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Magnetic shielding systems to support longer-term human exploration of Mars

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Space activities are primarily conducted for three purposes: scientific research, human space exploration, and space applications. Over the past few decades, commercial space applications have expanded rapidly and now significantly outpace the efforts of space agencies. Agencies such as NASA have largely shifted their focus away from operational applications, leaving this domain to private enterprise. An emerging domain is the integration of scientific research, exploration, and applications: human space development and cosmic defense. This concept includes initiatives such as mitigating space debris, advancing bio-regenerative life support systems for both Earth and space, and enabling infrastructure for future deep space human settlement and enterprise. This article makes the case for an international coalition of space agencies to spearhead this forward-looking effort aimed at altering the Martian environment to support human life. A core feature of this vision involves developing an artificial magnetosphere. This technology would not only support terraforming efforts but could also lead to the establishment of large-scale human colonies on Mars. The concept extends beyond Mars. If successful, magnetic shielding could also be applied to Earth to mitigate catastrophic solar storms or address the long-term degradation of Earth's geomagnetic field. These activities could yield critical insights into preserving our biosphere and ensuring the future safety of life on Earth. Three broad scenarios are presented to support human life on Mars. Together, they represent a new, integrative approach to space agency missions, one that supports human expansion into deep space and potentially even the revival of Mars as a living world.

KEYWORDS

atmospheric pressure, bio-regenerative life support systems, coronal mass ejections, human planetary engineering, Lagrange point, magnetic shielding, solar storms, terraforming Mars

1 Introduction

The Earth has an atmosphere that can sustain plant and animal life forms. Our planet has a mass of six sextillion tons that creates a 1-g gravitational field. It also has a molten iron core that produces a magnetic shielding system or magnetosphere. This magnetic shielding system, along with the ozone layer in the upper stratosphere, protects us against “solar weather” (Steinhilber et al., 2010), which could otherwise strip away our atmosphere and allow harmful ultraviolet radiation to reach the planet's surface. Without these conditions, planet Earth would not have a breathable atmosphere to sustain carbon-based life forms, including humankind (NASA, 2025).

When we consider conditions that allow life to thrive on Earth, we generally tend to list the following assets. These include:

- liquid water
- a breathable atmosphere with sufficient pressure that supports sufficient oxygen, carbon dioxide, and other non-noxious gases needed to sustain life, along with a protective ozone layer
- an optimal distance away from the Sun to provide the right amount of light, heat, energy, and sustainable orbital mechanics.

In this report, we suggest that there are other key conditions. These include a beneficial gravity that is well-suited to humans and other flora and fauna and a “hypo-magnetic field” (HMF), which also helps sustain life and protect the atmosphere from the Sun’s extreme solar storms and solar wind (Sarimov et al., 2023).

Here, we discuss several ways that Mars might be terraformed or transformed to be more “Earth-like.” Magnetic shielding might be artificially created for Mars in such a way that it could help sustain life for a long period of time. We believe that developing a Martian magnetic field could aid in sustaining a protective atmosphere that would support a surface supply of liquid water and oxygen. Furthermore, the presence of what are called magnetic field conditions is essential for healthy organic, biological, and human life. An early lunar magnetic field served to help block solar dangers to Earth during the time the Sun was producing extremely strong and more frequent space weather events (Green et al., 2022; Talbert, 2020).

The terrestrial planet Mars bears many similarities to Earth. However, it lost its magnetic shield approximately three billion years ago, having only a localized remnant field (Cain et al., 2003). At the beginning of the solar system, the planet Mars had a large ocean and was believed to be amenable to life. Today, Mars’ much more modest atmosphere has been largely diminished by ongoing solar wind erosion. A concept advanced some years ago suggested that Mars might be “terra-formed” to evolve a more extensive atmosphere over time. This concept included developing an artificial magnetic system to allow the reformation of a viable atmosphere on the Red Planet. What has been lacking is a practical, economically viable, and scientifically sound way to accomplish this.

The purpose of this article is to suggest a new vision of what NASA and other civilian space agencies might undertake in the next 30 years with a new set of future-oriented goals under a program for “Human Space Development and Cosmic Defense.” We propose, as a key element of this evolutionary new space effort, the possibility of developing a livable and artificially sustainable atmospheric pressure on Mars.

This article will focus on such a key new space initiative. We consider three options. These are as follows: i) creating an artificial magnetic field to support an initial human habitat on the Martian surface, over the landing site and crew area; ii) developing a suitable magnetic protective shielding system that originates from the two small natural satellite moons of Mars, Deimos and Phobos (NASA, 2024); and iii) developing a magnetic shielding system at the Mars Lagrange point-1 (L-1) location. The last two would be accomplished by deploying a well-designed artificial satellite network to create a powerful induction system that would serve to shield Mars from dangerous solar storms, ionic and proton winds, and cosmic radiation.

These comparative assessments of protective systems for Mars will present only initial synoptic design concepts to allow some basic feasibility assessments to be undertaken. Of course, much more

detailed follow-on studies need to be conducted for the design, engineering, fabrication, deployment, and longer-term operation, and cost estimation of future space missions. In this article, we will only seek to address basic viability and preliminary scientific and engineering assessments, as a first step toward such a future deep-space mission. Finally, we note that there are many other issues to be considered beyond scientific design and engineering. These include environmental concerns, safety standards and controls, operational resilience, and the survivability of the design. Ultimately, there are truly important legal, regulatory, ethical, and governance-related issues to be addressed and resolved before undertaking a mission of this magnitude that could alter the course of human history.

In theory, such an initiative could enable a sustainable, longer-term human presence on Mars for practical use. If this could be accomplished and proven to work for Mars, it also raises the possibility of creating a parallel type of magnetic shielding for Earth. Such an Earth-based magnetic shielding system could protect our planet’s vital electronic infrastructure much more effectively against extreme space weather than is presently the case. The current reversal of the Earth’s natural magnetic poles increasingly exposes human society to the possible great loss of vital electronic and satellite resources on which the world economy now depends (Anissimov, 2024). A Carrington Event-type “solar storm,” such as the one that occurred in September 1859 during the days when telegraphs were the only electrical devices in operation, could create tremendous losses if it were to occur today (Dobrijevic and May, 2022).

A Carrington-like solar storm could wipe out the world’s electrical power grid in many countries, destroy the Internet and its synchronization, and disable satellites and global pipeline controls (Odenwald et al., 2006). This, in turn, could lead to a catastrophic number of deaths as a residual impact of a massive coronal mass ejection (CME) event. This threat has mushroomed as a result of the growth of megacities, an increase in the global population, and an ever-greater reliance on modern infrastructure powered by electricity. Since massive solar storms occur approximately every 150 years, our vulnerability has increased gradually but is now increasing more quickly than ever since 1859. The need to take protective actions to safeguard the Earth’s vital infrastructure is not widely recognized.

Let us now consider three possible initiatives for the exploration and possible future settlement of Mars.

2 Creating a localized magnetic field on Mars for an astronaut outpost

Planning for a sustainable human colony requires providing a significant source of electrical power. The great distance from the sun suggests that solar power might be a supplementary but not the predominant source of electrical power supply. Nuclear power sources, and very likely fusion power sources developed for deep-space electronic ion propulsion, could be repurposed for electrical power infrastructure on Mars. Such nuclear power sources could also be reused to create artificial magnetic fields. Such a magnetic field generation system could be designed to serve several purposes. These could include the creation of a shielding system that could protect a spherical protective zone that might encompass a volume of multiple cubic kilometers, as illustrated in Figure 1. The design of this system would have two main objectives. The first would be to create a reflective magnetic dome that would locally repulse the solar

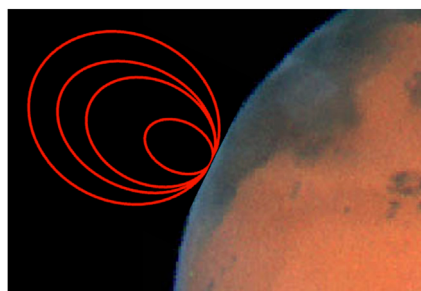


FIGURE 1
An illustration of the magnetic field generated by a surface system.

wind and some cosmic radiation. The solar wind currently strips away the naturally forming atmosphere that occurs as the planet outgasses and as frozen water in the subsurface and at the Martian polar caps thaws during the summer months. Cosmic radiation from the Sun and stars consists of protons and alpha and other heavy particles. This is important for the protection of life forms and for astronauts. This focused and shaped magnetic field would protect, perhaps, at least 10 cubic kilometers above the magneto-generators.

The second objective would be to generate a lower magnetic field within this protective habitat region designed to support organic and animal life, along with human biological health. [Table 1](#) below, provides the measured strengths of the magnetic fields of the Moon, Mars, and Earth. This internal magnetic field strength would likely be adjustable within the range of 30–60 microTesla to be able to test the health implications of induction levels within this scope.

The purpose of this article is to present the case for magnetic shielding as a key tool in the process of terraforming Mars, rather than designing and engineering the specifics of an inductive electromagnetic system that would be deployed, or defining the dimensions of this test case. In addition to magnetic shielding, microorganisms such as cyanobacteria and microalgae will be indispensable to early Martian bio-colonization experiments. Their proven roles in oxygen production and nutrient cycling provide the foundation for bio-regenerative life support systems. Integrating these biological processes with magnetic shielding strengthens the overall viability of a sustainable habitat.

A far greater challenge would be the design and engineering of a magnetospheric system that protects the entire planet of Mars and allows for longer-term terraforming of Mars. This would allow life to evolve as a natural atmosphere formed on the surface. A complete planet-wide magnetic shield, with the introduction of the appropriate microorganisms, could contribute to the terraforming of Mars in a series of phases.

Phase 1 (early decades): an increase in CO_2 and H_2O levels through the accumulation of the outgassing and polar ice sublimation, which is no longer eroded by the solar wind. The generation of O_2 would initially be consumed by regolith oxidation.

Phase 2 (intermediate): gradual accumulation of the trace O_2 and possibly O_3 , leading to partial UV shielding and the expansion of the Martian ozone layer, which currently resides over the polar caps, to lower latitudes.

Phase 3 (long-term): stabilization of CO_2 , H_2O , and O_2 at higher pressures, enabling surface liquid water and plant-based oxygen production. These chemical and possibly related organic consequences that come from the magnetic shielding of Mars should be a key part of the planning for any future implementation.

As an example of global magnetic protection, two different scenarios for the generation location of an artificial Mars magnetosphere will be explored next. Both would be difficult to design, engineer, construct, and operate in the long term and on a sustainable basis.

3 Creating an artificial magnetic field for Mars using Deimos and Phobos as the source for the electromagnetic induction system

One approach that has been considered, and for which conceptual studies have been undertaken, would be to create “induction instruments” on the surface of Mars’s two small moons (see [Table 2](#)). The relatively close orbit of these two minor moons allows them to be better suited to creating a more compact magnetic system than deploying such a protective shielding system at the Martian L-1 location. These small moons of Mars were discovered by Asaph Hall on 12 August 1877. They are believed to be either captured asteroids or material accumulated in space by significant asteroid impacts that blasted crustal material into space ([Anderson, 2024](#)).

TABLE 1 The relative strength of the magnetic fields in deep space, the Moon, Mars, and Earth.

Magnetic field strength of deep space	Average of approximately 6.6 nanoTeslas
Magnetic field strength of the Moon	No more than 300 nanoTeslas
Magnetic field strength of Mars	Ranges from 300 nanoTeslas to 5 microTeslas
Magnetic field strength of Earth	Ranges from 30 microTeslas to 60 microTeslas (weakest at the equator)

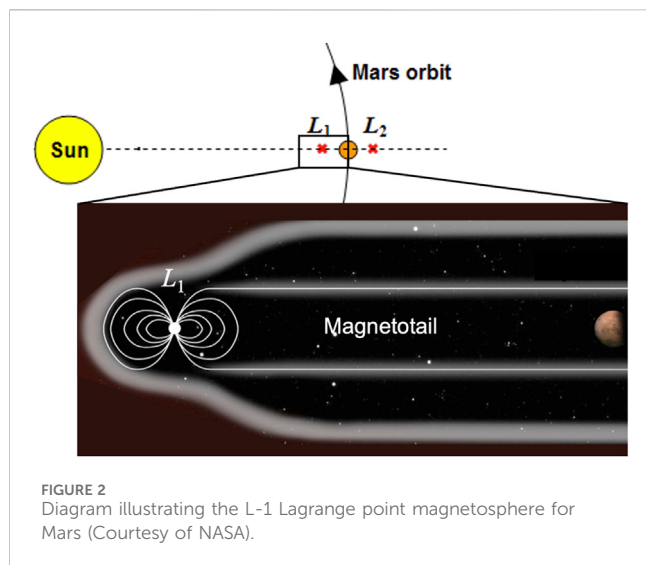
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References: [Steinhilber et al. \(2010\)](#), [Berguig et al. \(2011\)](#), [Cain et al. \(2003\)](#), and [Anissimov \(2024\)](#).

TABLE 2 Key characteristics of Mars’s moons Deimos and Phobos.

Moon	Mass	Orbital parameters (semi-major axis)	Orbital period	Dimensions
Deimos	1.5×10^{15} kg	23,460 km (14,580 mi)	30.35 h	12.6 km (7.8 mi) in diameter
Phobos	1.08×10^{16} kg	9,377 km (5,827 mi)	7.66 h	22.2 km (13.8 mi) in diameter

Reference: [NASA \(2024\)](#).



Deimos and Phobos have different orbital periods due to their relative elevations above the Martian surface. These conditions make creating a magnetic shielding field that would continuously block the solar wind from penetrating to the Martian surface a challenging task. Nevertheless, electromagnetic inductive systems deployed on these two small moons, plus supplementary satellites with similar magnetic inductive capabilities, could conceivably be designed to create a protective shielding system for Mars.

Until a specific program is approved and funded for such a magnetic shielding system for the Red Planet and initiated by NASA or a coalition of space agencies, the development of a well-engineered terraforming project would be premature. Nevertheless, at the conceptual level, this approach appears as perhaps the most cost-effective and viable approach because of the practical use of two existing resources already in place. Although Phobos' orbit is modestly unstable and is descending in its altitude by almost 2 m per year, this is a minor design consideration.

4 Creating an artificial magnetic field for Mars using inflatable structures at Mars L-1

Mars's so-called L-1 Lagrange point is designed by the two-body solution for the location where their gravitational fields tend to cancel each other out. Figure 2 below demonstrates a geomagnetic shielding system placed at the Martian L-1 Lagrange point. This represents the point at which the gravitational fields of the Sun and Mars would be of close to equal strength. Of course, the other planets, represented by Mercury, Venus, and Earth, plus our Moon and Mars's two small moons, complicate this equation to a slight degree. An even larger issue is that the two-body gravitational solution on which the Lagrange formulation is based is dependent on a circular orbit and not an ellipse. There is no such stable point but rather a relatively stable L-1 zone. It would be possible to deploy a constellation of satellites within this zone to generate a magnetic shielding system to shield the Martian atmosphere. The problem is that this zone is much further away from the surface of Mars. This means that the size and magnetic

strength of the Martian shielding system would need to be much larger, with a higher inductive force, to be as effective as the design option discussed above. An artificial magnetosphere generated at L-1 diverts the solar wind and would create a long magnetotail. This bullet-like structure would encompass Mars, keeping the direct solar wind from encountering and stripping the Martian upper atmosphere.

Although this was the initial conception of how a Martian atmospheric shielding system might be deployed, based on an L-1 zone location, the lower costs of the Deimos and Phobos-optimized design appear to be superior. This is not only because it would be easier and lower in cost to deploy, but also because of its improved and closer location to the Martian surface to prevent "tailing" of the incoming ionic stream. Overall, we believe that the Deimos- and Phobos-optimized approach would represent a better design option.

5 Creating an enhanced magnetic field for Earth to protect against solar storms

It should be obvious that if a magnetic shielding system could help restore an atmosphere for Mars, a magnetic shielding system to protect Earth could also be devised. A massive solar storm akin to the Carrington Event of 1859 could potentially cripple the global economy and disable critical infrastructure. The reversal of the Earth's magnetic North and South Poles would reduce the natural protection that now exists. Beyond shielding the Earth's atmosphere, the biological consequences of a rapidly fluctuating or decreasing geomagnetic field remain poorly understood. Preliminary studies indicate significant impacts on photosynthesis, metabolism, and neurological function in animals (Zadeh-Haghighi et al., 2023). Defining the optimum magnetic induction levels for human health and ecosystem stability should, therefore, be a priority research agenda accompanying any shielding deployment. It is likely that such efforts to undertake planetary shielding will be implemented first on Mars, providing valuable data on how to design a system for Earth in all regards, including the biological concerns noted here.

The technical challenges of shielding Earth from solar threats are far greater than those of shielding Mars. This is because we are closer to the Sun and a larger target. Furthermore, there is no obvious location for deploying such a shielding system. A shielding system placed at the Earth's L-1 region, located 1 million miles (or 1.6 million km)—or even possible supplemental protection originating from the Moon, which is some 240 K miles or approximately 385 K km—is still too far away to design an effective artificial magnetic shield for Earth. This would likely require an entirely new type of deployment approach, with the shielding system originating from the ground or from high-altitude platform systems designed for megacities or from some entirely new type of space architecture. What is clear at this stage is that technical knowledge developed to protect Mars would generate very valuable knowledge for the future design of a protective system for Earth's increasingly vulnerable infrastructure.

6 Conclusion

One of the greatest challenges in funding and then creating new protective systems occurs when the threat is very large but has a low frequency of occurrence, such as once every several hundred years. Comets, asteroids, and a violent solar storm are very real threats, but

politicians who control policy think in terms of 2-year or 4-year terms. The benefits of creating a new habitable planet in our solar system, or a magnetic shielding system that could protect Earth from a CME that wipes out the electrical grid, the Internet, our pipelines, worldwide telecommunications, and the global service economy, are potentially enormous. Needed expenditures could greatly exceed tens of billions of dollars. New multi-billion-dollar space programs are hard to sell to political leaders. They are forced to consider shorter-term needs and threats with a much shorter time horizon.

A new program for human space development and cosmic defense would logically focus first on ways to achieve active removal of space debris, global space traffic management controls and safety regulations, and clearly identified, shorter-term threats. But just as there is a need to create a global plan to address climate change, pandemics, and weapons of mass destruction, there is also a need to develop plans to cope with cosmic threats. We live on a large, six sextillion-ton spaceship that travels over 600 million miles (approximately 1 billion km) through a very hazardous arc of dangerous deep space territory each year. Cave dwellers were unaware of such dangers, but with modern scientific knowledge and a world that depends on modern infrastructure, we must be aware of cosmic threats and seek innovative solutions to both opportunities and threats. We have reached a level of scientific and engineering knowledge where we can begin to protect Earth from catastrophic solar storms and even transform Mars into a livable planet. It is time for a space effort known as “human space development and cosmic defense.”

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding authors.

Author contributions

JP: Conceptualization, Writing – original draft. JG: Conceptualization, Writing – original draft.

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