Instrument Science Report WFC3 2015-09

Combining WFC3 Mosaics of M16 with DrizzlePac

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ABSTRACT

This report highlights new mosaicking options in the DrizzlePac 2.0 software as applied to WFC3 observations of the Eagle Nebula (M16) for HST's 25th Anniversary. Prior to this new version of DrizzlePac, aligning mosaic tiles required an iterative approach. Now, mosaic alignment can be achieved in a single step by building up an expanded reference catalog 'on-the-fly'. New sky matching options make it easier to produce seamless mosaics, which can be challenging for extended sources with little or no 'blank' sky. The combined M16 mosaics are now available as High-Level Science Products from MAST. This ISR provides a step-by-step tutorial for aligning and combining the UVIS and IR observations in five filters. It also shows how to improve the UVIS calibrated data products used as input to DrizzlePac by correcting for instrumental artifacts, such as crosstalk, CTE.

1. Introduction

One of the most iconic images from the Hubble Space Telescope has been the 1995 WFPC2 image of the Eagle Nebula, also known as the 'Pillars of Creation' (Hester *et al.* 1996). Nineteen years after those original observations, new mosaics have been obtained by the Hubble Heritage Team with HST's Wide Field Camera 3 using both the UVIS and IR channels. The wider field of view, higher resolution, and broader wavelength coverage of the new observations highlight the improved capabilities of HST over its long-lasting operation, made possible by the upgraded instrumentation installed during Servicing Mission 4. Figure 1 shows both the UVIS and IR color composite images which were presented at the AAS 225th meeting to commemorate the 25th anniversary of HST's launch (Levay et al. 2015).

Since these combined mosaics represent a significant investment of processing beyond the standard archival products, the drizzle-combined FITS images have been delivered as High-Level Science Products (HLSPs) to the Mikulski Archive for Space Telescopes (MAST) and are available from the following page: http://archive.stsci.edu/prepds/heritage/m16. Both the science and weight images have been provided for each filter.

Table 1 summarizes the drizzled data products for each filter, including the number of mosaic tiles, the number of input frames, the average depth, and the total exposure time in seconds. To ensure that these data products are compatible and queryable with both MAST and the Hubble Legacy Archive (HLA), we used the standard naming convention for HLSPs: *hlsp_project_mission_instrument_field-name_filter_version_product.extension*.

Figure 1: Color-composite UVIS and IR images released at the 225th AAS. These composites images were created from the five individual WFC3 filter mosaics.

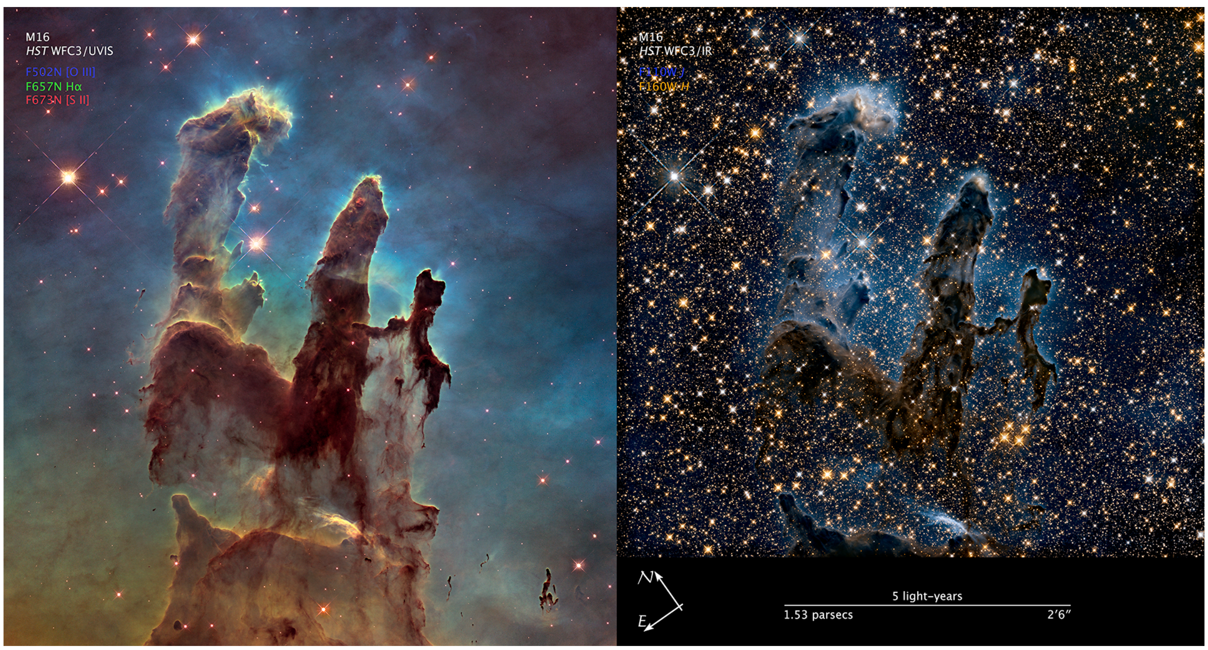

Table 1. High-Level Science Products

Drizzled Science Image	Filter	Tiles	Frames	Average Depth	Total Exposure
hlsp_heritage_hst_wfc3-uvis_m16_f502n_v1_drz.fits	F502N	6	16	3000 s	16000 s
hlsp_heritage_hst_wfc3-uvis_m16_f657n_v1_drz.fits	F657N	6	16	1800 s	9600 s
hlsp_heritage_hst_wfc3-uvis_m16_f673n_v1_drz.fits	F673N	6	16	2700 s	14400 s
hlsp_heritage_hst_wfc3-ir_m16_f110w_v1_drz.fits	F110W	4	8	1106 s	4424 s
hlsp_heritage_hst_wfc3-ir_m16_f160w_v1_drz.fits	F160W	4	8	1406 s	5624 s

This ISR provides a step-by-step tutorial for aligning and combining the separate sets of UVIS and IR observations. Section 2 provides a description of the M16 observing strategy and dither patterns. Section 3 highlights new mosaicking features available in the DrizzlePac 2.0 software package and describes how users may obtain the new software. Section 4 shows how to improve the UVIS calibrated data products by correcting for instrumental artifacts prior to drizzling. Finally, Section 5 provides the methodology for aligning and combining this large dataset with DrizzlePac. We include the command-line syntax for calling each task, so that users who wish to reproduce this example may easily copy and paste each step into their PyRAF session or python code.

2. Observations

The M16 observations were obtained in HST DD program 13926 (PI: Levay) in September 2014. Multiple pointings were obtained to create a 2x2 IR mosaic (~4 arcmin across) and a slightly larger 2x2 UVIS mosaic (~5 arcmin across). A summary of the WFC3 filters and their wavelength coverage is given in Table 2.

Table 2. WFC3 filters used to create the M16 mosaics.

Detector	Filter	Description	Pivot Wave (nm)	Rectangular Width (nm)
WFC3/UVIS	F502N	OIII [5007]	501.0	6.5
WFC3/UVIS	F657N	Wide Hα + [NII]	656.7	12.1
WFC3/UVIS	F673N	[SII] 6717/6731	676.6	11.8
WFC3/IR	F110W	Wide Y	1153.4	443.0
WFC3/IR	F160W	WFC3 H	1536.9	268.3

In Figure 2, the HST footprints of the UVIS (blue) and IR (red) mosaics are superposed on a DSS image of the region using the Aladin interface in the Astronomer's Proposal Tool (APT). The mosaic tiles were generated using APT's mosaicking tool with the target centered at *18h 18m 52.13s, -13d 50' 9.8"* (J2000) in the IR-FIX aperture and at *18h 18m 50.50s, -13d 49' 44.0"* (J2000) in the UVIS1-FIX aperture. ACS parallel observations with the F658N Hα filter cover a large region of M16 just northwest of the pillars, and these footprints are indicated in green. Overplotted in pink is the footprint of the original WFPC2 observations (program 5773, PI: Hester).

Figure 3 shows the WFC3 mosaic tiles by visit number, which can be found in the 5th & 6th characters of the HST filename. For example, the archival data product ick901020_drz.fits corresponds to tile (visit) 01. As part of the observing strategy, small shifts (dithers) between exposures in a given tile were obtained to allow for the removal of detector artifacts such as hot pixels, IR blobs, and the UVIS chip gap. These 'fine dither patterns' are summarized in Table 3.

Figure 2: HST Footprints. The blue and red footprints are the WFC3/UVIS and WFC3/IR observations, respectively. The green footprint to the north represents the ACS/WFC parallel observations, which will be released at a later date. The pink footprint shows the position of the original WFPC2 image.

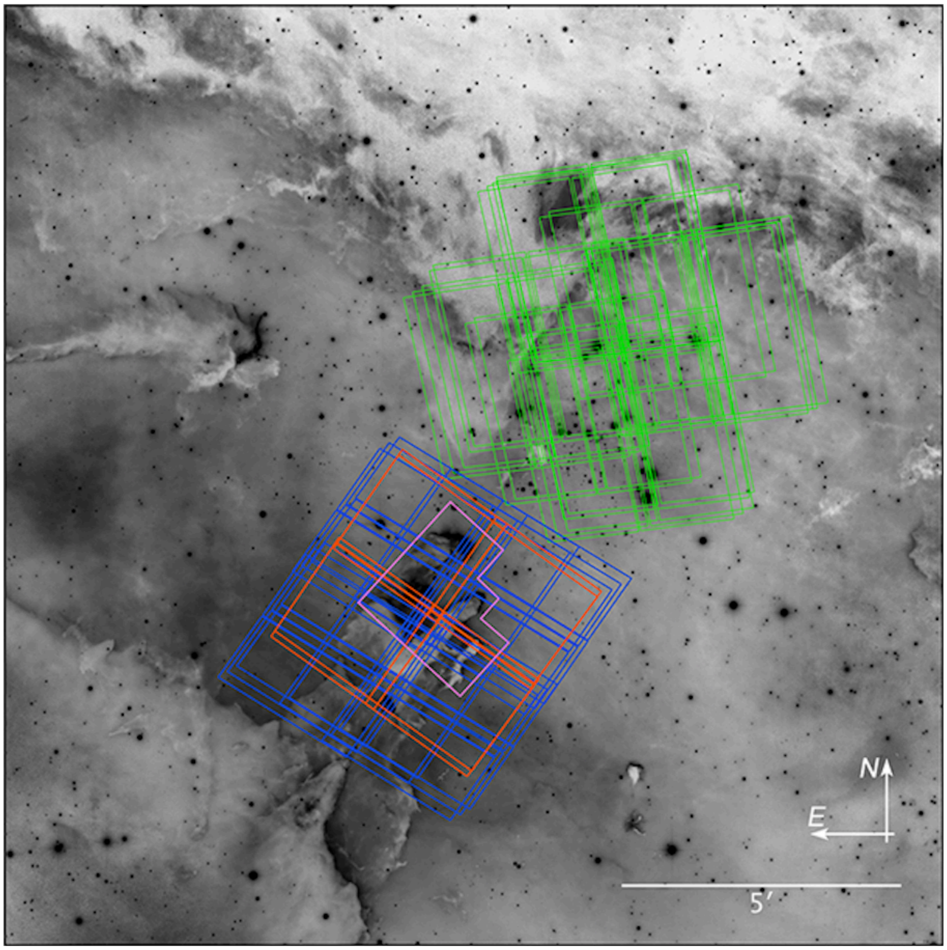

Figure 3: Visit numbers corresponding to the WFC3 mosaic 'tiles'. IR visits are indicated in red and UVIS in blue.

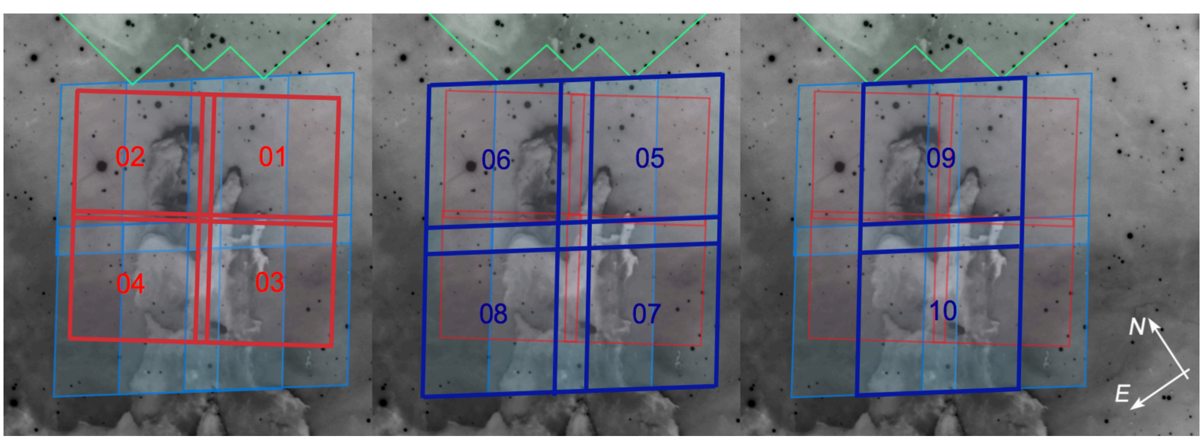

Table 3. Fine Dither Patterns

Pattern_Type	WFC3-IR-DITHER-BLOB	WFC3-UVIS-MOSAIC-LINE
Pattern_Purpose	DITHER	MOSAIC
Number_Of_Points	2	3
Point_Spacing	7.2 arcsec	12 arcsec
Pattern_Orient	90 degrees	65 degrees

For the IR 2x2 mosaic, two 'fine' dithers per filter in F110W and F160W were obtained in one orbit per tile for a total of four orbits in visits 01-04. For the UVIS 2x2 mosaic, three 'fine' dithers per filter in F502N, F657N, and F673N were obtained in three orbits per tile for a total of 12 orbits in visits 05-08. An additional 2x1 UVIS mosaic (visits 09-10) overlaps the primary UVIS mosaic to achieve higher signal-to-noise in the pillars. With two dithers per filter and two orbits per tile, these last two visits comprise a total of four orbits for a total of 20 orbits in the full observing program.

The M16 dataset is described in Tables 4 and 5 at the end of this ISR for the IR and UVIS detectors, respectively. The tables includes the association rootname for the visit-level data products (*drz.fits), the rootname of the exposures making up each association (*flt.fits), the filter, date of observation, sample sequence and number of samples (IR only), exposure time, and the X and Y dither (POSTARG) between tiles in arcseconds. More detail on the observing strategy may be found in the Phase II file of program GO/DD 13926: http://www.stsci.edu/hst/phase2-public/13926.pro.

3. New Drizzling Software

This ISR highlights a new version of the DrizzlePac software (v2.0) with improved features for aligning and combining mosaics. Additional software features and instructions on how to download and install the software may be found on the DrizzlePac webage http://drizzlepac.stsci.edu. While this new version is not yet in use by the OPUS pipeline, it is currently available as part of the SSBX release of Ureka via the following link: http://ssb.stsci.edu/ssb_software.shtml.

When writing this tutorial, we assume that the user already has some familiarity with the concept of drizzling to remove geometric distortion and create combined image stacks. A general understanding of the HST pointing accuracy is also useful, as this drives the need to tweak the image header World Coordinate System (WCS) before combining observations across visits. Familiarity with the examples on both the webpage and in the DrizzlePac Handbook (Gongaga *et al.* 2012) are also recommended, since these include more detailed discussion of concepts such as: defining a drizzled reference frame, controlling which data quality (DQ) flags will be respected in the final combination, and which parameters are important for accurate cosmic-ray rejection.

Before combining with AstroDrizzle, the WCS information in the header of each input frame should be aligned to sub-pixel accuracy. This may be achieved with the DrizzlePac task TweakReg which allows users to align sets of images to each other and/or to an external astrometric reference frame. TweakReg has been enhanced to support the alignment of observations that cover a large area on the sky. By calling a new parameter 'expand_refcat', the user can build up an expanded reference catalog on the sky to be used for aligning images. When this parameter is set to 'True', TweakReg selects two images from the input list with the largest overlap on the sky, generates source catalogs for each image, and computes a fit (shift, rotation, and/or scale change) from the matched source list. Next, the algorithm computes the area of overlap of each of these two images with the rest of the images, and the one with the largest "total" overlap with the rest is selected as the reference image. Sources from the second image that have not been matched to the reference image catalog are considered "good new sources" and are added to the reference catalog. In this way, the reference catalog keeps expanding with each new matched image. With a large (expanded) reference catalog it is therefore possible to align images that had no direct overlap with the starting image.

By setting a new optional parameter 'enforce_user_order=True', users may specify the order in which the images are aligned (and therefore the order in which the reference catalog grows), where the first image in the list defines the reference image. In some cases, providing the software a 'user-defined order' can significantly improve the overall alignment. This is an important point to consider when aligning frames, since errors in alignment are cumulative across the mosaic. When 'enforce_user_order=False' and the input list is set to '*flt.fits', the images will be read in alphanumeric order, with the first image in the list being selected by the task as the reference image.

The new TweakReg also makes it easier for users to align multiple HST detectors/filters. This is possible in a single call to the TweakReg which now contains separate sets of source detection parameters for the input images and the reference image. These two parameter sets, 'imagefindpars' and 'refimagefindpars', control key parameters such as 'threshold' and 'conv_width' which require unique values for aligning different HST detectors or for aligning different types of calibrated data products (*flt.fits versus *drz.fits). For example, Section 5.3 describes the parameter values for aligning a set of distorted (*flt.fits) IR input frames (F110W) to a drizzled (*drz.fits) IR reference frame (F160W). Section 5.4 gives the recommended parameter values for aligning a set of drizzled UVIS input frames (F657N) to a drizzled IR reference frame (F160W).

Also in DrizzlePac 2.0, the new AstroDrizzle makes it easier for users to match the sky background when tiling together large mosaics. In prior versions of the software, the sky background was always based on clipped statistics (defined by the parameters skyclip, skystat, skylsigma, and skyusigma) in the images separately. The sky background was measured for each chip and the lowest sky value (in electrons/arcsecond^2) among all of the chips was adopted. For observations of sparse fields, this approach generally works well. However, when large extended objects fill the detector, there is no true 'blank sky' and the background value will be an overestimate. Additionally, when extended targets are observed as mosaics (e.g. with large dithers), the 'scene' can change significantly between exposures and bias the background estimate.

An error in determining the sky background may in turn impact the cosmic ray rejection, and if severe enough, the resulting photometry. Additionally, by not properly matching the sky background before combining frames, correlated noise will be added to the final drizzled products when differences in the background levels are significant. Correlated noise appears as a faint 'screen door' pattern superimposed on the image, as shown in Figure 7.16 of the DrizzlePac Handbook. Until now, the recommended workaround has been for users to give AstroDrizzle an ASCII file ('skyfile') containing user-defined background values.

AstroDrizzle now features several new options for computing the sky. One of these, skymethod='match', is useful for "equalizing" the sky background across large mosaics. This method computes differences in sky values using only pixels in common between images. The sky values will then be set relative to the value computed for the input frame with the lowest sky value for which the MDRIZSKY keyword will be set to 0. In this way, the sky background is not removed, but instead equalized before the data are combined. For more information on the skypac.skymatch task called by AstroDrizzle, see the following webpage: http://ssb.stsci.edu/doc/stsci_python_x/stsci.skypac.doc/html/skymatch.html.

4. Improving the UVIS Calibration before Drizzling

The first time we combined the UVIS mosaics, several types of cosmetic artifacts were apparent in the drizzled products, two of which are illustrated in Figure 4. These artifacts include CTE tails, detector crosstalk, and flat field residuals in the upper left corner of UVIS1. For this reason, we demonstrate how the user can produce improved calibrated data products (i*flt.fits) to be used as input to AstroDrizzle.

A.) The UVIS CTE correction is expected to run as part of the CALWF3 pipeline starting in the fall of 2015. Until then, users who wish to correct their observations for charge-transfer losses during readout may obtain the Pixel-based Empirical CTE Correction Software from the WFC3 webpage http://www.stsci.edu/hst/wfc3/tools/cte_tools.

To perform the correction, both 'i*raw.fits' and 'i*flt.fits' products for visits 05-10 should placed in the same directory. Next, the CTE software may be compiled and run following the instructions on the webpage (shown below for the parallel processing version). The corrected data products will be given a new naming convention: 'i*flc.fits'.

> gfortran wfc3uv_ctereverse_parallel.F -o wfc3uv_ctereverse_parallel.e -fopenmp

> ./wfc3uv_ctereverse_parallel.e *raw.fits FLC+

Input: ick905k3q_raw.fits, ick905k3q_flt.fits

Output: ick905k3q_flc.fits

B.) To correct UVIS data for electronic crosstalk between amplifiers, users may obtain a standalone IDL tool from the WFC3 webpage: http://www.stsci.edu/hst/wfc3/tools/crosstalk. (Click on the link for the 'zip download'. Instructions for running the software may be found in the accompanying README file.) This software will restore impacted (low) pixels to a mean value within ~1 sigma of the mean of the surrounding pixels.

To run the code, users should start IDL and then correct the frames one-by-one, as shown below. The corrected images will be written to the users' working directory as FITS files with the same name as the original except with the first character changed to 'x'. Note that the '*_flc.fits' suffix from the CTE correction step is preserved after the cross-talk correction.

> idl

IDL> crosstalk_correct_wfc3,'ick905k3q_flc.fits'

Input: ick905k3q_flc.fits

Output: xck905k3q_flc.fits

C.) Repeated sets of dark horizontal stripes can be seen across the mosaic. These were originally suspected to be three rows on either side of the chip gap flagged with a DQ value of 512 as 'bad or uncertain flat value'. With the values set for the 'final_bits' parameter in this example, we confirmed that AstroDrizzle properly rejects these rows and replaces them with 'good' pixel values from dithered exposures when combining.

The specific set of stripes seen in Figure 4 corresponds to the three dither positions in visit 10 and has been traced to rows of low pixel values in the top left corner of UVIS1. A 100x100 subsection of this corner is shown in Figure 5 for one F657N input frame. The left panel shows the *raw.fits image, the center panel shows the *flt.fits image, and the right panel shows the corresponding region of the flat field reference file, where the detector sensitivity drops off quickly from a mean value of ~1.0 to a low value of ~0.05. This effect is likely due to slight vignetting in this corner of the detector (G. Hartig, private communication).

While the flat field does a fair job of correcting this feature, the calibrated image is very noisy in this corner. As a result, these pixels are difficult to fully reject using AstroDrizzle's cosmic-ray rejection parameters in Secton 5. Since each tile has three input frames, the AstroDrizzle parameter 'combine_type' has been set to 'minmed'. This produces an image that is generally the same as the median, except in cases where the median is significantly higher than the minimum good pixel value. In this case, "minmed" will select the minimum value. As a result, the final mosaics are left with only low (black) residuals, since the high values have been flagged as cosmic-rays and replaced with values from the other input frames.

To get around this, pixels in the corner of UVIS1 may be flagged by the user as 'bad in flat' in the DQ array of the new calibrated 'x*flc.fits' images. This will allow for proper rejection during combination with AstroDrizzle. Note that a new version of the UVIS flats will correct for this artifact, and those will be available in the fall 2015. Until now, the following workaround may be performed:

--> imreplace x*flc.fits[6][1:500,2045:2051] value=512

Once these various UVIS artifacts have been corrected, the user may begin the process of aligning and combining each filter using the improved calibrated data products.

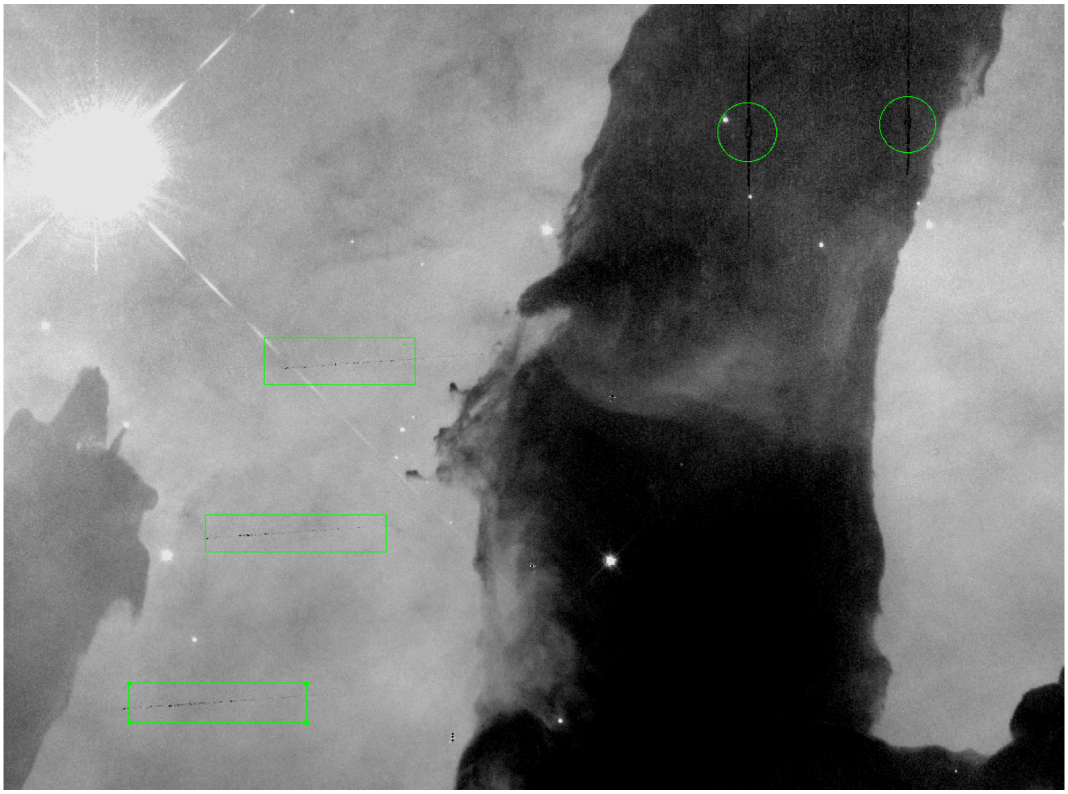

Figure 4: A subsection of the F657N mosaic. Crosstalk (green circles) and flat fielding artifacts (green rectangles) show low pixel values in our first set of UVIS combined mosaics.

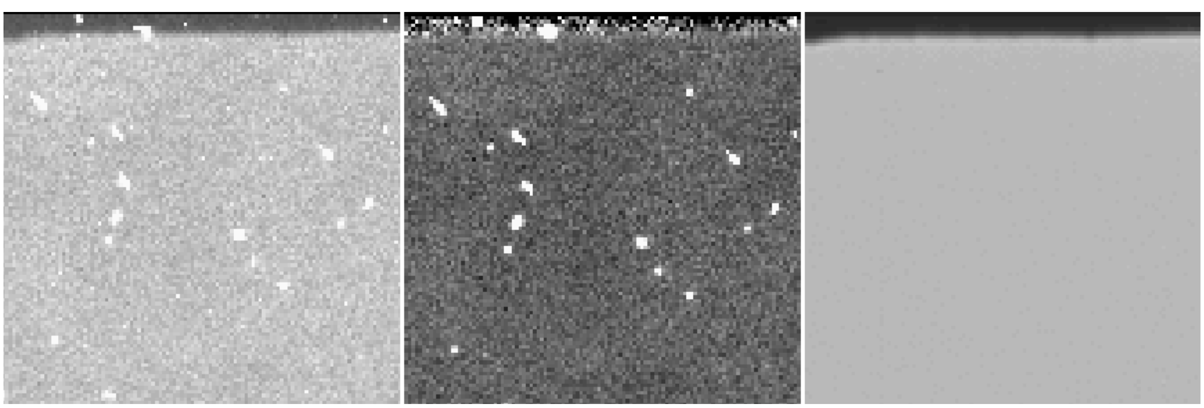

Figure 5: The top left corner (~100x100 pixels) of UVIS1 is shown for the raw dataset ick905k5q_raw.fits[4] (left), for the calibrated dataset ick905k5q_flt.fits[4] (middle), and for the corresponding region of the flat field reference file (right), where black indicates low pixel values. Note that the flat field response falls off rapidly from 1.0 in this region of the detector, where the lowest value in this region is ~0.05.

5. Image Registration and Combination

Two prior tutorials for creating HLSPs from Hubble Heritage observations (linked below) describe how to align and combine mosaics using an iterative process (TweakReg, AstroDrizzle, TweakReg, AstroDrizzle, etc.) to build up the field of view of the reference image for the first filter. Additional filters/detectors may then be aligned directly to the reference image. With new options in TweakReg in DrizzlePac 2.0, this iterative alignment procedure is no longer necessary.

http://archive.stsci.edu/prepds/heritage/horsehead/readme_HLSP_v3.txt

http://archive.stsci.edu/prepds/heritage/ngc2174/

This section of the ISR provides a step-by-step tutorial for generating the 5 filter mosaics (2 IR, 3 UVIS) with DrizzlePac 2.0, and it includes the syntax for running each task from the command line in PyRAF. In all cases, only non-default DrizzlePac parameters have been explicitly set.

5.1 Setup

To begin, the user must first import the DrizzlePac software and relevant tasks used in this example.

--> import drizzlepac

--> from drizzlepac import tweakreg

--> from drizzlepac import astrodrizzle

--> from drizzlepac import tweakback

To verify the version of DrizzlePac, users may type the command below, where a 'double underscore' is used before and after the word 'version'. The version used for making the HLSP's delivered to MAST was '2.0.0.dev33816'. This information may be found in the HISTORY comments in the header of the drizzled images.

--> drizzlepac.__version__

In some cases, users will need to run the task 'updatewcs' before starting to ensure that the image header WCS is compatible with the version of DrizzlePac installed on their local machine. This is important for those who wish to reprocess images from MAST that used an older version of DrizzlePac in OPUS processing. Running 'updatewcs' is also required for users who wish to reprocess with improved distortion reference files (e.g. D2IMFILE, IDCTAB, and NPOLFILE) available from the instrument webpages but not yet delivered to CRDS.

--> from stwcs import updatewcs

--> updatewcs.updatewcs('i*flt.fits')

5.2 F160W

For this large multi-filter dataset, the user must consider which observations to align and combine first. These will serve as a reference image for aligning additional filters. The broadband IR images are full of stars distributed uniformly over the field of view. The UVIS frames, on the other hand, are largely devoid of point sources and full of cosmic-rays which can trip up TweakReg when trying to compute a fit. Even though the IR detector has a smaller footprint on the sky, the high density of stars makes it a better anchor for aligning the UVIS tiles.

Of the two IR filters, F160W has the largest number of point sources and therefore makes the best choice for the reference image. To generate source lists for matching, users should set the TweakReg parameter ‘conv_width’ to approximately twice the FWHM of the PSF, ~2.5 pixels for IR observations and ~3.5 pixels for UVIS observations. By default, TweakReg will automatically compute the standard deviation of the sky background (‘skysigma’), so the number of sources in each catalog may be controlled simply by changing the ‘threshold’ parameter. Note that including more objects by going deeper does not necessarily translate to a better solution, since all sources are weighted equally when computing offsets between matched catalogs. This is especially relevant for aligning UVIS data where CTE tails can shift the centroid position slightly along the readout direction for faint sources and potentially bias the fit.

By setting the new parameters 'expand_refcat=True' *and* 'enforce_user_order=False', TweakReg will find the pair of images with the largest overlap and work out from there, expanding the reference catalog as it goes. The input list 'f160w.list' should contain the names of the 8 ‘*flt.fits’ frames obtained with the F160W filter. The rootname of these files is listed in column 2 of Table 4 at the end of this report.

Note that when aligning each set of filters, users are advised to run TweakReg twice, the first time in interactive mode (default) so that important diagnostic plots can be inspected to assess the quality of the fit. Once the parameters have been fine-tuned and the fit looks adequate, users may run TweakReg a second time to update the image header WCS keywords. To save time, the second run may be performed in ‘non-interactive’ mode (interactive=False), and the astrometric fit residuals and vectors diagrams will be saved as png files in the user’s local directory. The parameters indicated below in red are the only changes between the two runs. (Note that for aligning subsequent filters, only the second command is shown although both were run.)

--> tweakreg.TweakReg('@f160w.list',imagefindcfg={'threshold':50,'conv_width':2.5}, expand_refcat=True, enforce_user_order=False, minobj=5, shiftfile=True, outshifts='shift160_flt.txt', sigma=2.8, searchrad=3.0, ylimit=0.5, updatehdr=False, interactive=True)

--> tweakreg.TweakReg('@f160w.list',imagefindcfg={'threshold':50,'conv_width':2.5}, expand_refcat=True,enforce_user_order=False,minobj=5, shiftfile=True,

outshifts='shift160_flt.txt', sigma=2.8,searchrad=3.0, ylimit=0.5, updatehdr=True, wcsname='FLT',interactive=False, see2dplot=False,residplot='No Plot')

With these 'threshold' values, TweakReg generates catalogs with 500-600 objects per image. The computed offsets (given in pixels at the native IR scale=0.1283"/pixel) are recorded in an output "shift file" which is shown below. Three additional columns have been added with the x and y fit residuals and the number of sources matched with the reference catalog. Note that the first row corresponds to the reference image which was automatically selected by TweakReg as 'ick902neq_flt.fits'. Offsets in the shift file reflect the updates to the header WCS required to correct for small pointing errors.

Exposures making up visit-level drizzled products are typically aligned to 2-5 milliarcsecond (mas) accuracy with fine-lock on 2 guide stars (DrizzlePac Handbook, Appendix B, Gonzaga et al, 2012). The shift file below confirms this, with offsets (dx,dy) between pairs of exposures in each visit averaging ~0.05 pixel (6 mas). For different visits using the same set of guide stars, offsets of ~50-100 mas are expected. For visits with different sets of guide stars, the pointing accuracy is typically 0.2-0.5 arcseconds. Since the M16 tiles (visits) used different guide star pairs, the relatively large offsets (>1 arcsec) required for visits 03 and 04 to match the visit 02 reference image are not surprising, though are larger than expected. Note that for aligning multi-visit observations, we recommend increasing the parameter 'searchrad' from the default 1.0 arcsecond to ensure that TweakReg finds a good fit.

Image	**dx**	**dy**	**rotation**	**scale**	**xrms**	**yrms**	**#match**
ick902neq_flt.fits	0.00	0.00	0.0000	1.000000	0.000	0.000	--
ick902n9q_flt.fits	0.03	0.09	359.9998	1.000000	0.061	0.043	478
ick904obq_flt.fits	-8.75	-12.13	359.9972	0.999916	0.049	0.043	63
ick904ogq_flt.fits	-8.79	-12.22	359.9977	1.000070	0.062	0.043	384
ick901hzq_flt.fits	-0.16	0.42	359.9993	1.000085	0.057	0.037	43
ick901i7q_flt.fits	-0.21	0.36	0.0004	0.999920	0.059	0.051	446
ick903n4q_flt.fits	-6.98	-11.97	359.9993	0.999995	0.066	0.050	56
ick903ncq_flt.fits	-7.02	-12.04	359.9992	1.000016	0.062	0.046	406

Now AstroDrizzle can be used to combine the full set of F160W frames. In this case the final orientation has been set to -35 degrees so that the pillars will be oriented vertically. Note that users must first set the parameter 'final_wcs=True' in order to turn on parameters in AstroDrizzle's step 7a: "Custom WCS for Final Output". For these observations, the IR scale (0.08"/pixel) is chosen to be exactly twice that for the UVIS mosaics (0.04"/pixel), and the drizzled images have been oversized slightly to match the sky area on the sky covered by the UVIS. The sky background may be equalized across mosaic tiles by setting the parameter 'skymethod=match'.

The parameters 'driz_sep_bits' and 'final_bits' define which DQ flags in the *flt.fits[3] to treat as good. (All other pixels with non-zero DQ values will be assumed to be bad and rejected from the final mosaic.) For IR data, these two parameters are typically set to 64+512 in the pipeline, corresponding to warm pixels and IR blobs. Because this program included a blob dither, however, the 512 flag may be removed from the list of good DQ values so that these deviant pixels will be replaced with non-flagged pixels from the accompanying dithered pair. The user can set the name of the output file to reflect the filter, plate scale, and pixfrac used for the drizzled data products.

--> astrodrizzle.AstroDrizzle('@f160w.list',output='f160w_sc08px10', skymethod='match', driz_sep_bits='64', driz_cr_corr=True, final_bits='64', final_wcs=True, final_scale=0.08, final_pixfrac=1.0, final_rot=-35, final_ra=274.721587, final_dec=-13.841549, final_outnx=4000, final_outny=4200)

5.3 F110W

The user may now align the F110W frames directly to the drizzled F160W mosaic. The input list 'f110w.list' should contain the names of the eight '*flt.fits' frames taken in F110W. As discussed in Section 3, DrizzlePac 2.0 makes it easier to align directly to a reference image by allowing the user to specify separate sets of source finding criteria via the 'imagefindcfg' and 'refimagefindcfg' parameter sets, as shown below.

--> tweakreg.TweakReg('@f110w.list',imagefindcfg={'threshold':60, 'conv_width':2.5}, expand_refcat=False,enforce_user_order=False,refimage='f160w_sc08px10_drz_sci.fits ', refimagefindcfg={'threshold':250, 'conv_width':2.5}, minobj=5, shiftfile=True, outshifts='shift110_flt.txt', sigma=2.5, searchrad=3.0,ylimit=0.5, updatehdr=True, wcsname='FLT',interactive=False, see2dplot=False,residplot='No Plot')

With these settings, TweakReg finds between 200-300 objects in each F110W frame and ~2900 objects in the F160W drizzled image. Note that the reference catalog is fully defined by the drizzled F160W mosaic, so the parameter 'expand_refcat' has been set to 'False' for this filter. The shift file below contains the computed offsets and fit rms, where the units are now expressed in reference pixels (e.g. 0.08"/pixel versus the F160W shift file where the reference image scale is 0.1283"/pix). In visit 03, for example, an x-offset of ~7 pixels was found in F160W and ~11 pixels was found in F110W. Both correspond to a delta of ~0.9".

The full set of F110W images may now be combined, where the drizzled F160W mosaic defines the output reference frame (e.g. scale, orientation, RA/Dec of the central pixel, image size, etc.). Figure 6 shows the final IR mosaics and corresponding weight images. The weight images help the user visualize the number of input frames contributing to each output pixel. They show overlap between mosaic tiles, pixels rejected as cosmic-rays, and DQ flags from the calibrated input frames that have been excluded from the drizzled stack. When the input and output plate scales are equal, the weight image provides an effective exposure time map of each mosaic. For this filter, the average depth is ~1100 seconds per tile and AstroDrizzle properly scales the weight image by dividing by the ratio of the square of the plate scales $(0.128/0.080)^2$ to give an average weight of ~430 seconds.

Image	dx	dy	rotation	scale	xrms	yrms	#match
ick902n7q_flt.fits	0.45	-0.14	0.0001	1.000077	0.178	0.128	276
ick902nbq_flt.fits	0.38	-0.19	0.0005	1.000058	0.170	0.119	283
ick904o9q_flt.fits	-13.62	-19.63	359.9989	1.000007	0.151	0.128	199
ick904odq_flt.fits	-13.68	-19.69	359.9980	1.000008	0.194	0.129	201
ick901hxq_flt.fits	-0.00	0.47	0.0015	1.000058	0.186	0.134	247
ick901i4q_flt.fits	-0.04	0.43	0.0014	1.000071	0.184	0.128	230
ick903n2q_flt.fits	-10.90	-19.30	0.0003	1.000066	0.176	0.128	184
ick903n9q_flt.fits	-10.91	-19.37	0.0003	1.000073	0.164	0.132	194

--> astrodrizzle.AstroDrizzle('@f110w.list',output='f110w_sc08px10', skymethod='match', driz_sep_bits='64', driz_cr_corr=True, final_bits='64', final_wcs=True, final_refimage='f160w_sc08px10_drz_sci.fits')

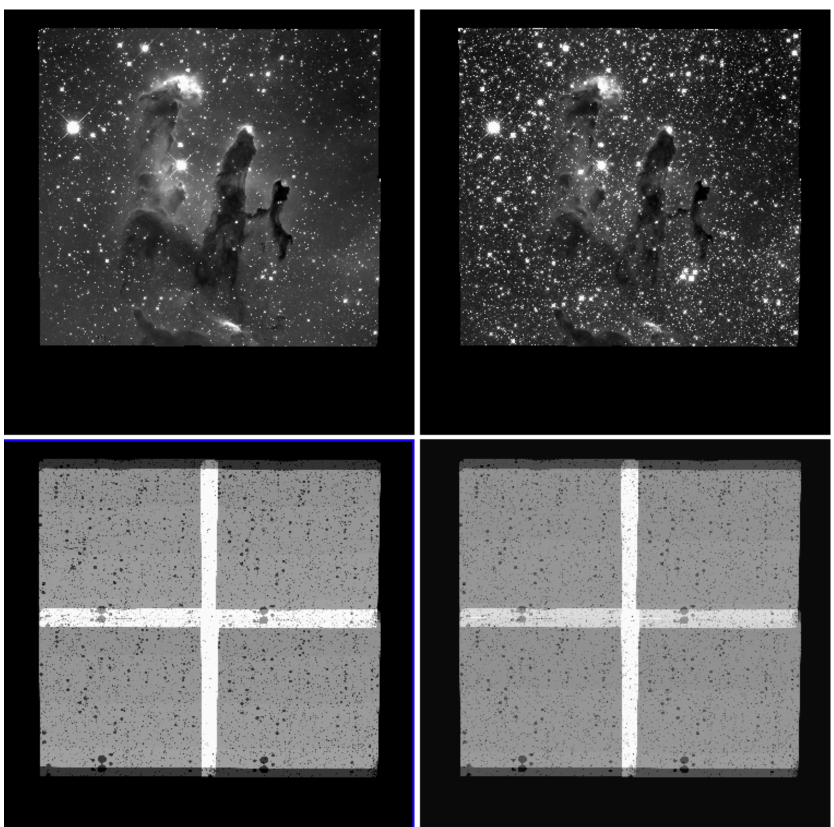

Figure 6: The F110W and F160W drizzled science images (top) and weight images (bottom). Dark circles in the weight image show where IR 'blobs' have been rejected and filled in with the second dithered image. The bright central 'plus' shows the image overlaps, which contain twice exposure time in the weight image and which contain sources used to align tiles. The drizzled IR mosaics have been oversized to match the area on the sky covered by the UVIS mosaics.

5.4 F657N

The F160W drizzled mosaic defines the reference frame for aligning the UVIS filters. Rather than using the '*flc.fits' frames, the input list 'f657n_DRZ.list' instead contains the names of the six visit-level '*drz.fits' products in F657N obtained from MAST. The rootname of these 6 input files is found in column 1 of Table 5. This alternate approach is chosen because the long UVIS exposures contain numerous cosmic-rays and few point sources. (The calibrated IR frames, on the other hand, are dominated by point sources and have already had cosmic-rays rejected by CALWF3's up-the-ramp fitting.)

As discussed in Section 5.2, exposures making up the visit-level drizzled products are typically aligned to better than 5 milliarcseconds (~0.1 UVIS pixels) with fine-lock on 2 guide stars and generally do not require 'tweaks' to the image header WCS. A quick way to verify this is to inspect the second extension of the MAST '*drz.fits' data products which contain the weight image. If the images were slightly misaligned when AstroDrizzle was run in OPUS, bright sources in at least one of the input frames would mistakenly be flagged as cosmic rays, and this would result in reduced values in the weight image for those pixels.

--> tweakreg.TweakReg('@f657n_DRZ.list',imagefindcfg={'threshold':10,'conv_width': 3.5}, refimage='f160w_sc08px10_drz_sci.fits', refimagefindcfg={'threshold':200, 'conv_width':2.5},minobj=5, shiftfile=True,outshifts='shift657_drz.txt', sigma=2.5, searchrad=5.0, ylimit=0.5, updatehdr=True, wcsname= 'DRZ',interactive=False, see2dplot=False,residplot='No Plot')

Next, the user can run the Drizzlepac task TweakBack to propagate the updated WCS from the drizzled image header back to the individual input frames making up each association. Note that in this case, the user must explicitly tell the software to update the improved CALWF3 products 'x*flc.fits' rather than the original 'i*flt.fits' products. These have been defined in the lists below 'f657n_v??_corr.list' for each visit.

--> tweakback.tweakback('ick905040_drz.fits', input='@f657n_v05_corr.list')

--> tweakback.tweakback('ick906040_drz.fits', input='@f657n_v06_corr.list')

--> tweakback.tweakback('ick907040_drz.fits', input='@f657n_v07_corr.list')

--> tweakback.tweakback('ick908040_drz.fits', input='@f657n_v08_corr.list')

--> tweakback.tweakback('ick909040_drz.fits', input='@f657n_v09_corr.list')

--> tweakback.tweakback('ick910040_drz.fits', input='@f657n_v10_corr.list')

The user may now drizzle the full set of 16 UVIS F657N 'x*flc.fits' frames to an output scale of 0.04"/pix (half the plate scale of the IR frames) using the same orientation and RA/Dec of the center of the IR mosaic. The later may be found in the header keywords CRVAL1 and CRVAL2 of the drizzled F160W image. Since the size of the IR mosaic was set to 4000x4200 pixels, the corresponding UVIS mosaic should be set 8000x8400 pixels to match the area on the sky.

--> astrodrizzle.AstroDrizzle('@f657n_corr.list', output='f657n_sc04px10', skymethod='match', driz_sep_bits='96', driz_cr_corr=True, final_bits='96', final_wcs=True, final_scale=0.04, final_pixfrac=1.0, final_rot=-35, final_ra=274.721587, final_dec=-13.841549, final_outnx=8000, final_outny=8400)

5.5 F673N

The UVIS F673N frames may now be aligned to the drizzled F657N reference image. The input list 'f673n_DRZ.list' contains the names of the 6 visit-level 'i*drz.fits' products in F673N. Because the IR mosaics subtend a smaller area on the sky than the UVIS mosaics, the aligned F657N drizzled product is now selected as reference to ensure that the 3 UVIS filters are aligned as accurately as possible to one another.

--> tweakreg.TweakReg('@f673n_DRZ.list',imagefindcfg={'threshold':10,'conv_width':3.5}, refimage='f657n_sc04px10_drz_sci.fits', refimagefindcfg={'threshold':100, 'conv_width':3.5}, minobj=5, shiftfile=True,outshifts='shift673_drz.txt', sigma=2.5, searchrad=5.0, ylimit=0.5, updatehdr=True, wcsname= 'DRZ',interactive=False, see2dplot=False,residplot='No Plot')

--> tweakback.tweakback('ick905050_drz.fits', input='@f673n_v05_corr.list')

--> tweakback.tweakback('ick906050_drz.fits', input='@f673n_v06_corr.list')

--> tweakback.tweakback('ick907050_drz.fits', input='@f673n_v07_corr.list')

--> tweakback.tweakback('ick908050_drz.fits', input='@f673n_v08_corr.list')

--> tweakback.tweakback('ick909050_drz.fits', input='@f673n_v09_corr.list')

--> tweakback.tweakback('ick910050_drz.fits', input='@f673n_v10_corr.list')

Now the user may combine the full set of 16 F673N 'x*flc.fits' frames with AstroDrizzle, where the F657N mosaic serves as reference for defining the size, scale, and orientation of the output frame.

--> astrodrizzle.AstroDrizzle('@f673n_corr.list', output='f673n_sc04px10', skymethod='match', driz_sep_bits='96', driz_cr_corr=True, final_bits='96', final_wcs=True, final_refimage='f657n_sc04px10_drz_sci.fits')

5.6 F502N

Finally, the user can align the F502N frames to the drizzled F657N reference image. The input list 'f502n_DRZ.list' contains the names of the 6 visit-level 'i*drz.fits' products in F502N which are listed in Table 5. As for the other UVIS filters, TweakBack propogates the updated WCS back to the improved calibrated input products 'x*flc.fits'.

--> tweakreg.TweakReg('@f502n_DRZ.list',imagefindcfg={'threshold':10,'conv_width': 3.5}, refimage='f657n_sc04px10_drz_sci.fits', refimagefindcfg={'threshold':100, 'conv_width':3.5}, minobj=5, shiftfile=True, outshifts='shift502_drz.txt', sigma=2.5, searchrad=5.0, ylimit=0.5, updatehdr=True, wcsname= 'DRZ',interactive=False, see2dplot=False,residplot='No Plot')

--> tweakback.tweakback('ick905030_drz.fits', input='@f502n_v05_corr.list')

--> tweakback.tweakback('ick906030_drz.fits', input='@f502n_v06_corr.list')

--> tweakback.tweakback('ick907030_drz.fits', input='@f502n_v07_corr.list')

--> tweakback.tweakback('ick908030_drz.fits', input='@f502n_v08_corr.list')

--> tweakback.tweakback('ick909030_drz.fits', input='@f502n_v09_corr.list')

--> tweakback.tweakback('ick910030_drz.fits', input='@f502n_v10_corr.list')

The full set of 16 UVIS F502N 'x*flc.fits' frames may now be combined using the F657N mosaic as reference. Figure 7 shows the final UVIS mosaics and corresponding weight images. Because the output plate scale is approximately the same as the native scale, the weight images provide an effective exposure time map for the UVIS mosaics.

--> astrodrizzle.AstroDrizzle('@f502n_corr.list', output='f502n_sc04px10', skymethod='match', driz_sep_bits='96', driz_cr_corr=True, final_bits='96', final_wcs=True, final_refimage='f657n_sc04px10_drz_sci.fits')

5.7 Inspecting the drizzled products

Once the five filter mosaics are complete, users are encouraged to blink the '*drz_sci.fits' and the '*drz_wht.fits' products for each filter to be sure there are no issues with the image combination. For example, reduced weight in regions corresponding to bright sources is generally caused by misalignment and improper cosmic-ray flagging. This is especially important in regions of the drizzled image where the mosaic tiles overlap.

> ds9 f110w_sc08px10_drz_sci.fits f110w_sc08px10_drz_wht.fits &

> ds9 f160w_sc08px10_drz_sci.fits f160w_sc08px10_drz_wht.fits &

> ds9 f502n_sc04px10_drz_sci.fits f502n_sc04px10_drz_wht.fits &

> ds9 f657n_sc04px10_drz_sci.fits f657n_sc04px10_drz_wht.fits &

> ds9 f673n_sc04px10_drz_sci.fits f673n_sc04px10_drz_wht.fits &

It can also be useful to blink the UVIS and IR drizzled mosaics to verify that the final products line up. This may be done by loading the 5 images in DS9 and clicking 'zoom to fit' for each one. This ensures that the frames are aligned in pixel space, albeit with a factor of 2 scale difference. Alternately, the user may click "align frames by WCS" to verify the accuracy of the updated image header WCS.

> ds9 f110w_sc08px10_drz_sci.fits f160w_sc08px10_drz_sci.fits \ f502n_sc04px10_drz_sci.fits f657n_sc04px10_drz_sci.fits f673n_sc04px10_drz_sci.fits &

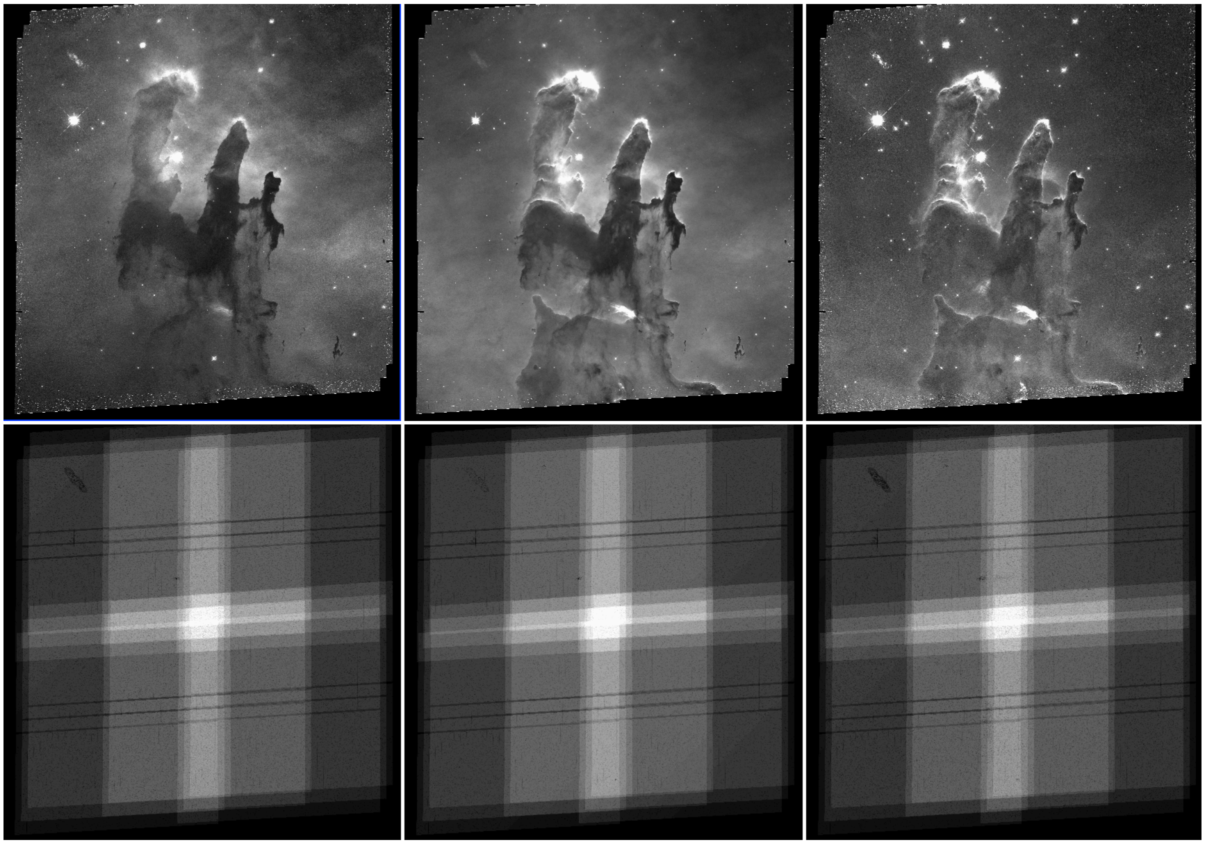

Figure 7: The F502N, F657N, and F673N science (top) and weight images (bottom). Dark horizontal rows in the weight image correspond to reduced weight in the UVIS chip gap. The dark ellipse in the upper left is due to a partially rejected window ghost. The bright 2x1 column in the center corresponds to visits 09-10 where additional exposures were obtained to obtain greater signal-to-noise in the pillars.

6. Conclusions

High Level Science Products of M16 are now available from MAST and the HLA. These products were created with DrizzlePac 2.0 which makes the process of aligning and combining mosaics more straightforward for users. This ISR provides the methodology to reproduce those data products using the new software, and it describes the thought process behind that work, as well as recommendations for key parameters. As such, it is relevant for users combining multi-visit observations from any HST imaging program, whether mosaics or single pointings.

In this example, the IR mosaic which defines the reference frame was only a 2x2 tiles. When making the expanded reference catalog, AstroDrizzle was allowed to select the order in which tiles were aligned, since it made little impact on the results. For aligning mosaics with more tiles, however, users are recommended to experiment with changing the order in which images are aligned and seeing how this changes the astrometric residuals. Specifying a user-defined order was important for combining ~3x3 mosaics of M83 from programs 11360 and 12513 which had varying amounts of overlap between tiles. Generally, users are advised to start from the center of the mosaic and work their way out to avoid propogation of errors across the mosaic.

DrizzlePac 2.0 is available for download from SSBX and is expected to run in OPUS in late-2015. Data products will still be limited to the visit-level drizzled frames, so users combining mosaics will need to obtain the software to manually process these type of observations.

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7. References

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Table 4. WFC3/IR observations

ASN	FLT	FILTER	DATE	SAMPLE SEQ	NSAMP	EXPTIME	POSTARG1	POSTARG2
ICK901020	ick901hxq	F110W	2014-09-01	SPARS50	13	552.9	-62.56638	-62.04747
	ick901i4q	F110W	2014-09-02	SPARS50	13	552.9	-62.56638	-54.84747
ICK902020	ick902n7q	F110W	2014-09-02	SPARS50	13	552.9	62.56638	-62.04747
	ick902nbq	F110W	2014-09-02	SPARS50	13	552.9	62.56638	-54.84747
ICK903020	ick903n2q	F110W	2014-09-07	SPARS50	13	552.9	-62.56638	54.84747
	ick903n9q	F110W	2014-09-07	SPARS50	13	552.9	-62.56638	62.04747
ICK904020	ick904o9q	F110W	2014-09-07	SPARS50	13	552.9	62.56638	54.84747
	ick904odq	F110W	2014-09-07	SPARS50	13	552.9	62.56638	62.04747
ICK901030	ick901hzq	F160W	2014-09-02	SPARS50	16	702.9	-62.56638	-62.04747
	ick901i7q	F160W	2014-09-02	SPARS50	16	702.9	-62.56638	-54.84747
ICK902030	ick902n9q	F160W	2014-09-02	SPARS50	16	702.9	62.56638	-62.04747
	ick902neq	F160W	2014-09-02	SPARS50	16	702.9	62.56638	-54.84747
ICK903030	ick903n4q	F160W	2014-09-07	SPARS50	16	702.9	-62.56638	54.84747
	ick903ncq	F160W	2014-09-07	SPARS50	16	702.9	-62.56638	62.04747
ICK904030	ick904obq	F160W	2014-09-07	SPARS50	16	702.9	62.56638	54.84747
	ick904ogq	F160W	2014-09-07	SPARS50	16	702.9	62.56638	62.04747

Table 5.WFC3/UVIS observations

ASN	FLT	FILTER	DATE	EXPTIME	POSTARG1	POSTARG2
ICK905030	ick905k3q	F502N	2014-09-02	1000.0	-65.383713	-74.272148
	ick905kaq	F502N	2014-09-02	1000.0	-60.312290	-63.396450
	ick905kjq	F502N	2014-09-02	1000.0	-55.240871	-52.520760
ICK906030	ick906kuq	F502N	2014-09-02	1000.0	65.383713	-65.127998
	ick906l1q	F502N	2014-09-02	1000.0	70.455132	-54.252300
	ick906laq	F502N	2014-09-02	1000.0	75.526550	-43.376610
ICK907030	ick907niq	F502N	2014-09-02	1000.0	-65.383713	65.127998
	ick907nxq	F502N	2014-09-03	1000.0	-60.312290	76.003693
	ick907oqq	F502N	2014-09-03	1000.0	-55.240871	86.879379
ICK908030	ick908p9q	F502N	2014-09-03	1000.0	65.383713	74.272148
	ick908pgq	F502N	2014-09-03	1000.0	70.455132	85.147842
	ick908ppq	F502N	2014-09-03	1000.0	75.526550	96.023529
ICK909030	ick909c1q	F502N	2014-09-05	1000.0	0.000000	-69.700073
	ick909cwq	F502N	2014-09-05	1000.0	5.071420	-58.824379
ICK910030	ick910d7q	F502N	2014-09-05	1000.0	0.000000	69.700073
	ick910deq	F502N	2014-09-05	1000.0	5.071420	80.575768
ICK905040	ick905k5q	F657N	2014-09-02	600.0	-65.383713	-74.272148
	ick905keq	F657N	2014-09-02	600.0	-60.312290	-63.396450
	ick905knq	F657N	2014-09-02	600.0	-55.240871	-52.520760
ICK906040	ick906kwq	F657N	2014-09-02	600.0	65.383713	-65.127998
	ick906l5q	F657N	2014-09-02	600.0	70.455132	-54.252300
	ick906leq	F657N	2014-09-02	600.0	75.526550	-43.376610
ICK907040	ick907nkq	F657N	2014-09-03	600.0	-65.383713	65.127998
	ick907o1q	F657N	2014-09-03	600.0	-60.312290	76.003693

	ick907ouq	F657N	2014-09-03	600.0	-55.240871	86.879379
ICK908040	ick908pbq	F657N	2014-09-03	600.0	65.383713	74.272148
	ick908pkq	F657N	2014-09-03	600.0	70.455132	85.147842
	ick908ptq	F657N	2014-09-03	600.0	75.526550	96.023529
ICK909040	ick909c3q	F657N	2014-09-05	600.0	0.000000	-69.700073
	ick909d0q	F657N	2014-09-05	600.0	5.071420	-58.824379
ICK910040	ick910d9q	F657N	2014-09-05	600.0	0.000000	69.700073
	ick910diq	F657N	2014-09-05	600.0	5.071420	80.575768
ICK905050	ick905k8q	F673N	2014-09-02	900.0	-65.383713	-74.272148
	ick905khq	F673N	2014-09-02	900.0	-60.312290	-63.396450
	ick905kqq	F673N	2014-09-02	900.0	-55.240871	-52.520760
ICK906050	ick906kzq	F673N	2014-09-02	900.0	65.383713	-65.127998
	ick906l8q	F673N	2014-09-02	900.0	70.455132	-54.252300
	ick906lhq	F673N	2014-09-02	900.0	75.526550	-43.376610
ICK907050	ick907nnq	F673N	2014-09-03	900.0	-65.383713	65.127998
	ick907o4q	F673N	2014-09-03	900.0	-60.312290	76.003693
	ick907oxq	F673N	2014-09-03	900.0	-55.240871	86.879379
ICK908050	ick908peq	F673N	2014-09-03	900.0	65.383713	74.272148
	ick908pnq	F673N	2014-09-03	900.0	70.455132	85.147842
	ick908pwq	F673N	2014-09-03	900.0	75.526550	96.023529
ICK909050	ick909c6q	F673N	2014-09-05	900.0	0.000000	-69.700073
	ick909d3q	F673N	2014-09-05	900.0	5.071420	-58.824379
ICK910050	ick910dcq	F673N	2014-09-05	900.0	0.000000	69.700073
	ick910dlq	F673N	2014-09-05	900.0	5.071420	80.575768