Gavrin - 01

Russian-American Gallium Experiment (SAGE) at the Baksan Neutrino Observatory INR RAS

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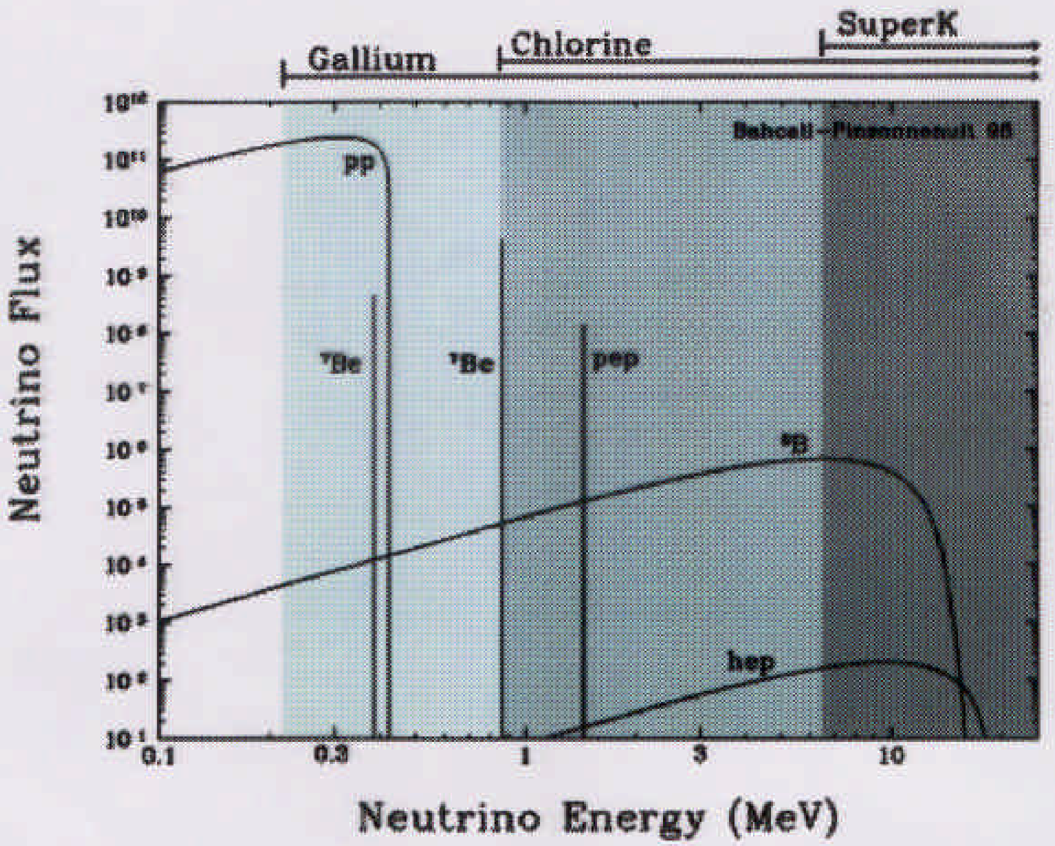
A Gallium Solar Neutrino Experiment

- Kuzmin 1965: $^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$ Q = 0.233 MeV

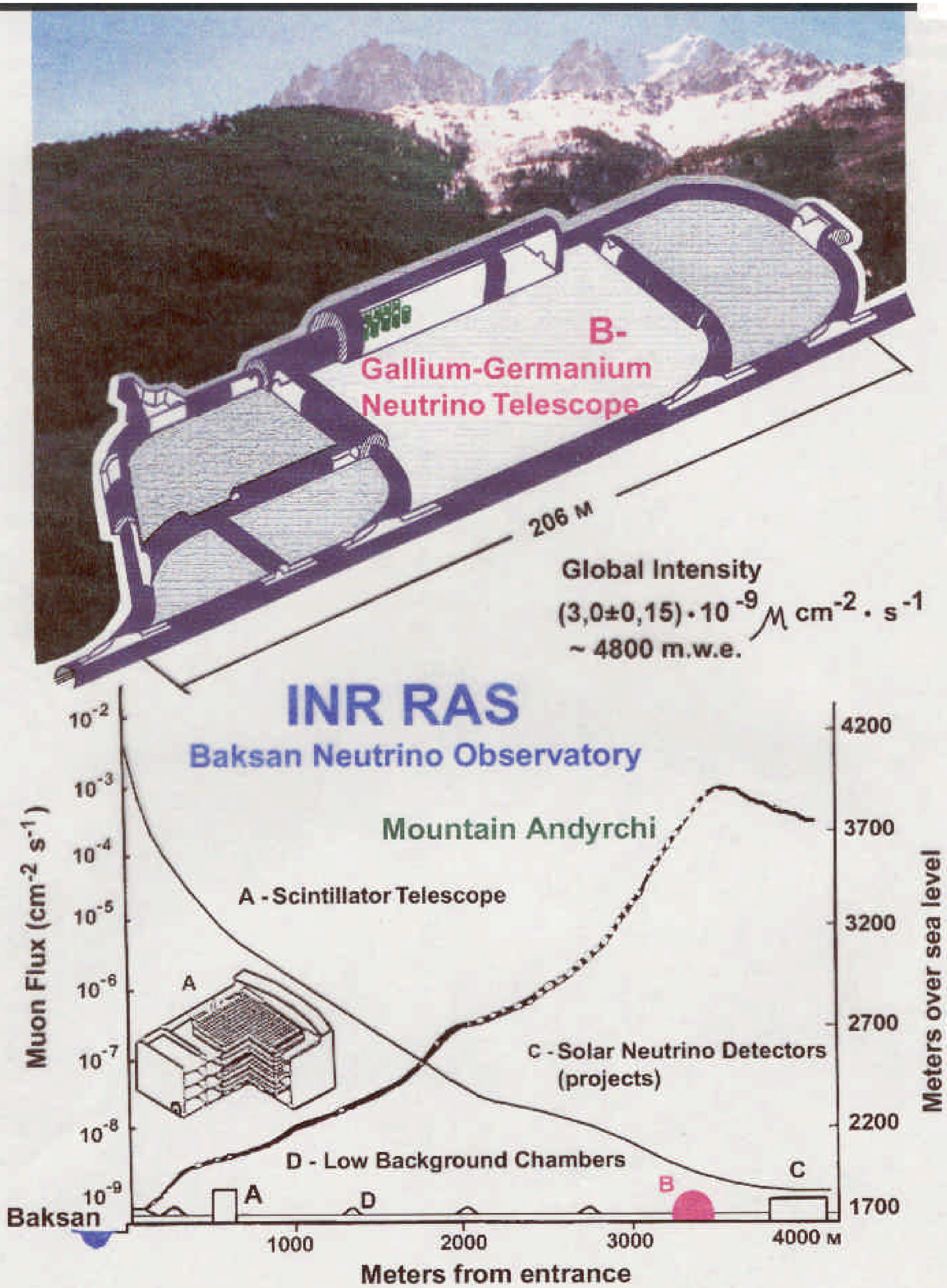


- Sensitive to dominant p-p neutrinos, which contribute 70 SNU (<=> 54%) of the rate

- The p-p flux is determined model independently at the few percent level from the measured solar luminosity. If one assumes only that the sun is in thermal equilibrium, then the minimum rate in a gallium experiment is 79 SNU.

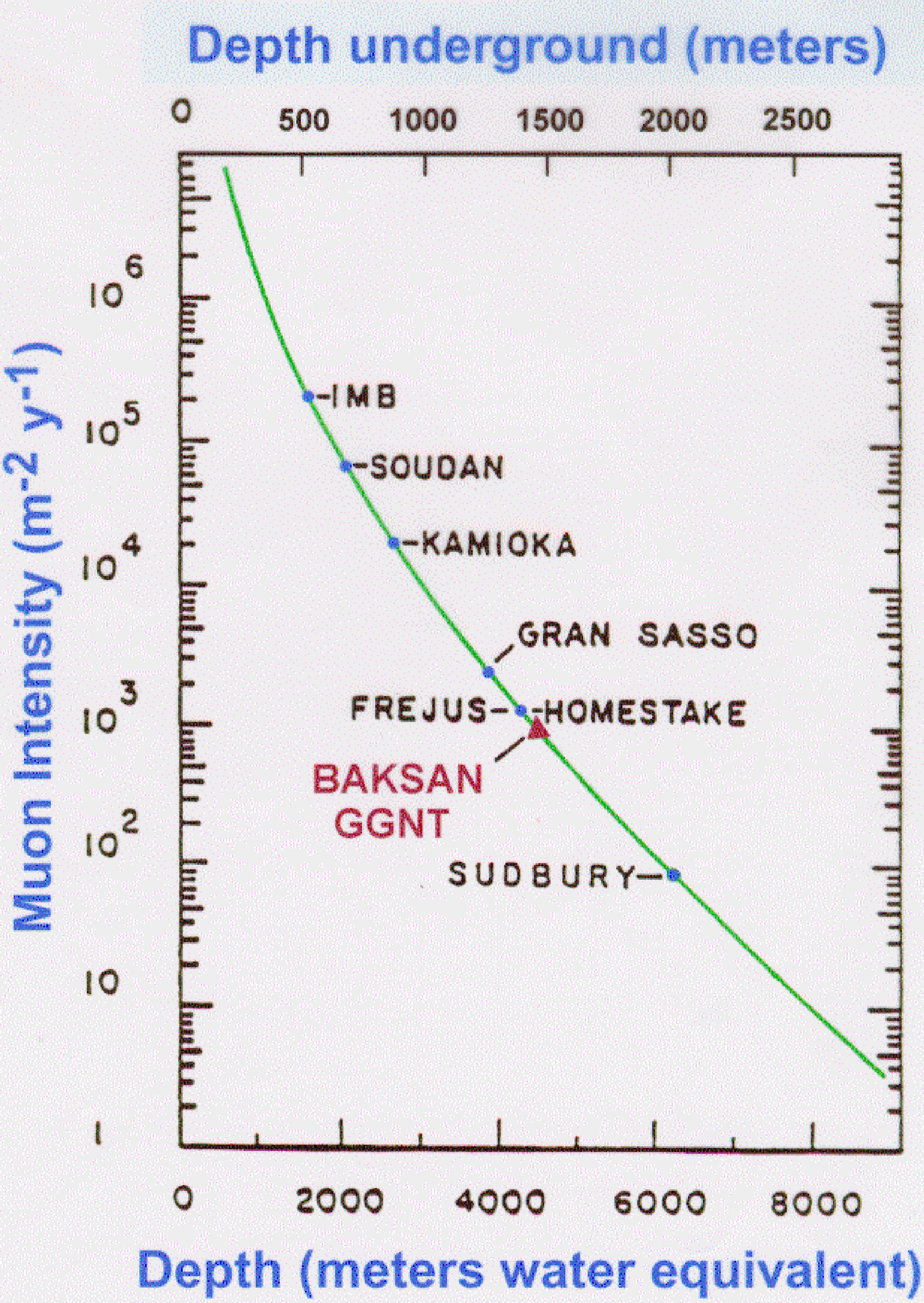
1 SNU = 1 interaction/s in a target that contains 10^{36} atoms of the neutrino absorbing isotope

Gavrin - 03

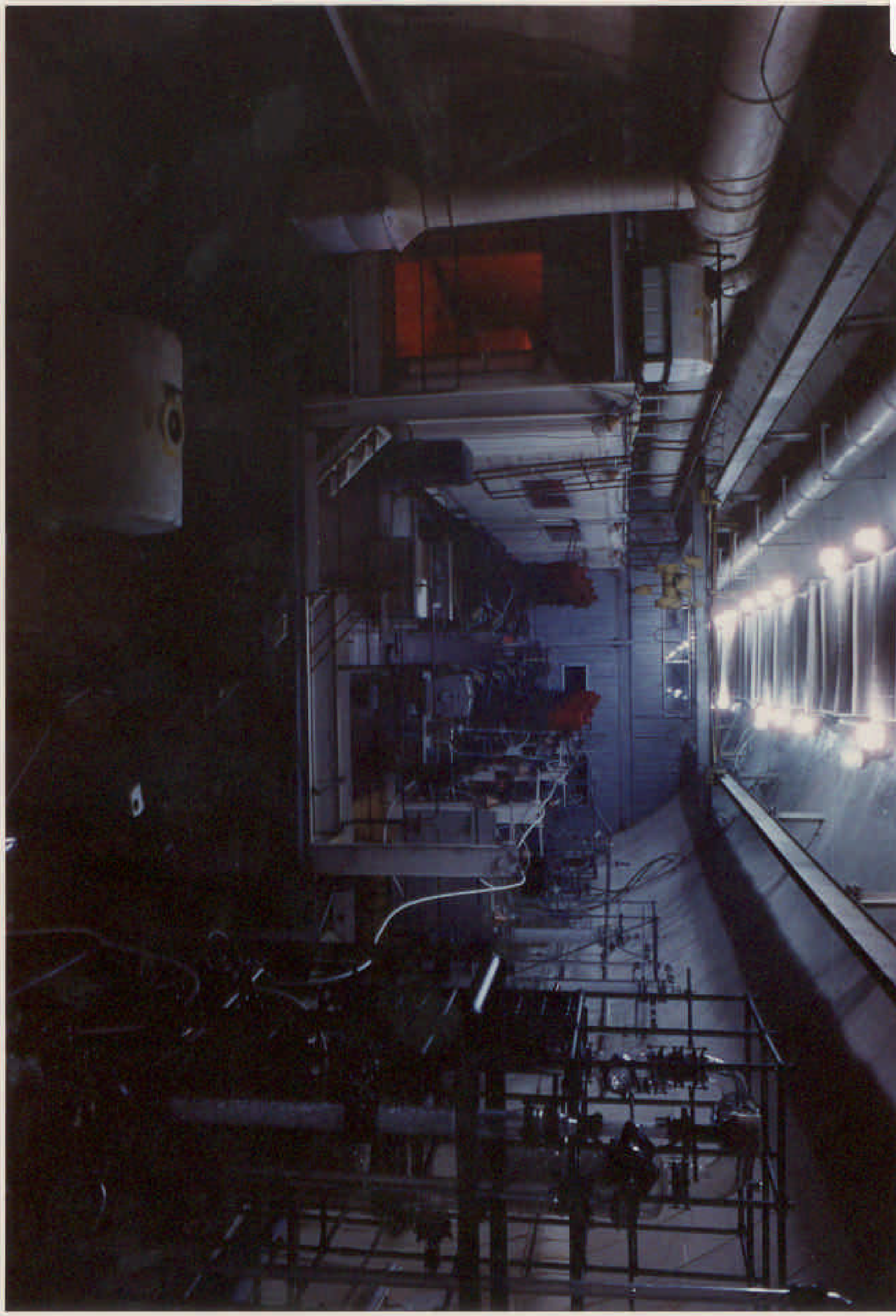


B-
Gallium-Germanium
Neutrino Telescope
206 M
Global Intensity
(3,0±0,15)·10 -9 μ cm -2 · s -1
~ 4800 m.w.e.
INR RAS
Baksan Neutrino Observatory
Mountain Andyrchi
A - Scintillator Telescope
A
C - Solar Neutrino Detectors
(projects)
D - Low Background Chambers
B
C
A
D
Baksan
Muon Flux (cm-2 s-1)
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
4200
3700
3200
2700
2200
1700
Meters over sea level
1000
2000
3000
4000 M
Meters from entrance

Gavrin - 05


Depth underground (meters)
0
500
1000
1500
2000
2500
Muon Intensity (m-2 y-1)
10^6
10^5
10^4
10^3
10^2
10
1
IMB
SOUDAN
KAMIOKA
GRAN SASSO
FREJUS
HOMESTAKE
BAKSAN
GGNT
SUDBURY
0
2000
4000
6000
8000
Depth (meters water equivalent)

Gavrin - 06



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Gallium-germanium neutrino experiment SAGE

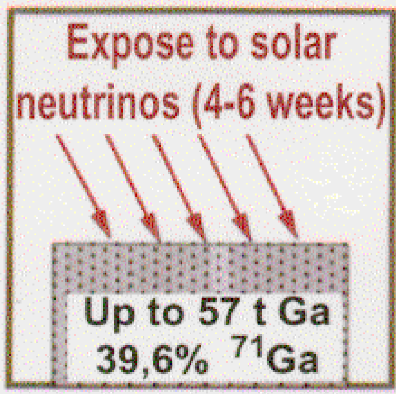
$$^{71}\mathrm{Ga} + \nu \rightarrow {}^{71}\mathrm{Ge} + e^{-}$$

(Vadim Kouzmine, 1965)

Reaction threshold

233 keV

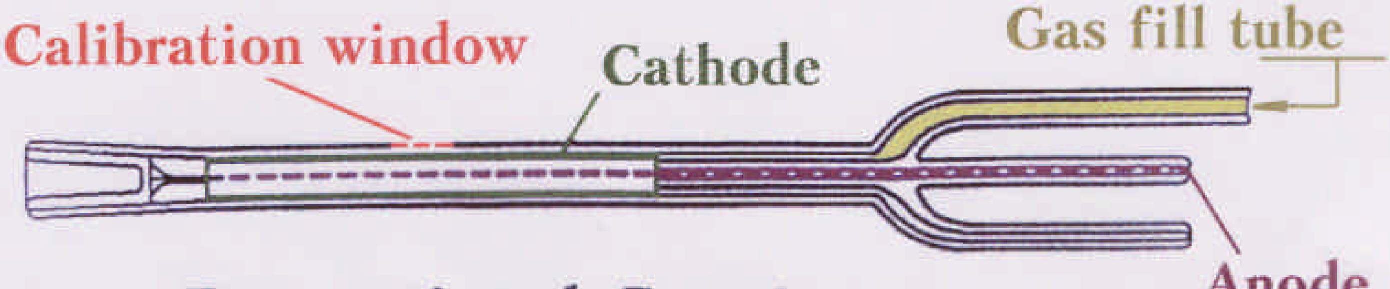
$T_{1/2} = 11.43$ d



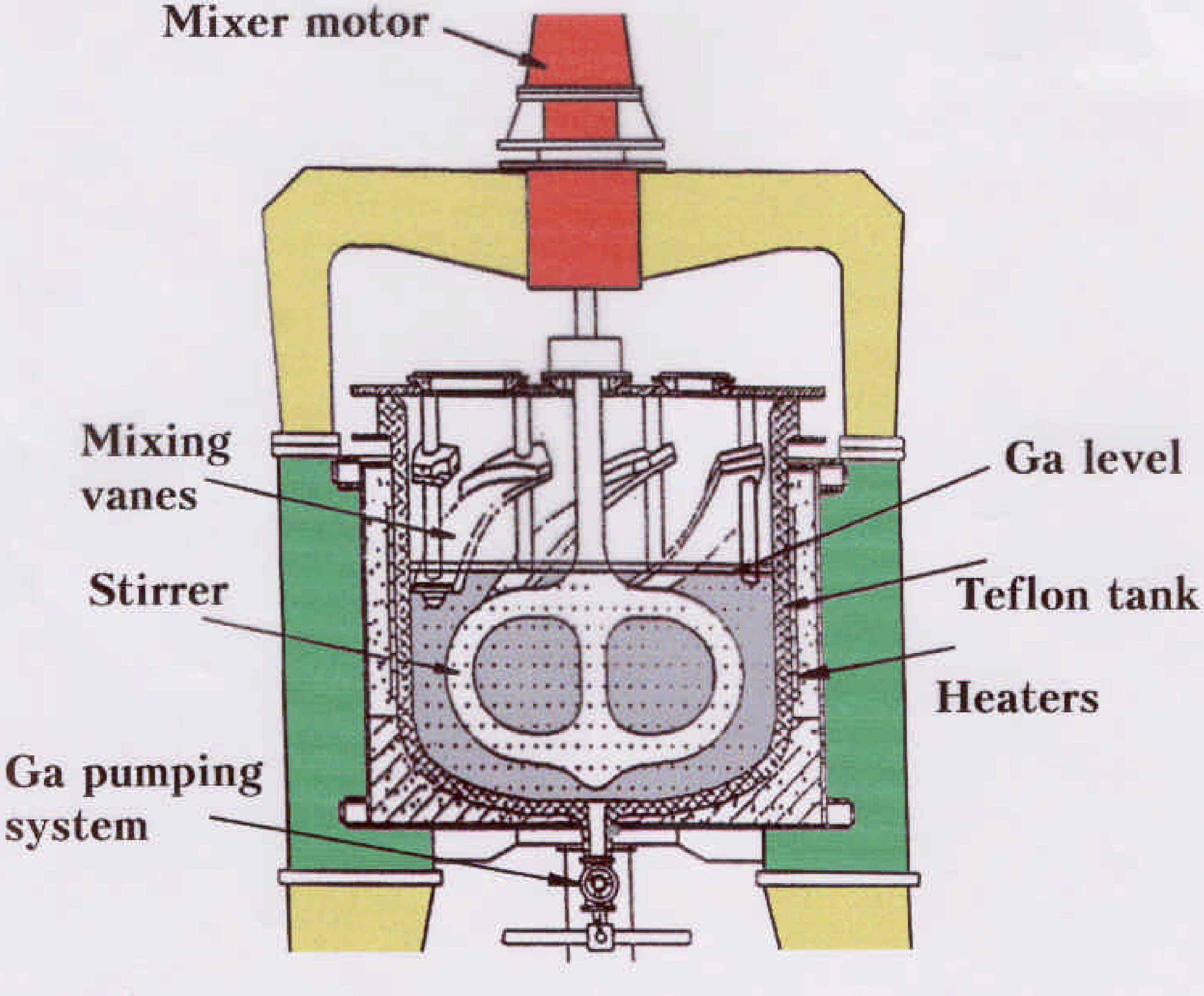
Chemical extraction (1,5 day)

^{71}Ge counting (5 months)

Sensitivity: One ^{71}Ge atom from $5 \cdot 10^{29}$ atoms Ga with efficiency ~90%



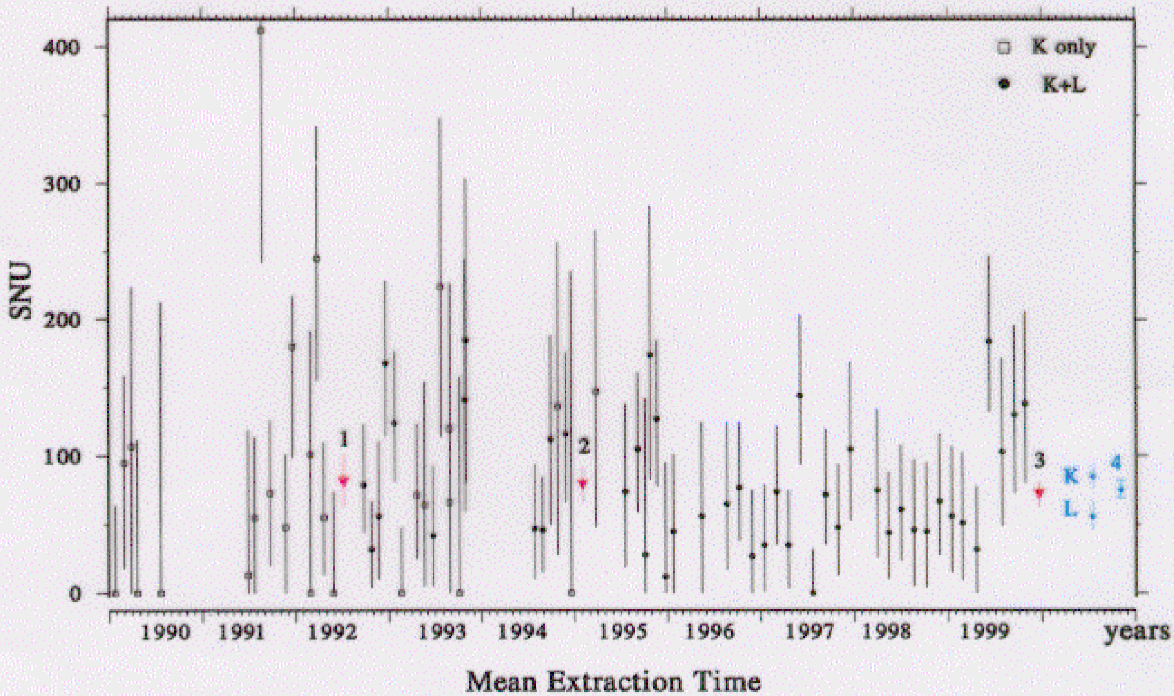
Proportional Counter



Chemical reactor

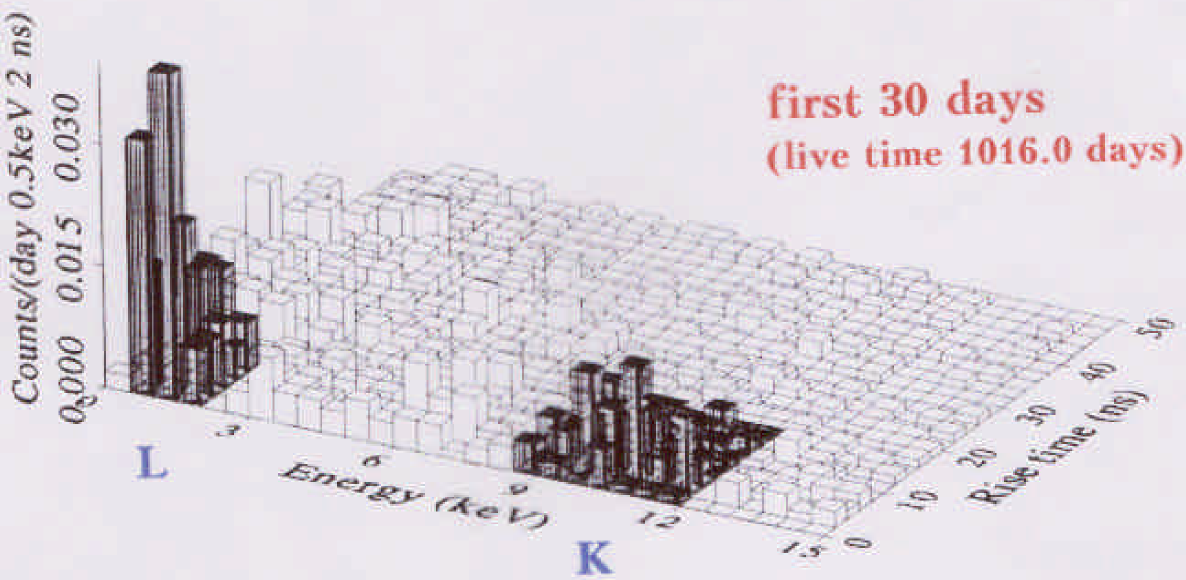
Gavrin - 09

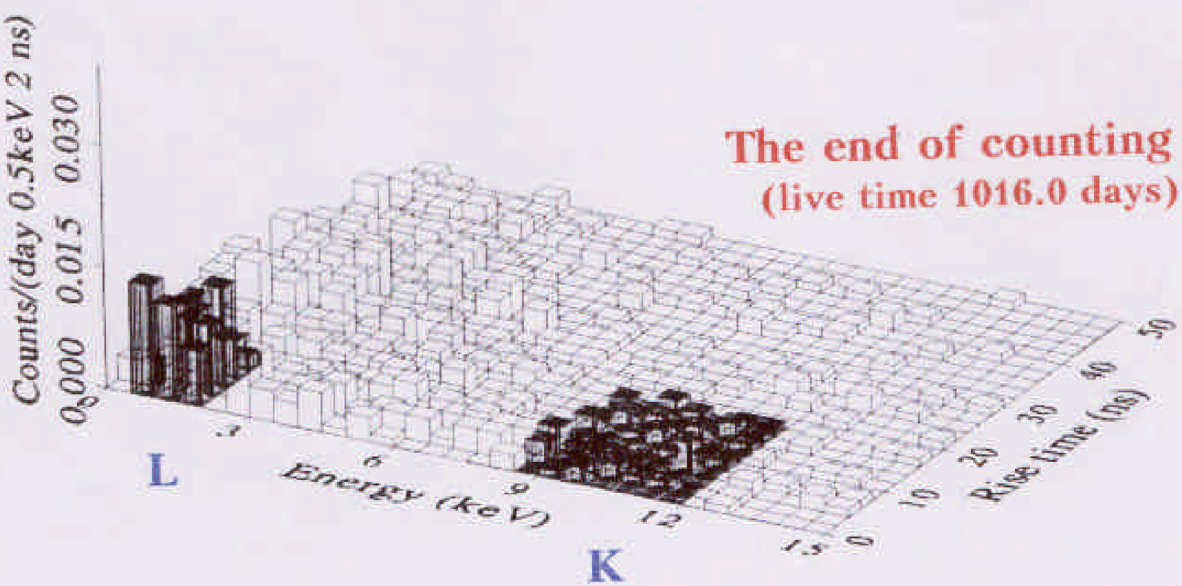
SAGE Results (1990-1999)



1. SAGE I (01.1990 - 05.1992) 81^{+20}_{-18} SNU
2. SAGE II (09.1992 - 12.1994) 79^{+13}_{-13} SNU
3. SAGE III (03.1995 - 10.1999) 72^{+9}_{-9} SNU
4. SAGE 75^{+7}_{-6} SNU
5. SSM (Bahcall and Pinsonneault) 129^{+8}_{-6} SNU
6. Astr. Min. (Bahcall) 79^{+2}_{-2} SNU

Energy rise time histogram





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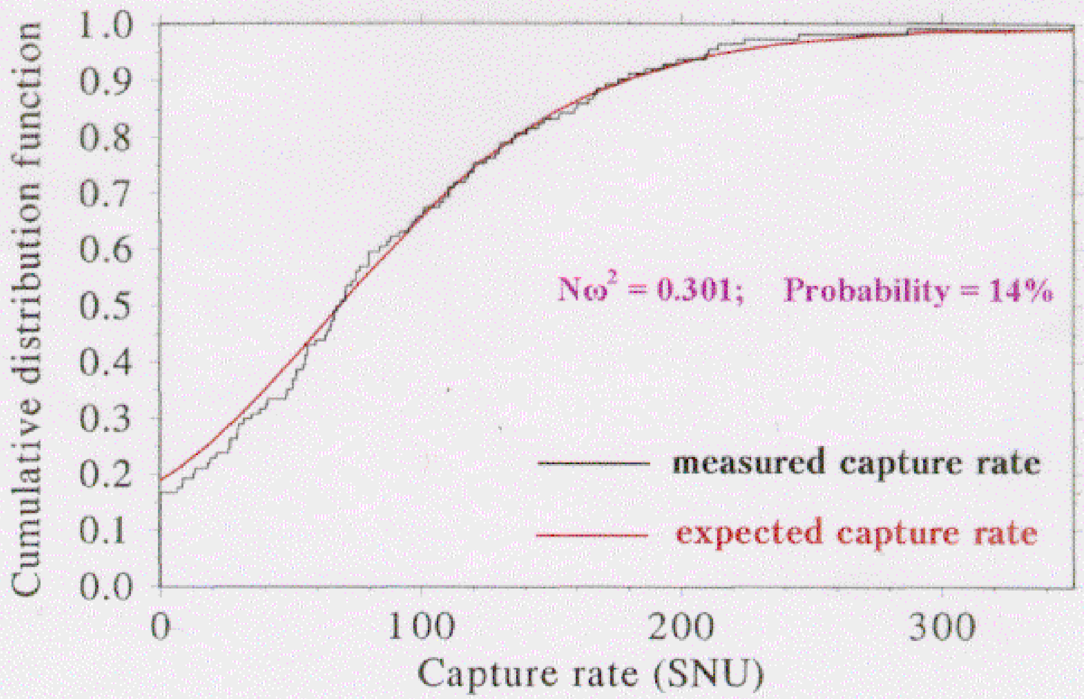
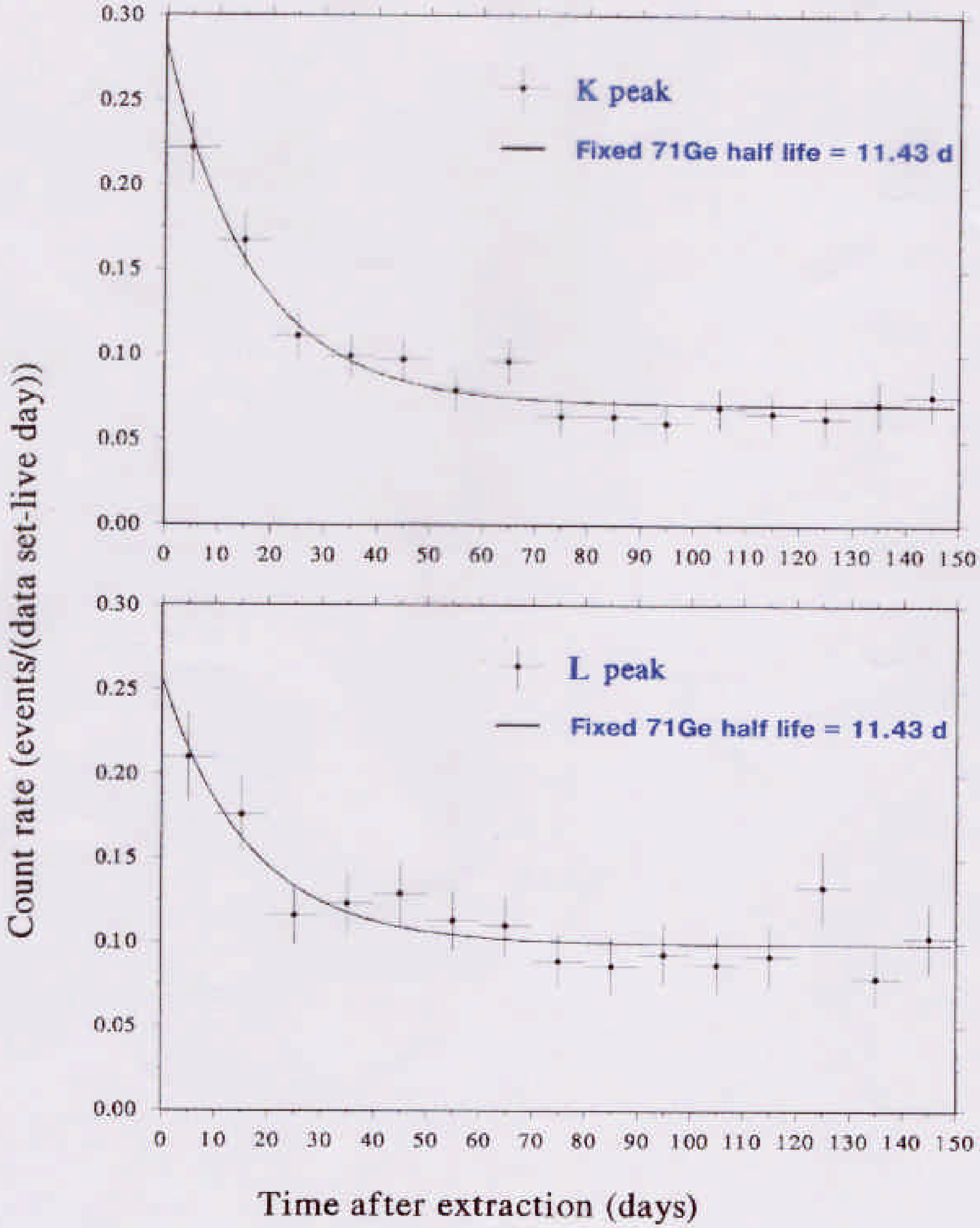
SAGE I+II+III

distribution for all data sets and the expected distribution from simulation



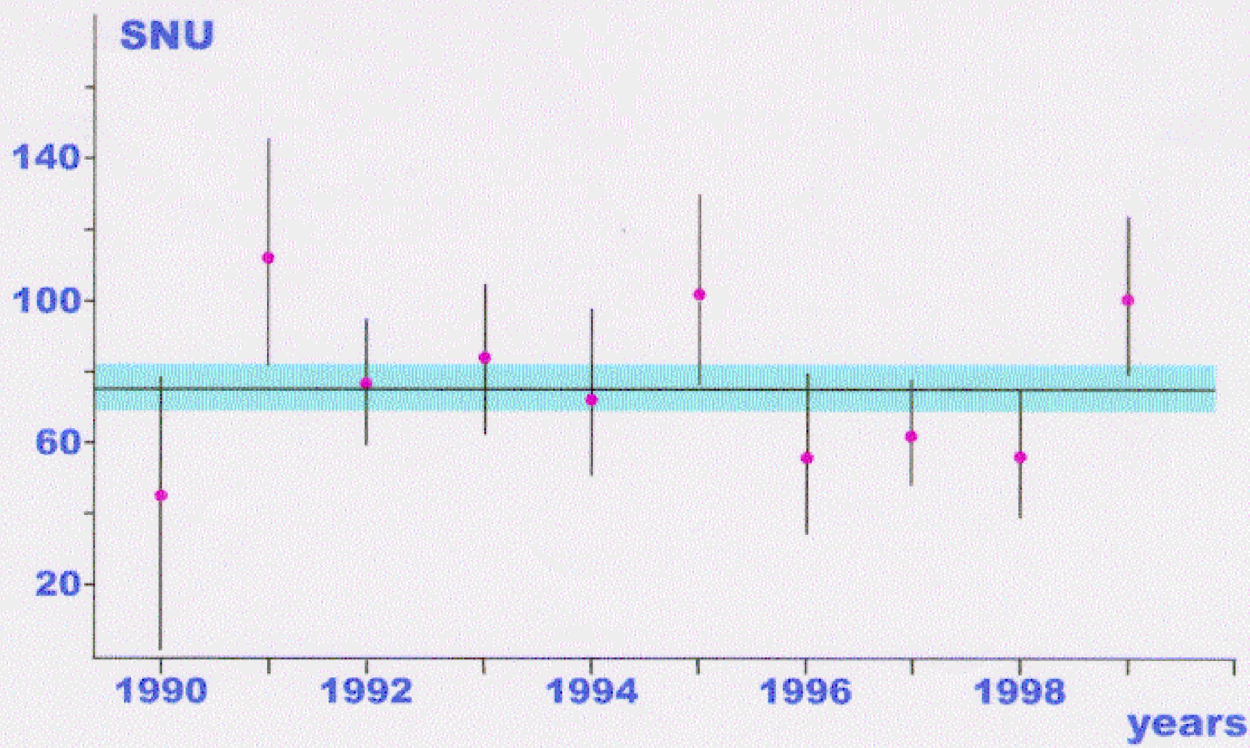
SAGE I + II + III
Half Life Evidence for ^{71}Ge

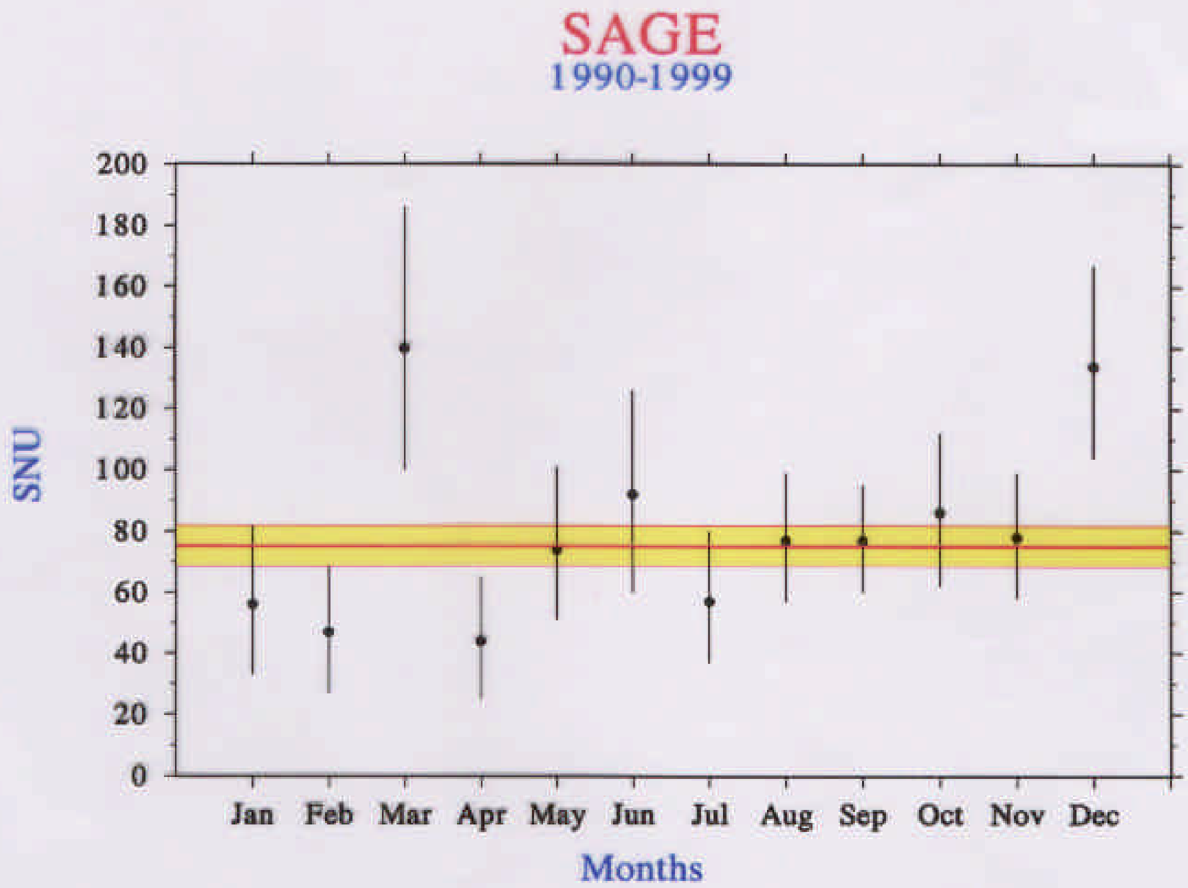


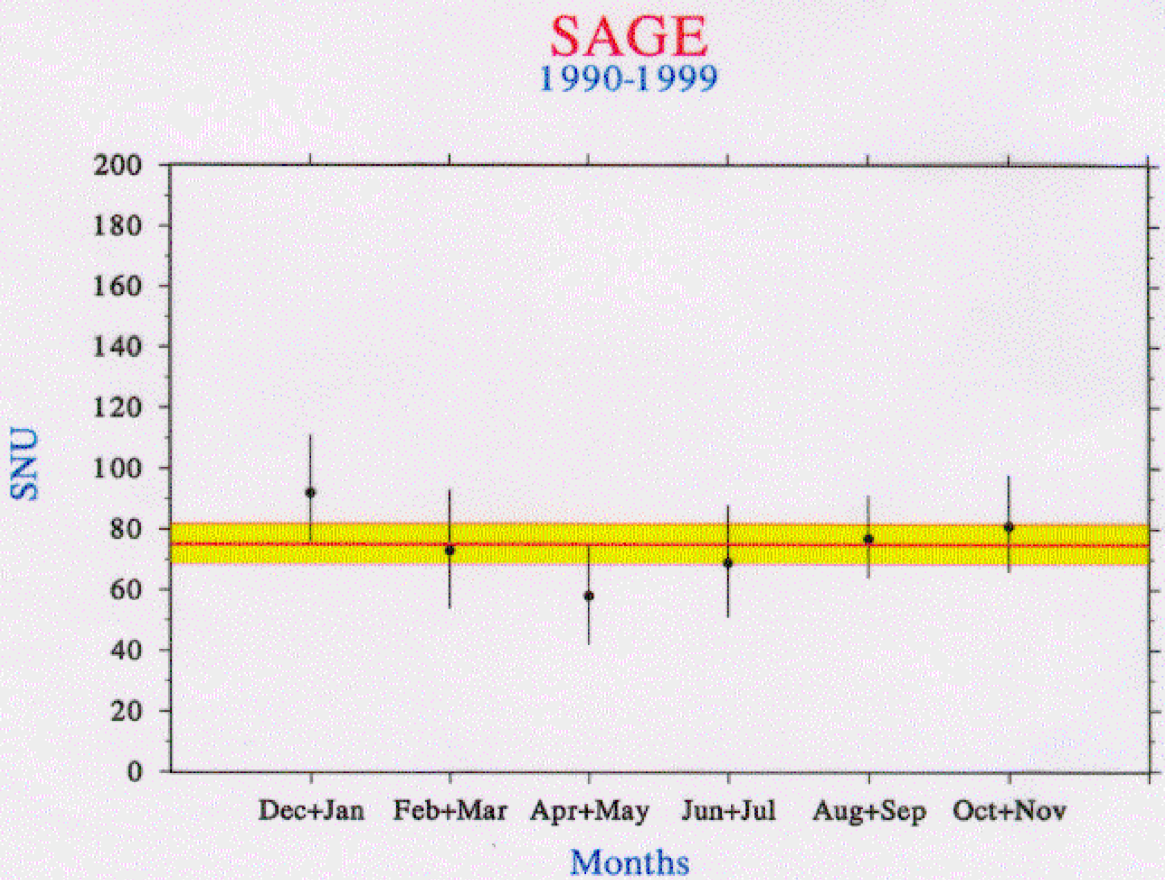
Results of combined analysis of all runs during each year

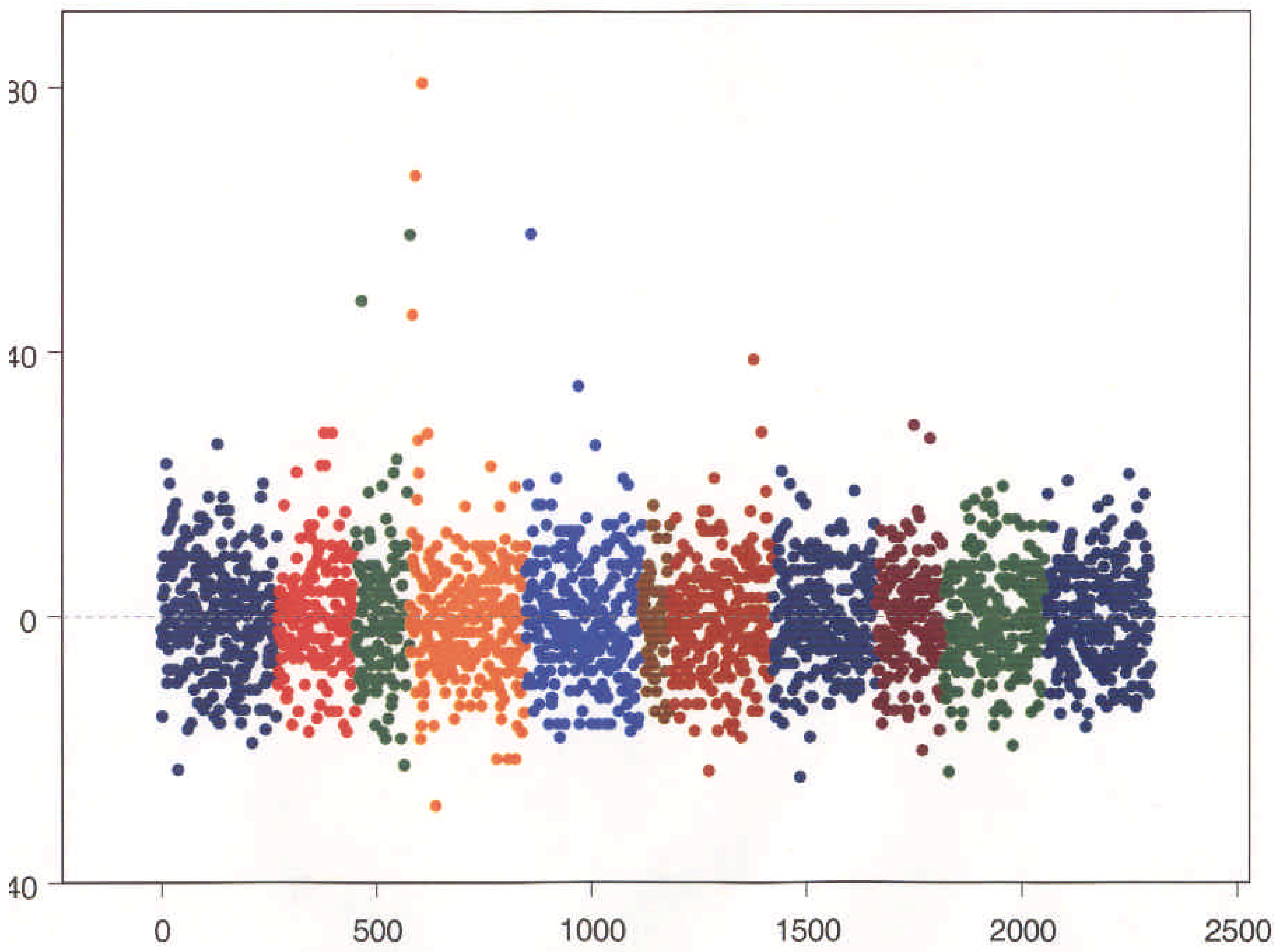
The uncertainty in the probability is ~ 4%.

Year of exposure	Number of data sets	Number of candidate events	Number fit to ^{71}Ge	Best fit (SNU)	68% conf. range (SNU)	Nw^2	Probability (%)
1990	5	43	4.9	43	2– 78	0.260	7
1991	6	59	25.5	112	82– 145	0.120	15
1992	13	145	39.8	76	59– 95	0.047	75
1993	15	97	33.2	84	62– 105	0.199	3
1994	10	155	24.1	73	51– 98	0.027	95
1995	13	210	37.7	102	77– 129	0.041	82
1996	10	121	19.4	56	34– 79	0.064	48
1997	16	183	35.7	62	48– 78	0.057	54
1998	12	189	26.7	56	39– 75	0.064	57
1999	14	123	47.6	101	79– 124	0.056	52

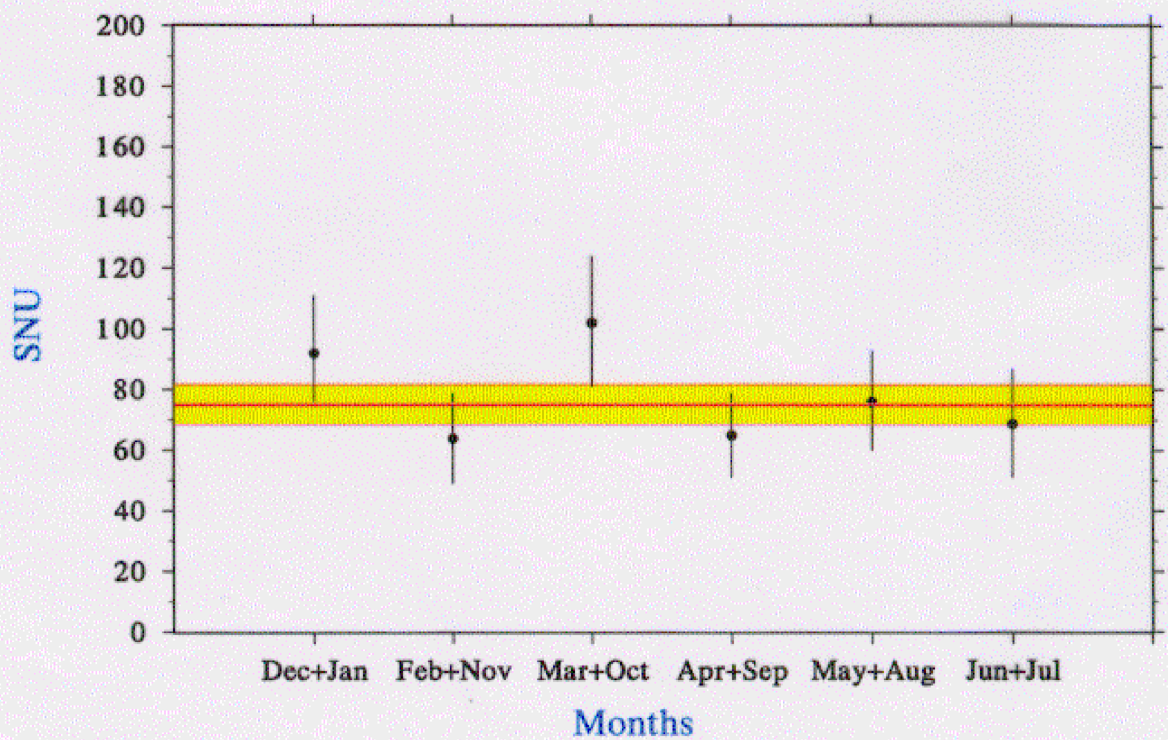


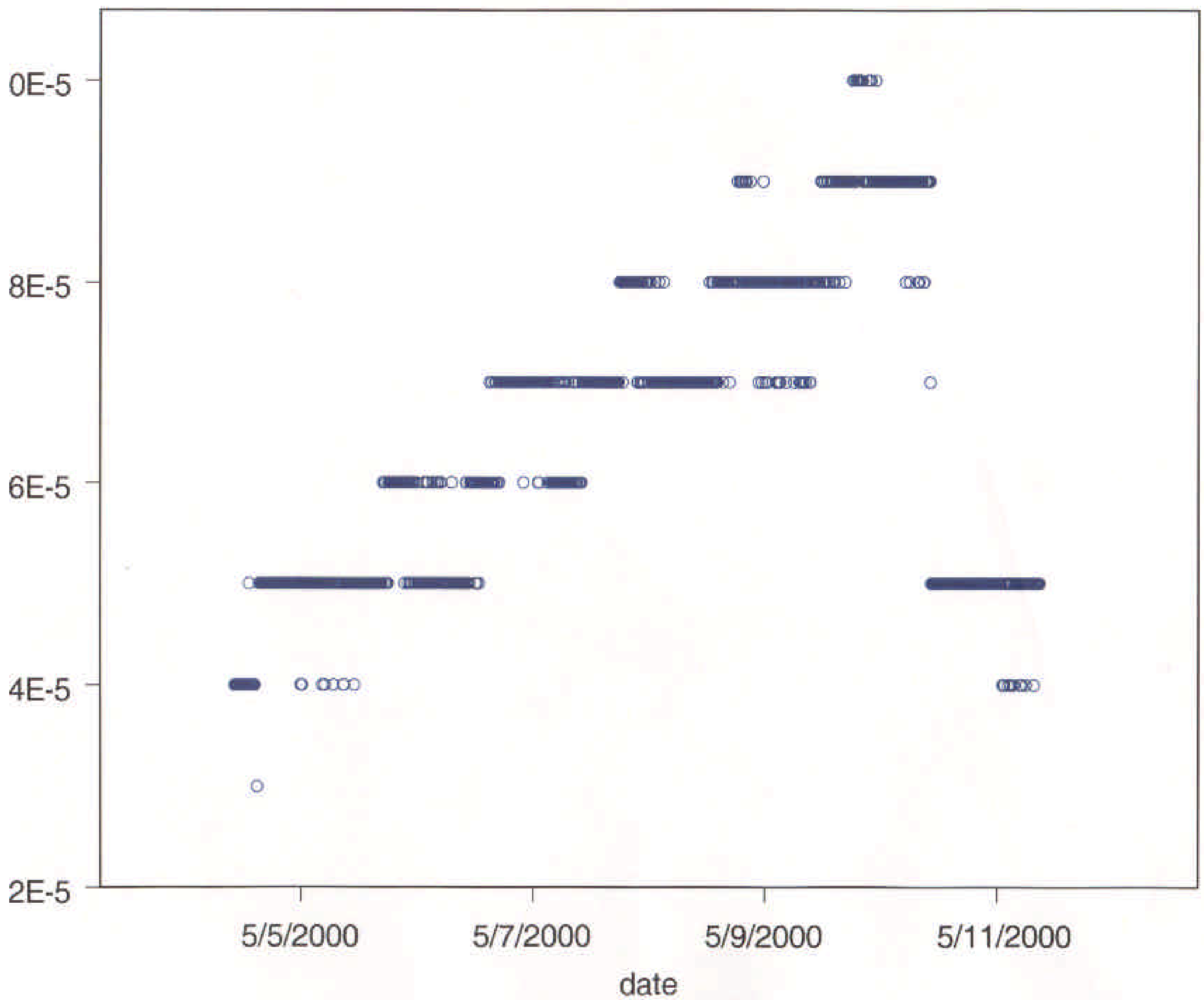

SAGE
1990-1999
200
180
160
140
120
100
80
60
40
20
0
SNU
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

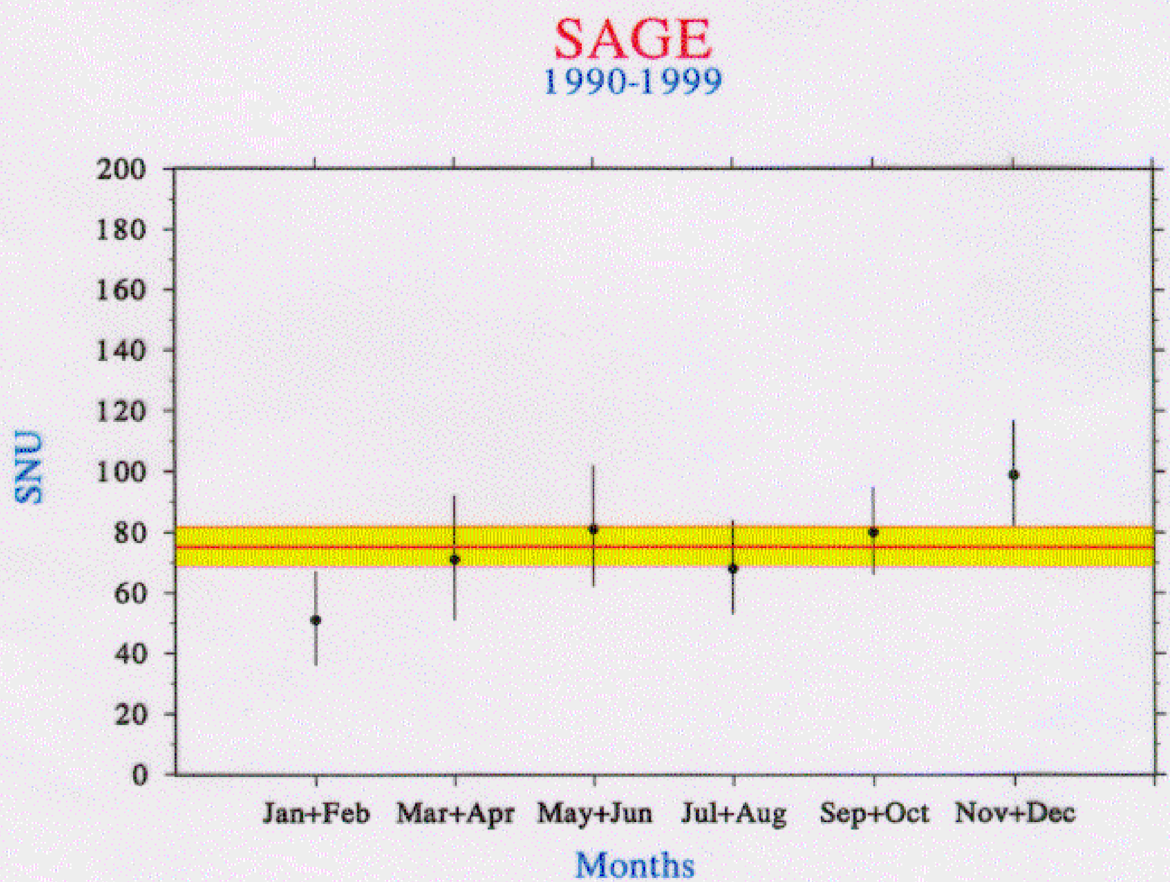

SAGE
1990-1999
SNU
200
180
160
140
120
100
80
60
40
20
0
Dec+Jan
Feb+Mar
Apr+May
Jun+Jul
Aug+Sep
Oct+Nov
Months


0
500
1000
1500
2000
2500

SAGE
1990-1999




0E-5
8E-5
6E-5
4E-5
2E-5
5/5/2000
5/7/2000
5/9/2000
5/11/2000
date


SAGE
1990-1999
SNU
200
180
160
140
120
100
80
60
40
20
0
Jan+Feb
Mar+Apr
May+Jun
Jul+Aug
Sep+Oct
Nov+Dec
Months

V.N.Gavrin' 2000

Results of combined analysis of all runs during monthly and bimonthly periods.

The uncertainty in the probability is $\sim 4\%$.

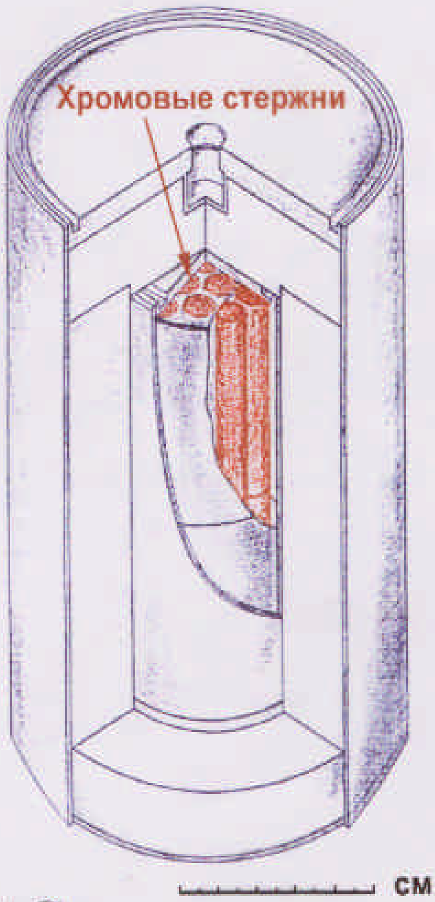
Month of exposure	Number of data sets	Number of candidate events	Number fit to ^{71}Ge	Best fit (SNU)	68% conf. range (SNU)	$N\omega^2$	Probability (%)
January	9	105	19.3	56	33– 82	0.062	59
February	8	64	12.3	47	27– 69	0.041	90
March	5	92	23.1	140	100– 186	0.046	67
April	7	64	9.9	44	25– 65	0.080	47
May	8	78	20.2	74	51– 101	0.066	45
June	7	65	24.4	92	60– 126	0.140	3
July	11	138	19.0	57	37– 80	0.063	63
August	11	126	28.3	77	57– 99	0.042	85
September	16	182	40.6	77	60– 95	0.033	91
October	13	143	31.4	86	62– 112	0.074	43
November	11	157	33.6	78	58– 99	0.027	95
December	8	111	35.7	134	104– 167	0.071	43
January-February	17	169	30.9	51	36– 67	0.066	49
March-April	12	156	27.6	71	51– 92	0.024	97
May-June	15	143	43.4	81	62– 102	0.132	12
July-August	22	264	47.5	68	53– 84	0.042	90
September-October	29	325	71.6	80	66– 95	0.027	98
November-December	19	268	69.0	99	82– 117	0.051	53
February-March	13	156	31.0	73	54– 93	0.051	66
April-May	15	142	28.8	58	42– 75	0.041	74
June-July	18	203	41.1	69	51– 88	0.065	53
August-September	27	308	69.0	77	64– 91	0.030	94
October-November	24	300	64.8	81	66– 98	0.047	81
December-January	17	216	56.3	92	75– 111	0.097	25
February-November	19	221	44.4	64	49– 79	0.027	98
March-October	18	235	54.2	102	81– 124	0.066	39
April-September	23	246	48.7	65	51– 79	0.042	84
May-August	19	204	48.6	76	60– 93	0.042	80

Summary of Systematic Uncertainties

Origin of Uncertainty	Uncertainty (%)	Uncertainty (SNU)
Extraction Efficiency		
Ge Carrier Mass	±2.1	±1.4
Mass of Extracted carrier	±2.5	±1.7
Residual Carrier	±0.8	±0.5
Ga mass	±0.3	±0.2
Total (extraction)	±3.4	±2.3
Counting Efficiency		
Volume Efficiency	±1.4	±0.9
End Losses	±0.5	±0.3
Monte Carlo Interpolation	±1.0	±0.7
Shifts in gain	-3.1	+2.1
Resolution	+0.5,-0.7	+0.3,-0.5
Rise Time Limits	±1.0	±0.7
Lead and Exposure Times	±0.8	±0.5
Total (Counting)	+2.3,-3.9	-1.5,+2.6
Non-solar Neutrino Production of ^{71}Ge		
Fast Neutrons		< -0.02
^{232}Th		< -0.1
^{226}Ra		< -0.7
Cosmic Ray Muons		< -0.7
Total (Non-solar)		< -1.0
Background Events that Mimic ^{71}Ge		
Internal ^{222}Rn		< -0.3
External ^{222}Rn		0.0
Internal ^{69}Ge		< -0.14
Total (Background Events)		< -0.3
Total		-3.0,+3.5

^{51}Cr neutrino source experiment

517 кCi source of ^{51}Cr was produced by irradiation **512.7 g** of **92,4%**-enriched ^{50}Cr in high-flux fast neutron reactor.



$^{51}Cr + e^- \rightarrow {}^{51}V + \nu_e$
(Eν=751 кeV, 90%)
$T_{1/2} = 27.7$ days

There were **8** irradiations of **13** t Ga.
The measured production rate of ^{71}Ge :
q_{exp} = 14.0 at/day (50 times higher, than from the Sun).

$$R = q_{exp.} / q_{pred.}$$

0.95 +/- 0.12 (exp.)+0.035/-0.027 (theor.) - Bahcall

0.87 +/- 0.11 (exp.)+/-0.09 (theor.) - Haxton

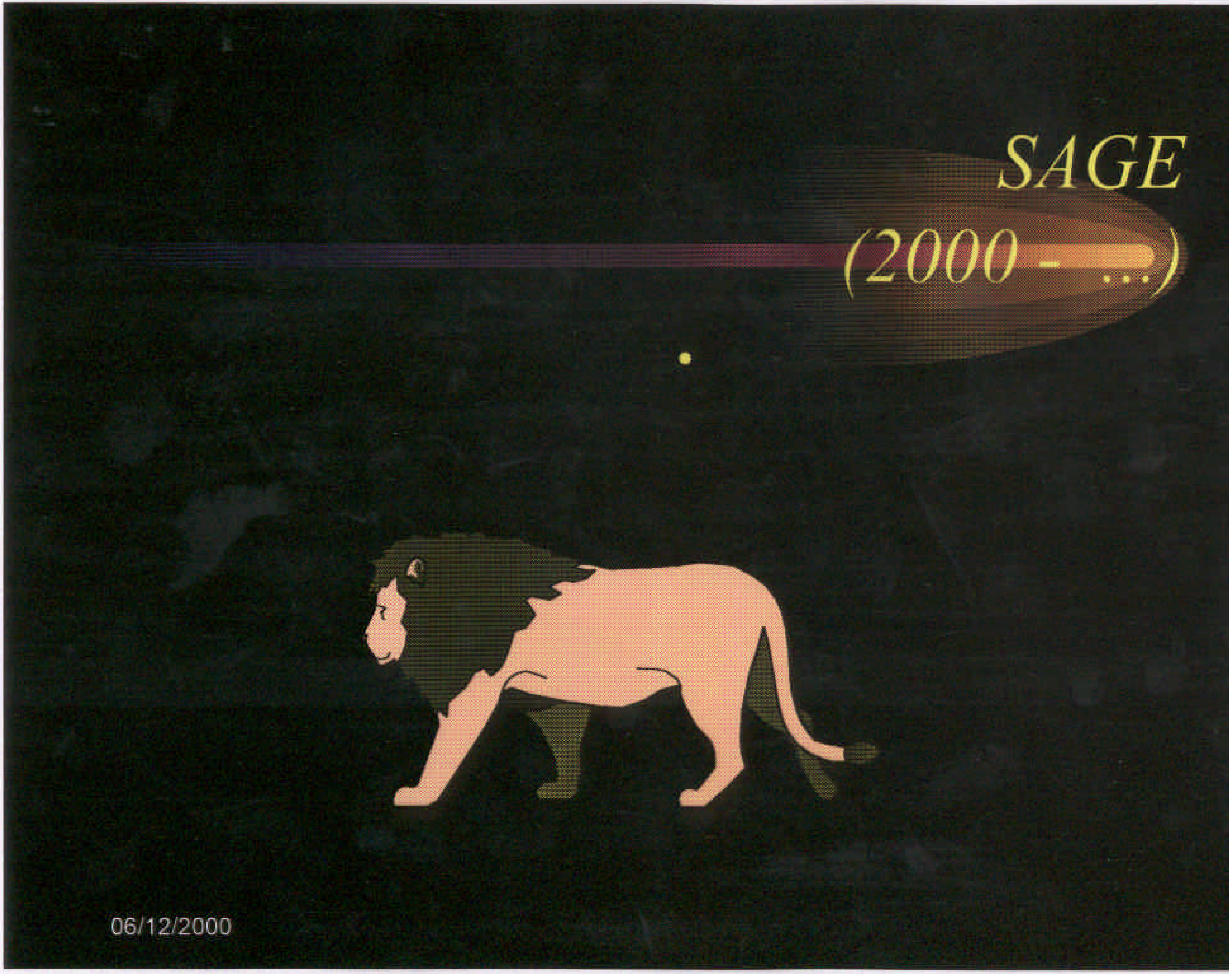
Future

- SAGE performs extractions every four weeks on 50 tonnes of Ga. We intend to recover about 8 tonnes from the $GaCl_3$ to increase the target back to 58 tonnes.

- SAGE is currently statistically limited. We intend to continue solar neutrino extractions through the year 2005 to further reduce the statistical uncertainty. Work continues on reducing systematic contributions. The Russian Ministry of Science and the DoE are funding this program for at least the next three years.

- We plan to measure the neutrino cross-section using an approximately 1 MCi ^{37}Ar source. Research is underway on the production of such a source.

- Radiochemical gallium experiments remain the only technique able to measure and monitor the predominant, p-p flux of solar neutrinos for the near future. SAGE will be happy to pass the baton to KamLand or other experiments that will be able to measure the p-p neutrinos.


SAGE
(2000 - ...)
06/12/2000

SAGE RESULT
(1990-1999)

$$75.4 \;^{+7.0}_{-6.8}\;(\text{stat})\;^{+3.5}_{-3.0}\;(\text{syst})\;\text{SNU}$$

With statistical and systematic uncertainties added in quadrature:

$$75.4 \;^{+7.8}_{-7.4}\;\text{SNU}$$

$Nw^2 = 0.051$; Probability = 75%

$$T_{1/2} = 11.0 \;^{+2.2}_{-1.8}\;\text{days}$$