# Structure of the Sun's core: Evolutional and seismological constraints

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A variety of solar models (namely, models of stars having solar values of mass, radius, luminosity) is a subject of our study. We apply an additional restrictions on the model which follow from recent helioseismic results: 1) calibration of the surface helium abundance and the specific entropy in the convection zone (Vorontsov *et al.* 1991; Baturin, Vorontsov 1994; there are few results on the helium calibration but we used cited ones because they contain simultaneous determination of the helium and the entropy): $Y = 0.2505 \pm 0.004$, $S/R_g = 21.03 \pm 0.08$ mol/g; 2) estimation of the convection zone depth (Christensen-Dalsgaard *et al.*,1991): $H_b/R = 0.287 \pm 0.003$; 3) sound speed profile inferred from oscillation frequencies (Vorontsov, Shibahashi 1992).

We used the relations between Y and S and opacities (Baturin, Ajukov 1994): the impossibility to change S while modifications of opacities and hydrogen profile $X(m/M)$ are limited in the energy-generating core; increase of core opacities leads to raising of Y in the standard models; changes of opacity near the convection zone bottom affect significantly the convection zone depth $H_b$ but not the rest of the model.

None of the standard models with different opacity tables correspond to helioseismological estimates. We assume that it is caused by errors in the opacity or/and chemical composition profile and try to reproduce the "correct" model varying the above parameters. Figure shows the relations between $H_b$ and $S/R_g$ for the different values of Y (solid lines). This figure is computed for IR91 (Iglesias, Rogers 1991) opacities. The fact that the grayed areas do not overlay indicates the inconsistency between the ($H_b$, Y, S) set of values and IR91 opacity. Provided (Y, S, $H_b$) are determined we can state that IR91 opacities must be significantly lowered (by 30–40%) at the temperatures about $2.3 \cdot 10^6$ K. In contrast, we might state that Y, $H_b$ and opacities indicate the error in the entropy calibration (the appropriate value may be $S/R_g = 21.3$ mol/g). We can also consider models with helioseismological values of (Y, S, $H_b$). These values obliously fix the structure of the envelope (i.e. convection zone). The model with this fixed envelope can be obtained with decrease of the opacity or/and the hydrogen content in the core. The necessary opacity correction is about 60% that is rather large but can be explained by additional mechanisms of heat transfer.

Next we used the sound speed profile. The changes to the model necessary are rather strange: decrease of opacity in the core by 80% and lowering the hydrogen content in the centre by 0.2 (up to $X_c = 0.15$). The another possibility is to have a nonstandard model, e.g., with helium diffusion (Christensen-Dalsgaard *et al.* 1993). It has proper sound speed profile, surface helium content and convection zone depth but not the entropy. If the helioseismic estimate of S is incorrect, this model gives the best results available.

The specific entropy in the adiabatic part of the convection zone of the solar models is in a disagreement with a helioseismological estimate: the latter is too low. Large and compicated opacity corrections (for IR91 opacity tables) are needed to construct solar model with the proper entropy. The best nonstandard model is probably a model including molecular diffusion effects: it has helium abundance lowered in the convection zone by 0.03.

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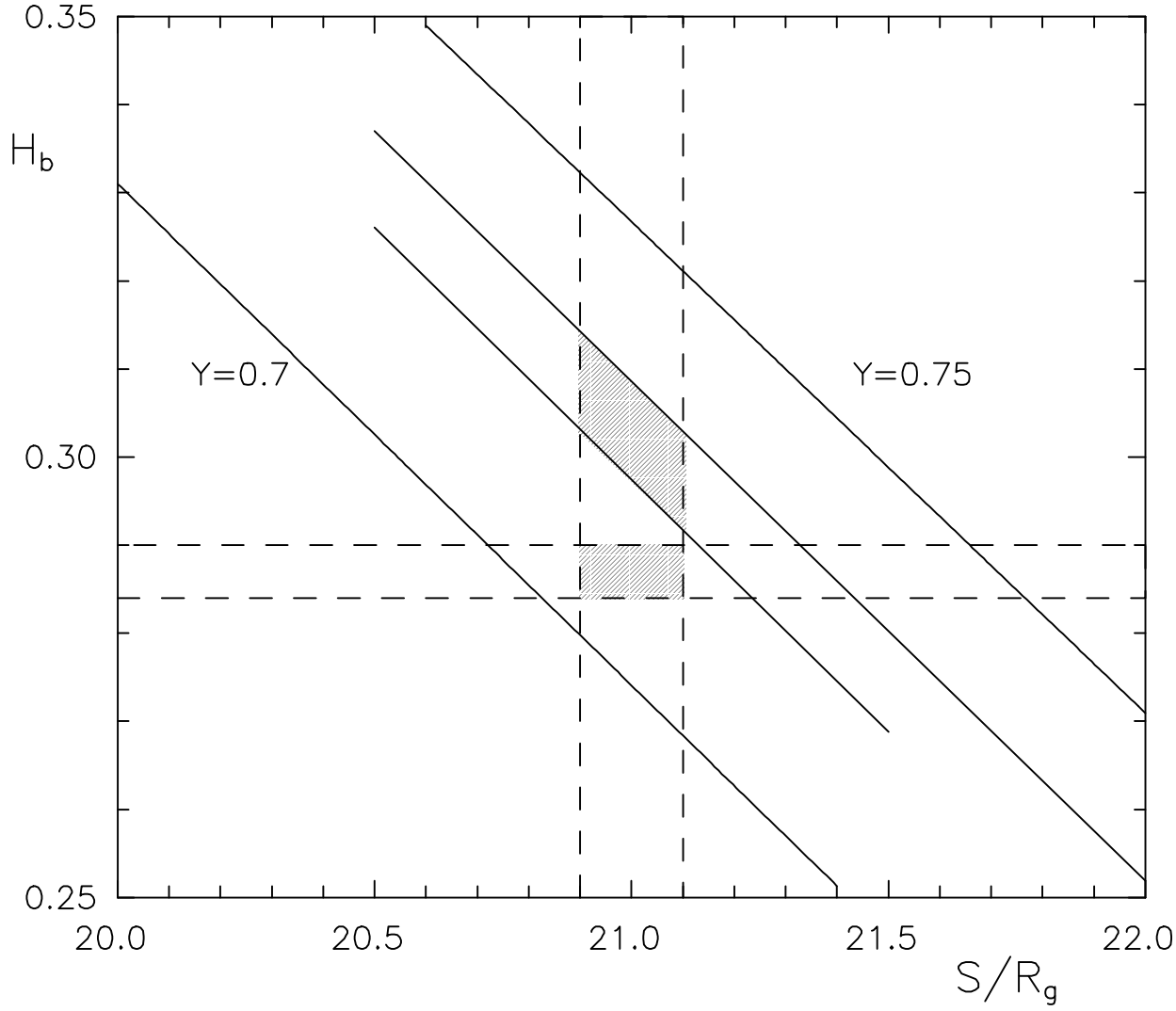


The relation between convection zone depth and entropy in the solar envelope.
Dashed lines—helioseismologically allowed ranges for $H_b$ and $S/R_g$ according Christensen-Dalsgaard, Gough, Thompson 1992 and Vorontsov, Baturin, Pamyatnykh 1991. Solid lines represent $H_b(S)$ dependence in envelopes with IR91 opacities, and two central lines correspond to $Y = 0.25 \pm 0.05$ as proposed in Baturin, Vorontsov 1994. You can note that the three values ($H_b$, Y, S) are in mutual disagreement when IR91 opacities are used.

inferred from oscillation frequencies. We are grateful to W.Dappen for providing us with MHD equation of state tables.

## References

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