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ABSTRACT

The Chree superposition analysis of the luminosities of the planets Jupiter, Saturn, Uranus, and Neptune indicates a correlation between solar activity and planetary luminosity. The variations of the solar constant in the visible range are considered to be too small to explain the observed changes in brightness. The interaction of solar extreme ultraviolet or solar wind particles with the atmospheres of these planets is probably responsible for the increased albedo during periods of high solar activity.

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SOLAR ACTIVITY AND PLANETARY LUMINOSITY

1. Introduction

Research during the last decade has pointed out the importance of solar activity influences on various geophysical and interplanetary phenomena. Studies of the eleven-year modulation of galactic cosmic rays indicate that estimates of the region of influence of solar activity range from 5 AU to 50 AU (Dessler, 1967; Simpson and Wang, 1967; Hundhausen, 1968; and Axford, 1968).

Shapiro (1953) has shown that the variations of Jupiter's disc brightness follow the sunspot numbers for the period 1926 - 1950. Recent study by Balasubrahmanyan and Venkatesan (1970a) shows that the data compiled by Peek (1958) on the intensity of the Red Spot of Jupiter, for the period 1891 - 1947, is suggestive of a positive solar-Jovian relationship. Becker (1933, 1949) finds large fluctuations in the visual magnitudes of Jupiter, Saturn, Uranus, and Neptune; but he does not postulate a single cause for these large variations of luminosity. Johnson and Iriarte (1965) have detected a 2% increase in the blue magnitude of Uranus and Neptune for the period 1952 - 58, and attribute this change to possible variations of the solar constant. In this paper, the data given by Becker (1933, 1949) are re-examined in order to ascertain possible means for extending the spectral regions where the effects of solar activity can be detected.

2. Luminosity of the Planets

The available data on the luminosity of the planets have been collected and reduced by Becker (1933, 1949) to the standard Harvard visual system. The data correspond to mean opposition and phase 0°. In the case of Saturn, corrections for the ring have been applied and that data has been standardized for the case of the vanishing ring and phase 0°. For Uranus, correction has been applied for the variation of the projected area caused by the flattened disc of the rotating planet. Becker (1933, 1949) has given detailed information regarding the original sources for the observations and corrections. The physical light variations that remained after these corrections are shown in Figure 1 (Becker, 1933, 1949). Becker tried to determine the periodicity of the light variations, but lack of observations had left large gaps in the data. The curves drawn by Becker are shown in Figure 1, and it is clear that a certain amount of subjectivity was difficult to avoid in the interpretation of these data. Becker compared the maxima and minima of the luminosity curves, and found that the absence of overlap of these features for the different planets justified his conclusion that there was no central cause for the luminosity fluctuations.

However, Shapiro (1953) examined the Jupiter data from the Lowell Observatory photographs (1926 to 1950), and concluded that the luminosity of Jupiter follows the sunspot number closely. Figure 2 shows the close correlation between the luminosity of Jupiter and the relative sunspot numbers. The correlation coefficient given by Shapiro is 0.859. The differences in the experiments, however, preclude direct combination and analysis of Becker's compilation and Shapiro's data.

Johnson and Iriarte (1965) have studied the blue magnitude change of the planets Uranus and Neptune from 1952 to 1958, and find a change of 0.02 magnitude. The luminosity increases during the period of study - a period of increasing sunspot numbers. They interpret this result as showing an ~2% variation of the solar constant. The existing evidence for variation of the solar constant will be discussed in a following section.

3. Present Analysis

The gaps in the observational data, in our opinion, preclude any detailed determination of the periodicity of the luminosity variation. We believe that it is more appropriate to analyze the data by the Chree (1913) superposition method. In this method, the limitations of the data are likely to have less effect. The zero epochs are chosen to be the solar maxima and minima of the sunspot cycle, according to Waldmeir (1961).

Figure 3 shows periodograms for Jupiter and Saturn around solar maxima and minima for data from 1943 to 1948. The curves for Jupiter and Saturn do indicate that the luminosity drops by ~20% during solar minimum. The increase of luminosity during solar maximum is roughly the same.

Figure 4 shows the results of a similar analysis for Uranus and Neptune. These data show a similar trend, although the limitations of the observations are more severe here than for Jupiter and Saturn. Comparing Figures 3 and 4, we conclude that all four planets seem to behave similarly in respect to their luminosities around solar maxima and minima. The results of Shapiro (1953) and Johnson and Iriarte (1965) for Uranus and Neptune are qualitatively consistent with our conclusion.

4. Discussion

The four planets, Jupiter, Saturn, Uranus, and Neptune, are quite similar in density, atmosphere, composition, albedo, etc. Table I gives various parameters of these planets and of the earth for comparison. The albedos range from ~ 0.4 to 0.5; the earth's albedo is 0.34. The atmospheres of these planets are optically thick and their solid surfaces are not visible. Table II gives the constituents suggested by Urey (1959) of the planetary atmospheres. These similar compositions probably are effective in producing similar interactions with solar activity and also similar types of radiative transfer within the planetary atmospheres. These results suggest that solar activity can be detected up to Neptune's orbit, or up to ~ 30 AU, by careful observation of planetary luminosities.

The eleven-year cycle of solar activity seems to have two distinct features: the solar wind consisting of corpuscular radiation, and solar extreme ultraviolet emission. Figure 5 gives the temperature variations of the earth's exosphere during a solar cycle. Nicolet (1964), Bordeau et al. (1964), and Jacchia and Slowey (1965) have shown that temperature and density variations of the earth's atmosphere are caused by the solar extreme ultraviolet emission (E.U.V.).

The contribution of corpuscular heating during short periods of enhanced activity has also been detected (Jacchia and Slowey, 1965); the major effect, however, is attributed to the solar E.U.V. The E.U.V. has been shown to correlate closely with the solar radio noise flux at 2800 Mc/S (Nicolet, 1964; Jacchia and Slowey, 1965).

In the case of the outer planets, the analysis at present is not detailed enough to show whether solar E.U.V. or plasma is the main agent responsible for the changes observed in planetary luminosity. Following Gnevyshev (1966), Balasubrahmanyan and Venkatesan (1970a, b) and Balasubrahmanyan (1969) have pointed out that many geophysical, interplanetary, geomagnetic, and cosmic ray phenomena demonstrate a double hump structure in their eleven-year modulation. This double hump structure, in principle, could be used to differentiate between phenomena related to solar wind, and phenomena related to solar E.U.V. Solar E.U.V. follows the Wolf sunspot numbers, and the 2800 Mc/S flux, and has a single maximum in the solar cycle. The planetary luminosity data seem to relate to E.U.V. when the general shapes of the variations of these two phenomena are considered. It is, however, possible that the small dip near the sunspot maximum has been smoothed out by observational errors in luminosity, and phase errors in the superposition analysis. A continuous and accurate monitoring of the intensities of these planets could be very instructive regarding the agent responsible for these fluctuations in luminosity.

Johnson and Iriarte (1965) attribute the ~ 0.02 change in blue magnitude (Figure 6) observed by them for Uranus and Neptune to an ~2% change in the solar constant. The data on the solar constant (Sterne and Dieter, 1958; Abbot, 1958) do not provide evidence for large changes in value. The changes in the solar constant appear to be ~0.2% in a solar cycle, and quite inadequate to account for the 20% luminosity changes in the visible region of the spectrum and the 2% change in the blue region.

The evidence for short term changes of the order of 2% due to the passage of large sunspot groups has been provided in the work of Abbot et al. (1922). In this case, the change in the solar constant is one of decrease because of the relatively cool sunspots occupying a larger fraction of the sun's disc during solar maximum. The change, however, is in a direction opposite to that needed to explain the changes observed in the planetary luminosities. The evidence for variation of the solar constant on a long-term basis is only for a few parts in a thousand, and in our view inadequate to explain the planetary effects seen by Becker (1933, 1949). As the planets reflect only sunlight, a change of 20% in the visible region is to be attributed to a 20% change in solar output. It is difficult to envision such a large change in the output of the sun in the visible region. The highly variable power output of the sun is in the coronal plasma environment. The solar E.U.V. (Malitson, 1965), for example, varies more than an order of magnitude in a solar cycle; but the energy output of these radiations caused by plasma processes of the solar atmosphere is quite small compared with the total optical output of the sun. If, for example, the planetary atmospheres respond to the E.U.V. and expand during solar maxima as the terrestrial atmosphere does, then the larger effective scattering regions during solar maxima may be responsible for the larger planetary luminosity during the active phases of the sun. Becker (1949) relates the intensity fluctuations of these planets to features such as the white spots on Saturn, and concludes that the intensity fluctuations are caused by the variable cloudiness of these planets. If this explanation holds, the synchronization of these fluctuations with solar activity in the case of these four planets with essentially similar planetary composition suggests that solar activity controls the extent of the cloud cover. It is interesting to recollect the numerous correlations of meteorological phenomena with variations of solar activity (Mitchell, 1965). In any case, accurate and continuous study of the planetary luminosity of the outer planets should be of great interest in detecting the effects of solar activity variations on short and long term bases.

5. Conclusions

(1) Fluctuations in the luminosity of Jupiter, Saturn, Uranus, and Neptune seem to be related to the sunspot cycle. It is interesting to note that the atmospheric compositions of these planets are similar, and interesting to note also that these planets have optically deep atmospheres.

(2) The planetary luminosity study of Neptune is indicative of the extension of solar plasma effects to ~30 AU.

(3) More detailed and accurate study of the luminosity variations of the outer planets will be useful for looking at shorter period fluctuations, and useful also to identify uniquely the agent responsible for these luminosity changes.

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TABLE I

Planetary Parameters (Allen, 1955)

	Semi Major Axis of Orbit (A.U.)	Equational Radius	Mass	Density g/cm^3	Siderial Rotational Period	Albedo
EARTH	1.00	1.00	1.00	5.52	23 hr 56 min	0.34
JUPITER	5.20	11.20	318.0	1.330	9 hr 50 min	0.41
SATURN	9.55	9.47	95.22	0.687	10 hr 14 min	0.42
URANUS	19.2	3.75	14.55	1.56	10 hr 49 min	0.45
NEPTUNE	30.1	3.50	17.23	2.27	15 hr 40 min	0.54

TABLE II

Composition of Planetary Atmospheres (Urey, 1959)

PLANET	SUBSTANCE	AMOUNT cm-atm (NTP)	BASIS OF ESTIMATE	REMARKS
Jupiter	CH_4	1.5×10^4	Spectroscopic	
	MH_3	700	"	Assumed to be present in solar proportions relative to Methane.
	H_2	10^6	Density of Planet	
	He	5.6×10^6		
	N_2	4×10^3		
	Ne	1.7×10^4		
Saturn	CH_4	3.5×10^4	Spectroscopic	
	MH_3	200	"	Assumed to be present in solar proportions relative to Methane.
	H_2	6.3×10^7	Density of Planet	
	He	1.3×10^7		
	N_2	9.5×10^3		
	Ne	2.7×10^4		
Uranus	CH_4	2.2×10^5	Spectroscopic	1. He and H_2 are assumed to be effective molecules in producing intensities of H_2.
	H_2	9×10^6	Calculated on Assumption 1.	
	He	2.7×10^7		
	H_2	4.2×10^6	Calculated on Assumption 2.	2. N_2 and H_2 are assumed to be effective molecules in producing transitions of H_2. Solar proportions of He and H_2 are assumed.
	He	8.6×10^5		
	N_2	4.2×10^6		
Neptune	CH_4	3.7×10^5	Spectroscopic	Assumed to be effective molecules in producing transition of H_2. Solar proportions of H_2 and He are assumed.
	H_2	Larger than in Uranus	"	
	N_2			
	He			

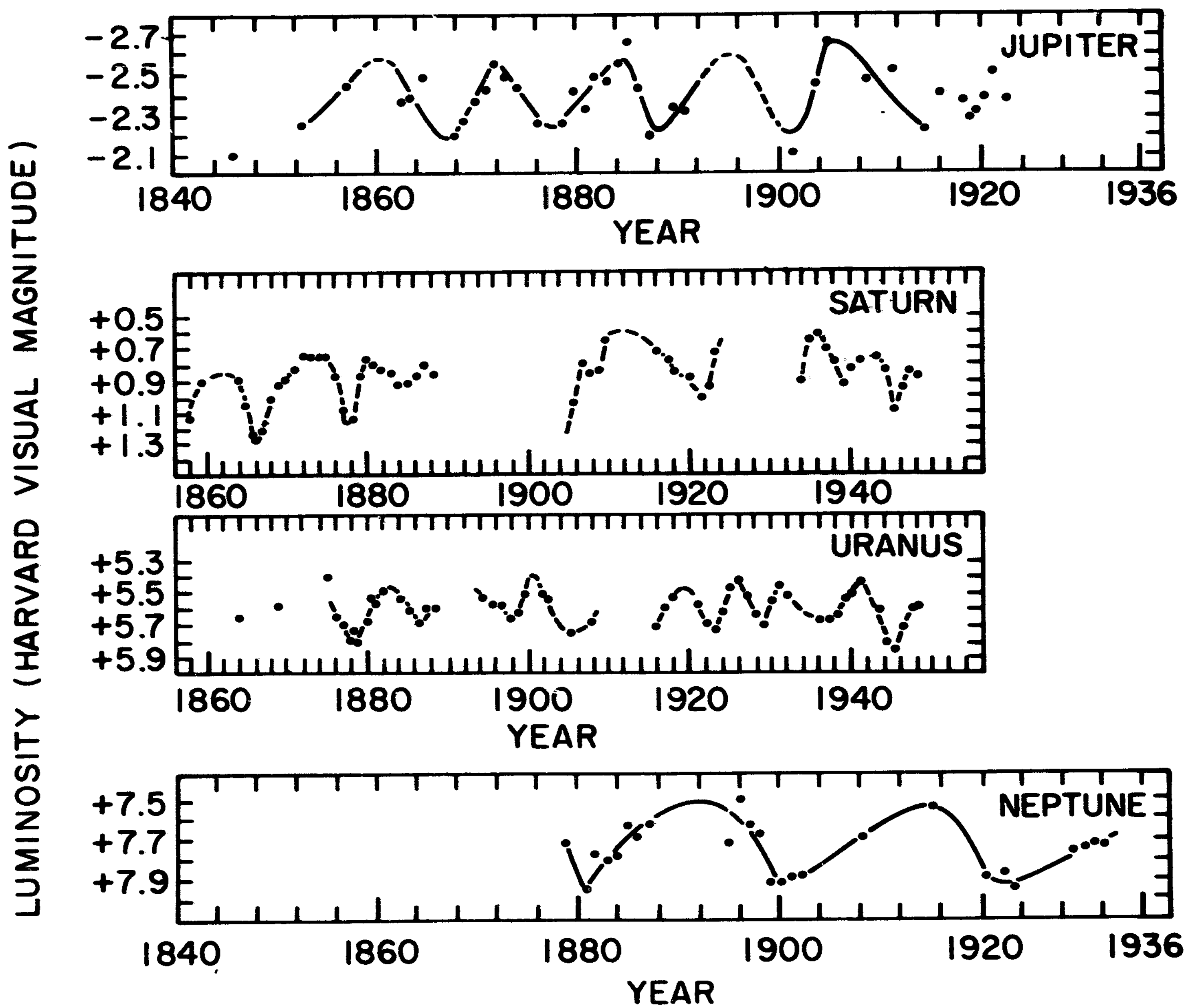

Figure 1. Planetary luminosity data compiled by Becker (1933, 1949). The data have been reduced to mean opposition and phase 0°. Corrections have been applied for Saturn's ring and the flattening of Uranus' disc.

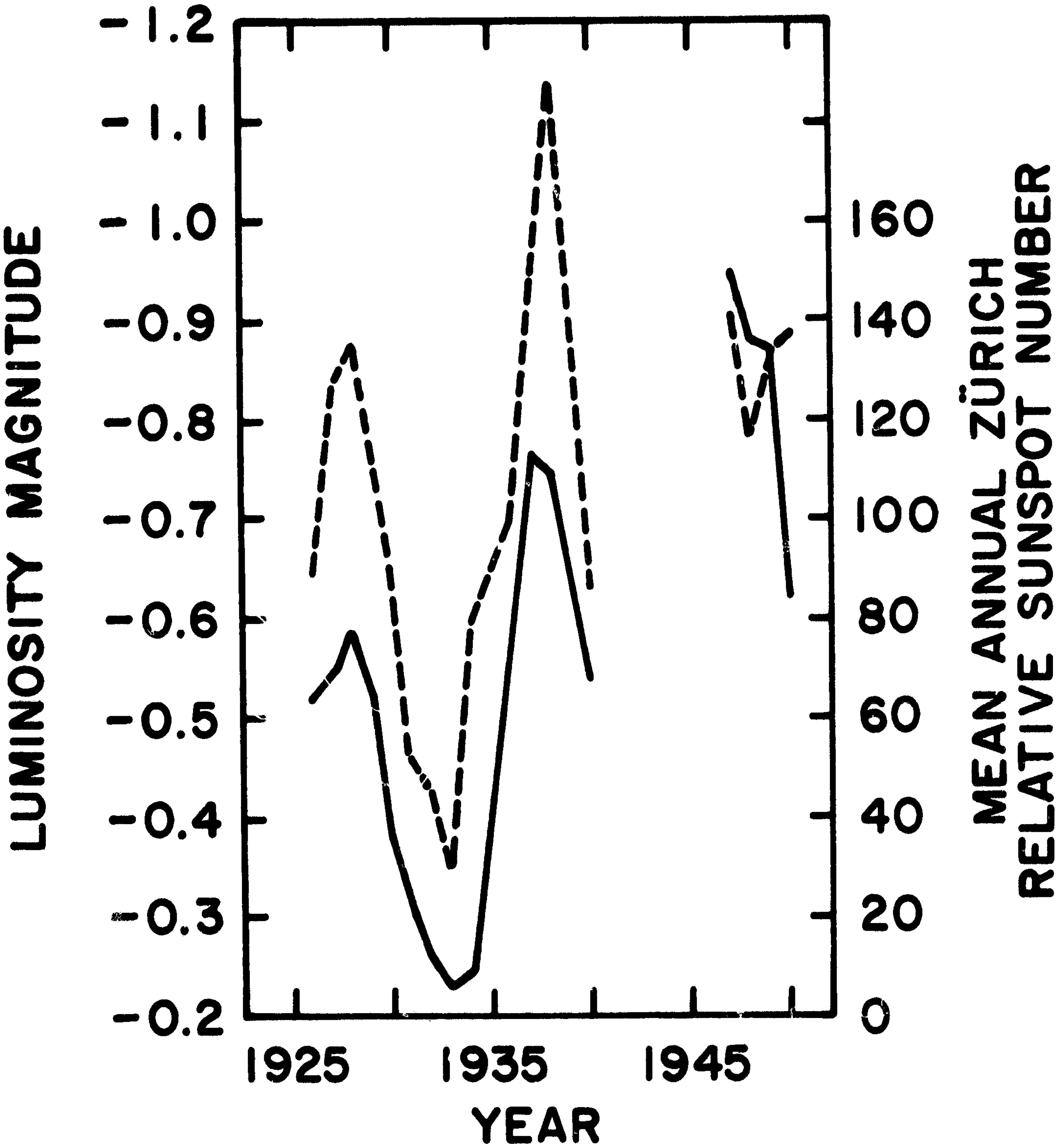

Figure 2. The relationship between Zurich relative sunspot numbers (solid curve) and the luminosity of Jupiter (broken line curve) as measured by Shapiro (1953) from the blue-sensitive plates of Lowell Observatory.

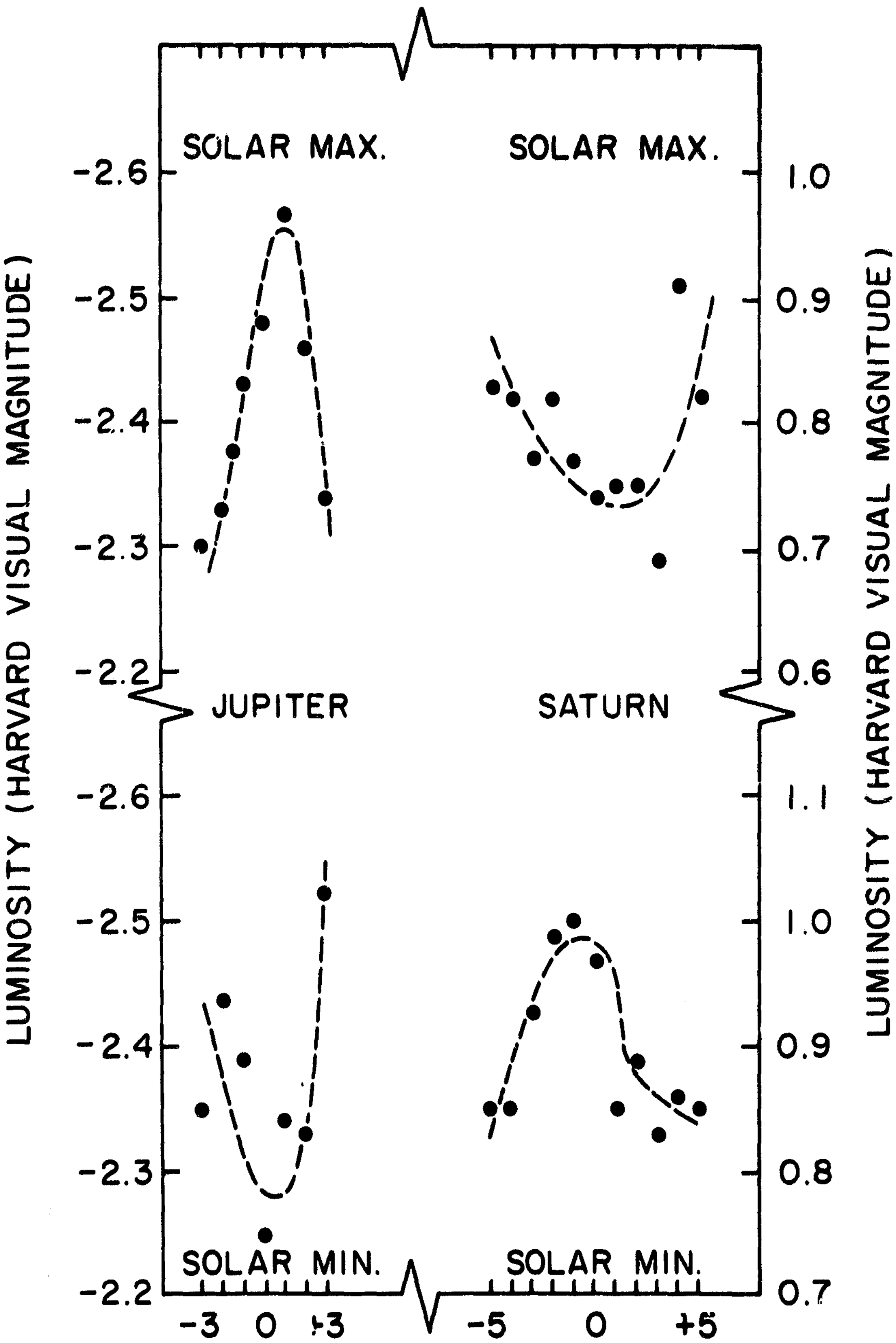

Figure 3. The luminosity variations of Uranus and Neptune according to the Chree superposition analysis. Note that for Saturn the luminosity magnitude is a positive number, while for Jupiter it is a negative number.

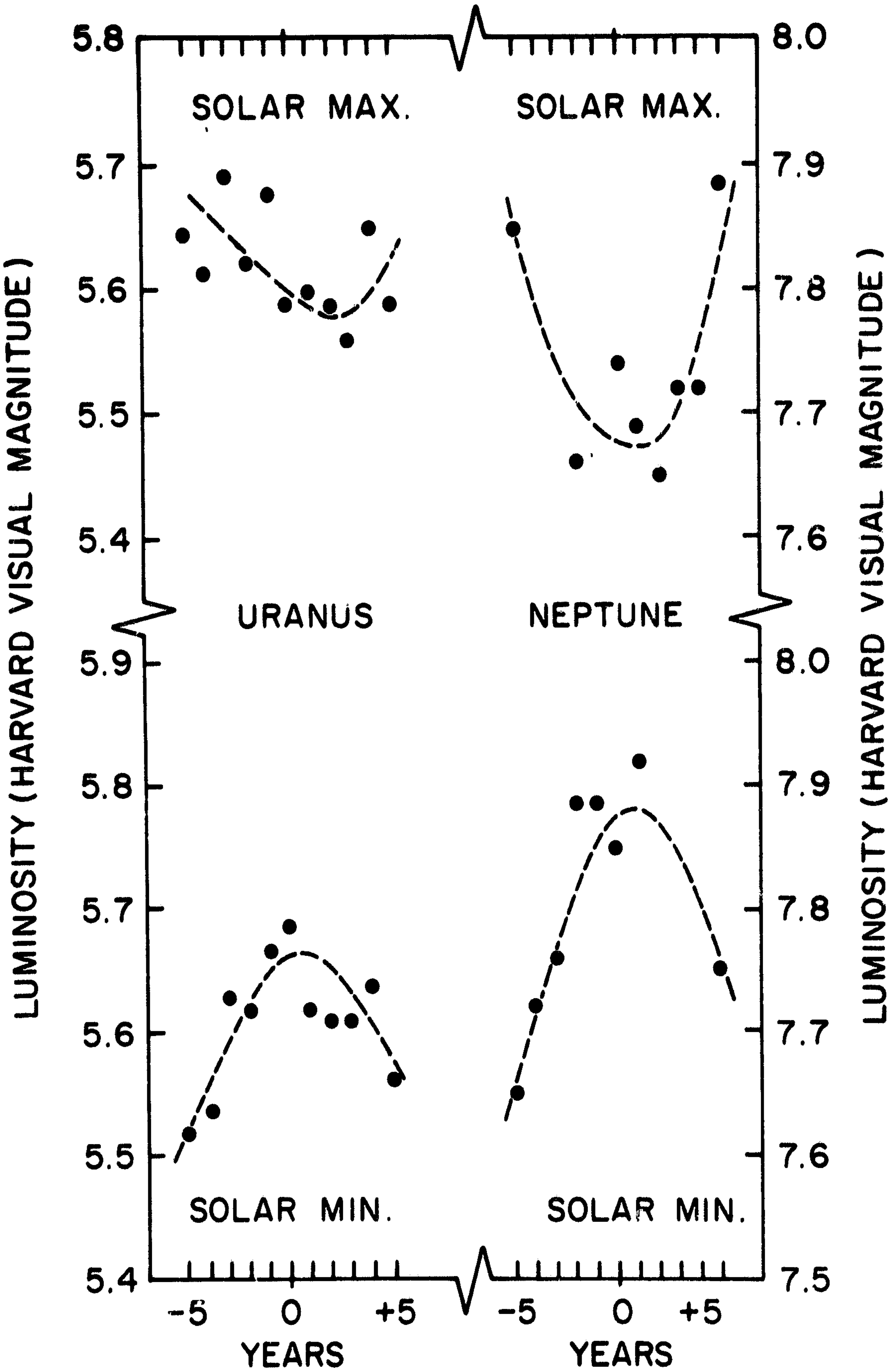

Figure 4. The luminosity variations of Uranus and Neptune according to the Chree superposition analysis.

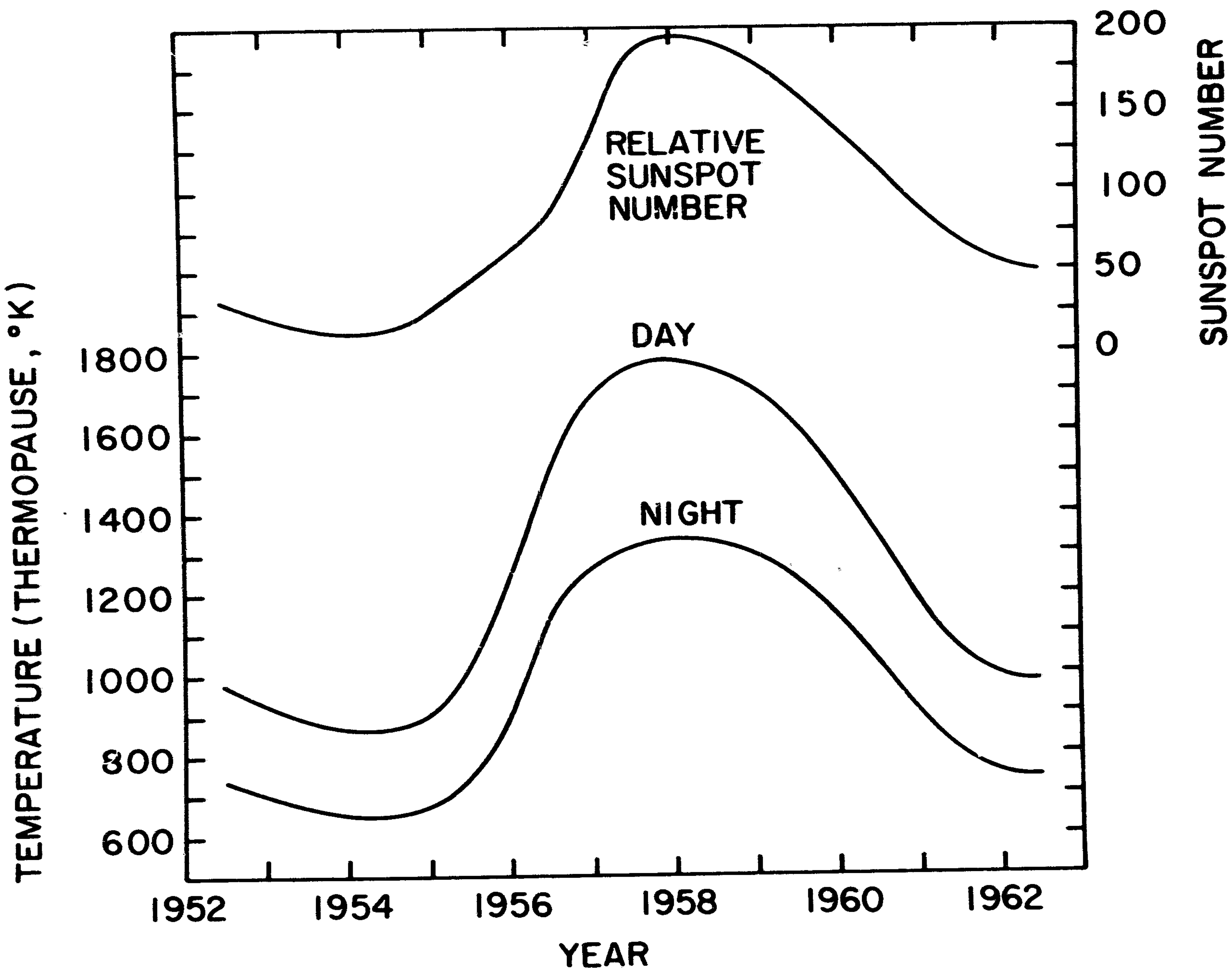

Figure 5. The variation of the upper air temperature of earth as a function of the phase of the eleven-year sunspot cycle (Nicolet, 1964).

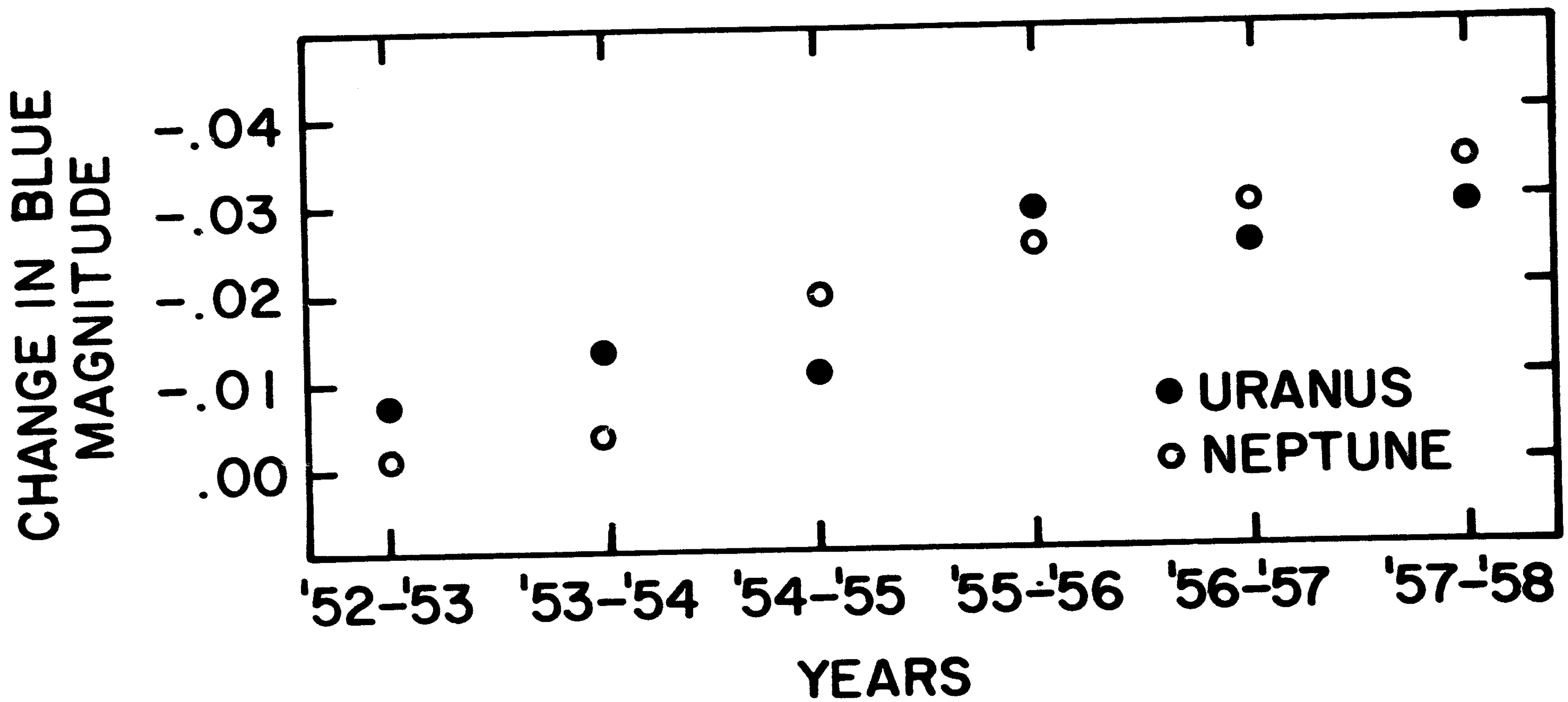

Figure 6. Change in blue magnitude of Uranus and Neptune according to Johnson and Iriarte (1965). The blue luminosity increases with solar activity for both these planets.