Numerical Experiments on the Neutron Star Magnetosphere

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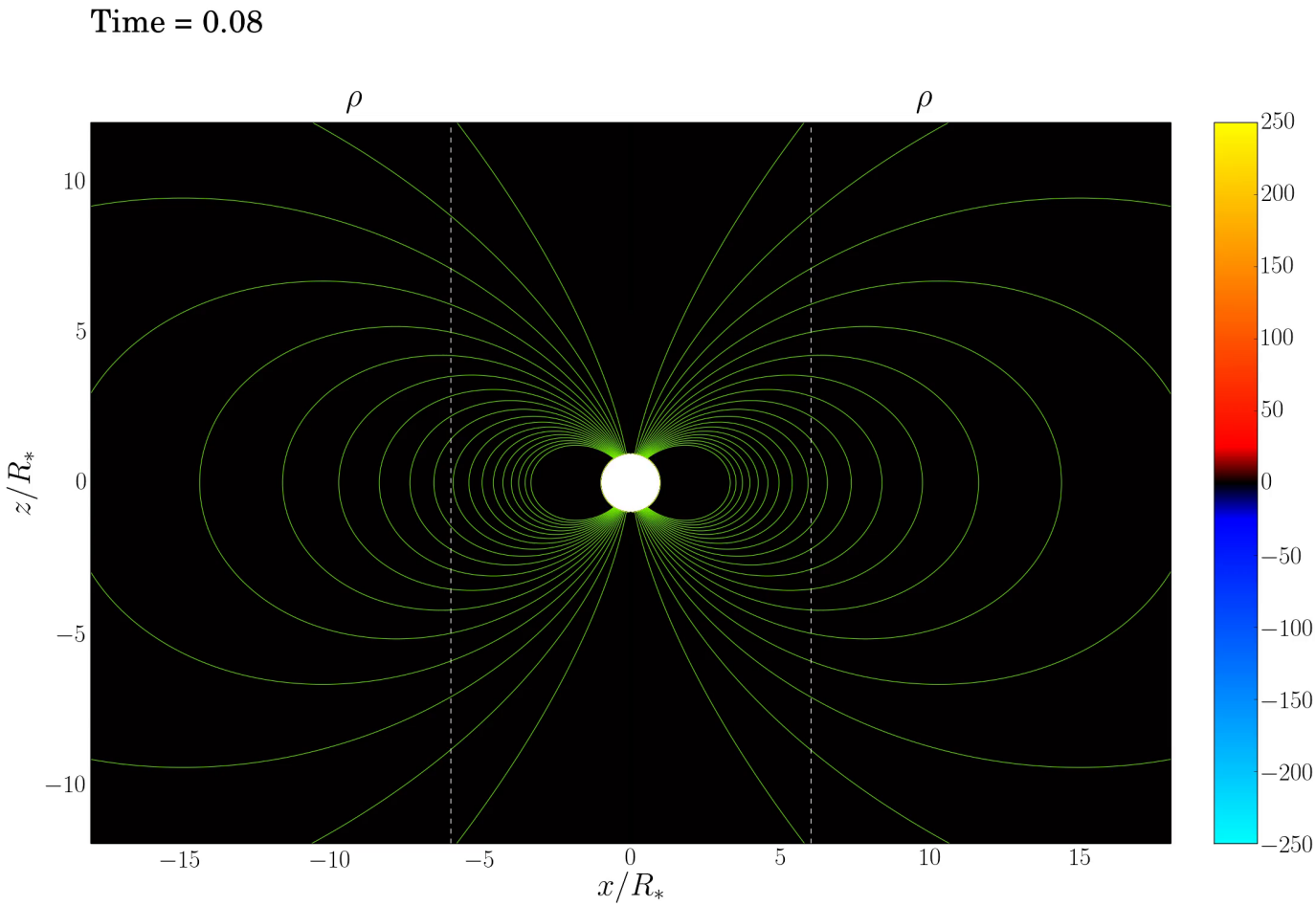
Aperture

Aperture is Particles, Electrodynamics, Radiative Transfer at Ultra-Relativistic Energies

- A general PIC framework we designed and developed from scratch, in order to study the neutron star magnetospheres.
- Models radiative cooling, curvature radiation and its conversion into electron-positron pairs
- Can run on workstation GPUs or on CPU clusters. Tested on the Yeti cluster at Columbia and shows good scaling.

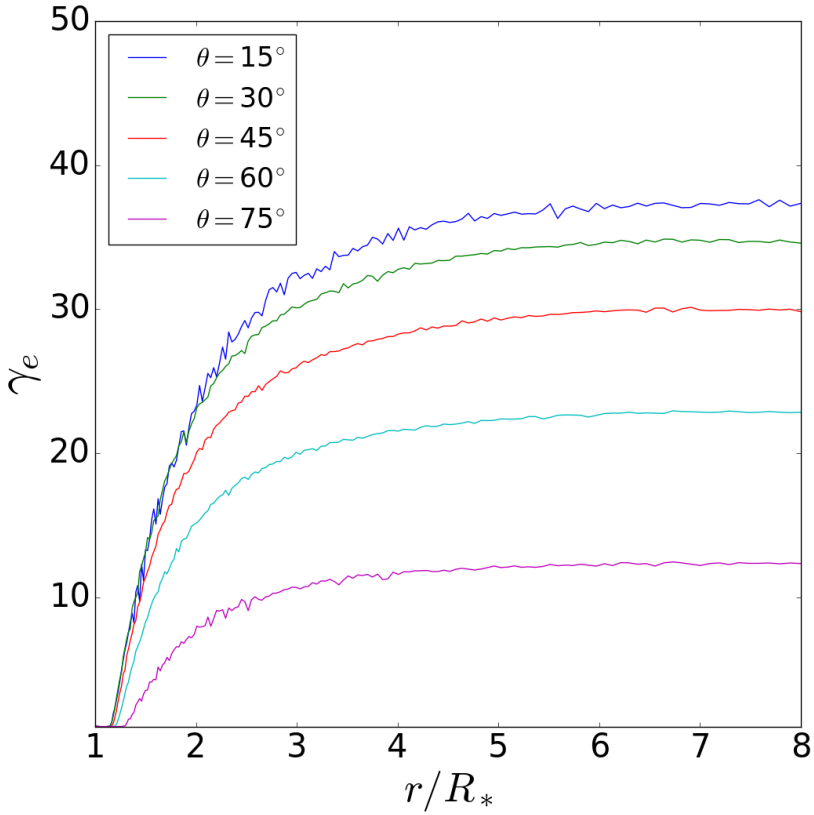
NE1: Pulsar Simulations

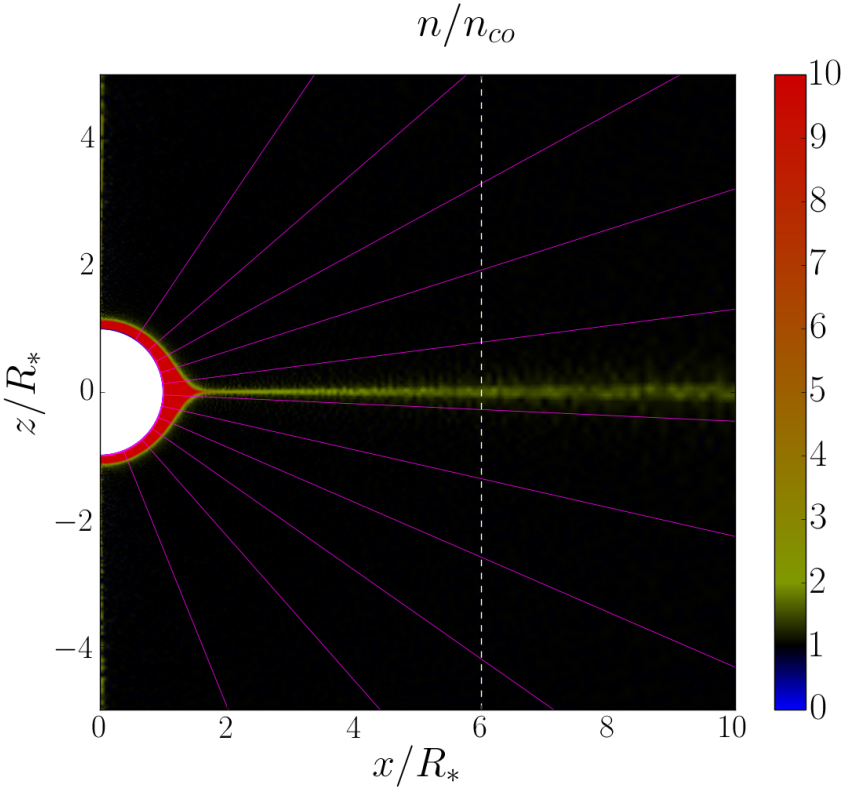
One of the first self-consistent kinetic pulsar magnetosphere simulations (Chen & Beloborodov 2014).



NE2: Monopole Solution

Mainly work done by Rui Hu

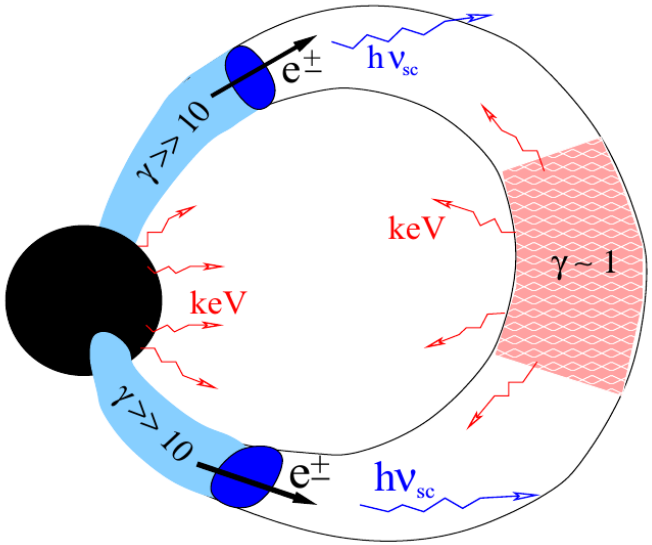




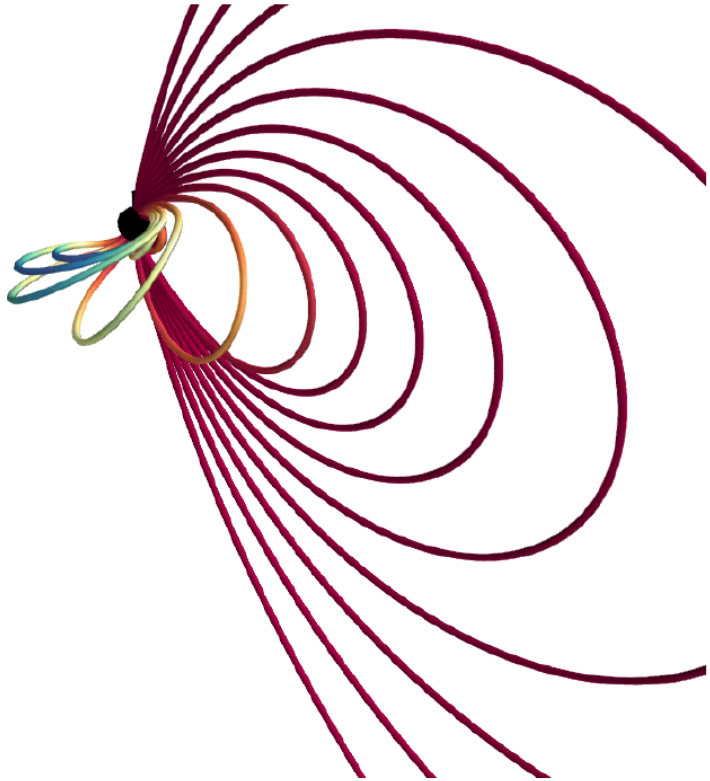
Michel monopole solution with a finite atmosphere

NE3: Corona of Magnetars

Simulating the twist and untwist of current bundles along dipolar field lines



(Beloborodov 2013)



(Parfrey et al. 2013)

Twisting the Magnetar Magnetosphere

The surface of the star rotates differentially, launching a twist on the magnetic field lines, traveling as Alfven waves along the flux tube.

Equatorial twist profile:

$$\omega(\theta) = \omega_0 \frac{\Theta}{\sin\theta} \exp\left[(1-\Theta^4)/4\right]$$

where $\Theta = (\theta - \pi/2)/\Delta\theta_m$. (Mikic & Linker 1994)

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Twist is implanted within a short time, but the resulting B_ϕ survives on a much longer time scale.

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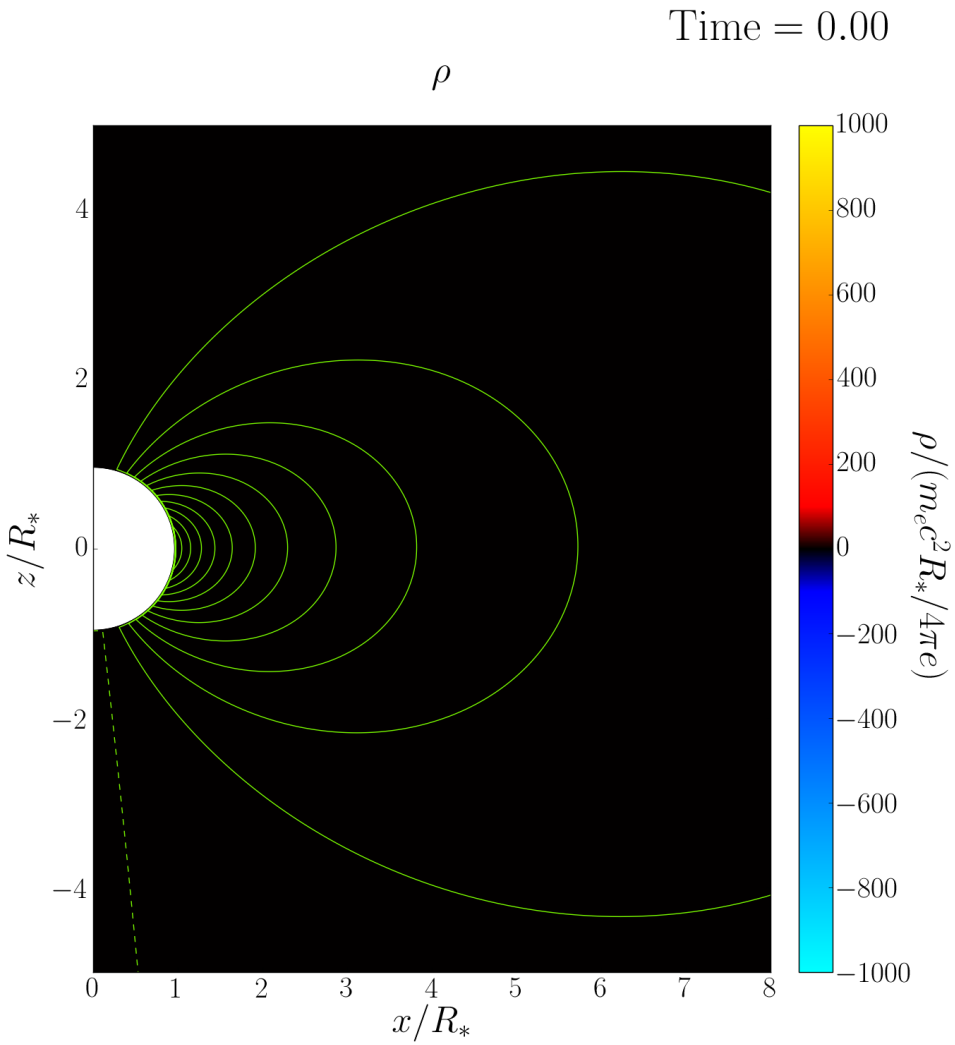

Mechanism of Untwisting

The current bundle untwists through Ohmic dissipation. Voltage drop is limited by the pair creation threshold voltage. In this simulation

$$e\Phi_e/mc^2 \approx 30, \qquad e\Phi_{max}/mc^2 \approx 200$$

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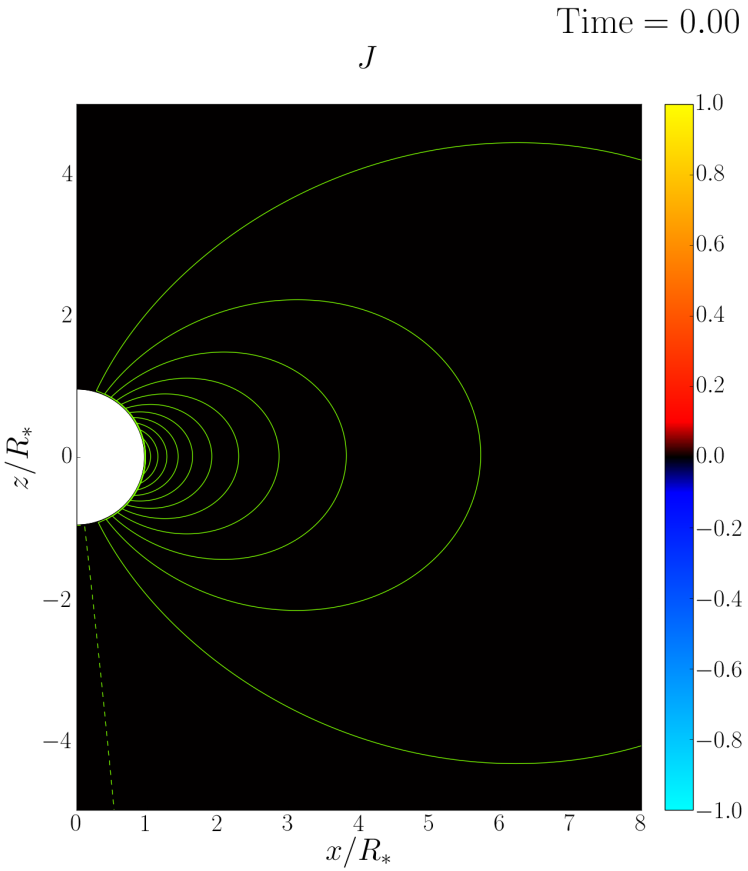
$$\frac{d\psi}{dt} = 2\pi c \frac{\partial \Phi_e}{\partial f}$$

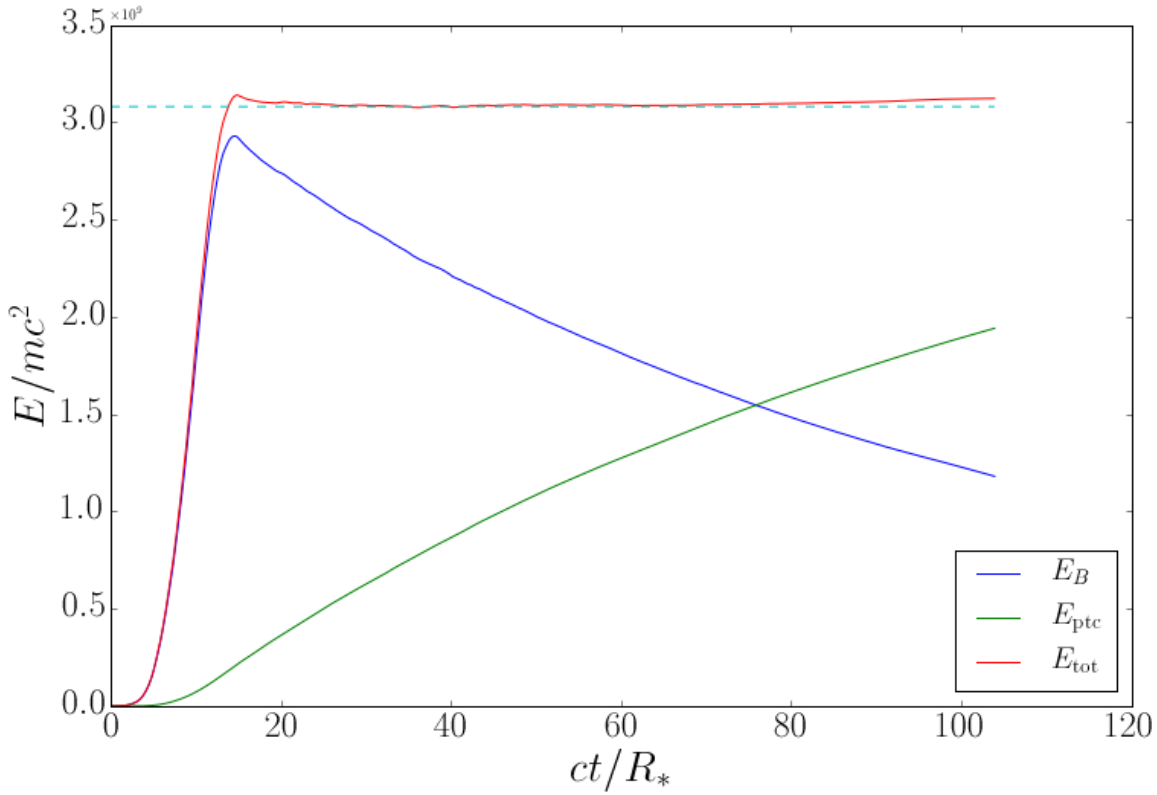
Mechanism of Untwisting

The magnetosphere untwists with a growing cavity of zero current (Beloborodov 2009).



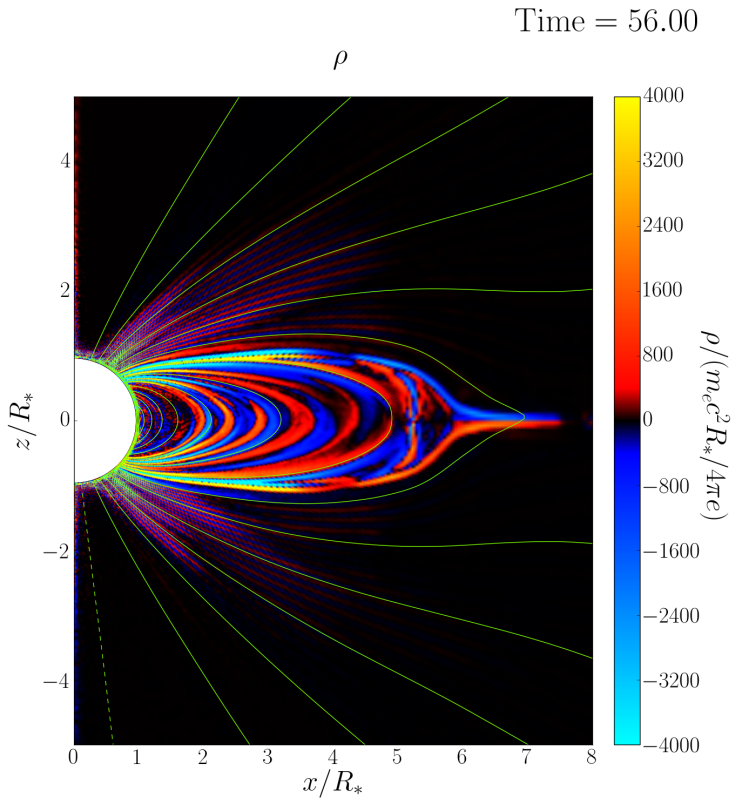
The Energy Dump

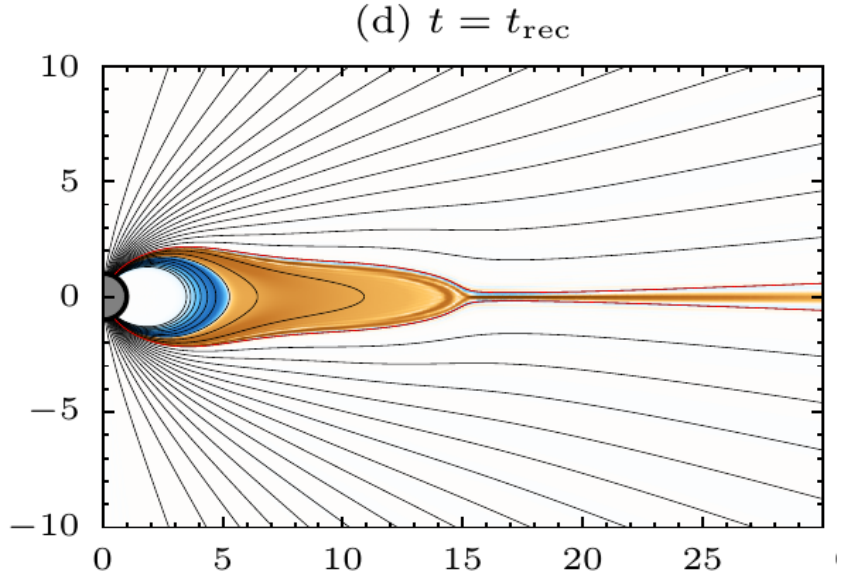
Magnetic energy is slowly converted to particle kinetic energy, and eventually advected into the star.



Over-twisted Magnetosphere

When the twist angle becomes larger than some critical angle ψ_{crit}, the behavior of the j-bundle changes qualitatively. Untwist happens violently via reconnection.





(Parfrey et al. 2013)

Would be interesting to study the reconnection!