Numerical Simulation of Jovian and Kronian Magnetospheric Configuration

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Context

Jovian and Kronian magnetosphere from MHD simulation

Jovian magnetosphere
- Global configuration of magnetospheric convection
- Variation of BS and MP location
- Magnetospheric convection with low dynamic pressure
- Recent simulation

Kronian magnetosphere
- Turbulent convection in the simulation and observation
- Vortex and aurora emission using the Cassini solar wind data
- Latest simulation results

Summary
Global Configuration of Jupiter

Global magnetospheric convection
From internal process to combination of internal and external processes

Fig. 1. Qualitative sketch of plasma flow in the equatorial plane (left) and of the associated magnetic field and plasma in a sequence of meridian surfaces (right) expected from the planetary wind model [Vasyliunas, 1983]

Fig. 2. Sketch of the flows in the jovian equatorial Plane [Cowley et al., 2003]
Latest Global Simulation

High resolution simulation

Now we can perform 1,000 times higher resolution simulation in 2000

- Grid interval : 0.15R\(J\)
- Inner boundary location : 7 R\(J\)

- Using average solar wind dynamic pressure, we do not see the interesting phenomena…
  → How about the low dynamic pressure?

Fig. 3. Plasma temperature and flow vector on the equatorial plane
Variation of Jovian magnetosphere

Dependence of BS and MP to dynamic pressure

- **(1)** Soft magnetosphere (sponge?)
- **(2)** Medium
- **(3)** Rigid magnetosphere

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

Fig. 4. Location of BS and MP as a function of $P_{\text{dyn}}$ from MHD simulation.
Variation of Jovian magnetosphere

Dynamically changing BS and MP from observation

Fig.5. Probability density of bow shock and magnetopause [Joy et al., 2002]
Periodic plasmoid ejection 1

Simulation of Jupiter's magnetosphere
Dsw = 0.01 nPa, IMF Bz = 0.105 nT, t = 3.5 hours

Fig. 6. Distribution of flow directions from Galileo [Woch et al., 2002]

Fig. 7  Jovian periodic plasmoid ejection from MHD simulation [Fukazawa et al., GRL, 2005]
Low Dynamic Pressure Simulation

Periodic plasmoid ejection 2

Fig. 8. Plasma observations from just after NH's inbound crossing of Jupiter's. [McComas et al., 2007]

Fig. 9. Jovian periodic plasmoid ejection from long tail MHD simulation [Fukazawa et al., JGR, 2010]
Relation of Plasmid and Pressure

Dynamic pressure mainly controls the corotation region

Corotation boundary determined by dynamic pressure.

Reconnection distance depends on IMF.

Periodic plasmoid ejection generates if reconnection ($\triangle$) occurs nearby corotation boundary ($\bigcirc$) and does not occur at much inner boundary ($\bullet$).
Recent Global Simulation

Coupling simulation of electron hybrid simulation and MHD simulation

Katoh’s electron hybrid simulation uses the magnetic field data from the results of MHD simulation
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Summary
In our early simulation results, the vortex and turbulent convection are appeared in the Kronian magnetosphere for three IMF (no / southward / northward) cases from the early simulation results.

Fig.10. The temperature and flow vectors in the equatorial plane for the simulations with no IMF (a), southward (b) and northward IMF (c) [Fukazawa et al., 2007a]
Vortex in the observations by Cassini

Fig. 11. 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.

These variations may indicate the configuration of vortex.
Clear Vorticity in the Simulation

Then we can simulate with the fine resolution.

Vortices are formed along the both dawn and dusk magnetopause

Fig.12. The vorticity parallel to the magnetic field in the equatorial plane at $t = 10, 12, \text{ and } 16 \text{ h}$. Vorticity with blue represents the clockwise motion, and red represents the anticlockwise motion [Fukazawa et al., 2012].
FACs on polar southern ionosphere

Patchy and spot like feature is appeared due to the vortices

Fig. 13. The distribution of field-aligned currents (FACs) in the southern polar cap mapped along the magnetic field lines from the simulation results to the southern ionosphere at t = 10, 12, and 16 h [Fukazawa et al., 2012].

Fig. 14. Pseudoimages obtained with the FUV channel of the Cassini - UVIS spectro - imager on DOY 239 (26 August) of 2008 [Grodent et al., 2011].
Solar Wind Data from Cassini

Cassini located at
\((X_{\text{KSM}}, Y_{\text{KSM}}, Z_{\text{KSM}}) = (24.5–26.7R_S, -1.3–3.1R_S, 7.4–13.0R_S).\)

→ Cassini was almost upstream the magnetosphere.

Polarity reversal

Enhancement of dynamic pressure
Simulation Results | Movie of equatorial plane

The position of magnetopause is varied dynamically then the magnetospheric convection becomes disturbed.

The big vortices are formed when the shock coming and they move into the tail.
Location of BS and MP from Simulation
Effect of dynamic pressure

Location of bow shock and magnetopause dynamically changes
- BS: 22.6 $R_S$, MP: 17.2 $R_S$ on the subsolar point at minimum (0.01 nPa)
- BS: 27.6 $R_S$, MP: 24.2 $R_S$ on the subsolar point at maximum (0.0025 nPa)
- These locations have 122% (BS) and 140% (MP) differences.
Effect of IMF

Northward turning creates the layer configuration of flow

- Reconnection occurs around subsolar point then the flow comes into the magnetosphere.
- This also makes the enhancement of upward field-aligned current.

Incoming flow

Upward FAC broadens

Layer configuration
Observation Results in February 2008

Fig. 7. Total auroral power from Saturn’s south polar region, best fit auroral oval radius, and SKR emission spectrum compared with propagated solar wind velocity and dynamic pressure in February 2008 [Clarke et al., 2009].

Fig. 8. Sample UV images of Saturn’s south pole in February 2008 with quiet and disturbed conditions [Clarke et al., 2009].

This period is corresponding to the simulation period.

HST has just observed the UV image during this period.
Comparison of Simulation with Observation

Enhancement of dynamic pressure just before becoming 2/13

Enhancement of By after the decline

Upward FAC around high latitude may be corresponding to the brightening of observation

Field-Aligned Current
Vorticity from Simulation

Vorticity in Saturnian Magnetosphere
2008-02-12/14:10:31 UT

last= 40 ii= 1 nexp= 150 nr= 900
x = 15,0Rs

[Diagram showing vorticity patterns with labels and axes]
Recent High Resolution Simulation

Simulation with no IMF@ FX10

Grid size
- (nx, ny, nz, nmhd) = (3000, 2000, 2000, 8) → about 700GB
- Use 7 times larger memory (5TB) than the grid size in the calculation
- Grid spacing is 0.06Rs (3600km)

Time scale
- Calculate for 35 hours in the real time
Recent High Resolution Simulation

Simulation with weak northward IMF @ FX10

High resolution Kronian Magnetosphere
Dyn = 0.0082 nPa, Bz = 0.02 nT, t = 51.87 h

last= 19 ii= 19 nxp= 250 nr=1500

z = 0.0Rs
Recent High Resolution Simulation

Simulation with IMF $B_Y = B_Z$ @ FX10

High resolution Kronian Magnetosphere
Dyn = 0.0082 nPa, By = Bz = 0.4 nT, t = 47.33 h

last= 50  ii= 50  nvp= 250  nr=1500

x = 0.0R_S
Recent High Resolution Simulation

Simulation with medium northward IMF@ FX10

High resolution Kronian Magnetosphere
Dyn = 0.0082 nPa, Bz = 0.4 nT, t = 44.29 h

\[ \dot{B} \]

\[ \dot{V} \]

last= 16 ii= 16 nxp= 250 nr=1500

x = 0.0Rs
Summary

Global configuration of Jovian and Kronian magnetosphere from numerical simulations

• Jupiter
  ✓ From high resolution simulation we do not get the interesting phenomena.
  ✓ Past simulation results suggest the low dynamic pressure reproduces the interesting phenomena due to the corotation region.

• Saturn
  ✓ Kronian magnetosphere well responds to the solar wind and a lot of phenomena are appeared in the magnetosphere.
  ✓ To see vortex we need medium magnitude of northward IMF.