Proposal: Biomarker Exoplanet Survey

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Abstract

Atmospheric spectroscopy of exoplanets will yield the first signs of organic life on other worlds in the nearby regions of the galaxy. Further, two dimensional atomic and molecular emission/absorption maps in the infrared can be produced by incorporating the image slicer spectrograph with space telescope observations. In this paper, I propose to use the star shade in concert with the James Webb Space Telescope and an image slicer spectrograph to directly observe a large sample of exoplanets around sun like stars in the infrared in search for spectral absorption features of N2O, CO2, and CH4, which are common byproducts of living organisms. These data will allow us to not only infer a calculated probability density of these biomarker gasses in exoplanets around sun like stars, but also produce some of the first low resolution two dimensional images of exoplanets in the wavelength bands of such biomarker gases, showing the distribution of such gases.

1 Introduction

Finding likely evidence for life on another world will be the most important astronomical discovery of mankind. One of the most viable ways to do this with spectroscopy is to study the spectra of exoplanet atmospheres in search for gasses indicative of organic life, thought of as biomarkers, such as N2O, CH4, and CO2. This spectroscopic analysis has been done extensively on solar system planets for decades, but until recently has hardly been possible on exoplanet systems. The overwhelming brightness of an exoplanet's host star makes it impossible to distinguish the planet directly with conventional instrumentation, as the host star is 10^{10} times brighter than the light reflected from exoplanets[2]. But it is now possible to for the Biomarker Exoplanet Survey project to observe and quantify how much of each atmospheric biomarker is observed in the spectra of exoplanets with the advent of the star shade and the powerful resolution of JWST. The variety and accelerated pace of exoplanet surveys have left scientists with more questions than answers. No doubt, the most profound of those questions is how likely an exoplanet is to have some form of life inhabiting it. The James Webb Space Telescope working in concert with the newly developed star shade can serve as unique platform from which an exoplanet survey can be conducted in order to begin answering the question of finding evidence of other life in the nearby regions of our galaxy.

Using the unprecedented space-based light gathering power of the JWST and the photon filtering power of the star shade, the light from exoplanet atmospheres can finally be studied with accuracy. The Biomarker Exoplanet Survey project proposes to use this powerful combination of the JWST and the star shade to resolve the atmospheric spectra of a large sample of exoplanets in search for the most likely and most common gases believed to be byproducts of living organisms and habitable atmosphere: N2O, CH4, CO2, all visible in the infrared spectrum which JWST operates. From a large sample size of sun-like stars, we can begin to statistically estimate the lower bound of the probability that exoplanets orbiting sun like stars would show potential signs of living organisms.

2 Materials and Methods

2.1 Instrumentation and Observations

2.1.1 James Webb Space Telescope

The spectral signatures of the chosen biomarker gases are found within the infrared and near infrared band, making JWST the ideal telescope from which to make the observations because this telescope operates specifically in this band. Additionally, the unprecedented aperture size and light gathering power for space based telescopes makes JWST the most desired telescope for this project. The typical SNR of the JWST observations will be far superior to even the Hubble or Spitzer space telescopes because of the aperture size and observed wavelengths.

2.1.2 Observing Plan

Each target will get four observations with exposure times appropriate for the distance to the target. Farther targets will require up to two hours of observations[5] and closer ones will require approximately 20 minutes. These observation times are expected to give instrumental flux high enough to achieve a high SNR for the spectral absorption lines observed. The exception to this rule is that the N2O absorption lines are predicted to be produced in relatively less abundant amounts so these spectral features will require longer exposure times to bring out from the noise of the images. Specifically, targets that hold high probability to contain these signatures will require six hours of continuous spectral observations to achieve high SNR. This project would produce optimal results with a sample size of 1000 exoplanets. If each star system observed had on average two exoplanets, then 500 star systems would need to be observed to achieve the required sample size. With 300 star systems observed for six hours and the remaining 200 star systems observed for two hours, the maximum required observation time would be 2200 hours.

2.1.3 Star Shade

The invention of the star shade will for the first time empower astronomers to achieve something only found in science-fiction: the direct imaging of exoplanets - up to 10 parsecs away. Designed to work in concert with other space based observatories, the star shade will be positioned approximately 72,000 kilometers from the JWST [1] and aligned directly between each target star.

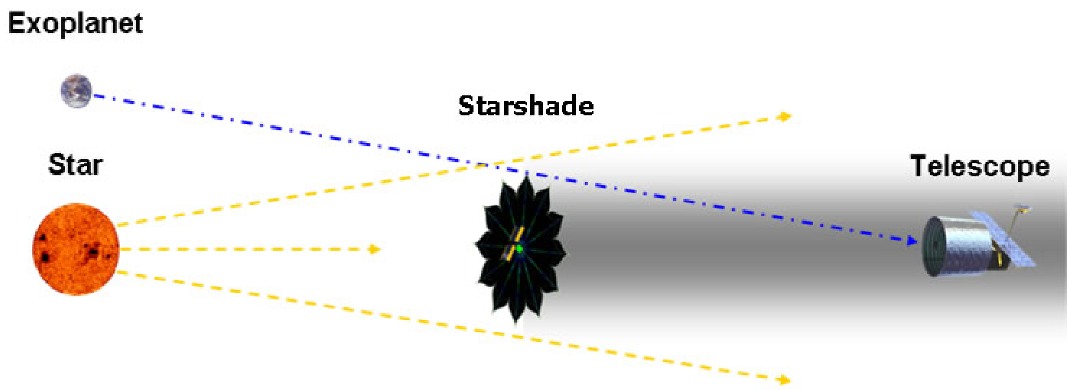

Figure 1: The conceptual geometry between the star shade, telescope, and observing targets.[3]

2.1.4 Spectral Image Slicer

Direct imaging of exoplanets in the form of CCD photometry is enabled by the use of the collaboration between the star shade and JWST. In order to use the light from exoplanets to the fullest extent possible, an additional instrument for this project will be used. The spectral image slicer resembles a typical spectrograph except that it takes incoming light and reflects it at a 45° angle onto multiple mirrors which spreads the light into multiple slices of 1μ" in height, sending the light into the spectrograph and giving a result similar to that of Figure 2, which is from an image slicer spectrograph observing the planet Mercury near the sodium D2 emission line.

3 Software and Reduction Methods

3.1 Detection of Biomarker Gasses

Reduction of astronomical spectroscopic data will be conducted within the IDL language. IDL's key advantage is that it can be used in an environment conducive to iterative data reduction and the imaging of the raw and processed data, which will be comprised of a large FITS image dataset. Significant data reduction analysis code can be leveraged from the Primary Investigator's previous spectroscopic analysis program developed for the *Mercury's NA Sodium Exosphere* project and applied directly to the analysis of the Biomarker Exoplanet Survey project with minimal adaptation.

The resulting data are spectral slice images which can be flat fielded, dark subtracted, and stellar spectrum subtracted to get the spectrum of just the target exoplanet. These spectral slices can then be averaged across the image (latitude of the exoplanet) to obtain a one dimensional array of spectral intensity. This data will be fit to known models of spectral absorption lines for identification in order to accurately identify the presence or absence of biomarkers.

The wavelength range of the observed biomarker gases (for example, 0.05 $\mathring{A}$ wide) can then be integrated to determine the abundance of absorption. The integrated absorption is then compared to a "quiet" region of the spectrum (with few or no emission or absorption lines) which is integrated on the same size spectral range in order to determine the relative significance of the absorption signal. An integrated absorption value that is 3σ from the mean of the

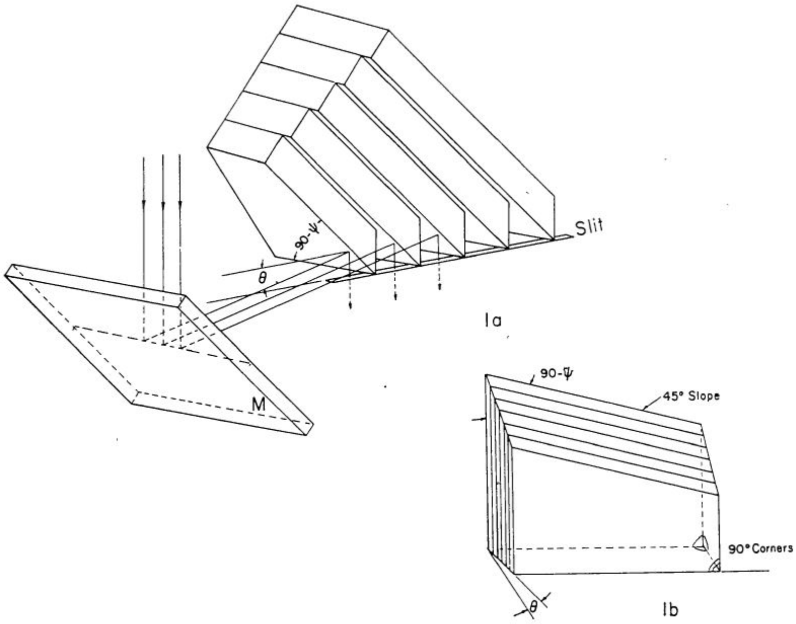

Figure 2: Schematic of the spectral Bowen image slicer [4]

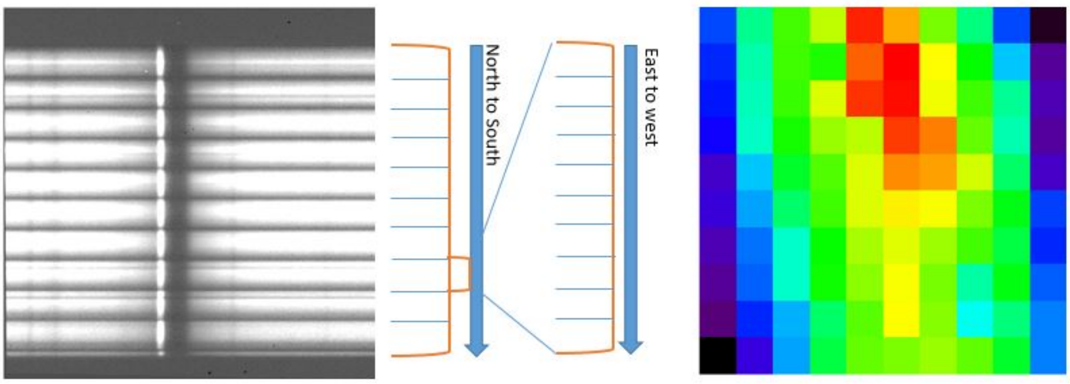

Figure 3: An image slicer image can be remapped to a 2D image of the exoplanet to show the intensity of absorption due to atmospheric gasses which are likely indicative of organic life on an exoplanets. This is an example of an image slicer observing Mercury, with the sodium D2 emission mapped to a 2D image of the planet.

intensity of the continuum region is considered to be a positive signal for that particular biomarker.

3.2 Conversion to 2 Dimensional Photometric Map of Biomarker Gasses

For exoplanets that do show signal of biomarker gasses, the followup science involves taking the slices of the image and reducing it to a 2D image of the exoplanet in the band of the biomarker gasses. Each slice of the ten or so slices in the image represents 0.01" of the exoplanet's latitude, or "north/south" direction. For example, the top slice represents the portion of the exoplanet that lies within top 0.01" of the slit. All of the slices will encompass a range that covers the entire image of the exoplanet. But each slice is also 100 pixels wide. Dividing the slice into ten additional "subslices" is what gives the other dimension, the "east/west" dimension.See Figure 3. By dividing every slice in the image into subslices and integrating along the absorption wavelength range, a 2 dimensional map of the exoplanet is produced showing the intensity of absorption across the disk of the exoplanet.

4 Predicted Results

The final products of this project will be (1) a calculated density of exoplanets that do or do not show signs of biomarker gasses in their atmospheres; (2) and for positive results of biomarker presence, a 2 dimensional photometric map of exoplanets in the spectral bands of the biomarker gasses. From these results, we can infer the relative abundance of biomarker gasses of each target and the spatial distribution of those gasses at low resolution across the disk of each exoplanet.

4.1 Contingencies

Even if the search for biomarkers reveals that no such gasses exist on even one of the planets, this would still be a statistically significant result. It would show evidence that the biomarkers we are in search of are actually quite rare, and that if life exists on the worlds observed then that life would not be producing gasses canonically thought of as biomarker gasses. At the very least, such a result would affirm the rarity of life in the nearby galaxy, indicating that our form of carbon based life is indeed quite rare within this galactic region.

5 Summary

The search for life in the universe is among the most exciting fields of science today and we are now in a position to make significant strides in this search. Scientists and inventors have now propelled engineering and science to the level of making such profound discoveries for the first time. In this proposal I have argued that it is possible, with funding from NASA, to begin a statistically quantitative search and characterization of exoplanetary atmospheres for the signatures of gasses that are highly indicative of organic life. These biomarker gasses can be detected through direct imaging of exoplanets using the combination of the star shade and JWST with the added spectral image slicer instrument. The reduced data would be among the first substantial and statistical based surveys of life signs in the nearby galactic region. This data can be further reduced to produce low resolution spectral maps of such biomarker gasses for observed exoplanetary targets. Even one positive result could have far reaching implications throughout not only science, but philosophy and possibly many faith-based belief systems. The successful funding and implementation of this project would spur unprecedented interest in astronomy and science throughout the world, and would warrant and validate dramatic Congressional budget increases for NASA to continue this exciting science.

References

[1] Seager S., Bains W. and Hu R. 2013 ApJ 775 104. *A Biomass-based Model to Estimate the Plausibility of Exoplanet Biosignature Gases.* 2013 ApJ 775 104. Accessed 3/26/2016.

[2] Northrop Gruman. *StarShade:Seeking Earth-like planets in our solar neighborhood.* `http://www.northropgrumman.com/Capabilities/starshade/Documents/Starshade_Datasheet.pdf`. Accessed 3/27/2016

[3] New Worlds Webpage. *Implementation* `http://newworlds.colorado.edu/implementation/index.htm`. Accessed 3/27/2016.

[4] Pierce, K. *Notes from Observatories* [*Construction of the Bowen Image Slicer*] 3/26/1965.

[5] M. Janson et. al. *Spatially resolved spectroscopy of the exoplanet HR 8799 c.* `http://www.eso.org/public/archives/releases/sciencepapers/eso1002/eso1002.pdf`