COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4846

Konkoly Observatory
Budapest
3 February 2000

HU ISSN 0374 – 0676

THE RV TAURI STAR V6 IN GLOBULAR CLUSTER M56

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The RV Tauri stars are a small group of radially pulsating yellow supergiants. The main observational feature of these stars is "the alternation of shallow and deep minima" in the light curve. Their periods, determined as an interval between two adjacent deep minima, fall in the range from 30 to 150 days. They are located between W Virginis stars and long-period variables in the instability strip of the H–R diagram. According to Jura (1986) RV Tauri stars are low-mass objects in a transition from the asymptotic giant branch (AGB) to the white dwarf phase. This post-AGB phase of stellar evolution is rather short by normal stellar standards (a few thousand years), which is consistent with the relatively small number of RV Tauri variables. While in our Galaxy about 120 such variables are known (Kholopov, 1985), there are only six stars classified as RV Tauri in the globular clusters listed in The Third Catalogue of Variable Stars in Globular Clusters (Sawyer Hogg, 1973). They are V1ωCen, V84M5, V17M28, V6M56, V2M10 and V11M2.

V6M56 is one of the brightest stars in the globular cluster M56 (NGC 6779) and one of the first identified as an RV Tauri star in a globular cluster. It was discovered by Helen Sawyer Hogg in 1940 (Sawyer, 1940), who suggested a 51-day period of the star (Sawyer, 1942). Later, using his own observations, Rosino (1944) suggested a 45.33-day period. Sawyer (1949) showed that V6M56 is an RV Tauri star with a period of 90.02 days. Up to now the most extensive investigations of this star were made by Wehlau and Sawyer Hogg (1985) and Wehlau et al. (1985).

The spectral type (F6-G4e) and the radial velocity of V6M56 were first determined by Joy (1949). Preston et al. (1963) in their classic paper on RV Tauri stars suggested that the star belongs to the Preston type C.

Our observations of V6M56 cover about 17 years, from 1977 to 1993. The variable star was observed with the 60-cm reflector of the Belogradchic Astronomical Station (Bulgaria) between 1977 and 1978 (31 observations on 14 nights) and with the 2-m telescope of the BNAO Rozhen (Bulgaria) from 1981 to 1993 (71 observations on 25 nights). The photometric system is near the B one, as was described in the paper on the red variable stars in M56 (Russeva, 1999). Table 1 lists the B magnitudes of the variable V6M56. The Belogradchic plate numbers are prefixed with 'B' and the Rozhen ones with 'R'. The fourth column gives the numbers of observations per night.

In addition to the present observational material we have used the B measurements by Wehlau and Sawyer Hogg (1985) and Rosino (1944) in order to investigate the period change in V6M56 through $O-C$ analysis. The available data consist of 653 measurements,

Table 1: A list of B observations of V6M56.

PL No.	JDH 24...	B	n	PL No.	JD H24...	B	n
B 53	43305.561	13.22	1	B233	44850.366	14.73	1
B 62	43308.542	13.78	1	R242-44	45112.480	14.62	2
B 76	43365.396	14.09	1	R247-48	45113.519	14.64	2
B 82-83	43366.406	14.15	2	R251	45114.500	14.52	1
B 89	43368.370	14.04	1	R255	45171.428	13.05	1
B 96-98	43664.511	13.32	3	R259-62	45172.480	13.02	3
B104-06	43667.518	13.35	2	R265-66	45173.485	13.00	2
B115	43669.416	13.42	1	R554-61	45470.556	14.60	2
B122	43672.436	13.67	1	R575	45523.437	13.41	1
B134-39	43720.485	13.92	6	R833-36	45938.463	13.60	4
B141-45	43721.478	14.00	5	R957-65	46230.451	13.94	9
B148-52	43722.453	13.39	5	R969-75	46231.456	14.00	7
B157	43723.405	14.02	1	R1037	46271.476	14.54	1
B161	43724.361	14.13	1	R1520-25	47739.441	14.50	6
R210	44787.527	13.36	1	R1667-69	48091.439	14.46	3
B210	44818.416	13.00	1	R1677-80	48096.462	14.83	4
B216-18	44843.436	14.60	3	R1822	48419.468	13.29	1
B219-20	44845.461	14.65	2	R1976-81	49161.470	14.82	6
B223	44846.426	14.73	1	R1982-89	49162.560	14.87	5
B224-28	44848.427	14.73	4	R1993-96	49163.458	14.90	4
B231	44849.370	14.72	1				

covering about 59 years, from 1934 to 1993 (JDH2428015 - 2449163). The analysis of all observations permitted the construction of 14 seasonal light curves using the following elements:

$$\text{Primary Min.} = \text{JDH } 2428016.8 + 90\overset{\text{d}}{.}0 \times E.$$

Then we determined the times of primary (deep) and secondary (shallow) minima and corresponding $O-C$ values for each one of the seasonal light curves. The average error is $\pm 0\overset{\text{d}}{.}05$.

Fig. 1a shows the $O-C$ diagram for the two minima, the primary (lower graph) and the secondary (upper graph), respectively. The change of the period, assuming a linear variation, is -0.000005 days/yr, which is less than the expected possible effect of the stellar evolution. According to the linear non-adiabatic calculations of Tuchman et al. (1993) the periods of RV Tauri stars should be decreasing with a measurable rate between -0.3 and -0.001 days/yr. Also Fig. 1a might be fitted with a wave function with a period of about 28879 days and an amplitude of 5-6 days. But this interpretation is quite doubtful, because there are no observations during 14 years (from JDH 2434992 to JDH 2440057). Fig. 1a allowed us to establish that the period $P = 90\overset{\text{d}}{.}0$ remains stable and presents the fundamental period of V6M56. Therefore Fig. 1a indicates that $O-C$ diagrams for the two minima are dominated by the effects of random, cycle-to-cycle fluctuations of the period.

The $O-C$ diagram for the times of the deep minima in the light curve is shown in Fig. 1b. The diagram clearly shows a cyclic variation. It is a reflection of periodic changes, manifested by the alternation of the deep and shallow minima in the role of primary minimum. It seems that the change of the minima do not happen suddenly, and

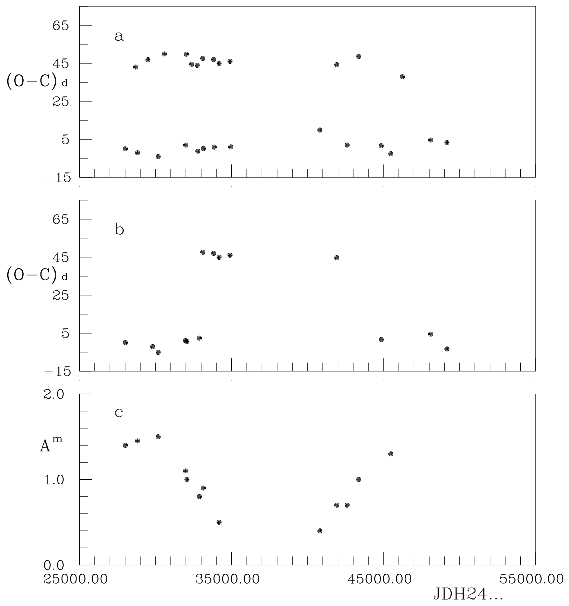

Figure 1. The O-C diagrams of V6M56 (a, b). The amplitude variation of the deep minimum (c).

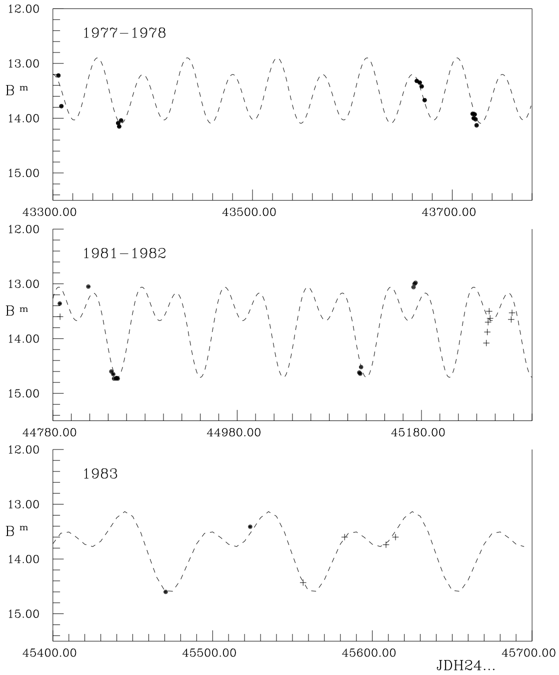

Figure 2. The blue light curves of V6M56. The dashed lines show theoretical ones.

for a few (4) cycles the depth of the minima varies only slightly.

The amplitude variation of the deep minimum is shown in Fig. 1c. The result of a least-squares sine fit is a wave with a cycle length of about 18000 days (200 formal periods of the star) and an amplitude of $1\overset{m}{.}4$. It is possible to interpret the $O-C$ diagram (Fig. 1b) with the same wave function but it is rather inaccurate. As mentioned above, the variable was observed quite irregularly and the data are sparse.

V17M28, one of the six RV Tauri stars in the globular clusters, has a period $P = 91\overset{d}{.}7$ close to the period of V6M56. The comparison shows: (1) V17 M28 belongs to the most metal-rich ([m/H] = −1.1 (Smith and Wehlau, 1985)) and V6M56 belongs to the most metal-poor ([m/H] = −2.32 (Webbink, 1985)) known clusters containing such vaiables. (2) The light curve of V17M28 exhibits larger differences in the amplitude during the years of observations (Wehlau et al., 1986), than those observed for V6M56. This confirms the suggestion that RV Tauri stars are not a homogeneous class at all, in agreement with the conclusions of Russell (1997) for the RV Tauri variables in the galactic field. The evolutionary status of these stars is still uncertain, but probably slightly different initial masses or metallicities may cause the RV Tauri phenomenon to occur for stars at several different stages of AGB (or post-AGB) evolution.

The recent non-linear hydrodynamical calculations of Fokin (1994) are made for models with low-mass (0.60 $M_\odot$) and luminosity ($3123 < L/L_\odot < 7000$). He supports the long-standing resonance hypothesis by revealing 2:1 ratio for the fundamental mode and the first overtone. These models describe the RV Tauri behaviour of the stars with periods between $52\overset{d}{.}0$ and $93\overset{d}{.}8$. Since the fundamental period of pulsation of V6M56 is practically constant, we suggest that in V6M56 two pulsational modes get excited simultaneously – the fundamental one with $P_\circ = 90^{\rm d}$ and the first overtone with $P = 1/2P_\circ$. In Fig. 2 parts of some seasonal light curves are shown. Fig. 2a and 2b are constructed using the data from Table 1 (dots) and from Table 1 of Wehlau and Sawyer Hogg (1985) (crosses). The dashed lines show the theoretical light curves obtained with least squares fitting functions for each of the intervals:

$$B = a_i + b_i \sin \omega_0 t + c_i + d_i \sin \omega_1 t + e_i,$$

where $\overline{a_i} = 13.67 \pm 0.08$, $\overline{b_i} = 0.22 \pm 0.10$, $\overline{c_i} = 2.71 \pm 2.00$, $\overline{d_i} = 0.47 \pm 0.02$, $\overline{e_i} = 1.14 \pm 0.34$.

This interpretation satisfactorily explains the alternating behaviour of the different season light curves. Obviously these two periods are not enough to describe the whole long series of observations. It appears that some parameters other than these must be acting here.

The author is extremely thankful to the referee, Prof. Amelia Wehlau, for helpful corrections improving the manuscript.

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