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CHINA AEROSPACE STUDIES INSTITUTE

China's Different Approach to Space Situational Awareness

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Introduction

This report attempts to answer two questions. First, what do Chinese authors writing in Chinese and English reveal about domestic satellites supporting space situational awareness (SSA).[i] Second, given the available open-source information, in what ways does China's approach to conducting space-based SSA differ from that of the United States.

This report identified at least ten spacecraft Chinese researchers have used for space-based SSA. Another eight inferred satellites are included based on Chinese discussion of their orbits or sensors. Among the known SSA satellites are two which are developed, owned, and operated by Chinese mixed-ownership enterprises.[ii] In the sections that follow, the reader can find all the satellites in Table 2, and descriptions in aggregate and in detail. This review covered previously or currently on-orbit satellites, not plans for future systems.

This report finds three significant differences between China's and the U.S.'s approach to space-based SSA. China has a different approach to space-based SSA architectures, different priorities for their placement in orbit, and a different rationale for enabling autonomous decision-making on satellites equipped with SSA sensors.

The primary factor driving these three differences is China's lack of consistent access to a worldwide network of radars and telescopes, a problem that the U.S. has not had to face. China has mitigated the impact of this constraint by prioritizing SSA satellites in low Earth orbit (LEO) that operate autonomously and watch LEO, over SSA satellites dedicated to geosynchronous Earth orbit (GEO). Given China's setup, it appears China needs space-based SSA, in particular systems with autonomous decision-making, more than any other leading space power.

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[i] This report is a follow up to CASI's prior reports: *Chinese Research in Space-Based Space Surveillance* and *China Can Track GSSAP.*

[ii] Mixed-ownership enterprises (MOEs) are Chinese companies with at least 51 percent funding from non-state or provincial sources. They often are often spinoffs from provincial or city projects, which distinguishes them from China's new space sector, companies which primarily start with private capital.

China's definition of space-based SSA is more encompassing than the U.S. definition of SSA.[1] China's definition includes satellite-to-space object scanning, tracking, cataloging, information fusion, intention determination, and maneuver decision processes.[iii] By enabling satellites with SSA sensors to autonomously determine intention and make maneuver decisions, China is attempting to mitigate its problem of limited ground stations and ground sensors. This different conception moves analysis that the United States usually processes on the ground with a human onto the satellite.

Key differences and their implications[iv]

1. Different architecture

As China may be unlikely to trust the data available from the U.S. Space Force and Russian space object catalogs, limited opportunities for a worldwide network of ground sensors and an already congested space environment mean that China has needed to make a unique SSA architecture in space just to keep its LEO constellations safe from collision. The U.S., on the other hand, operates a global network of ground sensors to update its space object catalog, but still maintains a satellite in LEO to support LEO and GEO SSA.[2] The first two generations of the U.S. satellite were in sun-synchronous Earth orbit (SSO), and the third generation is in an equatorial LEO orbit with a focus on GEO SSA.[v]

China, meanwhile, uses SSO for LEO SSA much more than the United States. China has at least four satellites working independently in SSO dedicated to LEO space situational awareness, such as ChuangXin-3. In addition, China has at least six SSO satellites with intersatellite data links between groups of three contributing to LEO and GEO SSA, for example ShiYan-6 (01-03) and the commercial JiLin ShiPin (04-06) series. In fact, the vast majority of the Chinese LEO technology demonstration satellites like the ShiJian and ShiYan series, and the JiLin commercial imagery satellites are in SSO.[3] While most of them are probably not for SSA, China still has more non-communications and non-Earth observation satellites in SSO than the U.S.[4]

China may not need the same space-based SSA GEO satellite architecture as the U.S. The U.S. space-based architecture focuses primarily on tracking GEO objects. As China continues to build out its catalog of GEO objects, China will still need its LEO SSA capabilities for LEO, but such systems will also enable different options for GEO. In addition, Chinese researchers have begun to look at how to stretch their LEO capabilities to support cataloging GEO objects, while also considering the U.S. methods to monitor GEO from GEO.[5]

[iii] China also includes space weather detection satellites as part of their space-based SSA architecture.
[iv] The section on key differences and their implications draws on the evidence cited later in the report. The additional sources in this section are those not referenced elsewhere.
[v] Midcourse Space Experiment (MSX, 1996); Space Based Space Surveillance (SBSS, 2010); Sensor Sat (ORS-5, 2017)

Implications

China's space-based SSA architecture may become increasingly dissimilar to the U.S., which could create challenges and opportunities. While political issues keeping China from building a global network of ground sensors have been beneficial for the U.S. in the short term, over the long-term, China's space-based adaptations could make it more difficult for the U.S. to anticipate and interpret China's on-orbit behavior. Forcing China's SSA into space means that much of China's space behavior remains classified because the chances to engage with Chinese space operators in China and overseas is politically limited, and the sensors collecting the data are classified, or held behind commercial contracts. The amateur astronomer community is small, and space news reporters regularly quote the same people. Hiring more intelligence analysts to analyze what will be an increasing amount of classified Chinse on-orbit behavior will perpetuate over-classification, and become a weakness in the long-term. Over-classification limits the numbers of U.S. and allied military personnel who can participate in space war games, and limits policymakers' ability to message about any unprofessional Chinese on-orbit behavior.[6]

Based on the architecture, a second implication is that China may be more reliant on its space-based SSA than the United States. This may very well increase China's perception of a threat if those systems experience anomalies or are directly threatened. If Chinese satellite operators lost the data from their space-based SSA systems, they would face more uncertainty in decision making than if the U.S. lost the Space Based Surveillance System (SBSS). This may cause disconnects between U.S. and Chinese perceptions of actions or incidents.

Similarly, if China's SSA data primarily comes from space-based systems, and the U.S.'s data is only supplemented by space-based systems, it is possible that China's data could provide it with different assessments of on-orbit activities. Generally speaking, SSA experts agree that data from different sensors can result in uncertainties in the orbit determination process. Although speculative, this may have been one factor that contributed to China's different interpretation of Starlink's proximity to the China Space Station in late 2021.[7]

A third implication of China's space-based SSA architecture is the creation of an independent Chinese space object catalog that could strengthen China's ability to demonstrate leadership in global SSA and potentially diminish U.S. influence. The migration of space tracking information to the U.S. Department of Commerce from the U.S. Space Force is occurring at a time of rising demand of more timely and detailed updates. This could create inconveniences for space-track users and cause some to switch to Chinese or Russian data.

Despite these challenges, an opportunity exists in China's different approach to SSA. More reliance on those systems for space traffic management and spaceflight safety could further China's commitment to maintaining stability in space. China's increasing reliance on space for economic, scientific, diplomatic, and military purposes, including space-based SSA, parallels the U.S. reliance on space and may make it less likely to disrupt its own access to vital space capabilities.[8]

2. Lower priority on GEO

Despite eye-catching headlines of U.S. and Chinese satellites chasing and fleeing each other, China to date has not given GEO the same priority as the U.S. There are two main reasons for China placing a lower priority on GEO. The first reason is that an independent ability to track objects in LEO for an indigenous catalog has been a unique challenge, and only after addressing that challenge could China shift resources to building an independent ability to track higher orbits, not just GEO. China's satellite maneuvers in GEO to avoid the U.S. Geosynchronous Space Situational Awareness Program (GSSAP) satellites are most likely enabled by its LEO SSA constellations and China's GEO satellite-based autonomous maneuver detection and collision avoidance sensors, with supplemental support from Russia's optical network.[9] Furthermore, the GSSAP satellites often stay in Eastern longitudes, increasing the likelihood that China can use its domestic optical telescopes to track them.[10]

The second reason China places a lower priority on GEO compared to the U.S. is because China has fewer high-value satellites in GEO and most are easy to observe from China given the satellites are in Eastern longitudes.[11,vi] The People's Liberation Army (PLA) is preparing for a battle off the coast of China, so emphasis will be on GEO in Eastern longitudes in the near term. The U.S., on the other hand, places high-value satellites in GEO away from U.S. territory to support global power projection.

Implications

Because China has not needed to use GEO like the U.S. for overseas military operations, China may be more open than the U.S. to a diversified commercial role in GEO beyond provision of SATCOM. Not until after 2015 did China begin to launch imagery and technology test satellites to GEO, starting their incremental use of higher orbits for military and intelligence purposes beyond dual-use communications and navigation.

At the same time, as early as 2016, Chinese national and provincial level funding opened for commercial and scientific on-orbit servicing projects, presumably for all orbits.[vii,12] This may have been when Chinese mixed-ownership enterprises began to propose space-based SSA projects as an on-orbit service. China has at least two mixed-ownership enterprises that have provided LEO, Medium Earth Orbit (MEO), and beyond-GEO space-based SSA to domestic customers. The two Chinese companies are the ChangGuang Satellite Technology Co., Ltd. and Origin Space Technology.

[vi] Except data-relay (TianLian) and China Satcom satellites in general Western longitudes, China has two satellites hovering over the Americas: the experimental satellite TongXin JiShu ShiYan-7 (TJS-7) and new internet satellite WeiXing HuLianWang GaoGui-03.

[vii] Most Western analysts, including this author, have interpreted China's interest in on-orbit services from a U.S. lens of imagery for anomaly resolution, grappling to refuel, or grappling for debris removal, which may have been the analytic error of mirroring.

While the U.S. inches along in allowing U.S. and allied companies to supply non-Earth imaging services in LEO, regulators should expedite the process for higher orbits to remain competitive with Chinese companies. Even before the U.S. updated its regulations in 2022 to allow commercial non-Earth imagery, the Australian company High Earth Orbit Robotics was driving this business.[13] High Earth Orbit Robotics primarily works in LEO, but in 2019 proposed GEO imagery, a plan it has said it will complete by 2027.[14]

A second implication is that the U.S. and Western countries may be at risk of overlooking the Chinese Communist Party's (CCP's) top level design for space in general, and GEO in particular, to serve a wide variety of national goals. Western analysts must be careful to not oversimplify the post-2015 trends in GEO as a grand strategy to support the establishment of the PLA Aerospace Force. The CCP has focused on using space for a wide variety of national goals beyond just its military goals. Rationales for China's increased diversification in GEO post-2015 include earlier ambitious goals to establish an independent space debris catalog as early as 2000, a goal which was updated in 2015 when China established its Space Debris Observation and Data Application Center.[15] At the same time, U.S. and Russian military and intelligence activity in GEO elevated the PLA's perceived threat, such as Russia's reestablishment of its orbital weapons program in 2013.[16,viii] Misinterpreting the CCP's broader goals in space, and mirroring the Western esteem for GEO onto China, could lead the West to emphasize the threat over other strategic considerations for economic and diplomatic leadership.

3. Autonomy

China's limited access to ground stations has led China to determine that much of spaceflight safety and orbital maintenance has to be done with autonomous decision-making on satellites equipped with SSA sensors and on-board processing. As early as 2008, the BanXing-1 satellite tested machine learning for autonomous detection and decision-making and in 2013 the ShiJian-15, ShiYan-7, and ChuangXin-3 satellites successfully tested China's autonomous collision avoidance sensors.

In contrast, the U.S. has not needed government satellites to autonomously maneuver in LEO due to its global network of uplink and downlink stations that provide more opportunities to send maneuver commands. Even new commercial satellites like Starlink implement autonomous collision avoidance with the help of global ground stations to uplink frequent catalog updates, not with satellite-based sensors nor by getting updates directly from SBSS.[17]

In addition, following the U.S. approach to use relay satellites to more quickly send information to ground stations has not alleviated the Chinese need for autonomy. While Chinese

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[viii] In 2013, Russia restarted its co-orbital weapons programs, primarily in LEO but also potentially in GEO. While in 2014, the U.S. announced GSSAP, which immediately opened a floodgate of concern in China's defense circles. As of 2019, the PLA wrote that they could not rule out that the Russian Luch-Olymp satellite, and the U.S. GSSAP and CLIO satellites in GEO were capable of downlink jamming. The PLA as early as 2020 even began testing GEO space-based SATCOM downlink jamming.

space operators have gained quicker access to space-based data with the slow build-out of China's TianLian data-relay constellation, Chinese researchers have consistently stated that on-board processing for autonomous collision avoidance is still needed to avoid over-tasking China's limited ground stations.[18,ix] Addressing over tasked domestic ground stations is one reason the PLA separated its new Aerospace Force Base 37 for space early warning from its major telemetry, tracking, and control base, Base 26.[19]

The U.S., on the other hand, has probably more autonomy built into its GEO satellites, given that the U.S. has prioritized that orbit earlier in its architecture design. If China has lagged in GEO spacecraft autonomy, they are quickly applying lessons learned in LEO to GEO. For example, a PLA Aerospace Force unit with expertise in algorithm development and on-orbit maneuver simulation, Unit 32032, recently wrote a report on autonomous maneuver detection for collision avoidance in GEO.[20,x] In 2023, authors from Unit 32032 wrote that,

> Sensing the abnormal orbit of space targets [in GEO] as soon as possible and identifying the collision risk … can leave sufficient response time for spacecraft to develop more reasonable response strategies… it is concluded that space-based optical detection… can quickly perceive anomalies [at 2km] without occupying additional ground resources.[21]

Implications

While it appears China may have had an earlier start on satellite autonomous collision avoidance in LEO, they have not had the ability to track orbital spacecraft and debris with high fidelity, which has probably limited their application of spacecraft autonomy. However, 2025 will mark the completion of China's 14th Five-Year Plan for space, at which point they are scheduled to achieve technological advancements in spacecraft autonomy, or what the Chinese plan calls "smart self-management of spacecraft."[22] Meanwhile, the U.S. Assistant Secretary of the Air Force for Space Acquisition and Integration in 2024 said he envisioned autonomous spacecraft that could act without needing to communicate with vulnerable ground stations in 10-

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[ix] If the JiLin ShiPin satellites are increasingly used for space-based SSA and more satellites are enabled to receive messages from them, this might enable less reliance on the over-tasked ground stations, and the probably highly tasked TianLian constellation. Optimizing bandwidth for intersatellite links and onboard processing for maneuver detection and collision avoidance is a challenge China has consistently worked to address.

[x] Since its creation, Unit 32032's scientific and technical research has demonstrated an expertise in algorithm development for simulating various technologies' performance and mission scenarios. The technologies and mission scenarios the unit has reported on thus far, in chronological order, generally make up three phases: artificial intelligence enhanced electronic intelligence and countermeasures for terrestrial and in-orbit uses (2018-2019), hypersonic missile scenarios (2019), and on-orbit servicing and rendezvous and proximity operations (RPO) scenarios with uncooperative spacecraft in LEO and GEO (2018-2021). A recent USAF CASI report hypothesized that Unit 32032 probably plans the operations for SJ-17, a satellite which has been active in several approximately 1-kilometer (km) RPOs since its launch in March 2016, and probably SJ-21. Unit 32032 has a body of technical analysis on satellite operator training and war gaming for on-orbit servicing scenarios with uncooperative Chinese and foreign spacecraft in LEO and GEO. (https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/PLASSF/2023-12-11%20Counterspace-%20web%20version.pdf)

15 years.[23] One should expect China to have established its space object catalog for improved on-orbit autonomy well before then.

If China is building a different SSA architecture and giving spacecraft more autonomy, the U.S. could be increasingly challenged to accurately interpret China's on-orbit behavior. China's different rationale to ensure collision avoidance now supports maneuver detection and avoiding foreign rendezvous and proximity operations (RPOs). It is important to consider that the ability to avoid unwanted RPO may have been a positive spillover, rather than the primary intention. China's different rationale has also led them to have a different definition of space-based SSA. This broader definition puts autonomous decision-making earlier in the information aggregation process, which is a fundamentally different approach than that taken by the U.S.

Chinese confirmed and inferred space-based SSA satellites—in aggregate

An extensive search for Chinese technical reports on space-based SSA unearthed 59 articles dedicated to the orbital segment. Of those, over 70 percent discussed specific orbits and sensors.[xi] The majority of Chinese authors examined SSA satellites in LEO, with missions to catalog other objects in LEO.

Only a quarter of the papers discussing specific orbits examined SSA platforms in higher orbits like MEO, highly elliptical orbit (HEO), or GEO to scan and track objects in similarly high orbits. However, in papers from the last few years, Chinese authors demonstrated a trend towards examining how satellites based in SSO conducting SSA of LEO satellites could be used to also support cataloging and tracking higher orbits.[xii] This would be similar to the United States SBSS, which is a single satellite designed to catalog and track objects in both LEO and GEO from SSO.[xiii] The difference is that China's setup was designed for LEO, and is still needed for LEO. Now they are also exploring how to stretch its functionality to GEO.

Regarding the sensors, the vast majority of Chinese authored space-based SSA papers were considering what they called optical sensors, a category in which they included star trackers and infrared sensors. Unexpectedly, a still large proportion of Chinese papers were dedicated to space-based radio frequency (RF) sensors.[xiv] Table 1 summarizes China's taxonomy of space-based SSA sensors, including the broad mission and ranges, aggregated across the optical and RF sensor types.

[xi] The author stopped searching for articles July 2024.
[xii] Sun-synchronous orbit (SSO) is a type of polar orbit, orbiting north to south. Satellites in SSO are synchronous with the Sun. This means the angle between the Sun and satellite's orbit plane stays fixed all year long. This helps to ensure consistent lighting on GEO, when the satellite is used for GEO SSA. (https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits#SSO)
[xiii] SSBS was launched in 2010. The precursor satellite, the Midcourse Space Experiment (MSX), was launched in 1996, and the follow-on satellites, Sensor Sat (ORS-5), was launched in 2017.
[xiv] This was surprising based on a prior CASI report that only looked at English language articles about China's SSA.

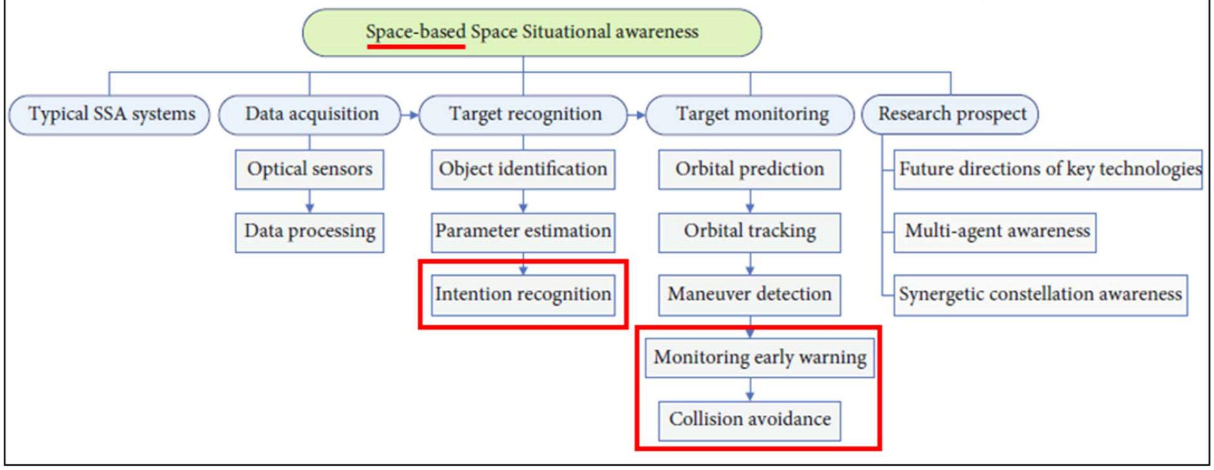
Table 1: Summary of Chinese Space-Based SSA Sensor and Mission Discussions			
Broad Category	Sub-Category	Missions Discussed	Ranges Discussed
Optical	Visible Light Star Tracker Mid-Far Infrared LiDAR	Scanning; Tracking; Maneuver Detection; Feature Recognition	2km - 1,300km
Radio Frequency	X-Band Radar Millimeter-Wave Radar SAR and ISAR	Maneuver Detection; Collision Avoidance; Feature Recognition	3km – 11,800km

The generalist reader should note that optical sensors are not simply cameras for close range photographs of satellites. Rather, the "optical" category in China's taxonomy not only includes visible light, used in cameras and star trackers, but also infrared sensors that detect heat. Chinese authors, for example, repeatedly described infrared sensors as good for SSA in the "Earth's shadow," which will be discussed in more detail below. In addition to having 30 percent of papers focused on RF sensors for applications like autonomous detection and collision avoidance, the other surprising aspect about Chinese discussions of RF space-based SSA sensors was the ranges, in some cases pulsed out to 11,800km.

Autonomous collision avoidance in all orbits was the top priority for China's research on space-based SSA, second only to the necessary first step of building a reliable and indigenous space object catalog. Because Chinese authors continue to be concerned with overtasking their limited ground sensors, researchers have developed solutions that place the collision avoidance assessment and maneuver decision process on the satellite, rather than having the data first routed through the ground. The Chinese experience with limited ground-based sensors has shaped China's definition of space-based SSA, as shown in the graphic published by Nanjing University in 2022 (Figure 1).[24,xv] China's definition of space-based SSA includes the whole satellite-to-space object scanning, tracking, cataloging, information fusion, analysis, intention determination, and in some cases, maneuver decision process.[xvi]

[xv] In Figures 1 and 2, the author added red lines for emphasis.
[xvi] Chinese researchers also include space weather detection satellites as part of their space-based SSA architecture.

Figure 1: Nanjing University Explanation of Space-Based SSA in China



<u>Chinese confirmed and inferred space-based SSA satellites—in detail</u>

This report identified at least ten spacecraft that Chinese researchers have used for space-based SSA. Another eight possible satellites are included based on Chinese discussion of the satellites' orbits or sensors. An examination of the confirmed satellites, and select additional information on the inferred satellites is included below.

Table 2 summarizes the orbit, sensor, and launch year of China's space-based SSA satellites. The first category, Specific Confirmation, captures satellites named by Chinese authors conducting space-based SSA, or named by the satellite's chief designer in interviews with Chinese media. The next two categories divide the inferred satellites based on the type of information that the Chinese authors provided. In the category of Real Data, the Chinese authors showed their analysis of what they called "real data" from the satellite at a specific orbit and with specific sensors. In the category of General Capability, the Chinese authors referenced general orbits or sensors, but the capability was detailed in one of two ways. The authors either included what they claimed was an image taken in space, or they detailed a problem that multiple Chinese researchers have attempted to solve. The approximate launch date of the inferred satellites is based on the relevant article's publication date.

Specific Confirmation

Table 2: Chinese Confirmed and Inferred Space-Based SSA				
Name (NORAD)	**Orbit to Orbit**	**Sensor**	**Launch Date**	**Status**
Specific Confirmation				
BanXing-1 (33392)	LEO to LEO	Optical	2008	Deorbited
ChuangXin-3 (39209)	LEO SSO to LEO and LEO SSO to GEO	Optical	2013	Operational
ShiJian-15 (39210)	LEO SSO to LEO (maybe also GEO)	Optical and RF	2013	Operational
TianTuo-2 (40144)	LEO to LEO	Optical, Video, and Star Tracker	2014	Operational
BanXing-2 (41834)	LEO to LEO	Visible, Infrared, and RF	2016	Deorbited
JiLin-1 ShiPin 04-06 (43022, 43023, 43024)	LEO SSO to Beyond GEO	Optical and Video	2017	Operational
ShiYan-6 01,02,03 (43711, 45859, 48157)	LEO SSO LEO and LEO SSO to GEO	?	2018, 2020, 2021	Operational
YangWang-1 (48841)	LEO SSO to LEO and LEO SSO to Beyond GEO	Optical and Ultraviolet	2021	Deorbited
TianZhou-3 (49222)	LEO to LEO	Optical	2021	Deorbited
JiLin-1-XX	LEO SSO to LEO/MEO	Optical, Video, and Star Tracker	2019-present	Operational
Real Data				
Unknown 1	LEO SSO to LEO. Spacecraft at 808.6km, inclined 99.82°. Targets in LEO altitudes 323km and 616km.	Optical	by 2014	?
Unknown 2	Circular high LEO/MEO to lower and higher orbits. Spacecraft at 1,600km altitude, inclined 54°. Target 1 at 20,000 km altitude, inclined 30°, ascending node right ascension 0°, and a true anomaly of 40°. Target 2 at 300 km altitude, inclination 45°, ascending node right ascension 358.8°, and true anomaly of 345.2°.	Optical	by 2018	?
Unknown 3	LEO to GEO. Spacecraft at 670km, inclined 54°.	Optical	by 2021	?
Unknown 4	LEO to LEO. Spacecraft at 550km altitude and target at 580km altitude, both inclined 53°.	Optical	by 2022	?
General Capability				
Unknown 5	LEO to LEO	RF	by 2011	?
Unknown 6	MEO to high MEO or to lower MEO/LEO	RF	by 2020	?
Unknown 7	GEO to GEO	RF	by 2023	?
Unknown 8	GEO to GEO or MEO to GEO or MEO to MEO	Infrared and Optical	by 2023	?

BanXing-1 (33392), BanXing-2 (41834), and TianZhou-3 (49222)

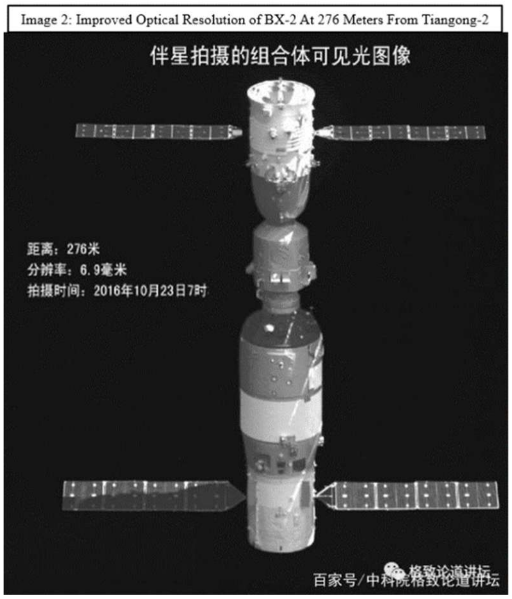
The most notable role BanXing (BX) 1 and 2 played in space-based SSA, separate from their images of cooperative Chinese human spaceflight vehicles, was their task to support scanning, tracking, and warning of uncooperative spacecraft and debris. BX-1 and 2's observation range around Chinese crewed vehicles was probably no more than 10km.[25] However, even with low resolution or degraded images, Chinese researchers have worked to use BX-1 and 2 to identify moving objects against a star background, and have begun attempts to autonomously send collision warnings or snap pictures. These attempts were not intended to get exquisite imagery of spacecraft for intelligence gathering purposes, but to rather more generally locate and identify objects for which lower resolution pictures would be sufficient.

Two recent Chinese research teams included BX-1 in their proposals for improving space-based SSA. Researchers from the Beijing Institute of Technology in 2022 used images from BX-1 to train an algorithm to identify unknown objects with degraded optical images of the Shenzhou-7 spacecraft (See Image 1).[26] According to the author of a 2023 Master's thesis from the Harbin Institute of Technology, with the security marking "public," "the focus of [BX-1 and 2] imaging experiments was to verify the ability of companion satellites to perform high-definition imaging and repeated observations of target satellites."[27] While only speculation, the target satellites could refer to uncooperative objects in the "confidential" version.

Image 1: Chinese Authors Use BX-1 Images to Build Space Object Identification Algorithm

BX-1 and 2 played an important role in China's early attempts at spacecraft autonomy, in this case satellite-based machine learning for orbit determination and automatic imaging. A news outlet affiliated with the Chinese Academy of Sciences (CAS) referred to BX-1 as "a security bodyguard, who conducts long-term observation, tracking, forecasting, and alarming of artificial or natural flying bodies that pose a threat."[28] The BX-1 chief designer also said that, "the satellite chooses a smart sunlight window, where the sun shines right on our spacecraft, and then goes to take a series of photos and videos," indicating an early attempt at space-based imagery without tasking from the ground.[29]

Image 2: Improved Optical Resolution of BX-2 At 276 Meters From Tiangong-2



Eight years later, apart from BX-2's improved visible light camera resolution (See Image 2), BX-2 also had other payloads to improve its ability to provide early warning and other space-based SSA. In 2016, the Chinese Manned Space Engineering Office said BX-2, “has an all-weather space observation capability and can monitor space targets that pose potential dangers to the space station, such as space debris.”[30] “All weather” capabilities usually refer to RF payloads because they can image through clouds. The official Chinese media outlet Xinhua reported, “[BX-2] is equipped with a high-resolution visible light camera and a wide-field bionic fisheye infrared camera, which can monitor potential dangers such as space debris or temperature anomalies from multiple angles throughout the day. [BX-2] can be used as a safety auxiliary tool for the main spacecraft…and for safety and defense.”[31]

The TianZhou-3 resupply vehicle for the China Space Station tested a debris detection payload composed of an optical camera, an in-orbit data processing unit, and a temperature control unit. Chinese media reported that the “large-field of view and high-sensitivity detection payload” tested a new algorithm for in-orbit detection and identification, and technology for rapid on-orbit processing of weak targets and massive data.[32]

ShiJian-15 (39210) and ChuangXin-3 (39209)

The chief designer of BX-2’s visible light camera was also the chief designer of one of ShiJian (SJ) SJ-15’s visible light sensors.[33] SJ-15’s contribution to space-based SSA far exceeds its RPOs with other Chinese satellites conducted in 2013. For the purposes of this research, SJ-15’s most significant contributions were twofold. First, SJ-15’s post-RPO “long-distance large-space target detection and recognition” demonstration in SSO with China’s early satellite-based visible and infrared optical sensor fusion, won the designers a national award.[34] Second, SJ-15’s RPO was actually an incremental step towards collision avoidance tactics, techniques, and procedures with a successful test of its “warning radar” with ShiYan-7 (SY-7) and SY-7’s subsatellite. The then General Armaments Department provided an award to the radar designers and satellite operators (see Image 3).[35]

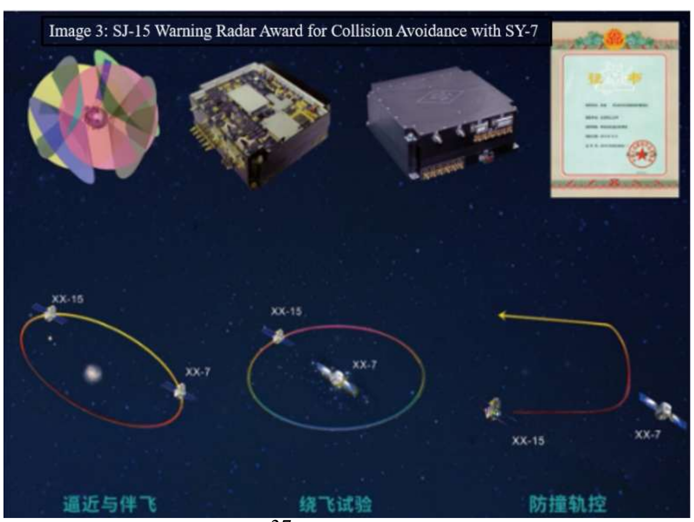


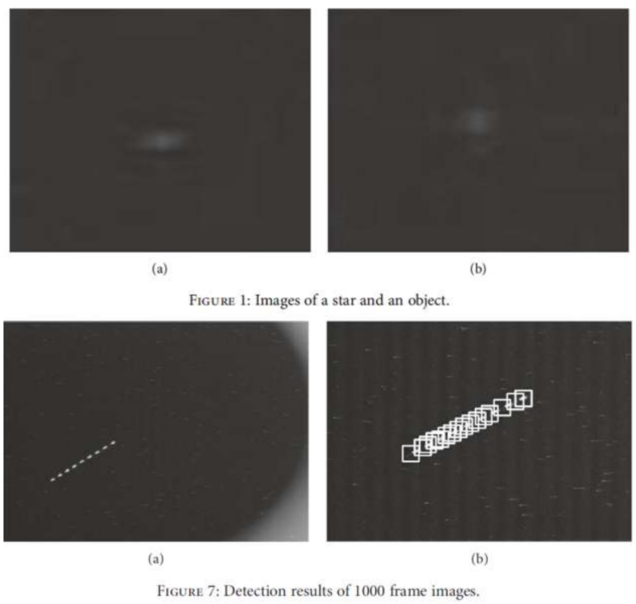
Image 3: SJ-15 Warning Radar Award for Collision Avoidance with SY-7

ChuangXin-3 (CX-3) was launched with SJ-15, and while its role in imaging the SJ-15 and SY-7 RPO was less attention-catching, it has an important position in China’s advancements in space-based SSA. CX-3’s deputy chief designer in a 2020 interview confirmed that post-RPO, CX-3 contributed to LEO and GEO observation from SSO.[36] The wider design team won a national award for the breakthrough … in the high-resolution imaging of space-based space targets.”[37] This breakthrough enabled the deputy chief designer of the CX-3 to later lead development of the SY-6 trio, which is probably China’s first space-based SSA constellation, as discussed in more detail below.[38]

TianTuo-2 (40144)

The TianTuo-2 (TT-2) satellite continues to support China's efforts to enable autonomous collision avoidance, less by way of identifying objects' general features, like the BX satellites, but more by way of detecting distant motion. The PLA National University of Defense Technology (NUDT) developed TT-2 as China's first small optical video satellite to track "dynamic targets," and test four different video imagery payloads from SSO.[39] As of late 2020, TT-2 was still functional, and the NUDT operators said they keep it in sleep mode until it is "needed."[40]

Image 4: NUDT and Tsinghua TT-2 Space Object Maneuver Detection Test



Researchers from NUDT and Tsinghua University in 2017 used TT-2 to build and test an improved space object maneuver detection algorithm. As illustrated in Image 4, the Chinese authors used TT-2's highest resolution sensor to take images of the star background and space objects to detect pixel differences, allowing them to identify maneuvering objects against comparatively stationary stars.[41] The authors noted that the TT-2 sensor could not initially distinguish between a star and a spacecraft, until after their algorithm improvements.

ShiYan-6 01, 02, 03 (43711, 45859, 48157)

As stated above, the deputy chief designer of the CX-3 was also the chief designer of the SY-6 trio (01, 02, and 03).[42] According to the launch manifest, SY-6 01-03 is also called ChuangXin (CX) 3A, 3B, and 3C, which is consistent with the chief designer's statements about the SY-6 constellation building on CX-3's work tracking LEO debris and GEO satellites.[43] An SSA satellite in SSO tracking satellites in LEO and GEO is similar to the U.S. SBSS, but China launched three. The SY-6 constellation is also in SSO, and probably has gimballed optical sensors for LEO and GEO observation, but confirmation of the sensors was unavailable at the time of writing.

At this time, however, even without knowing the sensor package, there are good reasons to believe that the SY-6 satellites are China's first space-based SSA constellation. The chief designer is known as having "built China's first space-based space environment detection system … that fills the gap in relevant fields … [and is a] security guard of China's space frontier." [44] It is possible that the constellation is for space weather, which is a more literal interpretation of "space environment detection" systems. However, the SY-6 chief designer describes his research focus as, "satellite system design space situational awareness space attack and defense" and has written papers on "geosynchronous space debris observation" and "a high orbit target surveillance system."[45] This research did not find the chief designer having any role in space weather.

JiLin-1-ShiPin (43022, 43023, 43024) and JiLin-1-XX

Important for accelerating progress in space-based SSA, China has, like the United States, allowed commercial space players to enter the non-Earth imaging market. At least two Chinese mixed-ownership enterprises (MOEs) have supported LEO and GEO SSA. The first example was in January 2022 with the MOE ChangGuang Satellite Technology Co., Ltd. and its JiLin-1 ShiPin [video] satellites. At that time, researchers from CAS published their experiment with the JiLin-1 ShiPin series, and the YangWang-1 discussed below, to "verify the use of existing space-based equipment to conduct near-Earth collaborative observation of asteroids."[46] According to the researchers, they conducted their test to image and track asteroid 1994PC1 in mid-2021 using the JiLin-1 ShiPin series launched in November 2017, of which there are three satellites, all in SSO. (See Image 5)

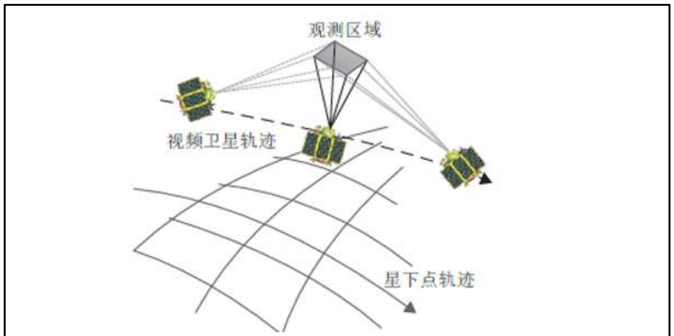


Image 5: Schematic diagram of inertial space stable imaging mode for video satellite of asteroid targets

While these satellites were launched in 2017, the confirmed beyond-GEO SSA test for asteroid observation was not until mid-2021. The successful test undoubtedly needed experiments in advance to be successful. As evidence of earlier tests with the JiLin video satellites in LEO, authors from Nanjing University in 2022 confidently stated that the JiLin-1 ShiPin satellites had been used many times for space-based SSA of LEO space objects, to include testing maneuver detection and collision avoidance. They wrote,

> The JiLin-1 satellite constellation has been used to image inertial space targets many times, which verifies the feasibility of the JiLin-1 satellite for space-based observation, and also carries out research on space target intersection prediction and video satellite imaging window search, coverage ability of typical low-orbit targets, and point target extraction based on multi-frame images.[47]

Referencing imaging stars and transiting satellites for "space target intersection prediction," indicates that a Chinese MOE is developing satellite-based machine learning for conjunction avoidance, which is a type of autonomous decision-making for space-based SSA.

According to two additional Chinese research groups, potentially the same JiLin-1 ShiPin video satellites are still conducting space-based SSA of LEO.[48] The researchers did not confirm which JiLin-1 series. However, both groups clarified that the ultimate goal of space target monitoring is to build the space object catalog to support spacecraft autonomy. For example, a

Master’s thesis from the ChangChun University of Technology in June 2023 used two on-orbit, but unspecified, JiLin-1 satellites to demonstrate binocular vision filtered with the researcher’s star tracker algorithm for improved observation and cataloging of LEO and MEO objects (see Image 6).[49] The authors selected the Jilin-1 XX satellites to test their binocular vision algorithm specifically because the algorithm assumed JiLin-1’s intersatellite datalinks.

A different Master’s thesis from the Harbin Institute of Technology in May 2023 described a mission planning system for on-orbit satellites to monitor and track objects without updates from ground stations. The satellites would have an on-board decision-making capability to track the “priority” satellites in LEO first.[50] The author implied the mission planning system was modeled with the JiLin satellites in mind because of the necessity for intersatellite datalinks.

Image 6: JiLin-1 XX satellite’s star map and satellite tracking demonstration

图 3.12 “吉林一号”XX 型号卫星真实在轨拍摄星图局部放大图

Figure 3.12 "JiLin-1 XX-type satellite real in-orbit star map (partial enlarged image)

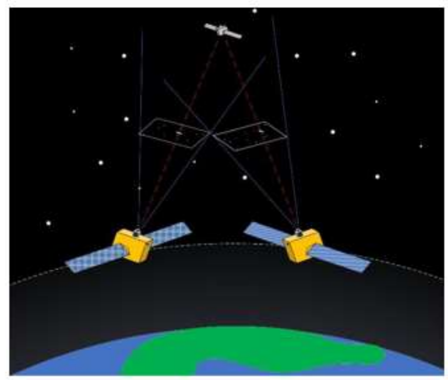


图 2.1 两颗卫星联合进行空间目标监视示意图

Figure 2.1 Schematic diagram of two satellites jointly monitoring space targets

YangWang-1

Another MOE, Origin Space Technology, has conducted LEO and beyond-GEO SSA with its YangWang-1 satellite.[51] The company first tested its sensors for space-based SSA in LEO, around the same time as the CAS researchers who used YangWang-1 with the JiLin-1 ShiPin satellites to image and track asteroid 1994PC1.[52] Soon after its launch in 2021, YangWang-1 imaged the China Space Station and a Starlink satellite, according to the company’s social media account (see Image 7).[53] There has been some confusion around YangWang-1’s name and satellite ID.[54] Representatives of Origin Space Technology said they planned to launch YangWang-2 in late 2023, but it is unclear if that happened.[55]

Image 7: WangYang-1 video of an orbiting Starlink satellite

比如，我们拍到了**马斯克的Starlink**

For example, we photographed Musk's Starlink

Real Data

A quick review of current on-orbit Chinese satellites that fit the exact characteristics of Unknown 2-4 in the Real Data category of Table 2 revealed no likely candidates.[xvii] Those satellites could have adjusted their orbit over time, or already deorbited. However, Wuhan University, the PLA's Beijing Institute of Tracking and Telecommunications Technology (BITTT), and the state-owned enterprise China Academy of Space Technology (CAST) detailed Unknown 1 twice. Given that the tests both collected data in 2014 from SSO, Unknown 1 is probably SJ-15 or CX-3, which were both satellites in SSO doing SSA in that timeframe.[56]

While Unknown 2 was not precisely identified, credible Chinese researchers have examined circular, near-equatorial LEO and MEO constellations to track MEO, HEO, and GEO multiple times.[57] These researchers also usually include the U.S.'s satellite in the same orbit, on the same mission. The U.S. Space Force's Operationally Responsive Space (ORS-5) is an equatorial LEO satellite with a non-gimballed optical sensor to track objects in GEO.[58] After reviewing methods to catalog GEO space objects in 2019, CAST concluded that,

> In the future, GEO orbit target cataloging satellites should be selected between zero-inclination low-orbit and super-synchronous orbit. The zero-inclination low-orbit satellite solution can achieve rapid cataloging data updates by increasing the number of satellites; super-synchronous orbit satellites need to adopt a constellation form to achieve real-time cataloging data updates for the entire GEO.[59,xviii]

Image 8: ChuangXin-16 A and B

The most similar Chinese orbiting satellite with a known history of contributing to space-based SSA is Chuangxin-16 A and B (CX-16 A and B). Since 2020, the CX-16 satellites are both orbiting in nearly-equatorial LEO orbits at a moderate inclination of 29 degrees (see Image 8).[60]

General Capability Confirmation

The last group of satellites in Table 2, labelled Unknown 5-8, capture Chinese references to RF and infrared space-based SSA sensors in general orbits, which the Chinese often discuss as solutions for a country without a network of global ground sensors. Even though these references are more general, they are significant for understanding China's different constraints and priorities.

For example, an author from CAST in 2023 stated that passive and active RF and infrared sensors are "commonly" used in China for space-based SSA of other satellites.[61] However, a

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[xvii] Greg Gillinger at Integrity ISR, LLC helped with the quick search.
[xviii] The super-synchronous constellation would sit above GEO, and was once proposed by the Australian space-based SSA company High Earth Orbit Robotics.

recent Western study of Chinese space-based SSA articles written in English either found no relevant examples of some types of RF sensors, or determined that the Chinese must be misguided in their focus on infrared SSA sensors.[62] As can be seen in CAST's chart below (Figure 2), these sensor types are common for China, based on China's priorities for building its space object catalog and developing autonomous detection and maneuver capability for collision avoidance. Hence, a Western author used to global ground sensors might not find relevant examples or be convinced.

Figure 2: CAST's 2023 Summary of Commonly used Space-Based SSA Sensors in China

Means of perception	Commonly used sensors	Measurement information	Main uses:
Proactive awareness	Lidar	Target distance, bearing, velocity, 3D imaging	Approaching target recognition, positioning, appearance and structure feature recognition
	Millimeter-wave radar	Target distance, bearing, velocity, imaging	
	Visible light camera	Target image, orientation information	Target search, tracking, appearance and structure feature recognition
	Mid-far infrared camera		
Passive perception	Laser alarm	Direction, wavelength, pulse width, power/energy density of the target laser, etc	Real-time alerting and traceability of potential and abnormal threats
	Microwave alarm	Direction, frequency, power/energy density of the target microwave, etc	
	Particle beam alarms	The direction of incidence of particles such as target electrons, protons, neutrons, etc., energy flux density, etc	

Space-based SSA involves more than high-resolution images of satellites. This section provides more explanation on RF and infrared sensors, given that these sensor types are not often discussed as part of the U.S. space-based SSA architecture. From the Chinese perspective, space-based passive and active RF for collision avoidance, even at a power and frequency insufficient for intelligence synthetic aperture radar (SAR) imagery or signals intelligence (SIGINT), is necessary when satellites are outside the footprint of the relatively few Chinese ground stations.

For example, false warnings of a conjunction may be better than no warnings for something as important as the crew in the China Space Station. To understand the usefulness and urgency for such a capability, even after the second Chinese GEO data-relay satellite TianLian launched in 2011, the satellites expanded data-relay enough to communicate with LEO satellites just 70 percent of their daily orbit.[63] It would still take another 10 years until the Chinese achieved 24-hour communication, even with the crew in the China Space Station, who probably needed on-orbit capabilities for conjunction warnings when outside the range of a Chinese or partner ground station.

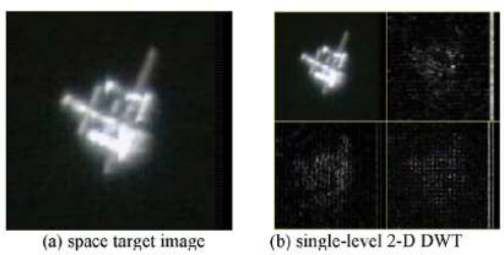
The last capability China's satellite developers discuss as a solution for a country with limited ground sensors is infrared satellites. The low data-relay coverage pre-TianLian compounded uncertainty of satellite safety during biannual season changes. During biannual equinoxes a satellite spends more time in "the Earth's shadow."[64] Most Western analysts seem unconcerned with this phenomenon in higher orbits because they face less uncertainty than Chinese operators, writing that "being in the Earth's shadow is mostly a problem for LEO." However, from a Chinese perspective, the 30-40 minutes per orbit during peak season for MEO and 70 minutes per orbit during peak season for GEO is a major problem, which they seek to remediate with infrared satellites.[xix] This will be discussed in more detail below, after discussion of the Chinese research on different active and passive RF space-based sensors.

Active RF

There are mainly two active RF methods to limit the high power and antenna size requirements typically used in ground systems when launching them into space. The first way is by using synthetic aperture techniques. The second way is to operate the radar transmitter only in short bursts. Authors from the Harbin Institute of Technology in 2007 designed a SAR satellite in LEO to detect debris in lower LEO at a max distance of 250km. They clearly understood the tradeoffs between imaging satellites and detecting debris writing,

> If we want to achieve 1.5cm azimuth resolution, the radar's bandwidth should be 10 GHz, which is unrealizable for existing radar technology. However, what we are interested in is the information of the debris position at a long distance, and we do not care about the precise configuration of target, so a radar bandwidth can be lower down. We choose it to be 5GHz [with a carrier frequency of 98 GHz].[65]

Image 9: Space-Based SSA Technique



Other authors from the Henan Polytechnic Institute in 2011 appear to have used an on-orbit satellite to develop space-based SAR X-band algorithms, not just for maneuver detection, but also for better object recognition, as shown in Image 9.[66] Their paper discussed LEO, but they did not provide other details about orbits or the target in the image. Probably to improve algorithms like the one used to process Image 9, authors from the University of Electronic Science and Technology in 2018 used a lab simulated space-based system to improve a SAR image processing algorithm.[67] The last example of SAR techniques is from 2020, where authors from CAS and BITTT proposed a constellation of X-band SAR satellites in high MEO to detect, track, and image space targets as far as 11,800km below, and as far as 8, 000km above. The authors simulated the sensors' ability to track several international satellites, including the U.S. Space Force spaceplane, OTV-5, the third mission of the X-37B.[68]

RF sensors can also be designed to transmit only in a series of short bursts to limit high power and antenna size requirements. Such a system could detect, but not image, small objects at long distances. Researchers from JiLin University and ChangAn University in 2018 postulated that such a "transient electromagnetic radiation" system could be useful for long range detection

[xix] Biannual equinoxes around March and September each last approximately 44 days. In the initial and final weeks, the satellites experience shorter periods of darkness per orbit in MEO, that is 10-20 minutes with 2-3 orbits per day, and in GEO that is 10-30 minutes with one orbit per day. In the peak period which lasts 1-2 weeks, the satellites experience longer periods of darkness per orbit. In MEO that is 30-40 minutes per orbit and in GEO that is up to 72 minutes per orbit.

of small debris, especially for debris hidden from view by other space objects. The authors were interested in "seeing through" objects for early preparation of collision avoidance.[69] In 2023, authors from the Northwestern Polytechnical University in XiAn and DaLian University of Technology simulated a GEO radar actively tracking a GEO spacecraft with the pulsed method. According to the, "the measurement sampling frequency is 5 kHz…and non-cooperative target maneuver tracking in GEO is achieved within 20km."[70]

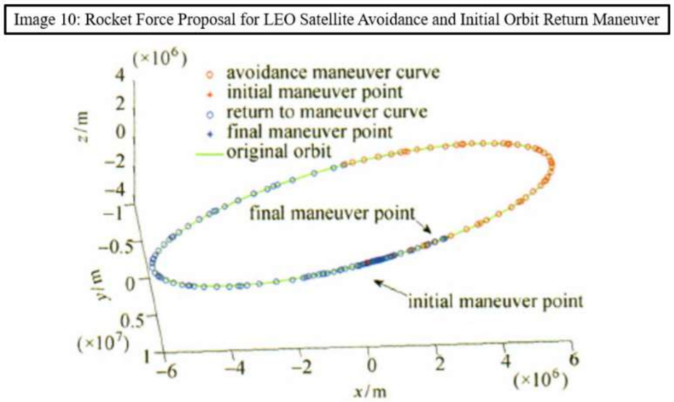
Passive RF

"Passive RF" can involve two different techniques. In one case, the antenna only listens. In another case, the satellite's antenna passively listens, but the satellite proactively takes advantage of uncooperative satellites' signals as illuminators. In the U.S., this is considered an active RF technique called bi-static radar because usually the secondary illuminator is working cooperatively with the listener. However, in the Chinese taxonomy, the passive antenna is using an uncooperative secondary signal, Chinese or foreign, so the Chinese call their RF antenna passive. Another type of passive RF is SIGINT. Historically, SIGINT satellites have large satellite busses and antennas, but as of 2019 at least one group of British researchers had designed a constellation of cube satellites with passive RF antennas to use uncooperative bi-static techniques to "detect and possibly track space debris and satellites." [71] Their proposal was to track LEO debris at higher LEO altitudes, from a maximum distance of 500km.

A recent Western study which looked for examples of Chinese passive RF in English, over a compressed research timeline of a few months, found no such examples.[72] As a follow up to that research, when searching in Mandarin, a handful of cases were discovered. Regarding systems using passive RF to listen, SJ-15's microwave alarm as discussed above, is just one concrete example of which the CAST chart says is a commonly used sensor on Chinese satellites.

A further justification that passive RF listening is common in China for the purpose of alerting and collision avoidance is a paper authored by officers at the PLA Rocket Force's training academy in 2015. Their paper proposed standardized procedures for a satellite to conduct a low fuel avoidance maneuver when the "passive space-based space target surveillance system" was triggered. They simulated a circular maneuver to avoid debris and return on mission using either 6.3 grams of fuel with a continuous thrust engine, or alternatively 40 grams of fuel with a pulse engine (see Image 10).[73]

Image 10: Rocket Force Proposal for LEO Satellite Avoidance and Initial Orbit Return Maneuver



The second type of "passive RF" that uses the host satellite's antenna, and secondary satellites' signals is also discussed in Chinese literature. For example, the tests that built up to the passive collision avoidance sensor on the

China Space Station began as early as 2006 with bi-static techniques listening to X-band.[74] In 2010 authors from CAS and CAST described a millimeter-wave sensor using bi-static techniques listening to Ka-band, which could detect 3-5cm sized debris at most 15km away.[75]

Chinese researchers have also discussed additional methods with passive RF, such as using passive inverse synthetic aperture radar (ISAR) techniques to determine the position of debris or a satellite. Authors from the Harbin Institute of Technology in 2008 proposed "slight space debris observation [in LEO] with the space-based ISAR previously designed," which they call a passive means of detecting space debris.[76] Authors from the Beijing Institute of Technology in 2008 proposed a space-based passive phased array antenna tuned to the X, Ku, or Ka-bands for debris observation in LEO with a required minimum 300km distance to achieve a warning time of just 30 seconds.[77] China's early techniques have probably evolved, but these are the only examples found during this research.

Infrared

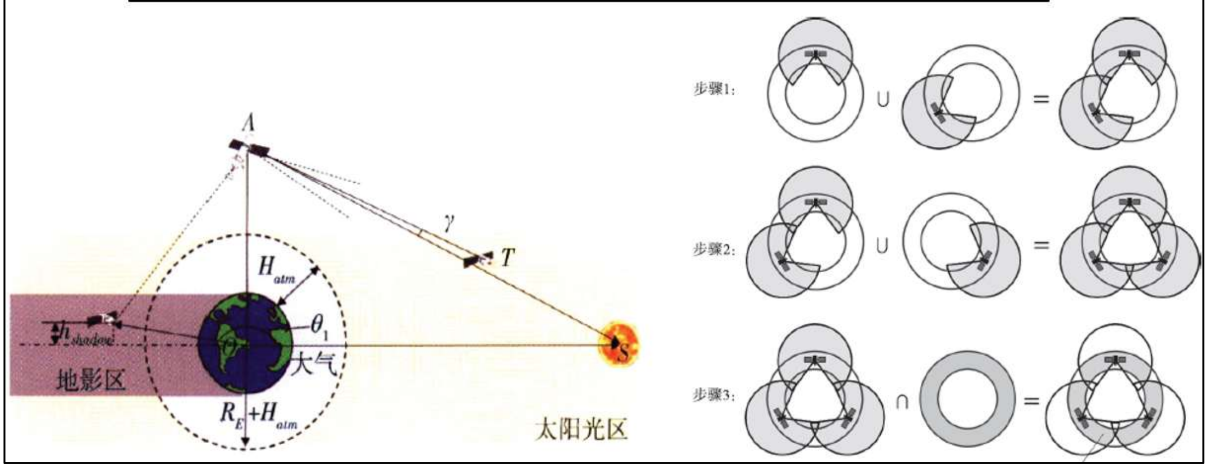
In the same Western study of Chinese space-based SSA articles written in English, the author was dismissive of the Chinese inclusion of the U.S. Space Based Infrared System (SBIRS) missile early warning satellites in the Chinese reviews of the U.S. space-based SSA architecture. However, the Chinese perspective diverges from the U.S. perspective on space-based SSA. China is focused on detecting and tracking all objects in space without a global ground-based sensor network. Since some missiles enter space or can target spacecraft, the Chinese see SBIRS as providing space-based data on objects that sometimes enter space.

More importantly, China views space-based infrared sensors as an important means to alleviate the blackout of space object data that they seem to face during annual seasonal changes. The blackout, or "being in the Earth's shadow" adds more uncertainty for China than the U.S., particularly in higher orbits, because the Chinese are still building their space object catalog above LEO. Even as recent as 2023, Chinese authors have persistently examined the problem they face when tracking higher orbit satellites in the Earth's shadow. [78]

To illustrate the problem, imagine that a satellite maneuvers in the shadow, and the satellite is in MEO or GEO. China probably has only inconsistent access to global ground based optical sensor data needed for precise orbit determination in higher orbits, and during equinox no global optical sensors can detect the sun's light off the satellite. A maneuver during equinox would probably be harder to track in MEO, but even in GEO, departing from RPO or releasing a subsatellite during equinox has already been a tracking challenge for ground-based optical telescopes.[79]

For this reason, authors from the Beijing Institute of Technology tried during the March 2022 equinox to test their proposed architecture of 6-12 satellites near GEO with fused infrared and light detection and ranging (LiDAR) sensors to keep tabs on objects in similarly high orbits. They said their simulation showed one solution to "solving the problem of perception and recognition of space targets under poor lighting conditions, as well as the problem of difficult optical imaging of long-distance space targets under complex backgrounds" (see Image 11).[80] Later in 2023, a key lab of CAS and the DongFangHong Satellite Company iterated on infrared sensors to propose a three satellite architecture, that would "extract the weak infrared characteristics of the target against the cold background" (see Image 11).[81]

Image 11: Chinese Solutions in 2023 to High Orbit Satellites in the Earth's Shadow During Equinox



Conclusion

This report confirmed at least ten Chinese SSA spacecraft, which are listed in Table 2. China has a different approach to the architectures for these systems, different priorities for their placement in orbit, and a different rationale for enabling autonomous decision-making on satellites equipped with SSA sensors. The primary factor driving these three differences is China's lack of consistent access to global ground-based radars and telescopes, a problem that the U.S. has not had to face. China has mitigated the impact of this constraint by prioritizing SSA satellites in LEO that operate autonomously and watch LEO, over SSA satellites dedicated to GEO.

The body of information included in this report supports the argument that China needs space-based SSA, in particular systems with autonomous decision-making, more than any other leading space power. The U.S. has not needed satellites to autonomously maneuver with only on-board sensors because the U.S. has a global network of ground stations to consistently update space object positions. To avoid overtasking China's limited ground stations, China's space operators need satellites to perform basic spaceflight safety functions autonomously, such as identifying debris and avoiding collision, even when outside the footprint of a Chinese ground station. This capability also supports China's ability to avoid unwanted RPO.

If China has a different architecture and more spacecraft autonomy, the U.S. will be increasingly challenged to accurately interpret China's on-orbit behavior. Western analysts must be careful to not oversimplify the post-2015 trend towards autonomy and more military satellites in GEO as a grand strategy to support the establishment of the PLA Aerospace Force, however. The challenge is multifaceted, because China is under different constraints. These constraints have led China to have a broader definition of space-based SSA, that puts autonomous decision-making earlier in the information aggregation process, even before it has been routed through a ground station. This is a fundamentally different approach that Western analysts must study.

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