Report on the Forum held at ISSI on the Future of magnetospheric research 24-25 March 2009

0. Preamble

Initiated by a discussion at the COSPAR Scientific Advisory Committee in March 2008, the International Space Science Institute (ISSI) decided to organize a Forum to debate the current status and potential future evolution of the physics of Earth's magnetosphere after 50 years of intense research activity. Twenty-four scientists from 12 different countries (see the Appendix) were invited and met at ISSI on 24-25 March, 2009. This report summarizes their opinions and suggestions. A more extended discussion of the achievements, status and future evolution of magnetospheric research will be published by participants of the Forum in COSPAR's Space Research Today.

1. Introduction

The discovery, exploration and detailed understanding of the Earth's magnetosphere have been key scientific goals and the focus of significant activities in scientific space research in the past fifty years. In terms of resources devoted to magnetospheric research and the numbers of scientists that have been directly engaged in it, the discipline dominated the early part of the space age. In the past thirty years or so, other scientific disciplines have progressed to match or surpass the activity levels in magnetospheric research. Nevertheless, the topic remains very active, although in parallel with other scientific areas, the sophistication of the missions that provide much of the raw material for the research has increased significantly. This has increased the cost of missions in general and therefore reduced their frequency. In common with what is needed to keep space research disciplines fresh and relevant, it is important to review the status of magnetospheric research and identify its future directions.

2. Present situation and potential evolution

The Earth's magnetosphere contains long-lived plasmas with well-separated scales and exhibiting examples of key universal processes that are amenable to in-situ as well as remote-sensing, global observations. This makes it a unique plasma physics laboratory, one that is recognised increasingly as one of the tools of wider scientific research interests, both on the large, astrophysical scale and the small, Earth-based laboratory scale. In addition, the magnetosphere is our immediate environment in the larger Sun-Earth system; the effects of the dynamics of this system are relevant to the whole range of applied activities in space and require secure forecasting of conditions in the magnetosphere.

While the overall picture as how plasma processes work in the magnetosphere is generally known, thanks to the observations gathered during the past decades, much of the basic physics at the micro-scale still remains unclear, as well as how the various processes interact. The future thrust of magnetospheric research should thus be primarily to understand the microphysics and its coupling to meso- and macro-scales. This represents a natural evolution of the subject and allows the links to other areas of research that are essential for the continued relevance of the research and can justify the resources devoted to it.

3. Outstanding questions

Outstanding questions in magnetospheric physics that are also relevant to its wider applicability concern in particular

- The identification of pathways to particle acceleration: reconnection, shocks, wave-particle interactions.
- The relative role of steady processes vs intermittent, multi-scaled coupling.
- The identification of those small-scale processes that lead to important macro-scale consequences.
- The coupling of the various regions and boundaries from the Sun to the Earth's atmosphere to exchange energy and drive the dynamics of the system
- Resolution of the multiplicity of coupled scales
- Determination of the 3D picture of global dynamics through in-situ measurements with large fleets of spacecraft, remote-sensing measurements, and modelling.

4. Relevance of magnetospheric science to other research areas

In the future, increasing importance must be attached to links between magnetospheric physics and the following scientific research areas:

- Other planets. Other planets have magnetospheres that are vastly different from Earth's. In some cases phenomena common at Earth (reconnection, particle acceleration, auroras) are found but with very different characteristics (e. g., Jupiter and Saturn). In other cases phenomena that are relatively unimportant at Earth have great consequences at other planets. These include plasma sources from satellites (Jupiter and Saturn), interchange instabilities (Jupiter and especially Saturn) resulting from the dominance of corotation, and the occurrence of dynamic phenomena like substorms without an ionospheric connection (Mercury). These and other planetary magnetospheres provide important additional laboratories to test the theories developed at Earth as well as to address vastly different phenomena which themselves can have counterparts elsewhere in the universe.
- Solar corona. Magnetic reconnection is known to be crucially important in the solar corona in connections with solar flares and coronal mass ejections. While remote sensing of these phenomena provides vast amounts of information on their scale sizes, temporal development, and energy transfer; the lack of in-situ measurements within them limits the information that can be applied to determining the processes that drive reconnection.
- Astrophysics. Astrophysical examples of reconnection include gravitationally bound magnetized accretion disks within which magnetic fields are continuously created by a differential-rotation dynamo and annihilated by magnetic reconnection. Similar to the solar corona, magnetic loops form and reconnecting while producing X-ray emissions. Reconnection has been inferred from the spin-down of Pulsars, during which open field lines are converted to closed field lines, and from their high-energy emissions, which have been related to intense current sheets and the acceleration of particles.
- Tokomaks. Plasma processes that occur in the magnetosphere are also known to limit the operation of Tokomaks. Examples include the transport of plasma through the confinement boundary by the ion drift wave instability and the occurrence of magnetic reconnection in connection with sawtooth crashes of the electron temperature.
- Laboratory plasmas. Studies of magnetic reconnection in the laboratory are now entering the collisionless regime as experienced in the magnetosphere, which will allow for

coordinated studies in the near future that involve computer simulations, laboratory experimentation and multi-spacecraft probes of reconnection.

The means and new tools that are required for further progress in magnetospheric physics and its application to other areas of space- and laboratory sciences were also outlined by the Forum:

- Multi-spacecraft in-situ measurements of composition-resolved plasmas, energetic particles, 3D electric fields and 3D magnetic fields with separations and time resolutions appropriate to the micro-, meso- and macro-scales,
- Global imaging of magnetospheric plasmas with energetic neutral atoms (ENA) and EUV photons.
- Global imaging of energetic particles with ENA.
- Imaging of electron and proton auroras with FUV photons.
- Imaging of foreshock and magnetosheath plasma densities using soft X-rays.
- Continued development of modeling and simulation capabilities, leading to three-dimensional studies of phenomena like magnetic reconnection with realistic mass ratios.

5. Conclusions and potential ISSI involvement

The Forum concluded that the natural evolution of the rich heritage of half a century of magnetospheric research implies and requires the application of its physical insights and results to a broader range of topics in space sciences. This will, together with new research undertaken in the magnetosphere, bring a renewal that is necessary for the continuation of the discipline.

As one of the outcomes of the Forum, topics have been identified that will be considered as possible subjects of future ISSI Workshops. The suggested topics are in all cases building on knowledge and understanding acquired in the study of the Earth's magnetosphere, but address wider areas in which interdisciplinarity will bring new and added insight. This approach takes advantage of the special mission of ISSI to bring together a broader scientific participation in addressing new and challenging topics in space sciences. The specific topics identified are:

- Magnetosphere-like structures in astrophysics – an examination of the phenomenology of interacting scales over a broad range of conditions and spatial scales.

- Physical aspects of the common ground between space and laboratory plasmas – an examination of the microscales and the influence of boundaries.

- Filamentation in plasmas – an important new perspective in examining the spatial structures in plasmas and their interactions.

- Particle acceleration on all scales – the role plasma dynamics and plasma boundaries in accelerating particles from thermal energies to high energy cosmic rays in different astrophysical contexts.

The Forum has also identified other topics of interest that may be pursued as subjects of team activities. Examples are: turbulence in the magnetosphere and laboratory plasmas: the effect of short temporal and spatial scales and boundaries; phenomenological linkages and the underlying physical processes in the magnetosphere; the study of the magnetosphere as a complex system.

APPENDIX: List of participants

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