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Final Project: Write-Up

The search for other habitable planets is a tale as old as time. As time has progressed and science has caught up, the search has continued and become more nuanced. It is now analyzed based on mass, the overall metallicity (Z) and O/Fe ratios. These are 3 key factors in examining the habitable zone (HZ) of an exoplanet based on physical characteristics - most older methods and schools of thought are being disproven or have conflicting data that has been presented in recent research. For the scope of this paper, the data set is focusing on varying Zsol levels of 0.3 Zsol - 1.5 Zsol with one Msol and the effects on the HZ over the lifetime of the star. The HZ will change as the luminosity (L) of the star changes and as a result will be pushed further back as L increases and vice versa. It is also necessary to analyze temperature (T) as that will also change over time in respect to the L revealing an evolutionary timescale for the star and therefore a rough map on where and when the HZs are (Figure 1).

Typically, looking for the boundaries where water can be sustained in a liquid state for a long period of time is a way to get a rough estimate on where the HZ should be. For Earth, water has been sustained on the planet for approximately 2 Gyr. The distance from Earth to the Sun is often used as a model for finding the 'Goldilocks' zone of another star. Another good indicator that helps eliminate candidates is looking at what kind of star it is. An O or B would not be realistic candidates for supporting life. These types of stars, O and B, burn fast compared to a M or K star often only lasting for about 3 - 200 Myr while smaller stars, like G, M and K stars, live for about 15 - 100 Gyr. G, K and M stars are much more likely to be better candidates and they also tend to be more similar to our own Sun, which is a G star. Ideally, it would at first thought behoove to limit the search to G stars but an M or K star would potentially offer the same value, just a closer and smaller HZ in comparison to the G stars offerings. As we currently know it, only Earth is confirmed to be supporting life though many other solar objects are thought to have the capacity to.

In general, two things occur when Z increases; 1) the luminosity decreases and 2) the lifetime increases considerably. Both of these factors can have heavy effects on the HZ throughout the lifetime. Say for in the case of 0.3 Z, the HZ would be generally less wider, more stable and would allow a greater chance for life to establish versus a case of 1.2 Z. The latter case would see a HZ that would exist for shorter increments of time equaling less stable conditions making it more difficult for life to take hold. Based on Earth's timescale, it takes about 2Gyr in the HZ in order for life to be sustained. The latter case though would have greater width in its HZ though. This is due to the increase of L that would come with a more metal rich star - the energy would be able to go a further distance and would have a less rapid gradient in T the further away from the star.

In general terms, each of the evolution tracks have the same shape with only the limits on T and L changing with respect to Z. As the Z increases, there is a decrease in maximum T reached but in return the star has a more time spent being in a more controlled environment than the less metal rich stars. The time spent on the main sequence (MS) is spent in a more narrow range of T with a star with a higher Z value and consequently this gives more time for habitable conditions for life to form. Conversely, the HZ for these stars are closer as they are less luminous and the planet(s) need to be positioned so to get their energy necessary to fuel life. This creates a more narrow window for where the planet could exist but provides a longer time frame.

With more metal rich stars, there are more reactions that are occurring and provides a diverse range of material. Only the slightest change is needed to reflect a big shift in the likelihood of life developing in any form. With increasing abundance of different elements, there is a host of new windows to give thought to. An increase of O/FE can provide an increase in MS turnoff age by about 1 Gyr. This is crucial as it changes the overall evolutionary model of the star - either all the phases are longer and processes are happening over a longer period of time or there are more phases taking place. The increased time can allow for a more evolved star once it reaches the turnoff point. Oxygen is a metal that can cause great change in the environment of the star.

The trends in the data support all of the theoretical analysis - that the habitable zone although smaller width at high metallicities do last for a greater period of time as well as being located closer to the star. For a star with a 0.3 Zsol value has the widest habitable zone with the boundaries being approximately 1.5 AU wide while for 1.5 Zsol value the boundaries are approximately 1 AU wide. The timescales begin around 2.25e-17 s at 0.3 Zsol and ending around 3.65e-17 s at 1.5 Zsol. The graphs that were produced for the HZ match up with the trends seen in the evolutionary track. Shortly after the starting point for the MS, the habitable zone comes into existence and follows an increase of distance from the star as the T and L increase. At the turnoff point for the MS, we see the HZ disappear as the star begins to enter the end stages of its life. This makes sense as the star is preparing to die, it expands immensely and reaches the most luminous and hottest stages of its life (minus its birth).

It is very interesting that life has begun so readily and healthily on Earth and there has been no further discoveries of life throughout the universense or even just our galaxy. As it has been pointed out, there is almost a problem of there being too many candidates to visit. Analysis using observational and mathematical techniques is key to weeding through the prospects. It would also be necessary to take into account for all errors that could go wrong with observations or human mistakes. In measuring the absolute magnitude of the stars, which is needed to establish L, there can be errors in humans interpretations of the data. It is possible that measurements could be incorrect enough to impact the data to shift the HZ it's width resulting in trouble finding a sweet spot in the modeling. This poses a huge problem in the process of picking candidates to be the subject of a mission.

As the search for life continues, the knowledge that is currently available should be used more readily in finding life on other planets. It is incredibly necessary to theorize with given information, search for more relevant information and to analyze it. It is going to be incredibly difficult as simple changes in metal abundances can change the width or location of the HZ but will be necessary to fine tune what is known. There also could be renewed interest as to why life has so readily developed and flourished on Earth - maybe there is a key bit of information or an unknown process that could change the current framework of thinking. It is critical to further our understanding of the factors that go into creating life and what elements are absolutely essential. From showing the HZ changes in respect to Z, and a host of other variables, it’s shown all the possibilities that lie in space.

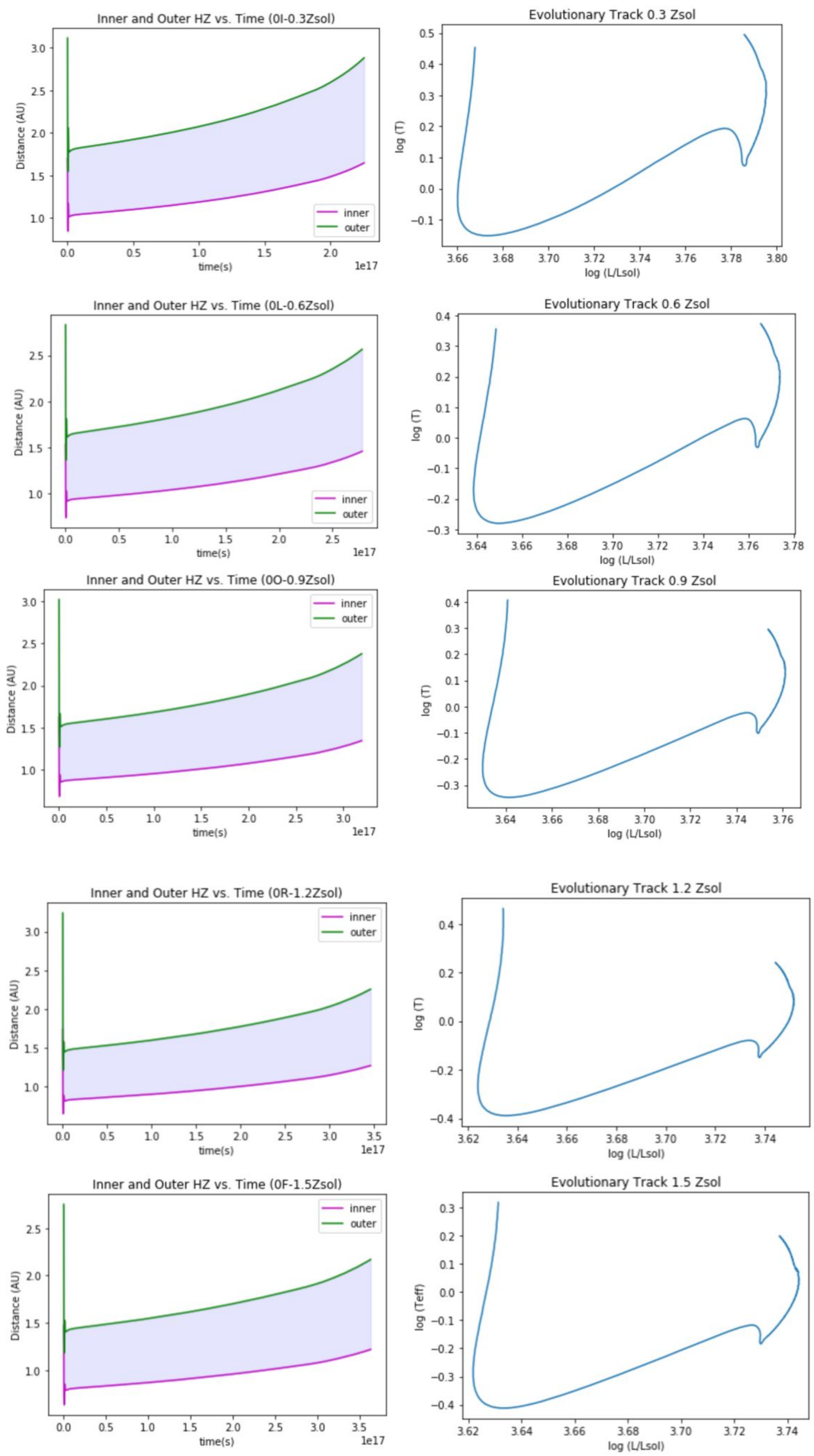

Figure 1: Evolutionary Tracks and HZ v. Time graphs for the various Zsol values at one Msol.

COPY OF CODE USED

```
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd

stellarModel = open('hr.0F 1.5zsol', 'r')

i = 1
tstep = 0

dataframe_hr = pd.read_table(stellarModel,delim_whitespace=True,names=np.arange(14))
nrows = np.shape(dataframe_hr)[0]

#Code reads in log(temperature) (T), log(luminosity/Lsol) (L), time in seconds (t), and stellar radius in cm (r).
T_array_hr = []
L_array_hr = []
t_array_hr = []
r_array_hr = []
for i in range(nrows):
	if i%19 == 0:
	T_array_hr.append(dataframe_hr[8][i])
	L_array_hr.append(dataframe_hr[7][i])
	t_array_hr.append(dataframe_hr[2][i])
	r_array_hr.append(dataframe_hr[4][i])

plt.plot (T_array_hr, L_array_hr)
plt.title ('Evolutionary Track 1.5 Zsol')
plt.xlabel ('log (L/Lsol)')
plt.ylabel ('log (Teff)')
plt.xlim (3.618,3.748)
plt.show ()


stellarModel.close()

S_eff_sol_in = 1.107
S_eff_sol_out = 0.356
a_in = 1.332e-4
```

```
a_out = 6.171e-5
b_in = 1.580e-8
b_out = 1.698e-9
c_in = -8.308e-12
c_out = -3.198e-12
d_in = -1.931e-15
d_out = -5.575e-16

S_eff_in = []
S_eff_out = []
for x in T_array_hr:
        T_star = 10**x
        T_eff = T_star - 5780
        S_eff_in.append(S_eff_sol_in + (a_in)*T_eff + (b_in)*T_eff**2 + (c_in)*T_eff**3 +
(d_in)*T_eff**4)
        S_eff_out.append(S_eff_sol_out + (a_out)*T_eff + (b_out)*T_eff**2 +
(c_out)*T_eff**3 + (d_out)*T_eff**4)
S_eff_in = np.array(S_eff_in)
S_eff_out = np.array(S_eff_out)

L = []
for x in L_array_hr:
        L.append(10**x)
L = np.array(L)

d_HZ_in = (L/S_eff_in)**(1/2)
d_HZ_out = (L/S_eff_out)**(1/2)

plt.plot (t_array_hr, d_HZ_in, 'm', t_array_hr, d_HZ_out,'g')
plt.title("Inner and Outer HZ vs. Time (0F-1.5Zsol)")
plt.xlabel("time(s)")
plt.ylabel("Distance (AU)")
plt.fill_between(t_array_hr, d_HZ_in, d_HZ_out, color='blue', alpha='0.1')
plt.gca().legend(('inner','outer'))
plt.show
```