Six Proper Motion Pairs Measured with the 2-meter Faulkes Telescope North

Rafael Caballero[1], Russell Genet[2,5], J.D. Armstrong[3,4,5,8], Steve McGaughey[4,5], Cindy Krach[5], Audreanna Leatualli[5,6], Aaron Rohzinski[5,7], Coleen Rohzinski[5], Eric Rohzinski[5], Noah Rohzinski[5,7], McKayla Wandell[5,6], John Martinez[8], and Thomas Smith[9]

1. Agrupacion Astronomical Hubble, Martos, Jaen, Spain
2. California Polytechnic State University, San Luis Obispo, California
3. University of Hawaii, Institute for Astronomy, Maui, Hawaii
4. Haleakala Amateur Astronomers, Maui, Hawaii
5. Maui Double Star Association, Maui, Hawaii
6. Baldwin High School, Wailuku, Maui, Hawaii
7. Seabury Hall Middle School, Makawao, Maui, Hawaii
8. Las Cumbres Observatory Global Telescope network, Santa Barbara, California
9. Dark Ridge Observatory, Weed, New Mexico

Abstract: Multiple observations were made of six faint common proper motion pairs with the 2-meter Faulkes Telescope North on Haleakala by Maui middle school and high school students and their supporters. Of the six pairs, two are reported as newly discovered proper motion binaries. Individual reductions versus a single 'track and stack' reduction were compared.

Introduction

The 2-meter Faulkes Telescope North (FTN) is located on the 10,000 foot summit of Haleakala, a dormant volcano on Maui (http://www.faulkes-telescope.com/). Haleakala is blessed with abundant clear dark skies and excellent seeing. FTN is one of the telescopes in the Las Cumbres Observatory Global Telescope (LCOGT) network. In addition to the FTN, a matching 2-meter telescope, Faulkes Telescope South (FTS), is located a Siding Springs Observatory, Australia.

More than a dozen 1-meter telescopes and approximately two dozen 0.4-meter telescopes are being designed, built, and installed by LCOGT at diverse longitude and latitude locations around the globe to conduct research in "time-domain" astrophysics. Objects can be kept under constant surveillance around the clock as they are automatically passed from one identical telescope to another as the Earth turns. All of the telescopes in the network will be fully robotic and well instrumented (including high speed, low noise EMCCD cameras that could be used for lucky imaging or speckle interferometry of double stars as well as spectrographs on the 1- and 2-meter telescopes).

A portion of the observational time on FTN has been allocated to the University of Hawaii's Institute for Astronomy (IfA) for public outreach and student education. J.D. Armstrong, one of this paper's coauthors, works jointly for IfA and LCOGT to coordinate the use of this observational time. Two of us, Russell Genet and Steve McGaughey, suggested that student observations of double stars that resulted in published papers would be good use of a small portion of this time. J.D. Armstrong agreed, and we set about organizing the Maui Double Star Association, which consists of Maui middle school and high school stu-

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Figure 1: Left to right, co-authors Steve McGaughey, J.D. Armstrong, and Russ Genet stand in front of the 2-meter Faulkes Telescope North on the summit of Haleakala. At far right is John Pye, Astronomy Instructor at University of Hawaii, Maui College.

dents and their supporters.

One of this paper's coauthors, Rafael Caballero, recently developed a method for generating common proper motion (CPM) pairs based on data bases including recent Sloan Digital Sky Survey (SDSS) releases (Caballero 2012). He applied a version of his method to generate CPM pairs for observation for this paper that were too faint to observe with his telescope in Spain, but would be relatively easy objects for the 2-meter FTN telescope.

In this paper we report on the selection, observation, and analysis of six faint CPM pairs. Four pairs had been previously recognized as double stars and were listed in the Washington Double Star (WDS) Catalog (Mason *et. al.* 2003). Two pairs have not been previously reported and we suggest they be considered for inclusion in the WDS Catalog as newly discovered proper motion binaries.

Figure 2: Looking up a “Rafa” double. Left to right, MacKayla Wandell, Audreanna Leatualli, Aaron Rohzinski, Steve McGaughey, and Eric Rohzinski

Selection

Although we selected ten pairs of stars for the observational session, we only had time to observe the six pairs listed in Table 1. The six pairs included two new uncataloged, common proper motion pairs, and four pairs already in the Washington Double Star Catalog (WDS, Mason et al. 2003). The two new pairs were found by looking for stars with noticeable movement in the Aladin plates (Bonnarel et al., 2000).

Observations

Observations were made on the evening of April 1, 2012 with the 2-meter Faulkes Telescope North using its Spectra series 600 CCD camera. This instrument uses a 4k x 4k chip with 15 micron pixels. Used in 2x2 bin mode on FTN, the plate scale is about 0.3 arc seconds per pixel, with a total field-of-view of about 10 arc minutes. Middle school and high school students manned the Real Time Interface (RTI) telescope controls at the University of Hawaii's Institute for Astronomy, Maui, under the supervision of J. D. Armstrong and Steve McGaughey. Russ Genet participated remotely via telephone and the Internet.

Astrometry

The images obtained were squares of around 10x10 arc minutes. This large size made these images very suitable for the software Astrometrica (please see http://www.astrometrica.at/). We used the *Track & Stack* option of this software to create a single image combining the 5-6 images of each pair. The reduction was performed with the following configuration:

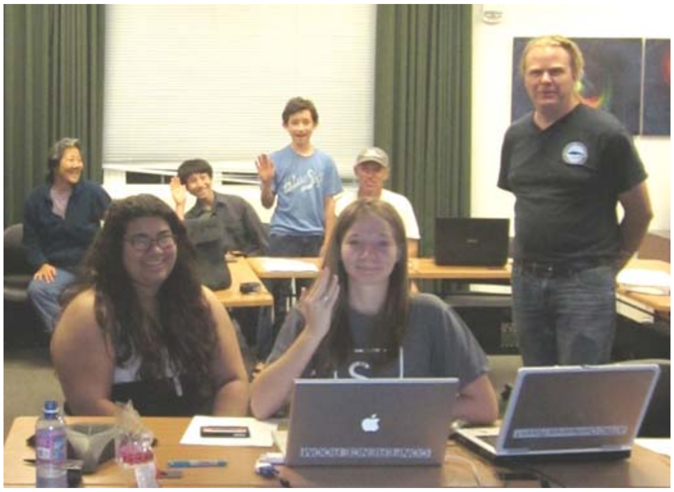


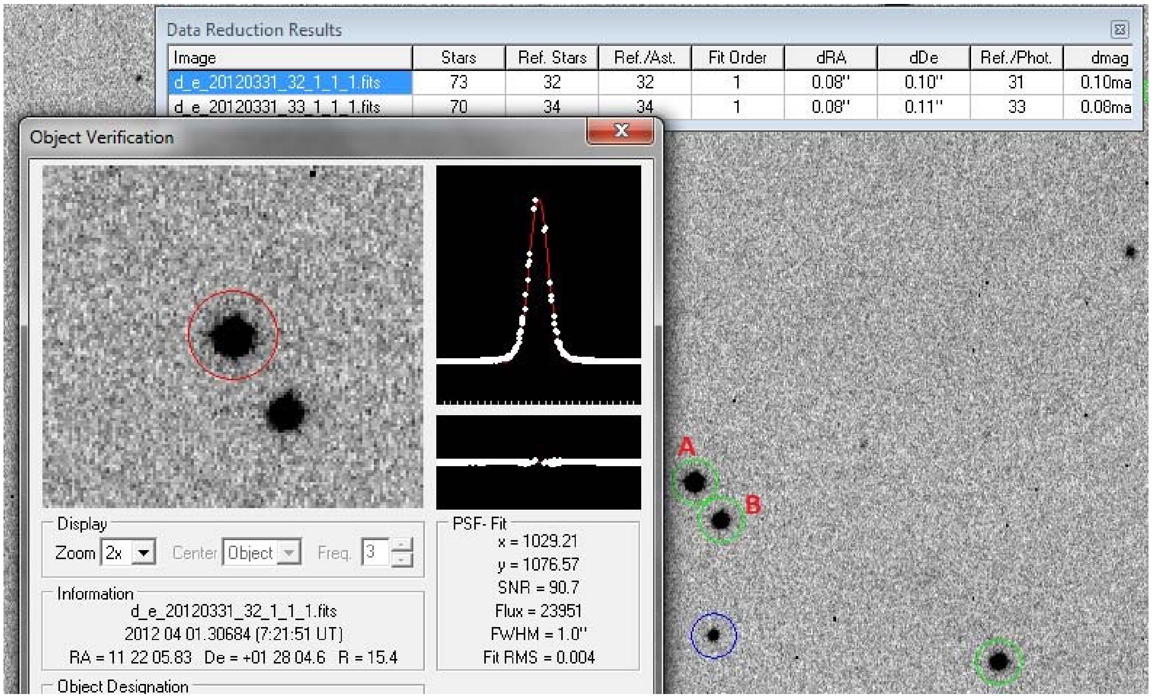
Figure 3: Making observations with the FTN at the University of Hawaii's Institute for Astronomy, Maui. Front row left to right: Audreanna Leatualli, MacKayla Wandell,, and J. D. Armstrong. Back row left to right: Coleen Rohzinski, Aaron Rohzinski, Noah Rohzinski, and Eric Rohzinski

- Focal Length: approximately 2000 mm (2 meter f/10)
- Pixel Width = Pixel Height = 15 microns (but 30 microns when binned 2x2 as was he case for our observations)
- Catalog: USNO-B1.0 (systematic errors recently reported for this catalog should not effect our relative astrometry)

The Focal Length was obtained by trial and error, while the Pixel Width and Pixel Height were taken from the camera spreadsheet configuration. The catalog USNO-B1.0 was selected because it yielded a higher number of reference stars. About 30 reference stars were located by the software in all the cases. After the reduction, the coordinates of each component were simply obtained by clicking over the star. The software automatically calculates the centroid as shown in Figure 4.

In order to obtain good estimates of the centroids, the *Aperture Radius* (option *Settings+Program)* was set to a large enough value (in our case 15 pixels) to include essentially all the light from the star. From the coordinates, the distances and the position angles of each pair were readily obtained using the Haversine formula (Sinnott, 1984). The results are shown in Table 1.

Coordinates and proper motions were obtained from the SDSS-DR8 survey (Adelman-McCarthy et al. 2011), unless explicitly stated. The position angles are in degrees, the separations are in arc seconds, and the proper motions are in milliseconds of arc/year.



Data Reduction Results

Image	Stars	Ref. Stars	Ref./Ast.	Fit Order	dRA	dDe	Ref./Phot.	dmag
d_e_20120331_32_1_1_1.fits	73	32	32	1	0.08"	0.10"	31	0.10ma
d_e_20120331_33_1_1_1.fits	70	34	34	1	0.08"	0.11"	33	0.08ma

Object Verification

Display
Zoom 2x
Center Object
Freq. 3

Information
d_e_20120331_32_1_1_1.fits
2012 04 01.30684 (7:21:51 UT)
RA = 11 22 05.83 De = +01 28 04.6 R = 15.4

PSF- Fit
x = 1029.21
y = 1076.57
SNR = 90.7
Flux = 23951
FWHM = 1.0"
Fit RMS = 0.004

Figure 4: Screen snapshot of Astrometrica centroiding.

Table 1 : Astrometric Measurements

ID	RA DEC (2000)	Mags	Angle	Sep.	DATE	PM-A	PM-B	Notes
NEW	05 42 00.85 +82 19 42.29	16.23 18.00	33.18	15.11	2012.260	+017 -152	+020 -146	
CBL 235	07 28 20.78 +31 00 11.7	15.1 17.8	296.06	9.45	2012.260	+025 -143	+020 -141	1
CBL 303	10 10 18.68 +01 07 19.8	16.9 18.2	113.77	8.68	2012.260	-106 +035	-099 +036	1
GWP1473	10 51 03.60 +14 58 19.8	14.0 15.1	73.98	13.89	2012.260	+018 -154	+042 -150	1
CBL 338	11 21 45.09 +02 16 58.0	14.4 18.9	98.78	10.62	2012.260	+009 -131	+012-141	1
NEW	11 22 05.89 +01 28 03.63	15.74 16.48	34.34	9.57	2012.260	-090 +086	-086 +072	2,3

Table notes:

1. only *Angle*, *Sep*., and *Date* are new data, the rest of each row is repeated from the WDS;
2. proper motions are from *The Naval Observatory Merged Astrometric Dataset* (NOMAD, Zacharias et al. 2005) for both components; and
3. R magnitudes are from SDSS-DR8.

Measurement Precision

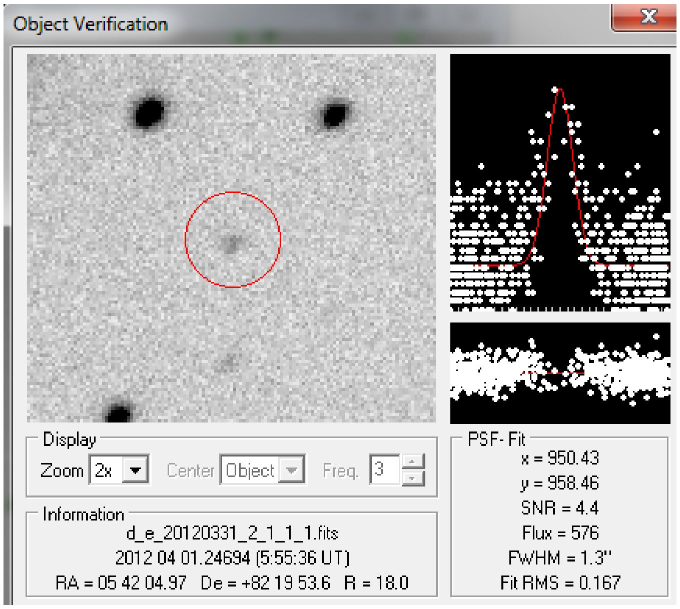
The data of Table 1 correspond to the average of the measurements over the individual images obtained for each pair. In order to determine the reliability of the results, Table 2 includes the following columns:

- The first two columns are the identifier and the coordinates of the pair.
- The third column includes the number of images taken for each pair (all of them consecutively during the same night).
- Columns 4 and 5 correspond to the average of the angle and separation obtained after the individual reductions in Astrometrica (these columns correspond respectively to columns Angle and Sep. of Table 1).
- Columns 6 and 7 include the sample standard deviation of the angle and separation individual measurements, respectively.
- Columns 8 and 9 correspond to the standard error of the mean (abbreviated by *Sem.*) of both the angle and the separation.

The values ≈0 indicate that the value is less than 0.01. A vital goal of our observations of faint double stars with FTN was to establish the precision of our observations and this table helps to determine this precision. We observe that the values are quite acceptable except for the new pair located at 05 42 00.85 +82 19 42.29. Checking the images in Astrometrica the reason for this lack of precision can be observed as shown in Figure 5: the histogram in an image for the secondary is too blurred to provide a precise measurement.

Table 2: Individual measurement statistics

ID	RA DEC (2000)	Number of images	Angle Avg.	Sep. Avg.	Angle St. Dev.	Sep. St. Dev.	Angle Sem.	Sep. Sem.
NEW	05 42 00.85 +82 19 42.29	5	33.18	15.11	0.83	0.18	0.41	0.09
CBL 235	07 28 20.78 +31 00 11.7	4	296.06	9.45	0.31	0.02	0.16	0.01
CBL 303	10 10 18.68 +01 07 19.8	5	113.77	8.68	0	0	0	0
GWP1473	10 51 03.60 +14 58 19.8	6	73.98	13.89	0.17	0.07	0.07	0.03
CBL 338	11 21 45.09 +02 16 58.0	5	98.78	10.62	0.23	≈0	0.11	≈0
NEW	11 22 05.89 +01 28 03.63	5	34.34	9.57	≈0	≈0	≈0	≈0



Zoom 2x
Center Object
Freq. 3

d_e_20120331_2_1_1_1.fits
2012 04 01.24694 (5:55:36 UT)
RA = 05 42 04.97 De = +82 19 53.6 R = 18.0

x = 950.43
y = 958.46
SNR = 4.4
Flux = 576
FWHM = 1.3"
Fit RMS = 0.167

Figure 5: Imprecise centroiding

‘Track & Stack’ Comparison with SDSS and 2MASS Measurements

As explained above, the reduced data for each pair have been obtained by

1. Reducing each image of the pair separately.
2. Computing the average of the results.

However the Astrometrica software offers the possibility of combining all the images automatically and then performing the reduction. This option, ‘Track & Stack,’ can be found in the *Astrometry* menu. The user can choose among three possibilities for combining the images of the same pair into a single image:

Add: sums up the pixel values from individual images. Before that, a pedestal is subtracted from the individual images to avoid saturation of pixel values.

Average: sets the pixel value to the mean of the individual images. The range of pixel values is therefore preserved, and pixels will not saturate when stacking images. For faint targets and/or images using only a small fraction of the dynamic range, pixel values in the stacked image might appear quantized.

Median: This option is useful for detecting comets in images, one of the main applications of Astrometrica. However, Median only removes stationary objects if the tracking option is used. Since we were not tracking a moving object, such as an asteroid, there was no angular velocity. In this case moving objects are removed.

Obviously the ‘Track & Stack’ option can save time by transforming many individual reductions into a single reduction over the combined image. However, the question is how the use of this option affects the precision. In order to clarify this point we compared the reductions obtained using the four Astrometrica possibilities (that is, average of individual reductions, ‘Track & Stack’ with *add*, ‘Track & Stack’ with *average*, and ‘Track & Stack’ with *median*) with the measurements obtained from external catalogs. In particular we chose the SDSS-DR8 survey (Adelman-McCarthy et al. 2011) and the Two Micron All Sky Survey (2MASS, Skrutskie et al. 2006). Since both are relatively recent surveys, and the doubles we are considering are wide and therefore probably with very long periods, it is plausible to assume that the astrometry obtained from our images and from the catalogs should be similar.

We compared the measurements we obtained using Astrometrica with the values of separation and position angle calculated from the coordinates given for each star in the SSDS-DR8 catalog. Table 3 shows

Table 3: Comparison of our measurement with SDSS-DR8 and 2MASS astrometry

	Diff. with SDSS-DR8 astrometry	Diff. with 2MASS astrometry
Average Individual reductions (Angle)	0.20	0.19
‘Track & Stack’ with *add* (Angle)	0.36	0.29
‘Track & Stack’ with *average* (Angle)	0.27	0.32
‘Track & Stack’ with *median* (Angle)	0.22	0.32
Average Individual reductions (Sep.)	0.05	0.06
‘Track & Stack’ with *add* (Sep.)	0.07	0.04
‘Track & Stack’ with *average* (Sep.)	0.04	0.03
‘Track & Stack’ with *median* (Sep.)	0.06	0.03

the average of the absolute value of the difference of the measurements in each case (angles in degrees, separations in arc seconds).

The table shows that the error (with respect to these surveys) in angle never exceeds 0.36 degrees, and that the error in separation is in all cases less than or equal to 0.07 arc seconds. This indicates the quality of the results. This range of errors is similar to that among the professional surveys. For instance, in this case the average absolute value of the difference between the astrometry of 2MASS and SDSS-DR8 yields 0.20 degrees in the position angle and 0.04 seconds in separation.

Regarding the method of reduction the results are not conclusive: the average of reducing individual images seems the most accurate for obtaining the position angle (0.20 and 0.19 degrees with respect to the two surveys), but the 'Track & Stack' average option provides more accurate results for the separation. However, since the difference of the error in the separation is very small we have chosen the average of the individual measurements as the source of the results in Table 1. These results are somehow surprising because it is usually assumed that it is better to first combine the images. Here we have found a counter example. A possible explanation is that the individually reduced images provide a cleaner point spread function and Gaussian profile and therefore contribute less error in the centroid that is ultimately generated when the images are combined. Another possible explanation is that the images were only shifted by integer pixel amounts or that the sub-pixel sifting is less than ideal. Future experiences with more images could help to clarify this issue.

Halbwachs' Criteria

Given that we have found a new common motion faint double star, the question then is whether or not it is likely to be a binary star rather than an optical double (albeit likely two stars in the same general area). We used the criteria proposed by Halbwachs (1986) based on statistics. Halbwachs' criteria are:

(1) $(\mu_1 - \mu_2)\ 2 < -2\ (e_1^2 + e_2^2) \ln (0.05)$

(2) $|\mu_1|, |\mu_2| \geq 0.05$

(3) $\rho / |\mu_1|, \rho / |\mu_2| < 1000$ yr

where μ_1, μ_2 are the two proper motion vectors in arc seconds/year, e_i is the mean error of the projections on the coordinate axes of μ_1, and ρ is the angular separation of the two stars. The first condition checks if the hypothesis $\mu_1 = \mu_2$ is admissible with a 95% confidence considering the given errors e_1 and e_2. The second condition fixes a value of 50 mas/yr as the minimum required for proper motion pairs. The third condition relates the separation and the proper motion. We have found that the two new pairs satisfy all the criteria.

Two New Common Proper Motion Binaries

05 42 00.85 +82 19 42.29

This pair has a proper motion of about 150 milliseconds of arc/year, and fulfills the criteria for the movement of binaries established in Halbwachs (1986), which indicates that the movement of both components must exceed the 50 milliarcseconds of arc/year. Using the *RGB* utilities included in Aladin we can observe the movement of the two stars as follows:

1. Launch Aladin. Click on File+Open. The server selector window opens. The Aladin images left-tab is selected by default.
2. Enter the coordinates: *05 42 00.85 +82 19 42.29* and click on the SUBMIT button. This shows a list of surveys that contain images for these coordinates.
3. Select the POSSI image sized 13'x 13', dated 1955, and any of the POSSII images of the same size, dated either 1997 or 1999. This gives an excellent timeline of about 42-44 years. Click on SUBMIT. The two images are loaded into Aladin's stack in the main window of the application.
4. Click on the rgb button of the main window. In the RGB image generator window, select one of the images in the red and the other one for instance in the blue plane. Click on Create. The result is a composition where most of the stars appear in white, except the new pair, which appears both in red and blue (see Figure 5).

Next we show the data at different photometric bands for the primary star in Table 4.

The first row in Table 3 corresponds to the Revised (NLTT) Catalog (Salim & Gould, 2003), the second row to Lépine & Shara (2005), and the third row to the Two Micron All Sky Survey. According to the Cambridge Handbook of Space Astronomy and Astrophysics (page 71), the M stars verify V-J > 2.82 and J-K between 0.89 and 1.15. Thus we can conclude that

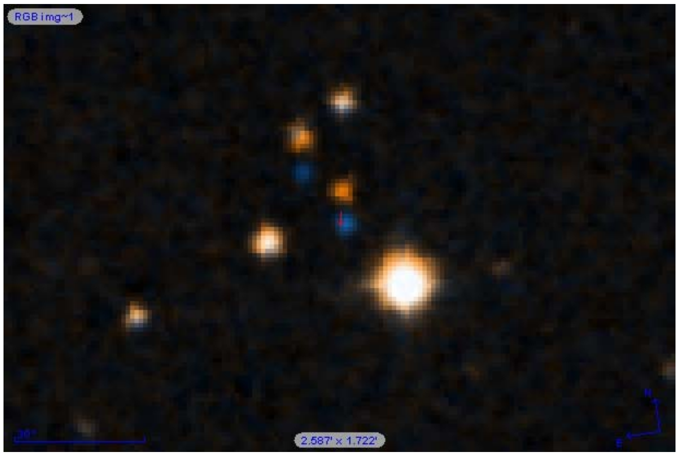


Figure 5: Red and blue stars reveal common proper motion over time.

the primary is likely an M star. The data available for the fainter secondary are not conclusive.

11 22 05.89 +01 28 03.63

This is a pair sharing proper movement over 110 milliseconds of arc/year, and it also fulfills the criteria established for binarity by Halbwachs (1986). In this case the photometry values found for both components suggest a K spectral type. The image in Figure 6 provided by the SDSS-DR7 (Abazajian et al. 2009) shows accordingly two red stars.

Conclusions

We found that the 2-meter Faulkes Telescope North on the summit of Haleakala is capable of measuring faint double stars with accuracy comparable with SDSS and 2MASS. Our comparison of separately reducing a number of individual images with first stacking the images and then making a single reduction suggested that for position angle, our individual reductions were closer to SDSS and 2MASS, while for separation some were closer and others were not.

A disadvantage of the track and stack option is that one does not have an error (measurement precision) estimate. Also, it is not easy to discard errant single measurements. On the other hand, it may be less time consuming to use track and stack if the individual measurement option is not automated.

Table 4: Color indices in two bands.

Catalog	V-J	J-K
NLTT	4.17	
LSPM		0.89
2MASS		0.89

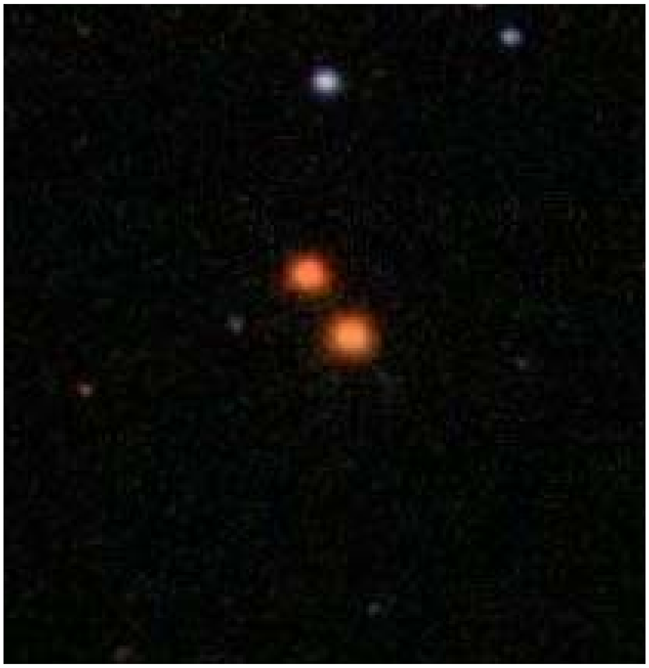


Figure 6: K spectral type components appear red on SDSS image.

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