# Magnetic topology inducing the substorm

T. Tanaka[1]
[1]*Professor Emeritus, Kyushu University*

In the substorm research, many misleading concepts have been believed stubbornly. For instance, the origin of the quiet arc has been attributed to the scattering of electrons by severely curved magnetic field lines. Correctly it is a collaboration between the convection shear as will be described later and the cusp-mantle dynamo. For the onset, the sequence of NENL (near earth neutral line) → BBF (bursty bulk flow) → CW (current wedge) is believed firmly. This sequence also lacks accuracy. Even if we believe the CW, no one has ever proved it from observational tracing of current lines. The anti-parallel magnetic field coordination for the NENL is extremely unnatural. Anti-parallel magnetic field configuration requires a null plane (=magnetic neutral plane). In the magnetosphere, the plausible null structure is null points or at most null lines. In such a way, formation of a null plane is quite difficult.

Such misleading concept comes from a limit of the traditional research that applies observing the part and estimating the whole. Since the satellite observation is large equipment, there is a tendency to have a prejudice that all can be seen from it. But satellite observations see only parts. It is not possible to trace magnetic lines from observation, and current lines are more difficult. To estimate the whole from the part, it employs some models. For models, old concepts such as the Dungey convection and the anti-parallel reconnection play an active part even now.

Now, the substorm can be reproduced by the global simulation, and the mechanism of the substorm has become clear without including estimations. Although the growth phase is a strengthening of convection, flow does not reach the center of the plasma sheet, but becomes reflux toward the dayside passing through the surface of the plasma sheet. In this flow pattern, shear motion induces the quiet arc. The thinning is due to the sweeping out of magnetic flux from the inner edge of the plasma sheet by convection. It is not due to the increase in lobe pressure.

Seeing most globally, the onset is a change in convective path. This change is a state transition of convection system. After the transition, flow passes through the center of the plasma sheet, reaches the inner magnetosphere, and returns toward the dayside from there. The transient tip is observed as the dipolarization front. The state transition is a change in force balance. The BBF and the injection are parts of the change in force balance. Injection at transient stage forms a compact pressure regime which acts as the near Earth dynamo and generates an onset current system. The dipolarization corresponding to the injection is an increase of magnetic tension, but not a decrease. In the expansion phase, the ionospheric Hall current generates polarization and forms the WTS (westward traveling surge).

Over the whole magnetospheric researches, the most obscure understanding may be for the origin of the FAC (field-aligned current). The dynamo is necessary for the FAC. The dynamo is a function of converting thermal energy to electromagnetic energy. The main driver of convection is the cusp-mantle dynamo. In the case of the onset FAC, the driver is the near-Earth dynamo that can be formed through the squeezing. Because the near earth dynamo is on the equator side of the sheer layer, so the onset starts from the equator side of the quiet arc. By substituting it with the CW, we are in the maze forever.

A large question left is the NENL formation process. What occurs if we inspect the NENL formation correctly? To do this, the null-separator structure is required. Under the northward IMF (interplanetary magnetic field), there are two nulls near the cusp of both hemispheres, forming the 2 null 2 separator structure. The deformation process from the 2 null 2 separator structure to the NENL formation is a key of substorm topology. It can be understood through three phases.

Phase 1: After a southward turning of the IMF, old 2 nulls retreat tailward, and new 2 nulls corresponding to the southward IMF are formed on the day side in the low latitude region. From new nulls, null lines extend along the frank magnetopause to old nulls.

Phase 2: The plasma sheet reconnection (also the early stage of the lobe reconnection) proceeds in the remnant tail structure formed under the northward IMF. In this structure, the retreating nulls change the configuration of the tail magnetic field to form a By outstanding structure in the plasma sheet just behind the dipole magnetic field. Strange to say, this deformation involves intersecting cross of magnetic fields. Similarly, retreating nulls generate magnetic field lines connecting themselves and the midnight inner mganetosphere. At the midnight reconnection point, a mixing occurs between different magnetic field lines through the By component. This process leads to the formation of the core By.

Phase 3: When By dominated magnetic fields of the plasma sheet is swept out downtail as the plasmoid, outer layers on the northern and southern sides contact to make the near earth tail shift to the state of the lobe reconnection. The midnight reconnection point is expanded to a line, and strong tension is activated in the x direction.