European Organisation for Astronomical Research in the Southern Hemisphere

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VERY LARGE TELESCOPE

X-shooter Imaging Mode Manual and A&G CCD Characteristics

Date: 22/01/2014
Version: 1st release v1 P93
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CHANGELOG

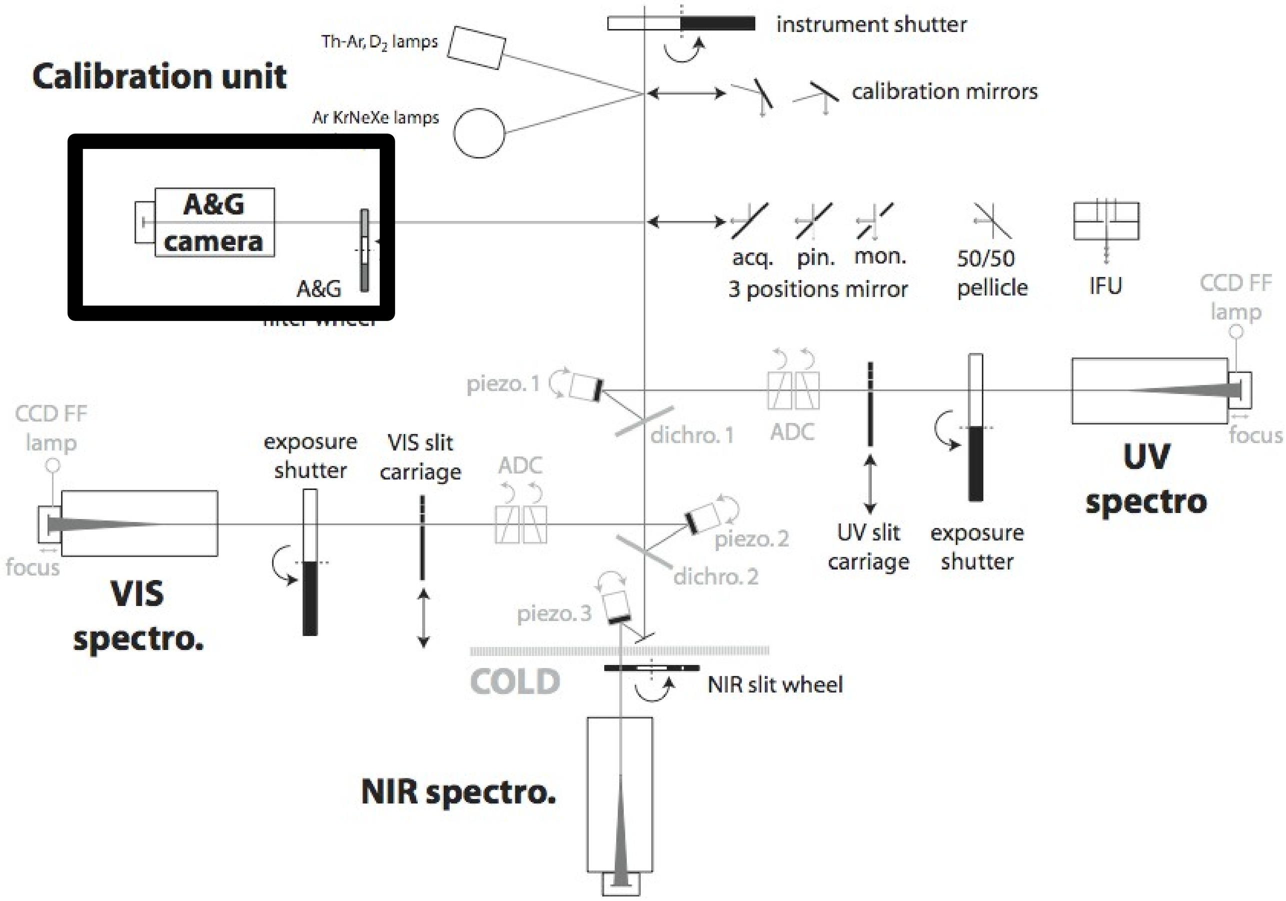
Version-Period-Date	Sections	Comments
v1-P93 27/11+16/12/2013	All	1st version, warning this is a preliminary release, some information is still missing and will come with the commissioning in January 2014.
22/01/2014	2	Small changes for some values after commissioning

1. Overview

X-shooter remains foremost a set of spectrographs, but a simple imaging mode with limited functionalities is offered to the community starting in P93. The imaging mode uses the 4th arm of X-shooter that corresponds to the Acquisition and Guiding (A&G) camera and its set of filters (see Figure 1). Acquisition images have already been used in past periods to obtain reference photometry to flux calibrate spectra in addition to the usual spectrophotometric observations. Other applications have been the determination of magnitudes of transient objects such as GRB counterparts, supernovae, and variable objects (e.g., stellar binaries and stars with exoplanets).

With the implementation of the imaging mode in P93 only one acquisition snapshot will be saved (and not after each applied offset as was previously the case). For direct target acquisition one snapshot will be saved once the acquisition process is finished. In case of a target acquisition using a blind offset one snapshot will be saved at the end of the acquisition of the reference star and one after the blind offset is performed.

Figure 1: Schematic overview of X-shooter.



2. Detector characteristics, filters, and zeropoints

The A&G unit consists of:

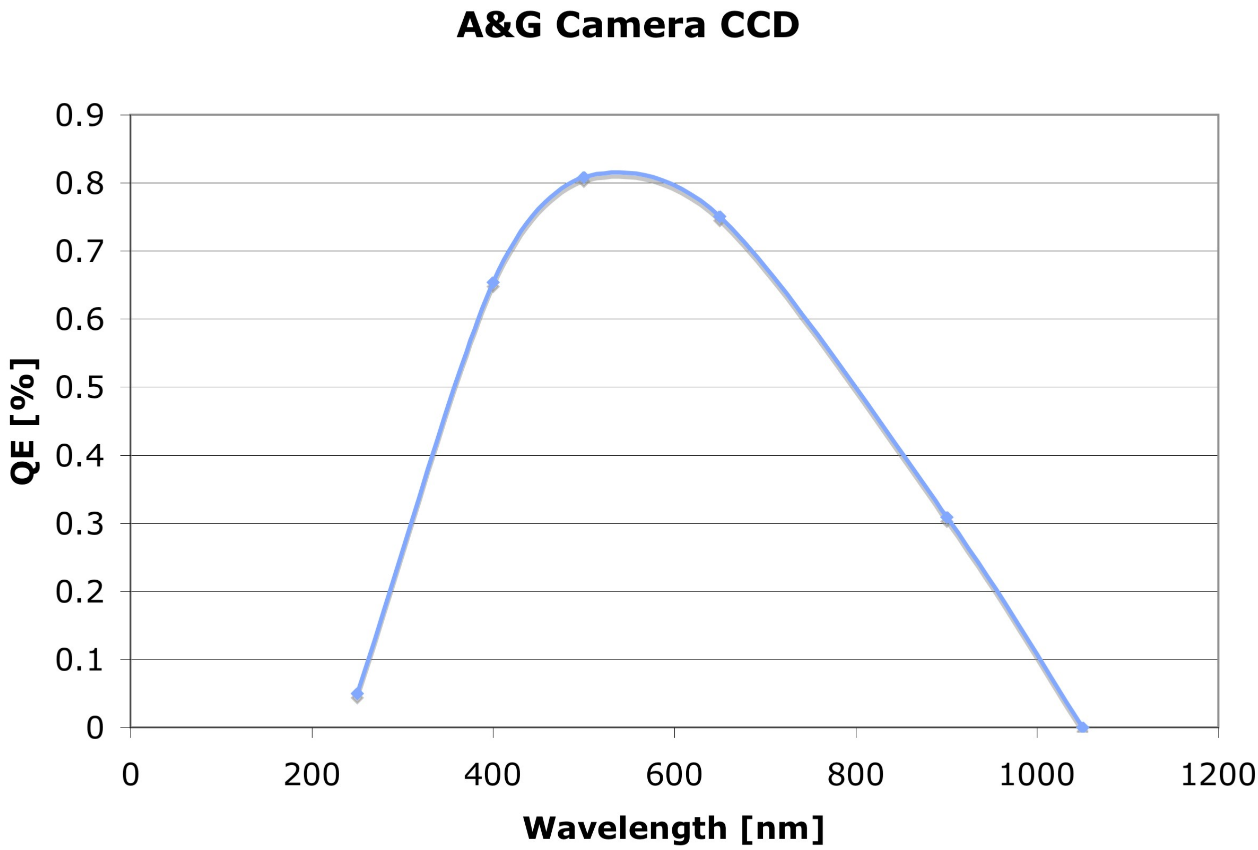
- A Pelletier cooled, 13 µm pixel, 512ξ512 E2V broad band coated Technical CCD57-10 onto which the focal plane is re-imaged at f/1.91 through a focal reducer. This setup provides a plate scale of 0.174”/pix and a field of view of 1.47’ξ1.47’.
- A filter wheel equipped with a full UBVRI Johnson filter set and a full Sloan Digital Sky Survey (SDSS) filter set.

Table 1: A&G CCD characteristics.

Detector type	E2V CCD57-10IE
Cooling system	Pelletier
QE	82 % at 580 nm, 50 % at 380 nm and 820 nm
Number of pixels	562x528
Pixel size **Pixel scale** ("/pixel) **Field of view**	13µmx13µm 0.1744 +/- 0.0016 (since P92 at UT3) 1.5'x1.5' (but filters do not cover the corners)
Gain (e^-/ADU)	4
Readout noise (e^- rms)	4.1
Saturation (ADU)	65535
Readout mode and overheads	Fast readout mode only. Wipe time: 0.01 s, readout time: 0.33 s, transfer time: 0.78 s, total time: 1.12 s.
Dark current level (ADU/pixel/h)	0.75 (exposure time of 10s)
Fringing amplitude	Not characterized yet. Depends on the filters. 3 % in I, z'
Non-linearity (ADU)	<1 % at 10000 and 50000 ADUs
ias level (ADU)	1900
Prescan and overscan areas	X: 1-26 and 538-562 Y: 1-15 and 528

TBC: to be confirmed during the commissioning in January 2014.

Figure 2: A&G CCD quantum efficiency curve.



The A&G CCD cooling system produces small oscillations of the CCD temperature. Temperature variations affect the dark current level. In case of short exposure times, when the image sampling frequency corresponds to the frequency of the temperature oscillations, this leads to “beats” and background level variations from one image to the next. These variations in background level disappear if a longer exposure time is selected. However, they do not affect the acquisition performance. In June 2011, the noise was improved and the quality of images now allows to detect objects as faint as magnitudes 25 in R and V bands in 3 min exposures and good weather conditions.

Figure 3: A&G camera filter curves.

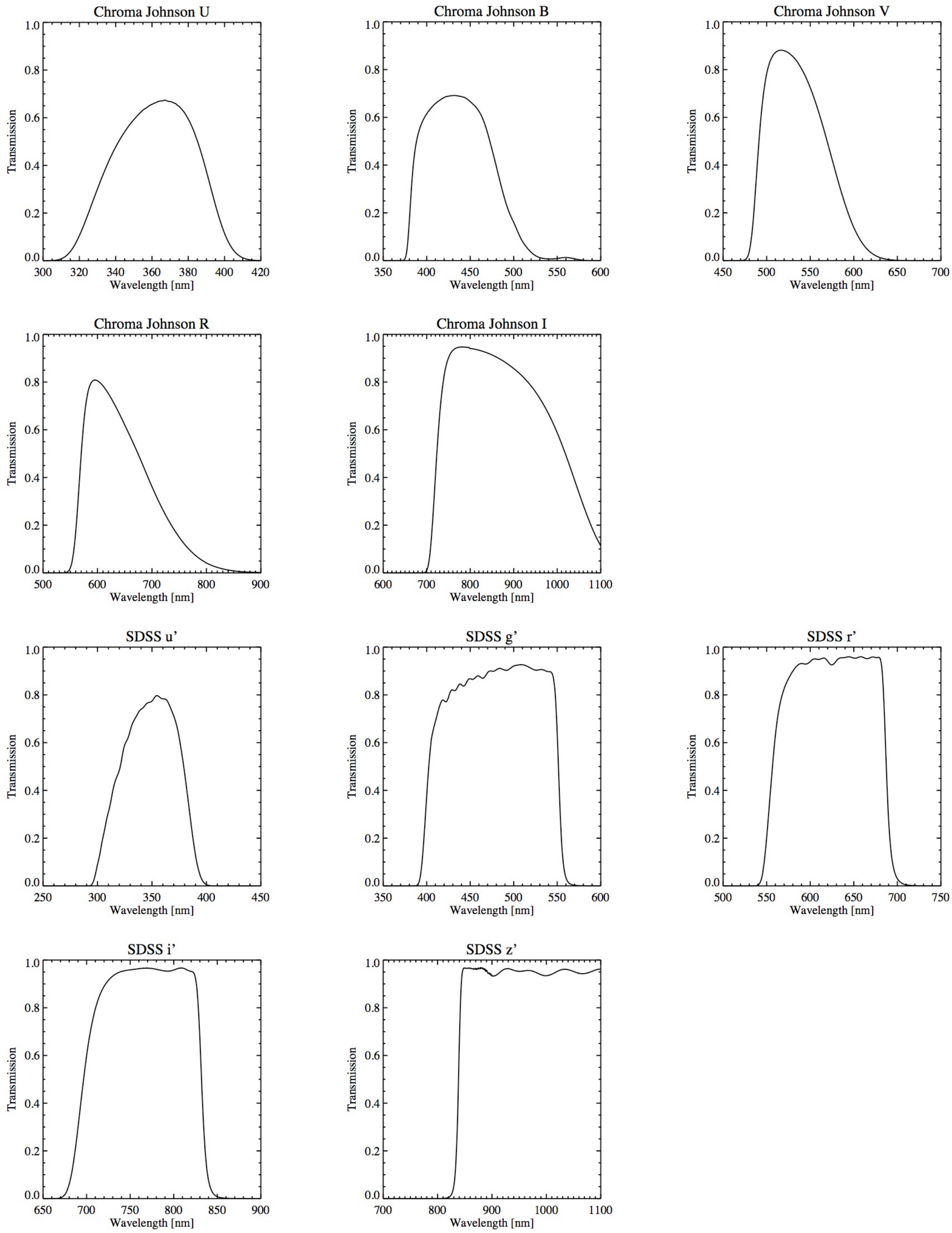


Table 2: A&G CCD zeropoints.

	U	B	V	R	I
ZP XSHOOTER (11/2013) at UT3 from P92	24.83	27.91	27.83	27.74	27.36
ZP XSHOOTER (07/2011) at UT2 till P91	24.95	27.74	27.63	27.83	27.49
ZP FORS2	24.31	27.68	28.09	28.32	27.67

Note: The A&G CCD zeropoints were determined for the Johnson filters under photometric conditions.The accuracy of the ZP X-shooter magnitudes determined with at UT3 are about 0.1 mag, at UT2 about 0.1-0.3 mag depending on the filters. FORS2 zeropoints are shown for comparison.

3. Calibration plan and observing strategies

a) Imaging mode acquisition and exposure times

A basic imaging observing block (OB) consists of a slit or IFU acquisition template, followed by science and/or calibration imaging templates. However, pure imaging OBs are approved only in visitor mode. Exceptions in service mode are observations of standard fields for zeropoint determination or distortion maps. In service mode, OBs can contain imaging templates in addition to the standard slit or IFU science spectral templates.

There is no ETC support for the imaging mode. We recommend to scale the exposures times using the limiting magnitudes listed in Table 3. These magnitudes were obtained under relatively bad weather conditions (thin cirrus, full Moon, seeing about 0.7”).

Those 2 paragraphs mostly concern the spectroscopic acquisition but are kept for information. The table 4 already provides few clues about S/N and exposure times but will be revised during the commissioning in January 2014:
We recommend to use blind offset acquisitions in case the object is fainter than 22-22.5 mag, especially if relaxed weather constraints were selected such as thin/thick transparency and seeing worse than 0.7”. In case of a blind offset acquisition, we recommend to select a reference star with a magnitude of 19 mag or brighter to ensure good centering.

Table 3 lists recommended exposure times for a set of magnitudes. These integration times should suffice for a direct acquisition in case of clear sky conditions, dark time, and 0.8” seeing. However, in case of very faint objects, a blind offset acquisition is the best solution as it shortens the acquisition overheads.

Table 3: Limiting magnitudes for a direct acquisition.

U	B	V	R	I
22	22	22.5	22.5	22.5
30 s	30 s	20 s	20 s	20 s

Table 4: Recommended exposure times for the A&G CCD (S/N>5).

V (mag)	6	7	16-20	23	>=24
Exposure time (s)	0.001	0.005	1-5	60-120	>=180

Note: These exposure times will be revised in the coming months.

b) Observing strategies

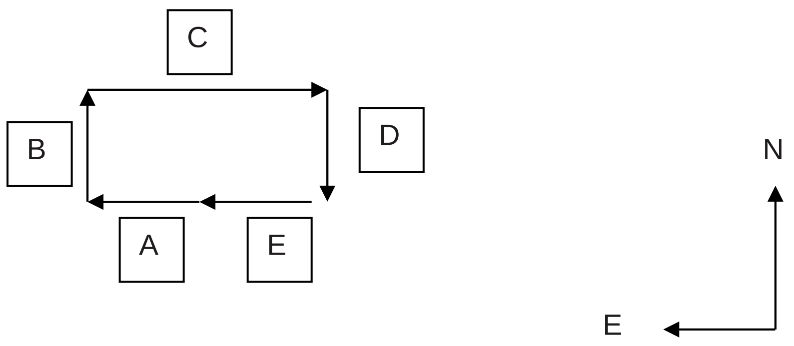
Two science templates are offered in P93:
1. *XSHOOTER_img_obs*: STARE mode observation, i.e., the object stays on the same detector pixel.
2. *XSHOOTER_img_obs_GenericOffset:* GENERIC-OFFSET mode observations, i.e., mapping or jittering around the area of interest.

Table 5: Imaging science templates.

	Templates	Readout speed and binning	List of filters	Angles
IMAGING	STARE GENERIC-OFFSET	Fast readout, binning 1x1	UBVRI u’,g’,r’,i’,z’	9999=parallactic angle or defined angle on sky

It is recommended to use the *XSHOOTER_img_obs_GenericOffset* template. This template results in better correction of the sky background and the dust marks present on the detector. One can define a sequence of small offsets as shown in the following example. Offsets are given in arcsec, but the reference system can be chosen to be the sky (Alpha,Delta) or X-shooter detector coordinate system (X,Y). Offset conventions are illustrated below. Templates use **cumulative offsets;** the position at a given time is derived from the *sum* of all offsets specified so far in the template. For example, the series of offsets: 0, -10, 0, 10 brings the telescope back to the original position for the last exposure.

Figure 4: Offset example.



Note: Offsets A = (RA = +10”, DEC = 0”); B = (RA = 0”, DEC = +10”); C = (RA = -20”, DEC = 0”); D = (RA = 0”, DEC = -10”); E = (RA = +10”, DEC = 0”) bring the telescope back to the original position.

c) Calibration plan

The calibration plan is defined below. It may evolve in the next months/periods.

Table 6: Calibration plan.

Type of calibration	**Template**	**Frequency**
Day: bias	XSHOOTER_img_cal_Dark	10, daily
Day: dark	XSHOOTER_img_cal_Dark	on request, 3x1200s, monthly currently : 3x10s weekly
Day: linearity	XSHOOTER_img_cal_DetLin	Monthly currently : weekly
Night: twilight flats	XSHOOTER_img_cal_Flat	10, monthly*
Night: zeropoints	XSHOOTER_img_obs_cal_phot	once per year or user provided
Night : distortion map	XSHOOTER_img_obs_cal_dist	once per year or user provided

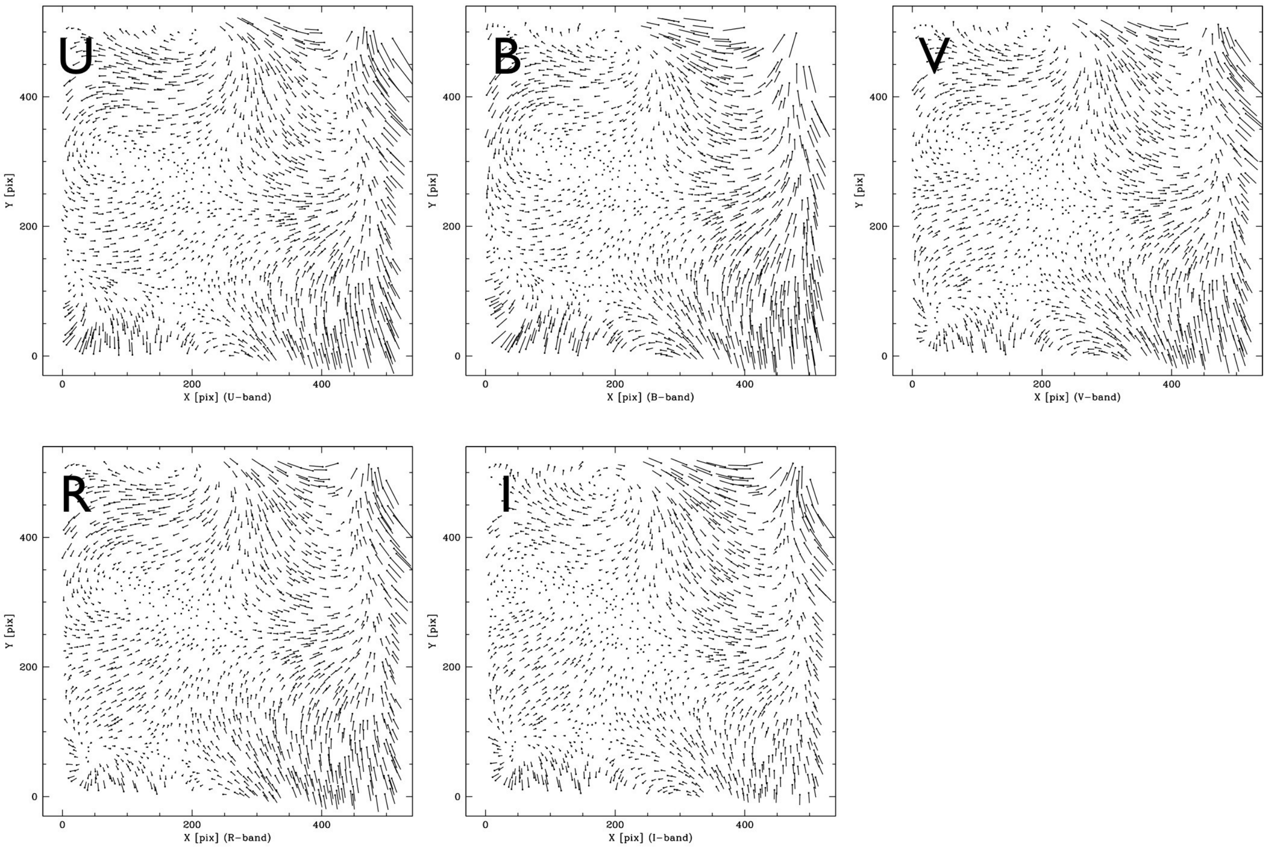
*The count levels of the twilight flats should be between 10000 and 55000 ADUs. In P93 they will be taken pointing to empty sky positions while until P92 they are taken at the zenith (thus star traces may be possible).

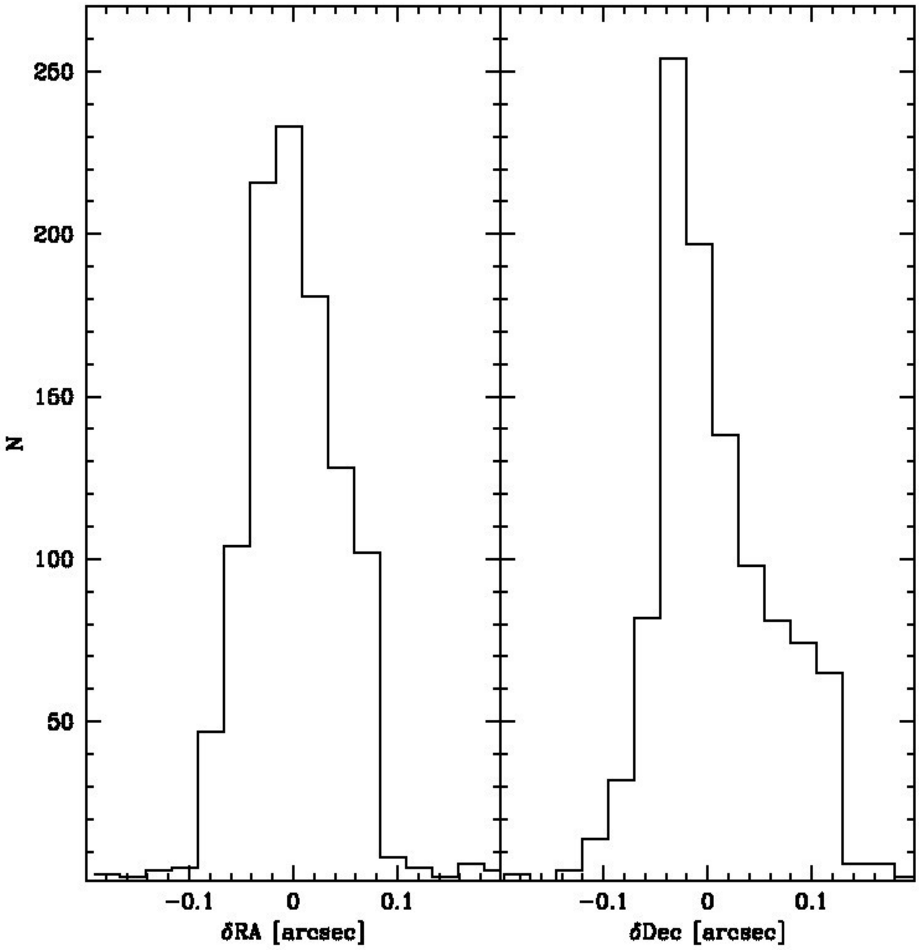
The QC scientist will provide some additional Health Check plots for the A&G CCD concerning the gain, readout noise, fixed pattern noise, dark current, and nonlinearity.

4. Distortion map and astrometric accuracy

Figure 5 shows the distortion maps of the TCCD with respect to the 2MASS astrometry.

Figure 5: UBVRI distortion maps magnified x20.

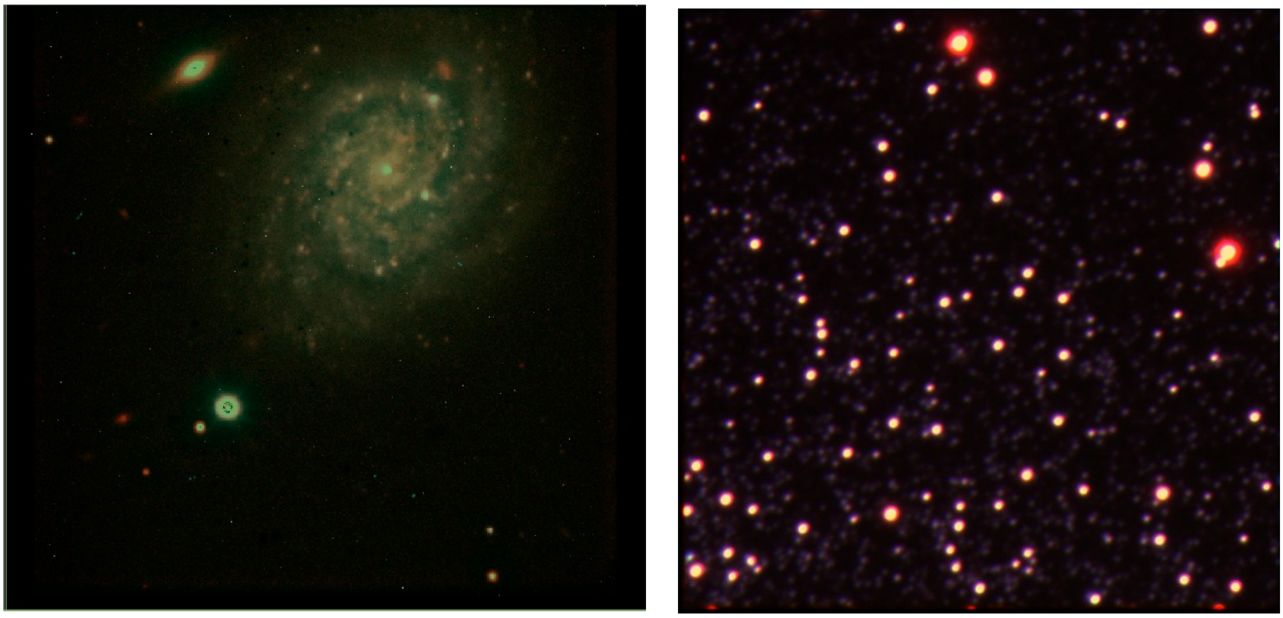




Distributions in RA and DEC of the difference between 2MASS and the AGCCD astrometry. The difference between 2MASS and the A&G CCD astrometry is +-0.1".

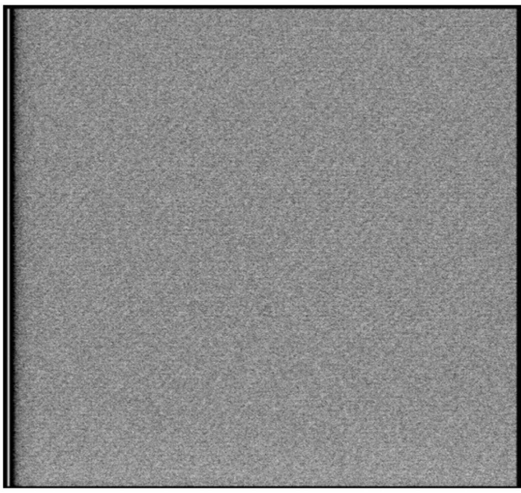
5. Calibration frames overview and examples

Figure 6: Three color (BVI) image of a galaxy with a supernova (left) and of a small field of 47Tuc (right).

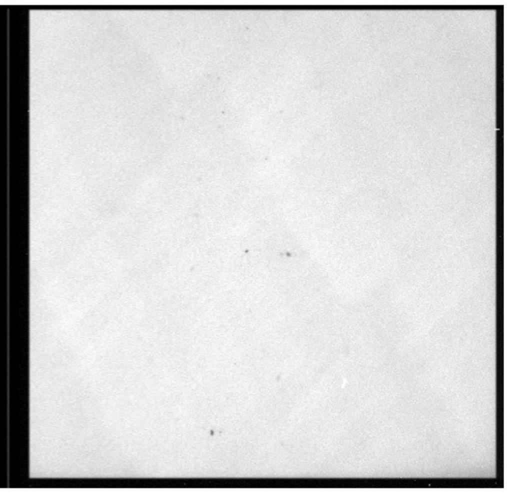


Observations were performed in stare mode.

Figure 7: Example calibration images.



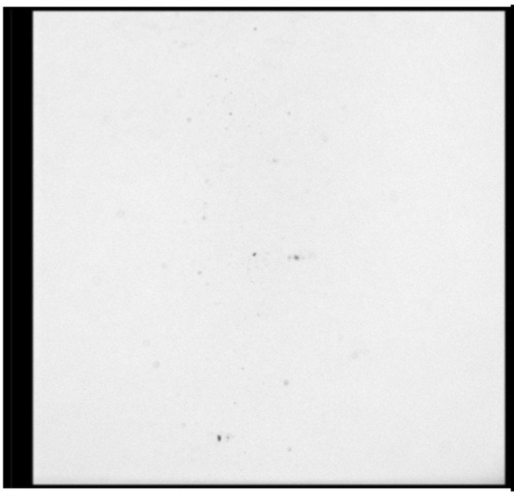
A&G CCD bias.



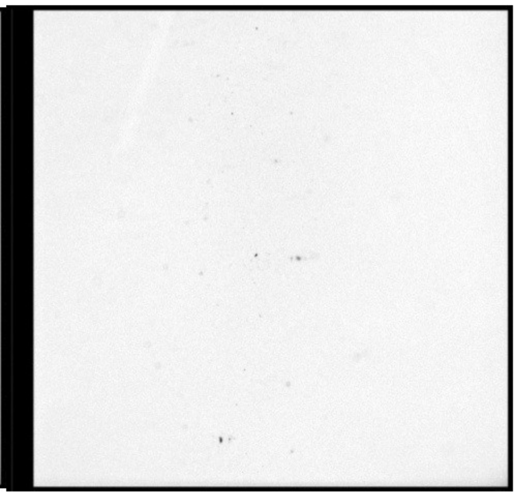
A&G CCD twilight U band flatfield.

A&G CCD twilight B band flatfield.

A&G CCD twilight V band flatfield.



A&G CCD twilight R band flatfield.



A&G CCD twilight I band flatfield.

6. Data reduction

No pipeline support will be provided for the imaging data as there are lots of tools to reduce imaging data, extract the objects, and do the photometry. Pipeline support will be provided for the detector linearity determination only. Below are some basic guidelines of imaging data reduction with IRAF and the swarp software:

0) Preliminary steps

- Inspect the images, reject the flat-fields with too many stars or star traces.
- Create files listing the frames per type.
- Make sure to use darks and flatfields with the same integration times.

1) Create the masterbias

- In IRAF, use the imcombine task to median combine the bias images.

```
cmartayan@nb015045:~/duties/xshooter/moveUT2to...
                                   I R A F
                      Image Reduction and Analysis Facility
PACKAGE = immatch
   TASK = imcombine

input   =          @listebias  List of images to combine
output  =     masterbias.fits  List of output images
(headers=                    ) List of header files (optional)
(bpmasks=                    ) List of bad pixel masks (optional)
(rejmask=                    ) List of rejection masks (optional)
(nrejmas=                    ) List of number rejected masks (optional)
(expmask=                    ) List of exposure masks (optional)
(sigmas =                    ) List of sigma images (optional)
(imcmb  =                 $I) Keyword for IMCMB keywords
(logfile=             STDOUT) Log file

(combine=             median) Type of combine operation
(reject =             minmax) Type of rejection
(project=                 no) Project highest dimension of input images?
(outtype=               real) Output image pixel datatype
(outlimi=                   ) Output limits (x1 x2 y1 y2 ...)
(offsets=               none) Input image offsets
(masktyp=               none) Mask type
(maskval=                  0) Mask value
(blank  =                 0.) Value if there are no pixels

(scale  =               none) Image scaling
(zero   =               none) Image zero point offset
(weight =               none) Image weights
(statsec=                   ) Image section for computing statistics
(expname=                   ) Image header exposure time keyword

(lthresh=              INDEF) Lower threshold
(hthresh=              INDEF) Upper threshold
(nlow   =                  1) minmax: Number of low pixels to reject
(nhigh  =                  1) minmax: Number of high pixels to reject
(nkeep  =                  1) Minimum to keep (pos) or maximum to reject (neg)
(mclip  =                yes) Use median in sigma clipping algorithms?
(lsigma =                 3.) Lower sigma clipping factor
(hsigma =                 3.) Upper sigma clipping factor
(rdnoise=                 0.) ccdclip: CCD readout noise (electrons)
(gain   =                 1.) ccdclip: CCD gain (electrons/DN)
(snoise =                 0.) ccdclip: Sensitivity noise (fraction)
(sigscal=                0.1) Tolerance for sigma clipping scaling corrections
(pclip  =               -0.5) pclip: Percentile clipping parameter
(grow   =                 0.) Radius (pixels) for neighbor rejection
(mode   =                 ql)
```

2) Optionally: create the masterdark

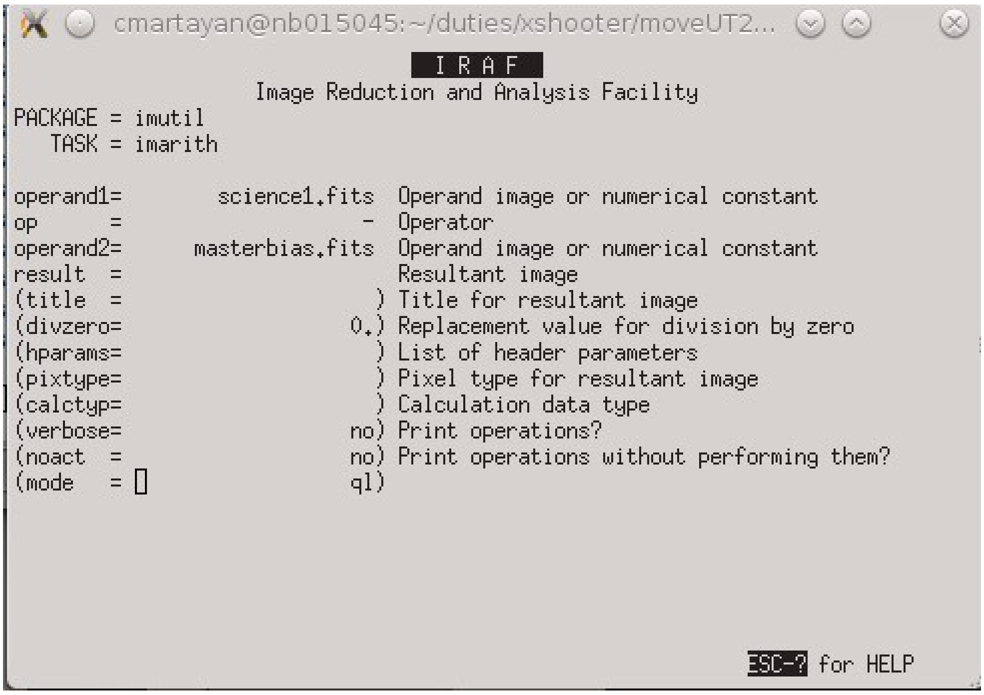
- Same than 1) for combining the images.

3) Create the masterflatfield

- Same than 1) for combining the images.
- Determine the count level with the IRAF imstat task.
- Normalize the image with the imarith task to obtain the master flatfield.

4) Correct the science images for bias, dark, and flatfield

- Use the imarith task.



5) Stack the science images WCS based: use swarp

It is possible to use the IRAF tasks imstack or imcombine to combine the science images. However, it has been shown that IRAF does not always properly handle large images or the WCS. Therefore, we recommend to use the swarp software from astromatic (ex-TERAPIX) from E. Bertin (http://www.astromatic.net/software/swarp).

Syntax:
swarp @liste_files_images -c configuration_file

the configuration_file contains all the parameters needed for the creation of the mosaic taking into account the WCS and recomputing it.

In the file liste_files_images: list all images that are needed for the mosaic.

7. Templates manual

a) Approved template combinations

VM only	XSHOOTER_img_acq+ XSHOOTER_img_obs, XSHOOTER_img_obs_GenericOffset
SM	XSHOOTER_img_acq+ XSHOOTER_img_cal_phot and/or XSHOOTER_img_cal_dist
	XSHOOTER_slt_acq* + 1 SLT science or std template Possibility to add: XSHOOTER_img_obs, XSHOOTER_img_obs_GenericOffset, XSHOOTER_img_cal_phot, XSHOOTER_img_cal_dist
	XSHOOTER_ifu_acq* + 1 IFU science or std template Possibility to add: XSHOOTER_img_obs, XSHOOTER_img_obs_GenericOffset, XSHOOTER_img_cal_phot, XSHOOTER_img_cal_dist

b) Template description

NIGHTIME IMAGING TEMPLATES:

Imaging acquisition template (also allows blind offset)

XSHOOTER_img_acq.tsf

To be specified:

Parameter	Hidden	Range *(Default)*	Label
DET4.WIN1.UIT1	no	0..36000 *(1)*	TCCD Exposure time
DPR.CATG	yes	*(ACQUISITION)*	Data Prod. Cath.
DPR.TECH	yes	*(IMAGE)*	Data Prod. Tech.
DPR.TYPE	yes	*(OBJECT)*	Data Prod. Type
INS.FILT1.NAME	no	u_prime g_prime r_prime i_prime z_prime U B V R I *(V)*	G Filter
SEQ.PRESET	yes	F T *(T)*	Preset flag
TEL.AG.GUIDESTAR	no	CATALOGUE SETUPFILE NONE *(CATALOGUE)*	Get Guide Star from
TEL.GS1.ALPHA	no	ra *()*	RA of guide star
TEL.GS1.DELTA	no	dec *()*	DEC of guide star
TEL.ROT.OFFANGLE	no	-179.99..179.99 9999.0 *(9999.0)*	Position Angle on Sky
TEL.TARG.ADDVELALPHA	yes	*(0.0)*	Additional Velocity RA in arcsec/s on the sky
TEL.TARG.ADDVELDELTA	yes	*(0.0)*	Additional Velocity DEC in arc-sec/s on the sky
TEL.TARG.ALPHA	no	ra *(000000.000)*	RA
TEL.TARG.DELTA	no	dec *(000000.000)*	DEC
TEL.TARG.EPOCH	no	1950 2000 *(2000)*	Epoch
TEL.TARG.EQUINOX	no	QUERY-TARG getEquinoxList *(2000)*	Equinox
TEL.TARG.OFFSETALPHA	no	-36000..36000 *(0.)*	Offset RA
TEL.TARG.OFFSETDELTA	no	-36000..36000 *(0.)*	Offset DEC
TEL.TARG.PMA	yes	-10..10 *(0)*	Proper motion in RA
TEL.TARG.PMD	yes	-10..10 *(0)*	Proper motion in DEC

Parameter	Hidden	Value	Label

Science STARE imaging observation

XSHOOTER_img_obs.tsf			
To be specified:			
Parameter	Hidden	Range *(Default)*	Label
DET4.WIN1.UIT1	no	0..36000 *(1)*	TCCD Exposure time
DPR.CATG	no	*(SCIENCE)*	Data Prod. Cath.
DPR.TECH	no	*(IMAGE)*	Data Prod. Tech.
DPR.TYPE	no	*(OBJECT)*	Data Prod. Type
INS.FILT1.NAME	no	u_prime g_prime r_prime i_prime z_prime U B V R I *(V)*	G Filter
SEQ.NEXPO	no	0..1000 *(1)*	Number of exposures

Parameter	Hidden	Value	Label

Science Generic-OFFSET imaging observation

XSHOOTER_img_obs_GenericOffset.tsf			
To be specified:			
Parameter	Hidden	Range *(Default)*	Label
DET4.WIN1.UIT1	no	0..36000 *(1)*	TCCD Exposure time
DPR.CATG	yes	*(SCIENCE)*	Data Prod. Cath.
DPR.TECH	yes	*(IMAGE)*	Data Prod. Tech.
DPR.TYPE	yes	*(OBJECT,OFFSET)*	Data Prod. Type
INS.FILT1.NAME	no	u_prime g_prime r_prime i_prime z_prime U B V R I *(V)*	G Filter
SEQ.NEXPO	no	0..100 *(1)*	Number of exposures
SEQ.NOFFSET	no	1..100 *(2)*	Number of offsets
SEQ.OBS.TYPE	no	*(O S)*	List of TYPE offsets: e.g. O S S O O S ...
SEQ.OFFSET.COORDS	no	SKY DETECTOR *(SKY)*	Offset coord type (RA/DEC - X/Y) in arcsec
SEQ.OFFSET.ZERO	no	T F *(T)*	Go to zero offset position at the end
SEQ.RELOFF1	no	-1000..1000 *(1)*	List of RA/X offsets
SEQ.RELOFF2	no	-1000..1000 *(1)*	List of DEC/Y offsets

Parameter	Hidden	Value	Label

Calibration template for observation of standard field for distortion map (same functionality as the science imaging generic-offset template)

XSHOOTER_img_obs_cal_dist.tsf			
To be specified:			
Parameter	Hidden	Range *(Default)*	Label
DET4.WIN1.UIT1	no	0..36000 *(1)*	TCCD Exposure time
DPR.CATG	yes	*(CALIB)*	Data Prod. Cath.
DPR.TECH	yes	*(IMAGE)*	Data Prod. Tech.
DPR.TYPE	yes	*(STD,ASTROMETRY)*	Data Prod. Type
INS.FILT1.NAME	no	u_prime g_prime r_prime i_prime z_prime U B V R I *(V)*	G Filter
SEQ.NEXPO	no	0..100 *(1)*	Number of exposures
SEQ.NOFFSET	no	1..100 *(2)*	Number of offsets
SEQ.OBS.TYPE	no	*(O S)*	List of TYPE offsets: e.g. O S S O O S ...
SEQ.OFFSET.COORDS	no	SKY DETECTOR *(SKY)*	Offset coord type (RA/DEC - X/Y) in arcsec
SEQ.OFFSET.ZERO	no	T F *(T)*	Go to zero offset position at the end
SEQ.RELOFF1	no	-1000..1000 *(1)*	List of RA/X offsets
SEQ.RELOFF2	no	-1000..1000 *(1)*	List of DEC/Y offsets

Parameter	Hidden	Value	Label

Calibration template for observation of standard fields for zeropoint determination (same functionality as the science imaging generic-offset template)

XSHOOTER_img_obs_cal_phot.tsf			
To be specified:			
Parameter	Hidden	Range *(Default)*	Label
DET4.WIN1.UIT1	no	0..36000 *(1)*	TCCD Exposure time
DPR.CATG	yes	*(CALIB)*	Data Prod. Cath.
DPR.TECH	yes	*(IMAGE)*	Data Prod. Tech.
DPR.TYPE	yes	*(STD,FLUX)*	Data Prod. Type
INS.FILT1.NAME	no	u_prime g_prime r_prime i_prime z_prime U B V R I *(V)*	G Filter
SEQ.NEXPO	no	0..100 *(1)*	Number of exposures
SEQ.NOFFSET	no	1..100 *(2)*	Number of offsets
SEQ.OBS.TYPE	no	*(O S)*	List of TYPE offsets: e.g. O S S O O S ...
SEQ.OFFSET.COORDS	no	SKY DETECTOR *(SKY)*	Offset coord type (RA/DEC - X/Y) in arcsec
SEQ.OFFSET.ZERO	no	T F *(T)*	Go to zero offset position at the end
SEQ.RELOFF1	no	-1000..1000 *(1)*	List of RA/X offsets
SEQ.RELOFF2	no	-1000..1000 *(1)*	List of DEC/Y offsets

Parameter	Hidden	Value	Label

DAYTIME IMAGING TEMPLATES

Calibration template for biases (DET4.WIN1.UIT1 = 0 s) and darks (DET4.WIN1.UIT1 > 0 s)

XSHOOTER_img_cal_Dark.tsf			
To be specified:			
Parameter	Hidden	Range *(Default)*	Label
DET4.WIN1.UIT1	no	0..36000 *(1)*	TCCD Exposure time
DPR.CATG	yes	*(CALIB)*	Data Prod. Cath.
DPR.TECH	yes	*(IMAGE)*	Data Prod. Tech.
DPR.TYPE	yes	*(BIAS)*	Data Prod. Type
SEQ.NEXPO	no	0..100 *(1)*	Number of exposures
Fixed values:			
Parameter	Hidden	Value	Label

Calibration template for twilight flatfields

XSHOOTER_img_cal_Flat.tsf			
To be specified:			
Parameter	Hidden	Range *(Default)*	Label
DET4.WIN1.UIT1	no	0..36000 *(1)*	TCCD Exposure time
DPR.CATG	yes	*(CALIB)*	Data Prod. Cath.
DPR.TECH	yes	*(IMAGE)*	Data Prod. Tech.
DPR.TYPE	yes	*(FLAT,SKY)*	Data Prod. Type
INS.FILT1.NAME	yes	u_prime g_prime r_prime i_prime z_prime U B V R I PV(B) PV(V) *(V)*	G Filter
SEQ.NEXPO	no	0..100 *(1)*	Number of exposures
Parameter	Hidden	Value	Label

Calibration template to measure the detector gain and linearity

XSHOOTER_img_cal_DetLin.tsf			
To be specified:			
Parameter	Hidden	Range *(Default)*	Label
DET4.WIN1.UIT1	no	0..36000 *(1)*	TCCD Exposure time
DPR.CATG	yes	*(CALIB)*	Data Prod. Cath.
DPR.TECH	yes	*(IMAGE)*	Data Prod. Tech.
DPR.TYPE	yes	*(FLAT,LINEARITY,DETCHAR)*	Data Prod. Type
INS.FILT1.NAME	no	u_prime g_prime r_prime i_prime z_prime U B V R I PV(B) PV(V) *(V)*	G Filter
SEQ.EXPO.STEP	no	0..3600 *(1)*	Exposure time step
SEQ.NEXPO	no	1..100 *(1)*	Number of exposures
SEQ.NLOOP	no	1..100 *(2)*	Number of loops (pairs)
Parameter	Hidden	Value	Label