Message in a Bottle - An Update to the Golden Record

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Abstract

Communication is an essential asset enabling humankind to forge an advanced civilization. Using approximately 31,000 languages from the Stone Age to our present digital information society, humans have connected and collaborated to accomplish remarkable feats. As the newly dawned Space Age progresses, we are attempting to communicate with intelligent species beyond our world, on distant planets and in Earth's far future. Absent mutually understood signs, symbols, and semiotic conventions, this study, the "Message in a Bottle", uses scientific methods to assess and design a means of communication encapsulating the story of humanity, conveying our thoughts, emotions, ingenuity, and aspirations. The message will be structured to provide a universal yet contextual understanding of modern human society, evolution of life on Earth, and challenges for the future. In assembling this space and time capsule, we aim to energize and unite current generations to celebrate and preserve humanity.

Message in a Bottle – An Update to the Golden Record

Part I: Objectives and key content of the Message

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Abstract

Communication is an essential asset enabling humankind to forge an advanced civilization. Using approximately 31,000 languages from the Stone Age to our present digital information society, humans have connected and collaborated to accomplish remarkable feats. As the newly dawned Space Age progresses, we are attempting to communicate with intelligent species beyond our world, on distant planets and in Earth's far future. Absent mutually understood signs, symbols, and semiotic conventions, this study, the "Message in a Bottle", uses scientific methods to assess and design a means of communication encapsulating the story of humanity, conveying our thoughts, emotions, ingenuity, and aspirations. The message will be structured to provide a universal yet contextual understanding of modern human society, evolution of life on Earth, and challenges for the future. In assembling this space and time capsule, we aim to energize and unite current generations to celebrate and preserve humanity.

1. Introduction

How would we want humanity to be perceived by extraterrestrial intelligences, by future generations, or by archeologists of different species if our civilization were to disappear? The *Voyager Golden Records*, an early attempt at off-world communication, served not only the purpose of sending a *record* about Earth and humanity into deep space, but also stands as a worthy effort to establish contact with advanced alien civilizations. Such extraterrestrial intelligences (ETIs), dwelling somewhere in our galaxy or even beyond, have long been theorized but remain completely unknown to us as perhaps they too are unaware of Earth. *Message in a Bottle* (MIAB) continues this quest of finding answers to the provocative question put forth by the Roman Epicurean Lucretius - *Are we alone in this vast ocean of the cosmos?*

MIAB would be sent into interstellar space aboard an uncrewed probe with the hope that an advanced, space-faring civilization would discover this communique from humanity. A direct descendant of the Golden Records launched aboard Voyager 1 and 2 in 1977, MIAB is a radically advanced and carefully detailed reconsideration of its predecessor. This paper, the first in a series, presents the possible nomenclatures, objectives, structure, and suggested key content of new and more expansive messages that recites humankind's and Earth's history to a distant civilization.

Although it is highly unlikely that an alien civilization would receive our message, the archived identical version maintained on Earth would likely give invaluable insights about us and our legacy to future generations or perhaps future intelligent beings who might someday arrive on Earth. The message shall not only serve the purpose of laying the groundwork for establishing successful communications with extraterrestrial civilizations, but will also set an ever-lasting impression of what humanity truly is and can achieve both in the vast ocean of the cosmos and here on Earth.

2. Purpose and Objective

Imagine if we received a message from aliens detailing themselves and their way of life. Such a confirmation of the existence of self-aware living beings in the cosmos has the potential to radically change humanity's perspective about our place in the universe and influence the course of human history. Extraterrestrials may be pondering the same question and if they receive a message from us, it could be similarly transformative. The importance of first contact, with all the hope, wonder and potential for advancing our civilization's technical and social knowledge, cannot be overstated. Accordingly, we need a clear vision and purpose in the design of messages humanity sends forth, leveraging diverse and collaborative efforts to sufficiently represent humanity. In the nearly half century since Voyager, our society and technology has advanced substantially, enabling the creation of more detailed and representative messages.

To properly design the structure and content of this new message, we must imagine our audience in broad terms as we develop a clear purpose and objective. In one scenario, our spacecraft is intercepted by a highly advanced space-faring civilization, Type 2 or greater on the Kardashev Scale [1]. Logic suggests three potential outcomes: 1. They ignore us because it is not worth the effort and resources to respond, perhaps considering humans to be too primitive to interact with, as if an ant tried to get a human's attention; 2. They make contact and our two species interact; 3. They simply learn about us but there can be no further interaction as humans have gone extinct. In all outcomes the message plays a critical role in influencing reaction, hence the purpose is one of diplomacy- i.e., inviting a response which can lead to greater possibilities. In order to facilitate understanding, any message should contain more than just facts and figures, but a window into our lives and achievements, our talents and passions, and our aspirations. In any case, it is crucial to show humans as an intellectual, emotional, caring species worthy of interacting with regardless of the distance, time, and energy required to respond. To capture their interest and imagination even in a future where humans are extinct, we should strive to make the message as engaging and informative as humanly possible.

In an alternative scenario, the spacecraft reaches pre-Type 1 civilizations who are not yet space-faring. Our message must arrive intact on the surface of their planet like a "black box" recorder found after an airplane crash. Accordingly, the structure and content of the message will be organized in two tiers to accommodate aliens with different levels of sophistication. Tier 1 content will consist of simply illustrated fundamental concepts and information about humanity and our environment using a medium not requiring power or specific devices to sense, thus accessible to a pre-industrialized society. Tier 2 content will include more complex information in a digital format intended for alien civilizations that are closer to Type 1, possessing the ability to view the content and learn about us in a more detailed and meaningful way. Even if the aliens are not technologically capable of interacting with the digital content at the time of the encounter, they can eventually learn more about us as their civilization matures. In either scenario, the purpose of our message is to inform about our existence and inspire them to someday make contact with us.

As the spacecraft travels through the vastness of the cosmos, with even the nearest star 4.2 lightyears away, the most likely outcome is that it will wander endlessly without ever making contact. Or it may be that we are alone in the universe; there are no other intelligent life forms to find our message. In this sobering case, the audience of the message is not extraterrestrials but rather humans ourselves. The purpose of the message will be to create and preserve a comprehensive record about humanity and Earth in videos, images, and sounds. In doing so, the message provides an opportunity to reflect on and celebrate our character, culture, knowledge, environment, and accomplishments. It would stand as a demonstration to our bustling civilization of so far eight billion individuals, as well as the generations to come, of how connected we are as one species, sharing a common origin, home, and purpose. While parted in so many ways, we are also united as members of the same species across our world with a shared feeling of pride in what we have accomplished and how far we have reached into an otherwise quiet cosmos. It is also a kind of time capsule of human civilization and the Earth prior to the 2030s, opening the prospect for future generations to find valuable historical relics. If Earth is destroyed in the future, we can at least take some measure of comfort that a record of humanity survives in deep space.

3. Suggested Message Names

To begin, we must first decide how the *Message in a Bottle* will itself be known among the technological race which creates and sends it forth into the cosmos. As the content of the MIAB is to be representative of all humanity, as well as be sourced in part from the public, the name we chose carries great importance. For such an undertaking the dryly descriptive, however sufficient in dispassionate correctness, is not likely to achieve the critical goal of inspiring broader wonder and engagement. The first impression, if succulently captured in a well-chosen name, can well be the key which opens the door to successful collaborative creation.

Keeping such considerations firmly in mind, a short list of possible names for the MIAB is suggested below, and their respective rationales are explained in the Appendix A.

1. *Earth and Our Nature (EON) Record & Archive.*
2. *Earth's Record & Archive.*
3. *Interstellar Wanderer.*
4. *Humans on Earth's Record & Archive,*
5. *大 Record.*

4. Suggested Content of the MIAB

The idea of *Time Capsules* has not only been an emerging realization of a more rational and scientific society, but its essence has been anticipated since millennia. In pursuit of this irresistible temptation of communicating with the future, virtually every ancient civilization attempted to create their record and in the best possible cases, these records allow us to paint a detailed picture of our own past, often giving us a *perspective of the significance of our own actions at this moment* *in the long journey of our species* [2]. In this section, we focus on the most important aspect of our proposed record — *content*. Taking into account the rich and carefully designed sequence of information embedded on board the first Voyager Golden Records, we discuss possible modifications besides proposing newer content in order to mark our socio-economic and technological advances since the launch of the Voyager in 1977. We also attempt to fix the imperfections (which may lead to misinterpretation of the message) that were present in the Golden Record due to the inadequacy of the necessary technologies required for their elimination [3]. In short, the content of the updated record will not only serve the purpose of yet another record, but will bear the timeline of human civilization from the ancient past to the latest present and possible causes of our extinction into the future.

4.1 Key Components of the MIAB

Figure 1 illustrates the key components we consider to be included in the MIAB, while Figure 2 (in the next subsection) illustrates the logic-based guidelines to design these components, detailed in follow-on papers. To support communicating meaningfully with an intelligent alien civilization, we have laid down three assumptions for establishing relevant parameters to guide efforts in effectively developing the structure and content of the message. Starting with our primary hypothesis, let us assume that all intelligent life with an advanced civilization, both scientifically and technologically, cannot do so without sophisticated communication and collaboration, regardless of their physiology and home planet's ecosystem. Even if they develop more advanced communication, extraterrestrials will still possess some method and system of communication that resembles language, or they might have the capability of more advanced forms of communication. For our second assumption, we assume the aliens possess sensory modalities to perceive and interact with the world around them, albeit their sensory organs may be very different from those of humans. Due to physical constraints in accordance with the laws of physics across the universe, there are a limited number of likely pathways that the evolutionary process could take to develop the most efficient sensory systems. Therefore, it is reasonable to assume they have an inherent ability to sense and process stimuli from electromagnetic (EM) waves, analogous to the human visual sense, and/or oscillations in pressure, comparable to our audio sense. Although the range and/or mode of interpretation of their perception of EM wavelengths might be quite different, they would fundamentally "see" the world around them and/or "hear" sounds within a certain range of auditory frequencies. For our final and most critical assumption, we consider that aliens can integrate and process information, think logically, and learn. With these three assumptions, we have a starting point for creating a message incorporating deep and complex information sufficiently representing the intricacies of humanity. While there are still many challenges to creating a universally understandable message, these assumptions lend a measure of confidence that extraterrestrial intelligence could decipher and understand the intended meaning of a carefully crafted message.

The message shall be housed in two mediums, a *scroll* and an advanced *minicomputer*. We propose incorporating a series of images to display elementary information about humanity and Earth on the *scroll*, intended for simple direct perception (e.g., visual or tactile sensing) by extraterrestrial civilizations that are relatively less technologically advanced. For civilizations at least at the current level of human technological advancement or beyond, the record shall consist of instructions based on a symbolic representation of the procedure to reveal the digital message in the correct sequence on the *minicomputer*. Vast amounts of information would then be accessible in the form of videos, images, sounds, games and simulations, text, mathematical models, and computer code.

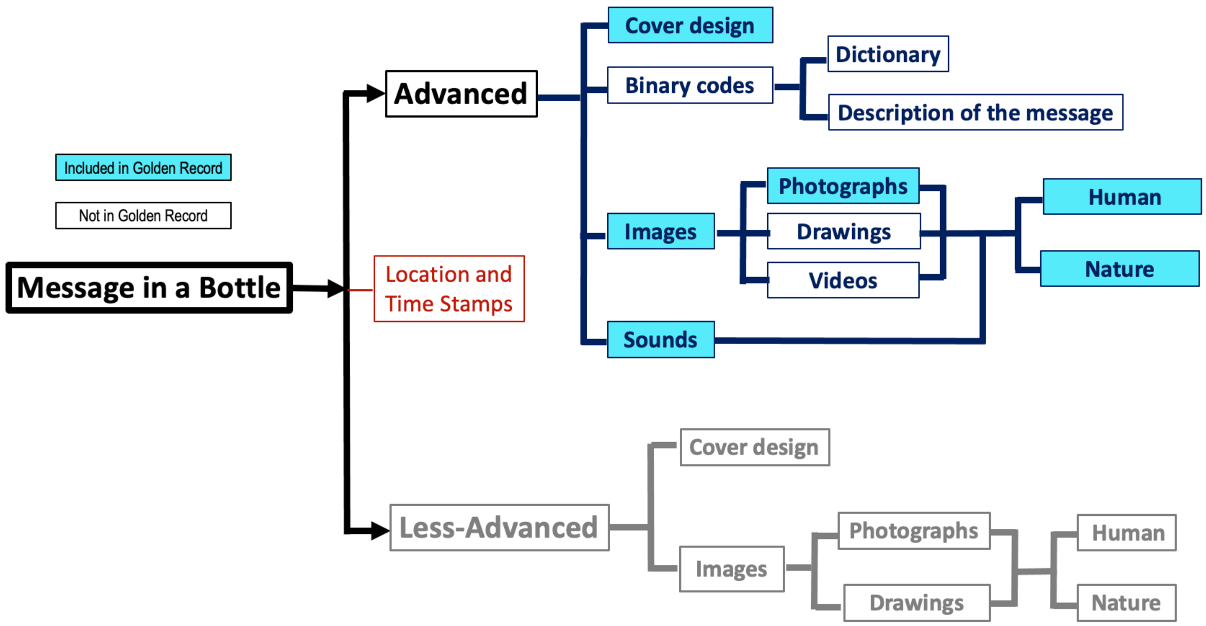

Figure 1. A diagram illustrating the key components of the Message in a Bottle (MIAB).

One challenge not easily recognized is that an interstellar message, if received by ETI, is received without any context to help interpret it. The message is not situated against any background outside of itself. By contrast, in trying to interpret the language of a newly discovered people or communication among animals, one can observe the behavior of the people or animals in question. Isolated, our message will not be received against this sort of background. Beyond that, ETI have no social, cultural, or historical background of humans or life on earth against which to interpret it. Finally, they may not share many of the ways we conceptualize the world as humans. These problems extend, in a more limited way, to future species on Earth or future humans not familiar with present culture. Key to the framework for the message is to fill this lacuna, i.e., the message should provide context for itself, as much as possible. We aim to accomplish this in three ways: using videos, carefully sequencing information presentation, and linking modalities (e.g., having combined images and sounds together rather than separate).

Video (including audio) provides a way of approximating the experience of landing on Earth and observing humanity directly. It also circumvents the issue of ETI first having to decode a symbolic system to understand the initial part of the message (though the instructions on how to play the video would have to be simply represented). The message will be hierarchical: each layer forms a key to the next, more complex layer, guided by the principle that each should be understandable and informative. In this way, earlier layers of video provide context for later layers; for example, the concept of music would be introduced in a simple way before major musical works and the importance of music in cultures around the world are conveyed. Furthermore, video provides context beyond that of separate images and sounds. Taking again music as an example, a video of a band playing a song has a better chance of being interpreted for what it is than an image of an instrument and a disconnected sound recording of a song.

The *Introductory Section* begins a scientific conversation through establishment of a common understanding using universal laws of nature on Earth and logical operations capable of bridging the gap between our comprehension to that of recipients. Some instances include discussion of basic mathematics, constant speed of light in vacuum, and the emission spectra of commonly occurring elements. We then introduce the Earth, our solar system and galaxy, based on fundamental concepts and facts that should be relatively straightforward to interpret by scientifically adept ETIs. Once we establish a basis for communication, it would follow to introduce translation tools with reference tables and dictionaries to create some building blocks and framework upon which more detailed communications would be rendered relatively simple. The second, *Teaching/Interactive Section*, will transition to topics about humanity and life on Earth which may be less familiar. Upon first contact, alien lifeforms would likely have little in common with humans and may not comprehend the intended purpose and meaning of the message. We therefore plan to include encoding and decoding keys for message encryption. Effective communication between two parties should be based on some commonalities and preestablished understanding regarding each other, thus the initial step would be to educate and initiate interactions with our message to develop shared experiences and a fundamental understanding. Accordingly, this section constitutes elementary information about various pertinent topics such as our emotions, social structure, culture, art, music and history. In addition to videos, sounds, text and images, we can include interactive activities and games to engage the recipients. By guiding the aliens to integrate some fundamental knowledge, in addition to glimpses of background and historical information, we can provide the foundation and context to rightly start understanding the more complex yet meaningful content that follows in the next section. Building on the second section with advanced knowledge and complex concepts, the third *Detailed Information Section* contains topics such as knowledge, technology, art, music, politics, culture, and economics, which represent the forefront of human ingenuity and creation. For economics, the second section will introduce basic concepts like trade interaction, supply and demand, and the value of money, while the third section will display the intricacies of global commodities markets, dynamic equity and debt markets, and intricate supply chains.

The taxa of knowledge that we plan to include will follow the principles developed by epistemologists and ontologists with respect to the organization and representation of knowledge as we have it today in our civilization. In computer science and information science, an ontology encompasses a representation, formal naming, and definition of the categories, properties, and relations between the concepts, data, and entities that substantiate one, many, or all domains of discourse. More simply, an ontology is a way of showing the properties of a subject area and how they are related by defining a set of concepts and categories that represent the subject. The three main branches of knowledge in the tree are: "Memory"/History, "Reason"/Philosophy, and "Imagination"/Poetry, as originally devised by Francis Bacon, and which largely also follow the epistemological classifications into perception, memory, introspection, inference and testimony. Additionally, we will use the classifications of science, cultures, and examples of what is a human, a society and life itself.

The team that designed and produced the original Voyager Golden Record did so in a span of weeks, but the effort to update that record into its new form, the *Message in a Bottle,* allows for years to design and produce a representative content of humanity. Along with leveraging this expanded time resource, the intent is to also engage the citizens of the world to provide ideas for the videos, images, sounds, games, and other digital content that will convey the essence of humanity and what life is like on Earth. The digital content shall explain what it means to hope and dream, to love and care about each other, to explore and create new knowledge, and to create art and music. This global effort will provide many perspectives and diverse ideas which illustrate the collective intelligence and experience of the human species. While all these components, though carefully engineered, may well make the message complex and thus difficult to understand, to be worthwhile it is imperative to capture the full array of humanity.

Harkening back to our past, but with an emphasis onto a detailed representation of the present scenario of human life and technological advancements, the contents of the newly designed message must incorporate the ideas of the Voyager Golden Records while including newer facts of the present. All of which, taken as a whole, shall be critical for a complete narration of our story – with whomever it may come to rest in the vast, seemingly endless ocean of the cosmos. In this context, the key components should include two broad categories based on the form in which the content would be encoded: imagery and sounds from Earth. Audio will not only include sounds from our natural surroundings, but also incorporate music and a myriad of others commonly encountered in our lives along with impressions of the modern and technologically advanced societal structure that we are all a part of. It should be noted, however, some images and their associated sounds should be connected, preferably by video, as de-contextualized sounds of Earth would be almost impossible to decipher. Considering a generally similar approach to that opted for in the content selection of the Voyager Golden Records, we shall as well suggest modifications while also including the most relevant content spanning the two generations which have elapsed. We have further classified the imagery content into two subsections that would address the three most important questions the recipients might be concerned with: the origin of the record, the senders of the record, and most importantly, a detailed overview of our nature.

4.2. Methodology for Key Components Design

The logic flow used in the overall construction of the MIAB content is illustrated in Figure 2. Essential in this endeavor are clearly stated controlling concepts serving as guiding principles, forming the conceptual foundation upon which the MIAB will be built. First, the location and timing of the MIAB's origin is articulated in objectively scientific terms, placing the message in context within the spacetime scale it is expected to traverse. Leveraging the methods of prior messages to ETIs afford an efficient means of accomplishing this. Next, the MIAB will be engineered as an emissary of Earth, encompassing the full spectrum of humanity, our planet including non-human life, and humanity's aspirations reaching to the future. Finally, in weighing the multitude of information to include, we employ as a sounding board what we, an emerging spacefaring civilization, would want to receive in a message from an ETI.

The bulk of the MIAB, which using present day technology could at least be derived in part from public input, will consist of the history of its creator species, descriptions of humanity's home world, and our hopes for what is to come. In describing ourselves, we logically begin with the long path evolution has taken us starting from the simplest of lifeforms, followed by the arc of civilization across the last 5,200 years. Encompassed within this description are our scientific achievements such as splitting the atom and space exploration, along with the wide array of cultures and knowledges which comprise the complex human tapestry. Having introduced ourselves, the physical Earth is then depicted in detail accompanied by an overview of the biosphere across the range of environments life has come to fill.

In completing the MIAB, humanity looks ahead to the far future. Our message can also be thought of as a testimonial, sent on behalf of our world and its life. To fulfill this role, an encapsulation of who we are in the present must also extend to what we intend to become – in short, our aspirations. Though assembled in a present whose troubles are all too apparent, the MIAB should speak to a helpful future of peaceful advancement above all else. In concert, such aspirations would see Earth and its biosphere preserved and protected even as humanity makes other worlds in the Solar System, and eventually worlds around other stars, our new homes. Returning to the most basic purpose, we conclude with an invitation to any ETI who may encounter the MIAB to reply with their own story. In summary, the MIAB's key components, collected and constructed via the logic flow described, will offer a comprehensive and eloquent statement worthy of humanity now and into the far future.

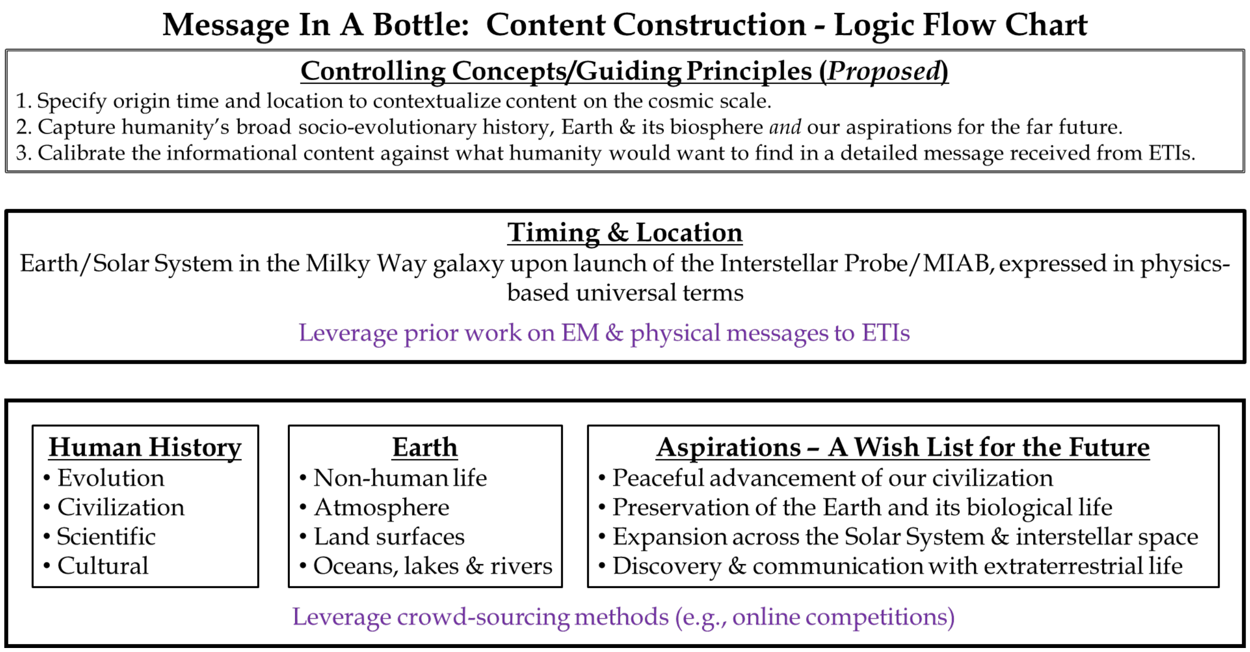

Figure 2: A diagram illustrating the methodology for the key components design.

4.3. Dictionaries

Dictionaries serve as one of the most efficient means of conveying large quantities of data due their immense potential for the symbolic and careful inclusion of rich and interconnected pieces of information through the utilization of concise imagery. Besides acting as a representative of the hierarchical classification of imagery chronicle with an increasing level of complexity, dictionaries exhibit the unique aptitude of their demonstration in the form of index tables, which reshape this genre into universally compatible set of information, often in conjunction with videography, the transfiguring notion of visualizing the world in unison with auditory effects that pose a phenomenal impact on the proposed next-generation of advanced content for the updated record. Dictionaries were a major constituent of the Voyager Golden Records and their forerunners, the Pioneer plaques, were themselves a type of dictionary, although with relatively lesser content.

For MIAB, we will utilize dictionaries as a means of not only ciphering answers, but also reflecting upon a prior universal knowledge that would indeed facilitate the understanding of our conventions and art of scientific communication from the perspective of the intended recipients. Therefore, the proposed dictionaries require carefully design methodology with an absolute priority on logic, a circumstantial discussion of which shall be laid out in further studies in this series. As a starting point, the projection of these distinctive documents might be two-fold, with a former class incorporating a detailed overview about the basic understanding of mathematics and physics (thus, also serving as a tool to unlock the rest of the quantitative information present in the record) and a latter class, conveying the more complex yet pivotal information about our origins, i.e., the solar system and our Earth as well as the major components that have made life possible on planet Earth, thereby signifying our home world as a planet where intelligent life is prevalent.

4.4 Our Location and Time Stamps

4.4.1 Location Stamp

One of the monumental aspects critical towards the careful design and construction of the proposed message is the inclusion of a logical representation indicative of our place in the cosmos. Assuming that the recipients are at least at the level of technological and scientific advancement as we are now, the need for schematic representation puts forth a myriad of diverse and wide-ranging options in terms of interpretable astronomical details. In other words, the design of an effective *galactic positioning system* (*GPS*) would take us one step closer towards the establishment of a generalized location map for the potential alien races to discover humanity and in-turn, our pale blue dot of a home.

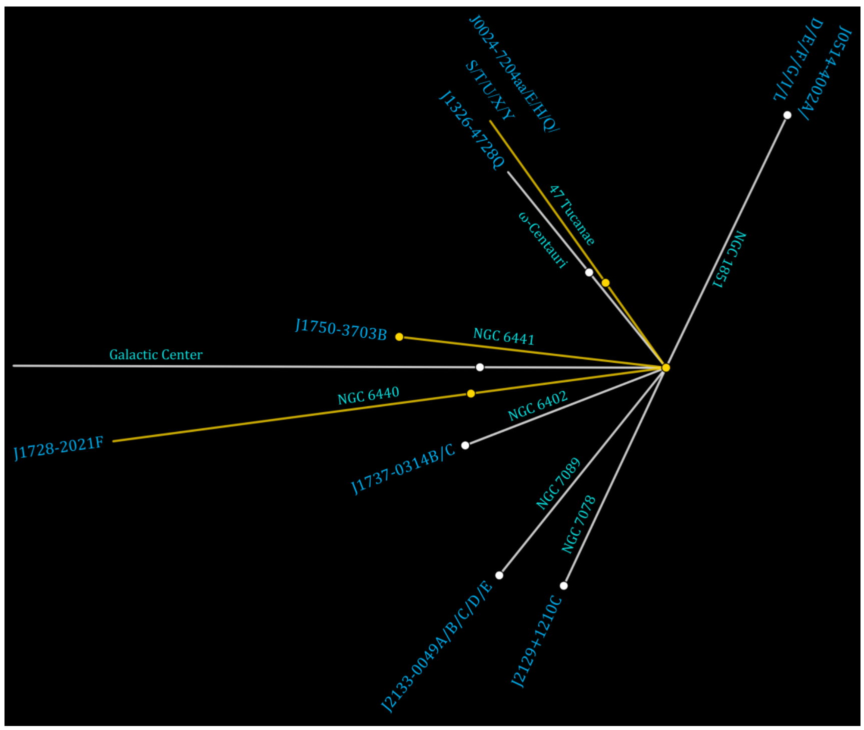

Figure 3: The proposed GC-Based Location Map for MIAB.

For MIAB we propose implementation of GPS with the application of globular clusters as the founding principle and millisecond pulsars acting as secondary indicators in the creation of the location map. This new map is based on a systemic inclusion of GCs' properties, such as luminosities, metallicities, and other observed factors. A detailed explanation of the proposed location map is presented in Appendix B.

4.4.2 Time Stamp

In general, due to the substructure evolution in the galaxy, it is critical to proclaim the design and launch time of the proposed location map. Otherwise, though future life may decode the map successfully, they would not necessarily realize the timeline of human existence and as a consequence, will not be able to manifest the galactic scenario at a specific time in the past. Fortunately, proper motion makes the map itself time-dependent, thus making the GC map enclose time information in the relative location of globular clusters. Combining Gaia's long-period precise location measurements and ESO or Keck's radial velocity data, the three-dimensional proper motion velocities of 154 globular clusters are available [4].

As illustrated in Fig. 4's left-panel, the proper motion velocities are distributed in the range of 0 to 500 km/s, and a large number of them are over 100 km/s. According to the GC map's spatial resolution of 1 ly, this can be converted to time resolution easily. Curves in Fig. 4's right-panel proclaim the time resolution of the GC map at different proper motion velocities and different spatial resolutions. As to the 1 ly space resolution GC map, its time resolution can reach 1000 years easily, once the GC's proper motion velocity exceeds 300 km/s. If we lower the spatial resolution to 10 ly to reduce the message size, the 10,000-year resolution also can be achieved.

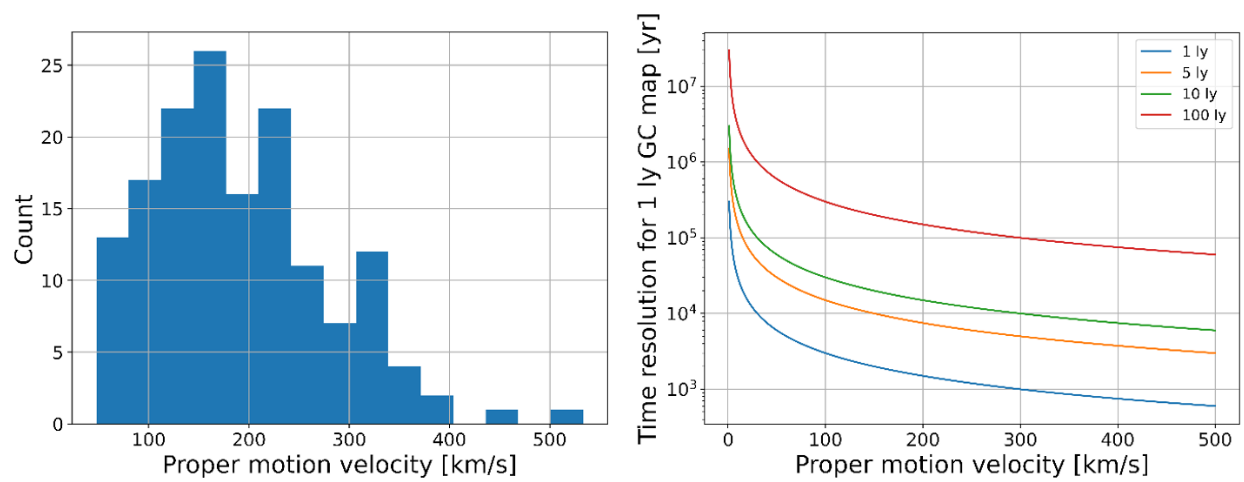

Figure 4: Left panel: distribution of 154 GCs' proper motion velocity, data from Baumgardt, H. et al. 2019 [4]; Right panel: time resolution of the GC map at different proper motion velocities and different spatial resolutions.

However, the time stamp precision not only depends on spatial resolution but on location precision as well. Three-dimensional location measurements of objects are still limited by the observation capability, especially the distance measurement. For example, for a 0.5 kpc distance error coupled with 500 km/s proper motion, the corresponding time is about 10^6 years, much higher than the time resolution as we mention above. If we have a more precise distance, like an error lower than 0.1 kpc, with the 300 km/s proper motion, the time error will decrease to 3.3×10^5 years, which is much better than before. Therefore, we suggest implication of location map as a medium of timestamp in itself. Further developments in observational technology, enabling the locations of GCs to be known with more precision, would foster even higher time resolution measurements.

5. Conclusion and Discussion

With the acceleration in our societal evolution towards a Type I civilization and beyond, we have come to the point of questioning the long-term continuation of our own existence. The relentless utilization of natural resources, with a still developing grasp towards renewal technology, is evident in our continued reliance on fossil fuels *which puts the global economy and energy security at the mercy of geopolitical shocks and crises* (as stated by the Secretary General of the

United Nations on 2021 United Nations Climate Change Conference). Hedging against scenarios of this and other potential Great Filter events [5] in the near or distant future that might threaten survival of our race, carefully designed and well-preserved time capsules can serve as an effective means of carrying into the future the legacy of humankind. The MIAB is one such bold approach towards representing humanity in all its complexity. The notion devises a logically universal symbolic and pictorial form of communication interpretable by intelligent extraterrestrial civilizations possessing a level of advancement at least equivalent to its senders. Starting from a foundation of a working design built from ideas of the creators of Voyagers' Golden Record, we strive to make the MIAB a state-of-the-art implementation of well-reasoned facts in an increasing order of complexity. To accomplish this goal, the message is communicated through apparently discrete yet interconnected segments of information, depicted in modes of imagery, audio-visual and textual documentation.

Considering the dual scenarios of potentially less and more advanced civilizations relative to our current level of technological advancement, the record is being crafted to incorporate meaningful content interpretable by both classifications of civilizations, dictated over the two-fold structural design of the key components of the record. Besides the primary focus on implementation aspects, we have analyzed a series of possible nomenclatures which embody the core principles of the proposed record. These include communication with extra-terrestrial intelligence, an Earth-based archive and the much greater near-term objective of global STEM educational campaigns, thus keeping the project aligned with promotion of citizen science. The methodology that we intend to apply for the careful construction and selection of the key components encompasses a three-tier logic flow. Involved is a diagrammatic representation of the central theme of the mission and proposed guiding principles. Contained within is the high-level detailing of the steps involved in efficient arrangement of message contents. In conclusion, we pose an in-depth discussion on the two major components of the record, namely, *dictionaries* and *location and timestamps*. These play the key role of illustrating the importance of the message and establishing an initial connection between the minds of the recipients and humans.

The first part of MIAB, being an introduction to the workflow of the anticipated mission, opens up the gateway to innumerable possibilities of relevant content to be discussed in subsequent papers concerning specific aspects of the curated contents. Taken in sum, the MIAB acts as the cornerstone to symbolizing humanity's presence in the vastness of the cosmos.

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Message in a Bottle – An Update to the Golden Record

Part I: Objectives and key content of the Message

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Abstract

Communication is an essential asset enabling humankind to forge an advanced civilization. Using approximately 31,000 languages from the Stone Age to our present digital information society, humans have connected and collaborated to accomplish remarkable feats. As the newly dawned Space Age progresses, we are attempting to communicate with intelligent species beyond our world, on distant planets and in Earth's far future. Absent mutually understood signs, symbols, and semiotic conventions, this study, the "Message in a Bottle", uses scientific methods to assess and design a means of communication encapsulating the story of humanity, conveying our thoughts, emotions, ingenuity, and aspirations. The message will be structured to provide a universal yet contextual understanding of modern human society, evolution of life on Earth, and challenges for the future. In assembling this space and time capsule, we aim to energize and unite current generations to celebrate and preserve humanity.

1. Introduction

How would we want humanity to be perceived by extraterrestrial intelligences, by future generations, or by archeologists of different species if our civilization were to disappear? The *Voyager Golden Records*, an early attempt at off-world communication, served not only the purpose of sending a *record* about Earth and humanity into deep space, but also stands as a worthy effort to establish contact with advanced alien civilizations. Such extraterrestrial intelligences (ETIs), dwelling somewhere in our galaxy or even beyond, have long been theorized but remain completely unknown to us as perhaps they too are unaware of Earth. *Message in a Bottle* (MIAB) continues this quest of finding answers to the provocative question put forth by the Roman Epicurean Lucretius - *Are we alone in this vast ocean of the cosmos?*

MIAB would be sent into interstellar space aboard an uncrewed probe with the hope that an advanced, space-faring civilization would discover this communique from humanity. A direct descendant of the Golden Records launched aboard Voyager 1 and 2 in 1977, MIAB is a radically advanced and carefully detailed reconsideration of its predecessor. This paper, the first in a series, presents the possible nomenclatures, objectives, structure, and suggested key content of new and more expansive messages that recites humankind's and Earth's history to a distant civilization.

Although it is highly unlikely that an alien civilization would receive our message, the archived identical version maintained on Earth would likely give invaluable insights about us and our legacy to future generations or perhaps future intelligent beings who might someday arrive on Earth. The message shall not only serve the purpose of laying the groundwork for establishing successful communications with extraterrestrial civilizations, but will also set an ever-lasting impression of what humanity truly is and can achieve both in the vast ocean of the cosmos and here on Earth.

2. Purpose and Objective

Imagine if we received a message from aliens detailing themselves and their way of life. Such a confirmation of the existence of self-aware living beings in the cosmos has the potential to radically change humanity's perspective about our place in the universe and influence the course of human history. Extraterrestrials may be pondering the same question and if they receive a message from us, it could be similarly transformative. The importance of first contact, with all the hope, wonder and potential for advancing our civilization's technical and social knowledge, cannot be overstated. Accordingly, we need a clear vision and purpose in the design of messages humanity sends forth, leveraging diverse and collaborative efforts to sufficiently represent humanity. In the nearly half century since Voyager, our society and technology has advanced substantially, enabling the creation of more detailed and representative messages.

To properly design the structure and content of this new message, we must imagine our audience in broad terms as we develop a clear purpose and objective. In one scenario, our spacecraft is intercepted by a highly advanced space-faring civilization, Type 2 or greater on the Kardashev Scale [1]. Logic suggests three potential outcomes: 1. They ignore us because it is not worth the effort and resources to respond, perhaps considering humans to be too primitive to interact with, as if an ant tried to get a human's attention; 2. They make contact and our two species interact; 3. They simply learn about us but there can be no further interaction as humans have gone extinct. In all outcomes the message plays a critical role in influencing reaction, hence the purpose is one of diplomacy- i.e., inviting a response which can lead to greater possibilities. In order to facilitate understanding, any message should contain more than just facts and figures, but a window into our lives and achievements, our talents and passions, and our aspirations. In any case, it is crucial to show humans as an intellectual, emotional, caring species worthy of interacting with regardless of the distance, time, and energy required to respond. To capture their interest and imagination even in a future where humans are extinct, we should strive to make the message as engaging and informative as humanly possible.

In an alternative scenario, the spacecraft reaches pre-Type 1 civilizations who are not yet space-faring. Our message must arrive intact on the surface of their planet like a "black box" recorder found after an airplane crash. Accordingly, the structure and content of the message will be organized in two tiers to accommodate aliens with different levels of sophistication. Tier 1 content will consist of simply illustrated fundamental concepts and information about humanity and our environment using a medium not requiring power or specific devices to sense, thus accessible to a pre-industrialized society. Tier 2 content will include more complex information in a digital format intended for alien civilizations that are closer to Type 1, possessing the ability to view the content and learn about us in a more detailed and meaningful way. Even if the aliens are not technologically capable of interacting with the digital content at the time of the encounter, they can eventually learn more about us as their civilization matures. In either scenario, the purpose of our message is to inform about our existence and inspire them to someday make contact with us.

As the spacecraft travels through the vastness of the cosmos, with even the nearest star 4.2 lightyears away, the most likely outcome is that it will wander endlessly without ever making contact. Or it may be that we are alone in the universe; there are no other intelligent life forms to find our message. In this sobering case, the audience of the message is not extraterrestrials but rather humans ourselves. The purpose of the message will be to create and preserve a comprehensive record about humanity and Earth in videos, images, and sounds. In doing so, the message provides an opportunity to reflect on and celebrate our character, culture, knowledge, environment, and accomplishments. It would stand as a demonstration to our bustling civilization of so far eight billion individuals, as well as the generations to come, of how connected we are as one species, sharing a common origin, home, and purpose. While parted in so many ways, we are also united as members of the same species across our world with a shared feeling of pride in what we have accomplished and how far we have reached into an otherwise quiet cosmos. It is also a kind of time capsule of human civilization and the Earth prior to the 2030s, opening the prospect for future generations to find valuable historical relics. If Earth is destroyed in the future, we can at least take some measure of comfort that a record of humanity survives in deep space.

3. Suggested Message Names

To begin, we must first decide how the *Message in a Bottle* will itself be known among the technological race which creates and sends it forth into the cosmos. As the content of the MIAB is to be representative of all humanity, as well as be sourced in part from the public, the name we chose carries great importance. For such an undertaking the dryly descriptive, however sufficient in dispassionate correctness, is not likely to achieve the critical goal of inspiring broader wonder and engagement. The first impression, if succulently captured in a well-chosen name, can well be the key which opens the door to successful collaborative creation.

Keeping such considerations firmly in mind, a short list of possible names for the MIAB is suggested below, and their respective rationales are explained in the Appendix A.

1. *Earth and Our Nature (EON) Record & Archive.*
2. *Earth's Record & Archive.*
3. *Interstellar Wanderer.*
4. *Humans on Earth's Record & Archive,*
5. *大 Record.*

4. Suggested Content of the MIAB

The idea of *Time Capsules* has not only been an emerging realization of a more rational and scientific society, but its essence has been anticipated since millennia. In pursuit of this irresistible temptation of communicating with the future, virtually every ancient civilization attempted to create their record and in the best possible cases, these records allow us to paint a detailed picture of our own past, often giving us a *perspective of the significance of our own actions at this moment* *in the long journey of our species* [2]. In this section, we focus on the most important aspect of our proposed record — *content*. Taking into account the rich and carefully designed sequence of information embedded on board the first Voyager Golden Records, we discuss possible modifications besides proposing newer content in order to mark our socio-economic and technological advances since the launch of the Voyager in 1977. We also attempt to fix the imperfections (which may lead to misinterpretation of the message) that were present in the Golden Record due to the inadequacy of the necessary technologies required for their elimination [3]. In short, the content of the updated record will not only serve the purpose of yet another record, but will bear the timeline of human civilization from the ancient past to the latest present and possible causes of our extinction into the future.

4.1 Key Components of the MIAB

Figure 1 illustrates the key components we consider to be included in the MIAB, while Figure 2 (in the next subsection) illustrates the logic-based guidelines to design these components, detailed in follow-on papers. To support communicating meaningfully with an intelligent alien civilization, we have laid down three assumptions for establishing relevant parameters to guide efforts in effectively developing the structure and content of the message. Starting with our primary hypothesis, let us assume that all intelligent life with an advanced civilization, both scientifically and technologically, cannot do so without sophisticated communication and collaboration, regardless of their physiology and home planet's ecosystem. Even if they develop more advanced communication, extraterrestrials will still possess some method and system of communication that resembles language, or they might have the capability of more advanced forms of communication. For our second assumption, we assume the aliens possess sensory modalities to perceive and interact with the world around them, albeit their sensory organs may be very different from those of humans. Due to physical constraints in accordance with the laws of physics across the universe, there are a limited number of likely pathways that the evolutionary process could take to develop the most efficient sensory systems. Therefore, it is reasonable to assume they have an inherent ability to sense and process stimuli from electromagnetic (EM) waves, analogous to the human visual sense, and/or oscillations in pressure, comparable to our audio sense. Although the range and/or mode of interpretation of their perception of EM wavelengths might be quite different, they would fundamentally "see" the world around them and/or "hear" sounds within a certain range of auditory frequencies. For our final and most critical assumption, we consider that aliens can integrate and process information, think logically, and learn. With these three assumptions, we have a starting point for creating a message incorporating deep and complex information sufficiently representing the intricacies of humanity. While there are still many challenges to creating a universally understandable message, these assumptions lend a measure of confidence that extraterrestrial intelligence could decipher and understand the intended meaning of a carefully crafted message.

The message shall be housed in two mediums, a *scroll* and an advanced *minicomputer*. We propose incorporating a series of images to display elementary information about humanity and Earth on the *scroll*, intended for simple direct perception (e.g., visual or tactile sensing) by extraterrestrial civilizations that are relatively less technologically advanced. For civilizations at least at the current level of human technological advancement or beyond, the record shall consist of instructions based on a symbolic representation of the procedure to reveal the digital message in the correct sequence on the *minicomputer*. Vast amounts of information would then be accessible in the form of videos, images, sounds, games and simulations, text, mathematical models, and computer code.

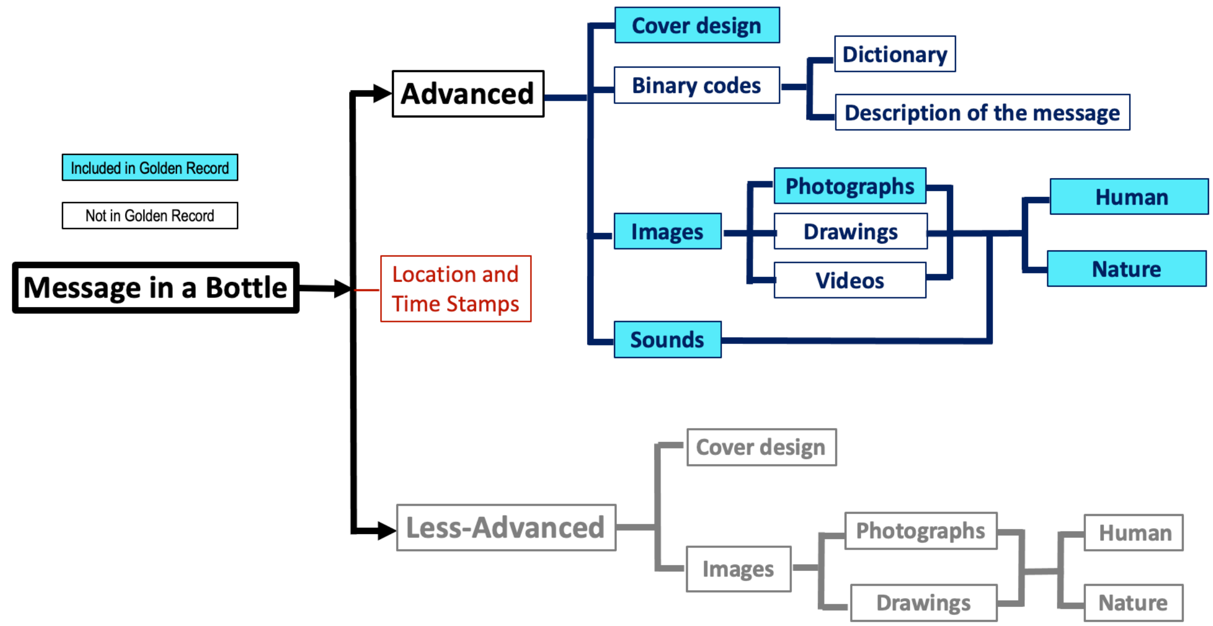

Figure 1. A diagram illustrating the key components of the Message in a Bottle (MIAB).

One challenge not easily recognized is that an interstellar message, if received by ETI, is received without any context to help interpret it. The message is not situated against any background outside of itself. By contrast, in trying to interpret the language of a newly discovered people or communication among animals, one can observe the behavior of the people or animals in question. Isolated, our message will not be received against this sort of background. Beyond that, ETI have no social, cultural, or historical background of humans or life on earth against which to interpret it. Finally, they may not share many of the ways we conceptualize the world as humans. These problems extend, in a more limited way, to future species on Earth or future humans not familiar with present culture. Key to the framework for the message is to fill this lacuna, i.e., the message should provide context for itself, as much as possible. We aim to accomplish this in three ways: using videos, carefully sequencing information presentation, and linking modalities (e.g., having combined images and sounds together rather than separate).

Video (including audio) provides a way of approximating the experience of landing on Earth and observing humanity directly. It also circumvents the issue of ETI first having to decode a symbolic system to understand the initial part of the message (though the instructions on how to play the video would have to be simply represented). The message will be hierarchical: each layer forms a key to the next, more complex layer, guided by the principle that each should be understandable and informative. In this way, earlier layers of video provide context for later layers; for example, the concept of music would be introduced in a simple way before major musical works and the importance of music in cultures around the world are conveyed. Furthermore, video provides context beyond that of separate images and sounds. Taking again music as an example, a video of a band playing a song has a better chance of being interpreted for what it is than an image of an instrument and a disconnected sound recording of a song.

The *Introductory Section* begins a scientific conversation through establishment of a common understanding using universal laws of nature on Earth and logical operations capable of bridging the gap between our comprehension to that of recipients. Some instances include discussion of basic mathematics, constant speed of light in vacuum, and the emission spectra of commonly occurring elements. We then introduce the Earth, our solar system and galaxy, based on fundamental concepts and facts that should be relatively straightforward to interpret by scientifically adept ETIs. Once we establish a basis for communication, it would follow to introduce translation tools with reference tables and dictionaries to create some building blocks and framework upon which more detailed communications would be rendered relatively simple. The second, *Teaching/Interactive Section*, will transition to topics about humanity and life on Earth which may be less familiar. Upon first contact, alien lifeforms would likely have little in common with humans and may not comprehend the intended purpose and meaning of the message. We therefore plan to include encoding and decoding keys for message encryption. Effective communication between two parties should be based on some commonalities and preestablished understanding regarding each other, thus the initial step would be to educate and initiate interactions with our message to develop shared experiences and a fundamental understanding. Accordingly, this section constitutes elementary information about various pertinent topics such as our emotions, social structure, culture, art, music and history. In addition to videos, sounds, text and images, we can include interactive activities and games to engage the recipients. By guiding the aliens to integrate some fundamental knowledge, in addition to glimpses of background and historical information, we can provide the foundation and context to rightly start understanding the more complex yet meaningful content that follows in the next section. Building on the second section with advanced knowledge and complex concepts, the third *Detailed Information Section* contains topics such as knowledge, technology, art, music, politics, culture, and economics, which represent the forefront of human ingenuity and creation. For economics, the second section will introduce basic concepts like trade interaction, supply and demand, and the value of money, while the third section will display the intricacies of global commodities markets, dynamic equity and debt markets, and intricate supply chains.

The taxa of knowledge that we plan to include will follow the principles developed by epistemologists and ontologists with respect to the organization and representation of knowledge as we have it today in our civilization. In computer science and information science, an ontology encompasses a representation, formal naming, and definition of the categories, properties, and relations between the concepts, data, and entities that substantiate one, many, or all domains of discourse. More simply, an ontology is a way of showing the properties of a subject area and how they are related by defining a set of concepts and categories that represent the subject. The three main branches of knowledge in the tree are: "Memory"/History, "Reason"/Philosophy, and "Imagination"/Poetry, as originally devised by Francis Bacon, and which largely also follow the epistemological classifications into perception, memory, introspection, inference and testimony. Additionally, we will use the classifications of science, cultures, and examples of what is a human, a society and life itself.

The team that designed and produced the original Voyager Golden Record did so in a span of weeks, but the effort to update that record into its new form, the *Message in a Bottle,* allows for years to design and produce a representative content of humanity. Along with leveraging this expanded time resource, the intent is to also engage the citizens of the world to provide ideas for the videos, images, sounds, games, and other digital content that will convey the essence of humanity and what life is like on Earth. The digital content shall explain what it means to hope and dream, to love and care about each other, to explore and create new knowledge, and to create art and music. This global effort will provide many perspectives and diverse ideas which illustrate the collective intelligence and experience of the human species. While all these components, though carefully engineered, may well make the message complex and thus difficult to understand, to be worthwhile it is imperative to capture the full array of humanity.

Harkening back to our past, but with an emphasis onto a detailed representation of the present scenario of human life and technological advancements, the contents of the newly designed message must incorporate the ideas of the Voyager Golden Records while including newer facts of the present. All of which, taken as a whole, shall be critical for a complete narration of our story – with whomever it may come to rest in the vast, seemingly endless ocean of the cosmos. In this context, the key components should include two broad categories based on the form in which the content would be encoded: imagery and sounds from Earth. Audio will not only include sounds from our natural surroundings, but also incorporate music and a myriad of others commonly encountered in our lives along with impressions of the modern and technologically advanced societal structure that we are all a part of. It should be noted, however, some images and their associated sounds should be connected, preferably by video, as de-contextualized sounds of Earth would be almost impossible to decipher. Considering a generally similar approach to that opted for in the content selection of the Voyager Golden Records, we shall as well suggest modifications while also including the most relevant content spanning the two generations which have elapsed. We have further classified the imagery content into two subsections that would address the three most important questions the recipients might be concerned with: the origin of the record, the senders of the record, and most importantly, a detailed overview of our nature.

4.2. Methodology for Key Components Design

The logic flow used in the overall construction of the MIAB content is illustrated in Figure 2. Essential in this endeavor are clearly stated controlling concepts serving as guiding principles, forming the conceptual foundation upon which the MIAB will be built. First, the location and timing of the MIAB's origin is articulated in objectively scientific terms, placing the message in context within the spacetime scale it is expected to traverse. Leveraging the methods of prior messages to ETIs afford an efficient means of accomplishing this. Next, the MIAB will be engineered as an emissary of Earth, encompassing the full spectrum of humanity, our planet including non-human life, and humanity's aspirations reaching to the future. Finally, in weighing the multitude of information to include, we employ as a sounding board what we, an emerging spacefaring civilization, would want to receive in a message from an ETI.

The bulk of the MIAB, which using present day technology could at least be derived in part from public input, will consist of the history of its creator species, descriptions of humanity's home world, and our hopes for what is to come. In describing ourselves, we logically begin with the long path evolution has taken us starting from the simplest of lifeforms, followed by the arc of civilization across the last 5,200 years. Encompassed within this description are our scientific achievements such as splitting the atom and space exploration, along with the wide array of cultures and knowledges which comprise the complex human tapestry. Having introduced ourselves, the physical Earth is then depicted in detail accompanied by an overview of the biosphere across the range of environments life has come to fill.

In completing the MIAB, humanity looks ahead to the far future. Our message can also be thought of as a testimonial, sent on behalf of our world and its life. To fulfill this role, an encapsulation of who we are in the present must also extend to what we intend to become – in short, our aspirations. Though assembled in a present whose troubles are all too apparent, the MIAB should speak to a helpful future of peaceful advancement above all else. In concert, such aspirations would see Earth and its biosphere preserved and protected even as humanity makes other worlds in the Solar System, and eventually worlds around other stars, our new homes. Returning to the most basic purpose, we conclude with an invitation to any ETI who may encounter the MIAB to reply with their own story. In summary, the MIAB's key components, collected and constructed via the logic flow described, will offer a comprehensive and eloquent statement worthy of humanity now and into the far future.

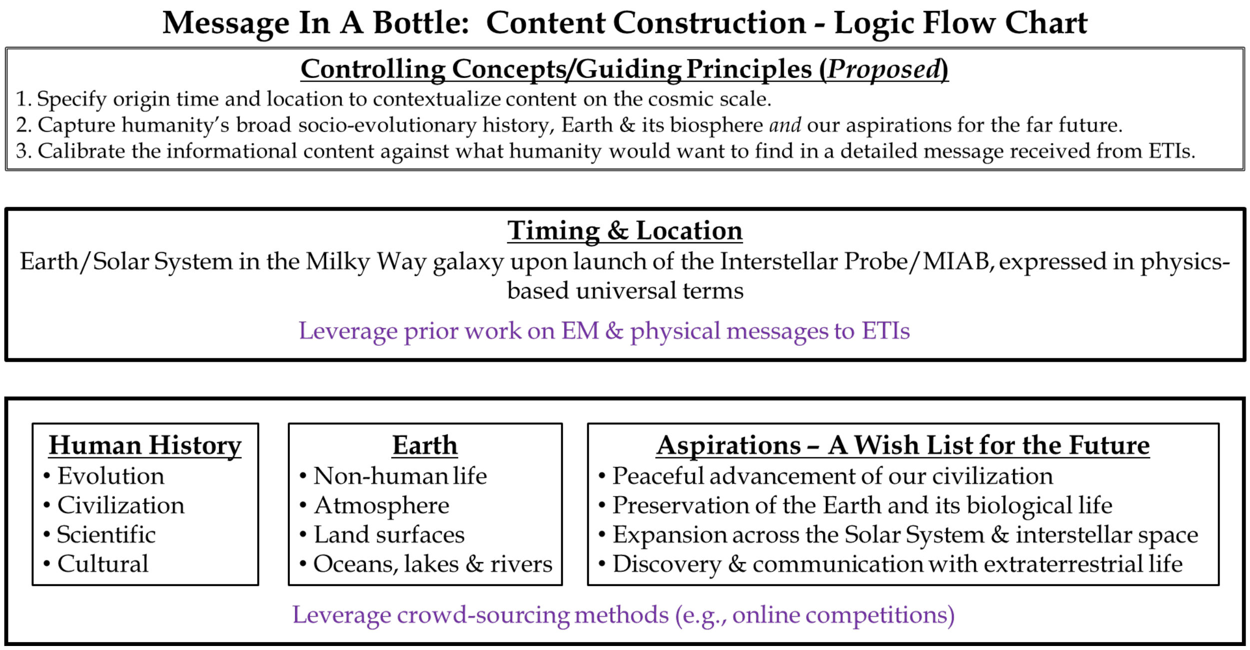

Figure 2: A diagram illustrating the methodology for the key components design.

4.3. Dictionaries

Dictionaries serve as one of the most efficient means of conveying large quantities of data due their immense potential for the symbolic and careful inclusion of rich and interconnected pieces of information through the utilization of concise imagery. Besides acting as a representative of the hierarchical classification of imagery chronicle with an increasing level of complexity, dictionaries exhibit the unique aptitude of their demonstration in the form of index tables, which reshape this genre into universally compatible set of information, often in conjunction with videography, the transfiguring notion of visualizing the world in unison with auditory effects that pose a phenomenal impact on the proposed next-generation of advanced content for the updated record. Dictionaries were a major constituent of the Voyager Golden Records and their forerunners, the Pioneer plaques, were themselves a type of dictionary, although with relatively lesser content.

For MIAB, we will utilize dictionaries as a means of not only ciphering answers, but also reflecting upon a prior universal knowledge that would indeed facilitate the understanding of our conventions and art of scientific communication from the perspective of the intended recipients. Therefore, the proposed dictionaries require carefully design methodology with an absolute priority on logic, a circumstantial discussion of which shall be laid out in further studies in this series. As a starting point, the projection of these distinctive documents might be two-fold, with a former class incorporating a detailed overview about the basic understanding of mathematics and physics (thus, also serving as a tool to unlock the rest of the quantitative information present in the record) and a latter class, conveying the more complex yet pivotal information about our origins, i.e., the solar system and our Earth as well as the major components that have made life possible on planet Earth, thereby signifying our home world as a planet where intelligent life is prevalent.

4.4 Our Location and Time Stamps

4.4.1 Location Stamp

One of the monumental aspects critical towards the careful design and construction of the proposed message is the inclusion of a logical representation indicative of our place in the cosmos. Assuming that the recipients are at least at the level of technological and scientific advancement as we are now, the need for schematic representation puts forth a myriad of diverse and wide-ranging options in terms of interpretable astronomical details. In other words, the design of an effective *galactic positioning system* (*GPS*) would take us one step closer towards the establishment of a generalized location map for the potential alien races to discover humanity and in-turn, our pale blue dot of a home.

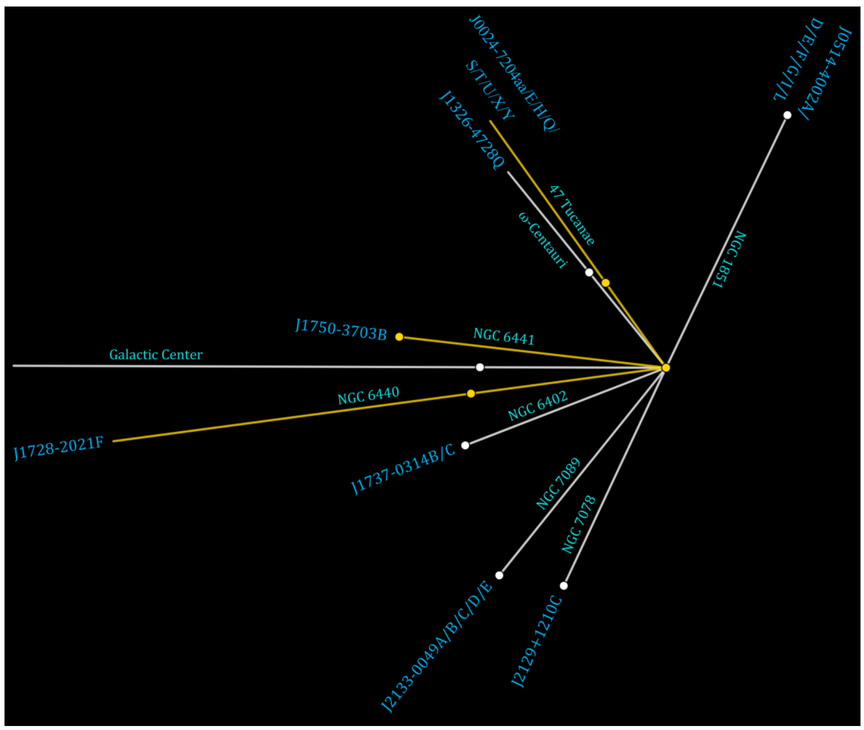

Figure 3: The proposed GC-Based Location Map for MIAB.

For MIAB we propose implementation of GPS with the application of globular clusters as the founding principle and millisecond pulsars acting as secondary indicators in the creation of the location map. This new map is based on a systemic inclusion of GCs' properties, such as luminosities, metallicities, and other observed factors. A detailed explanation of the proposed location map is presented in Appendix B.

4.4.2 Time Stamp

In general, due to the substructure evolution in the galaxy, it is critical to proclaim the design and launch time of the proposed location map. Otherwise, though future life may decode the map successfully, they would not necessarily realize the timeline of human existence and as a consequence, will not be able to manifest the galactic scenario at a specific time in the past. Fortunately, proper motion makes the map itself time-dependent, thus making the GC map enclose time information in the relative location of globular clusters. Combining Gaia's long-period precise location measurements and ESO or Keck's radial velocity data, the three-dimensional proper motion velocities of 154 globular clusters are available [4].

As illustrated in Fig. 4's left-panel, the proper motion velocities are distributed in the range of 0 to 500 km/s, and a large number of them are over 100 km/s. According to the GC map's spatial resolution of 1 ly, this can be converted to time resolution easily. Curves in Fig. 4's right-panel proclaim the time resolution of the GC map at different proper motion velocities and different spatial resolutions. As to the 1 ly space resolution GC map, its time resolution can reach 1000 years easily, once the GC's proper motion velocity exceeds 300 km/s. If we lower the spatial resolution to 10 ly to reduce the message size, the 10,000-year resolution also can be achieved.

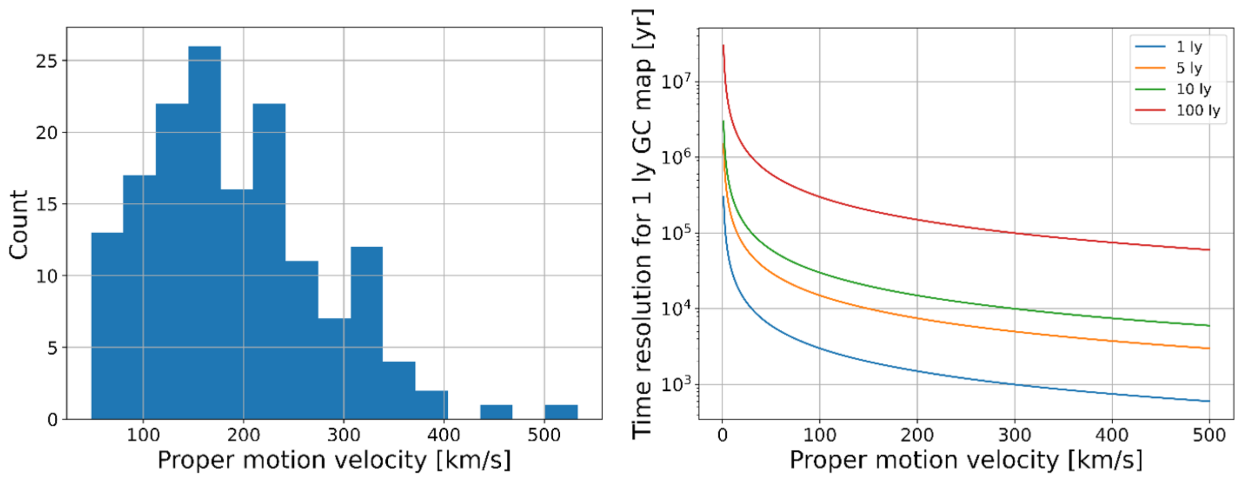

Figure 4: Left panel: distribution of 154 GCs' proper motion velocity, data from Baumgardt, H. et al. 2019 [4]; Right panel: time resolution of the GC map at different proper motion velocities and different spatial resolutions.

However, the time stamp precision not only depends on spatial resolution but on location precision as well. Three-dimensional location measurements of objects are still limited by the observation capability, especially the distance measurement. For example, for a 0.5 kpc distance error coupled with 500 km/s proper motion, the corresponding time is about 10^6 years, much higher than the time resolution as we mention above. If we have a more precise distance, like an error lower than 0.1 kpc, with the 300 km/s proper motion, the time error will decrease to 3.3×10^5 years, which is much better than before. Therefore, we suggest implication of location map as a medium of timestamp in itself. Further developments in observational technology, enabling the locations of GCs to be known with more precision, would foster even higher time resolution measurements.

5. Conclusion and Discussion

With the acceleration in our societal evolution towards a Type I civilization and beyond, we have come to the point of questioning the long-term continuation of our own existence. The relentless utilization of natural resources, with a still developing grasp towards renewal technology, is evident in our continued reliance on fossil fuels *which puts the global economy and energy security at the mercy of geopolitical shocks and crises* (as stated by the Secretary General of the

United Nations on 2021 United Nations Climate Change Conference). Hedging against scenarios of this and other potential Great Filter events [5] in the near or distant future that might threaten survival of our race, carefully designed and well-preserved time capsules can serve as an effective means of carrying into the future the legacy of humankind. The MIAB is one such bold approach towards representing humanity in all its complexity. The notion devises a logically universal symbolic and pictorial form of communication interpretable by intelligent extraterrestrial civilizations possessing a level of advancement at least equivalent to its senders. Starting from a foundation of a working design built from ideas of the creators of Voyagers' Golden Record, we strive to make the MIAB a state-of-the-art implementation of well-reasoned facts in an increasing order of complexity. To accomplish this goal, the message is communicated through apparently discrete yet interconnected segments of information, depicted in modes of imagery, audio-visual and textual documentation.

Considering the dual scenarios of potentially less and more advanced civilizations relative to our current level of technological advancement, the record is being crafted to incorporate meaningful content interpretable by both classifications of civilizations, dictated over the two-fold structural design of the key components of the record. Besides the primary focus on implementation aspects, we have analyzed a series of possible nomenclatures which embody the core principles of the proposed record. These include communication with extra-terrestrial intelligence, an Earth-based archive and the much greater near-term objective of global STEM educational campaigns, thus keeping the project aligned with promotion of citizen science. The methodology that we intend to apply for the careful construction and selection of the key components encompasses a three-tier logic flow. Involved is a diagrammatic representation of the central theme of the mission and proposed guiding principles. Contained within is the high-level detailing of the steps involved in efficient arrangement of message contents. In conclusion, we pose an in-depth discussion on the two major components of the record, namely, *dictionaries* and *location and timestamps*. These play the key role of illustrating the importance of the message and establishing an initial connection between the minds of the recipients and humans.

The first part of MIAB, being an introduction to the workflow of the anticipated mission, opens up the gateway to innumerable possibilities of relevant content to be discussed in subsequent papers concerning specific aspects of the curated contents. Taken in sum, the MIAB acts as the cornerstone to symbolizing humanity's presence in the vastness of the cosmos.

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Appendix A: Suggested Message Names for "Message in a Bottle"

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A short list of possible names for the Message in a Bottle (MIAB) is suggested below together with their respective rationales.

1. Earth and Our Nature (EON) Record & Archive

"Remember to look up at the stars and not down at your feet" —Stephen Hawking

As humanity reaches deeper into interstellar space, we do so on the bounty of our remarkably fertile home world and our evolution to Earth's only technological civilization. Innovation is the key, enabling our distant ancestors to fashion crude clubs, sharpened edges and other tools of survival on antediluvian savannahs. In the Modern Age, innovation has led our finest scientists and engineers to construct vehicles which roam the surface of a world orbiting tens of millions of kilometers away while other probes have departed the Solar System altogether. Expedience, however, leaves us no time to rest on yesterday's glories. As the great American poet Robert Frost so eloquently wrote, "But I have promises to keep, and miles to go before I sleep." We, too, have promises to keep to future generations, and still much further to go in our quest to understand the Universe and humanity's place within it. This is not a task measured in years, decades or even centuries – such is the vastness of the cosmos and the rules imposed by its physical laws, as far as our current understanding allows. Carrying our legacy and that of our world to worlds orbiting other stars may well require as much time as has taken humanity to advance from those ancient savannahs, through the uprising of Egypt's pyramids, to leaving footprints upon the Moon. Indeed, it is quite possibly the work of eons.

Although radio signals traveling at the speed of light and encoded with information about humanity and Earth are far swifter than any robotic deep space vehicle which could be constructed using current technology, their content is constrained by the imperative to mitigate transmission error, among other factors [4]. Alternatively, an archive recorded on physical media such as a laser disc or flash drive (and shielded from cosmic radiation) would offer a means to contain many orders of magnitude more data. Within the immense memory of what would mass only grams, a thorough archive of human and other species' evolutions, our development of language, knowledge (such as mathematics, science, and traditional knowledge), culture and art, along with extensive descriptions of our physical environment on Earth and that of the Solar System, could be contained. Almost without limit, the breadth and depth of the human experience – an Archive of Earth and Our Nature (AEON) — could be sent on a "slow boat to the stars". This endeavor, "EON", evokes the grand sweep of time involved, while "AEON" hints at a sense of cosmic immortality that might be gained should we decide to move forward.

In the literal sense, an "eon" is considered the longest unit of measure among geologic time scales. While the quantified span of an eon of geochronologic time is not precisely defined, it is broadly taken to range in the hundreds of millions of years with no established upper boundary. This nomenclature of large-scale time periods, including those of lesser extent such as "era" and "epoch", are closely associated with the history of Earth itself. "EON" would thus intrinsically encompass the home world of its creators, a self-evident theme speaking to space and time – the very dimensionality through which our message and its messenger will long travel. Rather than be humbled into meekness by the breadth of this undertaking, construction of a tangible and lasting means and message which communicates the details of Earth and our nature across interstellar space should be embraced as a challenge, indeed a purpose, to all who have and will call this world home.

"Aeon" is a somewhat more esoteric notion. While also denoting time, the concept is completely unbound in scale even as compared to the age of the Universe itself. In a sense this may seem contradictory to an implicit intent of sending forth a message – i.e., for it to eventually be received by other civilizations in the cosmos. If our message and its ark were to remain forever in transit, one could curtly argue this circumstance being tantamount to humanity choosing silence. Such a conclusion, however, tacitly ignores the project's more immediate goals of motivating humanity in the here and now to reach beyond ourselves. Pessimists, found in conspicuous abundance amid the many predicaments we clever tool users have conjured for ourselves in recent times, should not be afforded this safe rhetorical quarter. The messages launched aboard Pioneer and Voyager, however modest as compared to what is next envisioned, have served as inspiration for two generations of scientists, engineers and forward-thinkers. Indeed, were it not for those endeavors of the turbulent 1970s there may well be no serious thought given to leveraging technological advancements in the decades since to go further and faster.

Humanity, it can be stipulated, has stood at a critical crossroads in our troubled evolution since the beginning of the Nuclear Age in 1945. Battered by a cacophony of societal-wide neuroses, the impulse to withdraw inward upon ourselves - ever-present over our five millennia of civilization — has arguably never been stronger. A means to successfully resist these malevolent manifestations of social gravitation, perhaps the Great Filter itself, can logically be found in pursuing outwardly a common purposed project. No better example of that goal would be to redirect our creativity towards the grandest of communicative initiatives. Whether we are alone in the Milky Way, or just one among many technical civilizations longing to make contact with each other, the (A)EON recording will be our testimony to who we are, from where we came forth, and our aspirations for a still greater and still longer future among the stars.

2. Earth's Record & Archive

"The Earth is what we all have in common" —Wendell Berry

"What we all have in common" is we are Earthlings, the inhabitants of the planet Earth. Since the dawn of human civilization, intellectuals had begun to record their journeys about their lives at different stages adapting to the conditions prevailing in those ancient times. We have seen some of these records in the form of hieroglyphic scripts on the walls of magnificent structures of ancient Egypt, sometimes in the cuneiform inscriptions in Mesopotamia, writings on papyrus, cave paintings, etc. They used this approach perhaps to leave a legacy for future generations so that once they met their death, the records would remain for us to discover.

In the same way, if it is considered that we are not alone in the universe, scientists would logically want to send an Earth Record chronicling our world's formation to its current status into deep space, much like a MIAB. The record would be based on research from the samples of fossils and rock strata to understand the emergence and extinction of different living organisms – animals and plants at different geological stages, as well as phenomena of climatic conditions related to the structural changes of the Earth due to continuous movement of tectonic plates, and formations of different reliefs and oceans. Included as well would be data about the origin of Earth's magnetic field and its effects, its valuable ecosystem services, including different matter and energy sources and how the supply of energy in trophic chains maintains a vast diversity of ecosystems, lastly, the atmospheric, terrestrial, and oceanic conditions that support any form of life in addition to the most precious asset, humans, and our interaction with Earth.

According to the physicist Mark Buchana, any civilization detecting our presence is likely to be technologically very advanced [1]. Over many decades scientists and astronomers have suggested possible explanations, ranging from social to biological complexity, as to why we have not, as the Fermi Paradox asks, come across any advanced alien civilization. Despite this seeming silence, we cannot rule out all possibilities of intelligent life elsewhere. And if they do exist, we must not ignore opportunities to reach out to them, enriching our knowledge with their new and advanced technologies that can act as a helping hand for humankind to progress at a speedy rate, and protect our existence from sudden or slowly evolving catastrophes.

3. Interstellar Wanderer

"We began as wanderers, and we are wanderers still. We have lingered long enough on the shores of the cosmic ocean. We are ready at last to set sail for the stars." — Carl Sagan

As we orbit the Milky Way galaxy, we refer to space as a distant place to look at, to send spacecraft there and to visit one day. We find it difficult to normalize the fact we are already in space, flying in it with no barrier between us and the vastness of the universe. Our planet is itself an interstellar wanderer and humans have been a wandering species since the beginning of our existence. We have recently started to build spacecraft which will be winding between the stars of our interstellar neighborhood long after we have departed. It is our hope for the people of Earth who hear about our record that wandering can make us feel a little more connected to our small spaceship's slow journey, here tucked away in an otherwise backwater planetary system of the Milky Way's Orion-Cygnus Arm (https://erikwernquist.com/wanderers/).

4. Humans on Earth's Record & Archive

"We have a universe within ourselves that mimics the universe outside. None of us are just black or white, or never wrong and always right." —Suzy Kassem.

Space exploration has been among the most popular topics in the world since 1957, when the Soviet Union launched Sputnik and ushered in an era of increasing interest in the possibilities of discovering the existence of a cosmic life-form or civilization. However, we have yet to find evidence of an alien life form, thus the premise and viability of the MIAB is to be questioned given the lack of evidence that there is anyone else who might find it and be capable of understanding it. Nonetheless, the MIAB still has value even if it is only a representation of self-reflection about humanity and human-sustained efforts of space exploration in the past decades. Considering the difficulty and little chance of a civilization receiving our message, we should record as much information as possible in the message. Moreover, culture, knowledge, technology and languages should be the main focus of the message as they are the most fundamental areas of information about us human beings. Cultures, representing the behaviors and habits of humans; knowledge encompassing the vast diversity of understandings (e.g. modern and traditional knowledges); technology, meaning the history of human inventions, and languages, expressing the methods by which people communicate. All this fundamental information has one thing in common — they were all created and used by humans. Humans have been the most intelligent and dominant species on Earth for a long time. Thus, it must be taken into consideration that while we represent the planet we live on, we also represent ourselves, which is the Homo sapiens species. It may be predictable that the process of contacting an interstellar civilization will take such a long time that it may be perceived as forever. However, such a process has significant and unperceivable value to our kind. Humans have a long history of making contact and exploring other civilizations here on Earth. Just like the judicious writer William S. Burroughs once said, “Man is an artifact designed for space travel. He is not designed to remain in his present biological state any more than a tadpole is designed to remain a tadpole." Humans are designated to explore regardless of the time or the distance involved. The MIAB will make its way into the grand universe and humanity is destined to prosper whether it is now or the future. “To infinity and beyond!” — Buzz Lightyear.

5. 大 Record

“大 Record is a simple and elegant name that evokes emotions, thought, and imagination.”
—Bella Jew, an 8th grade student

Creating the name of the message using one language is insufficient in conveying the richness and variety of languages on Earth. Then again, it is impossible to incorporate all languages, so employing the concept of East meeting West shall enable us to use two languages to exemplify the range of possibilities. Among thousands of languages, Chinese and English are proposed for two reasons: first, these are the two most widely spoken languages worldwide and secondly, their construct is completely different.

In Chinese, 大 means huge, great, grand, and it is used in many names, like Great Britain 大不列颠, The Great Pyramid 大金字塔, The Grand Canal 大运河. Similarly, naming the new message 大 Record signifies that it is a Grand Record that is all encompassing. Additionally, Chinese characters visually look like something, which in this case, 大 reminds a stick figure drawing of a person, with a head, arms, and legs. Another interpretation of 大 Record is a record of the people.

In English, “The” is used when people want to emphasize the importance of something. For instance, this is not just a record, this is “The” record; He is not just a man, he is The Man. In popular culture, there is a colloquial term “Da Man” where Da is slang for The. The character 大 is pronounced “Da” and spelled “DA” using Pinyin. We can call this message “Da Record”, injecting a little humor with a play on words.

Open to diverse interpretations, 大 Record invokes emotions, thought, and imagination. This witty multilingual name represents the ideals of this mission, to send The Grand Record of Humanity into the Cosmos.

Reference

[1] Rebecca Boyle, Why These Scientists Fear Contact With Space Aliens, NBC News, 2017, https://www.nbcnews.com/storyline/the-big-questions/why-these-scientists-fear-contact-space-aliens-n717271.

Appendix B: An Explanation of the Modified Location Map

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This document presents a detailed exposition of the proposed location stamp being proposed for Message in a Bottle (MIAB) for future interstellar missions. Inspired by the propositions of Scott Ransom and the dramatic progress in stellar observations, we propose the creation of the *Galactic Positioning System* which utilizes globular clusters as its founding principle and millisecond pulsars (MSPs) as locational hints to these fascinating celestial objects. Besides an extensive selection of globular clusters found it *Harris 1996 (2010 edition)* and a rigorous analysis of the chosen set of binary MSPs, the map in Figure 1 has been constructed in a manner analogous to the Voyager Pulsar map, while also employing color encoding to display critical information about the type of our unique star, the Sun. In the following sections, we shall delve deeper into the design and underlying ideas that have been instrumental in devising the modified location map and portraying the interplay of information that lies embedded therein.

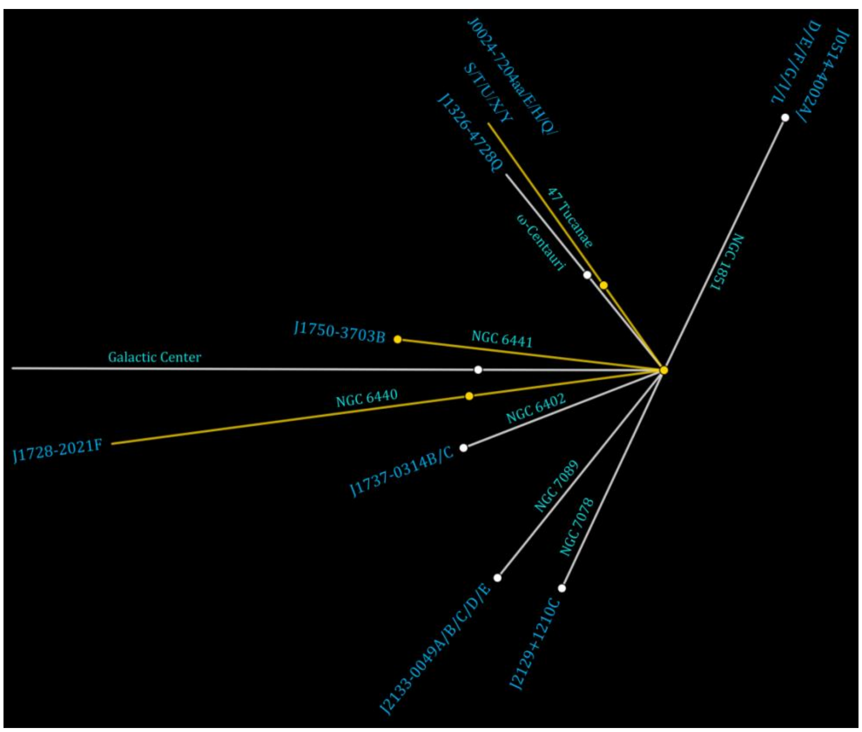

Figure 1: The modified location map for MIAB (Drawn to Scale).

1. Introduction

The *pulsar map* aboard the Pioneer and Voyager probes outline a pathway of radio pulsars whose locations are pinpointed with respect to our Sun. This map identified the distance and direction of 14 pulsars relative to the distance and direction of the center of the Milky Way, along with their periods of rotation (in units of the hyperfine transition period of hydrogen [1], which serves as the basic unit of time used to unlock the information that lies on the record). But despite the notable implications and intellectual design of the pulsar map, there remain some innate quantitative and qualitative inaccuracies that have emerged in comparison with later astronomical data (for instance, pulsar distances and their galactic longitudes found in the current ATNF Pulsar catalogue) and advanced modes of computation. For instance, one of the serious challenges that an intelligent species might be confronted with is how to correctly decipher the positions and periods needed to properly identify the intended 14 pulsars. This complexity is compounded by the non-uniqueness of pulsar periods [2] and the potential misinterpretation of the binary representation of the same, as well as the dramatic change in relative orientations and periods of the pulsars over timespans of millions of years. These challenging issues could be mitigated by utilizing one of the two (related) approaches — either the creation of a new location map based on the conceptual design behind the Pioneer and Voyager pulsar map, with careful updating in line with the quantitative analysis, or the introduction of radical changes to the map's design and the fabrication of a complete set of new norms and arguments with bold designs at par with modern astronomical observations and discoveries. The former might seem to be the more appealing approach, since it connects back to the basic logic behind the prior attempts at extraterrestrial communication, but it assumes the best-case scenario of both the Golden Records and MIAB finding their ways to an interpretive audience. Moreover, the core idea of using isolated pulsars, even with sophisticated application of the most recent astronomical observations, poses certain intrinsic defects [3], primarily pertaining to their long-tern endurance and the anisotropic nature of pulsar radiation, in addition to other shortcomings. Therefore, the proceedings of this study, and the greater mission of laying down the foundations of the MIAB, will follow the latter approach of introducing a radically new method of interstellar mapping, built on present-day qualitative and quantitative data. Accordingly, using globular clusters (GCs) as reference points is deemed to be a superior option for a multitude of reasons that are well-suited for implementation purposes [3].

Tracing back to prior works on the subject, one of the most appealing designs is the one proposed by astronomer Scott Ransom [4], a construction that utilizes GCs in addition to binary millisecond pulsars (MSPs) located within them. Unlike ordinary pulsars, millisecond pulsars *spin faster, and typically have longer lifespans while also aging at a slower rate* [4]. MSPs in binary systems orbit their dead companions, thus introducing the second identifier of *orbital periods*, which remain constant over billions of years [4]. Among the best aspects of a map constituting GCs as its underlying principle pertains to their long-term stability and the fact that these fascinating symmetrical stellar systems are each highly unique conglomerations of tens of thousands to several million stars, all held together by mutual gravitational attraction. Furthermore, the spectral classes of globular clusters, which can be inferred from simple stellar models reflecting the homogeneity of the stars within a given GC, afford the map with the extra potential of establishing a link to the spectral type of our Sun, thus setting up an interconnected set of information embedded within a single pictorial representation. Although this does not eliminate the problem of anisotropy in pulsar radiation, which would likely be known to advanced extraterrestrials, binary MSPs nonetheless serve as an efficient means to indicate their respective parent GCs, given the fact that every illustrated GC-embedded MSP has an association with some of the brightest GCs.

2. Globular Clusters

Globular clusters (GCs) are tightly bound conglomeration of tens of thousands to millions of stars *associated with all types of galaxies* [5]. The primary reason behind the homogeneous properties of the constituent stars, at least in terms of their initial composition, is the conventional assumption that all stars formed out of the same cloud of interstellar gas. Although some stars may in reality form earlier than others in comparison to their lifetimes, the spread in their formation times is small and can be ignored [6]. A second convention essential to the map's design is the fact that all constituent stars are assumed to be equally distant from the observer, owing to their insignificant spread of distances in comparison to the distance of the parent GC. Furthermore, the intense gravitational attraction between closely packed stars in a GC contributes towards their stability and the characteristic spherical shape. With GCs established as most suitable forming the basic protocol behind the next generation of interstellar location maps, this next section deals with the various modes of classification and the resulting selection of globular clusters, in addition to the inconsistencies that led to the designation of a separate set of GCs with slight deviation from the conventional notion.

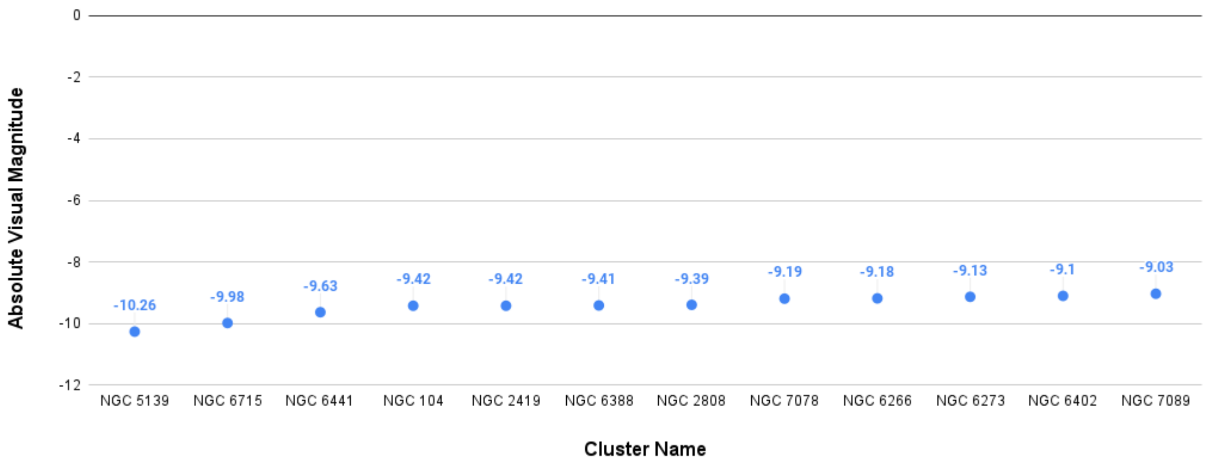

Figure 2: Scatterplot of first set of chosen GCs with $M_V \epsilon (-11, -9)$.

As a starting point, we pose the basic, yet evaluative condition of the *absolute magnitude (M)*, which is a measure of the luminosity of stellar objects, assuming that they were placed at a constant distance of 10 parsecs away from Earth [7, 8]. Analogous to other magnitudes on an astronomical scale, the absolute magnitude can be specified in different wavelength ranges, corresponding to specific filter bands. A common inference of the absolute magnitude is the *absolute visual magnitude (M_V)*, which utilizes the visual band of the spectrum in accordance with the UBV photometric system. The central reason behind leveraging this aspect of cluster luminosities as the foundation of the classification system is the mathematical fact that absolute magnitudes help in comparing the intrinsic brightness of different stars, as well as the fact that the visual band is a representative of humanity's mode of envisioning the world. The reason behind the non-inclusion of *absolute bolometric magnitudes (M_B)* (which projects the luminosity over all wavelengths) owes to the inadequacy of sufficient data to deduce the conversion results to M_B. Therefore, for the purpose of performing a proper in-depth analysis, we set the lower and upper bounds for M_V to be -11 and -9 respectively, concerning the aspect that intrinsic brightness of stellar object is inversely proportional to its absolute magnitude, and with -10.26 being the maximum reported luminosity. The aforementioned condition leads to the creation of the following *primary list* of limited set of GCs with their absolute magnitudes being projected by the scatterplot in Figure 2.

In contrast to the actual map in Figure 1, certain departures from the usual trend are detectable when it comes to selecting the ideal globular clusters for a specialized cosmic map. The primary cause can be attributed to the lack of attainment of the added factors that govern the design mechanism of the location map, namely, *reported discoveries of binary MSPs present within the chosen GCs (given that they satisfy the constraints critical to the structure)*, visually distinct representation of two or more GCs in terms of their galactic longitudes, and the auxiliary conception towards the inclusion of GCs across all four quadrants of the range of galactic longitudes (while considering the mapping of three dimensional space onto a two dimensional map), from 0 to 2π, as illustrated in Figure 3.

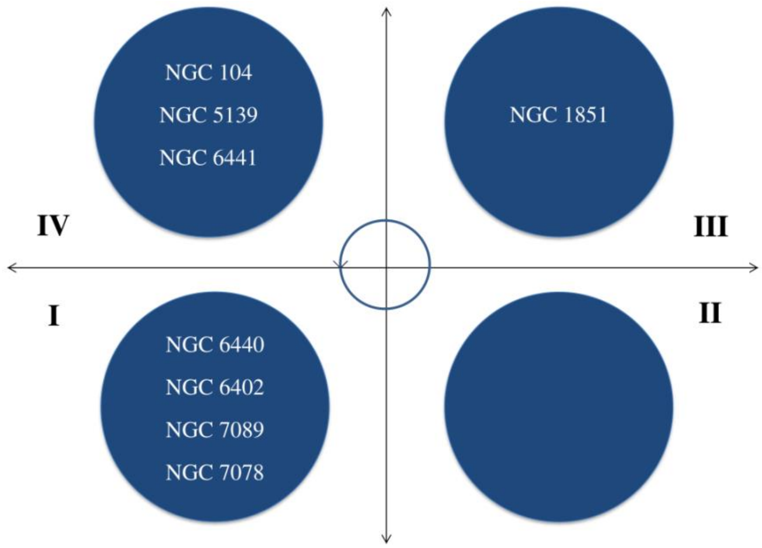

Figure 3: The four quadrants of the location map w.r.t. the galactic longitudes. All GCs in the second quadrant have no reported existence of binary MSPs, and thus were excluded from the location map.

Recurring over the prior rationalization, the inclusion of select globular clusters is primarily governed by three factors, namely, in-range absolute visual magnitudes, existence of binary MSPs, and distinct illustrations of chosen GCs, which together form the baseline of the rationale presented in Table 1. In the following two sections, we introduce and establish arguments towards the inclusion of GCs while not ignorant of the scientific inclination on selective GCs in lieu of the ones that had to be revoked, with respect to the *primary list* of 12 GCs .

Table 1: Globular Clusters in the Location Map

Name	Distance from the Sun (kpc)	L (Galactic Longitude)	B (Galactic Latitude)	Rationale
NGC 5139 (ω-Cen)	5.2	309.10	14.97	Based on M_V
NGC 6441	11.6	353.53	-5.01	Based on M_V and spectral class G
NGC 104 (47 Tucanae)	4.5	305.89	-44.89	Based on M_V and spectral class G
NGC 6440	8.5	7.73	3.80	Spectral Class G
NGC 6402 (M14)	9.3	21.32	14.81	Based on M_V
NGC 7089 (M2)	11.5	53.37	-35.77	Based on M_V
NGC 7078 (M15)	10.4	65.01	-27.31	Based on M_V
NGC 1851	12.1	244.51	-35.03	Third Quadrant

2.1. Included Globular Clusters

NGC 5139, popularly known as Omega Centauri, is the most massive and the brightest globular cluster in the Milky Way. Nevertheless, *its classification as a GC has been challenged, making it a possible candidate for being a stripped off core of an accreted dwarf galaxy* [9]. A unique feature of the location map, ω-Cen differs from other GCs because of its intricate composition of different populations of stars [10]. Multi-beam observations from MeerKAT as part of the TRAPUM GC Survey in 2021 revealed the presence of 13 new pulsars in Omega Centauri (besides the previously discovered five pulsars), more than half of which reside in binary systems; these are worth exploring in profundity.

NGC 6441 is a globular cluster in the southern constellation of Scorpius. With an absolute visual magnitude of -9.63, this GC is one of the most luminous globular cluster in the Milky Way. At a distance of 11.6 kpc from the Sun, this globular cluster is of particular significance due to the fact that the spectral type of the integrated cluster light is *G*, which in fact, acts as the first step towards hinting the spectral class of our own star, through the implementation of a visual encoding scheme based on color, allowing the demonstration of a clear manifestation of the same.

One of the magnificent showpieces of the night sky, NGC 104, famously known as 47 Tucanae, is part of the southern constellation of Tucana. With an absolute visual magnitude of -9.42 and located at a distance of 4.5 kpc from the Sun, this dense GC comprises of 27 millisecond pulsars [11] besides having a multitude of X-Ray sources which include LMXBs containing neutron stars that are not presently in accretion phase [12]. Analogous to the globular cluster NGC 6441, 47 Tucanae shows no disparity from the primary set of 12 GCs and exhibits a spectral class of G. In light of the diversity in pulsar population, NGC 104 stands out as an ideal GC, both in terms of exploration and design of the location map.

The depiction of multiple instances indicative of the spectral class of our Sun calls for exploration of other G type GCs in the Milky Way. By the same token, NGC 6440 in the constellation Aquila is a newly introduced member with respect to the primary convention pertaining to absolute visual magnitudes and is a substitution for the G-type globular cluster **NGC 6388**. The observational efforts using the Green Bank Telescope's (GBT) S-band receiver and the Pulsar Spigot spectrometer [13], resulting into the successful systematic search of binary pulsars besides the two-fold execution of the prior algorithm encircling cluster luminosities suggest the inclusion of the *fourth brightest GC of spectral class G*, i.e. NGC 6440, with NGC 6441, NGC 104 (47 Tucanae), and NGC 6388 as its forerunners. As a consequence of all the factual implications, the insertion of NGC 6440 appears to be more scientific and drives the audience one step closer to efficiently interpreting the information encoded.

With an absolute visual magnitude of -9.10 and located at an approximate distance of 9.3 kpc from the Sun, NGC 6402 is situated in the constellation Ophiuchus and is home to over 150,000 stars [14]. Unlike its antecedent, NGC 6402 does not exhibit divergence from the primary list of chosen globular clusters, pertaining to the presence of five MSPs [15] within the cluster and thus opening up the possible inclusion of a multitude of binary pulsar systems, chiefly determined by their nature and anticipated endurance of the system.

The first globular cluster to be added to the Messier catalogue, NGC 7089 (M2) is a globular cluster located at a distance of 11.5 kpc from the Sun in the constellation Aquarius [16]. With an absolute visual magnitude of -9.03, this GC stands out to be the dimmest among all the globular clusters tracked down in our initial inventory of plausible GCs, but is one of the brightest amongst all the GCs lurking around in the Milky Way. With the recent discovery of the first pulsars in M2 [15], this globular cluster happens to be a component of our initial derived record with no divergence from the convention, and thus forms a unique component of the modified location map.

A spectacular swarm of stars, the globular cluster NGC 7078 (M15) was the first GC to host a planetary nebula [17]. Located in the constellation Pegasus and situated at a distance of 10.4 kpc from the Sun, this GC hosts an Intermediate-Mass Black Hole (IMBH) at its center. With a cluster luminosity of magnitude -9.19, M15 is a major constituent of our conventional plot, which comprises of 12 GCs. Although studies suggest the existence of nine pulsars in the cluster, seven of those are known to be isolated MSPs, another is an NS-NS binary system, and the last is likely to be binary system, although substantive evidence of this has yet to be published.

The last element of the select list of globular clusters, NGC 1851 is a relatively massive GC sited in the southern constellation of Columba, at a distance of 12.1 kpc from the Sun. A plausible former member of the Canis Major Dwarf galaxy and with an absolute visual magnitude of -8.83, this GC forms the sole representative of the third quadrant, which in turn renders the complete schematic representation in three quadrants of the two-dimensional location map. Despite being an extrinsic inclusion, the choice of NGC 1851 over other clusters with galactic longitudes falling within the range of the same quadrant can be primarily credited to the conventional notion of maximum cluster luminosity and confirmatory studies proving the existence of binary MSPs. One of the GCs selected for the TRAPUM GC Survey, recent observations of NGC 1851 using the MeerKAT radio telescope have led to the outstanding discovery of 13 new pulsars, seven of which are classified as binary systems, thus enabling detailed studies of the cluster structure and dynamics [18].

2.2. Dropped Globular Clusters

In view of the one of most challenging aspects of determination of the ideal globular clusters for the location map, certain deviations from the initial hypothesis are evident and call for a careful analysis, down to the least significant detail. Parallel to the preceding section which outlines the rigorous profiling of the 8 GCs introduced in the location map, this section sheds light on the ones that had to be ruled out in regard to the primary list of 12 GCs.

In analogy to the *primary list*, the finalized set of included globular clusters excludes NGC 6715, NGC 2419, NGC 6388, NGC 2808, NGC 6266, and NGC 6273. Despite the fact that all of the GCs satisfy the primary prerequisite, auxiliary constrains pose restrictions on the incorporation of these globular clusters, with depiction of some notable instances beyond the known convention. Likewise, NGC 6388, although being a globular cluster of spectral class G2, shows no reported detection of pulsars [13], which therefore imped its inclusion. In contrast, the globular cluster NGC 6266, despite having reported existence of binary MSPs [19], confronted the drawback of indistinctive representation of both NGC 6441 and NGC 6266 onto the 2D location map, owing to a longitudinal difference of only 0.04 degrees. Similar to the reason of exclusion for NGC 6388 yet slightly different, we were unable to pinpoint prior literature reporting the presence of binary MSPs in the oblate globular cluster NGC 6273, and thus leading to omission. NGC 2808 possesses a unique shortcoming that challenges the sustainability of the map — the only existence of a transient accreting millisecond X-Ray pulsar (AMXP) with coherent pulsations at a period of 2.9 ms. A coherent AMXP which is transient is a binary system in which the neutron star emits X-ray pulsations at precise and stable period during the accretion phase, but also exhibits irregular and unpredictable outbursts, interspersed by periods of quiescence which may even last to several decades. Therefore, this GC, regardless of having a unique stellar realm worth depiction, had to be excluded in light of the plausible misinterpretation and perhaps non-detection of the very phenomenon intended to make it notable. At length, the globular clusters NGC 6715 (M54) and NGC 2419, besides lacking documented existence of binary MSPs (as per ATNF Pulsar Catalogue v1.70), challenge the intelligible representation of GCs in the two-dimensional location map. Therefore, in order to address this unique shortcoming of indistinct rendition centralized to that of a planar map, we have proposed the modeling of a three-dimensional version, as stated in the discussions.

3. Binary Pulsars

A fascinating class of astrophysical systems, binary pulsars comprise a neutron star and a binary companion orbiting about a common center of mass. The binary companion can be a main sequence star (MS), a white dwarf (WD) or even other neutron stars (NS). One of the key features of binary pulsars is the exchange of matter between the two stars. In some instances, the companion star is close enough to the neutron star to lose material through *Roche-lobe overflow*, which often happens by way of an accretion disk [20] around the neutron star. The accretion that follows may cause the rotation of the neutron star to speed up, and thus leads to the formation of a *millisecond pulsar (MSP)*.

MSPs comprise a new aspect of the modified location map, having been incorporated to serve as distinct cosmic identifiers indicative of their parent globular clusters, while also augmenting the effective sustainability of the map pertaining to the outstanding endurances of these intriguing stellar lighthouses. In light of the important GCs, subject to nomination above the new map, this section undergoes a detailed discussion of the binary pulsar(s) which appear to be the most feasible for our purposes including relevant scientific arguments based on past observations that support the same.

We propose yet another convention as a mechanism of prioritizing the nomination of the binary MSPs — inclusion of *non-eclipsing binaries* that are not associated with *black widow* and *redback* systems. Both black widows and redbacks have relatively shorter lifespans than other binary MSPs, which is a direct consequence of the intense mass transfer in these systems and that results in accelerated erosion and finally, consumption of the companion star by the pulsar. While most GCs analyzed seem to possess only one binary pulsar which ideally satisfy the constraints of our map, some notable instances have witnessed the uncertainty of prioritizing only one system over others, especially due to similar nature of two or more binary pulsars housed within the same GC. In such occurrences, we pose convincing arguments that support the inclusion of all such analogous binary systems. Further observations might eventually shed light on the plausible hierarchization scenarios, paving the path towards more scientifically detailed choices.

3.1. J1326-4728Q

MeerKAT observations of the majestic globular cluster NGC 5139 led to the revelation of 13 new pulsars, in addition to the previously discovered five. Among the newly discovered ones, seven have emerged as binary systems, with a clear majority of black-widow systems, while the rest turn out to be isolated MSPs with J1326-4728B being designated as an X-ray source [21]. The binary systems J1326-4728 G and H, with spin periods of 3.30 and 2.5 ms respectively, have orbital periods and minimum companion masses falling within the range of typical black widow systems. Despite the lack of eclipsing phenomena, the tight orbits, low mass companions and rapid spin periods further bolster these claims. Unlike the former, the binaries J1326-4728 K and

L (having periods 4.71 and 3.53 ms respectively) were determined to be eclipsing black widows [10]. In an alternate scenario, J1326-4728I, having a spin period of 18.95 ms, points to an orbital solution that suggests an orbital period of 26.71 hours with a companion mass range of [0.020, 0.046] $M_{\odot}$. In addition, the pulsar period indicates the fact that it might be a *mildly recycled pulsar* [10], although assertion of the nature of the pulsar is subject to further observations. The last sections of exploration encompass the analysis of J1326-4728 N and Q, with spin periods of 6.88 and 4.13 ms respectively. Despite the difficulties in constraining the orbital parameters for J1326-4728 N due to low and uneven orbital coverage in both observations in [10], yet pulsar Q was brightly detected in one observation and its companion mass is clearly suggestive of an MSP-helium white dwarf binary system. Therefore, the inclusion of J1326-4728Q acquires a position of unprecedented importance, enhanced by recent observational efforts and empowered with factual refinements that have been aided by ever-advancing technology.

3.2. J1750-3703B

Based upon the 1950 MHz pulse profiles obtained by adding all observations made with mode 2 of the Pulsar Spigot spectrometer, two MSPs of NGC 6441 were detected to be residing in binary systems — J1750-3703A and B [13], with pulsar periods of 111.6 ms and 6.07 ms respectively. In light of the spin periods, the latter is at the lower end of the spin period distribution which is a typical of what is found among similar MSP-WD systems in other GCs in the Galactic disk [13]. In contrast, the previously discovered J1750-3703A, with its high orbital eccentricity of 0.71, has a companion (with a 99% probability of being more massive than 0.53 $M_{\odot}$) yet to be discovered. Centered on these facts, J1750-3703B turns up to be the best scientific inference, especially in terms of establishing an encoded pattern of consistent, yet critical information housed within a two dimensional cosmic map.

3.3. J0024-7204aa/E/H/Q/S/T/U/X/Y

The largest repository of cosmic “lighthouses” after Terzan 5, the number of MSPs in NGC 104 presents a standalone projection of the diversity of pulsar population in the Milky Way. Out of the 27 binary pulsars reported in the cluster, 18 have been predicted to be associated with binary systems [11, 22, 23, 24]. Unlikely to be a fast binary system, PSR J0024-7204aa possesses a pulse period of 1.84 ms which is short relative to other MSPs in the cluster [23]. An in-depth search of MeerKAT data led to the recent revelation of two previously unknown binary MSPs, namely, J0024-7204ac and J0024-7204ad. While J0024-7204ac belongs to the class of eclipsing black widow systems, the binary mass function of PSR J0024-7204ad, indicative of the minimum companion masses, appertains to the eclipsing redback systems [11]. The pulsars J0024-7204I and J0024-7204J are black widow systems with eclipsing prevalent for about a quarter of the orbital period in case of the latter [25, 26]. Analogous to the prior two binary MSPs, J0024-7204O, P and R have short orbital periods and low companion masses. Although the period of J0024-7204R is considerably shorter than that of J0024-7204J, there is no reason to suspect these three systems as *fundamentally different* from the former duo [26, 27]. Based on the results observational inferences [27, 24], the pulsars J0024-7204E, H (mildly eccentric due to probable dynamic interaction [26]), Q, S, T, U, and Y are most likely to be binary systems with He-WD companions, while MSP J0024-7204W being one of the first binaries to be classified under redback systems [24]. Similarly, the 4.81 ms binary pulsar J0024-7204V, with its strong orbital variability and additional hints from mass function and presence of eclipses, offers substantial evidence that this MSP is redback pulsar, with observations predictive of the fact that the MSP is actually a transitional MSP, owing to the irregular eclipses, occasional disappearance of radio pulsations and mass of companion star [28]. In light of the slight ambiguity circling the true nature of WD companion (more likely to be a CO-WD) of the unique MSP J0024-7204X, this very pulsar does not belong to any of the groups of pulsars discovered in the cluster. With a long orbital period, the MSP looks just like many other MSPs in the field, which are in wide orbits coupled with a He-WD companion, yet dense and ionizing dynamical environment generally hinders visualization of such systems in GCs [28]. Therefore, based on the aforementioned observations and factual deductions from a myriad of observations over the past three decades of extensive research, the natural conclusion supports the inclusion of only half of the binary MSPs present in the cluster, although future observations from TRAPUM project and others might contribute to the list of potential MSPs for inclusion into the modified location map and as well, pose a better echelon for leveraging the scientific accuracy of the map.

3.4. J1748-2021F

Alongside J1750-3703B, this binary pulsar is located within NGC 6440, has an orbital period of 9.8d and a minimum mass companion of approximately 0.30 $M_\odot$ (assuming pulsar mass of 1.4 $M_\odot$), *and may be the only "normal" MSP-WD binary system among the recent pulsars discovered* [13]. Analogous to J1750-3703B, J1748-2021F is at the lower end of the spin period distribution but is typical of what has been reported among similar MSP-WD systems. In comparison to the highly eccentric NGC 6440B, the MSP has a relatively small orbital eccentricity ($e = 0.0531$) *but is nevertheless much larger than typical binary systems with similar orbital periods* [13]. Another unique binary system retained within the cluster is J1748-2021D, which is an *Eclipsing Low-Mass Binary Pulsar (ELMBP)* with a non-measurable orbital eccentricity and a period of 6.9 hours. The rationale behind choosing J1748-2021F over D owes to its simplicity of signifying non-eclipsing binary systems rather than eclipsing ones, which would otherwise open up a new realm of complexity (owing to the variations in pulsar signal) and thus hinder effective communication with advanced extra-terrestrial intelligences.

3.5. J1737-0314B/C

Observations through the Five-hundred-meter Aperture Spherical radio Telescope (FAST) led to the recent discovery of five pulsars in the M14 globular cluster, namely, J1737-0314A, B, C, and D. With a spin period of approximately 1.98 ms, J1737-0314A reveals itself as the second fastest spinning GC *black widow pulsar* [15]. On the other hand, J1737-0314D and E exhibit probable eclipsing and clear eclipsing phenomena respectively, implying that both are *redback pulsars* owing to the aspects of low-mass companions and circular orbits. Contrary to the former, J1737-0314B and C have relatively wide pulsar profiles with a slight variation of their spin periods in different epochs, *indicating they are binaries with orbital periods being of the order of a few days* [15]. Alongside an initial survey of the facts that support the inclusion of J1737-0314B and C, a sheer confirmation boils up with a deeper understanding of the endurance of the different types of binary MSPs, especially concerning the black widow pulsars and redbacks. Therefore, J1737-0314B and C unfold to be the ideal candidates for incorporation into the location map.

3.6. J2133-0049A/B/C/D/E

The observational efforts detailed in [15] have led to the recent discovery of the first five pulsars in the globular cluster M2. The variations of the observed spin periods indicate that all the pulsars are in fact *binary systems with orbital periods of several days* [15]. Primarily, the very high percentage of binary systems in the discovered pulsars can be delineated by their relatively low encounter rate per binary [29], which leaves *a high surviving probability* of a binary once formed [15]. Concerning the non-disclosure of the classification of each one of the newly discovered binary pulsar, there prevails an equal probability of all of the five binary systems to be included into the location map. Yet adopting the exact binary system at par with our current understanding of neutron stars requires a wealth of information based on further observations aimed to reveal the true nature of these binaries.

3.7. J2129+1210C

Aside from the MSP-WD binary systems that have dominated the modified location map, corroborations of other types of binary pulsar systems would serve as a mode of decentralizing encoded information, evincing the diversity of the pulsar population and thus portraying a deeper picture of our conceptualization of these fascinating stellar creations. J2129+1210C, residing in the globular cluster M15, belongs to a relatively rare class of binary pulsar system, termed Neutron Star-Neutron Star (NS-NS) systems, which are born out of two supernova explosions [30]. Another plausible binary pulsar system worth mentioning is J2129+1210I, which may be insinuated from the significant period variation during entire observation in [13].

3.8. J0514-4002A/D/E/F/G/H/I/L

In the last sections that guide the final components of the location map, the legacy of scientific exploration encompasses the eight binary pulsars in NGC 1851, seven of them being newly discovered ones based on the recent MeerKAT observations. J0514-4002F, G, H, I and L are binary systems with low mass companions and low-eccentricity orbits [18]. Furthermore, the pulsars F, G and H have *orbital periods which are typical of MSP-WD systems*. Even though J0514-4002I and L have orbital periods like those of redbacks, the absence of eclipsing phenomena is a *strong indication that the companion stars are not extended like the companions of redbacks, but instead, are also low-mass WDs* [18]. Amidst the new pulsars, [18] refers to J0514-0042D and E as the most interesting eccentric binary MSPs. With conditions resembling that of the previously discovered J0514-0042A, these pulsars are very likely to be the result of secondary exchange encounters, with the preliminary conclusion stating the present companion of J0514-0042D to be a more massive carbon-oxygen white dwarf [18]. Yet not deterministic about the true nature of the companion stars, which are influential in revealing the nature of the binaries in greater depth, we propose the possible inclusion of all of the binary pulsars, besides the intuitive predilection towards the pulsars A, D and E, owing to the fact that secondary exchange encounters might open up the possibility of increased system endurance (although difficult to predict without ample data), which in turn is governed by the separation between the neutron star and its new companion.

4. Final Note

As humanity embarks on its journey into deep space and beyond, the notion of existing intelligent lifeforms becomes increasingly realistic. While there has been no real evidence of other-worldly communication as of yet, the possibility of its occurrence raises the issue of how to effectively represent ourselves, and to a large extent, locate human civilization in the vast ocean of the cosmos. MIAB's location map, scientifically stated as a GC-MSP map, hopes to achieve universality at a cosmic scale, indicative of our place in the cosmos more accurately than prior attempts. While relying on a design mechanism analogous to the Voyager pulsar map, the modified location map utilizes globular clusters as its core mapping protocol, with millisecond pulsars in binary systems acting as secondary clues to pinpoint their parent GCs. Despite the significant difference in permanence of both classes of stellar wonders, yet the inclusion of binary MSPs serves as one the most effective modes of projecting the cosmological information we want to convey.

Yet the modified planar location map includes its own layer of shortcomings that need to be addressed. These shortcomings lie in the basic factor of projecting the galactic information on a two dimensional map, since the distribution of orbits in GCs is a complex and dynamic process, influenced by a variety of factors with an interplay of certain stochastic elements. When considering evolution on a long time scale, the encoded longitudinal information would substantially vary, which calls for the incorporation of a second governing factor in terms of coordinates of the GCs, i.e., the galactic latitude. Thus, the insertion of this critical aspect into the modified location map requires the important transition from the two dimensional map to one that deals with three dimensions, as projected in Figure 4.

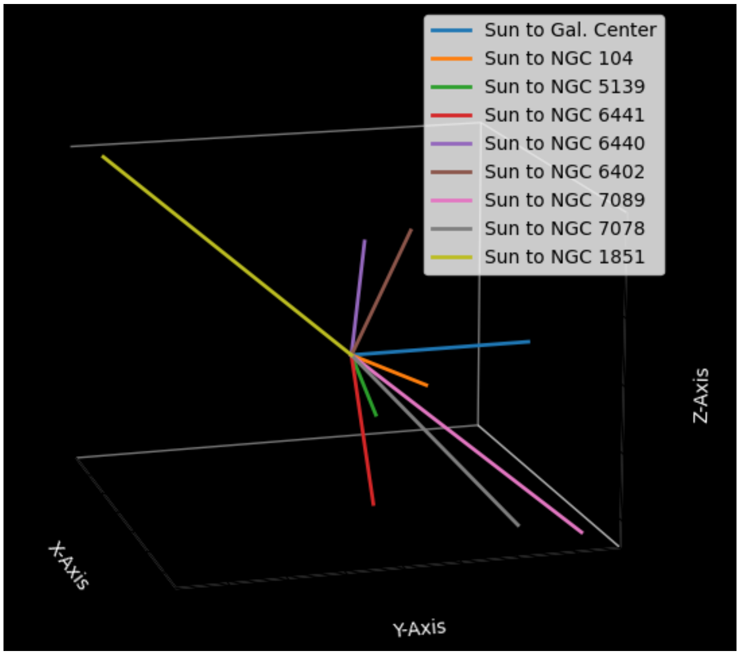

Figure 4: Skeletal structure of the three dimensional version of the modified Location Map.

Even though the upgrade to an interactive 3D map contributes to the increasing complexity of deciphering the encoded information, it should be possible to incorporate both types of maps on the record, granting recipients the liberty to interpret the duo based on their level of technological advancement.

In conclusion, this appendix presents the supporting arguments instrumental in designing the generalized location map of MIAB. In this document, the map has been redesigned to accommodate a more human-readable format, with the actual map to be presented in subsequent studies. While there are many future challenges to be overcome, the creation of a location map is the important step in preparation for the possibility of contact with other-worldly beings. By designing a sustainable map that is both near-accurate and easily interpreted, we may help to facilitate communication and understanding with potential extraterrestrials.

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