B Ricci*

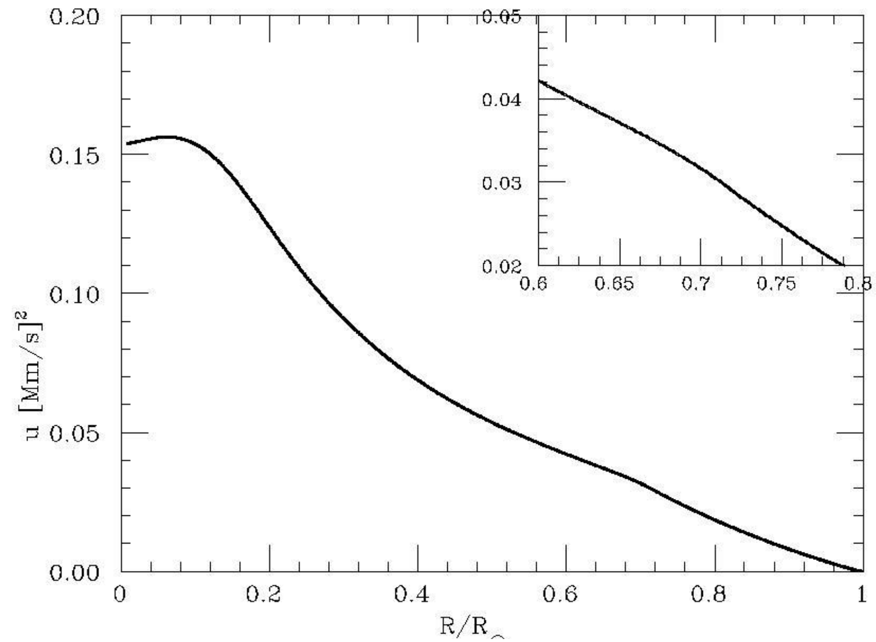
Helioseismology and solar models

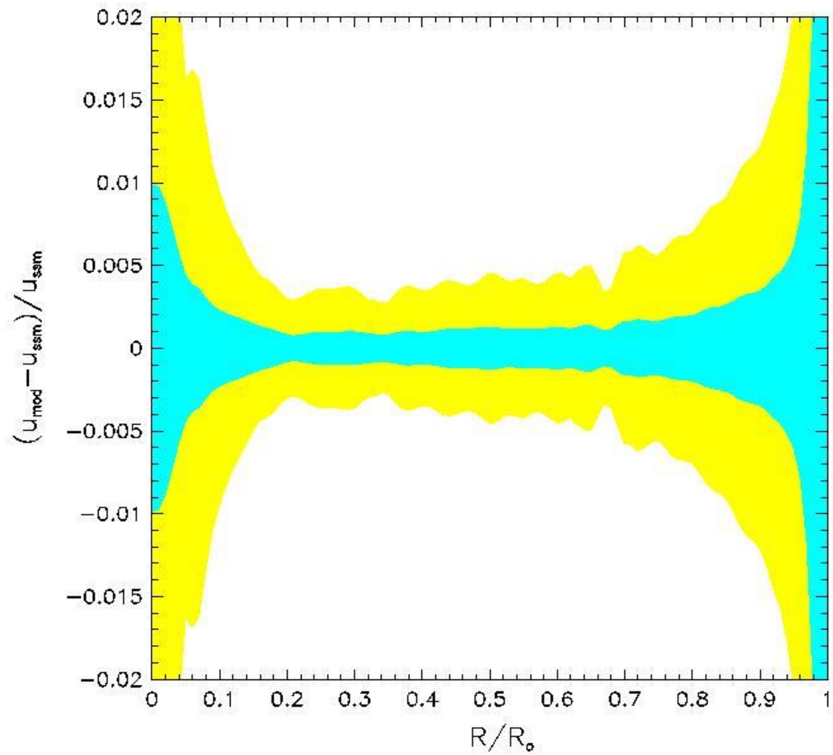
- Helioseismic observables
- SSMs and helioseismology 2000+
- Solar physics
  - metal abundance, age, mixing....
- Plasma physics
  - Diffusion, Statistics, Screening
- Nuclear Physics
  - S_{pp}, S_{33} & S_{34}
- Subnuclear Physics
  - The physics of extra dimensions

*..and Berezinsky, Cassisi, Castellani, Degl'Innocenti, Dziembowski, Fiorentini, Lissia, Quarati, Villante

Helioseismic observables

- From the measurements of p-modes one derives:
- a)sound speed profiles
- Accuracy is order 0,1% in the intermediate region, 1% near the center)
- blu uncertainties are "statistical" or "1sigma" of *GF et al*, and correspond to *Bahcall et al* uncertainty
- yellow is "conservative" or "3 sigma" uncertainty of GF





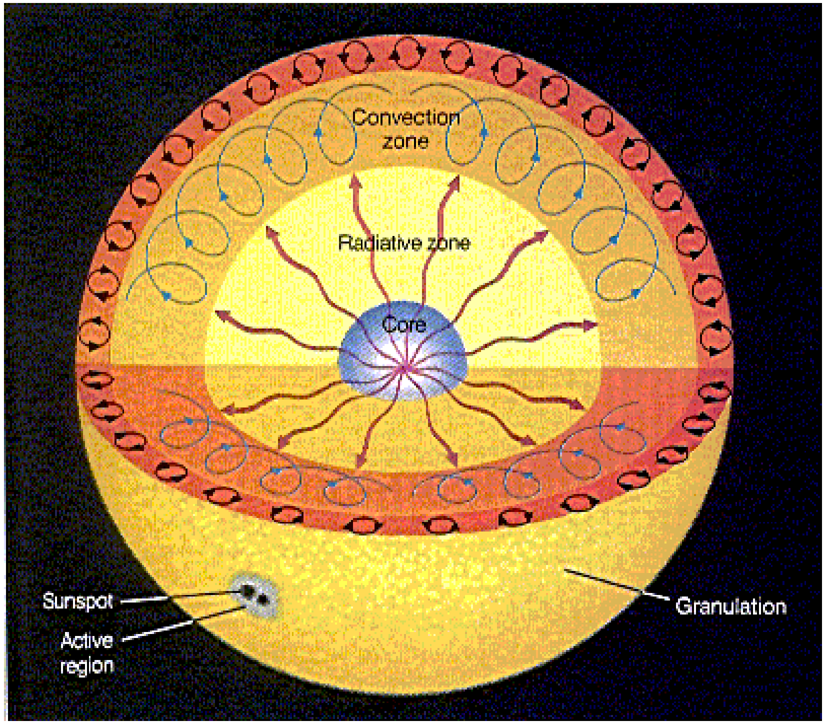
Helioseismic observables

- b) properties of the convective envelope

  $R_b / R_o = 0.711 \pm 0.001$

  $Y_{ph} = 0.249 \pm 0.003$

- the quoted uncertainties are "statistical" or "1sigma" of *GF et al*, and correspond to *Bahcall et al* uncertainty



The accuracy of helioseismic determinations

Helioseismic determinations are affected by several sources of uncertainties:

- errors on the measured frequencies
- dependence on the starting model
- free parameters of inversion method

Remarks:

- Experimental errors relatively unimportant
- Systematic errors are most important
- Errors can be combined in quadrature (statistical or 1sigma) or added linearly, after doubling unc. (conservative, or "3sigma")

See e.g Ricci et al Nucl Phys B supp 81(2000)95

Example: Y_{ph}

$(\delta Y/Y)_{mea}=\pm 0,1\%$

$(\delta Y/Y)_{mod}=\pm 1.3\%$

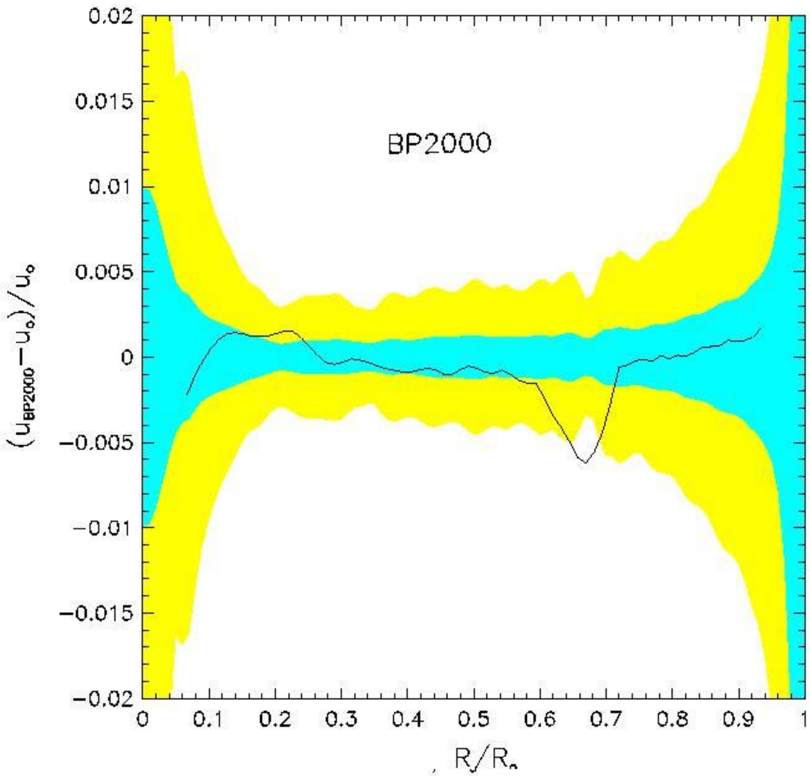
$(\delta Y/Y)_{inv}=\pm 0,7\ \%$

$(\Delta Y/Y)_{sta}=\pm 1.5\ \%$

$(\Delta Y/Y)_{con}=\pm 4.2\ \%$

SSM (2000)

- The model by Bahcall and Pinsonneault 2000 is generally in agreement with data to the "1sigma"level



- Some possible disagreement just below the convective envelope (a feature common to almost every model and data set)

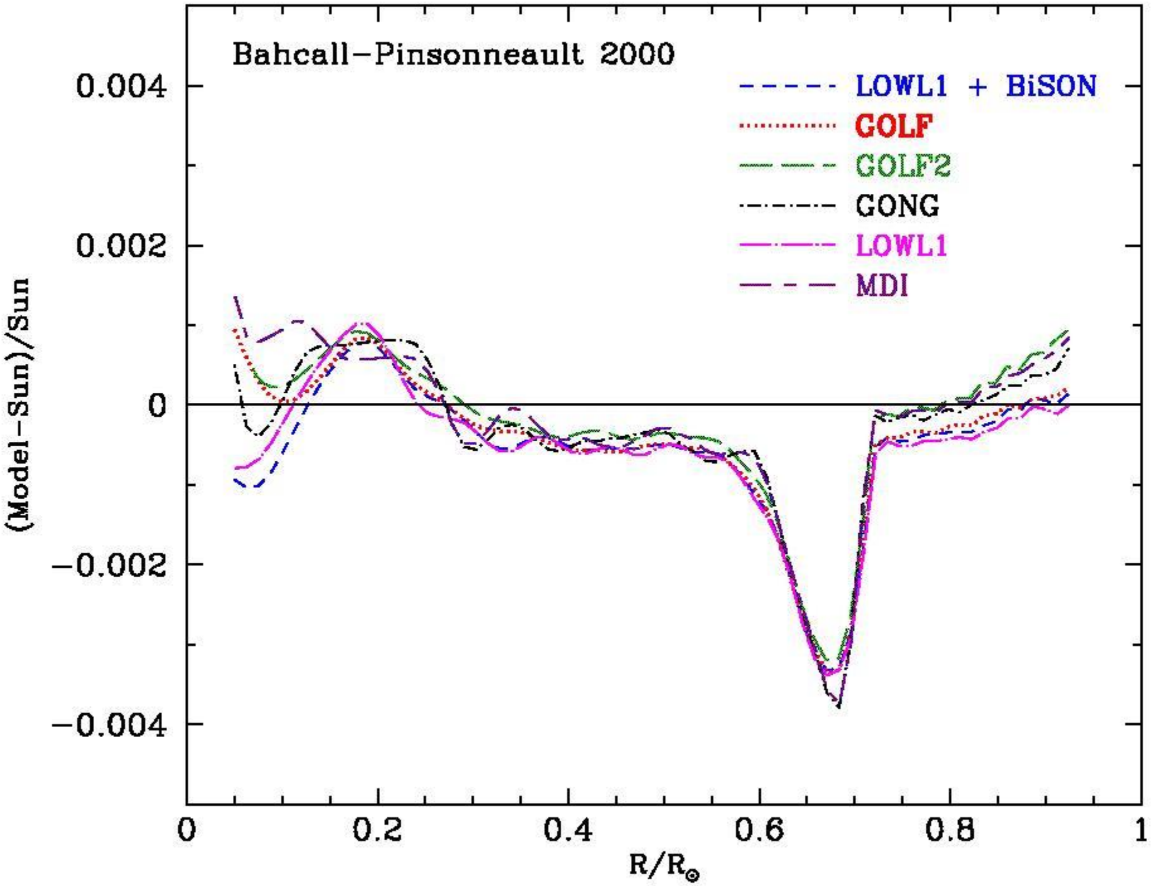
Y_{BP2000}=0.244 Y_O= 0.249±0.003

Rb_{BP2000}-=0.714 Rb_O =0.711 ± 0.001

See Bahcall Pinsonneault and Basu astro-ph 0010346

Using different data sets

- Results of inversion using different data sets are consistent
- Even at small R/R_0 differences are of order 0.1%



The sound speed in the solar core

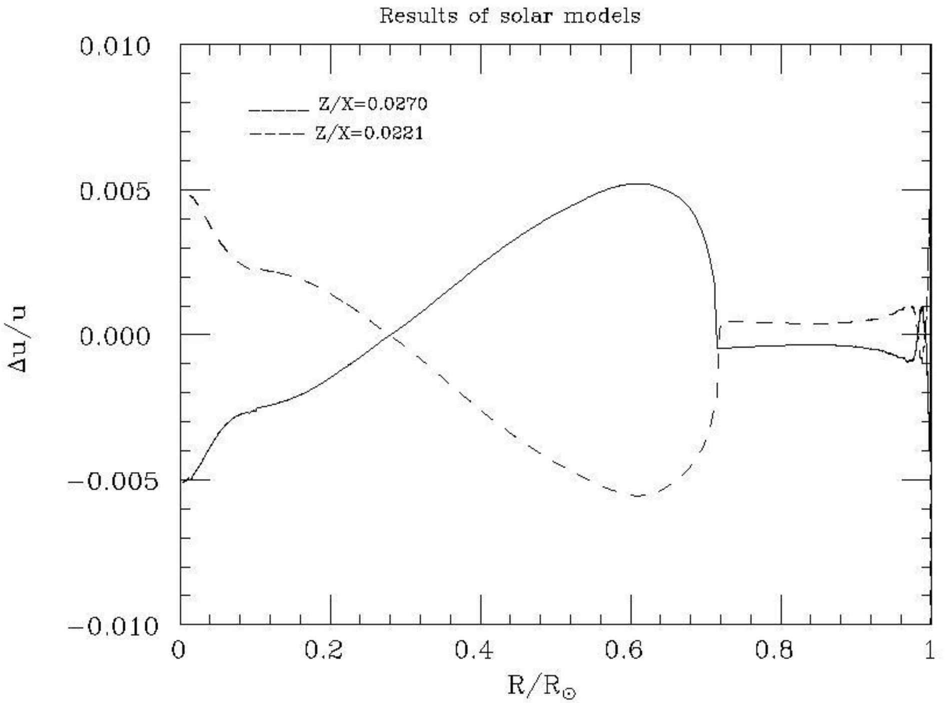
- Start inversion by using drastically different solar models

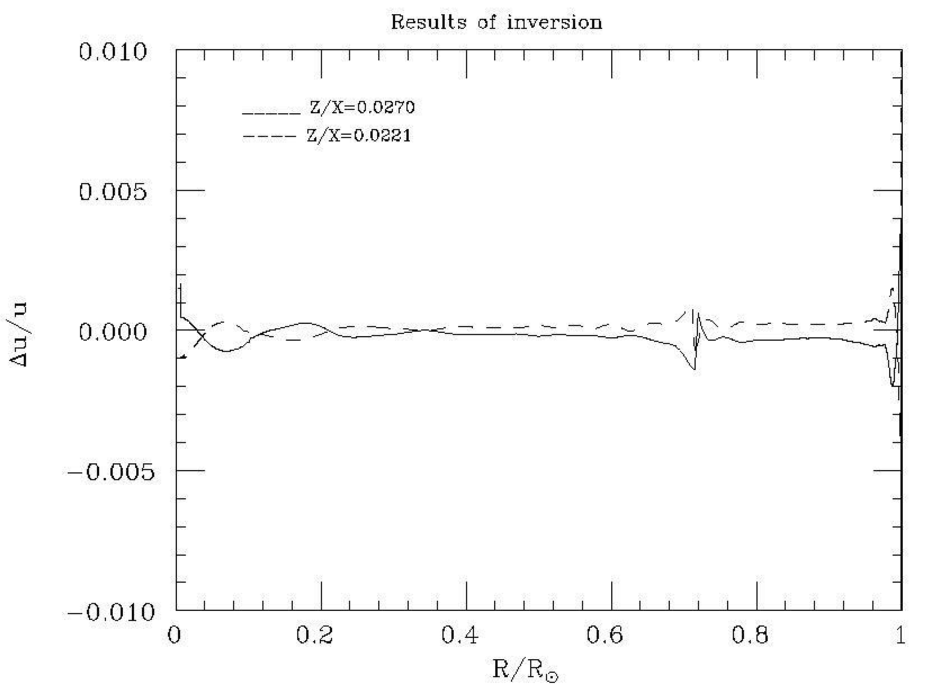
  ($\Delta u/u_{mod}$=1% at R=0)

- Inversion gives quite similar seismic models, even near the center

  ($\Delta u/u_{sei}$=0,1% at R=0)

Ricci et al Nucl Phys Bsupp 81(2000)95





Stellar evolution and large extra dimensions

Phys Lett B 481 (2000) 323

Stellar evolution and large extra dimensions

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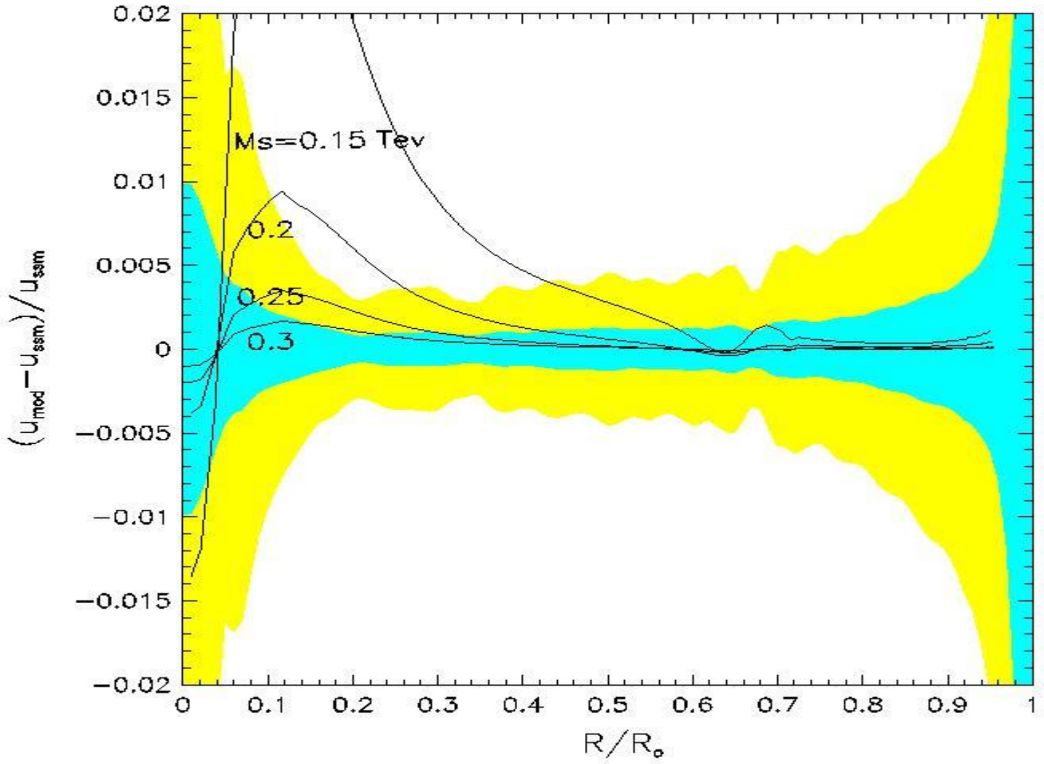
Abstract

We discuss in detail the information on large extra dimensions which can be derived in the framework of stellar evolution theory and observation. The main effect of large extra dimensions arises from the production of the Kaluza-Klein (KK) excitations of the graviton. The KK-graviton and matter interactions are of gravitational strength, so the KK states never become thermalized and always freely escape. In this paper we first pay attention to the sun. Production of KK gravitons is incompatible with helioseismic constraints unless the $4+n$ dimensional Planck mass M_s exceeds 300 GeV$/c^2$. Next we show that stellar structures in their advanced phase of H burning evolution put much more severe constraints, $M_s > 3$–4 TeV$/c^2$, improving on current laboratory lower limits.

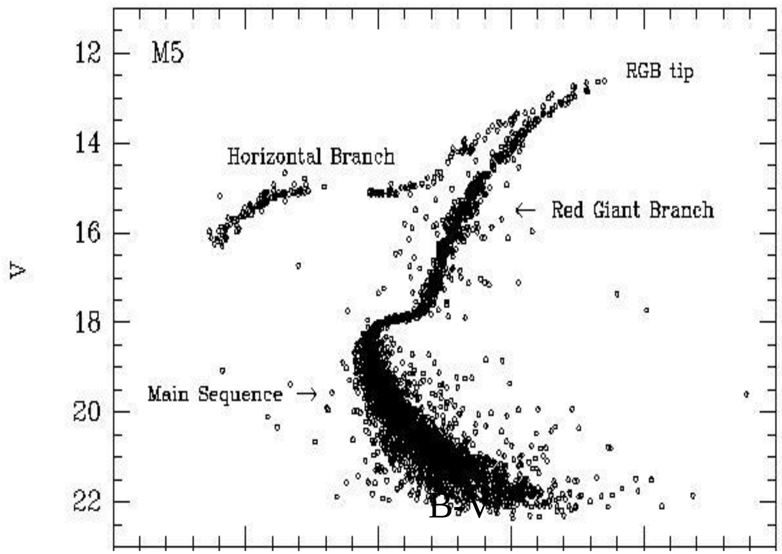
- We have studied the consequences of the energy loss due to KK graviton production

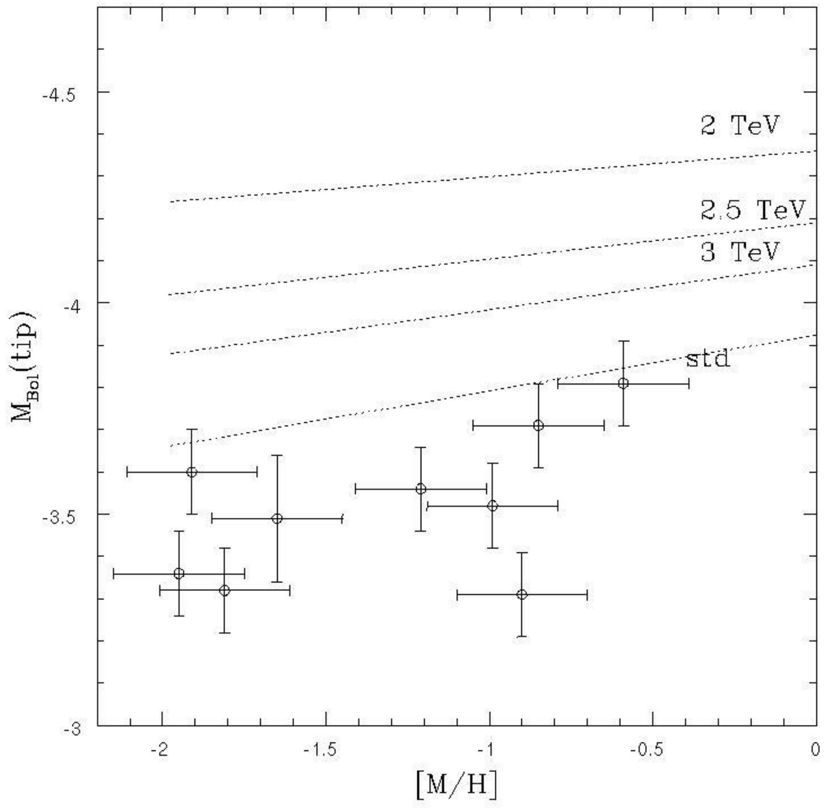
Solar models with KK graviton production



- Production of KK gravitons is incompatible with helioseismic constraints unless M_s> 300 GeV

Red Giants and KK gravitons





- Observational constraints on red giant –tip imply M_s>3-4 Tev

Heliosesimology and $p+p \to d + e^+ + \nu$

- The rate λ of hydrogen burning in the sun is fixed by the observed Luminosity
- In order to keep λ fixed, if the astrophysical factor S_{pp} is (say) larger than S_{pp}(SSM), temperature in the core has to be smaller than in the SSM, $T < T(SSM)$
- On the other hand, chemical composition is essentially fixed by Sun history
- (Isothermal)Sound speed (squared) $u = P/\rho = (kT/\mu)$ has thus to be smaller than u(SSM)
- Thus helioseismology can provide information on Spp

Degl'Innocenti,GF and Ricci Phys Lett 416B(1998)365

Helioseismic determination of S_{pp}

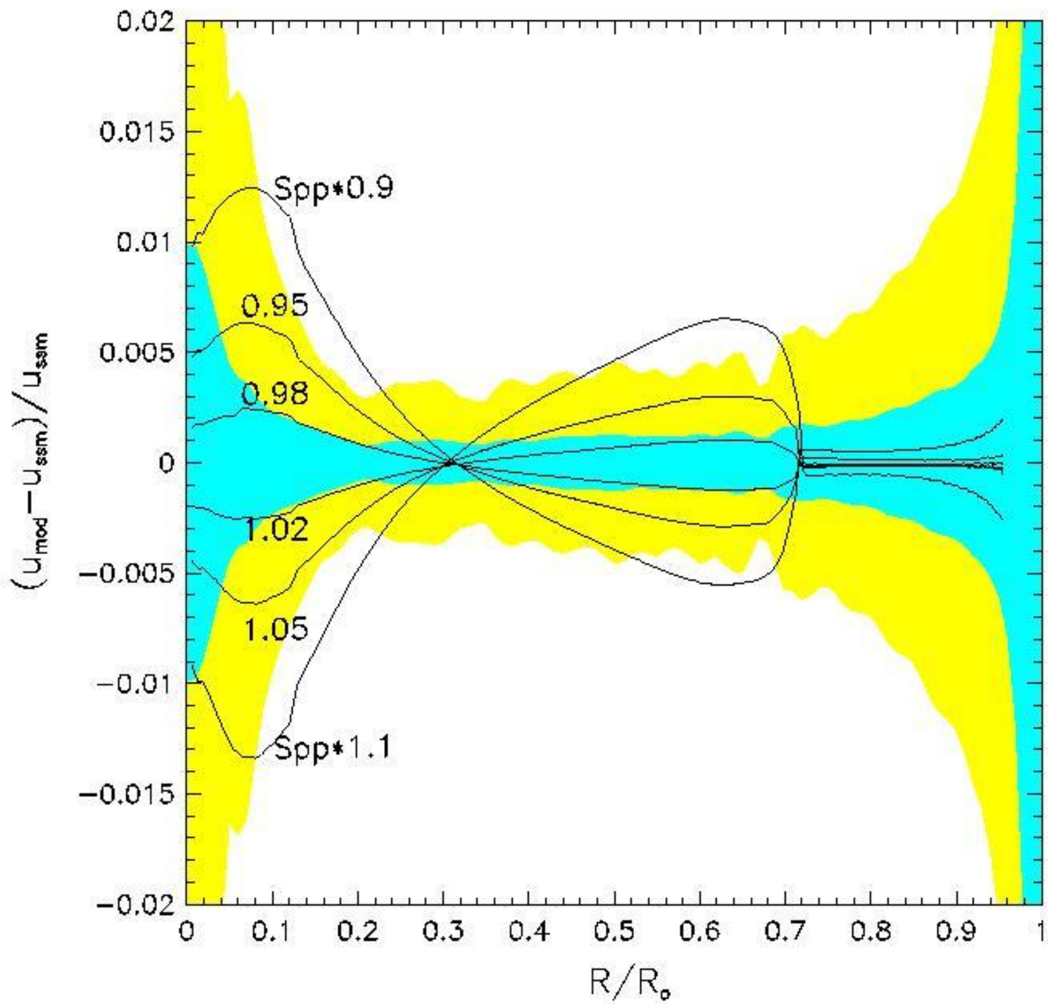
•Consistency with helioseismology requires:

Spp=Spp(SSM)(1 ± 2%)

•This accuracy is comparable to the theoretical uncertainty:

Spp(SSM)=4(1 ± 2%)

X **10^{-22}KeVb**



Helioseismology and Be-neutrinos

- Helioseismology can provide information also on the nuclear cross sections of

$$^3He+^3He \rightarrow \alpha + 2p$$

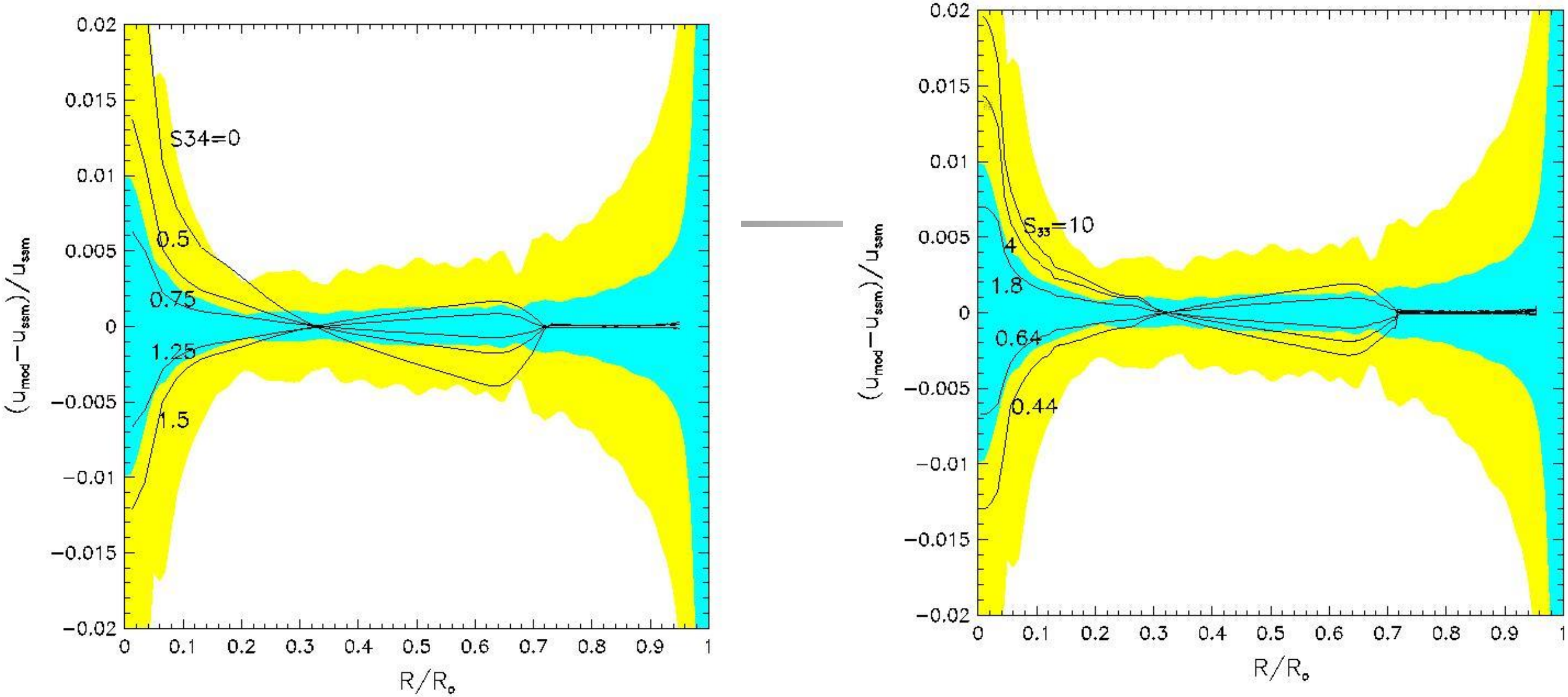
$$^3He+^4He \rightarrow {}^7Be + \gamma$$

- These govern Be-neutrino production, through a scaling law:

$$\Phi(Be) \propto S_{34}/S_{33}^{1/2}$$

- Can one measure Φ(Be) by means of Helioseismology?

Bounds on He+He cross sections

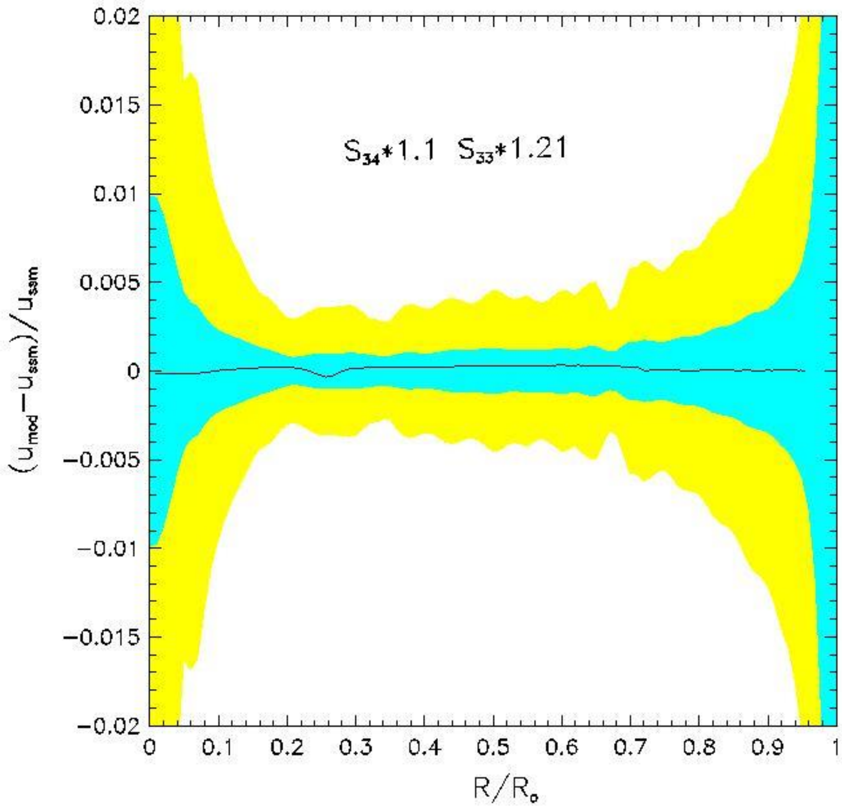


- One finds:

  $S_{34} = S_{34}^{SSM}(1 \pm 25\%)$ $S_{33} = S_{33}^{SSM}(1 \pm 70\%)$
- Φ(Be) is determined to within 25%
- (We remind that according to SSM the accuracy of Φ(Be) is about 9 %, and $S_{34}^{SSM}=0.53(1 \pm 9\%)$KeVb

  $S_{33}^{SSM}=5.4(1 \pm 7\%)$MeVb

Scaling law



- Also $u=P/\rho$ satisfies the same scaling relation as Φ(Be):
- $u = u\,(S_{34}/S_{33}{}^{1/2})$ <-> Φ(Be)
- ν(Be) waste more energy than ν(pp) . If their production is larger, more H->He is burnt for the same e.m. energy and the molecular weight increases
- Since T does not depend on S_{34} or S_{33} , sound speed decreases when ν(Be) is increased.
- The sound speed knows of Be-neutrinos

Deviations from Maxwell-Boltzmann Statistics?

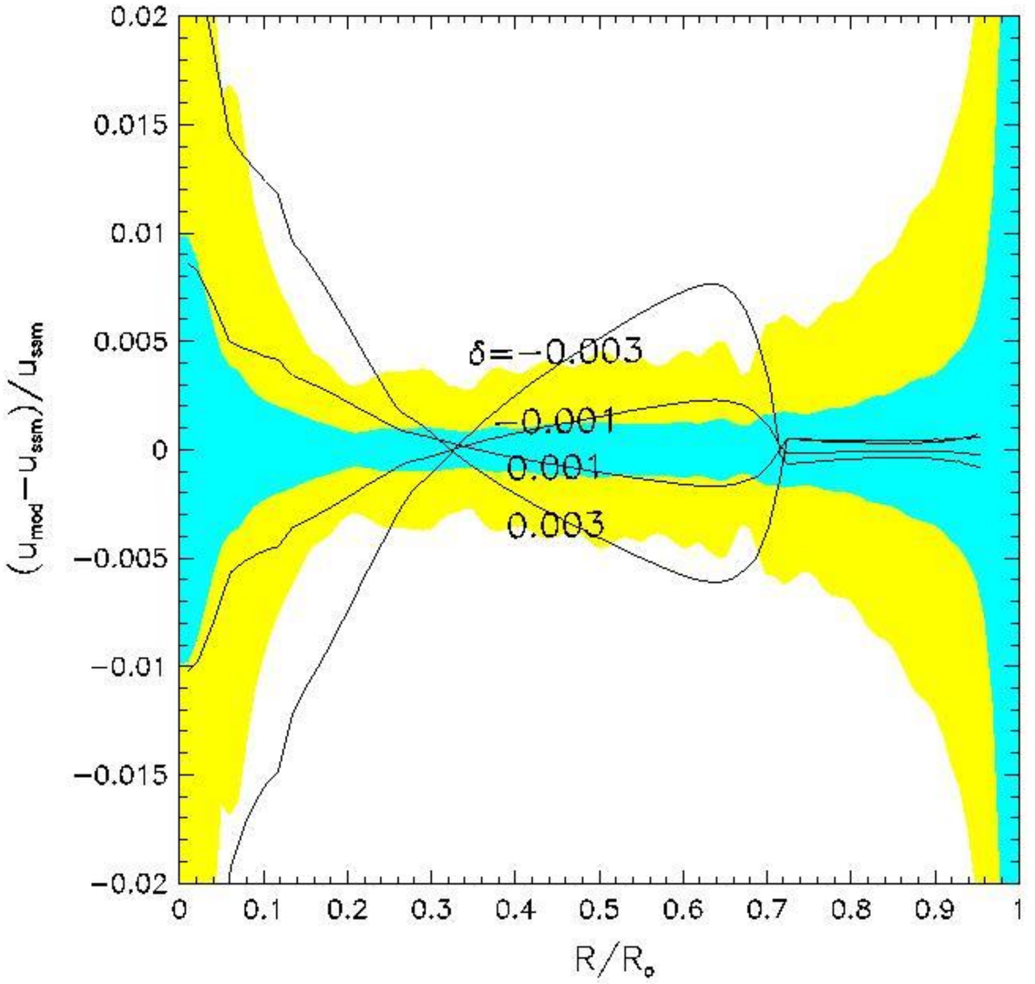
- Nuclear reactions in the sun occur between nuclei in the high energy tail of the particle distribution
- Nuclear reaction rate are sensitive to possible deviations from the standard energy distribution
- We can derive constraints on such deviations by using helioseismology

Degl'Innocenti,Fiorentini, Lissia, Quarati, Ricci PLB 441 (1998) 291

Helioseismic test of non standard statistic

- If the small deviation is parametrized with a factor exp[- δ (E/KT)] we find that:
  -0.001< δ <0.001

- Even such a small value of δ give effects on neutrino fluxes



Screening of nuclear reactions in the Sun and solar neutrinos

Solar neutrino production depends on nuclear reactions and thus can be affected by screening, as discussed in several papers

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Screening of nuclear reactions in the Sun and solar neutrinos

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(Received 22 November 1994)

We quantitatively determine the effect and the uncertainty on solar neutrino production arising from the screening process. We present predictions for the solar neutrino fluxes and signals obtained with different screening models available in the literature and by using our stellar evolution code. We explain these numerical results in terms of simple laws relating the screening factors with the neutrino fluxes. Furthermore we explore a wider range of models for screening, obtained from the Mitler model by introducing and varying two phenomenological parameters, taking into account effects not included in the Mitler prescription. Screening implies, with respect to a no-screening case, a central temperature reduction of 0.5%, a 2% (8%) increase of ^{7}Be- (^{8}B-) neutrino flux and a 2% (12%) increase of the gallium (chlorine) signal. We also find that uncertainties due to the screening effect are at the level of 1% for the predicted ^{7}Be-neutrino flux and gallium signal, not exceeding 3% for the ^{8}B-neutrino flux and the chlorine signal.

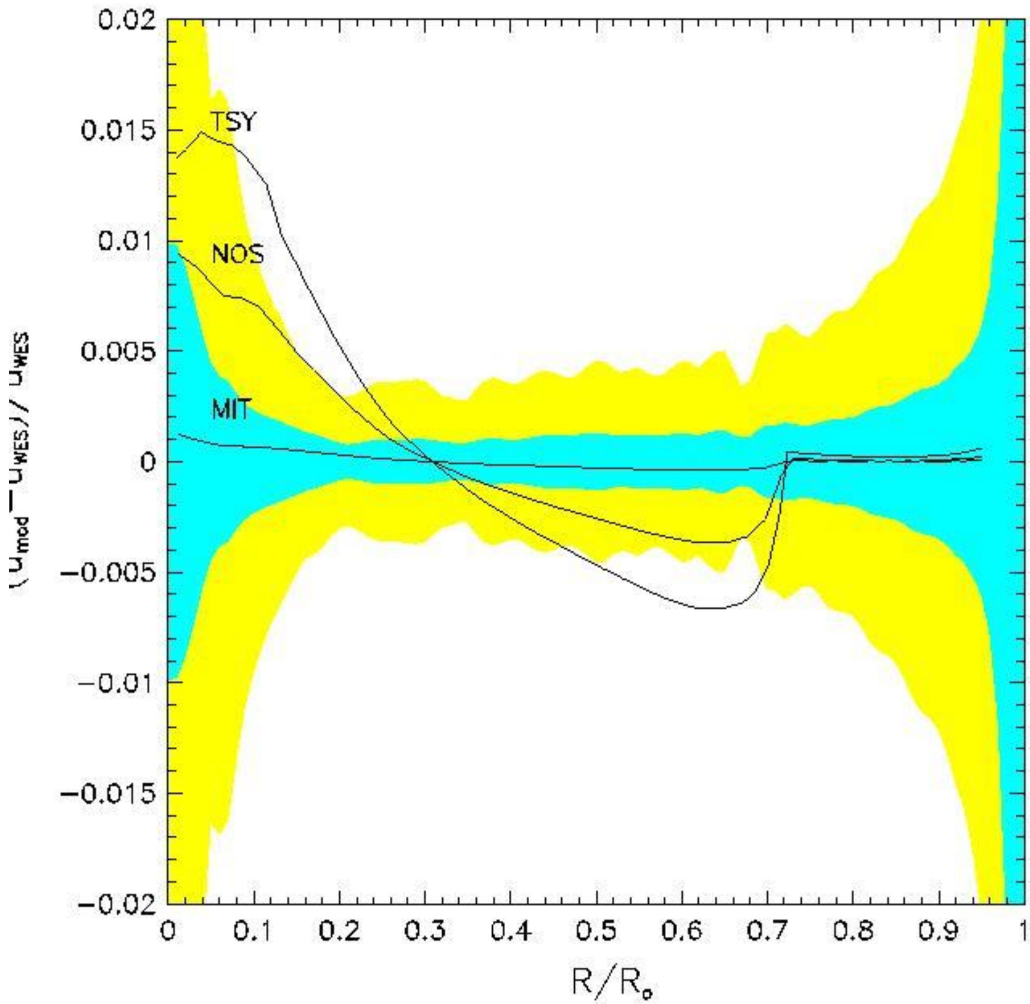
Screening in the Sun is the subject of a long debate...

Screening and Helioseismology

- Screening modifies nuclear reactions rates

  S_{pp}->S_{pp} f_{pp}
- Thus it can be tested by means of helioseismology

- TSYtovitch anti-screening is excluded at more than 3σ
- NO Screening is also excluded.
- Agreement of SSM with helioseismology shows that (weak) screening does exist.



GF, Ricci and Villante, astro-ph 0011130

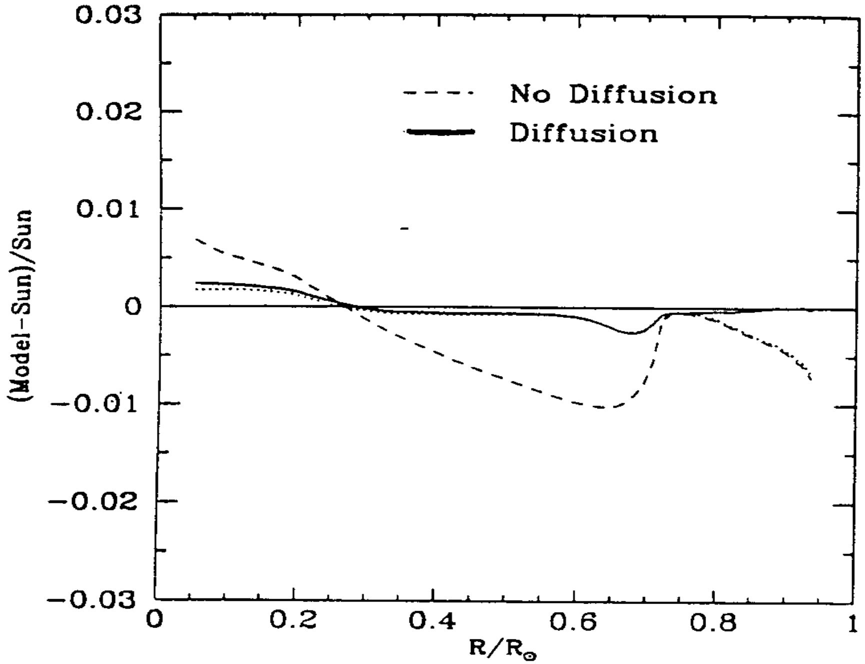
Elemental diffusion

$Rb_O = 0.711 \pm 0.001$ $Y_O = 0.249 \pm 0.003$

*) $Rb_{no\text{-}diff} = 0.726$ $Y_{no\text{-}diff} = 0.266$

$Rb_{diff} = 0.714$ $Y_{diff} = 0.244$

*)

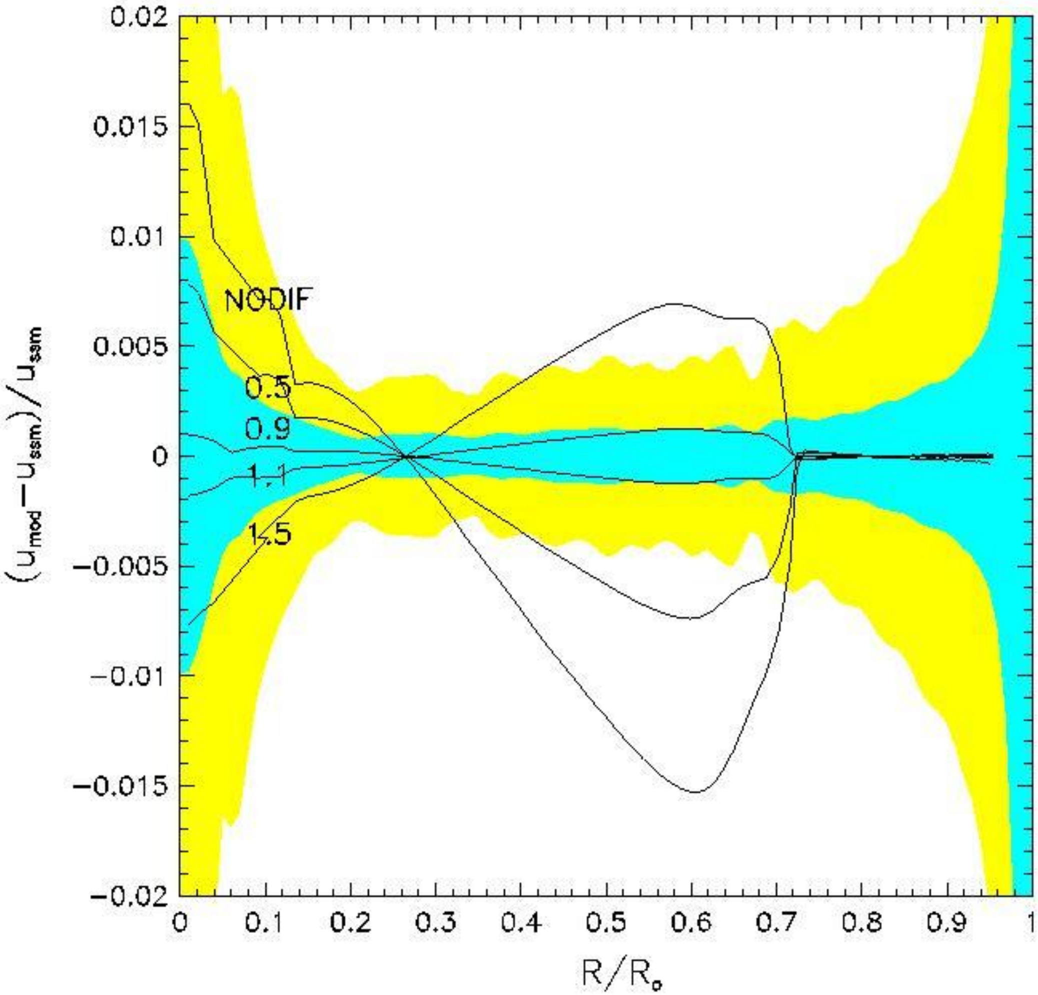


- Diffusion and gravitational setting are essential ingredients of SSM in order to satisfy helioseismic constraints, both on u and on properties of convective enevelope *(see Guzik&Cox 1993, Proffitt 1994, Bahacall et al 1997, Turck-Chieze et al 1998, ...)*

**) from Bahcall, Pinsonneault, Basu astro-ph/0010346 and PRL 1997*

Determination of the diffusion coefficients

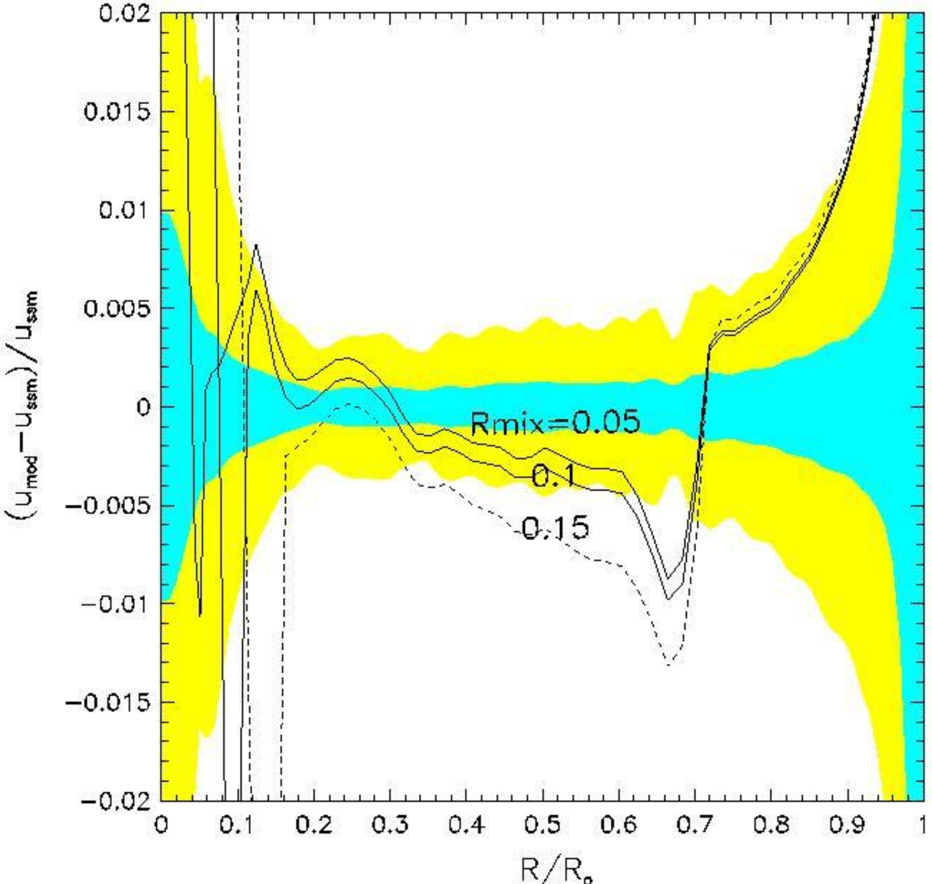
- Actually one can use helioseismology to test the accuracy of diffusion theory
- Helioseismic information confirms the diffusion efficiency adopted in SSM to the 10% level



Fiorentini,Lissia and Ricci A&A 342 (1999) 492

A mixed solar core?

- If mixing exists, must be confined in the region with R≤5%Ro (M ≤ 1%Mo)
- No hope for the solar neutrino puzzle (Tc increases)

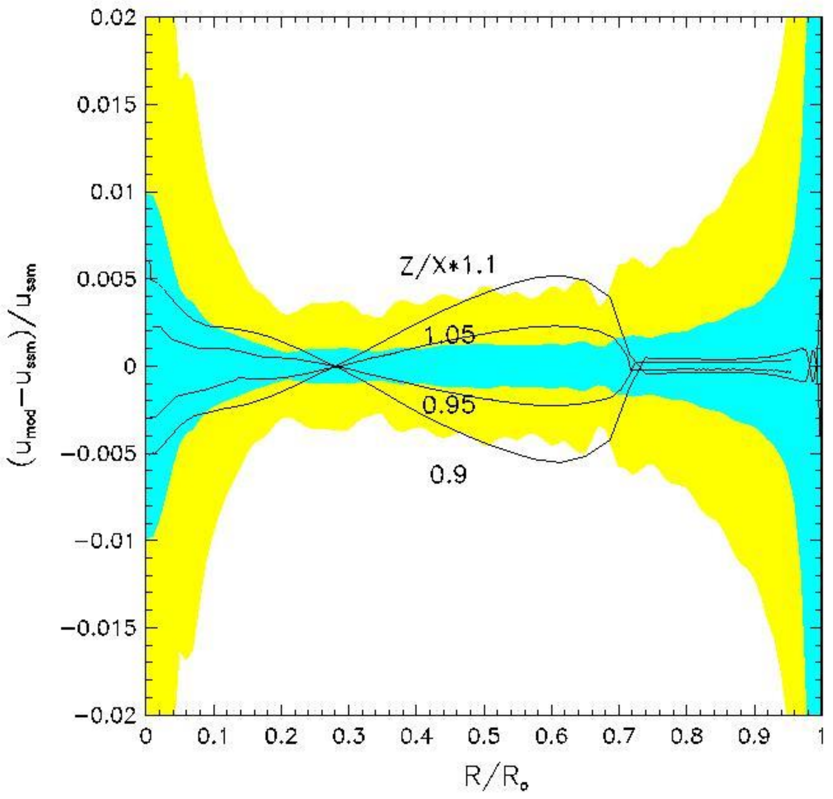


Degl'Innocenti and Ricci Astrop. Phys. 8 (1998) 8

The metal content in the sun

- Helioseismology constraints the ratio Z/X at the 5%

- We remind that $Z/X_{ssm}=0.0245(1\pm 6\%)$



Concluding remarks

Helioseismology is a powerfool tool which provides information on many aspect of physics.

e.g.:

- 4+n dimensional Planck Mass must be >300 Gev
- Beryllium neutrinos flux is determined within 25%
- Non-standard statistic ($|\delta|<0.001$)
- The diffusion efficiency adopted in SSM is confirmed at 10% level