S11-2

Cross Scale Coupling in Magnetospheric Plasma
磁気圏プラズマにおけるスケール間結合

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The time evolution of dynamic phenomena observed in magnetospheric plasma is determined by the cross scale coupling between global-scale dynamics and ion/electron scale dynamics in some key regions. In order to understand the phenomena in a true sense, understanding the cross scale coupling that exists over several different scales is indispensable. Currently, theoretical studies are in progress. In addition to these efforts, a formation flying satellite mission “SCOPE” is under study for the future empirical study of cross scale coupling.

1. Cross Scale Coupling in Magnetosphere

1.1 *Introduction*

Magnetospheric plasma is collisionless. This means that, unlike in the gas that surrounds us, the thermo-dynamical relaxation time scale is much larger than the time scale of interest. The non-Maxwellian distribution function is everywhere. Non-thermal particles are not necessarily minor and are not just test particles that only react to given electro-magnetic fields but can play a significant role in determining the time evolution of the system. Energetic particles fill the magnetosphere because they don’t lose their energies by colliding with the less-energetic thermal component. Explosive phenomena such as substorms occur because usual relaxation processes are absent and the dissipation processes that trigger them show anomalous behaviors. In other words, the dissipation sets in only when certain thresholds for certain parameters are crossed. Some if not most of the fascinating aspects of magnetospheric dynamics have their roots in this collisionless-ness of the plasma that fills the space.

Fascinating aspects of magnetospheric processes root in the collisionless-ness of the plasma. In other words, the true understanding of what we are attracted to comes only when the collisionless effects (kinetic effects or particle effects) are fully appreciated. MHD system in the present form treats sub-MHD scale dynamics only in an ad-hoc manner. On the other hand, previous studies on kinetic effects mostly dealt only with sub-MHD scales. The dynamical coupling among the scales, from the bottom of electron-kinetic up to MHD scales, has been recognized but has not been studied intensively. The traditional style has been to summarize the sub-MHD scale effects into a transport coefficient (viscosity, resistivity,…) and add the term to the MHD equations. This form does not necessarily fully appreciate the wonder of the collisionless plasma and that we should search for a style that features the cross-scaling coupling nature of the magnetospheric dynamics.

1.2 *Example: magnetic reconnection triggering problem*

Magnetic reconnection is one of the most important energy conversion processes in collisionless plasmas that releases the energy stored in the form of magnetic field. In the magnetospheric environment, a number of in-situ observations have clarified not only its existence but also its importance in regulating the flow of mass and energy into the Earth’s magnetosphere from the solar wind. The current sheet in the magnetotail is the site for explosive magnetic reconnection, in which various magnetospheric activities are considered to originate.

One of the candidates to initiate reconnection is the tearing instability. In contrast to the previous studies that focused mostly on electron scale current sheets, we have recently focused on thick current sheets and have inspected if vigorous growth out of quiet initialization is possible in them. We should consider how an ion-scale current sheet would become subject to reconnection triggering, beacuse current sheet thickness observed in the magnetosphere is of this order or even thicker. We have found that there is a critical thickness above which significant effects of the instability are not available.

While the above critical thickness severely limits the ability of the two-dimensional tearing mode for triggering quick reconnection, we have also recently shown that the tearing mode survives as a viable process by coupling to a three-dimensional effect. Only in three dimensional full particle simulations are the effects of the current-driven instabilities taken into account. For an anti-parallel magnetic field geometry and with the mass ratio of 400, we have shown that, even if the current sheet thickness is of ion-scale, large scale reconnection is triggered very quickly. The definitive contrast between 2- and 3-D results comes from the difference if the lower-hybrid-drift instability (LHDI) is allowed or not. Only in the 3-D case the freedom in the current direction is included and LHDI is allowed to develop around the outer edges of the current sheet. LHDI reduces the current density locally at the outer edges, which induces non-local redistribution of current density within the current sheet. We have revealed that the current density enhancement at the neutral sheet associated with this redistribution leads to the quick reconnection triggering (QMRT). The triggering is attained as soon as LHDI is saturated and is very quick even for an ion-scale current sheet. It is also emphasized that QMRT is obtained via non-local, cross-scale coupling with LHDI and is not something that can be modeled as a current driven anomalous resistivity.

2. SCOPE mission

The Solar Terrestrial Physics (STP) group in Japan has organized 'New Magnetospheric Mission Working Group' in order to consider a new magnetospheric satellite mission. The name of the mission is 'SCOPE' that stands for 'cross Scale COupling in Plasma universE'. Fig. 1 shows a conceptual diagram of SCOPE mission. The main purpose of this mission is to investigate the dynamic behaviors of plasma in the Terrestrial magnetosphere that range over various time and spatial scales. The basic idea of the SCOPE mission is to distinguish temporal and spatial variations of physical processes by putting five formation flying spacecraft into the key region of the Terrestrial magnetosphere. The formation consists of one large mother satellite and four small daughter satellites. High spatial resolution is realized by the coordinated observations among the mother and four daughter satellites. Three of the four daughter satellites surround the mother satellite 3-dimensionally maintaining the mutual distance that ranges between 100km and several thousand km (variable). The fourth daughter satellite stays near the mother satellite with the distance of about 10km. By this configuration, we can obtain both the macro-scale and micro-scale information about the plasma disturbances at the same time. Highly resource demanding high time resolution measurements are realized by concentrating available resources to the mother satellite. By doing so, we can realize the time resolution of electron measurement that is about 1000 times faster than that of our previous magnetospheric mission GEOTAIL. It is essential for the daughter satellites to be as small, and as light-weight as possible while maintaining the high performance. Fig. 2 shows model science instruments onboard SCOPE satellite. High performance Plasma/Particle sensors, DC/AC Magnetic and Electric field sensors, and Wave Particle Correlator are planned to be onboard.

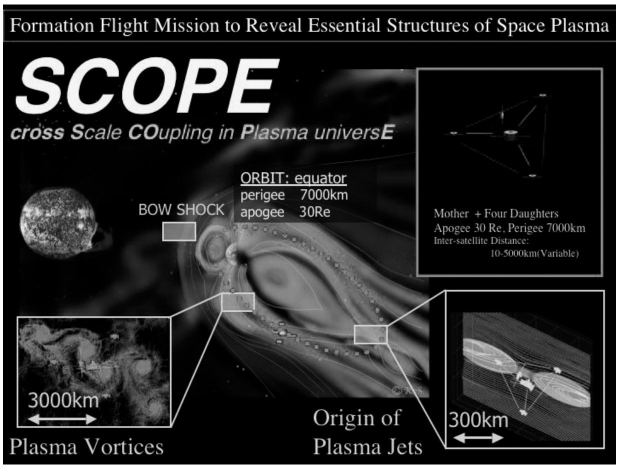
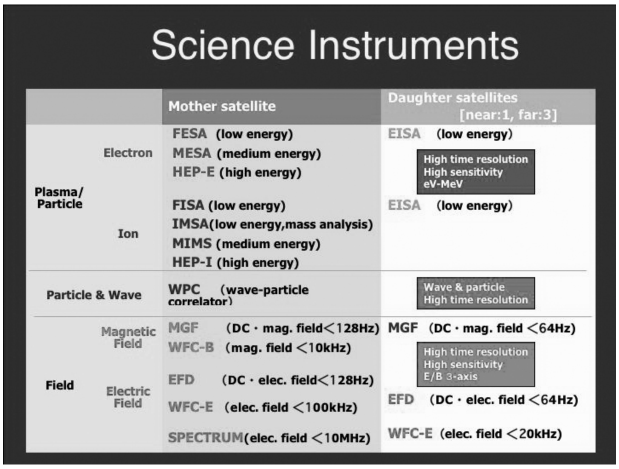


Fig. 1. Conceptual Diagram of SCOPE (cross Scale Coupling in Plasma universe) mission.


Science Instruments

		Mother satellite	Daughter satellites [near:1, far:3]
Plasma/Particle	Electron	FESA (low energy) MESA (medium energy) HEP-E (high energy)	EISA (low energy) High time resolution High sensitivity eV-MeV
	Ion	FISA (low energy) IMSA(low energy,mass analysis) MIMS (medium energy) HEP-I (high energy)	EISA (low energy)
Particle & Wave		WPC (wave-particle correlator)	Wave & particle High time resolution
Field	Magnetic Field	MGF (DC・mag. field<128Hz) WFC-B (mag. field <10kHz)	MGF (DC・mag. field <64Hz) High time resolution High sensitivity E/B 3-axis
	Electric Field	EFD (DC・elec. field<128Hz) WFC-E (elec. field <100kHz) SPECTRUM(elec. field <10MHz)	EFD (DC・elec. field <64Hz) WFC-E (elec. field <20kHz)

Fig. 2. Model Science Instruments onboard SCOPE satellites.