SEARCHING FOR BENCHMARK BROWN DWARF COMPANIONS TO SUBGIANT STARS

Alexander Ogden

School of Physics, Astronomy and Mathematics at the University of Hertfordshire, mentored by Federico Marocco and Professor David Pinfield

ABSTRACT

The aim of this project is to produce a list of benchmark systems containing a brown dwarf and a companion subgiant star by analysing a list of potential candidates.

Brown dwarfs have very complicated atmospheres compared to other objects like stars and as a result have very complicated spectra. This means much is still unknown about brown dwarfs. One way to infer the properties of a dwarf is to find a binary system containing a dwarf and a subgiant star as objects in a binary often have the same age and composition. Such a system is called a benchmark system and is very useful in finding out the properties of complex objects that would otherwise be difficult to determine from the spectra and other available data. Once these properties are known they can be used to understand the spectra and this can be used to calculate the properties of other dwarfs and hence teach us more about them.

I calculate the proper motions of a list of benchmark dwarf candidates by using data from multiple astronomical surveys and compare them to their subgiant companions and then evaluate them using a mixture of visual inspection and computer data analysis. I use this to rank each candidate based on how likely it is to be a benchmark dwarf and hence produce a list of likely benchmark systems. The best of these candidates will be observed by a telescope and confirmed if they are genuine benchmark systems, if they are then they will be used in future research in understanding brown dwarfs. This is a particularly important subject as understanding the atmospheres and characteristics of brown dwarfs are a key stepping stone to understanding more about exoplanet atmospheres, since brown dwarfs act as an intermediate class of object between small stars and large gas giants.

INTRODUCTION

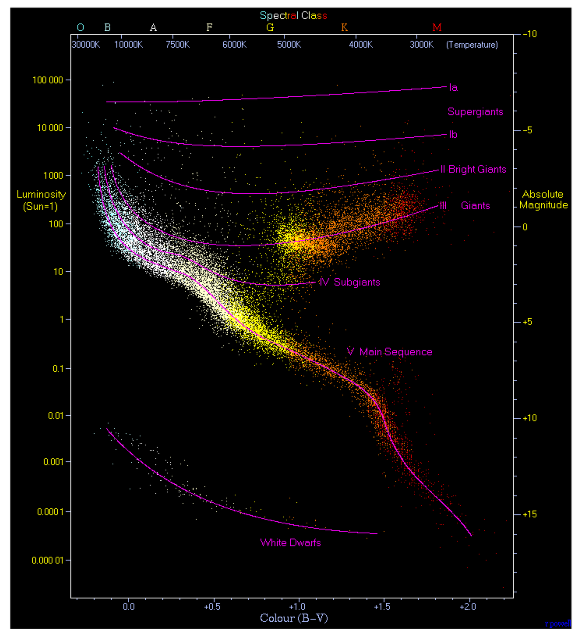


Figure 1. A Hertzsprung-Russel Diagram plotted from the Hipparcos and Gilese Catalogues (Powell, n.d.)

Approximately 90% of the stars with a mass over 0.5 $M_{\odot}$, that we have observed, are on the main sequence (Arnett, 1996): the longest part of a star's life in which it releases energy via the nuclear fusion of hydrogen into helium (Atnf.csiro.au, n.d.). It is easily identifiable on a Hertzsprung-Russel Diagram (see Fig 1.) as a dense band of stars in the centre of the graph where the luminosity and temperature are proportional e.g. the higher the temperature the brighter it is.

These main sequence stars are born inside nebulae: large interstellar clouds of gas and dust. Over time, gravity causes the gas to clump together into GMCs (giant molecular clouds) and if the nebula is dense enough, then these clumps can form stars (if this happens then the region is called a stellar nursery). Stars are born from these clouds if they have sufficient mass to undergo gravitational collapse.

But if the mass is too low, (lower than 0.08 $M_{\odot}$ (Hayashi and Nakano, 1963)) then the cloud never reaches the temperatures required for hydrogen fusion and never becomes a main sequence star. Instead, electron degeneracy pressure stops the cloud from collapsing and leaves it as a substellar object between the mass of a gas giant and a star (between a debated 13-65 MJ). These objects are known as brown dwarfs or failed stars.

Only the youngest and heaviest brown dwarfs are hot enough to sustain some deuterium fusion, most of them simply radiate their energy as infrared radiation as they cool slowly over time, meaning that they are cold and dim compared to stars, hence why they took until 1995 to be observed (Rebolo, Osorio and Martín, 1995). Consequently, brown dwarfs are found on the bottom end of the main sequence band. Their atmospheres are very complicated as they are sometimes cool enough to allow molecules to form which means brown dwarfs need extra spectral classes to compensate for this.

The problem is that this makes the spectra of the brown dwarfs complex and difficult to understand and, as such, there are lots of things still unknown about brown dwarfs such as the physics of their atmospheres and their initial mass function (Jeffries, 2012). It is very important to understand more about brown dwarfs because they could teach us more about gas giants since they have similar effective temperatures and structures. This is a crucial step in understanding more about extrasolar systems and exoplanets.

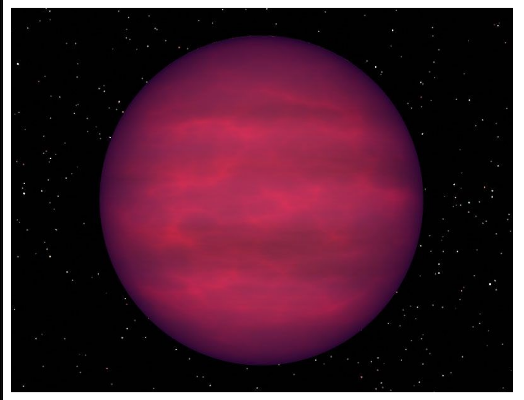


Figure 2. Artist's Impression of a Brown Dwarf (Hurt, 2006).

One way to learn more about brown dwarfs is by finding a binary system containing a brown dwarf and a star. Objects in binary systems often have very similar properties (e.g. age and chemical composition) because they are formed from the same nebula, so if the star's spectrum is observed and its properties are deduced, then it can be assumed that the brown dwarf will share these. If this is the case, then the star is known as the primary, the dwarf is known as the companion or as a benchmark dwarf and the system, as a whole, is called a benchmark system. Benchmark systems with subgiant stars are particularly useful as their age is much easier to calculate compared to main sequence stars.

For a star and a brown dwarf to be in a binary, they must be in the same area of sky and have a common proper motion. Proper motion (m) is the angular velocity of a star compared to the background stars, as seen from the sun (Koupelis and Kuhn, 2007). It is calculated twice; once each for the Right Ascension (RA or α) and once for Declination (DEC, DE or d). RA and DEC are the co-ordinates used to describe the positions of objects in the sky. Proper motion is calculated as the change in RA or DEC over time (t):

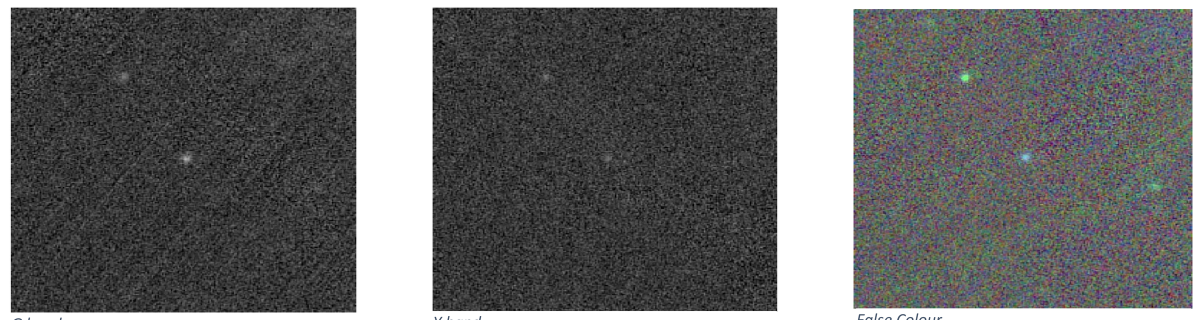
$$\mu_{\alpha} = \frac{d\alpha}{dt} \qquad \mu_{\delta} = \frac{d\delta}{dt}$$

METHOD

The first step was to generate a list of brown dwarfs which were close enough to a subgiant star to be in a binary. This was provided by my mentor. These dwarfs were found by a code which searched for brown dwarf like objects in a 3-arcminute radius around known subgiant stars. However, brown dwarfs look very similar to many other dim red objects in the sky for example: galaxies and quasars. This meant that each candidate found by the code needed to be visually inspected to remove any candidates that were clearly not brown dwarfs.

During the visual inspection I checked many criteria such as whether the object was very faint in the optical spectrum and brighter in the infrared spectrum i.e. bright in the y band but gets gradually less visible going up to the g band. This is because brown dwarfs are very cool and so emit light with a lower energy than other objects (see figures 3 and 4). I also checked whether the object was a point source, whether the object was being distorted by a nearby bright star and whether the object was actually a quasar or galaxy.

The next step was to gather data about each object's position from different astronomical surveys by using Aladin and VizieR in order to calculate its proper motion. I recorded each object's co-ordinates in a table which was then used by a code to calculate the proper motion and uncertainties for each object. . I could then compare these with the proper motions of the subgiant stars calculated by TGAS and determine whether they had common proper motion. It was highly unlikely that any of the proper motion values would have been exactly the same due to the uncertainties in the values, so instead I checked whether the confidence intervals overlapped.



G band · Y band · False Colour

Figure 3. HIP 6303 (Random Index 1165800) is clearly visible in g band and less visible in y band, this means it is unlikely to be a brown dwarf. Additionally, the false colour image shows this object as blue whereas most of the dwarfs were red or orange. (PanSTARRS, 2016)

G band · Y band · False Colour

Figure 4. TYC 60-858-1 (Random Index 1959516) is invisible in the g band but visible in the y band, this means it is likely to be a brown dwarf. It also appears red in the false colour image and this is expected for a brown dwarf. (PanSTARRS, 2016)

I performed multiple checks on the objects to evaluate how likely they were to be a good benchmark system e.g. whether they had enough data points to be accurate, whether the measurements were taken at far enough apart intervals to be reliable, the metallicity of the star and whether it was visible on the days that the university had telescope time. The most important check was whether the proper motions' confidence intervals overlapped, this was done by calculating the difference between the proper motion of the dwarf and the star and dividing by the uncertainty in the dwarf's proper motion (σ) . If the difference between the proper motions was less than 3σ then the proper motion was common. I ranked each object for each check I did to then calculate an average overall rank and colour coded each object based on how good their data was. A combination of the overall rank and the colour coding allowed me to create a ranked list of which objects were most likely to be benchmark systems.

WITHIN_3σ	WITHIN_2σ	WITHIN_1σ
Yes	Yes	Yes
Yes	Yes	Yes
No	No	No
Yes	Yes	No
Yes	Yes	No
Yes	Yes	No
Yes	Yes	No
No	No	No
Yes	Yes	No
No	No	No
No	No	No
Yes	No	No

Figure 5. A section of my Table that checks whether the m are less than 3σ apart. I also checked 2σ and 1σ as the lower the σ difference is the better and an object separated by 1σ is better than one separated by 3σ.

RESULTS

My results included 2 lists of candidates, one for optical detections and optical non-detections. I combined the most promising of these into one table.

Name	Rank	Observable Rank
PSO J032621.964+043814.299	1	1
1352766	1	1
705235	2	2
853120	4	3
1521053	5	4
484684	6	5
1124392	9	7
2002595	10	8
622549	12	9
1187843	13	10

CONCLUSION & EVALUATION

In conclusion, my project has successfully evaluated a list of potential brown dwarf benchmark system candidates and produced 2 ranked lists of how likely the candidates are to be benchmark systems relative to each other.

I think my project will yield good results as my methods were approved by my mentors and were similar to methods that they themselves had used in the past for similar work. Additionally, as my data set was relatively small it meant that I could visually inspect all my candidates thoroughly and I was very involved during the entire process. This allowed me to check for errors and manually check some of the automated operations made by the computer which meant that my results' reliabilities are improved.

A weakness of my project is that it is introspective. The candidates have been successfully evaluated against each other and those in the final list are definitely the most likely to be benchmark systems. However, I did not compare them to any already known benchmark systems and so if I were to repeat the project I would have compared my candidates to other previously studied candidates to check that my conclusions were consistent.

FUTURE WORK

If my candidates are confirmed to be benchmark systems then they will be used in future research to learn more about the properties of brown dwarfs. Their spectra will be measured and will have their proper motions measured more accurately with observatory telescopes to completely confirm the companionship between the subgiant and the dwarf. The subgiants will have their composition and age calculated which will then be shared by the brown dwarf, thus enabling the properties of the brown dwarf to be inferred. This will hopefully reveal many interesting properties held by the dwarf such as its metallicity, which can then be compared to its spectra to help understand some of its features. This knowledge will hopefully be able to be applied to other dwarfs and maybe eventually to extrasolar gas giants.

REFERENCES

- Arnett, D. (1996). *Supernovae and nucleosynthesis*. Princeton, N.J.: Princeton Univ. Press.
- Atnf.csiro.au. (n.d.). *Main Sequence Stars Australia Telescope National Facility*. [online] Available at: http://www.atnf.csiro.au/outreach//education/senior/astrophysics/stellarevolution_mainsequence.html [Accessed 29 Aug. 2017].
- Powell, R. (n.d.). *HRDiagram*. [image] Available at: https://upload.wikimedia.org/wikipedia/commons/6/6b/HRDiagram.png [Accessed 29 Aug. 2017].
- Hayashi, C. and Nakano, T. (1963). Evolution of Stars of Small Masses in the Pre-Main-Sequence Stages. *Progress of Theoretical Physics*, 30(4), pp.460-474.
- Rebolo, R., Osorio, M. and Martín, E. (1995). Discovery of a brown dwarf in the Pleiades star cluster. *Nature*, 377(6545), pp.129-131.
- Jeffries, R. (2012). Measuring the Initial Mass Function of Low Mass Stars and Brown Dwarfs. EAS Publications Series, 57, pp.45-89.
- Hurt, R. (2006). T Dwarf. [image] Available at: https://commons.wikimedia.org/w/index.php?curid=2133578 [Accessed 31 Aug. 2017].
- Koupelis, T. and Kuhn, K. (2007). In quest of the universe. Sudbury, Mass [u.a.]: Jones and Bartlett Publ, p.369.
- PanSTARRS (2016). [image] Available at: http://ps1images.stsci.edu/cgi-bin/ps1cutouts?pos=195.539424+28.980994&filter=color&filter=g&filter=r&filter=i&filter=z&filter=y&filetypes=stack&auxiliary=data&size=240&output_size=1024&verbose=0&autoscale=99.500000&catlist= [Accessed 26 Sep. 2017].
- PanSTARRS (2016). [image] Available at: http://ps1images.stsci.edu/cgi-bin/ps1cutouts?pos=51.590358+4.0195&filter=color&filter=g&filter=r&filter=i&filter=z&filter=y&filetypes=stack&auxiliary=data&size=240&output_size=1024&verbose=0&autoscale=99.500000&catlist= [Accessed 27 Sep. 2017].

ACKNOWLEDGEMENTS

- I would like to thank my mentors: Professor David Pinfield and Federico Marocco, for allowing me to complete this project with them. I really enjoyed the experience and hope that it proves to be useful for future research.
- I would also like to acknowledge my use of data from multiple astronomical surveys: 2MASS, SDSS, WISE, ULAS, PanSTARRS, UHS and TGAS. The full acknowledgements for which can be found in my written report.