DEEP MIXING STATISTICS IN THE GLOBULAR CLUSTER NGC5466

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1. Introduction

1.1. **Deep Mixing in Globular Clusters.** All globular clusters are assumed to be mono-metallic and of a single age. However, all globular clusters surveyed thus far have shown a strange star to star variation in C, N, O, Al, Na and sometimes Mg despite consistent levels of other elements in all stars. The thought behind this discrepancy is that stars undergo a process known as deep mixing. In order to better understand this phenomena, we sought to examine a transition case, that is to say a globular cluster that does not exhibit deep mixing patterns. We investigated the globular cluster NGC5466 as a possible transition case.

1.2. **Instrumentation.** The data was taken with a new instrument, VIRUS-P. VIRUS stands for Visible Integral-field Replicable Unit Spectrograph. VIRUS-P is the first unit of 145 identical spectrographs that will compose the final VIRUS instrument. VIRUS will ultimately be used on the HET to image galaxies and discover more about the nature of dark energy. Our project demonstrates that VIRUS-P can also be used to study globular clusters.

2. Observations and Analysis

2.1. **Data Reduction.** We took data with the 2.7m. Harlan J. Smith telescope at McDonald Observatory. The data were taken over three nights beginning on March 3, 2009. A VIRUS-P field consists of 246 apertures, each containing a fiber and resulting in a spectrum. Each of the fibers is 4 arcseconds across. When this is positioned on a field in a globular cluster, some flux from the stars falls between apertures. To account for this, three dithers are taken that together encompass all the stars in the field. Between three and six exposures were taken for each of the three dithers in three fields. Josh Adams reduced the raw data using VACCINE. The first step in establishing a spectrum with good S/N for each star was to examine each of the apertures in a single exposure and identify which stars had flux. In some densely populated fields, a flux cut off limit was introduced to enable matching of stars between dithers. The spectra were dispersion corrected and radial velocity corrected. Then the spectra were combined using IRAF. Our data produced a sample of 39 total stars. With data from Howard Bond we produced an HR diagram shown in Figure 1 for the stars in our sample (Howard Bond, private communication). All

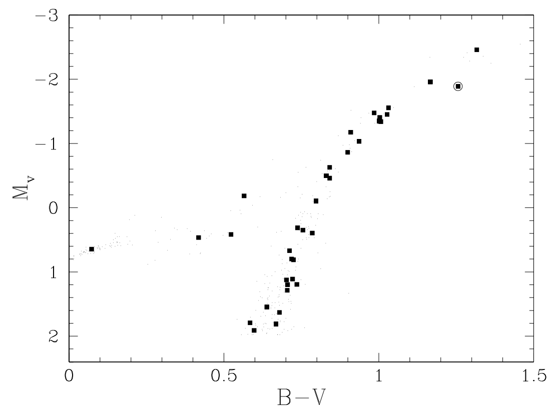

FIGURE 1. HR diagram

of our stars fall predictably along the red giant branch with the exception of the four horizontal branch stars and the star noted with a circle. This star exhibited strange levels of C and N. The four horizontal branch stars were removed to provide a sample copmarable with available literature–a sample of stars on the red giant branch.

2.2. **Exposure Time.** Each VIRUS-P field taken on the 2.7m telescope had an exposure time of 20 minutes. For the sum of our data, this totaled to about 10 hours of exposure time. Taking the spectra of individual stars with a 10m. telescope has a total exposure time of 10 hours for a sample the size of ours. Thus, VIRUS-P enables the 2.7m telescope to compete with other telescopes more than three times its size.

2.3. **Radial Velocity.** VIRUS-P enables observers to quickly determine the radial velocities of all the stars in a sample. By using the fxcor task in IRAF, i was able to calculate the radial velocities for each individual spectra and also an average radial velocity including all the spectra that composed the final star. By examining the radial velocities, I was able to easily determine which stars in the VIRUS-P field were outside the cluster. The following plot in Figure 2 depicts average radial velocities for each star in the sample. The cluster mean is depicted by the band near the bottom. All of our sample falls outside the cluster mean. A difference in resolution element is a plausible explanation for this discrepancy. Although the data are not accurate, that is to say centered on the cluster mean, they are precise in that most of our sample falls in a fairly tight line. A resolution element is six pixels, and each pixel is 80 km/s. The difference between our data and the cluster mean is one tenth of a resolution element. The error in the radial velocities is systematic.

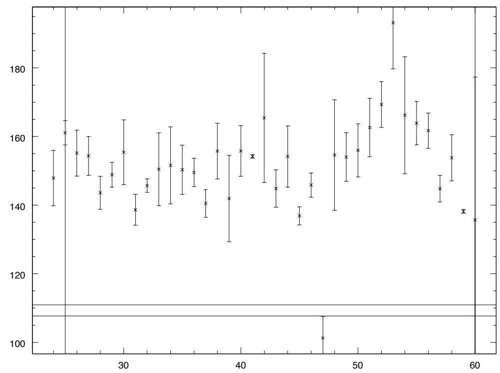

FIGURE 2. Radial Velocities for stars in NGC5466

2.4. **Band Indices.** To study the deep mixing pattern of the spectra in our sample, we focused on the CN and CH absorption features. To quantify the strength of these absorption features, we used band indices. Band indices are typically measured as the magnitude difference between the integrated flux inside an absorption feature ("the science band") and in the nearby continuum (the "comparison bands"). Stellar indices are useful tools for quantifying the strength of feature in spectra and relating them to intrinsic stellar parameters. The CN and CH absorption features are defined by the band indices $S3839$ and S_{CH} respectively. We used the band index from Martell 200, that is integral shown below.

$$S_{CH} = \frac{\int_{4280}^{4320} I_\lambda \, d\lambda}{\int_{4050}^{4100} I_\lambda \, d\lambda + \int_{4330}^{4350} I_\lambda \, d\lambda} \tag{1}$$

To verify the quality of our spectra we compared our sample with an independent sample taken at Keck. Our samples had three overlapping stars. To confirm our technique, I calculated the $S3839$ and S_{CH} band indices for the three spectra taken from Keck independently from our collaborator, Sarah Martell. The difference in our numbers was negligible. Then, I looked at the same indices for the spectra taken using VIRUS-P and LRIS at Keck. The differences were still negligible. The slight discrepancy might be due to the fact that our spectra taken with VIRUS-P are much lower resolution than the LRIS data from Keck.

3. DISCUSSION

CH and CN absorption is used to study deep mixing patterns in globular clusters. We plotted absolute magnitude against the band index $S3839$. We then applied a best fit line, and assigned all stars with an $S3839$ falling beneath the line a different symbol. Maintaining these symbols, we then plotted absolute magnitude against S_{CH} sand observed no correlation as shown in Figure 3 Stars that have undergone deep

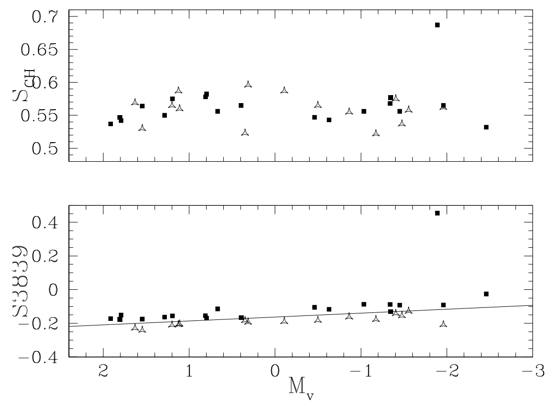

FIGURE 3. Absolute Magnitude plotted against $S3839$ S_{CH}

mixing tend to have stronger CN bands and are consequently nitrogen-enhanced. Nitrogen and carbon abundances are inversely proportional. If NGC5466 did exhibit deep mixing, $S3839$ and S_{CH} would have exhibited an anticorrelation. A plot in

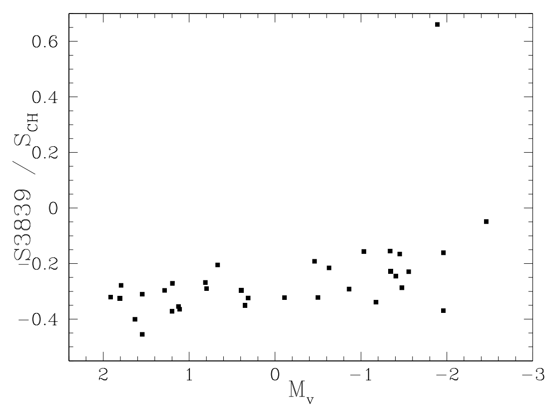

FIGURE 4. Ratio of $S3839$ to S_{CH}

Figure 4 of absolute magnitude against a ratio of the two indices produces a graph with a slight correlation. This also corresponds to the idea that NGC5466 has not undergone deep mixing. Clusters that have been deep mixed would exhibit an anti-correlation. In all plots, one stars is a clear outlier. This star exhibits hight levels of both C and N and consequently, has not undergone deep mixing because C and N abundances are inversely proportional. This star may be a part of a binary system, a star that underwent mass transfer. Finally, on order to situate our findings in the realm of available literature, we examined the $S3839$ levels for stars in the field and in globular clusters of similar metallicities in Figure 5. Of the two stars in the cluster

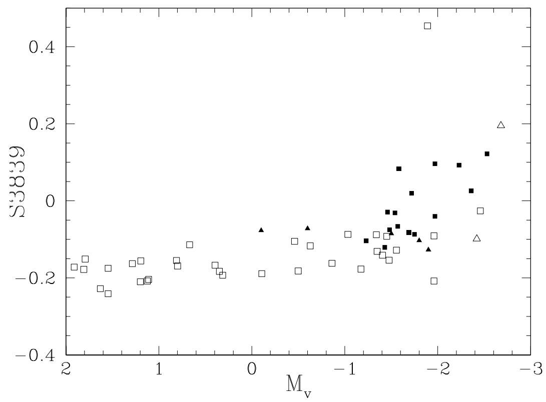

FIGURE 5. NGC5466 data vs. other metal poor globular clusters and field stars

M15, one can be classified as CN-strong while the other is CN-weak. The stars in NGC5466 fall alongside the CN-weak stars. Field stars never exhibit deep mixing patters–they are never CN-strong. Most globular clusters exhibit a spread of CN levels, as can be seen in M53 and M15.

4. CONCLUSIONS

Deep mixing is the ongoing depletion of carbon from the atmospheres of red giant stars in globular clusters. It is presently understood as a non-convective mixing process. Deep mixing exchanges the uprocessed material from the convective envelope of the star with CN(O)-processed material from the region of the hydrogen-burning shell. A deep mixing process that brings CNO-processed material to the surface will have the effect of removing carbon and some oxygen from the stellar atmosphere and replacing them with nitrogen. This process is not observed in the globular cluster NGC5466. This is the only known globular cluster of any metallicity to not show this pattern. The project also established VIRUS-P as an innovative tool effective in studying globular clusters. The data collected in this sample equals the summation of all previous data obtained throughout literature.

5. References

Martell,S..Carbon and nitrogen abundance variations in globular cluster red giants.Ph.D. dissertation, University of California, Santa Cruz, United States – California. Retrieved August 8, 2009, from Dissertations and Thesis Full Text.(Publication No. AAT 3323956).

Shetrone, Matthew D., Smith, Graeme H., Briley, Michael M., Sandquist, Eric, and Kraft, Robert P.. CH, CN, and NH Band Strengths of Metal?poor Cluster and Field Red Giants. Publications of the Astronomical Society of the Pacific 1999 111:763, 1115-1123.

Martell, Sarah L., Smith, Graeme H., and Briley, Michael M.. Deep Mixing and Metallicity: Carbon Depletion in Globular Cluster Giants. 2008 The Astronomical Journal 136 2522-2532. doi: 10.1088/0004-6256/136/6/2522

Martell, Sarah L., Smith, Graeme H., and, Briley, Michael M.. CN Bimodality at Low Metallicity: The Globular Cluster M53. Publications of the Astronomical Society of the Pacific 2008 120:863, 7-15