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THERMAL ION HEATING IN THE
VICINITY OF THE PLASMAPAUSE--
A DYNAMICS EXPLORER GUEST INVESTIGATION

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by

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This investigation has progressed through a series of independent, but related studies. The nature of the relationship among them was the possible impact of the results on different heating mechanisms associated with the plasmopause. Those studies concerned primarily with the ion thermal structure of the plasmasphere, we carried out ourselves, enlisting aid where needed. For those involving other structural characteristics, simulations of specific heating mechanisms, or studies already under way, we collaborated with colleagues, contributing thermal ion observations and other information as needed. This investigation cannot be considered complete because of the many unanswered questions which remain. But a number of different lines of inquiry seem to be coming together, leading toward an understanding of some of the very interesting processes which are taking place near the plasmopause.

At the same time, we have achieved a new appreciation for the complicated structure that the plasma in this region of space can display. For this reason, understanding obtained through observations alone must be viewed with a degree of skepticism until supported in a consistent way with numerical simulations. We are finding that for this dual observation-simulation approach, the two spacecraft concept of the Dynamics Explorer program is proving to be invaluable. A combination of using numerical simulations to bridge the gap between high and low altitude DE observations will go far in assessing the degree of understanding we have achieved about plasmasphere structure and dynamics.

Below we summarize some of the results obtained in the various studies in which we have participated. Details of the studies are reported in the references noted at the end of each paragraph.

CHARACTERISTICS OF PLASMASPHERIC ION THERMAL AND DENSITY STRUCTURES AND THEIR RESPONSE TO GEOMAGNETIC ACTIVITY

An early surprise in this study was finding examples of ion temperature profiles from magnetically very active periods indicating depressed temperatures in the middle to outer plasmasphere relative to quiet-time values. We were concerned that these examples might be isolated ones not representative of either the characteristic response or the range of variations associated with active periods. To meet these concerns, we developed a data base containing DE-1/RIMS ion temperature and density profiles for more than 100 plasmasphere transits and looked at the mean temperatures associated with different levels of magnetic activity. Morning side results are consistent with ion heating taking place with increasing activity; but evening side results continue to show depressed values at the highest levels of activity ($6 \leq K_p \leq 9$) in the middle and outer plasmasphere. The number of cases at this highest activity level remains very limited in the data set, so that these results must still be viewed with caution. Whether this result is indeed characteristic or, in fact, represents a skewed sample resulting from special circumstances, it raises questions about the spatial distribution of ion heating, about its timing relative to geomagnetic activity, and about ion thermal response times. (Ref. 1-6.)

Regarding ion thermal response times, some information can be gleaned from the morning and evening mean temperature and density profiles. The fact that for low and intermediate levels of magnetic activity, the outer plasmasphere mean temperatures and densities are virtually the same for local morning and local evening indicates that the outer plasmasphere acts as a relatively stable heat and particle reservoir on a diurnal time scale. This apparently is not true at high levels of magnetic activity, for which the observations suggest possible heating in the post-midnight to morning time frame, decaying through the dayside. For the inner L-shells (< 3), the thermal response appears to be fairly rapid (order of 2 - 3 hours), since the morning profiles appear to have reached stable (very small standard deviations) daytime values at early hours, and the evening temperatures show significant cooling to the underlying ionosphere. (Ref. 4-6.)

Work on a quantitative study of temperature and density gradients has been less fruitful. Results from using small samples turned out to be very sample dependent and, hence, unreliable. Hand analysis of the larger data set was prohibitively time consuming, so that development of appropriate software for automatically computing gradients has been necessary. This has had its own difficulties and is currently an on going project which will be pursued from other resources. This quantitative approach is ultimately necessary to verify any understanding we gain by other means, so it should be worth the effort invested. (Ref. 3.)

A qualitative approach has been used in another study in which we have participated. Plasmaspheric ion density profiles have been characterized both in terms of overall structure and with regard to certain specific features. Although the judgments have been qualitative, in the sense of subjective human assessments, a set of standard characteristics has been developed and systematically applied to a large data set (more than 500 passes of DE-1/RIMS through the plasmasphere) covering all universal times. Of the categories defined, two were by far predominate: smooth featureless profiles, and profiles containing multiple plateaus, each occurring in about 40% of the observations. The former predominated on the dawn side, while the latter were found most frequently in the afternoon/dusk sector. This suggests that filling times of the order of one day can have significant effects on the density structure of the outer plasmasphere. It was also found that the density gradients were generally steepest on the night side. For heating processes which depend on thermal electron or ion densities, this would suggest that such mechanisms would operate most effectively in producing higher temperatures (due to localization of the heating) on the night side. (Ref. 7,8.)

Another study in which we have participated has been concerned with a particular feature of plasmaspheric structure discovered by DE-1/RIMS, the heavy ion (O^+ , O^{++}) density enhancements observed in the vicinity of the plasmopause. This has been of particular interest to our overall investigation because one suggested explanation for the enhancements is heating near the plasmopause at high altitudes. The heat is conducted down field lines to

ionospheric altitudes causing an increase in heavy ion scale heights and/or in the ambipolar electric field, resulting in increases of heavy ion densities. If this explanation is correct, then the heavy ion density enhancement would be a signature of heating processes associated with the plasmopause. Much modeling work and further observations remain to establish the nature of this association, but preliminary simulations are promising. (Ref. 9,10.)

PLASMA HEATING NEAR THE PLASMAPAUSE

This study was comprised of two parts. For the first part we examined DE-1/RIMS data during 1982, which included the period when its orbit around apogee was nearly aligned with geomagnetic field lines. Here we identified a population of trapped thermal ions within a few degrees of the magnetic equator. Fluxes were enhanced, although densities remained approximately constant (as determined from PWI observations of the upper hybrid frequency) or even had local minima at the magnetic equator. These trapped ions had bi-Maxwellian distributions with parallel energies of about 1 eV or less and perpendicular energies of 10 - 50 eV and densities in the 10 - 100 cm^{-3} range. In more than half of the 300 cases, only H⁺ showed these characteristics. Equatorial noise at frequencies around 100 Hz is also associated with this population. These observations suggest transverse heating of the ions by waves in the vicinity of the equatorial plasmopause. (Ref. 11,12.)

The second part of the examination of plasmopause heating was a collaboration with J. Kozyra, The University of Michigan. The initial phase was oriented toward mechanisms for SAR arc production, but the scope is broadening. The focus of this initial phase was a demonstration that (1) Coulomb collisions between ambient thermal plasma and ring current and suprathermal ions could provide sufficient energy to magnetospheric electrons to drive SAR arc emissions; and (2) the latitudinal distribution of this heating was consistent with the distribution of SAR arc emissions. This was carried out with in situ observations from DE-1 and DE-2 instruments and ground based SAR arc observations. (Ref. 13-15.)

An interesting feature of these results is that most of the electron heating came from energetic O⁺ ions, which have been observed only relatively recently. This phase of the study was concerned with the consequences of heating of ambient electrons. In the course of the calculations, it was found that thermal ions were also heated through Coulomb collisions although at somewhat lower (10% - 80%) rates than the electrons. Preliminary modeling of the plasmasphere, using DE-2 observations for low altitude boundary conditions and heat input to the ions at high altitudes from Coulomb collisions, shows very satisfactory agreement with DE-1/RIMS observations of temperature density and composition. We hope to be able to pursue this line of investigation further in the future. (Ref. 16.)

CORRESPONDENCE BETWEEN IONOSPHERIC AND PLASMASPHERIC FEATURES

We have participated in two collaborative studies in examining the relationship between DE-1 observations at high altitudes and DE-2 observations at low altitudes. In a study led by the Huntsville group, the primary relationships observed were associated with the sensitivity of the ionospheric electron temperature to the structure (both temperature and density) of the plasmasphere at high altitudes. In particular, it was verified that there is frequently a clear peak in ionospheric electron temperatures at the base of field lines linked to the vicinity of relatively strong high altitude plasmopause density gradients. Ionospheric electron density structure, on the other hand, shows little indication of a relationship to high altitude plasma structure equatorward of the plasmopause. It appears that some form of energy is transferred to electrons at high altitudes and is then conducted to the ionosphere. This occurs for moderate as well as high magnetic activity. (Ref. 17-19.)

The second study, led by the University of Michigan group, was looking for high altitude features associated with field lines on which SAR arcs were observed in the ionosphere (or their signatures in ionospheric electron temperatures). Three principle signatures were found. First, a localized ion density enhancement is found in the region of field lines extending up from the location of heated ionospheric electrons, almost detached from the main body of the plasmasphere. Second, localized bands of intense ELF hiss are found on these same field lines. And finally, at energies below 17 keV, the ring current is dominated by O⁺. These signatures are consistent

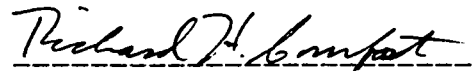
with and related to results and observations from several of the other studies noted above. (Ref. 20-22.)

CONCLUSION

From the results of these studies, a rough picture is beginning to emerge. It appears that energy may be generally available to ions and electrons in the vicinity of the plasmopause from Coulomb interactions between ambient thermal plasma and low energy ring current and suprathermal ions, particularly O^+ . The amount of energy transferred depends on the densities and energies of each of the components; and the spatial distribution of heating in turn depends critically on the spatial distribution of the different populations, especially on the density gradients. The spatial distribution of the thermal plasma is found to vary significantly on a diurnal time scale and is complicated by the plasmasphere erosion and refilling processes associated with magnetic activity and its aftermath. Likewise, the dynamics of the ring current depends on present and past magnetic activity. In general, it appears that the inner plasmasphere ($L < 3$) is little affected by such processes, while the outer plasmasphere is in a continuing state of change because of them.

Thermal ion composition also appears to be influenced by the heating taking place, often increasing the heavy ion population in the vicinity of the plasmopause. To what extent this influences wave activity, stimulating perhaps other forms of heating, remains an open

question. The observation of localized ELF hiss on SAR arc field lines could be either a cause or an effect of the other processes occurring there. The observations of equatorial heating near the plasmapause in the presence of equatorial noise also raise the likelihood of a wave source of energy. And it is not unreasonable to expect that both particle and wave heat sources are significant, although not necessarily at the same times and places. While the complications inherent in the number of variables which can influence the plasma in the outer plasmasphere tend to obscure what is happening there, a combination of observations from the two DE spacecraft, together with developing plasmaspheric models, should provide a means for taking the next significant steps.



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REFERENCES

1. Comfort, R. H., J. H. Waite, Jr., and C. R. Chappell, Response of plasmaspheric ion thermal structure to geomagnetic activity, EOS Transactions of the American Geophysical Union, 65, p. 1044, 1984; presented to the Fall Meeting of the American Geophysical Union, December 3-7, 1984, San Francisco, CA.
2. Comfort, R. H., J. H. Waite, Jr. and C. R., Chappell, Thermal ion temperatures from the retarding ion mass spectrometer on DE-1, J. Geophys. Res., 90, 3475, 1985.
3. Comfort, R. H., and C. R. Chappell, Variations in thermal ion temperatures near the plasmopause associated with geomagnetic activity, EOS Transactions of the American Geophysical Union, 66, p. 344, 1985; presented to the Spring Meeting of the American Geophysical Union, May 37-31, 1985, Baltimore, MD.
4. Comfort, R. H., I. T. Newberry, and C. R. Chappell, Characteristics of ionospheric plasma in the plasmasphere, presented to the Chapman Conference on Ionospheric Plasma in the Magnetosphere: Sources, Mechanisms, and Consequences, February 3-6, 1986, Yosemite National Park, CA.
5. Comfort, R. H., Plasmasphere thermal structure as measured by ISEE-1 and DE-1, invited paper, to be presented to the XXVI COSPAR Meeting, June 30 - July 12, 1986, Toulouse, France; and to be published in Adv. Space Res., 1986.
6. Comfort, R. H., T. E. Moore, J. H. Waite, Jr., M. O. Chandler, J. L. Horwitz, and C. R. Chappell, Thermal ion densities and composition from DE-1/RIMS, to be submitted to J. Geophys. Res., 1986.
7. Horwitz, J. L., R. H. Comfort, and C. R. Chappell, Plasmasphere and plasmopause characteristics as measured by DE-1, invited paper, to be presented to the XXVI COSPAR Meeting, June 30 - July 12, 1986, Toulouse, France; to be published in Adv. Space Res., 1986.
8. Horwitz, J. L., R. H. Comfort, and C. R. Chappell, Plasmopause and plasmasphere structure, to be submitted to J. Geophys. Res., 1986.
9. Roberts, Jr., W. T., J. L. Horwitz, R. H. Comfort, C. R. Chappell, J. H. Waite, Jr., J. L. Green, Heavy ion enhancements in the Earth's outer plasmasphere, to be submitted to J. Geophys. Res., 1986.
10. Chandler, M. O., J. L. Horwitz, R. H. Comfort, and J. T. Ponthieu,, Theoretical investigations of O⁺ and O⁺⁺ enhancements

in the outer plasmasphere, EOS, 67, 336, 1986; to be presented to the Spring Meeting of the American Geophysical Union, May 19 - 22, 1986, Baltimore, Maryland; also in preparation for submission to J. Geophys. Res., 1986.

11. Olsen, R. C., C. R. Chappell, and D. A. Gurnett, Ion acceleration at the magnetic equator, presented to the Chapman Conference on Ion Acceleration in the Magnetosphere and Ionosphere, June 3-7, 1985, Wellesley, MA.
12. Olsen, R. C., S. D. Shawhan, D. L. Gallagher, J. L. Green, C. R. Chappell, and R. R. Anderson, Plasma observations at the Earth's magnetic equator, submitted to J. Geophys. Res., 1985.
13. Kozyra, J. U., T. E. Cravens, A. F. Nagy, D. W. Slater, R. H. Comfort, and W. K. Peterson, An examination of the Coulomb collision excitation mechanism for SAR arcs using Dynamics Explorer satellite data, presented to the 5th Scientific Assembly of IAGA, Prague, Czechoslovakia, August 5-17, 1985.
14. Cravens, T. E., J. U. Kozyra, A. F. Nagy, R. H. Comfort, and W. K. Peterson, A re-evaluation of the Coulomb collision energy source mechanism for SAR arcs using Dynamics Explorer data, EOS, 67, 336, 1986; to be presented to the Spring Meeting of the American Geophysical Union, May 19 - 22, 1986, Baltimore, Maryland.
15. Kozyra, J. U., T. E. Cravens, A. F. Nagy, W. K. Peterson, R. H. Comfort, and L. H. Brace, The role of ring current O⁺ in the formation of Stable Auroral Red arcs, to be submitted to J. Geophys. Res., 1986.
16. Chandler, M. O., J. U. Kozyra, J. L. Horwitz, R. H. Comfort, L. H. Brace, and W. K. Peterson, Modeling of the thermal plasma in the outer plasmasphere: a magnetospheric heat source, submitted for presentation to The First Huntsville Workshop on Magnetosphere/Ionosphere Plasma Models, October 13-16, 1986, Guntersville State Park, Alabama.
17. Horwitz, J. L., L. H. Brace, R. H. Comfort, and C. R. Chappell, Near-conjugate measurements of plasmasphere and ionosphere structure, EOS Transactions of the American Geophysical Union, 65, p. 1044, 1984; presented to the Fall Meeting of the American Geophysical Union, December 3-7, 1984, San Francisco, CA.
18. Horwitz, J. L., R. H. Comfort, L. H. Brace, and C. R. Chappell, Dual spacecraft measurements of plasmasphere - ionosphere coupling, presented to the Chapman Conference on Ionospheric Plasma in the Magnetosphere: Sources, Mechanisms, and Consequences, February 3-6, 1986, Yosemite National Park, CA.
19. Horwitz, J. L., L. H. Brace, R. H. Comfort, and C. R. Chappell, Dual spacecraft measurements of plasmasphere-ionosphere coupling, J. Geophys. Res., in press, 1986.
20. Kozyra, J. U., T. E. Cravens, A. F. Nagy, D. A. Gurnett, R. L.

- Huff, R. H. Comfort, J. H. Waite, Jr., L. H. Brace, R. A. Hoffman, J. D. Winningham, J. L. Burch, and W. K. Peterson, Observations by the Dynamics Explorer satellite of correlated high and low altitude signatures on SAR arc field lines, EOS, 67, 336, 1986; to be presented to the Spring Meeting of the American Geophysical Union, May 19 - 22, 1986, Baltimore, Maryland.
21. Kozyra, J. U., T. E. Cravens, A. F. Nagy, D. A. Gurnett, R. L. Huff, R. H. Comfort, J. H. Waite, Jr., L. H. Brace, R. A. Hoffman, J. D. Winningham, J. L. Burch, and W. K. Peterson, Observations by the Dynamics Explorer satellites of new signatures in particle and field measurements associated with SAR arc field lines at magnetospheric heights, to be presented to the XXVI COSPAR Meeting, June 30 - July 12, 1986, Toulouse, France; and to be published in Adv. Space Res., 1986.
22. Kozyra, J. U., T. E. Cravens, A. F. Nagy, D. A. Gurnett, R. L. Huff, R. H. Comfort, J. H. Waite, Jr., W. K. Peterson, L. H. Brace, J. L. Burch, J. D. Winningham, Plasmaspheric signatures associated with stable auroral red arcs - new results from a coordinated DE-1 and -2 study, to be submitted to J. Geophys. Res., 1986.