MHD Simulation of the Saturnian Magnetosphere

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The features, such as a peculiar magnetic field, mass and rotation period differ for each planet. Therefore, the structure in the sphere formed as a result of interaction with the solar wind is also different. Saturn has a 1000 times as much peculiar magnetic field as the Earth and rapid rotation. In order to investigate the structure of the Saturnian magnetosphere, three-dimensional global MHD simulation of the Saturnian magnetosphere for northward and southward IMFs was performed, and the magnetospheric structure was compared with the Earth’s one.

1. Introduction

Saturn is the sixth planet from the Sun. It is the feature of appearance that there is a ring which looks clear to the surroundings of the planet. As physical character, an equatorial radius and mass are large to the next of Jupiter. (Jupiter is the largest in the planets of the solar system.) Rotation period is short and about 10 hours. (Rotation speed is fast) Magnetic moment is about 1000 times as large as the Earth’s one. However magnetic field on the surface is almost same. The inclination between the magnetic axis and the rotation axis is 1 degree or less. It is a small value in comparison with other planets. The pole of the magnetic field is contrary to the earth. In Saturn, north is N-pole. From these features, it is imagined that Saturnian magnetosphere differs from the Earth’s magnetosphere. It is useful to compare each magnetosphere for understanding of the heavenly body with intrinsic magnetic field and magnetospheric physics. Cassini reached Saturn in July 2004, and is due to continue inquiry for four years from now on. It is a heavenly body which attracts attention now. A 3D global MHD simulation of Saturnian magnetosphere was presented by Hansen, K.C et al[1]

2. Features of Saturnian Magnetosphere

We calculate locations of magnetopause and rotation boundary of plasma (Alfven radius) of each planet to show conceptual figure of magnetopause structure. Magnetopause position is computed from balance of solar wind dynamic pressure and magnetic pressure. Alfven radius is the position where the rotation velocity equals Alfven velocity. Fig. 1 illustrates the features for the planetary magnetospheres of Saturn, Jupiter and Earth. rM is the magnetopause distance from the planet. rA is the Alfven radius. Black dot shows a planetary position. Solar wind is blowing from the left. Rs, Rj, and Re express the radii of Saturn, Jupiter and Earth, respectively.

From Fig. 1, there exists wide space between the magnetopause and Alfven radius for the Saturn in comparison with other planets. There is a possibility that fluid instability occurs in this wide velocity shere region.

3. Simulation Model

We use a solar-magnetospheric coordinate system shown in Fig. 2. in this simulation. Number of grid is (nx, ny, nz) = (600, 400, 200) with a grid spacing of 0.3 Rs. The simulation box has dimension of -120Rs ≤ x ≤ 60Rs, -60Rs ≤ y ≤ 60Rs and 0 ≤ z ≤ 60Rs. We have solved the normalized resistive MHD and Maxwell’s equations as an initial-value problem in this region by using a modified version of the Leap-Frog scheme [2]. The solar wind flows into the simulation box through the upstream boundary (from positive direction of x-axis). The velocity of solar wind is 3.0 × 10 5 m/s, number of density 5.49 × 10-14/m3, temperature 1 × 105K, thermal pressure 7.58 × 10-14N/m2, and IMF Bz ± 0.4nT.

Fig. 1. Positions of Alfven radius and magnetopause for Saturn, Earth, and Jupiter.

Fig. 2. Solar-magnetospheric coordinate system of simulation.
4. Simulation Result

To understand the structure of the Saturnian magnetosphere for finite IMF, the solar wind-magnetosphere interaction was simulated for the southward (Bz = -0.4nT) and northward (Bz = 0.4nT) IMFs. In Fig. 3, is shown the flow of plasma (arrow) and the temperature (color) in xy plane at z=0 for almost steady-state. Vortices have occurred and temperature is high on the dawn side for southward IMF. It can happen because the direction of the plasma flow that rotates with the rotation of Saturn is opposite to the direction of the flow of the solar wind, and the stagnation point appears there. For northward IMF, high-speed plasma flow is generated in the both directions along x-axis in the tail by magnetic reconnection. Moreover, the vortices are seen on the dawn and dusk sides for southward IMF.

Fig. 3. Velocity vector and plasma temperature of the Saturnian magnetosphere on equatorial plain for southward IMF, Bz = -0.4nT (top) and northward IMF, Bz = + 0.4nT (bottom).

In Fig. 4, are shown the magnetic field (arrow) and magnetic field strength (color) in xz plane at y = 0 in the cases of Saturn and Earth’s magnetospheres. Compared with northward, lines of magnetic force at the Saturnian magnetosphere are round for southward which is similar to the Earth’s magnetosphere for northward IMF. The plasma sheet is thick. Lines of magnetic force are enlarged in x-direction, and the plasma sheet is thin for northward IMF. The structure of the Saturn magnetosphere for southward/northward IMF is similar to the Earth magnetosphere for northward/southward IMF.

Fig. 4. Magnetic field vector and magnetic field strength of Saturnian magnetosphere when southward and northward IMFs are imposed. The Earth magnetosphere is also shown in comparison.

5. Conclusion

A three-dimensional global MHD simulation of interaction between the solar wind and the Saturnian magnetosphere has been performed in order to study the magnetospheric structure and dynamics. As the result, a steady state magnetospheric structure could be obtained for southward and northward IMF conditions. This time, the solar wind including IMF was blown for the northward and southward IMFs and the obtained stationary state magnetospheric structure was examined.

The shape of the Saturnian magnetospheric structure (the lines of magnetic force, plasma sheet) is similar to that of the Earth magnetosphere. However, the dependency of IMF north-south direction is opposite. On the dawn and dusk sides of magnetospheric structure, large vortices appear. It may be originated from fluid instabilities such as Kelvin-Helmholz instability which is excited by velocity shear between the rotational flow and tailward flow of the solar wind. Generation of such a large vortices is not seen in the Earth’s magnetosphere.

Acknowledgments. Computing support was provided by the Information Technology Center, Nagoya University and JAXA ISAS Center for Planning and Information systems.

References