The Presence of the Wielen Dip in the Disk Stellar Luminosity Function

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Abstract: The disk stellar luminosity function has been redetermined by the mean absolute magnitude method, utilising the proper motion data of the LHS Catalog. The derived luminosity function shows a slightly deeper dip than that found by Wielen (1983) in the same magnitude range.

1. Introduction

Upgren and Armandroff (1981) have noticed the dip in the Wielen’s stellar luminosity function, which is derived from the Upgren and Armandroff (1981) have noticed the dip in the Wielen (1983) in the same magnitude range.

Therefore, we have checked whether the dip is real or not, by directly redetermining the disk stellar luminosity function from the Luyten’s (1979) LHS Catalog by the mean absolute magnitude method, utilising the reduced proper motion diagram (RPMD) to remove the contamination of sub-dwarfs.

2. Mean Absolute Magnitude Method and Reduced Proper Motion Diagram

(a) Mean absolute magnitude method

The essential part of the mean absolute magnitude method (Luyten 1925, 1928, 1938, 1968) is the relationship between the absolute magnitude \( M \) and the reduced proper motion \( \mu \) which is defined as

\[
H = m + 5 + 5 \log \mu = M - 3.378 + 5 \log \nu_t
\]

where \( m \) is apparent magnitude, \( \mu \) is the annual proper motion in arcsec and \( \nu_t \) the tangential velocity in \( \text{km s}^{-1} \).

If it is assumed that the tangential velocities of a given population of stars are statistically distributed in such a way that there exists a mean or most probable value of \( \nu_t \) at each \( M \), and the tangential velocity and the statistical distribution at a given \( M \) remain unchanged with distance from the Sun, the reduced proper motion \( H \) can be used as an indicator of \( M \) for the determination of the stellar luminosity function even though the absolute magnitude of an individual star can not be derived. Therefore, if we get a relationship in the form

\[
(M) = a + bH
\]

from the stars with known absolute magnitude and proper motion, we can obtain the distribution of the absolute magnitudes for the sample of proper motion stars. In applying this relationship it is assumed that the calibration stars are representative of the entire sample of proper motion stars.

(b) Reduced proper motion diagram

In the Galaxy we know that there are at least more than two kinetic stellar populations. The reduced proper motion \( H_v \) shows that it is a function of a colour through the colour-magnitude relationship \((M_v - B - V)\) and a function of \( 5 \log \nu_t \). Therefore, if we plot the reduced proper motion diagram \((H_v \text{ and } B - V \text{ colour diagram})\), stars will be distributed like a colour-magnitude diagram with part of vertical scatter reflecting the \( \nu_t \) distribution of each kinematic stellar population. Therefore the stellar populations are distinguished in RPMD. Jones (1972 a, b) calculated the ridge lines of various populations and luminosity classes in the RPMD and his work is improved and extended by Chiu (1980). We adopted Chiu’s (1980) criteria for population classification to get the sample of disk stars without the contamination of sub-dwarfs. According to his criteria, the stars with \( H_v < 6.84(B - V) + 7.6 \) and \( H_v > 6.84(B - V) \) in the range of \( 0.4 < B - V < 1.2 \) and the stars with \( B - V > 1.2 \) and \( H_v > 6.84(B - V) \) are main sequence stars, and the stars with \( H_v > 6.84(B - V) + 13 \) and \( B - V < 0.7 \) are white dwarfs.

3. Data Analysis

The proper motion data in the region \( \delta < -33^\circ, |\beta| > 10^\circ \) of the LHS Catalog has been proved to be \( \sim 90\% \) complete for proper motion stars brighter than \( \mu_{B} = 18 \) and with \( \mu \geq 0.05 \text{yr}^{-1} \) by Dawson (1986). The stars in this region (65.6% of the sky) are used for the determination of the luminosity function.

The magnitude \( m_{B} \) in the LHS Catalog has been improved on the basis of the proper motion stars with published photometric \( B \) magnitude. It is found that up to \( m_{B} \sim 8 \), the \( m_{B} \) of the LHS Catalog agrees well with the published \( B \) magnitude, but in the magnitude range of \( 8 < m_{B} < 12.5 \) and \( m_{B} > 12.5 \), \( m_{B} \) of the LHS Catalog should be corrected by \(-0.2 \) and \(+0.4 \) respectively.

The average \( B - V \) colours for the colour classes and the spectral types in the LHS Catalog are estimated for the stars without published \( B - V \), and used for RPMD, which are listed in Table 1 of Lee (1989).

The relationship between the mean absolute magnitude \( \langle M \rangle \) and the reduced proper motion \( H \) is derived on the basis of the proper motion stars with known trigonometric parallaxes whose errors are less than 5%. The relationships are

\[
\langle M_B \rangle = (1.26 \pm 0.14)H_B - (12.97 \pm 2.70)
\]

for main sequence stars and

\[
\langle M_B \rangle = (0.57 \pm 0.21)H_B - (5.90 \pm 0.90)
\]

for white dwarfs respectively. However, whether the calibration stars for these relationships represent the sample of program stars is difficult to test. We have checked how sensitive these relationships are to the sample stars of calibration. About 70% of the stars with proper motion larger than \( 2^\circ \) per year in the LHS Catalog are found to have trigonometric parallaxes. From these stars we derived the relationship between \( \langle M \rangle \) and \( H \).

They are

\[
\langle M_V \rangle = (0.96 \pm 0.07)H_V - (5.19 \pm 0.95)
\]

for main sequence stars,

\[
\langle M_V \rangle = (1.26 \pm 0.14)H_V - (12.97 \pm 2.70)
\]

for disk main sequence stars,

\[
\langle M_B \rangle = (1.25 \pm 0.12)H_B - (13.07 \pm 2.53)
\]

and

\[
\langle M_V \rangle = (0.59 \pm 0.22)H_V + (1.77 \pm 4.61)
\]

for sub-dwarfs, and

\[
\langle M_B \rangle = (0.69 \pm 0.20)H_B - (0.15 \pm 4.34)
\]

for white dwarfs.

It is found that the relationships for main sequence stars and white dwarfs derived from these stars are in good agreement with those of the original calibration stars. For all stars with
Figure 1 - Disk stellar luminosity functions: the crosses with solid line are from the present study, the triangles with dotted line are from Luyten (1968), and the filled diamonds with dashed line are from Wielen (1983).

\[ \mu > 20''0 \text{ per year and brighter than } m_{pg} = 13.3 \text{ in the LHS Catalog,} \]

trigonometric parallaxes are available. From these stars the overall relationship between the mean absolute magnitude and the reduced proper motion, without separating the luminosity classes, is derived as

\[ \langle M_v \rangle = (0.84 \pm 0.08) H_v - (3.85 \pm 1.18). \]

This agrees well with the previously derived relationships, namely

\[ \langle M_v \rangle = 0.86 H_v - 3.5 \text{ by Luyten (1938, 1968),} \]

\[ \langle M_v \rangle = 0.85 H_v - 2.5 \text{ by Wanner (1972), and} \]

\[ \langle M_v \rangle = 0.83 H_v - 2.5 \text{ by Lee (1984).} \]

It seems that the relationships derived from the quite different sample of calibrating stars are not much different from each other, but separate relationships should be derived for the main sequence stars, sub-dwarfs and white dwarfs respectively. Therefore, the errors in the previously derived stellar luminosity functions by this method could result if one relationship of \( M \) and \( H \) was adopted for the whole program stars including sub-dwarfs and white dwarfs, rather than a separate relationship for each group of stars. Thus, we adopted the relationships

\[ \langle M_v \rangle = 1.06 H_B - 5.90 \text{ for the main sequence stars, and} \]

\[ \langle M_B \rangle = 0.57 H_B - 1.75 \text{ for the white dwarfs respectively.} \]

Since the LHS Catalog is complete up to \( m_{pg} \sim 21 \), we assumed that it includes all stars with \( \mu > 0.5 \text{ per year within 10 pc.} \)

For the stars with proper motion \( \mu < 0.5 \), the correction factor is estimated by investigation of the Gliese catalogue of nearby stars. In the Gliese catalogue 37 stars are within 5 pc, but all except one have proper motions larger than 0.5 per year. Within 10 pc the Gliese catalogue contains 196 stars, but only 167 stars among them are found to have proper motions larger than 0.5 per year. Since the Gliese catalogue of nearby stars is found to be complete up to \( M_v \sim 13.5 \) within 10 pc, we roughly adopted the correction factor of 196/167 \( \approx 1.17 \) for the stars with proper motion \( \mu < 0.5 \text{ per year in the determination of the luminosity function.} \)

Thus we can choose the distance limit of 10 pc and correct for stars with proper motion \( < 0.5 \text{ annually by multiplying the factor of 1.17, and for the region of } \delta < -33^\circ \text{ and } |b| < 10^\circ \text{ by the factor 1.524 to the counted stars.} \)

The derived luminosity function is compared with those of Luyten (1968) and Wielen (1974, 1983) in Table 1 and Figure 1.

In Figure 1 the crosses with solid lines represent the luminosity function of the present study, while the triangles with dotted lines, and the filled diamonds with dashed lines are those of Luyten (1968) and Wielen (1983) respectively. The disk stellar luminosity function of the present study shows the dip, slightly deeper than that in the Wielen’s luminosity function in the same magnitude range. The overall shape of the stellar luminosity function of the present study is similar to Luyten’s (1968) luminosity function except for the presence of the dip, the slightly more extended maximum and the slightly larger values at the fainter portion of the luminosity function. It seems that in the Luyten’s luminosity function the dip was smeared out by the contamination of sub-dwarfs as well as by adopting one relationship between the mean absolute magnitude and the reduced proper motion for the whole program stars.

### 4. Conclusion

The dip in the disk stellar luminosity function is found by the mean absolute magnitude method utilising the proper motion data of the LHS Catalog, by making use of the reduced proper motion diagram to eliminate the contamination of the nearby sub-dwarfs. It is found to be important that in the mean absolute magnitude method for determination of the stellar luminosity function, separate relationships between the mean absolute magnitude and the reduced proper motion for disk main sequence stars, white dwarfs and sub-dwarfs should be adopted.

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Luyten, W. J., 1979, *LHS Catalog*, Univ. of Minnesota.