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Galactic structure and white dwarf populations

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Abstract. We developed a code for galactic star-counts making use of suitable assumptions on the evolutionary status, initial mass function (IMF) and star formation history of the various Galactic populations. Predicted results are obtained by randomly generating star masses according to the adopted IMF and by using stellar models (evolutionary tracks up to the white dwarf phase) to derive luminosities in the selected bands for each given value of the stellar mass and age. Star counts from solar neighborhood are used to give constraints on star formation rate and IMF.

Key words. Galaxy: structure – solar neighbourhood – fundamental parameters

1. The model

The model includes three components: halo, disk and thick disk. Halo stars are considered almost coeval and they are reproduced by populating a suitable theoretical isochrone of 12 Gyr (Z=0.0002, Y=0.23), while for both disk and thick disk stars, one has to take into account prolonged star formation episodes. Thus, for these two last components, star masses and ages are both randomly generated following the selected initial mass function (IMF) and star formation rate (SFR). For the disk we chose a constant SFR from 50 Myr to 9 Gyr to populate evolutionary tracks with Z=0.02 Y=0.27, while for the thick disk we adopted a metallicity Z=0.006 and a SFR centered at 10 Gyr with a spread of few Gyr. As usually, the distribution of halo stars is modeled as a de Vaucoleurs density law. The disk and thick disk law is the widely used double exponential in the Galactocentric distance on the Galaxy plane and in height over the plane.

The code relies on a set of homogeneous evolutionary computations covering both the H and He burning phase for stars with original masses in the range from H-burning limit to M_{up}. Very low MS tracks are from evolutionary calculations by Baraffe et al. (1997) and Baraffe et al. (1998). For $M > 0.6\ M_{\odot}$ we use the Castellani 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 (Kovalevski 1998) and open clusters (see e.g. Castellani et al. 2001) and with observational data of globular clusters at different metallicities (see e.g. Castellani et al. 1999, Brocato et al. 2000). The adopted color transformations are from Castelli et al. (1997). Comparisons between the predicted and the observed CMD for field stars require an ex-

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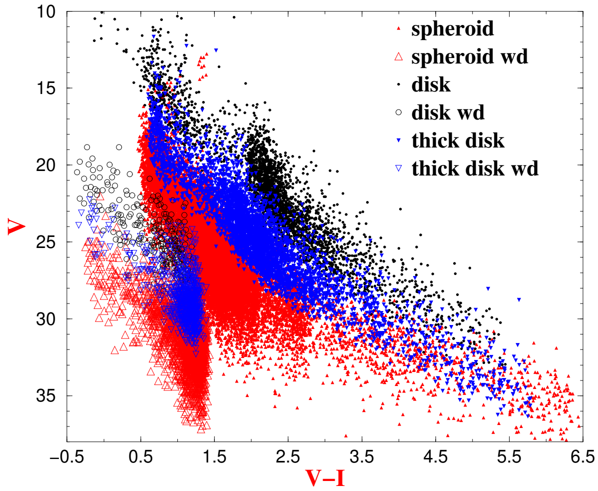

Fig. 1. Theoretical CMD for a field of area 0.5 □^{o} at the galactic latitude b=50° and longitude l=0°. Different symbols represent different galactic components. Open symbols represent the correspondent WD contribute.

pression for galactic obscuration, thus an exponential law with a reddening scale height of 100 pc is adopted (see e.g. Mendez et al. 1997). For intermediate-to-high Galactic latitudes (|b| ≥10°) we use the E(B-V) reddening maps by Burstein et al. (1982). The visual extinction A_V=3.12 E(B-V) and the reddening in the infrared colors are from Bessel et al. (1988) (see also Clementini et al. 1995).

The chosen theoretical approach is able to spontaneously produce predictions about the occurrence of stars in the various evolutionary phases. For a more detailed description of the model see e.g. Castellani et al. (2002). As an example, Fig. 1 shows the predicted CM diagram on a selected area of 0.5 □^{o} at the galactic latitude b=50° and longitude l=0°. The not realistic very low magnitude reached by the simulation is just to show the whole white dwarf (WD) population.

2. The white dwarf population

Our model can easily predict the WDs abundance, since each star evolved beyond the AGB phase and less massive than M_{up} is assumed to be a WD. However, to predict the CM location of WDs one needs further theoretical ingredients, as given by: i) a WD mass - progenitor mass relation ii) theoretical WD models giving luminosity and temperature of a WD as a function of mass and age and iii) suitable color transformations. The WD cooling age (that is the time spent on the cooling curve) is simply given by the difference between the age associated to the star and the age of the WD progenitor at the end of the AGB. For T_{eff} < 4000^o 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 temperature, the results of Bergeron et al. (1995) were used.

3. Constraining the IMF

3.1. The local luminosity function

Model outputs consist on colors and apparent magnitudes of field stars. Comparisons with observative color magnitude diagrams in different directions should constrain the parameters involved in IMF, SFR and spatial densities. However, to restrict the parameters' space and to find the normalizations for spatial distributions, a preliminary check of the adopted IMF and SFR by comparison with local luminosity

function (bypassing degeneracy due to star distances) is needed.
The IMF for the whole range of stellar masses is generally assumed as a two-part power-law M^{-s} (see e.g. Kroupa 2001), with different exponents above and below 0.6 solar masses. For each galactic component, the stellar luminosity function is assumed independent of the position in the Galaxy (see e.g. Kroupa 1995), so data from solar neighborhood can be used to constrain IMF and SFR for the whole Galaxy.
Unfortunately, the observed halo luminosity function is so uncertain (see e.g. Zheng et al. 1998), that one can only give weak constraints on halo IMF. For this component (as well as for the thick disk component) only a direct comparison with observations in several galactic fields could give additional informations on IMF.
Regarding the disk luminosity function, it is known that trigonometric parallax measurements with the Hipparcos satellite have a significantly larger stellar number density at $M_V > 13$ than stellar luminosity function estimated using photometric parallax from HST surveys. The scanned volumes are different, but, unless the solar neighborhood is peculiar, this could be a selection effect (due for instance, to binary stars unsolved, 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). Thus by comparison with these observational data we can obtain information on the disk IMF (for $M > 0.6 M_\odot$) and disk normalization. The best values for the s exponent is obtained through a χ^2 test, giving about 2.1. In order to check the statistical reliability we run 10.000 simulations for each s-value. We rejected the s-values which give a too low χ^2 (a χ^2 probability, ≤ 5 %) for more than 50% of the simulations. The results are issued in Fig. 2. Confidence level falls sharply out of the best value; s-values below 1.6 and above 2.6 can be rejected.

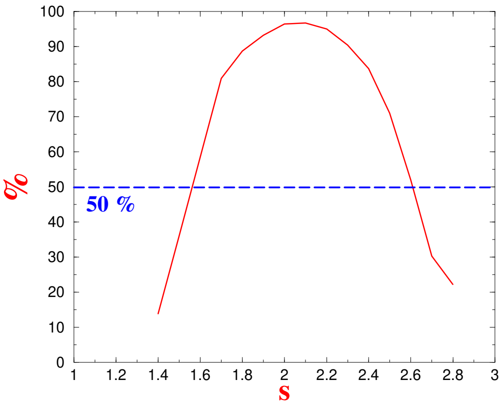

Fig. 2. Confidence test results. Every point stands for percentage (on 10000 simulations with fixed s-value) of $\chi^2 > 5$ %. Values below 1.6 and above 2.6 are rejected (over 50 % of simulations bringing χ^2 lower than 5 %). The best interval, in which more than 80 % of simulations gives χ^2 above 5 %, is for s between 1.8 and 2.4.

3.2. The white dwarf luminosity function

The value assumed for the IMF exponent at M $>0.6\ M_\odot$ affects the WD production, so an additional constraint comes from the local WD luminosity function, as inferred from a proper motion and magnitude limited sample. We compared our simulations with the WD luminosity functions by Legget et al. (1998) (cool WDs) and Liebert et al. (1988) (hot WDs) (see Fig. 3) finding that only simulations for high s-exponents (around 2.6) have a WD density quite close to the observed one; the theory predicting in any case a slightly higher number of stars. WD statistic is not enough to set the SFR shape (our disk SFR is flat beginning 9 Gyr ago), but a dichotomy seems exist: the IMF derived from the local luminosity function has an exponent of about 2.1, while a steeper IMF is required to reproduce the local WD sample.

Unfortunately the WD sample is too poor to analyze the origin of this difference; it could be due to steeper IMF for masses producing WDs ($M > 1.1\ M_\odot$), or to different SFR and disk age.

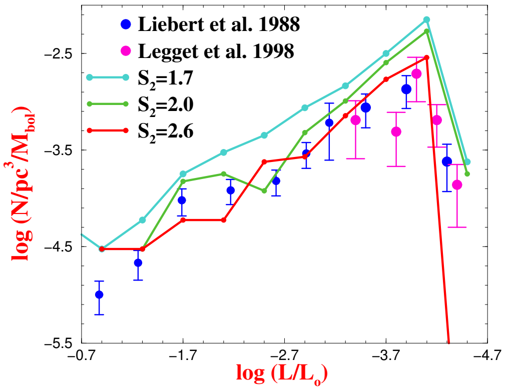

Fig. 3. Comparison among observative WD luminosity function (Legget et al. 1998 for cool WD, Liebert et al. 1988 for hot WD) and theoretical ones for different disk IMF.

4. Conclusions

Our theoretical predictions for local disk LFs of nuclear burning and WD stars are compared with observational ones. By assuming a flat SFR, in order to reconcile theoretical predictions with both the LFs it seems required a 3-parts IMF, with an additional slope above 1.1 $M_\odot$. However this conclusion can depend on the assumed SFR. Only an improvement of the WD sample size will allow to obtain more information about disk SFR and IMF.

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