Challenges in the Understanding of Auroral Acceleration Physics

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What We Do Know – A Lot!

- ‘Mono-energetic’ electron precipitation causes the aurora.
- Parallel current plus converging field lines requires a potential drop.
- Both upward and downward currents play a role, but the two regions are different.
- Background parameters: both ionospheric and plasma sheet source populations.
- Alfven waves play a key role.
Early Measurements

- From McIlwain, 1960: “The presence of monoenergetic electrons strongly suggests an electrostatic acceleration mechanism.”

Kletzing et al., [1998]
To get $j_{||}$ to the ionosphere, a potential drop was required.

- Magnetic mirror below and electrostatic mirror above explained observations.

\[
j_{||,i} (\Delta \Phi) = -en_m \left( \frac{k_B T}{2\pi m_e} \right)^{\frac{1}{2}} R_B \left[ 1 - \left( 1 - R_B^{-1} \right) \exp \left\{ - \frac{e \Delta \Phi}{k_B T_m (R_B - 1)} \right\} \right],
\]

Knight, [1973]
1. Upward current region
   $\mathbf{J}$

2. Converging electrostatic shocks.
   $\mathbf{E} \quad \mathbf{E}$

3. Large-scale density cavity
   $n_e$

   $\mathbf{e}^-$

5. Up-going ion beams. Ion conics.
   $\mathbf{i}^+$

6. Large-amplitude ion cyclotron waves and electric field turbulence.

7. Nonlinear time-domain structures associated with ion wave modes.

8. AKR source region.

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**Upward Current Region**

- Aurora
- Downgoing Electrons
- Converging Shocks
- Upgoing Ion Beam
- Strike atmosphere, produce visible light
- Downgoing Electron: $e^-$
- Upgoing Current Downward accelerated electrons
- $\mathbf{J}$
Downward Current Region

1. Downward current region.
   \[ \downarrow \downarrow \mathbf{J} \]

2. Diverging electrostatic shocks.
   \[ \mathbf{E} \quad \mathbf{E} \]

3. Small-scale density cavities.
   \[ n_e \]

   \[ \uparrow \mathbf{e}^- \quad \mathbf{E} \]

5. Ion heating transverse to \( \mathbf{B} \). Energetic ion conics.
   \[ \mathbf{i}^+ \]

6. ELF electric field turbulence. Ion cyclotron waves.


8. VLF saucer source \( \mathbf{J} \).

Inverse Aurora

Upgoing Electrons

Hot ion conic outflow

Dowgoing Hot plasma sheet ions

No visible light "Black Aurora"

Dowgoing Current

Upward accelerated electrons
Densities and Temperatures

**Acceleration Region**

\[ n(z) = n_0 e^{-(z-z_0)/h} + n_1 z^{-1.55} \]

Kletzing et al., [1998]

**Source Region**

Kletzing et al., [2003]
Alfven Waves

- Time dispersed electrons indicate Alfven waves.
- FAST survey shows they are ubiquitous.

Chen et al., [2005]

Chaston et al., [2007]
What We Don’t Know

- What is the distribution of the potential drop along the magnetic field?
- How/Do inertial scale Alfven waves evolve to establish a quasi-static potential drop?
- How do we construct a self-consistent model of the plasma along a field line.
- What are the details of current closure through the ionosphere.
Potential Along Field Line

- How to determine this?
- Particle distributions: Chiu and Schultz, [1978], Ergun, [2004]
- Direct measurements?

E_{||} \quad E_{\perp} \ni (>5\text{keV})
electrons
ions
waves

Ergun, [2004]
Measuring Potential Drop

- How to determine this?
- Particle distributions: Chiu and Schultz, [1978], Ergun, [2004]
- Direct measurements?
Alfven Waves & Stable Arcs

- What is the connection?
- Do Alfven waves evolve to ‘stable’ arcs?
- If so, how does this happen?

Lysak, [1985]
**Acceleration Region Model**

**Then**

- Borovsky and Joyce, [1983]
- Only small region of field line modelled.
- Not self-consistent.
- Current or voltage driven?

**Now**

- Newman et al., [2008]
- No suprathermal electrons
- Electrostatic potential (X2)
- Anti-earthward electrons
- Earthward electrons
- Electrostatic potential
- Log10(dE/dx)
- Energy flux
Current Closure

- Can ionization, electric fields and currents be self-consistently modeled?
- Downward region should be much lower density, but rarely observed.

Marklund et al., [1997]
Problems to Work On

- What is the distribution of the potential drop along the magnetic field? – *Need multipoint measurements*

- How/Do inertial scale Alfven waves evolve to establish a quasi-static potential drop? - *More realistic models needed*

- How do we construct a self-consistent model of the plasma along a field line. – *Large simulations?*

- What are the details of current closure through the ionosphere. – *More measurements and models.*
That’s all folks!