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Research Note

Oscillations of BT Cancri in the Praesepe cluster*

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Abstract. CCD observations in Johnson B of BT Cancri = HD 73575, the brightest δ Scuti variable in the Praesepe cluster, obtained on three nights in February 1994 are described. Using least squares Fourier decomposition, two modes of oscillation frequencies 9.783 and 7.005 c/d and amplitudes of 18.0 and 9.9 mmag, respectively, are determined. Comparison with data from the literature indicate that BT Cnc may show secular variations in the oscillation spectrum.

Key words: stars: oscillations – stars: δ Sct – stars: individual: BT Cnc (HD 73575)

1. Introduction

BT Cancri = HD 73575 = 38 Cancri was discovered as a δ Sct variable by Breger (1970), who also made a detailed analysis of the observations available until 1980 (Breger 1980). Breger found two definite oscillation frequencies and one probable frequency, and used the period ratios to suggest identification with low-order radial modes.

As a bachelor-project in 1994 two of the present authors (LMF and SSL) decided to observe a field in Praesepe with the purpose of studying known δ Sct variables and perhaps to discover new low-amplitude variables. The field contains two known δ Sct stars, HD 73450 and HD 73575, and no new variable was found. The data for HD 73450 turned out to be too uncertain to derive definite results due to relatively low signal-to-noise ratio. HD 73575 = BT Cnc, which is the brightest known δ Scuti star in the Praesepe cluster, is about 1.8 mag brighter than HD 73450, and we therefore expect more significant results for this star. Further, HD 73575 also has considerably higher pulsation amplitude than HD 73450. Here we present the observations of BT Cnc, and give a brief discussion of the resulting oscillation spectrum.

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* We dedicate this paper to the memory of Ralph Florentin Nielsen, whose enthusiastic work with the Brorfelde Schmidt telescope was essential for the observations.

Table 1. Observations of BT Cnc on three nights of February 1994. Beginning and end of each observation night are given by HJD of the first and last observation

Night	Time-interval HJD = 2449000 +	Number of observations
1	398.3732 - 398.6470	202
2	399.2865 - 399.6264	258
3	401.3016 - 401.6925	244

2. Observations and data reduction

On February 14th - 18th 1994 704 CCD observations in B of BT Cnc were obtained as specified in Table 1. The 0.77 m (0.45 m effective aperture) Brorfelde Schmidt telescope was used for the observations with a 1024×1024 pixel peltier-cooled CCD. The 28×28 arcminutes field was centered on α_{2000} = 08:39:40, δ_{2000} = +19:45:00 in Praesepe. In order to observe as many stars as possible in the open cluster, the telescope was slightly defocused in order to prevent saturated pixels from the brightest (about 6th magnitude) stars.

The photometric reductions were performed using MOMF, Version 2.1 (Multi Object Multi Frame photometric package, see Kjeldsen & Frandsen 1992).

3. Oscillation frequencies and amplitudes

We use least squares Fourier decomposition to determine oscillation spectra, applying the technique of *known constituents* as described e.g. by Andreasen (1987). For each trial frequency, ν, a simultaneous least squares solution is calculated for the amplitude of the *known constituents* (with known frequencies) and amplitude and phase of a sine term with the trial frequency. The resulting *reduction factor*, S(ν), gives the fractional decrease in

Table 2. Main pulsation properties of BT Cnc according to the four-frequency solution illustrated in Fig. 1. Phases are given with Epoch HJD = 2449398.3054 in column 3. The rms-scatter given in column 4 is the scatter obtained by successive inclusion of the four frequencies

Frequency [c/d]	Semiampl. [mmag]	Phase [rad]	Scatter [mmag]	Remark
9.781	17.7 ± 0.2	2.61 ± 0.01	8.5	Definite
7.002	10.3 ± 0.2	2.54 ± 0.02	4.6	Definite
17.183	1.7 ± 0.2	0.73 ± 0.14	4.4	Noise
13.871	1.6 ± 0.2	6.11 ± 0.14	4.3	Noise

the least squares error (norm) obtained by including the trial frequency. A series of S-spectra is calculated. In each spectrum the frequency which gives maximum S is determined, and this frequency is included as a known constituent in the following spectra.

Preliminary analysis of the full time-series for BT Cnc showed the presence of several outlying observations with excessive residuals. Removing 22 outliers we accept a time-series of 682 observations. In the following we first discuss this series.

Fig. 1 shows the window function and four power spectra and Table 2 gives detailed information on the resulting four-frequency solution. The upper panel a) gives the window function centered on 10 cycles per day (c/d). Besides the 1 c/d alias's, considerably lower side-lobes separated by $\frac{1}{3}$ c/d are seen. Panels b) and c) uniquely identify the primary and secondary oscillations with main properties given in Table 2. The main oscillation has frequency ν_a = 9.781 c/d, amplitude 17.7 mmag and phase 2.61 radian with Epoch Feb. 14.8 1994 (HJD = 2449398.3054). Formal errors of both amplitude and phase are very small, 0.2 mmag and 0.01 radian, respectively. Due to the fact that our time-basis is only about 3 d, we cannot determine very accurate frequencies and are not able to separate e.g. close frequency pairs. Comparing results of many numerical experiments (see later) we estimate the uncertainty in our frequencies to be about ±0.01 c/d.

Panels c) - e) of Fig. 1 show S-spectra resulting from taking the already known frequencies as known constituents. From Panel c) it is seen that the S-value, S = 0.72, of the new frequency, ν_b = 7.002 c/d, is even higher than the value found for the frequency of the primary oscillation, ν_a. Closer inspection of Panel b) shows the presence of a top at about 7.0 c/d, which does not belong to the main pattern. Taking the primary oscillation as a known constituent, this top becomes the center of the ν_b-pattern, which also closely resembles the window function.

While the primary and secondary oscillations are unambiguously identified, the following possible oscillations indicated in Table 2 have much smaller S-values and oscillation amplitudes, and no pattern in the S-spectrum resembling the window function can be identified. From Table 2 it is also seen that inclusion of the last two Fourier terms decrease the rms-scatter only marginally.

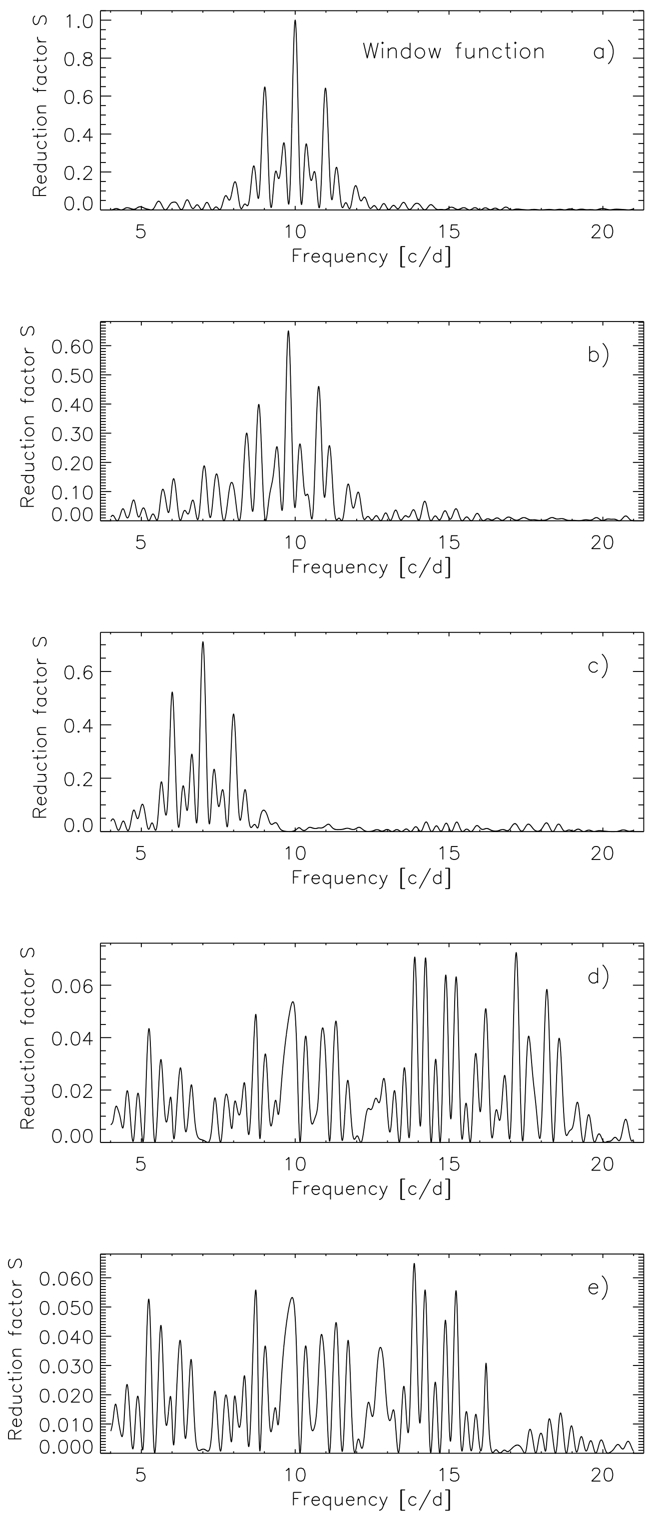

Fig. 1a-e. Power spectra of BT Cnc showing the reduction factor S as function of trial frequency. S gives the fractional reduction in the lsq-norm obtained by including the trial frequency. The upper panel **a** shows the window function. Panels **b** and **c** identify primary and secondary oscillation, respectively; see text for details. Panels **c**-**e** show the spectrum obtained by using all frequencies already identified as known constituents. Panels **d** and **e** show mainly noise

Table 3. Main pulsation properties of BT Cnc according to the solution with harmonics and interaction modes (in upper part). In column 4 the mode identification is given. The last two lines give main properties of possible modes identified by spectra (Fig. 2) with all previously known frequencies as known constituents

Frequency [c/d]	Semiampl. [mmag]	Phase [rad]	Identification
9.783	18.0 ± 0.2	2.55 ± 0.01	ν_a
19.566	0.7 ± 0.2	3.00 ± 0.26	$2\,\nu_a$
7.005	9.9 ± 0.2	2.54 ± 0.02	ν_b
14.011	1.1 ± 0.2	5.48 ± 0.16	$2\,\nu_b$
16.788	1.4 ± 0.2	2.98 ± 0.13	$\nu_a + \nu_b$
2.778	1.2 ± 0.4	3.09 ± 0.53	$\nu_a - \nu_b$
8.052	2.5 ± 0.3	2.39 ± 0.13	
6.273	1.0 ± 0.2	5.79 ± 0.24	

The difficult problem of deciding whether Fourier terms of low significance correspond to physical oscillations or are due to noise has been studied extensively in the literature, e.g. recently by Garrido & Rodríguez (1996) and Pardo & Poretti (1997). They emphasize that before searching for low-amplitude modes, both harmonics of the high-amplitude modes, i.e. $2\,\nu_a, 3\,\nu_a, \ldots,$ etc., and the interaction modes with frequencies $\pm\, n\,\nu_a \pm m\,\nu_b$, n and m integer, must be taken into account. In particular, for determination of the optimal set (ν_a, ν_b), harmonics and interaction frequencies must be included. In the present case we find that these terms all have small amplitudes. Fitting (ν_a, ν_b) taking into account also $2\,\nu_a$, $2\,\nu_b$, $\nu_a + \nu_b$ and $\nu_a - \nu_b$, we determine the optimal solution with maximum S given in Table 3. Here we have removed four more outliers, so that 678 observations are used. Table 3 also gives the results of searching for two further independent oscillations, and Fig. 2 shows the corresponding S-spectra and a comparison of the solution including all terms of Table 3 with the observations for each night. It is seen that several tops with S > 0.02 are present. However, we have not been able to identify a pattern that is robust to small changes in the calculation procedure.

4. Numerical experiments

Since additional low-amplitude modes in BT Cnc would be of high importance for asteroseismological applications, we have made several experiments to search for such modes, using different approaches. (i) A typical time-interval between successive observations is 0.0012 d. Since oscillation periods of the order of 0.1 d are relevant here, averages of about 5 observations can be expected to give suppression of high-frequency noise without significant loss of phase information. We have tested schemes using 3-7 neighbouring observations. Using averages, formal errors in amplitudes and phases of the Fourier components of lsq-fits decrease considerably. However, the resulting spectra do not show clear improvements. (ii) Due to the dense sampling we can apply weights by calculation of the deviation of each point from the local mean of the data, following Frandsen et al. (1995). Here we find little or no effect of applying weights.

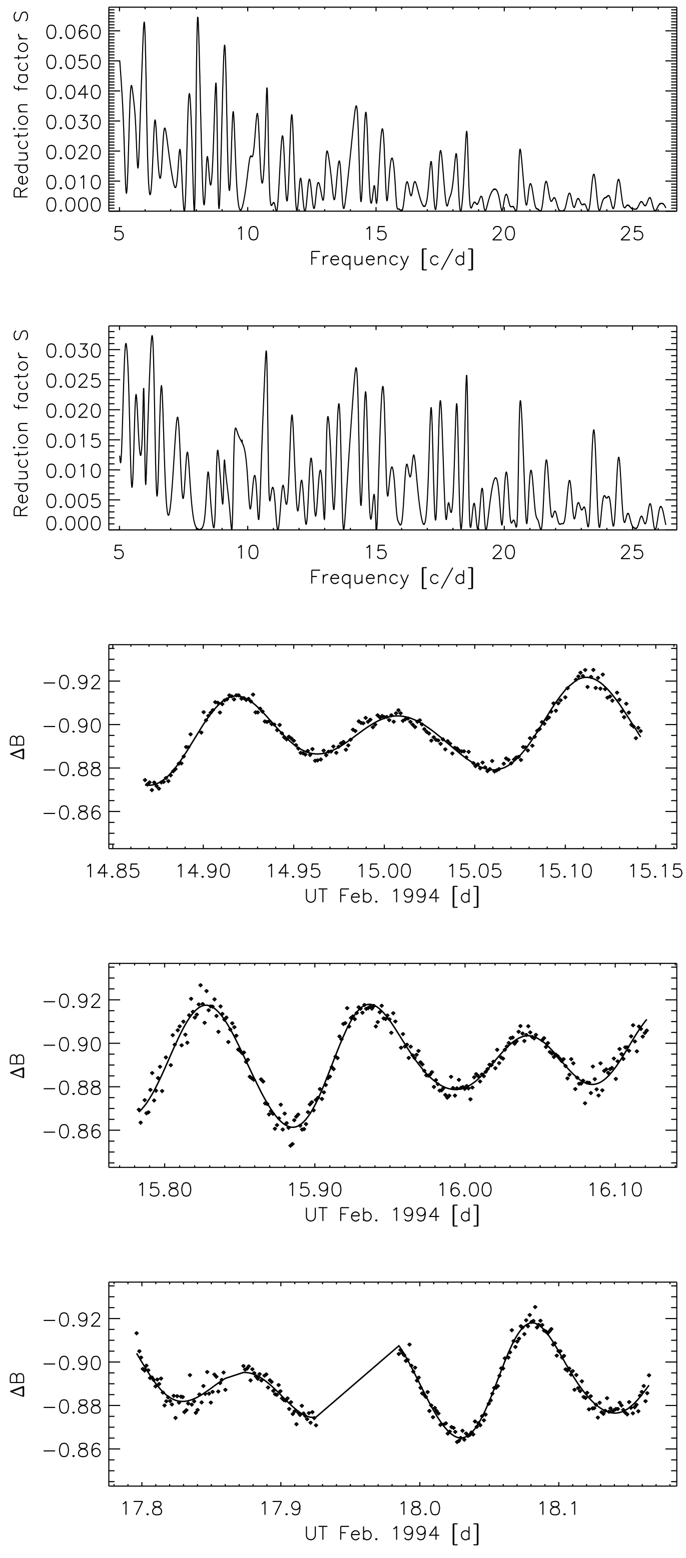

Fig. 2. Two S-spectra of BT Cnc identifying the last two modes given in Table 3 (upper panels) and the individual observations of each night shown together with the solution of Table 3 (lower panels). The rms-scatter of this solution is 3.0 mmag

(iii) We have taken slowly varying trends into account using for each night, in addition to a zero-point correction, also terms $d\,(t-t_m)+e\,(t-t_m)^2$, where t_m is the time (HJD) of the middle of the night and d and e are determined in each lsq-solution. Tests on synthetic data show that d and e-values can be determined together with standard lsq-coefficients without problems. The linear term often gives some suppression of low-frequency noise, while we usually find no significant effect of the second order term. (iv) Finally, we have excluded all observations from the night of February 15th - 16th, which has significantly larger scatter than the other nights, from the analysis. However, this results in a less favourable window function, and no improvement is obtained.

Comparing results of these numerical experiments, we have not been able to find systematic features in the S-spectra in addition to the two main modes. Because they are very stable against modifications of the lsq-procedure, we can conclude that these modes are definitely present in our data for BT Cnc with characteristics as specified in Table 3. We note that both main modes of BT Cnc are almost sinusoidal with small harmonic components.

5. Oscillation pattern of BT Cnc

Breger (1980) analysed two series of observations from 1967-1968 and 1975-1976. He concluded that two modes with frequencies 9.777 and 7.88 c/d and amplitudes in B of 20.1 and 8.0 mmag, respectively, are definitely present, and that one mode with frequency 5.95 c/d and amplitude 5 mmag is probably present. For the primary oscillation our data (Table 2) are in good agreement with Bregers. However, we find no evidence for a mode with ν = 7.88 c/d and amplitude of more than 1 mmag. The frequency ν = 5.95 c/d is very close to the 1 c/d alias of ν_b. However, if we introduce a constituent with $\nu \approx$ 5.95 c/d in the lsq-solution, we find a new frequency with $\nu = \nu_b$, and the amplitude at 5.95 c/d drops to almost zero. Thus we find that the 1994-data cannot be described by Bregers preferred solution.

At the recent Nice-meeting Belmonte et al. (1996) discussed δ Sct stars in Praesepe. Their Fig. 1 gives for BT Cnc two frequencies of 0.113 and 0.081 mHz, in very good agreement with ν_a and ν_b. The corresponding amplitudes are about 10.5 and 8.5 mmag, somewhat deviating from our data.

Thus we find that the available information on the pulsation properties of BT Cnc indicate that this star shows secular variations in the oscillation spectrum. Much more detailed observations over a long period of time are necessary to firmly establish the pulsation pattern of BT Cnc.

5.1. Modelling

We will not attempt detailed modelling of BT Cnc here (See e.g. Hernández et al. [1995] for modelling of δ Sct stars in Praesepe). Breger (1980) estimated the value of the pulsation parameter Q for the primary oscillation with period Π_a = 0.1022 d to be 0.021 $\pm$ 0.004 d. This can correspond to a radial overtone of order 1-4. The period ratio $\Pi_a/\Pi_b = \nu_b/\nu_a = 0.716$ is in agreement with Π_4/Π_2 in the population I models of Petersen and Dalsgaard (1996). However, since $v\,sin\,i$ = 154 km/s in BT Cnc (Belmonte et al. 1996), a significant correction for rotation must be expected (Hernández et al. 1995), and precise modelling is difficult.

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