Derived Abundances of the Leo II Dwarf Galaxy

David O. Cook
Department of Astronomy, University of Minnesota,
116 Church Street SE, Minneapolis, MN 55455

1. Introduction

Dwarf galaxies present the most useful tool available to determine the formation and evolution of galaxies. They are the most common class of galaxy in the universe, and are the progenitors of larger structures in the Universe. So in order to figure out how the Universe evolves we first have to understand how dwarf galaxies evolve. One of the best ways to do this is through comparing dwarf galaxies to globular clusters.

Globular clusters are very old stellar regions that ceased forming stars soon after being formed. Since the early Universe was dominated by massive stars only core collapse super novae (type II SN) injected their respective interstellar medium (ISM) with alpha elements leaving the iron core to collapse in on itself. This would have the effect of each globular cluster having uniform metallicities and relatively high alpha element to iron ratios [α/Fe] compared to other structures that have had continual star formation.

Dwarf galaxies have had sporadic but continual star formation over their lifetimes. Since their formation, enrichment of their ISM have allowed lower mass stars to form and therefore type Ia SN to occur. In this scenario, Type 1a SN expel their iron core as well as their outer alpha element shells. This process will allow more and more iron to be mixed with the ISM effectively reducing the alpha element to iron ratios in dwarf galaxies compared to globular clusters.

We have used spectroscopic data, with wavelength range 7000-9500 Å, previously obtained by Bosler et al. (2007) to study the relationship between the near infrared (IR) calcium triplet and metallicity of RGB stars in the Leo II dwarf galaxy. That study did not concentrate on the numerous iron, titanium, magnesium, and sodium lines contaminating the medium resolution spectra. We have used these lines to compare the [α/Fe] of Leo II to four globular clusters also obtained by Bosler for the same study.

However, an equivalent width method for studying these lines will not suffice since they are contaminated by weak molecular features and even blend with themselves at this resolution. Therefore we have opted to utilize the synthetic spectra method to model these lines in an attempt better account for blending issues.

The rest of this paper is split into 4 sections with section 2 discussing how the data was further reduced and the method for deriving abundance ratios. This will be followed by a discussion of the globular cluster and Leo II results in sections 3, and finally a summary will be presented in section 4.

2. Data Reduction & Analysis

Both the Leo II and globular cluster data was reduced as layed out by Bosler et al. (2007). However, since the alpha abundance spectral lines were not as strong as the calcium triplet, all data was renormalized to clean up the continuum using standard IRAF tasks.

Alpha abundances were derived based on matching stellar model synthetic spectra to the observed spectra of each RGB star. The model atmospheres had three parameters: effective temperature (T_{eff}), surface gravity (log g), and microturbulance (v_t).

The effective temperature was calculated using (B-V) photometry and the temperature-color relationship of Ramirez & Melendez (2005). The (B-V) photometry was used for consistency since not all clusters and Leo II had another full color system set. This method also took into account the metallicity of each star. We assumed the cluster metallicity for the globular cluster stars and used the results of Bosler et al. (2007) for the stars in Leo II. Unfortunately the metallicity tables given in Ramirez & Melendez (2005) did not cover ranges so intermediate metallicities were interpolated assuming a linear fit to the metallicities that were given.

In order to calculate the surface gravity of each star the temperature and bolometric corrected magnitude were used. The distance modulus used to calculate the bolometric correction were 15.07 for M3, 13.76 for M107, 15.59 for NGC 1094, and 15.19 for NGC 4590. Also, the calculation of log g required the mass of each star which we assumed to be 0.8 times the mass of the Sun.

The microturbulance was calculated according the formula layed out by ***So and So***. Although a typical value of 2 km s^{-1} for v_t would have sufficed for RGB stars in globular clusters, the individually calculated values were used due to the importance of these stellar model atmospheres. A range of 1.9 km s^{-1} to 2.4 km s^{-1} was observed for the data in both the globular clusters and Leo II.

The derivation of alpha abundances was done by comparing the observed spectrum to the model atmospheres of each star using the LTE line-analysis code MOOG (Sneden 1973). We used a Gaussian fit for all model atmospheres with a FWHM of 1.55 Å, as reported by Bosler et al. (2007), for smoothing. The model atmospheres were given an input metallicity of cluster metallicity, for the globular clusters, and the derived values given by Bosler et al. (2007), for the Leo II stars. The iron lines were then forced to match the observed spectrum as best as possible using multiple iron lines. A weighted mean of all the iron lines were used to determine the best [Fe/H] value for each star. The model was then set to this metallicity from which the [α/Fe] abundances were determined. This was done by holding all elements constant and varying the desired alpha element with three different abundances as can be seen in figure 1. The best fit was determined by the output difference from the observed spectra calculated by MOOG.

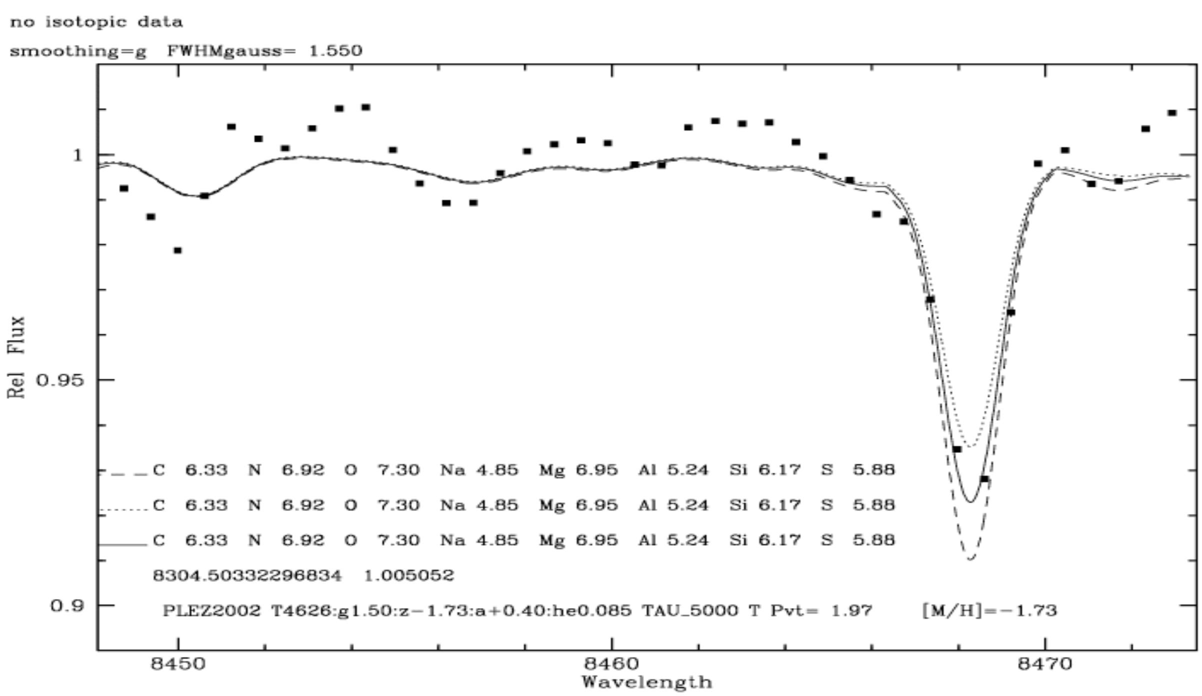

Figure 1: The graphical method for determining which abundance gave a best fit to the observed spectrum. Where the dotted line is the observed spectrum and the other three lines are the varied abundances of the synthetic spectra. The line shown is the iron line at 8469 angstroms.

The line list used was obtained from R. L. Kuruz line database. In order to calibrate this line list we created a solar model atmosphere with parameters of: T_{eff} = 5780, log g = 4.44, and v_t = 1.0 km s^{-1}. Matching the solar synthetic spectrum to the actual solar spectrum allowed us to force minor adjustments in the log (gf) and wavelength line list values to obtain a better match. However, the stars observed in this study are red giants and therefore the line list was also calibrated to a nearby red giant star, Arcturus. The model atmospheric parameters are: T_{eff} = 4290, log g = 1.94, and v_t = 2.0 km s^{-1}.

3. Results & Discussion

The results of this study are best presented in graphical form since it would be inconvenient and not very enlightening to list every star's metallicity and corresponding [α/Fe]. Therefore, the graphs in figures 2 through 5 illustrate the [α/Fe] vs. [Fe/H] relationship for the globular clusters and the Leo II dwarf galaxy. The cluster stars are the black diamonds and the dwarf galaxy stars are blue triangles. Also, it is easier to see a separation of the cluster and dwarf galaxy stars if the graphs are broken into metallicity bins, which increment by 0.5 dex, and averaged over the individual bins.

The titanium element had the most lines to study of all the alpha elements. Unfortunately, the Leo II data did not completely cover the metallicity range of the globular clusters. As you can see in figure 2, there is a trend of decreasing alpha abundance in the Leo II data compared to the GCs at intermediate and high metallicity. Due to the age/metallicity relationship, this implies that there is a trend of decreasing alpha abundance in the Leo II data at intermediate and young ages of these stellar structures. Also, except for the metallicity bin between -1.5 and -1 dex, the Gcs have a roughly constant alpha abundances as would be expected from the model of single star burst formation of globular clusters.

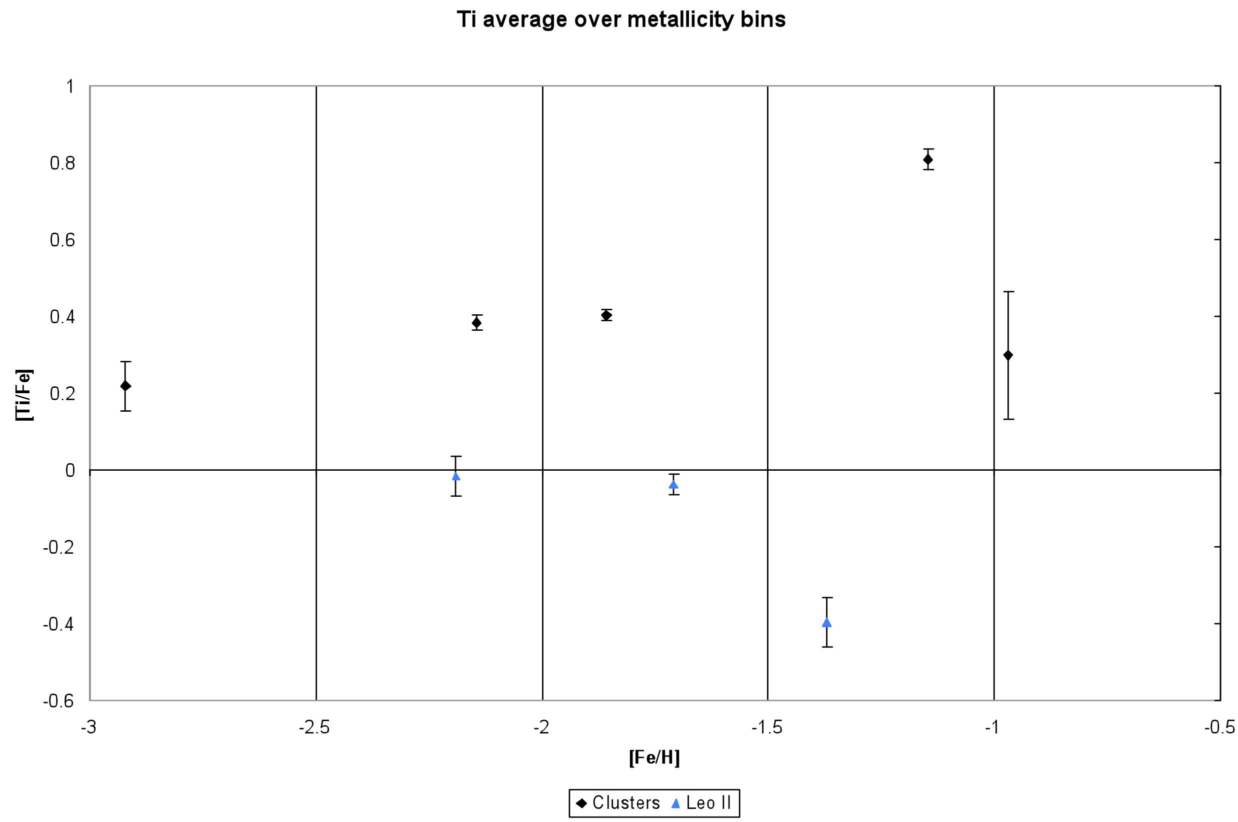

Figure 2: [Ti/Fe] vs. [Fe/H] averaged over incremental metallicity bins of 0.5 dex.

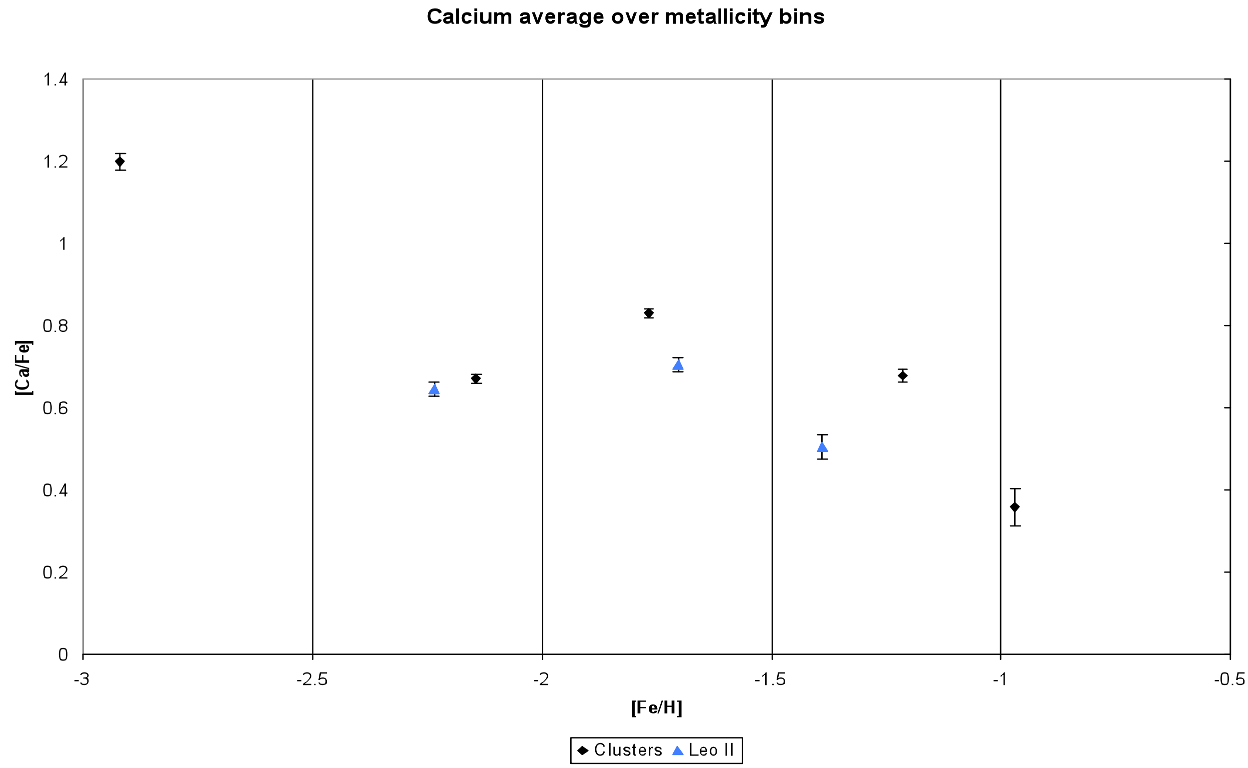

Figure 3: [Ca/Fe] vs. [Fe/H] averaged over incremental metallicity bins of 0.5 dex.

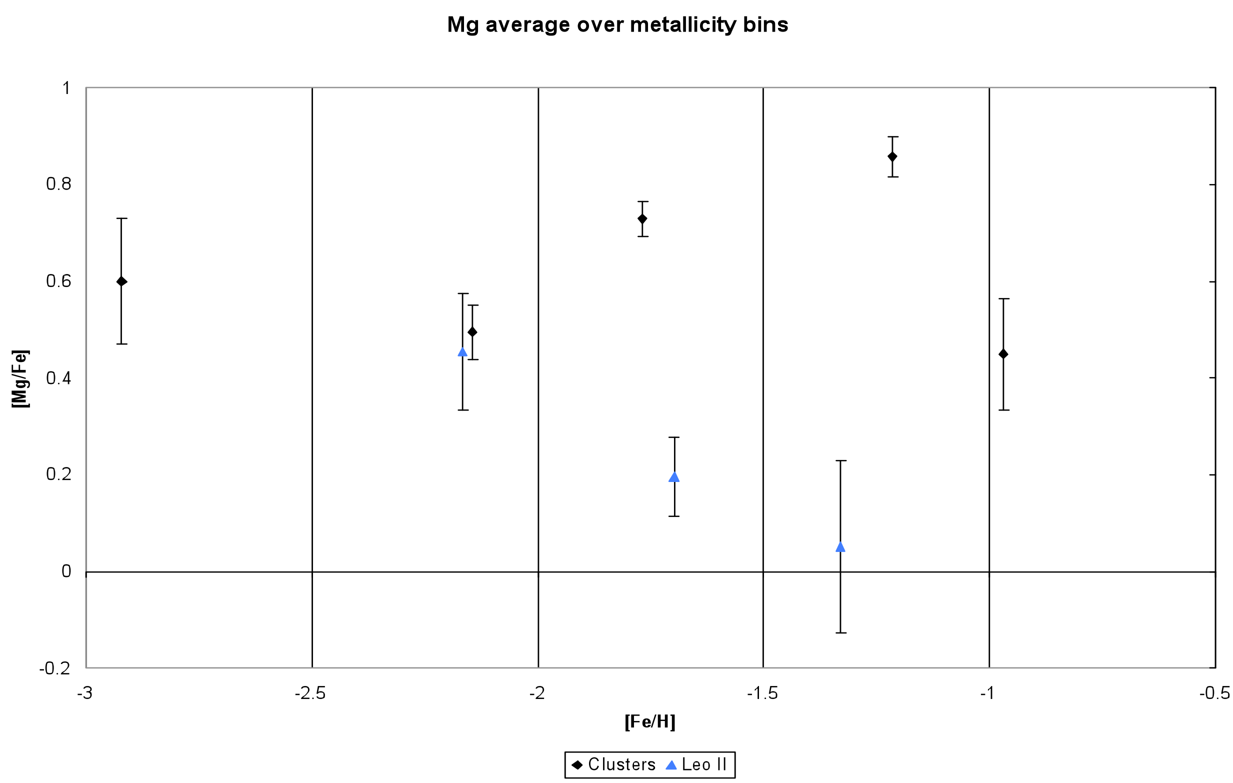

Figure 4: [Mg/Fe] vs. [Fe/H] averaged over incremental metallicity bins of 0.5 dex.

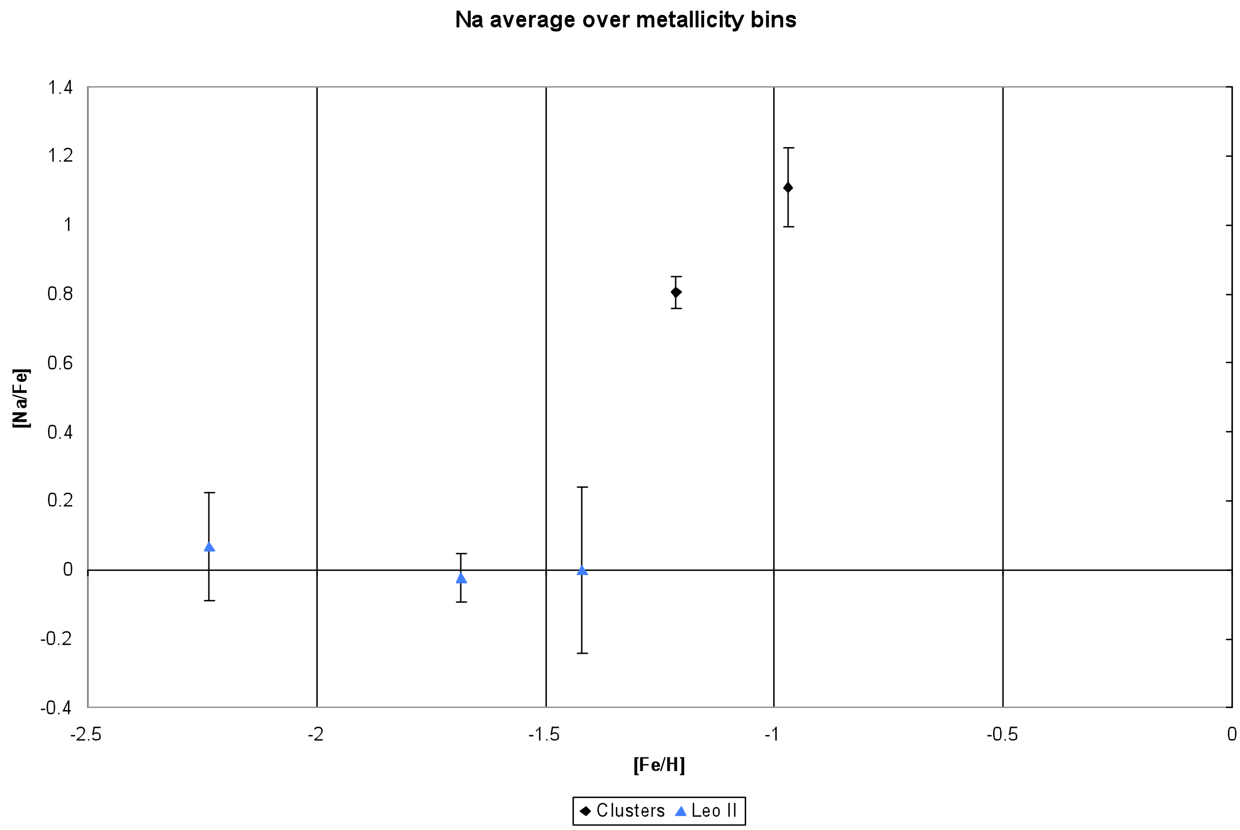

Figure 5: [Na/Fe] vs. [Fe/H] averaged over incremental metallicity bins of 0.5 dex.

Calcium had the strongest lines of all alpha elements throughout this study. This had a consequence of being observable in almost every star, both GC and Leo II. And although this would normally lead to very clear results, the calcium lines turned out have problems because they had such strong lines. When modeling a stellar atmosphere a very strong line can be difficult to simulate. Broadening effects can play a large role in determining abundances since the area under the absorption line will now have a significant fraction under the wings of the line. The synthetic spectra are unable to treat these lines like every other line, and so a strong line-list was used to account for each strong line's broadening. Each strong line's broadening was input manually and calibrated to the solar and Arcturus observed spectrum to best model the GCs and Leo II RGB stars. Although the calcium Leo II data appears to support the evolution model stated earlier, it is unclear how reliable it is (Figure 3). This uncertainty might be roughly estimated by noticing the wild fluctuations in the GC alpha abundance ratios, and how they are not constant over age/metallicity.

The magnesium alpha abundance ratios, shown in figure 4, seems to have the relationship that we were expecting for GCs and dwarf galaxies. In the metallicity range between -2.5 and -1, the GC and Leo II stars start out at the same alpha abundance and then separate at younger ages, in which the Leo II stars lower in alpha abundances and the GC stars remain roughly constant. However, the magnesium line was also a very strong line for which the broadening effects discussed earlier would play a major role.

The least frequent alpha element observable in both the GCs and the Leo II data was sodium. There were only two lines of sodium at 8183 and 8194 Å, which was not in the wavelength range of most of the GC and Leo II spectrum. This can be easily seen by the dearth of data points in the [Na/Fe] vs [Fe/H] graph of figure 5. There is only one overlapping metallicity bin between the globular clusters and the Leo II data, so there is little information that can extracted from the sodium lines. There was also an issue of blending with that particular region. The region was littered with multiple molecular features which lead to poor modeling of the sodium lines.

1. Summary

We derived the alpha abundance to iron ratios of RGB stars in four globular clusters and the dwarf galaxy Leo II. According to current formation and evolution models, [α/Fe] should decrease over time for the dwarf galaxy and should remain roughly constant for the globular clusters. This trend was observed in our study, however, the data is not overwhelmingly convincing.

The metallicity range for the stars in the dwarf galaxy did not fully cover the range of the GCs, therefore it is hard to say whether or not the dwarf galaxy and GC stars started off at the same metallicity, or whether they continued to diverge at higher metallicities Most of this problem is due to the difficulty in finding such low metallicty RGB stars in a dwarf galaxy.

Also, there are many difficulties in modeling the stellar atmospheres at the resolution of the data. Many lines were blended with weak molecular features which also changed from spectra to spectra. This caused a problem in that any one line could be contaminated to such a degree that is relatively far from it true value. The best way to combat this problem would be to use multiple lines for each element in the same spectra in order to make sure that one bad line will not distort the results.

The main conclusion of this study is that the synthetic spectra method utilized can feasibly analyze the abundances of low-medium resolution spectra and derive relationships from these abundances. However, only elements with multiple features in each spectrum would be accurate enough to allow any conclusions to be made.