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Data Pipelines for the TRES Echelle Spectrograph

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Abstract. An IRAF-based processing pipeline has been written to reduce spectra from the Smithsonian Astrophysical Observatory's TRES (Tillinghast Reflector Echelle Spectrograph) two-fiber echelle spectrograph on Mt. Hopkins in Arizona. A modular system was written in IRAF so that the same software could be used at the telescope for quick-look processing and later with more accuracy for scientific processing. IRAF tasks developed for the SAO FAST long-slit and Hectospec multi-fiber spectrographs, as well as NOAO-developed echelle tasks, were adapted for this instrument.

The TRES Spectrograph

The Tillinghast Reflector Echelle Spectrograph (TRES) (Szentgyorgyi & Furész 2007) is a two-fiber (object and sky spectra) echelle spectrograph on the 1.5-meter Tillinghast telescope at the Smithsonian Astrophysical Observatory's Fred L. Whipple Observatory on Mt. Hopkins in Arizona. It covers optical and near-IR wavelengths from 3850 to 9100 Angstroms at a resolution which varies from 0.03 to 0.07 Angstroms/pixel over the spectrograph's 51 orders.

Design Strategy

Our two design goals were to keep the maximum wavelength precision and to use the same software for both quick-look processing at the telescope and more accurate processing for scientific analysis.

To maintain accuracy, we fit a two-dimensional (order and pixel) dispersion function to each spectrum and maintain that function in the header through further processing using formats developed in IRAF for dealing with multi-order echelle data. Using IRAF made it possible to adapt and re-use tasks written to process data from other SAO spectrographs such as FAST (Tokarz & Roll 1997) , Hectospec (Mink et al. 2005) (Mink et al. 2007) and Hectochelle, as well as IRAF tasks written at NOAO (Valdes 1992) which process images and extract multiple-order Echelle spectra. For portability, all code is written in IRAF CL or SPP.

Data Structure

The process needed to be easy enough for scientists to use and even harder for them to misuse. This was accomplished by keeping all processed data in a different directory than raw data and enforcing that separation in code.

Each night's raw data resides in a directory designated by *[rawdir]/yyyy/yyyy.mmdd*, with filenames beginning with a three-digit sequence number, followed by an object name or calibration type (BIAS, DARK, FLAT, or COMP). These filenames are kept through all processing.

Corresponding processed data is in a directory *[procdir]/yyyy/yyyy.mmdd*. When composite files, such as sums and medians, are created, they are automatically given sequence numbers beyond those used for observed data.

Data Processing

One master IRAF CL script, **tproc**, runs the entire data processing pipeline. In the past, while processing data from other instruments, it has been difficult to work with IRAF scripts which called one master program with different arguments to do different processing steps. When tasked with writing a multiple purpose pipeline, however, it became apparent that having one main program made it easier to process all of the different data types identically. It works on a single spectrum or a group of spectra of the same object with the same fiber configuration and exposure time.

First, the standard IRAF **ccdproc** task is used to remove the bias levels from the overscan region of the chip and trim that region from the image file. Then the two amplifiers are corrected to the same gain and merged into a single image. Bad pixels are fixed in that merged and trimmed image because they can only be discovered in images combined to remove the many bright spots caused in each image by radiation from the anti-reflection coating on the dewar window. Each image is then corrected by the aperture flattening image to minimize fringing and pixel to pixel variation. If a median image is requested, it is made next, before particle hits and cosmic rays are removed from a group of similar images by a locally-written task which intercompares them. At this point a sum of all of the similar images may be made and added to the processing list along with a requested median file. Then a model of the scattered light is fit to the background of each image, with the spectrum or spectra masked out, and subtracted.

For ThAr wavelength calibration and flat field lamps, one spectrum is then extracted from each image. For object plus sky images, two spectra are extracted. Thorium Argon (ThAr) wavelength calibration spectra are compared to a reference spectrum, and a wavelength to pixel mapping is fit for each one. For each object or sky spectrum, wavelength solutions are found by combining the closest or most recent ThAr solutions. If the simultaneous sky spectrum is going to be removed from the object spectrum, it is first rebinned to the same wavelength solution as the object spectrum, and then corrected for fiber throughput before being subtracted.

Processing Data

Initalization

To make the separation of raw and processed data easy, the **trsdate** `yyyy.mmdd` command sets the processing and raw data directories based on the date. After this, all of the tasks can find the raw data and put the processed data only in the processing directory. Tasks that write data always check to make sure that they are writing to the processing directory.

Pipeline Processing

Quick Look

qtres reduces one raw spectrum image to one to three multi-order echelle spectra using **tproc**. Default flat fields and ThAr spectra can be used because night-to-night instrumental shifts are less than a pixel.

Quick Look with Cosmic Ray Removal

ctres is a quick-look task for multiple images with the same configuration reducing a list of raw spectrum images to dispersion- corrected multi-order echelle spectra with cosmic rays removed by tcosmic.

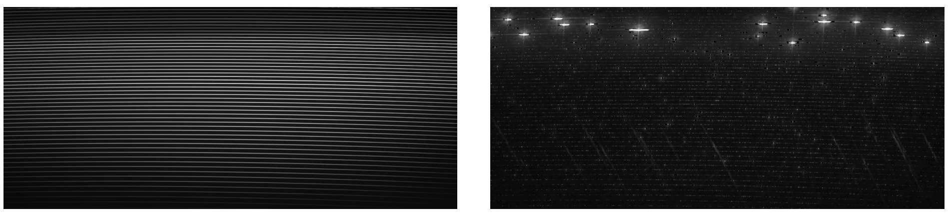

Figure 1. Processed flat field and flat field images

Setting Up and Processing a Full Night's Data

trsgroup makes lists all of the TRES files to be processed, grouped by object name, fiber configuration and exposure time *[obj][s m l][b if binned][fiber(s)]x[exposure in seconds].list.* Multiple groupings of exposures of the same object and configuration are split into separate lists. A master list of lists is made for object data. Processing then proceeds with optional interaction.

btres processes and takes the median of all bias images (those with BIAS as the object name), plotting a histogram of the combined image as an instrument check.

If dark field images are taken, **dtres** makes a median of all of them and plots a histogram of the combined image as an instrument check.

Images of flat field spectra (with FLAT as the object name) are used to create extraction functions, aperture flattening masks, scattered light masks, and throughput ratios. **ftres** is run on lists of short-exposure images from each fiber for each observation configuration, creating the necessary masks and functions.

Thorium Argon spectra (with COMP as the object name) are processed using **ttres**, which reads a list of raw ThAr spectrum images taken with the same fiber size and binning and extracts them to dispersion-corrected multi-order echelle spectra. Each extracted spectrum (see figure 1) is cross-correlated to a reference spectrum in pixel space using **rvsao.xcsao** (Kurtz & Mink 1998). The resulting pixel shift is added to the line positions in the reference spectrum database file which is then refit to the lines identified in the ThAr spectrum.

Object spectra are then processed by the **trsproc** task which runs **otres** on each list of similar object observations read from the list file created by **trsgroup**.

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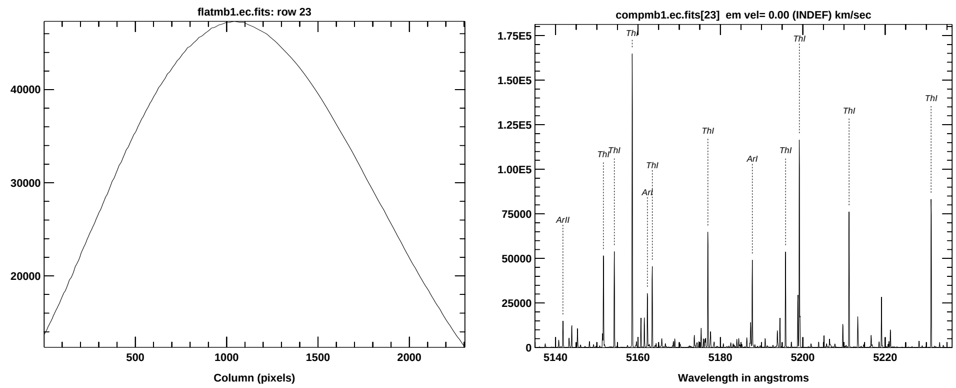

Figure 2. Single order of extracted flat field and ThAr spectra

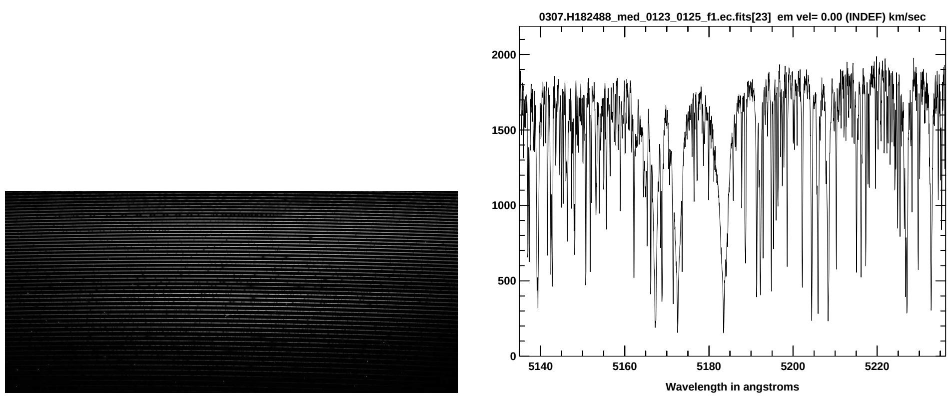

Figure 3. Raw stellar spectrum and one order of extracted spectrum

the pipeline and suggesting improvements, and Susan Tokarz for helping me clarify this description of how the pipeline works.

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