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A NEW APPROACH TO THE SURFACE BRIGHTNESS METHOD FOR CEPHEID RADII DETERMINATION [1]

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RESUMEN

Se han obtenido datos fotométricos en el sistema de Strömgren *uvby*-β, para un grupo de 127 Cefeidas. Actualmente poseemos curvas de luz y color para 72 estrellas. Hemos obtenido una calibración del parámetro de brillo superficial F_ν en términos del color $(b - y)_0$. Esto abre la posibilidad de calcular radios de Cefeidas a partir de la fotometría de banda intermedia. El problema de la no simultaneidad de las observaciones fotométricas y de las velocidades radiales puede resolverse aplicando corrimientos adecuados en las curvas de luz, color y velocidad radial. Las distancias de las Cefeidas han sido adoptadas según las predicciones de la relación P-L, lo cual deja al radio como único parámetro libre en el método. Reportamos radios para 54 Cefeidas y discutimos la relación Período-Radio.

ABSTRACT

Photometric data in the *uvby*-β Strömgren system have been obtained for a sample of 127 Cepheids. Presently, light and color curves for 72 Cepheids are available. A calibration of the surface brightness parameter F_ν has been obtained in terms of the intrinsic color $(b - y)_0$. This opens the possibility of calculating Cepheid radii from intermediate band photometry. The non-simultaneity of photometric and radial velocity data can be overcome by properly shifting the light, color and radial velocity curves. Cepheid distances are adopted from P-L predictions which leave the radius as the only free parameter. Radii are reported for 54 Cepheids and the implied Period-Radius relation is discussed.

Key words: **CEPHEIDS — STARS: FUNDAMENTAL PARAMETERS**

1. INTRODUCTION

The relation between the visual surface brightness parameter F_ν and the stellar photometric color (VSBR) has been amply discussed by Barnes, Evans, & Moffett (1978). The $(V - R)_0$ color has been preferred over $(B - V)_0$ since it produces a linear relationship over a larger color range and it is independent of the stellar luminosity. An immediate application of the VSBR is the calculation of radii and distances of variable stars. The most recent results for Cepheids have been published by Moffett & Barnes (1987) and Gieren et al. (1989).

Since the *uvby* Strömgren photometric system is of the intermediate band type and hence more precise than the *UBVR* Johnson system, some improvement may be expected when the VSBR is calibrated in terms of the $(b-y)$ color, despite not having the advantages of a redder color such as $(V - R)$. A program of $uvby - \beta$ photometry for a sample of galactic Cepheids is currently in progress. Good light and color curves are already available for about 60% of the sample. The use of these data to determine Cepheid radii is discussed in this paper. In the following sections we present the $F_\nu - (b-y)_0$ calibration and describe our approach towards the Cepheid radii determination. The Period-Radius relationship implied by our radii is also presented.

[1] This work is based on observations obtained at San Pedro Mártir Observatory and has been supported by CONACYT projects F-113 and 1219E9203.

2. OBSERVATIONS

The *uvby*-β observations have been carried out with a six-channel spectrophotometer on the 1.5-m telescope .t San Pedro Mártir Observatory, Mexico. We selected 127 Cepheid stars with UBV data in the literature and vhich were observable from our site. There are radial velocities for 89 of these stars in Barnes et al. (1987; 988) and Wilson et al. (1989). We have secured data for 72 Cepheids with periods between 2 and 40 days, adial velocity curves are available for 54 of them. These 54 stars are the sample studied in this paper.

3. THE METHOD

The surface brightness parameter F_ν defined as

$$F_\nu = log\ T_{eff} + 0.1\ BC \quad , \tag{1}$$

s correlated with the stellar magnitude V_0 and the stellar angular diameter ϕ' in milliarc seconds, by the quation

$$F_\nu = 4.2207 - 0.1V_0 - 0.5 \log\ \phi' \quad , \tag{2}$$

F_ν can also be obtained from the Johnson color $(V-R)_0$ from an empirical relation of the form (Barnes et al. 978)

$$F_\nu = a + b(V-R)_0, \tag{3}$$

Equation (3) was calibrated by Barnes et al. (1978) using 86 stars with measured angular diameters. To write quation (3) in terms of the Strömgren color $(b-y)_0$, we found values of $(b-y)$ color for 33 of those 86 calibrators 1 the literature. We adopted the color excesses from Barnes et al. (1978). Figure 1 shows the calibration for he two color indices where two domains are clearly seen. For $0. < (b-y)_0 < 1.0$ the calibration can be written s

$$\begin{array}{rcl} F_\nu & = & 3.961 - 0.541(b-y)_0 \\ & \pm & .007 \pm\ .017. \end{array} \tag{4}$$

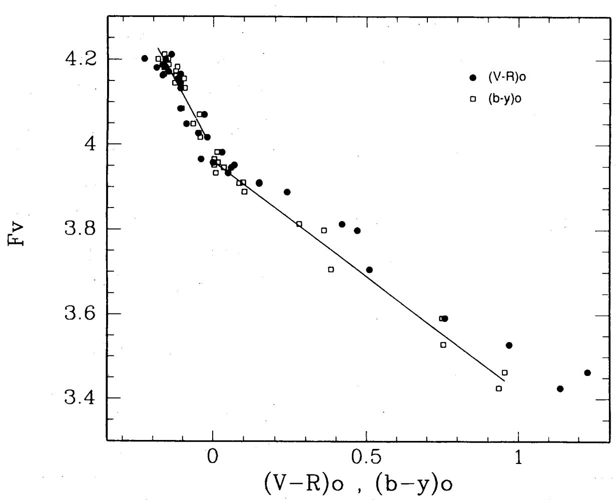

Fig. 1. The calibration of F_ν for the colors $(b-y)_o$ and $(V-R)_o$.

From geometrical arguments, the angular diameter in milliarc seconds, ϕ', and the stellar surface linear isplacement, ΔR, can be correlated by

$$\phi' = \frac{2\bar{R}}{10^{-3}r} + \frac{2}{10^{-3}r}\Delta R \tag{5}$$

where $\bar{R}$ and r are the mean stellar radius in solar radii and the distance in parsecs, respectively. The values o ΔR are obtained from the integration of the radial velocity curve. We have adopted a projection factor $p = 1.3$ (Parsons 1972). The dispersion in the ΔR-ϕ' plane is sensitive to the relative phase between light, color anc radial velocity curves and then to the fact that photometry and radial velocities are generally not obtainec simultaneously. To minimize this effect we have drifted the radial velocity curves until the dispersion in th above plane is minimum. The slope of equation (5) determines the stellar distance r and then the mean radius $\bar{R}$ is found from the zero point. We have however adopted the distance from the cepheid P-L relationship, leavin $\bar{R}$ as the only free parameter in equation (5). Our determinations of the radii are listed in Table 1 togethe with values from Baade-Wesselink methods obtained by various other authors. The average mean uncertaint of our radii is 15%. Agreement within the uncertainties is found with the recent results of Moffet & Barne (1987) and Gieren et al. (1989).

Table 1. Cepheids Radii.

Name	Log P	n	$R/R_\odot$ (1)	(2)	(3)	(4)	(5)	Name	Log P	n	$R/R_\odot$ (1)	(2)	(3)	(4)	(5
U Aql	0.8465	13	53.1	—	—	54.6	52.4	Z Lac	1.0368	5	77.0	—	—	68.8	66.4
TT Aql	1.1384	20	103.8	72	—	95.8	94.3	RR Lac	0.8072	5	48.0	—	—	45.6	43.7
FF Aql	0.6503	24	36.1	—	—	—	—	T Mon	1.4317	11	146.8	144	—	172.4	179.
FM Aql	0.7863	20	52.3	—	—	53.8	51.6	SV Mon	1.1827	10	115.4	—	—	99.6	97.3
V496 Aql	0.8329	19	59.0	—	34.4	45.5	43.7	CV Mon	0.7306	7	46.5	—	—	—	—
η Aql	0.8559	7	58.1	69	—	54.9	52.8	Y Oph	1.2336	27	98.3	79	—	71.8	—
RT Aur	0.5715	11	34.0	28	—	35.1	35.7	BF Oph	0.6093	25	40.3	—	35.6	35.8	33.8
RY CMa	0.6700	8	42.2	—	—	43.1	41.2	GQ Ori	0.9353	9	65.3	—	—	72.4	69.7
RZ CMa	0.6288	8	32.6	—	—	—	—	AU Peg	0.3804	4	30.0	—	—	—	—
TW CMa	0.8448	8	50.6	—	—	57.3	55.0	X Pup	1.4143	8	118.5	—	—	118.0	114.
δ Cep	0.7296	5	45.2	57	—	41.6	39.8	WX Pup	0.9512	8	56.8	—	—	76.5	73.7
X Cyg	1.2144	6	156.1	99	—	118.1	114.3	Y Sct	1.0145	21	84.3	—	—	83.5	80.4
SU Cyg	0.5849	17	31.6	—	—	—	—	SS Sct	0.5648	20	36.0	—	29.2	29.4	27.7
SZ Cyg	1.1792	5	164.7	—	—	117.6	113.7	S Sge	0.9233	7	69.6	60	—	—	—
VZ Cyg	0.6870	5	43.6	—	—	37.1	35.6	U Sgr	0.8290	25	55.6	—	53.8	57.3	57.
CD Cyg	1.2323	5	97.0	—	—	102.3	99.1	W Sgr	0.8805	23	50.8	—	—	63.2	60.8
DT Cyg	0.3977	7	25.9	—	—	—	—	X Sgr	0.8458	25	44.1	—	—	49.7	47.8
V386 Cyg	0.7207	6	55.8	—	—	41.9	40.1	Y Sgr	0.7614	24	48.3	—	—	50.0	48.
V532 Cyg	0.5163	5	32.0	—	—	—	—	YZ Sgr	0.9801	22	69.4	—	—	—	—
W Gem	0.8984	10	58.8	60-69	—	50.7	48.7	AP Sgr	0.7039	24	46.1	—	43.2	44.0	—
RZ Gem	0.7426	8	38.2	—	—	52.5	50.2	BB Sgr	0.8219	18	54.1	—	45.7	44.2	40.4
ζ Gem	1.0064	10	79.7	68	—	64.9	62.5	V350 Sgr	0.7121	19	42.8	—	43.3	47.9	49.5
TX Del	0.7900	7	59.7	—	—	43.8	42.1	AL Vir	1.0129	27	52.9	—	—	—	—
BL Her	0.1164	35	14.7	—	—	—	—	T Vul	0.6469	6	40.5	52	—	38.2	36.5
V Lac	0.6975	5	40.9	—	—	43.0	41.2	U Vul	0.9025	18	60.0	60	—	56.5	—
X Lac	0.7359	5	44.6	—	—	64.7	62.0	X Vul	0.8006	7	52.7	—	—	46.2	44.3
Y Lac	0.6358	5	35.7	—	—	50.2	48.0	SV Vul	1.6532	15	218.0	—	—	202.1	197.

(1) This work; (2) Evans (1976); (3) Gieren (1984); (4) Gieren et al. (1989); (5) Moffett & Barnes (1987).

4. THE PERIOD–RADIUS RELATION

The Period-Radius relation (P-R) derived from our radii in Table 1 is shown in Figure 2. The straight lin has the equation

$$\begin{aligned} log\ R &= 1.125 + 0.744 \log\ P \\ &\pm\ \ .030 \pm\ .030\ . \end{aligned} \qquad (6)$$

The slope of the P-R relation has been found to differ depending on the method used to calculate the radii see, for instance, Table 2 of Moffett & Barnes 1987). The slope of equation (6) is comparable both in value nd accuracy to others determined from surface brightness techniques. The agreement is particularly good with hose determined most recently from large samples, e.g., Moffett & Barnes (1987) and Gieren et al. (1989). Equation (6) is remarkably similar to the latest P-R relation derived by Fernie (1992) for Cepheids and δ Scuti tars. Our results are therefore very satisfactory, despite the fact that, as our *uvby-β* observations continue, ome radii have been determined from only partially covered light and color curves.

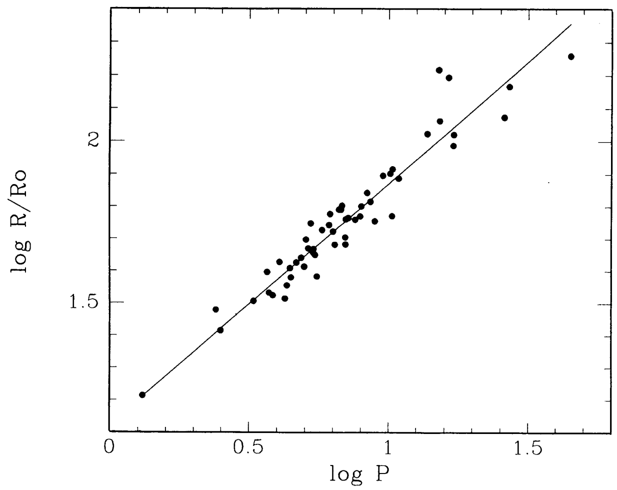

Fig. 2. The Cepheid Period-Radius relation from our radii in Table 1.

5. SUMMARY OF RESULTS

1. A homogeneous data bank of *uvby-β* photometry for galactic Cepheids is under construction.

2. The visual surface brightness equation has been calibrated in terms of an intermediate band photometry olor, the Strömgren $(b-y)_0$.

3. Such calibration, proper shifts in the radial velocity curves and adoption of the Cepheid distance from -L estimates, allowed the calculation of Cepheid radii which are comparable to the previous determinations. As he coverage of light and color curves improves and better radial velocities become available, lower uncertainties n the radii shall be attained.

4. An independent P-R relation has been presented that is in good agreement with the latest derived from urface brightness methods for radius determination.

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DISCUSSION

Robledo-Rella: Are period variations present in these Cepheids and how would they affect your results?

Arellano Ferro: Period variations are present and they are measurable in a number of Cepheids however the are too small to show their effect in non-simultaneous photometry and radial velocities separated a few years

Turner: a) Nancy Evans pointed out many years ago the problem of variable microturbulence during Cephe cycles on continuum colors, which are not tied solely to effective temperature changes. I worry that Strömgre system colors may also be susceptible to this problem. b) The various versions of the Baade-Wesselink metho in use (including the Surface Brightness technique) all give radii in close agreement with one another. I fir that a bit surprising.

Arellano Ferro: a) Using spectroscopically determined values of the microturbulence, I have checked tl dependence of Strömgren colors on the microturbulence velocity for a large number of F-G supergiants, I four no correlation. b) I find it encouraging. There are indeed some old calibrations of the surface brightne parameter in terms of $B-V$ which produce radii about 50% too small.

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