

## Description:

The Telescope Control System (TCS) in its simplest form just accepts a target and attempts to keep the telescope at that target. Only a few commands are needed to use the TCS in its simplest form. There are also a number of facilities to ease its use.

The following sequence is recommended to reduce the chance of problems.

### Start up:

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#### 1) MIU (Mechanical Interface Unit)

- located behind the observer's room, in electrical rack on floor
- turn the key to the 'AUTO' position.
- press the emergency stop 'RESET' button

#### 2) COMPUTER

- the terminal is on desk to right of door.
- you can find the system in one of 4 states. Hit the <cr> ('RETURN') key on the terminal and check the prompt.
  1. '72inch>' prompt. This is the program prompt. Hopefully this is running and you can go on.
  2. '-' (hyphen) prompt. This is the operating system. Type 'start' followed by a <cr> to start the program.
  3. '.' (period) prompt. This is the BIOS. Either something has gone wrong or it has been accidentally left in this state. Type 'b' followed by a <cr>. When the '-' prompt appears, GOTO 2.
  4. No response. Try turning off and on the terminal. If still no response, locate the TELESCOPE CONTROL INTEL in the rack, and press the red button on the lower left of the computer, and go back to the terminal. An asterisk should appear, followed by some diagnostics, followed by the '-' prompt within a couple of minutes. GOTO 2.

### A Few Things To Check:

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- Make sure the dome mode is 'AUTO'. This has the TCS maintain the dome opening in front of the telescope. The dome mode is displayed near the top right of the screen.
- Ensure that the telescope epoch (above the telescope current position) is the current date. If entering coordinates by hand, ensure that the correct epoch for the objects is displayed (above the object coordinates). See the command 'EPOCH'.

### Use:

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- use the command 'MOVE hh:mm:ss.ss +/-dd:mm:ss.s'. If the target is in an available location, the telescope should start moving at ~ 10% slewing speed, and the dome should start rotating.
- Hold down the 'N' button on the hand paddle. This enables the telescope to slew at full speed. Provided the telescope/spectrograph isn't about to hit something, wait until the telescope slows down and then release the 'N' button.
- In case of emergency (telescope or spectrograph about to hit the North or South pier or clock case), release the 'N' button and press the Emergency Stop button on the top of the hand paddle. If this unlikely event happens, call the Assistant on duty.
- When the telescope and dome status register 'On Target',

you are free to locate the object and start guiding.  
The keypad keys 8,4,6 and 2 are used for guiding, and the 5 key toggles the guide resolution which is displayed at the top right of the TCS terminal.

#### Facilities:

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- Auto precession. Entered coordinates are precessed from the default (or object) epoch to the current epoch, negating the need to precess coordinates separately. See the command 'EPOCH'.
- Get list. An observing list can be uploaded into the TCS, allowing objects to be referenced by a number. This is quicker, and less prone to errors in the wee hours of the morning.

#### USEFUL COMMANDS:

##### EPOCH (yyyy.yy)

Sets the epoch that coordinates entered with the 'move' command will be precessed from. Year may be entered on command line, or will be prompted for. Decimals are optional. If no year is given on the command line, and the prompt is answered with only a carriage return, the epoch will be set to current. This is the year on the screen above the 'OBJECT R.A.'. see - move

##### GOTO (hh:mm:ss.ss dd:mm:ss.s)

Goto an Hour Angle and Declination. The telescope will not track. If the motors were off and the brakes on, they will switch on and off. If coordinates are not given on the command line, they will be prompted for. Coordinates may be truncated, and colons must be used.

##### MOVE (hh:mm:ss.ss dd:mm:ss.s)

Move to a Right Ascension and Declination and begin tracking. If the motors were off and the brakes on, they will switch on and off. If coordinates are not given on the command line, they will be prompted for. Coordinates may be truncated, and colons must be used.

##### PARK

Turns on the motors, and releases the brakes if not already so, then moves the telescope to the normal park position (zenith). No parameters required.

##### SETDATE [yy/mm/dd]

Sets the system date. Shouldn't normally be needed. If date isn't entered on the command line, it will be prompted for.

##### SETST [hh:mm:ss]

Sets the sidereal clock. Shouldn't normally be needed. If time isn't entered on the command line, it will be prompted for. Colons are required.

##### SETUT [hh:mm:ss]

Sets the UT clock. Shouldn't normally be needed. If time isn't entered on the command line, it will be prompted for. Colons are required.

##### STOP

Turns off the motors and engages the brakes on both axis, regardless of the state of the system (tracking, still or slewing). Used at the end of the observing to turn things off and to 'reset' the system if it is mis-behaving.

How to start DICE:

> dice

Current detector: SITE-2

Current mode of observation: spectroscopy

Useful DICE commands:

autowrite\_on autowrite\_off

- turns on or off the autowrite function. Should be on for most normal observing. Note that frames will be written when cycling if autowrite is enabled

bye

- exits the controller environment. Should clear up the windows. Should be entered in the controller window.

cycle [exp\_time]

- prompts for exp. time (if not entered on command line) and number of items to take. Will write them if autowrite is enabled.

observer [name]

- to enter the observer into the system. This will appear in the FITS header.

quit

- stops a current exposure prematurely

raster [row\_size col\_size row\_start col\_start par\_bin ser\_bin]

- For changing the raster. If not all 6 parameters are on the command line, all will be prompted for. Note slightly different convention for rastering from Intel version.

save\_default\_raster

- will save the default raster in an init\_dice\_session file so that raster is recommended each time DICE is started up.

start [exp\_time]

- starts an exposure of the detector. Will prompt for an exposure time if not entered on the command line. The object name will be prompted for.

wcycle [exp\_time]

- as cycle, but writes the frames even with autowrite not enabled.

write

- causes the system to write the archive exposure. The result of this appears in the status window. Files can't be re-written.



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## The Plaskett 1.85m Telescope, Spectrograph and Imager

### [Newtonian Imaging](#)

Technical questions? You can [email us](#) at [HIATelescopesupport@nrc-cnrc.gc.ca](mailto:HIATelescopesupport@nrc-cnrc.gc.ca)

This telescope is known as the Plaskett Telescope, and since 1953 has held on its foundation pier a plaque commemorating John Stanley Plaskett. The official naming of the telescope took place on June 4, 1993.

### Overview

The 1.85-m diameter parabolic primary mirror of the telescope feeds an f/5 light cone either onto a flat aluminum secondary to illuminate an imaging focus, or alternatively onto a 0.5-m hyperbolic convex secondary, to provide an f/18 Cassegrain focus where the spectrograph is mounted. This telescope has seen considerable evolution since it went into operation on May 6, 1918, and it is roughly true that only the tube and mounting remain from the original telescope. The the all-reflection Cassegrain spectrograph dates from 1967, the Cervit primary mirror was installed in 1974, and the f/5 modified Newtonian secondary and imager in 1991. The telescope encoders and control system are the products of the last decade. Recent evolution of the telescope has been driven by "user-friendliness" and safety considerations: the original centrifugal-governor clock drive has been retired from operation, the dome shutters and windscreens are now activated by a remote control handset, and most structures protruding from the rotating dome have been removed. In late 1993, the telescope tube was enshrouded in a black canvas mantle to shield out stray light at the imaging focus.

The current style of operation and complement of instruments is comparable to equipment found at all major observatories, thus enabling students to gain experience directly relevant to the use of larger telescopes elsewhere. From the observer's room on the north side of the observing floor, the Telescope Control System (TCS) monitors the position of the telescope,

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while a Unix workstation controls data acquisition with instrument control software (DICE) that is uniform for all detectors and telescopes at DAO. An adjacent Xterminal allows field verification from the HST guide Star Catalogue or the Digital Sky Survey, and permits immediate data transfer and processing if desired. Routine observing operations can be performed with ease by a single observer. Observing manuals are available on-line to guide the observer.

The Cassegrain spectrograph is particularly versatile: its various apertures, gratings and detectors allow spectroscopy of objects down to 16th magnitude, at resolutions ranging from 0.4 to approximately 20 Å ( $\lambda/\Delta\lambda$  approximately 200-15000), with signal-to-noise ranging up to 150 or better. The practical range for spectroscopy is 3600 Å to 9500 Å subject to the constraints of atmospheric transmission. Long-slit spectroscopy and sky subtraction features are provided by using a conventional slit. Fe-Ar and Cd-Ne hollow cathode sources provide wavelength calibrations, and a tungsten lamp source provides flat-field calibrations for the spectrograph configurations.

## Telescope Control System

The TCS will automatically position the telescope and dome to star coordinates of any designated epoch, as entered on the keyboard. Alternatively, the TCS can be set by star number from a list on the UNIX network. See the section on [Before You Come ...](#) for the requirements for such a target or "get" list. The TCS can also accept offsets from a reference star, which can be useful for setting on very faint objects. The positional encoders are accurate to approximately 1", but residual errors in the system limit the whole-sky setting accuracy to something like 20".

For Cassegrain (spectroscopic) observing, the TCS terminal also controls the light feed into the spectrograph and/or TV viewer/guider. By choice of diagonal mirror above the Cass focus, the monitor for the TV guider will display either:

- view solid: a full 7' x 6' (alpha x delta) field to magnitude 17, to allow target identification and centering, or
- view holey: the outer ring of the 7' x 6' field, to allow offset guiding while the slit is illuminated by the target object, or
- view slit: direct viewing of the slit or image slicer aperture, to allow guiding on the target object itself. The field of view is determined by the dekker length adjustment.
- view solid or view holey: 1 sec exposure allows detection to 17th magnitude; a 10 second exposure, to 18.5 magnitude.
- view slit : 1 second exposure allows detection to 15th

magnitude.

Manual guiding of the telescope (either directly on the slit/image slicer or offset on a guide star, as seen on the TV guider screen) is accomplished with the keypad buttons on the TCS keyboard. These buttons move the telescope stepwise by preset amounts (usually 0.5" when guiding) in the north-south or east-west directions for each keystroke. Alternatively, an autoguider may be invoked at the TCS terminal for automatic guiding on longer exposures.

The TCS will not allow you to set the telescope outside safe limits: the permitted range of hour angle and declination is plotted on the safe zone map. There are a number of potential danger areas within the physical range of motion of the telescope: collisions between the spectrograph and either pier, the telescope tube and the north pier, the detector and the hour angle drive housing and collision between the telescope tube and the remaining portion of the Newtonian elevator access platform on the dome. If the TCS accepts any given target without returning a limit error to the user, it will automatically negotiate the danger areas to set on that target. This often results in an apparent slew to a "wrong" position which the TCS has deemed to be a safe intermediate position; final slew will begin immediately after the intermediate position is achieved. In particular, on the safe zone map the telescope will move from zone 7 to zone 2 through zone 1, from zones 2 to 6 through zone 3, and so forth. As presently cabled, the telescope is used with the tube east of the piers and must not be reversed, so it is not possible to circumvent the limits imposed in the northeast and southeast directions.

It is possible to move either dome or telescope under manual control with the handset, in which case the TCS will not impose the plotted limits: instead the operator must use extreme caution to ensure they are respected, and that the spectrograph does not approach either pier. Tracking cannot be engaged under manual control, so the TCS must be returned to auto control for observing.

## **Spectrograph Configurations & Exposure Times**

The Cassegrain spectrograph is an all-reflective system, except for the refractive field flattener just before the detector. Its optical elements are a 1750-mm focal length off-axis (to avoid internal obscuration) collimator, a diffraction grating, and a 538.7-mm (21-in) focal length f/5 camera, a diagonal mirror, and the field flattener. The collimator and camera mirrors exist as two interchangeable optics sets, differing in their reflective

coatings. The default set (designated "Al") has standard aluminum coatings, and is useable over the entire range of the spectrograph, or approximately 3000-9500 Å. The other optics set is gold (Au) coated for better reflectivity in the red-near infrared region, and is available if requested.

The various configurations of the spectrograph are listed below. The designation "21181" refers to the combination 21-in focal length camera, 18-hundred grooves per mm grating, 1-st order, and so on. All these gratings are used in first order. The wavelength of peak "blaze" efficiency is so designated; B,G,R indicate peak efficiencies in the blue, green, or red-IR regions. Peak blaze efficiencies are typically around 80%. The last column gives approximate exposure times in minutes for approx.  $m=12$  magnitude star exposed to approx.  $S/N=30$  at the wavelength of the blaze, with the SITe-5 CCD as detector. See the section on [digital detectors](#) for a comparison of detectors in their readout noise and spectral response characteristics. In practice, exposure times also vary widely according to detector binning, grating rotation, spectral type of the star, spectrograph aperture, and with the quality of the night ("seeing" and transparency). The best guide for exposure times is usually to check in the observing log book for an application similar to your own (particularly spectrograph configuration, wavelength and detector) and noting the exposure times and counts.

## 1.8-m TELESCOPE SPECTROGRAPH CONFIGURATIONS

NAME	GRATING g/mm	BLAZE Angstroms	DISPERSION Anstroms/mm	EXPOSURE minutes
21181	1800	5000	10	60
21121B	1200	4100	15	40
21121R	1200	8000	15	40
2161G	600	5000	30	20
2161R	600	7500	30	20
2141	400	3925	45	15
2131B	300	4200	60	10
2131R	300	6500	60	10
21(3/2)1	150	5000	120	5

## Slits & Image Slicers

The slit or one of several image slicers is mounted by wing clamps at the Cassegrain focal plane, to form the entrance

aperture to the spectrograph.

The slit is adjustable from 0.001 inch (1 thou) to wide open; the width should be matched (in microns) to the resolution of the detector employed. During conditions of poor seeing, wider settings may be used to conserve speed, although resolution will be sacrificed. Typically, a 1.5" slit is used, which allows a comfortable oversampling with all the CCDs. Note that the 0.8" slit (with projected slitwidth of approximately 37 microns (FWHM)) results in undersampling for the larger CCDs, such as the SITE-5 with 24 micron pixels, 48 micron resolution.

### 1.8-m TELESCOPE SLIT ADJUSTMENT

SLIT WIDTH		RESOLUTION AT FOCUS			
Thou	Arcsec	microns	10Ang/mm	15Ang/mm	30Ang/mm
5	0.8	37	0.4 Ang	0.6 Ang	1.1 Ang
7	1.1	50	0.5 Ang	0.8 Ang	1.5 Ang
10	1.5	71	0.7 Ang	1.1 Ang	2.1 Ang
13	2.0	92	0.9 Ang	1.3 Ang	2.7 Ang
19	3.0	134	1.3 Ang	2.0 Ang	4.0 Ang

RESOLUTION AT FOCUS	
60Ang/mm	120Ang/mm
2.2 Ang	4.4 Ang
3.0 Ang	6.0 Ang
4.2 Ang	8.4 Ang
5.4 Ang	10.8 Ang
8.0 Ang	16.0 Ang

For long-slit spectroscopy, the scale is 6.2" per mm at the slit, 20.1" per mm at the spectrograph focal plane. The slit length is adjustable with a decker to 20", 40" or 60", corresponding to widths of 1, 2 or 3 mm on the detector. There is, however, a perceptible deterioration of resolution at the tips of the lines with the longest (60") slit.

For well-guided stellar spectra, the sky spectrum will naturally be exposed alongside the stellar spectrum and recorded on the CCD detector. Because of the proximity of the city of Victoria, mercury and sodium emission features from the sky will usually be recorded on the spectra of stars around 12th magnitude and fainter, depending on the quality of the night, the direction of the star, and the wavelength region under observation. At about the same magnitude, the solar spectrum can be a contaminant at full moon under hazy skies. In these situations,



it is quite important to detect and subtract out the sky contribution to your spectra.

Richardson-type superpositioning image slicers may be used to optimize slit efficiency at the higher resolutions, where sky subtraction is not required. Four image slicers are available for the 21-in camera: they have either blue (B) or red (R) coated optics for maximum throughput, and come in two levels of resolution. The resolution of the "very short image slicers" (VSIS21) is approximately that of the 0.8 arcsec slit given in the above table. Resolution of the regular (IS21) slicers is usually limited by the pixel size of the detector.

### 1.8-m TELESCOPE IMAGE SLICERS

DESIGNATION	APERTURE SIZE	PROJECTED SLIT WIDTH
IS21B	3" x 5"	20 microns
IS21R	3" x 5"	20 microns
VSIS21B	4" x 4"	40 microns
VSIS21R	4" x 4"	40 microns

### Newtonian Focus Imaging

The modified Newtonian system on the telescope allows direct imaging at f/5 with any DAO CCD or IR detector. A flat secondary mirror is installed *below* the Cassegrain secondary to direct the axis of the light cone at a 30 degree angle to the primary optical axis, to form a focus about half way up the telescope tube. The scale at this focus is 22.5" per mm, which provides a well oversampled 9.2' x 9.2' field with the SITE-5 CCD.

The TV guider for the Newtonian focus is operated from the observer's room, and displays a field 7.5' x 6.5' (alpha x delta) on the monitors. As controlled by the `point' command of the TCS, the field by the TV guider can be either the co-ordinate position entered on the TCS (for field verification), or else a guide field offset from the detector field, for guiding during an exposure. Since the pointing errors of the telescope are small compared to the detector field sizes, field verification is usually unnecessary; hence the main use of the TV guider is indeed for guiding! The offset from the center of the CCD field is fixed: the guider position cannot be rotated or translated to acquire suitable guide stars. The offset of center of the guider field on the sky is 18.2 arcmin west and 3.2 arcmin south of the center of the CCD or IR detector. The autoguider is effective with guide stars as faint as  $m \sim 15$ , but occasionally at high galactic latitude no suitable guide stars will be found within the

guider field. For long exposures near the Galactic poles, it is advisable to verify that guide stars are available before you come to the telescope. See the [`Before You Come'](#) section below for how to do this.

The photometric capability of the system has been demonstrated to  $m=20$ , and may extend fainter if great care is exercised in sky subtraction. When configured for CCD imaging, a filter wheel holding four 50 x 50 mm filters (up to 7 mm thick) is mounted in front of the detector. Alternatively, three filters and one clear glass aperture (so that the focus is not shifted) may be used. Johnson-Cousins UBVRI filters are available. Transformation coefficients to standard UBVRI values for our filter set depend on the choice of detector. Approximate transformation coefficient values for the (now defunct) SITE-1 CCD detector are as follows (courtesy of Dave Balam, University of Victoria):

V coeff	= 0.023
b-v	0.990
v-r	0.956 (all are +/- 0.02)
r-i	0.895

Approximate transformation coefficient values for the Tek-2 CCD detector, prior to the last realuminization of the mirror, were:

V coeff	= 0.005 +/- 0.008
b-v	0.944    0.015
v-r	1.014    0.011

Dave Balam, University of Victoria reports on extinction and transformation coefficients for SITE-5, from the night of July 9, 1998, as follows:

k(v)	= 0.258
k'(bv)	0.159
V coeff	0.038 (all are +/- 0.01)
b-v	0.940

(solution from 13 Landolt standard stars and M92 standards)  
The terms are defined by Hardie (Photoelectric reductions - Stars and Stellar Systems)

CCD standards field on these pages. -->

For IR imaging, a cooled filter wheel accepting up to eleven 1/2 inch round filters is mounted within the Dewar itself. Infrared filters available include J, H and Cowie K filters, with central

bandpasses of 1.25, 1.65 and 2.1 microns respectively.

Filter selection is controlled from the workstation in the observer's room. Transmittance curves for the above filters are available on request.

## Before You Come ...

In preparing your observing program, the following points should be kept in mind:

- In addition to your base program, plan for a reduced or expanded program: weather conditions (bad or good) will often modify your hopes of what is achievable during your observing run.
- Have accurate coordinates; the telescope control system will accept coordinates of any epoch.
- Prepare adequate finding charts for faint objects or crowded fields; these are mandatory for service observing projects.

For ease of observing, particularly for projects with many objects, it is advantageous to write a file containing your program star list. The format for such a list is straightforward: for each object, enter on one line the *starname*, *right ascension*, *declination*, *epoch* and *comments*, with spaces or tabs as delimiters between the fields. If there is a space in the object name, enclose the name in double quotes; use colons and leading zeroes in the coordinate fields. For example:

```
HD47129 06:32:02.4 +06:13:10 1900 V=6.1, Plaskett's star  
"Epsilon-2 Lyrae A" 18:44:22.8 +39:36:46 2000 B comp. 2.3"  
away; quad system
```

Lines should not exceed 80 characters. This file will permit acquisition of the star by selecting within a Graphical User Interface (GUI). In order to transfer your file into the DAO computer network, please contact an observing assistant.

In preparing for a run, it may be wise to prepare charts for field verification, or to verify that suitable guide stars are located in the TV guider field (located 18.2 arcmin west, 3.2 arcmin south of the detector field for the guider at Newtonian focus), using either the HST Guide Star Catalogue (GSC) or the Digital Sky Survey (DSS). Both these resources are online at DAO, and may be summoned at the telescope as needed if you do not have time to check them before your run. The [Digital Sky Survey](#) may be accessed directly, or from the [CADC pages](#), and shows stars to much fainter limits than the TV guider will see, without direct photometric information. The stars of the GSC, on the other hand, are all sufficiently bright to be suitable

for guiding with the Newtonian guider.

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## CCD Digital Detectors

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### Charge-Coupled Devices (CCDs)

Because of their high quantum efficiency, low readout noise, large dynamic range, wideband spectral sensitivity and excellent dimensional stability, charge-coupled devices are now the detectors of choice for most spectroscopic and imaging projects on the telescopes. They do have pixel-to-pixel sensitivity variations of the order of a few percent, which can readily be calibrated and removed with flat-field exposures on some uniformly bright source or, for spectroscopic applications, on some featureless continuum spectrum.

Several of our earlier CCDs (RCA, FA2048, PM512, SITe-1) are permanently decommissioned, while others such as the Tek-1 and Tek-2 may be occasionally used on an emergency basis. At the present time, the latter three of the four chips described below are usually available for mounting at the telescopes:

#### DAO CCD DETECTOR CHARACTERISTICS

DESIGNATION	UBC-1	SITe-2	SITe-4	SITe-5
<b>Manufacturer</b>	Loral	SITe	SITe	SITe
<b>Commissioned</b>	Sept/94	Dec/95	Mar/00	June/98
<b>Type</b>	Thick	Thin	Thin	Thin
<b>Illumination</b>	Front	UV coated	Backside	Backside
<b>Cosmetics</b>	Good	bad column	V. Good	V. Good
<b># pixels</b>	4096x200	1752x532	4096x2048	1024x1024
<b>Pixel size(microns)</b>	15	15	15	24

DESIGNATION	UBC-1	SITe-2	SITe-4	SITe-5
<b>Chip size (mm)</b>	61.4x3.0	26.0x8.0	61.4x30.7	24.58x24.58
<b>Readout noise(e-)</b>	10	~12	6-7	~11
<b>Dark current (e-/m)</b>	0.5			<0.3
<b>Full well (Ke-)</b>	60			
<b>Gain (e-/ADU)</b>	1.5	~1	~1.8	~5
<b>Range, bits</b>	16			
<b>Range, ADU</b>	64K			
<b>QE (400nm)</b>	2%	35%		69%
<b>QE (500nm)</b>	20%	70%		
<b>QE (600nm)</b>	35%	72%		
<b>QE (700nm)</b>	47%	70%		80%
<b>QE (800nm)</b>	32%	57%		
<b>QE (900nm)</b>	23%	33%		48%
<b>QE(1000nm)</b>	6%	10%		

Abbreviations in the above table are as follows: e- (electrons), Ke- (kiloelectrons), ADU (analogue to digital units), QE (quantum efficiency). The SITe-3 chip (SITe is a descendent company from Tektronix) is identical in physical dimensions and similar in other properties to the Tek-2 chip.

Note that thinned, backside-illuminated CCDs, when illuminated with monochromatic light, display interference fringing in a manner that is only partially removable by flat-fielding. The effect is most pronounced at red and near-IR wavelengths (eg. the I band), and limits the signal-to-noise achievable when such chips are used for spectroscopy.

The DAO CCD's are fitted with identical dewars, and hence any CCD may be used on the 1.85-m Newtonian focus, the 1.85-m spectrograph, or either of the 1.22-m coudé spectrograph configurations.

All the current CCDs operate with compatible [hardware](#), and DICE (DAO Instrument Control Environment) software, thus their operation appears identical to the user. By the `raster' command, the observer has control over the area of the CCD to be sampled, and can invoke on-chip binning. For spectrographic use, it is common to sample only that area of the detector which is illuminated by the spectrograph, saving data storage space

and readout time. On-chip binning permits pixels to be summed together in either the serial or parallel direction while keeping the read noise per sample the same. This feature permits the sampling of larger areas of the detector without increased read noise, but at the expense of spatial resolution and particularly cosmic ray noise resolution, which can be a problem for longer exposures. Note the values quoted in the table for dark current and full well are for unbinned pixels, and will increase proportionally with bin size.

## Cosmic Ray Events

All silicon-based detectors record the passage of cosmic ray muons, which pass relatively unattenuated through the dome and detector housing. However, the bottom five kilometres of atmosphere does provide shielding equivalent to about a metre of lead: at 5000-m altitude there is approximately 1 muon event per square mm per hour; at sea level this rate is halved. (The rates also fluctuate with solar activity.) Thus, in cosmic ray background, low-altitude sites such as DAO offer an appreciable advantage over higher observatory sites.

Still, cosmic ray events will almost certainly be present on long exposures taken with a CCD. Their spikes are usually quite recognizable in the data, being typically hundreds or thousands of electrons in intensity, spread over only 1-3 adjoining pixels. Thus they are easily removed during data reduction.

## Cryogenics

The CCD detectors are mounted in Dewar flasks which must be refilled with liquid nitrogen at the start of the night, and also in some cases during the night and when shutting down at dawn (but not if another instrument is scheduled to go on the telescope that day). The liquid nitrogen will be found in reserve flasks, located on the observing floor near the 1.8-m telescope, and in the coudé chamber of the 1.2-m telescope. These reserve Dewars should be pressurized to 10 pounds per square inch through a plastic hose connection from compressed nitrogen tanks, in order to expedite filling of the detector Dewars from them.

As the CCD's are heated from liquid nitrogen temperature up to approx. -110 degrees C in order to maintain charge transfer efficiency, their Dewars require regular refilling, typically about every 8 hours. The CCD Dewars can be completely filled through a very narrow tube inserted inside a retaining tube, which requires about twenty minutes. When mounted on the 1.8-m Cassegrain spectrograph, the orientation of the CCD Dewar is such that it can only be half filled in any case: in this

situation a wider filling tube is used, reducing the filling time to a couple of minutes, and reducing the hold time to about 4 hours.

HOWEVER, the hold time at operating temperature depends on the individual CCD Dewar, the degree of vacuum of the Dewar (which itself depends on the elapsed time since being pumped down, and its thermal history during that interval) and the orientation of the Dewar canister at the telescope or spectrograph (i.e., whether it can be fully filled or not). In normal circumstances, the SITe-1 CCD at the 1.8-m imaging focus should remain at operating temperature for up to 12 hours. For the UBC-1 CCD at the 1.2-m coude focus, the cool-down time is ~3 hours, and the hold time ~7 hours. It is always best to consult with telescope support staff as to the current hold time for your particular detector, or look for messages in the observing room from them on this matter!

The Dewars may require pumping to regain a high vacuum if they do warm up. Daytime refilling of the CCD Dewars is usually performed by the telescope support staff on weekdays. On weekends, the observer is responsible. Automatic refilling of the Dewars via a timer-controlled valve is an option available to weekend observers.

For infrared observing, a NICMOS array detector is available; contact the [Telescope Group](#) at [HIATelescopesupport@nrc-cnrc.gc.ca](mailto:HIATelescopesupport@nrc-cnrc.gc.ca) for details.

## Data Acquisition Computers

The acquisition of data from the CCDs and the IR array is performed on Sun Workstations from the observer's rooms. The DAO Instrument Control Environment (DICE) software presents a graphic user interface that prompts the user for the required operating commands. Most functions are performed by the click of a screen button by the mouse. The DICE program allows the user to define the area of the chip to be sampled, and initiates an SAOimage window where the data frame is fully displayed. Monitoring that the CCD remains at operating temperature during the night can be performed by displaying row or column plots of bias frames, or of data frames including the overscanned strip.

The observer's rooms also have Xterminals with which data can be transferred to an appropriate disk for further storage and processing. The workstations and Xterminals are linked to the rest of the computer system via Ethernet fibre optic link.



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## Interference Filters

The table below provides a summary of interference filters currently available for use in the optical imaging camera of the 1.8-m telescope. We will be adding detailed bandpass information as well as transmission curves in the near future. For questions regarding specific filters please contact [HIATelescopesupport@nrc-cnrc.gc.ca](mailto:HIATelescopesupport@nrc-cnrc.gc.ca).

Observers may also request to use any of a set of narrow-band 2" x 2" filters owned by Dr. Chris Pritchett (UVic). Interested users should contact [David Balam](#) for additional information about the characteristics and availability of these filters.

	<b>Filter name</b>	<b>Central wavelength (Å)</b>	<b>Bandwidth (Å)</b>	<b>Maximum transmission (%)</b>

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	<b>Filter name</b>	<b>Central wavelength (Å)</b>	<b>Bandwidth (Å)</b>	<b>Maximum transmission (%)</b>
<b>Johnson</b>	B - blue	~4238		~60%
	V - violet	~5250		~85%
	R - red	~5930		~80%
	I - infra-red	~7580		~88%
	U - in house	~3550		~65%
<b>Gunn</b>	G	9207		
	R			
	V			
	I			
	U			
<b>Ströemgren</b>	B	4100	~160	
	V	4700	~190	
	Y	5500	~240	
	U			
<b>Kron-Cousins</b>	R			
	I			
<b>Barr</b>	H-Alpha	6564		
	Red-cont.	6650		
	PK50			
	[S-II]	6736		

All Filters are 50.8mm square.





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# Dominion Astrophysical Observatory

## The 1.2-m Telescope and Spectrograph

Technical questions? You can e-mail us at [HIATelesopesupport@nrc-cnrc.gc.ca](mailto:HIATelesopesupport@nrc-cnrc.gc.ca).

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The spectrographs of the 1.2-m telescope are named in commemoration of Andrew McKellar (1910-1960), who in 1941 made the first measurement of the radiation temperature of the universe, which became recognized in 1965 as the primordial cosmic microwave background, a direct remnant of the cosmogenesis event. The telescope itself is commonly referred to as the McKellar Telescope.

## Overview

The 1.2-m telescope was inaugurated in March 1962, and a new primary mirror was installed in April 1985. The current primary mirror is a low-expansion borosilicate glass called Ohara E-6; its coefficient of thermal expansion is about two-thirds that of Pyrex. During optical shop testing of the uncoated primary mirror in 1984, 70% of the light was concentrated within 0.5 arcsecond, 90% within 0.8", and 98.5% within 1.0" at prime focus. Thus the mirror quality considerably excels over typical seeing-limited image sizes obtainable at the DAO site.

As with the 1.8-m telescope, much effort in recent years has gone towards making the telescope and its instruments user-friendly and relevant to the training of students. The telescope and dome are under computer control from the ground-level observer's room. Automatic dome tracking is an added advantage for long exposures.

The 1.2-m telescope is normally used at the coudé focus, with high-reflectance coatings for the second, third, fourth and fifth mirrors to optimize throughput. The three mirror sets are Super Blue (3500-5300 Å), Aluminum (4500 Å-near IR) and Gold (6500 Å-IR) optics. These mirror sets are rapidly interchangeable and self-aligning, so that it is possible to change from one set to another in about two minutes, without the need to re-centre on the star being observed. The coudé beam is f/145 after reflection from the hyperbolic secondary

(third to fifth surfaces are flat), while the coudé spectrographs are designed to accept an f/30 beam, so a lens located immediately following the fifth mirror converts the beam from f/145 back to f/30. Actually, there are two interchangeable lenses, one coated for maximum transmittance in the blue (<5000 Å), the other for the red (>5000 Å) spectral region. The lens selected should conform with the mirror set in use, and of course with the spectral region being observed.

At the coudé focus, an image slicer ensures high throughput to the coudé spectrograph, where one of two optical paths may be selected. A 32-inch focal length spectrograph camera can be combined with one of six available diffraction gratings (of 300, 600, 830 and 1200 grooves per mm) which have various blaze angles, and some of which are efficient in either first or second orders. These yield many possible reciprocal dispersions, of which 6.5, 10, 18 and 41 Å per mm are the most commonly used. Alternatively, the beam can illuminate a mosaiced 830 groove per mm grating and a 96-inch focal length camera to give a spectrum in the red (1st order) at 4.8 Å per mm or in the blue (2nd order) at 2.4 Å per mm.

The corresponding resolution of all these spectrograph configurations ranges from 0.07 to 1.2 Å. A CCD may be mounted at the spectrograph focal surface for highly efficient, low-noise spectral measurements. The disadvantage of these detectors is their small physical dimension, which allows coverage of a rather modest wavelength range.

A popular instrument specific to the 1.2-m telescope is the Radial Velocity Scanner (RVS). This is a versatile instrument designed for photoelectric measurement of Doppler shifts of stars about 7,000 K or cooler. The velocity range to be searched is adjustable within wide limits, and the integrated signal is displayed in real time, allowing the observer to proceed to the next star whenever the measurement quality reaches an acceptable level.

Wavelength calibrations for the spectrographs are provided by hollow cathode discharge lamps; three are available: Fe-Ar (best for the blue region), Cd-Ar (mainly used with the RVS, so as to avoid conflict with the stellar Fe lines) and Th-Ar. Various configurations of lamp illuminations can be used for detector flat fielding, depending on the spectral region and precision required.

## Telescope Control System

The telescope and dome operate under a Telescope Control System (TCS) commissioned in March 1995. The TCS operates from a terminal in the observer's room, although both

telescope and dome can be moved under handset control from the observing floor if required. The TCS accepts coordinates of any specified epoch, and the commands it accepts are almost identical to those used on the 1.8-m telescope. The setting accuracy is currently about 15" over the whole sky (but much more accurate over a restricted region of the sky). The direct-viewing coudé field is only 3' diameter. A TV viewer eases guiding on faint objects, but is not usually necessary for  $m < 10$ . The TV guider views either an area  $3.1' \times 2.4'$  in the field or else  $1.2' \times 0.9'$  around the image slicer aperture.

The telescope cannot collide with the dome nor with any obstructions on the observing floor (with the sole exception of the ladder if it is improperly stowed). The polar axis is rotatable through more than one complete rotation, but is ultimately limited in travel by the cabling to the telescope. In the normal position (with the telescope tube east of the pier at the meridian), the limits in hour angle are 7.7 hours east to 20 hours west. If you plan to monitor a circumpolar object from (say) 9 hours east through 3 hours east, you can still do so without encountering these limits by reversing the telescope. This is done by driving the telescope through the north pole, and setting on a readout right ascension offset 12 hours from the desired coordinate. In this case the hour angle range which is attainable is also offset by 12 hours, viz. 19.7 hours east through 8 hours west. Note there is also a limit switch in altitude, which will cut off the telescope drive at 8 degrees above the horizon. The above limits suggest that the entire sky above 8 degrees altitude is accessible to the telescope. This is not really achievable in practice, as trees obscure the eastern and southern horizons to as high as approx. 20 degrees altitude in some directions. A practical limit in declination (near the meridian) is thus about -30 degrees.

## Spectrograph Configurations & Exposure Times

The coudé spectrograph optics are described in detail by E.H. Richardson in JRASC **62**, 313 (1968). Basically, there are two separate spectrographs in the coudé room, each with its own collimator/camera combination:

"96"

For highest dispersion, a 7600-mm focal length collimator illuminates a mosaic of four identical 830.8 g/mm gratings, whose dispersed light is focussed by a 2432-mm (96-in) focal length, on-axis camera at f/8.

"32"

For intermediate dispersions, one of two 4500-mm focal length collimators illuminates one of six available

gratings, whose dispersed light is focussed by an 813-mm (32-in) focal length, on-axis camera at f/5. The two collimators differ only in the aspheric correction for spherical aberration; choice of collimator is dictated by choice of grating.

Spectrograph configurations are designated thus: 9682M for 96-in camera, 830 g/mm *Mosaic*, 2nd order, and so on. The available configurations are:

### 1.2-m Telescope Spectrograph Configurations

Name	Grating g/mm	Blaze Ang	Range Ang	Dispersion Ang/mm
9682M	830M	4060	3500-5800	2.4
9681M	830M	8125	5800-9900	4.8
32121	1200	5000	3600-6500	10.1
32121H	1200H	6000	5000-8500	10.1
32122	1200H	3000	3200-4000	5.0
3282	830	4060	3500-6000	6.5
3281	830	8125	6000-9900	13.1
3261	600	4000	3200-5000	17.9
3261H	600H	7000	5000-9500	17.9
3262	600H	3500	3200-4200	9.0
3231	300	4200	3500-8000	40.9

Name	Exposure CCD (min)	Exposure Photo (min)
9682M	15.0	150
9681M	3.0	--
32121	3.0	20
32121H	2.0	30
32122	--	--
3282	3.0	30
3281	1.0	--
3261	1.0	10
3261H	2.0	15
3262	2.0	20
3231	0.5	4

where the last two columns give approximate exposure times in minutes for a sixth magnitude star exposed to approx. S/N=30

at the wavelength of the blaze, for the SITe-2 CCD and Kodak IIa photographic emulsions, respectively. Because of the wide dynamic range of CCDs, actual exposure times may vary considerably depending on the signal-to-noise required by the observer. A single-scale exposure meter allows comparison of exposures taken under different conditions of seeing and transparency.

For the spectrograph configurations using 830 groove/mm gratings such as 9682M, 9681M, 3282 and 3281 (which all use gratings replicated from the same master grating), efficiency curves are available here for first order reflection and second order reflection to allow an informed choice of which order will perform best at a given wavelength. On these plots, the reflectance of a freshly aluminized surface is also shown for comparison.

## Image Slicers

There are four Richardson superpositioning image slicers as follows:

### 1.2-m Telescope Image Slicers

Designation	Range Ang	Aperture Dimension "	Actual Slit Width microns
IS32B	5000	3.5 × 2.5	112
IS32R	>5000	3.9 × 2.5	112
ISRVS	<5000	3.8 × 5.6	250
IS96B	<5000	5.2 × 1.4	62

Designation	Projected Width (32) microns	Projected Width (96) microns
IS32B	20	36
IS32R	20	36
ISRVS	45	80
1596B	11	20

where the first number of the aperture dimension is the height in arcseconds. As seen through the image slicer guiding eyepiece it appears as the narrow vertical dimension of the entrance aperture. The relation:

Projected slit width = Actual slit width × (Camera focal length / Collimator focal length)



gives the tabulated projected slit widths for both 32- and 96-inch cameras. Since the projected slit width should match the resolution (i.e., two pixels) of the detector, the IS32's are normally adequate for either camera, and the IS32R should be used for all red configurations in any case. Although the ISRVS is intended for use with the Radial Velocity Scanner, the IS32B may be used in its place as this results in a significant reduction in guiding errors in velocity.

Image slicers greatly enhance the efficiency of coudé observing, as they effectively increase the slit width fourfold without loss of spectral resolution. That is, at the 5.6 arcsec per mm "plate scale" of this focus, the 112 micron width of the IS32's passes as much light as would a 450 micron slit, neglecting internal reflective losses within the slicer. A second advantage is that they enable light slices passing from the grating to the camera to pass above and below the flat mirror used to reflect light returning from the camera into the detector, thereby avoiding internal obscuration from the on-axis design.

An ordinary slit is very inefficient for stellar sources at this focus, and is rarely used. It may be used for spectroscopy of extended sources such as cometary comae (where the image slicer presents no advantage), in order to retain one-dimensional spatial resolution along the slit. The ordinary slit is adjustable for widths of 75 microns (0.003-inch) and larger. When using the ordinary slit, the square mask on the collimator should be replaced with a round one.

## Radial Velocity Scanner

The Radial Velocity Scanner (RVS) is installed on the 9682M spectrograph: a removeable diagonal mirror just before the focal surface directs the light into the scanner. The instrument is based on the prototype RVS built by Roger Griffin at Cambridge Observatories. That is, a mask resembling an ultrahigh-contrast negative of a late-type stellar spectrum is scanned back and forth through the focal surface: when the windows of the mask coincide in position with the principal stellar absorption lines, a minimum amount of light is passed through to a photomultiplier; the position at which this minimum occurs is a measure of the Doppler shift of the star under observation. The DAO RVS has a number of unique refinements, however. One is that the masks are etched from copper on glass, for maximum transmission. Also, the mask windows or slits are not parallel, but are tilted slightly with respect to the line of dispersion. By scanning the mask at a 45 degree angle in the focal surface the effect of the tilted lines is to stretch or shrink the mask to maintain proper registration at all velocities. Currently there are spectral masks based on

Procyon (F5) for F-stars, on Arcturus (K2) for G, K and M spectral types, and a carbon-star mask for C-type stars. Thus the RVS is suitable for all stars cooler than about 7,000 K. Following the mask, sets of five superpositioning mirrors focus the transmitted light onto a photocathode, whose small size permits minimal detector noise.

Another feature of the DAO RVS is the Guiding Error Minimizer (GEM). This consists of an image rotating prism located just after the spectrograph slit in the coudé room. The two positions of the prism result in two images of the slit, one inverted with respect to the other. If the GEM is invoked, the RVS records five scans in one position of the prism, followed by five scans in the inverted position; thus if the star is de-centred on the slit during this time, the non-uniform illumination will not result in a velocity-like shift of the spectrum at the mask. Also, the RVS mask position is continuously monitored by an encoder which is checked relative to the stepper motor position: if any discrepancies or discontinuities occur, an on-screen warning is sent to the observer.

The RVS is operated remotely from the observer's room. Repeated scans over a preselected velocity range are summed (to remove seeing and transmission fluctuations), and displayed on an oscilloscope screen. When a well-defined minimum is visible, the observer can interrupt the scan to compute a velocity. Generally a two minute integration yields precise velocities for magnitudes  $B \leq 9$ ; somewhat longer integrations (approx. 30 minutes) extend the observable range as faint as approx.  $B=15$ . Since the Telescope Control System (TCS) can acquire a star typically in one or two minutes, this means it is quite feasible to observe about fifteen stars per hour with the RVS, at least for stars brighter than about ninth magnitude whose velocities are approximately known. For stars whose velocity is quite unknown, it usually takes some time to locate the velocity "dip". On-line data reduction yields heliocentric radial velocities with a precision of about 0.2-0.3 km per second; these require only small zero-point corrections (from a hollow cathode arc and standard velocity stars) to become publishable velocities. The velocity "dip" profiles which the RVS records are also transferred directly into an archive area. This permits more sophisticated data reduction later if needed; in most cases, this is necessary only for double-lined spectroscopic systems of small velocity separation, which display a blended velocity minimum.

For further information on the Radial Velocity Scanner, see:

- Fletcher, Harris, McClure & Scarfe, 1982. *PASP* **94**, 1017.
- McClure, Fletcher, Grundmann & Richardson, 1985.

*Stellar Radial Velocities, IAU Colloquium # 88, p.49.*

## **Before You Come ...**

If you will be using the RVS, you should enter your list of program stars into a data file before your run commences, as it will greatly expedite your observing procedure. The format for such an observing list is the same as for the 1.8-m telescope.

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