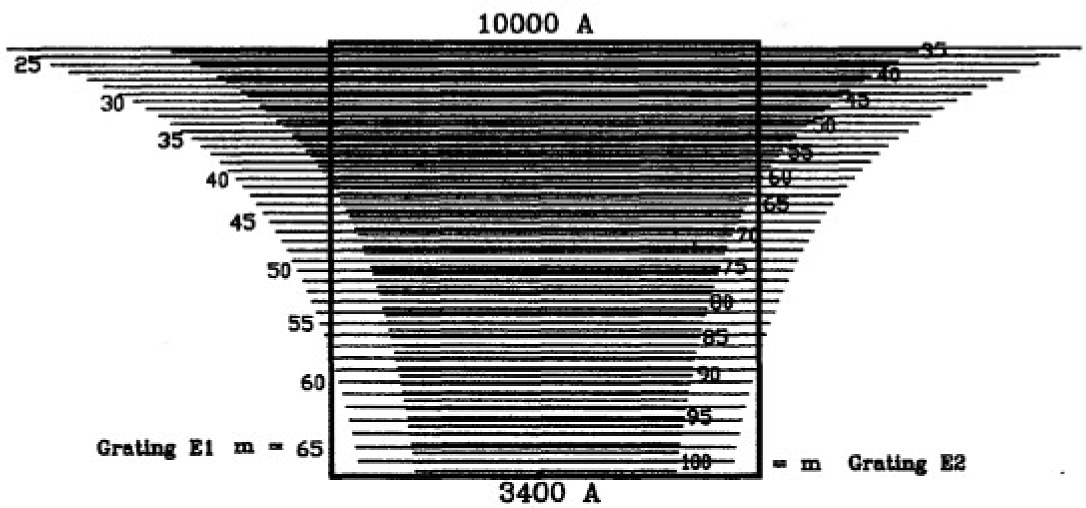
The Cross-Dispersed Echelle Spectrograph

February 2025

There are two spectrographs at coudé, designated TS1 and TS2. TS2 means Tull Spectrograph 2 (Tull, MacQueen, Sneden and Lambert, PASP 107, 251, 1995). TS2 is on the left side seen looking from the M5 mirror turret toward the spectrographs, and TS1 is on the right side[1]. TS2[2] has two foci – F1 and F3. TS23 indicates the lower resolving power F3 focus, with R=λ/Δλ=60,000 when using a CCD with 24 micron pixels such as TK3. TS21 indicates the higher resolving power F1 focus, with R~200,000 when using a CCD with 24 micron pixels. The scale at the detector with TK3 is 0.56 arcsec/pixel for TS23 and 0.13 arcsec/pixel for TS21.

As a cross-dispersed echelle spectrograph, the spectrum consists of many spectral orders (TS23 with grating E2 has >60) that cover the complete optical spectrum from ~3700Å – 5556Å, with continuing coverage out to 1.04 microns with increasing interorder gaps above 55556Å. TS21, with its higher resolving power, has 1/16 the wavelength coverage of TS23. The figure shows the spectral image format of TS23. Each line represents the length (FWHM) of a spectral order. Formats are shown for gratings E1 and E2. The square represents a CCD with 2048X2048 24 pixels. (image from Tull et al. 1995).



TS23 and TS21 are mostly operated in the same way. Therefore, the operation of TS23 is described first. Procedures that differ for TS21 are described in Section 5.

1 TS1 has now been retired but for compatibility with past documentation and papers, TS2 still remains the name of the active spectrograph.

2 TS2 was also referred to by the name 2Dcoude in the past.

Table of Contents

1.0 Choosing a setup

There are two gratings (E1 and E2) available for TS23 and each can be inserted into the beam at a variety of angles resulting in the spectra being centered on the blaze or off the blaze. Tables of the wavelengths covered for each grating and order can be found at Tull grating tables. It is recommended to use grating E2.E1's orders are physically longer so orders with wavelengths redder than about 3800Å have interorder gaps and only about 40 orders fit on the detector.

There are a variety of slit plugs available for the spectrograph, with different widths and heights. The recommended setup is 1x1 binning with slit plug 4 (1.2 arcsec wide by 8.2 arcsec tall slit). A document showing the trade-offs for slit sizes and binning can be found at choosing your slit.

2.0 Getting started

Both TS23 and TS21 are controlled with the "atlas" computer in the 2.7m control room. To start, login to atlas.as.utexas.edu using the credentials issued to you (if you do not yet have an account, contact mcd-os@utlists.utexas.edu).

2.1 Getting ICE ready before the first use

The control software for TS23 is IRAF with package ice (IRAF control environment). User accounts have been created with a default setup prior to the first time an instrument is used. The default setup for your account should have included a directory ~[username]/ice. Within that directory are sub-directories for instruments, including ts23. You will find your login.cl file and uparm directory in the ts23 directory. The launchers (see next section) will take care of changing to this directory prior to starting IRAF and ice. You may add other tasks to this login.cl if you wish.

There are many useful scripts that have been created by Phillip MacQueen that you probably want to use. These are in the directory ~/ice/scripts. Many scripts in that directory have readme files for usage.

2.2 Starting up the control tools

You will see a colorful bar across the middle of the screen that contains launchers (icons) for various tasks you will need. At a minimum, you will need the telescope control system (TCS), the night report (NR), DS9, ice-ts23, TS GUI, TS autoguider, and TS2 wavefront sensor. There is a launcher for the exposure meter and for a separate IRAF window. Other launchers exist for various cameras, firefox, spreadsheets, terminal windows, etc. Open the various tools mentioned here (be sure to launch DS9 before using ice).

To start ice actually running, in the ice window type "ice":

    ice > ice

You can now run mytasks to load the various scripts:

    ice> mytasks

Scripts can also be accessed by explicitly including them in the login.cl file if desired.

2.3 Parameter files

There are many ice parameter files that you will use. These include entering the observer information, the instrument details, etc. The par files you should pay attention to are:

obspars – enter observer and object details and what file naming scheme you wish

detpars – name of detector and location of detector parameters

instrpars – name of the instrument and location of its parameters

empars – details for running the exposure meter

telpars – details of the telescope

Examples are found at the par file link.

2.4 Confirming the CCD is functioning

Check the CCD is functioning properly by checking the status

ice> status

The program will show many details. One important detail is whether the vacuum gauge is on or not. For daytime, the gauge should be on; for night-time observing it should be off. To turn it off use the v2 command:

ice> v2 VGpower=0

Turn it on with VGpower=1**.**

Next you need to check that you can read out frames. First, you should create a folder on the data disk for your data. Use the script *tonight* which has a parameter file allowing configuration of its behavior.

ICE> tonight

This will create a folder for tonight's data on /data1/[user_name]/UT_date and will change into that directory. Note that the date on this directory is given in UT time not local time. Alternatively, you may manually create a directory on the data disk and call it what you want, and then within ICE change into that directory.

Be sure to do this each night so the data do not go into your home directory (limited room on the disk hosting /home compared with the disk hosting /data1) and they go into different directories by date.

Once you have changed to the data directory for the night, you should test that you can read out a frame.

ICE> test

number of exposures (1) (1): 1

Image type (object|zero|dark|flat|comp|focus|ir} (zero): zero

Choosing "zero" for the image type means you are taking a bias frame. If you get a nice looking frame with mostly a single signal level ~1000, you are doing well.

At this point you should start a log sheet (digital or paper) that records things like frame_name, UT, image-type, exposure time, coordinates and anything else you will need for reducing and interpreting the data.

It is very important that you verify that the CCD is working and start your setup during the afternoon before your first night. This is so that you discover any issues with the instrument or telescope prior to the staff finishing for their day. Thus, for your initial checkout on the first and subsequent days, you should confirm you have a working instrument before ~5pm.

2.5 First afternoon (or whenever a setup is to change)
In section 1.0 and in your Request for Services (RFS) you chose a setup. Observing support should have put in the correct slit and set the grating to match your grating choice. They also will open up the mirrors in the spectrograph and fill the dewar. You should check that the slit is uncovered and that the number five mirror is either pointed to the solar port or to the telescope. However, users should not go into the spectrograph because that can cause changes in the room temperature.

For some observers, getting the wavelength setting "close" to the desired wavelength or previous runs is sufficient. Other observers will need to place the spectrum on the detector precisely the same as used in prior runs. To set coarsely, you just need to set with parameters on the tsgui. For very precise setting to a prior solution, you will need a subsection of the ThAr spectrum to be matched and the script ts2cfg.cl. Check out the Disperser Advisory for details.

The script ts2cfg will measure any rotation of the current setup with respect to the fiducial setup. If the rotation is unacceptable, Observing Support (OS) will need to be asked to correct the rotation. This can either be done via a request in the night report or by a call to a member of OS. If needed prior to the first night, then you will need to call someone. Users should not enter the spectrograph and try to change the rotation themselves.

When set up, the spectral image shown in DS9 will have blue on the left of orders, red on right. The orders will go from blue on top to red at the bottom. The sign of DS9 images can be reversed using the negative of the axes in the display command.

Once the grating is at the correct setting. The spectrograph needs to be focused. This is done using Hartmann masks inserted in the lamp housing. To focus, use the ts2foc.cl script and make sure that the focus in the par file is set to TS23. The script will obtain ThAr spectra with the A and B masks individually inserted into the system and compute the change in focus. For TS23, the ts2foc script will actually change the focus. This process results in the best instrument focus.

2.6 Every afternoon
Many observers will not check the wavelength setting or focus every day, assuming it to be stable. However, temperature and pressure changes in the spectrograph will

cause slight changes in the settings and focus. Observers who want more precision for their observations will rerun the ts2cfg and ts23foc scripts every afternoon. There is no downside to running these tasks again except for the small amount of time used.

With a good setup and focus, it is now time to obtain calibration spectra. Generally, for each night, users will want at least 1 ThAr spectrum to define the dispersion curve for the instrument. They will also need frames to define the bias (zero frames) and flat fields. These calibration frames can be started with a single script called ts2cals.cl. The user is asked to specify if the ThAr should be obtained before or after the flat fields, how many flat fields should be obtained and how many bias frames. A flat field with the I_2 cell inserted can also be requested in this script. The quality of your data reduction is dependent on defining the flats and biases well, so do not scrimp on the numbers of these obtained. At least 25 each of the flat lamps and biases is suggested (to get adequate signal in the blue). The script mostly runs automatically with no user interface, so doing more observations is not a large burden.

The one place where the script will ask for intervention is for the first flat field frame. The script with obtain a sub-frame (for speed) of the flat field and ask if the amount of light is sufficient. The script targets 125,000 for a max level. If the answer is no, the script asks how bright the lamp currently is and will compute a different exposure time and try again (asking the user again to confirm). If the answer is yes, the script will proceed to obtain the requested number of flat lamp spectra.

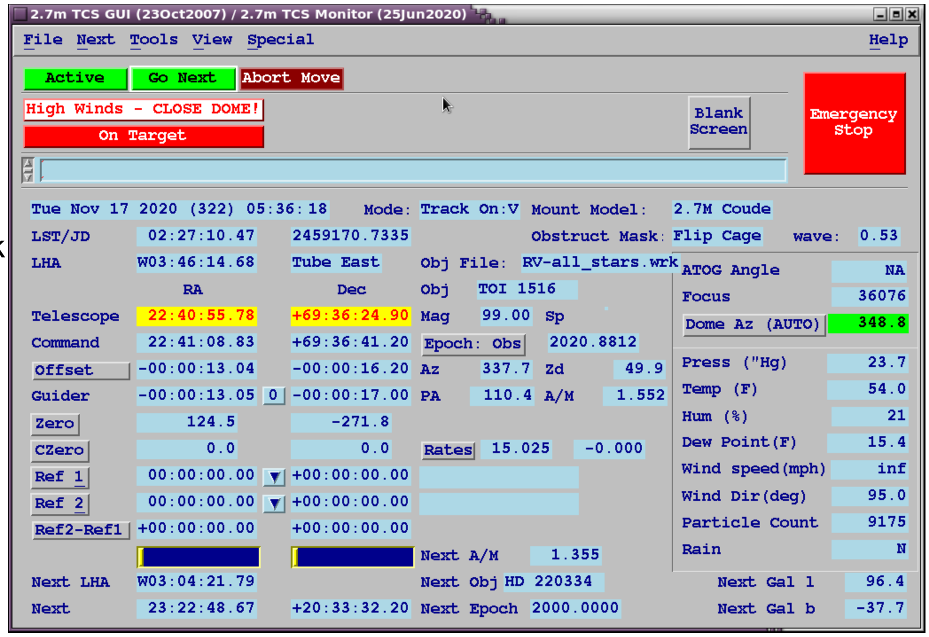
The CCD has essentially no dark signal in 30 minute observations, so taking and applying dark frames will simply increase the noise without any positive benefit.

Many users will observe the solar spectrum as a comparison for their data and a check on the wavelength scale. To do this, you use the solar port mechanism. This images the blue (daytime) sky through a ground glass and into the spectrograph via the appropriate number 5 mirror. The solar spectrum is then obtained with the same optical path through the spectrograph as stars. The observer needs to confirm that the number 5 mirror is set for the solar port. Instructions for opening the solar port mechanism can be found at the Solar Port mechanism manual.

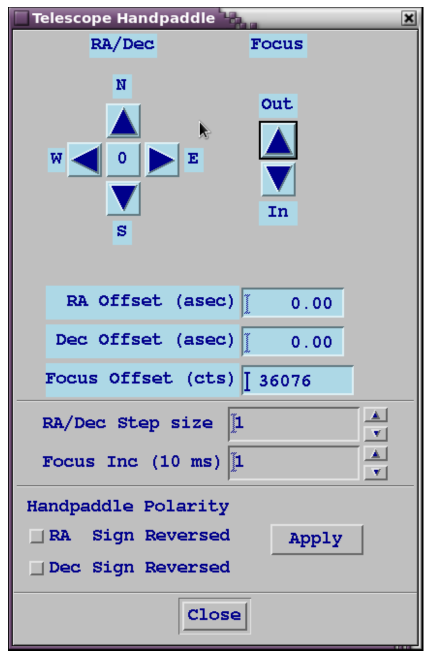
3.0 **Getting Started Observing**

It is assumed that the observer has been trained how to run the telescope, including how to start and stop tracking, how to turn on the automation so the dome follows the telescope, etc. Running the telescope is documented in the Telescope Control System manual. The TCS Control system GUI on atlas is a duplicate of the console on the dome floor and can be used to select targets and send the telescope to the next object. However, the observer must be on the dome floor holding down the deadman switch for the telescope to actually move.

To activate the GUI, click the button near the upper left to make the telescope control system *Active*. It is good practice to check that the correct mount model has been selected. It should be 2.7m coude or coudeover.



If you want a digital handpaddle on your atlas screen, under the "Tools" menu click on "handpaddle". It is good practice to confirm the the "HA/Dec" rates for digital telescope move commands are reasonable (≤ 1 arcsec) as a prior user may have set in large moves.



Once the Sun has set, you may open the dome. First confirm that the conditions are safe for the dome to be open. You may turn on the tracking at this point or wait for a slew to the first target (this will turn on the tracking as long as the target is not zenith or stow). Open the mirror cover, the doors to the catwalk and the lower louvers. Unless it is very windy, move the windscreens completely out of the way. If it is windy but below the wind limit, move the windscreens (also called curtains) to limit the wind entering through the dome slit and consider working only downwind. Turn off the fluorescent lights in the control room (light can leak down into the spectrograph).

Be sure to enter the time the dome was opened in the Night Report (and record clouds and seeing at least 3 times during the night).

3.1 Checking the telescope pointing and focusing the telescope

You will need the coude autoguider (cagdr) program started in order to observe. The program remembers which windows you have used in past runs and will open these. At a minimum, you will want the expose, view, history, display charts and fiducial windows in use. The guider views the slit and the surrounding region. You can choose magnification for the area to guide on. Most often you will want to choose the "acquire' mode ("A" in the upper right of the guider image) with a FOV of ~7 arcmin or the "guide" mode ("G" in the upper right of the guider image) with a FOV of ~50 arcsec. In the guide mode, you will probably want to mark the sides of the slit and create a sub-field for guiding. Other magnifications are available but these two modes are the primary ones used.

Since the coude slit is fixed with respect to the building, and the telescope FOV rotates as an object is tracked, there is a compass rose that keeps track of the slit orientation. It is also included in the headers of the observation spectra [Is this true?]. The user may choose to have the field shown with North up and East or West on the right with "N" and "E" buttons on the upper right. This is useful for matching the field to a finder chart.

In order to check the pointing of the telescope, choose a bright star near the zenith (on the TCS under the next menu click "Bright Stars Near Zenith"). A list and a sky plot will open. Choose a star from either the list or plot. It should load the coordinates into the next object on the TCS GUI. Choose "Go Next" and go out to the telescope and hold down the deadman switch until the TCS says "on target". In the control room, maneuver the star image to the slit. When on the slit, use the TCS GUI and click on zero to set in new zeroes. Do not change the "czeroes" from values of "0". In theory, you only need to zero the telescope once at the start of a run, but checking each night is a good policy in case something was done with the telescope during the day.

To focus the telescope, the coude wave front sensor is used. Details of this program and its usage are described in the Wavefront Sensor manual. You will need to put the wavefront sensor into the beam. This can be done either from the tsgui window or the WFS GUI window. The WFS program can be used either in the mode that it reports to the user what focus value to set or can automatically change the focus for the user.

The telescope can be focused with the WFS any time a star of sufficient brightness is observed. The focus should certainly be checked any time a large change in the weather occurs.

3.2 Observing Targets

Targets may be loaded into TCS from manual coordinates, members of built-in catalogues, members of worklists, ephemerides, etc. Choose your desired target and load it into the "next" object on TCS. When ready to observe the target, click the "Go

Next” button in the upper left of the TCS GUI. At this point, someone will need to hold down the deadman switch in the dome until the TCS reads “On Target”.

Back in the control room, the autoguider (cagdr) can be used to view the sky in either acquisition mode or guide mode. Clicking “snap” will obtain a single guider image and “image” will put the guider into continuous readout mode. The guider exposure time for images and any scaling can be controlled from the various cagdr windows.

Using the guider, the target should be verified and then placed onto the slit for observation. The target is held on the fiducial within a guide box when “guiding” is selected.

The detector integration times for targets depend on target brightness, spectral type and sky conditions. A guess for an appropriate exposure time can be made using the table below for signal/noise measured under good conditions.

Star	Spectral Type	V Mag	Exposure time (sec)	Method	S/N @ 7480Å	S/N @ 4800Å
61 Cyg B	K7V	6.03	575	1	470	220
				2	623	237
HR 447	G1V	5.76	383	1	320	200
				2	378	283
Theta Per	F8V	4.11	104	1	290	216
				2	385	290
Notes: S/N is per pixel Method 1 is to use IRAF splot to measure the variance around the wavelength. Method 2 is square root of counts at wavelength corrected for gain and readnoise.						

To start an exposure for a target, one uses the “object” command (or any variant of the “observe” command desired). The parameters can be loaded in with epars, filled in as responses to queries or can be typed as part of the command. As an example of the latter:

```
ice> object num_exp time_exp “STARNAME”
```

where num_exp is the number of exposures, time_exp is the integration time per exposure and STARNAME (in quotes) is the label for the object. If the exposure meter is used (see below), the exposure meter parameters may be put on the command line. Otherwise the empars file will be used.

Alternatively, the exposure time may be controlled by the Exposure Meter. The exposure meter allows users to specify a maximum desired exposure and a target signal for an observation. The exposure meter will cut off the exposure at the shorter of the time needed to achieve a certain signal or the defined exposure time. A user may decide to use the exposure meter to be more efficient (not waste time getting more signal than needed) or to limit the change in airmass or barycentric correction. In good conditions and with the same exposure meter settings, the exposure meter will cut off at a very consistent signal/noise at the chosen wavelength (5000Å for the data in the table).

To use the exposure meter, one needs to turn on the option in the empars parameter file. Then the maximum counts for the meter (not the CCD) are entered. The user must also indicate whether to save the flux trace of the exposure meter and set that option in empars. If the option to save is indicated, the exposure meter trace will be appended as an additional extension on the data fits file (accessed as file.fits[1] where file is whatever the file is called; the data are in file.fits[0]).

As targets get fainter, longer exposure times are needed to get the same signal/noise from a faint target as from a brighter target. However, the number of radiation events (aka "cosmic rays") hitting the chip also increases. Since the electronics on TK3 are excellent, with low readnoise, one can achieve similar signal/noise to that gotten with a single long integration with multiple shorter integrations. Thus, instead of observing a target for 1 hour, it is recommended that three 20-minute spectra be obtained and then cosmic ray median combined. The advantage to this process is the elimination of cosmic rays in spectra while the cost is the extra two (in this case) 89 second readouts. The integration times used for these shorter observations just need to be enough to get over the readnoise of the detector.

4.0 End of Night

When the observing time is complete (either because of dawn or bad weather) you will need to close the telescope and leave it for the daytime staff.

In the TCS GUI, set the next object to "STOW" and go next. Be aware of the warnings about where this command cannot be executed. The stow command should send the dome to slit west and park the dome. Close the dome and the mirror cover. Once the telescope and dome are both stowed, hit "E-stop" (on the console, a paddle, the TCS GUI in the dome or control room) and listen to the brakes drop into place. Turn the dome passage lights on low, to allow someone to safely traverse the dome floor.

In the control room, finish filling out the night report including the time and reason the telescope dome was closed. Include any notes concerning issues. Be sure to click on the button (middle left) to request that Observing Support fills the dewar.

If you want any more calibration spectra (i.e. an end of the night ThAr), take them now.

Unless you need to leave a process running (e.g. the cal script), log out of all of your windows and log out of atlas. This allows daytime staff access to atlas if needed. If you must leave a process running, put a note on the keyboard indicating when you will be done and they can log you out.

5.0 TS21 Specific Procedures

5.1 Setting the grating for TS21

With the higher resolving power of TS21, a lot fewer of the orders fall on the chip and more orders are longer than the width of the chip. These details can be seen in the Tull Grating Tables. Because of this substantial decrease in wavelength covered it is a bit more complicated to set the grating angle for TS21. In addition, the longer orders mean that for TS21, it might be appropriate to choose grating E1.

Unlike TS23, where the complete spectral range can be observed in only 2 or 3 grating angle settings, there are many more useful settings for TS21 that a user might wish to select. Instructions for how to choose the proper settings are described in TS21 Disperser Settings.

Note that the spectral image is rotated 180° with respect to TS23. When displaying spectra using DS9, blue orders are at the bottom of the spectral image and red on top and blue wavelengths are at the right on each order with red at the left. Users may switch the display orientation with IRAF's display tools or DS9.

5.2 Focusing the spectrograph at TS21

At the present time, the computer cannot change the focus of the TS21 CCD. It must be done by hand in the spectrograph. However, this process can be helped with the use of the TS2foc.cl script. First, the user should ensure that the focus in the ts2foc script is set to ts21. This defines scale and orientation. Then ts2foc can be used to run the Hartmann test, taking spectra with Hartmann A then B in the beam and the other out. The script will then compute what change in the knob in the spectrograph must be made to bring the CCD into focus.

Armed with the focus setting change that ts2foc reports, someone needs to go into the spectrograph and turn the appropriate knob. Going into the spectrograph can be risky if care is not taken with the exposure meter photometer. In addition, there is a risk of leaving on lights and warming the air in the spectrograph. Thus, unless an observer has been specifically trained and authorized to enter the spectrograph, it is recommended that the observer get help from someone in Observing Support and have them enter the spectrograph and make the adjustment.

what else?