Focus group: Tail Environment and Dynamics at Lunar Distances

Topic

As the magnetosphere magnetic field becomes weaker with increasing distance tailward while the shocked magnetosheath becomes more solar-wind like, the interaction between these two regions becomes more dramatically different from the near-Earth environment. Despite the fact that tail plasma and field beyond 30 R_E play an important role in regulating energy and particle flows from the solar wind to the near-Earth magnetosphere, this tail environment and its global interaction remain poorly understood. Now the two ARTEMIS probes have provided unprecedented observations of the tail plasma regimes at the lunar distances, including the solar wind, magnetosheath, plasma sheet, and plasma mantle, as well as their boundaries, including the bow shock, the magnetopause, low-latitude boundary layer (LLBL), and plasma sheet boundary layer (PSBL). Thus measurements from ARTEMIS and other near-Earth satellites now provide an excellent opportunity and also pose new challenges for both experimentalists and modelers to examine this tail environment and evaluate its global nature. Better understanding of this region will definitely lead to a new global view of geospace. Therefore, this newly proposed FG aims to bring together observation and simulation investigations to (1) establish fundamental observational understanding of different aspects of this tail environment, including particle and field structures, dynamics, and disturbances, (2) improve the capabilities and fidelity of current global and local simulations so that they can provide additional physical understanding of the environment, and (3) determine the role of this tail region in global interaction, particularly its coupling with the solar wind and interaction with the near-Earth environment.

(1) Establish observational understanding of the tail environment: The limited ISEE 3 and Geotail observations of the tail beyond 100 R_E two decades ago indicated that distant tail environment is dramatically different from its near-Earth counterpart. For example, the magnetosphere shape can be highly distorted. The magnetosheath plasma can be found deep within the magnetosphere. The mantle plasma can be seen at low latitudes in close contact with the plasma sheet. The tail can be in a turbulent state at times with strong mesoscale earthward and tailward flow bursts. However, many fundamental aspects remain to be established and physical questions remains to be answered:

– Structures: e.g., basic spatial variations of particles and plasma moments within different plasma regimes, occurrence of mantle plasma and PSBL next to the plasma sheet, magnetic field topology and thickness of the current sheet, characteristics of ion and electron populations, the thickness of the LLBL, magnetopause size and shape, rotational or tangential discontinuity at boundaries, locations of the bow shock, and dawn-dusk asymmetry of these structures and their dependences on the solar wind/IMF and geomagnetic activity.

– Disturbances: e.g., current sheet flapping, types of boundary motions, occurrence of bursty bulk flows and plasmoids, characteristics of waves and turbulences, transient phenomena at the boundaries, and association of these disturbances with SW/IMF and geomagnetic indices.

– Questions: Is the tail disconnected during a prolonged northward IMF period as some simulations have suggested? What are the underlying physical processes for the structures and disturbances? Are the particles mainly from the mantle or from the magnetosheath and are they energized adiabatically or non-adiabatically? What external or internal conditions lead to the formation of plasmoids, flux ropes, waves, and turbulences? Are the magnetopause fluctuations caused by the Kelvin-Helmholtz or other instabilities? How big are effects of the Moon?

The two-probe ARTEMIS can provide sufficient data for these investigations. The results will provide modelers the challenges to reproduce these structures and disturbances and to validate their physical explanation.

(2) Coordinated simulation investigations: There are many global models available now, but the performance of these models in this tail region has not been systematically evaluated and validated. For example, the lengths of the tail predicted by various simulations are strikingly different. This validation is an important challenge to models, and this FG will provide an efficient venue to conduct such studies. Thus, this FG will carry out two types of coordinated simulation investigations:

– Global MHD validations: By design, global MHD models include the distant tail region in the simulation domain. However, the details of the tail topology and dynamics (e.g., the location of distant X-line for southward IMF or the length of the tail during northward IMF) depend on the underlying numerics (such as grid resolutions, amount of numerical diffusion or specified resistivity). Thus, it is important to establish an observational baseline and benchmark the performance of global models in the lunar-distance tail against it. This investigation will identify the primary modeling challenges and attempt to resolve them ultimately leading to an improved understanding of the lunar-distance tail environment.
– MHD vs hybrid codes: In addition, the emerging global hybrid models are now ready to provide a more detailed view of this tail region. Thus, we will initiate coordinated MHD and hybrid simulation investigations to evaluate the extent to which the MHD and kinetic ion treatment can better account for the processes in this tail environment. The conclusions will help us identify the strength and weakness of the two approaches, again resulting in a better tool for understanding the tail environment.

Topics for these challenges will include large- and meso-scale structures, responses to steady and changing SW and IMF, boundary motions and processes, instabilities, and reconnection. Once the models have been validated, they can provide more reliable evaluation of the global role of the tail.

(3) Evaluating the global role: The electromagnetic coupling with the solar wind, particle entry from the mantle and magnetosheath, and energization and transport within the current sheet in this lunar-distance tail should play an essential role in global dynamics. However, limited by poor understanding, the lunar-distance tail has been treated as a passive boundary condition in global geospace studies. Thus this new FG aims to coordinate individual investigations toward evaluating the coupling of the lunar-distance tail with the solar wind driving and the near-Earth environment. Important scientific questions include:

– Coupling with the solar wind/IMF: e.g., how much magnetic flux is added to the lunar-distance tail lobes under various IMF directions and how the flux addition is different from that in the near-Earth tail lobes?
– Correlations with upstream phenomena: e.g., how do the transient phenomena at the dayside bow shock and magnetopause, such as foreshock bubbles and Kelvin-Helmholtz vortices, evolve as they propagate tailward and what are their overall effects on the tail environment? Do these upstream disturbances eventually lead to the disturbances seen within the tail and the near-Earth magnetosphere? Or do the transient phenomena at the lunar-distance boundaries result from local processes? Is the magnetosheath plasma on the dayside and distant-tail connected hydrodynamically as predicted by the Spreiter magnetosheath model?
– Interaction with the near-Earth magnetosphere: e.g., is this lunar-distance tail driving the near-Earth phenomena? How are the characteristics of disturbances in this tail region, such as BBFs and dipolarization fronts, and their occurrence relative to substorms similar or different from the

disturbances in the near-Earth tail? Are particles seen in this tail region the main particle source supply for the near-Earth? How often the reconnection occurs within this part of tail in comparison with the near-Earth tail? How do the tailward propagating plasmoids alter the background tail environment?

– Coupling with the ionosphere: This is a very challenging topic but possibly can be investigated. What is the magnetic mapping of the lunar-distance tail considering time-delays and spatial variability? How intense are the field-aligned currents created by distant-tail distortions and motions? What are the corresponding ionospheric signatures of the tail disturbances?

These investigations will utilize all available data from different missions, such as Geotail, THEMIS, RBSP, Cluster, and MMS. Conjunction events of these satellites are crucial for these investigations. Because the close connection of these topics with phenomena in other regions of geospace, we will also coordinate our investigations with other FGs.

Timeliness

(1) Unique dataset from the two ARTEMIS probes with different separations and alignments are excellent for determining the tail environment and dynamics, including both the steady-state macrostructure and transient local phenomena. Data have become available since late 2010 and ARTEMIS is expected to operate until at least 2019.

(2) Conjunctions with probes in the near-Earth, such as with THEMIS and RBSP, and with ground observations are available. ARTEMIS-MMS-THEMIS-RBSP conjunctions are expected for 2015 and the following years.

(3) In addition to many global MHD codes, global hybrid codes and 3-D local particle-codes have also become available for modeling this tail environment.

(4) Growing attention has now been paid to understanding local phenomena from a viewpoint of a global scale and of a coupling system. Understanding the global role of the lunar-distance tail will thus be important to the investigations of other FGs.

Fit

The tail plasma regimes, disturbances, and processes at lunar-distance can be very characteristically different from those in the near-Earth environment. Therefore, it is necessary to have this new FG as a platform to focus investigations on this largely unexplored tail environment. This new FG covers broad topics and many of them are closely related to other past and existing FGs. Thus this new FG will definitely benefit from the knowledge we have learned from these FGs, but it will provide new challenges to our understanding learned from the near-Earth environment. Most importantly, this new FG will complement other FGs by providing a tail point of view of the phenomena seen in the near-Earth region, thus establishing a more global view of geospace. To achieve that, we will closely work with the following FGs,

(1) Metrics and Validation: This is directly relevant to our planned simulation investigations. We will coordinate a joint session to address the challenges and to find solutions for better modeling the lunar-distance tail environment. We will also choose observational data suitable for validating simulations.

(2) Tail-Inner Magnetosphere Interaction (TIMI): Our understanding of the dynamics and disturbances of lunar-distance tail will certainly provide a broader view of the interaction that has been addressed by TIMI. We will coordinate a joint session to explore the connection by selecting conjunction events to determine the temporal correlations of near-Earth tail and lunar-distance tail during different types of disturbances, such as substorms, bursty bulk flows, dipolarization fronts, plasmoids, and interplanetary shock.

(3) Transient Phenomena at the Magnetopause and Bow shock: Our FG of studying transient

phenomena in the distant tail is complementary to dayside phenomena that have been addressed in this FG. We will have a joint session with this FG to understand the evolution and propagation of dayside transient phenomena to the tail.
(4) Geospace Systems Science: We will have a joint session with this FG to discuss our understanding of the solar wind-magnetosphere-ionosphere coupling in the lunar-distance tail environment which will provide a system-level view that is complementary to this FG.
(5) Magnetic Reconnection in the Magnetosphere. The occurrence of reconnection in different plasma regimes and boundaries of the tail environment will provide important information for understanding the conditions for reconnection.

We have consulted the leaders of FGs (1) to (4) and we agree that having joint sessions will provide a better platform for joining forces (see Expected Activities).

Goal & Deliverable

As described in Topic, the main goals of this new FG are:
(1) To establish fundamental understanding of the lunar-distance tail environment, dynamics, disturbances, underlying physical processes, and its global role and connections with the near-Earth environment.
(2) To improve current local and global models to better account for the physical processes and reproduce the observations.

The main deliverable will the improved observational context and understanding as well as improved global simulations that better determine the role of the lunar-distance tail.

Co-chairs

Chih-Ping Wang (UCLA), Andrei Runov (UCLA), David Sibeck (NASA), Viacheslav Merkin (APL), and Yu Lin (Auburn University).

Research Area

This FG is closely associated with the research areas of Magnetotail and Plasma Sheet, Global System Modeling, and Solar Wind-Magnetosphere Interaction.

Term

Five years (2015-2019) are necessary for investigating these proposed challenging topics.

Expected Activities

Session: What are structures of the plasma regimes and boundaries, disturbances, and physical processes observed at the lunar-distance tail?

Session: What is the global role of the lunar-distance tail?

Session: How to better model the lunar-distance tail in global simulations? Coordinated simulation investigations.

Joint session with Metrics and Validation FG: A new challenge for modeling the lunar-distance tail environment.

Joint session with TIMI FG: How do the disturbances in the near-Earth and the lunar-distance tail interact with each other?

Joint session with Transient Phenomena at Magnetopause and Bow Shock FG: How do the upstream phenomena evolve and affect the tail environment?

Joint session with Geospace Systems Science FG (2017): How do the lunar-distance tail regulate the energy and particle flow from the solar wind to the near-Earth environment?

Simulation challenges: The coordinated simulation investigation session will provide lists of events and statistical results for challenging different global models to reproduce the results.