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Generating JWST transiting exoplanet time series data-set

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Abstract

To prepare JWST observations of transiting exoplanets, we have developed a generator of time series spectra from exoplanet(s)–star systems as the planet orbit its host star. When coupled with a telescope-instrument simulator, it generates representative sets of data, which are used to optimize data reduction methods, retrieval methods and to identify the impact of various effects (limb darkening, 3D versus 1D exoplanet models). One of the first applications is the simulation of JWST observations of the WASP-43b exoplanet with the MIRI instrument in slitless low-resolution mode.

1 Introduction

The James Webb Space Telescope, to be launched in 2020, will open new perspectives in astrophysics and especially in exoplanets observations. Twenty-five percent of the JWST observing time in the framework of GTO (Guaranteed Time Observations) and ERS (Early-Release Science) programs will be dedicated to exoplanet observations. Most of them aim at characterizing exoplanet atmospheres (vertical structure, molecular content, hazes, clouds, winds, etc.). The JWST will bring a large collecting area and a large wavelength coverage (0.5 – 28 microns), with 3 instruments in the 0.5-5 microns range (NIRISS, NIRCAM and NIRSPEC) and one instrument in the 5 – 28 microns range (MIRI). To take full advantage of the JWST capabilities when observing transiting exoplanets, relative spectro-photometry precision down to the 10 ppm level should be achieved. This is not easy and the lesson learned from Spitzer and Hubble observations is that good knowledge of the instrumental systematic effects and their corrections are necessary to infer robust conclusions on the exoplanet atmospheres from the data. As the choice of data detrending method may affect the scientific results, instrument simulators have been developed to create benchmark data for testing the data reduction pipeline of Spitzer transit observations [1] and of HST transit observations [2]. Here we present a first version of the spectrum compiler (exoNoodle) and its first results. Coupled with the JWST-MIRI instrument simulator (MIRISim [3]), it can deliver representative time series data sets.

2 exoNoodle and MIRISim

ExoNoodle is a spectrum compiler to create a time series synthetic spectrum for the JWST exoplanets program. At each step of a time series, the compiler calculates the spectrum expected from the star and planet(s) system. It comes as Python package. Even though exoNoodle is developed with MIRI-LRS study case, it can be easily used for other MIRI observational modes or other instruments.

The code has to be versatile, along with the possibility to manage individual contributions from diverse models. The fig.1 describes the configuration chosen to achieve this. It shows the sequence of a computation, for a single run. Special attention is taken to calculate precisely ingress and egress. Three different type of variables or objects are described:

External These are the objects of interaction with the user. The variables are represented in light grey and in dark grey the files themselves. The source files are the data created from exoplanet or star models.

Calculation In green are the elements necessary for the computation, that will be created by the software based on the information given in the configuration by the user. In light green are the variables or dictionary. The darker boxes are the objects and their content (method, specified).

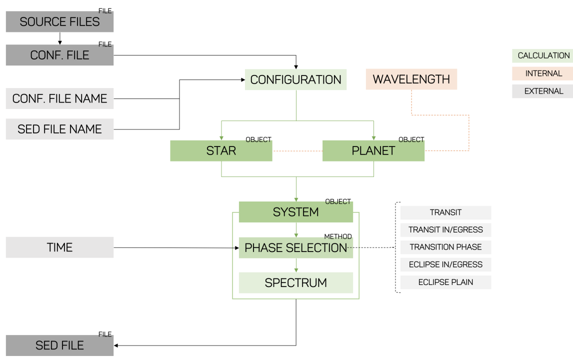

Figure 1: Sequential description of exoNoodel structure.

INTERNAL The internal variable, in light red, doesn't interfere formally with the computation. It is the wavelength on which all the λ-dependant variables are interpolated so that the computation is easier. The resolution of this wavelength array is chosen so that the sampling is good for JWST/MIRI LRS-Slitless, for further use by MIRISim. If no wavelength is chosen, this will be the star spectrum wavelength resolution.

The default values are the Sun/Jupiter system. The different models are read individually from files. The contributions taken are the following:

- **Star Spectrum**
  Default : Blackbody with temperature
  File : Modelled spectrum up to a map

- **Stellar Limb-Darkening**
  Default : Homogeneous star
  File : Values for various formulation of limb-darkening coefficients

- **Planet Emission Spectrum**
  Default : Blackbody with day and night temperature
  File : Modelled spectrum up to a map

- **Planet Reflection Spectrum**
  Default : Jupiter geometric albedo
  File : Albedo integrated on the surface or a map, especially with clouds, wavelength-dependent

- **Planet Transmission Spectrum**
  Default : None (no atmosphere)
  File : Modelled as a variable $R_p(\lambda)$, with possible inhomogeneities

It is already possible to combine several launches of the code to create a multi-planet system. This option will be better implemented in the package options later-on, along with the possibility to have a de-phase locked planet and the stellar spot activity (map).

3 Conclusions

We have created a software able to collect exoplanet and star models, to combine them and to create a representative transit, eclipse or phase curve data and to combine it with the instrument simulator. One of the first uses of the couple exoNoodle and MIRISim will be to provide data sets to test new spectral extraction, calibration and retrieval methods developed in the framework of the exoplANETS-A H2020 project. Another foreseen use is to generate a set of data representative of MIRI-LRS observations of WASP-43b as input for the data challenge to be organized in the framework of the 'Transiting Exoplanet Community Early Release Science program for JWST'.

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