# D3.4 UTARTU Echelle Spectrograph Data Processing Pipeline

## EXOHOST

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# Document Control Page

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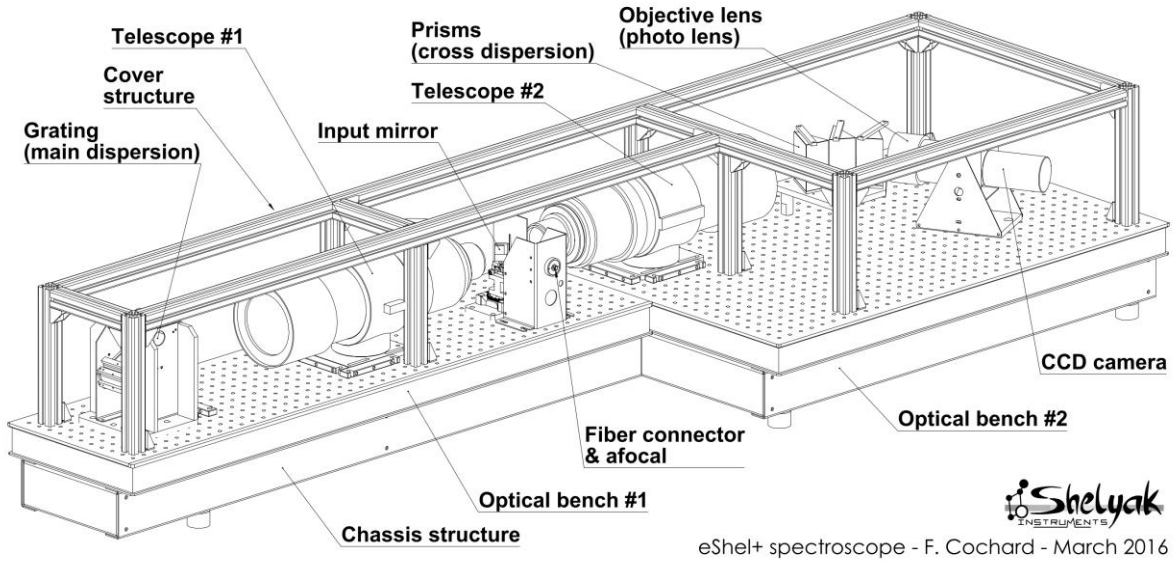
# 1 Introduction

Medium-to-high resolution echelle spectrographs (R ≳ 30 000) are essential to address a wide range of science cases, covering solar system, stellar, (extra-)galactic science and cosmology. In 2023, Tartu Observatory of the University of Tartu (UTARTU) acquired a new spectrograph, the Tartu Observatory Fibre-fed Echelle Spectrograph (TOFES). Installed in the Coudé room, TOFES will be connected to the 1.5-meter AZT-12 telescope via a four-channel instrument adapter at the Cassegrain focus. It provides an average spectral resolution of ~30 000 and covers the 390–900 nm wavelength range in a single exposure.




EXOHOST Task 3.3, *Design and development of the UTARTU echelle spectrograph pipeline*, was led by Uppsala University (UU) with essential contributions from the Space Research Institute of the Austrian Academy of Sciences (OEAW), and additional input from all partners. The resulting data reduction pipeline significantly strengthens UTARTU's capacity to exploit TOFES for high-quality research, ensuring that all stages of data reduction and preliminary analysis are reproducible, transparent, and accessible to the broader scientific community.

The aim of the pipeline is to automatically process spectroscopic observations obtained with TOFES and extract the best possible science data. To achieve this, we adopted PyREDUCE – the Python version of the REDUCE package (Piskunov & Valenti 2002, A&A, 385, 1095) developed at Uppsala University for echelle spectroscopy – adapted it for TOFES, and complemented it with a Python-based toolbox for preliminary data analysis.

# 2 Implementation

The implementation of the TOFES data reduction pipeline proceeded through four key stages. First, the UTARTU team received an introduction to REDUCE from its developer, Nikolai Piskunov (UU). This was followed by technical visits by Sandipan Borthakur (UTARTU and OEAW) and Tõnis Eenmäe (UTARTU) to Uppsala, where they learned the installation procedures, configuration requirements, and operational details of PyREDUCE. A final visit by Nikolai Piskunov to Tartu enabled the first on-site data reduction tests and validation of the pipeline setup. In parallel, work began on preparing a scientific article describing the new spectrograph and its data processing pipeline.

The implementation was delayed because the upgrade of the instrumentation at the 1.5 m AZT-12 telescope – carried out under a separate instrumentation development project – was not completed on schedule. As a result, the optical fibre interface required to connect TOFES to the telescope was not yet available, and the testing and commissioning observations had to be performed using a smaller auxiliary telescope. Due to this external delay, UTARTU requested an extension of the deadline for Deliverable D3.4 "*UTARTU Echelle Spectrograph Data Processing Pipeline*" from Month 24 to Month 36. This risk had been identified in the original project proposal.

# 3 Results

The adaptation of PyReduce for TOFES is now complete, and the operational software has been installed on a dedicated computer. The TOFES data reduction pipeline (TOFES-DRP), together with installation instructions, is publicly available at: https://github.com/Sandipan-Borthakur/TOFES-DRP.

A complementary Python package Spectroscopy-Toolbox was developed to support data diagnostics, developing linelists, and other analysis utilities, with the option to extend functionality as needed. The toolbox is publicly available with documentation and tutorials at: https://github.com/Sandipan-Borthakur/spectroscopy-toolbox

A detailed description of the new pipeline is presented in a paper submitted to *Publications of the Astronomical Society of the Pacific*:

**Borthakur et al.** "The Tartu Observatory fiber-fed Echelle Spectrograph (TOFES) Data Reduction Pipeline". The paper will be made available via arXiv and Zenodo upon acceptance.

## 3.1 Illustrations

Here are some illustrations of the intermediate reduction steps adapted from the submitted paper:

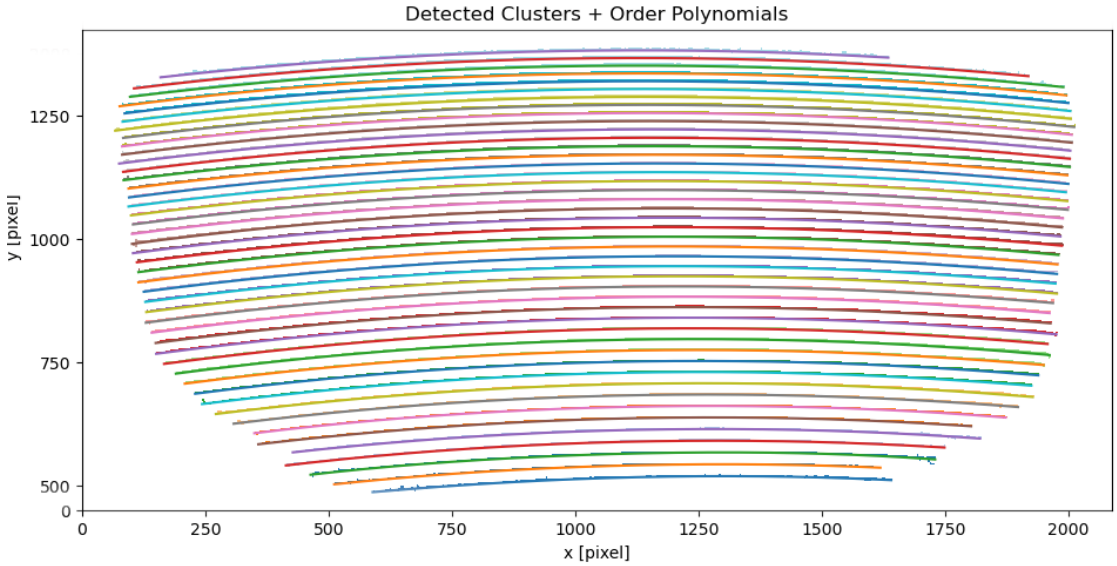



**Figure 1.** Automatic location of spectral orders.

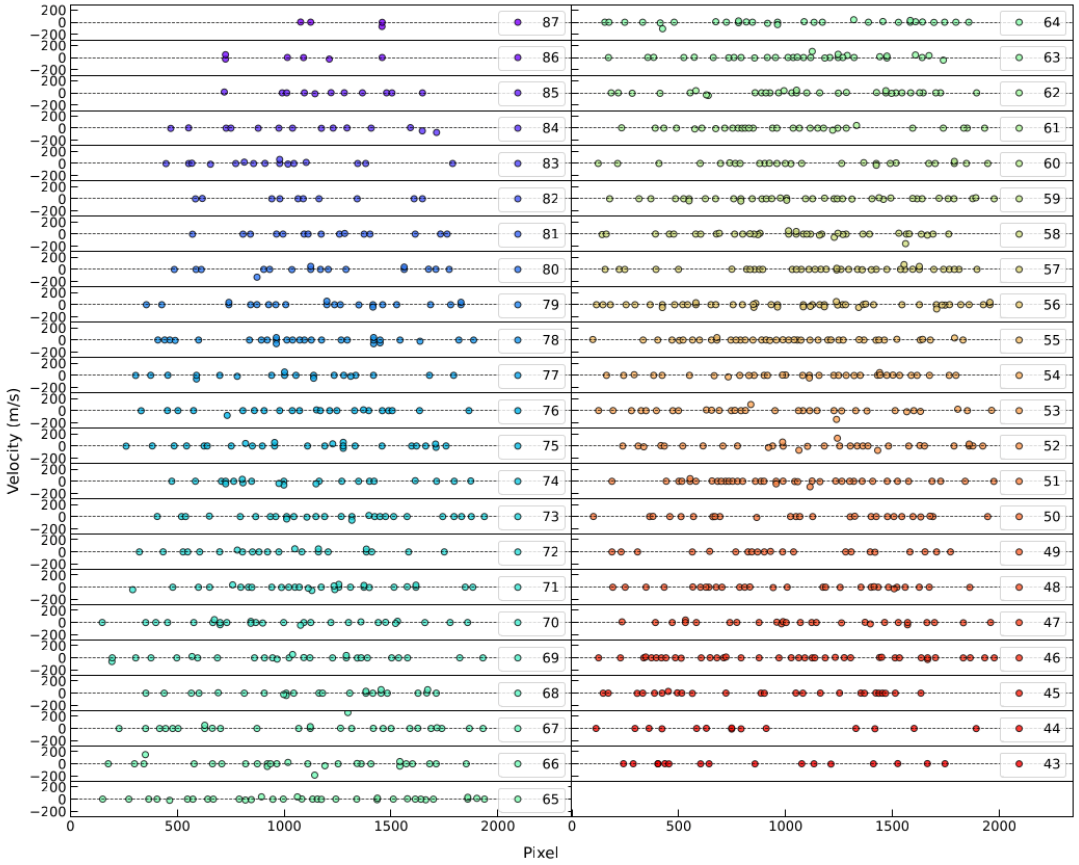



**Figure 2.** Construction of the wavelength solution based on the reference emission lines of ThAr lamp.

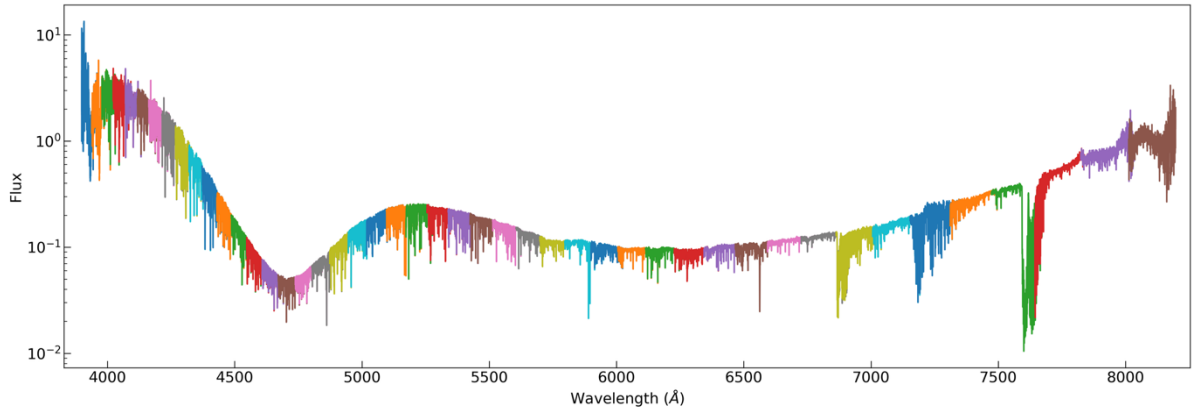



**Figure 3.** Final spliced spectrum of the Sun. Different colours show different spectral orders.

# 4 Conclusions

The TOFES echelle spectrometer is now equipped with a state-of-the-art, fully functional data reduction software capable of delivering the best scientific results from the science and calibration data collected with the new instrument. The software is well-tested, documented, and publicly accessible. The instrument is now ready for astronomical research.