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# OBSERVATION OF NEARLY MONOENERGETIC HIGH-ENERGY ELECTRONS IN THE INNER RADIATION BELT*

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Previous measurements[1-5] have given a rather incomplete picture of natural inner-belt electron spectra, but the energy distributions are thought to be generally monotonic and rather smooth. The purpose of this brief paper is to present some sharply peaked electron spectra observed in the inner belt. The data were acquired during the period 30 October to 4 November 1963, shortly after a major magnetic storm, in the narrow spatial interval where McIlwain's $L$ parameter[6] varies from 1.14 to 1.17, corresponding to a region where the high-energy electrons from Starfish had long since decayed. The electrons observed at ~1.3 MeV decayed at a rate in reasonable agreement with that calculated from atmospheric scattering theory, both with respect to absolute value and variation with $L$.

The measurements were performed from an earth-oriented satellite in polar orbit with 355-km apogee and 288-km perigee. The spectrometer was designed for high sensitivity and an acceptance solid angle of nearly $2\pi$ sr. It consisted of a 5.7-cm-diameter by 3.2-cm plastic scintillator shielded on the sides and back by at least 3.4 g/cm$^2$ of aluminum and light pipe, and on the front earthward-facing surface by a 0.33-cm tungsten sheet with a 2.54-cm-diameter entrance aperture. Data were recorded with a differential 16-channel pulse-height analyzer of the digital time-converter type operating in two energy ranges of 0.3 to 2.6 MeV and 0.3 to 10.0 MeV, thus providing resolution consistent with that of the detector, continuous energy coverage, and laboratory-like channel linearity and stability, all necessary for the type of measurements reported here. Individual counts were stored as four-bit words in an on-board tape recorder, giving complete orbital coverage. The spectra observed throughout most of the radiation belts were rather smooth and monotonic and have been reported elsewhere.[7-9]

On very low-$L$ shells, however, we consistently observed rather sharply peaked spectra. Reprocessing the previously analyzed[9] data in much shorter intervals revealed a systematic and rapid variation of spectrum with $L$. Figure 1 shows the raw spectra observed during one of the many passes through this narrow $B, L$ interval. At $L = 1.150$ the peak is not much wider than our instrumental energy resolution of ~18 % at 1.3 MeV.

Laboratory tests have shown that gamma rays or neutrons cannot produce such a narrow peak, nor can even monoenergetic protons in any pancake angular distribution because of varying energy loss with angle in the 0.025-cm polyethylene entrance foil. From many preflight calibrations and all of the in-flight data, we conclude that this peak could not have been caused by an electronic malfunction. For example,

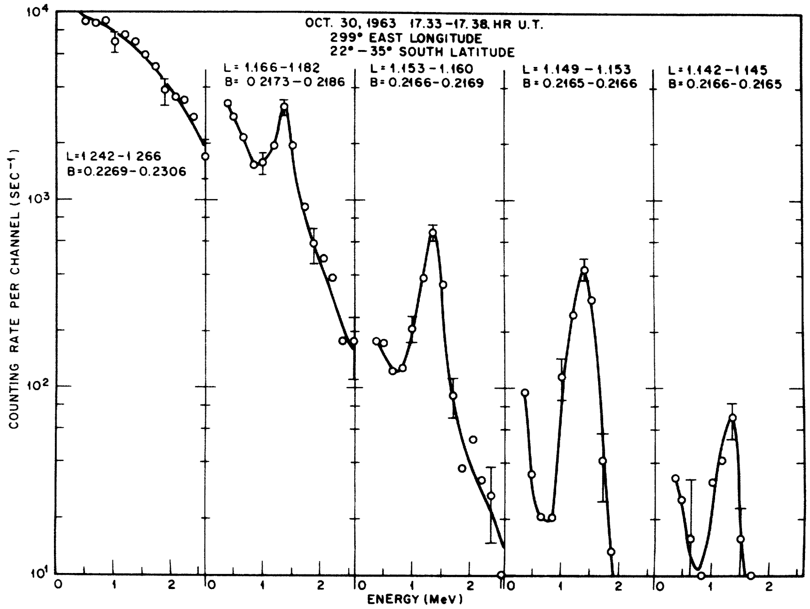


FIG. 1. Analyzer output per unit live time on different $L$ shells for one pass through the Brazilian anomaly. Channels 1 and 16 are not shown.

there was no correlation between the rates observed in the peak and in the overload channel, the latter rate being in agreement with that expected for high-energy protons.[10] Furthermore, the relationship between the spectra observed in stably trapped and transiently trapped regions on the same $L$ shell is consistent with that expected[8] for electrons.

Successive passes through a given $L$ shell showed a systematic decrease in peak intensity, allowing comparison with the decay expected from atmospheric scattering theory[11] as shown in Fig. 2. Calculations performed[12] at $L = 1.150$ have shown that an impulsively injected group of electrons at ~1.3 MeV will decrease in intensity much more rapidly than it spreads out in energy, consistent with the observations. For the period indicated, both the absolute value of the calculated decay constant and its variation with $L$ are in agreement with the experimental results.

We were not able to observe the onset of this group of electrons, and the decay measurements were limited to a relatively short time because of the subsequent appearance of yet another group of electrons at ~0.8 MeV. However, an extrapolation of the curves of Fig. 2 to earlier times indicates a substantially constant intensity over this narrow $L$ interval about one day before our first observation, suggesting an injection at the time of a major magnetic storm.[13] Furthermore, the lower energy group appeared at about the time of another $K_p$ increase. Thus, although the phenomenon appears correlated with magnetic activity, further speculation as to the source should await the availability of data acquired over a more extended time period.

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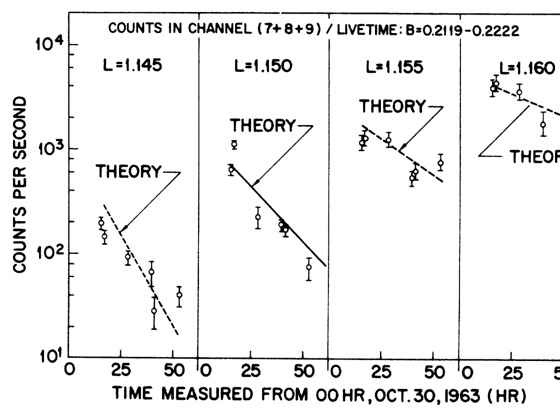


FIG. 2. The counting rate in channels 7 + 8 + 9 as a function of time for various $L$ shells. The data are restricted to a narrow $B$ interval, and within this interval corrections have been made for the variation of flux with $B$. The curves shown represent decay rates calculated from atmospheric scattering theory. The solid curve at $L = 1.150$ is a calculation at that precise $L$ shell, whereas the dotted curves are based on calculations at $L = 1.150$ and 1.186.

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## COMPTON WAVELENGTH OF SUPERCONDUCTING ELECTRONS

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The purpose of this Letter is to report a macroscopic determination of the quantum of circulation, $h/m$, for superconducting electrons, and thus the Compton wavelength, $h/mc$. This determination was made utilizing a superconducting deBroglie wave interferometer,[1-3] such as previously discussed and used for magnetic flux detection.[4] Here, however, the interferometer is operated in constant applied flux, the interference modulation being introduced by mechanical rotation.

The essential property of the superconducting deBroglie wave interferometer is that the maximum supercurrent flow ($I_{\max}$) through it is a periodic function of the normalized action, $(1/2\hbar)\oint p\,dq$, where $p$ is the canonical momentum of superelectron pairs, $\vec{p}=2(m\vec{v}+e\vec{A})$, $m$ and $e$ being the mass and charge of the electron. This interference modulation of the maximum supercurrent can be expressed as[2]

$$I_{\max}=I_0\left|\cos\frac{1}{2\hbar}\oint p\,dq\right|,$$

or, evaluating the line integral,

$$I_{\max}=I_0\left|\cos 2\pi\left(\frac{l}{\hbar}+\frac{e}{h}\Phi\right)\right|,$$

where $l$ is the mechanical "angular momentum" of the electron and $\Phi$ the magnetic flux. Experimental confirmation of both mechanical $l$ and electromagnetic $\Phi$ modulation have previously been reported. Flux ($\Phi$) modulation has been provided by both a magnetic field[1] and separately by a vector potential alone[4]; mechanical momentum modulation was provided indirectly by a current flow.[2]

In the experiment reported here the flux is held constant and the mechanical momentum provided directly by an actual rotation ($\Omega$) of the circular interferometer ($l=mr^2\Omega$). In terms of this rotation the maximum supercurrent through the interferometer is

$$I_{\max}=I_0\left|\cos 2\pi\{(2m/h)(\pi r^2)\Omega+(e/h)(\pi r^2)B\}\right|. \quad (1)$$

Measuring the maximum supercurrent ($I_{\max}$) as a function of rotation rate thus yields a direct measure of $h/m$. This type of measurement was done with a vanadium interferometer[5] with an effective area ($\pi r^2$) of 0.074 cm$^2$ at rotation rates ($\Omega$) ranging up to about 10 rad sec$^{-1}$. These measurements give a value for $h/m$ of

$$h/m=(7.3\pm0.3)\times10^{-4}\text{ J sec kg}^{-1},$$

and, consequently,

$$h/mc=(2.4\pm0.1)\times10^{-12}\text{ m}.$$