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Studies of the Intrinsic Complexities of Magnetotail Ion Distributions: Theory And Observations

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We have studied the relationship between the structure seen in measured distribution functions and the detailed magnetospheric configuration. Results from our recent studies using time-dependent large-scale kinetic (LSK) calculations are used to infer the sources of the ions in the velocity distribution functions measured by a single spacecraft (Geotail). Our results strongly indicate that the different ion sources and acceleration mechanisms producing a measured distribution function can explain this structure. Moreover, individual structures within distribution functions were traced back to single sources. We also examined the intrinsic variability of the magnetotail during quiet and steady solar wind conditions and found that the magnetotail possess an intrinsic variability caused by the non-adiabatic acceleration and loss of current-carrying ions from the magnetotail current sheet.

A. Ion Sources and Acceleration Mechanisms Leading to Observed Distribution Functions

Distribution functions observed by the Geotail spacecraft on May 23, 1995, on February 9, 1995, and on November 24, 1996 were investigated by using a time-dependent large scale kinetic model to investigate the sources and the acceleration mechanisms of the particles. Time dependent magnetic and electric fields were obtained from global magnetohydrodynamic (MHD) simulations of the magnetosphere driven by solar wind input indicated by Wind spacecraft measurements. These measurements provided the solar wind density, magnetic field, pressure, and velocity for the interval preceding the measurement of the local distribution functions. Ions were initially distributed at the location of Geotail according to the phase space densities measured by Geotail. They were followed backward in time through the MHD simulations' fields, which were also regressed in time, until they reached a magnetospheric boundary (magnetopause or ionosphere). A brief summary of the results of our calculations follows.

May 23, 1995 Event

1. Three sources of the high latitude ionosphere, the plasma mantle (with both a distant tai and a near-Earth tail segment, and the low latitude boundary layer (LLBL), contributed significantly to the equatorial ion population.

2. Most ionospheric particles were adiabatic and reached Geotail directly along field lines without mirror bouncing.

3. Low latitude boundary layer ions reached the Geotail location by convecting earthward from the dawnward flank of the magnetosphere adiabatic motion dominating. They primarily occupied the low energy part of the distribution.

4. Investigation of mantle ion trajectories indicate that they originated from two distinct populations. The first population consisted of adiabatic ions from the near-Earth plasma mantle, and the other population originated form the distant mantle. These ions had interacted strongly with the thin current sheet tailward of Geotail and experienced nonadiabatic ($k < 1$) acceleration and substantial energization. The second ion population supplied the bulk of the higher energy ions in the distribution.

5. There was a one-to-one correspondence between each of the structures in the low energy part of the Geotail distribution and a specific particle source.

6. Different source regions and acceleration mechanisms acting in the tail are responsible for the structure in the distribution function.

7. The structures at high energies results mainly from nonadiabatic behavior.

February 9, 1995 Event

Despite the quiet solar wind conditions observed on February 9, 1995, there were significant changes in distribution functions at Geotail between 1300 UT and 1400 UT. We modeled these changes with the MHD/LSK model as described above, with the following results.

1. At 1310 UT, all of the ions measured by Geotail originated from the duskside LLBL, from a narrow strip (in y and z) along the magnetopause. Because the magnetotail was twisted by the IMF By component, the current sheet is increasingly tilted out of the $z = 0$ plane at locations further down the tail. Therefore, while the location of the duskside LLBL source was close to the equatorial plane near the Earth, it increased steadily in z downtail. The particles followed guiding center orbits and were adiabatic. Counter-streaming ions seen in the distribution were due to mirror bouncing in the region around midnight, earthward of Geotail.

2. At 1325 UT, Geotail was entering a region of closed field lines. At that time ions from the dawnside LLBL gained access to the vicinity of Geotail. The LLBL ions had originated from broad regions in z centered on the equatorial plane. Most of them at this point experienced nonadiabatic acceleration. The duskside magnetopause remained the dominant source of ions during this time period. Unlike the previous time interval, ionospheric particles had contributed only a small fraction (1 %) of the particles measured by Geotail.

3. At 1347 UT, Geotail was embedded in closed field lines. During this time interval the dawnside replaced the duskside LLBL as the dominant source of ions. The particles' behavior during this interval was characterized by multiple nonadiabatic current sheet crossings prior to their dawnward drift to Geotail.

4. Time dependent MHD/LSK calculations were found to be helpful in explaining the physical processes leading to observed distribution functions.

November 24, 1996 Event

In contrast to the previous cases, this case examined the evolution of ion distribution functions during a magnetospheric substorm. During this day, Geotail progressed from the southern PSBL/lobe to the northern PSBL/lobe during the growth and expansion phases of the substorm, giving us the opportunity to examine the sources for plasma sheet ion distributions in detail. We found the following results.

1. The Geotail spacecraft is positioned in the southern PSBL at the start of the interval examined. The rotation of the current sheet in response to the IMF and the changes associated with the onset of the expansion phase cause a gradual shift in the spacecraft's location, such that Geotail is found to be in the northern PSBL and lobe at the end of the interval examined.
2. Early in the growth phase, the Geotail ion distributions are dominated by ions from the LLBL. As the substorm progresses, contributions from the plasma mantle increase significantly. The reconfiguration of the magnetosphere during the expansion phase causes LLBL ions to lose access to the spacecraft location, and the mantle source (from both hemispheres) becomes dominant.
3. The ionosphere does not make a significant contribution to the Geotail distributions during this substorm, despite a five-fold increase in the number of ionospheric ions reaching Geotail between the growth and expansion phases of the substorm.
4. During the expansion phase, plasma mantle ions reaching Geotail do so by two different entry mechanisms. The first population enters in the near-Earth ($-30\ R_E < x < -50\ R_E$) mantle during a period of high-latitude reconnection preceding the substorm growth phase. Ions from this mantle source reach Geotail approximately two hours after entering the magnetosphere. The southward turning of the IMF at 0725 UT causes the reconnection region to shift to the dayside subsolar magnetopause. Mantle ions from the distant ($-70\ R_E < x < -100\ R_E$) mantle source enter on open field lines in the manner traditionally identified with the plasma mantle.

B. Intrinsic variability of the magnetotail

We used a two-dimensional, self-consistent large-scale kinetic model of the magnetotail to investigate magnetotail equilibria under steady solar wind conditions. Our goal was to investigate the intrinsic variability of the magnetotail in the absence of external driving. By carrying out a parameter search over the convection electric field and particle influx ito the tail, we found that the rapid non-adiabatic acceleration and lateral loss of current-carrying ions from the magnetotail current sheet results in a quasi-steady state in which the X-line in the tail oscillates between x = 40 RE and X = 60 RE downtail. An increase in the cross-tail electric field decreases the period of oscillations, while an increase in particle influx causes the amplitude of oscillations to diminish. Results from the model show very good agreement with spacecraft observations of magnetotail ion flows originating near the X-line.

C. Publications

1. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, J. Raeder, R. J. Walker, R. L. Richard, L. M. Zelenyi, L. A. Frank, W. R. Paterson, J. M. Bosqued, R. P. Lepping, K. Ogilvie, S. Kokubun, and T. Yamamoto, Ion sources and acceleration mechanisms inferred from local distribution functions, *Geophys. Res. Lett., 24*, 955, 1997.

2. El-Alaoui, M., M. Ashour-Abdalla, J. Raeder, V. Peroomian, L. A. Frank, W. R. Paterson, J. M. Bosqued, Modeling magnetotail ion distributions with global magnetohydrodynamic and ion trajectory calculations, *Geophysical Monograph 104,* 291, 1998.

3. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, J. Raeder, R. L. Richard, R. J. Walker, L. M. Zelenyi, L. A. Frank, W. R. Paterson, J. M. Bosqued, R. P. Lepping, K. Ogilvie, S. Kokubun, and T. Yamamoto, Determination of particle sources for a Geotail distribution function observed on May 23, 1995, *Geophysical Monograph 104,* 297, 1998.

4. Ashour-Abdalla, M., J. Raeder, M. El-Alaoui, and V. Peroomian, Magnetotail structure and its internal particle dynamics during northward IMF, *Geophysical Monograph Series: New Perspectives of the Earth's Magnetotail,* edited by A. Nishida, D. N. Baker, and S. W. H. Cowley, *Geophys. Monogr. Ser., 105*, 77, AGU, Washington, D. C., 1998.

5. Peroomian, V., M. Ashour-Abdalla, and L. M. Zelenyi, Self-consistent simulation of the magnetotail, *Proceedings of the International Conference on Substorms-4*, edited by S. Kokubun and Y. Kamide, Lake Hamana, Japan, March 9-13, 165, 1998.

6. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, J. Raeder, R. J. Walker, L. A. Frank, and W. R. Paterson, Sources and transport of plasma sheet ions during magnetospheric substorms, *Proceedings of the International Conference on Substorms-4*, edited by S. Kokubun and Y. Kamide, Lake Hamana, Japan, March 9-13, 479, 1998.

7. El-Alaoui, M., M. Ashour-Abdalla, J. Raeder, L. A. Frank, and W. R. Paterson, A study of transport in the near-Earth plasma sheet during a substorm using time-dependent large-scale kinetics, *Proceedings of the International Conference on Substorms-4*, edited by S. Kokubun and Y. Kamide, Lake Hamana, Japan, March 9-13, 641, 1998.

8. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, R. J. Walker, J. Raeder, L. A. Frank, and W. R. Paterson, Source distributions of substorm ions observed in the near-Earth magnetotail, *Geophys. Res. Lett., 26*, 955, 1999.

9. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, J. Raeder, R. J. Walker, L. A. Frank, and W. R. Paterson, Origins and transport of ions during magnetospheric substorms, *Geophysical Monograph Series: Physics of Sun-Earth Plasma and Field Processesl*, edited by J. L. Burch, R. L. Carovillano, and S. Antiochos, *Geophys. Monogr. Ser.*, 1999.

10. Peroomian, V., M. Ashour-Abdalla, and L. M. Zelenyi, The influence of convection on magnetotail variability, *NATO Proceedings of the Interball-ISTP Workshop*, edited by D. Sibeck, Kosice, Slovakia, in press, 1999.

11. Peroomian, V., M. Ashour-Abdalla, and L. M. Zelenyi, Intrinsic variability in the quiet-time magnetotail, *Geophysical Monograph Series*, edited by S. Ohtani, AGU, Washington, D.C., in press 1999.

12. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, R. J. Walker, J. Raeder, L. A. Frank, and W. R. Paterson, The origin of the near-Earth plasma population during a substorm on November 24, 1996, *J. Geophys. Res.*, submitted April 1999.

E. Invited Presentations

1. El-Alaoui, M., M. Ashour-Abdalla, J. Raeder, V. Peroomian, J. M. Bosqued, D. J. Williams, and A. T. Y. Lui, Modeling the transport of oxygen ions using time dependent LSK in global MHD fields, AGU, Baltimore, MD, May 27-30, 1997 (*EOS, 78*, S285).

2. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, J. Raeder, L. A. Frank, and W. R. Paterson, Determining the sources and the transport of particlesin observed distribution functions, AGU, Baltimore, MD, May 27-30, 1997 (*EOS, 78*, S308).

3. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, J. Raeder, L. A. Frank, and W. R. Paterson, Determining the sources and the transport mechanisms of ions in the magnetotail by using correlative observations and numerical simulation, AGU, San Francisco, CA, December 8-12, 1997 (*EOS*, *78*, F611).

4. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, J. Raeder, R. Walker, L. A. Frank, and W. R. Paterson, Sources and the transport of plasma sheet ions during magnetospheric substorms, International Conference on Substorms-4, Lake Hamana, Japan, March 13-19, 1998 (Abstract book, 3-11, p. 57).

5. Ashour-Abdalla, M., M. El-Alaoui, V. Peroomian, J. Raeder, R. Walker, L. A. Frank, and W. R. Paterson, Tracing plasma sources in MHD codes, 1998 Cambridge Symposium-Workshop: Multi-Scale Phenomena II in Space Plasmas, Lisbon, Portugal, June 22 - July 3, 1998.

6. Peroomian, V., M. Ashour-Abdalla, and L. M. Zelenyi, A self-consistent study of the dynamic magnetotail, Western Pacific Geophysics Meeting, Taipei, Taiwan, July 21-24, 1998 (*EOS*, *79*, W87).

7. L. M. Zelenyi, M. Ashour-Abdalla, and V. Peroomian, Intrinsic variability of magnetotail dynamics at multiple scales, NATO Advanced Research Workshop on Coordinated Studies of the Solar Wind-Magnetosphere-Ionosphere Interaction: Interball Observations, Kosice, Slovakia, Sept. 7-11, 1998.

F. No patents or inventions were conceived or reduced under this award.