

The GALLEX solar neutrino experiment

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After more than four years of recording the solar neutrino flux with the GALLEX detector, the combined result from the 53 completed solar runs is 69.7 ± 6.7 (stat.) $^{+3.9}_{-4.5}$ (syst.) SNU (one SNU is one solar neutrino unit and corresponds to 10^{-36} capture/atom/second), only about 55 % of the predictions of “standard solar models”. The detector has been exposed two times to ≈ 60 PBq artificial neutrino ^{51}Cr sources. The ratio of the production rate of chromium-produced ^{71}Ge to the rate expected from the known source activity is 0.92 ± 0.08 , combined value for the two source experiments. This result validates the deficit observed by GALLEX compared to the predictions. The relevance of the GALLEX data to the ^7Be neutrino problem is discussed, as well as the interpretation of the solar neutrino deficit by neutrino oscillation via the MSW effect.

1. INTRODUCTION

The main objective of the radiochemical gallium experiments is the detection of pp-neutrinos which are produced in the primary pp fusion reaction in the core of the Sun. The GALLEX collaboration [1] has been recording the solar neutrino flux for more than 4 years, using a 30.3 tons gallium target.

Results for 53 completed solar runs (3-4 weeks each) are given (section 2), showing a significant deficit (about 45 %) compared to the predictions of standard solar models (SSM) [2-4]. The consequences of such a deficit are potentially important for stellar models or for neutrino physics beyond the standard model of particle physics. To check the reliability of the detector, two high intensity neutrino sources (≈ 60 PBq) made of ^{51}Cr have been built [5] and irradiated the detector for 3-4 months. The number of ^{71}Ge atoms produced by the 750 keV neutrinos from the source has been compared to the number expected from the measurement of the activity of the source and the agreement is good [6-8] (section 3). The previous GALLEX results provided the first observation of pp-neutrinos from the Sun, and indicated a deficit of the expected fluxes of the other neutrino branches, in particular of ^7Be neutrinos. The significance of this ^7Be neutrino problem has

evolved gradually, and the combined error on solar runs (± 12 %) has now approached a level where the limits on the derived contribution of ^7Be neutrinos to the GALLEX signal confront the predictions of solar models (section 4). The deficit, together with the deficit observed in the other solar neutrino experiments, can be interpreted in terms of neutrino oscillations via the MSW effect (section 5).

2. GALLEX RESULTS FOR SOLAR NEUTRINOS

The radiochemical GALLEX detector monitors solar neutrinos with energies above 233 keV using the reaction $^{71}\text{Ga}(\nu_e, e^-)^{71}\text{Ge}$. It is sensitive to the ν_{pp} which are produced in the primary pp fusion reaction in the core of the Sun, and for which the energy spectrum extends to a maximum value of 420 keV; but it is also sensitive to ^7Be - and to ^8B -neutrinos (ν_{Be} and ν_B), coming from other nuclear reactions in the pp chain. The radioactive ^{71}Ge produced decay (with a half-life of 11.43 days) by electron capture (87.7 %, 10.3 % and 2 % respectively for K, L and M peaks), emitting Auger electrons and X-rays.

The principle of the experiment is as follows : expose the gallium to solar neutrinos in a low background environment, extract by a chem-

ical method the ^{71}Ge atoms which are produced, transform into counting gas GeH_4 , fill a proportional counter and count them. GALLEX uses as a target a solution of GaCl_3 (SAGE, another gallium experiment, in the Baksan Laboratory (Caucasus, Russia), uses directly the gallium metal).

GALLEX is installed in the Gran Sasso Underground Laboratory (Italy), 120 km east of Rome. The detector (see figure 1) is a cylindrical tank (8 m high and 3.8 m diameter) containing 30.3 tons of gallium in the form of a solution of GaCl_3 (8.2 M/l of GaCl_3 and 1.9 M/l of HCl). The germanium (either the few ^{71}Ge atoms produced by neutrinos or the one mg of natural germanium used as carrier and introduced in the tank at the beginning of each exposure) is extracted by circulating a large flow of nitrogen ($300 \text{ m}^3/\text{h}$) through the tank for ~ 10 hours. The germanium, in the form of GeCl_4 , is very volatile in presence of HCl; it is flushed out with the nitrogen and then absorbed into pure water [9]. It is then transformed into GeH_4 and put into a small proportional counter (0.5 cm^3) made with ultrapure material. In the counter, ^{71}Ge decay is signified by a count observed in the L (1.2 keV) or K (10.4 keV) peak. The discrimination from the counter background itself (mainly Compton electrons) is done by a pulse shape analysis. The germanium extraction efficiency is larger than 95% and the counting efficiency about 65%.

The main source of background comes from the reaction $^{71}\text{Ga} (\text{p},\text{n})^{71}\text{Ge}$, where the major source of protons is due to cosmic ray muon interactions. The total background has been estimated to about 4 SNU (2.8 ± 0.6 SNU from muon induced background, 0.15 ± 0.1 SNU from neutron induced background, 1.0 ± 1.0 SNU from ^{69}Ge falsely attributed to ^{71}Ge), a few percent of the expected signal.

A typical solar exposure lasts about one month, followed by a 6-month period of counting of the ^{71}Ge after its extraction from the gallium target at the end of the exposure. We give here the results for the 15 runs corresponding to the GALLEX I period (May 91 to April 92), for the 24 runs corresponding to the GALLEX II period (August 92 to June 94), and for the 14 runs corresponding to the GALLEX III period (October

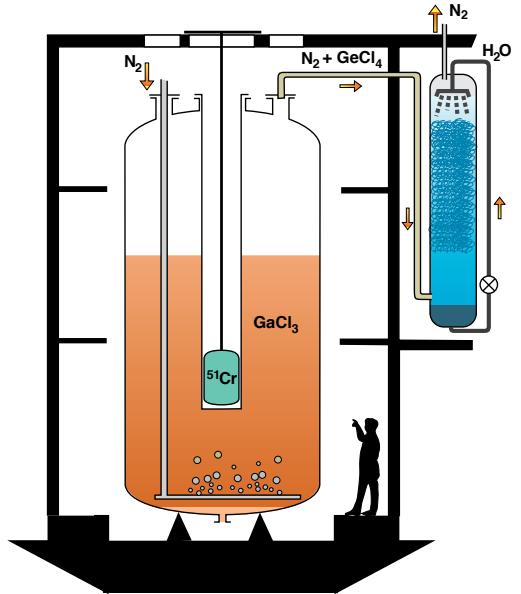


Figure 1. Scheme of the GALLEX cylindrical tank and of the germanium desorption system. The cylindrical thimble in the middle is used to install the ^{51}Cr neutrino source.

94 to October 95), i.e. for 53 completed runs. The total exposure time to the Sun is 1326 days.

Figure 2 shows the energy/risetime distribution for all counts registered during the first mean-life of ^{71}Ge (upper part) and during the 4th mean-life (lower part). The ^{71}Ge signal corresponds to a short risetime (pointlike ionization in the counter) and the background to a longer risetime (electrons crossing the counter). The fading out of genuine ^{71}Ge counts in the L- and K-acceptance windows after three mean-lives is obvious.

The results from the individual runs for the net solar production rates of ^{71}Ge are based on the counts in the L and K energy and rise-time windows (see [10,11] for details). They are shown in figure 3 and the corresponding numbers can be found in ref. [10–12].

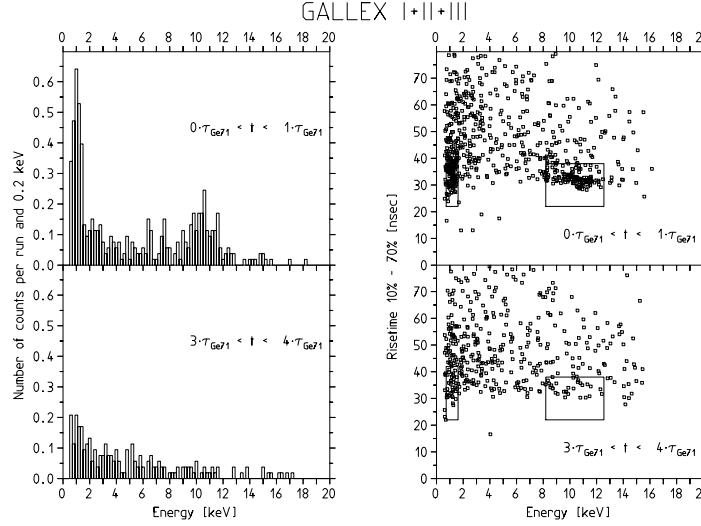


Figure 2. Energy spectra above 0.5 keV for all pulses surviving the risetime cut (left), and energy/risetime distributions for all pulses > 0.5 keV (right), registered for all 53 GALLEX solar neutrino runs. Top figures correspond to the first 16.5 days ($0 < t < 1\tau_{71}$, where τ_{71} is the mean-life of ^{71}Ge) and bottom figures during days 50-66 ($3\tau_{71} < t < 4\tau_{71}$). The L- and K-acceptance windows are indicated in the boxes. The L-peak (≈ 1 keV) and the K-peak (≈ 10 keV) of the ^{71}Ge energy spectrum are clearly seen and they are evidently decaying. It is also clear that the ratio of ^{71}Ge signal to background is larger for the K-peak than for the L-peak.

The combined result of the maximum-likelihood analysis for the 53 runs is 69.7 ± 6.7 (stat.) $^{+3.9}_{-4.5}$ (syst.) SNU (1σ) or $69.7^{+7.8}_{-8.1}$ SNU with errors combined in quadrature. By fitting separately the signals in the L- and in the K-region, we obtain 66.9 ± 10.5 SNU for the L and 71.5 ± 8.8 SNU for the K, in very good agreement. If we fit the mean life τ of the signal, we obtain $\tau = 13.9 \pm 2.0$ days, in good agreement with the mean life of the ^{71}Ge (16.49 d).

We note here that the latest value from the SAGE gallium experiment is 72 ± 13 SNU [13], in good agreement with our result.

The total number of observed decays of ^{71}Ge due to solar neutrinos is less than 5 per run (about 220 ^{71}Ge counts have been observed). It corresponds to a production rate by solar neutrinos of 0.7 ^{71}Ge per day.

The result for the GALLEX III period appears to be smaller (54 ± 11 SNU) than for the other periods (77.8 ± 10 SNU for GALLEX I+II). A detailed statistical analysis has been performed in reference [12]; we can summarize by saying that the probability for such a difference, about 20 %, is statistically acceptable. Possible experimental modifications which could have induced a loss of efficiency have also been investigated but nothing has been found until now (see [12] for details).

Our value, about 55 % of the predictions of SSM which range from 115 to 137 SNU [2-4], is significantly smaller than the model predictions. As will be discussed in section 4, this puts strict limits on the ^7Be -neutrino flux. The consequences of such a deficit are important for stellar models and/or for neutrino physics beyond the standard model of particle physics (it could im-

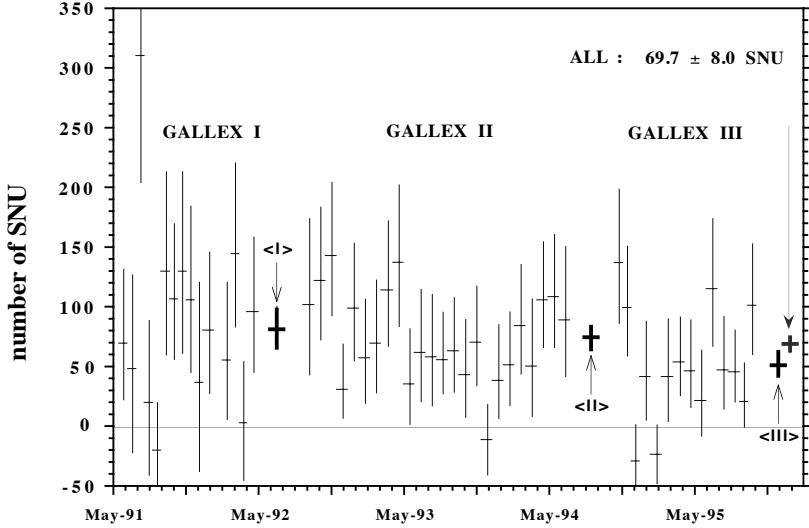


Figure 3. Results of the 53 GALLEX solar runs, together with the combined value. The left-hand scale is the measured ^{71}Ge production rate; the right-hand scale, the net solar neutrino production rate (SNU) after subtraction of side reaction contributions. Errors bars are $\pm 1\sigma$, statistical only.

ply neutrino masses through the MSW mechanism [14]). To check the reliability of the detector, it has been exposed to a high intensity artificial neutrino source.

3. THE Cr-SOURCE EXPERIMENTS

^{51}Cr has been chosen as the most convenient neutrino source. It is produced by neutron capture on ^{50}Cr and decays by electron capture with an half-life of 27.706 ± 0.007 days. 90 % of the decays correspond to the emission of a ≈ 750 keV neutrino, and 10 % to the emission of a ≈ 430 keV neutrino plus a 320 keV gamma.

36 kg of chromium enriched to about 40 % in ^{50}Cr were used in the form of small irregular chips ($\approx 1 \text{ mm}^3$). They were irradiated for more than three weeks in the core of the Siloé reactor, in Grenoble. A dedicated core has been specially built for our purpose (see figure 4). The source itself was formed by the irradiated chromium surrounded by gamma shielding made of tungsten

(8.5 cm thick).

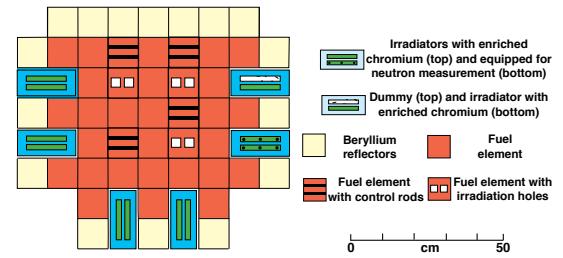


Figure 4. *Siloé core arrangement for the second chromium irradiation.*

Two sources have been made, one in June 94 and the other in September 95.

Table 1
Direct measurements of the activity of the two sources with different methods.

Method (Laboratory)	Value (PBq)
First source	
Ionization chamber (Saclay)	61.3 ± 0.8
Ge spectroscopy (Heidelberg)	63.2 ± 0.9
Ge spectroscopy (Karlsruhe)	63.1 ± 0.9
Ge spectroscopy (BNL)	63.1 ± 1.0
Calorimetry (Grenoble/Saclay)	61.9 ± 3.0
Neutronics (Grenoble)	64.4 ± 5.2
Gamma scanning (Grenoble)	64.0 ± 5.2
Vanadium content (BNL)	62.3 ± 1.1
Weighted mean	62.5 ± 0.4
Second source (preliminary)	
Ionization chamber (Saclay)	67.5 ± 1.3
Ge spectroscopy (Heidelberg)	68.3 ± 1.0
Ge spectroscopy (Karlsruhe)	70.3 ± 1.5
V analysis (Karlsruhe)	72.1 ± 3.0
Calorimetry (Grenoble/Saclay)	65.2 ± 6.0
Neutronics (Grenoble)	75.1 ± 6.0
Weighted mean	68.7 ± 0.7

Different methods have been used to measure the activity of the source, all based on the measurement of the 320 keV gamma. The results are summarized in table 1. The resulting mean activity of the ^{51}Cr source at the end of bombardment by neutrons in Silo  is 62.5 ± 0.4 PBq for the first and 68.7 ± 0.7 PBq for the second source, where 1 PBq corresponds to $10^{15} \nu/\text{s}$. To our knowledge, these are the strongest neutrino sources ever produced by man. See ref. [5] for details on the production of the sources.

The sources were installed for 3-4 months in the reentrant tube in the center of the GALLEX detector (see figure 1). The experimental conditions for the runs performed were kept as close as possible as for the solar runs. The main difference between the two source experiments consists in the different duration times chosen for the exposures of the gallium target to the source. In the first one, the 11 exposure times were chosen to optimize the use of the source by producing

about the same number of ^{71}Ge atoms per exposure. So, we used rather short exposures, ranging from 3 days to 2 weeks, and only one 3-week exposure at the end of the experiment. For the second source, the exposure times were chosen to resemble more closely the durations of the solar exposures : after two short exposures (3.3 and 4 days), we switched to two 3-week exposures (as in GALLEX I), followed by three 4-week exposures (as in GALLEX II). In total, 7 exposures were performed in the second source experiment.

The individual results (still preliminary) for the second source [8] are reported in figure 5. Those for the first source can be found in reference [7].

The activity of the sources deduced from a global fit of the ^{71}Ge data have been measured to be 62.7 ± 6.7 PBq and 57.1 ± 6.8 PBq respectively. The ratio, R, between this activity deduced from ^{71}Ge counting and the directly measured source activity is equal to 1.00 ± 0.11 for the first source and 0.83 ± 0.10 for the second.

The main characteristics and the results of the two sources are summarized in table 2.

The agreement between the predicted and the measured signal is less satisfactory for the second source experiment than for the first, being 1.7σ from the first Cr result. Possible systematic effects are being considered, but so far we have no indications of any experimental effects that might lower the results.

A combined analysis of the two source experiments has been performed, asking the program to fit directly a single number for the ratio R, using the value of the directly measured activity of each source as a normalization. This analysis gives $R = 0.92 \pm 0.08$.

This shows that the deficit of solar neutrino flux observed by GALLEX cannot be attributed to experimental artifacts and demonstrates the absence of any unexpected systematic errors. More details and discussion can be found in ref. [6]. We should emphasize here that the validation of the GALLEX result by the ^{51}Cr neutrino source experiment adds confidence in the conclusions that can be drawn from our solar neutrino results.

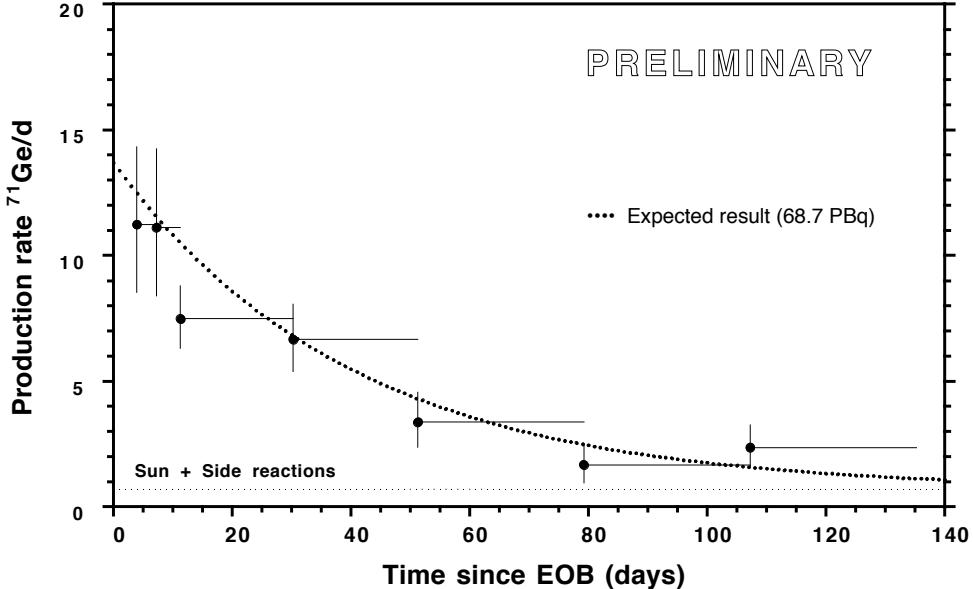


Figure 5. Number of ^{71}Ge atoms produced per day during the second source experiment (preliminary results). The points for each run are plotted at the beginning of each exposure (the horizontal lines show the duration of the exposures). The predicted curve (dotted line) decreases with the known half-life of ^{51}Cr and corresponds to the expected rate for a source activity of 68.7 PBq. Vertical bars are statistical errors. Small dots correspond to the constant 0.70 / day production rate due to solar neutrinos and side reactions.

4. RELEVANCE OF THE GALLEX DATA TO THE " ^7Be NEUTRINO PROBLEM".

The standard solar model (SSM) predictions for the gallium detector span a relatively narrow range varying from 115 ± 12 SNU [4] to 122.5 ± 14 SNU [3], to 137 ± 14 SNU [2] (2σ error for all models). Our present experimental result is $69.7^{+15.6}_{-16.1}$ SNU (2σ error, with statistical and systematic errors added quadratically). Compared to the values from the two most widely quoted SSM's : Turck-Chièze and Lopes (TCL) [3] and Bahcall and Pinsonneault (BP) [2], this result corresponds to 57 ± 15 % and 51 ± 13 %, respectively (95% c.l.), of the predictions of TCL [3] and BP [2]. The decrease in the errors since the first GALLEX result in 1992 is of marked im-

portance in focusing on the nature of the solar neutrino problem.

Table 3 summarizes the status of the solar neutrino problem. The experimental results for the four solar neutrino experiments which are actually running are displayed in the second column. The ratios between the experimental results and the predictions of the BP and TCL models are given in the last columns, showing a quantitative estimate of the solar neutrino deficit.

The values and the statistical significance of the deficits are different for the three types of detectors. This is not a priori surprising, since they are sensitive to different neutrinos, coming from different nuclear reactions, and with different energy spectra. Until recent years the deficit was mainly attributed to a ν_B deficit, but the GALLEX results have now focused on the ν_{Be} deficit, as dis-

Table 2
Characteristics of the two source experiments.
The combined value for the ratio of the activity deduced from the ^{71}Ge measurement and of the activity directly measured, R, is 0.92 ± 0.08 .

	First source	Second source (preliminary)
Irradiation period	June 94	Sept. 95
Duration	23.8 d	26.5 d
Start of exposure	June 23, 94	Oct. 10, 95
End of exposure	Oct. 5, 94	Feb. 14, 96
Nb of extractions	11	7
End of counting	May 2, 95	Sept. 17, 96
Activity directly measured (PBq)	62.5 ± 0.4	68.7 ± 0.7
Activity deduced from ^{71}Ge (PBq)	62.7 ± 6.7	57.1 ± 6.8
Ratio R	1.00 ± 0.11	0.83 ± 0.10

Table 3
Experimental results of the solar neutrino experiments and comparison to the predictions of the standard solar models of Bahcall and Pinsonneault (BP) and Turck-Chièze and Lopes (TCL). Quoted errors are 1σ . The chlorine detector (threshold 814 keV) is sensitive mainly to ν_{Be} and ν_B . Kamiokande (threshold 7 MeV) is sensitive only to ν_B . Gallium detectors (threshold 233 keV) are sensitive to ν_{pp} , ν_{Be} and ν_B .

Experiment	Results	Experiment/Predictions	
		BP [2]	TCL [3]
chlorine [15]	2.54 ± 0.20 SNU	0.27 ± 0.05	0.40 ± 0.10
Kamiokande [16]	2.80 ± 0.38 $10^6 \text{ cm}^{-2} \text{ s}^{-1}$	0.42 ± 0.09	0.64 ± 0.18
GALLEX [12]	70 ± 8 SNU	0.51 ± 0.06	0.57 ± 0.07
SAGE [13]	72 ± 13 SNU	0.53 ± 0.10	0.59 ± 0.11

cussed below. Moreover, the observation that the deficit observed is more important for the chlorine experiment than for Kamiokande gives problem, since the chlorine is also sensitive to ν_{Be} for which the predictions are more robust.

Simple calculations demonstrate the sharp constraints on ν_{Be} production that the present GALLEX results force upon the SSM [11]. The effect on the signal in gallium due to the reduction of the ν_{Be} flux by the factor, f_{Be} , is calculated keeping the solar luminosity constant, and taking the value directly measured by Kamiokande [16] for the contribution of the ν_B flux. Comparing the calculated production rate with the GALLEX measurement, including its overall error, then gives a range of allowed values of f_{Be} , and more importantly, its maximum allowed value. Using the current GALLEX result, 70 SNU, and taking the total 2σ -error to be ± 16 SNU, f_{Be} is found to be ≤ -0.20 for TCL and ≤ -0.32 for BP. This defines the scope of the “ ^7Be neutrino problem” (see ref. [11] for more details).

This is illustrated in figure 6. The horizontal lines show the gallium results (full line for the value, dotted line for the 1σ error and bold line for the 2σ error). The two first columns illustrate the predictions of two solar models [2,3] for the 6 main different sources of neutrinos, grouped here in four main categories (pp+pep, Be, B, CNO cycle). The right-hand column (called “consistent model” in the figure), contains only the predicted contribution from the pp + pep neutrino branches plus a reduced ^8B contribution as measured by Kamiokande. The resulting 86-SNU value agrees with the present GALLEX result, within the quoted 2σ -errors. Little room remains for the contributions from ^7Be .

Several other phenomenological analyses [17] have also pointed out that, relative to solar model predictions, the flux of ν_{Be} derived from the different solar neutrino detectors appears to be strikingly low, especially when compared to the measured Kamiokande flux of ν_B . This conclusion appears to argue against an “astrophysical solution” to the solar neutrino problem [18] : even those (non-standard) solar models that are able to reduce the ν_{Be} and ν_B fluxes still cannot come close to reproducing the experimentally derived

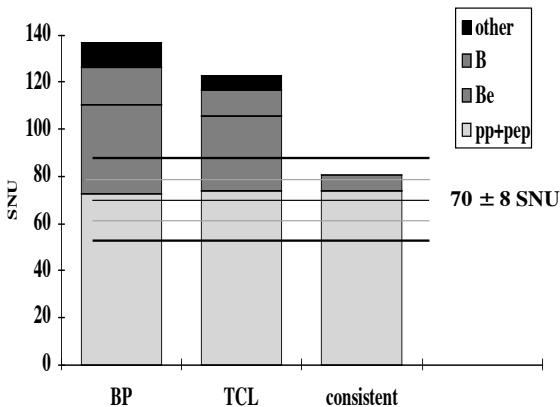


Figure 6. The horizontal lines correspond to the GALLEX results (dotted line : one-sigma, bold line : two-sigma). The two left columns indicate standard solar model expectations for gallium (Bahcall and Pinsonneault (BP) [2] and Turck-Chièze and Lopes (TCL) [3]), with their respective partitioning due to the different solar neutrino branches. The column on the right (“consistent model”) contains only the contribution from the pp + pep neutrino branches and a reduced ${}^8\text{B}$ contribution as measured by Kamiokande.

ν_{Be} and ν_{B} fluxes.

To conclude this subsection, the solar neutrino problem is now quantitatively established, it appears more likely as a ν_{Be} problem, and we know of no satisfactory nuclear physics or astrophysics solution to the observed deficit. An appealing solution could be the neutrino oscillation through the MSW mechanism.

5. INTERPRETATION OF THE DEFICITS IN TERMS OF NEUTRINO OSCILLATION.

The idea that neutrinos could oscillate between their different flavours and explain the deficit observed was first proposed by Gribov and Pontecorvo. The nuclear reactions in the Sun pro-

duce only ν_{e} and the detectors are sensitive only to ν_{e} (with the exception of Kamiokande which is sensitive to ν_{μ} and ν_{τ} , but with a cross section 6-7 times smaller). A transformation of ν_{e} into ν_{μ} or ν_{τ} between the core of the Sun and the detector clearly induces a decrease of the observed ν_{e} flux. It becomes then possible to interpret the reduction factors observed experimentally. To do this, one has to rely on the predictions of solar models, calculate the suppression factor and compare with the suppression factors calculated assuming neutrino oscillations.

In the two neutrino case, the two parameters of neutrino oscillations are Δm^2 , the difference of the squared masses of the neutrinos and $\sin^2 2\theta$, where θ is the mixing angle.

In the case of neutrino oscillations in matter through the so-called MSW effect [14], there is no strong constraint. Because the flavour changing probabilities depend on the neutrino energy and because the various reactions differ sharply in neutrino energies by more than an order of magnitude, the MSW effect has distinguishable effects, depending on the energy weightings, between the different experiments. Taking into account the experimental errors, each experiment defines its own triangular region in the $(\Delta m^2, \sin^2 2\theta)$ plane, since the three targets (chlorine, water and gallium) are not sensitive to the same energy. Their overlap defines the allowed areas within a given confidence level and an illustration is given in figure 7.

In all calculations and for all models (see for example [19] as well as the present figure 7), the small angle solution has a very good χ^2 (less than 1 per d.o.f.) independently of the solar model used and the large angle solution, though not excluded, a poorer χ^2 . For non standard models (see for example [20]), the small angle solution moves towards smaller mixings if the ν_{B} flux is smaller (or if the central temperature is smaller) and towards larger mixings in the opposite case. This last point is illustrated in figure 7 where the TCL model predicts less ν_{B} than the BP model.

The situation of the solar neutrino flux in the case of the small angle solution is illustrated in figure 8 which shows the probability of ν_{e} conversion in the Sun through the MSW effect, superposed

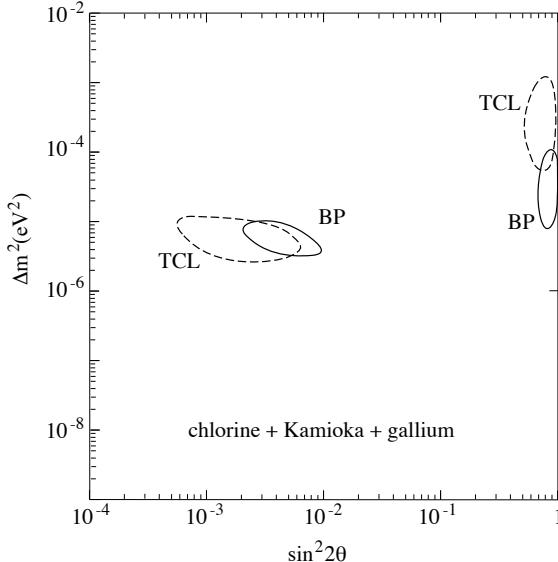


Figure 7. Regions of the parameter plane of neutrino oscillation allowed by the MSW effect for interpreting solar neutrino experiments (90 % C. L.) for the Bahcall and Pinsonneault (BP) and for the Turck-Chièze and Lopes (TCL) models.

to the different solar neutrino fluxes. The ν_{pp} flux is not suppressed at all. Most of the ν_{Be} are suppressed as well as the ν_{pep} and the neutrinos from the CNO cycle (not drawn). The reduction of the ν_B flux is smoothly decreasing from low energy values to higher ones, inducing a modification of the ν_B spectrum. It is clear from this figure that the ν_{Be} can be easily more suppressed than the ν_B , which cannot be done in any standard or non standard solar model.

Though this neutrino oscillation solution is very appealing, we cannot affirm that it is “the” solution. We have to wait for the forthcoming Sudbury, SuperKamiokande and Borexino experiments, which should be able from 1997-1998, if the small angle solution is the good one, to show either a distortion of the ν_B spectrum (Sudbury and/or SuperKamiokande), or an excess of

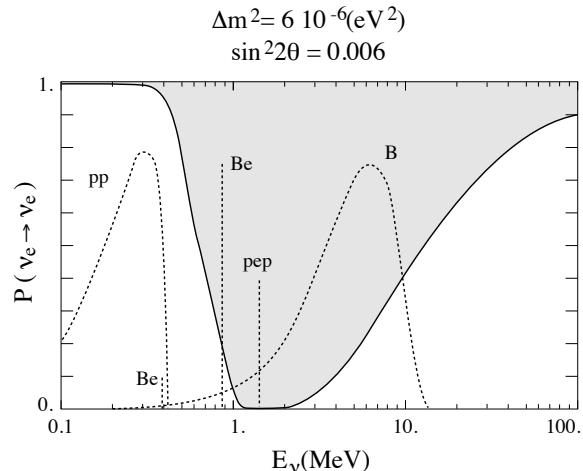


Figure 8. Probability of ν_e conversion in the Sun through the MSW effect for the neutrino oscillation parameters which give the best χ^2 . The grey area defines the ν_e suppression zone. Dotted lines correspond to the main solar neutrino fluxes (arbitrary vertical scales).

neutral current processes (Sudbury is sensitive to ν_μ and ν_τ interactions via this process), or a disappearance of the ν_{Be} (see for example [21]).

6. CONCLUSION

The GALLEX result is presently 70 ± 8 SNU, only about 55 % of the predictions of the standard solar models. The deficit has been validated by the two Cr-source experiments which find a ratio of the production rate of chromium-produced ^{71}Ge to the rate expected from the known source activity equal to 0.92 ± 0.08 .

The result by itself shows that GALLEX has observed a flux of solar neutrinos in sufficient quantity to account for the solar luminosity as reflected in the flux of low-energy pp-neutrinos from the primary hydrogen fusion reaction in the solar core. But we can go further : the present result, with its current 12 % error, puts strict lim-

its on the ${}^7\text{Be}$ flux, and it is very clear that we have already an interesting confrontation with the astrophysical model. An appealing solution to the observed deficit is neutrino oscillation via the MSW mechanism.

As planned at the beginning of the experiment, GALLEX will stop at the end of 1996. A possible future at the Gran Sasso is the monitoring of the solar neutrino flux during a 11-year solar cycle, using a 100-ton gallium target; the project, called GNO for Gallium Neutrino Observatory, is still under discussion.

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REFERENCES

1. GALLEX collaboration : Heidelberg, Karlsruhe, Munich, Milan, Rome, Nice, Saclay, Rehovot, Brookhaven.
2. J. N. Bahcall and M. H. Pinsonneault, Rev. Mod. Phys. 67 (1995) 781.
3. S. Turck-Chièze and I. Lopes, Ap. J. 408 (1993) 347 ; H. Dzitko et al., Ap. J. 447 (1995) 428
4. A. Dar and G. Shaviv, Ap. J. 468 (1996) 933.
5. M. Cribier et al., Nucl. Instr. Meth. A378 (1996) 233.
6. GALLEX Collaboration, P. Anselmann et al., Phys. Lett. B342 (1995) 440.
7. GALLEX Collaboration, P. Anselmann et al., "Update of the major results from the GALLEX Cr-source experiment", GALLEX internal note GX-79 ¹, July 1995.
8. GALLEX Collaboration, W. Hampel et al., "Preliminary results from the second ${}^{51}\text{Cr}$ neutrino source experiment in GALLEX", GALLEX internal note GX-90 ¹, July 1996.
9. E. Henrich and K.H. Ebert, Angew.Chem., Int. Ed. (engl.) 31 (1992) 1283.
10. GALLEX Collaboration, P. Anselmann et al., Phys. Lett. B285 (1992) 376 ; Phys. Lett. B314 (1993) 445 ; Phys. Lett. B327 (1994) 377.
11. GALLEX Collaboration, P. Anselmann et al., Phys. Lett. B357 (1995) 237.
12. GALLEX Collaboration, W. Hampel et al., Phys. Lett. B388 (1996) 384.
13. J. N. Abdurashitov et al., Phys. Lett. B328 (1994) 234 ; V. N. Gavrin, SAGE Collaboration, talk given at $\nu'96$, Helsinki, June 96.
14. S. P. Mikheyev and A. Yu. Smirnov, Nuovo Cimento 9C (1986) 17 ; L. Wolfenstein, Phys. Rev. D17 (1978) 2369.
15. R. Davis, Prog. Part. Nucl. Phys. 32 (1994) 13 ; B. T. Cleveland et al., Nucl. Phys. B (Proc. Suppl.) 38 (1995) 54 ; B. T. Cleveland et al., submitted to Ap. J.
16. Y. Suzuki, Nucl. Phys. B (Proc. Suppl.) 35 (1994) 407 ; Y. Fukuda et al. "Solar neutrino data covering Solar Cycle 22", to be published in Phys. Rev. Lett.
17. See for example J. N. Bahcall, Phys. Lett. B338 (1994) 276 ; W. Kwong and S. P. Rosen, Phys. Rev. Lett. 73 (1994) 369.
18. See for example V. Berezhinsky, G. Fiorentini and M. Lissia, Phys. Lett. B365 (1996) 185.
19. J. N. Bahcall and P.I. Krastev, Phys. Rev. D53 (1996) 4211 ; G. L. Fogli, E. Lisi and D. Montanino, Phys. Rev. D54 (1996) 2048 ; A. J. Baltz and J. Wenner, Phys. Rev. D50 (1994) 5971
20. V. Berezhinsky, G. Fiorentini and M. Lissia, Phys. Lett. B341 (1994) 38 ; P.I. Krastev and A. Yu. Smirnov, Phys. Lett. B338 (1994) 282
21. G. Fiorentini, M. Lissia, G. Mezzorani, M. Moretti and D. Vignaud, Phys. Rev. D49 (1994) 6298

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