Using the Six Astrometric Parameters from Gaia DR2 III: Revealing Optical Pairs in the Washington Double Star Catalog

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Abstract: The release of Gaia DR2 has led to the availability of up to seven million objects with six astrometric parameters from an homogeneous source with which an assumed common proper motion pair can be assessed for validity. Here an example is given by way of demonstrating 48 presumed common proper motion GRV objects listed in the Washington Double Star Catalog are in fact optical doubles.

Introduction

In Greaves (2019), Paper I, Gaia DR2 (Gaia Team, 2018) data were utilised to affirm common proper motion pairs of the GRV discovery code, this small subset of the Washington Double Star Catalog (henceforth WDS, Mason et al 2001) being chosen preferentially as the author was familiar with the nature of these pairs and the methodologies used to discover them due to being the original declarer of them. In this paper those same six astrometric parameters , namely the positions, parallax, proper motions, and radial velocities of the objects, are used to assess the full GRV subset within the WDS for optical pairs for the cases where all six parameters are available in Gaia DR2. As well as highlighting the mistakes made in the derivation of the original objects it will also demonstrate how the use of the full six parameters can distinguish between pairs that are reasonably safely assumed of common motion when only the basic four parameters of position and proper motions are used, and in some cases even when parallax is included as a fifth parameter, and pairs that appear to be equally safely assumed of common motion according to the same four or five parameters but which may not in fact be moving together.

Methodology

Using the CDS VizieR catalogue service the GRV discovery codes are bled from the WDS table (https://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=B/wds/wds) and then crossed with the Gaia DR2 Catalogue utilising the CDS X-Match service (http://cdsxmatch.u-strasbg.fr/). The search radius is left at a rather high 75 arcseconds as many of the early published GRV objects had separations of up to 70+ arcseconds. Thus for each input position taken from the WDS any object within the radius distance contained in Gaia DR2 will also be returned. As the common motion pair may have a larger separation than other field stars, especially given the limiting magnitude of Gaia DR2 relative to the limiting magnitude of the vast majority of the GRV objects, this also leads to some false positive matches.

However, as all full six parameters are needed many are removed simply by removing all the objects with blank and negative parallax, followed by the remaining handful that didn't have proper motions for both pairs and finally by the rather sizeable number of pairs that do not have radial velocity data for both objects. Then there is the issue of to how small a value for the parallax can be taken with confidence as a valid figure and here a parallax of 1 millarcsecond was taken as the lower limit, ostensibly 1 kiloparsec, below which parallax values are here deemed too noisy to aid in matching pairs, which leads to the further removal of

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objects. Stars of high to very high common proper motion are usually related but stars at such great distances of around a kiloparsec or more will not have proper motions of such sizes.

From within the outlook of this paper the results also unfortunately include many false positives in the form of pairs that are actually valid common motion pairs, although this is of course fortunate in terms of the GRV objects taken as a whole given that they are supposed to be common motion objects. Further, there still exist a number of cases where field stars also have a radial velocity available but these are usually plain enough to see as the CDS X-Match service returns an angular distance between the input position and the output position and this in tandem with the most recent separation quoted in the WDS can be used to assist filtering out irrelevant objects. This could be done automatically but in this instance it is done by hand.

Thus after the removal of all valid seeming objects and false objects a subset remains of pairs of objects, or rarely trios of objects, which are then double checked by hand as stated because it is still possible for a nearby field star having a radial velocity available by coincidence given the separations involved. In the case when the primary, the secondary and one or more field stars all have radial velocities available this is usually evident enough by each "pair" having had three or more objects returned during the crossmatch and the X-Match position and separation difference aid identification of the valid secondary. However checking by hand as opposed to automated checking also covered the remote possibility of either the primary or the secondary alone having radial velocity data available for them whilst a field star of coincident size of separation also had an available radial velocity, leading to an apparent pair of stars each with the full six parameters but with one of them not actually being part of the pair. This was in fact the case for a few GRV pairs due mostly to their separations being so high.

Then all six astrometric parameters were assessed and in terms of the proper motions and radial velocities any parameter value for an object within ten of the other object in the pair is deemed acceptable, giving a limit likely to be generously above the error value in nearly all cases. For radial velocities this will also be comfortably above any differential radial motion due to orbital motion, especially in the case of such large separation pairs at distances of hundreds of parsecs (thus of large projected actual separation) which would predominantly if not completely have a radial velocity difference of less than 1 kms-1 if valid pairs. Less leniency is given in terms of difference in parallax, nevertheless for parallax values of less than 5 millarcseconds a value within plus or minus 1 has been permitted even though that could lead to one of the pair appearing to have up to half/twice the parallax of the companion, 5 millarcseconds is 200 parsecs. A better system would use errors as a percentage of value to allow for such scaling issues arising from the use of small to large parameter values but in this instance the purpose is not to find common motion pairs but to debunk them by showing pairs blatantly not connected.

Results

This results in 48 GRV pairs being shown to be optical alignments, as listed in Table 1 where the identifier for the pair, the position angle and separation from the WDS (representing their positions), the parallax of each star, the proper motions of each star and the radial velocities are listed. Positions aren't given as the position in the derived form of the separation in tandem with position angle are inherent in the definition of the pair as being a "double star". Only the most evident cases are included in this instance. Roughly a quarter to a third as many again could not be firmly defined as optical and thus are not included in the list. Albeit somewhat contradictorily.

As noted, this approach is somewhat contradictory because in this paper the point is to show with some level of surety the pairs that are optical, despite earlier surveys having suggested they could be considered common motion objects and/or earlier methodologies permitting them to be considered as such. However, the proper approach is only to include two stars as a common proper motion pair with some level of surety such that given their ambiguity (in light of the new data, and possibly even originally) they should have never been included in the original GRV objects lists in the first place! That is, in the usual approach of adding data with confidence they may not have been included as GRV objects due to their ambiguity in the first place had the current Gaia DR2 data been available at that time, yet here in the current approach the somewhat opposite practice of objects only being removed from the list (that is, classed as optical) if there is confidence in doing so is taken.

This may sound somewhat artificial but the Gaia DR2 radial velocities are derived from what are relatively low resolution spectroscopy and often there is no independent confirmation for many of them. This can lead to the case such that there can be a not too wide a pair having parallax and proper motions that are comfortably similar yet the radial velocities differ markedly. Without any independent data it is not possible to say whether the other five astrometric parameters are in the wrong or whether the radial velocities are in the wrong, especially if the now available parallax values are also in good agreement.

Using the Six Astrometric Parameters from Gaia DR2 III: Revealing Optical Pairs in the WDS

Disc	PA	Sep	plx1	plx2	pmra1	pmra2	pmdec1	pmdec2	RV1	RV2
GRV 24	232	65.5	3.0	1.8	-8.1	-8.1	-10.3	-11.6	-8.0	-41.1
GRV 68AB	36	44.7	4.7	3.4	54.2	38.6	15.5	18.8	7.2	-1.4
GRV 69	332	63.1	1.0	2.7	8.5	12.2	-11.4	-13.6	22.7	-7.8
GRV 75	153	45.8	2.7	3.1	30.2	27.8	-25.0	-17.3	3.8	28.0
GRV 80	199	70.2	2.4	1.3	19.7	5.2	-11.4	-6.4	17.6	6.8
GRV 93	249	31.2	2.1	1.8	27.5	27.5	-8.9	-16.3	9.2	39.5
GRV 95	141	73.9	6.1	2.6	22.6	14.5	-16.0	-11.5	-35.2	-12.0
GRV 128	207	36.3	2.2	3.5	14.2	23.2	-11.1	-9.6	20.7	-23.1
GRV 134	165	30.9	4.0	3.7	48.5	38.2	-11.4	-17.6	16.9	44.5
GRV 282	194	69.5	1.4	2.9	-10.0	-4.8	-19.8	-11.9	18.0	-20.0
GRV 288	61	24.3	1.2	1.0	-10.2	-5.0	-15.9	-8.2	-54.7	-23.4
GRV 308	213	38.1	2.5	1.3	16.1	11.9	7.8	9.9	-61.5	-15.7
GRV 327	143	43.8	1.1	3.2	-12.9	-10.8	-13.0	-22.8	63.2	30.0
GRV 346	11	66.6	4.8	1.7	-11.0	4.4	-41.1	-7.9	23.7	-38.5
GRV 357	275	22.5	3.2	1.4	-9.8	-18.2	-22.8	-22.4	1.1	-14.1
GRV 381	340	35.8	1.4	3.4	-9.0	-10.3	-11.1	-12.6	-0.2	30.6
GRV 395	211	59.7	1.0	3.0	-11.1	-13.2	-10.2	-12.8	7.2	-14.5
GRV 407	221	59.2	2.5	1.6	-6.8	-12.8	-11.7	-8.8	8.0	-16.0
GRV 435	206	61.8	1.7	1.4	-8.6	-5.5	-9.1	-8.9	14.8	-63.9
GRV 463	32	35.2	1.9	3.0	-23.8	-30.8	-22.5	-17.8	0.9	-31.0
GRV 470	317	54.1	6.1	1.5	17.5	14.7	-17.6	-11.0	-16.0	-41.0
GRV 479	117	52.1	1.2	1.2	-19.5	-10.9	-14.8	-13.2	-71.0	-13.6
GRV 490	328	31.7	4.2	5.5	-15.2	-15.7	-22.0	-27.0	5.2	17.4
GRV 491	21	31.4	3.2	1.4	-15.1	-19.7	-16.5	-17.4	-30.8	3.3
GRV 492	171	58.7	2.2	3.0	15.4	15.0	-9.8	-7.3	-38.3	-24.3
GRV 501	154	24.5	5.7	1.2	-30.1	-20.9	-23.7	-17.6	13.6	-70.0
GRV 506BC	162	72.4	2.3	1.4	-16.5	-18.9	-24.0	-17.0	-45.9	-7.3
GRV 507AB	317	92.7	1.9	2.3	-13.0	-16.5	-11.7	-24.0	9.9	-45.9
GRV 521	306	45.5	2.0	1.0	-10.0	-14.2	-10.1	-10.1	8.1	-10.7
GRV 522	256	45.4	9.9	6.9	28.6	21.6	45.7	52.9	7.4	21.2
GRV 573	286	29.5	2.2	2.3	-21.1	-29.8	-15.0	-14.1	-32.7	12.1
GRV 575	113	59.4	7.5	2.1	38.0	23.0	16.4	21.2	-33.1	4.8
GRV 600	324	67.9	1.0	2.1	-14.1	-14.9	-14.2	-7.3	-11.2	-25.3
GRV 604	251	22.4	1.4	1.6	-27.7	-18.6	-22.9	-19.7	-46.7	-1.9
GRV 611	60	19.5	3.6	4.2	41.5	49.2	22.9	14.3	-16.3	-58.9
GRV 629	7	18.7	2.7	1.5	-37.4	-20.4	-29.5	-21.4	-36.0	8.9
GRV 665	174	64.7	4.8	2.2	12.9	12.2	-11.5	-9.2	-23.2	-1.9
GRV 676	320	32.8	1.3	1.4	-17.5	-12.3	-11.1	-15.7	-8.1	-25.2
GRV 681	340	44.6	1.7	2.5	20.0	27.9	15.1	17.3	9.6	-71.2
GRV 696	244	64.1	6.7	2.8	-13.8	-16.6	-20.0	-28.3	10.6	-20.2
GRV 698	252	49.9	1.2	9.6	17.0	10.0	-15.8	-9.6	-38.4	-15.5
GRV 710	59	61.6	1.9	3.8	-13.9	-17.4	-9.8	-19.1	-17.2	-4.4
GRV 727	180	31.9	3.7	2.2	-13.8	-13.2	-8.9	-6.7	-5.1	48.4
GRV 742	106	64.6	2.0	3.0	-10.7	-12.2	-13.3	-11.5	-22.5	47.5
GRV 754	24	22.9	1.3	3.0	-13.6	-9.7	-17.4	-17.5	60.4	31.4
GRV 790	212	26.0	5.3	1.5	-10.0	-7.8	-29.4	-22.2	-0.5	-34.5
GRV 954	261	58.1	1.0	1.4	-10.4	-7.9	-16.4	-11.2	-0.3	15.3
GRV 969	156	43.1	3.6	2.2	13.7	14.9	-10.2	-16.5	-30.6	8.3

Table 1. Astrometric Details For The Optical GRV Common Proper Motion Pairs. The GRV identifier, position angle in degrees and separation in arcseconds from the WDS, parallax in milliarcseconds, proper motion in milliarcseconds per year and radial velocity in kilometres per second for each star in each of the pairs taken from GAIA DR2, are given.

Table 1 consists of 48 optical GRV pairs, or more properly 46 optical GRV pairs and 1 GRV optical triple where not one of the three objects match any of the others. The total of 46 doubles and 1 triple is 47, not 48, the mismatch is because the triple seems to be listed in the WDS as GRV 507AB and GRV 507AC whilst the B and C comites are also there as GRV 506BC, such that GRV 506C = 507C and is nearer to GRV 507A than GRV506B = GRV507B is, which is a little confusing and probably stems back to an oversight in the original paper. Even more confusing is that Gaia DR2 now reveals that GRV507B is very roughly 30 arcseconds from a 16th magnitude star also having similar proper motion which could have been included in the system using the Greaves 2004 methodologies if known about at that time. Meanwhile GRV 507A has a 15th magnitude star lying only 4.3 arcseconds away with much closer, albeit relatively small valued, proper motion and parallax to GRV 507A which would have been unresolved in astrometric surveys prior to GAIA and yet would make a valid common motion comes to GRV507A than either GRV 507B or C! These other two stars have no available radial velocity data with which to assess them more deeply, however. This triplet (quintuplet) of stars lies in the constellation Pegasus which as noted in the Discussion has a handful of apparent similar motion pairs each of similar scale motions not confirmed when radial velocity is included.

Likely reasons for GRV pair stars formerly being wrongly assumed of common proper motion are given in the following Discussion section.

Discussion

Examination of Table 1 on an object by object basis revealed one certainty. The selection criteria for proper motions for the objects from the original Greaves 2004 paper were insufficiently stringent. Basically, the error ranges on the proper motions were taken too much at face value instead of using a larger multiple of that value. The method predominantly worked, but it was inadequate for pairs with motions only a little to twice the size of the error limit that also had motion differences of only just under the same error limit, and more especially so the wider the pair were. A caveat here is to note that the original search was targeted at proper motion pairs directly such that any pairs having differential proper motion due to significant orbital motion would also be rejected. Apparent orbital motion, however, is a function of distance from us and apparent separation and although this latter can be quite sizeable for stars quite close to the Sun differential motion can be shown empirically to shrink to negligible levels quite quickly for quite nearby stars, eg Greaves (2020). Similarly the further away a binary is the smaller the apparent separation can possibly appear such that this value falls below the angular resolution of the original paper's data.

Even then the main problem appears to have occurred as a consequence of "Galactography", or the nature of the distribution of stars in the Milky Way. Examination of the objects in Table 1 revealed that most of the demonstrably optical objects of this sort were in the constellation of Cygnus, with a handful more in the adjacent regions of Aquila and Vulpecula. Basically they were in the direction of the Local Spiral Arm. A large amount of the Local Arm lies within a kiloparsec radially for this particular direction and although it has a spread of about a kiloparsec or so in radial depth many stars within it will lie within the distance limits used in this analysis for the GRV objects, as now revealed by Gaia DR2. Thus in that direction there is not necessarily a random distribution of relatively adjacent field stars. Yet it is possible that the proximity of the Local Arm in Cygnus is enough for stars within it to have above error value level proper motions for pre-Gaia surveys. One noteworthy thing about these optical objects is that they mostly scale at roughly 20 masy-1 proper motion and often have similar Right Ascension and Declination motions overall, that is quite a few of the separate pairs have similar scale proper motions as any other pair in that group.

This gives the possibility of apparent motion due to their location within the relatively proximate Local Arm with any attendant general organised internal motion relative to the Sun that it may possess. This part of the sky is unique in providing a significant subset of the optical pairs of similar details only differentiated with the addition of radial velocity data. There also exists a handful of objects in a relatively not too large region of Pegasus that also seem to be similar in motion between themselves yet are shown not to be true pairs by their radial velocity difference, but these are much fewer in number as well as having no readily discernible reason for being of some level of commonality with other pairs.

Alternatively the Gaia DR2 radial velocity data towards these directions could simply be compromised. That is taken as unlikely however as such a systematic trend would have been noticed for although the proper motions for these optical pairs are relatively small they are not significantly so relative to the Gaia DR2 presumed errors.

As the current analysis utilises only data having all six astrometric parameters there are likely more GRV objects in the direction of Cygnus that are optical but due to null or negative parallax values and/or lack of radial velocity measure for both stars in the pair it is not easy to be certain for any particular pair. Certainly

GRV 268, the 17th most colour contrasted pair listed in Table 4 of Greaves 2004 appears to be the only valid pair in the list of colour contrast objects up to that point in said Table, with the previous 16 being readily assumed to be optical. Unfortunately none of them are common to this work so there is likely no joint radial velocity for them to be assessed as suggested in this paper.

Later published GRV objects had less of this problem because by then the author had understood that too much confidence had been given to the proper motion error values and besides the surveys used for later papers were of less accuracy anyway so the author tended to raise the threshold to around 50 $masy^{-1}$ or even 100 mas^{-1} in the case of some data sources (although part of that reason was an attempt to provide objects about which something could be said about either the stars and/or the utility of the data source for double star work rather than just providing large endless lists). Thus Table 1 carries few of the highest numbered GRV objects, although another reason for this will be that these tended to be fainter objects and therefore less likely to have all six astrometic parameters available in Gaia DR2 anyway.

For the rest of the objects from elsewhere on the sky the radial velocities show that the original identification of the pair as of common proper motion was simply wrong. There can be three reasons for this, one simply being that the proper motion values had too low a cutoff level both in absolute terms and also relative to their errors in tandem with too large an upper limit on separation distance. The table suggests that the wider the pair and the lower the proper motion the more likely a false common motion will be attributed to the pair, which also sounds somewhat intuitive when stated. A second reason may simply be that Gaia DR2 proper motion data are superior to the data used in the original analysis, again this could have been avoided somewhat by having not used such a low cutoff threshold for the proper motions thus avoiding potentially pushing the original source data beyond its capabilities.

Based on the author's experience over the years it becomes increasingly clear that the wider the separation between a pair the higher a proper motion value ought to be used. There aren't likely to be any orbiting pairs (which often have differential proper motions sufficient to emulate a mismatch) missed because just about all the nearby orbiting wide pairs are going to be known whilst the more distant and wide the pair the greater the chance of coincidental values, especially for large separations and low motion. There have been many attempts to define a double star over the centuries, with a famous name in the field per epoch usually putting forward their own method or variations upon older methods, but these are often geared towards gravitational interaction and thus orbital motion which is not a concern for the type of doubles that are co-moving objects. The situation is still not clearly defined after all these years even in the professional literature, with the Washington Double Star Supplement (http://ad.usno.navy.mil/wds/Supplement/wdss.html) containing many very wide pairs (arcminutes in some instances) from professional papers using various professional surveys and declaring pairs not always having particularly large proper motions and even if valid most certainly beyond the point of potential gravitational interaction. Meanwhile nearby young Moving Groups (eg TW Hya or b Pictoris Groups) are defined from objects which although having parameters more accurately and precisely defined by large professional instruments still have negligible proper motions and radial velocities in absolute terms not necessarily that markedly different from field adjacent field stars as well as being near enough to us for negligible radial distance (measured as parallax) differences to be ignored, as after all the Groups have depth as well as height and width.

It is still not clear, therefore, what limiting criteria to use safely for wider pairs, although proper motions over 50 $masy^{-1}$ are generally safe 100 $masy^{-1}$ is safer still, especially for some data sources, whilst restricting angular separation to 30 arcseconds or less reduces the chance of false alarm coincidence even further. This at least will result in lists having more quality over quantity but will also throw away a great number of valid wide pairs. The more distant the pair the more problematic especially for wide pairs with relatively low proper motions and the further the pair the smaller the proper motion is going to be. The possibility of adding, hopefully safe, radial velocity data thanks to Gaia DR2 can permit a double check when all the other parameters are in adequate agreement, including for wider, distant, low motion pairs, especially as radial velocity values are independent of distance. However the radial velocity values have also to be large enough and sufficiently different relative to the likely accuracy regime of their source.

If none of the above scenarios apply there only remains the third reason, hopefully in the minority, which is the simplest of all. The author just plain got it wrong! The GRV objects involved were manually double checked during publication on more than one occasion before both their submission and after, including at galley stage, yet clearly false candidates were still missed, and the error of selection was due to the author, not the data nor the methodology. It cannot get any simpler than that.

Conclusion

The six astrometric parameters from Gaia DR2 are used to find optical pairs in an ostensibly common motion subset of WDS doubles, with emphasis on radial velocity use although keeping the other parameters in play. A total of 48 GRV common proper motion pairs, more properly 46 pairs and 1 triplet, are found to be most likely optical. Some have a regional bias on the sky and may be due to a quirk of Galactic structure and commonality of kinematics in that direction, others may be a consequence of the difference in accuracy between the original source data and the Gaia DR2 data for proper motion but more likely reflect the use of too low threshold points in the original analysis rather than inherent failings in the original source data. Other pairs appear valid enough under the original four parameters and remain so when parallax is added as a fifth parameter until radial velocity is also taken into consideration. Finally it is clear that no matter how careful an analysis is conducted and checked and re-checked some results will still be just plain wrong due to author error.

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