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# Engineering Notes

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## Trapped-Electron Fluxes Measured by International Ultraviolet Explorer and AE-8 Model Predictions

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### Introduction

THIS investigation applies a geomagnetic field model that includes external currents, the Tsyganenko 1989 (T89) model,[1,2] in combination with the AE-8 NSSDC trapped-electron model (Vette[3]) to reproduce the diurnal radiation curves observed by the geosynchronous international ultraviolet explorer (IUE) satellite. The results are compared with representative IUE data and with analogous curves obtained using the Jensen–Cain[4] (JC60) field model. The T89+AE-8 models can reproduce the IUE data, given even crude estimates of detector parameters, a simple calibration, and the expected importance of shell splitting. A day–night asymmetry is present in the algorithm.

### Spacecraft and Detector

IUE[5] is a three-axis stabilized astronomical satellite launched on Jan. 26, 1978, into an elliptical geosynchronous orbit covering ±30° geographic latitude and 40–90° W longitude. The geocentric perigee, apogee, and inclination of the initial orbit were 32,000 km, 52,200 km, and 28.6 deg, respectively. The current values are 36,600 km, 47,700 km, and 34.7 deg, respectively. During the mission the perigee has moved from −30° to +20° latitude. The orbit transits the outer layers of the Van Allen belts. Since the orbital period is one sidereal day, the perigee point passes through $24^h$ of local time during the year.

The particle flux monitor (PFM) is a Geiger counter detector with a 32-deg conical field of view directed perpendicular to the telescope's optical axis. The attitude control system keeps the PFM on the antisun side of the spacecraft. The nominal (prelaunch) detector threshold energies are 0.96 MeV for electrons and 15 MeV for protons, and the average electron efficiency is estimated to be 0.4 for the expected outer-zone electron energy spectrum. The PFM first recorded data on Feb. 4, 1978, and was turned off in October 1991 after developing an electrical problem.

The incident flux is detected as an increased output voltage from the PFM. The data used in this Note consist of logarithms of averages of (generally) ten dex (voltage) recorded from telemetry over approximately a 2-min interval and plotted by the IUE telescope operators.

### Algorithm

The magnetic field line shapes and fluxes are obtained using a modified version of model T89c of Peredo et al.[2] The core field is calculated from coefficients in the[6] NSSDC IGRF-91 package. The code accepts a $K_p$ index, a Universal Time (U.T.), geographic coordinates, and geocentric altitude as input and yields the magnetic field vector at points along the line of force containing that position. To increase the density of calculated points along a line in the region relevant to IUE, the initial step size and error tolerance in the Runge–Kutta–Merson algorithm used to step along the field line in the original model package is reduced by 10×, and a 30-point cubic spline interpolation,[7] using the magnetic colatitude as the independent variable, is done between each pair of calculated points.

To obtain the $L$-shell and $B/B_0$ coordinates, the positions of IUE at 5-min intervals are calculated using the observatory support software and orbital elements archive. Using a single $K_p$ value, the field-line parameters for each time are obtained from the Tsyganenko code. The epochs for the field calculations are 1964 for years near solar minimum and 1970 for those near maximum, in order to allow for secular changes in the geomagnetic field and to ensure compatibility with the particle models.[8] The magnetic intensities $B$ at each position and the minimum magnetic intensities along the corresponding field lines readily yield $B/B_0$ values. The adiabatic integral invariants $I$ (see, e.g., McIlwain[9]) are calculated by trapezoidal numerical integrations along the field lines from the starting positions to the mirror points, here taken to be the second point along a given line with intensity $B$. With the Earth's magnetic moment of the chosen epoch and $I$, the $L$ values are obtained using the series expansion of McIlwain.[9] Using the $(L, B/B_0)$ coordinates, a modified version of the NSSDC code RADBELT[6] extracts the omnidirectional integral electron fluxes from the AE-8 trapped-electron model.

The flux $f_e$ is related to the expected detector count rate Cts by assuming an isotropic pitch-angle distribution (PAD). The actual PADs encountered by IUE are unlikely to be consistently isotropic, but the PADs displayed by West et al.[10] suggest that this assumption is often a reasonable first approximation for the relevant $L$ shells and energies. Using the prelaunch values of the detector geometric factor and average efficiency, the flux and counts are related by $f_e \approx 2500 \times$ Cts. The output voltage for a given count rate is obtained from ground calibration curves and corrected for temperature effects. The diurnal curves are normalized using a multiplicative factor to match the theoretical and observed maximum voltages for a given day.

Electron densities at geosynchronous altitude depend on the local time. Vette[3] provides a function correcting the AE-8 fluxes for this effect. This function is not applied to the Tsyganenko model results, because that code attempts to reproduce the field distortions, which influence the $(L, B/B_0)$ values, and intrinsically corrects for this phenomenon. However, the JC60 field is symmetric. These fluxes are corrected for local time using the Vette function.

### Results

Figure 1 displays theoretical PFM curves representing best fits, as determined by inspection, to the data for two U.T. dates. The dates are biased toward high-flux conditions, since the diurnal curves stay above the background threshold longer at these times. The $K_p$ values on the plots are the input values to the T89 code, compared with averaged observed $K_p$ of 4o and 3− for days 330 and 56/57, respectively.

Figure 1a shows that the simple fitting algorithm and the T89+AE-8 combination reproduce the details of the data surprisingly well. The shape of the curves change rapidly with $K_p$ for that time of year. This sensitivity is seasonal, being much less dramatic at other times (Fig. 1b). Note the deviations of the data from an otherwise well-fitting curve as IUE passes through dawn.

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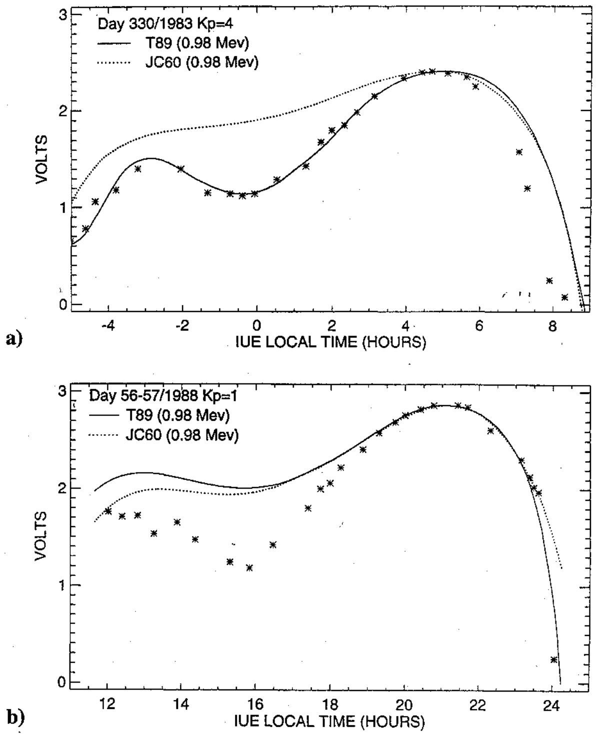


**Fig. 1 Theoretical particle flux curves calculated from the T89+AE-8 models.**

In Fig. 1b the calculated integral fluxes for the 0.98-MeV detector threshold clearly fail to fit the data. The analysis indicates that the data for this day can be fitted by using a 1.5-MeV threshold in the AE-8 model, as can the deviations from the fit in Fig. 1a. The pointing flexibility of IUE renders unlikely an origin for this discrepancy related to detector shadowing.

Figure 1a shows that the JC60 model significantly overestimates the flux on this day. At other times the JC60 and the T89 performance are more similar (Fig. 1b). In this case the T89 curves do not show much structure and are not sensitive to $K_p$, and the JC60 model can underestimate the flux. Not surprisingly, the JC60 and T89 models are also similar near perigee ($3^h$ and $21^h$ for days 330 and 56/57, respectively), since the multipole field dominates there.

## Discussion

The AE-8 fluxes are binned by McIlwain coordinates using the JC60 field and McIlwain's[9] value of the dipole moment, and this code should be used to extract fluxes self-consistently. An explanation for T89's often good performance in the outer zone may be as follows. The AE-8 model is constructed almost entirely from inner-zone data, where the JC60 field describes conditions reasonably well, and is extended to large $L$ by extrapolation. However, at high altitudes the external currents are important and JC60 is much less realistic than the T89 field, often resulting in significantly erroneous estimates of the critical $L$ value. Consider some average flux measured by a detector at a given location and local time in the outer zone. With a reasonable $B/B_0$, this flux yields an interpolated $L$ from the AE-8 model. The results in Fig. 1 suggest that T89 often yields an $L$ closer to this value than that obtained from JC60.

The day–night asymmetry in the fits shows that the T89 extraction algorithm can be improved. It is beyond the scope of this Note to discuss the possible physical origins of this behavior. The problem addressed here is the outer-zone extraction procedure. The construction method of AE-8 means that one cannot assume a priori that improving the field model or changing the algorithm (e.g., by using the mirror equation and known detector attitude to calculate new mirror points) will improve the fits. That determination must be made empirically. The IUE data represent a good resource for pursuing such investigations.


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## References


[1]Tsyganenko, N. A., "A Magnetospheric Magnetic Field Model with a Warped Current Sheet," *Planetary and Space Science*, Vol. 37, Jan. 1989, pp. 5–20.

[2]Peredo, M., Stern, P., and Tsyganenko, N. A., "Are Existing Magnetospheric Models Excessively Stretched?" *Journal of Geophysical Research*, Vol. 98, Sept. 1993, pp. 15,343–15,354.

[3]Vette, J. I., "The AE-8 Trapped Electron Model Environment," National Space Science Data Center, NSSDC/WDC-A-R&S 91–24, Nov. 1991.

[4]Jensen, D. C., and Cain, J. C., "An Interim Geomagnetic Field," *Journal of Geophysical Research*, Vol. 67, Aug. 1962, pp. 3568, 3569.

[5]Bogess, A., "The IUE Spacecraft and Instrumentation," *Nature*, Vol. 275, Oct. 1978, pp. 372–377.

[6]Bilitza, D., "Solar-Terrestrial Models and Application Software," *Planetary and Space Science*, Vol. 40, April 1992, pp. 541–579.

[7]Press, W. H., Teukolsky, S. A., Vettering, W. T., and Flannery, B. P., *Numerical Recipes in Fortran*, Cambridge Univ. Press, New York, 1989, pp. 86–89.

[8]Gaffey, J. D., and Bilitza, D., "NASA/National Space Science Data Center Trapped Radiation Models," *Journal of Spacecraft and Rockets*, Vol. 31, No. 2, 1994, pp. 172–176.

[9]McIlwain, C. W., "Coordinates for Mapping the Distribution of Magnetically Trapped Particles," *Journal of Geophysical Research*, Vol. 66, Nov. 1961, pp. 3681–3691.

[10]West, H. I., Buck, R. M., and Walton, J. R., "Electron Pitch Angle Distributions Throughout the Magnetosphere as Observed on Ogo 5," *Journal of Geophysical Research*, Vol. 78, March 1973, pp. 1064–1081.


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