Numerical models of pulsar magnetosphere

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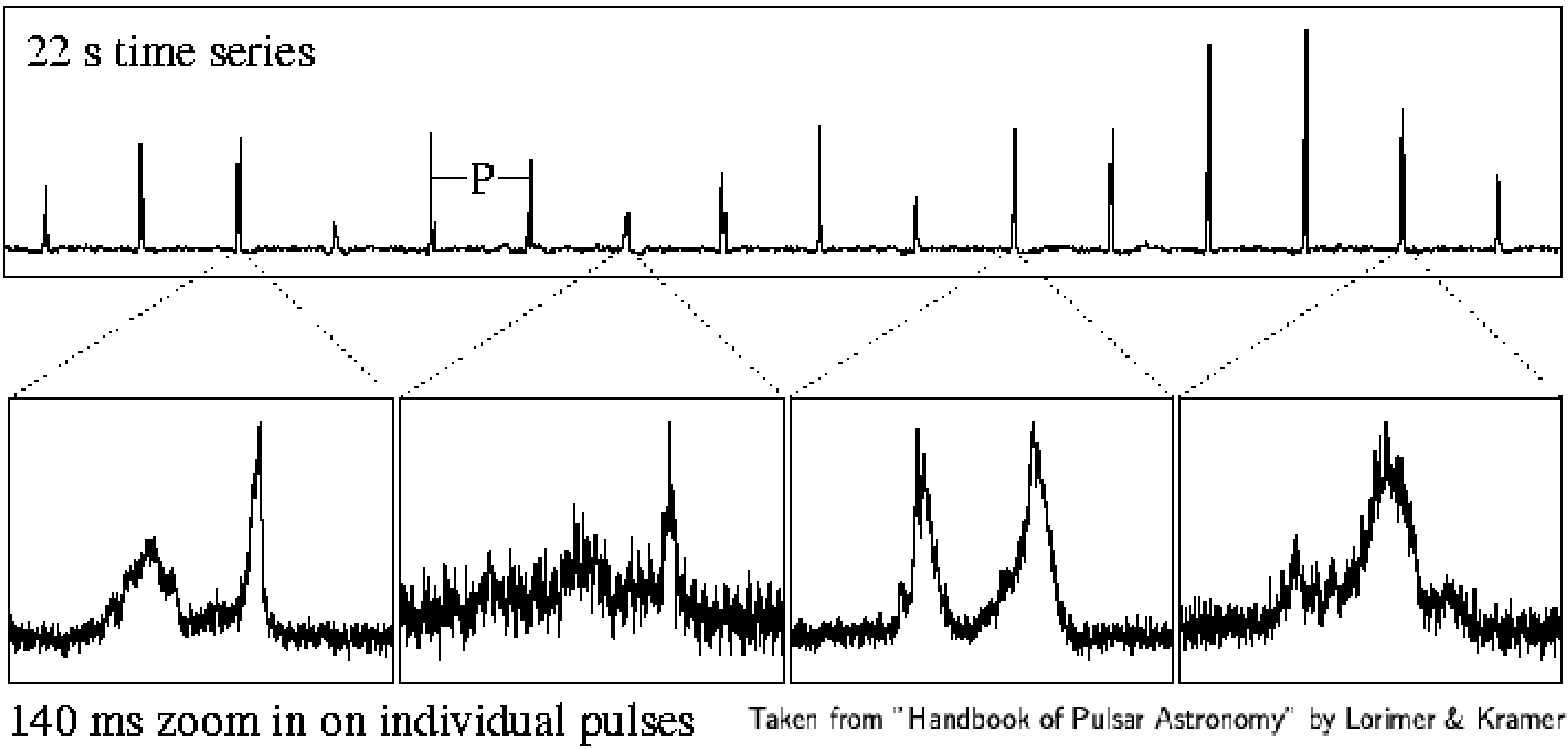
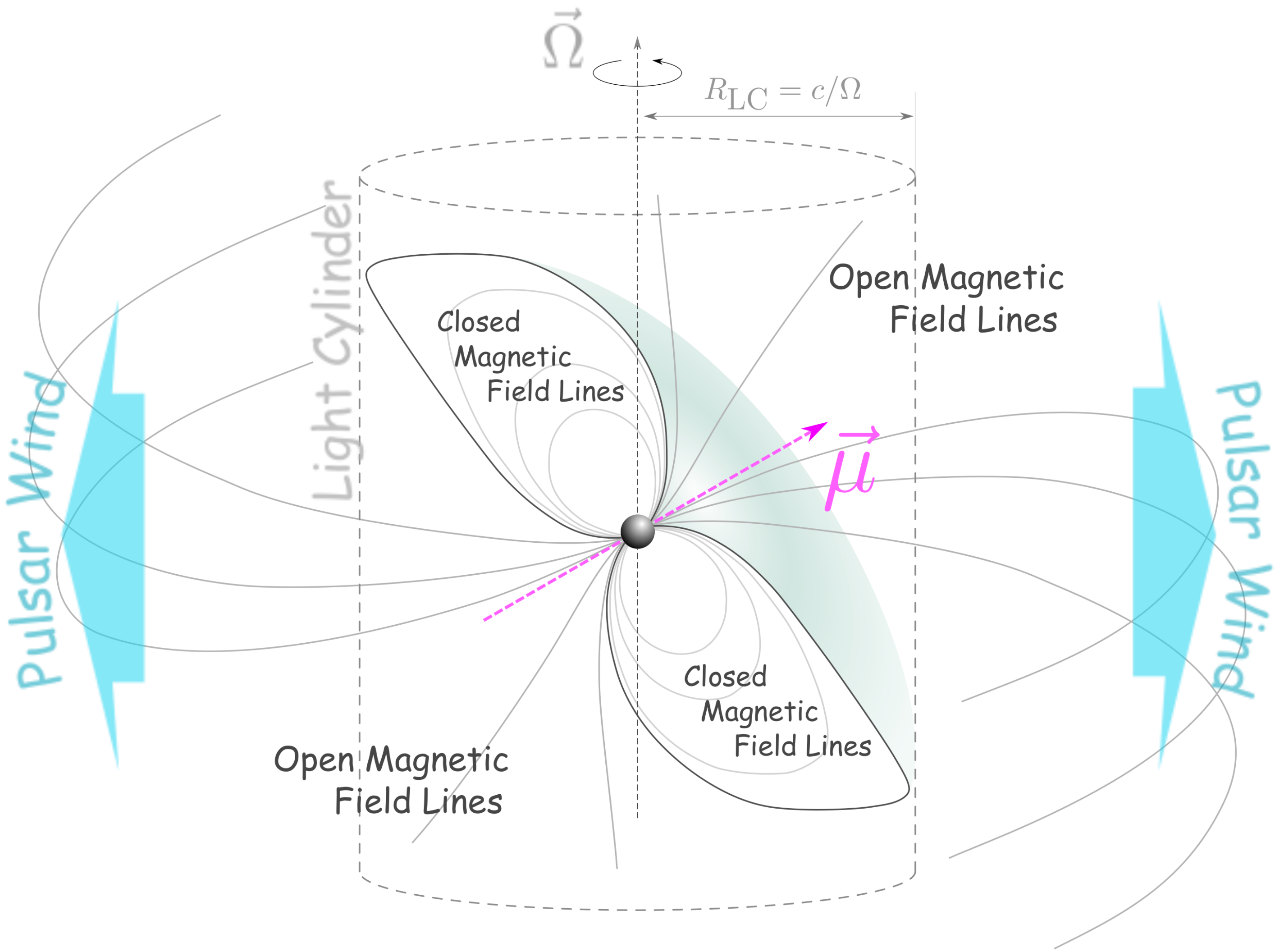
Pulsar as we see it

Pulses are narrow

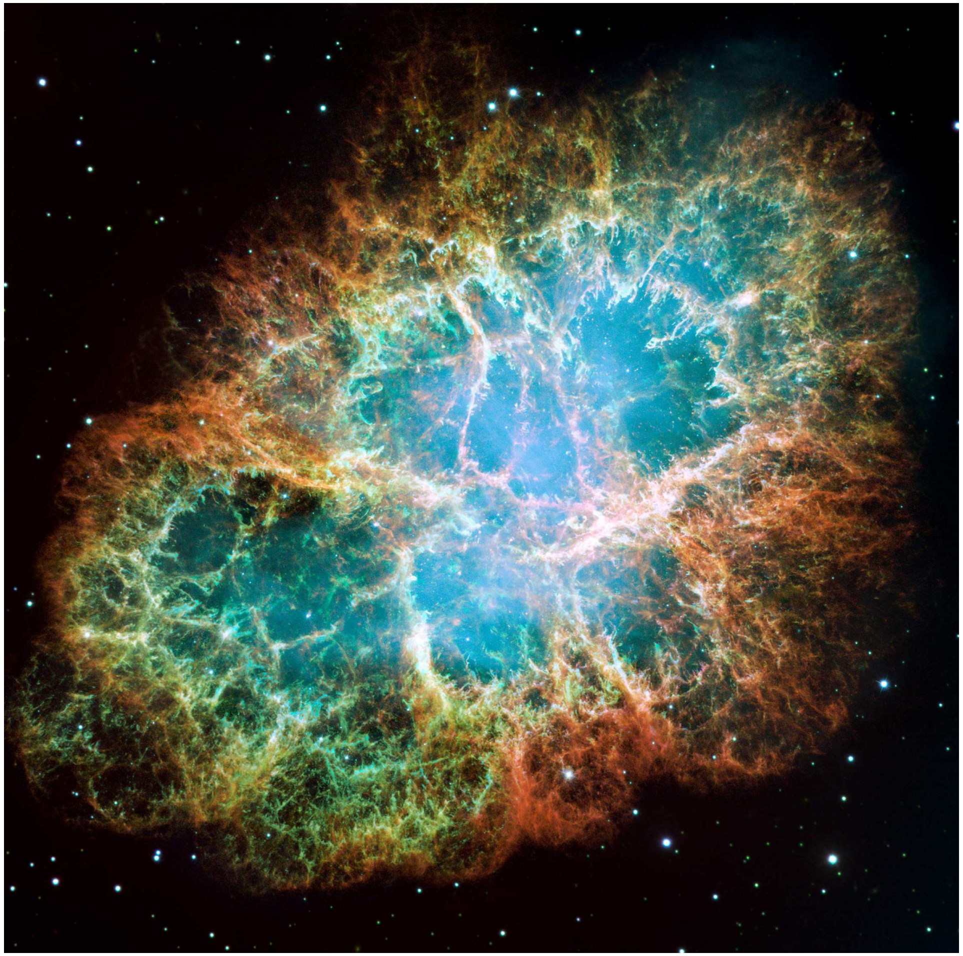


Pulsar as we think what it is

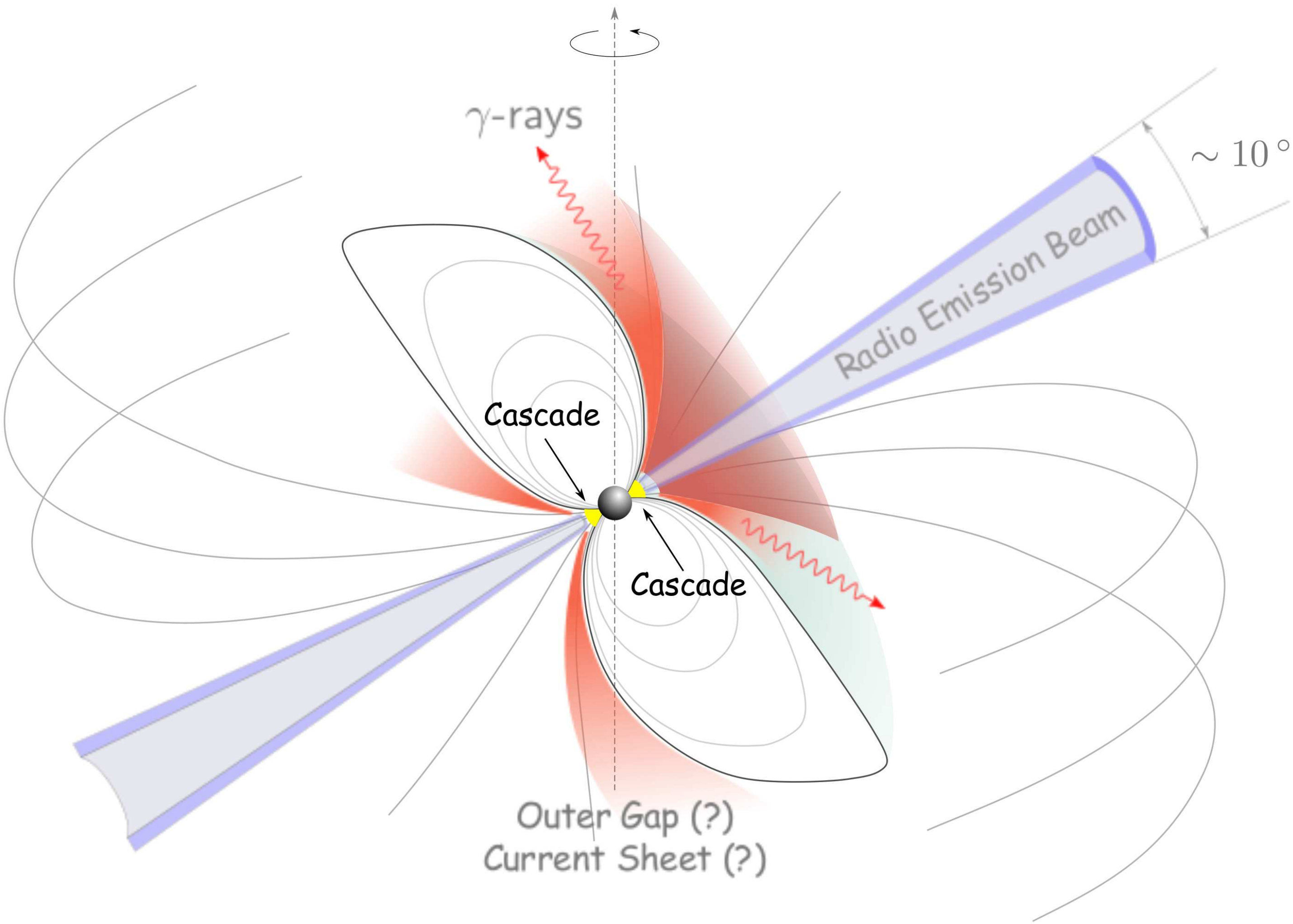


Pulsar Wind Nebulae

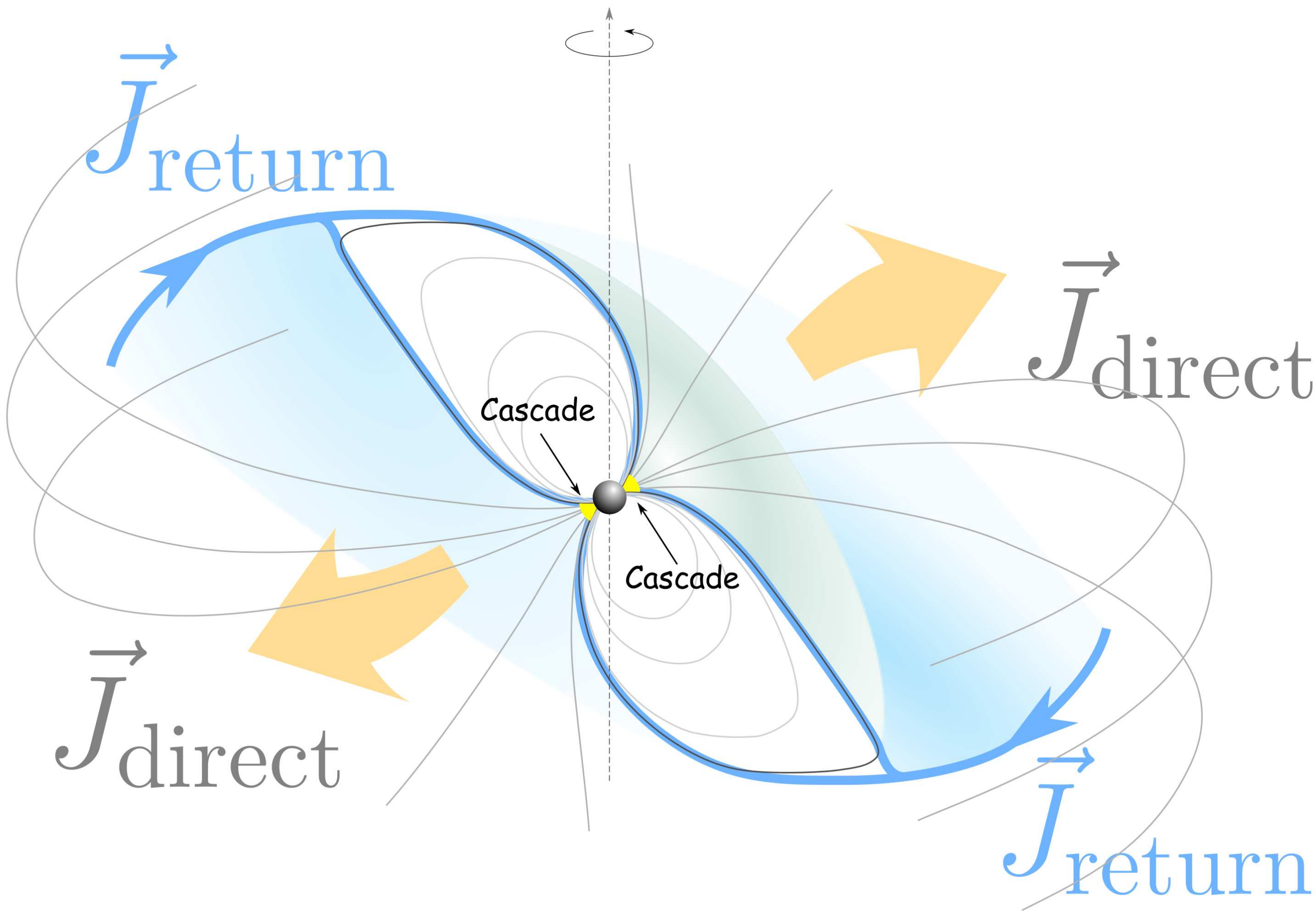
There are many electron-positron pairs and they radiate



Pulsar Magnetosphere: “Observer’s view”

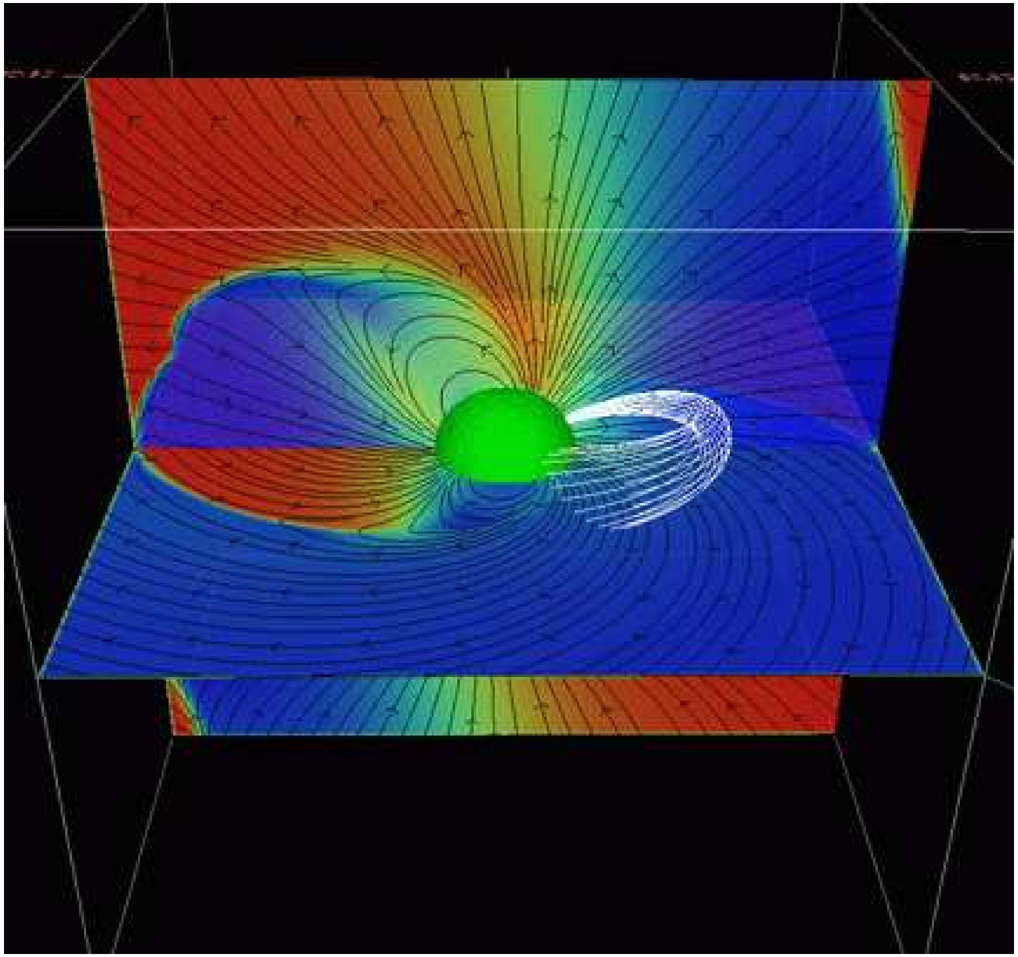


Pulsar Magnetosphere: "Theorist's view"



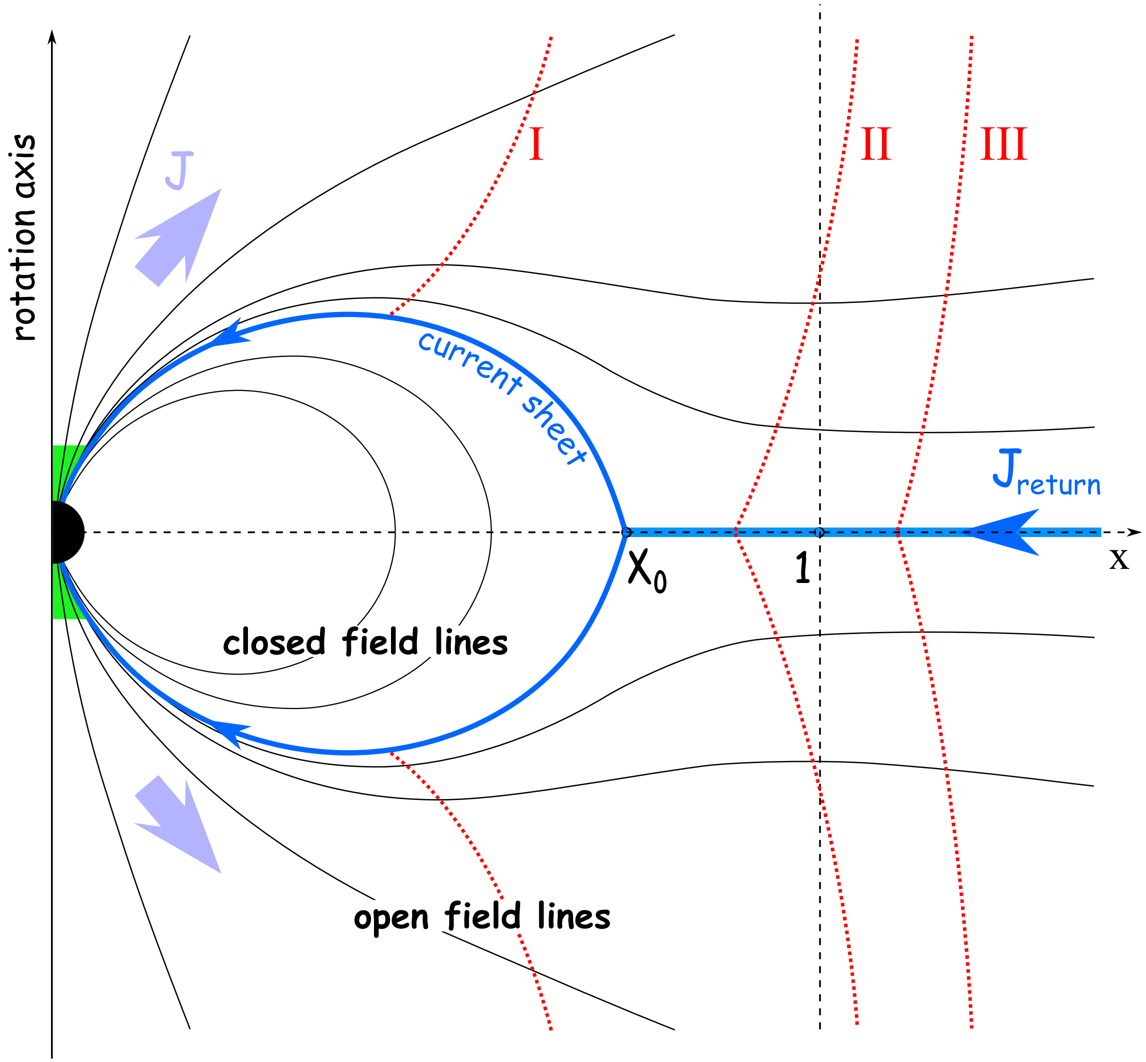
Magnetosphere	Enables smooth particle outflow $\rightarrow$ Sets the current density
Polar cap cascade	Supplies magnetosphere with plasma; Is part of the global electric circuit

Force-free magnetosphere: 3D Numerical Model



(Spitkovsky 2006)

Aligned Rotator-the simplest possible case



Free parameters of the model:

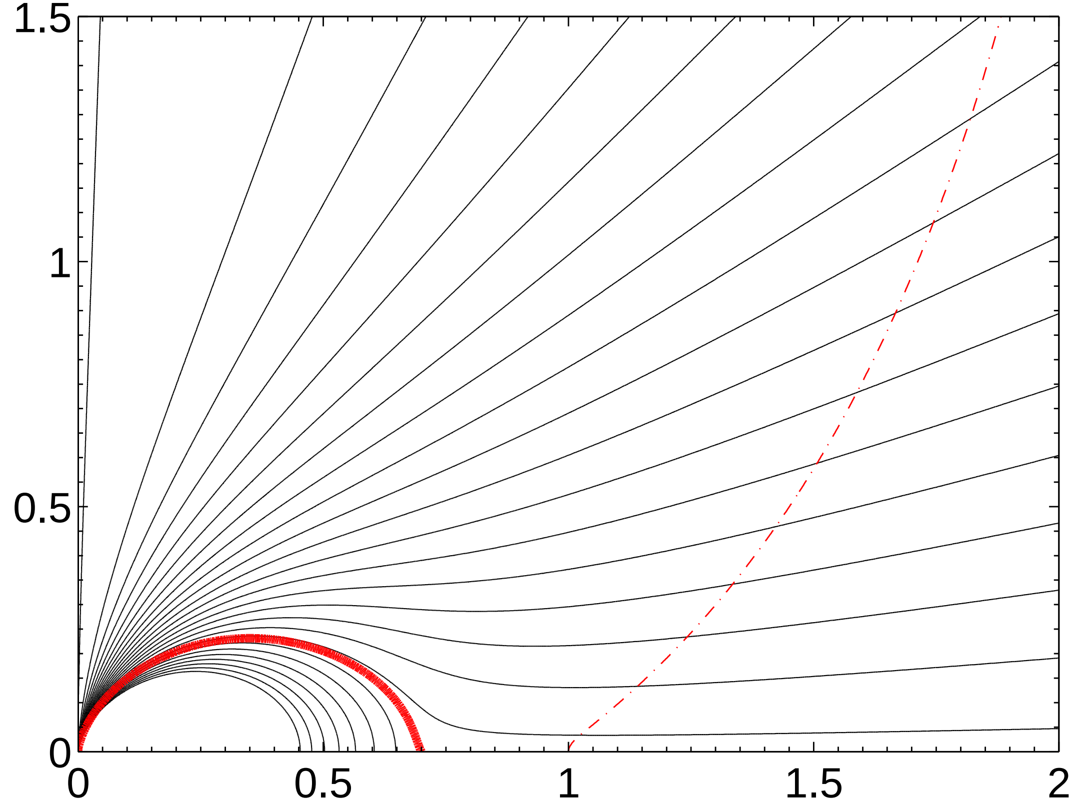
- ☐ Size of the corotating zone x_0:
  How many field lines cross the Light Cylinder

- ☐ Angular velocity of the open magnetic field lines

$$\Omega(\psi) = \Omega_{\mathrm{NS}} \left(1 + \frac{dV}{d\psi} \right)$$

Shape of the Light Cylinder

Magnetosphere with $\Omega(\psi) \le \Omega_{\text{NS}}$: $x_0 = .7$

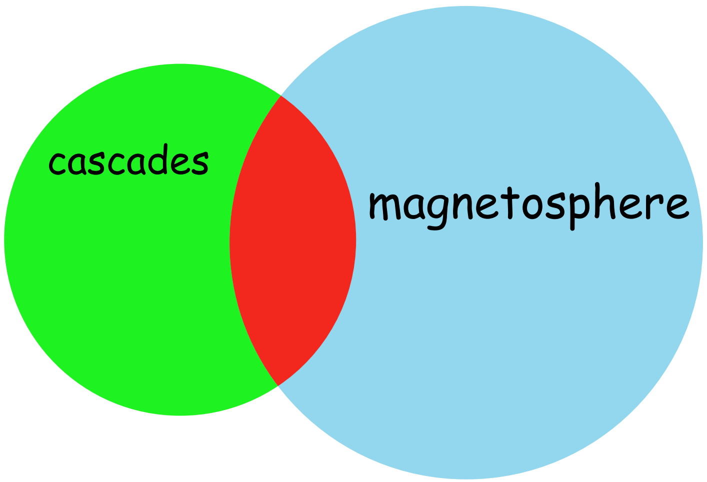


Force-free magnetosphere vs. polar cap cascades

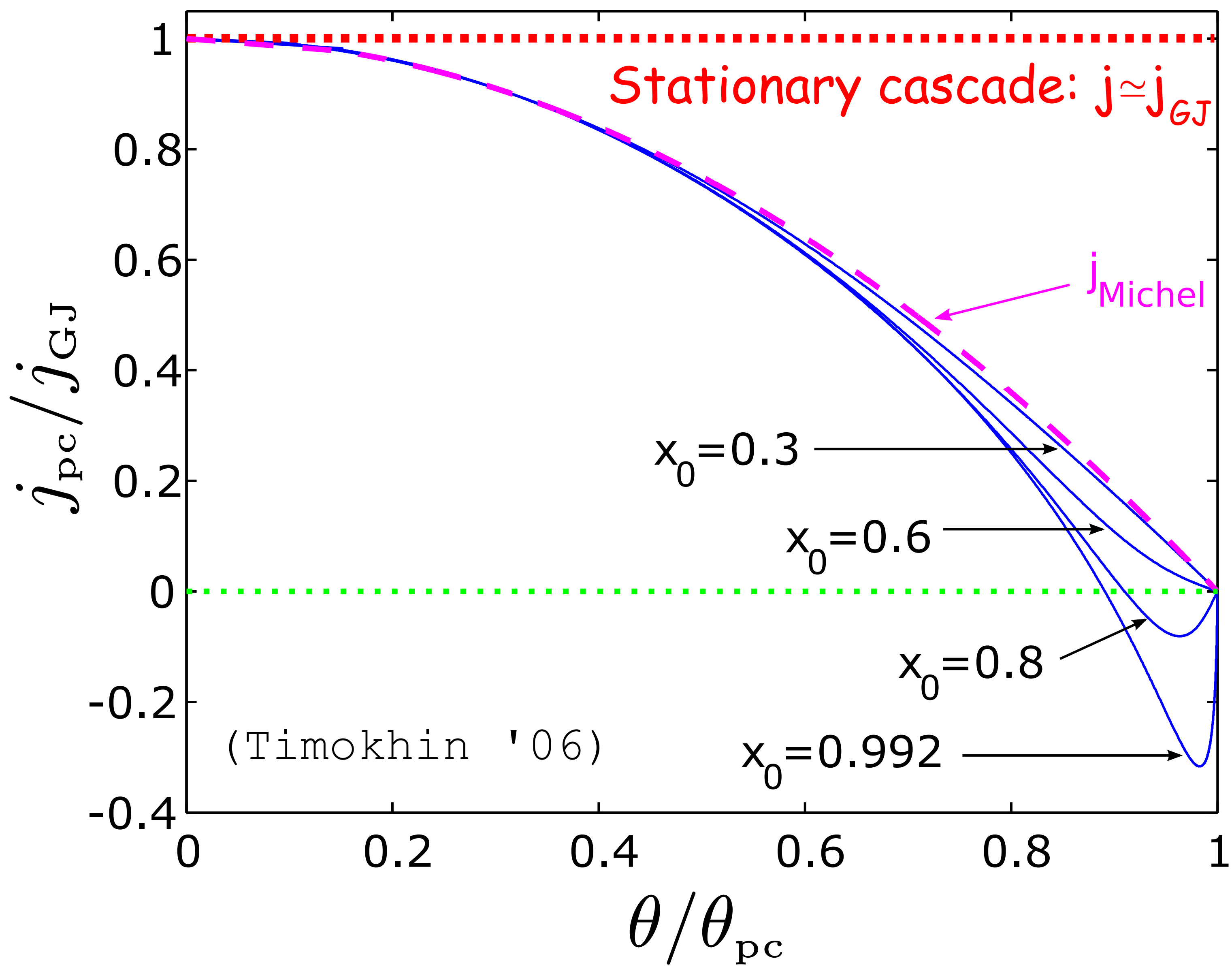
- Force-free magnetosphere cannot exist without electron-positron pair production in the polar cap

- Particles cannot move faster that the speed of light $\Rightarrow$ open magnetic field lines should have a special shape allowing particle motion with $v < c$. Requirement of smooth transition of magnetic field lines trough the Light Cylinder fixes the current density along that lines.

- Pair creation is a process with threshold. Current density which can flow through the cascade zone depends on the potential drop there. It is not obviously that any current density can flow through the cascade zone



Current density in the polar cap



Self-consistent modeling of electron-positron pair cascades

☐ What to model:

1. particles are accelerated by the electric field
2. emit gamma-rays
3. gamma-rays are absorbed in the strong magnetic field and creates electron-positron pairs
4. redistribution of charged particles changes the accelerating electric field

☐ How to do:

Particle acceleration $\leftrightarrow$ Electric field **PIC**

Particles $\rightarrow$ Photons $\rightarrow$ Particles(Pairs) **Monte Carlo**

Physical model

Ruderman-Sutherland model: no particles can be extracted from the NS surface

according to the original theory by Ruderman and Sutherland a 1D approximation should work perfectly for this problem.

SETUP

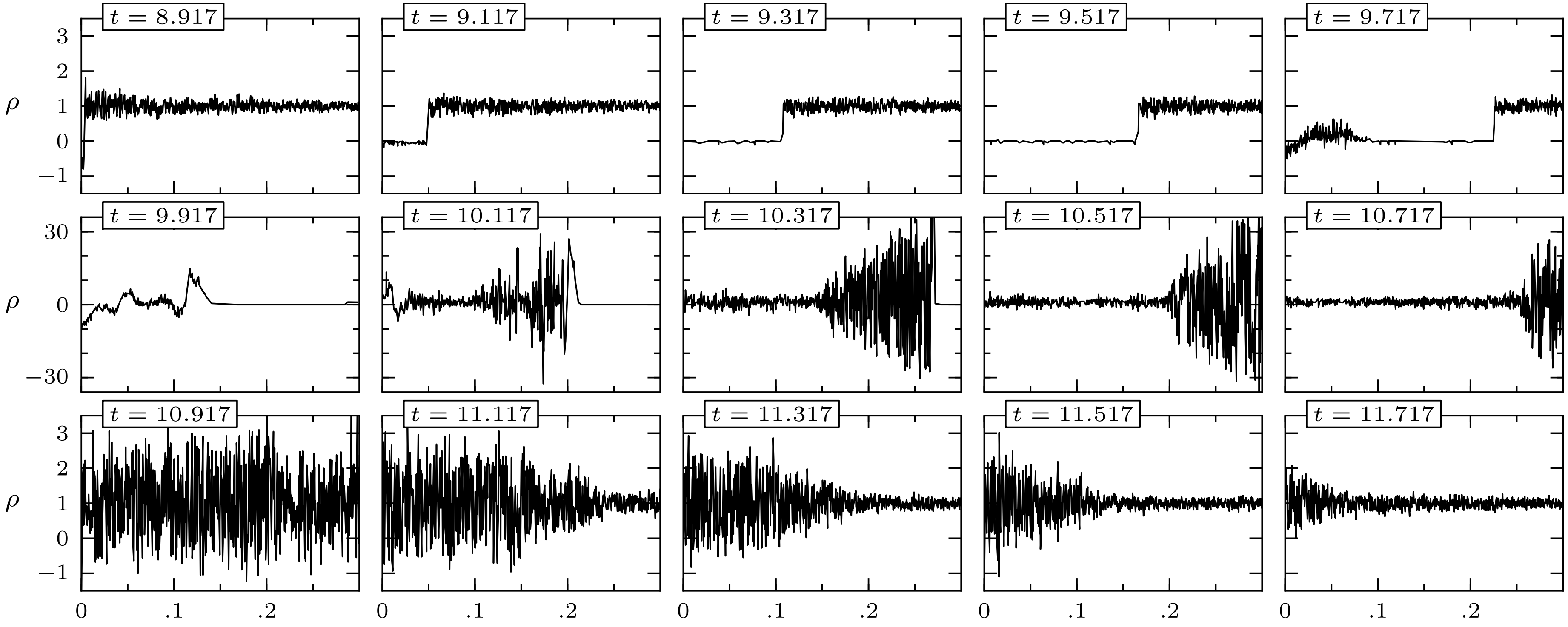
- **1D Electrostatic model**

$$\partial_t E_{\|} = -4\pi(j - j_0)$$

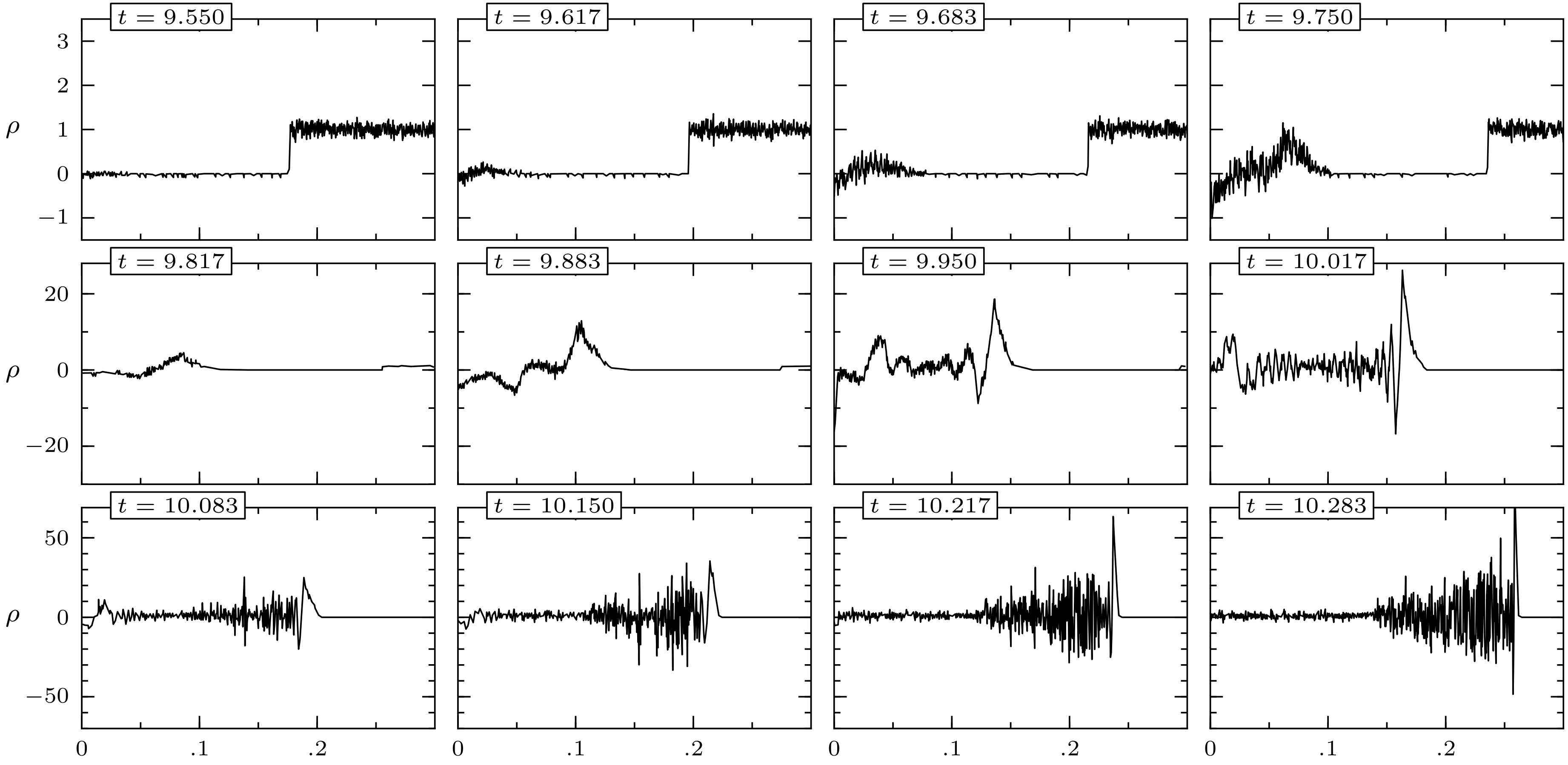
  $j_0 = c\nabla \times \mathbf{B}$ – the current density required by the magnetosphere

- **gamma-ray production**: Curvature radiation
- **pair creation**: single photon absorption in dipole magnetic field

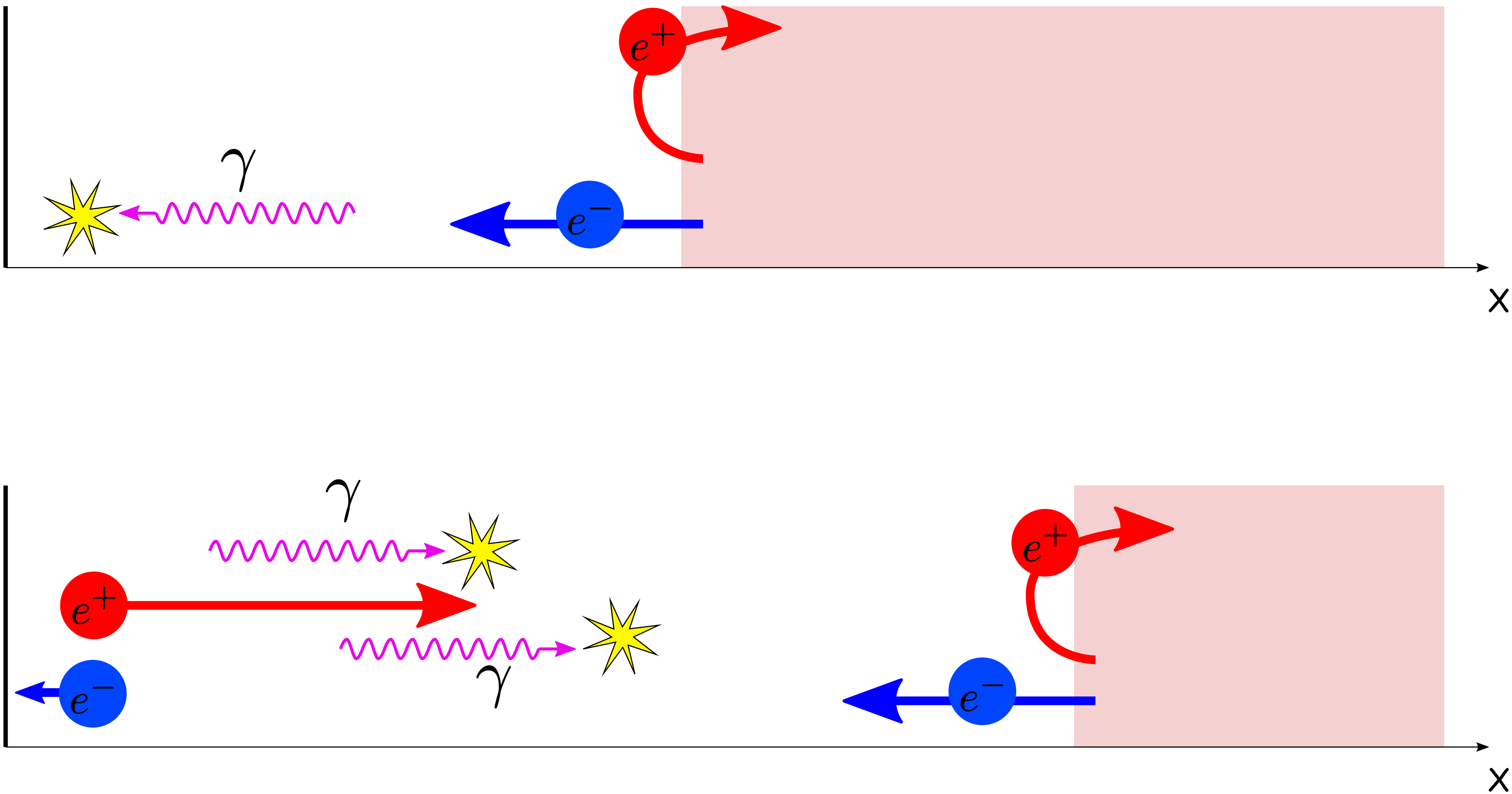
Cascade development: full cycle



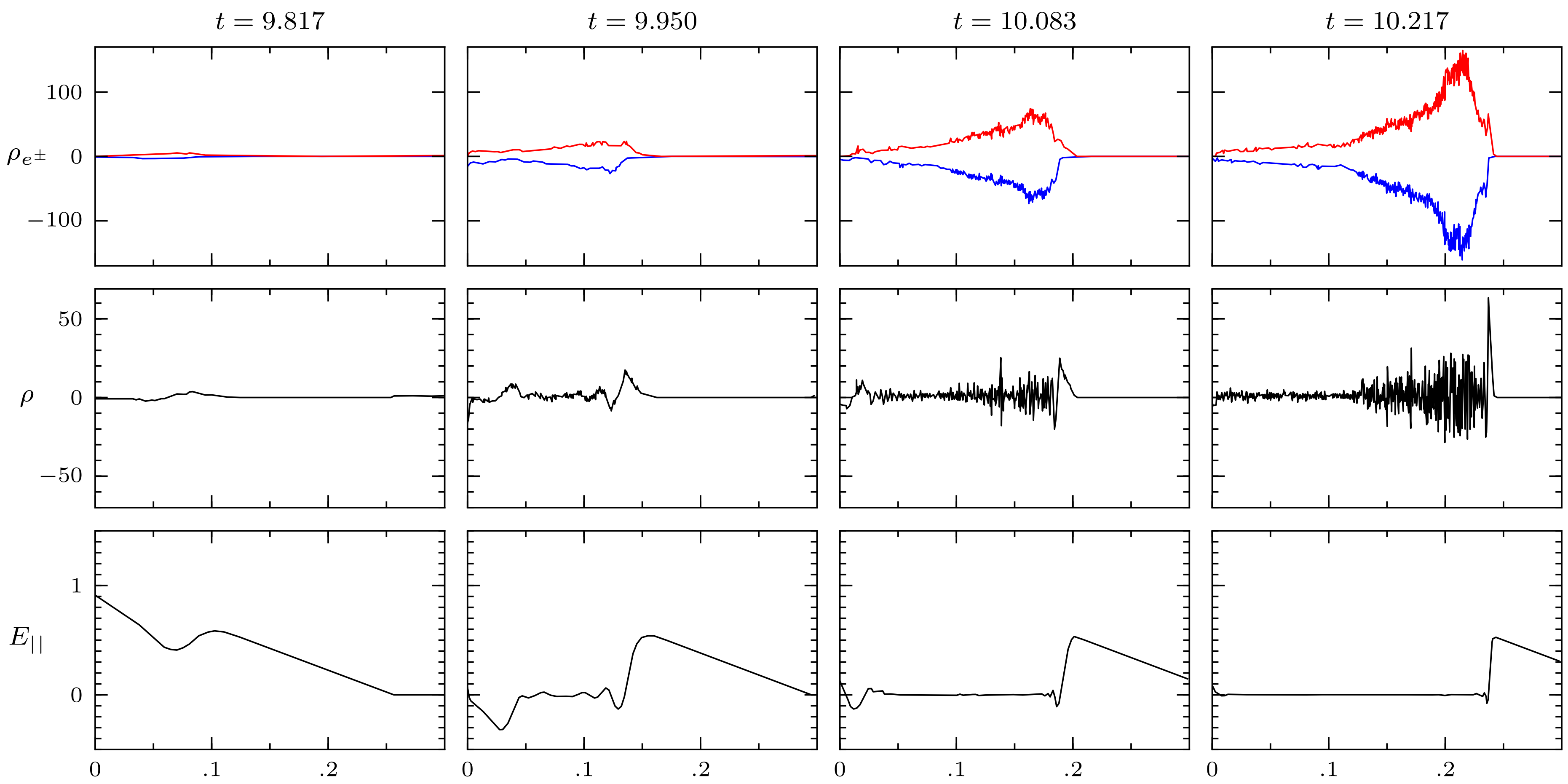
Cascade development: blob formation



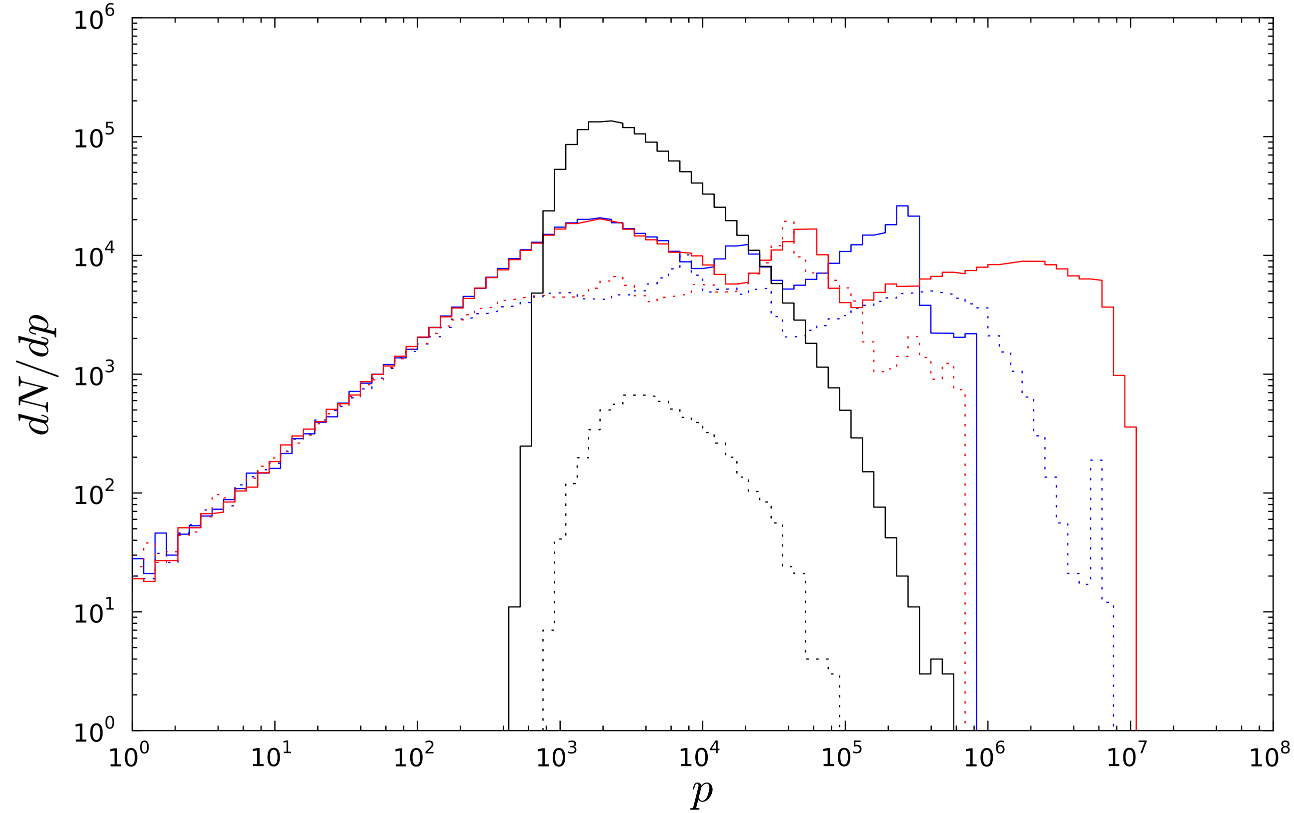
Cascade development



Cascade development: what is going on



Particle energy distribution



Summary

What we understand:

- □ Force-free magnetosphere

Open issues

- □ Emission mechanisms
- □ Pair plasma generation
- □ braking index problem: pulsar energy losses
- □ nulling, mode changing, drifting subpulses ...
- □ "σ-problem": dissipation of magnetic energy in the wind