3D-HST Documentation

Release v4.1.5

I. Momcheva, G. Brammer, P. van Dokkum

October 08, 2015

CONTENTS

CHAPTER

ONE

INTRODUCTION

3D-HST is an HST Treasury program to provide WFC3 and ACS grism spectroscopy over four extra-galactic fields (AEGIS, COSMOS, GOODS-South, and UDS), augmented with previously obtained data in GOODS-North. In addition to the grism spectroscopy, the project has provided reduced WFC3 images in all five fields, extensive multi-wavelength photometric catalogs, and catalogs of derived parameters such as redshifts and stellar masses. These ancillary data come from a wide range of other public programs, most notably the CANDELS Multi-Cycle Treasury program (Grogin et al. 2011, Koekemoer et al. 2011).

This document describes the first comprehensive grism spectroscopy release of 3D-HST, dubbed version 4.1.5. This release includes:

- Extracted 2D and 1D spectra for ~250,000 objects, corresponding to ~160,000 unique objects.
- Redshifts based on joint fits to the grism spectra and photometry for ~100,000 objects down to JH=26
- Emission line fits for to all major emission lines down to JH=26
- Best redshift catalog combining the spectroscopic, grism and photometric redshifts in the five fields
- Stellar masses, UV+IR star formation rates, rest-frame colors in 22 bands for the grism redshift and best redshift catalogs

This release follows the initial v0.5 release that accompanied the survey description paper (Brammer et al. 2012) and the v3.0 release which included the deepest near-IR HST grism spectra currently in existence, extracted from the 8-17 orbit depth observations in the Hubble Ultra Deep Field (van Dokkum et al., 2013, arxiv:1305.2140). In Skelton et al. (2014) we described the reduced WFC3 F125W, F140W, and F160W image mosaics of all five CANDELS/3D-HST fields; all ancilary imaging at other wavelengths that was used in the analysis; multi-wavelength photometric catalogs; and various derived parameters including photometric redshifts and stellar masses. The v4.1 release from March 2014 included all these data products. The the current v4.1.5 release we focus on the grism spectroscopy (Momcheva et al., 2015). As described in Skelton et al. (2014), the grism spectra are tied directly to the photometric catalogs described therein. The v4.1.5 release is based on the v4.1 Skelton et al. (2014) photometric catalogs.

When using data from this 3D-HST survey, please include the following acknowledgment: “This work is based on observations taken by the 3D-HST Treasury Program (HST-GO-12177 and HST-GO-12328) with the NASA/ESA Hubble Space Telescope, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555.” and cite the following papers: “The 3D-HST Survey: Hubble Space Telescope WFC3/G141 Grism Spectra, Redshifts, and Emission Line Measurements for 100, 000 Galaxies”, Momcheva et al., 2015, ApJS, submitted, and “3D-HST: A Wide-Field Grism Spectroscopic Survey with the Hubble Space Telescope”, Brammer et al., 2012, ApJS, 200, 13.

The v4.1.5 release is currently located at: http://3dhst.research.yale.edu/Data.html For question regarding this release, please contact Ivelina Momcheva (ivelina.momcheva at yale.edu)

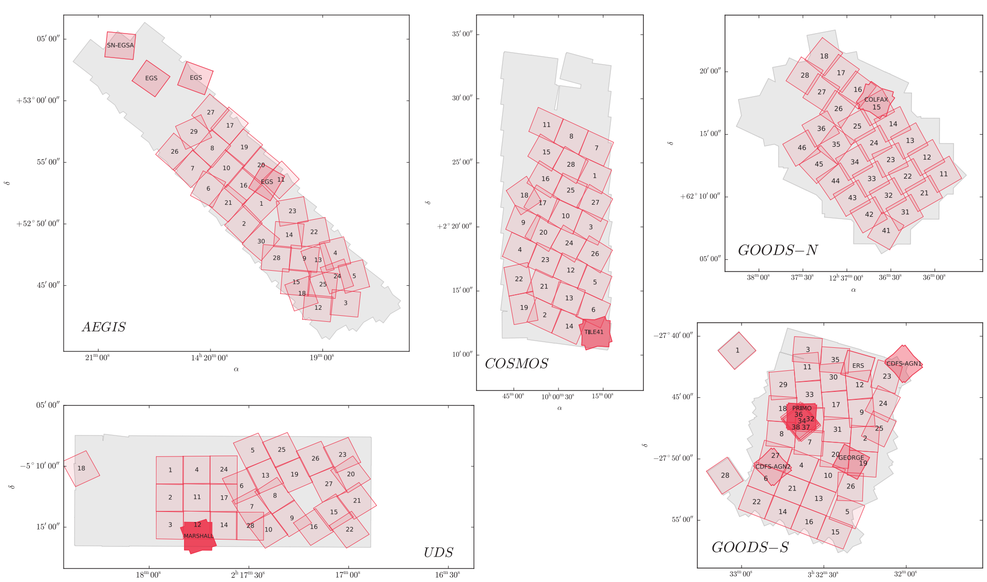
(For a release version vX.Y.Z, the numbering schema is the following. The first number, X, is incremented when new detection images are created. The second number, Y, is incremented when new photometric catalogs are generated. The third number, Z, is incremented when chages in the grism reduction pipeline are made.)

WFC3 GRISM DATA

The WFC3 G141 grism has spectral coverage from 1.1 to 1.65 um and a peak transmission of 48% at 1.45um. The G141 dispersion is 46.5 Angstroms per pixel (R~130) in the primary +1st spectral order. However, in practice, the spectral resolution for each (resolved) object is different as it is largely determined by its morphology. The uncertainties of the wavelength zero-point and the dispersion of the G141 grism are 8 Angstroms and 0.06 Angstroms per pixel respectively (Kuntschner10 et al., 2010). The field of view of the WFC3 IR channel is 136"x123".

The layout of the WFC3/G141 observations in the five deep fields is shown in below, overlaid on the CANDELS F160W imaging footprint. Across the five fields, 70% of the CANDELS area is covered with at least two orbits of WFC3/G141 data. In AEGIS, COSMOS and UDS, 60% of the CANDELS imaging area has complimentary G141 grism data, while 70% of GOODS-N and 86% of GOODS-S have G141 coverage. The total area of the G141 observations is 626 arcmin ^{2}.

The observations for the 3D-HST survey started October 30, 2010 and ended March 22, 2012. Two pointings in AEGIS, 1 and 22, were re-observed on April 21, 2013 and November 30, 2012, respectively. Each pointing of the 124 3D-HST pointings was observed for two orbits, with 4 paired F140W direct and G141 grism exposures. Typical total exposure times in each pointing are 800 s in F140W and 5000 s in G141. The four pairs of direct+grism exposures are separated by small telescope offsets to improve the sampling of the PSF, to enable the identification of hot pixels and other defects not flagged by the default pipeline processing, and to dither over some WFC3 cosmetic defects such as the "IR blobs" (Pirzkal et al. 2010). The sub-pixel dither pattern used throughout the survey is shown in Figure 3 of Brammer et al. (2012).



The 56 orbits from the AGHAST program in GOODS-N are divided into 28 pointings, each with two-orbits depth.

The observations were carried out between September 16, 2009 and September 26, 2010. Due to high background and scattered light artifacts, nine of the AGHAST pointings were partially re-observed between April 19 and 24, 2011. Analogous to 3D-HST, each two orbit observation was split in four sets of G141 grism images and F140W direct exposures. The dither patterns of AGHAST and 3D-HST are slightly different, but they both sample the WFC3 PSF on a grid that is 0.5x0.5 the native pixel size. The typical exposure time per pointing is 800 s in F140W and ~5200 s in G141. Further information about AGHAST can be found on the survey website: http://mingus.as.arizona.edu/~bjw/aghast/

A detailed description of the data reduction steps for the 3D-HST WFC3 data is provided in Momcheva et al. (2015). Here we provide a description of the data products in the v4.1.5 data release.

The data is organized by pointing, with all the data products for a given pointing provided in a separate directory. Within the directory are all data products derived from the pointing. The data products from the full pointing are at the top level inside the pointing directory. The outputs from the individual objects are grouped in directories by product type (2D, 1D, BIG, ZFIT and LINEFIT) and within each directory, by file type (FITS, DAT, ASCII, PNG). Throughout this section we use pointing **cosmos-01** as an example of the file-naming convention. The directory structure of this directory is the following:

```
cosmos-01/

        2D/
                FITS/   PNG/

        BIG/
                2D/             ZFIT/

        1D/
                FITS/   ASCII/  PNG/

        ZFIT/
                FITS/   DAT/    PZ/             PNG/    TILT/

        LINE/
                FITS/   DAT/    PNG/
```

2.1 Calibrated Images

The *FLT* images downloaded from MAST are re-processed as demonstrated in Momcheva et al. (2015). Many of the processing steps are not standard and for this reason we provide the final *FLT* images as a data product. These are accompanied by the association tables (*ASN*) tables and available as a separate download from the release website (cosmos_flt_files.tar.gz).

2.2 Pointing Data Products

- **cosmos-01-F140W_drz_sci.fits**: Drizzled F140W science image, created with the final processed *FLT* files.
- **cosmos-01-F140W_drz_wht.fits**: Drizzled F140W weight image, created with the final processed *FLT* files.
- **cosmos-01-G141_drz_sci.fits**: Drizzled G141 science image, created with the final processed *FLT* files.
- **cosmos-01-G141_drz_wht.fits**: Drizzled G141 weight image, created with the final processed *FLT* files.
- **cosmos-01-G141_maskbg.dat**: Parameters of the background model subtracted from the grism image.
- **cosmos-01-G141_ref_align.png**: Diagnostic image of the alignment between the projected reference image and the interlaced direct image.

- **cosmos-01-G141_maskbg.png**: Diagnostic image for the background subtraction of the grism image.
- **cosmos-01-F140W_inter.fits**: Interlaced F140W image.
- **cosmos-01-G141_inter.fits**: Interlaced G141 image.
- **cosmos-01-G141_ref_inter.fits**: Reference image (F125W+F140W+F160W) projected into the interlaced frame.
- **cosmos-01-G141_inter_seg.fits**: Segmentation map from Skelton et al. (2014) projected into the interlaced frame.
- **cosmos-01-G141_inter.cat**: Photometric catalog projected into the interlaced frame.
- **cosmos-01-G141_inter.reg**: DS9 regions file indicating the positions of all objects in the pointing.
- **cosmos-01-G141_inter_model.fits**: Contamination model for the full pointing.
- **cosmos-01-G141_inter_model.pkl**: Pickle file containing the information for creating the contamination model.
- **cosmos-01-G141_inter_0th.reg**: DS9 regions file indicating the positions of 0th order spectra.

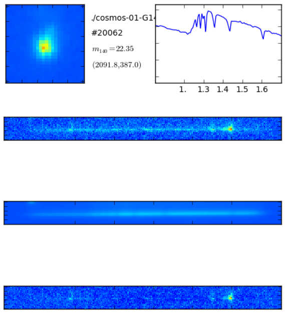
2.3 Data Products for Individual Objects

2D spectra and 1D spectra are extracted for all objects down to the limit of the photometric catalogs. There are ~250,000 2D and 1D spectra extracted for ~160,000 unique objects from the Skelton et al. (2014) catalogs. In this section we use object **cosmos-01-G141_20062** as an example of the file naming convention.

- **cosmos-01-G141_20062.2D.fits**: Two-dimensional WFC3 G141 grism products for object 20062 in AEGIS. This is a milti-extension fits file. The content of the file is:

```
Filename: cosmos-01-G141_20062.2D.fits
No.    Name        Type      Dimensions   Format      Description
0    PRIMARY   PrimaryHDU  ()
1    DSCI      ImageHDU    (40, 40)     float64   Reference image thumbnail (F125W+F140W+F160W)
2    DINTER    ImageHDU    (40, 40)     float64   Interlaced science thumbnail (F140W)
3    DWHT      ImageHDU    (40, 40)     float32   Interlaced weight thumbnail
4    DSEG      ImageHDU    (40, 40)     int32     Segmentation map thumbnail
5    SCI       ImageHDU    (153, 40)    float64   2D spectrum (includes contamination)
6    WHT       ImageHDU    (153, 40)    float64   2D weight map
7    MODEL     ImageHDU    (153, 40)    float64   2D model of the object
8    CONTAM    ImageHDU    (153, 40)    float64   Contamination model
9    WAVE      ImageHDU    (153,)       float64   Wavelength vector
10   SENS      ImageHDU    (153,)       float64   Sensitivity vector
11   YTRACE    ImageHDU    (153,)       float64   Position of the trace
```

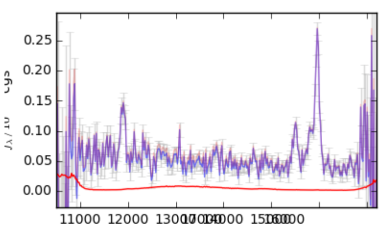
- **cosmos-01-G141_20062.2D.png**: Diagnostic *PNG*, showing the image thumbnail of the object from the reference image (Ext. 1 from the 2D *FITS* file), the 2D extracted spectrum (Ext. 5), the 2D model (Ext. 7), and the 2D spectrum minus the continuum model (Ext. 5 - Ext. 7).



- **cosmos-01-G141_20062.1D.fits**: Optimally-extracted one-dimensional G141 grism products. This is a *FITS* table. The content of the file is:

```
N Column                 Description
1 'wave'                 Wavelength vector
2 'flux'                 Optimally extracted 1D spectrum (includes contamination)
3 'error'                Error vector
4 'contam'               Contamination vector
5 'trace'                Position of the trace
6 'etrace'               Error in the trace position
7 'sensitivity'          Sensitivity vector
```

- **cosmos-01-G141_20062.1D.ascii**: *ASCII* version of cosmos-01-G141_20062.1D.fits with the same column names.
- **cosmos-01-G141_20062.1D.png**: Diagnostic *PNG* showing the 1D spectrum with error-bars (light red spectrum), the contamination (thick red line), and the contamination-subtracted 1D spectrum (blue line with error-bars).



Redshift fits have been done for all objects down to JH = 26.

- **cosmos-01-G141_20062.new_zfit.dat**: output from the redshift fitting, lists the best fit grism redshift, z_max_grism and the redshift confidence intervals:

```
#  spec_id   phot_id   dr   z_spec  z_peak_phot  z_max_grism z_peak_grism l95 l68 u68 u95
#  Phot: /3DHST/Photometry/Release/v4.1/COSMOS/Catalog/cosmos_3dhst.v4.1.cat
cosmos-01-G141_20062 20062 0.025 -1.00000 2.30500 2.18834 2.18833 2.18416 2.18582 2.18926 2.19092
```

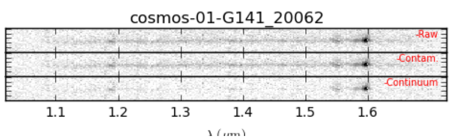
- **cosmos-01-G141_20062.new_zfit.fits**: grism spectrum continuum and emission line models using the best-fit templates at z_max_grism.

```
No.    Name         Type      Dimensions  Format          Description
0    PRIMARY     PrimaryHDU
1    CONT2D      ImageHDU     (312, 26)   float64         2D continuum model
2    LINE2D      ImageHDU     (312, 26)   float64         2D emission line model
3    CONT1D      ImageHDU     (312,)      float64         1D continuum model
4    LINE1D      ImageHDU     (312,)      float64         1D emission line model
5    COEFFS      ImageHDU     (10,)       float64         coefficients for the best-fit
                                                       template combination
```

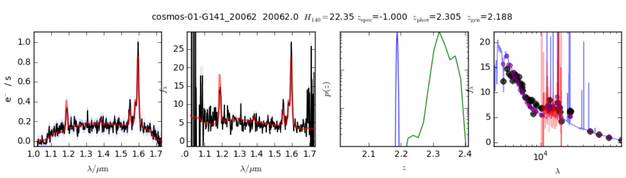
- **cosmos-01-G141_20062.new_zfit.pz.fits**: redshift probability distribution functions for the redshift fits.

No.	Name	Type	Dimensions	Format	Description
0	PRIMARY	PrimaryHDU	()		
1	ZGRID0	ImageHDU	(322,)	float64	Coarse z grid for separate phot and grism fits
2	LNP_PHOT_0	ImageHDU	(322,)	float64	p(z) for the photometry-only fit
3	LNP_SPEC_0	ImageHDU	(322,)	float64	p(z) for the grism-only fit
4	ZGRID1	ImageHDU	(233,)	float64	Fine redshift grid for final fit
5	LNP_BOTH_1	ImageHDU	(233,)	float64	p(z) for the joint photometry+grism fit

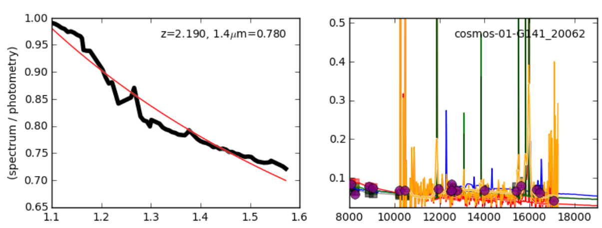
- **cosmos-01-G141_20062.new_zfit_tilt.dat**: a polynomial fit to the spectrum.
- **cosmos-01-G141_20062.new_zfit.2D.png**: Diagnostic plot for the redshift fit. Shows (top to bottom) the 2D spectrum, the contamination-subtracted 2D spectrum and the contamination- and continuum-subtracted 2D spectrum. The continuum model comes from for Ext. 1 of cosmos-01-G141_20062.new_zfit.fits.



- **cosmos-01-G141_20062.new_zfit.png**: Diagnostic plot for the redshift fit. The panels show: (1) 1D spectrum in units of e-/s (black) and the best fit template (red); (2) 1D spectrum in units of flux (black) and the best fit template (red); (3) redshift probability distribution functions for the fit to the photometry alone (green), the join photometry+grism fit (blue) and the ground-based spectroscopic redshift (if available, vertical red line); (4) broad-band photometry from Skelton et al. (2014, black points), the 1D grism spectrum (red) and the best-fit redshift template (blue).



- **cosmos-01-G141_20062.new_zfit_tilt.png**:



- **cosmos-01-G141_20062.linefit.fits**:

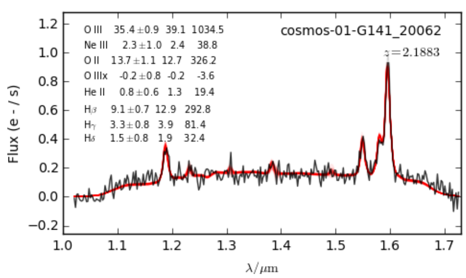
No.	Name	Type	Dimensions	Format
0	PRIMARY	PrimaryHDU	()	
1	S0	ImageHDU	(600, 50)	float64
2	OIII	ImageHDU	(600, 50)	float64
3	NEIII	ImageHDU	(600, 50)	float64
4	OII	ImageHDU	(600, 50)	float64
5	OIIIX	ImageHDU	(600, 50)	float64
6	HEII	ImageHDU	(600, 50)	float64
7	HB	ImageHDU	(600, 50)	float64
8	HG	ImageHDU	(600, 50)	float64
9	HD	ImageHDU	(600, 50)	float64
10	S1	ImageHDU	(600, 50)	float64

```
11   DRAW1D       ImageHDU     (312, 100)   float64
12   WAVE1D       ImageHDU     (312,)       float64
13   BEST2D       ImageHDU     (312, 26)    float64
14   BEST1D       ImageHDU     (312,)       float64
```

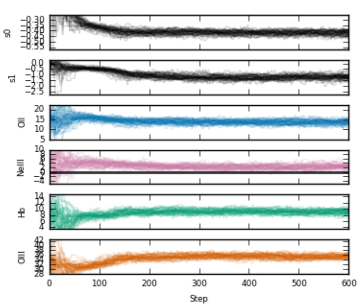
- **cosmos-01-G141_20062.linefit.dat**: ascii output from the emission line fit, listing the best fit emission line fluxes and equivalent widths. Only lines which fall within the grism spectrum at the best-fit grism redshift are listed in this file.

```
# line  flux error scale_to_photom EQW_obs EQW_obs_err
# z=2.18834
# flux: 10**-17 ergs / s / cm**2
# [xxx] tilt correction to photometry: s0 = -0.417 [ 0.020 ], s1 = -1.222 [ 0.188 ]
OIII   35.45  0.91  1.782 1034.53  51.75
NeIII    2.29  0.97  1.300  38.80  16.97
 OII   13.66  1.07  1.243 326.18  30.32
OIIIx   -0.16  0.76  1.506  -3.63  17.33
HeII    0.80  0.61  1.643  19.37  14.95
  Hb    9.06  0.70  1.719 292.83  25.73
  Hg    3.25  0.83  1.496  81.44  21.07
  Hd    1.48  0.79  1.396  32.42  17.58
```

- **cosmos-01-G141_20062.linefit.png**: diagnostic *PNG* showing the emission line fit



- **cosmos-01-G141_20062.linefit.chain.png**: diagnostic *PNG* showing the MCMC chains of the emission line fit



The cross dispersion size of the automated extractions is 3x the SExtractor FLUX_RADIUS (for small objects we impose a minimum limit of 26 pixels). For some applications, larger extractions may be needed. We have also created 2D extractions and redshift fit models with a constant cross-dispersion size of 80 interlace pixels. These files have the same file format as the 2D.fits and new_zfit.fits files described above:

- **cosmos-01-G141-big_20062.2D.fits**:
- **cosmos-01-G141-big_20062.new_zfit.fits**

CHAPTER

THREE

CATALOGS

The results from the redshifts and emission line fits are assembled into several different catalogs. For the majority of users these catalogs will probably be the main, or only, gateway to the 3D-HST dataset. We use the filenames for the *AEGIS* field as examples throughout this section.

3.1 Grism Catalogs

The first type of catalogs we produce are simply concatenations of the outputs of all redshift and emission line fits. These catalogs contain repeat fits for the same photometric object. The fits are done for each extracted 2D spectrum of each object separately (in conjunction with the photometric information) for a total of 98,668 individual spectra down to JH_{IR}= 26 (except for the UDS field where the fits reach approximately 0.5 magnitudes fainter). In these catalogs, each row corresponds to the outputs from a single spectrum. Each spectrum has a unique identifier of the format **aegis-01-G141_00001**, listing the field, the pointing number (zero-padded two-digit integer), the grism name (G141 for 3D-HST) and the photometric identification number of the object (padded five-digit integer).The objects are ordered by pointing number and, within that pointing, by photometric identifier. A list of all duplicate spectra is also provided (see below).

Two concatenated catalogs are produced, one containing the redshift fits and one containing the emission line fits. Both catalogs have the same length.

The concatenated catalogs provide information for **all** objects fitted as part of the current release. The JH_{IR}magnitude is included as a column in the catalog, however we do not preselect objects in any way for this catalog and we specifically do not exclude duplicate observations. These catalogs can be used to identify all the information available for a given object in the photometric catalogs.

List of all concatenated catalogs (*column descriptions for all files are available below*):

- **aegis_3dhst.v4.1.5.zfit.concat.[dat,fits]**: Concatenated grism redshift catalog. Available in both *FITS* and *ASCII* format.
- **aegis_3dhst.v4.1.5.linefit.concat.fits**: Concatenated emission line catalog. Only available in *FITS* format.

Column names for **aegis_3dhst.v4.1.5.zfit.concat.[dat,fits]**:

Column Name	Column Content
1 phot_id	Photometric id from Skelton et al. (2014)
2 grism_id	Grism id of the spectrum which yielded this fit
3 jh_mag	MAG_AUTO measured from the combined F125W+F140W+F160W image
4 z_spec	Spectroscopic redshift where available (-1 if not available)
5 z_peak_phot	Photometric redshift from Skelton et al. (2014)
6 z_phot_l95	Photometric redshift at the lower 95% confidence limit
7 z_phot_l68	Photometric redshift at the lower 68% confidence limit
8 z_phot_u68	Photometric redshift at the upper 68% confidence limit
9 z_phot_u95	Photometric redshift at the upper 95% confidence limit
10 z_max_grism	**Default grism redshift**: the redshift where the p(z ∣ grism, phot) is maximized
11 z_peak_grism	Integral of p(z ∣ grism, phot)*z*dz, integrated over the whole redshift range
12 l95	Grism redshift at the lower 95% confidence limit
13 l68	Grism redshift at the lower 68% confidence limit
14 u68	Grism redshift at the upper 68% confidence limit
15 u95	Grism redshift at the lower 95% confidence limit
16 f_cover	Fraction of spectrum within the image (0=bad, 1=good)
17 f_flagged	Fraction of flagged pixels (1=bad, 0=good)
18 max_contam	Maximum contamination
19 int_contam	Contamination integrated over the spectrum (= flux_contam/flux_object)
20 f_negative	Fraction of pixels with negative flux after contamination correction
21 flag1	Flag for the redshift quality (user 1), only available down to JH_{IR}= 24 (-1=no flag, 0=good, 1=bad, 2=unclear)
22 flag2	Flag for the redshift quality (user 2), only available down to JH_{IR}= 24 (-1=no flag, 0=good, 1=bad, 2=unclear)

Column names for **aegis_3dhst.v4.1.5.linefit.concat.fits**:

Column Name	Column Content
1 number	Photometric id from Skelton et al. (2014)
2 grism_id	Grism id of the spectrum which yielded this fit
3 jh_mag	MAG_AUTO measured from the combined F125W+F140W+F160W image
4 z_max_grism	Grism redshift
5 s0	Normalization coefficient s0, parameter for internal use
6 s0_err	Error for normalization coefficient s0
7 s1	Normalization coefficient s1, parameter for internal use
8 s1_err	Error for normalization coefficient s1
9 Lya_FLUX	Lya flux
10 Lya_FLUX_ERR	Lya flux error
11 Lya_SCALE	Lya flux normalization parameter
12 Lya_EQW	Lya equivalent width
13 Lya_EQW_ERR	Lya equivalent width error
14 CIV_FLUX	CIV flux
15 CIV_FLUX_ERR	CIV flux error
16 CIV_SCALE	CIV flux normalization parameter
17 CIV_EQW	CIV equivalent width
18 CIV_EQW_ERR	CIV equivalent width error
19 MgII_FLUX	MgII flux

Continued on next page

Table 3.1 – continued from previous page

Column Name	Column Content
20 MgII_FLUX_ERR	MgII flux error
21 MgII_SCALE	MgII flux normalization parameter
22 MgII_EQW	MgII equivalent width
23 MgII_EQW_ERR	MgII equivalent width error
24 OII_FLUX	OII flux
25 OII_FLUX_ERR	OII flux error
26 OII_SCALE	OII flux normalization parameter
27 OII_EQW	OII equivalent width
28 OII_EQW_ERR	OII equivalent width error
29 Hd_FLUX	Hd flux
30 Hd_FLUX_ERR	Hd flux error
31 Hd_SCALE	Hd flux normalization parameter
32 Hd_EQW	Hd equivalent width
33 Hd_EQW_ERR	Hd equivalent width error
34 Hg_FLUX	Hg flux
35 Hg_FLUX_ERR	Hg flux error
36 Hg_SCALE	Hg flux normalization parameter
37 Hg_EQW	Hg equivalent width
38 Hg_EQW_ERR	Hg equivalent width error
39 OIIIx_FLUX	OIIIx flux
40 OIIIx_FLUX_ERR	OIIIx flux error
41 OIIIx_SCALE	OIIIx flux normalization parameter
42 OIIIx_EQW	OIIIx equivalent width
43 OIIIx_EQW_ERR	OIIIx equivalent width error
44 HeII_FLUX	HeII flux
45 HeII_FLUX_ERR	HeII flux error
46 HeII_SCALE	HeII flux normalization parameter
47 HeII_EQW	HeII equivalent width
48 HeII_EQW_ERR	HeII equivalent width error
49 Hb_FLUX	Hb flux
50 Hb_FLUX_ERR	Hb flux error
51 Hb_SCALE	Hb flux normalization parameter
52 Hb_EQW	Hb equivalent width
53 Hb_EQW_ERR	Hb equivalent width error
54 OIII_FLUX	OIII flux
55 OIII_FLUX_ERR	OIII flux error
56 OIII_SCALE	OIII flux normalization parameter
57 OIII_EQW	OIII equivalent width
58 OIII_EQW_ERR	OIII equivalent width error
59 Ha_FLUX	Ha flux
60 Ha_FLUX_ERR	Ha flux error
61 Ha_SCALE	Ha flux normalization parameter
62 Ha_EQW	Ha equivalent width
63 Ha_EQW_ERR	Ha equivalent width error
64 SII_FLUX	SII flux
65 SII_FLUX_ERR	SII flux error
66 SII_SCALE	SII flux normalization parameter
67 SII_EQW	SII equivalent width
68 SII_EQW_ERR	SII equivalent width error

Continued on next page

Table 3.1 – continued from previous page

Column Name	Column Content
69 SIII_FLUX	SIII flux
70 SIII_FLUX_ERR	SIII flux error
71 SIII_SCALE	SIII flux normalization parameter
72 SIII_EQW	SIII equivalent width
73 SIII_EQW_ERR	SIII equivalent width error
74 HeI_FLUX	HeI flux
75 HeI_FLUX_ERR	HeI flux error
76 HeI_SCALE	HeI flux normalization parameter
77 HeI_EQW	HeI equivalent width
78 HeI_EQW_ERR	HeI equivalent width error
79 HeIb_FLUX	HeIb flux
80 HeIb_FLUX_ERR	HeIb flux error
81 HeIb_SCALE	HeIb flux normalization parameter
82 HeIb_EQW	HeIb equivalent width
83 HeIb_EQW_ERR	HeIb equivalent width error
84 NeIII_FLUX	NeIII flux
85 NeIII_FLUX_ERR	NeIII flux error
86 NeIII_SCALE	NeIII flux normalization parameter
87 NeIII_EQW	NeIII equivalent width
88 NeIII_EQW_ERR	NeIII equivalent width error
89 NeV_FLUX	NeV flux
90 NeV_FLUX_ERR	NeV flux error
91 NeV_SCALE	NeV flux normalization parameter
92 NeV_EQW	NeV equivalent width
93 NeV_EQW_ERR	NeV equivalent width error
94 NeVI_FLUX	NeVI flux
95 NeVI_FLUX_ERR	NeVI flux error
96 NeVI_SCALE	NeVI flux normalization parameter
97 NeVI_EQW	NeVI equivalent width
98 NeVI_EQW_ERR	NeVI equivalent width error
99 OI_FLUX	OI flux
100 OI_FLUX_ERR	OI flux error
101 OI_SCALE	OI flux normalization parameter
102 OI_EQW	OI equivalent width
103 OI_EQW_ERR	OI equivalent width error

3.2 Linematched Catalogs

We also produce redshift and emission line catalogs that are matched to the photometric catalogs of Skelton et al. (2014). These catalogs have the same length as those in the v4.1 photometric release with one entry per object from Skelton et al. (2014). The rows corresponding to objects in the photometric catalog that do not have grism spectra are set to default values, also listed in Momcheva et al. (2015). Duplicate objects appear only once in these catalogs. Repeat redshift measurements are reconciled as follows: if there are two (or more) spectral fits for a given object, we first remove those that have at least one flag set to "bad" or both flags set to "unclear'‘. Amongst the remaining, we chose the fit with the narrowest p(z) (as measured by the 68% confidence interval) to include in the catalog (if only one spectrum remains, it is the default choice). If all spectra for a given object have at least one flag set to ‘‘bad" or both flags set to "unclear", none of them are included in the catalogs (there are only 149 such objects in the full five fields).

In addition to the redshift and emission line catalogs, we create a row-matched listing of all duplicate spectra of a given object. We also make available the SEextractor catalog with JH fluxes measured from the F125W + F140W + F160W images. Using the grism redshift fits in the bright line-matched catalogs, we refit the stellar population parameters, rest-frame colors and star-formation rates as described in Skelton et al. (2014) and Whitaker et al. (2014).

List of all linematched catalogs (*column descriptions for all files are available below*):

- **aegis_3dhst.v4.1.5.zfit.linematched.[dat,fits]**: Linematched grism redshift catalog, same length as Skelton et al. (2014). Available in both *FITS* and *ASCII* format.
- **aegis_3dhst.v4.1.5.linefit.linematched.fits**: Linematched grism emission catalog, same length as Skelton et al. (2014). Only available in *FITS* format. The columns are the same as in the concatenated catalog above.
- **aegis_3dhst.v4.1.5.duplicates_zfit.dat**: List of repeated redshift fits, same length as the line-matched catalogs and Skelton et al. (2014). For each object in the photometric catalog, the corresponding line in this catalog lists the identifiers of grism spectra for all redshift fits that correspond to that object.
- **aegis_3dhst.v4.1.5.duplicates_2d.dat**: List of repeated 2D spectra, same length as the line-matched catalogs and Skelton et al. (2014). For each object in the photometric catalog, the corresponding line in this catalog lists the identifiers of all 2D grism spectra for that object.
- **aegis_3dhst.v4.1.5.z_max_grism.fout**: FAST fits using the grism redshifts down to JH_{IR}= 26
- **aegis_3dhst.v4.1.5.z_max_grism.sfr**: Star-formation rates using the grism redshifts down to JH_{IR}= 26
- **aegis_3dhst.v4.1.5.z_max_grism.rf**: Rest-frame colors using the redshifts down to JH_{IR}= 26
- **aegis_3dhst.v4.1.5.IR.cat**: SExtractor output based on the coadded F125W+F140W+F160W image. No column description is provided for this file. See the documentation to the v4.1 release for this information.

Column descriptions for **aegis_3dhst.v4.1.5.zfit.linematched.[dat,fits]**:

Column Name	Column Content
1 phot_id	Photometric id from Skelton et al. (2014)
2 grism_id	Grism id of the spectrum which yielded this fit
3 jh_mag	MAG_AUTO measured from the combined F125W+F140W+F160W image
4 z_spec	Spectroscopic redshift where available (-1 if not available)
5 z_peak_phot	Photometric redshift from Skelton et al. (2014)
6 z_phot_l95	Photometric redshift at the lower 95% confidence limit
7 z_phot_l68	Photometric redshift at the lower 68% confidence limit
8 z_phot_u68	Photometric redshift at the upper 68% confidence limit
9 z_phot_u95	Photometric redshift at the upper 95% confidence limit
10 z_max_grism	**Default grism redshift**: the redshift where the p(z ∣ grism, phot) is maximized
11 z_peak_grism	Integral of p(z ∣ grism, phot)*z*dz, integrated over the whole redshift range
12 l95	Grism redshift at the lower 95% confidence limit
13 l68	Grism redshift at the lower 68% confidence limit
14 u68	Grism redshift at the upper 68% confidence limit
15 u95	Grism redshift at the lower 95% confidence limit
16 f_cover	Fraction of spectrum within the image (0=bad, 1=good)
17 f_flagged	Fraction of flagged pixels (1=bad, 0=good)
18 max_contam	Maximum contamination
19 int_contam	Contamination integrated over the spectrum (= flux_contam/flux_object)
20 f_negative	Fraction of pixels with negative flux after contamination correction
21 flag1	Grism z flag (user 1): -1=no flag, 0=good, 1=bad, 2=unclear
22 flag2	Grism z flag (user 2): -1=no flag, 0=good, 1=bad, 2=unclear
23 use_grism	Flag defining objects with the most reliable grism-derived redshifts: 1=use, 0=do not use
24 use_phot	Photometric use flag from Skelton et al. (2014): 1 = use; 0 = do not use

Continued on next page

Table 3.2 – continued from previous page

Column Name	Column Content
25 z_best_s	Source of the best redshift: 1 = ground-based spectroscopy; 2 = grism; 3 = photometry; 0 = star
26 z_best_best	Best available redshift measurement (-1 for stars)
27 z_best_l95	Lower 95% confidence limit derived form the z_best p(z), -1 for stars and z_spec
28 z_best_l68	Lower 68% confidence limit derived form the z_best p(z), -1 for stars and z_spec
29 z_best_u68	Upper 95% confidence limit derived form the z_best p(z), -1 for stars and z_spec
30 z_best_u95	Upper 95% confidence limit derived form the z_best p(z), -1 for stars and z_spec

Column descriptions for **aegis_3dhst.v4.1.5.z_max_grism.fout**:

Column Name	Column Content
1 id	Unique identifier within a given field
2 z	Redshift used in fit, z_max_grism in this case.
3 ltau	logtau/yr
4 metal	metallicity
5 lage	logage/yr
6 Av	Dust attenuation in the V-band
7 lmass	log Mstar/Msun
8 lsfr	log SFR/Msun/yr
9 lssfr	log SSFR * yr
10 la2t	log age/tau
11 chi2	chi squared of fit

Column descriptions for **aegis_3dhst.v4.1.5.z_max_grism.sfr** (see Whitaker et al., 2014 and the file header for details):

Column Name	Column Content
1 id	Photometric id from Skelton et al. (2014)
2 sfr	Star formation rate: sfr = sfr_IR + sfr_UV [Msun/yr]
3 sfr_IR	IR star formation rate: sfr_IR = 1.09E-10*L_IR [Msun/yr]
4 sfr_UV	UV star formation rate: sfr_UV = 1.09E-10*(2.2L_UV) [Msun/yr]
5 L_IR	IR (8-1000micron) luminosity, measured from Spitzer/MIPS 24 um photometry [Lsun]
6 L_UV	Total integrated (1216-3000A) rest-frame UV luminosity, defined as L_UV=1.5muL_2800 [Lsun]
7 flag	flag = 1 for 24 um aperture flux densities with 0 < S/N < 1
...	flag = 2 for negative 24 micron aperture flux densities
...	flag = -99 when z_max_grism<=0.
8 z_max_grism	Redshift used in the fit
9 z_type	Redshift source: 1 = ground-based spectroscopy; 2 = grism; 3 = photometry; 0 = star
10 f24tot	Total 24 um flux [AB zeropoint of 25]
11 ef24tot	Error in the total 24 um flux [AB zeropoint of 25]
12 L_1600	Rest-frame 1600 A luminosity
13 L_2800	Rest-frame 2800 A luminosity
14 beta	Rest-frame UV spectral slope, determined from a power-law fit of the form f_lambda ~ lambda^beta.

Column descriptions for **aegis_3dhst.v4.1.5.z_max_grism.rf**:

Column Name	Column Content
1 id	Unique identifier within a given field, from Skelton et al. (2014)
2 z	Redshift used in the fit, z_max_grism in this case.

Continued on next page

Table 3.3 – continued from previous page

Column Name	Column Content
3 DM	Distance modulus for a W_M/W_L/H0 = 0.3/0.7/70 cosmology
4 L153	Fnu flux density for filter REST_FRAME/maiz-apellaniz_Johnson_U.res with an AB zeropoint of 25
5 n_153	Number of filters considered in RF fit for L153
6 L154	Fnu flux density for filter REST_FRAME/maiz-apellaniz_Johnson_B.res with an AB zeropoint of 25
7 n_154	Number of filters considered in RF fit for L154
8 L155	Fnu flux density for filter RREST_FRAME/maiz-apellaniz_Johnson_V.res with an AB zeropoint of 25
9 n_155	Number of filters considered in RF fit for L155
10 L161	Fnu flux density for filter 2MASS/J.res with an AB zeropoint of 25
11 n_161	Number of filters considered in RF fit for L161
12 L162	Fnu flux density for filter 2MASS/H.res with an AB zeropoint of 25
13 n_162	Number of filters considered in RF fit for L162
14 L163	Fnu flux density for filter 2MASS/K.res with an AB zeropoint of 25
15 n_163	Number of filters considered in RF fit for L163
16 L156	Fnu flux density for filter SDSS/u.dat with an AB zeropoint of 25
17 n_156	Number of filters considered in RF fit for L156
18 L157	Fnu flux density for filter SDSS/g.da with an AB zeropoint of 25
19 n_157	Number of filters considered in RF fit for L157
20 L158	Fnu flux density for filter SDSS/r.dat with an AB zeropoint of 25
21 n_158	Number of filters considered in RF fit for L158
22 L159	Fnu flux density for filter SDSS/i.dat with an AB zeropoint of 25
23 n_159	Number of filters considered in RF fit for L159
24 L160	Fnu flux density for filter SDSS/z.dat with an AB zeropoint of 25
25 n_160	Number of filters considered in RF fit for L160
26 L135	Fnu flux density for filter REST_FRAME/Bessel_UX.dat with an AB zeropoint of 25
27 n_135	Number of filters considered in RF fit for L135
28 L136	Fnu flux density for filter REST_FRAME/Bessel_B.dat with an AB zeropoint of 25
29 n_136	Number of filters considered in RF fit for L136
30 L137	Fnu flux density for filter REST_FRAME/Bessel_V.da with an AB zeropoint of 25
31 n_137	Number of filters considered in RF fit for L137
32 L138	Fnu flux density for filter REST_FRAME/Bessel_R.dat with an AB zeropoint of 25
33 n_138	Number of filters considered in RF fit for L138
34 L139	Fnu flux density for filter REST_FRAME/Bessel_I.dat with an AB zeropoint of 25
35 n_139	Number of filters considered in RF fit for L139
36 L270	Fnu flux density for filter RestUV/Tophat_1400_200.dat with an AB zeropoint of 25
37 n_270	Number of filters considered in RF fit for L270
38 L271	Fnu flux density for filter RestUV/Tophat_1700_200.dat with an AB zeropoint of 25
39 n_271	Number of filters considered in RF fit for L271
40 L272	Fnu flux density for filter RestUV/Tophat_2200_200.dat with an AB zeropoint of 25
41 n_272	Number of filters considered in RF fit for L272
42 L273	Fnu flux density for filter RestUV/Tophat_2700_200.dat with an AB zeropoint of 25
43 n_273	Number of filters considered in RF fit for L273
44 L274	Fnu flux density for filter RestUV/Tophat_2800_200.dat with an AB zeropoint of 25
45 n_274	Number of filters considered in RF fit for L274
46 L275	Fnu flux density for filter RestUV/Tophat_5500_200.dat with an AB zeropoint of 25
47 n_275	Number of filters considered in RF fit for L275

3.3 "Best" Catalogs

We create a ''best" redshift catalog, by merging the grism redshift fits with the photometric redshifts from Skelton et al. (2014). The best redshift is:

- **z_spec** if it exists from the Skelton et al. (2014) compilation of spectroscopic redshifts
- **z_max_grism** if there is no spectroscopic redshift and use_grism = 1
- **z_phot** if there is no spectroscopic redshift and use_grism <1

We emphasize that we only use the photometric redshift if there is no grism spectrum that can be used (either because an object was not observed or because the spectrum has a bad redshift use flag. Using the best redshifts, we also create merged catalogs of the stellar population parameters, rest-frame colors and star formation rates.

- **aegis_3dhst.v4.1.5.zbest.[dat,fits]**: best redshift catalog
- **aegis_3dhst.v4.1.5.zbest.fout**: FAST fits using z_best
- **aegis_3dhst.v4.1.5.zbest.sfr**: star-formation rates calculated using z_best
- **aegis_3dhst.v4.1.5.zbest.rf**: rest-frame colors caluclated using z_best

3.4 Master Catalogs

The master catalogs contain the joined outputs from the following files for all fields:

- [field]_3dhst.v4.1.5.zfit.linematched.fits
- [field]_3dhst.v4.1.5.linefit.linematched.fits
- [field]_3dhst.v4.1.5.zbest.fout
- [field]_3dhst.v4.1.5.zbest.sfr
- [field]_3dhst.v4.1.5.zbest.rf

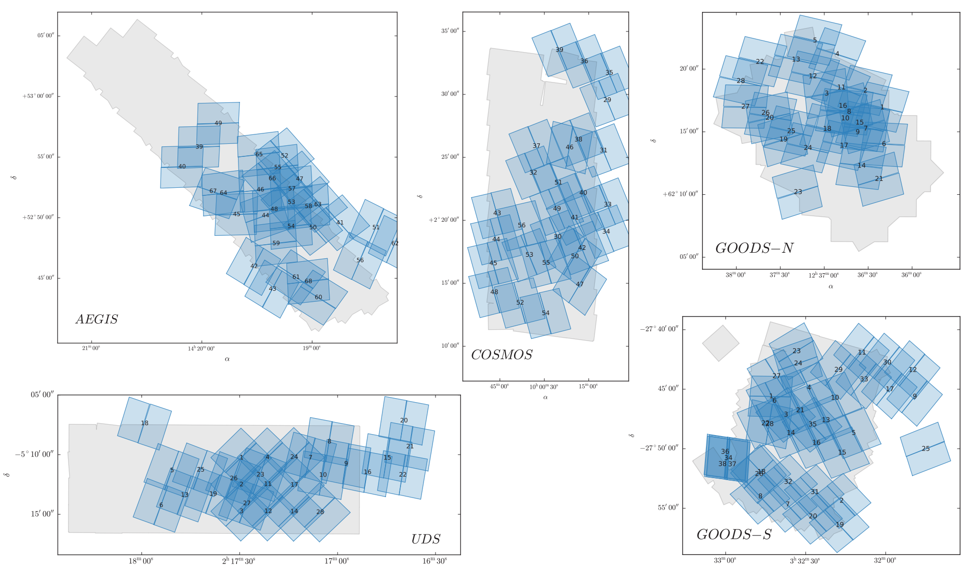
The columns are described above for all of these files.

CHAPTER

FOUR

ACS GRISM DATA

Exposures with the ACS G800L grism, accompanied by F814W direct imaging, were taken in parallel with the primary WFC3 exposures. ACS coverage of the GOODS-N fields was done in program GO-13420 (PI: Barro) as parallels to their WFC3/G102 primary observations. The G800L grism has a wavelength coverage from 0.55 um to 1.0 um with a dispersion of 40 Angstrom per pixel in the primary first order. The total exposure times in each pointing/visit are 480 seconds in F814W (1299 s in GO-13420) and between ~2800 (GOODS-N) and ~3500 seconds (AEGIS) in G800L. The Figure below shows the layout of the pointings in all five fields. Unlike the WFC3 pointings, the ACS pointings do not have a regular pattern but an effort was made to maximize the overlap between the two grisms. Fully 86.5% of the WFC3 grism observations also have ACS grism coverage. As a result of the larger ACS field of view (202”x202”) there is larger overlap between the pointings, with some areas covered up to a depth of 8 orbits.



We download the CTE-corrected *FLC* images and association tables *ASN* for all observations from MAST. The direct images are background-subtracted, aligned to the external photometric catalogs and re-drizzles. The F814W images are processed with AstroDrizzle to identify cosmic rays. A model for the grism background is obtained by carefully masking all detected objects and taking the median of all G800L exposures, after scaling each detector of each exposure so that the average sky values are matched. This background model, multiplied by the appropriate detector- and exposure-dependent scaling factor, is then subtracted from the individual exposures. The ACS grism images are not flat-fielded. Pirzkal et al. (2002) show that applying a direct-imaging flat to the grism observations introduces ~10% large scale differences. Without the flat-fielding, these differences are much smaller, ~5% across the detector. Combined images for both F814W and G800L are produced by shifting the distorted images to approximately the same position and co-adding the individual *FLTs*. The final product is similar to that from the WFC3 interlacing: distorted frames whose noise properties are preserved.

We use the direct drizzled F814W images as reference. The reference images are not padded. The reference segmentation maps are created from the detection segmentation map of Skelton et al. (2014). We use the MAG_AUTO from the F814W SExtractor catalog run on the PSF-matched image as a magnitude measurement for all fields except GOODS-N. In this field, we use the F606W MAG_AUTO. All objects down to F814W (F606W < 24 for GOODS-N) are extracted.

Several of the 3D-HST ACS pointings fall completely outside of the footprint of the CANDELS/3D-HST WFC3 imaging. Since the Skelton et al. (2014) images are used for WCS alignment, such pointings that fall outside these mosaics cannot be aligned to the same WCS and cannot be processed in the same manner as the rest of the pointings.There are 9 pointings which are fall completely outside the CANDELS/imaging footprints (marked with * below). We also do not extract spectra from pointings which fall on the edge of the CANDELS/3D-HST WFC3 images and/or have little to no overlap with the 3D-HST footprint. None of these pointings are processed past the preliminary reduction steps. This is list of pointings where no spectra were extracted:

- AEGIS: 41, 47, 51 *, 52, 59, 62 *, 63
- COSMOS: 29, 31, 33, 34, 35, 36, 39
- GOODS-N: 4, 5, 22
- GOODS-S: 2, 9 *, 12 *, 17, 19, 25 *, 30
- UDS: 15 *, 16, 18, 20 *, 21 *, 22 *

The data is organized by pointing, with all the data products for a given pointing provided in a separate directory. Within the directory are all data products derived from the pointing. The data products from the full pointing are at the top level inside the pointing directory. The outputs from the individual objects are grouped in directories by product type (2D, 1D, ZFIT and LINEFIT) and within each directory, by file type (FITS, DAT, ASCII, PNG). Throughout this section we use pointing **aegis-acs-39** as an example of the file-naming convention. The directoory structure of this directory is the following:

```
aegis-acs-39/

        2D/
                FITS/   PNG/

        1D/
                FITS/
```

4.1 Pointing Data Products

We make available the data products from the preparation steps of our pipeline. Since this processing is minimal (compared to WFC3), we do not make the individual *FLC* files available. The following data products are produced for every pointing:

- **aegis-39-F814W_asn.fits**: Association table for the F814W observations in this pointing.
- **aegis-39-G800L_asn.fits**: Association table for the G800L observations in this pointing.
- **aegis-39-F814W_drc_sci.fits**: Drizzled F814W science image, created with the final processed *FLT* files.
- **aegis-39-F814W_drc_wht.fits**: Drizzled F814W weight image, created with the final processed *FLT* files.
- **aegis-39-F814W_shifts.txt**: Shifts calculated in the alignment process for the images in this pointing. For pointings which fall outside the footprint of the CANDELS/3D-HST mosaics these are *NaN*.
- **aegis-39-G800L_drc_sci.fits**: Drizzled G800L science image, created with the final processed *FLT* files.
- **aegis-39-G800L_drc_wht.fits**: Drizzled G800L weight image, created with the final processed *FLT* files.

- **aegis-39-chip[1,2]-F814W_inter.fits**: Coadded direct F814W image of CHIP 1 and 2
- **aegis-39-chip[1,2]-G800L_inter.fits**: Coadded direct G800L image of CHIP 1 and 2

For pointings where spectra are extracted, we also produce several additional data products:

- **aegis-39-chip[1,2]-G800L_ref_inter.fits**: Reference images (from the F814W drizzled image above).
- **aegis-39-chip[1,2]-G800L_inter_seg.fits**: Reference segmentation map, blotted from the segmentation map of Skelton et al. (2014)
- **aegis-39-chip[1,2]-G800L_inter.cat**: Catalog of objects within the pointing, created from the F814W (F606W) SExtractor catalogs of Skelton et al. (2014), with X and Y coordinates projected in the distorted frame of the pointing.
- **aegis-39-chip[1,2]-G800L_inter.reg**: DS9 regions file indicating the positions of all objects in the pointing.
- **aegis-39-chip[1,2]-G800L_inter_0th.reg**: DS9 regions file indicating the positions of 0th order spectra.
- **aegis-39-chip[1,2]-G800L_inter_model.fits**: Contamination model for the full pointing.
- **aegis-39-chip[1,2]-G800L_inter_model.pkl**: Pickle file containing the information for creating the contamination model.

4.2 Data Products for Individual Objects

2D and 1D spectra of all objects down to I_{814}= 24 (V_{606} = 24 for GOODS-N) are extracted. A total of 24,264 objects are extracted. For each object, the following 3 files are produced:

- **aegis-39-chip2-G800L_21407.2D.fits**: Two-dimensional ACS G800L grism products for object 21407 in AEGIS. This is a milti-extension fits file. The content of the file is:

```
No.    Name       Type      Dimensions   Format      Description
0    PRIMARY   PrimaryHDU  ()
1    DSCI      ImageHDU    (40, 40)     float64   Reference image tumbnail (F814W)
2    DINTER    ImageHDU    (40, 40)     float64   Interlaced science tumbnail (F814W)
3    DWHT      ImageHDU    (40, 40)     float32   Interlaced weight tumbnail
4    DSEG      ImageHDU    (40, 40)     int32     Segmentation map tumbnail
5    SCI       ImageHDU    (153, 40)    float64   2D spectrum (includes contamination)
6    WHT       ImageHDU    (153, 40)    float64   2D weight map
7    MODEL     ImageHDU    (153, 40)    float64   2D model of the object
8    CONTAM    ImageHDU    (153, 40)    float64   Contamination model
9    WAVE      ImageHDU    (153,)       float64   Wavelength vector
10   SENS      ImageHDU    (153,)       float64   Sensitivity vector
11   YTRACE    ImageHDU    (153,)       float64   Position of the trace
```

- **aegis-39-chip2-G800L_21407.1D.fits**: One-dimensional ACS G800L grism products for object 21407 in AEGIS. This is a *FITS* table. The content of the file is:

```
N Column                Description
1 'wave'                Wavelength vector
2 'flux'                Optimally extracted 1D spectrum (includes contamination)
3 'error'               Error vector
4 'contam'              Contamination vector
5 'trace'               Position of the trace
6 'etrace'              Error in the trace position
7 'sensitivity'         Sensitivity vector
```

- **aegis-39-chip2-G800L_21407.2D.png**: Diagnostic *PNG* for object 21407, showing the image thumbnail of the object from the reference image (Ext. 1 from the 2D *FITS* file), the 2D extracted spectrum (Ext. 5), the 2D model (Ext. 7), and the 2D spectrum minus the continuum model (Ext. 5 - Ext. 7).