Particle acceleration in the polar cap of a pulsar

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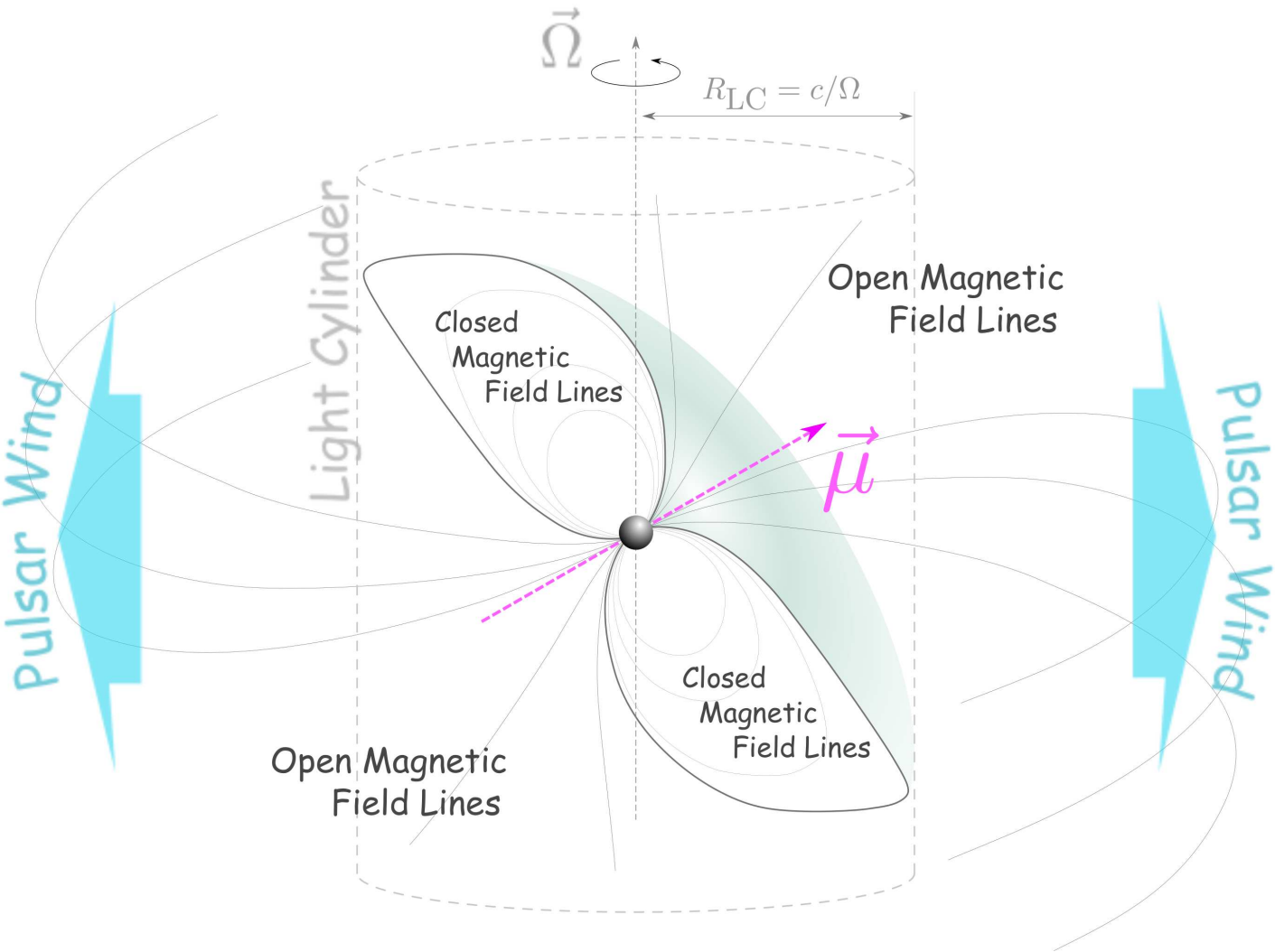
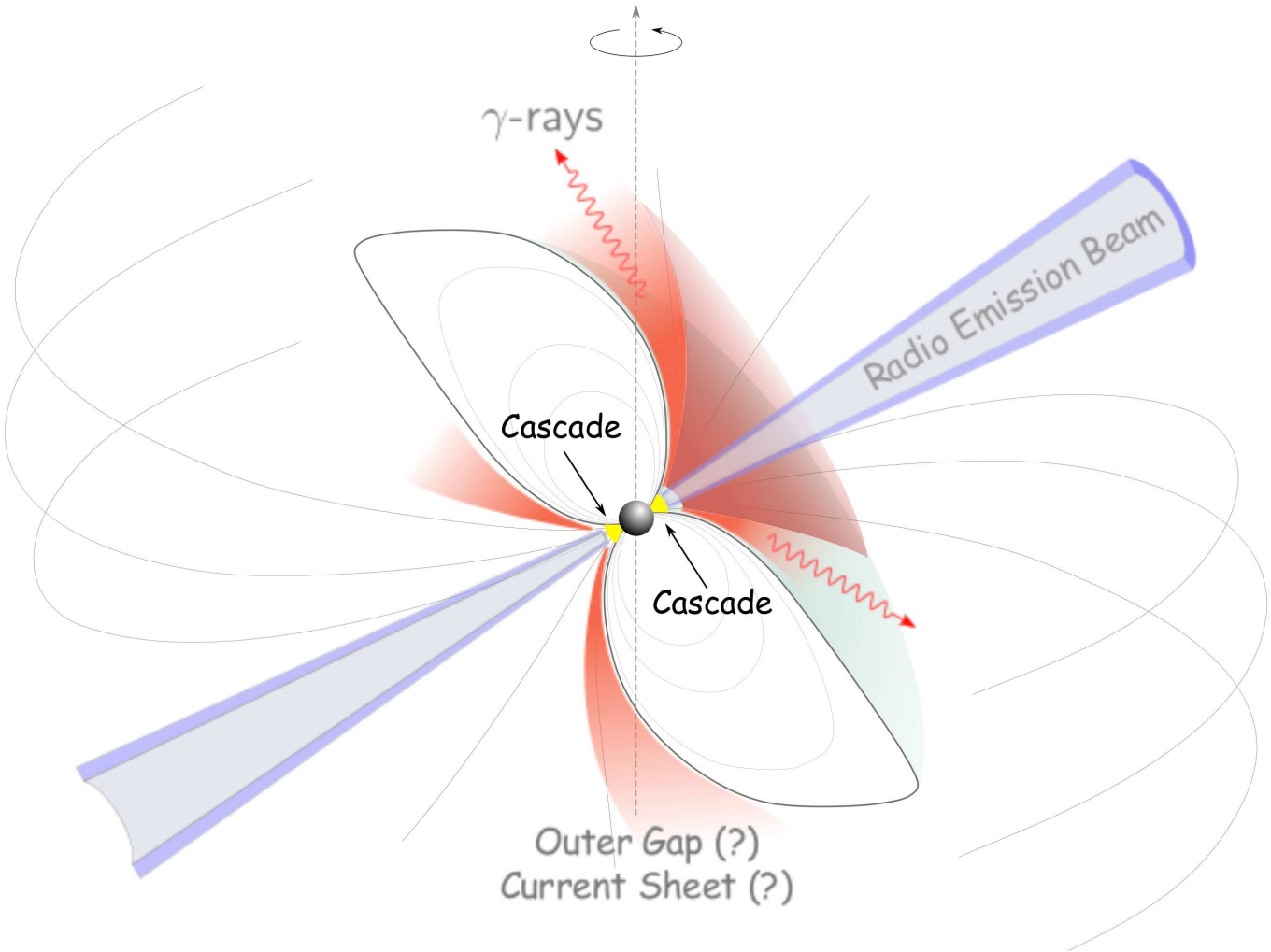
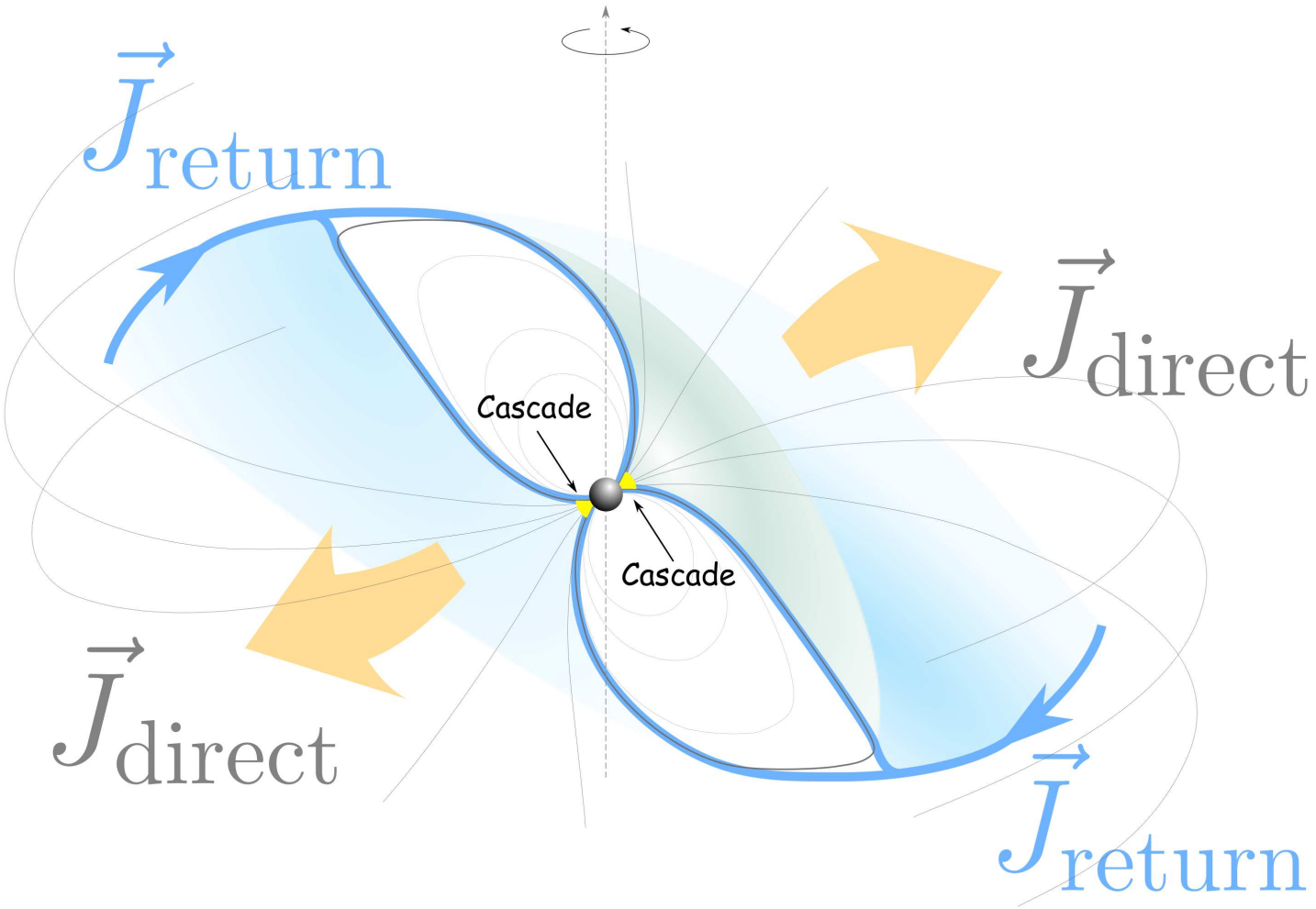
Pulsar Magnetosphere: "Large scale view"



Pulsar Magnetosphere: "Observer's view"



Pulsar Magnetosphere: "Theorist's view"

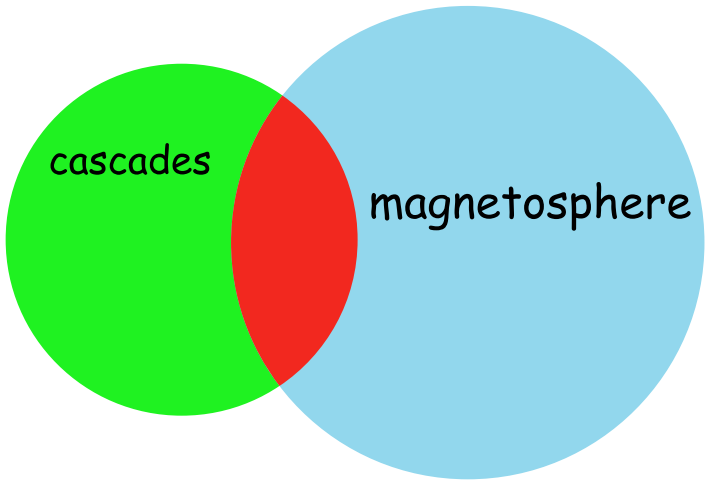


Magnetosphere Enables smooth particle outflow $\longrightarrow$ Sets the current density

Polar cap cascade Supplies magnetosphere with plasma; Is part of the global electric circuit

Force-free magnetosphere vs. polar cap cascades

- 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



Existing polar cap cascade theories

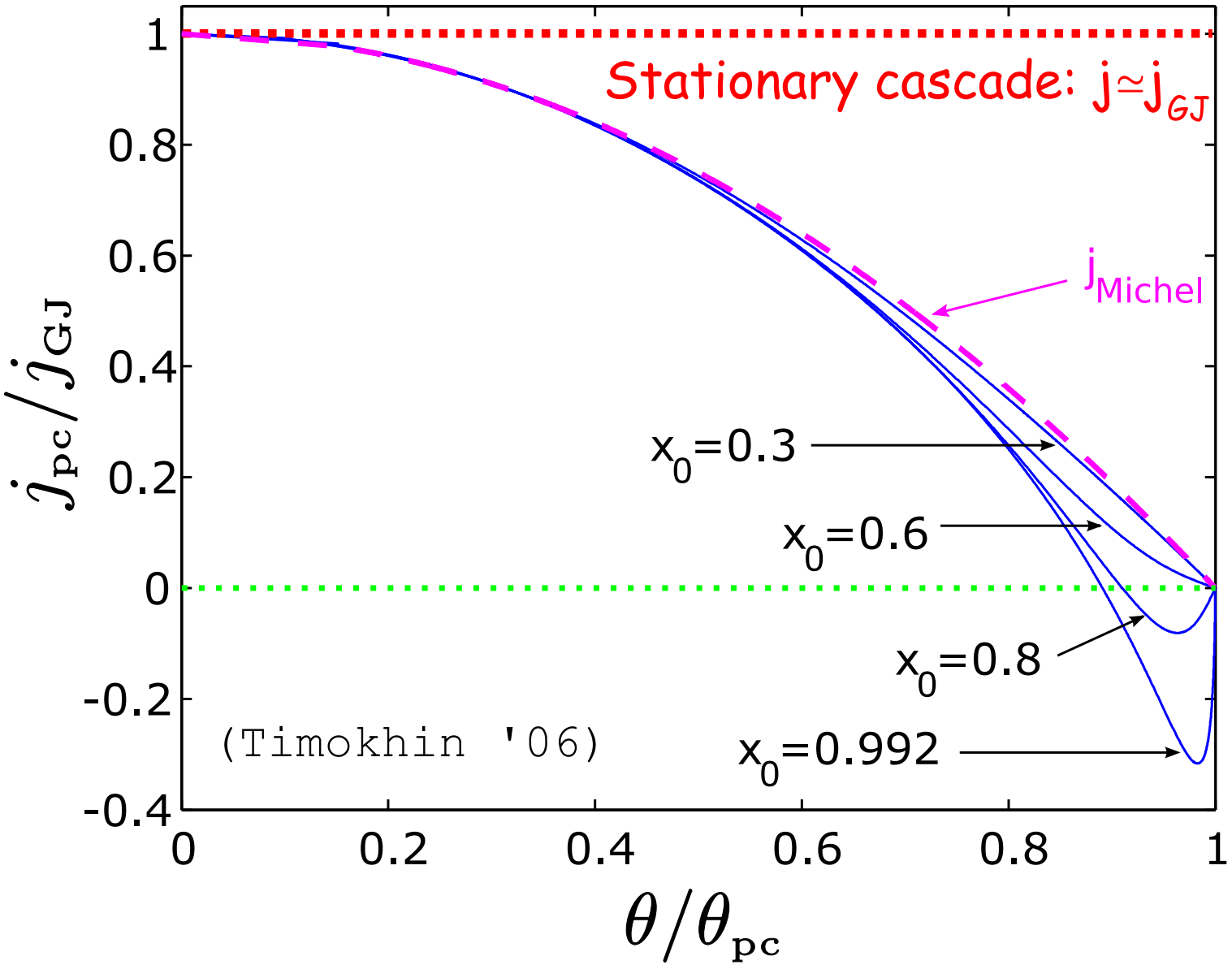
- **"Quantitative" detailed theories:**
  Arons & Scharlemann '79, Daugherty & Harding '82, Muslimov & Tsygan '92, Muslimov & Harding '98, Hibschman & Arons '01
  Underlying assumption: Stationary unidirectional particle flow (no trapped particles)
  - Current density is almost equal to the Goldreich-Julian current density
  - potential drop in the cascade zone is very small $\sim 1 - 2\% V_{\rm vac}$

  Do not work!- do not provide the required current density

- **"Qualitative" theories:**
  Sturrock'73, Ruderman&Sutherland'75,Alber et al. '75; Levinson et al.'05; Melrose et al. '08

  We do not know whether they work!

Current density in the Polar Cap



What do we want to know?

- What is the pair number density?
- γ-rays spectrum
- Pulsar death line
- How large is the heating of the NS surface? (X-rays/UV emission of the polar cap)
- Current-voltage characteristic (does the magnetosphere rotates differentially?)

Why should we do numerical modeling?

We do not know the flow pattern!

self-consistent model of electron-positron pair cascade

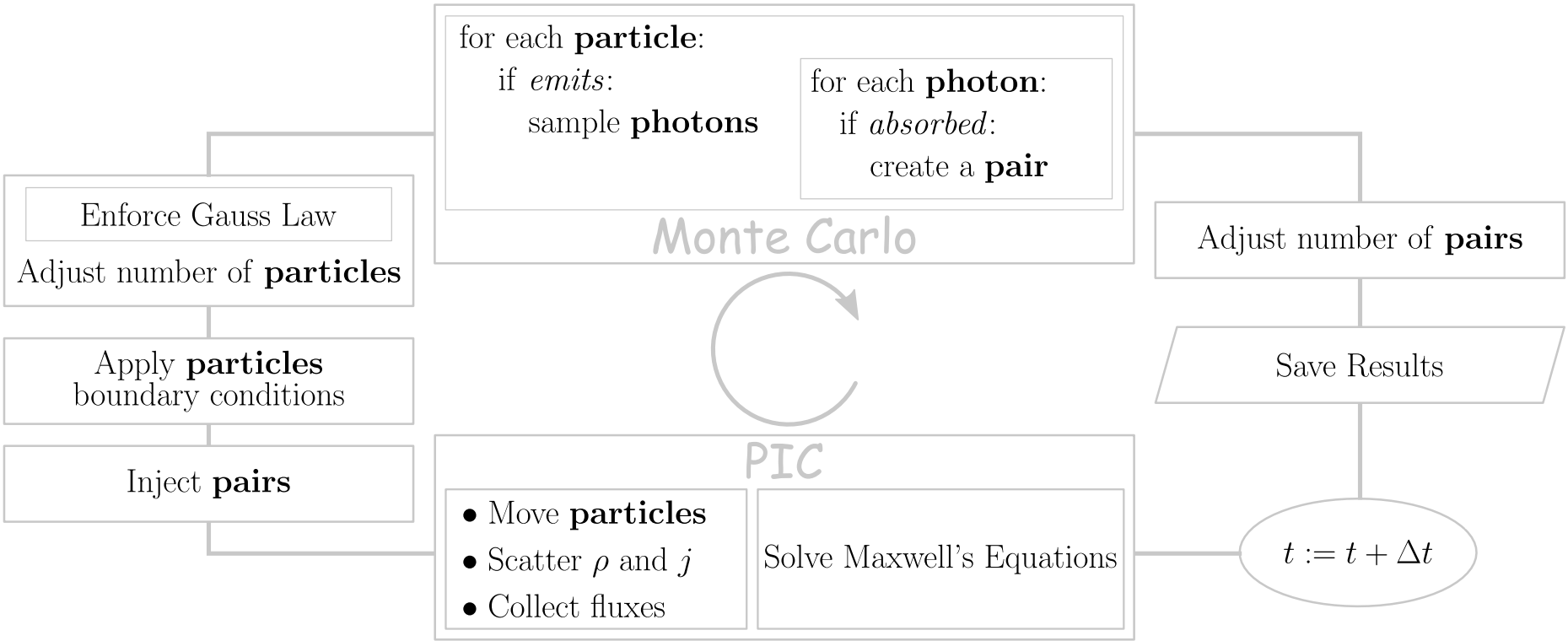
- What to model:
  1. particles are accelerated by the electric field
  2. emit gamma-rays
  3. gamma-rays are absorbed in the strong magnetic field and creates electron-positron pairs
  4. redistribution of charged particles changes the accelerating electric field

- How to do:

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

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

Code structure



Current 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.

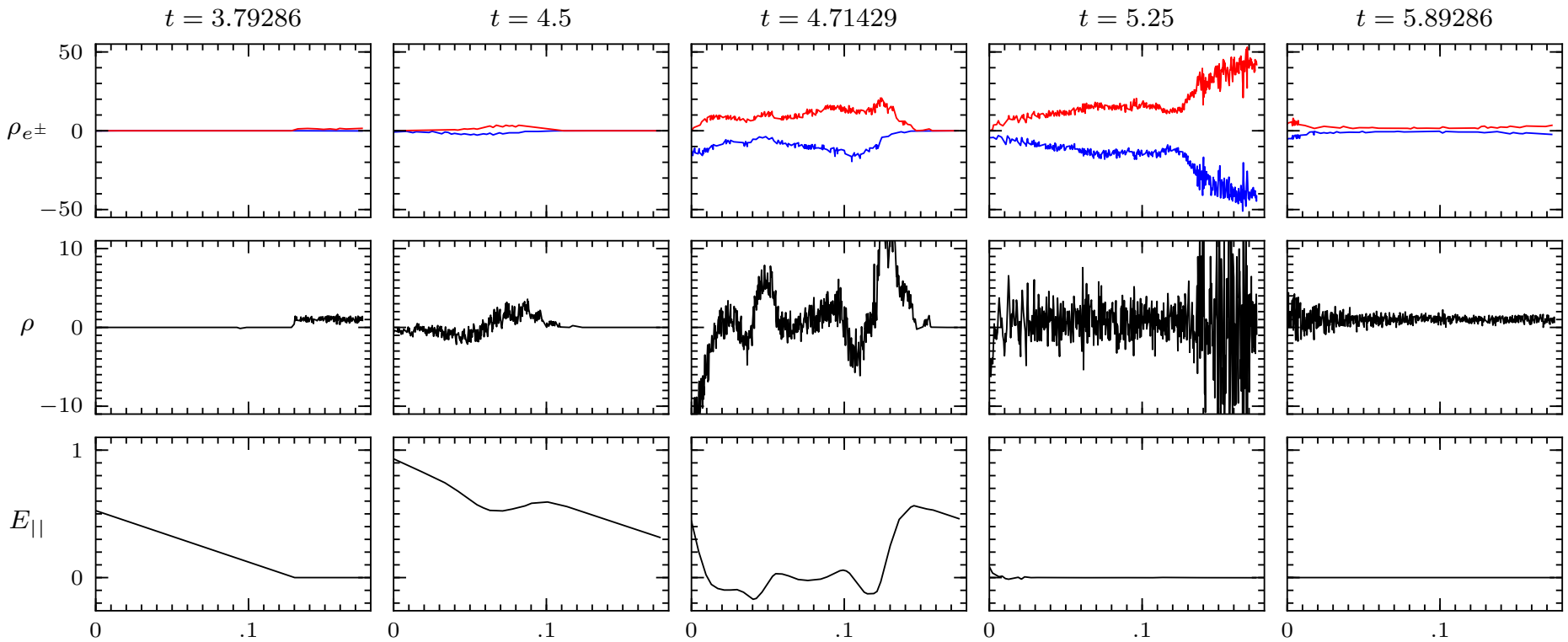
SETUP

- **1D Electrostatic model**

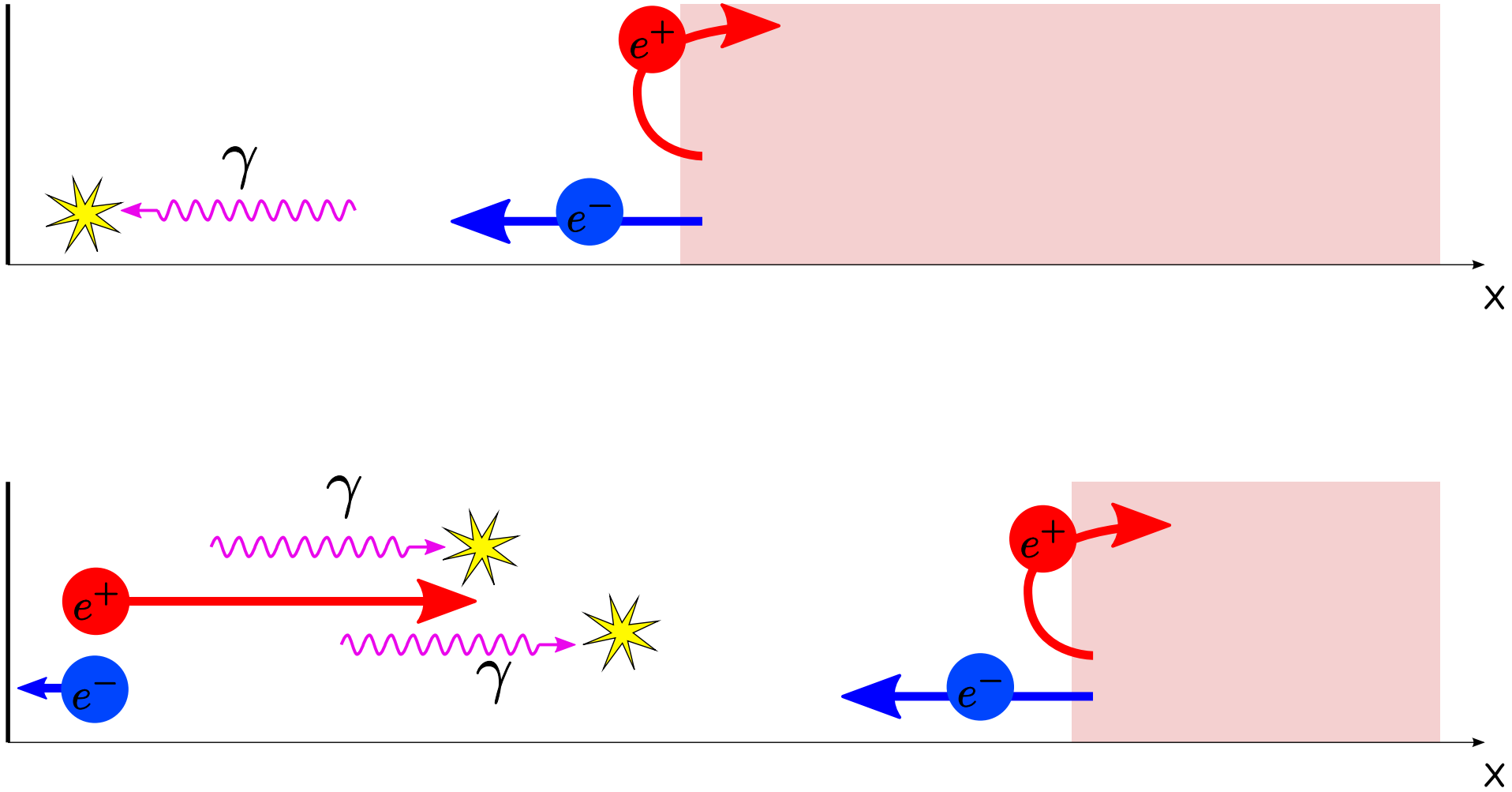
$$\partial_t E_{\parallel} = -4\pi(j - j_0)$$

  $j_0 = c\nabla \times \mathbf{B}$ **–** the current density required by the magnetosphere
- **gamma-ray production**: Curvature radiation
- **pair creation**: single photon absorption in dipole magnetic field

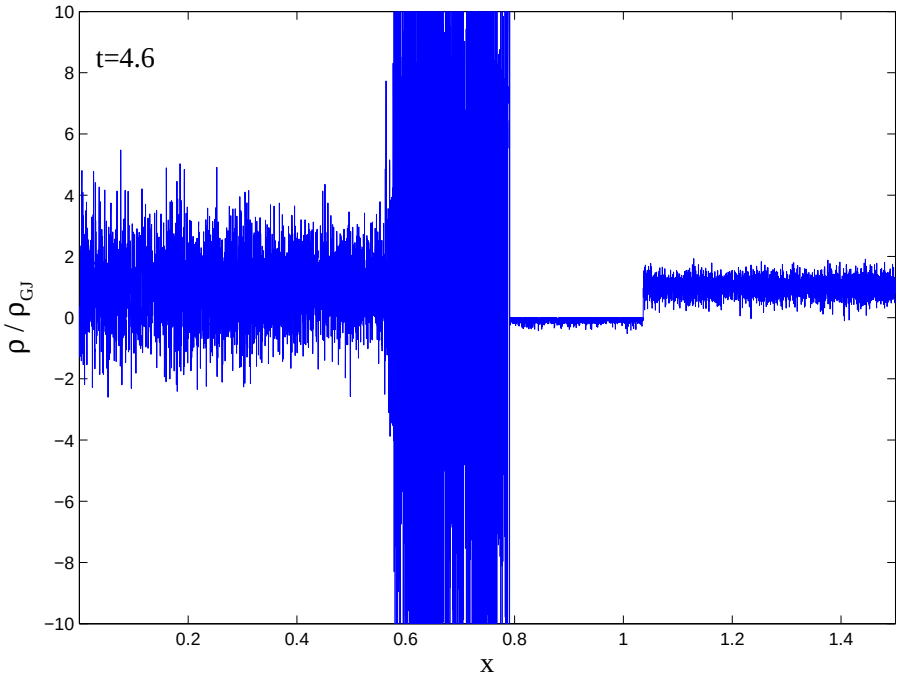
Cascade development: movie snapshots

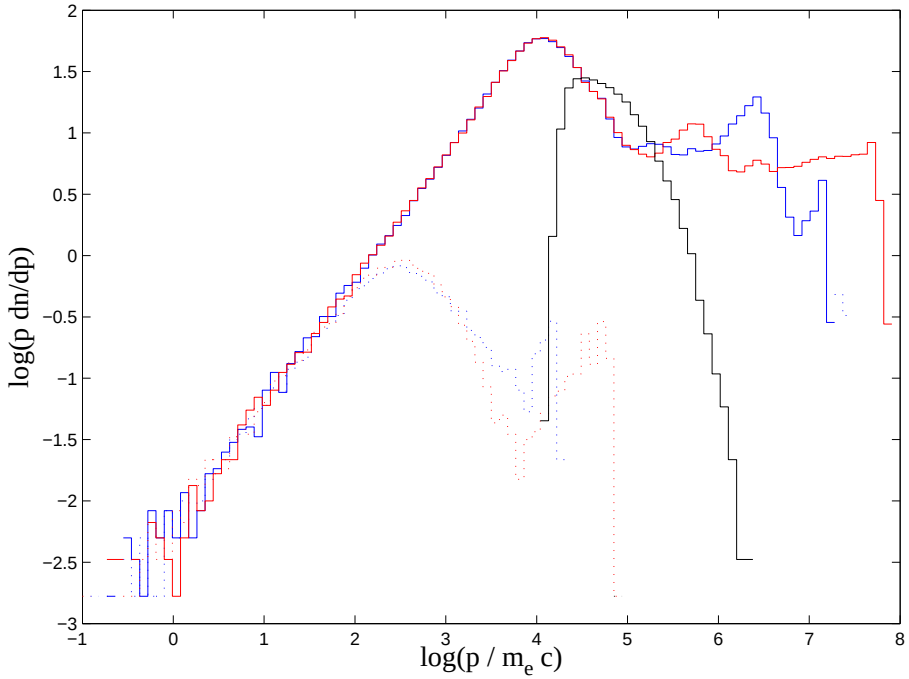


Cascade development

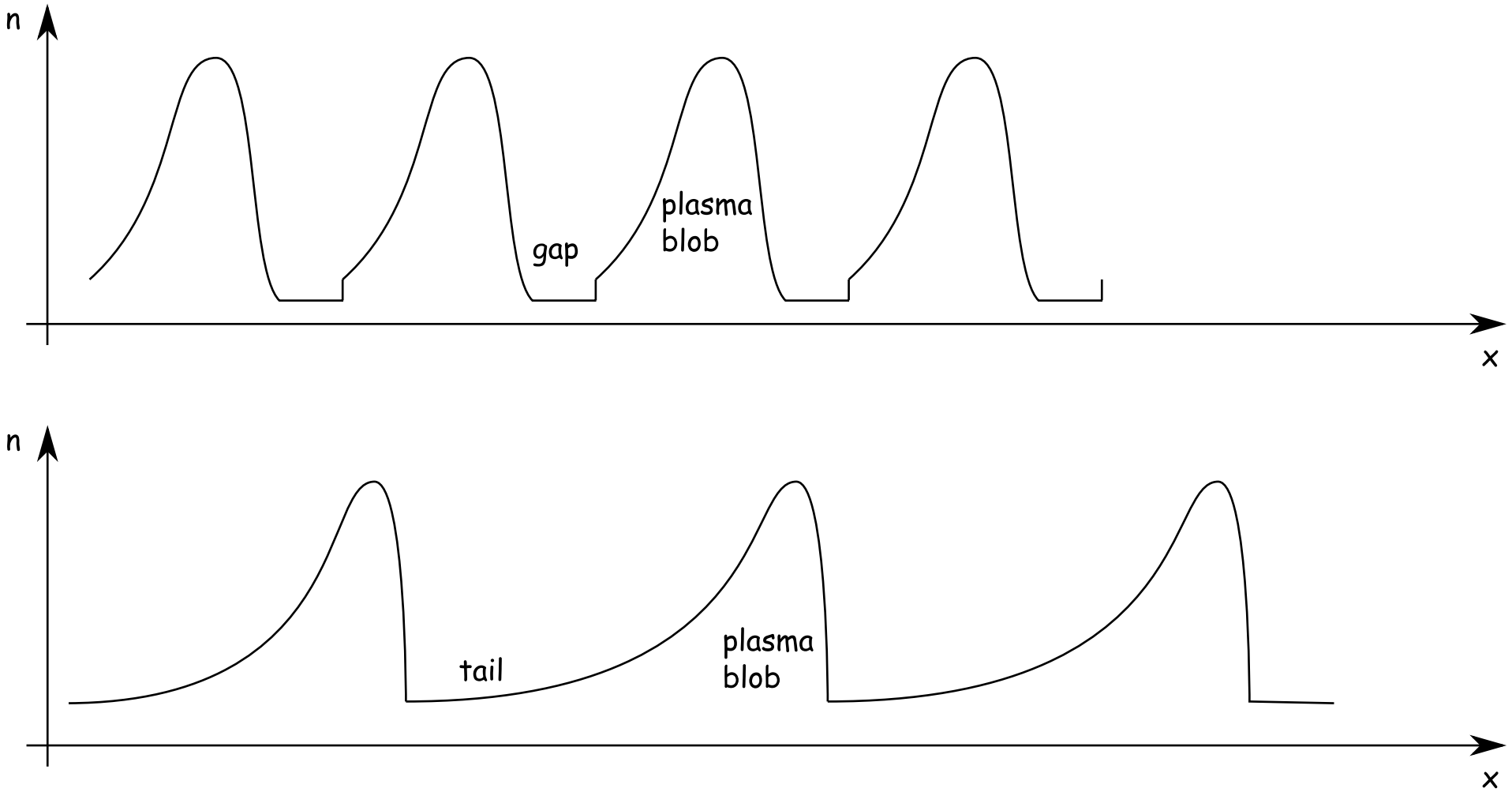


Particle energy distribution in the plasma blob





Possible plasma flow pattern



Summary

- cascade shows "limited cycle" behavior (which is independet on the initial configuration)
- cascade is self-sustained
- the flow is complicated – the gap releases from the NS surface and propagates some distance into the magnetosphere
- esmimates of Ruderman & Sutherland '75 provide an upper limits on particle fluxes
- spectral energy distribution of the most energetic particles is broad