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Can ^{3}He redistribution solve the solar neutrino problem ?

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The precisely measured frequencies of solar oscillations provide us with a powerful tool to probe the solar interior with great accuracy. Using the equations of thermal equilibrium along with the inverted sound speed and density profiles and the input physics, it is possible to infer the temperature and hydrogen abundance inside the Sun, provided the heavy element abundance profile is known (Antia and Chitre 1997b and references therein). The temperature and composition profiles in turn can be used to calculate the neutrino fluxes. The seismic models can thus be profitably employed to explore the possibility of an astrophysical solution to the solar neutrino problem (Roxburgh 1996; Antia and Chitre 1997a,b). Recently, Cumming and Haxton (1996) have suggested that mixing of ^{3}He in the core can alter the neutrino fluxes significantly, but Bahcall et al. (1997) ruled out such a model on the basis of helioseismic constraints. They have in fact, argued that any substantial mixing in the solar core is unlikely to have taken place as, otherwise, the composition profile will need to be fine tuned to produce the helioseismically inferred sound speed profile. This is true for a general mixing process of the type considered by them. On the other hand, if for some reason the ^{3}He abundance has not been estimated correctly, the mean molecular weight and hence the sound speed will not be affected by a change of ^{3}He abundance, since the abundance of ^{3}He is generally too small to affect the equation of state significantly. In this work, we attempt to constrain the neutrino fluxes after allowing for an essentially arbitrary variation in ^{3}He profile, even though it is not obvious how such profiles can arise in practice inside the Sun.

In the standard solar model, the ^{3}He abundance profile is derived by considering the change from zero age main sequence abundance due to nuclear reactions and in most of the core where the neutrinos are produced, the ^{3}He profile can be readily computed by assuming it to be in nuclear equilibrium. In the present work we relax this assumption and study the effect of departure from this equilibrium profile. Of course, it is not clear how such profiles can be produced in the actual Sun. We express the ^{3}He abundance, (Y_3) profile in terms of the cubic B-spline basis functions in the form,

$$Y_3(\mathrm{r}) = Y_{3\mathrm{s}}(\mathrm{r})(1+\sum_i b_i\phi_i(\mathrm{r})), \tag{1}$$

where $Y_{3\mathrm{s}}(\mathrm{r})$ is the equilibrium profile of ^{3}He abundance and b_i are arbitrary coefficients which determine the extent to which the profile is modified. We have generally chosen the composition profiles to be constrained within a factor of two of the standard profile. In all cases, one of the parameters (say, b_1) is adjusted to obtain the computed luminosity to match the observed solar luminosity.

Figure 1 shows the neutrino fluxes in the three solar neutrino experiments plotted against each other for 10,000 seismic models generated from random choice of coefficients in Eq. (1). It appears that no seismic model is simultaneously consistent with any two of the three solar neutrino experiments. Thus, even an allowance of arbitrary variation in Y_3 profile does not appear to solve the solar neutrino problem. In order to measure the departure of neutrino fluxes from the observed values we can define the χ^2 using the experimental uncertainties.

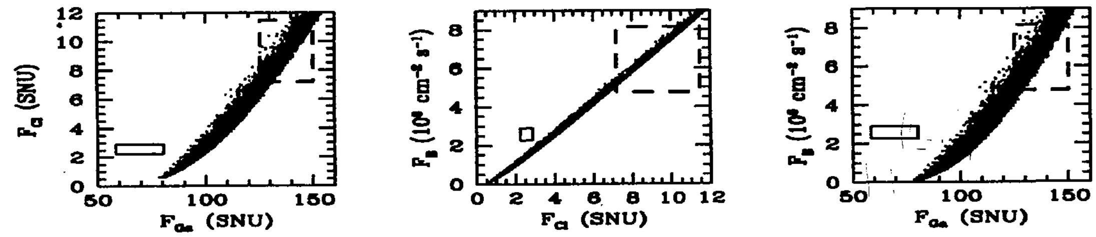

Figure 1. Predicted neutrino fluxes for various solar neutrino experiments plotted against each other for possible seismic models allowing for arbitrary ^{3}He profile. The boxes in each panel represent the 90% confidence limits on observed fluxes. The boxes with dashed outline denote the 90% confidence limits on standard solar models (Bahcall and Pinsonneault, 1995). F_{Cl} is the flux for ^{37}Cl experiment, F_{Ga} that in ^{71}Ga experiment and F_B is the ^{8}B neutrino flux.

It turns out that the minimum value of χ^2 for the three experiments is about 20. Clearly, by fitting the Y_3 profile, the χ^2 cannot be reduced to any reasonable value, even when the number of parameters that are fitted is much larger than the number of data values.

Apart from the possibility to ^{3}He mixing, there has been recently a suggestion (Kaniadakis et al. 1997) that the equilibrium energy distribution of particles departs from the Maxwellian, with the tail of the distribution going to zero slower or faster than exponentially. Such a departure will modify the nuclear energy generation rates and thereby affect the neutrino fluxes. Again a similar exercise can be done using arbitrary variation as parameterized by the parameter δ defined by Kaniadakis et al. (1997) for each of the relevant reaction. It turns out that in this case the χ^2 can be reduced to about 10. We are thus led to the conclusion that the solar neutrino problem is unlikely to yield an astrophysical solution with an arbitrary redistribution of ^{3}He or arbitrary heavy element abundance or any non-Maxwellian equilibrium energy distribution, provided, of course, we maintain the luminosity constraint. The solution to the solar neutrino problem should therefore be sought in terms of nonstandard neutrino properties (e.g., MSW effect). The forthcoming solar neutrino experiments would provide more constraints, which may help in resolving the solar neutrino problem.

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