THE TWENTY-TWO MOST FREQUENTLY CITED APL PUBLICATIONS – III

This set of "most frequently cited papers" deals with several topics in space physics. They pertain to the currently most active area of research at APL, with more than 100 scientific articles published in 1985 alone.

History provides a clue to why this particular field is planted so deeply in the intellectual subconscious of the Laboratory. More than 60 years ago, APL's founder, M. A. Tuve, began his pioneering studies (with L. R. Hafstad) on the propagation of radiowaves by measuring their refraction from the several ionized layers of the ionosphere. While their work was stopped by the onset of World War II (having contributed along the way to the discovery of radar ranging as a means of identifying the position of aeroplanes), Tuve resumed his interest in this region of space as soon as the development of the proximity fuze was crowned with success. He suggested to J. A. Van Allen, who was then a member of the APL staff, that captured German V-2 rockets be used for measurements during their flights through the upper atmosphere. While Van Allen's key discovery of radiation belts containing unexpectedly large concentrations of highly energetic charged particles had to await the arrival of higher flying rockets and was done elsewhere, this venture into space research was never forgotten at APL.

When, in the late 1950s, APL suddenly became immersed in a major satellite development program as a result of the invention of the Transit navigation system by F. T. McClure and it became possible – nay, mandatory – to investigate the regions in space where the satellites were to fly undamaged for many years, the need to learn more about the details of the upper atmosphere became a powerful stimulant.

G. F. Pieper and C. O. Bostrom arrived at APL in 1960 to design instrumentation to measure and study the radiation environment of the Transit satellites. Working with D. J. Williams, who arrived in 1961, and with A. J. Zmuda, they formed the core of APL's space research, using numerous flight experiments on Navy satellites. Many discoveries resulted, including field-aligned currents in the auroral region, reported in a 1966 paper by Zmuda and colleagues. The work on field-aligned currents has been continued by T. A. Potemra, who arrived in 1965 to work with Zmuda. After S. M. Krimigis joined APL in 1968, more experiments on NASA spacecraft were performed, and an effort was launched to explore other magnetospheres in the solar system through the Voyager spacecraft. All the planets except Neptune and Pluto have now been visited, culminating in the flyby of Uranus early in 1986. The measurements reports were received with great interest by the scientific community, as is evidenced by the citation record.

Merle Tuve would have been pleased with this vigorous pursuit of his early interest.

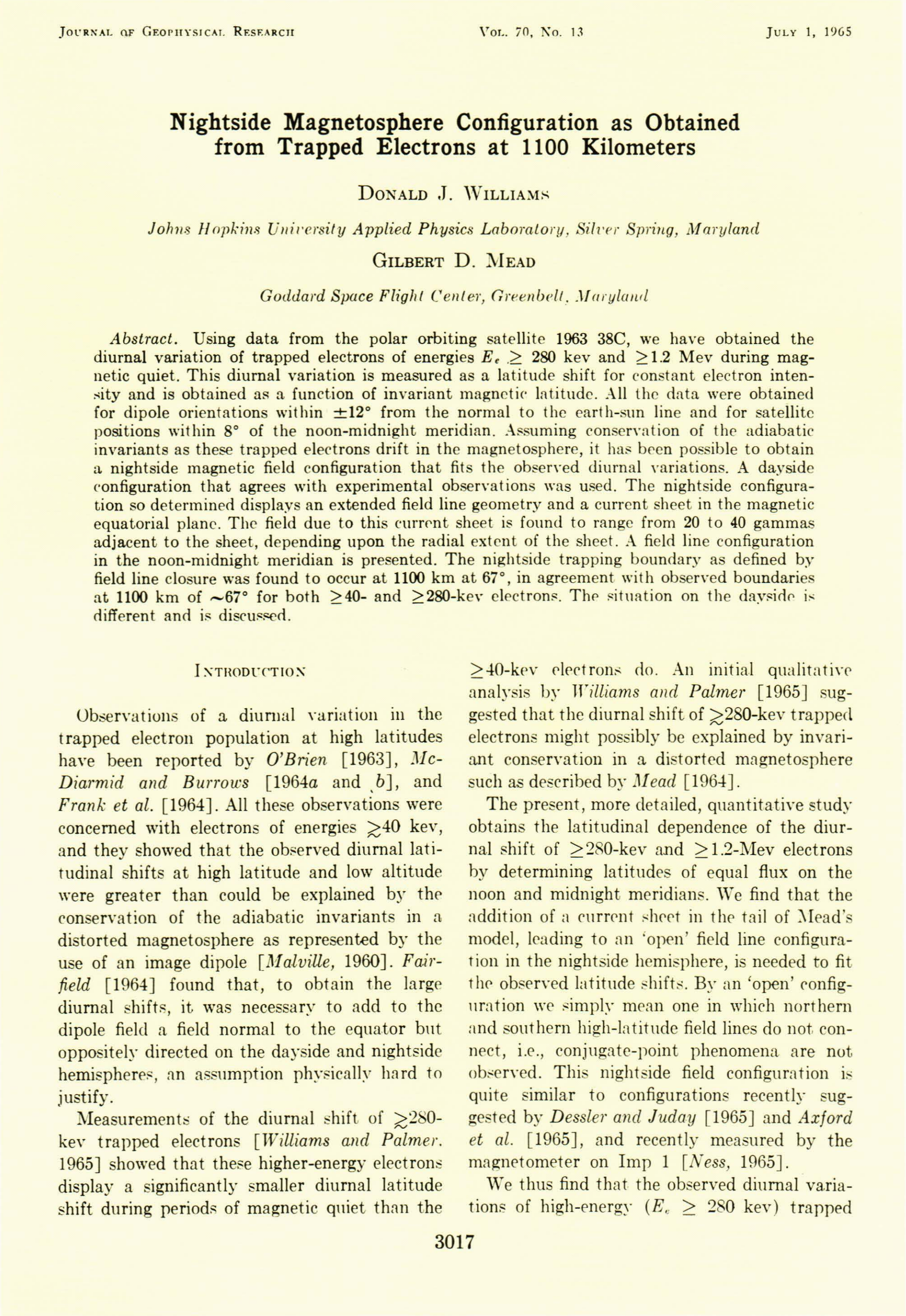
WALTER G. BERL

PARTICLES AND FIELDS IN SPACE

DONALD J. WILLIAMS

D. J. Williams and G. D. Mead, "Nightside Magnetosphere Configuration as Obtained from Trapped Electrons at 1100 Kilometers," *J. Geophys. Res.* **70**, 3017-3029 (1965).

The earth's basic dipolar magnetic field is greatly distorted at high altitudes by the outward-flowing, fully ionized magnetized plasma emitted by the sun, the solar wind. This paper presented the first analytical description of such a magnetospheric configuration. It was obtained from observations of the behavior of energetic Van Allen radiation belt electrons observed at low altitude by instruments on the APL-built satellite 1963-38C. The global magnetic field configuration (magnetosphere) that was obtained was consistently able to explain the behavior of those electrons under simple assumptions of charged particle motion in magnetic fields.



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Nightside Magnetosphere Configuration as Obtained from Trapped Electrons at 1100 Kilometers

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Abstract. Using data from the polar orbiting satellite 1963 38C, we have obtained the diurnal variation of trapped electrons of energies $E_e \geq 280$ kev and ≥ 1.2 Mev during magnetic quiet. This diurnal variation is measured as a latitude shift for constant electron intensity and is obtained as a function of invariant magnetic latitude. All the data were obtained for dipole orientations within ±12° from the normal to the earth-sun line and for satellite positions within 8° of the noon-midnight meridian. Assuming conservation of the adiabatic invariants as these trapped electrons drift in the magnetosphere, it has been possible to obtain a nightside magnetic field configuration that fits the observed diurnal variations. A dayside configuration that agrees with experimental observations was used. The nightside configuration so determined displays an extended field line geometry and a current sheet in the magnetic equatorial plane. The field due to this current sheet is found to range from 20 to 40 gammas adjacent to the sheet, depending upon the radial extent of the sheet. A field line configuration in the noon-midnight meridian is presented. The nightside trapping boundary as defined by field line closure was found to occur at 1100 km at 67°, in agreement with observed boundaries at 1100 km of ~67° for both ≥ 40- and ≥ 280-kev electrons. The situation on the dayside is different and is discussed.

INTRODUCTION

Observations of a diurnal variation in the trapped electron population at high latitudes have been reported by *O'Brien* [1963], *McDiarmid and Burrows* [1964*a* and *b*], and *Frank et al.* [1964]. All these observations were concerned with electrons of energies $\gtrsim 40$ kev, and they showed that the observed diurnal latitudinal shifts at high latitude and low altitude were greater than could be explained by the conservation of the adiabatic invariants in a distorted magnetosphere as represented by the use of an image dipole [*Malville*, 1960]. *Fairfield* [1964] found that, to obtain the large diurnal shifts, it was necessary to add to the dipole field a field normal to the equator but oppositely directed on the dayside and nightside hemispheres, an assumption physically hard to justify.

Measurements of the diurnal shift of $\gtrsim 280$-kev trapped electrons [*Williams and Palmer*, 1965] showed that these higher-energy electrons display a significantly smaller diurnal latitude shift during periods of magnetic quiet than the ≥ 40-kev electrons do. An initial qualitative analysis by *Williams and Palmer* [1965] suggested that the diurnal shift of $\gtrsim 280$-kev trapped electrons might possibly be explained by invariant conservation in a distorted magnetosphere such as described by *Mead* [1964].

The present, more detailed, quantitative study obtains the latitudinal dependence of the diurnal shift of ≥ 280-kev and ≥ 1.2-Mev electrons by determining latitudes of equal flux on the noon and midnight meridians. We find that the addition of a current sheet in the tail of Mead's model, leading to an 'open' field line configuration in the nightside hemisphere, is needed to fit the observed latitude shifts. By an 'open' configuration we simply mean one in which northern and southern high-latitude field lines do not connect, i.e., conjugate-point phenomena are not observed. This nightside field configuration is quite similar to configurations recently suggested by *Dessler and Juday* [1965] and *Axford et al.* [1965], and recently measured by the magnetometer on Imp 1 [*Ness*, 1965].

We thus find that the observed diurnal variations of high-energy ($E_e \geq 280$ kev) trapped

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A small group of motivated researchers, the clamor of a newborn research field, the opportunity to mix the two—these were elements in place at APL as the 1960s began. The small research group was the Space Research and Analysis Group established by G. F. Pieper in late 1960, the new research arena was space physics, and the mixing opportunity occurred with the APL satellite development program that led to the Navy's operational Transit navigation system. Encouragement of this new research effort by R. E. Gibson, then-Director, and R. B. Kershner, then-Head of the Space Department, fostered what has now become an internationally known and highly successful space research group.

I arrived at APL in August 1961, fresh out of graduate school and anxious to test the waters of this newly developing field of research. I joined the fledgling Group whose research staff, upon my arrival, consisted of G. F. Pieper, C. O. Bostrom, and myself. Over the next few years, the Group grew and became deeply involved in a hectic and exciting program of building and launching experiments and analyzing results. During that period, the Group built a collection of energetic particle detectors that was included on board the APL satellite 5E1, which, after being successfully launched into a low-altitude polar orbit, became known as satellite 1963-38C.

Data from that satellite resulted in the publication of our paper, one of a series using 1963-38C data concerned with the behavior of energetic particles trapped in the earth's magnetic field. The satellite also returned magnetometer data that allowed A. J. Zmuda and J. C. Armstrong to obtain the first in-situ measurements of magnetic-field-aligned currents in the earth's magnetic field.

In the early 1960s, attention had been focused on questions of how the solar wind affected the overall configuration of the earth's magnetic field in space and what were the nature and extent of the particle populations residing in that configuration. Was the earth's magnetic field distorted and, if so, how large were the distortions? How would the distortions affect trapped particle distributions? Would such a distorted configuration form a closed magnetic cavity or would it be open to the particles and fields from interplanetary space? Several excellent qualitative results indicated that distortions would exist and would be expected to be large at high altitudes. It was during this exciting and exploratory phase of space research that satellite 1963-38C was launched in September 1963.

Our initial studies of the temporal and spatial variations of energetic electrons measured by 1963-38C showed that (a) the intensity found at a given geomagnetic latitude on the local noontime meridian was higher than that found at the same geomagnetic latitude on the local midnight meridian, and (b) the intensity difference decreased as the geomagnetic latitude decreased. Those two facts plus results from earlier published work concerning the earth's magnetic field configuration by my colleague, Gilbert D. Mead of NASA's Goddard Space Flight Center, led me to a possible explanation of the electron observations.

Together, Gil and I performed the analyses that were the subject of our paper. We were able to obtain an analytical description of the global geomagnetic field configuration that consistently explained the energetic electron observations, using only the simple assumption of normal charged particle motion in a magnetic field. Our paper appeared in the same issue of the *Journal of Geophysical Research* that contained the first description of the earth's overall geomagnetic field configuration based on in-situ measurements. I am happy to report that our model bore a striking resemblance to the in-situ observations. Using those results, I was able to continue my studies of energetic particles in the geomagnetic field and to explain a variety of other phenomena observed in the data.

I feel that one of the main reasons the paper has been cited so often is that the model we presented was analytic. Simple polynomial expressions describing the geomagnetic field configuration could be used by researchers in the field without their having to resort to large numerical computational models requiring sophisticated computer techniques. Thus, the model became an early standard in testing particle observations throughout the earth's magnetic field configuration. It still does a good job of explaining many global features of the behavior of energetic particles trapped in the magnetosphere.

However, as a general research tool, the model is outdated today. We know now that in order to describe the overall magnetospheric configuration that exists around the earth we have to include electric fields, collisional effects, wave/particle interactions, and a host of other plasma processes—a description not yet attained quantitatively. It is also recognized that the earth's magnetospheric configuration represents a naturally occurring magnetized plasma laboratory that fortunately is available to our scrutiny within the relatively accessible neighborhood of the earth. This is fortunate, indeed, because such magnetospheric systems are now known to be a common occurrence throughout the universe, comparable systems occurring at several planets in our solar system, the extended solar atmosphere (the heliosphere), pulsars, and perhaps galaxies as a whole.

Those bold managers who encouraged and nurtured APL's first efforts in space research must be delighted by the outcome: a mature and still-stimulating APL research activity in the frontiers of such basic areas as space plasma physics, astrophysics, solar physics, and planetary physics.