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# China's Space Situational Awareness Capabilities For Beyond GEO[i]

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This paper reviews the publicly available information on China's existing and planned ground and space-based systems for its beyond geosynchronous Earth orbit (GEO) missions. This paper assumes that the PRC, like the U.S., has not needed a well optimized system for discovering, tracking, and cataloging multiple objects between GEO and the Moon, but might, like the U.S., consider how to leverage existing capabilities in anticipation of multiple actors operating beyond GEO.[1]

The PRC has many sensors to support its Lunar and Martian exploration programs but does not currently have any publicly known dedicated ground or space-based sensors capable of scanning the volume of space between the Earth and the Moon to discover unknown objects. The PRC is taking steps to increase its capabilities over the next 5-10 years. China has only recently begun to expand its systems for planetary defense, which could enable beyond-GEO scanning for unannounced spacecraft. Even if the Chang'e 5 orbiter is still at the Lunar Distant Retrograde Orbit (DRO), its updated camera, as discussed below, seems more tuned for close ups and distant bright objects, rather than scanning for unknown dim objects. This deficit might change as soon as 2023, but more likely by the end of 2024, when China will launch Chang'e 7, which will include a Lunar obiter planned to last several years.[2,3,4]

## Introduction

Chinese astronomers' interest in and ability to discover, observe, and track space objects beyond GEO dates back to at least 185 B.C., based on historical records of comet observations.[5] In modern times, the Chinese Academy of Sciences (CAS) Purple Mountain Observatory (PMO) first discovered an asteroid with an optical telescope in 1957, and Chinese military and civilian ground-based radar and radio telescopes have been tracking the PRC's Lunar missions since 2007.[6,7]

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[i] This paper should be read as a supplement to CASI's 2021 *China's Ground Segment: Building the Pillars of a Great Space Power*, which primarily covers China's national Earth orbit SSA stations. https://www.airuniversity.af.edu/CASI/Display/Article/2517757/chinas-ground-segment-building-the-pillars-of-a-great-space-power/. Similarly, this report is about the sensors and their location, not the software and algorithms to discover or track objects in non-repeating orbits. This report also assumes the reader has a basic understanding of the sensors themselves, for example, this report does not explain that optical telescopes can be limited by cloud cover whereas radio telescopes are not. It does not explain the difference between passive and active radio telescopes.

To scan space to find new objects and to track already identified objects requires different sensors. Both scanning and tracking are needed for space situational awareness (SSA).[ii] SSA refers to the ability to find, identify and track objects in space, establish their orbits, and predict their future positions and any natural or man-made threats to their operations. Countries with Lunar and Martian exploration programs usually have the required beyond GEO SSA capabilities to track their own systems, and some countries also have planetary defense sensors which look beyond GEO. However, because specific sensors are tailored for particular tasks, those geared for Earth orbit or deep space beyond the Moon are not always capable of identifying or tracking objects in the space between the Earth and the Moon.

While the extent to which planned Lunar missions will materialize is unknown, countries and companies will at least need to be able to better communicate with and track their own spacecraft between the Earth and the Moon. Depending on the multitude of activities, countries and companies may need to know the location of others for spaceflight safety. In absence of a formal mechanism to share this data, individual country SSA systems optimized for beyond GEO are an alternative.[8] The U.S. is in the process of learning how to leverage existing national, commercial and academic sensors in anticipation of future demand for Lunar space traffic management.[iii,9,10]

## Ground-Based Systems

### *Optical Telescopes*

Optical telescopes passively collect light reflected off space objects and amongst their benefits, they are well suited for detecting unknown objects in space, except when pointed in the direction of bright objects like the Sun. The vast majority of Chinese ground-based optical telescopes scheduled for SSA are focused on low Earth orbit (LEO) and GEO. Chinese military academics have repeatedly indicated concern with the U.S.'s ability to conduct operations in the graveyard orbit, which could indicate Chinese insecurity with their ability to persistently monitor activity just above GEO.[11,12,13] There are however a few ground-based optical telescopes which are primarily scheduled for astronomical studies that might potentially be capable of discovering unknown objects between GEO and the Moon.

CAS's National Astronautical Observatories (NAOC) and the affiliated PMO operate ground-based optical telescopes in China that contribute to the Minor Planet Center's database, indicating they can observe objects beyond GEO.[iv] PMO has six branch observatories across China, and as of mid-2022, it was ranked 21st globally for the highest number of minor planet

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[ii] PRC official and unofficial writings use the term space situational awareness (SSA) rather than space domain awareness (SDA), and one Chinese space consulting firm states the reason is because the latter is a term used by the U.S. to emphasize space is a warfighting domain.
[iii] The U.S. Space Command, Joint Task Force-Space Defense, Commercial Operations Cell's Public Satellite Research Analysis team supported the referenced event and reviewed this paper.
[iv] The Minor Planet Center is the official body for observing and reporting on minor planets under the auspices of the International Astronomical Union. Minor planets include asteroids, Pluto and other icy worlds beyond Neptune, and other bodies. Minor planets do not include comets nor other planets.

discoveries, which includes near-Earth objects (NEOs).[v] In order to discover an unknown object, PMO has used its Xuyi Observation Station in Jiangsu Province to discover 1,855 objects.[14]

NAOC's Xinglong Station near Beijing in the 1990s participated in a NEO survey which resulted in a new discovery, but has since then only recorded observations of known minor planets.[15] Other NAOC facilities have been able to observe already discovered minor planets from two additional stations: the Tibet Ngari (Ali) Prefecture Observatory and Yunnan Lijiang Gaomeigu Observatory. [16]

In addition to CAS, Chinese citizens and universities own and operate small and large optical telescopes. One Chinese study found that while there are numerous university observatories, no one has comprehensively reviewed them to date.[17] Most of China's amateur astronomers primarily use optical telescopes to view a solar eclipse, the Moon, or the Milky Way, but some have been credited with asteroid discoveries through the Minor Planet Center.[18,19,20,21] There is also a primarily independently funded observatory that has contributed to the Minor Planet Center's database: Xingming Observatory, Nanshan Station in Xinjiang Province. [22,23]

China has plans for many new ground-based optical observatories in its western regions which have lower light and air pollution, and higher altitudes. NAOC is building new facilities to include optical and infrared telescopes at Lenghu in Qinghai Province. PMO has considered relocating Xuyi there for better observation conditions. [24,25] Some of these new facilities will be useful for beyond GEO SSA.[26,27] Other new facilities include the 12 Meter Large Optical/Infrared Telescope (LOT), the location of which might be at existing observatories in Tibet, Xinjiang, or Sichuan provinces. [28,29]

*Laser ranging*

Laser ranging uses light to actively pulse a known object in space and collect the returned energy with optical systems to measure its relative distance. U.S., European, and Japanese deep space missions have used this method to support orbit determination. China installed a laser reflector on its Queqiao relay satellite at Earth-Moon Lagrange Point (EML) 2 to extend its Lunar ranging capabilities, using at least its 1.2 meter aperture telescope in Yunnan Province.[30] China's first successful lunar laser ranging experiment in 2018 was also conducted using the Yunnan telescope, at that time with the Apollo 15 retro-reflector.[31]

*Radio Telescopes and Very Long Baseline Interferometry (VLBI)*

Ground-based radio telescopes can passively and actively collect signals, which if designed for collecting the radio frequency of a transmitting satellite beyond GEO, could be useful for tracking known and even potentially finding unknown objects. VLBI is a technique that combines measurements from several radio telescopes to simulate a much larger aperture,

[v] A NEO is any small Solar System body whose orbit brings it into proximity with Earth.

which is used to determine the precise orbit of a spacecraft. In a later section, this paper will address space-based VLBI systems and their use for imagery.

China already has the ability to track and communicate with its own Lunar and Martian probes. China's Deep Space Network (CDSN) is composed of several components: at least seven different locations in China which host various radio telescopes, Yuanwang satellite tracking ships capable of uplink and downlink, as well as China's two overseas stations in Neuquén, Argentina and Swakopmund, Namibia.[vi,32,33] The CDSN also works in conjunction with CAS's VLBI network, which is also spread across at least seven locations.[34,35] When VLBI is used for orbit determination in China's Lunar program, the Beijing Aerospace Control Center (BACC) transmits data commands to the primary Shanghai VLBI station, which then sends the received information back to BACC.[36] China has tested extending its VLBI capability to its overseas stations in Argentina and Namibia, but found that there was not enough bandwidth for those stations to transmit real time tracking data and VLBI data back to Beijing, so the former will continue as the priority.[vii,37,38]

China's Change'e 5 sample return mission provides an example of how the two types of information work together for SSA. China used X-band tracking to communicate with its orbiter, lander, and ascender, and combined that information with VLBI for precise docking of the ascender to the orbiter.[39,40] As of at least 2018, Chinese VLBI could operate in at least six bands: S-, X-, Ku-, L-, C-, Q-, and possibly K-, and plans for a space-based component will open up four additional frequency bands from 30-1670MHz.[41,42,43]

Radio telescopes can sometimes have SSA applications for identifying unannounced spacecraft movements or even discovering unknown objects. Smaller passive radio telescopes could be used to identify broad location changes of known objects beyond GEO. For example, Western space enthusiasts were able to identify the X-band signal from Chang'e 5 as it moved from Earth-Sun Lagrange Point (ESL) 1 to the Lunar DRO in early 2022.[44] A large passive radio telescope could detect signals from beyond GEO if collecting in the same frequency band. Notable is that while China hosts the world's largest passive radio telescope in Guizhou Province called the Five-Hundred-Meter Aperture Spherical Radio Telescope (FAST), it receives signals in the L-band 70 MHz to 3 GHz, which could not pick up signals from S-, X-, and Ka-band transmitting spacecraft beyond GEO without significant upgrades.[45] FAST's size might also lead

[vi] The domestic facilities are located in Sanya in Hainan Province; Tianjin (70 meter); Jiamusi in Heilongjiang Province (66 meter); Beijing (50 meter); Kashgar and Urumqi in Xinjiang Province (4x35 meter and 25 meter, respectively); and Kunming in Yunnan Province (40 meter). The PRC regularly uses its overseas stations in Argentina and Namibia for tracking its Lunar exploration program and may also use its Antarctic Kunlun Station, when occupied. The PRC also coordinates with non-Chinese overseas tracking stations for additional data on its beyond GEO missions.

[vii] During China's 2014 Chang'e 5 T1 mission VLBI data was not available to confirm the separation of the service module and the return vehicle, according to Chinese researchers. Instead, they used a new GNSS measurement technique. They installed a GNSS receiver on the spacecraft with a L-band C/A code receiver for GPS and GLONASS tracking, with 2 receiving antennae mounted on opposite sides of the spacecraft to ensure that signals are omni-directionally received.

to over saturation of its sensors if used to listen to something too close, as it is designed for listening to the whole solar system, far beyond the Earth's Moon.[46]

In terms of planned ground-based radio telescopes, China is also building the world's largest steerable radio telescope near Urumqi, Xinjiang, which once completed in 2023 will be 110 meters and operate in the 300MHz-117GHz range that includes but is not limited to S-, X-, and Ka- bands.[47] China also plans a millimeter wavelength radio telescope at its Antarctic Kunlun Station.[48]

*Radar*

Since at least 2013, Chinese scientists and engineers have lamented China's slow development of ground-based deep space radar capabilities like the U.S. Goldstone, Haystack, and formerly Arecibo radars.[49] During China's 13th Five-Year Plan (2016-2020), Chinese scientists and engineers evaluated different designs and proposed a ground-based distributed coherent radar array, which can work in tandem with the CDSN and Chinese VLBI.[50] Researchers are particularly interested in the radar array's ability to image the Moon, Mars and NEOs.[51,52] CAS had previously faced challenges when trying to image the Moon with the Kashgar radar of the CDSN, the Yunnan 40m radar, as well as the Qujing, Yunnan incoherent scatter radar of China's space weather monitoring system. [53]

CAS has recently used the Sanya incoherent scatter radar to conduct preliminary Lunar imaging experiments for algorithm development.[54] A separate effort between the Chongqing Municipality government and Beijing Institute of Technology will also develop beyond GEO radar capabilities. The university team has completed the first phase of a three-phase project to build 400 20-meter S-band radars, with an estimated detection distance of 150 million kilometers. [55,56,57,58] If the sensors can be properly correlated, this ground-based radar array would be a good tool for SSA beyond GEO when pointed at key locations, like on and around the Moon, and even possibly Lagrange Points.

## Space-Based Systems

*Optical and Infrared Telescopes*

Through China's Lunar Exploration Program (CLEP), the PRC has developed and tested various optical sensors for the Lunar and deep space environment to perform local SSA, such as for landing and system checks.[59] Chinese space engineers have tested those cameras for different types of SSA, such as color imagery of the asteroid Toutatis during a 2012 flyby with Chang'e 2, and photos of the Earth-Moon system from EML 2 with Chang'e 5 T1 in 2014. The 2018 Longjiang-2 micro-satellite that China launched with the Queqiao relay satellite also carried an optical camera developed by Saudi Arabia and captured high-definition images of the Moon.[60] China made significant improvements to Chang'e 5's cameras, launched in 2020, for more detailed imagery of close-up objects and distant bright objects.[61]

In addition to enabling capabilities for CLEP, the PRC's 2021 space activities white paper stated that in the next five years China will, "[s]tudy plans for building a near-earth object defense system, and increase the capacity of near-earth object monitoring, cataloguing, early warning, and response."[62] This will require another set of SSA capabilities, to include wide-field of view scanning to discover unknown, potentially hazardous objects. Towards this end, Chinese scientists and engineers have proposed several beyond GEO optical and infrared satellite systems to contribute to international monitoring of potentially hazardous NEOs.

In 2016, the China Aerospace Science and Technology Corporation's (CASC's) Qian Xuesen Space Technology Laboratory proposed a seven satellite dispersed constellation with satellites at a Lagrange Point and in a Venus-like orbit around the Sun for search and spectral inspection of potentially threatening small celestial bodies.[viii,63,64,65] Since then, technical experts in China have debated what sensor type to prioritize for planetary defense, not just the location.[66] Such debates have spurred other proposals such as a mid- and long-wave infrared sensor at ESL 1 to enable an integrated optical-infrared-microwave space- and ground-based sensor network.[67] Scientists and engineers also proposed a heliocentric orbit for an Earth-trailing optical telescope as well as EML 4 and EML 5 infrared telescopes.[68,69]

Lunar-based Earth observation is also something China plans to further develop during the 14th FYP, which could enable wide-field SSA. The Chang'e 3 lander on the Lunar near-side has used its ultraviolet sensor to study the Earth's ionosphere for space weather forecasting.[70] Since then, Chinese researchers have reviewed sensor types for a long-term Lunar-based Earth observatory.[71,72] They seem to have decided to prioritize radar systems, according to a solicitation for applications under the 14th Five-Year Plan.[73]

*Space-based Radio/Microwave, Radar, and VLBI*

The Chinese plan for a potential Lunar-based radar system for Earth observation mentioned above builds off the PRC's existing space-based radio/microwave, radar and VLBI capabilities. The 2007 Chang'e-1 carried a microwave sensor and recently released the first full Lunar map after already releasing an updated stereo imagery map.[74,75,76] Microwave sensors are used to determine the material composition below surfaces or behind walls. The Chang'e-2's stereo mapping capabilities reached 7 meters, a notable improvement compared to the 120-meter resolution of the Chang'e-1 satellite.[77] Chinese experts said that the Chang'e-2 resolution can reach 1 meter when the satellite is closer to the moon.[78] Chang'e-3 and -4 used optical and radio sensors to perform local SSA, such as landing and localization updates.[79]

China's 2018 launch of the Longjiang-2 microsatellite to Lunar orbit initiated the PRC's first independent space-based VLBI tests and a continuation of its bilateral space-based VLBI cooperation, this time with a joint Netherlands instrument on the Queqiao relay satellite.[80,81] Later, the Chang'e-4 lander also carried an antenna for VLBI tests. It is possible that the Chang'e-5 orbiter's extended mission to Lunar DRO is experimenting with the longest VLBI baseline test yet.[82] China has several plans for future space-based VLBI systems which will

[viii] The project is called the "Near-Earth Object Heterogeneous Monitoring Constellation" (CROWN), which plans to equip "the "1+6" mother and child constellations" with a variety of payloads to carry out autonomous detection and discovery of near-Earth objects. The Lagrange Point is said to the Lagrange Point 2, probably in the Earth-Sun System, but could also be a typo, as similar Western proposals call for a Venus-like orbit and an ESL 1 combination.

operate at least 3-5 years. The Chang’e-7 will include a Lunar orbiter with a 4.2 meter relay antennae in X band for joint VLBI with ground based sensors.[83]

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