ESO Phase 3 Data Release Description

Data Collection	HUGS_UDS_K
Release Number	1
Data Provider	Adriano Fontana
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Abstract

HUGS (an acronym for Hawk-I UDS and GOODS Survey) is a ultra–deep IR imaging survey executed with the Hawk-I imager at the VLT, that observed in the K and Y bands the UKIDSS Ultra Deep Survey (UDS) and the Great Observatories Origins Deep Survey (GOODS)-South fields covered by the CANDELS survey.

The survey is a joint project between the Rome Observatory and the University of Edinburgh, and it is based on the data collected with a dedicated ESO Large Programs (P.I. A. Fontana, ESO programme no.: 186.A-0898) but includes all the imaging data taken with Hawk-I on the UDS and GOODS-S fields (in the case of GOODS-S, the survey includes data from the ESO programme no.: 181.A-0717).

The HUGS survey was designed to cover the two CANDELS fields accessible from Paranal that do not have suitably-deep K-band images: a sub-area of UDS and GOODS-S.

The depth of the images was chosen to be 0.5*mag* shallower than obtained with the Wide Field Camera 3 (WFC3/IR) at the Hubble Space Telescope (HST) in H160, as appropriate to match the average H-K color of faint galaxies.

In the UDS field deep Y-band images have also been acquired. They are an essential complement to the CANDELS data set, since neither Y098 nor Y105 imaging of this field has been obtained within CANDELS.

This release contains deep K-band images of the UDS field and the extracted source catalogue.

Overview of Observations

UDS pointings

Thanks to its quite regular shape, the UDS CANDELS field has been straightforward to cover with Hawk-I. Three different Hawk-I pointings are able to cover 85% of the UDS field. The layout is shown in Figure1. We show the position of the three different pointings (named UDS1, UDS2 and UDS3 in the following), assuming a nominal size of 7.5 ×7.5 arcmin for the Hawk-I image. It can be seen that the three pointings also provide two overlapping regions that have been used to cross-check the photometric and astrometric solutions in the three individual mosaics. The three pointings have been exposed with nearly identical exposure times of 13 hours in the K band.

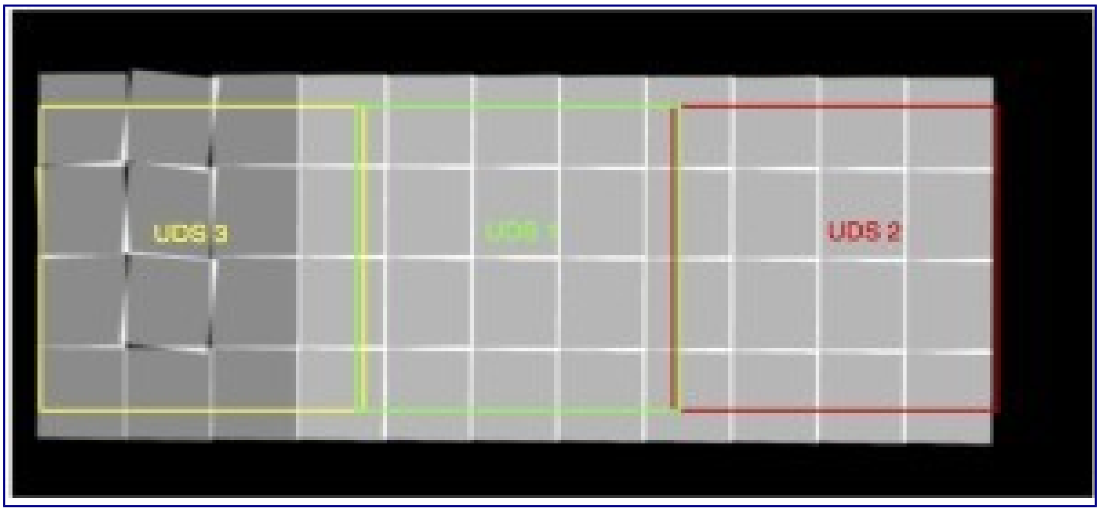

Figure 1: The location of the three Hawk-I pointings overlaid on the exposure map of the WFC3-CANDELS mosaic of the UDS. The greyscale of the WFC3/IR images is on a linear stretch from 0 to 4ks.

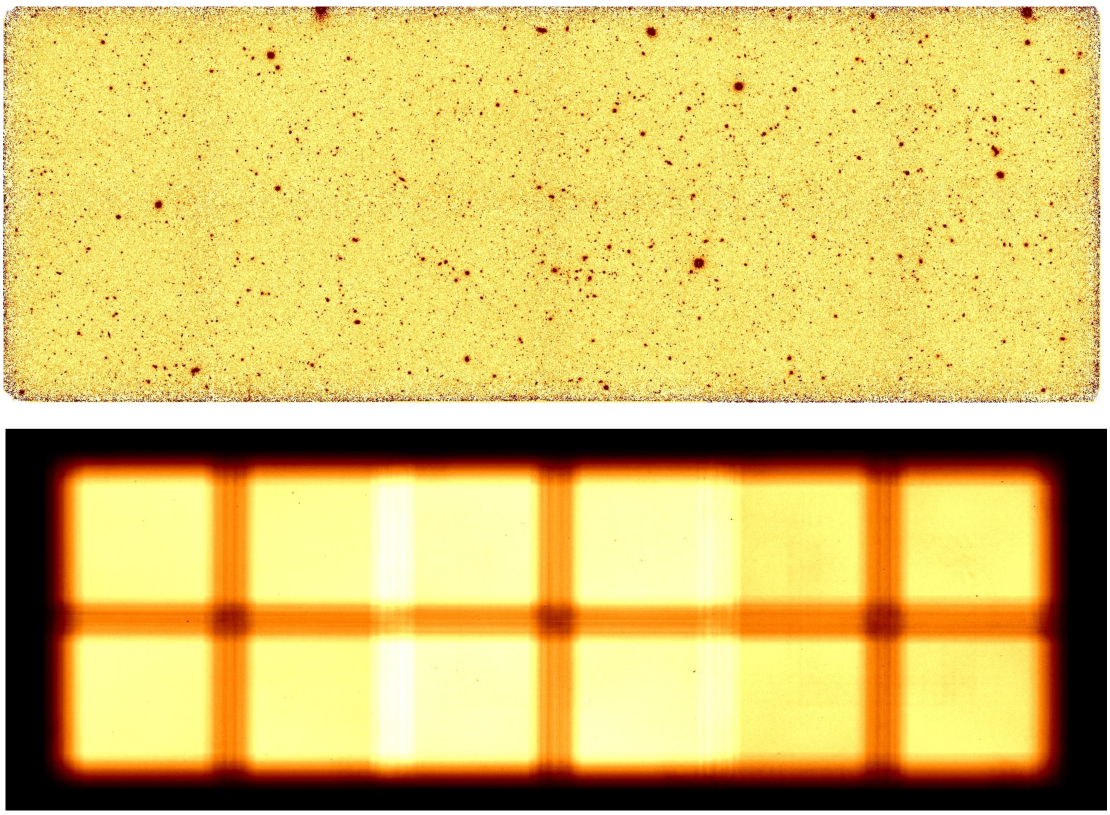

Figure 2: TOP: The final stacked image of the UDS field in the K band. BOTTOM: The weight image.

This is a brief summary of the observations this data release is based upon:

Table 1 – Summary of UDS-K observations for the various pointings

Field	**Band**	**Exposure time**	**Seeing**	**Lim. mag (AB, 1σ arcsec^{-2})**
UDS 1,2,3	K (2.2 μm)	12.5 – 13.5 hours	0.37” - 0.43”	27.3-27.4

A full data paper (Fontana et al, 2014, A&A, in press) describes the survey, where all technical details are given. Please refer to it for full details.

Release Content

The public release of the HUGS UDS K-BAND data includes coadded images of the individual pointings, as well as full mosaics and a release catalogue.

The following data set are made available:

1. **Individual mosaics (K band):** All the 3 coadded images (one for each pointing UDS1, UDS2 and UDS3) each with its own ancillary weight map are provided. Exposure times are about 12.5-13.5 hours for the three pointings.

2. **Homogenized-seeing mosaic (K band):** A global mosaic of the UDS field, obtained combining all the pointings (UDS1, UDS2, UDS3) after homogenizing to the same PSF, and its ancillary weight map are provided. This has been done by degrading the highest quality images to the one with the poorest seeing. The number of combined science data files is 1183, that is the sum of all the combined data files as shown in the summary above.
3. **Natural-seeing mosaic (K band):** A global mosaic of the UDS field, obtained combining all the pointings (UDS1, UDS2, UDS3) without any correction for the different PSFs, and its ancillary weight map are provided. These mosaic have varying PSF across the pointings (in a smooth way across the overlapping region) but do not show a varying degree of correlation in the background. The number of combined science data files is 1183, the same of the homogenized-seeing mosaic.
4. **Single K-band catalog:** We have obtained K-band detected catalog using the seeing-averaged images described above.

Please refer to the HUGS paper (Fontana et al. 2014, A&A, in press) for full details.

Release Notes

Data Reduction and Calibration.

We initially used two pipelines to independently reduce the images acquired in the first year of observations. One pipeline has been developed at the Rome Observatory, and is derived from a pipeline used to reduce LBT imaging data both in the visible and in the infrared. The second pipeline has been developed at the University of Edinburgh. We then compared the two pipelines and the resulting reduced images, both in terms of conceptual steps and algorithms adopted, as well as in terms of the final image mosaic. The two results agreed very well and this comparison was utilized to help yield a final, optimized version of the Rome pipeline. The basic steps of the pipeline follow the usual recipe of infrared imaging data reduction and can be summarized as follows:

- *Pre-reduction*. The raw images were retrieved from the ESO archive and each Observing Block was processed separately at this stage. The initial reduction procedure consists of the removal of the dark current and application of a flat-field in order to normalize the response of each image pixel. At first each scientific frame is subtracted by a median stack dark image obtained by combining a set of dark frames with the same EXPTIME and NDIT values of the observation set images. Then a median stack flat image (masterflat) is created, by combining a set of sky flats taken with the same filter as the observation set, each subtracted by its own dark. While combining, each flat is normalized by its own median background level, in order to obtain a final median stack flat normalized to unity. Each scientific image is then divided by the masterflat, so the response of pixels is finally homogenized. During this pre-reduction stage pixel masks are also created to flag saturated regions, cosmic ray events, satellite tracks and bad (hot/cold) pixels.

- *Background subtraction.* After the pre-reduction, the image backgrounds are still far from flat. Structures appear both at small and at large scales due to a variety of causes, such as pupil ghosts, dust, and sky-background variation during the observation (which is particularly strong in the near-infrared, especially in K). We have developed specialized algorithms to carefully remove these structures. Since they are assumed to be additive features, the basic operation is to create and then subtract maps of the background from each image. The first map is a sigma-clipped median-stacked image of the observations included in a temporal window – typically of about 10 minutes – around the processed image. A further large-scale polynomial fit to the residual features has been subtracted from the images. At the end of this stage, in which each Observing Block has been processed separately, images are flat and ready to be processed to create the final mosaic.

- *Astrometric solution.* In order to perform the coaddition, an accurate astrometric calibration has to be performed. In fact images show geometrical distortions arising from the positional errors of each pixel dueto many causes, such as optical distortions, atmospheric refraction, rotation of chips, non-integer dithering pattern, etc. The procedure of astrometric calibration consists of two basic operations: the correction of relative linear offsets between exposures and the refined absolute global calibration. For each exposure, a SExtractor (Bertin & Arnouts 1996) catalogue is created, and the relative linear calibration between exposures is achieved by correcting for the offsets between source coordinates, computed by the cross-matching with a catalogue chosen as reference. The absolute calibration is done by providing an absolute reference catalogue and correcting for distortions through the cross-matching of source coordinates and by storing the final corrected solution into the header of the images.

- *Estimate of absolute noise image.* Absolute noise maps for each exposure are created directly from the raw images. They are based on the assumption that the noise is given by the Poisson statistics of the counts detected in each pixel of the original frames. This contribution is propagated to take into account the scaling applied to each pixel during processing (including flat-fielding, normalization of exposure times rescaling of zero-points etc).

- *Coaddition*. Our pipeline uses SWarp (Bertin et al. (2002)) to resample all the processed images, implementing it into a procedure designed to properly propagate the absolute r.m.s. obtained as above. In order to obtain a physical exposure and an r.m.s. map of the final mosaic, during the resampling the internal WEIGHT TYPE parameter has to be set to the MAP RMS modality, so that a noise map has to be given for each exposure. During the resampling stage, images with bad astrometric information are rejected, while for each resampled image SWarp provides a weight map in output. The last step is to perform a final weighted coaddition of all the resampled images with the final associated weight and r.m.s. maps.

- *Photometric calibration*. At the end of each reduction we have adopted a careful procedure to calibrate the photometry and estimate the relative zero point independently for each pointing, making use of sets of standard stars observed at the same airmass as the scientific images, and as close as possible in time to the observations. After the relative calibration, all images (science and ancillary weight maps) were finally flux calibrated in nJy yielding AB magnitudes if a zero-point of 31.4 is adopted.

- *Catalog*. The catalogue has been obtained using the homogenized seeing mosaic. Note that this is formally correct to avoid systematic effects across the field due to inhomogeneous coverage, but somewhat limits the possibility of detecting the faintest galaxies in the pointings with the best seeing. The catalogue has been obtained with SExtractor using a minimal detection area of 9 pixels and requiring S/N>3 in such an area.

Please refer to the HUGS paper (Fontana et al. 2014, A&A, in press) for full details.

Data Quality.

Thanks to exquisite image quality and extremely long exposure times, HUGS delivers the deepest K-band images ever collected over areas of cosmological interest, and in general ideally complement the CANDELS dataset in terms of image quality and depth.

In the UDS field the average exposure time of K band is about 13.0 hours of integration, with a 1−σ magnitude limit per square arcsec of about 27.3 mags (AB). Hence, it is about one magnitude shallower than GOODS-S to match the correspondingly smaller depth of the CANDELS images, but UDS includes also the Y band, where WFC3 is lacking. The seeing is remarkably exceptional and constant across the various pointings, ranging between 0.37" and 0.43" as shown in the table:

Pointing	Central RA	Central DEC	Area (arcmin^2)	Exp. time (s/hr)	Final seeing	maglim[a]	maglim[b]
			K-band				
UDS1	02:17:37.470	−05:12:03.810	70	48360 / 13.43	0.37	27.4	26.1
UDS2	02:17:07.943	−05:12:03.810	70	46820 / 13.00	0.43	27.3	25.9
UDS3	02:18:06.896	−05:12:03.810	70	45240 / 12.57	0.41	27.4	25.9

(a) at 1σ arcsec^{-2}; (b) at 5σ in 1 FWHM

The final quality of the output data is simply spectacular, and shows that Hawk-I on VLT is capable of approaching HST performances even in the case of near-IR deep imaging, where HST is unrivaled.

Please refer to the HUGS paper (Fontana et al. 2014, A&A, in press) for full details.

Data Format

Files Types

This is a summary with the file naming conventions, the total numbers of combined science data files which yielded the imaging release data products and the associated weight maps:

Mosaic name	# of combined data files	Ancillary weight map
HUGS_UDS_K_UDS1.fits	403	HUGS_UDS_K_UDS1.wht.fits
HUGS_UDS_K_UDS1.fits	403	HUGS_UDS_K_UDS1.wht.fits
HUGS_UDS_K_UDS1.fits	377	HUGS_UDS_K_UDS1.wht.fits
HUGS_UDS_K_homogenizedseeing.fits	1183	HUGS_UDS_K_homogenizedseeing.wht.fits
HUGS_UDS_K_naturalseeing.fits	1183	HUGS_UDS_K_naturalseeing.wht.fits

This is a summary with the file naming conventions, the total number of detected sources and the total data volume related to the release catalogue:

Catalogue name	# of detected sources	Total data volume (megabytes)
HUGS_UDS_K_homogenizedseeing.ldac.fits	14373	2.7

Catalogue Columns

This is also the list of the contents of the catalogue columns:

Label	Data format	Description
SOUCE_ID	25A	HUGS source designation
NUMBER	I	Running object number
ALPHA_J2000	D	Declination of barycenter in decimal degrees (J2000)
DELTA_J2000	D	Declination of barycenter in decimal degrees (J2000)
X_IMAGE	D	Object position along x
Y_IMAGE	D	Object position along y
CLASS_STAR	E	Source classification (star, galaxy...)
MAG_BEST	E	K MAG_BEST
MAGERR_BEST	E	K MAG_BEST error
FLUX_BEST	D	K flux best
FLUXERR_BEST	D	K flux best error
MAG_APER1	E	K fixed aperture magnitude (1", AB)

MAG_APER2	E	K fixed aperture magnitude (2", AB)
MAGERR_APER1	E	K fixed aperture mag error (1", AB)
MAGERR_APER2	E	K fixed aperture mag error (2", AB)
FLUX_APER1	D	K fixed aperture flux (1", AB)
FLUX_APER2	D	K fixed aperture flux (2", AB)
FLUXERR_APER1	D	K fixed aperture flux error (1", AB)
FLUXERR_APER2	D	K fixed aperture flux error (2", AB)
MAG_ISOCOR	E	K isocor magnitude
MAGERR_ISOCOR	E	K isocor mag error
FLUX_ISOCOR	D	K isocor flux
FLUXERR_ISOCOR	D	K isocor flux error
MAG_AUTO	E	K MAG_AUTO
MAGERR_AUTO	E	K MAG_AUTO error
FLUX_AUTO	D	K auto flux
FLUXERR_AUTO	D	K auto flux error
FLUX_RADIUS	D	Radius of aperture containing half the flux of K MAG_AUTO
FLAGS	I	K Flag (SeXtractor)

Acknowledgements

Please use the following statement in your articles when using these data: Based on data products from observations made with ESO Telescopes at the La Silla Paranal Observatory under programme IDs *186.A-0898(A), 186.A-0898(C), 186.A-0898(E), 186.A-0898(G)*.