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Determining Chemical Homogeneity of the Open Cluster NGC 752 through High-Resolution Abundance Analysis

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ABSTRACT

Using high-resolution, high-signal-to-noise ratio Keck/HIRES spectra, we have derived the temperature and pressure structure, and elemental abundances of the atmosphere of six stars believed to be in the galactic open cluster NGC 752. Three of the stars are main-sequence dwarfs, and three are evolved red giant stars. We find the iron abundances to have an average value of $[\mathrm{Fe/H}] = -0.01$ (on a scale where the Sun has an iron abundance of $[\mathrm{Fe/H}] = 0$) with a standard deviation of 0.02 dex, providing evidence that the molecular cloud from which these stars formed was chemically homogeneous. We also derived the abundances of carbon, oxygen, sodium, magnesium, aluminum, and nickel to further demonstrate this claim. Additional derivation of the star's nitrogen abundance will be performed, and an analysis of the abundances will be done by testing stellar nucleosynthesis models.

1 INTRODUCTION

An open cluster is a group of a few thousand stars that were formed from the same molecular cloud. They are loosely gravitationally bound arrangement that are found in spiral and irregular galaxies, which have active star formation. Open clusters may become disrupted by neighboring clusters as they orbit the galaxy. So much so that stars in an open cluster can wonder off due to the gravitational pull of another cluster. Only about 10% of a molecular cloud's mass will condense into stars; the rest is blown away by radiation pressure from the cluster.

Open clusters give way for scientists to accurately study stellar evolution. Since the stars are all made from the same cloud (thought to be properly chemically homogeneous), the stars are all very similar in age and chemical composition. This allows for better analysis of other variables in stars that otherwise would go undetected.

NGC 752 is an open cluster located approximately 1,300 light-years away from Earth, in the constellation Andromeda (located between Perseus and the Great Square of Pegasus). It was discovered by Caroline Herschel, William Herschel's sister.

The basis for this investigation has to do with building a framework for another project that has to do with the CNO cycle. The CNO cycle (for carbon, nitrogen, and oxygen) is the dominant conduit for hydrogen (H) burning in main sequence stars more massive than the Sun. The cycle goes as follows. It starts off with carbon-12 capturing a proton to form nitrogen-13, followed by the emission of a positron to bring the atom to carbon-13. Afterwards, carbon-13 captures a second proton, forming nitrogen-14, which captures the third proton to form oxygen-15. This then releases a positron to form nitrogen-15. Finally, nitrogen-15 goes through the fourth and final proton capture reaction, reforming our initial carbon-12, and an extra helium atom. As we expected, this process uses hydrogen atoms to fuel the star, and the by-product is helium atoms, which depending on the mass of the star can continue to be used for more nucleosynthesis processes.

Although this a cycle and there is no net loss of C, N, and O, certain reactions happen at different speeds, especially the proton capture of nitrogen-14 to oxygen-15. Overtime, this bottleneck reaction builds up, allowing for a higher abundance of nitrogen, and a lower abundance of carbon (since it does not get reproduced). Because of stellar evolution theory, these numbers are calculable. However, (Schuler et al., 2011) have noticed that the observed carbon abundances for these evolved stars is slightly lower than what is expected. This could suggest there is something about stellar evolution we do not fully understand.

To test these findings, we have conducted our own investigation, starting with making sure that our sample was in fact chemically homogeneous (from the same cluster).

2 METHOD

Obtaining Data

High-resolution, high signal-to-noise ratio (S/N) spectra of our NGC 752 sample were obtained using one of W. M. Keck Observatory's 10-meter telescope, mounted with a High Resolution Echelle Spectrometer (HIRES), on Mauna Kea, Hawaii. With the addition of the echelle spectrograph we are able to capture more light and larger wavelength coverage without the expense of high resolution. Resolution (R) is defined by $\lambda/\Delta\lambda$, where λ is wavelength and $\Delta\lambda$ is the smallest distinguishable piece of the spectrum. The resolution of our data is $\lambda/\Delta\lambda \approx 60,000$, which allows for detailed absorption lines.

To derive the temperature and pressure structure, and elemental abundances of the atmosphere of the six stars believed to be in NGC 752, we analyzed the data at the Computational Astrophysics Laboratory at the University of Tampa.

Analyzing Abundances

We measured the area of the absorption lines by fitting them with Gaussian curves on a plot of intensity versus wavelength using SPECTRE (Fitz & Sneden, 1987), as seen in Figure 1. SPECTRE is a one-dimensional spectrum analysis package used to measure these areas and determine the equivalent width (EW) of each line. EW is a measure of the strength of an absorption line, denoted by the width of the rectangle of unit height formed from the area of the measured line.

The different EWs are then put in MOOG (Sneden, 1973), a spectral analysis code. However, MOOG needs an example model

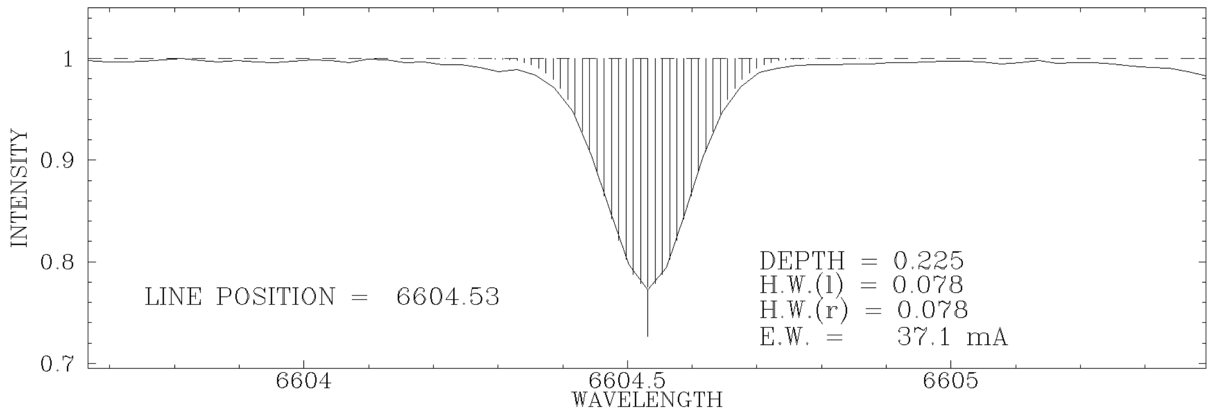

Fig. 1. Example absorption line from NGC 752 P506.

atmospheres to run; this model was pre-determined to be similar to the one we are looking for. A model atmosphere is a quantitative representation of the temperature and pressure structure of the stellar atmosphere. Thereafter, MOOG incorporates both the EW measured and the model atmosphere in order to get the abundances of elements in the star's atmosphere.

Determining Model Atmosphere

A model atmosphere consists of stellar parameters used to describe the atmosphere of the star. The parameters measured for the six stars were: effective surface temperature T_{eff}, log of the surface gravity ($\log g$), metallicity (p, fraction of the star's composition that is not hydrogen or helium), and microturbulent velocity (ξ, small turbulence in the atmosphere). This is done by finding the abundances for neutral and singly ionized iron lines, Fe I and Fe II.

To do this, we first measured the EW of 65 Fe I lines and 12 Fe II lines. The lines chosen are from (Schuler et al., 2011) for their little-to-no blending with neighboring absorption lines, and their non-proximity to the edge of the order. Some lines, however, were not measured for every star in the sample, for the quality of the data was not adequate. Atomic parameters such as excitation potentials (EP,χ) and transition probabilities were taken from the Vienna Atomic Line Database (VALD; see Piskunov et al., 1995).

After we measured all adequate lines, we certified there was no statistically significant correlation between EW of Fe I lines and EP, or rather, that the strength of the absorption is not related to the line's EP. For those stars that a significant correlation was found, we removed a small number of Fe I lines in order to decrease the correlation to non-significant standards.

Subsequently, we ran the information provided by MOOG into Super Mongo (SM), where we were able to determine the Fe I and Fe II abundances of a star relative to those of the Sun: [Fe I/H] and [Fe II/H], respectively. Additionally, we determined the correlation between [Fe I/H] and EP, and the correlation between [Fe I/H] and the reduced EW: $\log(\mathrm{EW}/\lambda)$. The parameters of the model atmosphere were then changed until the ionization balance was met: [Fe I/H] and [Fe II/H] were nearly equal, and and the excitation balance was met (both correlations were near zero).

Other Elemental Abundances

After determining and analyzing the stellar parameters, we used the model atmosphere to derived the abundances for six other elements: carbon (C), oxygen (O), sodium (Na), Magnesium (Mg), aluminum (Al), and nickel (Ni). The lines measured come from Schuler et al. (2011), the same list used for the iron lines. These abundances were derived the same way the iron abundances we derived.

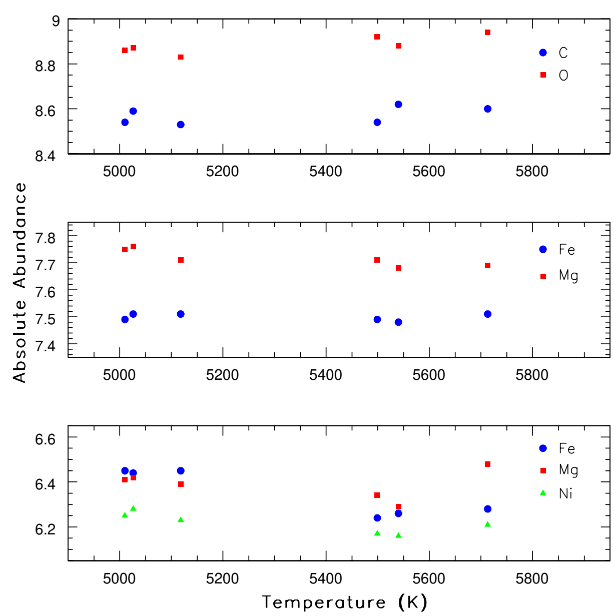

Fig. 2. Temperature dependence of elemental abundances.

Type	Name	Fe	C	O	Na	Mg	Al	Ni
Dwarfs	701	7.51± 0.13	8.60± 0.19	8.94± 0.05	6.28± 0.02	7.69± 0.14	6.48± 0.18	6.21± 0.10
	786	7.48± 0.13	8.62± 0.19	8.88± 0.15	6.26± 0.07	7.68± 0.14	6.29± 0.06	6.16± 0.11
	859	7.49± 0.13	8.54± 0.07	8.92± 0.07	6.24± 0.04	7.71± 0.15	6.34± 0.06	6.17± 0.11
Giants	506	7.49± 0.14	8.54± 0.46[a]	8.86± 0.08	6.45± 0.11	7.75± 0.16	6.41± 0.04	6.25± 0.13
	687	7.51± 0.13	8.59± 0.38[a]	8.87± 0.07	6.44± 0.05	7.76± 0.15	6.42± 0.07	6.28± 0.13
	1089	7.51± 0.14	8.53± 0.34[a]	8.83± 0.07	6.45± 0.11	7.71± 0.17	6.39± 0.09	6.23± 0.13
Sun		7.53± 0.12	8.51± 0.07	8.87± 0.07	6.29± 0.03	7.59± 0.25	6.32± 0.13	6.26± 0.09

[a]The standard deviation of these abundances are higher than expected. EW measurements for these values and will be revisited, before continuing investigation.

Table 1. Elemental Abundances for Six Stars in NGC 752

3 RESULTS

Table 1 contains the derived stellar abundances and their uncertainties provided by MOOG. All of our derived abundances have adequate uncertainties, with the exception of the abundances for carbon for all three giant stars. Figure 2 presents the data in Table 1 classified by the stars' T_{eff}. The stars clumped on the left plot are the giant stars, and the stars to the right are the dwarf stars. The right-most data points displayed are those for the Sun.

4 DISCUSSION

Although most of the data was in line with what was theorized, some results were not expected.

Homogeneity through Iron Abundances

We find the iron abundances to have an average value of 7.50 with a standard deviation (SD) of 0.01 dex between the mean abundances (with a true SD of 0.13 dex). This provides evidence that the molecular cloud from which these stars formed was chemically homogeneous.

It is interesting to note that the iron abundances for these stars are very similar to that of our own Sun. This furthers the claim that stars like our Sun are more common than not when it comes to its stellar parameters.

High Carbon Uncertainties

Recall that this data collection is a stepping stone to an investigation we will conduct in the future. Testing what Schuler et al. (2011) find in their research means that we at least needed to start with a chemically homogeneous sample. Presently, however, we are encountered with a different issue. In Table 1 we see high uncertainties for our carbon abundances. This might be due to the fact that the giants were the first stars measured, implying that the uncertainties arise from lack of experience measuring lines. These lines will be revisited before any further analysis occurs, so we may have more accurate data on carbon abundances. This will lead to a better conclusion whether we were able to replicate the aforementioned study.

The reason that nitrogen abundances are not displayed stems from the difficulty to measure the absorption lines directly caused by nitrogen. This abundance will be derived later on using a different method.

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