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Optical Effects of the 1963 Project West Ford Experiment

Photographic and photoelectric observations yield information on the brightness of the dipole belt.

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At the request of the Space Science Board of the National Academy of Sciences and of the International Astronomical Union, I agreed to serve as distributor, receiver, and analyst of all data pertinent to the optical appearance of the recent successful Project West Ford experiment, conceived by the Lincoln Laboratory of the Massachusetts Institute of Technology. Orbital information and "look angles" were sent to all observatories and astronomers requesting them. Since the first radar contact with the copper needle dipoles was made on 12 May 1963, I have received numerous observational results, positive and negative. This communication is the final official report on the optical effects of Project West Ford (*1*). Additional observations or reports of observations, although useful, will not greatly alter the conclusions given here, as subsequent paragraphs will make clear.

Predicted Optical Intensity of the West Ford Dipoles

Van de Hulst and Volders (*2*), Morrow and MacLellan (*3*), Blackwell and Wilson (*4*), and I (*5*) have at various times published predictions of the brightness of the West Ford belt. However, because of pre-launch changes in the design of West Ford's parent spacecraft, it is necessary to alter some of the parameters that we assumed. The experimenters not only decreased the approximate total weight of the dipoles from 27 to 18 kilograms but also changed the diameter of the needles from approximately 0.0025 to about 0.0018 centimeters. The net result was to increase the total number of dipoles by approximately 37 percent but to decrease the light intensity scattered from each dipole by 30 percent. Thus, the revised predicted value for the visual surface brightness of the belt would remain at 1.7 the brightness of a 10th-magnitude star, per square degree of arc, 60 days after ejection of the needles.

For purposes of comparison, we should remember that the visual brightness of the darkest part of a moonless night sky, away from artificial lights, auroras, and so on, is usually between 150 and 200 times the brightness of a 10th-magnitude star per square degree of arc. The latter figure is equivalent to 2.8×10^{-21} watts per square meter per cycle per second per steradian, or to 22.0 magnitudes per square second of arc. Let us assume in this article that a brightness of 200 10th-magnitude stars per square degree is a typical night-sky brightness in a well-located observatory.

Table 1 gives, as a function of time, the predicted mean visual surface brightness and the angular dimensions of the West Ford belt. These latter data were supplied by Lincoln Laboratory. It was predicted that after 60 days the dipole density would be fairly uniform along the belt, but that earlier in the history of the belt there would be a strong concentration near the center. Two especially noteworthy characteristics were predicted: (i) that the belt brightness would drop quite rapidly during the first few days after launch, due to the reciprocal relationship between belt brightness and time, and (ii) that the belt width would not become as great as 1 degree until 1 year after ejection, if it increased linearly with time.

According to the radar observations made at Lincoln Laboratory, the dimensions of the belt have closely followed the predictions of Table 1.

The predicted belt intensity, plotted as a function of time, appears in Fig. 1 as a smooth curve. The letters represent values for observed brightness (these are discussed in the next section). Since we cannot determine the exact time of dispensing of the needles into orbit, it is permissible to shift the curve horizontally by a day or two. For this article I have placed the curve so that it passes very nearly through the first observed point (as discussed in the next section), with $t = 0$ coming at 0^{hr} Universal Time (U.T.), 12 May 1963.

Lincoln Laboratory announced the successful dispensing of needle dipoles into orbit shortly after the north-to-south passage of the dipole cloud over the eastern United States at 17 hours U.T. on 12 May. Actually, the command to release the dipoles had been sent to the parent satellite 2 days earlier. However, because of an unfavorable sun-capsule orientation, the needles were released from their naphthalene cocoon at a rate slower than that originally planned (*6*).

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Observed Optical Intensity of the West Ford Dipoles

The optical observation of the belt may be summarized as follows. There were no definite visual sightings; two and possibly four series of photographs recorded the dipoles, and on no less than six occasions the belt was detected photoelectrically. The first known definite contact occcurred at $01^{hr}36^{min}$ U.T., 14 May; the last known definite contact occurred on 18 May, but it is possible that there were some contacts as late as 30 May. Nearly three dozen astronomers at at least 12 observatories or observing stations have sent in the results, positive or negative, of their efforts to establish the optical brightness of the West Ford belt.

Visual observations. Many individuals attempted to observe the belt visually. The parent satellite, which was of 5th or 6th magnitude, depending upon its distance from the observer, served as an excellent guide to the location of the belt, since, during the early days of the experiment, the belt was reportedly close to the parent. Unfortunately, moonlight seriously interfered with these attempts, since full moon occurred on 8.7 May, U.T. Both G. H. Newsom and R. D. Chapman, experienced satellite observers, made the first known attempt to observe the belt, at $03^{hr}26^{min}$ U.T., 13 May, in Cambridge, Massachusetts. Most of the United States was experiencing cloudy weather at that time, but eastern Massachusetts was very clear, and in Cambridge, Newsom and Chapman, using binoculars, searched carefully but unsuccessfully for the dipole cloud in the vicinity of the parent satellite. However, the pass was considerably less than favorable, and both city lights and moonlight were troublesome.

Later observations made at Kitt Peak by B. Faure suggested a haziness around the parent satellite, but this haze was not seen by other observers. Presumably, thin clouds noted over Kitt Peak at the time caused the apparent haziness.

Nearly all observers used the parent satellite as a means of verifying the "look-angle" setting at the time of observation. No observers other than Faure reported any haziness or beltlike formation. A. A. Hoag reported particularly careful attempts to make visual observations at the U.S. Naval Observatory in Flagstaff, Arizona.

Photographic observations. The earliest known definite detection of the belt was made photographically at the Smithsonian Astrophysical Observatory in San Fernando, Spain, with a Baker-Nunn satellite-tracking camera [*f*/1.0; 51-cm (20-in.) clear aperture; plate scale, 417 sec/mm]. A. Olsen and Donald Tingle obtained a series of seven 10-second exposures with Kodak Royal-X panchromatic film, starting at $01^{hr}35^{min}42^{sec}$ U.T. on 14 May (*7*). The camera was driven at very nearly the calculated rate of motion of the satellite. Consequently, on each photograph the satellite appears as a very short, bright trail 2.0 minutes of arc long, while the stars appear as much longer trails running parallel to the length of the film. The dipole belt appears as a narrow hazy band running roughly north and south and passing about 3 minutes of arc east of the parent satellite. The apparent belt width arises mainly from the slight difference in the rates of east-west motion of the camera and of the satellite and belt. The belt length is difficult to measure, but one can trace it with certainty for 6 or 7 degrees. Its apparent width is roughly 2.5 minutes of arc, indicating that its true width was extremely narrow. The sky was perfectly clear, and had it not been for the 20-day-old moon some 105 degrees away, conditions would have been ideal.

Twenty-two hours and 10 minutes later, another series of photographs was taken. All conditions were nearly the same as for the earlier series except that there was no moon. On these photographs one can barely see the belt, despite the much darker sky background.

Two other Smithsonian tracking stations, one in Florida and one in New Mexico, attempted to take photographs on 14 May, but clouds interfered with both attempts. On neither series of photographs can one definitely see the belt, although suggestions of it appear between clouds.

Table 1. Predicted characteristics of the West Ford belt.

Days after ejection	Mean visual surface brightness [10th-mag stars/(deg of arc)^2]	Angular length* (deg)	Maximum angular width* (min)	Maximum angular width at zenith† (min)
2	70	24	4	11
5	26	60	4	12
10	10	120	5	14
20	5	240	6	17
40	2.5	360	8	24
60	1.7	360	11	31

* Measured at earth's center. † Measured at earth's surface.

Table 2. Observed brightness of the West Ford belt.

Date	Days after ejection*	Observatory	Surface brightness of belt [10th-mag stars/(deg of arc)^2]	Remarks
14.1 May	2.1	San Fernando	20.	Photographs
14.3 May	2.3	Palomar	6.7	
15.0 May	3.0	San Fernando	8.	Photographs
15.3 May	3.3	Lick	< 4	
16.3 May	4.3	Kitt Peak	<10	Telescope not driven
16.3 May	4.3	Palomar	3.3	
16.3 May	4.3	U.S. Naval	< 2	
17.3 May	5.3	Palomar	4.3	
18.2 May	6.2	Palomar	4.0?	
18.3 May	6.3	Palomar	3.3	
21.2 May	9.2	Lick	< 6	
21.2 May	9.2	U.S. Naval	< 2	
21.2 May	9.2	Lowell	< 2	
21.4 May	9.4	U.S. Naval	< 2	
22.3 May	10.3	Lick	< 6	
25.3 May	13.3	Kitt Peak	< 4	
25.3 May	13.3	Lowell	2 ?	
27.3 May	15.3	Lowell	< 1	
29.3 May	17.3	Lowell	< 2	
30.4 May	18.4	Palomar	3.3?	
12. June	31.	Kitt Peak	< 6	Sky moonlit
23. June	42.	Palomar	< 2	
26. June	45.	Palomar	< 2	
26. June	45.	Kitt Peak	< 2	
27. June	46.	Palomar	< 2	

* Adopted values.

All photographs taken with the Baker-Nunn camera receive a sensitometric step-wedge calibration; in addition, the Smithsonian observers wisely photographed an extended astronomical source (the globular star cluster M 13) on the same film. Hence, it was possible to express the belt brightness in absolute units.

Because the dipole belt appears only faintly on even the best of the Baker-Nunn photographs, a single densitometer trace across the belt does not always show its presence. Therefore, I selected the best photograph from each of the two series taken in Spain by Tingle and made a number of densitometer scans across the belt image in each photograph at points separated by 15 minutes of arc. I then averaged these scans (see Fig. 2) and converted them to intensities in the usual manner. The results of Olsen's and Tingle's observations are listed in Table 2, and the maximum brightness is plotted in Fig. 1. Considering all sources of error, I would place the probable error of this observation in the neighborhood of 15 percent.

Because the Baker-Nunn photographs were taken with a panchromatic film without the use of a filter, the results are approximately equivalent to a visual-response system.

Parsons, Kofsky, and Miller, of Technical Operations, Inc., Burlington, Massachusetts, made an intensity contour map of the best Baker-Nunn photograph; a portion of their map appears in Fig. 3. The isophotes strongly indicate that the belt brightness was irregular, and at some points the belt seems to disappear completely. Four contour levels are shown: the solid curves correspond to intensities approximately 5, 15, and 25 percent above the average night-sky intensity; the dashed curve represents an intensity 5 percent below this level. For clarity, only a portion of the film in the vicinity of the belt is represented; clear sky shows brightness fluctuations averaging 10 percent. Figure 3 is included only to indicate the irregular nature of the belt; the averaged densitometer scans of Fig. 2 were used in deriving the brightness of the West Ford belt.

Photoelectric observations. Perhaps the most accurate information on the brightness of the West Ford dipoles comes from photoelectric observations. Palomar, Kitt Peak, Lick, Lowell, the U.S. Naval, and Harvard College observatories all participated actively. With few exceptions, the basic technique was the same in all cases. The observers set a moderate-to-large telescope, with associated photoelectric equipment, to the predicted "look angle" a number of minutes in advance of the predicted pass. They chose a region of the sky completely free of visible stars, with the telescope driving mechanism set at a sidereal rate so that stars would not pop into and out of the field of view. Then the output of the phototube, arising primarily from the light of the night sky, was carefully monitored on a pen-and-ink recorder. The passage of the West Ford belt through the field showed as a slight rise (of never more than a few percentage points) in the output. Usually

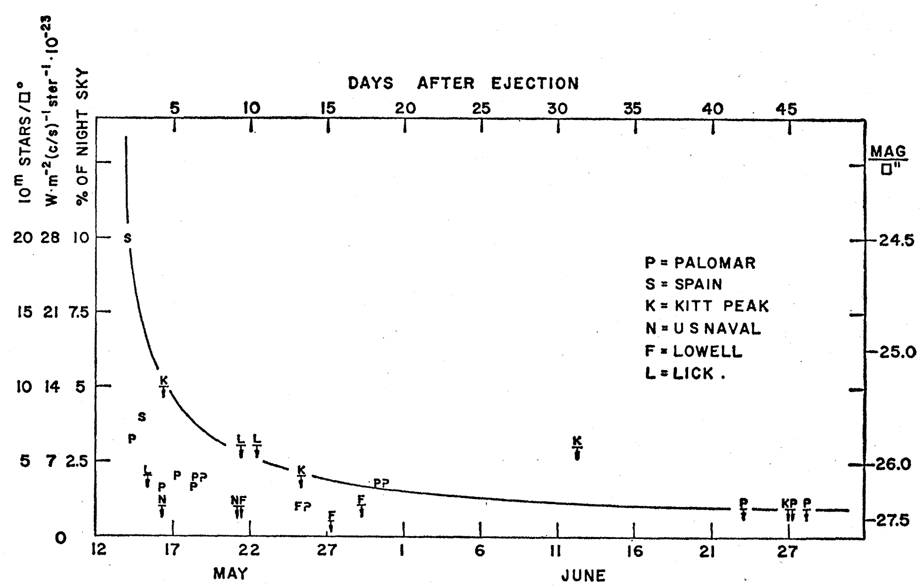

Fig. 1. The predicted and observed brightness of the West Ford belt plotted as a function of time.

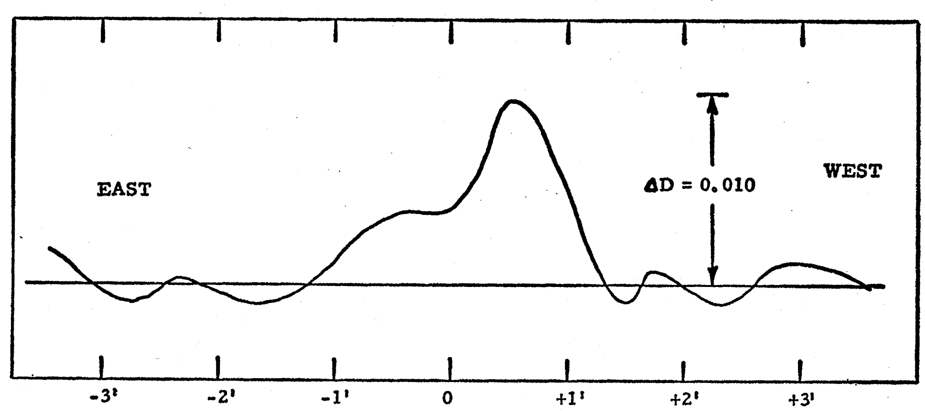

Fig. 2. The average of nine densitometer scans made across a photograph of the West Ford belt taken at the San Fernando station of the Smithsonian Astrophysical Observatory. The camera used was an $f/1$, 51-cm (20-in.) Baker-Nunn. The curve has not been corrected for instrumental "smearing." Difference in photographic density, ΔD.

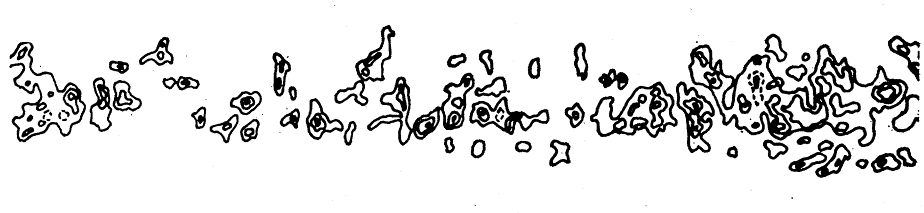

Fig. 3. Isodensity contours for the best of the photographs taken by Olsen and Tingle at the Spain Satellite Tracking Station of the Smithsonian Astrophysical Observatory. Only contours in the vicinity of the belt are included. North is to the left. For contour increments, $\Delta D = 0.012$ (see text).

the angular diameter of the field was comparable in size to the angular width of the belt (that is, a few minutes of arc); the belt, moving at a rate of about 1 degree every 3 minutes, remained in view for approximately 30 seconds. After passage of the belt the observers took further sky readings in order to establish background sky intensity.

Because of the reddish color of copper, most observers chose to observe the radiation reflected from the copper needles through yellow filters; use of the filters in combination with the phototube (usually a refrigerated RCA 1P21) resulted in a response system approximating the standard V, or visual, system (*8*). However, the B system and an unfiltered system were also used. (The V system roughly duplicates the response of the eye; B is a blue-sensitive system covering the region from $\lambda = 4000$ Å to $\lambda = 5000$ Å.)

All observations described here, and also the predicted brightness, are given in measures of the V system. The following procedure was used to convert B measures to the V system. Lincoln Laboratory, according to information from MacLellan, has made rough spectrophotometric measures of the copper dipoles and finds their reflectance to be almost identical to handbook values for pure copper metal. Using published response curves (*8*) and a published reflectance curve for pure copper (*9*), I find that all B-system measurements of brightness must be increased by a factor of 1.25 (−0.24 magnitude) to yield V, or visual brightnesses.

On several occasions observers sent me reproductions of the original observations, and I used them in estimating the upper limits of brightness indicated by the horizontal bars beneath the letters in Fig. 1. Some results were transmitted to me by telephone, and these may require slight adjustment or further explanation. I hope that all observations are reasonably well represented in Fig. 1.

The most uniform set of photoelectric data is that collected at Palomar Mountain by A. Sandage, C. Kowal, T. Greenfield, and S. Chandra. They made their observations with a 51-cm (20-in.) Cassegrain reflector on 5 nights in May. The results, presented in Table 2, are described in detail elsewhere (*10*). As may be seen in Fig. 1, their points consistently fall below the predicted curve, with the exception of one questioned observation. Three further attempts to observe the belt photoelectrically, made during the dark of the moon in late June, were unsuccessful. As Sandage and Kowal remark (*10*), their observations (and this is true of all photoelectric observations) must be considered lower limits, since they were not necessarily made at the point of maximum brightness in the belt.

Clouds, moonlight, and generally unfavorable passes of the belt during the early days of its history hampered observers at three Arizona observatories. Nevertheless, they obtained excellent observations, particularly during the later phases of the program, and established quite consistent upper limits of brightness. H. A. Abt directed observers at Kitt Peak National Observatory; at the U.S. Naval Observatory A. A. Hoag and his colleagues carried out observations; and at the Lowell Observatory, W. M. Sinton, J. B. Priser, and W. G. Tifft all were involved in the observational work. The last four observers have already published their work (*11*).

Elsewhere, M. Walker and his associates at the Lick Observatory tried on three occasions to detect the belt, without success. It was not possible for them to make observations more than once during the first few days of the belt's existence. Fluctuations in sky brightness on 21 and 22 May set limitations on the measurement of the brightness of the dipoles. On the night of 22 May they used both the 305-cm (120-in.) and the 91-cm (36-in.) telescopes simultaneously. The two instruments, about a half mile apart, recorded more or less the same fluctuation in sky brightness, amounting to as much as 3 percent.

At the Agassiz Station of the Harvard College Observatory, F. Stienon and J. Shao made several attempts to record the belt. However, skies brightened by the lights of neighboring Boston (about 50 kilometers away) made it impossible to detect the West Ford belt with certainty.

Finally, C. Heynekamp of the High Altitude Observatory, Boulder, Colorado, attempted to detect the belt by means of the K-coronameter. Earlier calculations by R. L. Shutt of the University of Colorado showed that it might be possible to detect the needles through their forward scattering of sunlight. On 10 days between 22 May and 15 June, Heynekamp and his colleagues observed the polarization of the sky at a distance of 3 earth radii from the center of the sun. No effects of the belt were noticed. However, on all days the scintillation noise was reported to be very bad.

A number of foreign observatories asked for and received "look-angle" data. As yet I have not received any word from them regarding the outcome of their attempts to detect the belt.

Discussion

As one can judge from Fig. 1, the predicted curve agrees moderately well with the observations. If anything, the belt is perhaps slightly fainter than had been predicted, but as Sandage and Kowal emphasize, the photoelectric data represent lower limits. In one or two instances there are some discrepancies; however, it seems certain that the density of the copper dipoles was far from uniform, especially during the first few days of the experiment. This conclusion comes not only from the radar observations made by Lincoln Laboratory but also from inspection of the isophotal contours made from the Baker-Nunn photographs.

The questioned observation from Lowell Observatory for 25 May, as well as the Lowell results in general, requires some discussion. Tifft, Sinton, Priser, and Hoag (*11*) report that on numerous occasions their data show a rise near the parent satellite, averaging about 0.5 percent of the night-sky background intensity, lasting for about 10 minutes. It is difficult to accept the corresponding belt width (~3 degrees) that they report when the predicted widths given in Table 1 are clearly smaller by an order of magnitude. Furthermore, radio echoes made by the Lincoln Laboratory group as late as the end of July 1963 show that the belt is, if anything, less wide than was originally predicted. For these reasons I have not included results from Lowell as confirmed observations in this report. Director John Hall of the U.S. Naval Observatory sent me some of the details of Priser's early observations. On one occasion (25 May) there was indeed a brief rise of 1 percent in the sky background intensity, and consequently the observation has been included in Fig. 1 as a questioned observation.

The same authors (*11*) suggest that if any of the copper evaporated in space, there would be extremely strong resonance scattering, occurring in the ultimate copper lines at λ 3247 Å and 3274 Å. Observations through a narrow band filter yielded no definite results, although fluctuations in airglow were quite severe.

Finally, Tifft *et al.* (*11*) report observing on several occasions a rise, of somewhat more than 0.5 percent of the night sky intensity, at a point approximately 180 degrees from the parent satellite. The duration of the rise is considerably greater than that of the increase noted near the parent satellite, and, again, some doubt attaches to these observations.

Conclusions

Photographic and photoelectric observations show that the West Ford dipole belt was no brighter than had been predicted. If the needles had been released during the dark of the moon the results might have been better; nevertheless, the surface brightness of the belt seems well established.

Unfortunately, no polarimetric observations were made. At best, they would have been extremely hard to make. I hope that any observations made during the early days of the experiment but not yet reported will be sent me in the near future.

References and Notes

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12. On behalf of the West Ford committees of the Space Science Board and the International Astronomical Union, I thank all astronomers who participated in this effort to measure the optical brightness of the West Ford belt. Many persons, both named and unnamed in this article, contributed to the results reported. Dr. John W. Findlay, chairman, and Dr. E. R. Dyer, secretary of the West Ford Committee, as well as the other members of the committee, helped me greatly in preparing this report. The assistance, on many occasions, of numerous Lincoln Laboratory scientists and technicians is likewise gratefully acknowledged.

Free Radicals and Unstable Molecules

Mass spectrometry and electron spin resonance yield insights on energies, reaction mechanisms, and structure.

S. N. Foner

The study of transient chemical species has fascinated researchers for many years. Aside from satisfying an innate curiosity about the mode of formation and subsequent demise of these normally short-lived chemical entities, such studies yield considerable information on chemical processes and contribute to a deeper insight into atomic and molecular structure.

In discussing unstable chemical species it is important to differentiate between intermediates whose lifetime is limited by chemical reaction (for example, free radicals) and those which are intrinsically unstable (for example, electronically excited atoms or molecules). Components in the first category can be transferred from their hostile environment into a high-vacuum region, where they may be examined for a short time; or they may, in many cases, be stored for an indefinite period by isolation in an inert matrix, and studied at leisure. On the other hand, there is no available means of preventing the radiative decay of components in the second category, and these have to be studied within a time span dictated by the component rather than chosen by the experimenter. The techniques described here have been applied predominantly to free radicals, although some progress has been made in the study of electronically excited species.

Mass spectrometry and electron spin resonance are particularly useful techniques for studying free radicals in chemical reactions. In reactions the concentration of free radicals is generally quite low, simply because radicals are highly reactive. Both mass spectrometry and electron spin resonance are methods of high sensitivity, and both can give unambiguous identification of radicals and can be used for quantitative analysis. The methods are complementary rather than competitive, since the mass spectrometer can handle only gaseous samples, whereas electron-spin-resonance studies are usually carried out on solid or liquid samples. In addition, the types of information derived by these methods, aside from identification, relate to different characteristics of the free radical. Furthermore, mass spectrometry measures all the chemical compounds present in the sample, while electron spin resonance responds only to species with unpaired electron spins.

Application of Mass Spectrometry

The earliest definitive application of mass spectrometry to the study of free radicals probably was the measurement by Hipple and Stevenson (*1*) of the ionization potentials of the methyl and ethyl radicals produced by pyrolysis of lead tetramethyl and lead tetraethyl in a heated quartz tube inside the mass spectrometer. The study of free radicals formed in gas-phase reactions, particularly combustion and thermal decomposition reactions, was pioneered by

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