Centre for Advanced Instrumentation

Durham University

Document Title	**Instrument Description (Systems Overview)**		
Document Number			
Issue	**4.0**		
Date	**18 August 2008**		
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Change Record

Issue	Date	Section(s) Affected	Description of Change/Change Request Reference/Remarks
2.1	15/03/05	Not Applicable	University of Canterbury - CDR version
3.0	18/12/07	All	CfAI controlled version - First issue
4.0	18/08/08	2.1, 3	Updated resolving powers in line with Stuart Barnes' SPIE paper

Applicable Documents

	Title	Document Number

Reference Documents

	Title	Document Number
RD1	Operational Concepts Definition Document	3200 AE 0018 (Currently under review)

Acronyms and Abbreviations

AD	Applicable Document
CfAI	Centre for Advanced Instrumentation of Durham University
SALT	Southern African Large Telescope
SALT HRS	SALT High-Resolution Spectrograph
FIF	SALT Fibre Instrument Feed

Table of Contents

1 Introduction

This document gives a high level summary of the optical, mechanical, electronics and software components that make up SALT HRS. Further design detailing is planned, and as such the document presented here captures the current state of the HRS instrument and provides the framework around which the design finalisation and construction work will continue.

This document replaces version 3200 AE 0017 Issue 2.1 which was written by the University of Canterbury team.

2 SALT HRS Design

2.1 Purpose

SALT HRS is a single-object spectrograph designed for very high resolution spectroscopy (R = 16,500-67,000) from 3700 to 8900 Angstroms. The instrument has a high predicted throughput and a predicted radial velocity stability of 3-4 ms^{-1}. (For more information on the scientific rationale for SALT HRS please refer to the OCDD [AD1].) Light enters the instrument via optical fibres positioned in the telescope focal plane by the FIF.

2.2 Optical Design

The original optical design for SALT HRS' dual beam, white pupil échelle spectrograph with fixed spectral format was developed by the University of Canterbury. (See 3210 AE 0005 Issue 2.7 for details.)

2.2.1 *Échelle Spectrograph*

The key elements of the spectrograph optical design are:

- A collimator as common first pupil mirror for both arms.
- An R4 échelle grating illuminated with a beam size of 200mm. The grating is a replicated mosaic of two 204 x 410mm ruled areas with 41.6mm groove spacing imprinted on a single substrate.
- A dichroic splitter which divides the light into two separate arms capable of simultaneous exposures. The blue arm covers wavelengths from 370-555nm and the red arm covers wavelengths from 555-890 nm.
- An exposure meter

Each arm has:

- A micro-positionable pupil mirror to enable focussing of the cameras.
- Volume phase holographic grating (positioned at the entrance to the camera) for cross dispersion.
- A fully dioptric camera (with slow shutter for independent red/blue arm exposure times).
- A cryogenically cooled, scientific grade CCD.

Figure 1 shows the ray diagram of SALT HRS. The input light is either by 'direct injection' or at 'intermediate injection' and deflected onto the collimator mirror by a fold mirror. The collimator serves as the first pupil mirror for both arms. A dichroic located just after the intermediate focus splits the spectrograph into its red and blue arms. Each arm has its own VPH cross-disperser and camera.

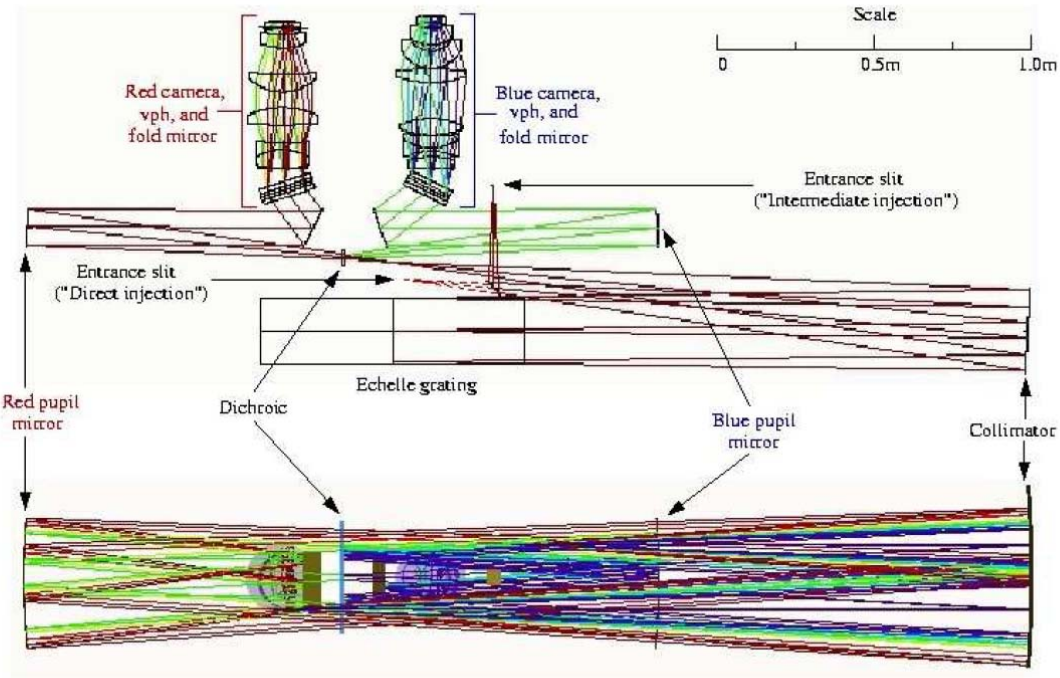

Figure 1. Schematic of the spectrograph optical layout.

The échelle spectra, as imaged onto the detectors, are shown in Figure 2. The combination of red and blue cameras will mean that in simultaneous exposures there will be complete wavelength coverage from 370 – 890nm.

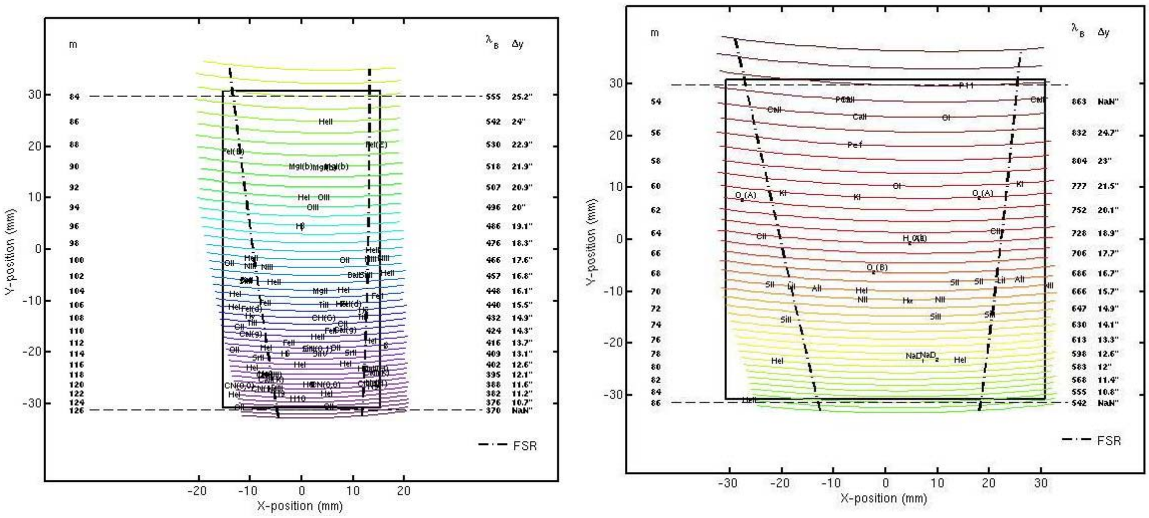

Figure 2 Camera spectral formats. The dot-dashed line shows the extent of one free spectral range (FSR). The central blaze wavelength (λ_B) for alternate orders (m), and the spatial separation (in arcsec) between each order projected on the sky are also indicated. The outline of CCD chips are also shown as solid line.

2.2.2 Input Optics

The input optics layout has been modified from the original Canterbury design to move the image slicers inside the vacuum chamber to avoid image shift at slit end due to air turbulence

There are multiple fibre feeds corresponding to the four operational modes (See §3). Each mode has a pair of fibres that are positioned by the SALT FIF to simultaneously acquire light from the object and adjacent sky.

For the low resolution modes the fibre feed comprises:

- A direct injection of light into the spectrograph at the collimator focus.
- Micro-lenses to re-image the 500 μm fibres onto the échelle grating
- Fast shutter

Light from the medium, high resolution and high radial velocity fibre pairs passes through an intermediate injection system which has:

- Re-imaging optics to re-image fibre exit faces onto image slicers.
- Pairs of modified Bowen-Walraven image slicers which 'cut' the circular image into three slices. The slicers are slightly tilted so that they point to same pupil direction.
- Re-imaging transfer optics
- Intermediate slits for each mode (viewable by CCD camera for engineering purposes).
- Pick off mirror to select mode. (Note the high precision radial velocity mode will not have any moving parts in the optical path.)

The intermediate injection system is housed inside the vacuum chamber to give immunity from pressure and temperature effects and contamination.

2.2.3 Calibration System

The calibration requirements for the instrument are still under investigation. Currently, it is anticipated that wavelength calibration will be provided using a reference calibration fibre or light from the SALT SAC calibration optics (AD 15?? AS 0001). The flat field calibration lamps have been removed from the original specification (TBC).

The direct injection wavelength calibration comprises:

- ThAr fibre illumination source
- A high resolving power direct injection fibre (100μm) illuminated by an emission line source.
- Micro-lens to re-image the 100 μm fibre onto the échelle grating.

The precision RV mode will most likely incorporate simultaneous ThAr injection as well.

2.3 Mechanical Design

SALT HRS is a large, static instrument (approximately 3.3m long x 1.1m diameter and weighing ~2,000 kg). The instruments mechanical structure consists of:

- Vacuum chamber (passively maintained at <2 mbar) to provide immunity from pressure and temperature effects. The chamber will in turn be housed inside a temperature controlled environment. Pneumatic vibration isolation is provided.
- Optical bench weldment to provide a stable and precise mounting platform for the optical components (including cameras and detectors). A truss extension will hold the collimator mirror.
- Mechanical support for intermediate injection input optics.
- Mechanical supports for main optics; collimator, red & blue pupil mirrors, red and blue fold mirrors, échelle grating, dichroic mirror, exposure meter direct injection optics.

2.4 Electronics Design

The control hardware and instrument monitoring hardware differs from the original design in that it is primarily LabView-based using National Instruments acquisition and control cards. The hardware to control all the electro-mechanical mechanism is distributed across 3 separate PCs.

- HRS Control PC for sequencing and communication with TCS/FIF and image arching PC. Motion control cards provide camera focus micro-positioning, fibre and mode selection and slow shutter drives. There are also DIO/DAQ cards controlling the fast shutters, calibration lamps, slit viewing camera (if required) and data acquisition from temperature and pressure sensors (up to 8 channels) and the exposure meter.

- Separate blue and red camera PCs interface to CCD controllers.

2.5 (Control) Software Design

The HRS Control Software provides the capability to control and monitor the instrument (including the detectors) and talk to the TCS/FIF. The control and sequencing software, like all SALT systems, is LabView-based.

The software comprises:

- HRS Man Machine Interface (MMI) to control and display the status of all aspects of HRS. Has a client display on the SALT Astronomer's PC.
- Motion control software to control all drives and motion mechanisms
- Auxiliary control software to control the data acquisition for condition monitoring.
- Camera control software to operate red and blue cameras and provide engineering level interface to the detectors.
- Client/Server communications to control distributed processes.
- TCS/FIF communication to provide telescope configuration facilities required by HRS (primarily in nod and shuffle mode).
- Image archiving and FITS header writing functions

2.6 Quick Look Data Reduction Software Design

The SALT Quick Look PC (QCPC) runs basic pipeline reduction software, utilising IRAF or IDL, to allow the SALT astronomer to quickly validate science data taken from exposures from any of the four modes.

3 Operational Modes

It is currently proposed that SALT HRS will have four operational modes:

Mode	Description	Fibre core (μm)	Sliced?/ No. slices	Resolution	
				Fixed object & sky	Nod & shuffle
1	Low-resolution	500	No	16,000	16,000
2	Medium-resolution	500	Yes/3	37,000	Not available
3	High-resolution	350	Yes/3	67,000	Not available
4	Precision radial velocity	TBD	TBD	TBD	Not available

The high precision radial velocity mode will have fibre double scrambling for the best precision.
The low resolution mode is capable of operating in fixed object & sky mode or nod & shuffle mode for accurate sky subtraction.

4 Interfaces

SALT has interfaces to HRS including:

- Optical feed from the Fibre Input Feed
- SALT network services for communication with TCS/FIF, QCPC and image archiving PC
- Services: power, water, air, vacuum

The HRS will be physically located in the Spectrograph Room at SALT.

5 Comparison with other Spectrograph Designs

Table 1 gives a comparison of the key design characteristics of SALT HRS with some other notable fibre-fed spectrographs.

Table 1 Comparison with other notable fibre-fed spectrographs.

	INSTRUMENT:		SALT HRS	HARPS	FEROS	UVES	HET HI-RES	HERCULES	HECTOCHELLE
Telescope	Telescope		SALT	La Silla 3.6m telescope	MPG/ESO 2.2m Telescope (La Silla)	UT2 (Kueyen) of VLT at Paranal	Hobby-Eberly Telescope	McLellan telescope at Mt. John Observatory	MMT on Mount Hopkins in Arizona
	Diameter	(m)	11 [9.2 effective aperture]	3.6	2.2	8.2	9.2 (effective aperture)	1	6.7
Spectrograph Specification	Purpose		The HRS will specialize in very resolution (R = 16500-65000) spectroscopy from 3700 to 8900 Angstroms	HARPS, the High Accuracy Radial velocity Planet Searcher is dedicated to the discovery of extrasolar planets.	The high efficiency (~20%), large wavelength range (the complete optical spectral region in one exposure) and high resolution (R=48000) makes possible a large variety of stellar and extra-galactic spectroscopic observation programs requiring high spectral	UVES is the high-resolution optical spectrograph of the VLT designed to operate with high efficiency from the atmospheric cut-off at 300 nm to the long wavelength limit of the CCD detectors (about 1100 nm).	A single channel adaptation of the ESO UVES spectrometer		High resolution multi-object spectroscopy suited to stellar radial velocity surveys and detailed spectroscopic studies
	Spectrograph mode		Quasi Littrow	Quasi Littrow	Quasi Littrow	Quasi-Littrow		Littrow angle, θ = 3.0º	
	Configuration		Dual beam, white pupil	White pupil	White pupil	White pupil	White pupil		
			Blue arm / **Red arm**			**Blue arm** / **Red arm**			
	Wavelength range	(nm)	370-555 / 555-890	378-530(lower); 533-691(upper)	370-920	300 - 500 / 420 - 1100	420 to 1100	380–880	
	Resolution/slit product		27,000			41,400 / 38,700			
	Resolving power		Mode #1: 70,000 (sliced) Mode #2: 37,000 (sliced) Mode #3: 16,000 Mode #4: (High stability) TBD	120,000	48,000	~80,000 (0.4" slit) / ~110,000 (0.3" slit)	*R* = 30,000 to 120,000		~34,000
	Nod & shuffle		Yes, in low-res mode only						
	R.V. precision	(ms-1)	~3-4 (predicted)	1	<25	2 (with iodine cell)	< 10	<10	30-50 expected with iodine cell
Fibre link	Type			Two 70 micron Polymicro FVP	100 µm diameter FV type [3]	8 multi-object fibres from FLAMES into red arm (R=47000)	Single object + sky	2 fibres with 100µm core (one with microslit) 1 fibre with 50 µm core	Multi-object (240 fibres)
	Mode scrambling?		On high stability mode only	Yes - double image scrambler at spectrograph entrance	No				
	Length	(m)	35+	38	~15 [3]				25
Slicer	Type		2 pairs of modified Bowen-Walraven slicers	No	Bowen-Walraven (2 beam, 2 slice)	Optional - 3, 4 (Bowen-Walraven type) or 5 slices	Yes		Pseudo-slit of fibres
Echelle	Type		R4, mosaic	R4, mosaic	R2	R4	R4	R2	R2 (mosaiced)
	Master		MR166	MR160-2-4-4.2-2-4?					
	Groove spacing	(grooves/mm)	41.6	31.6	79	41.59 / 31.6	31.6	31.6	110
	Size	(mm)	214 x 840 x 125	840 x214 x125 (has blind holes m/c)	154 x 306	214 x 840 x 125 / 214 x 840 x 125	210 x 836 ruled area	204 x 408	
	Mounting configuration		Face down	On side	Downward facing, bonded invar pads	The echelles are mounted face down in a stationary mount with a multi-point force support to avoid distortion due to gravity.	Face down		Grating is mounted (on its side) on rotary stage to optimize location of important spectral features
	Beam size	(mm)	200		136	200			
	Pupil magnification		1						
Camera	Type		Dioptric / Dioptric	Dioptric	Dioptric	Dioptric / Dioptric	Refractive	Folded Schmidt	Internal focus system
	f/#		f/1.5 / f/1.8	f/3.3	f/3	f/1.8 / f/2.5	f/1.9		
	Focal length	(mm)	166.8 / 208.5	728	410		500		
Cross dispersion	Type		VPH grating	Grism cross disperser	Prism	Gratings (x2) / Gratings (x2)	Gratings (x2)	Prism cross-dispersion	Single order instrument
CCD	Format		2k x 4k / 4k x 4k		2k x 4k	2k x 4k / 4k x 4k	4k x 4k	2k x 2k	Mosaic of 2 2k x 4.5k
	Type		Baseline: E2V CCD44-82 / Baseline: E2V CCD231-84	Mosaic of two 2kx4k EEV CCDs	EEV 44-82	EEV 44-82 / Mosaic of one EEV (EEV 44-82) and one MIT-LL (CCID-20)	Orbit CCD mosaic		E2V
	Grade		Grade 1 / Grade 1	Science grade (Grade 1)					
	Pixel size	(µm)	15 / 15	15	15	15 / 15			13.5
	Coating		Astronomy broadband anti-reflection coating / Extra Red Plus anti-reflection coating	Single layer AR	Single layer AR				
Calibration	Type		TBD	Simultaneous ThAr reference method using hollow-cathode Thorium-Argon and halogen lamps Uses dedicated 300 micron core Polymicro FVP fibres The iodine self-calibration is decommisioned	Object and sky fiber entrances illuminated with emission line spectra for the wavelength calibration and a continuum-light source for flatfielding purposes Object+Calibration mode gives best accuracy	Continuum lamps which in with various filters are used for flatfield calibration at the different wavelengths and one ThAr lamp for wavelength calibration. An iodine cell is available	Iodine cell is present		Thorium-argon (ThAr) hollow cathode lamps provide the primary wavelength calibration standard Hectochelle has a Precise Radial Velocity Mode (PRV) mode with a iodine vapour system under development [1]
Environment			Enclosed in vacuum chamber	Vacuum (<10^{-2} mbar) chamber Temp. variation << 0.1K	Bench-mounted	Bench mounted on nasmyth platform		Whole instrument in a large vacuum tank at 2–4 torr	Bench mounted
			Temp. stablised room	Insulated room	Designed for 16 ± 0.5ºC	Passive enclosure			Room is not temp. controlled so athermalised optical mounts on an Invar optical bench are employed
Source			-	1) http://www.ls.eso.org/lasilla/sciops/3p6/harps/instrument.html	1) FDR report, A. Kaufer (1997) 2) http://www.ls.eso.org/lasilla/Telescopes/2p2T/E1p5M/FEROS/ 3) FEROS-II User Manual, LSO-MAN-ESO-22200-0001, J.D.Pritchard (2005)	1) http://www.eso.org/instruments/uves/index.html 2) UV-Visual Echelle Spectrograph User manual, VLT-MAN-ESO-13200-1825, A. Kaufer et al (2007)	1) http://www.astro.psu.edu/het/instruments/HRS.html	1) THE HERCULES ÉCHELLE SPECTROGRAPH AT MT. JOHN, Hearnshaw et al,	1) Hectochelle Observers Guide, A. Szentgyorgyi et al (April 2006) 2) Hectochelle: a multi-object echelle spectrogrph for the converted MMT, A. Szentgyorgyi et al