Generation of the Arc Aurora

Takashi Tanaka[1]
[1]*Professor Emeritus, Kyushu University*

It is well known that auroras are roughly divided into two types, the arc aurora and the diffuse aurora. We would like to report here recent advances on what is the meaning of arc aurora and what process acts to generate the arc aurora. The arc aurora can be looked upon as a phenomenon in which the upward FAC is visualized. The fundamental role of the FAC is to transmit motion from the magnetosphere to the ionosphere [Tanaka et al., 2016]. Therefore, to understand the arc aurora, we must know first what motion is going to be excited together. In other words, we must identify from the arc aurora the series of process in which convection is excited by the solar wind-magnetosphere interaction and transported to the ionosphere, and together energy is transported and consumed. This is exactly the meaning of the statement that the polar region is the window for the space.

The above consideration shows that the excitation process of convection must be the starting point for the understanding of the arc aurora. The famous Dungey's model assumes that convection is excited by the tension of the open magnetic field lines generated through the reconnection. If we consider the dynamo for the FAC in this model, we must conclude that the dynamo is constructed by deceleration of magnetosheath flow. Recent research has shown that this is an error [Tanaka et al., 2016]. The FACs are excited by a dynamo inside the magnetosphere, which is formed as a part of the convection structure. Solar wind-magnetosphere interaction is loading of stress on the magnetosphere, and convection is the process to eliminate this stress [Tanaka. Obara, et al., 2019]. About 10 percent of discharging energy is converted by the dynamo to electromagnetic energy (FAC). The stress is loaded depending on solar wind conditions. This dependency has been understood so far by the degree of achievement for the antiparallel reconnection, but this concept is also not accurate. To be precise, it is necessary to consider dependency on the solar wind condition from the null separator structure.

Thus, the understanding of the arc aurora must begin with the null-separator structure. This structure determines the topology of magnetic field. In the magnetospheric physics hitherto studied, this has been approximated by the degree of achievement of the antiparallel condition. Here in this report to understand the arc aurora, we want to show that a successive occurrence of the null separator structure, convection, the dynamo, shear flow, and the FAC are required. This principle is the same for any arc auroras, such as the quiet arc during the substorm growth phase, the bright arc aurora associated with the onset, the fan arc and the sun-aligned arc when the IMF is northward, and the theta aurora associated with the IMF switching.

When the IMF is northward, the steady null-separator structure is the two-null two-separator. Through the dayside separator, weak coupling occurs between the solar wind and the magnetosphere. When weak convection associated therewith is projected onto the ionosphere, it becomes the sun-aligned arc [Tanaka, Obara, et al., 2017]. This arc is associated with the discharge through the LLBL of thermal energy in the cusp generated as a result of the solar wind-magnetosphere interaction. The fan arc occurs by the coupling with the LLBL instability [Tanaka, Obara, et al., 2019]. When the 4-null structure is created along with the IMF switching, the projection of this switching is the theta aurora [Tanaka, et al., 2018].

When the IMF is southward, the FAC associated with enhanced convection before the NENL onset is observed as the quiet arc [Tanaka, 2015; Tanaka, Ebihara, et al., 2017]. The main part of the quiet arc exists in the open field line region connected to the northward IMF. However, current lines from the quiet arc deviate from magnetic field lines and lead to the mantle dynamo through different path from magnetic field lines. The NENL generation occurs when the null separator structure is deformed as a result of growth phase convection so much to realize the condition for generating a new null [Tanaka, Ebihara et al., 2019]. The occurrence of a new null changes the configuration of convection to a new structure. The onset arc and the WTS correspond to the FAC that transmit the transient of this deformation to the ionosphere. This event appears in the magnetosphere as a fluctuation called the dipolarization front. The near earth dynamo for the onset FAC is formed from pressure gradient current due to the squeezing and electric field due to the direct penetration flow along the magnetic field line connected to the NENL [Tanaka, Ebihara, et al., 2017].

References

Tanaka, T. (2015), Substorm auroral dynamics reproduced by the advanced global M-I coupling simulation, in Auroral Dynamics and Space Weather, Geophys. Monogr. Ser., vol. 215, edited by Y. Zhang, p. 177–190, AGU, Washington, D. C.

Tanaka, T., M. Watanabe, M. Den, S. Fujita, Y. Ebihara, T. Kikuchi, K. K. Hashimoto, and R. Kataoka (2016), Generation of field-aligned current (FAC) and convection through the formation of pressure regimes: Correction for the concept of Dungey's convection, J. Geophys. Res. Space Physics, 121, 8695–8711, doi:10.1002/2016JA022822.

Tanaka, T., Y. Ebihara, M. Watanabe, M. Den, S. Fujita, T. Kikuchi, K. K. Hashimoto, and R. Kataoka (2017), Global simulation study for the time sequence of events leading to the substorm onset, J. Geophys. Res. Space Physics, 122, doi:10.1002/2017JA024102.

Tanaka, T., T. Obara, M. Watanabe, S. Fujita, Y. Ebihara, and R. Kataoka (2017), Formation of the Sun-aligned arc region and the void (polar slot) under the null-separator structure, J. Geophys. Res. Space Physics, 122, doi:10.1002/2016JA023584.

Tanaka, T., Obara, T., Watanabe, M., Fujita, S., Ebihara, Y., Kataoka, R., & Den, M. (2018). Cooperatives roles of dynamics and topology in generating the magnetosphere-ionosphere disturbances: Case of the theta aurora. J. Geophys. Res. Space Physics, 123, 9991–10,008. https://doi. org/10.1029/2018JA025514.

Tanaka, T., Y. Ebihara, M. Watanabe, M. Den, S. Fujita, T. Kikuchi, K. K. Hashimoto, and R. Kataoka (2019), Development of magnetic topology during the growth phase of the substorm inducing the onset of the near earth neutral line, J. Geophys. Res. Space Physics, 124, https://doi. org/ 10.1029/2018JA026386.

Tanaka, T., Obara, T., Watanabe, M., Fujita, S., Ebihara, Y., Kataoka, R., & Den, M. (2019). Magnetosphere-ionosphere convection under the due northward IMF, J. Geophys. Res. Space Physics, 124, https://doi. org/ 10.1029/2019JA026547.