Preliminary Growth of Photosynthetic Organisms Under Synthetic K Dwarf Light

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Abstract

K dwarf stars have been proposed as optimal hosts for habitable planets due to their long main-sequence lifetimes (15-45 Gyr) and stable luminosities. Recent experiments have demonstrated that photosynthetic organisms can successfully grow under simulated K dwarf spectra[1]. Using this as a foundation, we aim to incorporate realistic stellar activity evolution from our characterization of 580 K dwarfs[2] into experimental protocols. Our experimental design includes three grow tents: i. solar control, ii. K-dwarf analog using LED systems with optical filtering, and iii. aphotic control. Garden cress (*Lepidium sativum*) and rainbow radish (*Raphanus sativus*) are tested due to their durability. Preliminary trials show germination and growth of both species, however, also suggest low PAR values with a concern of overheating in the tents. To increase germination rates and K dwarf radiation accuracy, humidifiers and fans were implemented to create a more controlled environment.

Introduction

First oxygenic photosynthetic organism to use light and water to produce oxygen. The unique spectrum of the Sun and Earth's relative location to it, in part, explains the exponential evolution of blue-green algae. Understanding this relationship is crucial to understanding how our Sun assisted in the evolution of complex life on Earth.

Outside our G2V-type Sun, M-dwarfs have been the prime candidate for potentially hosting life-compatible exoplanets because of their extreme longevity and abundance. M-dwarf studies indicate the survival of photosynthetic organisms; however M-dwarfs have shorter pre-main sequence periods, and their habitable zone planets receive intense UV flares relative to visible light. Coupled with their low luminosity and mass; their habitable zones lie within reach of their damaging UV rays and tidal forces (Figure 1).

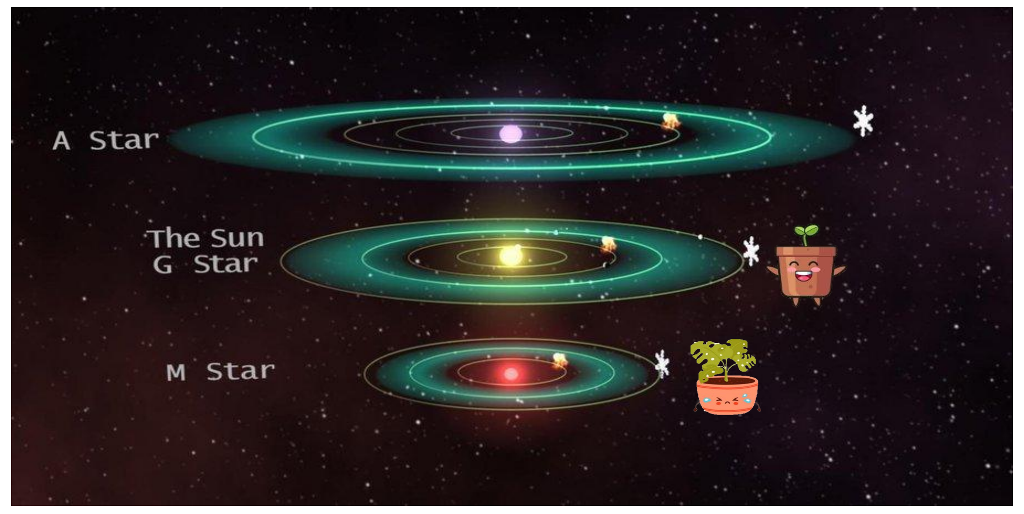

Figure 1 – (top to bottom) Labeled habitable zones of A, G, and M dwarf stars [3].

An alternative to the M-dwarf is the K-dwarf. These stars are more luminous with longer pre-main sequences. Arney (2019) argued that K dwarfs represent the best stellar hosts for detecting biosignatures on orbiting planets[4]. This creates habitable zones that are more comparable to our own. More enticingly, K-dwarfs have reduced occurrences of severe UV radiation and X-ray fluxes compared to M-dwarfs (Cuntz & Guinan 2016)[5]. Our spectroscopic survey of nearby K dwarfs identified activity and age indicators that characterize these stellar environments [6]. While life would have a more substantial chance of survival with an overall calmer star, the question remains, "Can life still flourish when exposed to different solar radiation ?"

The Photosynthesizers



Methods

Rainbow radish and garden cress were chosen to be the initial organisms tested due to their indifference to minor changes in their environment. To examine the potential effects of simulated K-dwarf radiation on oxygenic photosynthetic organisms, the plants are tested in three distinct photic environments: G2V analog (left Figure 2), K-dwarf analog (right Figure 2), and aphotic control. Due to the photo-sensitive nature of this project, all experiments are carried out in a dark room located in Agnes Scott College's Bradley Observatory.

VIVOSUN offers AeroLight LED boards that mimic our Sun's spectral profile. Using this as a base, a simulated K-dwarf profile can be curated. A first attempt to simply tape the LEDs to push the spectrum away from the blue/green and towards the orange/red failed leading to the development of custom acrylic plates that will hang between the plants and the AeroLight. These plates will be implemented upon the improvement of temperature and humidity consistency.

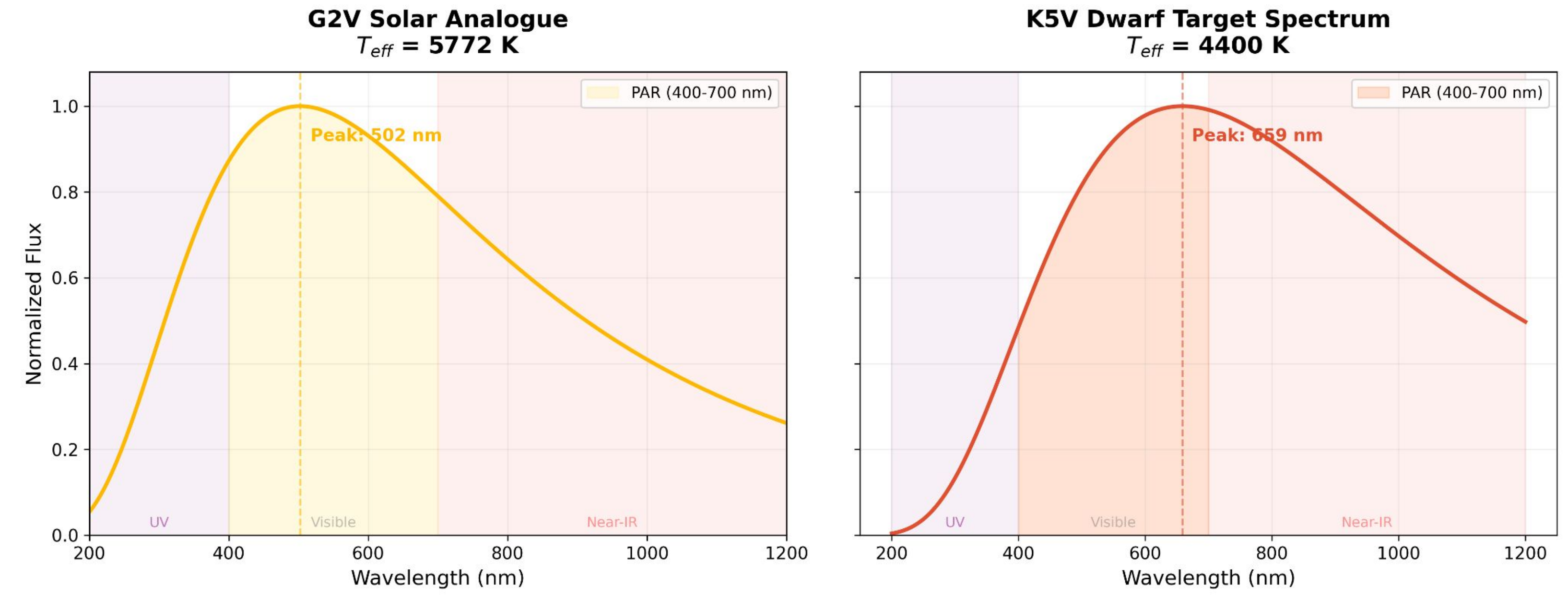

Figure 2 –Blackbody simulated spectra of a G2V Solar analogue (left, T_eff = 5772 K) and a K5V dwarf (right, T_eff = 4400 K). The K dwarf peak shifts ~157 nm redward. Shaded regions indicate PAR (400-700 nm).

The plants are grown in week-long cycles with uniform hours of illumination and water. At the end of each cycle, temperature and humidity fluctuations are analyzed. A PAR meter has recently been implemented to ensure the plants are receiving an accurate amount of radiation for their respective star analog.

Preliminary Results

Prior to the implementation of a K-dwarf analogue, two preliminary grow cycles were performed to ensure proper humidity and temperature levels. Grow 1 lasted 14 days and only a singular set of seeds and grow tent were used. Grow 2 lasted 6 days and included two grow tents equipped with humidifiers and a controlled dark grow tent.

The preliminary results showed that Grow 1 had lower humidities: 29%-54%. Grow 2 showed humidity had improved after the addition of humidifiers: 40%-90%. Combined with deeper initial rooting, the plants grew faster and taller in less time (Figures 3 and 4). The desired humidity for the experiment is ~ 70% to help the plants grow and to prevent mold.

400 μmol/m^2/s is needed for the K-dwarf plants and 800 μmol/m^2/s for the solar plants to accurately model the stellar environments. With initial PAR values at ~100, luminosity of the AeroLight was increased. Immediate results found intense overheating in the tents with grow tent 2 (Magic Grass) showing a temperature jump from 78°F to 87°F. After its intensity was lowered, it continued to stay above 80°F and around 10°F hotter than tent 1 (Astroturf), which had the same set up but lower luminosity. We want the max temperature to be 80°F to ensure the plants do not overheat.

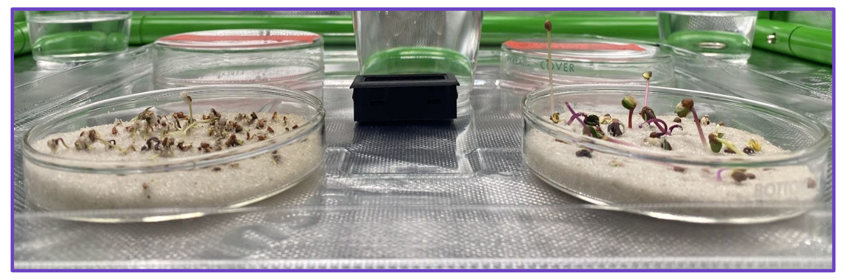

Figure 4 – Astroturf Grow #1, day 12, side view

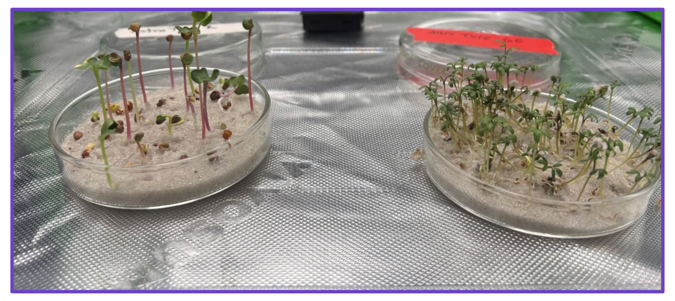

Figure 5 – Astroturf Grow #2, day 6, side view

Conclusions & Next Steps

In our previous grow trials, we had significant fluctuations in humidity and temperature, and low PAR values which contributed to inconsistent and slow growths. To manage this, we installed humidifiers that can be set to a specific humidities and have ducted them into both the G-dwarf and K-dwarf tents. Controlling the humidity will help control temperature since both factors influence one another. The temperature and radiation will also be controlled by the Vivosun. In addition, we are adding fans to improve airflow inside the tents. The fans will help consistently distribute humidity and temperature, preventing heat build up around the plants, and around the tent in general. Tables were added to elevate the plants, which will further improve air circulation and will allow for improved PAR values without cooking the tents.

PAR values are measured inside the tents using the Vivosun LED boards to determine the proper plant height and intensity settings. Our data showed that with the LED at 100% and the plants positioned higher in the tent, the PAR levels align with our G-dwarf target (Figure 6). At 50% intensity, the PAR levels align with our K-dwarf target (Figure 7). In earlier grows, the plants were positioned too low and were not receiving enough PAR, which contributed to the drooping we observed. To try and solve this, we are raising the plants closer to the LED to ensure they receive proper light intensity.

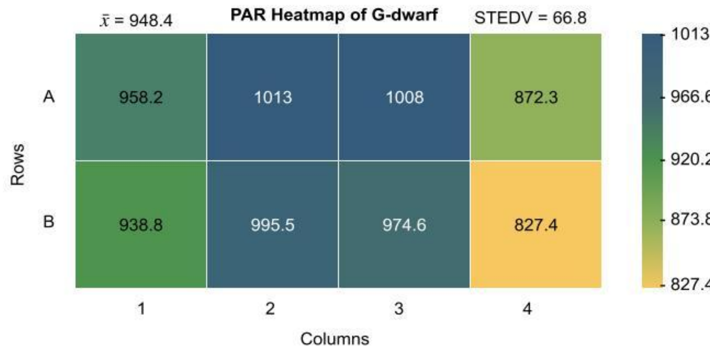

Figure 6: Heatmap of Photosynthetically Active Radiation (PAR) intensity across plastic table surface of the vivosun at 100%.

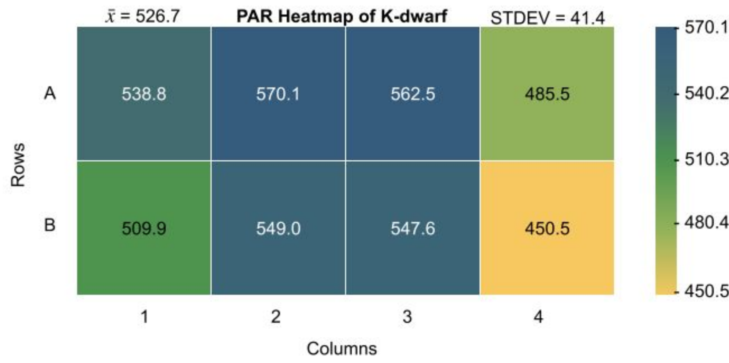

Figure 7: Heatmap of Photosynthetically Active Radiation (PAR) intensity across plastic table surface of the vivosun at 50%.

Finally, to better simulate young K-dwarf conditions, we plan to add additional LED strips to compensate for the excess UV radiation, targeting wavelengths near 300 nm. Acrylic plates will be incorporated to adjust the G-type Aerolight to a more K-type profile. K-dwarfs peak at approximately 660 nm (in the red) compared to G-dwarfs peak in the 500 nm (in the green). This adjustment shifts towards longer wavelengths, increasing infrared while also improving the UV range to better match young K-dwarf conditions.

Citations

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4. Arney, G.N. 2019, ApJL, 873, L7.
5. Cuntz, M. & Guinan, E.F. 2016, ApJ, 827, 79.
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Acknowledgments

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