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Helium abundance in the solar envelope

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Helioseismology is the most accurate way to determine the solar helium abundance. Since the solar photosphere is not hot enough to ionize helium, spectroscopic abundance determinations are very uncertain. Helium in the Sun ionizes fairly close to the surface. HI and HeI ionize by a radius of 0.99 $R_\odot$. HeII ionizes around 0.98 $R_\odot$. Ionization decreases the adiabatic index Γ_1, which in turn decreases the sound speed c (since $c^2 = \Gamma_1 P/\rho$). The decrease in sound-speed increases with the amount of helium present and can be detected helioseismologically and used to determine the amount of helium present.

Until recently all helioseismic estimates of the helium abundance in the solar envelope were based on the analysis of intermediate degree ($\ell < 250$) oscillations. These modes do not sample helium ionization zones properly. Frequencies of high-degree solar oscillations which sample the helium ionization zone properly are now available from MDI data (cf. Antia & Basu 1999). We determine the helium abundance in the solar envelope using these modes supplemented with low degree modes from Rhodes et al. (1997)

One does not need to determine the sound speed to be able to determine the helium abundance. In the asymptotic limit, one can show that the relative frequency differences between a model and the Sun are related by $S(w)\ \delta\omega/\omega = H_1(w) + H_2(\omega)$, where, $w = \omega/(\ell+½)$, $S(\omega)$ is a function of the known model and $H_1(w)$ is a function of the soundspeed difference between the model and the Sun(Christensen - Dalsgaard et al. 1989). Since the function $H_1(w)$ depends on c, it can be used to determine the helium abundance (Antia & Basu 1994). The function $H_2(\omega)$ also carries the signature of helium abundance difference. Both $H_1(w)$ and $H_2(\omega)$ can also carries the signature of helium abundance difference. Both $H_1(w)$ and $H_2(\omega)$ can be calibrated to determine the helium abundance (Antia & Basu 1994; Basu & Antia 1995).

We use the same technique as Basu & Antia (1995). We constructed a series of solar envelope models which differ only in their helium abundance. We determine $H_1(w)$ and $H_2(\omega)$ between neighbouring models and call them the calibration curves $\phi(w)$ and $\psi(\omega)$, respectively. The function $H_1(w)$ between any calibration model with known helium abundance Y and the Sun can then be written as $H_1(w) = \beta\phi(w) + H_s(w)$, where β is a constant which depends on the difference in the helium abundance between the Sun and the calibration models and the function $H_s(w)$ is a smooth function which takes care of the distortions due to equation of state (EOS) differences between the Sun and the models. $H_2(\omega)$ can be written in a similar way : $H_2(\omega) = \beta' \psi(\omega) + H'_S \omega)$. We determine β and β' for a series of calibration models with different helium abundance and interpolate to find the abundance for which β (or β') is 0.

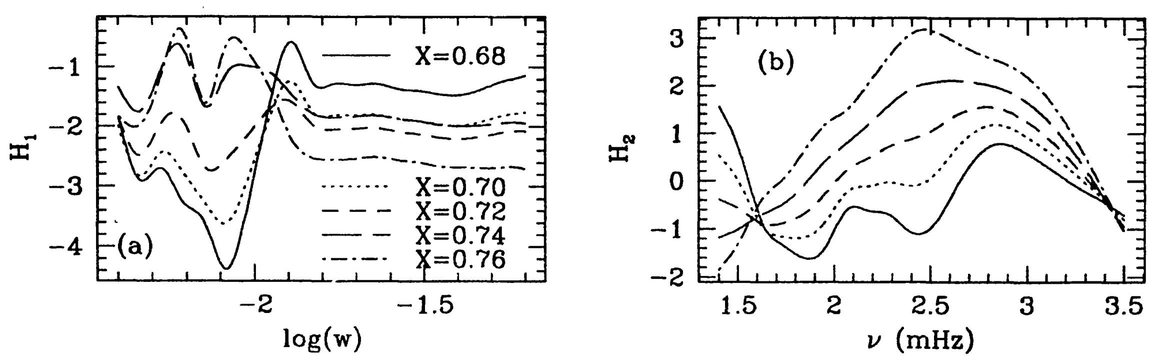

Figure 1. The functions (a) $H_1(w)$ and (b) $H_2(\omega)$ between the Sun and the OPAL calibration models with different hydrogen (and hence different helium) abundance X.

We have constructed two sets of calibration models, one with the MHD EOS (Däppen et al. 1988 and references therein) and one set with the OPAL EOS (Rogers et al. 1996). The calibration models have hydrogen abundance X of 0.68, 0.70, 0.72, 0.74 and 0.76.

Fig. 1 shows $H_1(w)$ and $H_2(\omega)$ between the Sun and the OPAL models. Using models with OPAL EOS, one gets $Y_\odot$=0.2472 ± 0.0009 with $H_1(w)$ and 0.2454 ± 0.0008 with $H_2(\omega)$. For MHD models one gets 0.2432 ± 0.0015 and 0.2452 ± 0.0008 for $H_1(w)$ and $H_2(\omega)$ respectively. The error bars only indicate the errors due to data-errors. Tests show that helium abundance is better determined with $H_1(w)$ than with $H_2(\omega)$ when high degree modes are available.

The OPAL results are consistent within errors with earlier results −0.249 (Basu & Antia 1995), 0.248 (Basu 1998), 0.248 (Richard et al. 1998) and marginally consistent with Y = 0.25 obtained by Kosovichev (1997). The MHD results show a change with respect to the Basu (1998) value of 0.251. Since the data set used by Basu (1998) is a subset of the current data set, the change can be attributed to the addition of high degree modes. The current result is consistent with the result of Basu & Antia (1995).

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