Multi-Gaussian Decomposition of Absorption Lines in High-Resolution ICD Spectra Using IDL

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Introduction

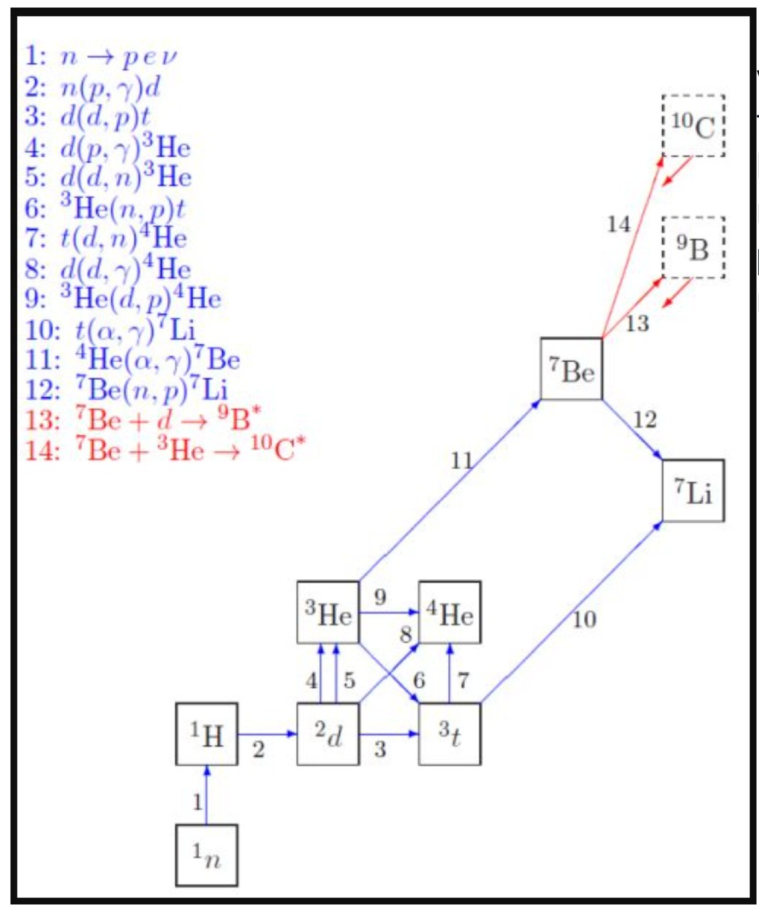

Figure 1: Simplified BBN nuclear network by Fields et al. 2011

Big Bang Nucleosynthesis (BBN) produced the universe's first light elements in the first 20 minutes after the Big Bang. While its predictions match observed helium and deuterium levels, old stars show 3 times more Li than expected (the 'lithium problem'). Three primary astrophysical sites have been proposed as major lithium contributors:

- Asymptotic giant branch (AGB) stars: Aging stars in their final phases, the actual contribution from AGB stars remains uncertain since the lithium they produce may be destroyed in later stellar phases.
- Galactic cosmic-ray spallation: They produce lithium via fragmentation of material due to the impact of accelerated protons, leading to expulsion of nucleons; Lemoine et al. 1998.
- Classical Novae: A notable aspect of nova nucleosynthesis is the beryllium-transport mechanism, as proposed by Starrfield et al. (1978), in which the extreme temperatures during the explosion generate radioactive Be, which later decays into Li.

This project will focus on the effect of classical novae on lithium production, which are thermonuclear explosions occurring on the surface of white dwarfs in binary systems, where material accreted from a companion star undergoes runaway fusion reactions. These explosive events eject processed material into the interstellar medium at high velocities, enriching the galaxy with new heavy elements.

Measurement

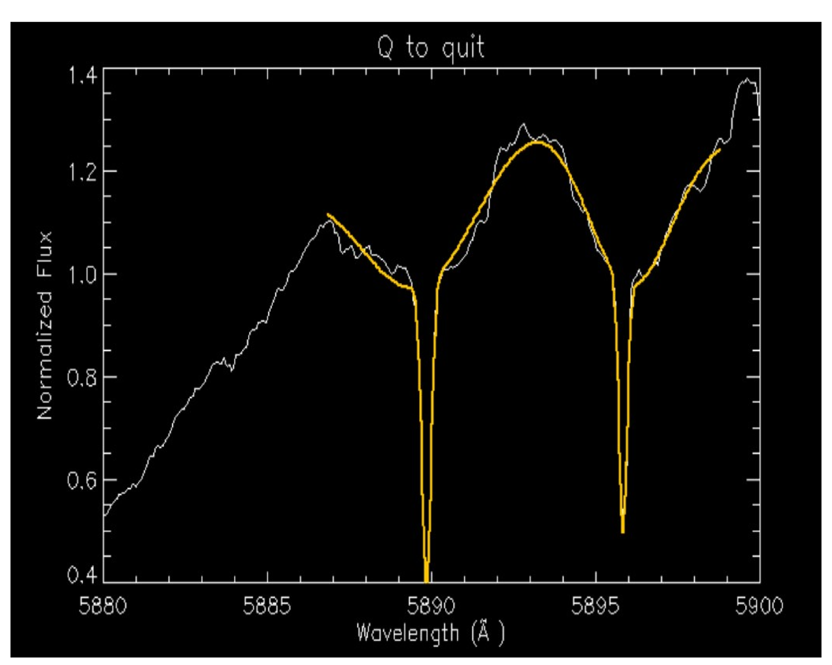

Figure 2: The Na I absorption feature was analyzed using a multi-component Gaussian fit (composite model shown in orange). The equivalent width was derived from the overall fit, while the individual Gaussian components (not shown) could be displayed to verify the accuracy of the decomposition.

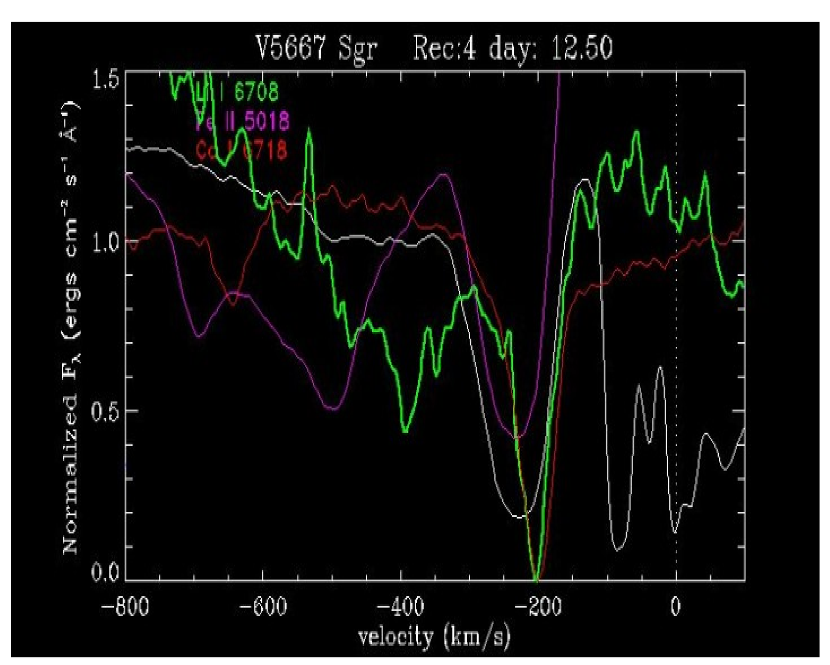

Figure 3: V5667 Sgr on day 13 after the outburst. The white line is the Na I line, green is the Li I 6708 line, purple is the Fe II 5018 line, and red is the Ca I 6718 line. Notice that the absorption features all line up at around -225 km/s

I used this equation to find the Equivalent Width

$$f(w) = A \cdot \exp\left[-\frac{1}{2}\left(\frac{w-\mu}{\sigma}\right)^2\right] \to W = |\sum f(w)| * \triangle w$$

where A is the amplitude, w is the wavelength range(from continuum), μ is the center wavelength, σ is the width parameter and W is the Equivalent width.

Results

Among dozens of novae we examined, V5668 Sgr (erupted in March 2015) displayed the clearest lithium absorption in its ejecta. The correlated evolution of Na I and Li I equivalent widths suggests these elements were produced together in the same nucleosynthetic event.

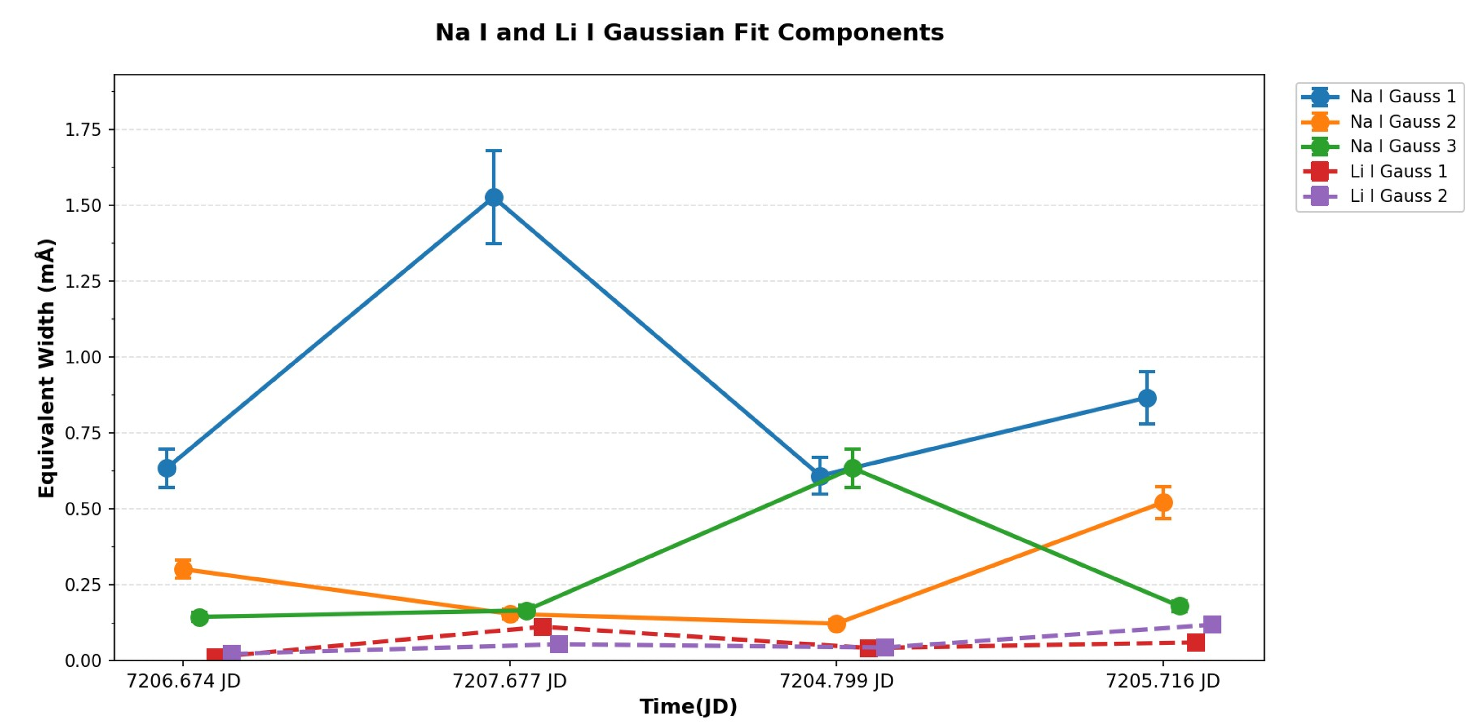

Figure 4: Equivalent width evolution of V5668 Sgr showing correlated Na I and Li I absorption

Following Izzo (2015, Equation (1))

$$\frac{A_m(Li)}{A_m(Na)} = \left[\frac{W_{Li\ 6708}}{6708^2} / \frac{W_{Na\ D2}}{5890^2}\right] * \frac{gf_{Na\ D2}}{gf_{Li\ 6708}} * \frac{u_{Li}}{u_{Na}}$$

where W is the measured equivalent width and u is the atomic mass of the corresponding element. $log\ gf = 0.174$, whereas the single components have, respectively, $log\ gf\ D1 = 0.00177$ and $log\ gf\ D2 = 0.3028$ (Kramida et al. 2013). We have the equivalent width measured, so for V5668 Sgr on 7204.799 JD, $\frac{A_m(Li)}{A_m(Na)} = .00317$. The relationship between $\frac{A_m(Li)}{A_m(Ca)}$ could also be found using the previous equation.

Nova	$Time(d)$	$W_{Li\ I}$	$V_{Li\ I}$	$W_{Na\ I}$	$V_{Na\ I}$	$W_{Ca\ I}$	$\frac{A_m(Li)}{A_m(Na)}$	$\frac{A_m(Li)}{A_m(Ca)}$
V1369 Cen	70∼130	32.7	353.6	169.3	303.5	14.8	0.023	0.187
V5667 Sgr	8.97∼15.3	93.4	226.9	876	215.3	146.5	0.012	0.054
V906 Car	14.98∼30.9	31.4	249.38	535.2	299.7	70.2	0.006	0.038
V6594 Sgr	3.0∼8.0	25.4	257.43	712.2	298.68	N/A	0.004	N/A
V5668 Sgr	5.1∼9.1	67	320.54	245.6	297.28	93.1	0.00317	0.061

Table 1: Li I, Na I, and Ca I absorption features in 5 classical novae. Time (days) indicates the period of lithium detection since the first observed date. Equivalent widths (W) are given in mÅ, with velocities (V) in km/s. Abundance ratios $\frac{A_m(Li)}{A_m(Na)}$ and $\frac{A_m(Li)}{A_m(Ca)}$(under low temperature) were derived from Spitzer (1998, Equations(3)–(48)). The stronger Na I and Ca I features compared to Li I suggest that lithium production occurs via ^{7}Be in these events.

Conclusion

To accurately determine the Li/Ca abundance ratio, ionization corrections (via the Saha equation) must be applied because Izzo's formula only provides the ratio of neutral atoms. Ca ionizes more easily than Li, so the Saha equation is essential to account for the true abundance ratio. However, if the temperature stays low, then the Saha equation is not needed because Ca would most likely stay neutral.

$$\frac{N_{i+1}}{N_i} = \frac{1}{n_e}\left(\frac{2\pi m_e k_B T}{h^2}\right)^{3/2} \frac{2g_{i+1}}{g_i} e^{-\chi_i/k_B T}$$

If neutrons are present, they will interact with ^{7}Be, resulting in the emission of a proton and the production of a ^{7}Li nucleus(Figure 1. Number 12).

$$^7Be + n \to {}^7Li + p$$

Another key nuclear physics aspect is the beryllium-transport mechanism, where ^{7}Be decays to ^{7}Li with a half-life of 53.22 days. This process must be accounted for when interpreting lithium abundances, as the observed Li represents both primordial and newly synthesized ^{7}Li from ^{7}Be decay.

$$^7\text{Be} \to {}^7\text{Li} + e^- + \nu_e \quad (t_{1/2} = 53.22\,\text{days})$$

Work To Be Done

Future work should model lithium production in novae via hydrodynamic simulations of the ^{3}He$(\alpha,\gamma)^7$Be$\to{}^7$Li chain, constrained by multi-epoch spectroscopy of Li I and companion lines (Fe II, Ca I), to quantify yields and mixing in ejecta.

Acknowledgments

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