The Revised Concept of the THEMIS and MMS Coordination

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Advances in our understanding of the dynamic changes to the space environment surrounding the Earth, commonly known as space weather, increasingly rely on prolonged simultaneous observations of the time varying conditions within the Sun-Earth system from various vintage points in space and from the ground. With eighteen operating solar, heliospheric, geospace, and planetary missions the Heliophysics System Observatory (HSO) monitors key processes of plasma interactions across the Solar System. Results from fortuitous conjunct observations have revealed various coupling processes on multiple scales and demonstrated the potential of coordinated cross-scale multi missions to quantify the driving mechanisms of the vast flows of energy and particles. Two magnetospheric NASA missions, *Time History of Events and Macroscale Interactions during Substorms (THEMIS),* operating in orbit since February 2007, and *Magnetospheric Multiscale (MMS)* launched on March 12, 2015, have the optimal instrumentation and are dedicated to become the first coordinated cross-scale multi mission. Although coordinating these two missions seems a natural candidate it comes with unprecedented challenges.

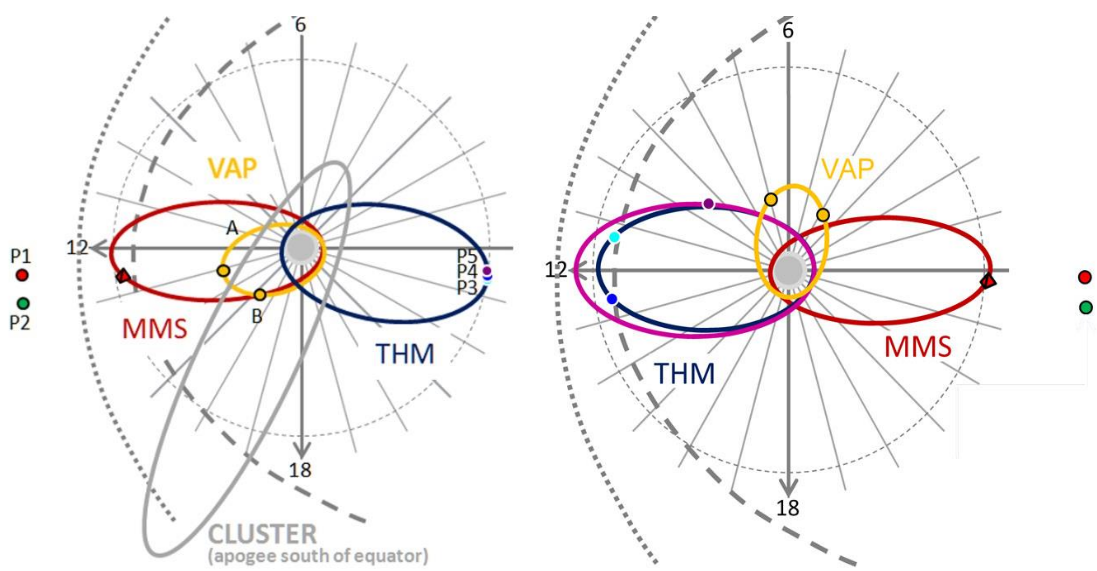

Figure 1: Snapshots of the dayside (left) and nightside (right) mission configurations in the ecliptic plane looking from north, the sun direction to the left side [1]. The dashed and dotted lines are the outer bounderies of the magnetosphere against the solar wind. CLUSTER, the Van Allen Probes (VAP), and ARTEMIS (P1, P2) are shown in addition to MMS and THEMIS (THM) . The three THEMIS probes start at similar orbits on the dayside and will have significantly different orbits after the first year with MMS.

The THEMIS mission is already in orbit and has very limited resources for orbit re-design. The MMS mission comes with various launch related uncertainties. Combining the total of seven spacecraft into a tetrahedral formation at small to medium-scale separations was considered the preferred configuration in terms of cross-scale science return. As this concept requires aligning the lines of apsides of both missions within a few degrees the THEMIS long-term strategy was to adjust the rotation rate of its line of apsides. Mitigating our fuel capacities and the launch uncertainties of MMS we started adjusting our rotation rate years ahead of the MMS launch and steadily fine-tuned it for an optimized alignment as we approached the MMS launch. While the final shift of the MMS launch into spring 2015 left too little time to comprehensively investigate changes needed on both missions in order to maintain the tetrahedral formation it supports an alternative alignment where the apogees of both missions are about 180 degrees apart. This provides the opportunity of prolonged simultaneous observations of the coupling between plasma processes on the dayside and nightside enhanced by the global view through the coordination with the HSO fleet, as illustrated in Figure 1.

As previously reported [2] THEMIS has committed its long-term active orbit design during its extended mission phases to coordinate with existing and future HSO assets. In this paper, we will give an overview over the next six years and outline our response to our new coordination strategy with MMS. We describe how we utilize our vary different remaining fuel reserves on the three Earth orbiting probes while frequently synchronizing THEMIS apogee passes with those of MMS and at the same time enacting separations on various scales between the THEMIS probes in order to quantify the local processes. We also address the new requirement to stay above 650 km in order to protect the electric field instrument from oxidization we started to experience about a year ago and explain how we minimize fuel consumption by integrating the minimum altitude constraint into the science targeting orbit design.

We believe our methodology of long term planning, strictly driven by fuel and spacecraft safety constraints including de-orbiting at end of mission and based on inherently flexible near term goals and probe specific orbit designs is a valuable contribution to the multi-mission concept and the HSO in particular.

References:
[1] http://www.themis.ssl.berkley

[2] Frey S. et al., Innovative THEMIS extended mission design and implementation to achieve cross-scale magnetospheric constellation, Proceedings 24th International Symposium on Space Flight Dynamics ï 24th ISSFD, Laurel, USA, 2014.