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Bulk Plasma Dynamics on Large Scales

The first ~50 years of magnetospheric in-situ space plasma exploration was focused primarily on high energy plasma (>10 eV) in the near instantaneous local environment of a given observation platform, and on determining the processes that energize these plasma populations. This exploration was conducted by missions such as Explorer, OGO, ISEE, Polar, FAST, and a number of others. These first ~50 years provided us with great understanding of where different plasma regimes are located in space and what plasma process play key roles in these environments.

However, single point observations are incapable of fully assessing all important physical processes in these environments. For example, high energy plasmas react to magnetic and electric fields, which are often determined by the cold core of the plasma distribution function. Using the plasmasphere as a specific example, the population of cold (<10 eV) plasma controls which processes act on the higher energy (>30 keV) plasma. For example, hiss waves, which scatter energetic particles and result in their loss to the atmosphere, typically occur inside the plasmasphere (plasmaspheric hiss), while outside of the plasmasphere, chorus waves can accelerate ~10's keV electrons to ~100 keV or multi-MeV energies. Because the spatial extent of the plasmasphere is controlled by large-scale convection in the inner magnetosphere, local processes controlled by the presence of cold, dense, plasma, are determined by large-scale system dynamics. Single point measurements can, most of the time, infer the causes and effects of plasma acceleration in local regions. Yet a full understanding of the acceleration and loss processes of energetic particles over large spatial scales requires multipoint measurements, demonstrating a clear need to move beyond single point measurements.

It is only over the last ~20 years that missions such as Cluster, THEMIS, Van Allen Probes, and MMS have provided us with multipoint observations. However, these missions are still based on individual measurement platforms that sample only their local, in-situ plasma environment. When used in conjunction with other missions as part of the greater Heliophysics Observatory, more measurement points are added, but with the limitation that there is a low probability of all spacecraft being in the right locations at the right time to study a given phenomenon. Further, the structure and properties of the intervening global plasma structure (between measurement points) must be inferred or modeled.

Such multipoint missions have been extremely valuable in determining the local velocity and structure of various boundaries such as injection fronts, bursty bulk flows, the magnetopause, plasmapause, and bow shock. And yet, locally sampled portions of these boundaries are only part of a much larger structure, the behavior of which is not fully known. In addition, these boundaries typically move fast relative to the spacecraft orbital period, such that much of the dynamic evolution between subsequent orbits is missed. In order to advance, space plasma research needs multiple platforms that can interact with each other in such a way that they can monitor large-scale plasma dynamics while still making measurements of changes in the local environment.

The next 20-50 years of magnetospheric space plasma research should focus on cold plasma dynamics using a system-wide approach, instead of relying on individual platform/instrument observations. To measure cold bulk plasma dynamics in a system-wide sense, the current paradigm of using a handful of individual charged particle instruments is not sufficient. Instruments that measure line-of-sight plasma column densities by transmission of electromagnetic signals through the plasma between a large number of platforms are needed. There are many valid concepts for such measurements, but to achieve this in a cost-effective manner requires careful attention to and planning of platform deployment, as mission success would be contingent on the placement, orientation, and phasing of their orbits; they cannot be randomly placed.

Over the last 10-20 years, the use of GPS signals to derive global column density maps (Total Electron Content – TEC) of the ionosphere has demonstrated that cold plasma can be successfully monitored on a large scale, and that such monitoring can lead to significant scientific advances.

Initial efforts to globally map magnetospheric cold plasma dynamics can focus on making 2-dimensional cuts through magnetospheric cold plasma systems. Key properties to observe include how mesoscale and macroscale plasma structures change in time and space, and in particular, their dynamics in response to changes in solar wind conditions. It will also be key to understand how different initial conditions of the system influence the response of the magnetosphere and eventually produce a different final state. Examples of physical systems where observing bulk plasma mesoscale dynamics can make significant advances include: solar wind-magnetosheath dynamics, magnetopause dynamics, the plasmasphere, cusp dynamics, and plasma injections from the tail. Depending on the geometry of the cut of the system (polar or equatorial 2-dimentional cut) the monitoring of the bulk plasma will address different critical questions in space plasmas.

For mission data sets of the type proposed here, the current paradigm for distributing each spacecraft's individual data will also need to shift. The resulting data sets will require a more collective, coordinated effort by the community to produce standardized data products that describe global plasma dynamics, much the way that TEC maps have been trending toward a standard global data product. A number of focused Guest Investigator and system modeling proposals should be awarded to further this effort by developing and standardizing the analysis approach until it reaches an operational status.

To make new progress understanding the global dynamics of the magnetosphere, and of cold plasma processes in particular, there is a pressing need for the NASA Heliophysics Division to move toward a more system-wide measurement approach. It is suggested that groups of 2-6 spacecraft can target specific processes and constellations of >20 spacecraft (and/or instruments hosted on large-constellation commercial platforms) can target large-scale system-wide investigations. Depending on the required instrumentation, the group missions could start at ~$10M and for constellations >$250M. The technology and launch opportunities exist today to make these investigations a reality. The recent Heliophysics MIDEX Phase A selections demonstrate several feasible examples of such observation platform swarms.

By embracing such system-wide science, we can move forward as a community on investigations of cold plasma dynamics and thereby truly understand the system-wide importance of the last 70 years of space plasma research into local acceleration processes that act on the high energy tails of magnetospheric plasma.