Investigating The Effects of Mass And Metallicity On The Rate Of Deep Mixing In Red Giant Branch (RGB) Stars.

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Motivation

In order to accurately model stellar evolution, we must be able to model how the internal structure and chemical composition of stars change as they age.

This project focuses on a currently poorly understood process called Deep Mixing.

Previous work focuses on stars in globular clusters and the correlation between mixing rate and metallicity.

Essential Knowledge

This slide contains some essential information that I will be using through out the presentation:

- $\odot$ means its a solar value (belongs to the Sun)
- Anything that is not hydrogen and helium is a metal.
  Commonly, we describe the chemical composition using bracket notation by comparing to the sun using a logarithmic scale. For instance:

$$\left[\frac{Fe}{H}\right]_{\star} = \log\left(\frac{N_{Fe}}{N_H}\right)_{\star} - \log\left(\frac{N_{Fe}}{N_H}\right)_{\odot}$$

- Surface gravity is measured in $cm\ s^{-2}$ and is represented in $\log(g)$.
- Effective temperature (T_{eff}) is an estimate of the star's temperature.

What is Deep Mixing?

Deep mixing:

- occurs in low mass red giants ($<2.2M_\odot$)
- is characterised by:
  - Decrease in $\left[\frac{C}{Fe}\right]$ and
  - Increase in $\left[\frac{N}{Fe}\right]$ (which means the mixing rate can be measured by measuring $\left[\frac{C}{N}\right]$).
  - Increase in $^{13}C/^{12}C$ ratio

What we expect:

- Noticeable dip in $\left[\frac{C}{N}\right]$ when mixing occurs

- Decrease in $\left[\frac{C}{N}\right]$ should only occur for stars with $M < 2.2M_{\odot}$

- The decrease is not reversible ($\left[\frac{C}{N}\right]$ will gradually decrease as $\log(g)$ increases.)

Overview of the project

The project is structured into the following stages:

1. Create and training a machine learning model to predict the mass of stars
2. Uses the model to predict the mass of stars in APOGEE
3. Determining the mixing rate as a function of mass and metallicity
4. Investigate unexpected phenomena

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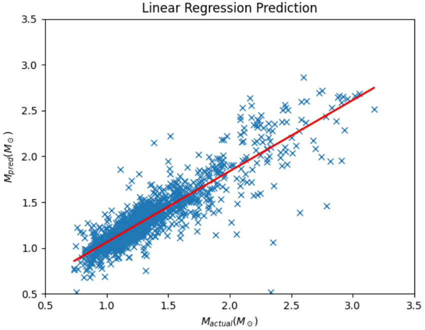
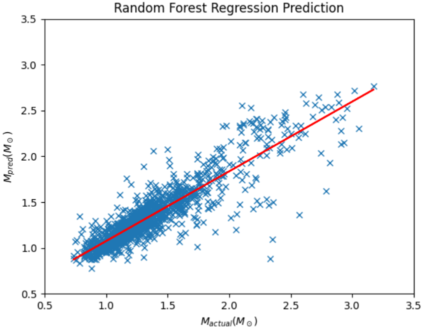
Goal: Predict mass for the APOGEE (Apache Point Observatory Galactic Evolution Experiment) catalog (APOGEE does not have mass included by default)
To do this, we use the APOKASC catalog (which contains mass derived using asteroseismic data) to train a model.
The training set will predict mass using:

- Effective Temperature T_{eff} Surface Gravity $log(g)$ Metallicity $\left[\frac{Fe}{H}\right]$ Alpha Abundance $\left[\frac{\alpha}{Fe}\right]$ Carbon Abundance $\left[\frac{C}{Fe}\right]$ Nitrogen Abundance $\left[\frac{N}{Fe}\right]$ Oxygen Abundance $\left[\frac{O}{Fe}\right]$

T_{eff} and $\log(g)$ were chosen as they vary with time in a way that is dependent on $\left[\frac{\alpha}{Fe}\right]$ and $\left[\frac{Fe}{H}\right]$.

Mass Prediction Model





Out of the two models used, Random Forest Regression is marginally better than Linear Regression (despite being both models being very close in terms of error and correlation)

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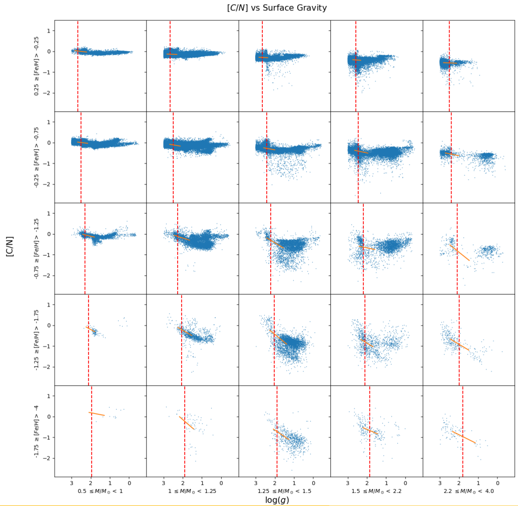
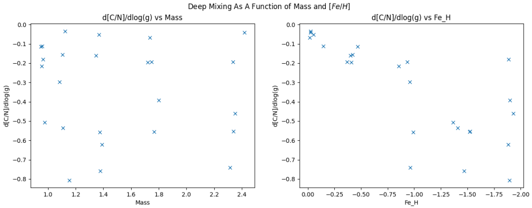
Results

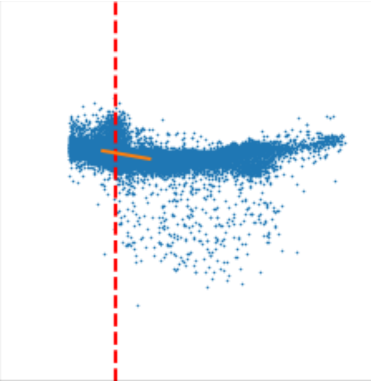


The $\left[\frac{C}{N}\right]$ for stars, separated based on mass and metallicity. The vertical red line indicates where deep mixing theoretically begins. The orange lines show the change between average $\left[\frac{C}{N}\right]$ before and after deep mixing has theoretically begun

Discussion



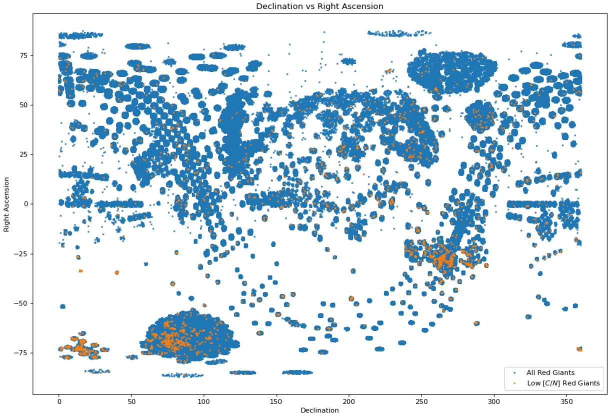
- As metallicity decreases, mixing rate increases (EXPECTED)
- As mass decreases, mixing rate does not increase (UNEXPECTED)
- Mixing occurs for stars with $M > 2.2M_{\odot}$ (UNEXPECTED)
- Recovery in $\left[\frac{C}{N}\right]$ for some stars (UNEXPECTED)
- Low $\left[\frac{C}{N}\right]$ stars (UNEXPECTED)

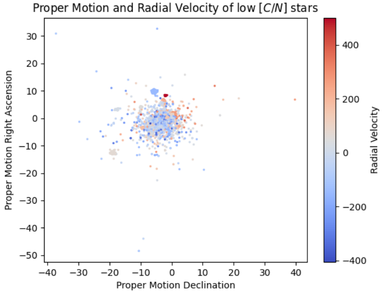


The figure shows stars with $\left[\frac{Fe}{H}\right]$ between -0.25 and -0.75 and mass between $1.25 M_{\odot}$ and $1.5 M_{\odot}$.

- We notice that towards the end of the graph (as $\log(g)$ decreases), the $\left[\frac{C}{N}\right]$ has an upwards trend. Why?
- We can also notice that there are significant number of stars below the main group. Why?

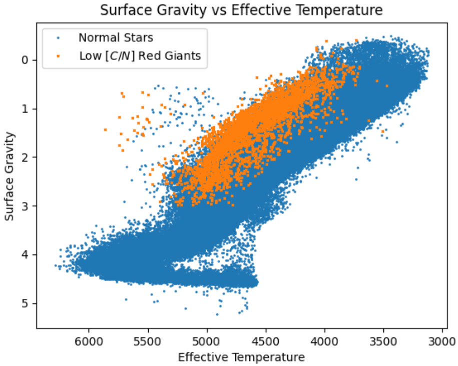
Globular Clusters





Verdict: Globular Clusters do not explain all the low $\left[\frac{C}{N}\right]$ stars.

Asymptotic Giant Branch (AGB) Stars



Verdict: AGB Stars do not explain all the low $\left[\frac{C}{N}\right]$ stars.

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Summary

We were able to show a negative correlation between metallicity and mixing rate in our research. However, a negative correlation between mass and mixing rate could not be inferred as indicated by the literature.

Future Research

- Mixing rate dependence on mass (include whether mixing occurs for stars with $M > 2.2M_\odot$ and whether mixing rate decreases as mass increases as the theory predicts)
- Presence of low $\left[\frac{C}{N}\right]$ stars (including determining AGB stars using asteroseismic data)
- Recovery in $\left[\frac{C}{N}\right]$

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In summary, during this project, I have:

- Crashed my computer 3 times when trying to open up an 18GB file
- Written more than 1000 lines of code
- 983701 characters in total for meeting minutes and code + other research (if my git command works like I think it does)

Also an FYI, we have a lot of spare tongs in the Research Student room on Floor 1 if you would like them owo.

Thank You!

Special thanks to my supervisor Sarah Martell for having a response time of 2 ms (amongst a ton of other things)