the ability of the phase to withstand the intense irradiance required. This last item may be the major limitation to the general applicability of the technique to smaller inclusions. Such problems can be minimized by selection of an excitation wavelength not absorbed by the sample or host.

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20. We thank S. Levine for the apatite sample and H. E. Belkin for sample preparation.

7 August 1975

Planetary Brightness Changes: Evidence for Solar Variability

Abstract. *Brightness changes of Uranus and Neptune at 440 nanometers were highly correlated from 1956 to 1966. Recent observations of Saturn's satellite Titan and of Uranus and Neptune show a steady brightening at 551 and 472 nanometers since 1972. Either the solar constant is slightly variable or solar activity causes correlated changes in the albedos of planetary bodies.*

The possibility of small variations in the solar constant (the integrated solar flux per unit area as seen at the top of Earth's atmosphere) is of great importance to climatologists, solar physicists, and planetary astronomers. Currently, the uncertainty in measures of the solar constant is about ± 1 percent, and variations of that size on time scales from days to years cannot be ruled out (*1*). Limitations in the accuracy of solar constant measurements are imposed by the difficulty of maintaining the calibration of the receiver and, for ground-based measurements, the difficulty of correcting for the effects of atmospheric extinction which change with wavelength, time, and the altitude of the sun.

However, one can make differential photoelectric measurements of reflected sunlight accurate to a small fraction of 1 percent by comparing the magnitudes of the outer planets and their satellites with stars of similar brightness and color located nearby in the sky. The observations are insensitive both to the extinction, which affects all objects about equally, and to changes in the sensitivity of the photometer. Although these measurements are not easily transformed to an absolute scale of physical units, they are very suitable for the detection of small changes over a long period of time.

Two sets of photometric data, spanning 25 years, are combined in this report. Uranus and Neptune were observed at Lowell Observatory in Flagstaff, Arizona (elevation, 2210 m), continuously from 1950 to 1966. In 1972, the program was reinstated, and Titan was added as a third object. This huge satellite of Saturn was a logical addition since it is the only satellite in the solar system known to have an atmosphere, and there was good reason to suspect that its reflecting power would be constant.

Since 1972, Neptune, Uranus, and Titan have been observed regularly with the 1.1-m and 0.5-m reflecting telescopes at Lowell Observatory. Some observations of Uranus and Neptune in 1972 and 1974 were made with the 0.6-m telescope at the Mauna Kea Observatory in Hawaii (elevation, 4200 m). All observations prior to October 1973 were made by M. Jerzykiewicz and those since then by me. The same photometer, filters, and photon-counting data system have been used for all measurements.

In these observations the blue (*b*, 472 nm) and yellow (*y*, 551 nm) filters of the Strömgren narrow-band (~ 20 nm) photometric system have been used. Color effects, due to differences in the color of the comparison stars, are virtually nonexistent for such narrow bandwidths. As an experimental control, two comparison stars are used for each object and are intercompared along with the primary objects in order to ensure that they are constant in brightness. Pre- and post-opposition mean magnitudes for each object and each apparition since 1972 are shown in Fig. 1. The magnitude scale is defined in terms of published ($b - y$) colors for standard stars (*2*) and a *y* scale that is being defined on the basis of the Lowell observations. To simplify comparisons from year to year, all magnitudes are routinely normalized to mean opposition distances and a solar phase angle of zero (*3, 4*).

From Fig. 1 it is clear that each object has brightened, but by different amounts, since 1972. The changes have been essentially linear with time and are highly significant, being many times larger than the annual mean errors. Variations in the brightness of Titan have been reported elsewhere, and there is also evidence that the Galilean satellites of Jupiter may have brightened from 1973 to 1974 (*5*).

The principal uncertainty in a long series of planetary observations such as these lies in the determination of the relative magnitudes of the different sets of comparison stars which must be used for each year's observations. As an example, comparison stars for Titan, two per apparition, are located at 12° (annual) intervals along the ecliptic path. Thus, considerable time and care must be invested in observing the comparison stars required for a planetary monitoring program of several years' duration.

The internal error of the mean of the differential observations for one observing period (consisting of measurements on 10 to 20 nights) is typically ± 0.001 to ± 0.002 mag, or 0.1 to 0.2 percent. External errors in the relative magnitudes of comparison stars for different years average ± 0.002 mag. Thus, the uncertainty in the resulting annual mean magnitude of a single planetary body is often as small as ± 0.003 mag or 0.33 percent. This is an order of magnitude smaller than the increases that have been observed, and so the reality of the brightening is very secure.

Further correlated changes in brightness are evident in broadband ***B*** (440 nm) measurements of Uranus and Neptune made

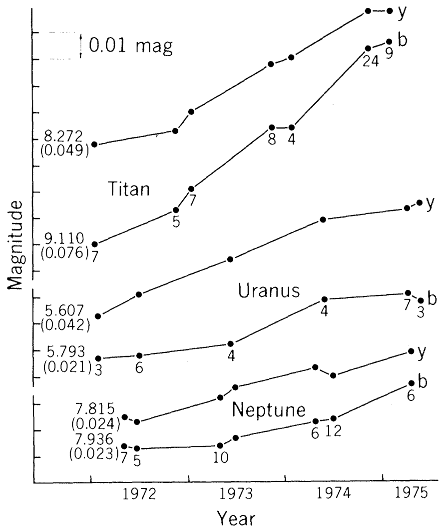

Fig. 1. Variations of the narrow-band blue (*b*) and yellow (*y*) magnitudes of Titan, Uranus, and Neptune since 1972, reduced to mean opposition distances of 9.539, 19.191, and 30.071 A.U., respectively, and corrected to a solar phase angle of zero. The zero point of the ordinate is arbitrary, with brightness increasing in the upward direction. Numbers at the left are the magnitudes of the first (leftmost) plotted points and (in parentheses) the subsequent increases. The number of nights on which measurements contributing to each mean were made is indicated below each point. Note that 0.01 mag ≃ 1 percent.

continuously at Lowell Observatory by various investigators from 1950 to 1966 (*6, 7*). Possible systematic errors in the data prior to 1956, resulting from changes in the early instrumentation, reduce the weight of these initial magnitudes, but later data show no evidence of such errors. The annual mean magnitudes are summarized in Fig. 2, which also includes the recent *b* magnitudes; I converted all the magnitudes here to the *b* scale, using a transformation based on the observations and reductions of Jerzykiewicz (*3*).

A strong variation in Uranus, illustrated in Fig. 2, results from its oblateness and changing aspect. From the observations a "photometric" oblateness of 0.045 was derived, in reasonable agreement with observed values of the geometrical oblateness (*8*). Variations in the brightness of Neptune during the same interval are also shown in Fig. 2.

Of considerably greater interest than the individual variations in the brightness of the planets is the fact that fluctuations in the brightness of the two planets, with respect to the oblateness curve for Uranus and the straight line curve for Neptune, are very highly correlated with one another. The correlation coefficient is 0.66, significant at the 97.5 percent level, and it is not sensitive to different adopted values of the oblateness of Uranus in the range 0.03 to 0.06. The initial data (1950–1955), despite their low weight, tend to confirm this relationship. Overall, there is a strong suggestion of common causation for the variations as in the data since 1972. No obvious association is seen between the fluctuations and the solar maxima of 1957 and 1968.

Systematic errors in the broadband data seem to be ruled out by the fact that the planets were observed at different seasons, with only a few overlapping nights. Magnitudes determined on the same nights, moreover, are totally uncorrelated and simply exhibit normal observational scatter.

The conclusion, then, is that the brightening trend of Titan, Uranus, and Neptune has been in progress since at least 1972. Furthermore, there is strong evidence for correlated photometric variations of Uranus and Neptune during the years 1956 through 1966. No reasonable explanation for the cause of the brightness variations is evident that does not involve the sun, directly or indirectly, as the causative factor.

Approximately half of the increase in the brightening of Uranus since 1972 may be explained in terms of the oblateness effect. This being the case, the increases in Uranus and Neptune may not be significantly different from one another. If, moreover, we choose to consider the brightening of Titan as anomalous, possibly due to a seasonal effect, then an increase in solar brightness of about 2 percent *may* have occurred since 1972. (Titan perhaps represents a special case since its orbit is inclined 26° with respect to the ecliptic. Maximum inclination of the orbit as seen from Earth occurred in mid-1973.)

Such a large variation in visible output, if real, would be unique for solar-type stars. Jerzykiewicz and Serkowski (*7*), in a 10-year survey of stars similar in luminosity and temperature to the sun, found no variations in excess of 0.8 percent. Even these may have been the result of normal observational errors. Therefore, it seems that an alternative explanation for the current variations of planetary brightness must be sought.

The sun is known to vary both at wavelengths shortward of the visible spectrum and in the solar wind flux, in response to localized activity (for example, flares) and the 11-year cycle. Geophysical effects due to this activity, such as auroras and ionospheric disturbances, are often dramatic, but the effects, if any, on Earth's albedo and radiation balance are not known. It appears reasonable, therefore, to hypothesize that the variations we see in the planets may be due, at least in part, to albedo changes caused by some form of solar variation not necessarily in the visible spectrum. Photochemical effects, for example, are a possibility.

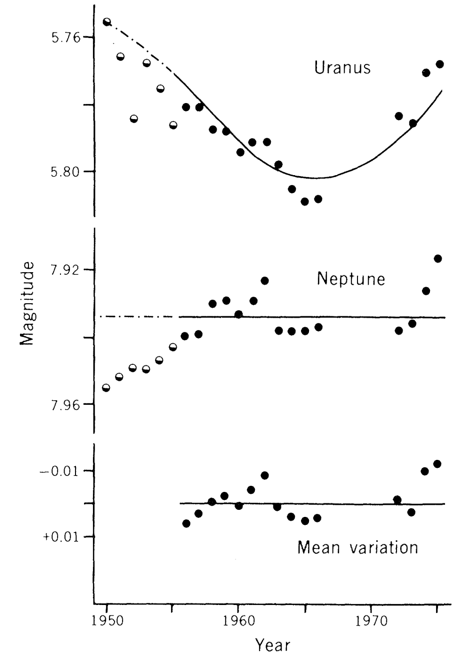

Fig. 2. (Top) Long-term variations in the *b* magnitude of Uranus uncorrected for oblateness. Data from 1950 through 1966 are transformed from the *B* magnitudes (*3, 7*). The solid curve is a least-squares fit of the oblateness function (*8*) to the data for 1956 through 1974, which gave an oblateness of 0.045. Half-filled circles are low-weight points. (Center) Variations in the *b* magnitude of Neptune. The solid line is the mean, 1956 through 1974. Half-filled circles are low-weight points. (Bottom) The mean variation of Uranus and Neptune, calculated because the mean fluctuations of the two planets from the adopted curves are highly correlated. The range is about 2 percent.

Continued observations over the next few years may reveal if this hypothesis is correct. A solar minimum is due to occur in 1975, and the subsequent rise in solar activity, if associated with a decrease in planetary brightness (that is, diminishing albedos), may settle the question. Increasingly accurate direct measurements of the solar constant may become available as well.

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scale by means of the relation $(B - b) = 0.324$ mag for Uranus and $(B - b) = 0.303$ mag for Neptune.
8. The oblateness of Uranus is important because the rotational axis of the planet lies nearly in the ecliptic plane. Hence, the apparent cross section varies as Uranus revolves around the sun. The pole of Uranus last faced Earth in 1946. Photometric oblateness corrections have the form (for an ellipsoid of revolution)

$$\Delta mag = 1.25 \log[1 - (1 - b^2)\cos^2(\theta - L)]$$

where b is the ratio of the polar-to-equatorial diameter (unity minus the oblateness) and $(\theta - L)$ is essentially the Uranocentric colatitude of Earth [see (6)]. Two modern determinations of the oblateness are 0.01 ± 0.01 [R. E. Danielson, M. G. Tomasko, B. Savage, *Astrophys. J.* **178**, 887 (1972)] and 0.03 ± 0.008 [A. Dollfus, *Icarus* **12**, 101 (1970)].
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7 July 1975

The Flowers Found with Shanidar IV, a Neanderthal Burial in Iraq

Abstract. *Analysis of soil samples from the Shanidar IV burial, Shanidar cave, revealed the same pollens throughout the sequence, with variations in frequency. However, samples 313 and 314 contained, in addition, several pollen clusters of as many as 100 pollen grains, evidence that complete flowers were introduced into the burial cave.*

Soil samples from Shanidar cave have been available since 1960 (*1*). The first palynological analysis indicated that the samples were poor in pollens and thus very difficult to process. Certain levels appeared to be completely sterile. In addition, a palynological atlas was still to be drawn up, and no other analysis had been undertaken in the area. Because of these difficulties, I dropped the idea of a larger and more complete report, even though I had already published a few articles touching on the botanical problems at Shanidar (*2*). I thought that other, richer paleolithic stations in the Near East would be discovered. However, no cave has yielded a last glaciation (Würmian) sequence of pollen evidence comparable to that of Shanidar. Since my comparative collection of recent flora is now much enlarged, and the pollens of Zawi Chemi and of Shanidar represent the only series associated with paleolithic industries, I decided to proceed with a new assay.

The preparations already done were restudied, and all of the samples not yet worked on were examined. Those determinations too ambiguous, as on difficult and fossilized pollen specimens (date and chestnut), were discarded. Even though the older layers yielded extremely poor results, the collection of about 6,000 determinations for Shanidar cave and 10,116 for Zawi Chemi Shanidar (the nearby early village site) gives a general view of the flora and its history.

With a few exceptions, the same pollens are found throughout the Shanidar cave sequence from top to bottom. However, their frequencies vary, particularly those of the arboreal pollens, which are clearly more numerous in the older levels. Climatic oscillations prompted fluctuations in the flora, but as a whole the assemblage remains very uniform.

Then, in 1968, two newly prepared samples (numbers 313 and 314) appeared, from almost the first glance, to be different from the others. The number of composites in these samples greatly exceeded those of the other samples. A remarkable fact was that instead of the normally isolated pollen grains found in caves, many of them appeared to be clustered in groups which contained from two to more than 100 pollen grains. Certain of these clusters have retained the form of the anther of the flower. Finally, another unusual trait manifested itself: of the 28 different plants identified in the samples, only seven were found in clusters. Some of these clusters contained two or three different species of ag-

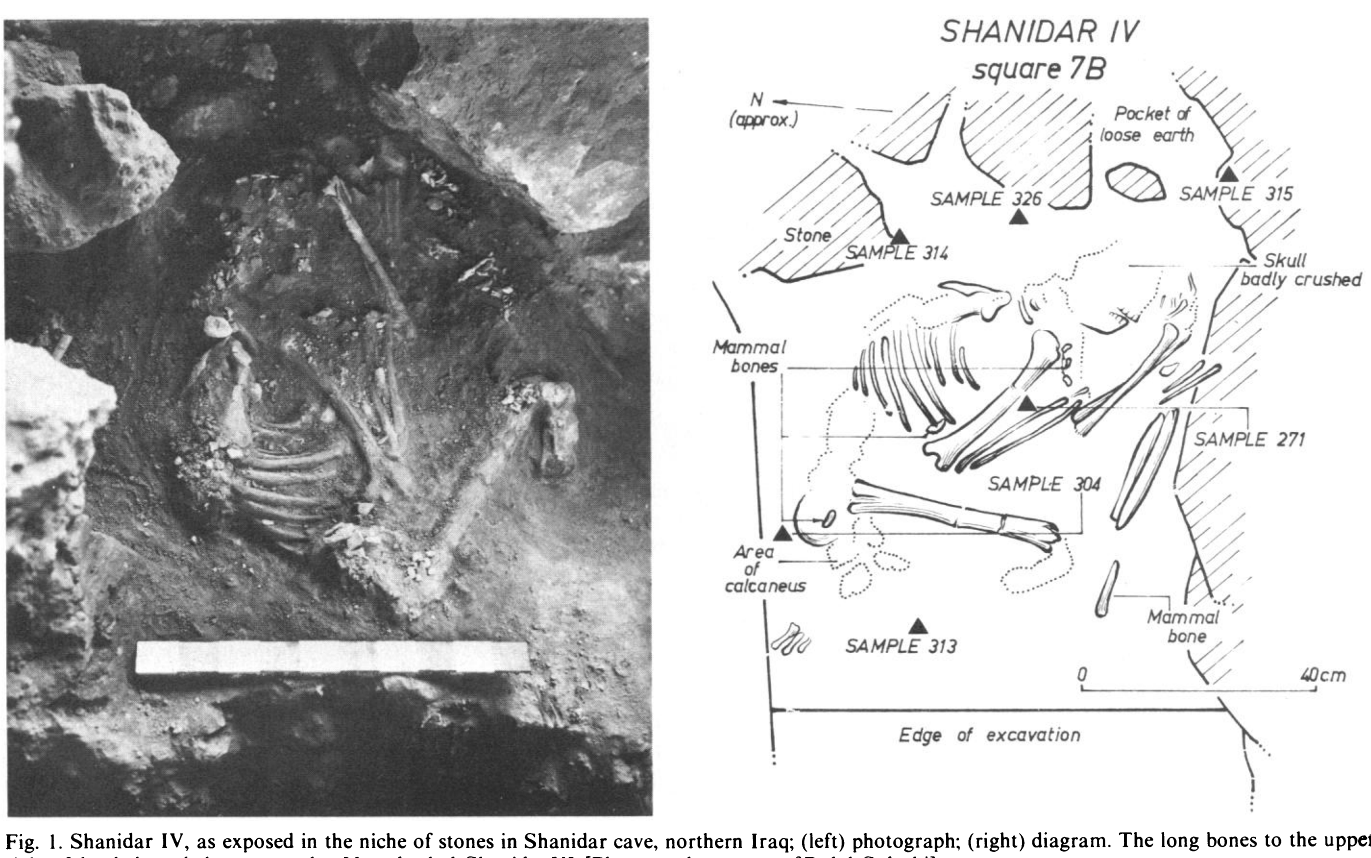

Fig. 1. Shanidar IV, as exposed in the niche of stones in Shanidar cave, northern Iraq; (left) photograph; (right) diagram. The long bones to the upper right of the skeleton belong to another Neanderthal, Shanidar VI. [Photograph courtesy of Ralph Solecki]