Exploring Earth-Analog Atmospheres with the James Webb Space Telescope

Morgan Saidel[1], Mark McConnell[1], Nikole Lewis[2], Lisa Kaltenegger[2], Jack Madden[2], Thea Kozakis[2]

[1]University of New Hampshire, [2]Carl Sagan Institute, Cornell University

INTRODUCTION

The search for life outside our solar system initially requires exploring potentially habitable Earth-analog exoplanets. The James Webb Space Telescope (JWST), scheduled to launch in 2021, will be able to detect the atmospheres of these potential Earth-analog worlds. Thus, it is imperative that we optimize the use of JWST by developing observational strategies to efficiently characterize potentially habitable Earth-like exoplanets.

To develop these strategies, we identified target planetary systems for JWST analysis, determined optimal configurations of JWST instruments for characterization of Earth-analog exoplanets, and estimated the number of transits required to detect key spectral features on our target worlds. This was accomplished by simulating atmospheric observations of Earth-analog exoplanets around a sequence of K and M stars with a variety of JWST instruments. Detection was signified by a three to one ratio between the amplitude of the spectral features and their spectral precision.

RESEARCH QUESTIONS

- What planetary systems are ideal for spectral feature detection by a wide range of JWST instruments?
- How many transits are required to detect key spectral features around the target planetary systems?
  - How does the transit number vary with J magnitude of the star?
  - How does the transit number vary with different observing modes?

METHODOLOGY

- Earth-analog exoplanets were modelled around stars of the following spectral type:
  - K0V, K2V, K5V, K7V, M0V, M2V, M5V, M8V
- JWST atmospheric detection was simulated using PandExo
- Detections were simulated using all four JWST instruments:
  - NIRCam, NIRSpec, NIRISS, MIRI
  - The observing modes used for each instrument are listed in Table 1 below.
- Analyzed the detection of four key spectral features:
  - H_2O at 1.4 µm
  - H_2O at 2.5 µm
  - CH_4 at 3.3 µm
  - CO_2 at 4.5 µm

Observing Mode	Wavelength Range
NIRSpec G140H	0.97-1.82 µm
NIRSpec G235H	1.66-3.05 µm
NIRSpec G395H	2.87-5.14 µm
NIRSpec Prism	0.60-5.30 µm
NIRCam F332W2	2.4-4.0 µm
NIRCam F444W	3.9-5.0 µm
NIRISS SOSS	0.6-2.8 µm
MIRI slitless	5-14 µm

Table 1. The JWST observing modes and their corresponding wavelength ranges that were used to detect the atmospheric features of Earth-analog exoplanets.

MODELLED SPECTRA

The following figures are modelled transmission spectra for Earth-analog planets around a variety of stellar hosts from Madden et al. (submitted).

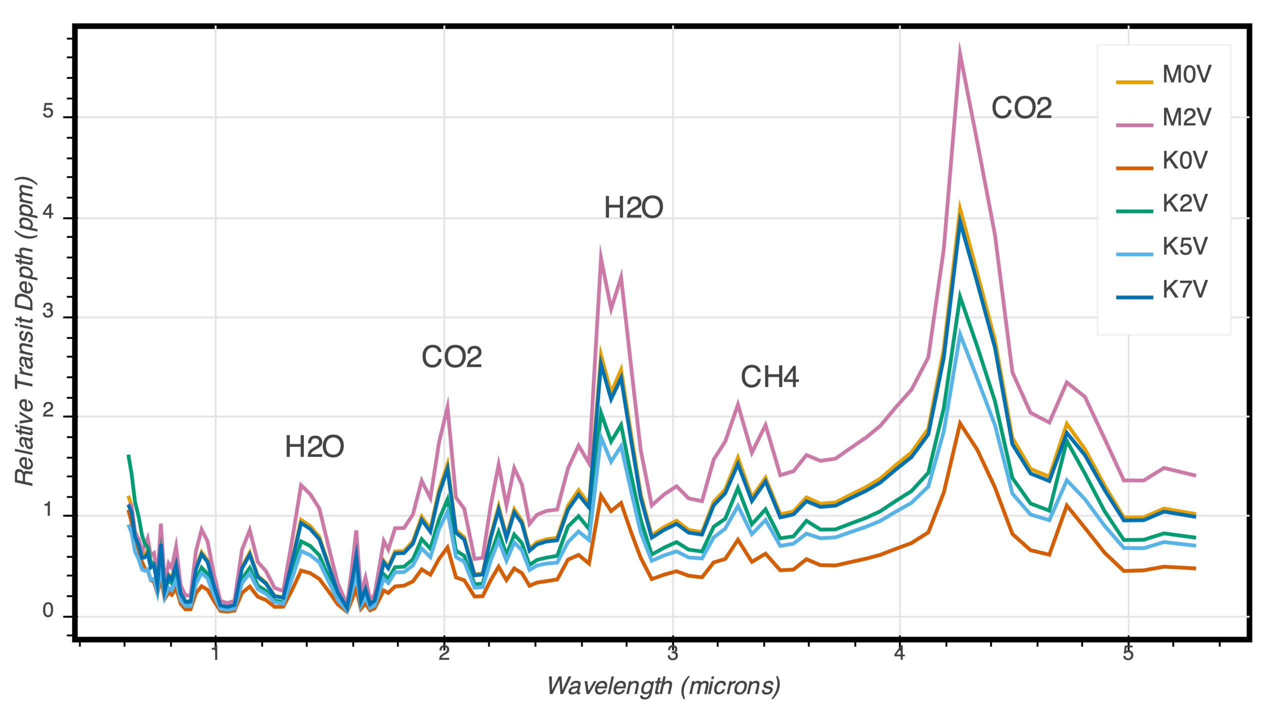

Figure 1. The modelled transmission spectrum detected by NIRSpec Prism for an Earth-like exoplanet around M0V, M2V, K0V, K2V, K5V, and K7V stars.

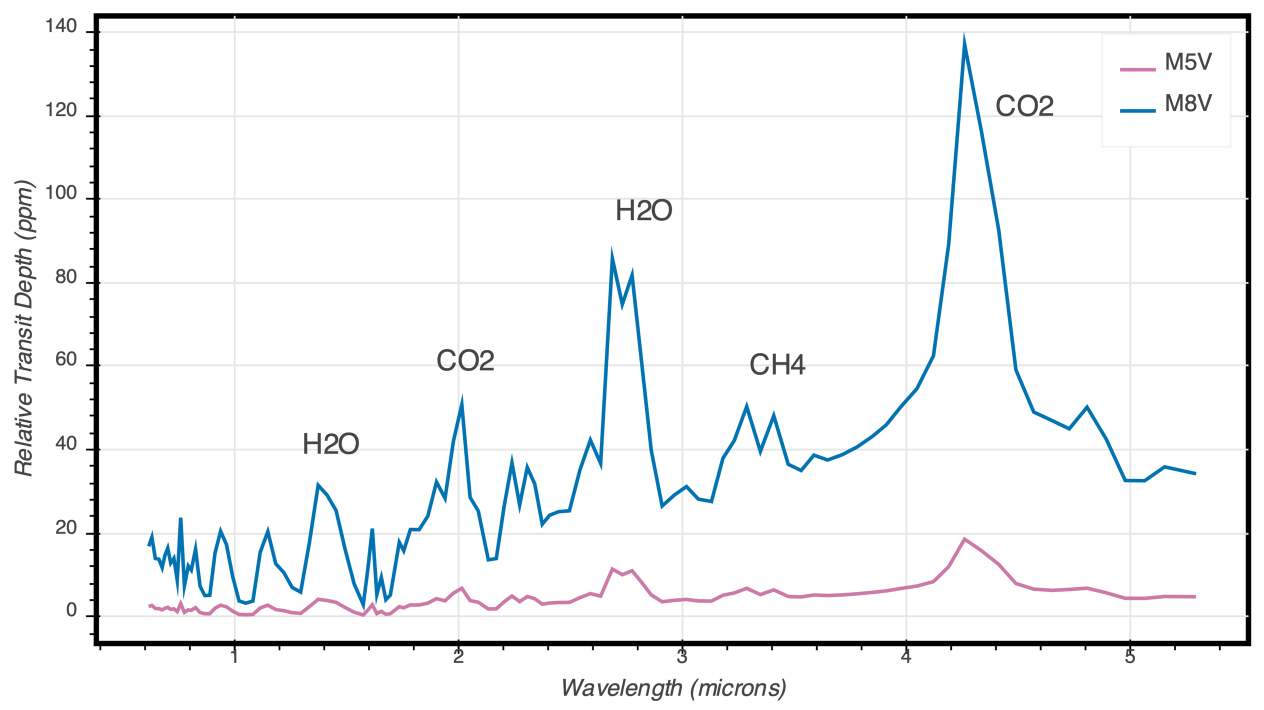

Figure 2. The modelled transmission spectrum detected by NIRSpec Prism for an Earth-like exoplanet around an M5V and M8V star.

SPECTRAL PRECISION ANALYSIS

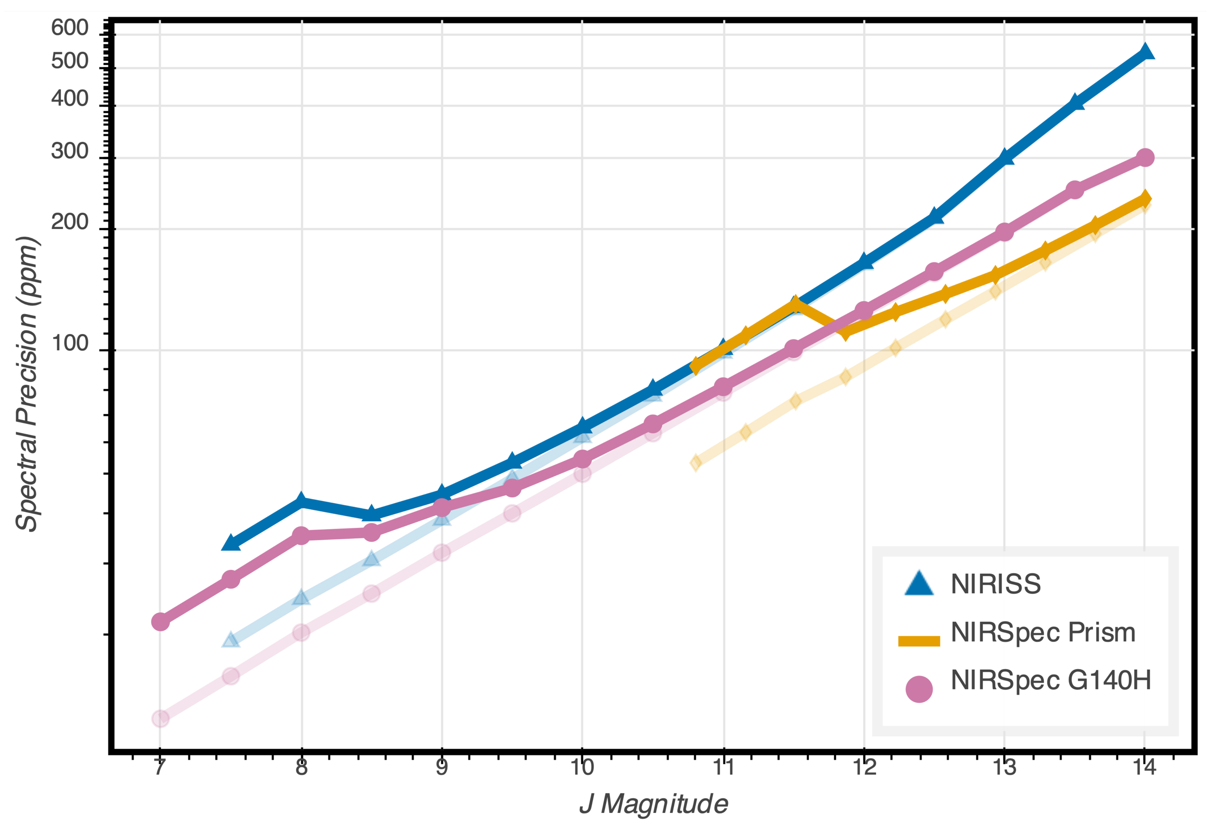

Figure 3. The spectral precision as a function of J magnitude for the 4.5 µm CO_2 feature detected by NIRISS SOSS, NIRSpec Prism, and NIRSpec G140H.

TRANSITS REQUIRED

H_2O

a.

Observing Mode	Number of Transits	J Magnitude
NIRSpec G140H	5-8	7-9
NIRSpec Prism	10+	10
NIRISS SOSS	10+	7

b.

Observing Mode	Number of Transits	J Magnitude
NIRSpec G235H	1-3	7-10.5
NIRSpec Prism	7	10
NIRISS SOSS	2-7	7.5-10

Table 2. a. The number of transits required to detect the 1.4 µm H_2O feature for an Earth-analog exoplanet around and M8V stellar host as a function of J magnitude. b. The number of transits required to detect the 2.5 µm H_2O feature for an Earth-analog exoplanet around and M8V stellar host as a function of J magnitude.

CH_4

Observing Mode	Number of Transits	J Magnitude
NIRCam F332W2	1-4	7-10
NIRSpec G395H	1-4	7-9.5
NIRSpec Prism	13	10

Table 3. The number of transits required to detect the 3.3 µm CH_4 feature for an Earth-analog exoplanet around and M8V stellar host as a function of J magnitude.

CO_2

Observing Mode	Number of Transits	J Magnitude
NIRCam F444W	1-3	7-11.5
NIRSpec G395H	1-3	7-11
NIRSpec Prism	6-9	10

Table 4. The number of transits required to detect the 4.5 µm CO_2 feature for an Earth-analog exoplanet around and M8V stellar host as a function of J magnitude.

CONCLUSIONS

- Earth-analog planets around M8V, M5V, and M2V stellar hosts yield the strongest overall spectral features for detection by a wide range of JWST observing modes.
  - Should be considered as target planetary systems for detection of Earth-analog exoplanets with JWST.
- NIRSpec Prism detected the widest range of atmospheric features.
  - Only detects features for stars with Jmag > 10.
  - Requires 10+ transits to detect smaller amplitude spectral features.
- For brighter host stars or smaller amplitude features, supplementary modes should be used in conjunction with or in replace of NIRSpec Prism:
  - NIRSpec G140H can detect the 1.4 µm H_2O feature (amplitude: ~30ppm) in 5-8 transits for stars with J magnitudes between 7-9.
  - NIRCam F332W2 can detect the 3.3 µm CH_4 feature (amplitude: ~48ppm) in 1-4 transits for stars with J magnitudes between 7-10.

REFERENCES

Kalirai, J., 2018, Contemporary Physics, 59, 3

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Batalha, N.E., Mandell, A., Pontoppidan, K., et al., 2017, PASP, 129, 976

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Contact Info:
Morgan Saidel is an undergraduate physics major at the University of New Hampshire.
Email: mls1052@wildcats.unh.edu