Space Astronomy and Solar Physics in 2011—2012

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Abstract

In the first part of this report we describe briefly the mid and long-term plan of Chinese space astronomy, its preliminary study program, the current status of satellite missions undertaken, and the current status of astronomy experiments in China's manned space flight program. In the second part, we summarize briefly the recent research progress made in the fields of solar physics, including solar vector magnetic field, solar flares, CME, and filaments, solar radio and non-thermal processes, EUV waves, MHD waves, and coronal waves, solar model and helioseismology, solar wind and behavior of solar cycle.

1 Space Astronomy

1.1 Mid and Long-term Plan of Chinese Space Astronomy

In 2009, "Space Science & Technology in China: A Roadmap to 2050" was published. This report was mostly based on "The Strategic Report of Long-term Plan of Chinese Space Sciences (2011–2025)". Space Astronomy is an important part of these two reports. Six programs belonging to space astronomy were proposed in this plan:

Black Hole Probe (BHP) Program: through observations of compact objects such as all kinds of black holes and gamma-ray bursts, to study high-energy processes of cosmic objects and black hole physics. Using extreme objects such as black holes as examples of how stars and galaxies evolve, to explore the extreme physical processes and laws in the universe.

Diagnostics of Astro-Oscillations (DAO) Program: to make high-precision photometric and timing measurements of electromagnetic radiation at various wavebands and non-electromagnetic radiation, in order to understand the internal structures of various astrophysical objects and the process of various violent activities.

Portraits of Astrophysical Objects (PAO) Program: to obtain direct photographs (portraits) of astrophysical objects beyond the solar system such as solar-like stars, exoplanets, white dwarfs, neutron stars, and black holes which are essential for understanding scientific questions such as the construction of the universe.

Dark Matter Detection (DMD) Program: based on space platforms, to detect the products of dark matter annihilation predicted in various theoretical models.

Solar Microscope (SM) Program: to study the physical processes such as interior solar structure and evolution, magnetic origin, coronal configuration and dynamics with multi-waveband and higher spatial resolution observations.

Solar Panorama (SP) Program: to study solar behavior on the whole, and establish a connection between the small-scale motion and the large-scale consequences, by diagnosing the solar variations via multi-waveband observations.

For each program, there are some mission candidates listed into the roadmap on the time scale of 2010–2020, 2020–2035, and 2035–2050. Most mission candidates are only in a phase of conception, and need to be studied by further phases.

1.2 Preliminary Study Program

Following the execution of the first round of preliminary study program of future space science missions in 2009, Chinese Academy of Sciences initiated the second round of the program in 2011, within the frame work of the Pilot Special Project of Space Science, by supporting a number of assessment studies and key technology R&D for future space missions:

DAO

Phase-A study: X-ray Timing and Polarization Satellite (XTP).

Phase-0 study: Wide-Field X-ray and Optical Monitor.

Phase-0 study: China's Space Gravitational Wave Detection.

PAO

Phase-0 study: Large Scale Multi-Color and Imaging and Spectroscopy Survey.

Phase-0 study: Infrared Spectroscopic Survey Space Telescope.

Technology R&D: Space Optical Interferometry Telescope.

Technology R&D: Space High Contrast Coronagraph.

DMD

Technology R&D: New High Energy Gamma-ray and Electron Detectors.

Technology R&D: Large Size BGO Scintillator Growth.

Technology R&D: New Space Dark Matter Detector Based on Fiber-ICCD Read out.

SM

Technology R&D: Space Magnetometer.

Technology R&D: Solar Hard X-ray Imaging Telescope.

SP

Phase-0 study: Advanced Space Solar Observatory.

Technology R&D: Lyman-α Telescope and Coronagraph.

1.3 Status of Satellite Missions Undertaken

There are several satellite missions currently at different stages of development:

HXMT

The Hard X-ray Modulation Telescope (HXMT) is a collimated broad-band X-ray (1−250 keV) telescope, which is composed of eighteen modules of NaI(Tl)/CsI(Na) phoswich detectors operating between 20−250 keV, three modules of SCD detectors operating between 1−15 keV, and three modules of SiPIN detectors operating between 5−30 keV. Its main objectives include large area sky surveys and pointed observations of Galactic compact objects emitting X-rays. It is currently in Phase C and expected to be launched between 2014 and 2015 into a low earth orbit.

SVOM

Space-based multi-band astronomical Variable Object Monitor (SVOM) is a joint China-France mission. Its scientific objectives include the study of the GRB phenomenon, GRB physics and progenitors, cosmology, and fundamental physics. The payloads include: A wide field (~2 sr) coded mask telescope (ECLAIRs, 4−250 keV); a gamma-ray monitor (GRM, 50 keV−5 MeV); a soft X-ray (MXT) and a Visible Telescope (VT). It is currently in Phase B and expected to be launched around 2015-2016 into a low earth orbit.

POLAR

POLAR is a China-Europe joint experiment on board China's manned spacelab. Its main scientific goal is to measure gamma-ray burst polarization between 30−350 keV. The instrument is made of a stack of plastic scintillators with a total weight of 30 kg. It is expected that POLAR will be launched into orbit in 2014 with the TG-2 spaceship, as part of the spacelab.

DMS

Dark Matter Satellite (DMS) is a high energy electron and gamma-ray telescope covering energy range from 5 GeV to 10 TeV. With high resolution observations of gamma-rays and electrons, it aims at finding the products of the annihilation or decay from dark matter particles. The energy resolution is 10 times higher than FERMI gamma-ray telescope, and geometry factor is 5 times bigger than CALET. DMS is actually now at the stage of Phase-A, and is expected to be launched around 2015 into a low earth orbit.

SST

Space Solar Telescope (SST) is consisted of a one-meter optical telescope, a hard X-ray telescope, an EUV imager, an energetic particle receiver, and a solar radio spectrometer at very low frequencies, *etc*. It is now selected to be launched to the first Lagrangian point (L_1) of the Sun-Earth system in about five years.

1.4 Status of Astronomy Experiments in China's Manned Space Flight Program

Astronomy observations from space are a solid element of China's manned space flight program:

TG-2 Spacelab: POLAR

See the description in Section 1. 3.

Space Station: the Cosmic Light House Program (CLH)

CLH is the astronomy program onboard China's Space Station, with an operation time around 2020. In 2011, the call for astronomy payloads proposals was announced. Among many submitted proposals, nine are selected for further studies as candidate payloads, with scientific objectives ranging from black holes, dark matter, dark energy, neutron stars, stars, the Milky Way, galaxies, large scale structures, solar physics, *etc*. The program is open to the international community and international collaborations are encouraged.

2 Space Solar Physics

During the last two years, the Chinese solar physicists made a great progress in solar physics researches by using all kinds of space observations at multi-wavelengths. The observations include the magnetograph obtained by SOHO/MIDI and Hinode, EUV by TRACE, STEREO and SDO, hard X-ray by RHESSI, soft X-ray by GOES and Hinode, *etc*. The research subjects include solar vector magnetic field, Solar flares, CME, filaments, solar radio and nonthermal processes, EUV Waves, MHD waves, and coronal waves, solar model and helioseismology, solar wind, and the behaviors of the solar cycle. They published about 120 papers in various academic journals, such as ApJ (49 papers), Solar Physics (19 papers), and A&A (10 papers), *etc*.

2.1 Solar Vector Magnetic Field

Yang *et al*.[1] investigated vector magnetic fields, current densities, and current helicities in coronal holes, and compared them with two normal Quiet Regions (QRs) for the first time from the observations of Hinode. They found that the areas where large current helicities are located are mainly co-spatial with strong vertical and horizontal field elements both in shape and in location. In the CHs, horizontal magnetic fields, inclination angles, current densities, and current helicities are larger than those in the QRs. These results imply that the magnetic fields, especially the strong fields, both in the CHs and in the QRs are non-potential.

Jin *et al*.[2] studied the cyclic behavior of solar small-scale magnetic elements by using the database of MDI/SOHO in solar cycle 23, and the follwoing results are found. (1) The quiet regions dominated the Sun's magnetic flux for about 8 years in the 12.25 years duration of cycle 23. (2) The ratio of quiet region flux to that of the total Sun equally characterizes the course of a solar cycle. The 6 month average flux ratio of the quiet regions was larger than 90.0% for 28 continuous months from July 2007 to October 2009, which very well characterizes the grand solar minima of cycles 23–24. (3) From the small to the large end of the flux spectrum, the variations of numbers and total flux of the network elements show non-correlation, anti-correlation, and correlation with sunspots, respectively.

Jin and Wang[3] studied the vector magnetic fields of a solar polar region (PR) based on measurements of SOT/SP on Hinode, and found (1) the average vertical flux density of PR is 16 G, while the average horizontal flux density is 91 G. (2) The kilo-Gauss field in the PR occupies 6.7% of the region. The magnetic filling factor in the PR is characterized by a two-peak distribution, which appears at strength close to 100 G and 1000 G, respectively. (3) For the network elements, a correlation holds between the vertical and horizontal flux densities, suggesting the same physical entity is manifested by the observed stronger vertical and horizontal components. (4) The ratio of the magnetic flux in the minority polarity to that in the dominant polarity is approximately 0.5, implying that only 1/3 of the magnetic flux in the PR opens to the interplanetary space.

Su *et al*.[4] analyzed photospheric vector magnetograms of solar flares to studied the evolution of photospheric magnetic fields. In particular, they investigate two-dimensional spatial distributions of the changing Lorentz force. Around the major flaring polarity inversion line, the net change of the Lorentz force is directed downward in an area of ~10^{19} cm^2 for X-class flares. For all events, the white-light observations show that sunspots darken in this location after flares, and magnetic fields become more inclined.

Jin and Wang[5] applied the unique data set of MDI/SOHO in solar cycle 23, and found that the cyclic variations of numbers and total flux of the small-scale magnetic elements covering fluxes of (2.9–32.0)×10^{18} Mx and (4.27–38.01)×10^{19} Mx behaving anti-correlated and correlated with sunspots, respectively.

Zhao *et al*.[6] analyzed the correlation between the Magnetic and Velocity Fields on the Full Solar Disk, and found that the observed large-scale weak magnetic field (weaker than 50 Gauss) is correlated with the velocity statistically.

2.2 Solar Flares, CME and Filaments

Cheng *et al*.[7] investigated the distinct properties of two types of flares: eruptive flares associated with CMEs and confined flares without CMEs. The sample includes nine M- and X-class flares, six of them are confined and other three are eruptive. The confined flares tend to be more impulsive in the soft X-ray time profiles and show slenderer shapes in the EIT 195 Å images, while the eruptive ones are long-duration events and show much more extended brightening regions. The location of the confined flares is closer to the center of the active region, while the eruptive flares are at the outskirts. Further, through nonlinear force-free field extrapolation, they found that the decay index of the transverse magnetic field in the low corona (~10 Mm) is larger for eruptive flares than for confined ones. The strength of the transverse magnetic field over the eruptive flare sites is weaker than it is over the confined ones.

Fan *et al*.[8] used the Poynting flux in active region 10930 by using data-driven time-dependent multidimensional MHD simulations around a flare event. The data have been obtained by the Hinode/SOT. They computed the magnitude of Poynting flux (S total), radial Poynting flux (Sz), a proxy for ideal radial Poynting flux (S proxy), Poynting flux due to plasma surface motion (S sur), and Poynting flux due to plasma emergence (S emg), and analyzed their extensive properties in four selected areas: the whole sunspot, the positive sunspot, the negative sunspot, and the strong-field polarity inversion line (SPIL) area. They found that (1) the S total, Sz and S proxy parameters show similar behaviors in the whole sunspot area and in the negative sunspot area. The evolutions of these three parameters in the positive area and the SPIL area are more volatile because of the effect of sunspot rotation and flux emergence. (2) The evolution of S sur is largely influenced by the process of sunspot rotation, especially in the positive sunspot. The evolution of S emg is greatly affected by flux emergence, especially in the SPIL area.

Guo *et al*.[9] studied the magnetic field structures of hard X-ray (HXR) sources and flare ribbons of an M1.1 flare by using RHESSI and TRACE observations and nonlinear force-free field extrapolation over the same polarity inversion line. They found a small pre-eruptive magnetic flux rope located next to sheared magnetic arcades, the magnetic reconnection occurred at several locations. It first started at the location of the pre-eruptive flux rope; then, the magnetic reconnection occurred between the pre-eruptive magnetic flux rope and the sheared magnetic arcades more than 10 minutes before the flare peak; next, HXR sources appeared at the footpoints of the larger flux rope at the flare peak. The associated high-energy particles may have been accelerated below the flux rope in or around a reconnection region.

Zhang *et al*.[10] applied time-dependent MHD simulation to investigate how physical features in the solar atmosphere affect the evolution of CMEs. They found that temperature and density play a crucial role in CME initiation. The lower temperature facilitates the catastrophe's occurrence, and the CMEs which initiate in low density could gain lower velocity.

Huang *et al*.[11] presented a detailed studied of the initiation and early development of a CME by using high temporal cadence radio observations and EUV observations combining three points of view of the STEREO and SOHO spacecraft. The beginning of the CME initiation phase is characterized by the magnetic reconnection. They found that imaging radio emissions in the metric range permits us to trace the extent and orientation of the flux rope which is later detected in interplanetary space.

Shen *et al*.[12] performed resistive MHD simulations to studied the internal fine structure of reconnecting current sheets that form during solar flares.

Shen *et al*.[13] reported a coronal blowout jet with high-resolution multi-wavelength and multi-angle observations taken from SDO, STEREO, and BBSO. For the first time, they found that simultaneous bubble-like and jet-like CMEs were dynamically related to the blowout jet that showed cool and hot components next to each other, and indicate that (1) the cool component resulted from the eruption of the filament contained within the jet's base arch, and it further caused the bubble-like CME; (2) the jet-like CME was associated with the hot component, which was the outward moving heated plasma generated by the reconnection of the base arch and its ambient open field lines. On the other hand, bifurcation of the jet's cool component was also observed, which resulted from the uncoupling of the erupting filament's two legs that were highly twisted at the very beginning. They proposed that the coronal blowout jet, in which the external reconnection not only produces the jet-like CME, but also leads to the rising of the filament, and the internal reconnection starts underneath the rising filament and causes bubble-like CME.

Ting Li *et al*.[14] reported a three-dimensional reconstruction of an erupting filament with SDO and STEREO Observations from three different viewpoints (STEREO A, STEREO B, and SDO) for the first time. The event mainly consisted of a C3.2 flare, a polar crown filament eruption, and two Earth-directed CMEs.

Jiang *et al*.[15] presented for the first time detailed observations of three successive, interdependent filament eruptions that occurred one by one within 5 hr from different locations beyond the range of a single active region, and found the sympathetic filament eruptions connected by coronal dimmings.

Jiang *et al*.[16] presented observations of sunspot evolution associated with the first X-class flare of the presented solar cycle 24, which occurred in AR 11158 on 2011 February 15, and the observations support the idea that the rotation can be attributed to the emergence of twisted magnetic fields.

Xia *et al*.[17] used grid-adaptive numerical simulations of the radiative hydrodynamic equations to investigate the filament formation process in a pre-shaped loop with both steady and finite-time chromospheric heating.

Liu *et al*.[18] statistically studied 362 solar limb prominences and well recognized by STEREO observations from 2007 April to the end of 2009. They found that there are about 71% disrupted prominences (DPs), among which about 42% did not erupt successfully and about 89% experienced a sudden destabilization process. Most DPs become unstable at a height of 0.06–0.14 R_s from the solar surface, and there are two most probable critical heights at which a prominence is very likely to become unstable, the first one is 0.13 R_s and the second one is 0.19 R_s; an upper limit for the erupting velocity of eruptive prominences (EPs) exists, which decreases following a power law with increasing height and mass; accordingly, the kinetic energy of EPs has an upper limit too, which decreases as the critical height increases.

Ding *et al.*[19] investigated the formation of jet-like features in the lower solar atmosphere, *e.g.* chromosphere and transition region, as a result of magnetic reconnection triggered by magnetic flux emergence. They found that magnetic reconnection can be an efficient mechanism to drive plasma outflows in the chromosphere and transition region.

Zhou *et al.*[20] used the STEREO A/B to calculate the interplanetary current sheets for the magnetic cloud related to the fast halo CME of 2006 December 13 with assembled observations.

Li *et al.*[21] used SOHO/MDI magnetograms, STEREO/SECCHI images, and GOES measurements to investigate the first productive active region in solar cycle 24, where emerged on February 5, 2010, is associated with 43 (8 M- and 35 C-class) flares, 53 coronal mass ejections (CMEs), 29 filament eruptions, 19 extreme ultraviolet (EUV) waves and abundant jets.

Chen *et al.*[22] investigated fifty Interconnecting Loops (ILs) that are induced by new-born active regions.

Gao *et al.*[23] investigated the energy and mass distributions of all CMEs observed by SOHO/LASCO from January 1996 to December 2009.

Feng *et al.*[24] conducted a data survey searching for well-defined streamer wave events observed by the LASCO) on-board SOHO throughout Solar Cycle 23.

Pan *et al.*[25] investigated the relationships between the kinematic properties of these CMEs and the characteristic times of the intensity-time profile of their accompanied SEP events observed at 1 AU by using an ice-cream cone model, the radial speed and angular width of 95 CMEs associated with SEP events during 1998−2002 from SOHO/LASCO observations.

Gui *et al.*[26] analyzed ten CME events viewed by the STEREO twin spacecraft observations to studied the deflections of CMEs during their propagation in the corona. They found that the deflections of CMEs are mainly controlled by the background magnetic field and can be quantitatively described by the magnetic energy density gradient model.

Yang *et al.*[27] presented detailed observations of the formations of four distinct coronal dimmings during a flare of 17 September 2002, which was followed by an eruption of a huge coronal loop system, and then an over-and-out partial halo CME, with the same direction as the loop system eruption but laterally far offset from the flare site.

Song *et al.*[28] presented 11 events with plasma blobs flowing outwards sequentially along a bright coronal ray in the wake of a CME by a survey through LASCO data from 1996 to 2009. They found that the apparent angular widths of the rays at a fixed time vary in a range of 2.1°–6.6° (2.0°– 4.4°) with an average of 3.5° (2.9°) at $3R_s$ ($4R_s$), respectively, and the observed durations of the events vary from 12 h to a few days with an average of 27 h. It is also found, that 58% (26) of the blobs were accelerated, 20% (9) were decelerated, and 22% (10) moved with a nearly constant speed.

2.3 Solar Radio and Nonthermal Processes

Huang and Li[29] made a co-analysis of solar hard X-ray and microwave spectral evolution in three separate sources located in one looptop and two footpoints of a huge flaring loop in the 2003 October 24 flare from the spatially resolvable data of the RHESSI and Nobeyama Radio Heliograph.

Huang and Tan[30] reported the microwave bursts with fine structures in the decay phase of a solar flare observed by the Chinese Solar Broadband Radio Spectrometer in Huairou, which showed a peak-to-peak correlation with 25−50 keV hard X-ray bursts observed by RHESSI. The similarity between 25 and 50 keV HXR light curve and microwave time profiles suggests that these microwave FSs are related to the properties of electron acceleration. The electron velocity inferred from the frequency drift rates in short narrowband bursts is in the range of 0.13−0.53c and the corresponding energy is about 10−85 keV, which is close to the energy of HXR-emitting electrons.

Tan *et al.* [31] reported several microwave zebra pattern structures in an X2.2 flare event on 2011 February 15 observed by the Chinese Solar Broadband Radio Spectrometer (SBRS/Huairou) at a frequency of 6.40–7.00 GHz and at a frequency of 2.60–2.75 GHz and by the Yunnan Solar Broadband Radio Spectrometer (SBRS/Yunnan) at a frequency of 1.04–1.13 GHz. They derived the magnetic field strengths at about 230–345 G, 126–147 G, and 23–26 G in the coronal source regions of ZP1, ZP2, and ZP3, respectively.

Song *et al.*[32] reported the co-analysis of the solar microwave and hard X-ray spectral evolutions in the 2000 June 10 and 2002 April 10 flares, which were simultaneously observed by the Owens-Valley Solar Array in the microwave, and by Yohkoh/Hard X-ray Telescope and RHESSI in hard X-ray, with multiple subpeaks in their light curves.

Li *et al.*[33] investigated the acceleration source of the impulsive solar energetic particle events on 2007 January 24, and demonstrated that the jets associated with the hard X-ray flares and type-III radio bursts, rather than the slow and partial CME, are closely related to the production of interplanetary electron streams. The jets, originated from the well-connected active region (AR 10939) whose magnetic polarity structure favors the eruption, are observed to be forming in a coronal site, extending to a few solar radii, and having a good temporal correlation with the electron solar release. The open-field lines near the jet site are rooted in a negative polarity, along which energetic particles escape from the flaring AR to the near-Earth space, consistent with the *in situ* electron pitch angle distribution.

Guo *et al*. [34] studied the relationship between high-energy, non-thermal, and impulsive evolution, and low-energy, thermal, and gradual evolution in a prominent ~50 s hard X-ray (HXR) pulse of a simple GOES class C7.5 flare on 2002 February 20. They used regularized methods to obtain time derivatives of photon fluxes to quantify the time evolution as a function of photon energy, obtaining a break energy between impulsive and gradual behavior. These break energies are consistent with a constant value of ~11 keV in agreement with those found spectroscopically between thermal and non-thermal components.

Cheng *et al*. [35] presented comprehensive analysis of a two-ribbon flare observed in UV 1600 Å by TRACE and in HXRs by RHESSI (25−100 keV) imaging observations. They found the UV brightening is substantially enhanced wherever and whenever the compact HXR kernel is passing, and during the HXR transit across a certain region, the UV count light curve in that region is temporally correlated with the HXR total flux light curve. After the passage of the HXR kernel, the UV light curve exhibits smooth monotonic decay; HXR kernels and UV fronts exhibit similar apparent motion patterns and speeds; UV emission is characterized by a rapid rise correlated with HXRs, followed by a long decay on timescales of 15−30 minutes.

He and Qin[36] determined solar energetic particles' mean free path by fitting the anisotropy time profiles from Shalchi *et al*.'s analytical formula to spacecraft observations. This new method can be called an analytical method. In addition, they obtained solar energetic particles' mean free path with the traditional simulation methods.

Qin *et al*.[37] simulated the SEP event by solving the five-dimensional focused transport equation numerically for 40 keV electrons with perpendicular diffusion, and found that a counter-streaming particle beam with deep depression at 90° pitch angle can form on Parker magnetic field lines that do not directly connect to the main particle source on the Sun in the beginning of an SEP event observed by the Wind spacecraft at 1 AU.

He and Wan[38] provided a direct analytical formula as a function of parameters concerning the physical properties of Solar Energetic Particles (SEP) and solar wind to directly and quickly determine the parallel mean free path of SEPs with adiabatic focusing. Since all of the quantities in the analytical formula can be directly observed by spacecraft, this direct method would be a very useful tool in space weather research.

He *et al*.[39] studied the propagation of solar energetic particles in three-dimensional interplanetary magnetic fields. They found that the observation location relative to the latitudinal and longitudinal coverage of particle source has the strongest effects on particle flux and anisotropy profiles observed by a spacecraft. When a spacecraft is directly connected to the solar sources by the interplanetary magnetic field lines, the observed particle fluxes are larger than when the spacecraft is not directly connected. When the particle source covers a larger range of latitude and longitude, the observed particle flux is larger and appears earlier.

Su *et al*.[40] reported the first evidence for both breaks in spectra measured with RHESSI during the GOES X1.2 class flare on 2002 October 31. The RHESSI X-ray spectral analysis shows both the breakup at ~49 keV and the breakdown at ~134 keV at the HXR peak time. The time evolution of both breaks also agrees with the non-uniform ionization (NUI) model. They found that the average column density of the fully ionized plasma changed from 2×10^{19} cm^{-2} in the rise phase to 7×10^{21} cm^{-2} after the peak. This indicates that plasma in the target was heated and became ionized during the flare, in agreement with heating by the nonthermal electrons and chromospheric evaporation expected in the collisional thick-target model.

Feng *et al*.[41] made a particle kinetic analysis by using the coronagraph observations of a polar jet observed by SECCHI onboard STEREO spacecraft. The derived initiation time is consistent with the jet observations by the EUVI telescope at various wavelengths. The initial particle velocity distribution is fitted by Maxwellian distributions and they found deviations of the high-energy tail from the Maxwellian distributions. The total kinetic energy of all particles in the jet source region amounts from 2.1×10^{28} to 2.4×10^{29} erg.

Zhang *et al*. [42] carried out a detailed multi-wavelength analysis of two neighboring Coronal Bright Points (CBPs) observed in soft X-ray (SXR) and EUV channels. It is seen that the SXR light curves present quasi-periodic flashes with an interval of ~1 h superposed over the long-lived mild brightenings, suggesting that the SXR brightenings of this type of CBPs might consist of two components: one is the gentle brightenings and the other is the CBP flashes. It is found that the strong flashes of the bigger CBP are always accompanied by SXR jets. The potential field extrapolation indicates that both CBPs are covered by a dome-like separatrix surface, with a magnetic null point above. They propose that the repetitive CBP flashes, as well as the recurrent SXR jets, result from the impulsive null-point reconnection, while the long-lived brightenings are due to the interchange reconnection along the separatrix surface.

Yang *et al*.[43] presented detailed observations of two solar filaments erupted successively from different confined arcades underlying a common overarching multiple-arcade bipolar helmet streamer on 2005 August 5, and identify them as sympathetic filament eruptions.

Wang and Yan[44] developed a code of dynamical Monte Carlo simulation of the diffusive shock acceleration under the isotropic scattering law during the scattering process, and found that the total energy spectral index increases as the standard deviation value of the scattering angular distribution increases, but the subshock's energy spectral index decreases as the standard deviation value of the scattering angular distribution increases.

Li, Xia and Chen[45] solved the transport equations incorporating the heating from turbulent Alfvén waves for an electron-proton solar wind along curved field lines given by an analytical magnetic field model, suggested that the field line curvature could be a geometrical factor which, in addition to the tube expansion, substantially influences the solar wind speed.

Ning[46] explored the speed distributions of X-ray source motions after the start of chromospheric evaporation in two RHESSI flares, and founds converging motion of the double footpoint sources along the flaring loop in these two events. This motion is dependent on the energy band and time and is typically seen at 3–25 keV, indicating a chromospheric evaporation origin.

Ning and Cao[47] explored the hard X-ray source distributions of an C1.1 flare occurred on 14 December 2007. Both Hinode/EIS and RHESSI observations are used. The results show a similar topology for the time-dependent source distribution as that for energy-dependent source distribution overlapped on EUV bright kernels, which seems to be consistent with the evaporation model.

2.4 EUV Waves, MHD Waves and Coronal Waves

Ma *et al*.[48] studied a limb coronal shock wave and its associated EUV wave that occurred on 2010 June 13 by using the high temporal and spatial resolutions of the AIA/SDO. Their findings support the view that the coronal shock wave is driven by the CME bubble, and the on-limb EUV wave is consistent with a fast wave or at least includes the fast wave component.

Taking advantage of the high temporal and spatial resolution of the AIA/SDO observations, Zheng *et al*.[49] presented four homologous Extreme Ultraviolet (EUV) waves within 3 h on 2010 November 11. All EUV waves emanated from the same emerging flux region, propagated in the same direction, and were accompanied by surges, weak flares, and faint CMEs. The waves had the basically same appearance in all EUV wavebands of the AIA/SDO. The waves propagated at constant velocities in the range of 280–500 km $\cdot$ s^{-1}, with little angular dependence. The waves are supposed to likely involve more than one driving mechanism.

Zhao *et al*.[50] investigated the morphology and kinematics of the CME-EIT wave event that occurred on 2010 January 17. Their results demonstrate that the propagation of the CME front is much faster than that of the EIT wave on the solar surface, and that both the CME front and the EIT wave propagate faster than the fast-mode speed in their local environments. Specifically, they show a significant positive correlation between the EIT wave speed and the local fast-mode wave speed in the propagation paths of the EIT wave. Their findings support that the EIT wave under study is a fast-mode MHD wave.

Wang *et al*.[51] presented, for the first time, measurements of arc-polarized velocity variations together with magnetic field variations associated with a large-amplitude Alfvén wave observed by the Wind satellite. They found that the magnetic field and velocity vector components, in the plane perpendicular to the minimum-variance direction of the magnetic field, are arc-polarized, and their tips almost lie on the same circle. They also found that the normalized cross helicity and Alfvén ratio of the wave are both nearly equal to unity, a result which has not been reported in previous studies at 1 AU. It is worthy to stress here that pure Alfvén waves can also exist in the solar wind even near the Earth at 1 AU, but not only near 0.3 AU.

Li *et al*.[52] presented SDO/AIA observations of the interaction of a global EUV wave on 2011 June 7 with active regions (ARs), coronal holes (CHs), and coronal bright structures. The primary global wave has a three-dimensional dome shape, with propagation speeds ranging from 430 to 780 km $\cdot$ s^{-1} in different directions. The primary coronal wave runs in front of the expanding loops involved in the CME and its propagation speeds are approximately constant within 10–20 minutes. Upon arrival at an AR on its path, the primary EUV wave apparently disappears and a secondary wave rapidly reemerges within 75 Mm of the AR boundary at a similar speed. When the EUV wave encounters a coronal bright structure, an additional wave front appears there and propagates in front of it at a velocity nearly a factor of two faster. Reflected waves from a polar CH and a coronal bright structure are observed and propagate fractionally slower than the primary waves.

Chen *et al*.[53] reported a spectroscopic analysis of an EIT wave event that occurred in active region 11081 on 2010 June 12 and was associated with an M2.0 class flare. The wave propagated nearly circularly. The southeastern part of the wave front passed over an upflow region near a magnetic bipole. They found a weak blueshift for the Fe XII λ195.12 and Fe XIII λ202.04 lines in the wave front, and the upflow and non-thermal velocities in the upflow region are suddenly diminished after the transit of the wave front.

Chen *et al*.[54] presented a novel method to evaluate the Alfvén speed and the magnetic field strength along the streamer plasma sheet in the outer corona. The method is based on recent observations of streamer waves, which are regarded as the fast kink body mode carried by the plasma sheet structure and generated upon the impact of a fast CME on a nearby streamer. They found that both the Alfvén speed and magnetic field strength at a fixed distance decline with time.

Zhao *et al*.[55] presented an excitation mechanism for Kinetic Alfvén waves (KAWs) created by the coupling between large-scale oblique AWs and small-scale KAWs.

2.5 Solar Model and Helioseismology

Zhang and Li[56] investigated the solar overshooting region in the framework of the turbulent convection model. The overshooting mixing is treated as a diffusive process. It is found that the sound speed profile can be improved to be in good agreement with helioseismic inversions. The bump in the sound speed differences between solar models and the helioseismical inversions below the base of the solar convective envelope is almost eliminated by the overshooting mixing. The overshooting mixing leads to a significant depletion of Li in the main-sequence stage. Li abundance in the solar surface can be reduced to about 1% of its initial abundance in the solar models with the overshooting mixing. The solar model with the overshooting shows a smooth profile of the temperature gradient, which is also favored by the helioseismology.

Zhao, Chou, and Yang[57] used a deconvolution scheme to obtain the wave function of the acoustic wave on the solar surface at various times from cross-correlation functions computed between an incident wave and the signals at other points on the surface. They studied the wave functions of scattered waves with the incident waves of radial order n = 0–5 for two sunspots, NOAAs 11084 and 11092.

2.6 Solar Wind

Feng *et al*.[58] provided a mechanism to decrease the dimensions of some Small interplanetary magnetic flux ropes (SIMFRs) as they propagate away from the Sun observed by spacecraft at 1 AU. They indicate that the boundaries of some SIMFRs were still evolving through interaction with the background solar wind, and their spatial scales would diminish gradually.

Yang *et al*.[59] chose Carrington rotation 2070 in 2008 to investigate the properties of the background solar wind by using the three-dimensional (3D) Solar–InterPlanetary Conservation Element/Solution Element MHD model and studied the effects of polar magnetic fields on the characteristics of the solar corona and the solar wind by conducting simulations with an axisymmetric polar flux added to the observed magnetic field. The numerical results are compared with the observations from SOHO, Ulysses, STEREO, WIND and ACE.

2.7 Behavior of Solar Cycle

Wang and Rebbrecht[60] applied potential-field source-surface extrapolations and photospheric flux-transport simulations to demonstrate the statistical tendency for the heliospheric current sheet (HCS) to be shifted a few degrees southward of the heliographic equator during the period 1965–2010, particularly in the years near sunspot minimum. They proposed a new method for determining the north-south displacement of the HCS from coronal streamer observations.

Li *et al*.[61] used the continuous wavelet transformation to study the temporal variations of the rotational cycle length of daily sunspot numbers from 1849 January 1 to 2010 February 28, from a global point of view. The rotational cycle length of the Sun is found to have a secular trend, which statistically shows a linear decrease by about 0.47 days during the time interval considered. The empirical mode decomposition analysis of the temporal variations of the rotational cycle length shows an acceleration trend for the surface rotation rate from cycles 11 to 19, but a deceleration trend from the beginning of cycle 20 onward.

Chen *et al*.[62] statistically re-parameterized the superactive regions (SARs) and studied their latitudinal and longitudinal distributions in solar cycles 21–23.

Zhang *et al*.[63] performed a global study of the longitudinal location of sunspots (all sunspots and first appearance sunspots) using a refined version of a dynamic, differentially rotating coordinate system. They found that the rotation parameters for sunspots vary differently with time in the northern and southern hemispheres. Both sunspots and flares strongly suggest that the northern hemisphere rotated considerably faster but the southern hemisphere slightly slower than the Carrington rotation rate during the last three solar cycles.

Du[64] found that the shape of each sunspot cycle is found to be well described by a modified Gaussian function with four parameters: peak size A, peak timing t_m, width B, and asymmetry α.

Song *et al*.[65] measured the differential rotation of strong magnetic flux during solar cycles 21–23 with the method of wavelet transforms, and found that the cycle-averaged synodic rotation rate of strong magnetic flux can be written as ω=13.47−2.58sin$^2\theta$ or ω=13.45−2.06sin$^2\theta$ −1.37sin$^4\theta$, where θ is the latitude. They agree well with the results derived from sunspots. A north–south asymmetry of the rotation rate is found at high latitudes (28°<θ<40°). The strong flux in the southern hemisphere rotates faster than that in the northern hemisphere by 0.2° per day. The asymmetry continued for cycles 21–23 and may be a secular property.

The Chinese solar physics community continues to promote space solar missions. The most prominent mission is to launch the Space Solar Telescope to the first Lagrangian point (L_1), which is located at a distance of about 1.5 million kilometers from the Earth. The payloads include the main optical telescope, the hard X-ray telescope, the EUV imager, the energetic particle receiver, and the solar radio spectrometer at very low frequencies, *etc*. The aperture of the main optical telescope is 1 meter, which can observe the solar magnetic elements with an unprecedented high spatial resolution.

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