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# HUSTLE-tools: A One Stop Shop For Hubble WFC3-UVIS/G280 Spectral Reduction

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## Summary

Fully understanding the complex physical and chemical processes that shape exoplanet atmospheres requires the complete spectrum from the ultraviolet (UV) to the mid-infrared (IR). In particular, UV-optical observations have proven vital for identifying UV-absorbing atmospheric species (e.g. Lothringer et al., 2022), detecting atmospheric escape (e.g. Bourrier et al., 2018), and constraining the presence of aerosols through their opacity and enhanced scattering of UV-optical light (Ohno & Kawashima, 2020).

The Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3) UV Imaging Spectrograph (UVIS) G280 grism is the only low-resolution spectrograph that gives us access to UV-optical wavelengths (0.2–0.8 microns) simultaneously. With most current instrumentation operating in near- and mid-IR wavelengths, and UV successors to HST still many years away, HST WFC3-UVIS/G280 emerges as the only instrument capable of unveiling the physics and chemistry that takes place in the upper atmospheric layers of exoplanets. Developed in the context of the Hubble Ultraviolet-optical Survey of Transiting Legacy Exoplanets (HUSTLE, GO-17183 PI: Wakeford), HUSTLE-tools is an open-source package of modules designed to easily download, organize, analyze, clean, and extract the target spectra from HST WFC3-UVIS/G280 spectral images.

## Statement of Need

While HST WFC3 has been operating since 2009, the WFC3-UVIS/G280 mode saw limited use until the recent surge of applications to transmission spectroscopy of exoplanets (Lewis et al., 2020; Wakeford et al., 2020). Most current HST WFC3 pipelines (e.g. Bell et al., 2022; Brammer, 2023; Zieba & Kreidberg, 2022) only service WFC-IR spectroscopy. Existing software tools for WFC3-UVIS data reduction are many years out of date (e.g. Sosey et al., 2023), restricted by licensed software such as IDL (e.g. Lusso et al., 2018; O'Meara et al., 2011), or not specialized for use with this detector (e.g. Radica, 2024). HST WFC3-UVIS/G280 observations offer unique challenges in extracting spectral information: a curved spectral trace with a varied width, overlapping spectral orders, and high cosmic ray counts. These are in addition to potential variations in spectral extraction based on the use of different sub-array sizes and positions on the detector for each observation. Such challenges make current HST pipelines unsuitable for reducing UVIS/G280 observations, and therefore a specialized, up-to-date, and fully open source pipeline is needed.

## Design and Features

Similar to other HST and JWST pipelines (Bell et al., 2022; Radica, 2024), HUSTLE-tools is built in a modular fashion consisting of three stages. These stages encompass the different steps and subroutines necessary for data quality assessment, reduction, and spectral extraction:

- Stage 0: allows the user to download and organize the files included as part of a specific GTO program number and visit number within that program. The user is also prompted to examine their observation's direct photometric image (typically taken through the F300X filter) and locate the target star, which is necessary for accurate wavelength calibration in Stage 2. This stage can produce a "quick look" GIF file displaying all the downloaded G280 frames, intended to be used to diagnose potential errors during the observation.
- Stage 1: allows the user to perform a suite of cleaning operations on the data to treat cosmic rays, hot pixels, and background signal, as well as track the motion of the trace across the detector between frames. Cosmic ray rejection is handled through iterative rejection of outliers in pixel time series. Hot pixels can be removed through spatial median filters or by Laplacian edge detection (van Dokkum, 2001). Background treatments range from simple uniform corrections to subtraction of a scaled empirical G280 sky image (Pagul et al., 2023). Trace motion is tracked by proxy through measurement of the zeroth order X-Y position as well as background stars if available. The output of this stage contains the cleaned frames together with several auxiliary variables such as the image displacement in X and Y detector axes.
- Stage 2: allows the user to extract spectra from each image. The data are calibrated using the GRISMCONF package (Pirzkal, 2020), which offers wavelength solutions and trace positions for orders up to $+/-4$, although orders beyond $+/-1$ are usually negligible unless the target star is of spectral type A or earlier. Calibration accuracy for all orders is dependent only on the S/N and correct APT configuration of the direct photometric image of the target star. Spectral extraction can be performed using a standard unweighted aperture of uniform size, or via the optimal weighting method described in Horne (1986) and Marsh (1989). Cross-correlation can then be applied to the output spectra to correct for telescope drift. The output of this stage is the extracted 1D spectral timeseries, with a separate output provided for each order extracted.

Each run for each stage is defined through a ".hustle" configuration file, where all the parameters and variables needed to perform the stage subroutines are defined. For reproducibility, a copy of each configuration file is saved within the run's output directory. These files ensure that the user can always recreate a past result and facilitate comparing different runs.

Included tutorials and example scripts ensure HUSTLE-tools can be run with minimal prior experience in pipeline development and operation. The modular and user-friendly design of HUSTLE-tools permits users to fine-tune their reduction to obtain optimal results. Users can toggle and tweak their desired processes within each stage and can easily rerun stages to explore different reduction techniques.

HUSTLE-tools is built from the 'Hazelnut' pipeline presented in (Boehm et al., 2025) and the 'Iluvia' pipeline presented in (Gascón et al., 2025).

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and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee as part of an ERC Starting Grant [grant number EP/Y006313/1]. This work benefited from the 2024 Exoplanet Summer Program in the Other Worlds Laboratory (OWL) at the University of California, Santa Cruz, a program funded by the Heising–Simons Foundation and NASA. HUSTLE-tools makes use of the following software dependencies: - SciPy: (Virtanen et al., 2020) - NumPy: (Harris et al., 2020) - Xarray: (Hoyer & Hamman, 2017) - astroquery: (Ginsburg et al., 2019) - Astropy: (Astropy Collaboration et al., 2013, 2018, 2022) - photutils: (Bradley et al., 2024) - Matplotlib: (Hunter, 2007) - tqdm: (Da Costa-Luis et al., 2021) - grismconf: https://github.com/npirzkal/GRISMCONF - WFC3TOOLS: https://github.com/spacetelescope/wfc3tools - `jwst`: (Bushouse et al., 2025)

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