

ON THE PROPAGATION OF MEV ELECTRONS FROM JUPITER TO THE EARTH

C. H. Barrow*

Abstract

Considerable evidence has been presented in the literature to demonstrate that some of the relativistic electrons observed by spacecraft near to the Earth have originated at Jupiter. It is believed that some of the Jovian electrons are transported along interplanetary magnetic field (IMF) lines between corotating interaction regions (CIRs) that have simultaneously encountered both the Earth and Jupiter while others reach the Earth by cross-field diffusion. This has been investigated further by comparing high energy electron count-rates (ECRs), measured at the geo-stationary orbit by GEOS 2 in 1979, with solar wind (SW) and interplanetary magnetic field (IMF) data taken both at Jupiter, by Voyager 2, and at the Earth, as catalogued in the NASA Space Science Data Center OMNI File. It is shown that during the period studied (the first six months of 1979 when Voyager 2 was approaching Jupiter) the Earth and Jupiter could not have been magnetically connected and therefore all electrons reaching the Earth from Jupiter must have been transported by cross-field diffusion unless some other unknown process exists. In agreement with other workers it is found that ECR enhancements are preceded by decreasing SW velocity. These decreases take place over some one or two days at the Earth but at Jupiter, where the stream structure is far more clearly defined, the decreases occur over longer periods, up to about 14 days, corresponding to the interval between successive CIRs. There are indications that cross-field diffusion can only occur when the SW velocity is not too high. Even though the present data sets only cover six months, they do give a very clear picture of the sequence of events at Jupiter associated with an ECR enhancement while also raising several interesting questions.

1 Introduction

Relativistic electrons originating at Jupiter were discovered in the interplanetary medium by Pioneer 10 in 1973 [Chenette et al. 1974; Teegarden et al., 1974]. Teegarden et al. suggested that these Jovian electrons were responsible for the increases in electrons observed near the Earth by McDonald et al. [1972] and by L'Heureux et al. [1972]. Jovian electrons were studied further by Krimigis et al. [1975], Mewaldt et al. [1976], L'Heureux and Meyer [1976], Conlon [1978], Eraker and Simpson [1979] and Chenette [1980]. Paulikas

*Max-Planck-Institut für Aeronomie, W-3411 Katlenburg-Lindau, Germany.

and Blake [1976] originally suggested that high-energy electrons at the geo-synchronous orbit were modulated by the passage of an IMF sector boundary. Subsequently, Paulikas and Blake [1979] and Baker et al. [1979] demonstrated that the solar wind speed and stream structure were more important in controlling these high-energy electrons; they also showed that, at $6.6 R_E$, a 27-day periodicity existed in electron fluxes during 1977 and 1978 which closely followed solar wind speed variations.

Chenette [1980] used characteristics of the electron energy spectra to separate solar electrons from Jovian electrons, observed by Imp 8 during 1973–1979. After filtering out solar electrons, taken as having a spectral index r greater than 2.0 in an assumed energy spectrum of the form $dJ/dE = kE^{-r}$ where E is the electron energy and J is the electron flux, he found an approximate 13-month periodicity in the Jovian electron flux which he identified with the synodic period of Jupiter. Chenette explained this flux variation in terms of a diffusion model for Jovian electron propagation, originally invoked by Conlon [1978] and based upon the Fokker–Planck equation [Parker, 1963], to explain the periodic variation in electron fluxes measured by Pioneer 11 within 2 AU of Jupiter. Conlon [1978] also extended his model to 1 AU from the Sun and found that it could explain the electron flux enhancements detected at the Earth even when Jupiter was not connected by the IMF. More recently, Baker et al. [1986] found large and frequent increases in 3–10 MeV electron fluxes observed at $6.6 R_E$ during the 1981–1984 approach to solar minimum; also, the 27-day periodicity was well-defined during this period. Some reduction in the electron fluxes was observed around solar maximum in 1979 to 1980, however.

Moses [1987] analysed observations of 5–30 MeV Jovian electrons made at 1 AU by ISEE 3 from 1978 to 1984. The 13-month periodicity is well shown but some of the 27-day variation cannot be attributed to CIR passages. The diffusion-convection model is again invoked to explain the 13-month periodic variation. Christon et al. [1989] compare intensity-time flux measurements at the geosynchronous orbit and in interplanetary space for the period 1976–1984. They find that the intensity envelope of the electron flux at $6.6 R_E$ does not correlate with the 13-month periodicity observed in interplanetary space near the Earth. It should be noted, however, that in the paper by Moses [1987] it can be seen that the daily count rates presented in his Figures 3 and 5 do not have identical time scales; the scale of one figure is displaced relative to the other. According to Moses [private communication, May, 1991], the scale in Figure 5 is in error by some 3 months, the first day of the data being Day of Year (DOY) 78227, as shown in his Figure 3. The same error also appears in Figure 3(a) of the paper by Christon et al. [1989]. This is unimportant as far as the 13-month periodicity is concerned although a 3-month advance of the time scale in Figure 3(a) of Christon et al. [1989] would certainly improve correlation of their Figure 3(a) with Figures 3(b) and 3(c); for example, the large spikes observed in mid-June 1980 would then align.

In the present paper we consider the count-rates of electrons having energies greater than 10 MeV measured by GEOS 2 during 1979. For these electrons, the transport time from Jupiter to the Earth would be quite short, of the order of one hour; it is not, therefore, unreasonable to compare count rates measured close to the Earth with SW and IMF parameters measured at Jupiter by Voyager 2. Although the data sets are relatively short, about six months, it is particularly interesting to make this comparison as it must

be SW/IMF effects at Jupiter that exert the fundamental control of the high-energy electron transport from Jupiter to the Earth. Also, SW/IMF control, insofar as this can be assessed, might be expected to be more obvious at Jupiter than at the Earth as the IMF sector structure tends to become more ordered and more clearly defined at greater distances from the Sun.

The electron count-rate data were taken by ESA Experiment S-321 [Wilken et al., 1977], the solar wind data at Jupiter were taken by the Voyager Plasma Science (PLS) experiment [Bridge et al., 1977] and the IMF data by the Voyager Magnetometer (MAG) experiment [Behannon et al., 1977]. Solar wind measurements close to the Earth are also compared, using data from the National Space Science Data Center (NSSDC) OMNI File [Couzens and King, 1986].

2 Preliminary survey of the problem

The background presented in the previous section gives a general picture of high-energy electron transport from Jupiter to the Earth which is, to some extent, dependent upon IMF connection between the two planets and, to some extent, dependent upon cross-field diffusion. Periodicities in the electron flux intensity of about 27 days, the solar rotation period observed from the Earth, and 13 months, the synodic Jovian year, are cited in support of CIR and/or stream structure control. Electron flux enhancements tend to be preceded by a decreasing solar wind velocity.

Several points arise out of this general picture which are interesting to consider further. If the Jovian electrons propagate to Earth when the Earth and Jupiter are magnetically connected, that is when a CIR encounters both planets simultaneously, this is only possible for typical SW velocities when certain geometrical Sun-Earth-Jupiter configurations occur. The condition for connection can be expressed in terms a limited range of Jovian elongations (ϵ) as shown in Figure 1. For typical velocities of 450 to 350 kms^{-1} this would correspond, respectively, to westerly elongations of about 42° to 105° ; for velocities of 600 to 300 kms^{-1} the respective elongations are about 6° E through conjunction ($\epsilon = 0^\circ$) to 161° W, indicated by the heavy line section of the Earth orbit. The Voyager 2 SW/IMF data available for the present study cover the first six months of 1979 during which time the Jovian elongation varied from about 154° W to 32° E, passing through opposition ($\epsilon = 180^\circ$) on January 24, 1979 as shown by the shaded section of the Earth orbit. It can be seen from Figure 1 that magnetic connection was impossible for all but the first few days of 1979. These days can be excluded, however, as the time series shown in Figure 2(a) indicates that SW velocity at Jupiter was then quite high, greater than 500 kms^{-1} and increasing to over 600 kms^{-1} at the beginning of the year, rather than close to the 300 kms^{-1} required for magnetic connection at that time. Thus we are justified in assuming that all of the Jovian electrons detected by GEOS 2 during the first half of 1979 must have travelled to the Earth by cross-field diffusion rather than by magnetic connection unless, of course, some other unknown process should exist.

If we think of diffusion as a random-walk process across the IMF, the general drift of electrons passing from Jupiter to the Earth will be along a direct line. As the distance

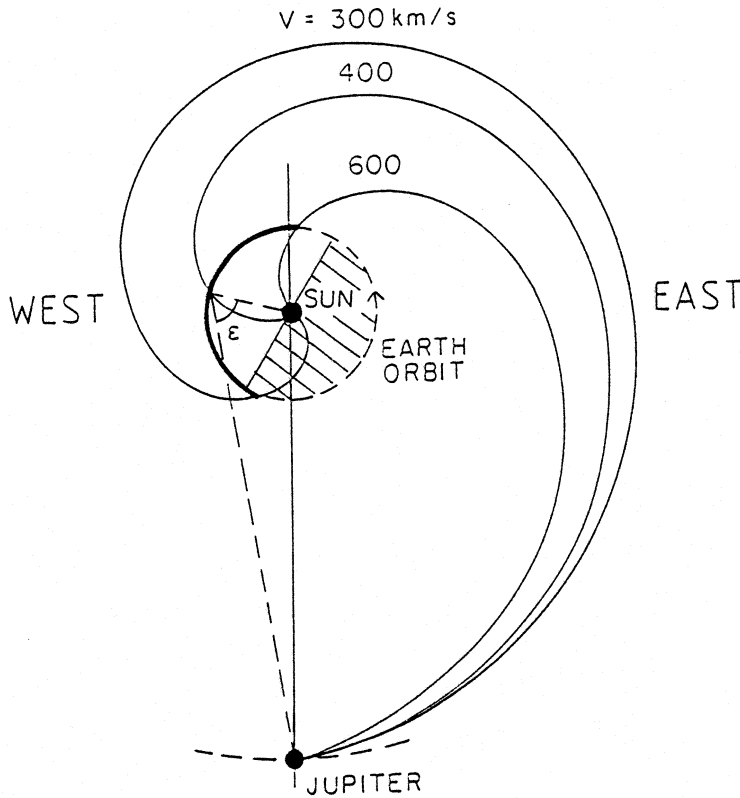


Figure 1: CIR geometry at given SW velocities for simultaneous encounter at Jupiter and at the Earth. The solid line sector of the Earth orbit represents positions of the Earth relative to Jupiter where magnetic connection can occur. The shaded sector represents the position of the Earth during the first half of 1979.

from Jupiter to the Earth varies from about 4 AU at opposition to 6 AU at conjunction, we might expect the changing distance to appear as a modulation in the time series of electron intensity with a maximum at opposition and a minimum at conjunction. Both this effect and the effect of changing elongation will introduce 13-month (Jovian synodic year) periodicities in the flux observed at the Earth although the two modulations will not be in phase. These are sketched in Figure 3(a) for the period 1978 to 1984 where the effect of diffusion, represented by a periodic change in flux due to the inverse square law (solid line), is combined with the effect of changing magnetic connection specified by Jovian elongation for SW velocities of 350, 400 and 450 kms^{-1} (broken lines), assuming that some common maximum value of electron flux is observed in each case when the conditions are most favourable. It is interesting that such simple common-sense considerations lead to a modulation curve (Figure 3b) that is very close to the form of the electron intensity time series given by Moses [1987] and aligned in Figure 3(c) with a corrected time scale. Note that it is not necessary to assume any specific value for the SW velocity. It is sufficient simply to consider the range of SW velocities most frequently observed, about 350 to 450 kms^{-1} .

The foregoing strongly suggests that any conclusions we may reach from the GEOS 2 data set used here should refer only to electrons transported by diffusion and not to transport by magnetic connection.

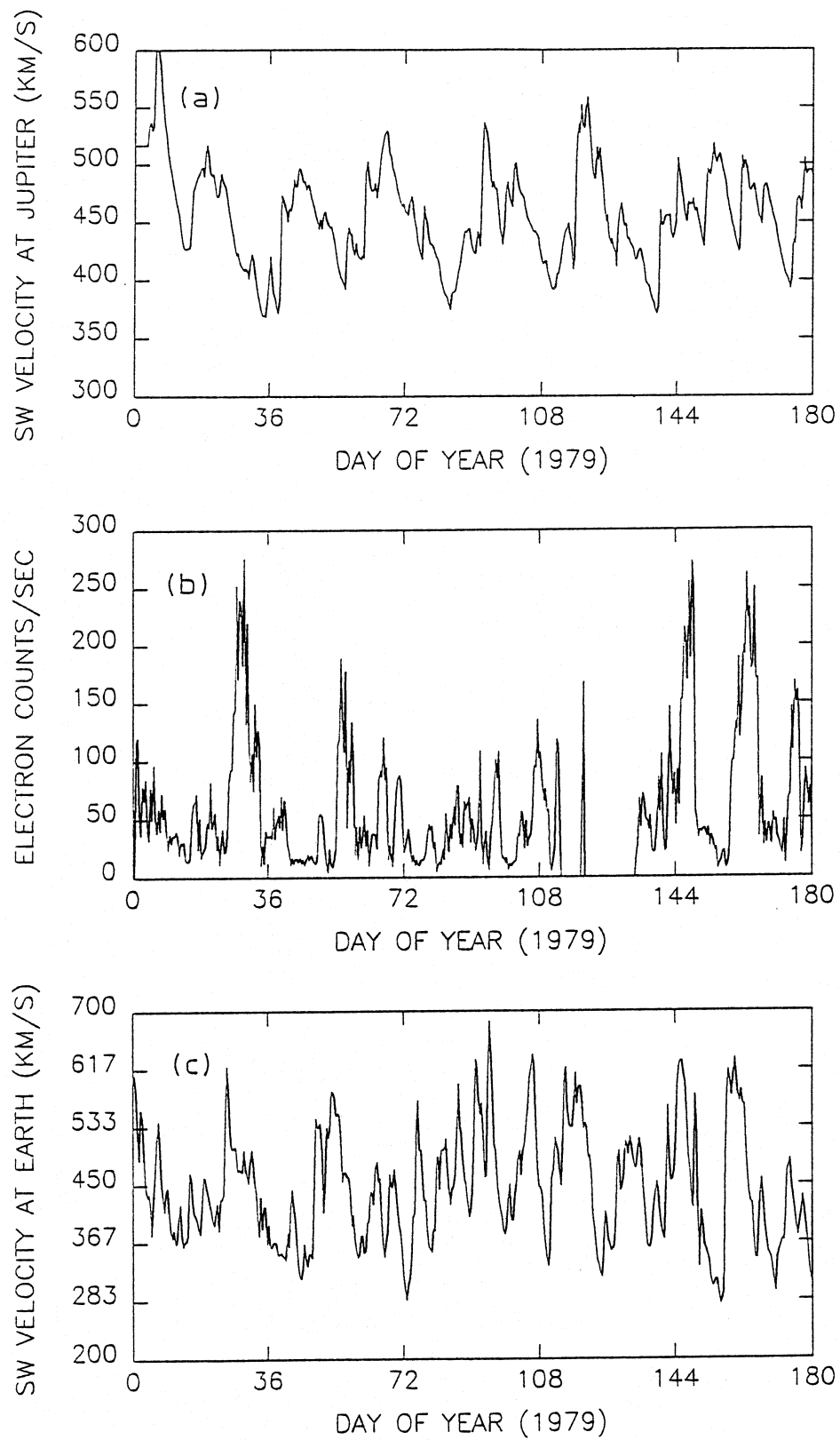


Figure 2: Time series of (a) SW velocity at Jupiter, (b) 10 MeV ECRs measured by GEOS 2 at $6.6 R_E$, and (c) SW velocity at the Earth, during the first six months of 1979.

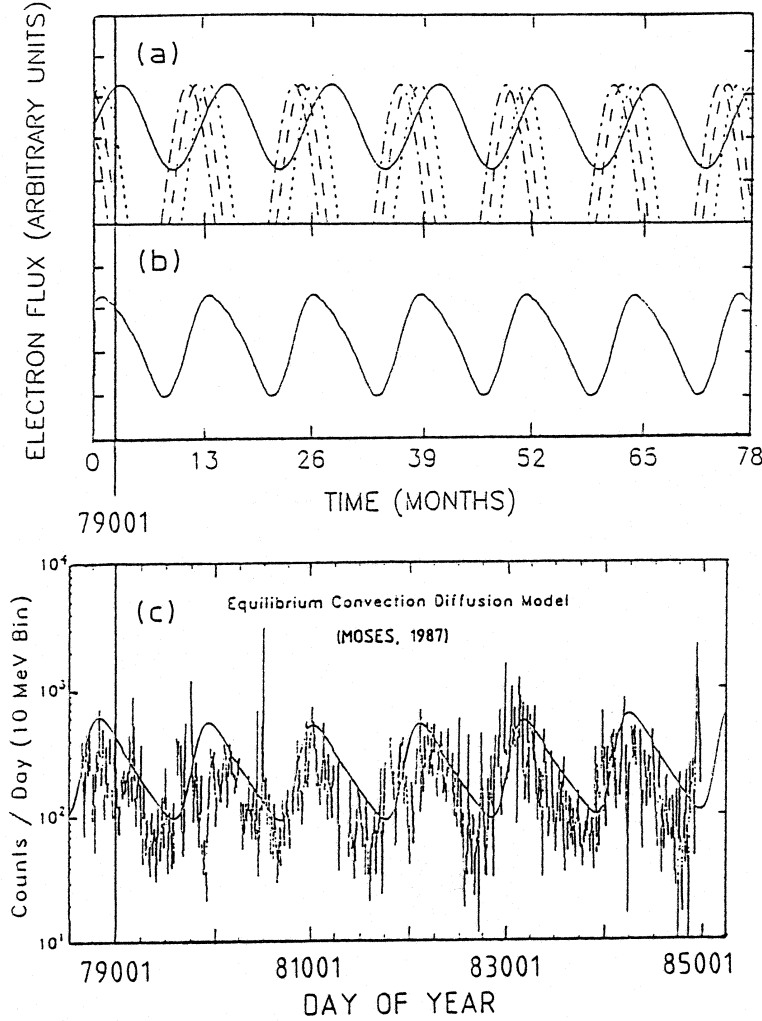


Figure 3: (a) Electron flux modulation due to magnetic connection for SW velocities of 350, 400, and 450 km s^{-1} (broken lines) and diffusion (solid line), (b) combination of these two effects, and (c) ECRs measured by ISEE 3 [after Moses, 1987].

3 Observational data

The analysis interval is from January 1, 1979 (DOY 79001) through June 29, 1979 (DOY 79180), prior to Voyager 2 encounter with Jupiter on July 9, 1979 (DOY 79190). During this period the spacecraft was approaching Jupiter from distances of about 1.3×10^8 to 9.5×10^6 km. There are occasional gaps in the SW and IMF data and values are interpolated during these relatively short periods. Generally, the data coverage is good, however. Burlaga [1984] has given a detailed review of Voyager SW/IMF measurements out to 10 AU.

Two different detection arrangements on GEOS 2 provided ECR data sets corresponding to electrons having energies greater than 1 MeV (K-electrons) and greater than 10 MeV (U-electrons). These have been described in detail by Wilken et al. [1977]. While the actual numerical count-rate values differed for each data set, the two corresponding time series of the count-rates showed little or no difference in profile; we will, therefore, concentrate attention on one data set only, the higher energy U-electrons. Note that there are gaps in the ECR data between DOY 79114 and 79119 and from DOY 79120 to 79133. The ECR time series is shown in Figure 2(b).

The ECRs are also compared with SW/IMF data close to the Earth taken from the

NSSDC OMNI File [Couzens and King, 1986]. This data set is a combination of data from various spacecraft and coverage is good for the analysis interval.

The Voyager SW data have been projected ballistically from the spacecraft to Jupiter in the manner described by Desch and Rucker [1983]. All of the data are averaged over a 10-hour period, approximately one Jovian rotation.

4 Data analysis

Time series of the ECRs measured by GEOS 2 are compared with SW velocities at Jupiter and at the Earth in Figure 2. Baker et al. [1986] found that the SW velocity at the Earth tended to decrease prior to an ECR enhancement and evidence of this can be seen in both Figures 2(a) and 2(c). It is more clearly shown in the data at Jupiter, however, where the stream structure is better defined and the decreases take place over longer periods. These periods correspond to the intervals between successive CIRs and have been called corotating quiet regions (CQRs) by Conlon [1978].

If the electron enhancements are associated with SW stream structures, as reported by Chenette [1980] and by Baker et al. [1986], we might expect to see correlation effects with other SW/IMF parameters, the SW density, for example. To investigate this possibility, superposed epoch analyses [Chree, 1912] were conducted with epochs defined by selected ranges of higher ECR in a similar manner to that described by Barrow and Desch [1989]. This proved to be inconclusive, however, due to the wide range of delay values between epochs and SW/IMF maxima. This is evident when the two SW velocity time series, shown in Figures 2(a) and 2(b), are compared with the ECR time series shown in the same figure. A pattern certainly exists but this is not an actual correlation. Autocorrelation does give a weak indication of approximate 27- and 14-day periodicities in the ECR data, however.

5 Detailed study of an ECR enhancement

Let us now consider the sequence of events associated with an ECR enhancement. This can be done by a detailed examination of a single event, for example, the event beginning close to opposition on about DOY 79025 in Figure 2. Enlarged time series of the various parameters of interest are shown in Figures 4 and 5.

In Figure 4, the SW velocity and IMF magnitude at Jupiter are compared with ECRs measured by GEOS 2 for DOY 79015 to 79065. It can be seen that the SW velocity reached a maximum value of about 515 km s^{-1} on DOY 79019 and then decreased to about 450 km s^{-1} on DOY 79025 when the ECR enhancement began and continued into DOY 79031. A subsidiary enhancement followed on DOY 79032 to 79034. The SW velocity continued its decreasing trend until DOY 79035 when a small increase was followed on DOY 79039 by a much larger increase to some 475 km s^{-1} . We note, from Figure 4(b), that the event occurred between two IMF maxima, in other words during a CQR. SW velocity and IMF magnitude at the Earth are compared in Figure 5. Again there is a decrease in SW

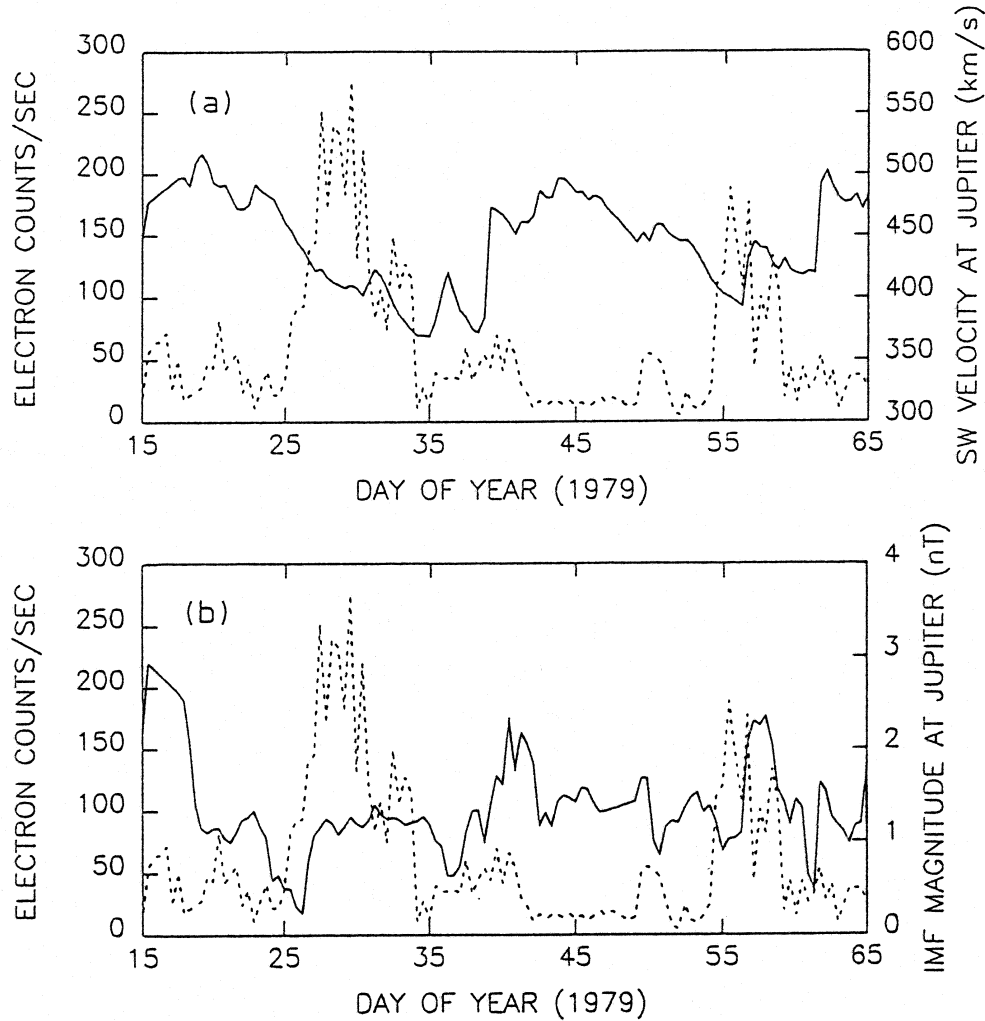


Figure 4: Time series at Jupiter of (a) SW velocity and (b) IMF magnitude (solid lines), compared with 10 MeV ECRs measured by GEOS 2 at 6.6 R_E (broken lines), during the period DOY 79015 to 79065.

velocity prior to the ECR enhancement but, in this case, the decrease takes place over a much shorter period of about 1.5 days; the IMF magnitude curve shows that the event occurred soon after an enhanced IMF magnitude at the beginning of the subsequent CQR.

Several workers have used Chenette's [1980] spectral index criterion to identify Jovian electrons and to separate these from solar electrons. Moses [1987, his Figure 10] implies that it is a valid procedure using spectra extending to energies well below 1 MeV. As GEOS 2 measured differential electron energy spectra from 23 to 300 keV, these have been checked for identification purposes. A typical average spectrum during the event is shown in Figure 6(a), compared with Figure 6(b) the idealized solar and Jovian spectra of the form used for comparison reference by other workers. By this criterion the event is evidently Jovian in origin. However, it must be stated that, although this procedure has been used as a means of separating Jovian from solar electrons on several occasions in the past, the distinction between a real spectrum and idealized spectra having indices of, say, 1.5 and 3.0 on a log-log plot can be uncertain. Fortunately, we can also refer to solar flare activity as high energy solar electrons are generally associated with flares. This

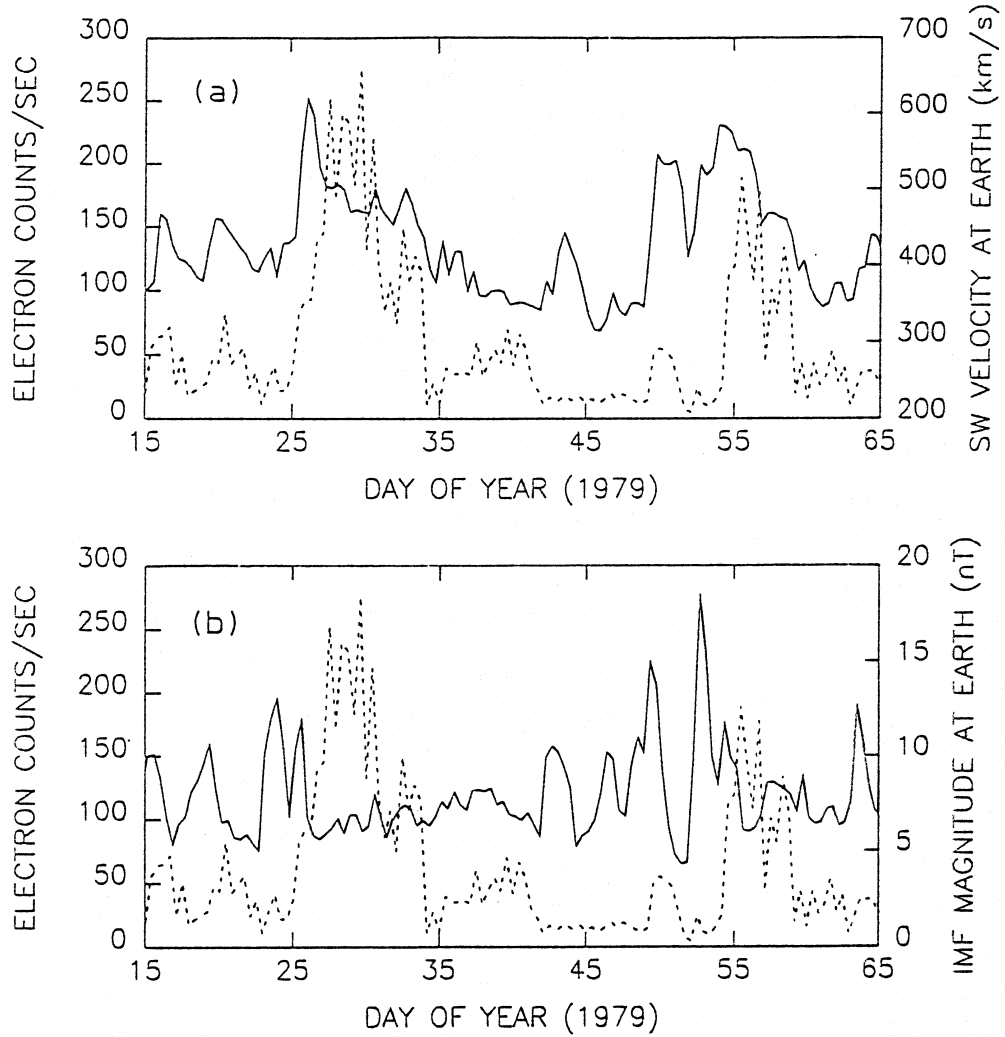


Figure 5: Time series at Earth of (a) SW velocity and (b) IMF magnitude (solid lines), compared with 10 MeV ECRs measured by GEOS 2 at $6.6 R_E$ (broken lines), during the period DOY 79015 to 79065.

is shown in Figure 7 where it can be seen that the main enhancement was not associated with high flare activity. The secondary enhancement does coincide with an increased flare index, however, and this suggests that the subsidiary event may have been due to solar rather than Jovian electrons.

The data shown in Figure 4 can be represented by the sequence of events sketched in Figure 8. On DOY 79019 (Figure 8a), a SW velocity of about 500 km s^{-1} was measured at Jupiter following a sudden increase in SW velocity on DOY 79015. The corresponding archimidean spiral is shown to encounter the Earth orbit at a position corresponding to an elongation of about 23° W . On this date the Earth was approaching opposition (DOY 79024) and far removed from any possible magnetic connection. The SW velocity then decreases steadily until on DOY 79025 it is about 450 km s^{-1} (Figure 8b) when an ECR enhancement is observed by GEOS 2 at the geo-stationary orbit. This enhancement peaks on DOY 79027.3 and continues well into DOY 79031 (Figure 8c) before decreasing suddenly. It is interesting to speculate that this decrease may have been due to some effect of the original 500 km s^{-1} CIR which by now has rotated to a position where it can

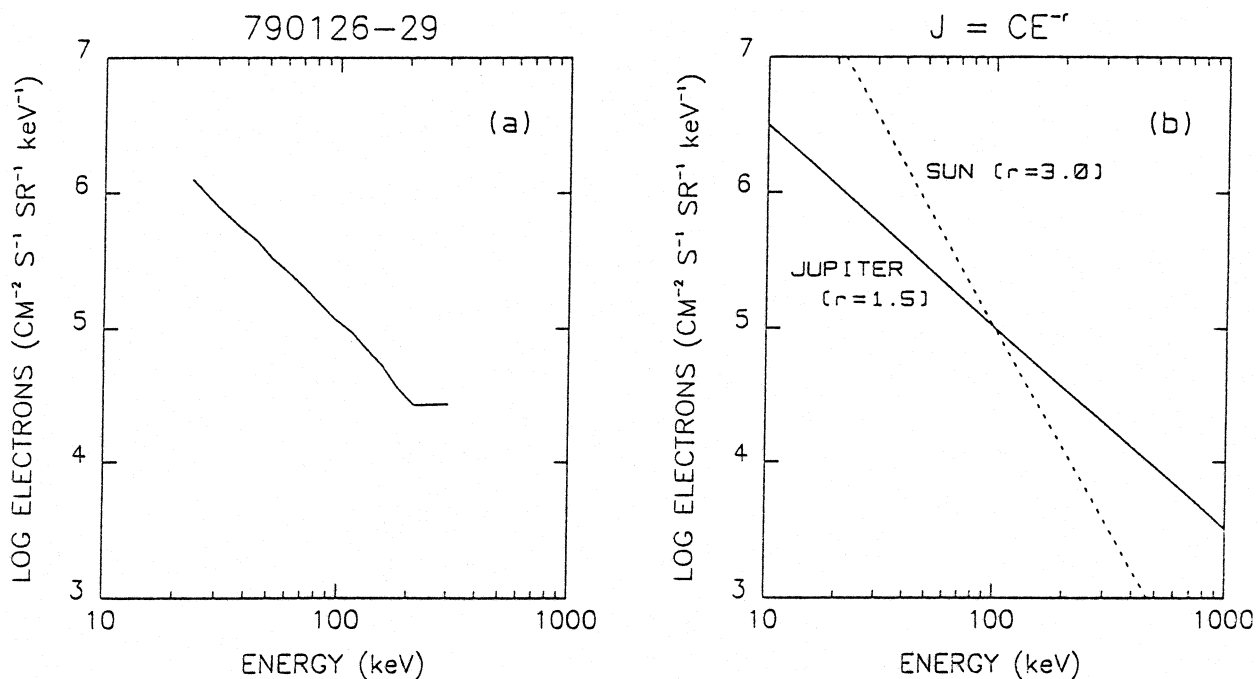


Figure 6: (a) Average differential energy spectrum for the event beginning on DOY 79025.5 compared with (b) idealized $dJ/dE = kE^{-r}$ spectra where $r = 1.5$ (Jovian electrons) and $r = 3.0$ (solar electrons).

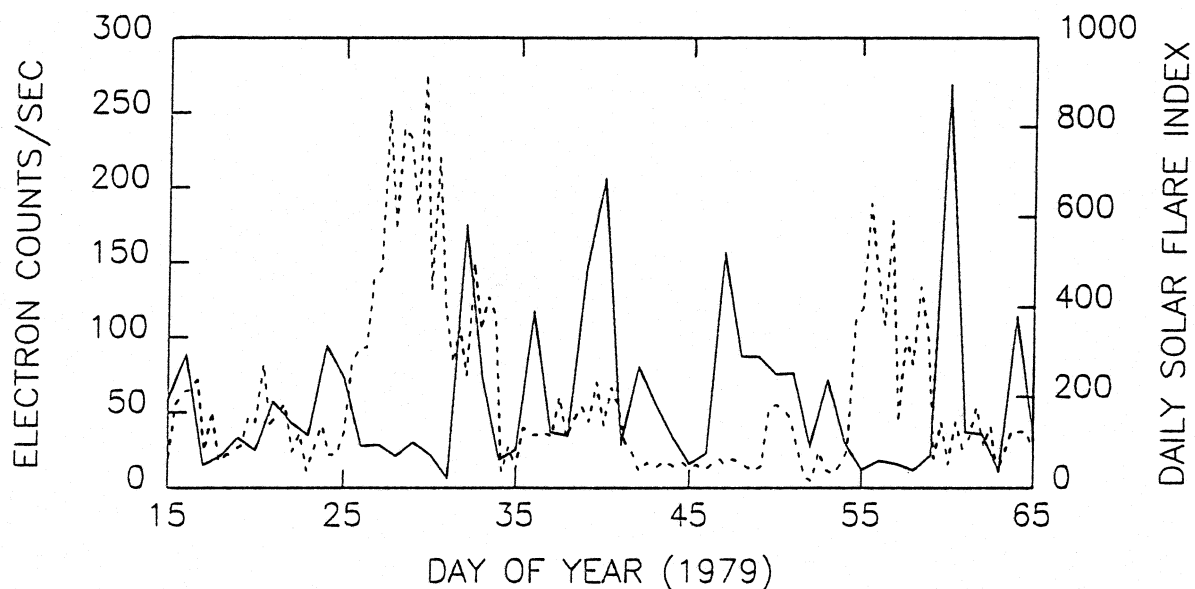


Figure 7: Time series of the solar flare index (solid line), compared with 10 MeV ECRs measured by GEOS 2 at 6.6 R_E (broken lines), during the period DOY 79015 to 79065.

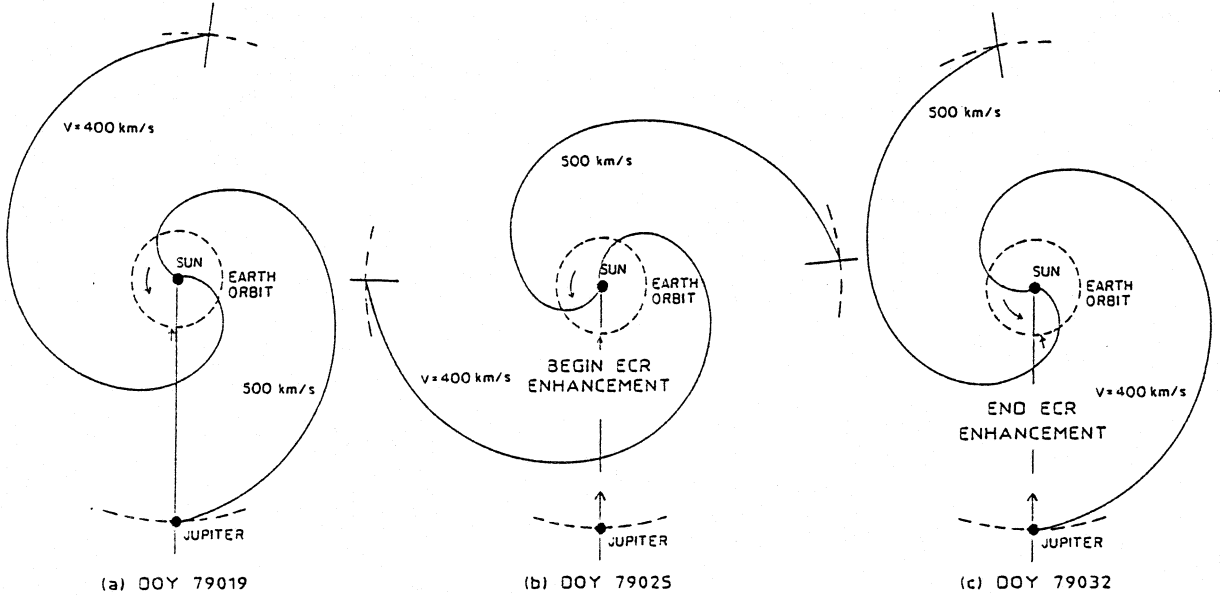


Figure 8: Sequence of sketches of CIR/CQR geometry for the ECR enhancement observed from DOY 79025 to 79031. (a) DOY 79019 when a high SW velocity is measured at Jupiter, (b) DOY 79025 when the main ECR enhancement begins, and (c) DOY 79032 when the ECR enhancement has ended and a subsidiary (possibly non-Jovian) enhancement is about to begin. The position of the Earth is indicated by a small arrow in each figure.

encounter the electrons on their way to the Earth. The SW velocity peaks in Figure 2(a) suggest that the structure remained sufficiently stable for this to take place.

6 Discussion

The data presented in the previous section provide a good picture of the sequence of events occurring at Jupiter as well as supporting what has already been established in previous investigations. Nevertheless, a number of open questions remain. These can be summarized as follows:

1. Source:

Is the source continuous or intermittent and is it localized or distributed around the planet? The relatively long duration of the ECR enhancements, typically several days according to Baker et al. [1986], strongly suggests a distributed and possibly continuous source. The simple rationale leading to the modulation curve presented in Figure 3(b) also implies this. Chenette et al. [1974], however, found that the electron flux varied with the Jovian rotation period and it is difficult to see how this could be reconciled with continuous and/or distributed emission.

2. Periodicities:

Why should a 27-day periodicity appear in the flux of non-magnetically connected electron-transport, i.e. in cross-field diffusion? Several authors have reported this

and even the limited data used in the present paper contain a weak indication of a 27-day periodicity. This suggests that diffusion as well as magnetic connection must be controlled in some manner by the solar wind. Can diffusion only take place when the SW velocity is not too high? Time series such as those presented in Figure 4(a) suggest that this may be the case, remembering that magnetic connection was not possible throughout the period studied. In this case, however, it would be the SW velocity at Jupiter which could initiate or inhibit the diffusion and the periodicity might then be expected to be 25 days rather 27 days, unless some other modification took place closer to the Earth.

3. Transport:

Presumably, at times when magnetic connection is not possible, some electrons are still transported away from Jupiter along field lines that are not magnetically connected to the Earth. However, we have seen that cross-field diffusion also occurs at such times. What determines this? Why are some electrons diffused while others travel along field lines? Both processes might be expected if the source were known to be isotropic but there is no indication that this is the case. Also, having started to diffuse towards the Earth, can the electrons cross a CIR encountered on the way, as shown in Figure 8(c)?

4. Identification:

The spectral index criterion, discussed in Section 5 and in Figure 6, can be uncertain if only due to the irregularities observed in many real spectra. We may ask how reliable is the separation of Jovian and solar electrons by this method? It is suggested that solar activity, represented perhaps by the solar flare index, should also be checked for confirmation.

5. Escape and entry:

Even if all of the conclusions concerning Jovian electrons close to the Earth are correct, it is still not known how the electrons escape from the Jupiter's magnetosphere and how they subsequently enter the Earth's magnetosphere.

7 Conclusion

SW/IMF data taken by Voyager 2 during the first half of 1979 has been compared with ECRs measured by GEOS 2 over the same period. While there is a clear pattern to the sequence of events at Jupiter associated with an ECR enhancement observed close to the Earth, formal correlation effects cannot be identified due to the wide range of delay times between SW/IMF effects and ECR enhancements. Insofar as it is possible to generalize from the relatively small data sets used, it appears that the SW velocity decreases to a certain value before electrons can be transported to the Earth by cross-field diffusion effects which take place during CQRs. This might explain the periodicity found in electron flux measurements at times when Jupiter and the Earth are not magnetically connected although, in this case, a 25-day periodicity might be expected unless SW effects closer to the Earth can modify or obscure this. As most enhancements continue for periods of

several days, this suggests that the electron emission is distributed around the planet and perhaps continuous. A number of other questions remain open, however.

Acknowledgements: I am grateful to B. Wilken, GEOS 2 ESA Experiment S-321 Principal Investigator, N. F. Ness, Voyager Magnetometer Team Principal Investigator and H. S. Bridge, Voyager Plasma Science Team Principal Investigator, for making data available for this work. I am also pleased to acknowledge solar wind and IMF data close to the Earth taken from the NSSDC OMNI File [Couzens and King, 1986], in particular, the ease with which this data can be accessed and copied electronically. I also thank W. I. Axford and B. Wilken for helpful discussions.

References

- Baker, D. N., P. R. Higbie, R. D. Belian, and E. W. Hones, Do Jovian electrons influence the terrestrial outer radiation zone?, *Geophys. Res. Lett.*, **6**, 531, 1979.
- Baker, D. N., J. B. Blake, R. W. Klebesadel, and P. R. Higbie, Highly relativistic electrons in the Earth's outer magnetosphere 1. Lifetimes and temporal history 1979-1984, *J. Geophys. Res.*, **91**, 4265, 1986.
- Barrow, C. H., and M. D. Desch, Solar wind control of Jupiter's hectometric radio emission, *Astron. Astrophys.*, **213**, 495, 1989.
- Behannon, K. W., M. H. Acuna, L. F. Burlaga, R. P. Lepping, and N. F. Ness, Magnetic field experiment for Voyagers 1 and 2, *Space Sci. Rev.*, **21**, 235, 1977.
- Bridge, H. S., J. W. Belcher, R. J. Butler, A. J. Lazarus, A. M. Mavretic, and J. D. Sullivan, The plasma experiment on the 1977 Voyager mission, *Space Sci. Rev.*, **21**, 259, 1977.
- Burlaga, L. F., MHD processes in the outer heliosphere, *Space Sci. Rev.*, **39**, 255, 1984.
- Chenette, D. L., The propagation of Jovian electrons to Earth, *J. Geophys. Res.*, **85**, 2243, 1980.
- Chenette, D. L., T. F. Conlon, and J. A. Simpson, Bursts of relativistic electrons from Jupiter observed in interplanetary space with time variation of the planetary rotation period, *J. Geophys. Res.*, **79**, 3551, 1974.
- Chree, C., Some phenomena of sunspots and terrestrial magnetism at Kew Observatory, *Phil. Trans. Roy. Soc. (A)*, **212**, 75, 1912.
- Christon, S. P., D. L. Chenette, D. N. Baker, and D. Moses, Relativistic electrons at geosynchronous orbit, interplanetary electron flux, and the 13-month Jovian synodic year, *Geophys. Res. Letters*, **16**, 1129, 1989.
- Conlon, T. F., The interplanetary modulation and transport of Jovian electrons, *J. Geophys. Res.*, **83**, 541, 1978.

- Couzens, D. A., and J. H. King, *Interplanetary Medium Data Book Supplement*, **3A**, 1977–1985, NSSDC Report 86–04, 1986.
- Desch, M. D., and H. O. Rucker, The relationship between Saturn kilometric radiation and the solar wind, *J. Geophys. Res.*, **88**, 8999, 1983.
- Eraker, J. H., and J. A. Simpson, Jovian electron propagation close to the Sun (< 0.5 AU), *Astrophys. J. Lett.*, **232**, L131, 1979.
- Krimigis, S. M., E. T. Sarris, and T. P. Armstrong, Observations of quiet-time interplanetary electron enhancements of Jovian origin, *Proc. 14th Internat. Cosmic Ray Conf. (Munich)*, **2**, 752, 1975.
- L’Heureux, J., C. Y. Fan, and P. Meyer, The quiet time spectra of cosmic electrons of energies between 10 and 200 MeV observed on OGO 5, *Astrophys. J.*, **171**, 363, 1972.
- L’Heureux, J., and P. Meyer, Quiet-time increase of low-energy electrons: The Jovian origin, *Astrophys. J.*, **209**, 955, 1976.
- McDonald, F. B., T. L. Cline, and G. M. Simnett, Multifarious temporal variations of low-energy relativistic cosmic ray electrons, *J. Geophys. Res.*, **77**, 2213, 1972.
- Mewaldt, R. A., E. C. Stone, and R. E. Vogt, Observations of Jovian electrons at 1 AU, *J. Geophys. Res.*, **81**, 2397, 1976.
- Moses, D., Jovian electrons at 1 AU: 1978–1984, *Astrophys. J.*, **313**, 471, 1987.
- Parker, E. N., *Interplanetary Dynamical Processes*, Interscience, New York, 1963.
- Paulikas, G. A., and J. B. Blake, Modulation of trapped energetic electrons at $6.6 R_E$ by the direction of the interplanetary magnetic field, *Geophys. Res. Lett.*, **3**, 277, 1976.
- Paulikas, G. A., and J. B. Blake, Effects of the solar wind on magnetospheric dynamics: Energetic electrons at the synchronous orbit, in *Quantitative Modelling of Magnetospheric Processes. Geophys. Monogr. Ser.*, **vol. 21**, edited by W. P. Olson, p. 180, AGU, Washington, D. C., 1979.
- Teegarden, B. F., F. B. McDonald, J. H. Trainor, W. R. Webber, and E. C. Roelof, Interplanetary MeV electrons of Jovian origin, *J. Geophys. Res.*, **79**, 3615, 1974.
- Wilken, B., A. Korth, and E. Keppler, Das MPAE-Elektron/Protonen-Spektrometer (EPI) auf dem ESA-Satelliten GEOS (S-321) *Z. Flugwiss. Weltraumforsch.*, **1**, 298, 1977.