Mass-radius Relations for Helium White Dwarfs [*]

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Abstract

We studied the static mass-radius relation of white dwarf stars with masses greater than 0.45 $M_\odot$. We assumed pure degenerate helium interiors at a finite temperature with luminosity-mass ratio due to neutrino energy loss. We compared the obtained M-R relation with those of other writers.

Introduction

In recent years, white dwarf stars are receiving increasing attention. The theoretical relationship between the mass and radius of a white dwarf is important in interpreting some of the observational results. M-R relation was first defined by Chandrasekhar [4]. Later Hamada and Salpeter [5] obtained numerical models for different core compositions by considering a fully degenerate configuration (zero-temperature) because of their higher densities (10^6-10^8 g cm^{-3}).

A real WD is not a zero-temperature object. The inclusion of hydrogen envelope increases the radius depending on the amount of hydrogen present which is not known with certainty (Koester, [10]; Hamada and Salpeter, [5]). Hamada and Salpeter (1961) mentioned that for massive WDs ($M_\odot > 0.7$) non degenerate envelope is rather insignificant. Benvenuto and Althaus [3] in their recent studies also concluded that thick H envelopes increase the radii especially in the case of low mass WDs.

The recent studies on the relation of M-R for the WDs are those of Wood [12], Vennes et al. 11 and Althaus and Benvenuto [1, 3]. Vennes et al. [11] computed static M-R relation for masses between 0.4 $M_\odot$ and 0.7 $M_\odot$ assuming non zero temperature effects. They assumed the luminosity is proportional to the mass which works for cool WDs but

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their results are in the range of high effective temperatures. As Althaus and Benvenuto [1] mentioned, luminosity is not proportional to a constant for hot WD interiors because of neutrino emission. One must include neutrino cooling which causes larger radii for WDs. Neutrino losses are important especially for masses greater than 0.4 $M_\odot$ (see Fig.11 of Althaus and Benvenuto, [1]).

The purpose of this study is to present the effect of neutrino emission at finite temperatures. We considered fully degenerate configuration for WDs with pure helium composition to obtain M-R relation for masses greater than 0.4 $M_\odot$ with neutrino emission taken into account as well. In section 2 we describe the procedure that we follow. In section 3 we present and discuss the results and compare the obtained M-R relation with the other results.

Procedure

Our stellar WD models are calculated on the assumption that the WD is spherically symmetric and in hydrostatic equilibrium. Then, four stellar structure equations that must be satisfied by this structure are integrated outward with Runga-Kutta iteration tecnique. For the equation of state, we followed the procedure given by Althaus and Benvenuto [1] for a dense plasma in which the electrons are strongly degenerate at a finite temperature, that is we included in the equation of state Coulomb interaction, Thomas-Fermi deviation from uniform charge distribution of the electrons and the exchange contribution to the free energy at finite temperature. As far as neutrino losses are concerned we considered photo neutrino process (Itoh et al., [8]), plasma neutrino process (Itoh et al., [8]; Itoh et al., [9]) and neutrino Bremstrahlung for the liquid phase (Itoh and Kohyama, [6]). For the conductive opacities we used the analytic fits given by Itoh et al. [7] for high densities.

Results

In this paper, we give the first results of our white dwarf models including neutrino emission, that is M-R relations of the fully degenerate helium WDs for masses greater than 0.4 $M_\odot$ are presented.

Figure 1. shows the M-R relations for helium WDs calculated by Hamada and Salpeter [5], Althaus and Benvenuto [1], Vennes et al. [11] and our results. In this figure, plus sign shows our results obtained at the temperature $T_c = 10^7$ K using the density values given in Table 1A of Hamada and Salpeter [5] for helium core (cross sign shows the results of Hamada and Salpeter). The difference in mass and radius is about 1%. As seen from the figure the static mass-radius relations are modified by thermal effects and neutrino emission particularly for WDs of low mass. These thermal effects and neutrino emission can cause deviations from the zero temperature M-R curve which are almost of the same order as Hamada-Salpeter corrections to the standard Chandrasekhar M-R curve. We repeated the calculations for a different central temperature $T_c = 5 \times 10^7$ K. The resulting data is also shown (circle sign) in the figure. The increase in T_c causes the curve to shift upward for the masses smaller than 0.7 $M_\odot$. We plot on the same figure also the

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results of Althaus and Benvenuto [1] for zero temperature (star sign) and for T_c= 5x10^7 K helium WD models (full box sign). The models of Vennes et al. [11] for masses smaller than 0.7 $M_\odot$ are shown by open box sign. Their models have larger radii than the other models plotted in the same figure due to the high effective temperature (49000 K) they used which means higher central temperature.
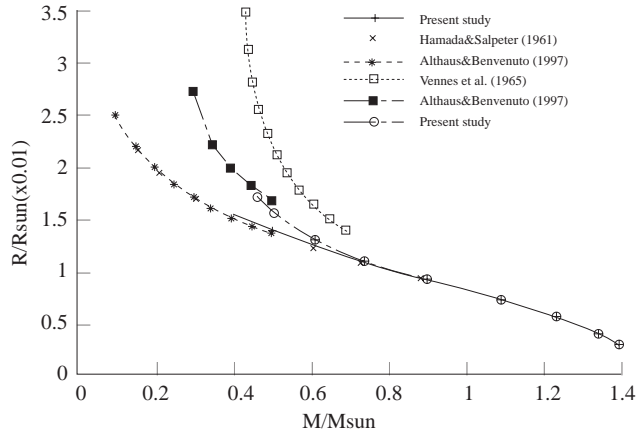
Figure 1. Mass-radius diagram for pure helium white dwarfs. Plus and empty circles are the results of the present study for central temperatures of 10^7 K and 5×10^7 K, respectively. Star and full box signs show the results of Althaus and Benvenuto [1] for zero-temperature and T_c= 5×10^7 K WD stars, respectively. Also shown are the data of Hamada and Salpeter (1961) (cross sign) and Vennes et al. [11] (empty box sign).

In our calculations with internal temperature of 5×10^7 K, we found R=0.015 $R_\odot$ for 0.5 $M_\odot$ WD. The effective temperature of 0.5 $M_\odot$ WD star can be assigned to be in the range 17×10^3 - 17.5×10^3 K using the results of Atweh and Eryurt-Ezer [2] for the lower boundary of convection zone of helium WDs in the case of strong convection. They give the depth of convection zone for this effective temperature range between 30 and 60 km. Therefore, about 7% difference in the radii of 0.5 $M_\odot$ WDs at the mentioned interior temperature, between our study and the study of Althaus and Benvenuto, is not due only to the absence of helium atmosphere in our study but also due to neglecting star's thermal history. Detailed evolutionary models are necessary for better interpretation of observations of WDs.

Acknowledgement.

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