Unsolved Problems in Magnetospheric Physics

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Overcoming Uncertainties in the Relation between Source and Aurora

Gerhard Haerendel

Max Planck Institute for Extraterrestrial Physics,
Garching,Germany

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Principles

Two principles govern structured auroral arcs:

- Arcs are generated to help maximizing the energy dumping from the magnetosphere.
- Structured auroral arcs derive their energy from the release of magnetic shear stresses.

A Classification Scheme

Forces:

(1) Pressure gradient

(2) Inertial forces/flow braking

3) Magnetic shear or normal stresses

Energy extraction:

(a) Release of previously stored free energy

(b) Contemporary build-up and release

Energy conversion mechanisms:

(α) Post-acceleration by parallel potential drops

(β) Energy dumping in topside ionosphere

(α) is realized when the forces act against ionospheric friction

(β) dominates flow braking events

Arc Classification

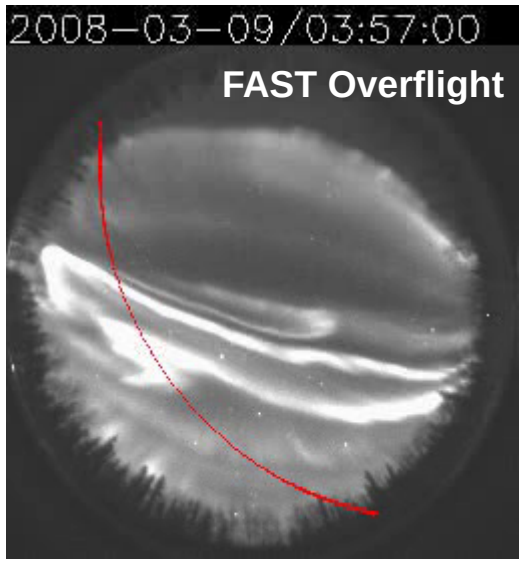
Nine arc types

	Forces			Extraction		Conversion	
	1	2	3	a	b	α	β
Sun-aligned arcs		x			x		x
Growth phase arc			x		x	x	?
Alfvénic arcs		x			x		x
Spirals (winding)		x	x ?		x	x	
Spirals (unwinding)		x	x ?	x		x	
Embedded arcs	x			x		x	
Auroral streamers			x?		x	x	
Breakup arc		x			x		x
AEJ, substorm current wedge			x		x	x	

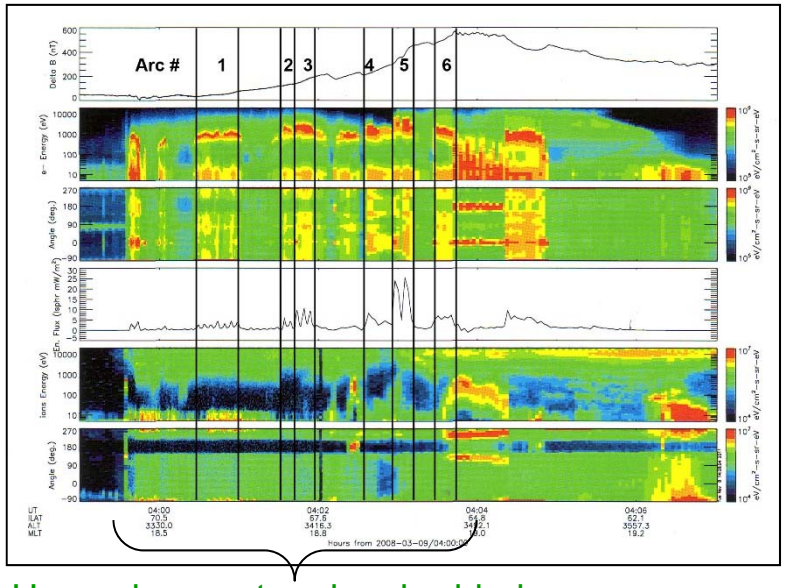
The Case of Embedded Arcs

Pressure gradient, release of stored shear stresses, and energy conversion in parallel potential drops.

Embedded Arcs

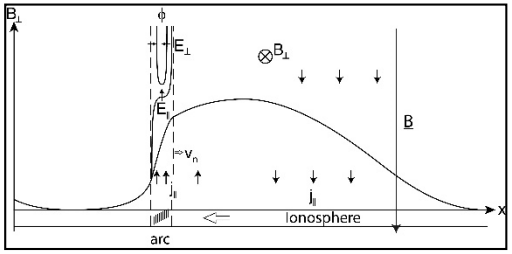


[Haerendel et al. 2012]

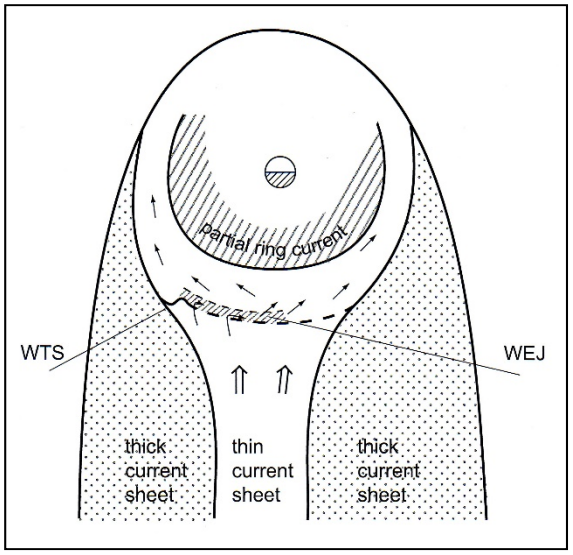


Upward current and embedded arcs

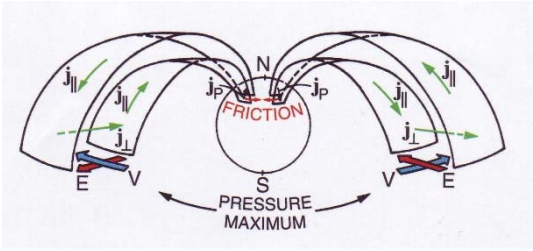
Comparing the released energy flux $\dot{W}_{tot} = \frac{B_{\perp u}^2 - B_{\perp d}^2}{2\mu_0} . \frac{R_w}{\mu_0}$ with the energy conversion rate in the arc $\dot{W}_{arc} = \frac{J_\parallel^2}{K\, w_{arc}^2}$ provided oportunity to check quantitatively the implications of the postulated spontaneous erosion of shear stresses against the measured quantities, as for instance arc width $w_{arc} \cong (R_W\, K)^{-1/2}$ and erosion speed: $v_n = w_{arc}/\tau_{arc}$, with no conflicting results.



The Environment of Embedded Arcs



The plasma entering the magnetosphere continues along the auroral oval. Field-aligned currents of Type II [Boström 1964,1975] are related to the shear stresses driving the convection. Pressure gradient is the driving force storing the energy that is released by the arc [Haerendel 2007]:



$$j_{\parallel} = \frac{B_{ion}}{2\,B_{gen}^{2}}\left(\nabla p \times \underline{B}_{gen}\right)\cdot\nabla\int\frac{d\ell}{B}$$

However, Vasyliunas [1970] claims that pressure gradients can drive only Region 2 currents, i.e. downward in the evening because of the outward increasing flux tube volume. On the other hand, Fujii et al. [1994] find that the Region 1 current carries at best a net current of 25% . 75% are balanced Type II currents.

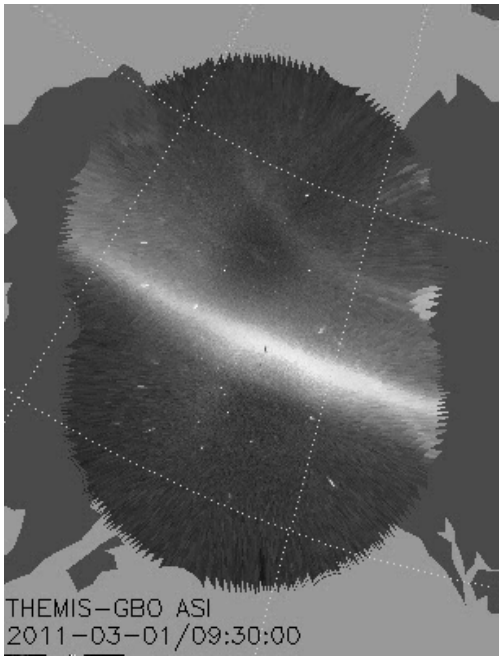
Does the pressure on the poleward side decrease faster than the flux tube volume increases?

The Case of Auroral Streamers

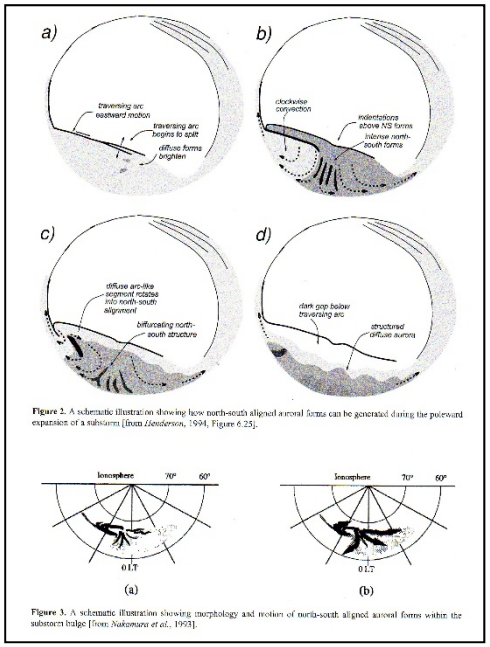
Magnetic stresses?, immediate release, energy dumping into ionosphere

Auroral Streamers

Auroral streamers emerge on the polar cap from poleward boundary intensifications (PBIs) preceding substorm onset and may play a role in the trigger of substorms [Nishimura et al. 2010].



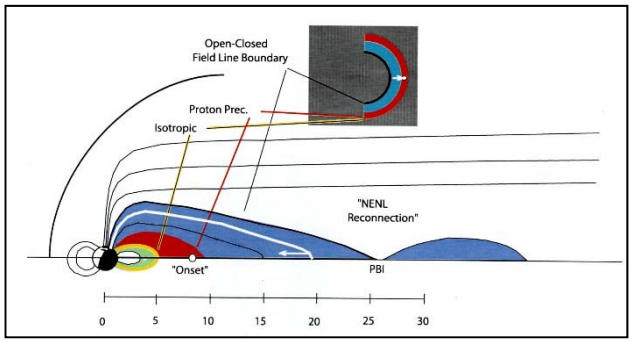
Measurements with the SuperDARN radar [Gallardo-Lacourt et al 2014] confirm an equatorward flow located just to the east of the visible streamer. This suggests a transport of new plasma across the polar cap boundary into the plasma sheet [Nishimura et al. 2010]. Polar cap patches arriving from the dayside may be precursors [Nishimura et al. 2013].



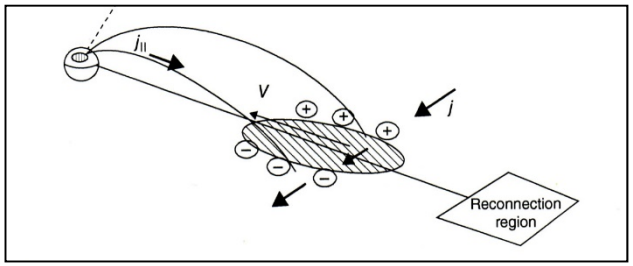
Streamers also appear inside the auroral oval during a substorm as result of plasma entry [Nakamura et al. 1993; Henderson et al. 1994; Haerendel 2015].

The equatorward flow indicates that work is done against ionospheric friction!

The Driver of Auroral Streamers



Is the streamer flow driven by the contraction of flux tubes originally extending to the distant neutral line and after near-Earth reconnection are drastically shortened [Mende et al. 2011]?

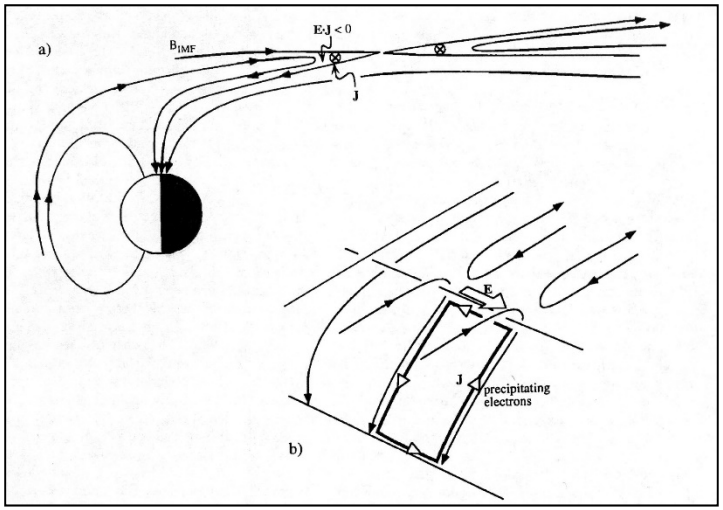


Or are the streamers bubbles of lower plasma pressure as suggested by Nakamura et al. [2001]? Do the diverted external currents connect to field-aligned currents extending into the ionosphere?

Lobe pressure and magnetic tensions join in driving the bubble plasma. However, does the plasma also do work on the ionospheric plasma as the equatorward flow suggests? Kauristie et al. [2000] suggest flow braking and vortex fomation.

The long duration and propagation of the streamers rather suggest a persistent flow channel [Haerendel 2015]. But what is the driver?

By Contrast: Sun-aligned Arcs



Sun-aligned arcs appear during IMF Bz >0.

They are related with anti-sunward flow.

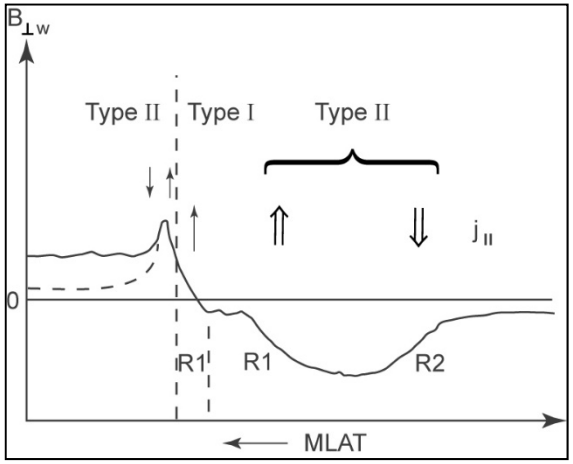
Drag forces (flow braking) exerted by the mantle flow, after lobe reconnection, are transferred to the ionosphere by magnetic shear stresses and do work against the ionospheric friction [Bonnell et al. 1999].

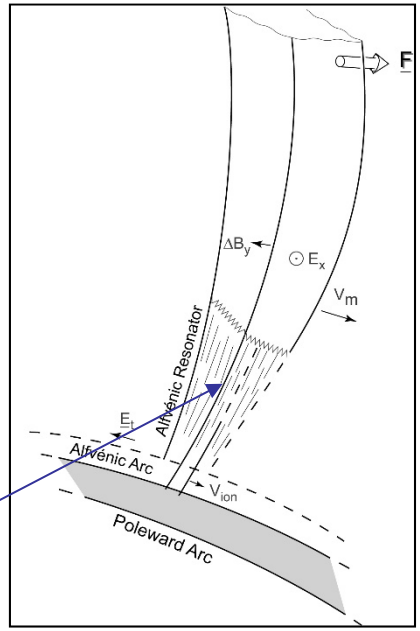
Build-up rather than release of shear stresses!

Two Sources of Kinetic Alfvén Waves

Kinetic Alfvén waves are ubiquitous, but rarely is their origin identified.

Low-altitude Source: Scale-breaking

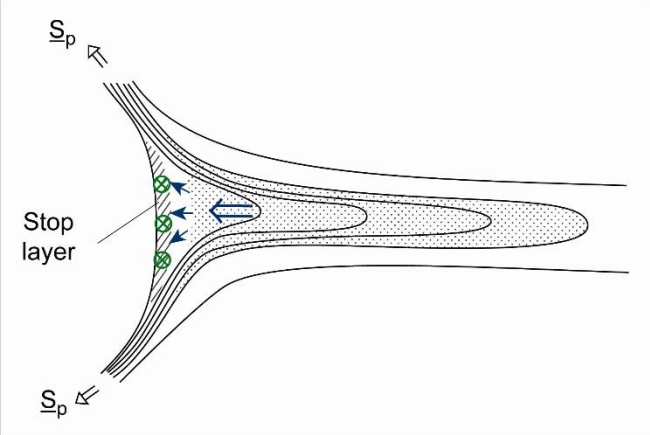


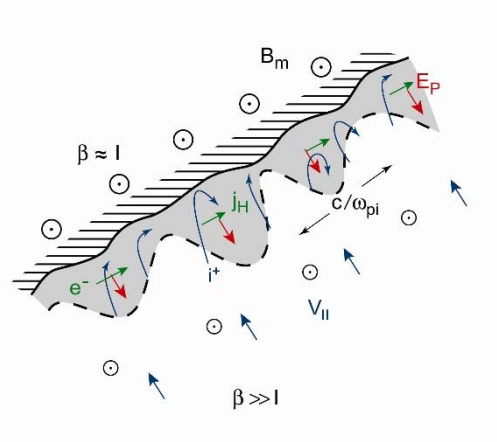


The Alfvénic arcs are embedded in an eastward flow region flanked by balanced FACs .

Small-scale electromagnetic structures (inertial Alfvén waves) are developing from the primary energy inflow by **multiple reflections** in the ionospheric Alfvén resonator and **scale-breaking** [Haerendel and Frey 2014]. The mechanism may be phase mixing [Lysak and Song 2008], tearing instabilities of thin current sheets [Seyler 1990], or turbulent cascade [Chaston et al. 2008]

High-altitude Source: The Stop Layer





The stop layer [Haerendel 2015]:

The flow from the central plasma sheet is stopped abruptly (within about 1 c/ω_{pi}). The momentum extracted from the ions by the electric polarization field is taken up by the magnetic field generated by the Hall current along the stop layer. The small-scale structure arises from balancing ion inflow with electron Hall drift. Each structure is flanked by a pair of anti-parallel FACs and is the source of a downward propagating kinetic Alfvén wave.

Summary

• Two principles govern the generation of structured auroral arcs: Maximiziation of energy dumping and release of magnetic stresses.

• Seven criteria are used for classification of the underlying processes related to forces, energy extraction, and conversion mechanisms. They are meant as a means to identify the source-arc relations.

• Classification of 9 types of arcs shows the important roles of flow braking, immediate energy release, and post-acceleration.

• The closer inspection of two examples, embedded arcs and auroral streamers, demonstrate the still existing uncertainties about the driving forces.

• Two sources of kinetic Alfvén waves are to be found in the ionospheric Alfvén resonator and at the inner boundary of the tail during substorms.