Measurement of the Cross Section of the $^{7}Be(n,\alpha)\alpha$ Reaction and the Problem of Primordial ^{7}Li

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1. **Primordial Big Bang Nucleosynthesis**
   The "^{7}Li Problem"
2. **The Letter of Intent (Gai & Weissman)**
3. **The SARAF Facility at Soreq**
4. **The $^{10}B(n,\alpha)^{7}Li$ Test**
5. **The $^{7}Be(n,\gamma\alpha)\alpha$ Experiment**

ERAWASTII,
PSI, Villigen, Switzerland, September 2, 2011

UConn-40870-00XX/ May 5, 2011

Letter of Intent: SARAF facility, Soreq Nuclear Center, Israel

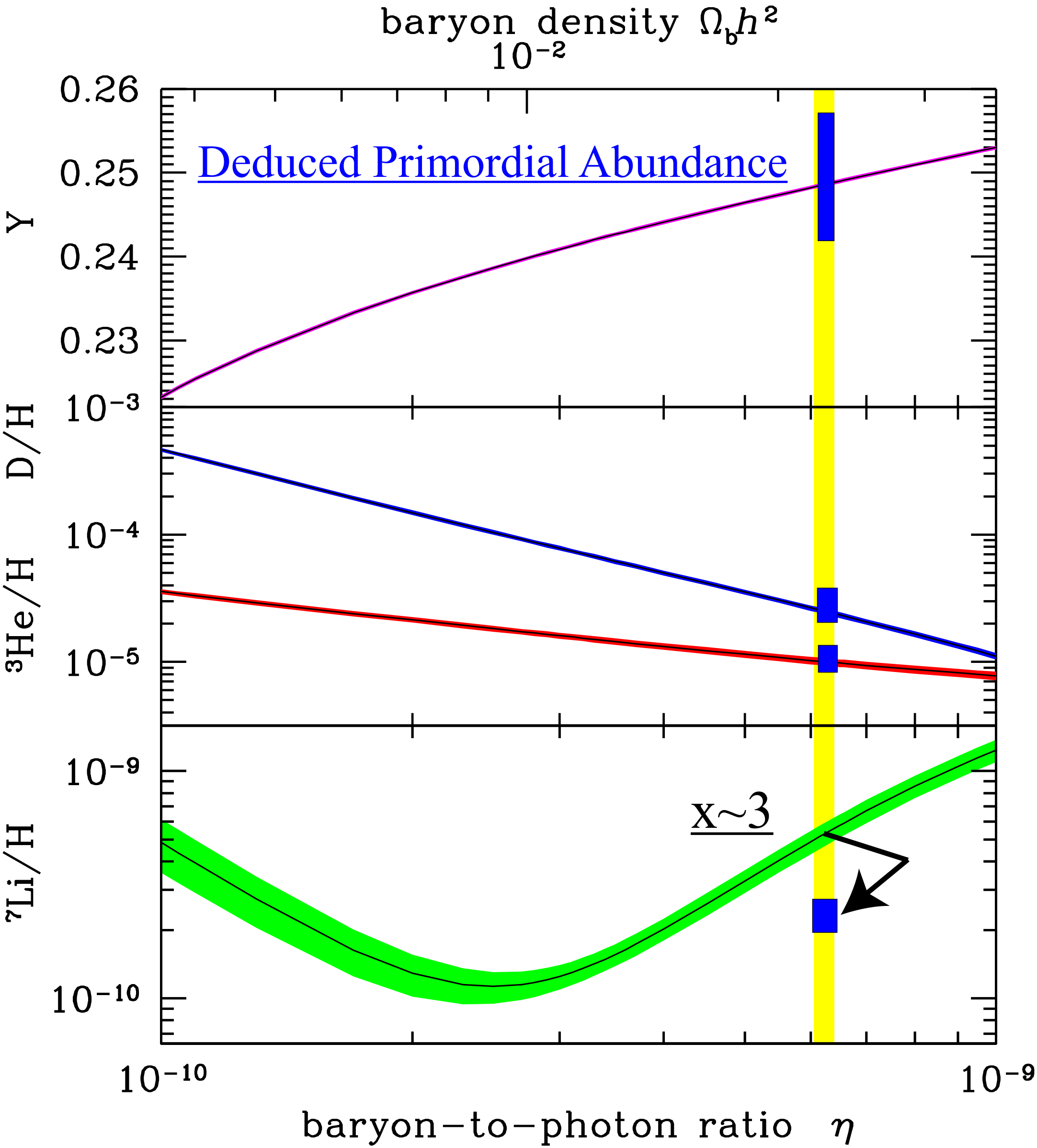
Measurement of the cross section of the ^{7}Be(n,α)α Reaction and the Problem of Primordial ^{7}Li

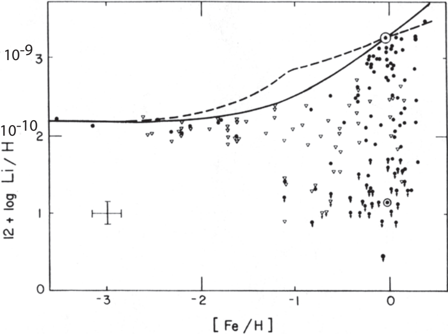
M. Gai (Yale and UConn) and L. Weissman (Soreq)

Abstract:

The disagreement of the predicted abundance of primordial ^{7}Li with the observed abundance is a longstanding problem in Big Bang Nucleosynthesis (BBN) theory. While BBN theory correctly predicts the abundances of ^{1}H, ^{2}H, ^{3}He and ^{4}He (that vary over five orders of magnitudes), it over predicts the abundance of primordial ^{7}Li by a factor of approximately 2.5-4.5 (approximately 4-5σ discrepancy). Primordial ^{7}Li is copiously produced directly (e.g. via the ^{6}Li(n,γ) reaction etc.) but later during the first 4-15 minutes approximately 99% of the so produced ^{7}Li is destroyed primarily via the ^{7}Li(p,α) reaction. Hence most of the predicted primordial ^{7}Li is predicted to be produced via the (electron capture beta) decay of the primordial ^{7}Be that is produced primarily in the ^{3}He(α,γ) reaction. We propose to investigate the destruction of ^{7}Be during (the first 10-15 minutes of) BBN via the ^{7}Be(n,α) reaction. If during that time the majority of the primordial ^{7}Be is destroyed (before decaying to ^{7}Li) it will lead to a reduction of approximately 3 of the predicted abundance of the primordial ^{7}Li, hence a resolution of the long standing disagreement. The rate of the 7Be(n,a) reaction relies on unpublished and not very well documented cross section of thermal neutron (only) measured in the 60's and tabulated for the first and last time by Wagoneer *et al.* in the 60's. We propose to measure the cross section of the ^{7}Be(n,α) reaction with neutron beams that mimic a quasi Maxwellian flux at 50 keV. A prototype experiment and the proposed final experiment could be performed at Phase I of SARAF using the LILIT target.

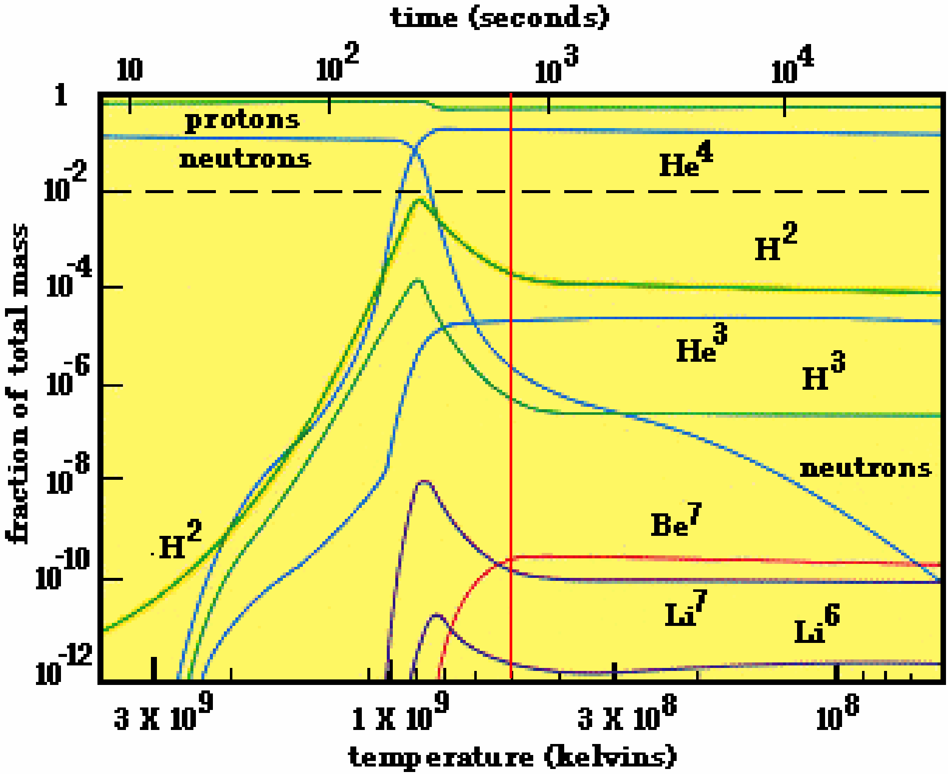
^{7}Li Problem: Cyburt-Fields-Olive; 0808.2818

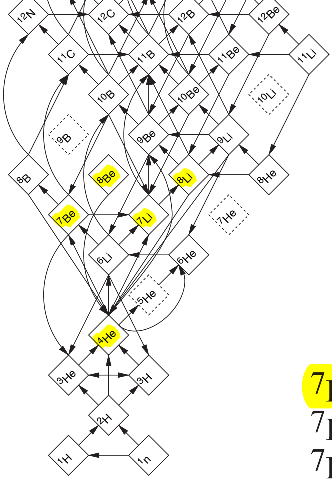


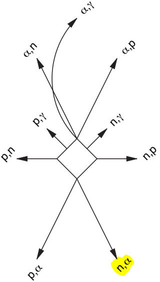


10^{-9}
10^{-10}
3
2
1
0
12 + log Li / H
-3
-2
-1
0
[Fe / H]

Big Bang Nucleosynthesis







^{7}Be(n,α)α
^{7}Be(d,p)2α
^{7}Be(^{3}He,2p)2α

Figure 1. The nuclear network used in BBN calculations.

Olive; astro-ph/0202486

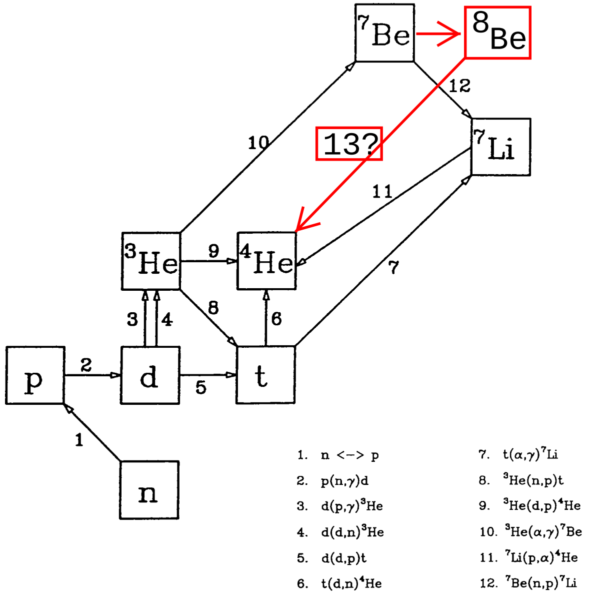


FIG. 10.—Network diagram of the 12 primary reactions in the processing of the light elements.

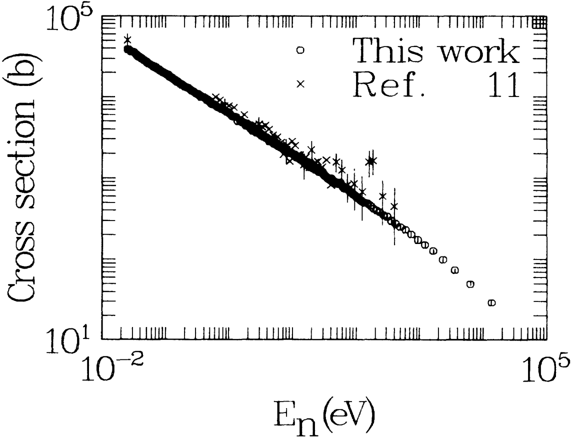


FIG. 4. The ^{7}Be(n,p)^{7}Li (p_0+p_1) cross section. Data from 25 meV to 13.5 keV are results of the present work (circles). Also shown are the data for this reaction from Ref. 11 (crosses).

THE ASTROPHYSICAL JOURNAL, Vol. 148, April 1967

ON THE SYNTHESIS OF ELEMENTS AT VERY HIGH TEMPERATURES*

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Received September 1, 1966

ABSTRACT

A detailed calculation of element production in the early stages of a homogeneous and isotropic expanding universe as well as within imploding-exploding supermassive stars has been made. If the recently measured microwave background radiation is due to primeval photons, then significant quantities of only D, He^3, He^4, and Li^7 can be produced in the universal fireball. Reasonable agreement with solar-system abundances for these nuclei is obtained if the present temperature is 3° K and if the present density is $\sim 2 \times 10^{-31}$ gm cm^3, corresponding to a deceleration parameter $q_0 \approx 5 \times 10^{-3}$. However, massive stars "bouncing" at temperatures $\sim 10^9$ ° K can convert the universal D and He^3 into C, N, O, Ne, Mg, and some heavier elements in amounts observed in the oldest stars. The mass gaps at $A = 5$ and 8 are bridged by the reactions $He^3(He^4,\gamma)Be^7(He^4,\gamma)C^{11}$. Bounces at higher temperatures bridge the mass gaps through 3 $He^4 \rightarrow C^{12}$ and mainly produce metals of the iron group, plus a small amount of heavier elements synthesized by a new kind of r-process (rapid neutron capture). It is found that very low abundances of He^4, as recently observed in some stars, can be produced in a universe in which the electron neutrinos are degenerate.

I. INTRODUCTION

In this paper we shall consider the synthesis of elements on short time scales and at very high temperatures. The time scales are typically of the order of 10–10^3 sec, while the temperatures range upward of 10^9 ° K. These conditions are in marked contrast to the situation in stars, where lower temperatures and longer time scales usually obtain. It will appear that synthesis proceeds differently in many respects, and that abundances, particularly with respect to isotopic composition, are different from those which are produced in stellar nucleosynthesis.

The short time scales of the present paper are applicable to systems in rapid dynamical motion. These include the universe itself, if indeed the universe evolved from a hot, dense state, and also large masses of gas that collapse to such a state and subsequently explode. Our investigation deals with masses upwards of $\sim 10^3\ M_\odot$.

Nuclear reactions were first applied to the early stages of a Friedmann universe by Alpher, Bethe, and Gamow (1948), and also by Fermi and Turkevich (1950). It was assumed in these investigations that initially all baryons were neutrons, an assumption which placed a severe restriction on the relation between the baryon density ρ_b and temperature. Writing

$$\rho_b = h\, T_9{}^3 \text{ gm cm}^{-3}\,, \qquad (1)^1$$

where T_9 is in units of 10^9 ° K, the parameter h had to be set rather precisely ($10^{-6} \gtrsim h \gtrsim 10^{-7}$) in order that hydrogen and helium emerged in approximately equal abundances in the final material. A small change of h was sufficient to make the difference between essentially all hydrogen and essentially all helium.

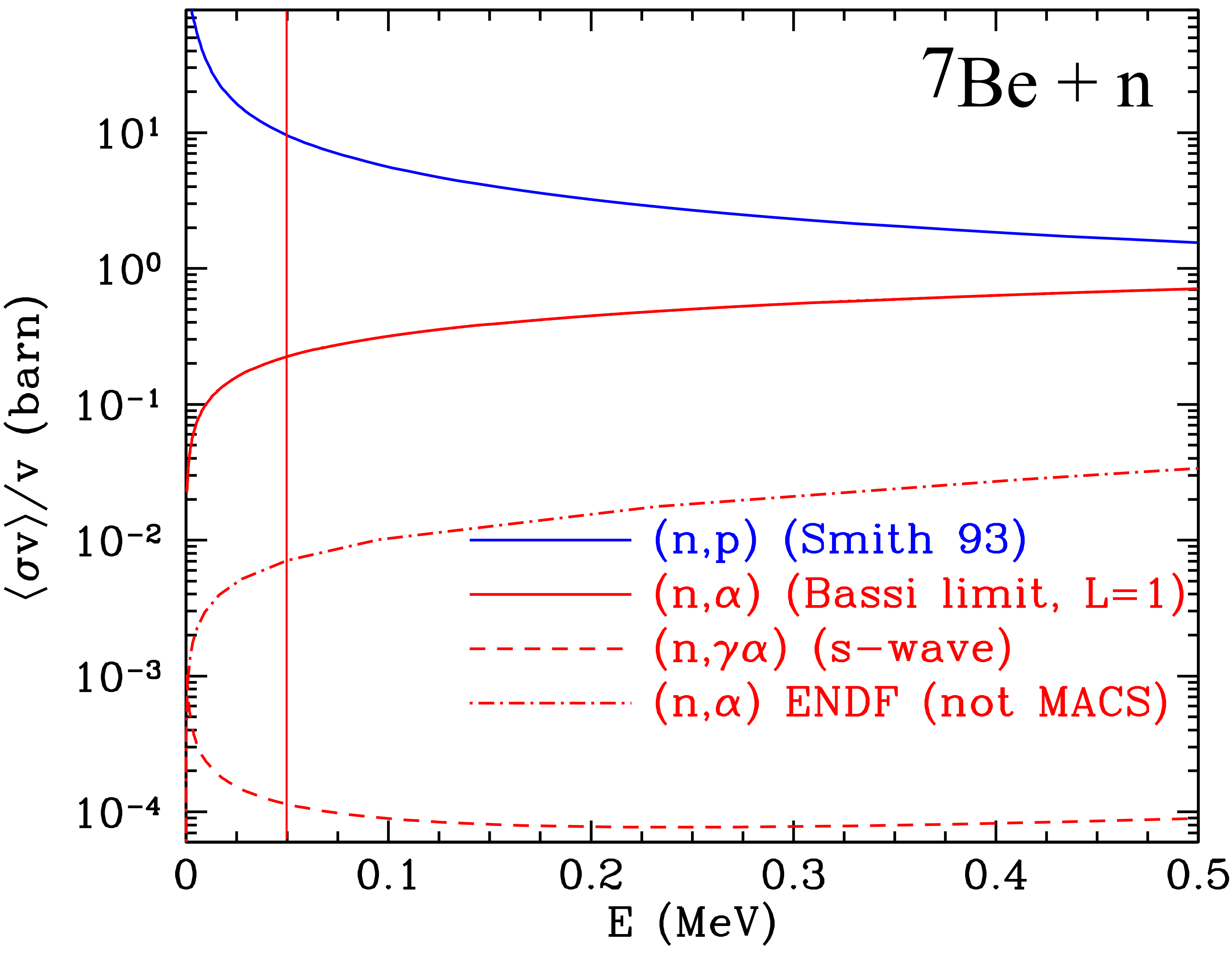
This situation was changed by Hayashi (1950), who pointed out that at very high temperatures neutrons and protons come into statistical equilibrium through the weak interactions; for example,

$$e^- + p \rightleftarrows n + \nu_e\,. \qquad (2)$$

* Supported in part by the Office of Naval Research [Nonr-220(47)] and the National Science Foundation (GP-5391).

[1] It should be noted that eq. (1) only holds exactly if no net energy is being transferred between the electrons and photons due to pair creation and annihilation (see § II).

Kenneth M. Nollett, ANL, Private Communication, 2011



IL NUOVO CIMENTO VOL. XXVIII, N. 5 1° Giugno 1963

The Reaction ^{7}Be(n, α)^{4}He and Parity Conservation in Strong Interactions (*).

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C. C. R. EURATOM - Ispra

(ricevuto il 15 Gennaio 1963)

Summary. — We have studied experimentally the reactions ^{7}Be(n, α)^{4}He and ^{7}Be(n, $\gamma\alpha$)^{4}He, produced by thermal neutrons. We have established an upper limit for the first of the two: $\sigma_1 \leqslant 0.1$ mb. For the second one we have found $\sigma_2 = 155$ mb. The limit for σ_1, in the hypothesis of (2^-) attribution to the 18.9 MeV level of ^{8}Be, corresponds to $F^2 \leqslant 4.10^{-10}$, where F is the ratio of the amplitudes of the opposite parity wave functions. This result is used to put an upper limit to the strength of a possible parity-violating interaction involving strange particles.

Introduction.

A clean experiment to test if parity is violated in strong interactions at low energy has been suggested by SEGEL, KANE and WILKINSON (1): it is the study of the reaction

$$ ^7\text{Be} + \text{n} \to 2\alpha , \tag{1}$$

which is not allowed for thermal neutrons (mainly absorbed in S-wave) because the 18.9 MeV level of ^{8}Be which is formed has spin 2 and — parity. They

(*) Work performed under Euratom-CNEN-INFN Contraet.
(1) R. E. SEGEL, J. V. KANE and D. H. WILKINSON: *Phil. Mag.*, 3, 204 (1958).

2. – Experimental results.

Method A. – Two Hughes SD1-23-1 cm² solid state counters were used. The source and the detector were placed coaxially at a distance of 9 mm with

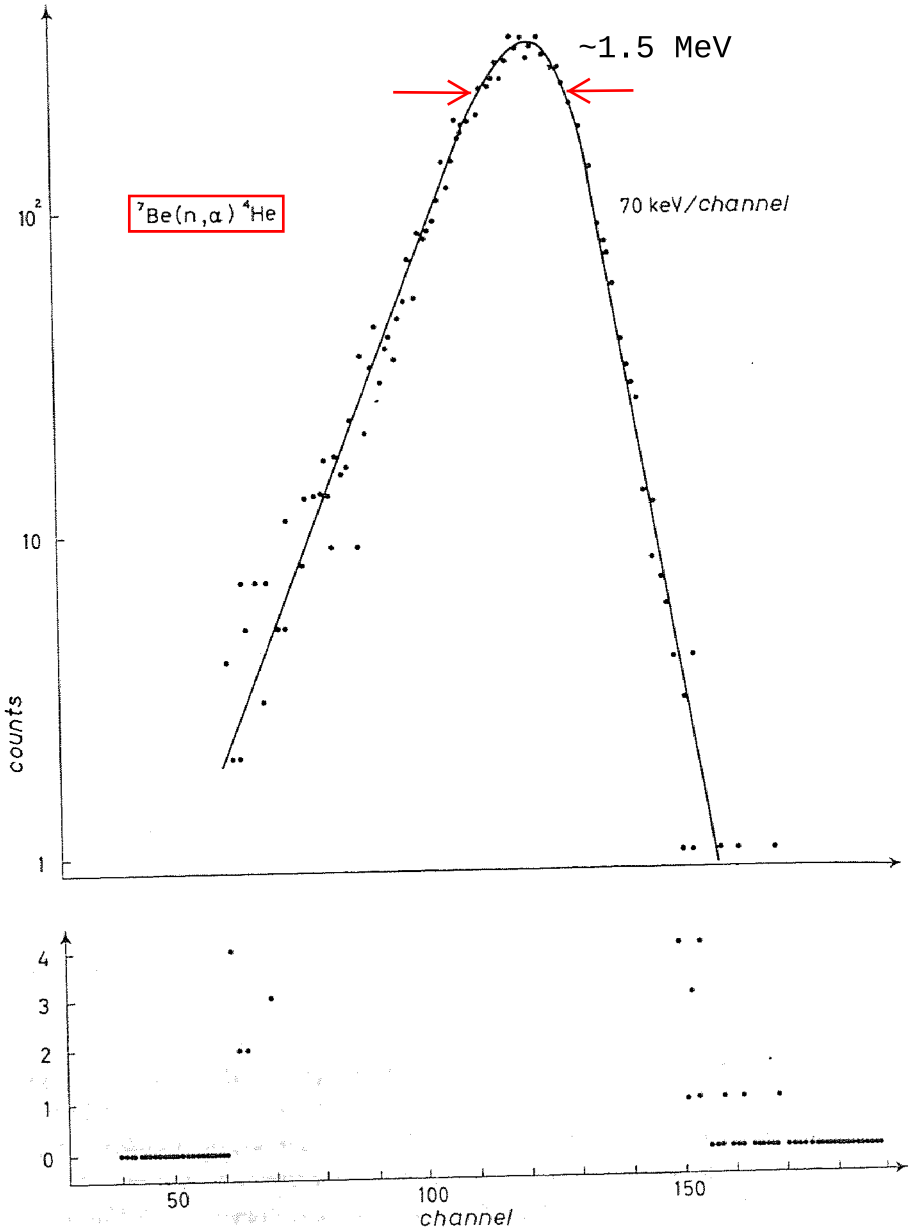
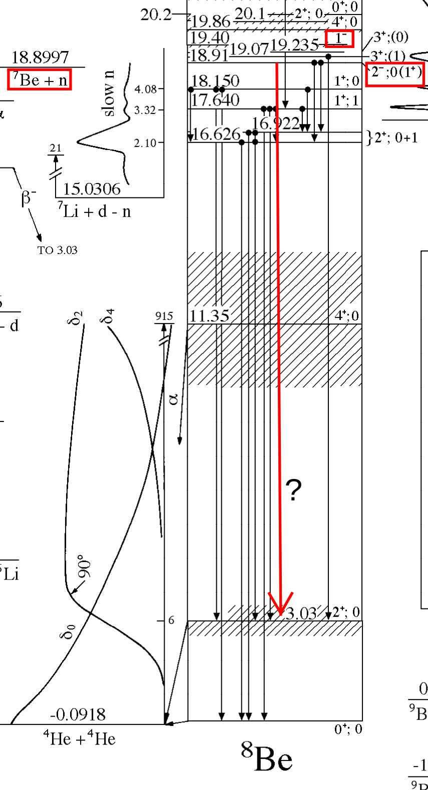


Fig. 5.



20.2
19.86
20.1
2+; 0
0+; 0
4+; 0
19.40
1-
3+;(0)
18.91
19.07
19.235
3+;(1)
2-;0(1+)
18.8997
7Be + n
slow n
4.08
3.32
2.10
18.150
1+; 0
17.640
1+; 1
16.922
16.626
2+; 0+1
21
15.0306
7Li + d - n
β-
TO 3.03
δ2
δ4
915
11.35
4+; 0
α
?
90°
δ0
6
3.03
2+; 0
-0.0918
4He + 4He
0+; 0
8Be

Table 8.9: Energy levels of ^{8}Be

E_x (MeV $\pm$ keV)	$J^\pi; T$	Γ_{cm} (keV)	Decay	Reactions
g.s.	$0^+; 0$	5.57 ± 0.25 eV [i]	α	1, 2, 4, 5, 10, 11, 12, 13, 14, 19, 20, 21, 22, 23, 25, 28, 29, 30, 31, 33, 36, 39, 40, 41, 42, 43, 44, 45, 46, 47, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62
3.03 ± 10 [i]	$2^+; 0$	1513 ± 15 [i]	α	2, 4, 5, 10, 11, 12, 13, 14, 19, 20, 21, 22, 24, 27, 28, 29, 30, 31, 33, 36, 40, 41, 42, 43, 44, 50, 51, 53, 54, 61
[i,j]	2^+			4, 24, 27, (29)
11.35 ± 150 [i]	$4^+; 0$	≈ 3500[b]	α	4, 12, 13, 19, 21, 29, 30, 31, 41, 51, 53, 54
16.626 ± 3	$2^+; 0+1$	108.1 ± 0.5	γ, α	2, 4, 10, 11, 13, 14, 19, 20, 21, 27, 29, 30, 31, 40, 41, 44, 51, 53
16.922 ± 3	$2^+; 0+1$	74.0 ± 0.4	γ, α	2, 4, 10, 11, 13, 14, 19, 20, 21, 29, 30, 31, 40, 41, 44, 51, 53
17.640 ± 1.0 [f]	$1^+; 1$	10.7 ± 0.5	γ, p	5, 11, 14, 16, 19, 20, 29, 30, 31, 41, 53
18.150 ± 4	$1^+; 0$	138 ± 6	γ, p	11, 14, 16, 19, 20, 29, 30, 41, 44
18.91	$2^-; 0(+1)$	122 [e]	γ, n, p	11, 14, 15, 16, 19, 23
19.07 ± 30	$3^+; (1)$	270 ± 20	γ, p	11, 14, 16, 19, 29, 30
19.235 ± 10 [i]	$3^+; (0)$	227 ± 16 [i]	n, p	15, 16, 19, 29, 30, 31, 41, 64
19.40	1^-	≈ 645 [i]	n, p	11, 15, 16, 29
19.86 ± 50 [g]	$4^+; 0$	700 ± 100	p, α	4, 11, 18, 21, 22, 30, 31, 41
20.1 [h]	$2^+; 0$	880 ± 20 [i]	n, p, α	4, 15, 16, 18, 19, 22, 41
20.2	$0^+; 0$	720 ± 20 [i]	α	4, 19, 41
20.9	4^-	1600 ± 200	p	16
21.5	$3^{(+)}$	1000	γ, n, p	14, 15, 41
22.0 [c]	$1^-; 1$	≈ 4000	γ, p	14

3.5.4. Reaction be7nα: $^7Be + n \leftrightarrow\ ^4He + \ ^4He$. To our knowledge, evaluations for the rate of this reaction have only been published in [9] and [23], without information on the sources of the data and error estimate. We did not find further analysis in the subsequent compilations by Fowler *et al* [10]. The two data sets of the reverse process published in [163, 164] refer to centre of mass energies of the direct one greater than 0.6 MeV, thus leaving a great uncertainty in the BBN window. They seem to be roughly consistent with the old estimate of the rate, and a new one in view of so scarce data would make little sense. For this reason we adopted Wagoner's rate, assuming a factor of ten uncertainty, as he suggested as a typical conservative value. Within this allowed range, this reaction could play a non-negligible role in *direct* ^{7}Be destruction, so it would be fruitful to have a new experimental determination. Apart from the role of unknown or little known ^{8}Be resonances, it is however unlucky that the used extrapolation may underestimate the rate by more than one order of magnitude, as this process mainly proceeds through a p-wave.

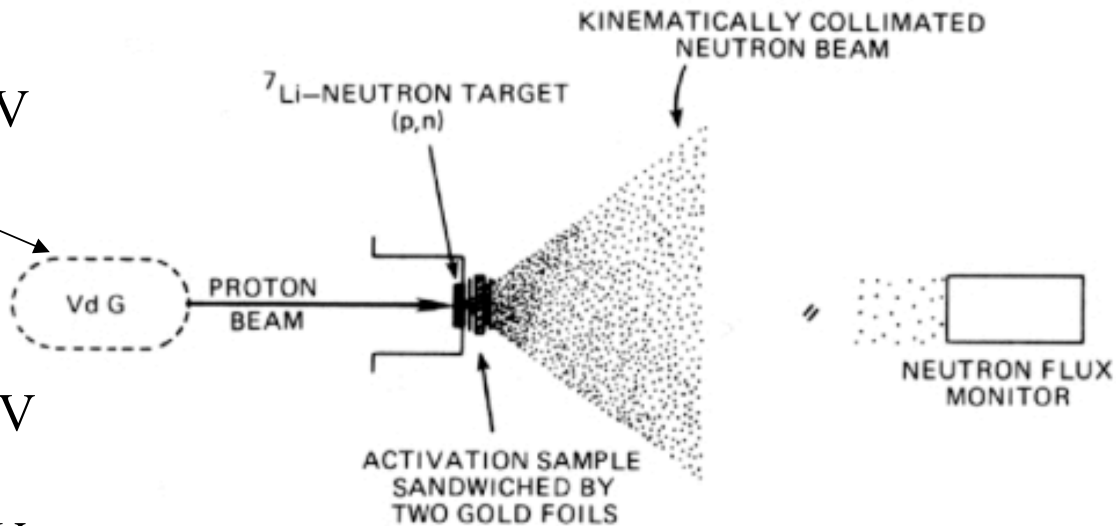
P. D. Serpico, S. Esposito, F. Iocco,
G. Mangano, G. Miele and O. Pisanti

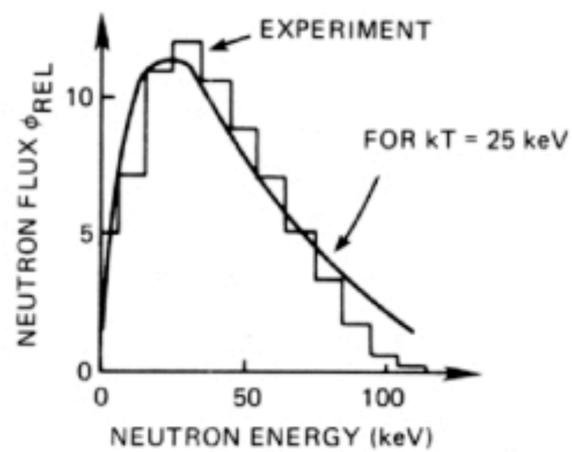
The $^7Li(p,n)^7Be$ reaction for production of stellar neutrons

E_p = 1912 keV
ΔE=1 keV

Q = -1644 keV

E_{th}= 1880 keV





$$\Phi_{MB} \cdot v \sim E \cdot e^{-E/kT};$$
$$kT = 25\, keV$$

$$I < 100\, \mu A$$
$$\phi \sim 10^9\, neutron / sec$$

W. Ratynski and F. Kaeppeler,
PR C 37, 595 (1988)
FZ Karlsruhe, Germany

The activation experiment scheme

SARAF phase I $\xrightarrow[\Delta E > 7\ \text{keV}]{E_p = 1912\ \text{keV}}$ LiLiT $^{7}Li(p,n)^{7}Be$ E_{th}=1880 keV $\xrightarrow{E_n \approx 30\ \text{keV}}$ Secondary activation target

The unique opportunity at SARAF:

High intensity proton beam + Liquid lithium target

⇩

High intensity neutron beam

Beam lines downstream the linac

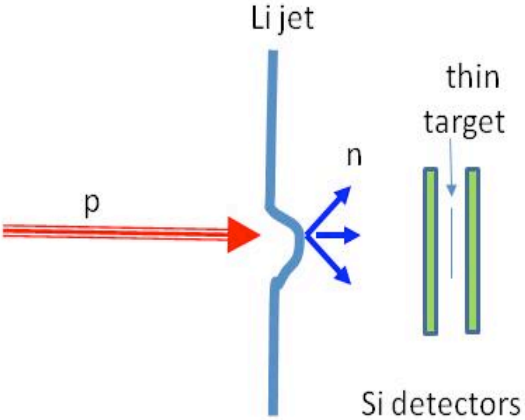


Fig.4: The experimental scheme

Ralph H. France III, Ph.D. thesis, Yale, 1995

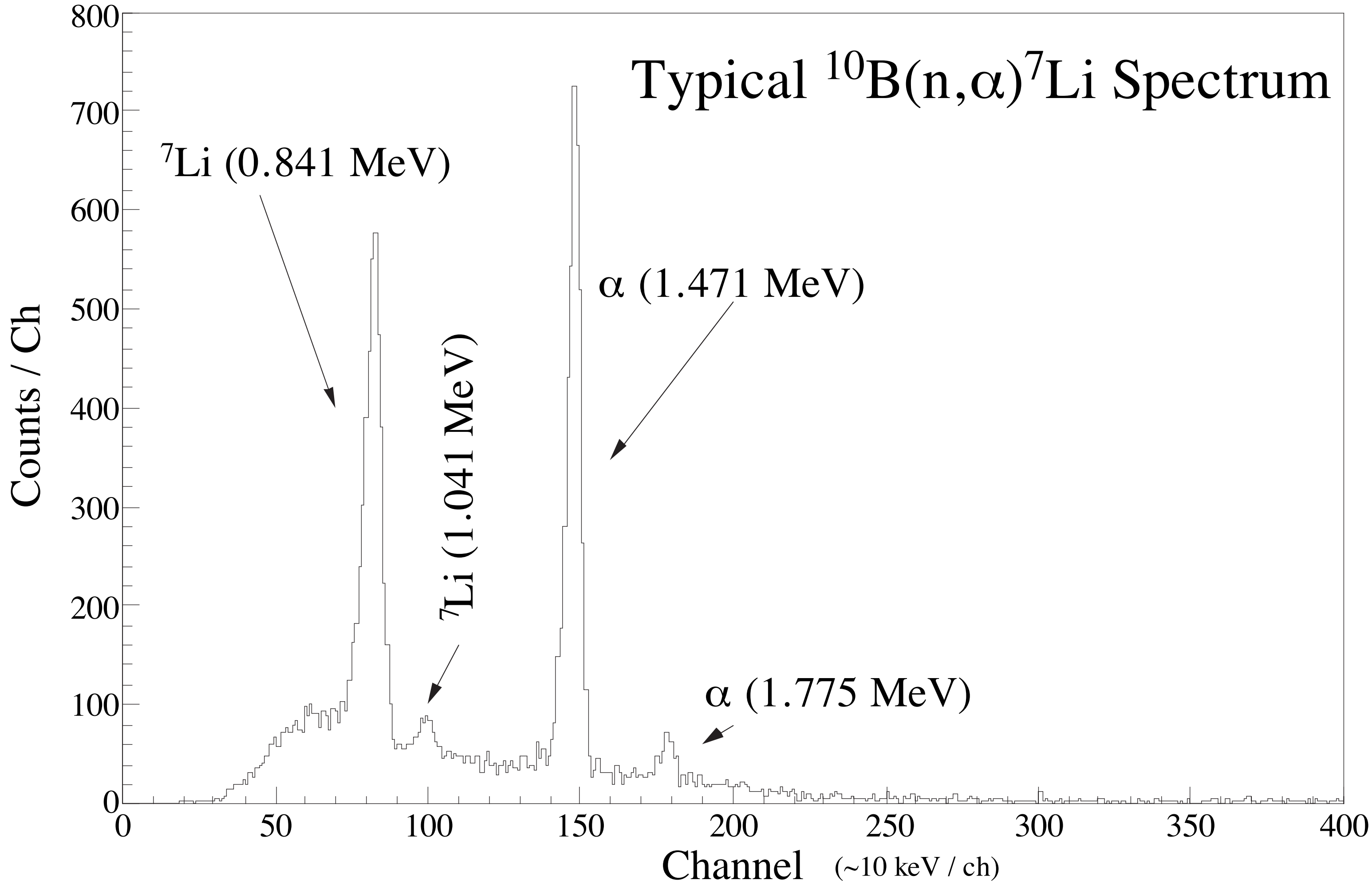


Figure 4.6: Typical Spectrum from the $^{10}B(n,\alpha)^7Li$ Reaction used to calibrate our alpha array at low energies exhibiting energy resolution of FWHM = 55 keV at 1.5 MeV.

We Need a Clean and Thin ^{7}Be Target (~100 mCi 0.4x0.4 cm^2)

target: ~10^{17} ^{7}Be/cm^2

Beam: ~10^9 /sec (30-50 keV)

$\mathcal{L} = 10^{26}$ /cm^2 sec

$\varepsilon/4\pi$ = 15% (M=2 → 30%)

$\mathcal{L}\sigma\varepsilon > 10$ CPH

$\sigma >$ 0.1 mb

Design Goal Sensitivity = 0.1 mb

(Current: ~ 200 mb at 50 keV)