NMSU ASTRONOMY CUME 460, 2 April 2022 **Jon Holtzman**

This cume is partly motivated by and will ask about material discussed in the letter: "Analysis of a JWST NIRSpec Lab Time Series: Characterizing Systematics, Recovering Exoplanet Transit Spectroscopy, and Constraining a Noise Floor" by Rustamkulov et al (2022). The paper is perhaps a little technical. Don't get overly hung up on all of the details; we'll just be using this to motivate some questions. As you're reading, think about transits and extrasolar planets and try to follow the basic idea of what they are saying.

A 75 percent grade will guarantee a pass.

Gravitational constant $G = 6.67 \times 10^{-8} cm^3 g^{-1} s^{-2}$,
mass of Sun $M_{sun} = 2 \times 10^{33} g$,
radius of Sun $R_{sun} = 6.96 \times 10^{10} cm$,
effective temperature of Sun $T_{eff,sun} = 5777$ K,
radius of Earth $R_{earth} = 6.38 \times 10^8 cm$,
radius of Jupiter $R_{jupiter} = 6.99 \times 10^9 cm$,
speed of light $c = 3 \times 10^{10} cm/s$, $1pc = 3.086 \times 10^{18} cm$,
$1au = 1.496 \times 10^{13} cm$

1. (23 points) Transits and Transit Spectroscopy
   (a) (5 points) Describe what an extrasolar planet transit is. Draw a diagram showing the star (drawn as a circle) and the planet during a transit, and a separate diagram showing a light curve of a transit, and show how the two diagrams are connected.
   (b) (3 points) If you are just measuring total brightness (photometric transit), what physical properties of the extrasolar planet are you learning about?
   (c) (4 points) If you could observe a transit of Jupiter across the Sun from another star, what would the fractional change in brightness be? How about Earth? (note constants above).
   (d) (5 points) Describe the idea behind transit spectroscopy. What part of an extrasolar planet are you trying to learn about with transit spectroscopy? Again, draw a diagram showing the relevant geometry, starting with the star as a circle.
   (e) (3 points) Imagine (it's not true!) that the atmosphere of some extrasolar planet was opaque at 889 nm, and transparent at 1000 nm. Sketch a light curve for the two different wavelengths.
   (f) (3 points) What is the expression that relates physical properties of the system to the spectroscopic difference that you described in 1e?

2. (16 points) The paper simulates observations of two objects: the warm Neptune GJ436b (T_{eq} 700K, J=6.9) and the temperate terrestrial planet TRAPPIST-1 d (T_{eq} 300 K, J=11.35)
   (a) (2 points) What is a J band magnitude (wavelength range and type of magnitude, i.e., apparent or absolute?)?
   (b) (2 points) What object is the J band magnitude referring to (remember we are talking about planetary systems)?
   (c) (2 points) What are the relative brightnesses (the flux ratio) of the objects with J=6.9 and J=11.35?
   (d) (2 points) What object is the equilibrum temperature (T_{eq}) referring to (remember we are talking about planetary systems)?
   (e) (3 points) Qualitatively (i.e., in words), what is the equilibrium temperature?
   (f) (5 points) What expression would you use to calculate T_{eq}?

3. (6 points) NIR Spectroscopy
   (a) (2 points) Given the resolution of the NIRSPEC PRISM mode (second paragraph of paper), what is the minimum width of a spectral feature that could be resolved?
   (b) (2 points) What type of absorbers/transitions do you think PRISM will be most sensitive to?

(c) (2 points) The paper describes the data reduction for NIRSpec, and talks about fitting the up-the-ramp count rate. Describe what this means in the context of how the infrared detector is being operated, in particular, how infrared detectors are read out.

4. (5 points) The paper suggests a noise floor of 10 ppm (parts per million). How many photons need to be collected per wavelength channel so that, statistically, the photon noise matches this noise floor?

5. (10 points) Statistics

   (a) (2 points) The paper talks about a 3σ upper bound of 14 ppm. What does 3σ mean in this context?

   (b) The paper talks about χ^2_ν.

      i. (2 points) How is this quantity defined?

      ii. (2 points) What would you need to know to determine whether the quoted values of χ^2_ν are consistent with the expected uncertainties?

   (c) The paper talks about fitting models to the light curves that include a "systematics model", S(x) (equation 1). It tries to motivate what terms are needed in the model using the Bayesian and Akaike Information Criteria (AIC and BIC).

      i. (2 points) Describe the concept behind AIC and BIC. What quantities do they depend on?

      ii. (2 points) Based on Table 1, which terms in equation 1 would you recommend are justified? Explain your reasoning.