Where Are The Habitable Planets in our Local Group of Galaxies?

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1 Abstract

We have combined the models on the habitability of passive and star forming galaxies completed by Gobat & Hong[5] with a local group galaxy data set created by McConnachie [8] to determine where in our local group the habitable planets are located. By approximating an upper habitability limit of -2.19, we were able to create a cumulative distribution function that demonstrated that the habitable star systems are predominantly located in the largest local group galaxies.

2 Introduction

With the release of the first James Webb Space Telescope (JWST) images being released in the last couple of weeks, the intrigue surrounding space has never been higher. This has resulted in the "*are we alone*" discussions returning as a predominant conversation topic. While the public focuses on *if* there is life, we have decided to direct our efforts to *where* there is life; more specifically on a scale relative to our local group (LG) of galaxies. With the concept of circumstellar habitable zones (HZ) being fleshed out in the past couple of decades, the idea that galaxies might contain a similar mechanism has been theorized. This region—later referred to as the galactic habitable zone (GHZ) [6]—has been sparsely defined as the region within a galaxy where star and planet formation can provide the necessary heavy elements for a planet to sustain an active biosphere for a consequential amount of time [12], [5]. It is theorized that too low of a metallicity threshold would hinder the protoplanetary disk's ability to accrete large enough rocky bodies and in turn would result in star formation winds blasting away aggregated gas and dust[4]. Furthermore, the concept of heavy elements, in particular CHNOPS (Carbon, Hydrogen, Nitrogen, Oxygen, Phosphorus and Sulphur) has become prominent in the field of astrobiology. These elements that make up the building blocks of life have understandably been linked to metallicity research and in early-stage star forming regions (SFR) and protoplanetary disks[3][9][10][11]. Simulations completed by Johnson and Li propose the idea that disks with metallicities $Z \geq 0.1Z_{\odot}$ are responsible for the formation of the first Earth-like planets[7]. Despite this, no known exoplanet discoveries have displayed these trends[4]. However, there is hope that over the next couple of years, further research and discoveries will help this field of research move forward and hopefully a correlation might be found.

The majority of GHZ and other habitability research has been primarily focused on the Milky Way (MW) thus far. This paper looks to expand the horizons of our knowledge by exploring the habitability of all galaxies in our LG.

3 Results

Rather than exploring where the habitable planets in our galaxies could be, we began our research with where the habitable planets are *not*. A planet's ability to retain an atmosphere over a billion-year time scale is critical to life evolving and thriving on that planet. Hence, phenomena capable of stripping planets of their atmosphere become critical to avoid. Such factors as stellar activity and extreme radiation from nearby high-energy sources fall into this category. One quantity that has been explored in detail is a variable known as the galacto-centric radius: an area by which a planet would need to be, in order for the active galactic nuclei (AGN) wind to overcome the magnetosphere and begin to destroy the atmosphere[2]. Through examining the atmospheric loss caused by extreme ultraviolet (XUV) radiation, Balbi & Tombesi were able to derive a useful equation for the distance from the galactic center where a planet loses an atmosphere mass M_{lost} after a time Δt :

$$D = \left[e^{-\tau} \varepsilon \left(\frac{M_{atm,\oplus}}{M_{lost}} \right) \left(\frac{L_{XUV}}{4.5 \times 10^{44} ergs^{-1}} \right) \left(\frac{\rho_{\oplus}}{\rho_P} \right) \left(\frac{\Delta t}{1.96 \times 10^7 y} \right) \right]^{1/2} kpc \tag{1}$$

Where τ is the optical depth, $M_{atm,\oplus}$ is the mass of present day Earth's atmosphere,$\rho_{\oplus}$=5.5g cm^{-3} is the density of the Earth, ρ_P is the bulk density, L_{XUV} is the average extreme ultraviolet luminosity, and ε is the efficiency parameter[2].

The other variable discussed in this paper involves the proximity to supernova (SN). At a distance less than or equal to 8 parsecs, a supernovae explosion can result in the depletion of 30% of a planet's atmospheric ozone. If you take that distance down to 0.04 parsecs, the outcome becomes complete atmospheric evaporation, and eradiation of all life, making SN the most direct threat for galactic habitability[1]. It should be noted that these values are calculated using an approximate magnetic field of similar strength to Earth and the assumption that the planet's magnetosphere would react to radiation in a similar way to that of Earth. The research completed in Gobat & Hong's *Evolution of Galaxy Habitability* provided useful knowledge on the topic as well as a definition of habitability that we adapted for our own research. They came to define the habitability h_G of a galaxy at redshift z to be the ratio of the number of main sequence stars of age $\leq$ t$_{min}$ = 1 Gyr, mass $\leq$ 1.5 $M_{\odot}$, and with planets in their HZ, to the total number of stars present in the galaxy at z[5]. The equation below is a simplified version of h_G used in our computations,

$$h_G = \frac{N_{hab}}{N_*} \tag{2}$$

With N_{hab} being the number of main sequence stars that meet the above criteria and N_* being the total number of stars present in the galaxy at z. Their team used this definition to create a plot that represented h_G with respect to the galactic mass for passive and star forming (SF) galaxies. Data from McConnachie[8] was then used to compile a list of all the galaxies in our LG and their masses. The following reasonable assumptions were made:

1. The average mass of a star was taken to be $9.945 \times 10^{29} kg : 0.5 M_{Sun}$. This is a rather crude approximation; however, it aids the purpose of this paper.

2. The habitability of any galaxy with a mass less than that, or which extends beyond that of the graph (9.0-11.5) will be taken to be the lowest value on either the passive or SF line the graph displays. This will create an upper limit for our values.

3. The total number of stars in each galaxy N_*, was approximated as $N_* = M_*$/average mass of a star, with M_* as the approximate mass of the galaxy.

With these assumptions in place, the habitability of each galaxy in our LG was approximated using the habitability plots from Gobat and Hong[5]. As mentioned in our assumptions, an upper habitability limit of -2.19 was set for our data. The habitability then scales with the size of galaxy with Andromeda having the largest value of h_G = -2.14. Using these habitability values, equation (2) was rearranged to solve for N_{hab}. This allowed for the computation of the number of MS stars in each galaxy that meet the criteria for habitable planets.

The largest galaxy in our LG, Andromeda, was found to have an N_{hab} value of 1.49×10^9 stars, whereas the smallest galaxy in our data set, Segue (I), had an N_{hab} value of 4.39 stars. The range expressed in this data can be better displayed using this cumulative distribution function in Figure 1.

As seen displayed in Figure 1, much of the stellar mass in our LG is present in the larger galaxies. Consequently, it can be expected that the bulk of stars that meet Gobat and Hong's criteria are also to be found in the larger galaxies such as Andromeda and the MW[5].

4 Conclusion

Based on the data sets created by McConnachie[8], and the habitability plots by Gobat and Hong[5], we arrived at the expected conclusion. The distribution plot was able to demonstrate how most of the LG stellar

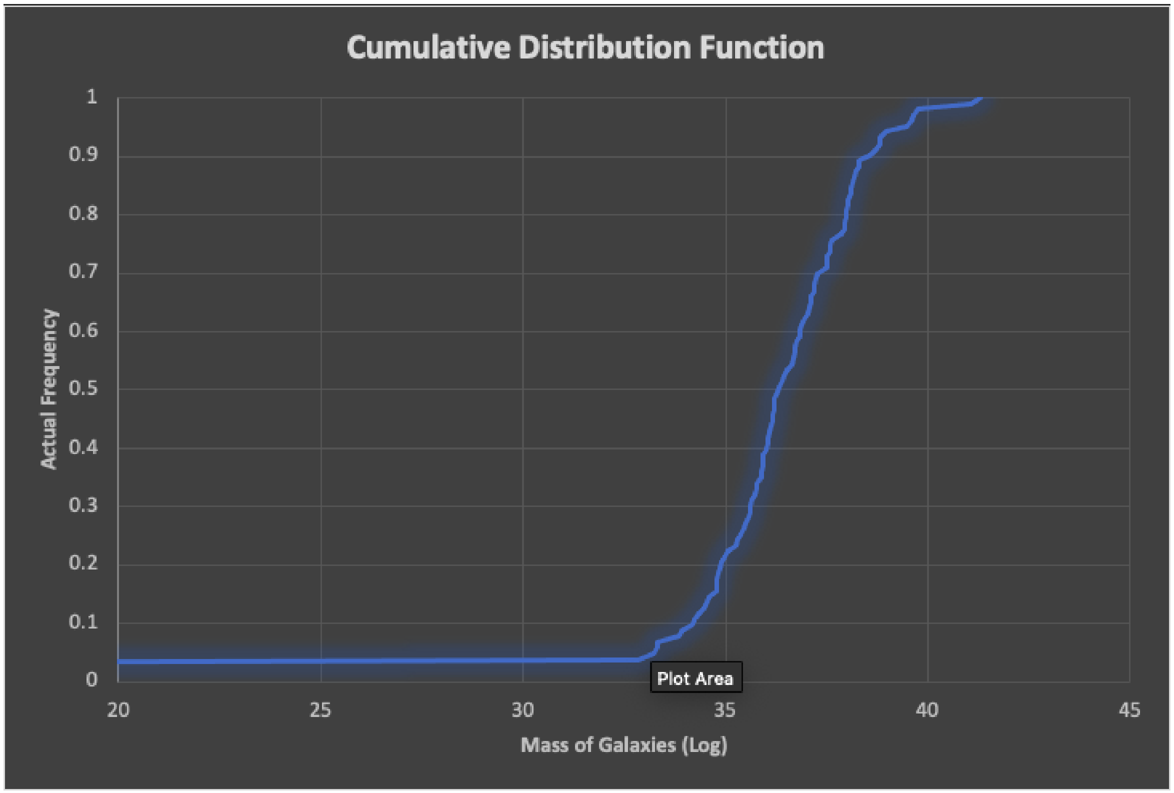

Figure 1: Cumulative distribution of planets in the galaxies with $M \geq M_{Galaxy}$, with respect to the log of the mass of the galaxies.

mass is predominantly located in the larger galaxies. Moreover, through the definition of the habitability constant h_G, the number of habitable planets in each galaxy with age $\leq t_{min} = 1$ Gyr, mass ≤ 1.5 $M_{\odot}$, and with planets in their HZ, was estimated. With each large galaxy in our LG containing millions of potentially habitable systems, the answer to whether we are alone in this universe becomes increasingly close to having a definitive answer.

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