RADIAL VELOCITIES WITH CORAVEL: RESULTS ON STELLAR VARIABILITY AND DUPLICITY

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ABSTRACT. The complete radial velocity curve has been determined with CORAVEL for many pulsating stars of various classes: cepheid stars in the Galaxy and in the Magellanic Clouds, RR Lyrae, δ Scuti and SX Phoenicis stars. These measurements allow the determination of the radius variation and of the surface acceleration of these stars. In addition, the mean stellar radius of many of these stars has been determined by applying the Baade-Wesselink method.

Systematic surveys of definite groups of binary or multiple stars are in progress with CORAVEL in order to determine the distribution functions of the orbital parameters. The eccentricity distributions for the binaries in the open clusters Pleiades, Praesepe, Coma Ber and Hyades are presented and their dependence on the physical processes (star formation mechanisms, mass exchange, tidal circularization, dynamical evolution) is briefly discussed.

1. INTRODUCTION

The very impressive advantages of the cross-correlation technique for the determination of radial velocities was shown some twenty years ago by Roger Griffin (1967). The efficiency gain defined by $Q = (t\ \varepsilon^2)^{-1}$, where t is the integration time and ε the radial velocity uncertainty, is more than 1000 times larger than in the photographic technique. Some fields of research which used to be unaccessible with traditional spectroscopy and large telescopes are now within the capabilities of 1 to 1.5 m telescopes owing to the cross-correlation spectroscopy (see Mayor, 1985). As examples we may cite the measurement of radial velocities in globular clusters with an uncertainty smaller than 1 kms^{-1} or the measurement of 10th magnitude RR Lyrae stars with an integration time shorter than 5 minutes. This last condition is necessary for a correct description of the phase of minimum radius, where the radial velocity variation is of the order of 1 $(kms^{-1})min^{-1}$.

The first CORAVEL scanner (Baranne et al., 1979), built jointly by

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Geneva and Marseille observatories, has been in full-time operation since 1977 at the Geneva 1 m telescope at the Haute-Provence Observatory (France). In the southern hemisphere measurements have been carried out since 1981 with a second CORAVEL on the Danish 1.5 m telescope at the European Southern Observatory in La Silla (Chile).

The CORAVEL scanner is particularly well suited for small telescopes due to its compactness (focal length 57 cm) and due to the fact that it could be mounted to the Cassegrain focus. An echelle grating with a cross disperser allows an efficient use of the stellar light (λλ 3600-5200 Å) combined with a large dispersion (2 Å/mm). The actual masks in both CORAVELs are based on Arcturus and allow the measuring of stars later than spectral type about F0.

The performances of the cross-correlation spectroscopy are not limited to radial velocity measurements. Such a technique has been successfully applied to stellar rotation measurements (Benz and Mayor, 1981, 1984; Benz et al., 1984), for the determination of stellar metallicities (Mayor, 1980), for the study of the turbulence in pulsating stars (Benz and Mayor, 1982; Benz and Stellingwerf, 1985) and for the detection of magnetic fields (Borra et al., 1984).

We shall not discuss here the number of important investigations done with the same instruments because it is not the aim of this review. Some of them are:

- The study of more than 400 supergiants in the LMC (Prévot et al., 1985).
- A similar investigation on 232 supergiants in the SMC (Maurice et al., 1985).
- The determination of the rotation velocity field in ω Cen and 47 Tuc and the detection of the heavy remnants in their nuclei (Meylan and Mayor, 1986), based on more than 500 radial velocities in each cluster (Mayor et al., 1983).
- A catalogue of 790 southern stars in order to achieve the completeness of the Bright Star Catalogue (Andersen et al., 1984).

Among the numerous investigations published or in progress, the study of pulsating stars (sect. 2) and of stellar duplicity (sect. 3) are good examples of the possibilities offered by an efficient instrumentation, combined with the continuity of measurements allowed by a small telescope dedicated exclusively to this task. Also, the completion of the various programs has frequently been made possible thanks to the kind contribution of several colleagues.

2. PULSATING STARS

2.1. Yields of the Radial Velocity Measurements

2.1.1. Pulsational velocity, radius variation and acceleration. From the radial velocity curve $V_r(t)$ of a pulsating star, several interesting curves can be derived. First, the pulsational velocity

$$\dot{R}(t) = -\beta (V_r(t) - \overline{V}_r) = -\beta \, \Delta V_r$$

where β is the conversion factor from radial to pulsational velocity. Second, the curve of the radius variation

$$\Delta R(t) = \int \dot{R}(t) dt = R(t) - R_o$$

where R_o is the mean stellar radius. Third, the acceleration of the stellar surface $\ddot{R}(t)$. This quantity is related to the gravity and to the pressure gradient by the expression

$$\ddot{R} = -(GM/R^2) - (1/\rho) \, (\partial P/\partial R) = -g + g_{eff}$$

Figure 1 shows two sets of such curves derived from CORAVEL observations of the small amplitude cepheid V636 Cas (Burki and Benz, 1982) and of the RR Lyrae star RR Cet (Burki and Meylan, 1986a). For the calculations of g, the values M = 5 $M_\odot$ and 0.6 $M_\odot$, R_o = 76 $R_\odot$ and 6.7 $R_\odot$ have been adopted for V636 Cas and RR Cet respectively. It clearly appears on Fig. 1 that the pulsational behaviour of the two stars exhibits important differences. In particular, the movement of the stellar atmosphere near the minimum radius is much more violent in the case of the RR Lyrae star.

2.1.2. Mean radius determination. The Baade (1928) - Wesselink (1946) method allows the determination of the mean radius R_o of a pulsating star from the knowledge of the curves of radial velocity, magnitude (generally V) and one color index related to T_{eff}. The simultaneity of the photometric and spectroscopic observations is required if either the period or the shape of the various curves change with time. Many versions of the Baade-Wesselink method exist, we only mention some of the recent ones: Balona and Stobie (1979a,b), Imbert (1981), Burki and Benz (1982).

An important variant of the method is due to Barnes et al. (1977). They use the remarkable relation between the surface brightness and color index V-R (Barnes-Evans relation) to derive, from the radial velocity, V and V-R curves, the mean radius and the distance of the star. A similar method, based on photometric calibrations in the Geneva system allowing the determination of T_{eff} for each photometric measurement, was applied by Burki and Meylan (1986a) to derive the mean radius and the distance of RR Lyrae stars. In recent years, many determina-

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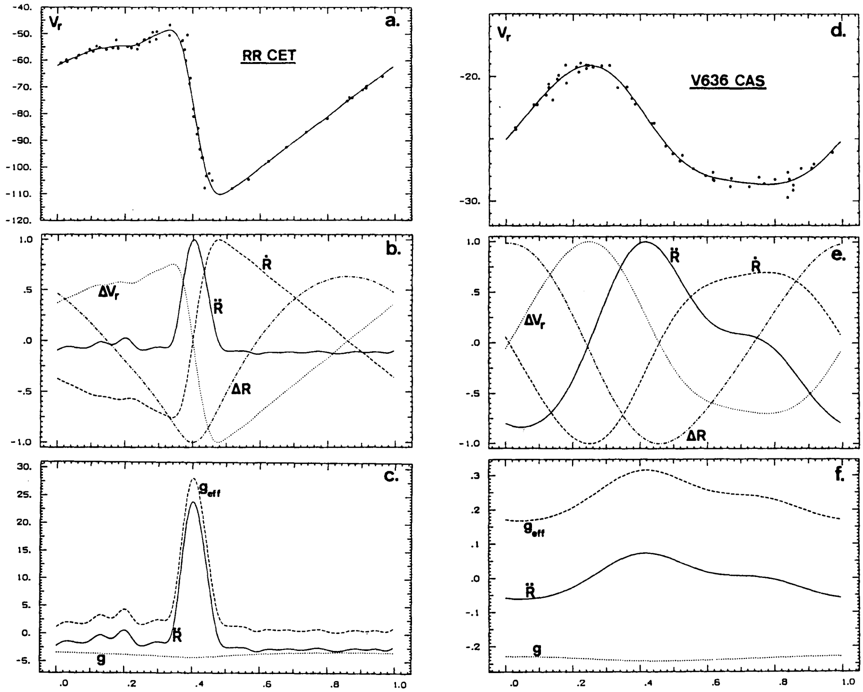

Figure 1. a. V_r curve of RR Cet (RR Lyrae).
b. Various curves derived from V_r. The value +1.0 of the ordinates is +36 kms^{-1} for ΔV_r, +49 kms^{-1} for $\dot{R}$, +0.51 $R_\odot$ for ΔR and +24 kms^{-2} for $\ddot{R}$.
c. $\ddot{R}$, $-g$ and g_{eff} curves in ms^{-2}.
d.-f. Same as a-c, but for V636 Cas (cepheid). The value +1.0 (e.) is +5.6 kms^{-1} for ΔV_r, +7.7 kms^{-1} for $\dot{R}$, +1.11 $R_\odot$ for ΔR and 0.073 ms^{-2} for $\ddot{R}$.

tions of the mean radius of pulsating stars have been performed, allowing a considerable improvement of the period-radius relation. This relation was essentially examined in the case of classical cepheids (see e.g. Fernie (1984) and Burki (1985a,b) for recent studies) and in the case of pop. II cepheids (Woolley and Carter, 1973). A complete log P - log R diagram, grouping all the classes of pulsating stars for which Wesselink radii have been determined, i.e. classical cepheids, W Virginis, BL Herculis, RR Lyrae, δ Scuti and SX Phoenicis stars, has been established by Burki and Meylan (1986c) and is summarized in another paper in this volume.

2.1.3. Turbulence variations (with CORAVEL). In the case of non-pulsating stars, the correlation function (dip) of CORAVEL is very well represented by a gaussian curve

$$c(v) = 1 - H \cdot \exp\left(-(v-V_r)^2 / 2\sigma^2_{gauss}\right)$$

where H is the depth and σ_{gauss} the width of the dip. The minimum value of σ_{gauss} is observed in the case of non-rotating and non-pulsating F and G stars of classes V to III: 6.88 kms^{-1} for the CORAVEL at the O.H.P.. The increase of the dip width by stellar rotation was described by Benz and Mayor (1981) and the effect of stellar pulsation was studied by Benz and Mayor (1982). They showed that the variation of the dip width with the pulsation phase is much too large in the cases of the cepheids SV Vul, X Cyg and δ Cep to be explained only by the movement of the stellar surface (geometrical effect). Following the spectroscopic study by van Paradijs (1971), Benz and Mayor (1982) suggested that the increase of turbulence during the phase of large pulsation velocity is the cause of this excess of line broadening. In fact, as shown by Fig. 2 (X Cyg), the maxima of the broadening correspond exactly to the maxima of $\ddot{R}(t)$.

This variation of the CORAVEL dip (or photospheric lines) broadening during the pulsation cycle is observed in all the pulsating stars, even in very small amplitude cepheids like V440 Per or V636 Cas (Burki and Benz, 1982). As to the peculiar cepheid HR 7308 (see section 2.2), the amplitude of dip width variation is strongly correlated to the amplitude of pulsation (Burki et al., 1982).

2.2 Cepheid Stars

M. Imbert (Marseille Observatory) has undertaken an extensive research to determine the mean radius of about 25 galactic cepheids. Three cases are already published (Imbert, 1981, 1983, 1984): XY Cas, AD Gem and SU Cyg. This last cepheid is a member of a binary system and the orbital elements were calculated simultaneously with the Fourier coefficients of the pulsation curve.

Two very small amplitude cepheids have been discovered, V636 Cas (see Fig. 1) and V440 Per (Burki et al., 1980). The latter is the classical cepheid with the smallest amplitude known so far, 5.6 kms^{-1} in radial velocity and $0^m.09$ in V (total amplitudes). The mean radii of these stars were determined by Burki and Benz (1982) using simultaneous photometry. Radius determination has also been performed for nine short period cepheids (Burki, 1985a): V465 Mon and possibly DX Gem are spectroscopic binaries, SW Tau could be a pop. II cepheid and EU Tau could be an overtone pulsator.

One of the most typical examples of fruitful research with a small telescope was the CORAVEL monitoring of the unique cepheid HR 7308 (V473 Lyr). The variability of this star was discovered by Breger (1969) and the cepheid classification is due independently to Percy et al. (1979), Burki and Mayor (1980) and Henriksson (1980). The remarkable characteristics of this short period (P = 1.49 d.) cepheid is the very large variation of the pulsation amplitude in a time of about 1400 d.:

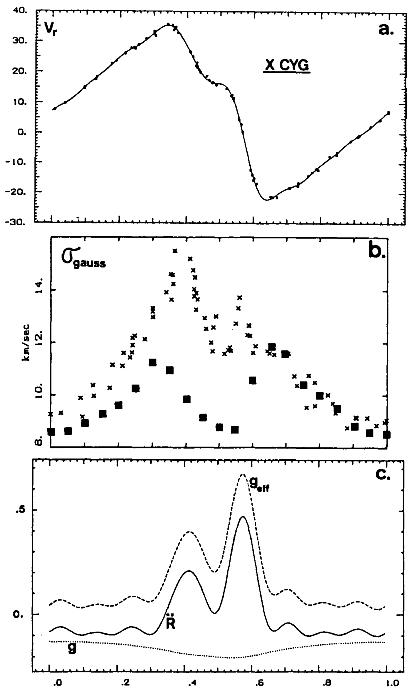

Figure 2.

a. V_r curve of X Cyg (cepheid).

b. Variation of the CORAVEL dip width (crosses) and predicted geometrical effect (squares).

c. $\ddot{R}$, $-g$ and g_{eff} curves in ms^{-2}.

the last maximum and minimum total amplitudes were 35 kms^{-1} (summer 1985) and 2.3 kms^{-1} (summer 1982). Two estimations of R_O are based on CORAVEL data, 34 ± 5 $R_\odot$ (Burki et al., 1982) and 44 ± 9 $R_\odot$ (Burki et al., 1986). Note that the mean radius does not vary during the 1400 d. period, since the pulsation period of 1.49 d. shows very little, if any, variation with time. These large values of R_O are in favor of an overtone pulsation (at least the 2nd one). The radial velocity curve, and probably also the light curve, is almost sinusoidal at minimum amplitude and becomes asymmetrical with increasing amplitude. Thus, HR 7308 offers the unique possibility for studying, in the same star, the variation of the shape of velocity (and light) curve with the intensity of the non-linear effects acting on the driving mechanism of the pulsation. Unfortunately, the physical cause for the amplitude variation in HR 7308 has not yet been found. The various possible mechanisms are: i) a star entering or leaving the instability strip (Burki and Mayor, 1980), ii) an interaction between pulsation and convection (Stellingwerf, 1984), iii) instability of the limit cycle in non-linear dynamical calculations (Auvergne, 1985).

A monitoring of about twenty cepheids in the Magellanic Clouds by M. Imbert is in progress. The radial velocity curves are published for six of them (Imbert et al., 1985) and the case of HV909 is shown in Fig. 3. The resulting σ_{O-C} of the fitted curves are from 1.1 to 2.7 kms^{-1}, depending on the stellar magnitude (from 14.1 to 15.5 in B at

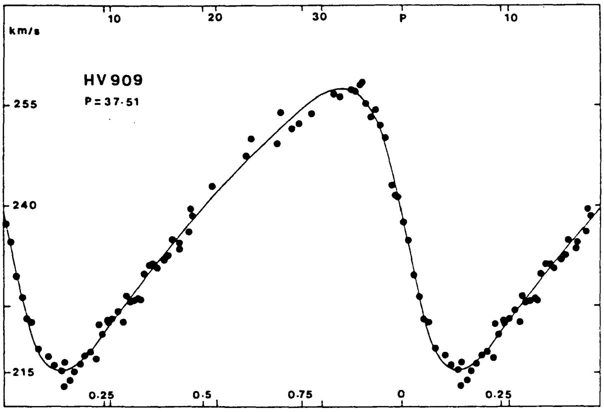

Figure 3.

Radial velocity of a cepheid in the LMC (Imbert et al., 1985).

minimum light). The accuracy on the centre-of-mass velocities is from 0.2 to 0.4 kms^{-1}. A Baade-Wesselink analysis will be published for these stars.

2.3. RR Lyrae Stars

L. Prévot, Marseille, and Burki and Meylan, Geneva, have undertaken independent but similar programs of radial velocity measurements on RR Lyrae stars in order to determine the radii, distances and absolute luminosities and to study the possible dependence of the luminosity on the physical parameters, in particular the metal content. Concerning the Geneva program, partial or complete radial velocity curves and quasi-simultaneous Geneva photometry were obtained for 10 stars and the entire analysis is completed for two cases: RR Cet (see Fig. 1) and DX Del (Meylan et al., 1986; Burki and Meylan, 1986a,b). The essential results are given in Table 1. The uncertainties on the parameters are only of mathematical nature and result from the least squares procedure. The total uncertainties are roughly twice as large as the values given.

	RR Cet	DX Del
Period	0.55 d.	0.47 d.
[Fe/H]	-1.3	-0.1
R_o	6.7 ± 0.2 $R_\odot$	5.5 ± 0.2 $R_\odot$
$\bar{M}_V$	0.28 ± 0.14	0.49 ± 0.16
distance	760 ± 40 pc	750 ± 45 pc

TABLE 1. Physical parameters of two RR Lyrae stars

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At present, the Baade-Wesselink method has been successfully applied by various authors to 7 RR Lyrae stars (see Burki and Meylan, 1986b, for references). By adopting the unique value $0^m.30$ for the individual $\overline{M}_V$ uncertainty a mean value $<\overline{M}_V> = 0.57 \pm 0.09$ is obtained for these RR Lyrae. This value is brighter, but compatible at the 1 σ level, than the recent value 0.76 ± 0.14 derived by Hawley et al. (1986) by means of a new statistical parallaxes analysis.

2.4. δ Scuti stars

A large number of measurements has been performed on δ Scuti stars (including the pop. I dwarf cepheids). The aims of the Marseille and Geneva programs are the study of the pulsation mode(s), the analysis of the multiperiodicity and the determination of the mean radii.

Imbert (1980) obtained the first velocity curve for V1719 Cyg and suggested that the observed amplitude variation is due to a second pulsation mode, a hypothesis recently confirmed by Mantegazza and Poretti (1986).

A new δ Scuti star, V356 Aur, was discovered by Burki and Mayor (1981). Despite a simultaneous survey in photometry and radial velocity it was not possible to determine the mean radius, because the difference in phase between the light and colour curves is almost zero: $\Delta\phi = -0.003 \pm 0.010$. This could be the signature of a non-radial oscillation mode with odd spherical harmonic order ℓ, but the large uncertainty on $\Delta\phi$ does not completely exclude a radial mode.

Bardin and Imbert (1981, 1982, 1984) determined the orbital parameters of two binary δ Scuti stars: V644 Her ($P_{orb} = 11.86$ d) and SZ Lyn ($P_{orb} = 1181.5$ d, $P_{puls} = 0.121$ d).

For BS Aqr, Burki and Meylan (1986c) obtained the following parameters from a Baade-Wesselink analysis: $R_o = 3.2 \pm 0.4\ R_\odot$, $\overline{M}_V = 1.4 \pm 0.3$, $d = 410 \pm 60$ Pc, $M = 1.8\ M_\odot$. These values are in good agreement with the classification of this dwarf cepheid as a pop. I δ Scuti star.

2.5. SX Phoenicis stars

This is the new classification for the short period ($0.03 \lesssim P \lesssim 0.08$ d) pulsating stars showing low metallicities, high space motions and low luminosities (e.g. Breger, 1980). This class of variable stars groups three blue stragglers in ω Cen (Jorgensen and Hansen, 1984) and five field stars (SX Phe, BL Cam, CY Aqr, DY Peg, KZ Hya) which are studied with CORAVEL. For DY Peg, the following values have been determined: $R_o = 1.4 \pm 0.4\ R_\odot$, $\overline{M}_V = 3.2 \pm 0.5$, $d = 250 \pm 80$ pc (Burki and Meylan, 1986c).

In the colour-magnitude diagram, DY Peg and the three variable blue stragglers in ω Cen form a surprisingly well-defined clump whose coordinates are $(B-V)_o \cong 0.20$ and $M_{V_o} \cong +3.0$. Then, DY Peg has probably the same evolutionary status as the three ω Cen blue stragglers. As to

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the possible physical interpretation of the blue stragglers as the result of a binary evolution, it must be noted that no binary motion has been detected in DY Peg on a time base of two years.

2.6. FG Sge

This is the nucleus of a planetary nebula ejected about 6000 years ago. Since 1950 its T_{eff} has been decreasing with a gradient of about $-300^{o}K/y$ (Stone, 1979) and the corresponding annual increase of the pulsation period is about 5 d (Jurcsik and Szabados, 1979). The star was monitored with CORAVEL and the resulting radial velocity curve has the following essential parameters (Mayor and Acker, 1980): 110 d for the period and 2.1 ± 0.3 kms^{-1} for the amplitude in 1978, 115 d and 3.7 ± 0.5 kms^{-1} in 1979. In addition, by means of photometric data given by various authors, it was possible to estimate the mean radius for the period 1978-1979, $R_o = 140 \pm 30$ $R_\odot$, and the other parameters, $M = 1.2 \pm 0.6$ $M_\odot$ and $M_V = -4.3 \pm 0.7$.

3. STELLAR DUPLICITY

3.1 Generalities

In the solar neighbourhood, roughly 2/3 to 3/4 of the mass locked in stars belongs to binary or multiple systems. The distribution functions of the orbital parameters of these systems depend on the star formation mechanisms, the stellar evolution (mass exchange, tidal circularization etc.) and the dynamical evolution. Despite the high frequency of stellar systems, these distribution functions are still badly known due to various observational selection effects.

Among the recent efforts to present unbiased views of definite groups of stars, the study by Abt and Levy (1976) on G-type dwarfs can be cited. Also, the work carried out by Griffin and Gunn to study the duplicity in the Hyades is to be mentioned: the distribution N(log P) for the SB (spectroscopic binaries) is slowly increasing in the range $1 < \log P < 3$ (Griffin, 1985), in good agreement with the corresponding distribution derived by Abt and Levy. Such a result would not have been obtained from the study of the actual general catalogues of binary stars, which are affected by selection bias.

Radial velocities derived by cross-correlation devices will certainly reduce this bias and an important part of the measurements can be made with small telescopes. Photoelectric scanners have already made significant contributions in this domain. Let us mention the outstanding work done by R. Griffin at Cambridge, mainly on late-type field giants, the high percentage of binaries in barium stars discovered by McClure (1984) and the measurements made in M3 by Gunn and Griffin (1979) and later by Pryor et al. (1985).

A series of systematic surveys based on CORAVEL measurements and related to binary stars are in progress, in particular on the following objects:

- Late-type dwarfs in the open clusters Pleiades, Praesepe, Coma Ber, α Per, ζ Scl and several others in the southern hemisphere. This program is carried out by J.C. Mermilliod and one of the authors (M.M.).
- Red giants in open clusters (more than 800 stars).
- Low main sequence stars in the solar neighbourhood (a program of the Geneva observers with the collaboration of J.L. Halbwachs).
- Galactic supergiants of spectral types F to M (see Burki and Mayor, 1983).
- SB with known orbits in order to detect a third, distant companion by nodal precession (Mazeh and Mayor, 1983; Mayor and Mazeh, 1986).
- Visual binaries with known visual orbits (more than 100 systems, see paper by Duquennoy and Mayor in this volume).
- Halo stars in the southern hemisphere (A. Ardeberg, H. Lindgren and other CORAVEL observers).
- Giant stars (more than 100 are measurable) in the nucleus of ω Cen, in view of detecting the binaries.

These large surveys for which the detection level of binaries is about 1 to 2 kms^{-1} should give new constraints on the physical and dynamical properties of the binary stars.

3.2. Eccentricity-Period Relation and Distribution of Orbital Eccentricities

3.2.1 Late-type dwarfs in open clusters. The radial velocity survey of the main open clusters with CORAVEL has allowed the determination of 22 orbits, essentially in Coma Ber, Pleiades, Praesepe and a few in the Hyades. By adding the orbits determined by Griffin and his collaborators (see Griffin et al., 1985 and references therein) in the same clusters but mainly in the Hyades, we now dispose of a sample of 46 SB later than F5V. Recall that an advantage of the binaries in open clusters is the knowledge of their age and evolutionary status.

The e vs. log P diagram for these systems is shown in Fig. 4a. The discontinuity appearing at P ~ 5.7 d can be interpreted in terms of tidal circularization; this value of the limit period is in agreement with the expected one for main sequence stars with an outer convection zone and having the same age as these clusters (Mayor, Mermilliod, 1984). However, one cannot reject the possibility that the circularization process has operated during the stellar evolution prior to the main sequence. Indeed, for a given period, the time required for the circularization, t_{circ}, is considerably shorter during the pre-main sequence evolution than during the main sequence, since the radii of the protostars are larger, the convection zone is more developed and the gravity is lower. This clearly appears from the relation giving, for a specified mass ratio, the expression of t_{circ}:

$$t_{circ} \sim (a/R)^5 \, g \, P^2 \, / \, (\lambda \, \eta \, v_c)$$

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where λ and η are the relative thickness and mass of the convective zone and v_c is the convective velocity (Lecar et al., 1976).

The normalized eccentricity distributions f(e) for our sample of SB with dwarf components are shown in Figs. 5a (P < 5.7 d) and 5b (P < 5.7 d). The distribution in Fig. 5b is certainly biased in the case of very eccentric orbits, but we estimate from the analysis of the data that this effect is only important for e larger than 0.8.

It is interesting to compare these distributions f(e) with that obtained from the study of Harrington and Miranian (1977) for the orbits of visual binaries. They have shown that selection effects diminish the probability of obtaining orbital elements in the case of very large values of e. Their "completeness factor", derived by numerical simulations, permits to correct the observational distribution f(e). This corrected distribution, established for visual binaries with log P ≳ 3, is shown in Fig. 5c. Note that the study of dynamical decay of larger stellar systems predicts a similar distribution f(e) (Harrington and Miranian, 1977) and that these distributions are not far from Ambartsumian's (1937) distribution f(e) = 2e (dashed line in Fig. 5c), expected if the orbital distribution in phase space is a function of energy only.

In consequence, the eccentricity distribution f(e) for late-type SB of very short period is depending on the tidal circularization mechanisms. For very long periods, f(e) can be explained in terms of the dynamical decay of larger stellar systems. In the intermediate range of periods (0.76 ≤ log P ≤ 3), f(e) probably gives direct information on the initial conditions.

3.2.2. Late-type giants in open clusters. The e vs. log P diagram established from orbital elements of SB with a red giant as primary component (Fig. 4b) is very similar to the diagram for red dwarfs (Fig. 4a), except that the limit period for the circularization appears at a larger value: between 127 d and 179 d (Mayor and Mermilliod, 1983). It seems that the tidal dissipation due to low gravity, large convective zone and big radii in giant stars is sufficient to explain this observed limit period (Mayor and Mermilliod, 1984).

During stellar evolution, the radius of a component of mass M_1 in a binary star will fill its Roche lobe if the orbital period is shorter than a critical value P_{RL}. Such a limit depends on the mass M_2 of the other component. By using the Kopal (1978) value for this limiting period in the circular case (e = 0), we have estimated P_{RL} for non-circular orbits, under the hypothesis that the primary component just fills its Roche lobe at periastron during its evolution (see Table 2).

The masses of the three giants in SB with circular orbits (see Fig. 4b) deduced from the age and evolutionary tracks of the parent clusters are between 1.5 and 1.8 $M_\odot$. From Table 2 it appears that these three systems could have experienced a small mass transfer if their initial orbital eccentricities on the main sequence were slightly larger than 0.3.

3.2.3. Late-type supergiants. The study of the binary F-M supergiants with known orbital elements shows that all systems with a period

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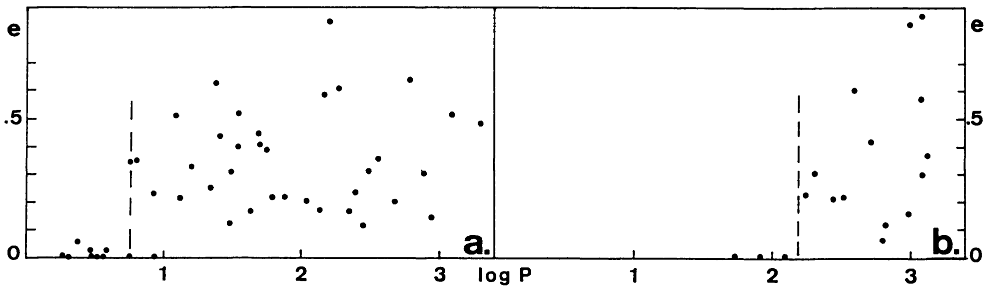

Figure 4. e vs. log P diagrams for the SB of late-types in open clusters. a. Dwarfs. b. Giants

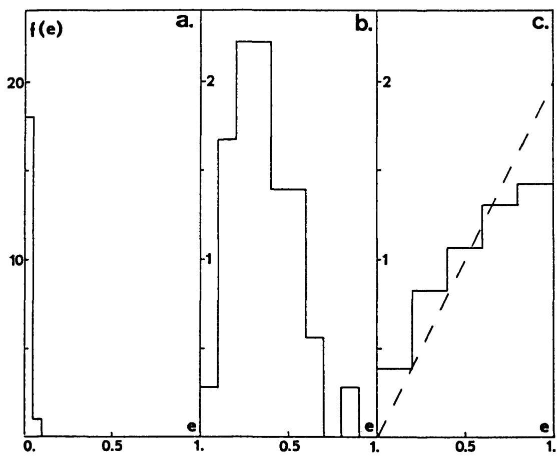

Figure 5. Distribution of the orbital eccentricities.

a. Short period SB (P < 5.7d) in open clusters with a late-type dwarf as primary component.
b. Same as a, but for P > 5.7 d.
c. Visual binaries (P ≳ 1000 d), with a correction for the observational bias (see sect. 3.2.1.).

M_2/M_1	$M_1 = 1\ M_\odot$			$M_1 = 3\ M_\odot$		
	e = 0.0	0.3	0.6	e = 0.0	0.3	0.6
1.0	20.8	35.6	82.2	39.2	67.0	155.0
0.6	19.4	33.2	76.6	36.5	62.0	144.2
0.2	15.9	27.2	62.8	30.0	51.3	118.5

TABLE 2. Limit period P_{RL} $(M_1/M_2, M_1, e)$ in days

$P_{circ} = P(1-e)^{1.5}$ smaller than a critical value P_{crit} have a nearly circular orbit (P_{circ} is the period of a hypothetical circular orbit which would have for radius the distance between components at the periastron of the real elliptical orbit). The value of P_{crit} depends on the luminosity class: 350 - 440 d for class Ib, 1400 - 3900 d for class Ia. This circularization of the orbits results probably from the transfer of angular momentum during the phase of binary mass exchange. In several systems with circularized orbits, the star actually observed as a supergiant was probably the secondary component at the origin of the system (see Burki and Mayor, 1983, 1984).

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DISCUSSION

Rucinski: You showed us a diagram showing the synchronisation of binaries in a few clusters differing in age by a factor of at least ten. Do you see differences in limiting synchronisation periods as a function of the cluster age?

Burki: Unfortunately the number of binary star orbits in each cluster is not sufficient to conclude anything at present.

Cameron: What duplicity rate do you find among the main sequence G-stars in these clusters?

Burki: The frequency of binaries does not require a complete orbit. Mermilliod and Mayor have already published this value : 34 ± 5% for the global rate of main-sequence binary stars in the Hyades, Pleiades, Praesepe, α Persei clusters.

Duncan: It is worthwhile doing something that someone has done before, since all the parameters may not have been determined. Marcy, a Mt Wilson post-doc, has just finished a study of the binary frequency of M-dwarfs. He finds a frequency of < 10%, and he has a velocity accuracy of $0.2 kms^{-1}$. Thus the M-dwarfs behave quite differently to the G-dwarfs. Only 2 out of 40 M-dwarfs showed companions in this survey.

Latham: His selection was for single stars not visual binaries. I think he would find a higher frequency of (spectroscopic) binaries amongst the visual binaries.

Levato: If you change the mask in CORAVEL for an earlier spectral type in the same wavelength region, what is the precision that you get on an early type star.

Burki: The precision of our machine is proportional to the number of lines one considers. The cross-correlation technique will therefore realize lower precision for early-type stars, but will be better than by traditional methods. We are not proposing to make an early-type mask as we first want to finish our programs on late-type stars.

Moffett: What would be the cost of reproducing the CORAVEL instrument?

Burki: About $US 100,000.

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