Report: first light with the Echelle spectometer on the 1.5-m CTIO telescope.

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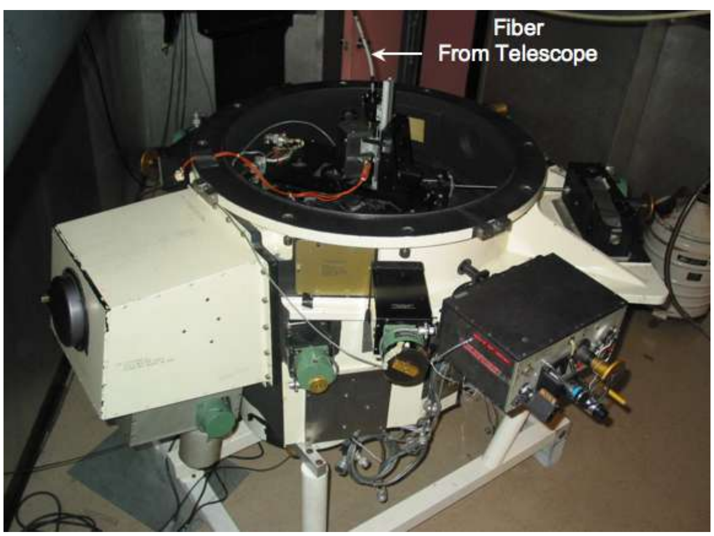
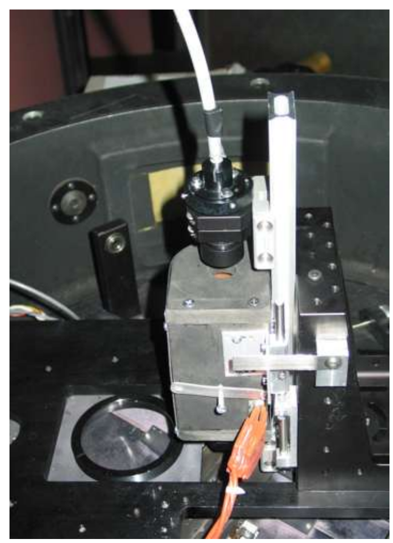
Status
Andrei Tokovinin and the folks at CTIO (notably Oscar Saa) have successfully commissioned the echelle spectrometer (retired from the Blanco telescope) for the 1.5-m telescope on a tight timescale. Their work permitted us to begin observing on the first night with little lost time for engineering. The nominal goal of this first run is to acquire enough spectra of alpha Cen A and B to carry out Doppler analysis and assess the radial velocity precision. In addition to the observations, the Doppler analysis requires an "intrinsic spectrum" of each star (generally obtained by deconvolving the PSF from a high resolution, high signal-to-noise spectrum) and a high-resolution iodine spectrum (generally an FTS scan of the iodine cell). Both the intrinsic spectrum and the FTS scan will be obtained in the next month.





The iodine cell was built at SFSU and shipped to CTIO a few weeks before the observing run began and was installed in a housing that rotates into place between the optical fiber and the entrance slit to the spectrometer (in the close-up figure on the right; the red cord connects to the temperature controller).

On the first two nights, the spectral format was established with

1. peak blaze at the center of the detector
2. dual amp readout
3. windowing of the chip to minimize r/o time but still include the full I2 region

4. 60 micron slit to maximize resolution.

The selected window from (column-start=1, row-start=400) to (column-end=2048, row-end=1599) resulted in wavelength coverage from 4400 – 6400 Angstroms with a read-out time of 60 seconds. Other users will be able to change this readout format to observe from 4360 – 7200 Angstroms by changing the software in the datataker ("detpars") with a readout time of about 2 minutes. No change in the spectrometer hardware settings is required. Other users are also able to open the spectrometer slit to increase the throughput (with some accompanying degradation in spectral resolution) for fainter targets. The stability of the spectrometer is critical for the alpha Cen project, so the decision about the spectral format was also made with the general community in mind.

Six of the first seven nights were clear, or only partly cloudy. The exposure times for clear nights are typically 10 and 20 seconds for alpha Cen A and B respectively. These exposure times yield S/N of 300 near blaze center. Under cloudy but still workable conditions, the exposure times increase to as much as 60 and 120 seconds (for A and B respectively) to maintain the same high S/N. However, there is not an exposure meter to calculate the photon-weighted centroid for our observations, so the maximum exposure time should be limited to 30 seconds in order to minimize midpoint errors that could result in ~1-2 m/s spurious scatter in the radial velocities. The number of observations per night ranged from 100 (under poor conditions with clouds) to more than 300. The initial simulations for this project assumed 100 observations per star per night, so we are exceeding our assumptions for the observing cadence. We were able to easily schedule observations of stars for Andrei Tokovinin to provide high sampling for interesting short-period stellar binary and multiple systems.

On the ninth night, condensation was detected in the I2 cell. The likely explanation is that residual water inside the cell condensed at a cool spot on the bottom of the cell where the light emerges to enter the slit of the spectrometer. This condensation is reported to result in a loss of light. As a temporary solution, a conducting ring of material was added to the perimeter of the optical flats and the temperature controller will be run at 60C (instead of 55C), with the option of increasing the SP temperature to 65C if the problem persists.

Tests

A number of tests were carried out to assess the stability of the spectrometer. As a diagnostic, we used bright B stars to illuminate the I2 cell and cross-correlated these iodine observations to measure pixel shifts. We checked for displacements due to guiding errors, charge transfer effects, and human activity in the coude room (e.g., filling the dewar, leaning on the spectrometer). ***Figure 1*** below summarizes these tests.

a. A single Bstar observation was used as a template for the cross-correlation.
b. Five Bstar-iodine observations comprised one set. Nine sequential sets taken on May 22, 2008 show the effect of guiding on the slit center ("GC"), then guiding to

the right of the slit ("GR").

c. The mean pixel displacement is plotted for each set (blue and red, respectively) and the error bars are represented by the standard deviation for each set.

There is no apparent trend with time in the first 9 (consecutive) sets of data and the mean for all sets is about 0.01 +/- 0.007 pixels demonstrating excellent stability in this short test. Likewise, three sets of B star-illuminated iodine taken with different exposure times (three at 30 sec, ten at 10 sec, three at 30 sec) show mean offsets of less than 0.02 pixels from the initial template and essentially no changes from different exposure times suggesting that no differences were seen in CTE for these observations.

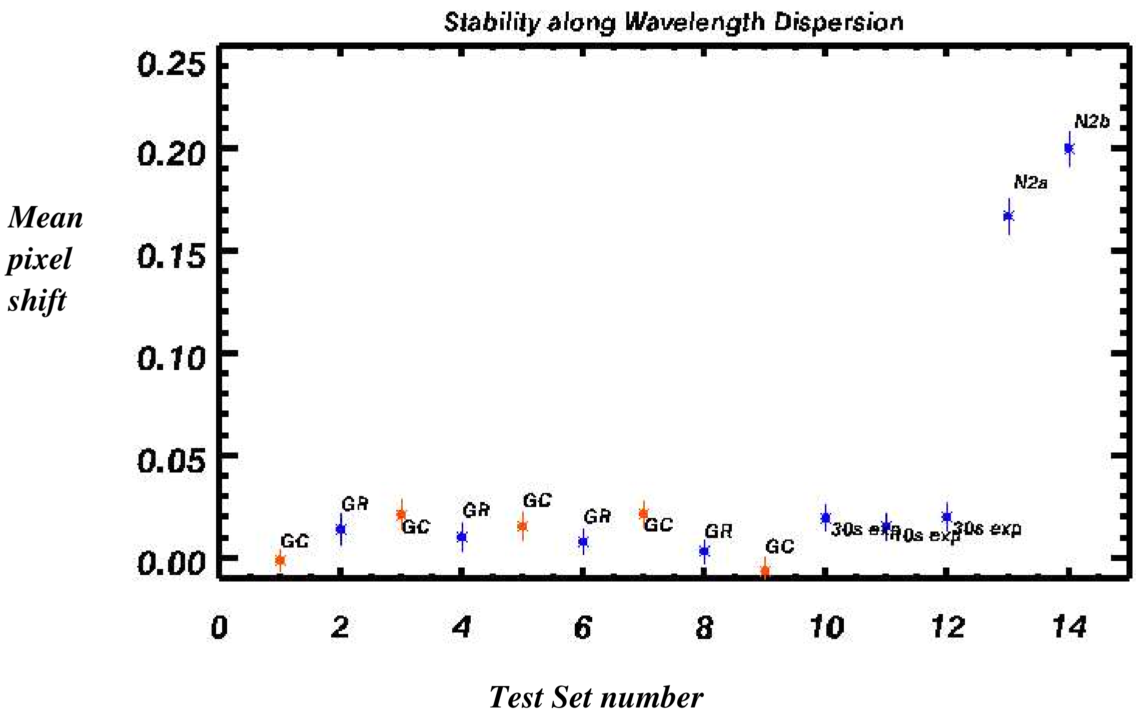


Figure 1. Pixel shifts along the dispersion direction. The first 9 points represent consecutive sets of Bstar-iodine observations with intentional guiding errors of 2 arcseconds. Points 9-11 were taken on the same night, with different exposure times to check for asymmetries or shifts due to CTE. The last two points were taken two nights later, but cross-correlated with the first night template and show that sub-pixel shifts will occur over time, as expected.

Two nights later (24 May, 2008) we obtained two more sets of Bstar-iodine observations (points 13 and 14 on ***Figure 1***) and cross-correlated with the original template from 22 May, 2008. One set of data was taken after filling the dewar and going into the coude room. The pixel offset shows that sub-pixel linear drifts can occur and we expect the iodine analysis to handle these drifts (as is the case at other telescopes).

We next guided alpha Cen A 5” off the slit to measure the low level flux, expected to contaminate the spectrum of alpha Cen B (to varying degrees, depending on seeing conditions). ***Figure 2*** shows a column cut of alpha Cen B (20 second exposure) on a log scale in intensity (y axis) to enable a qualitative comparison. In a two-minute exposure we measured 20 dN above the bias, while the 20 second exposure of alpha Cen B had about 30000 dN in the same order. This implies that the usual 20-30 second exposures of alpha Cen B will have contamination of order 1 part in 30,000 in good seeing conditions, when the stars reach closest approach. This test should be repeated under different seeing conditions.

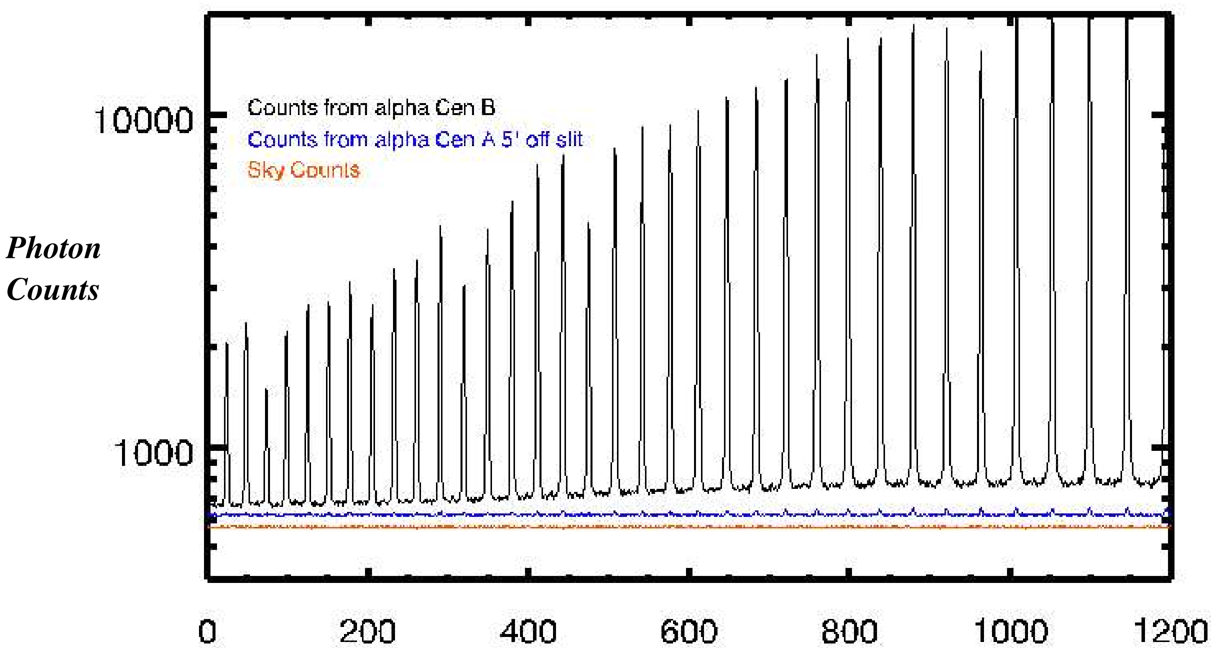


Figure 2. Column count of flux from a 20 second exposure of alpha Cen B, a 2 minute exposure of alpha Cen A when placed 5 arcseconds from the slit and a 2 minute sky exposure. The light spill-over from alpha Cen A is only 20 dN, suggesting it will contribute about 1 part in 30000 to the alpha Cen B counts (this should have no impact on the Doppler observations).

Software development

Work was started on IDL analysis pipelines that will be made available to general users.

1. Focusing program. The focusing program “foc.pro” is important for the alpha Cen project because it measures focus across the spectral format and shows if any shifts have occurred in the spectrometer. The spectrometer is not adjustable by the general user and we do not anticipate significant shifts under normal use, however, running foc.pro will allow us to monitor the focus and shifts.

2. Wavelength solution. Thorium-Argon wavelength calibration (“thid.pro”) was completed for the spectral format and can be easily run for the current echelle and collimator positions in the spectrometer.

3. Log-writing program. A program was written (“logmaker.pro”) that reads fits headers in the nightly directory and generates a logsheet. Some comments need to be added to the logsheet, so an “Observers Notes” was generated to capture special comments.

4. Gain measurement. The gain was measured for each side of the chip (two amplifiers are used to readout the chip) and found to be 1.38 for the left (blue) side of the chip and 1.27 for the right (red) side of the chip.

5. Raw reduction package. A raw reduction package carries out flat-fielding and order extraction to generate an array of intensity for each pixel in each order. This will be combined with the Thorium-Argon program to add the wavelength solution and the files will be written in a standard fits format (currently they are saved as IDL files to be read by the “rdsk” program).

An example of an extracted order is shown in ***Figure 3*** for a Bstar observation. A steep blaze function is apparent. The top (black) curve shows an observation without iodine (some weak telluric lines appear). A shoulder appears on the right side of the spectrum at about pixel 1500. The same spectrum was reduced with a flat-field set uniformly equal to 1.0 and demonstrates that flat fielding does not cause this feature. The spectrum was scaled (by 0.95) so that it would be offset in ***Fig 3*** from the Bstar observation with the standard flat-field. Also overplotted in ***Figure 3*** is a Bstar spectrum observed through the iodine cell, showing a rich forest of I2 spectral lines.

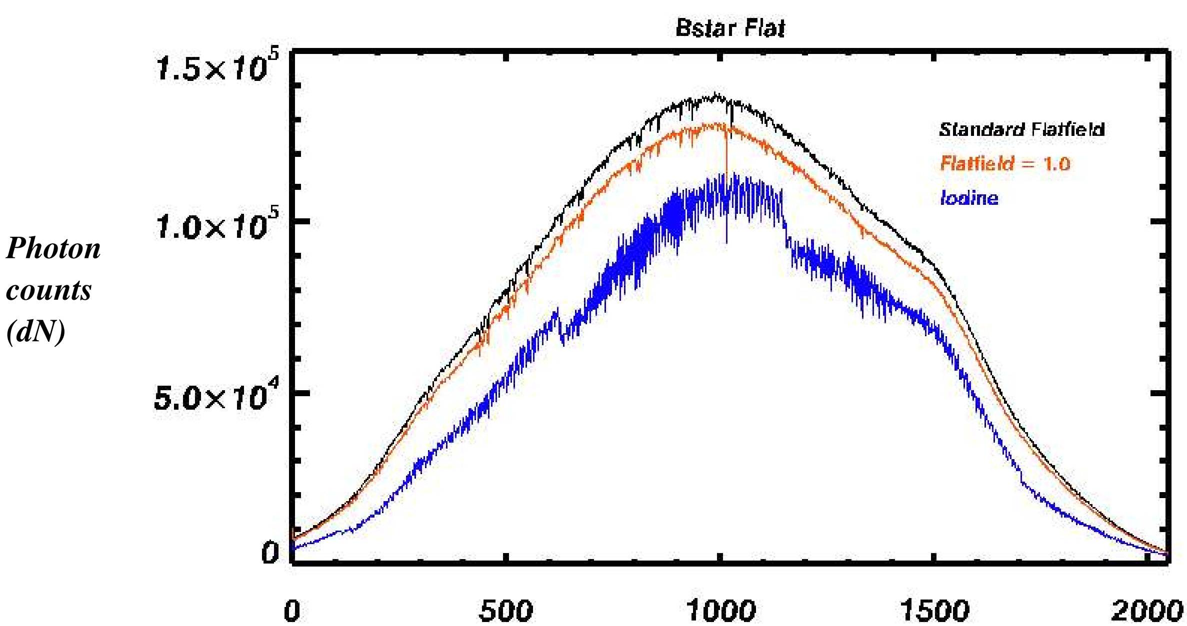


Figure 3. Extraction of one order of an observation of a bright Bstar. The top plot (black) is taken with the standard, normalized flatfield. The red curve is offset by 0.95, but extracted with a uniform flatfield of 1.0 and shows the same functional shape, perhaps a combination of the blaze function and some loss of flux on the red side of the chip (beyond about 1500 pixels). The blue curve shows an observation of the Bstar through the iodine cell, with the expected absorption line depth.

Plans and future work

Several issues for future work were discussed.

1) An FTS or other very high-resolution spectrum of the Iodine cell is needed to carry out a robust Doppler analysis. We are scheduled to obtain this FTS spectrum in July at the Pacific Northwest National Labs, but also have plans to use a dithering technique to obtain a high resolution (R~200,000) in situ at CTIO in August or September.

2) Motorizing the iodine cell

This improvement would make it possible to insert and remove the I2 cell from the control room. This makes it easier for the observer (where easier = more efficient) and reduces the chance for accidentally hitting the optical fiber and introducing misalignment. This upgrade would also permit the eventual thermal isolation of the spectrometer with bubble wrap.

3) TV guide camera

We considered increasing the focal length (magnification) of the guide camera with the goal of improving spatial resolution of the alpha Cen stars so they can be optimally positioned on the slit. It is also possible to purchase a new camera, which would include a frame-grabber and could be used to guide using the slit image.

4) Temperature control the coude room

Because of the demand for stability for this long term project, we considered stabilizing the temperature in the coude room. It would be ideal to select a constant temperature close to the typical temperature in the coude room (perhaps 17 C) or to target the temperature to match the summer temperature (perhaps 20 C). This would require thermostat control, and we considered mounting a temperature sensor on the aluminum frame of the spectrometer

5) BG38 filter for guiding and flats

The use of a BG38 (green) filter for the TV guide camera is useful because we observe alpha Cen A and B from the HA ~5 hour through zenith. Chromatic atmospheric dispersion smears the starlight out and TV guide cameras tend to be most sensitive to red light. The BG13 filter insures that we will guide on green wavelengths where the iodine lines are located. A green filter is also important for the flat field because a 1-second exposure currently saturates at 65000 counts redward of 5800 Angstroms.

6) Fiber scrambler
The use of a fiber scrambler was discussed, however the PSF appears to be remarkably stable without this, and we learned (when visiting La Silla) that the fiber scramblers are being pulled from most of the fiber-fed instruments because the cost (in photons) was not accompanied by a gain in RV precision

7) Diffuser for flat field observations
It would be valuable to insure that the quartz observations (used to flat field the image and thereby remove pixel-to-pixel Q.E. variations) is slightly wider than the stellar image in the cross-dispersion direction. If the stellar image does not coincide with the quartz image, then the flat fielding will not be as robust. This might be accomplished with a diffuser or piece of glass in front of the fiber optic cable before the slit of the spectrometer.

8) Moon Observations
The most critical next step is the Doppler analysis. Because it will take a few weeks to obtain a high-resolution, high S/N intrinsic spectrum of alpha Cen A and B, we took a series of about 50 observations of the moon over one hour. We will use the NSO atlas as the intrinsic spectrum for modeling these observations, and will identify the best match FTS iodine spectrum among our existing atlases. This analysis should be completed within the next week.

Documentation
We are working on documentation as we go to serve the general community. We currently have a "ctio_setup" guide, an observing checklist (for astronomers and an abbreviated version for the telescope operators), an "Observer Notes" form to supplement the logsheets generated automatically by reading fits headers for the nightly observations. We will provide help files for the software and provide the reduction pipeline (including the Doppler pipeline when desired) to the general user community.