ON THE PROBLEM OF THE NUMERICAL MODEL CONSTRUCTION OF ZERO-AGE SUBSTARS

V.A. Zakhozhaj [1], M.D. Blokhina [1], A.I. Pysarenko [1], A.A. Yatsenko [2], Yu.V. Slusarenko [2]
[1] Kharkov State University, Ukraine
[2] Institute of Physics and Technology, Ukrainian Academy of Science

ABSTRACT. The numerical modelling of substars inner structure is analysed and main definitions are suggested. Here we present results of calculation of degeneracy parameter ψ, permitting to make calculate the dependence of number of free electrons on function temperature and density typical interior of zero-age substars (ZAS).

Key words: substar: brown dwarfs: degeneracy parameter

Astronomical objects with masses smaller than the minimum stellar value are generally referred to as brown dwarfs (see, e. g., Tarter, 1975). Thermonuclear reactions of truncated $p-p$ chain in the interiors of the brown dwarfs occur, that is objects more massive than $0.07 M_\odot$ can burn hydrogen, objects with masses more than $0.015 M_\odot$ burn deuterium, combustion process of ^3He is unavailable due to the low core temperature (Burrows and Libert, 1993; Grossman, 1970; Grossman, 1974).

At about the same time Alexandrov and Zakhozhaj (1980) when characterising internal structure of stars and giant planets proposed a whole new class of low-mass objects containing matter with degenerate electron gas in their interior. It was suggested to call these objects substars taking into account that their maximum mass is coincident with lower stellar mass limit and their lower limit depends on central density that is equal to critical density of degenerate electrons ρ_{cr}.

Because central density of brown dwarfs with minimum mass is larger than ρ_{cr}, the definition of substar introduced above includes greater range of objects and is more general compared with the masses range of brown dwarfs. The first estimates of the minimal substars masses obtained from mass dependence of central density and mean density dependence of critical density yielded that values of minimum substar mass $M_{SS_{min}}$ is equal to $0.005 M_\odot$ (Alexandrov and Zakhozhaj, 1980; Landau and Lifshitz, 1976). As numerical simulations of their structure along the whole range of mass were not carried out, the value $M_{SS_{min}}$ is not conclusively established.

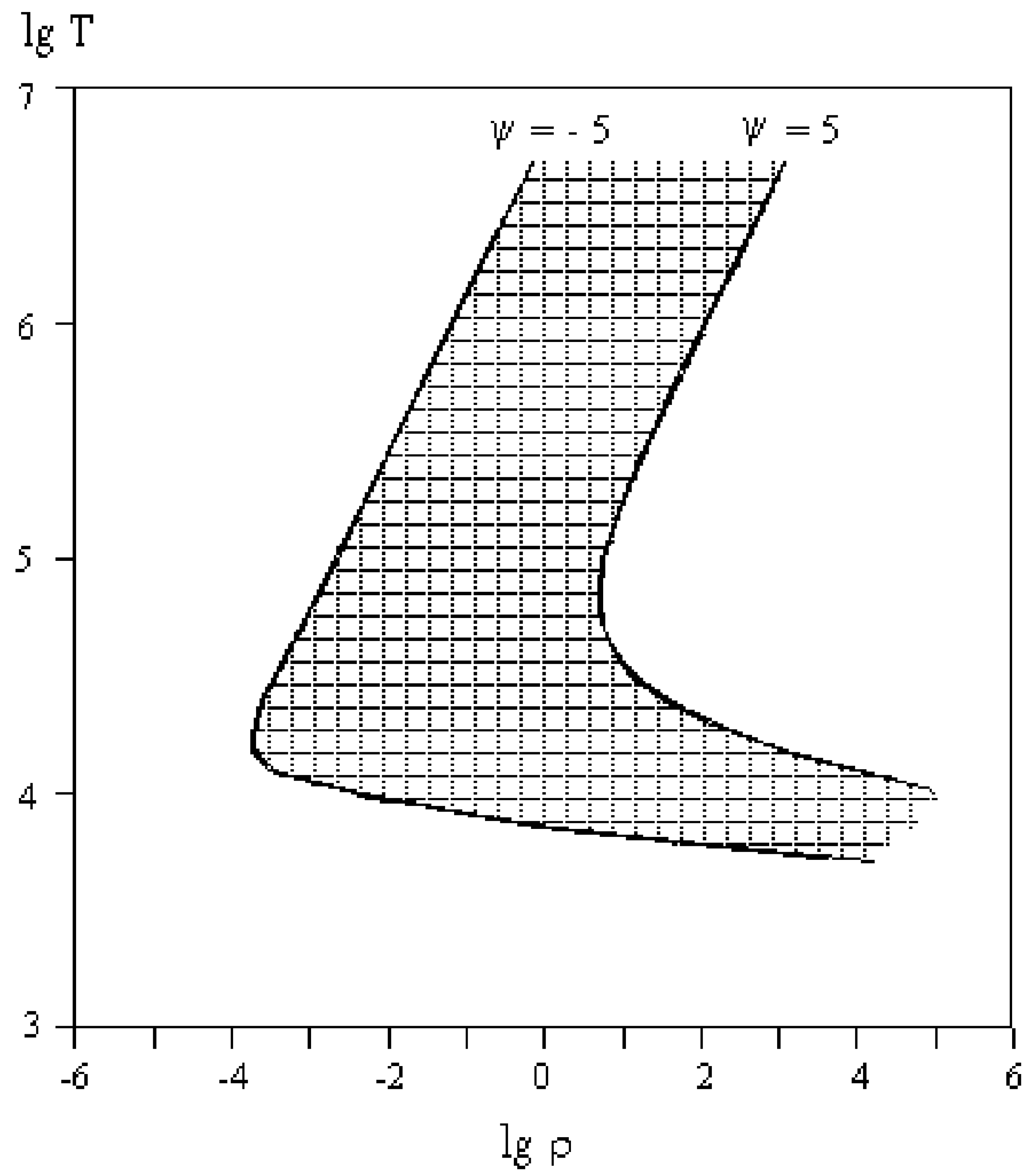

Figure 1: Dependence of degeneracy parameter ψ on temperature T and density ρ for mixture of gases H and He ($X = 0.75, Y = 0.25$). The electron configuration in the section on the left of the curve $\psi = -5$ is described by classic partition function; on the right of curve $\psi = 5$ lies the region of strongly degenerate electron gas; the hatched section represents schematically the realm of the partially degenerate electron gas.

The active phase duration of radiation and luminosity of brown dwarfs are connected with the burning process of hydrogen, deuterium and lithium. Massive brown dwarfs with mass above $0.07 M_\odot$ can sustain hydrogen-burning during the time interval of about 10^9 years until nuclear reactions cut off (Burrows and Libert, 1993). In the interior of brown dwarfs with mass larger than $0.015 M_\odot$ primordial deuterium burns within first ten million years (Grossman, 1970; Grossman, 1974). For mass down to $0.06 M_\odot$, primordial lithium is used up, though the process takes more time.

Further radiation on passive phase of brown dwarfs evolution, as in the case of low-mass substars with masses up to $0.015M_\odot$, is defined by reserves of thermal energy. Thus, for substars of the same age with the masses $\sim 0.015M_\odot$ on the H-R diagram, the first-order discontinuity should be observed, because of start cooling time shift of substars with different masses. It is useful to introduce the definition of zero-age substars (ZAS) by which we mean the age when a substar starts cooling. We also find it useful to categorise substars into two classes, those of low masses $M \sim [M_{ss\,min}, 0.015M_\odot]$, and brown dwarfs $M \sim [0.015M_\odot, M_{*\,min}]$. M_{*min} — minimal star mass, which is now considered $\approx 0.08M_\odot$ with small variations depending on a chemical composition (Bisnovatyi-Kogan, 1989).

Chandrasekhar (1932), Landau and Lifshitz (1976) constructed theoretical models for stable configurations of astronomical objects with the polytropic parameter $n = 3/2$ corresponding to the case of fully degenerate electron gas. Similar modelling was carried out by Kumar (1963) for fully convective substars with masses $0.04M_\odot$ and more. Further advancement of these ideas was continued by Grossman (Grossman, 1970; Grossman et al., 1970), Graboske (Graboske et al., 1973), Nelson (Nelson et al., 1986; Dorman et al., 1989), D'Antona and Mazzitelli (1985, 1986), Stevenson (1991) and other (Burrows and Libert, 1993; Burrows et al., 1989; Liebert and Probst, 1987). On the other hand, all these papers cover modern conceptions of electron screening effects, which influences the nuclear reaction rate. Also they used the results of calculation of opacity in the matter similar to that of substar interiors. However, their polytropic models provide rather a simplified idea about the substars internal structure.

In the absence of external energy sources, ZAS structure may be described by the system of differential equations: two standard equations of hydrostatic equilibrium and equation of adiabatic equilibrium. The system of equations has solution in the case when the equations of state of matter are specified. State of matter, by definition, is bound to vary from fully degenerate electron gas in the center of brown dwarf, to classic electron gas in the ZAS atmosphere, passing the partially degenerate region (see the hatched section on the Figure 1), which is specified by degeneracy parameter ψ. Atoms of matter across the whole width of ZAS interiors are described by equation of state for perfect gas.

All the recited equations have been investigated except the dependence degeneracy parameter ψ on temperature and density. In order to gain insight into dependence $\psi = \psi(T, \rho)$ we evolved a theory, which makes possible calculate number of free electrons as function of T and ρ typical for ZAS interiors, where Saha type equation takes into account the degree of electron gas degeneracy. Hence, our consideration goes far beyond the scope of the polytropic models.

In the nearest future we intend to publish the results of ZAS inner structure calculations taking into account the dependence $\psi = \psi(T, \rho)$.

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