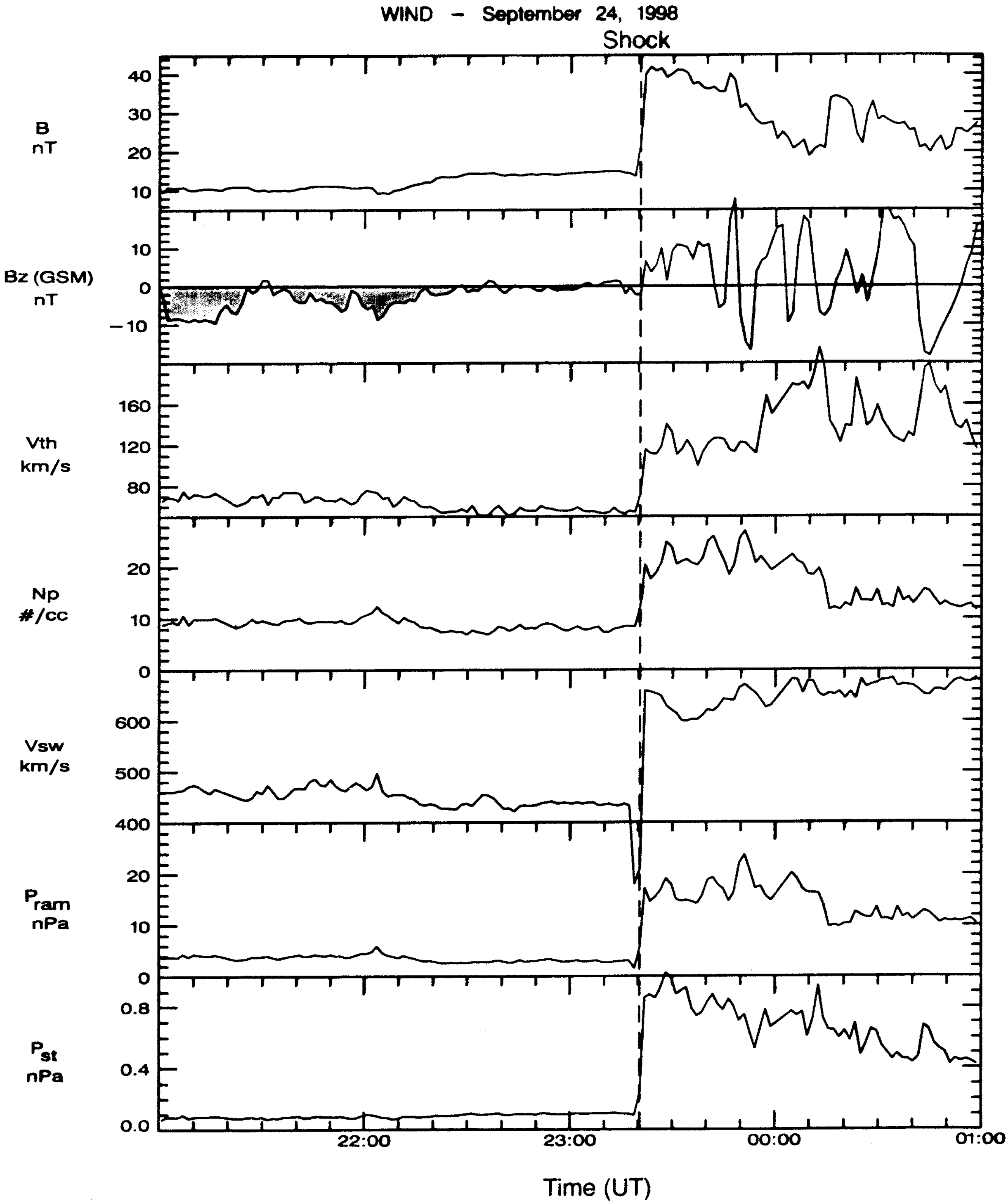
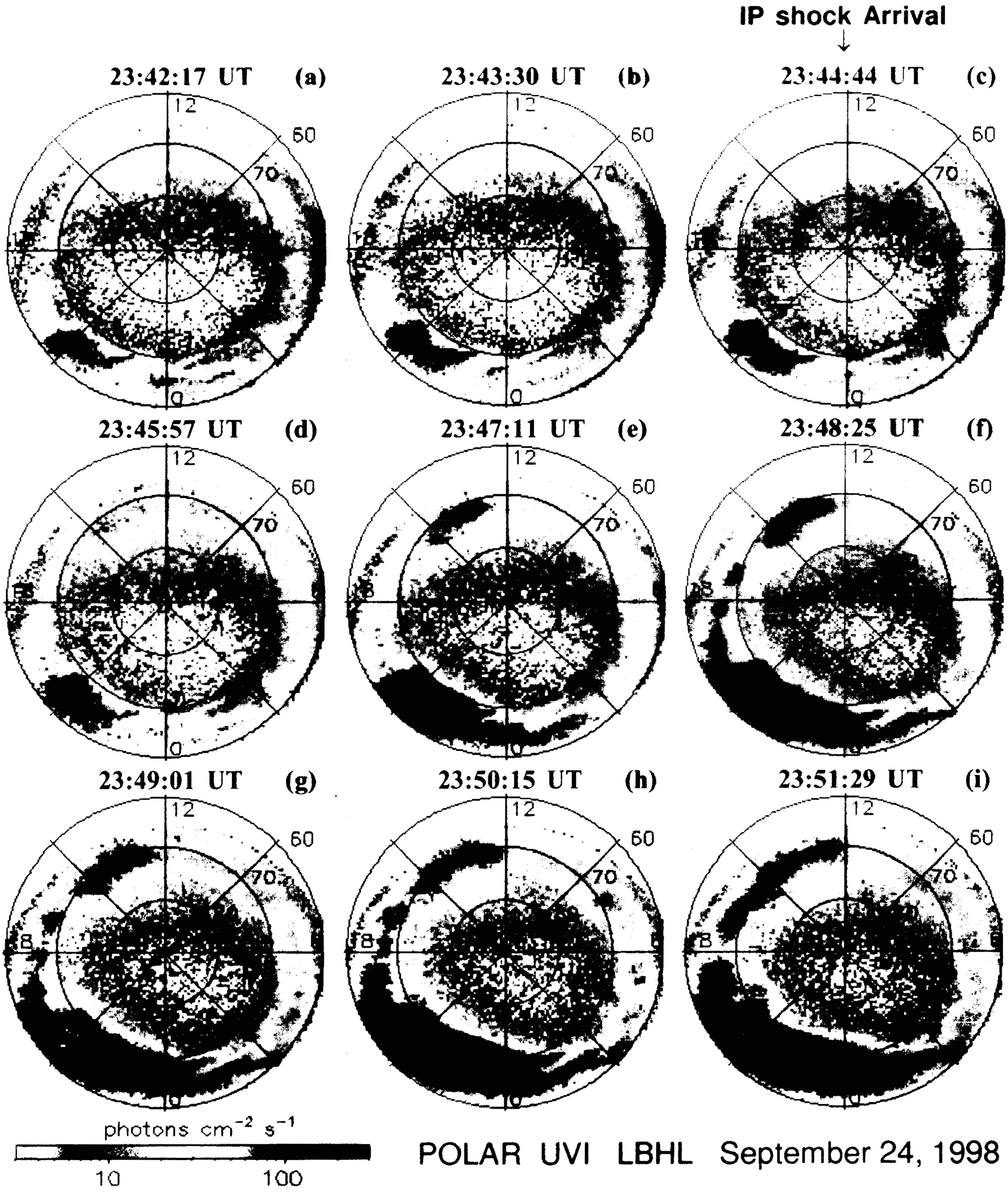
INTERPLANETARY SHOCK TRIGGERING OF AURORAL SUBSTORM ACTIVITY: A MECHANISM

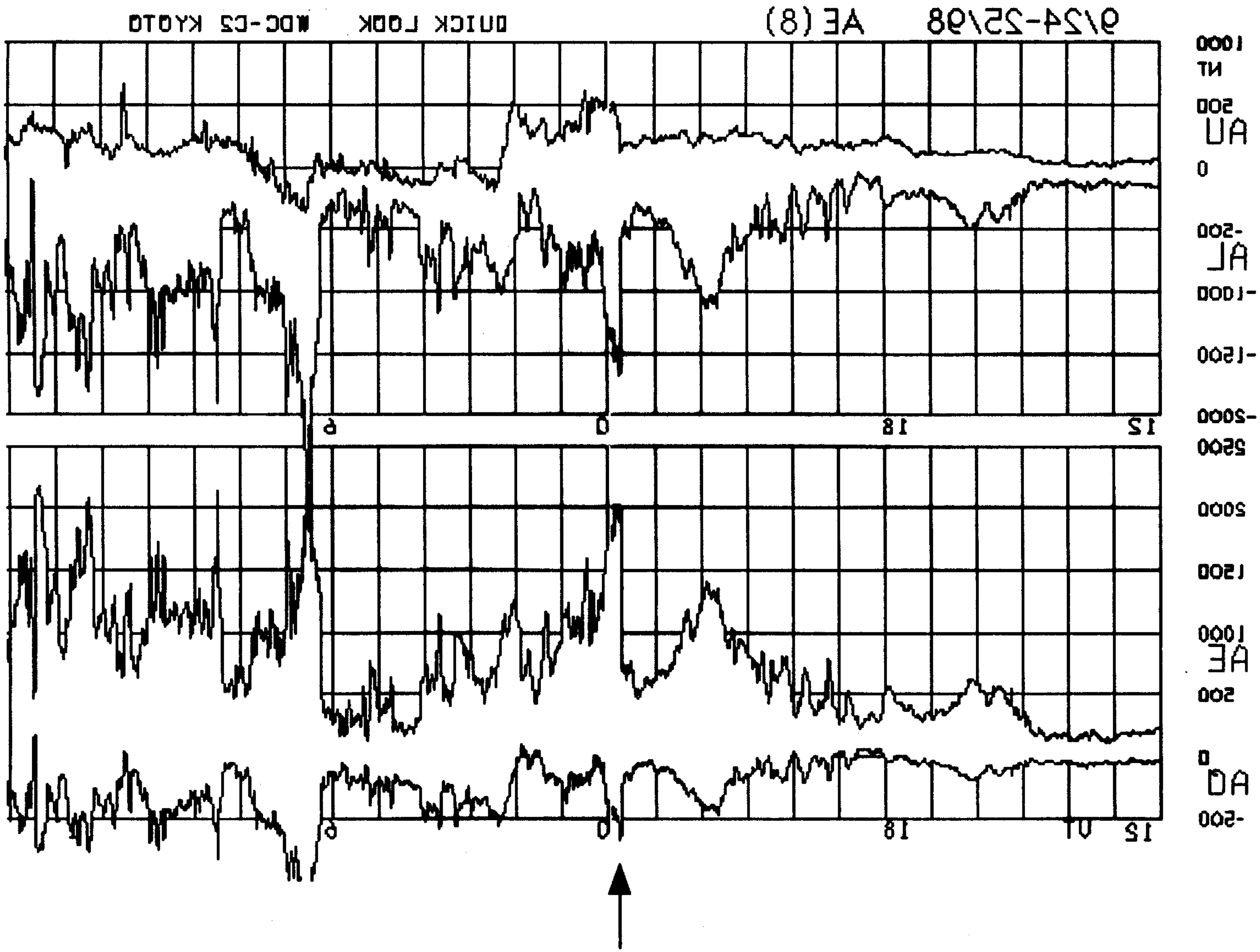
B. T. Tsurutani (1), **X.-Y. Zhou** (1), J. K. Arballo (1) and G. S. Lakhina (2)
(1) Jet Propulsion Laboratory, Pasadena, California, (2) Indian Institute of Geomagnetism, Colaba, Mumbay/Bombay, India.
btsurutani@jplsp2.jpl.nasa.gov

We use 1997-1998 WIND solar wind data and POLAR UV imaging data to study magnetospheric responses and substorm triggering mechanisms during and after interplanetary (IP) shock events. The nightside auroral responses are classified into three types: substorm expansion phase (SS) (or substorm further intensification) events, pseudobreakup (PB) events, and quiescent (QE) events. It is found that the solar wind precondition determines the causes of the different auroral responses, with a ~ 1.5 hr "precondition" (upstream of the IP shock) giving the best empirical results. The upstream IMF B_z is strongly southward prior to substorm triggerings (44% of all events), the IMF B_z is ~ 0 nT for PB triggerings (39% of all events), and the IMF is almost purely northward for quiescent events (17%). A magnetotail-compression substorm triggering model is developed and presented. This model uses dayside magnetic reconnection to load the near-Earth plasma sheet and a current disruption mechanism to unload the stored energy. We call this model a Dripping, Tilting Bucket (DTB) model.

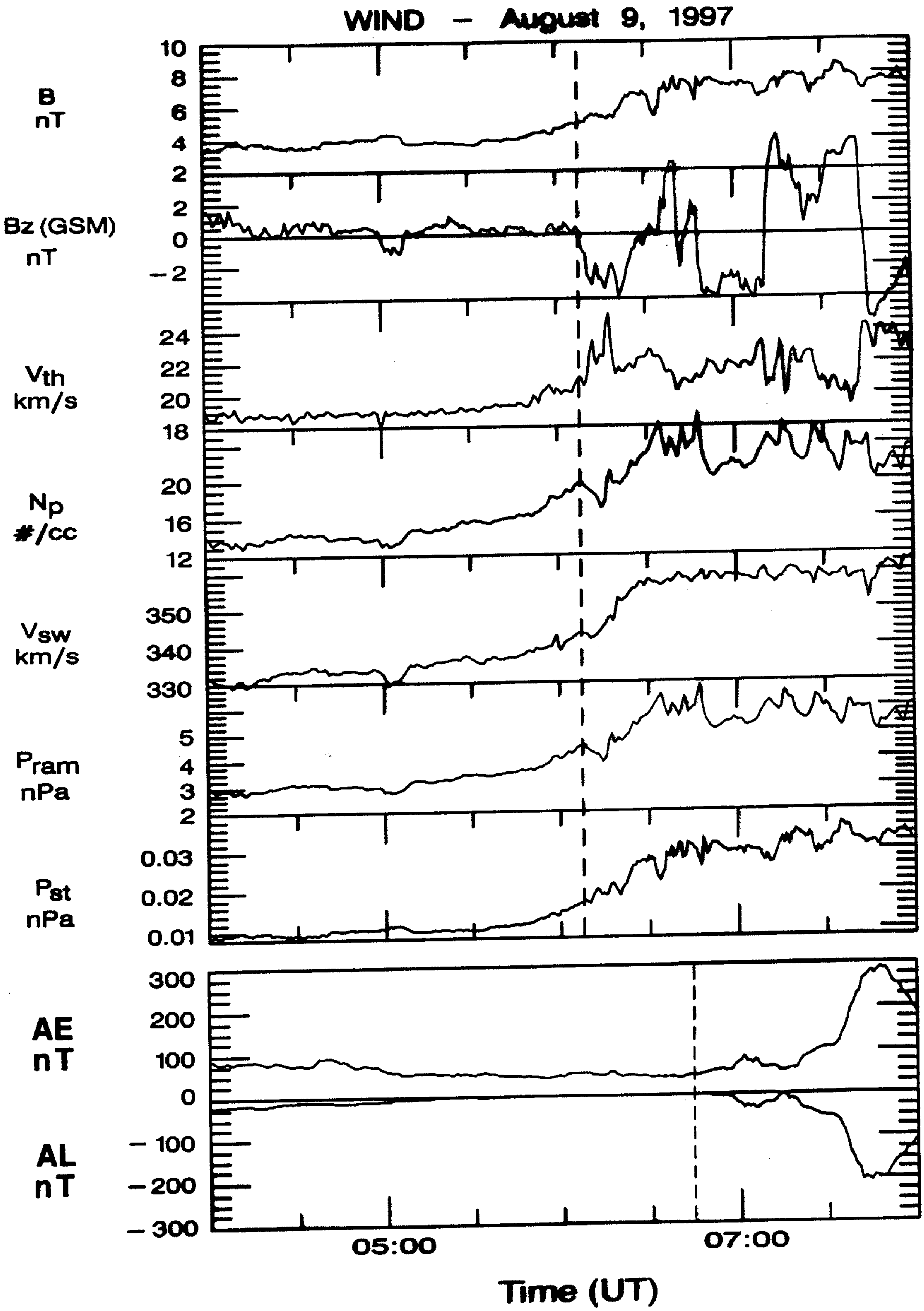


WIND - September 24, 1998
Shock
B
nT
Bz (GSM)
nT
Vth
km/s
Np
#/cc
Vsw
km/s
P ram
nPa
P st
nPa
22:00
23:00
00:00
01:00
Time (UT)

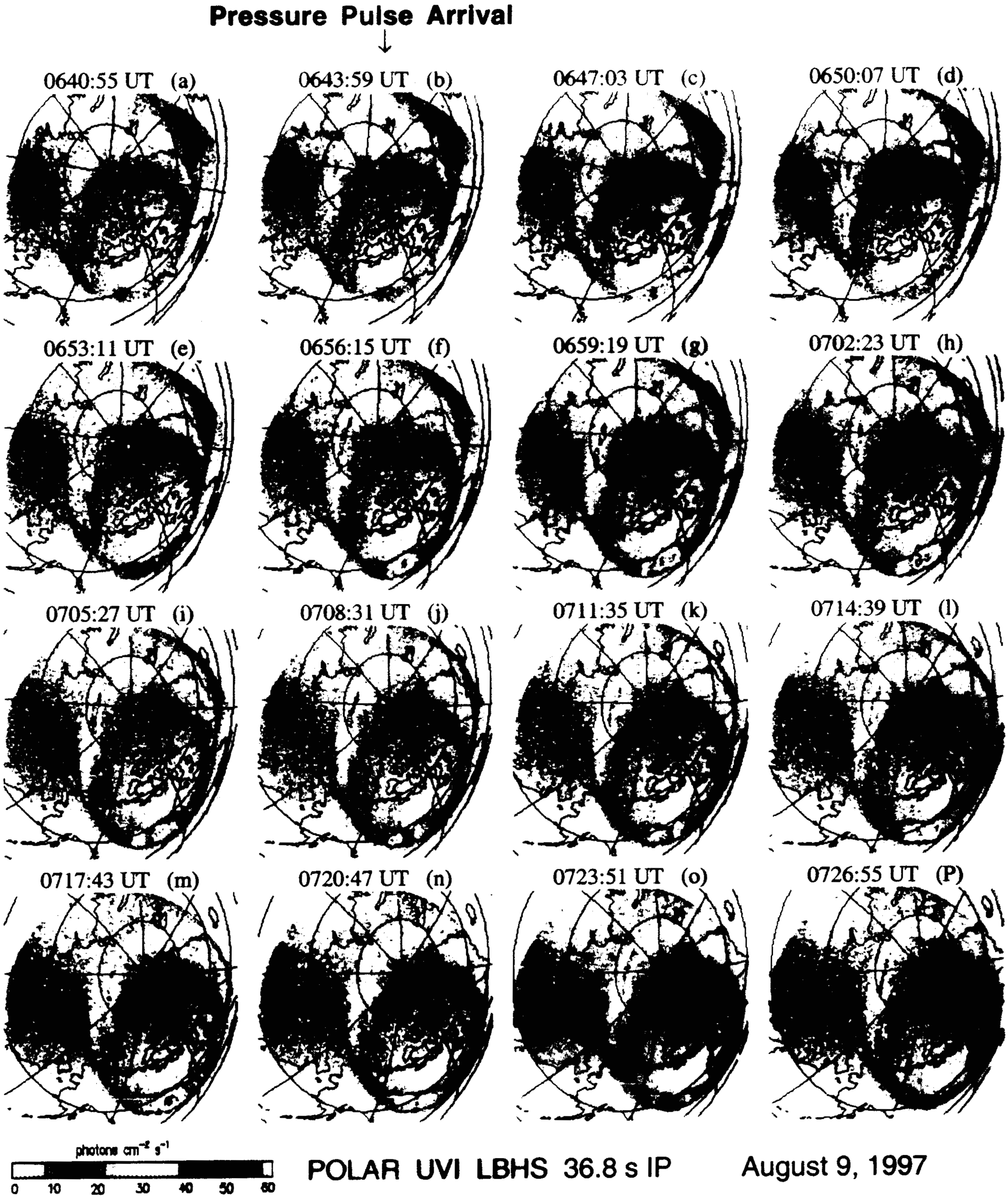

IP shock Arrival
23:42:17 UT (a)
23:43:30 UT (b)
23:44:44 UT (c)
23:45:57 UT (d)
23:47:11 UT (e)
23:48:25 UT (f)
23:49:01 UT (g)
23:50:15 UT (h)
23:51:29 UT (i)
12
60
70
18
0
photons cm^{-2} s^{-1}
10
100
POLAR UVI LBHL September 24, 1998



IP shock triggered
substorm intensification

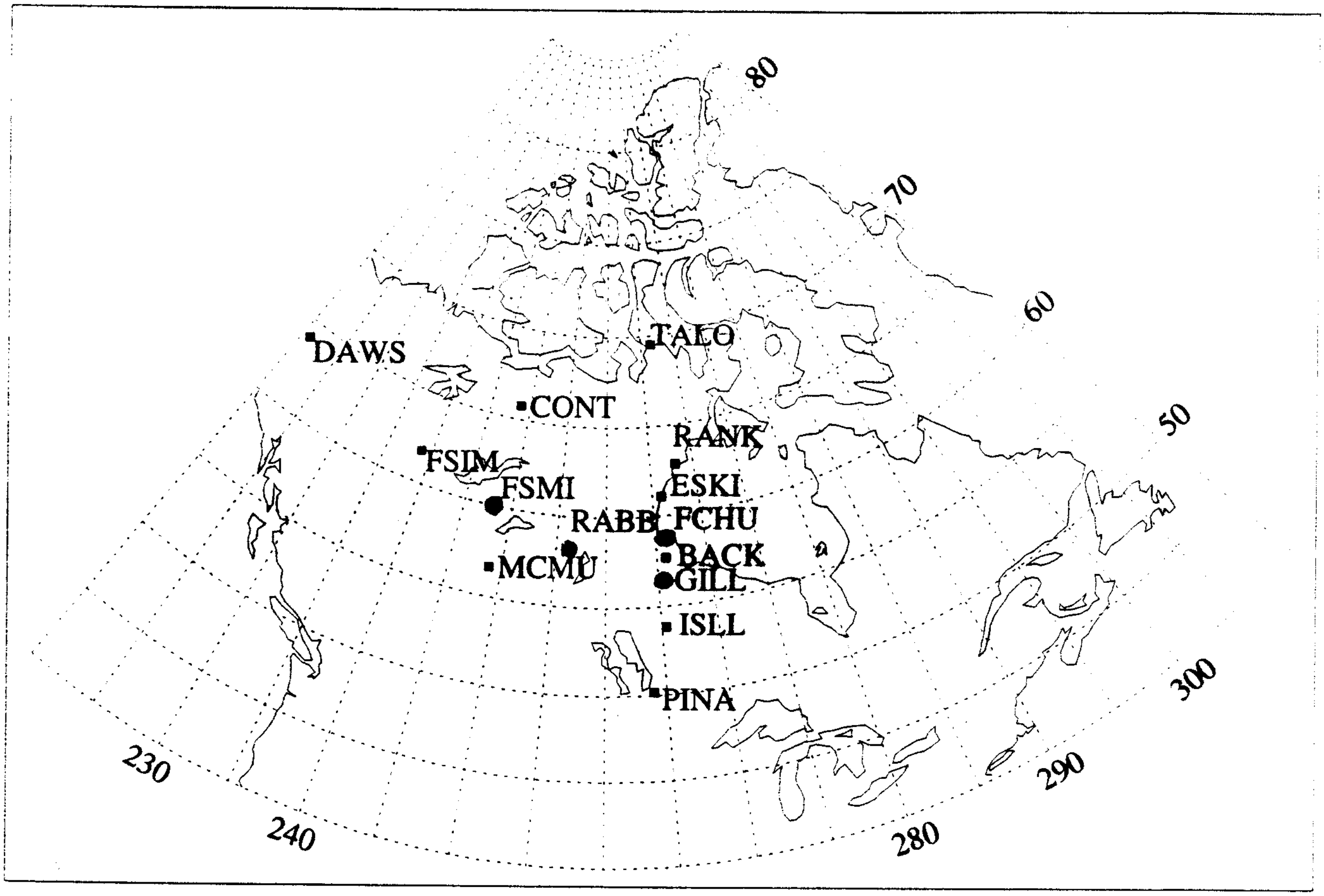


WIND – August 9, 1997
B
nT
10
8
6
4
2
Bz (GSM)
nT
2
0
−2
Vth
km/s
24
22
20
18
Np
#/cc
20
16
12
Vsw
km/s
350
340
330
Pram
nPa
5
4
3
2
Pst
nPa
0.03
0.02
0.01
AE
nT
300
200
100
0
AL
nT
−100
−200
−300
05:00
07:00
Time (UT)



Pressure Pulse Arrival
0640:55 UT (a)
0643:59 UT (b)
0647:03 UT (c)
0650:07 UT (d)
0653:11 UT (e)
0656:15 UT (f)
0659:19 UT (g)
0702:23 UT (h)
0705:27 UT (i)
0708:31 UT (j)
0711:35 UT (k)
0714:39 UT (l)
0717:43 UT (m)
0720:47 UT (n)
0723:51 UT (o)
0726:55 UT (P)
photons cm⁻² s⁻¹
0 10 20 30 40 50 60
POLAR UVI LBHS 36.8 s IP
August 9, 1997

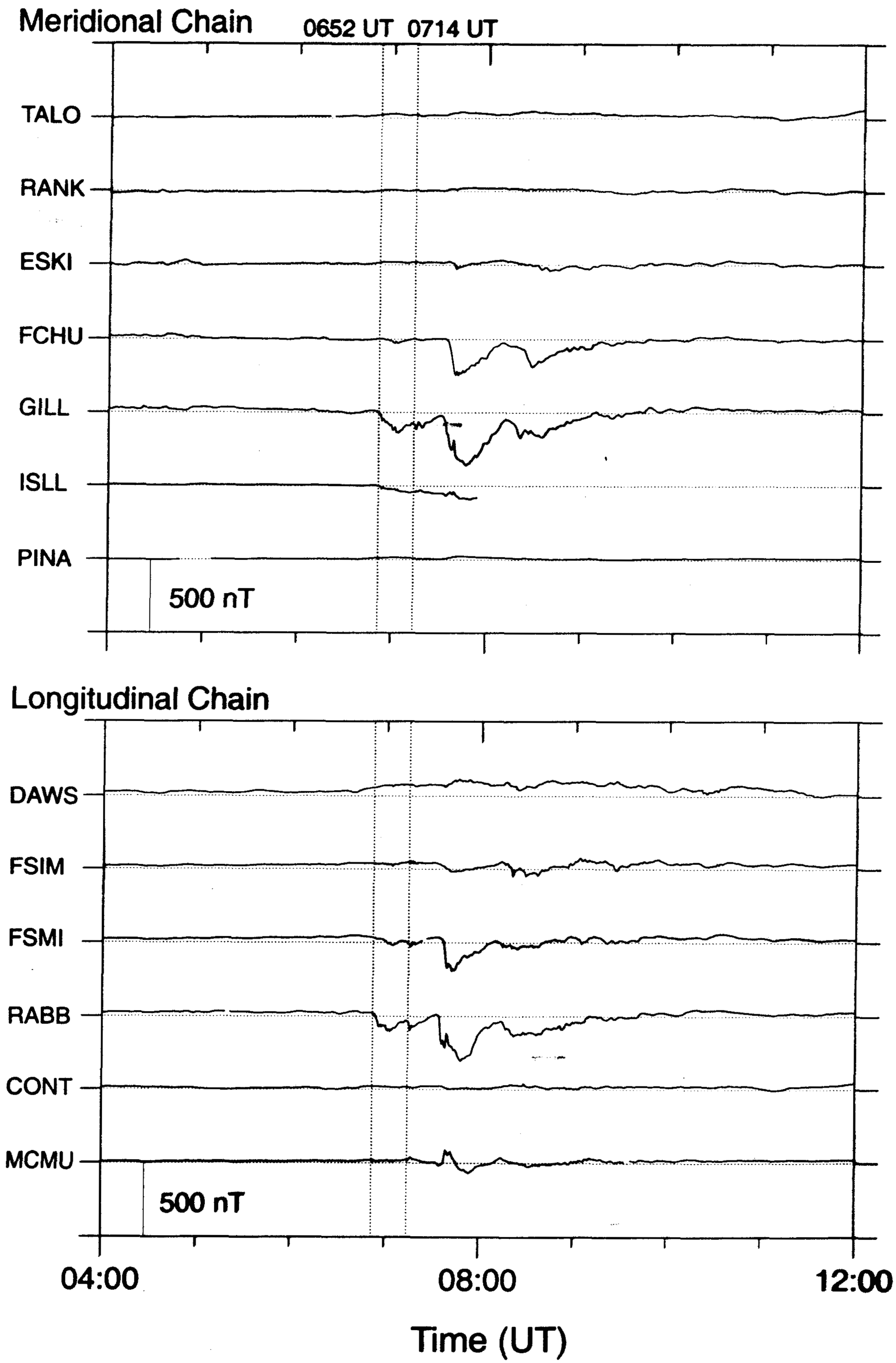
(By courtesy of Dr. Terry Hughes of CANOPUS team)



Magnetometer Site Coordinates

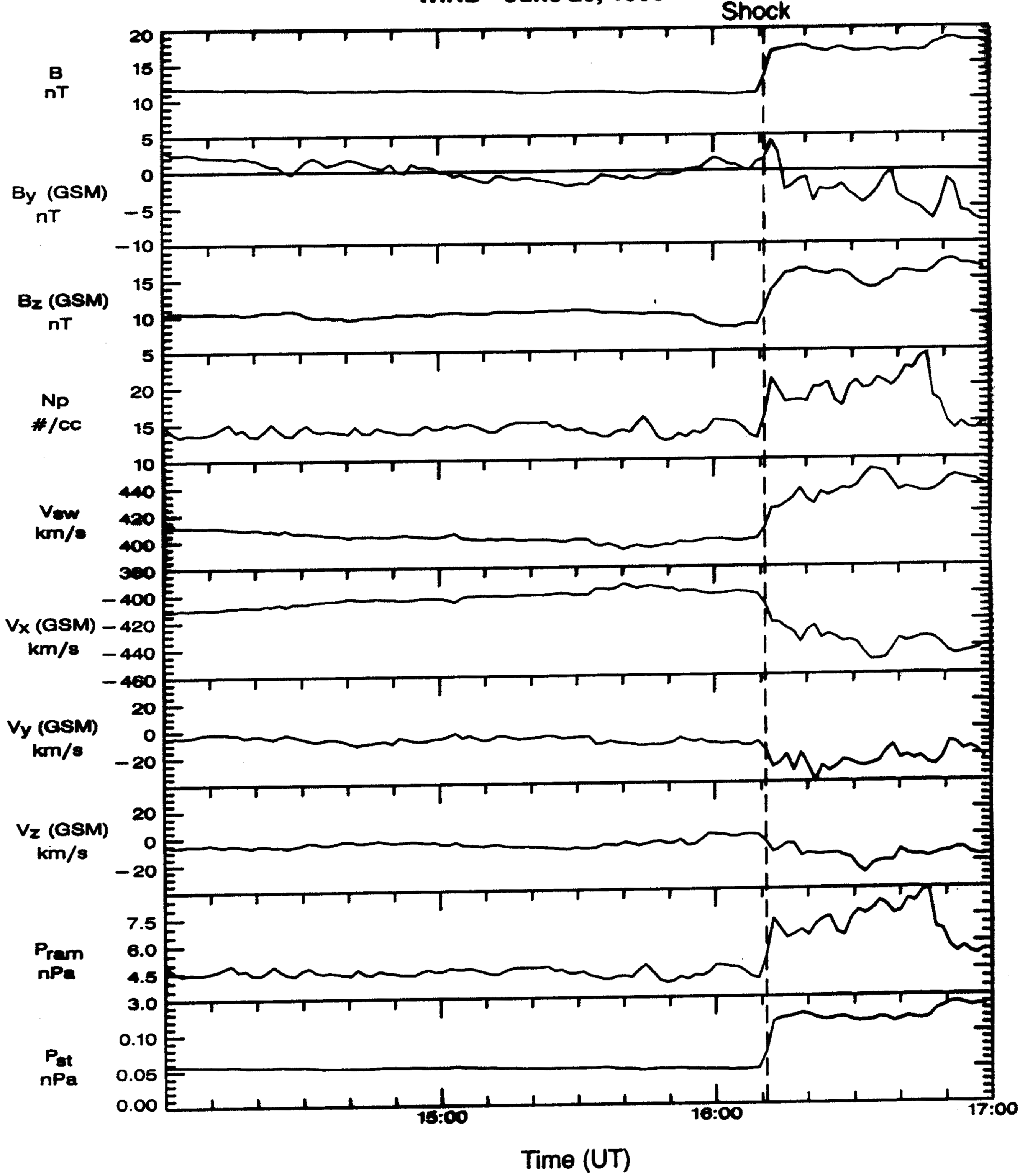
LOCATION	SITE CODE	GEODETIC LAT	GEODETIC LONG	CANOPUS EDFL[1] LAT	CANOPUS EDFL[1] LONG	L	INVLAT
Back	BACK	57.72	265.83	65.229	336.671	7.47	68.53
Contwoyto Lake	CONT	65.75	248.75	72.394	311.295	12.36	73.47
Dawson	DAWS	64.05	220.89	67.323	277.477	5.89	65.67
Eskimo Point	ESKI	61.11	265.95	68.621	336.465	10.20	71.75
Fort Churchill	FCHU	58.76	265.92	66.268	336.682	8.18	69.53
Fort Mcmurray	MCMU	56.66	248.79	63.233	315.304	5.49	64.74
Fort Simpson	FSIM	61.76	238.77	67.396	300.580	6.84	67.52
Fort Smith	FSMI	60.02	248.05	66.556	313.205	7.05	67.88
Gillam	GILL	56.38	265.36	63.883	336.205	6.66	67.20
Island Lake	ISLL	53.86	265.34	61.385	336.419	5.49	64.74
Pinawa	PINA	50.20	263.96	57.732	335.079	4.25	60.98
Rabbit Lake	RABB	58.22	256.32	65.333	324.380	6.94	67.69
Rankin Inlet	RANK	62.82	267.89	70.374	338.923	12.44	73.53
Taloyoak	TALO	69.54	266.45	77.145	335.856	29.96	79.47

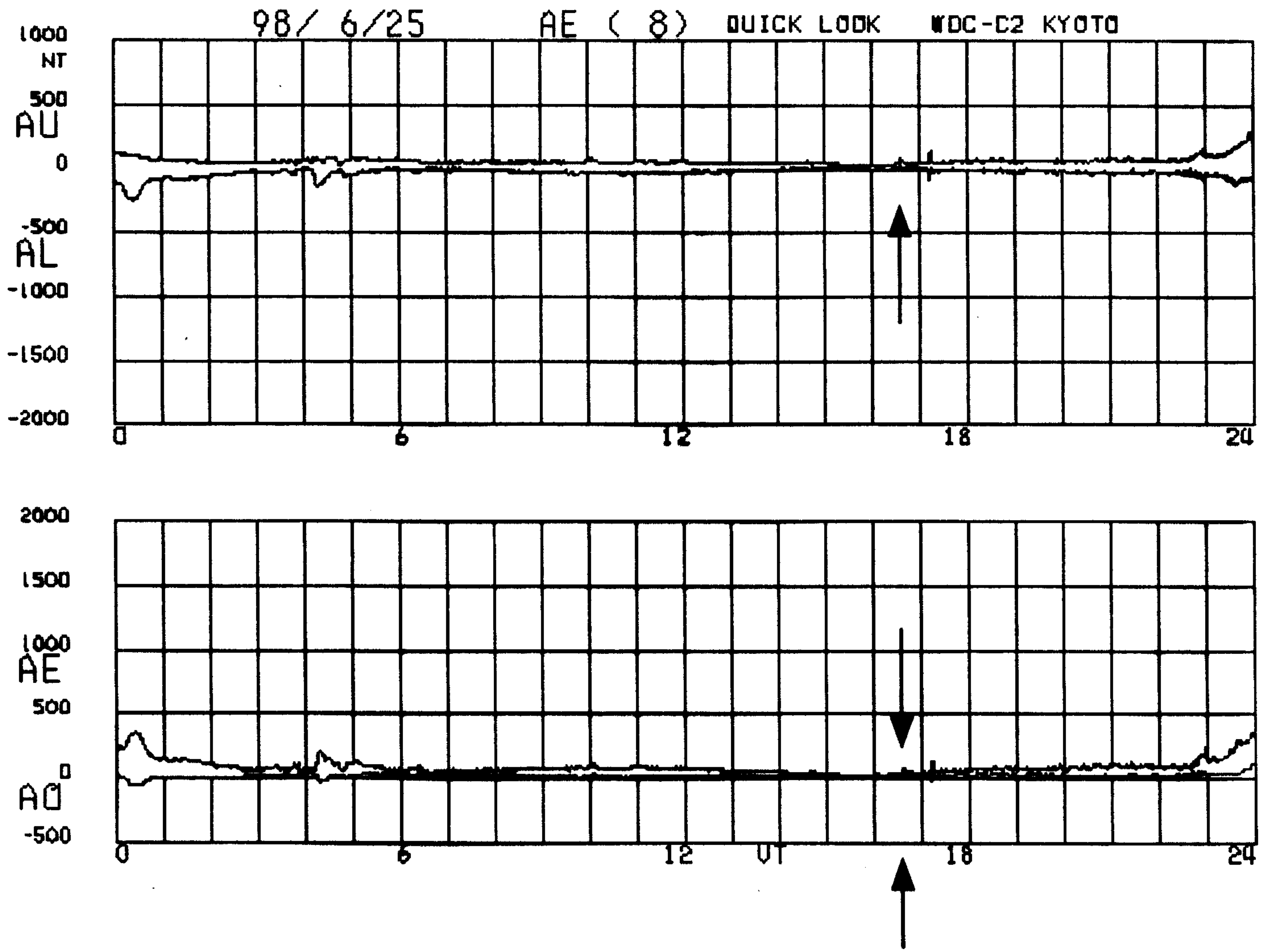
[1]EDFL ==> Eccentric Dipole Field Line traced coordinates.



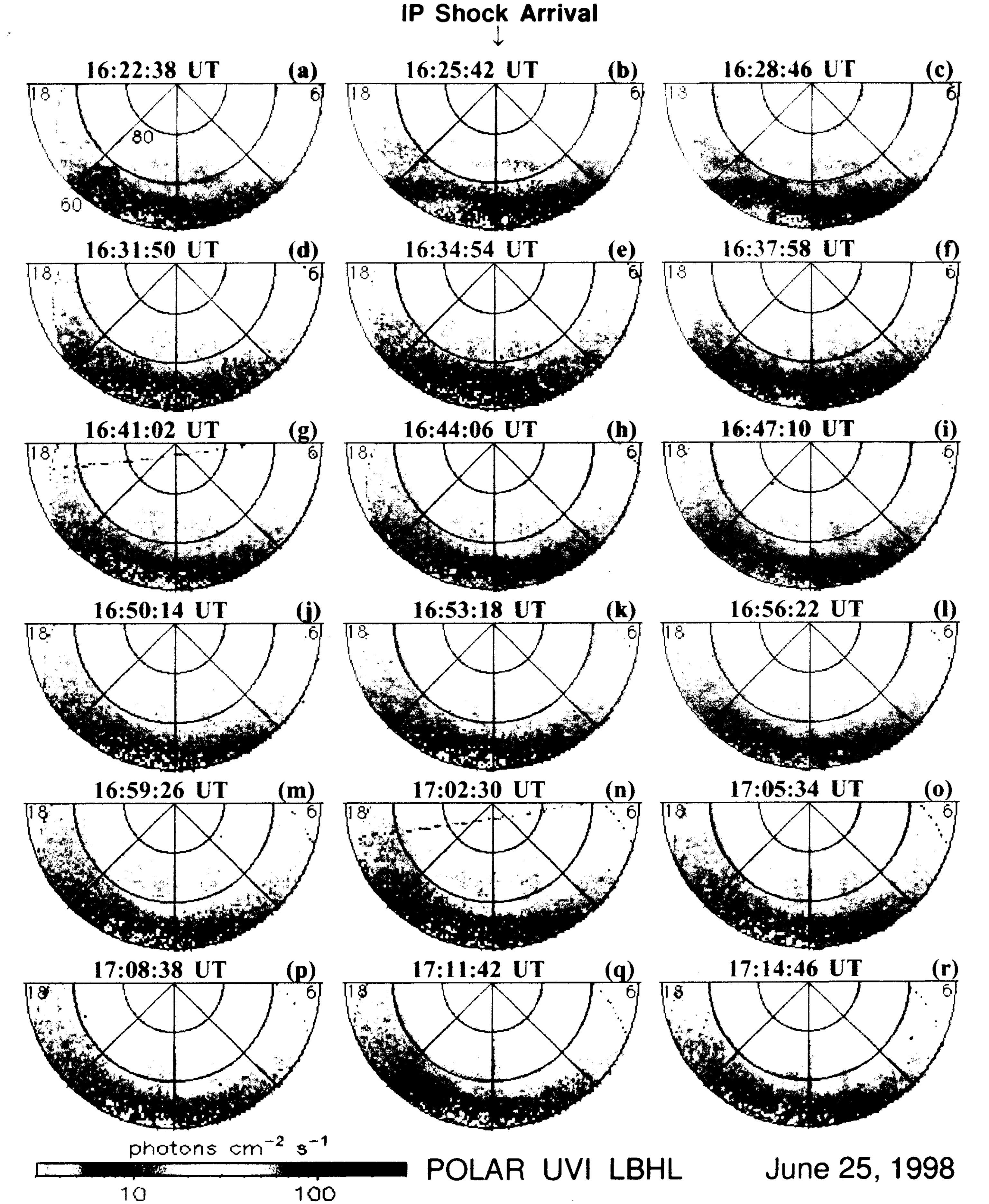
Meridional Chain
0652 UT
0714 UT
TALO
RANK
ESKI
FCHU
GILL
ISLL
PINA
500 nT
Longitudinal Chain
DAWS
FSIM
FSMI
RABB
CONT
MCMU
500 nT
04:00
08:00
12:00
Time (UT)

WIND - June 25, 1998





IP shock arrival



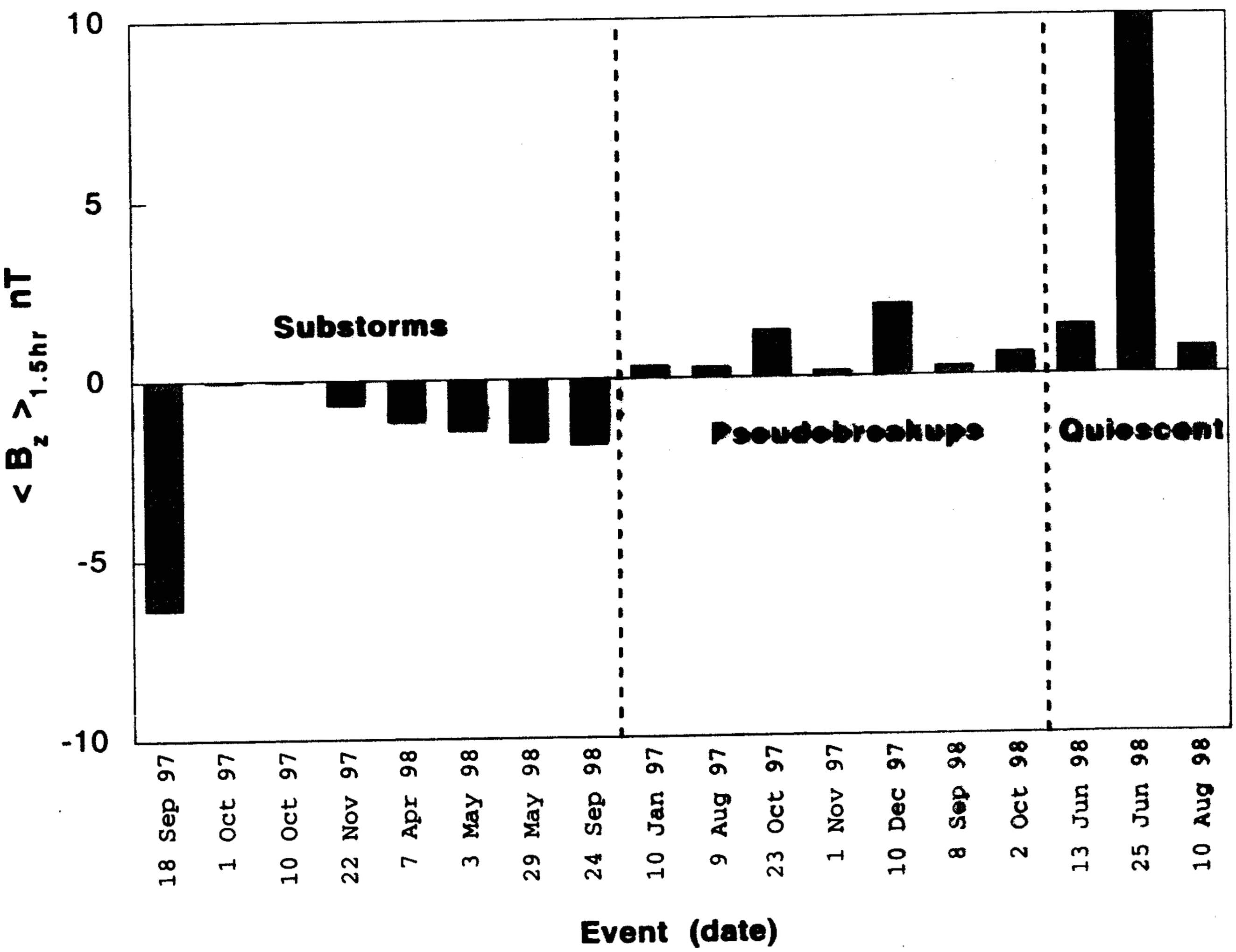
IP Shock Arrival
16:22:38 UT (a)
16:25:42 UT (b)
16:28:46 UT (c)
16:31:50 UT (d)
16:34:54 UT (e)
16:37:58 UT (f)
16:41:02 UT (g)
16:44:06 UT (h)
16:47:10 UT (i)
16:50:14 UT (j)
16:53:18 UT (k)
16:56:22 UT (l)
16:59:26 UT (m)
17:02:30 UT (n)
17:05:34 UT (o)
17:08:38 UT (p)
17:11:42 UT (q)
17:14:46 UT (r)
18
6
80
60
photons cm^-2 s^-1
10
100
POLAR UVI LBHL
June 25, 1998

Table 1. Preconditions of 18 IP shock associated events

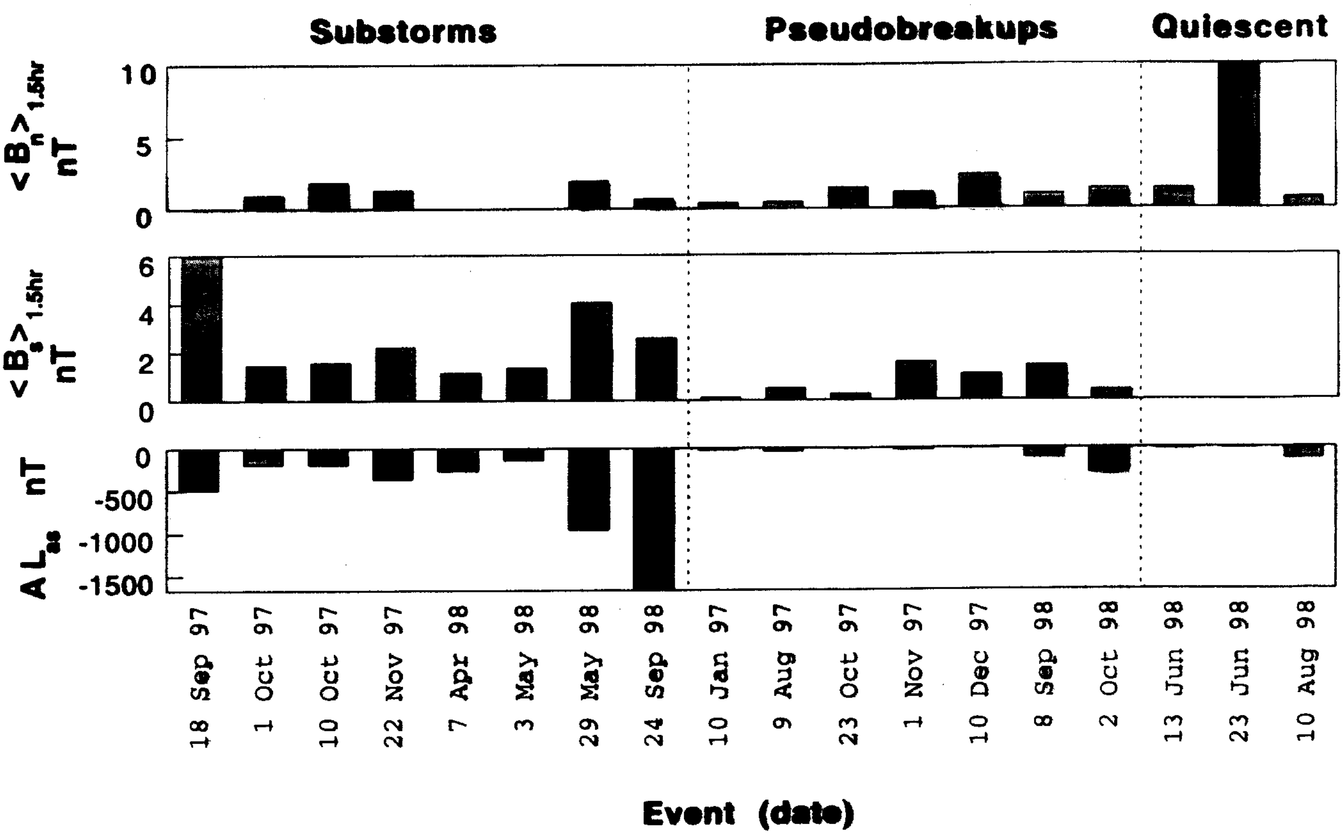
Type	Date	IMF $\overline{B}$ (nT)	IMF $\overline{Bs}$ (nT)	IMF $\overline{Bn}$ (nT)	IMF $\overline{Bz}$ (nT)	$\overline{Vsw}$ (km/s)	$\overline{Np}$ (#/cc)	$\overline{P}_{ram}$ (nPa)	$\overline{P}_{st}$ (nPa×10^{-3})	$\overline{AL}_{ps}$ (nT)
SS	Sep 18, 1997	6.7	6.4	0.0	-6.4	331	12.2	3.5	20.3	-302
	Oct 1, 1997	3.5	1.5	0.9	-0.05	429	12.6	4.1	11.4	-68
	Oct 10, 1997	8.9	1.6	1.8	-0.03	414	11.8	4.5	34.6	-43
	Nov 22, 1997	6.4	2.3	1.3	-0.7	349	12.6	3.4	32.7	-37
	Apr 7, 1998	7.1	1.2	0.0	-1.2	293	10.4	2.0	23.0	-35
	May 3, 1998	3.2	1.4	0.0	-1.4	430	4.7	2.0	4.6	-32
	May 29, 1998	11.3	4.2	1.9	-1.7	518	8.8	5.3	90.4	-165
	Sep 24, 1998	12.3	2.7	0.7	-1.8	446	8.6	3.9	94.8	-498
PB	Jan 10, 1997	2.4	0.1	0.4	0.3	375	7.7	2.4	5.5	-5
	Aug 9, 1997	3.9	0.5	0.4	0.3	335	15.0	3.8	10.8	0
	Oct 23, 1997	5.0	0.3	1.4	1.3	300	7.5	1.5	14.9	-8
	Nov 1, 1997	6.0	1.6	1.1	0.1	341	30.7	8.0	21.9	-42
	Dec 10, 1997	6.2	1.1	2.4	2.0	286	11.0	2.0	19.6	-5
	Sep 8, 1998	9.0	1.5	1.0	0.2	328	4.7	1.1	33.0	-61
	Oct 2, 1998	6.6	0.4	1.3	0.6	511	3.7	2.2	25.9	-22
QE	Jun 13, 1998	4.6	0.0	1.4	1.4	315	3.4	0.8	9.0	3
	Jun 25, 1998	11.1	0.0	10.0	10.0	400	14.1	5.1	51.4	9
	Aug 10, 1998	4.9	0.0	0.7	0.7	400	4.8	1.7	11.0	-89

Table 2. Solar wind parameter variations at IP shocks and geomagnetic responses

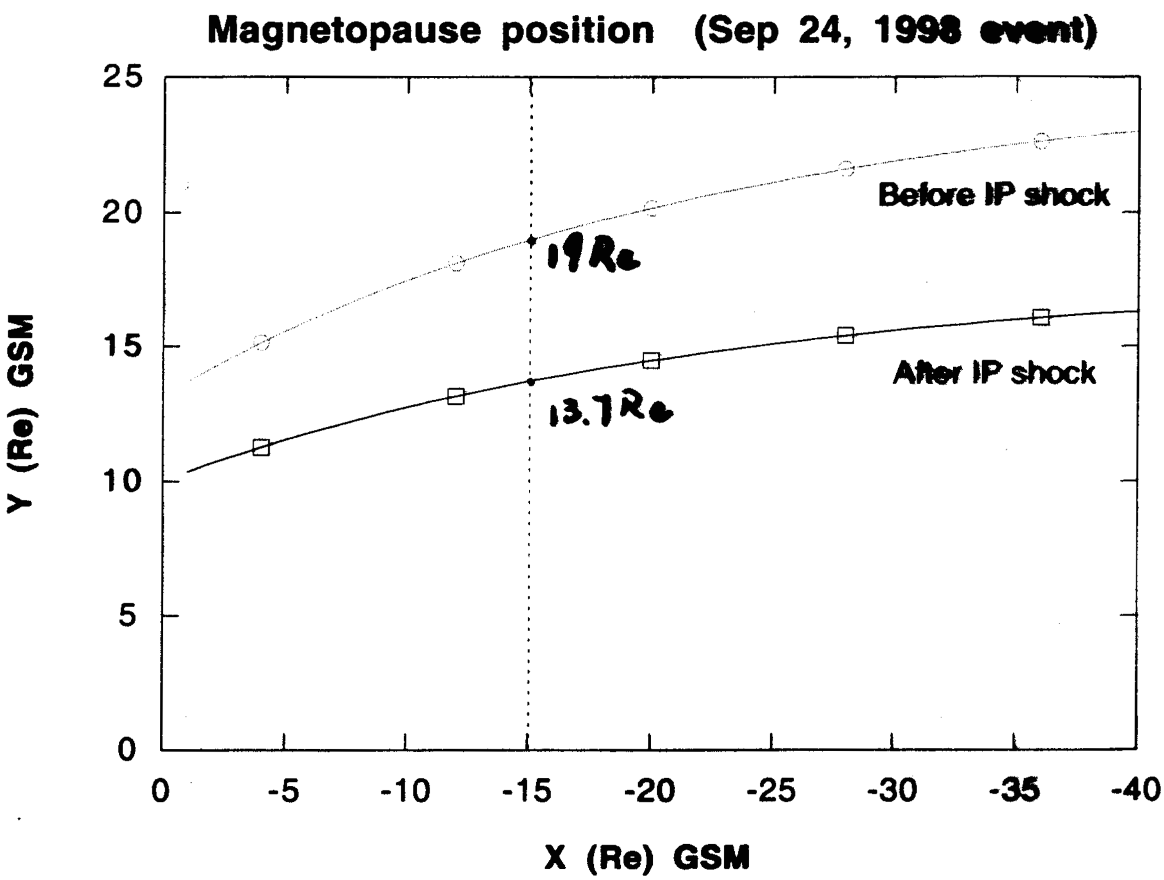
Type	Date	IMF Bz (nT) Turning	$IMF(\Delta B/\overline{B})$	$(\Delta V/\overline{V})_{sw}$	$(\Delta N_p/\overline{N}_p)$	$(\Delta P/\overline{P})_{ram}$	$(\Delta P/\overline{P})_{st}$	Delay T (min)	M Lat (°)	AL_{as} Peak (nT)
SS	Sep 18, 1997	-6 to -9	0.4	0.07	0.4	0.4	0.9	6	66	-491
	Oct 1, 1997	-2 to 5	2.8	0.08	2.3	2.3	3.9	9	67	-185
	Oct 10, 1997	-0.5	0.6	0.07	0.7	0.7	1.4	10	65	-190
	Nov 22, 1997	0 to -5	1.4	0.29	1.7	3.1	7.3	6	65	-363
	Apr 7, 1998	-1 to -7	0.8	0.14	1.4	1.6	2.4	6	70	-263
	May 3, 1998	-2 to -6	1.3	0.15	1.2	3.2	5.1	9	65	-136
	May 29, 1998	6 to -10	0.7	0.26	9.5	1.8	2.5	5	69	-955
	Sep 24, 1998	-1 to 3	2.3	0.48	1.4	4.1	9.7	4	65	-1670
PB	Jan 10, 1997	1 to 4	1.6	0.11	1.0	1.4	5.5	19	70	-24
	Aug 9, 1997	1 to -6	0.7	0.07	0.4	0.4	0.9	12	67	-35
	Oct 23, 1997	4 to 7	1.3	0.13	0.3	0.6	2.0	13	71	-9
	Nov 1, 1997	2 to 5	0.6	0.04	0.5	0.6	1.1	12	71	-22
	Dec 10, 1997	-1 to -3	1.7	0.26	1.6	2.4	6.0	12	72	-4
	Sep 8, 1998	1 to -2	0.2	0.12	2.8	0.9	0.6	12-13	68	-111
	Oct 2, 1998	5 to -2	1.8	0.40	1.8	3.3	9.9	6	70	-299
QE	Jun 13, 1998	2 to 8	1.1	0.19	8.6	3.5	4.7	N/A	N/A	-15
	Jun 25, 1998	9 to 13	0.6	0.09	0.1	0.6	1.3	N/A	N/A	-9
	Aug 10, 1998	1 to -1	1.1	0.12	9.4	1.6	3.3	N/A	N/A	-123



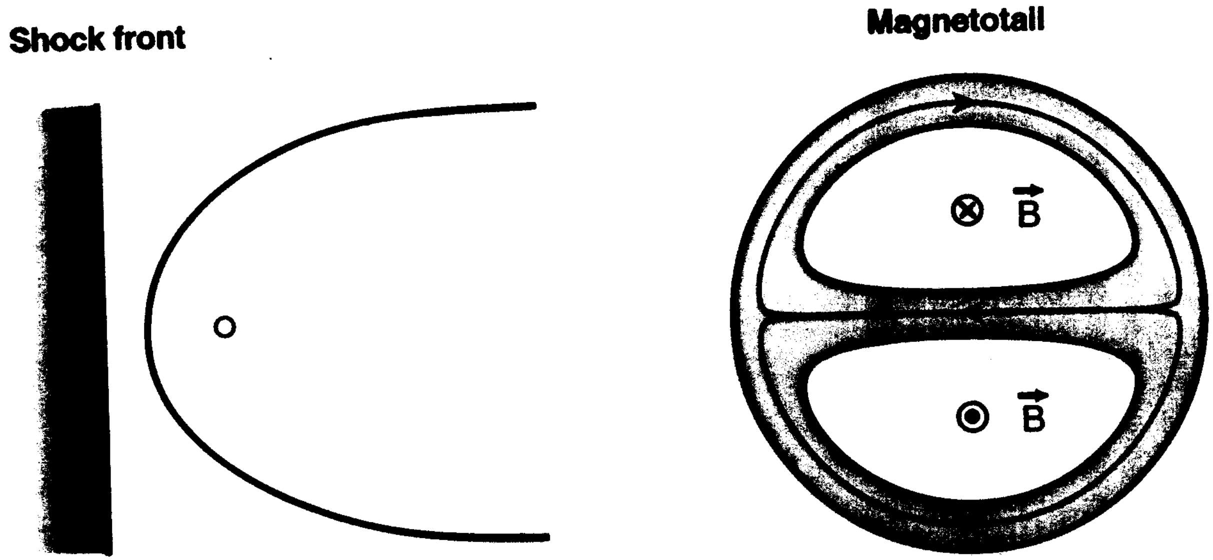
10
5
0
-5
-10
< B_z >_1.5hr nT
Substorms
Pseudobreakups
Quiescent
18 Sep 97
1 Oct 97
10 Oct 97
22 Nov 97
7 Apr 98
3 May 98
29 May 98
24 Sep 98
10 Jan 97
9 Aug 97
23 Oct 97
1 Nov 97
10 Dec 97
8 Sep 98
2 Oct 98
13 Jun 98
25 Jun 98
10 Aug 98
Event (date)



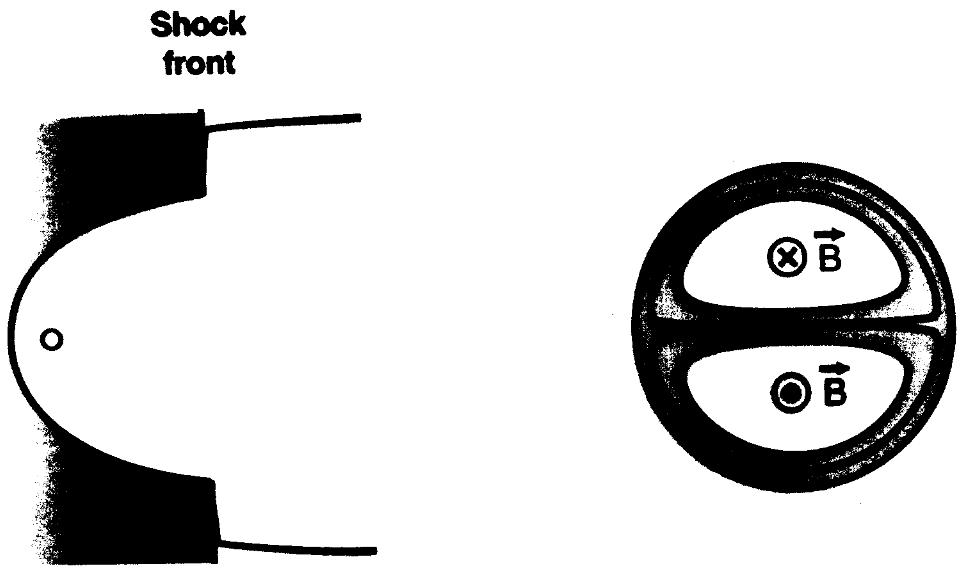
Substorms
Pseudobreakups
Quiescent
$\langle B_n \rangle_{1.5hr}$ nT
$\langle B_s \rangle_{1.5hr}$ nT
AL_as nT
10
5
0
6
4
2
0
0
-500
-1000
-1500
18 Sep 97
1 Oct 97
10 Oct 97
22 Nov 97
7 Apr 98
3 May 98
29 May 98
24 Sep 98
10 Jan 97
9 Aug 97
23 Oct 97
1 Nov 97
10 Dec 97
8 Sep 98
2 Oct 98
13 Jun 98
23 Jun 98
10 Aug 98
Event (date)



Magnetopause position (Sep 24, 1998 event)
Before IP shock
After IP shock
19 Re
13.7 Re
Y (Re) GSM
X (Re) GSM
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40



(a)



(b)

September 24, 1998 event

R:	$19 \Rightarrow 13.3\ Re$	$(at\ X = -15\ Re)$	
	$B_L \Rightarrow 2.1\ B_L$	$I \Rightarrow 2.1\ I\ (mA/m)$	
	$P_L \Rightarrow 4.4\ P_L$	$h \Rightarrow h/1.7$	$(PV^{\gamma})_{CS} = const.$
	$Vy \Rightarrow const.$	$Ey \Rightarrow 1.43\ Ey$	

For the ion Weibel instability, with certain simplicity the growth rate γ of the unstable wave is (Lui et al., JGR, 96, 11389, 1991)

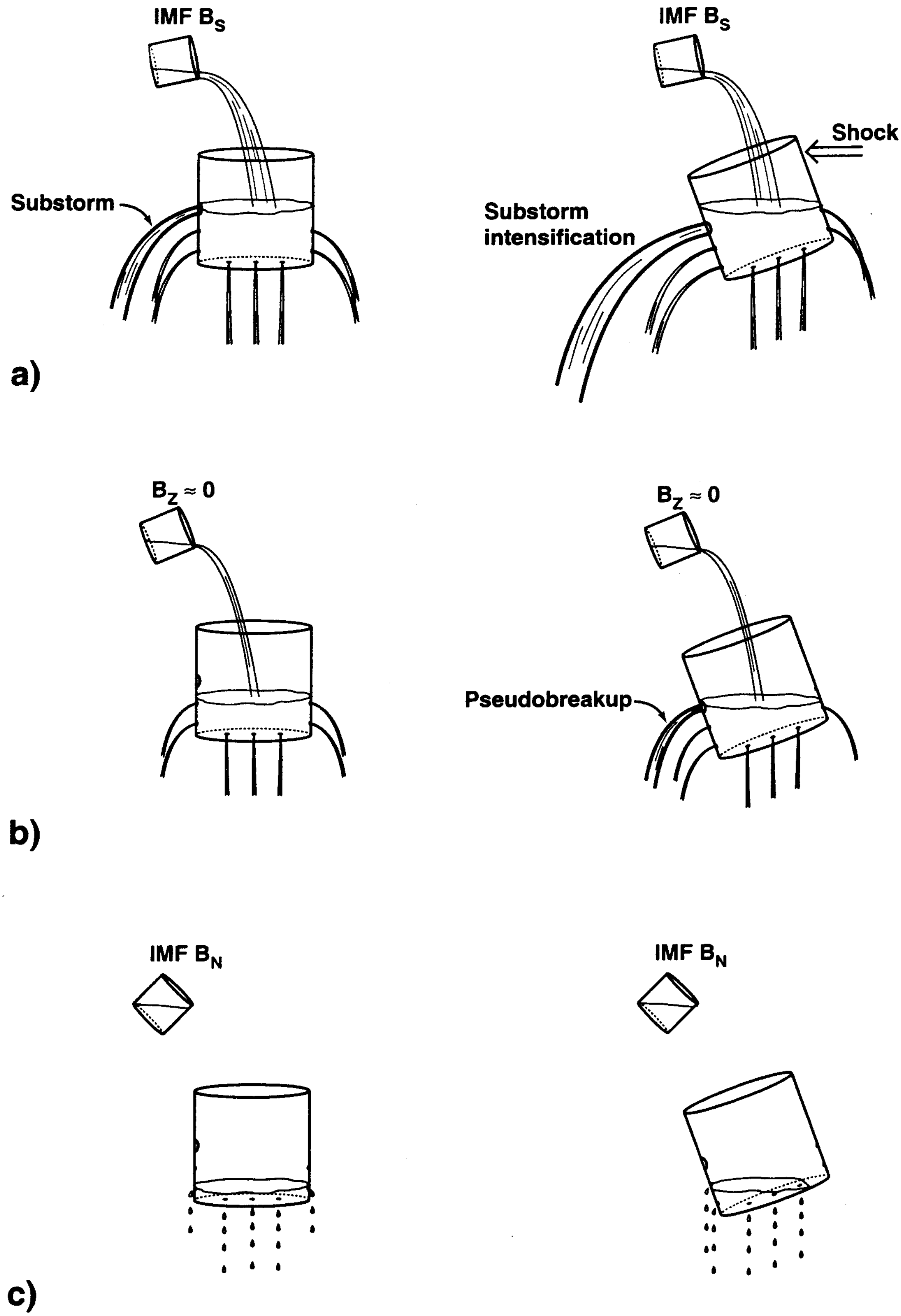
$$\gamma = \omega_{pi} V_0 / c$$

where ω_{pi} is the ion plasma frequency,
V_0 is the ion drift speed along the Ey direction.

During southward IMF, when the plasma density = 6.0 cm^{-3} ,
the current sheet disruption can occur when $V_0 > 170$ km/s.

During northward IMF, when the plasma density = 0.5 cm^{-3} ,
the current sheet disruption can occur when $V_0 > 600$ km/s.

Dripping, Tilting Bucket Model



SUMMARY AND CONCLUSIONS

1. IP shocks/pressure pulses can cause SSs, PBs or QE events. SS events are led by IMF Bs (precursors), PB events by IMF $Bz \approx 0$ and QE events by IMF Bn.

2. Compression of the near-Earth tail leads to an enhancement of the cross-tail current density (by 2.1 times), and an increase in Ey (by 1.43 times).

3. We have developed a Dripping, Tilting Bucket model which can explain all of the data reasonably well.

4. We therefore expect the substorm triggering signature in the near-Earth tail to be large, clear and fast. Thus by studying IP shock events, the mechanism for general substorm expansion onsets may be revealed.