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MEMOIRS

Sixty-Year Career in Solar Physics

C. Fang[1,2]

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Abstract This memoir reviews my academic career in solar physics for 60 years, including my research on non-LTE modeling, white-light flares, and small-scale solar activities. Through this narrative, the reader can catch a glimpse of the development of solar physics research in mainland China from scratch. In the end, some prospects for future development are given.

1. Introduction

My first touch with solar physics was to participate in the construction of the first Chinese coronagraph in 1958. Since then, I have spent 60 years on solar observations and research.

In most of the time of the 20th century, Chinese astronomy lagged far behind the world, despite a brilliant history in ancient times. The infrastructure of the Chinese astronomy was very weak 60 years ago, and the then-largest telescope was one with an aperture of 60 cm which was bought by Purple Mountain Observatory from Germany in 1924. The same is true for solar observations and research. There were only several small telescopes (with apertures between 10 and 20 centimeters), which were also bought from abroad and only used for making sunspot drawings by hand. Over the past 60 years, we have not only built a number of solar instruments, but also established a research community with more than 300 members all across mainland China. The number of solar physics papers published each year by Chinese researchers has risen to top three in the world. We have also established extensive and close collaborations with many foreign solar physics communities (Fang, 2011, 2015). I am proud of witnessing the development of solar physics in China, and making my own contribution to this process. However, I am deeply aware that there is still a big gap between the solar physics research in China and that in the leading countries. We still have a long way

✉ C. Fang
fangc@nju.edu.cn

1 School of Astronomy and Space Science, Nanjing University, Nanjing 210023, China

2 Key Laboratory for Modern Astronomy and Astrophysics, Nanjing University, Ministry of Education, Nanjing 210023, China

Figure 1 At the IAU executive committee meeting in 2004, with Oddbjorn Engvold, Silvia Torres-Peimbert, Karel A. von der Hucht, Franco Pacini, Hans Rickman, Catherine Cesarsky, Robert E. Williams, Brian Warner, myself, Ronald D. Ekers, Beatriz Barbuy, and Monique Leger-Orine.

to go! I have a lot of mixed emotions when looking back on this period of history, as well as on my personal experience of growing up and working hard in the field of solar physics.

I was enrolled in the Mathematics & Astronomy Department of Nanjing University in 1955, graduated in 1959, and then was promoted to professor in 1986. During the past 60 years, I was first in charge of the design and the construction of the solar tower telescope of Nanjing University. The telescope was completed in 1980. It was the only one of its kind in China and has been successfully operating for several decades. I was also responsible for the construction of the multi-wavelength solar telescope, called *Optical and Near-infrared Solar Eruption Tracer* (ONSET), which was put into operation in 2012. Meanwhile, I carried out a wide range of research in solar physics. I have trained 15 graduate students with Ph.D. or master's degrees. Even now I am still working hard, hoping to make more contributions to the development of astronomy.

From 1980 to 1982 I stayed in the solar physics group at Paris Observatory as a visiting scientist. Later on, I successively served as the director of the Department of Astronomy of Nanjing University, the president of the Chinese Astronomical Society, and the vice-president of the International Astronomical Union (IAU) (Figure 1). I was elected an academician of the Chinese Academy of Sciences in 1995, and elected a fellow of the Third World Academy of Sciences (TWAS) in 2005. I have won several national and ministerial major awards for scientific research achievements, and received the title of "Docteur Honoris Causa of Paris Observatory" in 2008.

In this memoir I will try to review my academic career of 60 years in solar physics, inquire into the path of the rapid development of solar physics in China, and look forward to the future. In my heart I always have a dream and firm faith to make China's solar physics more brilliant and make more contributions to the development of solar physics in the world!

2. Taking the Road of Studying Solar Physics

2.1. Study in Primary and Secondary Schools

The "Marco Polo Bridge Incident" in 1937 July marked the start of the Chinese people's war of resistance against Japan. As the war continued to spread, my father decided to flee from Shanghai with the whole family. The family finally arrived in Kunming, the provincial

Figure 2 My classmate group in high school in 1954. The second from right in the second row is me.

city of Yunnan Province in western China. Just a few months later, in 1938 August, a baby was born: that was me.

During my childhood, I often played near the Dian Lake. Sometimes I sat by the lake, looking at the vast sky while meditating: "What are there on the stars in the sky? How wonderful if I could fly to the stars! What is beyond the sky?"

After eight years, the anti-Japanese war finally ended in 1945. Another three years later, in 1948, my family moved back to Shanghai. This big city was completely strange to me. On my first day in a local primary school, the teacher asked me to give a self-introduction to the class before the podium. Then I said with the strong Kunming accent: "Hello everyone, I am Fang Cheng, from Kunming, Yunnan Province". Everyone burst into laugh, since the baldheaded guy on the podium looked like a rustic. Seeing my blushing face, the teacher said: "You can sit there." His hand pointed to a bench in the corner of the classroom, where a beautiful girl was seated. The girl was also a student transferred from another school. I did not expect that the girl named Shou Jiqing would become my wife in the future, and we would spend our whole life together.

One-year's time flew swiftly. I graduated from the primary school and entered the No. 1 High School affiliated to East China Normal University, which was not far from my home. It was a famous high school in Shanghai. The school attached great importance to education quality. It had strong faculty and facilities, including formal laboratories of physics, chemistry and biology, a library with huge collections, and even a swimming pool and a small botanical garden. The teachers' serious and rigorous attitude in teaching had a profound impact on me, and I benefited a lot from it (Figure 2).

The school paid much attention to the quality cultivation of students, inspiring and mobilizing the students' initiative in their studies. Our teachers encouraged and helped the students to organize various extra-curricular groups. I joined the drama, photography and biology groups in the school. I also served as a class leader, undertaking many social issues. These experiences undoubtedly had a positive influence on my future life. With time flying, the high school life of six years was like a fleeting show, and the moment quickly arived for me to choose a university to go to.

I had been longing to become an aircraft designer, driving the aircraft designed by our country and flying through the blue sky and white clouds. So I was eager to apply for aviation colleges. However, at that time students needed special recommendation for the admission to aviation colleges and must pass a political checkup. However, it was totally unexpected that I could not pass it. The reason was that my father was being censored, although it turned out that my father did not have any political problem.

At this critical moment, my head teacher, Mr. Xu, told me: "Your physics and math scores are very high, so you are suitable for learning astronomy". He suggested, "Now only Nanjing University has Mathematics & Astronomy Department in China. If you apply for this major, there must be no problem with your scores."

At that time I knew nothing about astronomy and guessed what I would really do with my physics knowledge obtained in high school. Mr. Xu's words were undoubtedly a beacon to guide me. In this way I accidentally applied for Mathematics & Astronomy Department of Nanjing University and was successfully admitted to become one of the 24 new students majoring in astronomy in 1955.

2.2. Study at Nanjing University

I came to Nanjing in the fall of 1955 for the first time. Nanjing University is a renowned university of higher education, which originated from Sanjiang Normal College established in 1902 May. After being adjusted and renamed several times, it was known as "National Central University" until 1949. Its grand scale, complete disciplines and strong faculty and facilities made it the best among all the universities in China at that time. The university has been renamed "Nanjing University" since 1950 October. In 1955, two closely related departments, Astronomy Department and Mathematics Department in the university merged into a single one, Mathematics & Astronomy Department.

China had a long history in Astronomy in ancient times. Astronomy, together with agriculture, medicine and mathematics, constituted the four most developed natural sciences. A complete system centering on calendar and astronomical observations was formed in Qin and Han Dynasties. A chapter, Minor Odes, in the ancient "Book of Poetry" recorded a total solar eclipse on 776 BC September 6. The record of sunspots in March of 28 BC was the earliest record in the world. Chinese astronomy developed to its peak in Song Dynasty. A supernova, *i.e.*, the later Crab Nebula, was observed and recorded in the first year of Renzong Emperor of Song Dynasty (in AD 1054). The positions of many stars were accurately measured in Yuanfeng period of Song Dynasty (from AD 1078 to 1085), during which the Suzhou Stone Carving Astronomical Map was made. Mr. Shen Kuo, a famous scientist in Song Dynasty, improved the Armillary Sphere. These great achievements demonstrated that Chinese astronomy in ancient times had led the world for a long time.

The publication of Copernicus' book "De Revolutionibus Orbium Coelestium" in 1543 marked the beginning of modern astronomy. At the same time, however, a complete system of scientific research and education had not been formed in China and some long-existing shortcomings slowed down the development of astronomy. In the past centuries, China suffered from frequent wars with severe loss in economy and science. After the Eight-Power Allied Forces invaded Beijing in 1900, the French and German armed forces completely removed the instruments of the Imperial Observatory of Qing Dynasty. Some observatories and instruments constructed later were mostly destroyed in the following wars.

When the People's Republic of China was founded in 1949, astronomy in China was really a desert. The only decent instrument was the 60 cm reflecting telescope which was bought by the Purple Mountain Observatory from abroad in 1924 and repaired in 1954. For comparison, the United States already built the world's largest reflecting telescope with a diameter of 508 cm in 1948. Such a huge contrast between China's roles in ancient and modern times as well as that between the advanced and the backward deeply shocked me. One day I saw a banner on the campus, which read: "Be determined to become the pioneers of astronomy for the motherland!" It touched my heart. I deeply felt the heavy load on my shoulders to re-build China's astronomy by our generations.

Figure 3 Testing the "rustic" coronagraph at 3900-meter-high Qilian Mountain in 1958.

At that time the astronomy major did not have its own teaching staff. We learned mathematics with the mathematics major and learned physics at the Physics Department. Together with the basic courses of astronomy itself, students in our department had the highest pressure in taking different kinds of courses. At that time we had classes for six days a week, and we had self-study in the evening. The students in my class worked very hard, and most of us even did not have a rest on Sunday. At the end of the first term, the average score of my class was ranked No. 1 in the university!

With more and more knowledge being accumulated, my interest in astronomy was also increasing; I was more and more attracted by and even obsessed with the vast and profound universe, and my determination of devoting myself to astronomical research was also further strengthened.

2.3. Astronomical Practice

Many students in our Astronomy Department had already obtained sufficient knowledge of astronomy before coming to university. One of my classmates, Mr. Su Dingqiang (who later became an academician of the Chinese Academy of Sciences), was very knowledgeable. He ground and polished a lens with a diameter of six inches, with which clear pictures of the Moon could be taken. We often went out and looked at stars at night, doing astronomical public outreach in some primary and secondary schools in Shanghai and Nanjing during our holidays.

During the "Great Leap Forward" era in 1958, our Astronomy Department organized students to build an astronomical optical instrument factory as a work–study program. I was elected the factory director. Students designed and artificially ground many lenses. We not only made the first Masksutov telescope in China but also manufactured batches of 10 cm telescopes for the popularization of astronomy.

When we were senior students, Mr. Su Dingqiang and other students designed and manufactured a simple coronagraph. Before that time, China did not have a coronagraph. We ground and polished mirrors and manufactured such a "rustic" coronagraph based on very limited literature and knowledge we had learned. Then I participated in the seven-member group organized by our Astronomy Department and went to test the coronagraph at the 3900-meter-high Qilian Mountain in Gansu Province (Figure 3). After several days of hard work, we finally installed the telescope, and successfully observed some prominences above the solar limb. The telescope was unable to observe the corona due to its simplicity in structure and the seeing conditions. However, this was my first exposure to solar physics equipment which gave me, a "young bull", an excellent exercise.

After graduation, I stayed in the university as a teaching assistant. One year later, the Astronomy major was promoted as an independent department, Department of Astronomy, and I became its faculty member.

3. Construction of the Solar Tower

3.1. Start-up

In 1958, the most famous newspaper in China, People's Daily, published an editorial "Go all out to the top" and proposed a comprehensive leap forward in the national economy. With such a background the Department of Astronomy in Nanjing University proposed to construct a solar tower telescope (hereinafter referred to as "solar tower")! Professor Dai Wensai, a former director of the Department, was very supportive of this proposal. He got his Ph.D. in the UK, supervised by Sir A. Eddington. Seeing the barren situation of astronomy in China, he was clearly aware that the solar tower was very important for Chinese astronomy and China could not be left behind any more!

The Mount Wilson Observatory in the US built the world's first solar tower as early as 1908, which had achieved good observational results. Since then, many countries built solar towers. However, China's industrial level in 1952 was lower than those of the UK in 1800 and France in 1890, and the average living standard was only equivalent to that of the UK in the late 18th century. In such a tough time, many people even did not know what the solar tower looks like, and of course they did not believe that the project can be completed. At that time we did not have opportunities of academic exchanges with foreign experts. It is easy to imagine how difficult it was to build a solar tower in China at that time!

In 1957, the Ministry of Education of China hired Professor Sidnik, a solar physicist in Moscow University of the former Soviet Union, to work in our department. After Professor Sidnik came, he made some simple drawings to explain the approximate structure of the solar tower and workflow for the project. Our department arranged several teachers and students to participate in the project. I was just a senior student at that time, but I was selected to participate in the project (Figure 4). With the help of Professor Sidnik, after countless computations and modifications with a hand computer, a preliminary design was finally finished.

3.2. Downs and Ups

However, owing to some political reason, the former Soviet Union withdrew all the experts from China on 1960 June 16. Professor Sidnik also returned back to his country. The solar tower project was suspended and everybody felt disappointed.

As a Chinese idiom says, joys come never more than once but sorrows never come singly. Between 1959 and 1961, China experienced the period of "three years of economic difficulties" with domestic food shortages. The solar tower project had to be suspended for a prolonged period. The difficult period ended in 1963 and people finally thought of the solar tower again. However, it seemed that the solar tower project could hardly be completed in any foreseeable future. Many of my colleagues also advised me not to carry out this project any more and some of them even thought that this project could not be accomplished at

Figure 4 Discussing the solar tower design in 1958. The standing guy on the right is me.

all. Being faced with the suspicion from many people, several colleagues and I insisted on restarting the solar tower project. One year later, the Department of Astronomy finally determined to put the solar tower project on the agenda again and organized a research group headed by me.

This time, without the help from the Soviet Union's experts, all problems should be solved by ourselves. The solar tower must be properly designed before it was built. We invited three teachers and more than 20 graduates from the Department of Precision Optical Mechanics of Zhejiang University to participate in the project. They did their best and finally completed the preliminary design in nearly one year. In the subsequent engineering work, engineers found that the drawings were neither standard nor rigorous and could not be used for processing.

While we knew that the scientific road was not always smooth, we actually faced a much more difficult period than before.

Astronomy underwent rapid advance in the 1960s with four major discoveries, including the discoveries of quasars, pulsars, microwave background radiation, and interstellar organic molecules. However, in 1966 the so-called "Great Cultural Revolution" movement started and the whole country was chaotic. The solar tower group was dismissed and the university was fully closed. All teachers and students went to do physical labor in the countryside in Liyang, a neighboring county. The task of our department was to make bricks in a kiln and I was appointed as the chief of the canteen for the department. Every morning I pulled a wooden handcart out to buy food and prepared meals after coming back. At that time the development of astronomy in our country was completely halted. Such a situation finally ended with the "formal reopening of schools" policy in 1973.

Shortly afterward, the Department of Astronomy reorganized the solar tower team and appointed me again as the team leader. The group included Huang Youran, Chen Zaizhang, Ni Xiangbin, and two engineers. After that, six more young teachers joined the group. This time the team members had much more experience than before. We put heads together and worked out four major steps: making a comprehensive survey; selecting an appropriate site; redesigning the telescope; manufacturing the telescope in certain factories.

The purpose of the survey was to understand the main principles and key difficulties in designing the solar tower and to figure out the problems in our previous design. A preliminary solar tower site should be selected first. That is, we needed to find a place relatively clean but not too desolate for ease of transportation. Note that at that time we had no cars.

Therefore, we rode bicycles to almost every place around Nanjing no matter when it was raining or windy. After the rough survey, we had a fine candidate site. Then we needed to measure the solar halo intensity and the atmospheric transparency. To this end we developed a dedicated telescope. Finally we determined on a site located in a deserted villa area with fruit trees near President Sun Yat-sen's Mausoleum.

In order to determine the height of the solar tower, a high pillar was built. We put a special thermometer, developed by ourselves and composed of platinum wire bridges, at different levels of the pillar to record temperature disturbances. We took turns on duty in observations for many days, and lived in a simple tent nearby. Finally, the height of the solar tower was set to be 20 meters based on the measurement result.

Then we entered the design stage of the solar tower. In order to achieve the best optical design, we specially went to a town near Nanjing to make calculations with the most advanced computer at that time in Nanjing. After this recalculation, we finally reached a promising optical design which met the requirements. In terms of mechanical design, two engineers carefully reviewed the previous drawings, revised them and plotted thousands of drawings. It is worth mentioning that, unlike the usual design that a window was made in the dome of the solar telescope, our design proposed a three-petal dome structure to ensure open-dome observation of the Sun. This was a unique design compared to other solar towers in the world.

After the design was completed, we moved into the factory processing stage. The solar tower is a large-scale precision instrument, which requires a much higher processing accuracy than common telescopes. We got support of the Secretary of Jiangsu Province Party Committee. The Industry Bureau of Jiangsu Province appointed the Municipal Industry Bureau of Nanjing to arrange factories for processing. After several rounds of coordinations, the Industry Bureau finally selected five factories, with the strongest capacities in Nanjing, to perform the processing of various components of the solar tower. Since 1975, each member of the solar tower team was responsible for the work of a factory, tracking the progress of each component. However, it was not smooth. We then went to Harbin, Shanghai, and many other places many times in order to get the key materials and equipments, including precision cutting tools, glass ceramics, and even bearings and motors.

The site of the solar tower was located to the south of the Min Tomb. The land belonged to the local government called the people's commune. The land acquisition should be approved successively by the farmers, the squad, the production brigade, the people's commune, and the local town. None of the steps were easy. To this end we negotiated with the local residents and official leaders. Finally, the Mayor of Nanjing organized a meeting and the land acquisition was settled after more than one year had passed since the first submission of the land acquisition application.

3.3. Formal Construction

The solar tower infrastructure got into the formal construction stage in 1977. There was no water, electric power, and even a road near the construction site. Before construction, we should make them available and level the land. This project required a lot of construction materials, which must be bought. In order to save money, the solar tower team decided to make the necessary preparations themselves. So our team members built a thatched shed there and took turns on duty. The conditions there were very bad. Without drinking water, we went to the foot of the mountain to collect water and carried it to the construction site. Without electricity, we lit a kerosene lamp at night. Without natural gas, we cooked on a small coal stove. Since there were too many mosquitoes at night, we had to protect ourselves with mosquito nets.

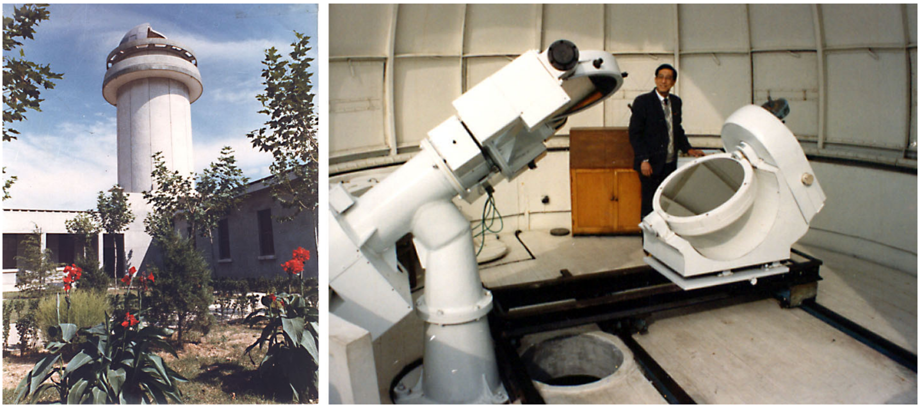

Figure 5 The Nanjing University solar tower installed in 1980 (*left*). I was doing observations (*right*).

Besides the team members, many faculty members of the Astronomy Department participated in the project from time to time. For example, the pinus koraiensis wood, imported for the project from abroad, was transported to the Nanjing railway station first. More than 20 faculty members of the Astronomy Department walked under the scorching Sun more than ten kilometers to carry the wood to the construction site by some wooden handcarts. In fact, everyone contributed a lot to the project, which indeed reflected the team spirit.

After about one year of hard work, we set up water and electricity supplies and a road as well, and the land became flat. Some workshops were established and the construction got onto the right track. From the second half of 1978, the professional workers and the solar tower team worked together to assemble the equipments and the components constructed by the five factories. Finally the solar tower telescope was thoroughly installed!

In the autumn of 1979, when the optical path of the solar tower was opened, we saw a very clear solar image! At that moment, the solar tower team members were so excited that they shed tears! During seven years starting from 1973, we did not have a rest even during winter and summer holidays. No matter at what time, in the sultry summer or in the chilly winter, everyone did his/her best in the construction of the solar tower... Our dream finally came true! It was a great joy that cannot be described with words. People felt proud of this achievement and more confident about the future of Chinese astronomy. It took us a total period of 22 years from the initial planning to completion of the solar tower. This extremely difficult but fruitful period of 22 years is not only a milestone in my research career but also an epitome of the development of solar physics in China (Figure 5).

Later we spent nearly two years installing and commissioning a multi-channel spectrograph. China's first solar tower was finally put into formal operation in 1982 (Fang and Huang, 1983). The spatial resolution of the telescope was up to 1 arcsec, and the spectral resolution of the spectrograph was 140 thousands. Later, between 1986 and 1989, considering the development of new technologies, we carried out successful upgrading of the solar tower. The coelostat diameter was enlarged from 46 cm to 60 cm, the diameter of the imaging lens was changed to 43 cm, the focal length became 2170 cm, and the solar image had a diameter of 20 cm. All the mirrors were manufactured using zerodur whose thermal expansion coefficient was almost zero. The multi-channel spectrograph can work at six wavebands: Hα, Hβ, Hγ and Hδ of hydrogen, H and K lines of ionized calcium and D3 line of helium. After 1992, we further developed a two-dimensional spectral data acquisition system with two CCD cameras for the spectrograph in Hα and H and K lines of ionized

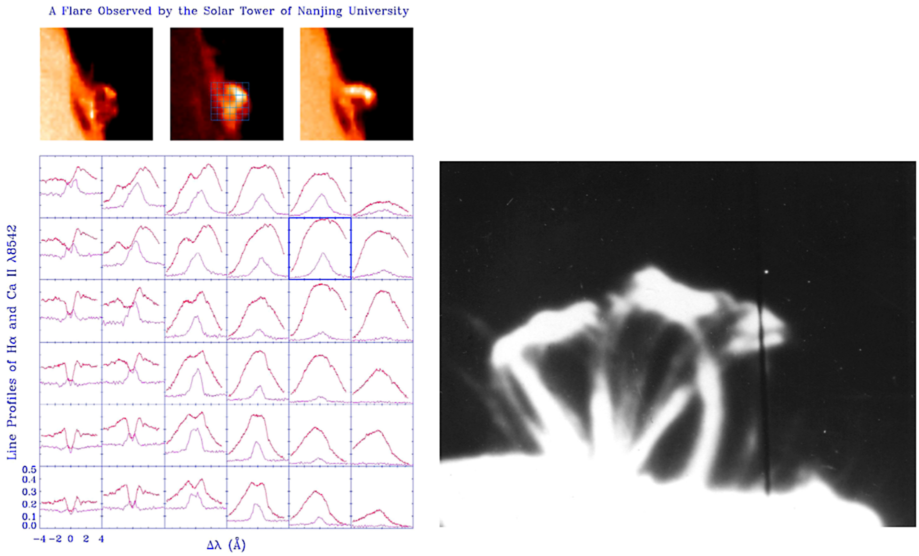

Figure 6 2D spectra of a flare (*left*) and a big loop prominence (*right*) observed by the Nanjing University solar tower in 1998 and 1983, respectively.

calcium, respectively. A two-dimensional spectrum can be obtained by a quick scan of the slit over the target region at a temporal resolution of less than 10 seconds. This means that the instrument was one of the state-of-the-art solar telescopes in the world.

The upgraded solar tower was put into operation in the 22nd solar cycle and obtained high-quality spectral data for over 300 solar active regions, prominences and sunspots, as well as multi-wavelength two-dimensional spectral data for 53 solar flares including two white-light flares (the temporal resolution of the spectral observation for the white-light flare on 1991 October 24 was up to 5 seconds), Figure 6.

Besides our own instrument, my colleagues and I also obtained plenty of high-quality observational data through collaborations with our colleagues in France, Spain, US, Japan, and other countries. With these data, we were able to conduct a series of research work including atmospheric modeling of solar active phenomena (flares, prominences, sunspots, Ellerman bombs, *etc.*). Our solar physics group has grown and now there are seven faculty members performing research in various topics including MHD simulations.

In the 1980s, besides the solar tower, the following solar observational instruments were built in China: a solar magnetic field telescope (led by Prof. Guoxiang Ai, who was elected an academician of the Chinese Academy of Sciences in 1993) and a high temporal resolution radio spectrometer at Beijing Observatory (later renamed National Astronomical Observatories), a multi-channel spectrograph and a fine structure telescope at Purple Mountain Observatory, a fine structure telescope and a full disk Hα monitoring telescope at Yunnan Observatory. Among them, the solar magnetic field telescope was one of the most advanced magnetographs in the world. Up to now it has accumulated a large amount information of magnetic field data in solar active regions over three solar cycles. This telescope has made an important contribution to the study of solar magnetic fields. Based on the data from this telescope and BBSO, Prof. Jingxiu Wang, who was elected an academician of the Chinese Academy of Sciences in 2013, and his collaborators made essential contribution in understanding the structure and evolution of solar magnetic fields. With the development of solar equipments and research, younger solar physicists have been trained and are growing up in China. We feel gratified and all our efforts are worthwhile.

4. International Collaboration and Exchange

The reform and opening policy of China, led by President Deng Xiaoping, activated science in the early 1980s. The same was truess for solar physics, which is one of the most important branches of astronomy in China. We established a series of international collaborations. The international symposium on solar physics, initiated and organized by Professor Chen Biao at Purple Mountain Observatory, was successfully held in Kunming in 1983. More than 120 Chinese and foreign solar physicists and scholars participated in the meeting. Such international conferences and collaborations effectively promoted the development of solar physics and paved the way for the development of solar physics in China.

4.1. Visiting Paris Observatory in France

In modern times, science and technology in China was left behind compared to the developed countries in the world. Such a gap was getting bigger and bigger in the decades before 1980s. In terms of solar physics research, I realized that, in spite of the successful construction of the first solar tower in China, we had too much to learn from the leading countries in order to catch up with them. Only in this way could we go forward step by step.

In 1980 January, I passed the exam organized by the Ministry of Education and obtained an opportunity to visit Paris Observatory of France as a visiting scholar supported by our government. France has a long history in solar physics research. Paris Observatory is among the leading astronomical institutes in the world.

I studied Russian as my first foreign language when I was an undergraduate. After I graduated, I began to learn English by myself. I did not know French at all at that time. Although I was asked to learn French for a month in the Shanghai Institute of Foreign Languages, I still had little knowledge of French.

I finally arrived in Paris in 1980 April. Paris is a modern and romantic city. However, I did not think of enjoying the scenic spots! The Chinese Embassy organized a three-month French-language training class, but I could only speak broken French. When I arrived at Paris Observatory on the first day, Dr. Z. Mouradian asked me, “Do you want to communicate in French or in English?” I thought that only speaking French can enable me to get close contact with French colleagues so that I can gain more knowledge about advanced research and technical achievements. So I replied to him, “I would like to speak French.” Apparently, he was surprised and did not understand my choice. Even though he still talked to me in French at my request.

In the beginning it was very difficult for me to communicate with others in French. So I spent more than one hour every day talking with French colleagues during lunch time. Our conversation topics were of a wide variety, from astronomy to geography. I often looked for guards of the Observatory for chatting. At night I also talked with my landlord. In a word, I sought chance to practice my French as much as possible. Shortly afterwards, my colleagues at Paris Observatory were surprised at my spoken French and said: “Mr. Fang, you can speak French so fluently so quickly. It is really incredible!”

At Paris Observatory I first saw the largest 80 cm solar tower telescope built in Europe in the early 1970s and the metric radio heliograph in Nancay. I also visited Pic du Midi de

Figure 7 I was doing observations with THEMIS at Canary Islands in 2000.

Bigorre in the Pyrenees, where I observed the solar activities with some advanced equipments like a coronagraph and a solar spectrograph. This enriched my knowledge on solar observations and data analysis.

During my stay in France, I carried out close collaborations with Dr. J.-C. Hénoux. He led me into the field of atmospheric modeling under non-local thermodynamic equilibrium (non-LTE) conditions. After my first visit in the early 1980s, Paris Observatory invited me four more times as a first-class visiting researcher for collaborative research. I have worked with Dr. B. Schmieder, Dr. M.J. Martres, Dr. P. Mein and N. Mein, Dr. Z. Mouradian and many other scientists. In particular, I used the 90 cm THEMIS telescope, built by France and Italy on the Canary Islands of Spain, through which I obtained excellent spectral data and published a number of articles (Figure 7).

Since 2006, some scholars from China and France had worked closely to promote the project of a small satellite, "*SMall Explorer for the study of Solar Eruptions*" (SMESE), supported by the National Natural Science Foundation of China (NSFC) and the French National Aeronautics and Astronautics. However, after a four-year effort, the SMESE project was finally halted for financial reasons, but the experience accumulated during the bilateral collaboration was a valuable asset to us. It helped train Chinese young researchers, who have grown up quickly and made important contributions to solar physics research in China, especially in the field of space exploration.

4.2. Collaboration with Japanese Colleagues

I met Professor E. Hiei of the National Astronomical Observatory of Japan (NAOJ) at the solar physics conference held in Sacramento, USA in the summer of 1985. The conference was also a celebration of the 60th birthday of the famous solar physicist Professor Z. Švestka. I shared a room with Professor E. Hiei, and was deeply impressed by his frankness, kindness and erudition. We kept no secrets from each other and became very good friends. He

Figure 8 *Top left panel*: At the Symposium of the NSO/*Solar Maximum Mission* held at Sacramento Peak, Sunspot in 1985, with Zdenek Svestka; *Top right panel*: Visiting NAOJ of Japan in 1991 with Tadashi Hirayama, Eijiro Hiei, Takashi Sakurai, and others; *Bottom*: Visiting Professor Hiei's home in 1991.

visited China in 1988 and had many conversations with me in Nanjing. In 1991, on behalf of NAOJ, Professor E. Hiei invited me to visit Japan as a guest professor. During this visit, I stayed in Japan for half a year. I analyzed high-quality spectral data obtained by NAOJ, especially the spectral data of white-light flares. I visited the newly installed solar flare telescope at NAOJ, the Norikura Station, and the Hida Observatory of Kyoto University for the first time. I learned a lot from these visits. More importantly, I established a close relationship with the solar physicists in Japan. Later on, I visited NAOJ several times. Our group has conducted long-term collaborative research with many Japanese colleagues, including Professors T. Sakurai and K. Shibata. Such collaborations are fruitful, not only in research but also in training young scholars (Figure 8).

4.3. Collaboration with Colleagues in Other Counties

In 1985 I visited National Astronomical Observatory of US and collaborated with Dr. W.C. Livingston to observe the Sun with the world's largest two-meter solar tower telescope and obtained a lot of high-quality solar spectral data. We jointly published several articles based on the observational data (Figure 9).

Since then, I have visited Germany, UK, South Korea, Czech Republic, Yugoslavia, Russia, USA, Egypt, India, and many other countries, either as a visiting scholar or as a participant of international conferences. I have also invited many solar physicists from foreign countries to visit China and established collaborations between us. This has no doubt played a positive role in promoting the development of solar physics in China (Figure 10).

It is particularly worth mentioning that, in recent years, the development of solar physics relies more and more on the high-resolution instruments. Following this trend, under the

Figure 9 I was doing solar observations with the McMath-Pierce solar telescope at Kitt Peak Observatory in 1985.

Figure 10 *Top left panel*: At the 70th anniversary ceremony of Professor Hong Sik Yun in Korea in 2003; *Top right panel*: At USA/SPD meeting in 2013, with Tongjiang Wang, Yingna Su, Ying Li, Jianxia, Chen, Zhi Xu, Jiong Qiu, Junwei Zhao, Wenda Cao; *Bottom panel*: At my home in China with solar scientists from Russia (Natalia Firstova), USA (David Jewitt and his wife Jing Li), and Japan (Eijiro Hiei and his wife) in 2002.

joint efforts of National Astronomical Observatories, Purple Mountain Observatory, Big Bear Solar Observatory (BBSO), and New Jersey Institute of Technology, Chinese scholars and graduate students can use the 1.6 meter Goode Solar Telescope (GST) at BBSO, the world's largest solar optical telescope so far, for observations of solar activities for one month a year from 2014. Chinese solar physicists and students also benefit a lot from such a joint project (Figure 11).

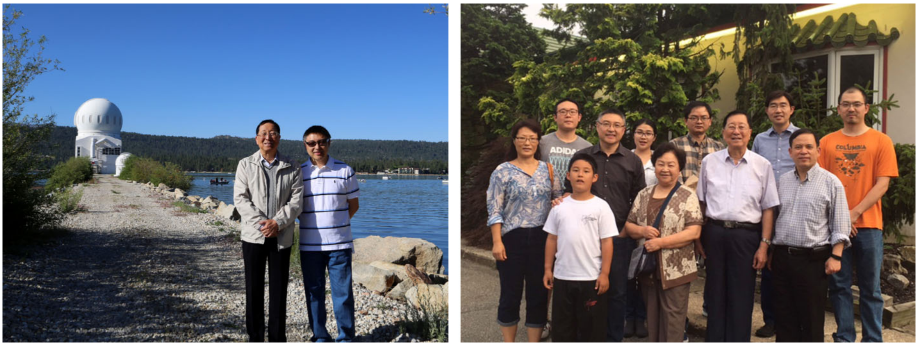

Figure 11 *Left panel*: At BBSO/USA with Prof. Wenda Cao; *Right panel*: Visiting NJIT/USA in the summer of 2017, with Wenda Cao, Haimin Wang, and others.

4.4. Numerous Bilateral International Meetings

Since the 1990s, there have been increasing collaborations between Chinese and foreign astronomical research institutes. Supported by NSFC and French National Center for Scientific Research (CNRS), Nanjing University successfully hosted the First Franco–Chinese meeting on solar physics in China in 1999 November. More than 20 experts from France, Germany, UK, and Italy and other countries, as well as 29 experts representative of some major domestic institutes were present. In the meeting we gained insight into the latest achievements in solar physics research and discussed how to continue and strengthen the collaborations in the future. The second Franco–Chinese meeting on solar physics was held at Paris Observatory in 2002 August. In 2005 November and 2011 November, the third and fourth Franco–Chinese meetings on solar physics were, respectively, held in Shanghai and Nice, which promoted the exchange and academic collaborations between solar physicists from both countries. I have also actively participated in and initiated numerous bilateral meetings on solar physics, including three Sino–Japanese solar physics meetings (1991, 1997 and 2004) and two Sino–Korean solar physics seminars (2005 July and 2007 October), thanks to the joint efforts in organization from Professors E. Hiei, T. Sakurai, H.S. Yun, and other colleagues. Under the impetus of Indian colleagues, Professors A.R. Choudhuri and S. Hasan, and some Chinese colleagues including me, three Sino–Indian solar physics meetings were held in 2006, 2008, and 2011. In recent years, in order to improve efficiency, these meetings have been merged into two main regional meetings, the Asia–Pacific solar physics meeting and the China–Europe solar physics meeting. The first Asia–Pacific solar physics meeting (APSPM) was launched in India in 2011. The second, third, and fourth Asia–Pacific solar physics meetings were, respectively, held in Hangzhou, China (2013), Seoul, Korea (2015) and Kyoto, Japan (2017). The first China–Europe solar physics meeting was successfully held in Kunming, China in 2017, and the second one will be held in Croatia in 2019 (Figure 12).

My personal career demonstrates the importance of international exchange and collaborations to scientific research. In recent years, more and more foreign astronomical institutes like to collaborate with Chinese institutes in a win–win situation. However, we are still in a developing stage and have much to learn from leading countries.

Figure 12 *Top left panel*: At the IAU No. 233 Symposium held in Egypt in 2006, with Eric Priest, Ahmed Abdel Hady; *Top right panel*: At the third Sino–Indian Solar Physics Meeting held in India in 2011, with Zongjun Ning, Hui Li, Mei Zhang, Yuanyong Deng, Jingxiu Wang, and Arnab Rai Choudhuri on my right side, and Haisheng Ji, Pengfei Chen, Piyali Chatterjee, and Bidya Karak on my left side; *Bottom left panel*: The second Asian–Pacific Solar Physics Meeting held in Hangzhao in 2013, with Arnab Rai Choudhuri, Dipankar Banerjee, Takashi Sakurai, Jongchui Chae, Pengfei Chen and others; *Bottom right panel*: The third Franco–Chinese solar physics meeting held in Shanghai in 2005.

5. The Non-LTE Theory and Its Application

In the 1970s, when we started to analyze the solar spectral data, we realized that the non-LTE (non-local thermodynamic equilibrium) theory is essential for the quantitative diagnostic of the solar spectra, particularly for the optically thick lines, such as Hα and Ca II K and H lines. When our solar tower was successfully constructed, it became an urgent task for us to study the non-LTE theory. Thus, when I went to Paris Observatory as a visiting scholar in 1980, I decided to learn the non-LTE theory as my first goal. At that time, Dr. Hénoux was an expert in this field; thus he became my first supervisor. I spent almost one year writing the numerical code for atmospheric modeling with the non-LTE equations. It was a tough period. Whenever my code run into bugs, we spent a lot of time to analyze where the problem was. At last the code could be run correctly, and we published a paper entitled "Self-consistent models of flare heated solar chromospheres" (Fang and Hénoux, 1983). In this paper, we used a method of complete linearization of the transfer equation to compute the radiation losses including Lyα, Lyβ, LyC, Hα, Mg II, Ca II and H^- emissions. Our result indicates that both the X-ray emission and the electron bombardment can heat the chromosphere to some extent. Once accomplishing the non-LTE code, we would be able to apply it, with some modifications, to various kinds of solar active phenomena, as shown in the next subsections.

5.1. Semi-Empirical Models of Solar Activities

The Sun has many different activities, such as flares, sunspots, prominences, plages, Ellerman bombs (EBs), *etc.* It is an interesting research topic to study their atmospheric structures. The best way is to analyze their spectra. It needs atmospheric modeling under non-LTE conditions. A usual method is the so-called semi-empirical modeling. That is, giving a preliminary temperature distribution, we solve the statistical equilibrium equation and the radiative transfer equation, coupled with the hydrostatic equilibrium and the particle conservation equations. Then we can get both theoretical lines and the continuum intensities from the models. Comparing the theoretical and the observed results, we can modify the temperature distribution based on the difference between them. We then repeat the procedure until the theoretical spectra well match the observational ones. Thus we can obtain the most promising temperature structure. For the uniqueness of the result, it is necessary to use several lines and continua from different elements.

In the past 30 years, using multi-wavelength observations, we have obtained semi-empirical models of flares (Fang *et al.*, 1986; Gan and Fang, 1987; Fang, 1988), microflares (Fang, Tang, and Xu, 2006), sunspots (Ding and Fang, 1989, 1991), prominences (Zhang and Fang, 1987; Fang *et al.*, 1990), plages (Fang *et al.*, 2001), and EBs (Fang *et al.*, 2006; Li *et al.*, 2015). These studies revealed the difference between different solar activities.

Semi-empirical models can also include some dynamic processes if their time scale is long enough compared with the ionization timescale. For example, we have calculated the semi-empirical model for the flare atmosphere with a chromospheric condensation (Gan, Rieger, and Fang, 1993).

5.2. Spectral Diagnostics of Non-Thermal Particles

Using the non-LTE theory, we have developed a method for spectral diagnostics of non-thermal particles. In fact, if we include the excitation and ionization via particle beam bombardment in the statistical equilibrium equation, then the non-thermal spectral characteristics can be computed, and compared with observational spectra. Hénoux and I derived the formula for non-thermal excitation and ionization caused by electron beam bombardment (Fang, Hénoux, and Gan, 1993) and by proton beam bombardment (Hénoux, Fang, and Gan, 1993, 1995). Our results indicate that in the case of electron beam bombardment, the Hα line is greatly strengthened and broadened with an obvious central reversal. This effect is weaker for the Ca II K line. In the case of proton beam bombardment, these effects are less obvious. Thus, one can use the spectral characteristics to diagnose the particle beams during flares (Fang *et al.*, 1996; Fang, Xu, and Ding, 2003; Ding and Fang, 1997; Xu, Fang, and Gan, 2005). We have also computed some non-thermal semi-empirical models with the excitation and ionization via electron beam bombardment included. It is shown that if the non-thermal effect is not taken into account, then the heating in the flaring atmosphere would be overestimated. Besides, using the non-LTE theory, we have computed the hydrogen line emission caused by an oblique incident proton beam through charge exchange (Fang, Feautrier, and Hénoux, 1995; Zhao, Fang, and Hénoux, 1998). It provides a method to diagnose the existence of proton beam in flares.

5.3. Dynamical Models of Solar Flares

The dynamical model of solar flares can be obtained by solving the conservation equations for mass, momentum, and energy. In the energy equation, there is a term of radiative losses, which, in general, should be calculated by solving the radiative transfer equation. We made a simplification and deduced an empirical formula by fitting the detailed non-LTE calculation results from the VAL-C model (Vernazza, Avrett, and Loeser, 1981), and F1 and F2 models (Machado *et al.*, 1980; Avrett, Machado, and Kurucz, 1986). Thus, considering the energy deposited by thermal conduction, X-ray irradiation, and the background heating for maintaining the quiescent atmosphere, we have calculated a hydrodynamic model of the flare in the gradual phase (Gan and Fang, 1990). By changing the energy deposition term, we also presented a hydrodynamic model of a solar flare in the impulsive phase (Gan, Fang, and Zhang, 1991; Gan, Cheng, and Fang, 1995). Recently, we have modified the empirical formula of radiative losses to better fit the non-LTE results, in particular for the activities in the solar lower atmosphere (Jiang, Fang, and Chen, 2010).

6. Observations and Study of Solar White-Light Flares

By definition, white-light flares (WLFs) are flares showing emissions visible in the optical continuum. Thus, the best way to detect WLFs is spectral observations. WLFs are thought to be very rare and belong to the most energetic flaring events. In the 1980s, only about 50 WLFs had been reported since 1859 (Neidig and Cliver, 1983). With the multi-wavelength spectrograph of our solar tower, we can record solar spectra with a wide waveband coverage (Fang and Hénoux, 1983; Huang, Fang, and Hu, 1986). It is very useful to detect WLFs.

During the first three-year observations, we detected five WLFs. Among them, three flares were weak SN class flares. So we suggested that the real number of WLFs could be much more than what people had expected (Huang, Fang, and Hu, 1985). Later on, we observed and analyzed several WLF, including the flares on 1974 September 10 (Hiei, 1982; Hu *et al.*, 1994), 1974 October 11 (Yin *et al.*, 1995), 1979 September 19 (Fang *et al.*, 1993; Ding *et al.*, 1994), and 1991 October 24 (Fang *et al.*, 1995). The first three WLF were observed by the coronagraph at Norikura station of NAOJ, which can cover a wavelength range of 359.0 – 399.0 nm, well containing the Balmer limit. Using the non-LTE theory, we constructed the corresponding semi-empirical models of the WLFs. In 1985, I participated in the meeting at Sacramento Observatory, during which WLFs were a hot topic. In the WLF working group report, we proposed two types of WLFs (Machado *et al.*, 1986). However, at that time, the properties of these two types of WLFs were not well known. By analyzing their detailed spectra and models, we pointed out the different spectral characteristics and models for the two types of WLF (Fang and Ding, 1995). That is, for Type I WLFs, there is a good time correlation between the maximum of continuum emission and the peaks of hard X-ray and microwave radiation, and the spectra show a strong Balmer jump and strong and broad Balmer lines. While for Type II WLFs, these characteristics are absent or not obvious. According to our semi-empirical models, we proposed that Type I WLFs were probably produced by electron beam bombardment followed by the radiative backwarming in the photosphere, while the energy source of Type II WLFs might be located in the photosphere. This was verified by our numerical simulations several years later (Chen, Fang, and Ding, 2001) (Figure 13).

Recently, owing to rapid development of space-borne and ground-based high-resolution observations, the sample of WLFs has been increasing quickly and attracting attention of solar physicists again. The *Yohkoh*/SXT observations had a broad-band filter in the Fraunhofer G-band around 4303 Å, with which a number of WLFs were observed (Matthews *et al.*, 2003). Using the white-light instruments aboard the *Transition Region and Coronal Explorer* (TRACE), Hudson, Wolfson, and Metcalf (2006) and Fletcher *et al.* (2007)

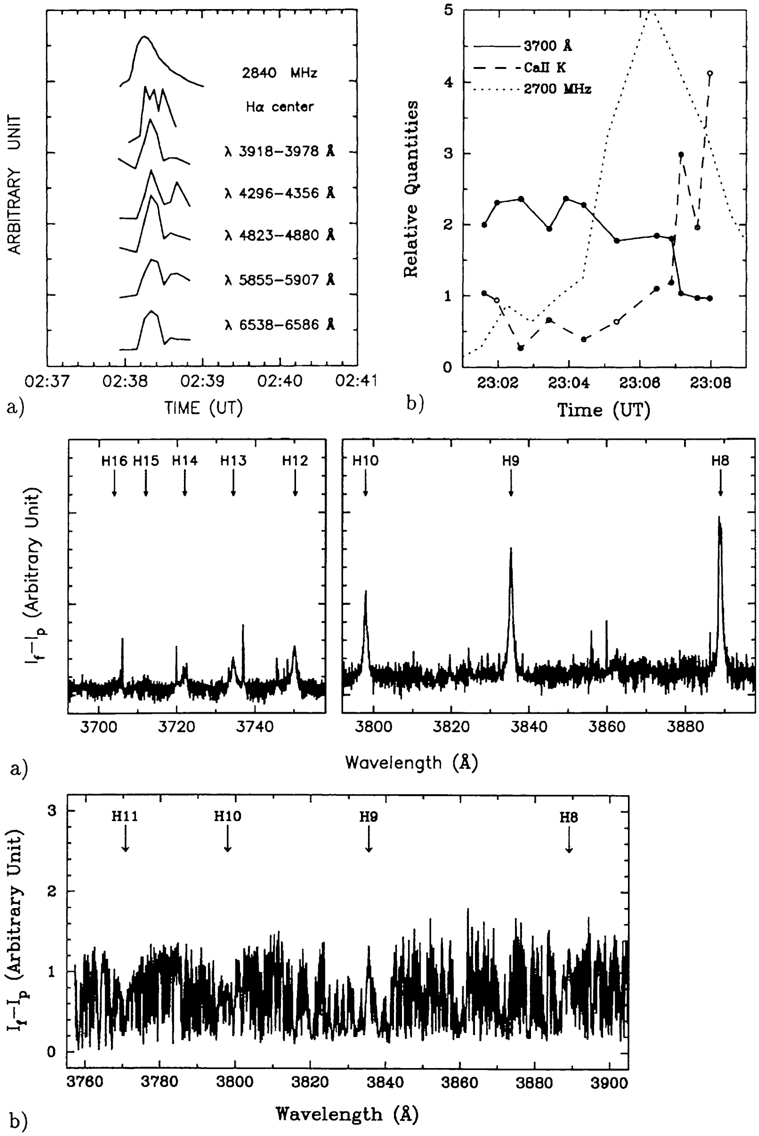

Figure 13 Characteristics of two types of WLF: The light curve of the Type I WLF on 1991 October 24 (*top left panel*), and that of the Type II WLF on 1979 September 19 (*top right panel*). The hydrogen spectra of the Type I (*middle panel*) and Type II WLFs (*bottom panel*) (Fang and Ding, 1995).

detected white-light emissions for events as weak as GOES C1.6 class. Jess *et al.* (2008) also detected white-light emission in the blue continuum for a C1.6 flare using the one-meter *Swedish Solar Telescope*. They concluded that white-light emission probably occurs in all flares with different magnitudes. The *Hinode* payloads have also a G-band filter with a higher spatial resolution than before. Some WLFs with fine structures were detected (Isobe *et al.*, 2007; Wang, 2009). More recently, SDO/HMI 6173 Å observations have provided a wealth of data which are very suitable for study of WLFs (Kerr and Fletcher, 2014; Kuhar *et al.*, 2016; Song *et al.*, 2018). An enhanced emission at the continuum near the Ca II 8542 Å line was observed in a WLF by our solar tower (Liu, Ding, and Fang, 2001) and an enhanced emission even at 1.6 μ was detected in an energetic WLF by the *Dunn Telescope* at NSO/SP (Xu *et al.*, 2004). However, it is worth mentioning that G-band observations may be contaminated by the CH or some line emissions (Watanabe *et al.*, 2010), and that the 6173 Å continuum is reconstructed from a fitting of six wavelength points across the line. Moreover, only one wavelength observation is not enough to explore some characteristics build a model of WLFs on it. The verification of WLFs should be made with caution. In the field of WLFs, Hudson (2016) published a very nice review in his recent memoir.

In recent years, using our new telescope ONSET (Fang *et al.*, 2013), we observed several interesting WLFs. One is the 2012 March 9 WLF. This event shows evidence of a two-step magnetic reconnection, and the WLF is triggered in the first-step magnetic reconnection at a relatively low altitude (Hao *et al.*, 2012). The other is a two-ribbon WLF associated with a failed solar eruption that occurred on 2015 January 13. It belongs to the Type I WLFs and is associated with high-energy electrons accelerated in the corona which then heat the chromosphere and even lower layers (Cheng *et al.*, 2015). The third one is a rare circular WLF that occurred on 2015 March 10, which consists of an impulsive source and a gradual source. The later is relatively long-lasting and not correlated with any HXR sources (Hao *et al.*, 2017). All these observations provide some insight into the nature of WLFs.

7. Observations and Study of Small-Scale Activities

Recently, high spatio-temporal resolution observations by both space-borne and ground-based telescopes with adaptive optics (AO) system have become available. Small-scale solar activities, such as EBs, jets, and microflares, have become hot topics in solar physics. Such small-scale activities have relatively simple structures and are thus relatively easy to study. Because of the similarity between solar activities in various spatial scales, study on the small-scale activities can help understand the physical nature of the major eruptions. Moreover, some studies show that small-scale activities may contribute to some extent to the heating of the solar chromosphere and corona, which is still a puzzling problem in solar physics.

I was first interested in the study of small-scale activities when I made observations with THEMIS in 2000. After that, I went to the Canary Islands several times for observations. THEMIS is a French–Italian 90 cm vacuum solar telescope dedicated to polarimetric and spectroscopic observations (http://www.themis.iac.es). We obtained nice spectral data of EBs and microflares in Hα, Ca II 8542 Å, and Fe I 6302.5 Å lines simultaneously. Recently, we often went to BBSO and make observations with the 1.6 meter off-axis *Goode Solar Telescope* (GST) (Cao *et al.*, 2010; Goode and Cao, 2012). A new AO system with 308 actuators was installed on the GST in 2013; therefore a spatial resolution close to the diffraction limit can be achieved. I was the first person to use this excellent system. High-resolution spectral data have been obtained by use of the *Fast Imaging Solar Spectrograph* (FISS) (Chae *et al.*, 2013). It allows us to study small-scale activities with unprecedented details. In the following I would like to mention some of our work on the EBs, jets, and microflares.

7.1. Ellerman Bombs

EBs (Ellerman, 1917) are small-scale, short-lived brightening events. The most obvious feature of EBs is the excess emission in the far wings of the chromospheric lines. Recently, using imaging data with high spatio-temporal resolutions, it was found that the lifetime of some EBs can be as short as 2 – 3 min, and their size can be smaller than 1 arcsec (Vissers and Rouppe van der Voort, 2012; Nelson *et al.*, 2013). To explore the physical mechanism of EBs, spectral data with high resolutions are important. However, up to now, there are only a few such observations.

Using the high-resolution spectral data of Hα, Ca II 8542 Å, and Fe I 6302.5 Å lines from THEMIS, we analyzed the characteristics of a number of well-observed EBs on 2002 September 5. Among them, we selected three EBs, representing bright, intermediate, and faint events, respectively, and constructed their semi-empirical atmospheric models in two cases, with or without considering non-thermal excitation and ionization effects (Fang *et al.*, 2006). Our results indicated that the temperature enhancement of EBs around the temperature minimum region is about 600 – 1300 K in the thermal models (Hong *et al.*, 2014). If the non-thermal effects are included, then the required temperature increase can be reduced by 100 – 300 K. These imply that the EBs can probably be produced by magnetic reconnection in the solar lower atmosphere (Ding, Hénoux, and Fang, 1998).

Using the spectral data from GST with a very high spatial resolution, we analyzed three small EBs with sizes in the range of 0.3 – 0.8 arcsec on 2013 June 6 (Li *et al.*, 2015). Our semi-empirical models indicate that the heating occurs around the temperature minimum region with a temperature increase of 2700 – 3000 K, which is surprisingly higher than previously thought. These three EBs are associated with bald patches, strongly implying that they are produced by magnetic reconnection in the solar lower atmosphere, consistent with the results from our numerical simulations (Chen, Fang, and Ding, 2001; Xu *et al.*, 2011).

However, there is still a debate on the EB temperature. With the *Interface Region Imaging Spectrograph* (IRIS; (De Pontieu *et al.*, 2014)) observations, it has been proposed that the temperature increase of some EBs (also called IRIS bombs or UV bursts) could be more than 10 000 K in order to explain the enhanced UV emission in those events (Peter *et al.*, 2014; Tian *et al.*, 2016). Using non-LTE semi-empirical modeling, we made a detailed study on this problem. Our result shows that the temperature of pure EBs is unlikely higher than 10 000 K around the temperature minimum region; otherwise, the Hα and Ca II 8542 Å line emission and the continuum emission would be much stronger than what are observed (Fang *et al.*, 2017). Indeed, the relationship between EBs and UV bursts needs to be studied further in the future.

7.2. Microflares

Microflares, or subflares, are small-scale and short-lived solar flares. They are larger than EBs, and show an obvious emission at both the center and the wings of some chromospheric lines (Shimizu *et al.*, 2002; Fang, Tang, and Xu, 2006). The study of microflares provides a clue to understand the mechanism and dynamical processes of major solar flares.

Using the high-resolution spectral data from THEMIS on 2002 September 5, we analyzed five well-observed microflares (Fang, Tang, and Xu, 2006), including an interesting C1.6 two-ribbon microflare (Xia *et al.*, 2007; Fang *et al.*, 2010). Our non-LTE semi-empirical models of the microflares indicate that the temperature enhancement is about 1000 – 2500 K in the low chromosphere. The two-ribbon microflare is triggered by the eruption of a small filament followed by magnetic reconnection appearing in the low corona. Using high-resolution data from BBSO and SDO/AIA, we analyzed the microflare on 2014 August 24, and found bidirectional outflows with velocities of $\pm 80\ \mathrm{km}^{-1}$, which is regarded as convincing evidence of magnetic reconnection in the solar lower atmosphere (Hong *et al.*, 2016). Our 2.5D compressible resistive MHD numerical simulation with ionization, radiation, and gravitation considered, reproduced qualitatively the temperature enhancement in the chromosphere (Jiang, Fang, and Chen, 2010). We also performed numerical simulations with a canopy-type configuration which is rooted at the boundary of a solar supergranule (Jiang, Fang, and Chen, 2012). We simulated and compared the coronal and chromospheric microflares; the former is triggered by reconnection in the corona, and its size and temperature enhancement are bigger than that of the latter. We also found a hot jet related to the observed EUV/SXR jet and a cold jet corresponding to the Hα and Ca II H/K surges in the former case. By contrast, there appear only Hα and Ca II H/K bright points in the chromospheric microflares. Our study also showed that the size and strength of the emerging magnetic flux are key parameters which determine the height of the reconnection place. These simulations implied that the magnetic reconnection in the low corona or the chromosphere could be responsible for the microflares.

7.3. Jets

Jets are often observed on the Sun, manifesting as dark ejecta projected on the solar disk. Some jets, called surges, are closely related to solar flare activities (Tandberg-Hanssen, 1995; Uddin *et al.*, 2012). We have conducted some investigations on their fine structure and dynamical processes.

Using the GST data at TiO, Hα and 1083 nm wavebands observed on 2013 June 5, we analyzed a large fan-shaped surge with spatial resolution better than 0.1 arcsec (Li *et al.*, 2015). The surge consists of many small-scale threads with a typical width of 100 km and a length up to 200 Mm. The threads come from material ejections, which start with a velocity of several $\mathrm{km\,s^{-1}}$, accelerate up to 60 – 80 $\mathrm{km\,s^{-1}}$ during 6 – 7 minutes, and then decay. There is an Hα brightening at the root of the fan-shaped surge, implying that there is heating in the chromosphere, which could be produced by low-atmosphere interchange magnetic reconnection. Our observation provides observational support to the reconnection model of the fan-shaped surges, which was predicted by 3D MHD simulation (Jiang *et al.*, 2011a,b). In this simulation, a new type of fan-shaped surges was proposed, which are formed along the guide field, and are driven by the Lorentz force at the initial stage, but by the gas pressure gradient in the later phase.

8. Dream of Chasing the Sun

8.1. Educating Students

No matter how busy I am involved in research, I always believe that imparting knowledge and educating students are the most important responsibility for a teacher. While nurturing students, I do not only attach importance to their research ability but also pay attention to their moral character. Students should be able to collaborate with others and always keep modest, prudent, and selfless. In terms of morality, students should work carefully, seek truth from facts and under no circumstances may falsify their results.

I am strict with my own graduate students and the young teachers who work in our Astronomy Department. I emphasize to them the importance of practical observations in astronomical research. I always encourage the students to do observations by themselves, participate in the observational work using the solar tower, ONSET and other solar instruments, with the purpose to increase their knowledge of solar physics. In the training of doctoral students, I require them not only to perform theoretical simulations but also they

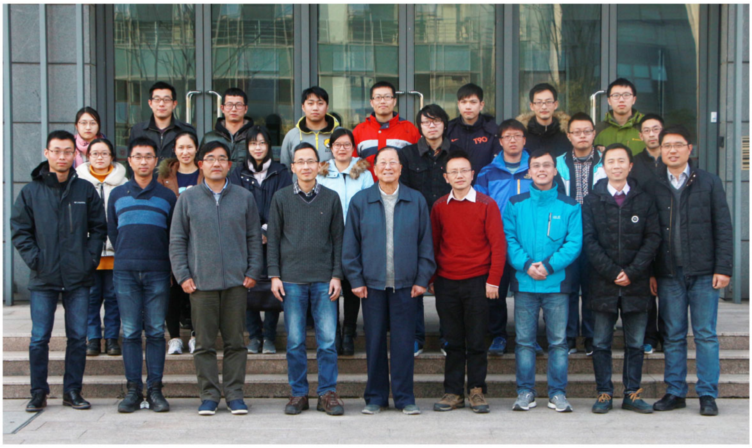

Figure 14 Picture of our solar group at Nanjing University in 2017, with Xin Chen, Qi Hao, Yu Dai, Mingde Ding on my right side, and Pengfei Chen, Chuan Li, Yang Guo, Zhen Li on my left side. Behind are all graduate students.

are required to participate in observations and the analysis of data from various kinds of instruments. I have taught many students, including Dr. Weiqun Gan, who once served as the deputy director of Purple Mountain Observatory and made contributions to solar high-energy physics, Professor Mingde Ding, who once served as the director of the School of Astronomy and Space Science of Nanjing University and made his mark in solar spectral observations and analyzes, Professor Pengfei Chen, who obtained significant results in numerical simulations of solar activities, Dr. Qizhou Zhang, who is now an associate professor at Harvard University and specialised in the study of star formation, Dr. Junwei Zhao, who is now a senior research scientist working at Stanford University and became an internationally known expert in helioseismology, . . . Every student is my pride (Figure 14).

Now the solar physics research group at Nanjing University includes three professors (Mingde Ding, Pengfei Chen and myself), four associate professors (Yu Dai, Chuan Li, Xin Cheng, and Yang Guo) and more than 10 young researchers and graduate students. We have worked hard together and been working on a number of research fields including spectral observations, MHD simulations (Chen, Fang, and Shibata, 2005; Chen, 2011), and radiation hydrodynamics of solar activities (flares, coronal mass ejections, filaments, jets, and EBs). We have become an active team in the field of solar physics.

During the past decades, I witnessed the growing up of several generations of solar physics researchers in China. For example, Drs. Hongqi Zhang, Yihua Yan, Yuanyong Deng, Jun Zhang, Mei Zhang, Huaning Wang in National Astronomical Observatories, Drs. Weiqun Gan, Haiseng Ji, Hui Li, Siming Liu, Li Ji in Purple Mountain Observatory, Drs. Jun Lin, Zhongquan Qu, Zhong Liu in Yunnan Astronomical Observatory, Dr. Hui Tian in Peking University, Dr. Yuming Wang in University of Science and Technology of China, Drs. Lidong Xia and Yao Chen in Shandong University, to name a couple of them. It is my greatest joy to see that solar physics research in China is well inherited by the next generation and a prosperous future is readily expected.

Figure 15 The NVST (*left*) and ONSET (*right*) telescopes installed aside the Fuxian Lake in Yunnan Province. The picture was taken in 2011.

8.2. A New Platform in Western China

In the 21st century, with the rapid development of urban construction in Nanjing, the seeing conditions at our solar tower became worse. The images of the Sun obtained by the solar tower became blurred and inadequate for scientific research. We believe that the time has come for us to build again a solar telescope at a place with a better seeing conditions.

After a site survey of more than 10 years by Yunnan Observatory, a place on the side of the beautiful Fuxian Lake, which is 60 km away from Kunming, was finally selected to be the location for the new telescope. The seeing is quite good there, the water temperature is stable and the surrounding environment is clean and quiet. Except for a little bit more rainy days, this site is comparable with the best solar observation sites in the world.

I played an active role in the construction of the Fuxian Lake Observation Station of Yunnan Observatory. As early as 2004, I and two young professors, Mingde Ding and Pengfei Chen, proposed the idea to construct the new telescope ONSET. Nanjing Institute of Astronomical Optics & Technology was responsible for the manufacturing of the telescope. After an effort of six years, ONSET was finally installed at the Fuxian Lake Station in 2011. It is a dedicated telescope that can observe the Sun at wavelengths of 1083 nm, Hα and two white-light bands (360 nm and 425 nm) simultaneously. It is used to track fast variations of solar active phenomena and in particular to record solar WLFs. Moreover, a one-meter vacuum solar tower telescope (NVST) with good performance was installed at this station. It is equipped with multi-waveband imaging instruments and high-resolution spectrographs (Figure 15). More and more data with high quality have been accumulated by NVST (Liu *et al.*, 2014).

On the long run, we are now seeking a new location for solar observations. National Astronomical Observatories and Yunnan Observatory organized a site survey team dedicated to the site selection in western China. On the basis of a preliminary survey, the Ali area in Tibet and Ganzi (Daocheng) in Sichuan were nominated as the candidate sites for further monitoring of weather and seeing conditions. I also went to Tibet and Daocheng for exploration. After the site is finally determined, we will build and install a large solar telescope and a coronagraph there, which can continually promote the development of solar physics research in China.

While maintaining our own telescope, my group has been actively participating in these projects. We collaborate with many institutes like Purple Mountain Observatory, National Astronomical Observatories, National Space Science Center, Changchun Institute of Optics and Fine Mechanics, and Institute d'Astrophysique Spatiale (IAS).

8.3. An Endless Pursuit of Solar Physics in China

In the 21st century, China has been playing more and more important roles in astronomy, including solar physics. Not only a number of excellent solar instruments such as NVST (Liu *et al.*, 2014), *MingantU SpEctral Radioheliograph* (MUSER) (Yan, Chen, and Yu, 2016), and ONSET (Fang *et al.*, 2013), have been constructed, but also some excellent research results have been achieved in the topics such as vector magnetic field observations, observational study of solar eruptions, MHD simulations of solar eruptions, and spectroscopy and modeling of the solar atmosphere. The number of papers published by Chinese solar physicists is now ranked third among all countries in the world and the number of total citations is ranked fifth.

However, space exploration in China is still far behind compared with leading countries. Japan launched the *Hinode* satellite in 2006 with a spatial resolution of up to 0.3 arcsec. *Solar Dynamics Observatory* (SDO), launched by the US in 2010, can simultaneously conduct multi-waveband observations of the chromosphere, transition region and corona. These satellites have yielded a large number of research papers. During this period, China has also proposed some space programs which, however, were temporarily suspended or canceled.

To our delight, the first solar satellite of China, the *Advanced Space-based Solar Observatory* (ASO-S), which is led by Weiqun Gan, has been officially approved and is expected to be launched in around 2022. We are still on the way to go ahead.

China is undergoing a rapid economic growth. This provides a solid basis for the development of scientific research including astronomy. Looking forward to the future, solar physicists in China are striving for two key projects: "One for space and One for ground". "One for space" refers to the *Deep Space Solar Observatory* (DSO), which will conduct high-resolution observations of solar magnetic fields, imaging and spectral observations of solar eruptions. This will enable in-depth study of the origin of solar activity. "One for ground" refers to the *Great Solar Observatory* of China, including a *Chinese Giant Solar Telescope* (CGST) and a coronagraph. CGST has a five-meter effective diameter and will be among the largest solar telescopes in the world if successfully completed.

It can be said that my career is an epitome of the development of solar physics in China. I feel gratified that I have devoted my whole life to solar physics, and have made some contributions, though insignificant, to our country and to the solar physics community.

Although I am now 80 years old, I am still working on the front stage instead of staying at home to enjoy a pressure-free life. "Idle boast the strong pass is a wall of iron, with firm strides we are crossing its summit". In the 21st century, I am still chasing the Sun, trying to explore its mysteries and to realize the Chinese Dream of rejuvenation in science!

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References

Avrett, E.H., Machado, M.E., Kurucz, R.I.: 1986, Chromospheric flare models. In: Neidig, D.F. (ed.) *The Lower Atmosphere in Solar Flares, Sunspot, NM*, *National Solar Observatory*, 216.

Cao, W., Gorceix, N., Coulter, R., Ahn, K., Rimmele, T.R., Goode, P.R.: 2010, Scientific instrumentation for the 1.6 m New Solar Telescope in Big Bear. *Astron. Nachr.* **331**, 636. DOI.

Chae, J., Park, H.-M., Ahn, K., Yang, H., Park, Y.-D., Nah, J., *et al.*: 2013, Fast Imaging Solar Spectrograph of the 1.6 meter new solar telescope at Big Bear Solar Observatory. *Solar Phys.* **288**, 1. DOI.

Chen, P.F.: 2011, Coronal mass ejections: models and their observational basis. *Living Rev. Solar Phys.* **8**, 1. DOI.

Chen, P.F., Fang, C., Ding, M.D.: 2001, Ellerman Bomb, Type II white-light flares and magnetic reconnection in the solar lower atmosphere. *Chin. J. Astron. Astrophys.* **1**, 176. DOI.

Chen, P.F., Fang, C., Shibata, K.: 2005, A full view of EIT waves. *Astrophys. J.* **622**, 1202. DOI.

Cheng, X., Hao, Q., Ding, M.D., Liu, K., Chen, P.F., Fang, C., Liu, Y.: 2015, A two-ribbon white-light flare associated with a failed solar eruption observed by ONSET, SDO, and IRIS. *Astrophys. J.* **809**, 1. DOI.

De Pontieu, B., Title, A.M., Lemen, J.R., Kushner, G.D., Akin, D.J., Allard, B., *et al.*: 2014, The Interface Region Imaging Spectrograph (IRIS). *Solar Phys.* **289**, 2733. DOI.

Ding, M.D., Fang, C.: 1989, A semi-empirical model of sunspot penumbra. *Astron. Astrophys.* **225**, 204.

Ding, M.D., Fang, C.: 1991, A semi-empirical model of sunspot umbra. *Chin. Astron. Astrophys.* **15**, 28. DOI.

Ding, M.D., Fang, C.: 1997, Influence of non-thermal processes on line asymmetries in solar flares. *Astron. Astrophys.* **318**, L17.

Ding, M.D., Hénoux, J.-C., Fang, C.: 1998, Line profiles in moustaches produced by an impacting energetic particle beam. *Astron. Astrophys.* **332**, 761.

Ding, M.D., Fang, C., Gan, W.Q., Okamoto, T.: 1994, Optical spectra and semi-empirical model of a white-light flare. *Astrophys. J.* **429**, 890. DOI.

Ellerman, F.: 1917, *Astrophys. J.* **46**, 298. DOI.

Fang, C.: 1988, Semi-empirical models of chromospheric flares and prominences. *Vistas Astron.* **31**, 1. DOI.

Fang, C.: 2011, Recent progress of solar physics research in China. *Res. Astron. Astrophys.* **11**, 1377. DOI.

Fang, C.: 2015, Past, present and future of Chinese astronomy. *Highlights Astron.* **16**, 19. DOI.

Fang, C., Ding, M.D.: 1995, On the spectral characteristics and atmospheric models of two types of white-light flares. *Astron. Astrophys. Suppl. Ser.* **110**, 99.

Fang, C., Feautrier, N., Hénoux, J.-C.: 1995, Hydrogen line spectra of a nonthermal proton beam due to charge exchange in solar flares. *Astron. Astrophys.* **297**, 854.

Fang, C., Hénoux, J.-C.: 1983, Self-consistent models of flare heated solar chromosphere. *Astron. Astrophys.* **118**, 139.

Fang, C., Hénoux, J.-C., Gan, W.Q.: 1993, Diagnostics of non-thermal processes in chromospheric flares I. Hα and Ca II K line profiles of an atmosphere bombarded by hecta KeV electrons. *Astron. Astrophys.* **274**, 917.

Fang, C., Huang, Y.R.: 1983, The solar tower telescope of Nanjing university and its multiple solar spectrograph. *Acta Astron. Sin.* **24**, 189.

Fang, C., Tang, Y.H., Xu, Z.: 2006, Spectral analysis and atmospheric models of microflares. *Chin. J. Astron. Astrophys.* **6**, 597. DOI.

Fang, C., Xu, Z., Ding, M.D.: 2003, Spectral diagnostics of non-thermal particles in the solar chromosphere. *J. Korean Astron. Soc.* **36**, 55.

Fang, C., Gan, W.Q., Huang, Y.R., Hu, J.: 1986, Semi-empirical time-varying models of chromospheric flares. In: Neidig, D.F. (ed.) *The Lower Atmosphere of Solar Flares*, 117.

Fang, C., Zhang, Q.Z., Yin, S.Y., Livingston, W.C.: 1990, Semi-empirical models at different heights of a quiescent prominence. In: *Dynamics of Quiescent Prominences*, 284. DOI.

Fang, C., Ding, M.D., Okamoto, T., Gan, W.Q.: 1993, Semi-empirical model of the white light flare on September 19, 1979. *Sci. China Ser. A* **36**, 217

Fang, C., Hénoux, J.-C., Hu, J., Xue, Y.Z., Gao, X.F., Fu, Q.J.: 1995, Semi-empirical models of the white-light flare on October 24, 1991. *Solar Phys.* **157**, 271. DOI

Fang, C., Ding, M.D., Hénoux, J.-C., Gan, W.Q.: 1996, Spectral diagnostics of the energetic particles in solar flares. *J. Korean Astron. Soc.* **29**, 295.

Fang, C., Ding, M.D., Hénoux, J.-C., Livingson, W.C.: 2001, Semi-empirical model of solar plages. *Sci. China Ser. A* **44**, 528.

Fang, C., Tang, Y.H., Xu, Z., Ding, M.D., Chen, P.F.: 2006, Spectral analysis of Ellerman bombs. *Astrophys. J.* **643**, 1325. DOI.

Fang, C., Chen, P.F., Jiang, R.L., Tang, Y.H.: 2010, Synthetic analysis of a two-ribbon microflare. *Res. Astron. Astrophys.* **10**, 83. DOI.

Fang, C., Chen, P.F., Li, Z., Ding, M.D., Dai, Y., Zhang, X.Y., Mao, W.J., *et al.*: 2013, ONSET – a new multi-wavelength solar telescope: optical and Near-infrared Solar Eruption Tracer (ONSET). *Res. Astron. Astrophys.* **13**, 1509. DOI.

Fang, C., Hao, Q., Ding, M.D., Li, Z.: 2017, Can the temperature of Ellerman bombs be more than 10000 K? *Res. Astron. Astrophys.* **17**, 31. DOI.

Fletcher, L., Hannah, I.G., Hudson, H.S., Metcalf, T.R.: 2007, A TRACE white light and RHESSI hard X-ray study of flare energetics. *Astrophys. J.* **656**, 1187. DOI.

Gan, W.Q., Cheng, C.C., Fang, C.: 1995, On thermal hydrodynamic models of solar flares with a high initial coronal density. *Astrophys. J.* **452**, 445. DOI.

Gan, W.Q., Fang, C.: 1987, Time-match semi-empirical models of the chromospheric flare on 3 February, 1983. *Solar Phys.* **107**, 311. DOI

Gan, W.Q., Fang, C.: 1990, A hydrodynamic model of the gradual phase of the solar flare loop. *Astrophys. J.* **358**, 328. DOI.

Gan, W.Q., Fang, C., Zhang, H.Q.: 1991, A hydrodynamic model of the impulsive phase of a solar flare loop. *Astron. Astrophys.* **241**, 618.

Gan, W.Q., Rieger, E., Fang, C.: 1993, Semiempirical flare models with chromospheric condensation. *Astrophys. J.* **416**, 886. DOI.

Goode, P.R., Cao, W.: 2012, The 1.6 m off-axis new solar telescope (NST) in Big Bear. *Proc. SPIE* **8444**, 3. DOI.

Hao, Q., Guo, Y., Dai, Y., Ding, M.D., Li, Z., Zhang, X.Y., Fang, C.: 2012, Understanding the white-light flare on 2012 March 9: evidence of a two-step magnetic reconnection. *Astron. Astrophys.* **544**, L17. DOI.

Hao, Q., Yang, K., Cheng, X., Guo, Y., Fang, C., Ding, M.D., *et al.*: 2017, A circular white-light flare with impulsive and gradual white-light sources. *Nat. Commun.* **8**, 2202. DOI.

Hénoux, J.-C., Fang, C., Gan, W.Q.: 1993, Diagnostics of non-thermal processes in chromospheric flares II. Hα and Ca II K line profiles for an atmosphere bombarded by 100 KeV–1 MeV protons. *Astron. Astrophys.* **274**, 923.

Hénoux, J.-C., Fang, C., Gan, W.Q.: 1995, Diagnostics of non-thermal processes in chromospheric flares III. Lyα and Lyβ spectra for an atmosphere bombarded by electron or proton beams. *Astron. Astrophys.* **297**, 574.

Hiei, E.: 1982, A continuous spectrum of a white-light flare. *Solar Phys.* **80**, 113. DOI.

Hong, J., Ding, M.D., Li, Y., Fang, C., Cao, W.: 2014, Spectral observations of Ellerman bombs and fitting with a two-cloud model. *Astrophys. J.* **792**, 13. DOI.

Hong, J., Ding, M.D., Li, Y., Yang, K., Cheng, X., Chen, P.F., *et al.*: 2016, Bidirectional outflows as evidence of magnetic reconnection leading to a solar microflare. *Astrophys. J. Lett.* **820**, 17. DOI.

Hu, J., Fang, C., Ding, M.D., Hiei, E.: 1994, Study of the white light flares of September 10, 1974. *Acta Astron. Sin.* **35**, 396.

Huang, Y.R., Fang, C., Hu, J.: 1985, Is the continuum flare emission in the visible spectral range a very rare event? In: Biao, C. (ed.) *Proc. Kunming Workshop on Solar Physics and Interplanetary Travelling Phenomena*, Science Press, Beijing, 728.

Huang, Y.R., Fang, C., Hu, J.: 1986, Continuum emission of flares on December 30, 1982 and on February 3, 1983. In: Neidig, D.F. (ed.) *The Lower Atmosphere of Solar Flares* **3**, 178.

Hudson, H.S.: 2016, Chasing white-light flares. *Solar Phys.* **291**, 1273. DOI.

Hudson, H.S., Wolfson, C.J., Metcalf, T.R.: 2006, White-light flares: a TRACE/RHESSI overview. *Solar Phys.* **234**, 79. DOI.

Isobe, H., Kubo, M., Minoshima, T., Ichimoto, K., Katsukawa, Y., Tarbell, T.D., *et al.*: 2007, Flare ribbons observed with G-band and Fe I 6302 Å, filters of the solar optical telescope on board Hinode. *Publ. Astron. Soc. Japan* **59**, 807. DOI.

Jess, D.B., Mathioudakis, M., Crockett, P.J., Keenan, F.P.: 2008, Do all flares have white-light emission? *Astrophys. J. Lett.* **688**, L119. DOI.

Jiang, R.L., Fang, C., Chen, P.F.: 2010, Numerical simulations of chromospheric microflares. *Astrophys. J.* **710**, 1387. DOI.

Jiang, R.L., Fang, C., Chen, P.F.: 2012, Numerical simulation of solar microflares in a canopy-type magnetic configuration. *Astrophys. J.* **751**, 152. DOI.

Jiang, R.L., Shibata, K., Isobe, H., Fang, C.: 2011a, Fan-shaped jets in three-dimensional reconnection simulation as a model of ubiquitous solar jets. *Astrophys. J. Lett.* **726**, L16. DOI.

Jiang, R.L., Shibata, K., Isobe, H., Fang, C.: 2011b, Detailed analysis of fan-shaped jets in three dimensional numerical simulation. *Res. Astron. Astrophys.* **11**, 701. DOI.

Kerr, G.S., Fletcher, L.: 2014, Physical properties of white-light sources in the 2011 February 15 solar flare. *Astrophys. J.* **783**, 98. DOI.

Kuhar, M., Krucker, S., Martinez Oliveros, J.C., Battaglia, M., Kleint, L., Casadei, D., Hudson, H.S.: 2016, Correlation of hard X-ray and white light emission in solar flares. *Astrophys. J.* **816**, 6. DOI.

Li, Z., Fang, C., Guo, Y., Chen, P.F., Xu, Z., Cao, W.D.: 2015, Diagnostics of Ellerman bombs with high-resolution spectral data. *Res. Astron. Astrophys.* **15**, 1513. DOI.

Liu, Y., Ding, M.D., Fang, C.: 2001, Enhanced emission at the infrared continuum in the flare of 2001 March 10. *Astrophys. J. Lett.* **563**, 169. DOI.

Liu, Z., Xu, J., Gu, B.Z., Wang, S., You, J.Q., Shen, L.X., *et al.*: 2014, New vacuum solar telescope and observations with high resolution. *Res. Astron. Astrophys.* **14**, 705. DOI.

Machado, M.E., Avrett, E.H., Vernazza, J.E., Noyes, R.W.: 1980, Semi-empirical models of chromospheric flare regions. *Astrophys. J.* **242**, 336. DOI.

Machado, M.E., Avrett, E.H., Falciani, R., Fang, C., Gesztelyi, L., Hénoux, J.-C., Hiei, E., Neidig, D.F., Rust, D.M., Sotirovski, P., Svestka, Z., Zirin, H.: 1986, White light flares and atmospheric modeling (working group report). In: Neidig, D.F. (ed.) *The Lower Atmosphere of Solar Flares*, 483.

Matthews, S.A., van Driel-Gesztelyi, L., Hudson, H.S., Nitta, N.V.: 2003, A catalogue of white-light flares observed by Yohkoh. *Astron. Astrophys.* **409**, 1107. DOI.

Neidig, D.F., Cliver, E.: 1983, A catalog of solar white-light flares, including their statistical properties and associated emissions, 1859–1982. NASA STI/Recon Tech. Rep. N 84, 24521.

Nelson, C.J., Doyle, J.G., Erdelyi, R., Huang, Z., Madjarska, M.S., Mathioudakis, M., *et al.*: 2013, Statistical analysis of small Ellerman Bomb events. *Solar Phys.* **283**, 307. DOI.

Peter, H., Tian, H., Curdt, W., Schmit, D., Innes, D., De Pontieu, B., *et al.*: 2014, Hot explosions in the cool atmosphere of the Sun. *Science* **346**, 1255726. DOI.

Shimizu, T., Shine, R.A., Title, A.M., Tarbell, T.D., Frank, Z.: 2002, *Astrophys. J.* **574**, 1074. DOI.

Song, Y.L., Guo, Y., Tian, H., Zhu, X.S., Zhang, M., Zhu, Y.J.: 2018, *Astrophys. J.* **853**, 64. DOI.

Tandberg-Hanssen, E.: 1995 In: *The Nature of Solar Prominences*, *Astrophysics and Space Science Library*, Dordrecht, Kluwer.

Tian, H., Xu, Z., He, J., Madsen, C.: 2016, Are IRIS bombs connected to Ellermen bombs? *Astrophys. J.* **824**, 96. DOI.

Uddin, W., Schmieder, B., Chandra, R., Srivastava, A.K., Kumar, P., Bisht, S.: 2012, Observations of multiple surges associated with magnetic activities in AR 10484 on 2003 October 25. *Astrophys. J.* **752**, 70. DOI.

Vernazza, J.E., Avrett, E.H., Loeser, R.: 1981, Structure of the solar chromosphere. III. Models of the EUV brightness components of the quiet-sun. *Astrophys. J. Suppl.* **45**, 635. DOI.

Vissers, G.J.M., Rouppe van der Voort, L.H.M.: 2012, Flocculent flows in the chromospheric canopy of a sunspot. *Astrophys. J.* **750**, 22. DOI.

Wang, H.M.: 2009, Study of white-light flares observed by Hinode. *Res. Astron. Astrophys.* **9**, 127. DOI.

Watanabe, K., Krucker, S., Hudson, H., Shimizu, T., Masuda, S., Ichimoto, K.: 2010, G-band and Hard X-ray emissions of the 2006 December 14 flare observed by Hinode/SOT and Rhessi. *Astrophys. J.* **715**, 651. DOI.

Xia, C., Fang, C., Chen, Q.R., Tang, Y.H.: 2007, Spectral analysis of a two-ribbon microflare. *Adv. Space Res.* **39**, 1402. DOI.

Xu, Z., Fang, C., Gan, W.Q.: 2005, Multi-wavelength diagnostics of bombardment by non-thermal particles in solar flares. *Chin. J. Astron. Astrophys.* **5**, 519. DOI.

Xu, Y., Cao, W., Liu, C., Yang, G., Qiu, J., Jing, J., Denker, C., Wang, H.: 2004, Near-infrared observations at 1.56 microns of the 2003 October 29 X10 white-light flare. *Astrophys. J. Lett.* **607**, 131. DOI.

Xu, X.Y., Fang, C., Ding, M.D., Gao, D.H.: 2011, Numerical simulation of magnetic reconnection in the lower solar atmosphere. *Res. Astron. Astrophys.* **11**, 225. DOI.

Yan, Y.H., Chen, L.J., Yu, S.J.: 2016, First radio burst imaging observation from Mingantu Ultrawide Spectral Radioheliograph in solar and stellar flares and their effects on planets. In *Proceedings of the IAU Symposium* **320**, 427. DOI.

Yin, S.Y., Fang, C., Ding, M.D., Hiei, E., Fu, W.J.: 1995, Spectral analysis of the white light flare on 11 October, 1974. *Acta Astron. Sin.* **36**, 279

Zhang, Q.Z., Fang, C.: 1987, Semi-empirical models of a quiescent prominence. *Astron. Astrophys.* **175**, 277.

Zhao, X., Fang, C., Hénoux, J.-C.: 1998, Non-thermal hydrogen line emission caused by an oblique incident proton beam through charge exchange. *Astron. Astrophys.* **330**, 351.