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PyIRD: A Python-Based Data Reduction Pipeline for Subaru/IRD and REACH

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Summary

`PyIRD` is a Python-based pipeline for reducing spectroscopic data obtained with IRD (InfraRed Doppler; Takayuki Kotani et al. (2018)) and REACH (Rigorous Exoplanetary Atmosphere Characterization with High dispersion coronagraphy; T. Kotani et al. (2020)) on the Subaru Telescope. It is designed to process raw images into one-dimensional spectra in a semi-automatic manner. Unlike traditional methods, it does not rely on IRAF (Tody, 1986, 1993), a software used for astronomical data reduction. This approach simplifies the workflow while maintaining efficiency and accuracy. Additionally, the pipeline includes an updated method for removing readout noise patterns from raw images, enabling efficient extraction of spectra even for faint targets such as brown dwarfs.

Statement of need

The reduction of high-dispersion spectroscopic data has traditionally been performed using IRAF, one of the most widely used software tools for astronomical data reduction and analysis. However, the National Optical Astronomy Observatories (NOAO) officially ceased its development and maintenance in 2013. As a result, there is a growing demand for a modern, flexible solution.

`PyIRD` addresses this need and has already been utilized in several papers (Kawahara et al., 2024; Kawashima et al., 2024; Tomoyoshi et al., 2024).

Key Features

`PyIRD` is designed to perform data reduction semi-automatically by following a general workflow for high-dispersion spectroscopic data reduction, as illustrated in Figure 1.

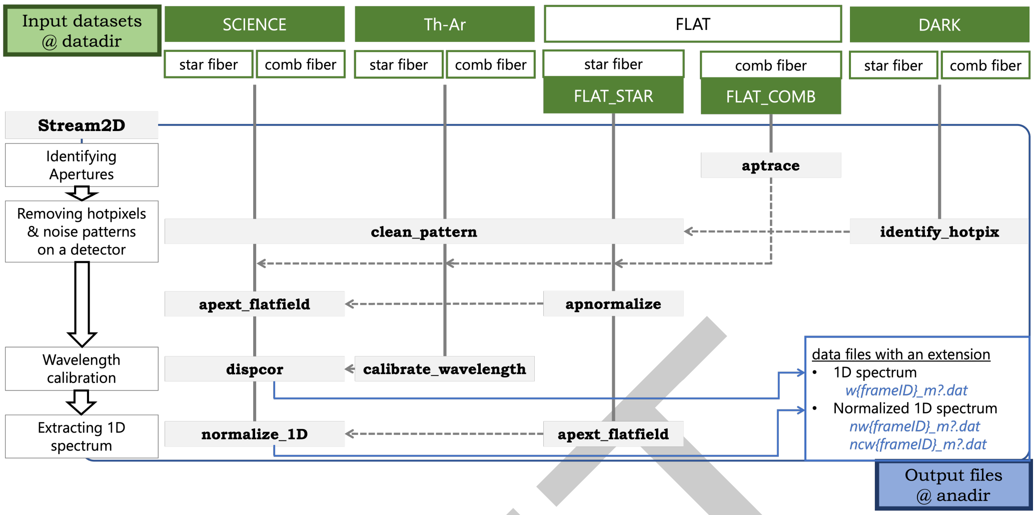

Figure 1: Flowchart of the reduction process for IRD and REACH data. The reduction process follows from top to bottom of this figure. Texts in the grey boxes represent instance names of each reduction step used in `PyIRD`.

Users can define a set of FITS-format files using a Python class named `FitsSet`, and functions in the `Stream2D` class are applied to generate the one-dimentional spectrum. Since all functions in `PyIRD` are written in Python rather than IRAF's subset preprocessor language (SPP), the package is easy to develop and maintain. This also significantly reduces the time required for the reduction process: users only need to execute a single Python script without complex IRAF configuration. For example, reducing data with `PyIRD` typically takes a few tens of minutes to produce one-dimensional spectra from raw data obtained during a single observing night, compared to approximately half a day with traditional IRAF methods.

Moreover, `PyIRD` achieves a higher level of readout noise pattern removal on final results. This feature is particularly important for processing data from faint objects such as brown dwarfs, where the astronomical signal is often comparable in strength to systematic noise. The dominant noise source is the readout pattern from the H2RG detector used in IRD. To address this, `PyIRD` models the noise by calculating a median profile for each readout channel and applying a 2D Gaussian Process using `gpkron` (Kawahara, 2022). This innovative method effectively mitigates the readout pattern, as shown in Figure 2, and improves data quality for faint targets.

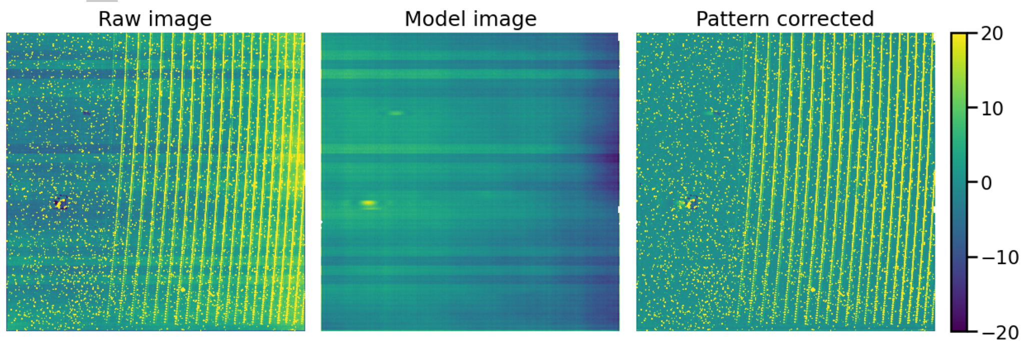

Figure 2: (Left) Raw image; (Middle) Readout pattern model created by `PyIRD`; (Right) Pattern-corrected image

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