Upward and Downward $E_{||}$ in the Auroral Region: Comparison Between Theory and Experiment

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Abstract

Magnetic field-aligned electric fields are closely associated with ion acceleration in both the downward and upward auroral current regions. In the upward current region, the parallel electric field accelerates ions into beams, while in the downward current region the parallel electric field traps transversely accelerated ions in a "pressure cooker". These parallel electric fields have been studied with a semi-empirical model based on a system of Fokker-Planck and Poisson equations in one spatial dimension. We compare the predictions of this model to data from a nightside auroral oval crossing of FAST in January 1997. In the downward current region, transverse ion acceleration by broad-band extremely low frequency turbulence plays a key role in supporting the $E_{||}$. We find that the upward current region includes three altitude regions: (1) a low-altitude region, in which cold ionospheric electrons reduce the total parallel potential drop to a few tenths of a volt and an inverted-V ion conic is observed; (2) a thin (few kilometers or less) transition region in which the cold electrons are expelled and the ion conic is accelerated into a beam, and (3) a high-altitude region consisting only of the ion beam and hot magnetospheric electrons. This model explains several of the features observed in the data.

Motivation

• Magnetic field-aligned electric fields play a key role in auroral acceleration

• Electric fields can be self-consistently supported by differential anisotropy of particles (Alfvén and Fälthammar, 1963) or by gravity (Pannekoek, 1922; Rosseland, 1924)

• Observational evidence suggests fields may be concentrated over small spatial scales, but most simulation studies suggest an extended potential drop

Method

- Specify kinetic boundary conditions at magnetospheric and ionospheric boundaries for ionospheric and magnetospheric ions, electrons

- Model turbulent heating semi-empirically based on data

- Self-consistently solve time-independent Fokker-Planck-Poisson system of equations in one dimension

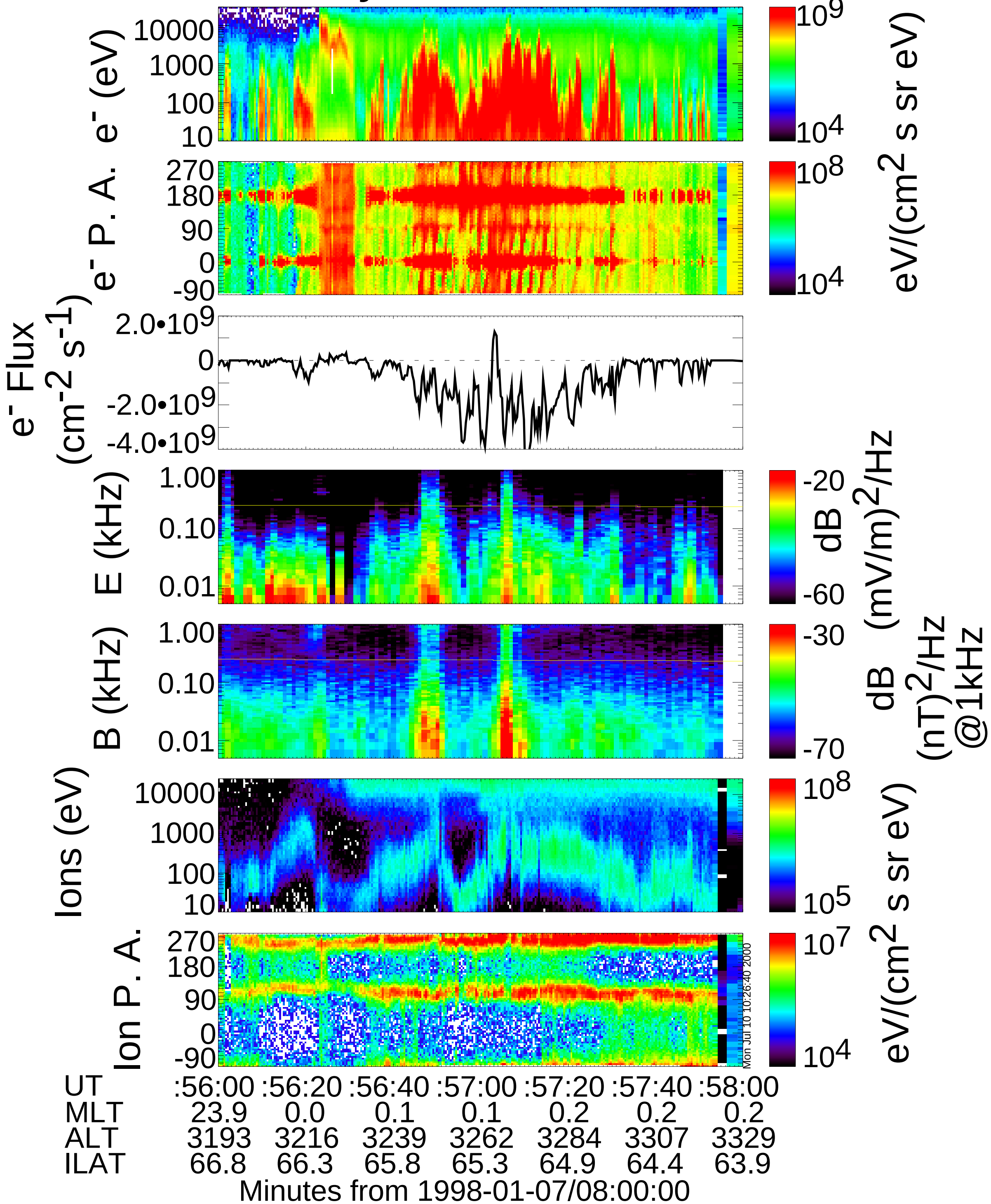
- Both multimoment fluid and kinetic versions of the model can be run

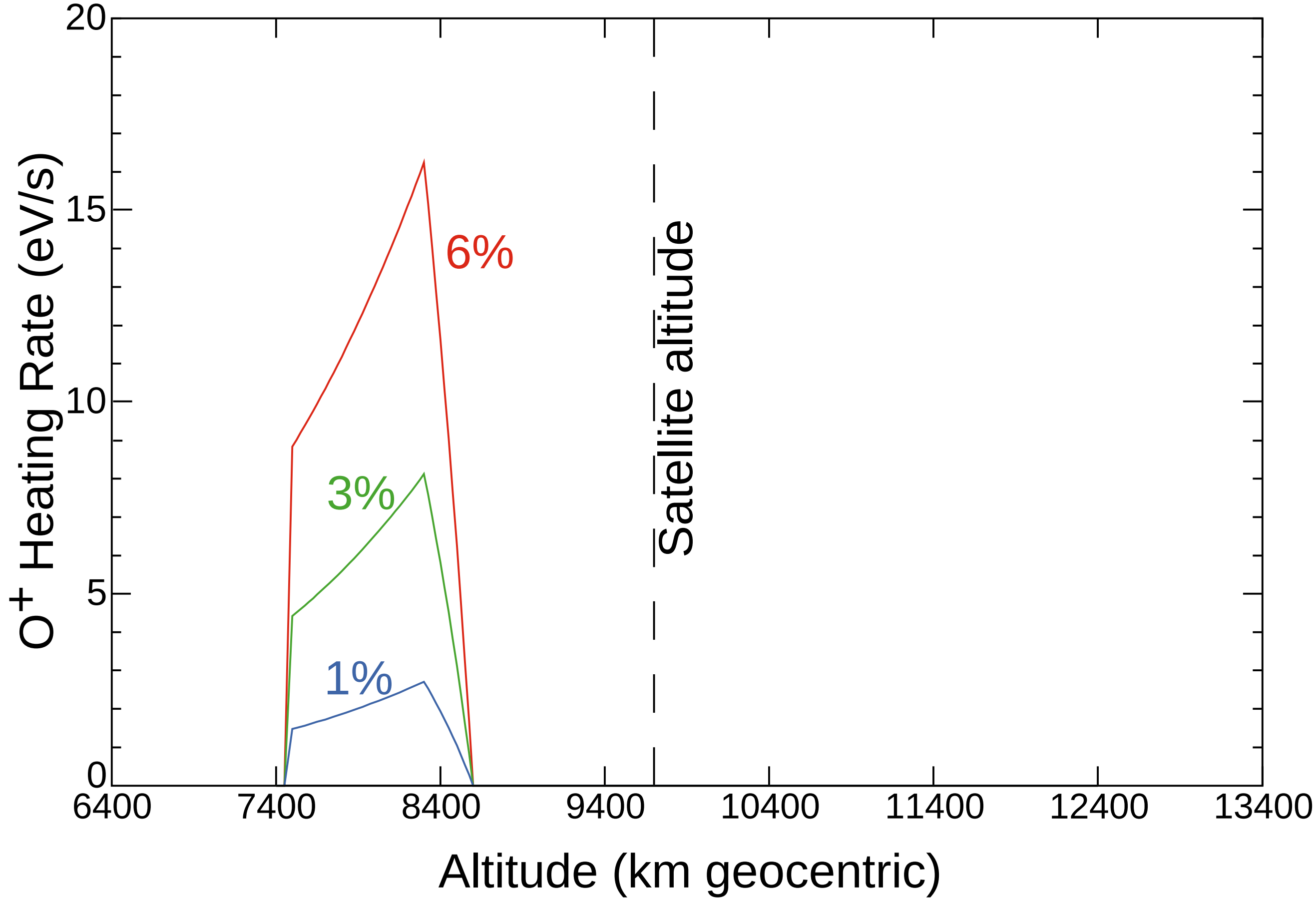
Downward Current Region

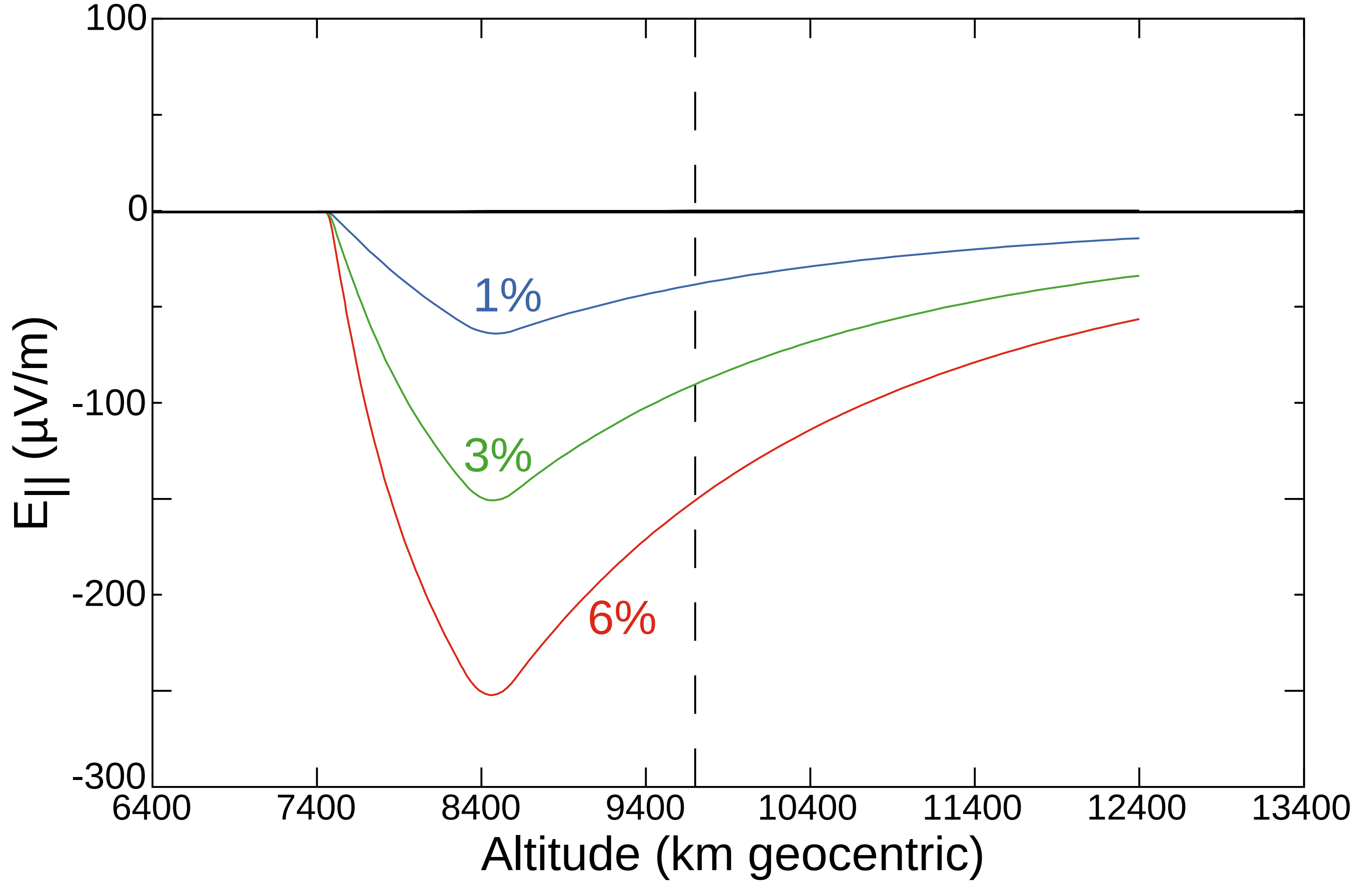
- “Pressure cooker” effect: Downward $E_{||}$ which accelerates electrons (Carlson *et al.*, 1998) traps ions, enhancing energization (Gorney *et al.*, 1985) and equalizing mass-dependent transverse acceleration (Lund *et al.*, 1999)

- Self-consistent model has reproduced features of cusp ion conics from S3-3 (Jasperse, 1998) and Freja (Jasperse and Grossbard, 2000)

1997 January 31   FAST Orbit 5451




20
15
10
5
0
6400
7400
8400
9400
10400
11400
12400
13400
O+ Heating Rate (eV/s)
Altitude (km geocentric)
6%
3%
1%
Satellite altitude



100
0
-100
-200
-300
6400
7400
8400
9400
10400
11400
12400
13400
Altitude (km geocentric)
$E_{||}$ (μV/m)
1%
3%
6%

Comparison of Data and Theory

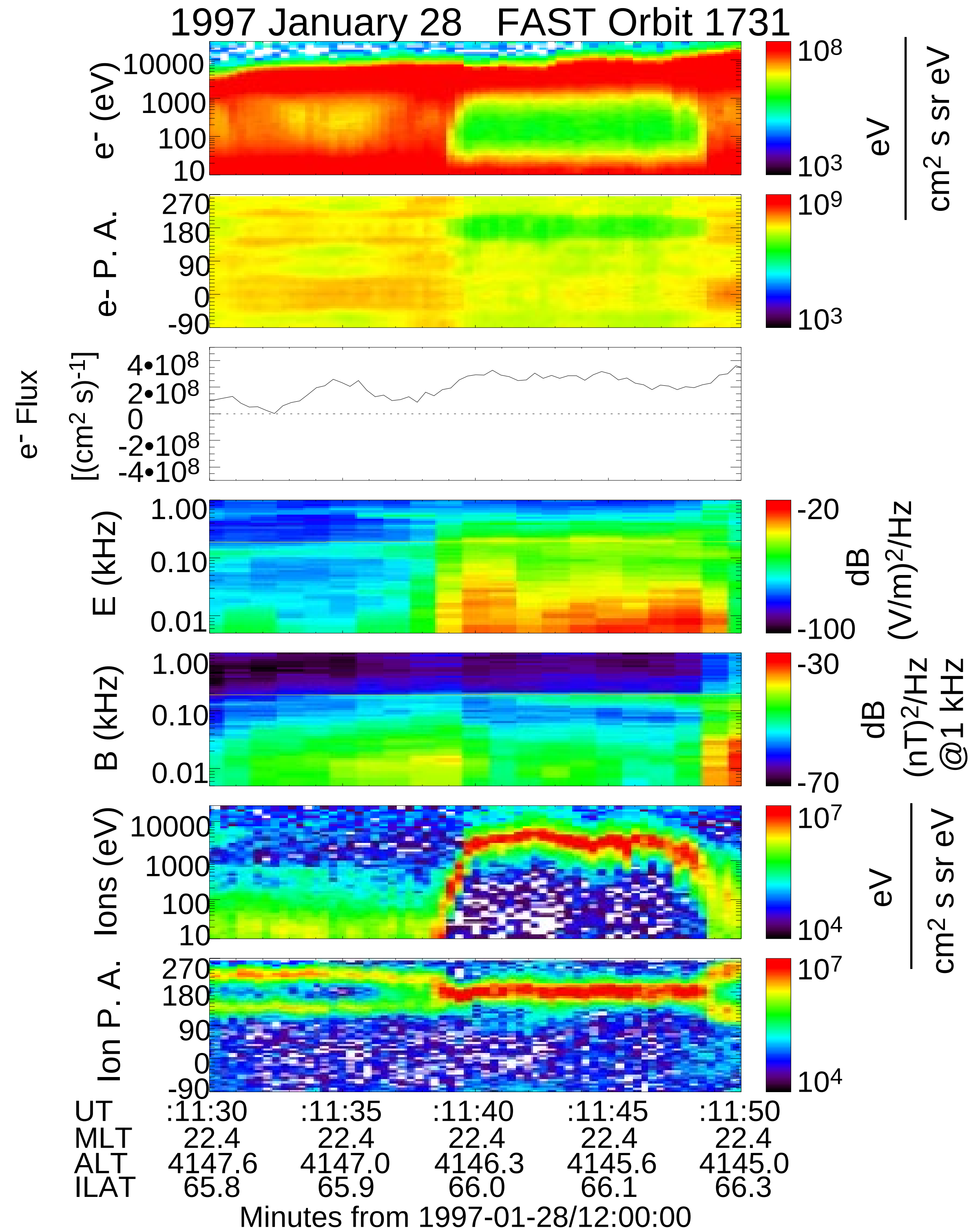
Quantity	Ions (O^+)		Electrons	
	Data	Theory	Data	Theory
n (cm^{-3})	5.3	6.0	5.6	6.0
u (km/s)	19	22	6.1×10^3	4.4×10^3
$w_\perp$ (eV)	280	400	≤1	0.45
$w_{\|\|}$ (eV)	64	90	220	250
$T_{\|\|}$ (eV)	65	100	240	390
E_c (eV)			460	220
$j_{\|\|}$ ($\mu A/m^2$)			-5.4	-4.3
$\Delta\phi_{\|\|}$ (V)			460	230
$E_{\|\|}$ ($\mu V/m$)				-90

Upward Current Region

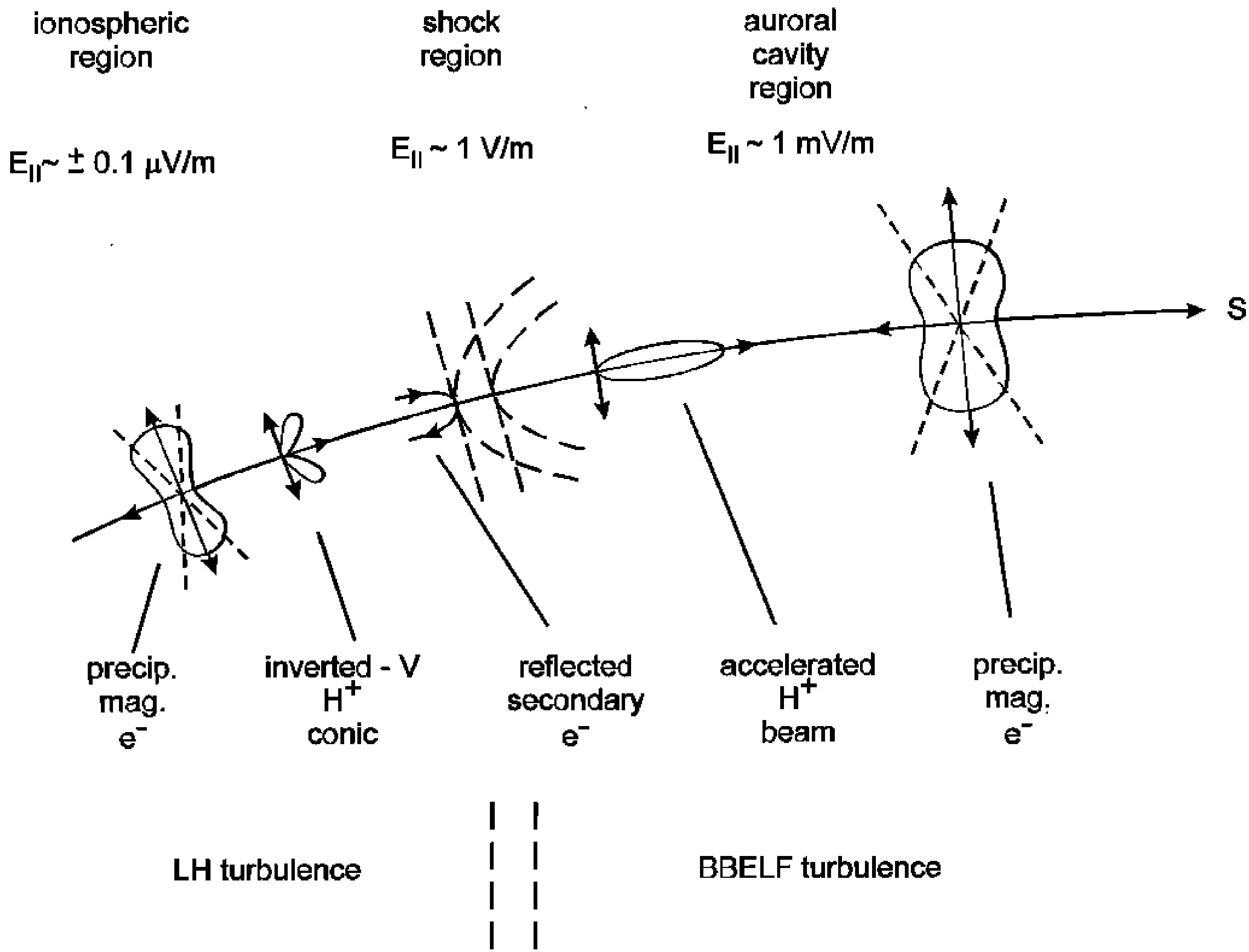
• Parallel electric field accelerates electrons downward and ions upward

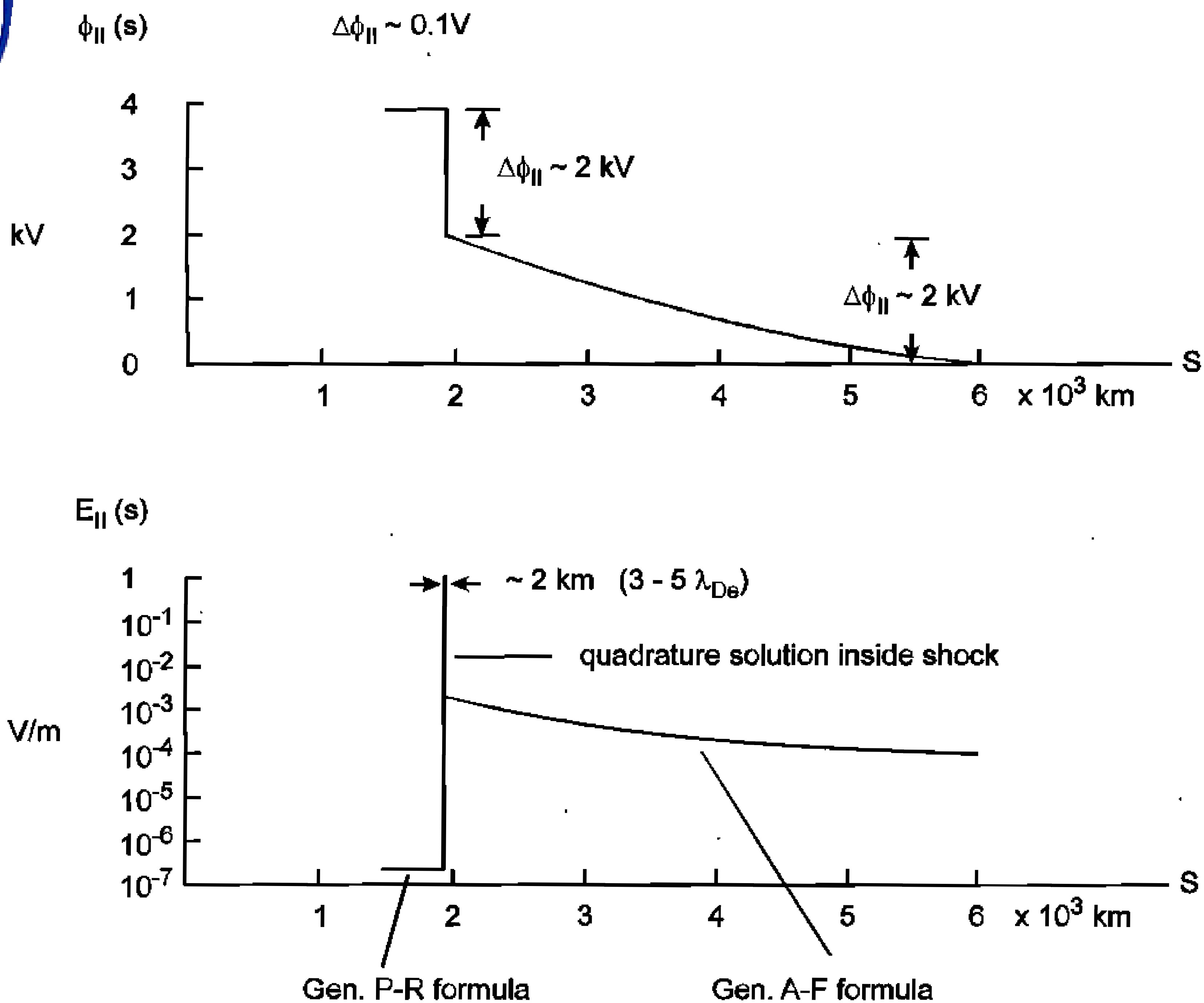
• No cold plasma in ion beam regions (Strangeway *et al.*, 1998; McFadden *et al.*, 1999)

• Evidence of oscillatory inverted-V potential (Arnoldy *et al.*, 1999) implies thin bottomside structure (limited by Alfvén transit time at oscillation frequency ~$f_{cH}/2$)

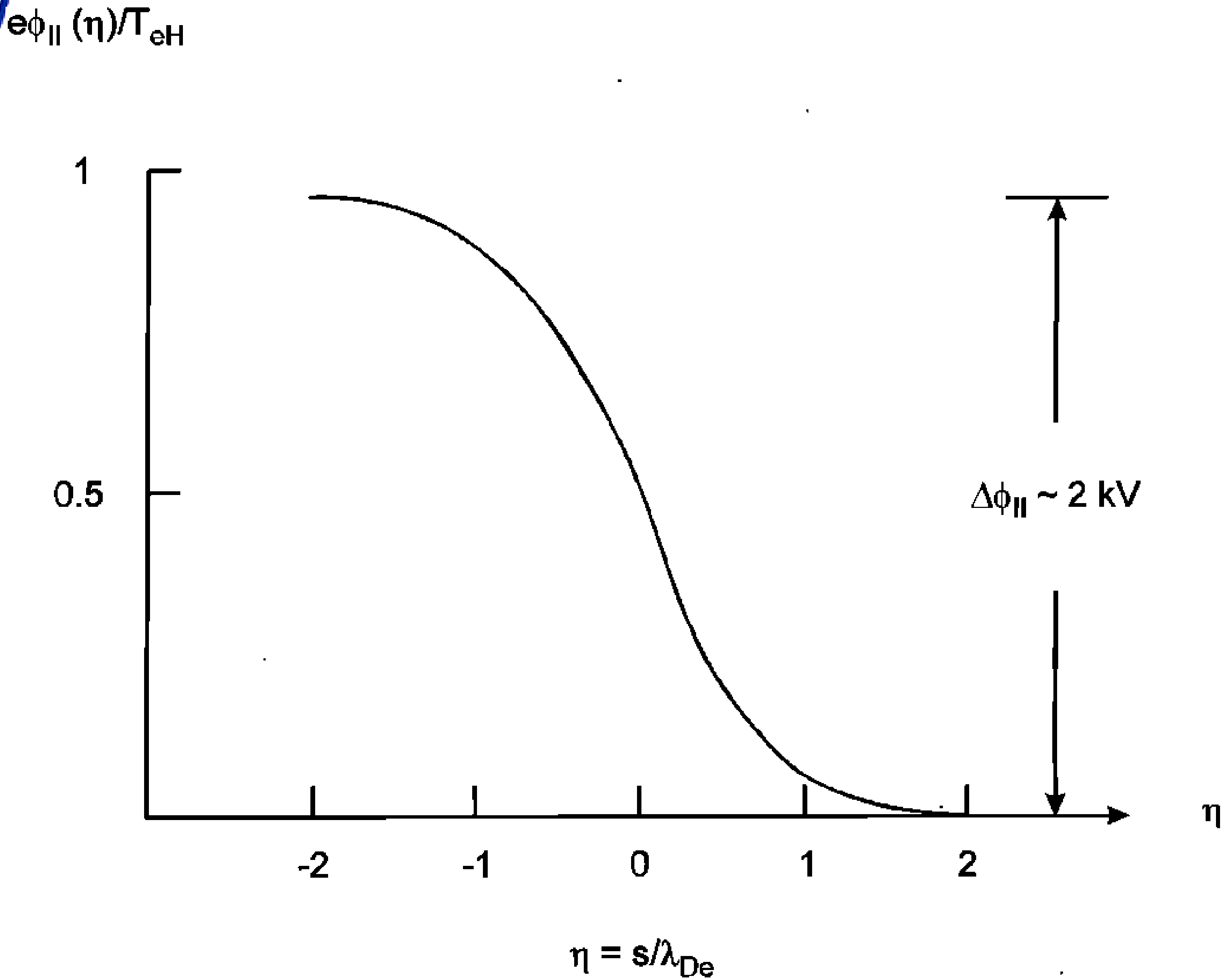


1997 January 28 FAST Orbit 1731
e- (eV)
10000
1000
100
10
e- P. A.
270
180
90
0
-90
e- Flux [(cm2 s)-1]
4•10^8
2•10^8
0
-2•10^8
-4•10^8
E (kHz)
1.00
0.10
0.01
dB (V/m)2/Hz
-20
-100
B (kHz)
dB (nT)2/Hz @1 kHz
-30
-70
Ions (eV)
Ion P. A.
eV / cm2 s sr eV
10^8
10^3
10^9
10^7
10^4
UT :11:30 :11:35 :11:40 :11:45 :11:50
MLT 22.4 22.4 22.4 22.4 22.4
ALT 4147.6 4147.0 4146.3 4145.6 4145.0
ILAT 65.8 65.9 66.0 66.1 66.3
Minutes from 1997-01-28/12:00:00


ionospheric region
$E_{||} \sim \pm 0.1\ \mu V/m$
shock region
$E_{||} \sim 1\ V/m$
auroral cavity region
$E_{||} \sim 1\ mV/m$
S
precip. mag. e^-
inverted - V H^+ conic
reflected secondary e^-
accelerated H^+ beam
precip. mag. e^-
LH turbulence
BBELF turbulence



$\phi_{||}$ (s)
$\Delta\phi_{||} \sim 0.1$V
kV
4
3
2
1
0
$\Delta\phi_{||} \sim 2$ kV
$\Delta\phi_{||} \sim 2$ kV
1
2
3
4
5
6
x 10^3 km
S
$E_{||}$ (s)
V/m
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
~ 2 km (3 - 5 λ_{De})
quadrature solution inside shock
1
2
3
4
5
6
x 10^3 km
S
Gen. P-R formula
Gen. A-F formula



$e\phi_{\parallel}(\eta)/T_{eH}$
1
0.5
$\Delta\phi_{\parallel} \sim 2$ kV
-2
-1
0
1
2
η
$\eta = s/\lambda_{De}$

Discussion

- Models reproduce many features observed in FAST data
- Empirical closure would improve accuracy of model
- Self-consistent, steady-state shocklike solution exists in upward current region

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