A SEARCH FOR BINARY HELIUM-RICH SUBDWARFS

RADIAL VELOCITY ANALYSIS OF TEN HELIUM-RICH SUBDWARFS

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Abstract:
Most Hydrogen-rich subdwarf B stars are known to be members of short period binary systems, but most extremely Helium-rich subdwarf B stars should not be in binaries. The situation is not clear for intermediate Helium-rich subdwarfs. My objective over the course of the four week project was to measure the radial velocities of ten intermediate Helium-rich subdwarfs and deduce whether they are likely to be in binary systems. Evidence that a star is part of a binary system can come from large shifts in its radial velocity. In order to calculate the radial velocity of a star, I had to become acquainted with the terminal commands and spectral analysis tools such as DIPSO and ELF to analyze the star’s spectra. From the spectra we could see the observed wavelength of absorption lines of certain elements, namely He I, N III and C III. From the National Institute of Standards and Technology (NIST) Atomic database we can get the line wavelengths. With these two values we can calculate the radial velocity of the star at the time the spectrum was taken using this equation.

\[ \frac{\Delta \lambda}{\lambda_0} = \frac{v_r}{c} \]

I repeated this process for multiple spectra of the star taken at different times and calculated radial velocity for each one. The Heliocentric correction also had to be calculated to account for the radial velocity caused by the Earth orbiting the Sun, for this I obtained Right ascension and declination of the star from the website SIMBAD (http://simbad.u-strasbg.fr/simbad/sim-fid) and the date and time of the observation made by the Paranal Observatory in Antofagasta, Chile. I then entered them into the ESO Airmass and Heliocentric correction online calculator (http://www.eso.org/sci/observing/tools/calendar/airmass.html) to obtain a value for the radial velocity caused by the Earth’s orbit of the sun. With this value I could find the corrected radial velocity and clearly see if there was a shift large enough to suggest the star was in a binary system.

Introduction:
Helium rich subdwarf B stars (He-sdB), in general, are very evolved stars, which are thought to be produced by merger of two Helium white dwarfs. They are usually about half the mass of the Sun and between a tenth and a half its radius. Their surface temperatures range from about 30,000 Kelvin to 45,000 Kelvin. They are therefore much hotter than the sun which has a surface temperature of 5,778 Kelvin. They are also much smaller and less massive than the sun. The surfaces of extreme He-sdB stars have little or no hydrogen left in them. The optical spectra of these stars are dominated by strong helium (He I) lines. In intermediate He-sdBs, the optical spectra show both Balmer lines and He I lines. Presently it’s not very clear how intermediate He-sdB stars are formed. If they are also double helium white dwarf merger products, most of them are expected to be in single star system. This situation has been changed after the discovery of binarity in an intermediate He-sdB star CPD-20 1123 (2012MNRAS.423.3031N). This was the motivation to search for more intermediate He-sdB stars in binary systems.

A hot subdwarf in binary star system might be formed by a common envelope ejection or a roche lobe overflow. An intermediate He-sdB star in a binary star system could also be formed by any of these binary evolution models.

The Doppler effect is the change in frequency of a wave for an observer moving relative to the source. The Doppler effect also occurs if the source is moving relative to the observer. Pictured right.

This effect is commonly observed when a vehicle with a siren drives past an observer. As the vehicle approaches the...
observer, the pitch of the siren appears to increase. Then as the vehicles drives away the pitch seems to drop again. This is because when the source is approaching the observer, each successive wave is emitted from a position slightly closer to the observer and therefore takes less time to reach the observer resulting in an increase in the frequency. While they are traveling, the distance between the wavefronts is reduced causing the wavelength to be reduced. Conversely, when the source is moving away, each wave is emitted from a position slightly further away than the last resulting in a decrease in frequency. This results in an increase in wavelength. But this effect is not limited to sound waves being emitted by vehicles, it is also of great use in astronomy. The Doppler effect results in either a redshift or blueshift in the electromagnetic waves being emitted by stars or galaxies. It has been used to measure the speed that stars or galaxies are approaching or receding from us.  

It is used to calculate the radial velocity of a star to detect whether a seemingly single star is actually part of a close binary system with another star. It is even used to detect the rotational speed of stars and galaxies. The spectra of stars are not continuous. They exhibit absorption lines at well defined frequencies that correlate with the frequencies needed to excite electrons from one level to another in various elements. The doppler effect is noticeable in these spectra because the exhibited absorption lines do not always appear at the frequency/wavelength that you would come to expect. They are instead, shifted slightly. If the source is approaching us, then the wavelength will decrease and the frequency will increase therefore the absorption line will shift toward the blue end of the electromagnetic spectrum. It will be blue shifted. Reciprocally, If the wavelength increases and the frequency decreases it will be Redshifted. The image below, shows a Nitrogen III absorption line which has been shifted. The red line is the shifted absorption line, the white is at the expected wavelength for that absorption line.

My main objective in this project was to determine whether or not any of the ten stars I was looking at were in a binary. A binary star is a star system consisting of two stars orbiting their common centre of mass. The brighter star is called the primary star and the other is known as the secondary or the companion star. Binary stars are extremely important in astrophysics because calculations of the orbit of a binary star system allows the mass of the two component stars to be directly
determined, which indirectly allows the density and radii of the component stars to be calculated. This also determines an empirical Mass-Luminosity relationship which can be used to estimate the masses of stars which are not part of a binary system.

There are a number of ways to detect binary systems. Including, optically, in which case they are called Visual binaries. Most visual binaries have long orbital periods, typically a few centuries or even a few millennia. Spectroscopy is another method of detecting binary systems. In this method the radial velocity is calculated using the Doppler effect and if there are large shifts in the radial velocity of a star it is likely it is part of a binary. If a binary star systems happens to orbit a plane along our line of sight then the components of the systems will transit and eclipse one another. Algol is the best known example of an eclipsing binary systems. Eclipsing binary systems give off fairly constant light except for dips in the light intensity when the two components eclipse one another. In my project I was looking at atomic lines in the spectra of intermediate He-sdB stars to identify the wavelength of the absorption lines in those spectra and comparing them to the known wavelength of the absorption lines of that element. The elements I was looking at included He I, N III and C III. The difference in these two wavelengths allowed me to calculate the radial velocity of the star. There are some complications in getting the radial velocity of a star though, for example, you also have to take into account the radial velocity that is caused by the orbit of the Earth around the sun. This is called the Heliocentric correction. There are many online calculators for the heliocentric correction and once you have it you can add it to the radial velocity to find the correct radial velocity and therefore be able to distinguish binary star systems from non-binary star systems.

Methods:
A total of twenty six spectra were obtained for analysis for this project. They were all taken by UVES at the VLT (very large telescope) operated by the european southern observatory in Antofagasta, Chile (pictured right) between the year 2000 and 2003. The VLT consists of four 8.2 m reflectors and operates in the visible and infrared spectrum.

To analyze these spectra, I first had to learn to use the terminal commands. Learning the basics of the terminal commands was essential because the programs needed for this project are operated through the terminal. Once comfortable with the terminal, I proceeded to analyze spectra for the various stars using DIPSO, obtaining the observed wavelength for HeI, N III and C III absorption lines. Then, using the NIST atomic database I got exact values for the expected wavelengths of these absorption lines. This provided me with a value for the difference between the two wavelengths ($\Delta \lambda$), with this value I was able to calculate the radial velocity. To get a more accurate reading for the radial velocity, I used the program ELF to fit a gaussian to a Helium I absorption line. The ELF could only be used to fit emission lines so I had to flip the spectra to fit one (pictured below). ELF gave the exact wavelength of the peak of the best fit gaussian, which gave a more accurate reading of the wavelength for the observed wavelength and therefore, the radial velocity. Using the website SIMBAD I got the right ascension and declination of the ten various stars and the date and time of the observations and input them into the ESO Airmass and Heliocentric correction online calculator.
This gave me the heliocentric correction. This value allowed me to correct the radial velocity to see if they had a significant enough variation between observations to be considered part of a binary system. The next step was to tabulate the data and results in a spreadsheet. Using the spreadsheet I was able to calculate a standard deviation for calculated radial velocity which provided me with an accurate measurement for the error in radial velocity.

**Results and Conclusions:**
This project successfully identified at least one star that was part of a binary star system, with the possibility of one or two more. The star HE0111-1526 exhibited definite signs of being in a binary system. It showed a difference of 52.5 km/s in radial velocity between the two observations, as shown in the results table. The error for the radial velocity was calculated to be was ±5.4 km/s for the first spectra and ±5.2 km/s for the second.

![This is the final results table, there is a larger, more detailed table shown later. These results show, that for the star HE0111-1526 the first calculated radial velocity is 12 km/s with an error of ±5.4 km/s. The next observation was taken just over 11 days later and this time the shift in the spectra indicated a much higher velocity and this time approaching rather than receding from us. The second spectra showed a velocity of -40.5 km/s with an error of ±5.2 km/s. This large variation in velocity is good evidence to suggest this star is part of a binary star system. Two more stars that could possibly be part of a binary include He1136-2504 and He1256-2738. Both these stars exhibit large variations in their radial velocity, but it's possible to attribute this to pulsation.](image)

The below image shows the first spectrum from the star HE0111-1526. The red line shows the line wavelength for a Helium I absorption line and the white line shows the observed wavelength of the He I absorption line. The observed wavelength minus the line wavelength (Δλ) is positive, representing a redshift. This means that the star is moving away from us. The magnitude of Δλ determines the radial velocity. In this case the Δλ is 0.535 Å, and using the radial velocity equation we can calculate the radial velocity, which, in this spectra is 39.8 km/s. But, this value also contains the velocity caused by the Earth’s orbit of the sun. For the time and date of this observation the value of the heliocentric correction to be added is -27.8 km/s, which leaves us with a value of 12 km/s. Which means that, with the Earth’s velocity accounted for, This star is receding from us at a rate of 12 km/s for the date and time for which this spectrum was captured.
This image (below) is the second spectrum for the star HE0111-1526. Again, for this image the red line represents the expected wavelength of the He I absorption line and the white represents the observed wavelength of the spectrum. In this case, Δλ is negative. This means the star is approaching us. Δλ exhibits a value of -0.16Å. This gives us a value of -12km/s for the radial velocity and a value of -40.5km/s when the velocity of the Earth’s orbit is accounted for, at the date in which the spectrum was taken. These two spectra were taken just 11 days apart and there is a 52.5km/s variation in radial velocity. A strong indicator of being part of a binary system.
**Conclusion & Evaluation:**

I consider my calculation for the radial velocity to be accurate to a reasonable degree, and I calculate the error in the calculations so I could be as accurate as possible. The first stage of calculations on DIPSO were significantly less accurate than when the gaussian was fitted. During the first stage of calculations I had to use my cursor to find the peak of any absorption lines. This was a very limited method of measuring the wavelength because it added to the error significantly due to human error in selecting the peaks and being directly in the mile of those peaks. The second stage of calculations included fitting parabolas to the absorption lines using the programme ELF. This programme, unfortunately, couldn’t fit parabolas to absorption lines and only to emission lines, therefore the spectra had to be flipped being fitted with a gaussian (shown below).

The main strength with using ELF to fit the gaussian was that it would tell me the wavelength of the peak for more accurately than I could measure it using the cursor and would also give me the error in the wavelength.

The results collected weren’t compared with stellar evolution predictions for further the understanding of how these Helium-rich stars are formed. They also weren’t compared with other Helium-rich stars, such as extreme Helium-rich stars or hydrogen rich stars to compare the likelihood of the different types of stars being part of a binary system.

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**Websites used include:**

[www.wikipedia.com](http://www.wikipedia.com) (for all internet obtained images)
[http://www.eso.org/sci/observing/tools/calendar/airmass.html](http://www.eso.org/sci/observing/tools/calendar/airmass.html)
[http://simbad.u-strasbg.fr/simbad/sim-fid](http://simbad.u-strasbg.fr/simbad/sim-fid)

I would like to thank these websites, as without them, this project would have been significantly more complicated and definitely could not have been completely within four weeks.