Discovery of Neptune's Ring at La Silla

R. HAEFNER, Universitäts-Sternwarte München,
J. MANFROID, Institut d'Astrophysique Liège, Belgium, and P. BOUCHET, ESO

The story of the discovery of the planet Neptune is well known: During the years 1841 to 1845 the English Cambridge student J. C. Adams calculated the position of an eighth planet based on the difference between the predicted and observed orbit of the planet Uranus, thought to be the outermost one in our solar system. However, J. Challis, at that time Director of the Cambridge Observatory, as well as G. B. Airy, Director of the Greenwich Observatory, refused to point their telescopes toward the calculated position. Challis considered a search to be too troublesome and expected a negative result. Airy, on the other hand, was convinced that the quadratic law of distance had to be changed to obtain the observed Uranus orbit. Independently and roughly at the same time the French astronomer J.J. Leverrier worked on the same problem and published nearly the same position of an eighth planet. He wrote then a letter to the Urania Observatory in Berlin which he thought to be the best one in Europe at that time. Thereupon, in the night of September 23, 1846, J.G. Galle and his assistant H.L. d'Arrest found the eighth planet Neptune in Aquarius just after one hour of comparing the observed star position with those on a star chart they had drawn half a year ago. This was one of the first examples of European astronomical cooperation. To be complete it should be mentioned that Challis after all started observations. He saw the new planet several times prior to Galle, but he did not realize it.

The next story is little known: The English amateur W. Lassell who promptly detected Neptune's satellite Triton at the Starfield Observatory in Liverpool, reported also on the discovery of a ring around Neptune on October 3, 1846 (fig. 1). He saw the "ring" as a diametrical bulge on the planet's disk again on several occasions in November and December 1846, interrupted by bad weather conditions. Lassel's discovery was widely discussed in the London *Times,* the *MNRAS* and the *Astronomische Nachrichten* and later on confirmed by Challis who was now eager to participate on a new detection. However, a comparison of their drawings revealed a different orientation of the suspected ring. Consequently, using the new Harvard refractor in 1847, W.C. Bond of the Cambridge Observatory (Massachusetts) was unable to see the phenomenon and attributed Lasell's finding to an optical appendage with preconception doing the rest. Extensive searching during the second part of the 19th century and the beginning 20th century by means of large refractors of high optical quality was not successful in finding any features which fitted the descriptions given by Lassell and Challis.

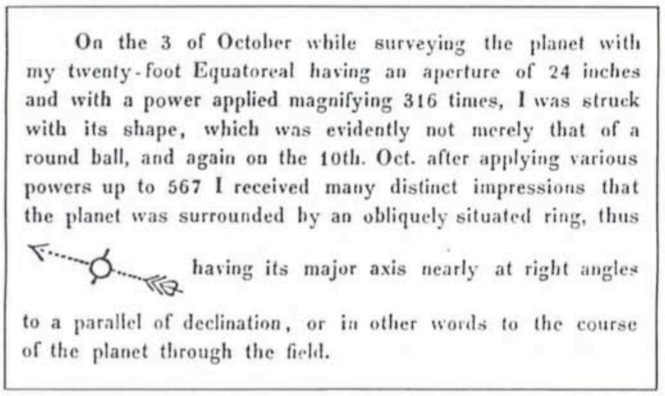
On the 3 of October while surveying the planet with my twenty-foot Equatoreal having an aperture of 24 inches and with a power applied magnifying 316 times, I was struck with its shape, which was evidently not merely that of a round ball, and again on the 10th. Oct. after applying various powers up to 567 I received many distinct impressions that the planet was surrounded by an obliquely situated ring, thus having its major axis nearly at right angles to a parallel of declination, or in other words to the course of the planet through the field.

Fig. 1: *Drawing of Neptune's "ring" as published by W. Lassell in* Astronomische Nachrichten **25,** *357, 1847.*

It is however interesting to note that after his discovery of Uranus in 1781, F. W. Herschel observed on several occasions during the years 1787 to 1792 a ring around this planet appearing as an elongate appendix on both sides of the planet's disk. Later on this phenomenon disappeared and Herschel was convinced to have been a victim of an optical delusion. However, there are in fact indications that Herschel really saw the ring system: a recalculation of the orientation of the rings detected in 1977 shows an exact agreement with the position given by Herschel; the disappearance can be explained by the edge-on position at that time (Schmeidler, 1985).

Indeed, the unexpected (re)discovery of the Uranian rings during an occultation of a late-type star by the planet in 1977 as well as the discovery of the faint Jovian rings by the Voyager 1 spacecraft in 1979 stimulated the search for such rings around the fourth of the giant planets, Neptune.

The main ground-based technique to establish the existence of faint rings around a distant planet is to follow a stellar occultation, which is one of the most ancient forms of astronomical observations. Using high-speed photometric techniques the intensity of the star light is measured during the passage of the rings through the line of sight which dims the intensity in the order of a few seconds. Such occultations by, and appulses to, interesting planets are predicted and published several years in advance together with information on where and when they will be visible. During the last years there was at least one good opportunity each year as far as Neptune is concerned. However, all experiments performed so far did not reveal any distinct hint for a ring system. The only confirmed occultation event was that observed on May 24, 1981 (Reitsema et al., 1982). It was interpreted to be caused by a so far unknown third satellite with a diameter of about 100 to 180 km orbiting at a distance of about 3 Neptune radii.

In July 1984 we performed different observing programs using the ESO 0.5 m (R.H.) and 1 m telescopes (J.M.) of the European Southern Observatory. Some days prior to July 22 Drs. Brahic and Sicardy from Paris Observatory called our attention to a star occultation by Neptune expected for that night and provided updated coordinates. Despite the fact that last-minute predictions showed that the planet would very probably miss the star and nothing extraordinary would happen, we decided to "waste" a few hours of our observing time to follow the spectacle.

The technical preparations were done by P. Bouchet and F. Gutierrez, who later on installed the data-acquisition systems at both telescopes. These systems allow integrations in the ms domain and a recording on magtapes. The time is synchronized with the central clock on La Silla every 1 ms. Strip chart recorders were additionally installed to provide on-line information. Since contrarily to the 1 m telescope the 0.5 m telescope has no off-set-guiding system available, continuous measurements have to be interrupted from time to time to check the position of the object within the diaphragm. Therefore, the time needed for a star to cross the diaphragm was determined for different positions along the Neptune track to loose later on as little observing time as possible. Since the star in question, SAO 186001 is very red, we intended to measure in the infrared region in order to enhance the contrast

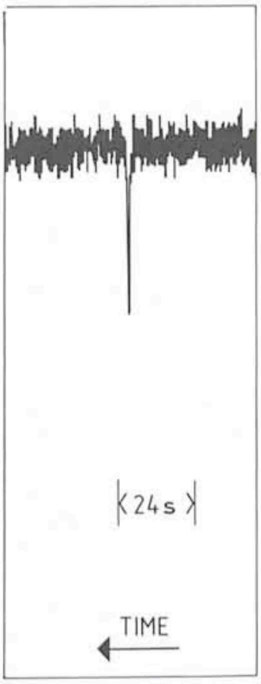

Fig. 2: *Original strip chart recording of the occultation event obtained at the 0.5 m telescope.*

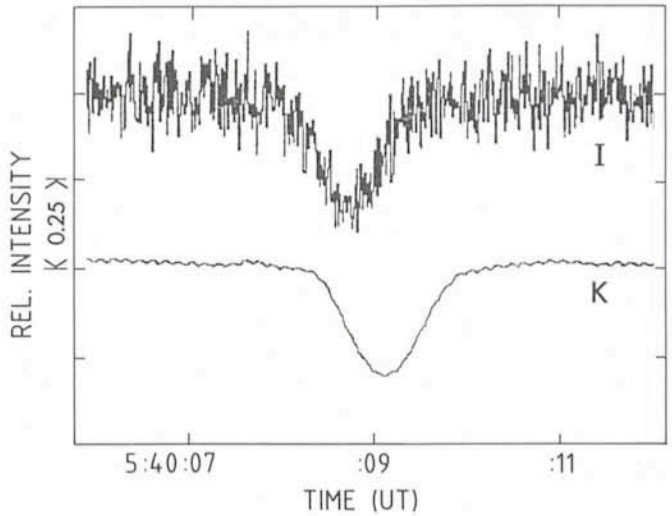

Fig. 4: *The occultation event as recorded by the two telescopes with high time resolution. Time delay and smoothed, wavy shape of the lower curve are due to technical reasons.*

between star and Neptune. We used an I-filter combined with a Quantacon (effective wavelength 0.8 μm) at the 0.5 m telescope and a K-filter (2.2 μm) at the 1 m telescope, which was equipped with the standard infrared photometer. R. Vega was assisting at the 1 m telescope. The on-line magnitudes as determined shortly before the start of the high speed measurements were for Neptune: V = 7.9, I = 9.0 and for SAO 186001: V = 9.2, I = 6.6 and K = 4.2.

The night of July 22, 1984 was of perfect quality: moonless, no cirrus, no wind, seeing around 1″, 10% relative humidity and constant temperature at about 14 °C all the time. This was probably due to the fact that a blizzard rushed over La Silla one week earlier and cleared up the skies.

The actual observations (10 ms integration time) were started at the 1 m telescope at about UT 1^h23^m using a diaphragm of 15″. Contrarily to the K-band there was a small contribution by Neptune in the I-band. Therefore at the 0.5 m telescope a diaphragm of 30″ was used and the measurements were started at UT 2^h50^m, when the separation between the star and Neptune was about 15″. This allowed to record the combined flux all the time. The occultation or the closest approach was scheduled for about UT 6^h30^m to 7^h. Suddenly, at UT $5^h40^m09^s$ the smooth tracings on our strip chart recorders were interrupted by a very short dip with a duration of about 1.2 s and a depth of about 35% (see fig. 2). Was this the ring so long searched for and did we record it by chance? Thereafter we followed still more intently the things going on. However, nothing particular happened any more; neither an occultation by Neptune nor a second occultation event like the one recorded before was noticed. We continued the measurements till UT 8^h when the very large air mass prevented any further high quality observation. Figure 3 shows the geometry of the appulse as projected on the sky. We telexed the recording of the single occultation event to the IAU Central Bureau for Astronomical Telegrams (Gutierrez et al., 1984) and started immediately with the reduction of the event and with additional measurements.

The differences in shape and timing of the occultation event as recorded by both telescopes (see fig. 4) can be explained in several ways. The telescopes are separated by about 200 m (see fig. 5) so that they were swept by different parts of the shadow of the occulting body. Different diffraction effects could be observed at different wavelengths; the optical

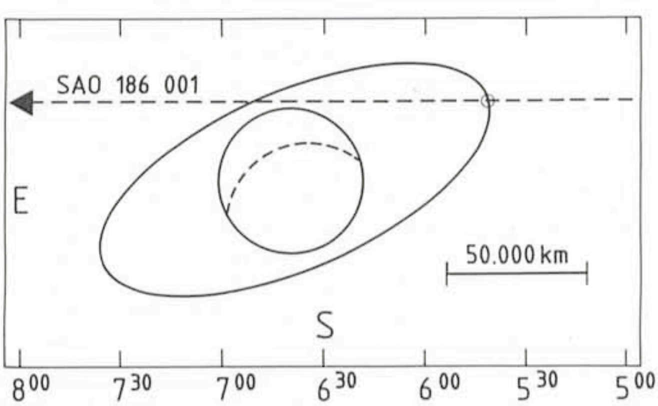

Fig. 3: *Apparent track of SAO 186001. The circle marks the location of the occultation event.*

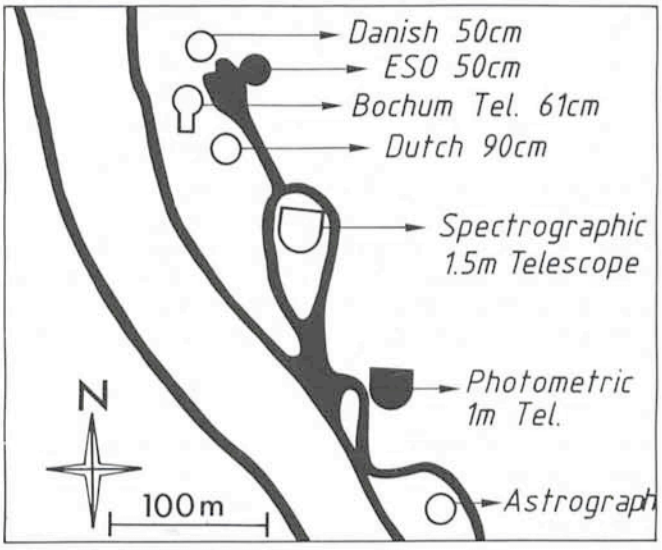

Fig. 5: *Location of the telescopes used on La Silla.*

characteristics of the absorbing material may be wavelength dependent as well as the relative intensities of the involved bodies. Furthermore, the chopping frequencies and the time constants of the infrared equipment induce differences of technical origin.

Previous experience and additional tests showed that the difference in shape as well as the time delay of 0.4 s is about what is to be expected for the 1 m recording because of technical reasons. This means that both telescopes recorded the event simultaneously within an unavoidable error of the order of 0.1 s imposed by the chopping procedure. This, the smooth regular profiles and the clear sky are enough to rule out an occultation by a body close to the Earth (e.g. Earth satellite, cloud, contrails).

A look at the ephemeris of minor planets showed that no catalogued one was in that area. We blinked Schmidt plates taken by H.E. Schuster and O. Pizarro in the following nights 48 hours apart and could not find any unknown moving object down to the 17th magnitude. Closer inspection of the field for fainter, slow moving bodies did not show any object down to the 19th magnitude. Moreover, the probability of such an occultation by a body neither associated with the Earth nor with Neptune, i.e. an asteroid, is extremely low. The coincidence with the Neptune appulse makes the case for the latter association overwhelming, excluding, however, the influence of Neptune's known satellites Triton and Nereid, which were at that time not close to the line of sight.

The orbit of the third satellite proposed by Reitsema et al. (1982) appears to be remarkably similar to that of our object if we assume them to be in the equatorial plane. It is not possible to give a more accurate distance because there was no occultation by the planet itself. The duration of the event combined with the supposed sky-plane velocity of Neptune of about 20 km/s and the shape of the light curve show that we recorded a much smaller body having a chord length of the order of 10 km. On the other hand, the probability of detecting a satellite in that manner is not large and it is nearly impossible to record that new satellite twice. Therefore, in order to enhance the probability we were led to imagine a full ring of bodies of various shapes and sizes circling the planet at a distance of about 3 Neptune radii. This would explain why occultations are not always detected when the orbit passes in front of a star. In particular, we did not detect the second crossing of the orbit which occurred about 1 hour after the first one. However, the irregular nature of this ring does not necessarily imply large, satellite-sized bodies. A ring composed of smaller particles showing an irregular width and optical depth can fit the observations as well. In fact similar rings are known in the Uranus system and perhaps also in the Saturn system. A summary of all these considerations was again sent to the IAU Central Bureau for Astronomical Telegrams at the end of July (Haefner and Manfroid, 1984).

These observational facts imply some theoretical problems: Assuming equal densities for planet and ring material, this ring is located beyond the Roche lobe which conventionally is thought to constitute the outer limit for the existence of such structures. Besides this, the retrograde motion of Triton is sometimes argued to have such an influence that no ring at all can exist. On the other hand the classical resonance theory combined with empirical arguments predicts a possible formation of a ring, although closer to the planet than what we observed (Rawal, 1981). It would then have been formed by tidal disruption of a satellite. This simple resonance law is grossly obeyed within the solar system but there are many exceptions, e.g. as has been shown by the Voyager spacecraft for the fine structure of the Saturnian rings. In fact no satisfactory theory has been worked out so far to explain all ring phenomena in detail.

Five months after our observations we received notice that a nearly identical occultation event had been recorded at the same time by a group of American astronomers working at the Cerro Tololo observatory situated about 100 km south of La Silla (Hubbard, 1984). According to a communiqué from the University of Arizona they "were unable to see the brief event on the computer print-out their telescope generated for every 3.4 s of data". Unaware of our IAU Circulars they did not check their high-speed photometric data (fortunately stored on magtape) before December 1984. These additional observations strongly favour the existence of at least part of a ring having a width of roughly 10–15 km over a length of at least 100 km. This is an unexpected and nice confirmation of our conclusions.

Hopefully more details of the nature of this fragmented ring will be obtained after the launch of the Hubble Space Telescope and during the Voyager 2 rendezvous with the Neptune system in 1989. Probably this spacecraft will need reprogramming to avoid the ring zone on its way to Triton, Neptune's extraordinary satellite.

Acknowledgement

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STAFF MOVEMENTS

Arrivals

Europe

BORTOLETTO, Favio (I), Fellow (Astronomical Detectors)
QUATTRI, Marco (I), Mechanical Engineer
SANDERS, Robert (USA), Associate

Chile

GELLY, Bernard (F), Coopérant
HEYDARI-MALAYERI, Mohammad (F), Astronomer
KOEHLER, Bertrand (F), Coopérant
REIPURTH, Bo (DK), Associate

Departures

Europe

BRINKS, Gloria (F), Receptionist
LUND, Glenn (NZL), Engineer/Physicist
MAZZARIOL, Severino (I), Electronics Technician
UNDEN, Christiane (B), Secretary