Table 1. Signals from West Ford dipoles. The figures in parentheses refer to observations that may not have been of the dipole belt.

Date (May 1963)	U.T. (hr min)	Sky brightness mag/□″	Belt brightness mag/□″	Belt % of sky	Duration of signal (sec)	Belt passage deviation (min)
14	07 11.0	22.4	25.8	4.5	52	on time
16	06 17.2	22.4	26.5	2.4	82	2.2 late
17	07 16.7	22.6	26.2	3.5	48	1.7 late
18	05 29.5	22.2	(26.3)	(2.2)	(105)	(0.5 early)
18	08 17.4	22.5	26.4	2.6	77	2.4 late
30*	08 51.5	21.8	(26.4)	(1.6)	(54)	(1.5 late)

* Observation on this date by S. Chandra.

ment. We estimate that the magnitude of the carrier is approximately between seventh and eighth blue magnitude. In each case, the passage was at the predicted time, to within the accuracy of our measurements.

Table 1 lists the data for the four definite observations of the belt, together with two uncertain observations on 18 May and 30 May U.T. The photometric records were reduced to the unit of equivalent B magnitude per square second of arc (mag/□″) by observing standard stars on each night.

The surface brightnesses were further converted to absolute units by noting that a star of blue magnitude $B = 0$ has a flux of 4.3×10^{-23} watts meter^{-2} per cycle per sec bandwidth, or 6.6×10^{-9} erg sec^{-1} cm^{-2} per Å bandwidth. Table 2 lists the data for the belt intensity expressed in these units.

These are probably minimum brightness values of the belt because we did not sweep the area to get the point of maximum signal. Since the belt was wider than our 6.4 minutes of arc diameter diaphragm we may have been observing on the fringes for some or for all of the time. It is, therefore, fair to state that the brightness was at least 4 percent of the night-sky surface brightness near the beginning of the observation period and that the densest part of the belt may have been brighter.

Evidently the surface brightness of the belt decreased with time. This may be suggested by column 4 of Table 1, but is more strongly suspected by attempts to observe the belt on 23, 26, and 27 June 1963. T. Greenfield, an observer from Rhodesia, had use of the telescope on these dates and we are indebted to him for his data. In these trials, no signal greater than 1 percent of the moonless night sky was found, which puts an upper limit of about 27.3 mag/□″ or 0.8×10^{-19} erg sec^{-1} cm^{-2} Å^{-1} (arcsec)$^{-2}$ for the belt brightness in the third week of June.

Our observations appear to be in agreement with the careful predictions of the optical surface brightness, made more than 2 years before launch by van de Hulst and Volders, by Liller as a check (*1*), and by Morrow and MacLellan (*2*). From the engineering standpoint we believe that the present belt does not constitute a serious interference to ground-based optical observation at the faintest light levels because the belt is highly localized in time and space and because it has become, and will continue to become, fainter as time goes on. Before the experiment was authorized, this aspect was discussed fully, first by the West Ford subcommittee of the Space Science Board, and later by a scientific committee, of which J. Tukey was chairman, accountable directly to J. Wiesner, the President's science advisor.

However, in our opinion, the broader aspects of the experiment must be questioned because no nation has the right to contaminate space unilaterally in an irreversible way. (The present experiment may be reversible if the lifetime of the dipoles is finite.) Although the data presented here suggest that the present West Ford test belt has been harmless to ground-based astronomy, future experiments of a similar nature with a larger payload may not be so lucky. If, for example, a West Ford operational belt is established with, say, 100 times the present payload, the belt would be four times brighter (shortly after launch) than the natural night-sky radiation, a level which would begin to be serious for certain types of astronomical observations. Once the principle of unilateral contamination is accepted, the doors are opened for disastrous future possibilities and man may well succeed in changing his environment (albeit astronomical) beyond repair.

Table 2. Data for belt intensity in absolute units.

Date (May 1963)	Flux [10^{-33} $wm^{-2} \times$ (cy/sec)$^{-1} \times$ (arcsec)$^{-2}$]	Flux [10^{-19} Erg $\times$ sec^{-1} cm$^{-2} \times$ Å^{-1}(arcsec)$^{-2}$]
14	2.2	3.3
16	1.1	1.7
17	1.4	2.1
18	1.3	2.0
18	1.1	1.7

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West Ford Dipole Belt: Photometric Observations

Abstract. *Photoelectric observations of the West Ford belt of copper dipoles covering the period from 1 week to 1 month after the launching show a feature considerably wider than the announced belt width. The present belt is not injurious to astronomical observations from the ground but it could seriously affect observations made from low-orbiting satellite systems. Much stronger belts would seriously interfere with astronomical observations.*

Photoelectric observations of the West Ford belt of copper dipoles were obtained on 13 occasions after the announcement of launch on 12 May 1963. The observations were obtained between 20 May and 21 June with five different telescopes and photometers (Perkins Observatory 69-inch reflector, United States Naval Observatory 40-inch reflector, and Lowell Observatory 42-inch, 24-inch, and 21-inch reflectors). The focal plane apertures ranged between 77 and 350 seconds of arc; the most frequently used diaphragms were in the neighborhood of 250 seconds. The spectral regions were isolated by glass or interference filters; the bands were relatively narrow and fell in the interval between 5000 and 6000 Å.

The observed sky fields were chosen, free of bright stars, and were monitored for some time before and after the passage time on each field. The parallactic motion caused by the earth's rotation within the orbital plane caused the belt to drift across the selected field. Original predictions on the passage times and positions were provided by Lincoln Laboratory of the Massachusetts Institute of Technology; in later observations we supplemented Lincoln Laboratory data with our own computations.

Observations were made with as many as four telescopes simultaneously; there appeared to be little difference in the records obtained with different telescopes, photometers, apertures, and wavelength bands. Therefore, in the average curves that are presented here, an observation from only one telescope for each night is contained in the mean. Thus any one night's observation has only unit weight. On 11 of the 13 independent records the passage of the band was apparent; there was some indication that the band was becoming harder to detect toward the end of the observing interval. For the sake of brevity only two mean curves are shown in Fig. 1. For several of the observations the upper-stage carrier rocket passed through the photometer aperture. When this did not occur corrections to the passage time were made, in combining different nights, according to available observations on the distance which the carrier rocket passed east or west of the field. Some observations were also made after the passage of the carrier rocket by setting on another previously selected field to allow a second transit of the band. The observed part of the band was then about 180 degrees behind the carrier rocket.

In Fig. 1 the mean of 9 nights of observations near the part of the band due to the carrier rocket is presented in the upper curve. The lower curve represents the mean of three observations, on different nights, of the opposite part of the band. The slope in the upper curve was caused primarily by the ending of twilight in the early evening. The band was clearly detected and extended from about the time of transit of the carrier rocket until about 10 minutes later. From the mean curves, the amplitude of the effect was 0.5 percent of the total sky light (mostly air glow) for the carrier rocket part of the band and somewhat greater for the orbital point 180° behind the carrier. From the observed duration the width of the band near the carrier is about 3°; the width at the 180-degree point is somewhat greater. The light of the entire band, if condensed to one

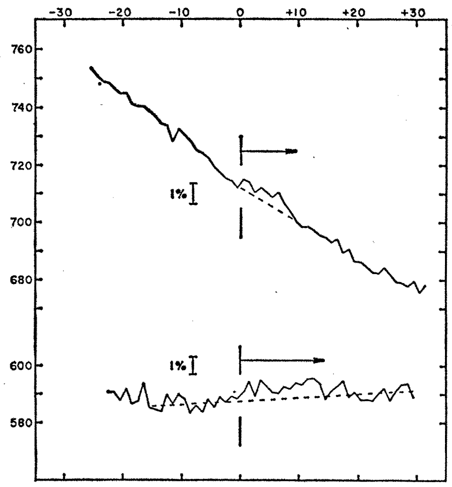

Fig. 1. Mean light curves for passage of the West Ford dipole belt. Ordinate, relative sky intensity; abscissa, time in minutes from the predicted time of passage of the belt across the fields observed. The upper curve is a mean of nine observations near the carrier rocket obtained on the dates 5/20, 5/24, 5/26, 6/12, 6/14, 6/17, 6/18, 6/20, and 6/21. The lower curve is a mean of three observations at points in the orbit nearly opposite to the carrier. These data were obtained 6/13 (199° behind carrier), 6/14 (205° behind), and 6/17 (187° behind). The noise level is relatively high for the lower curve since a narrow band filter was used, which required a very high amplifier gain. One additional observation obtained 5/26, behind the carrier, is not included in the mean since it extended only a short time before the passage time. With this exception there has been no editing of the data presented. A 1 percent-of-sky scale mark is shown for each set of observations.

point in the sky, if one assumes a 3-degree uniform width, is equivalent to that of a star of 3.2 magnitudes. Several years ago, Morrow and MacLellan (*1*) described the effects of the proposed belt of 35 kg of copper needles. The total light of the proposed belt, when integrated over the sky, is equivalent to a star of 5.1 magnitudes. The observed belt is 1.9 magnitudes or a factor of 6 brighter than the calculated one. Morrow and MacLellan's estimate of the width of the band was 9 minutes of arc while the reported radar width of the West Ford belt is 15 minutes of arc (*2*). We have been unable, however, to obtain really definitive data on the radar width to compare with our optical observations which show a width 12 times greater than expected. Our data suggest that the band has spread laterally much faster than expected. A recent report (*3*) suggested that such rapid lateral spreading might be present. If the band is as narrow as predicted, the brightness in the band should be several percent of sky to satisfy the brightness estimate of Morrow and MacLellan (*1*). Since the observed peak brightness is much less than expected the band must either have unexpectedly low reflectivity or have spread appreciably laterally which is more consistent with our observations. Until more definitive radar data is available, the question of width and lateral spreading cannot be finally resolved.

In view of the extensive width of the band, we considered that part of the light might be produced by emission from atoms or molecules in excited states. This is a possibility if any of the copper evaporated. There would then be extremely strong resonance scattering occurring in the ultimate copper lines at 3247 and 3274 Å. Additional observations were made with a silver-on-quartz filter which had peak transmission at 3225 Å and a width at half height of 225 Å. No evidence of the band was found with this filter, but airglow fluctuations at this wavelength were much more severe.

The optical effects of the belt are readily detected by the photoelectric techniques that are conventionally applied to faint stars. The brightness of the band is comparable to fluctuations of the airglow. Astronomical photometry from low-orbiting satellites will not be limited by fluctuations of the airglow and the present band represents a distinct hazard to such observations. Any band or bands stronger than the present one will produce effects noticeably greater than airglow fluctuations and we strongly disapprove of any such experiment. Bands with the large masses which have been suggested in the literature from time to time could reach brightness equal to the night sky. Such bands would be visible to the naked eye and have serious consequences to astronomy the world over.

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