Data mining for neglected double stars on Victor Blanco Telescope images archive

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Abstract
A set of neglected double stars measurements and analysis made on Victor Blanco Telescope archive images are presented. The objects were found using a data mining approach using some already developed tools presented in a previous article.

1. Introduction

Due to the continuous and fast growing number of archive telescope images in the last decade, searching and extracting data from already existing images seems to be also a very promising approach in observational astronomy. In most cases the archives contain images realized with big telescopes having generous fields, and this seriously increases the possibility to find on those images objects of interest different from the object targeted by the observing project. Moreover, most of the archives and images are freely available for researchers with the only condition that images are used in research projects. In most such archives the only restriction is to not use images produced in the last period of time in an interval than can vary between six months and one year, interval different from an archive to another. In most cases such images are not available for download even if they are listed.
The author already had a first attempt of such an approach for extracting double star measurements in 2016 using images from the 2m VLT survey telescope presented in a previous article [1]. After this first attempt it was noticed that some of the work needed for this project could be automated or could be made more efficient by developing some simple software tools. Combining some experience, ideas and also some code logic and data from the EURONEAR project [2] in which is also involved, the author developed some dedicated tools for double stars data mining projects presented in a previous article [3] next to new a set of measurements on the same VLT archive. Those tools give a consistent help in fast identifying images which contain double stars of interest and also identify the exact CCD from the mosaic which contains the targeted object.
To continue this approach of extracting measurements from existing images it was decided to use also images from a different big telescope which have an freely available archive and also is included in the EURONEAR Mega-Archive search index - a small database which unify basic data of the images from different telescopes archives and which is used by the already mentioned data mining tools. It was decided to use this time the images produced by the Dark Energy Survey project [4] using the 4m Victor Blanco Telescope and the DECAM mosaic camera [5] due to the experience gained by the author with this instrument from a recent EURONEAR VI asteroids recovery project [6]. The findings of this new project will be presented below.

2. The telescope and the camera

The 4 m diameter Victor Blanco telescope was commissioned in 1974, being located at 2207 m altitude Cerro Tololo Inter-American Observatory in Chile, part of the National Optical Astronomy Observatory (NOAO) of the United States.

Mounted at the prime focus of Blanco (instrument ratio F/2.7), the Dark Energy Camera (DECam) saw first light at 12 Sep 2012, producing images that with some exceptions are freely available on the NOIRLab Astro data archive[10].

Having 62 2048 × 4096 pixel science CCDs, DECam covers on sky almost 3 square degrees in a hexagon of 2.2 degrees diameter at a resolution of 0.263″/pixel. DECam is endowed with a filter wheel holding seven broad band filters, namely Sloan u, g, r, i, z, the "discovery" VR, and the near-infrared filter Y. The whole DECam unit is also a focal plane image corrector. The image archive from this instrument contains in the present more than 450.000 items.

3. Methods used and targeted objects

In order to select the most appropriate neglected double stars to analyze in this project the characteristics of the instrument were taken into consideration. With 4m diameter and exposures which in most cases are between 30 seconds and 2 minutes the limiting magnitude easily reaches 22 and goes in some cases to 24 or even more. Considering this it is clear that even the weakest double stars from WDS catalogue can be approached. On the other hand this can also generate a problem with the brightest objects which can be oversaturated in images. From the previous experience , as mentioned before in an asteroid data mining project, the author knew that in most cases stars brighter than 13 are oversaturated on DECam images and decided to approach only pairs which have the components of 14 magnitude or weaker. Of course this is a relative criteria because oversaturation depends also on exposure time, filters , weather conditions so, as a safety measure, this aspect was checked for any measured object by checking the associated histogram from the Astrometrica Object Verification window.

Another criteria to be considered in selecting double stars targets was, of course, the separation. Considering the pixel size of the instrument (0.263"/pixel) and the good location of the telescope it was considered a 2 arcseconds as the lowest limit for approached objects. Also considered to not approach very big separation objects that are easy accessible also to other smaller instruments and decided to upper limit the separation to 60 arcseconds.

A final criteria was to approach objects that are neglected so 20 years or more since the last measurement limit was considered.

Having those criteria a list of objects was generated using the WDSFilter tool [3] and a big part of the found objects was searched on images , measured or have their situation carefully analyzed if missing or different than expected. Of course there is a fraction of matches that produced no relevant results due to multiple reasons like: object was outside the field near the edge, object was in the CCD gaps which in DECam mosaic have different sizes between 53 and 56, oversaturated objects, bad images, wrong field center in image archive. On the other hand in many cases there were multiple candidate images for a single object making it possible that if one candidate had one of the mentioned issues to try to download another candidate. In conclusion the number of analyzed fields for producing the final result was about 30% bigger than the number of finally reported objects.

It is possible that in a few isolated cases the established limits can be exceeded. That happened in cases when the searched object had parameters which were different than expected but still was reasonably close to the proposed limits in order to not affect the quality of the result. The author judged each case in particular and measured only the ones that it was considered that can produce a useful result. Also there were a few cases when other objects were found in the same field. Such objects do not match exactly the 20 years old criteria or the 60 arcseconds separation criteria but it worth measuring them if they were already in the current field because they are easy handle with very little extra work.

In order to optimize the work , besides the already existing tools the author developed a small Windows batch script which automatically download a particular image from the achieve, it unpacks it and cuts the CCD frames in separate FITS file for each CCD of the DECam mosaic camera. This automation helped to save a lot of time of routine work for preparing each image. The script also set the correct image coordinates for each cut FITS using a small python script developed also by the author during this project. Besides the raw images the already corrected version of each image is available in the image archive as well so the download script was built to download this version of the image. In this way the images from DECam can be directly used without needing any other processing as in other instruments cases where different corrections have to be applied to raw images before using them.
On the downloaded images the targeted objects was identified with the assistance of the data mining tools from EURONEAR project [3] and the position of the main and secondary stars was measured using the Astrometrica software [7] using the GAIA catalogue[9]
In order to process the measurements the author used a spreadsheet developed in a previous double star project [8]. The spreadsheet computes the PA and separation from the coordinates measured with Astrometrica software by parsing a pair of Astrometrica report lines, extracting the coordinates of the main and secondary and computing the double star parameters.
During the analysis of the images, in some cases when the targeted object was difficult to find or identify the Aladin[11] software was used as well for checking proper motions, magnitudes, or double check different aspects in survey images which shows the analyzed field.

It has to be mentioned that using already existing images have the disadvantage that the images were taken with various filters. This can affect the measured magnitude so it is recommended to consider only the astrometry from the determination as having good precision but consider the magnitude only approximate. The filter for each image is mentioned after the data table.

It also has to be mentioned that when multiple data mining candidates were available for an object, there were preferred the images with smallest exposures in order to avoid the risk of oversaturation especially when the target object was bright and also there were preferred the newest image available when the other criteria was fulfilled.

4. The measurements

In the next tables there will be presented the obtained measurements and notes on some of the investigated objects.

4.1 Identified neglected double stars

Table 1: Neglected double stars measured

Star	Position	Magnitudes	PA	Separation	Date	N	Notes
ZHN 11	00077-0454	18.3 , 21.3	49.8	5.25	2018.854	1	
LDS 2101	00123-2729	16.5 , 17.7	57.2	1.90	2017.737	1	
LDS 3154	00206+2712	16.6 , 16.6	319.5	1.93	2018.788	1	
ITF 105	00260+1624	15.9 , 17.4	297.3	3.40	2016.614	1	
GWP 101	00550-0722	15.6 , 16.0	200.5	7.06	2018.793	1	1
ITF 48	00563+1053	14.6 , 16.5	125.5	2.10	2015.989	1	
ITF 112	01009+1546	16.0 , 16.4	28.4	3.73	2018.671	1	
ITF 114	01147+1327	15.4 , 15.9	266.2	25.45	2018.681	1	
ITF 115	01148+1326	14.3 , 16.1	130.1	20.97	2018.681	1	
ITF 116	01265+0933	16.6 , 16.9	142.5	4.81	2018.681	1	
SLN 53	01332+3012	19.6 , 20.4	99.0	7.56	2018.837	1	
LDS 1105	01342+3029	18.8 , 20.9	105.6	7.97	2018.837	1	2
GWP 219	01458+0043	16.2 , 18.2	53.2	25.37	2018.914	1	3
LDS 9128	01551-1204	17.9 , 19.2	176.5	2.38	2016.926	1	4
LDS 3325	01569+0332	14.0 , 17.8	240.5	9.19	2018.695	1	
ITF 63	02367-0927	17.4 , 18.8	335.8	1.95	2016.809	1	
GWP 418	03054-1432	11.7 , 15.9	248.3	21.39	2018.931	1	
GWP 466	03248-1533	17.0 , 17.8	347.5	5.27	2018.851	1	
GWP 472	03295-1558	14.4 , 18.7	130.1	94.30	2018.851	1	
UC 1083	03523-3115	14.6 , 16.0	150.3	10.06	2018.922	1	
SAR 3 AD	04315+1706	11.8 , 21.3	235.2	18.87	2019.094	1	5
LDS 1170	04267+1811	19.5 , 20.8	240.3	22.35	2019.089	1	6
UC 1241	04569-6629	15.9 , 16.2	30.0	47.62	2019.522	1	
GWP 655	05130+0532	18.3 , 19.1	319.7	9.26	2017.784	1	
POU 1285	06234+2332	14.9 , 15.8	120.7	24.33	2019.165	1	7

FAH 1 AB	08503+1057	13.5 , 20.1	82.4	248.91	2018.076	1	
KIR 8 BC	08503+1057	20.1 , 20.7	81.6	4.93	2018.076	1	
LDS 249	09069-4333	16.9 , 18.4	319.4	51.58	2016.230	1	
LDS 3962	10117+1416	15.7 , 22.1	170.1	4.58	2019.180	1	8
LDS 1256	10432+2652	22.0 , 21.5	353.0	5.60	2018.150	1	
LDS 4183	12085+0050	15.2 , 20.1	125.3	6.66	2018.374	1	9
LDS 1291	12189+3119	12.7 , 18.1	322.2	53.94	2018.145	1	10
GWP 2224	14070+0332	13.7 , 18.1	51.6	11.25	2017.168	1	
GWP 2079 AB	13458-0951	15.7 , 18.5	356.7	6.75	2018.462	1	11
LDS 4399	13456-3150	19.2 , 21.7	262.9	14.17	2019.065	1	
LDS 3099	13462+0559	8 16. , 18.5	292.1	70.91	2017.307	1	
UC 2620	13495-4537	16.4 , 16.0	117.9	50.54	2017.424	1	
OSO 56	14225-0416	15.0 , 15.0	151.5	17.63	2017.170	1	
GWP 2399	14304+0830	16.0 , 20.3	234.7	6.11	2018.284	1	
ITF 139 AB	14345+1913	16.2 , 16.4	276.6	5.99	2018.213	1	
VVV 25	14537-6019	15.7 , 19.6	295.7	3.43	2017.055	1	
LDS 4529 AB	15061-2201	14.8 , 18.4	42.9	5.42	2019.475	1	
DAM 689 BC	15061-2201	18.4 , 17.6	112.9	121.31	2019.475	1	

Notes:

1. There seems to be an issue with the last measurement of this object. In the initial measurement from 1998 the star had a PA of 204 degrees, but at the last from 2000 it had 20, so it is around 180 degrees difference. In the current measurement it was obtained a 200 degrees PA, so close to 1998 value. It was checked with extreme care the image and positions and one star is just a bit but clearly brighter than the other. This one is closer to the declared position, within a difference of about 2 arcseconds. The secondary have more than 8 arcseconds from the declared position, so from all points of view it seems it was chosen the correct star as the main star, but from the PA of 2000 year measurement the author considers it is possible that in the 2000 measurement the components were accidentally reversed. Still It has to be considered that current measurement was performed on a R - Filter image which might affect magnitude estimations.

2. Marked as lost, but it still found this pretty good matching candidate at the position: 01h34m12.906 s +30°28’46.01". It has to be mentioned that WDS do not contain precise position for this object, but the found pair also matches the approximate position magnitude and the PA and separation difference is small so a plausible movement during the time. The PPMXL data of the main and secondary stars suggest it is a physical pair. Strangely the PPM from the WDS do not match the PPMXL for the presumed main star, but due to the matching of all other parameters it is very probable this is the correct pair and maybe something might be wrong with the PPM from WDS for this object.

3. The coordinates of the main star are about 5 arcseconds greater than the catalogue ones. The difference do not seem to be explained by the proper motion which should give a difference around 1.7 arcseconds.

Measured position is 01h45m50.259s +00°43’00.87" versus 01h45m50.28s +00°43’06.30" which is catalogue position.
4. The object is marked in catalogue as a bogus binary and has no precise coordinates. Still, scanning the area by the low precision coordinates it was found this pair at coordinates: 01h 55m 05.069s -12°03’08.39" which matches quite well the expected parameters. The magnitude difference can be explained by the fact that images use a filter. The position is in range, the separation fits, and the PA variation is plausible. Unfortunately there is no PPM data in the WDS for this pair in order to compare with PPMXL.
5. Unfortunately the primary is a little oversaturated in the image, but there is no other image showing this field with shorter exposure in the telescope archive. Still it was considered important that the secondary was found on this image, because it was observed only once in 1995, even the precision of the determination can be worse. On the other side having a not very tight separation the error should not be very large.
6. The main star position matches exactly, the PA matches too, the separation difference is a little higher but it might be plausible. Also there is 1.5 mag difference on the main star.
7. At about 20 arcseconds from the specified position there is a 14 magnitude star . This is a good candidate for the main star, theoretically the difference in position could be explained by PPM during almost 100 years from discovery. Unfortunately the catalogue does not list PPM for the star. Moreover checking in PPMXL catalogue it was found a negative movement on declination and positive on RA which seems to not match with the noticed difference of position. There is also a second star approximately matching the PA (with a 12 degrees difference) and magnitude (1 magnitude difference), but at a much bigger separation (24 instead of 5). Also analyzing PPM of the components from PPMXL it do not seem to suggest a physical pair (8.10/-36.60 -7.00/-15.70) On the other hand there is no star at the 5 arcminutes difference neither in the nearby of this value and no other good candidate for the main star either. So the single candidate with high potential is the mentioned one. Having such a big interval from discovery maybe the movement could be possible or maybe there was some mistake in the catalogue data in the separation field.
8. Object found but with some issues. At the position there is a star brighter than expected. The secondary is weaker than expected. Still the separation is close, but the PA seems to be on the opposite quadrant. Maybe the quadrant was misinterpreted in the original observation. The PPM for the main star from the WDS catalogue is similar to the PPMXL. PPM data for secondary is not available neither in WDS catalogue nor in PPMXL.
9. Quite big differences on PA and separation, but also in the last catalogue measurement big differences versus initial measurements occurred. Position and magnitude fits pretty well also.
10. Positioned at about 40 arcseconds in southwest from the catalogue position at 12h18m52.653s +31° 18’25.40" but matching pretty well the expected parameters.
11. Both main and secondary stars have weaker magnitude than in catalogue. In this case it was found and used an image with no filters, so the magnitude determination should be quite accurate.

The images used in the previous determination used different filters. Most of them was taken with R-filter except the following:
G - LDS2101
I - ITF48, UC2620, OSO56
Y - LDS9128, ITF 63
Z - ITF112, FAH1 AB, KIR8 BC, LDS249, LDS3962
VR - SAR3 AD, LDS1170, POU1285, GWP2079 AB

4.2 Objects with special situations

In the next table there will be presented some neglected double stars determinations which still have some issues and it is not clear if the objects are the correct ones, but in these cases the author considered it worth to detail the possible finding even if they might not indicate the correct object in order to help other future search attempts.

Table 2: Neglected double stars with identification issues

Star	Position	Magnitudes	PA	Separation	Date	N	Notes
LDS 3209	00535+0006	20.2 , 21.0	245.8	0.85	2015.989	1	1
LDS 2234	04255+1631	15.9 , 21.5	69.8	15.50	2019.094	1	2
LDS 5666	05541-3206	16.6 , 19.2	239.0	13.17	2019.357	1	3
POU 1196	06177+2348	14.1 , 18.1	128.6	8.50	2019.163	1	4

Notes:

1. Nothing at position but very close at 8 arcseconds of declination there is a clearly elongated star with appropriate magnitude. It was tried to measure the object but being not completely separated the measurement could be quite inaccurate. Still considered it is important to mention this object because it could be a candidate for this apparently lost object. The main star's exact coordinates are 00h53 m40.813s +00°05’20.52". There are some differences at PA (54 degrees) and separation more than 1 degree. The PA difference is quite big but the other parameters match quite well with the expected ones. Unfortunately the PPM of the main star as listed in WDS do not seem to fit the PPM of the presumed star from the PPMXL catalogue. The image used for determination was taken using the R filter.
2. Close the position (but there is no precise position in WDS) there is a 16 mag star at position 04h25m40.110s +16°31’01.72". Also there is a 21 magnitude star in the expected quadrant but with a consistent difference on PA and separation. The last and single observation was made more than 60 years in the past. The PPM of the presumed main star does not match with the one from WDS and the PPM for the secondary is not available neither in WDS nor in the PPMXL catalogue. It is difficult to judge if this is the right pair. On the other hand it seems to be the single candidate which matches somehow the description if judging by magnitudes. The image used for determination was taken using VR filter.
3. There is no star at a precise position, but quite close at about 17 arcseconds distance at 05h54m15.712s -32°07’12.22" it can be found a 16.6 magnitude with a 19 mag pair at a PA close than the expected PA for the searched double. Still the separation difference is quite important: 13 arcseconds instead of expected 33. On the other hand the last and single observation is almost 60 years in the past. In conclusion there are multiple big differences (main star magnitude, separation) but on the other hand is the single candidate in the area that seems to resemble (main star position pretty close, PA close) the expected parameters. The PPM from WDS do not fit the PPMXL values but the PPM of the presumed main and secondary from PPMXL might suggest a potentially physical pair (-5.80 / 15.10 and -14.70 / 16.80) It is not sure if it is the right pair or not. The image used for determination was taken using the G filter.

4. At 10 arcseconds (06h17m41.825s +23°48’01.01") from the declared position there is a 14 magnitude star which is most probably the searched primary. There is only one possible match for the secondary with a separation close to the last one, but with a big difference in PA (60 degrees). Also the secondary magnitude is much weaker than expected. Still is the single candidate which is quite close to the description. Unfortunately there is no PPM data in the WDS for this pair. The PPM from PPMXL for presumed components does not seem to suggest a physical pair (-4.40/-1.50 1.80/-7.40). On the other hand the pair was observed last time almost one century ago. Overall is not clear if this is the object measured by the discoverer, but no other better match was found. The image used for determination was taken using VR filter.

4.3 Missing and erroneous objects

As in almost any neglected double stars hunt there were found pretty much objects with different issues which cannot be measured for various reasons. All those objects are listed below:

- LDS 2116 - Nothing at position. Multiple potential candidates in neighborhood, but neither of them close enough to make possible a reasonable safe presumption which one might be the right.
- LDS 5265 - At the position with a difference of around 5 arcseconds there seem to be a single star with no companion on a 2017 image with magnitude limit beyond 22.
- LDS 3155 - A star of expected magnitude at the precise coordinates but no secondary. No sign of elongation. On a 2 arcseconds separation on an image of such resolution something should be visible. One explanation is that in the almost 60 year interval which passed from the discovery (the data mined image is from 2017) maybe the secondary gets extremely close or is superimposed on the main star.
- LDS 9091 - Very near to the coordinates, about 6 arcseconds away, there is just a small little elongated object of 21 magnitude, but the object looks more like a galaxy than a double star with overlapped components.
- LDS 9094 - No object in the neighborhood to resemble the description.
- SLN 52 - Despite the fact that the last but only observation is in 2000 and is marked in catalogue as confirmed as a physical double by proper motion, it cannot be find anything at all at the coordinates. It have to be mentioned that stars of 22 magnitude are visible in the image, and the target one is 18. Moreover in the neighborhood on an area of about 2x2 minutes of arc there is nothing like the object in description. Probably there is an error in the coordinates in the catalogue.
- LDS 9120 - Not found. Searched near the expected position but nothing found to be at least alike with the expected parameters. So the fact that this pair is lost is reconfirmed once again as already marked in catalogue.
- LDS 1117 - Main star found but no secondary star at all. Not even a good candidate in the neighborhood.
- LDS 3343 - Found a 14 mag star at a precise position but no secondary around. No other matching candidate in the neighborhood
- GWP 426 - On the precise position there seems to be a weak prolonged ellipsoid, very probably a galaxy with the large semi axes having a PA of about 60 degrees. Very close to the galaxy as an extension of the large semi axes there seems to be a small 20 magnitude star. Probably somehow the initial observer has misinterpreted this object as a double star. Maybe there was a nova in the

galaxy at that moment or probably the galaxy was seen smaller if the telescope aperture was smaller than the instrument we use.

- LDS 5425 - Very close to the position within about 3 arcseconds difference there is a 17 magnitude star. There is no secondary around. Neither in the close neighborhood there is not any matching candidate
- LDS 5519 - Nothing at the expected position computed by using the declared proper motion neither at the discovery position. A 21 magnitude only at a few arcseconds distance. No other potential candidate in the neighborhood.
- LDS 3569 - Near the expected position there is a 19 magnitude star but no secondary can be seen around in an plausible range
- ROE 84 - No pair that could match in the neighborhood.
- LDS 260 - No star at the coordinates. No obvious candidate in the neighborhood.
- LDS 3721 - No star at the coordinates. No other pair candidate in the close neighborhood.
- LDS 5717 - Only a very faint star 22 magnitude star near the coordinates. No secondary visible.
- BRT 443 - Main star with found at the catalogue coordinates but no secondary found to match the expected position or in the close neighborhood
- LDS 1379 - No pair close to the expected descriptions in the area. There were no precise coordinates, but the search was performed carefully around the coordinates from WDS ID still with no success
- LDS 4344 - No star found at the coordinates. Nothing to match in the neighborhood
- LDS 4426 - No object at precise position. No other pair of stars that matches the description in the neighborhood.
- LDS 6286 BC - Main star found at catalogue coordinates but secondary not found

5. Conclusions

As already shown in other previous articles [1], [3] data mining seems to be a good approach for obtaining measurements of double stars. It has several advantages like: using big instruments which provides excellent resolution and magnitude limit allowing to approach objects that are unreachable for small instruments, very little time needed to get the images if using appropriate tools in comparison with observing directly. There are also some disadvantages like the constraint to use only existing images taken with already selected filters and exposure time, having limitations in approaching bright objects due to the oversaturation risk, having the risk that some images missed the object on edges or CCD gaps because the object was not in fact targeted by the observer. Overall the advantages probably exceed the disadvantages mainly by offering access to objects unreachable to small amateur telescopes and also by offering a huge quantity of images that covers a big part of the sky.

In the current project about half of the candidates list of more than 200 items were analyzed and it produced data or information for 69 objects within a reasonable quantity of work due to the automations provided by used tools mostly developed by the author. The other part of the list might be approached in a future project but the list it should be first updated because the current list was produced at the beginning of the project in the autumn of 2020 and in the meantime some new data might be produced by the used instrument. This is also an advantage of the data mining approach, that new data is continuously available. It has to be noted that this project was based on a single instrument archive but there are a lot of such archives available even if not all have such potential due to the instruments used in producing them which in some cases are smaller, have smaller fields or produce less images compared with used instrument which is one of the most productive listed in EURONEAR Mega-Archive. EURONEAR Mega-Archive contains in more than 100 instruments with more than 16 million images in the present and is continuously growing both by automatically adding newly produced images from already integrated archives and also by integrating new archives. Moreover there are a lot of still not integrated archives, so the potential is big and continuously growing.

Acknowledgements

This project used data obtained with the Dark EnergyCamera (DECam), which was constructed by the Dark Energy Survey (DES) collaboration [4]. We made use of the U.S. National Virtual Observatory (NVO) for extracting the entire DECam image archive and download the image candidates.

This research has made use of the Washington Double Star Catalogue maintained at the U.S. Naval Observatory [12].

This research has made use also of "Aladin sky atlas" developed at CDS, Strasbourg Observatory, France 2000A&AS..143...33B and 2014ASPC..485..277B. [11]

Data reduction was carried out using the Astrometrica software developed and maintained by Herbert Raab [7] using GaiaCatalogue [9]

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