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THE SOLAR ENVELOPE PARAMETERS AND RADIATIVE OPACITIES IN THE MODELS OF THE PRESENT SUN

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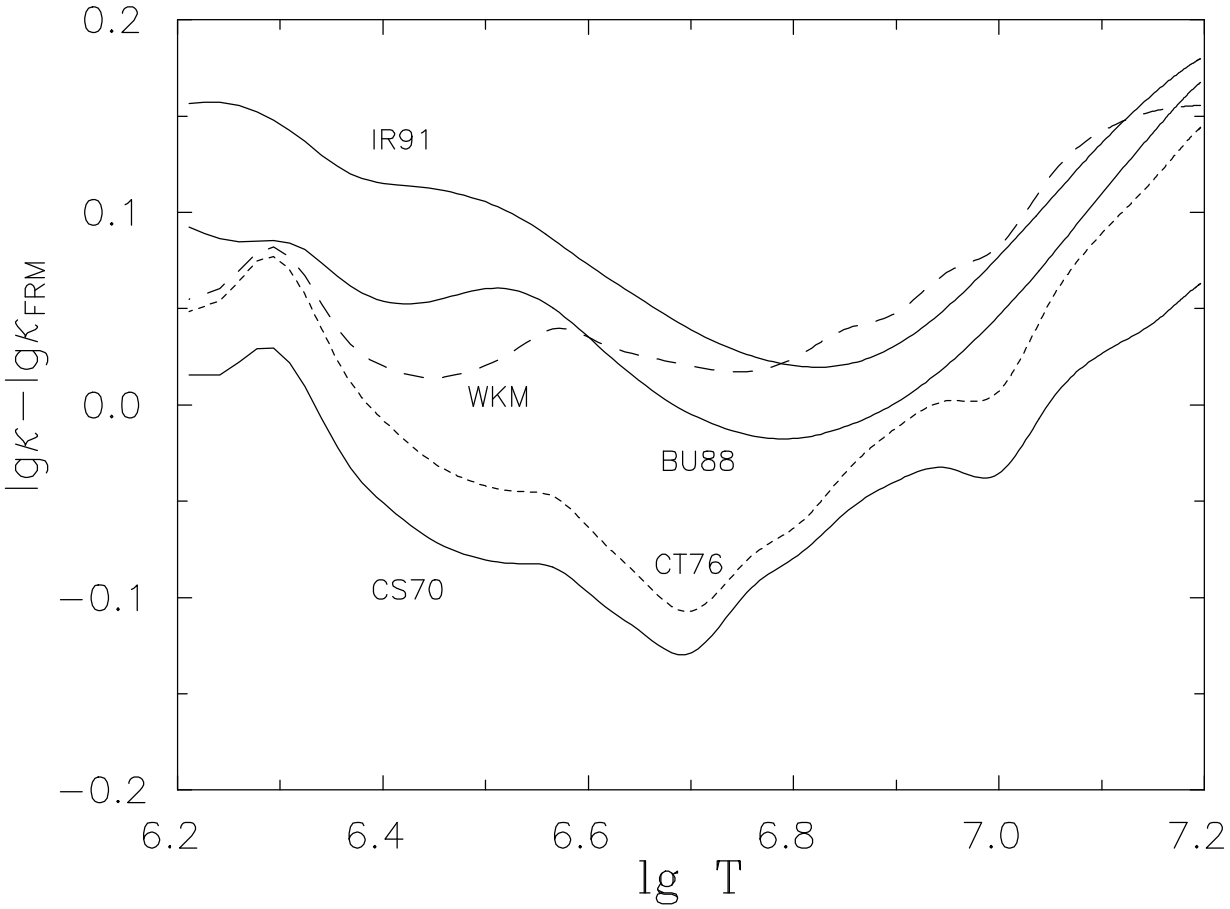
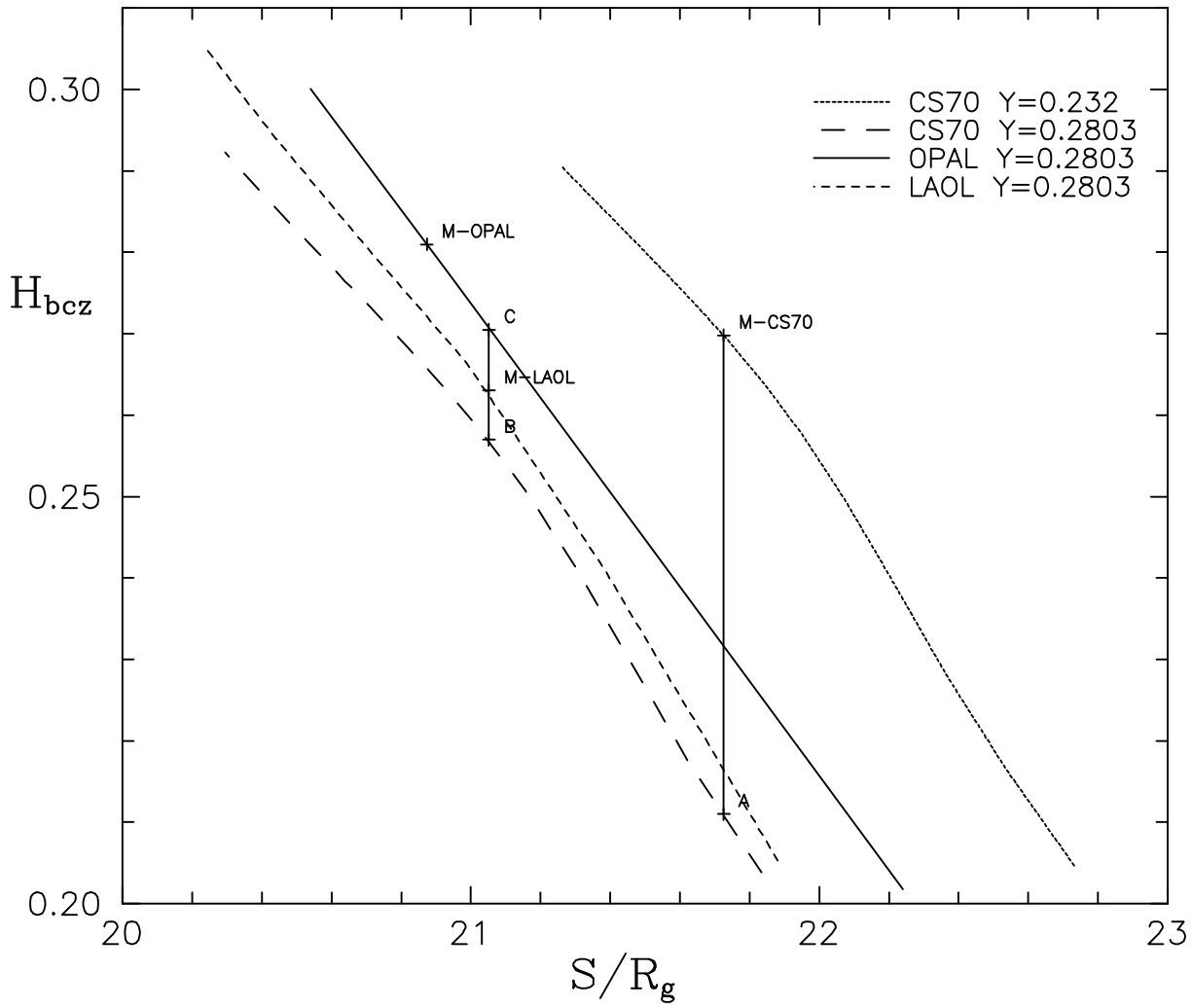


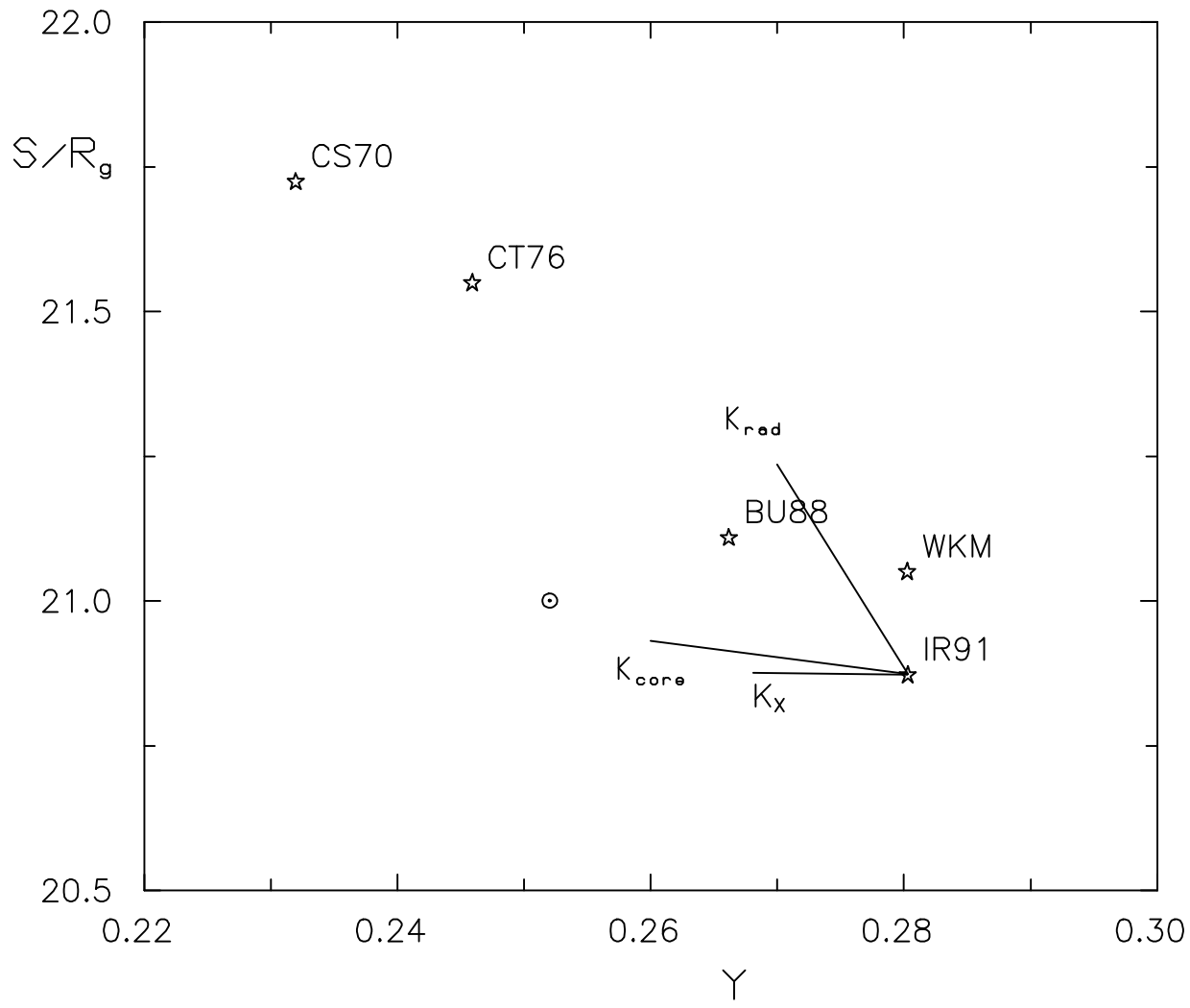
Comparison of the different opacity tables at the solar core conditions.
The decimal logarithm of the difference between the opacity table κ and analytic approximation κ_0 from *Christensen-Dalsgaard J., 1988, Computational Procedures for GONG Solar Model Project* is plotted. The points (T, ρ, X) were taken from the standard OPAL solar model. The type of the opacity table is shown near the each line.

CS70 – *Cox A.N., Stewart J.N. 1970, Astrophys. J. Suppl.,* ***19****, 243.*
CT76 – *Cox A.N., Tabor J. E. 1976, Astrophys. J. Suppl.,* ***31****, 271.*
BU88 – *Bahcall J.N., Ulrich R. K., 1988, Rev. Mod. Phys.,* ***60****, 297.*
WKM – *Weiss A., Keady J.J., Magee N.M. Jr., 1990, Atomic Data and Nuclear Data Tables,* ***45****, 209.*
IR91 – *Iglesias C. A., Rogers F. J., 1991, Astrophys. J.* ***371****, 408.*



The convection zone depth versus the envelope entropy for the three opacity tables.

1) M−CS70 → A – illustrates the change in H_{bcz} with increasing of helium;
2) A → B – change in H_{bcz} due to change of entropy;
3) B → M−LAOL – due to increasing of opacity from CS70 to LAOL;
4) M−LAOL → C – difference between the opacity tables LAOL and OPAL;
5) C → M−OPAL – increasing of the entropy.



Solar models on the (Y, S) plane.
Five asterisks indicate standard solar models. The abbreviations are:

CS70 – *Cox A.N., Stewart J.N. 1970, Astrophys. J. Suppl.,* ***19****, 243.*
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IR91 – *Iglesias C. A., Rogers F. J., 1991, Astrophys. J.* ***371****, 408.*
⊙ – Y and S obtained in *Baturin V.A., Vorontsov S.V., 1994, Proceedings of GONG'94 Annual Meeting.*

Two vectors K_{core} and K_{rad} indicate directions in which the standard model moves when *decreasing* opacity in the core and radiative zone, respectively. K_X respresents the vector of model change with varying hydrogen profile in the core.
R_g is the gas constant.

Introduction

Given the chemical composition profile and mass the internal structure of the star is determined by Vogt–Russell theorem. It gives that this model will have definite radius and luminosity (and they will not be equal to solar ones). So we need two parameters to adjust when computing static solar model. While computing the standard model these two parameters are initial chemical composition and convection theory parameter controlling te temperature gradient in the outermost layers. This choice is rather arbitrary and done due to lack of knowledge about these values. In the other words, these values were transformed from the parameters to the results (e.g., the solar evolution modelling gives the best estimate of the presolar helium abundance). The other results are neutrino fluxes, convection zone depth, oscillation spectrum etc. The input data (nuclear reactions, opacity, equation of state and description of convection) may contain significant errors, especially opacity. And there is a question: how can these error alter our results?

In this work we try to investigate some aspects of this problem. First, we replace the convection theory parameter with the entropy of the adiabatic part of the convection zone. Second, we study the influence of the opacity tables on the solar models. Third, we analyze the connections between the model parameters and the hydrogen profile and the opacities in the nonstandard models.

Convective envelope entropy as a solar model parameter

The standard solar model has two "calibration" parameters allowing to get the right values of the radius and luminosity at the given age—the initial chemical composition and the convection theory parameter. The second governs the temperature gradient in the superadiabatic layers of the convection zone. These two values allow to compute evotionary track; the choice was caused mainly by the historical reasons. The value of hydrogen abundance on the solar outer layers has its own meaning as an important cosmological and cosmogonical parameter but the information contained in the convection theory parameter is rarely used. Meantime this parameter is very important. It defines the adiabate of the convective envelope; any adiabate has $T \to 0$ and $r \to 0$ at the Sun's surface and we need some additional value to distinguish one adiabate from another. The most natural value parameterizing the adiabate is its entropy (S_{cnv}). Convection theory parameter is the most convenient parameter to vary in the model but not the most meaningful as it also depends on the convection theory internals and the atmosphere structure details (e.g., opacity).

Comparison of the evolutionary models based on the convection parameter is nonadequate due to fact that this parameter determines the structure of the atmospheric layers while the evolutionary model can't distinguish between the different atmospheres: the atmosphere details are irrelevant in the problem of computing the evolutionary model of the Sun. The theory of Sun's evolution can't answer the questions about the atmosphere and superadiabatic layers of convection zone; it can only give the thickness of these layers, their mass (very roughly) and the entropy of the convective envelope. These are the reasons why we choosed the convection zone entropy S_{cnv} as a model parameter to use together with surface chemical composition (helium abundance Y).

The influence of opacity on the standard solar model parameters

Increasing opacities from CS70 up to LAOL (WKM) (both in the core and the radiative zone) raises helium content by 4–5%. Changing from WKM to OPAL (IR91) doesn't change Y at all as versions of LAOL and OPAL tables used by us have nearly the same opacity values in the core of the Sun, so corresponding models have nearly the same Y.

On the other side, the transition from CS70 to LAOL decreased the convection zone depth, mainly due to increased helium content. This effect supersedes both the increasing of the opacity near the convection zone boundary and the decreasing of the entropy of the convection zone (they both lead to increasing of H_{bcz}). Substitution of OPAL instead of LAOL raised H_{bcz} due to increasing of the opacities and decreasing of the entropy.

The estimates of the neutrino fluxes for standard models are close to common values and significantly larger than Davis'. The attractive looking chlorine flux of CS70 model is due to low core opacities (and low central temperature).

Hence the average modern standard solar model (with LAOL or OPAL opacities) must have Y approximately equal to 0.28. Any opacity decrease in the core (e.g., due to WIMPs) or "collective effects" will lead to decrease of Y by 1% per each 3% in opacity. The opacity lowering also adjusts the chlorine neutrino flux but it depends mainly on the very central values whereas Y is sensitive to the opacities in the whole energy-generating core. So the dependence between the neutrino flux and Y isn't so straightforward.

Solar models with modified opacities

- The opacity variations in the energy-generating core are very similar to changes in the hydrogen profile in the core: they can compensate each other in terms of model parameters;
- Changing of opacity near the bottom of the convection zone does not affect model parameters; it only affects convection zone depth;
- Opacity in the core determines the model's surface helium abundance while opacity in the radiative zone changes mainly the entropy of the adiabatic part of the convection zone;
- The current helioseismological estimates of helium abundance and convection zone entropy are in disagreement with the standard solar models: the core opacities have to be lowered significantly.