# NEW EVIDENCE FOR SOLAR CYCLE VARIATIONS AT GREAT DISTANCES

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ABSTRACT Recent studies of solar planetary relationships are directed toward exploring how far out from the sun one could observe solar cycle variations. A positive solar Jovian relationship is suggested from a Chree superposed epoch study of the intensity of the great red spot of Jupiter over a period of about six solar cycles. The characteristic double maxima observed in the solar cycle variation is common to other observations of solar events in the photosphere, chromosphere, and corona; radio and corpuscular emissions from the sun; cosmic ray intensity and geomagnetic activity. The same method of analysis adopted for the study of luminosity changes of the planets Jupiter, Saturn, Uranus, and Neptune indicates that the fluctuations of luminosity follow the single maximum solar cycle represented by sunspot numbers. In conjunction with changes of upper atmospheric density and temperature, it is suggested that the extreme ultraviolet (EUV) emission from the sun may be connected with luminosity changes. Further, in principle, we have a method of distinguishing between phenomena related to solar wind and those related to solar EUV. The study concludes that there is evidence that the 11-year solar cycle variation is observed up to ~30 AU.

Long-term studies of aurorae, geomagnetic storms, various types of cosmic ray intensity variations, changes in the trapped particle population in the geomagnetic field, and other areas exhibiting solar-terrestrial relationship have all been undertaken with a view to establish the nature of solar modulation. From observations on the earth and in the immediate geophysical environment, there is general agreement about the existence of an 11-year solar cycle dependence.

In the past, investigators have generally used $R$, the Zurich relative sunspot number, as the parameter for solar activity. The 11-year solar cycle, as revealed by $R$, shows a fast rise to a maximum and a slower fall to the minimum. But recent studies have focused attention on the difference between the sunspot cycle with a single maximum and the 11-year cycle of many phenomena exhibiting a characteristic double maxima. The existence of a double maxima in the 11-year solar cycle of activity has been pointed out by *Gnevyshev* [1963, 1967], *Antalova and Gnevyshev* [1965] and by *Gentili di Giuseppi et al.* [1966] who in particular observe this feature in the intensity of the coronal green line 5303 Å. These studies reveal that this characteristic feature is substantiated by events at various levels on the sun: photosphere, chromosphere, and corona, as well as by radio and particle emission from the sun. This feature of double maxima during the solar cycle relates to occurrences of polar cap absorption events [*Gnevyshev*, 1967]; cosmic ray flares of MeV and BeV ranges [*Sakurai*, 1967]; solar type IV bursts [*Krivsky and Kruger*, 1966] and proton flares, occurrence of large sunspots [*Sakurai*, 1967] and microwave impulsive bursts [*Fokker*, 1963]. The studies of the amplitude of the quasiperiodic 27-day variation in cosmic ray intensity [*Venkatesan*, 1958] and of the mean cosmic-ray intensity and geomagnetic activity [*Balasubrahmanyan*, 1968; *Balasubrahmanyan and Venkatesan*, 1970*a*] also reveal the characteristic double maxima. Some of these

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are shown in figure 1 [from *Balasubrahmanyan and Venkatesan,* 1970*b*].

There are indications that the separation between the two maxima may vary from one cycle to another and the possibility of not being able to distinguish between the two peaks in any particular cycle cannot be ruled out either. Thus there is general agreement that in all these, the single maximum solar cycle variation represented by the sunspot numbers is not a very appropriate measure of solar variability.

The next question is, irrespective of the type of 11-year variation, be it one maximum or two maxima, how far from the sun can one detect this variation? This would give some indication of the extent of solar influence of physical phenomena. The investigations of *Dessler* [1967], *Simpson and Wang* [1967], and *Hundhausen* [1968] estimate that the boundary of the region of cosmic ray modulation may extend from 5 AU to 50 AU. Another useful approach would be to explore whether any recorded data of planetary activity over long periods of time could give some indication of an existence or otherwise of a solar cycle variation. Of course it should be realized from the start that a completely satisfactory set of data is hard to come by in this

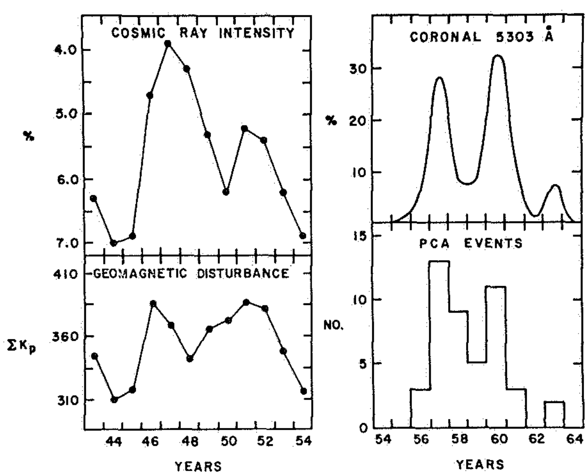


**Figure 1** *Examples of phenomena exhibiting double maxima during solar cycles 18 and 19; cosmic ray intensity refers to annual mean values at Cheltenham (Fredericksburg), in units of 0.1 percent from fiducial value; geomagnetic disturbance refers to the sum of daily values of Kp, the planetary geomagnetic index, for the 60 most disturbed days for the year (five values for each month); coronal 5303* Å *refers to the intensity of the coronal line at 5303* Å *averaged around the limb; PCA events refer to the annual number of polar cap absorption events. The last two curves have been taken from Gnevyshev [1967].*

area. Gaps are bound to exist in any such data and hence one can only hope to arrive at tentative conclusions, if any. Nevertheless, it was thought that the approach would be useful.

The great red spot of Jupiter is a predominant feature on the Jovian surface and has been observed continuously since 1891. The British amateur astronomer *Peek* [1958] has collated all the observations for the period 1892–1947. He assigns numbers to represent the intensity or darkness of the red spot, as described by observers at each apparition. Peek comments that some arbitrariness is unavoidable in assigning these numbers to the estimates of observers, but indicates that every care has been taken to avoid any serious distortion of facts. Thus annual means are published by him for the entire period, the numbers ranging as follows: 0 = invisible, 1 = visible but very faint, 2 = very difficult to see early in the apparition, later plain and distinct, 3 = fairly well defined, 4 = well defined, 5 = easy to see, 6 = easy to see and fairly conspicuous, 8 = very dark and conspicuous, 7 does not figure on the scale.

In view of the subjective nature of the evaluation, we have restricted ourselves to the use of only the data carefully collated by a single person, although some data are available for the period 1948-1967 [*Reese* as reported in *Solberg and Chapman,* 1969]. Visible changes of the red spot are observed even within a year [*Vsekjsvyatskii,* 1969]. We have no means of knowing how many observations are averaged over each year, as Peek does not give any indication. Hence we doubt very much whether we could meaningfully intercompare annual values from one year to another, but believe it is appropriate to study the average behavior over a number of solar cycles.

The superposition method similar to the Chree method [*Chree,* 1913; *Chree and Stagg,* 1928] was adopted for the analyses of the annual means of the Zurich relative sunspot number and Peek's darkness parameter for the Jovian red spot for the period 1892–1947. The zero epoch for both analyses corresponded to the years of solar maxima as determined from sunspot numbers – namely, 1893, 1905, 1917, 1928, 1937, and 1947. The values for 4 years preceding and 7 years following the years of maxima were used for superposition. The results are shown in figure 2 [from *Balasubrahmanyan and Venkatesan,* 1970*b*]. The double maxima in the average 11-year variation, in the case of the intensity of the Jovian parameter, are seen, consistent with other studies referred to earlier. It is relevant to refer to the study of *Newton and Milsom* [1954] of 420 non-sc geomagnetic storms during the period 1878-1879 to 1952-1955, which is comparable to our

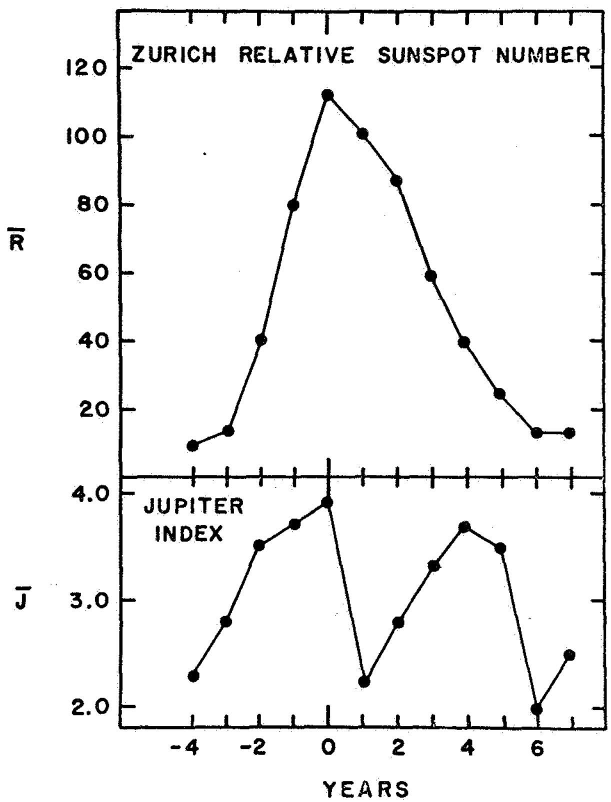


**Figure 2** *Chree type analysis; average over six solar rotations, zero epoch years correspond to years of maximum solar activity as chosen from annual means of sunspot numbers. Jupiter index refers to the darkness parameter of the great red spot of Jupiter [Peek, 1958].*

period of study of Jupiter. They find that the frequency distribution exhibits double maxima with a 4-year separation between the peaks. We do not claim that these two have the same cause. Our desire is merely to point out the existence of a similar feature in another study over a comparable period. Hence we believe we have evidence of the observation of an 11-year solar cycle variation, as far as 5 AU from the sun. Note that it is premature at the present time to speculate on exactly how the intensity changes of the Jovian red spot are related to solar activity.

Our next attempt was to look at the available data of the luminosity of the planets Jupiter, Saturn, Uranus, and Neptune collected and reduced to the standard Harvard visual system by *Becker* [1933, 1949]. He has given details about the original sources of observations and corrections. Data for Jupiter, Saturn, Uranus, and Neptune correspond to 1846-1923, 1858-1948, 1864-1944, and 1878-1932, respectively, with unfortunate gaps in data due to lack of observation. Becker concluded that there was no central cause for luminosity fluctuations.

However, in this context it is relevant to point out that *Shapiro* [1953] has shown that the variations of Jupiter's disc brightness follows the variation of sunspot numbers for the period 1926-1950. *Johnson and Iriarte* [1959] have pointed out that the blue magnitude change of Uranus and Neptune increases over 1952-1958, a period of increasing sunspot numbers.

It is unfortunate that the gaps in the observational data compiled by Becker preclude any detailed determination of the periodicity of the luminosity variation. However, we believe that the Chree method of superposition can be effectively used, at least to detect a possible solar cycle dependence. We have chosen for the zero epochs the years of solar maxima and minima of the sunspot cycle [*Waldmeier,* 1961]. The results of the Chree analyses are given for Jupiter and Saturn in figure 3 [from *Balasubrahmanyan and Venkatesan,* 1970*c*]. A solar cycle change of ~20 percent in the luminosity can be observed, with maximum planetary luminosity during solar maximum. Results of the analyses for Uranus and Neptune given in figure 4 [from *Balasubrahmanyan and Venkatesan,* 1970*c*] show a similar trend, although the limitations of observations are more severe for these than for Jupiter and Saturn. We conclude that all the four planets seem to exhibit similar behavior with regard to their luminosities around solar minima and maxima. The results of *Shapiro* [1953] for Jupiter and *Johnson and Iriarte* [1959] for Uranus and Neptune for short periods are qualitatively consistent with our results.

The density, atmosphere, composition, albedo, etc., are similar for the four planets [*Allen,* 1963]. The albedos range from ~0.41 to 0.56 in comparison with the value of 0.34 for earth. The planets have optically thick atmospheres and their solid surfaces are not visible. The compositions of their atmospheres are comparable [*Urey,* 1959] and hence it is reasonable to expect similar interactions with solar activity and also similar types of radiative transfer within the planetary atmospheres. Thus we believe we have evidence of a solar cycle variation up to ~30 AU from the sun. The importance of careful observations of planetary luminosities even in terms of solar activity and solar planetary relationships is clearly seen.

It is appropriate to conclude this article with some general comments on solar cycle variation. The 11-year cycle of solar activity seems to have two distinct features; that of the solar wind consisting of corpuscular radiation and that of the solar extreme ultraviolet

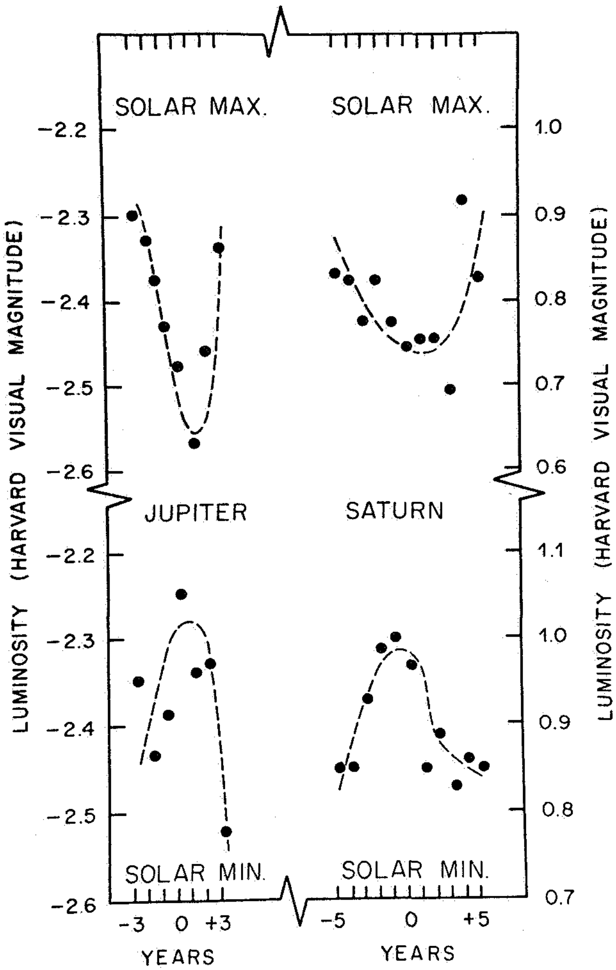


**Figure 3** *The luminosity variation of Jupiter and Saturn, according to Chree superposition analysis. Note that for Saturn the luminosity magnitude is a positive number while for Jupiter it is a negative number.*

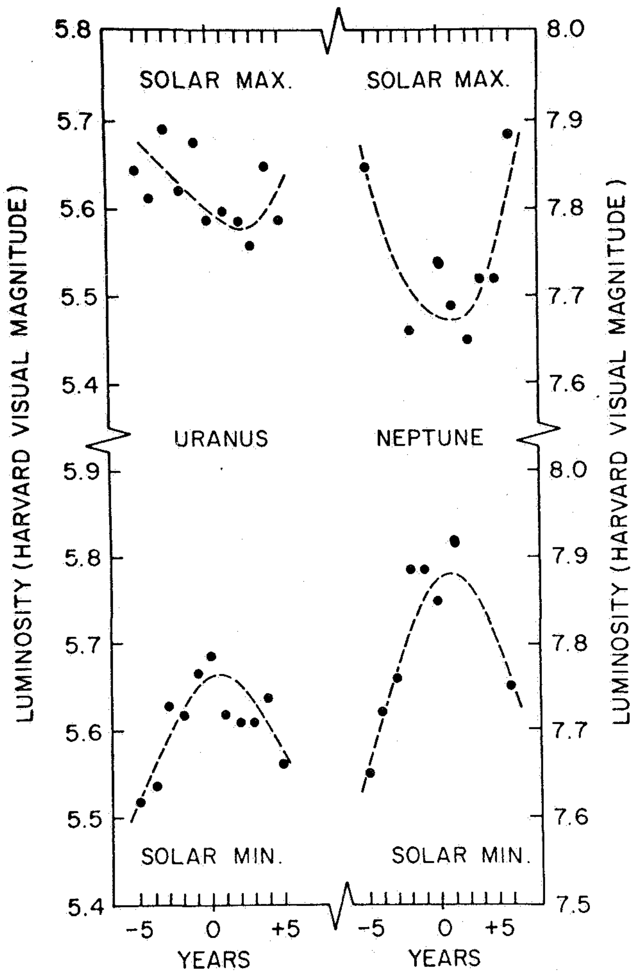


**Figure 4** *The luminosity variation of Uranus and Neptune according to Chree superposition analysis.*

emission. The investigations of *Bordeau et al.* [1964], *Nicolet* [1963], and *Jacchia and Slowey* [1964] show that the variations of density and temperature of the terrestrial atmosphere are due to the solar extreme ultraviolet radiation. While contribution due to corpuscular heating during short periods of enhanced activity has also been detected, the major effect, however, is attributed to the solar EUV.

The analyses of the planetary luminosity data are certainly not detailed enough to show whether the solar plasma or EUV is the primary cause for the observed changes. But we feel that the double maxima solar cycle variation, in principle, could be used to distinguish between the phenomena related to solar wind and EUV. The former exhibit the characteristic double hump structure in its 11-year variation, as conclusively indicated by the many geophysical, interplanetary, geomagnetic and cosmic-ray studies. The latter follows the Zurich relative sunspot numbers and the 2800 MHz flux with a single maximum in solar cycle. If, for example, the planetary atmospheres respond to the EUV just like the terrestrial atmosphere and expand during solar maxima, the increased luminosity of the planets is understandable in terms of the larger effective scattering region.

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