惑星磁気圏超並列高効率MHDシミュレーションの開発

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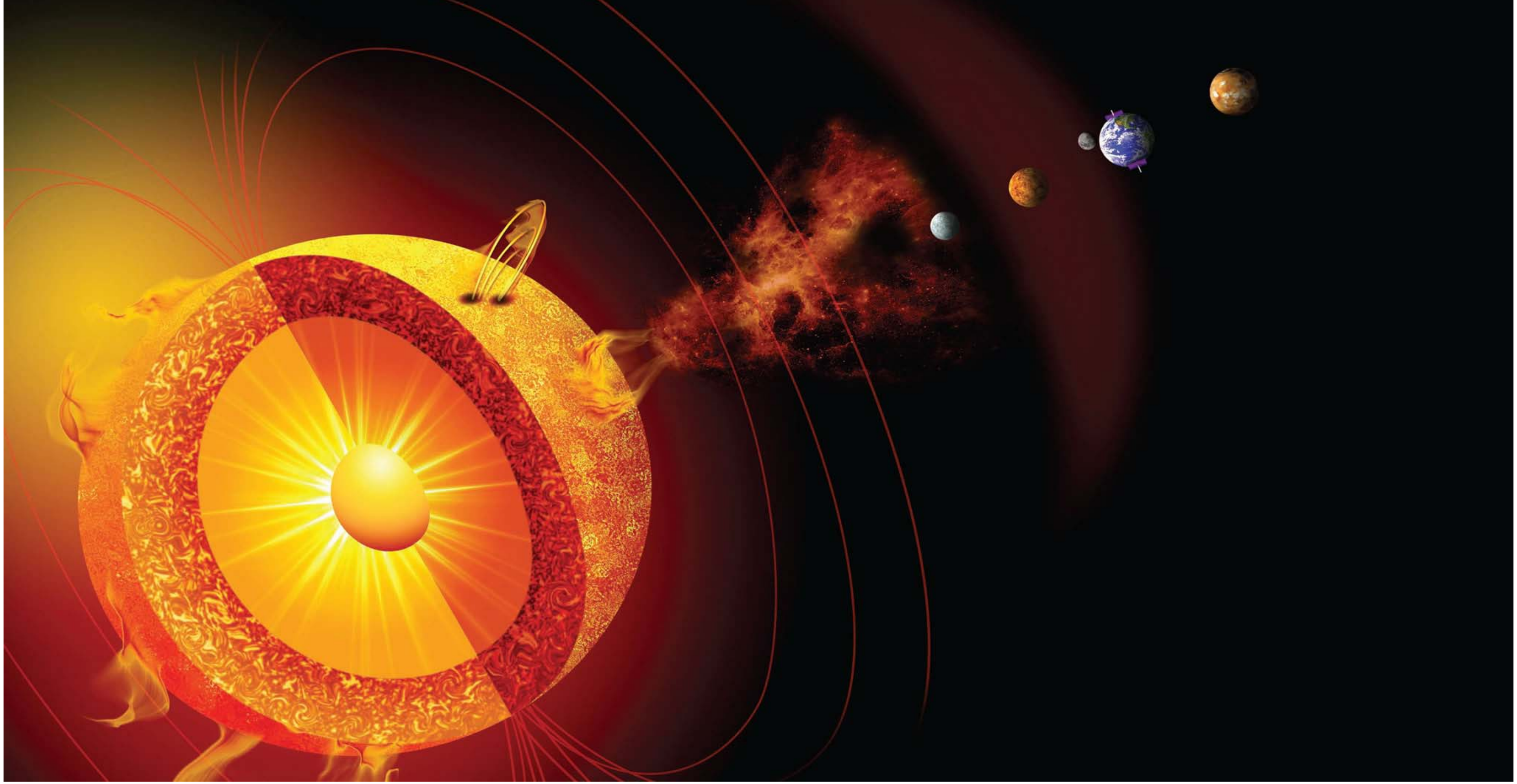
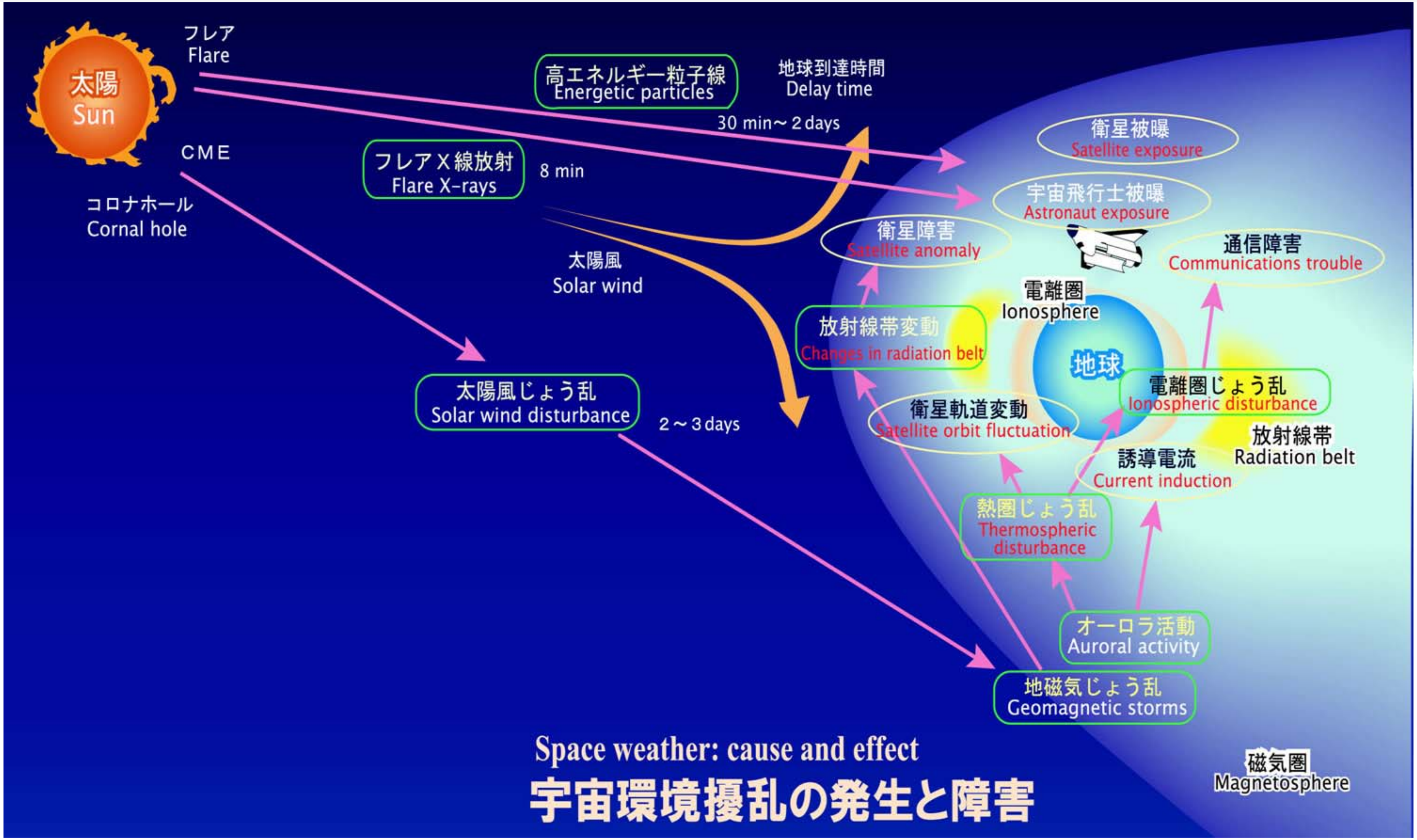
Introduction 1

What is Solar Terrestrial Planetary Science?



Introduction 2



Electric and magnetic characters of Earth, Jupiter and Saturn

	Jupiter	Saturn	Earth
Magnetic field [nT]	420,000	21,000	31,000
Magnetic polarity	N pole is north	N pole is north	N pole is south
Rotation period [hr]	10	10.65	24
Main plasma source	Io, ionosphere	Enceladus, ionosphere	ionosphere
Equatorial Radius [km]	71,492	60,268	6378
From Sun [A.U.]	5.2	9.55	1

Jupiter rotates rapidly with a huge magnetic field and plentiful plasma
Saturn rotates rapidly with a plentiful plasma

Configuration of Earth's and Saturn's magnetospheres

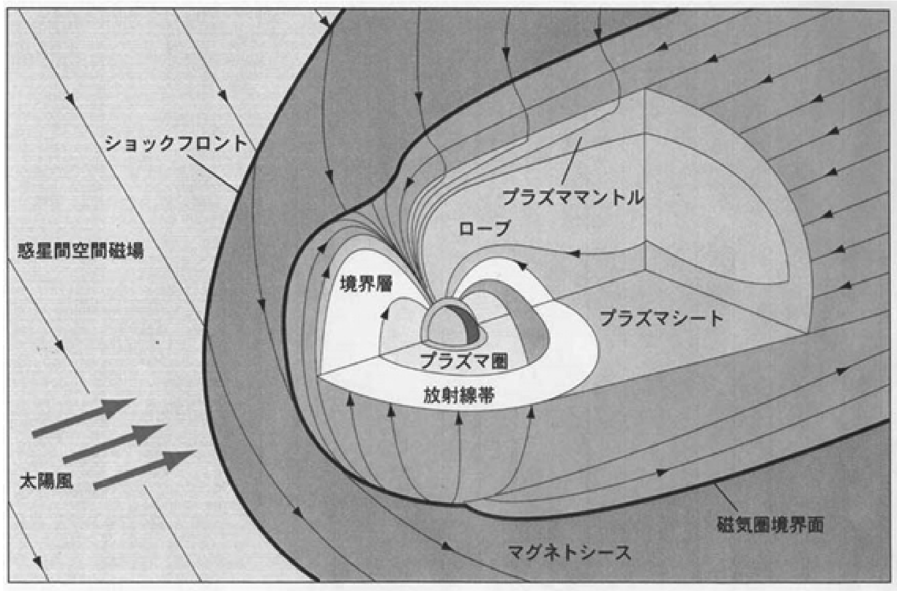


Fig.1. A schematic of Terrestrial magnetosphere

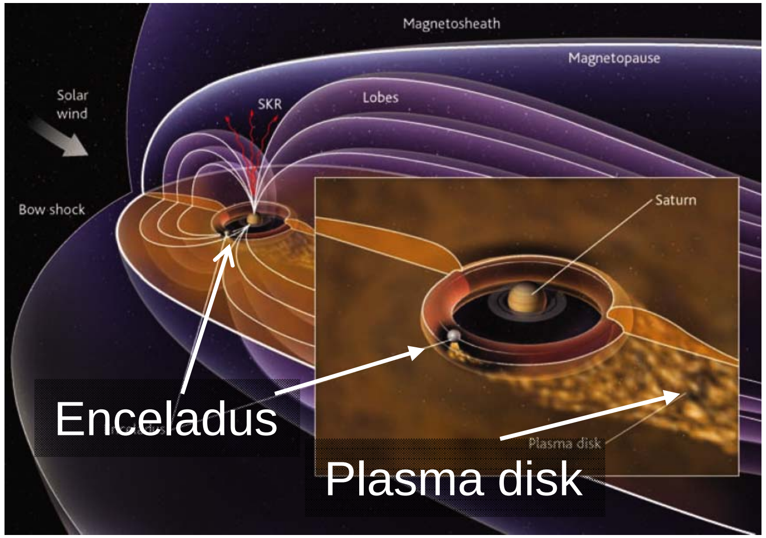


Fig.2. Schematic of Saturn's magnetosphere [*Kivelson,* 2006]

Magnetospheric convection of Saturn is disturbed due to the rapid rotation

Vortex at dawn in the observations by Cassini

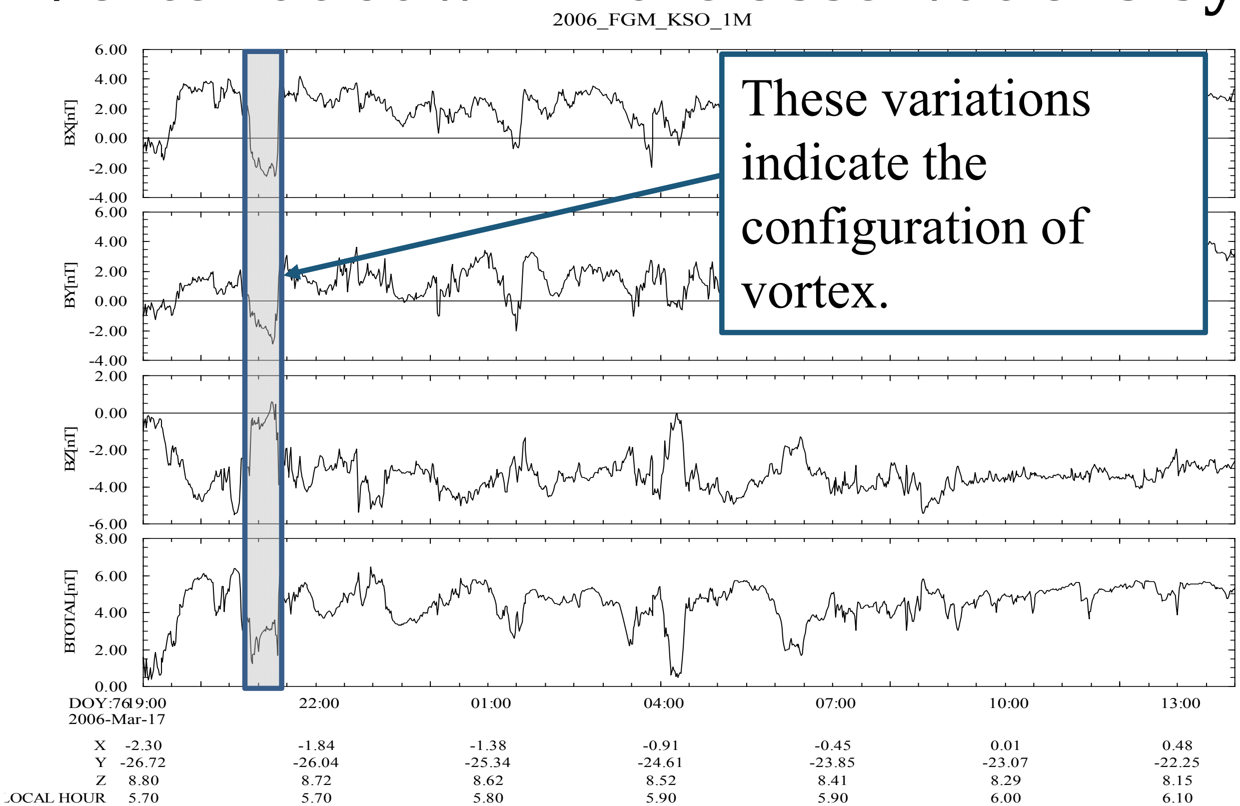


Fig. 3. One minute averages of Cassini magnetic field observations in KSO coordinates (X – Saturn to Sun, Z-upward normal to Saturn's orbital plane, Y – completes a right handed system) on March 17 and 18, 2006 [*Walker et al.*, 2011].

Masters et al. [2009] studied Cassini magnetic field and thermal plasma observations at the dawn magnetopause to infer tailward propagating surface waves on the boundary and suggested they were caused by the K-H instability.

Vortex configuration of Kronian magnetosphere

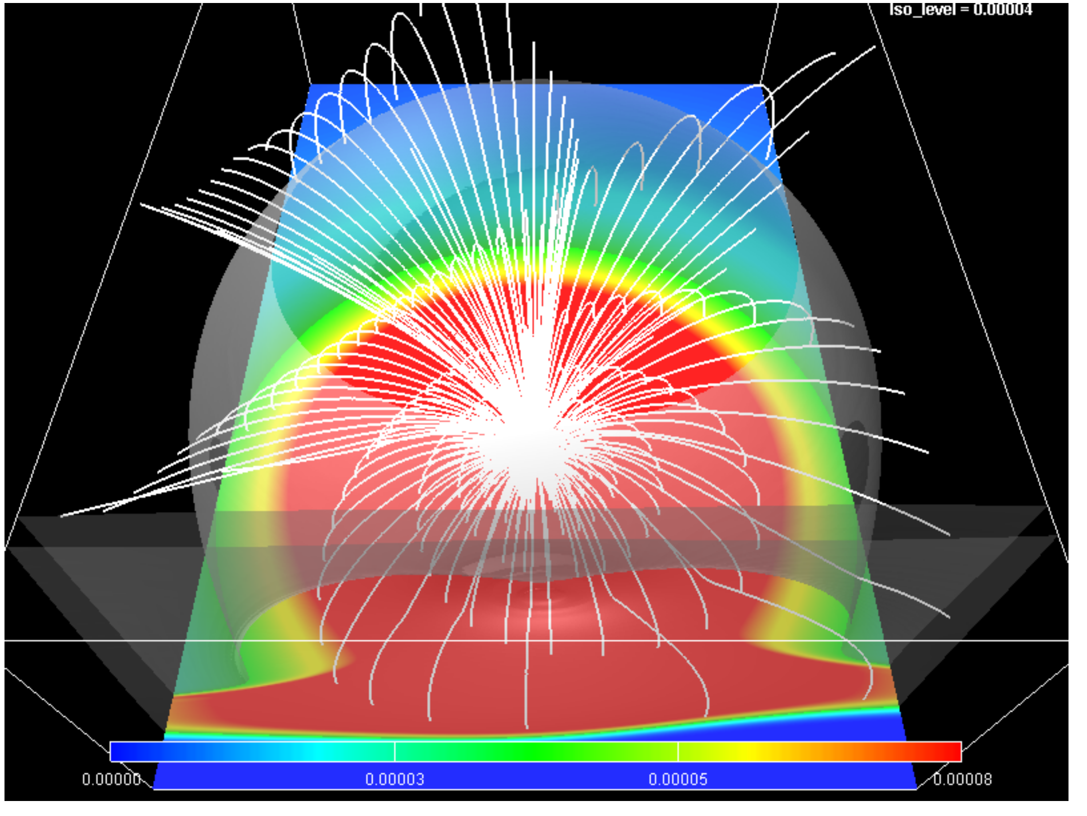


Fig. 4. Schematic diagram of the magnetopause (r_M) and corotation boundary (r_A) on the equatorial plane at Jupiter and Saturn. V_θ is the rotation velocity of the planet.

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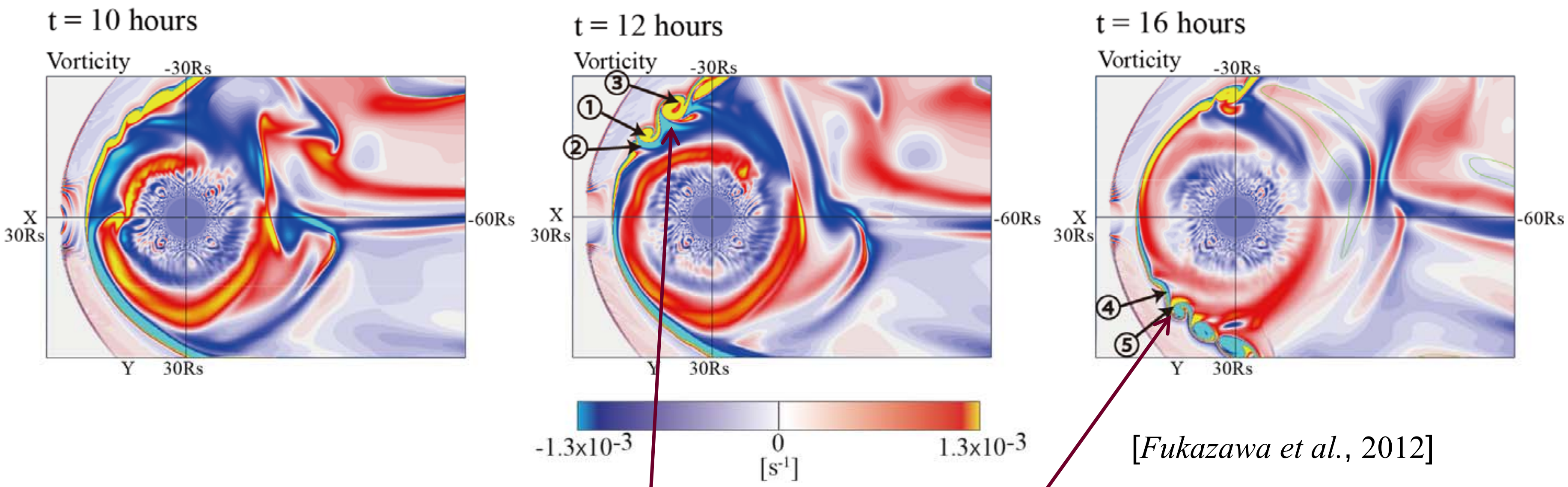
Vorticity on equatorial plane at three snapshots



[*Fukazawa et al.*, 2012]

Vortices are formed along the magnetopause

The flow has formed clear vortices which extend 2.7 to 4.1 R_S along the longer axis for these cases.

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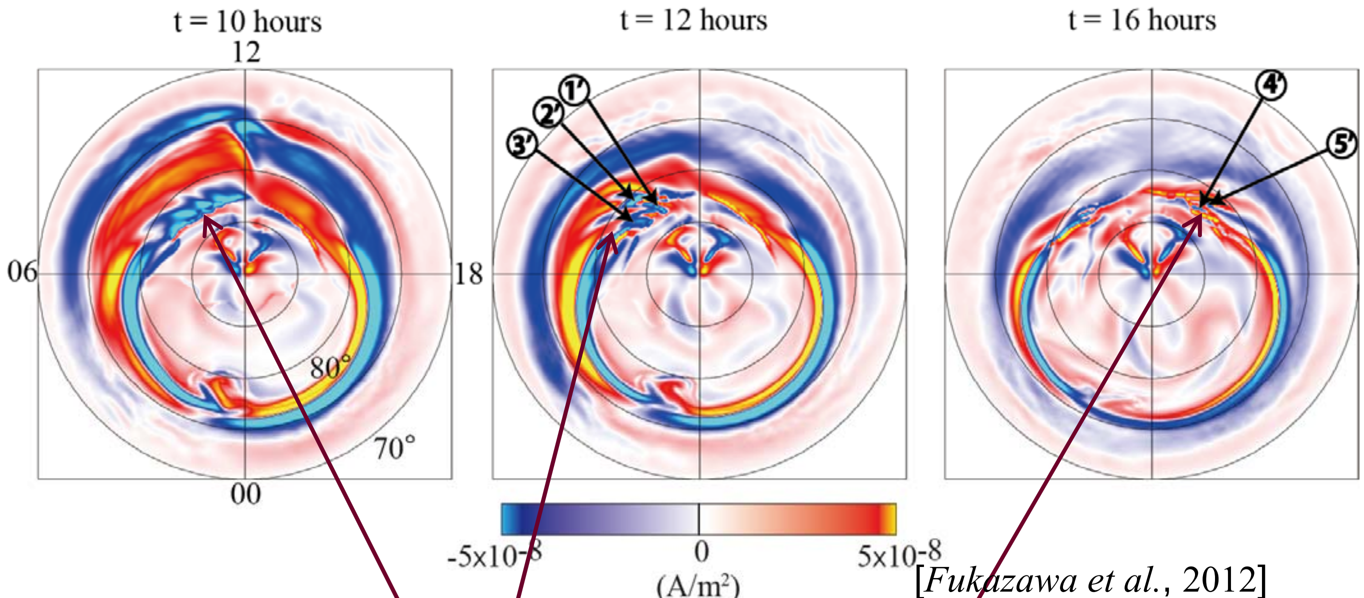
FACs on polar southern ionosphere



[*Fukazawa et al.*, 2012]

Patchy and spot like feature is appeared

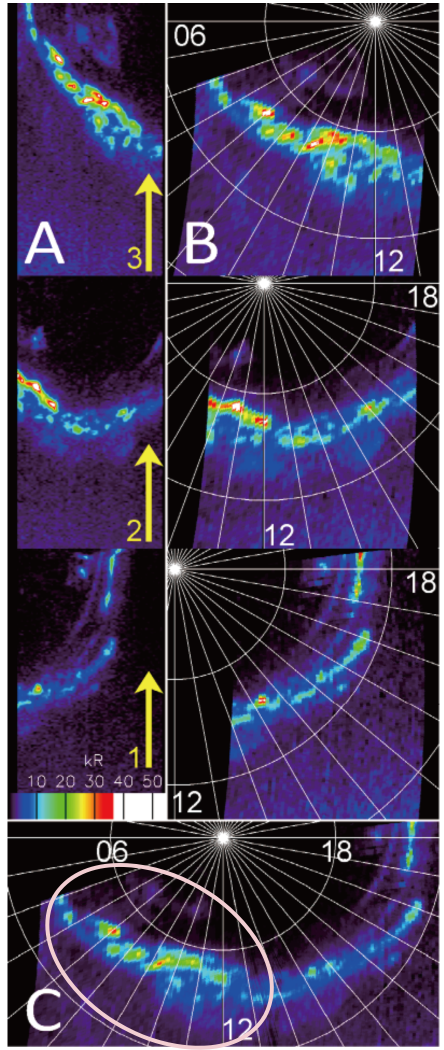


Fig.5. Pseudoimages obtained with the FUV channel of the Cassini - UVIS spectro - imager on DOY 239 (26 August) of 2008. [*Grodent et al.*, 2011]

Motivation

What parameters affect to the configuration of magnetosphere?

Rotation speed, magnetic field, plasma source…

- We are interested in the disturbed convection and vortex in the magnetosphere.
- It seems that those configurations are related to the cushion region.

Examine the relationship between the magnetospheric configuration and cushion region

Cushion Region Model

Character of cushion region in Jupiter and Saturn

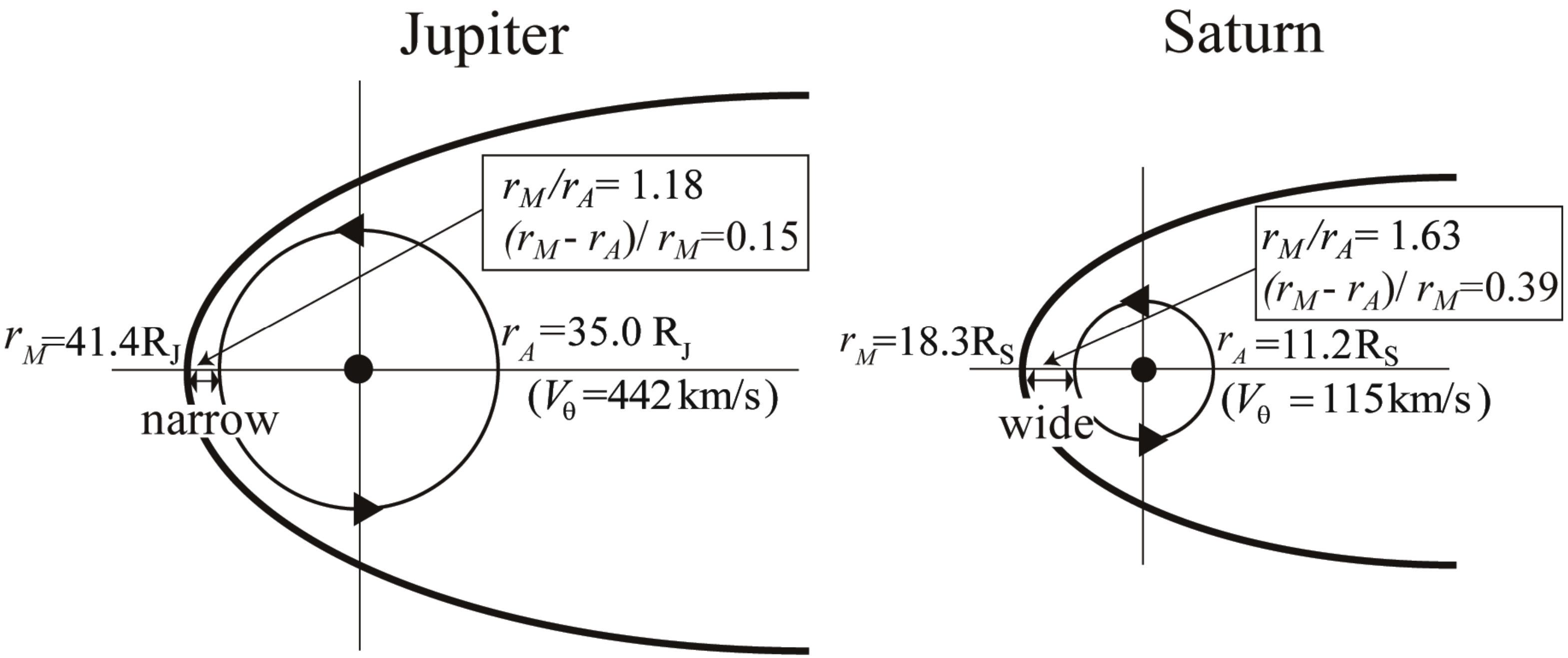


Fig. 6. Schematic diagram of the magnetopause (r_M) and corotation boundary (r_A) on the equatorial plane at Jupiter and Saturn. V_θ is the rotation velocity of the planet.

Alfvén radius (r_A) is distance where the rotation speed (V_θ) equal to the Alfvén velocity. $r_A \sim \omega^{-\frac{2}{5}}$

Cushion region of Jupiter

Table 2. The subsolar distance to the corotation region, thickness of the cushion region and ratio of cushion region to magnetopause as a function of solar wind dynamic pressure [*Fukazawa et al.*, 2006]

	Dayside magneopause (R_J)	Corotation boundary (R_J)	Cushion region (R_J)	Ratio of cushion region to MP (%)
P_{dyn} (nPa)	X_m	X_c	$C_r = X_m - X_c$	C_r/X_m
0.090	76	68	8	10
0.045	90	75	15	17
0.023	102	81	21	20
0.011	119	83	36	30

In Jovian magnetosphere the cushion region rate varies dynamically

Location of MP and BS of Jupiter

Jovian BS and MP from simulation

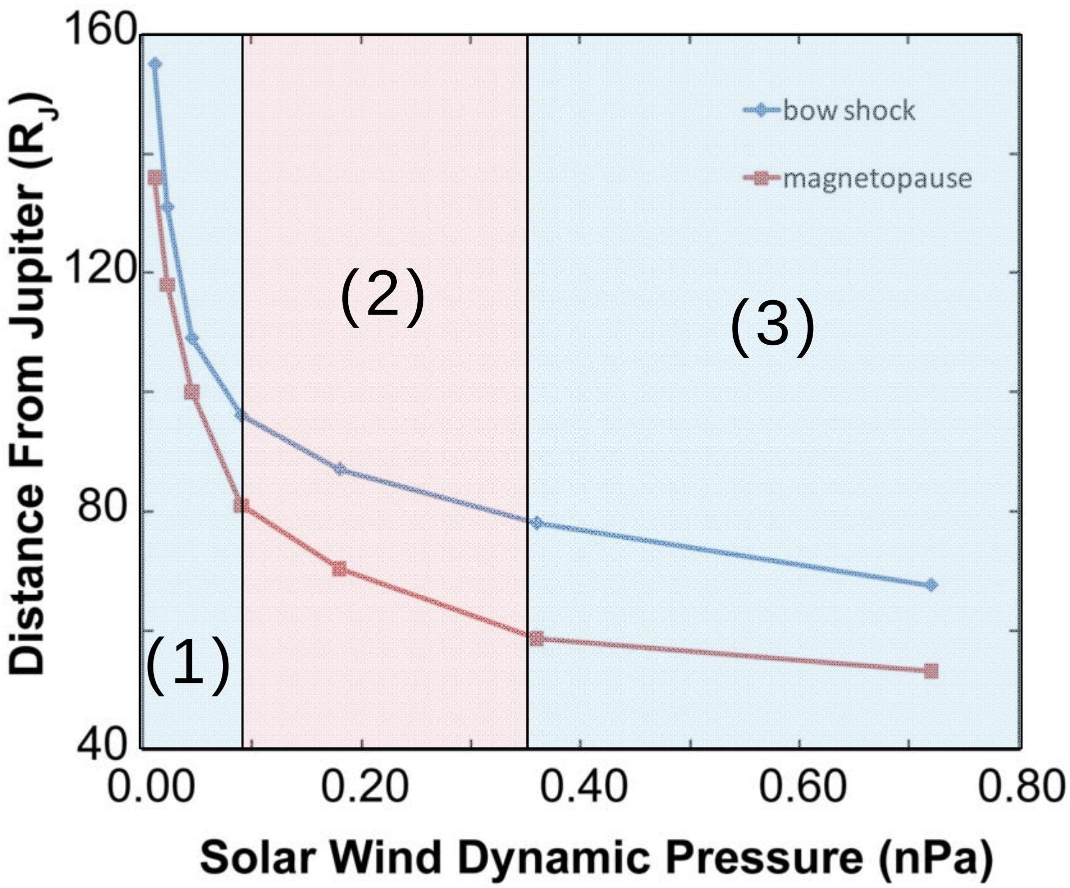


Fig.7. Location of BS and MP as a function of P_{dyn}

(1) Soft magnetosphere
(sponge?)

(2) Medium

(3) Rigid magnetosphere

Jupiter may have 3 types of magnetospheric cofiguration responding to the solar wind.

Cushion region of Saturn

Table 3. The boundaries of the corotation region, thickness of the cushion region at subsolar point and the cushion region. The cushion region is between the magnetopause and corotation boundary on the dayside. The cushion rate is the ratio of cushion region in the magnetopause.

P_{dyn} (nPa)	IMF (nT)		Magneto-pause (R_S)	Corotation boundary (R_S)			Cushion region (R_S)	Cushion region rate (%)
	B_Z	B_Y	X_m	X_c	Y_{avg}	Y_{dawn}/Y_{dusk}	$Cr = X_m - X_c$	Cr/X_m
0.0166	0.0	0.0	19.1	14.3	18.4	1.17	4.8	25
0.0166	–0.4	0.0	19.1	13.7	19.9	1.08	5.4	28
0.0166	0.4	0.0	19.1	14.9	18.3	1.30	4.2	22
0.0166	0.0	0.0	19.7	14.3	18.7	1.35	5.4	27
0.01[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.8	25
0.01[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.4	27
0.00[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.1	32
0.00[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.5	25
0.00[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.7	25
0.0083	0.0	0.4	19.1	15.8	19.6	1.33	5.8	27
0.0166	0.0	0.4	19.1	13.2	18.3	1.20	5.4	29
0.0166	0.0	0.4	19.1	13.8	18.0	1.25	5.4	28

The cushion region rate does not change in the Kronian magnetosphere compared to the Jupiter

Simulation Conditions

To see how the magnetosphere dynamically change to variation of rotation speed

Perform the simulation with the following conditions

- Use Saturn's parameters with changing the rotation angular speed as 1/2, 1/4, 1/8, 1/16, 1/32, 1/64.
- The solar wind conditions are 0.0083 nPa with no/northward IMF (0.4nT).
- Each run performs for 30 hours.
- Grid size is 600×400×400×8

Table 4. Variation of Alfvén radius and rotation speed at Alfvén radius.

ω	1/2	1/4	1/8	1/16	1/32	1/64
r_A (R_S)	14.8	19.5	25.7	34.0	44.8	59.1
V_θ (km/s)	75.9	50.1	33.0	21.8	14.4	9.5

Simulation Results 1

Simulation results for no IMF

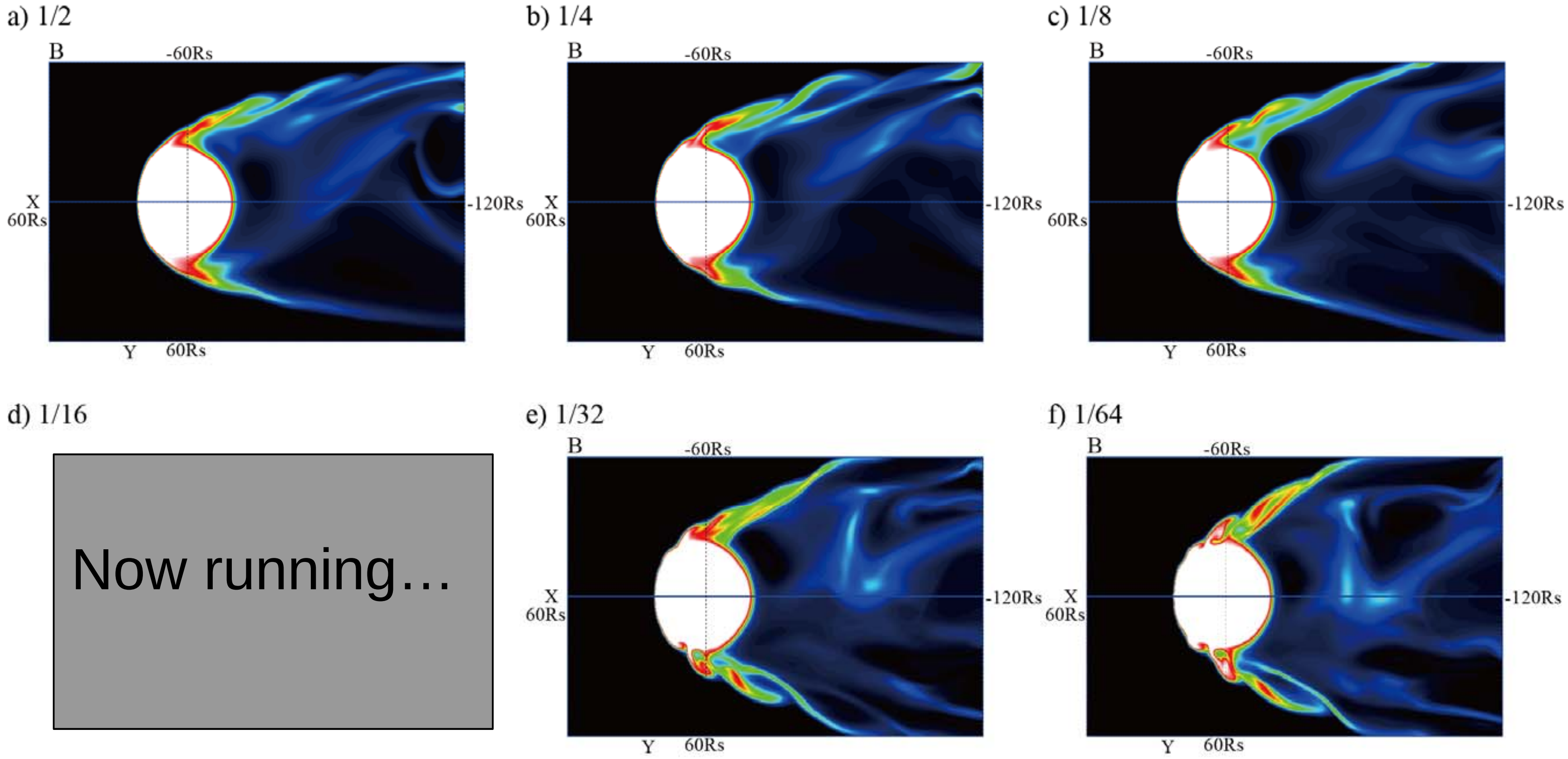


Fig. 7. The magnitude of magnetic field in the equatorial plane for the simulations with no IMF.

Simulation Results 2

Simulation results for northward IMF

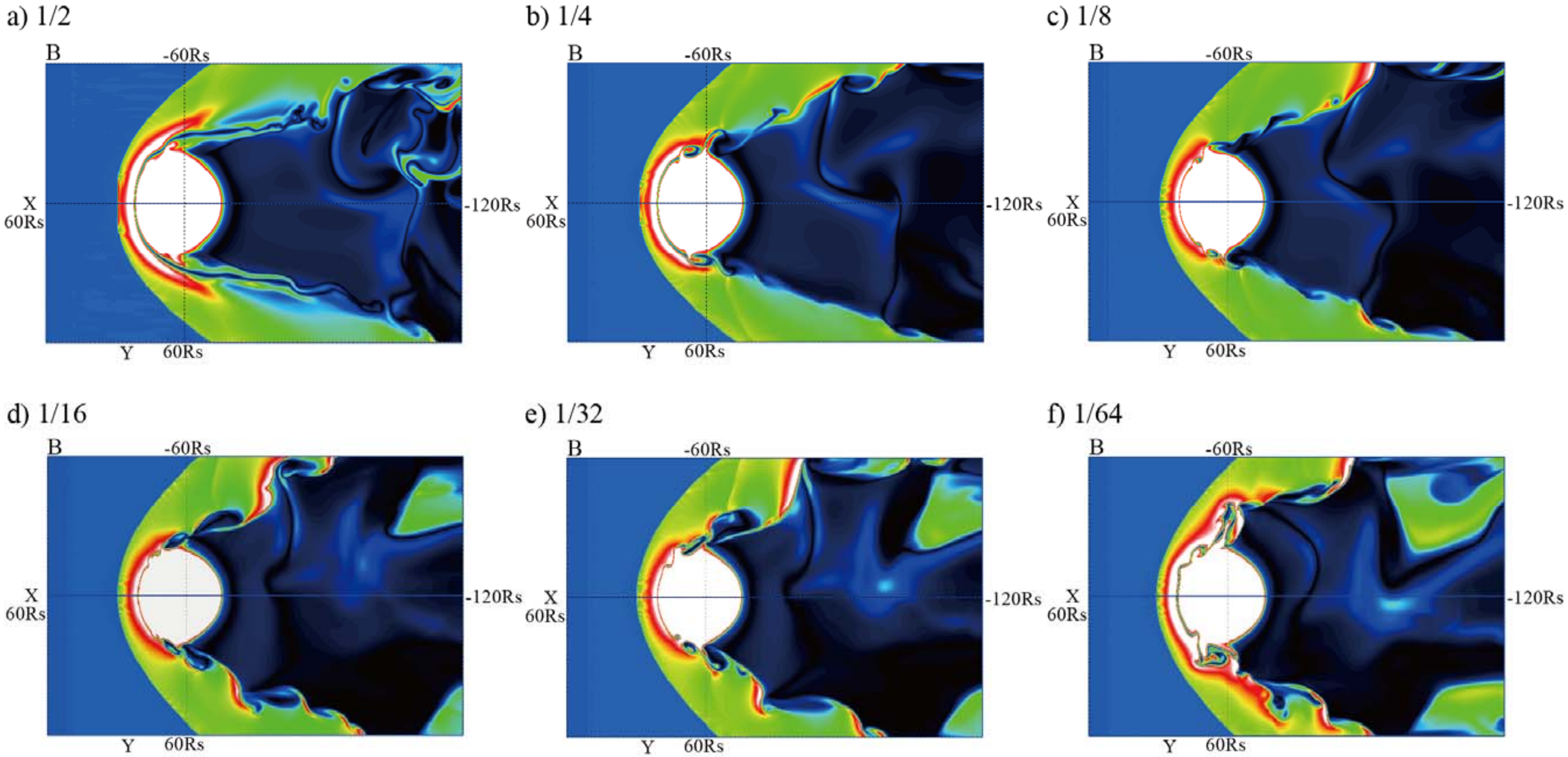


Fig. 8. The magnitude of magnetic field in the equatorial plane for the simulations with northward IMF.

Simulation Results 3

Cushion region

Table 5. The boundaries of the corotation region, thickness of the cushion region at subsolar point and the cushion region.

ω	IMF (nT)	Magneto-pause (R_S)	Corotation boundary (R_S)			Cushion region (R_S)	Cushion region rate (%)
	B_Z	X_m	X_c	Y_{avg}	Y_{dawn}/Y_{dusk}	$Cr = X_m - X_c$	Cr/X_m
1/2	0.0	22.4	14.3	12.5	0.92	8.2	36
1/2	0.4	21.6	14.3	13.2	1.14	7.4	34
1/4	0.0	22.7	14.3	12.9	0.73	8.4	37
1/4	0.4	21.1	12.7	11.1	0.97	8.4	40
1/8	0.0	23.2	14.8	12.7	1.06	8.4	36
1/8	0.4	21.1	12.1	11.6	1.06	9.0	43
1/16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1/16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53
1/32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61
1/32	0.4	21.1	10.0	8.4	1.00	11.1	53
1/64	0.0	23.2	8.4	5.6	0.60	14.8	64
1/64	0.4	21.6	10.6	6.3	0.89	11.1	51

The cushion region rate changes dynamically

Short Discussions

Effect of rotation to the magnetosphere

Magnetosphere becomes “soft” with decreasing the rotation speed

- In model calculation, decrease of rotation angular speed makes Alfven radius broader then cushion region decreases however, it is not appeared in the simulation.
- The rotation speed at the Alfven radius is too small compared to the magnetospheric convection which has ~100km/s.

- From these results to determine the cushion region, we need to consider the rotation speed and it may be around 70km/s.

Summary

To examine the relationship between the magnetospheric configuration and cushion region

We confirm the region between magnetopause and corotation region (cushion region) is the important parameter of magnetosphereic configuration.

- ✓ Cushion region at Jupiter varies dynamically to the dynamic pressure and magntospheric configuration also change.
- ✓ Kronian magnetosphere has broad cushion region and it does not change to the dynamic pressure.
- ✓ Cushion region expands with decreasing the rotation speed and magnetosphere becomes soft.
- ✓ Corotation boundary is determined by the Alfven radius and there rotation speed.