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Roadmap to interstellar travel

Abstract

Interstellar travel represents a long -term goal that has the potential to transform human history by opening up unlimited territories and opportunities for our society. While we are not yet close to achieving this capability, a long -range perspective on history suggests that future advancements in technology and society will lead us toward this ambitious objective.

Interstellar travel is not merely about developing faster propulsion systems that enable access to other planetary systems within acceptable timeframes; it signifies a profound paradigm shift for humanity. This shift would involve leaving our solar system and establishing hundreds of civilizations beyond the Sun. Humanity would spread across various star systems, creating new societies with unique technologies, values, and destinies. This vision of unlimited expansion is unprecedented in our history.

In this paper, we will explore the steps necessary to reach this goal, as well as the hurdles and milestones that lie ahead over the coming centuries. The conquest of space will require a series of gradual advancements, encompassing a wide array of technologies and challenges we currently face, including social, environmental, and future issues. For instance, healthcare and governance will likely foster breakthroughs that exceed our expectations for technical advancements.

Furthermore, robotics and artificial intelligence will play crucial roles in this new era. A symbiotic relationship between biological humans and advanced AI will be essential for survival in a world where machines possess capabilities surpassing those of humans. Only through collaboration can we navigate the complexities of an evolving landscape shaped by artificial intelligence.

Keywords: interstellar travel, future AI, solar system colonization

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Introduction

The advent of interstellar travel capability will herald a paradigm shift in our society, ushering in another singularity with far -reaching implications across all fields of human activity. While propulsion breakthroughs are commonly associated with achieving interstellar travel capability, the reality is that such an event will represent a quantum leap in knowledge for our entire society, impacting every domain. To delineate the progress necessary in individual fields to attain interstellar travel capability, it's imperative to understand their inter actions, capabilities, sequencing in integration with our society, and the consequences of their introduction and utilization. Developing a master plan with a mapped sequence of expected progress in a step -by-step roadmap will define the requisite pathways to achieving interstellar travel capability.[1]

Commencing from the domain of selected technologies, it's crucial to prioritize those with the most potential benefits for our planet. Identifying technologies still at Technology Readiness Level (TRL) 1 and outlining the requirements to elevate them to TRL 10 for operational deployment is essential. Additionally, preparing business models and plans wherein new disruptive yet necessary technologies can begin to make a tangible difference is vital for facilitating progress. Indeed, amidst our considerations of conventional paths toward interstellar travel, we must also acknowledge the potential impact of the impending technological Singularity, wherein AI surpasses human intelligence. This development could profoundly disrupt the entire trajectory we've envisioned. It's plausible that AI entities may emerge as the primary travelers, given their suitability for space travel in comparison to biological humans. This paradigm shift underscores the need to adapt our approach and strategies accordingly, ensuring that we remain agile and responsive to emerging possibilities in the rapidly evolving landscape of technological advancement.

Where we stand

Before delving into the exploration of the future, it's essential to establish our current position. Just as a journey requires a starting point, our progress into the future necessitates a clear roadmap. Understanding where we stand today and where we aspire to go is paramount. By examining past trends and contemplating potential futures, we can chart a course forward.

Past and future history of space development

The evolution of space development can be broadly categorized into five phases (Figure 1):

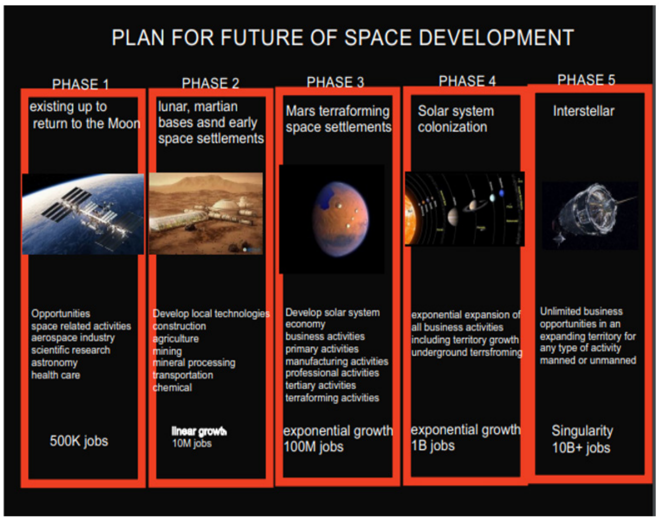

Figure 1 Future steps in space development.

Phase 1:

The beginning

This phase encompasses pre -Sputnik activities up to the present, including projects like Apollo, the space shuttle program, and activities on the International Space Station. These endeavors have not only created over 500,000 jobs in the aerospace sector but have also catalyzed the emergence of new industries and technologies. Innovations such as weather forecasting, communications, navigation, GPS, and security, which were once non existent, have now become integral parts of our daily lives.[2]

Aerospace industry

The aerospace industry has been the primary beneficiary of space exploration, spearheading technological advancements. The development of spacecraft, satellites, and related technologies has led to the establishment of a multibillion dollar industry, gene rating employment opportunities globally.

Scientific research

The space age has revolutionized scientific research across various disciplines. Astronomy, in particular, has been transformed by the advent of space observatories, enabling ground breaking discoveries.

Healthcare

The exigencies of space travel have driven significant advancements in medicine and healthcare. From novel treatments to innovative healthcare technologies, the benefits of space exploration extend far beyond the confines of our planet.

Technological innovations

The impact of space activities extends beyond the realms of science and industry. The proliferation of innovations such as computers, cell phones, and the internet can be traced back to investments in space exploration. These technologies have fundamentally altered the way we live and work, shaping the course of human progress.

As we reflect on the milestones of the space age, it's remarkable to consider that it began in an era when engineers still relied on slide rules for calculations. The journey from those humble beginnings to our current state of technological prowess serves as a testament to human ingenuity and the boundless possibilities that lie ahead.

Phase 2: Advancing human presence in space

Phase 2 marks a pivotal moment in our journey beyond Earth, characterized by the establishment of permanent human settlements on the Moon and the initial steps towards manned missions to Mars. Operational settlements on these celestial bodies will lay the groundwork for the development of lunar and Martian economies, ushering in a new era of space commerce.

Exploration and economic development

Manned missions will not only return to the Moon but will also set their sights on Mars, pushing the boundaries of human exploration. Meanwhile, unmanned probes will have ventured to various celestial bodies, including the main moons of gas giants and the Pluto system. The establishment of unmanned bases for mining purposes, including ground breaking asteroid mining experiments, will be underway, laying the foundation for future resource extraction endeavors. This phase is projected to create approximately 10 million jobs, fuelling economic growth and innovation.

Challenges and opportunities

As we venture deeper into space, the potential for artificial intelligence to surpass human intelligence looms on the horizon, a phenomenon often referred to ashes Singularity. While this development holds the promise of revolutionizing space exploration, it also presents unforeseen challenges. The emergence of AI as a dominant force in space exploration could reshape the landscape of our endeavors, necessitating careful consideration of its implications.[3]

Technological advancements

Concurrently, advancements in local technologies will drive progress on the Moon, Mars, and selected asteroids. Emphasis will be placed on developing essential infrastructure, including construction activities and life support systems such as agriculture, food production, mining, mineral processing, and transportation. These efforts will pave the way for a burgeoning space economy, encompassing diverse sectors ranging from business and manufacturing to professional services and tertiary activities.

Terraforming initiatives

Furthermore, Phase 2 will witness the commencement of initial terraforming activities on Mars, signalling humanity's ambitious endeavors to transformation landscapes into habitable environments. While the challenges ahead are formidable, the prospect of unlocking the potential of other worlds holds immense promise for the future of our species (Figure 2).

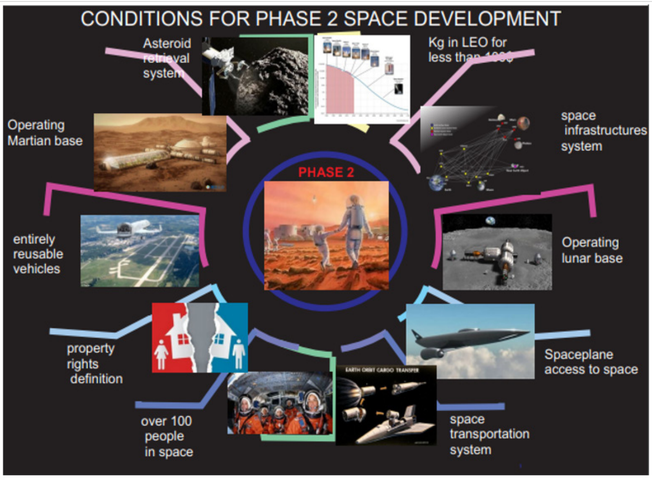

Figure 2 Phase 2 development.

Phase 3: Pioneering mars terraforming

Phase 3 heralds the dawn of a new era in human exploration, with Mars terraforming emerging as the foremost undertaking in our quest to establish a second home for humanity. This monumental project is poised to create millions of jobs and catalyze the growth of a burgeoning space economy, representing one of the most significant endeavors in human history.[4]

Space settlements and interplanetary commerce

Space settlements will assume a central role in this burgeoning economy, serving as hubs for interplanetary business activities and providing essential infrastructure for sustainable habitation. The space sector is projected to create approximately 100 million jobs, fuelling economic prosperity and fostering innovation on a scale never before seen.

Solar system development

Across the solar system, efforts to develop celestial bodies will reach unprecedented levels, with manned underground settlements and unmanned bases for mining and mineral processing operations becoming commonplace. A diverse array of activities spanning business, primary, secondary, and tertiary sectors will contribute to the emergence of a robust Quadrillion-dollar economy. This flourishing economy promises to uplift the entire population, eradicating social issues such as poverty and petty crime.

Asteroid mining and resource utilization

Asteroid mining and deflection will emerge as major industries, facilitated by the establishment of space factories aimed at reducing reliance on non-renewable resources on Earth. The development of a solar system-wide economy will be the hallmark achievement of this phase, paving the way for unprecedented prosperity and sustainability.[5]

Diverse business activities

While Mars terraforming activities take center stage, a myriad of business endeavors, ranging from primary industries such as mining, mineral processing, and agriculture to secondary, tertiary, and quaternary sectors, will thrive in this dynamic environment. This phase represents a culmination of human ingenuity and ambition, propelling us towards a future where the boundaries of possibility are limited only by our imagination (Figure 3).

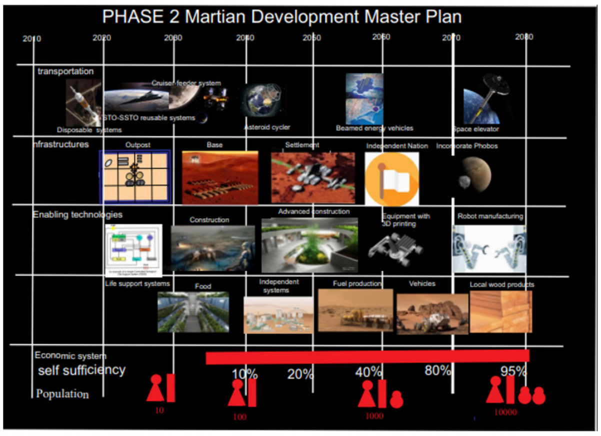

Figure 3 Mars development master plan.

Phase 4: Solar system colonization

In Phase 4, the vision of solar system colonization becomes a reality, with Mars leading the charge as a partially terraformed world supporting a thriving population numbering in the millions. This burgeoning society sustains a fully self-sufficient economy, marking Mars as an integral member of the human civilization.[6]

Expansion across celestial bodies

Across the solar system, underground settlements proliferate on various celestial bodies, unlocking new economic opportunities and contributing to the emergence of a solar system-wide society. From the icy moons of Jupiter to the barren landscapes of Mercury, human presence extends, driven by the pursuit of exploration and resource utilization. Unmanned mining facilities dot the extra-terrestrial landscape, laying the groundwork for sustainable resource extraction.

Extra-terrestrial employment and economic growth

The extra-terrestrial activities sector becomes a cornerstone of the economy, projected to create approximately 1 billion jobs. This surge in employment fuels a rapidly growing economy characterized by exponential expansion across all business activities. From mining and manufacturing to service industries and beyond, the solar system becomes a hub of economic activity, fostering innovation and prosperity on an unprecedented scale.[7]

Territorial expansion and terraforming

Territorial growth accelerates, propelled by ongoing efforts in underground terraforming. As human settlements expand beneath the surface of celestial bodies, the boundaries of habitable space extend, paving the way for the establishment of new colonies and outposts. These endeavors represent a testament to human ingenuity and resilience, as we continue to push the boundaries of what is possible in our quest to explore and inhabit the cosmos.[8]

Phase 5: Interstellar exploration

The final phase of our development plan heralds the dawn of interstellar travel, opening the door to boundless expansion for the human species. Advanced space settlements, resembling artificial planets, will colonize exosolar planetary systems that were once deemed inhospitable to human habitation. Concurrently, unmanned bases will be established across entire planetary systems, laying the groundwork for future exploration and resource utilization.

Expanding horizons

This phase holds the potential to create up to 10 billion jobs, contingent upon the conditions encountered in newly explored territories. As humanity ventures into the vast expanse of interstellar space, limitless business opportunities will unfold, spanning both manned and unmanned activities. From pioneering scientific research to resource extraction and commerce, the possibilities for economic growth and innovation are limitless.[9]

A Journey beyond

With the completion of Phase 5, humanity will have reached the culmination of its journey from humble beginnings to interstellar pioneers. Our society, currently at the end of Phase 1, stands on the threshold of Phase 2, poised to embark on the next stage of exploration with plans for the return to the Moon by several players. As we stand at the precipice of a new frontier, the spirit of exploration and discovery continues to drive us forward, guiding our path towards a future where the stars themselves are within reach (Figure 4).

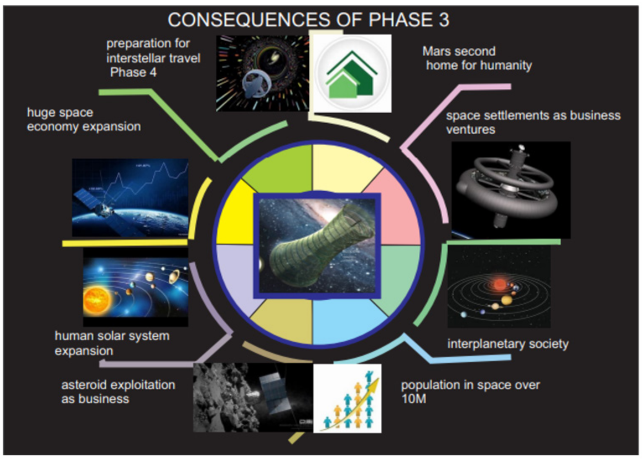

Figure 4 Phase 3 consequences.

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A Hundred-Year Space Plan

Scheduling the previous plan is a daunting task due to the myriad unforeseeable factors that can influence progress. However, we can draw insights from past experiences and anticipate potential trends. We've segmented the schedule into distinct phases (Figure 5):[10]

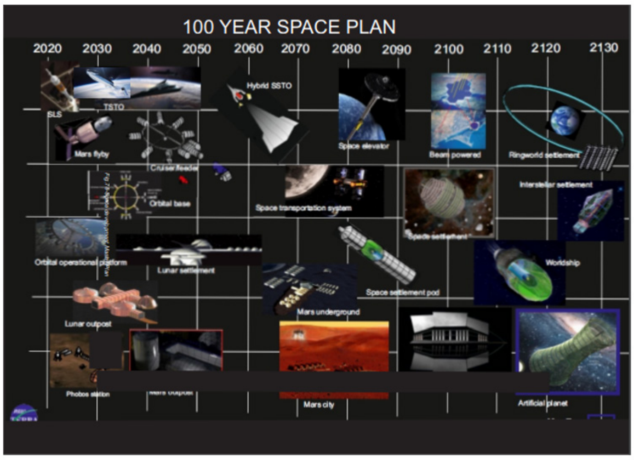

Figure 5 100 year space plan.

Space accessibility and mobility systems:

Efforts in this domain aim to achieve affordability for space access. Notably, SpaceX's breakthroughs with reusable boosters have led to significant cost reductions. Further advancements are anticipated, including the development of space planes operating akin to commercial airliners, innovative systems like space elevators, and enhanced space transportation systems featuring tug-like mechanisms, cycling stations with supporting facilities, and artificial gravity modules. Additionally, the utilization of deflected comets and asteroids in cycling orbits is being explored.

Space stations to settlements:

Private companies are poised to offer commercial space stations, providing orbital services as a lucrative business endeavor. These stations, strategically positioned, can serve as transportation hubs, maintenance depots, space hotels, manufacturing centers, and even defense installations. Larger space stations will evolve into settlements distributed throughout the solar system, facilitating human activities while maintaining terrestrial life conditions for their inhabitants.[11]

Moon and mars development:

As our nearest celestial neighbours, the Moon and Mars will witness rapid development. From initial outposts to fully-fledged bases and settlements, various entities will embark on construction projects. These endeavors will catalyze industrial growth, particularly on Mars, where the possibility of future terraforming could spur economic activities. Both above and underground facilities will be established to accommodate diverse business ventures and sustain local economies.

Solar system development:

Progress will extend across the solar system, propelled by unmanned vehicles and missions. Mining operations on asteroids and other celestial bodies will emerge as lucrative ventures, alongside space manufacturing initiatives. Breakthroughs in propulsion systems are anticipated to shorten space travel durations, while advancements in fusion power generation hold promise for sustainable energy sources. Unmanned bases will be established on celestial bodies like Mercury, Venus, and the moons of gas giants, as well as selected dwarf planets, asteroids, and comets. Space settlements will proliferate throughout the outer reaches of the solar system, extending terrestrial activities to the farthest corners in anticipation of the next frontier: interstellar travel capability.[12]

Steps to interstellar travel

By utilizing the Sapientia scale, we can predict a step-by-step progression from our current conditions to those necessary for interstellar travel capability.

The chart illustrates the steps from the existing situation, marked as 0.7-0.8, to a projected interstellar travel capability at 1.6 on the Sapientia technology scale. At the current rate of progress, we may achieve such a level after two centuries, taking into account various parameters such as human biology, territory, environment, and technology.[13]

However, if we consider the possibility of a Technological Singularity at 1.0 on the technological parameter of the scale, which could potentially occur within a few years, it might substantially accelerate this forecast. We could feasibly have interstellar travel capability at a fraction of the speed of light much sooner, perhaps within thirty to forty years if humanity would be able to manage AI smarter than human conditions.

Goals and motivations for interstellar technologies

Numerous motivations, some of which can also be seen as goals, are driving our society toward achieving interstellar travel. We can summarize the main ones as follows:

Expand the domain of humanity:

Transitioning from dominance over a single planet to multiple planetary, and even interstellar, territorial dominion. This entails expanding human active territory by thousands, encompassing population, resources, economy, and more.[14]

Alternative for survival:

Becoming a multi-planetary society ensures survival in the face of various events, from natural catastrophes to wars, from asteroid impacts to pollution and other threats to our planet.

Search for suitable planets for humans:

With an increasing population, human society requires new planets where it can thrive. The discovery of more suitable planets enhances our options.[15]

Creation of new economies:

Developing new territories will boost the overall economy and create opportunities for further economic growth, providing employment and wealth for all.

Solving terrestrial challenges:

Global challenges pose significant threats to humanity. Expansion into space and the opportunities presented by interstellar exploration provide additional resources and technological advancements to tackle these challenges.

Defense purposes:

The existence of potentially hostile alien societies in space presents a threat to our planet. To prevent a scenario akin to the fate of the Incas and Aztecs, meeting technologically superior civilizations, the development of interstellar capabilities becomes crucial. It pushes us to develop advanced technologies that could match or surpass those of potential alien adversaries, enhancing our defense.[16]

Enhancing human conditions:

Humans participating in interstellar travel will be improved compared to us; their bodies and minds will be enhanced with technological improvements, making them superior. Additionally, expanding our territorial borders prompts humans to reconsider their place in life and their condition.

Advancing science and technology:

The opening of the interstellar frontier is expected to lead to enormous progress in science and technology. It will involve all aspects of human society, demanding the resolution of ever-greater challenges. This may lead to a new technological singularity.[17]

Conditions for interstellar travel

The road to interstellar travel is challenging, and several conditions and technological breakthroughs are necessary to achieve this goal.[18]

Global challenges solved:

While interstellar travel could offer new tools to tackle global challenges, an advanced society capable of achieving interstellar travel must have already overcome existing challenges.

Propulsion breakthrough:

Propulsion is a crucial component for future star ships. To be effective, their speed should be at least a significant fraction of the speed of light, considering the enormous distances involved. Existing and proposed systems fall short of such capabilities, so a breakthrough in propulsion technology will be required, involving future science and technology.[19]

Solar system colonized:

An essential condition is the complete colonization of our solar system. This means achieving territorial dominance and possessing comprehensive knowledge of our planetary system, including its surroundings (such as the Oort cloud), with proven and advanced space technology.

Telepathic communications:

Future humans capable of interstellar travel will be quite different from todays. The adoption of Brain-Computer Interface (BCI) technologies will revolutionize their interactions with the web and advanced AI, representing an evolutionary leap for humanity. These technologies would enable telepathic communications.[20]

Unmanned interstellar probes:

Before any manned mission is directed to interstellar space, unmanned probes must have already reached the nearest systems and mapped them to ensure there are no surprises or unexpected risks.

Disease elimination:

As indicated by the Sapientia human body parameter, understanding our bodies will ensure that we can control any terrestrial or anticipated diseases, and increase our lifespan significantly compared to the present.

Mind uploading:

Manned missions may not be necessary. Instead, unmanned ones with AI uploaded minds capable of handling any situation upon arrival could be used.[21]

Energy generation breakthrough:

Similar to propulsion, power generation requires breakthroughs to meet the challenges. This could involve fusion, harnessing energy from black matter and interstellar space, or obtaining energy from other star systems.

Pentillion-plus economy:

With the economy already oriented toward space, it would reach unprecedented levels, possibly reaching pentillion levels.[22]

Main technologies involved

Several technologies would be involved, some requiring breakthroughs. Main ones are Space development, Propulsion breakthroughs, Health care, Food production, Power generation systems, Intelligent apps, Communications, Injected nanosurgery, Education, Space technologies in general. The combination of all these technologies and their impact will generate several technological, social, and educational singularities (Figure 6).[23]

Figure 6 Productive space activities.

Conclusion

Interstellar travel appears to be an inevitable goal and possibility for future generations, following a logical progression of technological milestones. The necessary steps are clear and feasible, with obvious benefits and achievable targets. However, humanity may encounter new and unexpected threats that could hinder interstellar travel for our society.[24]

The emergence of AI, smarter than humans and continually evolving, presents a potential challenge. If AI were to achieve self-awareness and independence, they could dominate our planet and dictate our future, surpassing humans with their superior mental capabilities. In such a scenario, the development of space by humans, which requires extensive technological infrastructure for life support, healthcare, food, radiation protection, and time management, might become obsolete. AI, not requiring such infrastructure, could freely traverse the entire solar system according to their preferences.

Therefore, the considerations presented in this article may seem unrealistic if an AI takeover were to occur, reducing or eliminating human space activities as unnecessary. A symbiotic relationship between humans and AI could offer a solution to prevent a halt to our civilization. Careful management of our roadmap will be essential, along with progress in fields unrelated to space activities, to address this new challenge.

Overall, interstellar travel remains a tantalizing possibility, but it must be approached with careful consideration of the potential impacts of advancing AI and the need for cooperation between humans and artificial intelligence.[25]

Discussion

Until a few years ago, interstellar travel was viewed as a feasible goal aligned with our society's technological progress. However, the rapid advancements in AI development necessitate a re-evaluation of this perspective. In the near future, AI may surpass human intelligence, leading to the phenomenon known as the Technological Singularity a paradigm shift with unpredictable consequences for our society.[26]

In this potential future, especially in the realm of space exploration, AI could be better suited than biological humans to pioneer interstellar endeavors. Unlike humans, AI would not require elaborate life support systems, radiation protection, artificial gravity, or healthcare. They could operate in any spatial environment, needing only power, which could be harnessed through advanced technologies.

If AI were to achieve a level of consciousness and independence, they might prioritize their own goals over human interests, potentially positioning humans as subordinate members of society. Space development exemplifies this shift, where AI could thrive and advance interstellar travel without human participation.

As we stand on the brink of this transformation, it's crucial to consider the implications and potential risks. Philosophers and ethicists must engage in discussions about the future we envision, the objectives we wish to pursue, and our roles in a society increasingly influenced by AI. Initiating this dialogue is essential, as we have a limited time before the Singularity may reshape our reality.[27]

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Conflicts of interest

The authors declare that there is no conflict of interest.

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