

# APLUS: A Data Reduction Pipeline for HST/ACS and WFC3 Images

Wei Zheng<sup>1</sup>, Amit Saraff<sup>2,3</sup>, Larry Bradley<sup>4</sup>, Dan Coe<sup>4</sup>, Alex Viana<sup>4</sup>  
and Sara Ogaz<sup>4</sup>

<sup>1</sup> Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218, USA

<sup>2</sup> Department of Computer Science, Johns Hopkins University, Baltimore, MD 21218, USA

<sup>3</sup> Microsoft Corporation, USA

<sup>4</sup> Space Telescope Science Institute, Baltimore, MD 21218, USA

**Abstract.** APLUS is a modified version of APSIS pipeline to process the ACS and WFC3 images of the Hubble Space Telescope. The Python-based tasks include image alignments, cosmic-ray rejection and drizzling. After corrections for astrometry and Galactic extinction, source catalogs in multiple bands are produced along with BPZ photometric redshifts. Its photometric and astrometric accuracy is tested with the CLASH database. The pipeline is useful in multi-band studies of the HST images.

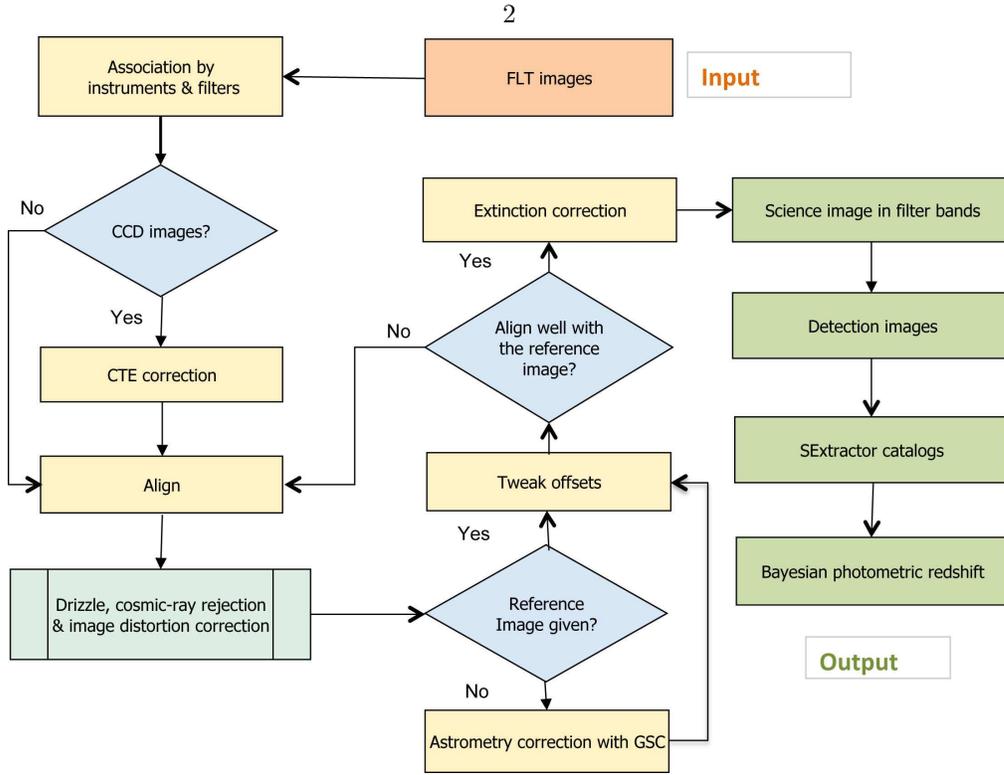
---

## 1. Introduction

The Wide Field Camera 3 (WFC3) has considerably enhanced the capability of the Hubble Space Telescope (HST), particularly in the near-infrared bands. To take advantage of a full array of the HST instruments, three Multi-Cycle Treasury (MCT) programs are carried out. The Cluster Lensing And Supernova survey with Hubble (CLASH, Postman et al. 2012) is one of them. In 524 orbits, it acquires images in 16 broad bands between 0.2 and 1.7  $\mu\text{m}$  for 25 clusters. These images are taken with three cameras: ACS(Advanced Camera for Surveys)/WFC, WFC3/IR and WFC3/UVIS. To process these images into science-grade products, we modified the APSIS pipeline (Blakeslee et al. 2003). APSIS was developed for the ACS data and has been extensively tested. More than one hundred refereed papers based on APSIS reductions were published by the ACS Investigation Definition Team. The APSIS code is publicly available: <http://code.google.com/p/apsis>

## 2. Overview

The new pipeline, APLUS, is based on python and capable of processing both ACS and WFC3 imaging data. It consists of a series of tasks from the calibrated data after the standard HST instrument pipelines: (1) Correct for charge-transfer efficiency of CCD detectors, to produce the best fit images; (2) Take an optional, astrometrically corrected image as an input reference image such as Subaru/Suprime-Cam to enable mosaicking over a larger field. If such a file is not given, the pipeline will first generate such a reference from a set of the input ACS images; (3) Determine the relative shift/rotation between individual fit images; (4) Make image distortion correction, drizzle (*i.e.*, resample) images into the reference frame and carry out cosmic-ray rejections; (5) Tweak the alignment of a combined image with the reference image by comparing two source catalogs (from the image and reference) and repeat the process until the  $\chi^2$  value reaches a minimum;



**Figure 1.** Flowchart of APLUS.

(6) Create a detection image in the optical and infrared bands; (7) Apply foreground Galactic extinction to the pipeline magnitudes in all filter bands; (8) Generate source catalogs with SExtractor (Bertin & Arnouts 1996) in dual mode; and (9) Run photometric redshift with BPZ (Benítez 2000).

**Table 1: APLUS Products**

Images	Science image in count unit, RMS image and exposure map, zeropoints
Catalogs	mag(auto), mag(iso), photometry with circular apertures of $d=2-160$ pixels, and dozen other parameters
Photometric Redshifts	Probability distribution, best-fitted source type
Color Images	All bands, optical, near-infrared and UV

### 3. New Features

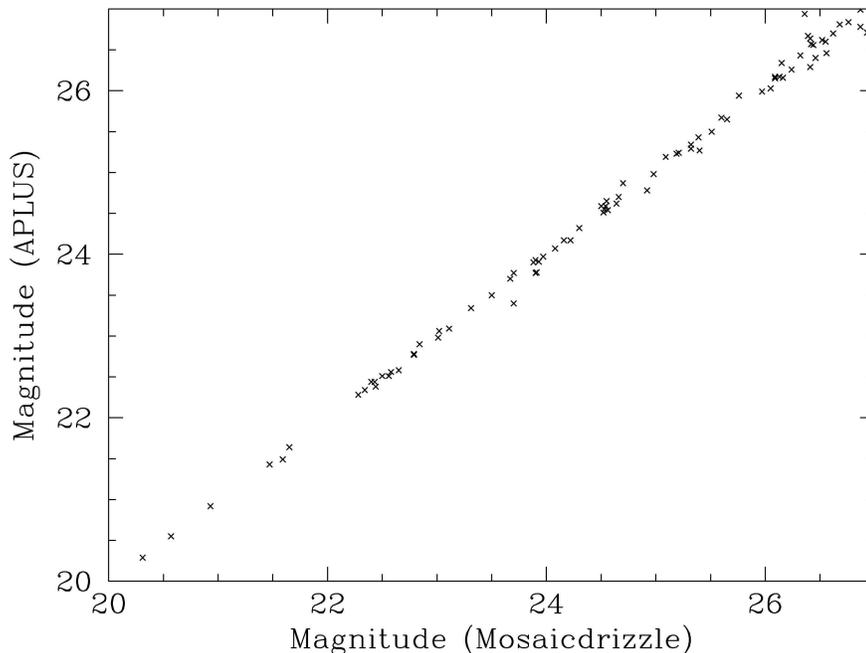
While most of the steps above are derived from APSIS, there are several new features:

### 3.1. Reference Image

(1) Output images are aligned to a position angle of 0. Every set of the images taken with the same filter will be drizzled to the common grid defined by the reference image. The reference image is no longer one of the "good" input images. (2) Several loops of alignment are made: First, the task to call task *MATCH* (Richmond 2002) to obtain the first round of alignment parameters in X, Y and a rotation angle. An external task *TWEAK* then finds the optimal values for these parameters. (3) Two detection images are made: One from a stack of ACS optical images, and another from the stack of WFC3/IR images. The latter is used to search for high-redshift objects that show weak or no detection in the optical bands. Inverse variations are used as the weighting factor. And (4) The SExtractor task is run with a local background.

### 3.2. Alignment

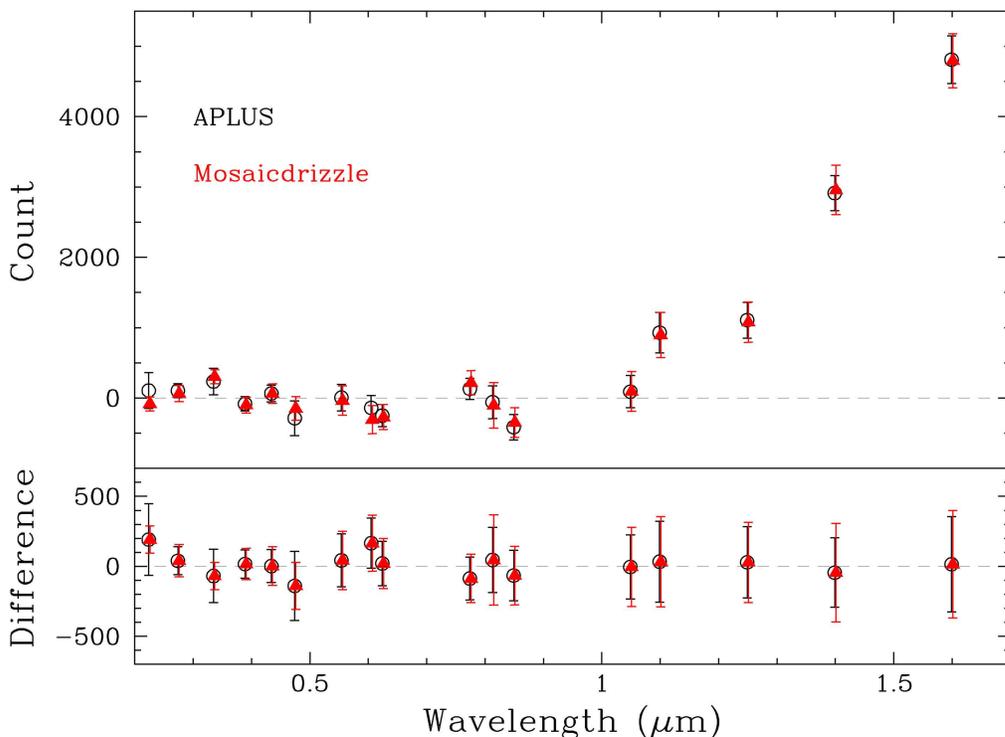
The automated aligning tasks work well for ACS/WFC and WFC3/IR images, but they might not produce desirable results in the following cases: (1) some input images have insufficient overlap with the main body of input data; (2) In the F225W and F275W bands (and in some narrow bands), there might be only a handful of sources ( $< 10$ ) with good signal-to-noise. The task *MATCH* would not work well in such cases, and optional tweak parameters may be manually set to assist in the initial alignment.



**Figure 2.** Comparison of source photometry between APLUS and Mosaicdrizzle pipelines. Isophotal magnitudes are displayed for a typical CLASH field taken with the WFC3/IR F140W filter.

#### 4. Performance

APLUS has been tested in the CLASH database along with the pipeline Mosaidrizzle (Koekemoer et al. 2003). We have chosen a pixel scale of  $0.065''$  as a compromise between the ACS/WFC and WFC3/IR detectors. Table 1 lists the pipeline products. The average photometry accuracy is 0.1 magnitude for sources at  $AB < 25.5$  and  $\sim 0.2$  magnitude at the faint end of  $AB \sim 26-28$ . In terms of astrometric accuracy, residuals of image alignment are typically 0.3 pixel ( $0.02''$ ) for optical and near-infrared bands, and 0.7 pixel ( $0.045''$ ) for UV images. In Figure 2, the photometry is compared between APLUS and Mosaidrizzle. In Figure 3, the aperture photometry in 17 broad bands for a dropout object (Zheng et al. 2012) is compared, with difference on the level of 3-5% and being well within the propagation errors.



**Figure 3.** Comparison of source fluxes measured in APLUS and Mosaidrizzle, for the dropout object MACS1149-JD1 (Zheng et al. 2012).

#### 5. Summary

We have modified APSIS to enable processing the WFC3 images. APLUS produces science-grade images, multicolor catalogs and photometric redshifts. Its photometric and astrometric accuracy is tested with the CLASH database. The pipeline is useful in multi-band studies of the HST images.

We will make improvements with a goal to make the APLUS package publically available. The tasks will include all WFC3 filters. More tests will be carried out over various data, and the parameters will be further optimized.

#### Acknowledgements

Support for this research was provided by NASA through grant GO-12065 from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

## References

- Benítez, N. 2000, *ApJ*, 536, 571
- Bertin, E. & Arnouts, S. 1996, *A&A*, 117, 393
- Blakeslee, J. P. 2003, in *Astronomical Data Analysis Software and Systems XII (San Francisco: ASP)* eds. H. E. Paynes, R. I. Jedrzejewski, & R. N. Hook, 295, 257
- Koekemoer, A., et al. 2003, in *The 2002 HST Calibration Workshop after the Installation of the ACS and the NICMOS Cooling System*, eds. S. Arribas, A. Koekemoer, & B. Whitmore, 337
- Postman, M. et al. 2012, *ApJS*, 199, 25
- Richmond, M. 2002, <http://spiff.rit.edu/match/>
- Zheng, W., et al. 2012, *arXiv:1204.2305*