Time Series Analysis of Particles and Fields data

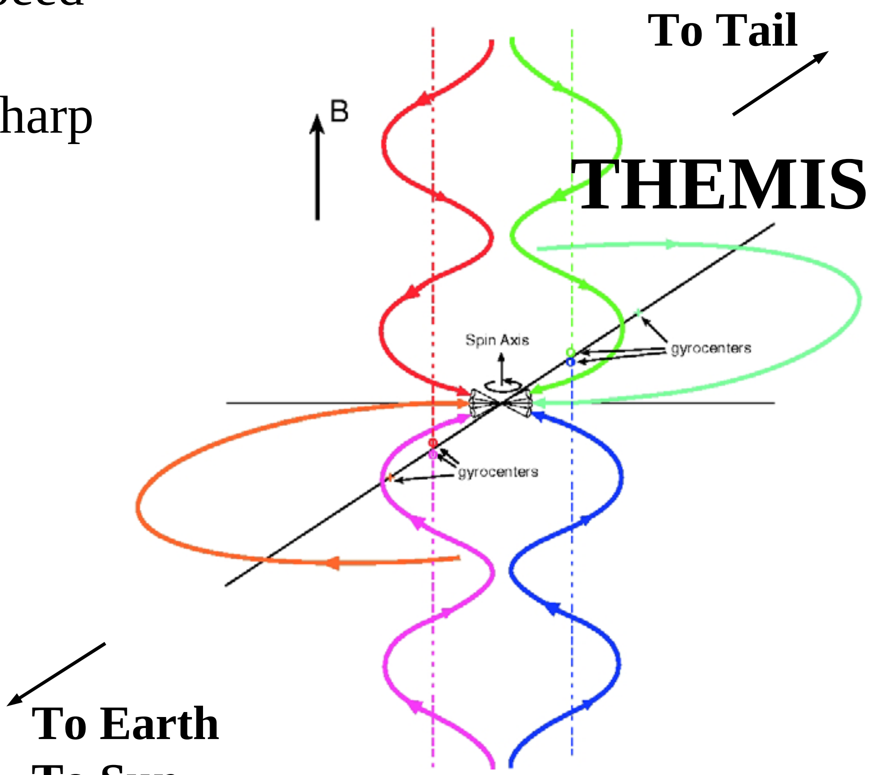
- Magnetopause sounding

Materials in:

http://www.igpp.ucla.edu/public/vassilis/ESS265/20080514
class_notes_time_series_analysis_A.ppt
Angelopoulos_V_etal_SST_First_Results_THEMIS_inpress.pdf
wave_motion.pro
remotesens.pro
intro_ascii.pro
plasma_parameters.xls
…

Finite gyroradius effects

- Ion Gyroradius large compared to magnetospheric boundaries
  - – Can be used to remotely sense speed and thickness of boundaries
  - – Assumption is that boundary is sharp and flux has step function across
    - Application at the magnetopause
    - Application at the magnetotail
  - – Can also be applied to waves if particle gradient is sufficiently high
    - Application on ULF waves at inner magnetosphere



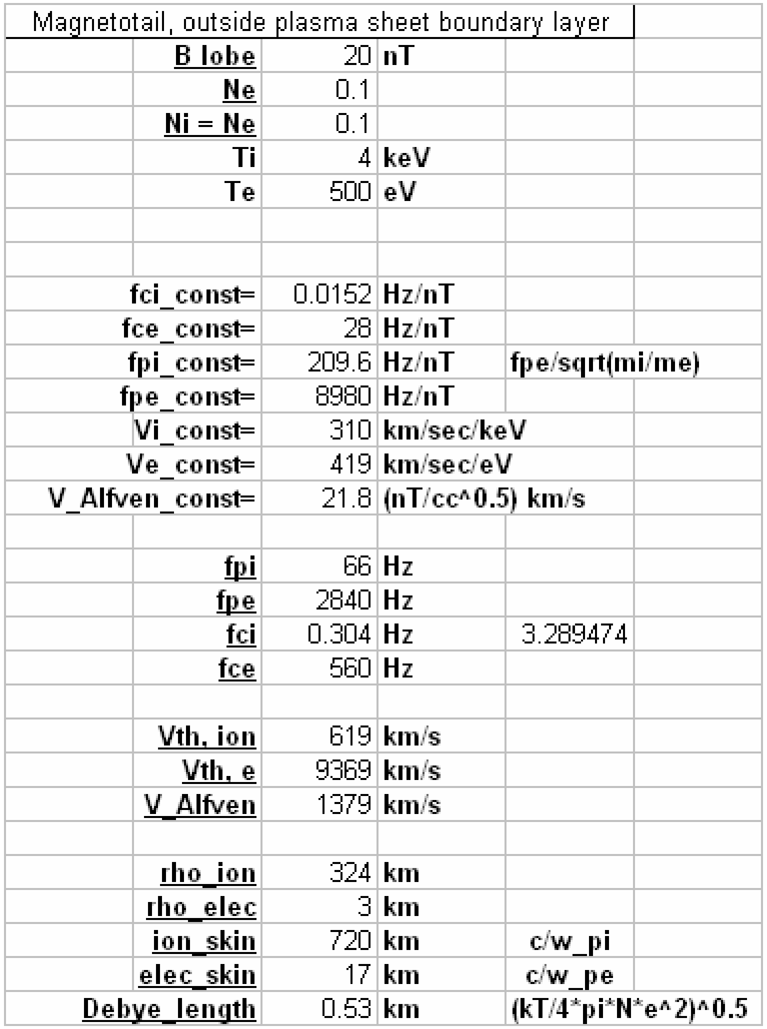
To Tail

THEMIS

To Earth
To Sun

Method exploits finite ion gyroradius to remotely sense approaching ion boundary and measure boundary speed ($V_\perp$)

At the magnetotail



Magnetotail, outside plasma sheet boundary layer

B lobe	20	nT	
Ne	0.1		
Ni = Ne	0.1		
Ti	4	keV	
Te	500	eV	
fci_const=	0.0152	Hz/nT	
fce_const=	28	Hz/nT	
fpi_const=	209.6	Hz/nT	fpe/sqrt(mi/me)
fpe_const=	8980	Hz/nT	
Vi_const=	310	km/sec/keV	
Ve_const=	419	km/sec/eV	
V_Alfven_const=	21.8	(nT/cc^0.5) km/s	
fpi	66	Hz	
fpe	2840	Hz	
fci	0.304	Hz	3.289474
fce	560	Hz	
Vth, ion	619	km/s	
Vth, e	9369	km/s	
V_Alfven	1379	km/s	
rho_ion	324	km	
rho_elec	3	km	
ion_skin	720	km	c/w_pi
elec_skin	17	km	c/w_pe
Debye_length	0.53	km	(kT/4*pi*N*e^2)^0.5

$\rho_{i,\text{thermal-tail (4keV,20nT)}}=$ ~325km
$\rho_{i,\text{super-thermal (50keV,20nT)}}=$ ~2200km

Plasma Sheet Thickness ~ 1-3 R_E
Boundary Layer Thickness ~500-2000km
Current layer Thickness ~ 500-2000km

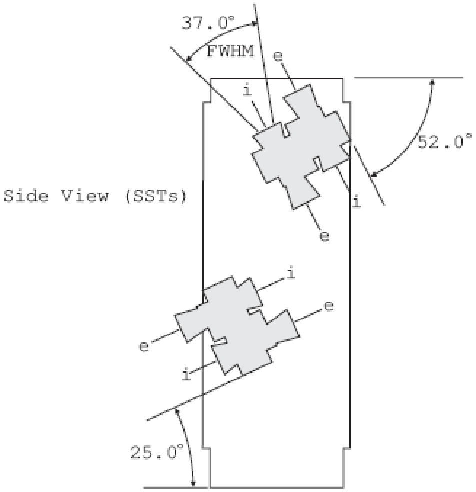
Waves Across Boundary: ~1000-10,000km
Along Boundary: ~Normal : 1-10 R_E

For magnetotail particles, the current layer and plasma sheet boundary layer are sharp compared to the superthermal ion gyroradius and the magnetic field is the same direction in the plasma sheet and outside (the lobe). This means we can use the measured field to determine gyrocenters both at the outer plasma sheet and the lobe, on either side of the hot magnetotail boundary.

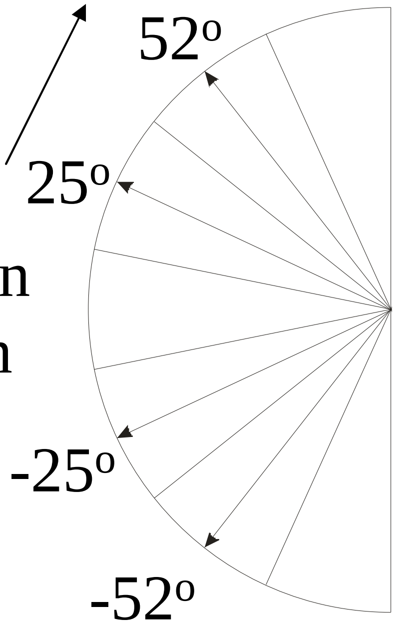
Side View (elevations)

Spin Axis

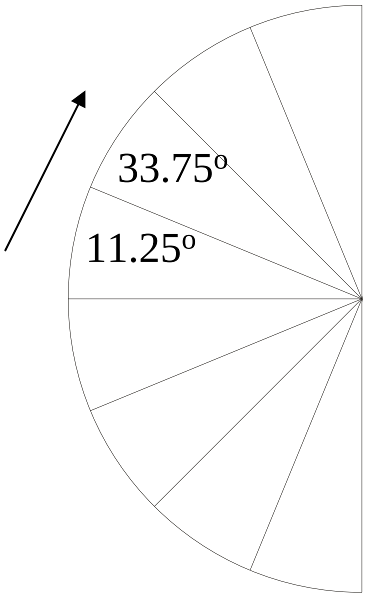
To Sun



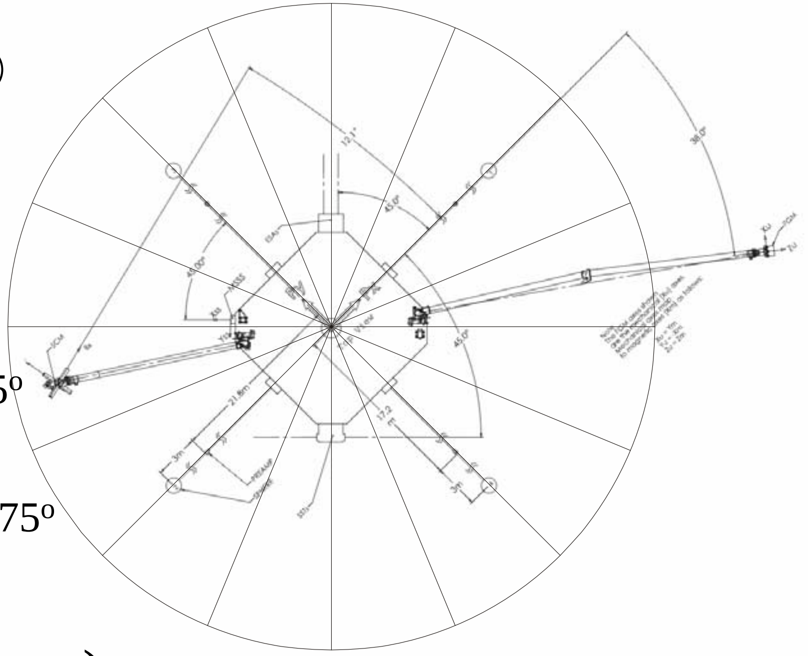
SST: Elevation direction (θ_{DSL})



ESA: Elevation direction (θ_{DSL})



Top View (sectors)
For ESA and SST (0=Sun)



Spin axis ⊙

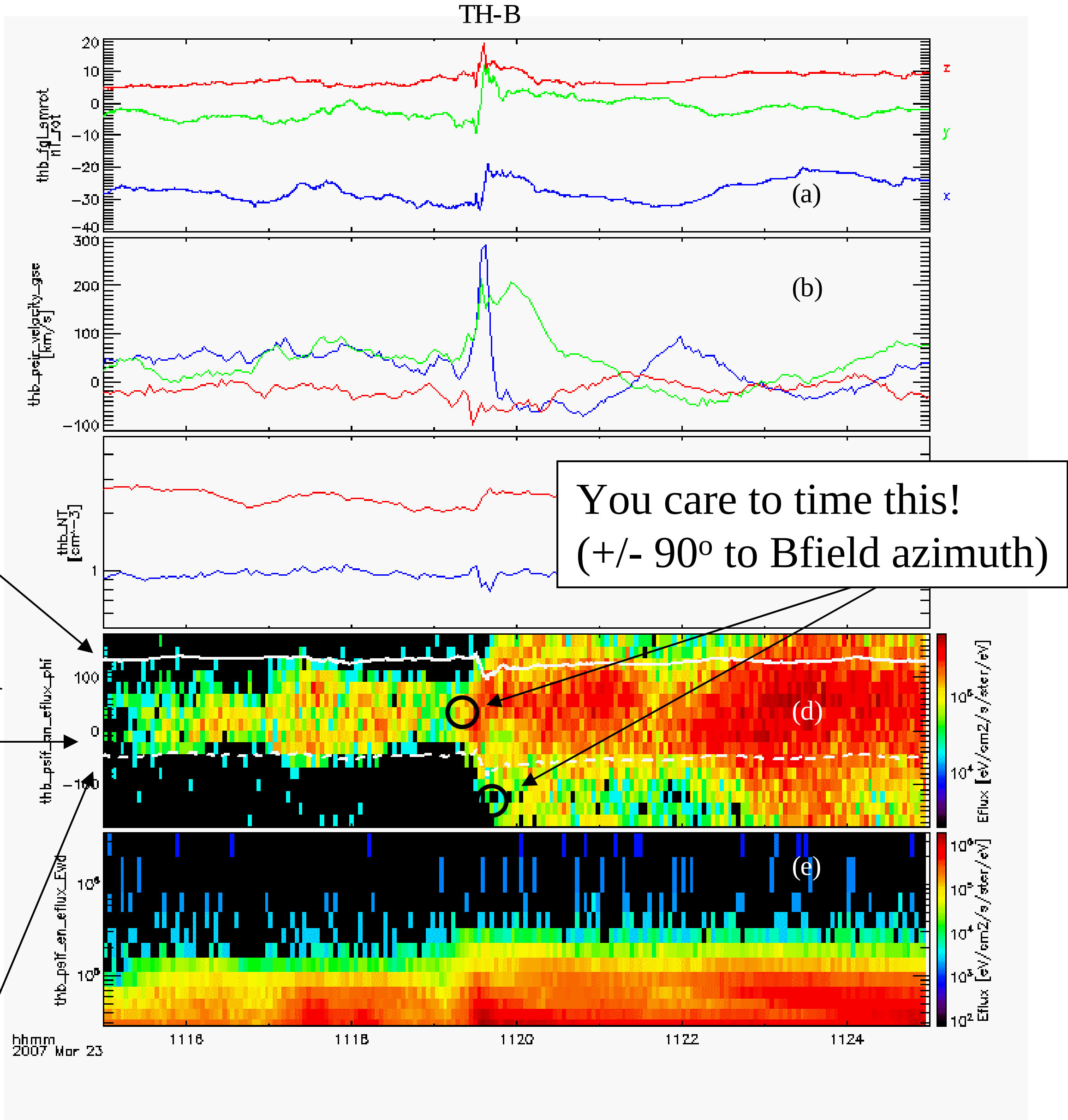
To Sun (0^o)

11.25^o

33.75^o

Spin motion direction (ϕ_{DSL})

Normal to Sun, $+90^o$



You care to time this!
(+/- 90° to Bfield azimuth)

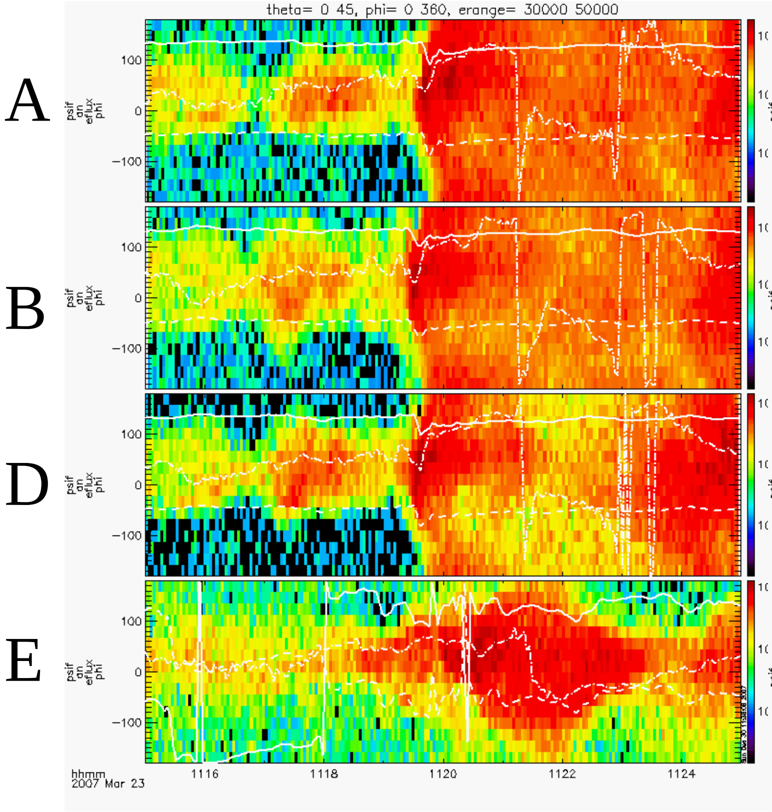
B field azimuth (solid white)

Particle motion direction
Coordinate: (ϕ_{DSL})
Energy: 125-175keV

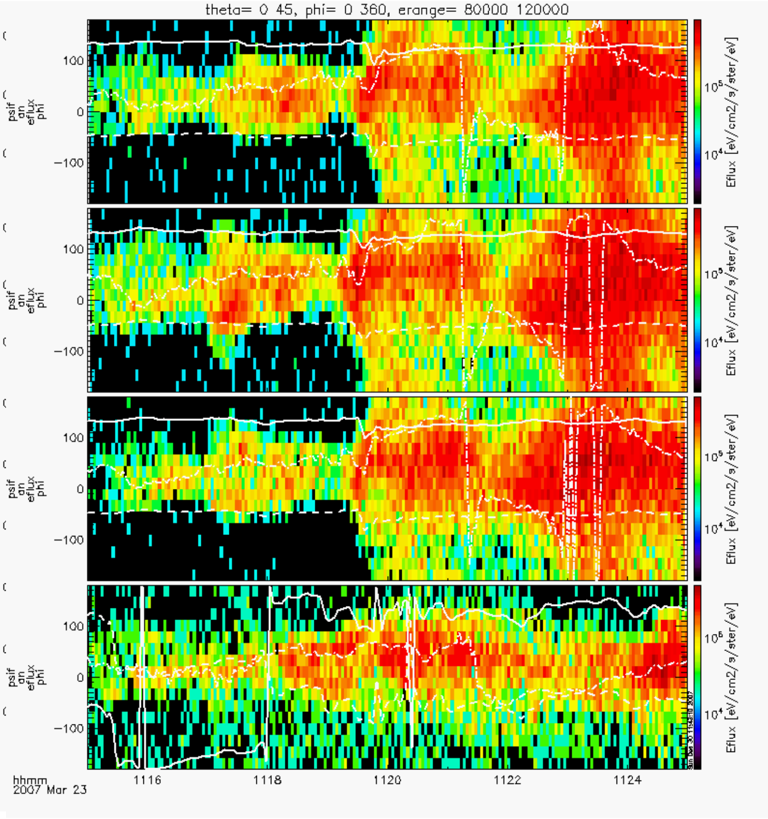
Note: direction depends on spin axis.

-B field azimuth (dashed white)

Multiple spacecraft, energies, elevations



Elev: 25deg E=30-50keV

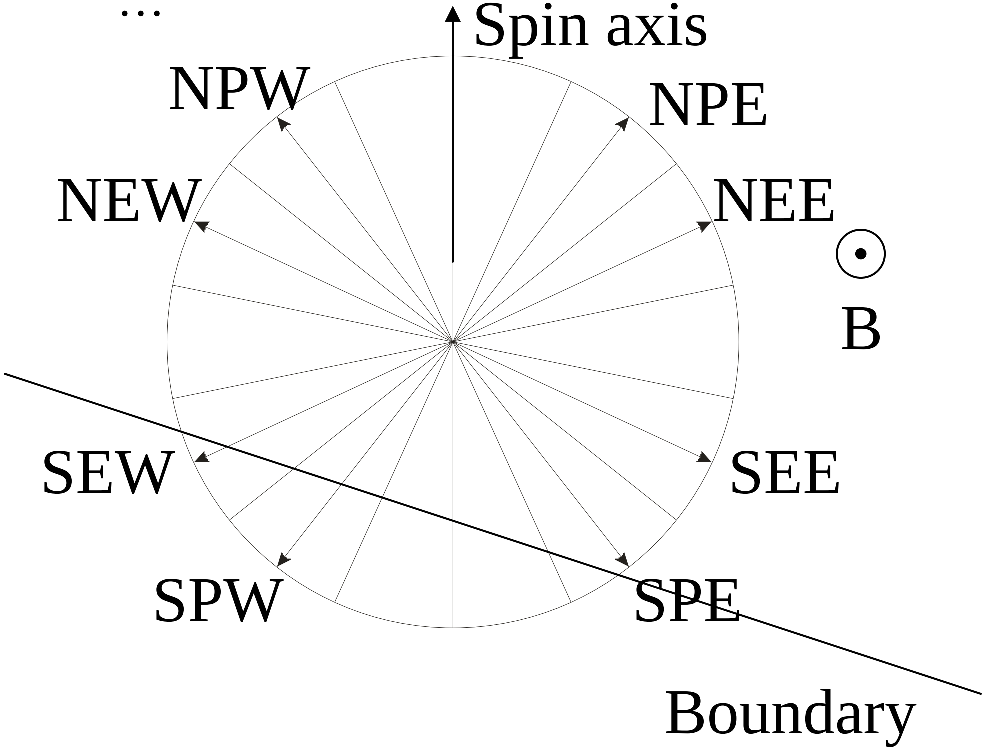


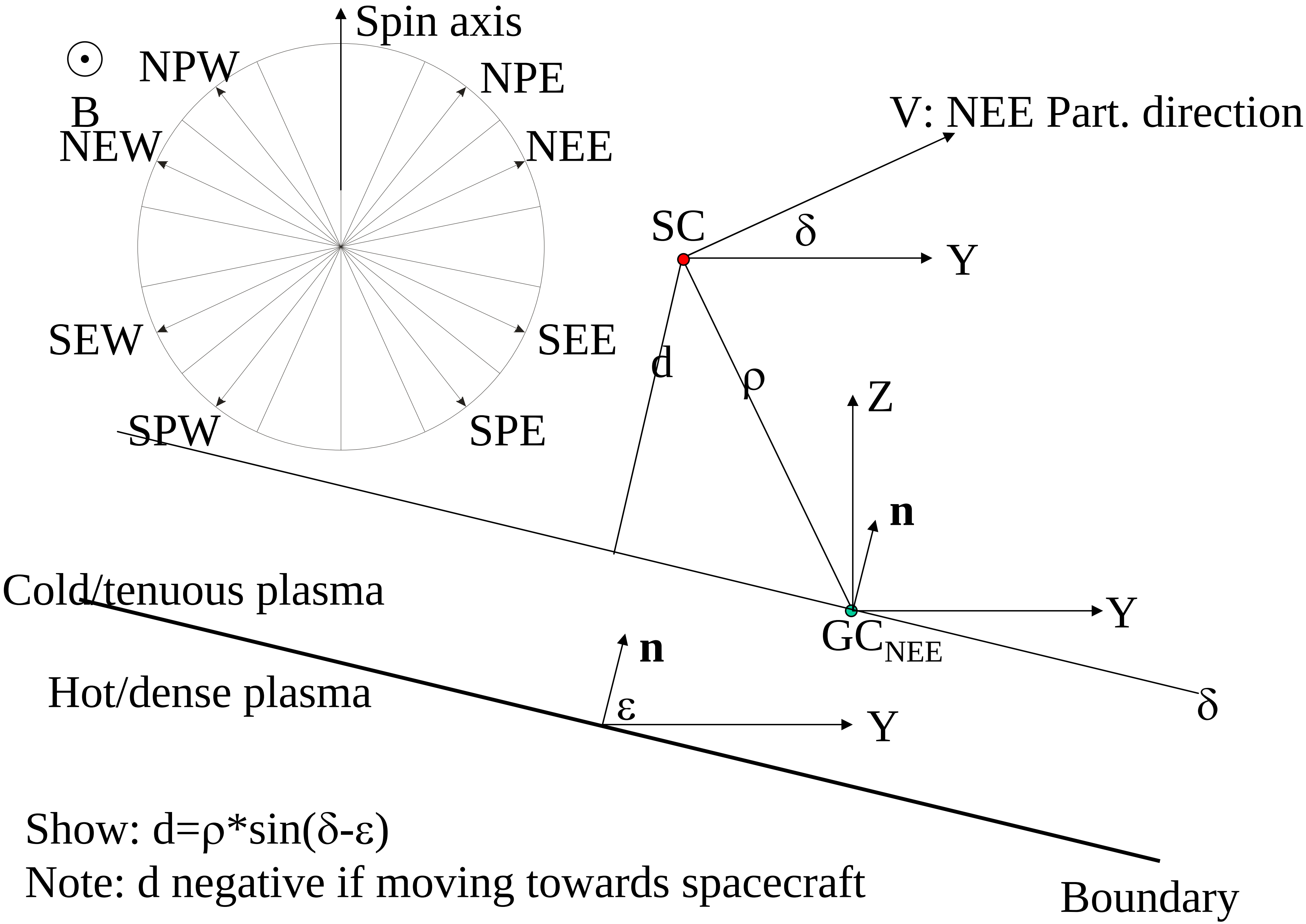
Elev: 25deg, E=80-120keV

....

```
Vi_const     310km/sec/keV          fci_cons  0.0152Hz/nT              B          30nT
Ti        40keV rho_ion       683km
Ti       100keV rho_ion      1081km
Ti       150keV rho_ion      1323km
Ti       300keV rho_ion      1872km

   SC   E (keV) detectord (deg)    r      time
   B       40     SPW    -128.0  683.4  11:19:29
   B       40     SPE    -52.0   683.4  11:19:39
   B       40     SEW    -155.0  683.4  11:19:18
   B       40     SEE    -25.0   683.4  11:19:42
   B       40     NPW    128.0   683.4  11:19:29
   B       40     NPE     52.0   683.4  11:19:38
   B       40     NEW    155.0   683.4  11:19:24
   B       40     NEE     25.0   683.4  11:19:43
   B      100     SPW    -128.0  1080.5 11:19:17
   B      100     SPE    -52.0   1080.5 11:19:42
   B      100     SEW    -155.0  1080.5 11:19:20
   B      100     SEE    -25.0   1080.5 11:19:45
   B      100     NPW    128.0   1080.5 11:19:20
   B      100     NPE     52.0   1080.5 11:19:45
   B      100     NEW    155.0   1080.5 11:19:23
   B      100     NEE     25.0   1080.5 11:19:48
   B      150     SPW    -128.0  1323.4 11:19:10
   B      150     SPE    -52.0   1323.4 11:19:44
   B      150     SEW    -155.0  1323.4 11:19:14
   B      150     SEE    -25.0   1323.4 11:19:51
   B      150     NPW    128.0   1323.4 11:19:23
   B      150     NPE     52.0   1323.4 11:19:45
   B      150     NEW    155.0   1323.4 11:19:13
   B      150     NEE     25.0   1323.4 11:19:48
   B      300     SPW    -128.0  1871.5 11:19:10
   B      300     SPE    -52.0   1871.5 11:19:44
   B      300     SEW    -155.0  1871.5 11:19:14
   B      300     SEE    -25.0   1871.5 11:19:51
   B      300     NPW    128.0   1871.5 11:19:23
   B      300     NPE     52.0   1871.5 11:19:45
   B      300     NEW    155.0   1871.5 11:19:13
   B      300     NEE     25.0   1871.5 11:19:48
```

Note:
NEE= North-Equatorial, East
NPW=North-Equatorial, West
Angles measured from East direction
-25deg elevation, 90deg East = SEE
+52deg elevation, 90deg East = NPE
…





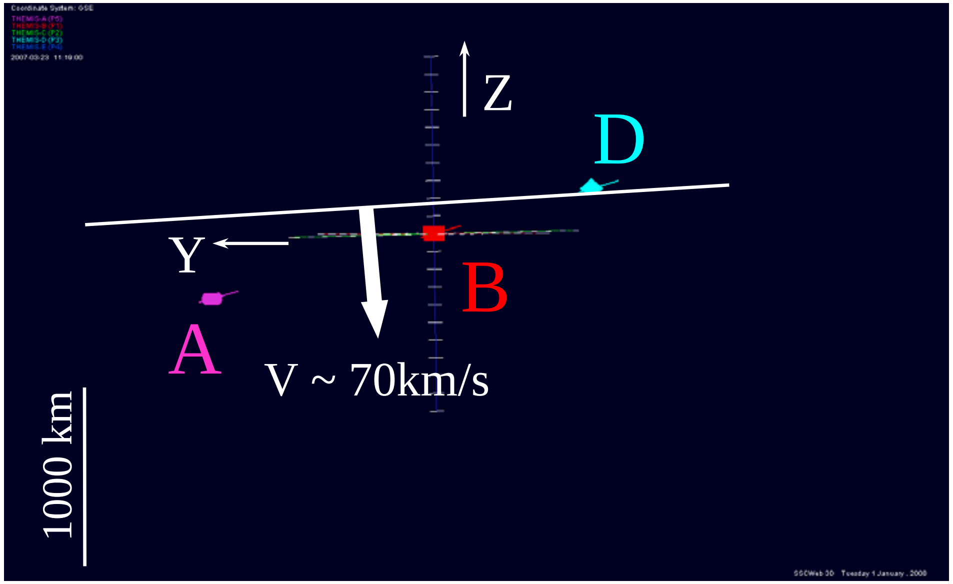
Show: $d=\rho*\sin(\delta-\varepsilon)$

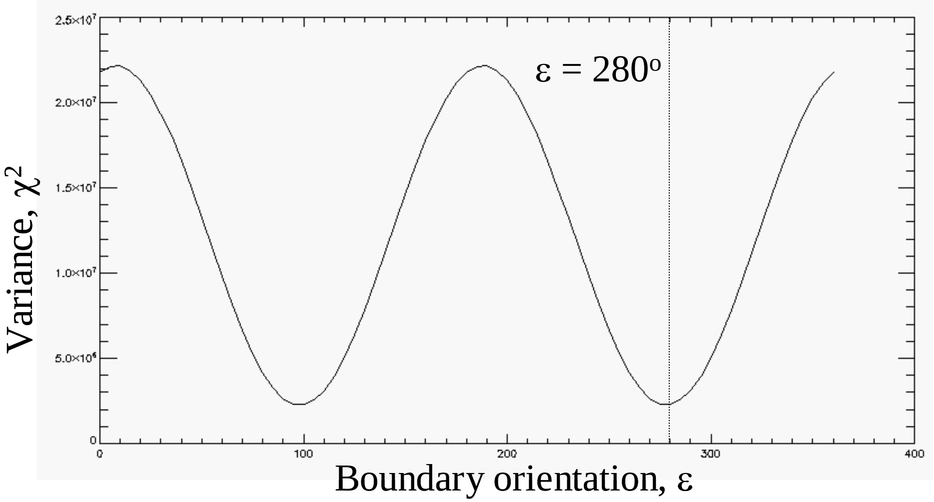
Note: d negative if moving towards spacecraft

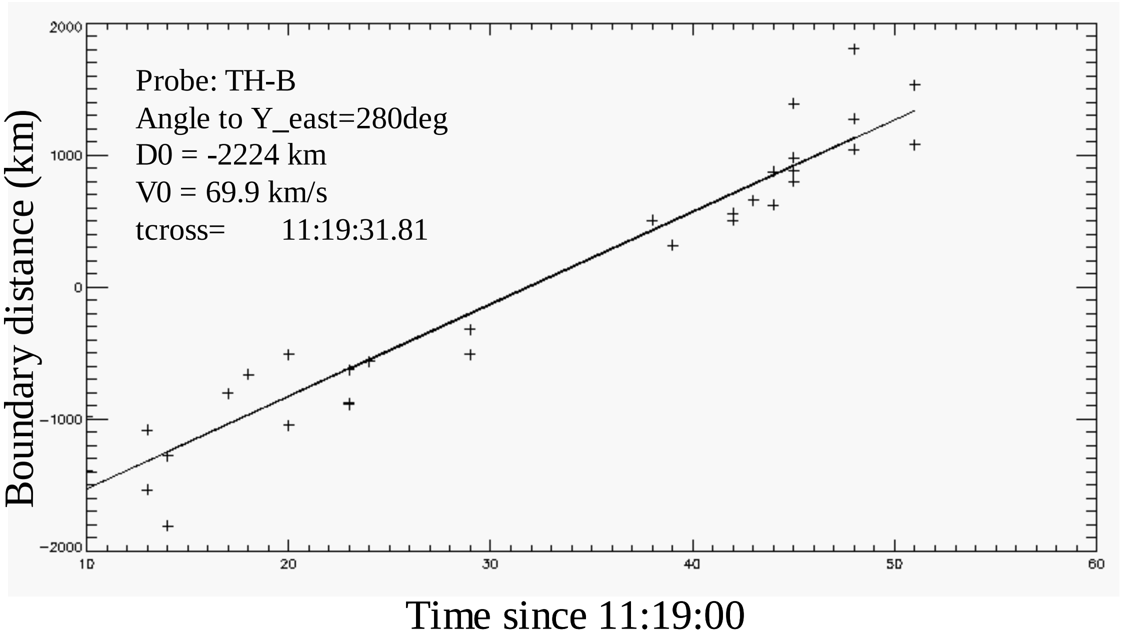
- Procedure
  - For a given ε, determine variance of data for all δ
  - Find minimum in variance, this determines ε (boundary direction)
  - Speed distance as function of time determines boundary speed

```
intro_ascii,'remote_sense_A.txt',delta,rho,hh,mm,ss,nskip=13,format="(25x,f6.1,f8.1,3(1x,i2))"
;
angle=fltarr(73)
chisqrd=fltarr(73)
for ijk=0,72 do begin
  epsilon=float(ijk*5)
  get_d_vs_dt,epsilon,hh,mm,ss,rho,delta,dist,times
  yfit=dist & yfit(*)=0.
  chi2=dist & chi2(*)=0.
  coeffs=svdfit(times,dist,2,yfit=yfit,chisq=chi2)
  angle(ijk)=epsilon
  chisqrd(ijk)=chi2
endfor
ipos=indgen(30)+43
chisqrd_min=min(chisqrd(ipos),imin)
plot,angle,chisqrd
print,angle(ipos(imin)),chisqrd(ipos(imin))
;
stop
```

- Procedure
  - Note two minima (identical solutions)
    - One for approaching boundary at V>0
    - One for receding boundary at V<0
      - Convention that d<0 if boundary moves towards spacecraft allows us to pick one of the two (positive slope of d versus time)





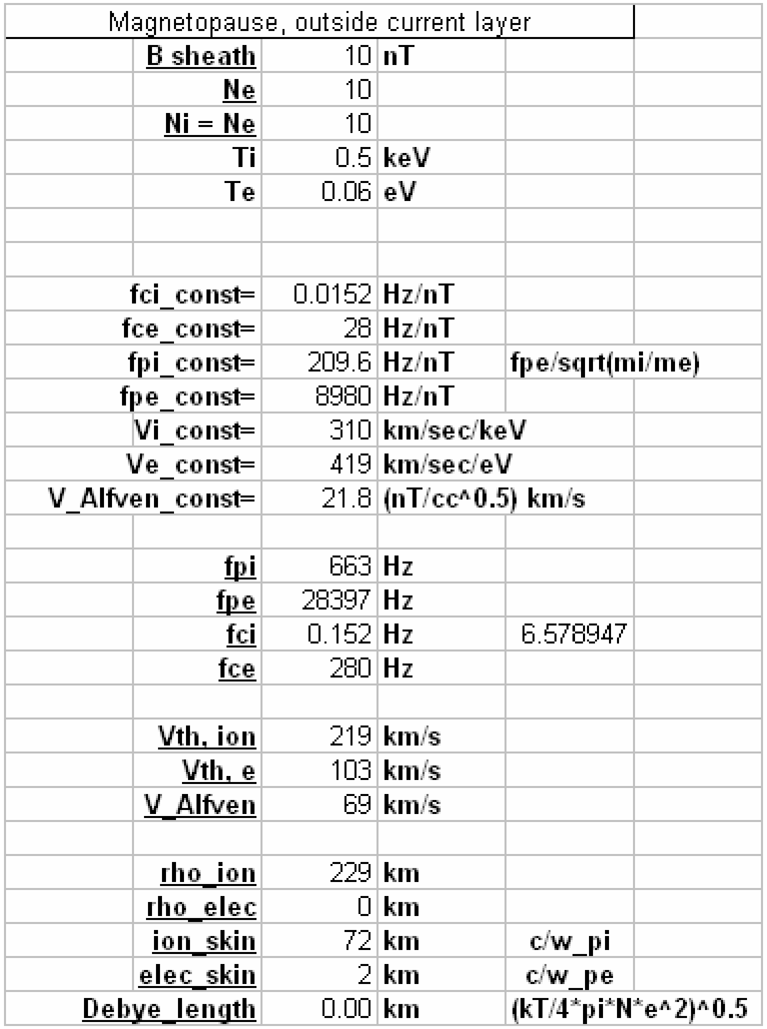


	t_{cross}	**V [km/s]**	**ε [deg]**
D	11:19:27.6	75	270
B	11:19:31.8	70	280
A	11:19:38.4	80	275

Table 1. *Results of remote sensing analysis on the inner probes*

Timing of the arrivals of the other signatures at the inner three spacecraft

At the magnetopause



Magnetopause, outside current layer			
B sheath	10	nT	
Ne	10		
Ni = Ne	10		
Ti	0.5	keV	
Te	0.06	eV	
fci_const=	0.0152	Hz/nT	
fce_const=	28	Hz/nT	
fpi_const=	209.6	Hz/nT	fpe/sqrt(mi/me)
fpe_const=	8980	Hz/nT	
Vi_const=	310	km/sec/keV	
Ve_const=	419	km/sec/eV	
V_Alfven_const=	21.8	(nT/cc^0.5) km/s	
fpi	663	Hz	
fpe	28397	Hz	
fci	0.152	Hz	6.578947
fce	280	Hz	
Vth, ion	219	km/s	
Vth, e	103	km/s	
V_Alfven	69	km/s	
rho_ion	229	km	
rho_elec	0	km	
ion_skin	72	km	c/w_pi
elec_skin	2	km	c/w_pe
Debye_length	0.00	km	(kT/4*pi*N*e^2)^0.5

$\rho_{i,\text{sheath (0.5keV,10nT)}}$= ~200km

$\rho_{i,\text{m-sphere (10keV,10nT)}}$= ~1000km

Magnetopause Thickness ~ 6000km

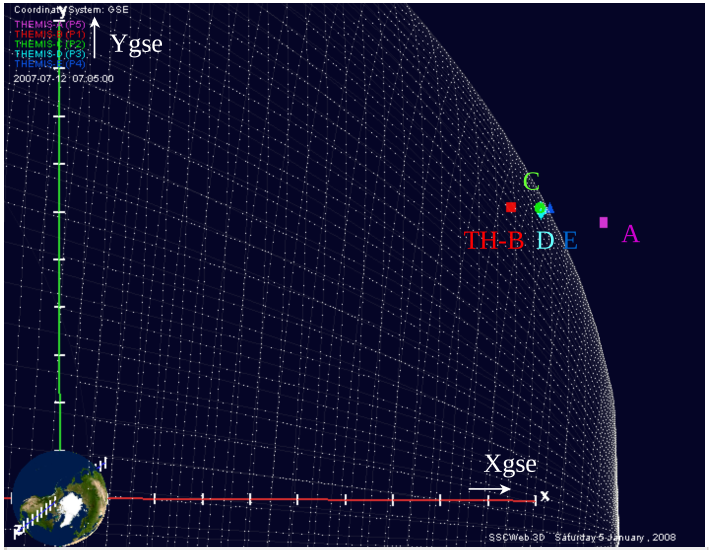
Current layer Thickness ~ 500km

FTE scale, Normal 2 Boundary: ~6000km

Along Boundary: ~Normal : 1-3 R_E

For leaking magnetospheric particles, the current layer is sharp compared to the ion gyroradius and the magnetic field is the same direction in the sheath and the magnetopause outside the current layer. This means we can use the measured field outside the magnetopause to determine gyrocenters both at the magnetopause and the magnetosheath on either side of the hot magnetopause boundary.

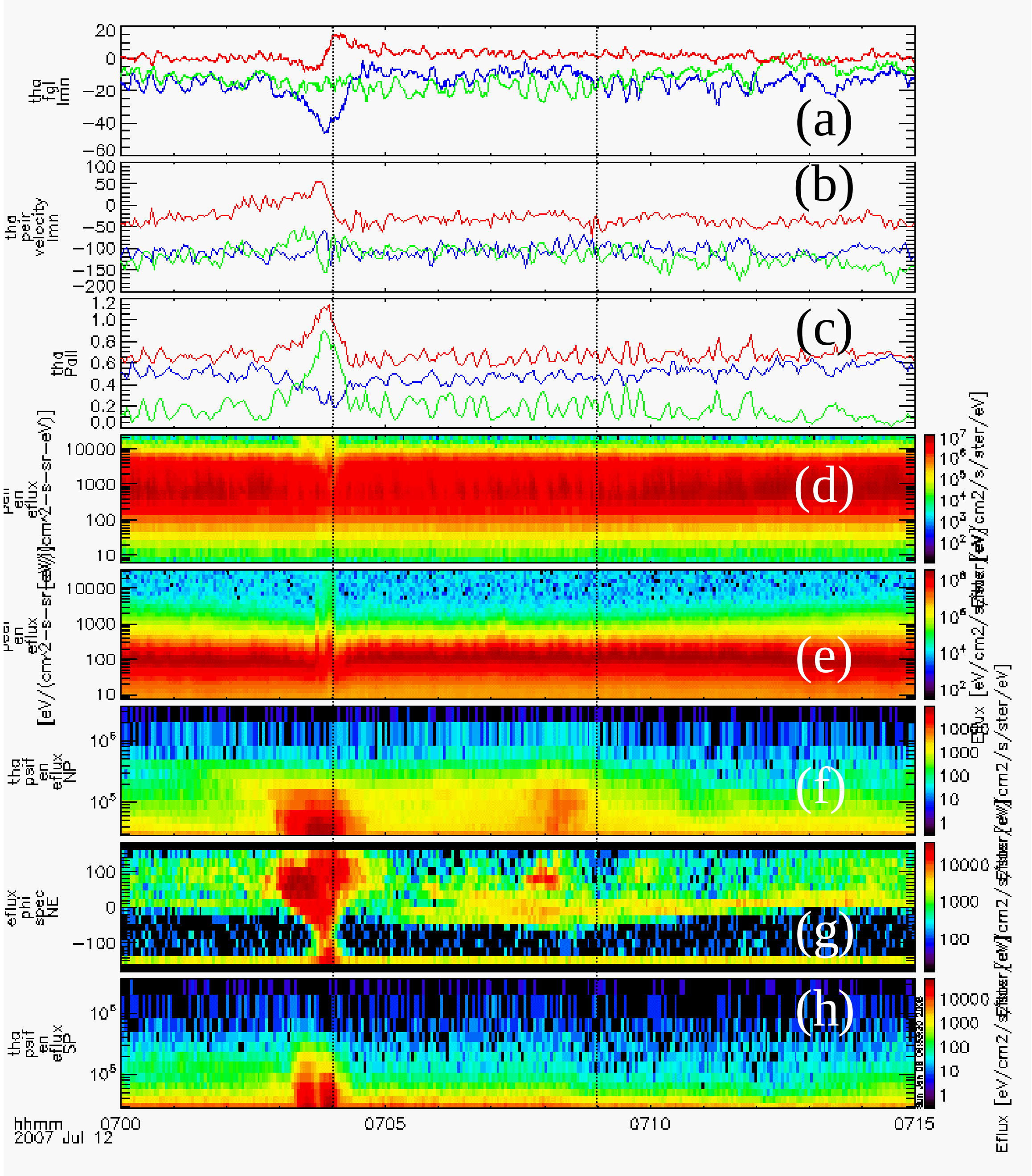
Magnetopause encounter on July 12, 2007



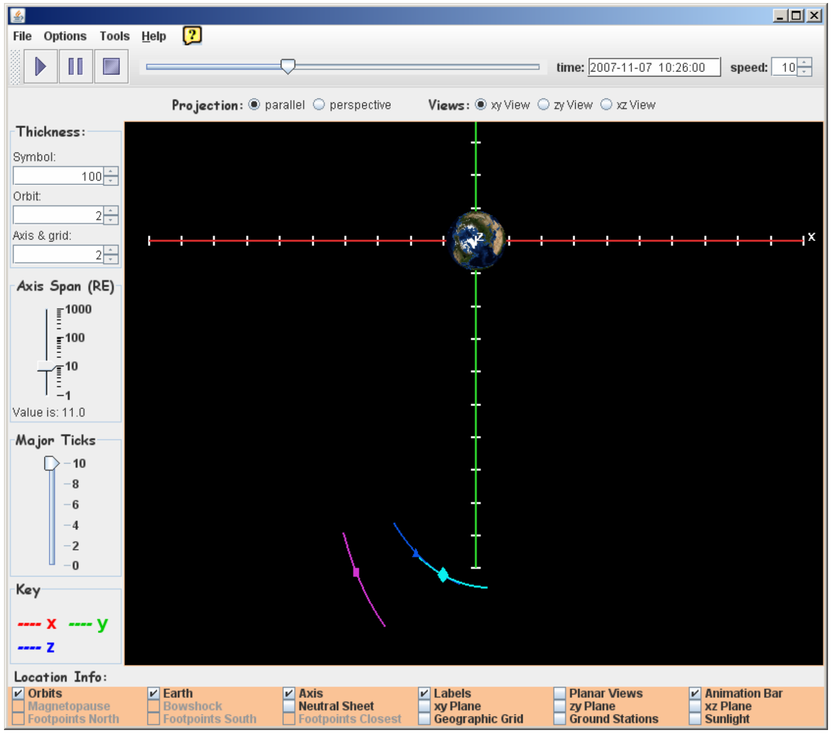
Satellite	Color	X	Y	Z
THEMIS-A (P5)	🟪	11.114	5.582	-3.39
THEMIS-B (P1)	🟥	9.214	5.928	-2.94
THEMIS-C (P2)	🟩	9.803	5.899	-3.101
THEMIS-D (P3)	🟦	9.827	5.849	-3.093
THEMIS-E (P4)	🟦	10.011	5.907	-3.174

Magnetic field angle is 60deg below spin plane and +120deg in azimuth i.e., anti-Sunward and roughly tangent to the magnetopause. The particle velocities, centered at 52deg above the spin plane, have roughly 90° pitch angles, with gyro-centers that were on the Earthward side of the spacecraft. The energy spectra of the NP particles show clearly the arrival of the FTE ahead of its magnetic signature, remotely sensing its arrival due to the finite gyroradius effect of the energetic particles.

ΔT=55s, $\rho_{(i,100keV,\ 28nT)}$ =1150km, V=40km/s



At the near-Earth magnetosphere



time: 2007-11-07 10:26:00

speed: 10

Projection: ● parallel ○ perspective

Views: ● xy View ○ zy View ○ xz View

Thickness:

Symbol: 100

Orbit: 2

Axis & grid: 2

Axis Span (RE)

1000
100
10
1

Value is: 11.0

Major Ticks

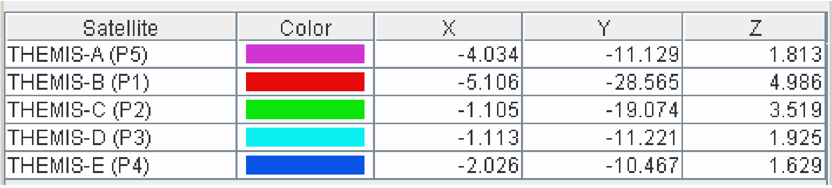
10
8
6
4
2
0

Key

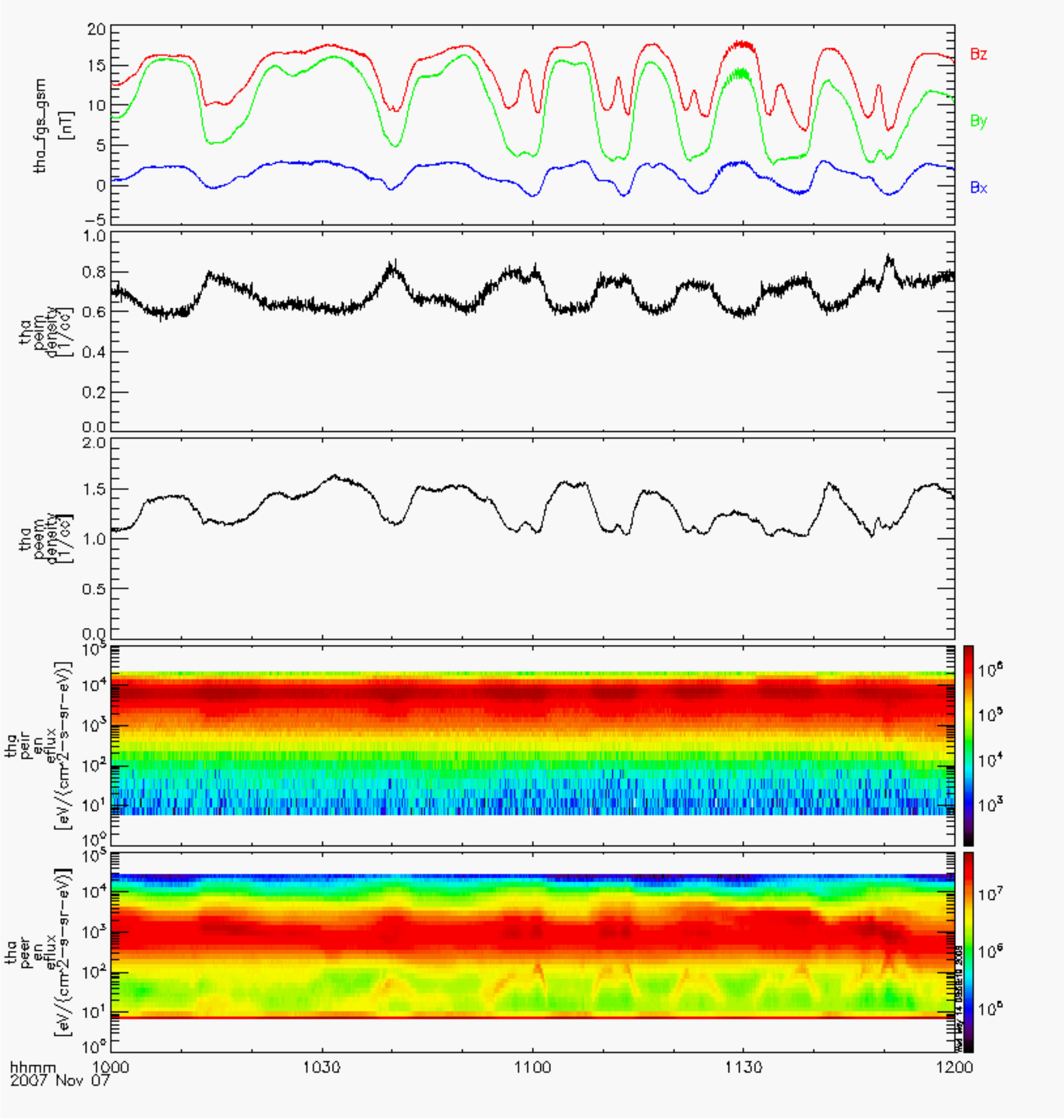
---- x ---- y
---- z

Location Info:

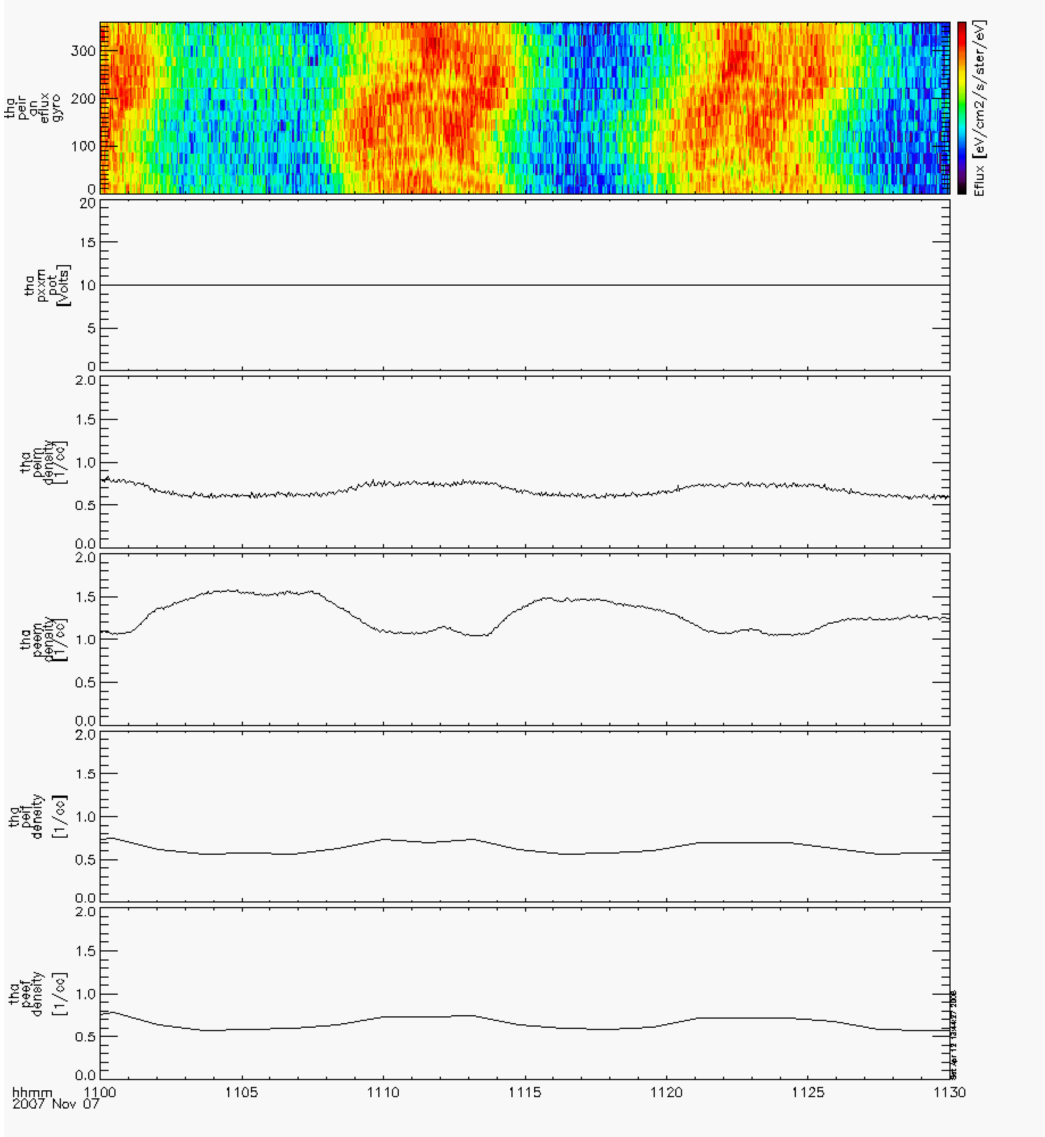
☑ Orbits	☑ Earth	☑ Axis	☑ Labels	☐ Planar Views	☑ Animation Bar
☐ Magnetopause	☐ Bowshock	☐ Neutral Sheet	☐ xy Plane	☐ zy Plane	☐ xz Plane
☐ Footpoints North	☐ Footpoints South	☐ Footpoints Closest	☐ Geographic Grid	☐ Ground Stations	☐ Sunlight



Satellite	Color	X	Y	Z
THEMIS-A (P5)	🟪	-4.034	-11.129	1.813
THEMIS-B (P1)	🟥	-5.106	-28.565	4.986
THEMIS-C (P2)	🟩	-1.105	-19.074	3.519
THEMIS-D (P3)	🟦	-1.113	-11.221	1.925
THEMIS-E (P4)	🟦	-2.026	-10.467	1.629



At the near-Earth magnetosphere

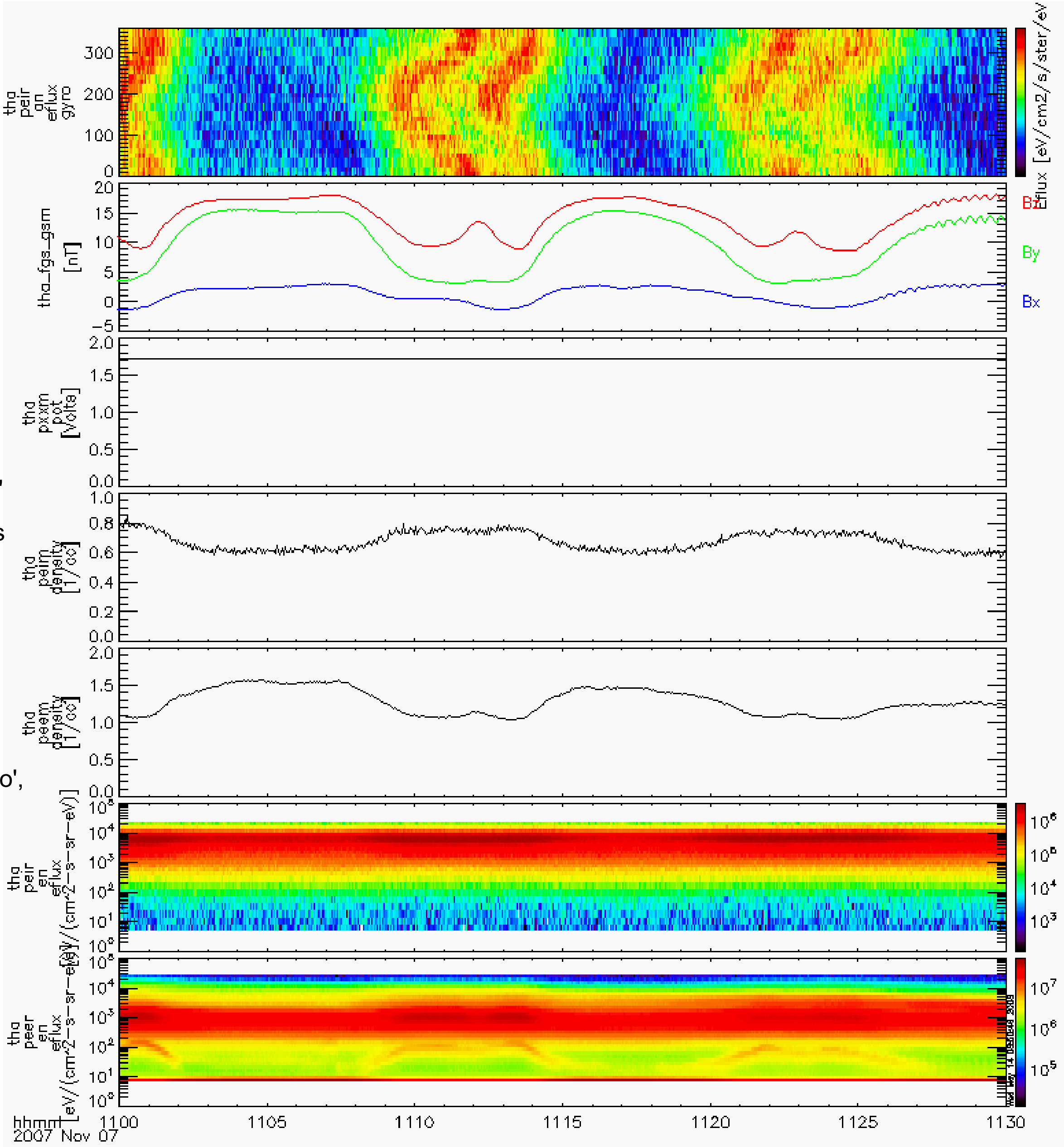


At the near-Earth magnetosphere

Remote sensing of waves in ESA data, at the most appropriate coordinate System, I.e, field aligned coordinates.
gyro=0º => Earthward particles

```
timespan,'7 11 07/10',2,/hours & sc='a'
thm_load_state,probe=sc,/get_supp
thm_load_fit,probe=sc,data='fgs',coord='gsm',suff='_gsm'
thm_load_mom,probe=sc ; L2: onboard processed moms
thm_load_esa,probe=sc ; L2: gmoms, omni spectra
tplot,'tha_fgs_gsm tha_pxxm_pot tha_pe?m_density
tha_pe?r_en_eflux'
;
trange=['07-11-07/11:00','07-11-07/11:30']
thm_part_getspec, probe=['a'], trange=trange, angle='gyro', $
                pitch=[45,135], other_dim='mPhism', $
;                /normalize, $
                data_type=['peir'], regrid=[32,16]
tplot,'tha_peir_an_eflux_gyro tha_fgs_gsm tha_pxxm_pot
tha_pe?m_density tha_pe?r_en_eflux'
```

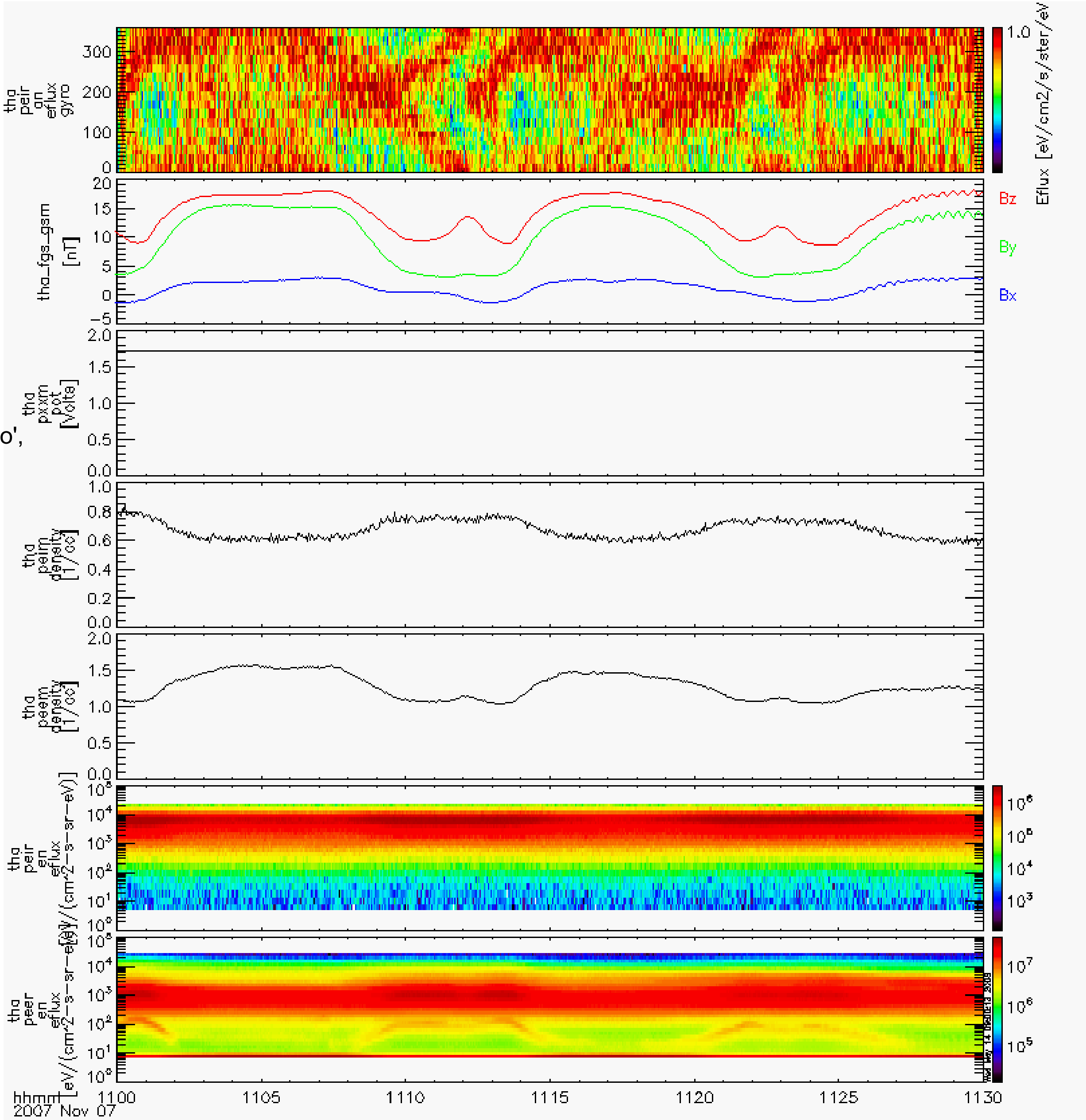
ESS 265



At the near-Earth magnetosphere

Same as before but using keyword: /normalize
I.e., anisotropy is normalized to 1, to ensure flux variations do not affect anisotropy calculation.

```
trange=['07-11-07/11:00','07-11-07/11:30']

thm_part_getspec, probe=['a'], trange=trange, angle='gyro', $

            pitch=[45,135], other_dim='mPhism', $

            /normalize, $

            data_type=['peir'], regrid=[32,16]

tplot,'tha_peir_an_eflux_gyro tha_fgs_gsm tha_pxxm_pot tha_pe?m_density tha_pe?r_en_eflux'
```



Topics for May 19 class

- Potential subtraction
- Cold plasma detection
- Density computation from three sources (Ne, Ni, scpot)
- Velocity, pressure corrections from SST
- Waves analysis