Additional Stars with Evidence of Orbital Motion

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Abstract: High proper motion pairs with similar parallax and similar but still differential proper motion are examined and presented as candidate orbital motion targets.

Introduction

In Greaves 2020 a list of potentially orbiting pairs lying within 20 parsecs is presented based on candidate selection processes relating to close similarity of parallax and high but significantly differential proper motion within a pair as obtained from Gaia Data Release 2 (eg Brown 2018). The list is also filtered to remove all pairs with published orbits and in some cases measures provided by the Washington Double Star Catalog (henceforth WDS, Mason et al 2001) are utilised as evidence of historic mutual motion for the pair of a form that can be interpreted as indicative of an orbital path.

Here additional candidates are presented to farther distances and with less stringent selection criteria whilst otherwise using the same methodology outlined in Greaves 2020. Basically a greater leniency is adopted with respect to the ratio of parallax for the pairs due to the vagaries of Gaia DR2 parallax measures, extending the parallax ratio threshold from 1:1.01 to 1:1.2. Despite a much larger value this approach is validated by the fact some of the farthest candidates with some of the worst parallax ratios given below lay adjacent in Gaia DR2 parameter space to long known classical pairs with published orbits that also appear in the course of the analysis. As a comparison in Greaves 2004 common proper motion pairs were checked against two astrometric catalogues with mean epochs up to a century or more apart, yet despite this the highest motion objects showed a fixed relationship over that time with both separation and position angle barely altering in the intervening time-- that is, they were either completely unchanged over roughly a century or they showed changes that were of a size that could be readily dismissed as being within the positional uncertainties of the catalogues. The figures presented here show motions in marked contrast to that even over temporal baselines much shorter than a century, although it has to be granted that the proper motions in that study are around an order of magnitude smaller than in the current one.

As with Greaves 2020, the presented objects are at times very challenging observationally. After all, if they were easy their details and orbits would likely already be known, as is the case for many easier pairs, and quite a few difficult ones. Nevertheless all but a few of the objects presented already appear as pairs in the WDS, thus have been observed and indeed measured at some point, at least for the “classical” pairs. Other pairs may well be amenable to the new digital imaging techniques such as drift scanning or so called lucky imaging. Still others may well be beyond even the best equipped amateur using a quality refractor at very high powers due to the pair’s faintness and/or large differential magnitude as most pairs able to show significant relative motion over decades are rarely more than a few arcseconds apart, even at greatest separation. Also, as distance increases the number of close-together-on-the-sky relatively nearby pairs found only very recently in modern high resolution surveys, such as Gaia, show a proportionate increase in number. It is not always clear whether these were missed in the past simply because of being too difficult visually as pairs with similar particulars had been discovered in the past and in some instances have even been sufficiently observed over time to have had published orbits. Past classical

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surveys intended to discover visual double stars with the potential to be orbiters often were undertaken as systematic visual searches down to a relatively bright limiting magnitude, whilst some objects will have been discovered purely serendipitously, whereas surveys like Gaia go deeper, more inclusively and to a high spatial resolution.

Results

These follow several levels.

The results for the most promising objects are presented in Table 1 with the pairs with good measurement history at the WDS having figures illustrating their motion based on data kindly provided by the WDS (Matson & Mason 2020). Some instances of isolated highly disparate measures have been left out of the figures for illustrative purposes, these are usually a small number of outliers not matching other more similar dated measures whilst for others having very long observational history the earliest measure(s) often appear to be approximate and can disagree quite markedly with other measures made only a few years afterwards. The remainder of Table 1 objects not having illustrative figures contain objects with either insufficient measures or measures at times contradictory enough to neither suggest nor deny relative motion analogous to that expected from orbital motion, that is the data are noisy. Individual objects are noted after the table with extra information for each system. For instance, some of these systems are hierarchical, that is there is a candidate orbiting pair which itself forms a common proper motion system with a third star showing relatively fixed motion in comparison to it. The projected separation is giving for some of the pairs as the intrinsically nearer a pair are together the higher the current rate of relative motion is likely to be.

In some instances the pair are logged in the WDS as having a linear solution, however given their similar distances, similar high to very high proper motions (albeit differential ones, yet the motion difference is negligible in comparison to the overall motion) and close projected separation (usually a few arcseconds at most) it would be a remarkable coincidence for them to be merely happenstance associations of two random field stars. Indeed, all WDS linear solution objects with separations of only a few arcseconds could benefit from a cross matching of both components' parallax (to a reliable distance) and their proper motions checked with Gaia DR2 as sufficient agreement listed in the former for objects with high motion in the latter would be indicative of a physical rather than a happenstance association. These objects therefore constitute two levels, those with at least good particulars as well as somewhat confirmatory historical measurements and those that have at least good particulars but few and/or internally contradictory confirmatory historical measurements.

Table 1 carries the WDS Discovery Identifier, the Gaia DR2 Epoch 2015.5 position of the primary, the respective proper motions of the pair, the distance in parsecs of the pair simply derived by inverting their Gaia mean parallax and rounding to the nearest whole number, the Gaia DR2 magnitude for each of the pair and their Gaia DR2 derived position angles and separations rounded to one and two decimals respectively. The table is sorted on increasing distance. The nearer the pair are to the Sun, in combination with the smaller their projected separation is and the greater their differential proper motion, then the 'faster' their orbit is likely to be. However, the projected apparent orbits are not circular, having multiple forms and levels of eccentricity and not strictly elliptical orbits as the primary can be offset from one of the foci, not to mention that as demonstrated by differential proper motion a fixed position primary is an idealised state used for convenience. Accordingly generalising from Kepler's Second Law of planetary motion the apparent motion of the secondary around the primary will not be at a fixed rate and an apparent 'fast' object may in fact be simply near periastron, whilst a slow moving secondary may be near apastron, with eccentric to highly eccentric orbits at times presenting relatively slow monotonic motion well represented by the same linear solution also applicable to optical pairs.

Meanwhile, many of the pairs spat out by the analysis are not "classical" pairs in that they have been first noted and added to the Washington Double Star Catalog since the turn of the millennium and thus have insufficient measures to demonstrate any relative motion at all, even if present. A significant number of these are in fact pairs revealed by datamining (at times better described as data-trawling) of Gaia DR2 so the only measure available for them is predominantly based on the single one derived from the data in that survey. Even some of the "classical" pairs have limited data with measures effectively often consisting of only their discovery epoch positions (of varied quality) and Gaia dr2 epoch positions and little to nothing else. All these other pairs, both "classical" and "new" are listed in Table 2 which is simply presented as a Finding List. These Table 2 objects have little to no confirmatory historical measures and their listing as candidate orbital motion objects is only via inference based on the similarity in their particulars to known orbiting cases and the better evidenced Table 1 cases. Roughly half of these objects have intrinsic projected separations of between 25 and 40 AU but will be difficult visually as the

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Additional Stars with Evidence of Orbital Motion

NAME	RA	Dec	pmra1	pmdec1	pmra2	pmdec2	dist	Gmag1	Gmag2	PA	sep
BEU 6	69.55464	28.21622	396	-92	381	-83	13	11.6	12.1	303.4	1.18
HDO 298	334.56825	-53.62978	441	-630	428	-665	14	5.2	9.2	49.0	1.87
WTR 1	327.29873	-41.55896	279	-229	308	-179	15	10.9	11.3	133.4	2.67
ST 8AB	130.68651	9.55397	224	-632	200	-575	16	8.9	11.9	41.7	1.49
A 53AB	79.80577	-3.07322	700	138	653	99	16	7.5	9.9	305.6	1.55
BU 1246AB	214.75201	-25.81385	-359	365	-366	344	18	5.7	10.6	230.5	3.57
HEI 31	58.61776	16.61533	214	-167	210	-194	20	6.6	10.4	238.8	3.55
WOR 4AB	51.02801	23.78451	215	-120	201	-114	21	9.9	10.8	340.0	2.60
LDS5677	97.66118	-2.09901	-116	-161	-113	-172	21	13.9	15.2	317.6	4.48
LDS 935	184.21326	2.96913	-651	258	-652	284	23	12.1	15.3	177.1	2.13
CPO 138	97.96133	-43.53416	-278	-30	-264	-13	24	10.0	11.6	219.2	3.34
LDS3331	29.80272	3.51934	263	24	266	44	24	10.5	11.1	54.5	4.15
HDO 127BC	152.05216	11.99699	-254	8	-225	9	24	7.9	11.3	94.0	2.05
A 322AB	89.59005	-4.65153	75	-201	79	-237	24	6.8	10.7	34.4	2.22
LDS4802AB	284.41001	53.52067	256	-53	241	-44	25	12.0	12.1	196.3	2.29
LDS1891	281.04350	71.48883	33	151	21	145	25	13.4	13.6	277.7	3.21
GIC 169	325.00791	54.13970	473	340	466	320	29	12.1	14.0	78.2	1.23
KUI 6BC	20.75457	-12.95850	452	-25	481	-34	30	9.8	11.7	327.4	1.37
STF2928AB	339.89525	-12.61580	223	-147	228	-168	37	8.3	8.3	280.8	3.08
HU 1153	222.90500	15.31796	-241	92	-207	102	43	8.2	10.5	296.2	3.02
STF 544AB	66.17416	-8.75398	-111	-171	-130	-153	45	8.3	9.2	352.0	3.34

Table 1. Orbital candidates with evidence of historical relative motion over time. (the Name is the WDS Discovery Code, Right Ascenscion and Declination are in decimal degrees, pmRA are proper motions for Right Ascension in milliarcseconds, pmDec are proper motions for Declination in millarcseconds, dist is the distance in parsecs from taking the mean of the pair's parallax and then simply inverting it, Gmag are the Gaia DR2 magnitudes which are red biased, the PA is the position angle in degrees and separation is in arcseconds).

Table 1 Notes:

BEU 6 This red dwarf pair is had a relatively recent close approach to the primary is but now widening again. Projected separation is around 16 AU, less than the Sun-Uranus distance.

HDO 298 Possibly closing towards periastron as shown in Figure 1. The primary has the spectral type G0 V. The projected separation is 26 AU.

WTR 1 There is a linear solution in the WDS.

ST 8AB The AB pair is widening after a close approach to the primary around the turn of the Millennium. Projected separation is 24 AU (or slightly further than the Sun - Uranus distance). The common motion similar distance LUY 6218 AB C has separation 114.6 arcseconds in position angle 96 degrees (2015.5) and is physically lying at a projected separation of roughly 1800 AU. The CD pair is optical.

A 53AB The historical motion is depicted in Figure 2. A53 AB C is optical. The AB pair have a 2015.5 projected separation of 25 AU.

BU 1246AB The WDS gives the AC pair a linear solution. The AB pair has been very slowly widening for over a century but with some more pronounced movement in position angle.

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(Table 1 notes continued from page 319)

HEI 31 The WDS measurements are few but it has widened by roughly an arcsecond in 35 years whilst changing about a dozen degrees in position angle. Radial Velocities for the pair are 19 and 18 km/s respectively.

WOR4 AB The pair is slowly widening with motion currently appearing linear as can be seen from Figure 3. There is also a third component giving LDS 884 AB C with C at 99.2 arcseconds separation in a position angle of 118 degrees and of common motion and parallax to AB. The AB projected separation is 54 AU whilst AB C are roughly 2100 AU apart.

LDS 5677 A red dwarf and white dwarf pair.

LDS 935 This red dwarf and white dwarf pair has been slowly closing over the past 80 years.

CPO 138 This pair has closed by one arcsecond over 70 years but with no real change in position angle such that a linear solution would readily represent the historical motion. The common high proper motion and very similar parallax suggest instead that it is in a relative monotonic phase of an eccentric orbit.

LDS 3331 This pair has closed by nearly one arcsecond over 50 years in tandem with over a 20 degrees change in position angle.

HDO 127BC This pair is a well known companion to Regulus, sharing both proper motion and parallax with it and lies 176 arcseconds from said in a position angle of 308 degrees. This equates to a projected separation of around 4250 AU whilst the BC pair have a projected separation of 50 AU at 2015.5. The pair have closed by around 2 arcseconds in 150 years with little change in position angle such that a linear solution would currently represent the motion.

A 322AB The pair has closed by roughly two arcseconds with appreciable change in position angle for just over a century, and gives some hint of an orbital arc, however there is a 70 year plus gap lying between the first and recent observations. A fourth star, denoted LDS 3684 D, lies 89 arcseconds away in 313 degrees position angle and shares the motion and parallax of the AB pair thus it has a projected separation of roughly 2150 AU from the pair in comparison to their own projected separation of 54 AU. The G dwarf primary has a radial velocity of 143 km/s and metallicity less, but not markedly so, than that for the Sun, so could be a Thick Disk object. A 322AB C is optical with a linear solution in the WDS.

LDS 4802AB The fainter star C lies 41.7 arcseconds distant in a position angle of 162 degrees and shares the same motion and parallax as the AB pair lying at a projected separation distance of roughly 1030 AU in comparison to the 57 AU projected separation of the AB pair. C is a white dwarf.

LDS 1891 For over 50 years the pair have widened by more than an arcsecond in tandem with a change in position angle of around a dozen degrees.

GIC 169 The projected searation is 36 AU, which is just a little beyond the Sun - Neptune distance.

KUI 6BC The primary, GAL 307A, shares the same motion and parallax as the BC pair as well as having the same 35 km/s radial velocity as B and lies 40.5 arcseconds from B at a position angle of 313 degrees which equates to a projected separation of around 1220 AU, whilst the projected separation of the BC pair is 41 AU, roughly one and one third the Sun - Neptune distance.

STF 2928AB This pair has a linear solution in WDS whilst Figure 4 suggests an orbital arc with the secondary slowly closing in on the primary in recent decades. Outliers have been retained as there is sufficient density of observations for them not to detract from the overall trend. Much fainter STF 2928 C actually shares the proper motion and parallax of this pair and lies at position angle 48 degrees some 138.6 arcseconds distant which at 2015.5 gives a projected separation of roughly 5100 AU from the 113 AU AB pair's projected separation. D is optical. The BC primary is spectral type G9 V with chromospheric emission lines and is listed as the extremely low amplitude BY Draconis variable of uncertain period NV Aqr, however for close pairs like this duplicity induced pseudo-variability is not unknown and BY Draconis variables are usually mid to late K or M dwarfs, although the differential magnitude between A and B suggests the latter may be a K dwarf which is not too faint to affect the overall brightness at the centimagnitude level. The A, B, C grouping may well present a yellow, orange, red combination visually, if it is possible to split AB whilst retaining C in the field and further C is not too faint for any colour to be discerned.

HU 1153 Noted as with a linear solution in WDS this slowly closing pair is shown in Figure 5. Radial velocities are -11 and -13 km/s respectively.

STF 544AB This pair has widened by just over an arcsecond in around 190 years whilst demonstrating little change in position angle, as shown in Figure 6, such that the motion to date could be well described by a linear solution. WDS notes that the primary is itself a spectroscopic binary. FOX 138C is optical.

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NAME	dPMRA	dPMDEC	dist	NAME	dPMRA	dPMDEC	dist
NSN 100	9	14	19	HDS 804	13	14	25
DAE 8	28	31	19	A 762	3	18	25
NSN 752	6	11	20	LDS2753	10	20	26
GRV1284	20	26	20	B 620	15	15	26
MCT 12	18	35	21	HDS2687	13	4	26
KPP3116	19	16	21	KPP2995	15	20	26
KPP2786	2	18	21	LDS6202	8	20	27
TSN 118	5	31	21	KPP3113	6	20	27
MCT 10	27	6	21	HDS1691	17	7	27
NSN 596	24	16	21	HDS 484	16	17	27
HDS 544	48	31	21	GRV1285	20	8	28
LDS1261	3	14	22	NSN 616	3	17	28
JNN 61	9	18	22	KPP3199	23	13	29
KPP2790	20	18	22	NSN 760	20	11	30
LAW 19	5	15	22	HDS1060	37	8	30
NSN 374	24	4	22	KUI 6BC	29	9	30
HDS3133	16	3	22	KPP3040	1	22	31
NSN 273	2	16	22	NSN 466	21	14	31
KPP3229	1	29	22	CRC 76	29	15	31
NSN 75	3	19	22	KPP2784	2	27	31
KPP3335	14	17	22	NSN 608	32	5	32
JAO 4	21	10	22	SKF1633	23	4	32
KPP3378	1	19	23	SKF2836	31	28	33
NSN 441	11	17	23	GRV1286	6	30	33
TOK 22	38	7	23	GRV1287	48	8	34
NSN 453	5	13	23	LDS6304	20	12	34
CRC 46	6	21	23	JNN 285	23	1	35
SKF 428	17	19	23	CRC 43	20	58	36
NSN 716	9	15	23	HDS 366	31	14	40
KPP3388	18	10	24	GRV1288	23	10	54
CRC 67	22	15	25	HDS 188	26	11	60
SKF 453AB	13	11	25	GRV1289	23	16	67

Table 2. A Finding List of Candidate Pairs With Orbital Motion Based On Common But Somewhat Different High Proper Motion and Common Distance (The WDS Discovery Code, differential proper motions in both Right Ascension and Declination given in milliarcseconds and their distances in parsecs as the inverted mean of the pairs' parallax are given. Objects denoted GRV1284 through GRV1289 are running numbers used for convenience as there is no matching pair in neither the WDS nor the WDSS at time of writing).

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separations on the sky lie between 0.75 and 2.0 arcseconds.

On a second level Table 2 also includes several objects with the Discovery Code column merely carrying a GRV running number for convenience due to want of a referential handle as they are not currently listed in either the WDS or the WDSS as of March 2020 thus having no identifiers, but are revealed by Gaia DR2 data as a natural consequence in this analysis. To not include them would be negligent as three of the pairs are currently just slightly farther apart than the Sun – Neptune distance and may well be liable to show marked relative motion to observers in the nearer future.

As stated, Table 2 is presented as a finding list for interested observers and/or measurers looking for a project, primarily provided as the data were generated by the analysis and may be of some utility or interest to some as opposed to just being thrown away. Accordingly, and as in the vast majority of cases the last measure in the WDS is either Gaia DR2 derived or the Gaia DR2 measure is given as the pair was discovered via Gaia DR2 data, only minimal information is provided to avoid cluttering things with endless detailed lists. The Discovery Code from the WDS as identifier plus their Gaia DR2 derived differential proper motion in milliarcseconds for each pair in both Right Ascension and Declination are provided plus their inverted mean Gaia DR2 parallax rounded to an integer. The novel pairs have their derived astrometric particulars mentioned after the table.

Table 1 enables better equipped observers to contribute further measurements to be added to those already known in order to enable enough data for orbits to be eventually determined. Table 2 enables all observers, whether well equipped or just the casual observer, to pick target stars to be followed over the years,

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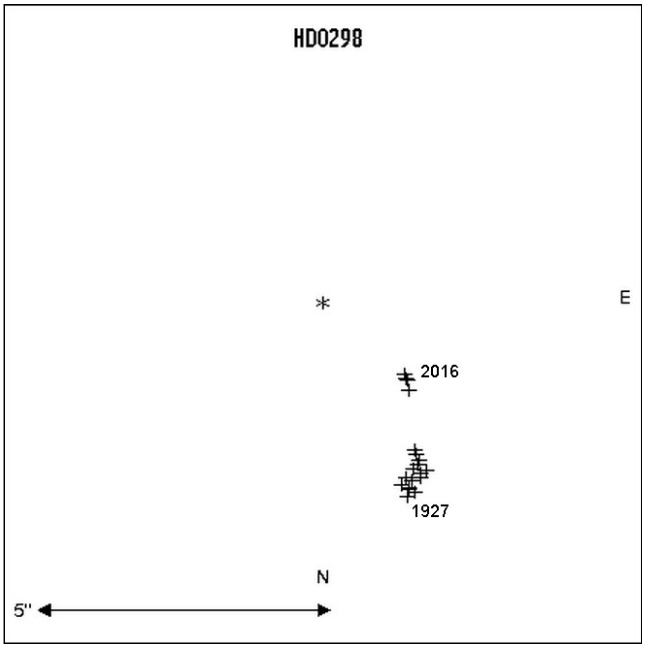

Figure 1 HDO 298

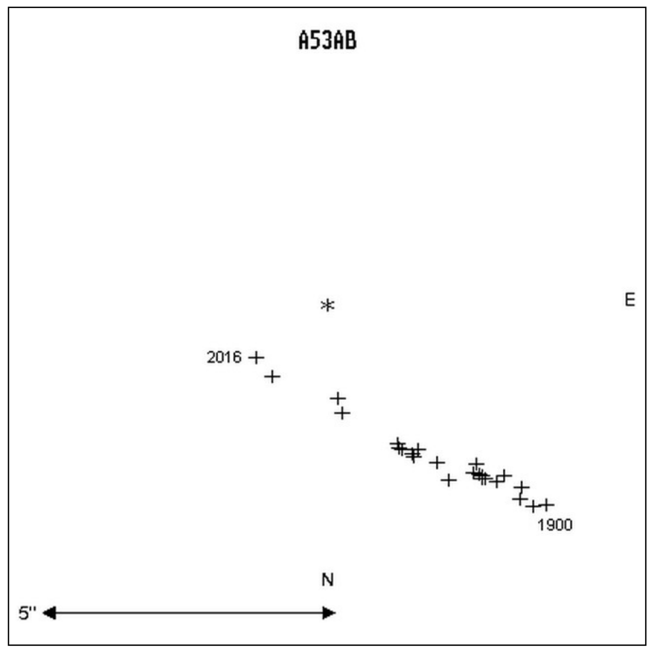

Figure 2 A 53AB

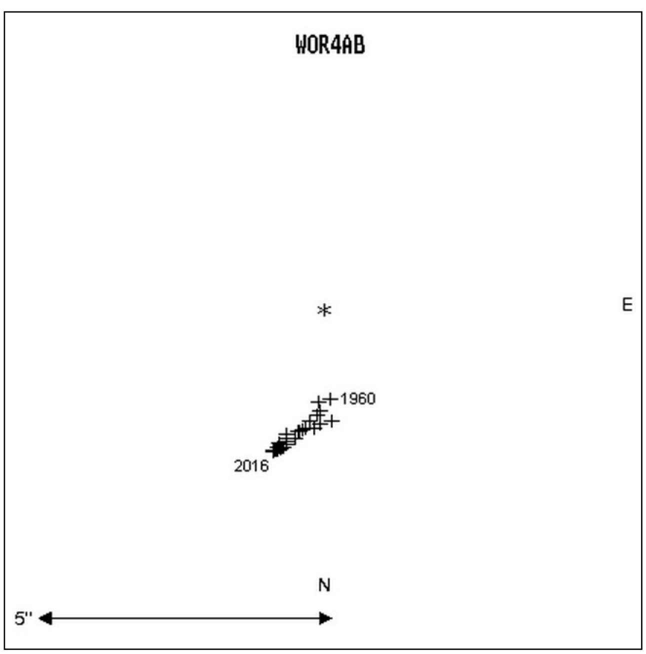

Figure 3 WOR 4AB

Additional Stars with Evidence of Orbital Motion

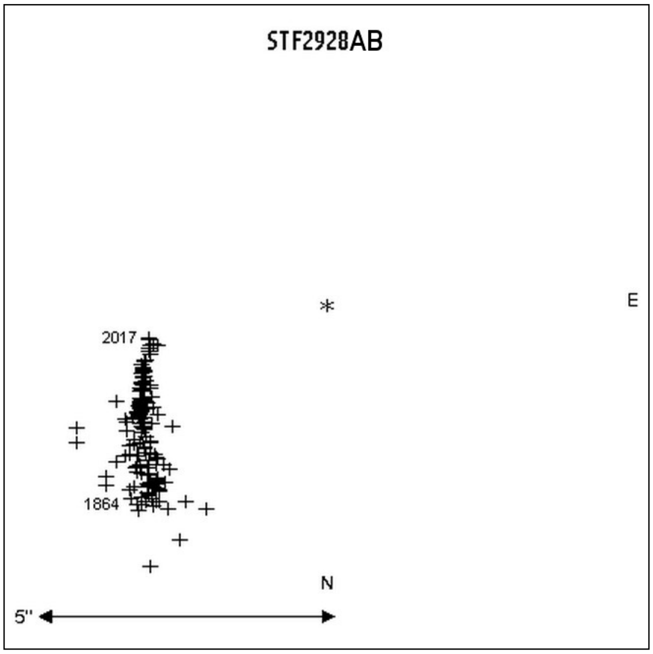

Figure 4 STF 2928AB

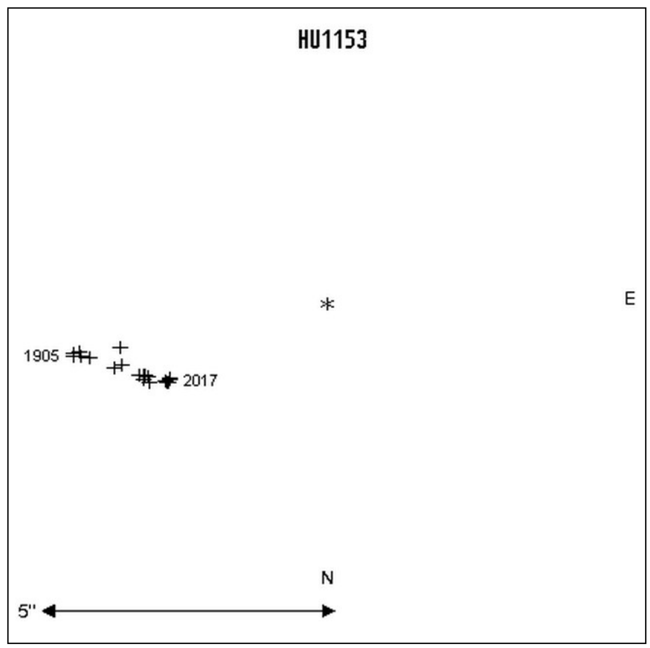

Figure 5 HU 1153

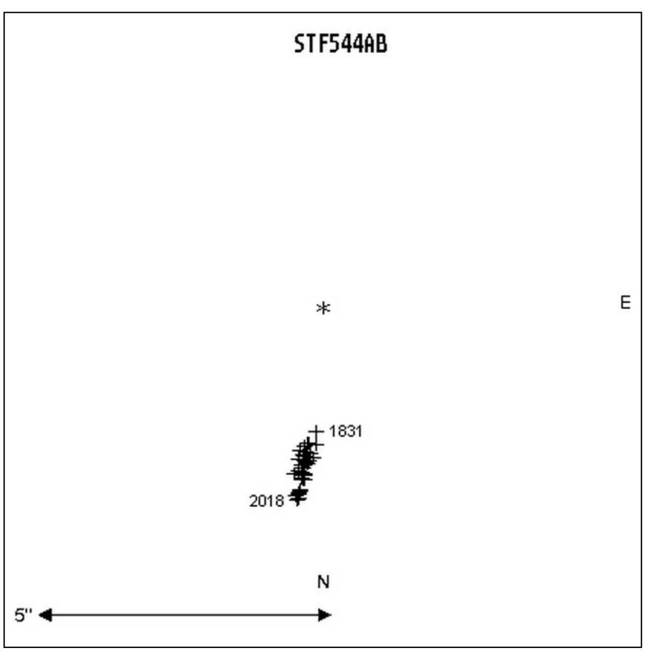

Figure 6 STF 544AB

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whether to make measures for future orbit determinations or simply for the aesthetic pleasure of seeing change in the "fixed heavens". This latter can be rewarding in itself, as it is very engaging to watch either a variable star change it's brightness, see a transient appear in a familiar star field, see the relative motion of very high proper motion star against field stars over years, or see a pair of stairs over years to decades became closer or wider apart and in some rare cases both. These data are therefore also presented to those interested in the changing of the "fixed heavens".

For the new pairs the Gaia DR2 derived positions in decimal degrees, position angles in degrees, separations in arcseconds and magnitudes respectively are GRV1265, 120.01167, -40.04233, 8.2, 1.93, 9.1, 12.7; GRV1266, 319.13574, -47.56831, 162.6, 2.19, 13.1, 13.3; GRV1267, 239.46925, 43.89477, 158.7, 0.93, 12.5, 12.5; GRV1268, 66.75275, 48.88013, 46.8, 1.10, 13.0, 13.1; GRV1269, 358.92394, 25.14404, 45.8, 3.41, 8.7, 14.5; GRV1270, 291.77344, 46.45236, 48.0, 1.67, 8.9, 12.5. GRV 1265, 1267 and 1268 have projected separations of 39, 31 and 37 AU respectively, which are around to just beyond the mean Sun – Neptune distance.

Conclusion

As demonstrated in Greaves 2020 Gaia data release 2 is able to provide high motion pairs of stars with sufficient differential proper motion to suggest orbital motion. Selection of appropriate objects from such a subset of data enables either the measurement over time of the pairs in order to provide extra data potentially enabling an eventual orbital determination, especially for pairs already having a long history of measurement, or for the simple enjoyment of watching (or imaging) the change over time.

References

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