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Cepheid radii and the CORS method revisited

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Abstract. We have refined the CORS method, introduced in 1980 for the computation of the cepheid radii, in order to extend its applicability to recent and extensive sets of observations. The refinement is based on the computation, from observational data only, of one of the terms of the solving equation, previously based only on precise calibrations of photometric colors. A limited number of assumptions, generally accepted in the literature, is used.

New radii are computed for about 70 cepheids, and the resulting P-R relation is discussed.*

Key words: stars: distances – stars: oscillations – stars: fundamental parameters – stars: cepheids

1. Introduction

The importance of a proper knowledge of the radii of Cepheid variables is well known, in particular, but not only, in connection with the problem of the cosmic distance scale. Notwithstanding extensive studies by several authors (Caccin et al. 1981; Fernie 1984; Gieren 1986; Moffett & Barnes 1987; Gieren et al. 1989, Laney & Stobie 1995), there are still doubts on the correct period-radius relation. Almost all methods used for determining the radius of a cepheid from the photometric and spectroscopic (radial velocities) observations, are based on the classical Baade-Wesselink method (Wesselink, 1946). Gautschy (1987) published a review of the different methods; this comparative study outlines that the CORS method (Caccin et al., 1981, Sollazzo et al., 1981) had the most solid physical basis, together with the surface brightness technique by Barnes & Evans (1976). However, the CORS method suffered from two major drawbacks that have so far prevented its application to most observational data; that is the mathematically difficult formulation, and the need of a good and complete calibration of the colors, able to derive detailed temperatures and gravity curves. In particular, the second problem is solved so far only for the VBLUW observations by Pel (1976,1978). The first problem is instead not a true problem, because, as we will show, the whole CORS method reduces itself to the fitting of the data and to the solution of an implicit equation which, once written in computer form, requires a fraction of a second to be solved in terms of the cepheid radius.

The purpose of the present paper is to introduce a modification of the CORS method, by taking into account the surface brightness method, in order to allow the determination of cepheid radii for a wider set of data than it was originally conceived.

In particular, we will face the case in which it is not possible to derive detailed gravity and temperature curves from the observations, thus making conceptually a step backward with respect to the original CORS method, but extending its practical usefulness.

In the following we will first recall the original surface brightness and CORS methods, and then we introduce its modified version, discussing its characteristics. Last sections are devoted to the application of the method and to the discussion of the results.

2. The new method

2.1. The surface brightness method

The surface brightness method (Barnes & Evans, 1976), as used by Gieren et al. (1989), is based on the visual surface brightness S_v, defined as the following equivalent relations:

$$S_V = V + 5 \cdot \log \alpha \quad (1)$$

$$S_V = -10 \cdot \log T_e - B.C. + const. \quad (2)$$

where α is the angular diameter, and B.C. the bolometric corrections. Or, equivalently, the surface brightness parameter F_v, given by

$$F_V = const. - 0.1 \cdot S_V = \log T_e + 0.1 \cdot B.C. \quad (3)$$

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* Table 2 is also available at the CDS via anonymous ftp 130.79.128.5 or via http::/edsweb.v.strasbg.fr/Abstract.html

An empirical relation has been found by Barnes & Evans (1976), which correlates F_v to the Johnson $(V-R)_0$ index, corrected for interstellar reddening:

$$F_V = b + m \cdot (V-R)_0 \tag{4}$$

where the angular coefficient m is in turn a function of the pulsational period (Moffett & Barnes, 1987):

$$m = -0.370 + 0.004 \cdot \log P \tag{5}$$

The practical application starts from the $(V-R)$ observations, which from (4) give F_v, which in turn from (3) give S_v, which in turn from (1) give α. Expressing the linear diameter $D = 10^{-3} \cdot r \cdot \alpha$ (r being the distance in parsec) as $\Delta D + D_m$ (ΔD being the instantaneous displacement) and performing a regression analysis of α against ΔD, one obtains the mean diameter D_m, as well as the distance r.

2.2. The original CORS Method

The CORS method also starts from (1), but proceeds mathematically by differentiating it with respect to the phase, multiplying by the color index $(B-V)$ and integrating over the whole cycle; after substituting:

$$\dot{R}(\phi) = -p \cdot P \cdot u(\phi) \tag{6}$$

it yields to the following equation, in which ϕ is the phase

$$a \int_0^1 \log\left\{R_0(\phi) - p \cdot P \int_{\phi_0}^{\phi} u(\phi') \cdot d\phi'\right\}(B \dot{-} V)(\phi) \cdot d\phi + -B + \Delta B = 0 \tag{7}$$

where $a = 5/\log_e 10$,

$$B = \int_0^1 (B-V)(\phi) \cdot \dot{V}(\phi) \cdot d(\phi) \tag{8}$$

$$\Delta B = \int_0^1 (B-V)(\phi) \cdot \dot{S_V}(\phi) \cdot d(\phi) \tag{9}$$

P is the period, u the radial velocities and p is the radial velocity projection factor (Parsons, 1972; Gieren et al. 1989). The practical application of the CORS method starts from a fitting of data with respect to the phase ϕ by means, e.g., of Fourier series. The data are given by the V magnitude, the $(B-V)$ and $(V-R)$ color indexes, and the radial velocities u.
The fit is easily obtained with an interactive procedure on a computer terminal with graphic capabilities; afterwards, the fitted curves are used to compute in an automated way the term B, the term Δ B, the derivatives and eventually to solve Eq. (7) to obtain R_0, the radius at an arbitrary phase ϕ_0; ϕ_0 is usually taken at the minimum of the radial velocity curve, but its choice is inessential; the mean radius comes from integrating twice Eq. (6).

2.3. The modified CORS method

We will now show how the two methods can be used together, to obtain what we will call the modified CORS method.
From Eq. (4) we can obtain F_V, and from it, we can obtain S_V, using also Eq. (3) and (5):

$$\begin{aligned} S_V &= const. - 10 \cdot F_V \\ &= const. - 10 \cdot m \cdot (V-R)_0 - 10 \cdot b \\ &= const. + (3.7 - 0.04 \cdot \log P)(V-R)_0 \end{aligned} \tag{10}$$

The value of the constant is of no importance in our case, since we are interested in computing ΔB; this term, given by Eq. (9), is the area of the loop described by the star in the plane S_V vs $(B-V)$. If we make the transformation of variable from S_V to $(V-R)_0$, given by Eq. (10), then:

$$\begin{aligned} \Delta B &= \int_0^1 (B-V)(\phi) \cdot \dot{S_V}(\phi) \cdot d(\phi) \\ &= (3.7 - 0.04 \cdot \log P) \cdot \\ &\quad \cdot \int_0^1 (B-V)(\phi) \cdot (V \dot{-} R)_0(\phi) \cdot d(\phi) \end{aligned} \tag{11}$$

Since the derivative of $(V-R)_0$ with respect to the phase is, in first approximation, the same as the one of $(V-R)$, we get from Eq. (11), with c=3.7-0.04$\cdot$ log P:

$$\Delta B = c \int_0^1 (B-V)(\phi) \cdot (V \dot{-} R)(\phi) \cdot d(\phi) \tag{12}$$

Let us pose $C = \int_0^1 (B-V)(\phi) \cdot (V \dot{-} R)(\phi) \cdot d(\phi)$, which represents the area of the loop described by the star in the plane $(V-R)$ vs $(B-V)$, we get to the final formulation, given the following observations:

i) the light curve
ii) the color curve $(B-V)$
iii) the color curve $(V-R)$
iv) the radial velocity curve

and the quantities, all based on the above observations:

i) B=area of the loop $(B-V)$ vs V
ii) C=area of the loop $(V-R)$ vs $(B-V)$

The radius R_0 at an arbitrary phase is obtained from the equation:

$$a \int_0^1 \log\left\{R_0(\phi) - p \cdot P \int_{\phi_0}^{\phi} u(\phi') \cdot d\phi'\right\}(B \dot{-} V)(\phi) \cdot d\phi + -B + c \cdot C = 0 \tag{13}$$

where $c = 3.7 - 0.04 \cdot \log P$ and $p = 1.39 - 0.030 \cdot \log P$, if we follow Gieren et al. (1989), or c=3.7 and p=1.36 in our approximation.

The mean radius is obtained from double integrating the radial velocity curve, since the first integration gives the radius curve and the second integration its mean value. Eq. (13) has to be solved by numerical methods, but this is easily accomplished with any computer, which nowadays is a common tool for any astronomer.

The assumptions and approximations which are behind this formulation are the following:

i) the observational data give a good coverage of the pulsational period, and do not show big noise, so that the Fourier fitting (or any other fitting which guarantees the periodicity of the data) is a good approximation to the observations.
ii) the photometric and spectroscopic observations are simultaneous, or at least separated by few tens of pulsational cycles, so that no phase-shift is present in the terms of Eq. (13)
iii) the correlation of Eq. (5), given by Moffett & Barnes (1987) represents a good approximation to the data.
iv) the proportionality between ΔB and C is valid; this was already proved in general terms by Onnembo et al., (1985), and therefore what we found here is just a confirmation, particularly valid for the colors (B − V) and (V − R).
v) the colors are not affected by other contributions, e.g. the presence of companions to the cepheid (see Russo et al. 1981).

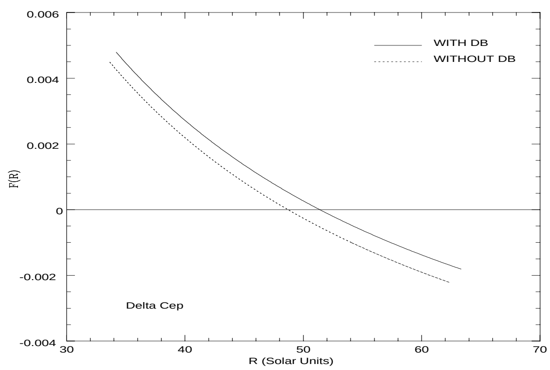

Fig. 1. Value of the solving function vs the radius of the star δ Cep.

3. Stability of the method

We want to study here the characteristics of the method, that is the sensitivity of the method to the parameters and data present in Eq. (13). First of all, the left side of Eq. (13) is a function of the following parameters: observational data (V, B-V, V-R, u); constants (c and p); the variable R. This function has a zero R_0 at a value which is determined numerically; it is important to study the behavior of such a function, with respect to R. Fig. 1 gives the plot of the above function for δ Cep; it is a well-behaved function whose zero can safely be determined. The plot varies of course according to the star, but the general shape is similar. Since the terms B and $c \cdot C$ in Eq. (12) are additive terms, their effect is to move the whole curve by a vertical shift, thus changing the value of R_0. This explains the importance of the loops for both B, the area in the plane (V, B-V) and C, the area in the plane (B-V, V-R). However, the observational data enter in these quantities only globally, that is all data together combinate to give B (and C), and this means that errors on individual points have less influence on the final value of B and C, and hence of R_0. However, the evaluation of B and C is very dependent on the regularity of the curve: if the noise of the data is high, and the data have a large scatter around the fitted curve in the planes (ϕ, V), (ϕ, B-V), (ϕ, V-R) then the area of B and C may be not well determined. Fig. 2 shows the plot of the magnitude-color and color-color loops for δ Cep. From this figure it is clear that the scatter in color-color loop is more critic with respect to that of the color-magnitude loop, so that the term ΔB will be more influenced by the eventual poor quality of the data. In any case, since the area described by the color-color loop is very small (due to the characteristic of ΔB to be a correction term) it is reasonable to expect that the error introduced in this way will be very small; an occurrence already noticed by Sollazzo et al. (1981), (see their Fig. 8).

For what concerns the dependence on the projection factor p, Fig. 3 shows the value of R_0 obtained for δ Cep, W Sgr and SZ Tau, for five different values of p: a change of 0.05 in p corresponds to a change of 3.5% in R_0.

This latter test is particularly important, because there is now much doubt about the fact that p, the projection factor has actually a constant value. The old Parson's (1972) constant value p=1.31 has been used for over two decades essentially for lack of better knowledge, and Gieren et al. (1989) using models by Hindsley and Bell (1986) have already used a value of p variable with the period as we quoted in Sect. 2.3. However, it is likely that p also varies along the pulsational cycle for a given period, as already argued by Hindsley and Bell (1986) and more recently shown by Sasselov and Karovska, 1994 and Sabbey et al. (1995).

Following referee's suggestion, we have therefore extended our tests as follows: for a particular star, ζ Gem the same discussed by Sabbey et al. (1995), we have solved Eq. (13) using the variable projection factor p as a function of the phase, given in Fig. 10 in the paper by Sabbey et al. (1995). The result of our test is reported in Table 1; we found a percentage variation for the radius of about 6%, i.e. a value equal to the one quoted by Sabbey et al (1995).

Bearing in mind that this effect certainly exists and introduces further uncertainty in the Baade-Wesselink radius, we hope that in the future further and more detailed indications on the variation of p with respect to the phase will be available.

For the present work we choose to use a constant value for p (p=1.36) either because it is appropriate for CORAVEL radial velocities (Burki et al., 1982) and approximates very well the p depending from the period by Gieren et al (1989) for a large range of periods, or because in this way we can compare our results with those ones from previous works.

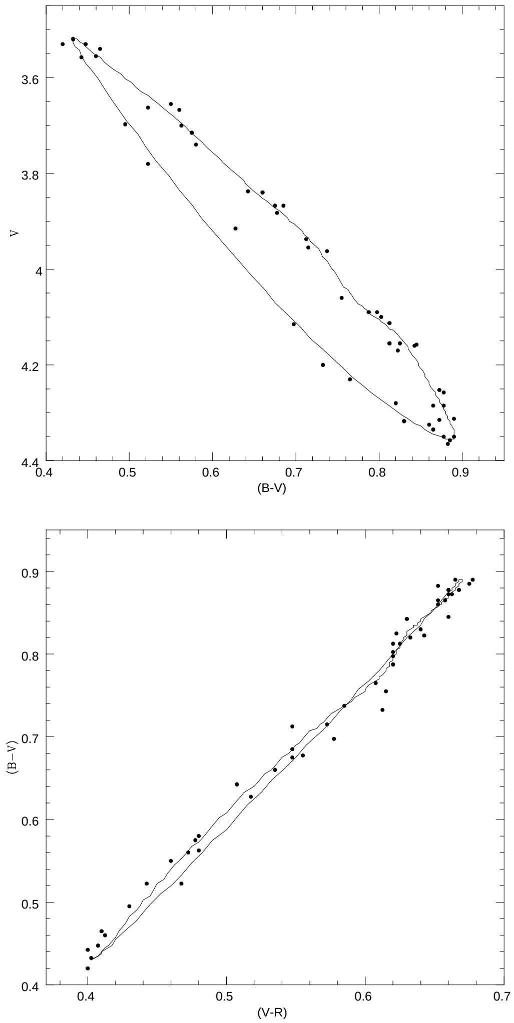

Fig. 2. Top: Loops in the plane (B − V, V) for δ Cep; Bottom: as in Left, but for the plane (V − R, B − V).

Table 1. Results of our test of using a variable projection factor p from Sabbey et al (1995) for the star ζ Gem.

p	CORS Radius (R⊙)	new CORS Radius (R⊙)
1.36	73.5	86.2
1.40	75.7	88.5
var.	80.1	93.7

However the problem of the correct estimate of the projection factor p for any star is still open.

4. Application of the method

4.1. The samples

In order to apply the method, we searched the literature for high quality sets of observational data. We considered mainly two large and homogeneous sets of data: one from Moffett & Barnes

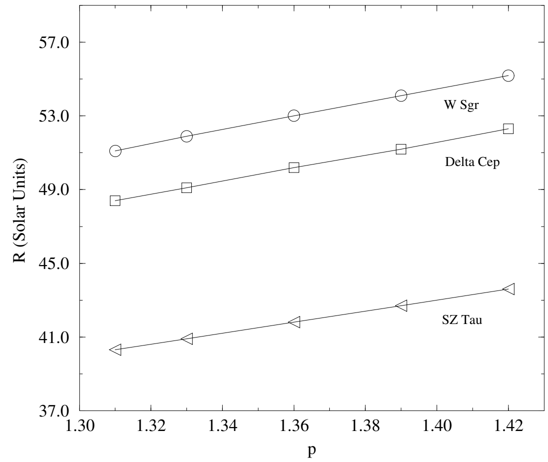

Fig. 3. Dependence of CORS output radii as a function of the conversion factor p, for three stars: Delta Cep, SZ Tau, T Vul.

(1980, 1984) (MB hereafter, BVRI photometry), Barnes et al. (1987,1988) (BMS hereafter), Wilson et al. (1989) (WCBCM hereafter, radial velocities), and the other from Bersier et al. (1994) (BBB hereafter, Geneva System Photometry), Bersier et al. (1994) (BBMD hereafter, CORAVEL radial velocities).

There were 26 variables in common between the two sets; in these cases, in general, we used photometry from MB (we proceed in this way either because these data was generally more accurate than those in the Geneva system, or because the presence of the V-R color allowed us to use our modified CORS method) and radial velocity data from BBMD (since these set of data were much more accurate than the other one). For other three stars: SY Cas, SY Nor and TW Nor for which are present radial velocity data from BBMD, but no photometry in the Geneva System, we used photometric data from Berdnikov (1992a,b,c, B in Table 2) for the first two, and Madore (1975, M in Table 2) for the third. The incompleteness of photometric data for SY Nor did not allow us to determine the radius of this star.

4.2. Particular stars

There were eight stars from BMS and WCBCM whose radial velocities curves were too poor to be used, they are: FF Aql, RU Cam, RW Cas, TU Cas, SU Cyg, AU Peg, VX Pup, S Sge.

For other two stars of the same sample: RW Cam and VY Cyg, the method did not reach the convergence, probably due to the poor quality of the data.

SW Tau was excluded because it is a Population II Cepheid.

From the BBMD sample we excluded from our computation V440 Per, which have convergence problems; CO Aur and V367 Sct because they are double or triple mode; the double stars DL Cas and V465 Mon because of problems in separating the orbital motion from the radial velocity curve.

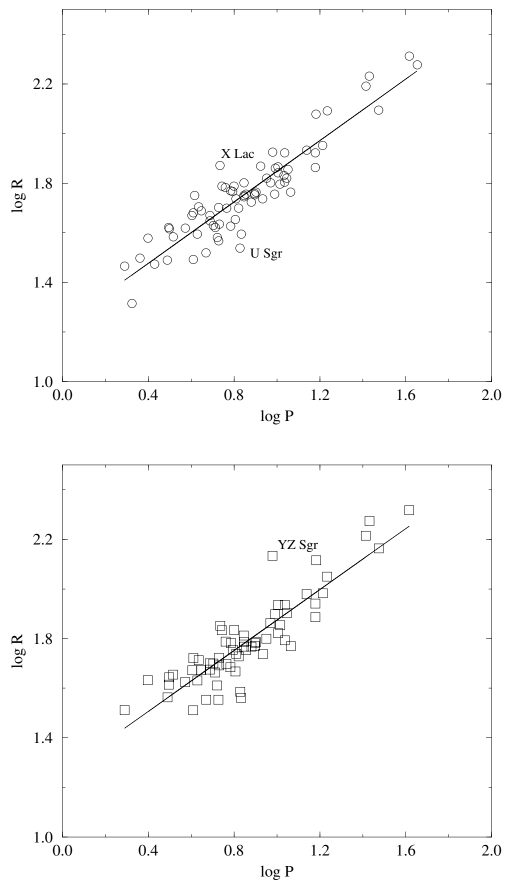

Fig. 4. Top: Period-Radius relation obtained from CORS method without ΔB; Bottom: as before, but with ΔB.

4.3. Double stars

From the literature is possible to find indications about the presence of a companion for several cepheids; in particular, following BBB, BBMD and Pont et al. (1994) the following variables result to be double: SU Cas, DD Cas, VZ Cyg, DX Gem, ζGem, RZ Gem, Z Lac, T Mon, S Nor, SV Per, Y Sct, U Sgr, W Sgr. Among these double stars, only U Sgr shows an anomaluos position in Fig. 4 (see below).

5. Results

In Table 2 we report the results of our analysis for all stars of our sample for which the CORS method reached the convergence; from left we report in the order: name of the cepheid; period; radial velocity data source; photometric data source; radius obtained with the surface brightness method (Gieren et al. 1989); radius obtained with CORS (without ΔB term); as before but with the ΔB term.

These data are plotted in Fig. 4 were we present the Period-Radius relation as a result of CORS method in two cases, with and without ΔB respectively; the solid lines superimposed represent a least square fit to our data that leads to the following Period-Radius relation (74 cepheids) without the ΔB term in Eq. (13):

$$\log R = (0.619 \pm 0.032) \log P + (1.229 \pm 0.028) \quad (14)$$

If we exclude from our fit X Lac (it shows a clear phase shift) and U Sgr (double star) we obtain a slightly better error:

$$\log R = (0.622 \pm 0.029) \log P + (1.226 \pm 0.026) \quad (15)$$

Now, if we consider the ΔB term in Eq. (13) for cepheids with BVRI photometric observations (65 stars) we obtain:

$$\log R = (0.614 \pm 0.040) \log P + (1.260 \pm 0.036) \quad (16)$$

And excluding the large scattering YZ Sgr (poor radial velocity data) we obtain:

$$\log R = (0.606 \pm 0.037) \log P + (1.263 \pm 0.033) \quad (17)$$

Our Period-Color relations are reported also in Table 3 in comparison with other selected results from the literature. We note that our P-R relations show a slope slightly shallower than either the more recent determinations via Baade-Wesselink methods, or theoretical determination.

Moreover the use of a second color (i.e. the inclusion of ΔB in the determination of radius) goes in the sense to reduce further on the slope. Since we use (at least partially) the same data of Gieren et al. (1989) it is surprising to find such a different result. Anyway, in their recent paper, Laney and Stobie (1995) applied a Surface Brightness method to a set of 31 Cepheids, using different pairs of magnitudes and colors, from (V,B-V) to (K,J-K), and found a dependence of the P–R relation from the colors used, in the sense that the slope is shallower if "blue" colors are used instead of the infrared ones. This could partially explain our shallower slope in the P–R relations, since our two determinations of R depend either from two or three "blue" colors.

6. Conclusions

We have presented a method for computing Cepheid radii, which merges the CORS and the Surface Brightness method into a single, easy to use method applicable to observations in different photometric systems.

An interesting feature of this method is its independence from the knowledge of the reddening corrections, at least within the limits of an assumption that the derivative of $(V - R)_0$ is the same as the one of $(V - R)$.

In this first implementation, we have shown that the method is efficient and gives coherent results; we were able to compute radii for 74 Cepheids with a rather straightforward procedure. However, the improvements in the P–R relation are almost negligible with respect to previous works at least in terms of the scatter of the data. This scatter can be explained by the fact that our ΔB is only an approximation to the correct ΔB of the CORS method; however, its presence gives the right trend to the slope of the P–R relation, which is lower with ΔB than without ΔB,

Table 2. Results from our method and comparison with previous determinations with the Surface Brightness Method by Gieren et al. (1989). The last two columns show the radius calculated in this work.

Cepheid	Period (days)	Photometric source	Rad. Vel. source	Surf. Brigh. radius (R⊙)	CORS radius (R⊙)	new CORS radius (R⊙)
U Aql	7.024100	MB	BMS	54.65	55.5	61.3
η Aql	7.176779	MB	BMS	54.93	57.1	56.7
FM Aql	6.114240	MB	BMS	54.82	58.8	60.6
TT Aql	13.755290	MB	BMS	97.62	86.0	95.3
V496 Aql	6.807164	MB	BMS	45.52	39.2	36.4
RT Aur	3.728220	MB	BMS	32.90	41.6	42.2
SY Aur	10.144698	MB	BMS	61.59	69.4	66.3
RX Cam	7.912190	MB	BMS	76.0	57.3	58.9
CF Cas	4.87514	MB	BBMD		46.9	50.2
DD Cas	9.81274	MB	BBMD	85.12	72.5	79.2
FM Cas	5.809232	MB	BBMD	62.05	49.9	49.9
SU Cas	1.949317	MB	BBMD		29.2	32.5
SY Cas	4.07110	B	BBMD		48.0	52.7
V636 Cas	8.375490	BBB	BBMD		74.1	
δ Cep	5.366269	MB	BBMD	41.60	50.2	52.8
CR Cep	6.232870	MB	BBMD		58.6	56.9
X Cyg	16.385692	MB	BBMD	118.13	89.6	96.2
DT Cyg	2.499086	MB	BBMD		37.9	42.9
SZ Cyg	15.109642	MB	BMS	117.74	83.8	87.3
VZ Cyg	4.8644	MB	BBMD	37.17	44.4	47.3
V386 Cyg	5.257655	MB	BMS	41.86	38.1	40.8
V532 Cyg	3.283612	MB	BMS		38.2	45.2
RZ CMa	4.254926	MB	BMS		39.4	42.8
RY CMa	4.678425	MB	BMS	43.11	33.1	35.8
TW CMa	6.995374	MB	BMS	57.28	63.3	64.8
ζ Gem	10.149955	MB	BBMD	64.94	73.5	86.2
W Gem	7.913960	MB	BMS	50.66	56.6	60.7
BB Gem	2.308207	BBB	BBMD		31.4	
DX Gem	3.136379	MB	BBMD		41.8	41.1
RZ Gem	5.529162	MB	BMS	52.49	61.4	68.2
X Lac	5.44487	MB	BBMD	64.71	74.3	71.2
Y Lac	4.323776	MB	BMS	50.27	50.7	51.7
Z Lac	10.8866000	MB	BMS	68.88	83.8	86.8
BG Lac	5.331938	MB	BMS	45.42	36.9	35.8
RR Lac	6.416190	MB	BBMD	45.61	45.1	46.4
BE Mon	2.70551	BBB	BBMD		29.7	
T Mon	27.022600	MB	BBMD	172.19	170.5	188.3
CV Mon	5.378793	MB	BMS		43.1	49.2
SV Mon	15.232780	MB	BMS	100.64	119.6	130.7
V508 Mon	4.133608	BBB	BBBMD		56.1	
S Nor	9.764244	BBB	BBMD		57.2	
TW Nor	10.78531	M	BBMD		67.5	
V340 Nor	11.28871	BBB	BBMD		71.6	
Y Oph	17.126780	MB	BMS	71.88	123.3	112.2
BF Oph	4.067695	MB	BMS	35.87	31.2	32.4
GQ Ori	8.616127	MB	BMS	72.44	54.6	54.7
AW Per	6.463720	MB	BMS	47.34	54.6	54.8
SV Per	11.129318	MB	BMS	63.97	65.9	79.9
VX Per	10.889040	MB	BMS	77.27	63.7	62.1
X Pup	25.961000	MB	BMS	118.04	156.1	164.1
RS Pup	41.415000	MB	BMS	262.60	205.7	207.9

Table 2. (continued)

Cepheid	Period (days)	Photometric source	Rad. Vel. source	Surf. Brigh. radius (R⊙)	CORS radius (R⊙)	new CORS radius (R⊙)
AQ Pup	29.839810	MB	BMS	197.20	124.8	145.9
WX Pup	8.937050	MB	BMS	76.54	66.1	63.1
RV Sco	6.061388	MB	BMS	49.29	42.2	48.3
V500 Sco	9.316862	MB	BMS	53.12	63.3	72.8
Y Sct	10.341650	MB	BMS	83.52	62.4	71.5
EV Sct	3.091047	MB	BBMD		30.9	36.6
U Sgr	6.745363	BBB	BBMD	60.03	34.5	
W Sgr	7.594935	MB	BBMD	63.28	53.0	58.6
X Sgr	7.012630	MB	BMS	49.77	56.5	58.6
Y Sgr	5.773400	MB	BMS	50.04	60.7	61.4
BB Sgr	6.637117	MB	MB	42.12	50.0	53.5
AP Sgr	5.057936	MB	BMS	44.02	42.6	50.0
YZ Sgr	9.553606	MB	MB		84.2	136.0
V350 Sgr	5.154557	MB	BMS	47.80	41.8	46.0
EU Tau	2.102182	BBB	BBMD		20.6	
ST Tau	4.034299	MB	BMS+BBMD	41.41	46.6	47.1
SZ Tau	3.149138	MB	BBMD	37.83	41.8	44.8
T Vul	4.435453	MB	BBMD	38.24	48.8	48.8
U vul	7.990821	MB	BBMD	56.54	57.9	61.1
X vul	6.31949	MB	BBMD	46.24	61.5	68.4
SV Vul	45.00061	BBB	BBMD	202.15	189.5	

Table 3. Comparison of coefficients of Period-Radius relation ($\log R = a \log P + b$) between this paper and selected other works available in literature.

Method	a	b	Source
Theory	0.692 ± 0.006	1.179 ± 0.006	Fernie (1984)
Theory	0.70	1.17	Cogan (1978)
Theory	0.72	1.07	Karp (1975)
Surf. Bright.	0.743 ± 0.023	1.108 ± 0.023	Gieren et al. (1989)
Surf. Bright.	0.751 ± 0.026	1.070 ± 0.008	Laney & Stobie (1995)
LMC cepheids	0.716 ± 0.010	1.139 ± 0.009	Di Benedetto (1994)
CORS (VBLUW) withoutΔB	0.654 ± 0.052	1.177 ± 0.058	Caccin et al. (1981)
CORS (VBLUW) with ΔB	0.700 ± 0.020	1.167 ± 0.024	Sollazzo et al. (1981)
CORS without ΔB	0.622 ± 0.029	1.226 ± 0.026	This paper
CORS with ΔB	0.606 ± 0.037	1.263 ± 0.033	This paper

as found also with the correct ΔB (see Sollazzo et al. 1981). The fact that we always use three bands (B,V,R in this paper) should also give more consistency to the results.

We have actually to warn the reader that, as stated in the introduction, the method illustrated here represents a step backward with respect to the original CORS method, in the sense that the usage of Eq. (4) is a simplification which avoids using the proper photometric calibration, but also gives lower intrinsic precision to the derived radius. In other words, whenever possible the complete CORS method, with the full ΔB term, should be used, because the method presented here gives a first order approximation to ΔB, which is better than neglecting ΔB, but worst than the second order approximation of the CORS method, i.e. the determination of ΔB by mean of theoretical model atmosphere. The advantage is the very quick computation, namely a couple of minutes at the terminal for each star.

Further work is needed to improve the approximation, but the basis of the method seems now well laid. A possible idea, which we will work on, is in computing ΔB as a sum of two terms, one based on the observations (like in the present paper) and one based on theoretical computations from Kurucz's models (like the original CORS method did, but only for a particular photometric system). We are also working on a method to compute statistically meaningful errors on the radii, based on the quality of the observations, rather than on the purely numerical errors of the fitting procedure.

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