A slope variation in the period-luminosity relation for short period SMC Cepheids[*]

The EROS collaboration

F. Bauer[1,2], **C. Afonso**[2], **J.N. Albert**[3], **C. Alard**[4], **J. Andersen**[5], **R. Ansari**[3], **É. Aubourg**[2], **P. Bareyre**[1,2], **J.P. Beaulieu**[4,12], **A. Bouquet**[1], **S. Char**[6,†], **X. Charlot**[2], **F. Couchot**[3], **C. Coutures**[2], **F. Derue**[3], **R. Ferlet**[4], **C. Gaucherel**[2], **J.F. Glicenstein**[2], **B. Goldman**[2,7,8], **A. Gould**[9,**], **D. Graff**[2,10], **M. Gros**[2], **J. Haissinski**[3], **J.C. Hamilton**[1], **D. Hardin**[2], **J. de Kat**[2], **A. Kim**[1], **T. Lasserre**[2], **É. Lesquoy**[2], **C. Loup**[4], **C. Magneville**[2], **B. Mansoux**[3], **J.B. Marquette**[4], **É. Maurice**[11], **A. Milsztajn**[2], **M. Moniez**[3], **N. Palanque-Delabrouille**[2], **O. Perdereau**[3], **L. Prévot**[11], **C. Renault**[2], **N. Regnault**[3], **J. Rich**[2], **M. Spiro**[2], **A. Vidal-Madjar**[4], **L. Vigroux**[2], and **S. Zylberajch**[2]

[1] Collège de France, PCC, IN2P3 CNRS, 11 place Marcelin Berthelot, F-75231 Paris Cedex, France
[2] CEA, DSM, DAPNIA, Centre d'Études de Saclay, F-91191 Gif-sur-Yvette, Cedex, France
[3] Laboratoire de l'Accélérateur Linéaire, IN2P3 CNRS et Université Paris-Sud, B.P. 34, F-91898 Orsay Cedex, France
[4] Institut d'Astrophysique de Paris, INSU CNRS, 98 bis Boulevard Arago, F-75014 Paris, France
[5] Astronomical Observatory, Copenhagen University, Juliane Maries Vej 30, DK-2100 Copenhagen, Denmark
[6] Universidad de la Serena, Facultad de Ciencias, Departamento de Fisica, Casilla 554, La Serena, Chile
[7] Department Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile
[8] European Southern Observatory, Casilla 19001, Santiago 19, Chile
[9] Department of Astronomy, Ohio State University, Columbus, OH 43210, USA
[10] Physics Department, Ohio State University, Columbus, OH 43210, USA
[11] Observatoire de Marseille, 2 place Le Verrier, F-13248 Marseille Cedex 04, France
[12] Kapteyn Laboratorium, Postbus 800, 9700 AD Groningen, The Netherlands

Abstract. We present the Period–Luminosity relations from 290 Cepheids towards the LMC and 590 Cepheids towards the SMC. The two data sets were obtained using the two wide field CCD cameras of the EROS 2 microlensing survey. We observe a significant slope change of the period–luminosity relation for the SMC fundamental mode Cepheids with periods shorter than 2 days. Many possible experimental biases have been investigated, but none can account for this effect. We also observe different spatial distributions for SMC Cepheids with different ages i.e. periods. Different possible explanations of the slope change are discussed.

Key words: surveys – stars: variables: Cepheids – galaxies: Magellanic Clouds

1. Introduction

The Cepheid period–luminosity (PL) relation has been one of the cornerstones of distance determination since the beginning of this century. Most of the recent determination of the Hubble constant H_0 are based on HST observations of Cepheids as far away as the Virgo and Fornax clusters (Ferrarese et al. 1996; Sandage et al. 1994; Tanvir et al. 1995), an assumed universal PL relation calibrated in the LMC, and the so-called Madore & Freedman (1991) method. At the same time, modern evolutionary and pulsation calculations are under way to obtain a theoretical calibration of the Cepheid PL relation (Baraffe et al. 1998; Wood 1998; Alibert et al. 1999; Bono et al. 1999; Chiosi et al. 1993; Yecko et al. 1998; Buchler et al. 1996).

The number of available Cepheids towards the Magellanic Clouds has been dramatically increased by the different microlensing surveys (e.g. Beaulieu & Sasselov 1996; Welch et al. 1996; Beaulieu et al. 1997a). With the commissionning of the new EROS survey equipment (EROS 2, Bauer et al. 1997), a new systematic search for Cepheid variables in the LMC and SMC was undertaken in October 1996. In this article, we present the first result from this search, a so far unreported slope change of the PL relation for fundamental mode SMC Cepheids at short periods.

We describe the observational setup and data reduction in Sect. 2. In Sect. 3 we present the PL relations of fundamental mode (hereafter F) and first overtone (hereafter 1-OT) Cepheids towards both Magellanic Clouds. The PL relation of F Cepheids towards the SMC displays a visible non–linearity for periods shorter than about 2 days, and we establish the statistical significance of this effect. We then discuss different possible observational biases. In Sect. 4 we study the spatial distribution and in

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Table 1. Coordinates (J2000) of the field centres.

field	LMC1	LMC2	SMC1	SMC2
α	5 23 34	5 15 36	0 51 54	0 41 54
δ	-69 44 22	-69 44 22	-73 36 32	-73 42 32

Sect. 5 we present the depth dispersion of our SMC Cepheids. In Sect. 6 we develop possible scenarios that could explain the effect, before summarizing in Sect. 7.

2. Observations and data reduction

We give here only a brief overview as more details will be available in the EROS 2 Cepheid catalog (Bauer et al. 1999). Observations were obtained using the new EROS 2 experimental setup, which consists of a 1 m Ritchey–Chretien telescope and two 4k × 8k CCD mosaic cameras, allowing simultaneous imaging in two focal planes with different colour passbands (420–650 nm, so called EROS-2 V_{EROS} passband; and 650–900 nm, so called EROS-2 R_{EROS} passband)[1]. Each CCD mosaic is made up of eight 2k × 2k three edge buttable thick CCDs developed by Loral/U.Arizona. The pixel size is 0.6 arcsec (15 μm). The available global field of view is 0.7° (right ascension) × 1.4° (declination). The whole system was mounted at the La Silla Observatory in Chile in June 1996; details can be found in Bauer (1997) and Bauer et al. (1997).

Between October 1996 and February 1997, a dedicated Cepheid campaign was undertaken. Two fields per Magellanic Cloud (see Table 1) were monitored about once per night with an exposure time of 20 seconds. Whenever possible, the four fields were imaged almost simultaneously at the same airmass. A total of ∼110–160 images was obtained for each field. After photometric reduction using the standard EROS 2 photometry package (Peida++, Ansari 1996), we obtained 1,134,000 and 504,000 light curves of stars towards the LMC and SMC, respectively. The relative inter–CCD calibration of these light curves has an accuracy of 0.04 mag.

In the following presentation we used only 2 × 6 out of 2 × 8 CCDs per field. One red CCD ceased to function in June 1996; Cepheid detection would still be possible on the blue counterpart CCD, but no color would be available. Another red CCD had a variable offset in time, so that a dedicated treatment would be necessary in order to get proper magnitudes for the detected Cepheids. This will be done in the future. As our main goal was to get a clean set of Cepheid data we concentrated our efforts on the remaining 2 × 6 CCDs.

A systematic search for periodic variable stars was then performed (for $P > 0.5$ day), using an algorithm proposed by Scargle (1982). We fitted a 5th-order Fourier series to the light curves; in the following, the reported magnitudes are intensity–weighted mean magnitudes[2] from this Fourier

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[1] We stress that these filters are different from those of the EROS 1 programme (see e.g. Sasselov et al. (1997), Grison et al. (1995)).

[2] The magnitude that corresponds to the average luminosity, as opposed to the average magnitude.
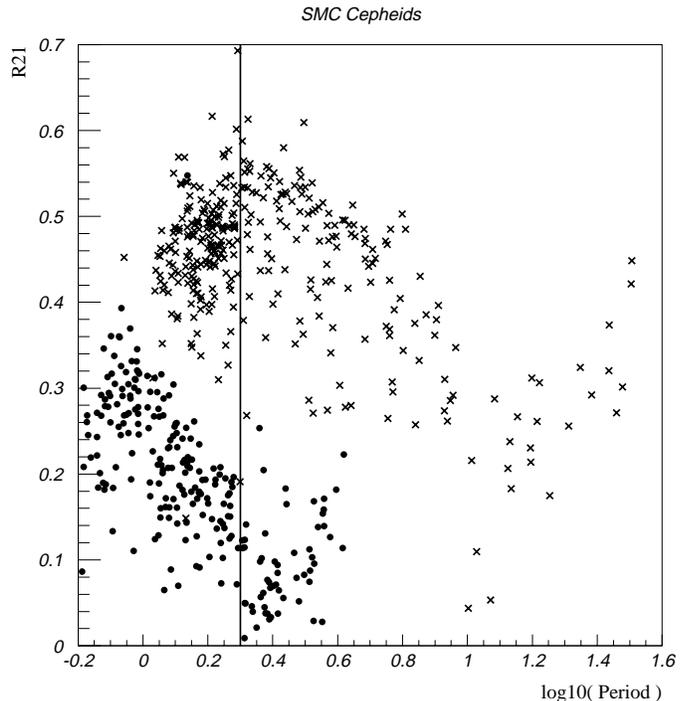
Fig. 1. The $R_{21} - \log P$ diagram for SMC F Cepheids (crosses) and 1-OT Cepheids (black dots). The vertical line indicates the slope change of the PL-relation at 2 days for F Cepheids.

analysis. Cepheid candidates were extracted using loose selection criteria in both the Colour–Magnitude (CM) and PL diagrams, excluding population II Cepheids. These cuts selected about 0.1% of the stars, that were all inspected visually to reject non–Cepheid variables (about one third of the scanned sample). Within this final Cepheid sample, Fourier coefficients allow to distinguish F Cepheids from 1-OT Cepheids, as was done in Beaulieu et al. (1995) following the suggestion of Antonello et al. (1986): 1-OT Cepheids have a lower content of second and third harmonics than F Cepheids. Fig. 1 illustrates how this separation can be done, using the amount of second harmonic, R_{21}, as a function of the pulsation period. A second visual inspection of Cepheid light curves was then performed for the few stars that lie in-between the F and 1-OT Cepheid samples.

As a result we obtained a new EROS 2 Cepheid catalog, that will be published in a forthcoming paper (Bauer et al. 1999), comprised of 590 Cepheids towards the SMC (351 F and 239 1-OT Cepheids) and 290 Cepheids towards the LMC (177 F and 113 1-OT Cepheids).

3. Data analysis

3.1. Phenomenology

The PL relations for the F and 1-OT Cepheids are shown in Fig. 2. For LMC Cepheids, and SMC 1-OT Cepheids as well, the relations are compatible with a linear behaviour. In contrast, that of the SMC F Cepheids displays a change in the slope for periods smaller than 2 days, visible in both colours. The magnitude
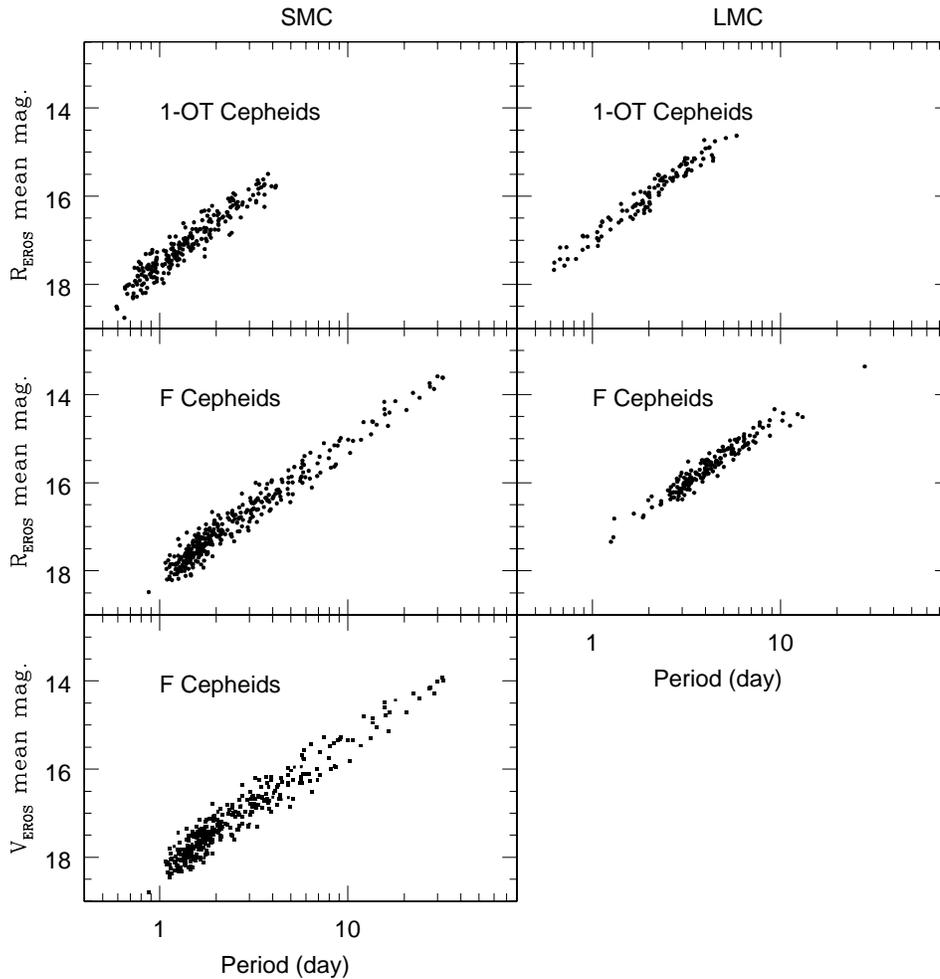
Fig. 2. PL relations for first overtone Cepheids (*top*) and fundamental mode Cepheids (*center*) towards the SMC (*left*) and the LMC (*right*) seen in R_{EROS}. The figure at bottom left shows the PL relation for SMC F Cepheids seen in V_{EROS}. The five panels are drawn to the same scale to facilitate comparison.

deviation for these short–period Cepheids, with respect to an extrapolation of the PL relation for longer period Cepheids, reaches 0.2 mag at $P = 1$ day. Hence, a simple linear fit to the full SMC F Cepheid sample would result in a biased slope and thus an incorrect estimate of the distance to the SMC.

3.2. Statistical significance of the effect

In order to quantify the significance of the non–linearity in Fig. 2, we fit the PL relations in two different ways: (1) using a linear regression for the full data; (2) using two straight lines that cross at a "break–period" P_{break},

$$m(P) = \alpha_{break} - \beta_i \, \log(P/P_{break}) \qquad (1)$$

where i is an index for $P < P_{break}$ (resp. $P > P_{break}$). We find the break–period to be 2.0 days for F Cepheids and tentatively use 1.4 day for 1-OT Cepheids from the known ratio of F and 1-OT Cepheid periods (see e.g. Alcock et al. 1995, Welch et al. 1996, Beaulieu et al. 1997b). The results from the fits are not sensitive to the removal of Cepheids that lie close to the limit we defined to distinguish between F and 1-OT Cepheids.

As the PL relation scatter is mainly due to the width of the instability strip, differential reddening effects and depth disper-

sion, one cannot use the measurement errors as errors in the fits. Instead, the errors used for the fits are, for each Cepheid, the dispersion σ_{res} from the standard linear regression (1). Our data is compatible with a constant dispersion whatever the Cepheid period, therefore we used an identical weight of $1/\sigma_{res}^2$ for all Cepheids in a given sample. The parameters from the fits are given in Table 2. Two results have to be pointed out: first, the slope of the SMC F Cepheids long–period sample from the fit of method (2) is closer to that of the LMC F Cepheid sample; second, the SMC F Cepheids with $P < 2$ days follow a PL relation with a much steeper slope.

We estimate the actual significance of the effect using the χ^2 gain between fits (1) and (2). For the SMC F Cepheids we calculate a significance of 2.9 σ in the R_{EROS} passband and 3.1 σ in the V_{EROS} passband, corresponding to a false detection probability of 0.2%. Thus, the slope change is statistically significant for SMC F Cepheids.

We have also searched for a similar slope change in the SMC 1-OT Cepheids, but find no significant effect (0.9 σ in R_{EROS} and 1.3 σ in V_{EROS}). There is a caveat: due to the smaller statistics and lever arm in $\log(P)$, we expect less sensitivity to any possible slope change in this sample.

Table 2. Parameters of the PL relation fits described in the text. N is the number of stars in the sample, σ_{res} the dispersion of the fit residuals, β the slope of the PL relation and α its offset at $P = 1$ day; in method 2 α is obtained as $\alpha_{break} + \beta_i \log(P_{break})$. We caution the reader that the offsets α are given in the EROS 2 filter system, which is not standard.

Population	Cloud	Method	N	V_{EROS}			R_{EROS}		
				α	β	σ_{res}	α	β	σ_{res}
F Cepheids	LMC	1: all	177	17.63 ± 0.04	2.77 ± 0.07	0.18	17.44 ± 0.04	2.89 ± 0.06	0.15
		2: P > 2 d	170	17.60 ± 0.05	2.72 ± 0.08	0.17	17.43 ± 0.04	2.89 ± 0.06	0.14
		2: P < 2 d	7	17.86 ± 0.16	3.59 ± 0.54	0.18	17.46 ± 0.13	2.99 ± 0.45	0.17
	SMC	1: all	351	18.29 ± 0.02	2.91 ± 0.04	0.24	18.12 ± 0.02	3.04 ± 0.03	0.20
		2: P > 2 d	164	18.20 ± 0.04	2.80 ± 0.05	0.25	18.05 ± 0.03	2.95 ± 0.05	0.20
		2: P < 2 d	187	18.40 ± 0.04	3.48 ± 0.19	0.22	18.21 ± 0.04	3.49 ± 0.16	0.20
1-OT Cepheids	LMC	1: all	113	17.11 ± 0.03	3.12 ± 0.08	0.18	16.93 ± 0.03	3.18 ± 0.07	0.16
		2: P > 1.4 d	87	17.13 ± 0.05	3.15 ± 0.12	0.19	16.96 ± 0.04	3.23 ± 0.11	0.16
		2: P < 1.4 d	26	17.11 ± 0.03	3.03 ± 0.23	0.16	16.93 ± 0.03	3.07 ± 0.20	0.16
	SMC	1: all	239	17.70 ± 0.02	3.07 ± 0.08	0.25	17.55 ± 0.02	3.21 ± 0.08	0.21
		2: P > 1.4 d	103	17.64 ± 0.05	2.90 ± 0.15	0.24	17.51 ± 0.04	3.07 ± 0.13	0.21
		2: P < 1.4 d	136	17.70 ± 0.02	3.27 ± 0.18	0.25	17.55 ± 0.02	3.37 ± 0.16	0.22
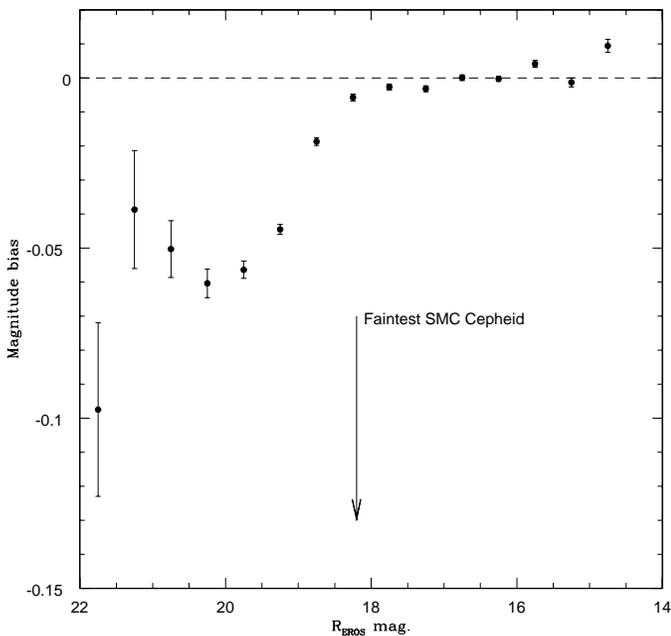
Fig. 3. Comparison of the stellar flux for images from the current study ($T_{exp} = 20$ s) with the stellar flux measured from images of the same field from the microlensing search (Palanque–Delabrouille et al. 1998; $T_{exp} = 300$ s). Stars with a mean magnitude brighter than 14.5 are omitted as they are saturated on the long exposure images.

3.3. Study of systematic biases

Several tests or checks were carried out to determine whether this slope change is due to a systematic bias or not:

1. We exclude that uncertainties on the period lead to a bias: where possible, comparison with existing catalogs (20 Cepheids) shows that the determined period is accurate to better than 10^{-3} day for a 2 days period.
2. For stars with fluxes comparable to the sky background our photometry is biased, such that the mean magnitudes could be underestimated. We have studied this by comparing the magnitudes of stars measured on images used for the present analysis, with those obtained on a high quality image (good seeing and longer exposure time) of the same field. Such images are available from our microlensing survey, and have a 15 times longer exposure (300 s). The result of this comparison is displayed in Fig. 3, which shows that stars at least as bright as the faintest SMC F Cepheid have a bias smaller than 0.02 mag, much lower than the observed deviation of 0.2 mag.
3. The non–linearity in the PL relation is visible for F Cepheids but not for 1-OT Cepheids of the same magnitude.
4. We changed various parameters of our photometry package (PSF shapes, window size of the PSF adjustment etc.) and were unable to reproduce the observed non-linearity. Thus the change in the slope is independent of our photometry package.

In addition, we looked directly in the SMC microlensing database of EROS 2 (Palanque–Delabrouille et al. 1998) for the non–linearity. This comparison was done for one CCD with a high density of Cepheids (102 F Cepheids and 57 1-OT Cepheids). The slope change is still visible. We also re-examined the PL relation for SMC F Cepheids in the EROS 1 catalog (Beaulieu & Sasselov 1996; see Fig. 4). The slope change is visible. In the EROS 1 analysis this phenomenon was ignored because of its marginal statistical significance. Note that the EROS 1 data set was obtained from measurements with another telescope, another CCD array, another photometry package and a different periodicity search program, so that observing the effect in both the EROS 1 and EROS 2 data sets seems a compelling argument against most biases.

These two data sets are the only published or available catalogs obtained from CCD observations that contain a significant number of short-period Cepheids ($P < 2$ days) towards the SMC. The only previously published catalog with sensitivity to short period SMC Cepheids (Payne–Gaposchkin & Gaposchkin 1961) was obtained using photographic plates; no slope change is visible in it. However
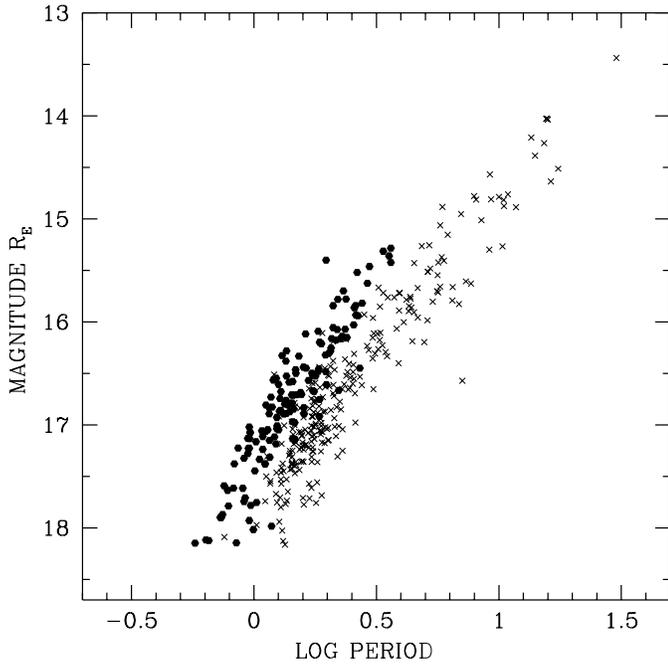
Fig. 4. The PL relations for F and 1-OT Cepheids seen in the EROS 1 database. The magnitudes are given in the EROS 1 filter system.

Table 3. Kolmogorov-Smirnov probabilities from the comparison of SMC Cepheids distributions along the Wesselink η coordinate. A small probability indicates different parent distributions. Similar tests along ξ yield probabilities always larger than 15%.

Populations		F P<2 d	F P>2 d	1-OT P<1.4 d	1-OT P>1.4 d
F	P<2 d	–	0.0005	0.9689	0.0003
F	P>2 d	0.0005	–	0.0049	0.5546
1-OT	P<1.4 d	0.9689	0.0049	–	0.0034
1-OT	P>1.4 d	0.0003	0.5546	0.0034	–

as none of the possible observational biases considered above is able to explain away the effect observed in our data, we consider the non–linearity established. We observe (Fig. 1) that this non–linearity occurs for periods similar to those where the $R_{21} - \log P$ diagram exhibits a maximum (R_{21} is the amplitude ratio between the second and first harmonic).

4. Spatial distribution

To further investigate the effect, we have compared the spatial distributions along the Wesselink η and ξ coordinates (Wesselink 1959) of SMC F Cepheids with $P < 2$ days and $P > 2$ days. Along the ξ coordinate, no significant difference is observed. Along the η coordinate, while SMC F Cepheids with $P < 2$ days are uniformly distributed in our field, those with $P > 2$ days are concentrated toward the center of the cloud (see Fig. 5). A comparison between SMC 1-OT Cepheids with $P < 1.4$ day and $P > 1.4$ day leads to a similar conclusion. These observations are quantified using a Kolmogorov-Smirnov test (see Table 3). From this table, it also appears that the distri-
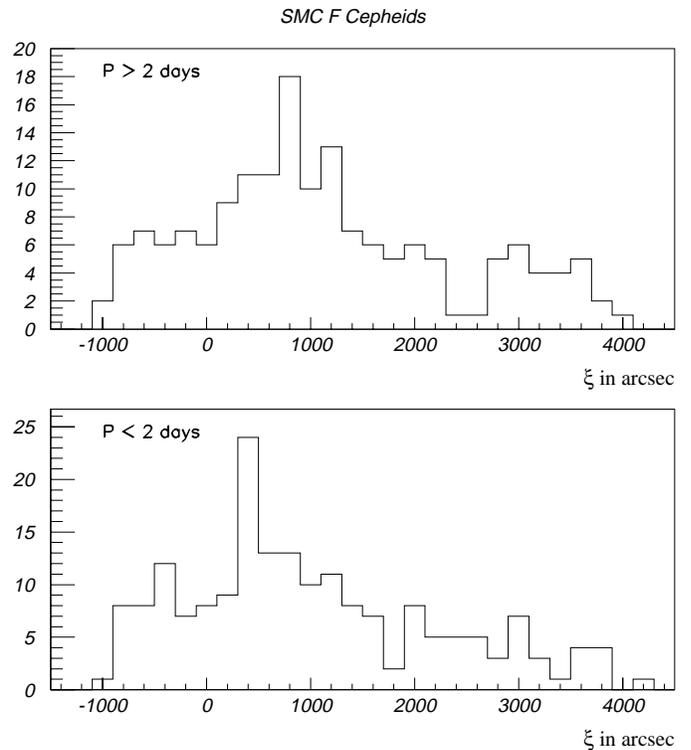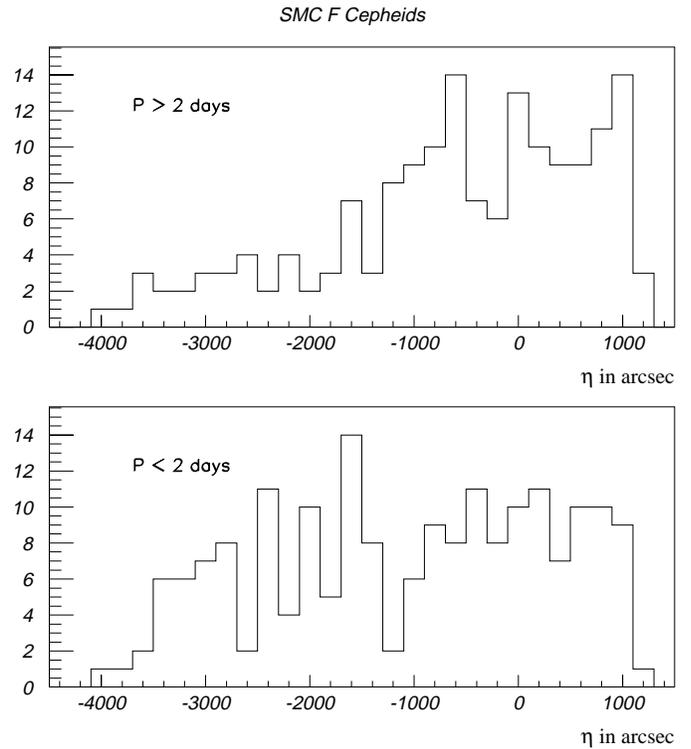
Fig. 5. The spatial distribution of SMC F Cepheids along the Wesselink η and ξ coordinates.

butions are similar for short period F and 1-OT Cepheids, and for long period F and 1-OT Cepheids as well. To summarize, the distribution along η of short period F and 1-OT Cepheids
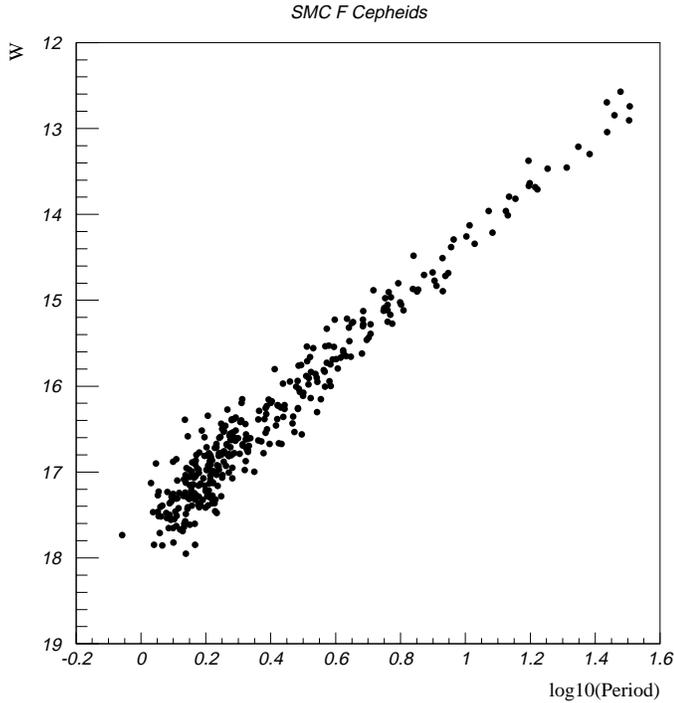
Fig. 6. The PL–relation as seen in W.

are incompatible with that of long period Cepheids at the 4.5 σ level at least.

In view of this, we have repeated the fits of Sect. 3 separately for $\eta < -1500$ and $\eta > -1500$ arcsec, to search for a possible spatial dependence of the slope change. This study is inconclusive however because of the much lower abundance of long–period Cepheids for $\eta < -1500$ arcsec (see top of Fig. 5).

5. Probing the depth dispersion

We have checked if the reported effect could be due to a distance effect, using the reddening free magnitude W, corresponding to:

$$W = V_{\mathrm{EROS}} - A * (V_{\mathrm{EROS}} - R_{\mathrm{EROS}}) \qquad (2)$$
$$A = R_{V_{\mathrm{EROS}}}/(R_{V_{\mathrm{EROS}}} - R_{R_{\mathrm{EROS}}}) = 3.44 \qquad (3)$$

The two factors $R_{V_{\mathrm{EROS}}}$ and $R_{R_{\mathrm{EROS}}}$ have been calculated using a convolution of the EROS transmission function with the extinction law given by Cardelli et al. (1989).

As observed by Graff et al. (1999), the reddening index A in Eq. (2) happens to be close to the color term γ in the Period-Luminosity-Color equation:

$$V_{\mathrm{EROS}} = \alpha + \beta \log(P) + \gamma(V_{\mathrm{EROS}} - R_{\mathrm{EROS}}) \qquad (4)$$

Subtracting Eq. (4) from Eq. (2) yields:

$$W \sim \alpha + \beta \log(P) \qquad (5)$$

Thus W is almost free from the effects of reddening and of color in the instability strip.

As shown in Fig. 7 a difference in spatial structure is visible for different intervals of W–residuals[3], that is probably a translation of the three dimensional structure of the SMC.

In Fig. 6 we show the PL relation for F Cepheids in the W band. The effect, though still visible, is not statistically significant. Note however that the photometric error of 0.04 mag for V_{EROS} and R_{EROS} translate into a 0.15 mag dispersion in W. Thus, given our photometric accuracy, we are unable to exclude a correlation between the observed non–linearity and depth dispersion using this approach.

6. Discussion

It is beyond the scope of the present paper to give a firm explanation of the reported effect. We discuss below four different hypotheses based on qualitative considerations, which ideally should explain:

– the observed non-linearity of the PL relation for SMC F Cepheids,
– the absence of non-linearity for SMC 1-OT Cepheids,
– the spatial distributions mentionned in Sect. 4.

They are:

– a superposition of two Cepheid populations of different ages at different distances;
– the mixing of two classes of variable stars;
– a non uniform filling of the instability strip;
– a thinning of the instability strip itself at short periods.

6.1. Superposition of two Cepheid populations

In the previous section we have seen that long and short period Cepheids are distributed differently along the η direction. If their distributions differ also along the line-of-sight, and if the short period Cepheids are in average more distant, the slope variation in the PL relation could be explained. For example a population of short period (older) Cepheids behind a population of long period (younger) Cepheids could indicate a star formation region in the foreground. In this case the population of short period Cepheids would be remnants of older star formation regions and thus exhibit a flatter spatial distribution along the η coordinate. On the other hand the absence of a non-linearity for 1-OT Cepheids, in spite of the fact that they have similar ξ and η distributions as F Cepheids, challenges this explanation. To further investigate this, we will soon extend the present study to a wider field. Confirmation of this scenario would provide a tool to study the recent history of star formation in the SMC.

6.2. Mixing of two classes of variable stars

This hypothesis involves the superposition of two stellar populations, classical Cepheids and the so-called anomalous Cepheids[4]. The latter have periods ranging between ≈ 0.5—2

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[3] Residuals of W with respect to a $W - \log(P)$ linear fit.
[4] Note that we have excluded W Virginis stars in the selection process.
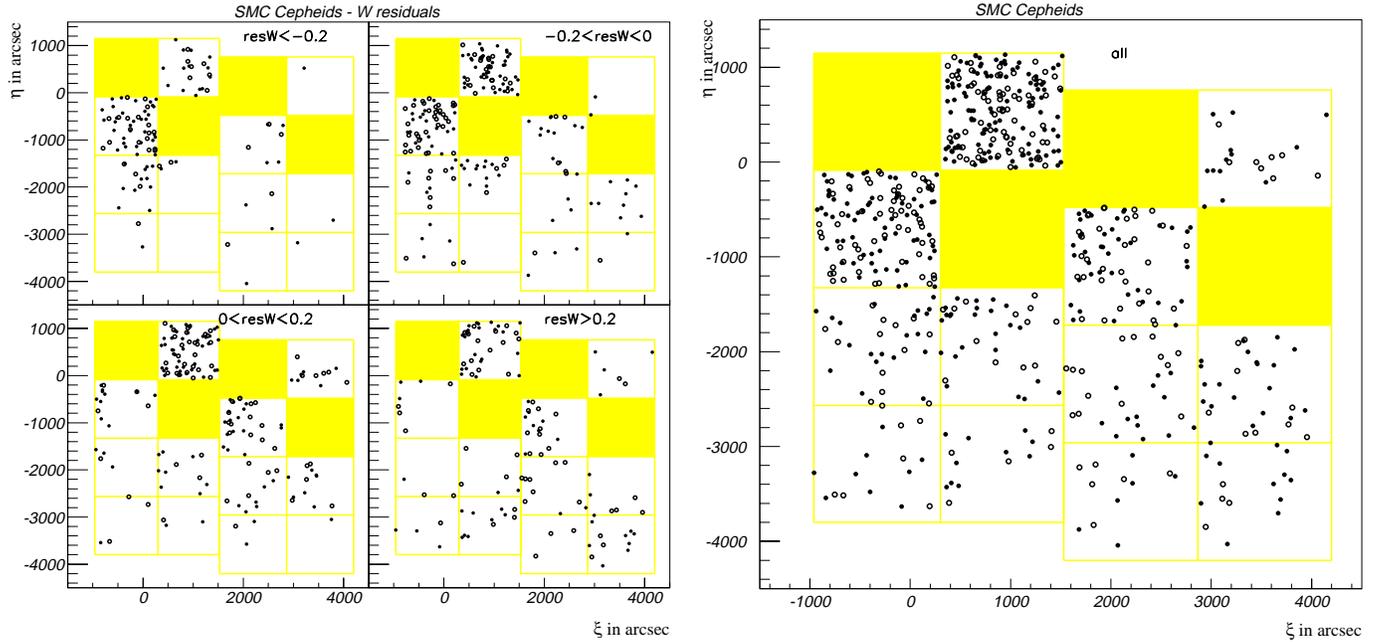
Fig. 7. The spatial distribution in Wesselink coordinates of the SMC F Cepheids (black dots) and 1-OT Cepheids (circles) for different bins of W–residuals. The two types of Cepheids follow almost the same spatial distribution. The two missing CCDs are indicated by shaded areas.

days and are seen in dwarf spheroidal galaxies. Their PL relation is known to be metallicity dependent (Nemec et al. 1994). For a typical SMC metallicity, anomalous Cepheids would be too faint for a superposition to occur. Using the PL relations of classical Cepheids (Madore & Freedman 1991) and anomalous Cepheids (Nemec et al. 1994), we estimate that a superposition requires values of [Fe/H] as low as -3.3 ± 0.6 for a 1 day period in the B passband, well below common SMC metallicities.

6.3. Stellar evolution;
a non uniform filling of the instability strip

As detailed in Madore & Freedman (1991), the PL relation is the projection of a narrow band in the period–luminosity–colour plane called the instability strip, where stellar envelopes become unstable and are subject to radial pulsations. During their evolution, stars in the mass range 2–8 M$_\odot$ will typically cross this zone three times. The first crossing occurs when stars evolve rapidly away from the main sequence. The two subsequent crossings occur when these stars start helium burning and evolve on horizontal evolution tracks (or blue loops). The extent of the blue loop is very sensitive to metallicity and will tell whether a star of given mass will cross the instability strip or not. It is also known that this loop becomes smaller with decreasing mass.

In this scenario (Fig. 8, scenario 3) the blue loop for stars with masses smaller than $\sim$3.6 M$_\odot$ (corresponding to $P \approx 2$ days SMC Cepheids) would stop before reaching the blue edge of the instability strip. The resulting observed non–linearity of the PL relation, below a given period, would be the consequence of this decreasing extent of blue loops at small masses. Following the observations reported here and in Bauer (1997), Baraffe

et al. (1998) have computed evolutionary models, coupled to a linear non-adiabatic stability analysis, in order to get consistent mass–period–luminosity relations. They report a change in the slope consistent with our observations.

On the other hand this hypothesis has to fulfil one important constraint: the instability strip for 1–OT Cepheids is in average bluer than that for F Cepheids; thus a depopulation of the 1–OT instability strip should also be visible, at about 0.7×2 days for SMC Cepheids. The absence of such a clear slope change for SMC 1–OT Cepheids challenges this explanation.

### 6.4. Pulsation theory; the shape of the instability strip

This hypothesis (Fig. 8, scenario 4) involves the physics of the pulsation itself and assumes that the blue edge of the instability strip becomes non–linear around $P = 2$ days for F Cepheids. In this admittedly speculative scenario, the absence of an effect for 1 OT Cepheids seems possible. The observed non-linearity could thus give a new and useful constraint for stellar pulsation theory describing short period (i.e. small mass) and low metallicity Cepheids.

6.5. LMC Cepheids

It is worth closing this discussion with remarks about LMC Cepheids in the light of the four scenarios discussed above.

Scenario 1 is specific to the SMC and has no implication for LMC Cepheids.

Regarding scenarios 2 and 3, in the interesting mass range (2—4 M$_\odot$), stellar evolution theory predicts smaller blue loops for the LMC than for the SMC because of the higher LMC

Scenario 3
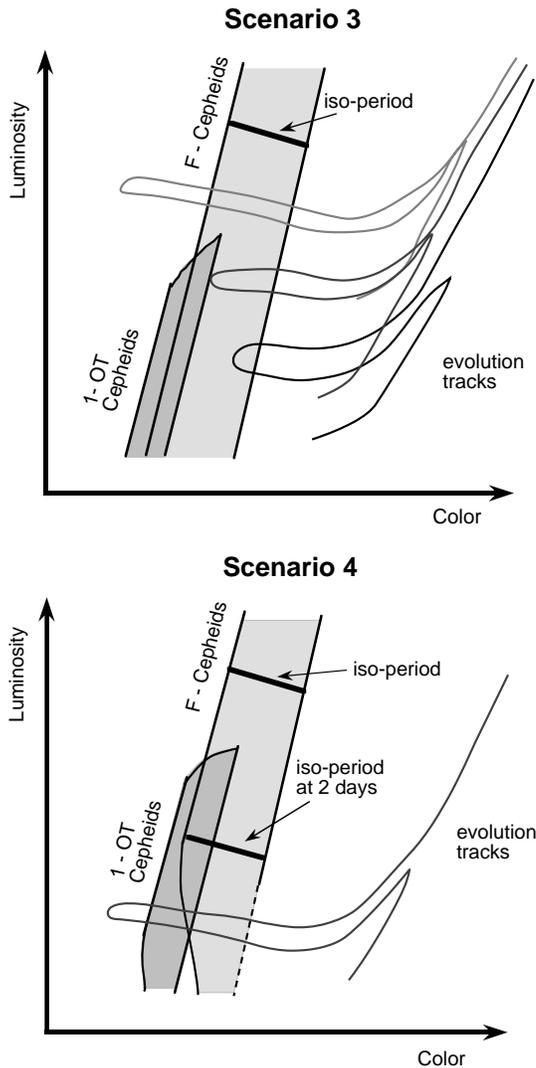
Scenario 4

Fig. 8. Two possible explanations of the reported phenomena. In the third scenario we are witnessing a gradual depopulation of the instability strip due to the fact that horizontal evolutionary tracks become smaller with decreasing mass or period. In the fourth scenario the blue edge of the instability strip could be non–linear.

metallicity. Thus a non uniform population of the instability strip (scenario 3) should also be visible in our LMC F Cepheid dataset, but for even longer period Cepheids. An indication for an abrupt end of the PL relation for LMC F Cepheids can be seen in Fig. 2 at 2.5 days; this has also been observed and modelled by the MACHO collaboration (Alcock et al. 1999), who explain the short period Cepheids as beeing anomalous Cepheids. In our sample the 12 LMC F Cepheids with $P < 2.5$ days and 37 LMC 1-OT Cepheids with $P < 1.7$ days, would belong to this anomalous Cepheid population.

In scenario 4 finally, we would not observe a non–linearity of the blue edge of the instability strip, if stellar evolution constrains the population of F Cepheids to periods larger than 2.5 days.

7. Conclusion

We have presented the PL diagrams from a dedicated LMC/SMC Cepheid observation campaign with the EROS 2 setup. For the first time, a change in the slope of the PL relation for short period SMC F Cepheids is observed. For SMC F Cepheids with periods smaller than 2.0 days the magnitude deviation compared to the entire PL relation reaches 0.2 mag. On the other hand we observe no similar effect for 1-OT Cepheids. Furthermore, long and short period SMC Cepheids display significantly different spatial distributions. We have presented different possible explanations for these observations and it is clear that further studies are needed to select the most likely one. With the amount of EROS data available and if the absence of a slope change for 1-OT Cepheid is confirmed, scenario 4 – a curvature of the blue edge of the instability strip – seems the most natural one. Finally, we remark that the reported phenomenon does not affect the PL relation used in the HST Key project for the determination of H_0, as it is based on longer period Cepheids.

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Note added in proof: After this paper was submitted, the OGLE collaboration presented results on beat and second–overtone Cepheids in the SMC based on a larger sample (Udalski et al. 1999a, 1999b). We observe good aggreement betweeen their $R_{21} - \log P$ diagram and ours, and remark that their data sample could be used to confirm or study further the non-linearity that we have reported here.