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Pulsation behavior of classical Am star 60 Tauri

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Abstract. Five nights photoelectric photometric observations through v and y bands confirm the pulsation of classical Am δ Scuti variable 60 Tau. Power spectrum of light curves shows multi-period pulsation behavior of 60 Tau and two pulsation modes f_1=13.0364 and f_2=11.8521 cycles per day are definitely identified. Classical Am star 60 Tau is a complicated pulsation δ Scuti variable. Considering the pulsation constant Q, 60 Tau is identified to be low overtone f or p_1 modes tendentiously.

Key words: stars: variables: δ Sct – stars: oscillations – stars: individual: 60 Tau

1. Introduction

The variables located in the low instability strip usually pulsate with a large number of simultaneously excited radial and nonradial modes, which makes them well-suited for asteroseismological studies. Stars in this strip usually are classified into normal stars, Ap and Am stars. It is accepted that normal stars and Ap stars could be variables. As for Am stars, because of their metallicism property, their instability becomes very complicated. Generally, for Am stars in which diffusion does occur, it is thought that the helium sinks out of the He II ionization zone, thus inhibiting the driving mechanism for pulsation that exists for δ Scuti stars. Baglin (1972), Vauclair et al. (1974) calculate that, in a star in which diffusion occurs, helium sinks rapidly from the He II ionization zone. For the special marginal Am stars and evolved Am stars, it is thought that they are able to drive the pulsation. Vauclair (1976, 1977) suggested a diffusion model with the following salient features for Am stars and δ Scuti stars: 1) Classical Am stars and δ Scuti pulsator should be mutually exclusive owing to the extinguishing of the κ mechanism by the downward diffusion of helium from the He II ionization zone; 2) After a stable phase in which abundance anomalies develop, turbulent motions arise which restore the helium content of the He II ionization zone, so that Am stars evolve into δ Scuti pulsator; 3) At medium rotational velocities of approximately 30–100 km s^{-1}, it should be possible for a star to exhibit both low-amplitude pulsation and mild abundance anomalies.

During the early period of photoelectric photometric observational study of δ Scuti variables, some evolved Am stars or δ Delphini stars have been found to be δ Scuti variables (Kurtz 1976). Then Kurtz suggested that for evolved Am stars, the helium depletion in the He II ionization zone is not sufficient to eliminate convection in that zone, providing a convective barrier between the upper and lower radiative zones so that the Am anomalies can arise quickly from diffusion in the upper radiative zone and then remain essentially time-independent during the Main-sequence lifetime of the Am star as required by the observations (Smith 1971, 1973). Enough helium remains in the He II ionization zone that pulsation instabilities can grow in an Am star as it evolves into the giant region, as the evidence that some Am stars evolve into δ Scuti pulsators requires.

Evolved Am stars are described by Kurtz (1976) that either (i)diffusion occurs below the He II ionization zone where the pulsation amplitude becomes small due to the increasing density, or (ii) mixing across the upper radiative zone is a slow enough process that these δ Delphini stars represent evolved Am stars in which diffusion no longer occurs but for which mixing has not yet eliminated the apparent surface anomalies.

The discovery of large amplitude pulsating evolved Am star HD 40765 provided a strong challenge to the diffusion hypothesis (Kurtz et al. 1995). Just as Kurtz et al. have pointed out, if the diffusion hypothesis is correct, then it implies that pulsation velocities of several km s^{-1} generate no turbulence at the level of fraction of a cm s^{-1}. If a lack of turbulence at that level should be theoretically surprising in such a pulsating star, then diffusion should be reconsidered as the sole explanation of the strongly metallic-lined spectrum of HD 40765, and by inference, other Am stars.

Marginal Am stars are metallic line stars in which there is a difference of less than five subclasses between the k-line type and the metal line type. These marginal Am stars belong to the kind of Am stars in which the line strength anomalies are mild. Kurtz (1978) found that two marginal Am stars HR 8210 and HR 4594 were δ Scuti variables. Kurtz (1984) found that another marginal Am star HR3321 also had δ Scuti variables pulsation. It seems that mild metallicism and pulsation can coexist in the same star among marginal Am stars. Cox et al.(1979) calculated the linear-theory radial-pulsation stability of low-helium δ Scuti variable models and concluded that pulsation can still occur with

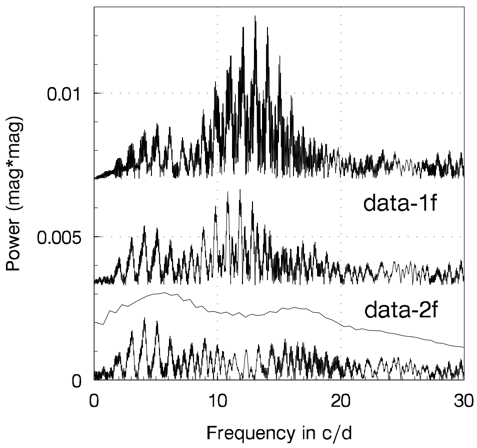

Fig. 1. The power spectra of 60 Tau for v band. The spectra are shown before and after applying multiple frequency solutions.

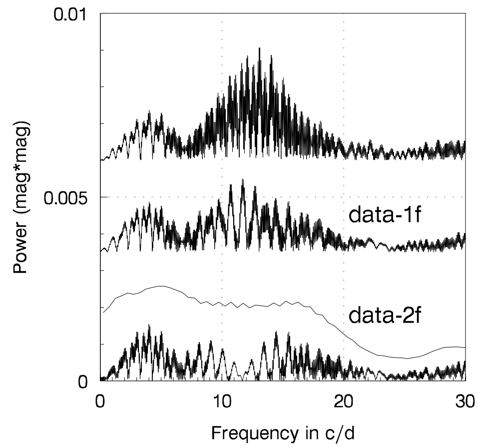

Fig. 2. The power spectra of 60 Tau for y band. The spectra are shown before and after applying multiple frequency solutions.

driving due to the residual helium and the enhanced hydrogen, the blue and red edges of the pulsation are estimated to be about half the width of that of the normal helium abundance.

At the beginning of 70s, it was generally accepted that the classical Am stars do not pulsate (Breger 1970), and no exceptions were found (Kurtz et al. 1976). In 1989, an extreme example of a classical Am star HD 1097 was discovered to be a δ Scuti variable by Kurtz (1989). If diffusion is the correct explanation of the abundance anomalies in the Am stars, then there must be sufficient residual helium left in the He II ionization zone to drive small-amplitude pulsation. Another possible classical Am star that was found to be δ Scuti variable is 32 Vir (Bartolini et al. 1983). However, it is still open whether 32 Vir is a classical Am star or an evolved δ Delphini star.

60 Tau (HR 1368, HD 27628, SAO 93892), a spectroscopic binary Am star (Cowley et al. 1969), was classified as a classical Am star by Kurtz (1978), and was confirmed by high resolution spectroscopic observations (Burkhart et al. 1989). In a photometric survey of the Hyades for δ Scuti variables, Horan (1979) observed it for about 9 hours and found that it is a δ Scuti variable with a period of around 1.5 hours. In order to confirm its pulsation and compare its pulsation behavior with normal δ Scuti variables, we observed and analyzed this star from Jan. 8 to 23, 1999 and hereby publish some of our results.

2. New photoelectric measurements and data analysis

The observations are made using 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 STEPHI Network campaign (Michel et al. 1995). During the observations, v filter with a center wavelength of 411 nm and band width of 20 nm and y filter with a center wavelength of 550 nm and band width of 40 nm were used. The stars SAO 93878 and SAO 93889 are selected as comparisons. Within the measuring error of about 4.0 mmag, a good data set covering five nights (about 30 hours) was obtained. No evidence of variability of the comparison stars was found.

A multiple-frequency analysis of 60 Tau 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.

Fig. 1 shows the power spectra of the data of the v band before and after subtraction of the best single and two frequency solutions. The existence of two frequencies of pulsation (13.0364 and 11.8521 c/d) is very convincing. This is also shown by their S/N ratios. The noise has been calculated as a function of frequency after subtraction of the best two frequency solutions. The curve corresponding to an amplitude S/N ratio of 4 is shown in the bottom panel of the figure. The two detected frequencies have amplitude S/N ratio of 10.2 and 5.8, respectively, and are accepted as real. After removal of the first and the second frequencies, the residuals are of the order of 4.6 and 3.8 mmag respectively. More peaks which are a little above the noise level can be picked up too. It seems that there are still other pulsation frequencies existing in 60 Tau.

The power spectra of the data of y band is shown in Fig. 2. The results are remarkably similar to the results obtained from the v filter. Two frequencies with values of 13.0350 and 11.8439 are confirmed and their detection is statistically significant, the differences against the values obtained from v band can be explained by the time resolution. After removal of the first and the second frequencies, the residuals are of the order of 3.5 and 3.2 mmag respectively. And the residual power spectrum also supports more than two pulsation frequencies in 60 Tau.

The two-frequency solution to v and y bands data with their amplitude and significance of detection are given in Table 1. The fits to the data are displayed in Fig. 3 and Fig. 4. From the figures we can find the fits are not good at the end of some data set. It is probably caused by the extinction, because at these periods of observations, the altitude of star is not high enough to accurately and completely cancel the effect of atmosphere.

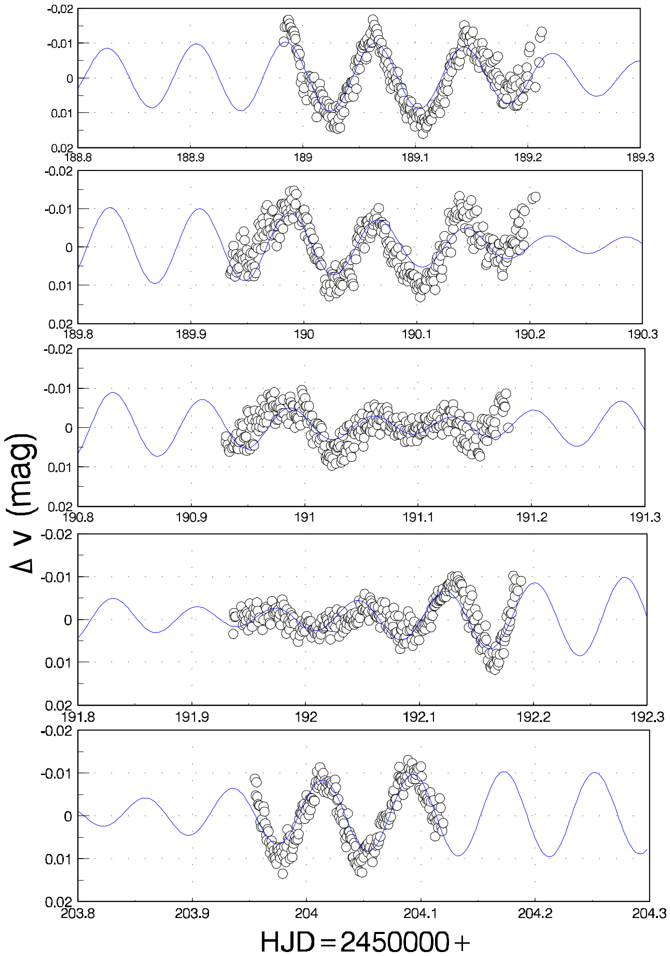

Fig. 3. The fits of the two-frequence solution to the v band data.

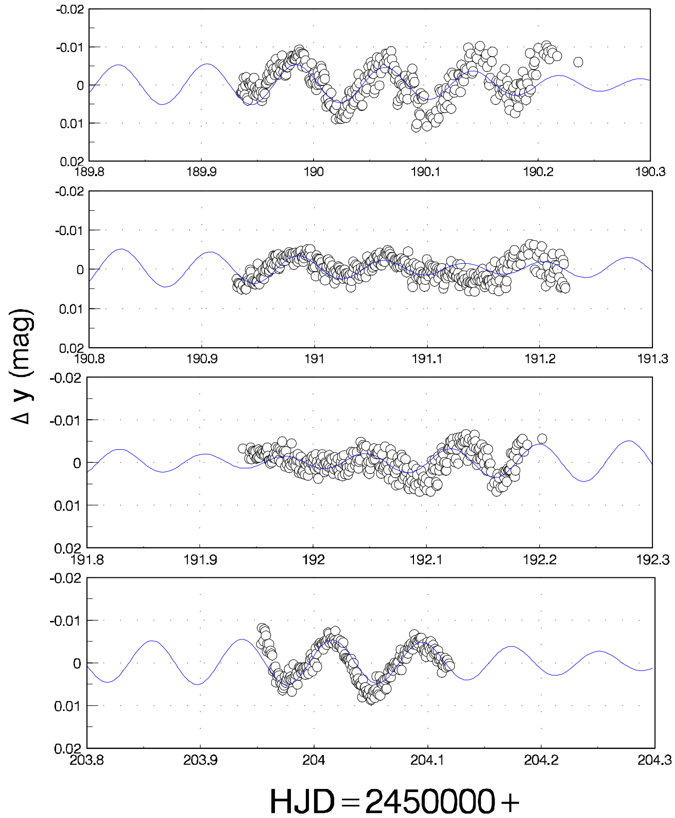

Fig. 4. The fits of the two-frequence solution to the y band data.

Table 1. The frequency spectrum of 60 Tau

Name	Frequency cd^{-1}	μHz/ID	Amplitude v Filter mmag	y Filter mmag	Significance of detection Amplitude S/N
f_1	13.0364	150.886	6.01	3.35	10.2
f_2	11.8521	137.179	3.95	1.99	5.8

3. Discussion

The luminosity of 60 Tau, M_v=2.52 mag, is accurately obtained from the Hipparcos data (Li Zhiping et al. 1999). The temperature and gravity come from spectroscopic analysis (Burkhart et al. 1989): T_{eff} = 7350 K and $\log g$ = 4.0. The values of the pulsation constants Q (day) can be estimated from the following equation (Breger 1990b)

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

where P is period in unit day, g is gravity in unit cm s^{-2}, M_{bol} in unit mag and T_{eff} in K. For f_1 and f_2, the Q value are 0.032 and 0.035d respectively which indicate either fundamental or first overtone pulsation. And the frequency distribution clearly supports a non-radial modal identification.

It has been confirmed that all kinds of Am stars, including evolved Am stars, marginal Am stars and classical Am stars, can be δ Scuti variables. It seems meaningless to discuss whether the pulsation and metallicism can coexist in low instability strip. The pulsations of HD 1097 and 60 Tau tend to show that even for classical Am stars, there is sufficient residual helium left to drive δ Scuti pulsation. For normal stars in the region, only about 30 per cent are δ Scuti stars which pulsate with amplitude ranging from a few mmag to nearly 1 mag. It is normal that the pulsations of some Am stars have not been detected.

The pulsation amplitude of Am δ Scuti variables is another topic which deserves attention. Usually people think that the amount of helium left in the He II ionization zone is limited because of the diffusion, Am δ Scuti variables are barely able to excite low-amplitude pulsation. However, compared with low-amplitude δ Scuti variables (about 0.01 mag), more and more Am δ Scuti variables are discovered to be larger amplitude pulsation variables, for example, the evolved Am star HD 40765 (Kurtz et al. 1995) with a peak to peak amplitude of ΔB= 0.21 mag and ΔV= 0.15 mag, evolved Am HD 188136 with a peak to peak amplitude of ΔV= 0.05 mag (Kurtz 1980), marginal Am δ Scuti HR 4594 with peak to peak amplitude around Δy= 0.035 mag (Kurtz 1978), classical Am δ Scuti variable HD 1097 with a B band peak to peak amplitude of about 0.02 mag (Kurtz 1989), and v band peak to peak amplitude of pulsation of 60

Tau beyond 0.02 mag etc. Though some Am δ Scuti variables pulsate with a very low amplitude, for example, the Marginal Am δ Scuti star HR 3321 (Kurtz 1984) with a B band amplitude in the range order of 0.01 mag, many normal δ Scuti variables, such as HD 23156, HD 20919 (Li Zhiping et al. 1999), pulsate with amplitude around 0.01 mag. It seems that the amplitude distribution of Am δ Scuti variables is not different from that of δ Scuti variables. Therefore, it is still open whether the amplitude distribution of Am δ Scuti variables show some special behavior (for example, preference of low-amplitude pulsation).

Whilst a few Am variables, such as HD40765 (Kurtz et al. 1995) and HR 3321 (Kurtz 1984), show singly-periodic pulsation, most of the others, such as HR 4594, HR8210 (Kurtz 1978), HD 188136 (Kurtz 1980) and HR 1097 (Kurtz 1989) etc., show multi-period pulsation. This is not surprising when we compare the result with those of normal δ Scuti variables. However, almost all pulsation modes of Am stars are reported to be in the range of fundamental or low overtone (f or low p; Bartolini et al. 1983, Kurtz 1978, 1980, 1984, 1989, Kurtz et al. 1995), the situation is a little different compared to normal δ Scuti variables which normally prefer middle overtones (p_2 or p_3). This phenomenon might be explained from the point of both pulsation theory and theory on the origin of the chemical peculiarities.

4. Conclusion

It has been reported that the classical Am star 60 Tau is a complicated pulsation δ Scuti variable, two main frequencies f_1=13.0364 and f_2=11.8521 cycle per day are found and are tentatively identified to be low overtone modes f or p_1. It is now clear that pulsation and metallicism can co-exist in A-type stars. The δ Del stars are evolved metallic line stars which often are δ Scuti stars, some marginal Am stars are δ Scuti stars, and now some classical Am stars have been found to be δ Scuti variables. So it is confirmed that there must be sufficient residual helium left in the He II ionization zone of Am stars to drive small amplitude pulsation.

The pulsation amplitude of Am δ Scuti stars is usually located in the range of normal δ Scuti variables, and large amplitude pulsation for Am δ Scuti variables is possible also. Although it is obvious that metallicism of Am stars does not require complete stellar stability, it still needs a further study whether the metallicism does suppress pulsation amplitude. Most Am δ Scuti stars show multi-period pulsation behavior, and almost all of them prefer low overtones (f or low p) model pulsation.

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