EVIDENCE FOR EARTH MAGNETOSPHERIC TAIL ASSOCIATED PHENOMENA AT 3100 R_E

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Abstract. Examination of Pioneer 7 NASA Ames Research Center plasma analyzer data obtained in February 1977 at ~3100 R_E, downstream from the earth in the vicinity of the expected extended geomagnetic tail indicate that tail related phenomena may have been observed. These observations are characterized by intermittent intervals of extremely low levels of plasma ion flux. Corresponding Prognoz 5 Space Research Institute plasma ion data obtained in the vicinity of earth indicate typical solar wind flux levels and a relatively steady character to the solar wind during this time. These recent Pioneer 7 observations in the vicinity of the expected geomagnetic tail at ~3100 R_E are consistent with our earlier Pioneer 7 observations in September 1966 at ~1000 R_E and our Pioneer 8 observations in January 1968 at ~500 R_E and represent the most extended positive observational information of the extended nature of the geomagnetic tail. These measurements suggest that at times Jupiter's magnetosphere may have tail associated phenomena extending to distances of ~10 AU downstream from the planet. These measurements also raise the possibility that at times comets may have tail associated phenomena extending downstream from the visible tail.

Introduction

In February 1977, almost 11 years after its launch, Pioneer 7 traversed the region at ~ 3100 R_E downstream from the earth. The Ames Research Center plasma analyzer on Pioneer 7, which was the only instrument on the spacecraft that was operating, observed some of the plasma parameters in this region during the four time intervals for which the spacecraft was tracked by ground stations. In this paper these plasma observations are compared with the solar wind data obtained in the vicinity of the earth on Prognoz 5 by the Space Research Institute plasma spectrometer. Comparisons of the data indicate that extended geomagnetic tail associated phenomena may have been observed by Pioneer 7 at ~ 3100 R_E. These observations are consistent with the earlier Pioneer 7 and Pioneer 8 observations of the extended geomagnetic tail at ~ 1000 R_E and ~ 500 R_E, respectively, and represent the most extended observations to date of geomagnetic tail associated phenomena. These observations also imply that Jupiter's tail may extend to a distance of 10 AU beyond the planet.

It is now recognized on the basis of *in situ* observations at Jupiter [*Intriligator and Wolfe*, 1976; *Smith et al.*, 1976] that there are some important similarities between the solar wind interaction with the earth's magnetosphere and its interaction with the Jovian magnetosphere. Therefore, knowledge of the geomagnetic tail, which directly affects models of geomagnetospheric circulation and the access and loss of particles to the geomagnetosphere, may also directly affect models of the Jovian magnetosphere and of cometary phenomena. It is known that the geomagnetic tail at the distance of ~ 80 R_E is well ordered and well defined (see review by *Wolfe and Intriligator* [1970]). The first positive observational information on the extended nature of the geomagnetic tail was obtained with Pioneer 7 which shortly after its launch (August 16, 1966) went through the expected region of the geomagnetic tail at a distance of ~ 1000 R_E downstream from the earth [*Wolfe et al.*, 1967; *Intriligator et al.*, 1972]. Intermittent intervals of disturbed plasma ion spectra were observed which were characterized by depressed levels of flux (or at times even an absence of measurable flux) and at times changes in their overall shape. The changes in the levels of flux and the spectra were so great that if they were solar wind spectra one would have expected them to be associated with wide changes in geomagnetic activity (e.g., as indicated by the Kp index). Since during these intervals of observation of disturbed spectra there were no such changes these disturbed spectra were identified as not being associated with the solar wind but as being indicative that geomagnetic tail associated phenomena were being encountered by the Pioneer 7 spacecraft. Similarly, results indicating extended geomagnetic tail associated phenomena were obtained in January 1968 when Pioneer 8, during its outbound trajectory, traversed the region of the expected geomagnetic tail at a distance of ~ 500 R_E downstream from the earth [*Intriligator et al.*, 1969, *Scarf et al.*, 1970].

Observations Near Earth and at ~ 3100 R_E

During the ensuing eleven years since its launch in 1966 Pioneer 7 has been in a heliocentric orbit. This orbit brought Pioneer 7 to the region of ~ 3100 R_E downstream from the earth in 1977. The ecliptic projection of the Pioneer 7 trajectory in the vicinity of 3100 R_E in February 1977 is shown in Figure 1. The earlier Pioneer 7 outbound trajectory in the vicinity of 1000 R_E in September 1966 and the Pioneer 8 outbound trajectory in the vicinity of 500 R_E in January 1968 are also shown in Figure 1. Throughout the February 1977 traversal of the region shown in Figure 1 the Pioneer 7 spacecraft was very close to the ecliptic plane as shown in the inset in Figure 1.

A tracking pass was planned to obtain observations on February 2 to establish a "baseline" for solar wind measurements outside the expected region of the extended geomagnetic tail since there had been no tracking of the Pioneer 7 spacecraft since September 1976. In addition, no experimenter data tapes have been available for Pioneer 7 since January 1974 and the sun pulse has not been operational on Pioneer 7 since February 1969. Unfortunately, the solar wind flux was unusually high on February 2, 1977 so that the Pioneer 7 plasma analyzer and plasma probes near earth [Solar-Geophysical Data, 1977] were saturated. As a result of these spacecraft limitations the available data during February 1977 are not of the quality of the Pioneer 7 data available from 1966 to 1969. In addition, there is no simultaneous Pioneer 7 magnetic field data available since the Goddard Space Flight Center magnetometer is no longer functioning. In spite of these imposed limitations, the Pioneer 7 data indicate that extremely high values of the total flux (at or near saturation) were observed on February 2 and that intermittent intervals of extremely low values of the total flux (near the noise level) were observed at the end of the February 9 - 10 pass. Wide variations such as these are not common in the quiet solar wind. Even though the extremely high values of the total flux observed on February 2 are larger than those associated with the nominal solar wind, it is tempting to speculate that the intermittent intervals of extremely

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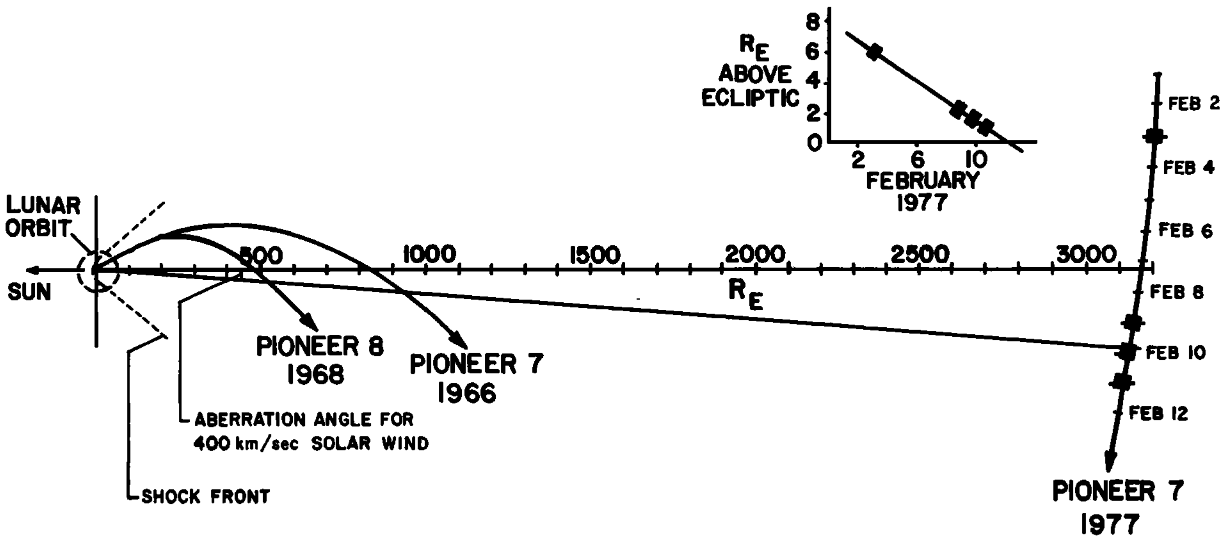

Fig. 1. Ecliptic plane projection of the recent (1977) Pioneer 7 traversal at ~ 3100 R_E through the expected region of the extended geomagnetic tail. The four black squares denote the times/spacecraft locations for which there were tracking passes. The inset indicates the spacecraft location with respect to the ecliptic. The earlier Pioneer 7 (1966) traversal at 1000 R_E and the Pioneer 8 (1968) traversal at ~ 500 R_E are also shown.

low flux observed near the end of the February 9 - 10 pass are indicative of extended geomagnetic tail associated phenomena.

To more fully study this possibility, the Pioneer 7 data on February 9 - 10 have been compared with the Prognoz 5 data obtained earlier (correcting for solar wind propagation time delays) in the vicinity of the earth and the available Pioneer 7 ion energy (per unit charge) spectra have also been examined. The total ion flux data obtained on Pioneer 7 in the vicinity of 3100 R_E for the third and fourth (the last) tracking passes are shown by the black lines in Figure 2. The Pioneer 7 data shown in Figure 2 indicate the individual measurements (i.e., not hourly averages of the total flux). The arrows in Figure 2 indicate some of the short periods of time when there are extreme dropouts in flux in the Pioneer 7 data. The dots in Figure 2 indicate the hourly average values for the (total) flux obtained on IMP 8 [Solar-Geophysical Data, 1977] .These Imp values are consistent with the more frequent solar wind flux measurements obtained on February 9 in the vicinity of the earth on Prognoz 5 by the Space Research Institue plasma spectrometer (O. L. Vaisberg, principal investigator). During this interval the solar wind speed was on the order of 600 to ~ 650 km/sec. The time delay between Prognoz 5 and Pioneer 7 for these speeds is approximately 9 hours. The flux values obtained on Prognoz 5 and IMP 8 are within the typical range of values associated with the nominal solar wind and indicate that the solar wind was relatively quiet and steady during this time. While the Kp values [Solar-Geophysical Data, 1977] reported for February 9, are relatively more disturbed than the other values recorded that month, in the absolute sense (e.g., 4^+, 3^+) they are not very high or unusual. Therefore, they are consistent with the observations of the relatively quiet and steady solar wind in the vicinity of the earth. It is tempting to identify the short periods of time when there are extreme dropouts in flux (e.g., as denoted by the arrows in Figure 2) as being associated with extended geomagnetic tail associated phenomena. An examination of the individual ion energy (per unit charge) spectra emphasizes these differences during this pass. Figures 3 and 4 indicate intervals during which extremely depressed levels of flux were observed. These intervals occur in Figure 3 from 0325 UT through 0340 UT and in Figure 4 from 0432 UT to 0444 UT, which was the end of this tracking pass. In both Figures 3 and 4 a number of consecutive spectra show this phenomenon indicating that these "dropouts" in flux are real and are not associated with time-aliasing of the data.

Discussion

The intermittent intervals characterized by low levels of measurable flux observed on Pioneer 7 at ~ 3100 R_E, as shown in

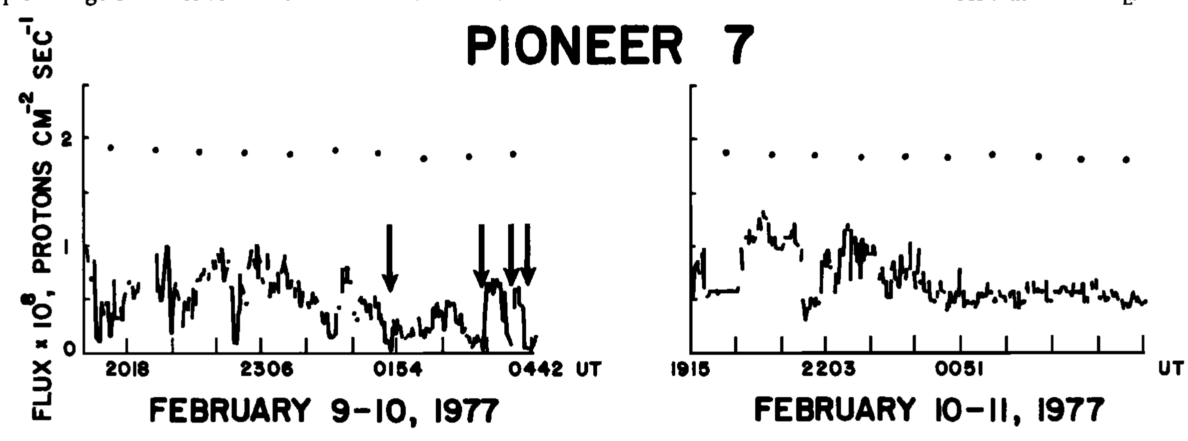

Fig. 2. The total ion data (the lines) obtained on Pioneer 7 in the vicinity of 3100 R_E for the third and fourth tracking passes. The Pioneer 7 data indicate the individual measurements (i.e. not hourly averages of the total flux). The arrows indicate some of the short periods of time when there are extreme dropouts in flux in the Pioneer 7 data. The dots denote the hourly average for the total flux obtained on IMP 8 corrected for the time delay (see text).

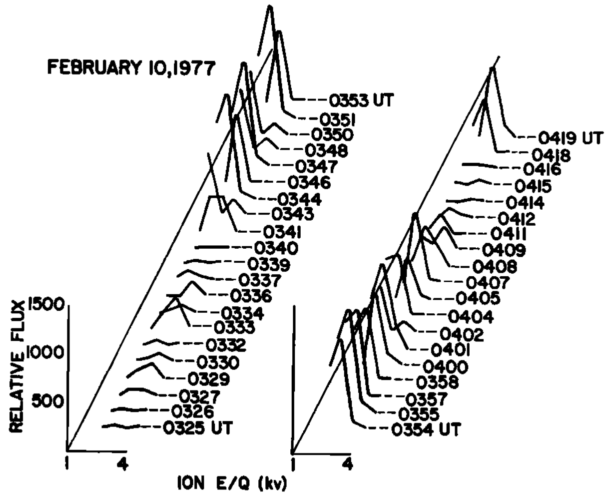

Fig. 3. Ion energy per unit charge (E/Q) spectra measured at Pioneer 7 on February 10, 1977 between 0325 UT and 0419 UT. The extremely depressed levels of flux observed (e.g. from 0325 UT through 0340 UT) may be indicative of tail associated phenomena at ~ 3100 R_E downstream from the earth.

Figures 2-4 are similar to the low levels of flux observed at ~ 1000 R_E downstream from the earth on Pioneer 7 in 1966 [*Intriligator et al.*, 1969, 1972]. Examples of these depressed levels of flux observed in the earlier ion energy spectra obtained in the vicinity of the expected geomagnetic tail at 1000 R_E are shown in Figure 5 which is taken from Intriligator *et al.* [1972]. In this figure, all eight of the spectra in the second graph (1046 - 1052 UT), all eight in the third graph (1801 - 1806 UT) and the first three spectra in the fourth graph (1807-1813 UT) are examples of geomagnetic tail associated phenomena.

It is tempting to associate this similarity of the low levels of measureable flux observed in the Pioneer 7 ion energy spectra obtained at ~ 3100 R_E in 1977 with those obtained at ~ 1000 R_E in 1966 and to speculate that geomagnetic tail associated phenomena can extend at times to a distance of at least 3100 R_E downstream from the earth. The corresponding Prognoz 5 data obtained upstream from Pioneer 7 in cislunar space indicate that 'typical' levels of solar wind flux were being observed at Prognoz 5. This further supports the supposition that Pioneer 7 was observing localized phenomena that were not associated with the solar wind but rather with the extended geomagnetic tail.

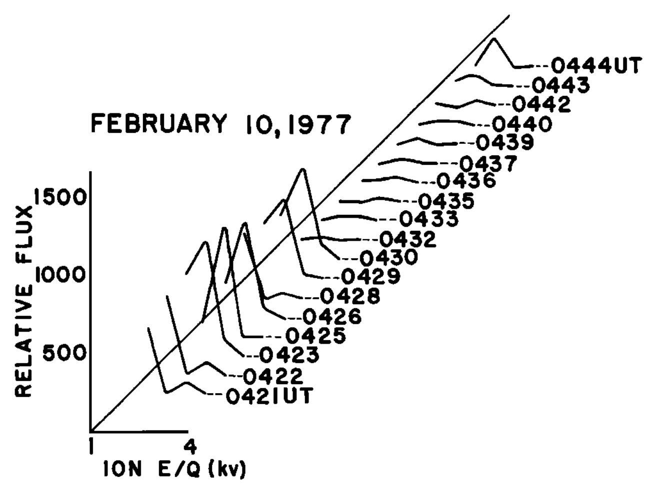

Fig. 4. Ion energy per unit charge (E/Q) spectra measured from Pioneer 7 from 0421 UT to 0444 UT (the end of the tracking pass) on February 10, 1977. The extremely depressed levels of flux observed from 0432 UT to 0444 UT are again suggestive of tail associated phenomena at ~ 3100 R_E downstream from the earth.

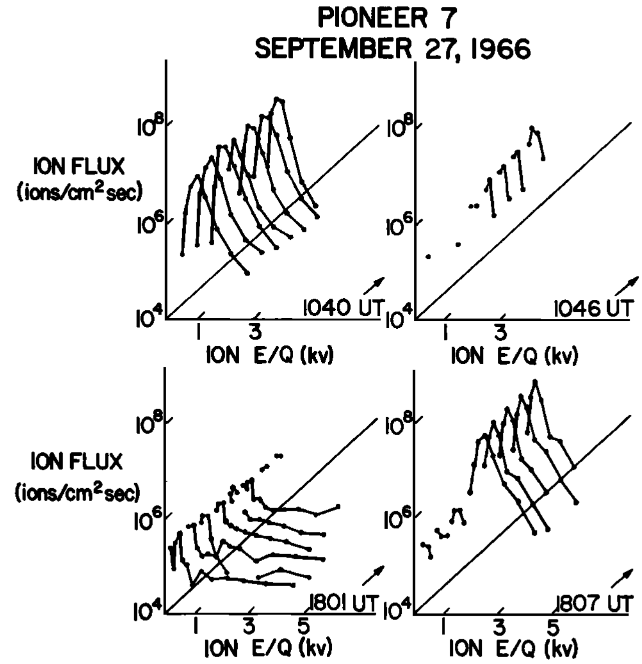

Fig. 5. Ion E/Q spectra obtained eleven years earlier (in 1966) on Pioneer 7 at ~ 1000 R_E downstream from the earth (Intriligator et al. 1972). All eight of the spectra in the second graph (1046 - 1052 UT), all eight in the third graph (1801 - 1806 UT) and the first three spectra in the fourth graph (after 1807 UT) were identified as examples of tail associated phenomena at ~ 1000 R_E.

In 1965 Mariner 4 passed through the expected region of the geomagnetic tail at a distance of 3300 R_E (~ 0.14 AU) downstream from the earth. No tail associated phenomena were observed by the suprathermal electron detector [*Van Allen*, 1966] or the magnetometer [*Coleman et al.*, 1965]. No plasma analyzer results are available from Mariner 4. D.D. McKibbin et al. (unpublished manuscript, 1976), however, have shown based on analysis of intervals of geomagnetic tail associated phenomena observed by the Pioneer 7 spacecraft in 1966, that even if the geomagnetic tail did exist at 3300 R_E in 1965 during the Mariner 4 traversal, the unlikelihood of the presence of observable suprethermal electrons in the tail at these

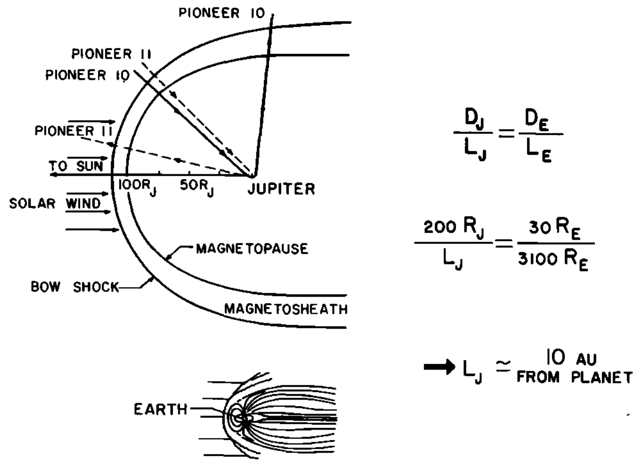

Fig. 6. Simple scaling ratio $D_J/L_J = D_E/L_E$ (where D_J and D_E are the diameters of the Jovian and Earth magnetospheres, respectively, and L_J and L_E are, respectively, the 'lengths' of the Jovian and Earth magnetospheres downstream at which tail associated phenomena may exist). Using the values indicated in the figure and solving for L_J we find that tail associated phenomena for the Jovian magnetosphere may exist at a distance of 10 AU downstream from Jupiter.

large distances and the sampling frequency of Mariner 4 (and its magnetometer) were such that it would not have been possible to identify such geomagnetic tail associated phenomena.

The Pioneer 7 observations at 3100 R_E reported in this paper are consistent with the earlier Pioneer 7 and Pioneer 8 observations that widely varying spectra and depressed levels of plasma flux are indicative of extended geomagnetospheric tail associated phenomena. These observations are also consistent with the plasma observations on Mars 3 [*Vaisberg et al.*, 1973] at a distance of ~ 3000 R_E downstream of the earth in which an apparent lack of measureable plasma was found. At this time, however, it is still not possible to distinguish between a number of theoretical predictions of the physical nature of these phenomena, of which the more likely include:

1) If the earth's magnetosphere has closed between 80 and 500 R_E, then the observations at 1000 R_E and 3100 R_E could be those of a turbulent downstream wake.

2) If the solar wind has not diffused into the geomagnetic tail, then the observations could be those of the tail flapping past the spacecraft at 3100 R_E.

3) If, at these extended distances, the tail has a filamentary structure, possibly quite intertwined, then the observations could be those of the various filaments.

4) If the tail has broken up into 'bundles' that are not connected to the earth, then the observations could be those of some of the bundles traveling past the spacecraft.

5) If magnetic merging [*Dungey*, 1965] has taken place, then the observations could be those of the subsequent acceleration of pinched-off gas to near solar wind velocities.

Clearly, a knowledge of the probability of occurrence of each of these possibilities would affect models of geomagnetospheric circulation and the access and loss of particles to the geomagnetosphere.

It is also interesting to consider Jupiter's magnetosphere and to speculate, based on the Pioneer 7 observations at 3100 R_E, as to the distance downstream of Jupiter where extended Jovian magnetospheric tail associated phenomena may exist. Using a simple scaling ratio, as shown in Figure 6 where D_J and D_E are the diameters of the Jovian and earth magnetospheres, respectively, and L_J and L_E are, rspectively, the 'lengths' of the Jovian and earth magnetospheres downstream at which tail associated phenomena may exist we can scale our results to the case of the Jovian magnetosphere. Using the values for each of the quantities shown in Figure 6 and solving for L_J we find that tail associated phenomena for the Jovian magnetosphere may exist at a distance of 10 AU downstream from Jupiter. This result implies that at times Saturn may traverse a region in which local phenomena associated with Jupiter's extended magnetospheric tail are present rather than the 'typical' solar wind. This may give rise to transient effects, which may be observable, in the vicinity of Saturn. It should be noted that the Ames Research Center Plasma Analyzer on Pioneer 10 observed intermittent depressed levels of plasma flux at a distance of ~ 5 AU downstream from Jupiter in 1976 and these observations [*Wolfe*, 1976] have been identified as being associated with the Jovian magnetospheric tail. It is anticipated that further *in situ* observations downstream of Jupiter and observations at Saturn will give us additional information concerning the specific nature of the Jovian magnetosphere at extended distances downstream from the planet and its possible interactions with Saturn. These recent Pioneer 7 observations also raise the possibility that if identifiable disturbances are present far downstream from an obstacle, cometary tail associated phenomena may extend at times well beyond the visible tail.

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