An Acad Bras Cienc (2021) 93(Suppl. 1): e20200808 DOI 10.1590/0001-3765202120200808
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

PHYSICAL SCIENCES

An Overview of Some Latest Development in Chinese Astronomy

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Abstract: We present brief highlights and updates on some newer projects, both in operation/construction and in preparation stages, of astronomical research on Mainland China, with an emphasis on those involving international collaborations. Limited by the scope of this paper, this sample is not meant to be uniform nor comprehensive, and in some cases it may not be fully up to date. For more specific and detailed information on these or other projects, we refer the readers to the official websites of these projects and those of the National Astronomical Observatories, Chinese Academy of Sciences.

Key words: Astronomy, Chinese observatories, China, development, telescope.

GENERAL INFORMATION ON CHINESE ASTRONOMICAL RESEARCH

Scientific research in astronomy is conducted in China (the Mainland) among two main types of institutions: astronomical observatories of the CAS (Chinese Academy of Sciences) system, and universities of the Ministry of Education system. The former includes the National Astronomical Observatories CAS (NAOC) headquartered in Beijing, with several sibling observatories around the country (see Fig. 1), and two relatively independent observatories (Purple Mountain Observatory PMO, and Shanghai Astronomical Observatory SHAO); While the latter encompasses an increasing number of national and provincial universities. In addition, the Institute of High Energy Physics of CAS, Polar Research Institute, and the National Time Service Center (NTSC) of CAS are also engaged in some related undertakings. The total number of scientists in active astronomical research is estimated to be around 4,200 as of 2019, including about 530 members of the International Astronomical Union (IAU).

Observing facilities of these institutions are distributed all around the country: while the observing sites tended to concentrate along the coast in the old days, now they are increasingly built toward the West and Southwest part of China (Fig. 2). The traditional sites include optical and radio telescopes and other astronomical instruments, but some newer sites also serve for observing in wavelengths such as gamma-rays and high-energy particles. In addition, there are a number of newly developed initiatives to conduct astronomical observations from space, taking advantage of the launch capabilities provided by the government. Through international collaborations, China is also committed to take part in a number of multi-national astronomy facilities being established around the world. Outside of the country, China has built an observing site in Antarctica, participated in a telescope operation in Hawaii, and is contemplating future facilities in Argentina and northern Chile (see below). Fig. 3 shows the facilities in operation, commissioning, and those still in construction.

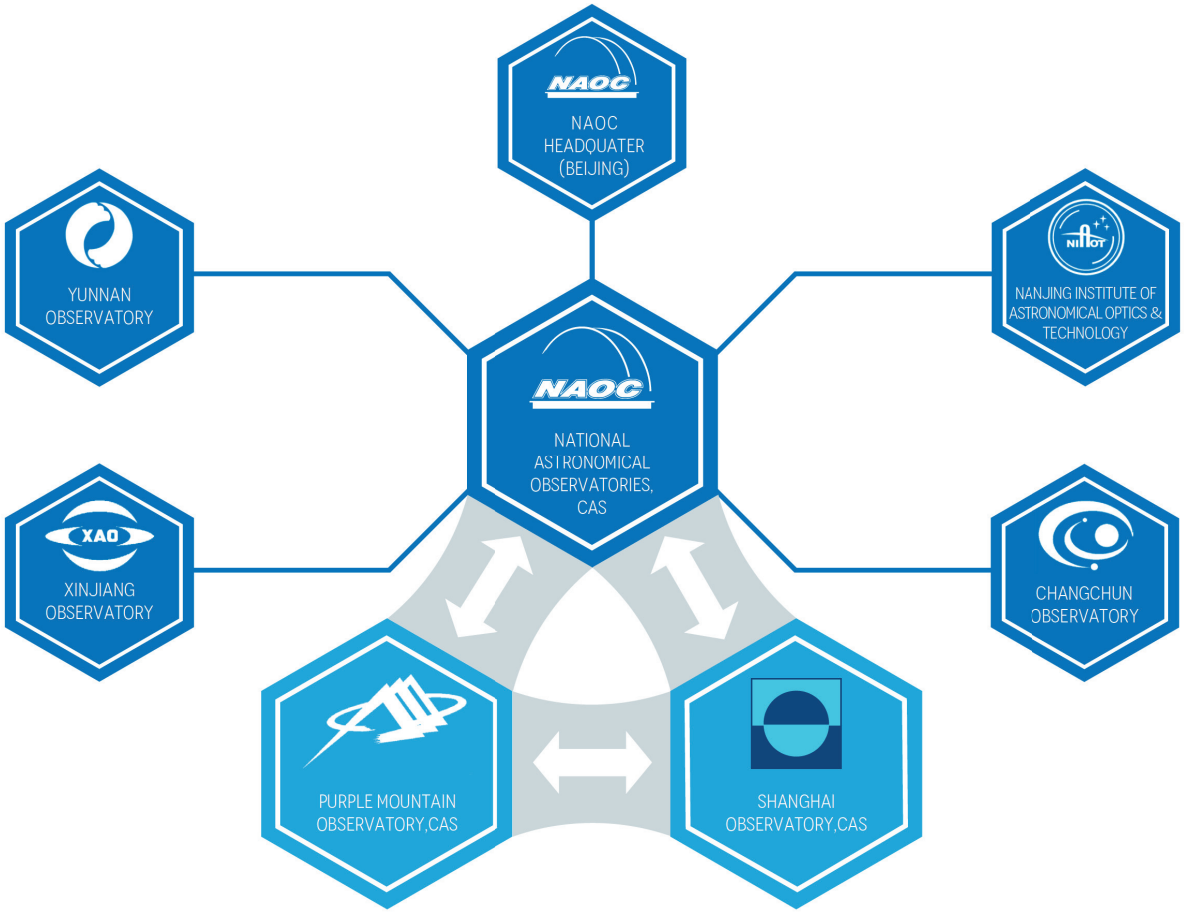

Figure 1. The Chinese Academy of Sciences (CAS) National Astronomical Observatories system. The Ministry of Education (Universities) system is not shown here as we do not yet have up-to-date statistics.

STATUS ON SOME OF THE FACILITIES IN OPERATION

Lamost

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (also known as Guo Shou Jing Telescope, named after a famous astronomer in ancient times, see Fig.4) is located at the Xinlong Observatory site near Beijing, operated mainly by NAOC. It combines a large aperture (a clear aperture up to 4.9 meters in diameter) with a wide field of view (5 degrees). Its design incorporates a combination of thin deformable mirror active optics and segmented active optics, with its spherical primary mirror and active aspherical correcting mirror both being segmented with 37 and 24 hexagonal submirrors respectively. LAMOST has 16 spectrographs with 32 CCD cameras, and can accommodate up to 4000 optical fibers at the same time.

This project is continuing its main scientific objective of large sky-area spectroscopic surveys. Accurate stellar parameters (radial velocities, effective temperatures, surface gravities and metallicities), elemental abundances (alpha-element to iron, and [C/H] and [N/H] abundance ratios), as well as values of the interstellar reddening, distances, and ages, have been derived from the measured spectra and the

Figure 2. Astronomical Facilities around China and some international collaborative projects.

results are used to buildunique samples for studies of the Milky Way[1].

As of 2019, LAMOST has obtained over 10 million spectra, hitherto the largest single spectroscopic data archive for astronomy in the world. A significant volume of contiguous sky coverage of the Galactic disk in the anti-center direction has been spectroscopically sampled with a special selection function down to r≈17.8 magnitude. Data releases are available on the project's official website, and international collaborations on survey-related research are highly encouraged.

FAST

The Five-hundred-meter Aperture Spherical Telescope (Li & Pan 2016) is located in Guizhou Province of southwestern part of China (Fig. 5), and it is also operated by NAOC. The commissioning phase of this telescope continued from 2016 to 2019, and it has officially started its science operation phase recently. It has also initiated open calls for ***Shared-risk Observations***, fostering collaborations with international partners[2].

In the proposal call of 2019, a total of 960h of night time and 360h of daytime observing were made available. Over 100 proposals were received from more than 20 institutions. Statistics show that the times requested are distributed among scientific categories as: Pulsar 36.1%, Galaxies 24.1%, ISM 12.8%, Compact Objects 10.5%, FRB 6%, and others 10.5%. The distribution among observing modes is: Pulsars 49.6%, Spectroscopy 41.4%, Continuum 3.8%, Others 5.2%. A new round of proposal call was conducted in April 2020,

[1]Websites: http://english.nao.cas.cn/ic2015/isatp2015/201703/t20170329_175448.html; http://www.lamost.org/public/?locale=en.

[2]Websites: http://english.nao.cas.cn/ic2015/isatp2015/201703/t20170329_175451.html; https://fast.bao.ac.cn/.

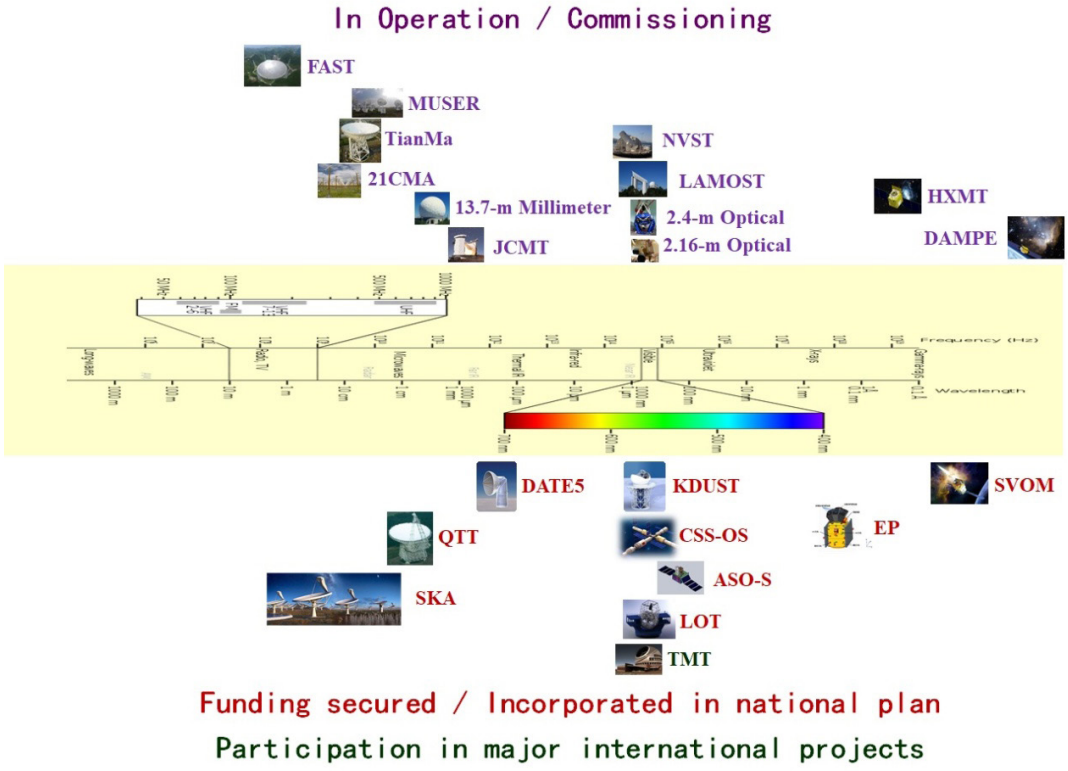

Figure 3. **Facilities in operation, commissioning (above), and those still in construction (below).**

and the telescope's times are currently open to international scientists on collaborative and shared-risk basis.

Tian Ma Radio Telescope

This is a new 65m-diameter fully steerable radio telescope located near the city of Shanghai, operated by SHAO. It is a horizontal-mode radio telescope equipped with an adjustment system for the active reflecting surface, equipped with dual-polarization cryogenic receivers in L, S, X, C, Ku, K, Ka and Q-band. This telescope greatly enhances the capabilities of the Chinese VLBI network. In addition to VLBI radio astronomy, its scientific objectives include spectral lines and pulsar observations. It also plays an important role in supporting deep space explorationsof the Chinese space program by providing radio tracking services. This telescope now accepts observing time requests through international collaborations[3].

DAMPE

The Dark Matter Particle Explorer Mission (also known as the WuKong, or Monkey King, Project) is a space mission launched as a satellite payload by the Chinese Space Agency on December 17, 2015, and has been in successful operation since. It is one of the first space-borne observing facilities for astronomical research in China, representing a milestone for the community. It is operated by the PMO, headquartered in Nanjing. The PI of this mission is Dr. Jing Chang. As of 2019, it has finished its first three-year mission and, based on the good working status of its

[3]Website: http://english.shao.cas.cn/fs/201410/t20141008_128903.html.

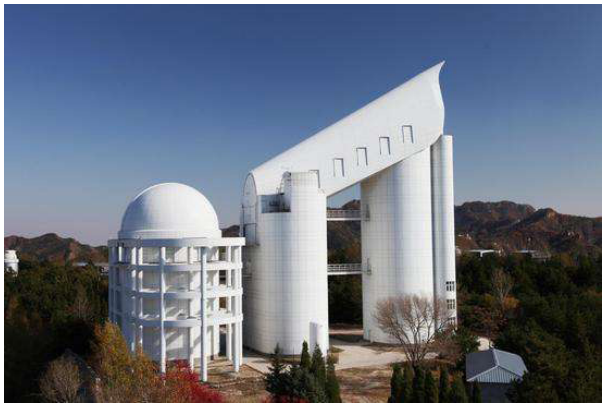

Figure 4. LAMOST telescope at the Xinglong Observatory of NAOC.

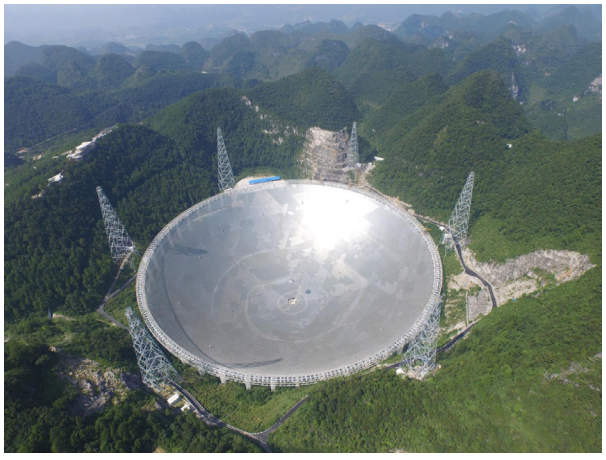

Figure 5. FAST Telescope operated by NAOC in Guizhou, China.

instruments, has been approved for operation of another 2 years[4].

The science goals of this mission include indirect detection of dark matter-related particles, and the study of the origin and propagation of cosmic rays through gamma-ray observations. To date, it has achieved direct detection of a break in the TeV electron spectrum of cosmic-rays, as well as detection of a spectral break at ~10 TeV in the proton spectrum.

Insight-HXMT

The Hard X-ray Modular Telescope is a newer space mission and is known as the first X-ray satellite mission by China. It was launched on June 15, 2017, and is operated by a team at the Institute of High Energy Physics (IHEP) of CAS, located in Beijing, with Dr. Shuangnan Zhang as its PI[5].

Its science goals include high energy phenomena such as gamma-ray bursts (GRBs), and accreting neutron stars. It is capable of detecting more than 100 GRBs per year in the 0.2 – 3.0 MeV energy band. In addition, it will spend roughly one-third of its observing time to map the Milky Way disk in a scanning mode.

Participation in the EACOA operation of JCMT

Since 2017, several Chinese research groups have participated in the successful operations of the JCMT radio telescope on Mauna Kea, Hawaii, led by a consortium of East Asian Core Observatories Association (EACOA), to which NAOC is the Mainland China representative. As one of the world's leading observing facilities in the millimeter and submillimeter wavelength window, this telescope continues to enable many ground-breaking science programs with its competitive proposal process, including some large-scale key science projects. EACOA also runs a postdoctoral fellowship program which support fellows to work in its member institutions, and some scientific symposiums[6].

21CMA

The 21 CentiMeter Array located in Tianshan Mountain in western China, is a ground based meter-wave interferometric array designed to probe the 21cm radiation of neutral hydrogen from the cosmic dawn and the epoch of reionization at z=6-27. The array, consists of 81

[4]Website: http://www.pmo.cas.cn/dampe/.

[5]Website: http://enghxmt.ihep.ac.cn/.

[6]Website: https://www.eaobservatory.org/; https://www.eaobservatory.org/jcmt/.

pods with 127 log-period antennas for each, which are deployed along two perpendicular arms of 6+4 km in length. A field of 10-100 square degrees centered on the North Celestial Pole is imaged 24 hours per day in a low frequency range from 50 MHz to 200 MHz with a resolution of 24 kHz. 21CMA is a unique low-frequency radio interferometer to server as SKA pathfinder in China[7].

Tianlai Pathfinder Experiment

This is a small pathfinder experiment of a future radio telescope array for 21cm HI line intensity mapping of cosmology studies, built to check the basic principles and designs, find out potential problems. It is located in the eastern part of the XinjiangUyghur Autonomous Region in northern China, and is operated by a NAOC group led by Dr. Xuelei Chen (the word Tianlai means "heavenly sound"in Chinese).The location was selected after a wide survey of radio quiet sites to minimize potential radio frequency interferences (RFI)[8].

To date, this experiment consists of three 15x40m cylinders with 96 dual polarization receiver units, and sixteen units of 6m diameter radio antennae. The antennae are distributed around a circular area of 17.6m in radius. The working frequencies of the receivers range from 700 to 800MHz, and can be tuned in 600-1420MHz range. If this experiment is successful, the plan is to expand to a full-scale array of as many as 2,500 units, covering an area of 120 X 120m in size.

CSRH

The Chinese Spectral Radioheliograph Experiment (also known as Mingantu spectral radioheliograph, MUSER) is a radio array telescope aimed at opening new windows for solar flares and coronal mass ejection(CMEs) studies. It is located in the Inner Mongolia Autonomous Region of northern China, operated by a solar physics research group led by Dr. Yihua Yan of NAOC (see Fig. 6). The main facilities of this experiment were built in 2013, and observations at 0.4-2 GHz frequency in its first phase, and at 2-15 GHzin the second phase have been successfully obtained. Continued observations and monitoring of solar activities are conducted at this site[9].

AN UPDATE ON FACILITIES UNDER CONSTRUCTION

The SKA and TMT Participations

China has also actively participated in the well-known Square Kilometer Array (SKA) and Thirty Meter Telescope (TMT) projects as major international partners. In March 2019, China signed the international treaty establishing the intergovernmental organization that will oversee the delivery of SKA, the world's largest radio telescope. This effort in China is supported by the Ministry of Science and Technology with the assistance of NAOC and SHAO[10].

For the TMT project, while China is not yet a full member of the consortium, many research institutions and instrument manufacturers have joined the research and development of the project's various components, making important contributions in design and manufacturing efforts to this leading optical/infrared observing

[7]Website: http://english.nao.cas.cn/Research2015/rp2015/201701/t20170120_173603.html.

[8]Website: http://tianlai.bao.ac.cn/.

[9]Website: http://english.nao.cas.cn/Research2015/Stations2015/201512/t20151229_158005.html.

[10]Website: http://english.nao.cas.cn/ic2015/isatp2015/201512/t20151228_157980.html.

Figure 6. The CSRH Array Telescope.

facility at the forefront of technological innovation[11].

NAOC and CASSACA in Chile

Since 2013, CAS established its South America Center for Astronomy (aka CASSACA), located at Cerro Calan (part of the campus of Universidad de Chile) in Santiago, Chile. This Center, led by Drs. Zhong Wang and Jiasheng Huang of NAOC, is meant to be a hub of collaborations with scientists and international observatories in Chile and the rest of South America. It also serves as the representative of NAOC to explore possible future observatory sites in northern Chile, where many of the world's leading facilities have already taken roots. In 2016, NAOC has been granted the *International Research Organization* status in Chile, paving the way for developing its own observing bases, the first for China in the Southern Hemisphere. Currently, at least one such base for optical astronomy (Cerro Ventarrones) is being developed through a collaboration reached with Universidad Catolica del Norte (UCN). Over the last few years, CASSACA has also been active in promoting China-Chile collaborations in research and manages a successful CAS-Chile Postdoctoral Fellowship program that is open to applicants from all around the world[12].

NAOC also develops stable and wide international collaborations with other countries and their respective institutions, such as those of Spain, France, Russia, South Africa, Brazil, Austrilia, Germany and so on.

GROUND-BASED PROJECTS IN DEVELOPMENT

KDUST and DATE5 Telescopes at Dome A

As part of China's scientific research efforts on Antarctica, it has developed the "Dome A" site for astronomical observations, taking advantage

[11]Website: http://english.nao.cas.cn/ic2015/isatp2015/201512/t20151228_157981.html.

[12]Website: http://english.nao.cas.cn/ic2015/isatp2015/201703/t20170329_175450.html; http://www.cassaca.org/en/.

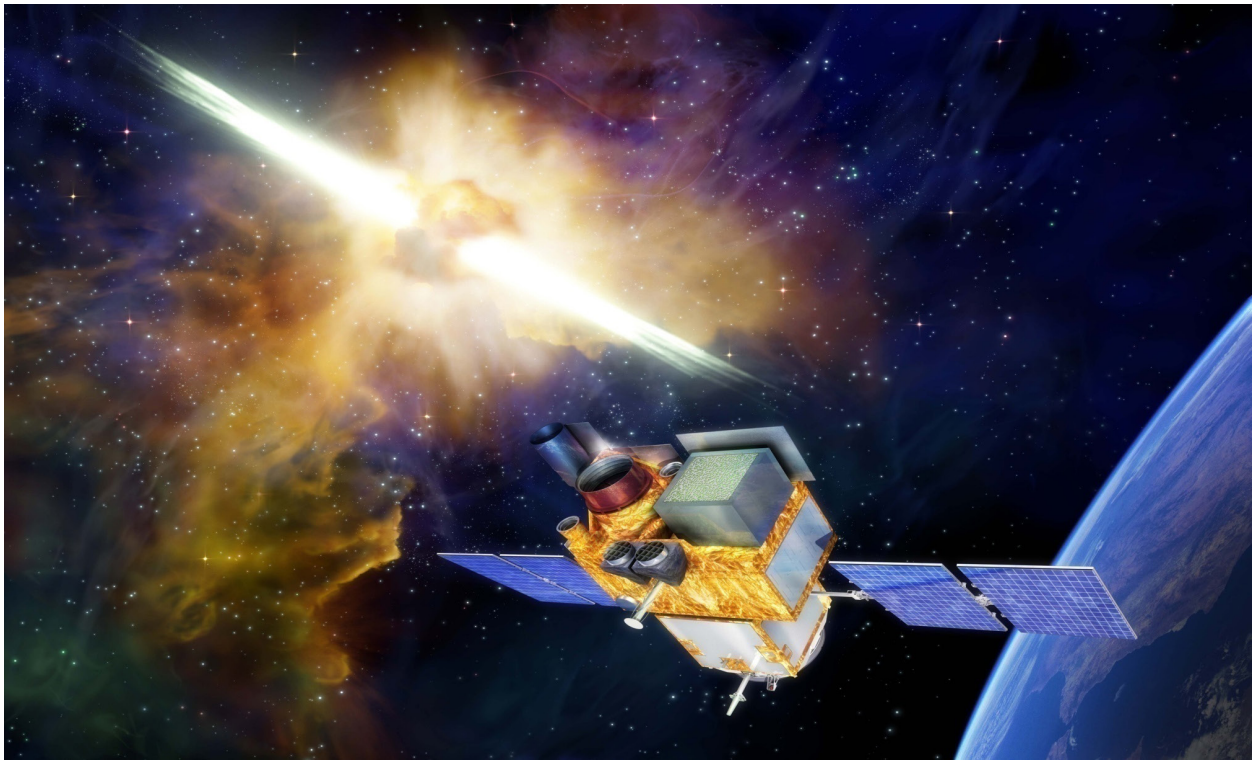

Figure 7. The SVOM Satellite – in artistic rendering.

of the unique geographical location and an ice plateau at more than 4,000 meters above sea level. For more than ten years, Chinese science teams have made annual traverses to the site and, in collaboration with international partners such as Australia, established a semi-permanent monitoring station(known as Kunlun Station, named after a famous mountain range in the western part of China) and small-size telescopes as pilot projects. The government is considering proposals to make the station year-round, and build and operate both optical/infrared and submillimeter telescopes with advanced technologies. These efforts are led by the Polar Research Institute of China based in Shanghai, along with the PMO of CAS.

The KDUST (Kunlun Dark Universe Survey Telescope) is planned as a 2.5-meter infrared/optical telescope perched on a high tower approximately 15 meters above the icy surface. It is intended as a discovery instrument for wide-field, time-domain surveys to detect faint and variable sources such as exoplanets in the Milky Way.

The DATE5 (Five-meter Dome A Terahertz Explorer) Telescope is designed as a unique, very high frequency, fully steerable, radio telescope with exceptional surface and pointing accuracies. Similar to its predecessors in the millimeter wavelength range, the observations with this telescope are expected to open up one of the last remaining spectral windows reachable from the ground.

Over the last few years, both telescope projects for the Dome A site have experienced certain delays due to budgetary and logistic issues, but as of this writing, they (and corresponding websites) are still in active preparations.

LOT Project

As of late 2018, the Chinese government has granted preliminary approval for a Large

Optical/infrared Telescope (with a tentative acronym"LOT") project, but its exact location is still undecided. This is intended to be a large aperture, segmented mirror telescope of 10-12 meter in diameter(Su et al. 2017). While its operation would be a few decades after 10m-class telescopes such as the Keck and GTC, once completed, it should still be among the largest and most powerful telescopes of its kind, and employ a large variety of new technologies, many of which are being developed in China. Once fully funded, the projected timeline for construction of this telescope is under ten years. The official website of this project is still under preparation.

QTT Radio Telescope

The Xinjiang QiTai 110m Radio Telescope is a fully steerable radio telescope to be built in the town of QiTai of the Xinjiang Autonomous Region. The site is at the far-northwestern corner of China, so this telescope, one of the largest of its kind in the world when built, will also be an important part of the Chinese VLBI Network. This project is led by the Xinjiang Astronomical Observatory, part of the CAS National Astronomical Observatories system, with its Director, Dr. Na Wang as the PI.[13]

The Sitian Network of Telescopes

This is a proposed network of optical telescopes to perform all-sky monitoring observations in at least three colors simultaneously, down to a limiting magnitude of 21.5. Its focus will be on fast variables on the time scales of minutes or shorter. In its current design, the 1m class telescopes will have Schmidt optics with 5x5 degree FOV, and be fully automated. In its first phase, the proposal calls for 60 of such telescopes to be installed on sites around China, with additional 12 elsewhere in the Northern hemisphere, plus three 4m class telescopes equipped with special instruments for fast-alert spectroscopic follow-ups. The second phase of this project would install a similar amount of telescopes at sites that cover the Southern hemisphere. This proposal is led by Dr. Jifeng Liu of NAOC.

SPACE-BORNE PROJECTS IN DEVELOPMENT

Optical Module for the CSS

As part of the future payload of the Chinese Space Station (CSS), an optical module is being developed at NAOC that will serve as a two-meter wide-field survey telescope. It will perform both imaging and slitless spectroscopic surveys on a wide range of astrophysical objects, in part overlapping with those of LAMOST and cover many different research topics. Down to a 5-sigma limiting magnitude of 25.5, its imaging survey will consist of six bands, and cover an estimated sky area of 17,500 square degrees, for regions with |b|>15-20 degrees. For the spectroscopic survey with R>200 and limiting magnitude of 22-23, a similar sky area is expected to be covered. In its deep survey mode, a smaller area of approximately 400 square degrees will be covered, to at least one magnitude deeper.

The telescope module will be docking with the CSS with opportunities of servicing and repairs. The development effort of this module is led by Dr. Hu Zhan of NAOC. It is targeting a launch date in 2022.

Einstein Probe Mission

This is a small mission for high-energy time-domain astrophysics, managed as part of the Pilot Space Science Program of CAS. Its development is led by a group at NAOC with Dr. Weiming Yuan as the PI. The scientific goal of this mission is to carry out sensitive and high

[13]Website: http://qtt.xao.ac.cn/.

cadence surveys of high-energy transients, and monitor variabilities in the soft X-ray band. It will also perform immediate X-ray follow-up observations, and produce fast downlinks of transient alert data to trigger follow-ups such as quick target-of-opportunity (ToO) observations. The planned launch date for this mission is at the end of 2022 or 2023[14].

The payload of this mission includes a wide-field X-ray telescope (WFT, with the so-called lobster-eye focusing technology), covering 3,600 square degrees in the 0.5-4 keV band, and a Follow-up X-ray Telescope (FXT) in the 0.5-8 keV band.This program is in collaboration with international partners such as the European Space Agency, MPE (Germany) and CNES (France).

Space Multi-band Variable Objects Monitor (SVOM) Mission

This is anotherspace mission with strong international collaborations (mainly between China and France), targeting primarily gamma-ray burst events (GRBs). This project, with its multiple instruments, will permit detection of all known types of GRBs, with special attention to the high-z, or low-z but sub-luminous varieties. It will provide fast, accurate GRB positions and determine the broad-band spectral shape and temporal properties of the prompt emission of these objects. The PI on the Chinese side of this mission (see Fig. 7) is Dr. Jianyan Wei of NAOC[15].

Acknowledgments

In collecting information on the diverse research projects, we would like to thank Drs. Jinxin Hao, Suijian Xue and Geng Li, the Office of International Cooperation, NAOC, for their assistance in preparing for this review. The original version of this paper was prepared as viewgraphs used for a visual presentation. The Chinese astronomy community remains very much interested in and has high expectations for the BRICS astronomy cooperation. It is our hope that this report provides a guide for BRICS astronomers to find more information and opportunities of collaboration with their counterparts in Mainland China.

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How to cite

WANG Z & LIANG Y. 2021. An Overview of Some Latest Development in Chinese Astronomy. An Acad Bras Cienc 93: e20200808. DOI 10.1590/0001-3765202120200808.

Manuscript received on June 2, 2020;
accepted for publication on November 16, 2020

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[14]Website: http://ep.bao.ac.cn/.

[15]Website: http://svom.bao.ac.cn/; http://www.svom.fr/en/.