OCCULTATIONS: A PRECISE METHOD IN ASTRONOMICAL STUDIES

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INTRODUCTION

OCCULTATIONS are the phenomena of one celestial body covering another These occur because the nearby objects belonging to the solar system have much larger angular extents and movements than the distant stars It so happens that some of the near bodies in their orbital paths sometimes cover distant stars for short durations, such phenomena are known as occultations Occultations provide a method by which many precise astronomical measurements are possible

Occultation types are usually named after the occulting bodies. Lunar occultations are by far the most frequent because of moon's large apparent size and motion Occulted objects are usually stars, although planets, satellites, asteroids etc , are also sometimes covered by the moon Covering of the object by the leading edge of the moon is known as "immersion" while the event when the star comes out from behind the lunar disc is known as "emersion" The transitions are very rapid and their timings had provided very precise checks on the calculations of lunar ephemerides and limb structures in the past[1].

Occultation of stars by planets, their satellites or asteroids are rare, and often yields important information about their shapes, structures and atmospheres. Accuracy in these determinations are comparable to those achieved by spacecraft instrumentation during close encounters

LUNAR OCCULTATIONS

Lunar occultations provide a precise tool for many measurements in astronomy. Positions of stars can be determined with a higher order of accuracy over the standard astrometrical techniques, dimensions of stars and stellar systems can be directly determined In measurements of sources in radio wavelengths, the method virtually provided the only way of precise determination of positions and structures before the recent developments in long base line interferometry Occultation measurements in radio, optical as well as infrared wavelengths are being done in different observatories at present

a) *Optical observations*

Measurements of structural details of distant sources are severely limited by the available resolution of ground-based telescopes Angular sizes of typical bright stars are a few thousandths of an arc second, but the seeing limited discs of these objects are about one arc second in diameter From spectroscopic and photometric measurements, we know that several of these have composite structures, details of which are lost in the smudged images at the telescope focal plane But when these stars are occulted by the dark edge of the moon, a characteristic pattern of light variations are generated which depends on their structure For a very small single star the pattern closely resembles the Fresnel diffraction pattern of a point source at a straight edge For a binary star with an apparent angular separation of a few milli arc seconds, two distinct diffraction patterns can be seen in the photoelectric records during immersion or emersion events.

In general, the recorded pattern of light variations can be shown to be given by the convolution of a single point Fresnel diffraction pattern with the strip intensity distribution function across the stellar disc[2] If a clear record of light variations during an immersion or emersion event be obtained, the intensity variations across the stellar disc can be computed by a method of deconvolution The computation involves information about the lunar speed, distance, movement and occultation geometry at the moment of the event, as well as the spectral response of the filter detector combination employed which are known with high accuracies Since the occulting edge of the moon is far away from the disturbing layers of the atmosphere, major limitations due to atmospheric seeing can be completely eliminated and structures of multiple star systems or diameter of large single stars can be determined

But a different type of limitations are encountered during these measurements The straight edge assumption of the lunar limb is more often than not, violated Small limb irregularities, particularly those of dimensions comparable to the central Fresnel zone can heavily distort the recorded light curve leading to erroneous results[1] Secondly, although seeing phenomena effects are eliminated, the recorded curve is modulated due to scintillation, which introduces uncertainties in the computed stellar model[4]

Several solutions of these problems have been suggested The same event can be observed in two spectral bands, when the two records will show different responses due to limb irregularities and stellar structure Such records may be obtained from the same telescope by a simultaneous two channel photometer employing dichroic beam splitters[5]. Comparative study of these can resolve considerable part of the uncertainties The same approach will also eliminate errors due to scintillations, because the scattering and differential refraction which are mainly responsible for this type of phenomena are wavelength dependent

A better solution lies in simultaneous observations of the event from more than one telescope The parts of the lunar limb encountered by the star beam before reaching these spaced telescopes will be different, and chances of presence of identical irregularities in both beams is very small If possible, simultaneous multi-colour photometry at each telescope will be of added advantage.

For a programme of utilisation of lunar occultation events for stellar measurements, such arrangements hold bigger promises Observations are quite often vitiated by local clouding, or electrical disturbances, which are less likely to affect telescopes separated by a distance No large telescopes are needed, as most of the objects are quite bright, and smaller telescopes in different locations can play very important roles Measurements of far-reaching importance can be obtained by co-ordinated efforts of several groups, without large investments

Success of the experiments depend on design of focal plane instrumentation The immersion and emersion events last for only a few milli seconds, it is necessary to incorporate a fast recorder to capture the rapid light variations Normal laboratory recorders for this purpose are unduly expensive not only in their capital costs, but also in their running expenses A reasonably priced recording system can be rigged up from commercially available equipment One such equipment was rigged up by the Kavalur observing group in which a modified domestic tape recorder was used[6] Inexpensive recording system employing magnetic cassette tapes have been designed and fabricated[7] A still more versatile system can be built around a microprocessor with a memory bank capable of holding a few thousand milliseconds' data Photometric data can be allowed to flow through and out of the memory bank and the flow can be stopped automatically by a level detector immediately following the event Relevant portion of the data can then be off loaded to any standard device for further analysis

The photometer need only be of standard design with changeable diaphragms and filters The detector should preferably be a photomultiplier with red sensitive S-1 or extended S-20 surface This is advantageous because, most of the useful measurements pertain to cool stars, where the use of a red-filter results in distinct signal to noise improvement

For optical records, common method of analysis consists of fitting a model of the computed occultation light curve to the observed one[8] For this purpose, an idea of the expected sizes of individual stars and separation of the components of the binary or multiple system is necessary. This information is normally available from photometric and spectroscopic studies, and based on that a series of model light curves for

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(ii) when immersions or emersions happen at right edge of moon or (iii) through clouds, but none of these restrictions apply to radio occultation observations All occultations observable from a place can be recorded provided the position of the moon at the moment of occultation is within the telescope's manouverable limits

Sizes of the Fresnel zones at lunar distances are much larger in case of radio observations and consequently the undulations in the signal strengths as the Fresnel pattern sweeps past the observing telescope with the speed of the lunar limb travel are much slower This enables the recording instruments to employ longer integration times, thereby reaching fainter limits Spatial structures of many faint radio sources have been measured by this method Direct deconvolution techniques can be applied on occultation records at radio wavelengths Several improved computational methods have been developed for analysis of occultation data[10]

OCCULTATIONS BY ASTEROIDS

Occultation of stellar objects by asteroids provides the same information about the stellar structure In such events, measurements can be extended to smaller stellar diameters, because of slower light variations and fainter background An additional advantage that these occultations provide is the information which can be used for measuring the shapes and sizes of the occulting bodies Major disadvantages in these events lie in the extreme narrowness of the shadow track Most of these objects have dimensions of only a few tens of kilometers, and the shadow cast by these objects in the light of the occulted stars' beam are only that much wide So like a total solar eclipse, the observers need station themselves with mobile equipment for observations within the predicted track

But there is an important difference in these two types of expeditions. In case of total solar eclipses, the tracks are very accurately known, and chances of missing the event by wrong positioning is virtually nil In contrast, considerable uncertainties exist in the positions of the asteroids and the faint stars and the predicted tracks are often in error by a few hundred kilometers This type of uncertainty requires a different approach to the observational problem

Attempts are made by all observatories which happen to lie on the predicted occultation track, but in addition, a few mobile units are stationed to cover possible deviations Amateur astronomer groups can play very important roles in these experiments, for besides covering the unexpected deviations, simultaneous observations from close nearby locations provide vital information about the structure of the asteroids Although photoelectric observations are preferable, they are not essential, good visual timings of disappearances and reappearances of the star give accurate measurements of the sizes and shapes of the occulting bodies[11]

Individual events, however, give the projection of the asteroid in the sky plane at the moment of occultations As some of the asteroids are known to have irregular shapes which project varying outlines due to their rotation, data during a few events are necessary to have a comprehensive idea about their three-dimensional figures This calls for collaboration among astronomers of different countries, in which all predicted tracks are adequately covered and observed data exchanged Combined with photometric and spectroscopic observations these reveal many details of the asteroids' physical properties

PLANETARY OCCULTATIONS

When the occulting body happens to be a planet with an atmospheric envelope, the shapes of immersion and emersion light curves become totally different Fresnel type fringe patterns are replaced by slower variations, in which the refractive dispersion by the surrounding atmosphere plays a major role Calculations show that the rate of dimming is mainly controlled by the scale height in the atmosphere, which is a function of the temperature, gravity and mean molecular weight of the constituent gases[12] A precise measurement of the rate of light reduction thus provides a method of estimating the physical properties of the planet's atmosphere

Measurements of intensity variation during such events involving the planet Jupiter have shown that the light curve exhibits sudden increases over and above the comparatively smooth changes Comparison of several observations at different points of the planet limb indicates that these spikes appear when the star light passes through layers at fixed heights above the planet's surface The phenomena can be explained in terms of changes in the temperature gradient in Jupiter atmosphere Very consistent temperature profiles of the planet's atmosphere can be derived from these data Recent observations of occultation events concerning the planet Uranus have also indicated similar features[14]

Existence of sharp spikes in the light curve is shown for dense atmospheres only Where the atmosphere is thin, the only effect seen is the comparatively slower decline rate of the star intensity Such an effect observed from two telescopes in India and Indonesia in 1972 resulted in the detection of a thin atmosphere on Jupiter's largest satellite, Ganymede[15] At the time of a similar event a year earlier, no trace of any gaseous envelope could be detected on Io, closest of the four Galilean satellites of Jupiter[16]

Occultation of stars by the planets also provides more accurate values of the planetary diameters As the faint shadow cast by the planet's body sweeps past observers on earth, distances between the shadow edges can be very precisely determined Occultation data thereby play a vital role in up-dating astrometric measurements of planetary dimensions

APPULSES, NEAR PASSES

Even close passages, known as appulses, can provide important observational data The occultation of a star SAO 158687 on 10 March 1977 by Uranus demonstrated this possibility The occultation proper was visible only in the extreme southern hemisphere, but the close passage could be observed from a much more extended area on the earth's surface The event resulted in the discovery of a ring structure surrounding the planet[17-19]. Very faint features close to the planet body are not normally detectable in the strong glare of light reflected from the planet, but such events can reveal their presence At the time of Uranus occultation event of March 1977, systematic dimming of the star light during the planet's passage in front of the star clearly pointed to the existence of a concentric ring system encircling the planet Many details of its structure could be estimated from the photoelectric light curve, which have been confirmed from later occultation events of this particular planet[20-22].

OTHER EVENTS

Besides the phenomena described above there are many other possibilities of occultation type of events There are events in which both the bodies are members of our solar system, occultations of the planets, their satellites or asteroids by the moon are quite common Solar eclipses are nothing but occultations of the sun by the moon The satellites of the big planets regularly get occulted by the planet bodies Each and every event has its own peculiar features and uses

Phenomenon of a star occulting another is very common in binary star systems, when two stars rotating about their common centre of mass periodically occult each other by turns Depending on the orientation of their rotation axes and relative sizes and separation between the components, the occultation events become noticeable as periodic light variations, the so-called eclipsing binaries have contributed more to the store of the information about star systems than any other method in astrophysics

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