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SIMULATED INSTRUMENTAL CONSTRAINTS ON SUB-STELLAR ATMOSPHERIC RETRIEVALS FOR THE JAMES WEBB SPACE TELESCOPE'S MID-INFRARED INSTRUMENT.

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ABSTRACT

Following its launch in 2021, the James Webb Telescope will provide the best infrared observations of exoplanets and brown dwarfs to date. In particular, the Mid-Infrared Instrument (MIRI), will allow for medium resolution spectroscopy across a wide wavelength band, from 4.9-28.8µm. This will allow us to derive atmospheric properties of objects at lower temperatures than currently possible. MIRI's medium resolution spectrometer (MRS) is an integrated field unit that will perform these observations, providing both spatial and spectral information about targets. Understanding the instrumental effects is critical to analyzing data from MIRI. With that in mind, the MIRISIM instrumental simulator was developed to provide observational simulations of the various sub instruments of MIRI.

This thesis improves the implementation of a thin-film fringing model for point sources to MIRISIM, considering how the fringing effect from the detector layers varies with position. Fringing is a periodic, wavelength dependent effect, and thus has a strong impact on any spectroscopic observations. A comparison to the existing model was made, demonstrating the necessity of considering this effect when analyzing data. We will improve the fringing removal by identifying the point source location from the constructed data cube, and select the correct fringe flat for removal.

Understanding the instrumental effects is key to quantifying the ability of MIRI to derive atmospheric properties. Existing literature has considered the NIRCAM instrument and the MIRI Low-Resolution Spectrometer, but to date no retrieval studies have been performed using MIRISIM, or for the MIRI MRS, though it is critical to extend wavelength coverage to improve the results of an atmospheric retrieval. Model atmospheres will be generated using PetitRadTrans, and processed using MIRISIM and the JWST pipeline to produce a mock observation. An atmospheric retrieval will be performed, demonstrating to what extent MIRI will be able to retrieve atmospheric parameters such as temperature, pressure and composition. The posterior distributions of these parameters are compared with and without the fringing removal, again demonstrating the importance of correcting for this effect.

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L-Type

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β Pictoris b

HR 8799 System

PDS 70 b,c

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Channels, bands, etc **ref:Chen2019**

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3 FRINGING EFFECTS IN MIRISIM

3.1 MIRISIM

The MIRI instrument has been modeled in python as a program known as MIRISM. This program takes in an astronomical 'scene' along with some configuration parameters to output a detector data product, similar to what will be produced by the actual instrument. This is relatively full-featured simulator, modelling the instrumental PSF, various noise sources and distortion maps, among other effects. While MIRISIM is functional for all of the MIRI sub-instruments, this report will only deal with the Medium-Resolution Spectrometer (MRS) sub instrument, described in section 2.2. The goal of this section is to describe the implementation and testing of an updated optical model of the 'fringing' effect - an optical effect caused by thin film interference from the multiple layers of the detector.

3.1.1 Architecture

SCENE - SEDs SIMULATOR PYSPECSIM

3.1.2 Data Products

3.1.3 Instrumental effects

3.1.4 Fringing

A key effect on spectral data is fringing, described in **ref:Argyriou2018**. MIRI uses a total of three Si:As impurity band conduction detector arrays, two of which are used by the MRS. These detectors consist of 7 layers, listed in table 1 and illustrated in Fig. 1.

Thin film interference occurs when light is coherently reflected at the boundary between two layers and interferes with the incident light. This is the principle on which Fabry-Pérot interferometers function. As we wish to determine the effect of fringing on the amplitude of the signal received by the detector, we are effectively interested in the transmittance of a series of Fabry–Pérot interferometers. Assuming an ideal plane-parallel optical cavity with a reflectance R at both boundaries, thickness D, and an angle θ at which the light travels within the cavity, we can compute the transmittance as:

$$T_c = \frac{1}{1 + \frac{4R}{(1-R)^2} \sin^2\left(\frac{\delta}{2}\right)} \tag{1}$$

Figure 1

Table 1

Figure 2

Where the phase δ at half λ ($\psi = \pi$) is:

$$\delta = 4\pi\sigma D \cos\theta - (\phi - \pi) \quad (2)$$

If all of the parameters were known, this would be sufficient to numerically solve for the fringing pattern within MIRI. Unfortunately, uncertainties in the thickness in the detector layers, variations in the layer deposition thickness, and the uncertainty of transmittance and reflectance of the materials used at cryogenic temperatures prevents the implementation of such a numerical model.

Instead, we turn to calibration data taken to characterize the fringing pattern.

DESCRIBE CURRENT MODEL - GENERIC FRINGING

However, due to the dependance of fringing on the incident angle of the light, a single model of fringing is insufficient to describe the full effect. Therefore, we use data taken in XXXXXXXXXX at various points across the detector and quantify how this changes the extracted spectra after processing in the JWST pipeline.

DESCRIBE HOW THE DATA WAS TAKEN HERE. - Problems with point vs extended sources - multiple collection runs

Ultimately this data collection produced a series of 'fringe-flats' of an almost point like at various position across the detector and in each channel. We implemented a new routine into the pySpecSim portion of MIRISIM to read in the location of point sources within a scene, and apply the correct position dependent fringe flat. This implementation comes with several caveats: namely that the fringing model is not yet fully developed, so it can only be considered accurate for point sources located at the same (α, β) location as the source used to produce the fringe flat. Additionally, the source used to generate the data is not a true point source, nor are there fringe flats produced for the full MRS wavelength range. We stress that the goal of this testing is to demonstrate the significance of this effect to justify the need for a more complete model along with additional calibration data to constrain the detector layer parameters.

FM Data

CV Data

3.1.5 Implementation

3.1.6 JWST Pipeline

Stage 1 Processing

Stage 2 Processing

Fringing correction

Aperture Photometry

3.1.7 Cross-Correlation

To quantify the similarity of the spectrum output by the JWST pipeline to the input into MIRISIM, we rely on the technique of cross correlation.

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