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Big Bang Nucleosynthesis - Characterizing Abundances of Light Abundances

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MOTIVATION

•Evaluator of Big Bang Cosmological Model
- 75% H, 25% ^{4}He, 10^{-5} D ^{3}H, 10^{-10} ^{7}Li, etc.
- Model uncertainties; parameter uncertainties; physical processes

•Good place to look at because of how early it is and how high the temperatures were. Standard Model BBN theory is well defined.

•Allows us to test theories beyond the Standard Model

•Some problems in standard BBN already
- Cosmological Lithium Problem: Observed amount is 3 times lower than calculated amount.
- Extra neutrino species? Dark matter density?

WAGONER KAWANO BBN Code

- BBN Code made in 1992 (3) based on an older code from late 60s. (1,2)
- Fortran 77 code used to calculate primordial abundances of light elements such as D, He, Li.
- Reaction Rate coefficients approximated as polynomial in temperature expansions using old nuclear reaction data.
- Doesn't give uncertainties in light abundance calculations in current form of code.
- Allowed to vary parameters at run time to study different physics as well as computational inputs.

Methods and Data

•Calculate uncertainties.
- Use more recent cross section data. Ex. From Luna Paper (4)
- Use MINUIT, minimization software from ROOT, to incorporate cross section data from multiple papers. (5)
- Compute a covariance matrix and equation for S factor.

```
0.000282763 -5.03169e-06 2.7613e-08 -4.73337e-11
-5.03169e-06 1.05406e-07 -6.5651e-10 1.25973e-12
2.7613e-08 -6.5651e-10 4.50305e-12 -9.39413e-15
-4.73337e-11 1.25973e-12 -9.39413e-15 2.10427e-17
```

- Use Gauss Laguerre quadrature to estimate squared rate error double integral.

$$\Delta R^2(T) = \int_0^\infty \mathrm{d}E'\, K(E',T) \int_0^\infty \mathrm{d}E\, K(E,T) \sum_{i,j} \frac{\partial S_{\rm th}(E',a)}{\partial a_i}\bigg|_{\hat{a}} \frac{\partial S_{\rm th}(E,a)}{\partial a_j}\bigg|_{\hat{a}} \mathrm{cov}(a_i,a_j). \quad (6)$$

- Calculate the error matrix from the squared rate error giving us uncertainties in light abundance values.

$$\sigma_{ij}^2 = \frac{1}{4}\sum_k [(X_i(\Gamma_k^+) - X_i(\Gamma_k^-)][(X_j(\Gamma_k^+) - X_j(\Gamma_k^-)] \qquad \sigma_i = \sqrt{\sigma_{ii}^2} \quad (6)$$

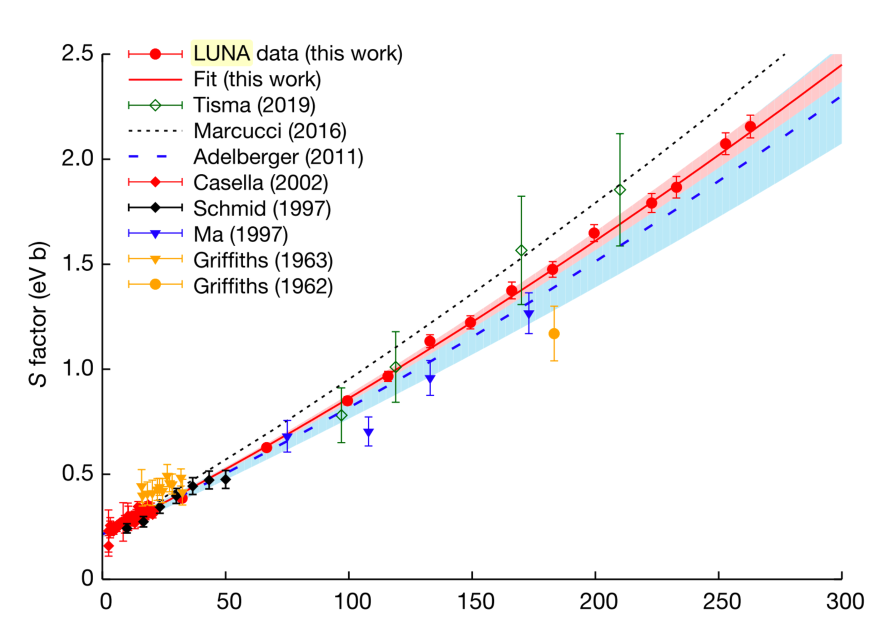

Figure 1: S factor vs Energy for Deuterium burning reaction. From ref. 5

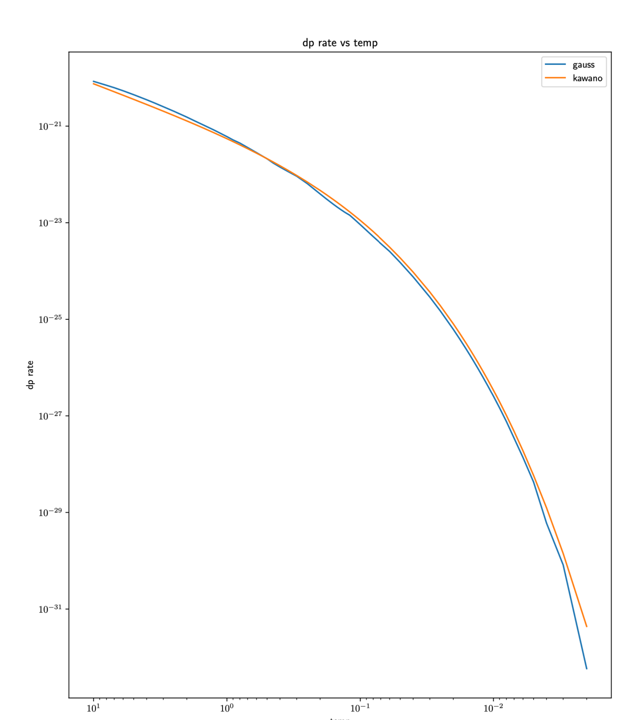

Figure 2: Deuterium burning cross section rates using recent data compared to Kawano rates.

Results

•Currently experimenting with d(p, γ)³He reaction as it's the best measured reaction.

•Have calculated abundances uncertainties for abundances of deuterium with reaction.

•Doesn't match well with predicted values. Error rate abundances look legitimate at lower temperature but ultimately become the same magnitude or even higher than the abundance values at higher temperatures.

•Possibility of error in double integral calculation.
- •Unit conversion error
- •Lack of double precision.

Conclusion

- Used Minuit to calculate S-factors and their respective covariance matrices.
- Wrote own program to calculate average cross sections using the integrated s factors along with their errors.
- Currently debugging the error in cross section calculations to get more accurate abundance values.
- Will incorporate data from more papers to get improved error margins.

References

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