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北向き IMF における太陽風磁気圏系での基本物理過程

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Fundamental physical processes of the solar wind-magnetosphere system in the northward IMF condition

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The physical processes in the solar wind-magnetosphere region are usually studied as interactions between independent magnetized plasmas in the two regions across the interface (the magnetopause). We propose an alternative approach that treats the solar wind and the magnetosphere as a single system, wherein the magnetopause is regarded as an internal structure. This approach entails studying the physical processes as interactions between the magnetic field and plasmas within this integrated system. In this approach, we should recall the magnetic field that is not affected by plasmas. It is the vacuum magnetic field which is a superposition of the Earth's main magnetic field and a uniform interplanetary field (IMF). Because the vacuum magnetic field does not have free energy, this field is the definitive ground state of the solar wind-magnetosphere system. Moreover, because the vacuum magnetic field has null points where two different magnetic fields meet [e.g., Cowley, 1973; Lau and Finn, 1990; Watanabe et al., 2005; Xiong et al., 2024], the stage is already set for the reconnection between the IMF and the magnetospheric magnetic field. Therefore, the vacuum field can be called the skeletal magnetic field of the solar wind-magnetosphere system. On the other hand, the solar-wind plasmas just pass the Earth and create a cylindrical shadow behind the Earth in the environment without the magnetic field. Therefore, the behavior of the solar wind-magnetosphere system is determined by the balance between the force that plasma exerts on the skeletal magnetic field and the restoring force caused by the deformed magnetic field (“the mechanical principle”). At this time, the vacuum magnetic field structure has two null points and two separator lines that connect the null points. This two-null two-separator topology is conserved when plasmas deform the skeletal magnetic field in the northward IMF condition (“the topology conservation property”). Therefore, our approach to the physical processes in the solar wind-magnetosphere system in the northward IMF condition is to manifest behaviors of the magnetic field and plasmas in terms of the mechanical principle under the constraints of the topology conservation property. Furthermore, the reconnection process transports magnetic flux and plasma from the solar wind into the magnetosphere, inducing magnetospheric convection. The convection of the plasmas and the magnetic field lines occurs to satisfy the mechanical principle and the topology conservation property. Based on these fundamental principles, we can explain that the lobe is generated as a consequence of the mechanical principle. In addition, the topology conservation property leads to the closed field line region extending long in the magnetotail. Furthermore, we will show that the mechanical principle and the topology conservation property control the generation of the plasma bulge in the lobe, energy transport from the solar wind to the plasma sheet, and formation of the current systems around the magnetosphere.

References

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