DETERMINATION OF THE INITIAL MASS FUNCTION IN THE SOLAR NEIGHBOURHOOD BETWEEN 1.2 AND 4 $\mathcal{M}_\odot$

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ABSTRACT

Galactic evolution models rely, among other things, on the Initial Mass Function (IMF) and on the Star Formation Rate (SFR). The high accuracy of positions, parallaxes and proper motions together with the completeness of Hipparcos data allow us to get a new insight into IMF and SFR. In particular, the Mass-Luminosity relationship, which is uncertain for the type of stars considered here is avoided.

In this work a complete sample of $B5-F5$ stars with apparent magnitudes $V \leq 6.5$ observed by Hipparcos is studied. The absolute magnitudes are computed using Hipparcos parallaxes. For stars with $\frac{\sigma\pi}{\pi} > 0.15$, a weighted mean is calculated between astrometric and photometric parallaxes. This sample is modelled by assuming the IMF to be of the form $\xi(\mathcal{M}) = \mathcal{M}^{-(1+x)}$. Taking different forms for the SFR (constant or decreasing exponentially), we compare the simulated sample with the observed one with a χ^2-test. The slope of the IMF is then determined in the $1.2 - 4\mathcal{M}_\odot$ range and compared to the reference values (Salpeter 1955, Scalo 1986) and more recent determinations over the whole mass range.

Key words : Hipparcos; A-type stars; IMF.

1. INTRODUCTION

The Initial Mass Function (IMF: number of stars formed by interval of mass) and the Star Formation Rate (SFR: number of stars formed by interval of time) which allow us to describe the distribution of stars in the solar neighbourhood are still not well known. Furthermore, they are interdependent, i.e. they cannot be studied independently.

Usually, the following form is adopted for the IMF:

$$\xi(\mathcal{M}) = \mathcal{M}^{-(1+x)}$$

x is called the slope of the IMF.

Salpeter, using field stars, determined in 1955 a slope of 1.35. In his review paper in 1986, Scalo estimated a value of 1.7 for the whole mass range. Since then, many studies have been performed for different ranges of masses, tending to adopt different slopes for high and low masses (Haywood et al. 1997).

During the last 20 years, many studies have been done on the Star Formation Rate in the galactic disc. These results show that the SFR remains more or less constant since the formation of the disc (see Haywood et al. 1997). Twarog (1980) tested a constant and exponentially decreasing SFR.

Using the model of stellar population synthesis (Robin & Crézé 1986, Haywood 1994), Haywood et al. (1997) derived the slope of the IMF for the cases of a constant, exponentially increasing and exponentially decreasing SFR.

In this work, we study $B5-F5$ main-sequence stars: their ages can reach 3 Gyr while the disc is estimated to be 10 Gyr old. Then it is the behaviour of the SFR during the last 3 Gyr of the life of the galactic disc which is the subject of this study. In particular, variations of the SFR on periods of several Myr may have occurred whereas the mean SFR remains constant.

1.1. Method

The method adopted here to study the IMF is to simulate a sample with a given SFR and a given slope of the IMF, reproducing the truncation made on the observed sample in visual absolute magnitude and effective temperature.

This simulated sample is compared with the observed sample O using a χ^2-test:

$$\chi^2 = \sum_i \frac{(O_i - S_i)^2}{O_i + S_i}$$

O_i is the number of stars in bin i for the observed distribution, S_i is the number of stars in bin i for the simulated distribution.

Until now, the determination of the IMF needed, as a preliminary step, the determination of the Luminosity Function (greatly improved with Hipparcos data) and the Mass-Luminosity Relationship which remains uncertain. To avoid the use of this relationship, the comparison is made using the distribution in absolute magnitude M_V.

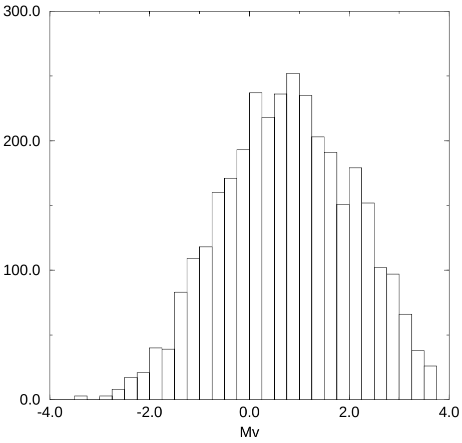

Figure 1. Distribution of absolute magnitudes.

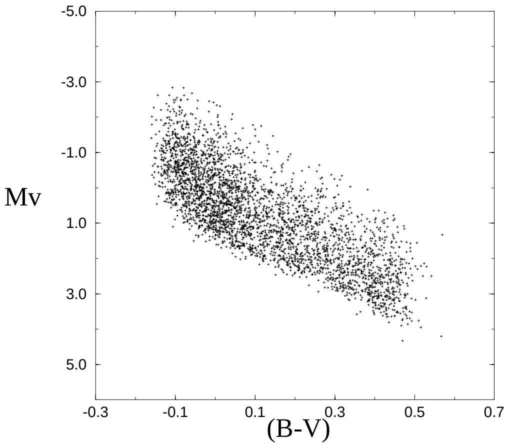

Figure 2. H-R diagram of the sample.

2. DESCRIPTION OF THE SAMPLE

We use a sample of 3361 $B5 - F5$ main-sequence stars, complete up to $\mathrm{V}_{\mathrm{lim}} = 6.5$. For these stars, we have:

- Stömgren photometry ($(b - y)_0$, m_0, c_0, β), which provides photometric parallaxes π_ϕ, effective temperature T_{eff}, metallicity $\left[\frac{Fe}{H}\right]$ and visual absorption A_V (compilation of the calibrations from Arenou 1993);
- Trigonometric parallaxes π_H from Hipparcos.

2.1. Determination of the Absolute Magnitude M_V

For stars with $\frac{\sigma_{\pi_H}}{\pi_H} \leq 0.15$ (88 per cent of the sample), we use only the trigonometric parallaxes. For the 391 stars left, we calculate a weighted mean value between trigonometric and photometric parallaxes, following the formula:

$$\pi = \frac{\frac{\pi_H}{\sigma^2_{\pi_H}} + \frac{\pi_\phi}{\sigma^2_{\pi_\phi}}}{\sqrt{\frac{1}{\sigma^2_{\pi_H}} + \frac{1}{\sigma^2_{\pi_\phi}}}}$$

Then we determine the absolute magnitude for each star, using this parallax:

$$M_V = V + 5 + 5\log\pi - A_V$$

Figure 1 shows the distribution of absolute magnitudes for this sample and Figure 2 the corresponding H-R diagram.

Individual masses and ages for the stars are calculated using Lebreton (1996) evolutionary tracks (calculated from CESAM code, Morel 1993, 1997): absolute magnitude (with bolometric correction from Malagnini et al. 1986) and effective temperature together with metallicity allow us to interpolate between tracks (Asiain et al. 1997).

3. SIMULATIONS

The first step consists in the generation of an age t and a mass $\mathcal{M}$ from a given SFR and a given IMF. The compatibility between t and $\mathcal{M}$, given by the stellar evolution models is checked. Then, these parameters allow us to derive the absolute magnitude and the effective temperature using, as for the observed sample, the CESAM code with Malagnini's (1986) bolometric corrections.

Position X, Y, Z: The distribution of stars in the galactic plane (X and Y) is assumed to be uniform. In the direction of the galactic pole, we have adopted a square hyperbolic secant:

$$\rho_Z = \left(\frac{2}{e^{\frac{-Z}{h_Z}} + e^{\frac{Z}{h_Z}}}\right)^2$$

where h_Z (the scale height) is taken as a function of M_V (Scalo 1986).

From $\mathcal{M}$, t, and the distance $d = (X^2 + Y^2 + Z^2)^{\frac{1}{2}}$, we use the Lebreton's evolutionary tracks to derive T_{eff} and M_V in order to reproduce the truncations in temperature and apparent magnitude. Then we obtain, for each simulated star, a position, temperature, absolute magnitude, mass and age.

4. RESULTS

For a given SFR, a sample has been simulated for each value of x in the range 0.0 to 2.0 by a step of

Table 1. Literature values for the slope x of the Initial Mass Function (Source: Richer & Fahlman 1997).

Author	mass range	x	Remarks
Salpeter (1955) (1)	$0.5 - 10$ M$_\odot$	1.35	field stars
Scalo (1986) (2)	$2 - 20$ M$_\odot$	1.7 ± 0.4	field stars
Massey et al. (1995) (3)	> 7 M$_\odot$	1.1 ± 0.1	OB associations young open clusters
Williams et al. (1995)(4)	$0.1 - 1$ M$_\odot$	1.1 ± 0.2	ρ Oph cluster
Francic (1989) (5)	$1 - 2.5$ M$_\odot$	1 ± 0.2	open clusters ($10^8 - 2.5 \times 10^9$ years)
Méra et al. (1996) (6)	< 0.6 M$_\odot$	0.7 ± 0.5	

0.1. Each simulated sample has been then compared with the observed one.

In the first case, a constant SFR is adopted. Figure 3 shows the χ^2 variation versus the slope of the IMF, x. The minimum (meaning the best reproduction of the observed sample) is obtained for a slope of 0.95 ± 0.17.

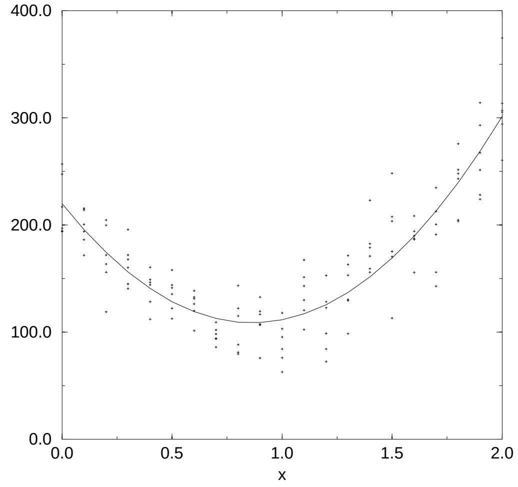

Figure 3. χ^2 versus the slope x of the IMF for a constant SFR.

In the second case, an exponential SFR ($B(t) = e^{\frac{-t}{t_0}}$) is taken. Different values of t_0 have been tested: a high value of this parameter tends to give a constant SFR. On the other hand, when $|t_0|$ is close to 0, the simulations are in bad agreement with the observations (very high value of the χ^2) for any value of the slope of the IMF. An intermediate value of $t_0 = 5$ has then been chosen to simulate an exponentially decreasing Star Formation Rate. Figure 4 shows that the minimum of the χ^2 is reached for $x = 0.85 \pm 0.22$.

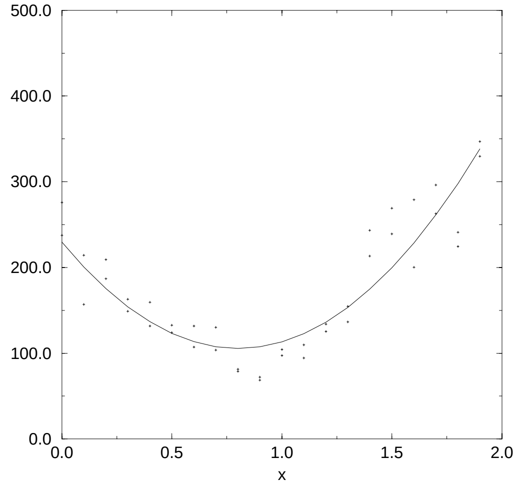

Figure 4. χ^2 versus the slope x of the IMF for an exponentially decreasing SFR $B(t) = e^{\frac{-t}{5}}$.

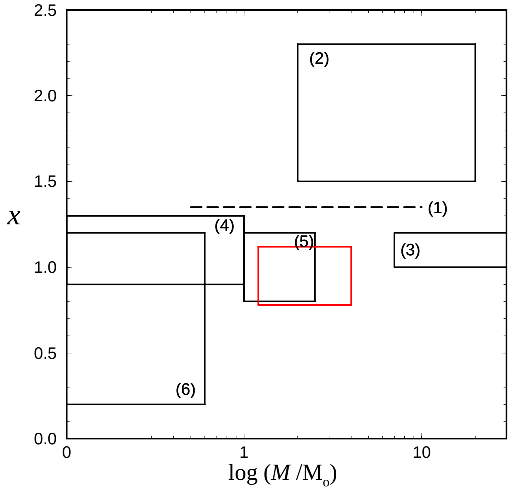

Figure 5. Comparisons with literature values (see Table 1).

5. CONCLUSIONS

Moffat (1996), discussing the slope of the IMF, concluded that there is a universal value $x = 1$ valid for the whole mass ranges ($0.1 - 100 M_\odot$). Richer & Fahlman (1997) derived a value of 0.86 ± 0.23 as a result of a compilation. Some of the slopes of the IMF cited in this paper are indicated in Table 1, with the reference values of Salpeter and Scalo.

Our best result for the slope is $x = 0.95 \pm 0.17$, lower than the value commonly accepted (around 1.7) for the stars in this range of mass $(1.2 - 4\mathcal{M}_{\odot})$.

This slope is depicted in Figure 5 with the values of Table 1. Our result is in excellent agreement with the conclusions of Moffat (1996) and Richer & Fahlman (1997).

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