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Have Starship, Will Travel

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Water, water everywhere, but which drops can we drink?

Jim Beall

Jim Beall (BS-Math, MBA, PE) has been a nuclear engineer for over 50 years, beginning as a nuclear engineering officer in the US Navy. Civilian experience includes design, construction, inspection, enforcement, and assessment with a nuclear utility, an architect engineering firm, and the US Nuclear Regulatory Commission (USNRC). Assignments at the USNRC included reactor inspector, safety analyst, and policy assistant to three different Presidential-appointed USNRC Commissioners while earning the agency's Meritorious and Distinguished Service awards.

Coauthor of Journal of the British Interplanetary Society (JBIS) paper, "Ecological Engineering Considerations for ISU's Worldship Project" and Elsevier's "Interstellar Travel: Purpose and Motivations." Baen Books has published several of his non-fiction articles on a variety of subjects, including generational starships, shipyards, the electrical grid, "Atomic Follies," recycling, borders, warships (of sea and space), and artificial intelligence.

Water may be the most important resource for sustained operations in space. Besides being vital for life support, it is a necessary component in many industrial and chemical processes, as well as being an attractive source of propellant.

Fortunately, water is very abundant in our Solar System. In fact, per NASA's former director of planetary science, "The solar system is now looking like a pretty soggy place." (Jim Green, March 12, 2015)

Unfortunately, most of it appears to be at the bottom of gravity wells. Even simply getting pure water from Earth up the 250 miles to the International Space Station (ISS) remains expensive. Although SpaceX reduced NASA's own cost by 75% in recent years, the price remains about twenty thousand dollars per gallon.

Further out in the Solar System, Neptune and Uranus appear to contain vast masses of ice, but their gravities preclude extraction by any near-term technology. Additionally, those gas giants' ice/water are thought to be rich in dissolved magnesium (causing their blue appearance). https://www.nature.com/articles/s41550-021-01368-2. The presence of magnesium might well present some attractive future mining opportunities, but it also hints at possible present-day challenges in water purification throughout the Solar System.

Gas giants are not the only ones to pose such question marks. Beneath its seventy-five-mile crust of ice and rock, the Jupiter moon Ganymede may contain more liquid water than all the oceans of Earth, but its chemical make-up is not yet known. https://www.space.com/28807-jupiter-moon-ganymede-salty-ocean.html

Similarly, Callisto, another Jupiter moon, may also harbor a significant body of water beneath its own thick crust. Closer to Earth, Mars has significant bodies of water ice at both poles, with possibly liquid water beneath its south polar cap.

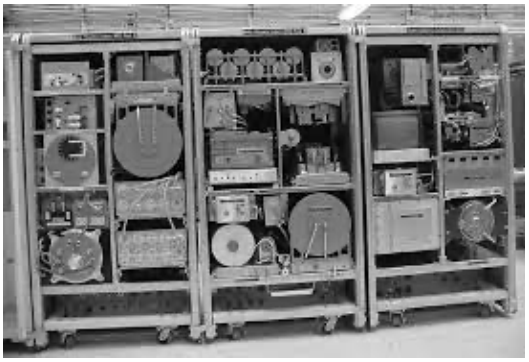
Closer still, the Moon is thought to have water ice in some craters at its own south pole. This proximity and the availability of continuous sunlight unattenuated by atmosphere are the two reasons the world's spacefaring nations are all planning bases there.

In short, there is a lot of water out there, but what's in it? There are legions of potential contaminants, including some which are dangerous at even low concentrations. The website of the US Environmental Protection Agency (epa.gov) is one useful tool with regards to potable water. There, one can peruse multiple tables of analytical methods for measuring contaminants like perchlorate, hexavalent chromium, radionuclides, and a great many more. Given long exposures to cosmic radiation, solar wind, and temperature/pressure cycles, even ice in smaller carbonaceous asteroids could harbor unexpected contaminants. One telling example phrase used to describe extraterrestrial ice is, "multicomponent, H_2O-dominated ices/fluids."

https://www.pnas.org/doi/10.1073/pnas.1812905116

NASA recently announced a new milestone in ISS water recycling, recovering 98% of water mass for reuse. The system involved is the Environmental Control and Life Support System

(ECLSS) which is housed in "three refrigerator-sized racks" to support the ISS crew, which is typically seven or fewer:



The ECLSS had previously recovered about 94%. The improvement was the result of a system upgrade that included an ionomer-microporous membrane pair that "contains the brine while transferring purified water vapor to the cabin air." (https://ttu-ir.tdl.org/items/046d5640-3ff6-4542-b9dd-2d903ceccac0)

Reverse osmosis (RO) systems that employ ionomer-microporous or biomimetic membranes also offer great promise for extracting potable water from space sources. RO system designs generally involve trade-offs in expense, efficiency, flowrates, and maintenance needs. Large-scale Earth-based systems with robust throughput typically use high pressure and/or power. NASA champions future In Situ Resource Utilization (ISRU), but systems such as those would be problematic for many off-Earth applications where bulk power may not be available and/or where waste heat rejection would be difficult (especially in vacuum).

The best space systems are ones that, like the ECLSS, are designed with knowledge of the likely input contaminants. Optimization such as achieved in the ISS may not be feasible until the specifics of the targeted space water source are well understood and designs tested.

The most likely challenging contaminant to turning space ice into potable water may be deuterium. Separating deuterated water molecules (D2O and DHO) from standard ones (H2O) has long been necessary for various nuclear programs. Typical processes involve boiling-distillation or electrolysis; both are energy intensive and involve significant installations:

Glace Bay Heavy Water Plant

As such, they are likely not feasible in space applications. One process still under development, however, offers considerable promise: adsorptive separation. (https://www.nature.com/articles/s41586-022-05310-y)

Small samples were retrieved from the asteroid Ryugu and, while debate may remain over the exact values, there does appear to have been some deuterium "enrichment." (https://iopscience.iop.org/article/10.3847/2041-8213/acc393)

More recently, a much larger sample was retrieved from the asteroid Bennu, the target of the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) mission. As of this writing, the material inside the returned capsule had yet to be analyzed. The materials' prediction, however, contained the following:

"Water adsorbed onto highly porous grains should also be detected provided that the sample return capsule remains below 300 K during Earth return, and this water should be isotopically heavy." https://iopscience.iop.org/article/10.3847/PSJ/abc26a

The words "isotopically heavy" refer, again, to water/ice with one or both hydrogen atoms replaced by deuterium. If this second sample prediction is confirmed, then much of the Solar System ice not at the bottom of gravity wells may be deuterium-enriched water. While this could be a future advantage for space-based fusion or heavy-water reactors, it would present a problem for human life support because isotopically heavy water is not potable water.

On Earth, deuterium is naturally present at a very low level in water (~1 molecule in 3,200 of hydrogen), and that level does not endanger human health. Humans begin to experience adverse health effects, however, when the hydrogen atoms in their body water reach 20% deuterium, with 50% being lethal. Thus, if the Bennu sample confirms isotopically heavy water, then advances in some process like adsorptive separation might become vital to support crewed space exploitation.

Spectrographic data from Venus and Mars also indicate higher than Earth percentages of deuterium. This is due to the heavier isotope being slower to be lost to space. In fact, the deuterium-hydrogen ratio signatures in those planets' atmospheres are used in various analyses.

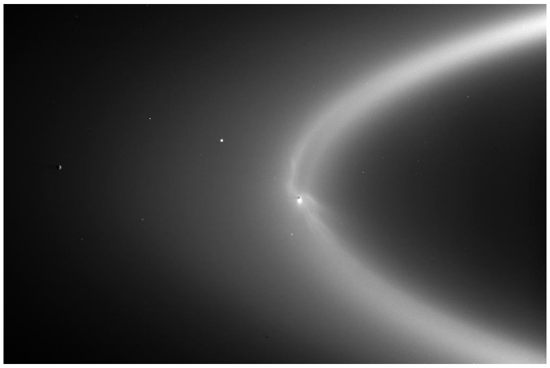
Mars:
https://go.gale.com/ps/i.do?p=HRCA&u=googlescholar&id=GALE|A6820871&v=2.1&it=r&sid=googleScholar&asid=393e9e61

Venus:
https://www.vanderbilt.edu/AnS/physics/astrocourses/AST101/readings/water_on_venus.html

The implication is that water found on or near the surfaces of, say, Mars and the Moon, may also be isotopically heavy. In those cases, however, large surface facilities employing bulk energy and massive waste heat rejection heat sinks would be more feasible.

The amazingly ambitious and successful NASA Cassini-Huygens Mission returned vast amounts of data concerning Saturn, including its moons and rings. Of all Saturn's moons, only Phoebe evidenced isotopically heavy water (and contained perhaps the highest "enrichment" in the entire Solar System).

Cassini also identified the water geysers on Enceladus as the source of Saturn's E-Ring, the outer-most of that planet's rings:



Detailed spectrographic mapping of the geyser plumes and all Saturn's rings revealed the waters not to be isotopically heavy. Thus, the rings of Saturn may well be the preferential source for space life support because no landings would be required to harvest water-ice. One possible approach, for example, might be a series of cyclers, with one end of each orbit to include a collection pass through the E-Ring with the other end at some inner System destination for water transfer.

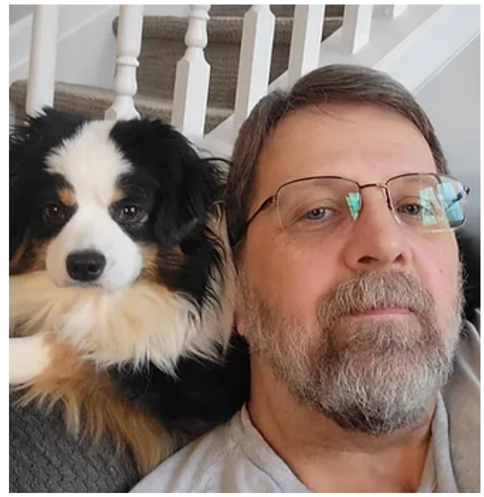
Missions to demonstrate recovery, testing, and treatment in situ (even if on a very small scale) of samples from ice-surfaced moons (soft landing but no retrieval) and the Saturn E-Ring would seem to be a challenging but important next step. Mission success would demonstrate that life support and liquid reaction mass could be made available at destinations or waypoints in support of operations or extended missions.

In summary, water is perhaps the most critical resource for space operations, and extra-terrestrial water is abundant in the Solar System. Most of it by mass, however, is at the bottom of gravity wells, some of them very deep indeed. Accessing much of the rest may well be feasible, but in situ confirmation of chemistry and treatment system effectiveness are important precursor steps for Solar System exploitation.

Pancosmorio Theory: The Limits of Human Settlement in Space

Ben Davis

Ben Davis has a Ph.D. in Nuclear Physics and an M.S. in Nuclear Astrophysics from the University of Notre Dame. He's had a storied career as a programmer, engineer and scientist. He currently teaches physics and engineering for ECPI university. He occasionally writes articles and unsuccessfully hunts ghosts.



I often think about the Fermi paradox. In a nutshell, the argument is "if there are advanced aliens, why aren't they already here?" To expound, let's say there is some technologically advanced civilization 10,000 years ahead of us on the evolutionary scale—a mere blink of the eye in cosmic time. Fermi reckoned such a civilization should have already colonized most galaxies. Given two or three, you'd likely be part of someone's empire no matter where you lived, but this interpretation is clearly naive in some way.

This naivete leads us to ponder the concept of a great filter. In the context of the Fermi paradox, this idea posits that civilizations can advance only so far before suffering collapse, "filtering them out" as spacefarers. The great filter is often assumed to be a permanent removal of that society and thought of as a catastrophic end such as nuclear war. However, the problem need not be so cataclysmic.

As humanity dreams of colonizing other planets and venturing beyond our solar system, a new theory emerges to cast a sobering light on our interstellar ambitions. The Pancosmorio Theory, coined by researchers Michael C. and Stephanie L. Irons, proposes a fundamental limit to human sustainability in space: the "all-world limit." Rooted in the principles of "ecological thermodynamics," it suggests that long-term survival in space may be far more challenging than anyone previously imagined.

The Core of the Theory

Building upon this foundation of ecological thermodynamics, the Pancosmorio Theory addresses the flow of energy and matter within ecosystems. It posits that any ecosystem, including a human settlement in space, requires a basal ecosystem to function. This basic system acts as the foundation, providing essential resources like food, water, air, and waste processing.

It's fair to say any system of colonization that doesn't include self-sustaining outposts would become top-heavy and doomed to failure in short order.

The theory then introduces the concept of the "all-world limit" (pancosmorio). This limit defines the minimum size and complexity of an ecosystem necessary for long-term human survival. Essentially, it outlines the minimum self-sustaining environment that can support a human population indefinitely without relying on external resources.

Levels of Sustainability

The theory proposes four levels of sustainability for human settlements in space, each with increasing requirements for their own basal ecosystems:

- *Level 1: Earth Replica*: This level represents a complete replica of Earth's biosphere with a self-contained ecosystem capable of producing all essential resources. Think of it as a giant, enclosed terrarium.
- *Level 2: Closed-Loop System*: A closed-loop system for key resources, like water and air, may still require external inputs for some materials. Imagine a space station with recycling and resource recovery systems.
- *Level 3: Partial Self-Sufficiency*: This level relies on a partially self-sustaining ecosystem with some food production and resource recycling but still requires significant external imports for essential materials. Think of a lunar base with greenhouses and limited resource extraction.
- *Level 4: Resource Outposts*: Settlements that are entirely dependent on external resources would act primarily as mining or research outposts. Imagine a Martian colony solely reliant on imported food and water.

Any system falling short of level 1 is intuitively problematic as a long-term solution. Widespread disasters occur, key people fall ill, and food stores become tainted. Counting on a lifeline that is months away becomes a game of Russian roulette that eventually will be lost.

The Challenges of Pancosmorio

The theory throws a wrench in our optimistic visions of sprawling space cities. It highlights the immense challenges of establishing a self-sustaining human presence in space. Some key challenges include:

- *Size and Complexity*: Achieving Level 1 sustainability, a complete Earth replica, would require a massive and complex artificial ecosystem, potentially exceeding the technological and logistical capabilities of the foreseeable future.
- *Resource Availability*: Finding planets or celestial bodies with the necessary resources to support a large basal ecosystem is a significant hurdle. Additionally, extracting and processing resources in space presents unique challenges.
- *Gravity and Radiation*: The lack of Earth-like gravity and the presence of cosmic radiation in space pose significant health risks for humans, requiring advanced mitigation technologies.
- *Psychological and Social Factors*: The long-term psychological and social implications of living in confined, isolated environments need careful consideration for the well-being of space colonists.

Implications for the Future

While the Pancosmorio Theory paints a challenging picture, it serves as a valuable wake-up call, emphasizing the need for a more realistic and sustainable approach to space exploration and colonization. Some potential implications include:

- *Prioritizing In-Situ Resource Utilization (ISRU)*: Focusing on technologies for extracting and utilizing resources directly from the local environment, like water ice on Mars or lunar regolith, can reduce dependence on external imports.
- *Developing Closed-Loop Systems*: Investing in research and development of closed-loop systems for air, water, and waste management is crucial for minimizing resource consumption and waste generation.
- *Exploring Smaller-Scale Settlements*: Smaller, more self-sufficient outposts with specific research or resource extraction goals may be more feasible in the near term than large-scale colonization efforts.
- *International Cooperation*: Collaborating on space exploration and development can pool resources, expertise, and knowledge, increasing the chances of success.

The number of baby steps required to settle even a relatively close and hospitable planet like Mars is nearly incalculable but certainly large. It took the build-up of 11 Apollo missions before our short visit to the moon, and before Apollo, Gemini and Mercury added another 30 test flights to that effort.

Conclusion

The Pancosmorio Theory is a sobering reminder that the vastness and harshness of space pose monumental challenges to our aspirations for interstellar expansion. It is not a call to abandon our dreams of exploring the cosmos - but rather a call for a more grounded and realistic approach. By understanding the pancosmorio limit and the challenges it presents, we can focus on developing the technologies and strategies necessary to overcome these hurdles and pave the way for a sustainable future for humanity in space.

Put simply, the Fermi Paradox doesn't take evolution (human or otherwise) into proper perspective. As is often said, we already live on the optimal planet for the human race; our brand of life has evolved here for the last 3.7 billion years. Anywhere else will have different gravity, radiation levels, atmospheric composition (with considerably less oxygen—a product of microbial evolution), pressure, fresh water, and much more that I've failed to even consider here. Many — but perhaps not all of these problems — are manageable with the proper technology. I'm no biologist, but what if the very dirt of any alien's home planet becomes the most precious resource of all when attempting to expand through the galaxy? Our topsoil teems with microbial life (not to mention worms and larger creatures) that prepare the ground with nutrients for plant growth. What if that ecosystem doesn't easily transfer to the dust of another world (rightly called "regolith" by experts to distinguish it from live soil)? That failure could occur for any number of reasons (pH values, lack of digestible organic material, ability to hold a proper range of moisture after watering, etc.). Imagine terraforming at this scale as a species travels light years in multiple directions to expand and colonize—and what if the soil from even a "successfully" colonized planet is insufficient or just too precious for further transplantation? As the home world gains mining resources and new scientific opportunities, it may lose its very essence. The return on investment may simply become too great to go any further.

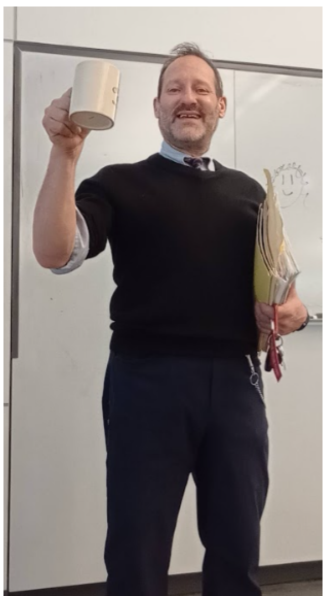
Further Resources

Irons, M.C., & Irons, S.L. (2023). "Pancosmorio (world limit) theory."

A DECADE OF PROGRESS ON THE CULTURAL DYNAMICS OF MULTIGENERATIONAL INTERSTELLAR VOYAGING

CAMERON M. SMITH, PHD

Cameron M. Smith studied anthropology and human prehistory in England, the US and Africa before earning a doctorate in archaeology in Canada in 2004; he has been teaching in these fields at Portland State University's Department of Anthropology since 2000. Since 2006 he has included the distant human future to his studies, publishing widely on an evolutionarily-informed approach to the question of 'humans beyond Earth' in multigenerational time. He continues to teach about the human past at Portland State University and coordinates research about the human future as co-director of the University of Arizona's Center for Human Space Exploration. Website: [*https://pdx.academia.edu/CameronMSmith*](https://pdx.academia.edu/CameronMSmith)



Introduction and Context

In 2013 I was invited by Andreas Hein of Icarus Interstellar to participate in the *100 Year Starship Symposium* in Houston, Texas. Specifically, I was asked to research human population dynamics to determine a reasonable interstellar voyaging population, which would be used in the consideration of propulsion. Since then I have increasingly structured my research around biological and cultural requirements for maintaining the multigenerational biocultural health of interstellar voyaging populations. In my 2019 book, *Principles of Space Anthropology; Establishing a Science of Human Space Settlement* (Smith 2019), I attempted to organize my thinking about this topic by identifying just what exactly would change through time for the interstellar voyaging culture. To guide my thought I focused on a set of formalized Human Cultural Universals; aspects of human cultural organization found in all societies, but slightly differing in each society. For example, all societies have a conception of a family (often two pair-bonded adults cohabiting with one or more offspring), but exactly how the family is defined varies somewhat. The 12 Human Cultural Universals (discussed more below) are akin to the controls of an aircraft (e.g. directional control, anti-ice controls, radar); properly adjusted, they fit new and changing conditions, allowing cultures to travel and survive in time and space.

I focused on this aspect of interstellar voyaging because discussions of the topic, in my experience, often quickly focus on what a particular person thinks is the 'best' organization for a culture. Thus the literature and thinking on the topic, I find, is often highly personalized to each author and their interests or expertise (Figure 1). I wanted rather to have a framework that realistically addresses the actual structure and organization of human cultures, not just the features of culture that we (often specialists) may be interested in, and thus over-emphasize in our thinking.

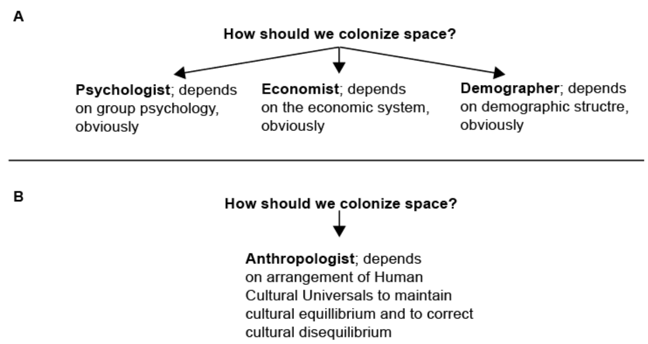


Figure 1. Common Trajectories of Conversation Regarding the Question of Human Space Colonization.

I discussed these topics in a *Centauri Dreams* blog post invited by Paul Gilster in 2014 and spent the following years completing *Principles of Space Anthropology*. I envisioned and titled the book akin to S. Gerathewohhl's 1963 *Principles of Bioastronautics*, written to address the then-completely new subject of human space exploration (Gerathewohl 1963). My book has had a few enthusiastic receptions, but just from a small population; the book is expensive and of interest to a very small audience as yet, though I am pleased to see that it is in about 200 libraries worldwide and may be usfeul in coming decades as the conception of interstellar voyaging grows in the collective consciousness.

I mention all of this to give you some context for the topics I will discuss below; currently I think the genetically-safe population estimations I have worked out, and which have been improved by University of Strasbourg's Dr. Frederic Marin), on the order of some low thousands to 20,000 (see Hein et al 2020) are very reasonable and my focus has shifted towards the cultural dynamics of interstellar voyages.

Cultural Universals and a Cultural Hierarchy of Needs

As mentioned, the Human Cultural Universals are domains of behavior that are adjusted to accommodate the material and cultural environment of a given culture. For example, all cultures have a mode of subsistence, (e.g. desert foraging, marine hunting, farming); and all cultures have means of enculturation (e.gt. formalized education, informal apprenticeship). By adjusting the specific configuration of behavior in each domain, humanity so far has been able to adapt to myriad physical and cultural environments across the globe in the past 50,000 years (see Smith 2018). Figure 2 uses icons to visually represent the 12 universals I recognize in my work. My proposal is that these are sufficiently plastic to accommodate interstellar voyaging conditions.

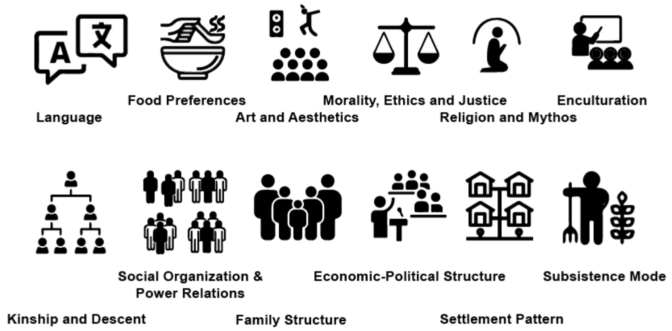


Figure 2. Iconic Representation of Human Cultural Universals. For example, the *Family Structure* variable has been used used to accommodate new phenomena; for early farming peoples some millennia ago, family structure was adjusted to promote large families, because even young children can do useful farming activity, whereas just a generation earlier, family structure ethos was that of the forager or hunter-gatherer, with an emphasis on smaller, mobile populations sufficiently agile to travel landscapes in pursuit of resources. These universals are not arranged in any particular order in this diagram.

Another way to think of the universals as the 'adaptive toolkit' of humanity is to consider them behavioral domains used to *maintain equilibrium* in a culture (preserve it multigenerationally) and to address *disequilibrating forces*, such as the failure of a certain food resource, or challenges to the dominant religious tradition. On a multigenerational interstellar voyage, I have pointed out that sources of disequilibrium will much more likely be internal (culture change due to new concepts) rather than external (e.g. environmental change over time), because the interstellar vessel would be built with a very stable closed ecosystem. And in general, I think an interstellar-voyaging culture would have as good a chance as any Earth culture known to date to accommodate such disequilibrating forces.

At least, until the very end of the voyage, and arrival at an exoplanetary destination. I have noted that we may sharpen our thinking about interstellar cultures by considering the time dimension, such that we think of the cultural issues of a Departure Age, an Interstellar Age and an Arrival Age. I currently add, in the Arrival Age, a period of Settlement, as settlement would require radical cultural accommodation to the new exoplanet environment.

Imagine, for example, how a culture would have to adapt to 'planetness' after many centuries of living in a closed system. Or imagine the concept of seasonality, and geographical variation in subsistence materials (e.g. plant foods) that would require accommodation after many centuries of a highly controlled, predictable and stable closed ecosystem. I am currently investigating the plasticity of the cultural universals in terms of such changes, from Worldship Culture to a Planetary Culture. To organize this thinking I have considered the equilibrating function of the cultural universals in terms of a 'Cultural Hierarchy of Needs'. Maslow's hierarchy of needs is a well-regarded framework of thinking about the requirements for the health of a given individual. Figure 3 depicts this framework (A) and, beside it (B), a conception of a Cultural Hierarchy of Needs. The diagram moves the cultural universals into a hierarchical order, with items lower making possible the items higher. For example, the mode of subsistence, settlement pattern and essential family structure are all strictly conditioned by the resource environment, and must be established and stable for higher-level activity. This arrangement, which is currently a provisional 'first draft', may strike some anthropologists as environmentally deterministic, attributing too much to environment; but I disagree. In my study of human adaptation, language, foodways, even kinship arrangements and so, all appear to be more-or-less adapted to the physical and cultural environment of a given culture. A time dimension is required here; over time, a culture may be well-adapted to a given environment, and the universals may 'shift' up or down in the hierarchy, having more or less influence, through time, on others (and I think this is where we do need to be careful about suggesting too much influence from the resource environment).

For the moment, I am thinking of the Cultural Hierarchy of Needs simply as a heuristic tool, a way to structure my thought. I anticipate adjusting it, but not abandoning it entirely.

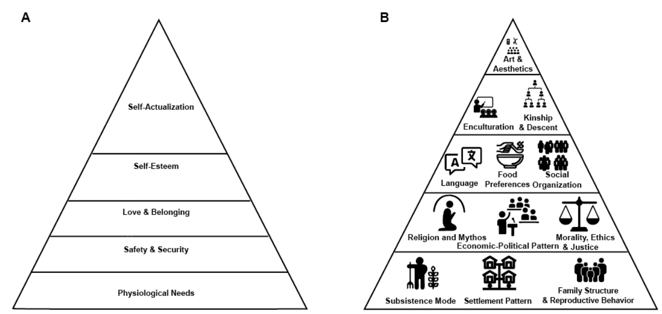


Figure 3. The Individual Hierarchy of Needs (A) and (B) Human Cultural Universals Similarly Arranged as an Heuristic Tool. Items higher on the hierarchy in (B) are not considered to be of any less value than those below, but are more conditioned by those below than above.

One example of applying the Cultural Hierarchy of Needs to the interstellar voyaging concept is seen below in Table 1. Here I simply show that through a Departure Age and an Interstellar Age, most of the cultural universals would be managed to maintain stability (note at present I only address a few of the universals in this table). But at the Arrival & Settlement Age, significant changes would be needed in all universals to accommodate the change from a Worldship Culture to a Planetary Culture. For example, consider row three, concerning Food Preferences and Language. However these are arranged during the Departure and Interstellar ages, on arrival at an exoplanet a myriad new resources and environments will have to be accommodated. At the exploration of such new places, foodways would have to be adapted; new conceptions of what is fit for consumption would have to be devised as people became acquainted with non-domesticated species, for example (which often differ significantly from domesticates). Even if stocks of Earth-originating food are taken to the exoplanet to establish new farming communities, these would likely differ somewhat from the domesticates used in the Interstellar and Departure ages. In the same way, as new environments are explored, new words, naturally, would be used to describe new environments. It is well-known that indigenous Arctic people have many more words to describe types of snow and ice than non-Arctic people; in the same way, attention will be paid closely to new phenomena which will need new descriptors. As these accumulate, regional vocabularies and even dialects would develop over time; just as they have in the past 50,000 years on Earth, where, just before the origins of globalization in c.1500 AD, there were about 6,000 languages worldwide, each strongly correlating with a local geography (Creanza et al 2014).

Table 1. Human Cultural Hierarchy of Needs in Three Ages of an Interstellar Voyage.

Cultural Universals	Departure Age	Interstellar Age	Arrival & Settlement Age
Art & Aesthetics	Stable & changes unlikely to be allowed to effect safety	Stable & changes unlikely to be allowed to effect safety	Radical changes likely due to new foods, landscapes, lifestyles, materials & media
Kinship & Descent	Stable; unlikely to change as population must not exceed closed environment resources	Stable; unlikely to change as population must not exceed closed environment resources	Radical change as populations disperse on new landscapes, grow & adapt to new phenomena
Language & Food Preferences	Some change towards closed-system diet; language changes very likely to reflect new conditions of a Worldship	Foodways likely stable though with innovations through time; language may change to reflect concerns of a culture moving between stars	Significant change to diet as new foods are encountered; significant change to language to describe, understand and control new resource environments
Religion and Mythos	Stable; likely used to promote stability of behavior over time	Stable; likely used to promote stability of behavior over time	Possible change with attention to 'planetness' rather than open space as the essential environment; highly unpredictable
Subsistence Mode, Settlement Pattern, Family Structure & Reproductive Behavior	Stable; closed ecosystem demands population control	Stable; closed ecosystem demands population control	Change to planetary farming concerns rather than closed-loop, highly controlled environment; family structure change to promote large populations quickly

Assuming the arrival at the destination of a bioculturally healthy and settlement-capable culture, I think the Arrival and Settlement Age will be one of significant change. Because evolutionary information systems (including culture) do not well sustain rapid and radical change, I suggest that in the generation or two leading to arrival at the exoplanet, the culture will wish to make some fundamental changes to many (perhaps all) of the universals as preparation for transforming from a Worldship to a Planetary culture. Such a change would have to accommodate some radical 'new' realities:

- As opposed to the closed system of the worldship, people would have to encounter and accept great 'opennesses'
- As opposed to the tremendous stability of the closed ecosystem of well-known domesticates, people will have to encounter and accept new species, should they exist on the exoplanet; this would be an experience of great instability and encounters with new phenomena, in contrast to centuries of well-known and rarely-changing phenomena
- As opposed to the strict population control over the prior generations, people would be encouraged to have large families and disperse widely on landscapes to increase the likelihood of survival in times of catastrophe

Likewise, consider some broad, novel conceptions that would have to be established as interesting and acceptable with the settlement of a planet after generations between planets:

- Uncertainty
- Variability
- Resourcefulness / problem-solving
- Self-sufficiency
- Large-space awareness

…And many, many more. Identifying such fundamental differences from Worldship Culture to Planetary Culture is a worthy goal. How would the Worldship culture promote the acceptance of these new experiences as the exoplanet destination is approached? Perhaps in the generation prior to arrival, enculturation would begin to emphasize new ideas and values; values of exploration, self-reliance, curiosity, movement, and so on. All of this would be communicated in a new generation of stories, words and phrases, art and so on. The cultural features of an Arrival Age people may well be a good subject for valuable and productive speculative fiction. For example, thinking freely I have envisioned Arrival Age youths being sent on expeditions to the *outside* of a given Worldship, where they might even clamber on artificial 'landscapes' constructed of ice -- part of the Worldship water supply sculpted on the outer surface of a generation ship, simply to give them a new sense of space, distance and experience with new and not-always-entirely controlled phenomena. Such conscious shaping of culture through time may be considered unacceptable 'social engineering', but I disagree; every culture transmits the concepts and values of its times to the next generation to equip that next generation for survival.

In considering the large-scale cultural changes required to become a Planetary culture, I have also considered a very different adaptation; to remain on the Worldship. I think it is entirely possible that at least some segment of the whole population may not wish to make these changes, and decide a generation or more beforehand that they will remain in the stability of the Worldship itself. Interesting, but beyond my concerns.

The changes from Worldship to Planetary culture will be significant enough to constitute significant reorganization of the information content of the culture, and thus may be considered genuine *evolutionary transitions* involving a *prior state*, multiple varieties of *transition phenomena* and of course the new, transformed state of the evolutionary information system. Such 'unpacking' of how significant evolutionary changes occur, aided by the field of *evolutionary transition theory* (see Szathmary 2015) can also help shape our thought on the issue of Arrival Age cultural evolution. For example, in Table 2, I speculate on changes FROM the Worldship Culture state TO the Planetary Culture state, again, to help corral my thinking towards specifics rather than generalizations.

Can we say anything specifically about the goals of the Arrival or Settling culture? Indeed we can. In a survey of species longevity on a palaeontological timescale, evolutionary biologist Geerat Vermeij concluded that the most successful species have been widely geographically distributed, exhibited genetic and behavioral diversity, and were numerous (Vermeij 2008). Each of these qualities contributed to multigenerational success by providing resilience (the capacity to return to equilibrium) in the face of disequilibria. The ‘shape’ of Arrival or Settling culture may well be informed by such knowledge.

Table 2. Human Cultural Hierarchy of Needs Transitions at the Arrival Age of an Interstellar Voyage.

Cultural Universals	FROM (Worldship Culture)	TO (Planetary Culture)	Speculation on Likely Specific Changes
Art & Aesthetics	All refer to and are historically contextualized in the ship and its voyage.	Novel local geography, flora, fauna, resources and therefore media for artistic / aesthetic expression.	Change due to new foods, landscapes, lifestyles and materials / media
Social Roles and Family Structure	Stable roles and family structure due to stable spiritual, cultural and physical closed-system environment for some centuries.	Tolerance for novelty and innovation in such roles and structures as adaptations to a new (importantly, open) environment.	Acceptance and social rewards for larger families than smaller.
Family Structure & Reproductive Behavior	Focus on limited population with strict rules to prevent growth over several centuries.	Encouragement of larger families and earlier marriage & childbearing to make the population safer by ‘numeracy, diversity and geography’ (Vermeij).	Change toward large families and rapid population growth play out in changing values of reproductive activity including lowered sex activity prohibition.
Subsistence	Highly-stable resources managed in closed-system predictability and regularity of planting, harvesting and processing of food sources, for centuries.	Highly experimental approach to new resources in farming practice (with shipboard closed system as backup). Focus on experimentation until a new, open, planet-based subsistence mode is formalized.	Change to planetary farming concerns rather than closed-environment; resources cannot be assumed to be effectively infinite; seasonality demands new variety of scheduling activities, etc.

Conclusion

As you can see, my work has specifically avoided prescribing specific ways that interstellar cultures might act to accommodate their new environment. Rather, I want to understand whether the human cultural universals are pliable enough to accommodate the Cultural Hierarchy of Needs for the interstellar venture and successful adaptation to a new planet. So far, they appear to be. Planners of interstellar voyaging, I think, may put aside vague arguments that no culture could survive so long in isolation or that that changes on arrival would be too large to accommodate. Rather, we can focus on the magnitude of reasonably-expectable disequilibria throughout various periods of such a voyage, and show examples of how such have been accommodated in the past. That, I think, is enough for now.

Thinking back to the origin of my involvement with the anthropology of interstellar voyaging, I feel significant progress has been made in both the biological and cultural dimensions of this breathtaking idea. Reasonable voyaging populations have been established, first by my original estimations and subsequently significantly improved by Frederic Marin. And the fuzziness of the cultural dimension has been significantly sharpened by focus on the Human Cultural Universals as the adaptive toolset of human culture, that which, to all appearances so far, appears equipped to accommodate reasonably-expectable perturbations on the multiple-centuries to one millennium timescale considered reasonable by modern studies of propulsion. It appears that some elements of the gigantic puzzle of multigenerational interstellar voyaging have been rather well-defined and are sliding into place. I am thrilled to be involved with this very exotic idea and the people shaping it, little by little, every day.

I would like to conclude with one final diagram. Figure 4 depicts what we really must preserve over time; a system of multigenerational health. Note that culture (including technology) and biology are both involved. A sound interstellar voyaging culture will have to arrange the human universals to fulfill the cultural hierarchy of needs in aid of supporting this multigenerational system. It seems entirely possible, buy it will have to accommodate new conditions at different times of the interstellar voyage.

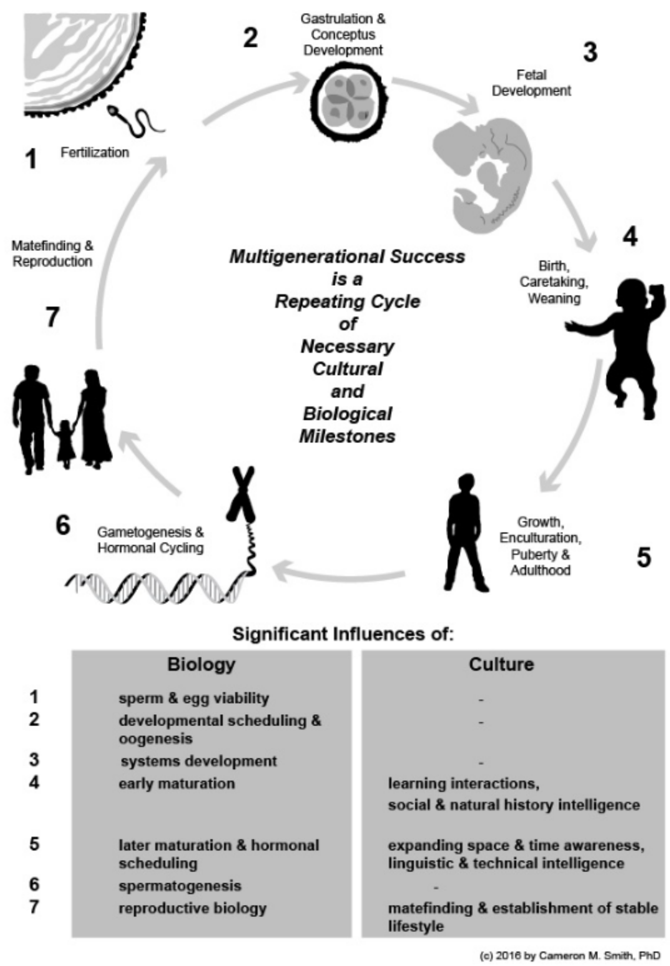


Figure 4. Multigenerational Success in Human Bioculture.

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Interstellar Seminar Course Introduces College Students to Interstellar Studies

Mark A. Schneegurt

Mark A. Schneegurt is an author, educator, scientist, and entrepreneur. His books range from scholarly works on biology and philology to popular literature. He has authored 100+ publications and has made 200+ public presentations of his research works in astrobiology, microbial ecology, soil science, plant biology, and microbiology. Recipient of awards for teaching and research, Dr. Schneegurt holds degrees from Rensselaer Polytechnic Institute and Brown University, with professional appointments at Purdue University, University of Notre Dame, and currently as a professor of Biological Sciences at Wichita State University.

How do we grow the interstellar community? Who is going to champion our push to become a multi-stellar civilization? Where will the next generation of leaders get captured by the idea of interstellar travel? Outreach and education are key to exciting young people – and everyone else – about the prospects of interstellar travel. How best to provide education than to offer courses at colleges and universities? Making these courses free to the public, opens the door for everyone to get involved. This is what we are doing with Interstellar Seminar at Wichita State University.

A few years ago, Steve Durst visited our campus and told me about his conceptual framework for Interstellar University. Steve is a space leader, involved in lunar missions, education and outreach, and founder of Space Age Publishing. Kansas seemed like the obvious place to house Interstellar University given that the state motto is Ad Astra Per Aspera – To the Stars Through Adversity. From my perspective as a university professor, it was clear that universities, by their nature, offer courses. Interstellar University should offer courses. Thus, the idea for Interstellar Seminar was born.

We consider Interstellar Seminar to be a pioneering course, the first of its kind. Yes, there are courses that cover topics in interstellar science and engineering. There are successful and powerful programs in aerospace at Wichita State; we are even home to the National Institute for Aeronautics Research. Those programs and courses are for students that dream of becoming engineers and scientists in the expanding New Space industry. Interstellar Seminar is not a technical course. You may get excited to pursue a career in aerospace by joining the course, but you will not learn the technical skills you need for that career.

The goal of Interstellar Seminar is to introduce students and the public to the interstellar community, exciting their imaginations for voyages to the stars. Interstellar Seminar meets for one hour each week on Wednesday afternoons. Students can attend the class in-person, synchronously online, or asynchronously through recordings archived online. Those that are enrolled in the course can earn one credit-hour through pass/fail grading. The required work is essentially keeping a journal, submitting a short reflective paper each week that expresses the impact of the lecture on their world view.

Students gain an understanding of space studies and the considerations for peopled missions. They will better recognize the challenges unique to interstellar travel and distinct from interplanetary travel. They will place human exploration in a clearer context of societal and ethical considerations. While not a technical course, students should increase their knowledge of the natural sciences, think critically and independently, and write more effectively. They also benefit from observing varied presentation styles and techniques for communicating scientific information. Often, they hear the convoluted career paths of the speakers, by which students like themselves eventually discovered a career that they love.

What makes Interstellar Seminar valuable is the quality of our amazing speakers, who mainly join the course remotely to present within their area of expertise. They offer an opportunity for students to interact with active space researchers, some of the most outstanding in their respective fields. The speakers inform and challenge their thinking about interstellar science and interstellar missions, both robotic and peopled. The seminar series broadly covers topics with nontechnical sessions, supported by straightforward accessible readings. While engineering and science topics related to interstellar travel are covered, the course includes philosophic and cultural topics. To introduce students to the concept of interstellar missions, the course begins with sessions on the nature of stellar systems, their distance from Earth and composition, and previous interstellar missions. The discussions then turn to exoworlds, their discovery and habitability. My astrobiology research is with NASA Planetary Protection Research, so I speak, along with outside experts, on topics in planetary protection, both forward and reverse, including SETI. Next the sessions cover more practical aspects of interstellar travel. We hear about chemical rockets and advanced propulsion systems. We address the support of an industrial ecology in space and how to deal with the impossibility of resupply through a discussion of additive manufacturing and regenerative machines.

We next turn to topics specific to human explorers. First a space philosopher joins us to explore the rationale for crewed missions to the stars, exposing the challenges of equitability and value-propositions from several perspectives. This leads into several sessions on human life support systems, crew health, and space psychology. We cannot address every aspect of these multi-faceted topics, but students are made aware that material recycling is key for interstellar missions and that there are health considerations from reproduction to toxicology to mental health.

The course concludes with topics in the Humanities. To be successful, the interstellar community needs more voices at the table, than just scientists, engineers, and businesspeople. The culture that develops on a multi-generational starship will not be the culture we have on Earth, since the constraints and realities of life in space are far different. We learn from a linguist how language might change and develop for these perpetual voyagers, becoming further removed from our civilization. Imagining the prospects for human colonization of the stars crystalizes in science fiction, where astounding new ideas are presented and considered. Our last session brings these perspectives to students, leading them to learn more and expand their thinking.

Students are intrigued by each of these varied topics, making them aware of the complexities and challenges of interstellar missions. It changes the lens through which they see New Space and the civilization they enjoy on Earth. In the inaugural semester, all of the enrolled students agreed (15%) or strongly agreed (85%) that the course was valuable, with the course ranking near the top of all university courses. Here are a few comments from students:

“This was a fantastic class and I hope to see it grow in the future. Way to go with speaker recruitment and course design!”

“This is one of the most accessible and thoughtful courses I've ever taken - the mission is clearly to put students and professionals in a dialogue and community of people who are fascinated by interstellar possibilities.”

“It is stress-relieving to have coursework that is about how your worldview is influenced by fascinating topics and to avoid the pressures of demonstrating mastery - to be allowed to simply learn and absorb is marvelous.”

You can join Interstellar Seminar too. The course (LASI 150G/750G) was offered in Spring 2024, starting in January, with several returning speakers and some new speakers. Information about the public zoom sessions and online recordings of the lectures will be available through Wichita Space Initiative at www.wichita.edu/space. An archive of previous lectures will appear there as well. If you want further information, please reach out to us at space@wichita.edu. We look forward to engaging a broader audience in space studies through this introduction to the interstellar community. Ad Astra!