# A New Reservoir Of Lithium Production In A Metal-Poor Universe

**Sam Ratcliff**
**Project Partner: Nick Bennett**
**Project Supervisors: Dr. Dorottya Szécsi, Prof. Ilya Mandel**

## Introduction

Lithium is a light element synthesized in the first few minutes of the Universe but is destroyed by the high temperatures required for nuclear fusion in a star's core. Therefore it is unclear why lithium is observed in second generations of stars which are thought to have formed in globular clusters from the nuclear processed materials ejected by massive stars in the previous generation. Big Bang nucleosynthesis is often thought to be the mechanism by which lithium in the universe is formed and sets the initial abundance at the beginning of the universe. However, later in a massive star's lifetime, models show a jump in the surface lithium abundance (as in figure 1) which suggest another method of lithium production taking place in stellar interiors which could explain this lithium abundance anomaly. The aim of this project is to investigate this method of lithium production, mechanisms of getting this enriched material into the intracluster medium (ICM), and to see if it is enough to explain the disparity in lithium abundance between first and second generation stars.

## Multiple Populations and Anti-Correlations

- Previously, globular clusters were thought to be simple stellar populations of one generation of stars. However there is now substantial evidence for multiple populations of stars in globular clusters.
- The observed abundances of light elements in the second generation of stars is thought to be due to pollution from elements fused in the stellar cores of the previous generation.
- Anti-correlations in the abundances of elements observed in stars (as in figure 2) are also observed in low mass stars.
- This anti-correlation gives strong evidence for these elements having been produced in sufficiently high temperatures in hydrogen burning reactions.
- So observing this effect in low mass stars (which do not have sufficiently high temperatures for these reactions) indicates pollution by massive stars.
- These anticorrelations are observed in second generation stars which also show higher lithium abundances than would be expected from material formed from nuclear processed material.
- This indicates that another form of lithium production is need to explain these observations.

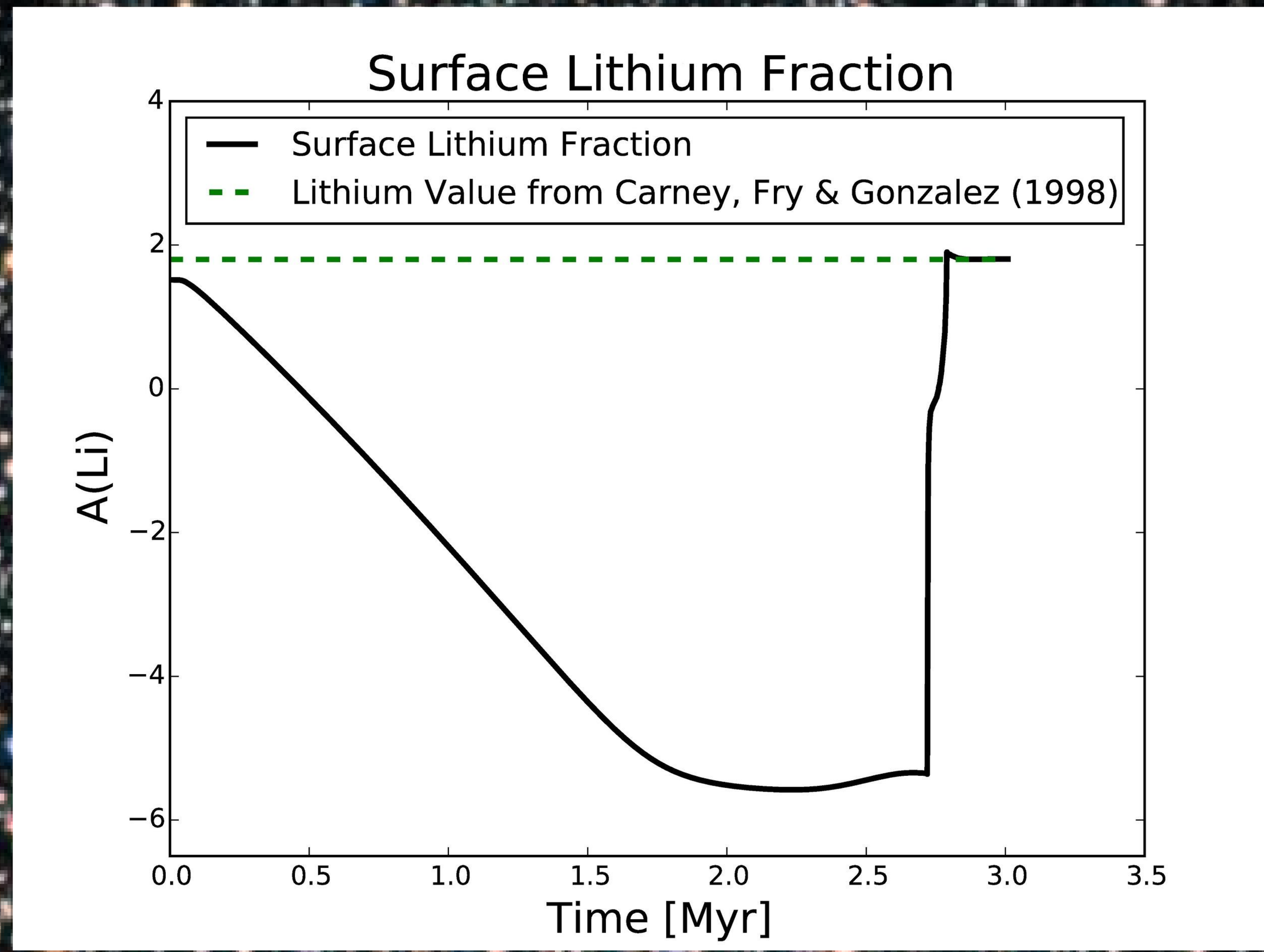


*Figure 1: plot of surface lithium for 77M$_\odot$ star with dotted line showing observational value from Carney et al. (1998).*

## Next Steps

- Next, it would be useful to produce more models of massive stars in the intermediate ranges between current models (i.e. models of 60M$_\odot$ and 85M$_\odot$ stars) to produce a more accurate estimate of the cluster mass of lithium.
- In the mass ranges between the models, the mean of the two models was taken- i.e. for a 85M$_\odot$ star, the values from the 77M$_\odot$ and 100M$_\odot$ models were averaged. To improve on this, a weighted mean could be taken, as lower mass stars are much more abundant than higher mass stars- i.e. the average would lie closer to the value of the 77M$_\odot$ model.
- Once this value has been improved, it would be useful to compare it to observational values of the lithium abundances of globular clusters to see if these methods of lithium production and pollution of the ICM are sufficient.
- It is also important to consider the means of accretion of the intracluster gas by other stars to see if accretion of a surface layer of enriched material could be a factor in the observed abundance anomalies.
- This would reduce the amount of pollution required as observations would show the higher surface lithium abundance, without the whole star having this high abundance throughout.

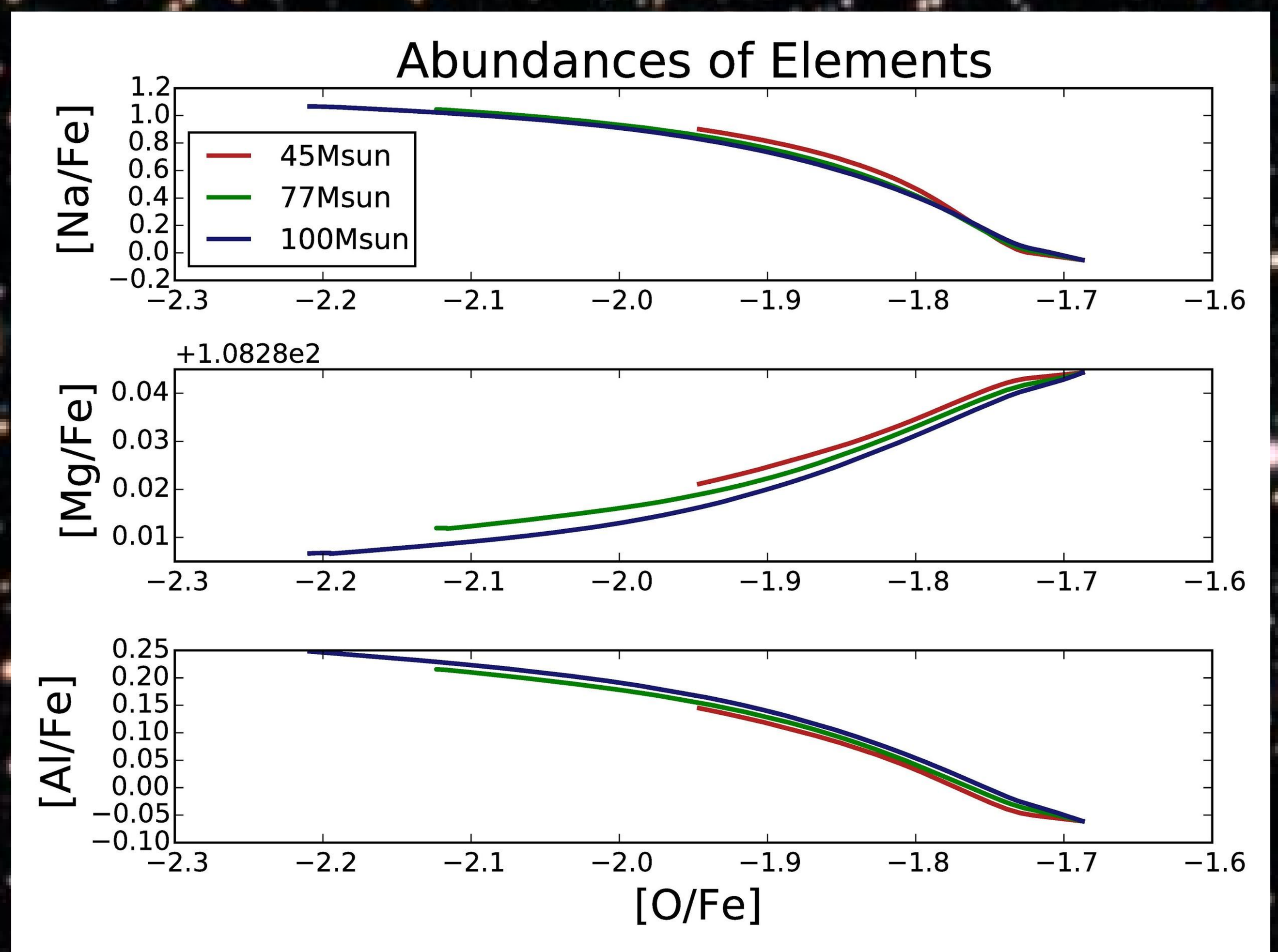


*Figure 2: plot of elements abundances against oxygen for 45M$_\odot$, 77M$_\odot$ and 100M$_\odot$ stars, showing the correlation/anticorrelation effects that indicate the presence of high temperature fusion reactions.*

## Preliminary Results

- We have used the Binary Evolution Code (BEC) interface to create models of 3 massive, low metallicity stars (45M$_\odot$,77M$_\odot$and 100M$_\odot$) that could pollute a cluster with enriched materials.
- Figure 2 shows that these models are capable of reproducing correlations/anti-correlations of elements shown in many papers such as Denissenkov et al. (1997).
- Figure 1 shows the initial depletion in surface lithium throughout time as it is destroyed in the core and this depleted material is mixed out to the surface layers by convection.
- Similarly, the jump in figure 1 is due to lithium being produced in the core by the proton-proton (pp) chain, and mixed out to the surface before this lithium gets destroyed in the core.
- Therefore this shows a previously unaccounted for method of lithium production.
- The total mass of lithium ejected by the star at each point in its lifetime was also calculated and the results showed that this late stage in the evolution of the star, when the lithium production takes place, also corresponds to the time where the most mass is ejected by stellar winds (by several orders of magnitude)- providing a mechanism for getting lithium into the ICM and enriching the next generation.
- Table 1 shows the total mass of lithium in each model (at its highest point), and also the total amount of lithium ejected in stellar winds by these stars throughout its lifetime.
- These results were used to obtain a preliminary estimate for the total mass of lithium in a cluster and ejected in stellar winds, scaled up using the Salpeter initial mass function.

| | Maximum Lithium Mass in Star (M$_\odot$ ) | Total Lithium Mass in Stellar Winds (M$_\odot$ ) |
|---|---|---|
| **45M$_\odot$ Model** | $7.66\times10^{-10}$ | $7.27\times10^{-11}$ |
| **77M$_\odot$ Model** | $8.67\times10^{-9}$ | $1.46\times10^{-9}$ |
| **100M$_\odot$ Model** | $7.38\times10^{-9}$ | $1.58\times10^{-9}$ |
| **$10^6$ star cluster** | 2..66x$10^{-6}$ | $4.53\times10^{-7}$ |

*Table 1: table showing the highest amount of lithium in each model and the total mass of lithium ejected in stellar winds throughout its lifetime. The last row shows these values scaled up for a $10^6$ star cluster.*

**References**

Carney et al., *Lithium and r-Process Abundances in the Population II Cepheid M5 V42*, 1998

Denissenkov et al., *The puzzling MgAl anticorrelation in globular-cluster red giants: primordial plus deep mixing scenario?*, 1997

Image: D. Verschatse (Antilhue Observatory, Chile)