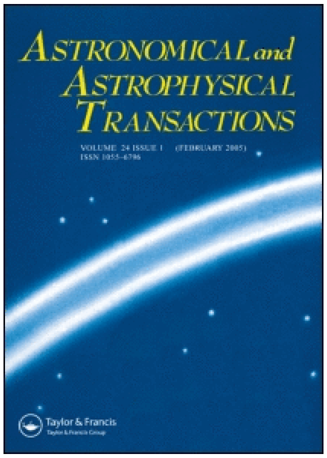

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

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Online Publication Date: 01 July 1992
To cite this Article: Goranskij, V. P., Kusakin, A. V., Mironov, A. V., Moshkaljov, V. G. and Pastukhova, E. N. (1992) 'New bright eclipsing binary in messier 67', Astronomical & Astrophysical Transactions, 2:3, 201 - 208
To link to this article: DOI: 10.1080/10556799208205340
URL: http://dx.doi.org/10.1080/10556799208205340

Astronomical and Astrophysical Transactions, 1992,
Vol. 2, pp. 201–208
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NEW BRIGHT ECLIPSING BINARY IN MESSIER 67

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(Received August 7, 1991; in final form September 26, 1991)

The bright blue straggler NSV 4276 in the old open cluster M67 was found to be an eclipsing binary with an orbital period of $1^{d}.0678$. Five primary and one secondary eclipses were detected. The amplitude of variability is $0^{m}.12$ both in B and V. The primary eclipse depth is $0^{m}.07$. The effect of ellipsoidality of the bright companion is seen. It is supposed that this star overflows its Roche lobe on the way to red giants, and that the system is a semidetached binary.

KEY WORDS Eclipsing binaries, periods, orbital variability

1. INTRODUCTION

The microvariability of NSV 4276, a blue straggler in the old open cluster M67, was first reported by Danziger and Dickens (1967); the dispersion of measurements was $0^{m}.007$ during 81 minute monitoring. Earlier a photoelectric search for light variability in a dozen so-called "horizontal-branch stars" in M67 had been carried out by Sears (1965), NSV 4276 being one of them. No variations more than $0^{m}.1$ were found, but the observations were not sufficient to exclude all possible periods. Later, Chiu (1970) reported his discovery of four variables in a sample of nine horizintal branch stars with amplitudes of $0^{m}.02$–$0^{m}.03$, and periods of the order of several hours. No specific star names were given.

Two of us (Mironov and Pastukhova, 1980) observed three of these horizontal-branch stars in December 1979 and confirmed small-amplitude variability of NSV 4276. But in a new set of observations in February 1981 they discovered a small-amplitude eclipse-like event in NSV 4276. During the following nine years we searched for light minima to determine the possible orbital period. We now have five primary and one secondary minima, which may make it possible.

NSV 4276 is also known as F131 (Fagerholm, 1906), vM160 (van Maanen, 1942), RGO417 (Murray *et al.*, 1965), and S1082 (Sanders, 1986). One can find the identification charts of the star in the two last cited papers, and in the paper by Racine (1971). Its accurate co-ordinats concerning to Epoch of 1950.0 are the following: $8^{h}48^{m}36^{s}.6214$, $+12°04'43''.239$, Equinox 1950.0 (Girard *et al.*, 1989). $V = 11^{m}.25$, $B - V = 0^{m}.40$, $U - B = 0^{m}.05$, Sp. F0 – F4IV (Eggen, Sandage, 1964; Eggen, 1981). The star is a proper-motion member of the cluster. The radial velocity $V_r = +14 \pm 3.2\,\mathrm{km \cdot s^{-1}}$ measured by Pesch (1967) made cluster membership doubtful. The calibration in the colours of Stroemgren uvby-photometry was another argument against membership (Eggen, 1981). But numerous modern CORAVEL observations by Mathieu *et al.* (1986) give a mean value of $V_r = 33.5 \pm 2.0\,\mathrm{km \cdot s^{-1}}$, supporting membership. Girard *et al.* (1989) give 99 per cent membership probability based both on proper motion and radial velocity. Moreover, the usually high scattering of V_r in the range of 30.3 and 37.7 $\mathrm{km \cdot s^{-1}}$ suggests that the star is a binary, which may be a cause of difficulties in photometric calibration. The orbital solution nevertheless is not yet found, and no evidence of the secondary companion is found in the spectrum.

2. OBSERVATIONS

The observations were carried out with five different pulse-counting photoelectric photometers in the B and V photometric bands. Two 60–cm Zeiss reflectors of the Sternberg Institute Crimean observatory and the 48-cm reflector of the Tian-Shan High-Altitude observatory were used. The comparison star BD +12°1918 and check star BD +12°1920 were chosen to measure the variable. The magnitudes of these and two other stars in the field of M67 in the WBVR system are given in Table 1. W is a revised ultraviolet photometric band described by Straižys (1967) ($\lambda_0 = 3500$ Å, FWHM = 500 Å). The observations are given in Table 3.

The diversity of devices used in our study and the large difference in colours between the variable and comparison stars prevents us from reducing the observations in a common photometric system accurately. So the light curve level varies by more than $0^m.05$ B and $0^m.04$ V. A clear systematic difference is seen between Crimean and Tian-Shan observations. The appearance of a neighbouring faint cluster star in the photometer diaphragms may be another cause of these variations. But the question whether the components of the system have intrinsic variability remains open. The Tian-Shan observations were made in the better high-altitude sky conditions, so they have higher accuracy than the Crimean ones.

The observations show the depths of primary eclipses to be of $0^m.07$ and the duration of the partial eclipse of approximately $3^h.6$. The exterior contacts of the eclipse are well seen in the light curve, so the star can be referred to classical Algol-type systems.

Table 1

	W	*B*	*V*	*R*	
BD + 12° 1918	10.831	10.095	8.998	8.118	comparison
BD + 12 1919	—	10.427	8.920	—	
BD + 12 1920	11.729	11.044	10.009	9.089	check
BD + 12 1927	9.741	8.927	7.840	6.995	
NSV 4276 max	11.57	11.56	11.16	10.82	variable
min I	—	11.68	11.28	—	
min II	—	—	11.24	—	

3. EPHEMERIS AND LIGHT CURVE

The period search was made with an EC-1045 computer using the well-known Lafler-Kinman method. The period of $0^{d}.5338989$ was the best found in the interval of periods tested between $0^{d}.4$ and 20 days. Analysis of the light curve shows that this value is a half of the real orbital period. The light curve shown in Figure 1 is computed with the next light elements:

$$\text{Min I hel} = 2444643.253 + 1^{d}.0677978 \cdot E.$$
$$\pm 5 \qquad \pm 50$$

The light curve with the given period and two minima is preferable because the two alternate minima have non-equal depth and different shape. The depth of the secondary minimum is twice less than the primary one, and its first contact displays badly.

The orbital period found on the basis of photoelectric photometry nevertheless disagrees with 26 radial velocities given by Mathieu *et al.* (1986). Any regular pattern or wave is not seen in the radial velocity curve, so we do not reproduce it here. We tried to search the radial velocities for periodicity with the same Lafler-Kinman method but without any satisfactory result. On the contrary, some periods fitting the radial velocity data disagree with photometry. This is a strange result in that the spectra of this bright star obtained by Mathieu *et al.* have a considerable signal-to-noise ratio, and that the velocities are based on high-quality correlation functions. The precision of individual values ranges from 0.3 to 0.8 $km \cdot s^{-1}$, so both photometric and radial velocity data should be verified.

Six moments of minima are given in Table 2.

The total range of the light variations in NSV 4276 are found to be $11^{m}.56$–$11^{m}.68$ in B, and $11^{m}.16$–$11^{m}.28$ in V. V magnitude in the secondary minimum is 11.24.

The duration of the primary minimum is $0^{P}.14$. It is clear that a small and faint companion passes in front of large and bright subgiant at the primary eclipse. The difference in the depths of primary and secondary eclipse suggests that the surface temperatures are slightly different. However, the flat bottom is not seen, which rejects both annular and total eclipses, but supports the partial eclipse hypothesis.

The out-of-eclipse light variations by $0^{m}.03$ V correlating with the phase of the

Table 2 The mid-eclipse moments of NSV 4276

Min_{hel} 244 · · ·	*Min*	*Observer*	*Device*
4643.253	I	Mironov, Pastukhova	1)
5325.586	I	Goranskij	2)
6773.482	I	Goranskij	3)
7861.609	I	Goranskij	2)
7920.336	I	Kusakin	4)
7944.335	II	Kusakin	5)

1) Tian-Shan one-channel WBVR photometer constructed by Kh.F. Khaliullin and S. B. Novikov in 1975;
2) Crimean one-channel UBV photometer constructed by V. M. Lyuti;
3) Crimean one-channel WBVR photometer;
4) Tian-Shan one-channel UBV photometer constructed by A. V. Kusakin;
5) Tian-Shan one-channel WBVR photometer constructed by V. G. Kornilov and A. V. Krylov.

Table 3

$JD_{\odot}$ 244 ···	B	V	n	$JD_{\odot}$ 244 ···	B	V	n
			Tian-Shan BV observations				
4223.3659	11.564	11.162	11	5767.2453	11.601		2
.3887	11.557	11.157	10	7913.276		11.199	5
.4110	11.562	11.161	10	.284		11.172	5
.4826	11.577	11.174	9	.301		11.199	5
4641.2315	11.597		11	7914.3730		11.229	
.2739	11.589		11	.3862		11.200	
.3093	11.577		12	.4009		11.205	
.3509	11.579		10	7915.2715		11.151	
.3870	11.575		10	.2871		11.184	
.4266	11.585		11	7916.256		11.181	4
4643.2016	11.630	11.238	e	.267		11.189	6
.2100	11.635	11.252		.281		11.174	3
.2190	11.648	11.257		.290		11.176	6
.2294	11.664	11.268		.300		11.179	5
.2370	11.669	11.276		.310		11.183	7
.2440	11.680	11.277		.321		11.184	5
.2509	11.672	11.282		.335		11.185	3
.2579	11.673	11.280		.345		11.204	6
.2655	11.670	11.275		.355		11.202	5
.2725	11.665	11.273		.380		11.202	6
.2794	11.657	11.267		.396		11.197	7
.2870	11.649	11.252		.419		11.213	9
.2947	11.644	11.249		7920.226		11.199	4 e
.3023	11.631	11.239		.237		11.189	6
.3093	11.619	11.236		.245		11.173	7
.3162	11.612	11.226		.268		11.206	8
.3239	11.609	11.219		.288		11.212	6
.3301	11.602	11.206		.299		11.236	4
.3373	11.606	11.210		.308		11.249	7
.3440	11.604	11.209		.319		11.259	8
.3511	11.602	11.201		.331		11.257	7
.3586	11.599	11.197		.336		11.255	6
.3662	11.600	11.206		.350		11.244	9
.3732	11.601	11.206		.364		11.241	8
.3808	11.603	11.202		.370		11.235	7
.3877	11.605	11.210		.385		11.220	6
.3954	11.600	11.204		.391		11.207	7
.4023	11.602	11.212		.403		11.200	6
.4107	11.597	11.207		.410		11.203	7
.4183	11.603	11.208		.421		11.202	6
.4259	11.596	11.210		7921.214		11.169	4
.4336	11.597	11.202		7922.226		11.169	7
.4412	11.591	11.198		.242		11.161	5
.4483	11.593	11.202		.252		11.162	5
.4565	11.600	11.201		.257		11.153	6
.4641	11.592	11.197		.266		11.160	8
4644.1120	11.575	11.193	3	7937.139		11.171	8
.1374	11.575	11.180	2	.150		11.163	6
4759.2151		11.209	3	.176		11.151	3
.2967		11.189	2	7942.3423		11.182	
4767.2453		11.227	2	7944.1330		11.192	6 e
5372.1996	11.602		3	.1416		11.190	7
.2502	11.600		2	.1521		11.192	16
.2837	11.606		2	.1641		11.190	9
5759.2151	11.604		3	.1745		11.189	15
.2967	11.592		2	.1868		11.193	14

Table 3—*contd.*

$JD_{\odot}$ 244 ···	B	V	n	$JD_{\odot}$ 244 ···	B	V	n
7944.1987		11.198	7 e	7953.3133		11.201	18
.2049		11.197	8	.3309		11.204	16
.2132		11.197	14	.3435		11.204	16
.2256		11.200	15	.3558		11.202	16
.2412		11.203	21	.3687		11.217	15
.2568		11.214	21	.3789		11.224	7
.2723		11.217	22	7979.1521		11.206	14
.2876		11.230	14	.1648		11.204	16
.2962		11.232	14	.1772		11.195	21
.3071		11.238	9	.1927		11.198	16
.3115		11.246	9	.2088		11.193	16
.3247		11.243	13	.2212		11.197	15
.3352		11.238	12	.2359		11.191	16
.3475		11.238	12	.2498		11.190	12
.3618		11.235	11	.2649		11.191	16
.3719		11.228	12	.2791		11.166	16
.3816		11.230	12	.2933		11.187	16
7953.2036		11.174	11	.3062		11.186	9
.2158		11.177	19	7984.1233		11.183	6
.2305		11.182	19	.1343		11.183	17
.2446		11.186	21	.1492		11.182	18
.2607		11.190	23	.1607		11.187	10
.2744		11.186	11	.1719		11.192	11
.2810		11.194	12	.1870		11.196	15
.2972		11.195	22	.1992		11.203	11
			Crimean BV observations				
4670.2519	11.561	11.186	5	5758.45	11.576	11.202	
4672.2816	11.561	11.194	2	5761.42	11.558	11.190	
4673.3302	11.551	11.189	2	.446	11.573:	11.176	
4695.2809	11.523	11.163	2	.451	11.563:	11.174	
.3246	11.518	11.168	2	5765.36		11.187	
4705.2948	11.581	11.214	3	6091.3890	11.554	11.185	3
.3225	11.591	11.190	3	.4076	11.556	11.185	3
5321.5218	11.523	11.170	5	.4361	11.553	11.178	3
.5464	11.519	11.175	4	.4623	11.557	11.182	3
5325.5511	11.594	11.247	e	.4819	11.561	11.186	3
.5595	11.619	11.263		.5067	11.561	11.181	3
.5643	11.640	11.275		.5289	11.567	11.189	3
.5720	11.628	11.264		.5454	11.567	11.184	2
.5796	11.642	11.269		6761.5407	11.544	11.168	3
.5865	11.632	11.273		.5641	11.549	11.176	3
.5935	11.640	11.265		.5857	11.535	11.166	3
.6011	11.627	11.245		.6106	11.556	11.183	3
.6088	11.627	11.241		.6349	11.568	11.194	3
.6157	11.601	11.248		6771.5613		11.210	
.6247	11.581	11.216		6772.5176	11.591		
5695.4826	11.543:	11.187:	2	.6023	11.576		
5699.4584	11.539	11.175	3	6773.4279	11.594	11.198	e
.5206	11.537	11.170:	3	.4385	11.594	11.187	
.5819	11.532	11.174	2	.4470	11.599	11.212	
5702.4601	11.60:	11.22:		.4538	11.598	11.228	
5703.4810	11.553	11.186	3	.4784	11.633	11.247	
5712.5129	11.551	11.179:	3	.4970	11.611	11.233	
5757.4020	11.576	11.212	2	.5060	11.619	11.239	
.4430	11.573	11.222	2	.5142	11.595	11.228	
.4570	11.587	11.218	2	.5204	11.610	11.229	

Table 3—*contd.*

$JD_{\odot}$ 244 ···	*B*	*V*	*n*	$JD_{\odot}$ 244 ···	*B*	*V*	*n*
6773.5269	11.605	11.237		7861.5097	11.570	11.171	e
.5352	11.605			.5155	11.570	11.169	
.5411	11.596	11.215		.5274	11.568	11.177	
.5488	11.587	11.220		.5351	11.582	11.179	
.5548	11.564	11.201		.5415	11.597	11.191	
.5628	11.560	11.203		.5521	11.581	11.185	
.5686	11.559	11.209		.5584	11.608	11.214	
.5769	11.552	11.178		.5704	11.624	11.206	
.5861	11.580	11.202		.5802	11.638	11.236	
.5946	11.575	11.198		.5871	11.626	11.224	
.6011	11.566	11.211		.5973	11.647	11.235	
.6102	11.575	11.195		.6037	11.644	11.245	
.6167	11.554	11.191		.6100	11.650	11.241	
.6260	11.559	11.207		.6160	11.645	11.247	
.6363	11.569	11.211		.6264	11.634	11.232	
.6409	11.555	11.198		.6319	11.625	11.221	
.6475	11.553	11.185		.6372	11.605	11.216	
.6547	11.571	11.197		.6430	11.604	11.207	
7861.5039	11.576	11.169	e				

n—number of individual measurements averaged. Single observations are given without number.
e—the nights when the eclipse was detected.

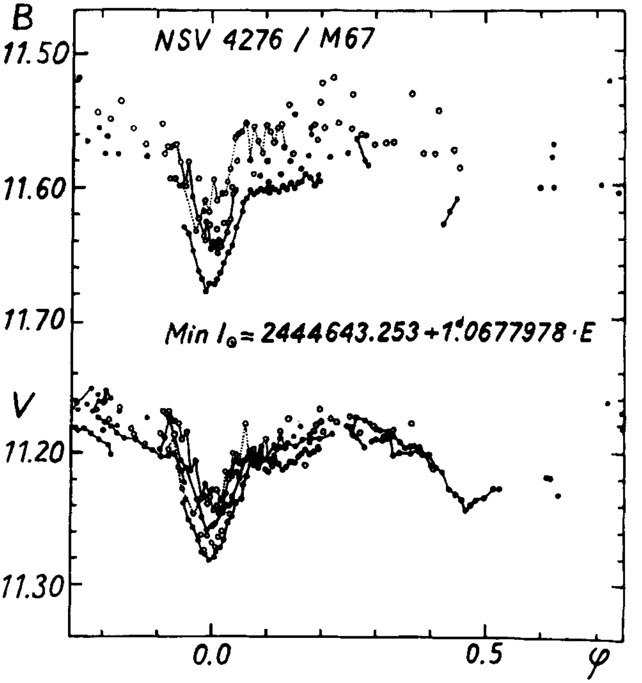

Figure 1 B and V light curves of NSV 4276. Tian-Shan observations are shown with black points, Crimean ones with open circles. The first discovered eclipse is seen on the lower level in both bands.

orbital period are clearly seen in the Figure 1. This may be an effect of the ellipsoidal shape of the bright F4 subgiant. Our observations do not cover all the phases of the orbital period; there is a gap in the light curve in the phases from $0^{P}.53$ to $0^{P}.74$. But one can see that the star brightness in the secondary maximum at the phase of $0^{P}.75$ is systematically higher than in the primary one at the phase of $0^{P}.25$ by $0^{m}.01$–$0^{m}.02$ V, and that the out-of-eclipse variations are non-symmetric relative to zero phase. The phenomenon, if it really exists, may be a result of the accretion from the bright star and of the hot spot on the surface of the faint star.

4. ON THE EVOLUTIONARY PHASE OF NSV 4276

Kholopov (1965) supposed in his photometric and proper motion study of bright stars in M67 that some of them form a horizontal branch resembling that of a globular cluster or Galactic halo stars. These stars distributed over the CMD region between $10^{m}.0$ and $11^{m}.6$V blueward of $B-V=1^{m}.0$ have absolute magnitudes typical to globular cluster HB stars (see Figure 2). The three reddest horizontal branch stars in M67 were found to be spectroscopic binaries by Mathieu *et al.* (1990). These stars are plotted in Figure 2 with open squares. The CMD in Figure 2 is built up using data by Eggen and Sandage (1964) and Racine (1971). NSV 4276 and other eclipsing binary in M67 AH Cnc are plotted with crosses.

Remember, AH Cnc (S 1282) is a contact W UMa type binary with an orbital period of $0^{d}.3604364$ (Whelan *et al.*, 1979).

The discovery of spectroscopic binaries and NSV 4276, a new eclipsing binary in the horizontal branch, makes the interpretation of bright stars in M67 as a horizontal branch typical to that of globular clusters questionable. Only metal-poor globular clusters are known to have horizontal branches distributed from blue to red. But M67 with normal metal abundance may be suspected to have a very red one. It seems that a clump of six red stars at $\langle V\rangle = 10^{m}.55$ and $\langle B-V\rangle = 1^{m}.11$ may be a real horizontal branch in M67.

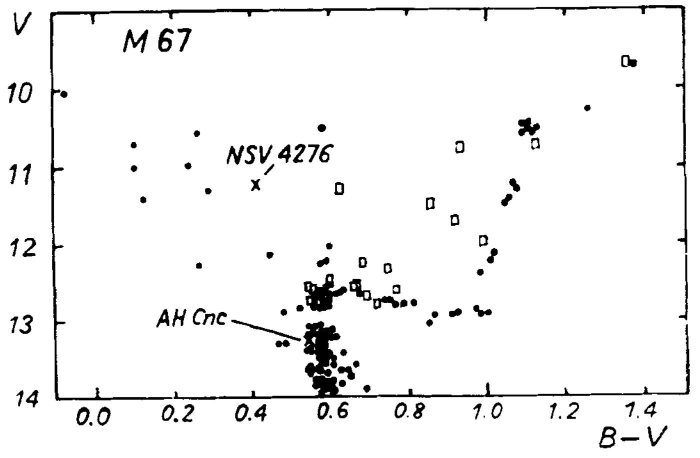

Figure 2 The location of NSV 4276 and other binaries in the colour—magnitude diagram of M67.

Another interpretation of bright stars in M67 as stragglers was given by Eggen (1981). These are main sequence stars delayed in evolution of CMD, supposed to be totally mixed stars after helium flash or binaries overflowing their Roche lobes. In the globular clusters both the binaries and the single pulsating SX Phe type stars are located above the main sequence turn-off point.

It is now clear that the unusual location of NSV 4276 out of the principal CMD sequences is caused by the F4 subgiant overflowing its Roche lobe on the way to the red giant phase. So the system may be expected to be a semidetached binary. The secondary component may be an ordinary main sequence star.

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Note added in proof:

G. Mathys has discovered a hot and rapidly rotating companion in this binary system with the spectrosopic method (*AsAp* **245,** No. 2, 467, 1991). M. Simoda detected variability of F131 again (IBVS No. 3675, 1991). One can see two more eclipses in his figure 3.