Searching for Biosignatures in Exoplanet Atmospheres: An Information Theory Approach

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Introduction: Recent missions such as Kepler and TESS have shown that exoplanets can be found in many star systems throughout the Galaxy [1]. Characterization of those exoplanets' atmospheres is critical to understanding their habitability. Transit spectroscopy is the principal method used to study exoplanetary atmospheres. In this work, we created simulated exoplanetary transmission spectra to model those that the James Webb Space Telescope could detect in the future [2]. We then calculate Jensen-Shannon divergence (D_{JS}) for Fourier transforms of exoplanetary spectra. D_{JS} quantifies the loss of information when one probability distribution is modeled by another. We hope this method will help automate the process of identifying biosignatures and determining planetary habitability.

Method: Traditionally, astronomers have classified biosignatures by hand, picking out individual peaks from a transmission spectrum. Biosignatures are most commonly regarded as the presence of molecules in a state that is out of thermodynamic equilibrium [3]. For example, the presence of a reducing and oxidizing gas (*e.g.*, methane and oxygen) would suggest life because constant production of both gases would be required to maintain such an equilibrium. Here, we examine the presence of biosignatures by using D_{JS} comparisons of exoplanetary transmission spectra to Earth's and Jupiter's spectra, all simulated with *Exo_Transmit* [4].

To calculate D_{JS}, we apply the method of Gleiser et al. in [5]. We first define a modal fraction as a weighted probability distribution composed of Fourier modes of the transmission spectrum. We quantify the information loss between modal fractions of two exoplanets, p and q, with Kullback-Liebler divergence (D_{KL}) [6]. However, D_{KL} depends on which spectrum precedes the other (*i.e.*, $D_{KL}(p||q) = D_{KL}(q||p)$). D_{JS} extends this assessment of information because it is an invariant measure. Early iterations of this method, strive to identify the class of exoplanet, such as Hot Jupiter vs. Super-Earth). Future iterations aim to use high-resolution spectra to pick out complex biosignatures and assess the strength of their expression.

Using *Exo_Transmit*, we simulated a sample of ten Hot Jupiter spectra, ten Super-Earth spectra, and spectra for Earth and Jupiter. We calculate D_{JS} for the Hot Jupiters and Super-Earths compared to Earth and Jupiter to determine if D_{JS} can distinguish between the two types of planets.

Analysis: We observe no overlap between the Hot Jupiters' D_{JS} calculations when compared to Earth versus Jupiter. The lowest D_{JS} value for a Hot Jupiter compared to Earth was 6.73×10^{-4} while the highest D_{JS} value for a Hot Jupiter compared to Jupiter was 5.44×10^{-4}. The low D_{JS} values for Hot Jupiter-Jupiter comparisons indicate low information loss, *i.e.*, similarity in the spectra. Thus, our preliminary results suggest D_{JS} could delineate between comparison to Earth or Jupiter.

The same was not true for the sample of Super-Earths. In that case, a large overlap existed between comparisons to Earth and Jupiter. One possible explanation for this phenomenon is the similar equilibrium temperatures of the Super-Earths to both Earth and Jupiter. The temperature influences the width and strength of absorption lines and could decrease the ability of D_{JS} to distinguish between Earth and Jupiter.

Conclusion: These results affirm that D_{JS} is sensitive to patterns in data, such as similarity in planetary transmission spectra. D_{JS} calculations may have been complicated by the similar equilibrium temperature of Earth and Jupiter. Future work will see whether D_{JS} can compare a Hot Jupiter and Earth more easily. This method shows promise for the analysis of JWST data.

References:

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