The Nuclear Physics Aspect of the Cosmological Lithium Problem

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The nuclear physics solution to the cosmological lithium problem is discussed in the context of the ^{7}Be + d reaction. The experiment was carried out at HIE-ISOLDE to study resonance excitations in the (d,p) and (d,^{3}He) channels. The theoretical calculations are normalized to the data and extrapolated to Gamow energies, giving an estimate of the contributions of the individual excited states. Inclusion of higher excited states in (d,p) reaction leads to an S factor substantially higher than the present value of 100 MeV b. However, the reduction of the primordial Li abundance is less than 1% and thereby fail to solve the anomaly.

1. Introduction

The cosmological lithium problem is a well-known and yet unresolved problem in nuclear astrophysics at present [1, 2]. The problem depicts an anomaly of about a factor of three between big-bang nucleosynthesis (BBN) calculations and the observed abundance of ^{7}Li in metal-poor stars. Since the BBN models rely on the experimentally determined nuclear reaction rates, a search for a nuclear physics solution to this problem involves the re-examination of the relevant nuclear reaction cross sections. It is important to better constrain nuclear physics inputs to BBN theory, before invoking exotic scenarios beyond standard BBN [3, 4].

As primordial ^{7}Li mostly originated from the β-decay of primordial ^{7}Be after the cessation of nucleosynthesis, nuclear reactions leading to the production and destruction of ^{7}Be are of significant interest. The ^{7}Be production channel ^{3}He$(\alpha,\gamma)^7$Be is well studied while destruction of ^{7}Be by (n,p), (n,α) and (d,α) channels are unable to solve the anomaly. Sensitivity studies [1] have shown that the lithium anomaly can be resolved if the reaction rate of ^{7}Be(d,p)^{8}Be$^*(2\alpha)$ is increased by a factor of 100 at the required Gamow energies. However, earlier works did not measure the contribution of higher excited states in ^{8}Be. Moreover, the data inside the Gamow window have large error bars both in energies and cross sections. The present work involves the measurement of the ^{7}Be(d,p)^{8}Be* and ^{7}Be(d,^{3}He)^{6}Li* reactions in the context of the Lithium anomaly.

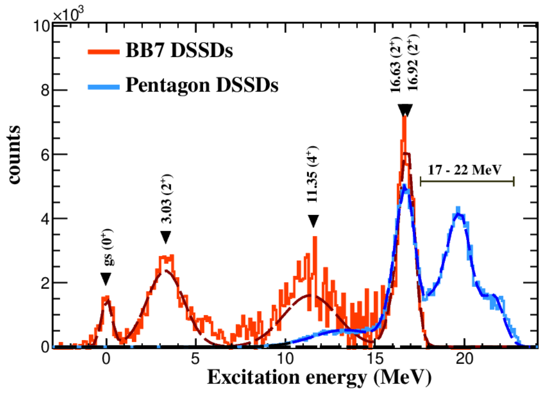

FIG. 1: The excitation energy spectrum showing the ^{8}Be states from the ^{7}Be(d,p)^{8}Be$^*(2\alpha)$ measurement at 5 MeV/u [5].

2. Experiment

The experiment was carried out at HIE-ISOLDE, CERN with a 5 MeV/u ^{7}Be beam of intensity $\sim 5 \times 10^5$ pps incident on a 15μm thick CD_2 target. An array of double sided Silicon strip detectors (DSSD) covering 8^o-165^o (Micron S3, W1, BB7) was placed inside the Scattering Experiment Chamber to detect

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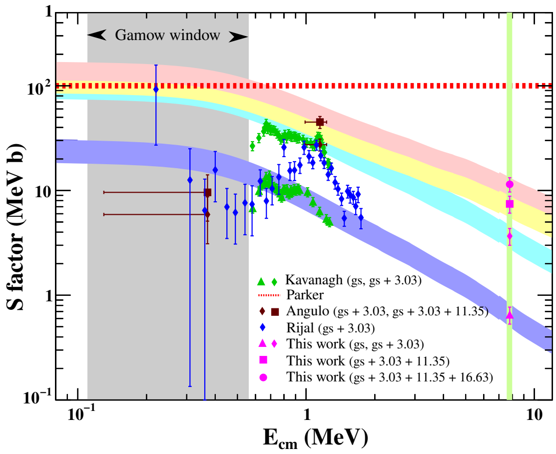

FIG. 2: S-factor for ^{7}Be(d,p)^{8}Be*. The solid triangle, diamond, square and circles correspond to total cross-sections due to gs, gs + 3.03, gs + 3.03 + 11.35 and gs + 3.03 + 11.35 + 16.63 MeV states respectively. The data in green, brown, blue are from earlier measurements and magenta represent the present work [5]. The violet (gs), cyan (gs + 3.03), yellow (gs + 3.03 + 11.35) and red (gs + 3.03 + 11.35 + 16.63) MeV bands are TALYS calculations normalized to the present data at 7.8 MeV (green vertical line). The bands do not include systematic uncertainty due to extrapolation. The red dotted line is the estimate from earlier work [3].

the emitted particles. The details of the experimental setup are available in Ref. [5, 6].

3. Results and Outlook

The earlier measurements of the ^{7}Be(d,p)^{8}Be* reaction could not account for the individual contributions of the excited states, particularly at higher excitations close to the Q value of 16.67 MeV of the reaction. The present work populated the higher excited states of ^{8}Be up to 22 MeV for the first time in this channel. Fig. 1 shows the excitation energy spectrum of ^{8}Be from protons detected at W1 (blue) and BB7 (red) detectors [5]. The corresponding Gaussian fits are also shown. The (d,p) S factor (Fig. 2) was obtained by normalizing the TALYS calculations to the present data at E_{cm} = 7.8 MeV. The contributions of the higher excited states in the total cross section at the relevant big-bang energies are obtained by extrapolation to the Gamow window. Including the 16.63 MeV state, the S factor comes out to be 167 MeV b while the estimate from earlier work is 100 MeV b. However, the reduction in the primordial Li abundance comes out to be less than 1% and thereby fails to alleviate the anomaly. The contribution of (d,^{3}He) reaction is also found to be negligible compared to the (d,p) reaction [7]. Nuclear physics solutions are thus found to be inadequate to solve the Lithium anomaly.

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