Sagan Summer Workshop 2016
Is There a Planet in My Data?

Detection and Spectroscopic Characterization of Transiting Exoplanet Observations with the James Webb Space Telescope (JWST)

Facilitator: Nikole Lewis
Contributors: Michael Line, Jason Rowe, Jeff Valenti, Laura Kreidberg

1 Spectral Extraction Exercise

1.1 Stellar SNR and Spectral Resolution

It is important to remember at the core of exoplanet transit observations are observations of the host star. Using the sum of the 1D stellar spectra, address the following questions: Given the information in the FITS headers and a key piece of information that the NIRISS detector gain is 1.5 e-/DN, what are the signal-to-noise (SNR) and achievable precision (σ) assuming the observations are photon-noise limited (SNR = N/$\sqrt{N}$ and σ = 1/SNR) as a function of wavelength? How does binning the data change these numbers? Discuss the trades between spectral resolution (R$\sim \lambda/\Delta\lambda$) and SNR/achievable precision. How might this be important in the context of detecting spectral features in a exoplanets ranging from hot Jupiters (large scale height, H$\sim$500 km, and large radius, $R_p \sim R_{Jupiter}$) to cool earth-sized planets (small scale height, H$\sim$10 km, and small radius, $R_p \sim R_{Earth}$)?

1.2 Spectroscopic Light Curves

It is important to understand how shape of a transit will change with wavelength. Using the 1D stellar spectra as a function of time, derive a white-light (summed over all wavelength) light curve (as a function of time). By measurement (or by eye) estimate the depth of the transit. Given that the transit depth is $(R_p/R_\star)^2$, what is your rough estimate of the planet radius? Use the stellar spectrum as a guide for the stellar type/size. Think about what combination of stellar types and planets might give a similar transit depth. Describe why small stars (M dwarfs) make advantageous host stars. Now create light curves for spectral resolutions (R$\sim \lambda/\Delta\lambda$) of roughly 10 and 100. Investigate how the transit shape/depth changes as a function of wavelength. At what wavelengths is the limb-darkening effect the strongest?

2 Transit Fitting Exercise

2.1 Limb Darkening

Using the 16 bin light curves stored in the *planet1_lcs.pic* python pickle file investigate how limb darkening choices affect your derived spectrum Begin by performing the simple MCMC fits that only the planetary radius ($R_p/R_\star$), center of transit time (T_0) and linear limb darkening (u) parameters to be "free" for the light curves in each wavelength bin. How do the parameters vary with wavelength? Are the center of transit times consistent to within 1 sigma? Plot up your planetary spectrum ($R_p/R_\star$ as a function of wavelength). Now rerun the MCMC fits, but fix the limb darkening (u) parameter to the value derived from the white light curve in the exercise notebook. Are your center of transit times still consistent within 1 sigma? How does fixing the limb darkening (u) parameter to be constant with wavelength change your planetary spectrum? Discuss potential issues with how limb darkening is handled when deriving the planetary spectrum from transit data. If time permits, rerun your MCMC analysis using the "nonlinear" 4-parameter limb darkening model and see how that affects your derived spectrum. Are the spectra consistent at the 1-sigma level?

2.2 Planetary Parameters

Using the white-light light curve stored in the *planet1_lcs.pic* python pickle file investigate how including additional parameters in your fits affects correlations and uncertainties in the planetary radius ($R_p/R_\star$). Start by including the semi-major axis ($a/R_\star$) and inclination (i) in set of fitted parameters (in addition to planetary radius ($R_p/R_\star$), center of transit time (T_0) and linear limb darkening (u) parameters). How do the uncertainties in ($R_p/R_\star$) change? Are your results consistent with previous three parameter fit? Are there parameters with significant correlations? Discuss possible methods to limit parameter correlation and incorporate information from other observations to help better constrain your results. If time permits, add the eccentricity (e) and longitude of periastron (ω) into the set of fitted parameters. Discuss the impact of assuming a circular orbit for this transiting planet. For further work, extend this same analysis to the wavelength dependent light curves stored in the *planet1_lcs.pic* python pickle file.

3 Spectral Retrieval Exercise

3.1 Forward Models

Using the forward transmission model as outlined in the first half of the spectral retrieval exercise, investigate how the spectral shape changes as a function of temperature and assumed composition. While holding the atmospheric species abundances constant, generate spectra at temperatures of 500 K, 1000 K, 1500 K, 2000 K, and 2500 K. What happens to the spectral feature sizes as a function of temperature? Explain these trends. Why might cold planets be hard observe? Now fix the planetary temperature to 1500 K and adjust the abundances of the atmospheric constituents, specifically water. What happens if you set water to a very low abundance (say -10.00)? What does the spectrum look like and why? What happens if you make the entire atmosphere water (say 0.00)? What happened to the feature sizes and why? For small changes in the water abundance, what wavelengths are most sensitive to water? If time permits, alter the abundances of other atmospheric constituents at note how they affect the planetary spectrum in the spectral range relevant to NIRISS SOSS (0.6-2.8 μm).

3.2 Retrievals

Using pre-generated "stair plots" for three different retrievals with a clear atmosphere, a cloudy atmosphere, and a cloudy atmosphere assumed to be clear (pdfs are in retrievals/ folder). investigate the impact of clouds on spectral retrievals. Compare the results from these three cases. How to the uncertainties on the retrieved molecular abundances change when fitting to a cloudy atmosphere? Do they get worse? What happens when one assumes a clear atmosphere when in fact the atmosphere is actually cloudy? How are the retrieved abundances biased?