A New Source of Lithium:

Probing massive low-metallicity stars

Nicholas Bennett | Supervisors: Dorottya Szécsi & Ilya Mandel | University if Birmingham | Project Partner: Samuel Ratcliff

Introduction

Globular clusters are dense concentrations of stars of similar ages which provide a unique look at the evolution of stars. A typical cluster may contain 10^5 - 10^6 stars with ages greater that 10 Gyr. Due to the age of the stars present in globular clusters many are remnants of much older populations. While we expect levels of light elements to be consistent with population II stars (stars formed from the gas enriched by a previous generation) several observations show anomalies in the expected levels of lithium in the surface of some of these stars. We attempt to explain these results using evolutionary models of massive low-metallicity stars in the range of 45-100 $M_\odot$. The observations of abnormal lithium abundances are found in a number of papers including Monaco et al., however the most interesting values and the motivation for this project are in the paper from Pasquini et al. researchers have posited that a previous generation of stars enriched the current generation, however, the mechanism by which is not well researched. This lithium source, as well as the mechanism to distribute this amongst stars in the cluster will be the topic of this project.

Background

The evolution of globular cluster is not greatly understood. This means that many observations of these objects can produce results that are difficult to decipher. Globular clusters contain stars from multiple generations meaning that there has been 2 or 3 different periods of star formation. With each star forming phase enriching surrounding space with light elements.

In all stars primordial lithium is destroyed by the high temperatures of nuclear burning. This leaves negligible amounts left near the end of the stars life. In high mass low-metallicity stars, however, a deep convective envelope reaches the hydrogen burning shell during the helium core burning phase. The lithium produced in PP chains can be mixed up to cooler surface layers before it is destroyed.

When the lithium is in these surface layers at relatively high abundances . Some may be ejected as winds. Another possibility is that binary companions or objects nearby can strip the entire lithium containing envelope from the massive star, spreading large amounts of lithium into the surrounding space, whether the material is ejected completely from the cluster will require more analysis.

Results

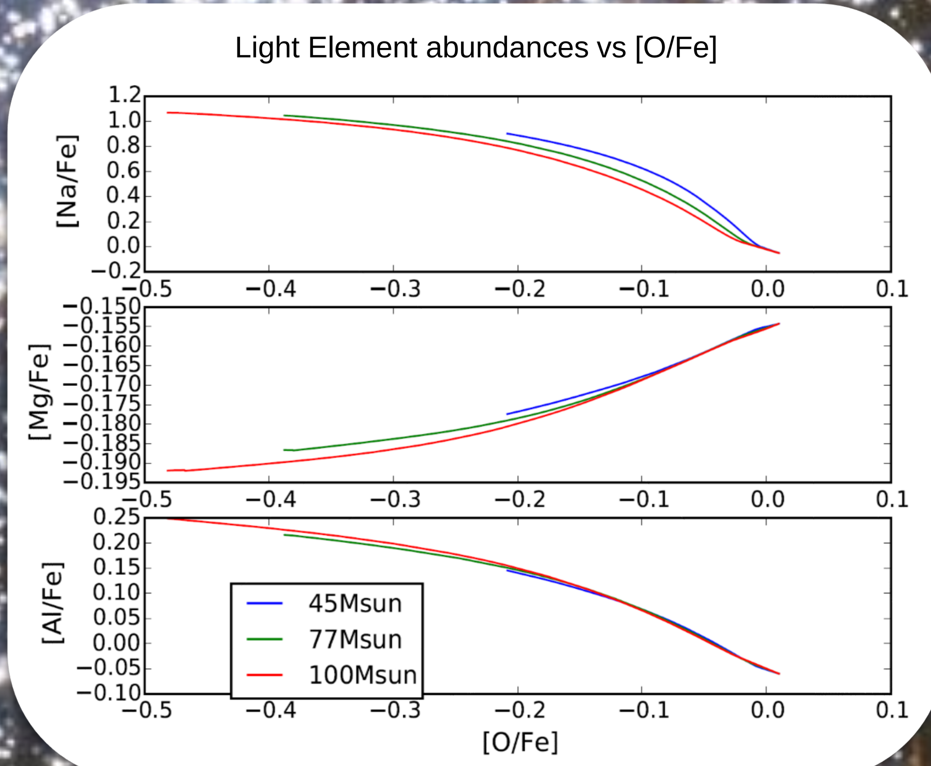
At this stage, we have closely studied 3 stellar models of high mass stars, each with the same rotational velocity and low-metallicity but each having a mass of 45, 77 and 100 $M_\odot$ respectively. These models all show an increase of surface lithium abundance during the core helium burning phase. With the 77 $M_\odot$ mass star showing the most production.

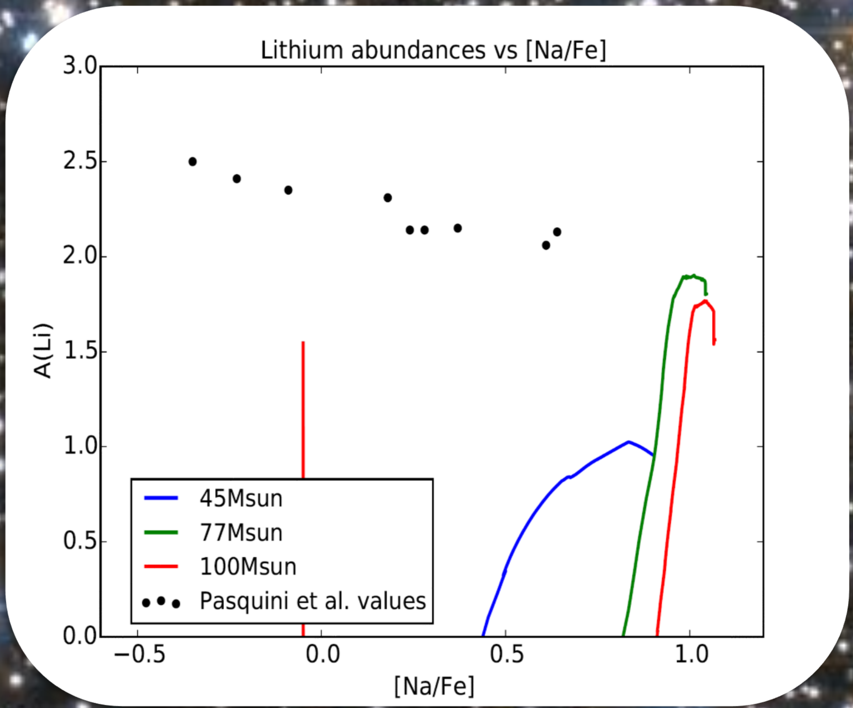
Plots of surface and core levels of lithium and other light elements have been plotted and compared to observational values with good agreement. The anti-correlations between lithium and other elements have also been investigated as these results have been observed several times in the past. The entire mass of lithium present in these models has been calculated as well, allowing for us to present an estimate of the expected lithium produced by an entire cluster of a certain mass. These values are shown below. An estimate of the amount of lithium produced by a cluster containing 10^6 $M_\odot$ worth of material was calculated using the Kroupa 2001 IMF(initial mass function). The estimate was calculated as ~2.5 X 10^{-6} $M_\odot$

Stellar Mass $M_\odot$	Mass of Lithium in Star $M_\odot$	Mass of Lithium Lost in Winds $M_\odot$	Total mass Produced $M_\odot$
45	7.12 X 10^{-10}	9.1 X 10^{-11}	8.03 X 10^{-10}
77	5,84 X 10^{-9}	1.53 X 10^{-9}	7.37 X 10^{-9}
100	3.42 X 10^{-9}	1.8 X 10^{-9}	5.22 X 10^{-9}

Light Element Anti-Correlations

To the right is a graph showing the surface abundances of Na, Mg and Al over the lifetime of 3 stellar models, with the masses shown. Below is a graph showing surface sodium vs lithium abundance for 3 stellar models, as well as reference values taken from Pasquini et al. These results are important as they demonstrate differences in initial composition.





Light Element Spreads

Below is a table showing the spread of light element abundances for the cluster NGC 6752 (Decressin et al.) and the 3 models that we have so far produced. This table demonstrates the change in elemental abundances as expected from destruction/production if elements given different initial compositions

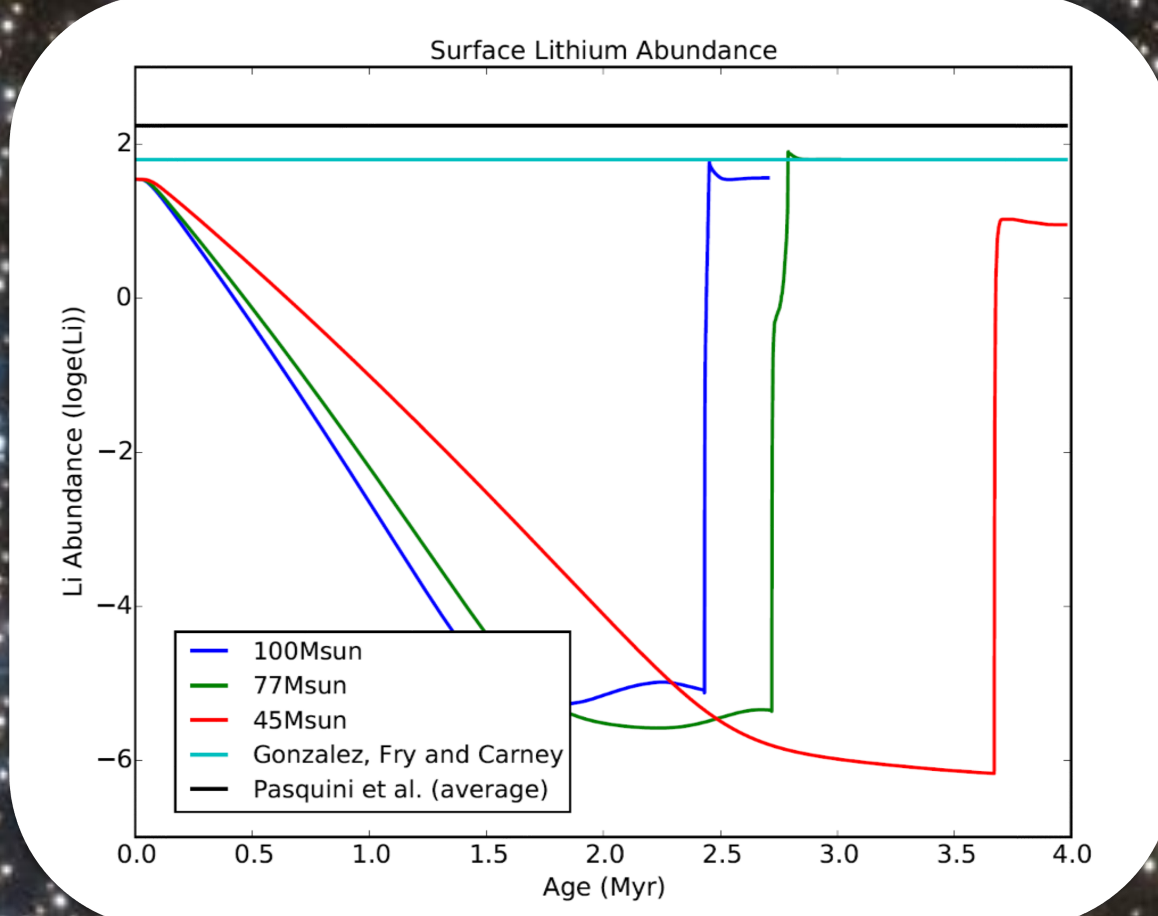
Model	δNa	δO	δMg	δAl
NGC6752	0.9	-1.0	-0.3	1.4
45	0.95	-0.23	-0.033	0.2
77	1.09	-0.41	-0.037	0.27
100	1.11	-0.48	-0.041	0.31

Aims

- To create evolutionary models of massive low-metallicity stars to test the lithium and other light elemental abundances in these stars.
- Look at the effect of rapid rotation on mixing and lithium production and to investigate the possibility that binary companions strip these high mass stars and enrich the surrounding space.
- To understand the details of the lithium production mechanism as well as whether this lithium is causing the anomalous results, and by which mechanism.

An interesting discovery!

To the left is a graph showing the surface abundance of lithium over the lifetime of 3 stellar models, with the masses shown. reference levels from different observed values are also shown. The large amount of lithium produced near the end of the stars life is indeed an interesting observation and may hold the key to the observed abnormalities in globular clusters.



Conclusions and Next Steps

So far we have shown that some models show more promise that others. There was clearly an optimum level of production at 77 $M_\odot$, so producing more models around this mass value is a logical next step. This flexibility with the models allows us to look closely at stars around this mass and more carefully carry out the analysis required. We will also be looking into the case of binary stripping, whereby a nearby companion strips the outer, lithium rich envelope. This mechanism for the enrichment or pollution of the cluster will be scrutinised both analytically and by simulations using the evolutionary models. In probing these objects we hope to learn more about their mysterious pasts and give insight into the evolution of not just massive low-metallicity stars but also globular clusters as a whole.

References

Pasquini et al. 2005 | Gonzalez Fry and Carney. 1997 | Decressin et al. 2007 | Monaco et al. 2012 | Kroupa. 2001 | Bastian et al. 2013

Background Image: NGC 6752 (taken by the NASA/ESA Hubble space telescope)

Top Right image: Wolf Rayet star 124 (taken by the NASA/ESA Hubble space telescope)

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