Description of X-line Behavior Based on Spatial Distribution of Energy Density and the Arrow of Time

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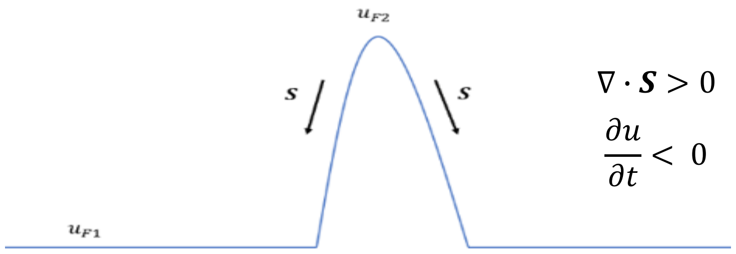
Poynting's Theorem & the Arrow of Time

Poynting's theorem can be thought of as an energy continuity equation, describing the conservation of electromagnetic energy in space

$$\frac{\partial u_F}{\partial t} = -\nabla \cdot \boldsymbol{S} - \boldsymbol{J} \cdot \boldsymbol{E}$$

In the absence of any significant plasma energization, Poynting's theorem describes a system of EM fields trending toward an equilibrium state

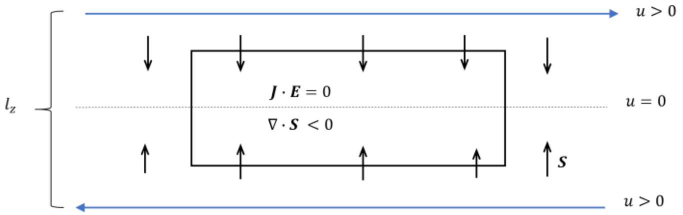
$$\frac{\partial u_F}{\partial t} = -\nabla \cdot \boldsymbol{S}$$



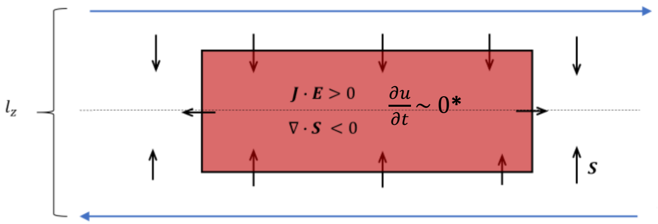
As the system trends toward an equilibrium state, the local max in u will decrease ($\frac{du}{dt} < 0$) until u is spatially uniform and all terms in Poynting's theorem are zero

Symmetric Reconnection

Pre-Onset: In perfectly symmetric reconnection, the neutral line has |B| = 0 by definition due to the field reversal. This constraint means that du/dt > 0 everywhere *except at the exact center*! As magnetic energy density builds up at +/- dz, the local valley in u becomes more narrow

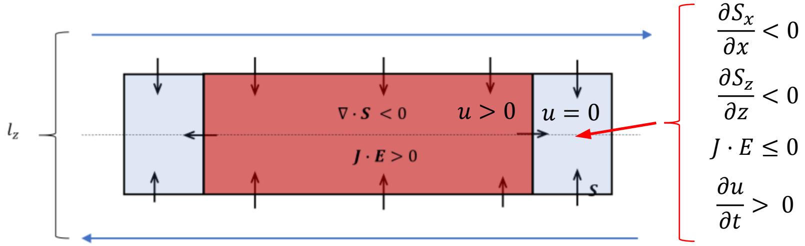


Onset: When the valley in u approaches kinetic scales, kinetic effects become more significant. Reconnection electric field provides local max in u



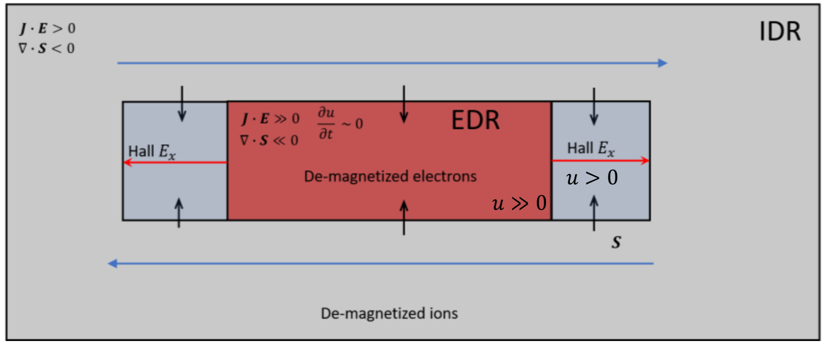
*See Genestreti et al., 2018 (GRL) and Payne et al., 2020 (JGR)

Post-Onset: Now that there is a localized max in u at the center, a component of Poynting flux is directed away from the onset location. EDR expands along outflow



Electron – Ion Plasmas

The multiscale nature of an EDR embedded in an IDR influences the gradient in u along the outflow. Hall electric fields make u nonzero immediately outside of the onset location along x. These fields act against electron motion along x, slowing the expansion of the EDR along the outflow



Closing Thoughts

In a nutshell, I describe reconnection as a compression of EM energy density until it reaches spatial scales where ideal MHD is no longer valid. At this scale, out-of-plane electric fields allow the local EM fields to dump energy directly into the particles.

My assumptions are that:

1) EM energy flux moves down gradients in EM energy density
2) At a small enough scale, sharp gradients in u will result in accelerated/energized plasma

Further complications such as guide fields, asymmetric reconnection, etc. are worth considering. Such scenarios would change the initial distribution of u (for example, a guide field means non-zero |B| and u at the center, even before onset).

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