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UBV Photometry of the Post-AGB Star IRAS 22272+5435=V354 Lac in 1990–2008

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Abstract

New UBV photometry obtained in 2000–2008 is presented for the post-AGB star IRAS 22272+5435 = V354 Lac. The star showed semi-regular light variations with varying amplitudes. The maximal amplitude did not exceed: $\Delta V = 0\overset{\mathrm{m}}{.}5$, $\Delta B = 0\overset{\mathrm{m}}{.}7$, and $\Delta U = 1\overset{\mathrm{m}}{.}0$. For 2000–2008, we have found a photometric period near 128 days. The analysis of long-term observations in 1990–2008 reveals variations with two close periods: 128 and 131 days, causing amplitude modulation. The $V-(B-V)$ diagram shows a clear correlation: the star is generally bluer when brighter. From our UBV data, we derive $E(B-V) = 0.5$ and conclude that the spectral type of the star varies between K1 and K7 during pulsations. The mean UBV data for V354 Lac have not changed during the past 19 years: $\overline{V} = 8\overset{\mathrm{m}}{.}60$, $\overline{(B-V)} = 2\overset{\mathrm{m}}{.}06$, and $\overline{(U-B)} = 2\overset{\mathrm{m}}{.}14$.

1 INTRODUCTION

The IR source IRAS 22272+5435 is identified with the bright star BD+54°2787 = HD 235858 ($22^{\mathrm{h}}29^{\mathrm{m}}10\overset{\mathrm{s}}{.}4$ $+54°51'06''$, 2000). It is one of the most reliable protoplanetary nebula candidates.

The spectral energy distribution of IRAS 22272+5435 shows a characteristic double peak, with about the same amounts of energy emitted in the visible plus near-infrared (from the reddened photosphere) and in the mid-infrared (re-emission from circumstellar dust) (Hrivnak and Kwok 1991).

The chemical composition of IRAS 22272+5435 is typical of carbon post-AGB stars. Začs, Klochkova, and Panchuk (1995) found the star to be iron poor: [Fe/H]= −0.49. The elements of the α-process are overabundant relative to the solar composition, and the carbon abundance is C/O≈12. In the spectra of IRAS 22272+5435, strong molecular bands of C_3 and C_2 are found (Hrivnak and Kwok 1991).

In the survey of protoplanetary nebula candidates with the Hubble Space Telescope, Ueta et al. (2000) discovered an elongated low-surface-brightness reflection nebulosity around IRAS 22272+5435. These authors believe that a multilobed nebula may be a progenitor of a complex planetary nebula.

The spectral classification of V354 Lac is a difficult problem because of its peculiar spectrum. In the HD catalog, HD 235858 has the spectral type K5. McCuskey (1955) classified the object as M0III and Hrivnak and Kwok (1991), as GpIa. The atmospheric parameters of IRAS 22272+5435, $T_{eff} = 5600$ K and $\log g = 0.5$, correspond to a G2 supergiant (Začs, Klochkova, and Panchuk 1995).

The brightness variability of BD+54°2787 was discovered by Strohmeier and Knigge (1960). They list it as a possible short-period variable with an amplitude of $0\overset{\mathrm{m}}{.}5$. Filatov (1961) reported irregular variability of the star with an amplitude of $1\overset{\mathrm{m}}{.}5$–$2\overset{\mathrm{m}}{.}0$. In the 62nd GCVS Name-List (Kukarkin et al. 1977), BD+54°2787 got the designation V354 Lac. The GCVS variability type currently listed for the star is LB (a slow irregular variable).

Table. UBV photometry of V354 Lac in 2000–2008

JD 245...	V	$B-V$	$U-B$	JD 245...	V	$B-V$	$U-B$	JD 245...	V	$B-V$	$U-B$
1708	8.506	2.049	2.101	2621	8.643	2.070	2.220	3622	8.528	2.035	2.059
1709	8.513	2.068	2.124	2635	8.650	2.045	2.128	3648	8.720	2.078	2.175
1710	8.523	2.058	2.225	2817	8.546	2.059	2.242	3676	8.608	2.060	2.115
1721	8.513	2.040	2.039	2820	8.527	2.056	2.206	3685	8.548	2.035	2.142
1724	8.521	2.064	2.097	2824	8.583	2.043	2.129	3748	8.617	2.066	2.076
1728	8.553	2.066	2.217	2857	8.649	2.044	1.863	3942	8.521	2.057	2.158
1734	8.566	2.045	2.204	2860	8.665	2.058	2.031	3946	8.496	2.032	2.129
1751	8.589	2.085	2.175	2866	8.668	2.110	2.234	3948	8.495	2.004	2.096
1752	8.605	2.067	2.132	2869	8.716	2.133	2.200	3950	8.464	2.063	2.108
1752	8.594	2.071	2.101	2870	8.700	2.078	1.911	3963	8.368	1.949	2.029
1754	8.569	2.072	2.163	2871	8.717	2.075	1.918	3964	8.351	1.952	1.982
1763	8.546	2.057	2.262	2872	8.708	2.133	2.049	3965	8.360	1.945	1.990
1766	8.538	2.055	2.097	2873	8.716	2.077	2.030	3966	8.353	1.955	1.957
1768	8.528	2.055	2.100	2874	8.736	2.122	2.270	3967	8.358	1.945	1.949
1778	8.571	2.063	2.105	2875	8.723	2.064	1.962	3978	8.391	1.952	2.058
1780	8.565	2.043	2.113	2882	8.744	2.140	2.217	3991	8.471	1.995	2.031
1781	8.567	2.069	2.220	2890	8.721	2.076	2.189	4011	8.671	2.078	2.112
1782	8.558	2.052	2.239	2903	8.776	2.089	2.149	4013	8.683	2.097	2.170
1791	8.600	2.063	2.291	2905	8.771	2.074	2.202	4014	8.697	2.110	2.123
1806	8.598	2.047	2.156	2915	8.744	2.090	2.175	4029	8.791	2.139	2.257
1810	8.565	2.014	2.117	2930	8.752	2.146	2.248	4036	8.787	2.112	2.220
1810	8.567	2.018	2.134	2944	8.747	2.086	1.983	4298	8.787	2.158	2.292
1816	8.561	2.018	2.080	2984	8.649	2.068	2.136	4301	8.793	2.147	2.270
1820	8.568	2.052	2.209	2996	8.702	2.119	2.248	4316	8.693	2.124	2.183
1822	8.574	2.035	2.118	3003	8.737	2.147	2.251	4317	8.682	2.118	2.261
1822	8.561	2.054	2.091	3015	8.762	2.142	2.171	4319	8.663	2.091	2.184
1834	8.564	2.018	1.916	3032	8.754	2.070	2.128	4322	8.630	2.062	2.108
1840	8.572	2.051	2.116	3176	8.507	2.014	1.891	4328	8.535	2.014	2.000
1843	8.570	2.078	2.314	3182	8.495	2.039	2.072	4332	8.451	1.988	2.047
1853	8.562	2.082	2.266	3193	8.439	2.032	2.078	4342	8.427	1.980	1.964
2086	8.653	2.055	2.162	3196	8.446	2.026	2.095	4349	8.452	1.993	2.074
2106	8.724	2.110	2.254	3202	8.411	2.001	2.080	4363	8.509	2.020	2.144
2112	8.653	2.086	2.003	3205	8.408	1.996	2.091	4369	8.532	2.005	2.189
2119	8.650	2.094	2.101	3212	8.406	1.963	2.031	4370	8.525	2.032	2.051
2132	8.581	2.053	2.108	3216	8.418	1.960	1.994	4372	8.551	2.014	2.079
2133	8.595	2.056	2.214	3223	8.440	1.989	2.045	4374	8.544	2.019	2.103
2137	8.580	2.034	2.068	3230	8.491	2.008	2.038	4385	8.550	2.004	2.116
2138	8.554	2.051	2.247	3255	8.707	2.137	2.182	4386	8.558	2.035	2.068
2142	8.556	2.043	2.117	3261	8.729	2.149	2.283	4393	8.598	2.048	2.088
2172	8.583	2.052	2.194	3268	8.775	2.144	2.313	4426	8.880	2.162	2.192
2186	8.619	2.083	2.204	3270	8.793	2.146	2.265	4654	8.552	2.078	2.245
2187	8.632	2.077	2.262	3273	8.814	2.133	2.222	4676	8.699	2.128	2.331
2192	8.643	2.104	2.231	3283	8.747	2.106	2.191	4677	8.699	2.125	2.063
2196	8.648	2.094	2.250	3291	8.722	2.077	2.179	4682	8.743	2.122	2.282
2199	8.647	2.108	2.284	3292	8.649	2.092	2.159	4686	8.751	2.131	2.294
2210	8.756	2.111	2.210	3304	8.543	2.084	2.157	4696	8.808	2.128	2.262
2454	8.557	2.021	2.092	3305	8.537	2.073	2.214	4700	8.833	2.128	2.220
2460	8.581	2.054	2.157	3313	8.463	2.064	2.215	4703	8.810	2.122	2.181
2462	8.580	2.044	1.911	3320	8.476	2.064	2.196	4705	8.799	2.123	2.270
2470	8.615	2.075	1.943	3383	8.535	2.180	2.115	4714	8.765	2.132	2.261
2518	8.579	2.093	2.211	3384	8.560	2.102	2.214	4715	8.765	2.127	2.286
2528	8.533	2.032	2.040	3547	8.833	2.060	2.060	4717	8.760	2.121	2.305
2586	8.480	1.981	1.960	3548	8.823	2.055	2.075	4742	8.586	2.080	2.228
2587	8.510	2.013	2.157	3563	8.639	2.037	2.059	4761	8.499	2.060	2.205
2595	8.481	2.037	2.114	3593	8.380	1.952	2.016	4768	8.502	2.087	2.205
2597	8.521	2.028	2.076	3595	8.388	1.937	1.958	4783	8.574	2.117	2.288
2613	8.590	2.089	2.217	3610	8.502	1.989	2.012	4799	8.672	2.125	2.282
2618	8.630	2.082	2.076	3614	8.519	2.005	1.971	4801	8.659	2.113	2.225
2620	8.645	2.086	2.242	3616	8.514	2.028	1.964	4802	8.667	2.123	2.261

The light-curve and radial-velocity studies of V354 Lac were carried out by Hrivnak and Lu (2000) respectively in 1994–1996 and 1991–1995. They found brightness and radial-velocity variability with the period $P = 127^{\rm d}$.

The radial-velocity monitoring of V354 Lac performed by Začs et al. (2009) confirmed regular variations with a peak-to-peak amplitude of about 10 km s^{-1} and a period of about 131.2 days.

2 UBV OBSERVATIONS OF V354 Lac

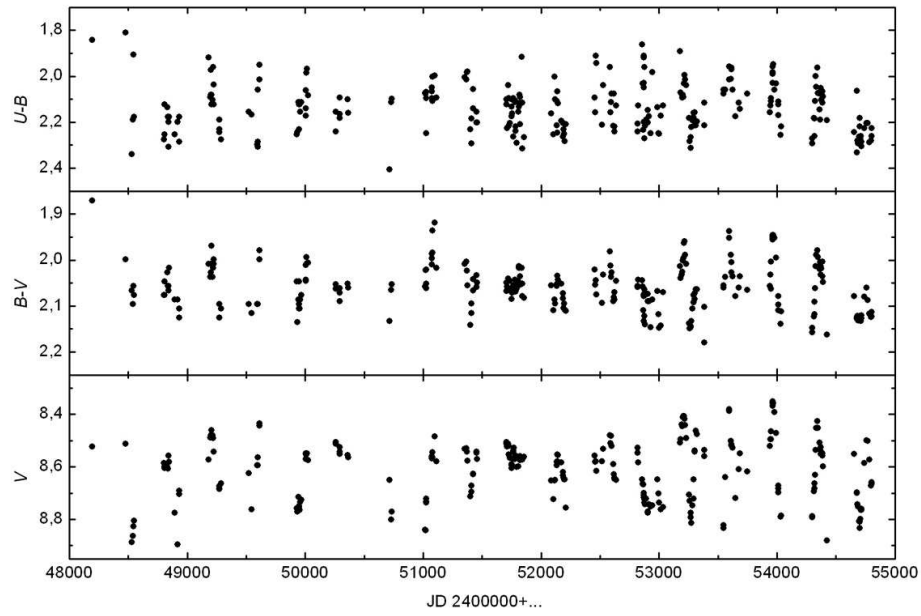

Figure 1. The light and color curves of V354 Lac in 1990–2008.

Our UBV photometry of IRAS 22272+5435 was performed in 1990–2008 with the 0.6-m telescope of the Crimean Station of the Sternberg Astronomical Institute. The measurements were obtained using a pulse-counting photometer with an EMI 9789 photomultiplier and a filter set consistent with the Johnson system. All observations were made with respect of the comparison star BD+54°2793 ($V = 8\overset{\rm m}{.}54$, $B = 10\overset{\rm m}{.}45$, $U = 12\overset{\rm m}{.}79$). The typical photometric uncertainties range from $0\overset{\rm m}{.}01$ in the V band to $0\overset{\rm m}{.}05$ in the U band. The observations obtained in 1990–1999 were published earlier (Arkhipova et al. 1993 and Arkhipova et al. 2000). The UBV photometry performed after 1999 is listed in Table 1. The light and color curves of V354 Lac for 1990–2008 are presented in Fig. 1.

During our observations, V354 Lac showed semi-regular brightness variations with varying amplitudes. Its largest amplitudes do not exceed $\Delta V = 0\overset{\rm m}{.}5$, $\Delta B = 0\overset{\rm m}{.}7$, $\Delta U = 1\overset{\rm m}{.}0$.

We searched for periodicity in the observations obtained in 1990–2008 using the DFT (Discrete Fourier Transforms) package by Dr. V.M. Lyuty.

In the power spectrum (Fig. 2), triplet frequencies are dominating: $\nu_1 = 0.00781$, $\nu_2 = 0.00763$, $\nu_3 = 0.00800$. The ratios ν_1/ν_2 and ν_3/ν_1 are close to 1.024. The periods

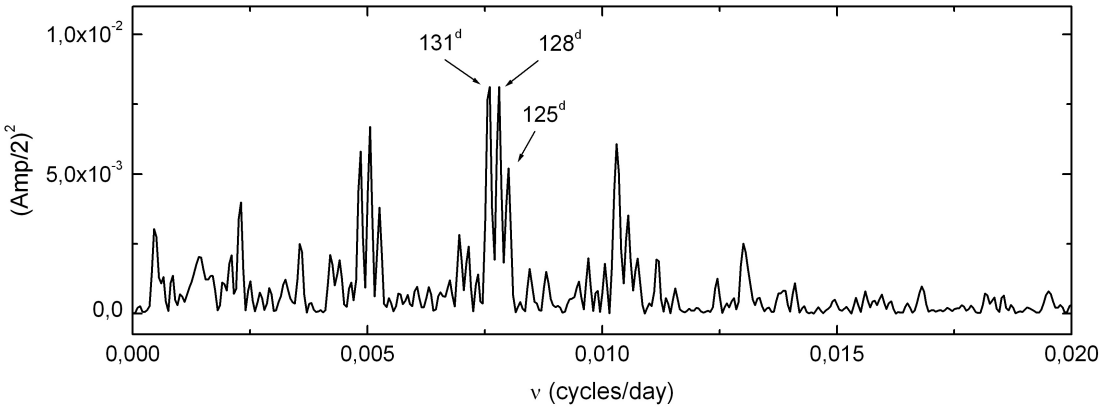

Figure 2. The power spectrum of V354 Lac for the observations of 1990–2008.

$P_1 = 1/\nu_1 = 128^{\rm d}$ and $P_2 = 1/\nu_2 = 131^{\rm d}$ have approximately the same amplitudes, about $0\overset{\rm m}{.}18$ in the V band.

A single period, $P = 128 \pm 2$ days, was found in the observations of 2000–2008. The corresponding power spectra and the V-band phased light curve are shown in Fig. 3.

Considering the radial-velocity variations (Začs et al., 2009) together with our light curve (Fig. 4) confirms the conclusion of Hrivnak and Lu (2000) that V354 Lac "is brightest when it is at its average size and expanding and faintest when at its average size and contracting". Hrivnak and Lu interpreted this variability as due to pulsation in the star rather than to its binary nature.

The $V-(B-V)$ diagram shows a clear correlation: the star is generally bluer when brighter (Fig. 5).

V354 Lac is located at a low galactic latitude ($b = -2\overset{\circ}{.}52$). The interstellar extinction in the direction of V354 Lac from maps of Neckel and Klare (1980) is $1\overset{\rm m}{.}2 < A_V < 1\overset{\rm m}{.}9$ at $r = 1$ kpc. From UBV data, we conclude that $E(B-V) = 0.5$ and $A_V = 1\overset{\rm m}{.}55$. Thus, practically all the color excess can be caused by interstellar extinction.

In the $(U-B)$–$(B-V)$ two-color diagram (Fig.6), the star moves along the sequence of supergiants in the course of its fluctuations. Correction of the color indices for reddening with $E(B-V) = 0.5$ puts the star on the sequence of supergiants, where the spectral type of the star varies during pulsations from K1 to K7.

3 Conclusions

Our long-term UBV photometry of the post-AGB star V354 Lac permitted to study its variability character. V354 Lac showed semi-regular light variations with varying amplitudes. The maximal amplitudes did not exceed: $\Delta V = 0\overset{\rm m}{.}5$, $\Delta B = 0\overset{\rm m}{.}7$, $\Delta U = 1\overset{\rm m}{.}0$. The observed behavior of V354 Lac is explained with beating of two closely spaced pulsation modes with the period ratio 1.02. The other post-AGB stars with amplitude modulation are IRAS 19386+0155=V1648 Aql (Arkhipova et al. 2009) and IRAS 08544–4431 (Kiss et al. 2007). The period ratio for them is 1.04. Some pulsating red variables on the asymptotic giant branch (AGB) show pulsations with two close periods. Such a phenomenon is detected, for example, for RX UMa and RY Leo (Kiss et al. 2000). The

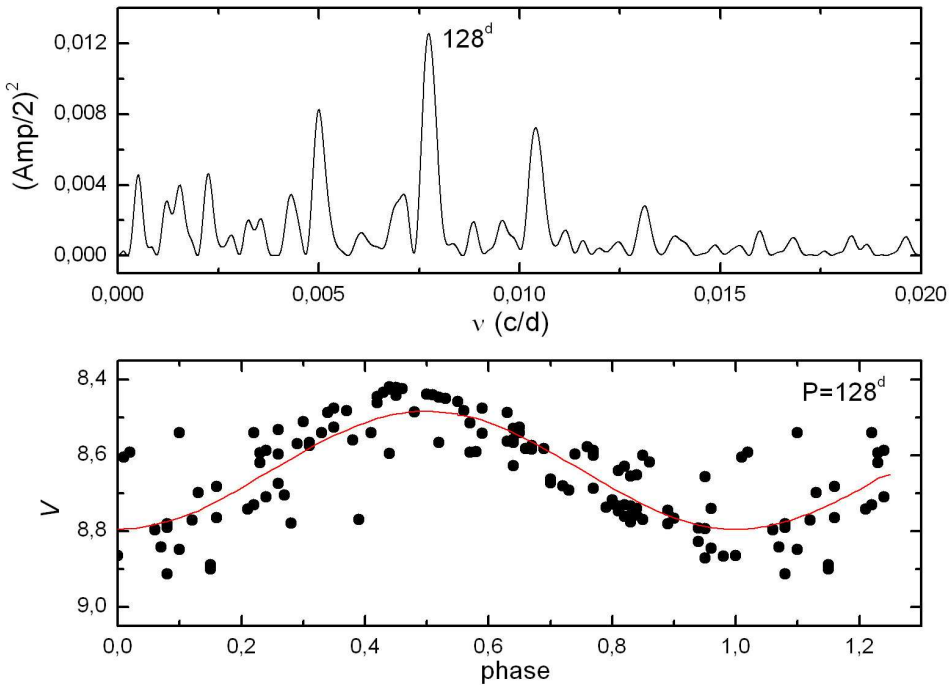

Figure 3. The power spectra (top panel) and the phased V light curve (bottom panel) of V354 Lac for observations of 2000–2008.

authors of the cited paper assumed that the period ratios found for these stars (1.03–1.10) suggested either high-order overtone or radial+non-radial oscillation.

The mean UBV parameters of V354 Lac have not changed during the past 19 years: $\overline{V} = 8\overset{\text{m}}{.}60$, $\overline{(B-V)} = 2\overset{\text{m}}{.}06$, and $\overline{(U-B)} = 2\overset{\text{m}}{.}14$.

The brightness and the colors change in phase: the star is generally bluer when brighter. The temperature variations during pulsations correspond to the changes of the spectral type between K1 and K7.

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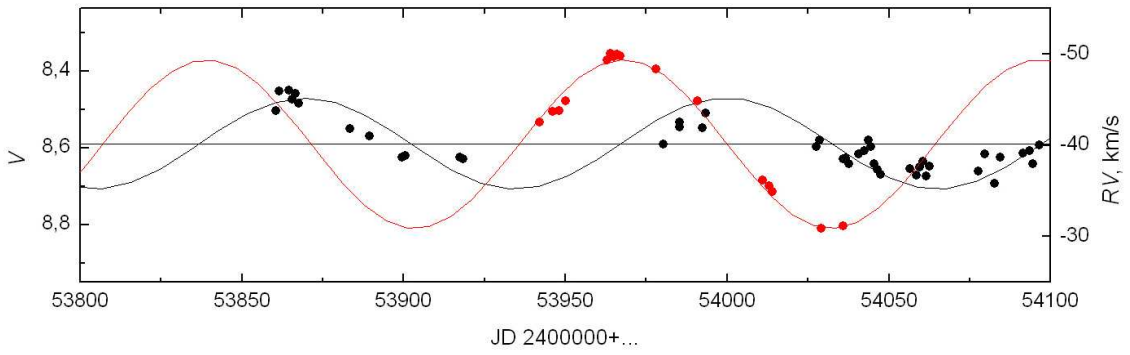

Figure 4. The radial-velocity variations of V354 Lac (black filled circles) with a sinusoid fit (P=131.2 days; black curve) and V light curve (red filled circles) with a sinusoid fit (P=128 days; red curve).

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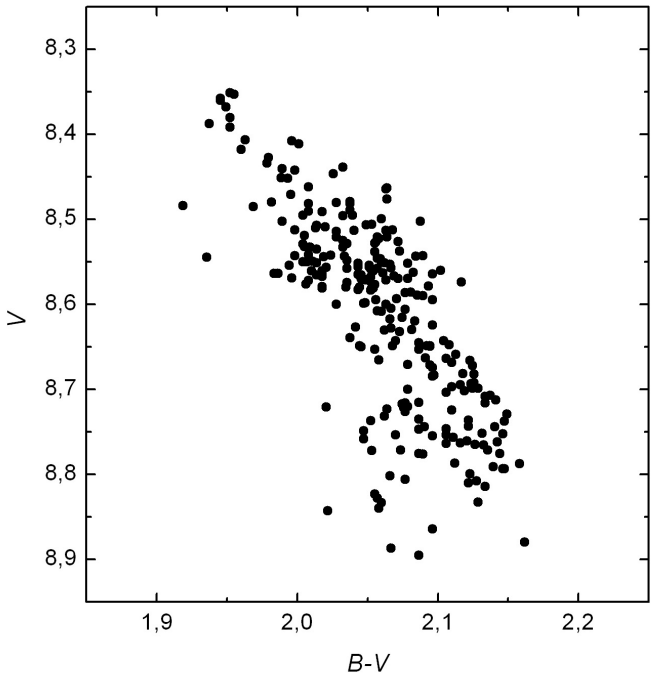

Figure 5. The color–brightness diagram for V354 Lac.

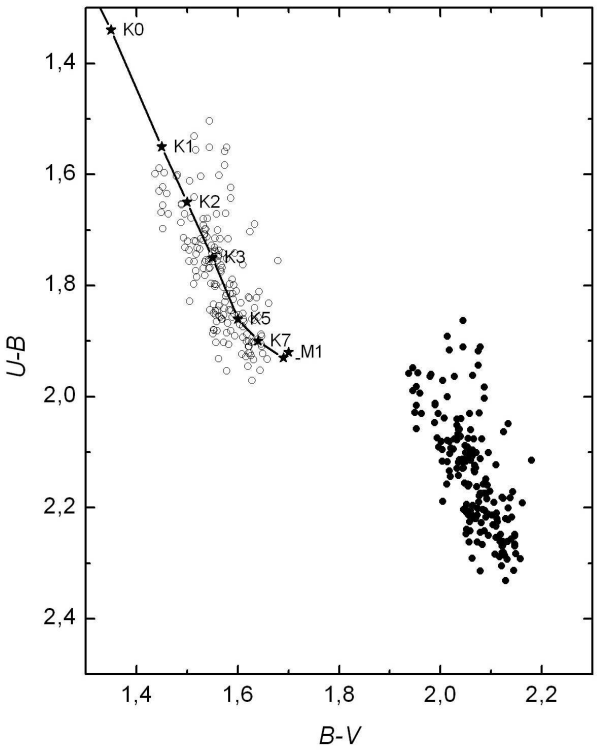

Figure 6. V354 Lac in the $(U-B)-(B-V)$ two-color diagram. The solid curve is the supergiant sequence according to Straižys (1977); the dots represent our observations and the open circles, data de-reddened with $E(B-V) = 0\overset{\mathrm{m}}{.}5$.