Magnetospheric and ionospheric responses to the passage of solar wind discontinuity on 24 November 2008

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Kim et al. (JGR 2012)

Issues to be addressed in this study

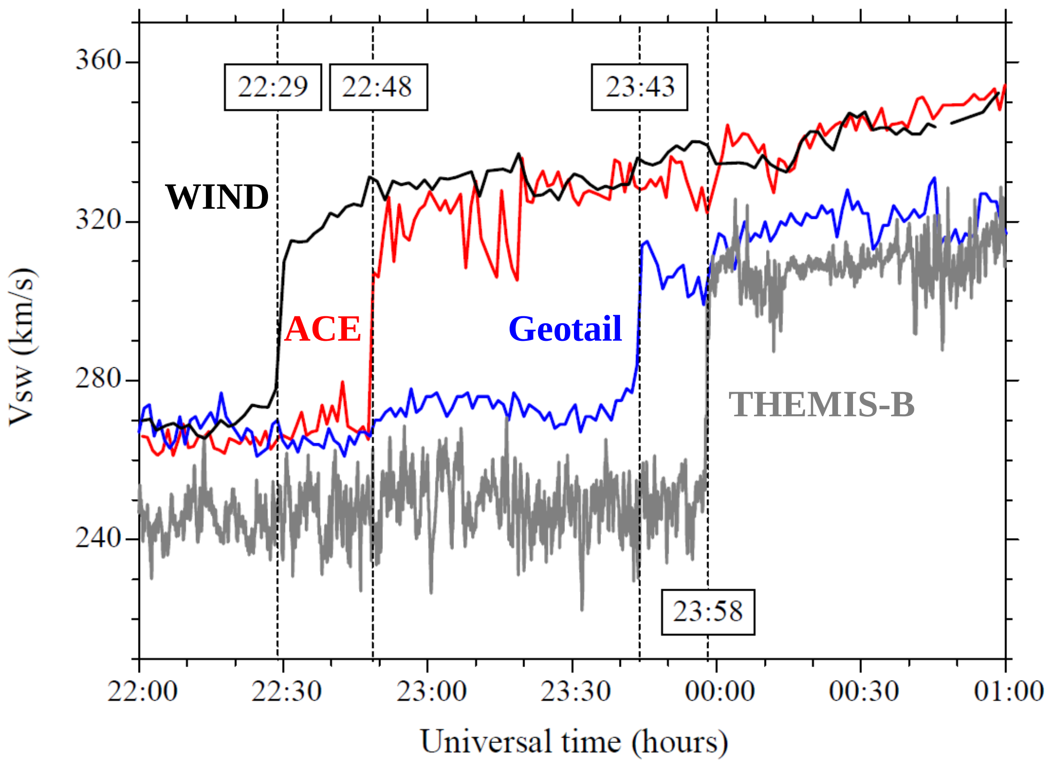
Magnetospheric and ionospheric responses to the passage of interplanetary (IP) shock on 24 November 2008.

- **Space**: Multi-spacecraft observations in the solar wind and in the magnetosphere.
*** Solar wind (4 spacecraft): Wind, ACE, Geotail, and THEMIS-B (THB)**
*** Dayside Magnetosphere (5 spacecraft): GOES11, ETS-VIII, THEMIS-E (THE), THEMIS-D (THD), and THEMIS-A (THA)**

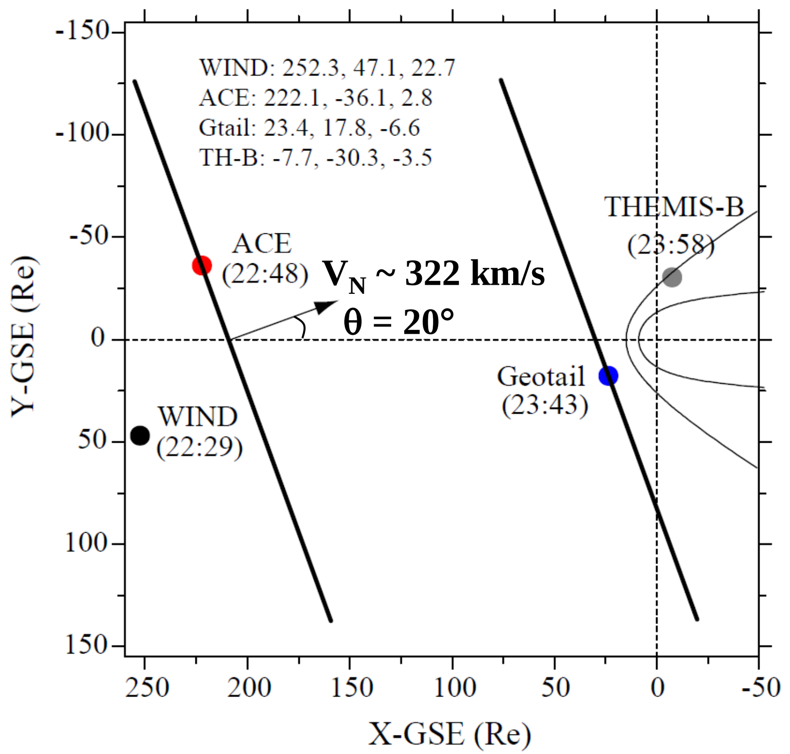
- **Ground**: Comparison of IP shock-associated high/low-latitude geomagnetic disturbances and ionospheric E-field variations determined by SuperDARN radar data.
*** High latitude: Chokurdakh (CHD, MLAT = ~65°) in Russia**
*** Low latitude: Bohyun (BOH, MLAT = ~30°) in Korea**
*** Hokkaido SuperDARN radar in Japan.**

Multi-spacecraft IP shock observations in solar wind

Satellite observations of the discontinuity in solar wind on 24-25 Nov. 2008



The discontinuity surface in the ecliptic plane

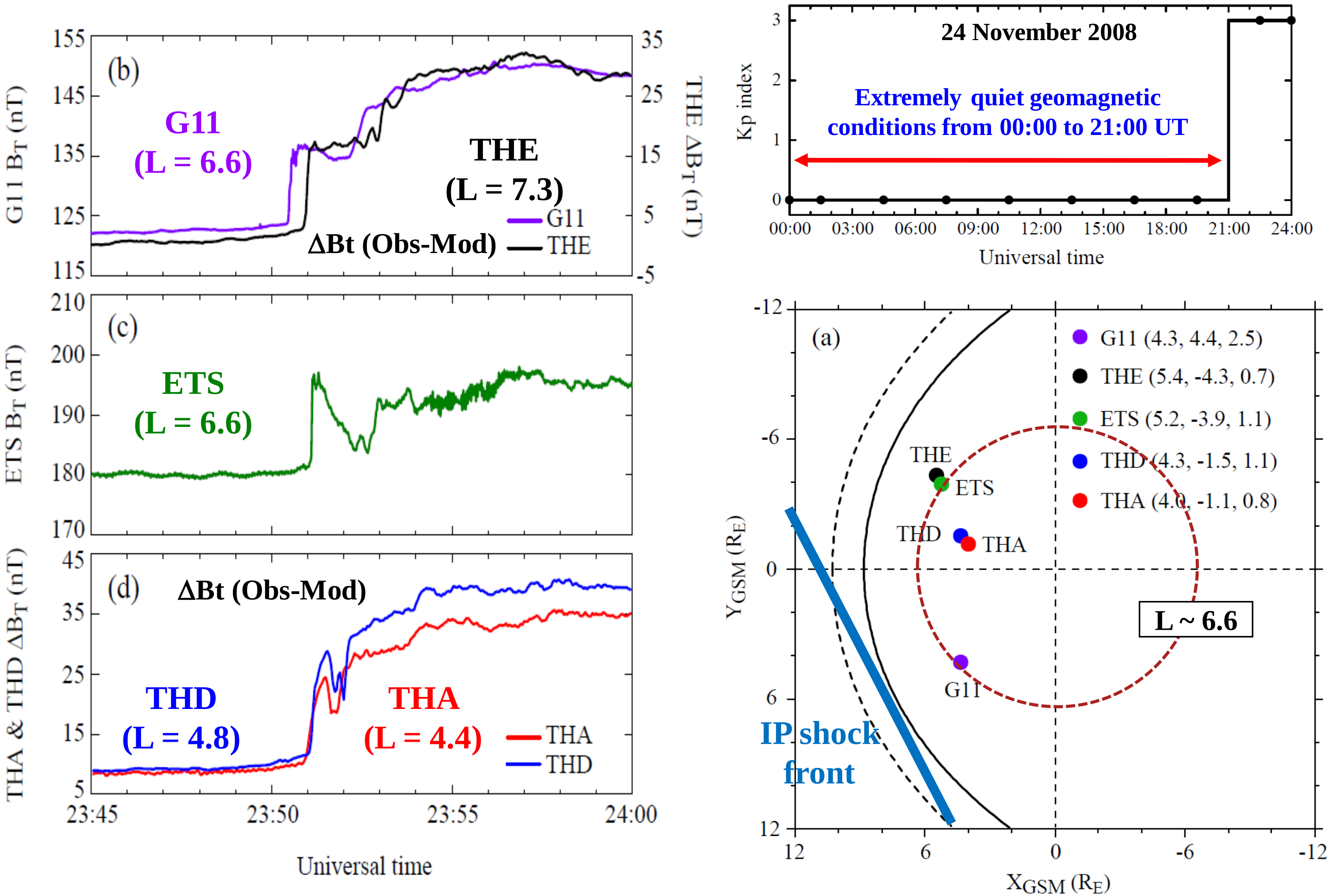


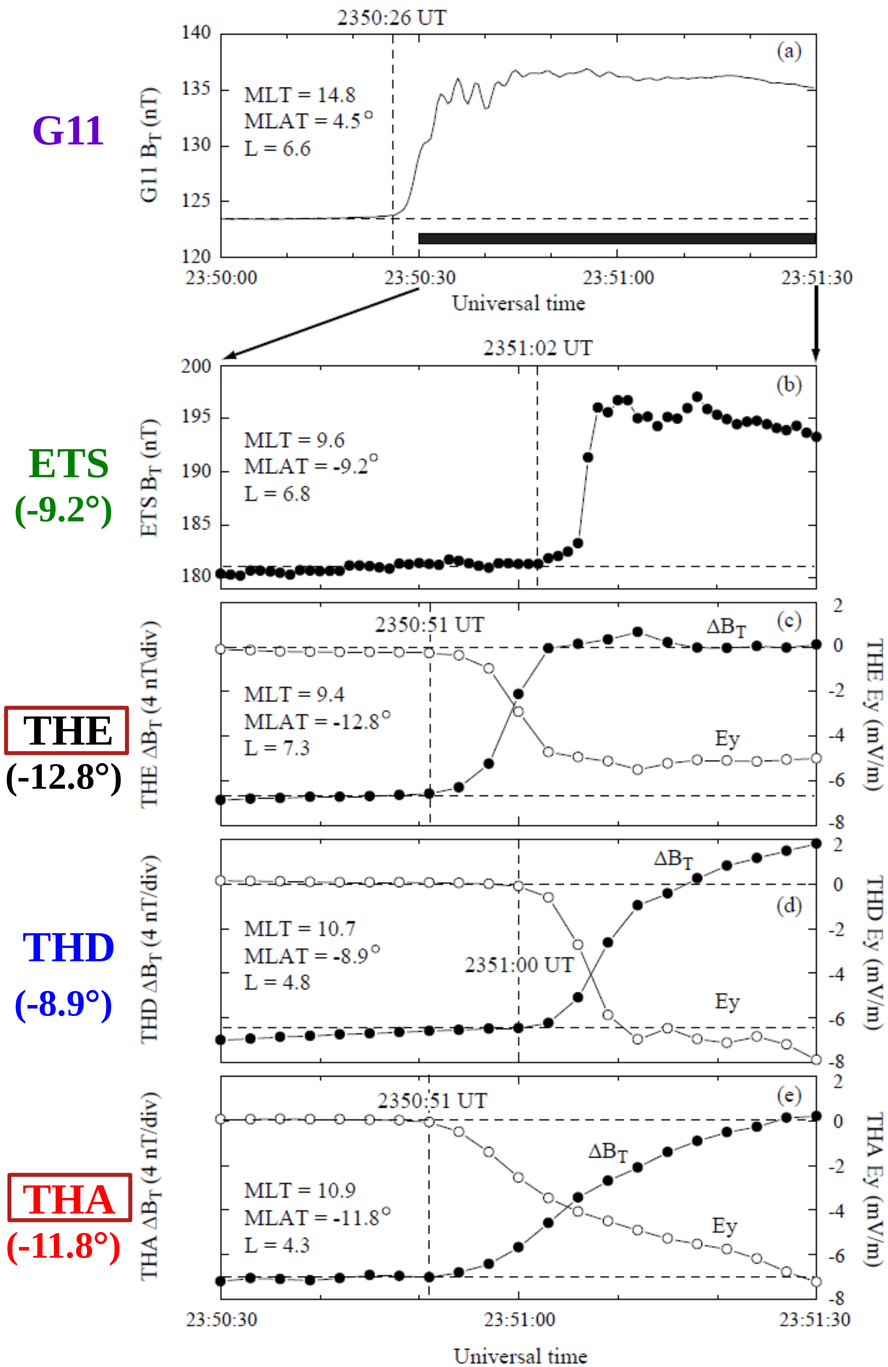
Shock normal vector ***n*** (x, y) = (-0.94, -0.35) in GSE, ***n*** (x, y, z) = (-0.94, -0.35, -0.04)

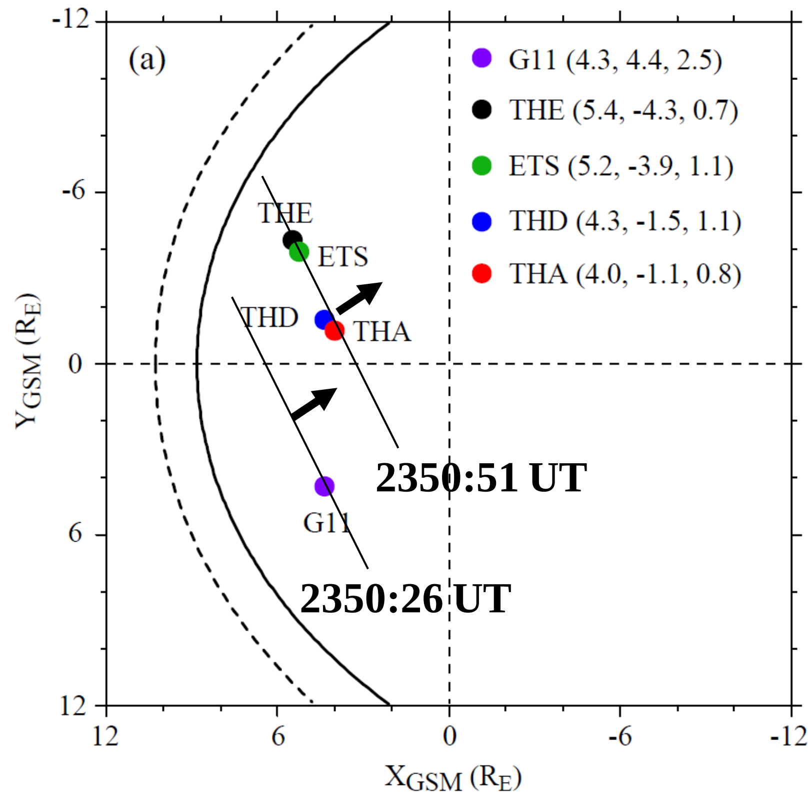
The angle between the shock normal and the Sun-Earth line is about 20°.

So, the surface of the shock front faces dawnward. V_N = ~322 (~324) km/sec.

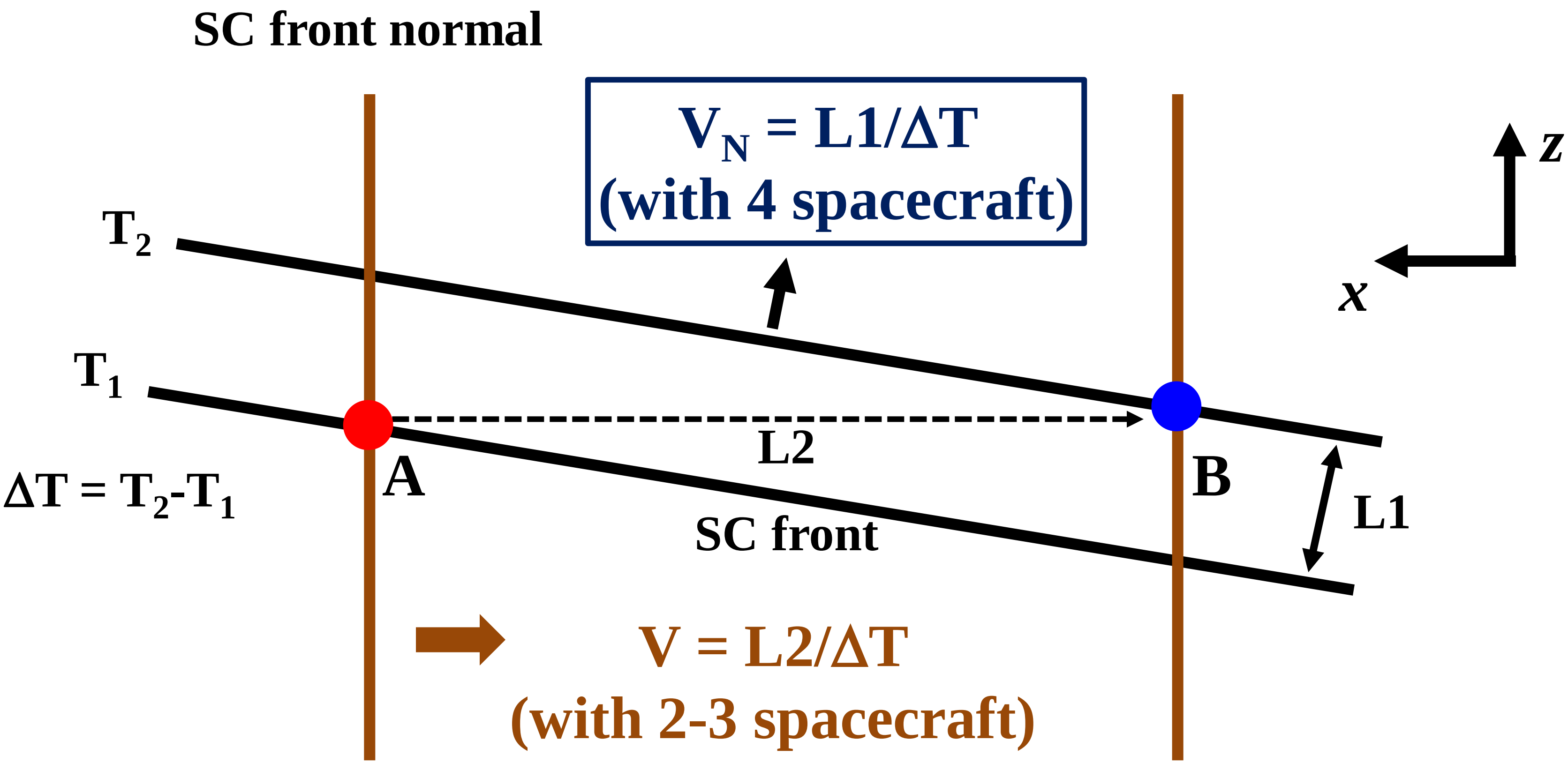
IP shock-associated geomagnetic field perturbations







- **Using the locations of THE and THA at the onset time, the SC front normal direction is ~24° to the Sun-Earth line.**
- **Assuming that the SC front normal is parallel to the *x-y* plane and using the normal angle of ~24°, the propagation speed between G11 and THA (or THE) is ~650 km/s.**
- **But, the above assumption is wrong ....**



Assuming that SC front propagates along the x axis, V = L2/ΔT, V is larger than V_N. (V > V_N)

• Using 4-spacecraft observation, the normal vector and its speed can be determined in GSM (*x*, *y*, *z*).

• Normal vector *k*:
  - elevation angle: ~37°-52°
  - azimuthal angle: ~21°-27°

That is, *k* is not parallel to the *x*-*y* plane.

• SC front normal speed V_N = ~70-180 km/sec. This speed is much smaller than the local Alfven speed.

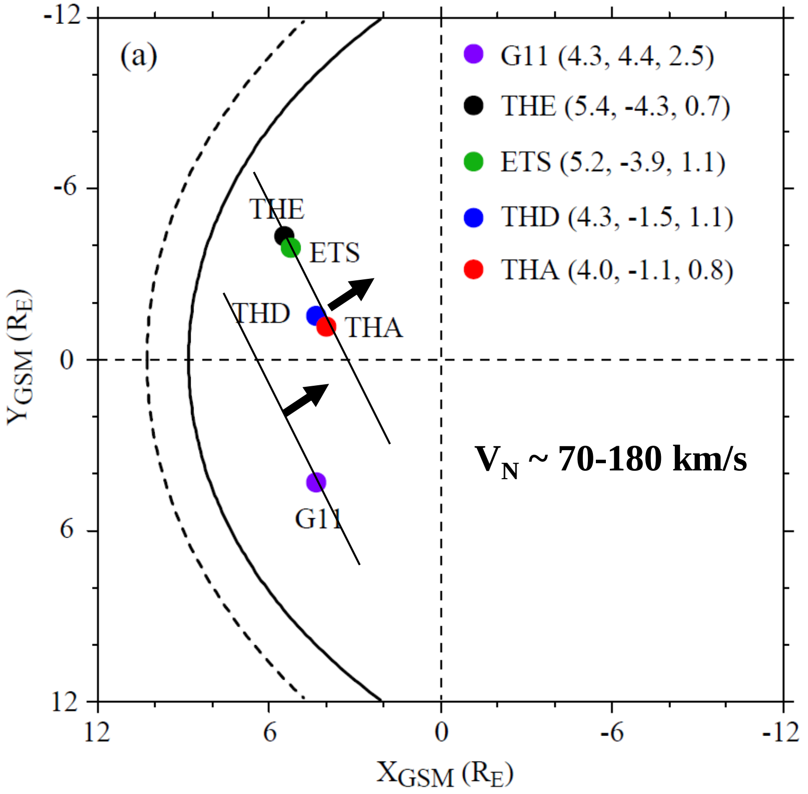
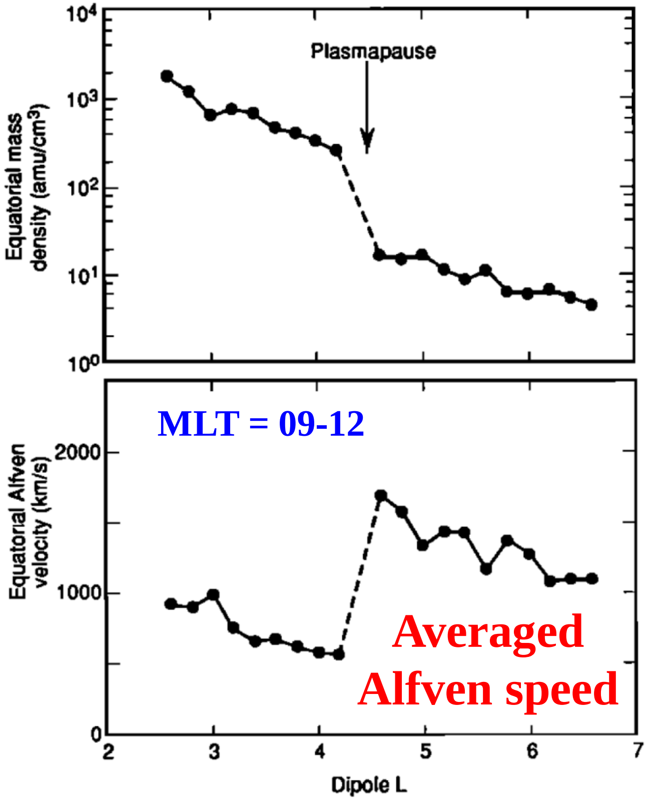
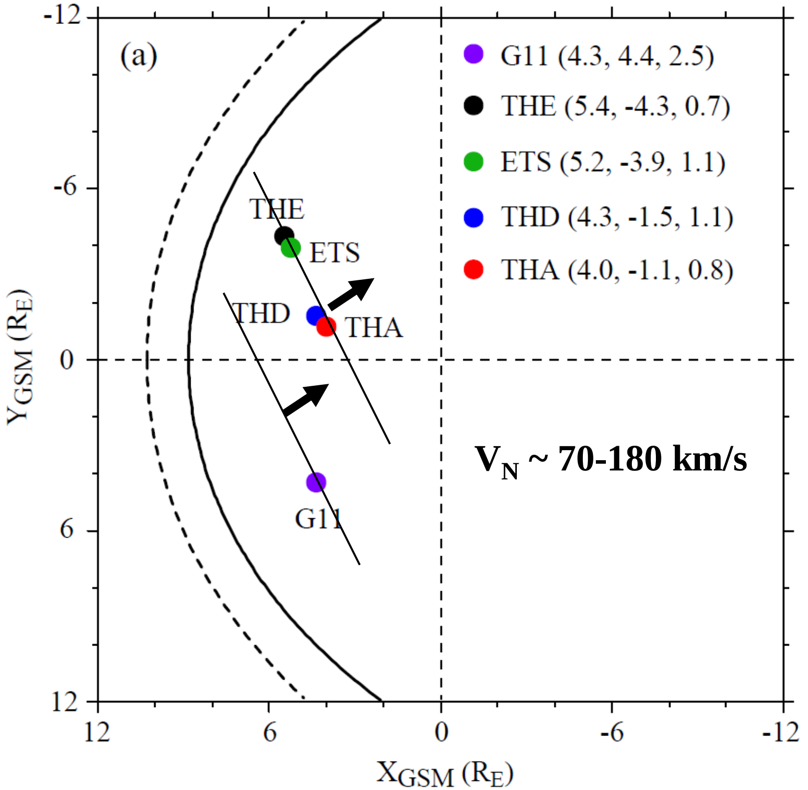


Table 1. SC Front Normal Direction in GSM Coordinates and Its Speed

Spacecraft	$\hat{x}$	$\hat{y}$	$\hat{z}$	Azimuth $\phi(°)$	Elevation $\theta(°)$	V_N(km/s)
G11-ETS-THE-THD	−0.740	−0.296	0.604	22	37	170
G11-ETS-THD-THA	−0.623	−0.237	0.746	21	48	70
G11-ETS-THE-THA	−0.621	−0.310	0.720	27	46	180
G11-THE-THD-THA	−0.552	−0.280	0.785	27	52	105
ETS-THE-THD-THA	0.151	0.039	0.988	104	81	240

Takahashi et al. (1992)



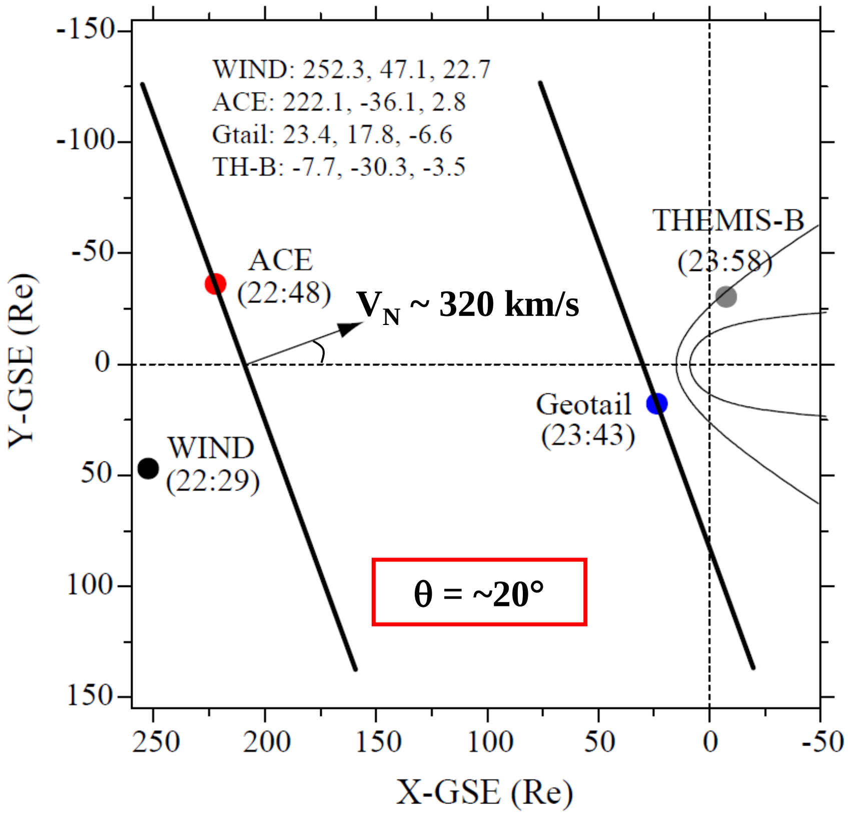


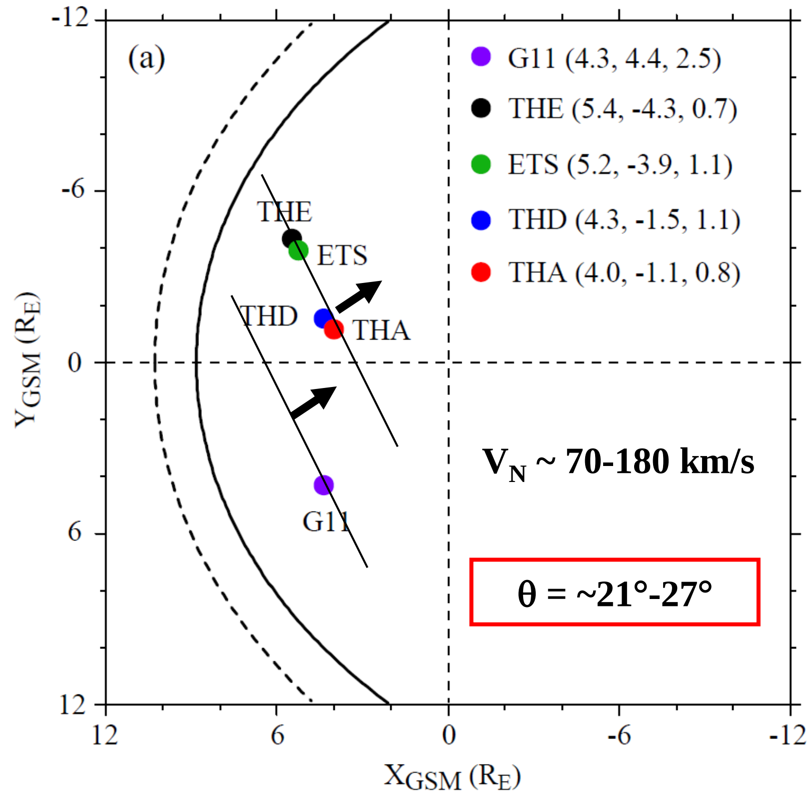
- Since V_N is much smaller than the Alfven velocity, the SC front propagating tailward is not a fast-mode propagation.
- The speed of V_N is about 30-60% of IP shock propagation speed in the solar wind (~320 km/s), which is comparable to the IP shock speed in the magnetosheath around MLT = ~9-10 hours (Spreiter et al., 1966).

- **So, we suggest that the dominant B field increase during the SC interval is due to the lateral solar wind pressure increase.**

The IP shock normal in the ecliptic plane

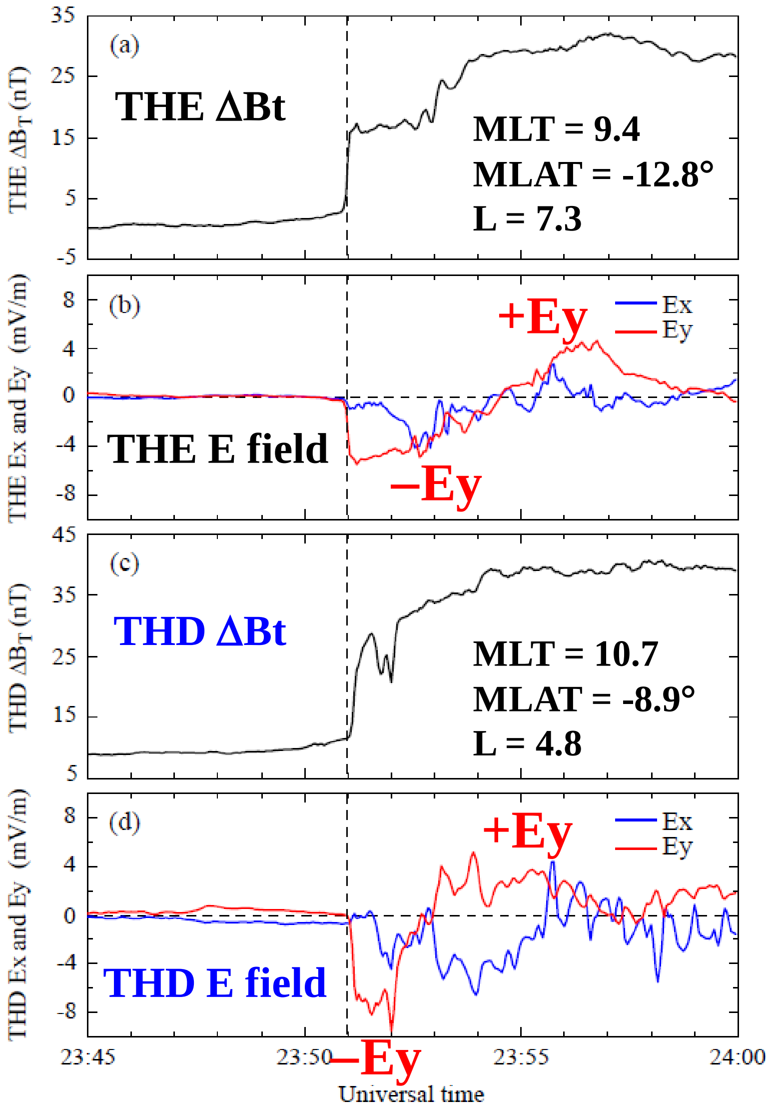
SC-associated compressional front propagating tailward

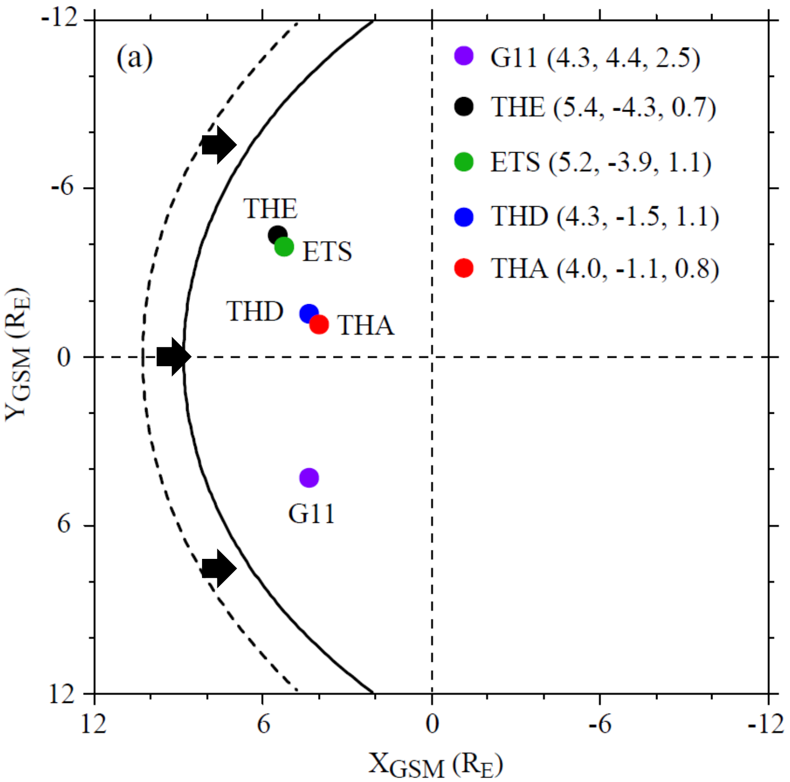




- **The angle (θ) between the IP shock normal and the Sun-Earth line is about 20°.**
- **The angle (θ) between the SC front normal and the Sun-Earth line is about 21°-27°.**
- **The SC front normal vector in the *x-y* plane is nearly aligned with the IP shock normal.**

IP shock-associated electric field (Ey) perturbations

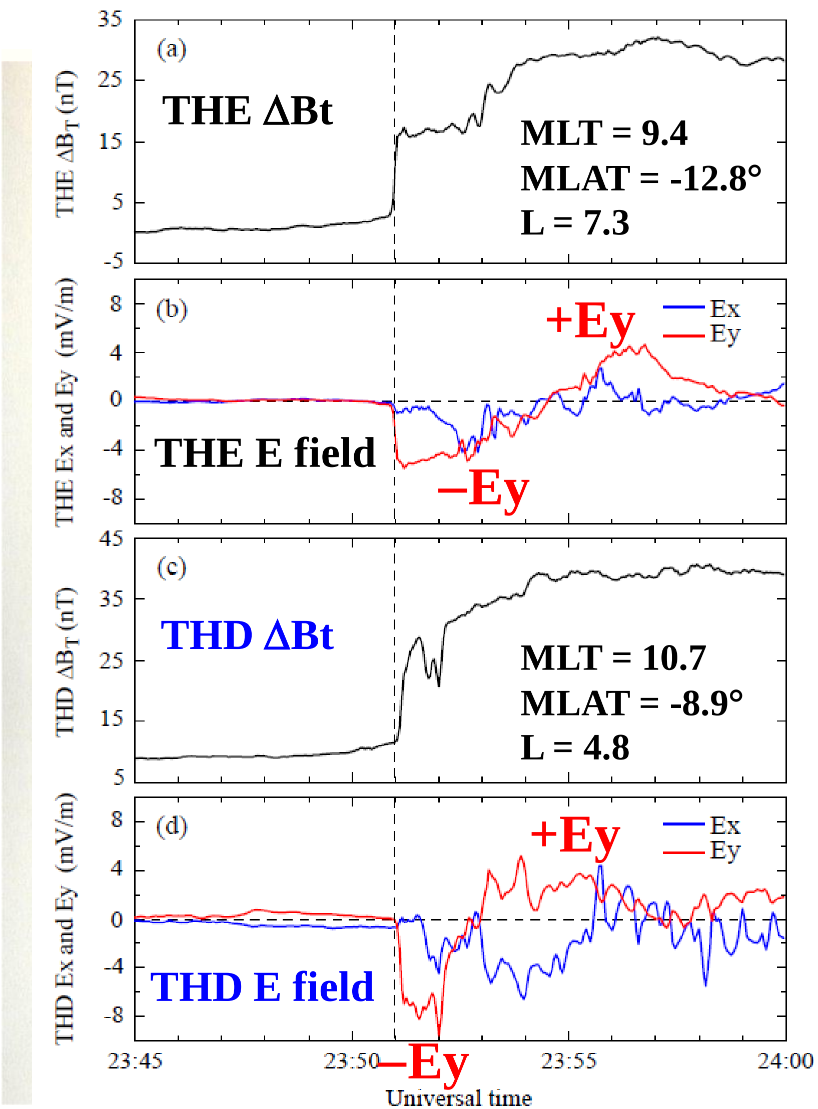


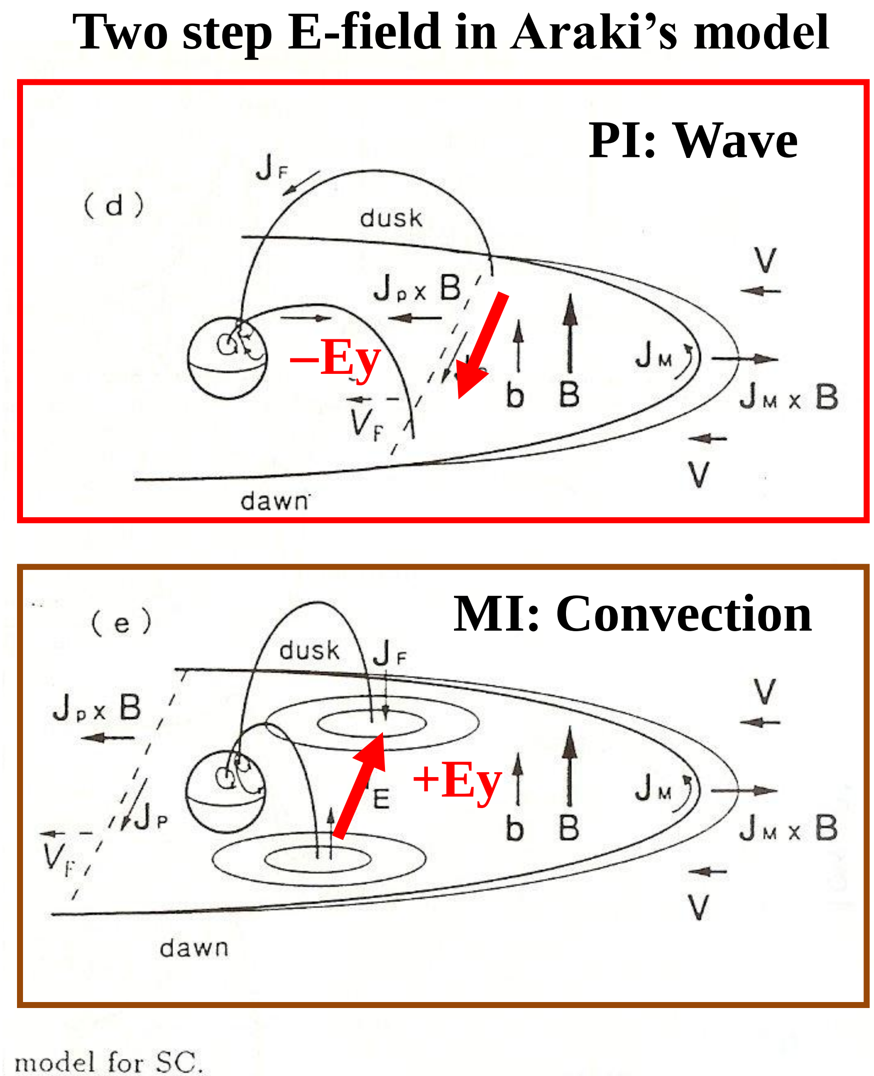


Ey: Negative and then Positive.

Negative Ey: corresponding to the Earthward plasma motion.

Comparison of Araki's SC model and Obs.

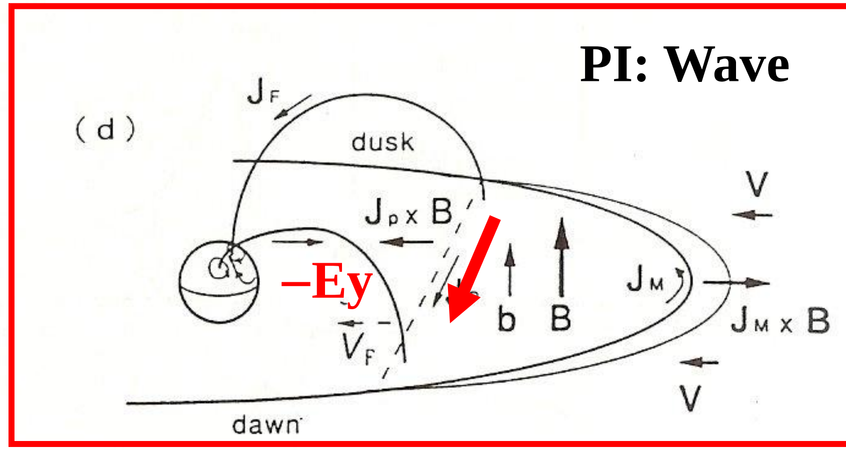


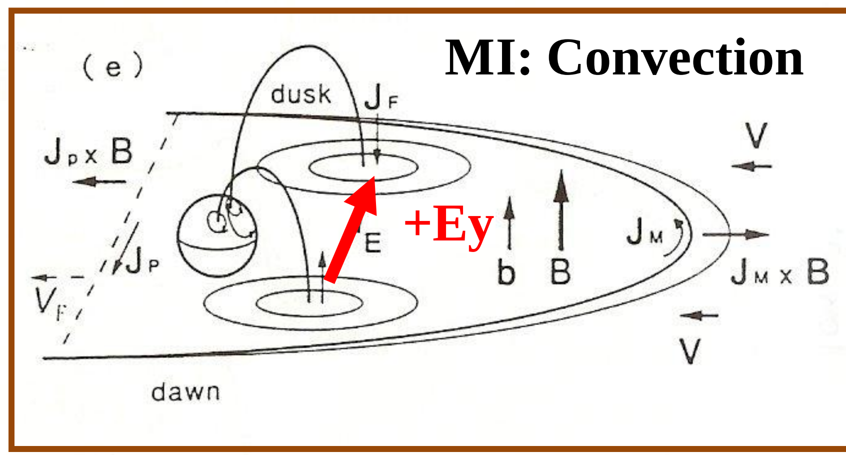


Comparison of Araki's SC model and Obs.

"After the passage of the compressional wavefront toward the magnetotail, the magnetospheric convection has to adjust to the new compressed state of the magnetosphere if the dynamic pressure of the solar wind remains high behind the shock or discontinuity. The convection E field in the dawn-to-dusk direction has to be enhanced in the compressed magnetosphere. The associated FAC flows into the dawn ionosphere and out from the dusk ionosphere" [Araki, 1994]

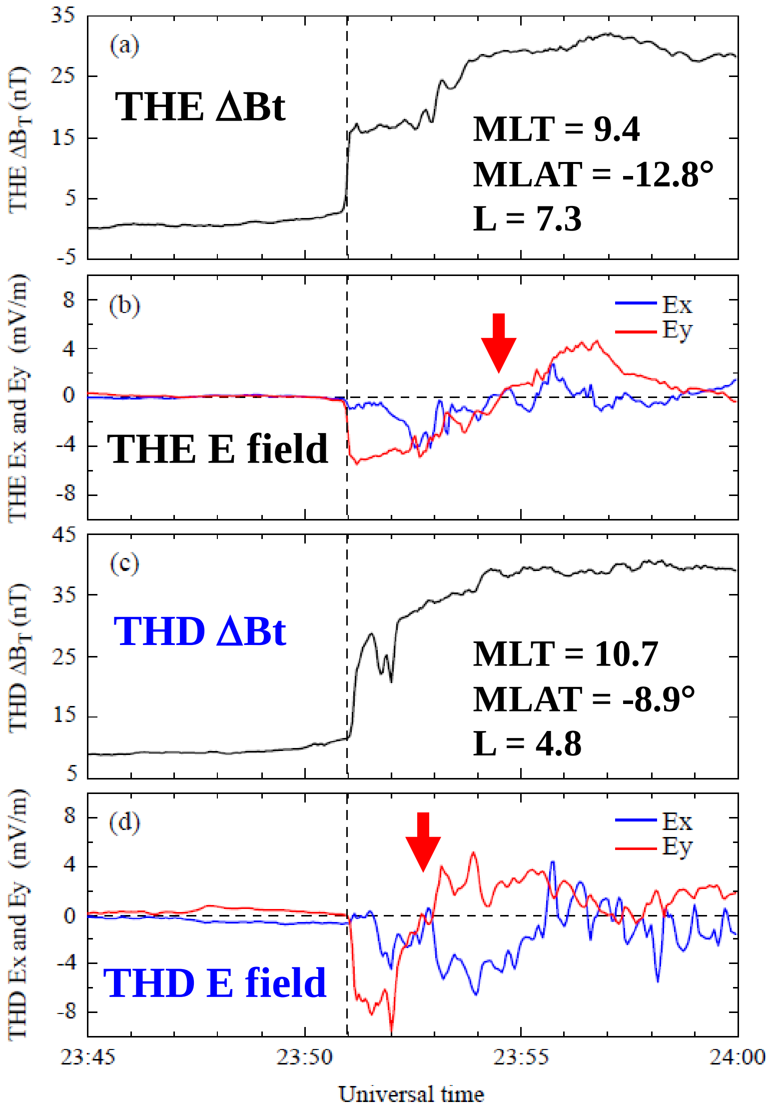
Two step E-field in Araki's model

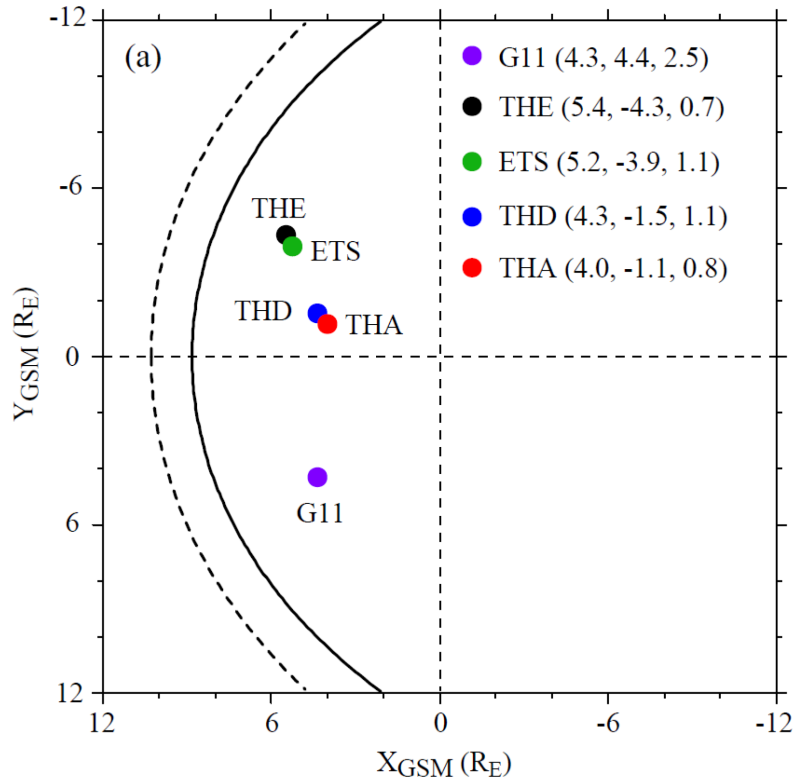




model for SC.

IP shock-associated electric field (E) perturbations

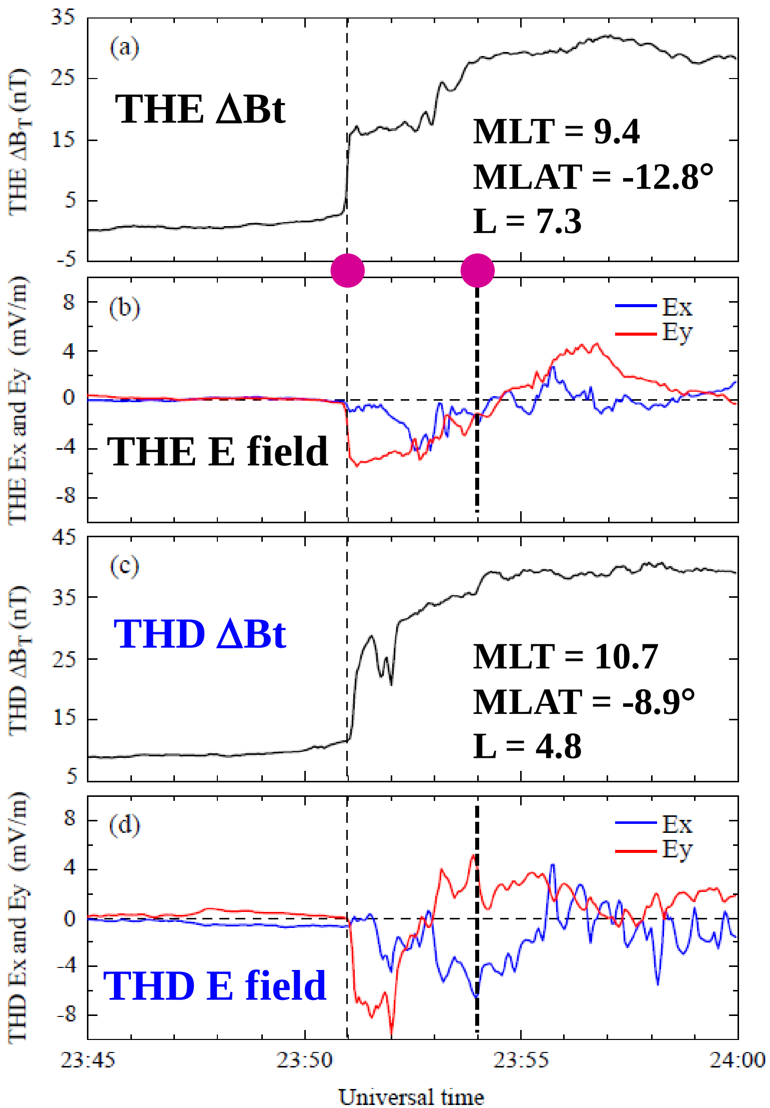


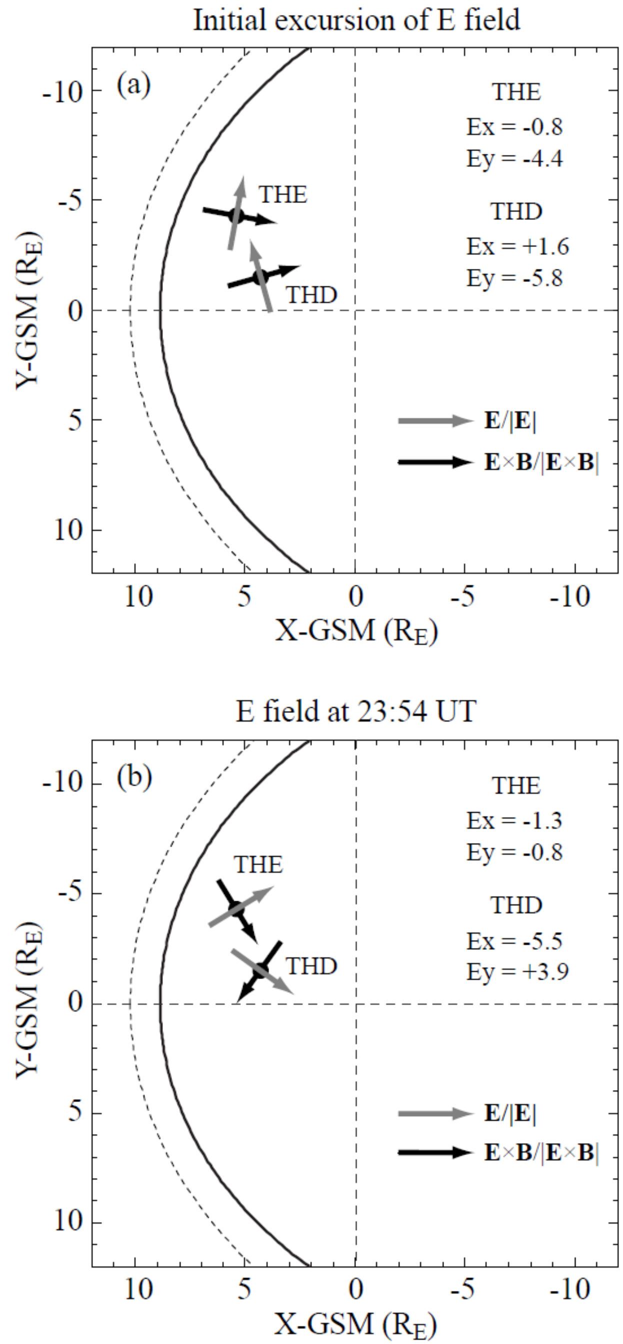


Then, why does the Ey polarity (negative and then positive) change at THE and THD occur at different times?

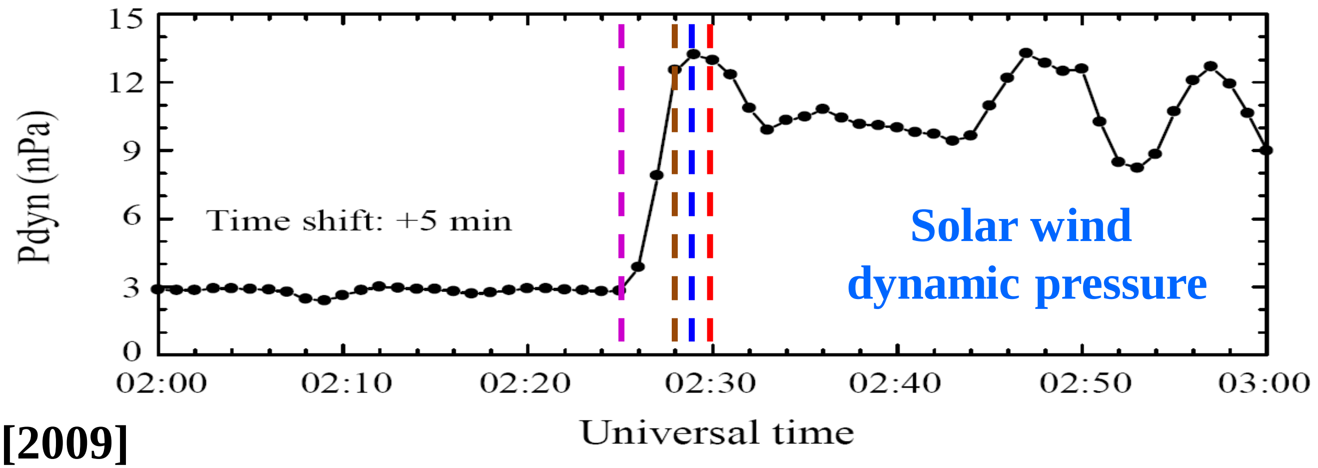
We suggest that this is due to SC-associated plasma vortical motion.

Vortical plasma motions

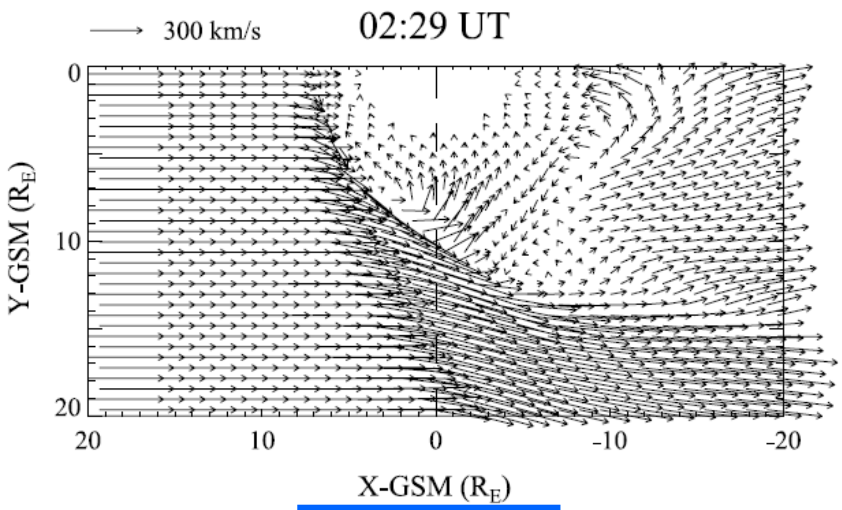




SC-associated magnetospheric convection vortices: MHD simulation on 21 Oct. 1999



Kim et al. [2009]



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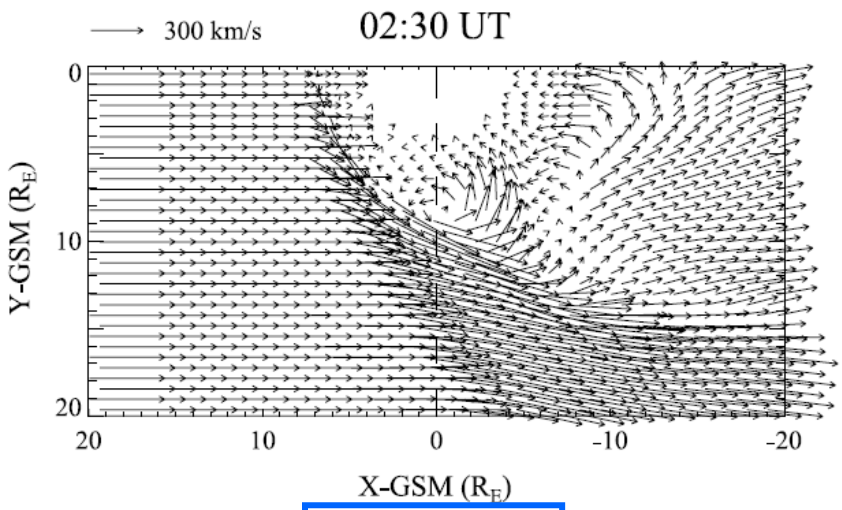
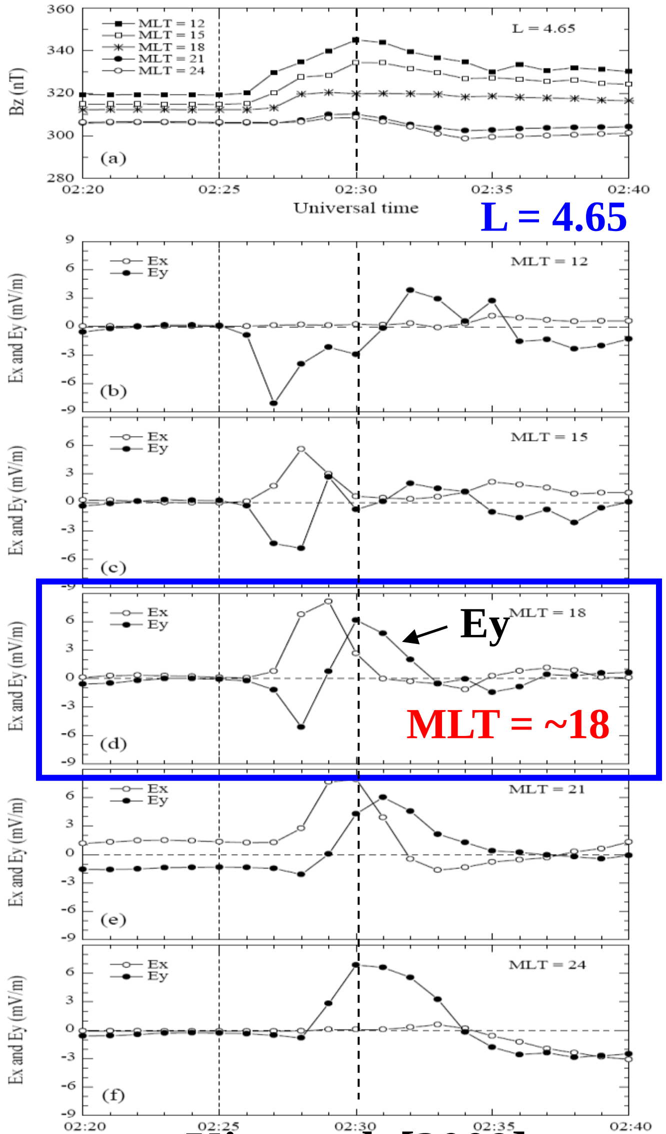


02:30 UT

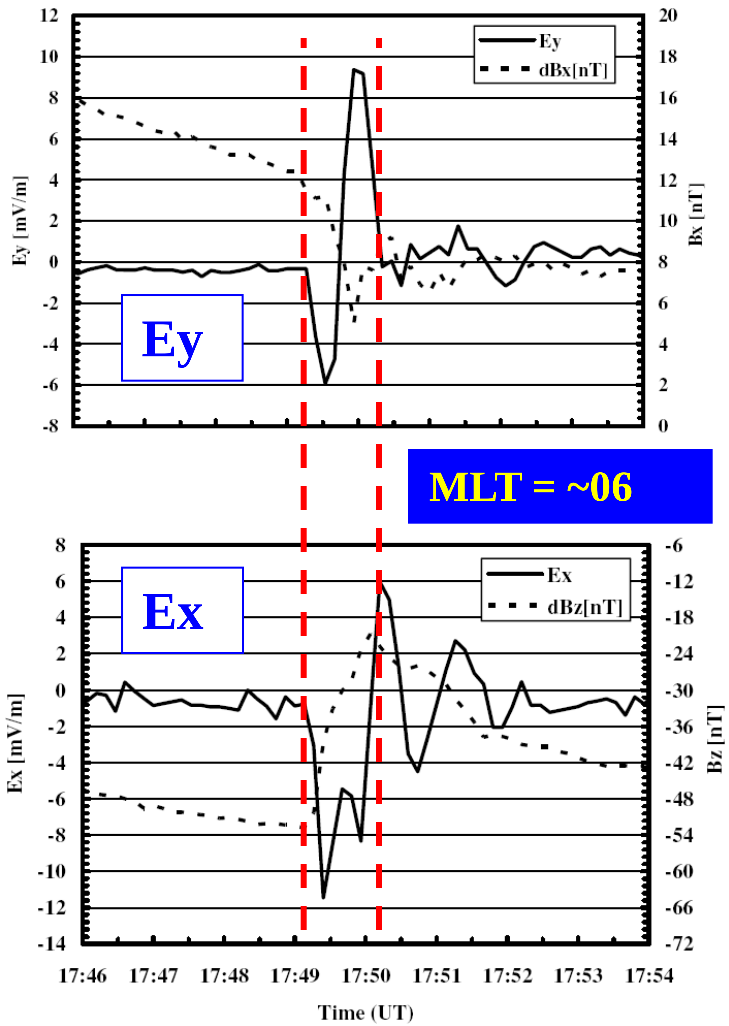
Comparison of Model and Observations of SC

MHD model



Kim et al. [2009]

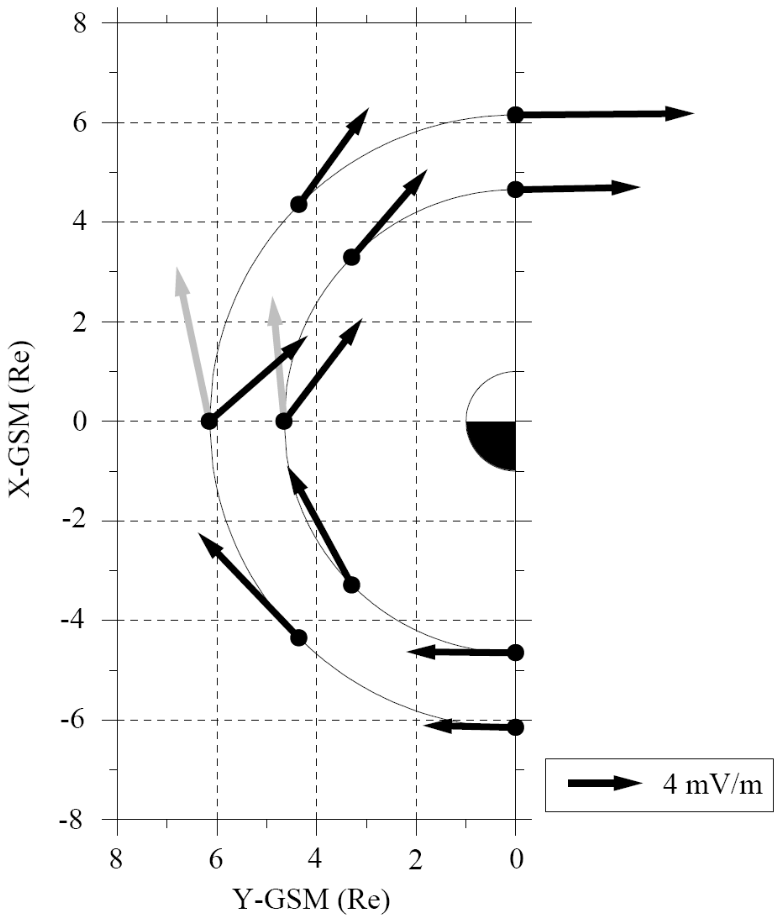
Akebono obs.



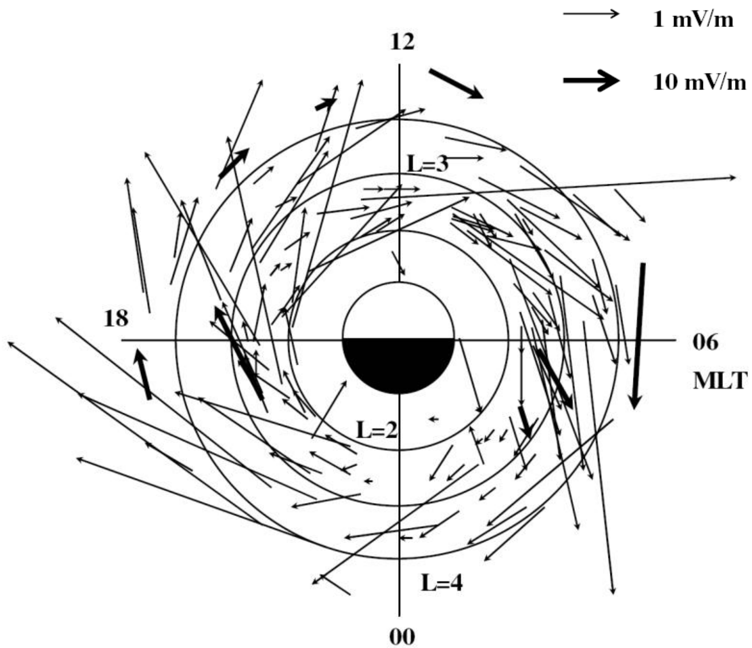
Shinbori et al. [2004]

Comparison of Model and Observations of SC

SC-E field: associated with plasma vortical motion in space



Kim et al. [2009]

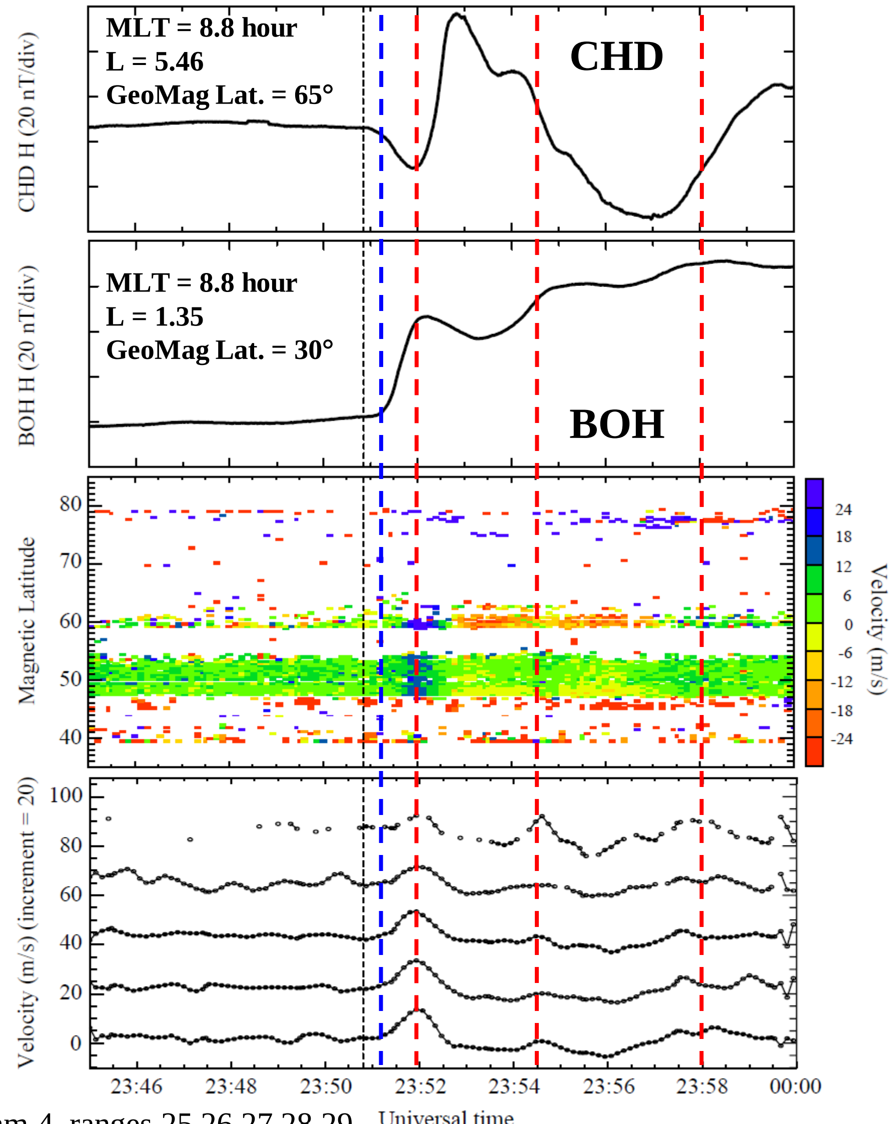


Akebono E field obs.

Shinbori et al. [2004]

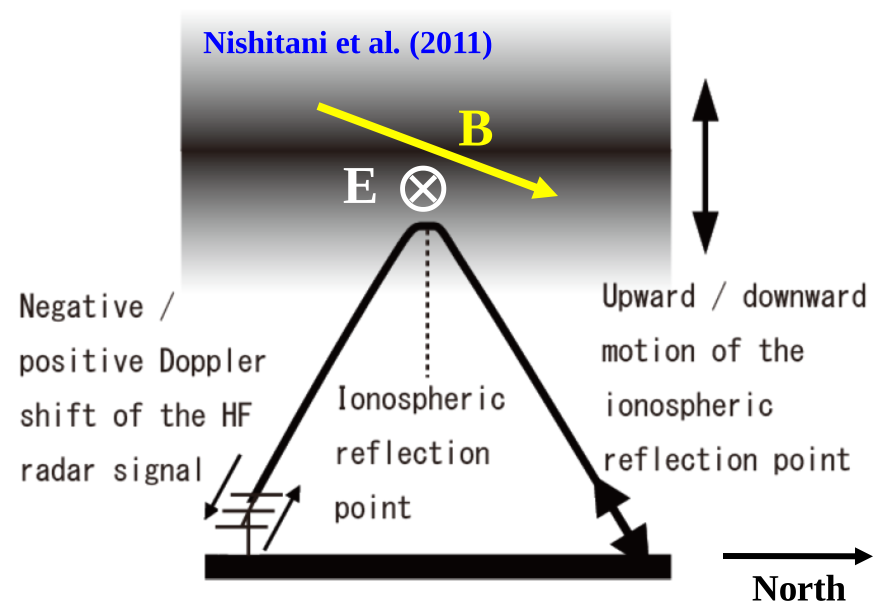
Comparison of high/low-latitude geomagnetic field and SuperDARN Hokkaido radar data

24 November 2008

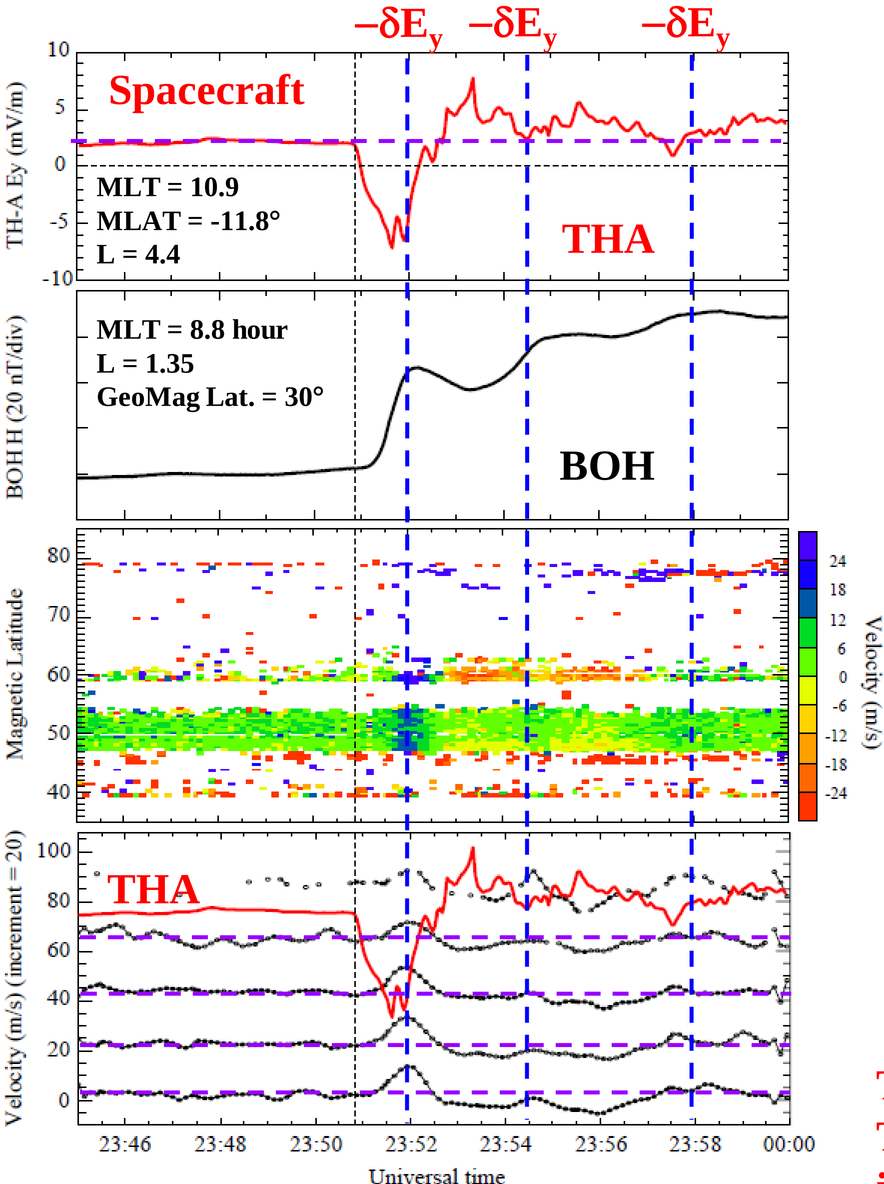


Beam 4, ranges 25 26 27 28 29

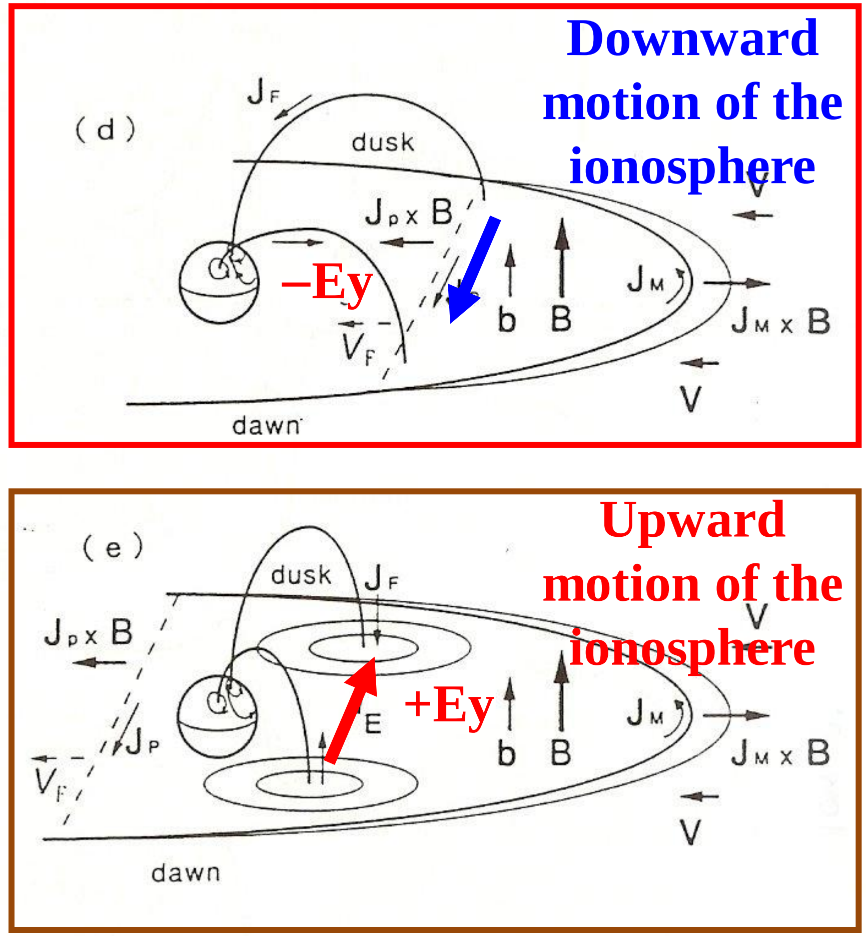
- The positive velocity corresponds to downward motion of the ionosphere.
- This indicates westward (dawnward) E field in the ionosphere.
- When positive perturbations are observed at BOH behind the SC event, SuperDARN data show positive perturbations.



Comparison of TH-A E field and SuperDARN Hokkaido radar obs. in the dayside

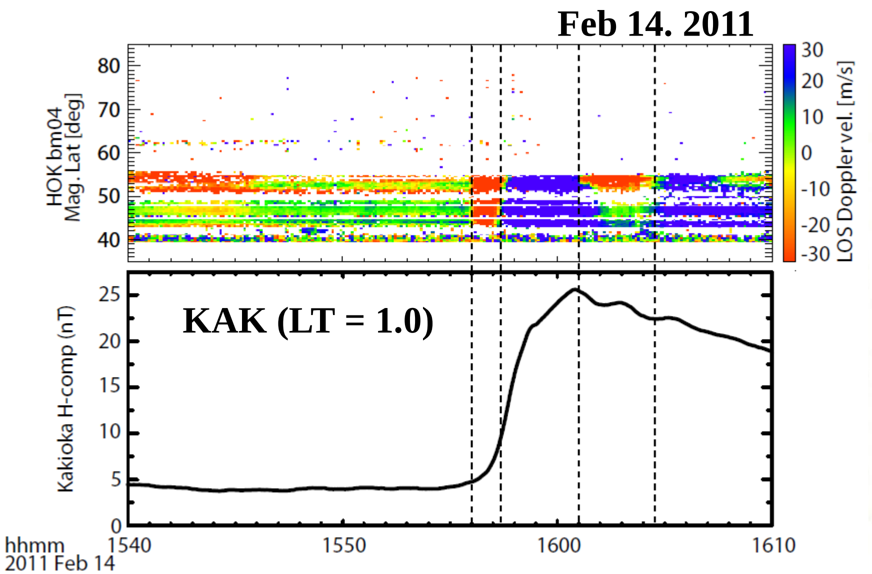


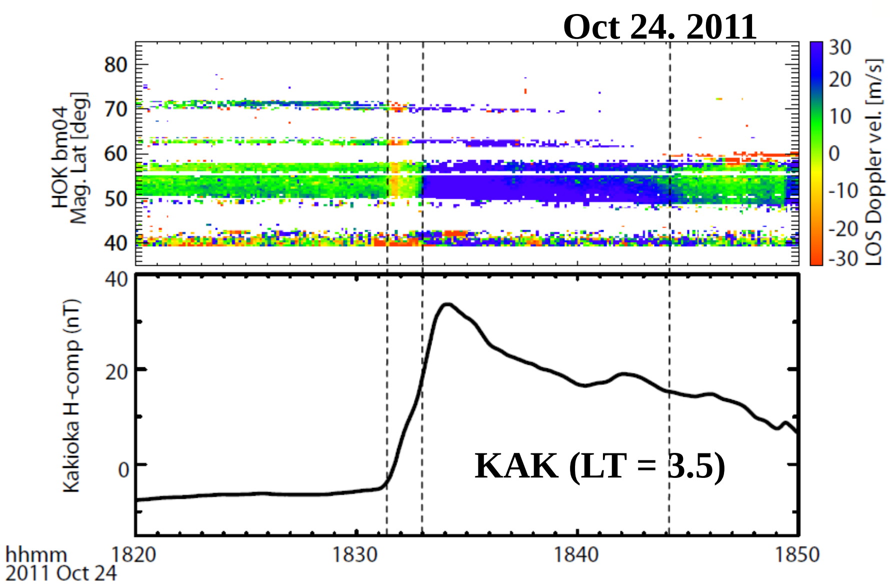
Two step E-field during SC



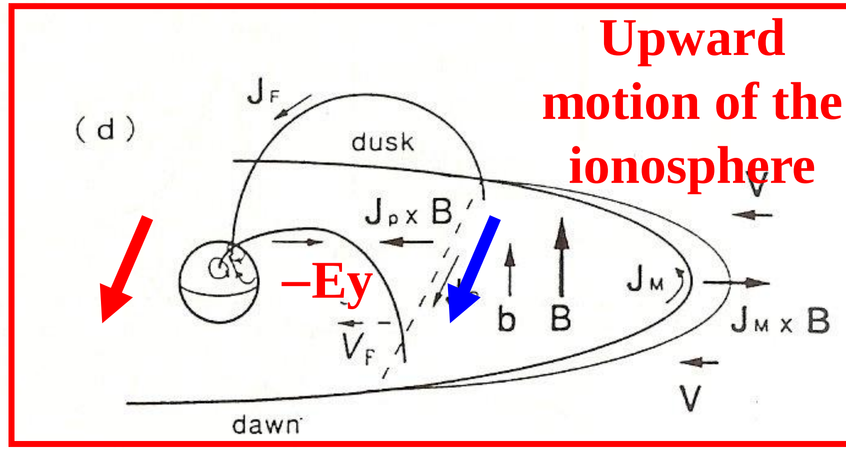
The SC-associated E field perturbations observed at THA are directly penetrated into the morningside ionosphere.

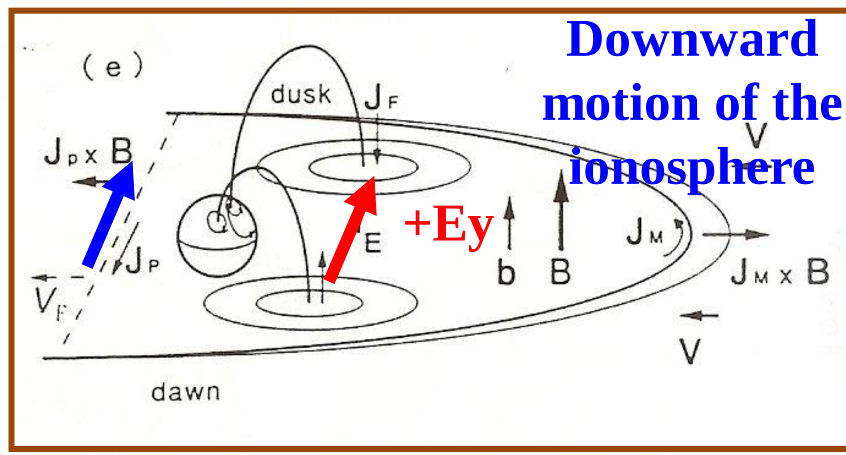
SuperDARN Hokkaido radar obs. in the nightside





Two step E-field during SC





model for SC.

Summary

• IP shock observations in the solar wind: The discontinuity front is aligned with Parker spiral and strikes the postnoon dayside magnetopause first.

• A tailward propagating SC, which is caused by the IP shock, in the magnetosphere:

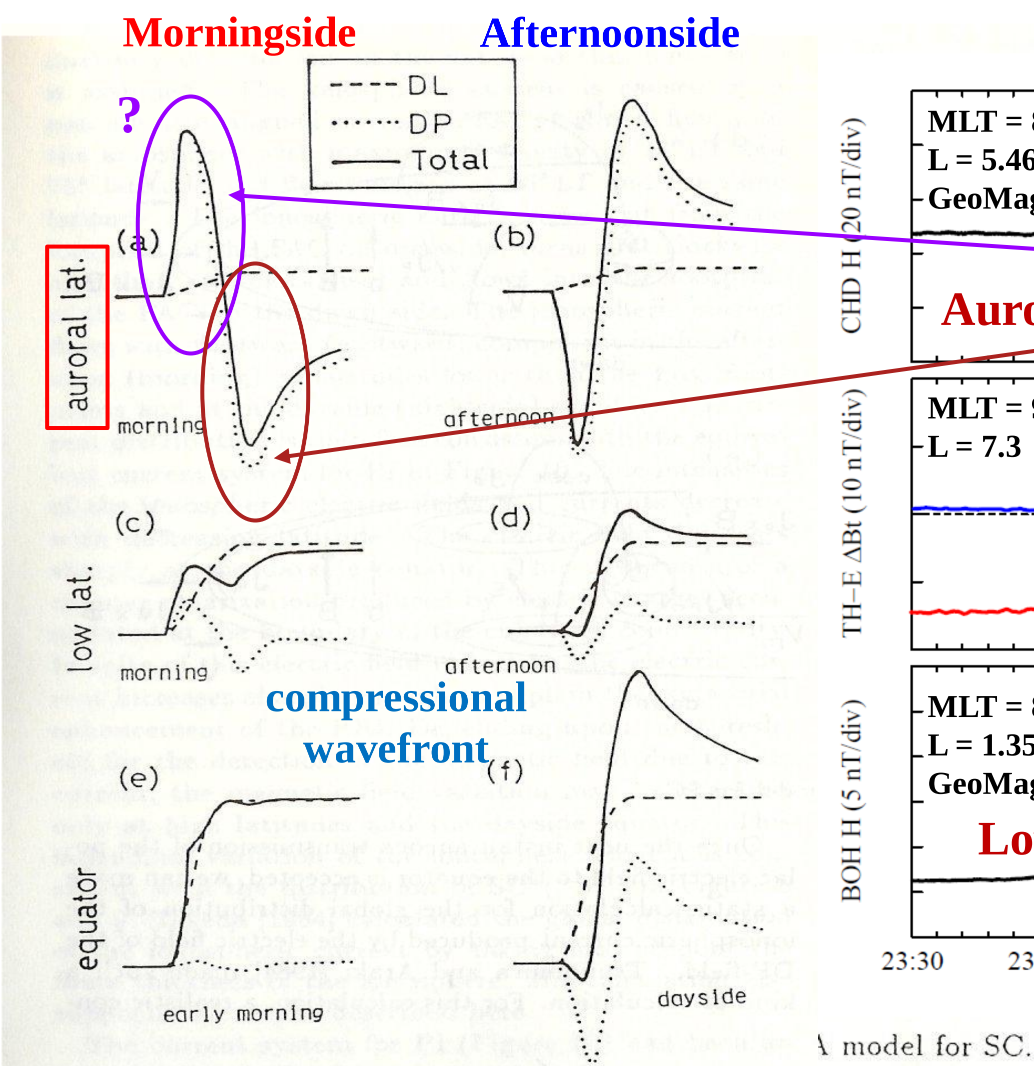
- The front of the SC-associated initial response retains alignment similar to that of solar wind discontinuity.

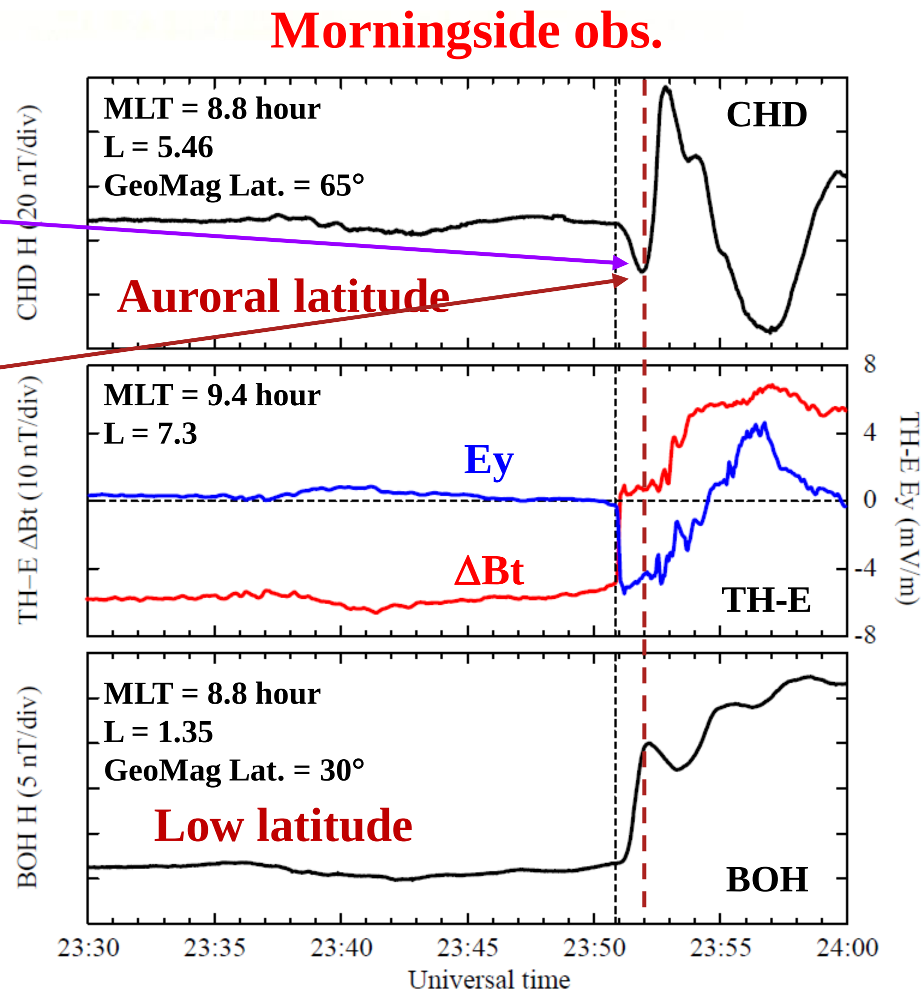
- Its propagation speed (V_N ~ 70-180 km/s) is smaller than the propagation of the IP shock in the solar wind and much smaller than the fastmode speed in the dayside magnetosphere.

• The SC event appears a negative-then-positive perturbation in the H component at high-latitude CHD station in the morning sector, which is opposite sense of normal SC event.

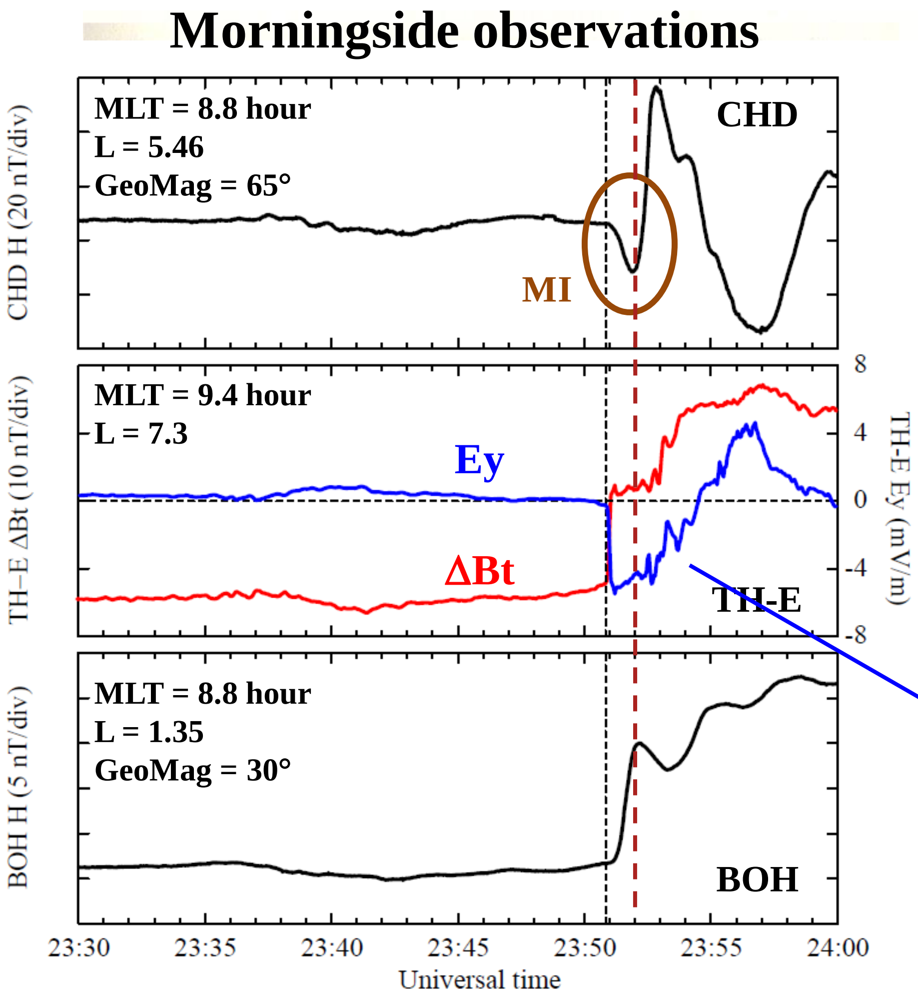
• The SC-associated E field perturbations observed at THA are directly penetrated into the morningside ionosphere.

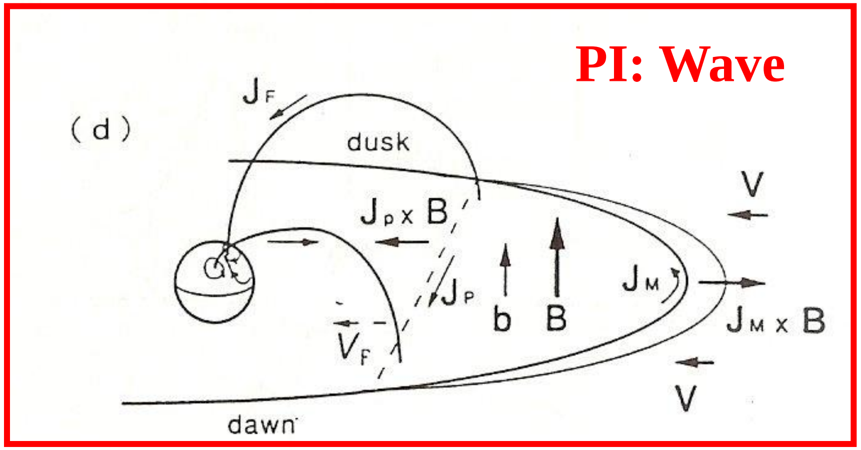
Comparison of Araki's SC model and ground observations

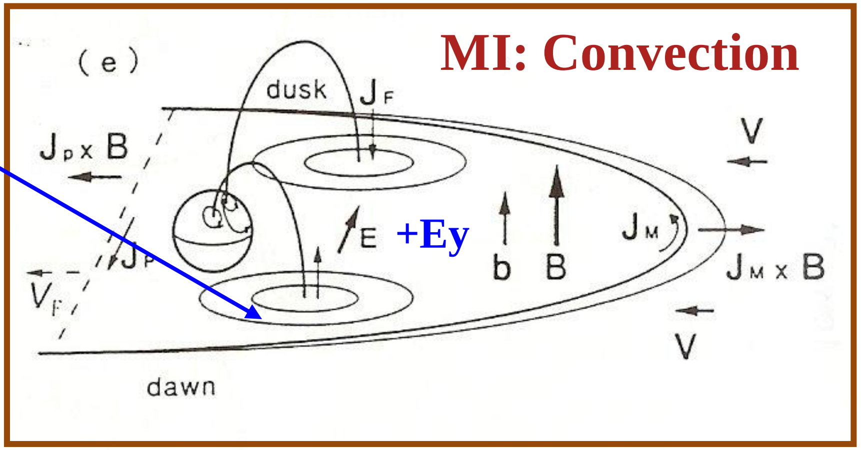




Comparison of Araki's SC model and Obs.

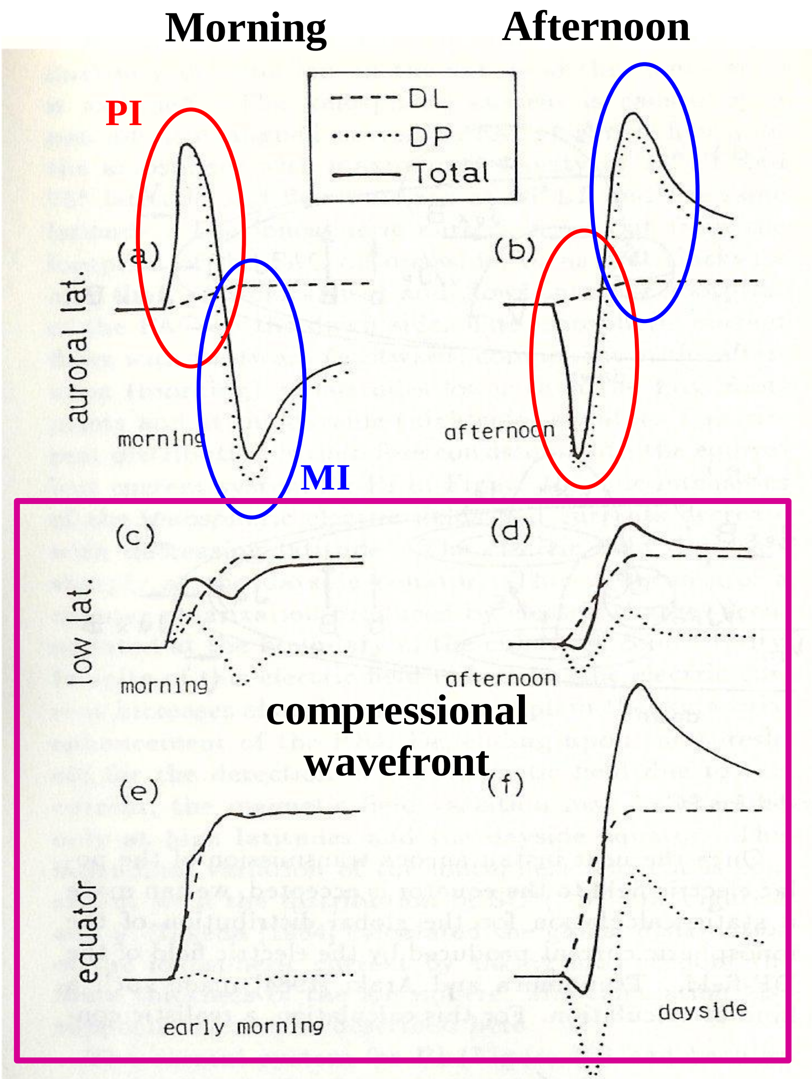


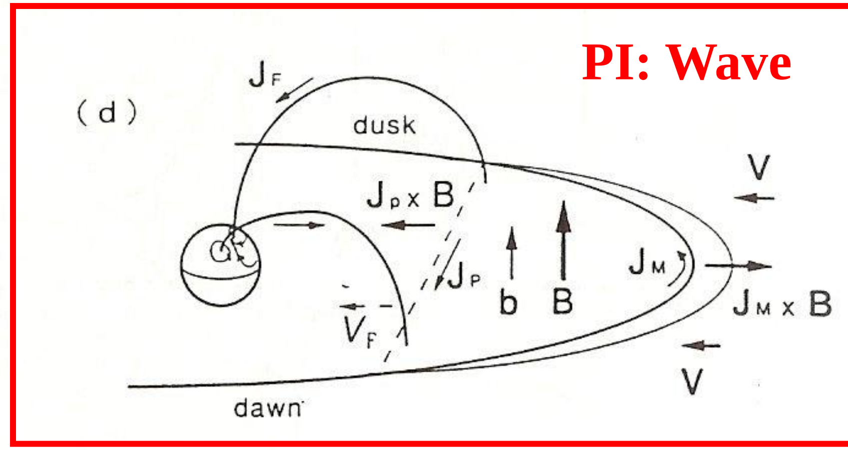


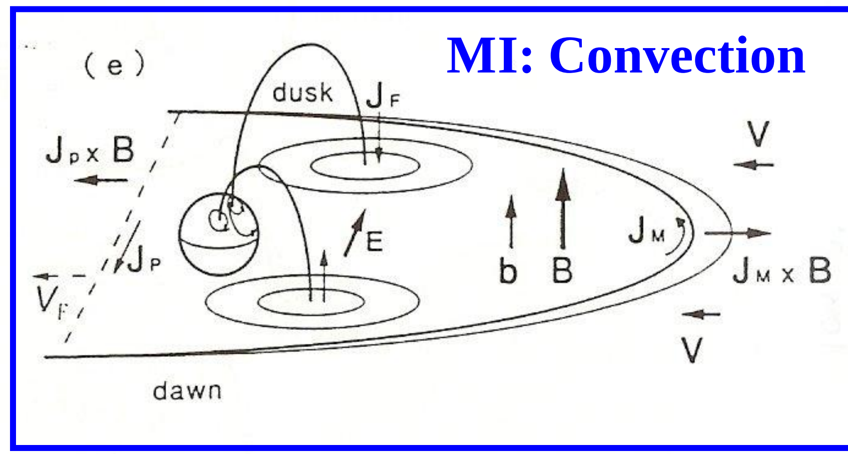


Bipolar (negative-then-positive) Ey perturbation in space: Flow vortical motion.

Araki's sudden commencement (SC) model [1994]







A model for SC.

PI (preliminary impulse): dusk-to-dawn E field transmitted to the polar ionosphere from the compressional wavefront propagating tailward .

MI (main impulse): enhanced dawn-to-dusk convection E field.