How does the change on solar abundances affect low degree modes?

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Abstract

The most recent determination of the solar chemical composition by Asplund *et al.* (2005), has been done using Time-dependent, 3D hydrodynamical model of the solar atmosphere, instead of the classical 1D hydrostatic models. This new determination exhibits a significant decrease on C, N, O abundances compared to their previous values. Solar models using these new abundances are not consistent with helioseismological measurements. However, the increase on neon abundance can minimize the inconsistency as suggested by Bahcall *et al.* (2005). We Investigate the change in solar abundances using low degree p-mode characteristics which are strong constraints of the solar core. As a result, none of the models match the observations. We also show the influence of the solar abundances on g-modes frequencies which are strongly related to the solar core properties.

Solar modeling

We have computed solar models with different sets of heavy chemical elements abundances using the stellar evolution code CESAM (Code d'Evolution Stellaire Adaptatif et Modulaire) Morel *et al.* (1997). OPAL opacity tables for each mixture, and Alexander and Ferguson opacity tables at low temperatures (T<6000K) have been used. All the computed models include microscopic diffusion of the elements. Table 1 summarizes the characteristics of and the chemical composition of each model.

Model	GN	AGS	M3	M4	M5	M6
$A(Ne)(dex)$	8.08	7.84	8.10	8.29	8.47	8.24
Z/X	0.0245	0.0166	0.0179	0.0192	0.0212	0.0210
Y_s	0.2437	0.2279	0.2328	0.238	0.2442	0.2420
ZC	0.7133	0.7292	0.7236	0.718	0.7117	0.7149
$T_c(*10^7K)$	1.574	1.549	1.555	1.559	1.565	1.566
$P_0(mn)$	35.08	35.66	35.48	35.28	34.72	35.13

Table1: Global characteristics for the considered solar models. A(Ne) is the Neon abundance in dex, Z/X is the surface metallicity, surface helium abundance Y_s and convection zone depth r_{ZC} , Tc is the central temperature, P_0 is the characteristic period of low degree gravity modes. The different models are using the following solar abundances GN: Grevesse and Noels (1993), AGS: Asplund, Grevesse and Sauval (2005), M3, M4, M5: AGS in which the Neon abundance has been changed, M6: AGS in which C, N, O, Si, Mg and Ar have been changed in addition to Ne: $A(C,N,O)=A(C,N,O)_{AGS}+0.05$, $A(Si,Mg)=A(Si,Mg)_{AGS}+0.02$ and $A(Ar)=A(Ar)_{AGS}+0.40$.

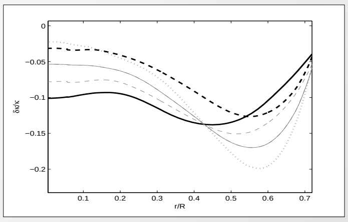

Fig.1: Relative differences between the opacities associated with the abundances of the different models and those associated with GN abundances: AGS (full heavy line),M3(light dashed line), M4 (light full line), M5 (light dotted line), M6 (heavy dashed line).The differences are estimated along a solar path for a given radius, density, temperature and chemical composition.

The change in solar abundances affects the opacity all along the solar interior. The contribution of neon to the opacity is shown by the big difference between 0.4Rs and 0.7Rs as noticed in Turck-Chièze *et al.* (1993)

Gravity and mixed modes

We are considering modes on the frequency range [100μHz,~600μHz] and 0 < *l*< 6 including both g-modes and mixed modes.

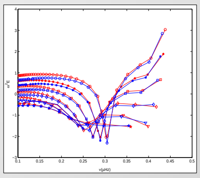

Fig.2: Logarithm of the energy $\omega^2\varepsilon_{n,l}$ of the modes of degrees l=1 to l=6 for the models GN (red), AGS (blue). See Provost *et al.* (2000) for the energy expression

Mixed modes are known by their low energy and have frequencies around 300μ Hz. Figure2 shows the energy of the modes for the models GN and AGS in which mixed modes are clearly distinguished

Relative differences of low frequency g-modes are close to relative differences of P0 periods which are given for all the computed models in table.1.
The biggest shift in the frequencies with the change in the model is given between GN and AGS, it goes up to 1.5% for low g-modes frequencies. This difference decreases for all the models after 200μHz and reaches its lowest value around 250 μHz. M6 frequencies are the closest ones to GN frequencies

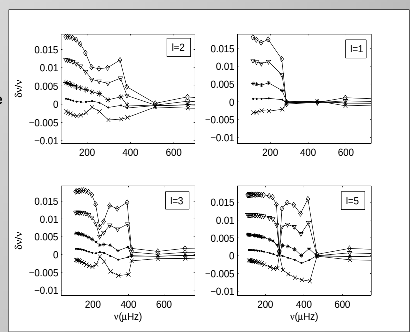

Fig.3: Relative differences between the frequencies of the reference model GN and the models: AGS (diamond), M3 (triangle down) ,M4 (star), M5(cross),M6(dot)

Helioseismic constraints

Sound speed profile

First, we compare seismic sound speed profile with those of the computed models. The worse concordance between the model using Asplund et. al abundances (AGS) and the seismic model is shown by a relative difference that peaks at 1.5% under the convection zone. Models M3, M4, M5 bring an idea of how big the neon abundance increase has to be in order to minimize the discrepancy. We have estimated this augmentation to 0.4-0.5Dex, which is in accordance with Bahcall *et al.* (2005).

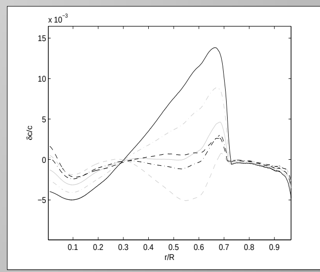

Fig4: Relative sound speed differences between the sun and the considered models. GN dark dashed, AGS dark full, M3 light dashed-dotted, M4 light full, M5 light dashed, M6dark dashed-dotted.

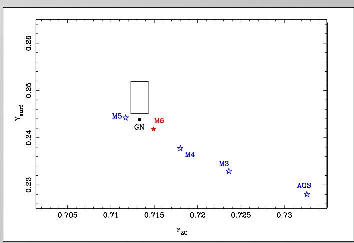

Fig5: Characteristics of the solar envelope Y_s and r_{ZC} for the models. Model GN full.The box represents the seismic values with their errors (Antia *et al.* 2005).

Solar envelope characteristics

Surface helium abundance Y_s and convection zone depth r_{ZC} increases and decreases, respectively, as the neon abundance increases. Nevertheless, none of the models is in accordance, simultaneously, with the 3 seismic values (sound speed, Y_s and Z_c). In the aim to bring closer all these parameters to the ones of the models, we constructed the model M6 in which the neon abundance is increased by 0.4dex in addition to slightly increases of other heavy elements. We notice that Y_s and r_{ZC} of the M6 model have been enhanced but not enough to reach the observations.

p-mode characteristics of the core

The set of p-mode oscillations frequencies can be characterised by the large and small frequency spacings:

$$\Delta\nu_{n,l} = \nu_{n,l} - \nu_{n-1,l}$$
$$\delta\nu_{02} = \nu_{n+1,l=0} - \nu_{n,l=2}$$
$$\delta\nu_{13} = \nu_{n+1,l=1} - \nu_{n,l=3}$$
$$\delta\nu_{01} = 2\nu_{n,l=0} - (\nu_{n,l=1} + \nu_{n-1,l=1})$$

$\Delta\nu_{n,l}$ is almost constant at high frequency. small frequency spacings $\delta\nu_{02}$, $\delta\nu_{13}$ and $\delta\nu_{01}$ are combinations of acoustic modes penetrating differently towards the center and thus are very sensitive to the central part of the solar interior. In order to compare the models to the observations, we compute the mean of the frequency small spacings $\delta\nu_{02}$, $\delta\nu_{13}$ and $\delta\nu_{01}$ for radial orders from 16 to 24, which corresponds to a frequency range about 2500 --3600 μHz. The low limit of this range insures that the behavior of the frequency is almost asymptotic, the high limit corresponds to modes observed with very high accuracy. As a result, figure 6 shows that the change of Neon induces changes in small frequency spacings much larger than the observational boxes. Note that the small spacings are also sensitive to the solar age.

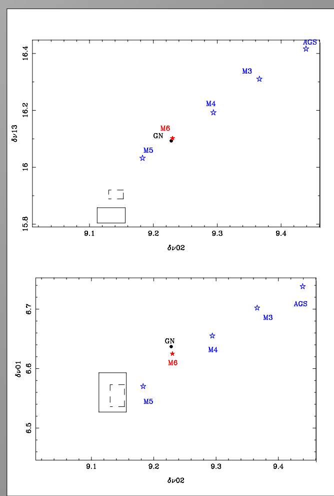

Fig.6: Upper panel: Mean frequency small spacing $\overline{\delta\nu13}$ as a function of the mean frequency small spacing $\overline{\delta\nu02}$ for the different models compared to GOLF observations (full box Gelly *et al.* (2002), dashed box Lazrek *et al.* (2006)) Lower panel: same for mean frequency small spacing $\overline{\delta\nu01}$ as a fuction of a mean frequency small spacing $\overline{\delta\nu02}$.

Conclusion

- Solar models constructed by the CESAM code, using the new solar abundances, reveal a significant discrepancy with helioseismological determinations of solar parameters. Increasing the neon abundance of about 0.4-0.5dex minimizes the discrepancy with seismic sound speed. This is in accordance with Bahcall *et al.* (2005).

- In addition to the already used seismic parameters (sound speed profile, Y_s and r_{ZC}) , models have been constrained to small mean frequency spacings using the latest results of Lazrek *et al.* (2006) in the low degree observed frequencies determinations from GOLF experiment. This constraint appears to be very strong and is not yet satisfied by the models.

- The calculation of gravity modes and mixed modes frequencies reveals the lower sensitivity of the modes around 250μHz to the change in solar abundances.

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