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LUMINOSITY AND INTRINSIC COLOR CALIBRATION OF MAIN-SEQUENCE STARS WITH 2MASS PHOTOMETRY: ALL SKY LOCAL EXTINCTION

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Abstract. We present a new color index vs. absolute magnitude calibration of 2MASS *JHK* photometry. For the A0 to ∼G5 and M segments of the main sequence information on the amount of interstellar extinction and its location in space may be obtained.

Key words: stars: fundamental parameters, 2MASS photometry, calibration – ISM: extinction

1. INTRODUCTION

Recently we used *Hipparcos* astrometry (ESA 1997) for calibrations of spectral classification in terms of intrinsic color and luminosity and used this to estimate distances and extinction for the local interstellar medium (Knude & Høg 1998, Knude et al. 2002). The optical calibration is limited to regions where Michigan classification is available and only measures color excesses that are small because of the bright limiting magnitude of the sample. Similarly the main sequence of the $H - K$ vs. $J - H$ diagram can be calibrated and the A0 to ∼G5 and the M segments can be used to estimate distance and reddening without giant contamination. The former provides extinction and distances for the nearest 1–2 kpc if A_V is less than 3 to 5 mag and the latter for the neighborhood within a couple of hundred parsecs. Individual extinctions and distances may complement/replace extinctions derived from the average $H - K$ colors calculated for small areas and compared to an unreddened typical $H - K$ value pertaining to the main sequence (Lombardi & Alves 2001) and from the clump giants providing both an average reddening and a distance (López-Corredoira et al. 2002).

2. CALIBRATIONS

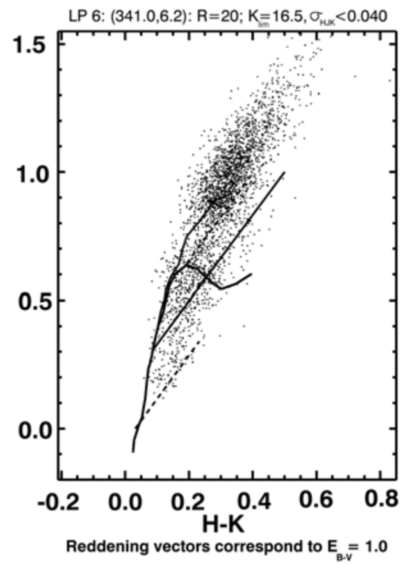

Fig. 1. 2MASS data within 20′ from Lupus 6 center. Standard sequences from Bessell & Brett (1988). Dotted lines are reddening lines of a length equivalent to E_{B-V}=1.

Figure 1 shows the $H-K$ vs. $J-H$ diagram for the Lupus 6 direction: $(l, b) = (341.0°, 6.2°)$ with a radius of 20′. Photometry with σ_{JHK} less than 0.040 and K brighter than 16.5 mag has been included. Main-sequence and giant relations from Bessell & Brett (1988) transformed to 2MASS (Carpenter 2001) are shown together with a set of reddening lines with a length equivalent to $E_{B-V} = 1$ mag. The intersections of the middle reddening vector, originating at the bluest point where the giant relation coincides with the main sequence, and the main sequence define the two segments whose calibrations may be used to estimate individual reddenings and distances. The part of the two color diagram located to the lower right of the line superposed on the middle reddening vector defines the stars that may be dereddened and have their photometric parallax estimated from the calibrations without any giant contamination.

2.1. The A0 to ∼G5 stars

We have compared the *Hipparcos* (ESA 1997) and 2MASS (Cutri, Skrutskie, Van Dyk et al. 2003) catalogs and further used the Michigan classification to confine the sample to main sequence stars. The calibration is confined to stars with $\pi > 8$ mas and $\sigma_\pi/\pi < 0.11$. More than 5000 stars remain in this sample. The parallax limit is chosen to minimize reddening and maintain a reasonable number of stars in each color bin along the main sequence. According to Figure 1 the range of $J-H$ makes it a better choice than $H-K$ as the independent parameter when projecting a star back along the reddening vector to the standard relation; on the other hand the small intrinsic range of $H-K$ is what makes the average $H-K$ values useful as a tracer of the mean reddening in small areas. The outcome of our calibration is the $(J-H)_0 - M_J$ relation.

2.2. The M-type dwarfs

There are not enough bright M-type dwarfs in the *Hipparcos* catalog to provide a calibration. Instead we rely on a sparse sample with terrestrial parallaxes compiled in Leggett et al. (2000) and from Dahn et al. (2002) the latter using Hipparcos parallaxes of primaries. Assuming no reddening of these local stars we compute M_J which we calibrate in terms of $H-K$. $H-K$ replaces $J-H$ due to the small $J-H$ variation among the M-type dwarfs.

3. LUPUS 6

In Figure 1 we had $\sigma_{JHK}<0.040$ and $K<16.5$. These limiting values are the compromise between sufficient accuracy and a significant number of stars. The slope of the reddening vector E_{J-H}/E_{H-K} is from Carpenter (2001).

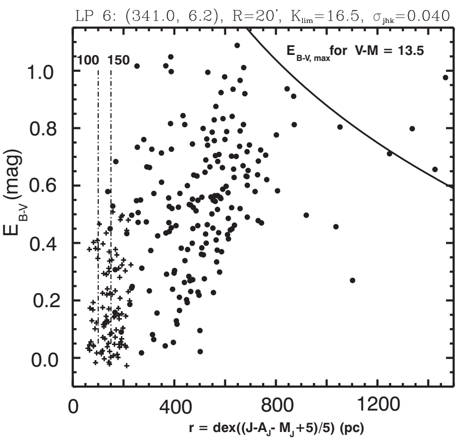

Fig. 2. Color excess E_{B-V} vs. distance in the Lupus 6 direction derived by the main-sequence stars. Dots are for the stars from A0 to G5, and crosses for M-type stars

For the data in Figure 1 it is seen that the dwarf sequence forms a blue envelope for the early segment and for the late segment as well (in $J-H$). This is not often found to be the case and is taken as evidence for nearby extinction.

For a star just below the late segment we can not confirm whether it belongs to the early or to the late segment. Some $J-H$ limits must be imposed in order to minimize this confusion. This is why we can not estimate extinctions A_V much larger than about 3–5 magnitudes from the early segment. The same is the case for the largest $J-H$ values where the giant stars are turning over and giants erroneously might be taken for late M dwarfs.

The resulting color excesses and distances in the Lupus 6 direction are shown in Figure 2. The early segment stars indicate a steep rise between 150 and 200 pc. Beyond 500–700 pc all stars are reddened by more than $E_{B-V} \approx 0.5$ which may be real. The upper limit of $E_{B-V} \approx 1.2$ mag may be due to the upper $J - H$ limit imposed on the stars from the early segment. These limitations will be lifted when the *Gaia* parallaxes become available.

Stars from the late segment are set off as crosses but show approximately the same range of reddenings as the early segment stars. Due to the small volume in front of Lupus 6 few stars are expected in front of the cloud, but anyway it seems that several excesses are in the range from 0.2 and 0.5 for stars between 100 and 150 pc.

We notice from Figure 2 the scarcity of stars in the distance slot from 200 to 400 pc where the late G and K dwarfs should be located. The G – K dwarfs are included in our calibration so a $(J-H)_0$ vs. M_J relation is at hand but due to the dwarf/giant ambiguity extinctions and distances cannot be derived. This problem will be solved when parallaxes become available.

4. A HIGH LATITUDE DIFFUSE CLOUD

In order to investigate whether the proposed method also may detect and measure diffuse clouds with much smaller extinction than the molecular clouds, we apply it to an isolated high latitude cloud detected from *uvbyβ* photometry and confirmed by IRAS 100 μm emission. The calibrated *uvbyβ* photometry permits estimates of color excess E_{b-y} and distance mainly for the main-sequence stars in the spectral range from A3 to early G type. The $(l, b) = (251.2°, 73.3°)$ cloud was studied by Haikala et al. (1995). It is found to be located at ∼120 pc and has a measured central color excess of $E_{b-y} \approx 0.10$ mag. The cloud is almost 3° across so we collate 2MASS data within 75′ from the central position. 2MASS data are taken with identical selection criteria as above. The reddenings and distances extracted from the 2MASS calibrations are shown in Figure 3 (left). We notice different results from the two segments of the main sequence. The early segment indicates that an extinction discontinuity might be located at 200 pc whereas the late segment propose a smaller distance of 100–120 pc for the onset of reddening.

Figure 3 (left) shows a remarkable resemblance to Figure 4 of Haikala et al. (1995) and it can hardly be a coincidence that distances as well as color excesses are similar from two such different observing methods. We take this near identity as support for the

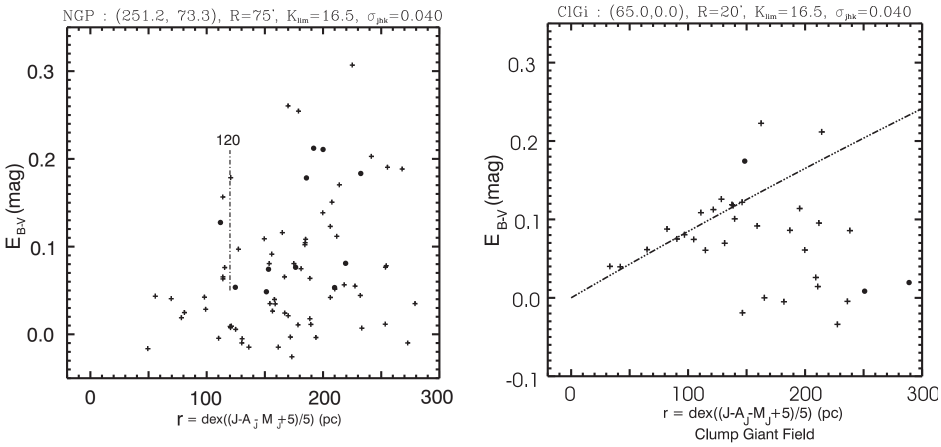

Fig. 3. Color excess vs. distance diagram for the stars within ~300 pc in a high latitude area (left) and a low latitude area (right)

validity of the calibrated 2MASS method.

5. LOCAL DIFFUSE MEDIUM

Drimmel et al. (2003) demonstrated that the NIR colors and almost constant absolute magnitude of clump giants may be used to estimate average distances and extinctions. We compared our excess vs. distance data to the three points that may be derived from their Figure 8. The clump giants are too distant for a direct comparison but follow the trend laid out by the dwarfs. The line of sight used for Figure 8 $(l, b) = (65°, +6°)$ turned out to be interesting in another way however: the M dwarfs within a few hundred pc follow a double exponential dust distribution valid for the diffuse dust clouds (Jønch-Sørensen 1994) rather well. Figure 3 (right) shows these local data pertaining to the diffuse medium. The diagram depicts two main components of the diffuse medium: a cloud part following the double exponential and the low density intercloud medium virtually without any reddening with measured excesses around $E_{B-V} = 0$.

6. DISCUSSION

We have calibrated the main-sequence relation of the $H - K$ vs. $J - H$ diagram in terms of a $(J - H)_0 - M_J$ relation. Due to the dwarf – giant degeneration only stars earlier than ~G5 and later than ~M3 may be used to estimate distance – color excess pairs by means of this relation and accurate JHK photometry. In principle this means that individual distances and color excesses may be estimated over most of the sky from the 2MASS photometry and 3-D extinction maps may be produced.

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