Using the Six Astrometric Parameters from Gaia DR2 II : Common Radial Velocity Pairs

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Abstract: Common proper motion pairs are a well known way to find pairs of possibly connected stars lying close to each in the sky, as long as the proper motion is sufficiently high to be above both background and data source noise levels. Using Gaia data release 2 it is now possible to search for pairs with little or no transverse motion. Here it is shown that possibly associated pairs of stars with negligible proper motion can be found this way, including very close pairs of high proper motion that are too close together on the sky for the resolution of past surveys to have separated. It is also possible to find large proper motion pairs that have been previously missed in earlier searches.

Introduction

In paper I (Greaves 2018) the six astrometric parameters available from Gaia data release 2 (Gaia Team 2018) were used in order to go towards confirming candidate common proper motion pairs listed in the Washington Double Star Catalog (WDS) (Mason et al 2001). Some reasonably rapid moving pairs will be lost to proper motion studies, however, due to them having little to no transverse motion in the sky as their movement is nearly entirely radial, that is either towards or away from us. Most proper motion surveys are of relatively poor resolution astrometrically due to being relatively wide field thus not being suited to distinguishing between pairs of small separation, or they are sometimes of insufficient star density to enable the situation where enough fairly adjacent stars can be measured. Gaia DR2 allows this by greatly increasing sky density sampling as well as enabling stars of much closer separation to be revealed. Ironically in some of these cases the stars were previously known as of quite high proper motion, but quite simply it had not been realised that they were in fact two stars, not just one, until the Gaia data. A similar situation has occurred for ground based radial velocity surveys of large areas of sky with the radial velocity of close pairs being represented as that for one object, or in the case of readily resolved pairs only one of the stars having been measured. This analysis will concentrate on stars primarily selected via their radial velocities.

A search for common radial velocity pairs was conducted and examples for all three potential cases are given. Some emphasis is placed on the close pairs as observers using Gaia DR2 to generate such a subset of stars enable themselves to create a small project of close pairs that may even have the added bonus of exhibiting some relative motion over the next few years to decades. Or for the more aesthetically minded, the chance to observe a close pair and simply know that they are quite likely some of the very few people ever to visually discern the pair as a close binary, possibly even the first.

Methodology

The general methodology follows the paths and tools already outlined in paper I (Greaves 2018), except TAP VizieR (http://tapvizier.u-strasbg.fr/adql) was used to generate a list of stars from Gaia data release 2 with listed radial velocities of 30 kms^{-1} or more or –30 kms^{-1} or less via SQL interrogation. Using these velocities in tandem with parallaxes of 2 milliarcseconds or more, a search list was generated by matching objects with very close parallax and radial velocity, which turned out to be quite a long shortlist. From this a candidate paired list was generated followed by honing including the cropping of objects with separations greater than 30 arcseconds and the removal of already WDS listed objects (often classically known pairs which were close enough to us to have been measured a long time and even have had known orbits computed), all checked against an early July 2018 version of WDS to ensure they were not already known. The results were also checked against an early July 2018 version of the Washington Double Star Supplement (http://ad.usno.navy.mil/wds/Supplement/wdss.html) a new service that enables the indexing of common proper motion pairs that have been generated from work based on large surveys and the ilk. Use of the latter dataset as a further check did actually preclude the use of a couple of "new" candidates in this paper that were not included in the standard WDS.

As mentioned in Paper I assessment of association can be somewhat subjective, although there have been attempts over the years to provide guide lines for assessing possible common proper motion stars. A statistical test would require testing the frequency of pairs of varying separations against an assumed randomly distributed background population, the latter likely modelled (that is, not truly random, but random at within the permitted limits). This could need three to four different tests, one each for Thin, Thick, Halo and possibly Bulge stars (though the latter are least likely to come near the Solar neighborhood). The most appropriate test would possibly involve space velocities which when examined against appropriate Population density could predict the chance of pairs of whatever distance apart on the sky sharing the same motion in space kinematics' parameter space. Such a system could also be used for looking for Moving Groups and Streams. The tests would however require the background Population to be well defined as to their global parameters, and that within those limits the background is random enough to have a truly normal distribution to sample against (and subjectivity creeps into assumptions at all levels). In this light one of the points of Gaia is to define Galactic Populations better and over the next years to decades will probably lead to such Populations being totally redefined.

It is also the author's past experience in both variable star (eg Greaves & Howarth 2000) and meteor shower analyses (eg Greaves 2012) that statistical tests do not always help in borderline cases. When something has a high probability of being something special (usually more properly a low probability of occurring via random chance) it is usually self evident anyway. When the converse situation applies, that is plainly no different from background noise, that too is usually self evident. However, even with statistical testing borderline cases are still borderline in many instances. Statistics lets populations be defined en mass, whether it be a population of long period variable light curves that vary meaningfully in period unlike the vast majority that don't, or a bunch of similar Solar System orbits that can be defined as a population differing from the local background population. Yet, when it comes to saying whether specific individual particular objects firmly belong within a particular population rather than just appearing that way by chance, the greater number of individual candidates often lie in the borderline area with the statistical tests not necessarily adding any further insight.

Numbers help clarify this. If the extremity of True is 1, or unity so to speak, and the extremity of False is 0, and anything within one standard deviation is 95%, or 0.95 in this case, lies above the "possibly true" threshold then a statistical test returning 0.23 says false and one returning 0.97 says true. A value of 0.50 is not a 50:50 chance, it's False. However, if a bunch of things only being tested because it is felt they are borderline crop up with values 0.88 to 0.94 we tend to not want them to be false, and feel they may pass later given future refined data, we do not tend to reject them totally, we tend to keep them around as candidates. Some will even interpret them as still true, as the statistical tests aren't perfect after all and the model may change with newer knowledge. However in the cases where things were of very low value or well above we could likely have assigned them without subjecting them to statistical testing anyway. In the author's experience border line cases remain borderline, self evident ones plain to see, and dismissable ones just as plainly seen. This does not mean statistical tests are useless, when used to give a general categorisation of a large sample they work fine. This is not quite the same as finding whether an individual object lies within a specific subset or not.

If an object has an 89% chance of being a connected pair of stars it is not shown to be a connected pair of stars, it is shown to be an object having an 89% of being a connected pair of stars, no more. That is, given 10 pairs then usually 9 pairs like this one will be connected but 1 will not, and with present data it is still not known whether this pair lies within the 1 or the 9 subset. Unfortunately with many common proper motion pairs it may never be known as their separation is sufficient that any real firm evidence, like mutual orbital motion, would take at least thousands of years to discern.

There is also the situation where assumptions with respect to the statistical model based on the assumed normal distribution background can also make the entire edifice stand or fall, or rather apply in some cases but not others. For example, Jupiter affects the motions of small objects within the Ecliptic Plane, especially

Sunward of itself, such that meteoroids in general and ones potentially derived from Jupiter Family Comets (short period comets with orbital parameters particularly modified by past Jovian influence) do not follow a normal distribution, nor can one be assumed. However, high inclination orbits that keep objects well out of the Ecliptic Plane appear to be safely random in distribution, at least at present.

Such tests tend to be applied to meteoroid orbits en mass, irrespective of the mixed populations. This can lead to multiple candidates for potential parent object association for near Ecliptic Plane orbit comets and even asteroids. Or more significantly here, it can associate many actually separate objects from orbits within the Ecliptic Plane. Simply because Jupiter causes their orbits to evolve over time into similar natures with a narrower set of discrete possibilities than that presented by a random background. That is, two totally different particles of completely different parent body genesis in both time and place can end up appearing similar in their current evolved orbits due to perturbations over time caused by Jupiter's gravity. For common proper motion pairs this would equate most nearly to Thin Disc stars, and to some lesser extent Thick Disc ones, which are of relatively low scale height. This does not necessarily mean that such tests would be completely inapplicable to these pairs but would certainly mean completely different threshold cutoffs in terms of separation and scale of proper motion. Again, tests would be most comprehensive if used against Space Motion, or particularly the Space Velocity vectors UVW for which latter six astrometric parameters of high quality are required in order to derive meaningful accuracy of values. Gaia can potentially provide these in time, but defined Galactic Populations will also be needed.

Qualitative tests can be applied, Knapp (eg 2018) has evolved and honed an approach. Unfortunately in recent papers he has been convinced that a numeric value is better than his original grading system to which suggests a "probability". I enquote the word not as a direct quote but in the sense the numerical route suggests for his work. A numerical value, especially a percentage one, suggests a quantitative, if not statistical, appraisal. His system is in fact qualitative. There is nothing wrong with using the latter, but it is far more heavily based on assumptions (no matter how reasonable) that have to be somewhat intuitively made, that is subjective. It is most certainly not even a probability nor even likelihood, however this latter pedant point is simply a reflection of the fact the words "probability" and "likelihood" have well defined technical descriptions in probability theory and are formal terms that overlap with their normal general English use (and this is likely also true of many other languages). This is something of a problem when finding synonyms to use when talking qualitatively, even the word "random" has a formal technical meaning.

Another important aspect is that an analyst must always ensure they are using primary data sources, that is catalogues based on measures. There has been a steady increase in recent times of compilation catalogues, a problem in tandem with greater computing power enabling readier massaging of large data, and the source catalogues utilised therein (which often are primary catalogues but themselves can be secondary compilations) are usually of very differing nature and especially error regimes. Such a thing often precludes the use of the included independent primary sources for double checking against each other for certain values or simply comparing different objects. Secondary catalogues based on data processed beyond the basic processing required to generate a table from measurement, and, compilation catalogues which are rarely critically compiled but usually whole datasets of varying internal quality just arbitrarily lumped together, should be avoided. Primary sources are (mostly) homogeneous. Homogeneity is by far preferable. Basically because no matter the quality or not of a primary source catalogue at least like is being compared with like.

The long preamble is to honestly introduce the fact that the following objects were tested qualitatively at the near intuitive level, not quite (but not entirely divorced from) the level of "if they aren't a pair given all these values, especially the size of some of these values, and their proximity to each other, then something damn weird is going on", but qualitative assessment more via process of elimination than positive inclusion. Reasons for using this approach is that it is no better nor worse than any other qualitative approach given our current understanding of the Populations and the pairs involved. Justification for its use here at the end of the day is mostly based on it appearing to work if enough cynicism is applied over optimism given the most general nature of stellar motions as currently known. However all intuitive appraisals have subjective underpinnings and as for some of the examples provided below being actually associated, well others may differ in their interpretations. They do not even have to give an alternative reason for apparent association, but to simply show based on the data why the data cannot be made to say certain things according to their opinion, and if the two opinions have no way to distinguish between them then we get the following :- the opinion that says a thing cannot be so wins over that that says it can be so. That is scientifically the case if there is no way to test between the two viewpoints and neither violate the basics. Preferably it should be show, not just simply "feel" or "disagree". These contradictions can be surprisingly common if the contrasting conclusions are based on independent data and/or independent but still valid approaches.

From the eventual still fairly sizeable list of hundreds of candidates a handful of objects are presented for illustrative purposes here.

One subset of these actually turned out to have large transverse motion anyway, that is they were high proper motion pairs as well as high radial velocity pairs which for some reason had been missed in past common proper motion searches. Also included in this subset were pairs such that until now only the much brighter primary had any reliable data, the proper motion of the secondary either being unknown or not well known (at times wrong) prior to Gaia DR2.

Another subset for wider pairs included the stars initially primarily targeted for, that is stars with low enough proper motions to make it meaningless to compare them with each other but that have now been revealed to have sufficiently high enough radial velocity to be seen to be common radial velocity pairs. Especially when things are further qualified by very similar parallaxes, as well as their spatial proximity on the plane of the sky.

The final subset consisted of pairs that could have high or low proper motion, overlapping the above, but were incapable of being noticed as more than one star due to the relatively lower spatial resolution of most land based telescopes, especially in the case of wide field surveys. As stated, this subset can contain proper motion pairs of either high or relatively low proper motion. As an extra aspect to the analysis some attempt has been made to confirm the duplicity of these close pairs by comparing the predicted pairhood against the images from some modern sky surveys (North is up in these images which are primarily illustrative and not mutually scaled). The minimum separation tested was around 1.5 arcseconds, Gaia gave smaller separations but the data are still being processed to final result and without independent imaging it is not possible to distinguish between true very close pairs and duplicate entries for an object due to processing issues.

By way of example a set of fifteen pairs are presented here with their particulars and with confirming images when available. For want of an identifier the thought was to categorise them GRV for Gaia Radial Velocity pair. However should they be end up being included in the WDS this would lead to the problem of GRV already being used as a discoverer acronym. That is until the author remembered why it is already used. So the same discoverer code is being used here, but with numbering starting at 1248, as GRV1247 is the last one currently in the WDS (said pair is possibly a false alarm pair according to just radial velocity, albeit said radial velocity sourced from different primary catalogues, see Paper I).

As with paper I, UVWXYZ are also generated using BDNYC (Brown Dwarfs in New York City http://kinematics.bdnyc.org/query) and used to assess the potential Galactic Population membership of each pair.

Results

The stars are listed in Table 1 where their epoch 2015.5 positions, the position of the secondary, and the six pairs of astrometric parameters are all obtained from Gaia DR2. The separation and position angle are also derived from the Gaia data being measured from the star with the brightest G magnitude from Gaia DR2. As in Paper I the marked increase in accuracy and precision given by Gaia has led to separations and position angles being quoted to one decimal higher than is normal practice (eg WDS) here.

For the pair with closest separation the derived (from a Gaia model) Gaia quoted luminosities were used in tandem with the angular separation and parallax via Newton's modification of Kepler's 3rd Law to get some idea of the potential orbital period. Basically dwarf stars are said to have luminosity and mass such that $L \propto M^3$. For pairs from Gaia where both stars have a luminosity in terms of Solar luminosity listed, the third root of the luminosity was taken for each star (in Solar mass units) and taken as representative and these summed together. If the pair's separation is in arcseconds, and the parallax given is also in arcseconds, then for an ideal world pole on orbit combining this with the combined mass in Solar masses gives the period in units equating to the orbital period of the Earth. That is, the period in years. The nearer the star, the smaller the separation, the lower the potential period. Remembering that the semimajor axis is a potential but highly unlikely representation which will at least be of a fairly similar scale to the true value for any real orbit.

The nature of the orbit is not known, however, or even if there is any orbital motion. The number mentioned as "period" is simply being used as a means of estimating the potential for noticing relative motion over time, for we do not know the shape of the orbit. However, we can assume an ideal, that is likely unreal, case to give an estimate of the scale of the orbital period. The "ideal" case takes the form where by sheer good luck we are staring straight down one pole of the pair's orbit and that further the pair are an even mass pair with circular orbit. In such a case the measured separation would be the same as the semimajor axis, for the orbit is circular and the pair's orbit is pole on to us.

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Table 1. The candidate objects showing a name for the pair RA and Dec for each of the pair to epoch 2015.5, parallax, RA proper motion, Dec proper motion, radial velocity and Gaia G magnitude for each star in each pair with position angle theta and separation rho calculated from the RA and Dec values and corrected for the cosine of declination.

Name	raA	decA	raB	decB	piA	piB	muraA	muraB	mudecA	mudecB	rvA	rvB	GmagA	GmagB	theta	rho
GRV1248	67.10455	-7.60107	67.10325	-7.60219	10.779	10.839	126.469	126.632	32.847	32.027	109.1	108.7	12.7	12.8	228.8	6.14
GRV1249	73.43672	-45.6547	73.43563	-45.6543	8.049	8.074	-15.879	-17.145	78.792	79.489	121.2	115.4	12.5	13.2	297.9	3.11
GRV1250	92.64291	-47.0174	92.6475	-47.0181	6.585	6.585	5.328	6.427	21.056	21.551	127.5	120.1	10.4	11.9	102.6	11.54
GRV1251	95.2957	-43.0405	95.29538	-43.0413	22.828	22.834	-0.43	-4.022	194.474	203.28	154.5	154.6	11.9	12.8	195	3.29
GRV1252	115.3809	-42.3835	115.3796	-42.3853	8.479	7.838	-141.703	-144.066	86.226	87.581	114.8	120.2	13.6	14	210	7.42
GRV1253	117.5513	13.551	117.5518	13.55074	12.365	12.401	-95.719	-98.279	87.359	81.454	120.3	117.9	12.5	13	117.9	2.00
GRV1254	150.7563	-53.4832	150.7563	-53.486	6.226	6.195	13.234	10.369	-1.813	-2.908	116.5	117.7	9.9	11.2	179.2	10.01
GRV1255	172.9478	-67.0102	172.9569	-67.0063	7.625	7.648	-4.07	-7.814	-52.964	-50.284	215.1	219.1	11	13.2	42.7	19.06
GRV1256	210.3268	12.3017	210.3266	12.30128	7.101	7.033	-50.128	-49.822	13.873	14.425	-38.1	-37.2	12.2	12.4	199.5	1.58
GRV1257	252.4111	47.97281	252.4099	47.97325	6.529	6.545	-35.262	-34.91	100.428	100.334	-106.2	-103.8	12.2	12.7	300	3.23
GRV1259	256.546	18.14253	256.5473	18.14507	13.113	13.089	3.829	3.173	19.978	23.642	-137.3	-137.2	10.3	11.7	25.9	10.19
GRV1260	270.1795	6.44579	270.1823	6.44141	8.117	8.116	-3.789	-3.838	15.118	15.414	-107.7	-107.8	10.7	12.2	147.4	18.75
GRV1261	275.9396	28.13296	275.9398	28.13355	5.746	5.847	9.161	11.82	27.913	21.41	-90	-92.4	12.2	13.1	15.9	2.2
GRV1262	276.6252	-2.43914	276.625	-2.43953	6.14	6.159	-19.369	-18.219	-4.996	-3.595	48	51.8	12.5	12.7	210.5	1.64
GRV1264	302.2932	-41.0785	302.2938	-41.0788	27.714	27.224	-96.947	-106.126	-141.539	-148.257	33.3	34.1	12	12.4	114.2	1.87

Table 2. The UVW space velocities for each of the pairs in kms^{-1}, where U is positive towards Galactic Centre, V is positive in the direction of the Sun's motion and W is positive in the direction of the North Galactic Pole.

Name	U	V	W	X	Y	Z
GRV1248	-106.34	-59.06	-17.07	-69.82	-29.09	-53.27
GRV1249	-72.42	-68.62	-83.54	-31.02	-91.02	-78.36
GRV1250	-44.78	-109.56	-49.93	-36.32	-131.35	-67
GRV1251	-86.6	-124.71	-51.41	-13.21	-37.97	-17.38
GRV1252	-108.7	-86.54	-68.78	-29.34	-117.28	-20.21
GRV1253	-127.7	-14.12	20.77	-67.96	-34.77	26.35
GRV1254	26.8	-114.73	6.05	26.32	-158.79	4.25
GRV1255	96.96	-187.71	-51.94	55.63	-117.92	-12.17
GRV1256	-44.02	-12.66	-23.81	52.94	-5.39	131.12
GRV1257	-97.15	-72.39	-50.59	31.99	113.02	98.01
GRV1259	-97.83	-67.46	-69.2	51.04	40.8	39.45
GRV1260	-92.76	-51.71	-20.6	100.23	64.98	30.22
GRV1261	-65.23	-60.98	-30.98	91.94	135.85	53.4
GRV1262	49.09	15.89	15.15	143.28	75.88	12.55
GRV1264	34.46	-27.32	-6.99	31.03	-0.31	-19.03

Another case would be the same situation but with the orbit edge on to us, rather than pole on, and by an even more highly unlikely coincidence we happened to be viewing them exactly when they were at widest apparent separation relative to our line of sight. For such a latter case of ideal and sheer coincidence any pair would consist of one star moving directly towards us and one moving away, which would show as a variation in radial velocity between the two. Rough estimates showed that at the very best the combined difference in linear radial velocity of even the closest and nearest pairs would be no better than, and usually smaller to much smaller than, around 2 kms^{-1} even in this doubly coincidental unreal ideal case, and not really discernible using Gaia DR2 radial velocities. This approach was therefore not used to test for potential orbital motion.

In such a situation the best candidate from this list for noting any potential relative motion would be the 1.9" separation pair GRV1264 which for the highly unlikely perfect case would have an orbital period of roughly 400 years or so. The apparent orbit is much more likely to be both eccentric, inclined and foreshortened to the line of sight in both the x and y planes, all of which will affect this figure, but it can give some idea of the scale.

To accompany the tabular data each star is noted in summary next. The primary is decided in the traditional manner of brightest stars, with there being no exactly equal brightness pairs here needing any further rule to be added. However, some are of close magnitude and the source data Gaia G magnitudes being used here which may not necessarily agree with other magnitude passbands (eg Johnson V or even visually for that matter) when it comes to deciding the primary.

GRV 1248

This fairly equal brightness pair of quite high radial velocity is also of high proper motion showing there are still fairly close common proper motion pairs that have not been found as of yet.

GRV 1249

This pair still has quite high proper motion but is more likely unnoticed due to it being close enough not to be resolved by most if not all proper motion surveys so far. As Gaia is a significant step up in spatial resolution as well as accuracy and precision past catalogues cannot normally be used to separate pairs this close. However, some recent Near InfraRed (NIR) wide field surveys have a higher spatial resolution than traditional optical wide field all sky surveys, one such being the VISTA Hemisphere Survey (VHS, Cross et al 2012). Figure 1 is in the J infrared passband (sourced from the WFCAM Science Archive, eg Hambly et al 2008) and shows an oblong object (the few other stars in the field are far more circular). The VHS catalogue itself does list this "object" as two discrete objects from which can be calculated a separation of 3.1 arcsecs and position angle of 298 degrees, in very good agreement with the Gaia data. The VHS data however only carries positional astrometric data as the survey is a photometric one.

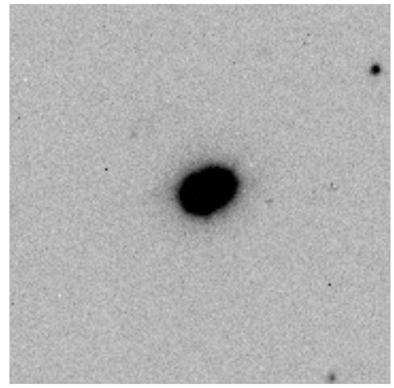

Figure 1. GRV1249 VHS J band image

GRV1250

This constitutes a pair of high radial velocity objects with fairly unremarkable proper motion of not much more than 20 mas^{-1}, about the scale of some traditional surveys and barely two or three times the typical error size for even several recent ground based ones. In other words, an association not particular striking from proper motion alone. In this instance RAVE dr5 (Kunder et al 2017) provides some fairly confirmatory radial velocity data, with both stars having been measured as having heliocentric radial velocity around 119 km^{-1}.

GRV1251

This is a close pair separated by Gaia where an individual high proper motion object has been shown in the past (SPM4, Girard et al 2011). Images served via

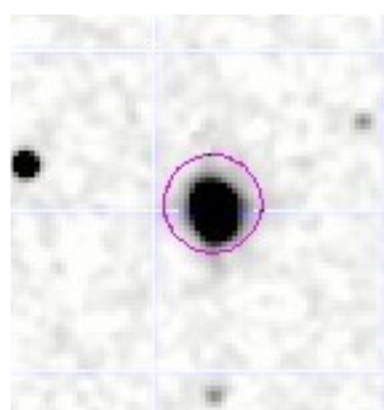

Figure 2. GRV1251 2MASS J band image

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irsa.ipac.caltech.edu reveal an oblong object as shown in Figure 2, furthermore their catalogue plotted position in this 2MASS J band image (Skrutskie et al 2006), which is to J2000, highlights the proper motion when compared to the Gaia positions for 2015.5. 2MASS catalogue data provides a separation of 3.3 arcsecs in a position angle of 193 degrees and will be to J2000. RAVE dr5 presents a single object at this pair's position (whether the two stars are merged in that dataset or only one was measured is not clear but likely the former) with a heliocentric radial velocity of 153 kms^{-1}, in very close agreement with Gaia's barycentric radial velocity.

GRV1252

This pair, which is not a particularly close pair, represents an example of an heretofore overlooked high common proper motion pair.

GRV1253

This close pair's members have both high radial velocity and high proper motions, all common. The parallaxes are not quite so tight but comparable. It has likely only been noted as a single object in past proper motion surveys, or just simply overlooked. One recently released optical sky survey of good resolution is PanSTARRS data release 1 (eg Flewelling et al 2016) and here an image in the g band is presented in Figure 3 as confirmation towards duplicity. (NB the usual meaning of the word duplicity makes the last three words sound like proof of falsehood, whereas here it's actually meaning proof of potential doubleness).

GRV1254

The small proper motions of this pair are fairly close to the typical error margins at these magnitudes for most surveys to say anything for certain about their similarity of motion, but here Gaia radial velocity and parallax declare a likely association.

GRV1255

A comfortably wide pair with proper motions sufficient to make it a candidate common proper motion pair but apparently so far overlooked.

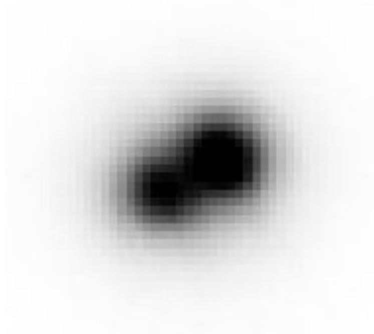

Figure 3. GRV1253 PanSTARSS g band image

GRV1256

Here is the closest pair presented in this analysis, and Figure 4a provides a PanSTARRS dr1 y band (a very near infrared passband) image helping to confirm it is really two objects. Figure 4b from a UKIDSS J band image (eg Lawrence et al 2007) suggests two stars (especially from the diffraction spikes), but does not resolve it and neither does the catalogue of sources appear to list more than one object at this position. This highlights the power of Gaia. LAMOST dr4 (eg Lou et al 2105) provides a single object heliocentric radial velocity of -39.8 kms^{-1} which is in good agreement with the Gaia values.

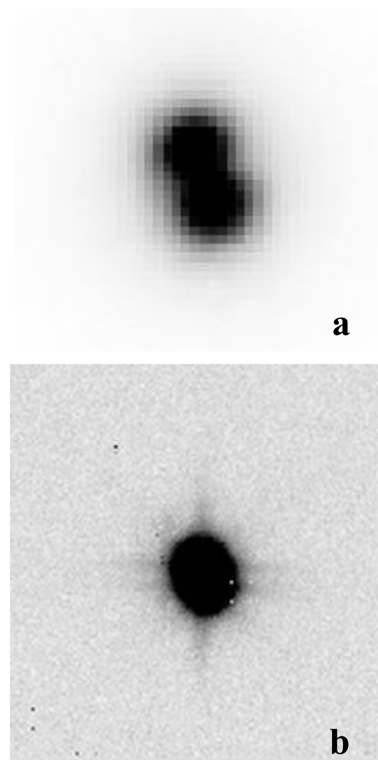

Figure 4. GRV1256 a) PanSTARSS y band image, b) UKIDSS J band image

GRV1257

This represents a fairly close high radial velocity pair with low but marked radial velocity. 2MASS J band image from the IRSA server show a quite extended object if not a cleanly separated one in Figure 5. The 2MASS catalogue does list two objects (likely centred on the respective centroids of the stars' images) which give a J2000 separation and position angle of 3.3 arcsecs and 300 degrees respectively at J2000, again comparing well with Gaia.

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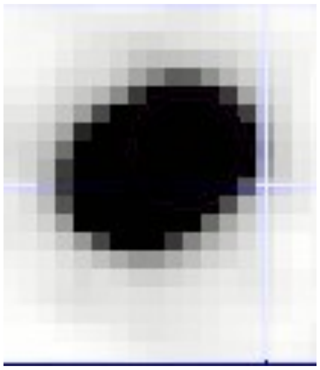

Figure 5. GRV1257 2MASS J band image

GRV1259

A comfortably separated pair of unremarkable proper motion that is highlighted by its high radial velocity.

GRV1260

A relatively wide pair with proper motions that are small enough for it not to be included in common proper motion lists but high receding radial velocity. LAMOST dr4 lists the primary as a G3 star with heliocentric radial velocity of –113 kms^{-1} and also gives a metallicity ([Fe/H]) of –0.37, a good candidate for a Thick Disk star (see Paper I).

GRV1261

A close pair of unremarkable proper motions but high radial velocity (note the bright star roughly eight arcseconds due North is of quite different radial velocity etc and merely a coincidental field star). This is an unequal brightness pair with some slight discrepancy in their proper motions. If this latter were real and they are at the same distance then with their differing luminosity suggesting differing mass this has the potential to be a more eccentric orbit even intrinsically and worth following over time. Figure 6 is a y band image from PanSTARRS dr1 showing the pair separated (and the field star highly overexposed at top).

GRV1262

This close pair can be shown as elongated in VHS dr3 J band (Figure 7a), an overlapping pair with separate diffraction spikes in UKIDSS J band (Figure 7b) and somewhat more distinct in PanSTARRS dr1 y band images (Figure 7c). These data represent a spread of epochs in the past few years or so but will be roughly contemporaneous. UKIDSS also lists this as two separate catalogue objects from which can be derived a separation of 1.6 arcsecs in a position angle of 209 degrees for J2000.

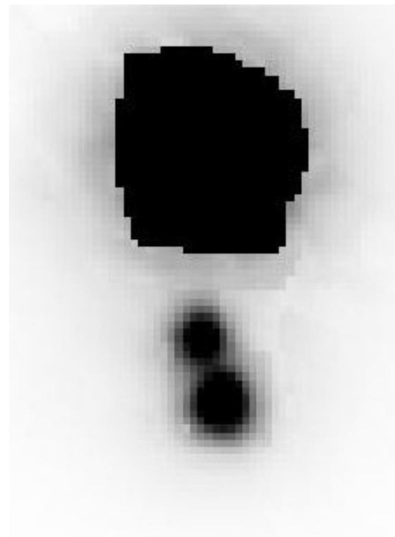

Figure 6. GRV1261 PanSTARSS y band image

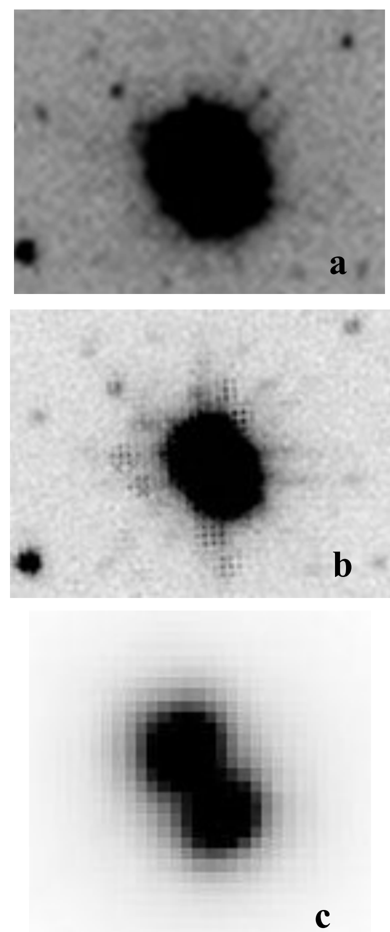

Figure 7.GRV1262 a) VHS J band image b) UKIDSS J band image c) PanSTARSS y band image

Using the Six Astrometric Parameters from Gaia DR2 II : Common Radial Velocity Pairs

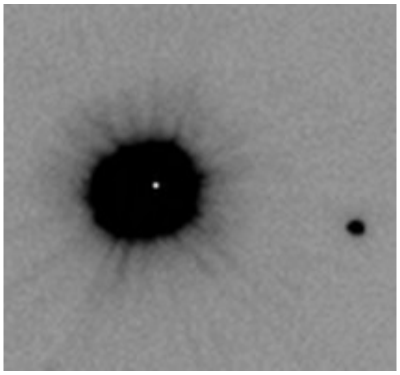

Figure 8. GRV1264 VHS J band image

GRV1264

This close pair is also the physically nearest with a mean distance of 36.4 parsecs according to its parallax. Despite having high common proper motion it has so far not been identified as such a pair, likely because such surveys have not previously resolved the pair. The radial velocity is not particularly high but the RAVE dr5 heliocentric velocity of 31.7 kms^{-1} is in good agreement. The VHS dr3 image in Figure 8 in this instance only shows a possibly elongated object so is not as firmly split a double as in earlier cases. If by coincidence we were looking at this orbit pole on and it was a circular orbit such that separation was the same as the semi-major axis then this pair's 68 Astronomical Units projected separation would also be the value for the semi-major axis. Utilizing Newton's modification of Kepler's third law, the assumed semi-major axis in arcsecs, the parallax also in arcseconds and using the assumed luminosities provided by Gaia to derive a rough total mass in Solar masses, the period of such an ideal orbit would be around 412 years. In comparison the very near circular orbit of the planet Neptune has a semi-major axis of approximately 30 Astronomical Units and an orbital period of approximately 165 years.

In this sample this is possibly the best candidate for detection of relative motion over time out of the pairs provided here. Note it is not the pair with the smallest separation in the sample but it is the one that is nearest. True size of any real orbit depends on both, with the combined separation and parallax of this pair leaving them with a current projected separation of 68 Astronomical Units, smaller than that of the other pairs listed here that are apparently closer together on the sky.

Population

Figure 9 presents a Space Velocity 3D scatter plot of the new objects in the UVW parameter space against some known Population types following the same principle as outlined in Paper I (see also references therein). In this instance most of the "new" pairs here appear to be Thick Disc Objects, although there are one or two Thin Disc candidates.

GRV1256 and especially GRV1262 and GRV1264 are most likely Thin Disc stars when the data are examined closely via TOPCAT 3D visualization plotting (eg Taylor 2005). GRV1255 seems the best Halo candidate although there are also a couple of borderline cases. The rest appear to be firmly Thick Disc stars with some clustering for quite a few, however that is possibly some selection effect on the sky that came from this small sample, nevertheless none of the selection criteria included position on the sky, separation was used to select pairs, not right ascension and declination, and Gaia is all sky.

Conclusion

Using data from Gaia data release 2 it is shown that pairs either having little to no transverse motion upon the plane of the sky, pairs that in the past were unresolved by surveys thus not known to be more than one star and pairs where the secondary is sufficiently fainter to not have been measured along with the primary to give proper motions, can be associated by their common radial velocities, especially when all six astromet-

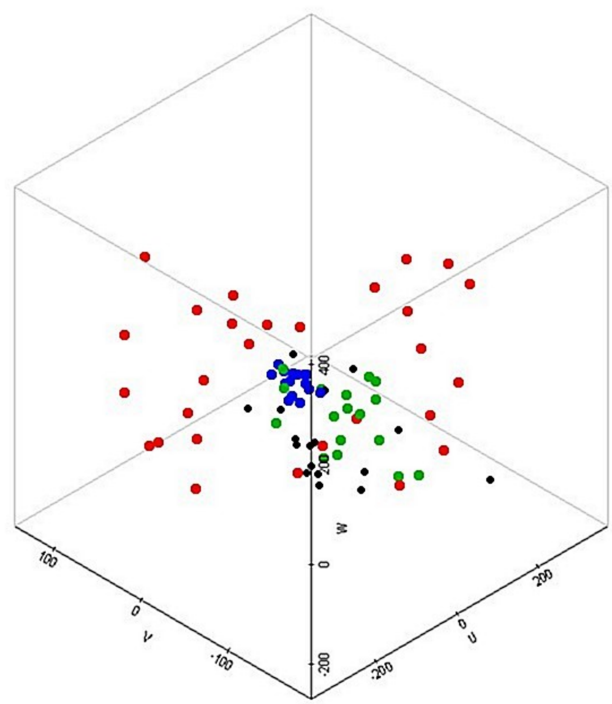

Figure 9. GRV1248 to GRV1264 shown as black dots plotted in UVW parameter space with blue dots representing Thin Disc stars, green dots representing Thick Disc stars and red dots representing Halo stars.

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ric parameters available from DR2 are utilized to back this up. For the closer separation objects candidates still measurable by observers can be generated which can be followed over time in the hope of finding relative motion which could eventually lead to discernible orbital parameters. This concept of searching for pairs in Gaia is presented in this light, as it is not as yet clear which types of object will be published with orbital parameters in the final Gaia data release up to half a dozen years hence, and the Gaia survey intends to publish such. Such pairs though actually quite close for visual observers may be too wide for Gaia over the period of the mission! However, for people wishing to notice relative motion in their own lifetime the procedures may be more biased towards the younger ones amongst us, although amongst the best candidates out there as it should be obvious that all the easy ones have probably already been found historically.

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