SUMMARY OF OPTICS AND INSTRUMENTATION AT CFHT

This summary is taken from a recent report to the Scientific Advisory Committee (SAC), and is intended for the discussion of future CFHT detector development. The primary focus is to meet the wide scientific needs of the astronomical community using instrumentation presently commissioned at CFHT, the levels of funding available, and future instrumentation developments. Throughout this article, the term "large-format" CCD refers to CCD's larger than 1024x1024 pixels without specific reference to pixel size. CCD's currently being manufactured have square pixels 15 microns or 27 to 30 microns on a side. The terms RCA1 and RCA2 refer to the single and double-density RCA CCD's (respectively) at CFHT. The discussion here is not necessarily limited to currently available CCD's, but at least uses current technology as a basis for planning and recommendation.

This section summarizes in tabular form the CFHT instrumentation. No detectors are specified. Each configuration is described in detail below.

Focus	Scale (1 arcsec)	Spectral Coverage	Comments
IMAGING (see details below)			
PF direct	65 µm		Images degrade off-axis
WFC	73 µm	380 nm - 1000 nm	
UVC	73 µm	300 nm - 600 nm	
F/8	139 µm		
F/36	580 µm		Poor image quality off-axis
SPECTROSCOPIC (see details below)			
Herzberg	35 µm	9 gratings	Modules: photographic = 48 mm
		41 - 330 Å/mm	Reticon red = 24 mm
		(15 - 25 µm resolution)	
	70 µm		DAO F/4 = 12 mm
CASSHAWEC	35 µm to 24 µm	25 Å/mm blue 48 Å/mm red 21 Å/mm blue 35 Å/mm red (20 µm resolution)	PCP: 31 mm x 12 mm field GCP: 40 mm x 15 mm field
Coudé	141 µm	600 l/mm mosaic	(6.7 Å/mm 5000 .101 Å/15 µm px
		830 l/mm mosaic	(4.8 Å/mm 8000 .072 Å/15 µm px
			(2.4 Å/mm 4000 .036 Å/15 µm px
		1800 l/mm monolith	(2.2 Å/mm 4000 .023 Å/15 µm px
			(1.5 Å/mm 9000 .033 Å/15 µm px
	(slicers)	projected slit area at f/8.2 camera focal plane	CFH UV : 26 x 870 µm CFH red: 23 x 750 µm CFH blue: 44 x 750 µm DAO blue: 34 x 760 µm
Focal Reducer	35 µm	480 nm - 720 nm "Carpenter prism"	limited by current optics (low resolution - VISITOR) (aperture plates - VISITOR)
UV Prime	21 µm	55 Å/mm 300 nm - 520 nm	VISITOR

DETAILS OF OPTICS AND INSTRUMENTATION AVAILABLE AT CFHT

(a) Prime Focus: The ultraviolet spectral region from the blue atmospheric cutoff redward is a region of particular interest for many astrophysical problems. The UV is a relatively new region for CCD work because few CCD's have high detector quantum efficiency blueward of 4000 Å. The UV-flooded TI, the UV-enhanced RCA, the UV-coated GEC (ESO), and presumably the UV-flooded Tektronix chips make the UV accessible, particularly on Mauna Kea. The characteristics of the instrumentation available for UV as well as visual observations are listed here.

DIRECT: The image quality of the direct PF (no corrector) degrades quickly off axis. the tangential coma at 6 mm is 1 arcsec (about 80 arsec off axis), and varies linearly with distance from the optic axis. For example, the tangential coma is about 0.2 arcsec at 16 arcsec radius from the optic axis. Obviously, off-axis guiding suffers from severe coma as well. Basically, the PF without a corrector is not of interest for CCD imaging, but is for some spectroscopic applications.

WFC: The Wide Field Corrector (WFC) image quality and field size is excellent over a broad (2000 Å) wavelength region up to 90 mm off axis (20 arcmin). Although chromatism is the dominant aberration for the WFC, it is not a problem even for the large Tektronix CCD (62 mm). The spectral range of the WFC is 3800 Å to 10,000 Å with a 70% throughput including internal transmittance and reflection losses. At 3500 Å, the throughput is 50%. The resolution with the 2000 Å/mm grens on the WFC is 30 Å for a 15 micron pixel.

FOCAS: The unvignetted field with FOCAS (imager) is approximately 20 mm assuming a back focal distance of 120 mm and a filter size of 50 mm. FOCAS is normally used with the WFC.

UVC: The image quality and field size with the Ultraviolet Corrector (UVC) is similar to the WFC; at 40 mm the field aberrations are about 0.5 arcsec for a 1000 Å wide bandpass. The spectral range of the UVC is 3000-6000 Å. Therefore, the WFC gives broader coverage, but if observations are restricted to the UV, the UVC is more appropriate.

UV PRIME SPECTROGRAPH: The characteristics of the CEA-UV prime spectrograph are: spectral range of 3000-5200 Å, dispersion of 55 Å/mm (0.8 Å per 15 micron pixel), slit length of 6 arcmin (the coma is noticeable at 2 arcmin because the UV Prime Spectrograph does not use either of the field correctors). The spatial scale along the slit is 0.7 arcsec per 15 micron pixel.

Prime focus is particularly well suited for survey work and deep photometry using a large format CCD with pixels < 30 microns. A large format device requires the design of a new camera and purchase of larger filters. Precision photometry of nebulae and crowded fields can be best accomplished with CCD's that have pixels < 15 microns. The 1985 CFHT CCD controller and future controllers also include on-chip binning to allow some compensation for seeing degradation, although 15 micron pixels correspond to about 0.21 arcsec (images are undersampled in good seeing).

(b) F/8 Cassegrain: The majority of spectroscopic and imaging instruments are commissioned at the F/8 Cassegrain focus. Good image sampling can be obtained with 30 micron pixels, and excellent sampling with 15 micron pixels. The 1985 CFHT CCD controller and future controllers will allow binning to optimize the relationship between seeing and pixel size for imaging. Binning can also be used to optimize spectroscopic applications.

DIRECT: The field size and image quality of the F/8 focus is affected by tangential coma. At 47 mm (5.6 arcmin) the coma is 1 arcsec, and varies linearly wth distance off-axis. Therefore, a corrector may be needed for the large-format CCD. Alternatively, it is important to cover as large a wavelength region as possible (3000 nm - 1000 nm) with large-format detectors and this may not be possible with one corrector. That is, the uncorrected field should still be available for CCD users.

The scale at F/8 is 1 arcsec = 139 microns or 0.22 arcsec/pixel (27-30 micron pixels) and 0.11 arcsec/pixel (15 micron pixels). Note that with 27 micron pixels, a FWHM of 2.5 pixels is 0.48 arcsec, and typical images will have 5 pixels/image profile (to 95% of the total light), which is good sampling for all applications except VHR.

FOCAS: At F/8 the unvignetted field with FOCAS (50 mm x 50 mm filters) is about 35 mm assuming a back focal distance of 120 mm. Filters are 50 mm square.

CASSHAWEC: This spectrograph is not matched well either spatially or spectroscopically by CCD's with pixels > 7 microns. CCD's with 15 micron pixels are usable, but RCA CCD's (15 mm x 9.6 mm) are much smaller than the available field size. Note that 1 arcsec subtends 30-38 microns at the detector, depending on the corrector, while the instrumental resolution is on the order of 20 microns in the spectral direction. The various correctors available are:

	field	focal distance	blue	red
PCP	31 mm x 12 mm (slit)	32 mm	25 Å/mm	48 Å/mm
GCP	40 mm x 15 mm (slit)	30 mm (with lens)	21 Å/mm	35 Å/mm

HERZBERG SPECTROGRAPH: This spectrograph also is not well matched by CCD's with pixels > 15 microns, while CCD's with 15 micron pixels are usable. One arcsec is approximately 35 microns at the detector, the slit length is about 4.4 mm at the detector, and the resolution of the spectrograph < 20 microns. This spectrograph has 9 available gratings, ranging from 330 Å/mm to 41 Å/mm (5.0-0.6 Å per 15 micron pixel). The correctors available are:

	field	focal distance
Photographic	48 mm	30 mm (field lens required)
Reticon red module	24 mm	10.8 mm
F/4 camera module	12 mm	7 mm (field curvature)

In the future, most new CCD packaging will require that the detector to the dewar window be > 10 mm; hence, the photographic module (with suitable lenses) will be required when this spectrograph is used. Note that the "F/4" module fabricated by DAO is designed for a detector located at very small back focal distance (< 8 mm). The Herzberg Spectrograph may have an aperture plate facility available; however, the image quality across the field will be variable.

FOCAL REDUCER, FABRY-PEROT, AND CARPENTER PRISM EXPERIMENT (Toulouse): The focal reducer provides an F/2 conversion intended for use with the Queensgate Fabry-Perot scanning etalon between 4800 Å and 7000 Å. The optics are optimized for very narrow-band work; for example, the image degradation is 0.5 arcsec per wavelength change of 100 Å in the vicinity of H-β. The image quality is degraded severely below 4800 Å and above 7000 Å and the spatial scale is poorly sampled with 30 micron pixels (0.9 arcsec/pixel). The unvignetted field size is about 15 mm at F/2 (60 mm at F/8) and is usually obstructed by the filters used (often 50 mm x 50 mm) because they are inserted in the F/8 focal plane.

The instrument also has been used with a Carpenter prism in place of the etalon (by B. Fort <u>et al</u>. in 1985). An aperture plate is drilled using coordinates generated from direct CCD exposures. Low resolution spectroscopy for many objects can be obtained simultaneously. It has been suggested that a new instrument designed along similar lines for low resolution spectroscopy could be made available by CFHT; however, it might be desirable to match more closely the detector pixel sizes.

(c) <u>F/36</u>: The IR focus has a scale of 580 microns per 1 arcsec. The image quality, focal plane curvature, and field distortions are being tested at CFHT second semester 1985. The coma is negligible, but the quality of the F/36 optics is not as good as one might have hoped. This is relevant not only for optical CCD's but IR imagers as well. The optics cannot be used below 4500 Å, and the full benefit of the primary is not used due to the diameter and central cone of the secondary mirror. The most appropriate optical detector at F/36 would be the large scale Tektronix chip with 0.05 arcsec per pixel. A detector that would be interesting for VHR work would be the 512x512 Tektronix CCD chip, which covers a 23 arcsec square field at F/36; however, the current optics preclude VHR work at this focus.

(d) <u>Coudé</u>: The coudé focus (at the slit) has a scale of 342 µm/arcsec (or F/19.6). The F/7.4 Coudé spectrograph (which is actually F/8.2 with the provisional small camera mirror), could benefit greatly from a CCD detector with 15 µm pixels, low readout noise, and on-chip binning, especially for low S/N work. CCD's with 30 µm pixels and a controller without binning capability are not advantageous for use at Coudé, since the light is spread over 12-15 times as many pixels compared to the Reticon, depending on which of the image slicers are being used (see article in this issue titled <u>Recent Improvements at Coudé</u>). If the CFH red slicer were to be used, for example, with the presently available RCA1 CCD at Coudé, the gain in speed would only be a factor of 2.3; note that this also means a loss in resolution. However, one 640x1024 RCA CCD could increase the capability of the Coudé spectrograph by about 2.5 magnitudes per exposure. Two such exposures would be required to obtain the same spectral coverage as that of the 1872 Reticon, the current detector. This coverage is 190 Å (1st order) with the 600 l/mm grating, 135 Å (1st order) or 66 Å (2nd order) with the 830 l/mm grating, and 60 Å (λ 4000) or 45 Å (λ 9000) with the 1800 l/mm grating. A rectangular large-format CCD or a 4096-element Reticon would obviously give a larger spectral range (300 Å with the 830 l/mm grating in 1st order); however, defocussing by 1-2 pixels near the limits of this range would necessitate the design and fabrication of a coudé field flattener. Also, it is clear that coudé guiding must be greatly improved if the limiting magnitude is extended by 2.5 magnitudes. Efforts in this direction are being considered by CFHT staff.

-from the report to the SAC by
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