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Database development of global Jovian magnetospheric simulation

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Motivation

To compare the observations and simulations

Hisaki observes good auroral and Io's activities

- Aurora is a proxy of magnetospheric phenomena
- We can see good time evolution of aurora

MHD simulation can represent the large scale magnetospheric phenomena.

- All the plasma and magnetic field information in 3D space are saved (off course MHD scale)
- Thanks to computer developing, it is easy to perform the simulation of parameter survey

It is good time to collaborate the simulation with Hisaki observations!

Database Set 1

Now we suppose the following data sets

Basic solar wind response

- To represent the basic configuration of Jovian magnetosphere under the steady solar wind condition

Event driven simulation

- Simulation using the realistic solar wind condition around Jupiter (such as Tao-san solar wind model)

Specific solar wind condition

- Experimental simulation of Jovian magnetosphere using specific solar wind condition
- E.g. first low solar wind dynamic pressure is added for long time then high dynamic pressure is coming

Database Set 2

Detailed information

Quasi-steady state on basic solar wind response

- Simulation size ($900R_J \times 600R_J \times 600R_J$) with $1.5R_J$ spatial resolution and 30 mins temporal resolution
- Solar dynamic pressure = 0.011, 0.023, 0.045, 0.090, 0.180, 0.360, 0.720 nPa and IMF Bz = 0, ±0.1, ±0.2, ±0.4, ±0.8 nT,

Event driven simulation

- Now we plan to use the solar wind condition at January 2014

Specific solar wind condition

- Low solar wind dynamic pressure (0.011nPa) for 7 days at maximum and then high dynamic pressure (0.036nPa)

Governing Equation

MHD equation with numerical terms

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\mathbf{v}\rho) + D\nabla^2 \rho$$

$$\frac{\partial \mathbf{v}}{\partial t} = -(\mathbf{v} \cdot \nabla)\mathbf{v} - \frac{1}{\rho}\nabla p + \frac{1}{\rho}\mathbf{J} \times \mathbf{B} + g + \frac{1}{\rho}\Phi$$

$$\frac{\partial p}{\partial t} = -(\mathbf{v} \cdot \nabla) p - \gamma p \nabla \cdot \mathbf{v} + D_p \nabla^2 p$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) + \eta \nabla^2 \mathbf{B}$$

$$\mathbf{J} = \nabla \times (\mathbf{B} - \mathbf{B}_d)$$

$$\Phi \equiv \mu \nabla^2 \mathbf{v} \qquad \eta = \eta_0 (T / T_0)$$

$$g = -g_0 / \zeta^3 \quad (\zeta^2 = x^2 + y^2 + z^2)$$

Simulation System

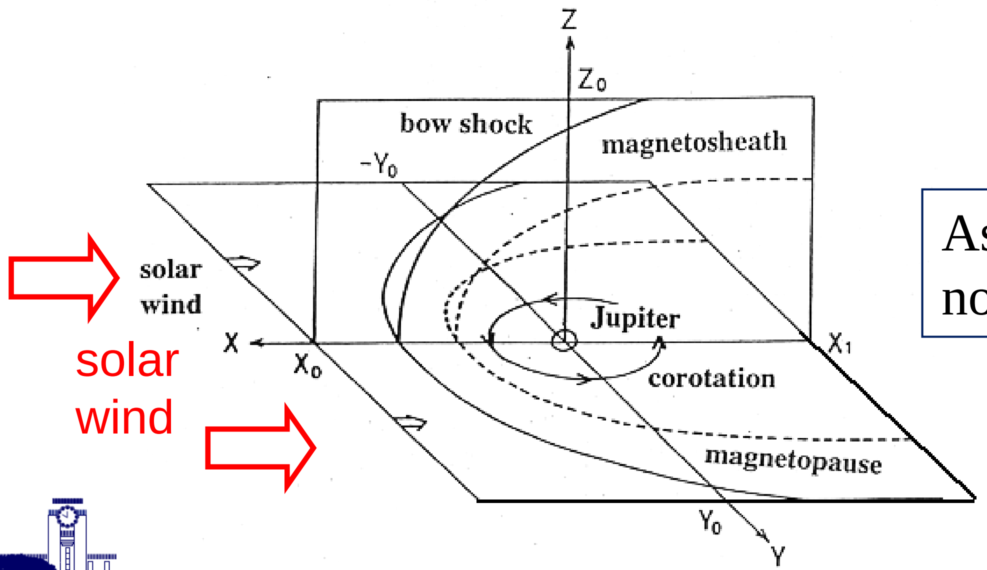
Simulation model

Simulation box (x, y, z) = (600, 400, 200)

Grid interval = $1.5R_J$

Inner boundary = $15R_J$

Scale of Simulation (xl, yl, zl) = ($900R_J$, $600R_J$, $300R_J$)



Assume north-south symmetry, not include magnetic dipole tilt

Planetary Parameters

Used parameter in the simulation of Terrestrial, Jovian and Kronian magnetosphere

	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

Data format 1

Simulation data is written by Fortran as following

```
do m=1,8 （1:plasma density, 2:Vx, 3:Vy, 4:Vz, 5:plasma pressure, 6:Bx, 7:By, 8:Bz)
  do k=1,402
    write(out) f(1:602,1:402,k)
  end do
end do
```

*one write adds one return (4byte). xy+4byte+xy+4byte･･･

Using Fortran, you can read the data like below.

```
do m=1,8
  do k=1,402
    read(in) f(1:602,1:402,k)
  end do
end do
```

Data format 2

Data type is unformatted and big endian.

The transform of endian (big to little) is following

```
open(10,file='./ju0720no100.data',convert='big_endian',
&     access='sequential',form='unformatted')
```

The length from Jupiter is calculated from

```
xl=0.5*hx*(2*i-nx2-1+2*nxp)
yl=0.5*hy*(2*j-ny2-1)
zl=0.5*hz*(2*k-3)
hx=1.5Rj:grid spacing, nx2=602, ny2=402, nxp=100
```

Normalization

Simulation data is normalized by the following values

ns=1.0e10 (/m**3) : number density of ionosphere

vs=9.167e7 (m/s) : Alfven velocity at equator

ps=1.403e-1 (N/m**2) : pressure of normalization

Bs=4.2e-4 (T) : magnitude of B-field at equator

Other physical values are normalized by followings

xs=RJ=7.140e7 (m) : radius of Jupiter

rohs=1.67e-17 (kg/m**3) : muss density of ionosphere

ts=0.779 (s) : time of normalization

gs=1.177e8 (m/s**2) : gravitational acceleration of normalization

Simulation Cover Area 1

Periodic plasma ejection

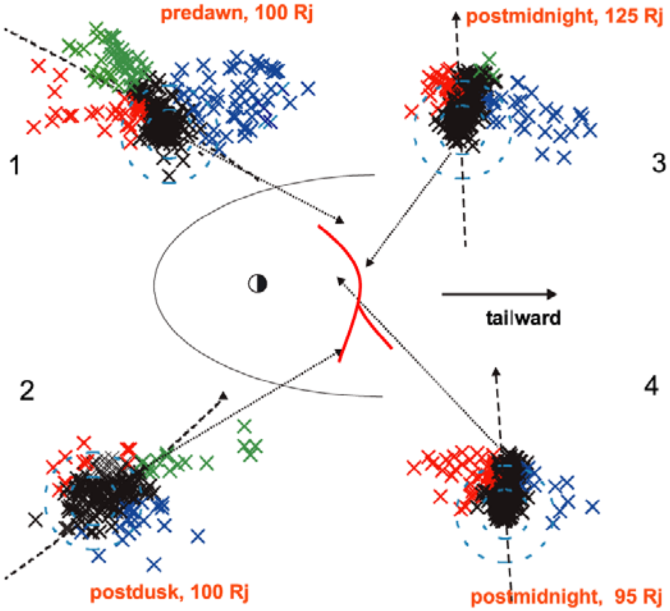


Fig.1. Distribution of flow directions from Galileo [*Woch et al.*, 2002]

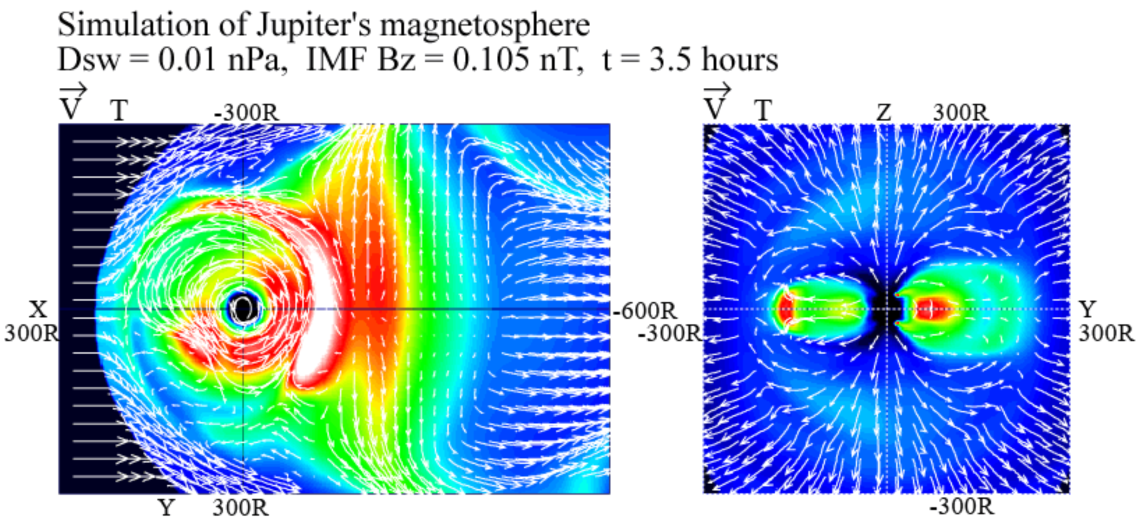


Fig. 2 プラズマの周期的放出現象 [*Fukazawa et al.*, *GRL*, 2005]

Simulation size 600×400×200=1.5GB

Simulation Cover Area 2

Location of bow shock and magnetopause

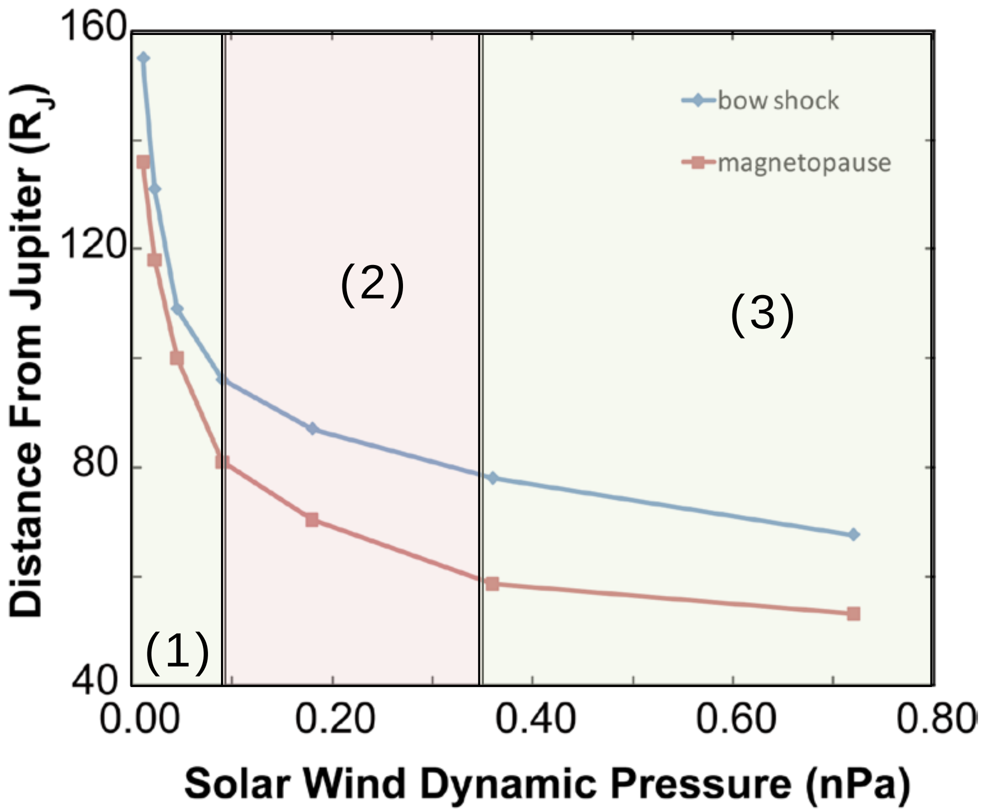


Fig.3. Location of BS and MP as a function of P_{dyn}

(1) Soft magnetosphere
(sponge?)

(2) Medium

(3) Rigid magnetosphere

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

Simulation Cover Area 3

Plasmoid ejection in the long tail

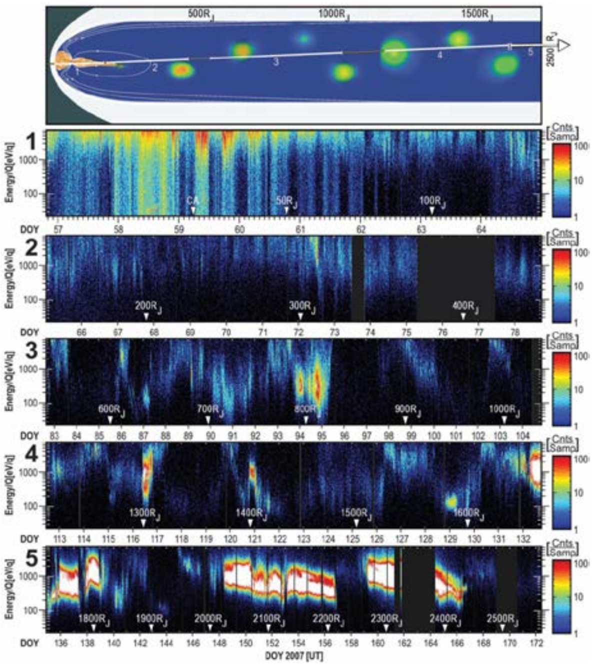


Fig.4. Plasma observations from just after NH's inbound crossing of Jupiter's. [*McComas et al.*, 2007]

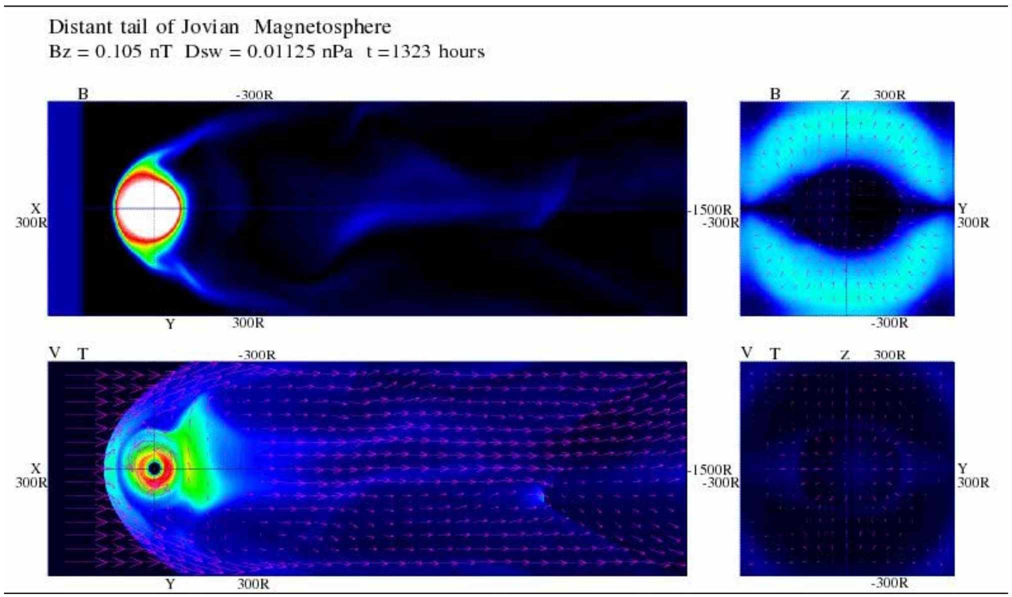


Fig. 5. Periodic plasma ejectiopn [*Fukazawa et al., JGR*, 2010]

Simulation size 1200×400×400=6GB

Data Location

Now we are wondering where the data will be located

Candidate of location

- Kyoto Univ.
  → (Now) Personal server or hosting server
- ISEE, Nagoya Univ.
  → Applying to collaboration research of using calculation system
- Integrated Science Data System Research Laboratory, NICT
  → Science Cloud (will negotiate to Murata-san)

Important points to select the location

- Easy to keep the disk space and server (cost and system)
- Network speed (SINET5 or JGN-X or 1Gbps at least)
- If possible, able to analyze the simulation data on the same server (license, compiler,…)

Present data

The test simulation in this fiscal year

Variation of dynamic pressure

- 0.011, 0.023, 0.045, 0.090, 0.180, 0.360, 0.720 nPa with no IMF for 300 hr
  ~1 TB (=7x100x1.5 GB)

Variation of IMF Bz

- 0.011, 0.023, 0.045, 0.090, 0.180, 0.360, 0.720 nPa with 0.1, 0.2, 0.4, 0.8 nT
  ~4.2 TB(=7x4x100x1.5 GB)

Kita-san's request

- 0.011 nPa for 1 ~ 7 days, then 0.360 nPa
  =0.675 TB(=(100+50x7)x1.5 GB)

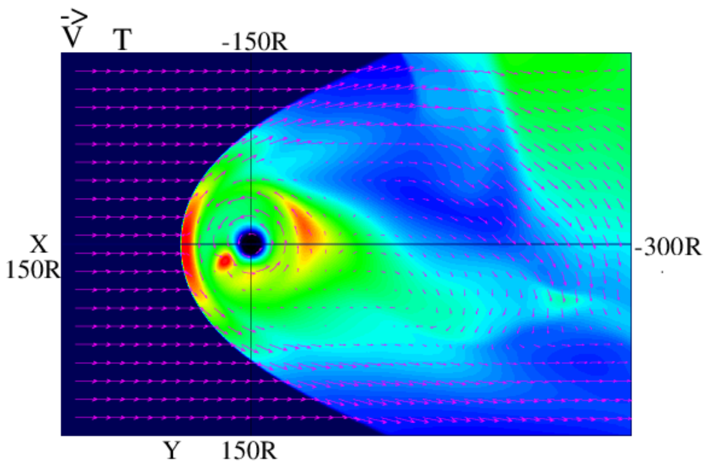
*sampling time is 3 hr.

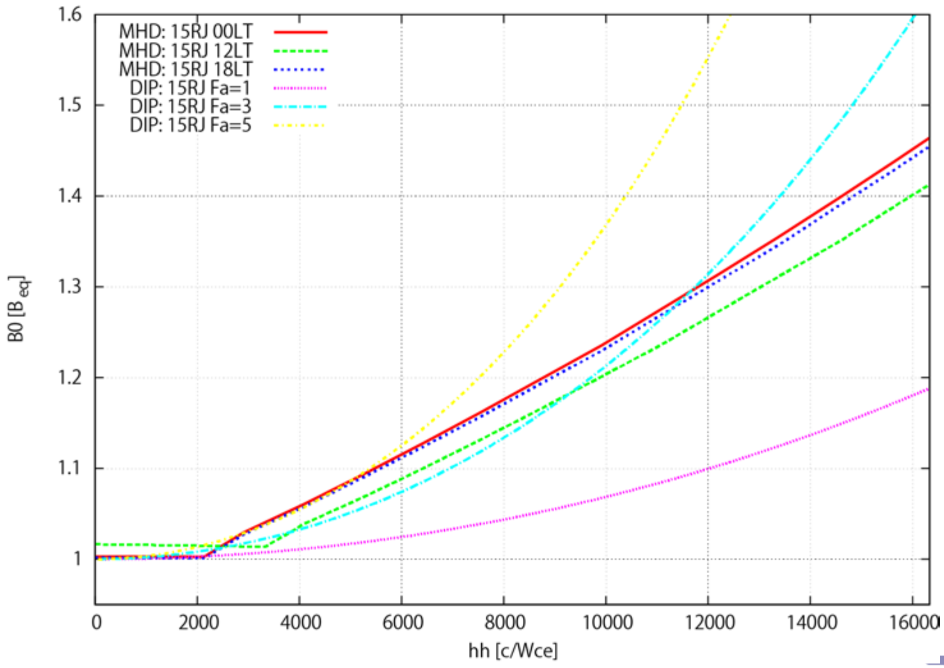
Long Term Simulation data

For Kato-san hybrid simulation

Background magnetic field data

- Simulation size: 6000×4000×2000=3TB
- Spatial resolution: $0.15R_J$
- Inner boundary: $7R_J$





京都大学
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In progress plan

Now we gather some requests from researcher of Jovian magnetosphere

High temporal resolution of xy-plane around $30R_J$ equatorial plane

- For calculating the entropy
  決まった線上や面上のデータだけを高時間分解能で保存すると良いかも。

Executable application on the Windows or Linux

- Calculate the required simulation data on your computer
- Required temporal resolution is different among phenomena however it is difficult to store the high temporal resolution data due to the storage size

Summary

We are developing the simulation database of Jovian magnetosphere

- ✓ Now is good time to collaborate the simulation with Hisaki's results.
- ✓ It is possible to perform the parameter survey simulation with the resolution 10 years before.
- ✓ First we are now calculating the basic configuration of Jovian magnetosphere under the variation of solar wind dynamic pressure in the quasi-steady state.
- ✓ Then we will try to run the simulation with realistic solar wind condition.
- ✓ In the near future the data size will be 100TB and we are looking for the location of data server.
- ✓ Finally we aim to open the simulation data to compare the observation data easily.