The Exoplanet Transmission Spectroscopy Imager (ETSI)

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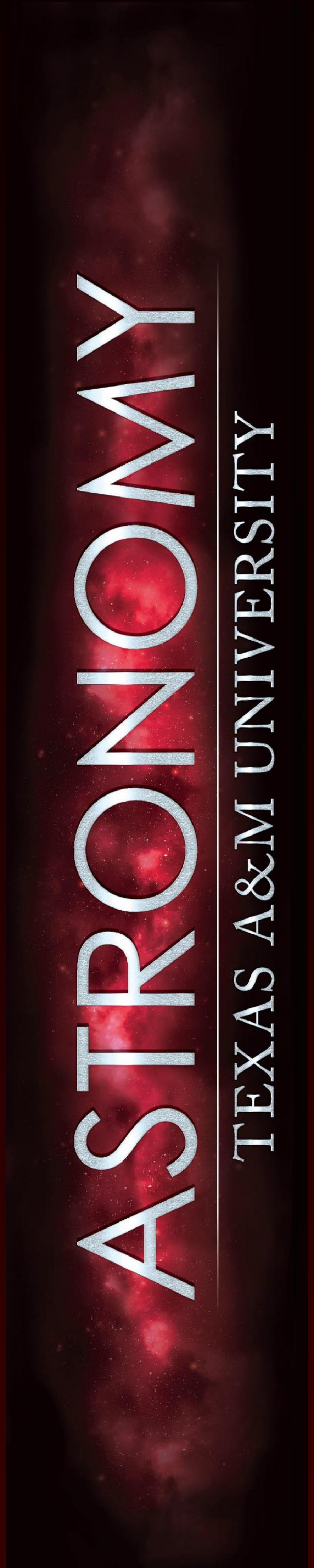

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ABSTRACT

We present the design of a novel instrument tuned to detect transiting exoplanet atmospheres. The instrument, which we call the exoplanet transmission spectroscopy imager (ETSI), makes use of a new technique called common-path multiband imaging (CMI). ETSI uses a prism and multiband filter to simultaneously image, on 2 detectors, 15 spectral bandpasses from 430-975nm (with an average spectral resolution of R=λ/Δλ=23) during exoplanet transits of a bright star. A prototype of the instrument achieved photon-noise limited results well below the atmospheric amplitude scintillation noise limit. We show the optical design of the instrument. Further, we discuss design trades of the prism and multiband filter which drive the science of the ETSI instrument. We describe the upcoming survey with ETSI that will measure dozens of exoplanet atmosphere spectra in ~2 years on a two meter telescope.

DESIGN OF ETSI

The Optical layout of ETSI is shown in Figure 1 and its design parameters are given in Table 1. ETSI makes use of a novel multiband filter.

ETSI Parameter	Value
Wavelength Range	430-975 nm
Spectral Resolution	λ/Δλ = 23
No. Spectral Bands	15
Field of View	7.5′ x 7.5′
Plate Scale	220 mas/pix
Photometric Accuracy (5σ, 30min, V = 7.5)	<200ppm

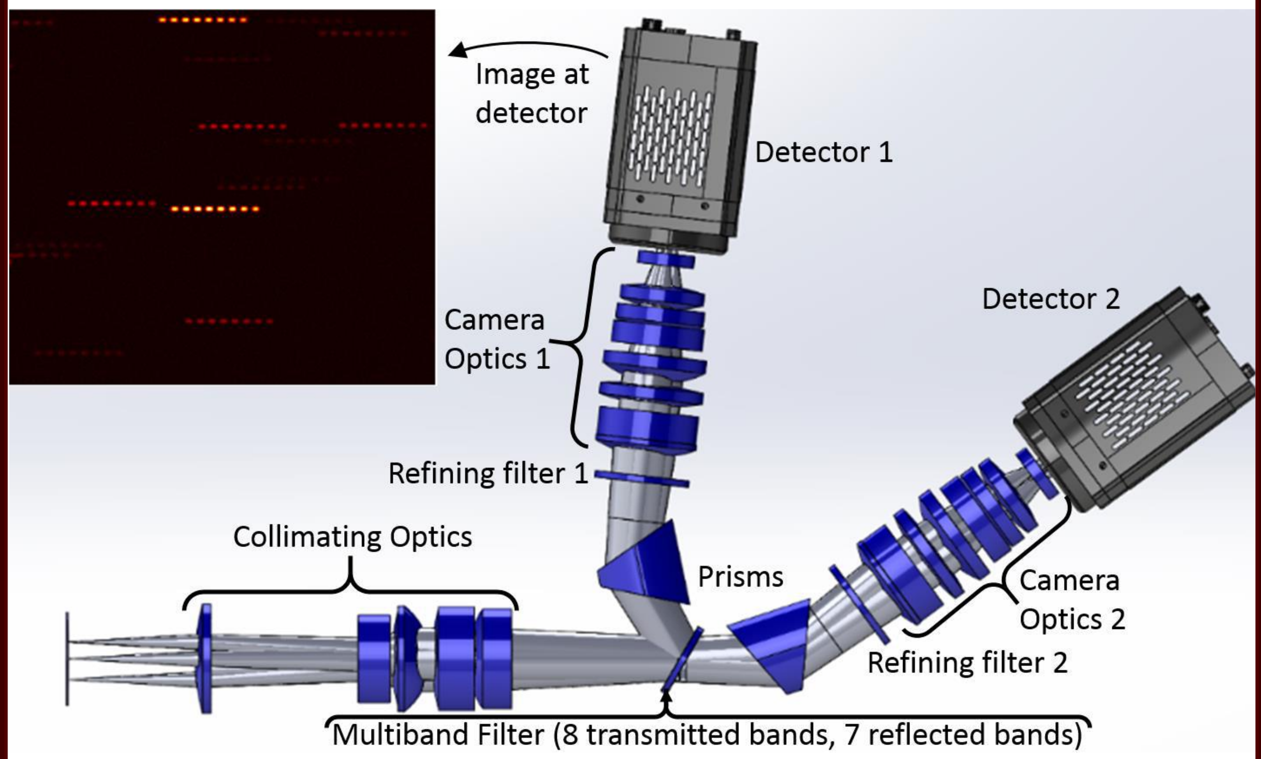

Figure 1. Optical layout of the ETSI instrument. The multiband filter splits seven and eight spectral bands into legs one and two of the instrument, respectively. The spectral bands are separated and further cleaned up by a second refining filter. An illustration of a 8-band image using the CMI method is shown in the upper left. Each line of 8 PSFs corresponds to one star in the field of view.

The multiband pickett fence filter, plus 2 downstream refining filters (all shown in figure 2) allow ETSI to image 15 spectral bands simultaneously on two detectors. ETSI's filter bands were chosen to allow for detection of various exoplanet atmosphere atoms, molecules and features, such as those shown in Figures 3 & 5.

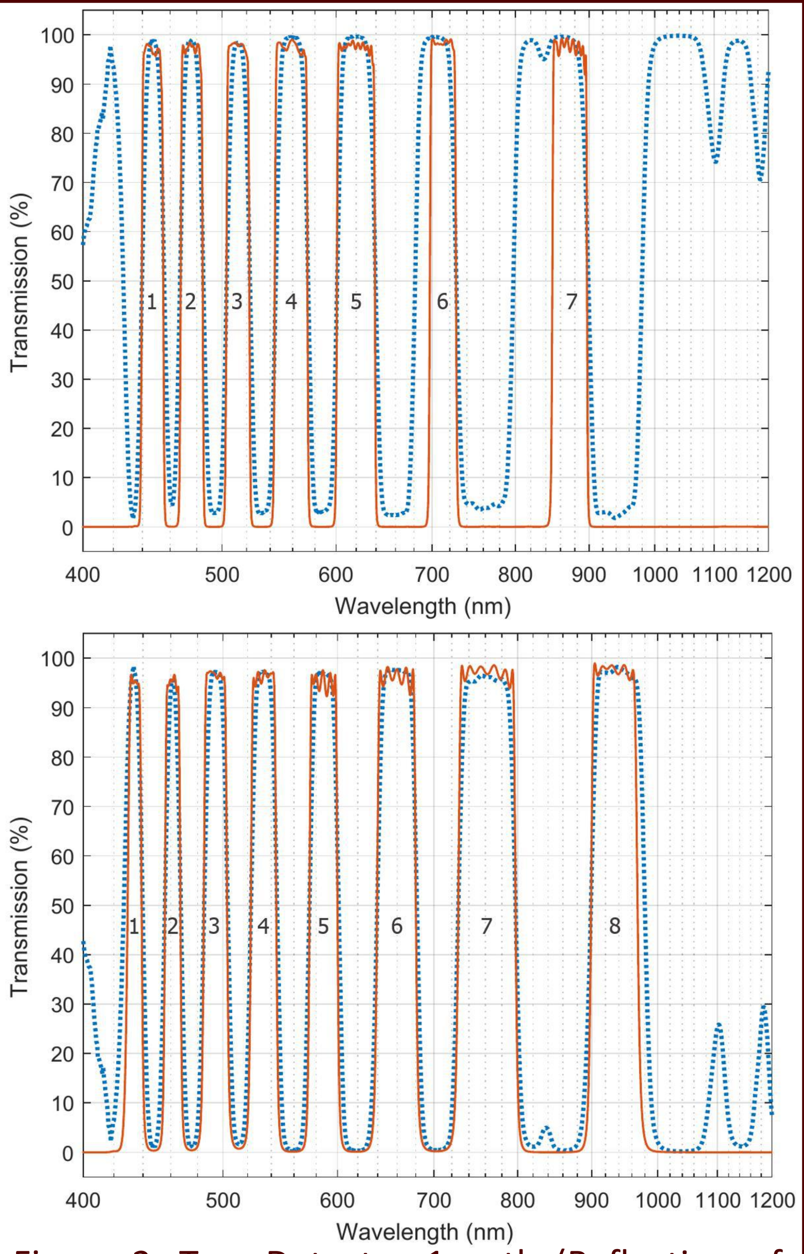

Figure 2. Top: Detector 1 path (Reflection of Octo-chroic and transmission of Filter 2). Bottom: Detector 2 path (Transmission of octo-chroic and Filter 3. ETSI bands are numbered.

ETSI's unique design enables band-to-band referencing which *eliminates achromatic systematic noise* (typically the dominant error source in exoplanet transmission spectrum measurements). For a more detailed explanation of how this is done see Limbach et. al 2021 in prep.

Figure 3 illustrates the spectral bands we chose for the ETSI instrument as well as some expected measureable atmospheric features in hot Jupiters.

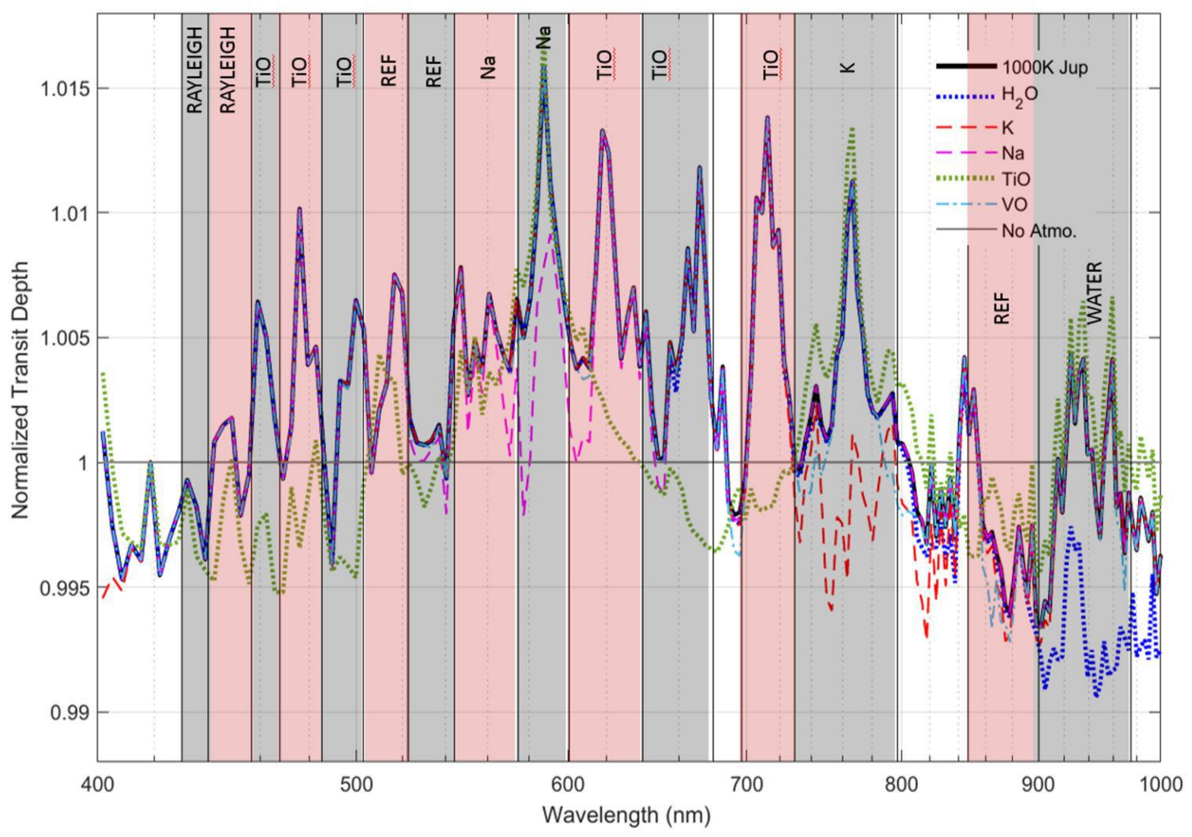

Figure 3. Spectrum of a hot Jupiter (T = 1000K), black line simulated with ExoTransmit (Kempton et al. 2016). Other colored lines are the same model with various species (see legend) removed to show their spectral contribution. The fifteen ETSI spectral bands are overlaid. The 8 gray bands are transmitted to detector 2 and the 7 pink bands are reflected to detector 1.

SCIENCE WITH ETSI

ETSI will measure the spectra of gas giant exoplanets. Figure 4 shows known transiting exoplanets (red dots) and TESS TOIs (blue dots) that can be characterized with ETSI on the 2.7m telescope at Mcdonald Observatory with an average signal-to-noise ratio >20 in each spectral band. There are 65 objects shown in Figure 4 which we intend to characterize with ETSI over the next two years. Figure 5 shows a simulated ETSI spectrum.

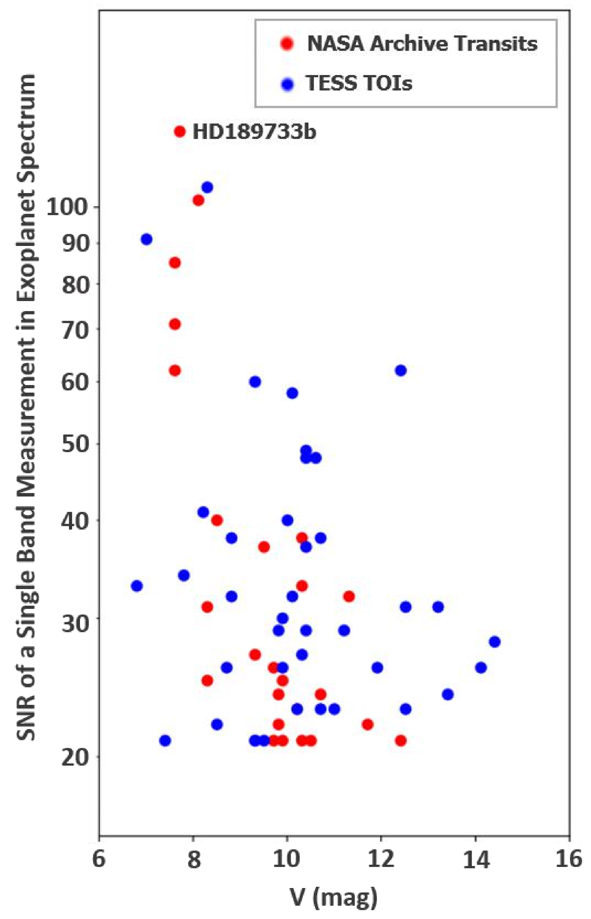

Figure 4. Objects to be surveyed with ETSI. SNR vs Stellar mag for known transiting exoplanets (red dots) and TESS TOIs (blue dots).

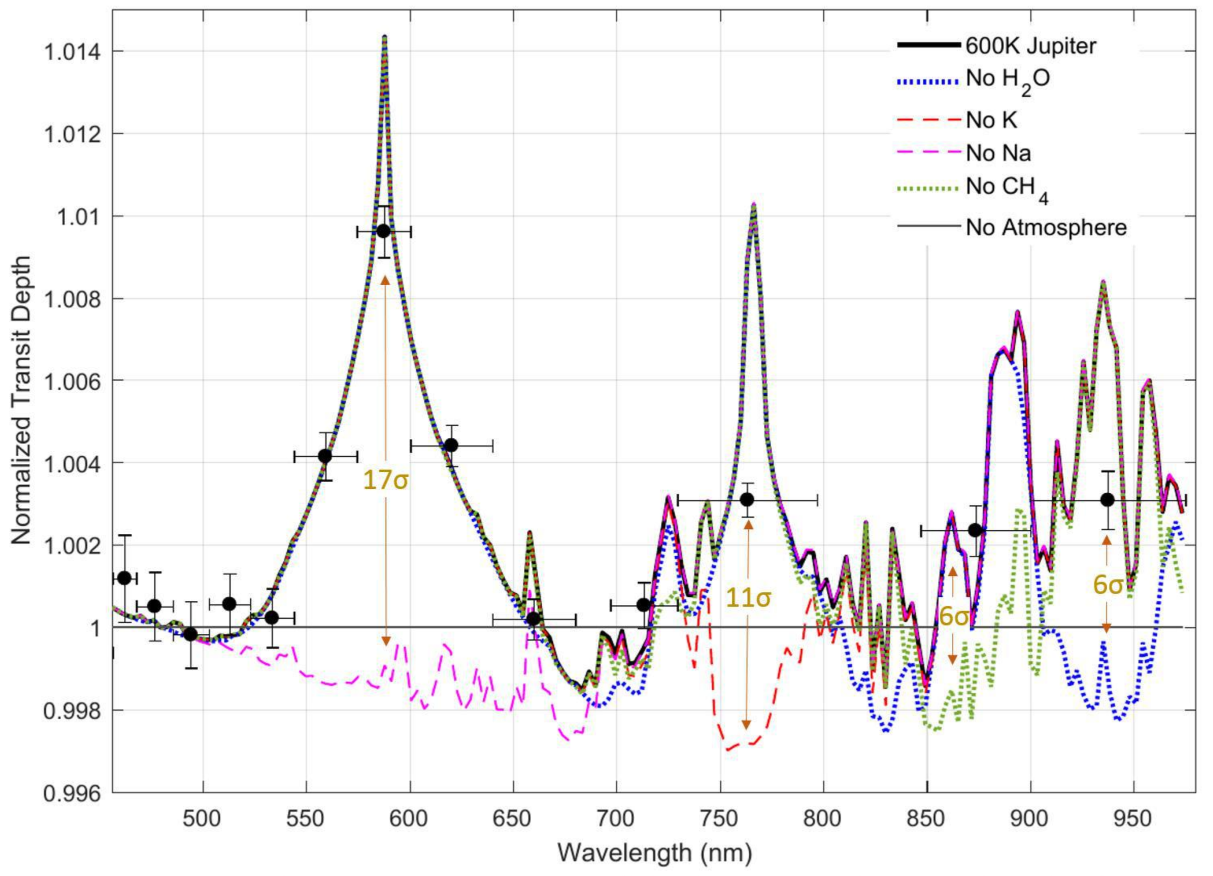

Figure 5. Simulated ETSI spectrum (black dots with error bars) of a R = R_J, T = 600K planet orbiting a V = 9 mag sun-like star. Lines on plot correspond to different atmospheric models: a nominal model (black line) and several models with various species removed (see legend) to illustrate their spectral imprint. Simulation assumes 2 hours of observations on a 2.7 m telescope during the exoplanet's transit. This figure illustrates that the four molecules/atoms (H_2O, CH_4, potassium and sodium) examined in this simulation are detectable with a signal-to-noise ratio > 5σ in only two hours.

CONCLUSION

We discussed the layout of the ETSI instrument and it's novel design. We demonstrated how ETSI can measure dozens of exoplanet transmission spectra. The ETSI survey will be the first of its kind capable of producing a large catalog of exoplanet spectra.

References: Kempton, E. M.-R. et al. 2016, arXiv:1611.03871
Limbach, M. A. et al. 2021, arXiv…

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