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CHINA AEROSPACE STUDIES INSTITUTE

CHINA'S GROUND SEGMENT

BUILDING THE PILLARS OF A GREAT SPACE POWER

A BLUEPATH LABS REPORT BY

PETER WOOD
WITH ALEX STONE AND TAYLOR A. LEE

FOR THE CHINA AEROSPACE STUDIES INSTITUTE

Printed in the United States of America
by the China Aerospace Studies Institute

ISBN 9798710347652

To request additional copies, please direct inquiries to
Director, China Aerospace Studies Institute,
Air University, 55 Lemay Plaza, Montgomery, AL 36112

Cover art is "Antena de la Estación del Espacio Lejano de la CONAE y la China Satellite Launch and Tracking Control General en Neuquén," Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Antena_de_la_CONAE-CLTC_Neuquén.jpg

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Acronyms

AIRCAS	Aerospace Information Research Institute of the Chinese Academy of Sciences
AR	Autonomous Region
AVIC	Aviation Industry Corporation of China
BITTT	Beijing Tracking and Communication Technology Research Institute
BDS	BeiDou Navigation Satellite System
BS EDI	Beijing Special Engineering Design and Research Institute
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAAA	China Academy of Aerospace Aerodynamics
CAS	China Academy of Sciences
CASC	China Aerospace Science and Technology Corporation
CASIC	China Aerospace Science & Industry Corporation
CAST	China Academy of Space Technology
CBERS	China-Brazil Earth Resources Program
CCP	Chinese Communist Party
CETC	China Electronics Technology Company
CFOSAT	China-France Ocean Satellite
CGWIC	China Great Wall Industry Corporation
CHEOS	China High-Resolution Earth Observation System
CLTC	China Launch and Tracking Control
CMC	Central Military Commission
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration
CRESDA	China Centre for Resources Satellite Data and Application
DF	Dongfeng [missile series]
EDD	Equipment Development Department
ESA	European Space Agency
FYP	Five-Year Plans
GAD	General Armament Department
GSD	General Staff Department
GEO	Geostationary Orbit
GNSS	Global Navigation Satellite Systems
ICBM	Inter-Continental Ballistic Missile
IRST	Infrared search and tracking system
ISR	Intelligence, Surveillance, and Reconnaissance
JIDS	Joint Integrated Data Link
JSLC	Jiuquan Satellite Launch Center
LEO	Low Earth Orbit
LPAR	Large Phased-Array Radar
MCF	Military-Civil Fusion
MIIT	Ministry of Industry and Information Technology
MOST	Ministry of Science and Technology

MUCD	Military Unit Cover Designation
NASA	National Aeronautics and Space Administration
NDU	National Defense University
NDRC	National Development and Reform Commission
PLA	People's Liberation Army
PLAAF	People's Liberation Army Air Force
PLAN	People's Liberation Army Navy
PNT	Positioning, Navigation and Timing
PRC	People's Republic of China
RADI	Institute of Remote Sensing and Digital Earth
RMB	Renminbi
SASTIND	State Administration for Science, Technology and Industry for National Defense
SLBM	Submarine-Launched Ballistic Missile
SOE	State-Owned Enterprise
SSA	Space Situational Awareness
TSLC	Taiyuan Satellite Launch Center
TT&C	Telemetry, Tracking and Command/Control
VLBI	Very Long Baseline Interferometry
XSCC	Xi'an Satellite Control Center
XSLC	Xichang Satellite Launch Center

Key Findings

CHINA HAS GRAND AMBITIONS FOR SPACE INFRASTRUCTURE

While China has not released its Great Space Power Strategy, projects such as the National Civil Space Infrastructure Mid- and Long-Term Development Plan and the Space-Earth Integrated Information Network Mega Project point toward a resilient system of systems that will allow data sharing between space, air, sea and ground assets, including unmanned vehicles for economic and defense purposes.

THE GROUND SEGMENT IS LARGELY OPERATED BY THE CHINESE MILITARY

The PLA, specifically the Strategic Support Force's Space Systems Department, plays a major role in the launch, tracking, command, and long-term operations of China's growing constellations of satellites. As the Chinese military continues to modernize on its path toward informatization and eventually intelligentization, space systems will play an even greater role, necessitating the PLA's continued involvement in defense and civilian space infrastructure programs.

THE GROUND SEGMENT FOR CHINA'S SPACE PROGRAMS HAS EXPANDED DRAMATICALLY

The last ten years have seen remarkable growth in the number and sophistication of ground stations to support China's scientific and defense-related space programs. Examination of commercial satellite imagery of stations built during that period saw the expansion of their capabilities through the addition of antennas and other infrastructure. New stations have been set up, and existing stations expanded. Based on public plans, this momentum is likely to continue.

COMMERCIAL APPLICATIONS AND OPERATORS WILL PLAY A GREATER ROLE IN GROUND SEGMENT OPERATIONS

The Chinese government, specifically the PLA and the Chinese Academy of Sciences (CAS), have been the main developers of space infrastructure. However, the commercial market, encouraged by government initiatives, is seeing rapid growth. Space services, including TT&C operations and equipment, have grown significantly. However, determining the degree to which this growth is independent from the well-established SOEs remains a challenge.

THE UNITED STATES REMAINS AHEAD IN SPACE INFRASTRUCTURE

While China's deployment of multiple constellations of satellites and the development of an extensive space ground segment is notable, it does not approach the technological sophistication or size of many of the systems deployed by the United States. In many cases, what appears to be novel in a Chinese context proved to be emulating programs that have been underway in the United States for decades.

Introduction

Space operations are not just a matter of rockets and satellites: ground stations, commonly recognized by their large satellite dishes, play an invaluable role in operating satellites and other spacecraft. Communicating with satellites and other spacecraft, downloading the data they collect, and other operations require multiple networks of sophisticated processing centers and receiving and monitoring stations.

Ground Segment Station Responsibilities	
Telemetry [遥测]	Data regarding a space object's position and velocity
Remote Control [遥控]	The ability to issue commands to a space object
Communications [通信]	Bi-directional exchange of data, including downlink

The ground segment, particularly Telemetry, Tracking and Command (TT&C) stations, provide a vital service in downlinking data and monitoring satellites' orbits. These stations and the control centers also help satellites respond to emergencies such as solar events (which can harm satellites or degrade communications with their ground stations) and regain control if they fall out of communication.

China's network of ground stations domestically and abroad and its fleet of space tracking and military support vessels are a less obvious but important player supporting the launches of new satellites, maintaining the accuracy of its PNT constellations, and downlinking data from its growing constellations of remote sensing satellites.[i]

This study is meant to provide a background on the development of this system, the various technological hurdles that have been overcome, its capabilities, and their implications for the United States. It provides an overview of China's ground segment, its satellite telemetry, tracking and command (TT&C) ground stations, military early warning radars, Satellite Laser Ranging (SLR) stations, and supporting radio and optical observatories.

TT&C stations ensure proper operation of satellites by receiving data, sending new commands, observing orbital position, and watching for debris. These stations are typically large permanent facilities. However, because they require line of sight to operate, road-mobile systems and specially-equipped ships are often used to ensure continuous contact with a satellite throughout its orbit. Therefore, countries frequently lease or build stations outside their territories to ensure coverage.

Lasers installed in permanent or mobile laser stations can bounce light off objects in orbits and observe the reflections to determine positions and ranges. Large scale radio antennas, sometimes networked together with other installations around the globe, can be used to pick up and enhance faint radio emissions. These stations can engage in science projects, listen to natural radio waves from distant stars and galaxies, or assist in maintaining connections with exploratory probes operating near the Moon or on their way to other planets.

i As will be detailed in a later section, space is playing a rising role in China's diplomacy and global economic strategies through the "Going Out" Strategy and Belt and Road Initiative (see Section 3).

While there are civilian uses for these facilities, their implications for China's ability to conduct campaigns in space and support its armed forces should not be understated. Ground segments also play a crucial role in modern military applications, controlling and downlinking data from remote sensing Intelligence, Surveillance, and Reconnaissance (ISR) satellites, and operating Positioning, Navigation, and Timing (PNT) satellites, which make up Global Navigation Satellite Systems (GNSS) such as the U.S.' Global Positioning System (GPS), Europe's Galileo, Russia's GLONASS and China's Beidou [北斗].

Many components of this ground segment are involved in providing Space Situational Awareness (SSA). From avoiding detection by enemy satellites to maintaining communications with key data-relay satellites, SSA is an important factor in a country's ability to prosecute and win wars in the future. Military early warning radars that scan the skies for incoming missiles also provide information on objects in low Earth orbit (LEO) such as satellites and debris.

Proper assessment of both China's plans to become a scientific great power and the capability of the Chinese armed forces must factor in the ground segment of its space infrastructure.

Scope Note

While the United States, Russia, and the European Space Agency have well-known ground segments, less has been written on China's.

This study will attempt to fill this gap in the literature, examining the permanent and mobile TT&C stations, TT&C ships, and stations established outside of China.

Note that while many Chinese commercial and state-operated satellite constellations are touched upon in this study, the focus here is on the ground segment and related organizations.

Organization of this Report

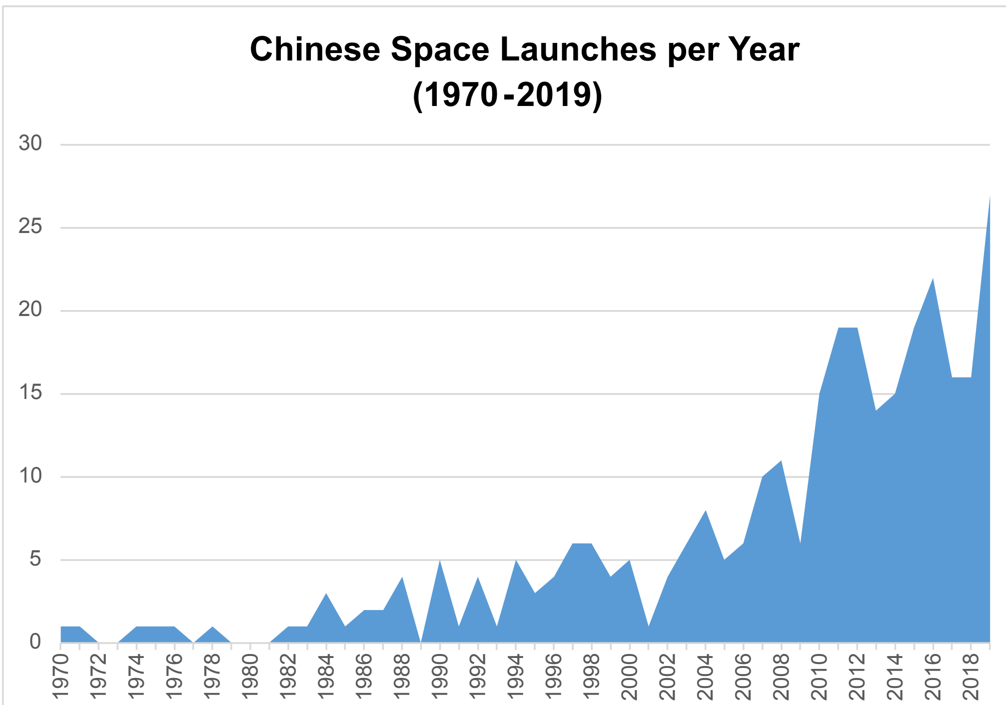
Section 1 first explains China's national plans for space exploration and development of space infrastructure before turning to examine the specific application and strategic plans for China's ground segment. It then provides an overview of the history of China's space program development and outlines the types of systems involved and their applications. Section 2 profiles the specific organizations and stations that make up the ground segment within China. Section 3 first discusses the drivers of China's development of ground segment stations abroad and the roles space plays in economic plans and international scientific cooperation.

1. China's Ambitions for Space

This section first outlines China's broader ambitions in space, then explores how the ground segment fits into the bigger picture through an analysis of its applications.

1.1 Strategic Plans for Space

China's space ambitions are no secret: with over 250 active satellites in orbit and ambitious scientific exploration programs, it has emerged as a major space power. Since 2009, China has consistently launched more than ten rockets per year, reaching an all-time high of 27 in 2019, and is on track to hit a new high in 2020, with a goal of 40 launches.[1]



China is determined to become what it calls a "Great Space Power" [航天强国], and this rapid launch tempo reflects a series of milestones for scientific exploration and space infrastructure projects set by the Chinese leadership to achieve that goal. Li Guoping [李国平], the spokesperson for CNSA and director of its systems engineering department, has described China's three-phase plan for space with major milestones in 2020, 2030, and 2050.[2]

Milestones for Chinese Space Programs		
2020	"Make major breakthroughs in key points and enter the ranks of Great Space Powers" [重点突破, 进入航天强国行列]	• Complete Beidou GNSS • Launch China's Mars mission (Tianwen-1) • Complete the "China High-Resolution Earth Observation System" • Lunar sample return mission (Chang'e 5) • Begin construction of a long-term space station (completion expected 2022)
~2030	"Make comprehensive improvements, join the front rank of global Great Space Powers" [整体跃升, 跻身世界航天强国的前列]	• Complete first flight of heavy launch vehicle (expected 2028) • Establish orbital service and maintenance system • Autonomous orbital refueling • Automated maintenance of spacecraft in orbit • Automated space debris removal • Establish the "Space-Earth Integrated Information Network" • Complete national civil space infrastructure (2025) • Crewed lunar landing
2050	"Take the lead, Comprehensively Become a Great Space Power" [超越引领，全面建成航天强国]	• Crewed mission to Mars • Establish long-term base on the Moon • Deep space exploration, including visiting the edge of the solar system • Creation of low-cost, reusable spacecraft transportation system

While parts of the programs listed above will be touched upon in later sections, two major efforts are playing an outsize role in defining the development of China's ground segment.

National Civil Space Infrastructure

In October 2015, NDRC, the Ministry of Finance, and SASTIND jointly issued the National Civil Space Infrastructure Medium- to Long-Term Plan (2015-2025) [国家民用空间基础设施中长期发展规划].[3]

According to the Plan, civil space infrastructure refers to space-Earth integrated engineering facilities that provide users with remote sensing, communications, broadcasting, navigation and positioning, and other products and services using space resources.[4]

The Plan proposed a phased approach to developing China's civil space infrastructure, divided among China's Five-Year Plans (FYP):

Phase	Objectives
12th FYP Period (2011–2015)	Establish the backbone of the national civil space infrastructure; Build a satellite development model and service support mechanisms; Formulate data sharing policies.
13th FYP Period (2016–2020)	Form three major systems including satellite remote sensing, satellite communications & broadcasting, and satellite navigation & positioning; Basically, complete the national civil space infrastructure; Create a commercialization model; Be capable of providing international services.
14th FYP Period (2021-2025)	Build a technologically advanced, highly efficient national civil space infrastructure system with global coverage that supports economic and social development domestically and globally.

Construction and development of the three major systems of satellite remote sensing, communication & broadcasting, and navigation & positioning are central to the success of the Plan. Each of these three systems can be divided into the space component and the ground component.

For the satellite remote sensing system, the space component mainly consists of the land, ocean, and atmospheric observation satellite series. The ground component mainly includes a network of remote sensing satellite receiving stations, data center(s), general application support platform(s), and a shared network platform. The Plan noted a need to coordinate the construction of ground facilities such as receiving stations, to expand the construction of overseas stations, to realize the coordinated operation of multiple stations, and to coordinate the services of land, sea, and meteorological satellite data centers.

For the communication and broadcasting system, the space component includes multiple fixed and mobile communication broadcasting satellite series. When it comes to the ground component, the Plan proposed both upgrading existing facilities and building new ones, including TT&C stations, gateway stations, uplink stations, and calibration fields for communication satellites.[5]

The Plan noted that the development of the navigation and positioning system had been incorporated into the unified planning and implementation of China's Second-Generation Satellite Navigation System National S&T Mega Project [中国第二代卫星导航系统国家科技重大专项].

The first phases of this plan, between 2011-2019, saw rapid growth in space infrastructure, expanding networks of ground stations, and a high tempo of satellite launches to deploy communications and remote sensing satellites. Other goals appear to have been met, with significant commercialization of China's space sector. Between 2016-2020, for example, China launched satellites for Algeria, Argentina, Belarus, Ethiopia, Indonesia, Pakistan, and Saudi Arabia. Additional developments in this area will be discussed in greater detail in Section 3.

While the plan is framed in civilian terms, each leg of the three systems will, of course, have strong potential for use in military operations as well as civilian applications. There do not appear to be public details about a military analog to this Plan, as will be discussed in greater detail in subsequent sections, though the Chinese military oversees large swathes of China's ground segment and space programs.

However, a second effort, described in a separate set of plans, is explicitly meant to unify both civil and military capabilities.

The Space-Earth Integrated Information Network Mega Project

Launched in early 2017, the Space-Earth Integrated Information Network Mega Project [国家天地一体化信息网络重大工程], managed by the Ministry of Science and Technology (MOST) and led by China Electronics Technology Company (CETC), is intended to achieve the comprehensive integration of a space-based information network, future internet, and mobile communication network.[ii],[6] Put another way, the megaproject is

ii The National Science and Technology Innovation Plan for the 13th Five Year Period, released by the State Council in July 2016, announced plans to launch a group of national S&T R&D megaprojects called titled S&T Innovation 2030, which includes the Space-Earth Integrated Information Network Mega Project. These megaprojects are designed to "reflect national strategic intentions" [体现国家战略意图], and, as the name suggests, seek to achieve significant breakthroughs by 2030. See: "Notice by the State Council on Releasing the National Science and Technology Innovation Plan for the 13th Five Year Period" [国务院关于印发"十三五"国家科技创新规划的通知], Gov.cn, 8 August 2016, http://www.gov.cn/zhengce/content/2016-08/08/content_5098072.htm.

designed for the purpose of “providing information network coverage wherever [China has] national interests.”[7] According to China Academy of Sciences (CAS) Academician and CMC Equipment Development Department (EDD) researcher Yin Hao [尹浩], the information network, when completed, will consist of various types of satellite systems (reconnaissance & surveillance satellites, communication satellites, navigation & positioning satellites, early-warning satellites, meteorological satellites, etc.) on different orbits, supplemented by land-, sea-, and space-based information systems and application terminals to form an organic, intelligent, distributed, space-Earth integrated global information network system.[8] This integrated network will support four application areas: spacecraft, guided missile, and space launch centers, near space[iii] flight vehicles, and unmanned aircraft (UAVs).

The Mega Project has already met some of its milestones. In April 2018, CETC announced its “first major achievement” since project inception: a “ground information port” [地面信息港] that “integrates information network, remote sensing, geographic information, positioning & navigation and other information to connect information resources and user needs.”[9]

China’s Military-Civil Fusion (MCF) strategy will play an important role in this Mega Project. In a journal article published in August 2017, CAS and China Academy of Engineering (CAE) Academician, Wuhan University Professor Li Deren [李德仁] highlighted the dual-use characteristic of the space-based information network, noting that the development of a positioning, navigation, timing, remote sensing, communication (PNTRC) network can significantly advance the MCF initiative. Li underscored the project’s enormous economic potential and national security implications but also noted that as a first step, much work is needed to promote the integration of the communication, navigation, and remote sensing satellite systems between the military and civilian sectors.

Importantly, this Mega Project gives an indication of the ultimate goal for space infrastructure: to reduce reliance on a ground segment. Writing in the ZTE Technology Journal in August 2016, a group of researchers from the Harbin Institute of Technology and Nanjing University argued that the design of the space-air-Earth integrated information network architecture should aim to downplay the role played by ground stations.[10] They indicated a need to “achieve uninterrupted space-based wide-area data acquisition, processing, and transmission functions without the need to establish a dedicated ground station network globally.”

But what are these plans intended to accomplish? The following section will briefly touch upon some of the key applications for the ground segment.

iii Near space is defined as the upper atmosphere above 20 kilometers and reaching the “Kármán Line” at 100 km typically used to define the beginning of space.

1.2 Composition and Applications of China's Ground Segment

Space Situational Awareness

A fundamental reason for China's ground segment is to help China maintain Space Situational Awareness (SSA), that is, the ability to detect, track, and identify objects in orbit. Satellites can be tracked through a number of means, including radar, optical telescopes, lasers, and radio receiving stations.

Space Situational Awareness Network

It is important to note that the U.S. operates a global network of ground-based radars and telescopes which in various incarnations has been in operation since the late 1950s. Russia and France also operate similar systems. The most recent version of the U.S. system, called "Space Fence" was declared operational in March 2020. The U.S. Space Force Space Surveillance Network already tracks some 26,000 objects and is capable of tracking objects ten centimeters across. The system is composed of an operations center at Redstone Arsenal, in Alabama, and radars on Kwajalein Atoll in the Marshall Islands.

Space tracking is also important due to the rising risk of collision between satellites or from space debris. Debris from anti-satellite (ASAT) missile tests by China in 2007 and India in 2019 have generated significant amounts of debris that is still in orbit. In 2009, Kosmos 2251, a Russian military communications satellite, collided with Iridium 33, a commercial communications satellite. The event generated significant debris, further illustrating the necessity of precise tracking of active and defunct satellites and responsible operation to ensure they do not harm other spacecraft after their mission ends.

SSA also has military implications. Identifying a reconnaissance satellite's orbit, for example, can provide sufficient time to take measures to conceal sensitive systems or for personnel to camouflage themselves from visual, infrared, or radar sensors. Most worryingly, precise characterization of an orbit is also vital to conduct attacks against a satellite, whether a direct kinetic, dazzling, or jamming attack. Access to ground stations also offers the potential for hacking attacks through the connections used to control the satellite. Networked databases of imagery and other data collected from satellites by ground stations are also vulnerable.[11] As one article described it, SSA is "continuous preparation of the battlespace in order to fight and win a war in space" or simply "Space Battle Management."[12]

As technology improves and especially high-quality optics and more powerful lasers become cheaper, there is likely to be a shift in the shape of China's space infrastructure. Worldwide there is an ongoing shift away from large, expensive stations as networks of small but cheap optical and radar satellite tracking stations become more popular.[13] These stations will not reduce the need for large installations necessary for deep space missions, but it will mean that China can easily build redundant and highly accurate systems to track satellites and space debris.

SSA, of course, is not the only military application for ground segment operations.

Ground Segment Military Applications

Modern warfare requires the use of space for intelligence collection, communications, and early warning. Ground segment infrastructure is an essential part of getting this data from satellite to receiving dish, to headquarters or units in the field. The PLA relies on an extensive ground network to collect data gathered from reconnaissance, weather, and early-warning satellites, determine unit locations through Beidou, and maintain communications with distant units via intermediary relay satellites. Maintaining communication with more than 200 satellites and downlinking their data for commercial and military purposes, including a nascent space-based early warning system and a communications network, will increasingly be vital for China's modernizing force. As will be discussed in subsequent sections, much of China's ground segment is operated by the PLA or organizations with close links and data-sharing agreements.

As China completes its transition to an informatized force and looks ahead toward intelligentized warfare [智能化战争], these ground-based links will become even more important in handling larger bandwidth and acting as redundancies combating jamming or degradation of satellite constellations.

Chinese sources make it clear that likely adversaries' reliance on space for warfighting makes space targets and supporting infrastructure an important target in a conflict. The 2000 edition of Science of Campaigns (2000), published by China's National Defense University Press, concludes "to cripple or destroy the enemy's information system would drastically degrade the enemy's combat capabilities by making it blind, deaf or paralyzed."[14] Developing the capability to degrade enemy reconnaissance capabilities in the early stages of a conflict appears to be a major priority for Chinese military planners. This will rely on precise tracking of enemy satellites, so China's ground segment, and particularly the space situational awareness component, will play a vital role in Chinese military space operations.

As a result, there has been major investment in both the ability to field satellites with military applications and in developing countermeasures to deny the use of space to China's adversaries. As noted in the public summary of the U.S. Space Strategy released in June 2020: "[China has] weaponized space as a means to reduce U.S. and allied military effectiveness and challenge our freedom of operation in space."[15]

To attack enemy space assets, China has developed a number of ground-based dazzling systems (which interfere with optics), high-powered lasers, jamming systems, and most famously direct-ascent anti-satellite missiles. In 2019, Acting Defense Secretary Patrick Shanahan stated that "China is deploying (counter space) directed energy weapons," confirming what had been widely speculated for more than a decade.[16]

Two additional areas are worth touching upon briefly as background: datalinks and strategic early warning systems.

Datalinks and Communications

Since the 1990s, China has been working on an automated theater-level C4ISR system called Qu Dian [区电].[17] The system was intended to link together airborne sensors with satellites, buried fiber-optic cable networks, and microwave transmission nodes.[18]

The PLA Navy began building satellite datalinks in the 1980s, but a practical satellite internet network for its ships and outposts (such as those in the South China Sea), called the BlueNet Project [蓝网工程], appears to have only taken shape in the mid-2000s.[19] While reporting on this system focuses on media and information streaming (providing sailors and marines access to digital publications, for example) through a digital portal, the system presumably involves high-bandwidth connections for other purposes.[20] In the early 2010s, China appears to have begun work to develop a tactical data sharing and cooperative engagement capability through the "Joint Integrated Data Link" (JIDS) [全军综合数据链] linking ships, aircraft, and ballistic missiles.[21] The Space-Earth Integrated Information Network Mega Project is likely part of an effort to ensure reliable and redundant links between sensors and forces in support of battle networks like JIDS.[22]

Strategic Early Warning

The Chinese military uses a network of large phased-array radars (LPAR) for early warning. This network, which appears to have been in place by the early 2000s, represents a modernization of the first early warning network of 7010 and 110 radars set up in the late 1960s to assist with missile instrumentation and space tracking. China has at least four LPARs, including stations in Jiamusi, Heilongjiang Province, Lin'an District, Zhejiang Province, Yiyuan County, Shandong Province, and possibly one in Hui'an, Fujian Province.[23] While their focus may be detecting incoming threats, their historical predecessors (the 110 and 7010 radars) participated in space tracking and missile instrumentation missions, and their placement under the SSF suggests a continuation of this role.

As with the other components of its ground segment, China appears to be moving toward space-based platforms. Russia has recently committed to supporting China's modernization of this system.[24] In 2016, S&T Daily stated that China had built a space-based constellation of infrared early warning satellites called the "Outpost" [前哨].[25]

As with other areas, China is not alone in building such satellites. The U.S. Space Development Agency has contracted L3Harris and SpaceX to build and launch eight hypersonic and ballistic missile early warning satellites by 2022.[26] The satellites will be equipped with optical data to be able to communicate with satellites in the DODs Transport Layer data-transmission system. This follows awards in August 2020 to Lockheed Martin and York Space for 20 satellites that will make up the Transport Layer, also required for delivery by 2022.[27]

China's views of space as a strategic domain are not restricted to military applications. Space, especially space-based services, is expected to be a major driver of economic growth.

Economic Development as Driver of Space Applications

China hopes that these satellite services will bolster the domestic economy, generating high-value jobs in advanced manufacturing and generating revenues through space services such as communication ground stations and PNT-related applications. China is expected to build a national civil space infrastructure system by 2025, provide continuous and stable business services, improve data sharing service mechanisms, form a commercial development model, and have international service capabilities.

Chinese analysts estimate that the global space industry will reach $485 billion in 2020, with China's market for launch vehicles, satellite applications, and satellite broadband internet worth over $114 billion.[28] In 2018, for example, Beidou and related satellite navigation applications were supported by a workforce of roughly half a million people.[29] Another example of the envisioned satellite-enabled "internet of things" is smart ships: largely autonomous cargo and other vessels linked to a global network of sensors, GNSS, and weather data. In November of 2018, a Chinese company tested the world's first "intelligent" cargo ship, Pacific Vision [明远], a

362-meter-long Very Large Ore Carrier (VLOC).[30] Chinese companies see fleets of similarly equipped ships as the future of maritime cargo shipping.

The Chinese government began actively encouraging greater investment in space in 2014, and as of 2020, there are over 100 “private” companies involved in space, though disentangling, which are still largely part of the established SOEs working in the sector, remains a challenge.[31]

As will be discussed in later sections, these types of emerging sectors are driving the growth of ground segments within China and abroad.

1.3 Historical Overview of China's Ground Segment

China's ground segment has undergone a series of spurts of growth related to national defense and civilian scientific projects. This section will address that history, charting the initial drive to develop infrastructure to support ballistic missile testing, communications satellites, and reconnaissance satellites, and the faster expansion to first support manned space missions and later deep space programs while accelerating the development of civil space infrastructures such as Earth observation, communications, and GNSS satellites.

Origins of China's Ground Segment

What would become the foundations of China's space tracking and control system dates to the creation of China's first missile test range in the 1950s. In 1956, Chinese scientists founded the Northwest Comprehensive Missile Testing Base [西北综合导弹试验基地], later to become the Jiuquan Satellite Launch Center, with the aid of Soviet technicians and R-2 missiles provided by Moscow.[32]

After the launch of the Sputnik and Explorer satellites by the Soviet Union and the United States in October 1957 and February 1958, the PRC leadership initially set its sights on launching a satellite by 1960. The program, codenamed Project 581 [581工程], was quickly canceled as the difficulty of the project became clear.

In 1960, with the withdrawal of Soviet advisors, Chinese leaders tasked the Chinese Academy of Sciences' Changchun Optical Machinery Institute with developing optical tracking systems under the code-named Project 150 [150工程]. This program and others developing support infrastructure for missile testing would lay the foundations for China's space ground infrastructure.

In June 1967, China established a Satellite Ground Measurement Department [卫星地面测量部] in Qiaonan [桥南], just outside the city of Weinan [渭南] in the central province of Shaanxi, to administer a network of TT&C stations for its space program.

By the beginning of 1970, an initial satellite TT&C network, consisting of stations in Guangxi, Hainan, Hunan, Shandong, Xinjiang, and Yunnan, was complete and was tested out by tracking U.S. Explorer satellites.[33] This network played a significant role in the launches of the Dongfanghong-1 [东方红一号] satellite and the return-type remote sensing satellite.

In 1972, China took the first steps toward building a satellite communications ground station, using equipment donated by the Nixon administration after it was used to transmit coverage of his visit to television audiences in the United States.[34]

To further support the development of domestic satellite communications capabilities, work began on the requisite ground segment infrastructure. In 1974, the Seventh Ministry of Machine Building [第七机械工业部], predecessor to the China National Space Administration (CNSA), China Aerospace Science and Technology Corporation (CASC), and China Aerospace Science & Industry Corporation (CASIC), launched the 450 Project [450工程], a system of tracking and measurement radars for the Dongfanghong-2, China's geostationary communication test satellite.[35] The first Dongfanghong 2 mission in January 1984 failed to achieve geostationary orbit (GEO), but a second test satellite, launched in April of that year, was successful. In the early 1970s, China developed early warning and missile tracking radars, including the large-scale 7010 radar (also called the Xuanhua Radar Station [宣化雷达站]), built into the side of a mountain in Hebei Province, and the Type 110 radar in Zhanyi, Yunnan Province.[36] The stations were used to track foreign satellites, including the Soviet Kosmos-1402.

They subsequently supported tests of the DF-3 and DF-5 missiles in 1979 and 1980.

In September 1977, the CMC approved the Three Grasps [三抓], three major technological development programs: intermediate-range and intercontinental ballistic missiles (ICBM), submarine-launched ballistic missiles (SLBM), and geosynchronous communications satellites. While these programs were initiated in the 1950s and 1960s, they were delayed due to a combination of the withdrawal of Soviet assistance, the Great Leap Forward, and the Cultural Revolution.

Developing the necessary supporting technologies, which ranged from computers to lasers, also required immense effort—and widespread adaptation of foreign technologies. China's limited access to computers was a major limiting factor. When China launched its first satellite in April 1970, for example, the control center in Shaanxi had very limited technologies, including a Doppler radar and single Type 717 computer, and technicians involved frequently had to resort to manual calculations and slide rules.[37] The now-expanded network of ground stations needed specialized ships to support missile-firing tests. The China Satellite Maritime Tracking and Control Department [中国卫星海上测控部] was founded in June 1968, but the construction of the Yuanwang [远望] tracking ships, which used some of China's early computers such as the Type 151 and Type 260, were not commissioned until 1978.[38] These ships played a key role in tests of China's first ICBM in the South Pacific in May 1980 and the Julang-1 submarine-launched ballistic missile in October 1982.

In 1986, China Launch and Tracking Control (CLTC) [中国卫星发射测控系统部] was established to manage China's network of TT&C stations.[39] In December of the same year, the China Remote Sensing Satellite Ground Station was founded to administer scientific Earth observation ground stations under the Chinese Academy of Sciences. As will be discussed in greater detail in Section 2, CLTC and its subordinate organizations are staffed by members of the PLA and are an integral part of China's military space operations.

Shenzhou: China's Manned Space Program

Perhaps the highest-profile component of China's space program is the Shenzhou [神舟] manned space program. China initiated its first manned space program in April 1971, the 714 Project [714工程], but the project was canceled due to the lack of necessary supporting technologies and infrastructure. Just over twenty years later, and having laid the groundwork for a robust space program, Chinese leaders began a new program. In 1992, the Manned Space Program (Project 921) was established. However, the complexity of spaceflight operations and the necessity of maintaining communications, particularly during reentry, appears to have required the Chinese government to begin making arrangements to build or lease ground stations outside China's borders.[40] The TT&C and communication system designed for the manned space program is the largest one to date, incorporating a much more comprehensive set of functions and the most advanced technologies.

Agreements were signed, and construction began in Africa, South America, and South Asia. These facilities in Chile, Kenya, Kiribati, Namibia, and Pakistan were used to support a series of missions in the early 2000s, culminating with the October 2003 launch of Shenzhou 5, China's first crewed spaceflight mission. Further manned spaceflights are planned for later in 2020, and China plans to complete construction of the 66-ton Tiangong-3 space station by 2022.

Lunar and Mars Exploration

As outlined in section 1, China has set major milestones for the exploration of the Moon and Mars.

The Chinese Lunar Exploration Program (CLEP) was initiated in 2003 and is divided into three initial stages: orbiting, landing, and sample return. The first lunar probe, Chang'e 1, was successfully launched in 2007, marking an important breakthrough in China's Deep Space TT&C capabilities. Chang'e 2, launched in 2010, went beyond lunar space to intercept an asteroid and required a more powerful TT&C network. The last of these initial stages of lunar exploration, the Chang'e 5 lunar sample return mission, is scheduled for late 2020.[41]

In July 2020, China launched its second mission to Mars, consisting of the Tianwen-1 [天文一号] spacecraft and a lander and rover.[42] The first mission, Yinghuo-1 [萤火一号], was intended to be China's first probe to visit Mars. However, the joint effort with Russia, launched with the Fobos-Grunt sample-return probe, ended in failure in November 2011, after the Russian deep space network lost contact with the probes.[43] Perhaps reflecting China's drive for self-reliance and the memories of that failed program, China's deep space, and Very-Long-Baseline Interferometry (VLBI) networks have been expanded to support the Tianwen-1 mission, which will arrive at Mars in April 2021.[44]

These programs, which require significantly larger antennae arrays, have been a driver of the growth of China's TT&C network domestically and abroad. Stations in Beijing, Jiamusi, Kashgar, Kunming, Shanghai, and Urumqi, when networked with stations in Namibia, Argentina, or elsewhere, provide a much more powerful capability than if the domestic network alone was used.[45] As a result, China has, independently and in partnership with others, established a VLBI network, which combines observations from several distant points for greater resolution.

China began work on large radio telescopes capable of deep space communications and VLBI projects in 1987 with the construction of the 25-meter Sheshan observatory outside Shanghai.[46] The Nanshan 25m radio telescope outside Urumqi followed in 1993. The CAS National Astronomical Observatories of China [国家天文台], founded in April 2001 through the merger of the Beijing, Xinjiang and Yunnan Observatories, the Changchun Satellite Observation Station, and other related organizations, operates many of these stations.

Ground stations in Australia (New Norcia), Chile (Santiago), Spain (Maspalomas) have also provided support to China's lunar Chang'e missions.[47] In 2006, deep space network facilities in Miyun, Beijing, and Kunming, Yunnan were completed to support the Chang'e 1 lunar mission. However, in 2007, Chinese authorities noted that they needed the stations abroad as China did not have a sufficiently large deep space tracking network of its own, especially to support the Chang'e 1 lunar mission.[48] Kouru and Maspalomas have continued to support these missions, including Chang'e 5.[49]

China has also launched a deep space communications relay satellite, Queqiao [鹊桥], to support operations on the far side of the Moon. Launched in 2018, Queqiao was positioned beyond the Moon in the L2 Lagrange point.[iv] Transmissions received from the satellite outside of the Moon's "shadow" could then be relayed on to the Chang'e lander and Yu'tu rover.

iv Lagrange points are areas of space where gravity from different bodies largely cancel each other out, allowing objects to remain in stable positions. This one is one of several between the Earth and the sun.

The Future: Space-Based TT&C

While the development of a global network of ground stations has opened doors for international cooperation, it does not come without risks. Access to stations abroad is contingent upon host-nations' permission and often features language restricting their use for military purposes. In a conflict, China can expect access to these stations to be further restricted, either by the host country or due to international pressure. Therefore, while these stations offer important new capabilities and flexibility, they do not resolve the longer issue of reliable access. As a result, China is investing heavily in communications and relay satellites as well as a larger network of domestic ground stations. The most important of these is the Tianlian [天链] series of data-relay satellites, which China has launched in part to help improve communications and reduce reliance on foreign tracking stations.[50]

The first satellite in the constellation was launched in January 2003. The second was launched in 2008, with the system reaching initial global coverage with the launch of a third in 2012. [51] The second generation of the system, Tianlian 2, was launched in 2019. The satellites sit in geostationary orbit (36,000 km) and can operate similarly to ground stations, though they offer significantly better coverage. The new system features an extended mission lifespan, up to 12 years, and has higher bandwidth transmission.[52]

Another leg of the space-based infrastructure is a space-based Internet of Things (IoT). On May 12, 2020, China launched the latest group of satellites of the Xingyun or "Moving Cloud" Project [行云工程], a planned constellation of 80 communication satellites in low Earth orbit that will provide global IoT connectivity.[53] The two satellites, Xingyun 2-01 and Xingyun 2-02, are testing inter-satellite laser communications as well as ground-connections with IoT devices. In August 2020, the first two satellites of the Xinyun-2 IoT project successfully conducted inter-satellite laser datalink.[54]

At the same time, China has begun launching large high-throughput satellites (HTS), such as the SJ-20 [实践二十号] testbed launched in December.[55] HTS Satellites offer significant increases in transmission capacity compared to other communication satellites.[v,56]

In the near future, these services will increasingly be distributed rather than restricted to a small number of downlink stations and control centers. In 2018, Guan Hui [关晖], CEO of commercial operator Space Wisdom [宇航智科] proposed a new decentralized "Three Nos" [三无] model of satellite management: "No Stations, No Control Center, No Frequency" [无测站、无中心、无频率] which will treat satellites like cloud IT applications.[57]

There are additional, physical reasons to move components of the ground segment into space. Space-based SSA offers several important advantages compared to ground-based systems. Satellite Laser Ranging (SLR) and optical systems used to identify debris are restricted to the hours of a day when there is sufficient sunlight to reflect off objects in orbit but when the sky is still dark enough to image effectively.[58] In contrast, optical and laser systems in orbit can operate 24/7. As a result, this appears to be the direction that both the United States and China have identified as optimal for space tracking duties. It is worth noting that while China has yet to field such a system, Boeing launched the first component of the Space-Based Space Surveillance (SBSS), which can track space objects from deep space to low Earth orbit, in 2010.[59] The US Air Force declared the SBSS fully operational in April 2013.[60]

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v HTS satellites are able to transmit at greater than 100 Gigabits/second, whereas conventional communication satellites typically transmit at 10 Gigabits/second or less.

These next-generations of space-based communications and SSA represent a new phase of China's space infrastructure development. Section 2 provides greater detail on China's existing ground segment and the history of its development.

2. China's Domestic Ground Segment

The preceding sections provided an overview of the trajectory of the development of China's ground segment. In this section, the organizations responsible for operating the ground segment, and to the greatest degree possible, the specific stations themselves, are profiled. Stations located outside China's borders are covered in Section 3.[vi]

2.1 PLA Strategic Support Force Space Systems Department

The organization with the most responsibility for China's ground segment is actually a service under the People's Liberation Army. At the end of 2015, the PLA underwent significant reorganization, including the creation of a new service, the PLA Strategic Support Force (SSF) [解放军战略支援部队]. The service is intended to act as an "information umbrella" and provide advantages to the PLA in the aerospace, space, cyber and electromagnetic domains.[61] This includes involvement in PLA information operations, electronic warfare, and cyberattacks, with these largely organized under its Network Systems Department [网络系统部].

Most relevant for this study is the creation of the Space Systems Department (SSD) [航天系统部] under the SSF, which has taken on many of the space launch, tracking, early warning and reconnaissance duties that had previously been allocated among the PLA's General Armaments Department (GAD) [总装备部] and the components of the PLA General Staff Department's (GSD) [总参谋部] 2nd and other Departments. As examined below, there is clear evidence showing that much of China's ground segment is now operated by the SSD. This includes most of China's SSA, space launch, and missile instrumentation infrastructure.[62]

Other areas with less clarity include the operations of China's constellations of spy satellites. China began launching photographic and electronic reconnaissance satellites (publicly referred to as technology demonstration satellites [技术试验卫星]) in the early 1970s.[vii],[63]

The PLA's current constellation of Earth observation satellites designated Jianbing [尖兵] but launched under civilian designations, likely consists of the Yaogan [遥感] 8, 15, 19, 22, and 27 satellites.[64] Elements of the Yaogan system may be similar to the U.S. Naval Ocean Surveillance System (NOSS) signals intelligence (SIGINT) satellites.[65] These are most likely subordinate to the Aerospace Reconnaissance Bureau [航天侦察局], formerly under the GSD's Second Department (Intelligence).

In addition, the structure of satellite development programs and frequent exchanges or connections between the SSF and the various organizations charged with downlinking data from China's other satellites strongly suggest SSF involvement in those programs.

The SSD almost certainly plays a hand in another component of the PLA's ground segment: operations of its communications satellites. China launched a series of communications satellites divided into two groups: Fenghuo [烽火], first launched in 2000, believed to be dedicated to military tactical communications, and Shentong [神通], first launched in 2003, for strategic communications.[66] At least six of these satellites (four Shentong, two Fenghuo) appear to be active as of writing.[67]

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vi The geographic coordinates of individual stations and areas of interest are provided in Appendix 2.

vii The first two missions of the Changkong [长空] series electronic reconnaissance satellites in 1973 and 1974 both failed shortly after launch. The first successful launch achieved low-Earth orbit in 1975.

The former GSD included a number of regional satellite communication stations [卫星通信地球站] which have subordinate numbered communications regiments [XX通信团]. The 2nd Satellite Ground Station, for example, is based in Xi'an and uses the MUCD 61068. It is likely subordinate to the SSF. In addition, each PLA service is believed to operate its own central satellite communication station [通信总站]. Provincial-level Military Districts [军区] also appear to have dedicated satellite ground stations as well.

The SSD also appears to have taken over roles such as operations of Beidou and other navigation systems for the PLA, such as the CMC Joint Staff Department Navigation Bureau [联合参谋部导航局] and its Central Satellite Navigation Station [卫星导航定位总站] (Unit 61081, an SSF unit), which is responsible for the Beidou navigation system.[68]

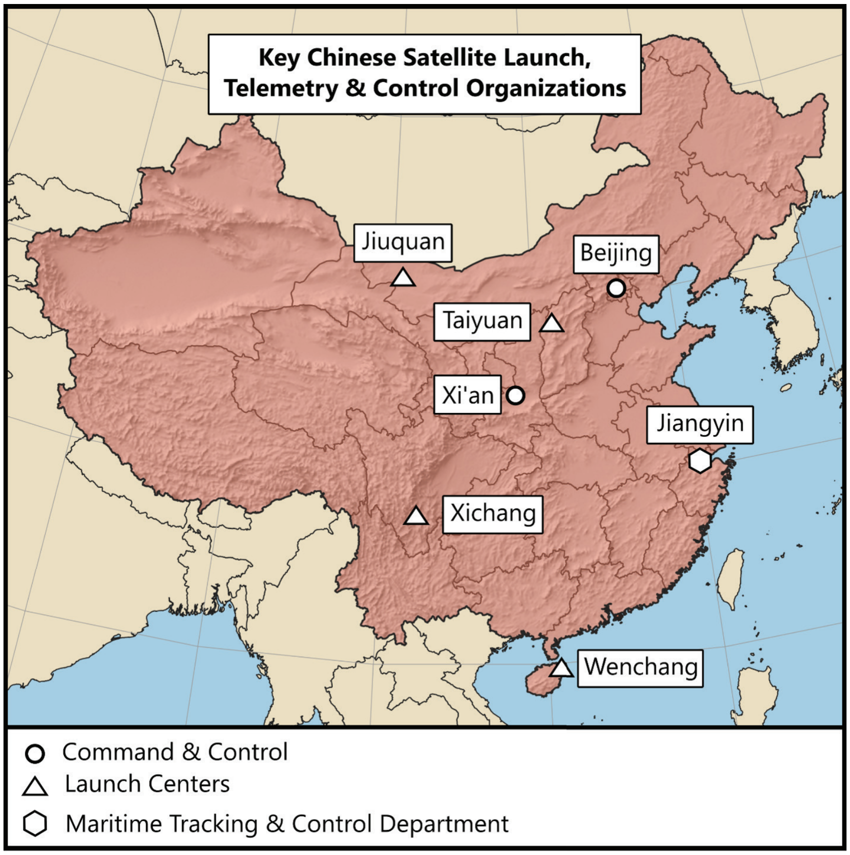
Lt. General Shang Hong

One of the SSF's deputy commanders, Lt. General Shang Hong [尚宏], is believed to be the commander of the SSD. He previously served as chief of staff for the former GAD, Chairman of the China Satellite Launch and Tracking General (CLTC), and commander of the Jiuquan Satellite Launch Center.[69] Hao Weizhong [郝卫中], deputy commander of the SSD, formerly served as commander of Taiyuan Space Launch Center.[70] Fei Jiabing [费加兵], who serves as chief of staff, previously commanded the China Satellite Maritime Tracking and Control Department, which operates China's fleet of shipborne TT&C stations.[71]

2.2 Commanding and Supporting Organizations

China Launch and Tracking Control (CLTC) [中国卫星发射测控系统部]

The organization believed to operate the majority of China's space ground infrastructure is the China Satellite Launch and Tracking General (CLTC) [中国卫星发射测控系统部] (lit. China Satellite Launch & Tracing Systems Department). Established in 1986, it manages China's space tracking network and space launch centers.[72]



While outwardly portrayed as an independent civilian organization, there are strong indications that is a major component—or potentially synonymous with—the PLA SSF Space Systems Department.[73] Its subordinate components are identified as SSF SSD units, and its current and former leadership includes SSF personnel: the Chief of Staff of the former PLA GAD (Headquarters Department) [总装备部 (司令部)] has historically concurrently occupied the role of CLTC chairman [主席].[74] In addition, a China Youth Daily article in 2011 noted that CLTC obeys the commands of the GAD. [75]

CLTC's scope of responsibilities has been described as including providing launch and TT&C services for domestic and foreign satellites, designing and producing satellite tracking, measurement & control, and launch site construction.[76] CLTC consists of the following entities: Xi'an Satellite Control Center (XSCC), Xichang Satellite Launch Center (XSLC), Jiuquan Satellite Launch Center (JSLC), Taiyuan Satellite Launch Center (TSLC), Beijing Tracking and Communication Technology Research Institute (BITTT), and Beijing Special Engineering Design and Research Institute (BS EDI).[viii]

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viii While analysis of the specific equipment types used in ground segment operations is beyond the scope of this study, it should be noted that China Electronic Technology Group Corporation's (CETC) [中国电子科技集团公

CLTC is heavily involved in China's space cooperation efforts globally, building stations in Chile and Argentina, among others. It provides services for many different nations, and its International Cooperation Department frequently holds outreach events promoting international space cooperation.[77] China Great Wall Industry Corporation (CGWIC), the government-owned commercial space service provider, for example, identifies CLTC as one of its primary subcontractors.[78]

Another organization under CLTC but which appears to have a limited direct role in space tracking is the Beijing Special Engineering Design and Research Institute (BS EDI/BSEDRI) [北京特种工程设计研究院/北京特工院], which is responsible for the overall design of China's space launch sites (Jiuquan, Xichang, Taiyuan, Wenchang).[79]

Beijing Tracking and Communication Technology Research Institute (BITTT) [北京跟踪与通信技术研究所]

Established in 1965, the Beijing Institute of Tracking and Telecommunications Technology [北京跟踪与通信技术研究所] (BITTT) leads the design of TT&C communication systems for China's space programs, including the construction of TT&C stations abroad. The Director of BITTT also sits on a panel of space experts convened by the CMC S&T Committee.[80]

BITTT is responsible for the design of both the TT&C system as well as the landing site system for China's manned spaceflight project. A May 2005 article in the PLA Daily noted that BITTT is the only organization that undertakes the design of two subsystems out of the seven major manned spaceflight systems in China.[81] BITTT's central task, as of 2016, was supporting China's manned space and lunar exploration programs, building on its previous experience participating in major space missions in the following capacity:[82]

- TT&C and recovery tasks of four unmanned flights and three manned flights under the Shenzhou program;
- TT&C tasks for flight tests of launch vehicles and satellites;
- The design of the TT&C systems for all satellite control centers, TT&C stations, and the Yuanwang fleet;
- Demonstration verification tests of the Beidou Satellite's rapid positioning system;
- The Chang'e-2 mission.

In its capacity operating as a general contractor of TT&C systems, BITTT has undertaken and completed the construction of ground TT&C systems for Nigerian satellites, Venezuelan satellites, and SinoSat, as well as the construction of overseas TT&C stations in Chile and Kiribati. As of 2016, R&D for the ground application and data receiving system for the Chang'e-3 lunar orbiter was underway at BITTT.

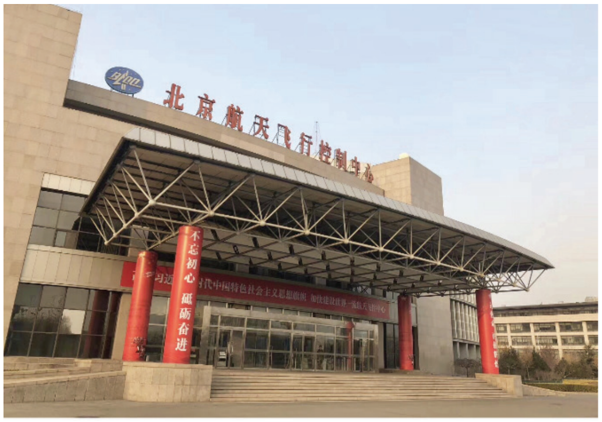
A study in 2020 for the U.S. China Economic and Security Commission suggests that BITTT, previously an organization under CLTC, is now subordinated to the SSF SSD.[83] This is supported by the fact that Dong Guangliang [董光亮], a senior engineer who sits on a panel of space experts convened by the CMC S&T Committee, was identified as the director of BITTT in an article from November 2017.[84]

Dong previously served as the chief designer of the TT&C systems that supported the manned space program, phase three of the lunar exploration program, and the high-resolution earth observation system [高分]. He also

司] 54th Research Institute appears to be the main contractor for China's ground segment, producing "Over 90% of communication & 30% of TT&C equipment" for China's manned space program. It also produces equipment for Deep Space and VLBI stations, Yuanwang ships and Beidou ground stations. See: "The 54th Research Institute of China Electronic Technology Group Corporation," CETC, 25 November 2017.

served as a deputy chief designer of the Chang'e 4 and Mars exploration missions. According to information from 2016, BITTT is located in Beijing Space City [北京航天城] in Haidian District and employs over 500 people. It has more than ten subordinate laboratories and offers graduate programs and post-doctoral research positions to civilian as well as active-duty military personnel.[85]

Beijing Aerospace Flight Control Center [北京航天飞行控制中心]



Beijing Aerospace Flight Control Center

The Beijing Aerospace Flight Control Center [北京航天飞行控制中心], a component of the PLA SSF SSD, serves as the command and control center for China's manned space, lunar exploration, and Mars exploration programs.[86]

Established in 1996, it is China's first modern flight control center capable of performing tasks such as transparent control, visual TT&C support, high-precision real-time orbit determination, high-speed data processing, and clear image transmission.[87] While launch phase operations are handled by the respective launch centers, the control center receives data from the Xi'an Control Center and relays commands throughout the remainder of a mission.

During the July 2020 Tianwen-1 Mars exploration mission, for example, the Center took on a myriad of functions, including command and control, computing, data processing, information exchange, and long-term aircraft management.[88] As the mission flight control center, this center is also responsible for Earth-Mars transfer orbit control, Mars orbit capture control, Mars surface teleoperation control, and orbiter operation management.

Li Jian named Director of the Beijing Aerospace Flight Control Center

Li Jian [李剑] was appointed Director of the Center in 2016.[89]

2.3 Xi'an Satellite Control Center [西安卫星测控中心]

The headquarters of China's Satellite Monitoring and Control Network [中国卫星测控网] is the Xi'an Satellite Control Center. It is also formerly known as the 26th Testing and Training Base [总装第26试验训练基地] of the General Armament Department (GAD). The Center remains part of the PLA, though it is now subordinate to the Strategic Support Force. Yu Peijun [余培军] has served as Director and Qi Yahu [祁亚虎] as Party Secretary since 2017.[90] In 2017, Qi was identified as a member of the SSF during his participation as a delegate to the CCP's 19th Party Congress, and he is believed to hold a rank above Major General.[91]

Its primary roles are satellite tracking, data transmission information processing, monitoring, and control. Spacecraft launched from China's launch centers are controlled from the Xi'an Center, with the participation of their subordinate TT&C infrastructure. Data from satellites and spacecraft is received and processed at the center, and then passed to the Beijing Aerospace Flight Control Center.

The Xi'an Center has major responsibility for tracking and reentry missions for China's crewed space program, which are handled by a combination of stations abroad, including the Swakopmund, Namibia station, and the Third Mobile Station in Inner Mongolia (both profiled in later sections).[92] The Shenzhou-1 mission in 1999, for example, involved three coordinating centers, 11 ground stations within China and abroad, and four maritime TT&C ships.[93]

The Center has multiple subordinate large ground stations and controls mobile stations. Some of these ground stations also have subordinate sub-stations [分站].

Under the Xi'an Center, the Xi'an Measurement and Control Technology Department [西安测控技术部] is the organization directly responsible for administering stationary and mobile TT&C stations.

History

Founded as the Satellite Ground Tracking Department [卫星地面测量部], in Qiaonan, Shaanxi in 1967, the department was initially subordinate to the 20th Base (Jiuquan SLC).

The department played an important role in all three of the "Three Grasps," providing TT&C support to the Dongfanghong communications satellite and missile tests. China's early warning radar network built during the early 1970s, including the 7010 radar and Type 110 radar, were operated by the Department. As part of the expansion of tracking infrastructure ahead of ICBM and SLBM testing in the early 80s, the organization was upgraded to a Center that was formally established in September 1975. The current form of the organization was created in 1987 when it moved from Weinan to Xi'an in 1987 to accommodate the requirements of its expanding size.[94]

In the 1980s and 1990s, the core aerospace launch and TT&C network [航天测控网] was composed of the three launch sites: Jiuquan, Taiyuan, and Xichang, supported by command and control sites in Xi'an and Beijing and assisted with data from ground stations in Changchun, Lingshui, Kashgar, Nanning, Weinan, Xiamen, and the fleet of Yuanwang ships in Jiangyin, Wuxi.

Ground Stations

The following ground stations are identified as subordinate to the Xi'an Satellite Control Center. While their personnel do not necessarily wear military uniforms, it is clear that these are units of the PLA Strategic Support Force.

Changchun Station

The Changchun Satellite Tracking & Control station [长春测控站] was established in 1968 and is located in Liming Village [黎明村], outside of Changchun, Jilin Province. It has been identified as subordinate to the PLA SSF and is believed to use the MUCD 63759.[95] It is equipped with a 154-IIB monopulse radar, and may also be a sub-station of the Jiamusi Satellite Tracking & Control station, which is part of the Deep Space Network.[96]

Kashgar Station

Kashgar (or Kashi) in Western Xinjiang AR is home to several TT&C stations, including China's first space TT&C station, established in 1968.[97] It appears to have been subordinated under Base 26 of the GAD until the military reorganization in 2016, when it was transferred over to the SSF. It uses the MUCD 63783.[98]

Lingshui Station
[陵水测控站**]**

One of several space tracking and downlink facilities based in Hainan Province is the Lingshui Control Station. The station began operations in April 2008.[99] It has been involved in tracking experimental SJ-series satellites.[100] While few details are available, commercial imagery indicates the facility was built in 2012 and features a 40m radome. The National Satellite Ocean Application Service [国家卫星海洋应用中心] operates a ground station 8 km to the northeast.[101]

Lingshui Station

Menghai Station
[勐海测控站]

A station appears to have been built in Menghai County, Xishuangbanna, Yunnan Province, possibly sometime before 2010. The Menghai station, identified as supporting the Xi'an Center, supported the Jilin-1 Gaofen-02A [吉林一号高分02A卫星], and possibly the Ningxia-1 [宁夏一号卫星], satellite launches in November 2019.[102]

Menghai Station

It also carried out tracking for a Jielong-1 carrier rocket [捷龙一号运载火箭] launch with three satellites in August 2019. While there does not appear to be a previous mention of the station in Chinese news media, a review of commercial satellite imagery suggests it has existed since at least 2010, had satellite dishes since at least 2012, and doubled in size between 2012 and 2016.[103] It may be a sub-station of the Nanning Station.[104]

Minxi Station
[闽西测控站]

The Minxi Station was originally founded as the Minxi Observatory in October 1967. It provided tracking support to the failed launch of the Changkong-1 [长空一号] electronic reconnaissance satellite in July 1974.[105]

In 1975, the station was expanded to house the 450 Project, the microwave measurement and control system for experimental Dongfanghong 2 communication satellite development program, also called the 331 Project.[106] The Dongfanghong 2 satellites were launched on 29 January and 8 April of 1984, the former failing to achieve the desired orbit.[107] After the end of the Dongfanghong 2 program the station was apparently closed, and a new station opened in Xiamen, Fujian. A review of commercial satellite imagery suggests it may have restarted operations in 2019.

Nanning Station
[南宁站]

The Nanning Station was established in 1967 as part of the original space tracking network.[ix] It is located in the Xixiangtang District [西乡塘区], of Nanning, in the Guangxi Autonomous Region.[108] Since its establishment, it has been involved in numerous launches, including the Shenzhou 7.[109] It also has a sub-station [分站] in Yao'an, Yunnan Province that was involved in a 2014 experimental launch as part of atmospheric reentry tests for the Chang'e-5 mission.[110] It uses an S-band tracking and control system and has been used for international tracking & control missions, including with France.[111]

It is identified as a SSF unit and uses the MUCD 63760.[112,x] As of 2019, the unit commander is Zhang Wuzhan [张武战].[113]

Qingdao Station
[青岛测控站]


Qingdao Station

Located in Qingdao's Chengyang District [城阳区], it is affiliated with Xi'an Satellite Control Center and was established to support China's manned spacecraft program. It is sometimes referred to as the Bohai Station [渤海站] and has 18-meter and 10-meter receiving dishes. The larger of these was added around 2007, and the station has roughly doubled in size since 2006. It has successfully supported the Shenzhou missions and received an award for "outstanding contribution" for its participation in the Shenzhou-1 test in 1999, the first step in China's manned space program.[114] It appears to be the successor to an earlier station established to support ICBM, SLBM, and communication satellite tests in the 1980s.

ix Elements of the Xiangxi / Western Hunan (Observation) Station [湘西观测站], one of China's first TT&C stations, may have moved to Nanning after it was shut down and the network reorganized around 1987.

x Its former MUCD may have been 89761.

Xiamen Station
[厦门测控站]

In 1991 construction of a second station began in Xiamen, Fujian province, to support the Shenzhou and later Beidou programs. It began operations in 1994.[115]

Satellite imagery indicates that Xiamen station underwent a major upgrade of its equipment in 2014.[116] It uses the MUCD 63758.[117]


Xiamen Station

Weinan station
[渭南测控站]

Located just an hour's drive to the east of downtown Xi'an, Weinan was the original home for China's space tracking network. After the Xi'an Center was established, it remained involved as a subordinate TT&C station and participates in the long-term management of over 100 satellites and spacecraft.[118]

It is also home to an SSF unit with the MUCD 63752, which is described as a comprehensive control station [综合性测控站]. As of 2020, the director of the Weinan Station is Wei Hui [尉辉].[119]


Weinan Station

Xiangxi (Western Hunan) Station
[湘西站]

Located in Xinhua County, Hunan Province [湖南省新化县], this station was originally part of China's first TT&C network. Construction of the station was approved in 1967, and equipment was installed in 1968. The completed station featured a Type 154 monopulse radar and Type 717 computer.[120] The unit was given the MUCD 89756. The station supported the launch of the Dongfanghong-1 and other launches but was ultimately closed in 1987 due to the reorganization of the TT&C network.

Zhanyi Station
[沾益测控站]

One of the earliest stations involved in satellite tracking and missile instrumentation is the Type 110 radar site in Zhanyi.[121] It began trial operations in 1971 and worked in conjunction with the 7010 radar in Hebei in tracking various domestic and foreign satellites and supported missile testing of the DF-3 and DF-5. The station has a Type 110 tracking radar, can identify targets up to 1,700 kilometers away, and track up to 1,200 kilometers away.[122]

As of writing, it appears to be active, with multiple upgrades to the power infrastructure and barracks areas around it in recent years.


Zhanyi Station

Mobile Tracking Stations [活动测控站]

Mobile tracking stations provide flexible support to space launches, maintaining contact with satellites as they move out of the line of sight with permanent ground stations.

Mobile Tracking Station, Chinanews.com

Three mobile tracking stations are subordinate to the XSCC Mobile Tracking & Recovery Department [西安卫星测控中心活动测控回收部] (MUCD 63762), which is located in Weinan, Shaanxi Province [陕西渭南]. [123]

The first station is also located in Weinan, while the second (at least partially) is based in Hetian, Xinjiang AR (aka Hetian Station [和田站]).[124] The third is located in Honggor, Inner Mongolia AR.[125]

The first two provide mobile spacecraft (satellite and manned spacecraft) tracking, while the third provides tracking for reentry of spacecraft. All have been involved in various Shenzhou manned spacecraft missions.

First Mobile Station, Weinan, Shaanxi

Few details appear to be available about this organization, but it is known that the station was established in 1969.[126] Another sub-station may also be present nearby. It is believed to use the MUCD 63771. They appear to have deployed to Xiamen to support the launch of a Beidou satellite in 2019.[127]

First Mobile Station

Second Mobile Station, Hotan, Xinjiang

Chen Songming

The Hotan (or Khotan/Hetian) Station, located in Xinjiang AR, supports the Xi'an Satellite Control Center. The Station was established around 1970.[128] It appears to have at least one antenna that is 5-meters tall.[129] One or more of the stations may have a 4.2-meter antenna.[130]

As of 2018, the Director of the Second Mobile Ground Station is Chen Songming [陈松明] (inset).[131] It may have the MUCD 63772.[132]

Third Mobile Station – Main Landing Station, Inner Mongolia

The third station is the "landing station" [着陆场站] for satellites and China's Shenzhou manned space missions.[133] The predecessor of these stations was involved in China's first recoverable satellite mission in 1975.[134] It appears to be also be known as the main station [主场站], short for main landing station [主着陆场站]. Also known as the Recovery Tracking Station [回收测量站], it has a search-and-rescue & recovery team [搜救回收队] composed of ground vehicles and helicopters.[135] Jiuquan Satellite Launch Center personnel may also be involved. It is located in Honggor Sum, Inner Mongolia [红格尔苏木]. There is also a secondary landing site [副着陆场] at the Jiuquan SLC, the Dongfeng Landing Station [东风着陆场], which is involved in testing and recovery of a new reusable crewed spacecraft that will be used to transport astronauts to China's future space stations.[136]

Deep Space Network

China has also built a Deep Space Network [深空网络] of large radio dishes to communicate with its manned space missions and lunar and mars space exploration missions.

The network is primarily composed of three dishes in Kashgar, Jiamusi, and Neuquén, Argentina, and is subordinate to CLTC through the Xi'an Satellite Control Center.[137] The network was expanded and upgraded to support the Chang'e-3 and Chang'e-4 missions.[138] The stations also contributed to European and U.S. space missions, with Jiamusi providing support to ESA's Cassini Saturn probe and NASA Juno probe missions. Other stations abroad have supported Chinese space missions, including stations in Kourou (French Guiana), Malargüe (Argentina), New Norcia (Australia), and Cebreros (Spain).

Kashgar Deep Space TT&C Station
[喀什深空测控站]

Kashgar's 35m Deep Space TT&C station [35米深空测控站] was designed and built by a team from the 54th Research Institute of CETC, a certified primary contractor for the PLA. The project was initiated in 2008 and completed at the end of 2012.[139] It is roughly situated about 160 km south of Kashgar in a part of the desert referred to as the Heizi Gobi [黑孜戈壁].

The Kashgar station represents a major improvement in the Institute's development of VLBI (Very Long Baseline Interferometry) technology. The station, along with a 65-meter radio telescope antenna in Sheshan, Shanghai, and a 50-meter radio telescope antenna in Beijing, form a VLBI network that has increased the accuracy of the ground station's angle measurement of deep-space targets by nearly three orders of magnitude.

The Kashgar Deep Space tracking station includes three 35-meter receivers. Construction began in August 2011, with a single antenna completed by 2013. Two additional receivers were added in 2020. The station participates in the Chang'e 4 mission, communicating with the lunar orbiter and Yutu-2 rover on the surface of the Moon.

The station appears to be a subordinate sub-station of the Kashgar TT&C station.[140]

Kashgar TT&C Station

Jiamusi Deep Space TT&C Station
[佳木斯深空站]

The Jiamusi Deep Space TT&C station is located in northeastern China in Heilongjiang Province.[xi] The 66m radio telescope was completed in 2012 and is used to study pulsars but is equipped with transmitters as well as receivers allow it to act as command and control for deep space missions.

As of 2019, its director is Han Lei [韩雷]. [141] In 2018, the station successfully made contact with the Queqiao relay satellite, allowing China to control the Chang'e 4 lander and lunar rover on the far side of the Moon. The stations are also involved in maintaining communications with the Tianwen 1, China's Mars spacecraft mission launched in July 2020.[142]


Jiamusi Deep Space TT&C Station

Neuquén, Argentina
[阿根廷深空站/内乌肯深空站]

The Neuquén Deep Space Station [阿根廷深空站/内乌肯深空站], also called Zapala station, is located in central Argentina.[xii]

Neuquén is crucial to the operation of China's Deep Space Network, filling the gap in global coverage between the Kashgar and Jiamusi stations to provide support to deep space missions, including the Tianwen Mars exploration mission launched in 2020.[143] It is also involved in lunar missions, maintaining communication with the Queqiao relay satellite at the L2 Lagrange point, which allows data to be transmitted to probes on the other side of the Moon.[144]

The station is the result of an agreement signed in 2015 by then-President Cristina Fernández de Kirchner and Xi Jinping. Controversially, the agreement granted China 50 years full sovereignty over a site with an area of almost a square mile (200 hectares) in Bajada del Agrio, Neuquén province, and exemption from taxes.

The station, which features a 35-meter receiver weighing 450 tons, was completed in 2017. Experts from the Xi'an Satellite Control Center helped manage the project, and construction was handled by China Harbour Engineering Company [中国港湾工程有限责任公司]. [145]

China and Argentina are "Comprehensive Strategic Partners," and the Neuquén station is one of a raft of joint projects including dams, a nuclear power plant, and modernization of a railway.[146]

Construction was expected to bring in 300 million pesos ($37.5 million USD at the time) and then- Ambassador to Argentina Yan Wanming said the facility would help create 1,500 jobs in Argentina.[147]

xi The station is also sometimes called Linhai [林海].

xii ESA has also operated a 35m deep space station in Malargüe, Argentina since 2012. "ESA's Malargüe tracking station," ESA, 15 November 2012. https://www.esa.int/ESA_Multimedia/Images/2012/11/ESA_s_Malarguee_tracking_station

Neuquén Deep Space Station

However, the station attracted controversy due to the station's links to the PLA through CLTC.[148] Others objected to legal exemptions given to the station and other restrictions. Entry to the facility is also reportedly controlled by Chinese personnel. [149] Chinese employees at the station work under Chinese labor law, not Argentina's, and Argentina's space agency, Comisión Nacional de Actividades Espaciales (CONAE), only have access to the station 10 percent of the time. [150]

While the station's stated purpose is to "promote activities such as interplanetary exploration, astronomic observation and to follow and control orbiting satellites and data acquisition," President Macri, who assumed office later in 2015, requested an annex to the agreement prohibiting military use of the station.

While its status remains controversial, it is an integral component of China's Deep Space Network and will be important to the completion of China's planned lunar and Mars exploration missions.

2.4 Launch Centers

While most components of the space tracking network fall under the Xi'an Satellite Control Center, each of China's Satellite Launch Centers and Sites has its own group of subordinate stations and substations. The Satellite Control Center is responsible for long-term monitoring and tracking of satellites, but for the launch phase of space missions or during missile testing, the launch centers appear to have lead responsibility.

Jiuquan Satellite Launch Center (JSLC) [酒泉卫星发射中心]

The birthplace of modern Chinese rocketry and China's space program, the Jiuquan Satellite Launch Center was established in 1958 as the Northwest Comprehensive Missile Testing Facility [西北综合导弹试验基地].[151] The center is located Buge Yin'a Rila [布格音阿日拉], in the western part of Inner Mongolia.[152]

The Center has also been known as the 20th (Testing and Training) Base [第20 (试验训练) 基地], Dongfeng Aerospace City [东风航天城], and in the West as the Shuang Cheng-Tzu Missile Test Center.[153] The Center, like all Chinese space launch centers, is subordinate to the SSF SSD and uses the MUCD 63600.[154] As of April 2020, its commander is Zhang Zhifen [张志芬], and its political commissar is Ji Duo [纪多].[155]

Jiuquan specializes in placing satellites in medium, low earth orbit, and high inclination orbits, as well as scientific and experimental, and recoverable satellite launches.[156]

The Center mainly launches CZ-2C/D, CZ-4B/C, and CZ-11 Long March rockets and has thus far been the country's only launch center for the manned spaceflight (Shenzhou) program.[157] The Center has carried out all Shenzhou manned spacecraft and both Tiangong [天宫] space station program launches, all Tianhui-1 [天绘一号] and several recoverable, Shijian [实践], Yunhai [云海], Gaofen [高分], Zhuhai-1 [珠海一号], Yaogan [遥感], Jilin-1 [吉林一号], LKW [陆地勘查] [158] satellite launches, among others.[159] Continuing its historical role, the Center also carries out short-range ballistic missile, land-attack cruise missile testing.[160]

While there is little information about it, some sources reference a Jiuquan Comprehensive Tracking Station [酒泉综合测控站], which may include space- and missile-related tracking stations in the area.[161] This may be related to the JSLC launch test station [酒泉卫星发射中心发射测试站], but it is unclear. There are several tracking facilities in and around the grounds of the Center that appear to be part of this organization: the Dashuli Radar Tracking Station [大树里雷达测量站], an optical tracking station [光学测量站点] to the northeast of the Center, and a telemetry station. [162]

Dong Feng Control Station

The Dong Feng Control Station [东风测控站] may be part of or another name for the Comprehensive Tracking Station and has been involved in the launches of various spacecraft, including the Shenzhou 7.[163] It also features a 68-meter calibration tower [标校塔] there. [164]

The JSLC also has a large phased-array radar (LPAR) in Korla, Xinjiang AR [新疆库尔勒市开发区].

Taiyuan Satellite Launch Center (TSLC) [太原卫星发射中心]

Established in 1967, the Taiyuan Center is also known as the 25th Testing and Training Base [第25试验训练基地].[165] While referred to in English and Chinese as Taiyuan, it is located over 150 km away from Taiyuan, the provincial capital of Shanxi, in Kelan County [岢岚县]. Historically it has been referred to as the Wuzhai Space and Missile Test Center by Western analysts, after the county to the northeast. The unit has a MUCD of 63710. As of December 2019, its commander is Yu Zhijian [于志坚], and political commissar is Wan Minggui [万明贵] (October 2019).[166]

Taiyuan Satellite Launch Center

It has launched various Long March rockets, Dongfeng missiles, and a range of satellites, specializing in low earth orbit and sun-synchronous orbit satellites.[167]

Civilian rocket launches from the center include CZ-2C/D, CZ-4B/C, and CZ-6 Long March rockets, and a range of satellites, in particular the Gaofen [高分], Haiyang [海洋], Yaogan [遥感], Gaojing [高景], Ziyuan [资源], Fengyun [风云], and Shijian [实践] series.[168] The Center is also thought to test medium- and intermediate-range ballistic missiles like the Dongfeng series.[169]

Befitting these roles, it has extensive TT&C infrastructure. There is a telemetry station on the grounds of the TSLC, which may be the same as the TSLC tracking & control station [太原卫星发射中心测控站].[170] The Center has eight tracking stations, including one main radar tracking station [雷达测量站] at Yangqu, Shanxi Province [阳曲站] and three secondary stations at Lishi, Shanxi [山西离石], Yulin, Shaanxi [陕西榆林], and Hancheng, Shaanxi [陕西韩城].[171] All four are subordinate to the Lüliang Command Post [吕梁指挥所].[172, xiii] The Yangqu Station has a vehicle-mounted radar tracking station, while the others' vehicle-mounted radar can only receive and not send signals. The remaining four stations appear to be optical tracking stations [光学测量站点]. There is also a radar station, though this may just be one of the aforementioned tracking stations.

A mobile radar station located in Yinchuan, Ningxia AR [宁夏银川] is identified as subordinate to the TSLC and uses the MUCD 63726. The unit also has a radar tracking station in Wuwei, Gansu Province [甘肃武威市凉州区].

An additional station that participates in manned spacecraft tracking and control and is believed to be under the TLSC is Xingxian Station [兴县站]. This radar tracking & control station [雷达测控站] is located in Xingxian, near Lüliang.[173] As of 2018, the unit has been in Xingxian for over 40 years and had carried out six Shenzhou manned spacecraft and over 100 satellite tracking and measurement missions as of 2007.[174] It appears to be an SSF unit with the MUCD 63717 and is described as subordinate to the Taiyuan tracking and control center [太原测控中心].[175]

xiii The Post is also known as the TSLC radar tracking station [太原卫星发射中心雷达测量站] and might also be known as the (Taiyuan) tracking & control center [(太原) 测控中心], and is located in Taiyuan (apparently at the TSLC) and not Lüliang.

In addition, there is a Unit 63726 Pingliang XL-3208 radar station in Pingliang, Gansu (甘肃省平凉市崆峒区), which could also be an LPAR. [176]

TSLC Sea Launch Base

In addition to land-based rocket launches, China in recent years has begun to conduct sea-launches as well. The two launches were carried out by a team from the Taiyuan SLC, which reportedly has a sea launch base [海上发射基地] in Haiyang, Yantai, Shandong Province [山东省烟台市海阳市], where both launch missions set off from and where a Dongfang Aerospace Port [东方航天港] was set up in recent years.[177] The first sea launch was on 5 June 2019, and a sea launch platform [海上发射平台] transport ship called the Duanrei [泰瑞号] was used. [178] The second launch was on 15 September 2020 and used a ship called the Debo-3 [德渤3号], which has a length of 160 meters and a carrying capacity of 20,500 metric tons. Both launches used Long March-11 (CZ-11) rockets and were carried out in the Yellow Sea.

Xichang Satellite Launch Center (XSLC) [西昌卫星发射中心]

The Xichang Satellite Launch Center is located in Mianning County [冕宁县], Liangshan Yi Autonomous Prefecture, in south-central Sichuan Province.[179]

The center was established in 1970 and has also been known as the 27th Testing and Training Base [第27 (试验训练) 基地] under the GAD.[180] It uses the MUCD 63790.[181]

Zhang Xueyu [张学宇] is the commander, and the political commissar is Dong Chongqing [董重庆] (both as of June 2020).[182] Li Shangfu [李尚福], current director of the CMC Equipment Development Department (EDD), previously served as director of the launch center.[183]

Zhang Xueyu

The Center launches mainly CZ-3A, CZ-3B (sometimes with Yuanzheng-1 [远征一号] upper stages), CZ-3C, and CZ-2C Long March rockets.[184] The Center has launched all of China's lunar exploration / Chang'e project spacecraft, all of the Beidou navigation, Tianlian-1 [天链一号], and communications technology test-series (TJS) [通信技术试验卫星] satellites, and several Apstar [亚太], ChinaSat [中星], Yaogan, Fengyun satellites, among others.[185] It focuses on geostationary orbit broadcast, communications, and meteorological satellite launches.[186]

Xichang appears to still carry out more foreign commercial satellite launches than any other Chinese launch site, including satellites for Nigeria (2007), Venezuela (2008), and Indonesia (2009).[187] Xichang was also reportedly the site of an anti-satellite weapon launch in 2007.[188]

Supporting tracking stations include the XSLC Niutoushan tracking station [牛头山观测站] located to the southeast of the launch site.[189] Another tracking station is located just to the west of Xichang City.[190] The XSLC also includes a "launch test station" [发射测试站].[191]

An additional SSF Satellite Observation and Measurement Station under the Xichang Center is located in Yibin [宜宾] in Sichuan province.[192] Built between 1976 and 1978, the station has participated in over 200 Chang'e, Beidou, Fengyun, and other satellite tracking and measurement missions from the Xichang, Jiuquan, and Taiyuan launch centers.[193]

The station has been identified as a PLA unit with the MUCD 63819.[194] As of June 2018, the station's commander was identified as Bao Zhenqing [鲍振轻].[195] Additional auxiliary satellite observation stations appear to be present in the Baita Mountain [白塔山] area, possibly built in 2020, and in the Xuzhou District [叙州区].[196]

Additionally, the Center has a Guiyang Observation Station [贵阳观测站] in Huaxi County, Guiyang, Guizhou [贵州省贵阳市花溪县].

Wenchang Spacecraft Launch Site [文昌航天发射场]

China's newest launch site is located in Wenchang, Hainan Province [海南文昌]. Although sometimes referred to as the Wenchang Launch Center, as of 2020, it is still identified as subordinate to the Xichang Satellite Launch Center.[197]

Due to its location closer to the equator, launches from this location require less energy and are capable of launching heavier loads, making it mainly responsible for geosynchronous satellites, polar-orbiting satellites, space stations, and deep space probes.

Tracking and control duties during the launch phase are handled by the Tongguling tracking station [铜鼓岭测控点] in Wenchang and the Paracel Islands tracking station [西沙测控站] on Duncan Island [琛航岛].

A Long March-5B rocket prepares for launch from the Wenchang Launch

2.5 China Satellite Maritime Tracking and Control Department [中国卫星海上测控部]

Yuanwang 5

When spacecraft (or missiles undergoing testing) are over the ocean, specialized ships, typically called tracking or missile instrumentation ships, are necessary to collect data and send instructions. Equipped with satellite receiving dishes, radars, laser rangefinders, and optical telescopes, they remain in contact with satellites and monitor them for issues as the spacecraft passes out of line of sight with ground stations.

China operates two groups of ships involved in these duties. The first is a small fleet of space tracking and rocket transport ships, designated Yuanwang [远望], that are operated by the China Satellite Maritime Tracking and Control Department (Base 23) [中国卫星海上测控部] in Jiangyin, Wuxi [江苏省无锡市江阴], more than 100 kilometers up the Yangtze River.

These ships were built to carry out both missile instrumentation and satellite tracking duties and help maintain communications with satellites and ballistic missiles as orbits pass through areas outside the range of ground stations. Though these ships allow China to conduct tracking missions in international waters, operating them is expensive, and while they operate for extended periods, the overall number of ships is limited compared to the demands for their support, as an individual launch can involve multiple ships. The fleet maintains a high tempo of operations, and as of June 2020, the Department has completed 200 tracking and control missions.[198]

History

Ship	Date Commissioned	Status	Mission
YW-1	1978	Museum Ship	Maritime TT&C
YW-2	September 1978	Museum Ship	Maritime TT&C
YW-3	May 1995	Active	Maritime TT&C
YW-4	October 1979	Destroyed in test	Maritime TT&C
YW-5	September 2007	Active	Maritime TT&C
YW-6	April 2008	Active	Maritime TT&C
YW-7	July 2016	Active	Maritime TT&C
YW-21	May 2013	Active	Rocket Transport
YW-22	June 2013	Active	Rocket Transport

In June 1968, Mao Zedong, Zhou Enlai, and the CMC approved a proposal from COSTIND [国防科委] regarding the development of far seas vessels, including escort ships, logistics, survey and other 'special engineering' vessels [远洋特种工程船]. A central goal of this proposal was to assist in the development of ICBMs, which would need tracking and instrumentation ships downrange (in the South Pacific) for testing.[199] The program was approved for inclusion in the state plan in December 1970 and established a leading small group for the development of maritime survey vessels [远洋测量船工程领导小组] under the State Council and CMC. The China Satellite Maritime Measurement and Control Department was established in April 1975.[200] In September 1977, the Party Center approved the "Three Grasps" [三抓] program to develop an ICBM, an SLBM, and a communication satellite, all of which would require maritime tracking and instrumentation support. In August and October 1977, China's first 20,000-ton space tracking ships were completed. By 1980 the special engineering project had completed the Yuanwang 1 and 2, as well as the Xiangyanghong 10 and various other special support and rescue vessels.

The Department's first major mission in May 1980 was to participate in tracking of a test of the DF-5 ICBM, which targeted an empty patch of the South Pacific 8,000 km away. Tests of the Julang-1 SLBM followed in 1982.

The fleet has been expanded and upgraded since 1986, but the two original two ships built in the 1970s have been retired, while another was damaged beyond repair in an accident and used as a target in a missile test.[201] The Yuanwang Ship Detachment [远望号船队] is currently composed of four tracking ships and two rocket transport ships.


Yuanwang 6

The Yuanwang ships are both physically large and built to withstand missions that can cover thousands of nautical miles lasting over 100 days away from home port. In 2019, for example, the Yuanwang fleet, including transports, carried out 17 tracking and control missions, one rocket transport mission, and spent a cumulative 550 days at sea.[202] These ships regularly deploy to the Central Pacific or the Indian Ocean in support of satellite launches.[203]

While their hallmark is their massive radio dishes, they also carry sophisticated radars, laser satellite ranging, communication, and precision timing equipment.[204] The Xi'an Satellite Control Center is connected to the Yuanwang ships via wired and satellite communications.[205]

The Yuanwang 21 and 22 are rocket transport ships [火箭运输船]. All are homeported in Jiangyin, Wuxi, Jiangsu Province along the Yangtze River. In February 2020, both ships transported Long March 7A and Long March 5B rockets.[206]


Yuanwang 21

Leadership

The Department's activities are highly publicized as scientific missions, and their leaders are rarely portrayed wearing uniforms.

However, its military ties are clear both historically and based on contemporaneous evidence. The Maritime Tracking and Control Department was formerly the General Armament Department's 23rd Testing and Training Base [总装第23试验训练基地].[207] The Department is also assigned the MUCD 63680.[208]

As of 2019, Unit 63680 was commanded by Wu Jingao [吴锦高]. Wu Hexian [吴贺宪] (below) serves as commissar and Party Secretary.[209]

Wu Jingao

Wu Hexian

Intelligence, Space Tracking, and Missile Instrumentation Ships

In addition to the Yuanwang ships under the China Satellite Maritime Tracking and Control Department, the PLA also operates at least six Auxiliary General Intelligence (AGI) ships that appear to be capable of space tracking and missile range instrumentation duties as well.


Chinese Auxiliary General Intelligence Vessel

Such range instrumentation ships can also be used to collect telemetry and other signals intelligence. Chinese AGI ships were present near training areas for the Rim of the Pacific (RIMPAC) international naval exercises hosted by the United States in 2014 and 2018.[210]

These appear to be parceled out among operational support fleets [作战支援舰支队] with a mix of ships providing logistical and intelligence support functions (see chart). Of these, the ships with the designation Diao [调] series includes vessels engaged in satellite tracking support and maritime survey operations.

Given the sensitivity of their missions, few details about their roles appear to be available. In addition to missile testing, they are likely involved in missions related to military applications for Beidou or military communications systems.[211]

Pennant Number	Romanization	Chinese	Fleet
851	Beijixing	北极星	ESF
852	Haiwangxing	海王星	SSF
853	Tianwangxing	天王星	SSF
854	Tianlangxing	天狼星	NSF
855	Tianquanxing	天权星	ESF
856	Kaiyangxing	开阳星	NSF
857	Tianquxing	天枢星	SSF
858	Yuhengxing	玉衡星	ESF
859	Jinxing	金星	NSF
	Beidiao 900	北调900	NSF

The ships' names are taken from the stars that make up the Big Dipper constellation (which is also the namesake for the Beidou GNSS).

Construction of these ships began in the early 1980s. The Type 814 Dadie Class "Xiangyanghong 28" geodetic intelligence ship officially began construction on December 22, 1983, at the Wuchang Shipyard, and was launched on June 12, 1986. It was later renamed the Beidiao 900.

2.6 Other Organizations involved in Space Asset Command, Tracking, and Management

In addition to the military-run organizations responsible for China's space programs, a number of other civilian agencies, observatories, and research institutes play supporting roles in China's space ground segment.

The Aerospace Information Research Institute (AIR) [空天信息创新研究院]

The Chinese Academy of Sciences plays a prominent role in space infrastructure operations, in part through the recently formed Aerospace Information Research Institute under the Chinese Academy of Sciences [中国科学院空天信息创新研究院]. It was created in July 2017 out of the merger and reorganization of three CAS research institutes:[212]

- Institute of Electronics [中国科学院电子学研究所/电子所], China's first comprehensive electronic and information science research institute established in 1956;
- Institute of Remote Sensing and Digital Earth (RADI) [中国科学院遥感与数字地球研究所], established in 2012 on the basis of the former Institute of Remote Sensing Applications (est. 1979) and the Earth Observation Center (2007).
- Academy of Opto-Electronics [中国科学院光电研究所], established in 2003, the Academy of Opto-Electronics is a research unit with overall management and technical functions in three main areas: optoelectronic engineering, aerospace, and applied technology.

A *China Science Daily* article from August 2019 chronicled the merger, describing it as unprecedented in scale in CAS's history. It involved 2,800 employees and 1,800 students spread across 12 campuses.[213] CAS Academician Wu Yirong [吴一戎], director of the Institute of Electronics, was appointed director of AIR in April 2018.

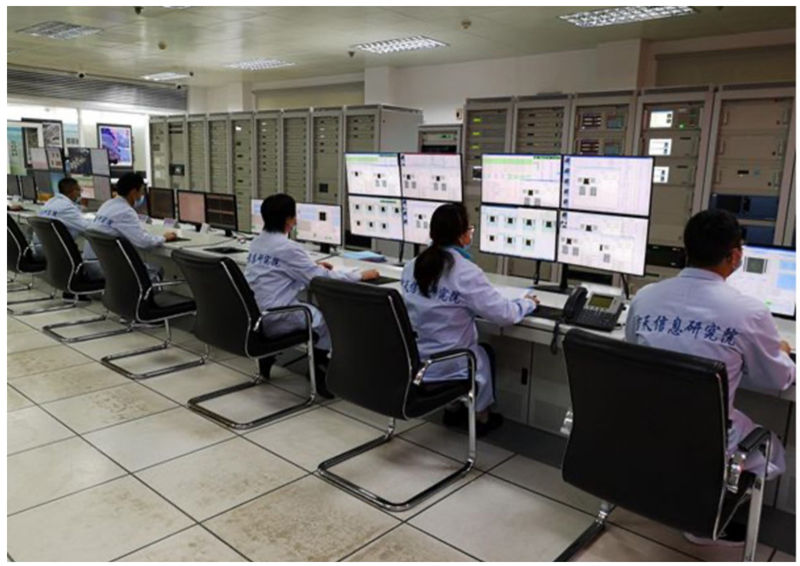
The creation of AIR is instructive because it reflects many of the larger issues that have slowed the development of China's ground segment in general. According to Wu, although China has managed to significantly increase the number of scientific papers and patents it produces, many areas remain reliant on foreign "chokehold" technologies. Many R&D projects are megaprojects by nature in the aerospace field, and institutional barriers have prevented strategic decision-making at the national level. AIR Party Secretary Cai Rong [蔡榕] noted the same problem and pointed out that the merger is intended to facilitate the development of a "group army" capable of shouldering big missions. As the AIR website notes, AIR will pool together resources and take on interdisciplinary missions oriented toward meeting major national strategic needs.

The merger officially began in April 2018 and, as of late 2019, remained a work in progress. A total of 14 management departments have been set up within AIR, and 20 research institutions have been created by the reorganization. AIR operates campuses across China, including six in Beijing, and another six in Suzhou (Jiangsu), Sanya (Hainan), Kashgar (Xinjiang), Dorbod Banner (Inner Mongolia), Huailai (Hebei), and Yingkou (Liaoning).

According to China Science Daily, since its inception, AIR has taken part in multiple large-scale missions such as the development of the National Civil Space Infrastructure Data Receiving System [国家民用空间基础设施数据接收系统], a component of the project mentioned in the preceding sections, and has successfully completed 29 data receiving missions for earth observation and space science satellites at home and abroad. It has also been actively expanding its international "circle of friends" through the promotion of international research personnel exchange and two-way technology transfer programs [技术涉外推广与转移]. Specifically, AIR has participated in projects such as the "Digital Silk Road," the Asia-Oceania GEOSS (AOGEOSS) GEO Initiative [亚洲大洋洲区域综合地球观测系统], and the Beidou (BDS/GNSS) Open Laboratory [北斗开放实验室].

China Remote Sensing Ground Station [中国遥感卫星地面站]

The organization under AIR directly responsible for parts of China's ground segment is the China Remote Sensing Satellite Ground Station (RSGS) [中国遥感卫星地面站]. RSGS is an S&T organization [科技机构] composed of a central headquarters and a network of ground stations. It was established in December 1986, as part of the 1979 "Sino-US Scientific and Technological Cooperation Agreement" signed by China's top leader Deng Xiaoping and U.S. President Jimmy Carter, a national major S&T infrastructure initiative. Between 2007 and 2018, it operated under RADI until its consolidation into AIR.[214] Although the 2018 merger appears yet to be fully completed, RSGS staff have been photographed wearing AIR work uniforms.

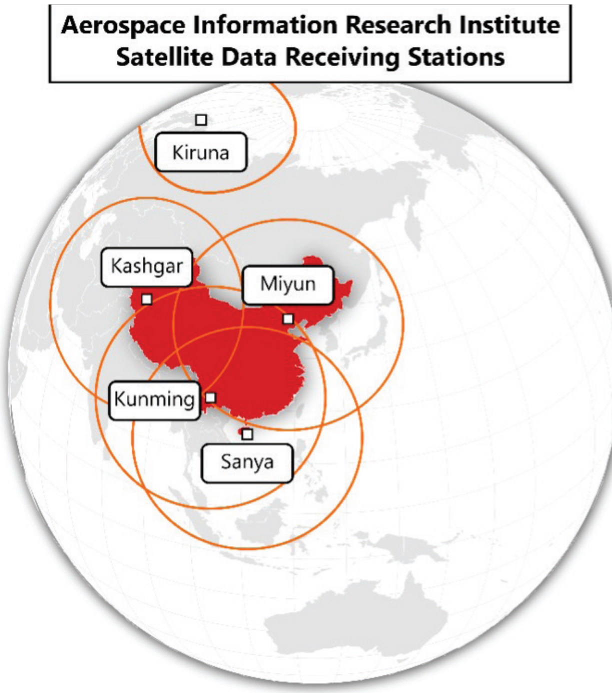


China Remote Sensing Satellite Ground Station

RSGS operates five ground stations globally. The Beijing headquarters is responsible for operation management and data processing and distribution, while its Miyun Station, Kashgar Station, Sanya Station, Kunming Station, and Arctic Station (Kiruna)[xiv] together form a data receiving network.

According to Huang Peng [黄鹏], deputy director of AIR RSGS, RSGS has the capability to receive satellite data in real-time covering the entire territory of China and 70% of the Asian landmass, as well as rapid downlink capability for satellite data from all over the world.[215]

RSGS is responsible for tracking most of China's earth observation satellites under the planned China High-Resolution Earth Observation System (CHEOS), including natural disaster monitoring and resource survey satellites. Several space science satellites such as the "Wukong" (which studies dark matter), "Micius" (part of quantum communications experiments)," and "Taiji-1" (gravitational wave detection) are also operated by RSGS ground stations.



Miyun Station, Beijing

Located in northeast Beijing, the Remote Sensing and Digital Earth (RADI) Miyun facility is China's main earth observation satellite data archive.[216] It began operations in 1986 and has several large-diameter receiving antennas. Its reception area covers central and northern China as well as surrounding border areas.[217] Commercial satellite imagery shows that this has almost doubled in size, and the number of large-scale dishes has doubled to ten since 2012.

China Remote Sensing Ground Stations

xiv Detailed in section 3.2

Kashgar Station, Xinjiang

RADI's RSGS Kashgar Station [中国遥感卫星地面站喀什站] was officially unveiled on 28 January 2008.[218] The station covers Western China and neighboring areas in Central Asia.[219] It primarily serves as a downlink station for a number of domestic constellations such as China's Environment and Disaster series of satellites [环境减灾系列卫星, HJ-series], China-Brazil Earth Resources Satellite (CBERS) and Natural Resources [资源; ZY-series] satellites, SJ-9 test platform satellites as well as Gaofen optical earth observation satellites, and international constellations such as the U.S. LANDSAT and French SPOT earth observation satellites.[220]

Kashgar Station Director Wang Jianping [王建平] told a reporter from China Science News: "Since its establishment, Kashgar Station has received data from more than 30 domestic and foreign satellites."[221] Since 2008, the facility has expanded from two 12m dishes to six 20m radomes, likely housing 12m dishes, and a seventh 12m radome.

Kashgar Station

Sanya Station, Hainan

The RSGS station in Sanya began operations in 2010. With five 12-meter satellite data-receiving antenna systems and supporting data-receiving, recording, and data-transmission equipment, it supports the operations of nearly 30 satellites.[222] The station is able to receive data from satellites over the South China Sea and neighboring countries in Southeast Asia.[223]

Sanya Station

Kunming Station, Yunnan

Kunming Satellite Station

The Kunming Satellite station began operations in May 2016. It consists of a single 7.3-meter antenna.[224] Few other details appear to be available.

Beidou Navigation Satellite System [北斗卫星导航系统]

For commercial and military applications, perhaps no other space-based system is more important than global navigation satellite systems (GNSS). For these systems, which include the U.S. GPS, European Galileo, and Russian GLONASS constellations, their accuracy is contingent upon maintaining a precise fix on their location in space relative to the ground and to each other. This requires large networks of ground stations equipped with atomic clocks that monitor the satellites' locations to keep the system accurate.

Prior to China's GNSS, Beidou, the PLA relied on radio navigation systems. Beginning in the mid-1960s, the Central Military Commission and the Communist Party's National Defense Science and Technology Commission [国防科委][xv] approved the development of intermediate- and long-range wireless radio navigational systems. The resulting Changhe [长河] system, with short-, intermediate-, and long-range versions, were the first steps toward a comprehensive navigational system, and many of the research institutes involved in its production remain at the center of satellite navigation systems.[225]

China's Beidou Navigation Satellite System (BDS) has been a driver of Chinese space launches and development since the launch of its first satellites in 2000. The constellation has expanded in phases, with Beidou-1 completed in May 2003, Beidou-2 in 2012, and finally, Beidou-3 in June 2020.[226] The system includes three main components: a space segment, with satellites in Geostationary Earth Orbit (GEO), Inclined Geo-Synchronous Orbit (IGSO) and Medium Earth Orbit (MEO); a user segment including various commercial receivers, chips and terminals; and most relevant for this study, a large ground segment.[227] The ground segment includes ground stations (including many of those profiled above) as well as master control stations, time synchronization/uplink stations, monitoring stations, and reference stations (RS), also called fiducial stations [基准站].

The latter is in a different category from space tracking stations but is of particular importance for GNSS. China has 150 national wide-area stations, 1200 regional RSs, and has set up others in the Arctic and Antarctic.[xvi] These stations, along with the National Beidou Ground-Based Augmentation System, will help Beidou achieve "meter and decimeter level for wide-area real-time services, centimeter-level for the areas within Beijing, millimeter level for postprocessing services" and "provide meter and decimeter level real-time location services for users in China, even centimeter-level service in some areas."[228] Beidou ground stations can also be used to augment the accuracy of the constellation or help compensate in the case of jamming or disabling of one or more of the satellites in the constellation.

While earlier iterations of the system had limited capabilities, the expanded constellation appears to have entered widespread use in China. In terms of the BDS's civil applications, a December 2019 report by the China Satellite Navigation Office [中国卫星导航系统管理办公室] noted BDS's applications in a wide variety of

xv Predecessor to the Commission of Science, Technology, and Industry for National Defense (COSTIND).

xvi For comparison, the U.S. GNSS fiducial station network has over 2000 stations.

fields, including agriculture, transportation, forestry, fisheries, hydrological monitoring, meteorological forecasting, communication, power grid, disaster relief, public security, and others.[229] According to the report, by the end of 2019, more than 6.5 million road operating vehicles, 40 thousand postal and express delivery vehicles, 80 thousand buses in 36 central cities, 3.2-thousand inland navigation facilities, and 2.9-thousand marine navigation facilities had adopted BDS, which forms the world's largest dynamic monitoring system for road operating vehicles. Other reports indicate that fishing boats and law enforcement vessels use 70,000 terminals, police 400,000, while municipal, provincial, and county-level emergency services use 45,000 Beidou terminals.[230] In the field of smartphones, mainstream chip manufacturers both at home and abroad have introduced integrated chips that are compatible with BDS. By the third quarter of 2019, more than 400 models of smartphones sold in China supported positioning functions, among which about 300 models supported BDS. In 2019 it was reported that 70 percent of smartphones in China were compatible with Beidou.[231]

While its prevalence among the PLA is unknown apart from scattered reporting on its use in exercises, reports from the China Satellite Navigation Office indicate widespread deployment of Beidou terminals. In January 2018, China Satellite Navigation Office Director Ran Chengqi [冉承其] told *China Youth Daily* that the BDS has become "standard issue" in fields related to national security.[232] In early 2020, Ran revealed that the BDS's high-precision positioning technology was widely utilized in support of the military parade to celebrate the 70th anniversary of the founding of PRC.[233]

The growth of both civil and military applications for the Beidou system indicates that the GNSS is likely to remain a driver of ground segment infrastructure.

While no official government structure has been published, Beidou itself appears to be administered in part through four organizations. The China Satellite Navigation Committee [中国卫星导航系统委员会] appears to be the leading organization setting policy, establishing cooperative agreements, and similar functions. It is led by Wang Zhaoyao [王兆耀], a PLA major general serving as deputy director of the CMC Equipment Development Department.[234]

An externally facing organization, the China Satellite Navigation Office publishes information on the system through the website Beidou.gov.cn, and Director Ran also serves as its spokesperson. However, the website does not list an office address or any other details. The ground segment and other operations of the Beidou system are likely to be run through the Central Satellite Navigation Station [卫星导航定位总站], an SSF unit under the Joint Staff Department discussed in Section 2.1, and SSF 1st Navigation Base / Base 35.


Wang Zhaoyao

China Centre for Resources Satellite Data and Application (CRESDA)

The China Centre for Resources Satellite Data and Application (CRESDA) is a research institute under the National Development and Reform Commission (NDRC) and China National Space Administration (CNSA) but is administratively run by the China Aerospace Science and Technology Corporation (CASC).[235]

CRESDA operates China's Natural Resources [资源; ZY] series of Earth-observing satellites. The ZY satellites include the ZY3-02 [资源三号02星], a multi-spectral earth observing satellite which provides imagery for land surveying and mapping, resource survey and monitoring, disaster prevention and reduction, agricultural and forestry water conservancy, ecological environment, urban planning and construction, transportation and other fields.[236]

China National Space Administration[国家航天局]

China's national space agency, CNSA [国家航天局], was founded in 1993 as part of the decision to split the former Ministry of Aerospace Industry [天工业部] into the China Aerospace Science and Technology Corporation (CASC) [中国航天科技集团公司] and a government agency. It is subordinate to State Administration for Science, Technology, and Industry for National Defense (SASTIND), which manages China's military and scientific R&D programs.[237]

While ostensibly responsible for China's manned space and lunar programs, these actually fall under the Central Military Commission's Equipment Development Department (EDD). China's Manned Space Office (921 Project Office) [中国载人航天工程办公室（921工程办公室）], for example, falls directly under the EDD and its current director, Hao Chun [郝淳], appears to be the first in that position who was not a uniformed officer since the office was established in 1992.[238] While sometimes described as having authority over China's launch centers, these, in fact, fall directly under the PLA through the SSF SSD.

Overall, CNSA appears to function much like China's National Defense Ministry [国防部] under the State Council, which is headed by a member of the CMC and has a limited portfolio largely restricted to external [对外] responsibilities such as international exchanges and exercises.[239]

CNSA is currently led by Zhang Kejian [张克俭], who is concurrently deputy minister of the Ministry of Industry and Information Technology (MIIT), director and Party Secretary of SASTIND, and director of China Atomic Energy Authority. [240]

With regards to China's ground segment, two organizations partially subordinate to CNSA play a role:

Space Debris Surveillance and Application Center [空间碎片监测与应用中心]

A growing danger for satellites or other spacecraft is space debris--the chips of paint, bolts, or even larger objects placed in orbit during the course of space launches or created during anti-satellite missile tests. Space debris moves at 10km/s, so even small objects have the potential to cause serious damage. However, tracking the estimated 200,000+ objects between 1 and 10 centimeters in size is difficult. According to an article from 2015, China's 129 spacecraft in orbit experienced, on average, 30 close encounters (passing within 100 meters) with space debris each year.[241] As referenced in Section 1, Chinese planners have committed to building an automated space debris removal system in the next ten years, which will require extremely accurate and up-to-date data on space debris' orbits.

To mitigate the risk from this debris, in June 2015, the Chinese Academy of Sciences' National Astronomical Observatories of China and CNSA established the Space Debris Monitoring and Application Center.[242] SASTIND (as the parent organization of CNSA) and the Observatory jointly manage the Center, which is believed to be the leading organization in charge of China's Space Debris Avoidance System (SDAS).[243] The Center provides early warning and analysis for more than 100 of China's satellites, tracking and maintaining an independent catalog of space debris.[244]

A press release announcing the Center's establishment also noted that it "can monitor not only debris, but also things much larger than debris, such as missiles, satellites, and high-speed aircraft. In other words, this Center has both civilian and military functions; in peacetime, it can provide early warning for Chinese spacecraft in orbit; in wartime, it can provide early warning and coordinates for the People's Liberation Army to destroy enemy aircraft."[245] The organization of the Center is unclear, but it appears to have begun receiving data from existing space debris tracking organizations. It is likely that the Changchun Observatory, which includes a space debris detection system [特大视场空间碎片探测系统], is involved.[246] As of 2018, a new component, a space debris monitoring base [空间碎片监测基地], is under construction in Korla, Bayingolin[xvii] Prefecture in Xinjiang.[247] The base was estimated to cost 200 million RMB ($28 million) and include large-aperture space telescopes, infrared optical sensors, and radars.[248]

The reference to its integration with missile and aircraft early warning systems suggests that the system is connected to China's network of missile early warning radars, believed to be operated by the SSF.

China also sees space debris as an area for international cooperation. It has participated in the Inter-Agency Space Debris Coordination Committee (IADC) since 1995 and regards the center as an opportunity to further cooperation in this field.[249]

Space Remote Sensing Demonstration Center[航天遥感论证中心]

This demonstration center, jointly operated with the China Academy of Sciences' Institute of Remote Sensing Applications [中国科学院遥感应用研究所], was established in January 2004.[250] It has participated in the calibration and testing of the CBERS, Fengyun, and Huanjing series satellites.

A key focus of this organization appears to be the recruitment of foreign talent and access to remote sensing technology through international cooperation.[251] It has cooperated with more than ten countries, including Thailand, France, Egypt, Australia, the United Kingdom, Germany, the United States, and Hungary.[252]

China Satellite Laser Ranging Network [中国卫星激光测距网]

Satellites can also be accurately tracked with ground-based laser rangefinders. China has built a large network of observatories equipped with satellite laser ranging (SLR) equipment. Led by the Shanghai Astronomical Observatory [上海天文台], the network includes stations in Beijing, Changchun, Shanghai, Kunming and Wuhan, and at least two mobile stations.[253]

xvii 巴音郭楞州, is the full name but it is given as Bazhou [巴州].

China's first SLR system began operations in 1972.[254] Most SLR systems are used to range objects in low Earth orbit, but some of the larger stationary systems, such as the one on Changchun, are described as capable of ranging objects up to an altitude of 40,000 km (which includes geostationary orbits) and giving a single-measurement-accuracy of less than 1.5 cm.[255]

Chinese organizations, including the Network and mobile SLR stations under the Ministry of Natural Resources [自然资源部], participate in the International Laser Ranging Service (ILRS), which conducts various scientific experiments, including measuring tectonic plate shifts.[256]

As with other organizations profiled in this study, this network is believed to have strong ties with the Chinese military, though these are frequently obscured. However, some level of participation is identifiable, such as the participation of an unidentified PLA organization, Unit 61084, in SLR Network conferences. It may be an organization under the PLA SSF 1st Navigation Base / Base 35.[257]

While SLR has previously been restricted to periods of darkness, a study in 2020 determined that lasers can now be used to detect space debris during daylight hours, suggesting that SLR systems will continue to grow in utility.[258]

These stations undoubtedly are part of Space Situational Awareness (SSA) for military and civilian purposes, but it is less likely that they are directly involved in offensive space operations. A study in 2009 assessed that "China's currently known SLR ranging stations should not be considered ASAT weapons due to the low probability of assured damage to a ground imaging satellite's imaging sensor." It went on to note that "the laser powers used for SLR are low enough that they would not interfere with satellites through heating effects or by causing physical damage to parts of satellites other than the sensors."[259]

National Remote Sensing Center [国家遥感中心]

The main operator of civilian ground stations involved in remote sensing data in China appears to be the National Remote Sensing Center (NRSCC), which is subordinate to the Ministry of Science and Technology (MOST).

Established in 1981, the Center has subordinate specialized departments for aviation, environmental, maritime and metrological remote sensing, which are described as "affiliated" [依托] with relevant departments under other components of the State Council, such as the National Satellite Ocean Application Service (under the Ministry of Natural Resources) and the National Satellite Meteorological Center, under the China Meteorological Administration.[260] The Center, therefore, appears to act as a coordinating umbrella organization for these specialized centers.

It is based in Beijing's Haidian District but has subordinate offices all over China. It appears to have some responsibility for GNSS system testing, and in addition to satellite data, it also collects information from UAVs and other aerial platforms, as well as ground-based sensors.[261]

National Satellite Meteorological Center [国家卫星气象中心]

China's weather satellite program has been a priority since the 1980s. The first "Fengyun" [风云; lit. "Wind and Clouds"] metrological satellite was launched in September 1988. China has launched 17 Fengyun satellites, and as of March 2020, nine remain active and in orbit, with the most recent launched in June 2018.[262, xviii] Two additional launches are planned for launch in 2021.[263]

These satellites are administered by the National Satellite Meteorological Center under the China Meteorological Administration [国家气象局].

Established in 1971, the National Satellite Meteorological Center is headquartered in Beijing's Haidian District.[264] The Center has weather satellite ground receiving stations [气象卫星地面接收站] in Beijing, Guangzhou, Jiamusi, and Urumqi, and Kiruna, Sweden.[265]

The Center also played a role in the development of ground systems, in-orbit testing, and receiving for the Gaofen [高分; lit. "High Resolution"] satellites and receives data and is involved in the operations of the series, which are believed to serve reconnaissance purposes. By 2012, the metrological center had archived 600TB of data, making it the largest digital remote sensing data center in China.[266]

The Fengyun program also plays a role in China's outreach through its international economic Belt and Road Initiative (BRI) [一带一路]. Several Fengyun satellites have been repositioned, and receiving stations set up to better provide coverage of areas along the Belt and Road.[267] A Fengyun receiving station was set up in Mozambique, for example, as part of BRI cooperation with the assistance of the National Satellite Meteorological Center.[268]

Beijing Weather Satellite Ground Station [北京气象卫星地面站]

Built in 1985, the Beijing Weather Satellite Ground Station, located in Beijing's Haidian District, plays a role in daily operations of nearly 20 domestic and foreign satellites, including from U.S. National Oceanic and Atmospheric Administration (NOAA) and NASA Earth Observing System (EOA) satellites.[269] As of 2013, the Station had five satellite antennas: two 15-meter and one 13-meter satellite data receipt & launch antennas [卫星数据接收与发射天线], and two 7.3-meter antennas.[270]

Guangzhou Weather Satellite Ground Station [广州气象卫星地面站]

Construction of the Guangzhou Weather Satellite Ground Station began in 1978, and it began operations in 1986.[271] It receives data and plays a role in the operations of the Fengyun series of weather satellites.[272] It also receives data from U.S. National Oceanic and Atmospheric Administration (NOAA) and NASA Earth Observing System (EOA), as well as Japan's Himawari/GMS satellites.[273] Its missions include satellite tracking, orbital testing, measurement & control, and data receipt, processing, storage, and forwarding.

The Station is under the dual administration of the National Satellite Meteorological Center and the Guangdong Meteorological Service [广东省气象局].[274]

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xviii A Fengyun-1C was destroyed in China's 2007 anti-satellite test.

As of 2013, the Station had two satellite antennas: one 15-meter satellite data receipt & launch antennas [卫星数据接收与发射天线] and one 7.3-meter satellite distance-measurement antennas [卫星测距天线].[275]

It is at least partially open to the public and is located in Guangzhou's Tianhe District.[276]

There is a second site co-located with the Guangdong Weather Satellite Remote Sensing Center [广东省气象卫星遥感中心] that has seven satellite antennas.[277]


Weather Satellite

National Satellite Ocean Application Service Center [国家卫星海洋应用中心]

Another component of the National Civil Space Infrastructure project is constellations of maritime observation satellites. These satellites, which measure sea temperature, wave height, and other data, are administered by the National Satellite Ocean Application Service Center. The group of satellites includes a series designated HY for Haiyang (lit: ocean), and one co-developed with France, the China-France Ocean Satellite (CFOSAT).[278] The satellites will also play a role in fisheries management and ship tracking.[279]

Chinese Maritime Satellites
HY-2A[384]
HY-2B [385]
HY-1C[386]
China-France Ocean Satellite (CFOSAT)
HY-1A [387] (Inactive)
HY-1B[388]

The Center is responsible for the planning and development of China's maritime remote sensing satellite programs as well as the construction and operation of ground stations to control and downlink data from the satellites.

The National Satellite Ocean Application Service has four main ground stations: Beijing, Hangzhou, Sanya, and Mudanjiang.[280]

As a central hub, the Beijing station not only receives, processes, and analyzes data but also distributes it. The Sanya and Mudanjiang stations are believed to be focused on data receiving.

The Miyun (Beijing), Kashgar, and Sanya stations of the Institute of Remote Sensing and Digital Earth appear to work with the Ocean Application Service's dedicated stations to downlink and share data, including imagery that could be used for intelligence purposes, such as microwave remote sensing data from the Gaofen-3 satellite.[281]

While subordinate to the Ministry of Natural Resources, the Center shares data through an online portal and is affiliated with the National Remote Sensing Center.[282]

The maritime satellite project and applications have been a major avenue for diplomacy, with agreements set up with Peru, North Korea, France, Germany, and Spain, among others, to exchange information. It also exchanges data under the World Meteorological Organization (WMO) [世界气象组织], including from the CFOSAT.

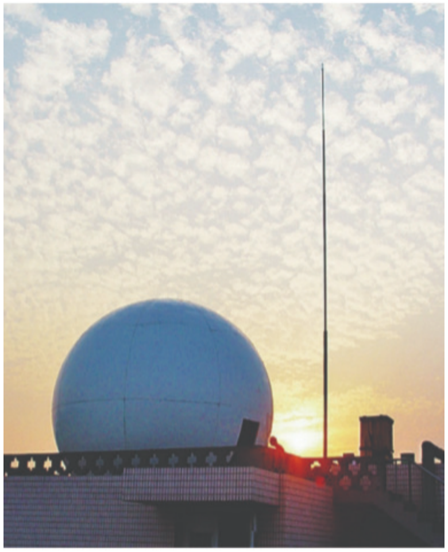
The first station was set up in 1988 in Hangzhou to receive data from China's first Fengyun weather satellite launched that year.[283] The Hangzhou station is affiliated with both the State Oceanic Administration and the Second Institute of Oceanography and is involved in real-time receiving, processing, archiving, and managing, as well as application and analysis.

In 2013, the Hangzhou ground station was incorporated into the national marine satellite ground application system's business operations and was renamed "National Marine Satellite Hangzhou Ground Station."

Work on a second station in Hangzhou, the Yuhang [余杭] station, began in October 2008, and test operations began in August 2009.[284] It began formal operation in March 2011.[285] Since beginning operation, it has provided support to multiple maritime satellite missions such as the HY-2.

It appears to have served as a "backup" station [备份站] and administered by the Second Institute of Oceanography under the Department of Natural Resources [自然资源部第二海洋研究所].

Construction of the newest station in Mudanjiang in Heilongjiang province began in June 2009.[286] The organization has strong links to the PLA SSF.


Hangzhou Station

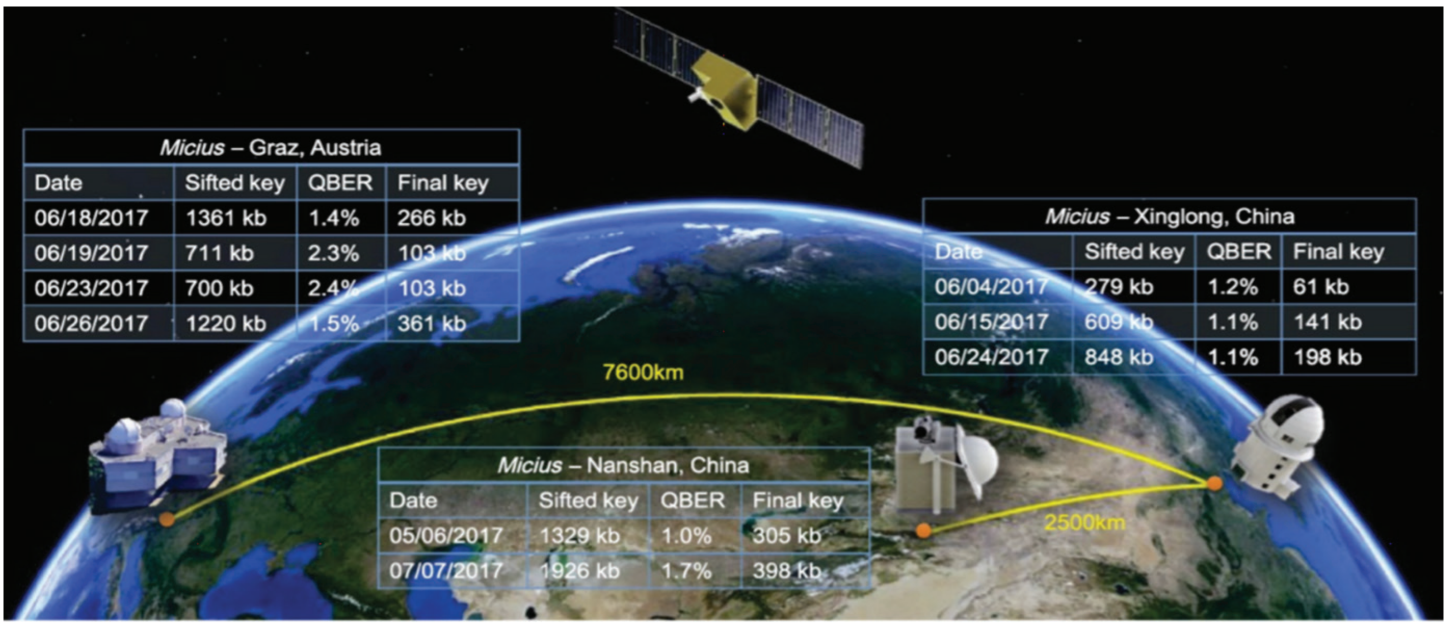

Yuhang Station


National Satellite Marine Application Center Mudanjiang Recieving Station Staff with members of local PLA Strategic Support Force units.

Quantum Satellite Experiment Ground Stations

An emerging role for satellite ground stations is quantum communications. China is engaged in a major research effort to develop a secure communication network using technologies based on quantum physics.[xix] Led by physicist Pan Jianwei [潘建伟], an important component of this research effort is called the Quantum Experiments at Space Scale (QUESS), part of China's space science Strategic Priority Program. In August 2016, China launched its "quantum satellite," Micius [墨子号], to test long-distance quantum communications. According to Dr. Pan, the main goals of the program are quantum key distribution from a satellite to ground station, a global-scale quantum communication network that uses satellites and fiber-optic cables, long-range entanglement testing involving two ground stations over 1,000 kilometers apart and a satellite, and ground-to satellite teleportation (sending quantum information from one location to another). In June 2017, China successfully entangled photons at two ground stations 1203 km apart, relayed through Micius.

The Chinese Academy of Sciences operates communication stations and observatories in Delingha, Qinghai Province, Nanshan, Xinjiang AR, Lijiang, Yunnan Province, and now a mobile station in Shandong Province.[287] Successful links have also been established between Beijing and Austrian scientists in Vienna and Graz (see inset).

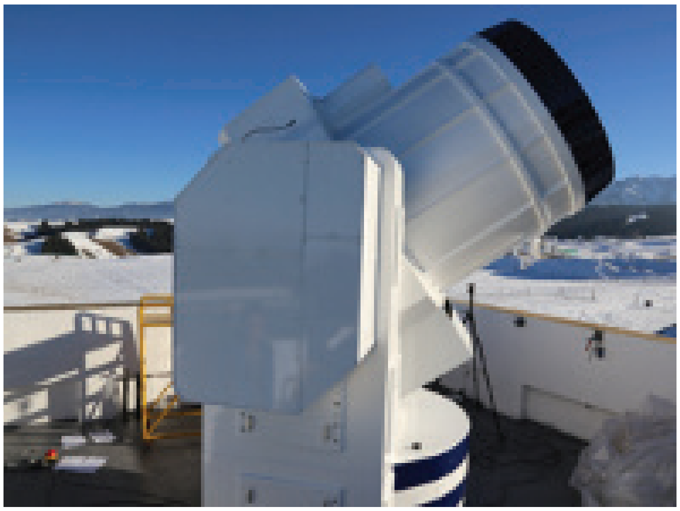


Progress of the Quantum Experiment Science Satellite (QUESS) 'Micius' Project

xix For more on China's quantum technology projects, see: Elsa Kania, John Costello, "Quantum Leap (Part 1): China's Advances in Quantum Information Science," China Brief, 5 December 2016. https://jamestown.org/program/quantum-leap-part-1-chinas-advances-quantum-information-science-elsa-kania-john-costello/ and Elsa Kania, John Costello, "Quantum Leap (Part 2): The Strategic Implications of Quantum Technologies," China Brief, 21 December 2016. https://jamestown.org/program/quantum-leap-part-2-strategic-implications-quantum-technologies/

The Nanshan Observatory also has a 1.2m optical telescope (left) that has participated in quantum communications experiments.

In late December 2019, the research team successfully established links between Micius and a mobile ground station.[288] While the technology is still under development, eventually, the network of ground stations could help support secure communications for the military.



Nanshan Observatory optical telescope

CCTV Image, 31 December 2019

State Radio Spectrum Management Center [中国无线电管理]

A little-discussed component of China's space ground segment and space tracking system is the State Radio Spectrum Management Center, which is responsible for radio monitoring and spectrum management (filling a role similar to one of the Federal Communications Commission (FCC) in the United States). It is directly under the Ministry of Industry and Information Technology (MIIT) and directly supports space tracking missions.[289] Monitoring stations [监测站] are located in Beijing, Chengdu (Sichuan), Fujian, Harbin, Shanghai, Shenzhen (Guangdong), Shaanxi, Urumqi (Xinjiang), and Yunnan, many of which feature large-scale radio-direction finding stations and radio satellite communication stations.[290] Other affiliated stations have been identified in Tibet and Inner Mongolia. The national network plays a role in locating and eliminating sources of radio interference with satellite transmissions.[291]

The Beijing station is part of the network of global stations of the International Telecommunications Union (ITU). Established in 2003, the facility is used for space radio monitoring. It has seven receivers capable of monitoring non-GSO satellites and GSO satellites with a visible arc of 50° East longitude to 180° East.[292]

The Beijing station (left) has satellite monitoring capability and played a role in supporting the Shenzhou-6 amd -7 missions, as well as multiple Chang'e missions.

The organization appears to closely coordinate with the SSF and other parts of the Chinese armed forces, for example, jointly holding an exercise All-PLA reserve spectrum management center [全军预备役电磁频谱管理中心].[293]

Beijing Station

Shenzhen Station

Very Long Baseline Interferometry (VLBI) Network

A technique called very-long-baseline interferometry (VLBI)[294] can be used to improve the reception of very faint radio signals such as those from distant galaxies or spacecraft operating in deep space. VLBI combines data from physically distant receivers to enhance the quality of that data, providing sharp imaging of distant objects or improved data reception from spacecraft.

To support its science projects and space exploration programs, China has built an expansive VLBI network, including stations in Nanshan (Urumqi), Miyun (Beijing), Kunming, Sheshan, and Tianma (Shanghai), Wuqing (Tianjin), and a data processing center in Shanghai.[295]

While these stations appear to coordinate closely with CLTC, the Xi'an Control Center, and other components of the PLA SSF Space Systems Department, they are, in most cases, directly subordinate to observatories under the China Academy of Sciences (CAS). They are briefly profiled on the following page.

China's first large-scale radio telescope that laid the foundations for a VLBI network is the 25-m Sheshan Observatory [佘山] in Shanghai, completed in 1986.[296]

Nanshan 25-m Radio Telescope

The Xinjiang Observatory's Nanshan [南山] station, located south of Urumqi, has a 25-m radio telescope that was completed in 1993. In 2016, a second 25-m dish was added to the facility, which also features a number of large optical telescopes. It is an important component of China's VLBI network.[297]

To support the Chang'e 1 mission, the Lunar Exploration Program Ground Application System was established, and in 2006 radio telescopes were built in Miyun (Beijing) and Kunming (Yunnan). The telescopes operate in the S/X band and participate in precision tracking of the Chang'e spacecraft's orbit and downlink scientific data it collects.[298] The Miyun station features a 50-m radio dish, and the Yunnan Astronomical Observatory's radio telescope in Kunming has a 40-m dish.[299]

Yunnan Astronomic Observatory

In 2012, the Shanghai Observatory added a second large radio telescope, a 65-meter receiver in Tianma [天马].[300] In 2016, China completed the Five-hundred-meter Aperture Spherical Telescope (FAST), a valley-spanning radio telescope in Pingtang County [平塘县], Guizhou, used to study pulsars and other cosmic phenomena.[301]

In late April 2020, a 70m station was completed in Tianjin's Wuqing District [天津武清区]. This newest addition to China's network of radio telescopes is part of the National Astronomical Observatories of China and will support China's Mars and lunar exploration missions.[302] Plans are already underway to expand this network, including a 110-m steerable Qitai Radio Telescope in Xinjiang scheduled for completion in 2023.[303]

These stations communicate with those under the Xi'an Satellite Control Center, including Swakopmund, Namibia, and components of international VLBI networks such as European Space Agency receivers in New Norcia (Australia) and Cebreros (Spain), and the East Asia Very Long Baseline Interferometry network, which includes radio telescopes in Japan and South Korea.[304]

3. China's Global Space Infrastructure

While the preceding sections have mostly discussed space ground infrastructure within China's borders since the early 1990s, China has built or leased many stations abroad. Though most are subordinate to the organizations outlined above, their histories and role in China's economic strategies and diplomatic efforts mean that they can be viewed together.

3.1 Overview

China has built or leased stations all over the globe to support its space program, which increasingly supports commercial operations.[xx] As outlined in the preceding sections, this growth was initially driven by the manned and lunar space programs. However, as Chinese industries became involved in satellite design and launch capabilities in the 1990s, exports of space platforms and services have risen in prominence, symbolized by the launch of the China-Brazil Earth Resources Satellite (CBERS) in 1999.

China's ground segment also plays a role in its two major externally-focused strategies: the Going Out Strategy and Belt and Road Initiative (BRI). In October 2000, China announced the "Going Out" Strategy [走出去战略] to promote Chinese companies abroad and improve their global competitiveness. Backed by heavy subsidies, Chinese companies have provided launch services for over 20 countries and international organizations.[305]

Space infrastructure has also been linked to the BRI, introduced in 2013. In October 2016, SASTIND and the NDRC issued Guiding Opinions setting out priorities for the development of the Belt and Road Space Information Corridor ["一带一路" 空间信息走廊].[306]

The Corridor's primary goals are to improve space infrastructure coverage of the areas of the Belt and Road (strategically important areas on China's periphery) and increase the competitiveness of China's space industries through sales of services and access to technology.

xx Building a global network of ground stations for space missions is itself not unusual. The U.S. set up stations in Nigeria and Singapore to support launch of the Explorer 1 satellite in 1958, and a global network of stations also supported the Apollo missions. The U.S. Army built a global network of satellite tracking and reference sites used to support the SECOR (Sequential Collation of Ranges) satellite series, a mapping and navigation initiative in the 1960s predating GPS, that had roughly 25 sites outside the continental United States in 1971. See: NASA Directory of Observation Station Locations [Volume 2], 2nd Edition., NASA, November 1971. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720012596.pdf

Commercial Stations Abroad

In addition to stations operated by the Chinese military and the Chinese Academy of Sciences, commercial operators are increasingly becoming involved in ground segment operations. As demand for satellite-based services increases, the demand for more numerous stations abroad will rise.[xxi] Several Chinese companies, including Shenzhen Haiweitong, CASC, and SinoSat, provide commercial satellite services. These systems often require a global network of ground stations in North America, Europe, and Sri Lanka, as well as stations within China in Kashgar in Xinjiang, Beijing, Zhoushan, and Hong Kong (see inset).[307] Sino Satellite Communications (SinoSat) supports its satellite broadband communication network with stations in Beijing, Hong Kong, Kashgar, Sri Lanka, Europe (and two in North America).[308] Others offer broadband satellite communications and internet connections to maritime users such as MarineSat [海卫通] and MarineTel [海星通]. These services use Very Small Aperture Terminals (VSAT) aboard the ships to communicate with a constellation of communications satellites in geosynchronous orbit.

The MarineTel platform is used by over 6,000 ships and oil platforms, including 4,000 fishing vessels.[309]

Other examples of commercial applications that will drive the deployment of additional stations include satellite collection of Automatic Identification System (AIS) tracking signals. AIS is emitted by civilian ships and are used for cargo tracking and collision avoidance. A private Chinese company, HEAD Aerospace [和德宇航], has launched five satellites since 2017 as the basis of a larger constellation to collect AIS data.[310]

As commercial opportunities expand—accelerated by the Chinese government's promotion of the National Civil Space Infrastructure Plan, Space-Earth Integrated Information Network Mega Project, and Belt and Road Space Information Corridor—more of these stations will likely come online and become important components in China's ground segments.

International Cooperation

China is a participant in a number of international space exploration and infrastructure sharing initiatives. Currently, CNSA has signed 117 cooperative agreements with 37 countries and four international organizations and participated in activities with 16 space-related international organizations.[311] It has also deepened cooperation in the development of sensors and other aspects of satellite R&D with countries including Switzerland, Italy, and Poland.[312]

NASA and the Chinese Academy of Sciences signed an agreement to cooperate in limited project-specific activities in plate tectonics and geodynamics research (satellite laser ranging and GNSS) in 1992 that remains in effect to this day.[313] China has also participated in U.S. data-sharing and downlinking initiatives such as the

xxi For comparison, U.S. commercial satellite imagery company Planet, which operates over 150 satellites, uses a global network of 45 ground stations to downlink data. See "Innovation, Iteration, and Automation," Planet, accessed July 2020. https://www.planet.com/company/approach/

Landsat Ground Station Operations Working Group.[314] Other international organizations the PRC participates in include the International Laser Ranging Service (ILRS).[315]

China is also a founding member of the Square Kilometer Array (SKA) Observatory Convention, along with China, Australia, Italy, the Netherlands, Portugal, South Africa, and the United States.[316] The project will build a massive array of small radio dishes in Australia and combine data with other radio observatories in participating countries to conduct a number of scientific experiments, including tests of general relativity, and provide observational data for the search for dark matter.

The Beijing Institute of Tracking and Telecommunications Technology (BITT) profiled earlier in this report created a Space Research and Development Center [航天研究发展中心] in 2000, which became the platform for engaging in international technological cooperation with over 20 nations including the United States and Russia.[317] It also plays a role in the construction of facilities overseas and was responsible for the construction of foreign TT&C stations in Chile and Kiribati.[318]

While the primary goal of China's stations abroad appears to have been commercial opportunities, it has also paid diplomatic dividends. Cooperation in satellite development with France and Brazil, including the China-Brazil Earth Resources Satellite (CBERS), has helped further relations with those countries. CBERS is similar to the NASA Landsat and European SPOT programs, which publish Earth observation data for agricultural, land-use planning, and environmental monitoring programs. Other domestically developed satellites, such as the Fengyun weather satellite, offer similar value and have been linked to China's Belt and Road Initiative. For example, China built a Fengyun receiving station in cooperation with the Mozambique National Institute of Meteorology as part of extending the BRI.[319]

In 2007 China announced that it was going to share data from the CBERS-02B satellite with African nations. Ground station operations began in South Africa in 2009.[320] The CBERS program was expanded globally in 2010 with the signing of the "CBERS Data Global Data Distribution Agreement" in Brazil.[321] CRESDA has created a platform for data-sharing from the CBERS-04 earth observing satellite with ASEAN countries.[322]

Space Infrastructure and the Question of Dual-use

China has made real achievements in space, but while there are regular calls within the United States and our allies and partners to deepen cooperation with China, strategic competition and fears that information or technology could be adapted for military use loom in the background. Since China began to build or lease TT&C stations abroad, they have been subject to intense scrutiny regarding their connections with China's military—and with good reason.

To some extent, this is to be expected; most countries' space programs emerged from military initiatives. The nature of space technology itself further complicates the issue, as much of space infrastructure is inherently dual-use.[xxii]

xxii Historically, the contemporary distinction between civilian, military, and "dual-use" in regards to space is largely derived from the American experience in space and the Eisenhower administration's attempts to prevent inter-service competition. See: Roger Handberg "Dual-Use as Unintended Policy Driver: The American Bubble," in Societal Impact of Spaceflight, Steven J. Dick and Roger D. Launius, eds. NASA, Washington D.C. 2007. https://history.nasa.gov/sp4801-chapter18.pdf, 356-357.

PNT or imagery satellites are useful for civilian as well as military applications, and military access to civilian communications satellites has been an important feature of war for at least 30 years.[xxiii] Militaries regularly make use of commercial imagery and other remote sensing data, and many countries that might compete in other ways cooperate to share data for land use or weather monitoring purposes. The National Reconnaissance Office (NRO), which operates U.S. reconnaissance satellites, has recently expanded its relationship with commercial imagery providers[323]. These relationships also benefit the commercial sector, and Chinese authors regard U.S. civilian success in space in part as a result of close cooperation between NASA and the U.S. Air Force.[324]

The overlap between TT&C stations, early warning systems, signals collection stations, missile instrumentation ships, and space tracking ships has been rather blurry. Ground stations, which have particularly provoked questions about sovereignty and military purposes, have a particularly complicated history serving in both roles since they can be used to assist in both missile and space launches—or to intercept those communications.[xxiv] This becomes more complicated when it involves establishing facilities on foreign soil, but this is also a regular feature of space operations. The U.S. required TT&C support for its first satellite launch, the Explorer 1 satellite in 1958, and set up stations in Nigeria and Singapore. In the 1960s, the U.S. Army built a global network of satellite tracking sites used to support the SECOR (Sequential Collation of Ranges) satellite series, a mapping and navigation initiative predating GPS, which included roughly 25 sites outside the continental United States in 1971.[325] The Apollo lunar program and subsequent U.S. space exploration missions have also required a global network of stations. Operations of NASA's Earth observation satellite constellation involves a global network of stations to operate, including a core network is composed of facilities within the United States, in Svalbard, Norway, Alice Springs Australia, and Neustrelitz Germany. It has also been joined by stations in Brazil, Canada, China, Germany, India, Indonesia, Italy, South Africa, South Korea, and Sweden.[326]

How then to understand China's development of similar infrastructure? A key point to make is that in China's case, this relationship is even closer due to historical factors and its political system, which is structured with the military directly subordinate to a ruling Leninist political party rather than to a national government. As outlined in this study, almost every component of China's space programs are administered by or works in close connection with its military. While organizations like CNSA present a civilian face for China's space programs, cursory analysis of their leadership and structure indicate they are civilian in name only. China Launch and Tracking Control (CLTC), the organization responsible for China's TT&C network and support ships, is believed to now be a component of the PLA Strategic Support Force Space Systems Department. The Yuanwang ships under the China Satellite Maritime Tracking and Control Department and their deliberately-obfuscated connections to the PLA (the SSF SSD specifically) are another point of concern.

More broadly, the civilian organizations under the China Academy of Sciences have close ties to the PLA. There appears to be significant cooperation between SSF units involved in space tracking, including the Deep Space Network, and the National Astronomical Observatories of China [国家天文台], which share data and

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xxiii Chinese observers reference the point that during the first Gulf War in 1991, U.S. use of military and commercial space infrastructure included over 70 satellites, 118 mobile ground stations and 12 commercial satellite terminals. See: Jiang Lianju [姜连举], ed. Lectures on Space Operations [空间作战学教程], Beijing: Academy of Military Sciences Press, 2013, 191

xxiv For example, the NSA built a collection station in Asmara, Eritrea—then a province of Ethiopia—to gather telemetry signals intelligence (TELINT) or Foreign Instrumentation Signals Intelligence (FISINT) on the Soviet command station for Soviet deep space objects and Soviet space probes. See: "Telemetry Intelligence (TELINT) During the Cold War," National Security Agency Center for Cryptologic History, 2016. https://www.nsa.gov/Portals/70/documents/about/cryptologic-heritage/historical-figures-publications/publications/misc/telint-9-19-2016.pdf, 24.

cooperate on technical issues. A Chinese article on cooperation between the Jiamusi Deep Space Station and the National Astronomical Observatories of China described it as "joint military-civil cooperation that achieved 'win-win' results."[327] Concerns that technologies developed in the commercial sector, often with foreign inputs, may be shared with the PLA are justified, as Chinese companies are themselves explicit that that technology will be spun-off for military use. The creation of a "Satellite Application Comprehensive Center" in 2018 under the CASC 5th Academy's [航天科技集团五院][xxv] Satellite Application General Department [卫星应用总体部], for example, is intended to encourage private investment in and use of satellite resources, and direct the results of these toward the military.[328]

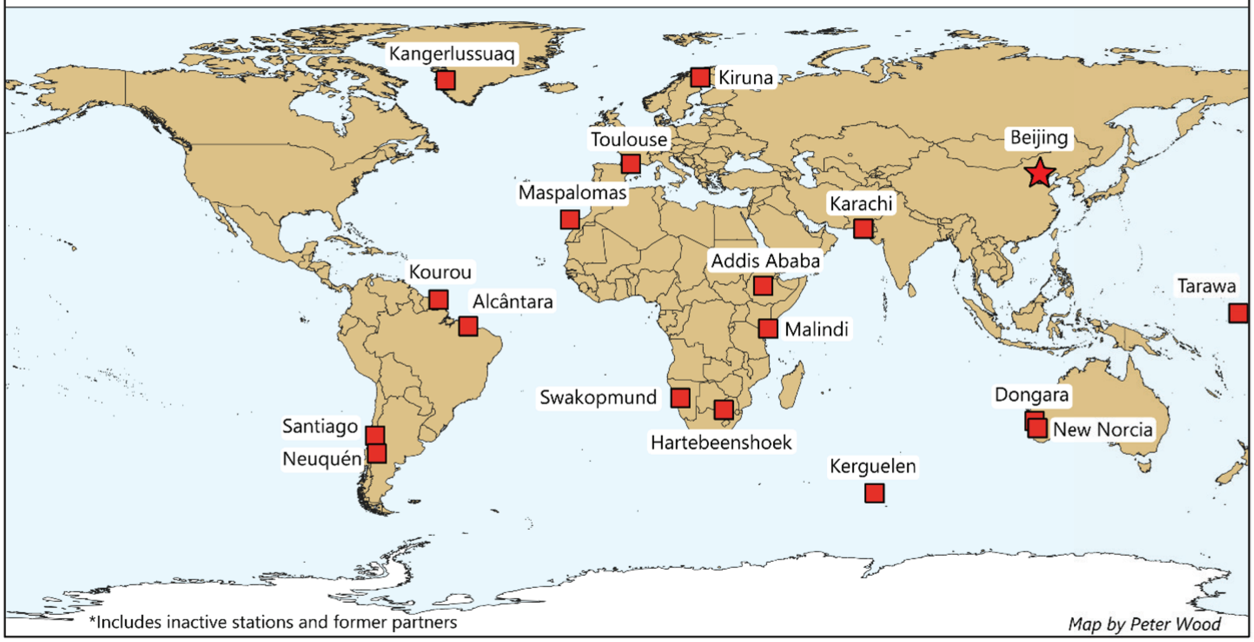
In summary, the overlap between civilian and military sectors is a regular feature of space operations, including the ground segment. Evaluating China's development of a network of stations outside its borders should be viewed through that lens, but with the understanding that China has chosen to obfuscate these ties.

xxv Also known as the China Academy of Space Technology [中国空间技术研究院], China's main developer of spacecraft.

3.2 Chinese TT&C Stations and International Partners

The following map and descriptions of ground stations, arranged alphabetically by country, are identified as having been leased by cooperating with or directly constructed and operated by China's space programs. While some of these stations are commercial operators that provide services to a wide range of other countries, they are included due to their identification by Chinese officials as part of "China's network."

Chinese Space Tracking Stations and International Partners



Country	Location	Mission	Coordinates
Argentina	Neuquén	Deep space tracking	-38.192607, -70.148405
Australia	Dongara	Shenzhou spaceflight missions	-29.046755, 115.351077
Australia	New Norcia	Deep space tracking, lunar missions	-31.0482, 116.191
Brazil	Alcântara Launch Center	CBERS	-2.334606, -44.419621
Chile	Santiago Station	Shenzhou spaceflight missions	-33.150239, -70.667962
Ethiopia	Entoto Observatory	ETRSS-1	9.108695, 38.807249
France	Kourou, French Guiana	Deep space tracking, lunar missions	5.222222, -52.773611
France	Issus Aussaguel, Toulouse	Shenzhou spaceflight missions	43.428655, 1.497401
France	Kerguelen Station	BNU-1 Polar Satellite	-49.351939, 70.256424
Greenland	Kangerlussuaq	Beidou	67.018341, -50.708817 *
Kiribati	Tarawa - Inactive	Shenzhou spaceflight missions	1.356354, 172.932916 *
Kenya	Malindi	Shenzhou spaceflight missions	-2.996044, 40.194204
Namibia	Swakopmund	Shenzhou spaceflight missions	-22.574645, 14.548539
Pakistan	Karachi, Dehmandro	Shenzhou spaceflight missions	25.193106, 67.099325
Spain	Maspalomas Station	Deep space tracking, lunar missions	27.7633, -15.6342
South Africa	Hartebeesthoek Station	CBERS	-25.890095, 27.685227
Sweden	Kiruna	Shenzhou spaceflight, downlinking	67.881219, 21.061046

*Imprecise location

Dongara, Australia [当加拉站]

Dongara Station

The fifth station to join China's network of overseas TT&C ground stations is located in Dongara in Western Australia. Owned by the Swedish Space Corporation (SSC), it was first leased to support the 2011 unmanned Shenzhou 8 – Tiangong docking mission.[329]

The decision to allow Chinese use of the facility was criticized. Des Ball, an Australian academic and security expert, claimed the station was dangerous as the Shenzhou 8 was being used to collect electronic intelligence.[330] In September 2020, SSC said it would not be renewing or carrying out any new Chinese satellite business.[331]

Santiago, Chile: Santiago Station [圣地亚哥站]

Santiago Station

Ambassador Lu Fan was invited to visit the Chilean branch of the Swedish space company.

China has also used antennas in Santiago, Chile, to support Chang'e, Shenzhou, and satellite missions.

China Satellite Launch and Tracking Control General (CLTC) began cooperating with the University of Chile's Space Research Center in 1994 and leasing satellite tracking and control equipment.[332] In 2008, CLTC built the Santiago China Ground TT&C Station [圣地亚哥中国卫星地面测控站], which supported the Shenzhou-7 mission that year. The facility is currently operated by SSC Chile.[333]

CLTC signed an agreement for access to a 10-m C-band antenna at Santiago in May 2010. The station appears to be under the Xi'an Satellite Control Center and to provide data to Xi'an and Beijing centers.

Addis Ababa, Ethiopia

Highlighting the ways China is using space for diplomatic inroads is its relationship with Ethiopia.

In 2018, the Ethiopian Ministry of Science and Technology signed a cooperative agreement with CNSA. The Chinese delegation indicated that they were "ready to provide training and support and to launch satellites in addition to the comprehensive cooperative agreement on space activities."[334]

China launched Ethiopia's first-ever satellite in December 2019. While donated by China, Ethiopian scientists participated in its design, and 20 Ethiopian engineers have been trained in China to operate the ground station.[335] The 65-kilogram microsat features a multi-spectral wide-angle camera to collect agricultural data.[336]

Ethiopian Ground Station

The purpose of the satellite is to support agricultural transformation, forest resource monitoring, weather forecast, and infrastructure projects. Ethiopia currently relies on data and services from foreign satellites, which costs millions of dollars each year. The new satellite is intended to be the first step toward Ethiopia developing its own capabilities.[337]

The ground station for the satellite is based at the Entoto Observatory and Research Center located in the mountains north of Addis Ababa. Construction of the observatory began in 2008, and it currently has two 1-meter telescopes and a satellite receiver.[338]

The Ethiopian Space Science and Technology Institute (ESSTI) [埃塞太空科学技术研究所] cooperates with, among others, China Aerospace Science and Technology Corporation (CASC), and China Great Wall Industrial Corporation (CGWIC).[339]

French Stations

In 1984, the Xi'an Satellite Control Center and the French government signed an agreement to cooperate on space tracking.[340] Since then, Chinese organizations and the French space agency Centre National d'Etudes Spatiales (CNES) have cooperated in several different areas of space exploration, notably using European Space Agency (ESA) and French-run stations in Toulouse, Kerguelen Islands, and at the Guiana Space Centre in French Guiana to support satellite tracking and deep-space communication missions.

Another area of cooperation is the China France Oceanography Satellite (CFOSAT). Initiated in 2016, CFOSAT is a joint mission devoted to the observation of ocean surface wind and waves undertaken by the Chinese and French Space Agencies.[341] Both countries contribute to the ground segment. The Chinese contribution to the ground segment is composed of a "Satellite Control Center" located in Xi'an (China), three TT&C ground stations in Beijing, Sanya, and Mudanjiang,[342] and a Mission Center for data processing, distribution, and archiving. The French CFOSAT Ground Segment is composed of two X-band Stations, located in Kiruna (Sweden) and Inuvik (Canada), and two mission centers: one operated by CNES in Toulouse (France) for near-real-time processing distribution of data, and data archiving, and a second one for differed-time data processing, distribution and archiving operated by Ifremer in Brest (France). Some ground stations within China, such as the China Academy of Sciences-operated station in Kashgar, downlink data from the French SPOT (Satellite Pour l'Observation de la Terre) earth observation satellites.[343]

Issus Aussaguel, Toulouse, France

Issus Aussaguel[xxvi] is home to a large TT&C station operated by CNES that has participated in various Chinese space missions, including the Tiangong-1/Shenzhou-8 docking mission in October 2011.[344] During that mission, the Aussaguel station worked as part of a network with Chinese TT&C stations as well as stations in Dongara, Australia, and Alcantara, Brazil, and Kerguelen station.

Port-aux-Français, Kerguelen Islands, France [凯尔盖朗站]

Located in the south-central Indian Ocean, the TT&C station at Port-aux-Français, in the Kerguelen Islands (also known as the Desolation Islands), is operated by CNES.

Chinese sources indicate the station has supported the October 2011 docking between the Shenzhou 8 and the Tiangong-1 station, among other missions.[345] Its location makes it ideal for providing coverage in an area that would otherwise require dispatch of one of the Yuanwang ships.

Port-aux-Français

xxvi This is usually referred to in Chinese sources as Aussaguel Station [奥赛盖尔站] or by the nearest large city Toulouse [土鲁斯]

Malindi Station, Kenya [马林迪站]

Malindi station, operated by the European Space Agency, is equipped with an S-band transmitter/receiver and L- and X-band receivers.[346] Malindi participated in tracking of the Shenzhou-5 mission, China's first crewed spaceflight, providing TT&C coverage between the Swakopmund (Namibia) and Karachi (Pakistan) stations.[347]

The station provided important data assisting with braking maneuvering and re-entry of the Shenzhou-6 mission[348].


Malindi Station


Malindi Station

Tarawa, Kiribati [吉利巴斯 or 基里巴斯; 塔拉瓦站]

As China made preparations for its crewed spaceflight program, it began identifying potential locations for ground stations. Located in the central Pacific, Tarawa offered more reliable coverage while being significantly cheaper than using the Yuanwang TT&C ships. Tarawa previously hosted a ground station for the U.S. Army Map Service's SECOR Geodetic Satellite Observation Station (part of a predecessor to GPS) in the 60s and 70s.[349]

Negotiations between China and Kiribati to build a station in Tarawa began in June 1996, and in September of that year, China signed a 15-year lease for a 1-hectare plot of land to build a space tracking station.

While the agreement stipulated that "The Chinese government promises that the measurement and control station will be used exclusively for peaceful purposes and will not be used for military purposes at any time," there were concerns about the station's proximity to U.S. missile testing ranges in the Marshall Islands.[350]

The station was completed in 1996 and was rented for 1.2 million RMB per year (roughly $143,000 at the time).[351] The establishment of the station was a significant cost-savings measure, as, without it, China would have been required to dispatch the Yuanwang space tracking ships, which cost three times as much.[352]

Kiribati maintained diplomatic relations with the PRC until November 2003, when it switched recognition to Taiwan. The tracking station was shut down, but the facilities were apparently mothballed, not removed.[353] Kiribati switched recognition back to the PRC in September 2019, raising the possibility that the station could be restored.

Swakopmund, Namibia [斯瓦科普蒙德]


Liu Yang, the first Chinese woman in space, speaks at the station in 2019

China and Namibia signed an agreement to set up the TT&C station for China's crewed space program in October 2000, with the particular goal of assisting with control of the re-entry and landing phases. The station was completed in July 2001 and is subordinate to the Xi'an Satellite Control Center.[354] In 2003, during the Shenzhou-5 mission, the station coordinated with the Yuanwang 3 TT&C ship operating off the coast of Namibia. Since 2008, Namibia has sent students to China to learn high-tech skills related to the station, with the goal of expanding the use of remote sensing data and other space applications in the country.

In 2010, Namibian Ministry of Education officials expressed hopes that the station would encourage the use of space applications for land and town planning, disaster and flood management, agricultural surveys, and other tasks.[355] In 2012 China and Namibia signed an agreement to employ Namibians at the station to facilitate skill transfers.[356]

Dehmandro, Karachi, Pakistan [卡拉奇站 or南亚站]


Karachi station

China has a long-standing history of cooperation with Pakistan's missile and space industries: in 1990, China launched Pakistan's first domestically produced satellite, the Badr-I. This program also extended to ground operations.

The Karachi station, China's second overseas TT&C station, was unveiled on October 1, 1999. It is housed inside the headquarters of Space & Upper Atmosphere Research Commission (SUPARCO), Pakistan's space agency.[357]

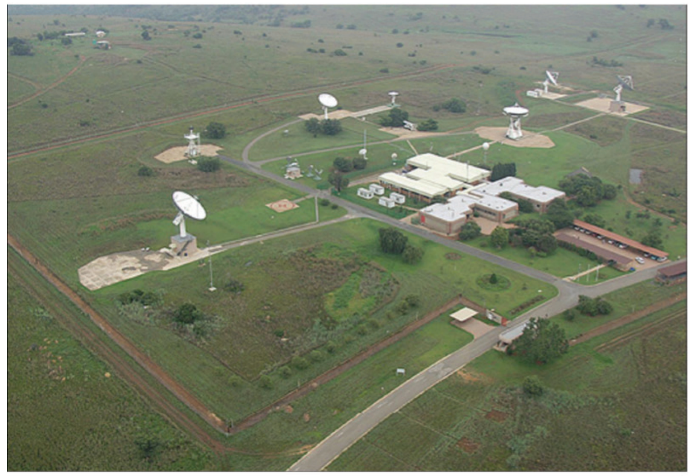
China signed a joint research agreement with Pakistan for space technology in 2006 that was extended in May 2007.

In November 2009, China Great Wall Industry Corporation, a subsidiary of CASC, was contracted to support the construction of a ground TT&C system for Pakistan's 1R communication satellite (PAKSAT-1R).[358] The included the Karachi main station and a secondary standby station in Lahore [拉合尔备站].

China has continued its cooperation with Pakistan in space, launching a second geostationary satellite in August 2011.

Hartebeesthoek, South Africa, Hartebeesthoek Ground Station

To help downlink data from natural resources satellites, China has established an agreement with the South African National Space Agency (SANSA) to use the Hartebeesthoek Ground Station.



Hartebeesthoek Ground Station

The station was originally built by NASA in 1961 as the Deep Space Instrumentation Facility (DSIF) to support tests of early space probes such as Ranger and Surveyor and later missions, including Apollo.[359] The site was closed in 1974 due to political instability and the Apartheid regime.

The China Centre for Resources Satellite Data and Application (CRESDA) and the South African National Space Agency (SANSA) signed an agreement in 2008, giving SANSA the right to freely receive, process, archive, and distribute CBERS satellite data.[360] The facility appears to work with other international organizations as well, including NASA.

Kiruna, Sweden, Arctic Satellite Receiving Station [北极卫星接收站]

This station in northern Sweden is part of the Aerospace Information Research Institute/China Remote Sensing Satellite Ground Station (RSGS) and was completed in December 2016. The station is able to receive data from earth-observing satellites and supports China's Gaofen project [高分重大专项], the umbrella for its Gaofen (lit. High Resolution) imaging satellites. China's National Satellite Meteorological Center also receives data from the Kiruna station.

Arctic Recieving Station

Kiruna also acts as one of two polar ground stations for the Chinese-French Oceanography Satellite (CFOSAT). The station consists of one 12-meter S/X/Ka Frequency antenna.[361] Its ability to receive data at higher bandwidths (such as Ka-band 4×1.5Gbps) means that it can more rapidly download and transmit data from satellites, which Chinese media note as significant.[362]

Kangerlussuaq, Greenland

In May 2017, Beijing Normal University (BNU) [北京师范大学], Greenland Tele-Post and the Greenland Institute of Natural Resources held a launch ceremony for the Greenland Satellite Ground Station [格陵兰卫星地面站] in Kangerlussuaq [康克鲁斯瓦格], Greenland.[363]

Beijing Normal University launches second arctic satellite ground station in Greenland

In addition to the Kangerlussuaq station, BNU plans to build a remote sensing satellite ground station in Nuuk, the capital of Greenland. It is unclear if this is related to the Kongsberg satellite ground station in Nuuk.[364] These satellites will help support not only the Beidou satellite navigation system but also China's larger ambitions for the Arctic.[365] One of the participants, Cheng Xiao [程晓] (second from the left in the photo above), is the Dean of BNU's Institute of Global Change and Earth System.[366]

According to an article in S&T Daily, part of the impetus for the project was China's reliance on U.S. satellite data when China's nuclear-powered icebreaker Xuelong [雪龙] was trapped in Arctic ice in January 2014.[367] To reduce this reliance and further Chinese scientific studies, China plans a constellation of 24 small satellites to provide continuous coverage. This will be later supplemented by high-orbit synthetic aperture radar satellites, with the overall project slated for completion by 2030. Chinese scientists, for example, note that the U.S., Europe, and Canada have achieved large-scale continuous observation of the Arctic and that existing polar-orbiting satellites (such as the Fengyun satellites) cannot provide the same type of observations.

China's current satellites, including the ZY-03, Gaofen-3, and Fengyun weather satellites, do not provide sufficient observations or at a sufficiently detailed level to complete necessary scientific projects.[368] In December 2019, China launched the BNU-1 satellite [冰路卫星; lit. "Ice Road Satellite"] built by BNU to conduct polar research.

BNU hopes to build follow-on stations in Antarctica as more polar monitoring satellites are deployed.[369]

Scientists at BNU are spearheading a so-called "Tri-polar Environment and Atmosphere Scientific Plan," often shortened to "Tripolar plan" [三极计划], which involves studying both poles as well the Tibetan plateau [青藏高原], which are major indicators of climate change. Satellites deployed as part of the plan are meant to augment the data collection capabilities of existing Gaofen and Fengyun Earth-observing satellites.

Additional Polar Sites

In addition to the sites in Sweden and Greenland, China has established research stations near both poles that may be upgraded to communicate with satellites in polar orbits.[370]

Arctic

Canada - Inuvik Satellite Station

Data from a joint Chinese-French Oceanography Satellite (CFOSAT) is downlinked to the Inuvik Satellite Station in northern Canada and Kiruna in Sweden.[371] Chinese scientists have also expressed interest in establishing a polar research station in Canada.[372]

Finland

In April 2018, the Institute of Remote Sensing and Digital Earth of the Chinese Academy of Sciences [中国科学院遥感地球所] and Finland signed a "Sino-Finnish Arctic Space Joint Research Cooperation Agreement" to support cooperation in four main areas: data exchange and information services in alpine and polar regions, satellite data downlink capabilities, scientific research and ground experiments, and personnel visits.[373]

The agreement also included plans to build an "Arctic Space Observation and Information Service Joint Research Center" in collaboration with the Arctic Space Centre of the Finnish Meteorological Institute (FMI-ARC) in Sodankylä [索丹曲莱] in northern Finland. The joint research center, officially inaugurated in October 2018, is positioned as the data and international network center for the alpine regions envisioned in the "Ice Silk Road" and "Digital Silk Road" plans under the Belt and Road Initiative.[374] Russian state-controlled news agency Sputnik cited this development as a new breakthrough in China's quest to conquer the Arctic following its establishment of the ground station in Kiruna.[375]

In September 2019, China's Aerospace Information Research Institute of the Chinese Academy of Sciences (AIRCAS) announced that the joint research center had been completed.[376] According to AIRCAS, this development marks an important progression of this cooperative relationship: the near-real-time download of data through FMI-ARC will provide strong data support for scientific research and information services in the alpine region.

Norway - Svalbard Satellite Station

China opened its first scientific research station in the Arctic in Ny-Ålesund (the Yellow River Station) in 2004.[377] The Svalbard Satellite Station, which is over 100 km away from the Yellow River Station, is a major station for global satellite networks. Chinese actors were alleged to have launched a cyber-attack on two U.S. satellites in October 2007 and July 2008 through the station, but these reports have not been verified.[378]

Maxar Technologies, Google Earth 2020

Antarctica

China has built several scientific research stations in Antarctica. On various expeditions, Chinese scientific research teams have set up radar reflectors for calibrating satellites and established a reference station [基准站] for the Beidou GNSS.[379] There are apparently plans to turn it into a fully-functional TT&C station.[380] A fifth station is being built in the Ross Sea area under the working name "Victoria Land Newly-Built Station" [维多利亚地新建站].[381] Basic surveying and mapping work for this station was completed in January 2014.[382]

In her examination of China's expanding interests and activities in Antarctica, scholar Anne-Marie Brady noted that China's draft Comprehensive Environment Evaluation (CEE) for the new base published in January 2014 highlighted climate change research, space science, and remote sensing as key projects, meaning that it will likely play a role in space tracking or related tasks.[383]

Chinese Scientific Stations in Antarctica	
Great Wall Station	长城站
Kunlun Station	昆仑站
Taishan Station	泰山站
Zhongshan Station	中山站

Conclusion

The size and sophistication of China's space ground segment within China and abroad has increased significantly. China seems on track to meet many of the milestones for the National Civil Space Infrastructure Plan, and is now capable of providing global control, downlink, and tracking operations of objects from low Earth orbit to deep space. This network of stations and the relationships that enable them to continue to bear fruit in terms of deepening relationships and opening markets for Chinese space services. China will continue to place a high value on space not only for its strategic significance but for the billions of RMB for China tens of thousands of jobs, space-related industries are expected to create. The ground segment will play a vital role in this endeavor.

Changes in technology are also going to reshape China's space infrastructure. There is an ongoing shift away from large, expensive stations, as networks of small but cheap optical and radar satellite tracking stations and radio ground stations become more popular. These stations will not reduce the need for large installations necessary for deep space missions, but it will mean that China can easily build redundant and highly accurate systems to connect space-based Internet of Things devices, downlink data, or track satellites and space debris.

Ultimately, as part of the Space-Earth Integrated Information Network Mega Project, Chinese scientists and engineers plan to build a constellation of space-based sensors, linked by data-relay satellites that can provide the necessary services without involving leasing or building stations abroad. While this project deserves to be monitored because it will have important impacts on China's economic and strategic capabilities, it must be noted that it lags behind military programs run by the DOD and is dwarfed by commercial projects underway in the United States.

The U.S. and its allies and partners have benefited from scientific cooperation with China, but going forward, this must be done with a realistic understanding of China's intentions and the real nature of the organizations to be partnered with. Navigating the need to cooperate in space as a global commons, including sharing tracking data, is complicated by its role as a strategic domain.

While China has, in many ways, benefitted from the opacity surrounding its space program and supporting organizations, this study makes it clear that with even cursory research, the curtain can be pulled back. The United States, along with our partners and allies who choose to engage with China on space issues, should, at minimum, understand the nature of the organizations they are working with and the consequences for international norms of a China strengthened by access to international space technology.

Appendix 1: Timeline of China's Space Program

1956	Jiuquan Satellite Launch Center (JSLC), Base 20, founded
1964/11/23	Seventh Ministry of Machine Building established to oversee space development
1965	China Satellite Maritime Tracking & Control Department, Base 23, founded; program to build China's first satellite (Project 651) initiated; work begins on Long March 1 based on the first two stages of the DF-4 missile
1965/6/28	Intelsat I - world's first commercial communication satellite - begins operation
1967/6/23	Satellite Ground Tracking Department, forerunner to the Xi'an Satellite Control Center (XSCC) / Base 26, founded
1967	China establishes the Taiyuan Satellite Launch Center (TSLC), Base 25
1970/1/30	First successful launch of a Long March 1 (CZ-1) rocket
1970/4/24	Dongfanghong 1 launched aboard a Long March 1
1970/6	China begins communications satellite project
1971/4	714 Project, China's first manned space program established; later canceled
1972	Beijing Satellite Communications Earth Station established
1975/9	Satellite Control Center, Base 26, established
1975/11/26	China becomes the third country to successfully launch and recover a satellite
1979/12	CAS Institute of Remote Sensing Applications founded
1979/12/29	Xichang Satellite Launch Center, Base 27, founded
1981	National Remote Sensing Center established
1981/9/20	China successfully launched a group of three satellites with a single rocket
1982/5	Seventh Ministry of Machine Building renamed Ministry of Aerospace Industry [航天工业部]
1982/10	Successful test of the JL-1, China's first SLBM
1984/4/8	Dongfanghong 2 experimental geostationary communication satellite launched
1983	Ministry of Aerospace Industry reformed into the Ministry of Aeronautics & Astronautics Industry
1986	China Launch and Tracking Control (CLTC) established; 25-m Sheshan Observatory radio telescope completed
1986/2/1	First practical Chinese communications satellite put in orbit
1986/12	Sino-US Scientific and Technological Cooperation Agreement signed, supporting the establishment of first Chinese RSGS ground station
1988	China-Brazil Earth Resources Satellite (CBERS) program established
1988/9/7	Fengyun-1experimental meteorological satellite successfully launched aboard Long March 4 rocket
1990/4/7	U.S.-made Asia-1 communications satellite launched, marking China's entry into the global space launch market.
1992/9/21	Work begins on China's manned spaceflight program
1993	CNSA formed from the former Ministry of Aerospace Industry
	Nanshan 25-meter radio telescope built outside Urumqi
1994	Beidou project established
1994	CLTC begins cooperating with the University of Chile's Space Research Center
1995	Satellite Control Center moved to Xi'an
1996	Tarawa TT&C station in Kiribati completed
1996/3	Beijing Aerospace Flight Control Center established

1997/6/10	Fengyun 2 launched
1998	General Armaments Department established
1999/10	China-Brazil Earth Resources Satellite Launched
1999/11/20	Shenzhou-1, China's first manned spaceflight experimental spacecraft, launched from Jiuquan
2000/10/11	China and Kenya signed an agreement on the establishment of an aerospace measurement and control station
2001/1/9	Shenzhou-2 unmanned mission
2001/4/25	National Astronomy Observatory of China founded through the merger of independent China Academy of Sciences observatories and related organizations
2002/3/25	Shenzhou-3 unmanned mission
2002/11/29	Shenzhou-4 unmanned mission
2003/5	Beidou-1 system completed
2003/10/15	Shenzhou 5, China's first manned spaceflight

Appendix 2: Chinese Ground Station Coordinates

Stations Within China

Organization	Location	Coordinates
China Satellite Launch and Tracking Control General Department (CLTC)		
	Beijing headquarters	39.962253, 116.385927
China Satellite Maritime Tracking and Control Department (Base 23)		
	Jiangyin, Wuxi, Jiangsu Province	31.942827, 120.288723
Unconfirmed Affiliation SSF Early Warning / Space Tracking Large Phased-Array Radars		
LPAR, Yiyuan County [沂源县], Shandong Province		36.024856, 118.092048
LPAR, Lin'an District [临安区], Zhejiang Province		30.286567, 119.128608
Beijing Aerospace Flight Control Center		
Headquarters		40.071983, 116.256847
Xi'an Satellite Control Center (XSCC) (Base 26)		
Changchun Station [长春站], Changchun, Jilin Province		43.725332, 125.540836
Qingdao Station [青岛测控站], Qingdao, Shandong Province		36.194830, 120.302880
Nanning Station [南宁测控站], Nanning, Guangxi Province		22.888060, 108.304440
	Menghai Station [勐海测控站], Menghai County, Yunnan Province	21.946553, 100.452665*
	Yao'an Substation [63760部队姚安分站], Yao'an, Yunnan Province	25.489181, 101.169445*
Lingshui [陵水测控站], Lingshui, Hainan Province		18.439798, 109.874072
Jiamusi Station (LPAR Sub-Station), Huanan County, Heilongjiang		46.528092, 130.755276
Weinan Tracking Station [渭南测控站], Dongyuan, Shaanxi Province		34.467904, 109.544941
Zhanyi Station [沾益(测控)站], Zhanyi County, Yunnan Province		25.638159, 103.715123
Mobile Tracking & Recovery Department [活动测控回收部], Weinan, Shaanxi Province		34.503420, 109.416442 *
1st Mobile Station, Weinan, Shaanxi Province		34.482661, 109.487657
2nd Mobile Station, Hetian, Xinjiang AR		37.164167, 79.871307 *
3rd Mobile Station (main base)		42.039565, 111.534044
Deep Space Network (under Xi'an SCC)		
Jiamusi, Heilongjiang Province		46.493403, 130.770409
Kashgar, Xinjiang AR		38.423420, 76.712207
Neuquén, Argentina		-38.191439, -70.149627
Jiuquan Satellite Launch Center (JSLC) (Base 20)		
Jiuquan Satellite Launch Center [酒泉卫星发射中心], Alxa, Inner Mongolia AR		40.983507, 100.206390
Secondary landing site [副着陆场]		40.536242, 101.022394 *
Dashuli Radar Tracking Station [大树里雷达测量站]		40.722291, 99.992276
U/I optical tracking station [光学测量站点]		41.326159, 100.365313*
U/I telemetry station		41.103952, 100.279730*
Large Phased Array Radar (LPAR) Korla, Xinjiang AR		41.641194, 86.236749
Taiyuan Satellite Launch Center (TSLC) (Base 25)		
Taiyuan Satellite Launch Center [太原卫星发射中心], Kelan County, Shanxi Province		38.848333, 111.610278
Telemetry station		38.808858, 111.611199

Dongfang Aerospace Port [东方航天港], Haiyang, Shandong Province		36.672862, 121.235374
Unit 63726 (possible) LPAR station [XL-3208雷达站], Kongtong Dist., Gansu Province		35.483025, 106.571871
Main radar tracking station [阳曲站], Yangqu, Shanxi Province		38.016892, 112.636536
Mobile radar station, 6th dui, Yinchuan, Ningxia AR [宁夏银川]		38.494519, 106.277348 *
Xingxian Station [兴县站]		38.507539, 110.920224 *
Xichang Satellite Launch Center (XSLC) (Base 27)		
Xichang Satellite Launch Center [西昌卫星发射中心] Liangshan Yi Autonomous Prefecture, Sichuan Province		28.245963, 102.028178
Niutoushan tracking station [牛头山观测站/牛头山测控点]		28.196568, 102.069191
Tracking station		27.911767, 102.209881*
Yibin Satellite Observation and Measurement Station [宜宾测量站], Yibin, Sichuan		28.743607, 104.611790
Yibin Barracks		28.764813, 104.641389
Baita Mountain, Yibin possible auxiliary station		28.775649, 104.634663 *
Guiyang Observation Station [贵阳观测站] in Huaxi County, Guizhou		26.409398, 106.670273
Wenchang Spacecraft Launch Site (WSLC) (Under Xichang SLC)		
Wenchang Spacecraft Launch Site [文昌航天发射场], Wenchang, Hainan Province		19.652510, 110.938741
	Tongguling tracking station [铜鼓岭测控点]	19.639694, 111.029314
	Paracel Islands tracking station [西沙测控站], Duncan Island [三沙市西沙群岛琛航岛]	16.451586, 111.713916
Unidentified / Possible Space Tracking or Missile Instrumentation Sites		
	Possible (PLAAF) LPAR Hui'an, Fujian Province [福建省泉州市惠安县]	25.126471, 118.751507
Aerospace Information Research Institute (AIR)		
Kashgar Station		39.504344, 75.930372
Miyun Station		40.451465, 116.858186
CAS National Astronomical Observatories of China [国家天文台]		
Beijing Observatory Station, Miyun, Beijing		40.557929, 116.976632
Changchun Satellite Observatory [长春人造卫星观测站]		43.790677, 125.443823
	Possible Substation	43.793982, 125.458251
Sheshan Observatory Station [佘山站], Shanghai (under Shanghai Observatory)		31.099321, 121.199758
Xinjiang Observatory Nanshan [南山]		43.471881, 87.177425
Yunnan Astronomical Observatory [昆明]		25.027370, 102.795947
National Satellite Meteorological Center [国家卫星气象中心]		
National Satellite Meteorological Center Headquarters, Beijing		39.947675, 116.320940
Beijing Weather Satellite Ground Station [北京气象卫星地面站]		40.050972, 116.276899
Guangzhou Weather Satellite Ground Station [广州气象卫星地面站]		23.164589, 113.338715
	Secondary location	23.243476, 113.411842
National Satellite Ocean Application Service [国家卫星海洋应用中心]		
Lingshui Station, Hainan		18.490251, 109.931629
State Radio Spectrum Management Center [中国无线电管理]		
Beijing Station		39.660041, 116.254973
Shaanxi Station		34.528998, 109.098328
Shanghai Station		30.864138, 121.582030

Shenzhen Station		22.579901, 114.499123
Urumqi Station		43.850092, 87.554027
Yunnan Station		24.617104, 102.949126
Communications Stations		
Beijing Satellite Communications Earth Station [北京卫星通信地球站]		40.050966, 116.274398
International Stations		
Argentina	Neuquén	-38.192607, -70.148405
Australia	Dongara	-29.046755, 115.351077
	New Norcia	-31.0482, 116.191
Brazil	Alcântara Launch Center	-2.334606, -44.419621
Canada	Inuvik	68.319464, -133.552426
Chile	Santiago Station	-33.150239, -70.667962
Ethiopia	Addis Ababa, Entoto Observatory	9.108695, 38.807249
France	Kourou, French Guiana	5.222222, -52.773611
	Issus Aussaguel, Toulouse, France	43.428655, 1.497401
	Kerguelen Station	-49.351939, 70.256424
Greenland	Kangerlussuaq	67.018341, -50.708817 *
	Nuuk	64.182770, -51.733997 *
Kiribati	Tarawa - *No longer active*	1.356354, 172.932916 *
Kenya	Malindi	-2.996044, 40.194204
Namibia	Swakopmund	-22.574645, 14.548539
Norway	Arctic Yellow River Station [黄河站], Ny-Ålesund, Svalbard	78.9232, 11.9345
	Svalbard Satellite Station	78.230302, 15.395534
Pakistan	Karachi, Dehmandro	25.193106, 67.099325
Spain	Maspalomas Station	27.7633, -15.6342
South Africa	Hartebeesthoek satellite ground receiving station	-25.890095, 27.685227
Sweden	Kiruna	67.881219, 21.061046
Chinese Scientific Stations in Antarctica		
Great Wall Station [长城站]		-62.216838, -58.961855
Kunlun Station [昆仑站]		-80.41734, 77.116449
Taishan Station [泰山站]		-73.85, 76.966667
Zhongshan Station [中山站]		-69.373587, 76.37165
*: Imprecise Location U/I: Unidentified or unconfirmed affiliation		

Appendix 3: Image Sources

Page	Img. No.	Source
24	1	“The students of Huabo Innovation and Technology’s “Love and Help the Wisdom” project visited Beijing Aerospace Flight Control Center” [华博创科“爱心扶智”项目的同学们参观北京航天飞行控制中心], Huabo Innovation, 27 April 2018. http://www.hbck.com.cn/portal.php?mod=view&aid=142
24	2	“Li Jian named Director of the Beijing Aerospace Flight Control Center [北京航天飞行控制中心主任李剑], SCIO, 18 November 2016. http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/33978/35474/pic35477/Document/1520027/1520027.htm
27	1	“长征五号成功发射！” Global Times, 27 December 2019. https://k.sina.cn/article_1974576991_75b1a75f02700oplo.html?from=mil
27	2	“175 minutes! Xi’an Satellite Control Center set the record for the shortest interval between space measurement and control missions in my country,” [175分钟！西安卫星测控中心创我国航天测控任务间隔最短纪录], S&T Daily, 15 November 2019. http://m.ce.cn/sh/sgg/201911/15/t20191115_33620613.shtml
29	1	[创业艰难 唯奋斗者进——追寻闽西创业史，追寻镌刻在血脉深处的基因],” 热心市民看社会, 26 April 2020. https://sa.sogou.com/sgsearch/sgs_tc_news.php?req=U9E5diOys2998A2fAf96dTmt4i-4j68fsIulhcqNXPfg=&user_type=1
30	1	Maxar Technologies, 2020 (12 December 2018).
31	2	“The measurement and control stations of Xi’an Satellite Control Center: Thousands of miles away, relay escort Beidou into orbit” [西安卫星测控中心各测控站点：远隔千里，接力护航北斗顺利入轨], Sina, 5 November 2019. https://k.sina.com.cn/article_3164957712_bca56c1002000zv96.html?from=mil
32	1	(Xi’an Satellite Control Center: Beidou 33rd and 34th satellites successfully fixed) [西安卫星测控中心：北斗第33、34颗卫星成功定点], CCTV, 12 August 2018. https://china.huanqiu.com/article/9CaKrnKbii8
33	1	“Dreams hold up the ‘Eye of Deep Space’” [梦想托起”深空之眼”], Hebei Workers’ News [河北工人报], 7 January 2014, http://www.hbgrb.net/epaper/html/2014-01/07/content_104909.htm.
36	1	“Reporters visited the Dongfeng measurement and control station to record the Shenzhou 9 launch drill process” [记者走进东风测控站 记录神九发射演练过程], Morning News, [朝闻天下], 13 June 2012.
37	1	“Just now! Taiyuan Satellite Launch Center Successfully Launches Jilin-1 video satellites 04, 05 and 06” 刚刚！太原卫星发射中心成功发射吉林一号视频04、05、06星], Shanxi Toutiao, 21 November 2017. https://www.sohu.com/a/205734460_395106
38	1	[专访西昌卫星发射中心主任 张学宇 任务涉及空间站 火星探测 北斗组网和嫦娥返回], CCTV, 25 March 2020. http://tv.cctv.com/2020/03/25/VIDENIe6lo1aghwQ85LpbYaH200325.shtml
39	1	A Long March-5B rocket prepares for launch from the Wenchang Launch Site Source: “The Long March 5B carrier rocket will be launched this evening” [长征五号B运载火箭将于今天傍晚发射], China Daily [中国日报], 5 May 2020. http://cn.chinadaily.com.cn/a/202005/05/WS5eb11a55a310eec9c72b6e14.html
40	1	Source: Xinhua, 10 November 2019. http://www.xinhuanet.com/2019-11/10/1125214192_15733754248521n.jpg
41	1	“Final star | Yuanwang 6 precision measurement and control land-sea relay to send Beidou” [收官之星 | 远望6号精准测控 陆海接力送北斗] Wen Wei Po [文汇报], 23 June 2020. https://www.sohu.com/a/403649333_120244154
41	2	S&T Daily, 26 February 2020. http://www.stdaily.com/index/kejixinwen/2020-02/26/888165/images/bcb51879f55d479194a4cf186accf53d.jpg
42	2	“The Consulate General in Auckland held a joint event with the Far Hope 6 space ocean survey ship” [驻奥克兰总领馆与远望六号航天远洋测量船举行联欢活动], Consulate-general of the PRC in Auckland, 2 December 2011. http://www.chinaconsulate.org.nz/chn/xwdt/t883644.htm

45	1	“China Remote Sensing Satellite Ground Station successfully realized high-resolution multi-mode satellite data reception” [中国遥感卫星地面站成功实现高分多模卫星数据接收], Xinhua, 06 July 2020, http://www.xinhuanet.com/politics/2020-07/06/c_1210688255.htm.
46	2	“China Remote Sensing Ground Stations” [中国遥感卫星地面站], Institute of Remote Sensing and Digital Earth [中国科学院遥感与数字地球研究所], Accessed February 2020], http://www.radi.cas.cn/jglb/kjtx/wxdmz/
47	1	“China Remote Sensing Ground Stations” [中国遥感卫星地面站], Institute of Remote Sensing and Digital Earth [中国科学院遥感与数字地球研究所], Accessed February 2020], http://www.radi.cas.cn/jglb/kjtx/wxdmz/
47	2	“China Remote Sensing Ground Stations” [中国遥感卫星地面站], Institute of Remote Sensing and Digital Earth [中国科学院遥感与数字地球研究所], Accessed February 2020], http://www.radi.cas.cn/jglb/kjtx/wxdmz/
48	1	“China Remote Sensing Ground Stations” [中国遥感卫星地面站], Institute of Remote Sensing and Digital Earth [中国科学院遥感与数字地球研究所], Accessed February 2020], http://www.radi.cas.cn/jglb/kjtx/wxdmz/
49	1	“Wang Zhaoyao Appointed Deputy Director of the CMC Equipment Development Department” [王兆耀任中央军委装备发展部副部长], Sina News, 29 October 2018. https://news.sina.com.cn/c/2018-10-29/doc-ifxeuwws9106156.shtml
50	1	“Leader Profiles” [领导简介], CNSA, Accessed July 2020. http://www.cnsa.gov.cn/n6758821/index.html
54	1	“Sit and watch the wind and the clouds, and see the weather, rain, and snow, this meteorological satellite ground station is not ordinary!” [坐看风起云涌，眼观阴晴雨雪，这个气象卫星地面站不一般！] , Sohu blog Golden sheep Network Travel [金羊网旅游吧] 19 August 2019. https://www.sohu.com/na/334891045_207916?scm=1002.45005a.15d015e01a3.PC_NEW_ARTICLE_REC&spm=smpc.content%2Fnew.fd-d.7.1566172800026oXoZw5N
55	2	“Leap into the “four-dimensional era” of observing the global ocean” [跃入观测全球海洋的”四维时代”], 《中国海洋报》第2386期A4版, 20 June 2018. http://www.argo.org.cn/index.php?m=content&c=index&f=show&catid=38&contentid=649
55	3	“A branch of the Mudanjiang Station Party Branch Joint Strategic Support Force carried out the special party class activity of “Strengthening Patriotism Education and Carrying Forward the Spirit of Patriotism” [牡丹江站党支部联合战略支援部队某部开展”加强爱国主义教育 弘扬爱国主义精神”专题党课活动], National Satellite Marine Application Center, 19 December 2019, http://www.nsoas.org.cn/news/content/2019-12/19/24_3708.html.
56	1	“Progress of the Quantum Experiment Science Satellite (QUESS) ‘Micius’ Project,” National Space Center, Accessed June 2020. http://english.nssc.cas.cn/ns/NU/201809/W020180906583002411445.pdf
57	2	“Our country’s first mobile quantum satellite ground station and “Mozi” successfully achieved an air-ground handshake” [我国首个可移动量子卫星地面站与”墨子号”成功实现空地握手], CCTV, 31 December 2019. http://wenhui.whb.cn/zhuzhan/rd/20191231/311649.html
59	2	“Nanshan 25-m Radio Telescope,” Xinjiang Astronomical Observatory, Chinese Academy of Sciences, accessed June 2020. http://english.xao.ac.cn/pr/25mrt/201712/W020171228685160184766.jpg
60	1	“China Lunar Exploration Project Kunming Ground Station 40-meter antenna completed and accepted” [中国探月工程昆明地面站40米天线建成验收], China News Network, 18 July 2006. https://tech.sina.com.cn/d/2006-07-18/10211042518.shtml
67	3	“Ambassador Lu Fan was invited to visit the Chilean branch of the Swedish space company” [驻智利大使吕凡应邀访问瑞典空间公司智利分公司], Chinese Embassy in Chile, 4 August 2010. http://cl.china-embassy.org/chn/sghd/t721576.htm
70	1	“Malindi station,” ESA, 2 March 2015. https://www.esa.int/ESA_Multimedia/Images/2015/02/Malindi_station

71	1	Liu Yang, the first Chinese woman in space, speaks at the station in 2019 Image source: “Chinese astronauts visit Namibia, China-N.S.A. space cooperation is on the rise [中国航天员再访纳米比亚 中纳航天合作方兴未艾], China Radio International Online [中央广电总台国际在线], 20 August 2019. http://news.cri.cn/20190820/39aad95b-5837-237b-8859-a69950262ca3.html
72	2	“Arctic Receiving Station” [北极接收站], China Institute of Remote Sensing and Digital Earth, China Academy of Sciences, http://www.radi.cas.cn/jglb/kjtx/wxdmz/201309/W020180528380751250791.png
73	1	“Beijing Normal University Launches Second Arctic Satellite Ground Station in Greenland” [北师大在格陵兰启动北极第二个卫星地面站建设], Science Net [科学网], 4 June 2017. https://web.archive.org/web/20170627154655/http://news.sciencenet.cn/htmlnews/2017/6/378159.shtm
74	1	Maxar Technologies, Google Earth 2020

Endnotes

1 “Launch Record” [发射记录], China Aerospace Science and Technology Corporation, accessed June 2020, http://www.spacechina.com/n25/n142/n152/n657792/index.html. Note: Data includes failed launches and does not include launches by private space companies.; “Successfully complete model task and create a miracle in the history of aerospace” [“圆满完成型号任务创造航天史上奇迹”], China Space News [中国航天报], 3 January 2020, http://211.100.197.201:8081/htb/2020-01/03/content_28888.html.

2 “Run to the next space ‘embrace’” [奔向下一个太空”拥抱”], People’s Daily, 24 April 2018. http://www.xinhuanet.com/science/2018-04/24/c_137132446_2.htm; Wu Weiren, Academician of the Chinese Academy of Engineering and chief engineer of China’s lunar program previously discussed other aspects of the plan in an article in 2018. See: “Wu Weiren: Among the major space powers, only my country does not have an aerospace law” [吴伟仁：在航天大国中，只有我国还没有航天法], Satellite and Internet [卫星与网络], 9 March 2018, https://www.guancha.cn/wuweiren/2018_03_09_449502_4.shtml.

3 “China plans to build a national civil space infrastructure system by 2025” [中国拟2025年建成国家民用空间基础设施体系], China News, 31 March 2018, http://news.sciencenet.cn/htmlnews/2018/3/407625.shtm.

4 “National Civil Space Infrastructure Medium- to Long-Term Development Plan” [国家民用空间基础设施中长期发展规划（2015-2025年）], beijing.gov.cn, 26 October 2015, http://invest.beijing.gov.cn/xxpt/fzgh/gjgh/201912/t20191206_904940.html.

5 TT&C station [测控站], gateway station [信关站], uplink station [上行站] and calibration field [标校场]. English translations taken from China’s Space Activities in 2016 [2016 中国的航天], State Council Information Office [国务院新闻办公室], 27 December 2016. A version of the document with side-by-side English and Chinese versions is available here: https://static1.squarespace.com/static/5e356cfae72e4563b10cd310/t/5ed934c561c86539a9037b10/1591293126759/China%E2%80%99s+Space+Activities+in+2016.pdf.

6 The original Chinese is “天地一体化信息网络。推进天基信息网、未来互联网、移动通信网的全面融合，形成覆盖全球的天地一体化信息网络.”; “‘S&T Innovation 2030’ Megaprojects launched” [科技创新2030项目启动], People’s Daily, 20 February 2017, http://www.xinhuanet.com//politics/2017-02/20/c_129485509.htm.

7 Fu Yifei [付毅飞], “‘Space-Earth Integrated Information Network Project Announces First Major Results” [‘天地一体化信息网络’项目首次发布重大成果,” Xinhua, 24 April 2018, http://www.xinhuanet.com/tech/2018-04/24/c_1122729995.htm. The original Chinese is “国家利益到哪里, 信息网络覆盖到哪里”

8 Yin Hao [尹浩], “Yin Hao: Military-Civil Fusion in Building a National Space Information Network,” Aisixiang [爱思想], 25 September 2017.

9 Fu Yifei [付毅飞], “‘Space-Earth Integrated Information Network Project Announces First Major Results” Xinhua, 24 April 2018, http://www.xinhuanet.com/tech/2018-04/24/c_1122729995.html

10 Gu Xuemai [顾学迈] et al., “Construction of Space/Sky/Terrestrial Integrated Information Network in China” [对中国建设天、空、地一体化信息网络的几点认识], ZTE Technology Journal 22, No.4 (August

2016), https://www.cnki.net/kcms/detail/34.1228.TN.20160630.0819.002.html.

11 Chinese actors were alleged to have launched a cyber-attack on two U.S. satellites in October 2007 and July 2008, through a station in Norway. A separate attack was carried out against systems of the National Oceanic and Atmospheric Administration by Chinese actors. See: Jim Wolf, "China key suspect in U.S. satellite hacks: commission," Reuters, 28 October 2011, https://www.reuters.com/article/us-china-usa-satellite-idUSTRE79R4O320111028; Mary Pat Flaherty, Jason Samenow, and Lisa Rein, "Chinese Hack Weather Systems, Satellite Network," The Washington Post, November 12, 2014, http://www.washingtonpost.com/local/chinese-hack-us-weather-systems-satellite-network/2014/11/12/bef1206a-68e9-11e4-b053-65cea7903f2e_story.html.

12 Salinas, Erin, "Space Situational Awareness is Space Battle Management," Air Force Space Command, May 16, 2018, https://www.afspc.af.mil/News/Article-Display/Article/1523196/space-situational-awareness-is-space-battlemanagement/.

13 See: Bhavya Lal, et. al, "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)," Institute for Defense Analyses, April 2018. https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx, 27. For examples of U.S. initiatives to promote these types of ground stations see: Lily Hay Newman, "Hackers Are Building an Army of Cheap Satellite Trackers" Wired, 4 August 2020, https://www.wired.com/story/nyansat-open-source-satellite-tracker/.

14 Wang Houqing [王厚卿], Zhang Xingye [张兴业], Eds. Science of Campaigns Beijing: National Defense University Press (2000), 95.

15 "Defense Space Strategy - Summary," DOD, 17 June 2020, https://media.defense.gov/2020/Jun/17/2002317391/-1/-1/1/2020_DEFENSE_SPACE_STRATEGY_SUMMARY.PDF.

16 This competition should come as no surprise. During the Cold War the United States and the Soviet Union both had ASAT programs, with U.S. programs in the 1970s focused on degrading Soviet maritime reconnaissance capabilities. See: Dwayne A. Day, "To attack or deter? The role of anti-satellite weapons, The Space Review, 20 April 2020, https://www.thespacereview.com/article/3927/1; "Shanahan: China Is Deploying Directed Energy Weapons," Breaking Defense, 9 April 2019, https://breakingdefense.com/2019/04/shanahan-china-is-deploying-directed-energy-weapons/.

17 Larry M. Wortzel, "PLA Command, Control and Targeting," in Roy Kamphausen and Andrew Scobell, ed., "Right-Sizing the People's Liberation Army: Exploring the Contours of China's Military," Carlisle PA: Strategic Studies Institute, September 2007, 212.

18 Larry M. Wortzel, "PLA Command, Control and Targeting," in Roy Kamphausen and Andrew Scobell, ed., "Right-Sizing the People's Liberation Army: Exploring the Contours of China's Military," Carlisle PA: Strategic Studies Institute, September 2007, p. 213.

19 "The iron spine on the Nansha reef" [南沙礁盘上的铁脊梁], 81.cn, 30 July 2012, http://navy.81.cn/content/2012-07/30/content_4975769.htm.

20 "Blue Culture: The Symphony of the Ocean" [蓝色文化: 建功大洋的交响曲], People's Daily, 15 June

2012, http://military.people.com.cn/GB/18189302.html.

21 “China’s Navy has equipped the Joint Comprehensive Data Link system to cope with harsher operational environments” [我海军已装备全军综合数据链 应对更严酷作战环境], Guangming Online [光明网], 24 November 2011, http://military.people.com.cn/GB/42967/16380909.html.

22 Zhao Rui [赵 锐], Zhong Bang [钟 榜], Zhu Zuli [朱祖礼], “战术数据链发展现状及其对战略 投送信息化建设的启示,” Sichuan Military Engineering Journal [四 川 兵 工 学 报], No. 33, Issue 12, December 2012.

Note that the United States is significantly ahead in similar technologies: publicized systems include a two-part constellation to collect and process data from LEO satellites for DARPA produced by Raytheon, which will help shift from transitioning from ‘operator-in-the-loop’ to ‘operator-on-the-loop’ methodology. The pairing, Pit Boss and Black Jack, is meant to streamline the loop from sensor to connector (communication satellite) to ground station and then on to final user. A separate project by the U.S. Space Development Agency is currently planning on building an initial mesh network of 20 satellites by 2022 to store, relay and transmit Link-16 data from space-based sensors to troops. See: “Pit Boss brings autonomous mission management to space,” Raytheon, 19 November 2019, http://raytheon.mediaroom.com/2019-11-19-Pit-Boss-brings-autonomous-mission-management-to-space; Nathan Strout and Valerie Insinna, “The Pentagon will solicit its first mesh network in space May 1,” C4ISRNet, 6 April 2020, https://www.c4isrnet.com/battlefield-tech/space/2020/04/06/the-pentagon-will-solicit-its-first-mesh-network-in-space-may-1/.

23 “China Integrates Long-range surveillance capabilities,” Jane’s Intelligence Review, accessed July 2020, https://web.archive.org/web/20171115140128/https://www.janes.com/images/assets/477/75477/China_integrates_long-range_surveillance_capabilities.pdf.

24 In 2019 Russian President Vladimir Putin told the audience at the Valdai International Discussion Club that [Russia] is “now helping our Chinese partners create a missile attack warning system.” Valdai Discussion Club session,” Kremlin.ru, 3 October 2019, http://en.kremlin.ru/events/president/news/61719.

25 “Space-based Infrared Early Warning Satellites - the Tireless Space ‘Outpost’“[天基红外预警卫星 永不疲惫的太空”哨兵”], S&T Daily, 7 February 2018, http://digitalpaper.stdaily.com/http_www.kjrb.com/kjrb/html/2018-02/07/content_388170.htm?div=-1; Other reporting indicates the system was launched between 2009 and 2014. See: “How powerful are Chinese missile early warning satellites? Not only can they detect the tail flame of ballistic missile launches, but can also locate large surface ships” [中国导弹预警卫星有多厉害？不仅能捕捉弹道导弹发射尾焰 还能发现大型水面舰船], Ordnance Technology [兵工科技], 12 June 2020, https://3g.china.com/mili/wuqi/37564211.html.

26 Sandra Erwin, “L3Harris, SpaceX win Space Development Agency contracts to build missile-warning satellites,” SpaceNews, 5 October 2020, https://spacenews.com/spacex-l3harris-win-space-development-agency-contracts-to-build-missile-warning-satellites/.

27 Sandra Erwin, “Lockheed Martin, York Space to produce 20 satellites for Space Development Agency,” SpaceNews, 31 August 2020, https://spacenews.com/lockheed-martin-york-space-win-contracts-to-produce-20-satellites-for-space-development-agency/.

28 “Building the Space Silk Road to help the construction of “One Belt, One Road” - From Silk Road to

Space · Sidelights on the First Silk Road Commercial Space Conference" [打造太空丝绸之路 助力"一带一路"建设 ——从丝路到太空·首届丝路商业航天大会侧记], S&T Daily, 19 November 2018, http://stdaily.com/cxzg80/guonei/2018-11/19/content_732220.shtml.

29 "China's Beidou System now has 39 satellites in Orbit, will be completed next year" [我国北斗系统在轨卫星已达39颗明年全面完成建设], Guangming Daily [光明日报], 12 September 2019, http://www.xinhuanet.com/politics/2019-09/12/c_1124988764.htm.

30 He Baoxin [何宝新], Qian Ping [钱平], "World's First Smart VLOC Successfully Completes Trial Voyage—The Era of Chinese AI Ships is Getting Closer" [全球首艘智能VLOC成功试航—中国智能船舶1.0新时代来临], China Ship News Online [中国船舶新闻网] 26 November 2018, http://chinashipnews.com.cn/show.php?contentid=14332.

31 "New Money: China's private space start-ups lift off," CGTN, 10 July 2020. https://news.cgtn.com/news/2020-07-10/New-Money-China-s-private-space-start-ups-lift-off-S0jCrO1Yzu/index.html; "Private space companies draw inspiration from successful rocket launch at sea," Global Times, June 5, 2019, http://www.globaltimes.cn/content/1153237.shtml.

32 "Tracing the origin of China Space Day: 'Dongfanghong-1' satellite that shocked the world" [中国航天日溯源：震惊世界的"东方红一号"人造卫星], The Paper, 24 April 2017, https://www.thepaper.cn/newsDetail_forward_1667459.

33 "Tracing the origin of China Space Day: 'Dongfanghong-1' satellite that shocked the world" [中国航天日溯源：震惊世界的"东方红一号"人造卫星], The Paper, 24 April 2017, https://www.thepaper.cn/newsDetail_forward_1667459.

34 "Chinese Voice of Chinese Satellite" [中国卫星的中国声音], Xinhua, 9 November 2015, http://www.xinhuanet.com/politics/2015-11/09/c_128409165.htm.

35 "Chinese Voice of Chinese Satellite" [中国卫星的中国声音], Xinhua, 9 November 2015, http://www.xinhuanet.com/politics/2015-11/09/c_128409165.htm.

36 "New China archives: from a blank sheet of paper to the modernization of aerospace measurement & control" ["新中国档案：从白纸一张到航天测控现代化"], Science and Technology Daily [科技日报], 29 September 2009, https://web.archive.org/web/20200624195156/http://webcache.googleusercontent.com/search?q=cache:swPjKvmM7YYJ:scitech.people.com.cn/GB/25509/56813/167036/167207/10137357.html+&cd=11&hl=en&ct=clnk&gl=uk&client=firefox-b-1-d.

37 "Chasing the Stars, Flying the Arrows, and Pasturing the Boats - Xi'an Satellite Control Center Technology Department "[追星揽箭牧舟行——西安卫星测控中心技术部], People's Daily, 9 September 2009, https://web.archive.org/web/20110130131319/http://scitech.people.com.cn/GB/10022463.html.

38 Wu Yuanping [吴远平], Zhao Xinli [赵新力], Zhao Junjie [赵俊杰], Research on the Shape and Development of the Defense Scientific System of New China [新中国国防科技体系的形成与发展研究], Beijing: Defense Industry Press (2006), 267.

39 "Cooperative Partners [合作伙伴], China Great Wall Industry Corporation, accessed June 2020, http://

cn.cgwic.com/Partner/index.html.

40 The full list is astronauts [航天员], spaceship applications [飞船应用], manned spaceships [载人飞船], carrier rockets [运载火箭], launch sites [发射场], landing sites [着陆场] and space tracking [航天测控]. The last three in particular all require involvement of the stationary, mobile and ship-based stations profiled in this report. See: The Seven Major Systems of China Manned Space Program [中国载人航天工程的七大系统], Xi'an Jiaotong University [西安交通大学], 14 October 2003, http://news.xjtu.edu.cn/info/1002/39671.htm.

41 "The interesting role of the Canary Islands in China's adventure on the Moon" [El interesante papel de Canarias en la aventura de China en la Luna], ABC Canary Islands, 11 December 2018, https://www.abc.es/espana/canarias/abci-interesante-papel-canarias-aventura-china-luna-201812111908_noticia.html.

42 "Xi'an Satellite Control Center provides measurement and control support for 'Tianwen No. 1' Mars exploration" [西安卫星测控中心为"天问一号"探火提供测控支持], West Online [西部网], 24 July 2020, https://sx.sina.com.cn/news/b/2020-07-24/detail-iivhuipn4870531.shtml.

43 "Fenghuo-1 in Distress: How to Take the Road to Mars Exploration in China" [萤火一号遇险：中国火星探测之路怎么走], Beijing S&T News, 16 November 2011, http://news.sciencenet.cn/htmlnews/2011/11/255521.shtm.

44 "The Beidou has just successfully built the network, 'Tianwen No.1' plans to land on Mars in 2021" [北斗刚组网成功，"天问一号"就计划2021年着陆火星], Sina News, 15 July 2020, https://tech.sina.com.cn/d/s/2020-07-15/doc-iivhvpwx5526837.shtml.

45 "China Deep Space TT&C and International Cooperation" United Nations Office for Outer Space Affairs, 2019, https://www.unoosa.org/documents/pdf/copuos/2019/copuos2019tech45E.pdf.

46 "Large-scale astronomical observation equipment of Shanghai Astronomical Observatory" [上海天文台大型天文观测设备], Shanghai Astronomical Observatory, accessed July 2020, http://www.shao.cas.cn/kyzhb/.

47 "For the first time, Chang'e-1 will directly use 4 foreign measurement and control stations for measurement and control" [嫦娥一号将首次直接使用4个国外测控站进行测控], PLA Daily, 24 October 2007, http://www.chinanews.com/gn/news/2007/10-24/1057437.shtml; "New Norcia station," European Space Agency, 12 December 2013, https://www.esa.int/ESA_Multimedia/Images/2013/12/New_Norcia_station.

48 "For the first time, Chang'e-1 will directly use 4 foreign measurement and control stations for measurement and control" [嫦娥一号将首次直接使用4个国外测控站进行测控], PLA Daily, 24 October 2007, http://www.chinanews.com/gn/news/2007/10-24/1057437.shtml.

49 "The interesting role of the Canary Islands in China's adventure on the Moon" [El interesante papel de Canarias en la aventura de China en la Luna], ABC Canary Islands, 11 December 2018, https://www.abc.es/espana/canarias/abci-interesante-papel-canarias-aventura-china-luna-201812111908_noticia.html.

50 "Tianlian-1 greatly increased the capacity of China's manned spaceflight measurement and control communication network" [天链一号使我国载人航天测控通信网能力大增], Xinhua, 3 October 2011, https://mil.huanqiu.com/article/9CaKrnJsCv2.

51 “Long March 3C Rocket Successfully Launches Tianlian-1 03 satellite” [长三丙火箭成功发射天链一号03星], China National Space Administration, 27 July 2012, http://www.cnsa.gov.cn/n6758823/n6758838/c6771191/content.html,

52 “China’s ‘Tianlian’ data-relay satellite kicks off an ‘information bridge’ between the satellites and the Earth” [我国”天链”中继卫星系统更新换代拉开序幕 星地之间架起”信息桥”], People’s Daily, 3 April 2019, http://www.cac.gov.cn/2019-04/03/c_1124320283.htm.

53 “China’s new space plan: will create the first ‘space-based Internet of Things.’” [中国航天新规划：将打造首个 ‘天基物联网], CCTV, 20 November 2019, http://www.xinhuanet.com/tech/2019-11/20/c_1125251253.htm.

54 “China successfully builds laser communication links for new-generation space-borne IoT project,” Global Times, 13 August 2020, https://www.globaltimes.cn/content/1197631.shtml.

55 “The Next 20 Years of Communications Satellites Will Depend on It” [未来20年通信卫星就靠它], Economic Daily [经济日报], 4 January 2020, http://www.xinhuanet.com/politics/2020-01/04/c_1125420981.htm.

56 “What is a high-throughput communications satellite?” [什么是高通量通信卫星?], China Aerospace News, 29 July 2016, http://www.spacechina.com/n25/n148/n272/n4789/c1383285/content.html.

57 “Building the Space Silk Road to help the construction of ‘One Belt, One Road’ - From Silk Road to Space · Sidelights on the First Silk Road Commercial Space Conference” [打造太空丝绸之路 助力”一带一路”建设——从丝路到太空 · 首届丝路商业航天大会侧记], S&T Daily, 19 November 2018, http://stdaily.com/cxzg80/guonei/2018-11/19/content_732220.shtml.

58 Doug Messier “First Laser Detection of Space Debris in Daylight” Parabolic Arc, 5 August 2020, http://www.parabolicarc.com/2020/08/05/first-laser-detection-of-space-debris-in-daylight/.

59 “Enhancing the Nation’s Space Situational Awareness,” Boeing, 18 March 2013, https://web.archive.org/web/20130318135309/http://www.boeing.com/defense-space/space/satellite/SSBS_Product_Card.pdf; “Space Based Space Surveillance,” Air Force Space Command, 22 March 2017, https://www.afspc.af.mil/About-Us/Fact-Sheets/Article/249017/space-based-space-surveillance-sbss/.

60 “Boeing Space Surveillance System Reduces Risk of Satellite Loss by 66 Percent,” Boeing, 14 January 2014, https://boeing.mediaroom.com/Boeing-Space-Surveillance-System-Reduces-Risk-of-Satellite-Loss-by-66-Percent.

61 See: John Costello, “The Strategic Support Force: China’s Information Warfare Service,” China Brief, 8 February 2016, https://jamestown.org/program/the-strategic-support-force-chinas-information-warfare-service/; Adam Ni, Bates Gill “The People’s Liberation Army Strategic Support Force: Update 2019,” China Brief, 29 May 2019, https://jamestown.org/program/the-peoples-liberation-army-strategic-support-force-update-2019/.

62 There is evidence of a number of missile instrumentation stations, some of which appear to serve in space tracking roles or under organizations that perform both duties. See for example “Unit 63601 Ground Equipment Station and Lanzhou University signed a joint military construction agreement” [63601部队地面设备站与兰州

大学签署军地共建共育协议], 4 August 2015, http://news.lzu.edu.cn/c/201508/35933.html.

63 "Chasing the 'star' and 'ship' to make wonderful achievements" [追"星"揽"舟"建奇功], Guangming Daily, 5 July 2009. http://www.cmse.gov.cn/art/2009/9/28/art_1355_22298.html; "Prequel to Shenzhou: China's first Recoverable Satellite's Debut in Space" [神舟前传：中国第一颗返回式卫星首征太空内幕], 6 October 2005, https://news.sohu.com/20051006/n227132560.shtml.

64 "Yaogan 8, 15, 19, 22, 27 (JB-9 1, 2, 3, 4, 5)," Gunter's Space Page, accessed June 2020, https://space.skyrocket.de/doc_sdat/yaogan-8.htm.

65 Marco Langbroek, "Open Question: Could US Military SIGINT satellites help to narrow down flight MH370's last location?," SatTrackCam Leiden Blog, 17 March 2014, https://sattrackcam.blogspot.com/2014/03/open-question-could-us-military-sigint.html.

66 The first was ChinaSat22, identified as Fenghuo-1 [烽火一号]. See: Carlo Kopp, "Advances in PLA C4ISR Capabilities," China Brief, 18 February 2010, https://jamestown.org/program/advances-in-pla-c4isr-capabilities; First launched in 2003 with the name ChinaSat-20: "China successfully launched the "Zhongxing" 20 communications satellite" [中国成功发射"中星"20号通信卫星], FMPRC, 13 May 2004, https://www.fmprc.gov.cn/ce/cefi/chn/xwdt/t104910.htm.

67 Celestrack Satellite Catalog Results, accessed August 2020, https://celestrak.com/satcat/search.php; See also: Kevin Pollpeter "Testimony before the U.S.-China Economic and Security Review Commission Hearing on 'China in Space: Strategic Competition,'" USCC, April 2019, https://www.uscc.gov/sites/default/files/Kevin%20Pollpeter%20USCC%2025%20April.pdf, 4.

68 "China PLA Unit 61081" [中国人民解放军61081部队], GNSS World of China [全球定位系统], No. 6, 2011, http://www.qqdwxt.cn/CN/volumn/home.shtml.

69 "Shang Hong, Deputy Commander of the Strategic Support Force and Commander of the Space System Department, has been promoted to the rank of Lieutenant General" [战略支援部队副司令员兼航天系统部司令员尚宏已晋升中将军衔], The Paper, 30 October 2017, https://www.thepaper.cn/newsDetail_forward_1838712.

70 "PLASSF Space Systems Department Revealed - Shang Hong Serves as Commander" [战略支援部队航天系统部亮相 尚宏任司令员], Caixin, 25 April 2017, http://m.china.caixin.com/m/2017-04-25/101082917.html.

71 "Vacancy left by Li Shangfu's promotion to deputy head of the General Armament Department has been filled by Fei Jiabing" [李尚福升任总装备部副部长 遗缺已由费加兵填补], Xinmin News [新民新闻], 6 April 2015, https://china.huanqiu.com/article/9CaKrnJJCAm.

72 "Partner," China Great Wall Industry Corporation, accessed July 2020, http://www.cgwic.com/Partner/ (English) / http://cn.cgwic.com/Partner/index.html (Chinese).

73 Reporting on the Tianwen 1 Mars mission in July 2020 identified CLTC as the organization in charge of the Xi'an Satellite Control Center. "'Tianwen 1' Everything's fine! Uncovering the deep space measurement and control station of the transportation pipe of Xi'an Satellite Control Center in China" ["天问一号"一切正常！揭秘中国西安卫星测控中心运管的深空测控站], Chinese Business View [华商报], 24 July 2020, http://news.

hsw.cn/system/2020/0724/1214440.shtml.

74 This was true for General Shang Hong [尚宏] during at least part of the years 2010-2012: “Hong Kong media: ‘post-60’ generals become the backbone of military circles, science & technology experts are put in important positions” [“港媒: “60后”将领成军界中坚 科技专家受重用”], China News Web [中国新闻网], 23 March 2011, http://www.chinanews.com/hb/2011/03-23/2924464.shtml; “Tianhui-1 satellite successfully launched” [“天绘一号卫星成功升空”], China Space News [中国航天报], 25 August, 2010. http://www.space-china.com/n25/n2014789/n2014804/c64937/content.html; “Ziyuan-1 02C satellite in orbit handed over” [“资源一号02C星在轨正式交付”], China National Space Administration [国家航天局], 8 June 2012, http://www.cnsa.gov.cn/n6758823/n6758838/c6771248/content.html.

75 “Chinese satellite tracking station settles in Australia for the first time” [“中国卫星跟踪站首次落户澳洲”], China Youth Online [中国青年报], 30 November 2011, http://qnck.cyol.com/html/2011-11/30/nw.D110000qnck_20111130_2-19.htm.

76 “Partners,” China Great Wall Industry Corporation, accessed June 2020, http://cn.cgwic.com/Partner/index.html.

77 “Sino-British Space Science Education Week Opens” [中英空间科学教育活动周开幕], people.cn, 24 July 2018, http://scitech.people.com.cn/n1/2018/0724/c1057-30166746.html.

78 ”Partners,” China Great Wall Industry Corporation, accessed June 2020, http://cn.cgwic.com/Partner/index.html.

79 “Beijing Special Engineering Design and Research Institute Enhances Launch Site Comprehensive Support Capability” [北京特种工程设计研究院加强发射场综合保障力], Xinhua, 29 September 2011, http://news.cntv.cn/20110929/116445.shtml.

80 “Dong Guangliang: Random Process and His Career” [人物 | 董光亮：随机过程与职业生涯], 26 November 2017, https://www.xuehua.us/a/5eba18c486ec4d574800c9f0. [BK: replaced broken link]

81 “An Account of the Talent Cultivation Practices at the Beijing Institute of Tracking and Telecommunications Technology” [北京跟踪与通信技术研究所科技人才队伍建设纪事], PLA Daily, 21 May 2005, http://mil.news.sina.com.cn/2005-05-21/1611290357.html.

82 “Beijing Institute of Tracking and Telecommunications Technology 2016 Graduate Program Recruitment Prospectus,” accessed July 2020, http://www.cnky.cn/xhtml/zhaopin/bjgztx/48.html.

83 See “Supporting the Infinitive Battlefield,” China Aerospace Studies Institute, 2019, 7; and Mark Stokes, Gabriel Alvarado, Emily Weinstein, and Ian Easton, “China’s Space and Counterspace Capabilities and Activities,” USCC, 20 March 2020, 23.

84 “Dong Guangliang: Random Process and His Career” [人物 | 董光亮：随机过程与职业生涯], Sohu, 26 November 2017, https://www.xuehua.us/a/5eba18c486ec4d574800c9f0.

85 “Beijing Institute of Tracking and Telecommunications Technology 2016 Graduate Program Recruitment Prospectus,” accessed July 2020, http://www.cnky.cn/xhtml/zhaopin/bjgztx/48.html.

86 “Beijing Aerospace Flight Control Center has a 100% flight control success rate in 20 years” [北京航天飞控中心二十年飞控成功率百分之百], People’s Daily [人民日报], 12 April 2016, http://news.sciencenet.cn/htmlnews/2016/4/343124.shtm.

87 “Dreams bloom in the nine heavens - a record of the innovative development of Beijing Aerospace Flight Control Center” [梦想绽放九天上——北京航天飞行控制中心创新发展记事], Xinhua [新华社], 11 April 2016, http://www.xinhuanet.com//mil/2016-04/11/c_128883524.htm.

88 “Beijing Aerospace Flight Control Center carefully preparing for China’s first Mars exploration flight control mission” [北京航天飞行控制中心周密做好我国首次火星探测飞控任务准备], Xinhua, 20 July 2020, http://www.xinhuanet.com/tech/2020-07/20/c_1126259686.htm.

89 “Li Jian named Director of the Beijing Aerospace Flight Control Center [北京航天飞行控制中心主任李剑], SCIO, 18 November 2016, http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/33978/35474/pic35477/Document/1520027/1520027.htm; “Beijing Aerospace Flight Control Center is carefully preparing for my country’s first Mars exploration flight control mission” [北京航天飞行控制中心周密做好我国首次火星探测飞控任务准备], Xinhua, 18 July 2020, http://www.xinhuanet.com/mil/2020-07/18/c_1210709100.htm.

90 “Yu Peijun serves as the director of Xi’an Satellite Control Center, and Qi Yahu serves as Party Secretary” [余培军任西安卫星测控中心主任，祁亚虎任党委书记], The Paper [澎湃], 10 August 2017, https://www.thepaper.cn/newsDetail_forward_1759175.

91 “Representatives of the People’s Liberation Army and People’s Armed Police Forces: Set sail for a new journey of strong army” [解放军和武警部队代表：扬帆再启航 强军新征程], CCTV Military [CCTV军事], 24 October 2017. http://military.cnr.cn/gz/20171024/t20171024_523999131.html; “Xia Xiaopeng, former political commissar of the Academy of Armored Forces Engineering, served as Party Secretary of the Jiuquan Satellite Launch Center of the General Assembly,” [装甲兵工程学院原政委夏晓鹏任总装酒泉卫星发射中心党委书记], The Paper [澎湃], 7 January 2015, http://www.thepaper.cn/baidu.jsp?contid=1292042. It is likely he has been promoted since his identification as a Major General in 2015.

92 “Impression Shaanxi: Xi’an Satellite Control Center” [印象陕西：西安卫星测控中心], ChinaWest Online, 8 August 2007, https://web.archive.org/web/20120622055843/http://shaanxi.cnwest.com/content/2007-01/08/content_396633.htm.

93 “Shenzhou 1 was born” [神舟一号: 横空出世], CMSE, 25 September 2009, http://www.cmse.gov.cn/art/2009/9/25/art_1357_22312.html.

94 “Composition of measurement and control communication network” [测控通信网的组成], Dreams of Flight [飞天圆梦], 17 September 2012, http://www.spacechina.com/N25/n148/n272/n4785/c284938/content.html; “Visit the Satellite Control Center in Xi’an, China” [探访中国西安卫星测控中心], China News [中国新闻网], 25 April 2016, https://web.archive.org/web/20170220083327/http://news.163.com/16/0425/14/BLGKJVSI00014JB6.html.

95 It may have previously been assigned the MUCDs 89759 and 481 [481部队].

96 “China aerospace measurement & control network: swapping an old look for a new face, still young” [“中国航天测控网：旧貌换新颜，我仍是少年”], Our Space [我们的太空], 24 April 2020, https://card.weibo.

com/article/m/show/id/2309404498064428630165?_wb_client_=1&object_id=1022%3A2309404498064428630165&extparam=lmid--4498064427639623&luicode=10000011&lfid=231522type%3D1%26t%3D10%26q%3D%23%E4%B8%AD%E5%9B%BD%E8%88%AA%E5%A4%A9%23.

97 “China’s space ‘first station’ - recording a GAD base Kashgar measurement and control station” [中国航天”第一站”——记总装某基地喀什测控站], China Youth Daily, 11 June 2002, http://mil.news.sina.com.cn/2002-06-11/70132.html.

98 “Decision on Naming Civilized Units, Civilized Communities and Civilized Villages in Kashgar City” [“关于命名喀什市文明单位、文明社区、文明村的决定”], Kashi Municipal Government [喀什市人民政府], 25 May 2016, https://web.archive.org/web/20200817221406/http://webcache.googleusercontent.com/search?q=cache:rx-mEW1KpsS4J:old.xjks.gov.cn/Item/37434.aspx&client=firefox-b-1-d&hl=en&gl=ca&strip=0&vwsrc=0.

99 “Sanya Aerospace Measurement and Control Station Begins Operations” [三亚航天测控站投入使用], Evening News [新闻晚报], 25 April 2008. https://news.sina.com.cn/c/2008-04-25/134613793630s.shtml.

100 “Retrograde ‘Shepherd’ guards the space ‘Chinese Star’” [逆行”牧星人”守护太空”中国星”], Shaanxi Daily [陕西日报], 21 February 2020. http://sn.people.com.cn/n2/2020/0221/c378288-33814796.html.

101 “The Party branch of Sanya Satellite Ground Station and the General Branch of the Five-Star Village Party of Wenluo carried out joint construction activities” [三亚卫星地面站党支部与文罗五星村党总支开展共建活动], National Satellite Ocean Application Service, 17 October 2019, http://www.nsoas.org.cn/news/content/2019-10/17/24_3196.html.

102 “Menghai tracking station successfully completes the ‘Jilin-1’ satellite launch tracking mission” [“勐海测控站圆满完成”吉林一号”卫星发射测控任务”], Global Times [环球时报], 13 November 2019. https://k.sina.cn/article_1974576991_75b1a75f04000n064.html?from=mil; “Xi’an Satellite Control Center sets shortest China space tracking mission interval record” [“西安卫星测控中心创中国航天测控任务间隔最短纪录”], China News Web [中国新闻网], 14 November 2019, http://www.chinanews.com/gn/2019/11-14/9007652.shtml.

103 “Jielong-1 successfully launched, Chinese spacemen have never stopped!” [“捷龙一号成功发射，中国航天人从未停止脚步!”], Our Space [我们的太空], 18 August 2019, https://kuaibao.qq.com/s/20190818A02LUB00.

104 “Lesiurely fire, ignite the southern sky” [“悠悠薪火 点燃南天”], People’s Daily [人民日报], 26 April 2020, https://news.tianyancha.com/ll_w9v6t7gjaf.html.

105 “The entrepreneurial history of Xiamen Observation and Control Station: 53 seconds, filling the gap of rocket signal capture!” [厦门测控站的创业史：53秒，填补火箭信号捕获的空白！], OurSpace, 26 April 2020, https://read01.com/5nKdzGz.html.

106 “Recalling the teacher: ‘He is a simple and serious doer’ - President Ren in the eyes of Academician Zhang Luqian” [追忆师长：”他是朴实认真的实干家”——张履谦院士眼中的任老总], China Space News, 15 February 2017, http://zhuanti.spacechina.com/n1581263/c1584550/content.html.

107 “Entrepreneurship is difficult, but the strugglers advance - the pursuit of the history of entrepreneurship in Shanxi, the pursuit of genes engraved in the depths of the blood” [创业艰难唯奋斗者进——追寻闽西创业史，追

寻镌刻在血脉深处的基因], Enthusiastic citizens look at society [热心市民看社会], 26 April 2020, https://sa.sogou.com/sgsearch/sgs_tc_news.php?req=U9E5diOys2998A2fAf96dTmt4i4j68fsIulhcqNXPfg=&user_type=1.

108 "Nanning idle land handling schedule (January-October 2018 has entered the disposal process)" ["南宁市闲置土地处置明细表 (2018年1月-10月已进入处置程序)"], Nanning Natural Resources Bureau [南宁市自然资源局], 15 October 2018, https://web.archive.org/web/20190827195701/http://zrzyj.nanning.gov.cn/yjrczcx/22339.htm.

109 "Long feature: Click on China aerospace measurement and control network" ["长篇特写: 点击中国航天测控网"], PLA Daily [解放军报], 3 April 2002, http://mil.news.sina.com.cn/2002-04-03/61247.html; "Just waiting to fly into space - writing on the eve of the launch of the Shenzhou 7" ["只待飞天走太空——写在"神七"发射前夕"]， Science & Technology Daily [科技日报], 25 September 2008, http://css.stdaily.com/special//shen7/content/2008-09/25/content_41842.htm.

110 "Yao'an Power Supply Company wins strong praise for its important task of power protection measures" ["姚安供电公司重大任务保电措施有力获赞誉"], Polaris Power Network [北极星电力网], 19 November 2014, http://news.bjx.com.cn/html/20141119/565653.shtml.

111 "Long feature: Click on China aerospace measurement and control network" ["长篇特写: 点击中国航天测控网"], PLA Daily [解放军报], 3 April 2002, http://mil.news.sina.com.cn/2002-04-03/61247.html.

112 "Nanning High-tech Zone carries out 'August 1' greeting activities" ["南宁高新区开展"八一"慰问活动"], "Guangxi Nanning High-tech Industrial Development Zone Management Committee" [广西南宁高新技术产业开发区管理委员会], 26 July 2017, https://web.archive.org/web/20190827192508/http://www.nnhitech.gov.cn/xxgkml/View.aspx?Keyid=060d5b39-2aca-4144-a04a-8f55be3a3ba2.

113 "Decision on naming autonomous region double support model city (county) and commending autonomous region double support model units and individuals" ["关于命名自治区双拥模范城（县）、表彰自治区双拥模范单位和个人的决定"], Guangxi Daily [广西日报], 25 July 2019, http://www.gxzf.gov.cn/gxyw/20190726-759015.shtml.

114 "Introduction to the Qingdao Spacecraft Control Station" [青岛航天测控站简介], 26 October 2007, http://club.qingdaonews.com/showAnnounce_129_3842918_1_0.htm; "Shenzhou 1 was born" [神舟一号：横空出世], CMSE, 25 September 2009, http://www.cmse.gov.cn/art/2009/9/25/art_1357_22312.html.

115 "Section 4 Military Organizations and Garrisons After Liberation" [第四节 解放后军事机构和驻军], Xiamen Government Website, accessed July 2020, http://www.fzb.xm.gov.cn/dqsjk/xmsz/xmsz2/201210/t20121007_852728.htm.

116 "Long March 5 was successfully launched!" [长征五号成功发射！], Global Times, 27 December 2019, https://k.sina.cn/article_1974576991_75b1a75f02700oplo.html?from=mil.

117 "Xiamen education system latest commendations list of advanced collectives and individuals in spiritual civilization construction at the national, provincial and municipal levels" ["厦门市教育系统荣获最新一届全国、省、市精神文明建设先进集体和个人表彰名单"], Xiamen Education Bureau [厦门市教育局], 21 July 2015, http://edu.xm.gov.cn/jyxw/bsjy/201507/t20150721_1158137.htm.

118 “Xi’an Satellite Control Center Weinan Measurement and Control Station completed the high-density launch measurement and control task,” [西安卫星测控中心渭南测控站完成高密度发射测控任务], China News, 1 June 2020, http://finance.eastmoney.com/a/202006011505314213.html.

119 “Xi’an Satellite Control Center Weinan Measurement and Control Station completed the high-density launch measurement and control task,” [西安卫星测控中心渭南测控站完成高密度发射测控任务], China News, 1 June 2020, http://finance.eastmoney.com/a/202006011505314213.html.

120 “Xi’an Satellite Control Center Xiangxi Measurement and Control” [西安卫星测控中心湘西测控], Zhonghua Manufacturing Space Stamp Collecting Blogs [钟华制造航天集邮博客], 13 October 2012, http://blog.sina.com.cn/s/blog_54e1284501018enm.html.

121 It is also known as Qujing [曲靖] Station Guijiang Station [桂江站] or Kunming (Zhanyi County) Station [昆明 (沾益县)].

122 “New China archives: from a blank sheet of paper to the modernization of aerospace measurement & control” [“新中国档案：从白纸一张到航天测控现代化”], Science and Technology Daily [科技日报], 29 September 2009, https://web.archive.org/web/20200624195156/http://webcache.googleusercontent.com/search?q=cache:swPjKvmM7YYJ:scitech.people.com.cn/GB/25509/56813/167036/167207/10137357.html+&cd=11&hl=en&ct=clnk&gl=uk&client=firefox-b-1-d; “Exploration of the internal secrets of the early-warning radar systems of China, the U.S., & Russia” [“中美俄三国反导预警雷达系统内部探秘”], Wangyi Military (via Jiangsu TV) [网易军事/江苏卫视], 12 August 2017, http://news.jstv.com/a/20170812/1502504665687.shtml.

123 “Reporters chase Shenzhou 5 from all different angles” [“记者兵分五路追”神五”“], Chinese Business View [华商报], 16 October 2003, http://news.sina.com.cn/o/2003-10-16/0618926729s.shtml.

124 “On-scene at China’s first manned space flight” [直击中国首次载人航天飞行], Xinhua Net [新华网], 16 October 2003, http://www.china.com.cn/zhuanti2005/txt/2005-10/14/content_5998398.htm.

125 Another unit, 63788, which has responsibility for recovery of astronauts and tracking, is based in Weinan and has subordinate units in Inner Mongolia, suggesting it may be a component of the Mobile Tracking & Recovery Department / Third Mobile Station. See: “China’s space department built a joint education camp for Weihua students” [祖国航天系共建共育 渭华学子入草原军营], Huashan Online [华山网], 15 August 2016. http://www.hshan.com/3g/folder166/2016-08-15/103404.html; “Shenzhou 11 landed successfully, Weinan Normal University sent such a congratulatory letter to 63788 troops!” Weinan Youth Portal [渭南青年门户网], 20 November 2016. https://kknews.cc/zh-cn/military/l82g3zg.html.

126 “The ‘star’-chasing steel fortress – scan of General Armaments Department base mobile tracking station strengthening mobile grassroots Party-building work” [“追”星”路上的钢铁堡垒—总装某基地活动测控站加强动中基层党建工作扫描”], People’s Liberation Army Daily [解放军报], 23 May 2010, ; Baidu Maps [百度地图], accessed July 2020, https://j.map.baidu.com/77/nnh.

127 “The measurement and control stations of Xi’an Satellite Control Center: Thousands of miles away, relay escort Beidou into orbit” [西安卫星测控中心各测控站点：远隔千里，接力护航北斗顺利入轨], Sina, 5 November, 2019, https://k.sina.com.cn/article_3164957712_bca56c1002000zv96.html?from=mil. The text on

the radar dish reads CASC 2nd Academy, 23rd Research Institute, [中国航天科技二院二十三所], one of China’s “backbone” research institutes for radar and satellite tracking R&D.

128 “Record of General Armaments Department base second mobile tracking station excelling at work campaign” [“总装某基地第二活动测控站开展创先争优活动纪实”], Shaanxi Daily [陕西日报], 18 October 2010, https://topics.gmw.cn/2010-10/18/content_1318087.htm.

129 “92 hours, 2150 kilometers, the star-chasing journey of the ‘caravan team’ across Xinjiang” [“92小时、2150公里，”大篷车队”横穿新疆的追星之旅”], Our Space [我们的太空], 10 November 2019, https://zhuanlan.zhihu.com/p/91191388.

130 “Processing and Application of Jilin No.1 Staring Imaging Mode” [“吉林一号凝视成像模式处理及应用”], Chang Guang Satellite Technology Co., Ltd [长光卫星技术有限公司], November 2017, http://www.spaceview.com/pdf/5-%E5%90%89%E6%9E%97%E4%B8%80%E5%8F%B7%E5%87%9D%E8%A7%86%E6%88%90%E5%83%8F%E6%A8%A1%E5%BC%8F%E5%A4%84%E7%90%86%E5%8F%8A%E5%BA%94%E7%94%A8.pdf.

131 “Xi’an Satellite Control Center: Beidou 33rd and 34th satellites successfully fixed” [西安卫星测控中心：北斗第33、34颗卫星成功定点], CCTV, 12 August 2018, https://china.huanqiu.com/article/9CaKrnKbii8.

132 “Select examples – 2” [“精选实例　二 “] , Mr. Chen old Traditional Chinese Medicine male and female infertility specialist [陈氏老中医男女不孕不育专科], 15 May 2007, http://www.csyyw.com/article/article.php?articleid=264.

133 “A walk through the Shenzhou spacecraft main landing site” [“走进神舟飞船主着陆场”], Xinhua, 14 October 2005, http://www.gov.cn/ztzl/2005-10/14/content_77868.htm.

134 “Chasing the ‘star’ and ‘ship’ to make wonderful achievements” [追”星”揽”舟”建奇功], Guangming Daily [光明日报], 5 July 2009, http://www.cmse.gov.cn/art/2009/9/28/art_1355_22298.html.

135 “Science Night - Science and education channel annual special program” [“科学之夜 - 科教频道年度特别节目”], Chinese Academy of Sciences [中国科学院], accessed July 2020, http://www.cas.cn/zt/kjzt/12thkexing/dsl/201301/P020130130510429473671.pdf.

136 “China’s new generation of manned spaceship test ship will return on the 8th” [我国新一代载人飞船试验船将于8日返回], Xinhua, 5 May 2020, http://www.gov.cn/xinwen/2020-05/05/content_5508965.htm.

137 “Xi’an Satellite Control Center provides measurement and control support for ‘Tianwen No. 1’ Mars exploration” [西安卫星测控中心为”天问一号”探火提供测控支持], West Online [西部网], 24 July 2020, https://sx.sina.com.cn/news/b/2020-07-24/detail-iivhuipn4870531.shtml.

138 “Space Expert: China will Build a Deep Space Network in 2016” [航天专家：我国2016年将建成深空测控网], China News Network, 7 January 2011, https://news.qq.com/a/20110107/000026.htm.

139 “Dreams hold up the “Eye of Deep Space” [梦想托起”深空之眼”], Hebei Workers’ News [河北工人报], 7 January 2014, http://www.hbgrb.net/epaper/html/2014-01/07/content_104909.htm.

140 “Announcement on Selection of Bidding Units for Unit 63753 Microwave Radiation Protection Technical Transformation Project” [“63753部队微波辐射防护技术改造项目施工投标单位选取公告”], Kashgar Metropolis Network [喀什都市网], 28 June 2019, https://wemp.app/posts/07fce846-079b-482b-b947-e18c78428ba3.

141 “‘Weaving together” with Queqiao over 400,000 km away” [四十多万公里外 “织”鹊桥], PLA Daily, 2 January 2019, http://www.cnsa.gov.cn/n6758823/n6758838/c6805007/content.html.

142 “Xi’an Satellite Control Center provides measurement and control support for ‘Tianwen No. 1’ Mars exlporation” [西安卫星测控中心为”天问一号”探火提供测控支持], West Online [西部网], 24 July 2020, https://sx.sina.com.cn/news/b/2020-07-24/detail-iivhuipn4870531.shtml.

143 “My country’s first overseas deep space measurement and control station provides measurement and control support for ‘Tianwen” fire detection’ [我国首个海外深空测控站为‘天问’探火提供测控支持], Xinhua, 24 July 2020, http://www.xinhuanet.com/tech/2020-07/24/c_1126282509.htm.

144 “La Estación CLTC – CONAE - NEUQUEN brinda soporte al satélite chino QueQiao,” 21 May 2018, https://www.argentina.gob.ar/noticias/la-estacion-cltc-conae-neuquen-brinda-soporte-al-satelite-chino-queqiao.

145 “Ambassador Yang Wanming visited Neuquen” [驻阿根廷大使杨万明访问内乌肯省], PRC Embassy in Argentina, 4 May 2016, http://ar.chineseembassy.org/chn/sgxw_1/t1360405.htm.

146 Walter Curia, “Carta de Macri a China: los acuerdos podraian ser inconstitucionales,” El Cronista, 13 March 2015, https://www.cronista.com/economiapolitica/Carta-de-Macri-a-China-los-acuerdos-podrian-ser-inconstitucionales-20150313-0052.html.

147 Martín Dinatale, “Tras la polémica por su eventual uso militar, la estación espacial de China en Neuquén ya empezó a funcionar, infobae.com, 28 January 2018, https://www.infobae.com/politica/2018/01/28/tras-la-polemica-por-su-eventual-uso-militar-la-estacion-espacial-de-china-en-neuquen-ya-empezo-a-funcionar/; “Argentina y China firmaron un acuerdo para la creación de una estación de misiones espaciales chinas en Neuquén,” Minister of Federal Planning, Public Investment and Services, 24 April 2014. https://web.archive.org/web/20150709185444/http://www.minplan.gob.ar/noticia/14725/argentina-y-china-firmaron-un-acuerdo-para-la-creacion-de-una-estacion-de-misiones-espaciales-chinas-en-neuquen.html#.

148 Miguel Angel Toma, “Con China, ¿acuerdo científico o cesión de soberanía?,” Clarin, https://www.clarin.com/opinion/china-base-soberania-ciencia-dolares-cristina_0_HJ8LX1OcP7g.html

149 Martín Dinatale, “Tras la polémica por su eventual uso militar, la estación espacial de China en Neuquén ya empezó a funcionar, infobae.com, 28 January 2018, https://www.infobae.com/politica/2018/01/28/tras-la-polemica-por-su-eventual-uso-militar-la-estacion-espacial-de-china-en-neuquen-ya-empezo-a-funcionar/.

150 Martín Dinatale, “Tras la polémica por su eventual uso militar, la estación espacial de China en Neuquén ya empezó a funcionar, infobae.com, 28 January 2018, https://www.infobae.com/politica/2018/01/28/tras-la-polemica-por-su-eventual-uso-militar-la-estacion-espacial-de-china-en-neuquen-ya-empezo-a-funcionar/.

151 “China’s space launch centers” [“中国的航天发射中心”], Xinhuanet [新华网], 27 September 2013, http://www.sastind.gov.cn/n6909/n6990/c34774/content.html.

152 “Jiuquan Satellite Launch Center actually isn’t in Jiuquan” [“酒泉卫星发射中心其实不在酒泉”], China Academy of Launch Vehicle Technology (CALT) [中国运载火箭技术研究院], accessed July 2020, http://m.calt.com/n1693/n1730/c14159/content.html.

153 “First Strategic Support Force unit has been established for 100 days, what powerful generals are under its command? [“首支战略支援部队成立百天 麾下有哪些厉害将军”], Guanhai Neican / Legal Evening News Reporter [观海内参/法制晚报记者], 8 April 2016, http://news.cnr.cn/native/gd/20160408/t20160408_521820195.shtml; “The mighty east wind from the desert” [“起于荒漠的浩荡东风”], World Military [世界军事], 25 August 2017, http://www.globalview.cn/html/history/info_19902.html.

154 “The preparation and mobilization meeting of the National Manned Space Standardization Technical Committee was successfully held” [“全国载人航天标准化技术委员会筹建动员会成功召开”], China Academy of Space Technology (CAST) 512th Research Institute [北京空间科技信息研究所], accessed June 2020, http://www.cast512.com/cn/news_detail.asp?ID=396; “Jiuquan Satellite Launch Center” [“酒泉卫星发射中心”], Tencent [腾讯网], 5 December 2018, http://wchtztly.runca.cn/htkp/htkp_zght/detail2018-12-05-46.html.

155 “Starting from the place where ‘Dongfanghong’ rises, running towards the loftier sea of stars” [“从”东方红”升起的地方再出发，奔向更高远的星辰大海……”], China Military Online [中国军网], 24 April 2020, http://www.mod.gov.cn/education/2020-04/24/content_4864136.htm.

156 “Launch Site,” China Great Wall Industry Corporation, accessed July 2020, http://cgwic.com/Launchservice/LaunchSite.html (English) / http://cn.cgwic.com/Launchservice/LaunchSite.html (Chinese).

157 “China’s space launch centers” [“中国的航天发射中心”], China Manned Space Project Web [中国载人航天工程网], 8 June 2012, http://guoqing.china.com.cn/2012-06/08/content_25600724.htm.

158 LDK or “Land Survey” [陆地勘查] earth observation satellites are a relatively new group of satellites launched since 2017. While the four currently in operations are described by official media as primarily for civilian land-use purposes, they are believed to be used by the Chinese military. See: “LKW 3,” NASA, accessed July 2020, https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2018-006A.

159 “Launch Record” [“发射记录”], China Aerospace Science and Technology Corporation (CASC) [中国航天科技集团有限公司], accessed July 2020, http://www.spacechina.com/n25/n142/n152/n657792/index.html.

160 China’s Space and Counterspace Capabilities and Activities,” Project 2049 & Pointe Bello, 30 March 2020, https://www.uscc.gov/sites/default/files/2020-05/China_Space_and_Counterspace_Activities.pdf.

161 “Composition of measurement and control communication network” [测控通信网的组成], Dreams of Flight [飞天圆梦], 17 September 2012, http://www.spacechina.com/N25/n148/n272/n4785/c284938/content.html..

162 “Launch Centers,” China Great Wall Industry Corporation, accessed July 2020, https://web.archive.org/web/20080517055255/http:/www.cgwic.com/launch/center3.html.

163 “16 control stations for ‘Shenzhou-7’ around the world complete joint testing and adjustment [““神七”全球16个测控站全部完成联试联调”], China.com.cn [中国网], 25 September 2008, http://www.china.com.cn/news/txt/2008-09/25/content_16531698.htm.

164 "Climbing a different way, just to ensure a smooth flow between the heavens and Earth" ["别样攀登，只为确保天地畅通"], China Space News [中国航天报], 16 September 2016, http://zhuanti.spacechina.com/n1432740/n1432825/c1442144/content.html.

165 "China's space launch centers" ["中国的航天发射中心"], Xinhuanet [新华网], 27 September 2013, http://www.sastind.gov.cn/n6909/n6990/c34774/content.html.

166 "New Chinese space record! Taiyuan Satellite Launch Center successfully completes two launch missions within 6 hours" ["中国航天新纪录！太原卫星发射中心6小时内连续成功完成两次发射任务"], Xinhua News Agency, 7 December 2019, http://www.gov.cn/xinwen/2019-12/07/content_5459345.htm.

167 "Launch Site," China Great Wall Industry Corporation, accessed July 2020, http://cgwic.com/Launchservice/LaunchSite.html (English) / http://cn.cgwic.com/Launchservice/LaunchSite.html (Chinese).

168 "Launch Record" ["发射记录"], China Aerospace Science and Technology Corporation (CASC) [中国航天科技集团有限公司], accessed July 2020, http://www.spacechina.com/n25/n142/n152/n657792/index.html.

169 "China's Space and Counterspace Capabilities and Activities," Project 2049 & Pointe Bello, 30 March 2020, https://www.uscc.gov/sites/default/files/2020-05/China_Space_and_Counterspace_Activities.pdf.

170 "Launch Centers," China Great Wall Industry Corporation, accessed July 2020, https://web.archive.org/web/20060709062600/http://www.cgwic.com/launch/center2.html; "Development of Cold Atom Interferometic Gyroscope," Optics Journal, 10 July 2014, http://www.opticsjournal.net/Articles/abstract?aid=OJ141023000328VrXu1w.

171 "Taiyuan Satellite Launch Center monitors the space environment for Shen-9 to ensure safety" ["太原卫星发射中心为神九监测太空环境保安全"], China News Net [中国新闻网], 26 June 2012, https://www.chinanews.com/gn/2012/06-26/3988079.shtml; "Tiangong-1 pathfinder: deciphering Taiyuan Satellite Launch Center's radar measurement stations" ["天宫一号探路者:解密太原卫星发射中心雷达测量站"], Taiyuan Evening News [太原晚报], 30 September 2011, http://www.sx.chinanews.com/news/2011/0930/49360.html.

172 "China Breakthroughs: Catching a closer resolution on Gaofen-3 satellite," CCTV.com, 26 July 2017, https://english.cctv.com/2017/07/26/ARTIZ9DKuCsOtAYFng77wAGN170726.shtml.

173 "Tracking and control communication network composition" ["测控通信网的组成"], "Realizing Dreams of Flight" [《飞天圆梦》], 17 September 2012, http://www.spacechina.com/N25/n148/n272/n4785/c284938/content.html.

174 "Chinese People's Liberation Army Unit 63717 carries out poverty alleviation activities in the Xing County 120th Division School" ["中国人民解放军63717部队在兴县120师学校开展扶贫济困活动"], Xing County News Network [兴县新闻网], 19 October 2018, http://xingxian.sxgov.cn/xinxian_content/2018-10/19/content_4663898.htm; "The Central Military Commission awards Unit 63717 first-class citation, Hu Jintao signs general order" ["中央军委给63717部队记一等功 胡锦涛签署通令"], Xinhua, 18 August 2007, http://www.gov.cn/jrzg/2007-08/18/content_720884.htm.

175 "Grain Bureau: Actively carry out military-civilian double support activities" ["粮食局:积极开展军民双拥活动"], Hancheng City Government Website [韩城市政府网站], 31 July 2018, http://archive.is/umM2K;

"[Education & Poverty Alleviation] Chinese People's Liberation Army Unit 63717 educates & helps poor students of the 120th Division School on '10.17 Poverty Alleviation Day'" [" 【教育扶贫】中国人民解放军63717部队"10.17扶贫日"教育扶助一二〇师学校贫困学生"], 120-Division School [一二0师学校], 17 October 2017, https://www.sohu.com/a/198572655_698937.

176 "Pingliang No. 1 Middle School's new campus site selection announcement! Come and see if it's far from your house?" ["平凉一中新校区选址公示！快来看看离你家远吗？"], Daily News [每日头条], 8 June 2018, https://kknews.cc/zh-cn/news/on6833p.html.

177 "Maritime space road: record of Taiyuan Satellite Launch Center successfully completing maritime space launch mission" ["海上天路：太原卫星发射中心成功完成海上航天发射任务纪实"], PLA Daily [解放军报], 18 September 2020, http://www.mod.gov.cn/education/2020-09/18/content_4871388.htm.

178 "Launch Record" ["发射记录"], China Aerospace Science and Technology Corporation (CASC) [中国航天科技集团有限公司], accessed July 2020, http://www.spacechina.com/n25/n142/n152/n657792/index.html; "Maritime one rocket with nine satellites! Long March 11 sea launches will become normal" ["海上一箭打九星！长11海射将进入常态化"], China Space News [中国航天报], 15 Sep 2020, https://mp.weixin.qq.com/s?__biz=MzA5NTgxNTQzMA==&mid=2650568680&idx=1&sn=47cfef437cd0589b7c2dab6b9e2ae184&chksm=88b14581bfc6cc973cafad1c54dcd05ea3ec0744a53277f85f0e59a4fc342327c471d4757ccd#rd.

179 "Guizhou Province impact area command department member work units symposium held" ["贵州省落区指挥部成员单位座谈会召开"], Provincial Civil Air Defense Office [省人防办], 31 July 2017, http://www.guizhou.gov.cn/xwdt/dt_22/bm/201709/t20170928_1065133.html.

180 "Unique contributors to Reform and Opening up" ["改革开放的独特贡献者"], Nationality Pictorial [民族画报综合报道], 30 December 2018, http://www.mzhb.com/zhuanti/%E6%94%B9%E9%9D%A9%E5%BC%80%E6%94%BE%E7%9A%84%E7%8B%AC%E7%89%B9%E8%B4%A1%E7%8C%AE%E8%80%85/; "China's space launch centers" ["中国的航天发射中心"], Xinhuanet [新华网], 27 September 2013, http://www.sastind.gov.cn/n6909/n6990/c34774/content.html.

181 "Xichang Satellite Launch Center" ["西昌卫星发射中心"], Tencent [腾讯网], 5 December 2018, http://wchtztly.runca.cn/htkp/htkp_zght/detail2018-12-05-47.html; "Guizhou Province impact area command department member work units symposium held" ["贵州省落区指挥部成员单位座谈会召开"], Provincial Civil Air Defense Office [省人防办], 31 July 2017, http://www.guizhou.gov.cn/xwdt/dt_22/bm/201709/t20170928_1065133.html.

182 "All of China's Beidou satellites have flown perfectly from Xichang" ["我国所有北斗卫星均从西昌完美飞天"], Xinhua News Agency, 23 June 2020, http://www.gov.cn/xinwen/2020-06/23/content_5521342.htm.

183 "Xichang Satellite Launch Center's 40-year contribution to China Aerospace" [西昌卫星发射中心40载建功中国航天纪实], China News, 5 January 2011, http://www.chinanews.com/gn/2011/01-05/2766591.shtml.

184 "Launch Record" ["发射记录"], China Aerospace Science and Technology Corporation (CASC) [中国航天科技集团有限公司], accessed July 2020, http://www.spacechina.com/n25/n142/n152/n657792/index.html.

185 "Launch Record" ["发射记录"], China Aerospace Science and Technology Corporation (CASC) [中国航天科技集团有限公司], accessed July 2020, http://www.spacechina.com/n25/n142/n152/n657792/index.html.

186 “Launch Site,” China Great Wall Industry Corporation, accessed July 2020, http://cgwic.com/Launchservice/LaunchSite.html (English) / http://cn.cgwic.com/Launchservice/LaunchSite.html (Chinese).

187 “Xichang Satellite Launch Center” [“西昌卫星发射中心”], Ministry of Industry and Information Technology of the People’s Republic of China [中华人民共和国工业和信息化部], accessed July 2020, https://archive.is/mwaZB; “Xichang Satellite Launch Center’s 40-year contribution to China Aerospace” [西昌卫星发射中心40载建功中国航天纪实], China News, 5 January 2011, http://www.chinanews.com/gn/2011/01-05/2766591.shtml.

188 “Chinese Test Anti-Satellite Weapon,” Aviation Week & Space Technology, 17 January 2007, https://web.archive.org/web/20070128075259/http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=space&id=news/CHI01177.xml.

189 “Visiting Xichang Satellite Launch Center Niutoushan Observation Station” [“探访西昌卫星发射中心牛头山观测站”], Military Report [军事报道], 24 March 2020, http://www.js7tv.cn/video/202003_211205.html.

190 “Launch Centers,” China Great Wall Industry Corporation, accessed July 2020, https://web.archive.org/web/20081201165007/http:/www.cgwic.com:80/launch/center1.html.

191 “The most beautiful Beidou people, holding up aerospace dreams” [“最美北斗人 托举航天梦”], People’s Daily [人民日报], 18 February 2018, http://www.xinhuanet.com/politics/2018-02/18/c_1122426061.htm.

192 “After completion of new satellite observation station, south bank buildings can break free of height limitations within the year” [“卫观站新址建成后 南岸建筑年内有望不再限高”], Sichuan Online – Huaxi Metropolitan Daily [四川在线-华西都市报], 22 July 2009, https://web.archive.org/web/20190903155435/https://sichuan.scol.com.cn/ybxw/20090722/200972215229.htm. It appeared to move between locations between 2008 and 2011.

193 “Yaogan-30 5th group successfully launched, with a precise measurement team behind it” [“遥感三十号05组卫星成功发射 背后有这样一支精准测量团队”], CCTV News [央视新闻客户端], 26 July 2019, http://m.news.cctv.com/2019/07/26/ARTIDgg5tSsJqiugBg3udpzD190726.shtml; “20 years sharpening a sword – Beidou & I grew up together” [“二十年磨一剑 我与北斗共成长”], Yibin Daily’s Jinjiang Web [金江网], 23 June 2020, http://archive.is/zC5d4.

194 “Yuchi Community: Learn from Lei Feng and Shu Xinfeng, military & civilians jointly build civilized community” [“鱼池社区：学雷锋、树新风 军民共建文明社区”], Yibin News Web [宜宾新闻网], 7 March 2014, http://www.ybxww.com/news/html/201403/102919.shtml.

195 “Three Rivers surveyors’ ‘178:0’ aerospace miracle” [“三江测量人”178:0”的航天测量奇迹”], CCTV News [央视新闻移动网], 27 June 2018, https://www.ixigua.com/i6571747849296413187/.

196 “Yibin Baita mountain satellite observation station auxiliary station construction project” [“宜宾市白塔山卫星观测站副站建设项目”], Yibin Public Resources Transaction Center [宜宾市公共资源交易信息网], 27 May 2020, http://webcache.googleusercontent.com/search?q=cache:https://ggzy.yibin.gov.cn/Jyweb/TBBZJView.aspx?Type%3D%25E5%25BB%25BA%25E8%25AE%25BE%25E5%25B7%25A5%25E7%25A8%258B%26SubType%3D250%26XMBH%3DLGQFJ2019120010001&strip=0&vwsrc=0; “Construction project site selection submissions” [“建设项目选址意见书”], Yibin Natural Resources and Planning Bureau [宜宾

市自然资源和规划局], accessed June 2020, http://zygh.yibin.gov.cn/yssz/jsxmxzyjs/.

197 “China Wenchang Space Launch Site has high-density launch capabilities” [中国文昌航天发射场具备高密度发射实战能力], Xinhua, 5 May 2020, http://www.xinhuanet.com/tech/2020-05/05/c_1125945018.htm.

198 “Final star | Yuanwang 6 precision measurement and control land-sea relay to send Beidou” [收官之星 | 远望6号精准测控 陆海接力送北斗] Wen Wei Po [文汇报], 23 June 2020, https://www.sohu.com/a/403649333_120244154.

199 Wu Yuanping [吴远平], Zhao Xinli [赵新力], Zhao Junjie [赵俊杰], Research on the Shape and Development of the Defense Scientific System of New China [新中国国防科技体系的形成与发展研究], Beijing: Defense Industry Press (2006), 68.

200 “Looking at the sea and the sky - into China’s satellite maritime survey and control department to feel the “spirit of distant hope” [遥望海天的目光——走进中国卫星海上测控部感受”远望精神”], PLA Daily, 28 September 2017, http://www.81.cn/jfjbmap/content/2017-09/28/content_189053.htm.

201 “From Shangyanghong 10 to Yuanwang 4” [从向阳红10号到远望4号], 708 Research Institute, accessed June 2020, http://www.archives.sh.cn/ztbd/fxcb/gsjc/201408/t20140815_41372.html.

202 “Yuanwang Space Tracking and Control Fleet Returns” [远望号航天测量船队返航], People’s Daily, 22 January 2020, http://paper.people.com.cn/rmrb/html/2020-01/22/nw.D110000renmrb_20200122_5-10.htm.

203 “The Yuanwang 5 and the Yuanwang 7 ships sailed at the same time to carry out the maritime survey and control mission” [远望5号船与远望7号船同时出航执行海上测控任务], Xinhua, 10 November 2019, http://www.xinhuanet.com/2019-11/10/c_1125214192.htm.

204 “Composition of measurement and control communication network” [测控通信网的组成], Dreams of Flight [飞天圆梦], 17 September 2012, http://www.spacechina.com/N25/n148/n272/n4785/c284938/content.html.

205 Min Shiquan [闵士权], Liu Guangming [刘光明], Liu Jianping [刘建平], “Initial Discussion on the Development Path of China’s Military-Civil Fusion Space TT&C Network” [我国军民融合航天测控发展之路探讨], Software Defined Satellite Technology Alliance, 20 May 2018, http://www.sdsalliance.net/a/news/172.html.

206“Yuanwang rocket transport fleet completed two missions today by returning to its home port” [远望号火箭运输船队完成两次任务今日靠回母港], S&T Daily [科技日报], 26 February 2020, http://www.stdaily.com/index/kejixinwen/2020-02/26/content_888165.shtml.

207 Also called the Aerospace Measurement Ship Base [远洋航天测量船基地].

208 “Huang Qin visited the condolences of the troops stationed in Wuxi with responsibility and deep love for the children and soldiers” [黄钦走访慰问驻锡部队 带着责任和深情关爱子弟兵], Wuxi Daily [无锡日报], 1 August 2018, http://jsnews.jschina.com.cn/wx/a/201808/t20180801_1803684.shtml.

209 “Li Xiaomin ‘August 1’ before the visit to the condolence troops stationed in Wuxi” [李小敏”八一”前走

访慰问驻锡部队], Wuxi New Media [无锡新传媒], 31 July 2019, http://js.ifeng.com/a/20190731/7647598_0.shtml; “41 years of sea exploration, Yuanwang 2 ‘retirement’. “ [41年蹈海探天，远望2号 ‘退休’了], Yangtze Evening Post [扬子晚报], 29 April 2019, https://k.sina.cn/article_1653603955_v628ffe73020007k4.html.

210 Sam LaGrone, “Navy: Chinese Spy Ship Monitoring RIMPAC Exercise, Again,” 13 July 2018, https://news.usni.org/2018/07/13/navy-chinese-spy-ship-monitoring-rimpac-exercise.

211 “‘Kaiyangxing’ entered the Chinese Navy’s electronic reconnaissance ship to add another member” [开阳星”号入列 中国海军电子侦察船再添一员], China Military Online, 22 January 2017, http://www.beijingreview.com.cn/shishi/201701/t20170122_800086014.html.

212 “Thank You for Visiting the Aerospace Information Research Institute (AIR),” Aerospace Information Research Institute, accessed July 2020, http://aircas.ac.cn/.

213 Ding Jia [丁佳], “Cast ‘Iron Army,’ Chain ‘Heavenly Roads’” [铸”铁军” 链”天路”], China Science Daily, 13 August 2019, http://news.sciencenet.cn/htmlnews/2019/8/429267.shtm?id=429267.

214 “China Remote Sensing Satellite Ground Station Has Received Tens of Millions of ‘space movies’” [中国遥感卫星地面站：已接收上千万景”太空大片”], China Youth Daily, 1 January 2020, http://www.xinhuanet.com/science/2020-01/01/c_138669124.htm

215 Ibid.

216 “China Remote Sensing Satellite Ground Station Has Received Tens of Millions of ‘space movies’” [中国遥感卫星地面站：已接收上千万景”太空大片”], China Youth Daily, 1 January 2020, http://www.xinhuanet.com/science/2020-01/01/c_138669124.htm.

217 “China Remote Sensing Ground Stations” [中国遥感卫星地面站], Institute of Remote Sensing and Digital Earth [中国科学院遥感与数字地球研究所], accessed February 2020, http://www.radi.cas.cn/jglb/kjtx/wxdmz/.

218 Gao Yali [高雅丽], “Remote Sensing Satellite Ground Station Kashgar Station” [中国遥感卫星地面站喀什站：坚守边陲十年”牧星人”], China Science Daily, 22 January 2018, http://news.sciencenet.cn/htmlnews/2018/1/400710.shtm.

219 “China Remote Sensing Ground Stations” [中国遥感卫星地面站], Institute of Remote Sensing and Digital Earth [中国科学院遥感与数字地球研究所], accessed February 2020, http://www.radi.cas.cn/jglb/kjtx/wxdmz/.

220 “CAS Satellite Ground Station Kashi: Shepherd for 10 years” [中科院卫星地面站喀什站：坚守边陲十年”牧星人], China Science Daily [中国科学报], 22 January 2018, (2018-01-22 第5版 创新周刊) https://www.cehui8.com/news/yuanxiao/20180123/9508.html.

221 Ibid.

222 “The tenth anniversary of the operation of China’s remote sensing satellite ground station in Sanya: annual data reception increased by 7.4 times,” [中国遥感卫星地面站三亚站业务运行十周年：

数据年接收量增7.4倍], ChinaNews, 2 February 2020, http://dw.chinanews.com/chinanews/content.jsp?id=9076102&classify=zw&pageSize=6&language=chs.

223 “China Remote Sensing Ground Stations” [中国遥感卫星地面站], Institute of Remote Sensing and Digital Earth [中国科学院遥感与数字地球研究所], accessed February 2020, http://www.radi.cas.cn/jglb/kjtx/wxdmz/.

224 “China’s remote-sensing satellite ground stations” [“中国遥感卫星地面站”], RADI [中国科学院遥感与数字地球研究所], accessed February 2020, http://www.radi.cas.cn/jglb/kjtx/wxdmz/.

225The Changhe 1 [长河1号] intermediate range system was jointly produced by the 20th RI [20□] and 764 Factory [764□]. Ten ground stations had been set up by 1974, and the system reached initial operational capability in 1976.

226 “System Introduction” [系统介绍], Beidou.gov.cn, accessed July 2020, http://www.beidou.gov.cn/xt/xtjs/.

227 “System,” Beidou Navigation Satellite System, accessed July 2020, http://en.beidou.gov.cn/SYSTEMS/System/.

228 Dr. Jun Shen, “Update on BeiDou Navigation Satellite System” The 56th Meeting of the Civil GPS Service Interface Committee at the ION GNSS+ 2016 Conference, September 2016, https://www.gps.gov/cgsic/meetings/2016/shen.pdf.

229 “Development of the Beidou Navigation Satellite System (Version 4)”, China Satellite Navigation Office, December 2019, http://m.beidou.gov.cn/xt/gfxz/201912/P020191227430565455478.pdf.

230 “Development of the BeiDou Navigation Satellite System (Version 4.0), China Satellite Navigation Office December 2019, http://m.beidou.gov.cn/xt/gfxz/201912/P020191227430565455478.pdf, 15, 16.

231 “BeiDou Navigation Satellite System celebrates 1-year of global services” CGTN, 28 December 2019. https://news.cgtn.com/news/2019-12-28/70-of-smartphones-in-China-compatible-with-BeiDou-MMF-DLVQRfW/index.html

232 “Where did ‘Beidou’ Go?” [“北斗”去哪儿了], China Youth Daily [中国青年报], 22 January 2018, http://www.xinhuanet.com/science/2018-01/22/c_136914823.htm.

233 “Beidou Shares Report Card, Navigation Application Enters Daily Lives” [北斗晒成绩单导航应用已经来到身边], S&T Daily [科技日报], 13 January 2020, http://www.xinhuanet.com/fortune/2020-01/13/c_1125453479.htm.

234 “Interview with China Satellite Navigation Committee Chairman Wang Zhaoyao” [访中国卫星导航系统委员会主席王兆耀], Xinhua, 7 July 2020, http://www.xinhuanet.com/mil/2020-07/07/c_1210690294.htm; John Dotson, “The Beidou Satellite Network and the “Space Silk Road” in Eurasia,” China Brief, 15 July 2020, https://jamestown.org/program/the-beidou-satellite-network-and-the-space-silk-road-in-eurasia/; in 2017 Wang was identified as leader of the Manned Space Office.

235 “CRESDA Introduction,” CRESDA, accessed July 2020, http://www.cresda.com/EN/gywm/zxgk/index.shtml.

236 “CBERS-04 Satellite Ground System in South Africa was Delivered Successfully”, CRESDA, 21 December 2015, http://www.cresda.com/EN/xwzx/xwdt/8559.shtml; “Natural Resources No. 3 02 Satellite” [资源三号02星], China Resources Satellite Application Center, 29 December 2016, http://www.cresda.com/CN/Satellite/10804.shtml

237 “SASTIND” [国家国防科技工业局], Gov.cn, accessed July 2020, http://www.gov.cn/fuwu/bumendi-fangdating/bumendating/guofangkegongju/index.html

238 Hao replaced Major General Yang Liwei [杨利伟] in 2018. See: “Yang Liwei, director of China’s manned space engineering office, stepped down” [郝淳担任中国载人航天工程办公室主任 杨利伟卸任], The Paper [澎湃新闻], 20 July 2018, http://www.chinanews.com/gn/2018/07-20/8574104.shtml.

239 Kenneth W. Allen, Christopher M. Clarke, John F. Corbett, Jr., and Lonnie D. Henley, “China’s Defense Minister and Ministry of National Defense,” in Kevin Pollpeter and Kenneth W. Allen, eds, The PLA as Organization 2.0, DGI, 2016, 100-101.

240“Leader Profiles” [领导简介], CNSA, accessed July 2020, http://www.cnsa.gov.cn/n6758821/index.html.

241 “China establishes space debris monitoring and application center” [中国成立空间碎片监测与应用中心], China Radio International Online [国际在线], 9 June 2015, http://www.cma.gov.cn/2011xwzx/2011x-mtjj/201506/t20150609_284820.html.

242 Institutional Composition [机构组成], CNSA, accessed July 2020, http://www.cnsa.gov.cn/n6758821/index.html.

243 “Space Debris Avoidance System (SDAS), Space Debris Surveillance and Collision Avoidance,” National Astronomical Observatories of China, accessed July 2020, http://english.nao.cas.cn/Research2015/rp2015/201701/t20170120_173607.html.

244 “There is more and more space debris, and the centimeter level can cause complete damage to the spacecraft” [“空间碎片越来越多，厘米级就可导致航天器彻底损坏”], China Academy of Launch Vehicle Technology, 20 June 2016, http://www.calt.com/n689/c5728/content.html.

245 National Astronomical Observatory of China Establishes China National Space Administration Space Debris Surveillance and Application Center [国家天文台挂牌成立国家航天局空间碎片监测与应用中心], CAS National Astronomical Observatory of China [中科院国家天文台], 18 June 2015. http://www.ciccas.ac.cn/a/weixingjiyingyong/xinwendongtai/2015/0618/4571.html

246 “Brief Introduction of Changchun Satellite Observatory of National Astronomical Observatories of Chinese Academy of Sciences”[中国科学院国家天文台长春人造卫星观测站简介], Changchun Observatory, accessed July 2020, http://www.cho.cas.cn/gkjj/jgjj/.

247 “The National Space Administration Space Debris Monitoring and Application Center project settled in the development zone” [国家航天局空间碎片监测与应用中心项目落户开发区], Korla Government Website,

30 October 2018, http://www.xjkel.gov.cn/news/zwyw/198030.htm.

248 Ibid.

249 “China establishes space debris monitoring and application center” [中国成立空间碎片监测与应用中心], China Radio International Online [国际在线], 9 June 2015, http://www.cma.gov.cn/2011xwzx/2011x-mtjj/201506/t20150609_284820.html.

250 “CNSA Remote Sensing Demonstration Center” [国家航天局航天遥感论证中心], Institute of Remote Sensing, accessed July 2020, http://www.irsa.cas.cn/jgsz/gjjyjjg/gjhtjhtyglzzx/.

251 “CNSA Remote Sensing Demonstration Center” [国家航天局航天遥感论证中心], Institute of Remote Sensing, accessed July 2020, http://www.irsa.cas.cn/jgsz/gjjyjjg/gjhtjhtyglzzx/yjfx/.

252 “Primary Work” [主要工作], Institute of Remote Sensing, accessed July 2020, http://www.irsa.cas.cn/jgsz/gjjyjjg/gjhtjhtyglzzx/dbcg/200912/t20091215_2708646.html.

253 “The 2017 China Satellite Laser Ranging Network Conference was successfully held in Weihai” [2017年度中国卫星激光测距网会在威海成功举办], Shanghai Astronomical Observatory, 12 October 2017, http://www.shao.cas.cn/xwzx/zhxw/201710/t20171012_4872000.html; “Satellite laser ranging techniques and their applications,” Shanghai Astronomical Observatory, 5 September 2014, http://english.shao.cas.cn/rh/rgs/200809/t20080905_9006.html.

254 “Satellite laser ranging technology and application” [卫星激光测距技术和应用], Shanghai Astronomical Observatory, accessed July 2020, http://ucar.shao.cas.cn/kytd/wxjgcjjshyy/.

255 “Satellite Laser Ranging Research Lab” [卫星激光测距研究], Changchun Satellite Observatory, 27 May 2015, http://www.cho.ac.cn/jgsz/kybm/jgcjyjs/. The Sheshan Observatory in Shanghai includes a 60cm telescope laser rangefinder and is likely capable of similar high-altitude observations.

256 “ILRS Operational Station Identification Table” NASA, accessed June 2020, https://ilrs.gsfc.nasa.gov/network/stations/active/.

257 “The 2017 China Satellite Laser Ranging Network Conference was successfully held in Weihai” [2017年度中国卫星激光测距网会在威海成功举办], Shanghai Astronomical Observatory, 12 October 2017, http://www.shao.cas.cn/xwzx/zhxw/201710/t20171012_4872000.html.

258 Doug Messier, “First Laser Detection of Space Debris in Daylight,” Parabolic Arc, 5 August 2020, http://www.parabolicarc.com/2020/08/05/first-laser-detection-of-space-debris-in-daylight/.

259 Yousaf Butt, “Effects of Chinese Laser Ranging on Imaging Satellites,” Science and Global Security, 17:20–35, 2009, http://scienceandglobalsecurity.org/archive/sgs17butt.pdf. 26, 32.

260 See: “Maritime Remote Sensing Department [海洋遥感部], NRSCC, accessed July 2020, http://www.nrscc.gov.cn/nrscc/ywfb/sjyzhfwl/201203/t20120331_30244.html; Meteorological Satellite Remote Sensing Department [气象卫星遥感部], accessed July 2020, http://www.nrscc.gov.cn/nrscc/ywfb/sjyzhfwl/201203/t20120331_30233.html.

261 “Introduction and main functions” [简介及主要职能], National Remote Sensing Center [国家遥感中心], accessed July 2020, http://www.nrscc.gov.cn/nrscc/zxgk/jjjzyzn/.

262 “Satellite Operations” [卫星运行], National Satellite Meteorological Center [国家卫星气象中心], https://www.nsmc.org.cn/NSMC/Channels/100003.html; Celestrack, accessed March 2020, https://celestrak.com/satcat/search-results.php.

263 “China plans to launch 2 more meteorological satellites in 2021,” Xinhua, 5 August 2020, https://www.chinadaily.com.cn/a/202008/05/WS5f2a551fa31083481725e664.html.

264 “Contact Us” [“联系我们”], National Satellite Meteorological Center [国家卫星气象中], accessed June 2020, https://www.nsmc.org.cn/NSMC/Channels/100159.html.

265 “Institute carries out precise coordinate measurement on the China Meteorological Administration’s Beijing Weather Satellite Ground Tracking Station ground monitoring station” [“院对国家气象局北京卫星地面跟踪站地面监控站进行精密坐标测量”], Beijing Institute of Surveying and Mapping [北京市测绘设计研究院], 26 October 2016, http://www.bism.cn/gzdt_5661/201610/t20161026_3072.html; “Center Introduction” [“中心简介”], National Satellite Meteorological Center [国家卫星气象中], accessed June 2020, https://www.nsmc.org.cn/NSMC/Channels/100029.html.

266 Meteorological Satellite Remote Sensing Department [气象卫星遥感部], accessed July 2020, http://www.nrscc.gov.cn/nrscc/ywfb/sjyzhfwl/201203/t20120331_30233.html.

267 “Fengyun 2H, Fengyun 3D Satellite Delivery, Service along the Belt and Road countries” [风云二号H星风云三号D星交付 服务一带一路沿线国家], Xinhua, 3 December 2018, http://www.spacechina.com/n25/n148/n272/n4789/c1977264/content.html.

268 “Fengyun satellite receiving and processing system landed in Mozambique” [风云卫星接收处理系统落地莫桑比克], China Meteorological News Agency [中国气象报社], 4 January 2020, http://www.nsmc.org.cn/NSMC/Contents/103554.html.

269 “{19th Party Congress Days – Beijing} Maintaining the forefront of meteorological satellite data” [“【十九大时光·北京】守好气象卫星数据最前端”], China Meteorological News [中国气象报社], 23 October 2017, http://www.cma.gov.cn/2011xwzx/2011xqxxw/2011xqxyw/201710/t20171023_452318.html; “National Satellite Meteorological Center Fengyun-4 Scientific Research Experimental Satellite Ground Application System Project Environmental Impact Report” [“国家卫星气象中心风云四号科研试验卫星地面应用系统工程环境影响报告书”], National Satellite Meteorological Center [国家卫星气象中], December 2013, http://www.nsmc.org.cn/NewSite/NSMC/UploadFiles/Files/20140107152942187.pdf; National Satellite Meteorological Center Beijing Weather Satellite Ground Station Beijing Ground Station Cleaning Service Transaction Announcement” [“国家卫星气象中心北京气象卫星地面站北京地面站保洁服务成交公告”], China Government Procurement Web [中国政府采购网], 30 October 2018, http://www.ccgp.gov.cn/cggg/zygg/cjgg/201810/t20181030_10998055.htm.; “A visit to the Beijing Weather Satellite Ground Station: joining the stars and the earth ‘seamlessly’” [“探访北京气象卫星地面站□让星地之间”严丝合缝”], China Meteorological News [中国气象报], 25 April 2017, http://www.cma.gov.cn/2011xwzx/2011xqxxw/2011xqxyw/201704/t20170425_408340.html.

270 “National Satellite Meteorological Center Fengyun-4 Scientific Research Experimental Satellite Ground

Application System Project Environmental Impact Report” [“国家卫星气象中心风云四号科研试验卫星地面应用系统工程环境影响报告书”], National Satellite Meteorological Center [国家卫星气象中], December 2013, http://www.nsmc.org.cn/NewSite/NSMC/UploadFiles/Files/20140107152942187.pdf.

271 “Satellite Station General Situation” [“卫星站概况”], Guangzhou Weather Satellite Ground Station [广州气象卫星地面站], accessed June 2020, http://web.archive.org/web/20081208043446/http://www.gmss.cn/about.asp.

272 “Institute carries out precise coordinate measurement on the China Meteorological Administration’s Beijing Weather Satellite Ground Tracking Station ground monitoring station” [“院对国家气象局北京卫星地面跟踪站地面监控站进行精密坐标测量”], Beijing Institute of Surveying and Mapping [北京市测绘设计研究院], 26 October 2016, http://www.bism.cn/gzdt_5661/201610/t20161026_3072.html; “Center Introduction” [“中心简介”], National Satellite Meteorological Center [国家卫星气象中], accessed June 2020, https://www.nsmc.org.cn/NSMC/Channels/100029.html.

273 “Satellite Station General Situation” [“卫星站概况”], Guangzhou Weather Satellite Ground Station [广州气象卫星地面站], accessed June 2020, http://web.archive.org/web/20081208043446/http://www.gmss.cn/about.asp.

274 “Satellite Station General Situation – Relationship of Administrative Subordination” [“卫星站概况 - 隶属关系”], Guangzhou Weather Satellite Ground Station [广州气象卫星地面站], accessed June 2020, http://web.archive.org/web/20070814060935/http:/www.gmss.cn/about2.asp; “Directly Subordinate Work Units” [“直属单位”], Guangdong Meteorological Service [广东省气象局], 11 May 2020, http://gd.cma.gov.cn/zdgx/jgyzn/201812/t20181220_101094.html.

275 “National Satellite Meteorological Center Fengyun-4 Scientific Research Experimental Satellite Ground Application System Project Environmental Impact Report” [“国家卫星气象中心风云四号科研试验卫星地面应用系统工程环境影响报告书”], National Satellite Meteorological Center [国家卫星气象中], December 2013, http://www.nsmc.org.cn/NewSite/NSMC/UploadFiles/Files/20140107152942187.pdf.

276 “Directly Subordinate Work Units” [“直属单位”], Guangdong Meteorological Service [广东省气象局], 11 May 2020, http://gd.cma.gov.cn/zdgx/jgyzn/201812/t20181220_101094.html.

277 “Guangzhou Weather Satellite Ground Station” [“广州气象卫星地面站”], Guangzhou Weather Satellite Ground Station [广州气象卫星地面站], 12 October 2018, http://kjj.gz.gov.cn/kpzl/kpjd/content/post_2676984.html.

278 “CFOSAT,” China National Satellite Ocean Application Service, http://www.nsoas.org.cn/news/content/2018-11/23/44_698.html.

279 Elizabeth Howell, “China launches Haiyang 1D satellite to monitor Earth’s oceans,” 12 June 2020, https://www.space.com/china-launches-haiyang-1d-ocean-satellite.html.

280 “Introduction to the Center” [中心简介], National Satellite Ocean Application Service, accessed June 2020, http://www.nsoas.org.cn/news/node_47.html.

281 “Ground Application Systems” [地面应用系统], National Satellite Ocean Application Service, Accessed

July 2020. http://www.nsoas.org.cn/news/node_45.html; "Gaofen-3 satellite's first batch of microwave remote sensing images released" ["高分三号卫星首批微波遥感影像图公布"], China Meteorological News [中国气象报], 25 August 2016, http://www.cma.gov.cn/2011xwzx/2011xqxxw/2011xqxyw/201608/t20160825_320143.html.

282 "China launches live online system of ocean satellite data," Xinhua, 14 May 2020, https://www.chinadaily.com.cn/a/202005/14/WS5ebce685a310a8b241155b55.html.

283 "Satellite Ground Station" [卫星地面站], State Key Laboratory of Satellite Ocean Environment Dynamics (SOED) [卫星海洋环境动力学国家重点实验室], accessed July 2020, http://183.134.199.2/achievement/27.

284 "National Ocean Satellite Hangzhou Ground Station officially enters the operational stage" ["国家海洋卫星杭州地面站正式进入运行阶段"], China Ocean News [中国海洋报], 1 April 2011, http://www.oceanol.com/keji/wxyy/14136.html.

285 "National Ocean Satellite Hangzhou Ground Station (Yuhang) officially entered the operation stage" [国家海洋卫星杭州地面站（余杭）正式进入运行阶段], Second Institute of Oceanography, 18 April 2011, http://www.sio.org.cn/redir.php?catalog_id=11125&object_id=7426.

286 "The construction of a marine satellite station Party members compete for the edge" [建设海洋卫星站 党员争先在边陲], 6 August 2014, http://www.nsoas.org.cn/news/content/2014-08/06/24_84.html.

287 "Progress of the Quantum Experiment Science Satellite (QUESS) 'Micius' Project," National Space Center, accessed June 2020, http://english.nssc.cas.cn/ns/NU/201809/W020180906583002411445.pdf.

288 "World's First Mobile Quantum Satellite Ground Station Successfully Executes 'Handshake' with 'Micius' Satellite" [全球首个可移动量子卫星地面站与 ‘墨子号’ 成功握手], S&T Daily, 2 January 2020, http://scitech.people.com.cn/n1/2020/0102/c1007-31531958.html.

289 "WHO WE ARE," State Radio Regulation of China, accessed March 2020, http://www.srrc.org.cn/en/whoweare1.aspx.

290 "Organizational Structure" ["组织机构"], State Radio Regulation of China, accessed March 2020, http://www.srrc.org.cn/about18549.aspx; archived photos of the stations can be found here: https://web.archive.org/web/20180429004754/http://www.srrc.org.cn/en/whoweare4.aspx.

291 "Beijing Monitoring Station: Construction of full-band monitoring technology highlands" [北京监测站：构筑全频段监测技术高地], China Electronics News [中国电子报], 11 September 2012, http://m.cena.com.cn/wireless/20120911/14957.html.

292 "Measurement facilities available for the measurement of emissions from both GSO and non-GSO space stations," ITU, 2017, https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-SM.2182-1-2017-PDF-E.pdf.

293 See for example "Zhang Feng Speech at the 'Ice and Snow Sword 2018' Combat Realistic Combined Training and Mobilization Meeting" [张峰出席”冰雪砺剑-2018”实战化集训开训动员大会并作动员讲话], Yunnan Communications Administration, 4 December 2018, https://ynca.miit.gov.cn/article/show/2090.html.

294 Very-long-baseline interferometry (VLBI) [甚长基线干涉测量].

295 “VLBI Network” [VLBI □], NRSCC, 13 November 2012, http://www.nrscc.gov.cn/nrscc/gjhz/ska/skaj/wyjjj/gn/201211/t20121113_31601.html.

296 Construction of a second, smaller radio telescope began in March 2017. CNES/Airbus satellite imagery, 1 March 2017.

297 “NanShan 25-m Radio Telescope,” Xinjiang Astronomical Observatory, Chinese Academy of Sciences, accessed June 2020, http://english.xao.ac.cn/pr/25mrt/.

298 “Introduction to the Yunnan Observatory” [云南天文台简介], Yunnan Observatories, 13 November 2015, http://www.ynao.cas.cn/jggk/jgjj/; “Introduction of 40m Radio Telescope” Yunnan Observatories, 6 January 2012, http://www.ynao.cas.cn/kyzz/40msdwyj/.

299 “China Lunar Exploration Project Kunming Ground Station 40-meter antenna completed and accepted” [中国探月工程昆明地面站40米天线建成验收], China News Network, 18 July 2006, https://tech.sina.com.cn/d/2006-07-18/10211042518.shtml.

300 “Tianma Radio Telescope, the place in the city closest to the universe” [天马山射电望远镜，城市最接近宇宙的地方], Shanghai Observer [上观新闻], 26 June 2016, https://www.jfdaily.com/news/detail?id=21554 .

301 “Five-hundred-meter Aperture Spherical Telescope (FAST),” National Astronomical Observatories of China, http://english.nao.cas.cn/Research2015/Facilities2015/Telescopes2015/201701/t20170120_173588.html.

302 “Over 400 million kilometers! Helping ‘Tianwen No. 1’ Mars exploration data to be received in Tianjin” [跨越4亿公里！助力”天问一号” 火星探测数据在天津接收], Sina, 26 April 2020, http://tj.sina.com.cn/news/2020-04-26/detail-iircuyvh9923174.shtml.

303 “China will build the world’s largest ‘antenna’ to track signal sources in outer space” [中国将新建世界最大”天线” 追踪外太空信号源], China Youth Daily, 18 January 2018, https://news.china.com/domesticgd/10000159/20180118/31974463.html.

304 “East Asia VLBI Radio Telescope Network to Start Scientific Commission,” China Academy of Sciences, 5 February 2018, http://english.cas.cn/newsroom/archive/research_archive/rp2018/201802/t20180205_189868.shtml.

305 “China Aerospace International Commercial Launch and Satellite Export Speed Up” [中国航天国际商业发射和卫星出口提速], Xinhua, 16 January 2016, http://www.rmzxb.com.cn/c/2016-01-16/673540.shtml.

306 “Guiding Opinions of the Development and Reform Commission of the National Defense Science and Industry Administration on Accelerating the Construction and Applications of the “One Belt One Road” Space Information Corridor” [国防科工局发展改革委关于加快推进”一带一路”空间信息走廊建设与应用的指导意见], NRDC, 22 October 2016, https://brgg.fudan.edu.cn/articleinfo_1958.html.

307 “Assisted smart shipping, Xinno Satellite Global Network officially opened” [助力智慧航运，鑫诺卫星全球网正式开通], Sino Satellite, accessed March 2020, http://www.sinosat.com.cn/SinoGlobal.htm.

308 “About Us” [关于我们], Sino Satellite Communications, accessed March 2020, http://www.sinosat.com.cn/AboutUs.htm.

309 “Covering 95% of the world’s routes, satellite broadband services 6000 Chinese ships and offshore platforms” [覆盖全球95%航线, 卫星宽带服务6000艘中国船舶和海上平台], China Aerospace Science and Technology Corporation (CASC) [中国航天科技集团] Weibo Account, 18 March 2020, https://www.weibo.com/ttarticle/p/show?id=2309404483882891214916.

310 “China’s first AIS commercial maritime satellite ‘Hede-1’ was successfully launched” [中国首颗AIS商用海事卫星”和德一号”成功发射], CCTV, 15 November 2017, http://www.xinhuanet.com/expo/2017-11/15/c_1121960175.htm.

311 “Wu Weiren: Among the major space powers, only my country does not have an aerospace law” [吴伟仁：在航天大国中，只有我国还没有航天法], Satellite and Internet [卫星与网络], 9 March 2018, https://www.guancha.cn/wuweiren/2018_03_09_449502_4.shtml.

312 “Out of the mystery - China is actively seeking international cooperation in the space field” [走出神秘——中国积极谋求在太空领域开展国际合作], Xinhua, 23 October 2018, http://www.xinhuanet.com/politics/2018-10/23/c_1123603084.htm.

313 Remarks by Patrick Besha, Senior Policy Advisor for Strategic Engagement and Assessment in the Office of the Administrator at NASA Headquarters “US-China Engagement in Space,” 29 March 2019, https://swfound.org/media/206424/us-china-engagement-in-space-transcript.pdf.

314 See for example 29th Landsat Ground Station Operations Working Group, Landsat, 2000, https://www.youtube.com/channel/UCEmsix8sbBOb5tuf6YRsQvw.

315 “ILRS Operational Station Identification Table” NASA, accessed June 2020, https://ilrs.gsfc.nasa.gov/network/stations/active/.

316 “China Signs Square Kilometer Array (SKA) Radio Telescope Observatory Agreement”[中国签署平方公里阵列射电望远镜（SKA）天文台公约], NRSCC, 14 March 2019, http://www.nrscc.gov.cn/nrscc/zxdt/201903/t20190314_34155.html.

317 “An Account of the Talent Cultivation Practices at the Beijing Institute of Tracking and Telecommunications Technology” [北京跟踪与通信技术研究所科技人才队伍建设纪事], PLA Daily, 21 May 2005, http://mil.news.sina.com.cn/2005-05-21/1611290357.html.

318 “Beijing Institute of Tracking and Telecommunications Technology 2016 Graduate Program Recruitment Prospectus,” accessed July 2020, http://www.cnky.cn/xhtml/zhaopin/bjgztx/48.html.

319 “Fengyun satellite receiving and processing system landed in Mozambique” [风云卫星接收处理系统落地莫桑比克], China Meteorological News Agency [中国气象报社], 4 January 2020, http://www.nsmc.org.cn/NSMC/Contents/103554.html.

320 “CBERS Series Satellite Ground Receiving Station in South Africa,” CRESDA, 9 November 2015, http://www.cresda.com/EN/gjhz/jwsjld/7455.shtml.

321 "South Africa CBERS series satellite ground receiving station," CRESDA, 15 July 2015, http://www.cresda.com.cn/CN/gjhz/jwsjld/4606.shtml.

322 "China - ASEAN Remote Sensing Satellite Data Sharing Service Platform," CREDA, 9 November 2015, http://www.cresda.com/EN/gjhz/jwsjld/7457.shtml.

323 "NRO Cracks Open Commercial Imagery To More Providers," *Breaking Defense*, 13 April 2020, https://breakingdefense.com/2020/04/nro-cracks-open-commercial-imagery-to-more-providers/.

324 For an excellent discussion of the implication of Military Civil Fusion in China for Space see: Lorand Laskai, "Testimony before the U.S.-China Economic and Security Review Commission Hearing on China in Space: A Strategic Competition? Building China's SpaceX: Military-Civil Fusion and the Future of China's Space Industry," USCC, 25 April 2019, https://www.uscc.gov/sites/default/files/Lorand%20Laskai%20USCC%2025%20April.pdf, 4.

325 NASA Directory of Observation Station Locations [Volume 2], 2nd Edition., NASA, November 1971, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720012596.pdf.

326 "USGS Landsat Ground Stations," USGS, accessed March 2020, https://www.usgs.gov/land-resources/nli/landsat/usgs-landsat-ground-stations?qt-science_support_page_related_con=1#qt-science_support_page_related_con.

327 "Xi'an Satellite Control Center Promotes Deep Space Exploration Equipment Capability" [西安卫星测控中心推动深空探测装备能力跃升], PLA Daily, 29 October 2018, http://military.cnr.cn/wqzb/jskj/20181029/t20181029_524398241.html.

328 "The 5th Academy of Aerospace Science and Technology Group established the Satellite Application General Department" [航天科技集团五院成立卫星应用总体部], China Space News, 12 December 2018, http://www.spacechina.com/n25/n1991299/n1991333/c2015984/content.html.

329 "Dongara Satellite Station," SSC, accessed March 2020, https://www.sscspace.com/ssc-worldwide/ground-station-network/dongara-satellite-station/.

330 "Spy expert warns of Beijing tie to satellite," *Sydney Morning Herald*, 17 November 2011, https://www.smh.com.au/national/spy-expert-warns-of-beijing-tie-to-satellite-20111116-1njdo.html.

331 "Exclusive: Swedish space company halts new business helping China operate satellites," Reuters, 21 September 2020, https://www.reuters.com/article/uk-china-space-australia-sweden/swedish-space-agency-halts-new-business-helping-china-operate-satellites-idUKKCN26C20A.

332 "Ambassador Lu Fan was invited to visit the Chilean branch of the Swedish space company" [驻智利大使吕凡应邀访问瑞典空间公司智利分公司], Chinese Embassy in Chile, 4 August 2010, http://cl.china-embassy.org/chn/sghd/t721576.htm.

333 "Santiago Station," ESA, accessed March 2020, https://www.esa.int/Enabling_Support/Operations/Santiago_station.

334 “Agreement is signed between CNSA and MOST,” ESSTI, 15 August 2018, https://etssti.org/agreement-is-signed-between-cnsa-and-most/.

335 “Ethiopian Prime Minister Praises China for Launching Satellite for Ethiopia” [埃塞俄比亚总理点赞中国为埃塞发射卫星], Xinhua, 21 December 2019, http://www.xinhuanet.com/world/2019-12/21/c_1125371611.htm; “China launches microsatellite for Ethiopia,” Xinhua, 20 December 2019, http://www.china.org.cn/china/Off_the_Wire/2019-12/20/content_75533791.htm.

336 “Ethiopian Prime Minister Praises China for Launching Satellite for Ethiopia” [埃塞俄比亚总理点赞中国为埃塞发射卫星], Xinhua, 21 December 2019, http://www.xinhuanet.com/world/2019-12/21/c_1125371611.htm.

337 “Interview: Ethiopia seeks enhanced space science cooperation with China,” Xinhua, 13 January 2020, http://www.xinhuanet.com/english/2020-01/13/c_138701522.htm.

338 “About EORC,” ETSSTI, accessed June 2020, https://etssti.org/centers/space-observatory-research-center/eorc/about-eorc/; James Jeffrey, “Ethiopia, phone home: Space observatory sees country’s future in the stars,” AlJazeera, 10 January 2015, http://america.aljazeera.com/articles/2015/1/10/ethiopia-space-observatory.html.

339 “Space Engineering Research and Development Directorate,” ESSTI, accessed June 2020, https://etssti.org/space-engineering-research-and-development-directorate/.

340 “China and international aerospace measurement and control have formed a good cooperative and mutually beneficial relationship” [中国与国际航天测控形成了良好的合作互惠关系], Xinhua, 23 September 2008, http://www.gov.cn/jrzg/2008-09/23/content_1103105.htm.

341 D. Hauser, C. Tison, T. Amiot, L. Delaye, A. Mouche, G. Guitton, L. Aouf, P. Castillan, “CFOSAT: a new Chinese-French satellite for joint observations of ocean wind vector and directional spectra of ocean waves,” Proc. SPIE 9878, Remote Sensing of the Oceans and Inland Waters: Techniques, Applications, and Challenges, 98780T (7 May 2016); https://doi.org/10.1117/12.2225619

342 “CFOSAT,” National Satellite Ocean Application Service, accessed June 2020, http://www.nsoas.org.cn/news/content/2018-11/23/44_698.html.

343 “CAS Satellite Ground Station Kashi: Shepherd for 10 years” [中科院卫星地面站喀什站：坚守边陲十年”牧星人], China Science Daily [中国科学报], 22 January 2018, (2018-01-22 第5版 创新周刊) https://www.cehui8.com/news/yuanxiao/20180123/9508.html.

344 “China’s land, sea and space-based TT&C communication network supports Tiangong-1 mission for the First Time” [我国陆海天基测控网首次携手为天宫一号保驾护航], Xinhua, 2 October 2011, http://www.gov.cn/jrzg/2011-10/02/content_1962117.htm.

345 “Tianlian-1 greatly increased the capacity of China’s manned spaceflight measurement and control communication network” [天链一号使我国载人航天测控通信网能力大增], Xinhua, 3 October 2011, https://mil.huanqiu.com/article/9CaKrnJsCv2.

346 “Malindi station,” ESA, 2 March 2015, https://www.esa.int/ESA_Multimedia/Images/2015/02/

Malindi_station.

347 "13 Monitoring Stations to Ensure Successful Manned Spaceflight," Xinhua, 15 October 2003, ttp://www.china.org.cn/english/msf/77350.htm.

348 "Astronauts visiting the Malindi Test and Control Station in Kenya came to our embassy to give a report" [驻肯尼亚马林迪测控站航天功臣到我馆做报告], Embassy of PRC in Republic of Kenya, 22 October 2005, http://ke.chineseembassy.org/chn/xw/t217940.htm.

349 NASA Directory of Observation Station Locations [Volume 2], 2nd Edition, NASA, November 1971, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720012596.pdf. 221.

350 "Agreement between the Government of the People's Republic of China and the Government of the Republic of Kiribati on the Establishment of the China Aerospace Measurement and Control Station in Kiribati," [中华人民共和国政府和基里巴斯共和国政府关于在基里巴斯建立中国航天测控站协定- 23 September 1996.], Peking University Law, accessed June 2020, http://pkulaw.cn/fulltext_form.aspx?Gid=100667013&Db=eagn.

351 "Base Station 'establishing diplomatic relations' warns of the safety of China's overseas space test and control stations" [基台 '建交' 警示中国海外航天测控站安全], International Herald Leader [国际先驱导报], 22 November 2003, https://web.archive.org/web/20031122012836/http://www.china.com.cn/chinese/2003/Nov/445211.htm.

352 Liu Zhen, "Could ties with Kiribati be a boost to China's space ambitions?," South China Morning Post, 21 September 2019, https://www.scmp.com/news/china/diplomacy/article/3029812/could-ties-kiribati-be-boost-chinas-space-ambitions.

353 "China eyes increased ties with Kiribati, site of space tracking station," Reuters, 6 January 2020, https://www.reuters.com/article/us-china-kiribati/china-eyes-increased-ties-with-kiribati-site-of-space-tracking-station-idUSKBN1Z5168.

354 "Chinese astronauts visit Namibia, China-N.S.A. space cooperation is on the rise" [中国航天员再访纳米比亚 中纳航天合作方兴未艾], China Radio International Online [中央广电总台国际在线], 20 August 2019, http://news.cri.cn/20190820/39aad95b-5837-237b-8859-a69950262ca3.html.

355 Servaas van den Bosch, "Namibia emphasizes the ground use of the Chinese satellite center" [纳米比亚强调中国卫星中心的地面用途], SciDevNet, 10 August 2010, https://www.scidev.net/global/news/zh-136528.html / https://www.scidev.net/global/cooperation/news/namibia-stresses-chinese-space-centre-s-earthly-uses.html [English].

356 "Namibia and China sign an employment agreement," Namibian Ministry of Education, 29 March 2012, http://www.moe.gov.na/news_article.php?id=60&title=Namibia%20and%20China%20sign%20an%20employment%20agreement.

357 "Demystifying China's Deep Space TT&C Network: Australian Ground Station Alerts the U.S." [揭秘中国深空探测网：在澳建监测站引美警惕], China News Week, 12 December 2013, https://mil.huanqiu.com/article/9CaKrnJDx4w.

358 “CASC Contracted to Support Pakistan’s 1R Satellite Ground Station Project” [航天科技签约巴基斯坦1R卫星地面测控站项目], CASC, 11 November 2009, http://www.sasac.gov.cn/n2588025/n2588124/c3847417/content.html.

359 “History of Deep Space Station 51 at Hartbeesthoek,” Hartebeesthoek Radio Astronomy Observatory, accessed June 2020, http://www.hartrao.ac.za/other/dss51/dss51.html.

360 “SANSA installs the new Earth resource terminal: CBERS-04,” SANSA, 14 October 2015, https://www.sansa.org.za/2015/10/22/sansa-installs-the-new-earth-resource-terminal-cbers-04/.

361 “China Remote Sensing Satellite Ground Station” [中国遥感卫星地面站], RADI [中国科学院遥感与数字地球研究所], accessed February 2020, http://www.radi.cas.cn/jglb/kjtx/wxdmz/; “中国遥感卫星地面站：已接收上千万景”太空大片”,” China Youth Daily, 1 January 2020, http://www.xinhuanet.com/science/2020-01/01/c_138669124.htm.

362 “China’s first Overseas satellite ground receiving station the Arctic Station Begins Trial Operations” [我国首个海外陆地卫星接收站北极站投入试运行], Xinhua, 16 December 2016, http://www.xinhuanet.com/politics/2016-12/16/c_129407823.htm.

363 For additional research on this station, see Jichang Lulu: “Greenland: China discreetly launches satellite ground station project,” Jichang Lulu Blog, 14 December 2017, https://jichanglulu.wordpress.com/2017/12/14/greenland-satellite/; “China wants Greenland station ‘ASAP’; one candidate site near planned China Nonferrous investment,” Jichang Lulu Blog,14 October 2017, https://jichanglulu.wordpress.com/2017/10/14/china-wants-greenland-station-asap-one-candidate-site-near-planned-china-nonferrous-investment/; “Beijing Normal University Launches Second Arctic Satellite Ground Station in Greenland” [北师大在格陵兰启动北极第二个卫星地面站建设], Science Net [科学网], 4 June 2017, https://web.archive.org/web/20170627154655/http://news.sciencenet.cn/htmlnews/2017/6/378159.shtm.

364 “Ground Station Services,” Kongsberg, accessed June 2020, https://www.ksat.no/services/ground-station-services/.

365 “Icy Xi-speak and northerly exoprop: the Arctic White Paper,” Jichang Lulu (Blog), 2 February 2018, https://jichanglulu.wordpress.com/2018/02/02/icy-xi-speak-and-northerly-exoprop-the-arctic-white-paper/.

366 “Playing with drones at the South Pole, Only Four Countries in the World Can Do it” [在南极‘玩’无人机，全球仅4国能做到],” Souluniq [心友汇旅行], 23 October 2017, https://www.sohu.com/a/199763331_803688.

367 “Ice Road satellite flying next month is expected to be the first test in this year’s Antarctic science examination” [冰路卫星下月飞天 有望在今年南极科考中初试身手], S&T Daily [科技日报], 19 August 2019, http://www.xinhuanet.com/politics/2019-08/19/c_1124891053.htm.

368 “Tri-polar observation urgently needs domestic specialized China-produced satellites” [三极观测急需国产专业卫星],” S&T Daily [科技日报], 18 May 2019, http://st.zjol.com.cn/rdzx15491/201905/t20190518_10149796.shtml.

369 Liu Yang [刘扬], “Experts to China’s Arctic strategy advice: “I can use the advantages of remote sensing technology” [专家给中国北极战略提建议: 可利用我遥感技术优势], Global Times, 25 September 2017,

https://mil.huanqiu.com/article/9CaKrnK5kOP.

370 Satellite communications are not without their downside: the distances radio waves must travel (for example, from an area within China to a satellite in geostationary orbit 36,000 km above the equator), in addition to processing time, introduces a significant delay of between 240-260 milliseconds. Line of sight is also an issue, and communications are even more difficult above 75°N or below 75°S. See: “The main disadvantages of satellite communications” [卫星通信的主要缺点], Jiayantech [石家庄嘉彦科技有限公司], 14 November 2017. http://m.jiayantec.com/index.php/news/337.html

371 “Inuvik Satellite Station Facility,” Earth Observation Portal Directory, accessed June 2020, https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/inuvik.

372 Iain Marlow “Northwest Territories sees trade missions to China paying off,” Globe and Mail, 22 March 2015, https://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/northwest-territories-sees-trade-missions-to-china-paying-off/article23574748/.

373 “China and Finland sign Arctic Space Joint Research Cooperation Agreement” [中芬签订北极空间观测联合研究中心合作协议], radi.ac.cn, 17 April 2018, http://www.radi.ac.cn/dtxw/rdxw/201804/t20180417_4997963.html.

374 “An Overview of Ice Silk Road Projects” [盘点”冰上丝绸之路”上的项目], chinadialogueocean.net, 9 January 2020, https://chinadialogueocean.net/12569-a-review-of-chinas-arctic-silk-road-projects/?lang=zh-hans.

375 “China and Finland Strengthens Arctic Partner Relationship” [中国与芬兰加强北极伙伴关系], Sputnik, 13 January 2019, http://www.polaroceanportal.com/article/2477.

376 “Phased progress in Sentinel Data Service and Research Cooperation at the Joint Research Center for Arctic Observations of the Aerospace Information Research Institute” [空天院北极观测联合研究中心哨兵数据服务及研究合作取得阶段性进展], aircas.cn, 30 September 2019, http://www.aircas.cn/dtxw/kydt/201909/t20190930_5403296.html.

377 “China’s first Arctic scientific research station-the Yellow River station begins the mission”[中国首个北极科考站——黄河站开始考察任务], CCTV, 26 May 2019, http://www.hellosea.net/Institute/5/63834.html.

378 Jim Wolf, “China key suspect in U.S. satellite hacks: commission,” Reuters, 28 October 2011, https://www.reuters.com/article/us-china-usa-satellite-idUSTRE79R4O320111028.

379 Beidou satellite navigation system Antarctic reference station opened” [北斗卫星导航系统南极基准站启用], Economic Daily [经济日报], 11 February 2015, http://www.cac.gov.cn/2015-02/11/c_1114327126.htm; “Playing with drones at the South Pole, Only Four Countries in the World Can Do it” [在南极 ‘玩’无人机，全球仅4国能做到],” Souluniq [心友汇旅行], 23 October 2017, https://www.sohu.com/a/199763331_803688.

380 Lu Qi [陆琦] “China Will Build Antarctic Beidou Reference Station,” China Science Daily [中国科学报], 30 October 2014, http://www.cas.cn/xw/kjsm/gndt/201410/t20141030_4233341.shtml.

381 “Large-Scale Engineering Equipment of China’s Antarctic New Station shipped to Inexpressible Island” [中国南极新建站大型工程装备运上恩克斯堡岛], Xinhua, 17 January 2018, http://www.gov.cn/

xinwen/2018-01/17/content_5257318.htm.

382 “Basic Surveying and Mapping Completed for Victoria Land Newly-Built Station” [维多利亚地新建站基础测绘完成], Shanghai Surveying and Mapping Geographic Information Association, 21 January 2014, http://www.ssgpc.cn/gk/zdgk/chzx/chyw/9921.htm.

383 Anne-Marie Brady, “China’s Expanding Antarctic Interests: Implications for New Zealand,” 3 June 2017, https://www.canterbury.ac.nz/media/documents/research/China’s-expanding-Antarctic-interests.pdf.

384 “HY-2A,” China National Satellite Ocean Application Service, http://www.nsoas.org.cn/news/content/2018-10/25/44_531.html

385 “HY-2B,” China National Satellite Ocean Application Service, http://www.nsoas.org.cn/news/content/2018-11/23/44_697.html

386 “HY-1C,” China National Satellite Ocean Application Service, http://www.nsoas.org.cn/news/content/2018-11/23/44_696.html

387 “HY-1A,” National Satellite Ocean Application Service, accessed June 2020. http://www.nsoas.org.cn/news/content/2018-10/25/44_533.html

388 “HY-1B,” National Satellite Ocean Application Service, accessed June 2020. http://www.nsoas.org.cn/news/content/2018-10/25/44_532.html