The Exoplanet Transmission Spectroscopy Imager (ETSI), a new instrument for rapid characterization of exoplanet atmospheres

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ABSTRACT

The Exoplanet Transmission Spectroscopy Imager (ETSI) amalgamates a low resolution slitless prism spectrometer with custom multiband filters to simultaneously image 15 spectral bandpasses between 430 nm and 975 nm with an average spectral resolution of R = λ/Δλ ≈ 20. This enables a new technique, common-path multi-band imaging (CMI), used to observe transmission spectra of exoplanets transiting bright (V<14th mag.) stars. ETSI is capable of near photon limited observations, with a systematic noise floor on par with the Hubble Space Telescope and below the atmospheric amplitude scintillation noise limit. We discuss the current status of the instrument optical and optomechanical design, detectors, control system, telescope hardware and software interfaces, data reduction pipeline, and upcoming science observations. ETSI requires only moderate telescope apertures (~2 m) and is capable of characterizing the atmospheres of dozens of exoplanets and other objects per year, enabling selection of the most interesting targets for further follow up with other ground and space-based observatories.

SCIENCE JUSTIFICATION

While thousands of exoplanets have been confirmed[1], only a small number of exoplanet atmospheres have been characterized[2]. ETSI was developed to enable rapid characterization of exoplanet atmospheres and other targets to identify interesting objects for follow up by larger ground and space-based observatories. We expect ETSI to contribute to three main areas.

Exoplanet Transmission Spectroscopy - ETSI spectral band filters coincide with spectral features of interest in exoplanet atmospheres. Specifically, ETSI transmission spectra measurements are sensitive to the presence of atoms (potassium and sodium), molecules (methane, water, and TiO), clouds, and aerosols in the exoplanet's atmosphere.

Occultation Spectroscopy - ETSI can measure the change in the system's color during occultation of an exoplanet or other low-mass companion (such as brown dwarfs). This provides an emission spectrum of the companion using a self-referencing differential photometric color measurement technique.

TESS TOI Follow up - ETSI is able to measure color changes during eclipses in these systems. The colors can be used to derive a temperature of the companion to quickly identify stellar companions in the TESS Object of Interest (TOI) data set. This provides a means to quickly identify (sub-)stellar impostors in the TOI database, and avoid more expensive radial velocity follow-up.

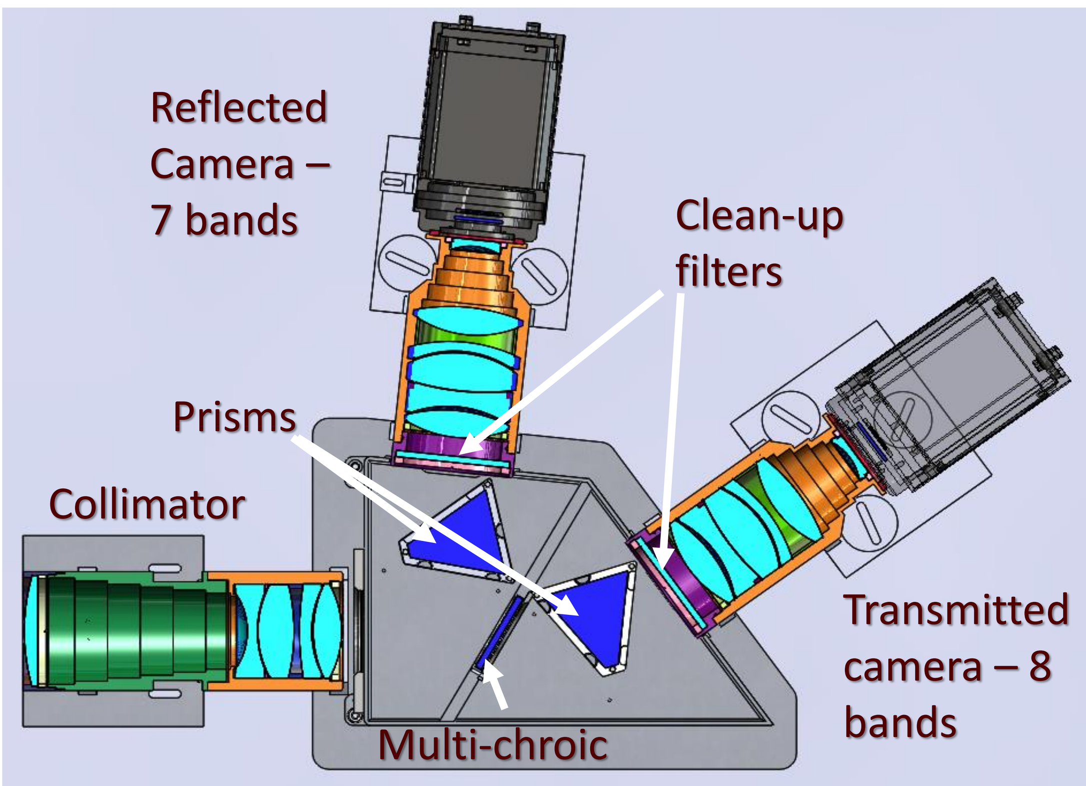

Figure 1. Section view of the ETSI optics and detectors. The telescope focal plane is to the left of the image. Light enters the collimator and is split into two channels by the multi-chroic which is located at the pupil. Identical prisms disperse the light which is then further filtered to sharpen the transmission cut on/off transitions and imaged with identical cameras onto sCMOS detectors.

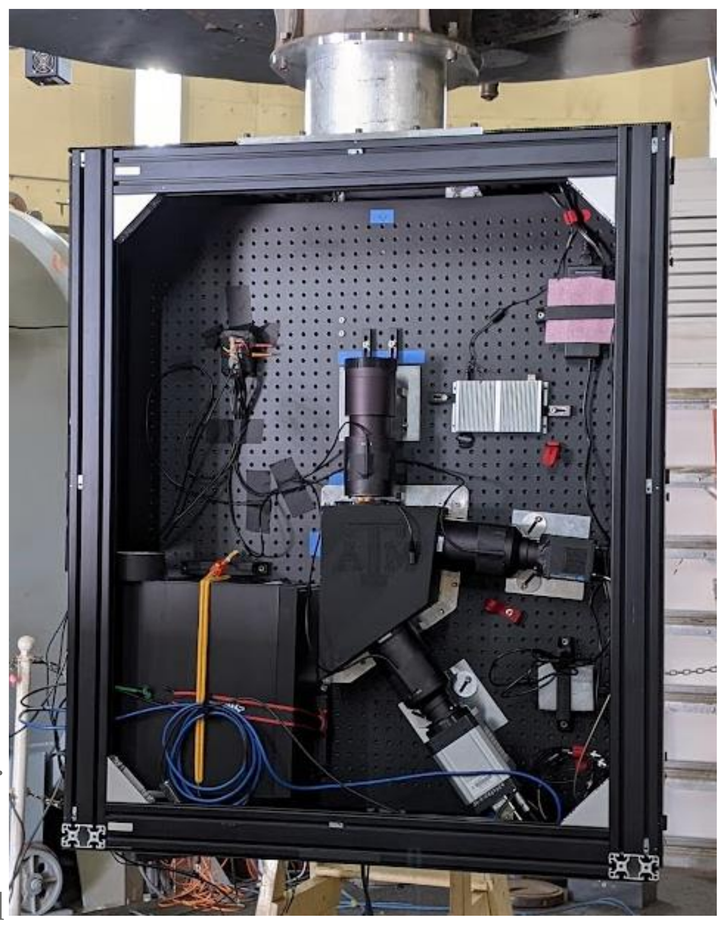

Figure 2. Inside the ETSI instrument enclosure. The collimator is in the center of the image, Octo-chroic and prisms are under the 3D printed cover with the reflected and transmitted camera optics and detectors located in the lower right corner of the image. A broken fiber optic communication cable required a last-minute mounting of the control computer inside the enclosure (lower left).

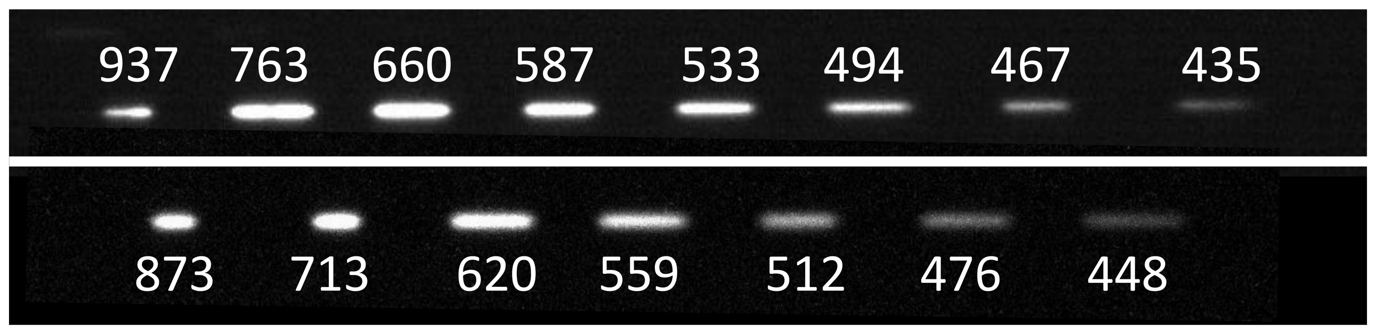

Figure 3. Images of an F-type star showing the 8 bandpasses from the transmitted channel (top) and 7 bandpass from the reflected channel (bottom), offset to show that when combined ETSI captures almost complete wavelength coverage from 430-975 nm. Bands are red to blue, left to right. Central wavelength given in nm above/below each band.

WHAT MAKES ETSI UNIQUE?

ETSI is based on traditional slitless spectroscopy, with a novel multi-band filter to split up each spectral band to enable quick, high precision PSF fitting photometry. This is more efficient and uncomplicated compared to traditional exoplanet transmission spectroscopy, which requires binning higher resolution spectra, wavelength calibration and spectral fitting techniques. The common path and simultaneous nature of ETSI observations mean that any instrumental or environmental common path errors, including atmospheric scintillation, are eliminated. By referencing one science star spectral band to another science star band, color changes over the course of a transit are detectable. The ETSI optical design was optimized for consistent imaging and through focus performance to minimize residual color errors during observation[3].

ENABLING TECHNOLOGIES

Two key components enable ETSI to make simultaneous photometric measurements in 15 filter bands with essentially zero time lost to image readout. The first is the multi-chroic, a multi-band interference filter produced by Alluxa Inc. In combination with the prisms and clean-up filters, this optic selects 8 well separated bands to be imaged by one channel and the interstitial bands are reflected to be imaged by the second channel. Up to the prisms, all light from a star follows a common path.

The detector systems for ETSI were chosen to be sCMOS. The combination of high sensitivity (peak QE >95%), low read noise (<2e-) and short readout time (20 ms) make them the preferred choice as CCD's have low observing efficiency due to the long readout times required to achieve low read noise and do not have the excess noise factor of EMCCD's.

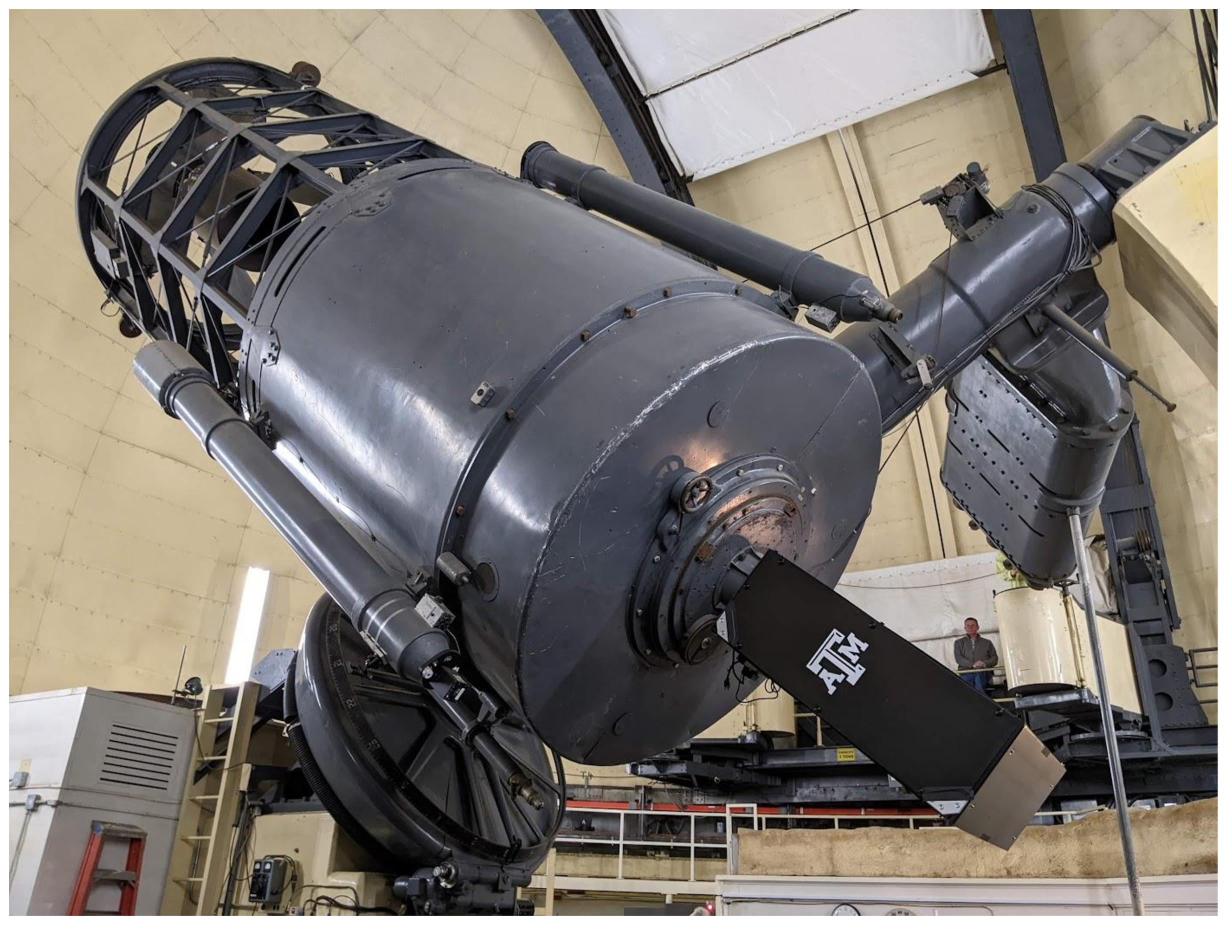

Figure 4. ETSI mounted to the Cassegrain focus of the McDonald Observatory 2.1 m telescope.

COMMISSIONING

ETSI had first light April 19-24, 2022 on the McDonald Observatory 2.1 m telescope with only the transmitted channel, allowing simultaneous photometry of eight spectral bands. Additional commissioning and science observations occurred June 6-21, 2022 and July 6-19, 2022 also on the McDonald Observatory 2.1 m telescope with both transmitted and reflected channels.

PRELIMINARY RESULTS

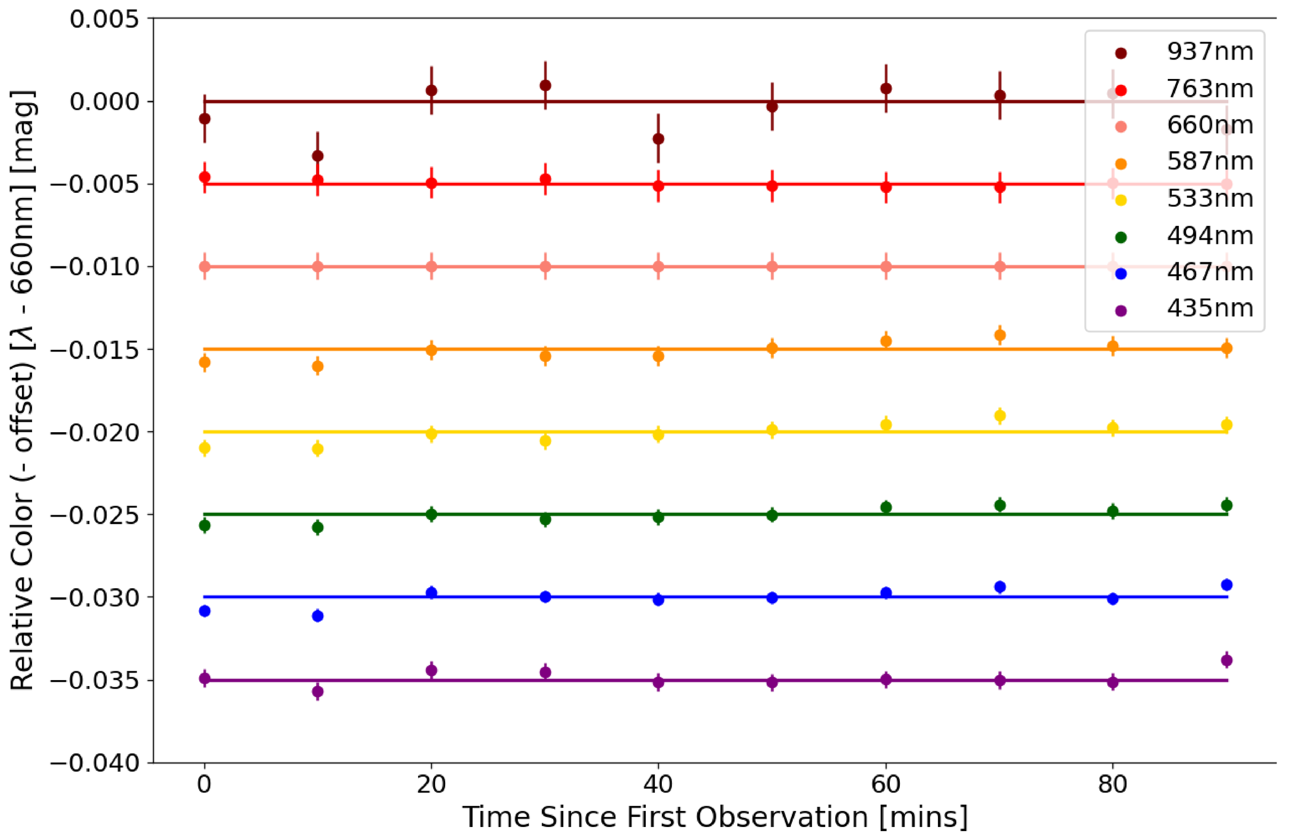

Figure 5. Light curve for the 8 transmitted bands over ~1.5 hours for HD 94883.

Light curves have been investigated for several objects using data obtained by the instrument during April 2022 commissioning. One such object, HD 94883 shown in Figure 5, is an A2 star observed at a cadence of 0.2 s over a baseline of ~1.5 hours. The change in magnitude for each bandpass was found to be consistent with a flat line (R^2~0), and the mean change in color of HD 94883 was found to be 0.05% over 90 minutes of observations, which is consistent with expectations and is expected to improve as the data reduction methods are finalized.

[1]https://exoplanets.nasa.gov/news/1702/cosmic-milestone-nasa-confirms-5000-exoplanets/ Accessed June 17, 2022
[2] Guillot et al. 2022, https://doi.org/10.48550/arXiv.2205.04100
[3]Limbach et al. 2020, https://doi.org/10.1117/12.2562371

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