Response of the Earth's magnetosphere and ionosphere to the small-scale magnetic flux rope in solar wind by the MHD simulation

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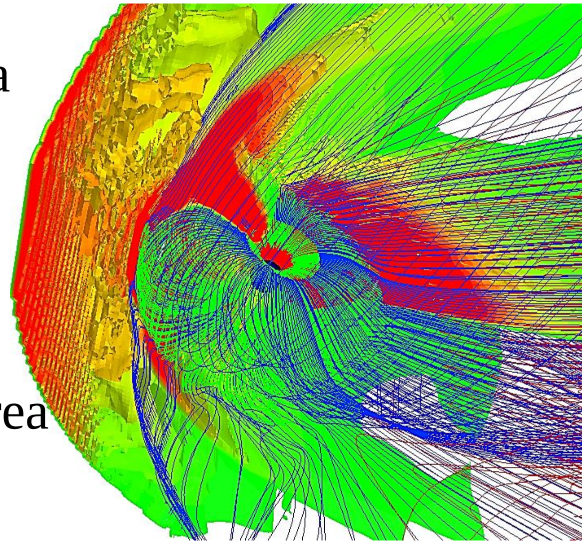
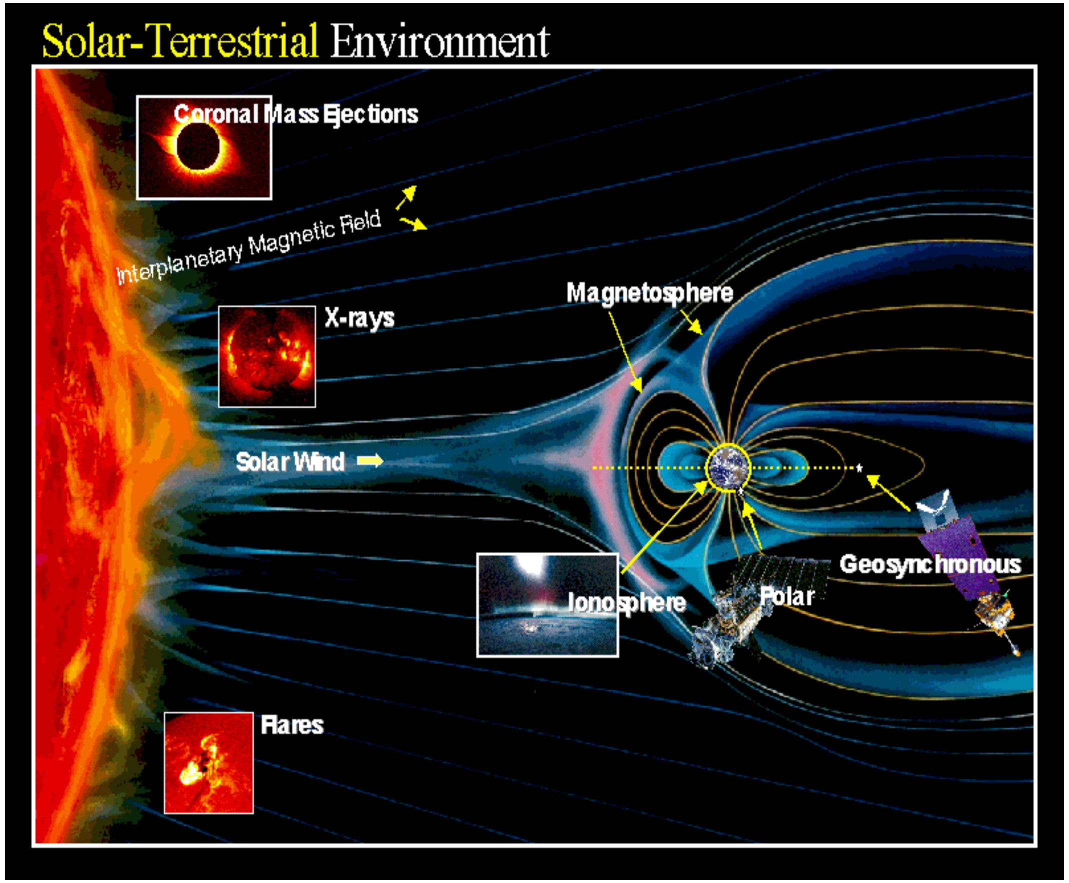


Introduction

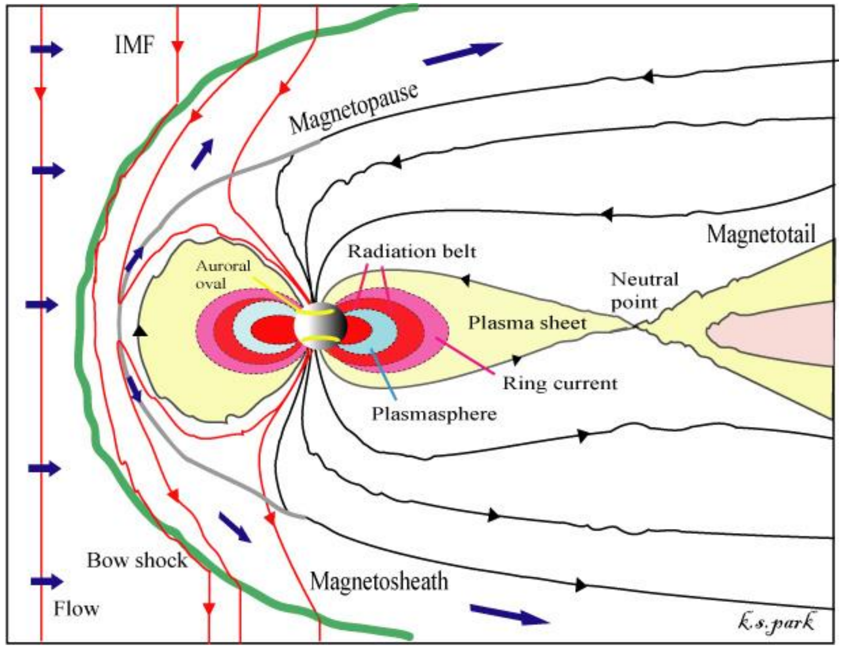
Interaction between the solar wind and Earth's magnetosphere



CME → Shock → High energetic particles, change of the magnitude and direction of the interplanetary magnetic field (strongly southward IMF)

Solar wind and IME arrives at the Earth's magnetosphere one to four days after the initial eruption, resulting in strong geomagnetic storms, aurora and electrical power blackouts.

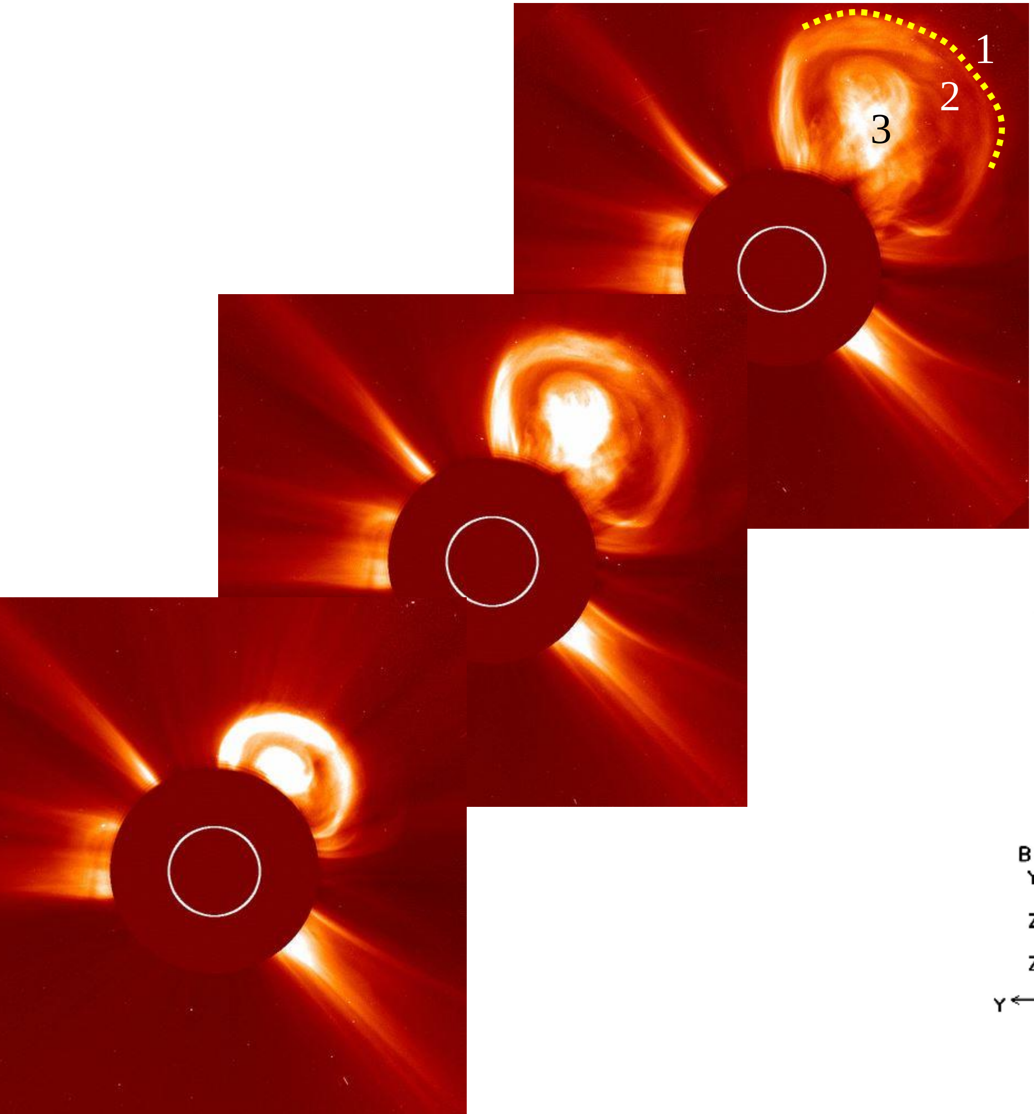
When the IMF turns southward, the energy of the solar is efficiently trapped by reconnection in the magnetosphere, and convection and currents within the magnetosphere increase.



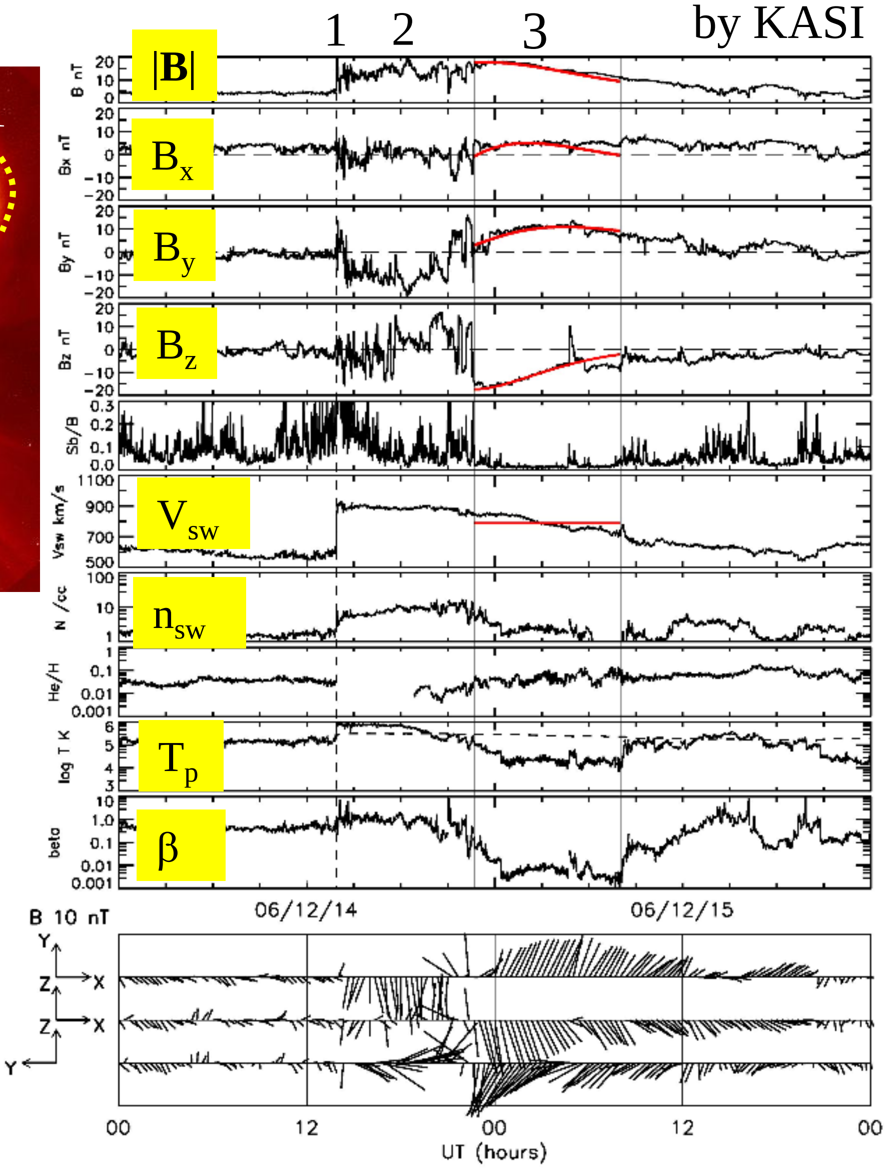
Introduction

Characteristics of interplanetary magnetic flux ropes

Coronal Mass Ejection



ACE: ICEM



1: Shock

2. Sheath

3. MFR

-Rotation of magnetic field direction

-Enhanced magnet field strength

-Low proton temperature

-Low plasma β value

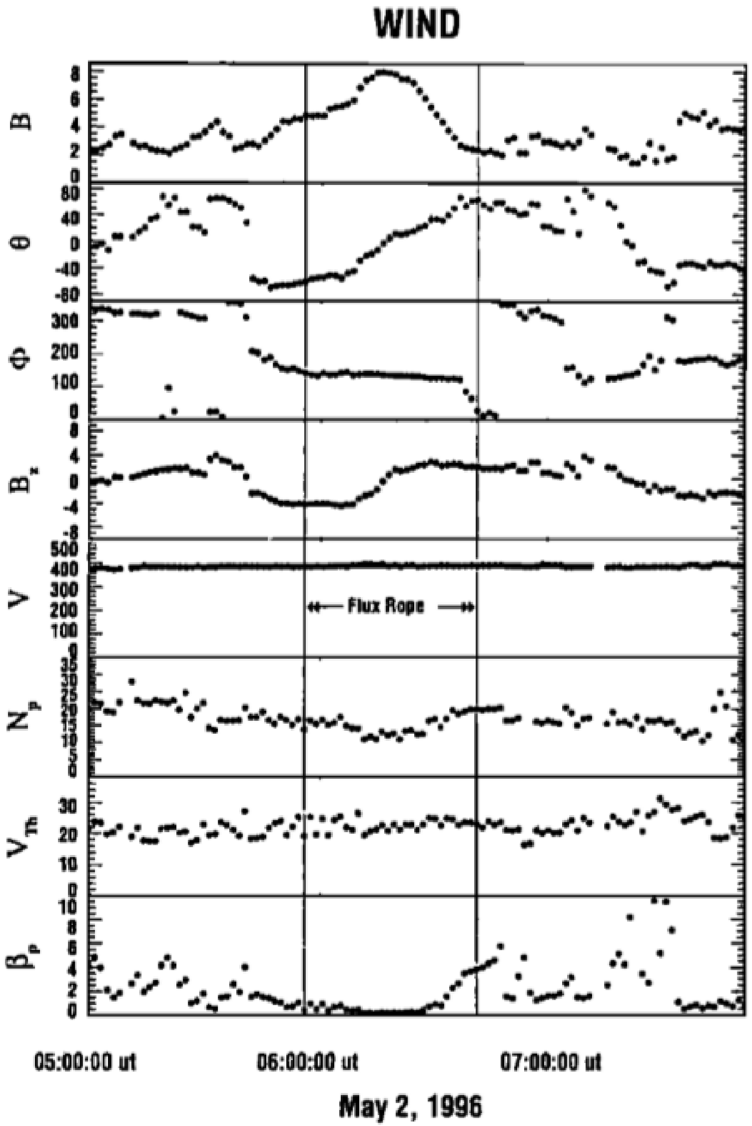
-Diameters: about 0.2 ~ 0.4 AU

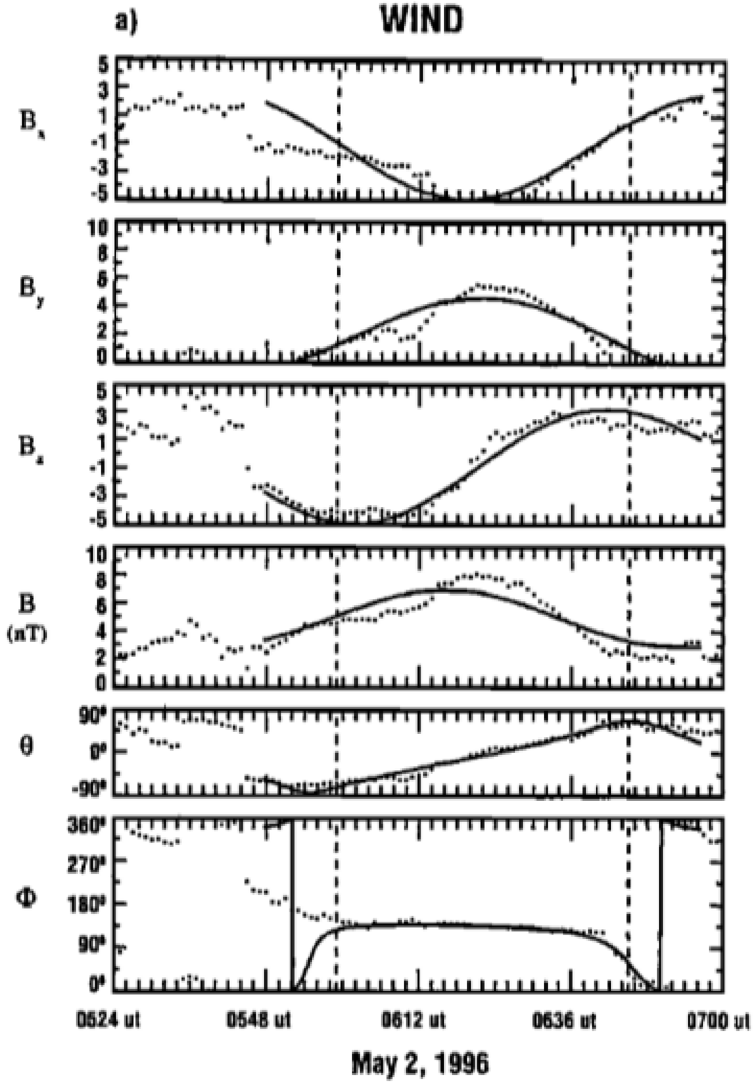
(4704 ~ 9407 R_E)

-Duration time: tens of min to tens of hours (~a few days) near the Earth orbit

Small-scale magnetic flux rope (SMFR)

New class of magnetic flux ropes in solar wind was identified by *Moldwin et al*. [1995, 2000]



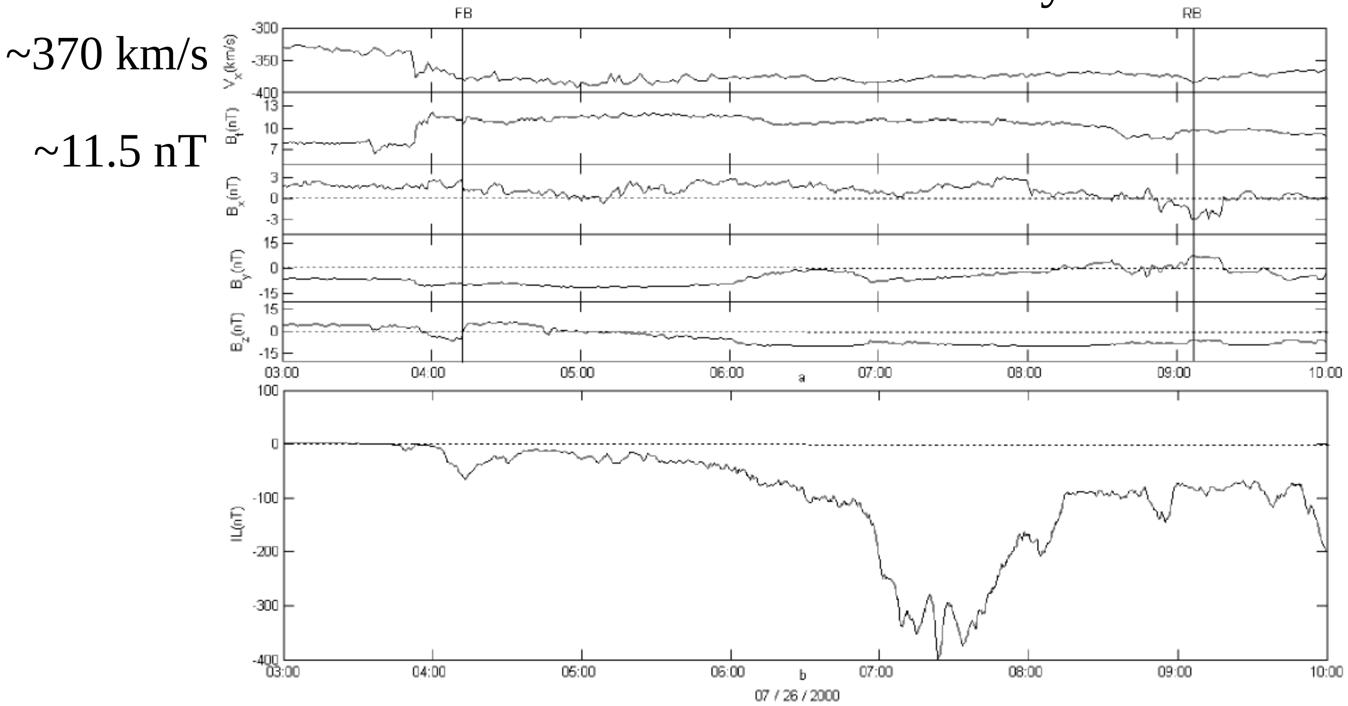


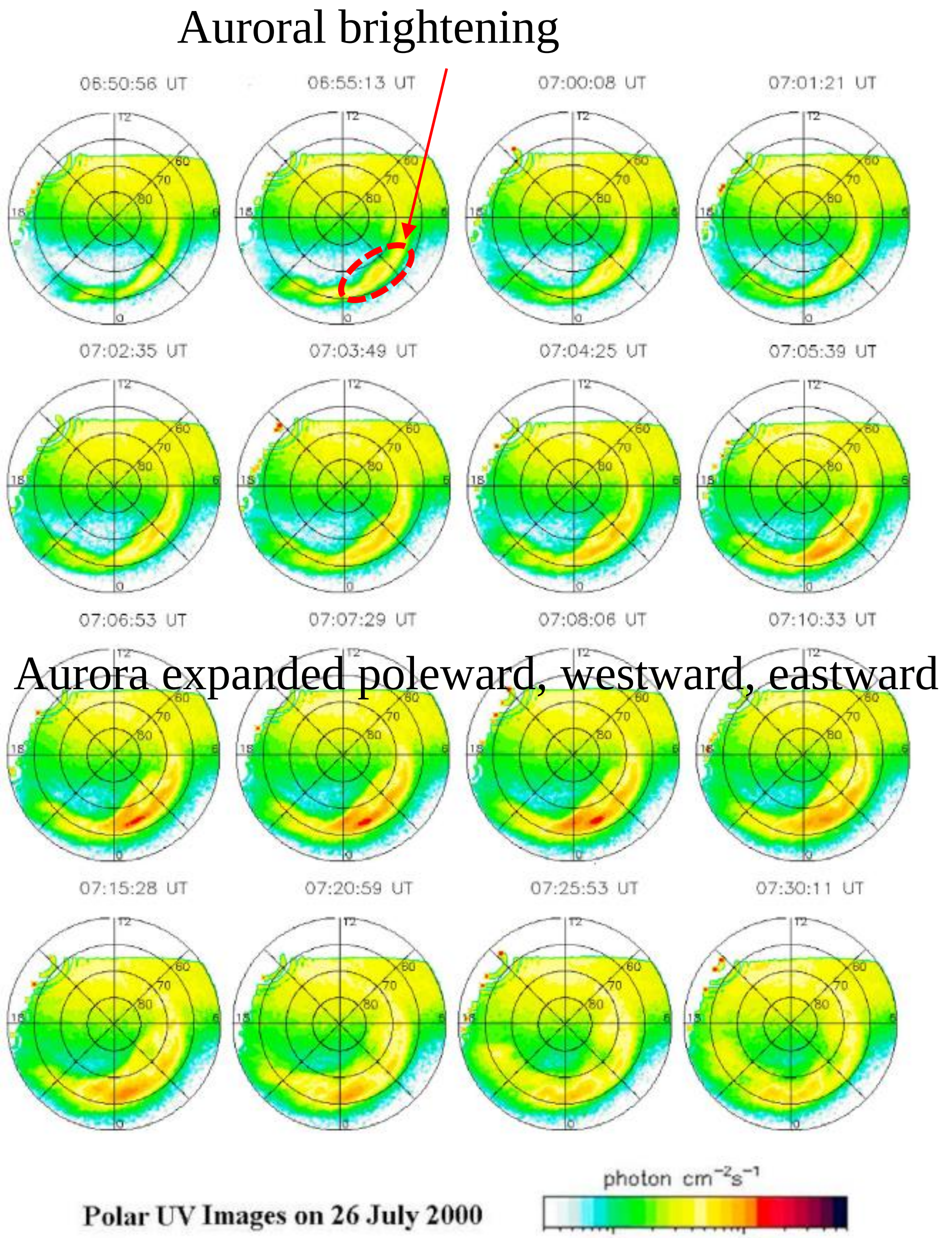
Average diameters: $270R_E$
($191 \sim 530R_E$)
with about an hour duration time

A flux rope model fit is shown superimposed on the data as a thick solid line.

Small magnetic flux rope and substorm expansion [*Feng et al.*, 2010]

WIND observation on 26 July 2000





18 (69%) small flux ropes triggered magnetospheric substorms

14 substorm expansion phases: northward turning of SMFR
4 substorm events: sudden changes in solar wind dynamic pressure

There have been no studies of the interaction between the SMFR and Earth’s magnetosphere and ionosphere by global MHD simulation.

From this study we want to know about:

What are characteristics of the SMFR by observation?

How/what does it affect the Earth’s magnetosphere and ionosphere.

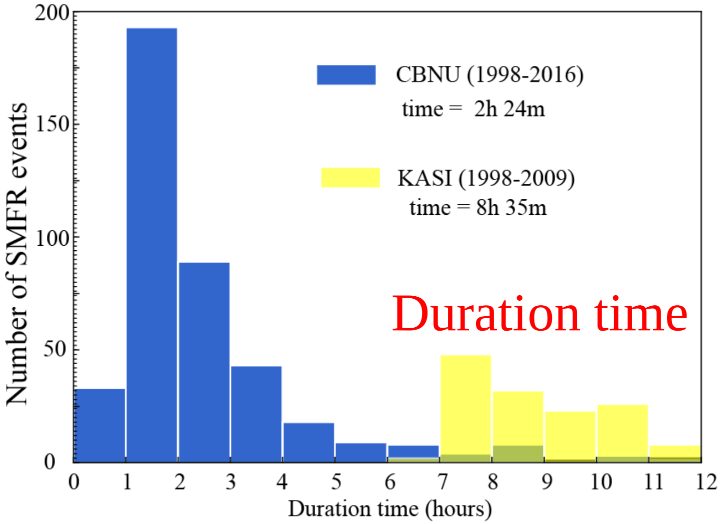
Events list by ACE observation data

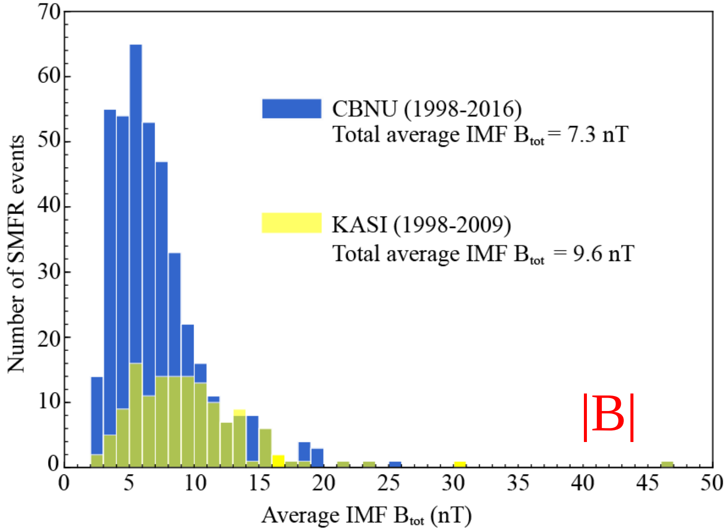
CBNU: 1998-2016
KASI: 1998-2009

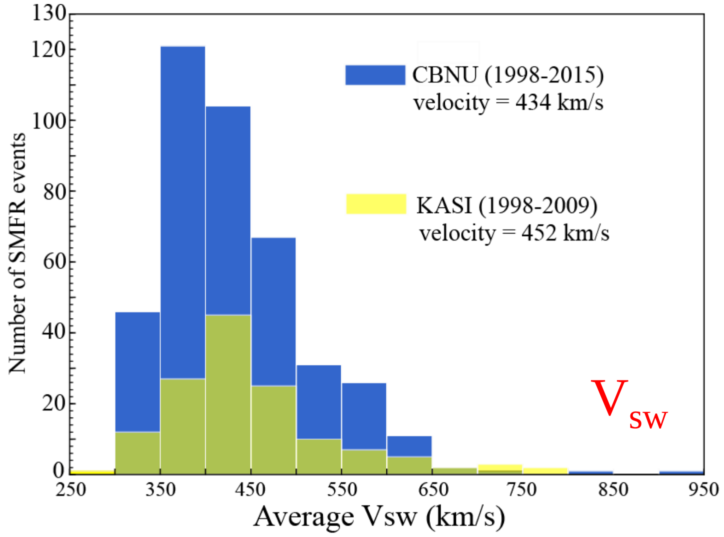
411 SMFR over 19 years

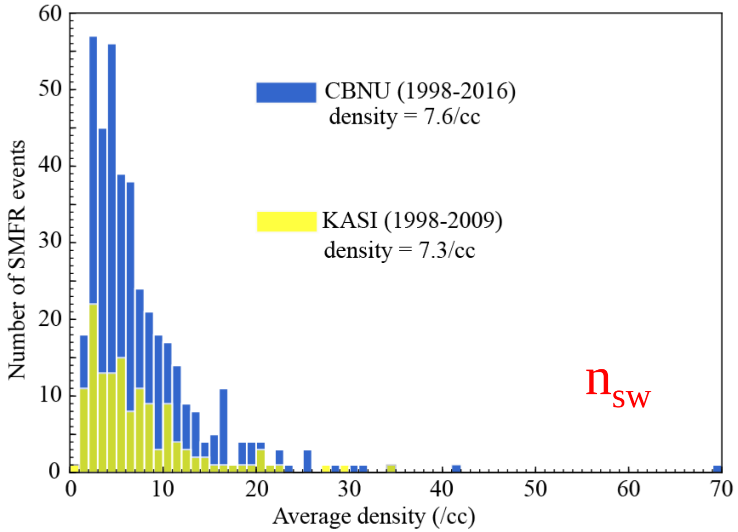
139 SMFR

used by *Marubashi* Fitting model









- Average properties of SMFR during 1998-2016

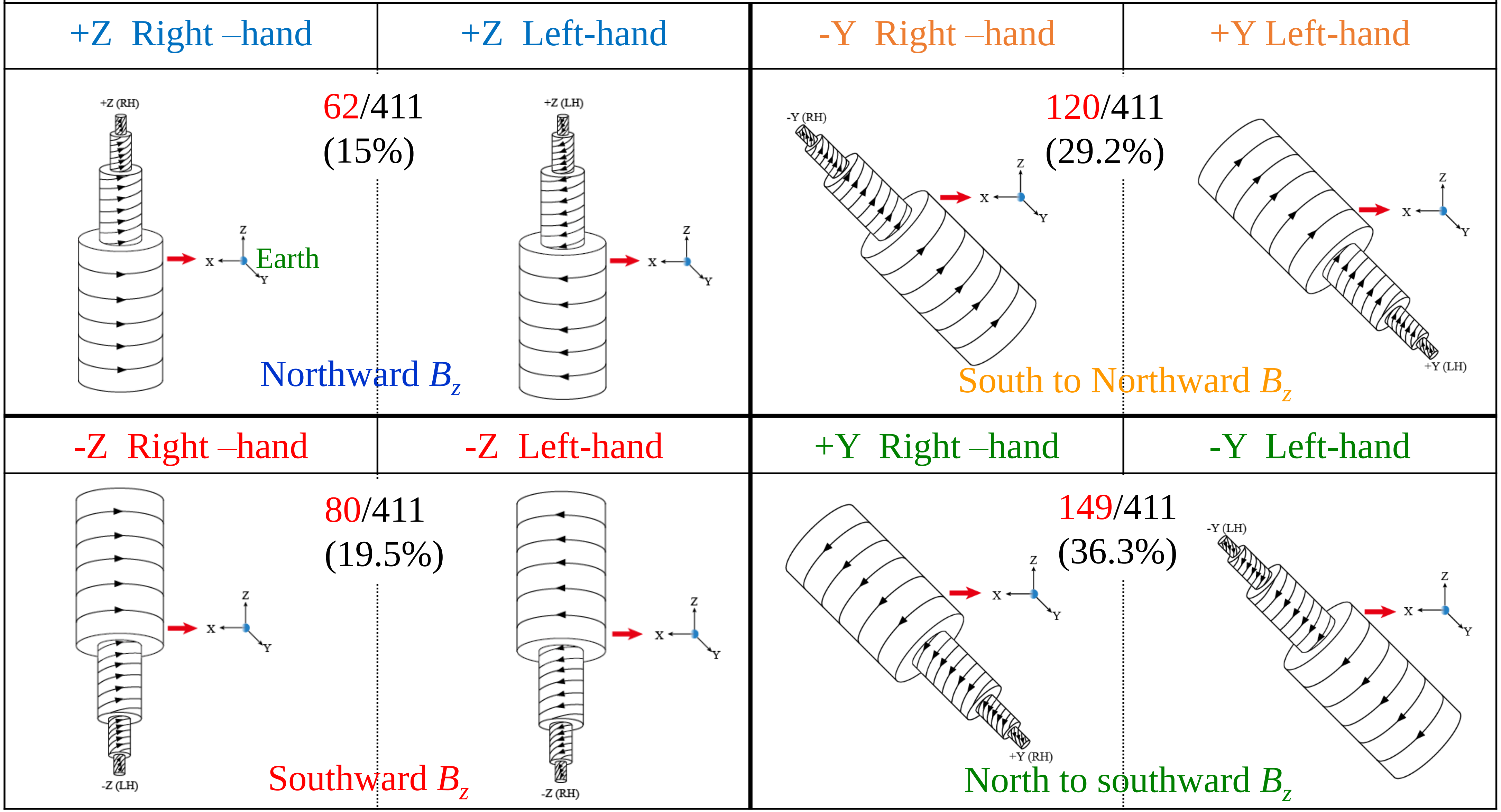
SMFR events having duration times 2h 24m

Magnetic field strength of 7.3 nT

Flow speed of 434 km/s

Proton number density of 7.6 cm^{-3}

Magnetic flux rope distinguished by four types



Global MHD Simulation conditions

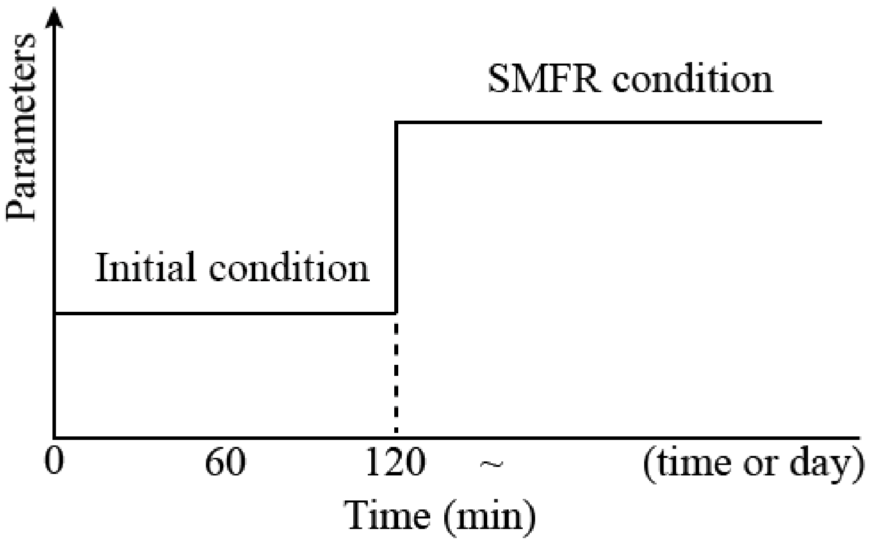
We have performed a three-dimensional global MHD simulation of interaction between the SMFR conditions and the Earth's magnetosphere and ionosphere.

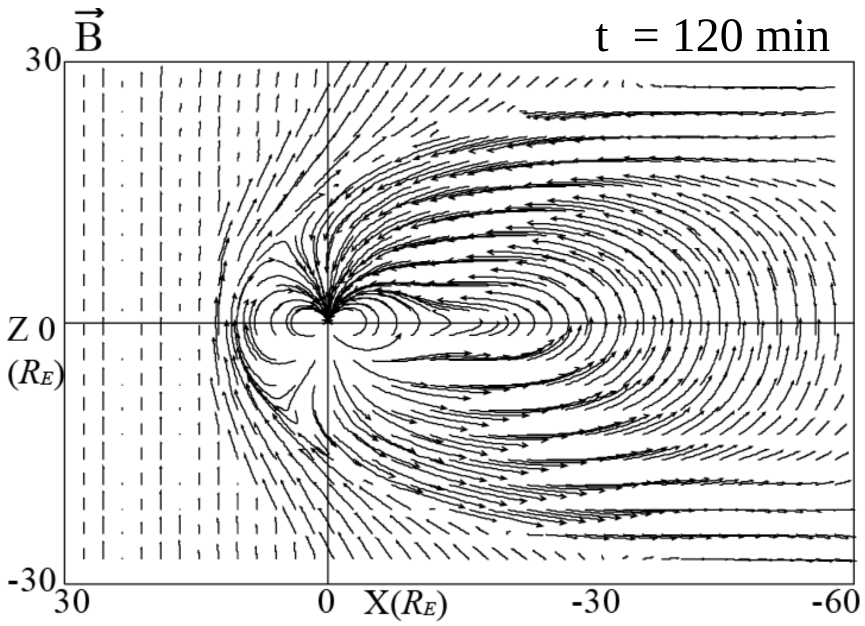
The number of grid points $(n_x, n_y, n_z) = (300, 100, 200)$ with a uniform grid spacing of $0.3R_E$.

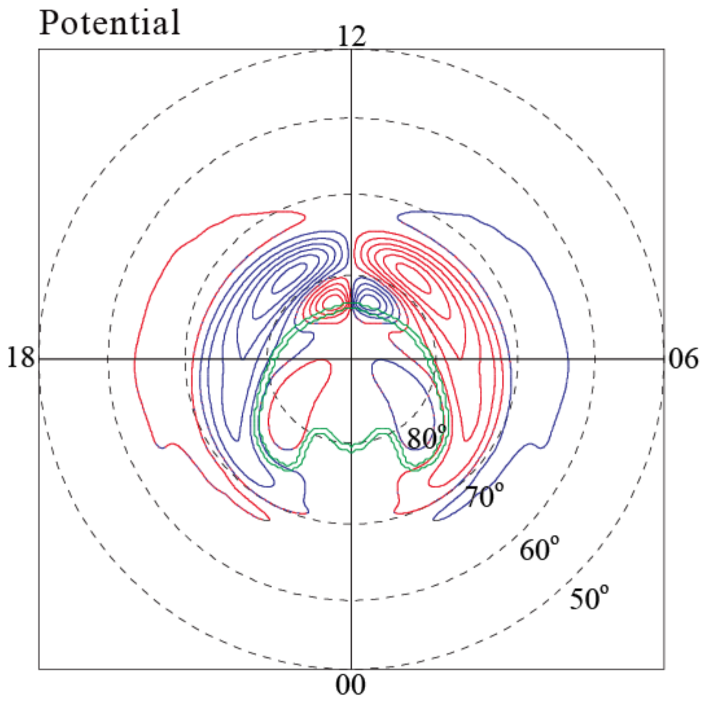
Steady state and quiet configuration,

Initial condition: IMF $B_z = 2$ nT, $V_{sw} = 400$ km/s, and $n_{sw} = 5$/cc

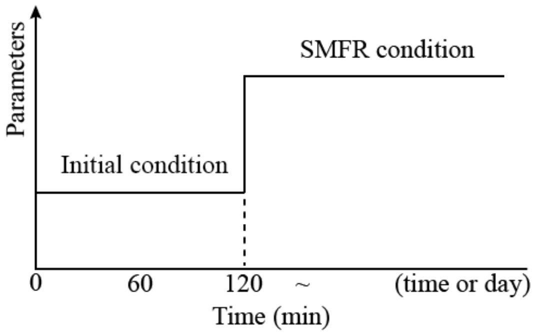
Cross polar cap potential: ~15 kV







Simulation input parameter



Duration time: 3 hours

V_{sw} = 400 km/s

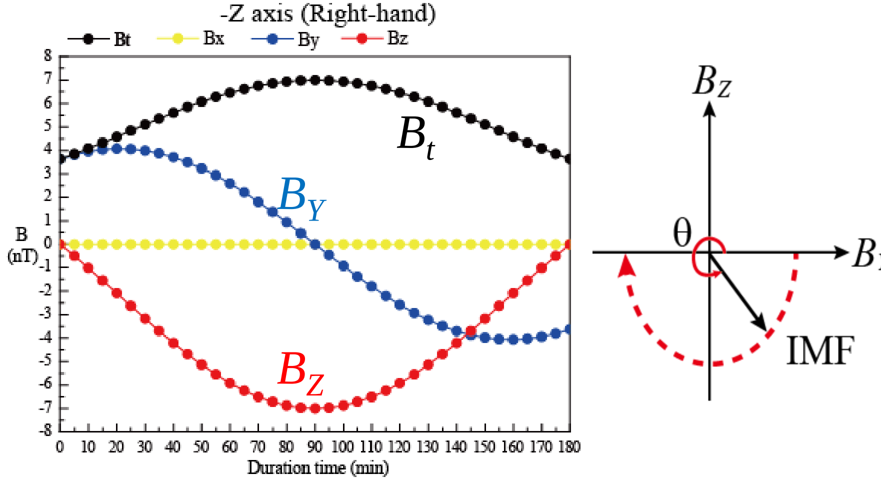
n_{sw} = 5 cm^{-3}

IMF |**B**|: 4→7→4 nT

Solar wind and IMF conditions during the SMFR

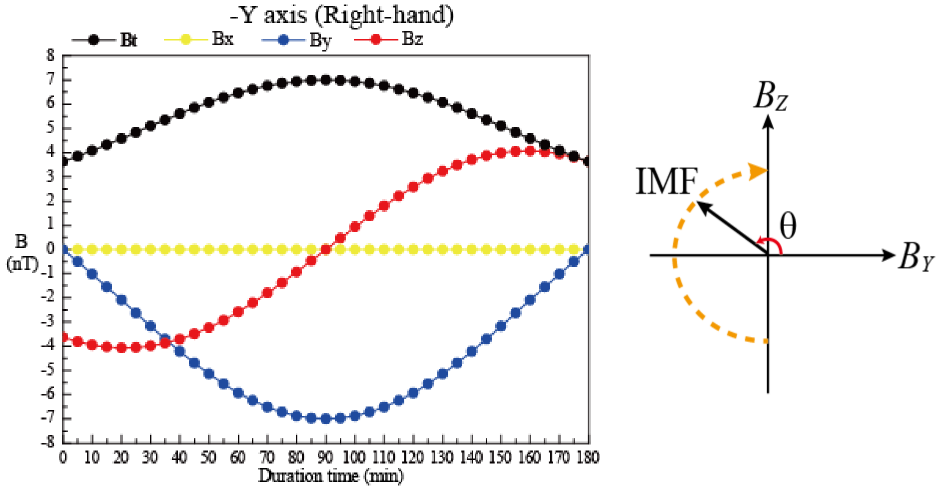
Case 1: -Z axis (RH)

B_Z (southward) and B_Y(dusk to dawn)



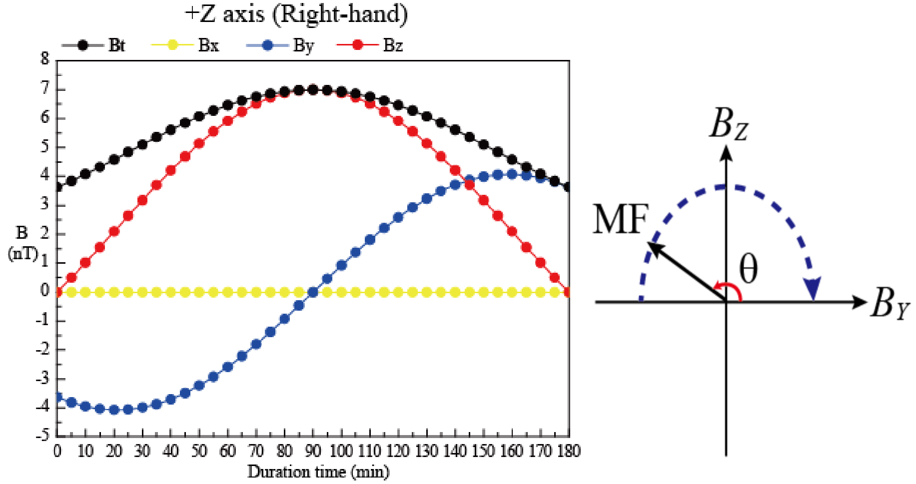
Case 3: -Y axis (RH)

B_Z (south to northward) and B_Y (dawnward)



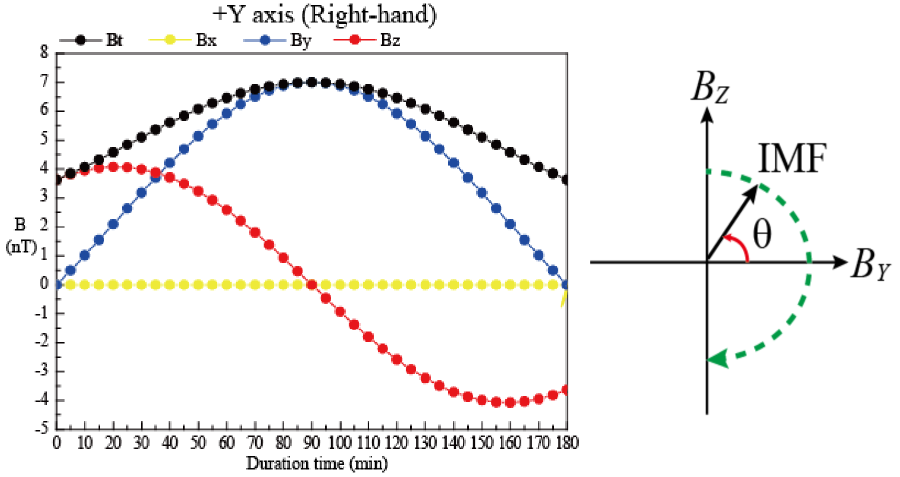
Case 2: +Z axis (RH)

B_Z (northward) and B_Y(dawn to dusk)



Case 4: +Y axis (RH)

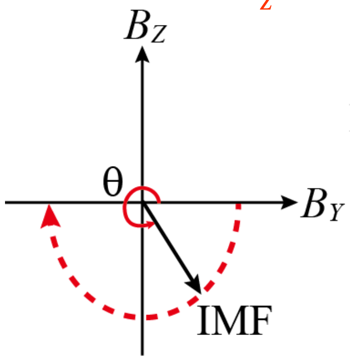
B_Z (north to southward) and B_Y (duskward)



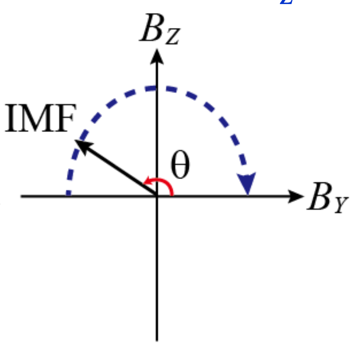
Simulation Results

Locations of the bow shock and the magnetopause at the dayside magnetosphere

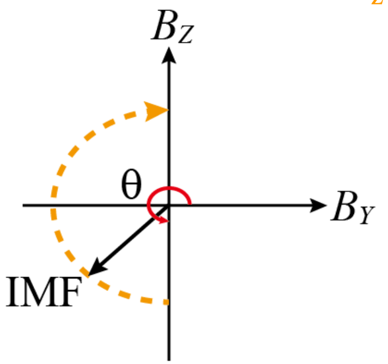
Case 1
Southward B_z



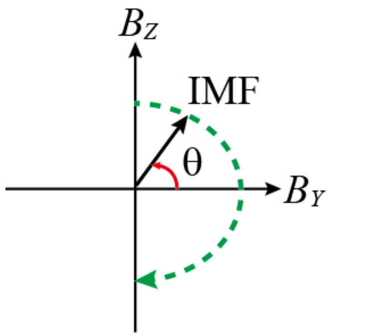
Case 2
Northward B_z



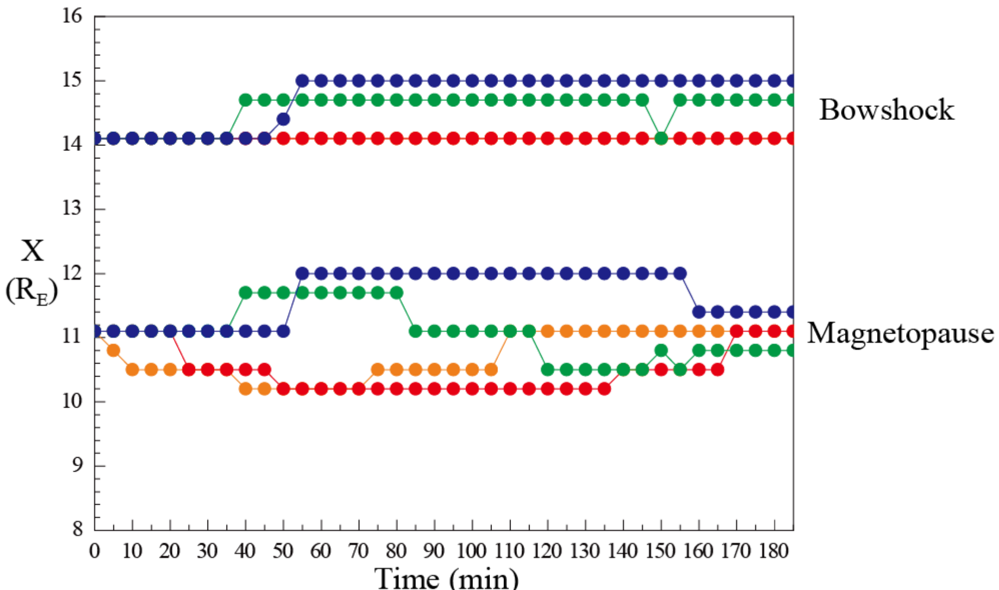
Case 3
South to Northward B_z



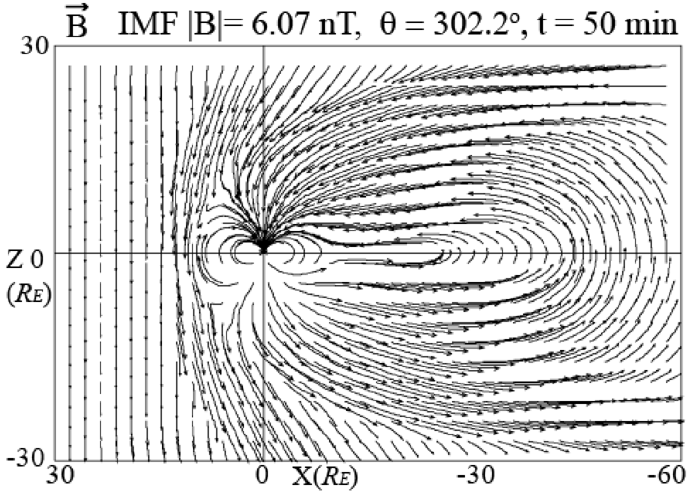
Case 4
North to southward B_z



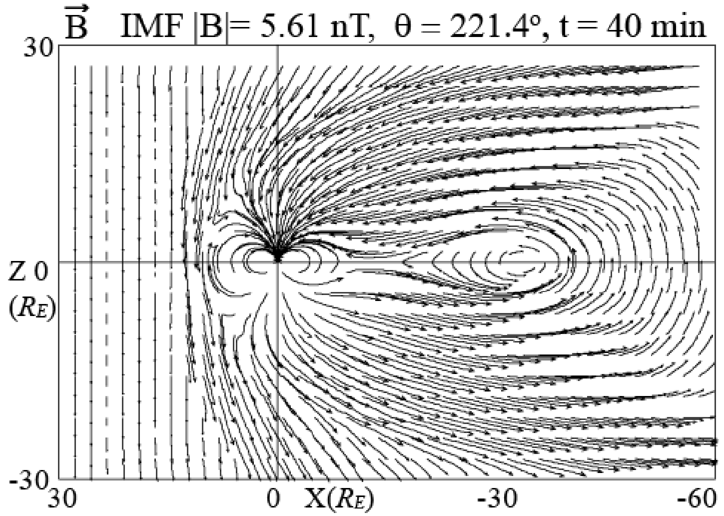
	Case 1	Case 2	Case 3	Case 4
Locations of Bow shock [R_E]	14.1	14.1→15	14.1	14.1→14.7
Locations of Magnetopause [R_E]	11.1→10.2	11.1→12	11.1→10.2→11.1	11.1→11.7 →10.5



Southward IMF



South to northward IMF



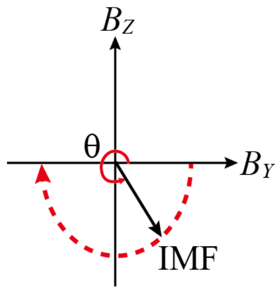
Simulation Results

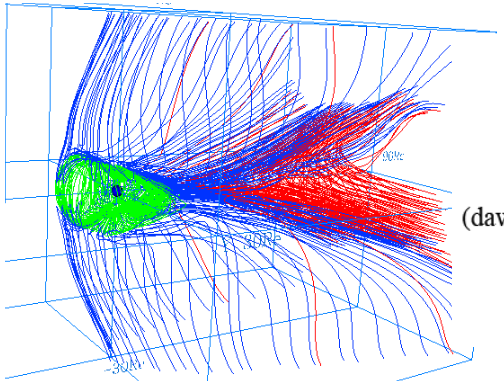
Configuration of the magnetic field lines

Green : closed field line
Blue : open field line
Red : reconnected field line

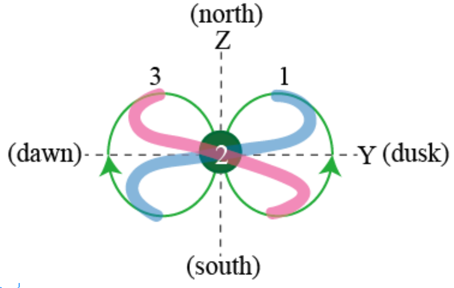
Case 1: -Z (RH)

Southward *Bz*



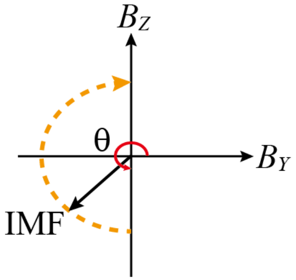


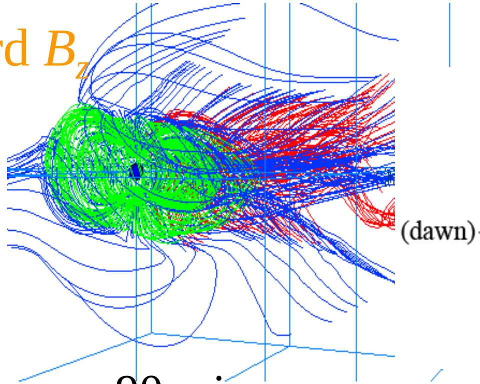
90 min



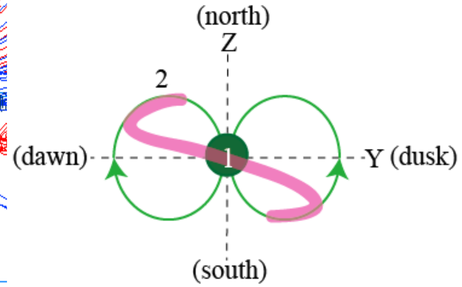
Case 3: -Y (RH)

South to Northward B_z





90 min

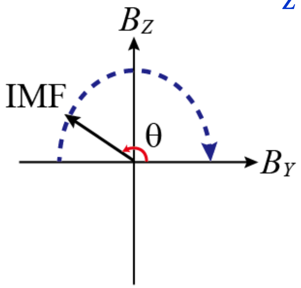


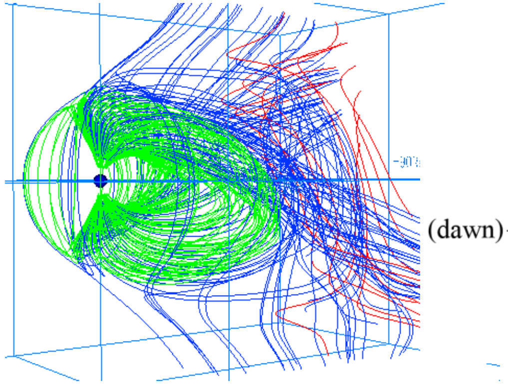
Dayside reconnection region

Dayside reconnection region

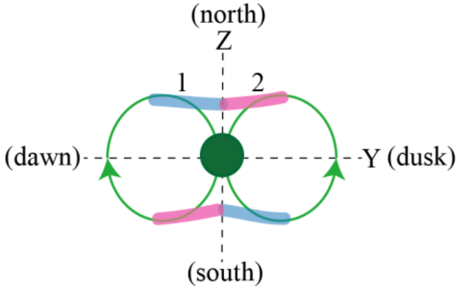
Case 2: +Z (RH)

Northward B_z



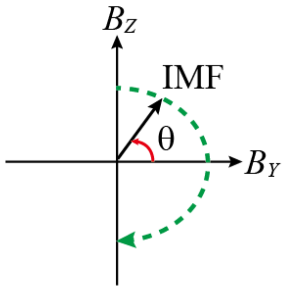


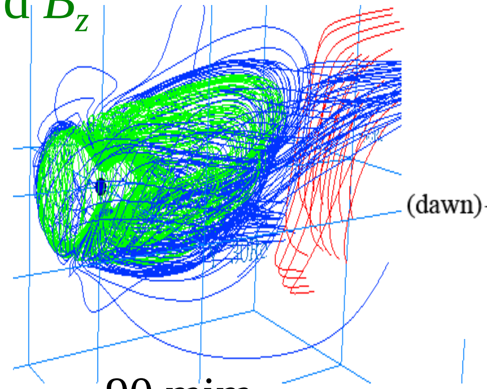
100 min



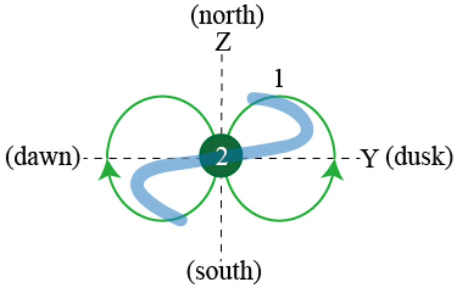
Case 4: +Y (RH)

North to southward B_z





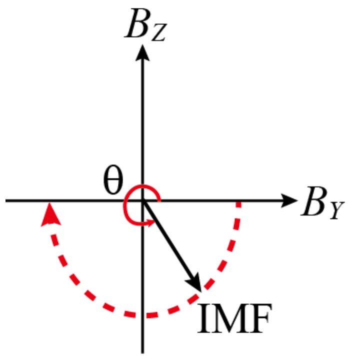
90 mim



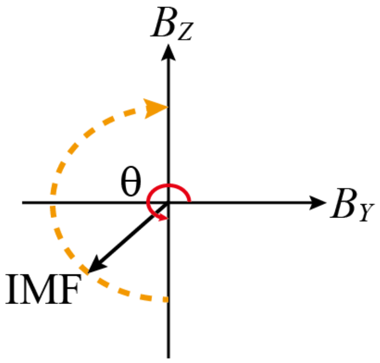
Simulation Results

Maximum value for each of the *Vx* and *Ey* in tail region

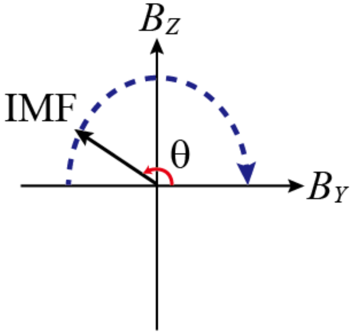
Case 1: -Z (RH)
Southward B



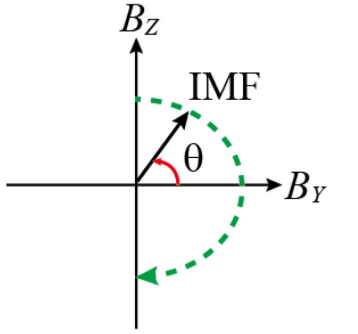
Case 3: -Y (RH)
South to Northward B_z

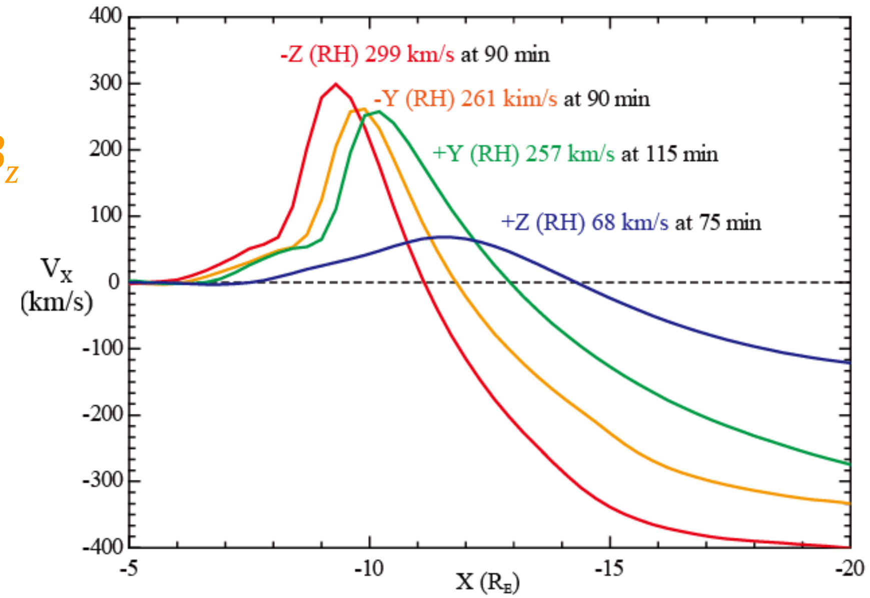


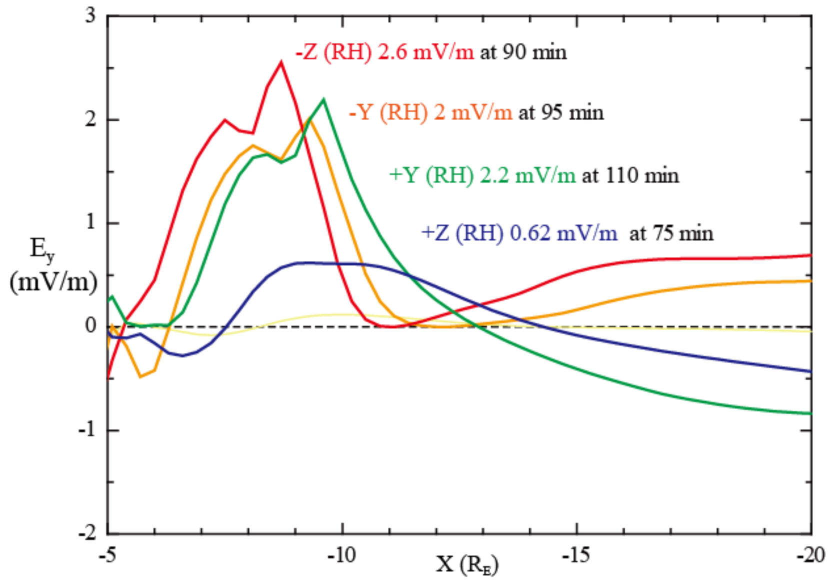
Case 2: +Z (RH)
Northward B_z



Case 4: +Y (RH)
North to southward B_z







- Tail reconnection:

Case 1: -11.1~-11.4R_E
Case 2: -14.1~-14.4R_E
Case 3: -11.7~-12R_E
Case 4: -12.9~-13.2R_E

- Earthward plasm flow ($V_X > 0$):

Case 1: 290 km/s at 90 min
Case 2: 68 km/s at 75 min
Case 3: 261km/s at 90 min
Case 4: 257 km/s at 115 min

- Duskward electric field, Ey

Case 1: 2.6 mV/m at 90 min
Case 2: 0.62 mV/m at 95 min
Case 3: 2 mV/m at 110 min
Case 4: 2.2 mV/m at 75 min

Simulation Results

- Case 1: -Z axis (RH)

B_Z (southward) and B_Y(dusk to dawn)

PCP is governed by Bz components.

- Case 2: +Z axis (RH)

B_Z (northward) and B_Y(dawn to dusk)

PCP is controlled By and Bz .

- Case 3: -Y axis (RH)

B_Z (south to northward) and B_Y (dawnward)

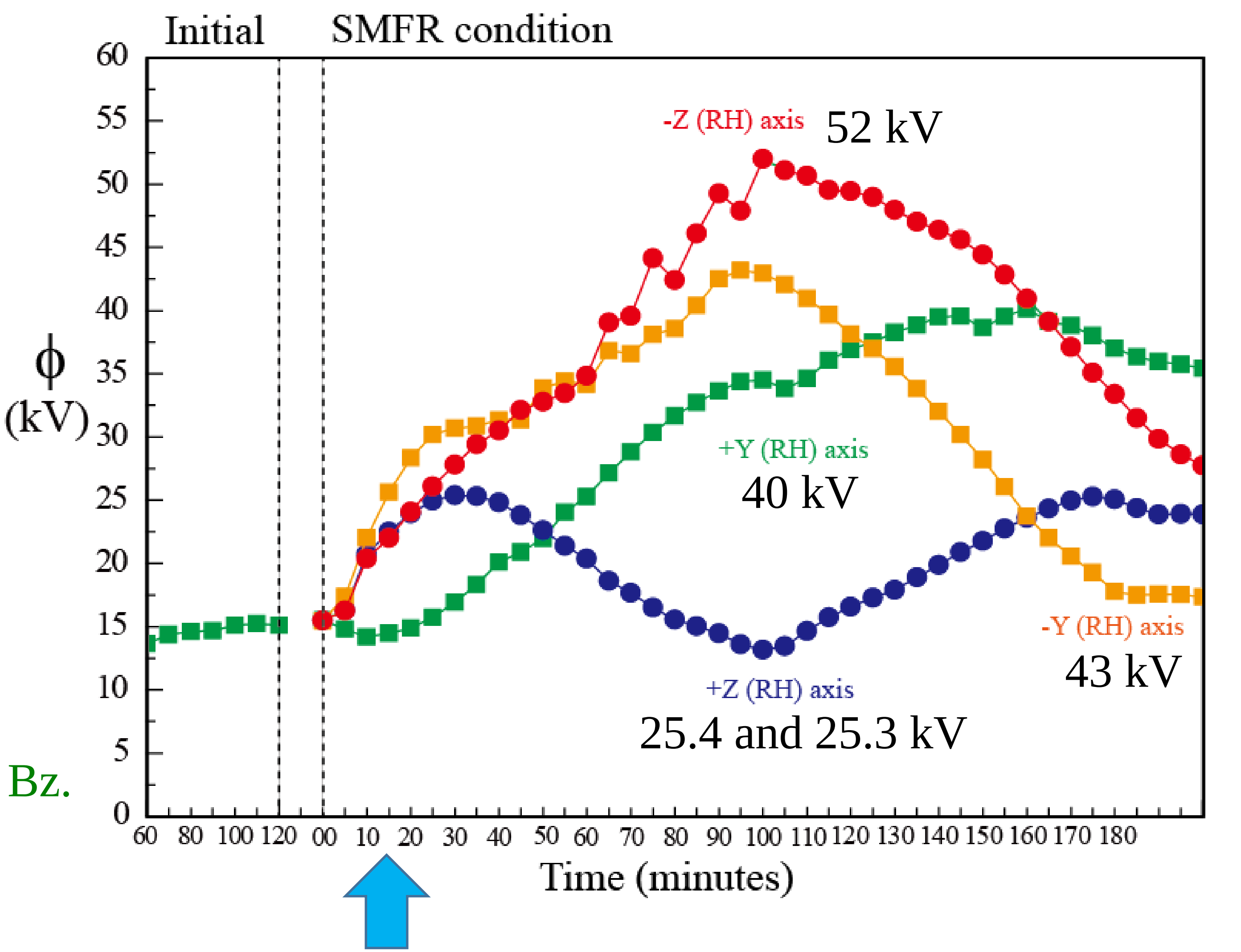
PCP is controlled by Bz component.

- Case 4: +Y axis (RH)

B_Z (north to southward) and B_Y (duskward)

PCP is controlled by magnitude total B and Bz.

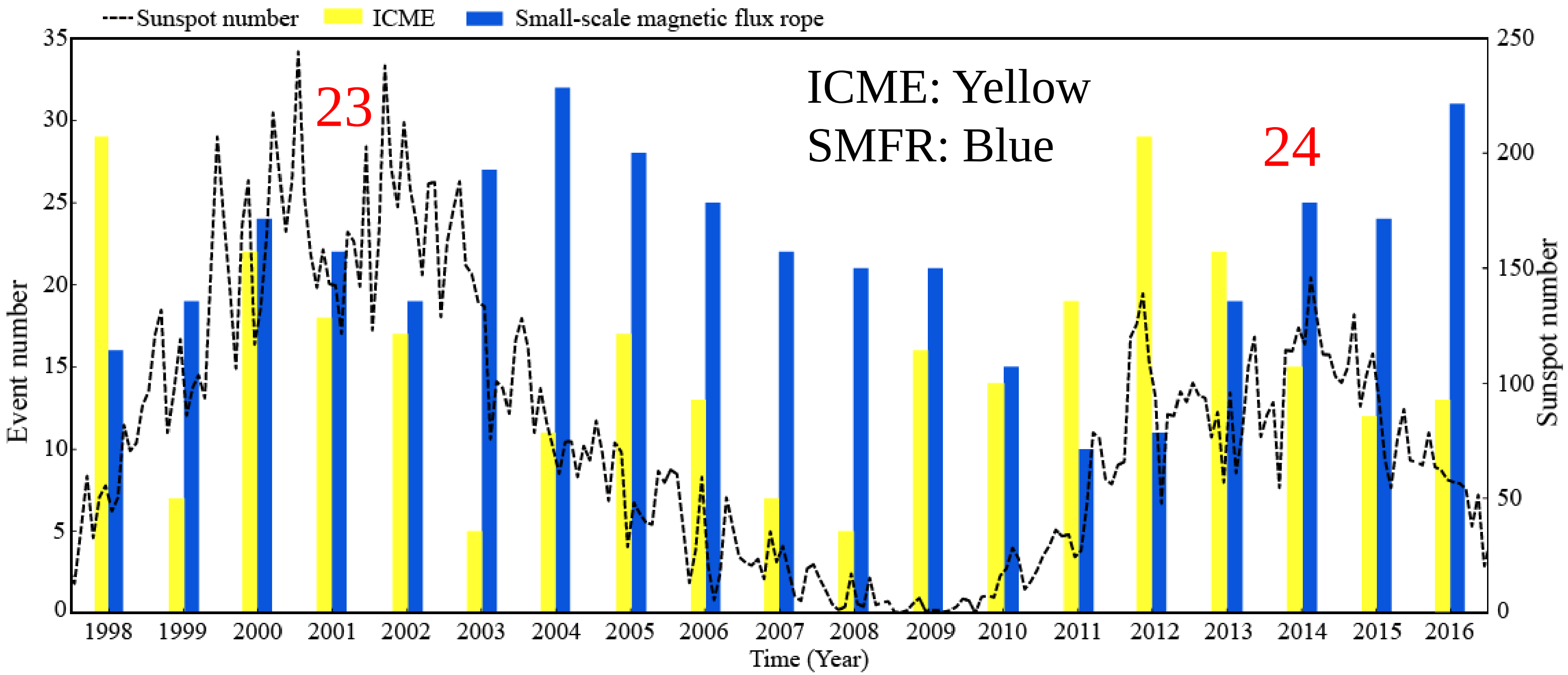
Cross polar cap potential



Summary and Conclusion

- We identified 411 small-scale flux ropes in solar wind over 19 years of ACE magnetic field data.

The results show that the mean values of duration time is 2h 24m and average of magnetic strength is 7 nT. Also average value of the solar wind speed is 434 km/s and density is 7.6 cm^{-3}.



Even though declining and minimum phase of solar cycle, SMFR consistently observed in solar wind.

Summary and Conclusion

- We also have performed a three-dimensional global MHD simulation to examine the effect of the four types of SMFR on the magnetospheric and ionospheric response.

Simulation input parameters for a four SMFR conditions:

Solar wind of velocity, V_{sw} = 400 km/s and n_{sw} = 5 cm^{-3}

Magnetic field rotates smoothly during 3 hours:

IMF $|\mathbf{B}|$ = 4 to 7 and to 4 nT

- Response of the magnetosphere:

During the southward IMF condition in case 1, 3, and 4, the bow shock and magnetopause are located in 14 R_E and 10~11 R_E in the subsolar region.

During the northward IMF condition in case 2, the bow shock and magnetopause move to 15 R_E and 12 R_E in the subsolar region.

Summary and Conclusion

- Response of the magnetosphere:

When the IMF has small duskward/dawnward components during the SMFR conditions, dayside magnetic reconnection occur in dusk/dawn side and high latitude region in northern hemisphere where IMF anti-parallel to the geomagnetic field.

The convective electric field becomes comparable to the solar wind electric field for -13 R_E < X < -7 R_E in tail region.

For three types SMFR conditions, E_y increases between 71% and 93% in the plasm sheet for a case of southward, south to north, and north to south of IMF B_z.
The tail reconnection can be seen at X= -11~-12 R_E with a southward IMF conditions.

Also, E_y is almost 21% in the plasma sheet and tail reconnection region still appears at X= -14 R_E while the IMF B_z is northward during the SMFR

Summary and Conclusion

- Response of the ionosphere:

The cross polar cap potential are mainly governed by IMF *Bz* as well as *By*/magnitude of **B**.

For all of the 4 types of SMFR, the cross polar cap potential, ϕ, increase over 20 kV.

→ possibly support the growth phase condition for substorm triggering

[Ref. *Feng et al*. 2010]

But, the effect depends on specific types of SMFR:

largest for –Z (RH) type, smallest for +Z (RH) type

Plan a further work to test dependence on initial conditions

(to test effect of preconditions on substorm triggering)