TWO NONSTANDARD SOLAR MODELS: WITH MIXED INTERIORS AND WITH ENHANCED HEAVY ELEMENT OPACITY

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Abstract. We present and briefly discuss basic characteristics of a standard solar model as well as those for two series of nonstandard models computed with Paczyński's stellar evolution code.

The solar models with mixed interiors seem to be more preferable, comparingly with the standard ones, as concerns solar neutrino experiments and solar pulsation problem - particularly, that of 160^m-pulsations (see, for example, Ezer and Cameron, 1968; Hoyle, 1975; Schatzman and Maeder, 1981; Gavryuseva et al., 1983). The mixing may be caused by existence of convective core which in it's turn may be related to opacity enchanced for some reason.

We have computed the standard solar model and two series of the nonstandard ones. In the first series we have postulated the solar interiors to be continuously mixed during the evolution from zero age main sequence. It was assumed implicitly that the timescale of the mixing is of order of 10^8 years or less. At the same time, the mixing was considered as not convective, i.e. it has no explicit influence on heat transfer which was computed in diffusion approximation, with Schwarzschild's criterion for convection. In the second series of models we have studied the effect of enchanced heavy element opacity, as it was suggested by Simon (1982) for models of double-mode and beat Cepheids. The enchanced heavy element opacity was imitated by use of opacity tables for increased heavy element abundances Z = 0.04 and 0.10, while the standard value Z = 0.02 was left in the rest of computations. Such a procedure is somewhat analogous to the one used by Simon (1982). The corresponding opacities were interpolated/extrapolated in Cox-Stewart tables (1969).

All the computations were performed with use of stellar evolution code by Paczyński (1970). In all cases we were computing evolution of 1 M☉ star with heavy element abundan-

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ce Z = 0.02 from zero age main sequence to the present age of the Sun. The initial hydrogen abundance X and the mixing length parameter α = l/Hp were adjusted to give solar luminosity and radius. Basic characteristics of the models computed are listed in Table 1. The standard model (no postulated mixing, standard opacity for Z = 0.02) is almost identical to the one computed by Shibahashi and Osaki (1981) also by using Paczyński's program.

Table 1. Basic characteristics of the models computed. (In all models the heavy element abundance is Z = 0.02. Mmix and Lmix - mass and luminosity of mixed core. Z_{κ} - value of Z in opacity calculations. r_{b} and T_{b} - radius and temperature at the base of the convective envelope whose mass is Mconv. Other symbols have their usual meaning.)

Model	stand.	with mixed interiors				"Z-opacity"	
Mmix/M	0	0.1	0.2	0.3	0.5	no mixing	
Lmix/L	0	0.554	0.804	0.910	0.987	no mixing	
Z_{κ}	0.02	standard value				0.04	0.10
X	0.77	standard value				0.704	0.623
α=l/Hp	1.30	standard value				1.48	1.67
L/L☉	0.985	0.966	0.978	0.979	0.977	0.989	1.008
R/R☉	0.994	0.987	0.991	0.986	0.975	0.995	1.005
Age, 10^9 y	4.50	4.42	4.50	4.53	4.60	4.41	4.42
T_c, 10^6 K	15.75	15.57	15.32	14.99	14.66	16.44	17.79
ρ_c, c.g.s.	193.0	144.1	128.6	117.4	108.3	208.6	246.7
X_c	0.369	0.546	0.605	0.648	0.689	0.298	0.154
Mconv/M	0.017	standard value				0.030	0.048
r_b/R	0.727	standard value				0.696	0.669
T_b, 10^6 K	1.987	standard value				2.432	2.988

The models with mixed interiors are similar to corresponding models by Shaviv and Beaudet (1968). In agreement with Ezer and Cameron (1968) and Shaviv and Beaudet (1968), the evolutionary tracks of such models in HR diagram practically coincide with the track for the standard model having the same initial chemical composition. Also the parameters of the convective zone in the standard model and in the mixed ones are the same. With increasing mass of mixed core the central temperature and density are decreasing. Such changes may be favourable for the solution of the neutrino problem and for the interpretation of 160^m-pulsations (see references above). The interesting feature of the mixed models is the existence of small convective core in the models with Mmix = 0.1 and 0.2 M☉ (Mconv.core = 0.0017 and 0.0013 M☉, respectively). The convective core appeared at the age of ~$4\cdot10^9$ years, shortly before the present stage. In the models with a more extended mixing the convective core appeared at later stages. It should be noted that even in the models without convective core the stability against convection is rather weak: the radiative temperature gradient in the center of the ZAMS-model is only 4.5% smaller than the adiabatic temperature gradient; for the models of the present Sun with Mmix = 0.3 and 0.5 M⊙ this difference is 1.5% and 2.5%, respectively. (For the standard model of the present Sun the difference of gradients is about 25%.) The appearance of convective core may enchance the efficiency of postulated mixing mechanisms.

The increase of the heavy element opacity causes the increase of central temperature and density in the models and the decrease of hydrogen abundance in the center. At temperatures of order of 10^5-10^7K the opacity in the model with $Z_{æ}$ = 0.10 is 1.5-3.5 times higher than in the standard model (the maximal difference lies at temperature ~10^6K). Even at such an opacity increase the convection in the core is absent. The difference between the radiative and adiabatic gradients in the center of the initial model and the present model with $Z_{æ}$ = 0.10 is 13% and 19%, respectively. But then the enchanced opacity causes the increase of convective zone whose depth increases from 0.273 R⊙ for the standard model to 0.331 R⊙ for the model with $Z_{æ}$ = 0.10. The temperature at the base of convective envelope increases in this case from $2.0\cdot10^6$ to $3.0\cdot10^6$K. This model may be suitable for the solution of Li/Be problem and for the interpretation of the spectrum of 5^m-oscillations (see, for example, Scuflaire et al., 1982, and references there). However, due to high central temperature this model has difficulties (when there is no convective core) in respect to the neutrino problem. Moreover, the hydrogen abundance in outer layers (X = 0.623) seems to be rather low when compared with observations.

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