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HELIOSEISMOLOGY AND SOLAR NEUTRINOS

1. Helioseismic tests of SSM predictions

2. Helioseismic refinements of SSM predictions

3. Predictions of Φ_ν independent of SSM

3a) How many Hep neutrinos ?

3b) Minimal predictions for Φ(Be)

3c)Minimal predictions for the Gallium signal

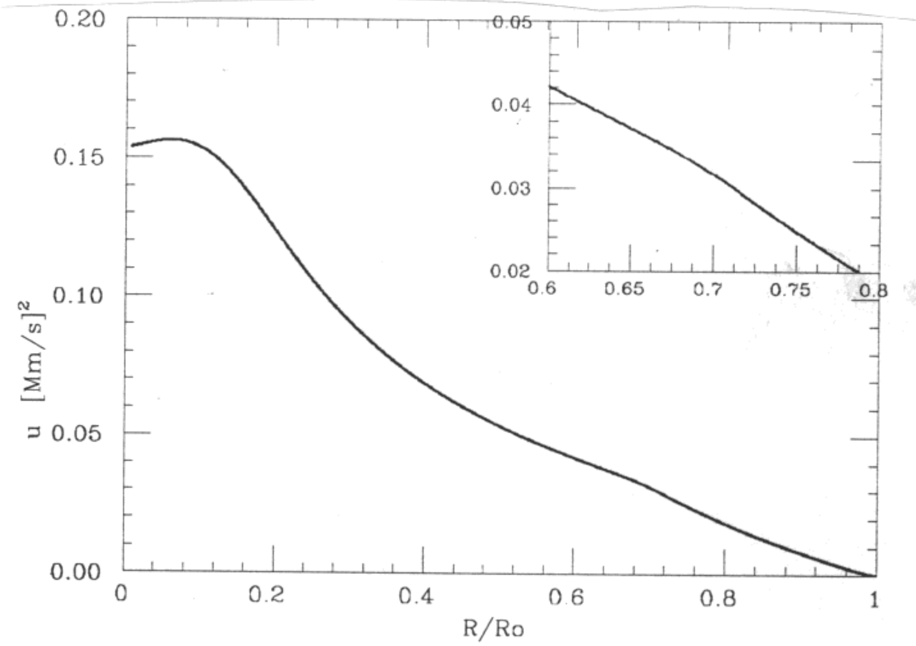
4. Tests of "exotic" solar models

How many axions fron the Sun?

SOLAR PROPERTIES FROM HELIOSEISMIC OBSERVATIONS

From the measurements of ≈ 10^3 frequencies with $\Delta\nu/\nu$ ≈10^4 one derives:

a)(isothermal)sound speed



b)properties of the convective envelope: depth, density and He abundance:

R_b=0.711 (1±0.4%)R_o
ρ_b=0.192 (1±4%)g/cm^3
Y_{ph}=0.249(1±4%)

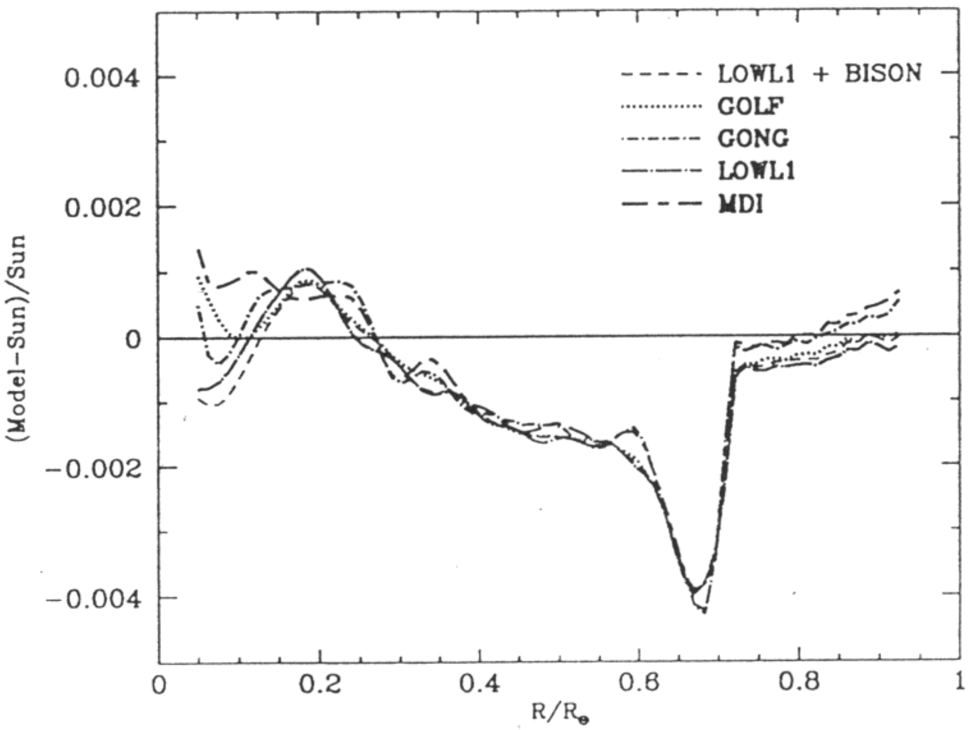
" 3σ" errors, mostly from systematic uncertainties in the inversion techniques.

Recent measurements (GONG) have not added much, concerning these observables.

Know u is not the same as know T

Helioseismic tests of SSM calculations

E.g: BP 98 *) model, compared with results of five recent measurements



BP-98	Helioseismology ($\pm 3\sigma$)	units
R_b=0.714	R_b=0.711 ±0.003	R_o
ρ_b=0.186	ρ_b=0.192 ±0.007	g/cm^3
Y_{ph}=0.243	Y_{ph}=0.249±0.090	-

*)See Bahcall, Basu and Pinsonneault PLB 433(1998)1 or astro-ph/9805135

AGREEMENT OR DISAGREEMENT ?

i)predicted u agree with observations within 0.5%

or

ii)predicted u's disagree with observation at the 0.1 %, just below the convective zone#1

This feature is common to any helioseismic data set#3

This feature is common to any SSM#2

We know that something is not understood there (why is solar Lithium abundance is 10^{-2} with respect to meteorites)

We all suspect that "mixing length"theory is too rough a description of convective transport

We know that using "older"opacities the problem disappear/gets smaller#2,3...

#1) Listen S. T.C. talk
#2)See Dziembowsky et al, Astroparticle Phys. 7(1997)77
#3)See Bahcall et al, PLB 433(1998)1

HELIOSEISMICALLY CONSTRAINED SOLAR MODELS

One can use helioseismology to constrain some input of solar model calculations (essentially opacity), so as to refine Standard Solar Models

When a simple rescaling of opacity is allowed then, the helioseismic constrain on the central solar temperature is[#1]:

$$T_{HCSM} = 1.58\,(1 \pm 1.4\%)\ 10^7\ K$$

where the quoted error is 3σ

As a comparison:

$$T_{BP98} = 1.5697\ 10^7\ K$$

#1) Berezinsky et al PLB 407 (1997)155

HELIOSEISMOLOGY, SOLAR MODELS, NEUTRINO FLUXES AND SIGNALS

In order to determine neutrino fluxes and signals, nuclear physics has to be known.

Nuclear cross sections relevant for the pp-chain have been recently rexamined by:

Adelberger et al, R.M.P. 70 (1998)1265
NACRE collab. Nucl.Phys. A, to appear

	BP95#1	BP98#2	HCSM#3	EXP
Be	5.15±0.3	4.8±.4	5.1±0.2±0.5	=
B	6.62±1.	5.15±.8	5.8±0.4±0.7	2.44±0.08
Cl	9.3±1.3	7.7±1.1	8.5±0.5±0.8	2.56±0.23
Ga	137±8	129±7	132±2.5±4.9	72±5.5

Be flux in 10^9/cm^2/s, B flux in 10^6/cm^2/s
Cl and Ga signal in SNU

All errors are "1σ"

For HCSM first (second) error corresponds to astrophysical(nuclear phys.) uncertainty

NUCLEAR PHYSICS ERRORS ARE MORE IMPORTANT THAN ASTROPHYSICAL UNCERTAINTIES

#1 R.M.P 67 (1995)781; #2 PLB 433(1998)1
#3 updated from PLB 407(1997)155

SOLAR MODEL INDEPENDENT PREDICTIONS ABOUT NEUTRINO FLUXES

The idea is to use Helioseismology in place of standard solar model calculations:

Neutrino production rates are given as:

$$dN/dt = \int dv\, n_i n_j <\sigma \quad v>_{ij} =$$

$$= \;..\; S_{ij} \qquad \int dv\, n_i n_j\, T^{\alpha_{i,j}}$$

Astrophysical S-factors S_{ij} have to be given by nuclear physics.

Power law coefficients $\alpha_{i,j}$ are given by Gamow formula.

Nuclear densities n_i (r) and temperature profiles T(r) are given by SSM calculations.

Alternatively, one can use helioseismology to constrain the above integrals

SOLAR MODEL INDEPENDENT PREDICTIONS ABOUT Hep FLUX

The anomaly at high electron-energy (E>12 MeV) reported by SK might be explained by a flux of Hep neutrinos[#1]:

$$\Phi(\text{Hep}) \approx 30\,\Phi_{ssm}(\text{Hep})$$

i)for the first time we have an excess of solar ν.

ii)it's marvelous that such a tiny fraction of the solar ν flux is in the process of being detected:

$$\Phi_{ssm}(\text{Hep}) = 2\;10^{3}\ /\text{cm2/s}$$

iii)The SSM prediction looks rather robust except for the calculated value of S_{13} :

$$\Phi_{ssm}(\text{Hep}) = 2 10^{3}\ (1 \pm 3\%)\ S_{13}/S_{13-SSM}\ /\text{cm2/s}$$

The $\pm$3% accounts for all astrophysical uncertainties;

whereas $S_{13\_ssm} = 2.3\;10^{-30}$ KeV b is uncertain by a factor 2, at least...

#1) Bahcall& Krastev, PLB 444(1998)387 ; see the talk by Inoue for a more recent determination

SUMMARY OF CALCULATED VALUES OF S_{13}

Calculated values of S_0(hep). The table lists all the published values with which we are familiar of the low energy cross section factor for the hep reaction shown in Eq. 1.

S_0(hep) (10^{-20} kev b)	Physics	Year	Reference
630	single particle	1952	[10]
3.7	forbidden; $M_\beta \propto M_\gamma$	1967	[11]
8.1	better wave function	1973	[12]
4-25	D-states + meson exchange	1983	[13]
15.3 ± 4.7	measured $^3He(n,\gamma)^4He$	1989	[14]
57	measured $^3He(n,\gamma)^4He$ shell model	1991	[15]
1.3	destructive interference, detailed wavefunctions	1991	[16]
1.4-3.1	Δ-isobar current	1992	[17]

If $S_{13} = S_{13\_SSM}$ then Φ(Hep)$\approx$ 1/3000Φ (B)and Hep neutrinos should be undetected by SK.

What if really

Φ(Hep) $\approx 30\Phi$ ssm(Hep) ?

Nuclear physics and/or SSM must be wrong

It is desirable to have predictions on Hep which do not depend on SSM

We can use helioseismology + local ^{3}He equilibrium to determine:

Φ(Hep) /S_13 =....$\int$ dv $n_1 n_3$ $T^{\alpha 13}$

This gives:

Φ(Hep) < 2 Φ ssm(Hep) S_{13}/S_{13_ssm}

If we relax local ^{3}He abundance, by using the luminosity constrain we find the weaker inequality

Φ(Hep) < 3 Φ ssm(Hep) S_{13}/S_{13_ssm}

In conclusion*:

If Φ(Hep) $\approx$ 30 Φ_{ssm}(Hep) is confirmed and if $S_{13} \approx S_{13\_ssm}$ is also confirmed, then:

i)Hep neutrinos are produced in a region where ^{3}He is drastically out of equilibrium

and

ii)nuclear power presently generated in the Solar core exceeds the observed solar luminopsity

Rem: all this does not rely on SSM calculations

***Berezinsky, S.Degl'Innocenti, B Ricci +G.F PLB...**

INFNFE-15-98

Bounds on *hep* neutrinos

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-ph/9810083
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Abstract

The excess of highest energy solar-neutrino events recently observed by Superkamiokande can be in principle explained by anomalously high *hep*-neutrino flux $\Phi_\nu(hep)$. Without using SSM calculations, from the solar luminosity constraint we derive that $\Phi_\nu(hep)/S_{13}$ cannot exceed the SSM estimate by more than a factor three. If one makes the additional hypothesis that *hep* neutrino production occurs where the ^{3}He concentration is at equilibrium, helioseismology gives an upper bound which is (less then) two times the SSM prediction. We argue that the anomalous *hep*-neutrino flux of order of that observed by Superkamiokande cannot be explained by astrophysics, but rather by a large production cross-section.

INFNFE-99-

Helioseismology, Beryllium neutrino flux and Gallium signal

Abstract

We derive a lower limit on the Berillium neutrino flux $\Phi(Be)_{min} = 1 \cdot 10^9$ cm^{-2} s^{-1} in the absence of oscillations, by using helioseismic data, the B-neutrino flux measured by SUPERKAMIOKANDE and the hydrogen abundance at the solar center predicted by Standard Solar Model (SSM) calculations. We emphasize that this latter is the only result of SSMs needed for getting $\Phi(Be)_{min}$. Correspondingly we also derive a minimal value for the Gallium signal, $S_{min} = 91 \pm 3$ SNU, which is 3σ above the experimental value $S_{exp} = 72 \pm 6$ SNU.

astro-ph/9902222
INFNCA-TH9814

Solar neutrino fluxes with arbitrary ^{3}He mixing

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(January 24, 1999)

Abstract

The ^{3}He abundance is not constrained by helioseismic data. Mixing of ^{3}He inside the solar core by processes not included in the solar standard model (SSM) has been recently proposed as possible solution to the solar neutrino problem. We have performed a model independent analysis of solar neutrino fluxes using practically arbitrary ^{3}He abundance. In addition, we have been simultaneously varying within very wide ranges the temperature in the neutrino production zone and the astrophysical factors, S_{17} and S_{34}, of the $p + {}^7$Be and ^{3}He + ^{4}He cross sections. Seismic data are used as constraints, but the solar-luminosity constraint is not imposed. It is demonstrated that even allowing ^{3}He abundances higher by factors up to 16 than in the SSM, temperatures 5% (or more) lower, the astrophysical factor S_{17} up to 40% higher, and varying S_{34} in the range (-20% ,+40%), the best fit is still more than 5σ away from the observed fluxes. We conclude that practically arbitrary ^{3}He mixing combined with independent variations of temperature and cross-sections cannot explain the observed solar neutrino fluxes.

Helioseismological constraint on solar axion emission

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(January 26, 1999)

Helioseismological sound-speed profiles severely constrain possible deviations from standard solar models, allowing us to derive new limits on anomalous solar energy losses by the Primakoff emission of axions. For an axion-photon coupling $g_{a\gamma} \lesssim 5 \times 10^{-10}$ GeV^{-1} the solar model is almost indistinguishable from the standard case, while $g_{a\gamma} \gtrsim 10 \times 10^{-10}$ GeV^{-1} is probably excluded, corresponding to an axion luminosity of about $0.20\,L_\odot$. This constraint on $g_{a\gamma}$ is much weaker than the well-known globular-cluster limit, but about a factor of 3 more restrictive than previous solar limits. Our result is primarily of interest to the large number of current or proposed search experiments for solar axions because our limit defines the maximum $g_{a\gamma}$ for which it is self-consistent to use a standard solar model to calculate the axion luminosity.

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