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INTRODUCTION TO A SPECIAL SECTION

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Special Section:
Unsolved Problems in Magnetospheric Physics

Key Points:
- Many unsolved problems exist in magnetospheric physics
- The UPMP workshop discussed these problems and suggested possible solutions
- For some problems, the community already have the data and the tools to make rapid progress

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Preface: Unsolved problems of magnetospheric physics

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Abstract The Unsolved Problems of Magnetospheric Physics Workshop was held in September 2015 in Scarborough, UK. In contrast to most other meetings, people were specifically asked not to present and discuss their recent results. Rather, they were asked to bring their opinions and thoughts on unsolved problems to the meeting. Short presentations were encouraged after which the audience would debate and discuss definitions of the problems and how they could be overcome. Were new observations required? New missions? Or simply did the community need to work better together to resolve pertinent and outstanding science questions? Around 50% of the meeting schedule was devoted to discussion sessions on these topics.

Magnetospheric physics, as a separate discipline, has existed for little more than 50 years [*Stern*, 1989, 1996]. In that time great strides have been made in understanding both the physical processes at work in the region and also in determining connections and links between these processes. However, for some problems (many of which have been in existence throughout the preceding decades), the community has yet to reach consensus regarding solutions. To address this, a meeting was convened to bring workers in the field together to discuss how we can define (and hopefully solve) the outstanding problems facing the community. Some outcomes from the meeting have recently been published in a dedicated Special Section of Journal of Geophysical Research on Unsolved Problems of Magnetospheric Physics. Many papers in the section take the form of a Commentary—a short article discussing specific problems in magnetospheric physics. Some outstanding questions, and possible routes to their solution, were distilled from audience discussions at the meeting.

Coupling of Solar Wind and Magnetosphere

Although it is integral to understand the driving, dynamics, and evolution of the entire magnetosphere, the physics of the coupling between solar wind and magnetosphere remains poorly understood. The solar wind quantities that control coupling are not agreed upon, and the physical mechanisms underlying the viscous interaction are unknown. The presence of the magnetosheath creates additional difficulties for understanding of the coupling.

Magnetospheric Plasmas

There is an almost complete absence of information about magnetospheric plasma properties and mass density along the dayside magnetopause. This absence prevents us from assessing the importance of heavy ions and magnetospheric mass density for the mass loading of dayside reconnection and the resulting feedback of the magnetosphere on solar wind/magnetosphere coupling (Note: since the workshop the Magnetospheric Multiscale (MMS) mission has made some progress on addressing these topics).

Radiation Belt Modeling

To improve predictions, the community should aim to transition away from generic modeling of the radiation belts during averaged conditions and toward event-specific modeling. Such a transition would require use of in situ measurements of the plasma environment (e.g., total electron density), the use of event-specific diffusion coefficients, and event-specific knowledge of the magnetic field configuration.

Chorus Waves and the Radiation Belts

Analysis of time series data shows that chorus waves in the magnetosphere are intense and bursty and that the wave normal angle of chorus can change by upward of 50° within a single rising tone. However, all global prediction-based models of the radiation belts currently rely upon statistical averages of time-averaged spectral intensity data, which we know to grossly underestimate the instantaneous wave amplitudes. The consequences of using time-averaged spectral intensity data when studying chorus waves need to be assessed, and the importance of large-amplitude oblique whistler mode waves for radiation belt dynamics needs to be determined.

Radiation Belt Precipitation

For energetic particle precipitation we have a theoretical framework that appears to explain the drivers of precipitation, and we have experimental measurements, but these are not consistent with one another. This has implications for understanding both the efficacy of radiation belt loss processes and the impact of those losses on the coupled climate system. In order to address this issue, dedicated measurements that are focused on energy-resolved, bounce loss cone, precipitation fluxes are required.

The Magnetosphere Influencing the Atmosphere

Research has shown that energetic electron and ion precipitation, from the magnetosphere into the atmosphere, has implications for the coupled climate system. The chemical changes in the atmosphere produced by the precipitation need to be studied in much greater depth than it has been to date. The statistical link between geomagnetic activity and the atmosphere's North Atlantic oscillation has yet to be explained.

Low-Energy Electrons and Ions

Low-energy electrons and ions (~0.1–100 s eV) permeate the magnetosphere although only limited work on understanding and quantifying their general morphology and dynamics has been carried out. Precise measurements of the thermal plasma (0.1 to a few eV) in the magnetosphere are essential to solve a variety of science questions. However, such data are currently unavailable due to the inherent technical challenge of routinely measuring this population. This issue needs to be addressed for the community to fully determine the role played by such low-energy particles. Further studies of (i) the role of low-energy electrons in modulating wave growth in the magnetosphere and (ii) the role of warm plasma cloak ions upon solar wind/magnetosphere coupling are also required.

Plasmasphere Refilling

Model calculations of plasmaspheric refilling rates do not agree with experimental measurements in the outer plasmasphere. Varying parameters in physics-based refilling codes appear insufficient to correct this disagreement. In addition, a robust experimental description of the ion composition of the plasmasphere, as a function of (i) location, (ii) stage of refilling, and (iii) storm time conditions, is urgently needed. Analysis of refilling also currently lacks the global context that can be provided by EUV imaging of the plasmasphere.

Magnetosphere-Ionosphere Mapping

We are greatly hindered by uncertainties in mapping the magnetic field between the ionosphere and magnetosphere. Consequently, our understanding of connections between magnetospheric phenomena and ionospheric phenomena remains ambiguous. For system science, understanding connectivity is crucial. Improved magnetic mapping would increase our ability to use auroral forms in the atmosphere to image and diagnose the processes acting in the magnetosphere. At high latitudes, and/or during active times, this mapping is very difficult, with implications for magnetic mapping between, and understanding of, auroral streamers and plasma sheet flow channels.

Ionospheric Conductivity

Ionospheric conductivity may be one of the least well quantified variables in the coupled ionosphere-magnetosphere system. The research community needs a readily accessible code that can provide quantification of the global Pedersen and Hall conductivity as a function of solar wind and IMF values. Such a tool is not presently available. Producing such a tool should be a community priority.

Ionospheric Ion Outflow

It is known that global simulations predict significant changes in the behavior of the magnetosphere when ionospheric outflows are included. Improved parameterizations of the rates of ion outflow as functions of latitude and local time, geomagnetic activity, and solar and solar wind conditions are urgently needed for implementation in global simulation codes.

Auroral Arc Generation

The physical mechanisms in the magnetosphere that produce and activate auroral arcs remain unknown. Although auroral arcs are sites of intense energy conversion, and energy transfer, from the magnetosphere to the ionosphere, the form of the energy that is converted is unknown. Understanding the emergence and activation of low-latitude auroral arcs would provide vital clues about substorm onset and substorm physics. Understanding auroral arc formation is one of the longstanding unsolved issues in the whole of magnetospheric physics.

Substorms

There remains an urgent need to tie down the timing of substorm evolution and associated auroral features. Much uncertainty exists regarding this issue. In part, this is likely due to the need for formal common definitions of the specific magnetospheric and ionospheric signatures of substorms and pseudobreakups. Improved magnetic mapping is a further essential ingredient in linking substorm signatures detected in the magnetosphere with those seen in the ionosphere (see above).

Simulations

For future generations of global simulations, which are able to model the solar wind-driven magnetosphere (and the development of evolving radiation belts), a methodology to account for ion and electron injections by substorms is needed. This would involve either developing MHD codes that can accurately capture substorm physics or forcing substorm effects in simulations, via temporal models of field collapse and induction electric fields.

It is clear from the list of topics above that our community has many opportunities for a busy future. Understanding of individual processes has, to date, largely followed the tried-and-tested methodology of breaking coupled systems down into individual subcomponents, and investigating these subcomponents in isolation. Such methodology has proven highly successful with regard to magnetospheric physics over the last 50 years.

The above list of "known unknowns" documents our lack of understanding of issues of which the community is aware. It is for these issues that we can, at the very least, see a path toward a solution. A challenge over the next 50 years will be linking together our understanding of individual processes to form a system-wide model of the magnetosphere that is fully coupled and provides improved predictability. Of even more interest, perhaps, will be the discovery and investigation of "unknown unknowns": the yet-to-be discovered processes at work in the magnetosphere, which will be revealed in the coming 50 years. These processes will, undoubtedly, challenge our understanding of magnetospheric physics in ways that we, as yet, cannot grasp.

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