U.S.-China Astro-Geopolitics on the Moon and Mars

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Introduction

For the first time in 4.5 billion years, humanity now has the opportunity to become a multiplanetary species. Such a feat was largely made possible in December 2015 by SpaceX's invention of reusable rocket boosters (Falcon 9) that fly themselves to land back on Earth with pinpoint precision. It took thousands of the most brilliant engineers seven years to successfully land a rocket booster, but now the American aerospace company has successfully landed more than 100 boosters and now flies multiple missions per week.[1] Such a track record has now led the company to focus on the next step: the development of a much larger-scale rocket and booster to facilitate cost-effective transport to the Moon and Mars and ultimately become a multiplanetary species. This program is known as the Starship program and there are thousands of engineers working around the clock on Starship in south Texas on the U.S.-Mexico border. At the same time such innovation by SpaceX is pushing the United States into an era where colonization of the Moon/Mars is now possible, China has invested heavily in its own national space program—leading it to top the world in rocket launches in 2021 (even beating SpaceX and the United States).[2] While China does not have self-landing rockets like SpaceX (yet), Beijing is the only other entity with the technological capacity to compete with the United States and SpaceX in the pursuit of permanently colonizing the Moon and Mars.[3] Therefore, the fate of humanity seems to lie in how the American (largely SpaceX) and Chinese colonization programs connect, overlap, interact, and play out together. If one steps back and imagines how this era will be viewed in the historical record, the early seeds of humanity off of Earth will develop in the 2020s (largely established by the United States) while China will enter the picture with force on both the Moon and Mars to join the United States in the 2030s.

Given the focus of EASTD196 as a political geography course, this paper will explore a geography-oriented question: *How will the geography of the Moon and Mars affect dynamics between the U.S. and China (the dominant and also likely first) two actors on the Moon and Mars?* This paper argues that—due to differing geographic characteristics like solar irradiance and ice deposits—the U.S. and China will likely experience more *competitive* dynamics on the Moon and *cooperative* dynamics on Mars. This paper will first explore contextualizing factors, then discuss the Moon, and finally end on Mars. To the author's knowledge, this is the first paper to define the new subdomain *astro-geopolitics* with an explicit focus on U.S.-China relations and a comparative lens between the Moon and Mars.

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[1] "Launches," SpaceX, accessed May 4, 2022, https://www.spacex.com/launches/.

[2] Deng Xiaoci and Fan Anqi, "China Scores 55 Orbital Launches in Super 2021, Topping US to Become 1st in the World," Global Times, December 23, 2021, https://www.globaltimes.cn/page/202112/1243233.shtml.

[3] Tim Fernholz, "Is SpaceX versus China the Only Space Race That Matters?," Quartz, December 31, 2020, https://qz.com/1949790/is-spacex-versus-china-the-only-space-race-that-matters/.

Literature Review

In reviewing existing literature, astro-geopolitics is such a new underexplored field of study that the author has not found any other analyses that specifically consider U.S.-China relations on the Moon and Mars in the context of lunar and Martian geography. There are, however, some comparative studies done that ask the question, "is the Moon or Mars a better body for permanent colonization efforts?" Most existing literature seems to arrive at the conclusion that while both bodies will see the development of a permanent human presence, the Moon is too harsh to be anything but a temporary stepping stone to Mars. The largest factor seems to be water: "spacecraft and samples from the Apollo missions have shown that the moon has potentially massive amounts of water frozen as hard as granite in deposits deep at its poles, which future astronauts could mine. But evidence suggests that water may exist in the subsurface all over Mars. This is not definitive, but it is a relatively strong possibility."[4] [5] Already most analysis seems to point to the premise that humans must live near the lunar poles to access this surface water. The second consideration besides water according to existing literature seems to be the presence of an atmosphere: "the Moon has no appreciable atmosphere, and though the atmosphere of Mars is only 1% the density of Earth's, the difference between no atmosphere and some atmosphere is significant."[6] These factors—water and an atmosphere—point to the general conclusion that Mars (over the long-run) has the potential to be terraformed whereas the Moon will remain a barren, lifeless body.

The difficult thing about predicting U.S.-China relations on the Moon and Mars in the context of geography is that it is an entirely speculative venture. No other analysis has compared geophysical properties for the most optimal areas for permanent colonization on the Moon and Mars before, but on top of this, introducing the idea that the United States (through NASA and SpaceX) and China will likely be the first and only two actors for quite some time, make for an interesting case study of game theory.

Background

Before diving into the geographic factors of the Moon and Mars, a brief background will provide some key contextualizing information about (a) the actors and (b) the timing.

The Actors

First, and perhaps most importantly, are exactly who (within the United States and China) are the specific Earth-based actors competing for influence on the Moon and Mars. China's national space program is government-run (and is expected to remain so) with divided responsibility

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[4] Marina Koren, "The Pros and Cons of a Lunar Pit Stop," *The Atlantic*, February 18, 2020, https://www.theatlantic.com/science/archive/2020/02/nasa-moon-mars-artemis/606499/.

[5] Aaron Ridley, "Is It Better to Live on the Moon or on Mars? A Scientific Investigation," Quartz, October 18, 2017, https://qz.com/1105031/should-humans-colonize-mars-or-the-moon-a-scientific-investigation/.

[6] "Mars vs. The Moon," The Mars Society of Canada, February 4, 2021, https://www.marssociety.ca/mars-vs-the-moon/.

among a number of state actors. This primarily includes the civilian space agency for interfacing with foreign space entities (China National Space Administration), the military (PLA), and the rocket manufacturer (CASC China Aerospace Science and Technology Corporation)/more specifically, CALT (China Academy of Launch Vehicle Technology).

On the other hand, the United States is more complicated. The U.S. will be working through its national space agency—NASA—to permanently colonize our Moon, but in collaboration with private sector space companies, primarily SpaceX. NASA has positioned itself as a "customer" of multiple innovative aerospace companies—all competing to win contracts as part of the larger Artemis mission framework. NASA's funding comes from the United States Congress and thus, the NASA administrator is somewhat beholden to the interests of lobbyists, legacy aerospace companies, and specific politicians who wish for manufacturing jobs to be supported in their jurisdictions. When it comes to Mars, though, SpaceX is the dominant American player with little to no involvement from NASA at this stage. There will be no NASA vehicles involved in Mars colonization[7] and it is not yet clear whether SpaceX will be sending NASA astronauts or their own private astronauts. Currently, the first humans to fly aboard SpaceX's Mars-bound Starship are not NASA astronauts, but will be a mix of SpaceX employees and private citizens on the recently-announced Polaris III mission.[8] For some, this was a particularly surprising choice given that test flights are typically flown by experienced NASA astronauts (and especially military test pilots). The first time SpaceX ever flew humans in May 2020, it worked closely with two experienced NASA astronauts—Bob Behnken and Doug Hurley. Whereas NASA has already selected its astronauts for the Artemis missions to the Moon, no such personnel have been selected by SpaceX for Mars.

Zooming out to the broader goals of colonizing each p body though, the Moon and Mars will likely develop two fundamentally different uses for humanity. Whereas both bodies will host permanent human life from the U.S. and China, there are expected to be three to four orders of magnitude more humans living on Mars than on the Moon. Whereas the Moon may become home to a lunar outpost that hosts several hundred research personnel, SpaceX is determined to build a self-sustaining colony on Mars with one million people by 2050. Given that the highest number of active astronauts at one time in the United States was a mere 149 individuals, and now the agency only has 48 "active" astronauts, when juxtaposed to the massive number of people SpaceX aspires to send to Mars, there just is no feasible way to train so many people to become a "professional astronaut" under the purview of a government agency like NASA.

NASA isn't without its own (vague) plan for sending humans to Mars in the late 2030s, but the government agency itself does not have *supersonic retropropulsion* technology, leaving SpaceX

[7] NASA's Space Launch System (SLS) and the Lockheed Martin-built Orion spacecraft are only going to be used for the Moon, not Mars. SpaceX can do in 2 launches for a Mars mission what SLS can do in 8-11 launches

[8] SpaceX announced the Polaris Dawn mission on March 2021—financed by private citizen, tech billionaire, and Inspiration4 mission founder Jared Isaacman.

as the only entity with rapidly reusable orbital rockets (for now)—necessary for a cost-effective and consistent launch tempo to colonize another astronomical body. NASA is subject to the unpredictable political whims of Congress and election cycles and either way, without reusable rockets, any colonization plan is going to be infeasible from a cost perspective. It remains to be seen if/when China succeeds in developing the requisite technology to enable their super heavy-lift launch vehicle—the Long March 9 长征九号火箭—to become rapidly reusable.

Put simply, NASA is focused on the Moon while SpaceX is focused on Mars. Even if SpaceX wished to become more collaborative with the Chinese on the Moon, NASA is an American government agency that takes direction from American political leaders. So long as SpaceX operates under a NASA-led framework, the company would likely be forced to comply quite closely with a Washington hostile toward Beijing on the Moon.

Timing

The Moon will set a precedent for Mars. Accepting projected timelines for lunar and Martian settlement, the U.S. will have a 4-year lead ahead of China on the Moon (U.S. 2026[9], China 2030[10]) and a 4-year head-start on Mars (U.S. 2029[11], China 2033[12]). The U.S. will also have humans on both planets at least one year before China has humans on *one* planet (the Moon). Despite the greater relative difficulty of Mars compared with the Moon, the leads are nearly identical. It's important to note that a 4-year lead on the Moon, though, should actually be thought of as a *real* 4-year lead given that missions can be launched *anytime* and reach the Moon in about 3 days. In comparison, a 4-year lead on Mars actually means only 2 opportunities to travel between Mars and Earth. For example, if SpaceX lands on Mars in 2029 as predicted, SpaceX only has one more opportunity to fly a mission to Mars in 2031 before simultaneously launching alongside Beijing in China's first attempt in 2033. One can only travel to Mars every 26 months when the Earth and Mars align for the shortest-possible journey of about 6 months.

Officially, the first lunar outpost is supposed to be set up by NASA in 2028 with the launch of the "Lunar Surface Asset"—a small habitat that will serve as the first crewed lunar base. China aspires to build a base on Mars and develop a "large-scale Earth to Mars transportation fleet"

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[9] Elizabeth Howell, "NASA's 1st Artemis Moon Landing Will Likely Slip Another Year to 2026," Space.com, March 1, 2022, https://www.space.com/artemis-moon-landing-likely-slip-to-2026.

[10] CCTV中文国际, "对话叶培建：我一定能够看到中国航天员去月球！20211112 |《鲁健访谈》CCTV中文国际" (Youtube, November 12, 2021), https://www.youtube.com/watch?v=eZ9_BftoO3U.

Andrew Jones, "Chinese Crewed Moon Landing Possible by 2030, Says Senior Space Figure," SpaceNews, November 15, 2021, https://spacenews.com/chinese-crewed-moon-landing-possible-by-2030-says-senior-space-figure/.

"Ye's words do not equate to an official statement of China formally approving a crewed lunar landing, but do reflect the strongest informal indication yet directly from the Chief Commander and Chief Designer of the Chinese Lunar Exploration Program."

[11] Lex Fridman, *Elon Musk: SpaceX, Mars, Tesla Autopilot, Self-Driving, Robotics, and AI | Lex Fridman Podcast #252* (USA: YouTube, 2021), https://www.youtube.com/watch?v=DxREm3s1scA.

[12] Deng Xiaoci, "Chinese Rocket Manufacturer Outlines Manned Mars Mission Roadmap, Timetable," Global Times, June 23, 2021, https://www.globaltimes.cn/page/202106/1226925.shtml.

with crewed missions in 2035, 2037, 2041, and 2043. Zhang Kejian, head of CNSA, said in a public statement that his space agency intends to build China's permanent research station at the moon's south pole—the same place as the Americans.

Either way, relations on the Moon between the U.S. and China are going to play out before Mars. This means the U.S. will have both the first-mover advantage and burden of being the first to build critical life-support infrastructure on both bodies—potentially used by China upon arrival. Given the multi-year leads the U.S. will have on China, the decision will be left to Chinese leaders as to how to proceed. Both the U.S. and China have already committed to sending robotic missions to prospect the lunar south pole. It's hard to imagine that China would abandon its aims of developing its lunar colony on the south pole when Americans get there first, and somehow pivot toward a new exploration timeline of the north pole instead. Thus, the first hints of how humanity's relations off Earth will develop will reveal themselves with competing robotic missions to the lunar south pole. China's 2024 Chang'e 7 mission[13] and the U.S.'s 2023 VIPER mission will be the first time in which American and Chinese missions operate in relatively close proximity to one another.[14] [15] When the U.S. lands humans on the lunar south pole in 2025, China will be forced to make a decision as to whether continuing its missions to the south pole make sense. China will weigh trying to cooperate with the Americans in co-existence on the same pole or shift to the north pole instead. The two rivals have not yet reached such a juncture where space leaders have been forced to make such a decision given that space stations—the International Space Station and Tiangong 天宫空间站—in low-earth orbit (LEO) are separate. The lunar south pole region, though, would force the U.S. and China together in the same tight geographic proximity.

To consider the alternative to co-existence on the south pole, the U.S. would continue the status quo of stiff-arming China (via the Wolf Amendment). China would land on the south pole and be forced to rebuild everything itself. The Chinese might justify such a decision on the basis that they can't depend on the Americans for any technology. If no initiation of cooperation occurs immediately after the landing of Artemis III in 2025, it's difficult to envision the subsequent development of cooperation in the years 2025-2030 in the lead up to China's first human mission to the Moon. Such a situation would result in a hostile relationship in which the commanders of each competing U.S.-led and China-led base at the lunar south pole will compete for permanent

[13] Chang'e-7 will target a lunar south pole landing and consist of an orbiter, relay satellite, lander, and rover. It will also include a small spacecraft capable of "hopping" to explore shadowed craters for evidence of potential water ice, a resource that, if present, could be used in the future for both propulsion and supplies for astronauts.

[14] Technically, in January 2019, China's current Chang'e 4 rover was the first to land in the lunar south pole within the immense South Pole-Aitken Basin (on the far side). The lunar south pole is just inside the rim of the South Pole-Aitken impact basin which has an enormous 2,500-km diameter.

[15] Robert Margetta, "NASA's Artemis Rover to Land near Nobile Region of Moon's South Pole," September 20, 2021, https://www.nasa.gov/press-release/nasa-s-artemis-rover-to-land-near-nobile-region-of-moon-s-south-pole.

areas of shadow and sunlight, potentially without strong mechanisms of communication and exchange in place to ensure conflicts over resource scarcity are settled peacefully.

The Moon

At a high-level, the Moon's geography may induce more competitive dynamics between the U.S. (through a collaborative effort between NASA and SpaceX) and China. This is primarily motivated due to a relative scarcity of resources—the two most important being solar irradiance (for energy/power) and ice deposits (for water).

The convergence of these two factors—solar irradiance and ice deposits—mean that there are only two relatively small optimal locations for a permanent human colony—the two poles. Due to the Moon's axial tilt, the Moon's poles are the only locations on the body with areas both almost constantly in the sun (rims of craters) and constantly dark (bottoms of craters). The reason why sunlight does not fluctuate dramatically at the Moon's two polar regions is because there are no "seasons" on the Moon. Although there does exist some degree of seasonal variability, the Moon is virtually "erect" with only a 1.54° tilt (compared with Earth at 23.5° and Mars at 25°). This means the amount of sunlight (whether significant or insignificant) is relatively constant all year—with some areas always lit by sunlight and others perpetually draped in shadow.

With solar irradiance, having near-constant sunlight would allow critical energy intensive operations to always have solar power available. Near constant solar power, thus is a major engineering advantage. It was initially thought that the lunar polar mountains received perpetual light—peaks of eternal light[16]—during both winter and summer, but the latest orbiter images suggest that *no points* on the Moon actually receive light during both lunar winter and summer. However, there are points on crater rims which have very extended periods of sunlight.

There exists contradictory research about which lunar pole boasts superior solar irradiance. Some of this contradictory research originates in the fact that there is a major information asymmetry between the two poles: the lunar south pole has been thoroughly examined by a number of different orbiting spacecraft, while the lunar north pole remains vastly underexplored in comparison.[17] Early research argued that the lunar north pole (specifically Peary Crater) was "home to the regions most illuminated and most likely to be permanently sunlit given that there are no constantly illuminated areas in the south polar region."[18] They continue, "we have

[16] Peaks of eternal light would require high altitude, high elevation, and be on a body with very small axial tilt. It was thought that the lunar polar mountains were the only location in our solar system.

[17] Humanity (collectively) has mapped nearly every square meter (even areas of permanent shadow) of the lunar south pole with precise details regarding its temperature, ice deposits, and topography. Because most of the Moon's polar regions are not visible from Earth, this was done remotely from orbiting spacecraft. The lunar south pole is also far from the landing sites of the historical Apollo missions—all clustered around the lunar equator.

[18] D. Ben J. Bussey et al., "Planetary Science: Constant Illumination at the Lunar North Pole," *Nature* 434, no. 7035 (April 14, 2005): 842, https://doi.org/10.1038/434842a.

identified areas that are constantly illuminated during a lunar day in summer and which may therefore be in permanent sunlight. All are located on the northern rim of Peary crater, close to the north pole."[19]

But more recent research has swung the favorability to the lunar south pole instead due to a difference in the permanency of sunlight at the north and south poles due to fluctuations in the lunar summer and winter because it is not possible to state definitively that these prior north polar areas are permanently sunny given that the data corresponds to a summer rather than a winter day. The latest research shows the south pole appears superior to the north pole in terms of solar irradiance with more than 80% sunlight at more than 5km² compared with 1km² at the north pole.[20]

While there exists some uncertainty regarding which pole is better evaluated on the basis of solar irradiance, the fact is that neither the north pole nor the south pole has an *abundance* of these permanently illuminated ridges. Each of these ridges, as one scientist put it, is "like an island of no more than a few hundred meters across in an ocean of eternal darkness."[21] At the south pole, there exist only two "points" of permanent sunlight ~8km from each other. Sunlight is scarce.

While it is uncertain which lunar pole is superior in terms of solar irradiance, when it comes to water ice, the lunar south pole is clearly superior to the lunar north pole. Water ice is critical to manufacture in-situ oxygen and chemical fuels. In 2018, NASA confirmed the presence of water ice at both of the Moon's poles using data collected by its Moon Mineralogy Mapper (M3) instrument aboard India's Chandrayaan-1 spacecraft and its findings suggest that ice is concentrated within craters at close proximity at the south pole, and widely/sparsely distributed at the north pole. Indeed, although only 0.08% of the surface of the Moon[22] is covered in permanently shadowed craters, maps show that the area of permanently shadowed craters is much larger at the lunar south pole than the lunar north pole because there are three large deep craters in the south while no single large crater exists in the north which results in less long-durable shadow regions.[23]

Almost every part of the Moon is constantly bathed in either sunlight or cloaked in darkness. This means that during the lunar day, temperatures reach 253°F, then during lunar night, drop

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[19] Ibid.

[20] H. Noda et al., "Illumination Conditions at the Lunar Polar Regions by KAGUYA(SELENE) Laser Altimeter," *Geophysical Research Letters* 35, no. 24 (December 30, 2008), https://doi.org/10.1029/2008gl035692.

[21] Michiel Kruijff, "Peaks of Eternal Light on the Lunar South Pole: How They Were Found and What They Look Like," *Exploration and Utilisation of the Moon*, July 2000, https://adsabs.harvard.edu/full/2000ESASP.462..333K.

[22] Of 31km² of total lunar surface area, ~31,000km² are permanently shadowed craters. This includes 324 known regions.

[23] Noda et al., "Illumination Conditions at the Lunar Polar Regions by KAGUYA(SELENE) Laser Altimeter."

down to -387°F.[24] In other words, during the daytime, temperatures are high enough to sublimate away ice. But the polar regions are the exception. The Moon's 1.54° axial tilt means that standing on the poles, the Sun would always appear on the horizon (never overhead). Due to this low angle, sunlight strikes the Moon's polar regions from the side—skimming the rims of deep craters and leaving their deep interior (called "cold traps") in a state of eternal darkness. Near-constant sunlight is a phenomenon humans experience at our own polar regions on Earth.[25] These craters are thought to reach -414°F—a temperature at which water ice is stable. Water ice is believed to have accumulated originally from comets, meteorites, and solar wind-induced iron reduction. The ice stays in these traps because of the thermophysical properties of the Moon like scattered sunlight, thermal re-radiation, internal heat, and light given off by the Earth.[26]

To clear one common misconception, frequently, there is often discussion about a "dark side of the Moon"—the side that perpetually faces away from Earth. The "dark side" is actually better described as the "far side" given that it isn't really any darker than the "near side." Sunlight falls equally on all sides of the Moon, but due to the fact that the Moon rotates exactly once every time it circles the Earth—keeps the same face pointed toward Earth. In other words, the Moon rotates on its axis at the same rate the Moon orbits the Earth. As a result, the Moon does not appear to observers from Earth to be spinning at all, but keeping perfectly still. This is termed "synchronous rotation."

Ultimately, while the Moon and Mars are both tough environments, even the two most optimal locations on the Moon (at the two polar regions) are especially difficult to permanently sustain human life. Water is one hundred times scarcer than the Sahara Desert. But water may be far more abundant on Mars—existing in the subsurface all over Mars (just at varying depths).[27] While the Moon has no atmosphere, Mars at least has a weak one (100x thinner than Earth's). Even at the two polar lunar regions, there isn't much space for competing American and Chinese colonies to share. The Moon is also about half the size of Mars, shrinking the already scarce resource availability. The extreme day-to-night temperature swings are a major problem for long-term sustainability on the Moon, but living at the poles would dampen these extremities.

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[24] On the Moon, the day is very hot and the night is very cold with an almost 300 degree temperature difference between day and night temperatures. In fact, the Moon's surface has the coldest temperatures in our solar system.

[25] Brian Dunbar, "Moon's South Pole in NASA's Landing Sites," NASA, April 15, 2019, https://www.nasa.gov/feature/moon-s-south-pole-in-nasa-s-landing-sites.

[26] Guangfei Wei, Xiongyao Li, and Shijie Wang, "Thermal Behavior of Regolith at Cold Traps on the Moon′s South Pole: Revealed by Chang′E-2 Microwave Radiometer Data," *Planetary and Space Science* 122 (March 1, 2016): 101–9, https://doi.org/10.1016/j.pss.2016.01.013.

[27] For reference, Mars is about half the size of Earth

Researchers have already raised concerns over competition over the (only) two suitable long-term colonization locations.[28] [29]

Mars

Turning toward Mars, a region on the Martian northern latitudes called "Arcadia Planitia" combines flat terrain with potential deposits of water ice, and an equatorial region well-suited for solar power. Few other suitable spots are thought to exist on the desert planet, but the region itself is vast.

Regarding Martian solar irradiance, the red planet lies more than 50 million miles further away from the Sun than the Earth/Moon. This means that the maximum intensity (brightness) of sunlight on Mars is 44% than that on Earth. It has been determined that latitudes between 30-60° in both hemispheres are most optimal. Given that the southern hemisphere lacks suitable terrain, a delicate balance must be struck between basing at latitudes high enough for adequate and shallow (polar) water resources, but latitudes low enough for adequate solar intensity. SpaceX has determined at minimum, the latitude of the base must be ≤40°N (i.e. below 40°N degrees).[30] SpaceX has also determined that Arcadia Planitia[31] is one of the few regions where abundant shallow ice is present at relatively low latitude. Hundreds of meters thick local ice deposits expressed as lobate debris aprons (LDAs) adjacent to Montes exhibit traits similar to relatively pure ice.[32]

Mars is remarkably similar to Earth in that the planet has no extreme day-to-night temperature variations like the Moon[33], but four distinct seasons like Earth (only with more variation given the planet's eccentric orbit shape and speed). The planet has an axial tilt only slightly greater than Earth's at about 25° from its orbital plane meaning that the distribution of solar irradiance roughly parallels the Earth, with the Martian equator receiving the most solar irradiance and gradually decreasing as one moves toward the Martian poles.

Regarding water, it is thought that water exists all over the subsurface of Mars, just at varying depths (and ease of access). In collaboration with NASA, SpaceX has already undertaken a study

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[28] Martin Elvis, Tony Milligan, and Alanna Krolikowski, "The Peaks of Eternal Light: A near-Term Property Issue on the Moon," *Space Policy* 38 (November 1, 2016): 30–38, https://doi.org/10.1016/j.spacepol.2016.05.011.

[29] Kaitlyn Johnson, "Eyes on the Prize," Aerospace Security, July 13, 2020, https://aerospace.csis.org/eyes-on-the-prize/.

[30] Golombek, Williams, Wooster, McEwen, Putzig, Bramson, Head6, Heldmann7, Marinova, and Beaty, "SpaceX Starship Landing Sites on Mars," (52nd Lunar and Planetary Science Conference 2021, 2021) (52nd Lunar and Planetary Science Conference 2021, 2021), https://www.hou.usra.edu/meetings/lpsc2021/pdf/2420.pdf.

[31] Constraints initially reduced candidate basing areas to Arcadia Planitia, Phlegra Montes, Utopia Planitia, Deuteronilus Mensae, and Erebus Montes.

[32] Ibid.

[33] While Mars' endless desert surface gives a first impression that the planet is a scorching planet, Mars is actually cold with average global temperatures around -80F. This can go all the way down to -220F and up to about 70F on Mars at lower latitudes during the summer.

and found the most ideal locations for the shallowest water ice to be Deuteronilus Mensae, Phlegra Montes, Arcadia Planitia, and Utopia Planitia—all located on the mid-latitude northern plains. Deuteronilius Mensae shows evidence of glacial activity in its surface features and in fact, "there are still glaciers there."[34] Phlegra Montes is a mountainous system of basins, hills, and ridges—tectonic in origin (rather than volcanic).[35] As a result, the region "probably contains large quantities of water ice, perhaps 20 meters below the surface."[36] Arcadia Planitia is a "smooth plain containing fresh lava flows" and "was shaped by periglacial processes, which supports the idea that ice is present just beneath the surface, making it a candidate for colonization efforts."[37] Finally, Utopia Planitia is perhaps the best explored of the four as the "region where the Viking 2 lander set down in 1976. It is the largest impact basin in the Solar System. In 2016, NASA found a huge deposit of underground ice there with the water estimated to be the same volume as Lake Superior."[38] These four areas all looked suitable in images from a medium-resolution camera on the Mars Reconnaissance Orbiter (MRO), but the High Resolution Imaging Science Experiment (HiRISE) was used to look more closely, the first three locations appeared too rocky leaving the fourth area—Arcadia Planitia—to be the most promising site.[39] Portions of Arcadia Planitia have the shallowest water ice at <0.1m. In other words, one wouldn't need complex extraction equipment to penetrate 1m into the Martian surface, but as the head of the JPL in California said, "you could use a shovel."[40]

Overall, Mars hosts a range of far more suitable locations for permanent basing than the Moon whereas the Moon sees really only two potential sites—both quite small. This means that while there might be some sites slightly better than others (for example, Arcadia Planitia over Utopia Planitia), Mars will perhaps induce less competitive dynamics than on the Moon. Whether "less competitive dynamics" means cooperation/coordination is uncertain, but at the very least, Mars doesn't have the same resource scarcity and tight geographic proximity that the Moon has.

Other geographic considerations beside solar irradiance and water ice

Astrophysics is incredibly complex and there remains an unending list of other factors this paper did not touch on. Below are a few.

(a) Terrain for launching and landing

On both planets, smooth, flat surfaces are optimal for landing spacecraft. On the Moon, the topography is quite consistent throughout the entire body. Mars, however, has great variation in its topography. With the southern hemisphere of Mars out of question given its rocky terrain, safe

[34] Ibid.
[35] Ibid.
[36] Ibid.
[37] Ibid.
[38] Ibid.
[39] Ibid.
[40] Tony Greicius, "NASA's Treasure Map for Water Ice on Mars," NASA JPL, December 10, 2019, https://www.nasa.gov/feature/jpl/nasas-treasure-map-for-water-ice-on-mars.

flat surfaces (with polygons as opposed to brain terrain) in the north for landing were identified in Arcadia Planitia, Erebus Montes, and Phlegra Montes.[41] Utopia Planitia and Deuteronilus Mensae appeared too rocky and thus SpaceX has focused on Erebus Montes (with 8 candidate sites compared with 1 at Phlegra Montes) *within* Arcadia Planitia.[42]

(b) Planetary Angular Velocity

Rockets are typically launched as close to the equator on Earth as possible to take advantage (and not try to fight) the planet's 30 km/s orbital velocity (the planet spinning). This is particularly important on Earth given the difficulty of exiting Earth's thick atmosphere. In comparison, the Moon has an orbital velocity 30x as slow as the Earth (1 km/s) while Mars is similar to Earth (24 km/s). Neither Mars nor Moon have a significant atmosphere that necessitates launch locations on the equator. But eventually, Mars will likely be terraformed (artificially warm up the planet/trapping heat within the Martian atmosphere to be more like Earth), and thus establishing a base as close to the Martian equator as possible would be a strategic decision in the long-term. The Moon—lacking an atmosphere—cannot undergo terraforming as easily and thus launching from either polar region (where orbital velocity is zero) is not a barrier.

(c) Temperature

On the Moon, a few mountain peaks receiving constant, stable illumination result in only very small temperature fluctuations compared to the equator. The night to day temperatures at the lunar equator range from about −180 °C/-150°C (lunar night) to 100°C (Sun is overhead). The surface temperature at Shackleton Crater or Peary Crater for a constantly sunlit polar region has been estimated to be roughly −50±10 °C, avoiding temperature extremes. This means it is advantageous to be at the lunar poles. On Mars, the temperatures are less extreme than on the Moon. In the mid-latitudes, the average temperature would be about -50°C, a summer midday maximum of about 0°C. Even taking into account that Mars has seasonal changes (as a function of axial tilt and an oval-shaped orbit), and thus greater temperature fluctuations than the Moon, it is possible to live in areas besides the Martian poles (unlike the Moon).

(d) Orbits

A final often neglected consideration is the stability of satellites in lunar and Martian orbit. On the Moon, it is advantageous to be located at the poles because satellites can be placed into low lunar orbit (LLO)[43] indefinitely without careful and constant adjustment. The Moon is the most "gravitationally lumpy body known in the solar system." Four lunar mascons—big holes in the ground with positive gravity (Mare Imbrium, Mare Serenitatis, Mare Crisium, Mare Humorum and Mare Nectaris) cause weird and erratic behavior of satellites in low lunar orbits. Such gravitational anomalies leave only a few orbital inclinations useful for long-term stays in LLO.

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[41] Golombek, Williams, Wooster, McEwen, Putzig, Bramson, Head6, Heldmann7, Marinova, and Beaty, "SpaceX Starship Landing Sites on Mars."

[42] Ibid.

[43] Orbits below 62 miles or ~100km

Specifically, only four orbits do not require a satellite to perform frequent course corrections[44]: 27°, 50°, 76°, and 86°. The last orbital inclination of 86° is nearly over the lunar poles allowing a satellite (or possibly a space station) to stay in low orbit indefinitely—a major strategic advantage that goes to the first mover.[45] Although mascons also exist on Mars, they are not as strong as those on the Moon.

(e) Resources

Mars has no valuable substances for life back on Earth, but the Moon (over the long-term) does. Helium-3 used for nuclear fusion is a rare isotope on Earth, but abundant on the lunar surface. Over the long-run, it is not inconceivable to imagine that in a century-long transition to sustainable energy back on Earth, nuclear fusion has become a large part of Earth's energy mix, but requires significant amounts of Helium-3—some of which may eventually need to be sourced from the Moon. Future rocket engines to propel missions to other places outside our solar system will require fusion engines using Helium-3 (replacing our primitive chemical rockets).

Other factors important, but not essential are highly localized features including : elevation, latitude, surface slopes, rocks, presence of a load bearing surface, multiple separate landing locations space within a few km of each other to support multiple missions needed to grow the base and/or for when landings damage landing sites, radar reflective to enable measurement of the distance to the surface).[46]

Conclusion

Given that astro-geopolitics between the U.S. and China will first play out on the Moon before Mars, all eyes should be turned toward how China will react to the relative success of the Artemis missions and adjust course based on Beijing's calculus regarding potential cooperation with the Americans. Upon a successful Artemis III mission, perhaps Beijing will attempt to negotiate with SpaceX instead of NASA. China may quickly come to recognize the technological superiority of SpaceX vis-à-vis NASA and use the success of Artemis III to broach the topic of a wider conversation regarding SpaceX-China relations in preparation for a SpaceX-dominated Martian planet (at least at the start). Such discussions between China and SpaceX may create a rift between SpaceX and NASA with the former questioning the true need for the latter if SpaceX's chief rival in the long-term will not be NASA, but rather the Chinese. None of the timelines alluded to in this paper take into account the active effort underway by China to

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[44] A maneuver every 2 months to keep itself in its initial circular orbit

[45] David Folta and David Quinn, "Lunar Frozen Orbits," in *AIAA/AAS Astrodynamics Specialist Conference and Exhibit*, Guidance, Navigation, and Control and Co-Located Conferences (American Institute of Aeronautics and Astronautics, 2006), https://doi.org/10.2514/6.2006-6749.

[46] Golombek, Williams, Wooster, McEwen, Putzig, Bramson, Head6, Heldmann7, Marinova, and Beaty, "SpaceX Starship Landing Sites on Mars."

emulate SpaceX designs.[47] [48] [49] China has the political consistency/stability and technological expertise to quickly close the gap and begin seriously competing with SpaceX, but with the financial resources of the entire Chinese economy.

It should be underscored that the Moon is a sideshow for SpaceX. SpaceX CEO Elon Musk is laser-focused on Mars. To this end, SpaceX's primary focus has been the development of a rapidly reusable orbital-class rocket and not on tackling technologies needed to survive and thrive on the surface like ISRU—in-situ resource utilization (producing propellant on the Martian surface through the Sabatier process). Starting in September 2018, SpaceX has begun convening conferences to solicit advice and support from partners to develop power, habits, science, food storage, and more. As Principal Mars Development Engineer Paul Wooster said at a conference, "the company has plans to do this on its own if it has to, but SpaceX would gladly allow others to assist."[50]

Finally, it should be noted that an entirely different dynamic than we see on Earth could develop on the Moon and especially Mars between the U.S. and China that does not reflect current Earth-based superpower geopolitics. Both the Moon and Mars are cold, dangerous, desolate places to live. American and Chinese colonies on the Moon—only being three days away—will likely not feel particularly far away. Regular flights able to take off anytime and return from the Moon will ensure that the American and Chinese colonies remain under the influence and control of terrestrial politics. Trips between the lunar south pole, south Texas, and Hainan Island, will become so frequent that it may feel as if the Moon is just an extension of Earth itself. Communication (at least with the near side of the Moon) will nearly be instantaneous with Earth. One-way communication traveling at the speed of light takes about 1.3 seconds making for a slight delay. Even when crews are on the other side of the Moon, a communications relay satellite in Lagrange Point 2 (where China has already deployed its Queqiao relay satellite) can fix this problem.

But on Mars, the one-way communication time with Earth increases to between 3 and 22 minutes depending on the Earth-Moon relative positions. Colonists on Mars will no doubt be able to maintain contact with Earth-based governments, but their minute-to-minute and day-to-day

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[47] Andrew Jones, "Starship Lookalike among China's New Human Spaceflight Concepts," SpaceNews, February 17, 2022, https://spacenews.com/starship-lookalike-among-chinas-new-human-spaceflight-concepts/.

[48] Eric Berger, "China's State Rocket Company Unveils Rendering of a Starship Look-Alike," Ars Technica, April 26, 2021, https://arstechnica.com/science/2021/04/chinas-state-rocket-company-unveils-rendering-of-a-starship-look-alike/.

[49] Andrew Jones, "Chinese Long March Launch Tests Grid Fins for Safety, Future Reusability," SpaceNews, July 30, 2019, https://spacenews.com/chinese-long-march-launch-tests-grid-fins-for-safely-future-reusability/.

[50] Ben Pearson, "SpaceX Beginning to Tackle Some of the Big Challenges for a Mars Journey," Ars Technica, June 3, 2019, https://arstechnica.com/science/2019/06/spacex-working-on-details-of-how-to-get-people-to-mars-and-safely-back/?comments=1.

activities are going to be decided much more independently compared with activities on the Moon. This small difference in communication delay may seem insignificant, but dramatically expands the mental and physical distance that SpaceX and Chinese colonists will feel with their Earth-based governments.

To be sure, the Chinese program will do everything to keep its colonies on the Moon and Mars as aligned with the government as possible and deter desires of autonomy from Beijing. Perhaps the Chinese Martian colony will espouse greater feelings of independence than their lunar counterpart, but the Chinese military will no doubt continue to play the leading role. This stands in stark contrast to SpaceX as a private entity. Imagining a future where the highest-ranking SpaceX and Chinese leader on Mars are military and civilian, while the highest-ranking leaders on Earth heading the Martian colonization programs are Elon Musk and the Chinese Secretary General (and potentially his subordinate Vice Chairman of the Central Military Commission), this makes for opportunities for miscommunication given how different the two command-and-control structures might be.

The Chinese Martian colony may seek closer relations with the SpaceX colony much to the irritation of Beijing. Mars—being 5-7 months away—is a different world than the Moon. Infrequent trips between the SpaceX and Chinese colonies with Earth will render a stronger feeling of independence of Earth—and thus potentially more amicable relations between early SpaceX colonists and Chinese colonists. With SpaceX likely to become the dominant first mover on the planet laying basic infrastructure and establishing early codes of conduct, Cold War II-esque tensions between the U.S. and China might feel literally “further away”—34 million miles away to be exact. With travel between Texas/Florida/Hainan and Mars only possible every 26 months, colonists will likely experience stronger feelings of common humanity that go beyond an Earth-based rivalry that seems less relevant so far away. Bringing this all back to geography, the 2020s are a decade where humanity will witness the “revenge of geography”—an allusion to Robert Kaplan’s book. Geography may be the most important factor in either forcing the U.S. and China together or apart on the next two worlds for humanity to conquer.

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Honor Code affirmation

I affirm my awareness of the standards of the Harvard College Honor Code.

John Ferguson
May 4, 2022