Angular Sizes of the Stars σ Aqr, SAO 138638, 23 τ Sco and 91 ν Leo Obtained from the Lunar Occultation Data

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Abstract: Photoelectric observations of the lunar occultations of stars σ Aquarii, SAO 138638, 23 τ Scorpii and 91 ν Leo with a time resolution of 1 ms were obtained in 1988-1989 with 60-cm reflector of the High-Altitude Middle-Asian observatory of the Sternberg Astronomical Institute (Uzbekistan, Mt. Maidanak). Processing of the data obtained were carried out by fitting the best model diffraction curve and, in the case of σ Aqr, by applying the Tikhonov's regularization method to solve a corresponding integral equation with respect to the brightness distribution over the stellar disk. The result obtained for SAO 138638 allows to suggest a duplicity of the star but perhaps this is a consequence of considerable noise in the curve recorded. Processing of σ Aqr occultation curve yielded the value of angular size of the object observed of about 0.003 - 0.004 arc second. The result obtained gives a basis to suggest that the star is actually binary or multiple system with a low limit of angular separation between two components equal to the value pointed above and perhaps with a faint third component at the angular distance (along the perpendicular to the lunar edge) of about 0.007 arc seconds from the main one. The fitting of the best single-star model diffraction curves in the cases of the stars 91 ν Leo and 23 τ Sco shows that the point-like source diffraction curves are the best for these stars.

In 1988 the photoelectric photometer which allows to carry out an observations of rapid processes with a high time resolution was designed at Mt. Maidanak observatory of the Sternberg Astronomical Institute (Uzbekistan, longitude is $4^h27^m36^s$, latitude – 39°41'18", altitude is about 2600 m). One of the main tasks which were solved with use of this device were photoelectric observations of the lunar occultations of stars with the purpose of measuring the angular diameters of stars and revealing of close binary stellar systems.

The device was built according to the standard scheme of one-channel photometer. The multialkaline photomultiplier was used as detector of radiation. The available set of the glass light filters allows to conduct observations in standard broad spectral bands B, V, R, in ultraviolet spectral band W of the Straizys photometric system, and in integral light.

Characteristic feature of the photometer described is the use of the two-channel counter which ensures a possibility of the light flux recording with 1 ms time resolution. During every cycle of a count accumulation one of the channels detects pulses arrived, while information which has been accumulated in the other channel is being transfered into computer memory. On the next cycle the channels exchange their roles. Such technique ensures a continuous recording with a count accumulation time of 1 ms and without losses of time by information exchange. When photometric data are being entered into computer memory, the ring buffer with capacity of 10000 storage locations is used. This allows to conduct a continuous data recording with a time resolution of 1 ms during 10 seconds. Recording should be stopped manually.

Precalculations of the occultation circumstances were made with use of the computer program that has been written by O.I.Mitin. It calculates the moments of disappearances of stars beyond and their reappearances from beyond the dark edge of the Moon, position angles of the contact points on the lunar limb, velocities of these points and their normal and tangential components (under the assumption of perfectly circular profile of the limb), linear distances from the observation point to the lunar edge, and other necessary parameters.

The position and motion of the Moon are determined by the polynomials of DE200/LE200 numerical theory. The Moon is assumed to be a sphere having 1737.3 km in diameter. We used the SAO Catalogue as a source of information on the stars occulted, which contains nearly all stars brighter than approximately 9^m. In calculating we didn't take into account the irregularities of the real lunar limb profile. The occultation moments are calculated according to the Bessel method. But in the grazing or near grazing cases, when the Bessel method does not operate, the time of the closest approach of the lunar limb to the star and the angular distance between them are computed.

An accuracy of our precomputations accounts for in most cases about 2-5 sec in time, with the exception of the cases when we deal with catalogue errors or near-grazing occultations; in those cases the deviations of the occultation moments recorded from precomputed ones could reach 20-30 seconds and more. This program has permitted to carry out a number of successful occultation observations.

Photoelectric observations of lunar occultations of the stars which are a subject of this paper, were carried out in 1988-1989 with 60-cm reflector of Mt.Maidanak observatory with use of the equipment described above. Unfortunately recording of the times of occultations with high accuracy of the order of 1 ms were not carried out because of technical reasons. During observations the diaphragm with angular diameter of about 12 arcsec in the cassegrain focus of the telescope was used.

Computer processing of the data obtained were conducted by fitting the best model diffraction curve in the framework of a single-star occultation model and, besides, in the case of Sigma Aqr, by applying the procedure of Tikhonov's regularization method in order to find a solution of the Fredholm integral equation with respect to the strip brightness distribution across the object occulted. Algorithms of the data processing which were employed are described in the papers [3,4]. In the processing we took into account an effect of a nonlinearity of photoelectric apparatus which is being usually presented when the level of the light flux recorded is sufficiently high; this factor could be specified by the dead time constant. With this purpose we corrected the values of the signal observed and processed the resulting realizations.

Occultation of the subgiant star Sigma Aquarii, which has a magnitude V = 4.82 and spectral class A0IVs [2], was observed in the spectral band "V" on November 17, 1988 at $16^h29^m03^s$ UT. The occultation point's position angle on the lunar limb was P=142°. The star is known as spectroscopic binary [2] but the detailed information concerning variability of radial velocities is absent in the Catalogue [2], as well as some data on this star are absent in the Catalogue [1]. This leads to suggestion that amplitude of such variability is small, and complete radial velocity curve was not obtained.

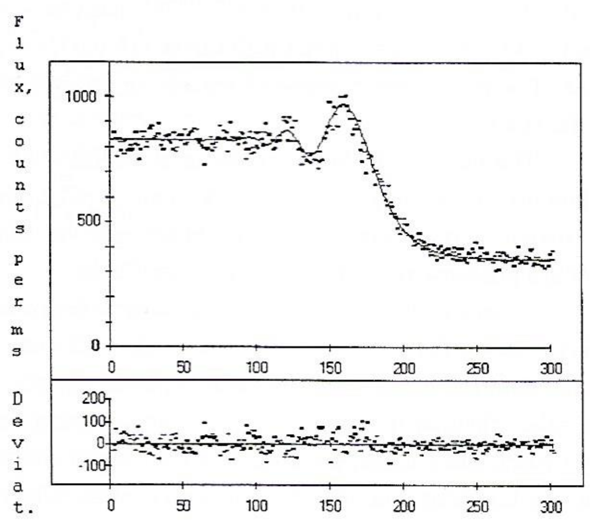

Figure 1.
Photoelectric occultation curve for σ Aqr observed on 17 Nov 1988 in the "V" band, and the best model diffraction curve which results from data processing. Here and in the other similar figures deviations of data recorded from the best model curve are presented in their lower parts.

Photoelectric occultation curve of Sigma Aqr consisting of 300 readings that corresponded to an accumulation time of 1 ms, and the best model diffraction curve for occultation of a single star having a uni-

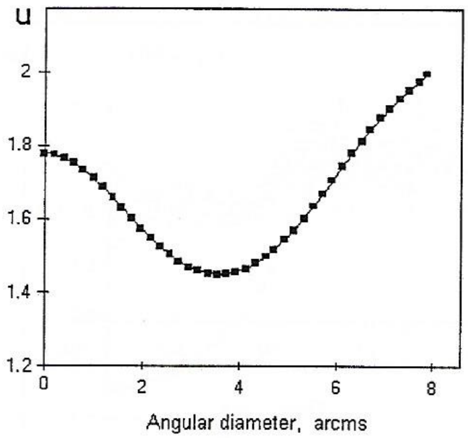

Figure 2.
Dependence $u(d)$ for σ Aqr's occultation curve which was obtained in data processing.

formly bright disk with the angular diameter d=0.0036 arcsec, are presented in Fig.1. In processing of observational data by fitting the best model diffraction curve we obtained a function $u(d)$ which represents a dependence of the sum of deviations squared of data recorded from the best model curve u on the given values of angular diameter d. This dependence for σ Aqr' occultation curve is presented in Fig.2. We can see a pronounced minimum of the function $u(d)$ near the value d=0".0036. Corresponding value of occultation velocity along a perpendicular to the real lunar edge derived in the processing is V_x=303 m/s, and the relative rms deviation of the readings from the optimal model curve (in percentage of the amount of signal falloff during occultation) is about 7%.

According to our precalculations, occultation of σ Aqr should be near grazing, i.e. the star should pass beyond the disk of the Moon at the angular distance 6,8 arcsec from the dark lunar edge. The position angle of the radius-vector of the lunar limb which intersects the line of star's relative motion in its middle point at right angles, was about 142 deg; the total predicted velocity of the lunar limb motion in the direction perpendicular to this radius-vector was equal to $V = 821$ m/s. On the basis of these data we can derive the value of the predicted occultation velocity as a projection of a total velocity on the direction of radius-vector which joins the lunar disk centre to the point of the first contact. That predicted value $V_p = 102$ m/s was used for determining the local slope of the lunar edge (+14°) and in data processing.

We have also restored the strip brightness distribution b(x) across the object occulted from the observational data by applying the procedure of Tikhonov's regularization method in order to find a solution of the Fredholm integral equation [4]. When regularization parameter is in accord with the accuracy of the initial data, the total width of a central maximum is about 4.8 arcms, and its width at the level of 0.5 of maximum is about 3 arcms. This result is in a good accord with the one derived when we used the method of the best model fitting. Next, the strip brightness distribution shows a secondary peak at the angular separation of 0".007 ± 0".0005 from the main one.

As one can see, the value d obtained exceeds the reasonable indirect estimate of angular diameter of the star with a given spectral class and luminosity class by several times. Really, with the values of trigonometric parallax of σ Aqr 0".021 [2] and of linear radius for the star of spectral class A0 IV (R = 4 solar radii) we obtain δ = 0".0008 .

The results presented could mean that the star Sigma Aqr is actually a close binary or multiple system. It is possible also that we deal with extended shell or disk-like structure around the star. The angular size of emitting region which has been measured corresponds to the linear dimension of about 37 solar radii. As we can judge by available literature sources, there were no any other measurements of the angular size of Sigma Aqr by lunar occultation observations.

Occultation of SAO 138638 was observed on 22 Jun 1988, at $15^h45^m01^s$ UT. It has visual magnitude 6.9^m and spectral class F5. Observation was carried out in spectral band "V". Photoelectric occultation curve of SAO 138638 is presented in Fig.3. One can see that this record unfortunately was burdened with considerable noise. The data processing by the best model fitting shows that the u value decreases while star's angular diameter increasing up to rather considerable values. Therefore we have improbable great value of the star's angular diameter. Formally this allows to suggest a duplicity of the star with relatively great separation between its components. But most likely such the result could be a consequence of the noise influence. Thus this occultation curve probably can be considered as the marginal case of application of model fitting method.

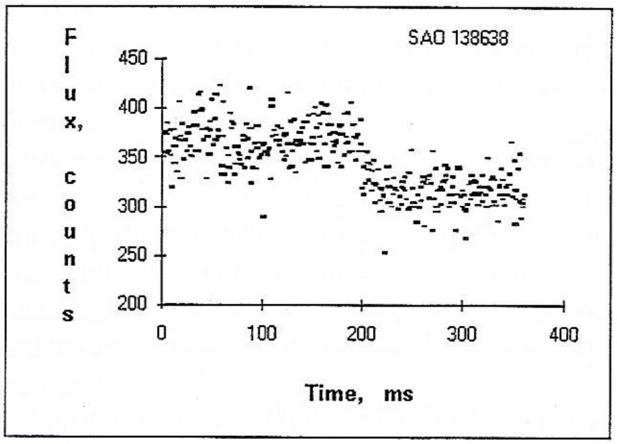

Figure 3.
Photoelectric occultation curve for SAO 138638 observed on 22 Jun 1988 in the "V" band.

Occultation of the star 23 Tau Sco (= HR 6165 = HD 149438 = SAO 184481) having visual magnitude 2.9^m, spectral class B0 V, trigonometric parallax 0.02 arcsec [2] was observed in the spectral band "R" on 11 Aug 1989. Occultation point's position angle on the lunar limb was 152^o. Photoelectric occultation curve recorded and the best model diffraction curve for a point-like source are shown in Fig.4. Corresponding *u(d)* function is shown in Fig.5. We can see the pronounced minimum of the *u(d)* function at d=0. The point-like source suggestion rusults naturally from this picture. Indirect estimate of the angular diameter of the star gives the value of about 1.4 milliarcsec. We suggest that the real diameter of the star could be less than estimated one since the possible error of measured value is probably not too much exceeds 1 marcsec.

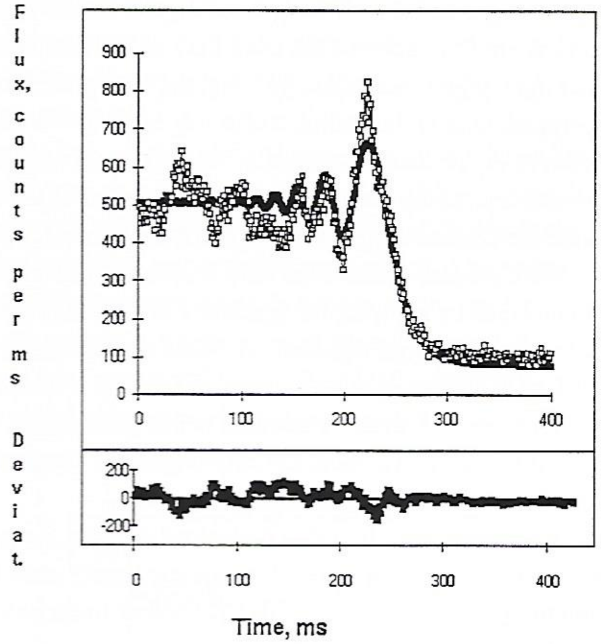

Figure 4.
Photoelectric occultation curve for 23 Tau Sco observed on 11 Aug 1989 in the "R" band, and the best model diffraction curve which results from data processing.

Occultation of the star 91 v Leo = HR 4471 = SAO 138298 = HD 100920, which has a magnitude V = 4.30 and spectral class G8.5 III CN 0.5 [2], was observed in the spectral band "R" on June 11, 1989 at 15^{h}58^{m}11^s UT. This star is the infrared source IRC 00209. The occultation point's position angle on the lunar limb was P=139^o. The star is known as occultation binary, with angular separation between components of 0.1 arcsec and magnitude difference 4.5^m [2]. The angular diameter of the star was determined from the lunar occultation observations and found to be 2.1 arcms (observation on 30 Apr 1977, uniformly illuminated stellar disk assumed) and 2.9 arcms (the same event, but the other observatory, fully limb-darkened stellar disk assumed) [5]. Photoelectric occultation curve of 91 v Leo consisting of 400 readings that corresponded to an accumulation time of 1 ms and the best model diffraction curve for occultation of a single point-like star is shown in Fig.6 . In processing of observational data by fitting the best model diffraction curve we obtained a function *u(d)* which we can see in Fig. 7. We can see the minimum of the function *u(d)* near the zero value of *d* . Therefore the model of point-like source is the best for this occultation curve. On the basis of the result obtained we can assert that the real angular diameter of the star could not be more than the probable error of determination (which accounts for, as it

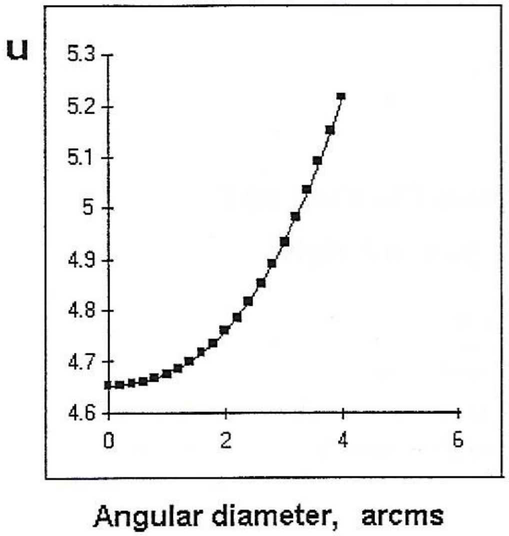

Figure 5.
Dependence *u(d)* for 23 Tau Sco's occultation curve which was obtained in data processing.

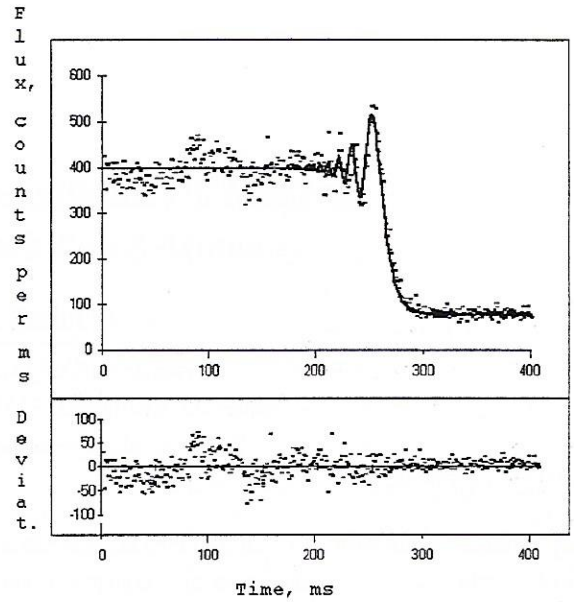

Figure 6.
Photoelectric occultation curve for 91 Leo observed on 11 Aug 1989 in the "R" band, and the best model diffraction curve which results from data processing.

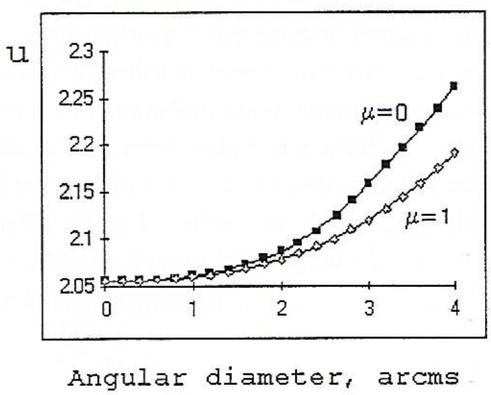

Figure 7.
Dependence *u(d)* for 91 Leo's occultation curve which was obtained in data processing.

follows from our experience, a quantity of the order of 1 arcmillisec). Such discordance of results may appear to be very interesting in connection with the other observational data. May be the orbital motion of binary system components can explain the available set of results.

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