Subaru Telescope High Dispersion Spectrograph(HDS) User Manual

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W. Aoki, K. Hełminiak, A. Tajitsu
National Astronomical Observatory of Japan
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Change Record

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1st release 13/3/2001
2nd release 14/9/2001
3rd release 5/9/2002 (Updated the throughput of the blue image rotator)
4th release 11/2/2014 (Many major updates, including image slicers, throughput, ETC, format calculator, data access and others. [KGH])

1. Introduction

The High Dispersion Spectrograph (HDS) is located at one of the Nasmyth foci of the Subaru telescope. The maximum resolving power of HDS is 165,000 for the optical wavelength region (3000~10000 Å). HDS was constructed as a first-generation instrument for the Subaru telescope, and has successfully achieved first-light in July 2000. Open use of this instrument has started in April 2001.

1.1 Contents of this User Manual and References

This document explains procedures for observation preparation, and the usual operation and data reduction tasks to be employed by HDS users in the open use phase. In Section 2, the structure and performance of the spectrograph and pre-slit instruments (e.g., image rotators, calibration sources) are described. The parameters users need to specify for setup of the instrument are described in Section 3, as well as the methods needed to determine the parameters and the exposure time. The tasks that users need to carry out during observation and the format of CCD data obtained with HDS are described in Section 4.

The tasks that HDS users need to carry out include the specification of the HDS setup, the exposure times for astronomical targets, and the identification of the calibration data required. The operation of the telescope and the instrument will actually be performed by operators located at the observatory. See *HDS Operation Manual* (T.B.D.) for details of the operation of HDS, and *High Dispersion Spectrograph (HDS) - Optical and Mechanical Designs* for details of the structure of the instrument.

1.2 Abbreviations and Acronyms

HDS: High Dispersion Spectrograph Messia: CCD control and data acquisition system for the Subaru instruments
OBCP: Instrument (HDS) control computer
OBS: Observation control computer
ADC: Atmospheric Dispersion Compensator
SV: Slit Viewer
AG: Camera for Auto Guiding
CAL: CALibration sources
IMR: IMage Rotator
TSC: Telescope control computer
IS: Image Slicer

2. Instrument Characteristics

2.1 Characteristics of the Echelle Spectrograph

The Echelle spectrograph enables us to obtain high-resolution spectra by a comparatively wide entrance slit using the higher orders of an *echelle* grating. Because of the high order numbers, light from different orders overlaps in the beam dispersed by the echelle grating. In order to resolve this overlapping, a lower dispersion grating (a so-called *cross disperser*) that disperses light in the direction perpendicular to the dispersion direction of the echelle is used (see Figure 1).

One strong point of the echelle spectrograph is its wide wavelength coverage, as the spectrum is "folded up" and recorded in a two-dimensional detector. Examples of the spectrum format are shown in Figure 7a, and in the Appendices (Section 5).

In general, a given wavelength appears in several spectra of different echelle orders. However, as the spectrum of each order has a blaze profile similar to a sinc function, the wavelength region which can be efficiently measured is limited. Usually, the efficiency is significantly different from one order to another. The wavelength range in one spectrum which does not overlap the similar range in the neighboring order spectra is called as the *free spectral range*, and can be represented by λ/m, where λ means wavelength and m means order number. The spectrum formats in Figure 7a is shown for the free spectral range. If the free spectral range is covered by the detector, a complete spectrum with full wavelength range can be obtained without any gaps.

For a cross disperser with higher dispersion, the interval between orders is wider and the number of the orders observed with a detector is smaller. Thus, the maximum slit length without any overlap of orders is larger but the wavelength coverage is narrower when the higher dispersion cross disperser is used. On the other hand, for the lower dispersion cross disperser, the interval between orders is narrower and the slit length is more limited. As a result, the observable region in the sky is narrower when the lower dispersion cross disperser is used. Thus, the choice of the appropriate cross disperser should consider these characteristics.

2.2 The HDS System

HDS is located at one of the Nasmyth foci (the so-called Optical Nasmyth) of the Subaru Telescope. Image rotators, calibration lamps (CAL), image slicer (IS), and an atmospheric dispersion compensator (ADC) are located ahead of the slit. In this subsection the HDS system is described following the order along the optical path of the beam. The important parameters of the optical elements and the detector are given in Table 1. The pre-slit unit elements and functions are explained in Section 2.4.

Table 1: System of HDS		
		Characteristics
Slit	length	1000~30000 μm (2-60arcsec)
	width	10~2000 μm (0.02-4arcsec)
Filter	1	ND1, ND2, SQ, OG530, KV408
	2	SC46, SC42, GG495, KV389, KV370
shutter		shortest exposure is 1 sec.
collimator	red	off-axis parabola
	blue	off-axis parabola
echelle		31.6 grooves/mm, blaze angle 71.25 degrees
cross disperser	red	250 grooves/mm, blaze angle 5.00 degrees
	blue	400 grooves/mm, blaze angle 4.76 degrees
	mirror	
camera system		focal length 770 mm
detector		EEV CCD 4100 pix × 2048 pix × 2, 13.5 μm/pix

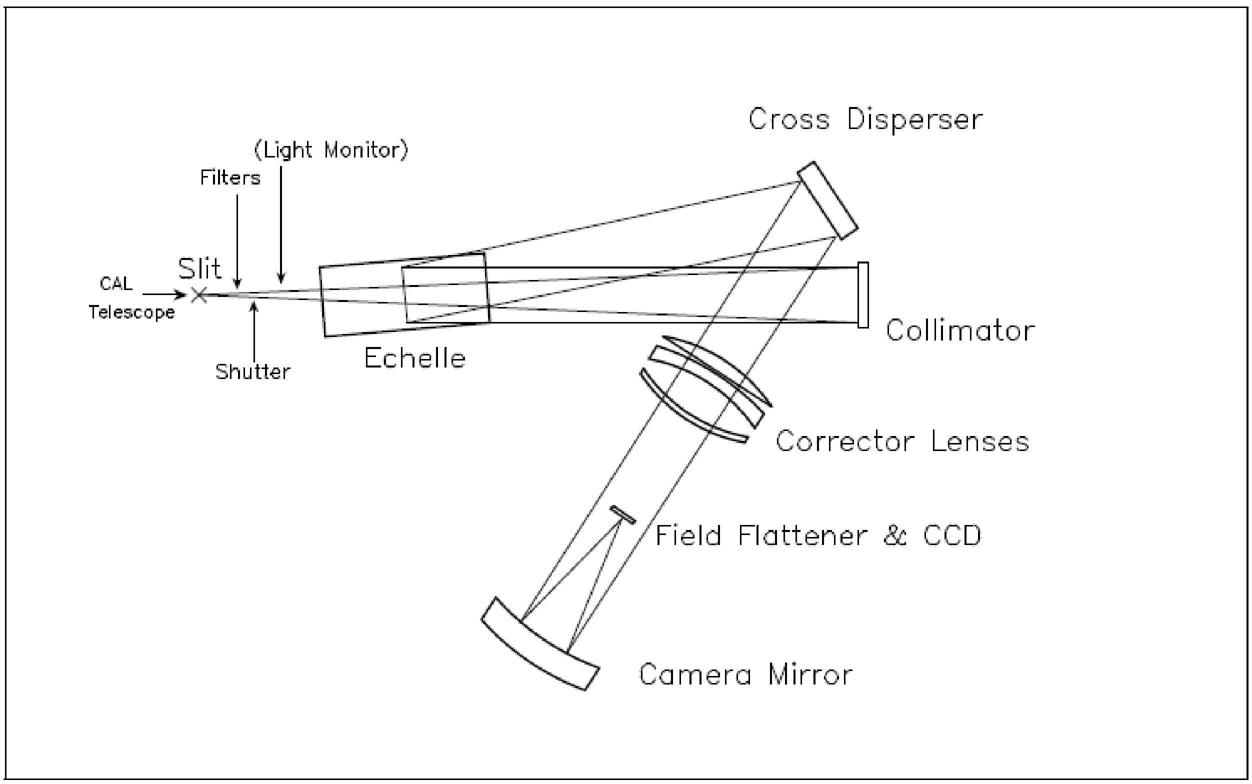

Figure 1: Optical layout of HDS

- Slit unit:

The length and width of the slit can be continuously changed.

Two filter wheels are mounted just behind the slit. Users select one of six filters (including an open filter) in each wheel.

An entrance shutter is located behind the filters for exposure control. Note that HDS has no shutter in front of the detector. Hartman shutters, used for focusing of the spectrograph, are mounted just behind the entrance shutter.

- *[Currently unavailable]* Light monitor unit:

The light monitor is used to measure the flux-weighted time of the exposition, used for precise bary- and heliocentric time and velocity corrections. In normal operation this subsystem is retracted. See Section 2.6 for details.

- Collimator:

The f/12 light cone is collimated into a 27cm beam with a collimator mirror mounted 3.3m away from the slit. Users select one of the two collimator mirrors, optimized for either the blue or red regions. Note that the collimator unit can slightly shift relative to the direction of the slit for focusing corresponding to the optical path of the filters used.

- Echelle grating:

The beam from the collimator is dispersed by the echelle grating, resulting in a very high-resolution spectrum. The inclination angle of the echelle grating can be continuously changed for adjustment of the spectrum format on the detector.

- Cross dispersing grating:

In order to resolve the overlapping of different orders, the beam from the echelle grating is dispersed by a cross disperser perpendicular to the dispersion direction of the echelle. One of two gratings, optimized for either the blue or red regions, is selected. The two gratings provide different order separation, so users should take this into account in the selection of the cross disperser. Instead of the cross dispersers, a plane mirror can be used for observations with a quite long slit using a narrow-band filter for order selection.

- Camera system:

The beam dispersed by the two selected gratings is collected on the detector by the camera system. The camera consists of three corrector lenses, a spherical primary mirror, and a field-flattening lens. Focusing of the camera is accomplished by shifting the position of the detector unit.

- Detector unit:

A mosaic of two CCDs (EEV 42-80 CCD) is used as the detector. The CCD has 4100 × 2048 pixels with pixel size 13.5 μm. Thus, the effective detector size is 55 mm by 55 mm (4100 by 4096 pixels), though a 1.1 mm gap between the two CCDs exists. The detector is mounted at the camera focus and cooled by a mechanical cooler. The control of the CCD and data acquisition are done by a system called Messia V, developed specifically for the Subaru telescope instruments.

2.3 Performance of HDS

- Spectral resolution:

The limiting spectral resolving power, R ~ 165,000 (1.8 km/s), is achieved with two pixel (27 μ) sampling. A standard slit width (0.4 arcsec) provides a resolving power of R ~ 90,000 (3.3 km/s).

- Efficiency

The efficiency curves of the system measured by wide-slit observations of standard stars are shown in Figure 2. The efficiency includes the atmospheric transparency, the throughput of the telescope and the spectrograph, and the quantum efficiency of the detector. It does not take into account the I_2 cell, which has a throughput of about 85%. The efficiency curves for the blue and red setups of the spectrograph cross at about 4400 Å.

In the Figure 3 the efficiency curves of the ADC and the two image rotators are shown. Very recently we have discovered a degradation of the efficiency of both (red and blue) image rotators, so be careful to employ them in your program. This effect has been implemented into the Exposure Time Calculator (after 1/28/14).

Three image slicers (IS) are available, and can be inserted into the optical path. Their transmission curves are also shown in Figure 4 below.

- Wavelength coverage

As shown in Figure 7a, and in the Appendices (Section 5), typically 1700 Å and 2500 Å are covered by one exposure for the blue and red setups, respectively. Note that the central wavelength region (one or a few orders) is not observed because of the gap between the two CCDs. For wavelengths longer than 7200 Å, the free spectral range is not covered by the CCD, hence a continuous spectrum cannot be obtained with one exposure.

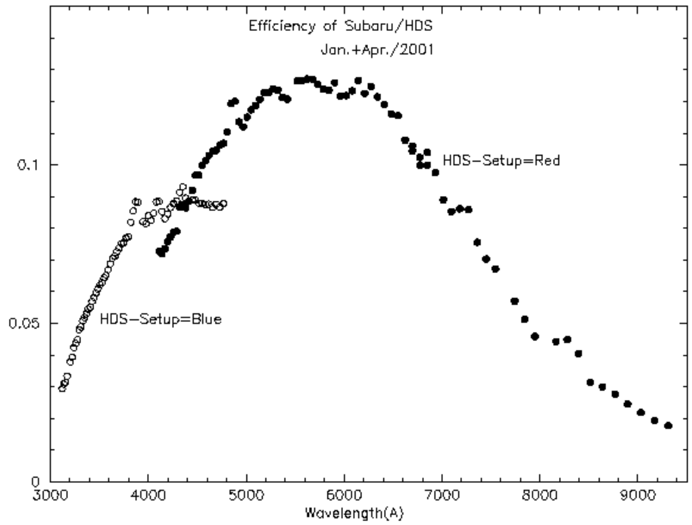

Figure 2: Efficiency of the telescope and the spectrograph measured by wide-slit observations of standard stars

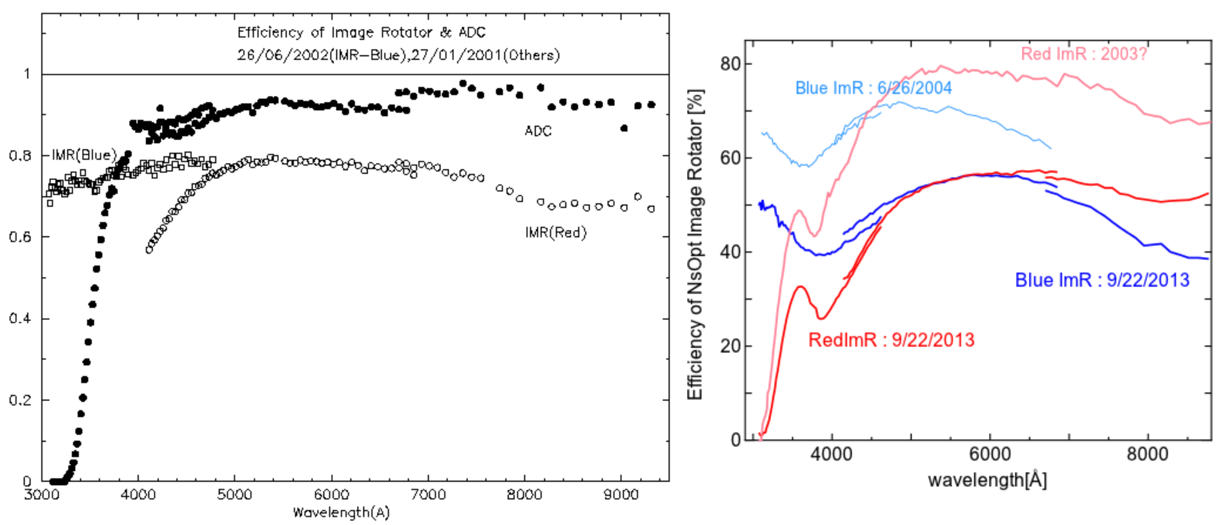

Figure 3: Throughput of the ADC and the image rotators. Right panel shows the recently found degradation.

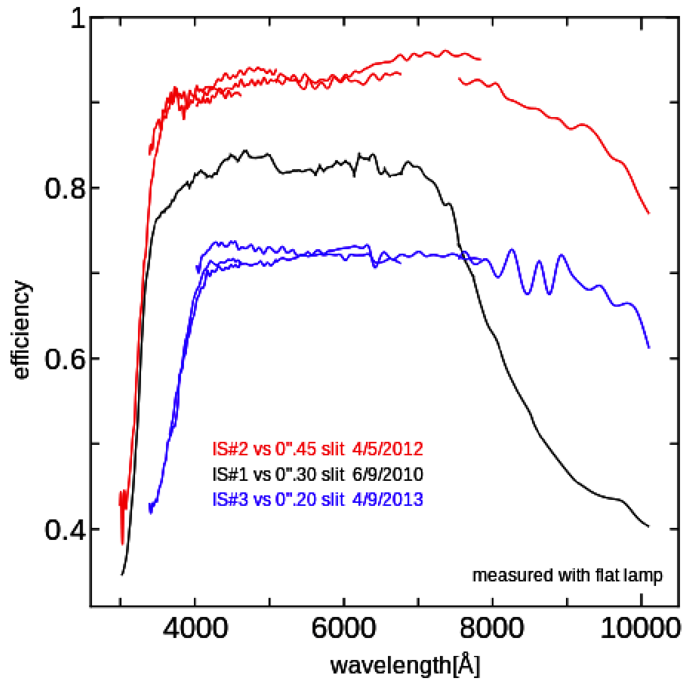

Figure 4: Transmission curves of the image slicers

- Slit length

The maximum slit length as a function of wavelength is given in section 3.1.3 for each setup using blue or red cross disperser.

Single order observing mode is also available by selecting order with some narrow band filter. For this observing mode, one can use the plane mirror instead of cross dispersing grating. The maximum slit length is 60 arcsec for this case.

- Repeatability of spectrum format

Even for the "same" setup of the spectrograph, the spectrum format can shift as a result of changes in the inclination angle of the echelle gratings and the cross-dispersing grating. The format may also be affected by changes in the collimator mirror. The repeatability of the spectrum format through the changes of these setups is within about one pixel of CCD on the detector.

- Stability of spectrum format

The spectrum format can shift even if the setup is fixed. The shift is primarily dependent on the temperature of the Nasmyth enclosure (temperature of the spectrograph). The measured shift along the dispersion direction is about 1.4 CCD pixels per degree. The temperature in the

Nasmyth enclosure is not actively controlled, but the temperature variation is expected to be less than 0.1 degree per hour.

- Stability of continuum profile (quality of flux calibration)

The continuum profile is mainly determined by the echelle blaze profile. But it is known that the profile changes during observation. The quality of the flux calibration using standard stars is limited by this problem. The change of the continuum profile is sometimes as large as 10%. The reason of this problem is under investigation, but it is likely caused by changes of the optical path within the telescope, and related to the telescope position during observations (alt-az) and/or focus length.

- Stability of spectrum

Since the temperature of the detector is well controlled, the spectrum, including the fringe pattern originating on the surface of the CCDs, is reproduced by different exposures. Therefore there is usually no problem obtaining calibration data for flat-fielding before and/or after the observation (see Section 4.5).

- Performance of detectors

The readout noise of the CCDs is 4.4 e^{-}. A time variation of 2-4 e^{-} has been measured in different bias exposures. This variation can be corrected by use of the data in the over-scan region (see Section 4.6 for details). The dark current of the detector is lower than 1 e^{-} per hour. However, there is some emission in the Nasmyth enclosure or some leakage of light from outside which causes almost homogeneous dark level about 10 e^{-} per hour. The gain (conversion factor) for the readout is about 1.7 e^{-}/ADU and is slightly dependent on the output amplifier.

A good linearity is confirmed in the data recorded for electron numbers less than 10,000e^{-} (~6,000ADU), significant nonlinearity appears for higher electron numbers. The nonlinearity effect is of the order of several percent at 50,000e^{-}. No clear pixel-to-pixel difference is observed in the nonlinearity effect in a given chip; however, there is a notable difference in the nonlinearity effect between two CCD chips used in the instrument. No significant time variation in the nonlinearity effect is found from our measurement up to June 2010.

See Tajitsu et al. 2010 for description of the effect. An IRAF CL-script for the correction of the effect is also available.

2.4 Pre-slit Unit

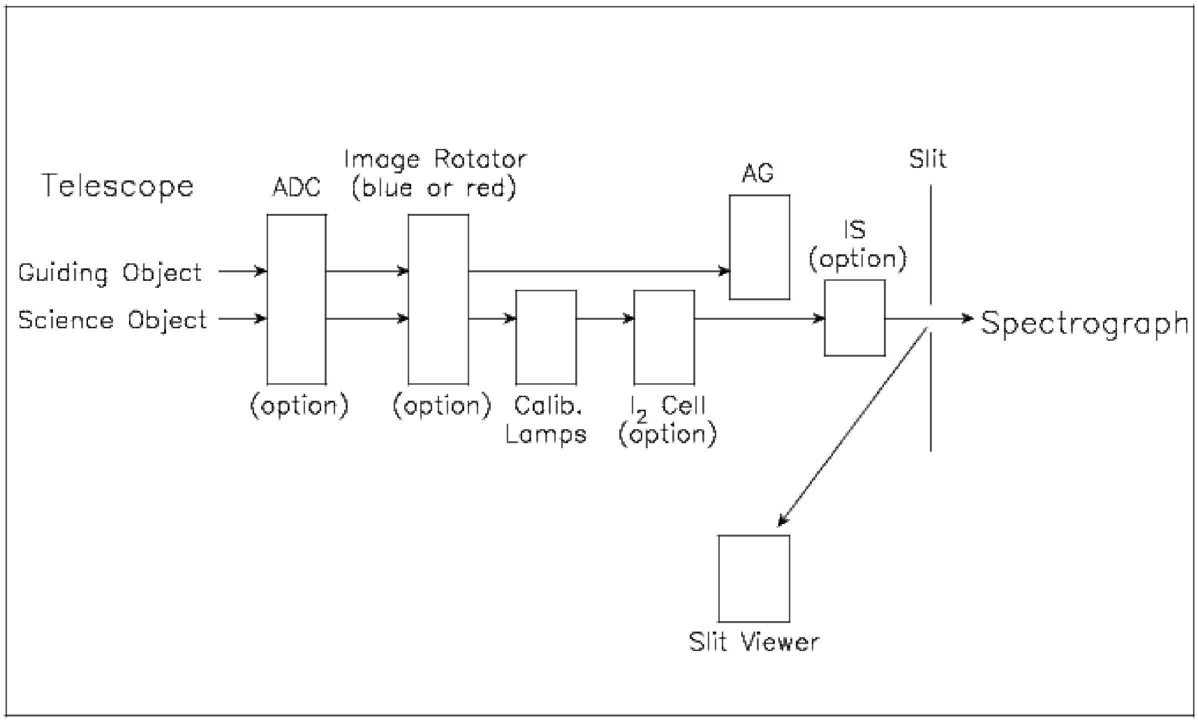

Figure 5: Schematic view of pre-slit unit

- Slit Viewer (SV)

The light reflected off the slit is observed by a camera called the slit viewer (SV). With this camera the object to be observed with the spectrograph is identified and then introduced to the slit. On a clear dark night, a point source with R ~ 18 magnitude is detectable. Objects as bright as V = 1 mag do not saturate when viewed with a neutral density (ND4) filter. Two other filters for the V and R bands are also available, as well as a BP530 filter (central wavelength: 529 nm, FWHM: 39 nm), optimized for I_2 absorption wavelengths.

- Guiding System

The quality of mechanical (open) tracking of the telescope is not sufficient for long exposures, hence a guiding system should be used in most circumstances. Currently, the guiding can be done either in the on-slit mode directly on the science target with the SV (preferred), or on a separate guiding object with the AG.

Guiding using the target itself (observed in the slit viewer) was introduced quite recently and is now the preferable mode. The current system works well on objects as faint as 20th magnitude with 5 sec exposure time.

With the AG unit, the guiding is done using a guide star approximately 1 arcmin from the target. The guide star is automatically selected when the position of the target is given to the telescope control system. With the current system a star brighter than 15th magnitude is acceptable as a guiding object (this will be improved in the future). As shown in Figure 2, the AG probe is located behind the image rotator, the position of the guiding object against the target is fixed when image rotator is used. On the other hand, the field of view rotates when image rotator is *not* used, and the change of the position of guiding object against the target is compensated by the rotation of the AG probe around the beam of the target. However, the quality of the driving (rotation) of the AG probe is not perfect, and the error of the guiding without image rotator is worse than that with rotator: the error is about 1 arcsec per hour when the field rotation is fast. The correction of the guiding position is possible during the exposure. But the quality of the guiding with image rotator is still better than that without rotator, so the observation with image rotator is recommended even for point sources when the guiding quality is quite important.

The ADC is not applicable to UV observation due to its low efficiency in that wavelength range. The guiding taking into account the atmospheric differential dispersion between the observing wavelength (on SV) and the guiding one (on AG) is available for UV observation without ADC. The guiding position *cannot* automatically be corrected corresponding to the change of the atmospheric differential dispersion during exposure. But the guiding position for the atmospheric dispersion at the exposure center can be given.

- Image rotator (IMR)

In order to control the position angle of the slit image, two image rotators for blue and red regions are mounted in front of the slit. The direction of slit image is not essential for the observation of point sources, but the image rotator can be useful for observation of objects with large atmospheric dispersion.

- Atmospheric Dispersion Compensator (ADC)

The ADC is useful when the elevation of the object is low. Since the ADC is designed for observations with elevation higher than 30 degrees, the quality of the correction of atmospheric dispersion is not good for objects with lower elevation (the correction is fixed to that for the elevation of 30 degree). The efficiency of the ADC is high for wavelengths longer than 3600 Å, but it steeply decreases at shorter wavelengths (see Section 3.5).

- Calibration Sources (CAL)

A halogen lamp and two hollow cathode lamps (Th-Ar and Fe-Ar) are available for flat-fielding and wavelength calibration, respectively. One ND filter and two color filters are mounted in this system.

The Th-Ar line atlas for the wavelength calibration of HDS spectra is available here.

- Image Slicer (IS)

In order to collect more photons while keeping high spectral resolving power in the same time, one of the three image slicers (IS) can be used. The IS reformats the 2D-image of an entrance aperture (different for each slicer) in the F/12.6 focal plane of the telescope into a series of narrow slits, which is imaged on the spectrograph entrance slit. The currently available slicers allow for the effective resolving power of 110,000 (IS#1), 80,000 (IS#2) or 165,000 (IS#3). With respect to a narrow slit giving a comparable resolving power, more light is collected and the final S/N of the spectrum is substantially higher.

Each of the slicers is put into the optical beam manually. Additionally, the focus of the telescope changes and must be adjusted, thus the IS should not be changed, removed or inserted during the night. Guiding should be performed directly on the science target with the SV.

For more details see Tajitsu et al. (2012), Section 3.1.3 or this webpage.

- Iodine (I_2) Cell

This instrument is used for the accurate measurement of radial velocities for astronomical objects. By inserting the I_2 cell into the optical path, the absorption lines of I_2 molecules are superposed on the spectrum of target objects in the wavelength range ~5000 - 6500 Å. Measurement of the variation of line position of objects by comparison with the I_2 molecular lines enables one to investigate the variation of the radial velocity of the objects with only a small influence of instrumental instability. Due to the iodine absorption, the throughput of the cell is about 85% in the visual. Observers need to take that into account when planning their observations.

The I_2 cell consists of a vacuum case including the cell itself and a temperature controller. The vacuum case is mounted on a stage for this instrument behind the slit unit, and can be inserted into or retracted from the beam coming through the slit. The temperature of the vacuum case (inside and out) are measured and recorded by the temperature monitor system of HDS. The form of the cell is a cylinder whose diameter is 55 mm and height is 38 mm. The liquid I_2 in the cell evaporates by warming the cell with a heater to 55 degrees.

2.5 Control System

Control of the spectrograph, divided into three control units (the optical system, the cooler and the detector), is carried out using computers in the control building (Figure 6).

The optical system is controlled by a local VME board computer, and the cooler is driven by the controller on the Nasmyth platform. The controller of the CCDs (Messia V) is also located on the platform.

Control of the instrument during observation is made possible by communicating with these controllers from the control computer OBCP. The setup and data acquisition, under normal circumstances, are done using several commands (so called *abstract commands*) from the computer OBS. Some information on the status of the telescope and information on the local environment are also provided by OBS. The CCD data acquired by OBCP using Messia V is transferred to the computer OBC, and stored in the Subaru database automatically.

Initialization, shutdown, and certain special settings of the spectrograph are carried out from OBCP.

Control of the telescope and pre-slit systems (e.g., the image rotators, the calibration sources) is available from the computer TSC, but usually, control during the observation is done from the OBS using abstract commands.

2.6 Light Monitor

- *[WARNING: This unit is currently unavailable due to communication problems between it and the control system. Once they are fixed, the light monitor will become operational again.]*

The light monitor is used to determine the effective mid-moment of the exposure. This procedure makes the correction of the variation of the radial velocity by the motion of the Earth much more accurate.

The light monitor consists of a beam splitter, photo-multiplier and a pulse counter. When the instrument is inserted to the beam, about 1% of the beam is extracted by a beam splitter and measured by a photo-multiplier. The photo-multiplier is driven by a 5V power supply which sends the output measured to the pulse counter.

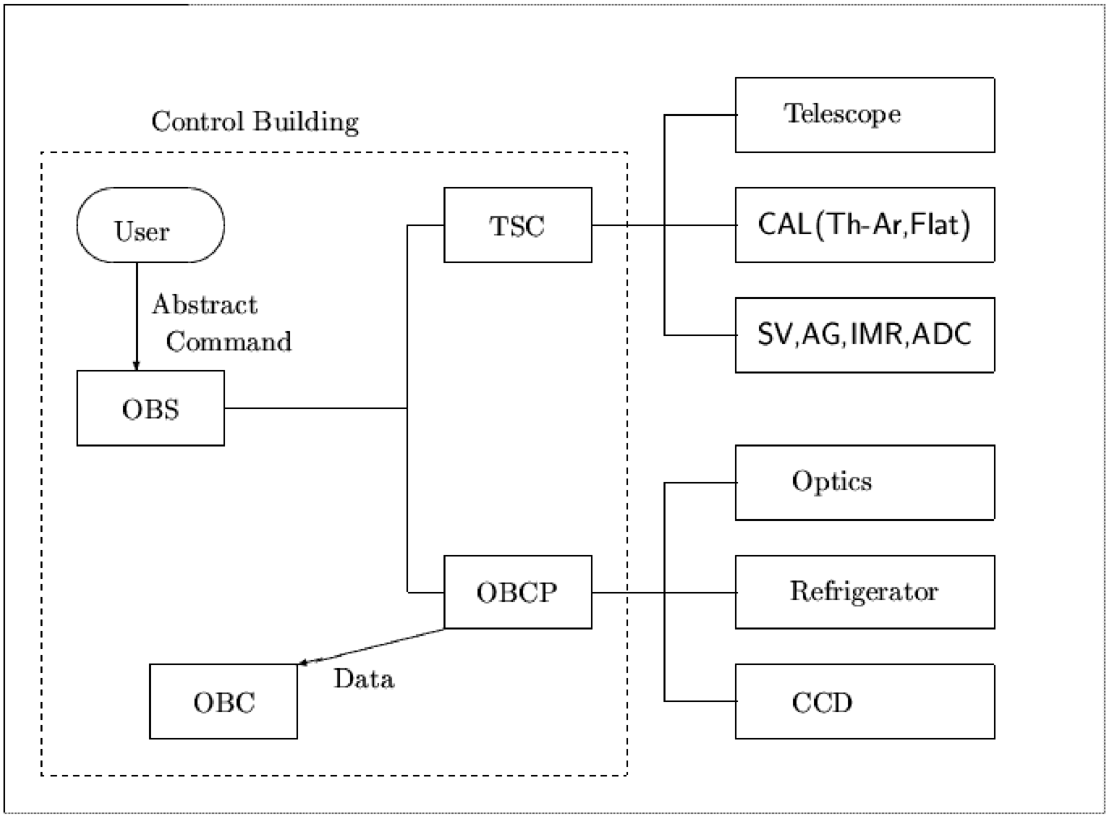

Figure 6: Control system of the telescope and HDS. OBC, TSC, OBCP and OBC are computers in the control building. Users access the computer OBS

3. Preparation for Observations

3.1 How to Determine HDS Setup Parameters

In this section, user-specified HDS setup parameters are described. *Users are encouraged to adopt a standard setup to improve the efficiency of observation and data reduction* (see Section 3.3). The spectrum format can be calculated by the software explained in Section 3.2.

3.1.1 Echelle Grating

The inclination angle of the echelle grating determines the spectrum format along the dispersion direction. Blaze wavelengths and free spectral ranges are given in Section 5.1. An inclination angle of 0.4 degrees (nominal value) provides a standard format in which blaze wavelengths are located near the center of the detector.

Since the free spectral ranges for near infrared regions (>7200 Å) are not covered by the detector, the inclination angle must be set for the appropriate spectrum format.

3.1.2 Cross-Dispersing Grating

The setting of the cross disperser determines the spectral orders observed. One cross disperser for the blue or red region is selected for higher efficiency in the wavelength region of interest. The efficiency curves for blue and red setups cross at 4400 Å (see Section 2.3).

Since the cross disperser for the blue regions provides higher dispersion, a longer slit is applicable for the same order (see Section 3.1.3).

3.1.3 Slit and Image Slicers

The spectral resolution is basically determined by the slit or image slicer used, though the maximum resolving power is limited by the data sampling of the detector. Within this limit, the relation between the slit width and resolving power is represented as:

slit width (mm)=1.8 x 10^4 */resolution (R)*

(ex.) resolving power R= 90,000 ⇔*slit width = 0.2 mm*

The image scale at the Nasmyth focus is 2.0 arcsec/mm, or 0.5 mm to 1 arcsec, thus the resolution of 90,000 corresponds to a slit that is 0.4 arcsec wide. The slit width can be set between 0.2 and 4 arcsec.

The amount of sky observed is determined by the slit length. If the slit in use is too long, overlapping of orders may occur. The maximum slit length for which orders do not overlap is given as a function of wavelength in Table 2. It is also possible to observe in a longslit mode, where only one echelle order is recorded, and other are blocked out by appropriate filters. The maximum slit length is 60 arcsec (30 mm).

Table 2: Maximum slit length without order overlap

Wavelength	Cross disperser	Maximum slit length	
		(mm)	(arcsec)
3100Å	Blue	2.2	4.4
3500Å	Blue	2.9	5.8
4000Å	Blue	3.8	7.6
4500Å	Blue	4.9	9.8
4000Å	Red	2.4	4.8
4500Å	Red	3.1	6.2
5000Å	Red	3.8	7.6
7000Å	Red	7.4	14.8
10000Å	Red	15.1	30.2

Image slicers allow for observations with higher spectral resolution and S/N, especially in poor seeing conditions. Their basic characteristics are summarized in Table 3. The entrance opening is different for each of them, but wider than the slit that gives a similar resolution, so more light is collected. Comparison of the efficiency of each IS with respect to slits of various widths, as a function of seeing, can be found here.

The image of the opening is chopped into 3- or 5-element pattern. The relation between the angular size of the pattern element and spectral resolution is similar to the one above, however the effective R is somewhat lower, e.g. the IS #1, which is 0".3×5, gives R=110,000, whereas the 0".3 slit gives 120,000.

All ISes are pre-slit units, thus to avoid unnecessary light blocking, the slit width is set to 4 arcsec when an IS is mounted. Guiding is done with the SV.

Table 3: Basic characteristics of the image slicers			
	IS #1	**IS #2**	**IS #3**
Slice pattern	0".3×5	0".45×3	0".2×3
Spectral resolution	*R*=110,000	*R*=80,000	*R*=165,000
Type	Bowen-Walraven type		Bowen-Walraven type + Focal Length Corrector
Entrance opening	φ1".5 circle	1".35×1".35 square	0".6×1".45 rectangle
Elongation along slit length	7".9 (λ > 5,000A for red settings , λ > 4,000A for blue settings)	5".2 (λ > 3,800A for red settings, λ > 3,600A for blue settings)	5".5 (λ > 4,000A for red settings, λ > 3,600A for blue settings)
Material	Fused quartz w/AR-coating		
Efficiency	> 83% (@4,000 ~ 7,000A)	> 93% (@3,800 ~ 8,000A)	> 73% (@4,000 ~ 8,000A)
Manufactured by	OptCraft		
Opened since	S11B	S13A	S14A

3.1.4 Filter

Filters are used to eliminate light from outside of the desired wavelength range. In particular, a blue-cut filter is used to eliminate second-order blue light when a red region is observed.

The filters installed in the system and their transparent wavelength ranges are given in Table 4. The following shows examples of the filter sets used in the standard setups for blue and red regions.

(ex.1) Red region (510-780nm): Filter 1=Free, Filter 2=SC-46

(ex.2) Blue region (340-510nm): Filter 1=SQ, Filter 2=Free

Since the optical path is changed by the insertion of filters, the focal length of the collimator is also changed. The standard position of the collimator is determined for one filter with a thickness of 5 mm. This is the reason why the SQ filter is used for the blue setup (see the above example). The thickness of the ND filters is negligible. Therefore, the standard position of the collimator is applicable to the combination of one color filter and one ND filter. If the observation is done with a special filter or without any filter, re-focusing of the collimator system may be required.

Users should also take into account that the ADC cuts-off all wavelengths shorter than about 360 nm.

Table 4: Filters and wavelength region			
Filter	Turret	Coverage*	Wavelength region (setup)
SQ	1	(quartz)	
ND1	1	(10%)	
ND2**	1	(1%)	
ND3**	1	(0.1%)	
ND4**	1	(0.01%)	
U340	1	?-?nm	?-?nm (Blue?)
OG530	1	590-980nm	590-980nm (Red)
KV408**	1	434-774nm	434-774nm (Red)
He4686**	1	467-470nm	467-470nm***
O5007	1	499-503nm	499-503nm***
O6300**	1	629-632nm	629-632nm***
Hα	1	654-659nm	654-659nm***
S6717**	1	670-675nm	670-675nm***
SC-46	2	485-896nm	485-896nm (Red)
GG495	2	550-900nm	550-900nm (Red)
SC-42	2	456-796nm	456-796nm (Red)
KV389	2	410-746nm	385-746nm (Red)
KV370	2	394-680nm	394-680nm (Blue)
WG335**	2	393-606nm	393-606nm (Blue)
RG610**	2	660-1120nm	660-1120nm (Red)
RG715**	2	780-1200nm	780-1200nm (Red)

* For the short-wavelength-cut filters, the 99% transparent wavelength and twice the 1% transparent (i.e., cut-off) wavelength.

** These filters are prepared, but not installed, to the filter turrets in the standard setup.

*** These are narrow-band filters used in the longslit mode and without cross disperser.

3.1.5 Detectors

Five modes of on-chip binning are available in the readout of the data from the CCDs. The readout time for each binning mode is given in Table 5. Note that the saturation level described in Section 2.3 is applied to the summation of the counts for binned pixels. Therefore the maximum S/N ratio achieved by a single exposure with binning is lower than that without binning. This point should be considered in observations which require very high S/N data for bright objects.

Table 5: CCD readout time

Setup for binning (spatial×dispersion)	Total dead time for one exposure (sec.)
1×1	~86
2×1	~60
2×2	~44
2×4	~36
4×4	~33

3.1.6 Rotation of Detector Unit

Rotation of the detector unit is used to align the slit image with the CCD pixel line. When the blaze wavelength of the echelle grating is set to the center of the detector, the inclination of the slit image to the CCD pixel line is minimized by using a rotation angle of −1 degree (nominal value). Fine tuning of the rotation angle may be required for more accurate alignment (e.g., for long-slit observations).

Since the inclination of the slit image to the CCD pixel line is large for the wavelength region far from the blaze, a rotation of the detector unit may be required (this may be the case for observations in the near-infrared range).

3.2 Determination of Spectrum Format

Users can simulate echelle spectrum formats by accessing this Web page. No simulator is available for the long-slit mode.

From the "Setup:" menu in the "Instrument setting" part the user can choose one of the standard spectrograph's setups, optimized for various wavelength regions, from UV to near IR. *We* *strongly recommend usage of one of them, instead of a non-standard setup.* However, if user decides to use a non-standard setting, the echelle format can be simulated with the instrument settings determined below. User can change between red and blue collimator and cross disperser, their cross scan angles, echelle grating inclination and detector rotation. In this part also the slit length may be set manually.

If the user is interested in particular spectral features, their location on the CCD chips may also be simulated. In the "Remarkable Lines" section, one can put a number of interesting lines, giving their name and wavelength. The redshift may also be set. User can also choose one of the pre-defined lists of lines given below.

Once the setup and lines are defined, click the "Calculate Format" button. Figure 7a shows an example of the result of the calculation. Two images are produced: (a) the location of orders, selected lines, and wavelength range on the CCD detectors; (b) the location of the CCD detectors over the full spectral format, with the free ranges plotted. One can see which echelle orders, representing which wavelengths can be recorded on the CCDs. The first image also shows the location of bad CCD columns, marked with red lines.

Both output images are also available as pdf documents.

Additional software for off-line calculation of the spectrum format is prepared for the determination of the setup parameters (*HDS_SPFv20.f* or *HDS_SPFv20wopg.f*). The source program is written in Fortran 77 and PGPLOT is used to plot the result (optional). The source program is available in the Web site:

`http://optik2.mtk.nao.ac.jp/HDS/index.html`

See the *README_SPen* file in the same site for details.

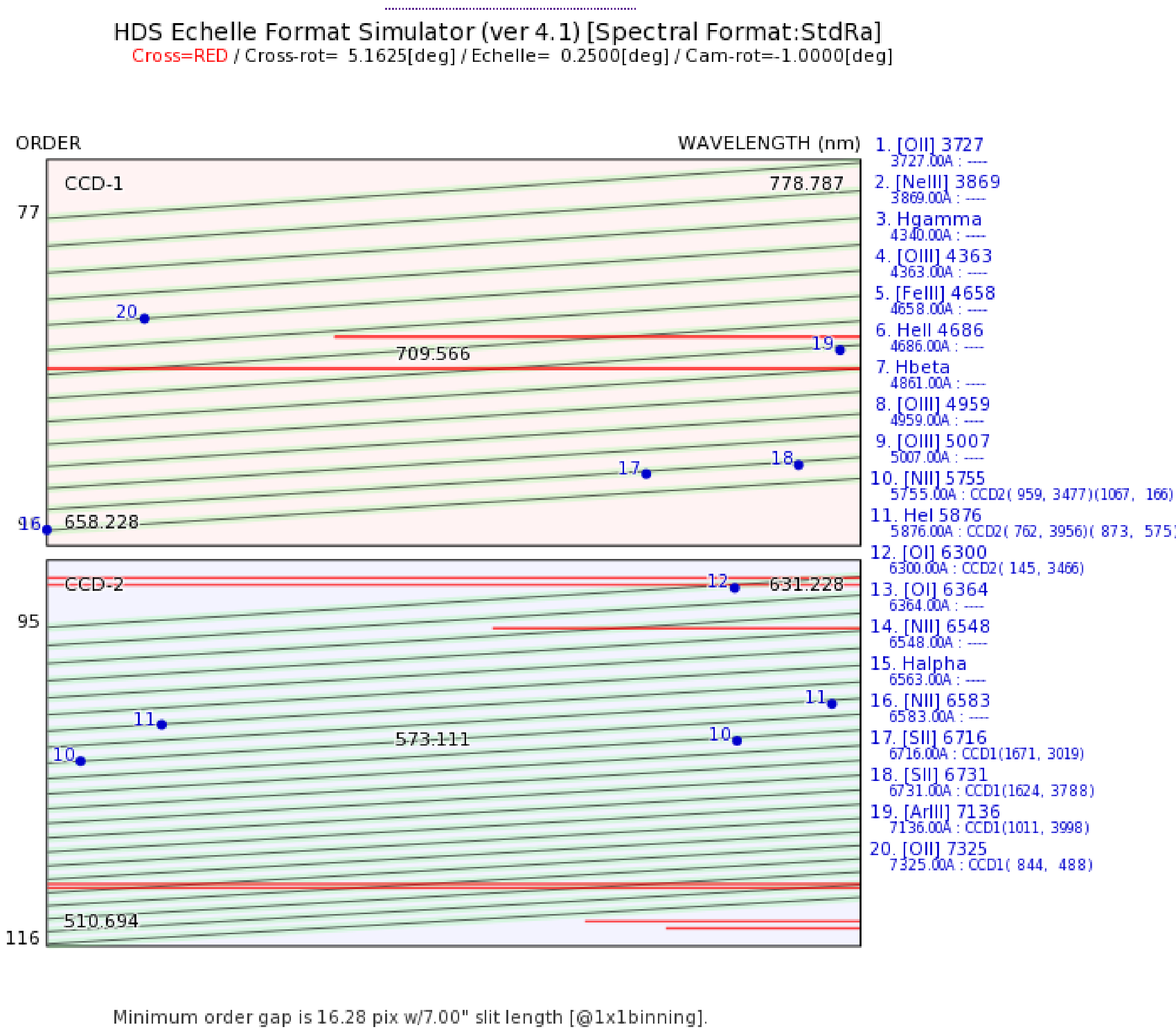

Figure 7a: Simulation of the CCD calculated with the echelle format simulator. Red lines mark known bad columns, blue points mark location of certain spectral features. For each CCD, the first and last full-recorded echelle orders are labeled, as well as shortest, central and longest wavelengths.

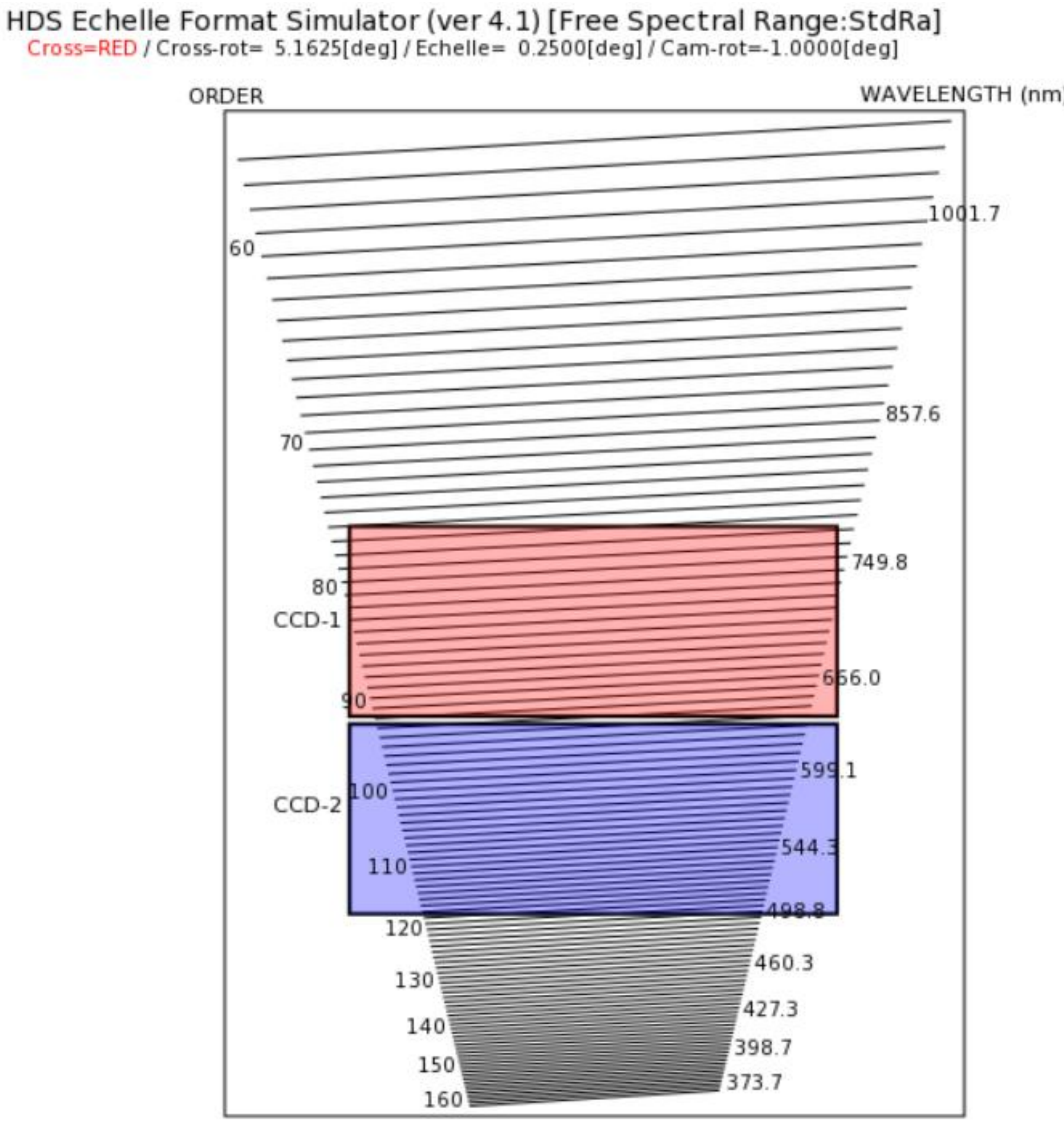

Figure 7b: An example of the spectrum format calculated with the simulator, with the orders covered by the two CCDs. Order numbers and wavelengths are given.

3.3 Standard Spectrograph Setup

As described above the setup of gratings, which determines the spectrum echelle format, can arbitrarily be determined within the range allowed. However, users are encouraged to use one of the standard spectrum formats for efficiency of observation and data reduction. Standard formats and setups of the HDS are given in Table 6. Default echelle and detector rotation angles are 0.25 deg (900 asec) and -1 deg respectively.

Table 6: Standard setup of the spectrograph and wavelength region

	CCD1 (nm)	CCD2 (nm)	cross disp./ /collimator	cross angle (arcsec (deg))	filter (1,2)
StdUa	310-387	400-476	Blue	17950 (4.986)	Free,Free
StdUb	298-370	382-458	Blue	17230 (4.786)	Free,Free
StdBa	342-419	432-508	Blue	19390 (5.386)	Free,Free
StdBc	355-431	445-521	Blue	20020 (5.561)	Free,Free
StdYa	403-480	494-566	Blue	22090 (6.136)	Free,Free
StdYb	414-535	559-681	Red	15860 (4.406)	Free,KV370
StdYc	442-566	586-705	Red	16630 (4.619)	Free,KV389
StdYd	406-531	549-666	Red	15610 (4.336)	Free,KV370
StdRa	511-631	658-779	Red	18584 (5.163)	Free,SC-46
StdRb	534-659	681-800	Red	19210 (5.336)	Free,SC-46
StdNIRa	750-869	898-1016	Red	25330 (7.036)	OG530,Free
StdNIRb	673-789	812-937	Red	22990 (6.386)	OG530,Free
StdNIRc	617-740	759-882	Red	21490 (5.969)	OG530,Free
StdI2a	498-618	637-759	Red	18130 (5.036)	Free,SC-46
StdI2b	355-476	498-618	Red	14170 (3.936)	Free,Free

For the observations in the longslit mode, one can currently use either of the five available setups. In all cases only the Red CCD is in use, filters are mounted in turret 1, and the cross disperser is replaced by a mirror (the cross angle is set to 0). These setups are summarized in Table 7.

Table 7: Standard setup and wavelength region for the longslit (narrow band) mode. [Exact names may be different.]			
	Filter	Centre (A)	Width (A)
StdHe	He4686	4688	28.4
StdO5	O5007	5010	31.7
StdO6	O6300	6307	29.7
StdHa	Hα	6580	54.6
StdS6	S6717	6728	42.3

3.4 Estimation of Exposure Time

The number of photons per pixel in the spectrum expected to be obtained for each wavelength range (U,B,V,R,I) can be calculated by the following equation:

$$N_{\mathrm{photon}} = a_{\mathrm{band}} \times 10^{-m_{\mathrm{band}}/2.5} \times T_{\mathrm{exp}} \times f$$

In this equation a_{band} is a constant for each wavelength range given in Table 8, m_{band} is a magnitude in that band, T_{exp} is the exposure time, and f is the fraction of the light entering the slit (which depends on the slit width and the seeing disk during the observation).

Table 8: Coefficients for the foton-per-pixel equation	
Band (Wavelength)	a_{band}
U (3670Å)	5.4×10^5
B (4360Å)	6.3×10^5
V (5450Å)	8.5×10^5
R (6380Å)	8.0×10^5
I (7970Å)	2.7×10^5

The S/N ratio achieved with a given exposure time for objects with a given brightness can be estimated by the HDS Exposure Time Calculator (ETC) available in the following Web page.

To determine the flux emitted from the source, user can define the brightness of the object in a given band, its redshift, and spectral energy distribution (power law, blackbody of a given temperature or template stellar spectrum from the available library).

For the instrument setting we encourage to use one of the standard ones, but if a non-standard is selected, one can choose between the red and blue grating and define the central wavelength. The ADC and image rotators are optional and can also be included. The Messia 5 CCD control system is set by default, as it is currently in use. User can also select one of the binning options, and choose between the normal slit (which width needs to be defined) and one of the image slicers. Other parameters are the size of the seeing disk and exposure time.

As the output, the ETC firstly gives various information related to the efficiency, readout time, dark current, etc. In the output table below a simplified echelle format is simulated - for each echelle order its location and wavelength range are given. Dispersion, source flux, peak counts and S/N ratio is calculated for the center of each order. Lines marked orange refer to orders that might be partially damaged by a bad column. Lines marked red mean saturation in a given order. In case one of the ISes is selected, the last two columns show how much the number of photons and S/N are improved relatively to the normal slit. Please read carefully all the notes below the table.

3.5 Elevation and Atmospheric Dispersion

The apparent position (elevation) of an object is dependent on wavelength, due to the atmospheric dispersion. When the guiding of the telescope is done for a given spectral band (e.g., the *V*-band), light of different wavelengths may not effectively be introduced to the slit. In Figure 8 the atmospheric differential refraction between a given wavelength and 5500 Å is shown as a function of the zenith distance at the summit of Mauna Kea (T = 0 degree Celsius and P = 625 hPa). Users should note that the effect of atmospheric dispersion is quite significant in the UV region.

Compensation for the effects of atmospheric differential dispersion is accomplished with the ADC. Though the ADC cuts-off wavelengths shorter than ~360 nm so is not suitable for the UV.

Another method to avoid the effect of atmospheric dispersion is to align the slit image with the zenith direction. By use of this setting, the light from different wavelength regions can be introduced to the slit regardless of the atmospheric differential dispersion. Automatic control of the image rotator to set the slit image to the zenith direction is implemented at present.

Observation with a fixed position angle of the slit image is possible. A FORTRAN program to calculate the position angle of the slit image which is aligned to the zenith direction for a target object as a function of time is available (CALCPA.f or CALCPAwopg.f) on the following Web page. See the *Readme* file in the same page for details.

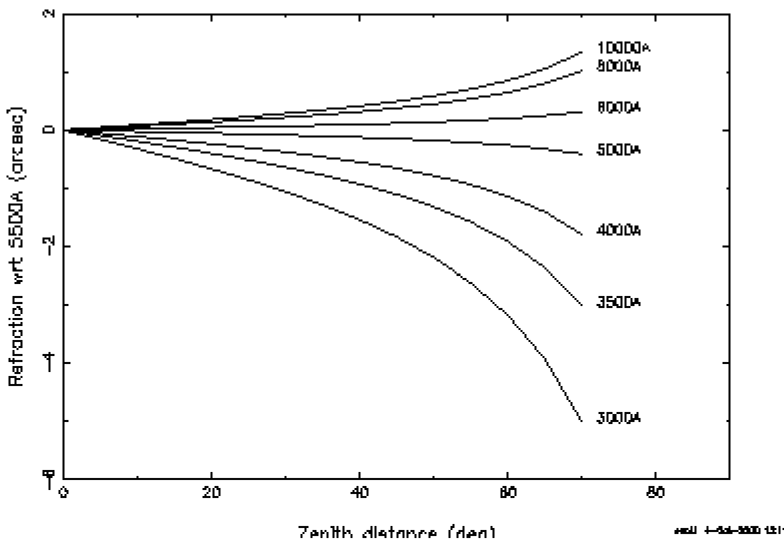

Figure 8: Relation between zenith distance (degree) and atmospheric refraction with respect to λ=5500 Å as a function of wavelength

3.6 I_2 Cell and Light Monitor

There is no significant difference between the preparation for observation with and without the I_2 cell and the light monitor. Note that the throughput of the I_2 cell is about 85%. One must carefully prepare the sequence of observations when the I_2 cell and the light monitor are used. Two standard spectrograph setups are available: StdI2a and StdI2b.

3.7 Check List

Following is a check list for the preparation for observations.

- Setup of Spectrograph:
  - Slit (width and length) or IS
  - Filter (turret 1 and 2)*
  - Blue/red region selection(cross disperser and collimator)*
  - Inclination angle of cross disperser*
  - Inclination angle of echelle grating*
  - Rotation angle of detectors
- Setup of CCD:
  - Binning (1×1, 2×1, 2×2, 2×4, 4×1, 4×4)
- Exposure time
- Position of object, position angle of slit image

* Using a standard setup is recommended at present

4. Observing

The main activities during observations are the setup of the spectrograph, target acquisition, and data acquisition. These activities are carried out by operators using commands in the observation control computer (OBS) in normal observations. Observers prepare the setup parameters of the spectrograph, position of the objects, and the exposure time, and are expected to contact the support astronomer prior to the run. The construction of the "Observation Procedure" is not required any more.

4.1 Setup of Spectrograph

The setup parameters of the spectrograph determined in Section 3 are given by an *abstract command* 'SetupOBE' from OBS. The parameters of this command and the ranges of the parameters are given in Table 9. The parameters are given in the command for the part which observers may wish to change - note that the previous setup is kept if one does not supply a parameter. Also, it should be noted that upper-case and lower-case letters are not distinguished in *abstract commands*.

ex.1) for slit width= 200 µm, filter= SQ, and inclination angle of cross disperser = 18000 asec;

```
SetupOBE OBE_ID=HDS SlitWidth=200 Filter1=SQ CrossScan=18000
```

ex.2) for the standard setup StdRa (see Table 6);

```
SetupOBE OBE_ID=HDS Filter_1=Free Filter_2=SC-46 Cross=Red CrossScan=18584
Collimator=Red
```

Table 9: Parameters of SetupOBE command

parameter	meaning	range/value
`Slit_Width`	slit width	10-2,000 µm
`Slit_Length`	slit length	1,000-30,000 µm
`Filter_1`	filter(turret 1)	ND1 / ND2 / SQ / OG530/ KV408
`Filter_2`	filter(turret 2)	SC-46 / SC-42 / KV389 / KV370 / GG495
`Collimator`	collimator	BLUE / RED
`Cross`	cross disperser	BLUE / RED / MIRROR
`Crros_Scan`	cross disperser angle	14,000 to 26,000 sec
`Echelle`	echelle grating angle	-3,600 to 3,600 sec
`Cam_Rotate`	rotation angle of detectors	-7,200 to 7,200 sec

4.2 Target Acquisition and Guiding

The positions (RA, DEC, and EQUINOX) of objects are given as parameters of an abstract command 'SetupField'. After telescope pointing, another abstract command 'SetupField_Fine' is used for the fine tuning of the target acquisition.

4.3 Data Acquisition

The following is an example sequence for data acquisition:

- CCD wipe
- Exposure (open and close of the shutter. Shutter is not opened for dark data. Exposure is not done for bias data).
- Acquisition of the status of the environment and instrument at start, middle and end of the exposure.*
- Readout of CCD data.
- Acquisition of frame ID (see Section 4.6).
- Production of FITS format data.
- Data transfer to OBC.
- Display data on OBS.

* The status of parameters that are variable during the exposure (e.g., the pointing of telescope, angle of the image rotator) is obtained at the start, middle and end of each exposure. These are written in the FITS header.

Data acquisition for objects and calibration sources are done with the following *abstract commands*.

Table 10: Commands for data acquisition

command	function	parameter
GetObject	data acquisition for object	ExpTime (exposure time) [sec]
GetStandard	data acquisition for standard star	ExpTime (exposure time) [sec]
GetComparison	data acquisition for Th-Ar	ExpTime (exposure time) [sec]
GetOBEFlat	data acquisition for flat (halogen lamp)	ExpTime (exposure time) [sec]
GetDark	acquisition of dark data	ExpTime (time) [sec]
GetBias	acquisition of bias data	-

The data set obtained by one exposure consist of *two* FITS files, corresponding to the two CCDs. The characteristics of the data are explained in Section 4.6.

4.4 Observation Procedure

Observation procedure is a file that describes the sequence of observations using *abstract commands* explained above. An example is given in Appendices (section 5.2). In order to create the observation procedures, prior to their run users should contact the support astronomer, providing the spectrograph setup, usage of optional units (ADS, iodine cell, etc.), list of targets (with positions and exposure times), and desired calibrations.

4.5 Calibration Data

Four types of data for calibration are usually obtained. These are the bias level, the dark level, flat fielding, and wavelength calibration exposures. The *abstract commands* used to obtain calibration data are given in Table 10.

The frequency of the acquisition of calibration data is dependent on the quality of the spectra requested. Some comments for the acquisition of calibration data are given here.

- Data for wavelength calibration (Th-Ar)

  The spectrum format moves when the setup of the spectrograph is changed. The spectrum format may slightly shift due to variation of the temperature even though the setup is fixed (see Section 2.3). Therefore the data for wavelength calibration (Th-Ar data) should be obtained during the course of observations throughout the night.

- Data for flat fielding

  The repeatability of the spectrum format is sufficiently good to allow for flatfield data to be obtained after changes of the setup of gratings (see Section 2.3). There are no significant problems if calibration data for flat fielding (halogen lamp data) are obtained at the beginning or end of each night, or even on a different day during the run.

- Dark current

  As shown in Section 2.3, the dark current is not so large that the correction is not required for usual exposures. No significant problems are encountered for usual calibrations if one obtains dark data before or after the observation.

- Bias

  As shown in Section 2.3, there is some variation in the bias level during the course of the night. However, this variation can be corrected using the data in the over-scan region which is attached to each CCD data frame. There is no problem if bias data are obtained before or after the observation.

For the Th-Ar lamp, appropriate intensities of the emission lines can be obtained when the data are acquired with the current of the lamp set to 15mA, exposure time of 20 sec, for slit width of 200 μm (no binning in CCD readout).

For the flatfielding, the standard exposure times and setup of the halogen lamp are given in Table 11, for the case of a slit width of 200 μm and no binning in the CCD readout. The setup may be changed corresponding to the target wavelength. Note that the "Filter" in the Table indicates the filters installed not in HDS, but in the calibration source system.

Table 11: Standard setup of parameters for flatfield data

Setup	CCD:	Lamp	Filter	Exposure
StdR	CCD-1:	3A	ND1	10sec
	CCD-2:	3A	B390	8sec
StdB	CCD-1:	4A	ND1	12sec
	CCD-2:	4A	T42A	4sec
StdU	CCD-1:	4A	ND1,B390	24sec
	CCD-2:	4A	U340*	16sec
stdYb	CCD-1:	3A	ND1	15sec
	CCD-2:	4A	ND1	7sec
stdI2b	CCD-1:	4A	ND1	4sec
stdNIR	CCD-1:	3A	ND1	10sec
stdHa	CCD-1:	3A	ND1	15sec

*U340 is now installed in HDS, but will also be installed in the CAL system in future.

4.5 I_2 Cell and Light Monitor

Observations involving the iodine cell require additional calibration frame. It is an exposition of the halogen (flatfielding) lamp taken with the I_2 cell in the optical path. This exposition should be done with the same settings (slit, echelle format, etc.) as the science spectra. Alternatively, such a calibration can be done during the night by observing a bright, early-type, rapidly rotating star, such that there are no sharp features in the stellar spectrum, only rotationally broadened hydrogen and helium lines.

At present, control of the I_2 cell and light monitor is possible only with the instrument control computer (OBCP).

4.6 Characteristics of the Data

- FITS data structure

The HDS data unit includes the output of one CCD with 2048 (slit direction) by 4100 (dispersion direction) pixels (in the case without binning) and the *over-scan* region. *Over-scan* indicates the additional readout to the CCD pixels exposed. The data in the over-scan region provides the bias level for the frame itself.

Since there are two output points for each CCD, the unit of one output is originally composed of 1024 × 4100 pixels. The over-scan region (50 × 4100 pixels) is added to this data unit. One file is composed of the two units, after the addition of the over-scan region. Then the two files, corresponding to the two CCDs (as shown in Figure 9) are obtained by one exposure. Note that the above explanation also applies to data obtained with binning of slit direction in the readout, i.e., the over-scan region of the same size (50 × 4100 pixels) is added to one data unit for the data with binning. In the case of the 2 × 2 binning, the over-scan region of 50 × 2050 pixels is added.

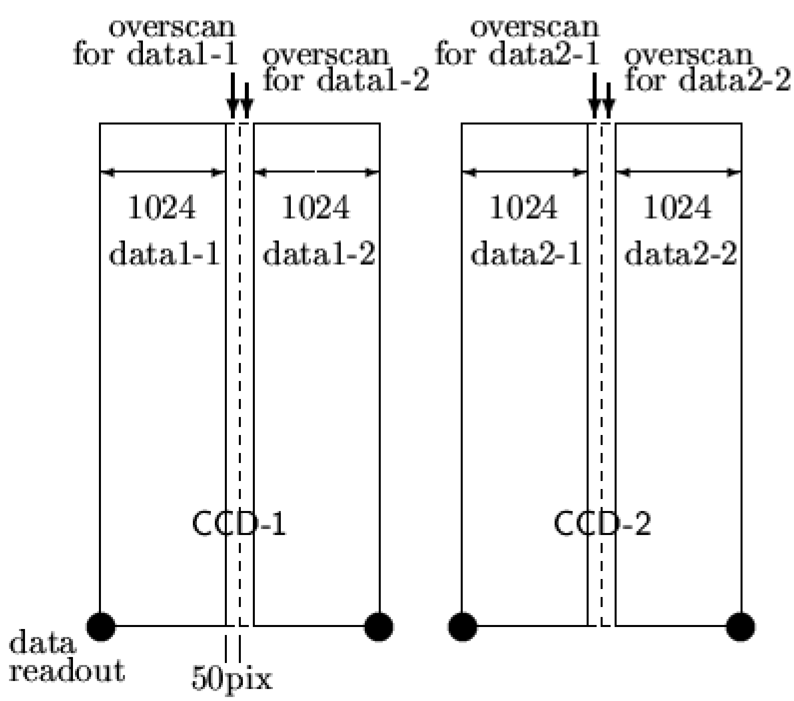

Figure 9: Schematic figure of the HDS CCD data

As mentioned in Section 2.3 it is desirable to correct the variation of the bias level using the data in the over-scan region.

- Frame ID

A sequential number (frame ID) is assigned to the data obtained with each exposure. Since two files are produced by one exposure, corresponding to the two CCDs, two frame IDs are given for each exposure. The frame IDs are the 8 figures following "HDSA," beginning with 'HDSA00000001'. The number does not go backwards, and the number will be missing if the data acquisition is canceled after frame IDs have been assigned. The file name is produced by attaching the extension '.fits' to the frame ID (e.g., HDSA00000001.fits).

- Characteristics of FITS Data

The FITS file obtained for each exposure consists of usual header/data unit, an ASCII extension table, and its header. In the extension table, the spectrum format (order, wavelength and position of the order projected on the detector) is described based on the calculation using the setup parameters of the gratings. Examples of a header unit and an ASCII extension table are given in Section 5.3.

When the light monitor is used, a second ASCII extension table is attached to the above data format. In the extension table, the data obtained by the light monitor are recorded.

4.7 Data Access

- Data base and data archive

The data obtained are automatically transferred to the Hawaii Observatory in Hilo and stored in the Subaru Telescope ARchive System (STARS), as well as in OBCP. Users are allowed to access their own data in STARS.

The data in STARS will be opened to public use 18 months following the observation. Publicly available data are stored in the Subaru-Mitaka-Okayama-Kiso Archive system SMOKA, and the Japanese Virtual Observatory JVO.

- Quick look data

For the purpose of evaluating the data obtained during the observation, the following two tools for "quick-look" are prepared on OBC and on the computer for data analysis (ANA).

  - Quick IRAF reduction on ANA

    A quick reduction with IRAF is possible on the summit, using scripts adopted specifically for the HDS (see Section 4.8).

- QDAS on OBS

  Two-dimensional image data and a cross-cut image at a given CCD line can be displayed. The count per pixel for data that are obtained can be estimated immediately.

- Ozeki on computer for data analysis

  Two-dimensional image data and a cross-cut image at a given CCD line can be displayed. Spectra of individual orders are shown by the order trace using the data written in the ASCII extension table (T.B.D).

4.8 Data Reduction

To reduce the HDS data, observers are free to use any software or platform of their own choice. However, a set of IRAF scripts adopted for the HDS specifically has been developed and is described on this Web page. These scripts are available on the summit during the observations for the purpose of a quick data evaluation. They may produce continuum-normalized or flux-calibrated spectra, either combined or in a 2D order-to-order format. The spectra are wavelength-calibrated on the basis of Th-Ar lamp expositions. No specific iodine-based reduction is available.

A general description of echelle data reduction in IRAF, is available in the Data Reduction Manual here.

5. Appendices

5.1 Echelle Spectral Format

An example of spectral format using the cross-dispersing grating for the blue region.

ORDER	WAVEMIN (nm)	WAVECEN (nm)	WAVEMAX (nm)	FSR (nm)	LD (nm/mm)	CDMIN (mm)	CDCEN (mm)	CDMAX (mm)	ORDSEP (mm)
199	298.782	299.535	300.287	1.505	0.0660	0.000	0.759	1.546	-
198	300.287	301.047	301.808	1.520	0.0663	0.485	1.246	2.036	0.490
197	301.808	302.576	303.343	1.536	0.0667	0.975	1.738	2.531	0.495
196	303.343	304.119	304.895	1.552	0.0670	1.469	2.236	3.031	0.500
195	304.895	305.679	306.463	1.568	0.0673	1.969	2.738	3.536	0.505
194	306.463	307.254	308.046	1.584	0.0677	2.474	3.245	4.046	0.510
193	308.046	308.846	309.647	1.600	0.0680	2.984	3.758	4.561	0.515
192	309.647	310.455	311.264	1.617	0.0684	3.500	4.276	5.082	0.521
191	311.263	312.080	312.897	1.634	0.0688	4.021	4.800	5.609	0.526
190	312.897	313.723	314.549	1.651	0.0691	4.547	5.329	6.141	0.532
189	314.549	315.383	316.217	1.669	0.0695	5.079	5.863	6.678	0.538
188	316.217	317.061	317.904	1.686	0.0698	5.616	6.404	7.221	0.543
187	317.904	318.756	319.608	1.705	0.0702	6.160	6.950	7.770	0.549
186	319.608	320.470	321.331	1.723	0.0706	6.709	7.502	8.325	0.555
185	321.331	322.202	323.073	1.742	0.0710	7.264	8.060	8.886	0.561
184	323.073	323.953	324.833	1.761	0.0714	7.825	8.624	9.454	0.567
183	324.833	325.723	326.613	1.780	0.0718	8.392	9.194	10.027	0.573
182	326.613	327.513	328.413	1.800	0.0722	8.965	9.770	10.607	0.580
181	328.413	329.323	330.232	1.819	0.0725	9.545	10.353	11.193	0.586
180	330.232	331.152	332.072	1.840	0.0730	10.131	10.942	11.785	0.593
179	332.072	333.002	333.932	1.860	0.0734	10.724	11.538	12.385	0.599
178	333.932	334.873	335.814	1.881	0.0738	11.323	12.141	12.991	0.606
177	335.814	336.765	337.716	1.903	0.0742	11.929	12.750	13.604	0.613
176	337.716	338.678	339.640	1.924	0.0746	12.542	13.367	14.223	0.620
175	339.640	340.614	341.587	1.946	0.0750	13.162	13.990	14.850	0.627
174	341.587	342.571	343.556	1.969	0.0755	13.789	14.620	15.485	0.634
173	343.555	344.551	345.547	1.992	0.0759	14.423	15.258	16.126	0.642
172	345.547	346.554	347.562	2.015	0.0763	15.065	15.903	16.775	0.649
171	347.562	348.581	349.600	2.038	0.0768	15.714	16.556	17.432	0.657
170	349.600	350.632	351.663	2.063	0.0772	16.370	17.217	18.096	0.664
169	351.663	352.706	353.750	2.087	0.0777	17.035	17.885	18.769	0.672
168	353.750	354.806	355.862	2.112	0.0782	17.707	18.561	19.449	0.680
167	355.862	356.930	357.999	2.137	0.0786	18.387	19.245	20.137	0.688
166	357.999	359.081	360.162	2.163	0.0791	19.076	19.938	20.834	0.697
165	360.162	361.257	362.352	2.189	0.0796	19.773	20.639	21.539	0.705
164	362.352	363.460	364.568	2.216	0.0801	20.478	21.348	22.253	0.714
163	364.568	365.689	366.811	2.243	0.0806	21.192	22.066	22.976	0.723
162	366.811	367.947	369.082	2.271	0.0811	21.914	22.794	23.708	0.732
161	369.082	370.232	371.382	2.300	0.0816	22.646	23.530	24.448	0.741
160	371.382	372.546	373.710	2.328	0.0821	23.387	24.275	25.198	0.750
159	373.710	374.889	376.068	2.358	0.0826	24.137	25.030	25.958	0.760
158	376.068	377.262	378.456	2.388	0.0831	24.896	25.794	26.727	0.769
157	378.456	379.665	380.874	2.418	0.0836	25.666	26.568	27.506	0.779
156	380.874	382.099	383.323	2.449	0.0842	26.445	27.352	28.295	0.789
155	383.323	384.564	385.804	2.481	0.0847	27.234	28.146	29.094	0.799
154	385.804	387.061	388.318	2.513	0.0853	28.033	28.950	29.904	0.810
153	388.318	389.591	390.864	2.546	0.0858	28.842	29.765	30.724	0.820
152	390.864	392.154	393.444	2.580	0.0864	29.663	30.590	31.555	0.831
151	393.444	394.751	396.058	2.614	0.0870	30.494	31.427	32.397	0.842
150	396.058	397.383	398.707	2.649	0.0875	31.336	32.274	33.251	0.853
149	398.707	400.049	401.392	2.685	0.0881	32.189	33.133	34.116	0.865

148	401.392	402.753	404.113	2.721	0.0887	33.054	34.004	34.992	0.877
147	404.113	405.492	406.872	2.758	0.0893	33.931	34.886	35.881	0.889
146	406.872	408.270	409.668	2.796	0.0899	34.819	35.781	36.782	0.901
145	409.668	411.085	412.503	2.835	0.0906	35.720	36.688	37.695	0.913
144	412.503	413.940	415.377	2.875	0.0912	36.633	37.607	38.621	0.926
143	415.377	416.835	418.292	2.915	0.0918	37.559	38.540	39.560	0.939
142	418.292	419.770	421.248	2.956	0.0925	38.498	39.485	40.512	0.952
141	421.248	422.747	424.246	2.998	0.0931	39.450	40.444	41.478	0.966
140	424.246	425.767	427.288	3.041	0.0938	40.416	41.417	42.457	0.980
139	427.287	428.830	430.373	3.085	0.0945	41.396	42.403	43.451	0.994
138	430.372	431.937	433.502	3.130	0.0952	42.390	43.404	44.459	1.008
137	433.502	435.090	436.678	3.176	0.0958	43.398	44.419	45.483	1.023
136	436.678	438.289	439.901	3.223	0.0966	44.421	45.450	46.521	1.038
135	439.901	441.536	443.171	3.271	0.0973	45.459	46.496	47.574	1.054
134	443.171	444.831	446.491	3.320	0.0980	46.513	47.557	48.644	1.069
133	446.491	448.176	449.861	3.370	0.0987	47.582	48.634	49.729	1.085
132	449.861	451.571	453.281	3.421	0.0995	48.667	49.728	50.831	1.102
131	453.281	455.018	456.755	3.473	0.1002	49.769	50.838	51.950	1.119
130	456.755	458.518	460.282	3.527	0.1010	50.888	51.965	53.086	1.136
129	460.282	462.073	463.864	3.582	0.1018	52.024	53.110	54.240	1.154
128	463.864	465.683	467.502	3.638	0.1026	53.178	54.273	55.412	1.172
127	467.502	469.349	471.197	3.696	0.1034	54.350	55.454	56.602	1.190
126	471.197	473.074	474.952	3.755	0.1042	55.541	56.654	57.812	1.209
125	474.952	476.859	478.766	3.815	0.1051	56.750	57.873	59.041	1.229
124	478.766	480.705	482.643	3.877	0.1059	57.979	59.111	60.289	1.249
123	482.643	484.613	486.583	3.940	0.1068	59.228	60.370	61.558	1.269
122	486.583	488.585	490.587	4.005	0.1076	60.497	61.649	62.848	1.290
121	490.587	492.623	494.659	4.071	0.1085	61.787	62.950	64.160	1.311
120	494.658	496.728	498.798	4.139	0.1094	63.098	64.272	65.493	1.333
119	498.798	500.902	503.007	4.209	0.1103	64.432	65.617	66.849	1.356
118	503.007	505.147	507.288	4.281	0.1113	65.788	66.984	68.228	1.379
117	507.288	509.465	511.642	4.354	0.1122	67.167	68.374	69.631	1.403
116	511.642	513.857	516.072	4.430	0.1132	68.569	69.789	71.058	1.427
115	516.071	518.325	520.579	4.507	0.1142	69.996	71.228	72.510	1.452
114	520.578	522.872	525.165	4.587	0.1152	71.448	72.693	73.987	1.477
113	525.165	527.499	529.833	4.668	0.1162	72.925	74.183	75.491	1.504
112	529.833	532.209	534.585	4.752	0.1172	74.429	75.700	77.021	1.531
111	534.584	537.003	539.422	4.838	0.1183	75.960	77.244	78.580	1.558
110	539.422	541.885	544.348	4.926	0.1194	77.518	78.817	80.167	1.587
109	544.348	546.857	549.365	5.017	0.1205	79.105	80.418	81.783	1.616
108	549.365	551.920	554.475	5.110	0.1216	80.721	82.049	83.429	1.646
107	554.475	557.078	559.681	5.206	0.1227	82.367	83.710	85.106	1.677
106	559.681	562.334	564.986	5.305	0.1239	84.044	85.403	86.815	1.709
105	564.986	567.689	570.393	5.407	0.1251	85.753	87.128	88.556	1.742
104	570.392	573.148	575.903	5.511	0.1263	87.495	88.886	90.332	1.775
103	575.903	578.712	581.522	5.619	0.1275	89.270	90.678	92.141	1.810
102	581.521	584.386	587.251	5.729	0.1287	91.080	92.505	93.987	1.845
101	587.250	590.172	593.094	5.843	0.1300	92.925	94.369	95.869	1.882
100	593.093	596.074	599.054	5.961	0.1313	94.807	96.270	97.789	1.920

An example of spectral format using the cross-dispersing grating for the red region.

ORDER	WAVEMIN (nm)	WAVECEN (nm)	WAVEMAX (nm)	FSR (nm)	LD (nm/mm)	CDMIN (mm)	CDCEN (mm)	CDMAX (mm)	ORDSEP (mm)
149	398.707	400.049	401.392	2.685	0.0881	20.124	20.913	21.726	0.541
148	401.392	402.753	404.113	2.721	0.0887	20.664	21.457	22.274	0.548
147	404.113	405.492	406.872	2.758	0.0893	21.212	22.009	22.829	0.556
146	406.872	408.270	409.668	2.796	0.0899	21.768	22.568	23.393	0.563
145	409.668	411.085	412.503	2.835	0.0906	22.331	23.135	23.963	0.571
144	412.503	413.940	415.377	2.875	0.0912	22.902	23.710	24.542	0.579
143	415.377	416.835	418.292	2.915	0.0918	23.481	24.293	25.129	0.587
142	418.292	419.770	421.248	2.956	0.0925	24.068	24.884	25.725	0.595
141	421.248	422.747	424.246	2.998	0.0931	24.663	25.483	26.328	0.604
140	424.246	425.767	427.288	3.041	0.0938	25.267	26.091	26.941	0.612
139	427.287	428.830	430.373	3.085	0.0945	25.879	26.708	27.562	0.621
138	430.372	431.937	433.502	3.130	0.0952	26.501	27.334	28.193	0.630
137	433.502	435.090	436.678	3.176	0.0958	27.131	27.969	28.832	0.640
136	436.678	438.289	439.901	3.223	0.0966	27.771	28.613	29.481	0.649
135	439.901	441.536	443.171	3.271	0.0973	28.420	29.266	30.140	0.659
134	443.171	444.831	446.491	3.320	0.0980	29.078	29.930	30.808	0.669
133	446.491	448.176	449.861	3.370	0.0987	29.747	30.603	31.487	0.679
132	449.861	451.571	453.281	3.421	0.0995	30.425	31.287	32.176	0.689
131	453.281	455.018	456.755	3.473	0.1002	31.114	31.981	32.875	0.699
130	456.755	458.518	460.282	3.527	0.1010	31.814	32.686	33.586	0.710
129	460.282	462.073	463.864	3.582	0.1018	32.524	33.402	34.307	0.721
128	463.864	465.683	467.502	3.638	0.1026	33.245	34.129	35.040	0.733
127	467.502	469.349	471.197	3.696	0.1034	33.978	34.867	35.784	0.744
126	471.197	473.074	474.952	3.755	0.1042	34.722	35.617	36.540	0.756
125	474.952	476.859	478.766	3.815	0.1051	35.478	36.379	37.308	0.768
124	478.766	480.705	482.643	3.877	0.1059	36.247	37.153	38.089	0.781
123	482.643	484.613	486.583	3.940	0.1068	37.027	37.940	38.882	0.793
122	486.583	488.585	490.587	4.005	0.1076	37.821	38.740	39.689	0.806
121	490.587	492.623	494.659	4.071	0.1085	38.627	39.553	40.509	0.820
120	494.658	496.728	498.798	4.139	0.1094	39.447	40.380	41.342	0.834
119	498.798	500.902	503.007	4.209	0.1103	40.281	41.220	42.190	0.848
118	503.007	505.147	507.288	4.281	0.1113	41.128	42.075	43.052	0.862
117	507.288	509.465	511.642	4.354	0.1122	41.990	42.944	43.929	0.877
116	511.642	513.857	516.072	4.430	0.1132	42.867	43.829	44.821	0.892
115	516.071	518.325	520.579	4.507	0.1142	43.759	44.728	45.729	0.908
114	520.578	522.872	525.165	4.587	0.1152	44.667	45.644	46.652	0.924
113	525.165	527.499	529.833	4.668	0.1162	45.591	46.576	47.592	0.940
112	529.833	532.209	534.585	4.752	0.1172	46.531	47.524	48.549	0.957
111	534.584	537.003	539.422	4.838	0.1183	47.488	48.490	49.523	0.974
110	539.422	541.885	544.348	4.926	0.1194	48.462	49.473	50.515	0.992
109	544.348	546.857	549.365	5.017	0.1205	49.454	50.474	51.526	1.010
108	549.365	551.920	554.475	5.110	0.1216	50.464	51.493	52.555	1.029
107	554.475	557.078	559.681	5.206	0.1227	51.493	52.532	53.603	1.048
106	559.681	562.334	564.986	5.305	0.1239	52.542	53.590	54.672	1.068
105	564.986	567.689	570.393	5.407	0.1251	53.610	54.668	55.760	1.089
104	570.392	573.148	575.903	5.511	0.1263	54.699	55.767	56.870	1.110
103	575.903	578.712	581.522	5.619	0.1275	55.809	56.888	58.002	1.131
102	581.521	584.386	587.251	5.729	0.1287	56.940	58.030	59.155	1.154
101	587.250	590.172	593.094	5.843	0.1300	58.094	59.195	60.332	1.177
100	593.093	596.074	599.054	5.961	0.1313	59.271	60.384	61.533	1.200
99	599.054	602.095	605.136	6.082	0.1326	60.471	61.596	62.757	1.225
98	605.135	608.239	611.342	6.207	0.1340	61.696	62.833	64.007	1.250
97	611.341	614.509	617.677	6.335	0.1354	62.945	64.096	65.283	1.276
96	617.676	620.910	624.144	6.468	0.1368	64.221	65.385	66.585	1.302
95	624.144	627.446	630.748	6.605	0.1382	65.524	66.701	67.915	1.330
94	630.748	634.121	637.494	6.746	0.1397	66.854	68.045	69.274	1.358
93	637.494	640.939	644.385	6.892	0.1412	68.212	69.418	70.662	1.388
92	644.385	647.906	651.427	7.042	0.1427	69.600	70.821	72.080	1.418
91	651.427	655.026	658.625	7.198	0.1443	71.018	72.254	73.529	1.450

90	658.625	662.304	665.984	7.359	0.1459	72.468	73.720	75.011	1.482
89	665.983	669.746	673.508	7.525	0.1475	73.950	75.218	76.527	1.515
88	673.508	677.357	681.205	7.697	0.1492	75.465	76.751	78.077	1.550
87	681.205	685.142	689.080	7.875	0.1509	77.015	78.318	79.663	1.586
86	689.079	693.109	697.139	8.059	0.1527	78.601	79.923	81.285	1.623
85	697.138	701.263	705.388	8.250	0.1545	80.224	81.564	82.947	1.661
84	705.388	709.612	713.835	8.448	0.1563	81.885	83.245	84.648	1.701
83	713.835	718.161	722.487	8.653	0.1582	83.586	84.967	86.390	1.742
82	722.487	726.919	731.352	8.865	0.1601	85.329	86.730	88.176	1.785
81	731.351	735.893	740.436	9.085	0.1621	87.114	88.538	90.005	1.829
80	740.435	745.092	749.749	9.314	0.1641	88.943	90.390	91.881	1.876
79	749.748	754.524	759.299	9.551	0.1662	90.819	92.289	93.804	1.923
78	759.298	764.197	769.096	9.797	0.1684	92.742	94.237	95.777	1.973
77	769.095	774.122	779.148	10.054	0.1705	94.715	96.235	97.801	2.024
76	779.148	784.308	789.467	10.320	0.1728	96.740	98.286	99.879	2.078
75	789.467	794.765	800.063	10.597	0.1751	98.818	100.392	102.013	2.134
74	800.062	805.505	810.948	10.885	0.1775	100.951	102.554	104.205	2.192
73	810.947	816.539	822.132	11.185	0.1799	103.143	104.776	106.458	2.252
72	822.131	827.880	833.629	11.498	0.1824	105.396	107.060	108.773	2.315
71	833.628	839.540	845.453	11.825	0.1849	107.711	109.408	111.154	2.381
70	845.451	851.534	857.616	12.165	0.1876	110.092	111.823	113.604	2.450
69	857.615	863.875	870.135	12.520	0.1903	112.542	114.308	116.125	2.521
68	870.134	876.579	883.024	12.891	0.1931	115.063	116.866	118.721	2.596
67	883.023	889.662	896.302	13.279	0.1960	117.659	119.500	121.394	2.674
66	896.300	903.142	909.984	13.684	0.1990	120.332	122.214	124.150	2.755
65	909.982	917.036	924.091	14.108	0.2020	123.088	125.012	126.991	2.841
64	924.089	931.365	938.642	14.553	0.2052	125.929	127.897	129.921	2.930
63	938.640	946.149	953.658	15.018	0.2084	128.859	130.874	132.945	3.024
62	953.656	961.409	969.163	15.507	0.2118	131.883	133.947	136.068	3.122
61	969.160	977.170	985.180	16.019	0.2153	135.006	137.120	139.293	3.226
60	985.177	993.456	1001.735	16.558	0.2189	138.231	140.400	142.627	3.334
59	1001.733	1010.294	1018.856	17.124	0.2226	141.565	143.790	146.075	3.448
58	1018.854	1027.713	1036.573	17.719	0.2264	145.013	147.298	149.643	3.568
57	1036.570	1045.743	1054.917	18.346	0.2304	148.581	150.928	153.337	3.694
56	1054.914	1064.417	1073.921	19.007	0.2345	152.275	154.688	157.165	3.827
55	1073.918	1083.770	1093.623	19.705	0.2388	156.102	158.585	161.132	3.968
54	1093.620	1103.840	1114.061	20.441	0.2432	160.070	162.626	165.248	4.116
53	1114.057	1124.667	1135.277	21.220	0.2478	164.186	166.820	169.521	4.273
52	1135.274	1146.296	1157.318	22.044	0.2525	168.459	171.175	173.960	4.439
51	1157.313	1168.772	1180.231	22.917	0.2575	172.897	175.701	178.574	4.614

5.2 Example of Observation Procedure

```
<HEADER>
OBSERVATION_PERIOD=2001-07-25-19:00:00 - 2001-07-26-06:00:00
PROPOSALID=O1403
OBE_ID=HDS
</HEADER>

<PARAMETER_LIST>
DEF_SPEC=OBE_ID=HDS OBE_MODE=SPEC
DEF_PROTO=OBE_ID=HDS OBE_MODE=PROTO
DEF_COMMON=OBE_ID=COMMON OBE_MODE=TOOL

# Targets
TGT_CS30301_015=OBJECT="CS30301-015"  RA=150625.200 DEC=+024144.00 EQUINOX=1950
TGT_CS30306_132=OBJECT="CS30306-132"  RA=151151.500 DEC=+073809.00 EQUINOX=1950

</PARAMETER_LIST>

<COMMAND>
#SetupOBE
SetupOBE $DEF_SPEC Filter_1=Free Filter_2=Free
SetupOBE $DEF_SPEC SLIT_WIDTH=200 SLIT_LENGTH=2500
SetupOBE $DEF_SPEC cross_scan=StdBc

FocusAGSequence $DEF_COMMON
FocusAG $DEF_COMMON
MoveToStar $DEF_COMMON
ShowImage $DEF_PROTO

################
# Observation

## Blue with ADC
# CS30301-015
SetupField $DEF_PROTO $TGT_CS30301_015 SVRegion=200 Exptime_SV=2000 IMGROT_FLAG=0
SetupField_FINE $DEF_PROTO Slit_Length=2000 IMGROT_FLAG=0
GetObject $DEF_SPEC Exptime=1800 $TGT_CS30301_015
# CS30306-132
SetupField $DEF_PROTO $TGT_CS30306_132 SVRegion=200 Exptime_SV=2000 IMGROT_FLAG=0
SetupField_FINE $DEF_PROTO Slit_Length=2000 IMGROT_FLAG=0
GetObject $DEF_SPEC Exptime=1800 $TGT_CS30306_132
# Calibration #
### BIAS
GetBias $DEF_SPEC OBJECT=BIAS
GetBias $DEF_SPEC OBJECT=BIAS
GetBias $DEF_SPEC OBJECT=BIAS

#COMPARISON
SETUPCOMPARISON_HCT $DEF_PROTO OBJECT=HCT LAMP=HCT2 AMP=15.0 FILTER01=1 FILTER02=1
FILTER03=1 FILTER04=1 F_SELECT=NS_OPT
SetupOBE $DEF_SPEC SLIT_LENGTH=2000
GetComparison $DEF_SPEC OBJECT=Comparison Exptime=20.0
SHUTDOWNCOMPARISON_HCT OBE_ID=COMMON OBE_MODE=TOOL OBJECT=HCT F_SELECT=NS_OPT


### Flat
#Flat for Blue CCD1
SETUPCOMPARISON_HAL $DEF_PROTO OBJECT=HAL LAMP=HAL1 AMP=4.0 FILTER01=2 FILTER02=1
FILTER03=1 FILTER04=2 F_SELECT=NS_OPT
SetupOBE $DEF_SPEC SLIT_LENGTH=2500
```

```
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=12.0
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=12.0
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=12.0
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=12.0
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=12.0
#Flat for Blue CCD2
SETUPCOMPARISON_HAL $DEF_PROTO OBJECT=HAL LAMP=HAL1 AMP=4.0 FILTER01=1 FILTER02=1
FILTER03=2 FILTER04=2 F_SELECT=NS_OPT
SetupOBE $DEF_SPEC SLIT_LENGTH=2500
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=4.0 Display_Frame=!STATOBS.HDS.C2
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=4.0 Display_Frame=!STATOBS.HDS.C2
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=4.0 Display_Frame=!STATOBS.HDS.C2
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=4.0 Display_Frame=!STATOBS.HDS.C2
GetOBEFlat $DEF_SPEC OBJECT=Flat Exptime=4.0 Display_Frame=!STATOBS.HDS.C2

SHUTDOWNCOMPARISON_HAL OBE_ID=COMMON OBE_MODE=TOOL OBJECT=HAL F_SELECT=NS_OPT

SHUTDOWNCOMPARISON_HCTLAMP $DEF_PROTO OBJECT=HCT F_SELECT=NS_OPT
SHUTDOWNCOMPARISON_HALLAMP $DEF_PROTO OBJECT=HAL F_SELECT=NS_OPT
```

5.3 Example of FITS Headers and Tables

Header unit

```
SIMPLE  =                    T / Standard FITS format
BITPIX  =                   16 / Number of bits for each pixel
NAXIS   =                    2 / Number of axes in frame
NAXIS1  =                 2148 / Number of pixels per row
NAXIS2  =                 4100 / Number of rows
EXTEND  =                    T / There is a standard extension 1 (ASCII table)
BSCALE  =              1.00000 / Real = (fits pixel value)*BSCALE+BZERO
BZERO   =         3.276700E+04 / Real = (fits pixel value)*BSCALE+BZERO
BUNIT   = 'ADU     '           / Unit of original pixel value
BLANK   =               -32768 / Value used for NULL pixels
DISPAXIS=                    2 / Main dispersion axis in frame
CTYPE1  = 'pixel   '           / Pixel coordinate system
CTYPE2  = 'pixel   '           / Pixel coordinate system
CUNIT1  = 'pixel   '           / Units used in both CRVAl1 and CDELT1
CUNIT2  = 'pixel   '           / Units used in both CRVAL2 and CDELT2
CRPIX1  =                    1 / Reference pixel in axis1
CRVAL1  =                    1 / Physical value of the reference pixel
CDELT1  =                    1 / Size projected into a detector pixel in axis1
CRPIX2  =                    1 / Reference pixel in axis2
CRVAL2  =                    1 / Physical value of the reference pixel
CDELT2  =                    1 / Size projected into a detector pixel in axis2
PROJP1  =                  0.0 / Projection type of the first axis
PROJP2  =                  0.0 / Projection type of the second axis
PC001001=           1.00000000 / Pixel Coordinate translation matrix
PC001002=           0.00000000 / Pixel Coordinate translation matrix
PC002001=           0.00000000 / Pixel Coordinate translation matrix
PC002002=           1.00000000 / Pixel Coordinate translation matrix
BIN-FCT1=                    1 / Binning factor in axis1
BIN-FCT2=                    1 / Binning factor in axis2
N2XIS   =                    2 / Number of axes for the slit projection
N2XIS1  =                 2148 / Number of pixels per row for slit spectroscopy
N2XIS2  =                 4100 / Number of scan lines for slit projection
C2YPE1  = 'DEC-TAN '           / Type of projection used for #1 axis in 2nd WCS
C2PIX1  =               1024.0 / Reference pixel in X
C2VAL1  =                 0.00 / Physical value of ref pix X for WCS
C2ELT1  =              0.00000 / Size projected into a detector pixel X
```

```
C2NIT1  = 'degree      '        / for C2VAL1 and C2ELT1
C2YPE2  = 'WAVELENGTH'          / Type of projection used for #2 axis in 2nd WCS
C2PIX2  =               2050.0 / Reference pixel in Y
C2VAL2  =               562.30 / Physical value of ref pix Y for WCS
C2ELT2  =              0.00166 / Size projected into a detector pixel Y
C2NIT2  = 'nm      '            / for C2VAL2 and C2ELT2
P2OJP1  =                  0.0 / Projection type of the first axis
P2OJP2  =                  0.0 / Projection type of the second axis
P2001001=           1.00000000 / Pixel coordinate translation matrix
P2001002=           0.00000000 / Pixel coordinate translation matrix
P2002001=           0.00000000 / Pixel coordinate translation matrix
P2002002=           1.00000000 / Pixel coordinate translation matrix
PRD-MIN1=                    1 / Start X position of partialy read out
PRD-MIN2=                    1 / Start Y position of partialy read out
PRD-RNG1=                 2148 / X range of the partialy read out
PRD-RNG2=                 4100 / Y range of the partialy read out
OBJECT  = ' BD+28.4211 '        / Target Description
DATA-TYP= 'OBJECT  '            / Characteristics of this data
RA      = '21:51:12.055'        / RA of the tracked pos. on the slit guide pos.
DEC     = '+28:51:38.72'        / Dec of the tracked pos. on the slit guide pos.
RADECSYS= 'FK5     '            / The equatorial coordinate system
EQUINOX =               2000.0 / Standard FK5 (years)
RA2000  = '21:51:12.055'        / Right accention (HH.MM.SS.SSS)
DEC2000 = '+28:51:38.72'        / Declination (+/-HH:MM:SS.SS)
PROP-ID = 'o99007  '            / Proposal ID
OBSERVER= ' Aoki et al. '       / Name(s) of observer(s)
OBS-MOD = 'SPEC    '            / SINGLE-ORDER, MULTIPLE-ORDER
DATE-OBS= '2000-08-21'          / Date of observation
EXPTIME =                150.0 / Exposure time in second
UT      = '10:38:28.865'        / Typical Universal Time during exposure
UT-STR  = '10:37:13.575'        / UTC at start of exposure
UT-END  = '10:39:49.764'        / UTC at end of exposure
HST     = '00:38:28.865'        / Typical Hawaii Standard Time during exposure
HST-STR = '00:37:13.575'        / HST at start of exposure
HST-END = '00:39:49.764'        / HST at end of exposure
LST     = '22:16:48.821'        / Typical Local SideReal Time during exposure
LST-STR = '22:15:33.324'        / LST at start of exposure
LST-END = '22:18:09.941'        / LSR at end of exposure
TIMESYS = 'UTC     '            / Time System
MJD     =       51777.44432826 / Modified Julian Day
MJD-STR =       51777.44432826 / MJD at start of exposure
MJD-END =       51777.44432826 / MJD at end of exposure
SECZ    =                1.018 / typical sec(Zemith Distance) during exposure
SECZ-STR=                1.018 / secZ at start of exposure
SECZ-END=                1.018 / secZ at end of exposure
AIRMASS =               1.0180 / Typical air mass during exposure
AIRM-STR=               1.0180 / Air mass at start of exposure
AIRM-END=               1.0180 / Air mass at end of exposure
ALTITUDE=             79.09255 / Altitude of the telescope pointing (degree)
ALT-STR =             79.09255 / Altitude at start of exposure
ALT-END =             79.09255 / Altitude at end of exposure
AZIMUTH =            327.22178 / Azimuth of the telescope pointing (degree)
AZ-STR  =            327.22178 / Azimuth at start of exposure
AZ-END  =            327.22178 / Azimuth at end of exposure
OBSERVAT= 'NAOJ    '            / Observatory
TELESCOP= 'SUBARU  '            / Telescope
OBS-ALOC= 'Observation'         / Allocation mode (OBSERVATION/STAND-BY)
TELFOCUS= 'NASMYTH-OPT'         / Focus where beam is reachable
FOC-POS = 'NASMYTH-OPT'         / Focus where instrument attached
FOC-VAL =               -0.037 / Focus position of the telescope
FOC-LEN =             104207.0 / Focal length of the telescope (mm)
F-RATIO =                12.71 / F-ratio of incident beam
INSTRUME= 'HDS     '            / Name of instrument
```

```
FRAMEID = 'HDSA00001069'       / Frame ID number issued by OBS
EXP-ID  = 'UNKNOWN '           / Exposure ID number locally defined
DATASET = 'DS000   '           / ID of observation dataset
DISPERSR= 'echelle '           / Identifier of the disperser used
WAVELEN =               562.30 / Center wavelength of the center order (nm)
WAV-MAX =               624.63 / Maximum wavelength recorded (nm)
WAV-MIN =               502.06 / Minimum wavelength recorded (nm)
SLTCPIX1=              1064.00 / Pixel of slit center (Axis1)
SLTCPIX2=               2050.0 / Pixel of slit center (Axis2)
FILTER01= 'SQ      '           / Filter wheel No.1
FILTER02= 'FREE    '           / Filter wheel No.2
SLIT    = 'SHORT   '           / Identifier of the entrance slit used (SHORT/LON
SLT-WID =                2.000 / Slit width (mm)
SLT-LEN =                2.000 / Slit length (mm)
SLT-PA  =                 0.00 / Slit position angle (degree)
SLT-PSTR=                  0.0 / Slit position angle at start (degree)
SLT-PEND=                 0.00 / Slit position angle at end (degree)
SLT-OBJP=                 0.00 / Object position on the slit (arcsec)
DET-ID  =                    1 / ID number of the CCD in the detector unit
DETECTOR= 'EEV     '           / Detector used to take this frame
DETPXSZ1=               0.0135 / pixel size in axis1 (mm)
DETPXSZ2=               0.0135 / pixel size in axis2 (mm)
DET-A01 =                0.000 / Rotation angle of the 1st detector (degree)
DET-A02 =                0.000 / Rotation angle of the 2nd detector (degree)
GAIN    =                 1.70 / Readout gain
DET-TMP =                156.9 / Nominal detector temperature (Kelvin)
DET-TAVE=                  0.0 / Average detector temperature (Kelvin)
DET-TMAX=                  0.0 / Maximum detector temperature (Kelvin)
DET-TMIN=                  0.0 / Minimum detector temperature (Kelvin)
DET-TSD =                 0.00 / Detector temperature fluctuation (Kelvin)
WEATHER = 'Clear   '           / Weather condition
SEEING  =                0.400 / FWHM of the star observed with Slit Viewer (arc
NAS-TAVE=                 0.00 / Average Nasmyth encl. temp. (Kelvin)
DOM-WND =                  0.4 / Wind speed inside dome (m/s)
DOM-TMP =               277.55 / Atmospheric temperature inside dome (Kelvin)
DOM-HUM =                 27.0 / Humidity inside dome (hPa)
DOM-PRS =                623.8 / Nominal atmospheric pressure in dome (hPa)
OUT-WND =                  6.7 / Wind speed outside dome (m/s)
OUT-TMP =               277.05 / Atmospheric temperature outside dome (Kelvin)
OUT-HUM =                 22.4 / Humidity outside dome (hPa)
OUT-PRS =                623.8 / Atmospheric pressure outside dome (hPa)
IMR-TYPE= 'BLUE    '           / Image Rotator (BLUE, RED, NONE)
IMGROT  =               -39.46 / IMR position during exposure (degree)
IMR-STR =               -39.46 / IMR position angle at start (degree)
IMR-END =               -39.46 / IMR position angle at end (degree)
ADC-TYPE= '#       '           / Atm. Disp. Compensator (BLUE,RED,NONE)
ADC     =                 0.00 / ADC position during exposure (degree)
ADC-STR =                 0.00 / ADC position angle at start (degree)
ADC-END =                 0.00 / ADC position angle at end (degree)
DAQ-VER = '1.0.0 '             / Data Aquisition System
INS-VER = 'HDS-1.00/HDS-1.00'  / hardware/software version
COMMENT revised on 1 Nov. 1999 by W. Aoki
COMMENT Sample header for HDS revised on 7 July 1998 by W. Aoki
COMMENT Sample header for HDS revised on 6 May 1998 by W. Aoki
COMMENT Sample header for HDS written on 27 November 1997
COMMENT by H.Izumiura, S. Kawanomoto, W. Aoki.
COMMENT  Keywords specific to HDS
COMMENT
COMMENT /SLIT
H_S-INCL=                 0.00 / Slit inclination angle wrt the horizontal plane
COMMENT /Detector
H_D-UNIT= '1       '           / ID number of the detector unit
H_D-OTHR= 'YES     '           / Use of the other CCD in this mosaic
```

```
COMMENT /SHUTTERS
H_SHUTTR= 'OPEN    '            / Entrance shutter (OPEN, CLOSE)
H_HARTMN= 'ALL-OPEN'            / Hartmann shutter (U-OPEN,L-OPEN,ALL-OPEN,ALL-CL
COMMENT /COLLIMATOR MIRROR
H_COLLIM= 'RED     '            / Collimator (BLUE, RED)
H_CLPSTN=                 0.00 / Collimator position (mm)
H_CLFOCL=              3396.51 / Collimator focal length (mm)
COMMENT /ECHELLE GRATING
H_ECONST=                31.60 / Ruling pitch (grooves/mm)
H_EBLAZE=                70.30 / Blaze Angle (degree)
H_EEPSRN=                 6.00 / Offset Angle of the Incident Beam (degree)
H_EGAMMA=                 0.00 / (degree)
H_EROTAN=              0.40070 / Echelle Rotation Angle (degree)
COMMENT /CROSS DISPERSER GRATING
H_CROSSD= 'RED     '            / Cross Disperser (BLUE, RED, MIRROR, NIR)
H_CCONST=              250.000 / Ruling pitch (grooves/mm)
H_CBLAZE=                5.000 / Blaze Angle (degree)
H_CEPSRN=                 0.00 / Offset Angle at Blaze Wavelengths (degree)
H_CGAMMA=                45.00 / (degree)
H_CROTAN=              3.95679 / Cross Disperser Rotation Angle (degree)
COMMENT /CAMERA
H_CMRFL =               770.85 / Camera focal length (mm)
COMMENT /Detector Focusinig Unit
H_FOCUS =              0.64999 / Focusing unit position (mm)
H_PITCH =             -0.00000 / Focusing unit pitching angle (degree)
H_YAWING=             -0.00000 / Focusing unit yawing angle (degree)
H_DETROT=             -0.99986 / Rotation angle of the detector unit (degree)
COMMENT /I2Cell and Light Monitor
H_I2CELL= 'NOUSE   '            / I2 Cell Mode (USE/NOUSE)
H_LM    = 'NOUSE   '
H_I2TEMP=                  0.0
H_LMINTG=                  0.0
H_I2POS = 'UNKNOWN '
H_LMPOS = 'UNKNOWN '
H_ETMP1 =                  2.4 / Nasmyth Temperature 1 (Kelvin)
H_ETMP2 =                  2.3 / Nasmyth Temperature 2 (Kelvin)
H_SUPER = 'NONE    '            / Super Resolution Mode (POS1, POS2, NONE)
COMMENT /Auto Guider (offset guider)
H_AG-OBJ= '        '
H_AG-ORA= '        '            / RA of the guide object
H_AG-ODE= '        '            / Dec of the guide object
H_AG-RA = '        '            / RA of the tracked pos. on the slit guide pos.
H_AG-DEC= '        '            / Dec of the tracked pos. on the slit guide pos.
H_GAIN1 =                1.628 / Readout gain of left (smaller X) side of CCD
H_GAIN2 =                1.615 / Readout gain of right (larger X) side of CCD
H_OSMIN1=                 1025 / Start of overscan region for AXIS1
H_OSMAX1=                 1124 / End of overscan region for AXIS1
H_OSMIN2=                    1 / Start of overscan region for AXIS2
H_OSMAX2=                 4100 / End of overscan region for AXIS2
HISTORY   File modified by user 'hdsuser' with fv  on 2000-07-11T04:42:41
END
```

Header unit of ASCII extension table

```
XTENSION= 'TABLE   '           / ASCII table extension
BITPIX  =                    8 / 8-bit ASCII characters
NAXIS   =                    2 / 2-dimensional ASCII table
NAXIS1  =                   72 / width of table in characters
NAXIS2  =                   23 / number of rows in table
PCOUNT  =                    0 / no group parameters (required keyword)
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                   12 / number of fields in each row
```

```
TTYPE1  = 'ORDER   '           / label for field   1
TBCOL1  =                    1 / beginning column of field   1
TFORM1  = 'I3      '           / Fortran-77 format of field
TUNIT1  = '        '           / physical unit of field
TTYPE2  = 'X-MIN   '           / label for field   2
TBCOL2  =                    5 / beginning column of field   2
TFORM2  = 'I4      '           / Fortran-77 format of field
TUNIT2  = 'PIXEL   '           / physical unit of field
TTYPE3  = 'Y-MIN   '           / label for field   3
TBCOL3  =                   10 / beginning column of field   3
TFORM3  = 'I4      '           / Fortran-77 format of field
TUNIT3  = 'PIXEL   '           / physical unit of field
TTYPE4  = 'WL-MIN  '           / label for field   4
TBCOL4  =                   15 / beginning column of field   4
TFORM4  = 'F8.3    '           / Fortran-77 format of field
TUNIT4  = 'nm      '           / physical unit of field
TTYPE5  = 'X-CEN   '           / label for field   5
TBCOL5  =                   24 / beginning column of field   5
TFORM5  = 'I4      '           / Fortran-77 format of field
TUNIT5  = 'PIXEL   '           / physical unit of field
TTYPE6  = 'Y-CEN   '           / label for field   6
TBCOL6  =                   29 / beginning column of field   6
TFORM6  = 'I4      '           / Fortran-77 format of field
TUNIT6  = 'PIXEL   '           / physical unit of field
TTYPE7  = 'WL-CEN  '           / label for field   7
TBCOL7  =                   34 / beginning column of field   7
TFORM7  = 'F8.3    '           / Fortran-77 format of field
TUNIT7  = 'nm      '           / physical unit of field
TTYPE8  = 'X-MAX   '           / label for field   8
TBCOL8  =                   43 / beginning column of field   8
TFORM8  = 'I4      '           / Fortran-77 format of field
TUNIT8  = 'PIXEL   '           / physical unit of field
TTYPE9  = 'Y-MAX   '           / label for field   9
TBCOL9  =                   48 / beginning column of field   9
TFORM9  = 'I4      '           / Fortran-77 format of field
TUNIT9  = 'PIXEL   '           / physical unit of field
TTYPE10 = 'WL-MAX  '           / label for field  10
TBCOL10 =                   53 / beginning column of field  10
TFORM10 = 'F8.3    '           / Fortran-77 format of field
TUNIT10 = 'nm      '           / physical unit of field
TTYPE11 = 'SLIT INCLINATION'   / label for field  11
TBCOL11 =                   62 / beginning column of field  11
TFORM11 = 'F5.3    '           / Fortran-77 format of field
TUNIT11 = 'degree  '           / physical unit of field
TTYPE12 = 'DISPERSION'         / label for field  12
TBCOL12 =                   68 / beginning column of field  12
TFORM12 = 'F5.3    '           / Fortran-77 format of field
TUNIT12 = 'nm/PIXEL'           / physical unit of field
EXTNAME = 'HDS_ASCII'          / name of this ASCII table extension

END
```

Data unit of ASCII extension table

ORDER	X-MIN	Y-MIN	WL-MIN	X-CEN	Y-CEN	WL-CEN	X-MAX	Y-MAX	WL-MAX	SLIT INCLINATION	DISPERSION
I3	I4	I4	F8.3	I4	I4	F8.3	I4	I4	F8.3	F5.3	F5.3
	PIXEL	PIXEL	nm	PIXEL	PIXEL	nm	PIXEL	PIXEL	nm	degree	nm/PIXEL
96	70	4096	617.121	176	2048	620.876	281	1	624.630	0.000	0.002
97	168	4096	610.759	273	2048	614.475	378	1	618.191	0.000	0.002
98	263	4096	604.527	368	2048	608.205	472	1	611.883	0.000	0.002
99	357	4096	598.421	461	2048	602.061	565	1	605.702	0.000	0.002
100	449	4096	592.437	552	2048	596.041	656	1	599.645	0.000	0.002
101	539	4096	586.571	642	2048	590.139	745	1	593.708	0.000	0.002
102	627	4096	580.820	730	2048	584.354	832	1	587.887	0.000	0.002
103	714	4096	575.181	816	2048	578.680	917	1	582.180	0.000	0.002
104	799	4096	569.651	900	2048	573.116	1001	1	576.582	0.000	0.002
105	882	4096	564.225	983	2048	567.658	1084	1	571.091	0.000	0.002
106	964	4096	558.902	1064	2048	562.303	1164	1	565.703	0.000	0.002
107	1144	4096	553.679	1244	2048	557.047	1344	1	560.416	0.000	0.002
108	1223	4096	548.552	1322	2048	551.890	1421	1	555.227	0.000	0.002
109	1300	4096	543.520	1399	2048	546.826	1498	1	550.133	0.000	0.002
110	1376	4096	538.579	1474	2048	541.855	1573	1	545.132	0.000	0.002
111	1450	4096	533.727	1548	2048	536.974	1646	1	540.221	0.000	0.002
112	1524	4096	528.961	1621	2048	532.179	1718	1	535.397	0.000	0.002
113	1595	4096	524.280	1692	2048	527.470	1789	1	530.659	0.000	0.002
114	1666	4096	519.681	1763	2048	522.843	1859	1	526.004	0.000	0.002
115	1735	4096	515.162	1832	2048	518.296	1928	1	521.430	0.000	0.002
116	1804	4096	510.721	1899	2048	513.828	1995	1	516.935	0.000	0.002
117	1871	4096	506.356	1966	2048	509.437	2061	1	512.517	0.000	0.002
118	1937	4096	502.065	2031	2048	505.119	2126	1	508.174	0.000	0.001