The Weak and Strong Lithium Anomaly in BBN

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What is the Lithium Anomaly?

- problems with the Standard Model for Big Bang Nucleosynthesis.

- Agreement between predicted and observed abundances of the stable hydrogen and helium isotopes.

- Good first order test of Model.

- does not accurately predict the abundance of the stable lithium isotopes $^7$Li and $^6$Li – hence lithium anomaly.
**The "Weak Lithium Anomaly"**

- **Predicted abundance $^7$Li**
  \[ \frac{[^7\text{Li} / \text{H}]}{} \approx 3.82 \times 10^{-10} \]

- **Observed abundance $^7$Li**
  \[ \frac{[^7\text{Li} / \text{H}]}{} \approx 1.5 \times 10^{-10} \]

- **Abundance primordial in nature and measured off Halo Stars (Spite Plateau)**

- Observed abundances a factor of three less than predicted.

- Could have a number of causes, including stellar mixing and astration.

- The "Weak Lithium Anomaly"
$^6$Li problem – Strong Anomaly

- Predicted abundance $^6$Li:
  
  \[
  \frac{[^6\text{Li}]}{[^7\text{Li}]} \approx 3.3 \times 10^{-5}
  \]

- Observed abundance $^6$Li:
  
  \[
  \frac{[^6\text{Li}]}{[^7\text{Li}]} \approx 8 \times 10^{-2}
  \]

- observed abundance is $\approx 2,500$ times greater than what is predicted.

- The Standard Model for BBN clearly fails its second order test.

- The “Strong Lithium Anomaly”.

- Is it possible that the Weak and Strong Lithium Anomaly are correlated?
Top Down production of $^6\text{Li}$?

- Standard Model assumes $^6\text{Li}$ is mostly produced by the "bottom up" fusion reaction $^2\text{H}(^4\text{He}, \gamma) ^6\text{Li}$.  

- Are there reactions involving $^7\text{Li}$ that produces $^6\text{Li}$ from the "top down"? Such reactions would need to remove a neutron from $^7\text{Li}$ to produce $^6\text{Li}$.  

- Candidate reactions may involve $^3\text{H}$ and $^3\text{He}$. To match BBN conditions these reaction would run at energies of $\leq 0.500 \text{ MeV}$.  

Candidate reactions for “top down” production of $^6\text{Li}$?

- The Standard Model for BBN does not take into account “top down” production of $^6\text{Li}$. 

- Candidate reactions that should be looked into include:
  
  $^7\text{Li}(^3\text{H}, ^4\text{He})^6\text{He}$
  
  $^7\text{Li}(^3\text{He}, ^4\text{He})^6\text{Li}$

- $^6\text{He}$ is a mirror nuclei to $^6\text{Li}$ and beta decays into $^6\text{Li}$ (806.7 ms).

- Cross section data for these reactions at astrophysical energies is sparse.

- The second reaction is of note given that the abundance of $^3\text{He}$ is comparable to that of deuterium during BBN.
The $^7\text{Li}(^3\text{H}, ^4\text{He})^6\text{He}$ reaction

- The abundance of $^3\text{H}$ is several orders of magnitude less than that of $^3\text{He}$ during BBN, however this may be compensated in other ways.

- The S(0) for $^7\text{Li}(^3\text{H}, ^4\text{He})^6\text{He}$ is 14 MeV-b (Phys. Rev. 27, 6, 1983)

- The Q for $^7\text{Li}(^3\text{H}, ^4\text{He})^6\text{He}$ is 9.38 MeV and $^6\text{He}$ has a decay $\Delta E = 3.507$ MeV. (total E released 12.88 MeV).
The $^7\text{Li}(^{3}\text{He},\; ^4\text{He})^6\text{Li}$ reaction

- The Q value for $^7\text{Li}(^{3}\text{He},\; ^4\text{He})^6\text{Li}$ is 13.32 MeV.
- Expect the astrophysical S-factor for the reaction $^7\text{Li}(^{3}\text{He},\; ^4\text{He})^6\text{Li}$ to be comparable to that for the $^7\text{Li}(^{3}\text{H},\; ^4\text{He})^6\text{He}$ reaction.
- A Back of Envelope estimate using these “top down” candidate reactions this provides the right order of magnitude for the abundance of $^6\text{Li}$. 
Energy level diagram for $^6$Li

- Does the energy level diagram for $^6$Li provides clues about the SLA?
  - lower energy levels Positive Parity (sym.).
  - upper levels Negative Parity (anti-sym.).

- The lower energy states appears to be symmetric $^2$H x $^4$He states.
- The upper energy states appear to be an anti-symmetric $^3$H x $^3$He states.
Energy Levels for $^6\text{Li}$

$^7\text{Li} + ^3\text{He} \rightarrow ^4\text{He} \rightarrow ^6\text{Li}$

13.32 MeV

![Diagram showing energy levels for $^6\text{Li}$]
The $^7\text{Li}(^3\text{He}, ^4\text{He})\ ^6\text{Li}$ reaction

- Pauli Exclusion Principle $\rightarrow$ final wavefunction anti-sym

- The Clebsch-Gordon coefficients linking the g.s. (3/2-) state of $^7\text{Li}$ to the $^3\text{H} \times ^3\text{He}$ final states correlates well to the upper levels of odd parity in $^6\text{Li}$.

- There is a spin 0 $\rightarrow$ 0 term that is of interest:

  $1/2 \times 1/2 <0,0|0,0>_{3/2 \times 1/2}$

- This may be the broad, state at around 15 MeV.

- BOE estimate for this cross section $\sim 250 \text{ mb}$
The “15 MeV” state

- The stated width for the 15 MeV state is 17 MeV.

- Its characteristic time is \( \tau = \hbar / \Gamma \approx 2.4 \times 10^{-22} \text{ s} \)

- Such a characteristic time points to a direct reaction.

- Speculate: for the \( ^7\text{Li}(^3\text{He}, ^4\text{He})^6\text{Li} \) is there an exchange interaction at work?

\[ |^3\text{H} \times ^4\text{He} \rightarrow |^3\text{H} \times ^3\text{He} \]

- Or ... is it possible that a neutron tunnels across from the \(^7\text{Li}\) nuclei to the \(^3\text{He}\), converting it to \(^4\text{He}\)?

- An ideal instrument to study the astrophysical implications of both candidate reactions is the new TACTIC detector at the Isotope Separation and Acceleration (ISAC) facility at TRIUMF.
TACTIC stands for the TRIUMF Annular Chamber for Tracking and Identification of Charged Particles.

TACTIC is a joint development of York University in England and TRIUMF in Canada.

TACTIC is 40.0 cm long and 18 cm in diameter.
The TACTIC Detector

- Time Projection Chamber
- Designed to allow study of reactions of light elements at astrophysical energies.
- Cylindrical design is made possible by the application of gas electron multipliers (GEM) for the amplification of weak electron drift signals.
- The target gas is also the drift media.
- The first planned reactions to be measured will be: $^{11}\text{Li}(\alpha,n)^{11}\text{B}$ and $^{7}\text{Be} + p$ elastic scat.
- TACTIC is ideal for inverse kinematic measurements at very low energy.
The TACTIC Group

- The $^7\text{Li}(^3\text{He}, ^4\text{He})\ ^6\text{Li}$ reaction will be the subject of study in spring 2009 (lab energy $\approx 0.1$ to $1.5$ MeV).

- The $^7\text{Li}(^3\text{H}, ^4\text{He})\ ^6\text{He}$ may be the subject of study in the fall of 2009 either at TRIUMF or elsewhere.

- The TACTIC Group includes:
  - Lothar Buchmann (TRI)
  - Pat Walden (TRI)
  - Alison Laid (York)
  - Gotz Ruprecht (TRI)
  - Alan Shotter (York)
  - Patrick Bruskiewich (UBC/TRI)
  - and others ...
Thank you

- For more information about the TACTIC Collaboration visit the TRIUMF website at

  www.TRIUMF.ca

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