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ExoSim: a novel simulator of exoplanet spectroscopic observations

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Abstract

ExoSim is a new simulator of exoplanet transit spectroscopy incorporating instrument and detector models. It is designed to capture both random and systematic noise, producing realistic image outputs. It is generic, easily adapted for different instruments, with multiple potential applications, including the design of future instrumentation, planning of observations and validation of previously obtained spectra.

1. Introduction

Chracterisation of exoplanet spectra by transit spectroscopy requires observational precision of the order of 10^{-5} or better. In addition to photon noise from the source and astrophysical backgrounds, such observations will be subject to various other experimental uncertainties including detector and electronic noise, telescope thermal emission, spacecraft jitter and pointing strategy, and other systematics, the ensemble total of which may be difficult to determine analytically. We are developing an observation simulator – ExoSim – that incorporates models of the astrophysical scene, the instrument and the detector as well as multiple noise sources. It builds on the experience of EChOSim [1], but is intended to be more general and versatile in its application.

2. Structure

Using a modular structure (Figure 1), the simulator initially models the astrophysical scene, including the stellar spectrum, the planet-star contrast ratio, and the transit light curve. The telescope and optical channels are modeled and the spectral signal is modulated in multiple ways including by transmission through and emission from optical surfaces and convolution with the psf. A detector module simulates the pixel response function, dark current, quantum efficiency variability and other detector non-idealities.

It is also modulated in time to model either a primary or secondary transit. Various sources of noise are added including photon noise, pointing jitter, and read noise, as well contributions from zodiacal foreground, telescope and instrument emission, and dark current. Different observational modes can be applied and the output images and noise studied. We intend to add a stellar variability capability to simulate star granularity, pulsation and active regions.

3. Applications

Since the simulator will produce spectral images akin to those produced as the primary data product of the instrument being modeled (Figure 2), its output can be utilized generically by different data reduction methods and pipelines to assess the confidence level of retrieved quantities such as chemical abundances, temperature and pressure. It can be used ‘predictively’ to calculate signal/noise ratio and determine the instrument requirements and observation strategy needed to observe all kinds of transiting planets, including those in the habitable zones of late-type stars. It can be used ‘retrospectively’ to evaluate results from previous or existing instruments e.g. by performing Monte Carlo simulations, to determine the uncertainties on the emergent spectrum. We are applying ExoSim to future space-borne exoplanet instruments including Ariel, as well as to the Hubble WFC3 infrared instrument, which is currently used for exoplanet transit spectroscopy. Initial results are returning ‘white light’ photoelectron counts in agreement with those of published results [2].

4. Figures

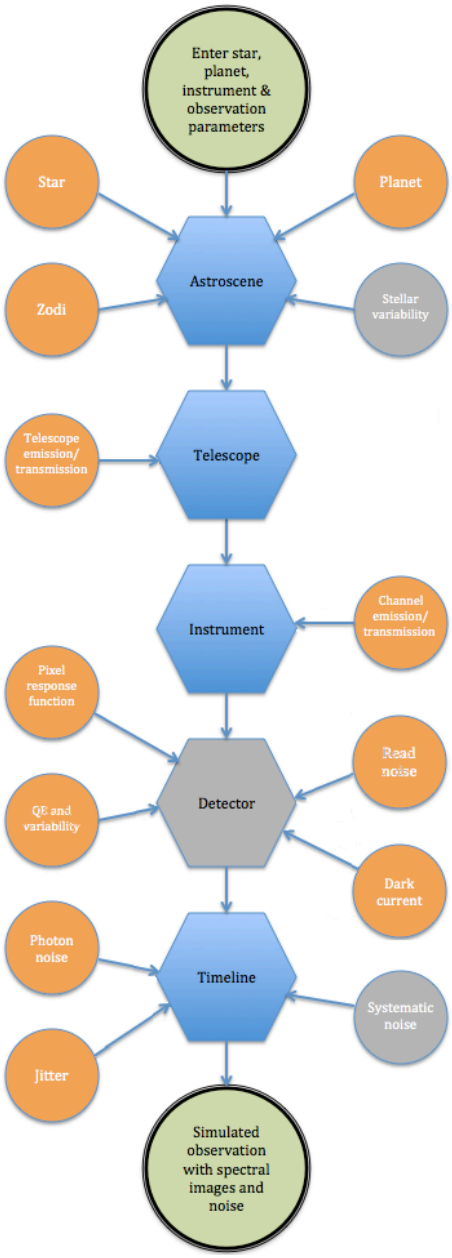

Figure 1: ExoSim architecture. A modular design is utilized and can be adapted for different instruments (grey elements are in the process of implementation).

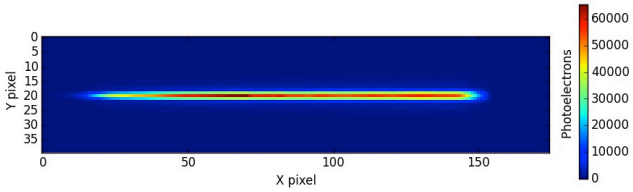

Figure 2: A simulated focal plane array image of the spectrum of GJ1214

5. Summary and Conclusions

We have demonstrated the capability of ExoSim to produce realistic spectral images and noise for two different instrument models, the proposed Ariel telescope and the Hubble WFC3 IR instrument. These simulations can be used for both predictive and retrospective studies. In the future ExoSim can be adapted for other instruments including SPICA and JWST.

References

[1] E.Pascale et al. EChoSim: The Exoplanet Characterisation Observatory software simulator. arXiv:**1406.3984** (2014).

[2] Kriedberg et al. Clouds in the atmosphere of the super-Earth exoplanet GJ1214b. Nature, **505**, 7481 (2014).