NIRISS SOSS Time-Series Observations of HAT-P-1

Example Science Program #31

This example science program provides a walk-through of a JWST observing program using the NIRISS Single Object Slitless Spectroscopy mode to make Time Series Observations. The example used will be the exoplanet transit of HAT-P-1b, focusing on overarching science goals from the GTO program "NIRISS Exploration of the Atmospheric diversity of Transiting exoplanets (NEAT)" for context, determining exposure times required to meet the science goals through the Exposure Time Calculator Old and PandExo tool, and setting up the observation templates in the Astronomers Proposal Tool.

> *Main article: NIRISS Single Object Slitless Spectroscopy, NIRISS SOSS Recommended Strategies, NIRISS-Specific Time Series Observations*
> *See also: Step-by-Step ETC Guide for NIRISS SOSS Time-Series Observations of HAT-P-1, Step-by-Step APT Guide for NIRISS SOSS Time-Series Observations of HAT-P-1*

NIRISS Exploration of the Atmospheric diversity of Transiting exoplanets (NEAT) program is a GTO program designed to study exoplanet atmospheric composition, energy budget, and dynamics. The main science goal is to obtain NIRISS single object slitless spectroscopy (SOSS) transit observations of a sample of 14 exoplanets. These targets span a temperature range from 300 – 3000 K and mass range from 1 Earth to 2 Jupiter masses. By spanning a range of both temperatures and masses, the NEAT program will consider a large span of planet formation and evolution regimes.

The NIRISS SOSS mode is designed to obtain spectra in the 0.6 – 2.8 µm wavelength range for a single source on the NIRISS detector. SOSS disperses the light both spectroscopically and spatially—to optimize for bright object time series observations—using the GR700XD grism coupled with a cylindrical lens. Because SOSS requires all TSO observations to be taken on the same pixels for maximum reproducibility over the lifetime of the mission, a target acquisition is required for all SOSS observations observed with a subarray (and strongly encouraged in full frame readout mode) to accurately position the source on the detector.

NIRISS SOSS is the only JWST observing mode that permits slitless spectroscopy between 0.6 and 2.8 µm and is thus well-suited to characterize exoplanet atmospheres. Five molecules of interest in exoplanet atmospheres (water, carbon monoxide, hydrogen cyanide, methane, and ammonia) are expected to show significant spectral features in the SOSS wavelength range—depending on atmospheric pressure and temperature. The spectroscopic resolution (R ~ 700 at 1.25 µm) and large cross-dispersion (which minimizes systematic errors) make SOSS optimal for exoplanet observations because the signal-to-noise ratios (SNR) of the host stars is greatest at lower wavelengths, enabling better precision in the measurement of exoplanet atmospheres.

The scientific measurement for an exoplanet transit is the "transit depth", which is a temporal measurement. The spectroscopic result is therefore a relative comparison between a contiguous sequence of time-series measurements – i.e. transit depth over wavelength. It is equivalent to measuring variations in the stellar spectrum over time.

Our goal in this example is to achieve a relative precision of <50 parts per million (ppm) on the transit depth per "spectral bin" or "channel," after subtracting the primary transit from the out-of-transit data. Atmospheric models predict that this should provide a useful signal-to-noise on the exoplanet atmospheric spectroscopic signal (~100-250 ppm). A "spectral bin" or "channel" is a set of pixels across the spectrum that we will combine ("bin") to maximize the temporal precision per spectroscopic channel.

To maximize the relative precision between the in-transit and out-of-transit flux (over time), we need to observe the science target long enough to observe the transit, plus a window of time before and after the transit. For this source, the transit duration is 2.784 hours. We will therefore choose a transit window of 9.352 hours (33667.199 s), which is 3 times the transit duration + 1 hour – for "detector settling" (see Noise Sources for Time-Series Observations).

The Step-by-Step ETC Guide walks the user through navigating the JWST Exposure Time Calculator (ETC) to determine exposure parameters appropriate for the science goals for this program, providing a conservative average SNR estimate.

The Step-by-Step PandExo Guide provides a more robust spectroscopic SNR estimate, using the same calculation engine as ETC (Pandeia).

The Astronomer Proposal Tool (APT) is used to submit JWST proposals. The Step-by-Step APT Guide provides instructions for filling out the APT observation templates. The exposure parameters determined by the ETC are specified in the APT observation template.

Continue the tutorial:

- Step-by-Step ETC Guide (conservative, average SNR estimate)
- Step-by-Step PandExo Guide (robust, spectroscopic SNR estimates)
- Step-by-Step APT Guide