POSSIBLE RING SYSTEM OF NEPTUNE

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Abstract. A re-analysis of the observations of occultation of MKE 31 by Neptune on September 12, 1983 (Pandey *et al.*, 1984) shows that the possible ring system of Neptune extends from 64400 km to 64190 km in Neptune's equatorial plane.

1. Introduction

Stellar occultation is the only ground based technique which can be used for detecting invisible planetary rings. Following the discovery of rings around Uranus and Jupiter, the possibility of rings around Neptune increased, on the basis of Neptune's similarity with the other three major planets. But this has been still a controversial matter even after the observations of several predicted occultations by Neptune. A brief summary of these observed occultations is given in Table I.

From Table I it is seen that the secondary occultations due to suspected ring system of Neptune were observed at 1.2 R_N to 3.7 R_N distances from the centre of the planet on several different observed occultations events. Recently Sicardy *et al.* (1985) have reported secondary occultations before the immersion, due to some occulting objects located at ~ 94000 km and ~ 74000 km from Neptune's centre and a secondary occultation event after the emersion which corresponds to an object having a size of about 17 km, located at ~ 51000 km from Neptune's centre in its equatorial plane. Possibility of existance of ring system around Neptune increased with the observations of the occultation event on July 22, 1984 and August 20, 1985 (Häfner and Manfroid, 1984; Hubbard, 1984; Sicardy *et al.*, 1985). On the basis of recent observations it is being considered that Neptune may have a broken ring system and it has two arcs, one at a distance of 54000 km and another at a distance of about 66000 km (Kerr, 1985).

Since the results presented by Pandey *et al.* (1984) were based on the predicted geometry of the occultation (Joseph E. Carroll, private communication); therefore, these results were affected because the precise geometry was not known for this event. In this paper we present a re-analysis of the observations of occultation of MKE 31 by Neptune on September 12, 1983 (Pandey *et al.*, 1984) based on an improved geometry for this event.

2. Observations

Continuous observations of the event were made from 15^h30^m to 16^h50^m UT. Observational details have been published by Pandey *et al.* (1984). The star

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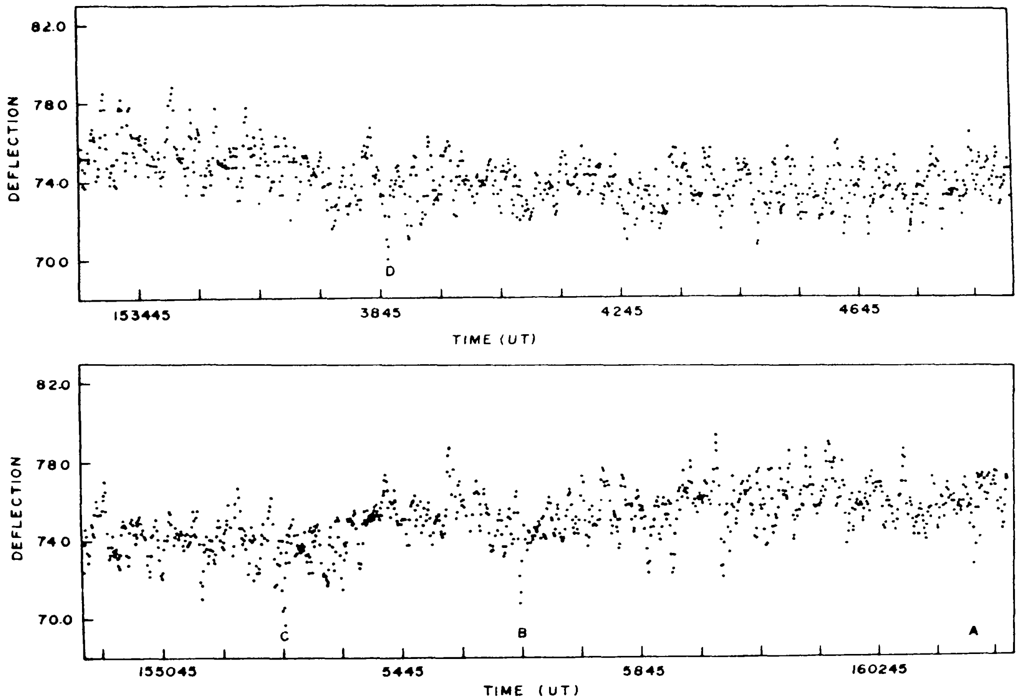

Fig. 1. Observed occultation light curve.

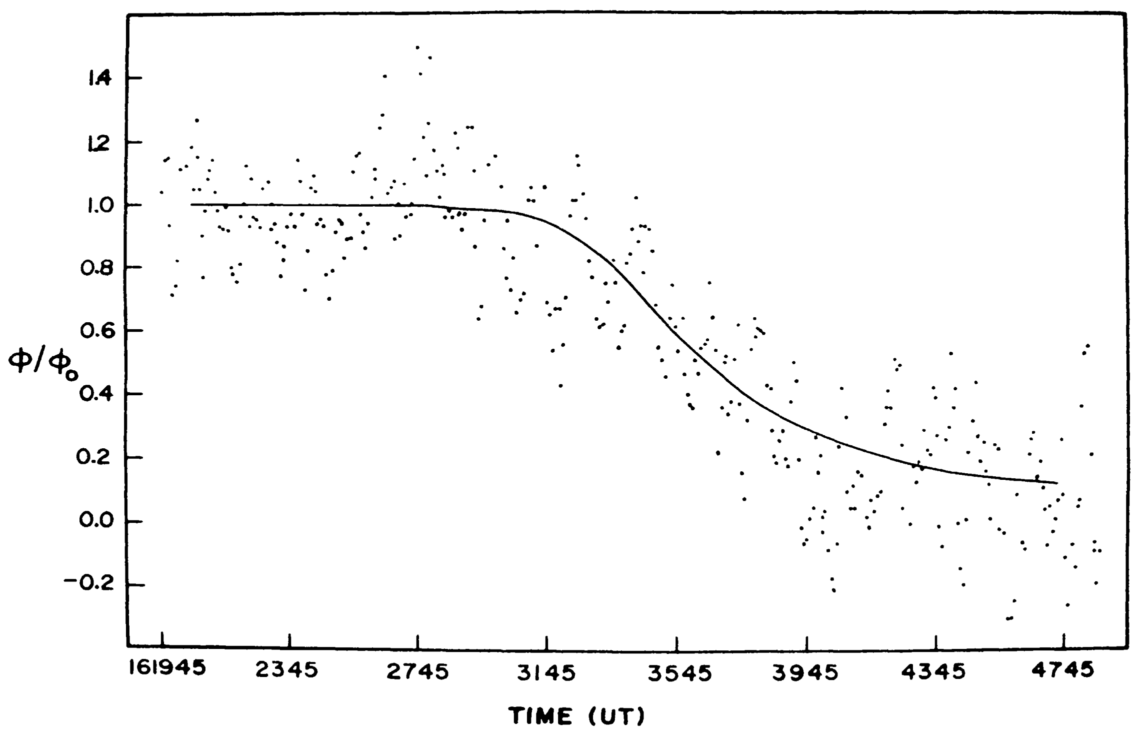

Fig. 2. Immersion light curve. The solid line represents the theoretical light curve for $H = 50$ km at a distance of 24000 km from the center of Neptune.

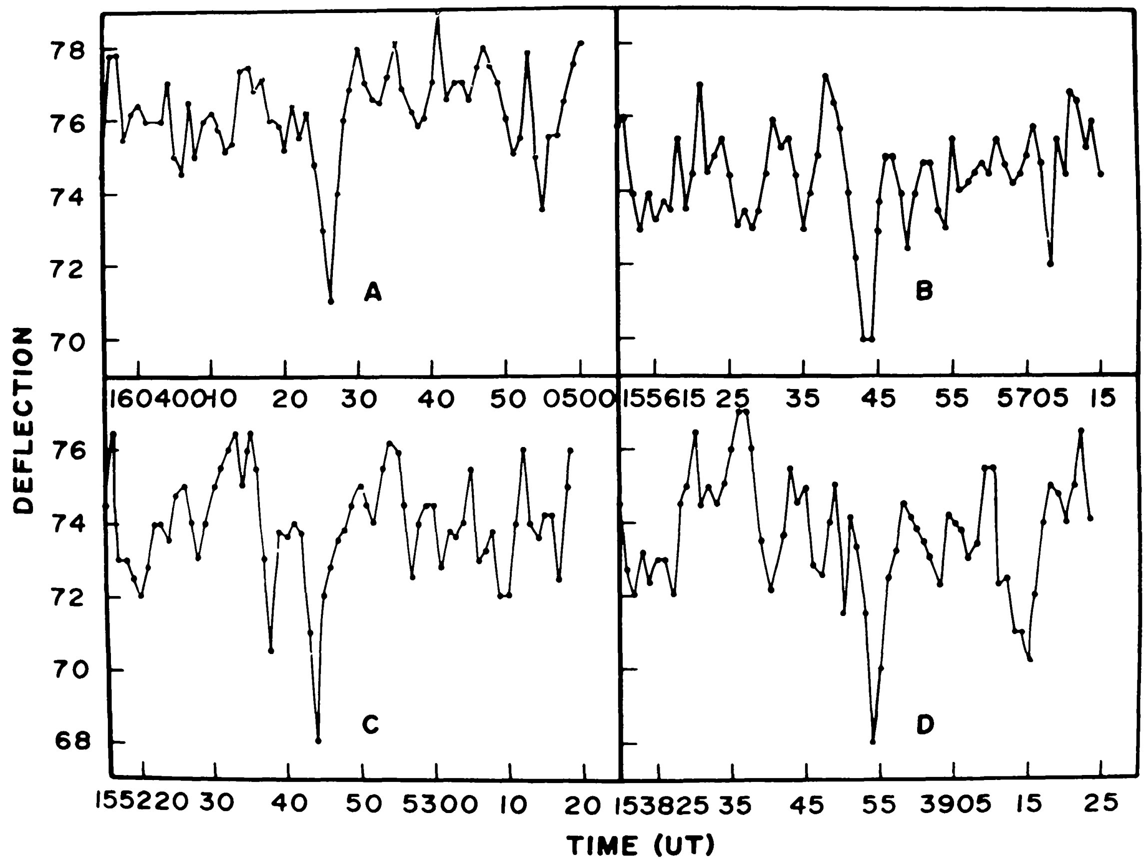

Fig. 3. The observed light variations corresponding to secondary occultations.

contributed about 7.5% of the total signal. The observed light variations are shown in Figure 1. Each point of the light curve represents the running mean of observations for 3 s. The light variations are clearly visible between $15^h36^m.5$ to $15^h54^m.5$ UT and $15^h55^m.7$ to $15^h58^m.0$ UT. Immersion event shown in Figure 2, occurred at $16^h36^m45^s$ UT. Four prominent dips termed as A B C and D having amplitude greater than 3σ and durations 1.5 to 3.0 s were recorded before the immersion event. The recorded intensities of the star with 1 s time resolution, corresponding to these secondary occultations, are shown in Figure 3. The observed spikes were considered significant on the basis of their amplitudes being significantly higher than the statistical probabilities in a normal gaussian distribution.

3. Analysis and Discussions

Since the precise geometry is not known for this event, we have therefore obtained the geometry for the present event on the basis of the determinations of the scale height to be 50 km (Elliot, 1979) and the prediction (Carroll, private communication) that the Neptune's centre passed north of the star.

The occultation light curve can be represented by the relation

$$(\phi_0/\phi - 2) + \ln(\phi_0/\phi - 1) = v(t - t_0)/H,$$

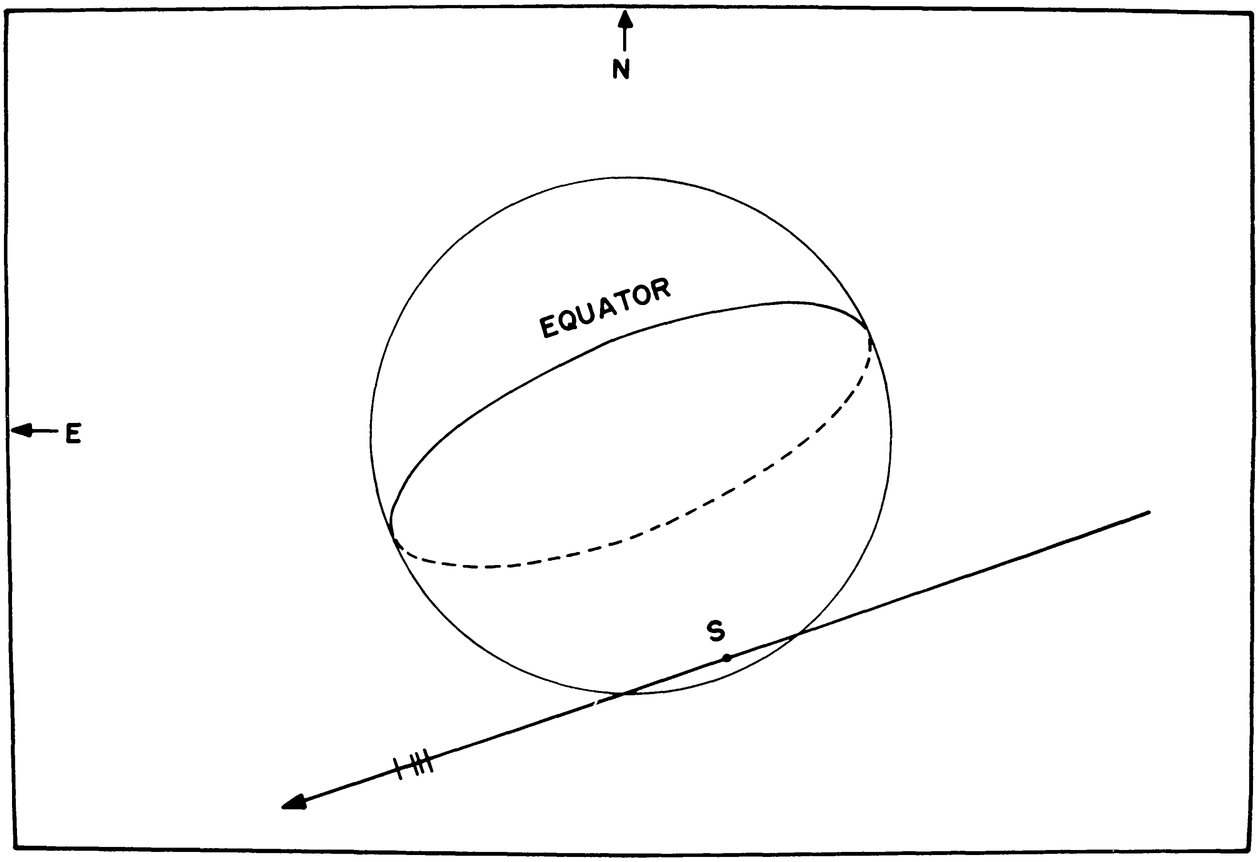

Fig. 4. Revised geometry of the occultation as projected on the sky plane. The locations of the secondary occultations are shown by vertical lines on the apparent path of the star.

given by Baum and Code (1953), assuming an isothermal atmosphere of homogeneous composition. In the above relation v is the velocity normal to the limb of Neptune, H is the scale height, t_0 is the time at half light level (i.e., $\phi/\phi_0 = 0.5$) and ϕ/ϕ_0 is the relative flux at time t. The above relation has been used to calculate the theoretical light curves corresponding to the occultation paths for various assumed distances from the centre of the planet, for comparison with the observed occultation curve. Comparing the theoretical light curves obtained for different distances from Neptune's centre and assuming $H = 50$ km, with the observed occultation curve, we find that the observed light curve shows a best fit with the theoretical light curve for an occultation path at a distance of 24000 km from the centre of Neptune.

The revised geometry of the occultation path, as projected on the sky plane, thus obtained is shown in Figure 4. Furthermore, assuming that the ring system lies in the equatorial plane of the planet, the distance from the centre of Neptune and other informations for the secondary occultation events and for broad zones I and II were obtained and these are given in Table II and III. The various parameters adopted for the calculations are given in Table IV.

TABLE I

A brief summary of observed occultations of stars by Neptune

Date	Remarks	Reference
April 7, 1968	Ring system extending from 4755 to 11080 km above Neptune. The results are based on re-analysis of the observations of the occultation by Neptune on April 7, 1968.	Guinan *et al.* (1982)
August 21, 1980	A possible secondary occultation event of duration 1.5 s and depth of 0.7 at a projected equatorial radius of 1.5 R_N.	Nicholson and Jones (1980)
May 10, 1981 May 24, 1981	No evidence of ring system.	Elliot *et al.* (1981)
May 24, 1981	Possible detection of a third satellite of Neptune with an orbital radius of $3 \pm 1\ R_N$.	Reitsema *et al.* (1982)
June 15, 1983	No evidence of ring system.	Elliot (1983)
	Re-examination of observations by T. Gehrels shows a single shallow event with a duration of 27 s and maximum decline of 2.5%. This corresponds to an object located at a distance of about 3 Radii in Neptune's equatorial plane.	Hubbard (1984)
September 12, 1983	Four secondary occultation events were recorded.	Pandey *et al.* (1984)
July 22, 1984	Occultation due to a body with a minimum size 10–15 km and with a depth of 35% at a distance of 3 R_N from the centre of Neptune.	Häfner and Manfroid (1984)
July 22, 1984	Confirms the results of Häfner and Manfroid (1984).	Hubbard (1984)
August 20, 1985	Three secondary occultations, two before immersion event with fractional depths of 0.35 and 0.15 located at 94000 km and 74000 km respectively and one after emersion event with fractional depth 0.18 which corresponds to 17 km wide object located at ~ 51000 km from Neptune's centre in its equatorial plane.	Sicardy *et al.* (1985)
August 20, 1985	Two possible secondary occultation events after the emersion event having 30% and 25% drops and width ~ 2 s each.	Hubbard (1985)

The light variations shown in Figure 1 manifest that the ring system starts with the shallow features. Zone I extends from 64400 km to 64270 km in the equatorial plane of Neptune with a maximum decline of 35% in star light and it includes prominent dips C and D. The zone II extends from 64250 km to 64200 km in the equatorial plane of Neptune and it includes a secondary occultation event termed as B. The error in these distance determinations is estimated to be about $\pm 0.05\ R_N$.

TABLE II

Secondary occultation events

Feature	Mid time UT	Duration (FWHM)	Fractional depth	Amplitude (σ)	Distance from the center of Neptune (km)
A	$16^h04^m26\overset{s}{.}0$	$1\overset{s}{.}5$	0.9	3.7	64190
B	15 56 43.5	3.0	0.9	3.6	64240
C	15 52 44.0	1.5	1.0	3.7	64280
D	15 38 54.5	1.5	1.0	3.3	64375

TABLE III

Occultation due to two broad zones

Zone	Maximum light diminution (%)	Mean distance from the center of Neptune (R_N)	Approximate width (km)
I	35	2.55	130
II	30	2.55	50

TABLE IV

Various parameters adopted for the calculations

Adopted planetary parameter	Reference
Coordinates of the north pole: $\alpha_p = 295\overset{0}{.}19$ $\delta_p = 40\overset{0}{.}61$	Astronomical Almanac 1983 (E5)
Equatorial radius at half light level: $R_N = 25225$ km	Kovalevsky and Link (1969)
Mean scale height, $H = 50$ km	Elliot (1979)

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