An Examination of the Large Mean Differential Magnitudes from Source Lists for WFPC2 and ACS Derived from DAOphot and SExtractor

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ABSTRACT

The study of the systematic properties of source lists that have been generated via a reduction pipeline within the Hubble Legacy Archive can disclose how satisfactorily the source lists are constructed. If the source lists are created in a robust and consistent manner then the investigation of the systematic properties of source lists can be done by removing astrometric and rotational offsets. This allows for the matching of sources between source lists that have the same field of view and are separated by time. As a result an examination of the differences in magnitudes *i.e.,* differential magnitudes, is possible. From this type of analysis information can be derived that point to charge transfer efficiency, throughput, sensitivity, and quantum efficiency losses. However, outliers have been identified as having mean differential magnitudes that are greater than 0.1 and less than -0.1. Furthermore, the distribution of differential magnitudes in magnitude space can also be a source of outlier classification. Examination of these outliers was completed using *imexam* an IRAF task and the IDL procedure, aper.pro. Magnitudes were calculated and differences derived (independent of the Hubble Legacy Archive) and were then compared to the differential magnitudes calculated from paired source lists whose individual source lists were generated by the Hubble Legacy Archive. This comparison showed that the source of the outlier behavior can be traced back to the single science drizzled images that went into creating the source lists. Additionally, if the outlier behavior cannot be traced to the single science images then this behavior can be traced to the combined science images that are generated from the single science images. Therefore, it can be implied that the Hubble Legacy Archive source list pipeline is operating nominally and not generating differential magnitude outliers.

1. Introduction

The examination of the systematic properties is an important step in producing a product that is robust in all aspects when that product is repeatedly demanded by a group of people. Therefore, this examination is essential in the production of source lists that are generated through the Hubble Legacy Archive (HLA) from Hubble Space Telescope (HST) photometric observations[1].

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[1]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/ESA) and the Canadian Astronomy Data Centre (CADC/NRC/CSA).

The exploration of the systematic properties of source lists can also expose any errors or non-optimal parameter values that go into source list generation. The source lists are created from a pipeline that uses DAOphot and Source Extractor (SExtractor; Bertin & Arnouts 1996) to calculate astrometry and fluxes. Note that this version of DAOphot is an IRAF[2] implementation, not Peter Stetson's original program (Stetson 1987). The fluxes derived from DAOphot and SExtractor are subsequently used to generate magnitudes in the AB magnitude system (Oke & Gunn 1983). In order to perform quality assurance pertaining to HLA source lists we assembled a catalogue of observations that cover an overlapping field of view (FOV), are separated in time, and done in several different filters. From these source lists we have matched, via right ascension and declination, objects found in the two source lists.

The astrometric offsets between the paired source lists have been subtracted out and a rotational offset (if any and however small) has been removed as well. The source lists have been compared and analyzed after the astrometric and rotational offsets have been eliminated. From this comparison, outliers have been identified and analyzed to determine if the cause is due to DAOphot/SExtractor or if the outlier behavior can be found in the exposures themselves. It is the examination of these outliers that is the topic of this paper. Note that each outlier is found in both DAOphot and SExtractor generated source lists.

2. Examination

The purpose of the examination is to determine whether the magnitudes calculated are a result of the DAOphot and/or the SExtractor pipeline that produces the HLA source lists. Since we are looking at differential magnitudes it is imperative that we re-produce these magnitudes via a process that is independent from the HLA source list pipeline. This was accomplished by using *imexam* in IRAF and aper.pro. The magnitudes are analyzed in the following manner: magnitude differences were calculated by differencing magnitudes from the same source in the associated single science exposures (01 compared to 01, 02 compared to 02, and so on) and then finding them in the paired source lists.

The first task in the examination of the differential magnitude outliers was the extraction of the drizzled single science images from HLA that went into the construction of the combined final drizzled image from which the source lists are derived. The second task was to examine the single science images using *imexam* to analyze the point spread function (PSF) profile, calculate magnitudes, determine full width half maximum (FWHM) of the PSF, and to get an estimation of the sky or background. These quantities and distributions were examined using the "a" command in *imexam*, which provided magnitudes, sky values, FWHM, and pixel coordinates of the sources

[2]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by Associations of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

chosen for the analysis. Additionally, the "r" command was used to inspect the radial profile of the sources *i.e.,* PSF of the object. Note that the sources that were picked for the examination came from the original matched source lists created by the idl program match_dao_cat.pro. The pixel coordinates were randomly chosen from the matched source lists and then found in the single science images. Furthermore, the magnitudes derived by using *imexam* were compared to the magnitudes found in the original paired source lists, which were used as the baseline.

Additionally, the combined drizzled images were used as well in conjunction with aper.pro an IDL procedure that adopts DAOphot for doing photometry. We made cuts in dmag and magnitude from Figures 1, 2, 3, and 4 to pick out sources with which to do photometry. The aperture sizes are $0.10''$ and $0.30''$. Note that these sources are also in the paired source lists.

Table 1 provides information pertaining to each outlier and the tabular columns are: column 1 contains the paired source lists, columns 2 and 3 house the mean differential magnitudes for the dmag $0.10''$ and dmag $0.30''$ apertures including the standard deviation of the differential magnitudes, respectively, and the last column has the filter used in the observations . Since the first three pairs (considered pairs because they have the same reference source list) of outliers listed in Table 1 have the same reference source list we need only one element of each pair of outliers. Therefore, we will only examine 8090_if and 6251_3w, 9677_m0 and 9677_l2, 7274_23 and 6251_3v, and 9710_vt and 9709_nh.

Table 1: Outliers in Differential Magnitudes

Paired Source Lists	dmag $0.10''$ Aper.	dmag $0.30''$ Aper.	Filter
8090_if, 6251_3w	0.228 ± 0.133	X	F606W
8090_if, 6251_3x	0.233 ± 0.132	X	F606W
9677_m0, 9677_l2	-0.280 ± 0.279	-0.181± 0.176	F606W
9677_m0, 9677_l3	-0.305 ± 0.297	-0.216 ± 0.189	F606W
7274_23, 6251_3u	0.234 ± 0.142	X	F814W
7274_23, 6251_3v	0.183 ± 0.136	X	F814W
9710_vt[a], 9709_nh[a]	0.087 ± 0.307	-0.022 ± 0.123	F606W

[a] These particular data sets are designated an outlier because of the shape of the differential magnitude distribution is peculiar in magnitude space. See Figure 4.

Before beginning the examination of differential magnitudes derived from paired source lists a brief description of the tables found in the subsequent sub-sections is in order. For example consider the tables found in the first sub-section (**2.1**), which analyzes the paired source lists 6251_3w and 8090_if. These tables are Tables 2, 3, 4, and 5. The columns of Table 2 are: column 1 has the data set used in *imexam* and note that the nomenclature is proposal, visit identification, and number of the single science exposure. Column 2 has the observation date, column 3 pertains to x and y pixel coordinates, column 4 presents the FWHM, column 5 reveals whether the PSF profile was nominal, column 6 has the magnitudes, and column 7 houses the sky values. Tables 3, 4, and 5 have the subsequent columns: column 1 contains the data set names, column 2 has the x and y pixel coordinates, column 3 houses the differential magnitudes from either *imexam* or aper.pro, and column 4 presents the differential magnitudes calculated from the text file containing astrometric and photometric data from the paired source lists. In conjunction with the tables found in each sub-section are figures that contain plots showing differential magnitudes plotted as a function of magnitude. Most figures show a mean differential magnitude greater or lesser than the absolute value of 0.1. Other figures show that the mean differential magnitude less than 0.1 but reveal peculiar differential magnitude distributions in magnitude space.

Additionally, we get more robust magnitudes from the paired source lists because the combined images have been cosmic ray cleaned using a cosmic ray mask generated from the single science images whereas and obviously the single science images have not. Furthermore, the single science images are undersampled but the combined images are undersampled to a lesser extent than the single science images. Please note that the aperture size used by *imexam* is $0.30''$.

The results of the examination of the single science images using *imexam* disclose that the differential magnitudes calculated are in fact related to the images themselves and not related to the HLA photometric values derived from the pipeline. The reason for this is two-fold. The first fold can be discerned by using *imexam* to derive magnitudes, PSF profiles, and sky values. The values for the FWHM and sky appear to be nominal and the PSF profiles are as they should be (see the Tables for the individual cases, particularly columns 3, 4, and 6 for FWHM, PSF profile, and sky values) suggesting that *imexam* is producing reasonable magnitudes and that the images themselves are not corrupted. Magnitudes were then employed and differential magnitudes calculated. The second fold is that when the combined images are used (employing aper.pro) the differential magnitudes are more or less consistent with what is found in the paired source lists. Thereby showing that the magnitude differences can be traced to the images themselves. Individual cases are described in the following sub-sections.

2.1. Source Lists: 6251_3w, 8090_if

Analysis of the paired source lists 6251_3w and 8090_if revealed a mean differential magnitude with the $0.10''$ aperture of 0.228 ± 0.133. The mean differential magnitude for the aperture of $0.30''$ for these paired source lists is less than 0.1 and thus not considered an outlier, however it will be employed in the analysis. The outlier nature for the $0.10''$ aperture can be found in Figure 1. The top plot shows the distribution of differential magnitude as a function of magnitude and the middle plot shows the same information but for the $0.30''$ aperture size. It is clearly evident in the top plot that the mean differential magnitude is much greater than 0.1.

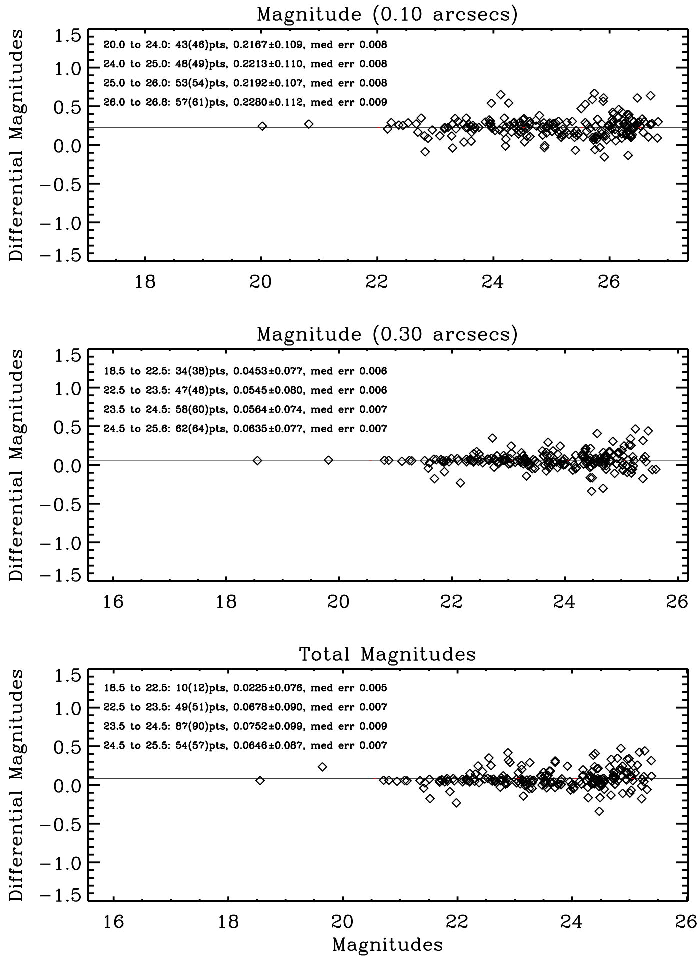

Fig. 1.— This is a plot of differential magnitudes with the mean overlaid as a black line shown in the plots. It is clearly evident in the top plot the outlier behavior of the paired source lists 6251_3w and 8090_if and has a mean differential magnitude of 0.228 ± 0.133.

After calculating magnitudes from *imexam* (see Table 2) the same sources used for *imexam* were then found in the paired source list, matches_08090_if_to_06251_3w.txt. These pairs of differential magnitudes can found in Table 3. Inspection of the *imexam* differential magnitudes (column 3) reveals negative values where the paired source list differential magnitudes (column 4) show only positive differential magnitudes. This is due to the fact that *imexam* was used on single science exposures, which are undersampled and not cosmic-ray rejected, while the paired source list differential magnitudes come from combined exposures, which undersampled to a lesser extent and cosmic-ray rejected, constructed from the single science exposures and come from the HLA source list pipeline. This is not a strictly fair comparison but a baseline was needed to make a comparison with the differential magnitudes derived from *imexam*. Therefore, despite the negative values of the differential magnitudes derived from *imexam* the differential magnitudes are of the same order of magnitude. This implies that the differential magnitudes are manifested in the single science images themselves.

Table 2: Individual Science Images (6251_3w, 8090_if)

Data Set	Observation Date	Coordinates (x,y) Pixels	FWHM	PSF Profile	Magnitude	Sky
6251_3w_01	07/09/1995	387.36, 1545.46	1.89	OK	21.34	0.025
6251_3w_01	07/09/1995	1569.18, 1277.27	2.44	OK	20.32	0.010
6251_3w_01	07/09/1995	1448.73, 1511.36	2.25	OK	20.80	0.024
8090_if_01	06/17/1999	387.36, 1545.46	2.24	OK	21.29	0.021
8090_if_01	06/17/1999	1569.18, 1277.27	2.80	OK	20.35	0.010
8090_if_01	06/17/1999	1448.73, 1511.36	2.28	OK	20.85	0.023
6251_3w_02	07/09/1995	387.36, 1545.46	2.01	OK	21.31	0.019
6251_3w_02	07/09/1995	1569.18, 1277.27	2.54	OK	20.38	0.009
6251_3w_02	07/09/1995	1448.73, 1511.36	2.32	OK	20.84	0.023
8090_if_02	06/17/1999	387.36, 1545.46	2.29	OK	21.29	0.020
8090_if_02	06/17/1999	1569.18, 1277.27	2.88	OK	20.34	0.010
8090_if_02	06/17/1999	1448.73, 1511.36	2.41	OK	20.83	0.024

Table 3: Differential Magnitudes ($0.30''$)

Data Set	Coordinates (x,y) Pixels	dmag (*imexam*)	dmag (match)
6251_3w_01, 8090_if_01	387.36, 1545.46	-0.050	0.057
6251_3w_01, 8090_if_01	1569.18, 1277.27	0.030	0.065
6251_3w_01, 8090_if_01	1448.73, 1511.36	0.050	0.061
6251_3w_02, 8090_if_02	387.36, 1545.46	-0.020	0.057
6251_3w_02, 8090_if_02	1569.18, 1277.27	-0.040	0.065
6251_3w_02, 8090_if_02	1448.73, 1511.36	-0.010	0.061

Furthermore, Tables 4 and 5 depict differential magnitudes derived from aper.pro and from the same text file containing the paired source lists. Examination of the third and fourth columns from Tables 4 and 5 show that both differential magnitudes are indeed approximately the same and also that the aperture sizes used in aper.pro give the same differential magnitude offsets found in the top and middle plots of Figure 1. This provides further evidence that the differences found in the magnitudes come from the images themselves and not from the HLA photometric and astrometric pipeline. This also supports the implication that the differential magnitudes originate in the single science images themselves.

Table 4: Differential Magnitudes (0.10″)

Data Set	Coordinates (x,y) Pixels	dmag (aper)	dmag (match)
6251_3w, 8090_if	1234.63, 989.90	0.261	0.286
6251_3w, 8090_if	1073.20, 482.15	0.243	0.227
6251_3w, 8090_if	1463.70, 1199.14	0.369	0.382

Table 5: Differential Magnitudes (0.30″)

Data Set	Coordinates (x,y) Pixels	dmag (aper)	dmag (match)
6251_3w, 8090_if	1778.78, 1237.93	0.061	0.069
6251_3w, 8090_if	894.06, 430.35	0.165	0.159
6251_3w, 8090_if	1017.39, 801.96	0.090	0.070

2.2. Source Lists: 9677_l2, 9677_m0

Analysis of the paired source lists 9677_l2 and 9677_m0 portrayed a mean differential magnitudes with the 0.10″ aperture of -0.280 ± 0.279 and a mean differential magnitude of -0.181 ± 0.176 for the 0.30″ aperture. The outlier nature for the 0.10″ aperture and 0.30″ aperture can be found in Figure 2. The top plot shows the distribution of differential magnitude (0.10″ aperture) as a function of magnitude and the middle plot show the same information but for the 0.30″ aperture. It is clearly evident in the top and middle plots that the mean differential magnitude is much greater than 0.1 and that the differential magnitude distribution is odd as well. Normally the differential magnitude structure as a function of magnitude is an essentially symmetric distribution about the mean differential magnitude with increasing scatter in differential magnitude as magnitudes get fainter. The increased scatter is due to the increase in magnitude error, because of fewer counts, for fainter magnitudes.

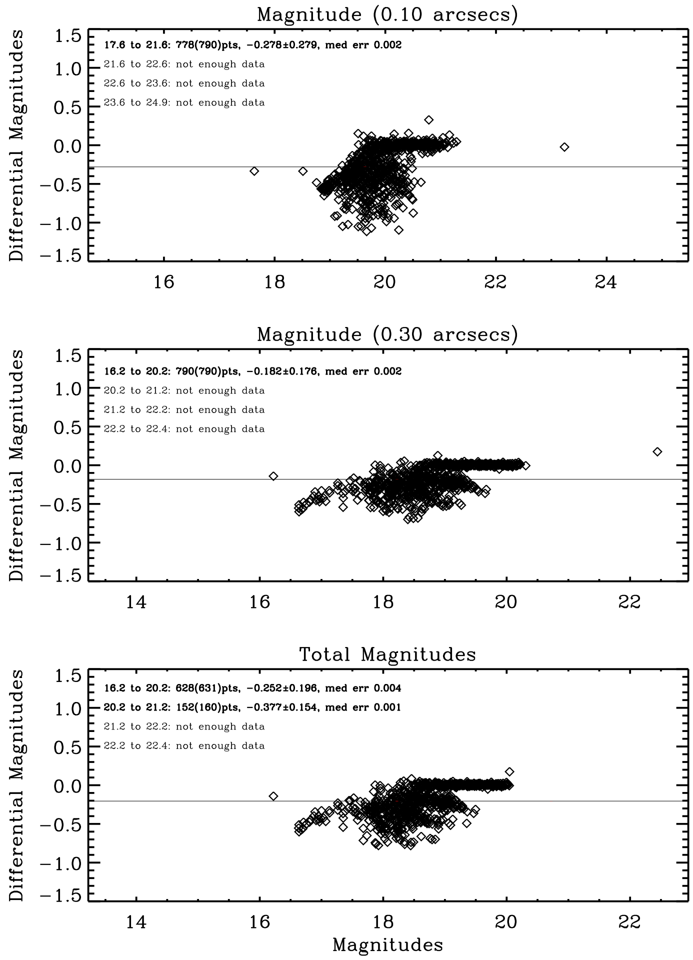

Fig. 2.— This is a plot of differential magnitudes with the mean overlaid as a black line shown in the plots. It is clearly evident in the top and middle plots the outlier behavior of the paired source lists 9677_l2 and 9677_m0. The mean differential magnitudes are -0.280 ± 0.279 and -0.181 ± 0.176 for the 0.10″ and 0.30″ apertures, respectively. Furthermore, the outlier behavior can also be clearly seen in the distribution of differential magnitudes as a function of magnitude.

To begin consider the magnitudes found in Table 6, from which differential magnitudes were calculated. The same sources were then found in the paired source list, matches_09677_m0_to_09677_l2.txt, and the corresponding differential magnitudes were derived. The results of this comparison can be found in Table 7. Inspection of the *imexam* differential magnitudes from column 3 and column 4 reveal values that are both negative and are essentially the same value. Note that for this comparison the matched source lists come from combined drizzled images that are created from only one single science drizzled image. This means that the comparisons of the differential magnitudes for this outlier are more robust than for the other outlier circumstances. This implies that the differential magnitudes are inherent in the single science images themselves.

Table 6: Individual Science Images (9677_l2, 9677_m0)

Data Set	Observation Date	Coordinates (x,y) Pixels	FWHM	PSF Profile	Magnitude	Sky
9677_l2_01	08/13/2002	1158.70, 844.50	2.33	OK	18.24	0.005
9677_l2_01	08/13/2002	1209.03, 1157.70	2.31	OK	18.51	0.024
9677_l2_01	08/13/2002	1311.56, 1612.57	2.36	OK	18.36	0.007
9677_m0_01	08/13/2002	1158.70, 844.50	2.15	OK	18.16	0.006
9677_m0_01	08/13/2002	1209.03, 1157.70	2.09	OK	18.41	0.029
9677_m0_01	08/13/2002	1311.56, 1612.57	1.88	OK	18.26	0.0005

Table 7: Differential Magnitudes ($0.30''$)

Data Set	Coordinates (x,y) Pixels	dmag (*imexam*)	dmag (match)
9677_l2_01, 9677_m0_01	1158.70, 844.50	-0.080	-0.086
9677_l2_01, 9677_m0_01	1209.03, 1157.70	-0.100	-0.170
9677_l2_01, 9677_m0_01	1311.56, 1612.57	-0.100	-0.176

Moreover, Tables 8 and 9 depict differential magnitudes derived from aper.pro and from the same text file containing the paired source lists. Examination of the third and fourth columns from Tables 8 and 9 show that both differential magnitudes are indeed approximately the same (in Table 9 the differential magnitudes are more divergent from each other) and also that the aperture sizes used in aper.pro give the same differential magnitude offsets found the the top and middle plots of Figure 2. This provides further evidence that the differences found in the magnitudes come from the images themselves and not from the HLA photometric and astrometric pipeline. This also supports the implication that the differential magnitudes originate from the single science images themselves.

Table 8: Differential Magnitudes ($0.10''$)

Data Set	Coordinates (x,y) Pixels	dmag (aper)	dmag (match)
9677_l2, 9677_m0	570.79, 675.86	-0.402	-0.388
9677_l2, 9677_m0	1366.80, 565.11	-0.319	-0.320
9677_l2, 9677_m0	636.99, 1650.51	-0.333	-0.353

Table 9: Differential Magnitudes (0.30″)

Data Set	Coordinates (x,y) Pixels	dmag (aper)	dmag (match)
9677_l2, 9677_m0	1430.86, 1091.31	-0.574	-0.454
9677_l2, 9677_m0	872.98, 1575.02	-0.532	-0.438
9677_l2, 9677_m0	1090.74, 1508.43	-0.488	-0.428

2.3. Source Lists: 6251_3v, 7274_23

Analysis of the paired source lists 6251_3v and 7274_23 disclosed a mean differential magnitude with the 0.10″ aperture of 0.183 ± 0.136 and a mean differential magnitude of less than 0.1 for the 0.30″ aperture. The outlier nature for the 0.10″ aperture can be found in Figure 3. The top plot shows the distribution of differential magnitude as a function of magnitude and the middle plot show the same information but for different aperture sizes. It is clearly evident in the top plot that the mean differential magnitude is much greater than 0.1.

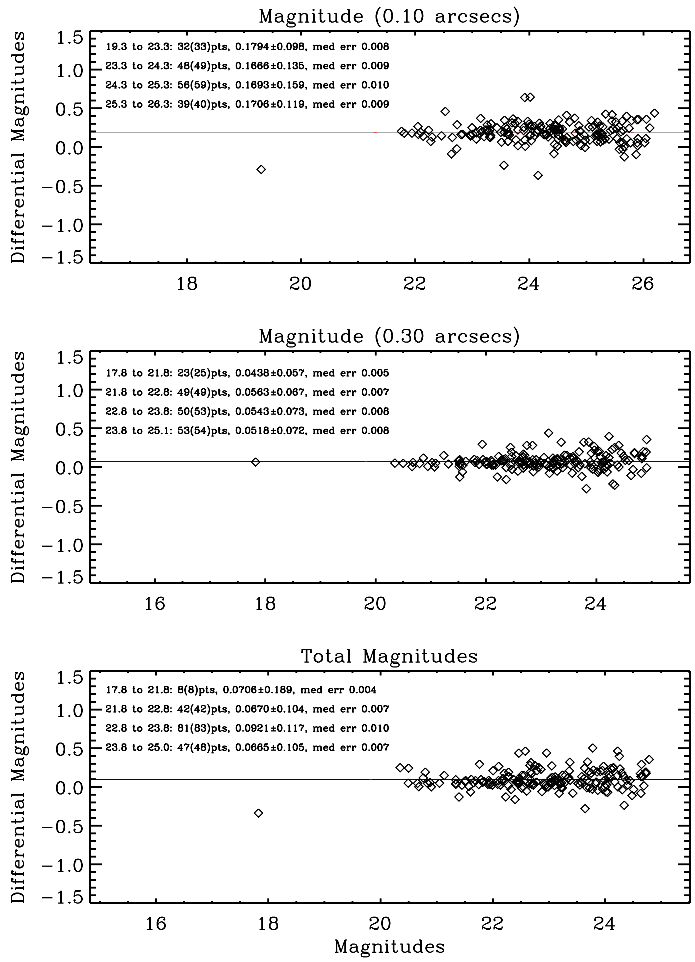

Fig. 3.— This is a plot of differential magnitudes with the mean overlaid as a black line shown in the plots. It is clearly evident in the top plot the outlier behavior of the paired source lists 6251_3v and 7274_23 and has a mean differential magnitude of 0.183 ± 0.136.

To begin consider the magnitudes found in Table 10, from which differential magnitudes were calculated. The same sources were then found in the paired source list, matches_07274_23_to_06251_3v.txt, and the differential magnitudes were derived. The results of this comparison can found in Table 11. Inspection of the *imexam* differential magnitudes (column 3) again reveals negative values where the paired source list differential magnitudes (column 4) show only positive differential magnitudes. This is due to the fact that *imexam* was used on single science exposures, while the paired source list differential magnitudes come from combined exposures constructed from the single science exposures and come from the HLA source list pipeline. Again, this is not a strictly fair comparison but a baseline was needed to make a comparison with the differential magnitudes derived from *imexam*. Therefore, despite the negative values of the differential magnitudes derived from *imexam* the differential magnitudes are of the same order of magnitude except for two entries where the *imexam* differential magnitudes are 0.130 and -0.130 (see column 3 in Table 11). This implies that the differential magnitudes are from the single science images themselves.

Table 10: Individual Science Images (6251_3v, 7274_23)

Data Set	Observation Date	Coordinates (x,y) Pixels	FWHM	PSF Profile	Magnitude	Sky
6251_3v_01	07/09/1995	1448.48, 1512.39	3.37	OK	21.12	0.018
6251_3v_01	07/09/1995	387.23, 1545.85	2.11	OK	21.66	0.019
6251_3v_01	07/09/1995	1568.46, 1276.59	2.56	OK	20.83	0.082
7274_23_01	06/17/1999	1448.48, 1512.39	2.82	OK	21.25	0.017
7274_23_01	06/17/1999	387.23, 1545.85	2.30	OK	21.59	0.016
7274_23_01	06/17/1999	1568.46, 1276.59	2.81	OK	20.82	0.008
6251_3v_02	07/09/1995	1448.48, 1512.39	2.50	OK	21.34	0.017
6251_3v_02	07/09/1995	387.23, 1545.85	2.21	OK	21.62	0.018
6251_3v_02	07/09/1995	1568.46, 1276.59	2.59	OK	20.82	0.008
7274_23_02	06/17/1999	1448.48, 1512.39	2.35	OK	21.32	0.018
7274_23_02	06/17/1999	387.23, 1545.85	2.27	OK	21.49	0.019
7274_23_02	06/17/1999	1568.46, 1276.59	2.72	OK	20.85	0.009
7274_23_03	06/17/1999	1448.48, 1512.39	2.50	OK	21.35	0.022
7274_23_03	06/17/1999	387.23, 1545.85	2.23	OK	21.61	0.022
7274_23_03	06/17/1999	1568.46, 1276.59	2.85	OK	20.82	0.012

Table 11: Differential Magnitudes (0.30″)

Data Set	Coordinates (x,y) Pixels	dmag (*imexam*)	dmag (match)
6251_3v_01, 7274_23_01	1448.48, 1512.39	0.130	0.007
6251_3v_01, 7274_23_01	387.23, 1545.85	-0.070	0.045
6251_3v_01, 7274_23_01	1568.46, 1276.59	-0.010	0.065
6251_3v_02, 7274_23_02	1448.48, 1512.39	-0.020	0.007
6251_3v_02, 7274_23_02	387.23, 1545.85	-0.130	0.045
6251_3v_02, 7274_23_02	1568.46, 1276.59	0.030	0.065
6251_3v_02, 7274_23_03	1448.48, 1512.39	0.010	0.007
6251_3v_02, 7274_23_03	387.23, 1545.85	-0.010	0.045
6251_3v_02, 7274_23_03	1568.46, 1276.59	0.000	0.065

Moreover, Tables 12 and 13 depict differential magnitudes derived from aper.pro and from the same text file containing the paired source lists. Examination of the third and fourth columns from Tables 12 and 13 show that both differential magnitudes are indeed approximately the same and also that the aperture sizes used in aper.pro give the same differential magnitude offsets found the the top and middle plots of Figure 3. This provides further evidence that the differences found in the magnitudes come from the images themselves and not from the HLA photometric and astrometric pipeline. This also supports the implication that the differential magnitudes originate from the single science images themselves.

Table 12: Differential Magnitudes (0.10″)

Data Set	Coordinates (x,y) Pixels	dmag (aper)	dmag (match)
6251_3v, 7274_23	1824.92, 1322.90	0.137	0.169
6251_3v, 7274_23	572.80, 1316.35	0.154	0.138
6251_3v, 7274_23	805.98, 1193.82	0.250	0.225

Table 13: Differential Magnitudes (0.30″)

Data Set	Coordinates (x,y) Pixels	dmag (aper)	dmag (match)
6251_3v, 7274_23	1397.55, 669.98	-0.066	-0.080
6251_3v, 7274_23	571.52, 1661.81	0.316	0.320
6251_3v, 7274_23	1343.37, 1180.00	0.456	0.396

2.4. Source Lists: 9709_nh, 9710_vt

Analysis of the paired source lists 9709_nh and 9710_vt disclosed a mean differential magnitude of 0.087 ± 0.307 and -0.022 ± 0.123 for the 0.10″ and 0.30″ apertures, respectively. The outlier nature for both apertures can be found in Figure 5. The top plot shows the distribution of differential magnitude as a function of magnitude and the middle and bottom plots show the same information but for different aperture sizes. It is clearly evident in the top and middle plots that the distribution of differential magnitudes in magnitude space displays an odd structure. Normally the differential magnitude structure as a function of magnitude is an essentially symmetric distribution about the mean differential magnitude with increasing scatter in differential magnitude as magnitudes get fainter. This is not seen in Figure 5.

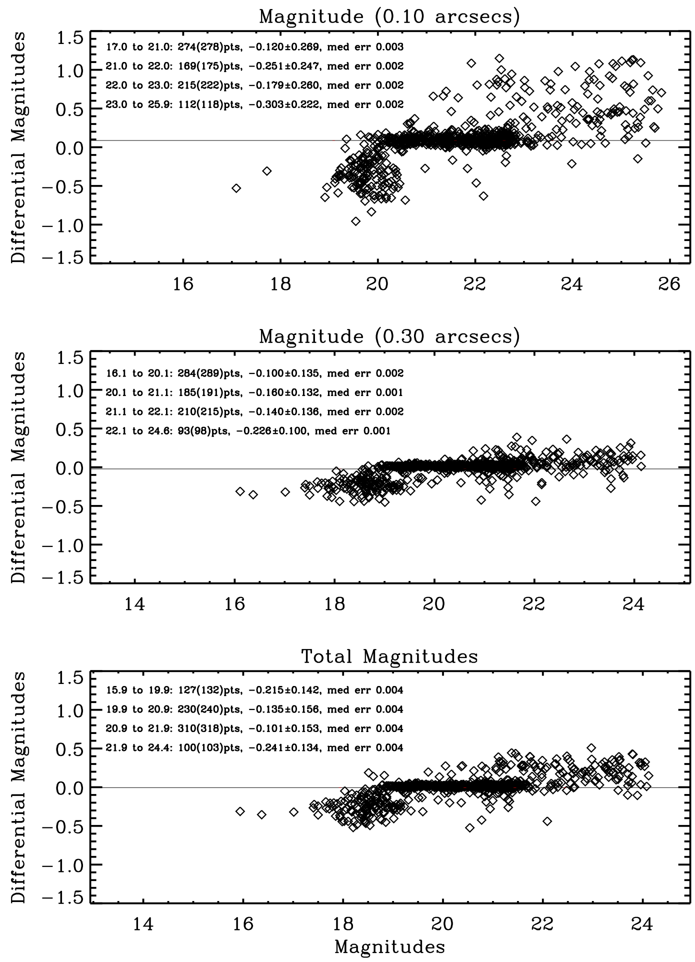

Fig. 4.— This is a plot of differential magnitudes with the mean overlaid as a black line shown in the plots. It is clearly evident in the top and middle plots the outlier behavior of the paired source lists 9709_nh and 9710_vt. The mean differential magnitudes are 0.087 $\pm$ 0.307 and -0.022 $\pm$ 0.123 for the $0.10''$ and $0.30''$ apertures, respectively. The outlier behavior is clearly seen the distribution of differential magnitudes as a function of magnitude.

To begin consider the magnitudes found in Table 14 and magnitudes were employed to calculate differential magnitudes. The same sources were then found in the paired source list, matches_09710_vt_to_09709_nh.txt, and the differential magnitudes were derived. The results of this comparison can found in Table 15. Inspection of the *imexam* differential magnitudes from column 3 and column 4 reveal values that are both negative and are essentially the same value except for two *imexam* entries of -0.160 and -0.150. This implies that the differential magnitudes are manifested from the single science images themselves.

Table 14: Individual Science Images (9709_nh, 9710_vt)

Data Set	Observation Date	Coordinates (x,y) Pixels	FWHM	PSF Profile	Magnitude	Sky
9709_nh_01	08/24/2003	707.52, 1571.62	3.06	OK	17.62	0.068
9709_nh_01	08/24/2003	619.43, 900.33	2.16	OK	18.37	0.024
9709_nh_01	08/24/2003	1442.28, 743.52	3.35	OK	17.50	0.051
9709_nh_02	08/24/2003	707.52, 1571.62	3.07	OK	17.61	0.068
9709_nh_02	08/24/2003	619.43, 900.33	2.17	OK	18.35	0.025
9709_nh_02	08/24/2003	1442.28, 743.52	3.46	OK	17.43	0.049
9710_vt_01	08/24/2003	707.52, 1571.62	2.66	OK	17.46	0.074
9710_vt_01	08/24/2003	619.43, 900.33	1.88	OK	18.20	0.029
9710_vt_01	08/24/2003	1442.28, 743.52	2.86	OK	17.28	0.050

Table 15: Differential Magnitudes ($0.30''$)

Data Set	Coordinates (x,y) Pixels	dmag (*imexam*)	dmag (match)
9709_nh_01, 9710_vt_01	707.52, 1571.62	-0.160	-0.049
9709_nh_01, 9710_vt_01	619.43, 900.33	-0.170	-0.167
9709_nh_01, 9710_vt_01	1442.28, 743.52	-0.220	-0.251
9709_nh_02, 9710_vt_01	707.52, 1571.62	-0.150	-0.049
9709_nh_02, 9710_vt_01	619.43, 900.33	-0.135	-0.167
9709_nh_02, 9710_vt_01	1442.28, 743.52	-0.150	-0.251

Moreover, Tables 16 and 17 depict differential magnitudes derived from aper.pro and from the same text file containing the paired source lists. Examination of the third and fourth columns from Tables 16 and 17 show that both differential magnitudes are indeed approximately the same and also that the aperture sizes used in aper.pro give the same differential magnitude offsets found in the the top and middle plots of Figure 5. This provides further evidence that the differences found in the magnitudes come from the images themselves and not from the HLA photometric and astrometric pipeline. This also supports the implication that the differential magnitudes originate from the single science images themselves.

Table 16: Differential Magnitudes ($0.10''$)

Data Set	Coordinates (x,y) Pixels	dmag (aper)	dmag (match)
9709_nh, 9710_vt	183.79, 1409.33	-0.121	-0.149
9709_nh, 9710_vt	846.58, 1038.05	-0.222	-0.226
9709_nh, 9710_vt	1695.76, 464.39	-0.162	-0.163

Table 17: Differential Magnitudes (0.30″)

Data Set	Coordinates (x,y) Pixels	dmag (aper)	dmag (match)
9709_nh, 9710_vt	246.65, 1387.81	-0.289	-0.285
9709_nh, 9710_vt	919.18, 1018.01	-0.285	-0.280
9709_nh, 9710_vt	1750.90, 507.59	-0.213	-0.215

3. Conclusions

The examination of the differential magnitude outliers has been accomplished using *imexam* and aper.pro to determine if approximately the same differential magnitude values can be reproduced by deriving magnitudes from the combined and the single science drizzled images. The results from the derivation of differential magnitudes from matched (same field of view) combined and single science images show that indeed the outlier differential magnitudes can be traced back to the single science images (this applies to the odd distributions of differential magnitudes as well). Additionally, if the comparison between the single science image differential magnitudes (from *imexam*) and the combined images used to generate the source lists are deemed unsuitable then the comparisons made with the aper.pro are still valid as these results were derived from the same combined images. If this is the case then the outlier behavior is still traced to the observations themselves and not to the HLA astrometric and photometric pipeline. Either way, the comparison of the differential magnitudes calculated from magnitudes derived from *imexam* and aper.pro to the matched source lists shows conclusively that the outlier nature of the differential magnitudes does not extend from the source lists generated by the HLA source list pipeline.

4. References

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