The Gemini-south High-resolution Optical SpecTrograph (GHOST) data reduction system

SPIE.

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The GHOST Spectrograph

GHOST is a fibre-fed echelle spectrograph. It has a wide variety of observing modes tuned to a range of science cases, which contribute to a number of unique data reduction challenges.

What makes GHOST special?

1. **Operates in both standard (50 000) or high (75 000) resolution mode**
2. **Uses 2 IFUs, allowing for simultaneous observations of 2 targets in standard resolution mode**
3. **Fibres in the IFUs are rearranged to form a pseudo-slit, utilizing more of the target's light while also slicing it for higher resolution**
4. **A slit-viewing camera keeps track of the slit profile over time, acquiring accurate exposure epochs**
5. **Concurrent observations of a ThXe lamp will allow for precision RVs (< 10 m/s) to be measured**
6. **The temperature- and pressure-controlled enclosure stabilizes the wavelength solution on the detector**

How the data reduction pipeline operates

The data reduction software for GHOST (GHOSTDR[1]) is the first instrument pipeline to be specifically developed for DRAGONS[2] , a python-based framework operating within the AstroConda environment.

The key core component of DRAGONS is the Recipe system (Fig. 1). Its functionality is provided by the Reduce class and associated reduce "primitives", the reduction steps that process each image. The GHOST slit-viewing camera images a pseudo-slit made from the rearranged fibres of the IFU(s). GHOSTDR traces this pseudo-slit, monitoring it over time, for a higher SNR and precision of RV measurements.

GHOSTDR uses a polynomial model for the various aspects of the GHOST detector (order trace, wavelength solution, etc.), which should experience very few changes over time. The pipeline returns a 1D spectrum (along with intermediate data products), along with corresponding variances, and 2D maps of the extraction weights for troubleshooting purposes.

GHOST has been designed as an extremely stable instrument, simplifying the data reductions.

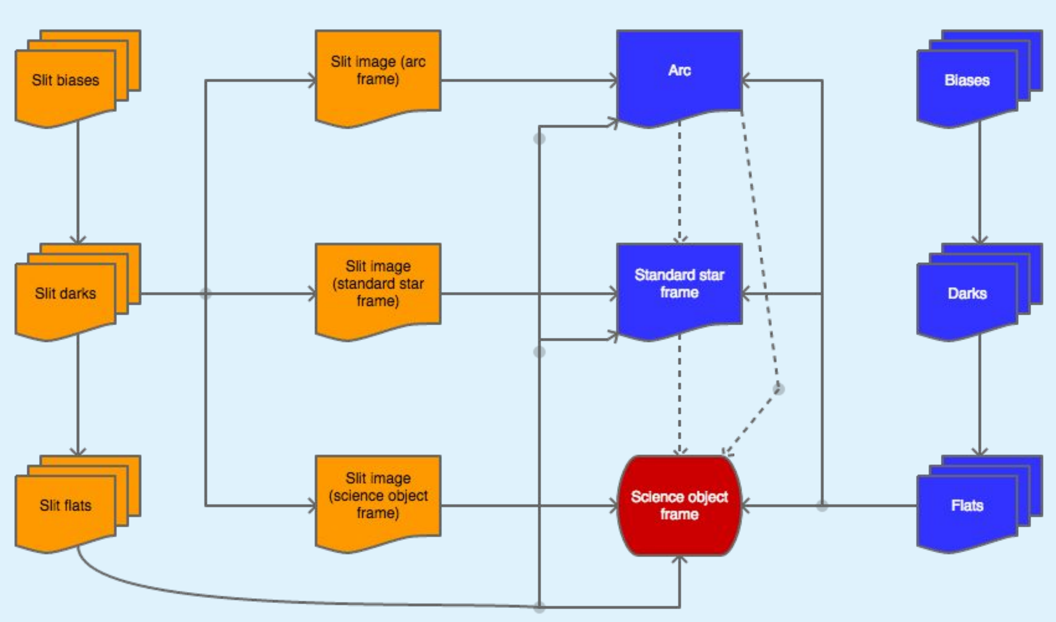

Fig. 1: GHOSTDR processing flowchart managed by dedicated recipes for each image type.

A case study: The solar spectrum

- Data taken on May 25, 2022 shown in Figs. 2-4.
- Sunlight directed onto an IFU before installation of the outer enclosure.
- Image reduced using GHOSTDR with new order tracing and wavelength solution using a ThXe arc spectrum taken the same day.

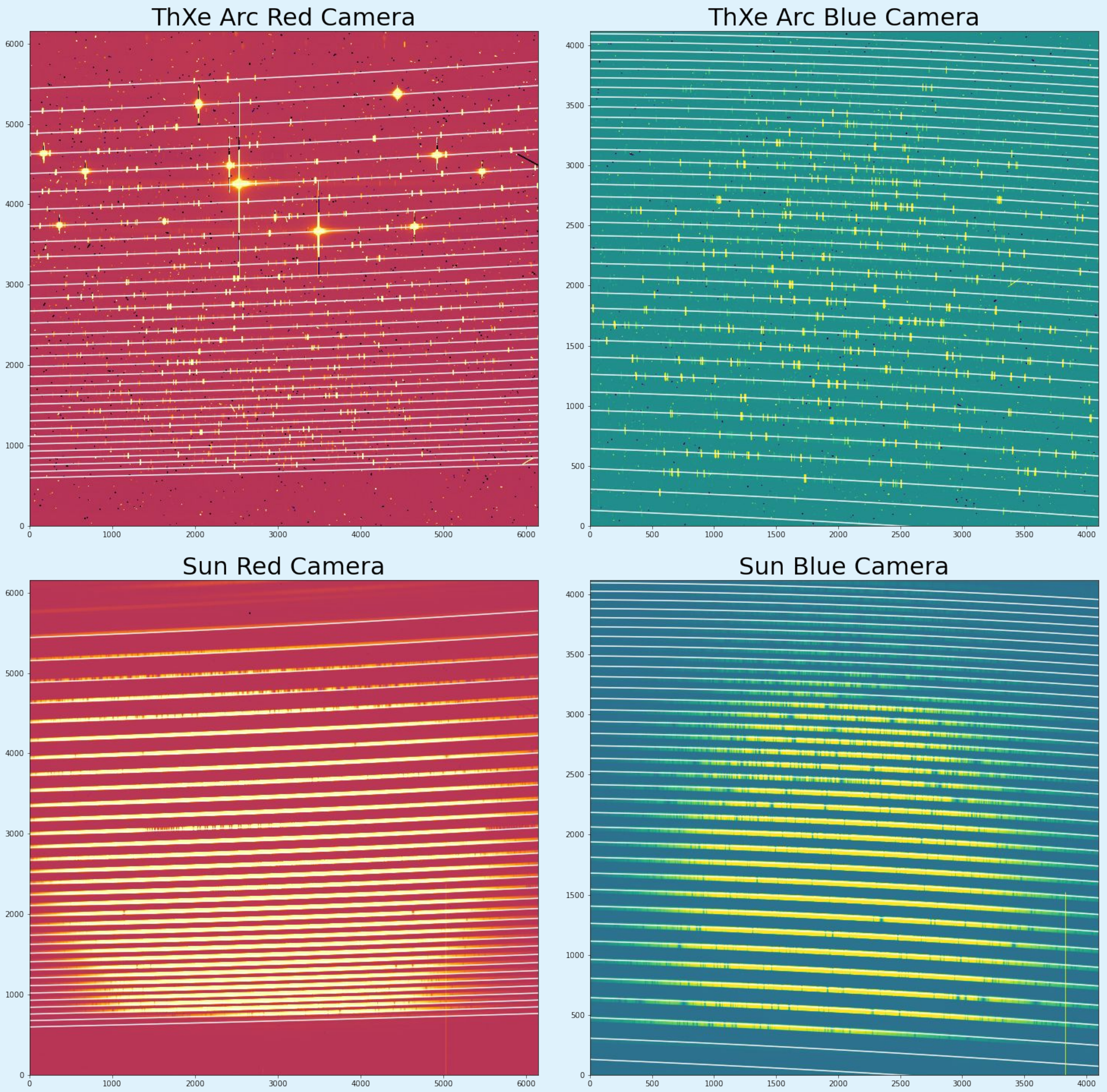

Fig. 2: Reduced and tiled images from the red and the blue cameras, for a ThXe arc lamp (top) and the Sun (bottom). White lines show the traces for orders 34-65 in the red (central wavelengths of 1014- 531 nm, respectively) and 63 (partial order)-98 in the blue (central wavelengths 546-351 nm, respectively). The bluest orders will suffer additional losses when GHOST is mounted on Gemini-S (due to Al coatings and reflective losses).

Extracted 1D solar spectrum

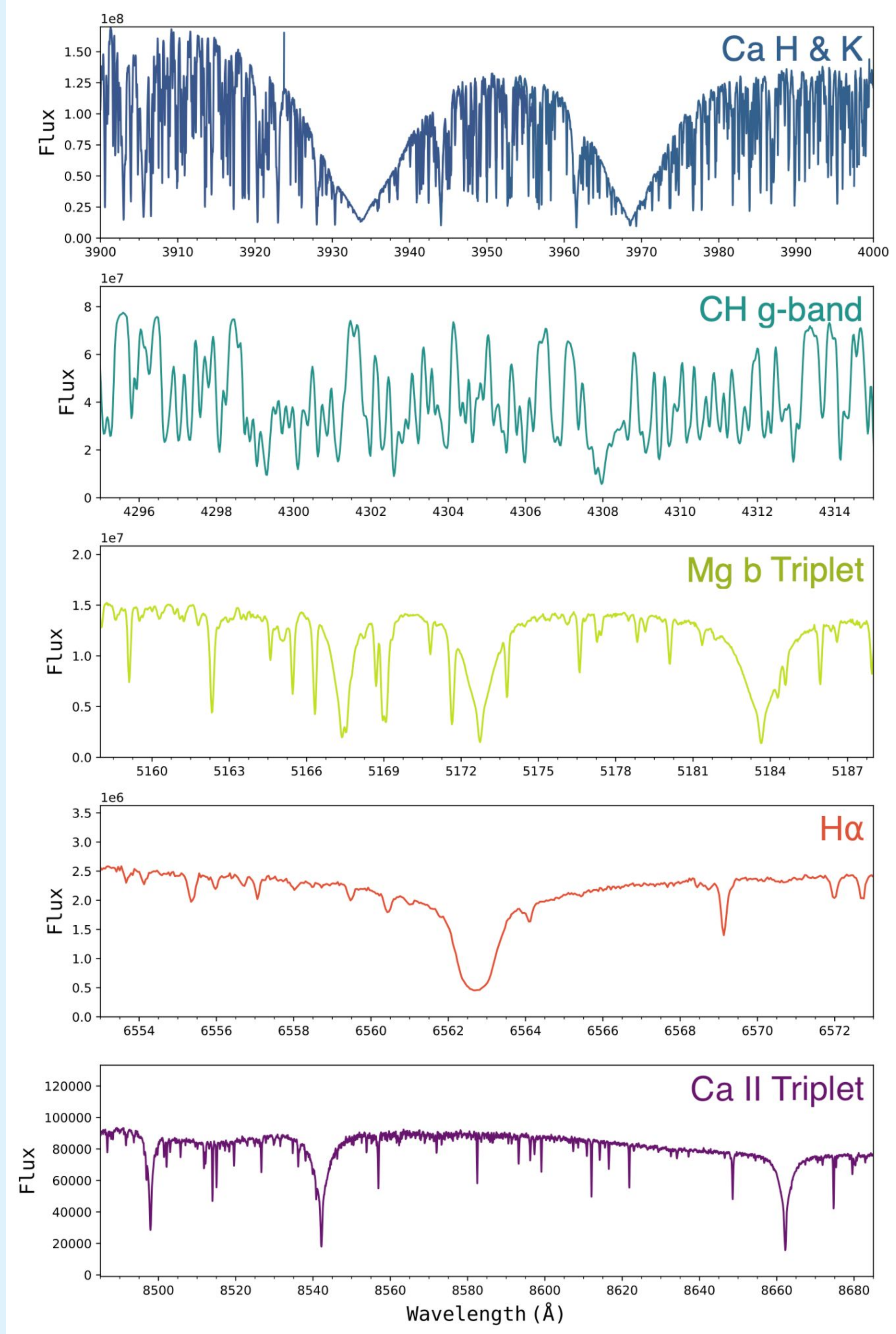

Fig. 3: Samples of the GHOSTDR extracted 1D solar spectrum. Strong Fraunhofer and weaker atomic lines shown. Full wavelength coverage is 348 to 1030 nm, with optimal sensitivity from 363 to 950 nm.

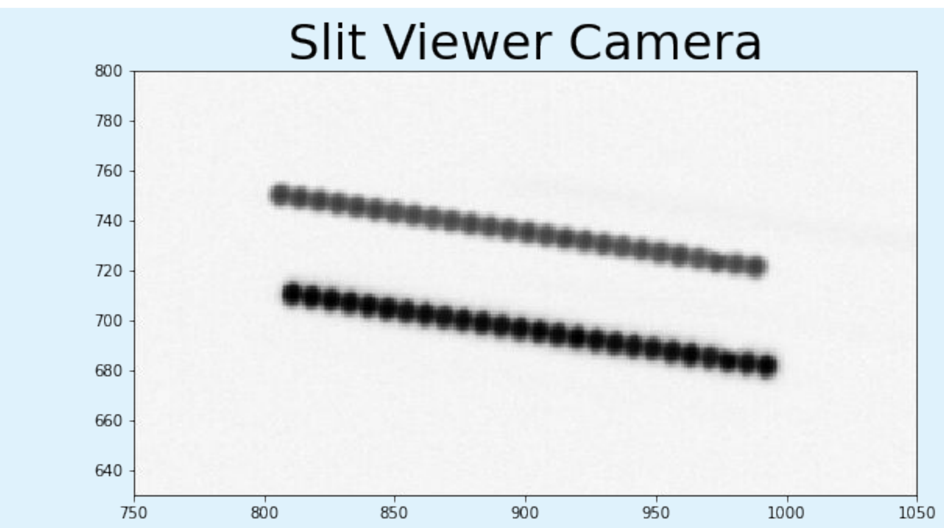

Fig. 4: Portion of the sllit viewing camera showing the red (bottom) and blue (top) images of the pseudo-slit, constructed from the reassembled fibers in the IFUs. Image taken with a 100W Quartz Halogen lamp.

Post-Commissioning

- GHOST commissioning in June 2022
- Integration into the Gemini Observatory DRAGONS framework
- Updates to work with Gemini South's GCAL calibration lamps (ThAr. CuAr)
- Noise-reduction, continuum normalization,flat field correction improvements.

[1]github.com/ANU-RSAA/GHOSTDR

[2]github.com/GeminiDRSoftware/DRAGONS (Data Reduction for Astronomy Gemini Observatory North South)