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SAGE: status and future

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Abstract. Present status, current results, and plans of SAGE for immediate future are discussed.

1. Introduction
The gallium experiments gave a great impact upon a view of neutrino oscillation and have supplied most important motivation for creation of SNO experiment whose result led us to solution of the solar neutrino problem. SAGE is currently the only operating solar neutrino experiment which provides the determination of the fundamental *pp* neutrino flux [1] and a continuous monitoring of the low energy solar neutrino flux with increasing sensitivity over very long time period.

2. Gallium results
SAGE is running with about 50 tons of metal gallium at Baksan Neutrino Observatory INR RAS [2] since January 1990. The global best fit capture rate for all SAGE data from January 1990 through December 2006 (157 runs and 288 separate counting sets) is $66.2^{+4.8}_{-4.5}$ SNU, where the statistical and systematic uncertainties are combined in quadrature.

The final result from 123 runs in the Gallex/GNO experiment is 69.3±5.5 (stat + syst) SNU [3]. The weighted combination of both Ga experiments, SAGE and Gallex/GNO, is thus

67.6±3.7 SNU. Present Ga experiment result.

The good agreement between results of the Ga experiments has led to increased confidence in the measured event rates. It was very good that for many years there were two Ga experiments operating at the same time and it is indeed unfortunate that the GNO experiment was terminated for non-scientific reasons.

3. Source experiments
The experimental procedures of both Ga experiments have been checked by exposing the gallium target to reactor-produced neutrino sources whose activity was close to ~ 1 MCi. Gallex has twice used ^{51}Cr sources [4]; SAGE has irradiated their target with a ^{51}Cr source and a ^{37}Ar source [5, 6]. The published results, expressed as the ratio R of the measured ^{71}Ge production rate to that expected due to the source strength, are shown in Figure 1. The weighted average value of the ratio for the four experiments is R = 0.88±0.05, more than two standard deviations less than unity.

The most likely explanation is that the cross sections for neutrino capture to the lowest two excited states in ^{71}Ge, both of which can be reached using either ^{51}Cr or ^{37}Ar sources, have been overestimated [7]. If the contribution of these two excited states to the predicted rate is set to zero, then R=0.93±0.05, reasonably consistent with unity. Recent reanalyzing of the data of Gallex two source experiments yields for the ratio R = 0.90±0.09 [8]. Since other auxiliary tests, especially the ^{71}As experiment of Gallex, have given great confidence in the knowledge of the various efficiencies in the Ga experiments, it lead us to conclusion that the source experiments on Ga have measured the contribution of the first two excited states to the ^{71}Ga capture cross section and found this contribution to be rather small. A new experiment with considerably higher rate from the neutrino source is discussed now in SAGE to settle this question.

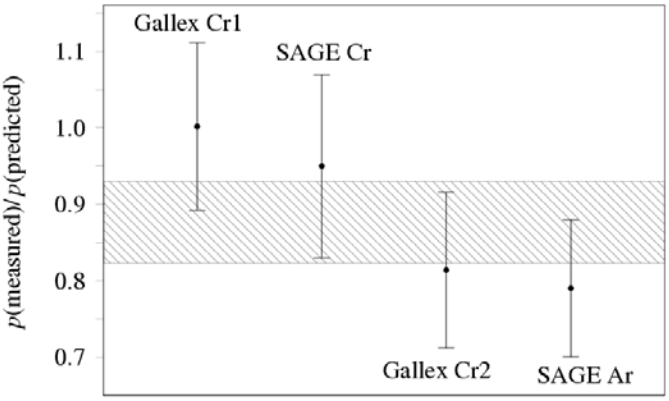

Figure 1. Results of all neutrino source experiments with Ga. The hashed region is the weighted average of the four experiments. See [6] for details.

4. Comparison of Ga result to theory

4.1. The solar neutrino capture rate in ^{71}Ga
For comparison to theory, the fluxes at the Sun from two standard solar models with differing composition [9] have been calculated taking into account neutrino propagation from the Sun to the Earth and the results of the neutrino source experiments with gallium [10]. There is an excellent agreement between the calculated ($67.3^{+3.9}_{-3.5}$ SNU) and observed (67.6±3.7 SNU) capture rate on ^{71}Ga.

4.2. The pp neutrino flux
Using the combined capture rate from the SAGE and Gallex/GNO experiments given above (67.6±3.7 SNU) and the data from Cl, SNO, and SK experiments an electron neutrino *pp* flux of $(3.41^{+0.76}_{-0.77})\times10^{10}/(\mathrm{cm}^2\ \mathrm{s})$ has been calculated. For comparison, the standard solar model calculates the *pp* flux produced in the Sun to be $(5.94\pm0.01)\times10^{10}/(\mathrm{cm}^2\ \mathrm{s})$ [9]. If we multiply this rate by the average survival probability for *pp* neutrinos, which from [10] is 0.555 ($1^{+0.038}_{-0.040}$), we obtain a *pp* flux at the Earth of $(3.30^{+0.13}_{-0.14})\times10^{10}/(\mathrm{cm}^2\ \mathrm{s})$, in excellent agreement with the value determined above from solar neutrino experiments.

5. Is the neutrino capture rate in Ga constant?
The possibility of variability over longer time periods has been considered by several authors [11,12,13,14]. In a plot of the data there appears to be a difference between early and late time periods, which gives a visual hint of a long-term decrease, as illustrated in Figure 2. The Gallex-GNO data are shown on the left and SAGE data on the right of Figure 2. The average rate prior to 1997 is higher in both experiments than in the data after 1997.

If one assumes the rate in Gallex-GNO varies linearly in time then the best fit gives [3] capture rate = 82±10 – (1.7±1.1) × [t(year) – 1990]. These trend lines are plotted for both experiments in Figure 2 and there is reasonably good visual agreement with the measured data.

When examined quantitatively, however, the evidence for long-term variability becomes less convincing. A χ^2 test applied to the Gallex-GNO data with (without) the assumed time variation yields χ^2/dof = 10.8/5 (13.2/6), prob. = 5.6% (4.0%), i.e., the fit to both the time-varying rate and to a constant rate is more or less equally bad. For the SAGE data the fit to a constant rate gives

χ^2/dof = 11.7/16, prob. = 76%, whereas the fit to the central Gallex-GNO trend line yields χ^2/dof = 11.4/17, prob. = 83%, i.e. the fit to both rate hypotheses is quite good.

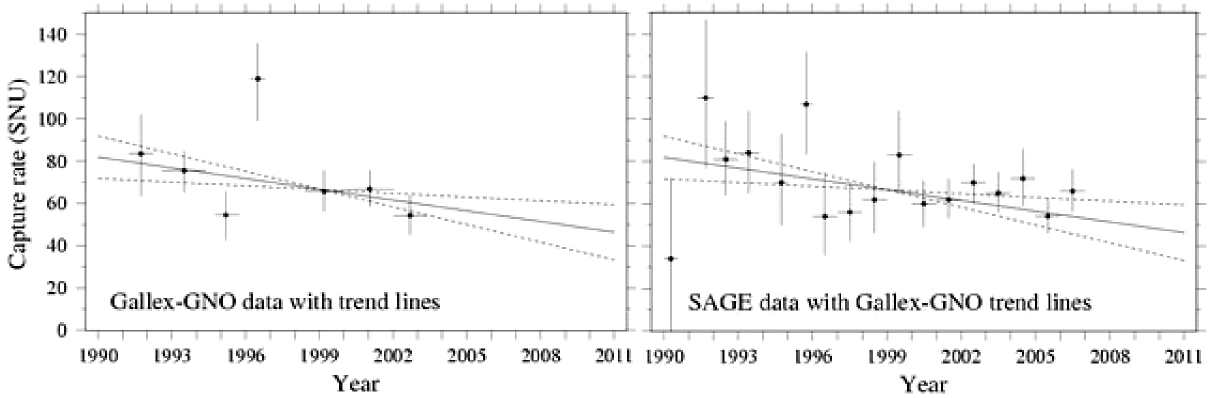

Figure 2. Gallex-GNO results (left panel) and SAGE results (right panel) vs time.

Up to now it is not known if this apparent variability is a statistical fluctuation or an indication of a real effect, such as has been considered by Pulido *et al*. [15]. At the present time we cannot differentiate between these two hypotheses, but it should become possible to do so with considerable additional data.

SAGE plans to continue running for at least nearest three years. We also consider a possibility of creation of a ^{51}Cr neutrino source with activity ~ 2 MCi to measure capture rate of neutrinos from this source on ^{71}Ga with accuracy ~ 4%.

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