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A SURVEY OF MARS TERRAFORMING IN SPECULATIVE FICTION

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ABSTRACT

Terraforming is the process of transforming the present climate of Mars into a more Earth-like environment for the future human settlement of the planet. Although implementing such a project appears infeasible in the near-term, writers of speculative fiction (SF) have envisioned what it might be like since the beginning of the 20th Century. One of the first portrayals of terraforming was in the 1917 novel *A Princess of Mars* by Edgar Rice Burroughs, who wrote of an "atmosphere factory" that made the arid world he called Barsoom habitable. From the post-World War II period to the present day, terraforming continues to be a popular topic in SF. This paper will survey some of the major works of terraforming fiction, including *The Sands of Mars* (1952) by Arthur C. Clarke, *Man Plus* (1976) and *Mars Plus* (1994) by Frederik Pohl, *Moving Mars* (1993) by Greg Bear, *Mining the Oort* (1992) by Frederik Pohl, the *Red Mars*/*Green Mars*/*Blue Mars* (1993-96) trilogy by Kim Stanley Robinson, and *White Mars* (2000) by Brian Aldiss.

INTRODUCTION

Terraforming is the process of altering the present climate of Mars to a more Earth-like environment to make the planet more suitable for human settlement. The basic concept of terraforming has been mentioned in SF since the beginning of the 20th Century. Starting with *A Princess of Mars* in 1917, Edgar Rice Burroughs wrote 11 novels that portrayed an arid Mars made habitable by an "atmosphere factory".[1] In the last 50 years, several SF novels have examined terraforming. This paper will survey some of the major works of terraforming fiction.

THE SANDS OF MARS BY ARTHUR C. CLARKE

The Sands of Mars chronicled the journey of a SF writer named Martin Gibson, who traveled to Mars to research a new book. He became involved with the planet's political difficulties with Earth, survived an airplane crash during a giant dust storm, discovered an indigenous non-photosynthetic plant that could extract oxygen from the Martian regolith, and uncovered a secret plan to terraform Mars called "Project Dawn". The plan was successfully executed, and Gibson decided to stay on the planet and work as an administrator in the Martian government.

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Before the initiation of the terraforming project, the human settlers on Mars lived under giant artificial domes. Oxygen was extracted from oxides in the regolith, and plants were used to remove carbon dioxide. The novel described a process in which "ore [was] cracked in electric furnaces, oxygen drawn off, purified and compressed, [and] various metallic messes [were] sent for more complicated operations".[2]

Clarke imagined an indigenous Martian plant called *Oxyfera*, or "airweed" as it was known to the human settlers, that could extract oxygen from the regolith and stores it in pods. The Project Dawn scientists managed to breed a new strain that released oxygen directly into the air. Unfortunately, airweed could only survive around the equatorial regions of Mars because this was where the planet was warmest.

To solve this problem, the Project Dawn scientists used a "meson resonance reaction" to turn Phobos into a second Sun. It was estimated that Phobos would take nearly 1,000 years to burn itself out. By providing enough sunlight to warm a greater portion of the planet, it was estimated that the airweed could spread over a large portion of the Martian surface, and that in 50 years there would be enough oxygen for humans to breathe without respirators.

Written over a decade before Mariner 4, the Mars flyby mission that transmitted the first close-up pictures of the Red Planet, Clarke can hardly be faulted for the biggest technical "mistake" of the book: there are no indigenous plants on Mars to provide oxygen. However, the novel is correct in concluding that the only mechanism capable of changing the bulk composition of the Martian atmosphere is planetary-scale biology. Since no indigenous biology exists to accomplish this, the required organisms would have to be genetically engineered and introduced to the planet.[3]

Clarke discusses the so-called "meson resonance reaction" in his non-fiction book *The Snows of Olympus*.[4] "Meson" is a term used generically to describe short-lived sub-atomic particles that come in a variety of masses. One of the most important of these is the mu-meson, or muon, which is similar to an electric except it is unstable and about 207 times heavier. In 1947, British physicist Charles Frank, who was working on cosmic ray research at Bristol University, hypothesized that mesons could be used to catalyze low temperature nuclear reactions. Frank's idea was put to the test in 1956 by Luis Alvarez at the University of California at Berkeley. Unfortunately, it was found that muons decay too quickly to support a chain reaction.

MAN PLUS AND *MARS PLUS* BY FREDERIK POHL

In *Man Plus*, the United States initiated a secret program to settle Mars in response to computer projections of imminent nuclear war. Instead of terraforming the planet, the goal of the Man Plus project was to "modify a human body [so] that it would survive on the surface of Mars as readily and safely as a normal man could walk across a Kansas wheat field."[6] After a series of surgical procedures, astronaut Roger Torraway was transformed into a Cyborg that successfully established an outpost on Mars.

The story was continued in *Mars Plus*, which was set 50 years later. A young woman named Demeter Coghlan from the Texahoma Martian Development Corporation, which was planning to terraform the planet, was sent to Mars to spy on the plans of a rival conglomerate. When Coghlan discovered her mission was actually a ploy by the Martian computer network to infiltrate a group of human settlers opposed to the omnipresence of the grid, she joined forces with Torraway to discover the computer's true intentions.

Man Plus described how all the biological human organs that cannot function on Mars might be substituted with artificial systems that could. Lungs were replaced with a "micro-miniaturized oxygen generation catalyst-cracking system".[6] Since blood would boil in the low atmospheric pressure of Mars, it was eliminated from the extremities and surface areas. This required replacing the muscles in the arms and legs with servomotors, reserving the remaining blood supply for the brain. A thick hide that served as a combination pressure suit and radiation screen was grafted onto the skin.

One of the most interesting technologies portrayed in *Man Plus* was the manner in which power was supplied to the Cyborg. Nominal power was supplied by a pair of thin-film solar arrays of 2.8 $m^{2\ mounted}$ like a pair of wings on the Cyborg's back. These wings could automatically orient themselves to collect the maximum sunlight. Supplemental power was provided by a fusion reactor in areostationary orbit that beamed microwaves down to the Cyborg on the surface. The energy density of the beam was low so that normal human astronauts working in the Cyborg's proximity would not be harmed.

It is questionable whether a pair of thin-film solar arrays with an area of only 2.8 m^2 could generate enough power to execute the catalyzed cracking of oxygen from the carbon dioxide of the Martian atmosphere. Even augmentation from the microwaves generated by the orbiting fusion reactor may be insufficient because of the low energy density of the beam. The reaction for splitting carbon dioxide into carbon monoxide and oxygen requires the ceramic catalyst beds to be heated to about 1000^oC.[7]

Two terraforming plans were described in the sequel *Mars Plus*. One was being executed by the Martian settlers, while the other was planned by the Texahoma Corporation of Earth. The Martian plan employed self-replicating von Neumann machines, or "Johnnies", that were originally developed for mining but were modified for the terraforming. The Johnnies were small robots that crawled over the Martian surface, sampling the soil and rocks. When the measured composition matched the parameters programmed in its microprocessor, the Johnny would stop and begin to feed. This raw material was used to replicate two new Johnnies. After reproducing itself the Johnny would continue onto the terraforming phase of its mission, deploying capsules of blue-green algae in protected areas of the Martian surface. When released, the algae would use sunlight to turn carbon dioxide into oxygen and carbon compounds, while the bacteria would extract the latent moisture from the air and permafrost layer. The bacteria would also fertilize the ground with its waste products, helping to turn the sterile regolith into organic soil.

The terraforming plan of the Texahoma Martian Development Corporation was much more dramatic. The company envisioned crashing a few stony asteroids and carbonaceous chondrites into the southern highlands in order to create a global dust cloud. This was supposed to heat up the atmosphere, which would in turn create a massive out gassing of water vapor from the permafrost layer. According to the company's estimates, just two impacts would cause it to rain for over half a Martian year.[8] Unfortunately, this scheme is simply not realistic. Instead of warming the atmosphere, the global dust cloud created by the impact would instead cool the planet through the "nuclear winter" effect.

On the other hand, the basic concept of cybernetically modifying an astronaut is theoretically feasible. Even before the flight of Yuri Gagarin, a paper published in *Astronautics* concluded that, "Altering man's bodily functions to meet the requirements of extraterrestrial environments would be more logical than providing an Earthly environment for him in space".[9] Three years after the *Astronautics* paper, NASA commissioned a report that analyzed the history, development, state-of-the-art, and possible future development of artificial lungs, hearts, kidneys, and oxygenating equipment for human spaceflight applications.[10] However, due to its controversial nature little further research has been done on this topic.

MOVING MARS BY GREG BEAR

Moving Mars was set about 200 years in the future, when a team of Martian physicists developed a machine that could manipulate the physical properties of matter at a very fundamental level. Fearing the discovery could further the drive for independence, Earth launched a devastating preemptive attack on Mars using a weapon based on the same theory. To save the planet, the physicists used their device to move Mars to a new star system 10,000 light-years away from the Sun. Since Mars now orbited 80-million kilometers closer to the new star than it did to the Sun in the Solar System, not only was it safe from Earth attack but it also became more habitable.

The device was called a "tweaker", and it could directly manipulate the "descriptors" which encode the basic properties of matter and energy. Instead of physically moving an object, the tweaker could just reach into the particles and alter its descriptors for position in space-time. Once a descriptor was changed, the "Bell Continuum" automatically adjusted the corresponding descriptors for all the other particles in the Universe in order to maintain the conservation of mass, momentum, and energy. According to one of the physicists in the novel, "Distance and time mean nothing, except as variations in descriptors."[11]

The idea of the tweaker appears to have been inspired by Ed Fredkin, a former MIT professor who produced some radical theories on the nature of reality. Our everyday experience tells us that information can be represented by either matter (i.e. ink on a piece of paper) or energy (i.e. electrons in a computer). But Fredkin speculated that the opposite might be true, that matter and energy are actually manifestations of information. Under such an interpretation, the properties of matter and energy are bits, the scientific laws that govern physical systems are algorithms that affect those bits, and reality is just a program running on a computer called the Universe.[12]

Bear calls Fredkin's bits "descriptors" that reside in the "Bell Continuum", a fictitious dimension named after J.S. Bell, a physicist who wrote many seminal papers on quantum mechanics. How such a system might work may be illustrated with an example. Normally, the temperature of an object is lowered by placing it in a cold environment and allowing the "algorithm" of thermodynamic heat transfer to take its course. Using tweaker technology, one could just go in and directly set the "temperature" descriptor of the object to the desired value.

The tweaker technology described in the novel is highly speculative. Even if Fredkin's theories are correct, the technology for building a tweaker may be centuries way. However, there is a way to change the orbit of Mars using classical orbital mechanics.

A gravity assist maneuver is a planetary encounter designed to change the heliocentric velocity of a spacecraft. If the spacecraft passes behind a planet, its trajectory is rotated in the same direction as the planet's orbit around the Sun and its heliocentric velocity is increased. Since momentum must be conserved, the heliocentric velocity gained by the spacecraft is lost to the planet. The velocity decrease experienced by the planet is extremely small due to its great mass. For example, the 2,000-kg Galileo spacecraft increased its heliocentric velocity by 5.2 km/s and 2.7 km/s following two Earth flybys in 1990 and 1992, respectively. The orbital speed of the Earth slowed by only a billionth of a centimeter per year from the two events.[13] Using similar calculations, it can be shown that if an Amor-class asteroid (one whose orbit takes it between the orbits of Earth and Mars) with a mass comparable to that of 433 Eros ($6.4H10^{23}$ kg) could be diverted to perform a hyperbolic flyby of Mars with a closest approach altitude of 5,000 km above the surface, the orbital speed of the planet would be reduced by about 0.01 mm/s. Mars currently orbits the Sun at a mean radius of 1.52 astronomical units (AU). In order to slow its orbital speed enough to bring it into a closer 1.25 AU orbit, approximately eight million such asteroid flybys would be required.

MINING THE OORT BY FREDERIK POHL

"There isn't anything much wrong with Mars that a decent atmosphere won't fix right up," says the opening line of *Mining the Oort*.[14] To get that decent atmosphere, the Martian settlers in the novel initiated a program to use comets as a source of volatiles for terraforming the planet. These comets were harvested from the Oort Cloud. The novel told the story of a young Martian named Dekker DeWoe, who dreamed of becoming an Oort miner. But during his training at the Oort Corporation on Earth, he learned that some of the backers of the project were thinking about moving their investments to orbital habitats instead. He also learned of a secret plan to blackmail these investors into reinstating their support for terraforming by threatening to divert a small comet towards an impact with Earth.

The comet harvesting process began with the Oort miners in the Cloud, who identified the most promising comets. Desirable comets were ones that were heavy with water ice and ammonia, the latter of which was needed on Mars as a source of nitrogen. After being identified by the miners, the selected comets were processed by the "snake handlers". These workers threaded the comet with a chain of instruments called a snake and installed an antimatter drive

before sending it towards the inner Solar System. The final approach and impact on Mars was handled by a constellation of space stations in low-Mars orbit. The comets could not impact within 500 km of any settlement or outpost. They were also not allowed to strike Valles Marineris, Olympus Mons, or any of a hundred Martian surface features deemed sites of significant value.

In the novel, the project was estimated to take about 50 years to complete. It was hoped that once enough comets were dumped on the surface to raise the surface pressure and temperature sufficiently, the frozen indigenous Martian volatiles at the poles and in the permafrost would also start outgassing. Even then, there was expected to be too much carbon dioxide and not enough free oxygen and nitrogen in the atmosphere. After the cometary bombardment, Mars would have to be seeded to blue-green algae and lichen for oxygen production and nitrogen fixation.

Pohl's description of mining the Oort comets is generally accurate and might be feasible if technologies like antimatter drives existed. The main problem with the plan is the extreme distance of the Oort Cloud. The Cloud is estimated to extend from about 40,000 to 100,000 AU from the Sun (6- to 15-trillion kilometers).[5] In the novel it is written that, "Distance doesn't matter much in space, where if you just start a thing off with the right kind of shove, sooner or later it will get where you want it to go."[14] The problem is that without the advanced propulsive capabilities of something like an antimatter drive, a comet from the Oort Cloud on a minimum energy Hohmann trajectory would take about a million years to reach Mars.

In his book *Disturbing the Universe*, physicist Freeman Dyson suggested mining ice from the Saturnian moon of Enceladus.[15] Another possible source of volatiles is the Kuiper-Edgeworth Belt. Since it is "only" 30 to 50 AU (4.5- to 7.5-billion kilometers) away from the Sun,[5] it may be a more accessible source of icy planetesimals than the Oort Cloud. A Hohmann trajectory would still take about 30 years to deliver a comet to Mars, so some sort of advanced propulsion system would still be required Other sources of volatiles may exist within the inner Solar System. Students at the International Space University have proposed a mission to characterize and extract the possible water resources of near-Earth objects (NEOs).[16]

THE *RED MARS*/*GREEN MARS*/*BLUE MARS* TRILOGY BY KIM STANLEY ROBINSON

This ambitious trilogy chronicled in detail the future human settlement of Mars. In 2026, the United Nations sponsored a mission to terraform Mars. The settlers soon found themselves divided into rival factions: the Greens who wished to pursue full terraforming at any cost, and the Reds that wanted to keep Mars in its pristine condition. This division, combined with the political and economic tensions with Earth and the ethnic rivalries among the settlers, eventually erupted in revolution. Management of the terraforming project was shifted from the UN to a conglomerate of multinational corporations. With greater monetary and technological resources at their disposal, the changes to the Martian climate accelerated. But some of their techniques appeared to do more harm than good to the nascent environment, and a second revolution swept

the planet. A compromise between the Reds and the Greens was reached in which the full terraforming pursued by the corporations is abandoned in favor of a minimal Arctic-like environment in which humans could survive but much of the planet was kept close to its original state.

The first step of terraforming in the novel was to increase the surface temperature of the planet. A giant mirror was stationed in areostationary orbit to reflect sunlight onto the dawn-dusk terminator. This mirror was constructed from the solar sails of the cargo freighters from Earth. When a new freighter arrived at Mars, its sail would be detached and linked to a large collection of earlier sails parked in areostationary orbit. The mirror was programmed to swivel to reflect sunlight on the terminator, adding a little bit of energy to each day's dawn and dusk.

The next step was to genetically modify terrestrial microorganisms to survive on the Martian surface. These organisms had to be resistant to cold, dehydration, and ultraviolet radiation, as well as have a low requirement for oxygen and be able to live in rock or soil. Unfortunately, no single terrestrial microbe had all these traits, and those that had them individually were slow growers. The engineers therefore started a "mix-and-match" program in which genes were recombined from a variety of terrestrial algae, methanogens, cyanobacteria, and lichens. Out of these efforts were produced a variety of fast-growing lichen, radiation-resistant algae, extreme-cold fungi, and a halophytic bacteria that ate salt and excreted oxygen.

The solar sail-based mirror was for a time supplanted by a more advanced system consisting of an "annulus" and a "soletta". The annulus spun around Mars in a polar orbit. Its mirror ring faced the Sun and reflected inward the peripheral light that would otherwise just miss the planet. The light was focused on the Sun-Mars L1 point, where the soletta was stationed. The soletta consisted of a web of slatted rings that were set at angles like circular Venetian blinds. Sunlight striking the soletta cascaded through these blinds, hitting the Sun-side of one and then the Mars-side of the next, all the way down to the planet. This was done to harness countervailing solar radiation pressure for stationkeeping purposes. While very impressive, this system was eventually abandoned because it was too successful in warming the planet, resulting in an excessive release of carbon dioxide.

To scrub this unwanted gas, trees were planted. Once the temperature and pressure of the planet reached near Arctic conditions, it was found that terrestrial trees could be planted on Mars with little genetic modification. It turned out that a lot of spruce and pine species had temperature tolerances much lower than was needed in their native terrestrial habitats due to holdover adaptations from the last Ice Age. With the increasing oxygen content of the atmosphere came the introduction of animal life. The first of these were genetically altered insects. Later, small mammals like moles were added for soil aeration, and birds were introduced to help spread seeds.

The final state achieved was one of "least-impact" terraforming or "ecopoesis". A breathable but water-poor and largely carbon dioxide atmosphere was created. The problem of the carbon dioxide rich atmosphere was solved not by changing Mars but (like *Man Plus*) by altering the physiology of the human settlers. A medical procedure was developed in which the

genes that coded for certain characteristics of crocodile hemoglobin could be introduced into mammals. Crocodiles could stay underwater for long periods of time because the carbon dioxide that usually built up in the blood instead dissolved into bicarbonate ions that bound to the amino acids in the hemoglobin. This bond caused the hemoglobin to release oxygen molecules, which meant that in one stroke this crocodile gene could increase both carbon dioxide tolerance and oxygen efficiency.

The terraforming technologies described in this trilogy are based largely on work already published in the scientific literature, most notably that of Christopher McKay and Martyn Fogg. Robinson appears to have been particularly influenced by the latter's concept of "synergistic terraforming". This is the idea that no single technique for terraforming Mars can work in isolation, and that only a combination of several technologies, requiring a massive industrial effort on both the planet's surface and in space, can hope to succeed.[17]

There is one significant difference between the terraforming technique portrayed in the trilogy and that most often described in the scientific literature. McKay wrote of a two-phase approach to terraforming, in which the planet is first warmed by a massive release of carbon dioxide, followed by a modification of the atmosphere to scrub out the carbon dioxide and increase the oxygen content in order to support complex life. The time scale for such a two-phase approach was estimated to be about 100 years for the first step and up to 100,000 years for the second. McKay explicitly stated in his paper that he had limited consideration in his study to technologies that were not far beyond the current state-of-the-art.[3] In contrast, Robinson postulates that through new technologies and a massive synergistic industrial effort, a single-phase approach to terraforming may be possible in which the final habitable atmosphere is directly reached.

WHITE MARS BY BRIAN ALDISS

In many ways, *White Mars* may be thought of as the antithesis of Robinson's trilogy. After the first human landing on Mars, the United Nations decreed that no terraforming was to take place for 30 years in order to keep the planet in a pristine state so that fundamental research in physics and astronomy could be conducted. A small settlement on Mars was just getting established when the world economy collapsed due to a corruption scandal. Suddenly cut off from Earth, the Martians banded together and attempted to create a utopian society based on the search for knowledge, the improvement of the human condition, and the elimination of hatred.

Since *White Mars* is largely a sociological study, there is very little discussion of actual terraforming. One technology that is mentioned is the concept of using Mars as a pristine laboratory for fundamental research in physics. A particle accelerator was supposed to be constructed on Mars in order to detect the Higgs boson. Mars was thought to be ideal because there was no tectonic activity and volcanism was dead, while the Moon was no longer suitable because of mining activities and the construction of the "transcore subway".[18] The other technology mentioned was the "Zubrin Reactor", in which atmospheric carbon dioxide was reacted with hydrogen to generate methane fuel and oxygen. This is clearly a homage to Mars

Society founder and president Robert Zubrin and his Mars Direct architecture of using *in situ* Martian resources to dramatically reduce cost and complexity of missions to the Red Planet.[7]

CONCLUSION

While the full-scale terraforming of the planet Mars may not be feasible in the near-term, the process has been and will continue to be a major theme in works of speculative fiction. Traditionally, SF has given contemporary audiences a "sneak peek" into the possibilities of the far future. In the case of terraforming, perhaps that future is not so far away. The conclusion reached by Martyn Fogg in his paper could apply equally well to all the novels surveyed here: "The fact that a scenario for the full terraforming of Mars can be conceived within the parameter space of current planetological models, and without violating any known laws of physics, demonstrates that such an idea is, at least, feasible in principle. To bring such a project to fruition would require engineering capabilities greater than those of the present day, but not necessarily out of the question for a future civilization several centuries ahead of our own."[17]

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