The Rings of Uranus : Story of Its Discovery

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IN astronomy, several vital measurements are handicapped by the presence of the earth's atmosphere. This is due to the absorption of many regions of the electromagnetic spectrum which convey information about the physical processes happening in the cosmos. Even the small portions of the radiation which come through are heavily distored while traversing the layers of atmosphere and deciphering the information contained therein becomes uncertain. These barriers are partially eased by nature during certain opportune events in astronomical history. These happen when the earth and some of the nearby astronomical bodies come in favourable positions and some of these impossible measurements come within grasp of earth-bound astronomers. The example of total solar eclipses can be quoted in this connection. These are the moments when the two outer layers of the sun—the chromosphere and the corona, reveal their secrets to inquisitive scientists. Actually, almost a major part of the information about these two layers of our sun have been gathered during the precious few seconds of totality over the past hundred and odd years. Many important discoveries, not only in astronomy, but in fundamental physics as well, have been made during such astronomical events. No wonder that scientists have endured extreme hardship and even death in order to observe these eclipses.

A similar astronomical event, though not as spectacular as total solar eclipses, unfolds some secrets of the universe to the astronomers. These are occultations; the events occur when the moon or other closeby bodies momentarily cover distant objects. So great is the importance of such events that elaborate preparations are often made for such observations. A subtle description of such an observation is given in a recent book by Professor Fred Hoyle. The event was the occultation of a radio source by Moon, and was observable from Australia. This ultimately provided the astronomers the information about the structure of the source 3C 373—a quasar—which would have been impossible to measure by other means. Hoyle writes : "Several tons of metal were sawed off the telescope to permit observation at a lower angle of elevation than the normal operational range. For hours before the occultation all local radio stations broadcast repeated appeals : that no one should switch on a radio transmitter during the critical period of the observation. All roads leading anywhere near the telescope were patrolled to make sure that no cars were in motion in the vicinity. A final somewhat macabre touch : after the observation, Hazard and Bolton carried duplicate records back to Sydney, on separate planes."

The occultation by planets or their satellites are rather rare. Actually one can count the total number of such occultations during the past 25 years on one's fingertips. Therefore whenever such an event occurs, astronomers are extra careful about the observations. In case of planetary occultations emphasis is more on the planets, rather than on stars. These are opportune moments when the shape and the size of the planet can be determined very accurately. The moments of immersion and emersion are determined with highest precision possible, from a few locations distributed on earth, and these data provide the much needed answers. I can cite the example of the determination of the diameter of the third satellite of Jupiter—Ganymede, from such an occultation on 7th June, 1972. Our group at Kavalur produced valuable data in this experiment. The Kavalur data brought about a very important piece of new information on the solar system. It showed the presence of a thin atmosphere on Ganymede. The only other satellite on which an atmosphere has been detected is the satellite of Saturn, Titan. Ganymede is thus now known to be the second small body in the solar system containing an atmosphere and the information came mainly through the records obtained at Kavalur. Similar were our aims when we conducted some special observations at Kavalur on the night of 10/11 March 1977. The occasion was the occultation of a star by the planet Uranus. The event was predicted in 1973, and is the first occultation by Uranus in recent years that was followed closely. When the observation was over, we found that the event had yielded a totally unexpected information about presence of a structure around the planet Uranus.

Before I describe the happenings of that memorable night, let me recount some of the features of the solar system, and in particular, the planet Uranus. Uranus is the seventh planet, in order of distance from the Sun, and the first beyond the naked eye visibility limit. It was discovered by William Herschel in 1781 wlth the help of a teleseope. Herschel also discovered two of its-five known satellites. The planet is one ofthe outer planets, rather large in size with a diameter about 4 times that of the earth and believed to be similar in composition and structure to Jupiter and Saturn. The distance of the planet from the Sun is about 19 astronomical units, i.e. 19 times the mean distance between the Sun and the earth. The angle subtended by the planet is about 4 seconds of arc and it has a visual magnitude around 6. The brightness and size of the planet is rather too small for detailed studies of its structure, but its spectra reveal strong absorption bands due to methane in the near infra-red region. Some markings on its surface were detected, but detailed studies of those have not yet been feasible.

Like all planets, Uranus spins round its axis while going round the Sun. Its orbital period is 84 years ; its rotation period is not accurately known ; some place it at around 10 hours while according to others it is close to 25 hours. One feature of its rotation is peculiar: the axis of rotation almost lies in the plane of the ecliptic. In our school days we used to get some questions like what would have happened, if the earth's rotation axis was not tilted by $23\frac{1}{2}°$ or if the tilt was 90°. We know what catastrophic changes in the seasonal pattern would result. One of those hypothetical cases actually exists in the case of the planet Uranus with consequent effects on likely seasonal changes on the planet's surface.

Among all the planets in the solar system, Saturn held the unique distinction of having a ring structure around it. This is in the form of a combination of thin luminous discs with clear spaces in between. The analysis of the spectral lines shows systematic higher doppler shifts on the inside edges, indicating that the structur is composed of smaller bodies in orbit around the planet. The rings are optically thin ; bright stares are seen to shine through them during occultations. During the planet's passage around the Sun sometimes the rings are seen edge-wise at which time they virtually disappear. Their thickness, judged from measures made at that time, should be around 1 km. Their widths on the other hand, are quite large, of the order of 20,000 km for each of the three bright sections. The innermost edge is about 10,000 km from the planet body.

The question why should such a unique feature be present around Saturn, has been bothering the minds of astronomers. The idea has no logical support; because outer planets have comparable masses and satellite systems, but no rings. In scientific circles, speculations about hitherto undetected ring systems around the big planets were voiced from time to time, but all attempts to find them had failed. Scientists had some hopes of the Pioneer 10 and 11 missions bringing information about similar belts ; but again they were disappointed.

For the event of March 10, 1977, initial calculations showed that the shadow of the Uranus event will sweep over India. The time of occultation was such that the planet would be almost on the meridian at Indian longitudes ; the weather in March was promising, and so on all counts India was considered the best location for the observation. Alternate locations were in South East Asia, and less favourably in Western Australia, where dawn will interfere with observation at the emersion time. South Africa was not favoured because the elevation of the planet would be low ; a team in Mauritius was afraid of the seasonal clouding at that time ; but all telescopes around the Indian ocean were fully reserved for the observation.

Now, these predictions were based on the positions of the star and the planet, which are extrapolated from previous measurements. There is always a possibility of very small errors, in extrapolating these positions to the day of observation. In normal astronomical measurements these errors, which are really small, do not matter, but in any occultation experiments, particularly planetary occultations, the errors should be minimised to the lowest possible level. For that purpose, fresh photographs of the field were taken in January 1977, and it was noticed that both the star and the planet were out of the estimated positions. The total discrepancy due to this was 1.44 are seconds. In a normal photographic sky atlas, the diameters of even the faint stars are more than this ; but even this small shift indicated that the occultation will not be visible in India. The new calculations showed that the northern most limit of the planet's shadow will miss India by at least 2000 km. Even the grazing occultation by the planet's atmosphere became doubtful.

This finding was indeed a blow to us in India who were hoping to make observation. Teams of foreign astronomers who were planning to come to India, changed their plans in a hurry. The chances of a successful observation from an Indian location however, could not be completely ruled out, because there were uncertainties about the exact value of the diameter of the planet. With a favourable error, there was still some chances of observing the atmospheric occultation.

Our observation was planned on the 40 inch telescope at Kavalur. The standard photometer, incorporating a selectable diaphragm, a filter slide and Fabry lens was planned to be used. The detector was a photomultiplier with extended S-20 response, an EMI 9558 B cooled to dry-ice temperature. This has a detector surface which is sensitive even in the near infra-red. The star was three magnitudes fainter than the planet, i.e. the star light in the visual filter was a mere 6% of the total light. In these occultation measurements, there are no ways of keeping the planet's light out ; you have to measure the variation of star light in the background of this strong source. That is the reason why very faint stars cannot be used in occultation experiments. To reduce the three-magnitude gap, we resorted to selective filtering. The light from the planet is basically sunlight, with all the spectral characteristics plus the modifications introduced by the process of reflection from the planet. The Sun is of spectral class G with a 6000°K temperature, with its continuum strongest in the yellow falling off both ways. The star to be occulted was a K type star, with equivalent temperature of 4000°K emitting mostly in the red and infra-red. The contrast between them is lessened if one measures, therefore, in the infrared. Also in the light reflected from Uranus, strong absorption bands around 8000Å ascribed to methane in the planet's atmosphere are prominent. If one centers ones observation band over this region, a further improvement in contrast can be obtained. We resorted to this scheme. We selected a filter and phototube so that our observation was centred around 8000 Å. The comparative brightne s of the star thus increased by a factor of five. The recording arrangements we had chosen were conventional since the duration of the event did not need the fast photometric procedures that we normally use at Kavalur for lunar occultations. The photomultiplier output was amplified by an electrometer amplifier and recorded on a potentiometric strip chart recorder. Time marks were provided by a quartz clock whose corrections were accurately known and compared to the International Time Broadcasts. The sky was cloudless and the seeing superb. The disc of Uranus was clearly seen slowly approaching the reddish star. We used a 16 seconds of arc diaphragm that enclosed both objects. According to calculations the closest approach was expected at 21 UT i.e. at 0230 IST in the morning. Uranus rose after 11 P. M. and was safely centered on the diaphragm before 1 A. M. We did a number of tests, measuring the star, Uranus and the sky background to be used for calculations later and by 0130 hrs started continuous recording. Such an early start would not normally have been the practice but we figured that our occultation, if at all, would be very shallow, and for detection of this dip the performance and stability of the whole recording system should be well determined. We were working at a wavelength which is not standard for our photometric observation and therefore it is advisable to determine the extinction coefficient due to atmosphere, and this can be done only if we have a long record. But it was really a lucky decision ; because we later found that several teams missed the very important interesting events just because they started their observations too late !

Let me now describe to you the happenings of those crucial minutes at the telescope. The trace of the record was level, with the usual noise superposed on it. After about 20 minutes of running, the recorder pen suddenly dropped to a new position. We had a very alert young man Sri Kuppuswamy, watching the recorder. He called out at the unusual behaviour and at the moment I was wondering what happened to the star; because looking through the 8 inch guide telescope I could find the disc of Uranus, but the star had literally disappeared into the blue. For a time, which appeared to me about 5 seconds, but later we measured from the record to be 9 seconds, the star was missing ; then as suddenly as it had disappeared, I saw the star appear back again. Visually this is the only event detected and indeed it turns out that this was the only visual observation of the phenomenon anywhere in the world. But on the photoelectric record, several other sharp drops appeared, which could not have been seen visually.

We started wondering about these drops ; power line fluctuations can cause the smaller spikes on the record, but the visual one must be real. We considered all possibilities, right from a hovering bird straying in the path of light to a chance asteroid, and rejected them one by one. The only possibility which seemed logical was that one of the known satellites of Uranus, had come in between us and the star. But we could not be too sure without further checks.

Soon after sunrise we drove upto Bangalore with the recorder tracings. Here we were joined by Dr. Bappu, the Director of our Institute, and other scientists-for a critical examination. The strip chart was spread out and very carefully scrutinized. Two things came out of the examination : 1) there was a shallow dip in the photoelectric record at the time when the two bodies were closest and (2) the 9 seconds occultation cannot be due to any of the known satellites, and hence one was left with the only possibility that it was due to a hitherto unknown satellite. We sent off a telegram to the Central Bureau of the International Astronomical Union about both these facts. That was around sunset on the 11th. We verified later that the cable had reached its destination before midnight.

Similar records were obtained by two more observing teams on the same night, and both came to the same conclusion independently. The first was by the Cornell University team of the United States led by Dr. Elliot. They were observing from the NASA airborne observatory flying over the Southern Indian Ocean. Dr. Elliot did not take a chance and went as far south as was practicable. Flying at 40,000 ft he was free from possible trouble due to clouds. He observed the event and announced it as "due to small occulting bodies, possibly in orbit around Uranus."

The second team was also from the United States. It belonged to the Lowell Observatory, that had the distinction of discovering the planet Pluto nearly fifty years ago, This team was led by Dr. Robert Millis and they were in Perth, in West Australia. He got the sudden diminution in light, and decided to check his instruments. This necessitated his stopping the recording for a minute or so ; thereby he missed two minor events, which followed. But he was also sure that the diminutions in light were due to a hitherto unknown occulting body – a possible new satellite of Uranus.

Due to some reason or the other, no other team detected this feature on their record and made the relevant inference. Some sharp spikes suggesting occultations by very small bodies or inhomogeneities were present in almost every record ; but at that time no significance was attached to these features.

This was the first chapter of the story. The second chapter opened a few days later, when details of the three reports were examined by Elliot. He noticed that there is a remarkable order in the times of occurrence of these occultation features. He had the longest record, and it was seen that the times of pre-occultation and post-occultation events were mirror images of each other. He then drew the logical conclusion that the large and the small features are due to numerous occulting bodies all orbiting round the planet and contained in narrow belts concentric with the planet. In other words, there is a ring system around Uranus. But unlike the case of Saturn, these rings were extremely narrow.

This announcement made others to go over their records and examine once more the data they had at their disposal ; and indeed they found the sharp occultations exactly in accordance with the ring system postulated by Elliot. Confirmations came from everybody who had a record. A group of observers from the U. P. State Observatory had obtained a record at Nainital. They confirmed four of the spikes. Other observers in Australia, South Africa, and Japan confirmed the sharp spikes in their record. The proof of existence of the narrow Uranian rings was thus established beyond any reasonable doubt. The monopoly of Saturn being the only planet with a ring system was over.

But still there remained significant differences in the two ring systems. Saturn's rings are disc like structures, very thin but having appreciable widths, whereas, the Uranian rings announced by Elliot have hardly any width at all. Such narrow structures raise doubts about their stability. Some scientists suggested a jet stream type phenomenon to explain their narrowness; otherwise such Uranian rings as proposed by Elliot appeared unstable and hence dynamically impossible.

Elliot has named these rings alpha, beta, gamma, delta and epsilon in order of their distances from the planet. The whole bunch is almost 40,000 to 50,000 km from the planet centre. Epsilon is the outermost ring and is the widest among them. Its width has been estimated as 100 km. The other four rings are not more than 10-20 km wide. The rings may have little eccentricity; some indications of the plane of ring not being in the equatorial plane of the planet are also present.

The thin ribbon like structures of the Uranian rings, however, appeared incompatible to general laws of celestial mechanics; is it possible that the thin ring structure is only a part of a larger disc type ring system similar to that around the planet Saturn? The question loomed large and some observational evidence were urgently needed to support such an acceptable picture. The irony is that indications of existence of such a structure were already available, but a clear picture still escaped the minds of astronomers. What was now called for was a systematic analysis of the records which could explain the undulations of the light curve in terms of a thin disc type ring surrounding the planet.

The evidence was the shallow dip announced by the scientists of the Indian Institute of Astrophysics in their discovery communication. Initially it was thought to be due to an extended atmosphere of the planet; but when properly corrected coordinates of the star and planet were introduced in the computer program, it was seen that the zone causing this extinction is at least five thousand kilometers from the planet's visible surface. Even in the giant planet Uranus such a vast atmosphere is difficult to comprehend; is it not more likely that a belt of particles surround the planet that would explain the dip in the light curve? Based on this hunch, our group in Bangalore undertook a program of detailed analysis of the occultation light curve. Several corrections due to atmospheric extinction, small departures from linearity of response of the detecting system etc. were employed and the final corrected curve clearly showed that not only the central dip corresponds exactly to a concentric belt of extinction materials but there are indications of several other such shallow, but wide zones encircling the planet. The positions of the five narrow ringlets earlier announced are found to lie in the outermost zone thus detected. Similar narrow structures were seen to be present in other zones as well. Kavalur records displayed nineteen additional signs besides the dips due to five rings found earlier. All these results were described in a paper and promptly published in a reputed international scientific journal.

The picture of the Uranian rings described in this paper is very similar to that of Saturnian rings: broad annuli with hardly any thickness and with clear gaps in between. Four zones were described named A, B, C & D from the outer rim of the ring system inwards. The density of materials comprising the rings is not uniform; there are variations not only from ring to ring; but inside the rings as well. The new interesting feature is the indication of dense narrow lanes of matter inside the rings, which was earlier interpreted as the peculiar ring system of Uranus. These features are not, however, completely unexpected; several observations of Saturn's rings had suggested existence of such narrow ringlets. First direct evidence of these structures in planetary rings came through this occultation event.

But there were skeptics, too. We were deluged with letters from scientists all over the world; some of them raised doubts. How are we sure that the dip was not due to a passing thin layer of clouds or slight drift in our receiving system? We really did not have any effective argument countering that. We argued that chances of such happenings exactly synchronous with the close passage of these two heavenly bodies are extremely remote. But a more effective answer dispelling these doubts was needed.

As already stated, the U. P. State Observatory at Nainital had obtained a photoelectric record of the event. In fact, the observations were recorded by using a telescope identical to that used at Kavalur; and these are the largest telescopes used in the observation of this event. A copy of this record was obtained and subjected to similar treatment. The light curve thus calculated was remarkably similar to that obtained at Kavalur. Doubts about chance passing of a thin cloud or instrumental malfunctioning could now be completely overruled. The shallow dips in the light curve can only be attributed to an extended ring around Uranus. The final results were presented at the meeting of the International Astronomical Union at

Montreal in August 1979 and have subsequently appeared in another international journal.

The Uranian ring system are thus seen to be composed of discs, similar to the rings of Saturn. As deduced from Kavalur and Nainital records, there are four broad divisions, provisionally named A, B, C & D with comparatively clear annular spaces in between. The materials comprising these rings are poor reflectors of sunlight, making the case of direct detection almost impossible. Nevertheless, some attempts were made by the scientists of the California Institute of Technology for its registration in infrared by image scanning and computer processing of the digital data, where a faint indication of a thin extended system could be seen.

After the March 10, 1977 event, there had been a few cases of occultation by Uranus, of much fainter stars. The conditions of observation in these cases were definitely poorer, but still confirmation of the densest structures e g. ring condensations could be found. No occultation of bright stars are foreseen in near future, but similar observations of faint star occultations will continue to contribute vital bits of information about the Uranian ring system.

The existence of ring structure around another planet of the solar system has meanwhile been proved. The spacecrafts Voyagers 1 & 2 have sent clear pictures of the ring system around Jupiter. The structure as expected is again similar to the Saturnian rings – broad annuli with narrow gaps, which appears as the general pattern of planetary rings. We may expect a direct confirmation of this, when Voyager 1 will approach this far away planet around January 1986, and be able to send some clear pictures of this ring system.