Mean Angular Diameters and Angular Diameter
Amplitudes of Bright Cepheids

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ABSTRACT

We predict mean angular diameters and amplitudes of angular diameter variations for all monoperiodic Population I Cepheids brighter than $\langle V \rangle = 8.0$ mag. The catalog is intended to aid selecting most promising Cepheid targets for future interferometric observations.

1 Introduction

Because of high intrinsic brightness and existence of a tight period–luminosity relation, classical Cepheids play a central role in building cosmological distance ladder. An accurate calibration of their $P–L$ relation is, therefore, of fundamental importance. While the slope of the $P–L$ relation is well determined by Cepheids of the Large Magellanic Cloud (e.g. Udalski et al. 1999), the zero point is less certain. It is usually calibrated by nearby Cepheids, whose individual distances have to be accurately measured. This is not an easy task. Despite several different methods being applied (cf. Fouqué et al. 2003; Feast 2003), the zero point of the $P–L$ relation remains uncertain at $\Delta M_V = \pm 0.1$ mag level.

The advent of long-baseline interferometry offered a novel way of Cepheid distance determination, by using purely geometrical version of the Baade-Wesselink method (Lane et al. 2000). This approach yields the distance by comparing angular diameter changes measured by interferometry with linear diameter changes inferred from observed radial velocities. So far, the technique was successfully applied to only five Cepheids (Lane et al. 2002; Kervella et al. 2004a), but with increased resolution of next generation of interferometers (CHARA and AMBER) more Cepheids will become accessible.

The goal of this paper is to identify Cepheids, which are most promising targets for observations with existing and future interferometers. For that purpose, we calculated expected mean angular diameters and angular diameter amplitudes for 79 brightest monoperiodic Cepheids. Assumptions used in the calculations and accuracy of the method are discussed in Section 2. In Section 3 we describe the Cepheid sample and the sources of data. The results are presented in Section 4 and conclusions of the paper are summarized in Section 5.
2 Method

The goal of this paper is to estimate for Pop. I Cepheids the mean angular diameters and the amplitudes of angular diameter variations. To achieve this, we need to find for each Cepheid its distance, mean linear radius and radius changes.

Cepheid distances were calculated with the help of the period–luminosity relation. We adopted $P - L$ relation of Fouqué et al. (2003):

$$M_V = -2.735 \log P - 1.352,$$

whose slope was determined from the LMC Cepheid sample and the zero point was calibrated with Galactic Cepheids analysed with infrared surface brightness method. Eq.(1) is valid for the fundamental mode pulsators. For the first overtone Cepheids, the observed period, $P_1$, was converted to the fundamental mode period, $P_0$, with empirical formula

$$P_1/P_0 = -0.027 \log P_1 + 0.716,$$

which was derived by least square fit to periods of Galactic double-mode Cepheids (Alcock et al. 1995; modified by Feast & Catchpole 1997). Comparison of the absolute magnitudes, $M_V$, given by Eq.(1) and dereddened intensity mean observed magnitudes, $\langle V_0 \rangle$, yielded the Cepheid distances. Standard extinction coefficients were used: $A_V = 3.30 E(B-V)$.

The mean Cepheid radii were calculated with the period–radius relation of Gieren et al. (1998):

$$\log \langle R/R_\odot \rangle = 0.750 \log P + 1.075.$$

This formula is essentially identical to those derived by Laney & Stobie (1995) and Turner & Burke (2002). Again, periods of first overtone Cepheids were fundamentalized with Eq.(2).

Variation of Cepheid radius during pulsation cycle was calculated by integrating the observed radial velocity curve, $V_r(t)$:

$$\Delta R(t) = -p \int_{t_0}^t [V_r(t) - \gamma]$$

where $\gamma = \langle V_r \rangle$ is the mean radial velocity of the Cepheid and $p$ is the projection factor converting observed radial velocity to pulsational velocity. For all the Cepheids we used the same constant projection factor of $p = 1.36$ (e.g. Laney & Stobie 1995; Kervella et al. 2004a).

With the mean radius and the distance to the star known, the mean angular diameter can be calculated with the formulae

$$\langle \theta \rangle = 9.305 \frac{\langle R \rangle}{d}$$
where $\theta$ is expressed in milliarcseconds ([mas]), $R$ in units of solar radius and $d$ in parsecs. Similarly, the total range of angular diameter variations is given by

$$\Delta \theta = \theta_{\text{max}} - \theta_{\text{min}} = 9.305 \frac{R_{\text{max}} - R_{\text{min}}}{d}. \quad (6)$$

### 2.1 Accuracy of Angular Diameter Estimate

The $P - L$ and $P - R$ relations represent Cepheids only in the average sense. In addition to the observational scatter, both relations have also intrinsic dispersion, which reflects non-zero width of the Cepheid instability strip. This directly affects accuracy of predicted Cepheid angular diameters.

When built with the reddening-independent Wesenheit index, the $P - L$ relation for Galactic Cepheids displays scatter of 0.17 mag (Gieren et al. 1998). There is a small contribution from distance errors of individual calibrating Cepheids, which according to Gieren et al. are accurate to $\pm 3\%$. Taking this into account, we find intrinsic dispersion of the $P - L$ relation to be 0.157 mag. This corresponds to 7.2% uncertainty of distances derived with Eq. (1) and of angular diameter amplitudes derived with Eq. (6).

Estimating uncertainty of $\langle R \rangle$ and $\langle \theta \rangle$ is somewhat more elaborate. We will do it with the help of simple theoretical relations. First, we recall that Cepheids obey well known period–mass–radius relation (e.g. Moskalik & Buchler 1993):

$$P \approx M^{-0.68} \langle R \rangle^{1.70}. \quad (7)$$

Vast majority of Pop. I Cepheids undergo core helium burning. Stars in this evolutionary phase obey a mass–luminosity relation:

$$\log(\langle L \rangle) = 3.55 \log M + \text{const.} \quad (8)$$

We adopted here the slope derived for metalicity of $Z = 0.02$ by Alibert et al. (1999), but evolutionary calculations of other authors yield very similar values. Combining Eqs. (7) and (8) we find that at a constant period, luminosity and radius of a Cepheid are related by

$$\log(\langle L \rangle) = 8.88 \log(\langle R \rangle) + \text{const.} \quad (9)$$

Knowing intrinsic dispersion of the $P - L$ relation, we find intrinsic dispersion of the $P - R$ relation to be $\sigma(\log(\langle R \rangle)) = 0.007$, or equivalently $\sigma(\langle R \rangle)/\langle R \rangle = 1.6\%$.

The estimate of mean angular diameter of a Cepheid is based on its mean radius and its distance. It is evident, that uncertainty of $\langle \theta \rangle$ is dominated by intrinsic dispersion of the distance determination. However, when derived from $P - R$ and $P - L$ relations, the radius and the distance are not independent and their inaccuracies compensate each other. Indeed, Eq. (9) shows that if Cepheid’s radius is larger than average for its period, its luminosity (and consequently derived distance) is also larger. Taking this into account, we find $\sigma(\log(\langle \theta \rangle)) = 0.39 \sigma(\log(\langle L \rangle))$. Thus, 0.157 mag intrinsic dispersion of the $P - L$
relation implies 5.6% uncertainty of mean angular diameters estimated with Eq. (5).

Apart from the intrinsic width of the instability strip, the accuracy of \( \langle \theta \rangle \) and \( \Delta \theta \) estimation is also affected by observational errors. Of these, by far the most important is the error of the colour excess \( E(B - V) \), which is \( \sim 0.03 \) mag (Fernie 1990). This corresponds to the distance uncertainty of 4.6%. Taking into account both intrinsic and random scatter, we find that our method should yield \( \langle \theta \rangle \) and \( \Delta \theta \) accurate to 7.2% and to 8.5%, respectively (1\( \sigma \) errors).

The error budget presented here does not account for systematical errors, which may result from poor knowledge of \( P - L \) and \( P - R \) relations or of the projection factor \( p \). The question of possible systematical bias of our method will be addressed in Section 5.1.

### 3 The Data

For the purpose of this paper, we limited the analysis to brightest Pop. I Cepheids, specifically to those with \( \langle V \rangle < 8.0 \) mag. The starting source was the online DDO Database of Galactic Classical Cepheids (Fernie et al. 1995), which includes 81 stars satisfying our brightness criterion. We supplemented this catalog with three recently discovered bright Cepheids: CK Cam, V898 Cen and V411 Lac. We excluded from the list four double-mode variables (CO Aur, TU Cas, EW Sct, and U TrA) as well as a peculiar variable amplitude Cepheid V473 Lyr. Because of complicated form of pulsations, these stars are not suitable targets for interferometric investigation. Our final sample contains 79 objects.

In our analysis, we adopted intensity mean magnitudes \( \langle V \rangle \) and colour excesses \( E(B - V) \) given by DDO Database. The latter are defined on a uniform scale of Fernie (1990). For \( \alpha \) UMi and V1334 Cyg, colour excesses in DDO Database are negative. We assumed \( E(B - V) = 0 \) for these two stars. For CK Cam and V411 Lac, the values of \( \langle V \rangle \) were taken from Berdnikov et al. (2000) and from Groenewegen & Oudmaijer (2000), respectively. In case of V898 Cen, we determined \( \langle V \rangle \) directly from published photometry (Berdnikov et al. 1999; Berdnikov & Caldwell 2001; Berdnikov & Turner 2001). The colour excesses of CK Cam and V898 Cen were calculated with formula of Fernie (1994), which puts them on the same scale as used in DDO Database. For V411 Lac, \( E(B - V) \) was determined by comparing observed \( (B - V) \) colour (Groenewegen & Oudmaijer 2000) with \( (B - V)_0 \), predicted by period–colour relation of Laney & Stobie (1994).

The radial velocity data were collected from literature and supplemented, when needed, by unpublished data available to the authors. No \( V_r \) measurements were found for V737 Cen, V898 Cen and LR TrA. Several Cepheids display orbital velocity variations. This is the case for U Aql, FF Aql, V496 Aql, RX Cam, XX Cen, AX Cir, BP Cir, SU Cyg, V1334 Cyg, T Mon, S Mus, AW Per, S Sge, W Sgr, V350 Sgr, V636 Sco, U Vul and \( \alpha \) UMi. For these stars, orbital motion was removed before pulsation velocity curve was built. We refer the reader to Moskalik et al. (2005) for detailed discussion of this procedure,
Table 1: Predicted Angular Diameters of Bright Classical Cepheids

| Star   | log $P$ | $\langle V \rangle$ | $E(B-V)$ | d     | $\langle R \rangle$ | $\Delta R$ | $\langle \theta \rangle$ | $\Delta \theta$ |
|--------|---------|---------------------|----------|-------|--------------------|------------|---------------------|----------------|
| ℓ Car  | 1.551   | 3.724               | 0.170    | 564   | 173.0              | 33.060     | 2.854               | 0.545          |
| SV Vul | 1.653   | 7.220               | 0.570    | 1748  | 206.5              | 50.755     | 1.099               | 0.270          |
| U Car  | 1.588   | 6.288               | 0.283    | 1622  | 184.7              | 44.013     | 1.059               | 0.252          |
| RS Pup | 1.617   | 6.947               | 0.446    | 1778  | 193.9              | 47.730     | 1.015               | 0.250          |
| η Aql  | 0.856   | 3.897               | 0.149    | 263   | 52.1               | 6.386      | 1.845               | 0.226          |
| T Mon  | 1.432   | 6.124               | 0.209    | 1382  | 140.9              | 32.557     | 0.949               | 0.219          |
| β Dor  | 0.993   | 3.731               | 0.044    | 339   | 66.0               | 7.823      | 1.810               | 0.214          |
| X Cyg  | 1.214   | 6.391               | 0.288    | 1054  | 96.8               | 20.870     | 0.855               | 0.184          |
| δ Cep  | 0.730   | 3.954               | 0.092    | 251   | 41.9               | 4.870      | 1.554               | 0.181          |
| RZ Vel | 1.310   | 7.079               | 0.335    | 1519  | 114.1              | 27.793     | 0.699               | 0.170          |
| ζ Gem  | 1.006   | 3.918               | 0.018    | 391   | 67.6               | 6.712      | 1.607               | 0.160          |
| TT Aql | 1.138   | 7.141               | 0.495    | 988   | 84.9               | 16.721     | 0.800               | 0.158          |
| W Sgr  | 0.881   | 4.668               | 0.111    | 410   | 54.4               | 6.632      | 1.235               | 0.151          |
| X Sgr  | 0.846   | 4.549               | 0.197    | 326   | 51.2               | 4.790      | 1.463               | 0.137          |
| Y Oph  | 1.234   | 6.169               | 0.655    | 558   | 100.1              | 8.044      | 1.668               | 0.134          |
| VY Car | 1.279   | 7.443               | 0.243    | 1986  | 108.1              | 23.831     | 0.507               | 0.112          |
| S Sge  | 0.923   | 5.622               | 0.127    | 655   | 58.5               | 7.177      | 0.832               | 0.102          |
| Y Sgr  | 0.761   | 5.744               | 0.205    | 502   | 44.3               | 5.327      | 0.821               | 0.099          |
| U Aql  | 0.847   | 6.446               | 0.399    | 575   | 51.3               | 5.994      | 0.830               | 0.097          |
| U Vul  | 0.903   | 7.128               | 0.654    | 573   | 56.5               | 5.574      | 0.917               | 0.091          |
| U Sgr  | 0.829   | 6.695               | 0.403    | 626   | 49.7               | 5.741      | 0.739               | 0.085          |
| S Nor  | 0.989   | 6.394               | 0.189    | 924   | 65.6               | 7.809      | 0.661               | 0.079          |
| S Mus  | 0.985   | 6.118               | 0.147    | 863   | 65.1               | 7.147      | 0.703               | 0.077          |
| RX Cam | 0.898   | 7.682               | 0.569    | 837   | 56.1               | 6.776      | 0.623               | 0.075          |
| AW Per | 0.810   | 7.492               | 0.534    | 724   | 48.2               | 5.728      | 0.619               | 0.074          |
| RT Aur | 0.571   | 5.446               | 0.051    | 435   | 31.9               | 3.308      | 0.682               | 0.071          |
| W Gem  | 0.898   | 6.950               | 0.283    | 923   | 56.1               | 7.084      | 0.566               | 0.071          |
| R Mus  | 0.876   | 6.298               | 0.120    | 851   | 53.9               | 6.184      | 0.590               | 0.068          |
| AX Cir | 0.722   | 5.880               | 0.153    | 550   | 41.4               | 3.933      | 0.700               | 0.067          |
| V Cen  | 0.740   | 6.836               | 0.289    | 711   | 42.6               | 5.096      | 0.559               | 0.067          |
| T Vul  | 0.647   | 5.754               | 0.064    | 541   | 36.3               | 3.656      | 0.625               | 0.063          |
| YZ Sgr | 0.980   | 7.358               | 0.292    | 1217  | 64.6               | 7.740      | 0.494               | 0.059          |
| RV Sco | 0.783   | 7.040               | 0.342    | 760   | 45.9               | 4.716      | 0.562               | 0.058          |
| R Cru  | 0.765   | 6.766               | 0.192    | 823   | 44.6               | 4.986      | 0.504               | 0.056          |
| S TrA  | 0.801   | 6.397               | 0.100    | 835   | 47.4               | 4.912      | 0.528               | 0.055          |
| XX Cen | 1.040   | 7.818               | 0.260    | 1702  | 71.6               | 10.016     | 0.391               | 0.055          |
| S Cru  | 0.671   | 6.600               | 0.163    | 708   | 37.9               | 4.124      | 0.498               | 0.054          |
| V636 Sco| 0.832  | 6.654               | 0.217    | 819   | 50.0               | 4.766      | 0.568               | 0.054          |
| RX Aur | 1.065   | 7.655               | 0.276    | 1592  | 74.8               | 9.167      | 0.437               | 0.054          |
| BB Sgr | 0.822   | 6.947               | 0.284    | 836   | 49.1               | 4.779      | 0.547               | 0.053          |
Table 1: – continued

| Star        | log $P$ | $\langle V \rangle$ | $E(B-V)$ | d    | $\langle R \rangle$ | $\Delta R$ | $\langle \theta \rangle$ | $\Delta \theta$ |
|-------------|---------|---------------------|----------|------|-------------------|-----------|---------------------|-------------|
| T Cru       | 0.828   | 6.566               | 0.193    | 811  | 49.7              | 4.279     | 0.570               | 0.049       |
| AP Sgr      | 0.704   | 6.955               | 0.192    | 831  | 40.1              | 4.419     | 0.449               | 0.049       |
| V350 Sgr    | 0.712   | 7.438               | 0.312    | 893  | 40.7              | 4.510     | 0.424               | 0.047       |
| ER Car      | 0.888   | 6.824               | 0.101    | 1132 | 55.0              | 5.311     | 0.452               | 0.044       |
| BG Vel      | 0.840   | 7.635               | 0.448    | 915  | 50.7              | 4.266     | 0.516               | 0.043:       |
| FF Aql      | 0.650   | 5.372               | 0.224    | 434  | 47.8              | 1.983     | 1.024               | 0.042       |
| SU Cyg      | 0.585   | 6.859               | 0.096    | 792  | 32.6              | 3.556     | 0.383               | 0.042       |
| CK Cam      | 0.518   | 7.544               | 0.457    | 577  | 29.1              | 2.626     | 0.469               | 0.042       |
| BF Oph      | 0.609   | 7.337               | 0.247    | 809  | 34.0              | 3.438     | 0.391               | 0.040       |
| AP Pup      | 0.706   | 7.371               | 0.208    | 985  | 40.2              | 4.084     | 0.380               | 0.039       |
| V Vel       | 0.641   | 7.589               | 0.209    | 1002 | 35.9              | 4.168     | 0.334               | 0.039       |
| V381 Cen    | 0.706   | 7.653               | 0.205    | 1127 | 40.2              | 4.454     | 0.332               | 0.037:       |
| V482 Sco    | 0.656   | 7.965               | 0.360    | 965  | 36.9              | 3.826     | 0.356               | 0.037       |
| V Car       | 0.826   | 7.362               | 0.174    | 1201 | 49.5              | 4.665     | 0.383               | 0.036       |
| V636 Cas    | 0.923   | 7.199               | 0.700    | 566  | 58.5              | 2.134     | 0.961               | 0.035       |
| AT Pup      | 0.824   | 7.957               | 0.183    | 1555 | 49.3              | 5.929     | 0.295               | 0.035:       |
| R TrA       | 0.530   | 6.660               | 0.127    | 644  | 29.7              | 2.207     | 0.429               | 0.032       |
| V1344 Aql   | 0.874   | 7.767               | 0.574    | 837  | 53.7              | 2.873     | 0.597               | 0.032       |
| V496 Aql    | 0.833   | 7.751               | 0.413    | 1008 | 50.1              | 3.390     | 0.462               | 0.031       |
| AH Vel      | 0.626   | 5.695               | 0.074    | 614  | 45.8              | 1.931     | 0.695               | 0.029       |
| V1162 Aql   | 0.730   | 7.798               | 0.205    | 1242 | 42.0              | 3.817     | 0.314               | 0.029       |
| SZ Tau      | 0.498   | 6.531               | 0.294    | 548  | 36.6              | 1.561     | 0.621               | 0.027       |
| SU Cas      | 0.290   | 5.970               | 0.287    | 328  | 25.4              | 0.916     | 0.721               | 0.026       |
| MY Pup      | 0.756   | 5.677               | 0.064    | 730  | 57.5              | 1.566     | 0.734               | 0.020       |
| V659 Cen    | 0.750   | 6.598               | 0.134    | 995  | 57.0              | 2.135     | 0.533               | 0.020       |
| GH Lup      | 0.967   | 7.635               | 0.364    | 1220 | 63.2              | 2.561     | 0.482               | 0.020       |
| DT Cyg      | 0.398   | 5.774               | 0.039    | 501  | 30.7              | 0.944     | 0.570               | 0.018       |
| BG Cru      | 0.524   | 5.487               | 0.053    | 505  | 38.3              | 0.930     | 0.705               | 0.017       |
| IR Cep      | 0.325   | 7.784               | 0.434    | 632  | 27.0              | 1.122     | 0.398               | 0.017       |
| V950 Sco    | 0.529   | 7.302               | 0.267    | 847  | 38.6              | 1.472     | 0.424               | 0.016       |
| AV Cir      | 0.486   | 7.439               | 0.397    | 701  | 35.9              | 1.185     | 0.476               | 0.016       |
| α UMi       | 0.599   | 1.982               | 0.000    | 120  | 43.7              | 0.173     | 3.388               | 0.013       |
| V440 Per    | 0.879   | 6.282               | 0.273    | 822  | 71.5              | 1.066     | 0.809               | 0.012       |
| BP Cir      | 0.380   | 7.560               | 0.235    | 828  | 29.7              | 1.047     | 0.394               | 0.012       |
| V1334 Cyg   | 0.523   | 5.871               | 0.000    | 653  | 38.2              | 0.797     | 0.545               | 0.011       |
| V411 Lac    | 0.464   | 7.860               | 0.171    | 1166 | 34.5              | 1.326     | 0.275               | 0.011:       |
| V737 Cen    | 0.849   | 6.719               | 0.216    | 863  | 51.5              | 0.555     | —                   | —           |
| LR TrA      | 0.385   | 7.808               | 0.281    | 871  | 30.0              | 0.321     | —                   | —           |
| V898 Cen    | 0.547   | 7.959               | 0.000    | 1762 | 39.9              | 0.211     | —                   | —           |
as well as for the list of velocity data used in the current paper. We would like to stress that the list of binaries given above is not intended to be complete. Several other Cepheids are likely binaries, e.g. U Car and T Cru (Bersier 2002) or X Sgr (Szabados 1990), but their orbital motion does not show up in the data used here.

Our Cepheid sample contains eighteen overtone pulsators. Except of α UMi, they have all been identified by Fourier decomposition of their lightcurves (Antonello et al. 1990; Zakrzewski et al. 2000) or radial velocity curves (Kienzle et al. 1999, 2000; Moskalik et al. 2005). The overtone nature of Polaris was first established by Feast & Catchpole (1997) on the basis of Hipparcos parallax. It was later confirmed with different methods by Moskalik & Ogozla (2000) and by Nordgren et al. (2000).

4 Results

Results of our calculations are summarized in Table 1. For each Cepheid we list logarithm of observed period $\log P$ in [d], intensity mean magnitude $\langle V \rangle$ and colour excess $E(B-V)$, both in [mag], inferred distance $d$ in [pc], mean radius $\langle R \rangle$ and full amplitude of radius variations $\Delta R = R_{\text{max}} - R_{\text{min}}$, both in units of $R_\odot$, and mean angular diameter $\langle \theta \rangle$ and full amplitude of angular diameter variations $\Delta \theta$, both in [mas]. First overtone pulsators are marked with symbol FO placed next to the Cepheid’s name. The stars are ordered by decreasing $\Delta \theta$.

For three Cepheids listed at the bottom of Table 1, $\Delta R$ and $\Delta \theta$ cannot be calculated because of lack of radial velocity data. For these stars only rough estimates can be given. From our Cepheid sample we find $\Delta R/(\langle R \rangle) = 0.020-0.045$ for the overtone pulsators and $\Delta R/(\langle R \rangle) = 0.070-0.125$ for the fundamental mode pulsators with $\log P \sim 0.85$. On this basis, we estimate angular diameter amplitudes to be in the range of $0.039-0.069$ mas for V737 Cen, $0.006-0.014$ mas for LR TrA and $0.004-0.009$ mas for V898 Cen.

4.1 Comparison with Observations

It is instructive to compare Cepheid angular diameters predicted in Table 1 with those determined from actual interferometric observations. So far, mean angular diameters were measured for nine Pop. I Cepheids, but angular diameter variability was detected only in five of them. These observational results are summarized in Table 2. The values of $\langle \theta \rangle$ (and their errors) were taken from Kervella et al. (2004b), except of α UMi, for which result of Nordgren et al. (2000) is listed. The amplitudes of angular diameter variations, $\Delta \theta$, are usually not given in the papers. We recovered them from plots of Kervella et al. (2004a) and Lune et al. (2002). For η Aql, weighted mean of the two measurements is given. In all cases we assumed, somewhat arbitrarily, that the error of $\Delta \theta$ determination is the same as the corresponding error of $\langle \theta \rangle$. 
Table 2: Observed Angular Diameters of Cepheids

| Star     | log $P$ | $\langle \theta_{LD} \rangle$ | $\Delta \theta_{LD}$ |
|----------|---------|-------------------------------|----------------------|
| $\alpha$ UMi | 0.599   | 3.280 ± 0.020                | ——                   |
| $\delta$ Cep | 0.730   | 1.521 ± 0.010                | ——                   |
| X Sgr     | 0.846   | 1.471 ± 0.033                | ——                   |
| $\eta$ Aql | 0.856   | 1.791 ± 0.022                | 0.212 ± 0.026        |
| W Sgr     | 0.881   | 1.312 ± 0.029                | 0.163 ± 0.029        |
| $\beta$ Dor | 0.993   | 1.884 ± 0.024                | 0.207 ± 0.024        |
| $\zeta$ Gem | 1.006   | 1.688 ± 0.022                | 0.179 ± 0.030        |
| Y Oph     | 1.234   | 1.438 ± 0.051                | ——                   |
| $\ell$ Car | 1.551   | 2.988 ± 0.012                | 0.529 ± 0.012        |

NOTE – $\langle \theta_{LD} \rangle$ and $\Delta \theta_{LD}$ (in [mas]) are limb darkened angular diameters, see e.g. Kervella et al. (2004a).

In Fig. 1 we plot observed vs. predicted values of $\langle \theta \rangle$ and $\Delta \theta$ for Cepheids of Table 2. A very good overall agreement is evident. Ratios of observed-to-predicted values of $\langle \theta \rangle$ and of $\Delta \theta$ are plotted vs. fundamental mode period in Fig. 2. The ratios show no trends with the pulsation period. Predicted angular diameter amplitudes, $\Delta \theta_{\text{pred}}$, differ from the observed ones by no more than 1.3$\sigma$. The weighted mean of $\Delta \theta_{\text{obs}}/\Delta \theta_{\text{pred}}$ ratio is

$$\frac{\Delta \theta_{\text{obs}}}{\Delta \theta_{\text{pred}}} = 0.973 \pm 0.021.$$  

In case of $\langle \theta \rangle_{\text{obs}}/\langle \theta \rangle_{\text{pred}}$, a statistically significant scatter of $\sigma = 0.042$ is seen. This is not unexpected and reflects intrinsic dispersion of $P - L$ and $P - R$ relations used to estimate $\langle \theta \rangle$. The weighted mean of $\langle \theta \rangle_{\text{obs}}/\langle \theta \rangle_{\text{pred}}$ ratio is

$$\frac{\langle \theta \rangle_{\text{obs}}}{\langle \theta \rangle_{\text{pred}}} = 1.011 \pm 0.014.$$  

We conclude, that the method outlined in Section 2 yields estimates of $\langle \theta \rangle$ and of $\Delta \theta$, which are statistically unbiased and in good agreement with the observations across the entire range of pulsation periods.

### 4.2 Prospective Targets for Interferometric Observations

In Fig. 3 we display $\langle \theta \rangle$ and $\Delta \theta$ vs. pulsation period for all Cepheids of our sample. Fundamental mode and overtone pulsators are plotted as filled and open circles, respectively.

At currently demonstrated level of technology, the achievable accuracy of $\langle \theta \rangle$ determination is about 0.01 mas (see Table 2). This implies a lower limit of $\langle \theta \rangle = 1.0$ mas, if measurement with 1% accuracy is required. Angular diameters of 13 Cepheids are above this limit, four of which have not been yet observed.
Figure 1: Observed vs. predicted mean angular diameters (top) and angular diameter amplitudes (bottom) for Cepheids of Table 2. Error bars of $\langle \theta \rangle$ are smaller than the symbols. The dotted lines have slope of unity and are not fits to the data.
Figure 2: $\langle \theta \rangle_{\text{obs}}/\langle \theta \rangle_{\text{pred}}$ (top) and $\Delta \theta_{\text{obs}}/\Delta \theta_{\text{pred}}$ (bottom) vs. fundamental mode period for Cepheids of Table 2. Period of $\alpha$ UMi was fundamentalized with Eq.(2)
Figure 3: Predicted mean angular diameters (top) and full amplitudes of angular diameter variations (bottom) for Classical Cepheids brighter than $\langle V \rangle = 8.0$ mag. Fundamental and overtone pulsators are plotted with filled and open circles, respectively. Reference values of $\langle \theta \rangle = 1.0$ mas and $\Delta \theta = 0.15$ mas (see text) are marked with dotted lines.
(SV Vul, U Car, RS Pup and overtone pulsator FF Aql). Measuring \( \langle \theta \rangle \) with 2\% precision is achievable for additional 39 stars.

Most interesting for interferometric observations are those Cepheids, whose angular diameter variations can be detected. Such a feat has been possible for stars with \( \Delta \theta > 0.15 \text{ mas} \) (cf. Table 2). 13 Cepheids satisfy this condition. These variables cover uniformly the period range of \( \log P = 0.73 - 1.65 \) (see Fig. 3) and as such, are very well suited for calibration of Cepheid \( P - \dot{L} \) and \( P - \dot{R} \) relations. So far, only for five of them angular diameter variations have been measured. The remaining eight Cepheids are SV Vul, U Car, RS Pup, T Mon, X Cyg, \( \delta \) Cep, RZ Vel, and TT Aql. Their pulsations can be resolved with accuracy already demonstrated by existing interferometers. We encourage observers to concentrate their efforts on these objects.

5 Conclusions

Optical/near infrared long-baseline interferometry offers new ways of studying Cepheid pulsations. With the goal of aiding such studies, we calculated expected mean angular diameters and amplitudes of angular diameter variations for all monoperiodic Population I Cepheids brighter than \( \langle V \rangle = 8.0 \text{ mag} \). Distances to the stars and their mean linear radii were estimated with \( P - \dot{L} \) (\( V \)-band) and \( P - \dot{R} \) relations, respectively. The amplitudes of radius variations were calculated precisely, by integrating the observed radial velocity curves. Resulting mean angular diameters and angular diameter amplitudes are listed in Table 1. This catalog is intended to serve as a planning tool for future interferometric observations of Cepheids.

Of particular interest are Cepheids, in which angular diameter changes associated with pulsations can be detected. For such stars, distances and linear radii can be determined by purely geometrical Baade-Wesselink method (e.g. Lane et al. 2000; Kervella et al. 2004a). This approach combines measured angular diameter variations with linear displacement of the photosphere, inferred by integrating the observed radial velocity curve.

Determination of mean angular diameter, which is possible for many more Cepheids, is also of great interest. Such measurements combined with accurately calibrated period–radius relation can yield distances to low amplitude or far away Cepheids, whose angular diameter changes are too small to be detected. This will vastly enlarge the sample of objects available for calibrating Cepheid \( P - \dot{L} \) relation.

Measuring angular diameters for many Cepheids covering widest possible range of effective temperatures is also invaluable for precise calibration of surface brightness-colour relations (Nordgren et al. 2002; Kervella et al. 2004c). These relations are a cornerstone of the near-IR Barnes-Evans method, which has a potential of measuring accurate distances even to Cepheids in the Magellanic Clouds (e.g. Storm et al. 2004; Gieren et al. 2005).

We identified 13 Cepheids with angular diameter amplitudes large enough to be measured with precision already provided by VINCI/VLTI and PTI inter-
ferometers. For seven of them, no interferometric observations exist and for the eighth one (δ Cep) only mean angular diameter was published. Five of these stars are easily accessible to VLTI facility.

With VLTI/AMBER interferometer (baseline 202m) coming into service in 2005 and CHARA array already in operation (baseline of 330m), the number of Cepheids accessible to interferometric study will sharply increase. Currently, the magnitude limit for both instruments is $K \sim 6$mag (Sturmann et. al. 2003; AMBER Commissioning 2 preliminary report, [http://www-laog.obs.ujf-grenoble.fr/amber/]. This places almost all Cepheids of our sample within reach. Both AMBER and CHARA can work not only in $K$-band ($\lambda = 2.18\mu m$), but also in $H$-band ($\lambda = 1.65\mu m$). With shorter wavelength and longer baseline the expected angular resolution will increase 2-3 times, as compared to VINCI/VLTI performance. Consequently, the number of Cepheids, for which angular diameter variations (hence geometrical distances) can be measured will more than double, reaching $\sim 30$. The mean angular diameters could be determined to 1% precision in more than 50 Cepheids and to 2% precision in all Cepheids of our sample. With planned extension of CHARA and AMBER capabilities to $J$-band and eventually to $V$-band, further increase in resolution is expected in the future. The list of Cepheids with interferometrically detectable pulsations will continue growing longer, creating excellent prospect for very accurate calibration of Cepheid $P - L$ and $P - R$ relations.

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