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FRONTIERS IN MAGNETOSPHERIC PLASMA PHYSICS

Celebrating 10 Years of Geotail Operation

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FRONTIERS IN MAGNETOSPHERIC PLASMA PHYSICS

Celebrating 10 Years of Geotail Operation

Proceedings of the 16th COSPAR Colloquium
held at the Institute of Space and Astronautical Science (ISAS), Kanagawa, Japan
July 24–26, 2002

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PREFACE

The 16th COSPAR Colloquium entitled *Frontiers of Magnetospheric Plasma Physics: Celebrating 10 Years of Geotail Operation* was held at the Institute of Space and Astronautical Science (ISAS), Kanagawa, Japan, from July 24-26, 2002. There were 101 participants, and a total of 42 oral presentations – both invited and contributed – were given. In addition, there were 55 posters, making an overall total of 97 contributions.

Beginning with the discovery of the Earth's magnetosphere by Professor James Van Allen in 1958 and the initial explorations of the Earth's space environment in the early 1960s, numerous spacecraft missions have greatly increased our knowledge about the structure and physical processes in the magnetosphere. In order to understand in more quantitative and fundamental detail the global dynamics of the Earth's space environment, the 1990s saw the bringing to fruition of an international collaborative enterprise, the International Solar-Terrestrial Physics (ISTP) science initiative, consisting of ISAS, the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA), and the Space Research Institute (IKI) of Russia. The Geotail spacecraft, built in Japan with international participants in the instruments and which was launched on July 1992, is a central element of this initiative. Geotail is designed to measure global energy flows and transformations in the magnetotail to increase understanding of fundamental magnetospheric processes.

The main purpose of this symposium, on the tenth anniversary of the Geotail mission, was to outline the basic discoveries and new understanding enabled by Geotail and the ISTP initiative, including discussions of the dynamical structure and evolution of the Earth's magnetosphere under the coupling processes between macro- and micro-scale plasma physics. The symposium comprised eight general sessions: progress of magnetospheric observations: overview; thin current sheets; microscopic processes in space plasmas; magnetospheric substorms; particle acceleration in the sun and interplanetary space; remote sensing of the magnetosphere with plasma waves; magnetosheath and magnetopause; and magnetotail dynamics. The main achievements that were accomplished through the collaborative efforts among ISTP participants include the plasma dynamics of magnetic reconnection in a thin plasma sheet, the action of the solar wind on the plasma population in the plasma sheet and around the magnetotail boundary layer, the relationship between the substorm expansion region and the X-line formation in the magnetotail, and the temporal evolution of the dipolarization front from the near-Earth to the distant tail.

In addition to the new observations that have been provided by Geotail and other mission in the ISTP initiative, it is important to note that the new measurements of plasma dynamics have stimulated numerous innovative numerical simulations of plasma process that have provided new understanding of key issues. The Hall current system and plasma distribution functions in and around the reconnection region have been clearly understood by means of the kinetic simulation studies. The solitary electric field signatures that are observed in many key regions in the Earth's magnetosphere have stimulated comprehensive simulation studies of micro-scale plasma dynamics. The results of this COSPAR Colloquium show that scientists are now making great strides in understanding the structure and dynamics of Earth's magnetosphere by means of modern satellite observations and innovative theoretical/computational investigations.

We would like to thank the convener, T. Mukai, and the scientific and program committee: M. Acuna, A. Balogh, C.P. Escoubet, D.H. Fairfield, M. Hoshino, L.J. Lanzerotti, K. Maezawa, Y. Omura, G. Paschmann, L.M. Zelenyi, for assistance in formulating the programme and selecting the papers. Finally, we are grateful to the authors of the papers presented in this volume as well as the following people who refereed these papers: G. Anagnostopoulos, R.R. Anderson, T. Araki, T.P. Armstrong, W. Baumjohan, D.N. Baker, R.F. Benson, M. Brown, J. Buechner, W.S. Daughton, R.B. Decker, S.R. Elkington, M.J. Engebretson, C.P. Escoubet, D.H. Fairfield, M. Fujimoto, C.C. Goodrich, W. Heikkila, M. Hesse, M. Hirahara, A. Ieda, Y. Kasaba, R. Kataoka, H. Kawano, H. Kojima, S. Kokubun, T. Kosugi, B. Lembege, L.R. Lyons, K. Maezawa, S. Machida, K. Marubashi, A. Matsuoka, A. Miura, A. Morioka, T. Mukai, T. Nagai, T. Nakagawa, M. Nakamura, R. Nakamura, A. Nishida, D. Nunn, T. Obara, T. Ono, T.G. Onsager, A. Otto, G. Paschmann, T. Phan, P. Pritchett, T.I. Pulkkinen, M. J. Reiner, E.T. Sarris, M. Scholer, K. Seki, V.A. Sergeev, I. Shinohara, N. Shimada, K. Shibata, J.A. Slavin, T. Sugiyama, D. Summers, S. Tanuma, T. Terasawa, R.A. Truemann, B.T. Tsurutani, M. Ugai, H. Usui, S. Wing, D. Winske, P.H. Yoon.

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TEN YEARS OF GEOTAIL AND ITS CURRENT STATUS: A BRIEF SUMMARY

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ABSTRACT

Since its launch in 1992, GEOTAIL has extensively surveyed the magnetotail with a full set of plasma and field instruments over a wide range of distances from 9 Re to 220 Re away from the Earth by means of a sophisticated orbit strategy. In the first two years, the orbit was optimized to explore the distant tail, and thereafter was changed to study substorm processes in the near-Earth tail region. The near-tail orbit has also facilitated exploration of the dayside outer magnetosphere, the magnetopause, the magnetosheath, and the bow shock, as well as the upstream solar wind. GEOTAIL observations have revealed a number of new phenomena in these regions, and as of the end of 2003, about 600 papers have been published in refereed journals. Recent GEOTAIL studies have significantly advanced our understanding of the structure and formation of thin current sheets in the mid-tail plasma sheet during substorms, and have elucidated new kinetic aspects of magnetic reconnection. GEOTAIL has operated far beyond the designed mission life of three and half years. Most of the onboard instruments are still functioning well, and it is expected that GEOTAIL will continue to generate scientifically useful data.

GEOTAIL MISSION

The GEOTAIL spacecraft was launched on 24 July 1992 by a Delta-II launch vehicle from Cape Canaveral, Florida, U. S. A. This is a joint program of the Institute of Space and Astronautical Science (ISAS) of Japan and the National Aeronautics and Space Administration (NASA) of U. S. A. ISAS developed the spacecraft and provided about two thirds of the science instruments, while NASA provided the launch and about one third of the science instruments. The spacecraft is operated from ISAS, but the data are acquired by both agencies.

The prime objective is to investigate the structure and dynamics of the Earth's magnetotail with a comprehensive set of scientific instruments [Nishida, 1994]. As shown in Figure 1, in the first two years, the apogee was maintained on the nightside of the Earth by means of the lunar double swingby maneuvers, ranging from 80 to 220 Re in order to explore the distant tail. Later, from November 1994 the apogee was reduced first to 50 Re and then to 30 Re in order to study substorm processes in the near-Earth tail region. The perigee was set at 10 Re, and in June 1997, slightly reduced to about 9 Re. The inclination was set at -7° with respect to the ecliptic plane, so that the spacecraft has most frequently traversed the neutral sheet at the apogee near the December solstice. This orbit strategy has worked highly satisfactorily for the mission objectives, and also enabled exploration of the dayside outer magnetosphere, the magnetopause, the magnetosheath, the bow shock, and the upstream solar wind.

Figure 2 shows a schematic view of the GEOTAIL spacecraft. The spacecraft weighed 1008kg initially, but now it is about 660 kg, since most of hydrazine propellant has been consumed for the orbit maneuvers. It has a cylindrical shape with diameter of 2.2 m and height of 1.6 m. Two masts which are 6-m long are deployed symmetrically to separate the magnetometers from the main body, and four 50-m antennas are deployed to measure the electric field from DC to 800 kHz. The spacecraft is spin-stabilized with the spin axis being nearly perpendicular to the solar ecliptic plane. The spin rate is 20 rpm.

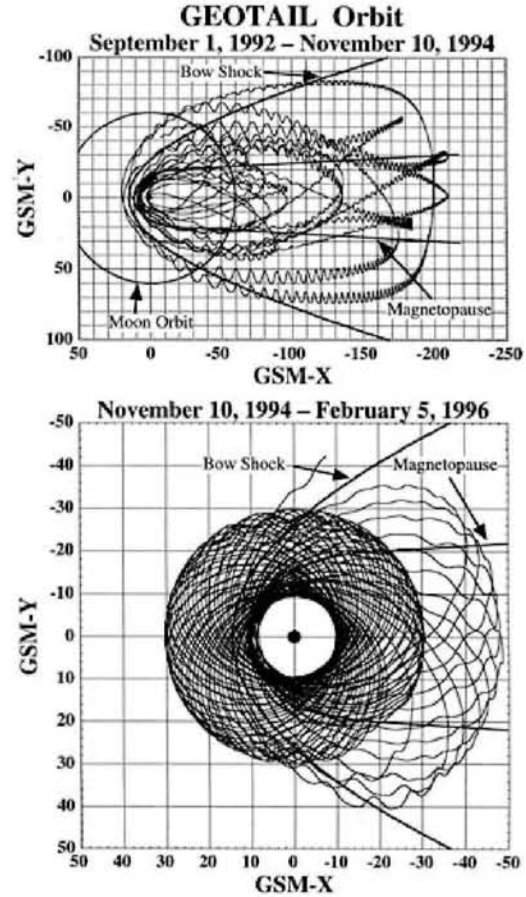

Figure 1 GEOTAIL orbit in the Geocentric Solar Magnetospheric (GSM) coordinates.

The upper and lower panels show the distant-tail orbit (from September 1, 1992 to November 10, 1994) and the near-tail orbit (from November 10, 1994 to February 5, 1996), respectively. The present one is nearly the same as that shown in the lower panel.

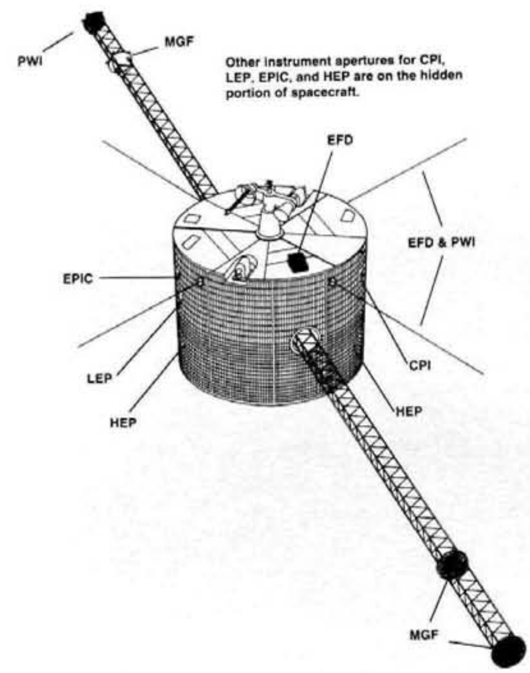

Figure 2 A schematic view of the GEOTAIL spacecraft on orbit.

BRIEF SUMMARY OF RESULTS FROM GEOTAIL

The initial GEOTAIL results were summarized in a special section of Geophysical Research Letters [December, 1994], and some highlights were compiled in Journal of Geomagnetism and Geoelectricity [Vol. 48, Nos. 5,6, 1996], a special section of Journal of Geophysical Research [March, 1998] and the AGU Geophysical Monograph 105 "New Perspectives on the Earth's Magnetotail" [1998]. Nishida [2000] reviewed the dynamic magnetotail based on the GEOTAIL observations. As of the end of 2003, about 600 papers have been published in refereed journals, as shown in Figure 3.

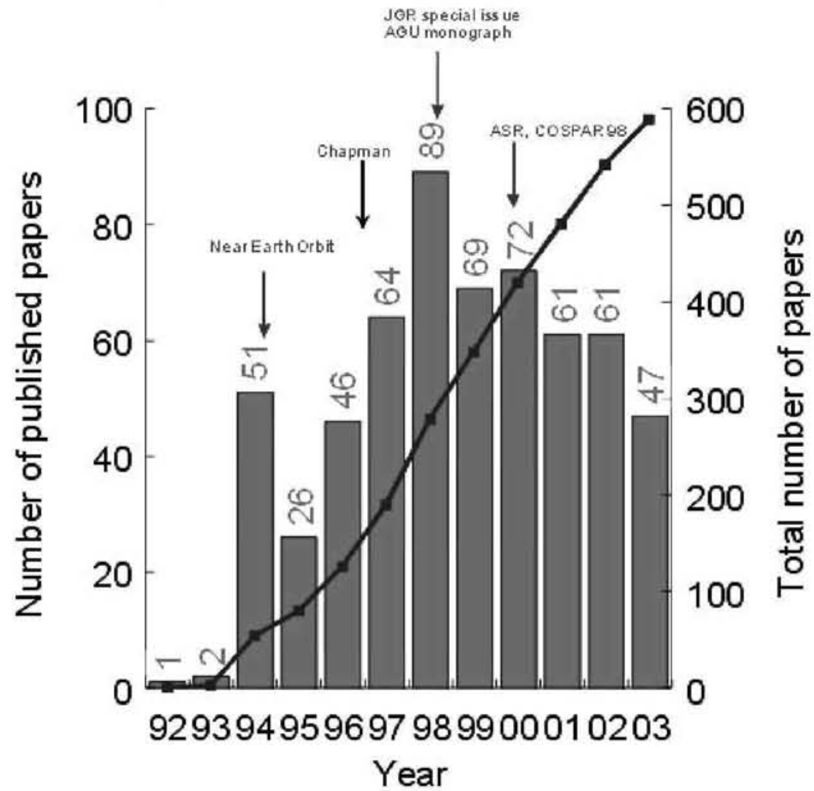

Figure 3 Number of GEOTAIL papers

Several new discoveries have resulted from the GEOTAIL observations, not only due to the orbit strategy optimized to the first extensive survey of the magnetotail over a wide range of distances, but also as a result of sophisticated measurement techniques. For example, the discovery of electrostatic solitary waves (ESW) in the plasma sheet boundary layer was due to the waveform capture (WFC) technique of the Plasma Wave Instrument [Matsumoto et al., 1994]. The WFC method has produced a number of new findings in wave properties in the magnetotail, the dayside magnetosphere, the magnetosheath, the bow shock and the upstream solar wind. Another important contribution to the success of GEOTAIL was the high time resolution measurement of 3-D distribution functions of ions and electrons with the Low Energy Particle (LEP) experiment [Mukai et al., 1994]. In particular, the LEP ion measurements with high sensitivity (large geometrical factors) have been quite effective for measurements of tenuous plasmas in the magnetotail; for example, the discovery of cold oxygen ion beams in the distant lobe/mantle regions [e.g., Seki et al., 1998]. The LEP ion measurements have also provided 24-hour continuous data of the ion fluid parameters (velocity moments; density, velocity and temperature), which have been very useful for statistical analysis of plasma properties. Combined with the magnetic field data, these plasma properties have been used to investigate the magnetotail structure and dynamics, which are well expressed in terms of the ideal MHD.

Magnetic reconnection is one of the most important processes in space plasmas. Its in-depth understanding was the main target of GEOTAIL in terms of space plasma physics, and in the following we briefly summarize some important results on magnetic reconnection. Firstly, GEOTAIL has established that that the structure and dynamics of the magnetotail are basically determined by magnetic reconnection under both southward and northward IMF conditions, except possibly when IMF is almost due northward [Nishida et al., 1998]. A further important finding is that the neutral sheet in the distant tail is twisted under the influence of the By component of IMF, the twisting being more severe when the IMF is northward.

GEOTAIL observations have clearly demonstrated the importance of magnetic reconnection for the magnetospheric substorms. Statistical results of plasma flow properties suggest that near-Earth reconnection starts before the expansion phase starts on the ground, and that this neutral line is initially formed at the distance of 22-30 Re in the midnight-premidnight region, coinciding with the local time range where the auroral and geomagnetic signatures of the expansion phase onset take place [Nagai, et al., 1998]. Studies on evolution of plasmoids have revealed that plasmoids, after initial formation in association with the near-Earth neutral line, expand toward the flank sides (dawnwad and duskward) during tailward propagation until the mid-tail region (~70 Re), and they have a full width of the magnetotail beyond this distance down the tail [Ieda et al., 1998]. The plasmoids are accelerated tailward until ~100 Re, whereas the tailward speed is reduced beyond this distance, probably due to an interaction with pre-existing plasmas.

In addition to the above MHD features, GEOTAIL observations of electron and ion velocity distribution functions have produced a new kinetic understanding of plasmoids and flux ropes [Mukai et al., 1998]. Characteristic signatures of the ion distribution functions are identified during the passage of plasmoids, and by comparison with computer simulations, they are qualitatively and quantitatively understood in terms of temporal/spatial evolution of the particle acceleration and heating by the magnetic reconnection [Hoshino et al., 1998]. Suprathermal electron acceleration in magnetic reconnection is also revealed by comparison between GEOTAIL observations and computer simulations [Hoshino et al., 2001].

Recent studies have significantly advanced our understanding of the evolution of thin current sheets and the associated occurrence of magnetic reconnection during the course of substorms [e.g., Mukai et al., 2000; Asano et al., 2003]. For these studies, the availability of reliable electron data has been crucial, and the structure of an extremely thin current sheet has been revealed with the current density estimated from the electron and ion velocity moments. One of the most important GEOTAIL discoveries is that the cross-tail current sheet in the late growth phase and the early expansion phase temporally forms a bifurcated structure in which the current density becomes the largest away from the neutral sheet [Asano et al., 2003]. The intense current sheet is thinner closer to the X-line, and the thickness becomes less than the ion inertial length. In the thin current sheet, the current is mainly carried by electrons, contrary to the ion-dominated diamagnetic current with the higher ion temperature than the electron one. The Hall electric field toward the neutral sheet causes the electron-dominated current sheet by enhancing the dawnward drift for both ions and electrons. GEOTAIL observations have also revealed the structure of the Hall current system and characteristic features of the associated electron distribution functions carrying the field-aligned current for magnetic reconnection [e.g., Nagai et al., 2003; Asano et al., 2004].

CURRENT STATUS

Two data bases, namely the Key Parameters and the Science Data Base, have been produced from experiments onboard GEOTAIL. The Key Parameters are produced by the NASA Goddard Space Flight Center from the 24-hour continuous data dumped over the NASA/DSN, and are made available to the worldwide science community for event search and preliminary studies via the NASA/CDAWeb system. The calibrated plasma and magnetic field data with high time resolution are archived in the Science Data Base, and are also made available to the worldwide science community via DARTS (Data ARchive and Transmission System at the Center for Planning and Information Systems, ISAS/JAXA) at <http://www.darts.isas.ac.jp/spdb/>. The plasma wave data and energetic particle data are also available via web-pages at the home institutions of the principal investigators, <http://www.kurasc.kyoto-u.ac.jp/> and <http://sd-www.jhuapl.edu/>, respectively.

GEOTAIL has operated beyond the designed mission life of three and half years. The occurrence of eclipses with duration longer than the designed length (2 hours) is unavoidable, but the spacecraft could be operated without any serious problem for an eclipse lasting for 269 minutes in February 2000, the longest period in the past. Most of the onboard instruments are still functioning well, and it is expected that GEOTAIL will continue to generate scientifically useful data.

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SECTION 1: Magnetospheric Dynamics