Revisiting Wing Emissions in the Ca K Band and their Relation with Absolute Magnitude

Introduction and Goals:

Ever since astronomy was established as a science, distance determination has been one of the most challenging aspects. Trigonometric Parallax is adequate when the stars are in a close proximity to the Sun, but the reliability of a measurement drops off steeply as the distances get greater. Spectroscopy and other methods have their limitations which mean independent methods must be used. Wilson and Bappu (1957) saw the relation between the width of the Ca K line and the absolute magnitude of a star in the so-called Wilson-Bappu Effect (WBE), which is precise to an error of 0.25 magnitudes. Stencel (1977) determined there was also a relation between the wing emission lines of the Ca K line and the absolute magnitude, which becomes important when high luminosity stars loss their Ca K cores (Hagen et al. 1981).

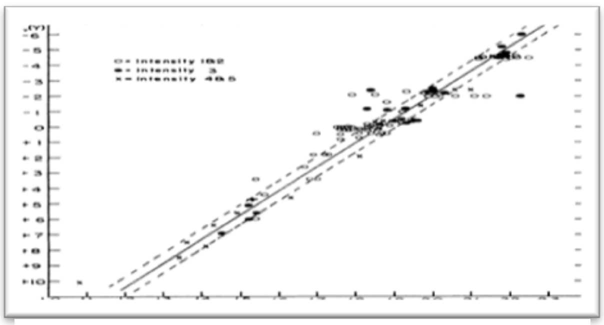

Figure 1: Original Graph published by Wilson and Bappu

Interest was lost for this method when lengthy exposure times were required for the faint stars, but with the rise in digital cameras, improved signal to noise became achievable. For this project, I have used archival spectral data gathered by M. Shetrone at the University of Texas, as well as gathered new data, via the 82" Otto Struve Telescope at McDonald Observatory. My goal is to refine and extend the relation for the wing emission line width versus absolute magnitude to a more precise and accurate measurement.

Archival and New Observations:

Data was gathered by measuring the width using the iraf command, splot. The archival observations were all smoothed by a factor of 6. The widths were measured using the minimum of the troughs on either side of the main emission. The widths of the both the Ca K core and wing emission lines were measured by subtracting the beginning wavelength from the ending wavelength, and then they were divided by the central wavelength and multiplied by the speed of light in km/s. In order for the graph to become linear, a base 10 logarithm needs to be taken of each width. An example is of the spectrum of HD163770 in which the beginning wavelength is 3932.430 Å and the ending wavelength is 3935.031 Å, which was divided by the central wavelength of 3933.731 Å. The width of HD163770 becomes 198.361 km/s. This was done with all of the Ca K core emission lines.

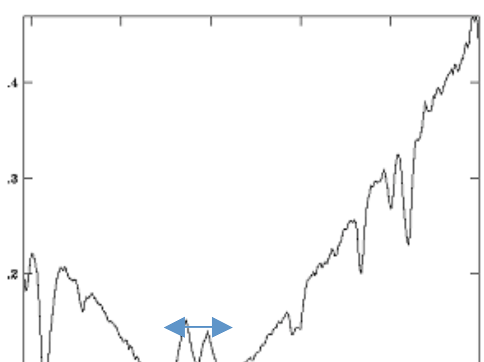

Figure 2: Ca II K lies at around 3933 angstroms

The wing emission proved to be more difficult to measure. A normalization line had to be made so a clearer beginning and ending wavelength could be determined. After the normalization line was made the wavelengths were determined and the same process as the core was taken. For example, in HD163770, the beginning wavelength of the wing emission was

3935.498 Å, the ending wavelength was at 3936.475 Å. The central wavelength was 3935.987 Å and the width became 74.467 km/s.

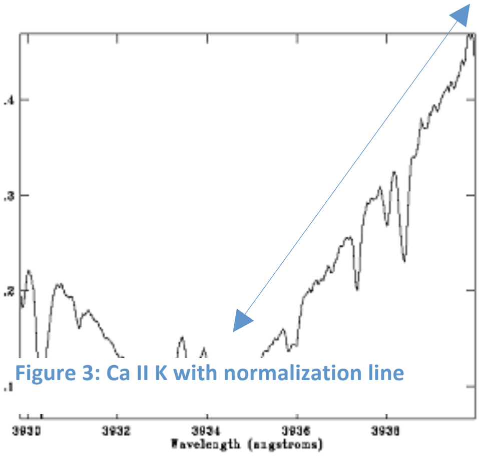

Figure 3: Ca II K with normalization line

The absolute magnitudes were determined in two ways. In the archival data, the spectrum used in the papers published by Matthew Shetrone had the absolute magnitudes published in them as well. As for the spectra used from UVES and the new observations, absolute magnitudes were determined by using the visual magnitude and the parallax published on Simbad. The distance modulus formula was then used to determine the absolute magnitude.

Analysis:

In order to create a better fitting, the logarithm of every width was taken. This was plotted against the absolute magnitude of each star. The core was analyzed first which lead to a couple of observations. First of all, the absolute magnitude errors were mostly very small in comparison to the fitting. Second, there were a couple stars that extended well above the main grouping of stars. Those were the A and F type stars used in the study. These two observations lead to a very poor fitting with a χ^2 of 10.31. It was then decided to segregate some of the stars by luminosity class and star type, for better fitting. In this study, stars with a common type-M were chosen because of the number of type-M stars in the sample. Also, stars with luminosity class of I and II (now known as Lum I and II) were used because they appeared to have the best fit. Type M stars had a χ^2 of 5.41 and an RMS of 1.71. Lum I and II stars had a χ^2 of 2.88 and an RMS of 0.72.

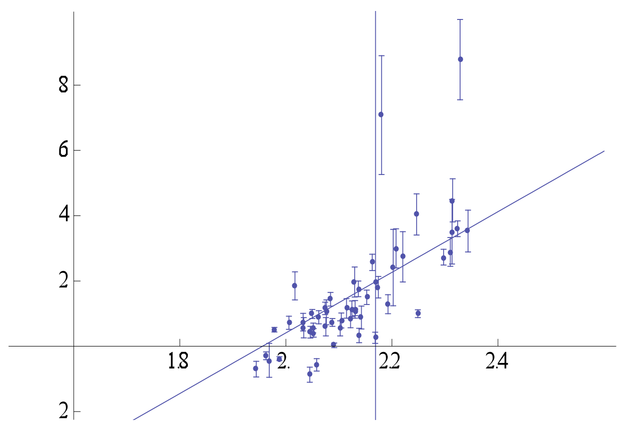

Figure 4: Graph of Absolute magnitude and Core width

This was also done with the wing emissions. For consistency and comparison, the wing emissions were also plotted using Type M stars and Luminosity Class I and II stars. Type M wing emission stars had a χ^2 of 4.71 and an RMS of 1.40. Luminosity Class I and II stars had a χ^2 of 5.35 and an RMS of 1.92.

Results:

The first step taken after analyzing the data was to compare the results using the WBE (core) and the parallax method. For stars in the Lum I and II fit, stars HD 190421 and HD 49331 were used. HD 190421 had a distance of 384.6 ± 106.5 pc using the parallax method and 301.6 ± 38.6 using the WBE; HD 49331 had a distance o0f 401.6 ± 117.7 pc using the parallax method and 543.27 ± 40.2 pc. For Type M stars HD 42995 and HD 175865 were used. HD 42995 had a distance of 107.1 ± 22.8 pc using parallax and 66.3 ±20.8 using WBE; HD 175865 had a distance of 107.2 ± 6.0 pc using parallax and 116.4 ± 20.4 pc using WBE.

Star (HD #)	Spec Type/Lum Class	Parallax Distance (pc)	WBE Distance (pc)

190421	M1 IIb	384.6 ± 106.5	301.6 ± 38.6
49331	M1 Iab	401.6 ± 117.7	543.3 ± 40.2
42995	M3 III	107.1 ± 22.8	66.3 ± 20.4
175865	M5 III	107.2 ± 6.0	116.4 ± 20.4

This table shows the Spectral Type, Luminosity Class, Parallax Distance, and WBE Distance (using the core) of 4 different stars.

From these comparisons in the Lum I and II fit, the distances are more accurate to about 40 pc while the parallax exceeds accuracy of 100 pc. However, using the Type-M star fit, the accuracy of the WBE is the same, if not worse, than the parallax method.

The wing emissions tell a somewhat similar story. The same stars were used for the wing emissions. For the Lum I and II, HD 190421 had a distance of 384.6 ± 106.5 using parallax and 325.2 ± 54.1 pc using WBE. HD 49331 had a distance of 401.6 ± 117.7 pc using parallax and a distance of 537.5 ± 89.9 pc using WBE. For the Type-M stars, HD 42995 had a distance of 107.1 ± 22.8 pc using parallax and 78.0 ± 28.6 pc using WBE. HD 175865 had a distance of 107.2 ± 6.0 pc using parallax and 115.6 ± 28.0 using WBE.

Star (HD #)	Spec Type/Lum Class	Parallax Distance (pc)	WBE Distance (pc)
190421	M1 IIb	384.6 ± 106.5	325.2 ± 54.1
49331	M1 Iab	401.6 ± 117.7	537.5 ± 89.9
42995	M3 III	107.1 ± 22.8	78.0 ± 28.6
175865	M5 III	107.2 ± 6.0	115.6 ± 28.0

This table shows the Spectral Type, Luminosity Class, Parallax Distance, and WBE Distance (using the wing emissions) of 4 different stars.

The WBE wing emission-distances are not nearly as accurate as the WBE core distances. For Lum I and II stars, the errors on each star was only fractionally smaller than the errors on the parallax, while the Type-M stars, the errors exceeded that of the parallax errors.

Lastly, the core and wing emission distances were compared.

Star (HD #)	Spec Type/Lum Class	WBE core Distance (pc)	WBE wing emission Distance (pc)
190421	M1 IIb	301.6 ± 38.6	325.2 ± 54.1
49331	M1 Iab	543.3 ± 40.2	537.5 ± 89.9
42995	M3 III	66.3 ± 20.8	78.0 ± 28.6
175865	M5 III	116.4 ± 20.4	115.6 ± 28.0

This table shows the comparison between the WBE core distances and the WBE wing emission distances.

The table above shows that wing emissions and core emissions, generally, give distances that are consistent with each other. However, the comparison of errors shows that core emissions are more accurate than the wing emissions. Thusly, when using the WBE, the core emissions would appear to be safer to use for gathering the distance.

Conclusion and Next Steps:

The WBE can be a powerful way to determine distances to stars, in some cases being better than parallax. But there are many complications to it. First, when the core has disappeared and the wing emissions are the only part of the spectrum to use, it can be difficult to figure out the width of the emission, leading to error in the absolute magnitude. Second, while in some cases (Lum I and II stars being an example) the WBE is a better, more accurate way to find the distance, other cases (Type M stars) are just as accurate as parallax, if not less. In the wing emissions the accuracy of the WBE diminishes so Lum I and II only become slightly better than parallax and in Type M stars, they become much worse than parallax. So depending on which type or class of star being used, the accuracy can be much better or equal to or worse than parallax. However, the third complication seems to overshadow how accurate the WBE measurements are.

Originally the idea for WBE was to seek out better, well determined distances to far galaxies. But to get a spectrum of these galaxies can be extremely time-consuming. The LMC and SMC would take nearly 3814 hours to get a spectrum on the 2.1 m telescope at McDonald Observatory, and the Andromeda galaxy would take 106 years! The HET at McDonald Observatory, being a newer telescope with more up-to-date features, would significantly decrease these times but to a degree that is still unrealistic (201 hours for the LMC and SMC). Thusly, the WBE could only be used, realistically, to find distances to objects in our own galaxy, possibly nearby clusters.

Other problems lie in the fact that very high luminosity stars don't follow any trend, as well as very low luminosity stars. A and F type stars don't seem to follow any noticeable trend either, making this method only accurate to certain types or classes of stars. So the original plan was to create or more precise measurement, but what was actually done was showing that the WBE isn't a practical way of finding new distances, given still lengthy exposure times.

Next steps can be made to make this method better, though. Type M stars and Luminosity class I and II stars were the only trends made here, but there are many others that can be made. Determining what trends work and don't work would be ideal to the progression of the WBE. Finding a better way to finding the widths would also be ideal, especially for wing emissions, so that better measurements can be made. Lastly, more accurate equations would need to be made.

Acknowledgments:

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