Strong interactions between g - and p -modes in the hybrid γ Doradus- δ Scuti CoRoT star ID 105733033^{★,★★}

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ABSTRACT

Context. The presence of stellar p - and g -modes allows us to test stellar structure models in great detail from the core to the envelope. As the driving mechanisms are not yet fully understood, the first important step is to provide clear evidence of these pulsation modes. **Aims.** Recent space missions have confirmed that the γ Doradus and the δ Scuti observational instability strips overlap and consequently that many stars may be hybrids. CoRoT ID 105733033 is an excellent example of these hybrid pulsators as it shows g - and p -modes with almost similar amplitudes in two clearly distinct frequency domains. We present a detailed frequency analysis of the CoRoT star ID 105733033, which is obtained with a classical Fourier analysis.

Methods. After removing residual instrumental effects from the CoRoT light curve of N2 level, frequencies with an amplitude as small as 0.1 mmag were determined with Period04 and SigSpec up to 50 d⁻¹, although if deemed necessary lower amplitudes and higher frequencies were also investigated. The frequency spectrum of CoRoT ID 105733033 clearly consists of two distinct ranges, which are typical of γ Doradus and δ Scuti pulsation. Focus was placed on the identification of linear combinations and frequencies due to the coupling between γ Doradus and δ Scuti modes.

Results. We detect 198 γ Doradus type frequencies in the range [0.25; 4] d⁻¹, of which 180 are not combination frequencies, and 24 of them are separated by a constant period-interval $\Delta P = 0.03074$ d. According to the asymptotic theory, these 24 frequencies correspond to a series of g -modes of the same ℓ -degree and different radial orders n . We also detect 246 δ Scuti type frequencies in the range [10.1; 63.4] d⁻¹. The dominant frequency $F = 12.6759$ d⁻¹ was identified as the fundamental radial mode. Our most noteworthy result is that all the main γ Doradus frequencies f_i are also detected in the δ Scuti domain as $F \pm f_i$ with four times smaller amplitudes. Once these frequencies were removed, only 59 can be considered as individual δ Scuti frequencies.

Conclusions. A coupling between g - and p -modes is proposed to be a tool for detecting g -modes in the Sun, but this coupling has never yet been observed. Our present study may be valuable input to theoretical studies, addressing the mutual influence of g - and p -mode cavities and the deviation from classical theory. Furthermore, we identify a sequence of g -modes belonging to the same ℓ but with consecutive orders n .

Key words. asteroseismology – stars: oscillations – techniques: photometric – stars: variables: general

1. Introduction

The knowledge of solar and stellar interiors has improved tremendously in the past few decades due to both theoretical work such as new opacity tables (Cox et al. 1992) for the destabilisation of β Cephei and SPB stars and the convection/pulsation coupling for γ Doradus stars (Guzik et al. 2000; Dupret et al. 2004), and new observing facilities such as the space missions CoRoT (Baglin et al. 2006), MOST (Walker et al. 2003), and Kepler (Borucki et al. 1997; Christensen-Dalsgaard et al. 2008).

Until recently, δ Scuti and γ Doradus stars seemed to be clearly distinct, even if their respective instability strips overlap

within a small region. A few hybrid star candidates have been identified e.g. by Henry & Fekel (2005), Rowe et al. (2006), and Handler (2009). The hybrid stars have become extremely interesting targets because p - and g -modes probe different regions of the stellar interiors. The presence of both types of modes in a same star provides complementary model constraints.

With the availability of space observations, considerably lower-amplitude pulsation modes have become detectable compared with ground observations. The instability strips (IS) of δ Scuti and γ Doradus stars have been found to overlap and their respective hot and cool borders have become seemingly less well-defined. In addition, many CoRoT and Kepler stars do not show in their pulsation spectra a clear distinction between their γ Doradus and δ Scuti-frequency regions.

In this paper, we discuss the very interesting case of a star being unambiguously hybrid, with a frequency gap between 4 d⁻¹ and 10 d⁻¹, and indications of strong interactions between the p - and g -modes. The data are described in Sect. 2, and

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** Full Table 1 is available in electronic form at <http://www.aanda.org>

the frequency analysis is presented in Sect. 3. The frequency spectrum is discussed in Sect. 4 for the low-frequency region (γ Doradus domain) and in Sect. 5 for the high-frequency region (δ Scuti domain). A theoretical interpretation of the interaction of the γ Doradus- δ Scuti modes is given in Sect. 5. The effects of the rotation are discussed in Sect. 6 and some conclusions are provided in Sect. 7.

2. The CoRoT data

The observations of CoRoT ID 105733033 were collected during CoRoT's second long run, LRC02, which targeted the Galactic center. We used the reduced N2 light curves (Auvergne et al. 2009) throughout this paper. The observations lasted 145 days, from 2008, April 15th to September 7th. Among the 388 950 measurements obtained with a temporal resolution of 32 s, we retained only the 345 908 points flagged “0” by the CoRoT pipeline, the other measurements being affected by instrumental effects such as straylight, cosmic rays, and perturbation by Earth eclipses.

The light curve is recorded in “chromatic” light i.e., in three non-calibrated bands unevenly spanning the wavelength interval 370–950 nm, obtained by the insertion of a prism just in front of the exo-planet CCD. To increase the signal-to-noise ratio (S/N), we added the three components of the colour bands to a “white” light curve. Unless specified otherwise, we refer in the following to the “white” light curve.

CoRoT data are known to be affected by several instrumental effects, such as long-term trends and jumps due to cosmic rays (Auvergne et al. 2009). In addition, many individual measurements can be considered as outliers. The data of the most significant outliers (mainly high-flux data points caused by cosmic ray impacts) were removed by an iterative procedure during the Fourier analysis. Jumps were corrected by applying simple vertical shifts to the data. The resulting light curve is represented at different timescales in Fig. 1 and clearly contains both low and high frequency components. As noted by Balona et al. (2011) for other high amplitude γ Doradus stars, the light curve displays sometimes a Blazhko-like behaviour: the maxima vary far more than the minima. This effect can also be observed for our star. In the following, the timescale is labeled in units of the CoRoT Julian day (JD), where the starting CoRoT JD corresponds to HJD 2 445 545.0 (2000, January 1st at UT 12:00:00).

Information provided by the EXODAT database (Deleuil et al. 2009) indicates that the star has an A5V spectral type and magnitude $V = 12.8$. The conversion of the flux values to magnitudes of CoRoT ID 105733033 is calibrated to a CoRoT magnitude of $C = 12.543$. The BEST survey of the LRC02 field classifies the star as a pulsating star of SX Phoenicis type (Kabath et al. 2009) and 2MASS provides ($J = 11.445$, $H = 11.205$, $K = 11.094$). The CoRoT contamination factor is very small (1.7%), hence we assume that the signal originates entirely from CoRoT ID 105733033.

3. Frequency analysis of the CoRoT dataset

The frequency analysis was performed on the filtered data using two independent methods: Period04 (Lenz & Breger 2005) and SigSpec (Reegen 2007). We first used the Period04 package and searched the interval $[0; 100] \text{ d}^{-1}$ i.e., well below the Nyquist frequency. However, since the computations were very time-consuming, we limited our search mostly to the interval $[0; 50] \text{ d}^{-1}$, and explored the second part of the interval only every 50 newly detected frequencies. For each detected frequency,

Fig. 1. Light curve of the star CoRoT ID 105733033 corrected for long-term trends, jumps, and outliers (see text) with different timescales. From top to bottom, the complete light curve over 145 d, then a subset over 22 d and finally a zoom into a 3.5 d subset.

the amplitude and phase were calculated by a least-squares sine fit. The data were then prewhitened and a new analysis was performed on the residuals. We did not use the option `improve a11`, available in the Period04 package, which computes a multi-sine fit. From experience, it is known that the frequency differences derived from an individual least-squares sine fit relative to a multi-sine fit, depend largely on the quality of the spectral window, which in our case of CoRoT is characterized by a very high duty cycle. Tests have confirmed that differences smaller than 0.001 d^{-1} are typical in our case of frequencies higher than 0.05 d^{-1} , except in cases of a small-amplitude frequency within a $1/\Delta T$ -bin close to a large amplitude one. Our analysis was conducted until a $S/N = 3.9$ was reached, slightly below the usual $S/N = 4$ value (Breger et al. 1993; Kuschnig et al. 1997) and corresponding to an amplitude of about 0.1 mmag, which resulted in a detection of 559 frequencies.

The uncertainties in the frequencies, amplitudes, and phases were computed with the formulae proposed by Montgomery & O’Donoghue (1999) providing a 3σ estimate. However, as we used a step size of $1/20\Delta T$ in the Fourier analysis, and since the accuracies of the frequencies were not improved by a multi-sine fit, the uncertainties in the frequencies are certainly no smaller than $1/40\Delta T$. Therefore, the frequency uncertainties are $1/40\Delta T$ when the aforementioned formal 3σ estimate is smaller. Some of the lowest frequencies are actually linked to instrumental fluctuations, which were not corrected by the reduction pipeline. Once the 559 frequencies are removed, the periodogram of the residuals shows that some signal is still present (Fig. 2) but mainly located in high-density peak regions, and many of the peaks are actually residuals of previously detected frequencies.

Fig. 2. Amplitude spectra computed with Period04 for the 444 retained frequencies. From top to bottom: the amplitudes in μmag , and the same with a logarithmic scale, the Fourier spectrum computed from the residuals, and the spectral window normalized to unity, but plotted only to 0.1 in amplitude.

In a next step, the frequency analysis was repeated by applying SigSpec to the data filtered with a cubic spline function to get rid of the main CCD variations. However, this procedure also eliminated possible low-frequency pulsations. To be consistent with the Period04 results, the program was stopped after detecting 600 frequencies. The threshold magnitude turned out to be about 0.08 mmag.

The results of the two methods agree fairly well. With SigSpec, we detected fewer low-frequencies since the data were prewhitened with a cubic spline, but some additional frequencies emerged with marginal amplitudes between 0.08 and 0.1 mmag. The main difference concerns the frequency values derived by the two techniques, which can amount sometimes to 0.004 d^{-1} , but remains well within the Rayleigh criterion of 0.007 d^{-1} . As we needed consistency to detect couplings, we used Period04 in the following.

The next step consisted in the sorting of stellar and non-stellar frequencies. As usual for CoRoT data, we eliminated both the frequencies corresponding to the orbital frequency $f_{\text{orb}} = 13.97 \text{ d}^{-1}$ and its harmonics, and the $2f_{\text{sid}} = 2.0054 \text{ d}^{-1}$ value due to the passage over the South Atlantic Anomaly, which occurs twice each sidereal day (Auvergne et al. 2009). Small-amplitude frequencies separated by $1/\Delta T$ from a large-amplitude frequency were ignored in the following as the effects of the spectral window (data set length).

As usual in the CoRoT data, variations in the properties of the CCD perturb the lowest part of the periodogram, so we decided to analyze only frequencies higher than 0.25 d^{-1} . We made an exception of the low amplitude frequency $F_{144} = 0.2482 \text{ d}^{-1}$

as it corresponds to the coupling $f_1 - f_4$. We tested our 0.25 d^{-1} limit in Sect. 5 and found that it is realistic.

As a result, 444 frequencies were retained that have no clear instrumental origin (in Table 1, only the first 25 frequencies are given here and the full table is only available electronically, and in Fig. 2). These frequencies can be divided into two main groups: 198 in the interval $[0.2483; 3.9936] \text{ d}^{-1}$, corresponding to the typical γ Doradus frequency domain, and 246 in the interval $[10.1038; 63.3800] \text{ d}^{-1}$, which is typical of the δ Scuti domain. No frequency with an amplitude larger than 0.1 mmag was detected in the interval $[4; 10] \text{ d}^{-1}$, except perhaps an isolated frequency $f = 5.6038 \text{ d}^{-1}$ with an amplitude of 0.09 mmag.

This clear distinction between low- and high-frequency regions may be the consequence of a quite low angular rotation velocity Ω . Following the rotation perturbation theory, the observed frequencies are indeed shifted from the co-moving frame ones by a quantity that is, to first order, proportional to Ω . Hence, in the case of rapid rotators, the “observed” frequency spectrum might differ significantly from those measured in a “co-rotating” frame and the two frequency regions might even overlap. It is thus imperative to obtain a spectrum of this star, which allows us to measure $v \sin i$ and estimate the rotation velocity Ω . Unfortunately, no spectroscopy is yet available for CoRoT ID 105733033. However, the clear gap between rather compact low- and high-frequency regions strongly argues in favor of a slow angular rotation, which we therefore predict. A low Ω would also be consistent with a rotation period of 20.57 d, which is proposed by us in Sect. 6. In the following, we therefore assume that the observed frequencies do not differ significantly from the co-rotating ones.

4. The γ Doradus domain

From the Fourier analysis, we found 198 frequencies in the range $[0.2483; 3.9936] \text{ d}^{-1}$, of which 176 were detected between 0.25 and 2.6 d^{-1} (Fig. 3). In the following, we re-numbered the 198 frequencies in order of decreasing amplitude, starting from f_1 . The main frequency is $f_1 = 0.7428 \text{ d}^{-1}$ with an amplitude $A_1 = 11.15 \text{ mmag}$. Data phased with this frequency are represented in Fig. 4. The shape of the curve is nearly sinusoidal, hence only $2f_1$ is detected with an amplitude of 0.77 mmag.

We identified 17 cases in which a linear combination of detected γ Doradus frequencies coincide to within $\Delta = 0.001 \text{ d}^{-1}$ with 17 other detected frequency (Table 2). This Δ refers to the uncertainty in the lowest amplitude frequencies (see Table 1).

Another interesting finding is the presence of coupling between p - and g -modes (see Sect. 5), where we found for 82% of the 50 candidates with the largest amplitudes a frequency difference between coupled modes and observed frequencies of less than 0.001 d^{-1} . On the other hand, in the case of the 100 lowest amplitude g -modes (for which no coupling is expected) we found in only 1.5% of the possibilities a difference smaller than 0.001 d^{-1} . We interpret this finding as support of the chosen value of $\Delta = 0.001 \text{ d}^{-1}$. A few expected combinations were not detected, e.g. $f_1 + f_5$, as they were masked by pulsation frequencies with higher amplitudes (within a distance smaller than $1/\Delta T$). After elimination of harmonics and coupled frequencies, 180 independent frequencies of γ Doradus type were retained.

In the case of large radial numbers n , the first order asymptotic theory (Tassoul 1980) predicts for g -modes of the same degree ℓ , a constant period spacing between consecutive radial orders n . Searching in Table 1 for equidistant γ Doradus periods, we found a series of 24 asymptotic ones with a mean separation of $\Delta P = 0.03074 \pm 0.00005 \text{ d}$ (Fig. 5). The periods extend

Table 1. The first 25 stellar frequencies.

	Frequency d ⁻¹	<i>S/N</i>	<i>A</i> mmag	Φ rad	Ident.	Linear comb.	<i>n</i>
<i>F</i> ₁	12.6759	1100.7	27.077	2.259	<i>F</i>	–	–
<i>F</i> ₃	0.7428	453.1	11.146	0.564	<i>f</i> ₁	–	0
<i>F</i> ₄	0.6952	310.7	7.642	1.752	<i>f</i> ₂	–	3
<i>F</i> ₅	25.3521	298.7	7.349	0.277	2 <i>F</i>	–	–
<i>F</i> ₆	0.9345	239.7	5.896	3.932	<i>f</i> ₃	–	–9
<i>F</i> ₇	0.9907	167.8	4.127	3.319	<i>f</i> ₄	–	–11
<i>F</i> ₈	0.9083	167.4	4.118	1.604	<i>f</i> ₅	–	–8
<i>F</i> ₉	0.9624	165.4	4.068	3.683	<i>f</i> ₆	–	–10
<i>F</i> ₁₁	0.7979	162.1	3.988	3.713	<i>f</i> ₇	–	–3
<i>F</i> ₁₂	0.8390	145.0	3.566	6.123	<i>f</i> ₈	–	–5
<i>F</i> ₁₃	11.9335	113.5	2.792	5.642	<i>F</i> – <i>f</i> ₁	–	–
<i>F</i> ₁₄	13.4186	108.3	2.663	4.104	<i>F</i> + <i>f</i> ₁	–	–
<i>F</i> ₁₅	1.1656	86.8	2.136	1.735	<i>f</i> ₉	–	–
<i>F</i> ₁₆	11.9807	76.2	1.875	4.814	<i>F</i> – <i>f</i> ₂	–	–
<i>F</i> ₁₇	13.3714	73.4	1.805	3.970	<i>F</i> + <i>f</i> ₂	–	–
<i>F</i> ₁₈	38.0279	70.8	1.742	4.804	3 <i>F</i>	–	–
<i>F</i> ₁₉	0.5279	69.0	1.697	0.657	<i>f</i> ₁₀	–	–
<i>F</i> ₂₀	0.7262	65.2	1.605	3.151	<i>f</i> ₁₁	–	1
<i>F</i> ₂₂	11.7417	60.6	1.491	2.099	<i>F</i> – <i>f</i> ₃	–	–
<i>F</i> ₂₃	0.8835	60.3	1.483	6.217	<i>f</i> ₁₂	–	–7
<i>F</i> ₂₅	0.6655	59.1	1.454	0.456	<i>f</i> ₁₃	–	5
<i>F</i> ₂₆	13.6104	56.0	1.378	1.123	<i>F</i> + <i>f</i> ₃	–	–
<i>F</i> ₂₈	1.4380	54.3	1.335	3.424	<i>f</i> ₁₄	<i>f</i> ₁ + <i>f</i> ₂	–
<i>F</i> ₂₉	0.6786	54.3	1.335	2.761	<i>f</i> ₁₅	–	–
<i>F</i> ₃₀	0.3659	54.2	1.333	4.255	<i>f</i> ₁₆	–	–

Notes. The successive columns respectively correspond to the frequency detection order, its value and related *S/N*, amplitude, and phase. We also indicate the new identification, the eventual linear combination, and finally the eventual *n* radial order (relative to *f*₁) of the asymptotic *g*-modes. (Full table is available in electronic form.)

Table 2. Linear combinations of frequencies detected in the γ Doradus domain.

Frequency	Combination	Δ Period04 [10 ⁻⁵ d ⁻¹]	Δ SigSpec [10 ⁻⁵ d ⁻¹]	
F_{28}	f_{14}	$f_1 + f_2$	4	13
F_{40}	f_{20}	$f_1 + f_3$	39	372
F_{47}	f_{23}	$f_1 + f_4$	73	-26
F_{55}	f_{27}	$f_1 + f_7$	-31	30
F_{89}	f_{51}	$f_1 + f_8$	66	not detected
F_{110}	f_{58}	$f_1 + f_{10}$	-35	88
F_{256}	f_{112}	$f_1 + 2f_3$	70	123
F_{57}	f_{28}	$2f_1$	-31	157
F_{470}	f_{175}	$2f_1 + f_2$	-64	19
F_{358}	f_{149}	$2f_1 + f_5$	4	194
F_{218}	f_{97}	$2f_1 + f_7$	5	-194
F_{346}	f_{146}	$2f_1 + f_9$	66	127
F_{83}	f_{47}	$f_2 + f_5$	73	17
F_{286}	f_{123}	$f_2 + f_9$	33	377
F_{134}	f_{68}	$f_2 + f_{10}$	68	-48
F_{412}	f_{165}	$2f_2 + f_3$	75	-36
F_{122}	f_{62}	$f_3 + f_4$	2	68
F_{144}	f_{71}	$f_4 - f_1$	35	343

Notes. Columns are respectively the label of the frequency from Table 1 together with its new label, the linear combination, and the differences between the linear combination and the actually measured values for Period04 and SigSpec [$\times 10^{-5}$ d⁻¹].

from 0.693 d to 1.593 d with the highest concentration being between 1.009 d and 1.439 d. In this region, we detected 15 consecutive and equidistant periods among the 18 possible. Most of them have relatively large amplitudes, and are indeed among the largest amplitude *g*-mode frequencies detected. Further away from the central region, the amplitudes decrease, but we detected

9 other periods fitting the sequence. Several values are missing in the asymptotic series probably owing to their low amplitudes. The 24 retained periods correspond to *n*-values ranging from –23 to +8, with the largest amplitude period *P*₁ = 1.3470 d (*f*₁ = 0.7428 d⁻¹) being arbitrarily taken as order zero. The sequence is listed in Table 3 and illustrated in Fig. 6.

5. The δ Scuti domain

In the δ Scuti frequency domain, we retained 246 frequencies in the interval [10.1038; 63.3800] d⁻¹ (Table 1, Fig. 7). One frequency clearly dominates the spectrum, *F* = 12.6759 d⁻¹, with an amplitude *A*₁ = 27.08 mmag. Figure 7 represents a light curve that has been phased with frequency *F*. The curve is very asymmetric and unsurprisingly harmonics up to 5*F* were detected. The Fourier parameters ϕ_{21} = 4.03 rad (phase difference of first overtone and twice the phase of fundamental frequency) and *R*₂₁ = 0.26 (the amplitude ratio of first overtone to fundamental frequency) were in perfect agreement with those of fundamental radial pulsators (Poretti 2001). Hence, we can conclude that *F* is a radial mode.

To corroborate the identification of this pulsation mode, we have only the measurements provided by the EXODAT database (Deleuil et al. 2009), which are indicative of an A5V spectral type. On the basis of this classification, the star would have an absolute magnitude of *M*_V = +2.0 mag and an effective temperature of *T*_{eff} = 8000 K. The period-luminosity relation given by Templeton et al. (2002) supports the identification of the main frequency *F* as a radial fundamental mode. Likewise, using the equation given by Poretti et al. (2008) *M*_V = –1.83(±0.08) – 3.65(±0.07) log *P*, we also obtain for the absolute magnitude: *M*_V = +2.20(±0.16) mag.

Fig. 3. Enlargement of Fig. 2 [second] showing the detected frequencies in the γ Doradus domain. The ordinates are on a logarithmic scale.

Fig. 4. Data phased with the main γ Doradus frequency $f_1 = 0.7428 \text{ d}^{-1}$.

The most remarkable property of CoRoT ID 105733033 is the coupling of most of the δ Scuti frequencies with γ Doradus ones: the first tens of γ Doradus frequencies f_i are present in the δ Scuti domain as $F \pm f_i$. We also detected $2F \pm f_i$ and $3F \pm f_i$ for the γ Doradus frequencies with the largest amplitudes. For the 40 first γ Doradus frequencies f_i , both $F - f_i$ and $F + f_i$ frequencies are present except for a few ambiguous cases. Coupling with lower amplitude γ Doradus frequencies (up to f_{100}) were also detected as $F - f_i$ or $F + f_i$, but not so regularly. We were able to detect 146 couplings within the limit of $\Delta f = 0.001 \text{ d}^{-1}$: 110 for $F \pm f_i$, 30 for $2F \pm f_i$, and 6 for $3F \pm f_i$. The three first

Fig. 5. Plot of the frequencies detected in the interval $[0.4; 1.8] \text{ d}^{-1}$. “Positive” amplitude frequencies represent the identified asymptotic frequency series, while the “negative” ones are the other detected frequencies in this interval.

Fig. 6. γ Doradus periods that obey the asymptotic period spacing law as a function of radial order n with an arbitrary zero point [top]. The bottom part shows the residuals of this period spacing; a straight line has been added for better visibility.

Fig. 7. Data phased with the main δ Scuti frequency $F = 12.6759 \text{ d}^{-1}$.

Table 3. Asymptotic frequencies.

Frequency	Period	Amplitude	n
F_{163}	f_{79}	0.6393	-23
F_{313}	f_{130}	0.7001	-21
F_{191}	f_{88}	0.7325	-20
F_{365}	f_{150}	0.7627	-19
F_{339}	f_{144}	0.7943	-18
F_{296}	f_{126}	0.8877	-15
F_{70}	f_{36}	0.9483	-13
F_7	f_4	1.0094	-11
F_9	f_6	1.0391	-10
F_6	f_3	1.0701	-9
F_8	f_5	1.1010	-8
F_{23}	f_{12}	1.1319	-7
F_{207}	f_{93}	1.1604	-6
F_{12}	f_8	1.1919	-5
F_{42}	f_{22}	1.2231	-4
F_{11}	f_7	1.2532	-3
F_{82}	f_{46}	1.2843	-2
F_{54}	f_{26}	1.3176	-1
F_3	f_1	1.3463	0
F_{20}	f_{11}	1.3770	1
F_{80}	f_{44}	1.4098	2
F_4	f_2	1.4385	3
F_{25}	f_{13}	1.5026	5
F_{86}	f_{48}	1.5925	8

Notes. Columns are respectively the label of the frequency from Table 1 together with its γ Doradus label, the corresponding period value [d], the related amplitude [mmag], and the order n of the pulsation mode (arbitrarily shifted to $n = 0$ for the main frequency f_1).

groups of coupling are presented in Table 4, the complete list being presented in Table 1.

The amplitude ratios of the γ Doradus frequencies to the associated high frequencies of δ Scuti characteristics are remarkably constant, being 4.1 ± 0.1 ($A_{f_i}/(A_{F \pm f_i})$), 15 ± 1 ($A_{f_i}/(A_{2F \pm f_i})$), and 53 ± 4 ($A_{f_i}/(A_{3F \pm f_i})$). The amplitudes of the $F - f_i$ frequencies were slightly larger (1.3%) than those of $F + f_i$. We also note that the beatings of $F \pm f_i$ frequencies are in phase with the f_i frequencies i.e., the highest amplitude of the beating of F and $F \pm f_i$ occurs when the light curve of f_i reaches a maximum.

Thus, it appears that a fundamental property of this star is the coupling between g - and p -modes. This coupling was previously predicted for the Sun (Kennedy et al. 1993). Following

Table 4. First three groups of coupled γ Doradus and δ Scuti frequencies.

Frequency	Coupling	Δ	Ratio
F_{13}	$F - f_1$	34.5	4.00
F_{14}	$F + f_1$	0.3	4.19
F_{16}	$F - f_2$	0.4	4.09
F_{17}	$F + f_2$	38.9	4.22
F_{22}	$F - f_3$	35.1	3.96
F_{26}	$F + f_3$	0.6	4.28
F_{59}	$2F - f_1$	11.2	14.93
F_{64}	$2F + f_1$	34.2	16.40
F_{94}	$2F - f_2$	4.0	15.08
F_{104}	$2F + f_2$	40.4	16.97
F_{119}	$2F - f_3$	0.1	14.46
F_{121}	$2F + f_3$	34.9	14.69
F_{233}	$3F - f_1$	18.1	48.73
F_{284}	$3F + f_1$	0.0	57.52
F_{355}	$3F - f_2$	34.9	49.32
F_{378}	$3F + f_2$	68.6	52.04
F_{555}	$3F - f_3$	0.1	58.95
F_{490}	$3F + f_3$	43.8	51.98

Notes. Columns are respectively the frequency label of the first column of Table 1, the related coupling, $\Delta = |F \pm f - F_{\text{measured}}|$ in units of 10^{-5} d^{-1} , and the amplitude ratio $A_{f_i}/(A_{kF \pm f_i})$. We recall that the Rayleigh frequency resolution ($1/\Delta T$) corresponds to $70 \times 10^{-5} \text{ d}^{-1}$.

this study, the low-frequency g -modes, trapped in the stellar interior, induce slow periodic thermodynamic perturbations in the envelope, leading to a frequency modulation of the outer p -modes. This causes the formation of a pair of spectral side-lobes (not to be confused with sidelobes caused by the spectral window!) that are symmetric relative to the unperturbed p -mode frequency. This is exactly what we see for our $F \pm f_i$ peaks. A complementary study (Lou 2001) shows that, in principle, a spectrum of sidelobes would appear to be centered on each p -mode frequency and that the spectral structure may be complicated by the presence of several g -modes. The predicted amplitude ratio of the first sidelobe A_s to the central p -mode A_p is $\frac{A_s}{A_p} = \frac{1}{2} \frac{A_{F \pm f_i}}{A_{f_i}} \approx 0.125$, but this ratio was not measured by us.

On the other hand, measured sidelobe amplitudes are directly linked to the amplitude of the respective “parent” g - and p -modes. The first non-radial mode of δ Scuti-type (p_1) also contains sidelobes. The amplitude ratio of F to p_1 is 23, where the sidelobes of the $p_1 \pm f_i$ peaks are “only” nine times smaller than those corresponding to $F \pm f_i$. Hence, the relationship does not seem to be linear. In conclusion, except for the influence of the amplitudes of the concerned modes, the coupling mechanism proposed by Kennedy et al. (1993) and Lou (2001) operates in this star. Initiated first as a help to the detection of g -modes in the Sun, there is no obvious reason for not assuming that this mechanism operates in other stars.

Without all the coupling frequencies 100, δ Scuti-type frequencies remained. For a list of “pure” δ Scuti frequencies, we also discarded frequencies with $|kF \pm f_i - F_{\text{measured}}| \leq \Delta = 0.0015 \text{ d}^{-1}$ (instead of our standard $\Delta = 0.0010 \text{ d}^{-1}$), if their amplitude ratio was compatible with the value of three obtained in our “standard” case. We derived 25 of these possible couplings, which are all of $F \pm f_i$ type.

We used this interaction mechanism in order to test the low frequency region. If γ Doradus-type frequencies, f_i , lower than 0.25 d^{-1} and with amplitudes larger than 0.4 mmag were to exist, we should detect them as $F \pm f_i$. No such frequencies were

Fig. 8. *Top:* enlargement of Fig. 2 [second] showing the detected frequencies in the δ Scuti domain. *Bottom:* the δ Scuti frequencies without linear combinations with γ Doradus frequencies. The ordinates are on a logarithmic scale.

detected, so we conclude that the lower limit for γ Doradus frequencies really is about 0.25 d^{-1} .

The physical characteristics of the star (mass, effective temperature, radius, evolutionary state, ...) are uncertain, as was previously mentioned at the beginning of this section. Using the values computed by Fitch (1981), the frequencies associated with the first overtones 1O, 2O, and 3O should be close to respectively 16.55 , 20.66 , and 24.85 d^{-1} . Values associated with the 1O and 2O modes are located in regions that have a low density of frequencies, and the frequencies $F_{98} = 16.4019 \text{ d}^{-1}$ ($A_{98} = 0.49 \text{ mmag}$) and $F_{215} = 20.7007 \text{ d}^{-1}$ ($A_{215} = 0.25 \text{ mmag}$) could correspond to these modes. As neither the fundamental stellar parameters, nor the true errors of the models, are known with sufficient accuracy, we can only speculate that the overtones are a correct interpretation.

The non-radial δ Scuti frequencies were renamed in order of decreasing amplitude starting from $p_1 \equiv F_{33}$ (see also Table 1). They are presented in the lower part of Fig. 8. These frequencies are dominated by $p_1 = 13.8566 \text{ d}^{-1}$ with an amplitude of 1.18 mmag and all the others have amplitudes smaller than 0.5 mmag . We detected three couplings between p_1 and the γ Doradus frequencies f_3 , f_5 , and f_6 according to $p_1 + f_i$. The mean amplitude ratio $A_{p_1}/(A_{p_1+f_i})$ is 35 i.e., about nine times larger than the corresponding ratio associated to F .

We also detected 9 couplings between F and other δ Scuti type frequencies. Therefore, we end up with 59 independent δ Scuti frequencies, three of which are probably associated with radial modes, and the 56 others with non-radial modes.

Fig. 9. Binned data phased with the candidate rotation frequency $f = 0.0486 \text{ d}^{-1}$, corresponding to a rotation period of 20.57 d . Different symbols refer to different rotation cycles and data averaged in steps of 0.1 in phase.

6. Rotation

We searched for equidistant frequencies that could be related to rotational splitting. The only possibilities we found were quadruplet components formed by $p_{31} \equiv F_{381} = 12.5776 \text{ d}^{-1}$, $p_{29} \equiv F_{360} = 12.6276 \text{ d}^{-1}$, $F = 12.6759 \text{ d}^{-1}$ and $p_{41} \equiv F_{444} = 12.7231 \text{ d}^{-1}$. The separations are respectively 0.0500 , 0.0483 , and 0.0473 d^{-1} . The radial fundamental mode F cannot of course lead to any rotational splitting, but its high amplitude may conceal a non-radial $\ell = 2$ mode that could be responsible for the aforementioned detected quadruplet. Another interpretation is that the star belongs to a binary system, and that the equidistant peaks are actually orbital sidelobes to the central pulsation frequency modulated by the Doppler effect, as proposed by Shibahashi & Kurtz (2012).

Among the frequencies below 0.25 d^{-1} (see Sect. 3) was a frequency at 0.04862 d^{-1} that has an amplitude of $A = 1.46 \text{ mmag}$, which is close to the separation values mentioned in the previous paragraph.

A possible interpretation of this low frequency could be the rotation of the star with a period of 20.57 d causing light variations associated for instance with surface inhomogeneities. We note that a phase plot (Fig. 9) of the residuals after prewhitening with the pulsation frequencies, when using the candidate rotation period looks reasonable. This rotation period would also be long enough to account for the two clearly distinct groups of γ Doradus and δ Scuti frequencies because the observed frequency spectrum should not differ significantly from the co-rotating one. Our speculations concerning a rotation period of course have to be taken with the utmost caution as the very low frequency range is populated by signal caused by instrumental effects, imperfect data reduction, g -modes, and combination frequencies. A dedicated spectroscopic observing program focused on the detection of rotation and eventual binarity effects in this star would be needed to resolve the ambiguities. However, the evidence presented in this paper is both consistent and plausible.

7. Summary

The star CoRoT ID 105733033 appears to be a very powerful test case for hybrid star studies. First, its frequency spectrum is quite rich. Second, two separate domains are clearly detected, with 198 frequencies in the range of $[0.2483; 3.9936]\text{d}^{-1}$, which is typical for g -modes, and 246 frequencies in the range of $[10.1038; 63.3800]\text{d}^{-1}$, typical of p -modes. Among these frequencies, 180 and 59 are respectively neither combination frequencies nor caused by coupling between g and p -modes, hence seem to represent pure γ Doradus and δ Scuti pulsation modes. The sole exception is the frequency $f = 5.6038\text{d}^{-1}$, but with an amplitude slightly smaller than 0.1 mmag, which is our chosen lower magnitude limit. This gap between the two domains is a strong indication of slow rotation, since the modes in the observer's frame are not mixed.

We found 17 linear combinations among the γ Doradus frequencies. More are probably present, but the time coverage of our data may not be sufficiently long to detect them. The asymptotic theory is very well-illustrated by this star, which has 24 periods that are equidistant at intervals of $\Delta P = 0.03074\text{d}$.

The high-frequency region shows a dominant peak F that could be identified with the radial fundamental mode. It is most remarkable that of the 246 δ Scuti frequencies, only about 70 ($\approx 30\%$) seem really independent of a γ Doradus frequency. Twice as many (146) couplings of the form $kF \pm f_i$ were detected. Depending on Δ , which is the minimum frequency difference to allow for a clear determination of neighbouring frequencies, this number could increase to 171 and more. Additional coupled frequencies are certainly present, but hidden in the noise or too close to a frequency of larger amplitude.

Kallinger & Matthews (2010) claimed that the several hundreds of δ Scuti-type frequencies detected in A-F type stars observed by CoRoT and *Kepler* could not all be attributed to pulsation. Since the observable amplitudes of modes with ℓ larger than 4, which are required to explain the large number of pulsation modes, suffer strong cancellation effects when integrated over the stellar disk, only some tens of frequencies should be detected. The authors demonstrated that many low amplitude frequencies could alternatively be the signature of non-white granulation background noise and that fewer than about 100 of the frequencies of the investigated stars are actually stellar p -modes. In our case, we detected “only” 59 independent modes. Therefore, only ℓ -values up to 5 are necessary to attribute the frequencies to p -modes, but significantly higher ℓ values are discussed nowadays for *Kepler* data. However, as the granulation level is not known for CoRoT ID 105733033, we cannot be entirely sure that all the 59 δ Scuti-type frequencies are really associated with pulsation.

We also detected equidistant frequencies very close to F that could be interpreted as a signature of rotational splitting or Doppler effect modulation. If this were indeed true, the rotation or binary period of the star would be 20.57 d.

We have clearly established the influence of the γ Doradus variations on the δ Scuti behaviour, and convincingly confirmed the thermodynamical and mechanical interactions between the two p - and g -mode cavities, as predicted many years ago as a tool for detecting g -modes in the Sun (Kennedy et al. 1993; Lou 2001).

We now know that the instability strips of γ Doradus and δ Scuti stars are not as clearly defined as previously thought (Uytterhoeven et al. 2011), and the star CoRoT ID 105733033 might be the Rosetta stone for hybrid stars, where coupling similar to those detected in the present paper should be systematically searched for. We are presently studying other candidates in the CoRoT exofield (see e.g. Mathias et al. 2009; Hareter et al. 2010).

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Table 1. List of the 444 frequencies of stellar origin detected by Period04.

F	Freq.	dF	S/N	A	Phi	dPhi	Ident	L.C.	n
F1	12.67586	0.00017	1100.7	27.077	2.259	0.001	F	–	–
F3	0.74276	0.00017	453.1	11.146	0.564	0.002	f1	–	0
F4	0.69517	0.00017	310.7	7.642	1.752	0.003	f2	–	3
F5	25.35207	0.00017	298.7	7.349	0.277	0.004	2F	–	–
F6	0.93449	0.00017	239.7	5.896	3.932	0.004	f3	–	–9
F7	0.99069	0.00017	167.8	4.127	3.319	0.006	f4	–	–11
F8	0.90828	0.00017	167.4	4.118	1.604	0.006	f5	–	–8
F9	0.96242	0.00017	165.4	4.068	3.683	0.006	f6	–	–10
F11	0.79793	0.00017	162.1	3.988	3.713	0.007	f7	–	–3
F12	0.83897	0.00017	145.0	3.566	6.123	0.007	f8	–	–5
F13	11.93345	0.00017	113.5	2.792	5.642	0.009	F-f1	–	–
F14	13.41863	0.00017	108.3	2.663	4.104	0.010	F+f1	–	–
F15	1.16555	0.00017	86.8	2.136	1.735	0.012	f9	–	–
F16	11.98069	0.00017	76.2	1.875	4.814	0.014	F-f2	–	–
F17	13.37143	0.00017	73.4	1.805	3.970	0.014	F+f2	–	–
F18	38.02793	0.00017	70.8	1.742	4.804	0.015	3F	–	–
F19	0.52794	0.00017	69.0	1.697	0.657	0.015	f10	–	–
F20	0.72623	0.00017	65.2	1.605	3.151	0.016	f11	–	1
F22	11.74173	0.00017	60.6	1.491	2.099	0.017	F-f3	–	–
F23	0.88347	0.00017	60.3	1.483	6.217	0.018	f12	–	–7
F25	0.66553	0.00017	59.1	1.454	0.456	0.018	f13	–	5
F26	13.61036	0.00017	56.0	1.378	1.123	0.019	F+f3	–	–
F28	1.43797	0.00017	54.3	1.335	3.424	0.020	f14	f1+f2	–
F29	0.67864	0.00017	54.3	1.335	2.761	0.020	f15	–	–
F30	0.36587	0.00017	54.2	1.333	4.255	0.020	f16	–	–
F31	0.49725	0.00017	51.1	1.256	5.798	0.021	f17	–	–
F33	13.85662	0.00017	48.3	1.187	3.061	0.022	p1	–	–
F34	0.38484	0.00017	48.0	1.181	3.020	0.022	f18	–	–
F35	11.71379	0.00017	47.6	1.171	2.437	0.022	F-f6	–	–
F36	11.68513	0.00017	46.3	1.140	4.131	0.023	F-f4	–	–
F38	11.76759	0.00017	45.3	1.114	4.892	0.023	F-f5	–	–
F39	1.35762	0.00017	44.9	1.105	1.923	0.024	f19	–	–
F40	1.67763	0.00017	44.4	1.092	5.440	0.024	f20	f1+f3	–
F41	1.08796	0.00017	44.2	1.088	1.590	0.024	f21	–	–
F42	0.81761	0.00017	43.7	1.074	3.838	0.024	f22	–	–4
F43	11.87794	0.00017	41.4	1.019	2.839	0.026	F-f7	–	–
F44	13.63862	0.00017	41.1	1.011	0.604	0.026	F+f6	–	–
F45	11.83690	0.00017	40.3	0.992	0.437	0.026	F-f8	–	–
F46	13.66690	0.00017	40.2	0.988	0.246	0.026	F+f4	–	–
F47	1.73418	0.00017	39.7	0.976	4.512	0.027	f23	f1+f4	–
F48	0.42518	0.00017	39.5	0.971	5.405	0.027	f24	–	–
F49	0.41346	0.00017	38.6	0.950	5.768	0.027	f25	–	–
F50	13.47345	0.00017	38.5	0.947	1.431	0.027	F+f7	–	–
F51	13.58449	0.00017	38.2	0.939	4.785	0.028	F+f5	–	–
F52	13.51448	0.00017	37.8	0.931	3.903	0.028	F+f8	–	–
F54	0.75899	0.00017	35.5	0.873	3.885	0.030	f26	–	–1
F55	1.54038	0.00017	35.2	0.866	5.812	0.030	f27	f1+f7	–
F57	1.48521	0.00017	31.3	0.769	2.568	0.034	f28	2f1	–
F58	0.56105	0.00017	30.9	0.761	3.392	0.034	f29	–	–
F59	24.60908	0.00017	30.4	0.747	1.705	0.035	2F-f1	–	–
F60	0.53622	0.00017	30.1	0.740	3.843	0.035	f30	–	–
F61	0.44794	0.00017	28.9	0.711	5.309	0.037	f31	–	–
F63	0.59622	0.00017	27.9	0.687	5.823	0.038	f32	–	–
F64	26.09483	0.00017	27.6	0.680	1.602	0.038	2F+f1	–	–
F67	0.51346	0.00017	27.1	0.666	1.397	0.039	f33	–	–
F68	0.58829	0.00017	26.5	0.653	4.668	0.040	f34	–	–
F69	1.81832	0.00017	26.2	0.645	2.608	0.040	f35	–	–
F70	1.05451	0.00017	26.2	0.644	4.542	0.040	f36	–	–13
F71	0.48070	0.00017	25.6	0.630	2.850	0.041	f37	–	–
F73	1.70280	0.00017	25.0	0.615	1.855	0.042	f38	–	–
F74	0.64209	0.00017	24.6	0.604	1.999	0.043	f39	–	–
F75	1.90660	0.00017	24.5	0.602	5.813	0.043	f40	–	–
F76	1.84522	0.00017	24.4	0.601	4.955	0.043	f41	–	–
F77	1.79039	0.00017	24.2	0.596	5.627	0.044	f42	–	–
F79	0.45760	0.00017	23.7	0.583	2.866	0.045	f43	–	–
F80	0.70933	0.00017	23.7	0.582	5.490	0.045	f44	–	2
F81	1.65349	0.00018	22.9	0.563	6.135	0.046	f45	–	–

Table 1. continued.

F	Freq.	dF	S/N	A	Phi	dPhi	Ident	L.C.	n
F82	0.77864	0.00018	22.8	0.562	0.418	0.046	f46	–	–2
F83	1.60418	0.00018	22.7	0.558	3.548	0.047	f47	f2+f5	–
F86	0.62795	0.00018	22.3	0.549	5.929	0.047	f48	–	8
F87	0.60657	0.00018	21.9	0.539	5.493	0.048	f49	–	–
F88	1.75970	0.00019	21.3	0.523	2.929	0.050	f50	–	–
F89	1.58108	0.00019	21.3	0.523	1.643	0.050	f51	f1+f8	–
F93	1.33383	0.00019	20.8	0.512	3.796	0.051	f52	–	–
F94	24.65659	0.00020	20.6	0.507	2.002	0.051	2F-f2	–	–
F95	0.50518	0.00020	20.5	0.505	5.808	0.052	f53	–	–
F96	1.46762	0.00020	20.5	0.504	0.269	0.052	f54	–	–
F98	16.40189	0.00020	19.9	0.490	1.087	0.053	1O?	–	–
F99	1.63108	0.00021	19.3	0.476	5.005	0.055	f55	–	–
F100	1.41486	0.00021	18.9	0.464	3.474	0.056	f56	–	–
F102	11.00587	0.00021	18.7	0.461	2.103	0.056	p2	–	–
F103	12.14794	0.00022	18.6	0.458	5.673	0.057	F-f10	–	–
F104	26.04731	0.00022	18.3	0.450	1.550	0.058	2F+f2	–	–
F105	1.95278	0.00022	18.3	0.450	3.389	0.058	f57	–	–
F107	11.23828	0.00022	18.0	0.443	1.955	0.059	F-f14	–	–
F108	15.92931	0.00022	18.0	0.442	0.461	0.059	p3	–	–
F109	13.84173	0.00023	17.5	0.430	5.463	0.061	F+f9	–	–
F110	1.27035	0.00023	17.2	0.423	4.046	0.062	f58	f1+f10	–
F111	1.39176	0.00023	17.2	0.422	3.078	0.062	f59	–	–
F112	11.94966	0.00023	17.2	0.422	3.043	0.062	F-f11	–	–
F113	1.86832	0.00024	17.1	0.420	2.519	0.062	2f3	–	–
F114	50.70398	0.00024	16.8	0.414	5.685	0.063	4F	–	–
F117	0.55312	0.00024	16.8	0.413	4.532	0.063	f60	–	–
F118	0.27173	0.00024	16.7	0.411	0.458	0.063	f61	–	–
F119	24.41724	0.00024	16.6	0.408	0.786	0.064	2F-f3	–	–
F120	13.20311	0.00025	16.4	0.404	5.312	0.064	F+f10	–	–
F121	26.28656	0.00025	16.3	0.402	4.898	0.065	2F+f3	–	–
F122	1.92519	0.00025	16.3	0.401	2.044	0.065	f62	f3+f4	–
F123	14.11380	0.00025	16.1	0.396	1.138	0.066	F+f14	–	–
F124	0.31552	0.00025	16.1	0.395	4.038	0.066	f63	–	–
F125	18.17690	0.00025	15.9	0.391	1.937	0.067	p4	–	–
F126	1.50311	0.00026	15.8	0.388	5.269	0.067	f64	–	–
F127	11.31863	0.00026	15.8	0.388	3.131	0.067	F-f19	–	–
F128	10.99828	0.00026	15.7	0.385	0.397	0.068	F-f20	–	–
F129	1.65967	0.00026	15.7	0.385	3.764	0.068	f65	–	–
F131	1.46070	0.00026	15.5	0.381	2.565	0.068	f66	–	–
F132	1.83243	0.00026	15.4	0.380	1.753	0.069	f67	–	–
F133	14.35355	0.00026	15.3	0.377	1.432	0.069	F+f20	–	–
F134	1.22379	0.00026	15.2	0.374	4.079	0.070	f68	f2+f10	–
F135	16.40931	0.00026	15.2	0.374	1.850	0.070	p5	–	–
F136	12.97862	0.00027	15.1	0.372	2.483	0.070	p6	–	–
F137	13.04138	0.00027	15.1	0.371	1.898	0.070	F+f16	–	–
F138	16.34483	0.00027	15.0	0.370	5.599	0.070	p7	–	–
F139	11.79209	0.00027	15.0	0.369	6.181	0.071	F-f12	–	–
F140	13.40242	0.00027	15.0	0.368	0.345	0.071	F+f11	–	–
F142	1.30380	0.00027	14.7	0.362	0.037	0.072	f69	–	–
F143	1.68760	0.00027	14.7	0.361	3.835	0.072	f70	–	–
F144	0.24828	0.00028	14.2	0.350	1.818	0.074	f71	f4-f1	–
F145	0.26208	0.00028	14.2	0.349	0.965	0.075	f72	–	–
F147	12.31035	0.00029	14.1	0.347	2.062	0.075	F-f16	–	–
F148	1.51521	0.00029	14.0	0.345	3.628	0.075	f73	–	–
F149	0.47139	0.00029	14.0	0.344	3.853	0.076	f74	–	–
F150	1.64004	0.00029	13.9	0.342	2.688	0.076	f75	–	–
F151	1.59038	0.00029	13.7	0.337	2.122	0.077	f76	–	–
F153	13.34070	0.00030	13.6	0.335	5.146	0.078	F+f13	–	–
F154	1.32383	0.00030	13.6	0.334	1.562	0.078	f77	–	–
F155	24.96726	0.00030	13.4	0.330	0.596	0.079	2F-f18	–	–
F158	12.01040	0.00030	13.3	0.326	4.876	0.080	F-f13	–	–
F159	1.20210	0.00031	13.2	0.324	1.750	0.080	f78	–	–
F160	10.94172	0.00031	13.1	0.323	1.141	0.081	F-f23	–	–
F161	24.36173	0.00031	13.0	0.320	0.233	0.081	2F-f4	–	–
F162	24.39035	0.00031	13.0	0.320	5.742	0.081	2F-f6	–	–
F163	1.56418	0.00031	13.0	0.319	0.703	0.082	f79	–	–23
F164	11.58760	0.00031	13.0	0.319	4.808	0.082	F-f21	–	–

Table 1. continued.

F	Freq.	dF	S/N	A	Phi	dPhi	Ident	L.C.	n
F165	0.65760	0.00031	12.9	0.317	0.495	0.082	f80	—	—
F166	13.35449	0.00031	12.8	0.316	0.209	0.082	F+f15	—	—
F168	1.98350	0.00032	12.7	0.313	5.227	0.083	f81	—	—
F170	11.13518	0.00032	12.6	0.311	0.336	0.084	F-f27	—	—
F171	0.28311	0.00032	12.6	0.311	5.439	0.084	f82	—	—
F172	13.56044	0.00032	12.6	0.310	1.008	0.084	F+f12	—	—
F173	12.18003	0.00032	12.6	0.309	4.784	0.084	F-f17?	—	—
F174	24.44380	0.00032	12.5	0.307	2.335	0.085	2F-f5	—	—
F176	1.89488	0.00032	12.4	0.306	4.625	0.085	f83	—	—
F180	1.24831	0.00033	12.1	0.297	1.133	0.088	f84	—	—
F181	13.06000	0.00034	12.0	0.295	1.459	0.088	F+f18	—	—
F182	14.41004	0.00034	12.0	0.294	1.942	0.089	F+f23	—	—
F183	1.80384	0.00034	11.8	0.291	1.388	0.089	f85	—	—
F184	0.35380	0.00034	11.8	0.290	1.603	0.090	f86	—	—
F185	13.10207	0.00034	11.7	0.289	1.719	0.090	F+f24	—	—
F186	13.49415	0.00034	11.7	0.288	0.538	0.090	F+f22	—	—
F187	15.98724	0.00034	11.7	0.288	5.761	0.090	p8	—	—
F188	2.12247	0.00035	11.4	0.281	5.364	0.093	f87	—	—
F189	11.19070	0.00035	11.4	0.281	3.308	0.093	F-f28	—	—
F190	14.21624	0.00035	11.4	0.280	3.243	0.093	F+f27	—	—
F191	1.36521	0.00036	11.2	0.276	3.420	0.094	f88	—	−20
F192	29.07801	0.00036	11.2	0.276	0.726	0.094	p9	F+10	—
F193	11.99651	0.00036	11.2	0.275	5.314	0.095	F-f15	—	—
F194	26.34277	0.00036	11.2	0.275	4.374	0.095	2F+f4	—	—
F196	11.51071	0.00036	11.1	0.272	3.932	0.096	F-f9	—	—
F197	26.31380	0.00037	11.0	0.271	5.523	0.096	2F+f6	—	—
F199	0.76966	0.00037	11.0	0.270	5.681	0.096	f89	—	—
F200	1.74418	0.00037	10.9	0.269	0.805	0.097	f90	—	—
F201	0.29966	0.00037	10.9	0.269	0.258	0.097	f91	—	—
F202	10.88655	0.00037	10.9	0.267	4.957	0.098	F-f42?	—	—
F203	14.03347	0.00037	10.9	0.267	5.723	0.098	F+f19	—	—
F205	0.32794	0.00037	10.8	0.265	0.647	0.098	f92	—	—
F206	11.85796	0.00038	10.7	0.264	2.328	0.099	F-f22	—	—
F207	0.86175	0.00038	10.7	0.264	1.263	0.099	f93	—	−6
F208	24.55345	0.00038	10.7	0.262	1.031	0.099	2F-f7	—	—
F209	1.45245	0.00038	10.6	0.261	2.021	0.100	f94	—	—
F210	24.51242	0.00039	10.4	0.257	5.032	0.101	2F-f8	—	—
F211	13.76387	0.00039	10.4	0.255	4.365	0.102	F+f21	—	—
F212	14.16112	0.00039	10.3	0.253	4.956	0.103	F+f28	—	—
F213	26.14966	0.00039	10.3	0.253	5.206	0.103	2F+f7	—	—
F214	13.17276	0.00039	10.2	0.251	3.573	0.104	F+f17	—	—
F215	20.70069	0.00040	10.2	0.250	1.466	0.104	p10	—	—
F216	0.43449	0.00040	10.2	0.250	3.502	0.104	f95	—	—
F217	2.57110	0.00040	10.1	0.249	1.638	0.105	f96	—	—
F218	2.28350	0.00040	10.1	0.248	1.992	0.105	f97	2f1+f7	—
F219	0.48931	0.00040	10.0	0.246	0.780	0.106	f98	—	—
F222	12.26142	0.00041	9.8	0.240	1.438	0.109	F-f25?	—	—
F223	1.72210	0.00041	9.8	0.240	3.631	0.109	f99	—	—
F224	11.02242	0.00042	9.7	0.238	5.916	0.109	F-f45	—	—
F225	26.26001	0.00042	9.7	0.238	3.068	0.109	2F+f5	—	—
F226	1.27830	0.00042	9.6	0.237	1.853	0.110	f100	—	—
F227	12.29073	0.00042	9.6	0.236	3.374	0.110	F-f18	—	—
F228	0.85415	0.00042	9.6	0.235	5.531	0.111	f101	—	—
F229	2.01966	0.00042	9.5	0.234	5.110	0.111	f102	—	—
F230	26.19104	0.00043	9.4	0.232	0.792	0.112	2F+f8	—	—
F231	11.09381	0.00043	9.4	0.232	5.009	0.112	F-f51?	—	—
F233	37.28501	0.00043	9.3	0.229	4.662	0.114	3F-f1	—	—
F234	2.07245	0.00043	9.3	0.229	0.620	0.114	f103	—	—
F235	29.02111	0.00043	9.3	0.228	2.099	0.114	p11	F+p7	—
F237	0.34553	0.00044	9.2	0.227	1.795	0.115	f104	—	—
F238	10.97242	0.00044	9.2	0.227	4.646	0.115	F-f38	—	—
F239	2.44488	0.00044	9.2	0.226	4.890	0.115	f105	—	—
F241	13.12351	0.00044	9.1	0.223	2.416	0.117	F+f31	—	—
F242	0.95069	0.00045	9.0	0.221	3.244	0.118	f106	—	—
F243	2.31661	0.00045	9.0	0.221	5.457	0.118	f107	—	—
F244	2.25730	0.00045	9.0	0.221	1.731	0.118	f108	—	—
F245	10.83097	0.00045	9.0	0.221	1.525	0.118	F-f41	—	—

Table 1. continued.

F	Freq.	dF	S/N	A	Phi	dPhi	Ident	L.C.	n
F246	29.08560	0.00045	9.0	0.221	4.477	0.118	p12	F+p5	–
F247	14.28035	0.00045	8.9	0.220	1.025	0.118	F+f47	–	–
F248	10.76931	0.00045	8.9	0.219	6.127	0.119	F-f40	–	–
F249	11.07173	0.00045	8.9	0.219	2.172	0.119	F-f47	–	–
F251	13.08899	0.00046	8.7	0.214	3.127	0.122	F+f25	–	–
F252	1.94418	0.00046	8.7	0.214	5.471	0.122	f109	–	–
F254	1.03692	0.00047	8.6	0.212	4.366	0.123	f110	–	–
F255	2.23624	0.00047	8.6	0.211	2.336	0.123	f111	–	–
F256	2.61242	0.00047	8.5	0.210	5.235	0.124	f112	f1+2f3	–
F257	2.13108	0.00047	8.5	0.210	3.374	0.124	f113	–	–
F259	0.86931	0.00047	8.5	0.209	5.697	0.125	f114	–	–
F260	2.04796	0.00048	8.5	0.208	5.856	0.125	f115	–	–
F261	2.14038	0.00048	8.4	0.207	2.696	0.126	f116	–	–
F262	1.77002	0.00048	8.3	0.205	1.151	0.127	f117	–	–
F263	11.91693	0.00048	8.3	0.205	1.763	0.127	F-f26	–	–
F264	14.33242	0.00049	8.3	0.204	5.818	0.128	p13	–	–
F265	13.26417	0.00049	8.3	0.204	1.719	0.128	F+f34	–	–
F266	2.34627	0.00049	8.3	0.204	0.668	0.128	f118	–	–
F267	12.24935	0.00049	8.2	0.202	2.085	0.129	F-f24?	–	–
F268	12.22725	0.00049	8.2	0.202	1.745	0.129	F-f31	–	–
F270	12.47794	0.00050	8.1	0.199	5.705	0.131	p14	–	–
F272	10.91690	0.00050	8.1	0.199	1.779	0.131	F-f50	–	–
F273	1.47726	0.00050	8.1	0.199	5.419	0.131	f119	–	–
F274	13.15760	0.00050	8.0	0.197	4.731	0.132	F+f37?	–	–
F275	1.87626	0.00050	8.0	0.197	0.426	0.132	f120	–	–
F277	14.79069	0.00051	8.0	0.196	3.184	0.133	p15	p1+f3	–
F278	1.61623	0.00051	8.0	0.196	3.312	0.133	f121	–	–
F279	14.52070	0.00051	8.0	0.196	3.144	0.133	F+f41	–	–
F280	18.16966	0.00051	8.0	0.196	0.334	0.133	p16	–	–
F282	1.37932	0.00051	7.9	0.194	3.770	0.134	f122	–	–
F284	38.77035	0.00051	7.9	0.194	6.205	0.134	3F+f1	–	–
F285	14.37897	0.00051	7.9	0.194	5.795	0.134	F+f38	–	–
F286	1.86039	0.00051	7.8	0.193	4.798	0.135	f123	f2+f9	–
F287	2.41075	0.00052	7.8	0.192	5.334	0.136	f124	–	–
F288	10.84552	0.00052	7.8	0.191	2.277	0.136	F-f67?	–	–
F289	10.80725	0.00052	7.8	0.191	3.385	0.136	F-2f2	–	–
F290	11.62072	0.00052	7.8	0.191	2.119	0.136	F-f36	–	–
F291	1.55450	0.00052	7.7	0.190	0.317	0.137	f125	–	–
F292	25.65449	0.00052	7.7	0.190	0.692	0.137	p17	p1+p6	–
F293	26.53276	0.00052	7.7	0.190	5.889	0.137	p18	F+p1	–
F294	13.24003	0.00052	7.7	0.189	3.685	0.138	p19	–	–
F295	12.08762	0.00052	7.7	0.189	1.169	0.138	F-f34	–	–
F296	1.12656	0.00052	7.7	0.189	0.489	0.138	f126	–	–15
F297	10.72311	0.00053	7.6	0.188	2.891	0.139	F-f57	–	–
F298	11.21105	0.00053	7.6	0.187	2.346	0.139	p20	–	–
F299	1.19175	0.00053	7.6	0.187	6.152	0.139	f127	–	–
F301	14.25690	0.00053	7.6	0.186	6.218	0.140	F+f51	–	–
F302	0.97761	0.00054	7.5	0.185	2.895	0.141	f128	–	–
F303	2.30075	0.00054	7.5	0.184	4.118	0.142	f129	–	–
F306	30.85311	0.00054	7.4	0.182	6.021	0.143	p21	F+p4	–
F307	10.85966	0.00054	7.4	0.182	0.313	0.143	F-2f5	–	–
F308	11.04484	0.00055	7.4	0.181	0.584	0.144	F-f55	–	–
F309	12.98801	0.00055	7.3	0.180	5.394	0.145	p22	–	–
F310	13.43588	0.00055	7.3	0.180	0.202	0.145	F+f26?	–	–
F312	13.72968	0.00055	7.3	0.179	2.989	0.145	F+f36	–	–
F313	1.42831	0.00056	7.2	0.177	1.380	0.147	f130	–	–21
F315	13.21415	0.00056	7.2	0.176	4.828	0.148	F+f30??	–	–
F316	1.06692	0.00056	7.2	0.176	1.081	0.148	f131	–	–
F317	2.86732	0.00056	7.2	0.176	5.232	0.148	f132	–	–
F318	1.02968	0.00057	7.1	0.175	3.144	0.149	f133	–	–
F319	1.81074	0.00057	7.1	0.175	5.786	0.149	f134	–	–
F320	24.98655	0.00057	7.0	0.173	4.903	0.151	2F-f16	–	–
F321	12.68690	0.00058	7.0	0.172	3.969	0.151	p23	–	–
F322	13.84900	0.00058	7.0	0.171	1.154	0.152	p24	–	–
F323	2.53075	0.00058	7.0	0.171	5.046	0.152	f135	–	–
F324	2.09074	0.00058	6.9	0.170	1.103	0.153	f136	–	–
F326	2.38419	0.00059	6.8	0.168	3.882	0.155	f137	–	–

Table 1. continued.

F	Freq.	dF	S/N	A	Phi	dPhi	Ident	L.C.	n
F327	2.50731	0.00059	6.8	0.168	1.179	0.155	f138	—	—
F328	1.15382	0.00059	6.8	0.168	5.372	0.155	f139	—	—
F329	13.99970	0.00059	6.8	0.167	4.476	0.156	F+f77	—	—
F330	28.66241	0.00060	6.7	0.166	5.017	0.157	p25	F+p8	—
F331	13.38002	0.00060	6.7	0.166	3.860	0.157	p26	—	—
F332	2.54627	0.00060	6.7	0.165	2.464	0.158	f140	—	—
F333	12.16828	0.00060	6.7	0.164	3.597	0.159	F-f53?	—	—
F334	3.02387	0.00060	6.7	0.164	2.154	0.159	f141	—	—
F335	1.14417	0.00060	6.7	0.164	0.817	0.159	f142	—	—
F336	2.24730	0.00061	6.6	0.163	0.033	0.160	f143	—	—
F338	10.74966	0.00061	6.6	0.163	5.252	0.160	F-f62	—	—
F339	1.25900	0.00061	6.6	0.163	4.007	0.160	f144	—	−18
F340	12.13686	0.00061	6.6	0.163	0.786	0.160	F-f30	—	—
F341	14.46492	0.00061	6.6	0.162	3.679	0.161	F+f42?	—	—
F342	2.58524	0.00061	6.5	0.161	4.154	0.162	f145	—	—
F343	11.40519	0.00061	6.5	0.161	2.699	0.162	F-f58	—	—
F345	14.30695	0.00061	6.5	0.161	1.641	0.162	F+f55	—	—
F346	2.65041	0.00061	6.5	0.161	1.076	0.162	f146	2f1+f9	—
F349	2.37489	0.00063	6.4	0.157	5.843	0.166	f147	—	—
F350	14.50558	0.00063	6.4	0.157	1.073	0.166	p27	—	—
F352	15.95725	0.00063	6.3	0.156	4.077	0.167	p28	—	—
F353	11.34243	0.00063	6.3	0.156	1.685	0.167	F-f52	—	—
F355	37.33277	0.00064	6.3	0.155	0.233	0.168	3F-f2	—	—
F356	2.83800	0.00064	6.3	0.155	2.573	0.168	f148	—	—
F357	13.18967	0.00064	6.3	0.155	4.095	0.168	F+f33	—	—
F358	2.39384	0.00064	6.3	0.154	5.036	0.169	f149	2f1+f5	—
F360	12.62760	0.00064	6.3	0.154	3.816	0.169	p29	F-Frot	—
F361	14.58286	0.00064	6.3	0.154	1.576	0.169	F+f40	—	—
F364	14.43460	0.00065	6.2	0.152	0.228	0.171	F+f50	—	—
F365	1.31107	0.00065	6.2	0.152	2.744	0.171	f150	—	−19
F366	1.17486	0.00065	6.2	0.152	1.128	0.171	f151	—	—
F367	11.28381	0.00065	6.2	0.152	3.155	0.171	F-f59	—	—
F368	12.46798	0.00066	6.1	0.151	5.829	0.172	p30	—	—
F369	3.72724	0.00066	6.1	0.151	3.873	0.172	f152	—	—
F370	2.15799	0.00066	6.1	0.151	5.114	0.172	f153	—	—
F372	14.06733	0.00066	6.1	0.150	6.054	0.174	F+f59	—	—
F373	10.77933	0.00066	6.1	0.150	2.590	0.174	F-f83?	—	—
F377	11.89624	0.00067	6.0	0.147	0.472	0.177	F-f46	—	—
F378	38.72345	0.00067	6.0	0.147	0.215	0.177	3F+f2	—	—
F379	1.13554	0.00068	5.9	0.146	0.314	0.178	f154	—	—
F380	12.48488	0.00068	5.9	0.146	1.064	0.178	F+f1-f3 −	—	—
F381	12.57764	0.00068	5.9	0.146	4.501	0.178	p31	F-2Frot	—
F382	12.16004	0.00068	5.9	0.146	1.419	0.178	F-f33?	—	—
F383	2.47385	0.00069	5.9	0.144	5.025	0.181	f155	—	—
F384	0.94347	0.00069	5.9	0.144	1.398	0.181	f156	—	—
F385	12.11418	0.00069	5.9	0.144	3.005	0.181	F-f29	—	—
F387	11.37312	0.00069	5.8	0.143	5.007	0.182	F-f69	—	—
F388	13.23524	0.00069	5.8	0.143	1.246	0.182	F+f29?	—	—
F389	2.07971	0.00070	5.8	0.142	5.647	0.183	f157	—	—
F390	14.49182	0.00070	5.8	0.142	1.924	0.183	F+f35?	—	—
F391	28.60552	0.00070	5.7	0.141	4.359	0.185	p32	F+p3	—
F392	2.65903	0.00070	5.7	0.141	0.647	0.185	f158	—	—
F393	12.19556	0.00070	5.7	0.141	2.699	0.185	F-f37	—	—
F394	2.76317	0.00070	5.7	0.141	4.241	0.185	f159	—	—
F395	2.33315	0.00070	5.7	0.141	3.931	0.185	f160	—	—
F396	1.75279	0.00070	5.7	0.141	3.409	0.185	f161	—	—
F398	14.62872	0.00071	5.7	0.140	5.021	0.186	F+f57	—	—
F399	10.98829	0.00071	5.7	0.140	2.225	0.186	F-f70	—	—
F400	12.07659	0.00071	5.7	0.140	3.614	0.186	F-f32?	—	—
F401	23.91380	0.00071	5.7	0.139	0.236	0.187	2F-f14	—	—
F403	12.55143	0.00072	5.6	0.138	0.120	0.189	p33	—	—
F404	14.13802	0.00072	5.6	0.138	2.568	0.189	F+f66?	—	—
F405	2.88007	0.00072	5.6	0.137	2.775	0.190	f162	—	—
F406	11.16174	0.00072	5.6	0.137	0.476	0.190	F-f73	—	—
F408	2.01004	0.00073	5.5	0.136	4.117	0.191	f163	—	—
F409	26.07796	0.00074	5.4	0.134	4.716	0.194	2F+f11	—	—
F410	2.42143	0.00074	5.4	0.134	1.389	0.194	f164	—	—

Table 1. continued.

F	Freq.	dF	S/N	A	Phi	dPhi	Ident	L.C.	n
F411	11.26140	0.00074	5.4	0.134	1.344	0.194	F-f56	—	—
F412	2.32557	0.00074	5.4	0.134	2.112	0.194	f165	2f2+f3	—
F413	11.18312	0.00074	5.4	0.134	4.134	0.194	p34	—	—
F417	26.78970	0.00075	5.4	0.132	4.550	0.197	2F+f14	—	—
F418	2.96145	0.00075	5.4	0.132	2.447	0.197	f166	—	—
F419	10.69207	0.00076	5.3	0.131	0.915	0.199	F-f81	—	—
F421	12.23385	0.00076	5.3	0.131	3.601	0.199	p35	—	—
F422	13.18278	0.00076	5.3	0.131	1.237	0.199	F+f53?	—	—
F424	12.66656	0.00076	5.3	0.130	1.329	0.200	p36	—	—
F425	11.45209	0.00076	5.3	0.130	2.028	0.200	F-f68	—	—
F427	10.87450	0.00076	5.3	0.130	0.956	0.200	p37	—	—
F429	14.01038	0.00077	5.2	0.129	5.910	0.202	F+f52	—	—
F430	2.17246	0.00077	5.2	0.129	2.023	0.202	f166	—	—
F431	27.95104	0.00077	5.2	0.129	0.070	0.202	p38	—	—
F432	14.36315	0.00077	5.2	0.129	1.134	0.202	F+f70	—	—
F433	2.50040	0.00077	5.2	0.129	2.264	0.202	f167	—	—
F437	37.64310	0.00078	5.2	0.127	5.346	0.205	p39	—	—
F440	13.14898	0.00078	5.2	0.127	4.977	0.205	p40	—	—
F441	2.26522	0.00079	5.1	0.126	5.812	0.207	f168	—	—
F442	1.93280	0.00079	5.1	0.126	4.658	0.207	f169	—	—
F444	12.72311	0.00079	5.1	0.126	0.620	0.207	p41	F+Frot	—
F447	11.70004	0.00079	5.1	0.125	0.011	0.208	p42	—	—
F449	13.87663	0.00079	5.1	0.125	6.232	0.208	F+f78?	—	—
F450	26.51656	0.00080	5.0	0.124	4.752	0.210	2F+f9	—	—
F451	12.43799	0.00080	5.0	0.124	1.750	0.210	p43	—	—
F453	13.27316	0.00080	5.0	0.124	0.962	0.210	F+f32	—	—
F454	12.21928	0.00080	5.0	0.124	3.372	0.210	F-f43	—	—
F456	3.25111	0.00081	5.0	0.122	3.223	0.213	f170	—	—
F458	24.82384	0.00081	5.0	0.122	2.677	0.213	2F-f10	—	—
F459	10.10380	0.00081	5.0	0.122	5.226	0.213	F-f96?	—	—
F460	10.95311	0.00081	5.0	0.122	2.996	0.213	F-f99?	—	—
F461	11.08518	0.00082	4.9	0.121	4.268	0.215	F-f76	—	—
F462	2.55800	0.00082	4.9	0.121	2.146	0.215	f171	—	—
F463	3.31457	0.00083	4.9	0.120	2.774	0.217	f172	—	—
F464	14.54423	0.00083	4.9	0.120	5.212	0.217	F+2f3	—	—
F465	2.98352	0.00083	4.9	0.120	0.824	0.217	f173	—	—
F466	2.48765	0.00083	4.9	0.120	1.575	0.217	f174	—	—
F467	14.81769	0.00083	4.8	0.119	2.904	0.219	p44	p1+f6?	—
F468	12.88798	0.00083	4.8	0.119	3.412	0.219	p45	—	—
F470	2.18005	0.00084	4.8	0.118	0.358	0.221	f175	2f1+f2	—
F471	2.82110	0.00084	4.8	0.118	3.379	0.221	f176	—	—
F473	2.06522	0.00085	4.8	0.117	0.225	0.223	f177	—	—
F474	23.99450	0.00085	4.7	0.116	1.052	0.224	2F-f19	—	—
F475	12.06793	0.00085	4.7	0.116	2.445	0.224	f-f49?	—	—
F476	12.85177	0.00085	4.7	0.116	4.711	0.224	p46	—	—
F477	14.15209	0.00085	4.7	0.116	3.843	0.224	p47	—	—
F478	20.38776	0.00086	4.7	0.115	4.318	0.226	2O?	—	—
F479	1.34380	0.00086	4.7	0.115	0.571	0.226	f178	—	—
F480	2.85076	0.00086	4.7	0.115	4.673	0.226	f179	—	—
F481	2.72415	0.00086	4.7	0.115	6.119	0.226	f180	—	—
F483	23.81104	0.00086	4.7	0.115	4.411	0.226	2F-f27	—	—
F484	14.26629	0.00086	4.7	0.115	4.797	0.226	F+f76	—	—
F485	1.52414	0.00086	4.7	0.115	1.548	0.226	f181	—	—
F486	12.70312	0.00086	4.7	0.115	1.837	0.226	p48	—	—
F487	14.16899	0.00087	4.6	0.114	4.757	0.228	p49	—	—
F488	13.30655	0.00087	4.6	0.114	5.365	0.228	p50	—	—
F489	12.36173	0.00087	4.6	0.114	1.863	0.228	F-f63?	—	—
F490	38.96252	0.00088	4.6	0.113	1.088	0.230	3F+f3	—	—
F491	2.75415	0.00088	4.6	0.113	2.101	0.230	f182	—	—
F492	2.45208	0.00088	4.6	0.113	4.844	0.230	f183	—	—
F493	1.96244	0.00088	4.6	0.113	3.450	0.230	f184	—	—
F494	12.80312	0.00088	4.6	0.113	3.614	0.230	p51	—	—
F495	3.99355	0.00088	4.6	0.113	0.163	0.230	f185	—	—
F497	0.57760	0.00088	4.6	0.113	3.002	0.230	f186	—	—
F498	24.46796	0.00088	4.6	0.113	4.175	0.230	2F-f12	—	—
F499	11.47381	0.00088	4.6	0.113	4.283	0.230	F-f78	—	—
F500	1.29001	0.00088	4.6	0.112	6.054	0.233	f187	—	—

Table 1. continued.

F	Freq.	dF	S/N	A	Phi	dPhi	Ident	L.C.	n
F501	12.93140	0.00088	4.6	0.112	3.604	0.233	p52	–	–
F502	12.03414	0.00088	4.6	0.112	3.948	0.233	F-f39	–	–
F503	12.27483	0.00089	4.5	0.111	0.239	0.235	p53	–	–
F504	23.67518	0.00089	4.5	0.111	3.140	0.235	2F-f20	–	–
F505	16.35587	0.00089	4.5	0.111	4.152	0.235	p54	–	–
F506	2.35518	0.00089	4.5	0.111	0.526	0.235	f188	–	–
F507	11.35201	0.00089	4.5	0.111	5.689	0.235	F-f77	–	–
F508	2.20730	0.00089	4.5	0.111	5.653	0.235	f189	–	–
F509	10.55380	0.00089	4.5	0.111	6.037	0.235	F-f87	–	–
F510	13.95726	0.00089	4.5	0.111	1.336	0.235	p55	–	–
F511	2.92207	0.00089	4.5	0.111	4.802	0.235	f190	–	–
F512	11.11138	0.00090	4.5	0.110	5.480	0.237	F-f79	–	–
F513	3.10242	0.00090	4.5	0.110	3.429	0.237	f191	–	–
F516	63.38000	0.00092	4.4	0.108	0.739	0.241	5F	–	–
F517	13.65208	0.00092	4.4	0.108	2.253	0.241	p56	–	–
F519	11.22518	0.00093	4.3	0.107	1.582	0.243	F-f94?	–	–
F520	13.45035	0.00093	4.3	0.107	3.666	0.243	p27	–	–
F522	13.45759	0.00093	4.3	0.107	6.118	0.243	p58	–	–
F524	12.04759	0.00093	4.3	0.107	1.331	0.243	F-f48	–	–
F526	41.75759	0.00093	4.3	0.107	2.524	0.243	p59	–	–
F528	2.46347	0.00093	4.3	0.106	0.651	0.246	f192	–	–
F529	14.99287	0.00093	4.3	0.106	1.014	0.246	p60	–	–
F530	14.19037	0.00093	4.3	0.106	2.238	0.246	F+f73	–	–
F531	24.62658	0.00093	4.3	0.106	5.465	0.246	2F-f11	–	–
F532	12.53795	0.00094	4.3	0.105	2.887	0.248	p61	–	–
F534	3.34663	0.00094	4.3	0.105	2.393	0.248	f193	–	–
F535	2.88900	0.00094	4.3	0.105	0.323	0.248	f194	–	–
F537	13.28276	0.00095	4.2	0.104	2.481	0.250	F+f49	–	–
F538	25.76592	0.00095	4.2	0.104	4.913	0.250	2F+f25	–	–
F539	14.09933	0.00095	4.2	0.104	6.017	0.250	p62	–	–
F541	15.12070	0.00096	4.2	0.103	3.045	0.253	p63	–	–
F542	24.93935	0.00096	4.2	0.103	3.559	0.253	2F-f25	–	–
F544	3.36759	0.00096	4.2	0.103	3.813	0.253	f195	–	–
F546	12.45794	0.00097	4.1	0.102	1.150	0.255	p64	–	–
F548	2.03518	0.00097	4.1	0.102	1.963	0.255	f196	–	–
F550	14.23934	0.00098	4.1	0.101	5.487	0.258	F+f79	–	–
F553	14.76517	0.00098	4.1	0.101	1.439	0.258	p65	p1+f5	–
F554	23.56242	0.00098	4.1	0.101	2.717	0.258	p66	–	–
F555	37.09311	0.00099	4.1	0.100	5.092	0.260	3F-f3	–	–
F556	12.56966	0.00100	4.0	0.099	4.100	0.263	p67	–	–
F558	11.17380	0.00102	3.9	0.097	5.969	0.268	F-f64?	–	–
F559	41.69690	0.00103	3.9	0.096	1.928	0.271	p68	2F+p7	–

Notes. Columns: 1: the name of the detected frequency in the detection order; 2 and 3: value of the frequency and its uncertainty [1/d]; 4: S/N value; 5: amplitude [mmag]. The corresponding uncertainty is 0.027 mmag; 6 and 7: corresponding phase and its uncertainty [rad]; 8: identification of the frequencies: list over the couplings between F1 and the gamma Doradus modes, over the radial modes and harmonics (F, 10, 20), the candidate rotation frequency (Frot), and the new names for the independent gamma Doradus (fi) and the non-radial delta Scuti modes (pi). The “?” sign means that the uncertainty is between $\Delta f = 0.0010$ and 0.0015 c/d; 9: detected linear combination; 10: arbitrary radial order n for the asymptotic relation detected in the Gamma Doradus periods. Remark: The 444 detected frequencies are numbered until F559; the missing ones are those that are discarded as instrumental or prewhitening residuals (see text).