EQ Eridani, a Multiperiodic δ Scuti Star

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Abstract DSLR photometry of the δ Scuti star EQ Eridani (HD 28665) was undertaken on six nights between 2 November and 8 December 2013. Comparison and check stars were HD 28508 and HD 28901, respectively. Inspection of the light curves revealed an irregular pattern and variation in amplitude that signified the presence of two or more periods. Fourier analysis using the software PERIOD04 yielded at least three pulsation frequencies of 14.3663, 11.6862, and 7.2128 cycles per day, corresponding to periods of 0.0696, 0.0856, and 0.1386 day, respectively. The first of these frequencies is very close to the period of 0.0700 day listed in a catalogue of δ Scuti stars published in 2000. This is the first report of multiperiodicity in EQ Eri. None of the period ratios fall within the range of 0.74–0.78 expected for the ratio of the first overtone to the fundamental mode of δ Scuti stars pulsating in the radial mode.

1. Introduction

Koen and Roberts (1993) reported the star HD 28665 to be a δ Scuti pulsator with a frequency of 15.136 cycles per day (period 1.58 hours) and a semi-amplitude of 0.049 magnitude. Koen *et al.* (1995) later reported a frequency of 14.2 cycles per day and an amplitude in V of approximately 0.1 magnitude. The catalogue of stars published by Rodríguez *et al.* (2000) lists EQ Eri as having a period of 0.0700 d, with no mention of other periods, and an amplitude in V of 0.1 magnitude. Because of the paucity of published studies of EQ Eri, it was decided to investigate its light curve utilizing DSLR photometry and Fourier analysis.

2. Observations

DSLR photometry reduction was performed on RAW images taken with a Canon EOS 500D DSLR camera imaging through a refracting telescope with an aperture of 80mm at f/7.5, mounted on a Losmandy GM8 German equatorial mount. A total of 680 magnitude determinations, transformed to the Johnson V system, were obtained during a cumulative observing time of 35.07 hours. The shortest observing run for one night was 3.38 hours, and the longest 7.54 hours, including short gaps in the data due to meridian flips and intermittent cloud. Photometric data reduction from instrumental magnitudes

utilized the software package AIP4WIN. The comparison and check stars were HD 28508 and HD 28901, respectively. Transformed magnitudes in V were calculated using transformation coefficients for the blue and green channels of the DSLR sensor, obtained from images of standard stars in the E regions (Menzies *et al.* 1989).

3. Analysis

Inspection of the light curves revealed an irregular shape and varying amplitude, indicating that the star has two or more periods. Fourier analysis using the software PERIOD04 revealed several frequencies of pulsation, which are shown in Figure 1. The first three frequencies (with standard errors in brackets), 14.3663 (±0.0002), 11.6862 (±0.0004), and 7.2128 (±0.0006) cycles per day, are each associated with a single peak in the Fourier spectra, but other adjacent peaks are seen, among which are peaks representing one cycle per day aliasing, as would be expected from data obtained at one geographic site. A fourth frequency of low amplitude, 11.0935 (±0.0009) cycles per day (Figure 1d), differed in amplitude (and power) by very little from adjacent close frequencies, and because of this it is not considered to be a proven real frequency of pulsation.

The standard errors of the above frequencies are assigned by the software PERIOD04. They represent uncertainties in the frequencies uncorrelated with amplitudes and phases, and apply to "an ideal case." It is therefore considered that they may be optimistic.

The periods corresponding to the above frequencies are 0.0696, 0.0856, and 0.1386 day, respectively.

Figure 2 shows the light curves from the six nights of observation, the fitted functions using the three frequencies noted above, and their corresponding amplitudes and phases from PERIOD04.The fit is considered sufficiently close to explain most of the irregularity of the light curves.

EQ Eri has been recognized as a δ Scuti variable star since the publication of Koen and Roberts (1993), who reported a frequency of 15.136 cycles per day, which corresponds to a period of 0.0661d. This frequency was derived from observations made over 1.9 hours, with the light curve in their Figure 1 showing only thirteen data points. The light curve showed two peaks, with the earliest of the measurement apparently being just after the first peak.

Koen *et al.* (1995) obtained data on EQ Eri over 4.5 hours, with the light curve in their Figure 10 exhibiting a variation in amplitude that implies more than one frequency of pulsation, although the authors do not mention this possibility. They reported a frequency of 14.2 cycles per day, which corresponds to a period of 0.0704d.

The catalogue of δ Scuti stars published by Rodriguez (2000) quotes the period as 0.0700d, as seen in the Vizier Catalogue (CDS 2014).

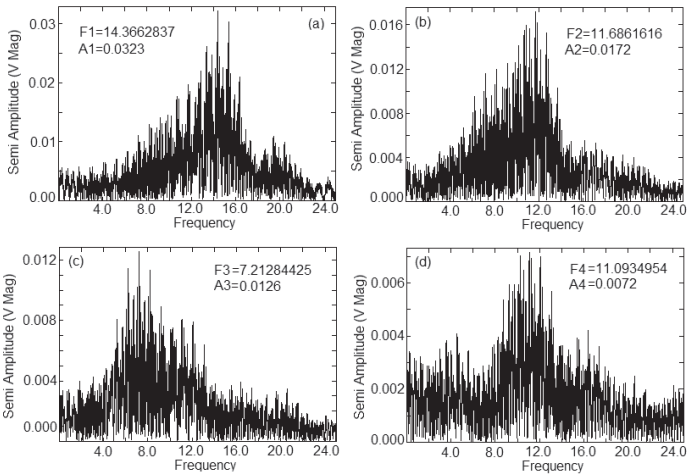

Figure 1. Periodograms of EQ Eri, showing the first four frequencies (F1 to F4) and corresponding amplitudes (actually, semi-amplitudes) (A1 to A4) revealed by the software PERIOD04. The first three frequencies (F1 to F3) appear to represent relatively isolated peaks, although other nearby peaks are seen, including those representing 1 cycle/day aliasing. The fourth frequency (F4) is so closely associated with nearby peaks that it is not considered to be a proven frequency of pulsation.

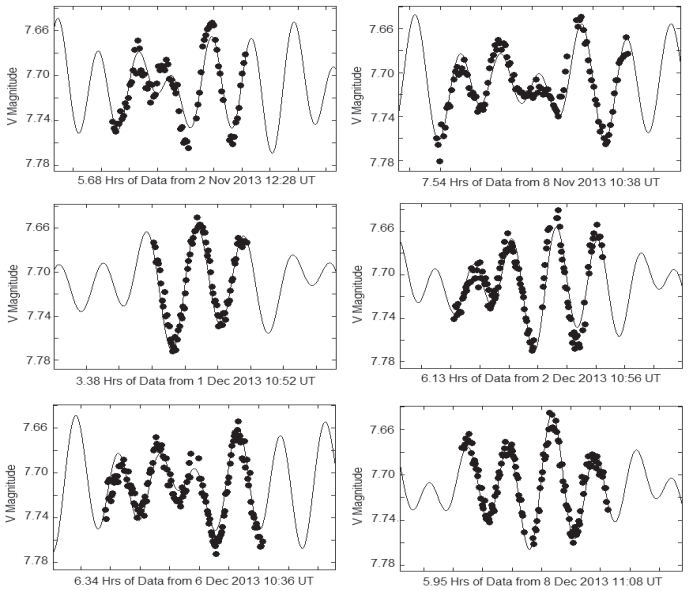

Figure 2. Light curves of EQ Eri obtained on each of the six nights on which measurements were made. The continuous lines associated with the data points represent the function fitted by PERIOD04 from the the first three frequencies shown in Figure 1, calculated from the frequencies themselves and their respective amplitudes and phases.

The present study revealed a principal frequency of 14.366 cycles per day, which corresponds to a period of 0.0696 day, very close to the period of 0.0700 day of Rodriguez (2000). Minor differences between previously published frequencies could perhaps be accounted for by the small datasets of the previous publications not providing a long enough baseline to accurately establish the primary frequency.

Although only one period is reported in the literature, the data presented in this paper suggest that EQ Eri is multiperiodic, with at least three frequencies being identified by Fourier analysis. Although the amplitude of pulsation is only 0.1 magnitude, and although there are limitations to the precision of photometry achievable in low amplitudes with the sensor of a DSLR camera in time series photometry, we believe that the fitted function from Fourier analysis is sufficiently close to the actual measured magnitudes to consider that the assumption of multiperiodicity is valid. It would, however, be more optimal to repeat the present study using a longer baseline and equipment capable of achieving higher precision in the determination of magnitudes.

For δ Scuti stars pulsating in the radial mode, the ratio of the first overtone to the fundamental mode should lie in the range 0.74 to 0.78 (Breger 1979). None of the period ratios which can be calculated from the present results fall within that range, implying that the star is not a purely radial pulsator oscillating in the fundamental and first overtone modes. The relationships between astrophysical parameters which determine the periods of δ Scuti stars are complex, and their detailed analysis is beyond the resources of the present author. In view of this, no definitive interpretation of the nature of the oscillations in EQ Eri can be provided in this paper. It is noted, however, that the period ratio of 0.8134 for the first and second periods from our data is close to the value of 0.810 listed by Breger (1979) in his Table II for the ratio of the second overtone to the first overtone, in a typical δ Scuti star with radial pulsation.

4. Conclusions

It is proposed that the present paper provides evidence for at least three frequencies of pulsation in EQ Eri, and if this conclusion is correct, it is a new discovery. However, the conclusion is based on analysis of data from only six nights of observation, and it would appear likely that a more extensive dataset collected from a larger number of observing runs might improve the quality of the results. Furthermore, the amplitude of each of the discovered frequencies is less than 0.1 magnitude in V, for which the precision of DSLR time series photometry is not entirely optimal. Ideally, CCD images (rather than images from a DSLR camera) should be used, in order to improve the precision of the photometry, provided that a sufficiently large field of view could be achieved, and that exposures could be long enough to avoid scintillation errors, as EQ Eri is a seventh magnitude star.

Another issue is that one cycle per day aliasing in the Fourier analysis is clearly evident, as would be expected for data collected at one geographic site. Since aliasing is recognized as a complicating factor in the analysis of data from δ Scuti stars with two or more frequencies, it would be appropriate to try to design a program of data collection at two or more geographic sites to reduce the number of alias peaks, and thereby enhance the ability of Fourier analysis to recognized true frequencies of oscillation.

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