ON SOME STARS PROBABLY HAVING EXTENDED ATMOSPHERES OR GAS-DUST SHELLS, OR CIRCUMSTELLAR DISK-LIKE STRUCTURES, ACCORDING TO THE RESULTS OF HIGH-SPEED PHOTOMETRY OF THEIR LUNAR OCCULTATIONS

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When the edge of the dark part of the lunar disk covers (occults) one or another star, at the movement of the Moon relatively stars in the sky, a diffraction effects arise, and as a result one can record a diffraction curve of stellar occultation. A typical duration of passing of the first Fresnel zone over line of sight of the observer for the light source with a very small angular diameter (of the order of a few milliarcseconds (mas)) is of the order of 20 milliseconds (ms), therefore for a sufficiently detailed registration of changes of the light flux in the diffraction pattern it is necessary to record them with a time resolution of the order of 1 ms. For that one should have some modern photometric recorder which allows us to record light flux from the investigated star with the mentioned time resolution. If the diffraction curve of the lunar occultation of a star is recorded then it is possible to do it's analysis in order to distinguish it from the diffraction curve corresponding to the occultation of a point-like source, and thus to determine directly the angular size of the star under study. During more than 35 years a several tens of occultation diffraction curves of various stars have been recorded with a time resolution of 1 ms in the Observatories of Sternberg Astronomical Institute of M.V.Lomonosov Moscow State University. When processing the data obtained the angular sizes of some stars have been determined directly. Among the stars studied by the method described, the author discovered a number of objects that, in all probability, have a complex structure and include either an extended stellar atmosphere, or a gas-dust envelope, or a circumstellar disk-like structure. Some examples of such results are presented.

Keywords: Stars - Ultrafast photometry – Lunar occultations of stars – Diffraction curves – Detailed study of complex objects structure - Personal

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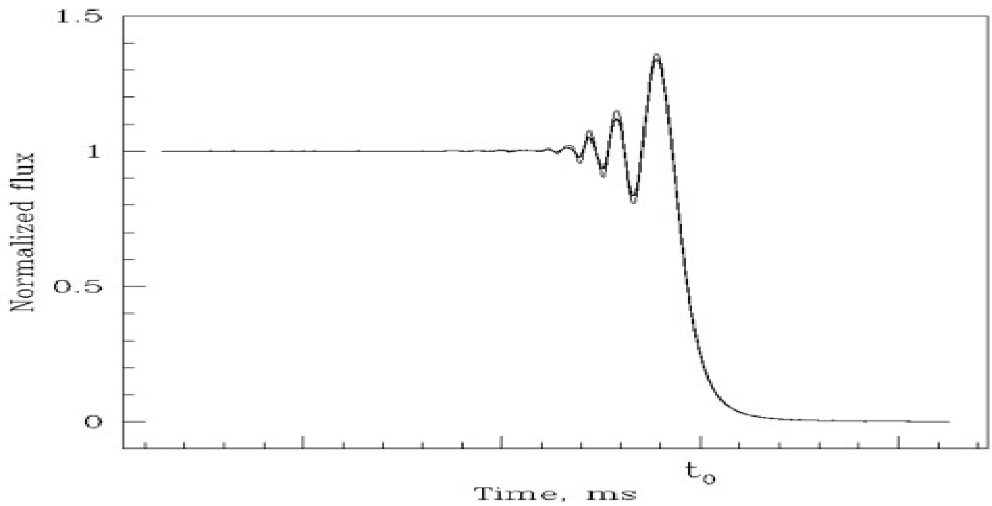
1. GENERAL PRINCIPLES

When the edge of the dark part of the lunar disk covers (occults) one or another star, at the movement of the Moon relatively stars in the sky, a diffraction effects arise, and as a result one can record a diffraction curve of stellar occultation. Of course, a model of Fresnel diffraction on the infinite rectilinear edge of the remote screen is applied. A typical duration of passing of the first Fresnel zone over line of sight of the observer for the light source having a very small angular diameter (of the order of a few milliarcseconds (mas)) is of the order of 20 milliseconds (ms), therefore for a sufficiently detailed registration of changes of the light flux in the diffraction pattern it is necessary to record them with a time resolution of the order of 1 ms. For that one should have a photoelectric photometer which allows us to record light flux from the investigated star with the mentioned time resolution. If the diffraction curve of the lunar occultation of a star is recorded then it is possible to do it's analysis in order to distinguish it from the diffraction curve corresponding to the occultation of a point-like source (having a zero angular diameter), and thus to determine directly the angular size of the star under study. In case of a close double star it is also possible to analyze the recorded occultation diffraction curve and to determine angular sizes of it, though in this case a model of the occultation process is more complex [2].

2. SOME TYPICAL ASTROPHYSICAL RESULTS OBTAINED FROM THE ANALYSIS OF THE OCCULTATION DIFFRACTION CURVES RECORDED IN THE OBSERVATORIES OF STERNBERG ASTRONOMICAL INSTITUTE

During more than 35 years in the observatories of Sternberg Astronomical Institute of M.V.Lomonosov Moscow State University several tens of occultation diffraction curves of various stars have been recorded with a time resolution of 1 ms. When processing the obtained data the angular diameters of some stars have been determined directly, and in some other cases a close binarity of the stars under study has been discovered, and the angular distances between their components and their luminosity ratios have been measured.

Further, we will focus on those cases where the results of processing of the recorded occultation curves suggest the presence of either extended atmosphere or gas-dust envelope, or a circumstellar disk-like structure around the studied star.

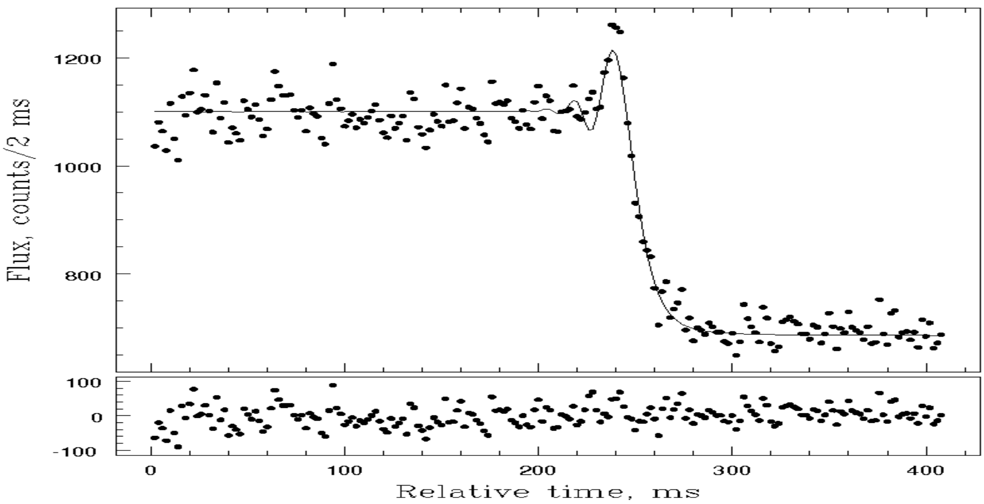


Theoretical diffraction curves for a single star.The thin line is an occultation curve for a point-like source; the thick line shows an occultation curve for a star with some small finite angular diameter (about 2 mas) . On the horizontal axis time t is given, t_o is the moment of geometric occultation of the stellar disk centre.

3. THE CARBON STAR Y TAURI

The occultation diffraction curve of the very interesting carbon star Y Tauri has been recorded by the author with a time resolution of 1 ms in the "R" spectral band of optical range on February 4, 1982, with the 48-cm telescope-reflector AZT-14 of the High-Mountain Tien-Shan' Observatory of Sternberg Astronomical Institute located near Alma-Ata (Kazakhstan). The results of this observation have been first published in the paper [1]. The figure below shows the recorded occultation curve and the optimal model diffraction curve corresponding to the determined value of the star's angular diameter.

The horizontal axis here presents the time in milliseconds relative to a certain conditional moment. Vertical axis - signal values proportional to the measured flux. Dots - photometer counts corresponding to the accumulation interval of 2 ms (obtained by adding each two consecutive counts accumulated over 1 ms); solid line - optimal model curve for the occultation of a single star. The lower part of the figure shows the deviations of the counts from the optimal model curve.



In the processing of the photoelectric occultation curve the dependences of u – the sum of the squared normalized deviations of photoelectric counts from the model curve - on the angular diameter value d, under different limb-darkening assumptions have been obtained. The following angular diameter values (in milliseconds of arc) corresponding to the minima of the function u(d) were obtained from these dependences: **d = 5.0 mas** for a uniformly illuminated stellar disk, and **d = 5.6 mas** for a fully limb-darkened disk. The error of d was estimated by the value $\sigma_d \approx$ **1.2 mas**. This estimate was obtained by constructing "quasiobserved" realizations by perturbing the resulting optimal model curve with use of the data on the observed noise in the recorded occultation area.

The analysis of the available results of direct angular diameter measurements of this carbon star in different spectral bands of the optical and near-IR spectral ranges has been carried out in the paper [3]. Currently, the author is aware of the results of seven (7) direct measurements of the angular diameter of Y Tau obtained from the analysis of photoelectric lunar occultation curves recorded from May 14, 1975 to February 20, 1994. It should be emphasized that among the known occultation observations only two were made in the optical range (in the red part) of the spectrum. All the remaining occultation observations of this star were conducted in the near-IR spectral range.

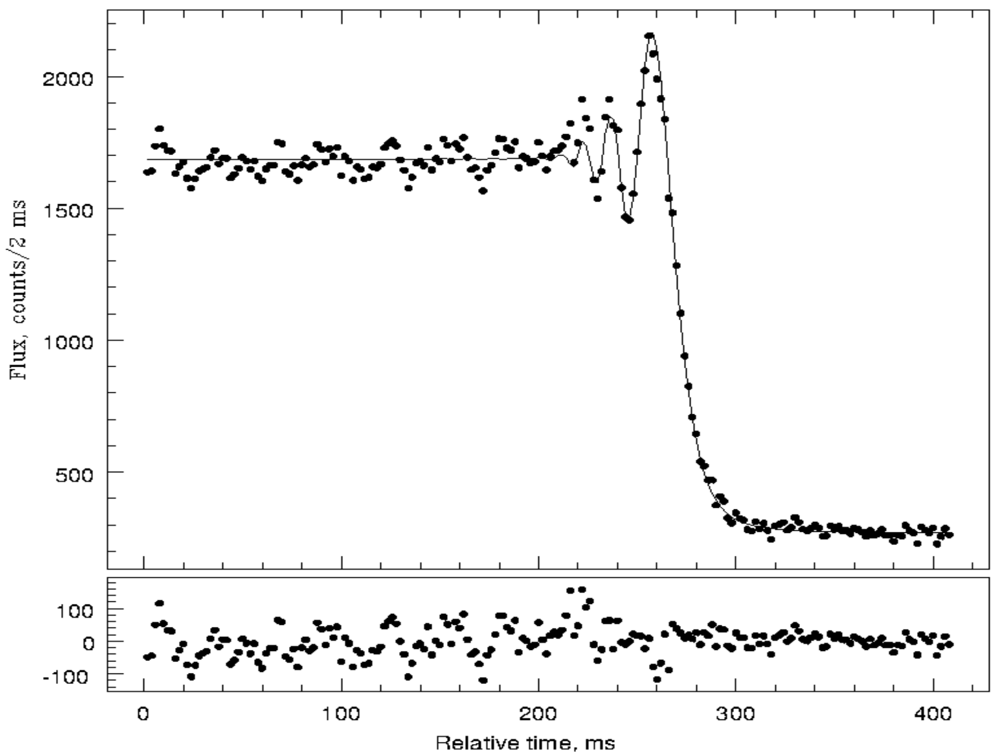
The existing picture is generally such that the values d in the near-IR range are significantly larger than the values obtained in the red region of the optical range. Therefore, a possible interpretation of the measurement results suggests that the values of the star's angular diameter d obtained from the observations in the red part of the optical spectral range correspond to the star's photosphere, whereas the values d obtained from observations in the near-IR range correspond to the optically thick radiating layers of its extended atmosphere or envelope.

4. 68 δ^3 TAURI = HR 1389

This is the case when a visual inspection of an occultation curve reveals no obvious indications of binarity, however the diffraction curve analysis disagrees with the indirect estimates of a star's angular size. Such discrepancies could be due to a previously unknown binary or multiple nature of the star, or the presence of circumstellar matter (extended envelope or atmosphere, disk-like structure, etc.) around the primary component. In the given case, the analysis of the lunar occultation curve using a single-star occultation model results in angular diameters far in excess of any reasonable indirect diameter estimates for a star of the given spectral type and corresponding luminosity, though the agreement of the model curve with the photometric data is fairly good.

In the next figure the diffraction occultation curve of 68 δ^3 Tauri = HR 1389 obtained by the author on March 2, 1982 at $14^h46^m29^s$ UT in the B band ($\lambda_0 \approx 0.44\mu m$) at the Tian-Shan' High-Altitude Observatory with the 48-cm reflector is presented. The points are light-flux measurements (photometer counts for 2 ms intervals); the solid curve is the best-fit model diffraction curve for the occultation of a single star. The horizontal axis plots the time from an arbitrary zero point (in milliseconds); the vertical axes of the upper and lower panels plot the light flux (2-ms counts) and the deviations of the counts from the best-fit model diffraction curve (2-ms counts). The star's magnitude is V= 4.29 and its spectral type is A2 IV; it is a visual triple star (ADS 3206), with the angular separation of the two brightest components, A and B, being 1.6", with a magnitude difference of $3^m.7$. The third component C is at an angular distance of 77" from the component A, and its magnitude is $\sim 11^m$. 68 δ^3 Tauri is also known as variable V776 Tau.

The occultation curve presented here corresponds to the **primary component** A; its angular diameter d was estimated using several indirect methods as 0.0006", 0.00046", or smaller. The primary A was itself long known as a spec-



troscopic binary with a period of 57.2^d; however, some spectroscopic observations obtained in the 1990s did not confirm its binary nature. Thus, information about the structure of the primary is somewhat contradictory.

From analysis of the similar manner as in the case of Y Tau where we assume fitting a best-fit diffraction curve for the occultation of a single star we have obtained the following angular diameter values for the **component** A of 68 δ^3 Tauri: **d = 0.00182"** (for a uniformly illuminated stellar disk, with the limb-darkening coefficient $\mu = 0$) or **d = 0.00204"** (for a stellar disk with full limb darkening, $\mu = 1$).

The relative rms deviation of the photometer counts from the best-fit model curve is fairly small (compared to many similar occultation light curves), approximately 3.2% (which is corresponding to a signal-to-noise ratio S/N $\sim$ 30), so the quality of the curve is fairly high, and our results are reasonably reliable. As it follows from our numerical simulations the possible uncertainty in the measured diameter d due to the influence of stochastic noise present during the observations should not be much larger than 0.001"; and for the noise level in our particular case, this is within 0.0007".

Thus, the value of d derived from our occultation observation is much larger than reasonable diameter estimates for the primary, and can be considered as a kind of effective size of the object, which possibly has a complex structure. This could mean that the primary of 68 δ^3 Tau is actually a very close binary or multiple system, especially if we take into account the indications of close binarity noted above. On the other hand, since information on the primary's binarity is somewhat contradictory, the presence of an extended envelope or some kind of a disk-like structure around the primary star is also possible. In principle, the presence of exoplanets in a hypothetical circumstellar disk is not ruled out. The angular diameter of the radiating region determined from our occultation observation corresponds to a linear size (projected on the plane of the sky) of about 0.1 AU.

5. CONCLUSIONS.

From the material presented above we can see that photoelectric observations of the lunar occultations of stars with a high time resolution allow us to reach a very high angular resolution of the order of 1 milliarcsecond, and on this basis to measure directly the angular sizes of various stars and to study in detail their structure. This, of course, gives a possibility to obtain very valuable and unique information for stellar astrophysics and physics in general.

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