A REVISED CALIBRATION OF THE $M_V-W(OI\ 7774)$ RELATIONSHIP USING HIPPARCOS DATA: ITS APPLICATION TO CEPHEIDS AND EVOLVED STARS$^1$

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ABSTRACT

A new calibration of the $M_V-W(OI\ 7774)$ relationship has been calculated using better estimates of reddenings and distances to a sample of 27 calibrator stars of A-G spectral types, based on accurate parallaxes and proper motions from the Hipparcos and Tycho catalogues. The present calibration predicts absolute magnitude with accuracies of $\pm 0.38$ mag. for a sample covering a large range of $M_V$, from $-9.5$ to $+0.35$ mag. The colour term included in a previous paper has been dropped since its inclusion was not bringing any significant improvement to the calibration. The variation of the OI7774 feature in the classical cepheid SS Sct has been studied. We calculated a phase-dependent correction to random phase OI feature strengths in Cepheids, such that it predicts mean absolute magnitudes using the above calibration. After applying such correction, we could increase the list of calibrators to 58 by adding $M_V$ and OI triplet strength data for 31 classical Cepheids. The standard error of the calibration using the composite sample was comparable to that obtained from the primary 27 calibrators, showing that it is possible to calculate mean Cepheid luminosities from random phase observations of the OI7774 feature. We use our derived calibrations to estimate $M_V$ for a set of evolved objects to be able to locate their positions in the H-R diagram.

Key Words: ABSOLUTE MAGNITUDES, TRIGONOMETRICAL PARALLAXES, OI 7774 LINE STRENGTHS

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1. INTRODUCTION

Positioning a star or a family of stars in the H-R diagram is fundamental to understand the structure and evolution of stars since it enables proper comparison with evolutionary tracks and computed isochrones. When supplemented by chemical composition data, one can get a much deeper insight into the evolutionary processes that the star might have undergone before arriving at the present stage. Though the temperature of the star can be estimated by different methods like photometry, scanner observations, shapes of hydrogen and helium lines, from excitation equilibrium of species like Fe, Cr, Ti etc. with increasing accuracy, estimating absolute magnitudes is not always easy. For hot stars, the profiles of helium and hydrogen are employed whereas for cool stars Mg II lines at 2796.3 Å, Ca II H and K lines at 3933 and 3967 Å and Mg I triplet in 5167-5184 Å region are found to be good indicators of luminosity. A summary of spectral features that are good indicators of spectral types and luminosity types can be found in Jaschek & Jaschek (1987).

For stars of spectral type A-F the OI triplet at \(\lambda\lambda\ 7771.954, 7774.177\) and 7775.395 Å is found to be a very good indicator of luminosity. The sensitivity of the OI7774 triplet to the stellar luminosity has been well known since Merril (1925, 1934) noted striking strength differences of the feature among supergiants and main sequence stars. Keenan & Hynek (1950) studied the variation of the feature with spectral type and proposed the use of this feature as a luminosity indicator, noticing its large strength in A and F type stars. Osmer (1972) performed the first calibration of the OI7774 triplet in terms of absolute magnitudes using a photoelectric approach for 10 F-type supergiants. After his pioneering work, several calibrations of the feature were carried out spectroscopically and photometrically (e.g. Baker 1974, Sorvari 1974, Kameswara Rao & Mallik 1978, Arellano Ferro et al. 1989; 1991, Arellano Ferro & Mendoza 1993, Mendoza & Arellano Ferro 1993, Slowik & Peterson 1993; 1995). A good compendium on the feature intensity across the H-R diagram can be found in the work of Faraggiana et al. (1988). In the paper by Arellano Ferro, Giridhar & Goswami (1991) (paper I) a calibration of the feature was made using high resolution data and a discussion of the role of the resolution is given. It was demonstrated that the equivalent widths at low resolution can be overestimated by as much as 30% and that a better calibration of the \(M_V - W(\text{OI} 7774)\) relationship can be obtained at the resolution \(R \sim 18,000\). For the large \(M_V\) range \((-10\) to \(+2\) mag). We felt that a calibration covering a larger range in spectral type would have wider application. Though we have reduced calibration errors by measuring the \(W(\text{OI} 7774)\) feature at high resolution data, the \(M_V\) data on the calibrators (mostly members of clusters and associations) was not meeting the required accuracy.

Fortunately, great improvement has been made in the last decade in the determination of distances and reddenings to the parent groups that contain the calibrator stars used in paper I. With accurate parallaxes and proper motions from Hipparcos (ESA 1997), the data on open clusters, such as number of confirmed members, mean proper motions and parallaxes has vastly improved (e.g. Baumgardt, Dettbarn, & Wielen 2000; Tadross 2001). We, therefore, decided to redetermine \(M_V\) for the calibrators and calculate a new \(M_V - W(\text{OI} 7774)\) relationship that would help in determining \(M_V\) for field stars more accurately. We describe in section 2 our observational material. In sections 3 and 4 the list of calibrators and their new \(M_V\)-values are presented and the new calibration is discussed. In section 5 we discuss the behaviour of the OI 7774 feature in classical Cepheids and explore the possibility of using them as additional calibrators. In section 6, we calculate the luminosities for a group of selected evolved stars and their position in the H-R diagram is given using our estimated luminosities. We summarize our findings in section 7.

2. OBSERVATIONS

Most observations were carried out in August 2001 and January 2002, with the 2.1m telescope of San Pedro Martir Observatory (SPM), Mexico, equipped with a Cassegrain Echelle spectrograph and a CCD Site SI003 of 1024×1024 pixels. This instrument gives a resolution of \(\sim 18,000\). at 7774 Å. Along with the stellar observations, bias frames and He-Ar lamp spectra were obtained to carry out background subtraction and wavelength calibration. All reductions were made using standard procedures and tasks contained in the IRAF package.

The observations of the cepheid \(\zeta\ Gem\) were obtained with the 1.0m telescope of Vainu Bappu Observatory at Kavalur, India. This telescope is equipped with a Coude Echelle spectrograph giving a resolution of 18,000. The spectra were recorded on a Thompson-CSF77882 CCD of 384×576 pixels.

3. THE CALIBRATORS STARS

We have chosen from the calibrator stars employed in paper I (Table 1), only those objects that
are observable from the latitude of SPM. We have retained in our present list of calibrators only those stars for which we have a new determination of $W(\text{OI} 7774)$, and/or a new $M_V$ estimated as discussed below. Several calibrators are members of open clusters or OB associations as listed by Arellano Ferro & Parrao (1990) (their Table 1). However, their absolute magnitudes have been recalculated as new proper motions studies can be used to confirm their membership (Baumgardt, Dettbarn & Wielen 2000) and new distances and reddenings (Tadross 2001) are available for clusters. Accurate parallaxes and proper motions are available even for some field stars (Hipparcos, ESA 1997) now. Therefore, the list of calibrators also contains some field stars for which new values of $M_V$ have been estimated.

3.1. The calibrators in clusters and associations

The accurate parallaxes and proper motions given in the Hipparcos catalogue, when combined with their ground based counterparts and radial velocities of known cluster and associations members, can lead to much improved values of the mean proper motions and parallaxes for a large number of galactic clusters and associations. Baumgardt, Dettbarn & Wielen (2000) have derived these quantities for 205 open clusters. These authors also give a list of confirmed and possible members of these clusters. Their work also indicates downward revision in the distances by about 12% compared to the photometric estimates. This paper enabled us to further confirm the membership in clusters of the stars used in the present work and to re-evaluate $M_V$.

**HD 7927 ($\phi$ Cas).** It is a member of open cluster NGC 457. Tadross (2001) estimates $E(B-V)=0.5$ and a distance of 2851 pc for the cluster, leading to $M_V=−8.76$.

**HD 9973** belongs to the association Cas OB1 with distance modulus of 12.4, with adopted $E(B-V)=0.54$ Oestreicher & Schmidt-Kaler (1999) find $M_V=−7.36$.

**HD 10494** is a member of open cluster NGC 654. Tadross (2001) estimates $E(B-V)=0.90$ and a distance of 2483 pc for NGC 654, thus $M_V=−7.34$.

**HD 14433** is a member of open cluster NGC 884 ($\chi$ Persei) for which Tadross (2001) estimates $E(B-V)=0.50$ and a distance of 2483 pc. Therefore $M_V=−7.08$.

**HD 14535** is also a member of NGC 884 ($\chi$ Persei). As for HD 14433 we estimated $M_V=−5.97$.

**HD 17971** belongs to IC 1848 with distance modulus of 11.81, with adopted $E(B-V)=0.76$ Oestreicher & Schmidt-Kaler (1999) find $M_V=−6.58$.

### Table 1

| HD      | Sp.T. | W71  | W74  | $M_V$ | $(b-y)_o$ |
|---------|-------|------|------|-------|-----------|
| 7927    | F0ia  | 0.855| 2.221| −8.76 | 0.111     |
| 9973    | F5Iab | 0.541| 1.399| −7.36 | 0.225     |
| 10494   | F5Ia  | 0.612| 1.578| −7.34 | 0.215     |
| 14433   | A1Ia  | 0.661| 1.641| −7.08 | 0.013     |
| 14535   | A2Ia  | 0.496| 1.198| −5.97 | 0.124     |
| 17971   | F5Ia  | 0.538| 1.404| −6.58 | 0.247     |
| 18391   | G0Ia  | 0.611| 1.438| −6.6  | 0.949     |
| 20123   | G6Ib  | 0.124| 0.279| −2.0  | 0.645     |
| 20902   | F5Ib  | 0.374| 1.020| −4.9  | 0.274     |
| 31964   | F0Ia  | 0.969| 2.316| −8.7  | 0.035     |
| 36673   | F0Ib  | 0.449| 1.249| −5.1  | 0.116     |
| 48329   | G8IIb | 0.087| 0.182| −1.0  | 0.816     |
| 54605   | F8Ia  | 0.691| 1.750| −7.97 | 0.355     |
| 62058   | G0Ia  | 0.579| 1.485| −7.32 | 0.981     |
| 62345   | G8IIa | 0.042| 0.084| +0.35 | 0.541     |
| 65228   | FII   | 0.216| 0.547| −1.9  | 0.46      |
| 71480   | F0Ia  | 2.273*| −9.0 | 0.094 |
| 75276   | F2Iab | 1.114*| −6.45| 0.011 |
| 84441   | G1I   | 0.117| 0.289| −1.31 | 0.36      |
| 87283   | F0II  | 1.017*| −4.01| 0.113 |
| 90772   | F0Ia  | 2.051*| −8.3 | 0.054 |
| 101947  | G0Ia  | 1.757*| −7.9 | 0.439 |
| 102070  | G8IIa | 0.040| 0.1118| −0.5 | 0.439 |
| 164136  | F2II  | 0.286| 0.753| −2.73 | 0.253     |
| 194093  | F8Ib  | 0.490| 1.288| −6.18 | 0.397     |
| 204876  | G0Ib  | 0.237| 0.622| −3.37 | 0.40      |
| 217476  | G0Ia  | 0.910| 2.174| −9.2  | 0.674     |

* – $W(\text{OI} 7774)$ values taken from paper I.

**HD 18391** is listed as a possible member of h-\(\chi\) Per by Schmidt (1984). From the reddenings and $M_V$ compilation of Arellano Ferro & Parrao (1990) we adopt $M_V=−6.6$.

**HD 20902** (\(\alpha\) Per) is a member of the \(\alpha\) Persei cluster. Using the distance and reddening to the cluster, Humphreys (1978) found $M_V=−4.7$. Using Hipparcos parallaxes Jaschek & Gómez 1998 have calculated $M_V$ for some MK standards. For HD 20902 they give $M_V=−4.9$.

**HD 31964** belongs the associations Aur OB1 (Stothers 1972). From the reddenings and $M_V$ compilation of Arellano Ferro & Parrao (1990) we adopt $M_V=−8.7$.

**HD 54605** belongs to Collinder 121 with distance modulus of 9.4, with adopted $E(B-V)=0.12$ Oestreicher & Schmidt-Kaler (1999) find $M_V=−7.97$. 

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THE $M_V − W(\text{OI} 7774)$ RELATIONSHIP REVISED
**HD 62058** is a member of open cluster NGC 2439. Tadross (2001) estimates $E(B-V)=0.37$ and a distance of 3669 pc for the cluster, leading to $M_V=-7.32$.

**HD 74180** is a member of Vel OB1 association (Humphreys 1978). Two recent estimates of the distance are available 1600 pc (Damibis, Melnik & Rostorguev 2001) and 1750 (Cameron Reed 2000). The later author has also provided the value of the total selective absorption ratio $R = 3.7$ for the association and $E(B-V)=0.478$ for HD 74180. This leads to $M_V = -9.1$ and $M_V = -8.9$ respectively. We adopted $M_V = -9.0$.

**HD 75276** is also a member of Vel OB1 (Humphreys 1978). Following the steps taken for HD 74180 and adopting $E(B-V)=0.315$ (Cameron Reed 2000), it is found to give $M_V = -6.6$ and $M_V = -6.3$ respectively for the two distances. We adopted $M_V = -6.45$.

**HD 87283** is a member of open cluster NGC 3114 (Schmidt 1984) for which Tadross (2001) estimated $E(B-V)=0.50$ and distance of 2483 pc. Therefore we adopted $M_V = -4.01$.

**HD 90772** is a member of open cluster IC2581 (Lloyd Evans 1969). From the reddenings and $M_V$ compilation of Arellano Ferro & Parrao (1990) we adopt $M_V = -8.3$.

**HD 101947** belongs to Stock 14, (Schmidt 1984). From the reddenings and $M_V$ compilation of Arellano Ferro & Parrao (1990) we adopt $M_V = -7.9$.

### 3.2. The field calibrators

We have included in the list of calibrators a few field stars whose $M_V$ values can be correctly estimated using Hipparcos data. Hipparcos parallaxes alone can be used to derive distances if the value of the parallax is larger than 5 times the error of the parallax value.

**HD 20123.** Using Hipparcos parallax Wallerstein, Machado-Pelaez, & Gonzalez (1999), have derived $M_V=-2.0$.

**HD 36673** is a field star with $E(B-V)=0.02$ Oestreicher & Schmidt-Kaler (1999) find $M_V = -5.1$.

**HD 48329.** As in paper I we adopted $M_V = -1.0$ from parallax value.

**HD 62345.** Using Hipparcos parallax Allende Prieto & Lambert (1999), have derived $M_V = 0.35 \pm 0.16$.

**HD 65228** has a parallax of 6.49 leading to a distance of 154 pc. With $E(B-V)=0.057$ given by Bersier (1996) one gets $M_V = -1.9$.

**HD 84441** has a large parallax of 13.01, indicating a distance of 76 pc. With this distance and $E(B-V) = -0.04$ from Arellano Ferro & Parrao (1990) one gets $M_V = -1.31$.

**HD 102070** has parallax of 9.31 leading to a distance of 107 pc. With $E(b-y)=0.02$ or $E(B-V)=0.025$ given in Paper I, we find $M_V = -0.5$.

**HD 164136** has a parallax of 4.10 leading to a distance of 467 pc. With $E(B-V)=0.07$ (Bersier 1996) then $M_V = -2.73$.

**HD 194093** has a parallax of 2.14 leading to a distance of 244 pc. With $E(B-V)=0.026$ (Bersier 1996) leads to $M_V = -6.18$.

**HD 204867** has a parallax of 5.33 leading to a distance of 187.6 pc. With $E(B-V)=0.026$ (Bersier 1996) one finds $M_V = -3.37$.

**HD 217476** is considered an hypergiant. Its $\log(L_*/L_\odot)$ is estimated to be 5.6 by de Jager (1998), that leads to $M_V = -9.2$.

In Table 1 we summarize the newly calculated values of $M_V$ for each calibrator. We also tabulate in Table 1, the individual strength of OI at 7771.95Å along with the strength of 7774 blend comprising the three components. It should be noted that between the OI line at 7771.95 Å and the next one at 7774.17 Å, features of Fe I at 7772.59 Å and CN at 7772.9 Å are present. These lines are weak or non-existent in A type stars but become prominent in stars of spectral type G or later. The contributions from these lines could cause overestimation of triplet strengths in relatively cooler stars. However, for OI 7771.95 Å the blue side of its profile remains largely unaffected, hence more accurate estimate of its strength can be made. At our resolution, OI 7771.95 Å was distinctly separated from the rest of the blend. In an attempt to get a calibration with smaller dispersion and possible extension of the calibration to the cooler stars we calculated two separate calibrations, one using only the first component at OI 7771.95 Å hereinafter called W71 and the other, using the combined strength of three components hereinafter called W74. The W74 value for those stars with a new estimate of $M_V$ but not observed in SPM has been adopted from paper I, these cases are marked with an asterisk in Table 1 and plotted as circles in Figs. 1b and 6b. It should be noted that the spectra used in paper I were also of resolution very similar to that of SPM spectra. The $(b-y)_o$ values were calculated from Strömgren data and colour excesses given in the literature (e.g. Arellano Ferro & Parrao 1990 and paper I).
Fig. 1. Calibration of the equivalent widths of OI7771 (W71) and OI7774 (W74) (blend of three components) in terms of the absolute magnitude $M_V$. The solid lines are represented by equations 1 and 2, which hold for the absolute magnitude range $-9.5$ to $+0.35$ mag. Open circles are the stars with adopted W74 from paper I.

4. THE $M_V - W$(OI 7774) CALIBRATION

Fig. 1 shows the distribution of the calibrators in equivalent width versus absolute magnitude diagram for W71 and W74. The solid lines are the least square fits to the points and can be represented by the equations:

$$M_V = 0.604 -17.079 \, W71 +7.227 \, W71^2, \quad \pm 0.282 \pm 1.346 \pm 1.383$$  

$$M_V = 0.427 -6.234 \, W74 +0.907 \, W74^2. \quad \pm 0.292 \pm 0.572 \pm 0.243$$  

The standard errors of the fits are 0.38 mag. for both calibrations. Figure 1b and equation 2 can be compared with Figure 3 and equation 1 of paper I,

$$M_V = 0.49 -6.33 \, W74 +0.85 \, W74^2, \quad \pm 0.75 \pm 1.57 \pm 0.68$$  

where the standard error of the fit was 1.5 mag.

It is evident from the standard deviations of the fit and the reduced standard errors of the coefficients, that the new calibrations of equations 1 and 2 are better, by more than a factor of three, than the old calibration, this is undoubtedly due to the improved values of $M_V$ calculated from the Hipparcos data. As in paper I, we have investigated the effect of the temperature variation over the spectral types, represented by the colour $(b - y)_o$, in the relationship. The equations including the colour term are of the form

$$M_V = A - BW + CW^2 - D(b - y)_o \quad (4)$$

with $A= 1.015 \pm 0.403, \quad B=-17.961 \pm 1.489, \quad C=7.924\pm1.468, \quad D=-0.424\pm0.407$ for W71 and $A= 0.947 \pm 0.402, \quad B=-6.544 \pm 0.603, \quad C=0.986 \pm 0.246, \quad D=-0.734 \pm 0.414$ for W74. The standard deviations of the fit are 0.35 and 0.33 mag respectively, and, although a bit smaller than for eqs. 1 and 2, the colour term does not appear to be significant. Further, the plots of the residuals versus $(b - y)_o$ show no trend with colour, as demonstrated in Fig. 2, thus the colour term was dropped from the calibration. Equations 1 and 2 hold good for absolute
Fig. 3. W71 and W74 curves of the Cepheid SS Sct. The
phases were calculated using a period of $P = 3.671280\,\text{d}$
and epoch of maximum light $\mathrm{HJD} = 2444398.419$. The am-
plitudes of W71 and M74 variations are 0.098 and 0.220
angstroms respectively.

magnitudes in the large range –9.5 to +0.35 mag.
and spectral types between A1 and G8.

In Fig 7-a examples of the OI7774 triplet are
given for three clibrator stars. They illustrate
the considerable range of variation of the OI7774
strength between low and high luminosity stars.

5. THE BEHAVIOUR OF OI(7774) FEATURE IN
CLASSICAL CEPHEIDS

The $M_V - W(\text{OI} 7774)$ calibrations discussed so
far had been obtained using A-G giant and super-
giant calibrators with a large $M_V$ range of nearly
10 magnitudes. Therefore, they are expected to be
valid for classical Cepheids too that are generally F-
G supergiants. But, it should be noted that calibrat-
ing $M_V - W(\text{OI} 7774)$ independently from Cepheids
alone may not be possible due to their small range
in $M_V$ (–1 to –5 mag.) and variations in W74 as a
function of phase. On the other hand, Cepheid lumin-
ositities are believed to be well determined from the
Period-Luminosity (P-L) relation, hence they can be
used to enlarge the list of calibrators.

Since the luminosity of a Cepheid changes as the
star pulsates, the values of W71 and W74 also change
along the cycle, thus W71($\phi$) and W74($\phi$) at a given
phase $\phi$ must be corrected to be brought to the mean
values of W71 and W74. Knowing the lines con-
tributing to the OI triplet are luminosity sensitive,
it is reasonable to assume that the amplitudes of the
W71- and W74-curves are proportional to the
V-light curve amplitude. Thus, the size of the equiv-
alent width correction to be applied to bring it to the
mean value depends on the phase of the observation
and the V-light amplitude. To properly estimate the
scale between V-light and W74 amplitudes, one should measure W71 and W74 at
several phases for a group of Cepheids. However, due
to observing time limitations we were able to measure
W71 and W74 only at a few phases in SS Sct. The variations are shown in Fig. 3, where we have
used the ephemeris

$$\phi_i = \frac{t_i - 2444398.419}{3.671280}.$$  

For a sample of Cepheids we can represent the
light curve using the Fourier coefficients calculated
by Arellano Ferro et al. (1998). The expression used
is of the form,

$$V(\phi) = V_o + \sum_{k=1}^{n} A_k \cos(2\pi k \phi + \Phi_k), \quad (5)$$

where $A_k$ and $\Phi_k$ are the amplitude and the dis-
placement of each harmonic $k$. Thus we can cal-
culate $\Delta V(\phi) = V(\phi) - V_o$. We now assume that
$F_{74} = A_V/A_{W74}$, i.e. the ratio of the V light am-
plitude to the W74 variation amplitude $A_{W74}$, is con-
stant over the complete cycle, or

$$F_{74} = A_V/A_{W74} = \Delta V(\phi)/\Delta W74(\phi), \quad (6)$$

where $\Delta W74(\phi) = W74(\phi) - W74_o$. Then the esti-
imated mean value of W74 would be given by

$$W74_o = W74(\phi) - \Delta V(\phi)/F_{74}, \quad (7)$$

which can be used to estimate the mean absolute
magnitude for a cepheid from equation 2. Similar
arguments hold for W71 and eq. 1.

The estimated $F$-values for the reference star SS
Sct are $F_{71} = 4.388$ and $F_{74} = 1.955$. The uncer-
tainties of these values are proportional to the scat-
ter of both V-light and W(OI) curves. In Figure 4
we have presented the W71 curve for the cepheid $\zeta$
### Table 2

OI 7774 Data for Classical Cepheids

| Name    | W71(⊙) | W74(⊙) | P     | \(M_V\) | \(φ\) | W71 o | W74 o |
|---------|---------|---------|-------|---------|-------|-------|-------|
|         | (Å)     | (Å)     | (days) | (mag.)  | (Å)   | (Å)   |
| DT Cyg  | 0.268   | 0.679   | 2.499035 | -2.548  | 0.45  | 0.278 | 0.702 |
| V532 Cyg| 0.320   | 0.826   | 3.283612 | -2.881  | 0.92  | 0.289 | 0.755 |
| SS Sct  | 0.262   | 0.665   | 3.671280 | -3.017  | 0.44  | 0.280 | 0.718 |
| RT Aur  | 0.187   | 0.447   | 3.728220 | -3.036  | 0.61  | 0.238 | 0.563 |
| SU Cyg  | 0.205   | 0.485   | 3.845733 | -3.074  | 0.40  | 0.240 | 0.564 |
| CM Sct  | 0.218   | 0.566   | 3.916977 | -3.096  | 0.60  | 0.257 | 0.653 |
| BQ Ser  | 0.251   | 0.632   | 4.316700 | -3.215  | 0.74  | 0.247 | 0.621 |
| T Vul   | 0.165   | 0.477   | 4.435532 | -3.248  | 0.65  | 0.247 | 0.722 |
| VZ Cyg  | 0.259   | 0.687   | 4.864504 | -3.361  | 0.19  | 0.226 | 0.611 |
| V Lac   | 0.289   | 0.716   | 4.983149 | -3.390  | 0.17  | 0.232 | 0.587 |
| AP Sgr  | 0.198   | 0.542   | 5.057936 | -3.408  | 0.75  | 0.295 | 0.760 |
| V350 Sgr| 0.193   | 0.583   | 5.154557 | -3.431  | 0.51  | 0.234 | 0.741 |
| V386 Cyg| 0.338   | 0.946   | 5.257655 | -3.455  | 0.90  | 0.314 | 0.894 |
| δ Cep   | 0.242   | 0.577   | 5.366316 | -3.480  | 0.32  | 0.252 | 0.633 |
| X Lac   | 0.209   | 0.561   | 5.444990 | -3.498  | 0.26  | 0.208 | 0.557 |
| Y Sgr   | 0.239   | 0.589   | 5.773400 | -3.570  | 0.34  | 0.238 | 0.588 |
| FM Aql  | 0.314   | 0.838   | 6.114240 | -3.640  | 0.08  | 0.232 | 0.656 |
| X Vul   | 0.219   | 0.655   | 6.319562 | -3.680  | 0.70  | 0.344 | 0.932 |
| RR Lac  | 0.219   | 0.599   | 6.416190 | -3.698  | 0.75  | 0.295 | 0.771 |
| AW Per  | 0.190   | 0.470   | 6.463589 | -3.707  | 0.70  | 0.267 | 0.645 |
| U Aql   | 0.362   | 0.921   | 7.024100 | -3.809  | 0.91  | 0.322 | 0.830 |
| η Aql   | 0.228   | 0.519   | 7.176779 | -3.835  | 0.67  | 0.303 | 0.687 |
| V600 Aql| 0.298   | 0.471   | 7.238748 | -3.846  | 0.71  | 0.254 | 0.652 |
| V459 Cyg| 0.160   | 0.444   | 7.251250 | -3.848  | 0.71  | 0.231 | 0.602 |
| W Sgr   | 0.210   | 0.532   | 7.595080 | -3.904  | 0.55  | 0.294 | 0.760 |
| U Vul   | 0.343   | 0.930   | 7.990736 | -3.966  | 0.92  | 0.296 | 0.829 |
| S Sge   | 0.270   | 0.680   | 8.382044 | -4.025  | 0.31  | 0.254 | 0.644 |
| YZ Sgr  | 0.291   | 0.738   | 9.553606 | -4.184  | 0.63  | 0.305 | 0.769 |
| Y Sct   | 0.306   | 0.822   | 10.341650| -4.281  | 0.05  | 0.224 | 0.639 |
| TT Aql  | 0.316   | 0.842   | 13.755290| -4.629  | 0.92  | 0.287 | 0.777 |
| CD Cyg  | 0.344   | 0.764   | 17.073967| -4.893  | 0.85  | 0.420 | 0.935 |
Gem for which W74 curve is very noisy. Since this star has large variation in temperature and during the cooler phase the contributions from the Fe I and CN features mentioned in section 3 are large, hence the errors in W74 also become large. For this star we calculate $F_{71} = 6.01$ and it would therefore produce similar corrections to those using SS Sct. For the other Cepheids corrections, we have used SS Sct as a reference for both W71($\phi$) and W74($\phi$).

It should be noted that the above approach may have limitations since the amplitude scale factor calculated in this manner may not be applicable to Cepheids with highly asymmetrical light curves. However, this should be considered as a maiden effort with considerable room for improvement. We intend carrying out a similar calculation for a large sample of Cepheids.

This approach to random phase correction in Cepheids is nevertheless presented here as a preliminary result and as a promising method to estimate the $M_V - W'(OI 7774)$ from random-phase observations of Cepheids.

The above method has been applied to both W71 and W74 data of 31 Cepheids, listed in Table 2 along with their random phase W71($\phi$), W74($\phi$), $M_V$ and the mean values $W71_o$ and $W74_o$. The $M_V$ values were obtained from the Feast & Catchpole (1997) P-L relationship $M_V = -2.81 \log P - 1.43$. This calibration is brighter than other solid calibrations (e.g. Sandage & Tammann 1968; Feast & Walker 1987; Madore & Freedman 1991), but only at the level of $\sim 0.1$ mag (Sandage & Tammann 1998; Madore & Freedman 1998), thus, adopting a calibration of the P-L relationship with a slightly smaller zero point, would have a very minor effect on our calculations and conclusions, especially considering that the uncertainty of our OI7774-$M_V$ calibration is of the order of 0.4 mag. The periods and epochs are usually known with large precision, the values in Table 2 were adopted from the sources listed in the paper by Arellano Ferro et al. (1998) in their Table 2. In the present Table 2, we include the phase at which the OI observation was obtained and, on the basis of which, the absolute magnitude is corrected.

Fig. 5a shows the distribution of uncorrected W71 measurements in the W71-$M_V$ plane. The solid curve is the calibration in equation 1. While the Cepheids fall along the path defined by the non-cepheid calibrators, their dispersion is, as expected, unacceptably large as the phase effect is yet to be corrected. In Fig. 5b the corrected W71-values for the sample of Cepheids are plotted along with the
Fig. 7. a) Three examples of calibrator stars from very low to very large luminosity. b) Three examples of evolved stars. These stars known for having Hα in emission do not show emission in the OI7774 feature. Other stars in Table 3 were inspected and no emission was found, thus their values W71 and W74 reliable for the estimation of \( M_V \). c) The three upper spectra are from single Cepheids while the three examples in the bottom are of Cepheids known for having hot companions (see Table 2 of Evans (1995) for details). Numbers between parenthesis are their periods in days. The presence of the companion does not seem to affect the nature of the OI7774 in Cepheids.

non-cephed calibrators. The process has been repeated for W74 and is shown in Fig. 6. The present corrections of W71 and W74 in fact brought the Cepheids closer to the mean trend, and their dispersion is now comparable to that of cluster, associations and field calibrators. Once the Cepheids are included the calibrations take the forms:

\[
M_V = 0.260 - 15.889 \, W71 + 6.393 \, W71^2, \\
\pm 0.281 \pm 1.387 \pm 1.390
\] (8)

\[
M_V = 0.131 - 5.831 \, W74 + 0.789 \, W74^2, \\
\pm 0.287 \pm 0.563 \pm 0.231
\] (9)

The standard deviations in \( M_V \) are 0.42 and 0.43 mag, thus comparable to the calibrations in eqs. 1 and 2.

Many Cepheids have hot companions, generally late B-type main sequence stars. And while contamination of the cepheid OI7774 Feature is unlikely since hot main sequence stars have very weak OI7774 relative to supergiant stars (Faraggiana et al. 1988), we have compared in figure 7-c the OI7774 profiles of three Cepheids with B-A type main sequence companions (SU Cyg, AW Per and S Sge) with those of presumably single Cepheids of similar periods (RT Aur, δ Cep, and U Vul). We do not see any pecularity introduced by the companions, hence it is concluded that the OI7774 feature in Cepheids is not affected by their companions.

6. ESTIMATED LUMINOSITIES FOR AGB CANDIDATE STARS

We felt it would be important to estimate the \( M_V \) of possibly evolved objects from their W71 and W74 using the calibration derived in the present work. In a different program we had chosen a sample of A-G stars with high galactic latitude and detected IR flux in search of post-AGB stars. Not all of them turned out to be objects showing very significant chemical peculiarities caused by evolutionary processes. But we were interested in determining their locations in the H-R diagram, hence used their W71, W74 to estimate \( M_V \) for them. Their temperatures are those estimated using fine spectral analysis as described in Arellano Ferro, et al. 2001. In absence of such data we relied upon uvbyβ or 13-colour photometry calibrations or their spectral types. The stars under consideration are listed in Table 3 along with their W71 and W74 values. Also reported in Table 3 is \( < M_V > \), the mean of the absolute magnitudes
obtained from eqs. 1 and 2 which agree within 0.2 mag. The corresponding \( \log L/L_\odot \) is also given in Table 3. At the bottom of the table, we have presented the data for five well-established post-AGB stars and their OI derived luminosities. Previous \( M_V \)-values are given between parenthesis and their sources are listed in Table 3.

The OI7774 profiles of evolved stars in table 3 were inspected to make sure that Equivalent widths were not affected by emission often present in evolved or unusual stars. To demonstrate that it was not the case, in Fig. 7-B three spectra, of stars HD 224014 (\( \rho \) Cas, G2Ia0e), HD 163506 (89 Her, F2Ibe) and HD 161796 (F3Ib) are shown. These stars were selected for illustration since they are well known to have H\alpha In emission. Nevertheless, the OI7774 feature appears to be in absorption. There could be weak underlying emission, but its effect, if any, would be negligible.

The positions of the stars on the H-R diagram are shown in Fig. 8. The evolutionary tracks for several masses of Schaller et al. (1992) for \( Z=0.02 \) and \( Y=0.30 \) are presented for reference. These models do not show blue loops for stars with 4 \( M_\odot \) and below, hence do not cross the instability strip. On the other hand, lower metallicity models (\( Z=0.001 \)) do show blue loops for masses down to about 2-3 \( M_\odot \) (Schaller et al. 1992) and cross the lower part of the cepheid instability strip. While such selection of metallicity would be adequate for old low mass stars, it would be inappropriate for Pop I Cepheids.

To produce longer blue loops at this low mass range, Alongi et al. (1991) have introduced an extra overshoot parameter that extends towards the interior of the outer convective envelope. Post red giant branch stars located on the H-R diagram might serve as landmarks for theoretical work.

The stars from the Table 3 with \( \log L/L_\odot \) in the range of 3.5 to 5.0 have certainly passed the red giant phase and populate the blue loop for masses between 7 and 10 \( M_\odot \). Blue loops for higher masses are not populated in part due to the specific sample considered but also due to the fact that evolution in this region of the diagram is fast (Blöcker 1995). However it is not possible to say if a given star would evolve to the left or to the right. Stars like HD 137569 and HD 172324 might be useful observational input that can be used to examine the extent of blue loops in this mass range.

The five established post-AGB stars, plotted as dots in Fig. 8, have been plotted according to their OI luminosities and their spectroscopically determined temperatures. Although the OI7774 feature is sensitive to the luminosity, it is also partially sensitive to the oxygen abundance. The calibrations have been established using nearly solar abundance calibrators. Therefore its application to highly evolved stars with peculiar oxygen abundances is a little uncertain and hence might give luminosities with large error bars. The oxygen [O/H] abundances for these five post-AGB are: \(-0.33 \) (HD112374; Luck et al. 1983), \(+0.08 \) and \(-0.27 \) (HD 161796 and HD163506; Luck et al. 1990), \(+0.41 \) and \(-0.58 \) (HD 172324 and 172481; Arellano Ferro et al. 2001), therefore their positions on the H-R diagram may have larger uncertainties. Mildly evolved stars like those given in the upper part of Table 3 have essentially solar [O/H], hence the calibration certainly gives good \( M_V \) estimates for them. For C-rich strongly evolved objects the relation might give low values of the luminosity.

Also as a reference, the position of the instability strip has been indicated in Fig 8. The upper strip is the classical cepheid strip from Sandage & Tammann (1969) and the lower strip comes from Marconi & Palla (1998). Given the 0.4 mag. uncertainty in \( M_V \) produced by eqs. 1 and 2, we cannot assure that borderline Cases are in or out the instability strip. It is worth however pointing at the variables sitting well inside the strip, HD 112374 whose variability was discovered by Arellano Ferro (1981), HD62058 (R PUP) and HD 194093 (37 Cyg). Variable stars in the upper part of the diagram, like HD 54605 (25 CMa), HD 163506 (89 Her), HD 161796 (V814 Her) and HD224014 (\( \rho \) Cas) lie in a region where the instability strip is ill-defined.

7. CONCLUSIONS

The newly estimated values of the absolute magnitude \( M_V \) for a group of selected A-G supergiant calibrators enabled us to revise the \( M_V - W(OI 
7774) \) relationship. The results show an improvement in \( M_V \) predictions accuracies of at least a factor of three relative to the previous calibration from high resolution data in paper I, over a large absolute magnitude range \(-9.5 \) to \(+0.35 \) mag. The calibrations presented in equations 1 and 2 are our final calibrations and they predict \( M_V \) values with an accuracy of \( \pm0.38 \) mag.

It is shown that the OI7774 feature in Cepheids follow the basic calibration. A method to correct \( W(OI 
7774) \) obtained at random phases is described and successfully applied to a sample of 31 Cepheids. At our resolution, the bluemost component of the triplet at \( \lambda 7771.954 \) is resolved from the two redder components and being unaffected by FeI, CN lines may be more useful for G-type stars and later. We
Fig. 8. H-R diagram with the positions of selected evolved stars (open circles) and five established post-AGB stars (dots). The evolutionary tracks are from Schaller et al. (1992) for Z=0.2 and Y =0.30.

have calculated the calibrations for both the blue component (W71) and for the blend of the triplet (W74) including the Cepheids along with the primary calibrators. The calibrations for composite data, given by eqs. 8 and 9, predict $M_V$ values within ±0.42 and ±0.43 mag. and therefore are comparable to the calibrations based solely on A-G non-variable supergiants. Hence the present calibration with phase-corrected W71 or W74 shows that the OI7774 feature in Cepheids is as sensitive to luminosity as in non-variable supergiants.

The new calibrations have been applied to a group of intermediate temperature, high galactic latitude stars with detected IR fluxes that are considered good candidates to post-AGB stars. The luminosities determined by the present work, not only help in ascertaining the evolutionary status of the sample of stars but can also be used by theorist doing evolutionary calculations in the post red giant evolution, in order to establish the loci of the blue loops for stars of five solar masses and below.

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| HD  | Sp.T. | W71 | W74 | <MV> | logL/L⊙ |
|-----|-------|-----|-----|------|---------|
| 725 | F5Ib-II | 0.450 | 1.220 | −5.723 | 3.905 |
| 1457 | F0Iab | 0.461 | 1.198 | −5.737 | 3.927 |
| 4266 | F2Iab | 1.028 | 1.280 | −5.023 | 3.633 |
| 9167 | F1I | 0.544 | 1.379 | −6.530 | 4.240 |
| 9233 | A4Iab | 0.489 | 1.328 | −6.136 | 4.142 |
| 12533 | K3IIIb | 0.070 | 0.146 | −0.510 | 2.008 |
| 12545 | G5 | 0.148 | 0.345 | −1.691 | 2.316 |
| 15257 | F0III | 0.655 | 0.655 | −3.267 | 2.939 |
| 15788 | G8III | 0.048 | 0.129 | −0.281 | 1.772 |
| 27381 | F2 | 0.505 | 1.343 | −6.244 | 4.121 |
| 54605 | F8Iab | 0.691 | 1.750 | −7.726 | 4.710 |
| 55612 | F0III/IV | 0.068 | 0.211 | −0.686 | 1.906 |
| 55661 | A7:V | 0.198 | 0.558 | −2.632 | 2.705 |
| 57321 | F2II | 0.661 | 1.027 | −6.273 | 4.133 |
| 61227 | F0Ib | 0.148 | 0.383 | −1.796 | 2.343 |
| 62058 | F8/G0Ia | 0.456 | 1.144 | −5.599 | 3.864 |
| 137569 | B5III | 0.290 | 0.804 | −3.870 | 3.704 |
| 191635 | F0 | 0.234 | 0.610 | −3.018 | 2.839 |
| 194093 | F8Iab | 0.436 | 1.149 | −5.504 | 3.821 |
| 209747 | K4III | 0.046 | 0.087 | −0.137 | 1.899 |
| 216756 | F5II | 0.322 | 0.987 | −4.494 | 2.508 |
| 224014 | G2IIa0e | 1.468 | 6.777 | 4.340 |

Notes. 1. Luck et al. (1983), 2. Arellano Ferro & Parrao (1990), 3. Arellano Ferro et al. (2001).