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Construction Progress of Chinese Meridian Project Phase II*

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Abstract The Chinese Meridian Project (CMP) is the Space Environment Ground Based Comprehensive Monitoring Network of China, a national major science and technology infrastructure project. The CMP consists of the Space Environment Monitoring System, Data Communication System, and Science Application System. Its construction has been divided into two steps: the Phase I was from 2008 to 2012; the Phase II started at the end of 2019, expected to be completed at the end of 2023. Beyond 2023, the CMP as a whole will be in operation to make observations. This report introduces the construction progress of CMP Phase II in the past two years, covering the construction progress of both the Data Communication System and the Science Application System. As for the Space Environment Monitoring System, this report mainly gives an introduction to the construction progress of large-scale advanced monitoring equipment, such as, the solar radio telescope, interplanetary scintillation telescope, incoherent scatter radar, high frequency radar, MST radar, and large-aperture Helium Lidar. In addition, this paper presents the construction plan for the next two years and the future outlook as well.

Key words Chinese Meridian Project (CMP), Ground-based observation network, Space weather, Solar-terrestrial physics

Classified index P35

1 Introduction to the Chinese Meridian Project

The Space Environment Ground Based Comprehensive Monitoring Network of China (hereinafter referred to as the Chinese Meridian Project, CMP) is a national major science and technology infrastructure project. The CMP is composed of the Space Environment Monitoring System, Data Communication System, and Science Application System.

The constructions of the project are carried out in two steps: CMP Phase I and Phase II. The Phase I has

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built 15 conventional observation stations along longitude 120°E and latitude 30°N. The instruments include magnetometers, radio radar sets, optical observation equipment, and sounding rockets[1]. The construction of Phase I started in 2008 and completed in 2012. Since 2012, the CMP Phase I has entered into operation.

The CMP Phase II started construction at the end of 2019, and is expected to be completed by the end of 2023. On the basis of CMP Phase I, it will add 16 stations. Finally, a whole-space environment monitoring network will be set up, composed of 31 stations and nearly 300 instruments along longitudes 100°E and 120°E, and latitudes 30°N and 40°N.

The CMP adopts geomagnetic, radio, optical and other means to build a networked monitoring capacity for the ionosphere, middle and upper atmosphere and geomagnetism in China (three networks). Internationally advanced large-scale monitoring equipment will be deployed in four key monitoring areas: high latitude in the polar region, middle latitude in the north of China, low latitude in Hainan and the Tibetan Plateau, carrying out comprehensive fine detection of the space environment (four focuses). A series of advanced solar interplanetary monitoring equipment is added to build the monitoring capability of the whole chain of solar terrestrial space (one chain). The framework of one chain, three networks and four focuses will realize the multi-element and comprehensive three-dimensional detection of the solar terrestrial space environment for the first time in the world.

The scientific goals of CMP are: (i) to explore the propagation and evolution of space weather events and the paths and characteristics affecting the space environment, through monitoring of the whole chain with nationwide coverage and high temporal and spatial resolution from the solar atmosphere to near Earth space; (ii) to reveal the characteristics of change and differences of space environment over different regions of China, as well as the fine process of space environment change in special regions such as the Tibetan Plateau, the north and south of China; (iii) to study the coupling process of solid Earth, lower atmosphere and near-Earth space environment under special geological and geographical conditions in China.

For a detailed introduction to CMP Phase II, please refer to Ref.[2]. The timeline of the construction and operation of the whole CMP is shown in Fig.1.

2 Main Construction Progress of Various Systems and Monitoring Equipment of CMP Phase II

The CMP is divided into three systems, that are, the Data Communication System, Scientific Application System, and Space Environment Monitoring System.

The Data Communication System is responsible for data transmission, collection, processing, distribution and sharing. The Scientific Application System is in charge of various advanced data products, application demonstration, model research and development, formulation and implementation of the joint scientific observation campaign plan, international cooperation, scientific research, *etc*. The Space Environment Monitoring System performs conventional and intensive observations, data acquisition and data inversion of various monitoring equipment. It is also responsible for the normal operation of monitoring equipment, equipment maintenance, transformation and upgrading of equipment, *etc*.

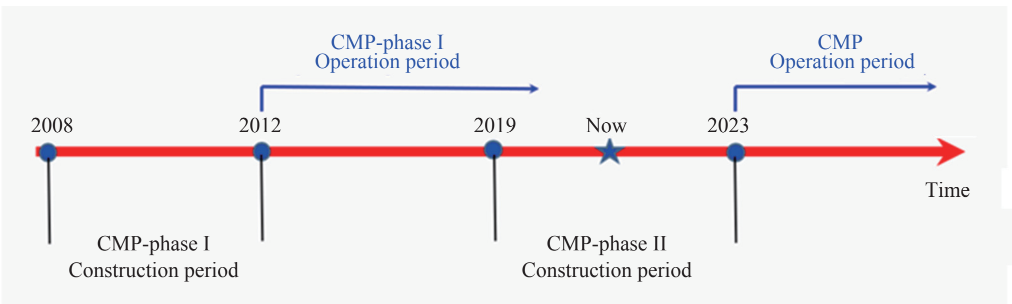

Fig. 1 Timeline of CMP's construction and operation

2.1 Construction of the Data Communication System and Scientific Application System

The Data Communication System and Scientific Application System will be installed in the integrated information and operation control center building. The building is located in Huairou campus of National Space Science Center of Chinese Academy of Sciences. It will become an important control hub, data center and research platform of CMP. The main construction of this building has been completed. It is estimated that the construction of the Data Communication System and Science Application System will be accomplished at the end of 2022. From then on, these two systems will be eligible to promote joint testing with the Space Environment Monitoring System.

2.2 Construction Status of the Space Environment Monitoring System

The Space Environment Monitoring System is composed of eight subsystems which belong to "one chain" (solar interplanetary monitoring chain subsystem), three networks (geomagnetic monitoring network subsystem, ionospheric monitoring network subsystem, and middle and upper atmospheric monitoring network subsystem), and four focuses (polar high latitude monitoring subsystem, north middle latitude monitoring subsystem, south low latitude monitoring subsystem, and Tibetan Plateau monitoring subsystem).

The three networks in the Space Environment Monitoring System in CMP are mainly made up of magnetometers, atmosphere electric field monitors, ionosondes, TEC and scintillation monitors, lidars, Meteor radar sets, airglow imagers, and other conventional observation equipment. The construction and installation of these equipment will be completed by the end of 2022 and then put into use.

In addition to these conventional monitoring instruments for three networks, the CMP will build a series of internationally advanced large-scale monitoring equipment for the observation of the four key areas-four focuses, and a series of advanced solar interplanetary monitoring equipment for monitoring the whole chain of solar terrestrial space-one chain. The internationally advanced large-scale monitoring equipment includes solar radio telescope, interplanetary scintillation telescope, incoherent scatter radar, high frequency radar, MST radar, large-aperture Helium Lidar, and so on. These advanced large-scale monitoring instruments will be developed, installed and put into use by the end of 2023. Here is a brief introduction to the development and construction progress of some of them.

2.2.1 Solar Radio Telescope

The Solar Radio Telescope is one of the key observatories in the solar interplanetary monitoring chain subsystem of CMP Phase II, which is an important tool to monitor and diagnose solar activities. Two solar radio telescopes will be built in the CMP. One is the Daocheng Solar Radio Telescope (DSRT), and another is the Mingantu Spectral Radioheliograph (MUSER).

DSRT is located at Daocheng, Sichuan province (100.246°E, 29.011°N), south-west of China, and surrounded by mountains which provide an excellent radio environment. The interferometric array of DSRT is composed of 313 antennas of six meters in diameter. All antennas are uniformly distributed along a circle of 1000 m in diameter. A calibration antenna is placed on the top of a tower at the center of the circle, from where an arbitrary calibration signal is transmitted to all antennas omni-directionally. Combining with dedicated internal calibration and traditional astronomical calibration sources, DSRT will enable accurate phase calibration over the 313 elements, therefore providing highly dynamic radio images of solar bursts (Fig.2). The operational frequency band of DSRT is 150–450 MHz for tracing Coronal Mass Ejection (CME) in the high atmosphere region of the Sun.

At the time of this report so far, a 16-element small system has been installed for observation and concept verification (see Fig.3). The whole system with 313 element antennas will be installed by the end of 2022. DSRT will be tested and commissioned in 2023. At the end of 2023, it will be reviewed for acceptance and enter the observation stage.

The construction of Mingantu Spectral Radioheliograph (MUSER) was fulfilled during 2009–2016 and it covers the frequency range of 400 MHz–2 GHz. MUSER is located at Mingantu, Inner Mongolia (42.71°N, 115.25°E, 1365 m). In the CMP Phase II, MUSER's frequency regime will be extended to 30–400 MHz with 224 Logarithm-Periodic Dipole Antennas (LPDAs)[3]. The array configuration for extending MUSER to a lower frequency range of 30–400 MHz with 100 LPDAs has been optimized to achieve minimum RMS deviation of antenna distributions in the axial direction and minimum RMS deviation of antenna distributions with respect to a Gaussian distribution in the radial direction.

The basement construction of MUSER was finished in 2021 and the facilities will be constructed in 2022. The technical acceptance will be carried out at the end of 2023 before use.

2.2.2 Interplanetary Scintillation Telescope

The Interplanetary Scintillation (IPS) telescope is one of the key monitoring equipment in the solar interplanetary monitoring chain subsystem of CMP Phase II, which is an important tool to monitor the propagation of solar eruptions in interplanetary space.

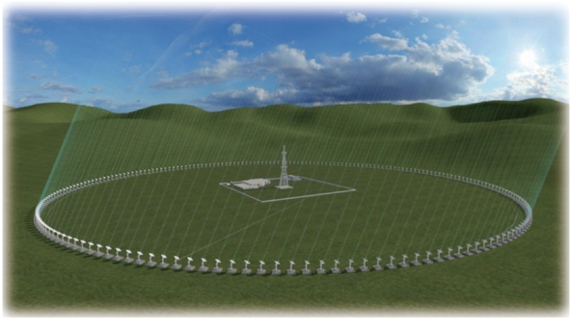

Fig. 2 Artistic concept of DSRT. 313 element antennas form a circular array of 1000 m in diameter. A 100 m tower locates right at the center and carries a transmitting antenna on the top for amplitude/phase calibration of the system

In the CMP Phase II, a three-station interplanetary scintillation telescope system will be built. The main station locates at Mingantu, Inner Mongolia (42.71°N, 115.25°E, with an altitude of 1365 m), where 3 cylinder antennas will place side by side, with 140 m long in the N-S direction and 40 m long in the E-W direction. Two 30 m dish antennas will be constructed at other two sub-stations respectively in Abaga County (44.73°N, 115.12°E, 1163 m) and Sunit Right County (43.50°N, 113.06°E, 1075 m) in Inner Mongolia[4].

The IPS basement construction was finished in 2021 and the facilities will be constructed in 2022.

These radio facilities of solar radio telescopes and interplanetary scintillation telescopes will be key tools for monitoring solar disturbances from the Sun to the Earth's environment and they will play a fundamental role in studying and monitoring space weather.

2.2.3 Sanya Incoherent Scatter Radar

The Incoherent Scatter Radar (ISR) is one of the most powerful ground-based instruments for detecting multiple plasma parameters of the ionosphere from 100 km to 1000 km. Sanya Incoherent Scatter Radar (SYISR) is a tristatic system located in Sanya, Hainan. It is one of the advanced large-scale monitoring equipment of CMP Phase II, which belongs to the south low latitude monitoring subsystem.

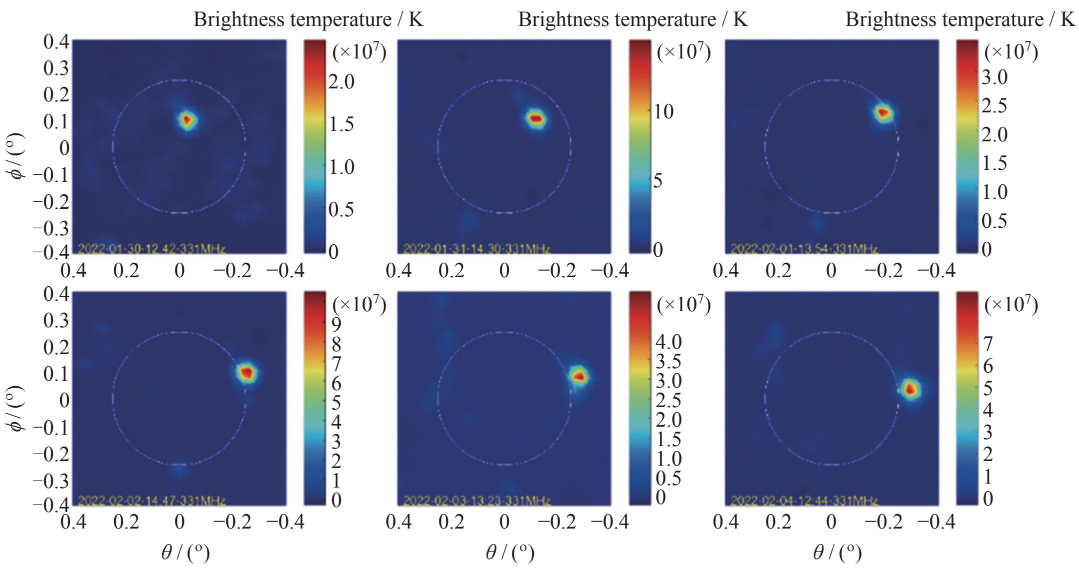

Fig. 3 Preliminary observation with 16-element only showing the high temperature spot rotating along with the rotation of the Sun in six days

Supported by the CMP Phase II, SYISR will extend the current Sanya transmitter/receiver from 4096 channels (located at Sanya, 18.3°N, 109.6°E)[5], which is supported by the National Natural Science Foundation of China, to 8320 channels. Simultaneously, two new 4096-channel receivers in Wenchang (19.6°N, 110.8°E) and Fuke (19.5°N, 109.1°E) will be built [6,7]. The sketch map is shown in Fig.4. The signal transmitted by Sanya station will be collected by all three stations after being scattered by the ionospheric plasma, which could be used to derive the plasma density, temperature, and velocity. Through the combination of three independent observations of the same scatter volume by three receivers, we can derive the vector information of the 3D velocity of plasma, which will be greatly beneficial to the investigation of low latitude ionospheric dynamics.

The whole system will be completed at the end of 2022 and is now under construction in full swing.

2.2.4 Middle Latitude Agile High-Frequency Radar Group

In the CMP Phase II, a Middle Latitude Agile High-frequency Radar Group (MiLARG) will be set up to continuously observe the distribution and movements of the ionospheric irregularities over the north of China. It is the core monitoring equipment in the north middle latitude monitoring subsystem. The MiLARG is composed of six (three pairs) High-Frequency (HF) radar sets deployed at Hejing (42.8°N, 83.7°E), Siziwang (41.8°N, 111.9°E) and Longjing (42.8°N, 129.4°E). The high-frequency radar sets are all digital phased array radar sets which can operate over a wide range from 8 to 20 MHz with a Field of View (FOV) of about 78°. At every radar site, two radar sets are designed to form a large FOV of about 156°. Moreover, the radar sets at neighboring sites will have common coverage to obtain the velocity of echoes. Therefore, the coverage of MiLARG can be up to about 120° (see Fig.5).

MiLARG is under construction. At present, the radar to the northwest at Siziwang station (SZW for short) has been completed and in trial operation. The first observation of ionosphere from SZW on 14 March 2022 is illustrated in Fig.6. Ionosphere echoes within about 2000 km were observed.

The construction of MiLARG is expected to be completed by the end of 2022. Joint commissioning and testing will be carried out in 2023.

2.2.5 MST Radar

The Mesosphere-Stratosphere-Troposphere radar (MST Radar) has proven to be a powerful tool for investigating various atmospheric dynamics in the lower and middle atmosphere and ionosphere. The MST radar works in the VHF band, observing the atmosphere under all weather conditions and at all times by detecting the echoes from the atmospheric refractive index variations induced by the fluctuations in humidity, temperature, electron density, *etc*. The MST radar can provide continuous high time-height resolutions and quasi-simultaneous observations of the horizontal wind and vertical ve-

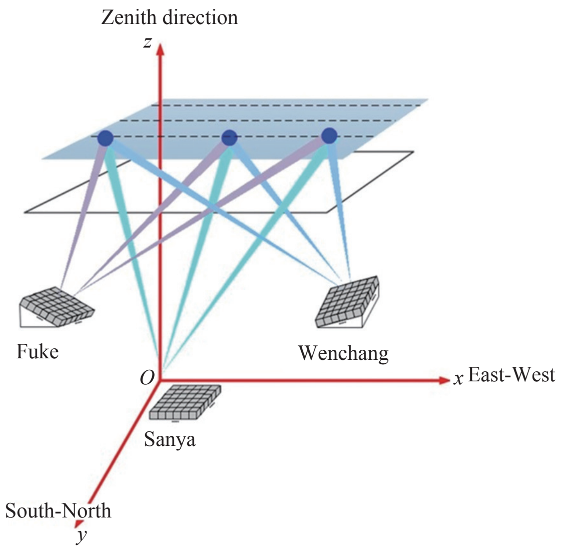

Fig. 4 A sketch map of Sanya Incoherent Scatter Radar (SYISR) tristatic system

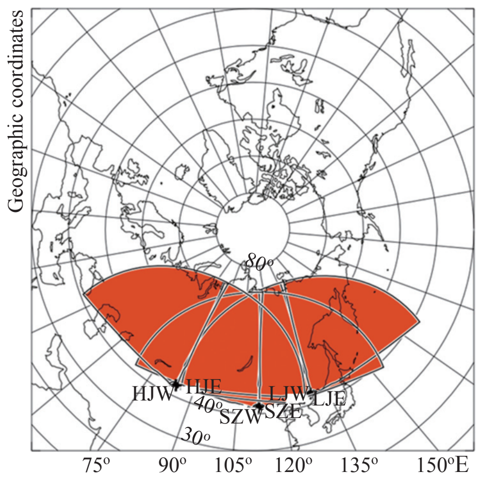

Fig. 5 Coverage of the Middle Latitude Agile Radar Group (MiLARG)

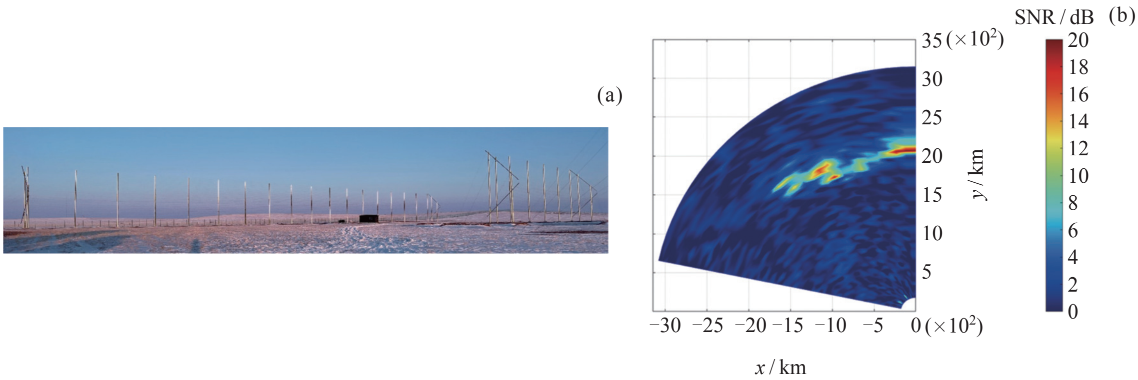

Fig. 6 SZW radar has been in trial operation. (a) Full view of SZW radar. (b) Echo from ionosphere

locities of different height range below 100 km except for about 25–60 km.

In the CMP Phase I, two MST radar sets have been built, that are Beijing MST Radar at Xianghe of Hebei province (39.78°N, 116.95°E) and Wuhan MST Radar at Chongyang of Hubei province (29.51°N, 114.13°E), respectively.

In the CMP Phase II, two new powerful MST radar sets will be established. One is Tibetan Plateau MST Radar at Yangbajing of Tibetan Plateau (30.08°N, 90.53°E; 4300 m). Another is Qinzhou MST radar at Qin zhou City in Guangxi Province (22.132°N, 108.272°E).

With advanced technology and under scientific design, the MST radar will be the first full digital full polarized active phased array radar to lead the development of MST radar sets. They have a circular array of 153 m in diameter, consisting of 931 3-element crossed Yagi antennas. The peak power is close to 2 MW.

The two new MST radar sets are under construction, to be finished by the end of 2022. Then joint commissioning and testing will be carried out in 2023. After that, they will enter into the observation stage.

The four MST radar sets of CMP, which are the Beijing MST radar, Wuhan MST radar, Qinzhou MST radar, and Tibetan Plateau MST radar, will play a unique role in broadening our knowledge of the turbulence, gravity waves, planetary waves, tides, mean circulation, interaction between different scales of dynamical and electrodynamical processes, and vertical coupling between layers from the boundary layer to the ionosphere.

2.2.6 Large-Aperture Helium Lidar

The Large-Aperture Helium Lidar (LAHL) supported by the CMP Phase II is designed to investigate the metastable Helium in the Earth's thermosphere, which has a significant population between 200–1000 km for the resonant remote sensing[8]. The Lidar will be located at Fuke (19.5°N, 109.1°E) in Hainan province. It is one of the key equipment in the south low latitude monitoring subsystem.

The key scientific goal of the LAHL is to explore the interaction between the neutral and ions, wave-induced transport and its influence on the constituent, as well as the geomagnetic effect on the neutral atmosphere within the thermospheric region using the metastable helium as the tracer.

The state-of-the-art instruments of LAHL, *e.g.*, the telescope array, modern high-power pulse laser, as well as high-efficiency and low-noise detectors, enable observations of the neutral metastable helium at an altitude of 1000 km with a vertical resolution of 50 km and time resolution of 30 min to 1 h.

The telescope array consists of an array of six one-meter diameter telescopes yielding a total collecting area of approximately 4.5 m^2. The array is designed so that each telescope can be pointed to the same atmospheric region. The back-scattered metastable helium fluorescence photons collected by each telescope, are combined together through a 0.7 m diameter telescope which is mounted at the center of the 6-telescope array (Fig.7). The primary mirrors of the telescopes are made of glass ceramics, and their RMS error of the surface accuracy is below $\lambda/40$ @ 632.8 nm after multilayer dielectric coating.

The modern high power pulse laser is generated by an OPO+OPA system, which is pumped by a high power 532 nm seeded Nd: YAG laser. The output 1083 nm

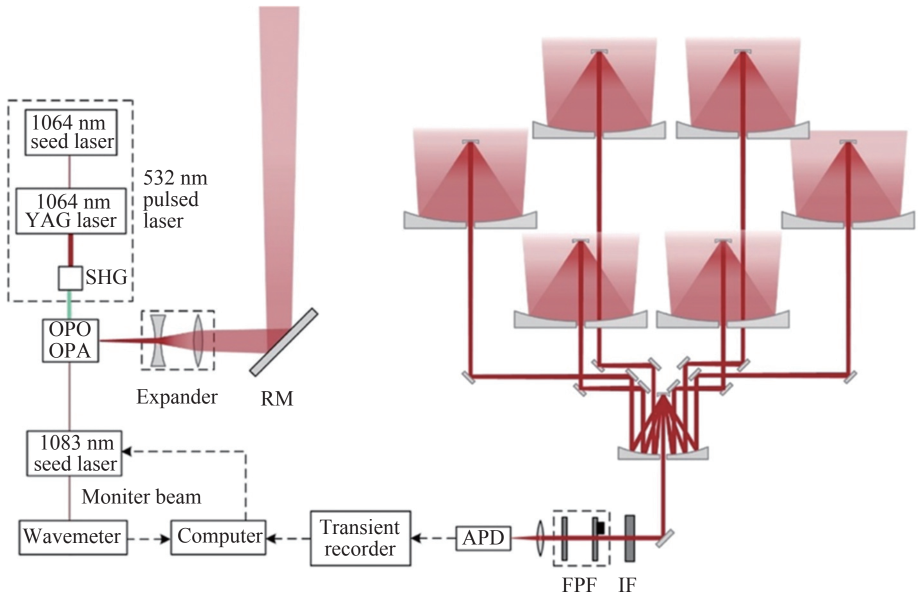

Fig. 7 Sketch map of the Large-Aperture Helium Lidar (LAHL)

laser is designed to have a linewidth of 200 MHz, a pulse power of 140 mJ, and a repetition rate of 50 Hz. Three such laser systems will finally be combined and achieve a total power of about 20 W@1083 nm.

At present, we have developed a demonstration system which can output 80 mJ pulses at 1083 nm with a linewidth smaller than 200 MHz. The measured center frequency accuracy of the laser is smaller than 20 MHz within 30 min.The equipment is planned to be tested, accepted and observed in 2023.

3 Prospect and Plan of Construction in the Next Two Years

At present, all the monitoring equipment of CMP Phase II are in the process of development and installation. By the middle of 2023, all equipment installation will be finished. Joint testing of the whole system will be started. The national acceptance of CMP Phase II is expected to be carried out by the end of 2023.

In addition, all monitoring equipment of CMP Phase I will be upgraded by the end of 2023 and incorporated into CMP Phase II to form a complete CMP monitoring system. In this regard, the CMP will complete all construction tasks.

After 2023, the CMP will enter the operation stage. We believe and expect that the CMP will produce outstanding scientific research results in the future.

References

[1] WANG C. New chains of space weather monitoring stations in China[J]. *Space Weather*, 2010, **8**(8): S08001

[2] WANG C, CHEN Z Q, XU J Y. Introduction to Chinese meridian project-phase II[J]. *Chin J Space Sci*, 2020, **40**(5): 131-135

[3] YAN Y H, CHEN Z J, WANG W, *et al.* Mingantu spectral radioheliograph for solar and space weather studies[J]. *Frontiers in Astronomy and Space Sciences*, 2021, **8**: 584043

[4] YAN Y H, WANG W, CHEN L J, *et al.* New interplanetary scintillation array in China for space weather[J]. *Sun and Geosphere*, 2018, **13**(2): 153-155

[5] YUE X A, WAN W X, XIAO H, *et al.* Preliminary experimental results by the prototype of Sanya Incoherent Scatter Radar[J]. *Earth and Planetary Physics*, 2020, **4**(6): 579-587

[6] LI M Y, YUE X A, ZHAO B Q, *et al.* Simulation of the signal-to-noise ratio of Sanya incoherent scatter Radar Tristatic System[J]. *IEEE Transactions on Geoscience and Remote Sensing*, 2021, **59**(4): 2982-2993

[7] ZHANG N, LI M Y, ZHAO B Q, *et al.* A detection performance analysis of Sanya incoherent scatter Radar Tristatic System[J]. *Radio Science*, 2021, **56**(5): e2020RS007144

[8] GERRARD A J, KANE T J, MEISEL D D, *et al.* Investigation of a resonance Lidar for measurement of thermospheric metastable helium[J]. *Journal of Atmospheric and Solar-Terrestrial Physics*, 1997, **59**(16): 2023-2035