Double Stars in the Hubble Archive: First Results

R. M. Blake[1], Harris Kain[1]

[1]Department of Physics and Earth Science, University of North Alabama, Florence, Alabama, rmblake@una.edu

Abstract

The Hubble Space Telescope images, with their high resolution offer the potential to add to the historical measurements of double stars. We have begun a project to identify and measure double stars that appear on images in the Hubble Space Telescope (HST) archive; (Whitmore et al. 2016). Our search uses the fact that the Hubble archive contains both targeted observations and the "ANY" fields that can contain unmeasured images of double stars. Here we present our first results covering the stars WDS00405+4044 (SKF1512) and WDS00242-7205 (HJ3363). WDS00405+4044 (SKF1512) happens to lie near the halo of M31, resulting in more than a decade of HST imaging, which have not yet been measured, based upon the measurements not appearing in the Washington Double Star Catalog (WDS). We measure the position angle and separation of the double 27 times from images spanning from 1994 to 2009. GAIA parallaxes of both components suggest that they are a visual double and are likely not a physical system. WDS00242-7205 (HJ3363) lies near the globular star cluster NGC 104, (47 Tuc), which has been imaged many times by the HST. The Hubble images reveal star B in this system to be a pair of stars, rather than a single star.

Introduction

The Hubble Space Telescope provides nearly diffraction limited images of celestial objects, and therefore makes a great resource for doing astrometry of close double stars that would be difficult to measure without taking advantage of advanced techniques such as Lucky imaging, (e.g. Anton 2012), or Speckle imaging (e.g. Turner 2012). The Hubble Space telescope (HST) archive data, (Whitmore et al. 2016), are publically available, and so we decided to conduct a search of the HST archive for images with double stars from the Washington Double Star (WDS) Catalog. The Hubble Archive contains images of selected targets, but the Hubble archive also contains "ANY" fields that were taken of somewhat random areas near targets as part of an effort to create a more useful archive.

1.1 Obtaining and Measuring Hubble Images

For our effort the only search criteria was that the search was done for a circle within 4 arcminutes around the coordinates of the doubles list in the WDS catalog; 4 arcminutes being, the maximum size across a Hubble image. To conduct our searches, we used the Hubble Archive query tool, (Whitmore et al. 2016), which allowed the search of up to 1000 coordinates at a time. To search the WDS in the HST archive we therefore had to conduct multiple searches, using separate input files with 1000 stars each. Python software was written to parse the WDS coordinates into the 1000-star input files and convert the WDS coordinates of the doubles to decimal degrees as required by the HST archive. The searches returned lists of images

within the search radius. We then conducted a visual search of all the images to locate the double stars on the images. For this we took advantage of the fact that the Hubble images have a World Coordinate System, (WCS), in them and used the Hubble Archive image viewer. The Hubble CCD cameras provide images that are not rectangular and oriented along right ascension and declination axes, but instead are mosaics of four images taken with four CCD chips, three of which are the same size and one with smaller pixels for planetary work (e.g. Figure 1). Because of the shape and orientation of the images, we often found that the images did not in fact have the double star on the image, but the star was just off the frame. This made manual checking of each image essential.

We next selected two sample stars, WDS00405+4044 (SKF1512) and WDS00242-7205 (HJ3363), to measure from the HST archive. These were selected because they were near targets re-observed by HST, M31 and 47 Tuc respectively, providing multiple images to measure. Many images were unacceptable because they were unprocessed, contained cosmic ray events or had short exposure times because they were pointing tests. The images were downloaded individually from the Hubble Archive, because we found that frequently the zipped files obtained when many images were requested at once were often empty. An additional problem arose because we wished to use AstroimageJ (Colins et al. 2017), to perform the astrometric measurements. AstroimageJ is unable to directly load the HST FITS images because they are mosaics, with FITS headers that are not recognized as such by AstroimageJ, and so that AstroimageJ did not recognize them as FITS files. We worked around this issue by first loading the images into the SAOimage viewer (VanHilst 1990), and then saving the images. This created a new FITS format file that AstroimageJ could load. For the astrometry we used the WCS contained in the Hubble images and used AstroimageJ for computing the centroids of each star. We will publish a complete list of the WDS stars which are on Hubble images in a future publication.

1. Example Measurements

2.1 **WDS00405+4044 (SKF1512)**

The first star we selected for further measurement was WDS00405+4044 (SKF1512). This star happens to lie in direction of the halo of the Andromeda Galaxy, M31, and as such it has been imaged many times by the HST between 1994 and 2009; (Table 1; Figure 1). The WDS gives observations of WDS00405+4044 (SKF1512) between 2005 and 2015 (Matson 2021). Thus, the Hubble images provide data on the star covering more than a decade, predating the WDS measurements and extending the observational record for WDS00405+4044 (SKF1512). The results of our measurements are contained in Table 1.

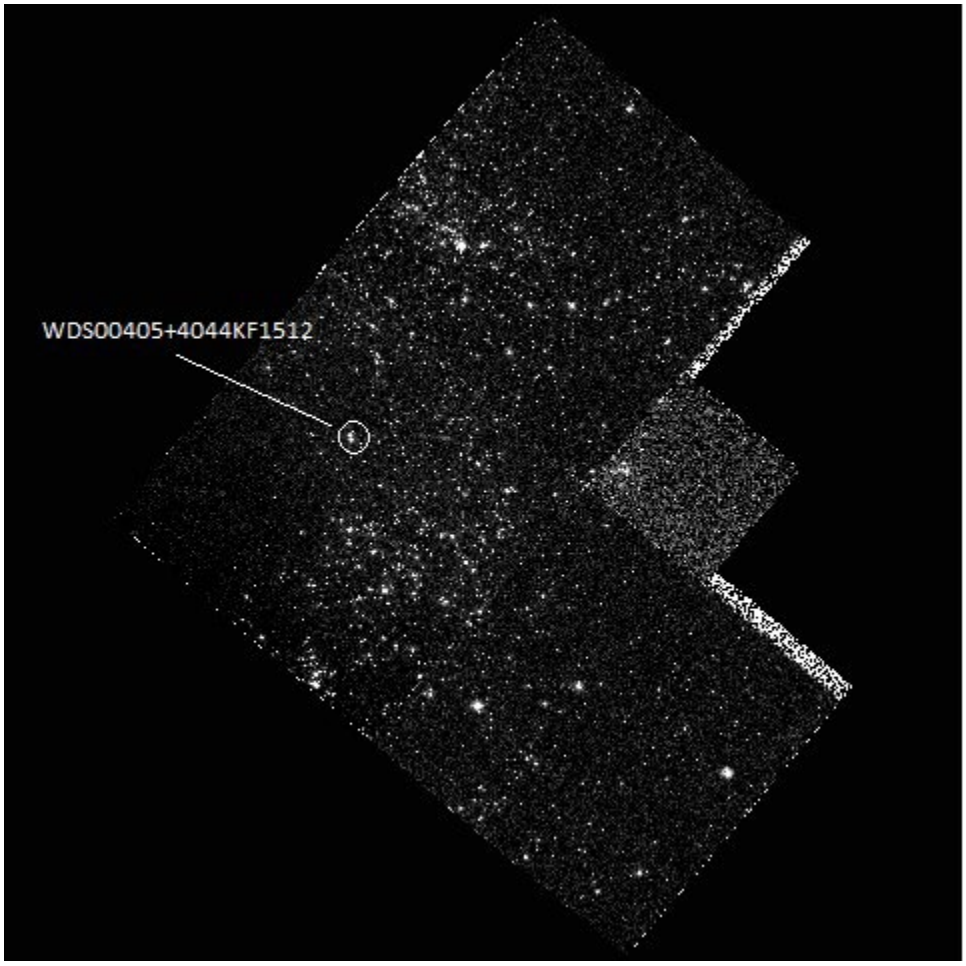

Figure 1. A WFPC2 image of the M31 field showing the layout of the four CCD chips and the location on the image of WDS00405+4044 (SKF1512). The image was taken on May 29, 1994.

Table 1. Measurements of WDS00405+4044 (SKF1512) from Hubble Images

Date	PA (°)	SEP ('')	Nobs	note
1994.405	190.657	1.106	1	
1994.405	188.397	1.121	1	
1994.405	188.317	1.131	1	
1998.699	189.516	1.237	1	
1998.699	187.638	1.231	1	
1998.699	187.638	1.231	1	
1998.699	191.374	1.245	1	
1999.063	197.222	1.244	1	Poor exp.
1999.063	199.166	1.244	1	
1999.063	195.722	1.208	1	
1999.063	201.202	1.131	1	
2007.537	180	1.217		Poor exp.
2007.537	180	1.217	1	
2007.537	180	1.217	1	
2007.537	180	1.217	1	
2007.537	180	1.217	1	
2008.452	182.393	0.980	1	Blended?
2008.452	180	0.814	1	poor
2008.454	180.	0.850	1	Blended?
2008.454	187.767	0.908	1	Blended?
2008.454	189.807	0.961	1	blended
2009.690	184.167	1.126	1	good
2009.690	186.297	1.119	1	good
2009.690	186.317	1.112	1	good
2009.690	184.248	1.10	1	good
2009.690	184.221	1.112	1	good
2009.690	184.167	1.126	1	good

There are only three previous measurements of the relative positions of WDS00405+4044SKF1512, as obtained from the WDS (Matson 2021). These span the time between 2005 and 2015. Table 2 gives these measurements. In Figure 2 we plot the position angle versus time, and in Figure 3 we plot the separation versus time. Examining our results, we see that there is considerable variation in the measurements of the position angle, but relatively little change in the separation, with the exception of a set of values in 2008 where the separation is lower than the rest of the data. We see a range of position angles between 201 and 180, nearly 20-degree change. There seems to be a trend towards the position angle decreasing, but there is considerable scatter in the measurements. Part of the reason for this is that on some of the poorer exposures the two stars are blended, and a small aperture had to be used in centroiding to avoid AstroimageJ picking the point between the two stars as the centroid. On some images the stars are noticeable pixelated. However, examining the historical data for the system we also see a trend towards smaller position angles with time, with a 7 degree change in ten years. The variation in our position angle on a single epoch varies about 9 degrees in some cases, which suggests that is likely the true error in that parameter.

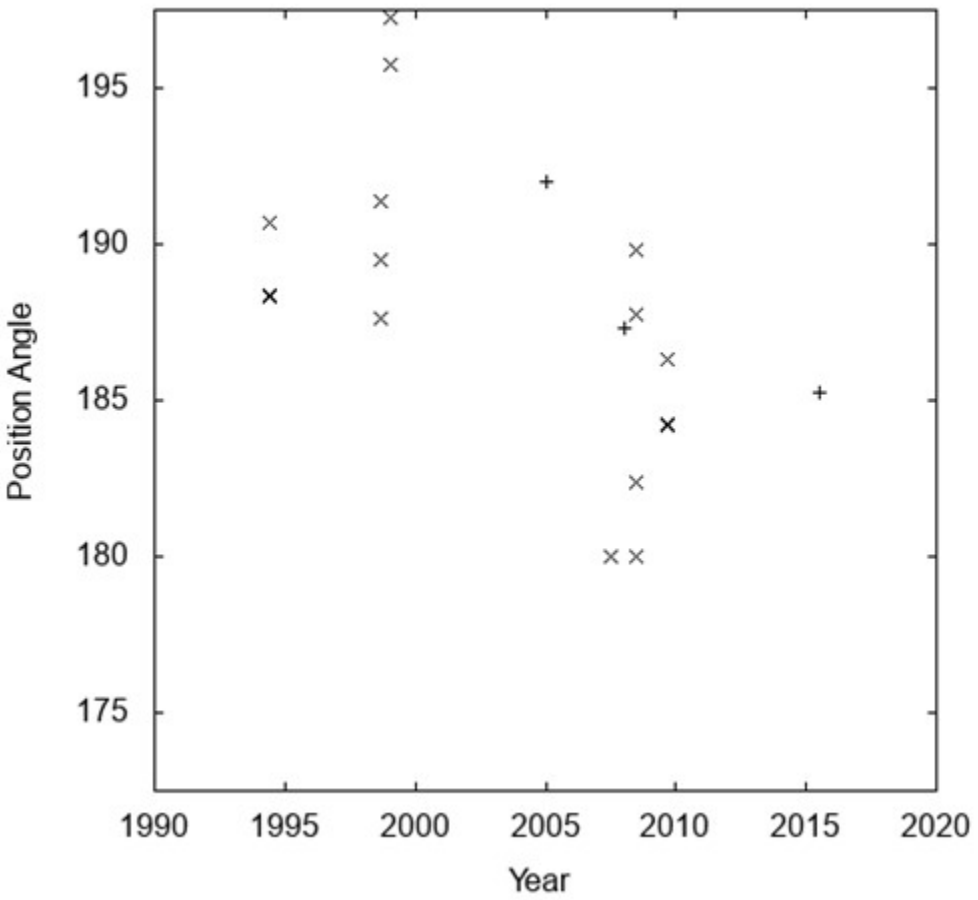

Figure 2. A plot of the position angle versus year for WDS00405+4044SKF1512. The X's are from this work while the +'s are from the three historical measurements. There is a general trend for the position angle to be decreasing, but there is large scatter.

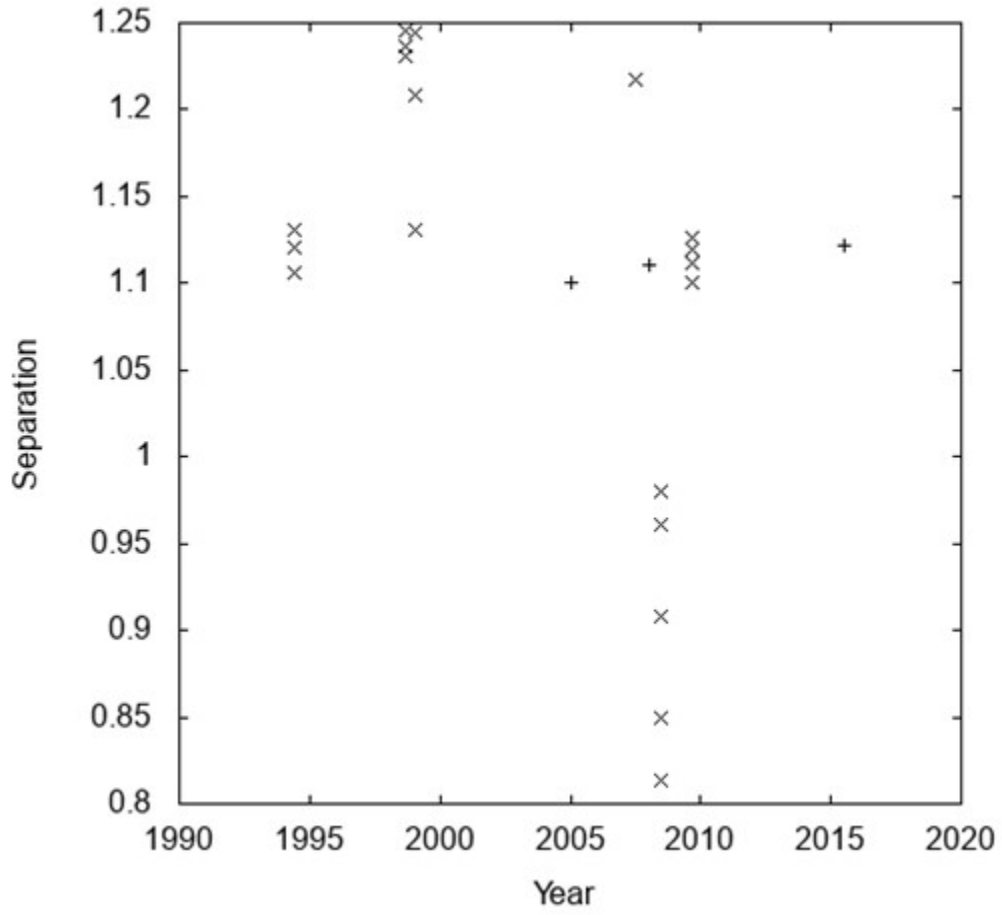

Figure 3. A plot of the separation versus time for WDS00405+4044SKF1512. The X's show our measurements from HST data while the +'s show the three historical measurements. The five points that lie lower than the others are from poorly exposed, pixelated images.

Table 2. Historical measurements of WDS00405+4044 (SKF1512)

Date	PA (°)	SEP (")	Reference
2005	192	1.1	Bianchi et al. (2012)
2008	187.3	1.11	Knapp et al. (2019)
2015.5	185.223±0.016	1.12178±0.00030	Skiff,(2015)

GAIA (2016) has made measurements of both components of the system, as given in Table 3. We see that the parallax of Star A is 3.8175 mas, while star B has a parallax of 1.2108 mas. This would place star A between 250 to 274pc in distance, while star B would be between 963 and 723 pc, with no overlap in the maximum and minimum distances for the two objects, suggesting the system is an optical double. Harshaw (2018) used the GAIA database to estimate likelihood of doubles being physical systems, and concluded that WDS00405+4044 (SKF1512) was not a physical system, in agreement with our conclusion.

Table 3. GAIA Measurements of WDS00405+4044 (SKF1512)

Object	μ (mas)	PM RA	PM DEC
WDS00405+4044SKF1512 A	3.8175±0.1745	2.721±0.253	-2.0389±0.2924
WDS00405+4044SKF1512 B	1.2108±0.1724	5.0945±0.781	-5.1479±0.2670

2.2 WDS00242-7205 (HJ3363)

The second star we present is WDS00242-7205 (HJ3363), which happens to lie near the star cluster 47 Tuc. Figure 4 shows an example of the stars measured with A being the primary star and B being the secondary star. The Hubble images resolve star B into two separate components which are similar in brightness and about 0.55 arcseconds apart. This would make it challenging for ground-based observations to split the two stars composing star B.

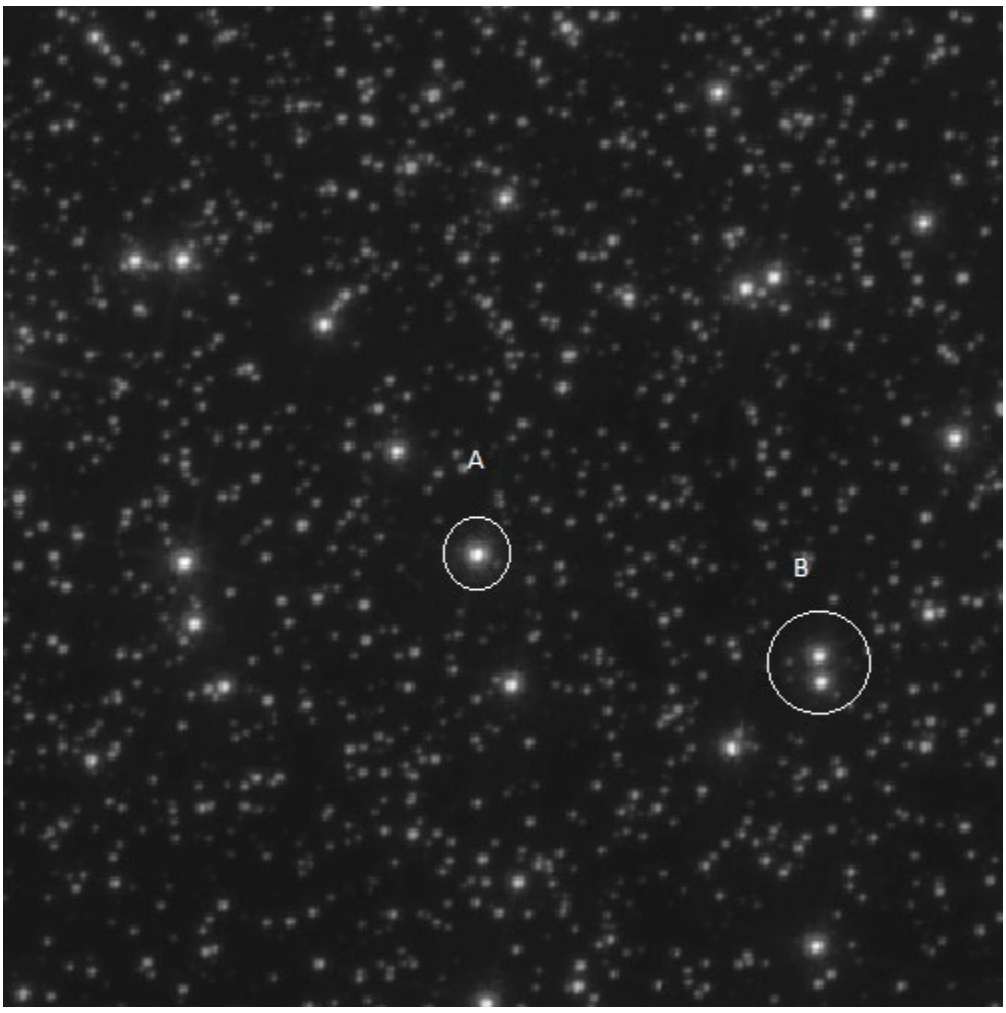

Figure 4. Part of a HST ACS/WFC image of 47 Tuc. WDS00242-7205 (HJ3363) can be seen on the image with the primary star labeled as "A", the secondary star as "B". Star B is resolved by the HST into two components.

We attempted to investigate if Star A and B might be at the same distance using the GAIA archive, and a whether the two components of Star B might be physically related, but the GAIA archive does not have parallaxes for them. Therefore, we cannot comment on if they are a physical system or not.

Table 4. Historical measurements of WDS00242-7205 (HJ3363)

Date	Rho	Theta	Reference
1916.92	6.21	251.0	Dawson (1918)
1998.60	7.56	250.3	2MASS (2003)
2015.0	7.421	253.448	Knapp & Nanson (2018)

Conclusions and Future Work: We have presented first results from our survey of double stars in the HST archive, presenting a study of WDS00405+4044 (SKF1512) and WDS00242-7205 (HJ3363). There seems to be some scatter in the position angle measurements, with the position angle nominally decreasing over time. Combined with GAIA measurements of the system, we conclude that the WDS00405+4044 (SKF1512) does not represent a physical system. For WDS00242-7205 (HJ3363) we find that the star B in the system is in fact a pair of stars rather than a single object. The results show the value of mining the Hubble archive for data on double stars that can add to the observational record of the systems. We plan to publish a list of all systems visually identified to appear on Hubble archive images in the future. We also plan on conducting studies of individual double stars.

Acknowledgements

This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement. Based on observations made with the NASA/ESA Hubble Space Telescope, and obtained from the Hubble Legacy Archive, which is a collaboration between the Space Telescope Science Institute (STScI/NASA), the Space Telescope European Coordinating Facility (ST-ECF/ESAC/ESA) and the Canadian Astronomy Data Centre (CADC/NRC/CSA). This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory. We wish to acknowledge the help of R. Matson of the U.S. Naval Observatory for supplying the historical data for this object.

References

Anton, R., 2012, "Lucky Imaging", Chapter 16, in "Observing and Measuring Visual Double Stars, Argyle, R. W. Ed., Springer.

Colins, K. A., Keilkopf, J. F., Stassun, K. G., and Hessman, F. V., 2017, "AstroImageJ: Image Processing and Photometric Extraction for Ultra-precise Astronomical Light Curves", AJ, 153, 77.

GAIA Collaboration et al. 2016, "The GAIA Mission", A&A, 595.

Harshaw, R., 2018, “GAIA DR2 and the Washington Double Star Catalog: A tale of Two Databases”, JDSO, 14, 734.

Matson, R., 2021, Private Communication.

Turner, N., 2012, “Astrometric Speckle Imaging for the Amateur Astronomer”, Chapter 18, in “Observing and Measuring Visual Double Stars, Argyle, R. W. Ed., Springer.

Van Hilst, M., 1990, “SAOimage”, BAAS 22, p.935.

Whitmore, B. C., Allam, S. S., Budavari, Tamas, Casertano, S., Downes, R. A., Donaldson, Thomas, Fall, S. M., Lubow, S. H., Quick, L., Strolger, Louis-Gregory, Wallace, G., and White, R., 2016, AJ, “Version 1 of the Hubble source Catalog”.