The JWST Tunable Filter Imager and its Calibration

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Abstract. The JWST Tunable Filter Imager (TFI) is a sensitive camera that shares the optical bench of the Fine Guidance Sensor (FGS). It provides JWST with the capability of imaging a $2.2' \times 2.2'$ field-of-view through narrow-band filters over a wavelength range of $1.5 - 5.0 \ \mu\text{m}$, with a non-functional region between 2.5 and 3.2 μm . The narrow-band filters are characterized by spectroscopic resolving powers of ~ 75 to ~ 120 for central wavelengths selected by the user. The TFI is also capable of high-contrast imaging with a choice of four coronagraphs and an aperture mask. Here, we provide a brief summary of the technical specifications and scientific capabilities of the TFI and present an overview of the upcoming ground calibration and on-orbit commissioning activities.

1. Description and Capabilities

The primary components of the integrated TFI are identified in Fig. 1 (left panel) and the optical layout is shown schematically in Fig. 1 (right panel). The overall characteristics of the instrument are summarized in Table 1. The heart of the TFI is a Fabry-Pérot etalon (Fig. 2, left panel). It consists of a pair of flat, semi-transparent surfaces that are held parallel to each other under active control. After multiple reflections within the etalon cavity, only those wavelengths that interfere constructively are transmitted. By changing the spacing ("gap") of the etalon, the wavelength of constructive interference at some reference position (e.g., the optical axis of the instrument) can be tuned to any desired value within the functional wavelength range. Since the response of an etalon is periodic, a blocking filter (in the Filter Wheel; Fig. 3, right panel) is moved into the light path to reject light from adjacent orders of interference.

The operational wavelength range of the TFI is $\sim 1.5 - 5.0 \ \mu\text{m}$ but there is a nonfunctional region over $\sim 2.5 - 3.2 \ \mu\text{m}$. This region is unusable for scientific observations. The TFI will be routinely operated in the third order on the blue side of this region and in

Table 1: TFI Characteristics

| Imaging | Wavelengths: $1.5 - 2.5 \ \mu \text{m}$ $3.2 - 5 \ \mu \text{m}$ | Full FOV: 2.2' × 2.2' Bright-object subarrays: 16² to 512² pixels High angular-resolution imaging: 7-hole aperture mask with non-redundant spacing that provides 75 mas resolution at 4.6 μm | |
|--------------|--|--|------------------------------|
| Coronagraphy | Occulters: 0.58", 0.75", 1.5", 2.0" | Lyot masks: MASK21, MASK66, MASK71 | $20'' \times 20''$ subarrays |
| Detector | Dark rate: | Noise: | Gain: |
| (HAWAII-2RG) | $< 0.0137 \ e^{-}/{ m sec}$ | $23 \ e^- \ (\text{CDS})$ | $1.5 \ e^{-/DN}$ |
| Filter Wheel | Blocking filters: | | |
| | 1-F158M, 2-F175M, 3-F200M, 4-F229M, 5-F246M, 6-F349M, | | |
| | 7-F425M, 8-F470M, 9-CLEAR | | |
| Pupil Wheel | 1-MASK21, 2-CLEAR, 3-FLAT, 4-LINE, 5-MASK71, 6-MASK66 | | |
| | 7-FND, 8-OPAQUE, 9-MASKNR | | |



Figure 1: Left: Light from the optical telescope element (OTE) is incident on the pickoff mirror (POM) and directed through the collimator, pupil wheel, filter wheel, etalon, camera, and onto the detector. Right: Optical layout of the TFI.



Figure 2: Left: The etalon in its mounting. The six cylindrical extensions house the piezoelectric actuators that control the spacing and parallelism of the etalon plates as part of an active feedback loop. Right: The TFI Dual Wheel assembly showing the Pupil Wheel. The Filter Wheel is on the opposite side.

the first order on the red side. Other orders can be accessed for engineering purposes. The resolving power of the TFI is ~ 100 over its full wavelength range.

The Pick-Off Mirror (POM) assembly includes a focus mechanism which can be translated with a stepper motor. The four coronagraphic occulters are engraved on the POM and are paired to three Lyot apodization masks located in the Pupil Wheel. Internal calibration units consist of miniature incandescent lamps mounted behind the Dual Wheel assembly. They produce internal flat fields through the FLAT element of the Pupil Wheel and monochromatic spots centered at five different reference wavelengths through the LINE element. The intensity level of the lamps is adjustable.

Astronomical sources can be imaged in narrow, user-selected bandpasses over the entire field-of-view (FOV) or in a suite of subarrays (bright objects, coronagraphic occulters, and aperture masking with the non-redundant mask (NRM)). The TFI science team will exploit all the capabilities of the TFI in their guaranteed observing time, which includes "First Light" programs such as the detection of high-redshift (z > 12) Ly α emitters and programs to characterize the assembly of galaxies and the orbits and atmospheres of exoplanets.

2. Ground Calibration

The primary goal of the ground-based calibration effort is to perform a comprehensive characterization of the TFI flight model which will serve as a baseline for on-orbit calibrations and data processing. This pre-launch verification of the performance of the instrument and its detector will provide a good understanding of the fully integrated instrument in a simulated on-orbit environment and will allow the acquisition of calibration files that would be difficult or impossible to obtain in orbit. It also permits the early detection, diagnosis, and resolution of problems, both with the hardware and the flight software.

The ground-based calibration of the TFI will make use of the large vacuum and cryogenic chamber at the David Florida Laboratory (DFL) in Kanata, Canada. In this chamber, the instrument will be subjected to the full range of temperatures that it will experience from launch to normal operation (35 - 40 K) at the L2 Lagrangian point. The external stimulus is provided by the Optical Ground Support Equipment (OGSE) built by ABB Bomem (Fig. 3). This apparatus can illuminate the detector with nine broad-band and/or monochromatic point sources over the detector's field-of-view.

A wide array of calibration items will be addressed in the final cryogenic calibration campaign of the TFI in the spring of 2011 when the instrument will be in its final flight



Figure 3: The OGSE consists of three arrays of telescopes that provide point-source illumination for the fields of view of the two Guider channels (top section; 16 telescopes) and the TFI (lower section; 9 telescopes). The assembly shown here resides inside the cryogenic vacuum chamber. Fiber optic cables couple each of the telescope to the light source, which is located outside the chamber.

configuration. The tests have been devised by the COMDEV, STScI, and U de M teams and will include: measurements of the detector dark current, noise, non-linearity and cross-talk, the transmission of the FLAT, LINE, and OPAQUE elements, the focus, and end-to-end system throughput; characterization of the detector persistence, the blocking filter profiles, the neutral density filter and the NRM; the acquisition of internal flat fields; the wavelength calibration of the etalon and measurement of its detuning and parallelism. A library of calibration reference files will be assembled from these activities to process the on-orbit science images through the JWST pipeline.

3. On-orbit Commissioning

The on-orbit commissioning of the TFI is scheduled over a six-month period immediately following launch. The commissioning will encompass a series of engineering and science activities to verify the integrity and performance of the instrument while it is cooling down and once it has reached its operating temperature. An aggressive plan is being devised to characterize fully the instrument in orbit. The plan may be augmented with programs that directly address issues or problems that were uncovered during the ground calibration at DFL. The activities will include: a basic checkout of the instrument electronics, calibration lamps, detector noise, dark current, and electronic gain; calibration of the etalon wavelength, control electronics, and detuning; adjustment of the focus; updates to the plate scale, geometric distortion, coordinate system, photometric zero-points, and location of the coronagraphic occulters; characterization of stray light contamination and PSF wings; verification of the coronagraph target acquisition and performance of the Lyot masks and the NRM. The Early-Release Observations will be taken as soon as feasible during commissioning, followed by the science programs of the TFI science team and of the guest observers in Cycle 1.