Exploring the Neutrino Mass Hierarchy Probability with Meteoritic Supernova Material, ν-Process Nucleosynthesis, and θ_{13} Mixing [1]

MATHEWS, Grant J. (University of Notre Dame)
KAJINO, Toshitaka (NAOJ/University of Tokyo)
AOKI, Wako (NAOJ)
FUJIYA, Wataru (University of Tokyo)
PITTS, J. B. (University of Notre Dame)

Oscillations in the three-neutrino flavor mixing scenario are described by three angles θ_{12}, θ_{23}, and θ_{13} plus a CP-violating phase δ_{CP}. Solar, atmospheric, and reactor neutrino oscillation measurements have provided information on the neutrino mass differences, i.e $\Delta m^2_{12} \equiv |m^2_1 - m^2_2| = 0.000079\ \mathrm{eV}^2$ and $\Delta m^2_{13} \approx |\Delta m^2_{23}| \approx 2.4 \times 10^{-3}\ \mathrm{eV}^2$. These measurements, however, are unable to determine the mass hierarchy, i.e. whether $\Delta m^2_{23} > 0$ (normal) or $\Delta m^2_{23} < 0$ (inverted) is the correct order. Also, solar, atmospheric and reactor neutrino oscillation experiments have determined θ_{12} and θ_{23} to reasonable precision. However, only recently have measurements of θ_{13} become available. The best current measurements [with $\delta_{CP} = 0$ and $\theta_{23} = \pi/4$] is from the the Daya Bay experiment that has reported $\sin^2 2\theta_{13} = 0.092 \pm 0.016(\mathrm{stat}) \pm 0.005(\mathrm{syst})$ [2], This is also consistent with the previously reported lower limit and upper limits to θ_{13} from the T2K collaboration [2] of $0.03(0.04) < \sin^2 2\theta_{13} < 0.28(0.34)$. These results, however, do not yet determine whether the normal or inverted hierarchy is the correct ordering of mass eigenstates.

In this context it is noteworthy that the synthesis of ν-process elements ^{7}Li and ^{11}B in core collapse supernovae is sensitive to the neutrino mass hierarchy and θ_{13}. Previous studies [3] pointed out that for a finite mixing angle $\theta_{13} > 0.001$ the relative synthesis of ^{7}Li and ^{11}B in the ν-process is sensitive to the mass hierarchy. Since $\theta_{13} > 0.001$ is indeed implied by the Daya Bay +RENO + Double Chooz results to better than the 5σ C.L., we could reconsider the supernova ν-process as a means to constrain the neutrino mass hierarchy. The width of the shaded region of Figure 1 shows the current constraints on the θ_{13} mixing compared with the extended results of ^{7}Li and ^{11}B nucleosynthesis from [3].

Moreover, there has also been a recent possible discovery [4] of ν-process ^{7}Li and ^{11}B supernova material in SiC X grains from the Murchison meteorite. The top of the shaded region on Figure 1 shows the 1σ upper limit to the ^{7}Li/^{11}B ratio from that study. The goal of this paper was to examine the likelihood of one neutrino mass hierarchy over another in a Bayesian statistical analysis that took proper account of all of the supernova model uncertainties as well as the measurement uncertainties of the SiC X grains and the θ_{13} limits. In our five dimensional Bayesian analysis we found that there is a preference for an inverted hierarchy at the level of 74 %/26 % compared to a prior expectation of 50 %/50 %.

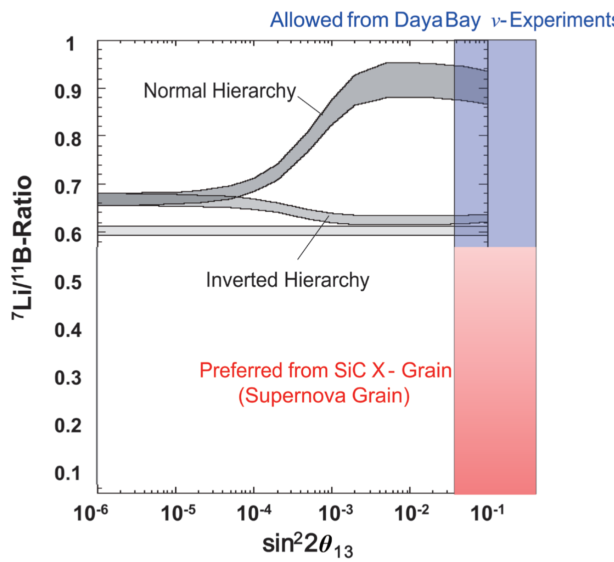

Figure 1: Produced ^{7}Li/^{11}B abundance [3] as a function of mixing angle for both a normal and inverted neutrino mass hierarchy. This ratio varies in models with different neutrino temperatures in the range indicated by the lower and upper solid lines. The width of the blue shaded region indicates the 2σ confidence limits to $\sin^2(2\theta_{13})$ from the Daya Bay result [2]. The red shaded region is the 1σ upper limit on the observed ν-process ^{7}Li/^{11}B ratio as deduced here from the SiC X grains. This is reprinted from [1].

References

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