Astron. Astrophys. 362, 595–598 (2000)

ASTRONOMY
AND
ASTROPHYSICS

Complicated pulsation in the δ Scuti variable 59 Aurigae

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Received 7 February 2000 / Accepted 3 July 2000

Abstract. Eight-night photoelectric photometric observations through v and y bands confirm the complicated pulsation of δ Scuti variable 59 Aurigae. Power spectra of light curves show multi-period pulsation behavior, and eight pulsation frequencies f_1=6.8283, f_2=6.3179, f_3=5.0074, f_4=5.9535, f_5=4.3285, f_6=5.6854, f_7=9.0206 and f_8=8.6260 cycles per day are identified. After subtraction of the best eight frequency solution, there are still more peaks that can be distinguished in the residual power spectrum. The eight frequency solution covers the frequency solution of Gupta (1980) and fits his data. The close frequency distribution supports a non-radial pulsation identification. Pulsation constant values of eight modes are distributed in a wide range from g_1 to p_3 mode.

Key words: stars: variables: δ Sct – stars: oscillations – stars: fundamental parameters – stars: individual: 59 Aur

1. Introduction

The variables located in low instability strip attract more and more attention. One reason is that these variables usually pulsate with a large number of simultaneously excited radial and nonradial modes, which makes them well-suited for asteroseismological studies. Another reason is that their differences in macrostructure usually result in fine differences in the distribution of pulsation frequencies, making the analysis of frequency distribution an important tool to study the effects caused by fine difference in model structure. It is important to find some complicated pulsation δ Scuti variables and identify their main pulsation frequencies. Based on this idea, we organized one-site observations of some low-amplitude variables.

The star 59 Aurigae (HD 50018, HR 2539, SAO59571) is a visual binary, the fainter component being of apparent magnitude $10^m.20$. Danziger & Dickens (1967) and Breger (1970) suspected the star to be a variable of unknown type during their photoelectric surveys. Gupta & Bhatnager (1974) made about six hours of observations of this star and found a mean period of $0^d.136$(7.353 c/d) with a light variation amplitude of about $0^m.03$ during one cycle. They concluded that the variable is a δ Scuti variable. From 1975 to 1976, Gupta performed ten-night observations on this variable. Through a periodogram analysis and least-squares solution (Gupta 1980), two frequencies 8.662 and 6.457 cycle per day were selected from indistinct amplitude spectra. According to the pulsation constant values and period ratio, these two frequencies were identified as fundamental and first overtone. As the amplitude spectrum is not very clear and the data window is not good enough, we observed this star from Jan. 13 to 23, 1999 and here publish some of our results.

2. New photoelectric measurements and data analysis

The observations were made applying the 85 cm reflector installed at the Xinglong Station of Beijing Observatory, China, with a six-channel two-filter photometer which is a new version of the one once used in the STEPHI Network campaign (Michel et al. 1995). During the observations, a v filter with a center wavelength of 411 nm and bandwidth of 20 nm and a y filter with a center wavelength of 550 nm and bandwidth of 40 nm were used. The stars SAO 59589 and SAO 59576 were selected as comparisons. The observations in the v filter were of high quality, a good data set covering eight nights (about 70 hours) was obtained within the measuring error of about 6.0 mmag. For the y filter, the observation error is a little larger than that of the v filter. In some nights a drift was very obvious, which maybe caused by the multichannel photometer or the variable star. The measuring error for y is around 7.0 mmag; the data set also covers eight nights (about 70 hours). No evidence of variability of the comparison stars was found.

A multiple-frequency analysis of 59 Aurigae was performed with a package of computer programs employing single frequency (Fourier) and multiple-frequency least-squares techniques (program PERIOD, Breger 1990a) which utilize Fourier as well as multiple-least squares algorithms. The latter technique fits a number of simultaneous sinusoidal variations in the magnitude domain and does not rely on prewhitening. As the quality of the y band is not high enough, our period analysis is mainly based on the v filter data.

Fig. 1 shows the power spectra of the v data before and after subtraction of the best single to eight-frequency solution. At the top of the figure the spectral window based on the times of available observations is plotted. We note that alias patterns, including the 1 c/d daily aliases, are quite low in the spectral window. The existence of eight frequencies of pulsation (6.8283, 6.3179, 5.0074, 5.9535, 4.3285, 5.6854, 9.0206 and 8.6260 cycles per day) is suggested. This is also shown by their S/N ratios. The noise has been calculated as a function of frequency after subtraction of the best eight frequency solution. The eight detected

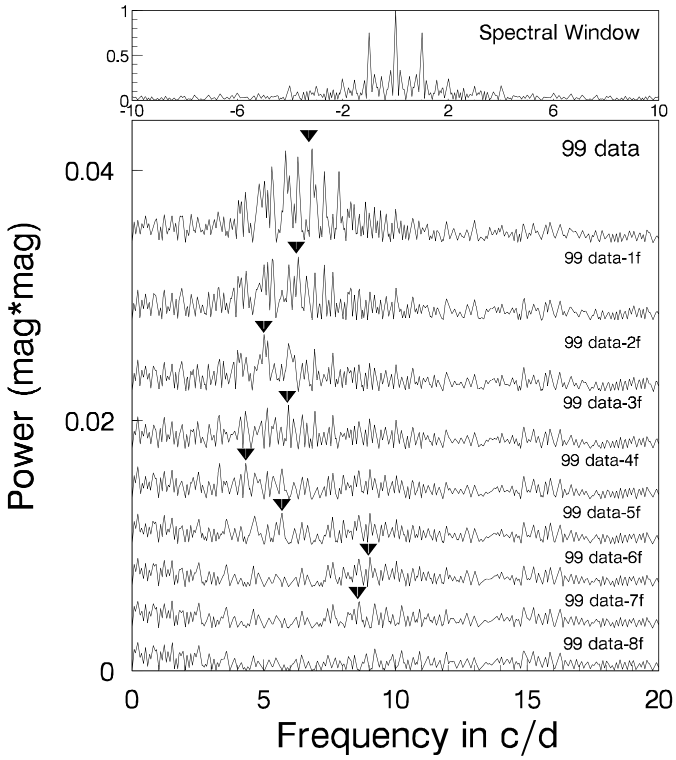

Fig. 1. The power spectra of 59 Aurigae for the v band. The spectra are shown before and after applying multiple frequency solution.

frequencies have amplitude S/N ratio of 11.0, 9.1, 9.6, 9.9, 5.4, 5.3, 4.0 and 3.8, respectively. The first 6 frequencies are convincing and are accepted as real. The seventh and eighth frequencies lie in the region between being selected or abandoned. Considering that the eighth frequency is the best solution of observations of Gupta (1980), we chose to keep the last two frequencies in our frequency solution. After removal of the eight frequencies, the residuals are of the order of 7 mmag. More peaks, which are a little above the noise level, also can be picked up. It seems that other pulsation frequencies may also exist in 59 Aurigae.

As the y band data are not of high quality, it is difficult to obtain the same solution from the period analysis of y data alone. However, the eight-frequency solution fit the light curves very well (see Fig. 3). The fitted residuals are around 7.5 mag; this is very close to the observed uncertainty. Table 1 shows the eight-frequency solution to v and y bands data with their amplitude as well as significance of detection from v. The fits to the data are displayed in Fig. 2 and Fig. 3. It is necessary to point out that not all the amplitude differences between v and y are completely real, especially for f_5 and f_1. We suggest that some system error caused by the binary system or the drift between different channels may be significant.

In order to check the reliability of our eight-frequency solution, we fit our frequency solution to the data obtained by Gupta from 1975 to 1976. We list the frequency solution in Table 1. With the exception of the low-frequency term f_5=4.3285 that is not clear and is omitted, other frequencies fit the original solution very well. The fitting residuals lay in the range of 7.1 mmag,

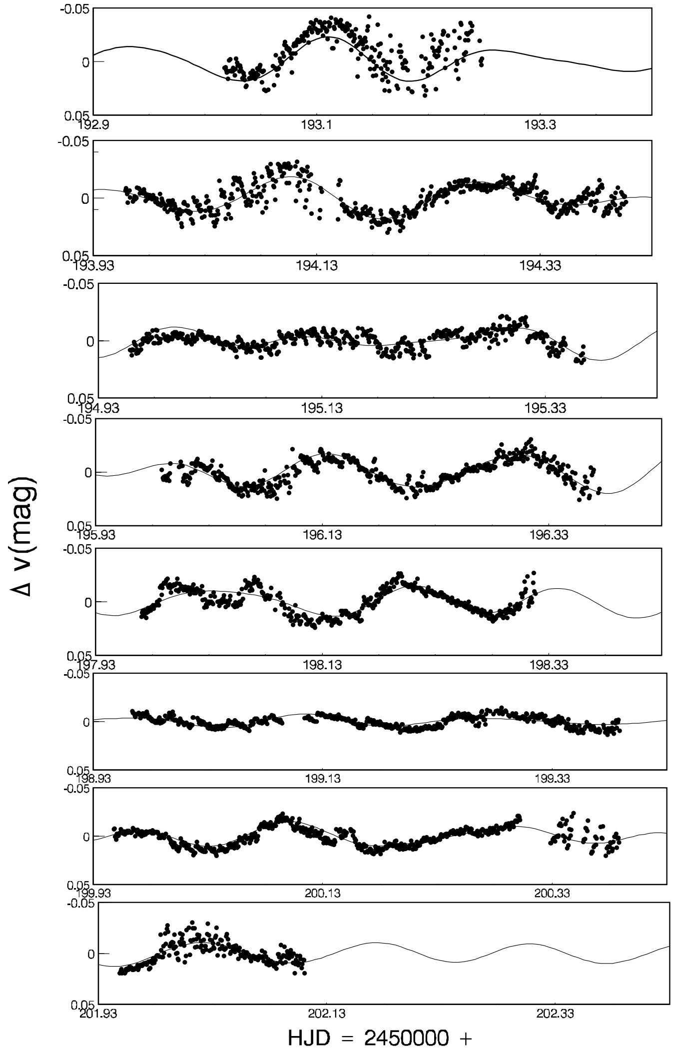

Fig. 2. The fit of the eight-frequency solution to v band data.

which is better than that of the solution of Gupta (1980). As to why the frequency 4.3285 disappears, we think there are two possibilities. One possibility is that the value 4.3285 is not accurate and may be caused by the extinction or drift of photometer. The other possibility is that the value 4.3285 is correct, but the data set of Gupta is not large enough to cover this frequency. In all observations of Gupta (1980), the longest continuous observation is around five hours and among all observations, only two nights are consecutive. In this kind of data file, it is difficult to cover a frequency that is smaller than 4.5 c/d. We display the fits in Fig. 4. The result is much better than the frequency solution obtained by Gupta himself.

3. Discussion

Comparing the frequencies 8.662 and 6.475 c/d obtained by Gupta (1980) with our frequency solution, we did not find a contradiction between the results. The first frequency 8.6620 can be identified as our frequency $f_8 = 8.6260$. The second frequency 6.475 is almost the same as our second frequency

Table 1. The frequency spectrum of 59 Aur.

Name	Frequency cd^{-1}	μHz/ID	Amplitude (1999) v Filter mmag	y Filter mmag	Amplitude (1975–1976) V Filter mmag	Significance refer to v(1999) Ampltude S/N
f_1	6.8283	79.03	6.1	2.8	6.3	11.0
f_2	6.3179	73.12	4.7	3.8	6.6	9.1
f_3	5.0074	57.96	5.4	4.6	2.2	9.6
f_4	5.9535	68.91	5.4	2.7	2.7	9.9
f_5	4.3285	50.10	3.5	5.2	?	5.4
f_6	5.6854	65.80	2.9	4.6	2.9	5.3
f_7	9.0206	104.41	2.5	1.7	3.8	4.0
f_8	8.6260	99.84	2.3	2.1	4.5	3.8

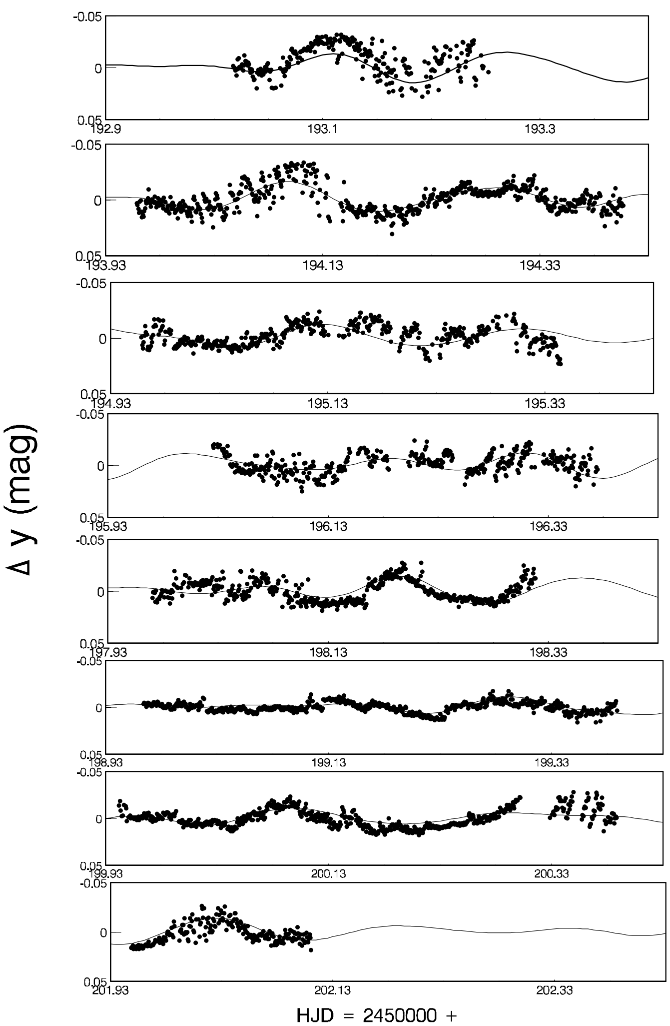

Fig. 3. The fit of the eight-frequence solution to the y band data.

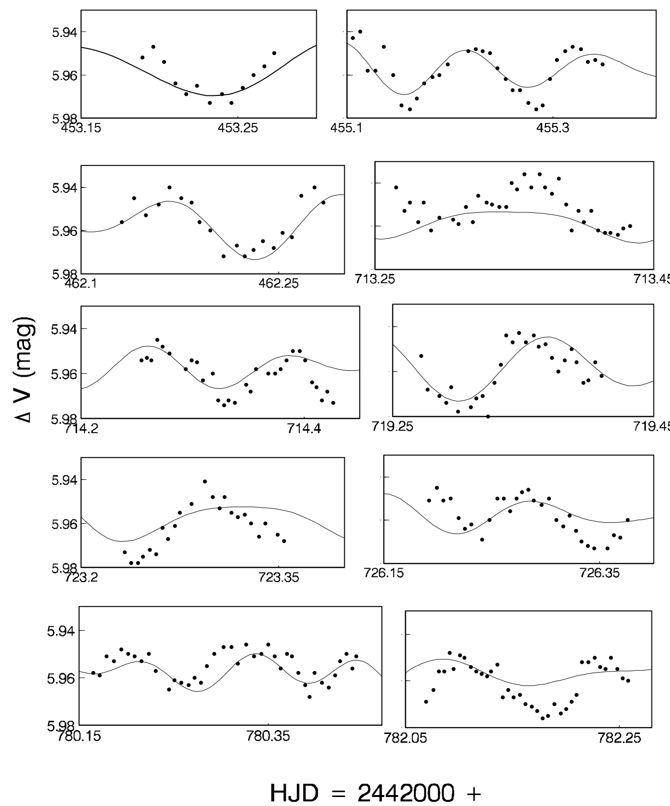

Fig. 4. The fit of the eight-frequence solution to the data obtained by Gupta in 1975–1976.

6.3137; the difference can be explained by distortion of other frequencies such as $f_1 = 6.8283$, $f_4 = 5.9535$, etc.

In Table 2, We list the physical parameters of 59 Aurigae selected from the catalogue of Rodriguez et al. (1994). By use of the T_e-(b-y) calibration (Breger 1975), we find the effective temperature is derived to be $7100 \pm 150\,$K. The gravity based on uvby-H_β is derived to be $\log g$=3.59 $\pm\, 0.1$. 59 Aurigae is Hipparcos #33041 with parallax 6.15 ± 0.79 milli-arcsec. Antonello & Mantegazza (1997) showed that Hipparcos distances give more reliable values of M_v than the older photometric calibrations. For 59 Aurigae $M_v = 0.04 \pm 0.28$. The values of the pulsation constants Q (day) can be estimated from the following equation (Breger 1990b)

$$\log Q = -6.454 + \log P + 0.5 \log g + 0.1 M_{bol} + \log T_{eff}.$$

We find the Q values for f_1 to f_8 to be 0.023 ± 0.004, 0.025 ± 0.005, 0.031 ± 0.006, 0.026 ± 0.005, 0.036 ± 0.006, 0.028 ± 0.005, 0.017 ± 0.003, 0.018 ± 0.003 d respectively, where an uncertainty of 18% was adopted (Breger 1990b).

Table 2. The uvbyβ of 59 Aur.

star	V	b-y	m_1	c_1	β	vsini	sp.
HD 50018	6.12	0.24	0.186	0.764	2.702	130	F2V

According to these values, corresponding pulsation modes seem to be distributed in the range from g_1 to p_3 mode, and the frequency distribution clearly support a non-radial model identification. As 59 Aurigae has vsini as high as 130 km s^{-1}, considerable frequency changes due to rotation can be expected. Further, frequency splitting for nonradial modes can greatly complicate the mode identification. Accurate mode identifications need more observations, and a multi-site campaign may provide significant asteroseismological information.

4. Conclusion

It has been shown that 59 Aurigae is a complicated pulsation δ Scuti variable. Eight main frequencies f_1=6.8283, f_2=6.3179, f_3=5.0074, f_4=5.9535, f_5=4.3285, f_6=5.6854, f_7=9.0206 and f_8=8.6260 cycles per day were found. 59 Aurigae has a non-radial pulsation character with pulsation modes distributed in the range from g_1 to p_3. It is a good candidate for δ Scuti variable asteroseismology.

Acknowledgements. This work has been supported by the Chinese National Natural Science Foundation

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