TO THE MOON

STRATEGIC COMPETITION IN THE CISLUNAR REGION

Shawn Willis

China's advancing space capabilities, particularly in the cislunar region, call for increased cislunar space domain awareness on the part of the United States. US military and civilian decisionmakers must take into account the full scope of China's cislunar plans and capabilities as the military builds space strategies and future force designs. The United States must also increase near-term investments that support more robust cislunar space domain awareness.

Approximately 20 lunar missions have been launched by multiple nations and space agencies since 2003.[1] Within the next decade, more than 100 lunar missions are expected.[2] The projected increase in cislunar activity presents security concerns for the United States and a need to increase cislunar space domain awareness (SDA).[3]

Both China and the United States are actively pursuing cislunar programs and officially promote the peaceful use of cislunar space. The US National Cislunar Science & Technology Strategy, the first interagency strategy to guide US activities in cislunar space, states, "The United States will lead the world in responsible, peaceful, and sustainable exploration and utilization of Cislunar space, including the Moon, consistent with the U.S. Space Priorities Framework."[4] Similarly, in a document submitted to the United Nations General Assembly, China states, "We should preserve space as a new frontier for

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1. Steve Parr et al., *Cislunar Security National Technical Vision* (Laurel, MD: Johns Hopkins Applied Physics Laboratory LLC, 2022), 1-1.
2. Quilty Analytics, *Leveraging the Emerging Space Economy to Meet Critical Government Needs* (St. Petersburg, FL: Quilty Analytics, 2021), 34, https://www.quiltyanalytics.com/, qtd. in John M. Olson et al., *State of the Space Industrial Base 2021: Infrastructure & Services for Economic Growth & National Security,* ed. Peter Garretson (Washington, DC: US Department of Defense, Defense Innovation Unit, 2021), 24, https://www.diu.mil/.
3. Parr et al., *Cislunar Security*, 1-2.
4. Cislunar Technology Interagency Working Group, *National Cislunar Science & Technology Strategy* (Washington, DC: Executive Office of the President of the United States, National Science and Technology Council, November 2022), 2, https://www.whitehouse.gov/.

cooperation rather than a battlefield for competition and confrontation."[5] An investigation of past and current cislunar missions by China and the United States reveals not only the challenges of operating systems in cislunar space but also possible security concerns that could jeopardize the US cislunar vision if the technologies are used for nonpeaceful purposes. Since China is the United States' strongest strategic competitor in space, US decisionmakers should 1) fully consider Chinese cislunar plans and capabilities when building future strategies and force designs, and 2) continue ramping up near-term investments in cislunar space domain awareness.

Background

Cislunar Space

Cislunar space is "the region of space in the Earth-Moon system beyond GEO, including the Moon's orbit and all of the Earth-Moon Lagrange points."[6] (Of note, this article uses the terms geosynchronous orbit and geostationary orbit interchangeably, with GEO to indicate both.) This area of space presents orbital mechanics challenges not seen in near-Earth orbits since, in this region, the gravitational interaction of the spacecraft with the Moon is no longer negligible. Tracking objects in cislunar space is more difficult than tracking objects in near-Earth orbits, because in general, orbits are no longer circular or elliptical, do not repeat, are no longer contained in a single plane, and are not easy to geometrically describe.[7] As a result, very small changes in initial conditions can result in very large trajectory changes of the orbit that are difficult to predict.[8]

Consistent observations are needed to keep track of objects in cislunar orbits, but due to the extreme distances from the Earth, or even from GEO, this is challenging. Therefore, space domain awareness—the foundational knowledge and characterization of objects in space and the operational environment —in cislunar space is critical.[9] Finally, cislunar space contains five Lagrange points, where the sum of the gravitational forces from the Earth and Moon on an orbiting body result in equilibrium. This means that in the rotating frame of the Earth-Moon orbiting system, an object at one of the Lagrange points remains in the same relative position to the Earth and Moon.

Strategic Applications in Cislunar Space

Both the Moon and cislunar space have critical strategic value. The main advantages of developing lunar capabilities come from the economic potential through re-

5. "Document of the People's Republic of China Pursuant to UNGA Resolution 75/36 (2020)," Permanent Mission of the People's Republic of China to the UN (website), April 30, 2021, http://un.china-mission.gov.cn/.

6. Parr et al., *Cislunar Security*, 1-2.

7. M. J. Holzinger, C. C. Chow, and P. Garretson, *A Primer on Cislunar Space* (AFRL 2021-1271) (Wright Patterson AFB, OH: Air Force Research Laboratory, 2021), 5, https://www.afrl.af.mil/.

8. Parr et al., *Cislunar Security*, 3-10.

9. Chairman of the Joint Chiefs of Staff (CJCS), *Space Operations*, Joint Publication 3-14 (Washington, DC: CJCS, April 10, 2018, incorporating change 1, October 26, 2020), ix.

source extraction and from the space exploration potential, as a base from which to launch deep-space missions. At the same time, cislunar space has current and future national security applications.[10] China has indicated a long-term goal for economic dominance of cislunar space.[11] To that end, China is already using a halo orbit around the Earth-Moon L2 Lagrange point to communicate with the far side of the Moon.

Future uses of the cislunar region include military satellites in orbit at the Lagrange points used to monitor and possibly control access between the Earth and the Moon. Because of the low fuel requirements, a system of SDA satellites and dual-use satellites could interfere with another country's injection of satellites at the Lagrange points, preventing them from establishing transfer station facilities.

Position, navigation, and timing (PNT) satellites make up another mission suited for the L2, L4, and L5 Lagrange points because of their ability to reach the near and far sides of the Moon. As lunar surface activity increases, PNT will enable lunar guidance capabilities like those on Earth.[12] Spacecraft in deep space currently require Earth-based ground sensors to determine the spacecraft's position and velocity, which is expensive due to the limited number of deep-space ground stations.[13] Position, navigation, and timing capabilities in cislunar space will enable space security functions such as autonomous navigation.

The low energy requirements to transit between Lagrange points and near-Earth orbits introduce another set of security challenges for US assets in near-Earth orbits.[14] The ability to keep a spacecraft at one of the Lagrange points using minimal fuel combined with the difficulty of monitoring these locations could enable the spacecraft to surreptitiously transition from the Lagrange point and interfere with US satellites in near-Earth orbits, giving operators little to no time to take defensive measures. The AsiaSat-3 telecommunications satellite is one example of how cislunar space can be used to affect near-Earth orbits and how similar techniques could threaten US cislunar space security.

AsiaSat-3 Case Study

In 1997, Russia launched a communications satellite to provide television and phone services in Asia for the Hong Kong-based Asia Satellite Telecommunications Company Ltd (AsiaSat). Yet the launching rocket failed to deliver the AsiaSat-3 satellite to GEO and left it in an unusable 51-degree inclination, "too low and too tilted relative to the

10. Spencer Kaplan, *Eyes on the Prize: The Strategic Implications of Cislunar Space and the Moon* (Washington, DC: Aerospace Security, Center for Strategic and International Studies [CSIS], July 13, 2020), 5, https://aerospace.csis.org/.

11. Namrata Goswami, "China's Future Space Ambitions: What's Ahead?," The Diplomat, November 4, 2019, https://thediplomat.com/.

12. Kaplan, *Eyes on the Prize*, 7.

13. "CAPStm: A Peer-to-Peer Navigation and Communication Technology," Advanced Space (website), n. d., accessed November 12, 2023, https://advancedspace.com/.

14. Parr et al., *Cislunar Security*, 1-3–1-4.

equator."[15] AsiaSat-3 did not have enough fuel to reach geostationary orbit because of the large amount of energy required to change inclinations and was declared a total loss.

Engineers from the company that built the satellite, Hughes Electronics Corporation, continued working on the problem and came up with a plan to use the Moon's gravity to assist the satellite into a nearly geostationary orbit.[16] This was possible since the fuel requirements to reach the Moon were less than that needed to change the orbital inclination. The gravitational assist from the Moon could then supply the energy to make the inclination change. The maneuver was successful and greatly improved the satellite's Earth orbit. The decision was made to make one more lunar assist maneuver, and after completion of the second lunar assist, the satellite was parked in geostationary orbit and available for use.[17]

AsiaSat-3 performed the first commercial mission to the Moon, but the real significance of the mission was the use of cislunar space to reach GEO.[18] The mission successfully demonstrated a novel method for a satellite to change Earth orbits using less onboard fuel; however, it also raised concerns that this movement strategy could be used aggressively in surprise attacks.[19] An adversary could launch a satellite on a translunar trajectory and then make orbit adjustments near the Moon to place it on course to intercept a US national asset.

The surprise comes into play because the interception comes from "above" the US asset in GEO, which is not typical. The adversary satellite may not be detected due to the lack of cislunar space domain awareness. Furthermore, hostile satellites could be parked in orbits at the Lagrange points ready to be used to disable US satellites. Due to the difficulty of keeping track of assets in cislunar space, the United States might have little to no time to take protective measures before it is too late.[20] Therefore, developing robust cislunar SDA is critical to US space security both in the cislunar regime and near-Earth orbits.

Space Domain Awareness in Cislunar Space

Space domain awareness is a critical cislunar technology. Understanding US adversary actions in cislunar space is the first step to achieving cislunar space security.[21] The US Space Force has been tasked to increase its surveillance to the cislunar region, which means a tenfold increase in range and 1,000 times increase in volume. Yet the

15. Andrew Pollack, "Trying to Save Satellite, Company Is Sending It to Moon," *New York Times*, April 30, 1998, https://www.nytimes.com/.

16. Pollack.

17. Hughes Global Services, Inc., "HGS-1 Arrives in Earth Orbit," press release, June 17, 1998, National Aeronautics and Space Administration (NASA) (website), https://solarsystem.nasa.gov/.

18. Hughes Global Services.

19. Kaplan, *Eyes on the Prize*, 5.

20. Paul D. Spudis, "The Moon's Role in the New U.S. Space Force," *Smithsonian Magazine*, August 17, 2018, https://www.smithsonianmag.com/.

21. Parr et al., *Cislunar Security*, 1-4–1-5.

Space Force is limited by current technologies and an architecture that was designed for a legacy mission.[22]

Several complicating factors make cislunar space domain awareness difficult. First, Earth-based and Earth-orbit-based optical and radar systems are very far from the regions of interest and provide poor resolution. Next, due to the chaotic nature of the orbiting body's motion in the three-body problem—the problem of determining the motion of three gravitationally interacting celestial bodies—determining orbital tracks is challenging. Finally, optical sensors placed in cislunar orbits need new algorithms to determine what is being viewed. To address these challenges, enabling technologies must be developed that consist of sensor placement, mission autonomy capabilities, orbit determination methodologies, and low-thrust propulsion.[23]

Electro-optical, infrared, and radar sensors each have advantages and limitations in performing space-domain-awareness missions. The sensor limitations are increased when trying to perform cislunar SDA since no single location in cislunar space provides coverage of the entire domain. Therefore, effective sensor placement is critical and should include sensors located on Earth, in near-Earth orbits, and in cislunar space. Assuming successful lunar-basing missions, sensor placement on the Moon could also help with cislunar SDA, but this is a much longer-term goal.[24]

Currently, most space observation sensors are either designed for Earth-orbit objects or for looking beyond the Moon. Yet the United States is engaged in advancing capabilities to leverage existing national, commercial, and academic sensors to provide coverage of the space between GEO and the Moon.[25] China is also looking to leverage existing sensors and is developing additional capabilities to provide the same coverage.[26]

Multiple sensors from different domains and locations need to work in coordination to effectively track objects in cislunar space since there is no predictable pattern the object must follow. Additionally, communication with sensors may not always be possible for certain locations in cislunar space. This makes managing the sensor constellation a difficult task and even more so for a large constellation. Therefore, cislunar sensors must have the ability to complete common tasks on their own and likely need to be able to make cooperative decisions between sensors autonomously. This includes letting the spacecraft determine its trajectory on the fly and collaborating with other sensor systems.[27]

22. James F. Bridenstine and John W. Raymond, Memorandum of Understanding between the National Aeronautics and Space Administration and the United States Space Force, NASA, September 2020, https://www.nasa.gov/.

23. Parr et al., *Cislunar Security*, 3-5.

24. Parr et al., 3-7–3-8.

25. Sandra Erwin, "U.S. Space Force Sees Future Demand for Surveillance beyond Earth Orbit," *SpaceNews*, May 16, 2022, https://spacenews.com/.

26. Kristin Burke, "China's Space Situational Awareness Capabilities for beyond GEO," Chinese Aerospace Studies Institute, Air University, September 12, 2022, https://www.airuniversity.af.edu/.

27. Parr et al., *Cislunar Security*, 3-8.

Orbit determination methodologies for the two-body problem in near-Earth orbits are well established between algorithms and regular observation updates. The task is much more difficult in the three-body problem of cislunar space: including effects from the Moon result in chaotic motion of the spacecraft, where a small change in the initial condition can result in very large trajectory changes. New algorithms interpreted through machine learning may be helpful to predict spacecraft trajectories. Additionally, other inputs such as the desired behavior and operation of the spacecraft could enhance the orbit determination effectiveness.[28]

Finally, the ability to move freely through the cislunar orbit family members and orbit around convenient locations other than the Lagrange points would open new mission utility for sensors in cislunar space. Low-thrust technologies such as electric propulsion that operate continuously could enable the ability to orbit around artificial equilibrium points.[29] Low-thrust spacecraft also make it very challenging to track the spacecraft because the constant low thrust is difficult to distinguish from other perturbations. In addition to their use for SDA, low-thrust spacecraft have the potential to be used as tugs to move large amounts of material to and from the Moon.[30]

Because cislunar space domain awareness is critical to space security and to future utilization of cislunar space, both the United States and China are actively pursuing cislunar SDA capabilities. The following sections examine these activities to better understand these capabilities and the direction in which each country is moving.

China's Cislunar Space Domain Awareness Activities

Optical telescopes provide good capability to search for unknown objects in space. The majority of China's SDA optical telescopes are designed to focus on objects in low-Earth orbit and GEO. Yet the Chinese Academy of Science has a few telescopes used for astronomical studies that could possibly be used to detect objects in the space between the Earth and the Moon. Additionally, citizens and universities in China own and operate a variety of optical telescopes that could be used to help detect and track objects between geosynchronous Earth orbit and the Moon.[31]

Western astronomers demonstrated the feasibility of using publicly available passive radio frequency data combined with dedicated optical measurements from an academic telescope to demonstrate optical recovery and tracking of China's first lunar sample return mission on its journey all the way to the Moon.[32] China has the capability to employ the same techniques in the region between GEO and the Moon.

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28. Parr et al., 3-10.

29. Andrew D. Cox, "Transfers to a Gravitational Saddle Point: An Extended Mission Design Option for LISA Pathfinder" (master's thesis, Purdue University, April 2016), https://docs.lib.purdue.edu/.

30. Parr et al., *Cislunar Security*, 3-9.

31. Burke, "China's Space."

32. Roberto Furfaro et al., "Tracking Objects in Cislunar Space: The Chang'e 5 Case" (technical paper, Advanced Maui Optical and Space Surveillance Technologies Conference [AMOS], Wailea, HI, September 15, 2021), https://amostech.com/.

Ground-based radio telescopes can be used to collect radio transmissions from transmitting satellites located beyond GEO. Multiple radio telescopes can be used together in a technique called very long baseline interferometry to simulate a much larger telescope aperture, thus enhancing resolution. China demonstrated the capability to use very long baseline interferometry collections with its Chang'e 5 lunar mission combined with X-band communication—communication via the secure and regulated super-high frequency range used primarily by the military and government—to precisely dock the Chang'e 5 ascender vehicle to the orbiter vehicle.[33]

Radio telescopes can also be used to identify unknown spacecraft movements and to discover unknown objects as shown by the Western astronomers who tracked Chang'e 5 as it moved from the Sun-Earth L1 point to a lunar distant retrograde orbit in 2022.[34]

China currently owns the world's largest radio telescope called the Five-hundred-meter Aperture Spherical Radio Telescope (FAST). Yet it only receives signals in L-band (70 MHz to 3 GHz)—the chief operating low frequency range used by applications such as radars, telecommunications, and global positioning systems—and cannot be used for S-, X-, or Ka-band transmissions without significant upgrades.[35] China is also currently building what will be the world's largest steerable radio telescope. The receiver will have a diameter of 110 meters and is expected to be completed in 2023. It will operate from 300 MHz to 117 GHz, covering the S-, X-, and Ka-bands.[36] Additionally, China plans to build a millimeter wavelength radio telescope in the Antarctic.[37]

Active ground-based radar detection of cislunar objects is difficult due to the energy requirements. Yet China is currently constructing a high-definition, deep-space radar facility codenamed "China Fuyan" (faceted eye) in Chongqing, China, that is expected to be able to detect objects 150 million kilometers from Earth.[38] China Fuyan will consist of over 400 distributed radar antennas with diameters of 25 to 30 meters.[39]

Three phases are planned for the project. In the first phase, four 16-meter diameter antennas will be constructed to verify the system's feasibility and test 3-D imaging of the Moon's surface. Two of the four antennas have currently been constructed. The plan for the second phase will increase the number of antennas to over 20, creating a distributed antenna with an equivalent diameter of 100 meters. The distributed system will verify the technology

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33. Jia Wang et al., "Localization of the Chang'e-5 Lander Using Radio-Tracking and Image-Based Methods," *Remote Sensing* 13, no. 4 (2021), https://doi.org/.

34. Ye Ruolin, "Amateur Astronomers over the Moon for Chang'e 5 Mission," Sixth Tone, December 8, 2020, https://www.sixthtone.com/.

35. Rendonng Nan et al., "The Five-hundred-meter Aperture Spherical Radio Telescope (FAST) Project," *International Journal of Modern Physics D* 20, no. 6 (2011), https://doi.org/.

36. Burke, "China's Space."

37. Zhong Wang and Yanchun Liang, "An Overview of Some Latest Development in Chinese Astronomy," *Physical Sciences Anais da Academia Brasileira de Ciencias* 93, suppl. 1 (2021), https://doi.org/.

38. Deng Xiaoci, "China Begins Construction on World's Most Far-reaching Radar System, to Boost Defense against Near-Earth Asteroid Impact," *Global Times*, July 10, 2022, https://www.globaltimes.cn/.

39. Burke, "China's Space."

and is expected to detect objects tens of millions of kilometers from Earth.[40] The final phase is expected to extend the active observation range to 150 million kilometers.[41]

Chinese aerospace and technology officials stated the Fuyan radar will be used to study near-Earth asteroids and provide sensing capabilities for the Earth-Moon system. Plans are in place to use the radar to support the Tianwen-2 probe that will carry out a decade-long mission to observe a near-Earth asteroid and return samples from the asteroid. Tianwen-2 is expected to launch in 2025. The radar is also expected to monitor Chinese spacecraft missions to the Moon.[42] If the program is successful, the radar facility will become an integral part of China's cislunar space domain awareness capability.

With spaced-based SDA, China's Lunar Exploration Program demonstrated local SDA capabilities using optical sensors to conduct landing and systems checks and high-resolution images of the Moon.[43] China's future cislunar space-based SDA plans include developing sensors for a long-term lunar-based Earth observatory and enhancing their space-based very long baseline interferometry capabilities.[44]

US Cislunar Space Domain Awareness Activities

The United States is tackling the cislunar SDA problem using all three spacepower sectors: military, commercial, and civil. First, in April 2022, the United States stood up the 19th Space Defense Squadron (19 SDS) at Naval Support Facility Dahlgren, Virginia. The 19 SDS works with its sister squadron, 18 SDS, located at Vandenberg Space Force Base, California, to provide foundational space domain awareness and is responsible for maintaining custody of human-made objects in orbit, processing space events, and predicting the likelihood of on-orbit collisions.[45]

In addition to operating and maintaining several mission systems, 19 SDS was specifically created to focus on cislunar space domain awareness.[46] The 19 SDS works with the National Aeronautics and Space Administration (NASA), the Air Force Research Laboratory, and Space Systems Command to improve space security and defense. Specifically within the Space Force, 19 SDS is tasked to focus on cislunar sensors and systems deployed in cislunar space.[47]

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40. Deng, "China Begins Construction."
41. Burke, "China's Space."
42. Deng, "China Begins Construction."
43. Kaichang Di et al., "Geospatial Technologies for Chang'e-3 and Chang'e-4 Lunar Rover Missions," *Geospatial Information Science* 23, no. 1 (2020), https://doi.org/; and Leonard David, "A Tiny Chinese Lunar Orbiter Just Crashed on the Moon's Far Side (on Purpose)," Space.com, August 3, 2019, https://www.space.com/.
44. Huadong Guo, Guang Liu, and Yixing Ding, "Moon-based Earth Observation: Scientific Concept and Potential Applications," *International Journal of Digital Earth* 11, no. 6 (2018), https://doi.org/; and Burke, "China's Space."
45. "19th Space Defense Squadron," Peterson and Schriever Space Force Base, US Space Force, current as of January 2023, https://www.petersonschriever.spaceforce.mil/.
46. "19th Space Defense Squadron"; and Jen Judson, "US Space Force Space Defense Squadron Tasked to Focus on Deep Space," C4ISRNET, April 20, 2022, https://www.c4isrnet.com/.
47. Judson.

Looking at near-term solutions to the cislunar space domain awareness problem, 19 SDS leverages techniques studied in the Blue Horizons program at the US Air Force's Air War College during the 2022–2023 academic year.[48] The cislunar tracking study, called Project Rocket, used optical, passive radio frequency, and radar assets from the US Space Surveillance Network along with telescopes operated by universities and private companies to identify and track China's Chang'e 5 orbiter and Queqiao relay satellite, India's Chandrayaan-1 and Chandrayaan-2 lunar exploration missions, several NASA missions, and the James Webb Space Telescope.[49]

Project Rocket was supported by ExoAnalytic Solutions (Exo), headquartered in Foothill Ranch, California. Exo has been demonstrating cislunar SDA capabilities since 2020 using commercial solutions that are available today. In November 2022, Exo used its global network of over 350 telescopes at 35 sites around the world to test and demonstrate cislunar SDA by tracking the Artemis 1 mission as it traveled around the Moon and back to Earth.[50]

Long-term solutions for cislunar space domain awareness involve placing dedicated SDA sensors in cislunar space. The Air Force Research Laboratory is attempting to tackle the challenge of placing SDA spacecraft in cislunar space with its Oracle program—previously called the Cislunar Highway Patrol System. The Oracle spacecraft is planned for launch in 2026 with the aim to prove cislunar-sensing capabilities, provide operational experience in cislunar's complicated gravitational environment, and help mature communication and navigation technology near the Moon.[51]

Specific challenges the program will address include keeping the satellite in a halo orbit around the L1 Lagrange point so that it can look back toward Earth to detect potential threats and developing the algorithms necessary to autonomously process what the sensor sees.[52] If Oracle is successful, it will be strategically located to monitor activities in cislunar space better than terrestrial telescopes and Earth-orbiting satellites.[53]

NASA's Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) is another US program to test operating in cislunar space. CAPSTONE launched in June 2022 and entered its targeted near-rectilinear halo orbit in November 2022.[54]

In addition to providing information on using the near-rectilinear halo orbit, CAPSTONE will test the ability to communicate directly with NASA's Lunar Reconnaissance Orbiter that has been orbiting the Moon since 2009. The goal is for CAPSTONE to be

48. "Air Force Blue Horizons Fellowship Partners with ExoAnalytic to Collect Data on the Artemis I Launch," press release, ExoAnalytic Solutions, September 2, 2022, https://exoanalytic.com/.

49. Erwin, "U.S. Space Force."

50. "Blue Horizons Fellowship."

51. "Oracle," Air Force Research Laboratory (website), accessed March 21, 2023, https://afresearchlab.com/.

52. Theresa Hitchens, "Oracle's Vision: Understanding Cislunar Satellite Images Poses AFRL's 'Biggest' Challenge," Breaking Defense, November 28, 2022, https://breakingdefense.com/.

53. Hitchens.

54. Roxana Bardan, "CAPSTONE Forges New Path for NASA's Future Artemis Moon Missions," press release, NASA, November 21, 2022, https://www.nasa.gov/.

able to determine its position in space using data from the orbiter and CAPSTONE's autonomous navigation system, Cislunar Autonomous Position System, without the need to exclusively rely on tracking from Earth.[55] Finally, CAPSTONE will attempt to use an onboard chip-scale atomic clock to demonstrate one-way ranging, which could lead to position determination without the need for a dedicated ground link on the spacecraft.[56]

Not only is robust cislunar space domain awareness a challenging task, it is also a critical component of space security and an enabler for future advanced missions. Should Oracle and CAPSTONE prove successful, they could provide the foundational components of a US SDA architecture in cislunar space.

Additional Chinese Lunar and Cislunar Activities

Moving beyond SDA, China has multiple current and planned cislunar missions. Although China proclaims the peaceful use of space and its cislunar missions have thus far been scientifically focused, the advanced capabilities China has demonstrated present security concerns because of the potential to interfere with US spacecraft. Therefore, it is important to understand the achievements China has accomplished in cislunar space and possible future programs. To that end, the following section discusses China's retrograde GEO orbit and premier lunar exploration program.

Lunar Assist to Retrograde Geostationary Orbit

The AsiaSat-3 case study demonstrated how the Moon can be used to reach orbits that would otherwise be too costly in terms of energy. In 2021, authors from China's space telemetry, tracking, and command network headquarters, Xi'an Satellite Control Center, published an article in *Nature*'s *Scientific Reports* that investigated using lunar gravity assist to place a satellite in retrograde GEO (retro-GEO) for monitoring activities and debris warning.[57]

It is very difficult to launch directly to retrograde GEO because of the energy requirements to overcome launching against the rotation of the Earth. Yet as with the AsiaSat case, using cislunar space can reduce the energy requirements to reach the desired orbit. The *Scientific Reports* article concluded that the authors' calculations show it is possible to reach retro-GEO using the lunar assist method. The authors describe using a satellite in retro-GEO for updated debris warning every 12 hours.

Concerns have been expressed about placing a satellite in retro-GEO. The director of program planning for the Secure World Foundation, Brian Weeden, called it

55. Loura Hall, "What is CAPSTONE?," NASA, April 29, 2022, https://www.nasa.gov/.

56. Bardan, "CAPSTONE."

57. Bo-yong He, Peng-bin Ma, and Heng-nian Li, "Properties of the Lunar Gravity Assisted Transfers from LEO to the Retrograde-GEO," *Scientific Reports* 11, no. 18813 (2021), https://doi.org/; and Andrew Jones, "China Looked at Putting a Monitoring Satellite in Retrograde Geostationary Orbit via the Moon," *SpaceNews*, October 20, 2022, https://spacenews.com/.

"dangerous" since the satellite would be travelling at a much higher relative velocity to other satellites in GEO and in the opposite direction—similar to a car speeding down the wrong way on a freeway.[58]

In addition to the risk of collisions, a satellite in retro-GEO could survey the entire GEO belt every 12 hours and has the potential to disable or destroy adversary GEO satellites with little warning. The idea to use a lunar assist trajectory to place a satellite in retro-GEO that could then quickly destroy adversary satellites has been around for decades. In 1984, James Oberg published an article titled "Pearl Harbor in Space" that described exactly this concept.[59] The Chinese team cite this article in their *Scientific Reports* article but limit their stated application to debris warnings, thus ignoring the potential use for surprise offensive maneuvers.

Chinese Lunar Exploration Program

China is currently very active in cislunar space with its premier program, the Chinese Lunar Exploration Program (CLEP). This program was divided into three phases for goals before 2020: orbit the Moon, land on the Moon, and return from the Moon.[60] Although it just barely missed the timeline, China successfully achieved all three phases with the Chang'e 1 to 5 probes and demonstrated first-ever accomplishments. Chang'e 1 was launched in 2007 and was placed into low lunar orbit where it took high-resolution images of the Moon and surveyed the Moon for Helium-3.[61]

Chang'e 2, which launched in 2009, also performed a lunar mapping mission and identified landing locations for future missions.[62] Following the mapping mission, Chang'e 2 then transitioned to the Sun-Earth L2 Lagrange point and later rendezvoused with a near-Earth asteroid.[63] These two missions were important since Chang'e 1 successfully met CLEP's first goal to orbit the Moon and Chang'e 2 demonstrated China's ability to reach locations within and beyond cislunar space.[64]

The next two missions achieved CLEP's second goal to land on the Moon. Chang'e 3 launched in 2013 and performed a soft-landing on the Moon—a feat that had not been accomplished since the Soviet Union's Luna 24 mission in 1976 nearly 40 years prior.[65] The probe carried the Yutu lunar rover, which had operational challenges but still managed to gather information even after it lost the ability to move.[66]

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58. Jones.

59. James Oberg, "Pearl Harbor in Space," *OMNI Magazine* 6, no. 10 (1984), http://www.jamesoberg.com/.

60. Xu Lin, Zou Yongliao, and Jia Yingzhuo, "China's Planning for Deep Space Exploration and Lunar Exploration before 2030," *Chinese Journal of Space Science* 38, no. 5 (2018), https://doi.org/.

61. Kaplan, *Eyes on the Prize*, 8.

62. Spudis, "Moon's Role."

63. Kaplan, *Eyes on the Prize*, 8.

64. Spudis, "Moon's Role."

65. Rui C. Barbosa, "China's Chang'e-3 and Jade Rabbit Duo Land on the Moon," NSF [NASA Space Flight], December 14, 2013, https://www.nasaspaceflight.com/.

66. Jeff Foust, "China's Immobile Rover Passes a Purely Figurative Milestone," *SpaceNews*, October 30, 2015, https://spacenews.com/.

In 2018, the Chang'e 4 lander launched and became the first-ever to land on the far side of the Moon.[67] The probe carried the Yutu-2 rover that is still operational today.[68] The Chang'e 4 mission is significant not only for being the first lander and rover on the far side of the Moon, but also because the mission includes the first-ever lunar relay satellite located in a halo orbit around the Earth-Moon L2 Lagrange point.[69] The relay satellite, named Queqiao, enables direct communications with the lander and rover.[70] CLEP's final goal to return from the Moon was given to the Chang'e 5 and Chang'e 6 missions. Chang'e 5 launched in November 2020 and successfully returned over 1.7 kilograms of lunar regolith—the layer of unconsolidated rock over the bedrock—back to Earth.[71]

Several technical feats were achieved with the Chang'e 5 mission. Four modules were used to complete the mission. Once the probe arrived in lunar orbit, the descender carried two modules, the ascender and the lander, to the lunar surface. After landing on the Moon's surface, the lander collected regolith and returned it to the ascender, which then lifted off the lunar surface and docked with the orbiter. After transferring the sample to the return capsule, the ascender jettisoned and crashed into the Moon. Five days later, the orbiter module entered a transfer orbit and started the return to Earth. Before arriving at Earth, the orbiter separated from the sample return vehicle and headed to the Sun-Earth L1 Lagrange point for further technology testing and to observe the Sun. The sample capsule successfully made the transition to the Earth's surface and was collected.[72]

After about six months at the Sun-Earth L1 point, the orbiter returned to the Earth-Moon system and demonstrated the first operational use of a distant retrograde orbit.[73] This orbit is important because of its orbital stability. This was a significant technical capability no other nation had accomplished. NASA's Artemis 1 mission has now also demonstrated use of the distant retrograde orbit.[74]

The Chang'e missions demonstrated China's ability to successfully maneuver throughout and beyond cislunar space as well as the ability to return to the Earth-Moon system after travelling to the Sun-Earth L1 point. The entire Chang'e 5 mission was tracked by amateur space enthusiasts using multiple observations from across the

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67. Kaplan, *Eyes on the Prize*, 8.

68. Andrew Jones, "China's Yutu 2 Rover Still Going Strong after 4 Years on the Moon's Far Side," Space.com, January 26, 2023, https://www.space.com/.

69. Luyuan Xu, "How China's Lunar Relay Satellite Arrived in Its Final Orbit," Planetary Society (website), June 15, 2018, https://www.planetary.org/.

70. Kaplan, *Eyes on the Prize*, 8.

71. NASA Space Science Data Coordinated Archive (NSSDC), "Chang'e 5," NASA, accessed March 21, 2023, https://nssdc.gsfc.nasa.gov/.

72. NSSDC.

73. Andrew Jones, "A Chinese Spacecraft is Testing Out a New Orbit around the Moon," *SpaceNews*, February 15, 2022, https://spacenews.com/.

74. Sandra Jones, "Artemis I – Flight Day 10: Orion Enters Distant Retrograde Orbit," *Artemis* (blog), NASA, November 25, 2022, https://blogs.nasa.gov/.

world to overcome small antenna sizes and limited equipment calibration.[75] The autonomous rendezvous and docking in cislunar space demonstrated by Chang'e 5 is a significant technical capability that no other nation has demonstrated. In addition to the technical achievement, however, it raises serious security concerns about China's ability to interfere with US spacecraft in cislunar space.

To achieve its next set of goals, China is working toward establishing a lunar research station by 2030.[76] The path to get there includes Chang'e 6, which was originally a backup in the event that Chang'e 5 failed. Yet with Chang'e 5's success, Chang'e 6 will now try a more complicated lunar sample return mission by returning samples from the lunar south pole and the far side of the Moon. China is also hosting payloads from France and Italy on Chang'e 6, and Russia and Sweden are other possible partners.[77]

Chang'e 7 is planned for a 2024 launch and is expected to include a cislunar telecommunications relay, a lunar orbiter, a lunar lander, a rover, and a flying probe.[78] The Chang'e 7 mission will be to study the lunar south pole.[79] The Chang'e 8 mission is still being finalized, but it is expected to have similar components as Chang'e 7—lander, rover, and flying probe—and will conduct experiments in preparation for establishing a lunar research station.[80]

As noted earlier, China's long-term goal is economic dominance of cislunar space. Beijing plans to accomplish this through incremental steps undertaken by its national space agency, consisting of developing advanced capabilities in all areas of space. Specific areas of focus include building launch capacity, developing a permanent space station, creating systems to enable supremacy in cislunar space, building a sustainable presence on the Moon, and maturing its systems for deep-space exploration.[81]

While the CLEP missions have been scientifically focused, they have been instrumental in developing and demonstrating capabilities needed for operating in cislunar space such as communications relays at the Lagrange points, payload transfers at the Lagrange points, and transit from the Lagrange points back to Earth orbits and from other heliocentric orbits.

The leadership structure of CLEP shows the People's Liberation Army (PLA) is involved with the program.[82] CLEP is one of the Chinese Communist Party's (CCP)

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75. Jones, "Chinese Spacecraft."

76. Kaitlyn Johnson, *Fly Me to the Moon: Worldwide Cislunar and Lunar Missions* (Washington, DC: Aerospace Security Project, CSIS, February 2022), 11, https://www.csis.org/.

77. Andrew Jones, "China's Chang'e 6 Mission Will Collect Lunar Samples from the Far Side of the Moon by 2024," Space.com, July 8, 2021, https://www.space.com/.

78. Xu Lin et al., "China's Lunar and Deep Space Exploration Program for the Next Decade (2020–2030)," *Chinese Journal of Space Science* 40, no. 5 (2020), https://doi.org/.

79. NSSDC, "Chang'e 7," NASA, accessed March 21, 2023, https://nssdc.gsfc.nasa.gov/.

80. Johnson, *Fly Me to the Moon*, 11.

81. Goswami, "Space Ambitions."

82. Kristin Burke, "Understanding China's Space Leading Small Groups—The Best Way to Determine the PLA's Influence," Chinese Aerospace Studies Institute, Air University, July 2022, https://www.airuniversity.af.edu/.

leading small groups—important permanent and ad hoc cells which operate within the Chinese government and CCP. The Party uses these cells to implement and coordinate policies nationwide. It has appointed the State Council to lead China's space leading small groups: CLEP and the China Manned Space Engineering program. This sets civilian control over CLEP. Yet even though the Central Military Commission is not in the leadership position, the Chinese military is still involved in the program. There are five subsystems that report to the chief designer and chief commander who runs the cell. Two of the five subsystems are led by the PLA. Therefore, it is not unreasonable to assume the PLA could leverage technology developed through CLEP for military purposes, highlighting the need for US decisionmakers to understand China's capabilities when building future strategies and force design.

Conclusion

Understanding the challenges of operating systems in cislunar space as well as possible security concerns from the United States' strategic competitor, China, contribute to achieving the US cislunar vision of fostering "the responsible, peaceful, and sustainable exploration and use of Cislunar space."[83] Robust cislunar space domain awareness is the first step to achieving security in cislunar space and from effects initiated in cislunar space on near-Earth orbiting spacecraft. Yet domain awareness in cislunar space is challenging due to the large distances from the Earth and the difficulty predicting orbital paths. Both the United States and China are investigating methods to use existing capabilities for the cislunar SDA challenge. Additionally, both nations are working to put sensors in cislunar space to increase their cislunar SDA capability.

China has demonstrated advanced technologies in cislunar space with the Chinese Lunar Exploration Program. Through CLEP, China has shown the capability to use the Earth-Moon Lagrange points as transfer stations for spacecraft, land on the Moon and bring regolith back to the transfer vehicle, return Moon samples to the Earth, and transition between Sun-Earth Lagrange points, Earth-Moon Lagrange points, and near-Earth orbits.

Since the role of cislunar space and the Moon will continue to expand in space, and therefore impact national security, the United States must maintain current knowledge of strategic competitor activities in cislunar space. Increasing cislunar space domain awareness and the ability to track objects in cislunar space are key components to achieving comprehensive space domain awareness. **Æ**

83. Technology Interagency Working Group, *National Cislunar Science*, 2.