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DYNAMICS OF THE MAGNETOSPHERE

Edited by S.-I. Akasofu

VOLUME 78

PROCEEDINGS

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DYNAMICS OF THE MAGNETOSPHERE

PROCEEDINGS OF THE A.G.U. CHAPMAN CONFERENCE
'MAGNETOSPHERIC SUBSTORMS AND RELATED PLASMA PROCESSES'
HELD AT LOS ALAMOS SCIENTIFIC LABORATORY, LOS ALAMOS, N.M., U.S.A.
OCTOBER 9–13, 1978

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ASTROPHYSICS AND SPACE SCIENCE LIBRARY

A SERIES OF BOOKS ON THE RECENT DEVELOPMENTS
OF SPACE SCIENCE AND OF GENERAL GEOPHYSICS AND ASTROPHYSICS
PUBLISHED IN CONNECTION WITH THE JOURNAL
SPACE SCIENCE REVIEWS

VOLUME 78
PROCEEDINGS

FOREWORD

The Los Alamos Chapman Conference on *Magnetospheric Substorms and Related Plasma Processes* can be considered the fourth in a series devoted to magnetospheric substorms, after the Moscow (1971), Houston (1972), and Bryce Mountain (1974) meetings. The main motivation for organizing the Los Alamos Conference was that magnetospheric substorm studies have advanced enough to the point of bringing experimenters, analysts and theorists together to discuss major substorm problems with special emphasis on theoretical interpretations in terms of plasma processes. In spite of an extremely heavy schedule from 8:30 A.M. to 10:00 P.M., every session was conducted in an enjoyable and spirited atmosphere. In fact, during one of the afternoons that we had put aside for relaxation, John Winckler led a group of the attendees in a climb to the ceremonial cave of a prehistoric Indian ruin at Bandelier National Monument, near Los Alamos under a crystal blue sky and a bright New Mexico sun. There, they danced as the former dwellers of the pueblo had, perhaps as an impromptu evocation of a magnetospheric event.

This volume is an outcome of this exciting Conference, including most of the review papers and some contributed papers. It is very appropriate that this particular volume is included in the *Astrophysics and Space Science Library* series because other books on magnetospheric substorms have been published in the same series. The review papers are general enough for all students in magnetospheric physics, as well as for the specialists in substorm studies. This feeling was expressed by a number of attendees of the Conference.

During the planning of this conference, it was felt that differences of opinion on many morphological aspects should be discussed in a morphology workshop, rather than during the Los Alamos Conference, since in the first three substorm conferences a great deal of time had been devoted to discussing details of various morphological aspects of substorms. The workshop was held at the University of Victoria on August 21-23, 1978, and was attended by nine workers. Some jokingly called this group the "Victorian nine" during the Los Alamos Conference.

The Conference began with well prepared reviews of progress made in substorm studies in the past several years. If the Conference was, indeed, successful, we owe the invited reviewers for their great effort. Some of the reviewers concluded that it is much more reasonable to consider that the magnetosphere is an open system rather than a closed system. This open magnetosphere responds specifically to a specific change of the interplanetary magnetic field (IMF).

S.-I. Akasofu (ed.), Dynamics of the Magnetosphere, ix–xi.

Then, what is a magnetospheric substorm? Perhaps there is little disagreement among substorm workers about the fact that the magnetosphere develops a particular mode of energy dissipation when the power generated by a dynamo process, partially controlled by the IMF, is high. Various characteristics of this particular mode of energy dissipation are reflected in the nature of magnetospheric substorms.

The convenor is most thankful to the theoretical reviewers for their extensive treatment. It is understandable, however, at the present stage of our study that a unified theoretical concept of this phenomenon did not emerge during the Conference. Some proposed, on the basis of their numerical simulation studies, that it is a spontaneous process in the magnetotail. On the other hand, on the basis of a recent finding of the energy coupling function and its correlation with the AE index, some concluded that a substorm is a driven process. It is important that such a fundamental issue of substorms has finally been brought to the attention of substorm workers by contrasting the two views.

In this search for substorm mechanisms, it may be important to note the fact that the "Victorian nine" agreed unanimously that a magnetospheric substorm is associated with diversion of the cross-tail current to the polar ionosphere. On the other hand, there were also serious disagreements as to how the magnetosphere enhances its energy dissipation rate and how the current diversion is triggered. Some workers described their morphological models in terms of the formation of a magnetic X-line. Some others presented another morphological model which includes interruption of the cross-tail current near the earthward edge of the current sheet and the subsequent diversion to the polar ionosphere, without invoking the formation of an X-line. The morphological interpretation of magnetotail phenomena during substorms is thus a very controversial subject at the present time.

In the final panel session, some panel members gave a very comprehensive theoretical review on the subject of magnetospheric substorms, putting various possibilities into proper perspective. One of them considers that both reconnection and current interruption are equally possible at this stage of theoretical study of magnetospheric substorms. He considers that reconnection can be spontaneous tearing or forced X-line formation, but remarked in essence that the applicability of MHD treatment in a collisionless plasma should be carefully re-examined. Another panel member stressed also the possibility of both reconnection and current interruption in the magnetotail and showed examples of numerical simulation results for both cases. It should be mentioned that the origin of field-aligned currents and some of their consequences (the V-potential formation) were also an important topic during the Conference. In summary, most panel members pointed out specifically that it is vital to develop a three-dimensional simulation model in order to treat the diversion of the cross-tail current.

The convenor felt that the objectives of the Los Alamos Conference were reasonably well accomplished. It is one of his hopes that a vigorous theoretical effort will be made during the next several years in understanding basic plasma processes involved in substorms. It is hoped that by conveying the content of this Conference, this volume will represent an important milestone in substorm studies.

Finally, as the Convenor of the Conference and the Editor of this volume, I would like to thank the American Geophysical Union in endorsing this symposium as a Chapman Conference and for organizing it. Thanks are due to the Los Alamos Scientific Laboratory for hosting the Conference. The National Aeronautics and Space Administration and the National Oceanographic and Atmospheric Administration provided funds which enabled us to bring a number of graduate students and some foreign participants.

July 1979 S.-I. Akasofu

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THE CONTROL OF THE MAGNETOPAUSE BY THE INTERPLANETARY MAGNETIC FIELD

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Abstract. The solar wind dynamic pressure determines the "zeroth-order" location of the earth's magnetopause. However, the normal stresses of the solar wind dynamic pressure are also accompanied by tangential stresses which erode the magnetopause from its equilibrium position and transport magnetic flux into the magnetotail. It is clear that the tangential stress on the magnetopause is at least in part controlled by the southward component of the interplanetary magnetic field. When the interplanetary magnetic field turns from northward to southward, the magnetopause moves in toward the earth, the polar cusp moves equatorward, and the polar cap increases in size, as does the diameter of the magnetotail. Since particle observations show that the polar cap magnetic field is directly connected to the interplanetary magnetic field, this observation of magnetopause erosion is an unambiguous demonstration that the process of reconnection is occurring. However, it does not elucidate the physical mechanisms by which such reconnection occurs. The study of the physical processes at the magnetopause and their control by the IMF is actively being investigated on the ISEE mission. Initial results indicate that when the magnetosheath magnetic field is southward the connection takes place in a series of flux transfer events capable of transporting 10^{16} Mx or more per hour.

1. INTRODUCTION

The magnetosphere is a very sensitive object, and since its surroundings are quite variable, the magnetosphere is a very dynamic entity. When we draw a sketch of it, we deceive ourselves somewhat because this quiet and serene object we have drawn is not this way at all. In fact, it has been quite difficult for us to get to our present level of understanding because of every time we try to take its picture the magnetosphere moves. The size and shape of the magnetosphere depends on the strength of the solar wind blowing against it, and hence depends on the velocity and number density of the solar wind. It also depends on the strength and orientation of the interplanetary magnetic field.

S.-I. Akasofu (ed.), Dynamics of the Magnetosphere, 3–21.

Figure 1 shows Dungey's classic models of the reconnection of interplanetary magnetic field lines with the magnetospheric field (Dungey, 1961, 1963). In the top panel southward field lines convected along by the solar wind break in half and join partners with magnetospheric lines. The interplanetary field now has one foot on the ground and the other off at infinity and the field line convects past the earth but eventually drifts down and finds and joins its old partner and convects back to earth, only to repeat the process sometime later. When the interplanetary field is northward as shown in the bottom panel reconnection cannot take place at the nose of the magnetosphere. However, there are other places where antiparallel fields occur and it might take place there.

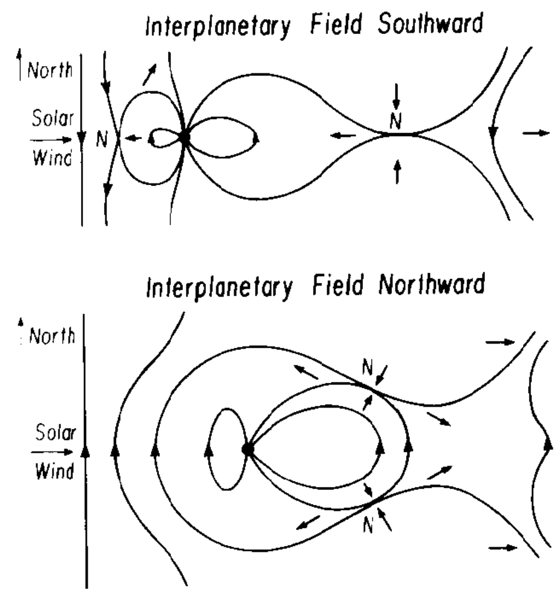

Figure 1. The Dungey model of the magnetosphere. The letter N denotes a neutral point. Arrows indicate the direction of plasma flow. The model is highly qualitative and in particular no attempt has been made to draw these diagrams to scale (after Dungey, 1963).

Dungey pointed out that the reconnection rate at the nose and in the tail had to balance on the average. Thus if you have reconnection at the nose you must eventually have reconnection in the tail and vice versa. However, these rates do not need to balance instantaneously. If they did we would not have substorms. The fact that these rates can get out of balance makes the magnetosphere interesting but understanding the magnetosphere very difficult.

Any paper on the effect of the interplanetary magnetic field or IMF on the magnetopause has to concern itself with the process of reconnection. However some people don't like the word reconnection. They would like to call what happens at the magnetopause something else and say reconnection doesn't occur. To make it perfectly clear what we mean by reconnection we will use Vasyliunas' (1975) definition. "Reconnection is the process whereby plasma flows across a surface that separates regions containing topologically different magnetic field lines. The magnitude of the plasma flow is a measure of the merging rate."

The theoretical development of the reconnection problem is hampered by the three dimensional nature of reconnection in a magnetospheric geometry. However, the difficulty of the theoretician should not be viewed as grounds for rejecting the validity of the mechanism. The validity of reconnection as a significant magnetospheric process can and should be judged by the experimental evidence in its favor or against it.

Most of our present understanding of the macroscopic effects of the IMF on the magnetopause came before the magnetosphere's 10th birthday. In 1961 Dungey proposed his reconnection model of the magnetosphere in order to explain the aurora. It was a few years before the data became available to test this idea. When the data were available it is only fitting that one of Dungey's students D.H. Fairfield provided the first real evidence that the model was correct (Fairfield and Cahill, 1966). When the magnetosheath magnetic field was southward as seen by the Explorer 12 magnetometer, ground based auroral zone magnetometers recorded substorms and when the magnetosheath field turned northward ground level disturbances ceased.

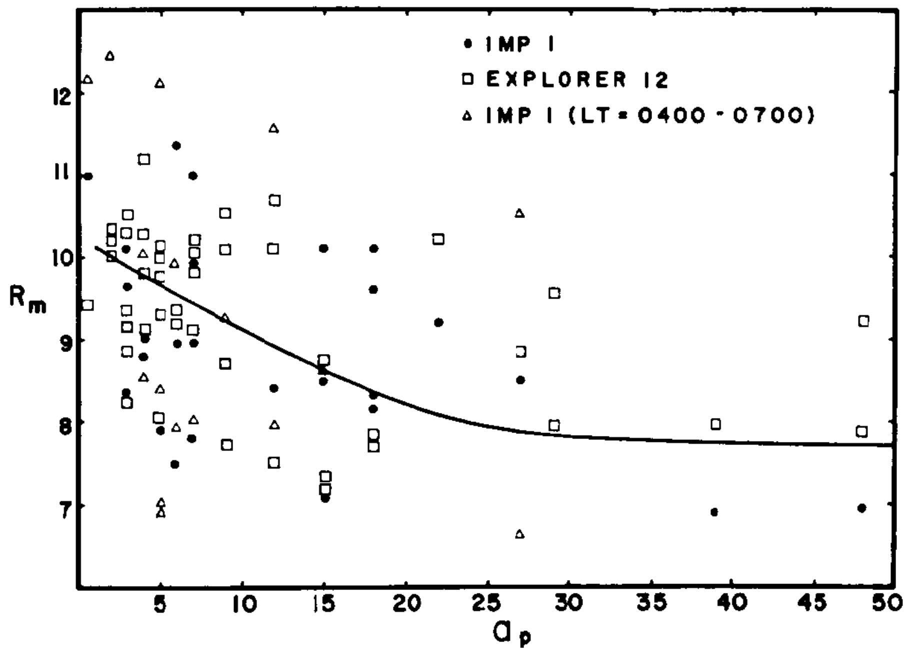

Figure 2. Normalized magnetopause distances Rm versus the geomagnetic ap index (Patel and Dessler, 1966).

Later the same year Patel and Dessler (1966) with the data of Figure 2 showed that the magnetopause was smaller for high Ap. Unfortunately they were alarmed by the large scatter in the data and dismissed the correlation. Furthermore, they did not expect solar wind dynamic pressure, which they thought caused the decreases of magnetopause radius, to affect Ap. The next year Patel et al. (1967) published Figure 3 which is a plot of the Ap index versus the angle between the magnetosheath field and the magnetospheric field. This is in effect a duplication of Fairfield and Cahill's result and at face value supports Fairfield and Cahill's work. However again these authors dismissed the correlation because of the large scatter in the data. The sparcity of points at small θ is due to the frequent difficulty in finding the magnetopause for northward magnetosheath fields.

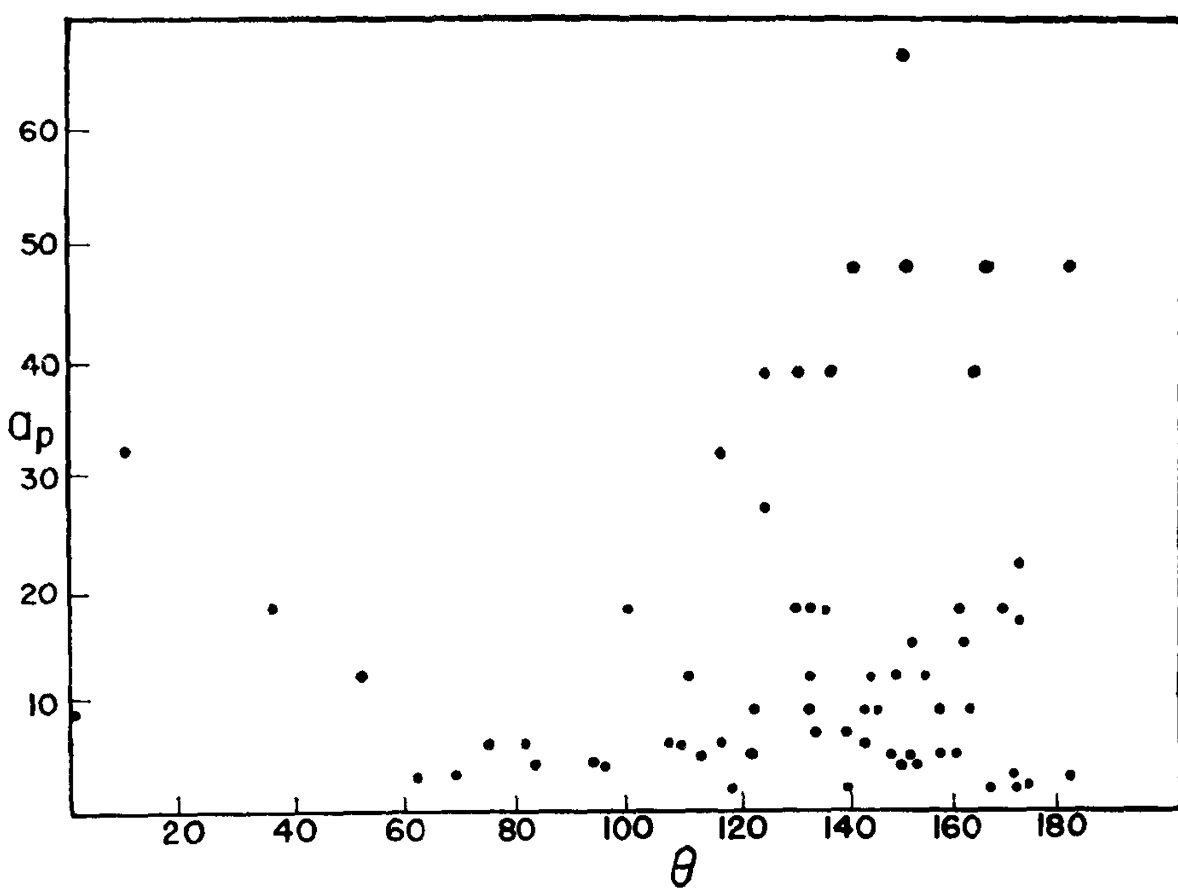

Figure 3. Planetary index ap versus the angle between the magnetosheath and magnetospheric fields. The scarcity of points for small angles is due to the difficulty of identifying magnetopause crossings when the magnetosheath field is northward (Patel et al., 1967).

In the next few years there ensued much work on the correlation of the IMF and geomagnetic activity and it became generally accepted that when you put the interplanetary magnetic field in the right coordinate system then there was a strong correlation. One notable paper during this period was that of Rostoker and Falthammar (1967) who used hourly averages of the interplanetary electric field rather than the magnetic