SCALEHEIGHTS OF LOW MASS STARS FROM THE LUMINOSITY FUNCTION OF THE LOCAL WHITE DWARFS

N.C. Rana
Tata Institute of Fundamental Research
Homi Bhabha Road, Bombay 400005, India

It is shown that a combination of the observed luminosity function of the local white dwarfs and the theoretical cooling rates of a typical white dwarf suggests an approximately constant rate of formation of the white dwarfs. This rate is found to be about a factor of three lower than the observed birthrate of their immediate progenitors. This discrepancy is here interpreted as a three-fold increase in the scaleheight of the white dwarfs due to dynamical interaction with stars, molecular clouds; an average white dwarf being much more aged than an average progenitor. Since the low mass stars on an average are even slightly more long-lived than these white dwarfs, one can place a lower bound on the scaleheights of the low mass stars to be given by the required scaleheights of the white dwarfs, which is, according to the present work, 660 pc in the solar neighbourhood.

The Figure 1 shows the cooling curves for 0.6 $M_\odot$ white dwarfs with surface composition ranging from DA (with hydrogen envelope) to DB (helium rich envelope) types.

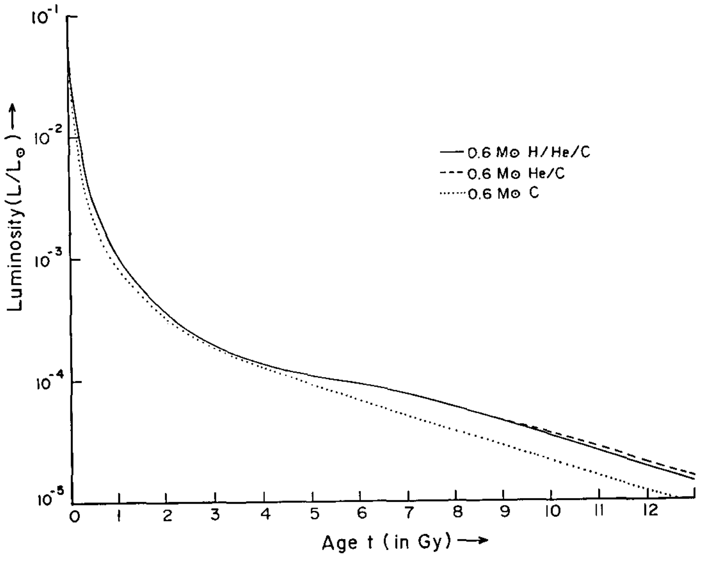

Figure 1. Theoretical cooling curves for white dwarfs of mass $0.6M_\odot$.

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In Table 1, the observed luminosity function of the local white dwarfs has been taken from Winget et al (1987). Combining this data with the cooling rates derived from Figure 1, the past history of the rate of formation of white dwarfs per unit volume of space in the solar neighbourhood (expressed in units of $pc^{-3}\ Gy^{-1}$) is determined and shown in the last column of Table 1. The average rate seems to have remained

Table 1

Luminosity function and birthrates of the white dwarfs in the solar neighbourhood

$\log (L/L_{\odot})$	M_{Bol}	$\log [\phi(M_{Bol}, T_d)]$; ϕ in $pc^{-3} M_{Bol}^{-1}$	$\frac{d \log (L/L_{\odot})}{dt}$	Look back time $(T_d - t)$ in Gy	Birthrate of white dwarfs $\log [C(t)]$; $C(t)$ in $pc^{-3}\ Gy^{-1}$
-0.50	6.00	-5.81 ± 0.13	79(52) *	0.0044(0.0084)*	$-3.51^{+0.15}_{-0.30}$
-0.93	7.07	-4.96 ± 0.07	25(20)	0.015(0.022)	$-3.16^{+0.10}_{-0.15}$
-1.46	8.39	$-4.79^{+0.08}_{-0.09}$	7.1(7.6)	0.059(0.068)	$-3.54^{+0.12}_{-0.10}$
-1.95	9.62	$-4.10^{+0.09}_{-0.06}$	2.6(3.7)	0.180(0.164)	$-3.29^{+0.25}_{-0.10}$
-2.36	10.64	$-3.79^{+0.15}_{-0.08}$	1.6(2.1)	0.39(0.28)	$-3.19^{+0.25}_{-0.10}$
-2.70	11.49	$-3.73^{+0.10}_{-0.09}$	1.0(1.1)	0.65(0.52)	$-3.33^{+0.13}_{-0.10}$
-3.04	12.34	$-3.51^{+0.09}_{-0.13}$	0.57(0.63)	1.10(0.90)	-3.36 ± 0.13
-3.58	13.69	$-3.14^{+0.13}_{-0.30}$	0.28(0.27)	2.50(2.35)	$-3.29^{+0.13}_{-0.30}$
-4.04	14.84	$-3.27^{+0.25}_{-0.60}$	0.075(0.14)	5.95(5.00)	-4.00 ± 0.60
-4.40	15.74	$-2.92^{+0.14}_{-0.18}$	0.125(0.135)	9.55(7.92)	-3.42 ± 0.20
-4.66	16.39	$-4.20^{+0.45}_{-0.50}$	0.125(0.125)	11.6(10.05)	-4.70 ± 0.50

*The quantities in the parenthesis are for He/C $0.6M_{\odot}$ WDs.

fairly constant over the life-span of the disc with the value given by

$$\log < C > = -3.28 \pm 0.15$$

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This can readily be compared with the observed rate of formation of the immediate progenitors (C_p) of the white dwarfs, such as planetary nebulae, stars on the AGB or HB of the HR diagram. Various authors have estimated this number to be roughly agreeing within a factor of 5 or so, with the lowest of the values given by Drilling and Schönberner (1985):

$$\log C_p = -2.78.$$

Even though it is the lowest of the estimates, it matches exactly with the predicted value, provided Rana (1987)'s IMF is taken. So I consider the above one to be a reasonable estimate.

Now obviously, there is a discrepancy between $\langle C \rangle$ and C_p, at least by a factor of 3. The observed average rate of formation of the white dwarfs per unit volume is at least a factor of three less than that of their immediate progenitors.

We interpret this discrepancy to be arising due to longer life as well as stay of an average white dwarf than an average progenitor star. According to Wielen (1977), a longer stay of any object, be it a star or a cloud in the disc, makes the object increase its velocity dispersion with time, which means that the vertical amplitude of oscillation or its so-called scaleheight also increases with time. If we take the population average of the lifetime of the possible progenitors of the observed white dwarfs to be a measure of the average lifetime of the progenitors, then this lifetime is much shorter than the average age of the white dwarfs in the disc. So one could naturally expect that the white dwarfs would have a larger scaleheight than their progenitors. In fact, the ratio between $\langle C \rangle$ and C_p may be interpreted as the inverse of the ratio between the respective scaleheights of their distributions.

In Table 2, the data on the mass function of the stars in the solar neighbourhood are taken from Rana (1987). The population average of the scaleheights of the progenitor stars of the white dwarfs is estimated to be

$$\langle H \rangle_{*pg} = \int_{m_1}^{m_2} H(m)\, n(m)\, dm \Big/ \int_{m_1}^{m_2} n(m)\, dm = 220 \text{ pc},$$

where $m_1 = 0.95\ M_\odot$ and $m_2 = 8\ M_\odot$. Hence, we claim that the scaleheight of the vertical distribution of the local white dwarfs is at least 660 pc, that is, three times that of their immediate progenitors.

Now since on an average a low mass star lives slightly longer than an average white dwarf, the scaleheight distribution of the former should in general be somewhat larger than that of the white dwarfs. Therefore, we expect that the average scaleheight of the low mass stars that can outlive the disc would be given by

$< H >_{low\ mass*} \gtrsim 660$ pc.

Table 2

Basic data on the mass functions, lifetimes and the scaleheights distribution of main sequence stars in the solar neighbourhood.

Stellar mass (in $M_\odot$) log m	Present day mass function ϕ_{ms} (in $M_\odot$ pc^{-2}) log ϕ_{ms}(log m)	Total life-time T_t (in Gy) log T_t	Main sequence lifetime (in Gy) log T_{ms}	Scaleheight (in pc) log(2H)	Initial mass function (in $M_\odot$ pc^{-2}) log ξ(log m)	Volume density mass function (in pc^{-3}) log n(log m)
1.08	-2.91	-1.63	-1.70	2.27	-0.13	-2.40
0.92	-2.40	-1.40	-.1.50	2.30	0.18	-2.12
0.73	-1.89	-0.98	-1.10	2.33	0.29	-2.04
0.54	-1.28	-0.42	-0.61	2.38	0.41	-1.97
0.39	-0.43	-0.07	-0.27	2.46	0.92	-1.54
0.26	+0.15	0.35	0.15	2.59	1.08	-1.51
0.16	0.78	0.68	0.48	2.76	1.38	-1.38
0.06	1.32	1.05	0.85	2.97	1.55	-1.42
-0.02	1.62	1.35	1.15	3.01	1.62	-1.39

Both these conclusions about the scaleheight distributions can be tested once the more deep sky surveys of the low mass stars and the white dwarfs become available. It may be mentioned that Van der Kruit (1986)'s model of the galaxy and the IRAS image of the local disc suggest the scaleheight of the local disc stars to be in the range of 500-600 pc. With such a large scaleheight for the low mass stars and the white dwarfs, the problem of the local dark matter can also be satisfactorily resolved.

References

Drilling, J.S., and Schönberner, D., 1985, Astron. Astrophys. 146, L23.

Rana, N.C., 1987, Aston. Astrophys. 184, 104.

Van der Kruit, P.C., 1986, Astron. Astrophys. 157, 230.

Winget, D.E., Harsen, C.J., Leibert, J., Van Horn, H.M., Fontaine, G., Nather, R.E., Kepler, S.O., and Lamb, D.Q., 1987, Astrophys. J. 315, L77.

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