δ Scuti Stars in Stellar Systems: a Review

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Abstract. We present a list of δ Scuti stars in double and multiple systems, ranging from the very wide binaries to the very close ones such as spectroscopic and eclipsing systems including the optical visual pairs which are of no further use here. Our aim is to group the information from the binarity on the one hand and the pulsational characteristics on the other hand for as complete a sample as possible of δ Scuti stars in stellar systems. A selection of 18 well-documented cases, taking care that every type of binary is being represented, is discussed more extensively.

1. Introduction

It is well known that the vast majority of stars belong to a binary or a multiple system, irrespective of their spectral type. Recent surveys with improved astrometric accuracy, either from space or from the ground, present clear evidence that the higher the accuracy, the larger the number of binary detections. Up to 3000 new binaries have thus been discovered during the Hipparcos satellite mission (Lindegren 1997). The frequency of binaries is estimated to be at least 60% in the solar neighbourhood (Duquennoy & Mayor 1991) but this is probably an underestimation as modelisation tends to show. For example, Odenkirchen and Brosche (1999) found that a frequency of at least 70% was needed in some models to account for the existence of another 2400 (up to now undetected) astrometric binaries in the Hipparcos catalogue. The same is also true with respect to the improvement of the photometric accuracy: the higher the accuracy, the larger the number of variable star detections. The results of the Hipparcos photometric survey are again quite illustrative: some 8000 new variable stars have been identified (van Leeuwen 1997). It is thus not at all a surprise to encounter pulsating δ Scuti stars as components of stellar systems. The catalogue of Seeds and Yanchak (1972) contains a third of double stars over a total of 155 δ Sct variables or suspected ones. Szatmáry (1990) also quotes a binary fraction of about 30%. To study such cases presents some obvious advantages: we have additional constraints on some important physical parameters such as distance, mass, radius... but this of course will depend on the type of binary or multiple system of which the pulsating star is a member. We may find them among the wide visual binaries (VB), the closer visual binaries with orbital motion (VB/O), the (unresolved) astrometric binaries (AB), the spectroscopic binaries (SB), or even eclipsing and ellipsoidal binary systems (E). In almost all these cases it is generally accepted that both components pertaining to the system originate from the same parent cloud, therefore have the same age and chemical com-
position. Additional information on the non-variable component can then be extrapolated unto the variable one and used to better constrain the variability characteristics such as the pulsation type and modes. But we could go further and address such questions as: does binarity modify the pulsation properties or even trigger the pulsation? Is there any correlation between rotation, pulsation and orbital motion?

For all these reasons the identification of such objects offers an interesting challenge toward a better comprehension of pulsation in the $\delta$ Scuti instability strip. A comparative study between the two companions allows to restrict for example the domain in mass in which the $\delta$ Scuti phenomenon takes place. Various recent studies exist that investigate the pulsating $\delta$ Scuti stars in open clusters for similar reasons (e.g. the Praesepe cluster (Peña et al. 1998; Alvarez et al. 1998)). One should however also keep in mind that star formation in some open clusters is not always a single-epoch process (e.g. M16 (Hillenbrand et al. 1993)).

2. Summary tables

We here summarize the available information for as complete a sample as possible of $\delta$ Scuti stars in stellar systems in two tables, one for the binarity and one for the variability characteristics. The basis was drawn on the catalogue work by García et al. (1995), supplemented by our own list and literature search. The Catalogue of the Components of Double and Multiple Stars (CCDM, Dommanget & Nys 1995) was used to retrieve information on the visual components of the stellar systems. Table 1. lists the name and the HD number (or BD number if HD does not exist), the Hipparcos number, the V magnitude, remarks concerning the multiplicity, the Hipparcos parallax and error. Next comes the information regarding the duplicity in the Hipparcos Catalogue (ESA 1997): a flag referring to that part of the Annex of Double and Multiple Systems (DMSA) where the star has been classified, the component designations, the angular separation (in arcsec), followed by the information about the variability: the periodicity, a flag indicating in which Variability Annex the star has been classified (P/1=periodic variable; U/2=unsolved; M=possible microvariable; D='duplicity-induced variability'; C='constant'). The final columns list the median Hp magnitude with standard error and the differential Hp magnitude with standard error.

Table 2. lists the name and the HD number (or BD number if HD does not exist), remarks concerning the variability, the number of frequencies, the dominant periodicity and semi-amplitude, the projected rotational velocity of the $\delta$ Sct star, the spectral types of the $\delta$ Sct and additional components. Among the remarks the following notations are used: N=narrow range of frequencies; W=wide range of frequencies; R=radial pulsator; NR=non-radial pulsator.

3. Visual binaries

3.1. Orbits and physical parameters

In Table 3 we present additional information regarding the physical parameters of the components of some of the visual binaries listed in Tables 1 and 2. Given
| HIP  | V | BD/BC/BG/BH/BE/BI/BJ/BF/BL/BG/BA/BH/BK | BE/BK/BL/BF/BJ/BI/BA/BD/BG | BE/BK/BL/BF/BJ/BI/BA/BD/BG | BE/BK/BL/BF/BJ/BI/BA/BD/BG |
|------|---|-----------------------------------------|-----------------------------|--------------------------------|--------------------------------|
| 5988 | 1 | BD/BC/BG/BH/BE/BI/BJ/BF/BL/BG/BA/BH/BK | BE/BK/BL/BF/BJ/BI/BA/BD/BG | BE/BK/BL/BF/BJ/BI/BA/BD/BG | BE/BK/BL/BF/BJ/BI/BA/BD/BG |

Table 1: Summary table of 6 Scuti stars in binary systems.
| Identifiers | HIP  | V | Binary class and remarks | \( \pi (\text{m} / \text{yr}) \) | DSM \( \varphi \) | \( P_{\text{orb}} \) | VAR | \( H \) | \( \sigma_{H} \) | \( \sigma_{\varphi} \) |
|-------------|------|---|----------------------------|-------------------|----------------|--------------|------|-----|--------|--------|
| AI Hya +06 2259 | - | 9.0 | EA | - | - | - | - | - | - | - |
| \( \vartheta \) Tuc | 3112 | 2629 | 6.11 | SB (P=7.1d) | 6.65(08) | - | U 2 | 6.1872 | 0.0016 |
| CC And +41 119 | 3432 | 9.36 | Probably a binary with \( P_{\text{orb}}=10-40 \text{yr} \), \( e=0.05 \) | 2.39(36) | 0.12 | P 1 | 9.4405 | 0.0004 |
| AB Cas +76 1103 | 12255 | 10.21 | EA/SD (P=1-300yr) | 3.36(29) | 1.37 | P 1 | 10.2809 | 0.0049 |
| RZ Cas 17138 | 13133 | 6.27 | EA/SD | 15.9(0.04) | - | 2.0 | 6.3106 | 0.0024 |
| WX Eri 21102 | - | 8.5 | EA | - | - | - | - | - | - | - |
| RY Lep 33882 | 27490 | 8.25 | Escaping binary? | 6.27(0.19) | V | 0.22 | P 1 | 8.3455 | 0.0156 |
| V1004 Ori | 34372 | 28771 | 5.89 | SB (P=27-46d) | A has add. comp. B (sep=37") | 9.2(0.11) | 2.74 | P 1 | 5.5078 | 0.0009 |
| V474 Mon | 40335 | 28231 | 6.15 | SB? (P=15.493d) | 10.32(0.08) | 0.14 | P 1 | 6.2379 | 0.0147 |
| UZ Lyn 42378 | 50650 | 4.44 | Radial-velocity series (P=818d, a=0.0085", e=0.30) | 21.89(0.04) | O | - | C | 4.6594 | 0.0004 |
| Y Cam +76 286 | 37440 | 10.54 | EA/SD SB1 (P=3.5d) | 1.50(0.10) | - | 3.31 | P 1 | 10.0299 | 0.0044 |
| UX Mon 65007 | 39682 | 8.42 | SB2 (P=5.9d) | 2.06(0.59) | 5.9 | P 1 | 5.0805 | 0.0116 |
| SZ Lyn 67308 | 39960 | 9.44 | SB (P=11815d, e=0.09) | 2.2(0.11) | - | 0.12 | P 1 | 5.7575 | 0.0037 |
| KZ Hya 94093 | - | 10.08 | SB? | - | - | - | - | - | - | - |
| R5 Cha 77747 | 42784 | 6.05 | EA/DM (P=1.67d) | 10.23(0.04) | 1.67 | P 1 | 6.1158 | 0.0056 |
| DL UMa 82620 | 47165 | 7.29 | Escaping binary with P=6.427d | 8.0(0.09) | M | 7.7270 | 0.0014 |
| FM Vir 11603 | 62267 | 5.22 | SB2 (P=38.328d, e=0.074) | 13.36(0.06) | - | 5.9757 | 0.0013 |
| V444 Hcr 152880 | 82798 | 6.35 | SB (P=11.850d, e=0.365) | 12.7(0.00) | - | 6.4929 | 0.0011 |
| e Ser 106013 | 86565 | 4.24 | SB? | 19.4(0.01) | - | C | 4.2762 | 0.0005 |
| V577 Oph +06 3079 | 89578 | 11.01 | EA (P=671d, e=0.14) | 1.30(0.11) | - | P 1 | 11.1429 | 0.0067 |
| \( \delta \) Sct | 172748 | 91726 | 4.76 | Perhaps a binary with P=27" + VB | 17.4(4.05) | 0.19 | P 1 | 4.7870 | 0.0106 |
| CE Oct 188528 | 99813 | 8.01 | EB variability? (P=82108d or 0.02006) | 7.7(0.10) | G | 8.0774 | 0.0012 |
| l Vul 191747 | 99484 | 5.51 | SB | 7.7(0.08) | - | 5.551 | 0.0005 |
| \( \delta \) Del 197401 | 16248 | 6.44 | SB2 (P=48.584d, e=0.7) | 16.0(0.04) | 0.16 | P 1 | 6.1429 | 0.0007 |
| IK Peg 201488 | 105860 | 6.08 | SB1 (P=21.724d) | 21.72(0.04) | - | 6.1429 | 0.0007 |
| GX Peg 213234 | 111191 | 6.33 | SB1 (P=2.349d) | 8.0(0.09) | 1.17 | P 1 | 6.2517 | 0.0019 |
| \( \delta \) Cas 432 | 7.40 | 2.28 | VB (sep=3") (Not SB) | 20.89(0.10) | 0.19 | P 1 | 5.2770 | 0.0023 |
| GN And 2628 | 2250 | 5.20 | VB ADS 409A (sep=2.4") | 17.0(2.05) | 0.07 | P 1 | 5.2770 | 0.0023 |
| AV Cet 8511 | 65380 | 6.21 | VB (sep=8") | 14.83(0.05) | - | C | 6.2821 | 0.0009 |
| V479 Tuc 24560 | 18265 | 7.44 | VB B=HIP 18254 (sep=5") (BC is VB/O(P=117yr)) | 7.17(1.0) | D | 7.5224 | 0.0009 |
| V400 Oph 30788 | 22265 | 5.08 | VB A (sep=1") | 17.27(4.0) | M | 5.1512 | 0.0010 |
| OK Aur 50018 | 33841 | 6.10 | VB A (sep=2") | 6.15(0.13) | M | 6.1925 | 0.0009 |
| o Pup 67323 | 39757 | 2.83 | VB (sep=2") | 51.9(0.01) | 0.14 | P 1 | 2.9117 | 0.0038 |
| FZ Vel 77148 | 44953 | 5.17 | VB (sep=2") | 14.7(1.0) | C | 5.2267 | 0.0009 |
| RX Sex 90386 | 51075 | 6.67 | VB A (sep=11") B=HIP 51072 BC (sep=0.7") | 8.0(0.12) | D | 6.7154 | 0.0011 |
| FG Vir 106284 | 59876 | 6.56 | VB ADS 8471A (sep=2") | 12.0(0.06) | 0.08 | P 1 | 6.6361 | 0.0030 |
| o Lyn 172067 | 31262 | 0.02 | VB (sep=6") | 128.5(3.0) | - | U 2 | 6.0888 | 0.0083 |
| V1644 Cyg 192046 | 99770 | 4.00 | VB B=HIP 99777 (sep=212") | 24.3(7.02) | - | U 2 | 4.9901 | 0.0013 |
Table 2. Summary table for δ Scuti stars in binary systems:

| Identifiers | Pulsation | #Freq. | Period | Amp(V/B) | v sin i | SpT 1 | SpT 2 |
|-------------|-----------|--------|--------|----------|--------|-------|-------|
| VW Ari      | W         | > 7    | P1=0.161 | A1=0.020 | 90     | F0IV  | B=F2IV|
| BN Hyi      |           | 2      | 0.065  | 0.006    | 47     | F2III- |      |
| V534 Tau    | 23567     |        |        | 0.032    | 0.09   | 90AIV |       |
| V647 Tau    | 23607     |        | 0.047  | 0.007    | 10     | A7V   |       |
| V650 Tau    | 23643 R+NR,W | 5 | 0.031 | 0.004?  | 185    | -     |       |
| V483 Tau    | 27397     | Q=0.038| 0.0548 | 0.013    | 100    | F3V   |       |
| V775 Tau    | 27628     |        | 0.06   | ≤ 0.005  | 30     | A3m   |       |
| V777 Tau    | 28052     |        | 0.182  | 0.010    | 195    | F0V   |       |
| δ² Tau      | 28314 N   | > 5 P1=0.0756 | A1=0.097 | 140    | A7III | B=G7III |
| δ Scuti     | 28910     |        | 0.07   | 0.005    | 103    | A8V   |       |
| KW Aur      | 33959     | P1=0.0881 | A1=0.016 | 25     | A9IV  | C=F3V |
| BR Cru      | 73475     |        | 0.040  | 0.010    | 170    | F0V   |       |
| BQ Cru      | 73729     |        | 0.064  | 0.003    | 165    | F2V   |       |
| ℓ6 Uma     | 84999     | NR high | mmany  | 0.07-0.09 | ≤ 0.03 | 115   | F0V   |
| AI Com      | 108662    |        | 0.052  | 0.02     | 10     | A0p   |       |
| GG Vir      | 110377    |        | 0.023  | P<0.083  | 0.014  | 160   | A7Vn  |
| θ² Boo      | 124975    |        | 0.0648 | 0.0064   | 140    | A8IV  | F1V   |
| δ Scuti     | 125161 sus. | 17 | 0.026 | 0.0035   | 130    | A9V   |       |
| V1208 Aql   | 181333 Q=0.034,N | 2 | P1=0.146v | A1=0.013v | 48     | F0II  | G5    |
| δ¹ Tau      | 220392    | N      | 0.156  | 0.01-0.02 | 70     | F0Iv  |       |
| γ¹ Cyg      | 140436    | > 2    | 0.1110 | K=1.2 kms<sup>-1</sup> | 100 A1V |       |
| α¹ UMa      | 181333 Q=0.034,N | 2 | P1=0.146v | A1=0.013v | 48     | F0II  | G5    |
| δ¹ Tau      | 220392    | N      | 0.156  | 0.01-0.02 | 70     | F0Iv  |       |
| γ¹ Cyg      | 202444    |        | 0.083  | 0.125    | 0.01   | 91    | F1IV  |
| α¹ UMa      | 31908     | many   | 0.0178 | 0.015    | 18     | A8IV  | Am?   |
| δ¹ Tau      | 104513    |        | 0.026  | 0.015    | 78     | A7IV  |       |
| γ¹ Cyg      | 140436    | > 2    | 0.1110 | K=1.2 kms<sup>-1</sup> | 100 A1V |       |
| α¹ UMa      | 31908     | many   | 0.0178 | 0.015    | 18     | A8IV  | Am?   |
| V1004 Ori   | 40372     |        | 0.058  | 0.010    | -      | A7    |       |
| V1208 Aql   | 181333 Q=0.034,N | 2 | P1=0.146v | A1=0.013v | 48     | F0II  | G5    |
| δ¹ Tau      | 220392    | N      | 0.156  | 0.01-0.02 | 70     | F0Iv  |       |
| γ¹ Cyg      | 202444    |        | 0.083  | 0.125    | 0.01   | 91    | F1IV  |
| α¹ UMa      | 31908     | many   | 0.0178 | 0.015    | 18     | A8IV  | Am?   |
| δ¹ Tau      | 104513    |        | 0.026  | 0.015    | 78     | A7IV  |       |
| γ¹ Cyg      | 140436    | > 2    | 0.1110 | K=1.2 kms<sup>-1</sup> | 100 A1V |       |
| α¹ UMa      | 31908     | many   | 0.0178 | 0.015    | 18     | A8IV  | Am?   |
| V1004 Ori   | 40372     |        | 0.058  | 0.010    | -      | A7    |       |
| V1208 Aql   | 181333 Q=0.034,N | 2 | P1=0.146v | A1=0.013v | 48     | F0II  | G5    |
| δ¹ Tau      | 220392    | N      | 0.156  | 0.01-0.02 | 70     | F0Iv  |       |
| γ¹ Cyg      | 202444    |        | 0.083  | 0.125    | 0.01   | 91    | F1IV  |
| α¹ UMa      | 31908     | many   | 0.0178 | 0.015    | 18     | A8IV  | Am?   |

* More frequencies are present, due to pulsation in comp A, also δ Scuti
are the name and HD designation, the orbital period in years, the semi-axis major in AU, the sum of the masses, and if known the radii $R_1$, $R_2$ and the individual masses $M_1$, $M_2$ as well as a reference.

We recall that the sum of the masses, $\Sigma M$ (in solar mass), and the orbital elements, $P_{\text{orb}}$, the orbital period (expressed in years), and $A$, the true semi-axis major (in AU), are linked through Kepler’s third law:

$$\Sigma M = \frac{A^3}{P^2}.$$  

There are three VB/O cases ($\delta$ Ser, $\gamma$ CrB, $\tau$ Cyg) but only two have a reliable orbit determination. Of course, only if the mass ratio is known from either the absolute astrometry or the spectroscopy can precise individual masses be obtained.

$\sigma^2$ CrB is not listed since it is very probably not a $\delta$ Scuti star. This orbital pair is in fact a triple system. The visual binary has a period of $\approx 1000$ yr and a semi-axis major of 140 AU. It also contains a double-lined and chromospherically active spectroscopic binary. From differential spectrophotometry, Frasca et al. (1997) deduce that there is no evidence for a 0.1 day periodicity but that all the variation is linked with the period of rotation. They conclude that the photometric variability is due to dark spots on the secondary component of the SB and very probably not of $\delta$ Scuti type. This conclusion is also supported by the spectral classification (F6+G0). We also discarded the following two visual double stars: V377 Cas ($\text{sep}=2.1''$) because the light variations are not typical of the $\delta$ Scuti type (Lowder 1989) and DL Dra (HR 5492, $\text{sep}=3.9''$), shown to be probably constant already in 1990 (Paparò et al. 1990).

We next focus on some particular objects of this category.

Table 3. $\delta$ Scuti stars in visual binaries

| Designation | HD | $P_{\text{orb}}$, years | $A$, AU | $\Sigma M$, $M_{\odot}$ | $R_1$, $R_{\odot}$ | $R_2$, $R_{\odot}$ | $M_1$, $M_{\odot}$ | $M_2$, $M_{\odot}$ | Remark | Refs |
|-------------|----|----------------|--------|----------------|----------------|----------------|----------------|----------------|--------|------|
| VW Ari      | 15165 | $\approx4.10^5$ | $\approx8700$ | 4.0 | 3.5 | 1.6 | 2.2 | 1.8 | AC95 |
| $\theta^2$ Tau | 28319 | $<8.10^5$ | $\approx15000$ | > 4.5 | - | - | 4.5 | - | TSL97 |
| KW Aur      | 33959 | $<21000$ | $\approx1200$ | > 3.7 | - | - | 3.7 | - | FW79 |
| $\kappa^2$ Boo | 124675 | $\approx8500$ | $\approx640$ | 3.5 | 2.8 | 1.5 | 2.1 | 1.4 | FJ95 |
| $\delta$ Ser | 138917 | 3200: | 320: | 3-4: | - | - | - | - | B var? BP89 |
| $\gamma$ CrB | 140436 | 92.7 | 32.5 | 4.2 | - | - | - | - | SS99 |
| $\tau$ Cyg | 202444 | 49.9 | 18 | 2.5 | - | - | - | - | e=0.25 BP89 |
| - Phe | 220392 | $\approx1.10^5$ | $\approx3300$ | 4.1 | - | - | 2.3 | 1.8 | corr. P LV99 |

References: AC95 = Abt & Morrell (1995); BP89 = Baize & Petit (1989); FJ95 = Fu & Jiang, 1995; FW79 = Fitch & Wisniewski (1979); LV99 = Lampens & Van Camp (1999); SS99 = Söderhjelm (1999); TSL97 = Torres et al. (1997)

3.2. Selected stars

VW Ari A. This very wide binary consists of an A-type primary showing $\lambda$ Boo peculiarities in the spectrum and a F-type secondary of solar-like composition in common spatial motion (similar proper motions (CCDM, Dommanger...
& Nys 1995) and radial velocities (Fehrenbach et al. 1987)). Because of its very wide separation and the different chemical composition of its components, stellar capture was proposed as the probable mechanism of formation. However, Chernyshova et al. (1998) recently argued that capture is improbable and also no longer needed to explain the differences in composition since these could be due to the specific evolution of the primary star solely. The primary is the $\delta$ Scuti star that was intensively observed by the STEPHI network in 1993 (Liu et al. 1996). They detected more than seven frequencies, more or less grouped. Non-radial rotationally split modes might therefore be present in this star, a medium to fast rotator with $v_{\sin i}=90$ kms$^{-1}$. Andrievsky et al. (1995) concluded from their spectral analysis that VW Ari A has no sharp lines while the lines of VW Ari B are ”sharp and strong”, so fast rotation is not applicable to the companion. Such a difference in rotational velocity between both components was not considered by Liu et al. (1996), who also found a much smaller surface gravity value for component A via photometric calibration, thereby resulting in masses surprisingly small to match the given spectral types.

$\theta^2$ Tau  $\theta^2$ Tau is the most massive main-sequence star of the Hyades cluster, the primary of a common proper motion pair with $\theta^1$ Tau (at a separation of 5′6), and a member of a single-lined spectroscopic binary (SB1) of period 140.7 days with an (highly eccentric) interferometric orbit from the Mark III optical interferometer (Pan, Shao, & Colavita 1992; Hummel & Armstrong 1992). Torres, Stefanik & Latham (1997; hereafter TSL97) determined individual masses and the distance of the system by treating it as a double-lined spectroscopic binary (SB2), thereby exploring a range of values for the mass ratio and the rotational velocity. The derived orbital and the Hipparcos trigonometric parallaxes agree very well. This spectroscopic binary is formed by two stars of nearly identical colour and mass but with different projected rotational velocities: TSL97 obtained a best fit with $v_{B\sin i}= 110$ kms$^{-1}$ while $v_{A\sin i}= 80$ kms$^{-1}$. Both are therefore considered to be rapid rotators. From the location in a colour-magnitude diagram and a best fit with an isochrone of age $\approx 630$ Myr, they conclude that the primary is in a phase near H core exhaustion, immediately preceding the phase of overall contraction. However, because both the binarity and the fast rotation may affect the colour indices, its evolutionary status may still be ambiguous (see also Krölikowska 1992).

Various multi-site campaigns have been conducted. Breger et al. (1989; hereafter BG89) obtained five closely spaced and stable frequencies, all of which had amplitudes below 0.01 mag. They discarded rotational splitting since it could not explain the observed frequency separations and proposed a mixture of modes of different $l$ and $m$ values. Kennelly et al. (1996) discussed a large set of radial velocity and line profile data from which up to seven frequencies emerged with only three frequencies in common with the previous analysis. They suggested long-term ($> 6$ yr) amplitude variability and a combination of low and high degree modes. Amplitude variability on a 10 yr time scale is also claimed by Li, Zhou & Yang (1997). Both components lie within the $\delta$ Scuti instability strip but it seems well established that the more massive primary is the pulsating star (BG89, KW96). Even though a wealth of information about physical parameters is known for $\theta^2$ Tau, the situation regarding variability is very confused and
there is up to now no clear mode identification possible for the apparently very complex (not solved) frequency spectrum.

**KW Aur A**  
KW Aur A is an ellipsoidal, single-lined spectroscopic binary system (Harper 1938) as well as the primary component of the visual multiple system ADS 3824 that is in common proper motion with the tertiary component situated at a distance of some 1000 AU with a period of about 24000 yr (Tokovinin 1997). Though well-detached, both components of the inner system must be tidally deformed due to the short period of the binary (P=3.79d). Photometric and radial velocity variations analyzed together gave evidence for three non-radial modes (Fitch & Wisniewski 1979) (FW79). In addition, they also identified a frequency that corresponds to twice the orbital frequency due to the ellipticity effects on the mean light curve. They suggested a single pulsation frequency split by tidal modulation (instead of rotational modulation) as the cause for the observed non-radial triplet (same \( \ell \), different \( m \)). In an analysis of line profile variations for this star, Smith (1982) corroborated their conclusion. Rotational effects are expected to be small due to the fact that there is synchronization of the rotation with the orbital motion (see also Table 2). More theoretical work needs to be done in this context: computations should be done for inhomogeneous models, with a density gradient from core to envelope, better applicable to \( \delta \) Scuti stars in general and to KW Aur A in particular.

**κ\( ^2 \) Boo A**  
κ\( ^2 \) Boo forms a common proper motion system with κ\( ^1 \) Boo, itself consisting of a spectroscopic binary with a period of 1791 days and a high eccentricity (Batten, Fletcher, & MacCarthy 1989). Both stars have colours that locate them in or near the \( \delta \) Scuti instability strip. The intrinsic separation is \( \approx 600 \) AU, consequently the orbital period could be about 8000 yr long if one adopts 3.5 M\( _{\odot} \) as the sum of the masses. The primary is a fast rotator but this is improbable for the secondary (\( v_{B\sin i} \approx 40\) km\( s^{-1} \)). Frandsen et al. (1995) (FJ95) observed both adopting a scheme of programme star (comp. A) versus comparison star (comp. B) in order to study the pulsation behaviour of κ\( ^2 \) Boo. They detected a multiperiodic pattern with up to four frequencies of which three are very close and one is a probable radial mode. All associated amplitudes are below 0.01 mag. FJ95 found a matching model by fitting a common isochrone through both stars and derive a distance that is in perfect agreement with the (later published) Hipparcos distance. They are hesitant to invoke rotationally split modes since their model produces a good match of the observed set of frequencies, even though rotation was not considered! One problem of this analysis is that they were not able to identify which component is responsible for the variability, let stand for what frequencies. Since component B is an early F-type binary, in principle it could also be a pulsating variable star (as admitted by the authors themselves). It would thus be very interesting to precisely identify the source of the multiple frequencies detected in this triple system.

**HR 8895**  
An interesting common origin pair is formed by HD 220392 and HD 220391. Both components are located in the \( \delta \) Scuti instability strip but up to now only the primary seems to present short-period pulsations of the \( \delta \) Scuti type. More observational effort should be spent on both stars to investigate their
behaviour with respect to pulsation. For a more detailed analysis we refer to Lampens & Van Camp (1999). A very recent and exciting information concerns new radial velocity measurements: Grenier et al. (1999) confirm that the radial velocities are in agreement and furthermore also show that component B has a variable radial velocity!

**γ CrB** This is an orbital binary with a period of 93 yr, a high eccentricity and a semi-axis major of some 33 AU (Hartkopf & McAlister 1989). The system consists of a B9/A0 IV primary, a suspected Maia star, and a 1.5 mag fainter A3/A4 main-sequence secondary. Lehmann et al. (1997) measured the radial velocity of the system and concluded that stars of the Maia type can pulsate in the same way as δ Scuti stars. In a first possible scenario they invoke an additional mechanism for the amplitude variation of the NR modes, while a second possible scenario implies spontaneous excitation and damping of these modes. One more alternative is that component B could well be the δ Scuti variable star.

**DG Leo** This system is also triple, consisting of a double-lined spectroscopic binary and a visual component B that is the δ Scuti pulsating star. The spectroscopic double has an orbital period of 4.147 days and a mass ratio close to unity. All three stars are possibly nearly identical with a global spectral type A8IV and with marginal metallicity. Rosvick & Scarfe (1991) (RS91) detected a velocity change of the visual component with respect to the centre of mass of the spectroscopic pair that is due to the orbital motion. Specke measurements show that this system is highly inclined, possibly also highly eccentric (Hartkopf, McAlister, & Mason, 1999). This was also claimed by RS91, who presented evidence for the occurrence of very shallow eclipses with a possible inclination of ≈70°. They obtained a mass of some 2 M⊙ for each spectroscopic component. Resolving the visual orbit will lead to more accurate masses for all three stars. Only one periodicity seems to be known for the δ Scuti variable companion but more may be present since amplitude and phase changes have been reported (RS91). It is a very interesting multiple system where both metallicity and binarity effects can potentially influence the pulsational characteristics (on stabilization and tidal mixing see Budaj (1996; 1997)).

**ε Cephei** This is the primary of a visual double system that is a chance alignment of a bright foreground and a much fainter background star (ρ=128″; ∆m=5). However, ε Cephei was recently also found to be a new astrometric binary discovered by the Hipparcos satellite (ESA 1997, part DMSA/G). We have no further binarity information. Observations by Lopéz de Coca et al. (1979) in the B band indicate two periods, perhaps three. Ratios are compatible with the second overtone and the fundamental radial modes. But the amplitudes are very small. From an analysis of the line profiles, Baade et al. (1993) found evidence for intermediate to high order NR p-modes with 6 ≤ |m| ≤ 8. Why such high order p-modes are also detected in integrated light data is unclear. This star shows a rich spectrum of modes according to Horner et al. (1996) and it is not improbable that it still belongs to the main sequence. Given its spectral type of F0, it is a medium to fast rotator.
β Cas  ADS 107 A was reported to show radial velocity variations with an apparent period of about 27 days (Mellor 1917) and was therefore subsequently classified as SB (for example in δ Scuti stars catalogues). However Abt (1965) already concluded that there was no evidence for such a binarity, as was later on confirmed by the results of Yang, Walker, & Fahlman (1982). They showed that the radial velocity curve varied with a very short period, close to the photometric period of pulsation. In conclusion, β Cas is a monoperiodic δ Scuti pulsator with a very stable small amplitude but for which the mode identification is uncertain (Rodríguez et al. 1992; Riboni, Poretti, & Galli 1994). We have classified it among the probable optical visual double stars and do not consider it as a pulsating star in a binary system (cfr. bottom part of Tables 1 and 2).

4. Spectroscopic and eclipsing binaries

An interesting feature of pulsating stars in binary systems is the so-called light-time effect: the orbital motion of the variable star produces a Doppler effect, and the observed period of variation will decrease and increase. This effect, together with mass transfer in a semi-detached system and apsidal motion, can be the cause of regular period changes in a binary system. For a circular orbit of radius $a$, orbital period $P$ and inclination $i$, the time of light maximum is given by (e.g. Barnes & Moffett, 1975):

$$T_{\text{max}} = T_0 + EP_o - \frac{a \sin i}{c} \cos 2\pi \left( \frac{EP_o}{P} - \phi \right),$$

(1)

where $E$ is the number of elapsed periods, $T_0$ is the initial epoch of maximum, $P_o$ is the pulsation period and $c$ is the speed of light. The light-time phenomenon has been observed in many binary δ Scuti stars and offers a useful way to obtain the orbital period.

Another feature of very short-period binaries is tidal deformation: the components can no longer be considered as spherical objects but have a triaxial symmetry with the longest axis directed toward the companion. The effects on the pulsation may be quite diverse and very difficult to detect: a) frequency shifts; b) amplitude modulation in the case of radial pulsation (e.g. θ Tuc, De Mey et al. 1998); c) frequency splitting in the case of non-radial pulsation (e.g. KW Aur, Fitch & Wiśniewski 1979)....

4.1. Single-lined spectroscopic binaries

Table 4 contains the orbital elements for the δ Scuti stars which are reported in the literature as SB1. The table lists the name, HD designation (or BD number if HD does not exist), spectral type, orbital period in days, eccentricity, semi-amplitude of the radial velocity in $\text{km s}^{-1}$, mass function in solar mass and finally the reference of the orbit. For simplicity, when the orbit was published in the Catalogue of Batten et al. (1989), we only refer them and not the original papers. In this case, the spectral type is also the one they quote. Let us recall here that the mass function is given by

$$f(m) = \frac{M_2}{(M_1 + M_2)^2} \sin^3 i,$$

(2)
where $M_1$ and $M_2$ are the mass of the primary and secondary, respectively, and $i$ is the unknown inclination of the orbit with respect to the line-of-sight.

We do not claim to have the complete list of $\delta$ Scuti members of spectroscopic binaries. The classification of a $\delta$ Scuti star as a spectroscopic binary is indeed not easy if no detailed study is done. A simple variation of the radial velocity over the years may not be an indication of duplicity but solely the result of pulsation. The misclassification of AI CVn (King & Liu, 1990) is very illustrative in this respect. Szatmáry (1990) gave a list of $\delta$ Scuti stars in binary systems, either eclipsing or spectroscopic. Some stars of his table do not appear in our Table 4: ET And, DV Aqr, MM Cas, RX Cas, AZ CMi, ZZ Cyg and θ Vir.

- The binary system ET And contains a B9p primary which was believed to be pulsating. However, Weiss et al. (1998) have found that it is the main comparison star, HD 219891, which pulsates, with a period of 0.1 day and a semi-amplitude of 2.5 millimag. Thus, HD 219891 is the $\delta$ Scuti star while ET And appears very stable!

- The $\delta$ Scuti nature of DV Aqr needs to be confirmed.

- MM Cas is an eclipsing binary reported by Chauhney (1983) to have brightness fluctuations of 0.08 mag amplitude and a period of $3^h40$. Chauhney therefore conjectured that the star is a $\delta$ Scuti variable. This needs confirmation.

- RX Cas is a semi-detached system whose orbital period is increasing. The A-type primary spectrum is that of a shell or disc that completely conceals from view the primary star.

- AZ CMi is a pulsating star of spectral type F0 III. The long orbital period (2625 days) quoted by Szatmáry (1990) is derived from a sinusoidal fit to the O-C data, assuming that they can be attributed to the light-time effect. A spectroscopic study of this object would thus be useful.

- Frolov et al. (1982) could not confirm the $\delta$ Scuti status of ZZ Cyg. We did not retain it in our list.

- Finally, θ Vir (HR 4963 = HD 114330) also deserves some attention. This star is a spectroscopic binary with a 17.84 years orbit, which is itself a visual binary. The star has been classified as a hot Am star and Beardsley & Zizka (1977) detected a variability at the level of 5 kms$^{-1}$ with a period of $0.152360$. Adelman (1997), however, found no evidence for variability, although Scholtz et al. (1998) note that there is "remarkable scatter which could possibly indicate real variations". These authors also remark that Hipparcos revealed a variability at the 8 millimag level with a period of $0.0697382$. From their spectroscopic investigation, they detected a well defined period of $0.0614$, with an amplitude of 0.4 kms$^{-1}$. It could be the case that θ Vir is another example of a pulsating Am star in a binary system. This needs however to be more definitively ascertained.
There are some other stars which could enter our list of \( \delta \) Scuti in multiple systems. Among these pending cases, let us consider the high amplitude \( \delta \) Scuti variable, V474 Mon (HR 2107) which is quoted in the Yale Bright Star Catalogue (see King & Liu 1990) as a 15.\,492 spectroscopic binary, although no trace of any orbit could be found in the literature. It is also noteworthy that the quoted binary period is exactly twice the value of the period of the Blazhko-effect (Romanov & Fedotov 1979). Another example is V650 Tau (HD 23643), which is quoted by Garcia et al. (1995) as spectroscopic binary. No mention of this could be found in the literature. Abt et al. (1965) give several radial velocity measurements in the range -35 to 2 \( \text{km s}^{-1} \), with errors up to about 10 \( \text{km s}^{-1} \). Unless a detailed study is performed, this is however not a proof for binarity.

CC And is probably a binary with an orbital period of 10.469 days (Fitch, 1976) and an eccentricity of 0.12 (Fitch, 1969). The shape of the light curve does indeed vary with this period, a phenomenon attributed to tidal modulation of the fundamental by a faint companion. Fitch (1967) detected 6 pulsation frequencies in the light curve, while 7 were found more recently by Fu & Jiang (1995).

### Table 4. \( \delta \) Scuti stars in single-lined spectroscopic binaries

| Designation | Sp.T. | \( P_{\text{orb}} \) | \( e \) | \( K \) | \( f_{\text{m}} \) | refs |
|-------------|-------|----------------|------|------|----------|-----|
| RZ Cas      | A2V   | 1.1952        | 0.   | 70.1 | 0.043    | B89 |
| \( \rho \) Tau | F0V   | 488.5         | 0.09 | 18.5 | 0.32     | B89 |
| V493 Tau    | F0IV  | 2.486         | 0.03 | 29.9 | 0.0069   | K99 |
| V775 Tau    | A3m   | 2.1433        | 0.   | 26.6 | 0.0042   | B89 |
| \( \theta \) Tau | A7III | 140.728       | 0.75 | 31.0 | 0.13     | B89 |
| KW Aur      | A9IV  | 3.7887        | 0.   | 23.0 | 0.0048   | B89 |
| UZ Lyn      | A2V   | 20.819        | 0.367| 3.77 | 0.000093 | S98 |
| Y Cam       | A9IV  | 3.3055        | 0.   | 35   | 0.015    | B89 |
| SZ Lyn      | F2    | 118.1         | 0.188| 9.6  | 0.101    | M88 |
| V644 Her    | F3Vs  | 11.8586       | 0.365| 27.44| 0.02054  | B89 |
| IK Peg      | A8m   | 21.724        | 0.   | 41.5 | 0.16     | B89 |
| GX Peg      | A5m   | 2.34          | 0.02 | 84.9 | 0.15     | B89 |

References: B89=Batten et al. (1989); BI82=Bardin & Imbert (1982); K99=Kaye (1999); M88=Moffett et al. (1988); S98=Scholtz et al. (1998)

We will now further discuss some of the stars listed in Table 4.

**UZ Lyn** The orbital elements for UZ Lyn (2 Lyn = HD 43378 = HR 2238) quoted in Table 4 are only preliminary and need confirmation. It was obtained by Scholtz et al. (1998), although in their spectroscopic run covering 240 min, the radial velocity was found to be constant. However, Caliskan & Adelman (1997) had published some radial velocity measurements, suggesting the star to be a spectroscopic binary. Combining their velocities with the one obtained by Caliskan & Adelman (1997), Scholtz et al. (1998) found three orbital solutions with periods of 21, 33 and 87 days. They kept the 21 days solution as it had the smaller residuals. Additional data are clearly called for.
SZ Lyn  The pulsation behaviour of SZ Lyn was discovered by Hoffmeister (1949). It was later classified as a dwarf Cepheid by Broglia (1963) and is now considered as a monoperiodic (0.12) high-amplitude δ Scuti star. Moffett et al. (1988) improved the value of the pulsation period to 0.1205215 days. This period is apparently undergoing a secular change of 3 \times 10^{-12} \text{ d/cycle} (Soliman et al. 1986). McNamara (1997) derived a semi-empirical \( P - L \) relation of SX Phe and large-amplitude δ Scuti stars:

\[
< M_v > = -3.725 \log P - 1.933
\]  

For SZ Lyn, he quotes an absolute magnitude of \( M_v = 1.35 \) and a period of 0.1205 d, as well as a mass of 1.92 M\(_\odot\) and a radius of 3.18 R\(_\odot\). Rodríguez et al. (1996) found that, like all other high-amplitude δ Scuti and SX Phe variables, it is a radial pulsator. Rodríguez (1999), analyzing all available photometric datasets, did not find any long-term change of amplitude of the light curve.

The binary nature of SZ Lyn was first suggested by Barnes & Moffett (1975) as an explanation for the periodic ephemeris needed to account for the observed times of maximum. The expected period was around 1146 days. The binary nature was confirmed by CORAVEL radial velocity measurements by Bardin & Imbert (1981) who obtained a preliminary eccentricity of 0.26. They also obtained a total amplitude in radial velocity of 39.9 km s\(^{-1}\), which, combined with their preliminary orbit, suggests a variation of 0.115 R\(_\odot\) over one pulsation cycle for the radius of the star. With additional observations, Bardin & Imbert (1984) however obtained a slightly longer (1181.5 d) and less eccentric (0.191) orbit. Using photometric data, Soliman et al. (1986) found the orbital period to be 1173.5 ± 2 days. Moffett et al. (1988), using both photometric and spectroscopic data, determined an orbital period of 1181.1 days and an eccentricity of 0.188. The value of the mass function, 0.101 M\(_\odot\), implies that the unseen companion is most likely on the main sequence with a spectral type between F2 and K3, that is, in the mass range 0.7 - 1.6 M\(_\odot\).

V644 Her  Like FM Vir (see below), this star was first known as a spectroscopic binary before being noticed as a variable. The first published orbits gave orbital periods of 11, 11.848, 11.857, 11.878 and 11.851. Bardin & Imbert (1982) used CORAVEL to derive more precisely the orbital elements and obtained a period of 11.858592 days and an eccentricity of 0.365. From Hipparcos data, the absolute magnitude of the system is \( M_v = 1.87 \), a possible value for a F2 IV star of about 1.5 - 2 M\(_\odot\). The absence of the secondary from the spectra as well as from the CORAVEL trace, implies that the secondary is fainter by at least two magnitudes, corresponding to a star cooler than F6-8 V, and therefore less massive than about 1.2 M\(_\odot\). Breger (1973) showed the variable nature of the star, with a period of 0.098 day and an amplitude of 0.02 mag. Elliott (1974) found the period to be 0.1150 day with an amplitude of 0.044 mag. It might be of interest to note that the ratio of the orbital to the pulsation period is exactly an integer value, 121 when using Breger’s period, and close to 103 when using Elliott’s one (see also Sect. 5).

GX Peg  From the results of their three weeks multi-site campaign, Michel et al. (1992) unambiguously detected five frequencies. Goupil et al. (1993) identified two radial modes of order \( n=2,3 \) and one non radial mode \( l=1, n=3 \) split
by rotation. The orbital elements of GX Peg were first determined by Albitzky (1933) and by Harper (1933). Although the two sets of data were contemporary (data obtained between 1928 and 1932, and between 1926 and 1933, respectively), there is a difference of \(6 \text{ km s}^{-1}\) in the radial velocity amplitude of the derived orbits. Bolton & Geffken (1976) obtained 25 spectrograms between 1971 and 1974 to derive a new orbit. They also recomputed the orbit from Albitzky and Harper data. Although they found a good agreement between Albitzky’s orbit and theirs, the significant discrepancy between the periastron longitudes lead them to conclude to the possibility of apsidal motion with a period of about 260 years. The very small eccentricity of the orbit makes this possibility unlikely. The Lucy & Sweeney (1971) test indeed indicates that the eccentricity is compatible with zero. As the typical time to have synchronization between orbital and rotation motion is smaller than the time needed to circularize an orbit, this small orbital period (2.34 days) system has certainly achieved synchronization. The rotational velocity therefore implies a value of \(R \sin i \simeq 2.75 \, R_\odot\).

4.2. Double-lined spectroscopic binaries

Table 5 gives the orbital elements of those \(\delta\) Scuti stars which are classified as SB2 and for which we could find details in the literature. The outline of the table is similar to Table 4 except that we mention the two spectral types when available, as well as two semi-amplitudes of radial velocity. We also list the mass ratio instead of the mass function.

To this list, we should also add BQ Cnc (HD 73729) which has been classified as an SB2 (Abt & Biggs, 1972) but for which no orbital elements are known. Again, some cases of either misclassification, either lack of precise elements can be mentioned. 56 Ser (HD 160613) for example, is listed in the Bright Star Catalogue as having two spectra, while only one spectrum is visible on the Parkins plate (Slettebak, 1954). On the other hand, DL UMa (HD 82620) is quoted by Henriksson (1979) as an eclipsing binary with a period of 0.42 days, while he previously (Henriksson 1977) considered it as a \(\delta\) Sct variable with an amplitude of 0.056 mag and a period of 0.0831. If confirmed, the almost exact integer ratio between the pulsation period and the orbital period might be of great interest.

When studying CE Oct (HD 188520), Kurtz (1980) discovered a second period of 0.621 which may result from a g-mode pulsation or ellipsoidal variability. Morris (1985) rejected the latter as being the least likely.

\(\theta\) Tuc  
Cousins & Lagerwey (1971) were the first to notice the variability of \(\theta\) Tuc and to derive a period of variation around 70-80 minutes. Later, Stobie & Shobbrook (1976) classified the star as a \(\delta\) Sct star and Kurtz (1980) determined a set of 8 stable frequencies. This was later extended to 10 highly-stable frequencies by Paparò et al (1996). From their high-resolution spectra, De Mey et al. (1998) could derive 4 frequencies, the most significant one corresponding to the main photometric frequency. They showed that this pulsation mode is radial.
Table 5. δ Scuti stars in double-lined spectroscopic binaries

| Designation | Name  | Sp.T₁ | Sp.T₂ | Pₐₗₜ | e   | K₁     | K₂     | q     | refs     |
|-------------|-------|-------|-------|-------|------|--------|--------|-------|----------|
| Al Hya      | +00 2259 | F2    | F0    | 8.29  | 0.23 | 8.57   | 95.6   | 0.92  | A91      |
| θ Tuc       | 3112   | A7 IV | KO    | 7.1036| 0    | 60.1   | 138.9  | 0.98  | DM98     |
| WX Eri      | 21102  | A5    | K0    | 0.82327| 0.7  | 60.1   | 138.9  | 0.98  | BD80     |
| UX Mon      | 65607  | G2 III| A5 III-IV | 5.9   | 0.  | 136.1  | 138.9  | 0.98  | B89      |
| FP Cha      | 75747  | A8 IV | A8 IV | 1.6699| 0.  | 136.1  | 138.9  | 0.98  | B89      |
| RS Eri      | 110951 | F0 III |     | 38.324| 0.074| 48.05  | 52     | 0.92  | B57      |
| Δ Del       | 197461 | A7 IIIp |    | 40.58 | 0.7  |        |        |       | R76      |

References: A91=Andersen (1991); B57=Bertiau (1957); B89= Batten et al. (1989); BD80= Brancewicz & Dworak (1980); DM98= De Mey et al. (1998); R76=Reimers (1976)

A new frequency, \( f_2 = 18.82 \text{ c/d} \) was found, not appearing in the photometric data. It must therefore correspond to a high degree pulsation mode.

Paparò et al (1996), noting periodicity of the long-term variations, suggested for the first time that θ Tuc might be member of a binary system. This was confirmed by Sterken (1997) which showed the star to be in a non-eclipsing binary system with ellipsoidal variations, with a period of 7.404 and a mass ratio of about 0.1-0.15. Both the primary and the secondary minima were observable in the light curve. De Mey, Daems & Sterken (1998) made an extensive study of this object. Using high-resolution spectroscopy, they could classify the system as a double-lined spectroscopic binary with a circular orbit and they derived the orbital elements listed in Table 5. The orbital period (7.1036 d) is not very far from the previously determined photometric period. The resulting mass ratio is \( q = 0.0896 \), a rather low value for a SB2. De Mey et al. (1998) concluded that the mass of the components are constrained by \( M_1 < 4.3M_\odot \) and \( M_2 < 0.4M_\odot \), while the radii of the primary and secondary lie between 1.7 \( R_\odot \) and 2.6 \( R_\odot \), and 1.6 \( R_\odot \) and 2.2 \( R_\odot \), respectively. One can therefore believe that θ Tuc is a post-mass transfer binary, in which the secondary is probably the remnant of an Algol-like mass-losing star. Sterken (1997) emphasizes the strong similarities between the orbital light curves of θ Tuc and HD 96008, a system with a very small mass ratio. It has to be noted however that while in the case of HD 96008, one of the component nearly fills its Roche lobe, this is not the case for θ Tuc. Using De Mey et al. (1998) results, one can see that the primary lies well inside its Roche lobe, while the secondary fills maybe only about 50% of it. It is also noteworthy that θ Tuc seems to show a rotational velocity (vsin i=80 kms⁻¹) too large for synchronization between the orbital and the rotational motion.

**FM Vir**  FM Vir (=32 Vir) is one of the very few Am stars reported as a pulsating star. FM Vir was recognized as a metallic-line star by Roman, Morgan & Eggen (1948). The Am phenomenon is generally attributed to slow rotation and the effect of diffusion (e.g. Abt & Morrell, 1995). Bertiau (1957) quotes vsin i of 20 km s⁻¹ for FM Vir.

The velocity variation was detected by Adams (1914) and the first orbit was
determined by Cannon (1915) who found an orbital period of 38.3 days and also detected double-lines. Petrie (1950) confirmed the double-lined nature of FM Vir and derived a magnitude difference between the two components of $0.43 \pm 0.11$ mag. Bertiau (1956) derived a new orbit, with an orbital period of 38.3 days, a rather typical value for Am stars. In the spectral region in which he was observing ($\lambda \lambda$ 4350-4650), he could not observe the lines of the fainter star. However, the lines of the primary are shallow, as if filled in by the continuous spectrum of a companion. He also observed a fairly large scatter of the individual velocities around the mean velocity curve, something which can now be explained by the variability of the component.

Bartolini, Grilli & Parmeggiani (1972) found the star FM Vir to be variable with an amplitude ranging from $0.02$ to $0.05$ and a period of about 0.07. Bartolini et al. (1983) confirmed that the star is pulsating with a strongly variable amplitude. The period $P=0.07188$ has the highest amplitude and is constant. Kurtz et al. (1976) performed a photometric and spectroscopic study of FM Vir. Their light curves had an observed range in the visual amplitudes between 0.01 and 0.035 mag, while the derived periods for the different nights range from 0.07 to 0.084 days, with an average of 0.0756, clearly suggesting the $\delta$ Scuti character of the star. The Am character of the star was also confirmed. They also concluded that FM Vir is a double-lined binary system and obtained $v \sin i$ values of $24 \pm 6$ kms$^{-1}$ and $140 \pm 25$ kms$^{-1}$ for the primary and the secondary, respectively. Therefore, while the primary has a rotation slow enough for the Am phenomenon to appear, the secondary is above the observed cutoff for Am stars. The secondary must then have normal abundances. The properties of the components place them both inside the instability strip. Because Breger (1970), from an extensive survey, found that classical Am stars do not pulsate, the suggestion was made that it is the secondary which pulsates. Assuming a magnitude difference between the two components of 0.43 mag and a light variability of the system of 0.035 mag indicates that the pulsational amplitude of the secondary should be 0.09 mag. Mitton and Stickland (1979) suggested that the primary is an evolved Am star (or $\delta$ Delphini star) of subgiant luminosity, which pulsates, while the secondary is a main-sequence star of spectral type near A7. They were able to detect the secondary in their spectra and to derive a magnitude difference between the two components between 0.6 and 0.9 mag. A semi-amplitude for the secondary could also be determined, leading to a mass ratio of $0.92 \pm 0.03$. This, combined with the mass function of the system, implies that the system must be nearly edge-on for the masses not to be unrealistically large. Masses around 2.05 M$_\odot$ and 1.89 M$_\odot$ are derived for the primary and the secondary, respectively.

FM Vir is clearly a system of great interest. The fact that we have two components of almost the same mass, but with different chemical composition should lead to a better understanding of stellar evolution mechanisms. Although it is clear that the primary owns its Am status to its slow rotation, one could wonder why two very similar stars in a close binary would have a different rotation. This should certainly not be the case if the slow rotation was due to tidal effects. However, the orbital period might be too large for synchronization to have taken place (e.g. Levato 1976). The clue may lie in the subgiant status of the primary : being more evolved, the star’s rotation decreased. This should
not be much more than a factor 2 however, so that we conclude that there was already a large difference in rotational velocity between the two components when the system was formed.

**δ Del**  The spectroscopic binary nature of δ Del was discovered by Frost (1924). Eggen (1956) discovered its photometric variability with a period of 0.\(d\)13505 and a variable range in brightness, with a mean around 0.05 mag. Spectroscopic observations by Struve, Sahade & Zebergs (1957) indicated that the radial-velocity is variable with a period of 0.\(d\)13447.

δ Del is the prototype of a sub-class among the δ Scuti stars with metal-line subgiant or giant spectra which might be characteristic of evolved Am stars (Breger 1979). Preston (1973, quoted in Reimers 1976) found the star to be an eccentric double-lined spectroscopic binary with a 40.5 days orbital period. Both components are δ Scuti variables and Reimers (1976) showed that they have identical chemical compositions, i.e. all metals up to the iron group are deficient relative to the Sun by a factor 2, while the abundance of heavy elements (Sr, Y, Zr, Ba, Ce, La and Eu) are enhanced by factors between 4 and 8 relative to iron. Smith (1982) considered the fact that both components could be δ Scuti stars and concluded that comp A is probably a monoperiodic radial pulsator while comp B, with the strongest δ Del peculiarity, oscillates in a mixture of radial and non-radial modes. Baade et al. (1993) confirmed that δ Del is a SB2 with well separated and almost identical spectra.

### 4.3. Eclipsing binaries

Among the stars quoted in Tables 4 and 5, some are eclipsing systems. Such systems are very powerful tools in astrophysics as they allow the determination of the individual masses and radii of the components.

| Name  | Sp.T1 | M1 | R1 | Teff1 | Sp.T2 | M2 | R2 | Teff2 |
|-------|-------|----|----|-------|-------|----|----|-------|
| Y Cam | A9 IV | 1.9 | 3.15 | 8000 | K1 IV | 0.4 | 3.05 |
| AB Cas | A3 V | 1.78 | 2.9 | 8000 | K1 V | 0.39 | 1.7 | 4460 |
| RS Cha | A5V | 1.86 | 2.14 | 7400 | K0V | 1.56 | 1.73 | 5840 |
| WX Eri | A5 | 2.23 | 1.84 | 7400 | K0V | 1.56 | 1.73 | 5840 |
| AI Hya | F2 | 2.15 | 3.92 | 6700 | F0 | 1.98 | 2.77 | 7100 |
| UX Mon | A6V | 3.47 | 4.30 |  |

Here again, some misleading examples appeared in the literature. For example, RY Lep is among the list of southern eclipsing binaries observed by Popper (1966) but he could only observe sharp single lines. Diethelm (1985) showed that this star is actually a relatively bright high-amplitude δ Scuti star with a period of 0.\(d\)2254 and an amplitude of 0.35 mag.

**AB Cas**  As reviewed by Rodriguez et al. (1998), AB Cas is one of the clear examples where the light curves simultaneously and clearly show both types of variability: binarity and pulsation. It is an Algol-type binary system with a period of 1.\(d\)3668, while the primary component is a monoperiodic δ Sct star
with a pulsation period of 0.0583. The star is pulsating in the fundamental radial mode. Rodríguez et al. (1998) using a previously determined value for the mass ratio of 0.22 and assuming the secondary to fill the Roche lobe, found the parameters quoted in Table 6.

**Y Cam** Together with AB Cas this is one of the oldest δ Sct variables known to be in an eclipsing system: its variability was discovered in 1903 by Mrs. Ceraski. Its components (A9 IV and K1 IV) have rather different masses (1.9 $M_\odot$ and 0.4 $M_\odot$) but rather similar radii (3.15 $R_\odot$ and 3.05 $R_\odot$, respectively). The light curve is very reminiscent of the Algol-type and the system is thought to be semi-detached, with the K star filling its Roche lobe. Shapley (1917), using the data of Miss Harwood, computed the first orbital elements of Y Cam, although a light curve was already obtained by Nijland as quoted in the catalogue of Shapley (1913). Dugan (1924) obtained a complete visual light curve and computed a solution for the system. It was shown that the dimensions of the two components were nearly the same. Szczepanska (1955), on the basis of 176 times of minimum, found it necessary to introduce a sinusoidal term into the elements of Y Cam which Plavec et al. (1961) thought to be only the main part of the whole period variation. They moreover concluded that the large periodic term could not be due to a third body nor to apsidal motion. Y Cam nevertheless appeared in the catalogue of systems with apsidal motions of Petrova & Orlov (1999), with an apsidal period of 60 years. Broglio & Marin (1974) revealed the primary to be a δ Sct star with a period of 0.0634697 and a variable light amplitude. The amplitude variation is not correlated with the phase in the orbital motion which led them to conclude that the "amplitude variations in δ Sct stars are not necessarily caused by a companion". Broglio & Marin (1974) confirmed the variation of the orbital period, which they considered as a proof for mass transfer in the system.

5. Discussion

Does the binarity influence the pulsation properties of δ Scuti stars? In the light of the previous sections, it is obvious that there is no clear and easy answer. Every discussed case seems to be particular in its own way. Apart from the binarity, many other phenomena are involved that may even have a stronger impact on the pulsation properties of the stars: evolution, chemical composition, rotational effects... In an effort to generalize, some authors consider the ratio between the pulsation period and the orbital period in order to search whether a resonance mechanism between both can occur (e.g. Frolov et al. 1980, Tsvetkov & Petrova 1993). This is however only possible if both periods are determined with very high accuracy. For example, in the case of SZ Lyn, the ratio between both periods is almost exactly 9800 (taking the orbital period from Moffett et al. (1988)). But with a slightly different value of the orbital period (1181.5 instead of 1181.1), this ratio, 9803.26, is not indicative. Such an exercise is therefore only applicable to very close systems for which tidal interactions are expected to be important! We computed the ratio between the orbital and pulsation periods for the closest binary systems of our list (with orbital periods up to 20 days) and, in general, we do not find values close to an integer. Five systems however form
an exception: KW Aur, CC And, DL Uma, V644 Her and WX Eri. DL Uma and WX Eri have very short orbital periods (0.42 and 0.82 days, respectively) and in both cases, this is almost exactly 5 times the pulsation period. For KW Aur, CC And and V644 Her, this ratio is 43, 84 and 103, respectively. It is not clear whether these last values have any physical meaning at all.

In very close systems tidal forces may force the system towards synchronization. For spectral types typical of δ Scuti stars, this happens for binary systems with orbital periods of a few days up to 10 days if the stars are evolved. Synchronization will slow down the star. Thus, an indirect effect of binarity may be the change of the rotational velocity. Possible correlations between the amplitude of the pulsation and the rotation have been discussed before (e.g. Breger 1980; Solano & Fernley 1997). Such a correlation is also seen in the data presented here.

Some cases present better evidence than others: e.g. amplitude modulation in the case of the radial pulsator θ Tuc (De Mey et al. 1998) or possible frequency splitting in the case of the non-radial pulsator KW Aur (Fitch & Wiśniewski 1979) but other effects may also occur (e.g. frequency shifts) that are almost impossible to detect. We need better models to check whether any of the above presented assumptions on the link between binarity and pulsation are valid and whether these can explain the observational facts in the most interesting cases.

Nevertheless, we should carefully investigate δ Scuti stars in binary systems from the observational point-of-view since they provide additional constraints on the physical parameters of the pulsating star, and therefore also on the characteristics of the pulsation. For single field δ Scuti stars, the position in the HR diagram and thus the evolutionary phase may be ambiguous, especially at the end of the core H burning phase, while δ Scuti stars in binary systems can be located with much better accuracy. It may also be especially worthwhile to study the differences in variability between two nearly identical components of a binary system, of which one or both may be δ Scuti stars. Various such cases have appeared in the present discussions and many deserve further observations and study.

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