Impact of White Dwarf Parameters On Surface Metal Accretion

Shubham Apte

0.1 Aim:

White dwarfs (WD's) are very dense stellar core remnants having volume comparable to earth but mass nearly equal to that of sun. Therefore, it was believed that there cannot be any heavy elements on the white dwarf surface. Being heavy as compared to Helium and Hydrogen, these elements would sink to the core of the WD. But according to studies, there were signatures of heavy metallic elements on the WD surface. As per the study conducted later by Zuckerman, it was found that these signatures can point towards an ongoing metal accretion from nearby objects, like comets/planets, etc. Thus, along with direct spectral analysis of such objects, their composition is being found out by studying the surface metal pollution of nearby WD's. This project tries to achieve the following:

- The different stellar parameters like Effective temperature, surface gravity, Mass, Cooling age of White dwarfs might have an impact on metal proportion observed on the surface. To study if any such correlation exists.
- To find correlation between occurrence of different heavy metals and mass parameter, and determine the most significantly observed metals for DZ, DAZ, DBZ type WD's.
- To find how well the findings match with the theoretical expectations.
- To get an idea of how well above parameters can explain surface metal pollution using basic linear and polynomial machine learning model.

0.2 INITIAL DATA PROCESSING:

The dataset was obtained from Montreal White Dwarf Database for the three types of WD's:

- DZ : White dwarfs with metal lines and no hydrogen or helium lines dominating.
- DAZ : Hydrogen-dominated white dwarfs with metal lines present.
- DBZ : Helium-dominated white dwarfs with metal lines present.

  The dataset was cleaned and preprocessed. It includes data for all the parameters discussed above.

0.3 CORRELATION ANALYSIS

0.3.1 CORRELATION BETWEEN MASS AND METAL ABUNDANCE:

Using Pearson correlation, Correlation and P-values were found for "Mass of White Dwarf" and each heavy metal present on its surface. Based on this analysis, the metals which were most commonly observed to have a relationship with WD mass, were determined to be the "Significant Metals". The criteria for selection followed:

- The absolute value of correlation factor should be maximum amongst all other metals. AND
- The result should be statistically significant, i.e., P-value ¡ 0.05

The following "Significant Metals" were obtained:

DZ:

- **Calcium/He**:

1. Pearson correlation: 0.150 → weak positive correlation.
2. P-value: 0.00008 → highly statistically significant, indicating a strong relationship between calcium/helium ratio and mass.

- **Magnesium/He**:

1. Pearson correlation: 0.252 → moderate positive correlation.

2. P-value: 0.0016 → highly statistically significant, suggesting a strong relationship between mass and magnesium/helium ratio.

The thing to note here is that both the elements have a positive correlation with mass. This means as the mass of White Dwarf increases, the proportion of these elements on its surface also increases. The reason for this is discussed afterwards.

DAZ:

- **Nickel/H**:

1. Pearson correlation: -0.999
2. P-value: 0.027
3. Interpretation: Extremely strong negative correlation and statistically significant (p ¡ 0.05). This indicates that as white dwarf mass increases, nickel abundance decreases significantly in DAZ white dwarfs.

DBZ:

- **Calcium/He**:

1. Pearson correlation: -0.242
2. P-value: 0.026
3. Interpretation: Weak negative correlation but statistically significant (p ¡ 0.05). This indicates that as white dwarf mass increases, calcium abundance tends to decrease in DBZ white dwarfs.

0.3.2 CORRELATION BETWEEN AGE AND METAL ABUNDANCE:

Using Pearson correlation, Correlation and P-values were found for "Age of White Dwarf" and each heavy metal present on its surface. This time only the "Significant metals" obtained above were considered for the analysis. With the same selection criteria as above the following result was observed:

Magnesium/Helium (For DZ type) had the highest correlation with Age parameter amongst the four significant metals:

1. Pearson correlation: -0.266
2. P-value: 3.1e-05
3. Interpretation: There is a moderate negative correlation between age and magnesium/helium abundance, and this result is statistically significant (p ¡ 0.05). This suggests that as white dwarfs age, magnesium proportion decreases the most, possibly due to sinking processes that depletes it over time.

0.4 MULTIVARIABLE ANALYSIS:

We have analyzed two of the most important parameters one by one, Age and Mass. Using Multivariable analysis we verify our result. Also, the impact of remaining two parameters is also analyzed. This is achieved using Linear regression and Polynomial regression. The results by the Linear regression gives the correlation as:

- **T eff (Temperature)**: 5.19288193e-05

  Interpretation: This small positive coefficient indicates a weak positive relationship between temperature and metal abundance. A very small increase in temperature slightly increases metal abundance in the white dwarf atmosphere. Since the effect is small, **temperature might not be a major factor in explaining metal abundances**.

- **Log g (Surface Gravity)**: -1.38727640e+00

  Interpretation: A negative coefficient suggests that higher surface gravity is associated with lower metal abundances. This makes sense, because surface gravity is often related to the mass of the white dwarf, and heavier white dwarfs tend to experience faster sinking of metals. The large magnitude of this coefficient suggests that log g plays a significant role in determining metal abundance. **This matches with Theoretical predictions**.

- **Mass**: 1.51629846e+00

  Interpretation: Surprisingly, this positive coefficient implies that higher mass results in higher metal abundance, which **does not match with theoretical predictions**. As per theory, heavier white dwarfs typically show lower metal abundances due to faster sinking. **This might suggest that other factors, like ongoing accretion is the reason behind the discrepancy.** Or the data might be biased, containing masses only in a specific range.

- **Age**: -6.07063246e-01

  Interpretation: The negative coefficient indicates that older white dwarfs tend to have lower metal abundances, which aligns with Theory. Over time, metals sink into the star's interior, leading to reduced metal abundances in the atmosphere. The magnitude of this coefficient shows that **age has a noticeable effect on metal depletion**.

0.5 MACHINE LEARNING TO DETERMINE EFFECTS OF PARAMETERS ON METAL ACCRETION:

First, we performed the Linear model, fitting each parameter separately with the metal abundance to visualize the extent of error in our model. We then calculated the R^2score shows how well the model explains the relation between Metal abundance and the parameters.

The R^2score for the linear model = 0.1139.

This is a low R^2score, meaning linear model only explain about 11% variance in metal abundance based on the parameters.

To increase the R^2score, we perform Polynomial model of degree 5, which gives the maximum R^2score for our data.

The R^2score for the Polynomial model = 0.5440.

This score indicates that our basic machine learning model has succeeded in explaining about 54% of the variation in the metal abundance based on the parameters.

0.6 ACHIEVEMENTS AND CONCLUSION:

- **Objective Achieved**: The project successfully modeled the relationship between White Dwarf parameters and surface metal abundance, with a particular focus on spectral types DZ, DAZ, and DBZ.

- **Key Achievements**:

1. Significant correlations were found between mass, age, and metal abundance. Some metals like Calcium, Magnesium were found to have strong relationships with the parameters.
2. Polynomial regression using machine learning helped capture non-linear trends, achieving nearly 55% accuracy.

- **Comparison to Theory**: The trends observed matched the theoretical predictions, especially regarding metal retention in older, more massive white dwarfs. However,the observed relationship of mass and the surface metal occurrence did not match the theoretical expectations. The possible

  reasons can be an ongoing metal accretion by the White Dwarf which resulted in a constant flow of metals on the surface. This project has a scope to include current accretion events to correctly predict the mass correlation.