THE PROGRESS OF SOLAR-TERRESTRIAL SCIENCES IN CHINA

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I. SOLAR-TERRESTRIAL SCIENCES

The solar-terrestrial sciences study how the solar energy, momentum and mass transfer through the interplanetary space, the earth magnetosphere, the ionosphere and the neutral atmosphere, and their influence on earth environment. The solar-terrestrial sciences are also called, sometimes, the solar-terrestrial physics, solar-terrestrial relations, solar-terrestrial research, etc. The solar-terrestrial sciences involve solar physics, interplanetary physics, magnetospheric physics, ionospheric physics, thermospheric and atmospheric physics and chemistry, and the related field of earth sciences. However, more emphases will be laid on the correlations between different regions of the solar-terrestrial system, and the cause and effect connection of the related processes. Based on the limitation of the present exploration level, the coupling processes of two linked regions are much concerned.

The primary records of sunspots were given in the Shang Dynasty in about 1500 B. C. Vast sunspot records in Chinese historical publications provide valuable data for the research on the solar-terrestrial relations. The solar-terrestrial sciences become an important part of the natural science since the 17th century when the telescopes were used to observe the solar processes, and substantial results obtained by the space observations and measurements since the 1960s have made the solar-terrestrial sciences stand in the front of modern sciences. The space explorations have opened a new step of whole wavelength, high resolution and synthetic observations; a lot of important phenomena have been discovered such as the high energy processes of solar flare, solar corona hole, the corona transient, the interplanetary sector structures, the collisionless shock wave, the kilometer radiation in earth magnetosphere, the distribution of ionized oxygen in magnetosphere, the irregularities in ionosphere of lower latitude, the reconnection of magnetic fields. It is recognized more and more deeply that, several critical regions should be monitored at the same time to obtain the spatial and temporal variations of the pattern for exploration of the coupling processes in the solar terrestrial system. Of course, space explorations also have some limitations, and the research of solar-terrestrial sciences depends on the measurements of multi-approach, such as the facilities on the ground, the balloon, sounding rocket and, in addition, the satellite.

The solar-terrestrial sciences may have great progress in the 1990s, which is marked mainly by the performance of several international cooperation programs. In the solar maximum period, there are Japanese satellite solar A and long duration balloon flight program of the United States; they, together with the magnetograph, optical and radio telescopes, could discover the details of solar flare processes. The International Solar-Terrestrial Physics Program will launch several spacecrafts equipped with advanced instruments in the critical orbits to explore coordinately the coupling relations between different regions of solar-terrestrial system. Undoubtedly the program will greatly promote the developments of solar-terrestrial sciences. The related committee of the International Science Union suggests the Solar-Terrestrial Energy Program (STEP) from 1990 to 1995 or even later for promotion of the international collaborated research under the background. In addition, many programs for special regions such as the Middle Atmosphere Program, Worldwide Ionosphere-Thermosphere Study, Solar Connection with Transient Interplanetary Processes, Flare Research at the Maximum of Solar Cycle 22 must also promote the development of solar-terrestrial sciences.

II. Major Progress of Solar-Terrestrial Sciences in China

Many Chinese scientists have devoted themselves to the fields of cosmic rays, solar physics and atmospheric physics since the 1940s. The systematic research on the solar-terrestrial sciences in China has been carried out in the last 30 years. Professor Zhao Jiuzhang made great efforts in both scientific research and organizations in the early 1960s, and a lot of work has been completed by the scientists of related fields such as Professors B. Chen, B. W. Lu, B. X. Liang and G. K. Zhu to promote solar-terrestrial sciences in China. A lot of middle-aged Chinese scientists are working actively at the front and have made much progress in solar-terrestrial research at the present time[1—5].

As the energy and disturbance sources, the sun plays the nuclear role in the solar-terrestrial system. China has better basis for the research of solar physics, the convention facilities on the ground are relatively complete in four astronomical observatories, and are operated well. Recently, the magnetic field telescope, which was designed by the team headed by G. X. Ai in the Beijing Observatory, could give magnetic field and flow field in two levels at photosphere and chromosphere respectively and its properties are on the international advanced level[6]. In addition, there are also some results of space measurements[7]. Chinese scientists have completed a lot of theoretical researches on solar physics, mainly on the solar flare (see, for example, Ref. [1]), which involves the pressing or shearing process for the energy storage mechanism and the solar atmospheric motion induced by the solar flare and others[8]. Many papers studied the solar magnetic field configurations, in particular, the cancellation process of small scale magnetic field[9], the model of isolated magnetic flux tube[10] and the three-dimensional magnetic field research[11]. The progress on some subjects of solar physics in China has forced our way in the international advanced rank, but there are still many weak fields such as the high energy process of solar flare, the helioseismology, the plasma dynamics.

The main materials in the interplanetary space are solar wind plasma and interplanetary magnetic field. C. Y. Tu explained successfully the important problem of solar wind energy by the wave energy cascade theory of Alfven fluctuations in solar wind, which agrees well with the observation data at solar corona and the earth orbit[12]. X. P. Chao optimally fit the observed solar wind data projected in solar disk by using the heliospheric coordinates[13]. Y. Q. Hu et al. developed multi-step numerical method of concealed meshes, and applied it successfully to unsteady MHD processes with large range of parameters, especially the numerical simulation of solar and interplanetary disturbance propagations[14]. F. S. Wei studied the propagation of solar flare shock wave in the interplanetary space[15]. Moreover, it seems that the speed of the solar wind may be accelerated in far field even if the energy and momentum are added in the subsonic region[16]. The three-dimensional structure of heliospheric magnetic field is a concerned problem; the analytical solutions given by W. R. Hu could describe qualitatively many observed features[17]. G. L. Zhang discussed the modulations of cosmic ray in the interplanetary space which is also an important subject of interplanetary physics[18], and recently he analyzed the features of magnetic cloud[19]. Being short of interplanetary exploration abilities in China at the present time the research work are limited to the theoretical analyses.

The space physical research in China started from the front subjects of magnetospheric physics, such as the mechanism of magnetospheric storm and substorm. The technical developments of space detections are emphasized in the last 30 years. The scientific experimental satellites Practice I and Practice II were launched, respectively in 1971 and 1981, and the scientific payload test had been carried in some other Chinese satellites several times. A lot of space instruments such as the solar soft X-ray spectroscope, UV radiation receiver, infrared radiometer receiver, scintillation gauge, magnetometers, particle components detector, and the scientific data have been obtained as the basis of further developments of solar-terrestrial physics, particularly the processes in near earth space. There are active workers doing magnetospheric research in China. Z. F. Fu et al. suggested the theory of multi-reconnection of X configuration, which is an advanced approach for research of coupling processes and also a breakthrough from the traditional idea of stationary reconnection and is applied to explaining the transfer of flux event[20, 21]. Z. X. Liu proposed the reconnection theory induced by vortex, which is applied to explaining the process at the magnetopause of high latitude[22]. R. L. Xu completed systematic calculation on the particle motion and accelaration in the neutral sheet of magnetotail[23]. Moreover, the research work involves also the tangential velocity instability at magnetopause in association with the plasma process in the magnetosphere[24], the instability of current sheet with flows[25] etc. (see, for example, [4]).

The research on the ionospheric physics in China started in the 1940s; there are ten ionospheric stations equipped with ionosonde, polarization receiving, ionospheric absorption equipment, Doppler interference equipment, digital vertical sounding and so on. Backward scattering radar of short wavelength is a giant facility on the ground and has been operated successfully in the China Institute of Radio Wave Propagation[26]. The Chinese Academy of

Sciences founded the sounding rocket site in Hainan Island, and it has the ability to explore the ionosphere under 120 km in height. Excellent results of ionospheric physics have been obtained by triangle array of Doppler shifts in the Wuhan Institute of Physics. The networks of ionospheric stations in China have been arranged in suitable scale. In addition, the data of geomagnetic micropulsations and whistler have been accumulated in the last ten years, and the whistler was successfully received in lower latitude region recently[27]. The Chinese scientists of elder generation, Professors B. X. Liang and Z. T. Gui made important contributions to the discovery of symmetrical distributions of equatorial abnormality in the geomagnetic latitude[28]. J. Li demonstrated the reverse principle of ionospheric motion profiles, which is important both in scientific meaning and in applications[29], P. R. Chen explained the two-day oscillation phenomena in the ionosphere with the planetary wave theory[30], and many research works on the ionospheric physics have attracted attention of the international colleagues[31]. On the other hand, more attention has been paid to the coupling processes in the solar-terrestrial sciences. According to the foreign satellite data, the current pattern in higher latitude and polar region and the position of plasmaspheric pause have been studied systematically by M. X. Zi[32], the global electric current systems are analyzed and demonstrated by W. Y. Xu[33], and Z. Xiao proved that the variations of lower ionosphere are associated with the temperature increment in the stratosphere[34].

The thermospheric physics is a relatively weak field in China. The late Z. M. Chen solved the dynamic equations of thermospheric atmosphere, and discussed systematically the response in the thermospheric atmosphere to the heating source, thus a relatively complete system is formed[35].

The facility of Dobson observation system was founded after the International Geophysical Year. According to the systematic studies on the relations between ozone content variation in long term and the atmospheric circles, the oscillations of two-year periodicity QBO are related to the solar activities[36]. The relation between the solar cycles of longer periodicity and the periodicity of 11 years has also been found through analyses of reversed historical weather obtained from the historical references[37]. From the viewpoint of solar-terrestrial global character, people are very much concerned in the influence of solar variations, near earth environment variations, and even the volcanic eruption, structure variation, weather and biosphere on the middle atmosphere, and also in the mechanism of the influence of solar variations on the region in the neighbourhood of the earth. The latter problem has been discussed actively in China, and several workshops were held. However, the mechanism of the work should be studied further.

The periodicity of solar activities is a fundamental phenomenon for the research of global character in solar-terrestrial system. The regularity of the periodicity itself should be studied on the one hand, and the response of solar cycle on the other regions of solar-terrestrial system, particularly, the earth system should be analyzed on the other hand. Z. T. Xu and M. T. Jiang proved the existence of solar activity even in the Maunder Minimum period, which is extensively interesting[39]. Many papers have been published on this subject in

China, there is either agreement or disagreement. B. R. Lo and Y. J. Ding demonstrated statistically the periodicities of 11 years and longer of solar activities from the Chinese historical references[40]. The studies of periodicity in China are the results with features.

III. Global Character Research of Solar-Terrestrial System in Solar Maximum Period

The coherent observations in the solar maximum period of the 21st solar cycle were processed by the solar physicists in China. The project on the global character of solar-terrestrial research in the 22nd solar cycle has been organized by the Chinese Academy of Sciences (CAS) since 1987, and several hundreds of scientists in more than a dozen institutes and observatories of CAS covering the fields of solar physics, space physics and geo-sciences are involved in the project. Meanwhile, many other institutes and universities also join in the activities of the project.

To study the global character of the solar-terrestrial system, the project coordinates the coherent observations and measurements of the instruments and facilities in the field of solar-, space- and geo-sciences according to the typical events of solar activities for the exploration of the cause-and-effect relations between so many phenomena. The command post was set in the Yunnan Observatory for coordination and conduction of the coherent observations and measurements based on the prediction and monitoring of the solar flare. More than 50 pieces of instruments and facilities, including a dozen or more heart and important facilities, such as the solar magnetograph, solar spectroscope with multichannel wavelength, solar radio telescopes, vertical sounding of ionosphere, monitor of ionospheric electron total content, geo-magnetometers, Dobson spectroscope, direct monitor of atmospheric component by balloon flight and the others, have been operated during the coherent actions. The purpose of the coherent observations and measurements is to further explore the solar flare and its influence on the solar-terrestrial system, especially the geophysical effects. The actions promote also the research on the predictions of solar flare and the earth magnetospheric substorm, the rapid fluctuations of solar radio burst, the environment in near earth space, and the atmospheric dynamics in middle and upper atmosphere. Twelve coherent actions including the observation together with the observatories in the United States and Japan have been respectively organized since 1988. The instruments and facilities in the different institutions have been used coordinately, and many good data are obtained which are helpful for further analyses and studies[41].

In the meantime, the project emphasizes the analyses and theoretical research based on the data of coherent observations and measurements. Several major subjects of global character behavior in the solar-terrestrial system are stressed in the primary period according to the abilities of facilities and the features of geography in China. Many processes of solar physics such as the large-scale solar magnetic structure, the interaction of solar plasma and strong magnetic field, the solar flare mechanism could be studied by using the data of magnetograph of Beijing Observatory and the multiwavelength solar spectroscope and other telescopes of Yunnan

Observatory[42]. The idea of ionospheric abnormality in the far eastern region was suggested by a British scientist since the 1950s. The ionosphere over China has distinguishing features such as the existence of more and stronger Es with the configurations which appear often in the equator and polar regions, the phenomena of strong F spread. It is important not only for the promotion of the research on ionospheric physics, but also for the monitoring of the near earth environment in China by analyses of the ionospheric features over China and studies of the mechanism on how the features are formed[43, 44]. The chain of geomagnetic field is an effective method to study the global electrical current systems. Most present chains of geomagnetic fields are there in the regions of America and Europe. The research of electric current distributions and their variations in the earth magnetosphere will be greatly benefited by establishing China's chain of geomagnetic field extending from north to sourth in the middle and lower latitudes, and the electrical currents in the magnetosphere and ionosphere could be obtained separately by the reverse demonstrations[45]. According to the project the China's chain of geomagnetic field has been recently disposed, and the related analyses and research work have been made. The variation of minor gaseous components in the atmosphere is important subjects of global change of the earth environment and of coupling processes of solar-terrestrial system too. The data of minor component, such as ozone, could be measured directly by the balloon flight or monitored by the ground facilities. The project will accumulate the data of this subject and study the influence of solar activities and variations on the content of atmospheric minor components[46].

The polar dynamic processes are significant for the studies of coupling between the magnetosphere and ionosphere, and also the middle and upper atmosphere. The limitation of the continent of China located in middle and lower latitude is remedied by the China's Zhongshan Station in the Antarctic pole region, whose main purpose is to do research on the solar-terrestrial sciences. This arrangement not only extends the present network of observations and measurements, but also is helpful to the research of the global coupling processes.

Because of the limited ability of space exploration in China at present time, the measurement bases of probing the interplanetary space and the magnetospheric space are relatively weak. The Chinese scientists have performed some beneficial researches on the interplanetary physics and magnetospheric physics, mostly the theoretical research on the physical processes or the data analyses based on the space measurements of foreign satellites. The interplanetary and magnetospheric processes are the links, which cannot be neglected in the global character research of the solar-terrestrial system.

There are frequently strong solar activities, especially the high energy events such as the solar proton flare in the period of solar maximum; it provides excellent opportunities to study the cause-and-effect relations of the coupling processes in the solar-terrestrial system. As it is generally expected, the maximum of the 22nd solar cycle will appear in the spring of 1990 and it is one year earlier than that the people expected a few years ago. The research project of CAS will promote the research both in maximum and on the solar-terrestrial sciences, and should be a part of the international research program. The solar-terrestrial

sciences will be progressed by the efforts of the scientists all over the world.

IV. The Applied Research of Solar-Terrestrial System

The variation of earth environment has direct influences on the military and civil businesses such as the aerospace, communication, mine exploration, earthquake, and in turn, the earth system has close relations with the environment of the existence and evolution of mankind. Therefore, the solar-terrestrial processes not only form the front field of fundamental research, but also have the great significance in applications.

The monitoring and prediction of solar-terrestrial environment are needed by many ministries and civil institutions. The prediction of solar activity and solar flare have been proceeded by the Beijing Observatory, the Purple Mountain Observatory and Yunnan Observatory since the 1960s. The prediction releases of short, middle and long term solar activities by the Beijing Observatory and Yunnan Observatory not only satisfy the routine requirements, but also become an important part of the monitoring and prediction network in China[47, 48]. The China Research Institute of Radiowave Propagation is the major and representative institution in collecting ionospheric data and predicting the ionospheric disturbances in China, and much effort has been made on the business of communication and ionospheric monitoring[49]. Many ionospheric disturbances are reflections of the geophysical effect induced by the solar flare, and there are good correlations between these two phenomena[50]. The predictions of medium term geomagnetic disturbances made by the Institute of Geophysics, CAS since the late of 1970s are helpful to the businesses of aerospace, communications, mine explorations, and earthquake etc.[51] According to the development of national economy and the increment of space activities, the requirements for the monitoring in real time and the predictions of the solar-terrestrial environment, particularly the near earth one, are more and more urgent, and it could be performed by combining the network on the ground and the measurements on board of the spacecrafts.

The satellite communications play more and more important roles in the information transfers. The small scale structure in ionosphere, especially the irregularities in the equator and lower latitude region, will scatter the electromagnetic waves propagating between the satellite and ground, and the quality of the communication is influenced by the distortion of the waves. The ionospheric bubble and the associated VHF scintillations were measured in the Guangzhong region[52]. The reflection of the radiowave by ionosphere is still widely used in many fields of communication. The increment of ionization by the aurora and substorm changes the conditions of ionosphere thus decaying the signals of middle and high frequencies, or it may change the phase of low and very low frequency waves. More serious event is that, the high frequency communication will be worsened or even interrupted for a few days in the higher latitude by the enhanced ionization due to the polar cap absorption event induced by the solar proton event. The ionospheric physics is the bases for understanding the ionosphere structures, predicting the ionospheric disturbances, adopting the frequency and improving the quality of communications. In addition, the disturbances in ionosphere such

as typhoon, aerolite fall, explosion of atom bomb, and even large amount of energy released by the launch of rocket and mission may excit waves, and significant social and military benefits could be obtained by monitoring and analysing the disturbance source from the signals of wave propagations[53].

The influences of solar activities on the earth's climate and weather are the problem concerning the people all over the world. Large solar flare may induce the variation of atmospheric circulation in the middle and high latitudes, and give a delay effect. Z. H. Ye pointed out that the maximum disturbance is delayed three days after the appearance of solar flare through analysing the influence of solar flare on the area index of atmospheric vortex in the period 1966—1978[54]. Many researches show that there are correllations between the solar flare and the thunderstorm activities[55, 56]. More research works concern the correlations between solar periodicity of solar activities and the variation of climate and weather. S. W. Wang studied statistically how the solar periodicity correlated with the average precipitation in China in the last 500 years[57], and with the average temperatures in large range of China since 1913 (see page 575 of [1]). The statistical results show that there do exist some correlations between the solar periodicity and the climate of China. Q. Liu showed that, there are high correlations between the data series of monthly mean sunspot numbers and the monthly area indexs of subtropical marine highs at 500 hPa in the northern hemisphere in the last 28 years[58]. The relationship between the solar variation and the earth's climate and weather is a problem with attractions and also with great arguments of different ideas. Further studies are needed, such as the monitoring of solar radiation in longer period especially in the relations between the solar variation and the climate and weather, the coupling problem of mesosphere in response to the processes of upper and lower layers should be emphasized[59]. The mechanism will be studied based on these researches. H. C. Zhong emphasized recently a possible mechanism on the coupling solar activities and the electric process of thunderstorm[60]. The relations between the solar variation and the calamity events such as the thunderstorm rain, the inundation, the earthquake attract many people's attention in China. However, as a scientific subject further study is needed.

The interaction of solar variation with the geosphere and biosphere is also a significant subject with great social implication in the solar-terrestrial system, and the associated research works are in progress in China.

By accumulation and efforts made in the last several decades, great progress has been made in the fields associated with the solar-terrestrial sciences some research results concerning the coupling processes of related fields have been got. As the emphasized subject of the national fundamental research program, the solar-terrestrial research in China will be continued successfully.

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