LETTER TO THE EDITOR

Pseudomagnitude Distances: Application to the Pleiades cluster

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ABSTRACT

The concept of pseudomagnitude was recently introduced by Chelli et al. (2016), to estimate apparent stellar diameters using a strictly observational methodology. Pseudomagnitudes are distance indicators, which have the remarkable property of being reddening free. In this study, we use Hipparcos parallax measurements to compute the mean absolute pseudomagnitudes of solar neighbourhood dwarf stars as a function of their spectral type. To illustrate the use of absolute pseudomagnitudes, we derive the distance moduli of 360 Pleiades stars and find that the centroid of their distribution is 5.715 ± 0.018, corresponding to a distance of 139.0 ± 1.2 pc. We locate the subset of ~ 50 Pleiades stars observed by Hipparcos at a mean distance of 135.5 ± 3.7 pc, thus confirming the frequently reported anomaly in the Hipparcos measured distances of these stars.

Key words. stars: distances – methods: observational – methods: data analysis – techniques: photometric

1. Introduction

In astrophysics, the calculation of interstellar extinction is a complex and recurring problem. For many objects, such as those buried in star-forming regions, unreddening the photometries is a difficult and demanding task. In the case of a star, the calculation of interstellar extinction requires a detailed knowledge of its luminosity class, spectral type, and intrinsic colors. That is a lot of parameters, not always available, whose robustness is often uncertain. This leads to the accumulation of errors, and makes it nearly impossible to attempt any massive statistical analysis.

We recently introduced the concept of pseudomagnitude for the calculation of the apparent size of stars, thus avoiding to deal with the problem of visual extinction (Chelli et al. 2014, 2016). This has allowed us to compile a catalogue of 453,000 angular diameters, with an accuracy of the order of 1% (2% systematic). Pseudomagnitudes are linear combinations of magnitudes constructed in such a way as to eliminate interstellar extinction. They are purely observational quantities that are unaffected by reddening effects, and can be applied to any type of object. As in the case of magnitudes, pseudomagnitudes are distance indicators, and absolute pseudomagnitudes, measured at a distance of 10 pc, are luminosity indicators.

Knowledge of the pseudomagnitudes and absolute pseudomagnitudes of stars allows their distance to be estimated. In the present study, we use the parallax measurements of Hipparcos (ESA 1997; van Leeuwen 2007) to calculate the mean absolute pseudomagnitude of field dwarf stars, as a function of their spectral type. As an example, we use this technique to determine the centroid of the distance distribution of 360 stars in the Pleiades cluster.

In section 2, we explain the concept of pseudomagnitudes. In section 3, we use distance filtered parallax measurements to calculate the mean absolute pseudomagnitudes (V,J) and (V,Ks) of dwarf stars, and the centroid of the distance distribution of our Pleiades stars is calculated and discussed in section 4.

2. Pseudomagnitudes

We define the pseudomagnitude pm_{i,j} of an astrophysical object as follows:

\[ pm_{i,j} = \frac{c_i m_j - c_j m_i}{c_i - c_j} \]  (1)

where \( m_i \) and \( m_j \) are the magnitudes measured in the photometric bands \( i \) and \( j \), \( c_i \) (resp. \( c_j \)) is the ratio of the interstellar extinction coefficients \( R_i \) and \( R_j \) between band \( i \) and the visible band. We note that when one of the coefficients \( c_i \) or \( c_j \) tends to zero, the pseudomagnitude tends to the magnitude \( m_i \) or \( m_j \). The pseudomagnitude is by construction a reddening free distance indicator. It can be written as:

\[ pm_{i,j} = \frac{c_i M_j - c_j M_i}{c_i - c_j} + DM \]  (2)

where \( M_i \) and \( M_j \) are absolute magnitudes and \( DM \) is the distance modulus. At this stage, we define the absolute pseudomagnitude \( PM_{i,j} \) as:

\[ PM_{i,j} = \frac{c_i M_j - c_j M_i}{c_i - c_j} = pm_{i,j} - DM \]  (3)

The absolute pseudomagnitude is a reddening free luminosity luminosity indicator that can be computed very easily. This requires the knowledge of two magnitudes and a distance. On the other hand, once the mean absolute pseudomagnitude has been calculated for a group of stars sharing the same physical properties, the distance modulus of a star from the same group can be estimated with the knowledge of just two magnitudes.

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3. Absolute pseudomagnitudes of dwarf stars

For our calculations, we use Eqs.1 and 3, with the second reduction of Hipparcos parallaxes (van Leeuwen 2007), the spectral type and the magnitude pairs (V,J), (V,H) and (V,Ks) provided by SIMBAD. We adopt the interstellar extinction coefficients determined by Fitzpatrick (1999), thus leading to the following expressions for the pseudomagnitudes:

\[
\begin{align*}
    pm_{(V,J)} &= 1.389 \times m_J - 0.389 \times m_V \\
    pm_{(V,H)} &= 1.205 \times m_H - 0.205 \times m_V \\
    pm_{(V,Ks)} &= 1.136 \times m_{Ks} - 0.136 \times m_V
\end{align*}
\]

(4)

3.1. Hipparcos data

A priori, the absolute pseudomagnitude of a group of stars with the same spectral type and luminosity class should be constant as a function of distance. Figure 1a plots the pseudomagnitude (V,Ks) of Hipparcos class III and V stars with a spectral type K0 (3747 objects), as a function of their distance modulus. Figure 1b shows the absolute pseudomagnitude (V,Ks), with the dwarfs lying at the top and the giants lying at the bottom. For the same class of stars it is firstly constant, to within the limits resulting from noise, but beyond a certain distance it then appears to decrease. It is a mere artifact, due to the fact that below 10% noise, the inverse of the parallax begins to be numerically biased. In this example, 75% of the dwarfs and only 26% of the giants have a parallax noise smaller than 10%.

3.2. Practical absolute pseudomagnitude calculation

In order to calculate the mean absolute pseudomagnitudes of dwarf stars, we proceed as follows: a) we consider all of the stars in the Hipparcos catalogue having the same spectral type, with or without selecting their luminosity class, depending on the possible degree of confusion; b) we place a limit on the distance of the sample in order to minimize the influence of the numerical bias; c) since we do not control the astrophysical biases (see below), we assume that all of the objects are statistically equivalent, and adjust the fit of the absolute pseudomagnitude distribution to one, or even—in some cases—to two Gaussian functions.

This is a difficult operation because the absolute pseudomagnitude distribution is not always strictly Gaussian. In practice, stars from the same luminosity class and with the same spectral type often have stratified luminosities as a function of their distance. This phenomenon confirms what was already known, i.e. that for any given spectral type and class of luminosity, there are hidden sub-classes of stars with distinct physical properties. Although the absolute pseudomagnitudes would permit a detailed investigation of these physical properties, for the time being we do not have sufficient statistical information to implement such an analysis. This will become possible when the measurements provided by GAIA (de Bruijne 2012) become available.

Manual calculations were made for each spectral type, and were repeated several times on various samples of stars. These were based on the analysis of the pseudomagnitudes of approximately 6000 dwarf stars, distributed over 56 spectral sub-types. It corresponds to about 25% of the Hipparcos stars identified as dwarfs. 90% of the selected data have a parallax with less than 10% noise, 98% less than 20%. Figure 2 shows the mean absolute pseudomagnitudes (V,Ks) of these dwarf stars as a function of their spectral types, ranging from O9 to M4.

The median statistical error on the mean absolute pseudomagnitudes is equal to 0.03 magnitudes, which corresponds to an error of 1.5% in terms of distance. For a given group of stars, the observed dispersions can be accounted for by the natural width of the group, which is increased by the influence of multiplicity, errors of magnitude, distance and classification. To a lesser extent, they also reflect the star’s age or metallicity. We estimate, to within a factor of 2, that the systematic error on a correctly characterised single dwarf star is of the order of 0.05 magnitude.

Although pseudomagnitudes have many potential applications, the most immediate of these is the determination of the mean distance of a spatially concentrated group of stars, as for
example in the case of stellar clusters and galaxies. In the following section we calculate the centroid of the distance distribution of 360 stars in the Pleiades cluster, and whenever possible compare our results with those obtained by other authors.

4. Pseudomagnitude distance of the Pleiades

The Pleiades is one of the most commonly observed young open clusters, and the properties of its stars provide a de facto definition of the properties of main sequence stars at age zero. Numerous studies continue to be published regarding the census of this cluster’s coeval stars, and the highest possible accuracy is needed in their distance determinations in order to test the models of stellar structure and evolution. The pseudomagnitude method can be applied to all of the stars in this cluster, for which it is perfectly adapted to the calculation of the cluster’s mean distance, and could even be sufficient for the accurate evaluation of the individual distances of these stars (see section 4.3).

4.1. On the Pleiades distance controversy

Whereas an history of distance estimations of the Pleiades cluster can be found in An et al. (2007) and Melis et al. (2014), Table 1 provides a summary of the measurements published in the last 20 years. Various methods have been used. Excluding Hipparcos, the other direct distance measurements (ground and spaceborne parallaxes, binaries, VLBI) have relied on the analysis of a total of ≈ 30 stars, and position the Pleiades at a distance between 130 and 139 pc. The indirect photometric methods were applied on a total of ≈ 120 stars and have positioned the cluster at a distance of 132 pc. In contrast, the mean distance of 54 Pleiades stars of spectral types B, A and F by Hipparcos (van Leeuwen 2009) lead to the controversial distance of 120.2 ± 1.7 pc, which is indeed markedly lower (by 10%) than all other measurements.

It should be recalled that the Pleiades cluster probably contains more than one thousand stars. When projected onto the sky, it extends over a distance of the order of 10 to 20 pc, and it would be reasonable to assume that the Pleiades has a similar size along its line of sight when viewed from Earth. Under these conditions, the distances measured on a few, or even a few tens of objects, with an accuracy much better than the cluster’s expected size, are representative of these objects distances only. In view of the size of this cluster, it could well be possible to find star concentrations at distances of the order of 15 pc from one another. The controversy does not have as much to do with the so-called distance of the Pleiades cluster2, as with the mean distance of the 54-odd stars used in the Hipparcos estimate.

It is difficult to compare various distance measurements, as they are based on generally small and generally disjoint samples of stars. The Hipparcos sample was not used by other independent distance estimations, it was only reused in new attempts to refine the Hipparcos reduction, first by Makarov (2002) which led to a distance of 129.0 ± 3.3 pc, and then by van Leeuwen (2009), who determined a value of only 120.2 ± 1.7 pc. We note that in view of their uncertainties, these two distance estimations are only marginally (2.4σ) different.

Our absolute pseudomagnitude calibration allows us to evaluate the distance of any sample of stars. In the following section, we calculate the distance of 360 Pleiades stars, as well as that of the Hipparcos sample.

4.2. Distance of 360 Pleiades stars

In this section, we assume that Pleiades stars have, at the same spectral types, the same pseudomagnitudes (VJ), (VH) and (VKs) that field dwarfs. Significant differences occur for cool stars somewhere within the M spectral class. Our sample of Pleiades stars was obtained from a total of 3721 stars associated with the “M45” identifier in the Simbad database. After filtering (multiplicity, variability, etc.), a total of 512 stars remained, of which only 360 had the required information for the calculation of their distance. As the Pleiades cluster is very young, in order to increase the size of our sample, we assumed all of the selected stars to be of luminosity class V. As the pseudomagnitude is sensitive to the luminosity class, any non-dwarf star will contribute to the broadening of the distance distribution, or will get a distance very different to that of the cluster and will thus be excluded from the analysis. We did not try to perform filtering for membership, non members will form a diffuse background that is taken into account in our statistical modeling.

We observe that, given the currently achievable precision on an individual star distance and the size of the cluster compared to its distance (≈ 10%), the concept of “Pleiades distance” is bound to loose its intended meaning.

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Table 1. Measured distances of Pleiades stars, errors are between parenthesis.

| Refs | Method | N | DM/distance (pc) |
|------|--------|---|-----------------|
| 1    | Hipparcos first release | 54 | 5.32 (0.05) / 115.9 (2.7) |
| 2    | Photometry | 55 | 5.60 (0.04) / 131.8 (2.4) |
| 3    | Moving cluster | 65 | 5.58 (0.18) / 130.6 (11.1) |
| 4    | Ground parallax | 9  | 5.58 (0.12) / 130.6 (7.0) |
| 5    | Photometry | 30 | 5.61 (0.03) / 132.4 (1.8) |
| 6    | Hipparcos (Makarov) | 54 | 5.55 (0.06) / 129.0 (3.3) |
| 7    | Binary | 1 | 5.60 (0.03) / 131.8 (1.8) |
| 8    | Binary | 1 | 5.65 (0.03) / 134.9 (1.9) |
| 9    | Binary | 1 | 5.60 (0.07) / 131.8 (4.2) |
| 10   | HST parallax | 10 | 5.66 (0.06) / 133.5 (3.7) |
| 11   | HST parallax | 3  | 5.65 (0.05) / 134.9 (3.1) |
| 12   | Binary | 1 | 5.72 (0.05) / 139.3 (3.2) |
| 13   | Hipparcos (van Leeuwen) | 54 | 5.40 (0.03) / 120.2 (1.7) |
| 14   | VLBI | 5  | 5.67 (0.02) / 136.2 (1.2) |
| 15   | Binary | 1 | 5.61 (0.08) / 132.4 (4.9) |
| 16   | Photometry | 120 | 5.62 (0.03) / 132.7 (1.8) |
| This work | Pseudomagnitude | 360 | 5.715 (0.018) / 139.0 (1.2) |

Fig. 3. Distance moduli distribution for 360 Pleiades stars, fitted by a Gaussian distribution plus second degree polynomial. The Gaussian dispersion (0.28 mag) is dominated by spectral classifications errors.
The adopted distance modulus of each object is the average of the distance moduli computed from the photometric pairs (VJ), (VH) and (VKs), and its error is the dispersion of the three estimates. The (VKs) pseudomagnitudes of our sample, outliers excluded, are shown in Figure 2b as a function of the spectral type. It is not a classical color-magnitude diagram. The observed dispersions per spectral type, 0.2 to 0.4 magnitude, are not imposed by the physics of the cluster but by spectral classifications errors, which is probably the limiting noise of our present approach. We fit the resulting distance modulus distribution by a Gaussian plus a second degree polynomial, see Figure 3. The centre of the Gaussian function provides the barycentre of the distance moduli of the 360 stars studied, i.e. 5.715±0.018, which corresponds to a distance of 139.0±1.2 pc. Although this comparison is somewhat risky, in view of the small samples used previously, our distance calculation is globally in agreement with most estimations, but tends to position the cluster at the high end of measured “distances”.

What of the stars measured by Hipparcos? We have all of the information needed to characterise 44 of the 54 stars given in the list of Makarov (2002). The distribution of their distance moduli exhibits two maxima, at approximately 5.4 and 5.7, a possible indication of sub-clustering. A gaussian fit of this distribution leads to a mean distance modulus of 5.66±0.06, i.e. a distance of 135.5±3.7 pc, respectively 1.3σ and 3.8σ above Makarov (2002) and van Leeuwen (2009) estimates. Our result tends to confirm that on average Hipparcos distances of these stars are underestimated. Soon we will have the answer on who is right or who is wrong. But the answer probably will not be as simple as yes or no.

However, the baby should not be thrown out with the bathwater, since all of our distance moduli were obtained using absolute pseudomagnitudes derived from correctly distance-filtered Hipparcos parallax measurements. The fact that we obtain a barycentric distance that is compatible (and probably more accurate in terms of defining the cluster’s centroid, as a consequence of the much greater sample size) with distances measured from the ground, together with the fact that we are able to apparently correct the same controversial Hipparcos measurements, indicates that Hipparcos parallaxes at large are robust.

4.3. Distance to the VLBI stars

Among recent distance measurements, those of Melis et al. (2014) determined by VLBI are the most accurate. As they make it possible to test the robustness of our pseudomagnitude estimations, we calculate the distance of 6 of the 10 stars scheduled for VLBI observation by Melis et al. (2013) (the 4 others are either not single dwarfs or lacking spectral type information). Table 2 summarises our predicted distances. For the two stars in common with Melis et al. (2014), the agreement between VLBI and pseudomagnitude distances is remarkable, with relative differences of 1% (0.5σ) and 4% (1.6σ).

5. Conclusion

Pseudomagnitudes are remarkable distance indicators, since they are free of interstellar reddening effects. We have calculated the mean absolute pseudomagnitudes of field dwarfs from O9 to M4, based on the Hipparcos parallax measurements of approximately 6000 stars, allowing us to estimate the distance of 360 Pleiades stars. We position the centroid of these stars at 139.0±1.2 pc, and we confirm that the Pleiades stellar distances measured by Hipparcos are on average underestimated by 10%.

### Table 2. Pseudomagnitude distance (PMD) of 6 Pleiades stars of the Melis et al. (2013) list. (1) Melis et al. (2014)

| HIP | SpT | PMD (pc) | VLBI distance (pc) (1) |
|-----|-----|----------|------------------------|
| 75  | G7  | 136.2 (3.6) |                         |
| 253 | G1  | 143.7 (2.1) |                         |
| 625 | G5  | 137.0 (2.4) | 138.4 (1.1)            |
| 1136| G7  | 141.0 (3.3) | 135.5 (0.6)            |
| 1883| K2  | 139.0 (1.4) |                         |
| 2244| K2  | 145.1 (2.1) |                         |

ESA’s recently launched GAIA mission will make it possible to accurately determine the fine structure of absolute pseudomagnitudes, their natural width, and the influence of various parameters such as age and metallicity. It will be possible to calibrate these very accurately, in several different optical bands. But already, our initial results obtained with the Pleiades cluster, together with their comparison with VLBI measurements, are very encouraging. This technique is purely observational, direct and simple to implement, since it needs the knowledge of only the spectral type, two magnitudes and the corresponding absolute pseudomagnitude.

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Table 3. Pseudomagnitude distance (PMD) and errors (pc) of 360 Pleiades stars. Names are those returned by CDS when searching for “M45”. The PMDs are the mean of the 3 distances (V,J), (V,H), (V,K). The error is the dispersion of those distances. Only the subset of 360 stars for which our method is applicable are reported.

| Name | PMD (pc) | Error (pc) |
|------|----------|------------|
| BD+17 558 | 179.47 | 11.01 |
| Cl* Melotte 22 MSK 211 | 144.95 | 1.01 |
| HD 23326 | 147.74 | .54 |
| * 22 Tau | 114.57 | 1.61 |
| HD 23195 | 140.02 | 1.66 |
| HD 282960 | 126.31 | .90 |
| V* V1084 Tau | 114.71 | 2.52 |
| V* V623 Tau | 160.84 | .03 |
| Cl* Melotte 22 H II 1593 | 142.55 | 1.99 |
| Cl* Melotte 22 DH 507 | 132.47 | 1.48 |
| V* V1272 Tau | 143.68 | 2.14 |
| 2MASS J03461174+2437203 | 151.53 | 2.01 |
| V* V1288 Tau | 136.17 | 3.57 |
| Cl* Melotte 22 DH 290 | 138.06 | 1.91 |
| V* V1046 Tau | 119.18 | 2.65 |
| BD+23 521 | 134.79 | .80 |
| HD 23568 | 142.38 | .56 |
| Cl* Melotte 22 SK 671 | 115.15 | 1.00 |
| BD+22 521 | 153.75 | .08 |
| HD 282963 | 117.26 | 3.60 |
| V* V540 Tau | 157.70 | .38 |
| Cl* Melotte 22 H II 974 | 137.64 | 1.12 |
| HD 24087 | 114.78 | 2.25 |
| V* LT Tau | 99.67 | 2.60 |
| V* V1187 Tau | 156.35 | 1.82 |
| Cl* Melotte 22 DH 131 | 116.10 | 1.08 |
| V* V815 Tau | 139.99 | .88 |
| Cl* Melotte 22 MSK 184 | 141.33 | .66 |
| BD+26 592 | 126.75 | 1.74 |
| HD 23312 | 151.37 | 1.27 |
| V* MS Tau | 144.56 | 1.64 |
| HD 23872 | 139.56 | 1.74 |
| HD 23061 | 158.92 | 2.14 |
| V* q Tau | 92.06 | 2.07 |
| Cl* Melotte 22 DH 525 | 137.69 | .54 |
| BD+22 548 | 126.47 | 1.71 |
| Cl* Melotte 22 SRS 80212 | 128.48 | 3.10 |
| V* V715 Tau | 136.53 | .90 |
| * 21 Tau | 117.65 | .95 |
| Cl* Melotte 22 SRS 52852 | 124.27 | .91 |
| HD 282967 | 117.87 | 2.25 |
| HD 23464 | 67.20 | 1.05 |
| HD 23061 | 150.41 | .67 |
| V* LV Tau | 125.90 | .46 |
| V* V642 Tau | 106.17 | 1.26 |
| HD 282971 | 149.25 | .96 |
| HD 23732 | 131.41 | 1.08 |
| Cl* Melotte 22 SK 775 | 175.25 | .23 |
| V* V814 Tau | 136.98 | .19 |
| HD 283046 | 193.01 | 2.21 |
| Cl* Melotte 22 MSH 175 | 134.88 | 1.80 |
| HD 283132 | 134.70 | 2.24 |
| TYC 1799-272-1 | 144.22 | 2.83 |
| HD 23873 | 139.10 | 1.51 |
| TYC 1803-1156-1 | 133.77 | 1.33 |
| Cl* Melotte 22 H II 1110 | 134.36 | 1.49 |
| 2E 857 | 133.60 | 4.08 |
| Name                        | PMD (pc) | Error (pc) |
|-----------------------------|----------|------------|
| BD+23 527                   | 150.35   | .08        |
| V* V497 Tau                 | 144.71   | 1.23       |
| * 27 Tau                    | 46.63    | .54        |
| V* V811 Tau                 | 137.04   | 2.42       |
| Cl* Melotte 22 DH 212       | 128.57   | 1.96       |
| HD 24194                    | 126.86   | .60        |
| V* V641 Tau                 | 143.41   | 2.07       |
| Cl* Melotte 22 DH 293       | 157.91   | 1.91       |
| BD+21 504                   | 120.15   | 2.06       |
| Cl* Melotte 22 DH 267       | 112.64   | 2.81       |
| V* V1274 Tau                | 47.75    | .69        |
| 2MASS J03441466+2406065     | 91.95    | 3.08       |
| HD 23763                    | 100.51   | 1.10       |
| HD 282975                   | 98.92    | .81        |
| Cl* Melotte 22 MSK 74       | 140.34   | 4.94       |
| Cl* Melotte 22 SK 40        | 162.67   | .75        |
| V* OS Tau                   | 115.60   | 3.38       |
| Cl* Melotte 22 DH 108       | 123.33   | 2.93       |
| Cl* Melotte 22 DH 184       | 141.75   | 1.00       |
| V* V1010 Tau                | 133.73   | .54        |
| TYC 1803-1351-1             | 98.47    | .85        |
| V* V1228 Tau                | 117.20   | .61        |
| V* V644 Tau                 | 139.39   | 2.44       |
| HD 23608                    | 113.83   | 1.24       |
| V* V378 Tau                 | 160.17   | .64        |
| Cl* Melotte 22 SK 488       | 133.65   | 3.45       |
| Cl* Melotte 22 HHJ 437      | 207.91   | 2.11       |
| HD 23924                    | 161.74   | 2.23       |
| SAO 76387                   | 185.78   | 1.88       |
| Cl* Melotte 22 DH 143       | 134.44   | .87        |
| V* V476 Tau                 | 97.93    | .16        |
| 2MASS J03493653+2417460     | 179.22   | 1.55       |
| Cl* Melotte 22 DH 436       | 146.34   | .51        |
| Cl* Melotte 22 DH 562       | 127.81   | 3.78       |
| HD 23387                    | 108.94   | 1.44       |
| V* V446 Tau                 | 143.41   | 2.00       |
| HD 283420                   | 110.87   | .51        |
| BD+22 553                   | 169.93   | 2.09       |
| HD 282958                   | 126.44   | 1.88       |
| Cl* Melotte 22 SK 754       | 150.36   | 3.04       |
| CCDM J03481+2409AB          | 111.98   | 1.84       |
| V* V703 Tau                 | 133.83   | .41        |
| * 16 Tau                    | 130.34   | 1.47       |
| V* V1065 Tau                | 140.96   | 3.31       |
| Cl* Melotte 22 SSHJ G315    | 165.54   | 1.70       |
| V* V664 Tau                 | 145.15   | 3.11       |
| Cl* Melotte 22 HII 102      | 122.18   | 1.24       |
| HD 24463                    | 114.36   | 1.94       |
| HD 282973                   | 117.76   | 3.80       |
| V* V727 Tau                 | 96.25    | .99        |
| V* V1224 Tau                | 148.57   | 5.47       |
| BD+23 472                   | 150.45   | 1.28       |
| BD+22 624                   | 143.38   | .79        |
| HD 23352                    | 164.74   | 3.79       |
| Cl* Melotte 22 DH 153       | 93.01    | 2.47       |
| V* V855 Tau                 | 114.57   | 3.98       |
| Cl* Melotte 22 DH 875       | 155.64   | 1.71       |
| HD 23327                    | 128.01   | .71        |
| * eta Tau                   | 41.17    | .44        |
| Cl* Melotte 22 DH 349       | 148.80   | .71        |
| BD+22 552                   | 167.99   | .44        |
Table 3. continued.

| Name                                      | PMD (pc) | Error (pc) |
|-------------------------------------------|----------|------------|
| HD 23975                                  | 113.28   | 1.96       |
| Cl* Melotte 22 DH 603                     | 133.62   | 1.12       |
| Cl* Melotte 22 DH 734                     | 177.77   | 1.85       |
| HD 23886                                  | 154.19   | 1.30       |
| HD 224444                                 | 89.73    | 1.89       |
| V* V700 Tau                               | 129.73   | .45        |
| Cl* Melotte 22 SRS 68435                  | 184.05   | .18        |
| BD+25 555                                 | 148.92   | 2.95       |
| V* V647 Tau                               | 160.26   | 2.34       |
| Cl* Melotte 22 DH 486                     | 139.59   | 2.71       |
| Cl* Melotte 22 SK 709                     | 138.63   | 1.28       |
| HD 23935                                  | 123.82   | 3.02       |
| Cl* Melotte 22 MSH 82                     | 161.58   | 1.22       |
| V* V810 Tau                               | 176.53   | 8.31       |
| BD+23 551                                 | 140.10   | 2.78       |
| V* V650 Tau                               | 142.39   | 1.35       |
| V* V652 Tau                               | 103.63   | .37        |
| V* V966 Tau                               | 141.91   | 1.82       |
| TYC 1799-102-1                            | 154.68   | 1.44       |
| V* V813 Tau                               | 195.53   | 6.05       |
| * 17 Tau                                  | 69.10    | 1.15       |
| V* LR Tau                                 | 33.04    | .61        |
| HD 23514                                  | 146.05   | 2.29       |
| V* V812 Tau                               | 131.48   | .75        |
| Cl* Melotte 22 LLP 15                     | 140.66   | 1.43       |
| V* V1041 Tau                              | 131.69   | 2.10       |
| UCAC2 40300217                            | 109.71   | 1.29       |
| Cl* Melotte 22 DH 421                     | 106.65   | .82        |
| V* V1045 Tau                              | 162.03   | 2.77       |
| HD 23351                                  | 133.79   | 1.26       |
| Cl* Melotte 22 DH 417                     | 149.93   | .80        |
| Cl* Melotte 22 DH 462                     | 140.35   | .28        |
| BD+20 672                                 | 121.96   | 1.68       |
| V* V1283 Tau                              | 128.04   | 2.36       |
| V* V1210 Tau                              | 139.54   | 1.26       |
| Cl* Melotte 22 DH 456                     | 162.22   | 2.37       |
| * 20 Tau                                  | 52.64    | 1.86       |
| V* PR Tau                                 | 149.08   | 1.09       |
| Cl* Melotte 22 DH 271                     | 133.39   | 2.75       |
| Cl* Melotte 22 MSK 44                     | 161.22   | 3.76       |
| V* V643 Tau                               | 110.74   | .65        |
| NAME 1RXS J034412.1+240200SE             | 135.08   | 2.99       |
| V* OU Tau                                 | 151.78   | 3.78       |
| V* V1170 Tau                              | 133.91   | 2.06       |
| V* KO Tau                                 | 118.00   | 5.35       |
| HD 23511                                  | 148.60   | 3.30       |
| V* V1175 Tau                              | 148.48   | 3.71       |
| Cl* Melotte 22 K 78                       | 135.25   | 3.82       |
| V* V382 Tau                               | 117.31   | 1.33       |
| V* V534 Tau                               | 130.10   | 1.40       |
| V* V660 Tau                               | 139.00   | 1.43       |
| Cl* Melotte 22 LLP 28                     | 103.66   | 2.49       |
| V* V1090 Tau                              | 153.17   | 3.79       |
| V* V371 Tau                               | 94.09    | 1.18       |
| V* V535 Tau                               | 145.83   | .36        |
| V* V1169 Tau                              | 153.65   | 2.73       |
| V* V1171 Tau                              | 310.83   | 11.59      |
| V* V969 Tau                               | 90.48    | 1.03       |
| Cl* Melotte 22 HII 2209                   | 151.73   | 3.20       |
| HD 282954                                 | 133.28   | .95        |
| HD 23513                                  | 148.86   | 1.06       |
| Name | PMD (pc) | Error (pc) |
|------|----------|------------|
| HR 1183 | 142.46 | .91 |
| V* V1282 Tau | 101.59 | .96 |
| HD 23489 | 130.18 | 2.37 |
| HD 24665 | 116.06 | 1.25 |
| BD+27 545 | 159.50 | 1.79 |
| HD 23512 | 142.27 | 1.43 |
| HD 23791 | 157.58 | 4.36 |
| V* V1176 Tau | 100.40 | 1.12 |
| V* V1193 Tau | 143.70 | .66 |
| HD 23584 | 139.06 | 2.88 |
| HD 23598 | 134.56 | 1.77 |
| Cl* Melotte 22 DH 730 | 149.09 | 2.56 |
| V* V963 Tau | 131.11 | 1.08 |
| V* V1173 Tau | 141.24 | 1.39 |
| HD 23912 | 146.43 | .76 |
| HD 23158 | 148.63 | .53 |
| HD 23361 | 147.82 | 1.48 |
| HD 23409 | 143.08 | 1.41 |
| V* V1172 Tau | 143.41 | 2.13 |
| V* V816 Tau | 152.73 | 4.91 |
| V* V545 Tau | 151.08 | 1.32 |
| V* V844 Tau | 163.42 | 2.94 |
| HD 23479 | 125.96 | .22 |
| HD 23733 | 131.23 | .71 |
| HD 23632 | 126.62 | 4.35 |
| * 18 Tau | 119.70 | 1.26 |
| HD 23863 | 157.47 | .78 |
| HD 23778 | 127.42 | .27 |
| V* V785 Tau | 142.26 | .94 |
| V* V1174 Tau | 189.61 | 3.19 |
| HD 282952 | 159.92 | 6.83 |
| BD+23 513 | 128.94 | 2.07 |
| HD 24076 | 102.17 | .69 |
| HD 23269 | 127.53 | 3.76 |
| * 24 Tau | 104.48 | 1.15 |
| V* II Tau | 29.56 | .63 |
| BD+19 587 | 143.25 | .63 |
| * 28 Tau | 82.99 | 3.27 |
| HD 23610 | 179.87 | 1.89 |
| HD 23948 | 171.39 | 1.86 |
| HD 24132 | 138.60 | 1.68 |
| BD+21 508 | 153.17 | 2.71 |
| V* V370 Tau | 159.63 | .39 |
| V* V518 Tau | 184.17 | 3.43 |
| V* V677 Tau | 136.39 | 1.51 |
| * 23 Tau | 78.99 | .69 |
| HD 23375 | 136.76 | 2.21 |
| HD 23631 | 156.43 | 1.05 |
| Cl* Melotte 22 DH 304 | 150.95 | 1.83 |
| Cl* Melotte 22 MSH 74 | 146.85 | 1.10 |
| HR 1172 | 106.54 | .82 |
| Cl* Melotte 22 MSK 140 | 137.55 | 3.96 |
| GJ 3219 A | 29.19 | .21 |
| V* V452 Tau | 87.67 | 1.61 |
| BD+20 628 | 213.30 | 1.91 |
| BD+23 514 | 143.40 | 3.25 |
| HD 283117 | 129.62 | 1.59 |
| V* V539 Tau | 91.22 | .18 |
| HD 283031 | 739.44 | 19.91 |
| BD+24 501 | 326.31 | 1.98 |
| Wolf 1260 | 89.06 | 2.21 |
Table 3. continued.

| Name | PMD (pc) | Error (pc) |
|------|----------|------------|
| V* CL Ari | 176.87 | 2.72 |
| V* V1085 Tau | 182.90 | .50 |
| Cl Melotte 22 SK 792 | 325.49 | 1.26 |
| HD 282926 | 582.29 | 16.02 |
| BD+24 470 | 453.13 | 9.08 |
| HD 283222 | 110.23 | 1.20 |
| V* V1227 Tau | 10.51 | .72 |
| V* V613 Tau | 123.89 | 1.72 |
| V* V372 Tau | 101.83 | 1.31 |
| HD 23157 | 118.59 | .60 |
| TYC 1807-1756-1 | 183.99 | 3.55 |
| BD+24 456 | 436.57 | 6.13 |
| HD 22693 | 189.20 | 5.42 |
| HD 283079 | 177.62 | 1.76 |
| TYC 1805-572-1 | 248.78 | 1.59 |
| HD 282998 | 142.82 | 1.77 |
| Cl Melotte 22 SK 646 | 164.77 | .89 |
| HD 24105 | 73.22 | 3.48 |
| V* V349 Tau | 112.88 | 2.23 |
| V* V638 Tau | 142.50 | .79 |
| BD+26 580 | 102.94 | .85 |
| Cl Melotte 22 WCZ 141 | 1119.62 | 18.23 |
| HD 283044 | 42.57 | .80 |
| V* V352 Tau | 143.20 | 2.38 |
| V* SZ Ari | 304.14 | 10.70 |
| HD 283058 | 62.35 | 1.11 |
| V* LO Tau | 118.57 | 2.20 |
| V* V468 Tau | 179.05 | 2.66 |
| V* PP Tau | 143.72 | 2.30 |
| GJ 3227 | 24.03 | .14 |
| V* V338 Tau | 124.47 | 1.43 |
| V* V377 Tau | 137.61 | 1.27 |
| Cl Melotte 22 DH 368 | 170.68 | 4.08 |
| HD 282942 | 49.30 | .75 |
| BD+25 604 | 125.24 | 1.53 |
| V* CG Ari | 80.46 | 1.54 |
| GJ 3240 | 22.47 | .33 |
| V* V561 Tau | 137.48 | 2.05 |
| V* EQ Tau | 178.99 | 1.32 |
| V* QS Tau | 1383.72 | 90.87 |
| SiKM 1-406b | 53.58 | .32 |
| V* V361 Tau | 131.28 | 1.51 |
| LP 355-27 | 33.41 | .75 |
| HD 23431 | 260.15 | 1.28 |
| BD+24 479 | 340.82 | 7.25 |
| V* V358 Tau | 133.71 | 2.42 |
| V* V366 Tau | 101.41 | 1.12 |
| BD+18 541 | 121.01 | 1.33 |
| HD 283014 | 437.72 | 3.74 |
| BD+19 589 | 107.11 | 4.69 |
| BD+26 586 | 314.70 | 1.70 |
| BD+26 553 | 283.42 | 3.47 |
| BD+17 637 | 228.69 | 5.36 |
| HD 23410 | 130.63 | 4.62 |
| HD 23289 | 142.45 | 1.22 |
| V* V679 Tau | 88.24 | 1.01 |
| V* V502 Tau | 144.40 | .95 |
| V* V357 Tau | 149.65 | 2.15 |
| BD+20 549 | 154.47 | 1.80 |
| HD 283139 | 125.47 | 1.44 |
| BD+23 433 | 285.71 | 2.96 |
| Name                  | PMD (pc) | Error (pc) |
|-----------------------|----------|------------|
| V* FL Tau             | 113.78   | 1.62       |
| HD 285234             | 145.61   | 1.23       |
| Cl* Melotte 22 DH 504 | 107.90   | 1.18       |
| HD 282972             | 154.18   | 6.75       |
| V* V1229 Tau          | 122.60   | .45        |
| TYC 1787-384-1        | 247.45   | 4.40       |
| HD 283038             | 230.53   | 2.11       |
| V* V380 Tau           | 126.91   | 1.41       |
| V* V470 Tau           | 154.77   | 2.24       |
| V* V354 Tau           | 128.81   | 2.72       |
| BD+20 626             | 109.33   | 2.22       |
| BPM 85549             | 68.12    | .56        |
| 2MASS J03235551+2339273 | 65.16   | 3.11       |
| BD+16 455             | 304.16   | 1.27       |
| BD+19 594             | 150.76   | 2.43       |
| V* V739 Tau           | 130.51   | 3.61       |
| V* V376 Tau           | 154.42   | 3.50       |
| BD+19 607p            | 179.56   | 2.80       |
| BD+25 592             | 246.77   | 4.79       |
| 2MASS J03273245+2554003 | 73.26   | 1.41       |
| BD+22 512             | 32.64    | .45        |
| HD 283032             | 423.77   | 8.11       |
| HD 24344              | 378.83   | 1.53       |
| HD 283055             | 161.93   | 2.79       |
| V* V1286 Tau          | 126.09   | .56        |
| NAME 1RXS J034412.1+240200NW | 196.43 | 15.41 |
| HD 285243             | 93.75    | .88        |
| HD 283006             | 141.52   | 1.05       |
| TYC 1798-1002-1       | 125.91   | 2.30       |
| BD+25 539             | 170.07   | 1.61       |
| LH98 95               | 119.66   | 1.10       |
| V* CU Tau             | 260.27   | 6.18       |
| BD+20 565             | 253.31   | 2.43       |
| Cl* Melotte 22 MSK 100 | 117.43 | 5.48       |
| V* V399 Tau           | 129.12   | .78        |
| GJ 3239               | 35.30    | .73        |
| SiKM 1-417            | 89.95    | 1.17       |
| 2MASS J03181744+1824202 | 72.59 | 1.94       |
| 2MASS J03414386+1824061 | 39.48 | .55        |
| BD+25 610             | 129.16   | 2.21       |
| BD+20 594             | 128.88   | .58        |
| HD 282955             | 383.91   | 3.69       |
| HD 283036             | 282.28   | 6.21       |
| GJ 3225               | 32.09    | .82        |
| BD+22 468             | 181.70   | 1.81       |
| HD 24355              | 303.59   | 2.30       |
| GJ 140 C              | 21.81    | .23        |
| BD+25 572             | 68.08    | 1.86       |
| TYC 1805-890-1        | 155.43   | .13        |
| HD 22139              | 137.84   | 2.49       |
| V* QX Tau             | 123.85   | .51        |
| V* V343 Tau           | 146.99   | 2.75       |
| HD 24088              | 214.86   | 3.73       |
| BD+23 538B            | 93.64    | 2.68       |
| 2MASS J03164389+1923041 | 177.42 | 5.74       |
| V* CK Ari             | 33.27    | .16        |
| HD 282928             | 246.31   | .86        |
| HD 282990             | 150.14   | 2.82       |
| HD 23964C             | 113.88   | .93        |