The Uranus Occultation of August 15, 1980

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The Rings of Uranus

One of the very exciting discoveries in astronomy and planetary sciences in recent times is the detection of a series of narrow rings around Uranus. During more than three centuries, the rings of Saturn have had a special fascination and symbolism and an enormous amount of literature has been devoted to studies of their nature, properties and origin. The discovery of Uranus' rings, and two years later of Jupiter's rings has not only renewed interest but also raised a number of new cosmogonical questions.

Planetary rings are important not only because of the dynamical problems which they pose, but also because it is probable that processes which played a role in planet and satellite formation are still at work in these rings: ring systems afford a good opportunity for studying some of the accretion mechanisms which operated in the early solar system. Techniques used for galactic dynamics have been particularly fruitful for the understanding of planetary rings. Conversely, a detailed study of ring structure can lead to a better understanding of other flat systems like spiral galaxies or accretion disks. Collisions which play such an important role in the Universe can be studied in rings. Furthermore, particles of planetary rings are natural probes of the internal structure of the central planet.

Discovery of the Rings of Uranus

It is almost impossible to observe directly from the Earth a system of dark rings of 8 arcseconds around a planet which has an apparent diameter of 4 arcseconds. The Uranian rings have been discovered during the occultation by Uranus of the late-type star SAO 158687 of visual magnitude 9.5 on March 10, 1977. High-speed photometry of occultations provides a powerful tool for probing the upper atmosphere of a planet, as has been shown during the past decade from occultations involving Mars, Jupiter, and Neptune. In 1977, all of these efforts paid off when not only the predicted occultation by the planet, but also a series of secondary occultations by the previously unsuspected rings, were observed (Elliot *et al.*, 1977 a, b; Millis *et al.*, 1977). It is pleasant to note that occultation techniques are very powerful: they give a resolution slightly better than the one obtained from a Voyager-type spacecraft flying by the planet. From the Earth, the resolution is limited by Fresnel diffraction and by the angular size of the occulted star.

Deductions from Observations

Seven useful occultations have been observed up to now. The Uranian rings pose a number of new and unexpected dynamical problems. At least nine rings encircle the planet, extending between 1.60 and 1.95 planetary radii. Compared to their circonference (some 250,000 km), they are exceedingly narrow: most do not exceed 10 km in width and only one, the outermost ring, spans as much as 100 km. Three rings are circular, but six are eccentric and have variable widths. Both of these characteristics are best illustrated by the external ring: it is the largest, its distance from Uranus varies by about 800 km and its width changes from 20 to 100 km linearly with its distance from Uranus. The remarkable thing is that these elliptic rings precess slowly about the planet (1.364° per day for the outer ring). Normally, the rate of precession around an oblate planet would depend on the distance to the planet and this differential precession would shear each ring into a circular band. In fact, each ring precesses as a rigid body. The profile of the rings looks the same everywhere. The rings have sharp outer edges, and structure bigger than noise appears within a number of rings. A more detailed review of the observations is given by Elliot (1981) and Brahic (1981).

Ring Dynamics

Similar intriguing situations have been recently observed around Saturn and Uranus by Voyager spacecraft (narrow rings, eccentric rings, sharp edges, nearby satellites, . . .). It seems that a confining mechanism which played a role for the formation of planets and satellites is actually at work in ring systems.

Unconfined rings of free colliding particles spread under the combined effect of differential rotation, inelastic collisions, and Poynting-Robertson drag (Brahic, 1977; Goldreich and Tremaine, 1978). Resonances with known satellites are too weak and too few to explain the observed features directly.

A satellite near a ring of colliding particles exerts a torque on the ring material. They exchange angular momentum; this leads to a mutual repulsion of the ring and the satellite. Like in a spiral galaxy, a nearby satellite creates leading and trailing spiral density waves which are controlled by a combination of the Coriolis force and the ring's own gravity. Small undetected satellites on each side of the ring could constrain its edges and prevent ring spreading; elliptical rings can also be generated by such a confining mechanism. Kilometre-sized bodies are massive enough to confine the observed rings. They are the largest "particles" of the original ring (Goldreich and Tremaine, 1980; Hénon, 1981).

The Occultation of August 15, 1980

Time was allocated at the 3.6-m telescope for the occultation of the star KMU 12 (Klemola and Marsden, 1977) by Uranus and its rings.

It was the first Uranus occultation successfully observed by a European team. The best signal-to-noise ratio was observed during this occultation. New features were discovered in the ring system and new information obtained on the atmosphere of Uranus. Two American teams around Elliot, Nicholson and Goldreich, working with the large telescopes at Las Campanas and Cerro Tololo observatories obtained data of similar quality. It was the first time that an occultation had been observed, with such quality of results, from three different points simultaneously. The reduction of the data is being done in the frame of a common American-European programme and is leading to new results. The ESO data are being reduced by Bruno Sicardy. The study of correlations is particularly important.

Observations

The observations were made using the new infrared photometer mounted on the 3.6-m telescope at La Silla. A standard K

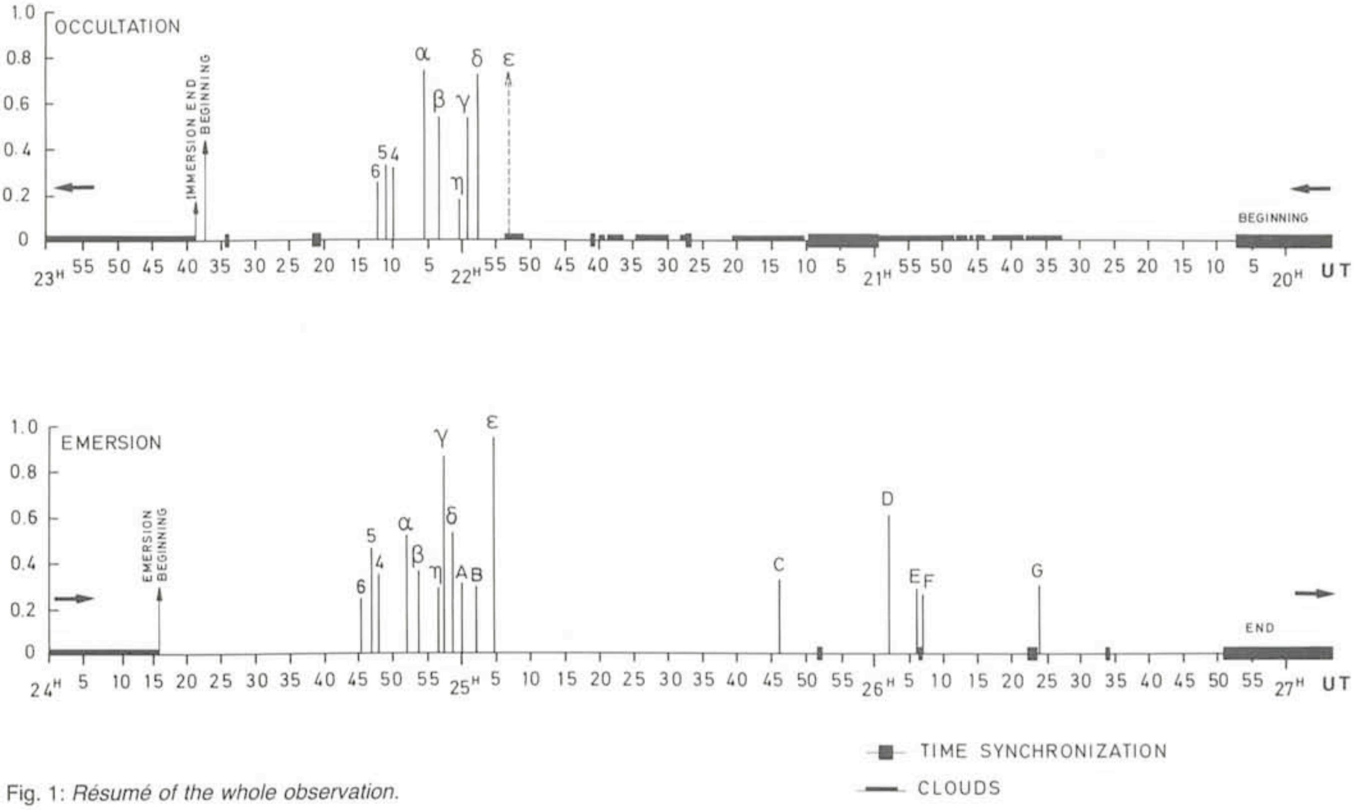

Fig. 1: *Résumé of the whole observation.*

filter ($\lambda_o = 2.20\ \mu m$; $\Delta\lambda = 0.5\ \mu m$) was used with an InSb detector cooled to 55°K. The choice of this wavelength is due to the strong methane band which greatly depresses the light reflected from the planet. Actually, at this wavelength, the albedo of Uranus is only 10^{-4}. Thus, quite fortunately, the star KMU 12 (K = 8.5) was considerably brighter than the Uranus system at 2.2 μm, giving a high contrast during the eclipses. Sky subtraction was achieved by chopping at 18 Hz to a secondary beam located 20″ to the South. An aperture diameter of 10″ was selected to reduce thermal background noise without introducing noise from guiding and seeing effects. Therefore, the noise was mainly due to detector and background radiation from the telescope and the sky. A signal-to-noise ratio of ~ 100 could be achieved with a time resolution of 0.1 s.

Thanks to F. Gutiérrez, at La Silla, who promptly wrote for these observations a new version of the fast acquisition programme, it was possible to record the signal with a "sampling period" of 0.1 s. UT was drawn directly from the La Silla caesium clock and automatically controlled every 10 s, and reset if necessary. This was rather risky since this resetting could have occurred precisely during a ring occultation, but fortunately that did not happen.

The star was centered by finding the half-power points of the 2.2-μm signal 45 minutes before the first occultation and centering was maintained during daytime trying to keep the signal to this level. The excellent tracking of the telescope and the tests performed the previous night to find the optimum tracking rate, plus the fact that we were looking at rapid decrease of the signal, rather than slow variation, allowed us to proceed in such a way. As soon as it became possible—right after emersion from Uranus—we used an offset-guider/Quantex TV-system to maintain centering. During the occultation by the planet itself it was impossible to point dead on the star, which explains our lack of accuracy at emersion.

Uranus' centre passed 0″7 ± 0″3 S-SW of the star. As the planet's apparent radius was 1″9, its disk completely occulted the star. The span of the ring system being 7″, it was almost diametrically crossed by the path of the star. Note that all crossing times occurred 10 minutes earlier than predicted. The first one (star passing behind ring ε) was observed through clouds at around 21 : 50 UT. Luckily, clouds vanished completely right after, which allowed us to *see* the rings passing in front of the star during the following half hour.

Sunset occurred at 22 : 30 UT. At 22 : 31 UT the star disappeared progressively during 3 minutes. The record then shows many randomly scattered and very fast jumps or spikes in the signal. The progressive shape of the lightcurve is due to refraction in Uranus' atmosphere (exponentially decreasing distribution of its density with altitude) while scintillation in it caused the spikes. After ~ 1 ½ hour of total eclipse, the star reappeared exactly as it had disappeared, its path crossing the ring system in reversed direction.

Preliminary Results

Figure 1 shows the depth of the observed events vs. UT. Rings α, β, γ, δ, η, ε, 4, 5 and 6 are the already known ones, as they were first identified. Events A, B, C, D, E, F and G are

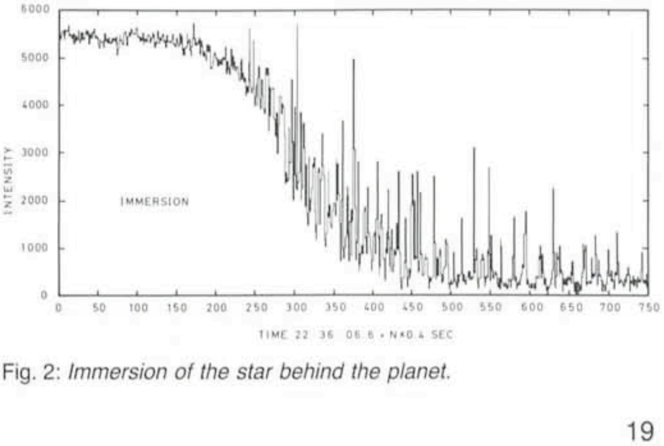

Fig. 2: *Immersion of the star behind the planet.*

possible new phenomena which we may have observed and which will be discussed later.

Figure 2 shows the immersion of the star behind the planet. This interesting lightcurve may unveil some fundamental aspects of Uranus' atmosphere and mesospheric temperature.

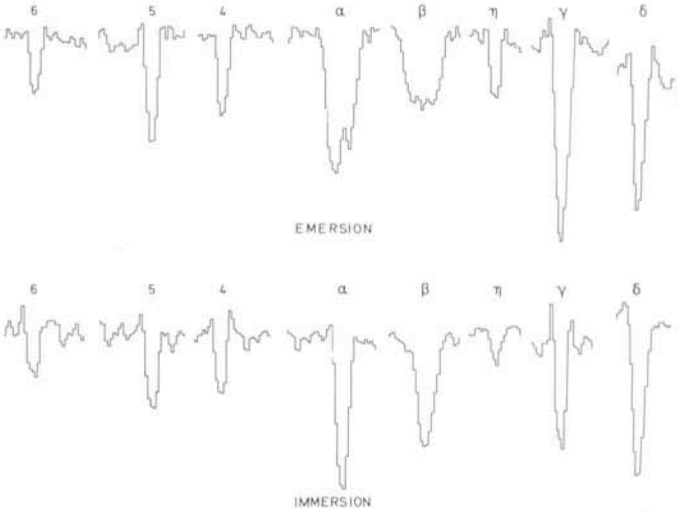

Fig. 3: *Observed occultation profiles of rings* α–η.

Figure 3 depicts the observed occultation profiles of rings α–η and Figure 4 that of ring ε, unquestionably the most intriguing. The similarity of these profiles with already observed ones (Nicholson *et al.,* 1978; and for the same event, Elliott *et al.,* 1980) is evident. Note, for instance, the "double-dip" structure of the α ring and diffraction fringes mainly at the edges of the γ ring, but present in other rings as well.

Another important result is the lack of evidence, at the 5% level, of any smoothly varying background absorption. This feature is also in agreement with Nicholson *et al.* (1978) and Elliot *et al.* (1977 a, b, 1980).

A new and most exciting aspect of our observations is that we may have observed further significant occultations. Figure 5 samples profiles corresponding to the more prominent of these events. Striking as it may seem, observers at Cerro Tololo and Las Campanas recorded no occultation at these particular times. Nevertheless, we do feel that these phenomena are real—although a possible instrumental or atmospheric origin cannot be totally excluded—for the following reasons:

(a) Although cirri were present at the very beginning of the observations, it seems that they disappeared later and did not disturb the observations from the occultation of ring δ on. Anyhow, the time scales of the variations due to the presence of cirri are far longer than those of the actual occultations. Moreover, they never look like isolated spikes, as is the case in our reported events.

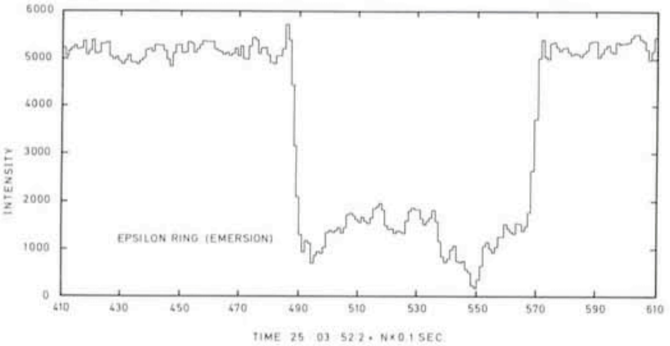

Fig. 4: *Observed occultation profile of* ε-ring in emersion.

Fig. 5: *Observed profiles of possible events (see text).*

(b) Also questionable is the argument that attaches their origin to bad centering. Indeed, these new occultations were detected during night-time with an offset-guider/Quantex-TV system allowing excellent *guiding* and we noticed no decentering at all. Furthermore, immediately after each reported event we recorded the same stellar flux and noise levels as just before them. This would have been very difficult to achieve had there been a decentering effect using a system which did not give in that time, an optimum beam profile.

However, apart from the explanations mentioned above, we feel another situation is worth reporting. Once the observations of the actual occultations were over, we kept on centering on a star with the same K magnitude. This was done during one hour in order to check for any variations in the signal. Here we were *lucky* enough, though rather disappointed, to observe an effect which may be called "seeing fluctuation". The result is the same profile as observed for some known rings as well as possible new events.

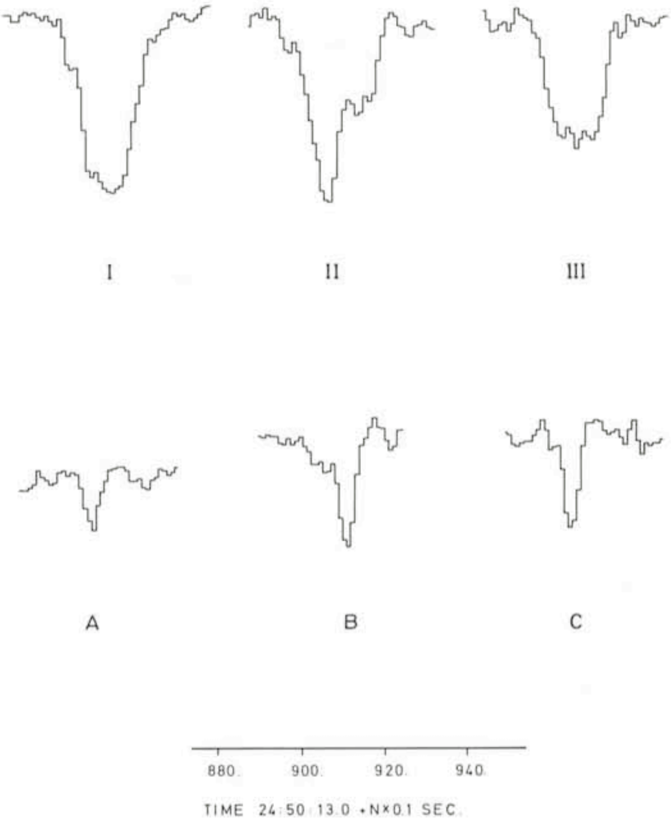

Fig. 6: *"Play with us" (see text).*

So the question is open! Are these observations reflecting real events? (IAU Circ. No. 3503 and No. 3515.) Maybe the answer lies in the results of future observations. Meanwhile, let us consider Figure 6 which gives an idea of the problem.

With the same stellar flux level, I, II and III in this figure show the profile obtained with an intentional decentering (followed by immediate recentering, what we never did during the observations), the one of a possible newly discovered event, and the one of a known ring, respectively.

In the same figure, A, B and C correspond to the profile of a known ring, a seeing fluctuation and a possible event. Which is which?

Finally, let us recall the events reported by Churms (1977) and Millis and Wasserman (1978) during the March and December 1977 occultations and which have never been confirmed. On the other hand, one should bear in mind the fact that Nicholson *et al.* (1978) claimed that rings 5 and 6 are not two complete rings, but rather a collection of incomplete arcs. Again, only future occultations, preferably observed with telescopes less than 1 km apart, will throw more light upon the question of whether these random phenomena are caused, as suggested by J. Lecacheux (1980) by a profusion of large boulders not organized to form a ring.

Conclusion

The result of this observation will be published in the next months. Here, we can only give an abstract of the main results:

- The already observed structure of the rings has been confirmed and additional features have been discovered such as broad structures near the narrow rings. Rings have a very complex internal structure and the existence of incomplete arcs or additional satellites around Uranus has to be investigated.
- The observations from La Silla, Las Campanas and Cerro Tololo are used to compare the structure of the atmosphere of Uranus at points separated by about 100 km, along the planetary limb. There are striking, but not perfect, correlations of the lightcurves. This rules out the isotropic turbulence as the cause of lightcurve spikes. The atmosphere is strongly layered and its mean temperature is 150 ± 15°K.

In order to have a better understanding of the dynamics and the structure of the rings and the atmosphere of Uranus, it is necessary to observe additional occultations, each one being a high-precision scan of the planet and its rings, in order to reconstitute point by point the ring system.

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RCW 58: A Remarkable HII Region Around a WN 8 Star

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In the course of a programme of detailed study of galactic ring nebulae around Wolf-Rayet stars, we obtained an $H\alpha$ photograph, $H\alpha$ interferograms and Boller and Chivens spectrograms of the H II region RCW 58 (Rodgers *et al.* 1960).

The $H\alpha$ photograph is reproduced in Figure 1. The overall shape, as was known previously (Smith, 1968), is a ring centered on the WN 8 star HD 96548[1]. However, the nebula is remarkable for its clumpiness, the presence of large scale curls to the south, and above all the existence of radial features never observed for any other H II region.

The spectrograms indicate a relatively low degree of ionization, electron densities in the range 200 to 500 cm^{-3}, and large variations of the line intensity ratio of [S II]$\lambda\lambda$6717–6731/[N II]λ6584 over the nebula.

The radial velocity field, obtained from $H\alpha$ interferograms, is complex; different clumps display different velocities, from about -60 km s^{-1} to $+60$ km s^{-1}. On the spectrograms, the [N II]λ6584 and $H\alpha$ lines are tilted, and even split; the velocity difference between the two components reaches 100 km s^{-1} in the direction of a low brightness central region. This behaviour is reminiscent of those observed for NGC 6164–5 and M1–67[2], two nebulae formed of condensations ejected respectively by an O6f and a WN 8 star.

The complexity of the radial velocity field does not allow any estimate of a kinematical distance for RCW 58. If its central star is a typical massive WN 8 star ($M_v \simeq -7.0$, Van der Hucht *et al.*, 1981), its spectroscopic distance is about 4 kpc.

Moffat and Isserstedt (1980) showed recently that the central star displays small periodic radial velocity variations; this may indicate the existence of a compact companion, so that the star would be a second-generation Wolf-Rayet star during the evolution of a binary system. This assumption is consistent with the large distance of the star from the galactic plane ($z = 333$ pc for $D = 4$ kpc) which could result from the ejection of the system when the primary star exploded as a supernova. Under this assumption, the spatial motion of the

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[1] HD 96548 = number 40 in the Catalogue of Wolf-Rayet stars by Van der Hucht et al. (1981) = MR 34 in Roberts (1962).

[2] M1–67 in the catalogue of Minkowski (1946) = Sh2–80 in the catalogue of Sharpless (1959); the $H\alpha$ radial velocity fields of NGC 6164–5 and M1–67 were obtained respectively by Pismis (1974) and Pismis and Recillas-Cruz (1979).