Astrodrizzle Data Reduction of COSMOS Field WFC3/IR Archival Data

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June 15, 2017

1 Data Reduction Process

The objective of this paper is to summarize the image processing I performed on the available WFC3/IR data. My goal was to provide a database of images with the best subsampling possible using the astrodrizzle software. The MAST pipeline does not perform this subsampling and simply adds the exposures together to generate a final *drz.fits image, with a plate scale identical to that of an individual exposure. The pipeline also has sub-arcsecond deviations in random directions when compared to ACS data, so the astrometry must be redone as well. In brief, I take the calibrated images and re-do the astrodrizzling process using ACS images , available through the COSMOS collaboration's cutout service, to calibrate the WCS solution during the combination of the WFC3 exposures. Before starting I'd like to thank Carlos Gómez Guijarro (cgguijarro@dark-cosmology.dk) for his advice on using ACS data to correct the WCS data. Let's take a look at how this process was actually done.

1.1 Data Retrieval

First I used mast.stsci.edu to find observation programs within the Cosmos Field (centered at 10:00:28.601 +02:12:20.99) which had observations taken with WFC3/IR using the filters F105W, F110W, F125W, F140W, or F160W. Programs which observed the CANDELS field were ignored, as this area has already been processed. (Your mileage may vary as some extra observations may have slipped in, but hey, free science). Some programs still had proprietary observations, so please check the program summary in Section 2 to verify your program of choice was available or drizzleable. The *flt.fits files for each of these programs were downloaded in order to insure the latest calibrations were used, as the MAST system uses an on-the-fly reduction system identical to the calwf3 process I would otherwise have used IRAF for.

Second, we retrieved the ACS data available through the COSMOS Cutouts webpage. This service allowed me to create 123" square cutouts of the COSMOS field ACS mosaics. These are needed as a reference WCS system during the drizzling process.

1.2 Cosmic Ray Rejection

You'll see some WFC3 data reduction papers say that the IR exposures have cosmic ray rejection already done during the calwf3 step the MAST pipeline does. I elect to re-do this step in order to verify that cosmic rays are truly gone. The astrodrizzle software enables me to re-do this process with control over the cosmic ray SNR cutoffs. This is accomplished using astrodrizzle to produce separate new files for each of the original observations but not combining them yet. By including the cosmic ray step, a cosmic ray cleaned image can be produced. After we `import drizzlepac`, my code and parameters are as follow:

```
astrodrizzle.AstroDrizzle(input='*flt.fits',
    driz_sep_kernel='square',
    driz_sep_fillval=99999.9,
    driz_sep_bits=4352,
    combine_type='median',
    combine_hthresh=8888.8,
    combine_lthresh=-8.8,
    driz_cr_corr=True,
    driz_cr_snr='2.5 0.7',
    driz_cr_scale='1.2 0.7',
    driz_combine=False)
```

The custom quantities are a sep_fillval=99999.9 so that combine_hthresh=8888.8 cuts off the filled undefined pixels. The driz_cr_snr=2.5 0.7 is lower than the recommended 10.0 8.0 due to the propensity for cosmic rays to survive the pipeline settings.

NOTE: A bug exists in the cosmic ray rejection routine of astrodrizzle, which occurs when processing WFC3/IR data. Pixel values are multiplied by exposure time, but the header keyword for flux units are not changed accordingly. To correct for this, I use the IRAF task `imcalc` to immediately divide the pixel values in each cosmic ray corrected file by the exposure time in the header of that file. This returns a cosmic ray cleaned exposure with the correct flux and flux unit combination.

```
images=glob.glob('*_crclean.fits')
iraf.flpr()
for img in images:
    hdulist = pyfits.open(img)
    EXPTIME=float(hdulist[0].header['EXPTIME'])
    print EXPTIME
    hdulist.close()
    newimg=img.replace('crclean','crcor')
    iraf.imcalc(img,newimg,'im1/%f'%EXPTIME)
```

1.3 sourceExtractor

So now we have *crcor.fits files corresponding to each of our original observation files. These are the cleaned up images we want to drizzle. What's stopping us is the pipeline WFC3 astrometry. It's ok, but for subarcsecond precision which we want for future target identification, this can be optimized as well. To do this, we use sourceExtractor to find targets in the WFC3 and ACS images. IRAF has a task called tweakreg, but it's built for detecting bright objects. The COSMOS field was built to *not* observe lots of bright stars, but lots of comparatively dim galaxies. So we use sourceExtractor which we can customize. We leave the .conv, .nnw files alone and verify that the .param file has X_IMAGE and Y_IMAGE uncommented, as we will use these coordinates for the alignment. I also include FLUX_AUTO, FLUX-ERR_AUTO, and FLAGS. The first two can be used by source Extractor to verify targets, and you always want FLAGS for the inevitable issues. For the WFC3 and ACS data, I wrote a script to mass-execute sourceExtractor using the following syntax. Each file gets a sourceExtractor command, an example is shown below with j8xi0xs0q_crcor.fits as the example file name. We also want to specify that sourceExtractor should run on the science image layer of the fits image, normally extension 1:

```
sex -catalog_name j8xi0xs0q_crcor_ext1.cat -checkimage_name
    j8xi0xs0q_crcor_ext1_aperturecheck.fits j8xi0xs0q_crcor.fits‘[1]’
```

sourceExtractor itself needs to be customized between the WFC3 and ACS images due to differences in the detector plate scale, FWHM, etc. You can tell sourceExtractor which settings file to use by adding ”-c ACS.sex” to the above commands (in this example, for the ACS settings file).The non-defaults settings are as follows:

```
    For ACS:
DETECT_MINAREA 7.0
DETECT_THRESH 3.0
MAG_ZEROPOINT 25.9433
PIXEL_SCALE 0.05
SEEING_FWHM 0.08

    For WFC3:
DETECT_MINAREA 10.0
DETECT_THRESH 2.5
MAG_ZEROPOINT:
    26.2687 (F105W)
    26.8223 (F110W)
    26.2303 (F125W)
    26.4524 (F140W)
    25.9463 (F160W)
PIXEL_SCALE 0.13
SEEING_FWHM:
    0.130 (F105W)
    0.130 (F110W)
    0.137 (F125W)
```

```
0.141 (F140W)
0.151 (F160W)
```

WFC3 settings are found in the Optical Performance section of the WFC3 Instrument Handbook. ACS settings are also from the ACS Instrument Handbook.

1.4 TweakReg

We will use TweakReg in IRAF to change the WCS coordinates for the individual WFC3/IR images such that they're all aligned and can be drizzled together without issue. We use the ACS image as a reference image, and its corresponding sourceExtractor output catalog to supply a reference WCS to which to match the WFC3 images. We customize the convolution width for the WFC3 setting of 2.5. The following commands suppresses the plots of residuals, and changes the header WCS. If you wish to experiment, change updatehdr to False and residplot to True to not change the WCS solution and to see how well your pixels are aligning. You want an rms $\sim$ 0.15 or lower (normally). Due to us matching different instruments, we usually get around 0.3-0.4, which is comparable to the CANDELS results.

```
tweakreg.TweakReg('*crcor.fits',updatehdr=True,
    catfile='astdriz_catfile.list',
    imagefindcfg='conv_width':2.5,'threshold':3,
    interactive=False,xcol=5,ycol=6, fluxcol=3,
    refimage=ACS[0], refcat=ACScat[0],
    refxcol=5,refycol=6,refxyunits='pixels',rfluxcol=3,rfluxunits='counts',
    minobj=15, searchrad=3.0,residplot='No plot',sigma=2.8)
```

1.5 Astrodrizzle

Now for the final step, putting all the images together in a subsampled product. We simply use our aligned crcor files from tweakreg as the input for astrodrizzle and turn driz_combine to True. The other tasks such as masking the IR hotspots were already done during the cosmic ray step, so those can be set to false.

```
astrodrizzle.AstroDrizzle('*crcor.fits',output='Final',build=True
    crbit=0,resetbits="",clean=True,
    static=False,skysub=True,
    driz_separate=False,median=False,blot=False
    driz_cr=False,driz_combine=True, final_wht_type='IVM',
    final_wcs=True,final_bits="",final_scale=0.0642, final_pixfrac=0.8)
```

The key setting here is setting final_scale=0.0642, which is double the resolution of the standard pipeline. Final_pixfrac is also lowered to 0.8 from 1 to narrow the psf.

Finally, the science extension layer of the drizzled *drz.fits products is copied for use in the COSMOS archives.

2 Reduced Datasets

The following is a short summary of which datasets from which filters were reduced using the pipeline described above. Each dataset is described by the PI followed by the Proposal ID. CANDELS datasets are not included as those observations have already been drizzled to the scale used here. Some observation sets did not have the optimal 4 pointing box pattern and are noted here.

2.1 F105W

2.1.1 Bouwens 13792

4 observations using a 6 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.1.2 Capak 13641

9 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.1.3 Riess 12461

2 observations using a 3 pointing pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.1.4 Sukuzi 14808

16 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.2 F110W

2.2.1 Forster Schreiber 12578

14 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.2.2 Negrello 12488

1 observation using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.3 F125W

2.3.1 Capak 13641

8 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.3.2 Karim 13294

3 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.3.3 Riechers 13384

1 observation using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.4 F140W

2.4.1 Bouwens 13792

1 observation using a 2 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.4.2 Bowler 13793

15 observations of the program using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.4.3 Koekemoer 12190

4 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.4.4 Sukuzi 14808

16 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.5 F160W

2.5.1 Capak 13641

8 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.5.2 Forster Schreiber 12578

14 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics. An additional 14 observations are available at the same coordinates if we want to try deeper.

2.5.3 Franx 12167

7 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.5.4 Karim 13294

3 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.5.5 Kartaltepe 13657

30 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.5.6 Kocevski 13868

11 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.5.7 Muzzin 12990

13 observations using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.5.8 Reichers 13384

1 observation using a 4 pointing box pattern. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.

2.5.9 Riess 12461

8 observations with a mix of 2-3 pointing patterns. Successfully astrodrizzled to 0.06"/pix with astrometry corrected to ACS coordinates using the COSMOS cutouts mosaics.