PERIODOGRAM ANALYSIS OF THE LIGHT CURVES OF 59 AURIGAE

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Abstract. The photoelectric V observations of the δ Scuti star 59 Aur have been analysed using the techniques of periodogram analysis and least-squares solutions. The fundamental mode is found to be more prominent than the first overtone in the pulsation of 59 Aur. The period ratio of the first overtone to the fundamental (i.e., $P_1/P_0 = 0.748$) indicates that the star pulsates in the radial mode. The absolute magnitude, effective temperature and mass of the star are derived to be $1^{\mathrm{m}}22$, 7300 K and 2.0 $M_\odot$, respectively. No variations exceeding $\pm 0^{\mathrm{m}}01$ about the mean values of $B - V$ and $U - B$ colours have been found during a pulsation cycle.

1. Introduction

The star 59 Aurigae [$\alpha(1900) = 6^{\mathrm{h}}46^{\mathrm{m}}9^{\mathrm{s}}$, $\delta(1900) = +38°59'$, $V = 5^{\mathrm{m}}96$, Sp. A7n] is a visual binary, the fainter component being of apparent magnitude $10^{\mathrm{m}}20$. Danziger and Dickens (1967) and Breger (1970) found the star to be a suspected variable of unknown type during their photoelectric surveys. Gupta and Bhatnagar (1974) made observations of one cycle of this star and found a mean period of $0^{\mathrm{d}}136$ and an amplitude of light variation of about $0^{\mathrm{m}}03$ during a cycle. On the basis of its period and amplitude of light variation, this star belongs to the group of δ Scuti variables. In this paper we show in detail the pulsation characteristics of the star.

2. Observations

The δ Scuti star 59 Aur was photoelectrically observed on ten nights from 1975 to 1976 on the 38 cm Cassegrain reflector of the Uttar Pradesh State Observatory. A 1P21 photomultiplier tube cooled to −20 °C and UBV filters of the Johnson and Morgan system have been used. At first, 60 Aur and 61 Aur were observed for a few nights as comparison stars. The star 61 Aur was found to be more stable than 60 Aur, with a standard deviation of $\pm 0^{\mathrm{m}}006$ in V filter. Hence, the subsequent observations and final reductions were carried out using 61 Aur only. By use of the transformations

$$\begin{aligned} \Delta V &= \Delta v_i + 0.053\,\Delta(B - V), \\ \Delta(B - V) &= 1.009\,\Delta(b - v)_i, \\ \Delta(U - B) &= 1.017\,\Delta(u - b)_i \end{aligned}$$

all the observations were reduced to the standard UBV system as described in the

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TABLE I

V magnitudes and colours of 59 Aur

JD (Hel)	V	$B-V$	$U-B$	JD (Hel)	V	$B-V$	$U-B$
2442 453.189	$5^{m}.952$	$0^{m}.345$		2442 462.140	5.945	0.352	0.141
.196	5.947	0.337		.149	5.953	0.347	0.137
.203	5.954	0.337		.159	5.948	0.336	0.149
.210	5.964	0.337		.167	5.940	0.346	0.140
.217	5.969	0.347		.176	5.945	0.337	0.153
.224	5.965	0.331		.184	5.947	0.345	0.146
.232	5.973	0.337		.190	5.956	0.335	0.143
.240	5.969	0.341		.198	5.960	0.347	0.137
.246	5.973	0.331		.208	5.972	0.336	0.133
.253	5.966	0.344		.218	5.967	0.342	0.136
.260	5.960	0.340		.224	5.972	0.344	0.144
.267	5.956	0.335		.231	5.969	0.346	0.143
.273	5.950	0.346		.238	5.965	0.353	0.148
455.106	5.943	0.343	$0^{m}.145$	.246	5.968	0.347	0.144
.113	5.940	0.334	0.155	.253	5.961	0.341	0.145
.120	5.958	0.340	0.135	.260	5.963	0.342	0.150
.128	5.958	0.349	0.132	.267	5.944	0.346	0.140
.136	5.947	0.336	0.142	.277	5.940	0.348	0.131
.145	5.960	0.350	0.130	.284	5.947	0.348	0.142
.153	5.974	0.339	0.144	713.265	5.942	0.339	
.161	5.976	0.337	0.150	.271	5.953	0.333	
.168	5.971	0.331	0.149	.275	5.949	0.334	
.175	5.964	0.337	0.138	.281	5.958	0.331	
.183	5.961	0.339	0.131	.285	5.949	0.345	
.190	5.960	0.341	0.137	.290	5.962	0.339	
455.198	5.955	0.340	0.143	.296	5.956	0.342	
.218	5.949	0.339	0.145	.306	5.957	0.350	
.225	5.948	0.356	0.132	.310	5.959	0.347	
.232	5.949	0.355	0.134	.315	5.951	0.344	
.239	5.950	0.350	0.143	2442 713.320	5.958	0.340	
.246	5.957	0.349	0.138	.324	5.946	0.339	
.254	5.962	0.333	0.141	.330	5.949	0.347	
.261	5.967	0.344	0.143	.334	5.950	0.334	
.268	5.967	0.352	0.143	.339	5.951	0.325	
.276	5.973	0.336	0.137	.344	5.951	0.344	
.284	5.976	0.321	0.139	.348	5.940	0.348	
.290	5.974	0.332	0.131	.352	5.943	0.345	
.297	5.962	0.339	0.150	.357	5.936	0.350	
.304	5.953	0.334	0.145	.362	5.942	0.332	
.312	5.949	0.348	0.148	.368	5.936	0.347	
.319	5.947	0.343	0.151	.372	5.942	0.345	
.327	5.948	0.334	0.146	.377	5.945	0.342	
.334	5.954	0.342	0.136	.382	5.938	0.345	
.341	5.953	0.331	0.132	.387	5.950	0.345	
.348	5.955	0.338	0.140	.391	5.962	0.341	
462.131	5.956	0.338	0.137	.396	5.953	0.350	

(continued)

Table I (Continued)

JD (Hel)	V	$B-V$	$U-B$	JD (Hel)	V	$B-V$	$U-B$
2442 713.400	5.958	0.333		2442 719.323	5.980	0.336	
.405	5.953	0.343		.328	5.965	0.344	
.410	5.962	0.346		.333	5.957	0.340	
.415	5.963	0.340		.337	5.944	0.337	
.419	5.963	0.350		.342	5.947	0.333	
.424	5.964	0.333		.347	5.943	0.350	
.428	5.961	0.339		.352	5.947	0.340	
.433	5.960	0.342		.358	5.944	0.346	
714.254	5.954	0.336		.362	5.949	0.340	
.259	5.953	0.334		.367	5.948	0.347	
.263	5.954	0.349		.372	5.954	0.339	
.268	5.945	0.344		.377	5.960	0.337	
.273	5.948	0.351		.382	5.955	0.345	
.279	5.951	0.349		.387	5.950	0.346	
.294	5.958	0.334		.391	5.956	0.339	
.299	5.954	0.347		.396	5.965	0.338	
.304	5.955	0.342		.400	5.964	0.331	
.309	5.963	0.345		.405	5.956	0.343	
.318	5.960	0.338		.410	5.962	0.350	
.323	5.972	0.348		723.233	5.973	0.334	
.328	5.974	0.331		.238	5.978	0.352	
.332	5.972	0.348		.243	5.978	0.349	
.338	5.973	0.336		.247	5.975	0.341	
.348	5.965	0.334		.252	5.972	0.335	
.352	5.968	0.341		.257	5.974	0.340	
.357	5.958	0.333		.262	5.962	0.343	
.368	5.960	0.352		.266	5.967	0.345	
.374	5.960	0.340		.271	5.961	0.338	
.379	5.958	0.343		.275	5.955	0.334	
.384	5.954	0.343		.284	5.951	0.345	
.390	5.950	0.350		.294	5.941	0.336	
.396	5.950	0.338		.300	5.948	0.342	
.401	5.954	0.331		.305	5.953	0.355	
.407	5.964	0.337		.309	5.948	0.347	
.411	5.966	0.338		.314	5.955	0.338	
.416	5.972	0.330		.319	5.957	0.342	
.421	5.968	0.338		.324	5.956	0.333	
.426	5.973	0.333		.329	5.960	0.349	
719.272	5.953	0.340		.335	5.966	0.350	
.277	5.968	0.342		.340	5.960	0.346	
.286	5.971	0.339		.349	5.965	0.347	
.291	5.974	0.342		.354	5.968	0.338	
.295	5.967	0.335		726.192	5.951	0.330	
.300	5.978	0.339		.199	5.945	0.344	
.305	5.981	0.332		.205	5.951	0.348	
.310	5.976	0.343		.212	5.950	0.346	
.314	5.972	0.340		.219	5.959	0.346	
.319	5.971	0.344		.225	5.964	0.341	

(continued)

Table I (Continued)

JD (Hel)	*V*	*B−V*	*U−B*	JD (Hel)	*V*	*B−V*	*U−B*
2442 726.231	5.962	0.348		2442 780.370	5.950	0.341	0.140
.241	5.969	0.345		.375	5.951	0.337	0.141
.248	5.960	0.352		.382	5.958	0.347	0.139
.255	5.950	0.353		.389	5.963	0.349	
.261	5.950	0.350		.394	5.968	0.345	
.267	5.956	0.333		.399	5.958	0.348	
.273	5.950	0.343		.407	5.962	0.338	
.278	5.947	0.346		.414	5.964	0.341	
.284	5.946	0.352		.421	5.959	0.336	
.289	5.951	0.346		.426	5.953	0.330	
.296	5.953	0.351		.433	5.950	0.343	
.303	5.950	0.345		.439	5.956	0.345	
.310	5.960	0.336		.443	5.951	0.337	
.316	5.963	0.342		782.069	5.969	0.340	
.322	5.958	0.341		.076	5.964	0.341	
.328	5.965	0.340		.081	5.956	0.331	
.333	5.970	0.330		.086	5.956	0.331	
.339	5.972	0.341		.091	5.948	0.348	
.345	5.973	0.334		.095	5.955	0.348	
.357	5.973	0.350		.101	5.949	0.347	
.363	5.967	0.344		.105	5.950	0.346	
.369	5.968	0.337		.111	5.954	0.345	
.376	5.960	0.342		.116	5.956	0.342	
780.165	5.958	0.343	0^m138	.121	5.957	0.340	
.172	5.959	0.337	0.150	.126	5.958	0.343	
.179	5.951	0.350	0.136	.130	5.956	0.333	
.187	5.953	0.335	0.141	.136	5.953	0.340	
.195	5.948	0.334	0.141	.141	5.967	0.346	
.202	5.950	0.350	0.140	.146	5.964	0.342	
.209	5.951	0.338	0.138	.151	5.967	0.340	
.216	5.953	0.347	0.145	.157	5.966	0.338	
.224	5.950	0.340	0.138	.162	5.970	0.328	
.231	5.957	0.349	0.147	.168	5.971	0.335	
.245	5.965	0.336	0.139	.173	5.973	0.339	
.251	5.961	0.334	0.140	.178	5.976	0.341	
.258	5.962	0.346	0.146	.183	5.975	0.352	
.266	5.963	0.350	0.150	.189	5.970	0.333	
.272	5.960	0.351	0.135	.195	5.974	0.333	
.279	5.962	0.346	0.146	.200	5.972	0.335	
.285	5.955	0.347	0.144	.205	5.969	0.335	
.293	5.950	0.347	0.145	.210	5.966	0.333	
.303	5.947	0.351	0.132	.215	5.952	0.346	
.311	5.947	0.344	0.146	.221	5.952	0.332	
.318	5.954	0.342	0.145	.227	5.950	0.332	
.327	5.946	0.345	0.153	.232	5.954	0.350	
.335	5.951	0.339	0.134	.237	5.955	0.339	
.343	5.950	0.353	0.138	.242	5.950	0.343	
.350	5.946	0.349	0.139	.248	5.955	0.336	
.357	5.951	0.346	0146	.253	5.959	0.337	
.363	5.956	0.342	0.147	.258	5.960	0.344	

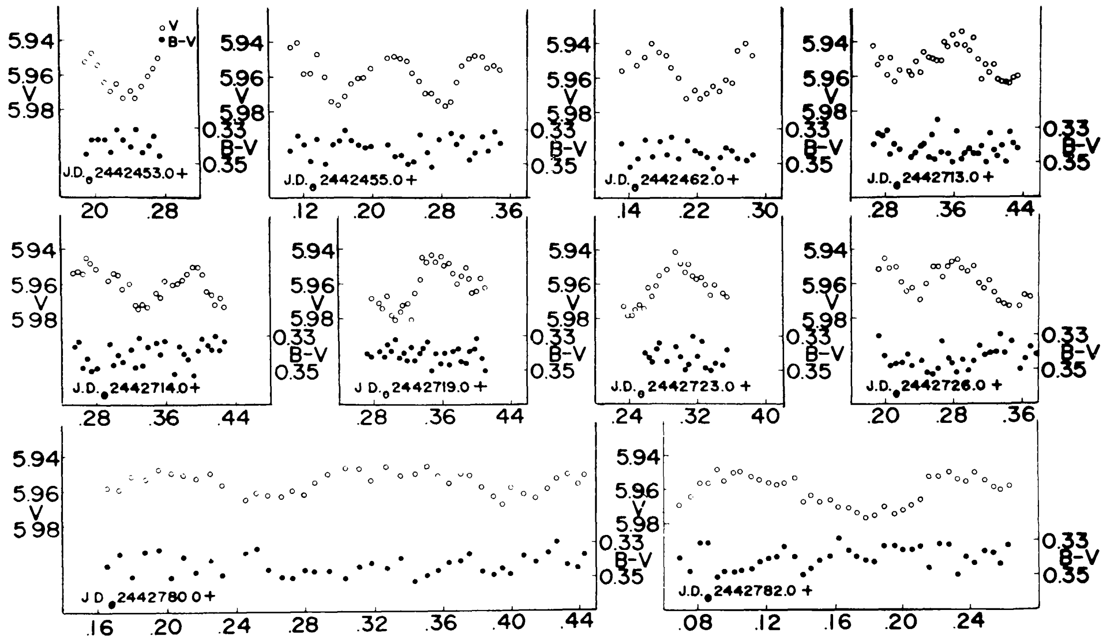

Fig. 1. Light and colour curves of 59 Aur.

earlier paper (Gupta, 1979). The V magnitudes, $(B - V)$ and $(U - B)$ colours are tabulated in Table I, and the light and colour curves are plotted in Figure 1.

3. Period

The light curves (Figure 1) show variable amplitudes on different nights and suggest a beat phenomenon. A periodogram analysis and the least-squares solution, as

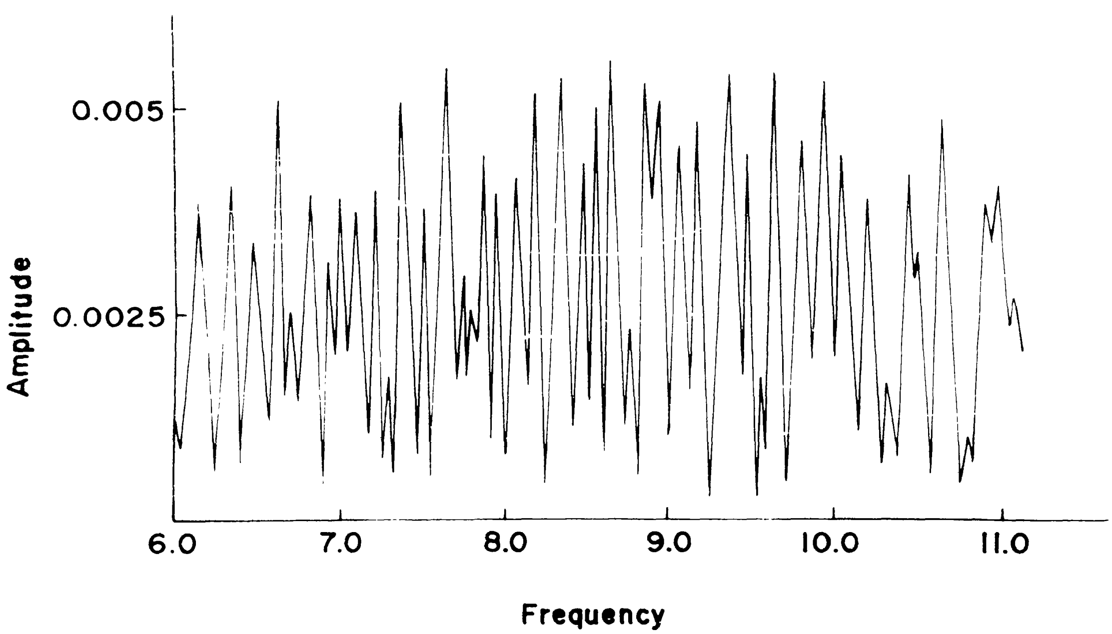

Fig. 2. Periodogram analysis for 59 Aur using V observations.

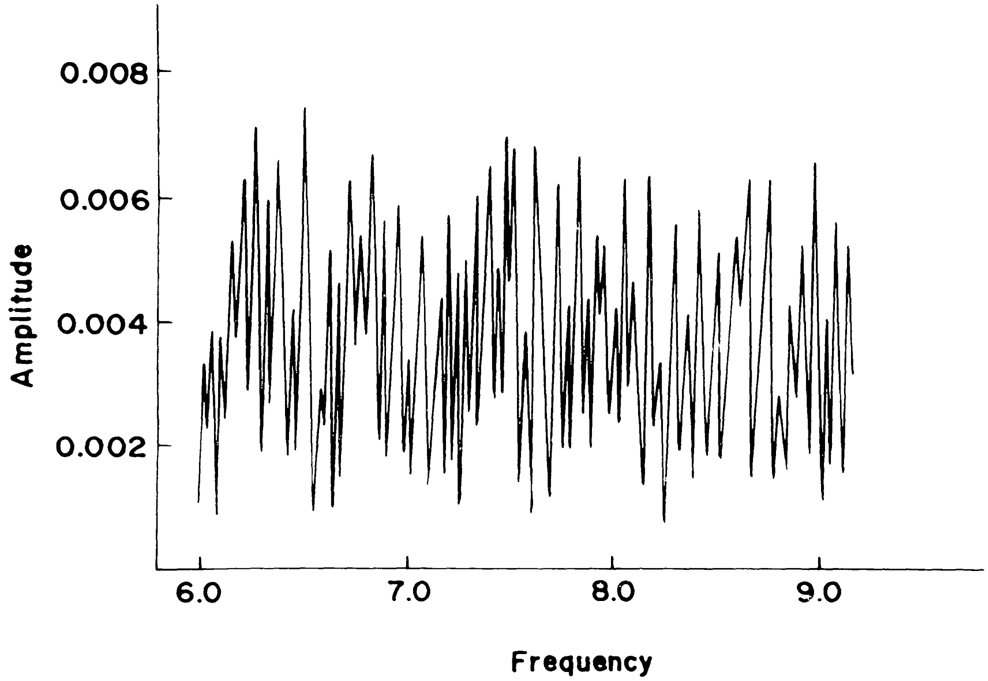

Fig. 3. Periodogram analysis of the residuals, for 59 Aur after subtraction of the peak at 8.662 c/d.

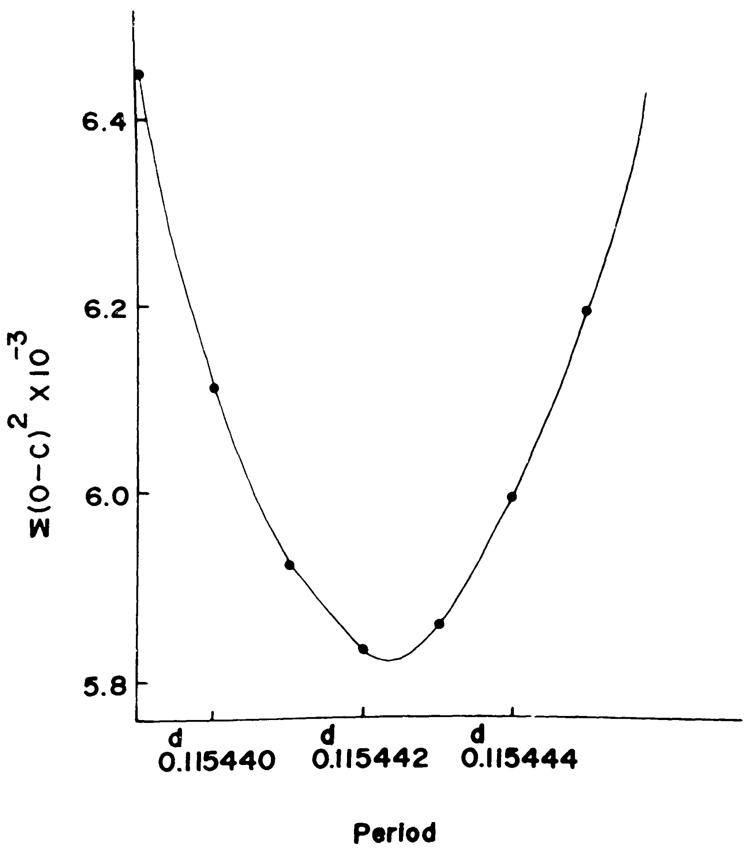

Fig. 4. Plot between trial values of primary period versus $\Sigma\,(O - C)^2$ for 59 Aur.

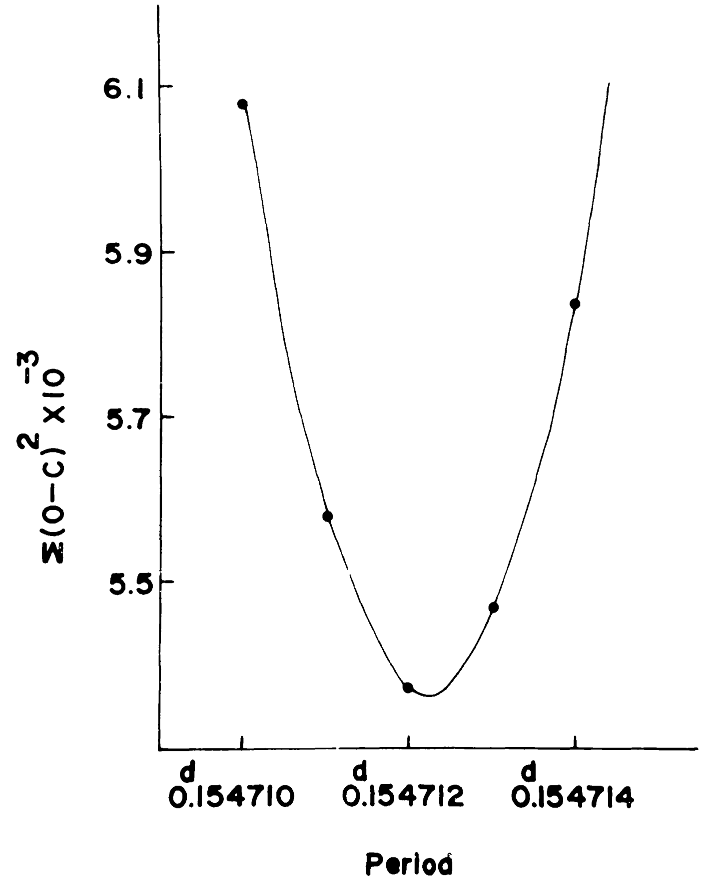

Fig. 5. Plot between trial values of secondary period versus Σ (O − C)^2 for 59 Aur.

described in the earlier paper (Gupta, 1979), have been carried out to determine the frequencies present in the light variations of 59 Aur. In the periodogram analysis, the tallest peaks are obtained at 8.662 c/d (Figure 2) and 6.475 c/d (Figure 3) which correspond, respectively, to the primary period of $0^d.1154$ and the secondary period of $0^d.1544$. These periods are in fair agreement with the values of $0^d.115442 \pm 0^d.000001$ (Figure 4) and $0^d.154712 \pm 0.000001$ (Figure 5), respectively determined from the least-squares solution. The implications of the periods are discussed in a later section.

4. Discussion

Eggen (1963) obtained the mean value of V magnitude of 59 Aur to be $6^m.14$, and according to Danziger and Dickens (1967) the V magnitude of the star is $6^m.12$. However, on the basis of our observations the mean V magnitude of 59 Aur is found to be $5^m.96$, which is in close agreement with the value of $5^m.96$ given by Hoffleit (1964) and with the value of $6^m.00$ obtained by Baglin *et al.* (1973).

The $B - V$ and $U - B$ colours of 59 Aur have been found to be $+0^m.38$ and $+0^m.14$, respectively, by Eggen (1963), while Danziger and Dickens (1967) obtained values of $B - V = +0^m.37$ and $U - B = +0^m.12$. In the present investigation, the

$B - V$ and $U - B$ colours are derived to be $+0^m.34$ and $+0^m.14$, respectively. The $B - V$ colour obtained by us is lower than the previous estimates, while the $U - B$ value is in fair agreement with the value derived by Eggen (1963). No variations exceeding $\pm 0^m.01$ about the mean values of $B - V$ and $U - B$ have been found by us during a pulsation cycle.

The effective temperature (T_e) of 59 Aur based on *uvby* β-photometry by Petersen and Jorgensen (1972) was derived to be nearly 7000 K. By use of the new $T_e - (b - y)$ calibration (Breger, 1975), the effective temperature is derived to be 7100 K, while we estimated its effective temperature to be nearly 7300 K from our estimated $B - V$ value. In deriving the effective temperature we have used the $(B - V) - (b - y)$ calibration given by Golay (1972) and $T_e - (b - y)$ calibration given by Breger (1975).

The absolute magnitude of 59 Aur is derived to be $1^m.22$ from the improved P–L–C relations given by Gupta (1978) for the δ Scuti variables. Likewise, the bolometric magnitude is derived to be $1^m.03$. Based on *uvby* β-calibrations, Baglin *et al.* (1973) derived the absolute magnitude to be $1^m.33$.

Further, from the relation given by Breger and Bregman (1975) for the pulsation constant (Q) and using the period $0^d.1544$ and the related parameters T_e, M_{bol} derived by us, and using the value of gravity derived by Petersen and Jorgensen (1972), we calculated the value of Q to be $0^d.032$, which is closer to the value of $0^d.0333$ derived from model calculations for δ Scuti stars pulsating in the fundamental mode. Likewise, from the period $0^d.1154$, the value of Q is derived to be $0^d.024$, which is closer to the model-based value $0^d.0252$ derived for first overtone δ Scuti pulsators (Petersen, 1976). Thus, it appears that the fundamental ($P_0 = 0^d.1544$) as well as first overtone ($P_1 = 0^d.1154$) modes are present in the light variation of 59 Aur.

In the periodogram analysis, the amplitude of light variation is found to be larger for the fundamental than for the first overtone. This indicates that the fundamental mode is more prominent in the pulsation. The period ratio P_1/P_0 is derived to be 0.748, which is in fair agreement with the theoretical value of 0.757 derived for the δ Scuti pulsators pulsating in the radial modes (Petersen, 1976). Thus, it appears that the complexity in the light variation of 59 Aur is due to the superposition of radial modes.

Employing our observations, and using the empirical relation given by Petersen and Jorgensen (1972), the mass of the star is derived to be 1.7 $M_\odot$ while from Iben's (1967) evolutionary tracks for Population I stars evolving from the Main Sequence towards the red giant branch, the mass is found to be 2.0 $M_\odot$. Both these estimates of mass are within the range $1.5\ M_\odot \leqslant M \leqslant 2.5\ M_\odot$ in which most of the δ Scuti stars lie (Baglin *et al.*, 1973).

Acknowledgements

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Note added in proof Recent work by Kraitcheva, Popova, Tutukov and Yungelson (1979, *Nauch. Inform.* **56**, 520) shows that the real initial mass ratio distribution is concentrated towards $q = 1$. However, such distribution does not affect the general outlook of the transformed distribution after mass exchange, which is primarily dominated by β.

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