THE RUSSIAN-AMERICAN GALLIUM SOLAR NEUTRINO EXPERIMENT

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The Russian-American Gallium solar neutrino Experiment (SAGE) is described. The solar neutrino flux measured by 31 extractions through October, 1993 is presented. The result of $69\pm10^{+5}_{-7}$ SNU is to be compared with a standard solar model prediction of 132 SNU. The status of a ^{51}Cr neutrino source irradiation to test the overall operation of the experiment is also presented.

Introduction

The solar neutrino problem (SNP) has persisted for nearly 30 years. However its character has changed significantly. Originally the problem was defined by a discrepancy between an absolute capture rate measurement and an absolute capture rate calculation; i.e. the Cl experiment result of 2.55 ± 0.25 SNU[1] differed from the standard solar model (SSM) calculations of 8.0 ± 1.0 SNU[2] and 6.4 ± 1.4 SNU[3] (where 1 SNU = 10^{-36} interactions/atom/sec). A large number of astrophysical and particle physics solutions were proposed to resolve this discrepancy[4]. Recently, however, results from the Kamiokande[5], SAGE[6], and GALLEX[7] collaborations have significantly influenced the interpretation of the SNP solution.

Thus, at the present time we have four experiments, three of which have different energy thresholds, and therefore each experiment has different sensitivity to the various components of the solar neutrino flux. The Kamiokande experiment is predominantly sensitive to the high-energy ^{8}B neutrinos. The Cl experiment also detects ^{8}B but in addition ^{7}Be neutrinos. Finally, the gallium experiments are sensitive to all three major solar neutrino components: ^{8}B, ^{7}Be, and the low energy pp neutrinos. As a consequence, the problem can be analyzed in a nearly model-independent way that requires minimal input from the SSM. Using only neutrino spectral shapes and neutrino-target cross sections as input assumptions, the experimental signals can be expressed as linear combinations of the three neutrino type fluxes with only small corrections for the minor neutrino components. Solving these expressions for the fluxes, results in a very small ^{7}Be neutrino flux although the ^{8}B neutrino flux is appreciable. Since the stellar formation of ^{8}B requires the presence of ^{7}Be, this result is a contradiction which forms the basis for a more modern statement of the SNP. It is a contradiction which is difficult to resolve without invoking non-standard-model particle physics as discussed by several authors[8,9,10,11,12]. This manuscript describes the status of the Russian-American Gallium Experiment.

SAGE Operation

SAGE is a radiochemical experiment based on the inverse beta decay reaction on ^{71}Ga. The low energy threshold of this reaction (233 keV) provides sensitivity to pp neutrinos. The laboratory is in a deep underground cavity (4800 m.w.e.) at the Baksan Neutrino Observatory in the Caucusus Mountains in southern Russia. Data acquisition began in 1989 with backgrounds reduced sufficiently to provide sensitivity to solar neutrinos by early 1990. A second phase of the experiment (SAGE II) began in September 1992 after a number of improvements.

The experiment presently uses 55 tons of gallium contained in 8 chemical reactors. At the beginning of an exposure to solar neutrinos, approximately 700 µgm of natural Ge in the form of a Ge-Ga alloy is added to the Ga in roughly equal parts to each reactor. At the end of the exposure, typically 30 days, the Ge carrier and any ^{71}Ge produced by solar neutrinos are chemically extracted. From the extractant, the gas germane (GeH_4) is synthesized, mixed with Xe in a 20%:80% ratio, and used to fill a 0.75-cm^3 cylindrical proportional counter. The extraction and synthesis chemistry have been described previously[6)].

^{71}Ge decays via electron capture and is detected in the proportional counter by the Auger electrons or X rays produced during the electron shell relaxation. Not only do the ^{71}Ge events possess a characteristic energy (10.4-keV K peak, 1.2-keV L peak) but their pointlike ionization produces a fast risetime in contrast to the extended ionization of common background processes. Thus the energy and risetime of each event is measured providing a strong signal/background ratio improvement. The ^{71}Ge candidate events, selected by risetime and energy, are then analyzed using a maximum likelihood procedure[13)] assuming an exponential decay superimposed on a constant-rate background.

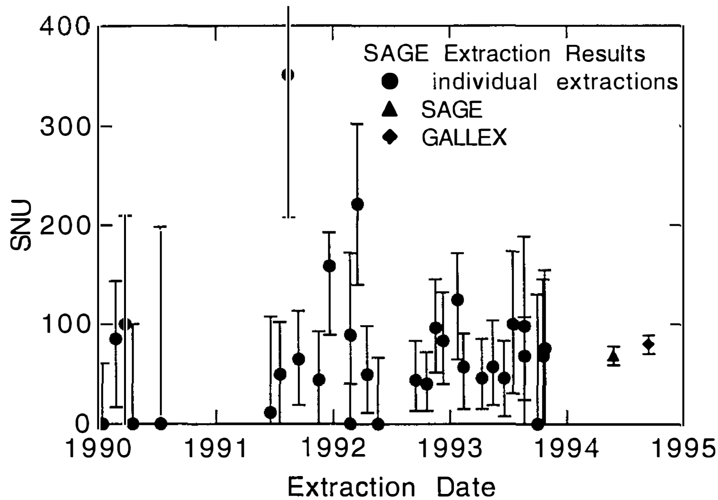

Figure 1: The individual extraction results. Also shown are the combined fits of the SAGE and GALLEX data[7)].

The Data

Data taken up to May 1992 is referred to as SAGE I and is discussed in detail in Ref. [6)]. SAGE II began in September 1992 and data analyzed similarly to SAGE I including extractions through October 1993 are presented in Table 1. Improvements in the electronic noise and ambient radioactivity significantly reduced the background and hence the K-peak-candidate count rate in SAGE II (0.036 cpd) is much lower than SAGE I (0.103 cpd). Results from 31 extractions from SAGE I and II are shown graphically in Fig. 1. A combined fit to all data, requiring that the signal be the same for each extraction but allowing the background to be different, yields a result of $69 \pm 10^{+5}_{-7}$ SNU. (Here the former uncertainty is due to statistics and the latter is due to systematic effects.) This result is derived holding the ^{71}Ge half-life constant. If this parameter is allowed to float, the best fit gives 12 ± 3 days in good agreement with the known half-life of 11.43 days. Fig. 2a shows the energy distribution of the fast events for SAGE II for times early in counting when ^{71}Ge should be present. Fig. 2b displays a similar spectrum but for events occuring at long times when the ^{71}Ge has all decayed away. The K and L peaks are clear in Fig. 2a and are missing in Fig. 2b just as one expects.

We have considered a number of systematic uncertainties to this result which were summarized for the SAGE I data in Ref. [6]. We take those values as the preliminary estimates of the corresponding values for SAGE II.

Table 1: The summary of the individual run results. The exposure date is the Ge-71 half-life weighted average of the exposure period (See Ref. [4] pg 316).

exposure date	mass Ga	best fit SNU	68% CL SNU
1992.696	55.600 t	43	12-83
1992.786	55.482 t	39	12-71
1992.868	55.377 t	96	50-145
1992.942	55.263 t	83	40-132
1993.067	55.136 t	125	65-172
1993.112	55.026 t	56	14-80
1993.277	48.220 t	46	15-85
1993.363	48.171 t	57	19-104
1993.454	54.656 t	45	8-83
1993.536	40.441 t	101	30-174
1993.630	40.358 t	69	25-109
1993.628	14.090 t	99	0-190
1993.746	14.055 t	0	0-130
1993.797	14.100 t	69	0-147
1993.809	14.021 t	76	0-155

The ^{51}Cr Experiment

During the winter of 1994-1995, a number of extractions were done on a sample of Ga which contained a neutrino source at its center. To make the source, 513 gms of Cr metal enriched to 92% in ^{50}Cr, were irradiated in the fall of 1994 at the fast breeder reactor BN-350 in Kazakhstan. The activated Cr was then contained within a tungsten cylinder and installed in a chemical reactor containing 13 tons of Ga. Normally, the reactors used for storing the Ga during solar neutrinos exposures have a large stirring mechanism used during the extractions. The reactor used for the ^{51}Cr runs had its stirring mechanism removed to permit room for additional Ga. At the end of each exposure, the Ga was transferred from this special reactor to two normal reactors which contained stirring mechanisms where the extraction chemistry could be performed. Prior to the ^{51}Cr experiment, several solar neutrino runs were made with gallium in this special reactor and no difficulties were observed.

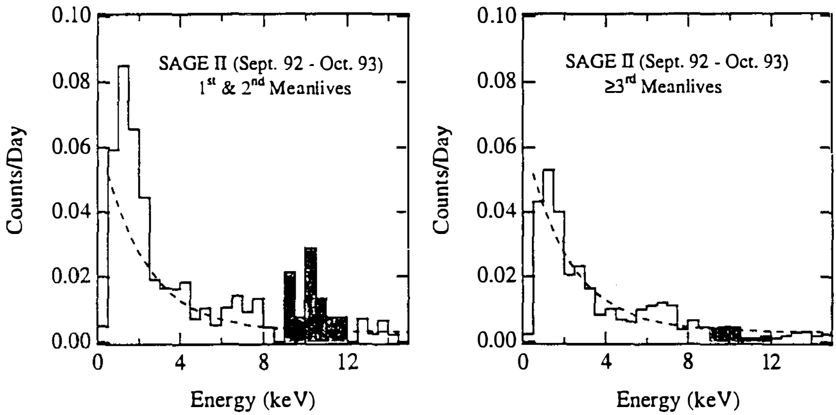

Figure 2: The energy spectrum of the SAGE II data. The left (right) figure shows the spectrum at early (late) times. The shaded areas indicate the K-peak region.

On December 26, 1994, the source was initially placed in the Ga test reactor. Preliminary estimates of the activity from calorimetry indicate a source strength of 510 kCi at that time. At this strength, the expected production rate in 13 tons of metallic Ga is 15 ^{71}Ge atoms per day compared to the 0.3 ^{71}Ge atoms/day produced by solar neutrinos. The first 5 exposures had durations chosen to produce roughly equal signal rates (~15 counts in the K peak) and an additional 3 extractions with 1 month exposures were also done. The counting of the samples from these extractions will continue throughout the summer of 1995.

Summary

The results of the first 31 extractions from the SAGE experiment yields a result of $69 \pm 10^{+5}_{-7}$ SNU. This includes analysis of the ^{71}Ge K-peak-only data from SAGE I and SAGE II through October 1993. The solar neutrino data from SAGE II extends until January 1995 and a waveform analysis of the proportional counter signals from this data should provide sensitivity to the L peak. The ^{51}Cr experiment extractions are completed and will check the experimental operation.

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References

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1) B. T. Cleveland *et al.*, Nucl. Phys. (proceed. supl.) **B38**, 47 (1995).
2) J. N. Bahcall and M. H. Pinsonneault, Rev. Mod. Phys. **64**, 885 (1992).
3) S. Trck-Chieze and I. Lopes, Astrophys. J. **408**, 347 (1993).
4) J. N. Bahcall Neutrino Astrophysics (Cambridge U.P., Cambridge, 1989).
5) Y. Suzuki, Nucl. Phys. (proceed. supl.) **B38**, 54 (1995).
6) J. N. Abdurashitov *et al.*, Phys. Lett. **B328**, 234 (1994).
7) P. Anselmann *et al.*, Phys. Lett. **B327**, 377 (1994).
8) J. N. Bahcall, Phys. Lett. **B338**, 276 (1994).
9) V. Berezinsky, Comm. Nucl. Part. Phys. **21**, 249 (1994).
10) S. Parke, Phys. Rev. Lett. **74**, 839 (1995).
11) N. Hata, S. Bludman, and P. Langacker, Phys. Rev. **D49**, 3622 (1994).
12) V. Castellani et al., Phys. Rev. **D50**, 4749 (1994).
13) B. T. Cleveland, Nucl. Instrum. Methods **214**, 451 (1983).