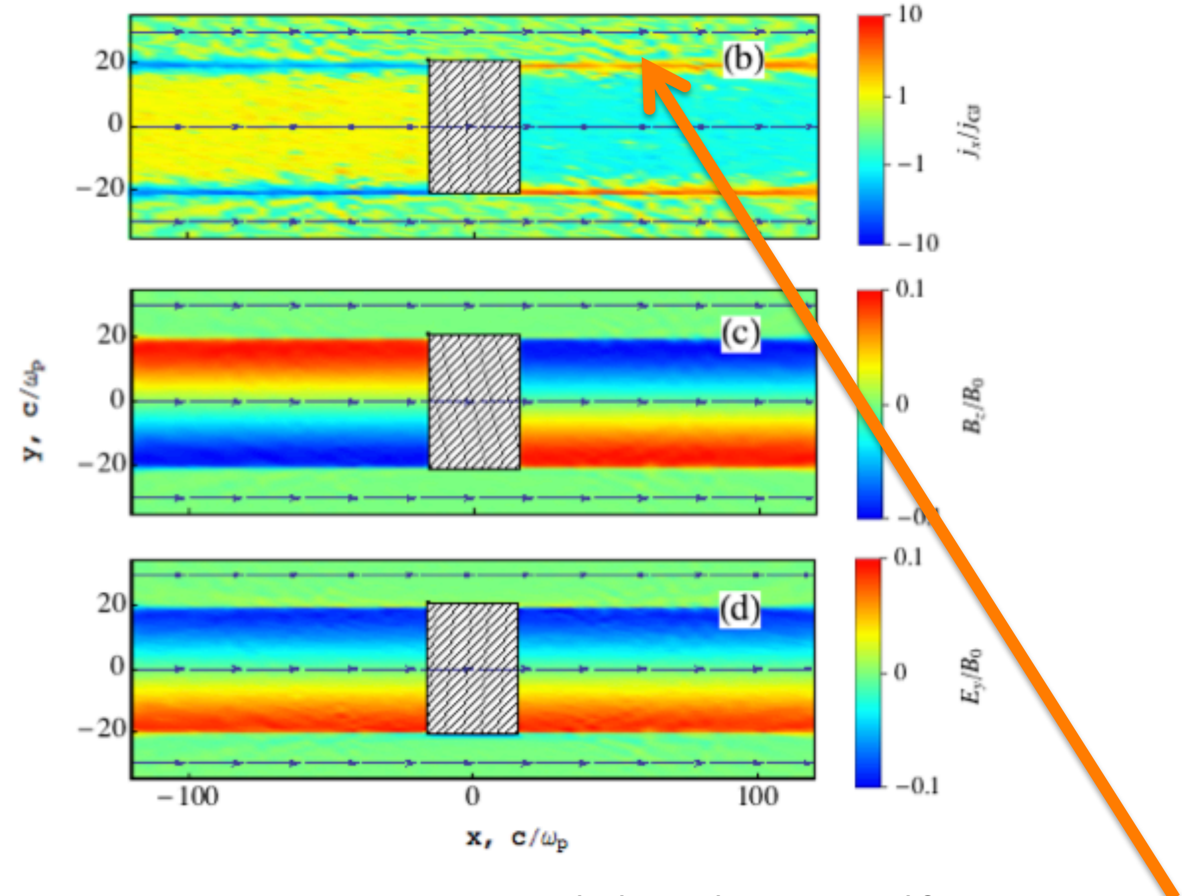
New boundary condition



- We model conductor as a dense magnetized plasma ball with particles that are pushed into rotation by external drag force
- Does not require control of the injection rate at the surface
- Provides good current closure, supports formation of thin return currents

A. Philippov and A. Spitkovsky, ApJ, 2014, L785

Alfven wave test problem



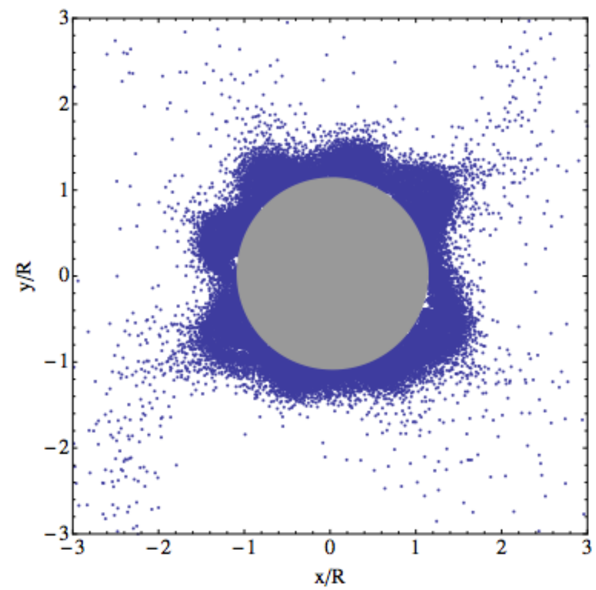
Possible interests: two-stream instability, kinetic alfven waves and particle acceleration in strong return current layer

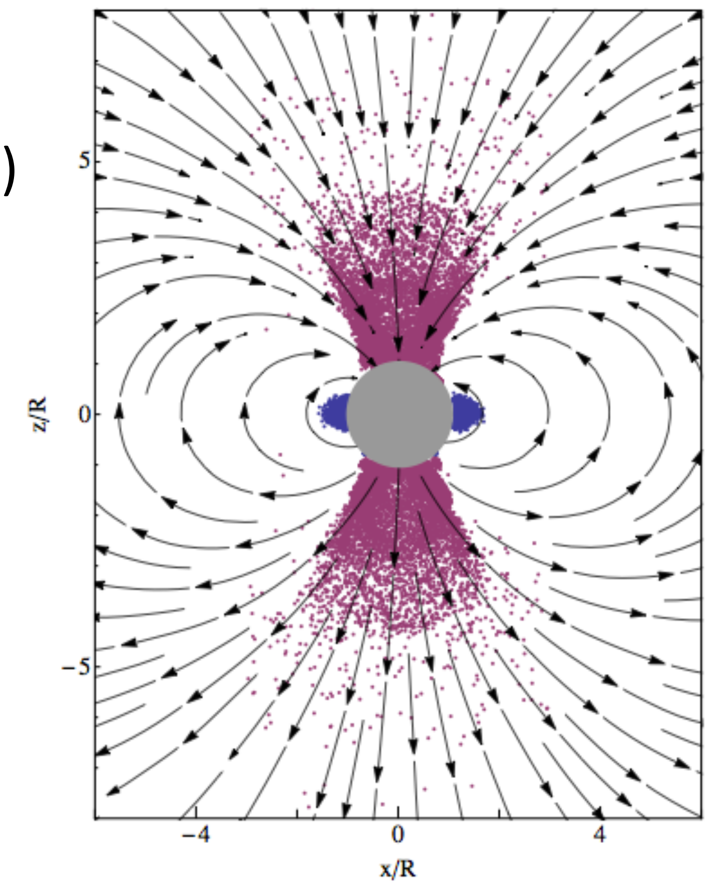
Extremes: plasma supply from the star

- Disk-dome solution (J. Kraus-Polstorff,

F. Michel, 1985) (A. Spitkovsky, J. Arons, 2002)

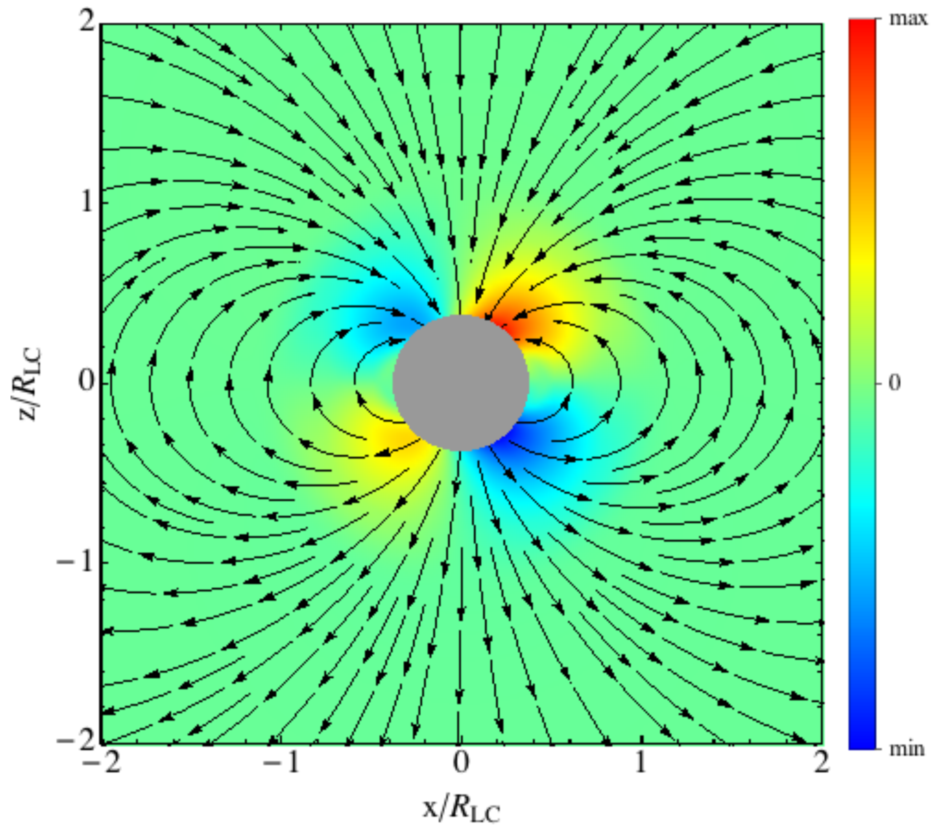
- Disk is unstable to diocotron instability
- No outflow





Extremes: volumetric production of neutral plasma I

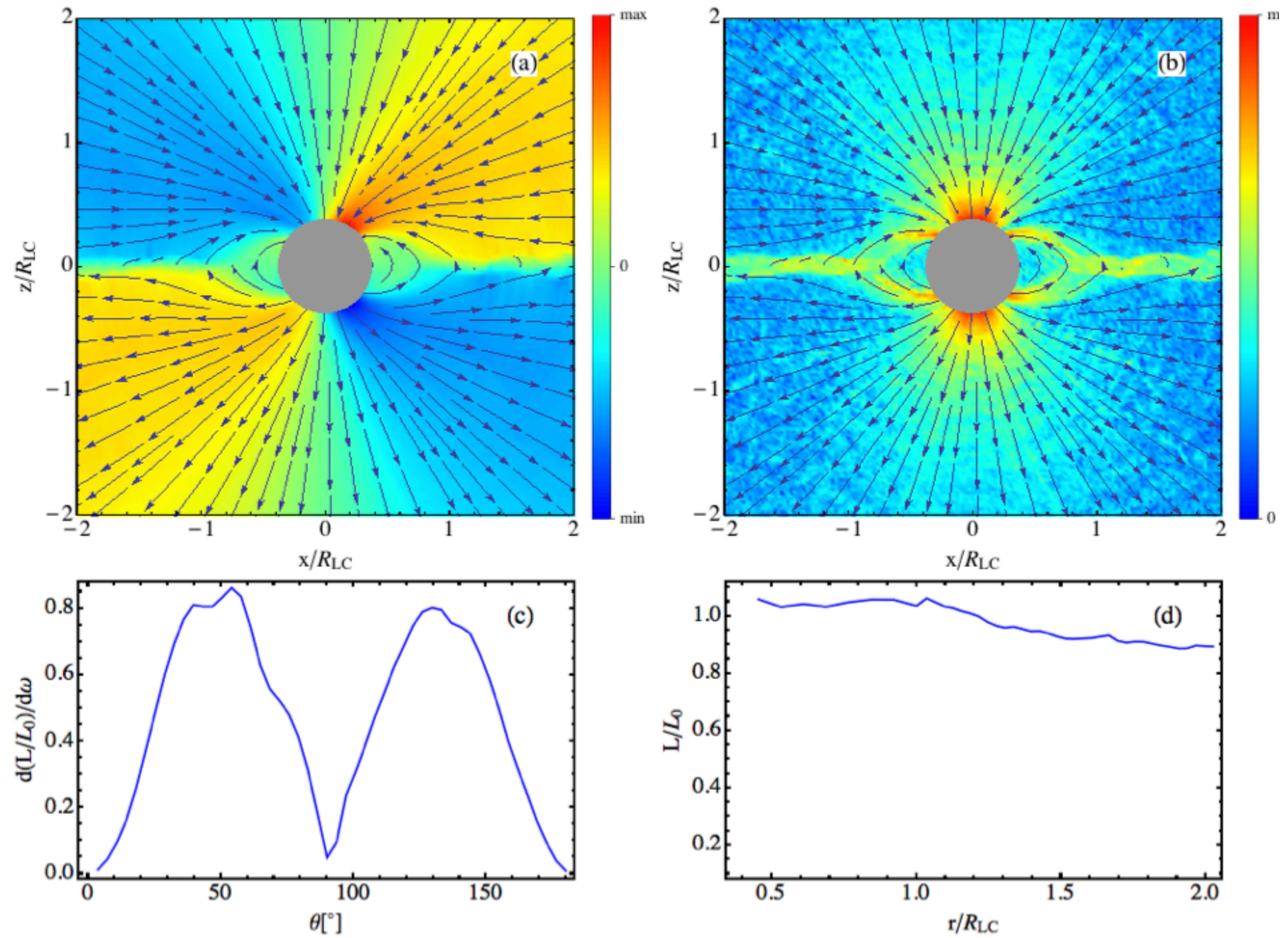
- Approaches force-free
- Self-consistent current sheet
- 10% of Poynting flux is dissipated within $2R_{LC}$



A. Philippov and A. Spitkovsky, ApJ, 2014, L785

Extremes: volumetric production of neutral plasma II

- Approaches force-free
- Self-consistent current sheet
- 10% of Poynting flux is dissipated within $2R_{LC}$



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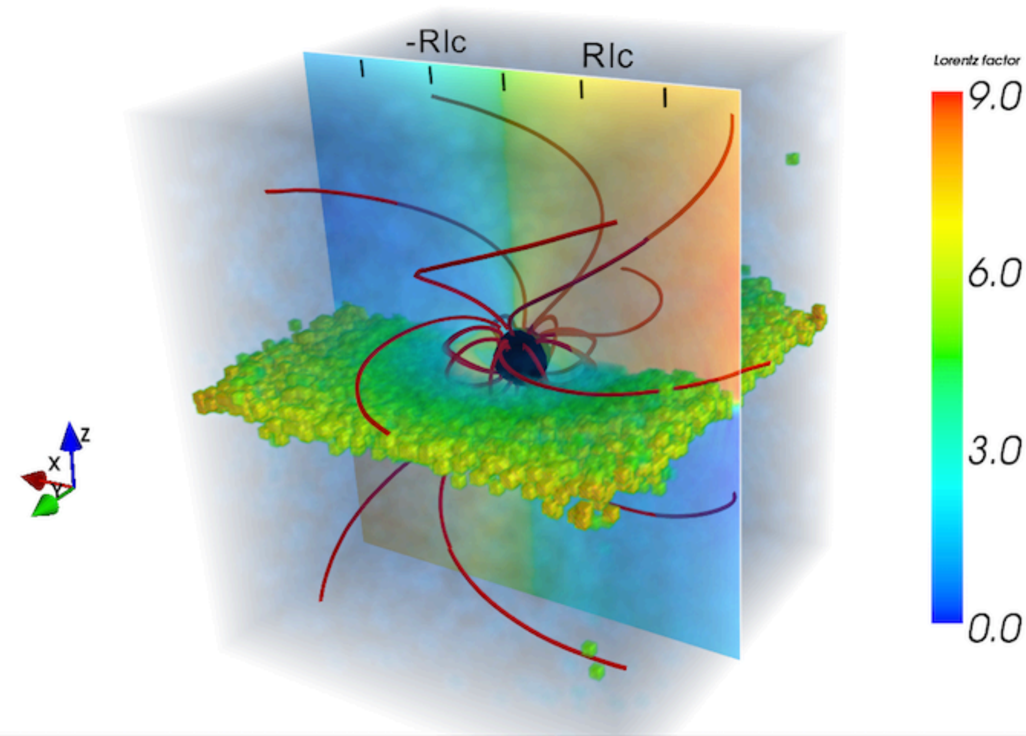
Extremes: volumetric production of neutral plasma III

- Approaches force-free
- Self-consistent current sheet
- 10% of Poynting flux is dissipated within $2R_{LC.}$
- Particles spectrum is drifting Maxwellian.
- Resolution is not sufficient to carefully study tearing mode; observe the drift-kink mode.



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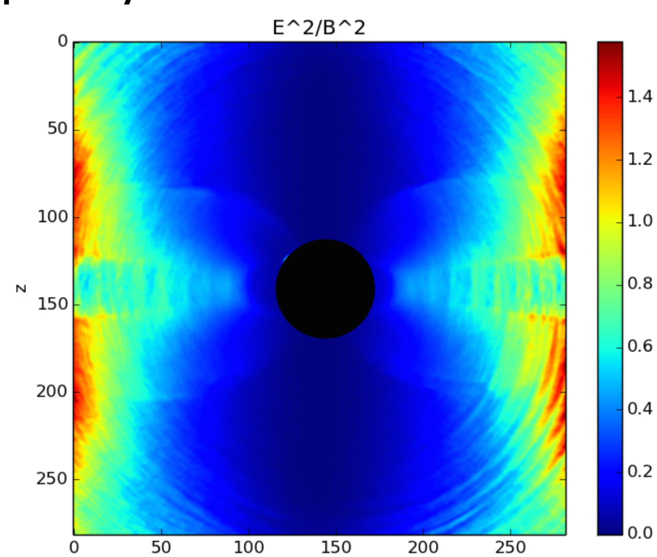
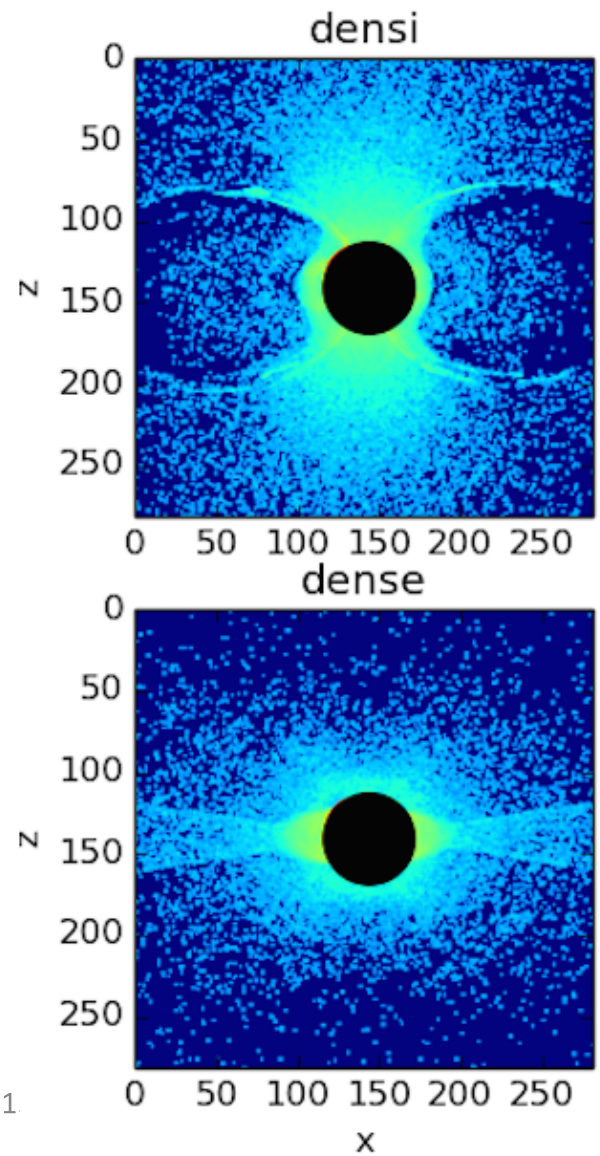
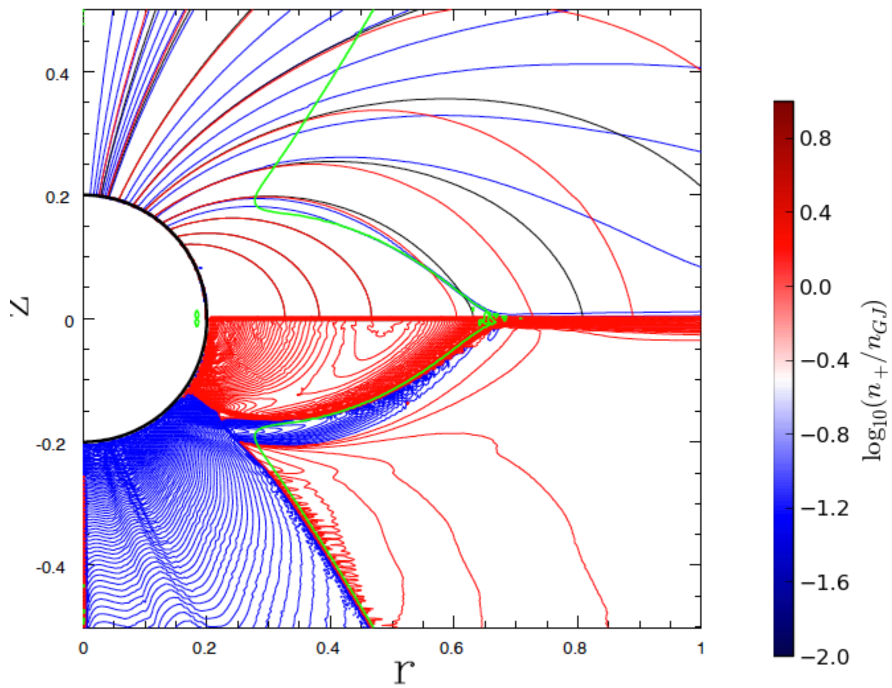
Towards realistic pair production: low production rate close to the star

- Produce pairs close to the star
- Give them relativistic velocity along the field lines
- Vary the rate of pair production
- Case when production rate supports multiplicity < 1



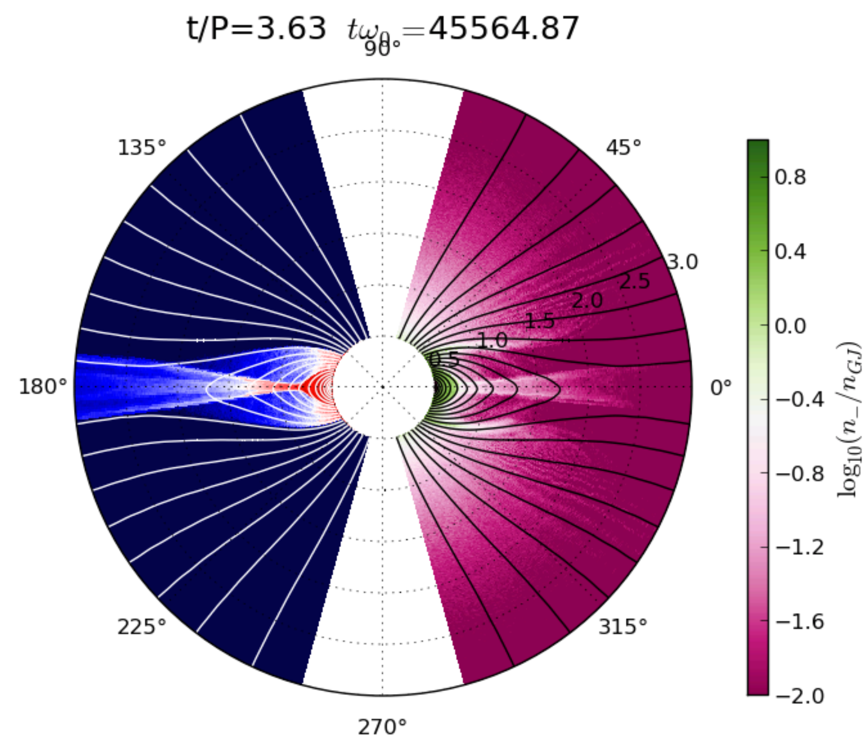


Towards realistic pair production: low production rate close to the star



A. Gruzinov (2013); his talk

Same stuff in Wada & Shibata (2011)



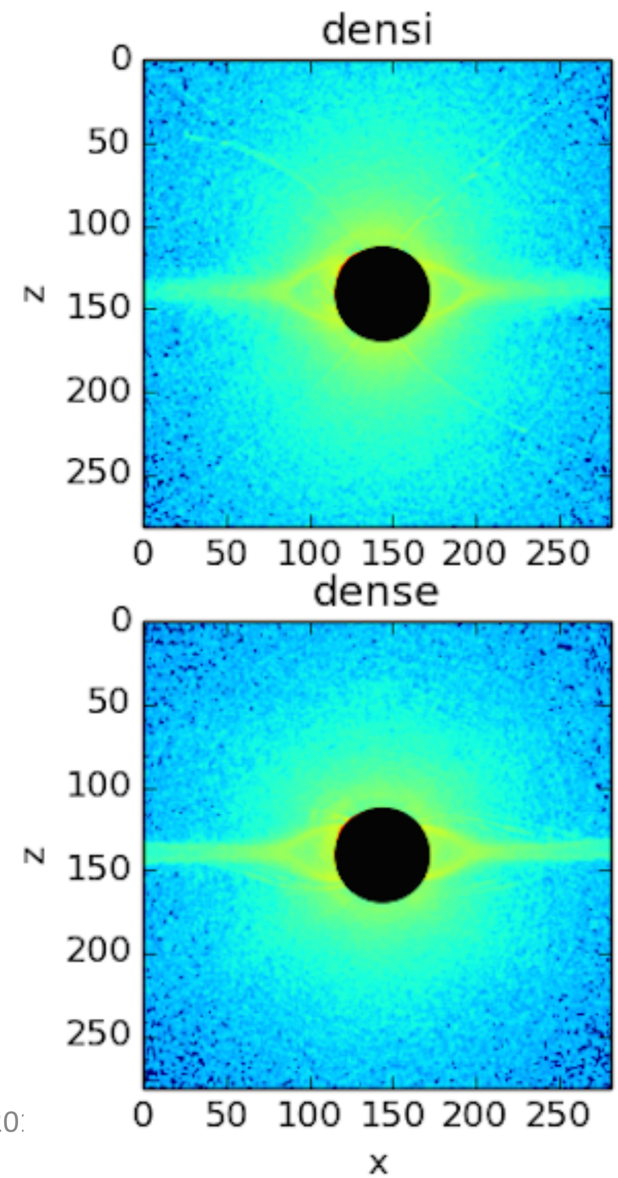
B. Cerutti, with Zeltron (initially monopole field); see his talk on Tuesday

Towards realistic pair production: low production rate close to the star

NOT THE CASE OF YOUNG ACTIVE PULSAR!

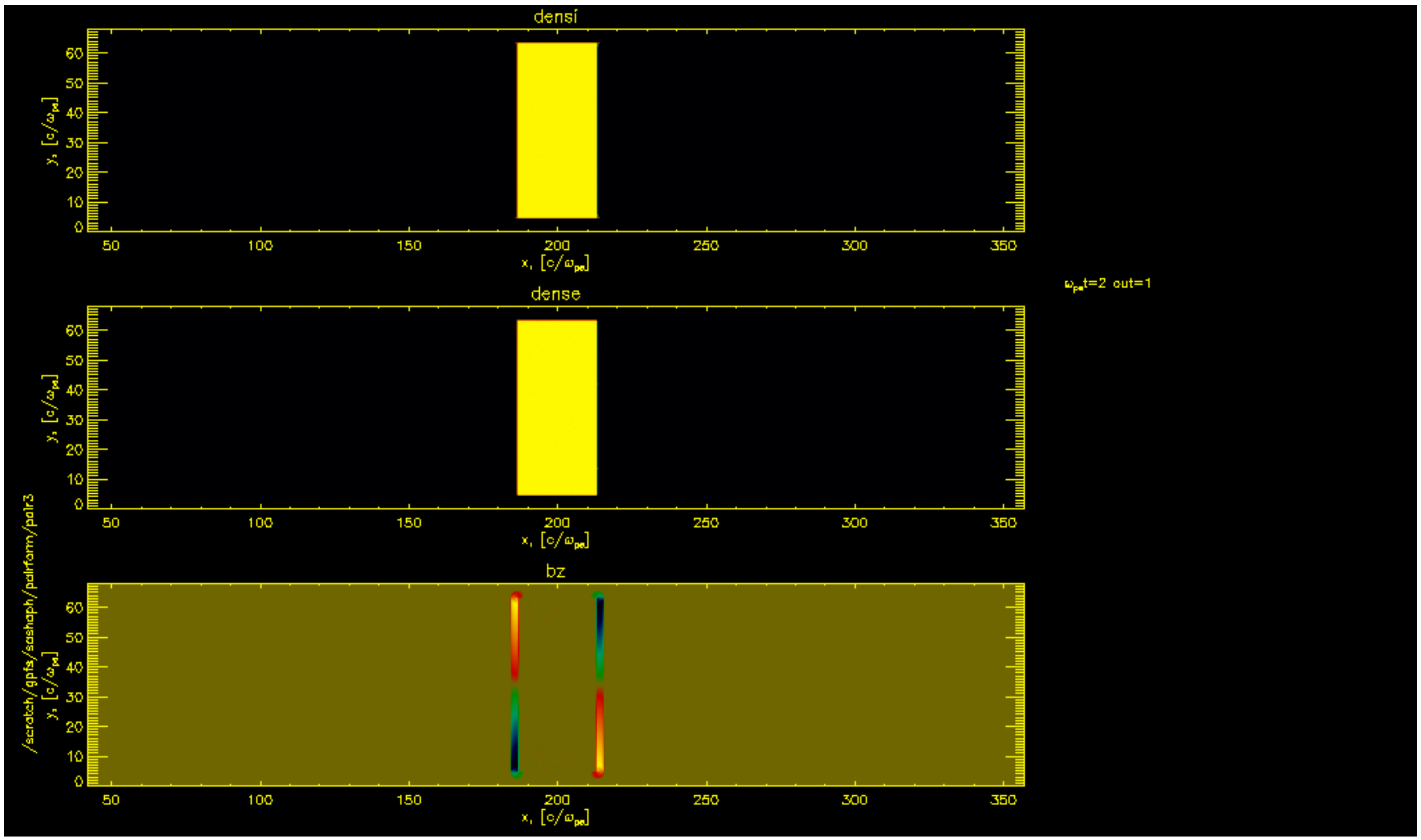
Towards realistic pair production: high production rate close to the star

- Produce pairs close to the star
- Give them relativistic velocity
  along the field lines
- Vary the rate of pair production
- Gets back to force-free like solution
  in regime of multiplicity > 1



Realistic prescription for pair formation

- Produce pairs only if the parent particle energy exceeds the threshold; rates etc. computed in OTS approximation



Conclusions

- 3D fully kinetic models of magnetospheres are available now.
- Can trace the pulsar magnetosphere structure from birth to death.
- We will extend this study to oblique rotators.