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Projected Context and Enablements of Deep Space Development

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Introduction

The space faring age began in Oct. of 1957 with the launching of Sputnik, and space faring is about to venture out beyond geostationary orbit (GEO) into deep space. The first truly major space faring effort was the Apollo Project from 1961 – 1972 [ref. 1]. This project successfully landed a crew five times on the lunar surface and returned them safely to Earth. The cost of this project was $158 B in 2020 dollars and, at its peak, employed around 400,000 workers with 20,000 industrial firms and universities involved. The politics responsible for the project included the Cold War, national prestige, and economics/technology/jobs. The actual public support for Apollo was less than 50%. The major reason for this support level being concern about the cost [refs. 2, 3]. The project greatly enhanced and accelerated many technologies including computers, integrated circuits, avionics and telecom, and increased training and interest in STEM (science, technology, engineering, and math). The impacts were massive: 1,800 technical spinoffs (especially the "blue marble" photo of Earth from the Moon which encouraged the environmental movement), improved international relations, new industries, products, processes and jobs, integrated circuits and by various estimations between 6X and 15X greater benefits than the total cost. An additional impact was the invigoration of big idea thinking which, along with the integrated circuits, some say were responsible for Silicon Valley and its culture, products, and subsequent huge economic and societal impacts. Since Apollo, the next sizable space faring projects were development of the space shuttle and subsequent efforts to replace it, which fairly recently resulted in the Space X reusable, low space access cost rockets. Alongside shuttle replacement efforts was the development of the International Space Station (ISS), now facing end-of-life considerations. These projects were all U.S. government funded. Results from a Pew Research Center national survey indicated that over 60% of the respondents consider the two top priorities of NASA should be monitoring the Earth's climate system and working asteroid defense. Sending humans to Mars as top priority was 18% and sending them to the Moon was 13%. However, regarding space overall, 72% said it was essential that the U.S. be a world leader in space exploration and 65% said it was essential that NASA be involved in this [refs. 4 – 6]. Therefore, evidently there is good public support for space faring in general, but far less support for humans in space. On site and in-space humans are orders of magnitude greater in cost than the rapidly developing autonomous robotics.

More broadly, space development at GEO and below has, since the early1960s, branched out into a plethora of national security, commercial, science, and recently the beginnings of activities aimed at colonization of Mars, resulting in us becoming a two-planet society [refs. 7 – 13]. Also, space faring technology has developed greatly and reduced costs to where most nations are now involved in space, and there are now the beginnings of deep space faring, beyond GEO, which is the subject of this report. Current commercial space at GEO and below provides positional Earth utilities or space – for – Earth, including telecommunications, navigation, and imaging, and is the major component (some $350 B) of global space faring economics. Next are government programs such as exploration, national security, and space science, including space science for Earth (e.g., atmospheric science). With the development and globalization of space technology, space access and space equipage has increasingly shifted from government efforts to industry, with government addressing such government specific issues as emissions, acoustics, safety, traffic management, space radiation and micro g health issues, space infrastructures, regulation and monitoring, space science, and human exploration. There is significant public interest in getting humans to Mars. The major organizations pursuing this include the National Space Society, The Mars Society, Space X, Explore Mars, and NASA.

Societal Drivers for Deep Space Colonization and Commercialization

Society is changing rapidly. The ongoing IT, bio, nano, and now quantum and energetics tech revolutions are enabling "tele-everything", tele-travel, work, commerce, education, medicine, etc. We are passing through the IT Age into the Virtual Age, with ever better virtual reality and initial stages of the metaverse. Driven by climate issues and the shift to ever-less costly renewable energy generation and storage, we are heading toward electric everything. With the rapid development of artificial intelligence (AI) and smart-to-brilliant autonomous robotics, there is the possibility of much reduced need for "employment". Due to the various aspects of the Bio Revolution, there is increasing life span. With the ongoing development of fly/drive electric vehicle take-off and landing (VTOL) personal vehicles, and distributed, at home energy generation, the possibility to live anywhere without the need for roads and wires, is emerging. From the evolving smaller, cheaper, more numerous distributed sensors, we are evolving a global sensor grid, which could, along with the web, enable human level and possibly beyond machine intelligence and a defacto networked global mind. Humans are increasingly becoming cyborgs, including brain chips for direct brain/machine interactions. Going forward, the major trends appear to be climate mitigation, longer lives, less need to "work", and currently unimaginable developments from machine ideation and execution.

Then there are the societal "issues", some existential. These include climate, the competition of now ever smarter machines, possibilities for biohacking resulting in a pathogen that is a serious health threat, solar storms that devastate the electricity the humans are now wholly dependent upon, sizable asteroid impacts, eruption of Yellowstone and other large calderas, and the overuse and ongoing serious erosion of the ecosystem. These various "issues" can be addressed in various ways; however, some could be existential. That possibility, along with the ongoing tech enablements making humans to Mars both safe and affordable going forward, and the huge variety and magnitude of resources on Mars, has awoken a musing of, developing into a program to colonize Mars and become a two-planet society [refs. 14 – 16]. The rapid and wide spectrum of ongoing tech revolutions and developments are the enablers for such. At this point, both government and private-to-commercial efforts are beginning to head to the two-planet solution. This bodes well for increased societal support of both governmental efforts and the associated rise of commercial deep space, including Martian exploration, pioneering, and colonization [e.g., refs. 17 – 19]. There are sufficient resources on Mars and the enabling tech going forward to develop an independent Martian economy. Therefore, the outlook, society wise, for moving space faring out beyond GEO to deep space (initially to Mars) appears to be favorable. The major impetus to develop the key requirement for viable deep space development is establishment of a viable Martian Economy, which may not be primarily governmental. As stated, apparently the public wants NASA to work climate and protect Earth from asteroids; Mars is apparently farther down the list of public NASA priorities.

Deep Space Econometrics

In terms of commercial deep space, the zeroth order business case is commercial execution of government funded efforts. These may not be sufficient to support serious development of a Martian economy and resulting commercial deep space but could be a serious enabler for infrastructures and possibly frontier technologies. Real commercial, profit making activities are required to move seriously into deep space faring. Once those are established, there will be a plethora of service businesses that will depend upon changing deployed technologies including power and energy sources and radiation protection among many others. Such services could include refueling depots, repair/maintenance, search and rescue and "utilities" such as supplying food, water, energy, communications, "transportation", "supplies", and lodging.

The core enablers for commercial deep space are humans to Mars, two-planet species/a Mars economy and profitmaking closed business cases, and some space-to-Earth possibly, but mostly space-to-space going forward. Thus far there have been some space-to-Earth commercial deep space initial efforts regarding asteroid mining and Moon water. Increasing cost competition from Earth-based resources enabled by ever less costly space access has resulted in problematical business cases currently for these. Space tourism, now with plans to move on beyond GEO to the Moon, is a smallish thus far but positive deep space business case. For GEO and below, space manufacturing and space debris removal appear to be new space for Earth business activities, although the latter would probably have to be government funded. There is some interest in utilizing the "quiet", low disturbance nature of space to delay quantum decoherance, but that at least initially would be below GEO and the ongoing successful development involving use of "vibrated" systems to delay decoherence may obviate any urgency of moving quantum technology to space. There is increasing interest in space solar power, but the cost and capacity competition of terrestrial renewables and storage (and possibly low energy nuclear reactions or LENR) will perhaps obviate that, and it is also at GEO, not deep space. Issues with space-based solar power include the huge number of launches required, especially their cost and atmospheric emissions, and the cost competition from the rapid, ongoing cost reductions of terrestrial renewable generation and storage and their increased efficiency. Then there is space mining. There are only a very few minerals that, in a century or so, could be in short supply. Also, the ever less-costly energy developments should enable ocean mining with its vast natural resources [refs 17 - 19]. Some have pointed to precious metals in space for a space mining opportunity. Many of the economic estimates for this appear to assume the maintenance of current prices for such. However, a much greater supply via space mining would probably reduce their cost and profitability on Earth.

Therefore, thus far the only nearly demonstrated closed business case for deep space is space tourism (assuming businesses are going beyond GEO and aside from providing services in deep space such as refueling, etc.). A nucleus settlement on Mars, such as projected by Musk, opens the spectrum of major space-to-space closed business cases. The basic deep space industry then will be in situ resource utilization (ISRU), utilizing Martian resources for Mars, mining and manufacturing on Mars, and services for Mars. Martian resources can provide habitation (ditch and bury for radiation protection), fuels/propulsive mass, life support, hardware/equipage, food, thermalization, pressurization and dust protection, essentially what is needed to survive, thrive, and establish a viable Mars economy. Some have suggested that a possible space-to-Earth export from Mars could be ideation/ innovation. However, the developing capability of AI/generative adversarial networks (GANs) and other machine ideation approaches, improving as more and wider spectrum input training data is utilized, suggests going forward that Martian ideation would not be an especially viable export to Earth due to competition from Earth and machines. Ideation would obviously be a critical component of both Earth and Mars economies. In addition to Mars resources for Mars commercial deep space, there are in deep space vacuum, low temperatures, solar energy, micro g, magnetic fields, photons, gravity fields, minerals, and volatiles that could be considered for commercialization. The vastly decreasing costs of space access changes much in favor of commercial Earth-to-space vice space-to-Earth, to the point where the outlook appears to be what is done in space stays in space (i.e., space-to-space commerce and services, which pioneering and colonization on Mars results in). In addition to Mars, possible pioneering space sites include the upper atmosphere of Venus, the poles of Mercury, and several solar system moons such as Titan. The exploration and pioneering/colonization of Mars have over the years produced an extensive literature [e.g., and refs 20 – 35] explicating a spectrum of options and approaches which change as the space technology capabilities change [refs 17 – 19]. One of these [ref. 28] specifically addresses a myriad of approaches to getting humans to Mars both safely and affordably.

Considering the huge economic value of IT on Earth, a further sizable deep-space economic opportunity is to conduct extensive robotic on-site filming, etc., and to develop superb, five senses reality and holographic projection of virtual deep space exploration content for education and entertainment.

Space Science

There are two solar system major space science arenas from space, deep space science and atmospheric Earth science. There are a plethora of major unsolved problems in physics involving space [ref. 36, 37], some of which include not finding dark matter or dark energy, casting doubt on the big bang, and other aspects of the standard model of cosmology. This doubt is spawning research on such as “many worlds”, a holographic universe, greater than four dimensionality, alternative explanations of red shift, and a plethora of other ideas. The now rapidly developing area of quantum technology is exploiting quantum entanglement, whose speed has been measured at greater than 10,000 times light speed, with the physics of this wholly unknown. There is also the infamous 120 orders of magnitude overprediction by quantum of the cosmological constant. There have long been efforts to develop a theory of everything that includes quantum and relativity that also explicates the too many unsolved problems in physics, thus far with not much solid progress. Some thought that the various flavors of string theory would suffice, but now less so. The theory of noncommutative structure of quantum space-time appears to be interesting, with claims to be nonlocal, and positing explication of many of the unsolved problems, TBD [ref. 38]. The search for life off Earth is focused on carbon-based life (“following the water"). There may also be silicon- and sulfur-based life. For atmospheric space science, the major unknown is aerosols, whose climate change impacts are nearly equal in magnitude but opposite in sign to CO_2. Human activities have increased the aerosol content of the atmosphere. Without this occurring, the effects of the CO_2 increase would be greater. We need to learn much more about the basic mechanisms of aerosols and cloud micro physics. It may be possible, using hosted payload instruments on the massive LEO constellations being lofted, to hop from satellite to satellite to stare at a particular portion of a cloud and record what is happening. Cloud micro physics is a four-phase problem that includes plasma effects. References 39 and 40 document the scientific opportunities enabled by human exploration beyond Earth’s orbit.

Deep Space Applicable Emerging Technologies and Their Impacts [Refs. 17-19 and 28]

There are five major issues for space faring that require advanced technology solution spaces: power and energy, mass/weight, human health, safety and their enabler, cost [refs. 17 – 19]. Conditions on Mars that humans need technology-based protection from include: lethal atmospheric pressure, temperature, radiation [refs. 41, 42] and atmospheric composition, along with dust related health issues. The foremost technology enabler for deep space development, as well as GEO and below, is reduced cost of access to space [refs. 17 – 19]. Utilizing enhanced manufacturing, reusability, and advanced technologies, Space X has already reduced the cost of space access much, and the Starship in development is now slated to provide space access for some $20/kg, essentially the cost of the fuel. Traditional costs are in the thousands of dollars, with SLS topping the space access cost level at some $60K/kg. Decades of studies of the cost elasticity of space business indicated major increases in space activity level and diversity of activities at the $100/kg level. The projected Starship number is far less than that. There are several companies working to emulate the Space X LEO access cost reduction success. The pre-Starship Space X LEO cost reductions, along with continuing payload miniaturization, is increasing the number of Earth satellites from thousands to tens of thousands.

The obvious issue with cheap space access, in fact continued utilization of space, is space debris. Some project, in regard to LEO, that we are a very small number of collisions from closing out LEO access. There is now increasing angst and emphasis upon designing future satellites to self-deorbit, but the extant population of space debris obviously needs to be cleaned up to enable the huge, expected uptick in space business, including deep space activities, enabled by cheap space access. The basic approaches to debris cleanup include physical capture and deorbit and laser abrading. Physical capture can be either chemical fueled or via tethers. Studies indicate fuelless tether capture is far less costly and for that reason may be the approach of choice [ref. 43]. A further possibility for debris management is to capture and put it in a space junk yard. Conceivably, that could include the ISS at end of life. ISS is composed of high quality aluminum and much else, already up there for repurposing of piece parts and remanufacture.

The next level enabling technology requirement for deep space development is advanced energetics [ref. 44]. The historical option has been chemical energy, with efforts again beginning with nuclear fission reactors. Chemical maxes out at an Isp of around 460 seconds, and nuclear fission around 850 seconds. With the Starship cheap space access, we could afford the increased chemical fuel for chemical fast transits to Mars of eight to nine months round trips vice the usual almost three years. Such fast trips would greatly mitigate the serious health impacts of galactic cosmic radiation (GCR) particle radiation at some 30 to 50 GeV of fully ionized nuclei and microg. There are extremely high Isp (on the order of 6,000 secs) thrust options for fast transits including VASIMR [ref. 45], which requires a lightweight tens of megawatts energy source. Fission nuclear is too heavy for this application. Fortunately, there are now two revolutionary energy sources in development which could power VASIMR and essentially everything else in space at much less cost and weight: the nuclear thermionic avalanche cell (NTAC) and low-energy nuclear reactions (LENR).

The first of these revolutionary, light weight, low-cost new space energetics approaches, termed NTAC [ref. 46], a gamma solid state nuclear battery breaks loose the inner band electrons to produce up to 22 kWs per kg of isotope with an Alpha, total kgs/kW of order one, some factors of 20 and greater lighter than a reactor. NTAC scales from milliwatts to tens of megawatts and therefore could be applied locally to power everything in space such as spacecraft, habitats, ISRU, satellites, manufacturing, on-body transportation, etc., as well as ultra-high Isp in-space propulsion. The new revolutionary alternative to NTAC for distributed, low-cost energy is the recent Japanese development of LENR [ref. 44] commercial devices at the kW level, with work ongoing on a 600 kW device. LENR has no radiation issues, is a heat battery that utilizes a minimal amount of hydrogen and nickel, is long lasting and rechargeable, operates off the weak force, is scalable, and if successful, would solve climate concerns as well as power nearly everything in space.

Thus far, the tech discussion has addressed two of the major enablers for deep space development: low-cost space access and energetics and proffered orders of magnitude improvements in both. These would to a major degree drive down overall costs and enable human safety. A third major developing deep space enabler is computation/AI/autonomous robotics/energetics. Since the cost of on-site human operations in space is orders of magnitude greater than robotics, increasing use of autonomous robotics to execute ever increasingly complex tasks and systems is another major cost reduction enabler. Regarding materials, there is an ongoing revolution there also.

The combination of machine material selection/processing/application design and optimization, where over 100 thousand possibilities are considered, is/will produce unique material capabilities at reduced weight. Already, nano printing to produce superb microstructure has resulted in 5X improvements in some material properties; more weight/cost reduction and capability enhancements are expected from ongoing materials-related developments. In addition, there is printing manufacturing technology that saves material and enables rapid and intricate manufacture. One major materials-enabled weight reducer is to employ membranes, possibly rigidizable with sensors and actuators, for a plethora of space functionality devices including antennas, sails, heat exchangers, solar panels, filtration, mirrors, light buckets, solar concentrators, structures/habs, telescopes, cushions, radiators, and Sun shades. Printing manufacture is assumed.

Synthetic biology [refs. 47 – 51] is another interesting emerging deep space applicable technology with studies addressing food, materials, electronics, biocement, biopolymer, bioadhesives, biofuels, pharma, biophotovoltaics production, along with biomining. Early days yet, but those and additional bio in-space possibilities should be seriously evaluated, considered, and triaged. Of particular interest is the recent development of lab grown and dark foods vice “agriculture”. A major deep space development serious issue is radiation protection. The ultra-high energy particle GCR seriously adversely impacts nearly the entire set of physiological systems in the body. Radiation-induced health effects include carcinogenesis, radiation sickness, tissue, cognition and immune system degeneration, neurologic impacts, anemia, DNA damage, and cataracts and heart/circulation issues [ref. 52]. Fast transits as noted would be very efficacious and reduce exposure. On Mars and the Moon, being on body protects from the order of half of the incoming radiation, but the exposure is still on the order of that in ISS. The optimum cost and effectiveness approach to protect from GCR on Mars is ditch and bury under some three meters of regolith. The surface habs, except for thick ice igloos, are expensive and lack sufficient radiation protection. There is a potential tech revolution in the making for radiation protection using small, curved silicon crystals proven by the large accelerator community to redirect incoming particle radiation at energies up to TEV levels. They have the potential to be light weight protection, TBD.

Cheap chemical fuel, separating propulsive mass and energy using NTAC or LENR to enable CO_2 breathing retro propulsion, could provide a revolution regarding landing human scale payloads on Mars. The current approach uses inflatable aerostructures to increase drag area. Then there is the vector/scaler quantum potential non-E-M communications approach under study that is projected to provide high bandwidth reliable communications. Artificial gravity for in-space transits would greatly reduce the serious and pervasive adverse health impacts of micro g, which include vision changes, motion/balance issues, DNA damage, chromosome mutations, weakened immune system, bones and musculature, heart degeneration, liver damage, kidney stones, and sensory dysfunctions [ref. 52]. The fundamental keys to the development of a viable Mars economy are the detailed mapping of Martian resources and clever, low cost, autonomous robotic exploitation of those resources, termed ISRU. A simplex but very useful ISRU activity would be to cool a surface and obtain CO_2 from the atmosphere and using NTAC or LENR microwave the regolith for water. Having thus obtained C, O, and H, we can produce plastics and provide much of the requisite equipage along with water and fuels. The Martian resources are varied and extensive enough to power a serious Martian economy. The many and various deep space applicable tech breakthroughs mentioned should be well along in development within another decade, aided by ongoing effects to “space harden” humans. A long-term dream is terraforming Mars, for which there are several extant suggested approaches but minimal realism. Overall, the safety of space faring is some two to three orders of magnitude less than commercial aviation. An order of magnitude of this is due to human factors, which should be aided by going to autonomous robotics. Sociability in space could be perhaps improved by utilization of holographic crew members/visitors and five senses VR interactions. To the maximum extent possible, the Martian economy will probably be “circular”, with very extensive reusability and repurposing throughout.

The Martian Resources And Martian ISRU [refs. 53 - 60]

"Of all bodies in the solar system other than Earth, Mars is unique in that it has the resources required to support a population of sufficient size to create locally a new branch of human civilization" [Zubrin, The Economic Value of Mars Colonization, ref. 21]. The following is a summary of the resources available for frontier ISRU at Mars:

1. Water: There is a very low concentration in the atmosphere, but massive amounts of water ice at the poles, especially the North Pole. There is enough, if melted, to put a shallow ocean over the entire planet if it were flat. Near the polar regions there is much water ice within the regolith, absorbed on minerals and available from sulfates and silicates. The water concentration in the regolith varies from 3% to 8% near the equator to 40% plus at 60 degrees latitude. Also, there are the recent indications of sizable ice lakes near the surface. The regolith water could be extracted via heating, "solar tents," and microwaving. This plethora of water and its ready availability provides water constituents H_2 and O_2.

2. Oxygen: Immense amounts of oxygen are present in the atmosphere (as CO_2), and more is available from water. In addition, the regolith is highly oxidized, and it has been suggested that oxygen could be obtained by simply adding water to the regolith. Considerable oxygen is also available chemically from these oxides.

3. Carbon: The atmospheric CO_2 can be extracted easily via either cooling or compression, providing C and O_2. Using Martian H_2, O_2, C, and water plastics, methane and hydrogen fuels, and life support fluids can be produced.

4. Inert Gases: There is argon and nitrogen present in the atmosphere for life support atmospheric composition.

5. Minerals: Various measurements indicate the presence in the regolith of nickel, titanium, iron, sulfur, magnesium, calcium, phosphorus, chlorine, bromine, aluminum, silicon, sodium, manganese, chromium, deuterium, and possibly other minerals, localized in what, like Earth and Venus, is a volcanic geology which tended to concentrate minerals. Then there is localization due to/from meteoroid impacts.

6. Ceramics and Glass: Clay-like minerals are also ubiquitous in the Martian surface soils, making the manufacturing of ceramics for pottery and similar purposes a straightforward enterprise. The most common material measured by the Viking landers on Mars was silicon dioxide (SiO_2), making up about 40% of Viking soil samples by weight. Silicon dioxide is the basic constituent of glass, which thus can readily be produced on Mars using sand-melting techniques similar to those that have been used on Earth for thousands of years.

Efficient, effective ISRU requires requisite power/energy levels and autonomous robotics, along with printing manufacture. The evolving, scalable, years-long weak-force nuclear batteries at some 10,000 times chemical energy density could provide power and energy where, when, and at whatever levels are needed. Also, AI is developing rapidly enough now, as is robotics, such that ISRU, resource extraction, processing, manufacture, and utilization via autonomous robotics would be a basic enabler of Martian pioneering and colonization. The use of scalable nuclear weak force batteries obviates the need for solar PV and ISRU for propellants. On planet and for propulsive EDL, the batteries can enable CO_2 "breathing"/heating and acceleration. As an ISRU example, Martian CO_2 could be utilized for shielding, fuel cells, O_2 production, carbon for carbon nanotubes (CNTs), pressurized rockets, CH_4 fuel production, polyethylene production, and in-atmosphere solar pumped CO_2 lasers.

Human Health in Deep Space [Refs. 52, 61 – 68]

Due to current lack of definitive information, the following is an incomplete list of human health issues and concerns for a human mission to and from Mars. The basic differences in health-related parameters between the ISS in LEO and the missions to and from Mars include a far longer time frame for the current some three year roundtrip duration versus six months on ISS, spacecraft exposed to full GCR versus 45% on ISS, and attendant increased time-related reliability, safety, psychological issues, and other health concerns.

The detailed nature of the potential clinical health impacts at Mars-Mission conditions and their potential synergistic effects are largely unknown. Where the impacts are known, the effects appear to scale in severity with the exposed time in space to and from Mars. The potential effects of the 0.38 g on Mars are also unknown, but partial gravity is expected to relax the issues experienced on ISS during microgravity. The many and various adverse health mitigation approaches thus far are mainly directed at trying to establish conditions closer to those on Earth, conditions which resulted in current human physiology.

There is no analog on Earth that can fully represent conditions on Mars. The identified human health issues associated with humans-Mars on site exploration include:

1. Mars dust which contains small, sharp, and highly oxidative particles that affects respiratory and cardio-pulmonary systems. Their health impacts at the high oxygen, high pressure conditions inside the habitat are of concern.

2. Pathogens or biologics in space that appear to become more virulent at in-space conditions, in combination with immune system degradation, resulting in illnesses that medications could prove ineffective for. Other immune systems impacts are expected from weakened T cell function and immune system due to a combination of radiation, micro gravity, psychological, and diet/sleep issues.

3. Micro gravity allows fluid shifts that causes eye/vision changes that blurs vision upon abrupt motions, motion sickness, affects balance and appetite, causes dizziness, and stuffiness. It also can result in DNA damage such as double strand breaks, chromosome aberrations/mutations, attenuated repair process, down regulation of the P53 tumor suppressor protein, weakened T cells, 1% per month bone mineral loss (especially calcium), early onset osteoporosis plus kidney stone propensity, muscle atrophy (up to 20% loss in 5-11 days), skin irritation, cardiovascular deconditioning, cardio arrhythmia, heart degeneration including 30% to 50% decrease in maximal O_2 uptake due to blood cell and capillary altered interactions and blood volume loss, orthostatic hypotension and low blood pressure, neurologic, brain, cerebrovascular, and neurovestibular changes, reduced release of neuro-transmitters, effects on spinal fluid, sensory changes and dysfunction, increased homocysteine, liver damage (including long term scarring), non-alcoholic fatty liver disease, and fibrosis. Mitigation for many of these via exercise and other approaches has been pursued on ISS.

4. Space radiation present both in space and on planet/body causes radiation sickness, degenerative tissue effects, DNA damage, DNA repair process alterations, oxidative DNA damage, immune system degradation including significant reduced ability to produce blood cells, anemia, carcinogenesis including leukemia, tissue degeneration, respiratory effects, cataracts, heart, cardiovascular and digestive system impacts, neurologic effects, central nervous system and cognitive impairment, Alzheimer’s precursor (white matter hyperintensities of the brain) reduced length and area of dendrites, performance decrements and memory deficits, loss of awareness, focus, and cognition, collateral tissue damage to adjacent cells (called bystander cell damage from heavy nuclei) which could increase the cancer risk by some factor.

5. Psychiatric effects due to a combination of physiological effects already noted plus distance from Earth, diet changes, sleep deprivation, and proximity to other crew members.

6. Toxic chemical exposure from spacecraft components as well as from Martian dust.

7. Reliability/life support system failures, spacecraft/propulsion, and other mechanical failures including sensors.

8. The usual space conditions of cold, vacuum, and the presence of exhaled CO_2 which tends to stay near the face and be rebreathed.

There are also the potential synergistic effects of all of these, which at this point are an early-stage work in progress. Thus far, only the Apollo crews have been subjected to micro g and full GCR and for only a few days. As stated, where examined, these mostly tend to become more worrisome with time in space, as evidenced by Scott Kelly's comments with respect to changes and effects of his nearly one year versus the usual six months in space sojourn on ISS [ref. 69]. Some of the effects, to the extent currently known, appear to be permanent. Then there is the potential adverse combinatorial interaction of these effects and "bugs" in space are known to become superbugs, with increased pathogenesis, while the human immune system in space is significantly degraded.

Deep Space Development Outlook

There are several possible variants regarding Mars colonization. These include surface/undersurface on Mars, on the Martian Moons, and off surface in space habs. The latter require significantly greater resources and expense/effort, so initial Mars colonization will probably be on/under the surface(s). However, if the Martian surface 0.38 g has serious health impacts, then space habitats, which can be rotated to provide artificial gravity, would become efficacious. Some have posited "embryo" colonization, where the survival of the human species is ensured by human embryo storage on Mars. Others have studied terraforming Mars, making it more salubrious for human habitation. The keystone of such terraforming is the release of sufficient CO_2 and water from the planet into the atmosphere to increase solar heating and atmospheric pressure/temperature. Recent studies of the amount of such volatiles available on the planet, aside from the time and effort considerations to release them, indicate only minimal improvements in atmospheric conditions. Therefore, the Mars surface would have to be colonized using technology to live/operate in the presence of the current surface conditions of near vacuum pressure, low temperature, micrometeroid impacts, toxic dust and some 50%ish of full in-space GCR levels, along with 0.38 g. In terms of cost and time considerations, this portends undersurface living for humans, and surface operations of nearly all flavors being conducted by autonomous robotics. The evolving direct machine-to-brain communications technology and five senses virtual reality would facilitate the surface robotic operations and provide the humans with a Martian "metaverse".

The technologies and approaches described herein, especially the Space X class space access cost reductions, NTAC, LENR and cheap chemical energetics, autonomous robotics, VASIMR plus NTAC or LENR, syn bio, curved silicon crystals, designer materials, inexpensive tether solutions for space debris cleanup, and quantum vector/scaler potential communications, etc. should enable humans to Mars exploration, pioneering and colonization, and the development of a viable Martian economy to be both affordable and safe. Costs can be reduced sufficiently to afford serious safety. Such a Martian economy would uniquely support and produce/constitute viable major commercial deep space development. Given the advent of cheap space access, commercial space for Earth beyond positional Earth utilities, beyond GEO, is apparently not yet viable econometrics – wise except for in space services and space tourism. That leaves commercial deep space closed business case opportunities as space for space. The key to a major such is a viable Martian economy. Such an economy, developed from Martian resources, could also be the supply center, source for supplies for/development of the asteroid belt and the outer planets/moons. As the Martian economy is developing and becoming viable, a service deep-space economy will develop, providing communications, fuels, transportation/transport, maintenance/repair/replacement/upgrade, life support/rescue, governance, hoteling, recreation, food/water, energy etc. The physiological impacts over time of the 0.38 g gravity on Mars are currently unknown, as are the effects of the Martian soil/regolith components in the high density, temperature, and oxygen content in the habitat upon both equipage and humans.

If we can successfully develop the long-sought physics theory of everything that incorporates both relativity and quantum as special cases and explicates the too many unsolved problems in physics including the greater than 10,000 times light speed of the action of quantum entanglement and perhaps unidentified aerial phenomena (UAPs) there is at least hope that we could develop a useful interstellar transportation approach. Thus far we have identified some 5,000 exoplanets and expect to detect many more yet. That would allow us to move on from a two-planet society to being an interstellar one. As some Russians tell me "we will live, and we will see". The other "wild card" going forward regarding deep space colonization is the continuing development of human cyborgism. We now-tosoon can have cochlear implants for hearing, artificial retinas for seeing, artificial hearts and organs for living, artificial limbs for moving, and brain chips for directly communicating-to-merging with machines. The ultimate human-machine merge, brain uploading, has moved from science fiction to the lab, no longer an untoward possibility, TBD. The humans, who are evolving nearly everything on the planet at some million times natural evolution rates, are also evolving themselves. The only constant is change. Humans on Mars also would probably "naturally" evolve to deal with the 0.38 g level and greatly enhanced radiation, becoming Martians.

Concluding Remarks

Extensive development of commercial deep space, beyond GEO, deep space for deep space, evidently requires the markets and services associated with human colonization on Mars. If the human health issues can be worked, deep space tourism should be viable. The deep-space-for-Earth commercial possibilities including mining are seriously affected going forward by the ever lower costs of space access enabling inexpensive Earth-for-space including such as water and fuels and advanced ever less costly energetics to mine the Earth's oceans. A long list of possibilities, advanced technologies, and systems should ensure Mars colonization that is both safe and affordable. The realities of the radiation environment on Mars and economics heavy mitigates in favor of humans living underground for radiation protection with most surface operations performed by autonomous robotics. There are two recent energetics developments, advanced nuclear batteries and Japanese LENR, that will possibly be able to power everything space, greatly enabling viable commercial deep space. The long-term effects of the Martian 0.38 g on human health are currently unknown. Longer term humans would evolve to accommodate this lower gravity level and become "Martians". The large number of unsolved problems in physics appears to require serious renewed efforts to develop the long sought "theory of everything", especially to explicate the measured greater than 10,000 times light speed of quantum entanglement. That would require enhanced deep space science activities.

Overall, deep space going forward will be enabled by reusability/repurposing, extreme miniaturization, AI/autonomous robotics, ISRU, revolutionary energetics and foods, synbio, and continuing efforts to mitigate the deleterious impacts of space faring upon human health including "space-hardening" the humans. Government funding for initial infrastructures and capabilities would accelerate the rate of commercial deep space development. Deep space activities are required to determine our origins and future course, develop the theory of everything in physics, enhance survivability of the human species and provide a unique perspective regarding the human condition.

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