Mem. S.A.It. Suppl. Vol. 3, 143
© SAIt 2003

Memorie della
Supplementi

Local disk star counts: observational constraints on the stellar IMF

M. Cignoni[1], P.G. Prada Moroni[1,2,3], S. Degl'Innocenti[1,2]

[1] Dipartimento di Fisica, Università di Pisa, Via Buonarroti 2, 56127 Pisa, Italy
e-mail: `cignoni@df.unipi.it`
[2] INFN, Sezione di Pisa, Via Buonarroti 2, 56127 Pisa, Italy
[3] Osservatorio Astronomico di Collurania, Via Mentore Maggini, 64100, Teramo, Italy

Abstract. We predict the local disk star counts through a galactic code which adopts stellar models (evolutionary tracks up to the white dwarf phase) together with a star formation rate (SFR) and an initial mass function (IMF). Results are compared with the disk luminosity function and the local white dwarf (WD) density to obtain constraints on IMF and SFR. We take into account three different ages (7.5, 9, 12 Gyr) and several star formation histories. Our analysis for a 7.5 Gyr disk and a flat SFR shows that a simple power law IMF (Salpeter like) for $M > 0.6 M_\odot$ reproduces both the above observational quantities and the WD luminosity function cut-off. This result doesn't hold for a disk age larger than ~ 9 Gyr. In general, an increase of the disk age determines too many faint WDs. Even a steeper IMF exponent in the WD progenitor mass range cannot lead to agreement with observations.

Key words. Stars: luminosity function, mass function; Galaxy: disk, solar neighborhood

1. The disk model

In our galactic model star masses and ages are randomly generated following a selected initial mass function (IMF) and a star formation rate (SFR). The code relies on a set of homogeneous evolutionary computations with Z=0.02 Y=0.27 covering both the H and He burning phase for stars with original masses in the range from H-burning limit to $M_{\rm up}$. Very low MS tracks are taken from evolutionary calculations by Baraffe et al. 1997 and Baraffe et al. 1998. For $M > 0.6\,M_\odot$ we use the Cassisi et al. 1998 and the Castellani et al. 1999 evolutionary tracks up to the end of the AGB, which are in excellent agreement with recent results from the Hipparcos satellite for nearby stars and open clusters (see e.g. Castellani et al. 2001, Kovalevski 1998) and with observational data of globular clusters at different metallicities (see e.g. Cassisi et al. 1999, Brocato et al. 2000). The model spontaneously predicts stars in various evolutionary phases (for model de-

---

Send offprint requests to: M. Cignoni
Correspondence to: Via Buonarroti 2, 56127 Pisa

tails see e.g. Castellani et al. 2002).

In particular we obtain the WD abundance. However, to predict the CM location of WDs one needs further theoretical ingredients: i) a WD mass - progenitor mass relation (Weidemann et al. 2000), ii) theoretical WD models giving luminosity and temperature of a WD as a function of mass and age (Salaris et al. 2000), iii) the progenitor age at AGB phase, and iv) suitable color transformations. For $T_{eff} < 4000^{\circ}$ K we adopt the color relations by Saumon & Jacobson 1999, which include a detailed treatment of collision induced absorption of H_2, whereas for higher temperatures, the results of Bergeron et al. 1995 are used.

2. Constraining the IMF

The IMF for the whole range of stellar masses is generally assumed as a two-part power-law $dN/dM \propto M^{-s}$ (see e.g. Kroupa 2001), with different exponents above and below $\approx 0.6\,M_{\odot}$.

To reproduce observations in the solar neighborhood is clearly the first check for possible IMF and SFR. Unfortunately, the disk LF at low luminosity is still quite uncertain. The results by the Hipparcos satellite show a significantly larger star density at $M_V > 13$ than the luminosity function estimated from photometric parallaxes from HST surveys. The volumes of sky scanned in the two studies are different, but, unless the solar neighborhood is peculiar, this cannot be the solution. The differences could be produced by a selection effect due, for instance, to unsolved binary stars (see e.g. Kroupa 1995).

However, for the high luminosity end ($M_V \leq 9$) the disk luminosity function is well known and the Hipparcos sample should be complete (Jahreiss et al. 1997). This gives the chance to obtain information on the disk IMF for $M \geq 0.6\,M_{\odot}$. However, the obtained LF is the result of both the adopted IMF and SFR thus, as already known, the disk LF alone cannot give information about the disk age and does not allow to put firm constraints on the IMF exponent.

Additional information on the disk IMF and SFR can be derived from the local WD density (Holberg et al. 2002). This sample consists of spectroscopically identified WDs observed within 20 pc (for most of them trigonometric parallaxes have been measured, while for some stars only photometric distances are available). The sample is estimated complete within 13 pc, however, due to the low number of stars in the sample, the WD LF has a poor statistical significance and only the total WD density can be used as a constraint (Holberg et al. 2002 estimated a WD density of $5.0 \pm 0.7 \times 10^{-3}\,pc^{-3}$). We make simulations taking into account observational values for both disk LF and WDs.

Regarding disk LF, the best solutions for the IMF s-exponent are determined through a χ^2 test. To check the statistical reliability we run many simulations for each s-value accepting only the s-values with χ^2 probability $\geq 5\,\%$ for more than $80\,\%$ of the simulations. As a first step we assume a flat SFR with disk ages of 12, 9 and 7.5 Gyr. The results are shown in figure 1.

For a disk age of 7.5 Gyr only IMF exponents of 2.1 ± 0.35 pass our test, while for disk ages of 9 and 12 Gyr the acceptable IMF values are in the range of 2.0 ± 0.4 and 1.8 ± 0.4, respectively. The results of our simulations for the comparison with the WD density are plotted in figure 2 together with the observational values. For a disk age of 12 Gyr the predicted WD local density matches the data only for an IMF exponent higher than 2.6, in disagreement with the disk LF results. By decreasing the age the disagreement with the IMF exponent obtained from the disk LF analysis is reduced: for a disk age of 9 Gyr we find acceptable values only for $s > 2.45$ (in partial agreement with the disk LF results), while for an age of 7.5 Gyr we find $s > 2.3$.

Thus, for a disk age of 12 Gyr it seems not possible to simultaneously reproduce the disk luminosity function and the WD density with the same IMF exponent for $M > 0.6\,M_{\odot}$, at least for a flat SFR.

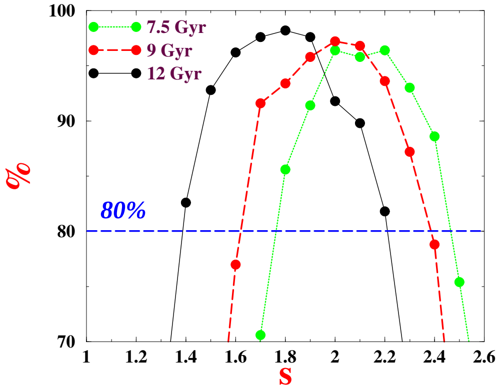

Fig. 1. Percentage of simulations with χ^2 probability $> 5\,\%$ as a function of the adopted s-exponent (for $M \geq 0.6\,M_\odot$) for the comparison between theory and observation for disk LF. Only IMF exponents with more than over $80\,\%$ of χ^2 probability $> 5\,\%$ are accepted. A flat SFR with the three labelled ages of the disk has been adopted.

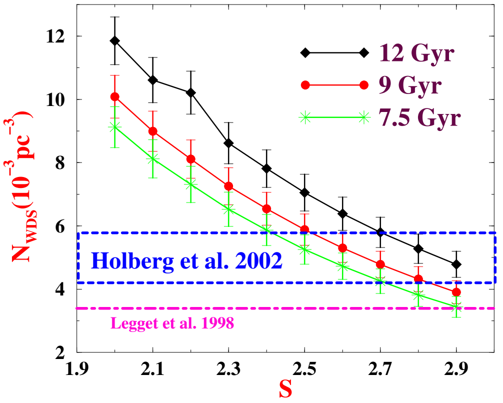

Fig. 2. Predicted local WD density versus IMF exponent. Error bars indicate the standard deviation over many simulations. Horizontal lines stand for the observed white dwarf density according to Holberg et al. 2002 (dashed box) and Legget et al. 1998 (dot-dashed horizontal line). A flat SFR for the three labelled disk ages has been adopted.

Numerical simulations show that this results also holds if we make the hypothesis of an increase of the IMF exponent in the WD progenitors mass range. That is, even if we suppose a two exponents IMF (for $M > 0.6 M_\odot$), it seems not possible to find an agreement with the disk LF and the WD density for a disk age of about 12 Gyr. For a disk of 9 Gyr the discrepancy between the exponent inferred from the disk LF and the one from the WD density is small, although still present: a slightly steeping of the IMF for $M > 1\,M_\odot$ can reconcile both values.

For a disk of about 7.5 Gyr, simulations indicate that a single IMF exponent ($s \sim 2.4$) for $M > 0.6\,M_\odot$ is enough to reproduce the WD local density and the disk luminosity function.

Moreover, even if we know that statistic is poor to trust in the WD LF shape, we can compare the faintest WDs in the sample with the faint end of the theoretical WD LF. Figure 3 shows that only for a disk age of about 7.5 Gyr the predicted cut-off of the WD LF approaches the observed one; while 9 and 12 Gyr disk ages lead to a too much large number of WDs at the lowest luminosities; this result is independent on the adopted IMF exponents. Previous results are obtained under the assumption of a flat SFR but seem to hold for more generic star formation histories too.

If we allow SFR to variate, even for a 12 Gyr disk it is possible to reproduce with only one exponent both the disk LF and the WD density but the number of the faintest WDs remains highly overestimated.

This conclusion clearly relies on the completeness of the sample. Furthermore, a large fraction of WDs are non-DA, while our model considers only DA-type. So accounting for the faster evolution of non-DA WDs relative to DA ones, our estimated disk age could actually be an overestimate. Moreover we note that uncertainties in the physical inputs adopted in the WD models can lead to relevant uncertainties in the WD cooling times (see e.g. Prada Moroni & Straniero 2002) and thus on the estimated

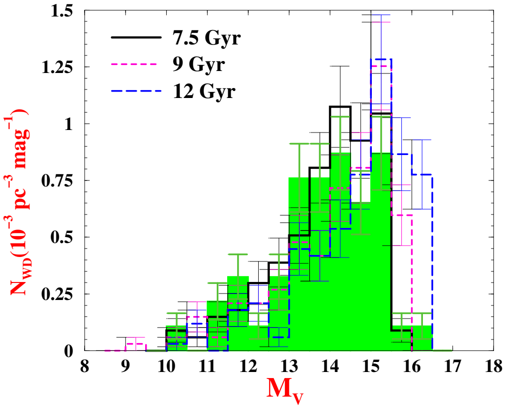

Fig. 3. Comparison among the observational white dwarf luminosity function by Holberg et al. 2002 (filled histogram) and the theoretical ones. We assumed a flat SFR with a disk age of 7.5 Gyr (solid line), 9 Gyr (dashed line), and 12 Gyr long-dashed line. Theoretical and observational poissonian errors are shown.

disk age, as shown by the wide range of values available in the literature.

Acknowledgements. We warmly thank Vittorio Castellani for his advice and Steve Shore for careful reading of the manuscript.

References

Baraffe I., Chabrier, G., Allard, F., & Hauschildt, P. H. 1997, A&A, 327, 1054

Baraffe I., Chabrier, G., Allard, F., & Hauschild, P. H. 1998, A&A, 337, 403

Bergeron, P., Wesemael F., Beauchamp A., 1995, PASP 107, 1047

Brocato E., Castellani, V., Poli F. M., Raimondo G., 2000, A&AS 146, 91

Cassisi S., Castellani V., Degl'Innocenti S., Salaris M., Weiss A., 1999, A&AS 134, 103

Cassisi S., Castellani V., Degl'Innocenti S., Weiss A., 1998, A&AS 129, 267

Castellani V., Cignoni M., Degl'Innocenti S., Petroni S., Prada Moroni P. G., 2002, MNRAS 334, 69

Castellani V., Degl'Innocenti S., Prada Moroni P.G., 2001, MNRAS 320, 66

Castellani V., Degl'Innocenti S., Marconi M., 1999, MNRAS 303, 265

Holberg J. B., Oswalt T., & Sion E. M., 2002, ApJ 571, 512

Jahreiss H. & Wielen R. 1997, Proc. ESA Symp. Hipparcos Venice 97, ESA SP-402, Noordwijk, 675

Kovalevski J. 1998, ARA&A 36, 99

Kroupa P. 2001, MNRAS 322, 231

Kroupa, P. 1995, ApJ, 453, 358

Leggett S.K., Ruiz M.T. & Bergeron P. 1998, ApJ 497, 294

Prada Moroni P.G., Straniero O., 2002, ApJ 581, 585

Salaris M., Garcia-Berro E., Hernanz M., Isern J., Saumon D., 2000, ApJ 544, 1036

Saumon D., Jacobson S.B., 1999, ApJ 511, L107

Weidemann, V. 2000, A&A 363, 647