We sincerely appreciate the reviewer's comment pointing out that, while the paper provides a review of studies on three-dimensional reconnection, a review of magnetospheric dynamics is insufficient. In addition to this comment, we realized that the current presentation could create the misconception that the purpose of our research is to elucidate the structure of the magnetosphere. Based on this comment, we will revise the paper according to the following policy.

In this reply, as in the present paper, we will limit our discussion to the behavior of the solar wind–magnetosphere system under obliquely northward IMF conditions.

① Revision policy

(We will revise parts of the Abstract and Introduction in accordance with the explanation in ①.)

Previous studies of three-dimensional reconnection in the solar wind–magnetosphere system have focused on the null–separator structure that characterizes the global magnetic-field topology of the system, together with the associated Σ surfaces (fan surfaces) and γ lines (spine) [Lau and Finn, 1990; Priest and Forbes, 2000; Dorelli et al., 2007]. These studies have discussed the global topology and geometrical structure of reconnection using the magnetic skeleton formed by null points, separators, Σ surfaces, and γ lines. On the other hand, how the magnetic-field structures near these null points constrain the magnetic-field and plasma structures far from the reconnection regions has not been sufficiently discussed.

In contrast, studies of the large-scale structure of the solar wind–magnetosphere system from the perspectives of plasma dynamics and magnetic-field topology have primarily discussed the deformation and twisting of open-field-line regions and the magnetotail [Sibeck et al., 1985a,b; Raeder et al., 1995; Berchem et al., 1998]. These studies have explained the large-scale shape and twisting of the magnetotail in terms of the response of the plasma and magnetic field to plasma dynamics driven by the solar wind and IMF. However, it has not been sufficiently examined how the fact that, in a quasi-steady solar wind–magnetosphere system, the large-scale magnetic-field topology is governed by a null–separator structure centered on two null points (more precisely, null clusters) with opposite signs of topological degree constrains the large-scale structure of the magnetosphere. Furthermore, it has not been sufficiently discussed how magnetic-field structures such as the γ lines (spine) extending from the vicinity of the null points constrain the global magnetic-field structure of the solar wind–magnetosphere system away from the reconnection regions.

Thus, previous studies of three-dimensional reconnection and large-scale structure in the solar wind–magnetosphere system have clarified important aspects of magnetic-field topology and plasma dynamics, respectively. However, from the perspective of viewing the solar wind–magnetosphere system as a system in which magnetic-field topology and plasma dynamics mutually constrain each other, there remain aspects to be examined in developing a framework for understanding the two aspects in a unified manner. Therefore, in this study, we first consider the fundamental principles that determine the large-scale structure of the system. We then explain the large-scale structure of the solar wind–magnetosphere system as an interaction between magnetic-field topology and plasma dynamics within a framework based on these principles.

The physical framework proposed in this study connects the magnetic-field topology and plasma dynamics addressed in these two lines of research and provides a conceptual framework for a unified understanding of the solar wind–magnetosphere system.

② Fundamental principles of the quasi-steady solar wind–magnetosphere system under obliquely northward IMF conditions

Here, we explain the physical framework proposed in this study. This part constitutes the central point of the present paper, and its content is essentially unchanged from Section 2 of the original manuscript, entitled “Fundamental physical processes in the quasi-steady solar wind–magnetosphere system.”

Mechanical principle: The magnetic field obtained by superposing the Earth's dipole field and the IMF is a current-free magnetic field. Therefore, when this field is deformed by the plasma, it has a restoring force that acts to return it toward its original state.

Topology conservation property: This superposed magnetic field has a 2-null–2-separator structure, which represents the fundamental magnetic-field topology of the solar wind–magnetosphere system. In addition, Σ surfaces (the open–closed field-line boundary and the solar-wind open-field-line boundary) and γ lines can be defined through the null points. Under northward IMF conditions, this topology is preserved, and the null points remain located near the positions of the null points of the superposed magnetic field.

This magnetic field can be regarded as a magnetic-field structure embedded in the solar wind–magnetosphere system. We therefore refer to this magnetic field structure as the **skeleton magnetic field**.

In summary, the skeleton magnetic field not only provides the topology of the solar wind–magnetosphere system but also interacts dynamically with the plasma. Thus, the skeleton magnetic field has two functions.

As applications of the fundamental principles described above, we illustrate how these principles operate in representative magnetospheric structures, including the magnetotail, the slit (window), and the plasma sheet.

③The structure of the magnetotail
(4.1.1 Magnetic Field Structure of the Magnetotail as a Manifestation of the Mechanical Principle)

Section 4.1.1 discussed that the large-scale structure of the magnetotail using the mechanical principle of competition between the restoring tendency toward the skeleton magnetic field and the deformation of the magnetic field caused by the solar-wind plasma. As a result, it can be understood that, in the region closer to the Earth, the effect of magnetic-field deformation by the solar-wind plasma is relatively strong, and the field lines on the nightside Σ surface are stretched along the solar-wind flow. (In the paper, it was called the rear side, but in the revised version, it is referred to as the nightside Σ surface.) In contrast, farther from the Earth, the restoring tendency toward the skeleton magnetic field becomes more pronounced, and the field lines gradually bend toward the IMF direction.

The bending of the magnetotail toward the IMF direction in the distant tail has long been studied as the twisting of the magnetotail [Sibeck et al., 1985a,b; Raeder et al., 1995; Nishida et al., 1995; Maezawa et al., 1997; Nishida and Ogino, 1998; Maezawa and Hori, 1998; Berchem et al., 1998; Nishida, 2000]. Previous studies have discussed the magnetic torque exerted by the IMF as a physical process responsible for the twisting of the magnetotail [Berchem et al., 1998; Maezawa and Hori, 1998]. This magnetic torque corresponds physically to the magnetic effect that we interpret in the present study as the restoring tendency against deformation of the skeleton magnetic field.

Therefore, the result presented in this study regarding the structure of the magnetotail is consistent with the magnetotail twisting reported in previous studies and does not contradict their results. The distinctive feature of the present study is that we interpret these structures in a unified manner as the result of the interaction between the skeleton magnetic field, which forms the basis of the solar wind–magnetosphere system, and its deformation by plasma dynamics. In other words, the skeleton magnetic field not only determines the global magnetic-field topology of the system but also provides a reference magnetic-field structure against which magnetic-field deformation by the plasma occurs. From this perspective, the magnetotail twisting and bending discussed individually in previous studies can be understood in a unified manner as a consequence of the interaction between magnetic-field topology and plasma dynamics.

Furthermore, this mechanical principle provides specific predictions regarding the dependence of magnetotail bending on solar-wind conditions. Namely, an increase in IMF strength is expected to enhance the bending of the magnetotail toward the IMF direction. Conversely, an increase in solar-wind density is expected to weaken the bending because the effect of magnetic-field deformation by the solar-wind plasma becomes stronger. To make these predictions clear to the reader and to demonstrate that the physical framework proposed in this study provides testable predictions concerning magnetotail behavior, we will add these discussions to the Discussion section of the revised manuscript.

④The slit (window) structure
(4.1.3 Slit Generation as an Effect of Both the Mechanical Principle and the Topology Conservation Property)

In Section 4.1.3, we explained the formation of the slit as a consequence of the interaction between the mechanical principle and the topology conservation property, which constitute the fundamental principles of the solar wind–magnetosphere system. First, according to the mechanical principle, the field lines on the nightside Σ surface bend toward the IMF direction in the distant tail as a result of the competition between magnetic-field deformation by the solar wind and the restoring tendency toward the skeleton magnetic field. On the other hand, according to the topology conservation property, the γ line (spine) extending from the null point that forms the endpoint of the dayside separator maintains its connection with the solar-wind magnetic field. Therefore, it is not simply convected downstream by the solar wind in the same manner as ordinary open field lines. As a result, the opening that forms the boundary between the solar-wind field lines and the open field lines is deformed, leading to the formation of an elongated and narrow slit. Thus, the slit is a structure formed through the simultaneous action of the mechanical principle, which determines the deformation of the magnetic field, and the topology conservation property, which constrains the connectivity of the magnetic field.

The structure corresponding to the slit considered in the present paper has previously been reported as a *window* formed on the flank of the magnetotail [Cowley, 1973; Sibeck et al., 1985a,b; Kaymaz et al., 1994; Kaymaz and Siscoe, 1998]. In these studies, the window has been interpreted as a structure formed when the open field lines of the twisted magnetotail become connected to the IMF. Our results do not contradict the existence of this structure. On the other hand, regarding its formation process, the present study provides a different interpretation from previous studies from the perspective of the interaction between global magnetic topology and plasma dynamics.

Therefore, the window reported in previous studies and the slit presented in the present paper can basically be regarded as corresponding to the same magnetic-field structure. Although this structure itself has already been reported, the present study explains its formation process from the fundamental principles of the solar wind–magnetosphere system, in terms of the interaction between magnetic-field topology and plasma dynamics. In particular, we demonstrate that the formation of the slit involves not only the mechanical process that determines the deformation of the magnetotail but also the global magnetic topology represented by the γ line (spine). In this sense, the present study does not simply rediscover the previously reported window structure; rather, it provides an understanding of its formation mechanism within a unified framework of magnetic topology and plasma dynamics.

⑤The plasma sheet
(4.2 Deformation of the Torus)

Section 4.2 considered the formation process of the plasma sheet based on the fundamental principles of the solar wind–magnetosphere system. According to the topology conservation property, the null points and separator structures that characterize magnetic-field connectivity do not deviate substantially from the global structures prescribed by the skeleton magnetic field. Therefore, the boundary structures of the open-field-line regions are also constrained by the null–separator topology of the skeleton magnetic field. On the other hand, according to the mechanical principle, the two open-field-line regions on the nightside twist in different directions, resulting in a structure in which nearly antiparallel field lines become adjacent at their interface. For the system to remain in a quasi-steady state, these two open-field-line regions cannot be directly connected because of the topology conservation property, and a closed-field-line region must exist between them. In the present paper, we consider this closed-field-line region formed between the two open-field-line regions to correspond to the plasma sheet. Thus, the plasma sheet is formed through the interaction between the mechanical deformation of the open-field-line regions and the global magnetic-field topology that constrains this deformation.

The existence of the plasma sheet as a closed-field-line region surrounded by lobes consisting of open field lines, as well as the distinction of this region from the surrounding magnetic-field regions by separatrices, has been discussed previously [Dungey, 1961; Fedder and Lyon, 1995; Song et al., 1999; Petrukovich et al., 2003].

From the perspective of magnetic-field topology, it has also been discussed that, under northward IMF conditions, open field lines formed by high-latitude reconnection and closed field lines subsequently formed by reconnection of these open field lines contribute to the formation of the plasma sheet and boundary layer [Petrukovich et al., 2003]. Therefore, the present study does not newly propose that the plasma sheet is a closed-field-line region or introduce new magnetic-field topology associated with the formation of the plasma sheet. On the other hand, in the present study, we explain the formation of the plasma sheet between the two open-field-line regions by simultaneously considering the mechanical process by which the two open-field-line regions constituting the magnetotail twist toward the IMF direction and the constraint on magnetic-field connectivity imposed by the topology conservation property. To our knowledge, such a formation process of the plasma sheet, linking the large-scale deformation of the magnetotail with the null–separator topology, has not been sufficiently discussed in previous studies.

The fact that the plasma sheet extends far into the nightside is not essential to the plasma-sheet formation mechanism proposed in the present paper. On the other hand, the existence of the plasma sheet over a broad nightside region in the actual magnetotail is well established observationally. Therefore, we cite Mooney et al. (2024) to demonstrate that the results of our calculations reproduce a realistic large-scale structure of the magnetotail.

⑥Conclusion

In response to the referee's comment, "By reading these papers, one will reach the same conclusions as the authors, so it is difficult to identify any advance made by the present paper," we would like to clarify that the purpose of the present paper is neither to discover new magnetospheric structures nor to rediscover individual, previously known magnetospheric structures. Rather, the purpose of this paper is to propose the interaction between magnetic-field topology and plasma dynamics as a fundamental physical framework for understanding the large-scale structure of the solar wind–magnetosphere system.

As concrete examples of this framework, we consider the magnetotail twist, the slit (window), and the plasma sheet, whose structures have already been identified through observations and numerical simulations. We then explain how these structures are formed in a unified manner based on common fundamental principles.

Therefore, the primary advance of the present paper is not the discovery of individual magnetospheric structures themselves, but the placement of these known structures within a unified physical framework based on the interaction between magnetic-field topology and plasma dynamics, and the proposal of common fundamental principles for understanding their formation processes.

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