Research Progress of Solar Corona and Interplanetary Physics in China: 2010—2012

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Abstract

The scientific objective of solar corona and interplanetary research is the understanding of the various phenomena related to solar activities and their effects on the space environments of the Earth. Great progress has been made in the study of solar corona and interplanetary physics by the Chinese space physics community during the past years. Here we will give a brief report about the latest progress of the corona and interplanetary research in China during the years of 2010 – 2012. The paper can be divided into the following parts: solar corona and solar wind, CME-ICME, magnetic reconnection, energetic particles, space plasma, space weather numerical modeling by 3D SIP-CESE MHD model, space weather prediction methods, and proposed missions. They constitute the abundant content of study for the complicated phenomena that originate from the solar corona, propagate in interplanetary space, and produce geomagnetic disturbances. All these progresses are acquired by the Chinese space physicists, either independently or through international collaborations.

1 Solar Corona and Solar Wind

It has already been established that the solar wind may originate at the edges of Active Regions (ARs), but the key questions of how frequently these outflows occur, and at which height the nascent solar wind originates have not yet been addressed. He, Marsch *et al.*[1] study the occurrence rate of these intermittent outflows, the related plasma activities beneath in the low solar atmosphere, and the interplanetary counterparts of the nascent solar wind outflow. They use the observations from XRT/Hinode and TRACE to study the outflow patterns. The occurrence frequency of the intermittent outflow is estimated by counting the occurrences of propagating intensity enhancements in height-time diagrams. The observations of SOT/Hinode and EIS/Hinode are adopted to investigate the phenomena in the chromosphere associated with the coronal outflows. The ACE plasma and field in-situ measurements near Earth are used to study the interplanetary manifestations. They find that in one elongated coronal emission structure, referred to as strand, the plasma flows outward intermittently, about every 20 min. The flow speed sometimes exceeds 200 km·s^{-1}, which is indicative of rapid acceleration, and thus exceeds the coronal sound speed at low altitudes. The inferred flow speed of the soft-X-ray-emitting plasma component seems a little higher than that of the Fe IX/X-emitting plasma component. Chromospheric jets are found to occur at the root of the strand. Upflows in the chromosphere are also confirmed by blue-shifts of the He II line. The heliospheric plasma counterpart close to the Earth is found to be an intermediate-speed solar wind stream. The AR edge may also deliver some plasmas to a fraction of the fast solar wind stream, most of which emanate from the neighboring CH. The possible origin of the nascent solar wind in the chromosphere, the observed excessive outflow speed of over 200 km·s^{-1} in the lower corona, and the corresponding intermediate-speed solar wind stream in interplanetary space are all linked in their case study. These phenomena from the low solar atmosphere to the heliosphere near Earth in combination shed new light on the solar wind formation process. These observational results will constrain future modeling of the solar winds originating close to an AR.

Coronal jets and mass ejections associated with erupting loops are two distinct and frequently observed types of transient upflows of plasma in Coronal Holes (CHs). But the magnetic and spectroscopic properties of these events at the supergranular scale are not well known. He, Marsch *et al*.[2] aim at studying in a polar hole the plasma and field characteristics of coronal jets and erupting loops of a supergranular size, for which they use observations from XRT, EIS and SOT on Hinode as well as EUVI on Solar TErrestrial RElations Observatory (STEREO). The open magnetic field structures related to the coronal jets are obtained by magnetic field extrapolation into the corona from SOT magnetograms. Furthermore, they use the EIS observations to analyze ultraviolet line intensities and Doppler shifts in association with the erupting loops. They find that the coronal jet plasma is indeed ejected along open field lines, thus confirming the conjecture of jet formation in an open magnetic environment. The magnetic evolution at the jet base is investigated, and the results indicate that the interaction between two flux tubes of opposite magnetic polarities as well as the squeezing of several tubes with identical polarities might be responsible for the jet initiation. They reveal for the first time the spectroscopic signatures of a supergranular-size erupting loop at its early stage, which consists of three steps. The first step is the onset, which is featured by a sudden brightening of one footpoint, as well as by the occurrence of blueshifts along almost its entire path. The second step is the initial expansion of the closed loop, which is estimated to move upward at a speed of about 20 km·s^{-1}, as derived from the Line-of-Sight (LOS) blueshift and the loop enlargement projected onto the plane of the sky. In the third step, the loop's bright footpoint is apparently diminishing its intensity and enhancing its blueshift, which indicates that plasma upflow from the leg is filling the expanding loop volume. They conclude that in polar CHs, where the steady fast solar wind is known to emanate, there are also at least two possible ways of causing transient plasma outflows at supergranular scale. One is related to coronal jets guided by open field lines, the other to the eruption of closed loops, which is triggered by magnetic reconnection at their footpoints.

Persistent outflows have recently been detected at the boundaries of some active regions. Although these outflows are suggested to be possible sources of the slow solar wind, the nature of these outflows is poorly understood. Through an analysis of an image sequence obtained by the X-Ray Telescope onboard the Hinode spacecraft, Guo, Tian and He[3] find that quasi-periodic outflows are present in the boundary of an active region. The flows are observed to occur intermittently, often with a period of 5–10 min. The projected flow speed can reach more than 200 km·s^{-1}, while its distribution peaks around 50 km·s^{-1}. This sporadic high-speed outflow may play an important role in the mass loading process of the slow solar wind. Their results may imply that the outflow of the slow solar wind in the boundary of the active region is intermittent and quasi-periodic in nature.

The origin of the solar wind is one of the most important unresolved problems in space and solar physics. Tian, Tu *et al*.[4] report the first spectroscopic signatures of the nascent fast solar wind on the basis of observations made by the EUV Imaging Spectrometer on Hinode in a polar coronal hole in which patches of blueshift are clearly present on Dopplergrams of coronal emission lines with a formation temperature of lg(T/K)>5.8. The corresponding upflow is associated with open field lines in the coronal hole and seems to start in the solar transition region and becomes more prominent with increasing temperature. This temperature-dependent plasma outflow is interpreted as evidence of the nascent fast solar wind in the polar coronal hole. The patches with significant upflows are still isolated in the upper transition region but merge in the corona, in agreement with the scenario of solar wind outflow being guided by expanding magnetic funnels.

Tian, Potts, *et al*.[5] study horizontal supergranule-scale motions revealed by TRACE observation of the chromospheric emission, and investigate the coupling between the chromosphere and the underlying photosphere. A highly efficient feature-tracking technique called balltracking is applied for the first time to the image sequences obtained by TRACE (transition region and coronal explorer) in the passband of white light and the three ultraviolet passbands centered at 1700 Å, 1600 Å, and 1550 Å. The resulting velocity fields are spatially smoothed and temporally averaged in order to reveal horizontal supergranule-scale motions that may exist at the emission heights of these passbands. They find indeed a high correlation between the horizontal velocities derived in the white-light and ultraviolet passbands. The horizontal velocities derived from the chromospheric and photospheric emission are comparable in magnitude. The horizontal motions derived in the UV passbands might indicate the existence of a supergranule-scale magnetoconvection in the chromosphere, which may shed new light on the study of mass and energy supply to the corona and solar wind at the height of the chromosphere. However, it is also possible that the apparent motions reflect the chromospheric brightness evolution as produced by acoustic shocks which might be modulated by the photospheric granular motions in their excitation process, or advected partly by the supergranule-scale flow towards the network while propagating upward from the photosphere. To reach a firm conclusion, it is necessary to investigate the role of granular motions in the excitation of shocks through numerical modeling, and future high-cadence chromospheric magnetograms must be scrutinized.

The fluctuating magnetic helicity is considered an important parameter in diagnosing the characteristic modes of solar wind turbulence. Among them is the Alfvén-cyclotron wave, which is probably responsible for the solar wind plasma heating, but has not yet been identified from the magnetic helicity of solar wind turbulence. He, Marsch, *et al*.[6] present the possible signatures of Alfvén-cyclotron waves in the distribution of magnetic helicity as a function of θ_{VB}, which is the angle between the solar wind velocity and local mean magnetic field. They use magnetic field data from the STEREO spacecraft to calculate the θ_{VB} distribution of the normalized reduced fluctuating magnetic helicity σ_m. They find a dominant negative σ_m for $1\ s < p < 4\ s$ (p is time period) and for $\theta_{VB} < 30°$ in the solar wind outward magnetic sector, and a dominant positive σ_m for $0.4\ s < p < 4\ s$ and for $\theta_{VB} > 150°$ in the solar wind inward magnetic sector. These features of σm appearing around the Doppler-shifted ion-cyclotron frequencies may be consistent with the existence of Alfvén-cyclotron waves among the outward propagating fluctuations. Moreover, right-handed polarized waves at larger propagation angles, which might be kinetic Alfvén waves or whistler waves, have also been identified on the basis of the σ_m features in the angular range $40°<\theta_{VB}<140°$. Their findings suggest that Alfvén-cyclotron waves (together with other wave modes) play a prominent role in turbulence cascading and plasma heating of the solar wind.

The work of Yao, He, *et al*.[7] focuses on the relation between the electron density and the magnetic field strength in the solar wind, and aims to reveal its compressive nature and to determine the level of compressibility. For this purpose, they choose a period of quiet solar wind data obtained at 1 AU by the Cluster C1 satellite. The electron density is derived with a sampling time as high as 0.2 s from the spacecraft-potential measurements made by the Electric Field and Waves instrument. They use the wavelet cross-coherence method to analyze the correlation between the electron density and the magnetic field strength on various scales. They find a dominant anti-correlation between them at different timescales ranging from 1000 s down to 10 s, a result which has never been reported before. This may indicate the existence of pressure-balanced structures (PBSs) with different sizes in the solar wind. The small (mini) PBSs appear to be embedded in the large PBSs, without affecting the pressure balance between the large structures. Thus, a nesting of these possible multi-scale PBSs is found. Moreover, they find for the first time that the relative fluctuation spectra of both the electron number density and the magnetic field strength look almost the same in the range from 0.01 Hz to 2.5 Hz, implying a similar cascading for these two types of fluctuations. Probable formation mechanisms for the multi-scale possible PBSs are discussed. The results of their work are believed to be helpful for understanding the compressive nature of solar wind turbulence as well as the connections between the solar wind streams and their coronal sources.

To determine the wave modes prevailing in solar wind turbulence at kinetic scales, He, Tu, Marsch, and Yao[8] study the magnetic polarization of small-scale fluctuations in the plane perpendicular to the data sampling direction (namely, the solar wind flow direction, V_{SW}) and analyze its orientation with respect to the local background magnetic field $B_{0,\ local}$. As an example, they take only measurements made in an outward magnetic sector. When $B_{0,\ local}$ is quasi-perpendicular to V_{SW}, they find that the small-scale magnetic-field fluctuations, which have periods from about 1–3s and are extracted from a wavelet decomposition of the original time series, show a polarization ellipse with right-handed orientation. This is consistent with a positive reduced magnetic helicity, as previously reported. Moreover, for the first time they find that the major axis of the ellipse is perpendicular to $B_{0,\ local}$, a property that is characteristic of an oblique Alfvén wave rather than oblique whistler wave. For an oblique whistler wave, the major axis of the magnetic ellipse is expected to be aligned with $B_{0,\ local}$, thus indicating significant magnetic compressibility, and the polarization turns from right to left handedness as the wave propagation angle (θ_{kB}) increases toward 90°. Therefore, they conclude that the observation of a right-handed polarization ellipse with orientation perpendicular to $B_{0,\ local}$ seems to indicate that oblique Alfvén/ion-cyclotron waves rather than oblique fast-mode/whistler waves dominate in the “dissipation” range near the break of solar wind turbulence spectra occurring around the proton inertial length.

The basic characteristics of the global distribution for the corona plasma and magnetic field near 2.5 R_s are analyzed by Shen, Feng, *et al*.[9] with the statistical and numerical methods for 136 Carrington Rotations (CRs) covering four different phases of solar activity. By using the observational data and the velocity distribution model in the corona, the statistical average distribution of the magnetic field, density and the coronal mass outputs are analyzed for the four different phases. Then, a numerical study of the global distribution near 2.5 R_s is made by solving a self-consistent MHD system. Finally, the solar wind speed at 1 AU is given by mapping the speed at 2.5 R_s to that near 1 AU, and the comparison of the numerical results with the observational measurements and the simulation result of the Wang-Sheeley-Arge (WSA) model are made during more than 5 years. The numerical results indicate that the global distributions on the source surface of 2.5 R_s at different phases of solar activity could be used to predict the change of the solar wind in interplanetary space.

The temperature curve in the solar chromosphere has puzzled astronomers for a long time. Referring to the structure of supergranular cells, Song, Feng and Shen[10] propose an inductive heating model. It mainly includes the following three steps: (1) a small-scale dynamo exists in the supergranulation and produces alternating small-scale magnetic fluxes; (2) the supergranular flow distributes these small-scale fluxes according to a regular pattern; (3) a skin effect occurs in the alternating and regularly-distributed magnetic fields. The induced current is concentrated near the transition region and heats it by resistive dissipation.

Song, Feng *et al*.[11] measure the differential rotation of strong magnetic flux during solar cycles 21–23 with the method of wavelet transforms. The cycle-averaged synodic rotation rate of strong magnetic flux is found to be written as $\omega=13.47-2.58\sin^2\theta$ or $\omega=13.45-2.06\sin^2\theta-1.37\sin^4\theta$, where θ is the latitude. It agrees well with the results derived from sunspots. A north–south asymmetry of the rotation rate is found at high latitudes ($28°<\theta<40°$). 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.

Zhang, Wang, and Liu[12] have developed a computational software system to automate the process of identifying solar Active Regions (ARs) and quantifying their physical properties based on high-resolution synoptic magnetograms constructed from Michelson Doppler Imager (MDI) images on board the Solar and Heliospheric Observatory (SOHO) spacecraft from 1996 to 2008. The system, based on morphological analysis and intensity thresholding, has four functional modules: (1) intensity segmentation to obtain kernel pixels, (2) a morphological opening operation to erase small kernels, which effectively remove ephemeral regions and magnetic fragments in decayed ARs, (3) region growing to extend kernels to full AR size, and (4) the morphological closing operation to merge/group regions with a small spatial gap. They calculate the basic physical parameters of the 1730 ARs identified by the auto system. The mean and maximum magnetic flux of individual ARs are 1.67×10^{22} Mx and 1.97×10^{23} Mx, while that per Carrington rotation are 1.83×10^{23} Mx and 6.96×10^{23} Mx, respectively. The frequency distributions of ARs with respect to both area size and magnetic flux follow a log-normal function. However, when they decrease the detection thresholds and thus increase the number of detected ARs, the frequency distribution largely follows a power-law function. They also find that the equatorward drifting motion of the AR bands with solar cycle can be described by a linear function superposed with intermittent reverse driftings. The average drifting speed over one solar cycle is 1.83° ± 0.04° a^{-1} or 0.708 ± 0.015 $m\cdot s^{-1}$.

Zhang, Xia, *et al*.[13] search for signatures of transition region Explosive Events (EEs) in hydrogen Lyβ profiles. The relationship between the peak emission of Lyβ profiles and the wing emission of C_{II} and O_{VI} during EEs is investigated. Two rasters made by the SUMER (Solar Ultraviolet Measurements of Emitted Radiation) instrument onboard SOHO in a quiet-Sun region and an equatorial coronal hole are selected for their study. Transition-region explosive events are identified from profiles of C_{11} 1037 Å and O_{VI} 1032 Å, respectively. They compare Lyβ profiles during EEs with those averaged in the entire quiet-Sun and coronal-hole regions. They find that the central part of Lyβ profiles reverses more and the distance of the two peaks becomes larger during EEs, both in the coronal hole and in the quiet Sun. The average Lyβ profile of the EEs detected by C_{II} has an obviously stronger blue peak. During EEs, there is a clear correlation between the increased peak emission of Lyβ profiles and the enhanced wing emission of the C_{II} and O_{VI} lines. The correlation is more pronounced for the Lyβ peaks and C_{II} wings, and less significant for the Lyβ blue peak and O_{VI} blue wing. They also find that the Lyβ profiles are more reversed in the coronal hole than in the quiet Sun. They suggest that the jets produced by EEs emit the Doppler-shifted Lyβ photons, causing enhanced emission at positions of the peaks of Lyβ profiles. The more-reversed Lyβ profiles confirm the presence of higher opacity in the coronal hole than in the quiet Sun. The finding that EEs modify the Lyβ line profile in QS and CHs implies that one should be careful in the modeling and interpretation of relevant observational data.

It has been established that cold plasma condensations can form in a magnetic loop subject to localized heating of its footpoints. Xia, Chen *et al*.[14] use 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. Comparing to previous works, they consider low-lying loops with shallow dips and use a more realistic description for radiative losses. They demonstrate for the first time that the onset of thermal instability satisfies the linear instability criterion. The onset time of the condensation is roughly ~2 h or more after the localized heating at the footpoint is effective, and the growth rate of the thread length varies from 800 $km\cdot h^{-1}$ to 4000 $km\cdot h^{-1}$, depending on the amplitude and the decay length scale characterizing this localized chromospheric heating. They show how single or multiple condensation segments may form in the coronal portion. In the asymmetric heating case, when two segments form, they approach and coalesce, and the coalesced condensation later drains down into the chromosphere. With steady heating, this process repeats with a periodicity of several hours. While their parametric survey confirms and augments earlier findings, they also point out that steady heating is not necessary to sustain the condensation. Once the condensation is formed, it keeps growing even after the localized heating ceases. In such a finite-heating case, the condensation instability is maintained by chromospheric plasma that gets continuously siphoned into the filament thread due to the reduced gas pressure in the corona. Finally, they show that the condensation can survive the continuous buffeting of perturbations from photospheric *p*-mode waves.

Using one-dimensional test particle simulations, the effect of a kinetic Alfvén wave on the Velocity Distribution Function (VDF) of protons in the collisionless solar wind is investigated. Li, Lu *et al*.[15] first use linear Vlasov theory to numerically obtain the property of a kinetic Alfvén wave (the wave propagates in the direction almost perpendicular to the background magnetic field). They then numerically simulate how the wave will shape the proton VDF. It is found that Landau resonance may be able to generate two components in the initially Maxwellian proton VDF: a tenuous beam component along the direction of the background magnetic field and a core component. The streaming speed of the beam relative to the core proton component is about 1.2–1.3 Alfvén speed.

Interplanetary linear magnetic holes (LMHs) are structures in which the agnetic field agnitude decreases with little change in the field direction. They are a 10%–30% subset of all interplanetary Magnetic Holes (MHs). Using magnetic field and plasma measurements obtained by Cluster-C1, Xiao, Shi *et al*.[16] survey the LMHs in the solar wind at 1 AU. In total 567 interplanetary LMHs are identified from the magnetic field data when Cluster-C1 was in the solar wind from 2001 to 2004. They study the relationship between the durations and the magnetic field orientations, as well as that of the scales and the field orientations of LMHs in the solar wind. It is found that the geometrical structure of the LMHs in the solar wind at 1 AU is consistent with rotational ellipsoid and the ratio of scales along and across the magnetic field is about 1.93:1. In other words, the structure is elongated along the magnetic field at 1 AU. The occurrence rate of LMHs in the solar wind at 1 AU is about 3.7 per day. It is shown that not only the occurrence rate but also the geometrical shape of interplanetary LMHs has no significant change from 0.72 AU to 1 AU in comparison with previous studies. It is thus inferred that most of interplanetary LMHs observed at 1 AU are formed and fully developed before 0.72 AU. The present results help us to study the formation mechanism of the LMHs in the solar wind.

Chen, Feng *et al*.[17] present 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 Coronal Mass Ejection (CME) on a nearby streamer. The mode propagates outward with a phase speed consisting of two components. One is the phase speed of the mode in the plasma rest frame and the other is the speed of the solar wind streaming along the plasma sheet. The former can be well represented by the Alfvén speed outside the plasma sheet, according to a linear wave dispersion analysis with a simplified slab model of magnetized plasmas. The radial profiles of the Alfvén speed can be deduced with constraints put on the speed of the solar wind, which is done by making use of the measurements of streamer blobs flowing passively in the wind. The radial profiles of the strength of the coronal magnetic field can be depicted once the electron density distribution is specified, this is done by inverting the observed polarized brightness data. Comparing the diagnostic results corresponding to the first wave trough and the following crest, they find that both the Alfvén speed and magnetic field strength at a fixed distance decline with time. This is suggestive of the recovering process of the CME-disturbed corona.

Li, Chen and Li[18] examine whether the flow tube along the edge of a coronal streamer supports standing shocks in the inner slow wind by solving an isothermal wind model in terms of the Lambert *W* function. It is shown that solutions with standing shocks do exist and they exist in a broad area in the parameter space characterizing the wind temperature and flow tube. In particular, streamers with cusps located at a heliocentric distance $\geqslant 3.2\ R_s$ can readily support discontinuous slow winds with temperatures barely higher than 1 MK.

Both remote-sensing measurements using the Interplanetary Scintillation (IPS) technique and in-situ measurements by the Ulysses spacecraft show a bimodal structure for the solar wind at solar minimum conditions. At present it still remains to be addressed why the fast wind is fast and the slow wind is slow. While a robust empirical correlation exists between the coronal expansion rate f_c of the flow tubes and the speed v measured in situ, a more detailed data analysis suggests that v depends on more than just f_c. Li, Xia *et al*.[19] examine whether the non-radial shape of field lines, which naturally accompanies any non-radial expansion, could be an additional geometrical factor. They solve 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, which is representative of a solar minimum corona. The field line shape is found to influence the solar wind parameters substantially, reducing the asymptotic speed by up to ~130 km·s^{-1} or by ~28% in relative terms, compared with the case where the field line curvature is neglected. This effect was interpreted in the general framework of energy addition in the solar wind: compared to the straight case, the field line curvature enhances the effective energy deposition to the subsonic flow, which results in a higher proton flux and a lower terminal proton speed. Their computations suggest that the field line curvature could be a geometrical factor which, in addition to the tube expansion, substantially influences the solar wind speed. Furthermore, although the field line curvature is unlikely to affect the polar fast solar wind at solar minima, it does help make the wind at low latitudes slow, which in turn helps better reproduce the Ulysses measurements.

Feng, Chen *et al.*[20] conduct a data survey searching for well-defined streamer wave events observed by the LASCO on-board SOHO throughout Solar Cycle 23. As a result, eight candidate events are found and presented. They compare different events and find that in most of them the driving CMEs' ejecta are characterized by a high speed and a wide angular span, and the CME-streamer interactions occur generally along the flank of the streamer structure at an altitude no higher than the bottom of the field of view of LASCO C2. In addition, all front-side CMEs have accompanying flares. These common observational features shed light on the excitation conditions of streamer wave events. They also conduct a further analysis on one specific streamer wave event on 5 June 2003. The heliocentric distances of four wave troughs/crests at various exposure times are determined; they are then used to deduce the wave properties like period, wavelength, and phase speeds. It is found that both the period and wavelength increase gradually with the wave propagation along the streamer plasma sheet, and the phase speed of the preceding wave is generally faster than that of the trailing ones. The associated coronal seismological study yields the radial profiles of the Alfvén speed and magnetic field strength in the region surrounding the streamer plasma sheet. Both quantities show a general declining trend with time. This is interpreted as an observational manifestation of the recovery process of the CME-disturbed corona. It is also found that the Alfvénic critical point is at about 10 R_s, where the flow speed, which equals the Alfvén speed, is about 200 km·s^{-1}.

2 CME-ICME

Zhao, Feng *et al.*[21] perform a detailed analysis of a Coronal Mass Ejection (CME) on 2008 January 2. The combination of the SOHO and twin STEREO spacecraft provides three-point observations of this CME. They track the CME in imaging observations and compare its morphology and kinematics viewed from different vantage points. The shape, angular width, distance, velocity, and acceleration of the CME front are different in the observations of these spacecraft. They also compare the efficiency of several methods, which convert the elongation angles of the CME front in images to radial distances. The results of their kinematic analysis demonstrate that this CME experiences a rapid acceleration at the early stage, which corresponds to the flash phase of the associated solar flare in time. Then, at a height of about 3.7 solar radius(R_s), the CME reaches a velocity of 790 km·s^{-1} and propagates outward without an obvious deceleration. Because of its propagation direction away from the observers, the CME is not detected in situ by either ACE or STEREO.

An EIT wave, which typically appears as a diffuse brightening that propagates across the solar disk, is one of the major discoveries of the Extreme ultraviolet Imaging Telescope on board the SOHO. However, the physical nature of the so-called EIT wave continues to be debated. In order to understand the relationship between an EIT wave and its associated coronal wave front, Zhao, Wu *et al.*[22] investigate the morphology and kinematics of the coronal mass ejection (CME)-EIT wave event that occurred on 2010 January 17. Using the observations of the SECCHI EUVI, COR1, and COR2 instruments on board the STEREO-B, they track the shape and movements of the CME fronts along different radial directions to a distance of about 15 R_s; for the EIT wave, they determine the propagation of the wave front on the solar surface along different propagating paths. The relation between the EIT wave speed, the CME speed, and the local fast-mode characteristic speed is also investigated. 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 magnetohydrodynamic wave.

Based on time-dependent MHD simulation, Zhang, Feng and Song[23] investigate how physical features in the solar atmosphere affect the evolution of Coronal Mass Ejections (CMEs). It is found that temperature and density play a crucial role in CME initiation. They argue that lower temperature facilitates the catastrophe's occurrence, and that the CMEs which initiate in low density could gain lower velocity. In their numerical experiment, by employing different values of β, the resulting eruptions of either slow or fast events may be obtained.

A three-dimensional (3-D), time-dependent, numerical Magnetohydrodynamic (MHD) model is used by Shen, Feng *et al*.[24]to investigate the evolution and interaction of two Coronal Mass Ejections (CMEs) in the nonhomogeneous ambient solar wind. The background solar wind is constructed on the basis of the self-consistent source surface with observed line of sight of magnetic field and density from the source surface of 2.5 R_s to Earth's orbit (215 R_s) and beyond. The two successive CMEs occurring on 28 March 2001 and forming of a multiple magnetic cloud in interplanetary space are chosen as a test case, in which they are simulated by means of a two high-density, high-velocity, and high temperature magnetized plasma blobs, and are successively ejected into the nonhomogeneous background solar wind medium along different initial launch directions. The dynamical propagation and interaction of the two CMEs between 2.5 and 220 R_s are investigated. Their simulation results show that, although the two CMEs are separated by 10 h, the second CME is able to overtake the first one and cause compound interactions and an obvious acceleration of the shock. At the L_1 point near Earth the two resultant magnetic clouds in their simulation are consistent with the observations by ACE. In this validation study they find that this 3-D MHD model, with the self-consistent source surface as the initial boundary condition and the magnetized plasma blob as the CME model, is able to reproduce and explain some of the general characters of the multiple magnetic clouds observed by satellites.

A three-dimensional (3-D) time-dependent, numerical magnetohydrodynamic (MHD) model with asynchronous and parallel time-marching method is used by Shen, Feng *et al*.[25] to investigate the propagation of Coronal Mass Ejections (CMEs) in the non-homogenous background solar wind flow. The background solar wind is constructed based on the self-consistent source surface with observed line-of-sight of magnetic field and density from the source surface of 2.5 R_s to the Earth's orbit (215 R_s) and beyond. The CMEs are simulated by means of a very simple flux rope model: a high-density, high-velocity, and high temperature magnetized plasma blob is superimposed on a steady state background solar wind with an initial launch direction. The dynamical interaction of a CME with the background solar wind flow between 2.5 and 220 R_s is investigated. The evolution of the physical parameters at the cobpoint, which is located at the shock front region magnetically connected to ACE spacecraft, is also investigated. They choose the well-defined halo-CME event of 4–6 April 2000 as a test case. In this validation study they find that this 3-D MHD model, with the asynchronous and parallel time-marching method, the self-consistent source surface as initial boundary conditions, and the simple flux rope as CME model, provide a relatively satisfactory comparison with the ACE spacecraft observations at the L_1 point.

On 9 November 2004, the WIND spacecraft detected a Magnetic Cloud Boundary Layer (MCBL) during the interval from 19:07 UT to 20:30 UT. Within the MCBL, there is intense southward magnetic field and the dynamic pressure is rather high, which makes it much geoeffective. Twenty-three minutes later, the MCBL arrived at the magnetopause. An intense geomagnetic storm main phase was driven by the sustaining strong southward magnetic field within the MCBL. During the passage of the MCBL, a typical magnetospheric substorm was triggered. The substorm onset was synthetically identified by the aurora breakup, magnetic dipolarization, dispersionless particle injection, Pi2 pulsation, and the polar bay onset. The substorm triggering is related to the special magnetic and plasma structure within the MCBL. The MCBL accompanying adjacent sheath region formed a dynamic pressure enhancement region, which strongly compressed the magnetosphere and even pushed the magnetopause into the geosynchronous orbit so that two dayside spacecraft GOES-10 and GOES-12 were directly exposed in the magnetosheath for a long interval during the passage of the MCBL. In terms of Shue *et al*. (1998) model, the closest subsolar standoff distance even reached 5.1 R_e during the passage of the MCBL. It can be inferred that the strong dynamic pressure and the strong discontinuities within the MCBL determine the intense compression effect. In addition, a very intense Geomagnetically Induced Current (GIC) event was directly caused by the MCBL. Similar to this case, majority of MCBLs are dynamic pressure enhancement regions, and there are strong southward magnetic field and several strong discontinuities inside these regions, which can potentially drive large-scale magnetospheric activities. Zuo, Wei *et al*.[26] take a case study to discuss the magnetospheric activities and the space weather effects caused by MCBLs.

Guo, Feng *et al*.[27] examine and compare the statistical properties of interplanetary coronal mass ejections (ICMEs) and their sheath regions in the near-Earth space, mainly focusing on the distributions of various physical parameters and their geoefficiency. The 53 events studied are a subset of events responsible for intense ($Dst \leqslant -100$ nT) geomagnetic storms during the time period from 1996 to 2005. These events all fall into the single-type category in which each of the geomagnetic storms is caused by a well-isolated single ICME, free of the complexity of the interaction of multiple ICMEs. For both sheaths and ICMEs, they find that the distributions of the magnetic field strength, the solar-wind speed, the density, the proton temperature, the dynamic pressure, the plasma beta, and the Alfvén Mach number are approximately lognormal, while those of the B_z component and the Y component of the electric field are approximately Gaussian. On the average, the magnetic field strengths, the B_z components, the speeds, the densities, the proton temperatures, the dynamic pressures, the plasma betas, and the Mach numbers for the sheaths are 15, 80, 4, 60, 70, 62, 67, and 30% higher than the corresponding values for ICMEs, respectively, whereas the Y component of the electric field for the sheaths is almost 1s of that for ICMEs. The two structures have almost equal energy transfer efficiency and comparable Newell functions, whereas they show statistically meaningful differences in the dayside reconnection rate, according to the Borovsky function.

The interaction of the solar wind and Earth's magnetosphere is complex, and the phenomenology of the interaction is very different for interplanetary coronal mass ejections (ICMEs) compared to sheath regions. A total of 71 intense ($Dst \le -100$ nT) geomagnetic storm events in 1996–2006, of which 51 are driven by ICMEs and 20 by sheath regions, are examined by Guo, Feng *et al.*[28] to demonstrate similarities and differences in the energy transfer. Using superposed epoch analysis, the evolution of solar wind energy input and dissipation is investigated. The solar wind-magnetosphere coupling functions and geomagnetic indices show a more gradual increase and recovery during the ICME-driven storms than they do during the sheath-driven storms. However, the sheath-driven storms have larger peak values. In general, solar wind energy input (the epsilon parameter) and dissipation show similar trends as the coupling functions. The trends of ion precipitation and the ratio of ion precipitation to the total (ion and electron) are quite different for both classes of events. There are more precipitating ions during the peak of sheath-driven storms. However, a quantitative assessment of the relative importance of the different energy dissipation branches shows that the means of input energy and auroral precipitation are significantly different for both classes of events, whereas Joule heating, ring current, and total output energy display no distinguishable differences. The means of electron precipitation are significantly different for both classes of events. However, ion precipitation exhibits no distinguishable differences. The energy efficiency bears no distinguishable difference between these two classes of events. Ionospheric processes account for the vast majority of the energy, with the ring current only being 12%–14% of the total. Moreover, the energy partitioning for both classes of events is similar.

Wang, Cao *et al.*[29] present an automated system, which has the capability to catch and track solar limb prominences based on observations from the Extreme-Ultraviolet (EUV) 304 Å passband. The characteristic parameters and their evolution, including height, position angle, area, length, and brightness, are obtained without manual interventions. By applying the system to the STEREO-B/SECCHI/EUVI 304 Å data during 2007 April – 2009 October, they obtain a total of 9477 well-tracked prominences and a catalog of these events available online. A detailed analysis of these prominences suggests that the system has a rather good performance. They have obtained several interesting statistical results based on the catalog. Most prominences appear below the latitude of 60° and at the height of about 26 Mm above the solar surface. Most of them are quite stable during the period they are tracked. Nevertheless, some prominences have an upward speed of more than 100 km·s^{-1}, and some others show significant downward and/or azimuthal speeds. There are strong correlations among the brightness, area, and height. The expansion of a prominence is probably one major cause of its fading during the rising or erupting process.

How to properly understand Coronal Mass Ejections (CMEs) viewed in white light coronagraphs is crucial to many relative researches in solar and space physics. The issue is particularly addressed by Wang, Chen *et al.*[30] through studying the source locations of all the 1078 LASCO CMEs listed in Coordinated Data Analysis Workshop (CDAW) CME catalog during 1997–1998 and their correlation with CMEs' apparent parameters. By manually checking LASCO and Extreme Ultraviolet Imaging Telescope (EIT) movies of these CMEs, they find that, except 231 CMEs whose source locations cannot be identified due to poor data, there are 288 CMEs with location identified on the frontside solar disk, 234 CMEs appearing above solar limb, and 325 CMEs without evident eruptive signatures in the field of view of EIT. On the basis of the statistical results of CMEs' source locations, there are four physical issues: (1) the missing rate of CMEs by SOHO LASCO and EIT, (2) the mass of CMEs, (3) the causes of halo CMEs, and (4) the deflections of CMEs in the corona, are exhaustively analyzed. It is found that (1) about 32% frontside CMEs cannot be recognized by SOHO, (2) the brightness of a CME at any heliocentric distance is roughly positively correlated with its speed, and the CME mass derived from the brightness is probably overestimated, (3) both projection effect and violent eruption are the major causes of halo CMEs, and especially for limb halo CMEs the latter is the primary one, and (4) most CMEs deflect toward equator near the solar minimum; these deflections can be classified into three types: the asymmetrical expansion, the nonradial ejection, and the deflected propagation.

The second paper by Chen, Wang *et al.*[31] reports statistical study of coronal mass ejection (CME) source locations, in which the relationship between CMEs and

Active Regions (ARs) is statistically studied on the basis of the information of CME source locations and the ARs automatically extracted from magnetic synoptic charts of Michelson Doppler Imager (MDI) during 1997–1998. Totally, 224 CMEs with a known location and 108 MDI ARs are included in their sample. It is found that about 63% of the CMEs are related with ARs, at least about 53% of the ARs produce one or more CMEs, and particularly about 14% of ARs are CME-rich (3 or more CMEs were generated) during one transit across the visible disk. Several issues are then tried to be clarified: whether or not the CMEs originating from ARs are distinct from others, whether or not the CME kinematics depends on AR properties, and whether or not the CME productivity depends on AR properties. The statistical results suggest that (1) there is no evident difference between AR-related and non-AR-related CMEs in terms of CME speed, acceleration and width, (2) the size, strength and complexity of ARs do little with the kinematic properties of CMEs, but have significant effects on the CME productivity, and (3) the sunspots in all the most productive ARs at least belong to βγ type, whereas 90% of those in CME-less ARs are α or β type only. A detailed analysis on CME-rich ARs further reveals that (1) the distribution of the waiting time of same-AR CMEs, consists of two parts with a separation at about 15 hours, which implies that the CMEs with a waiting time shorter than 15 hours are probably truly physical related, and (2) an AR tends to produce such related same-AR CMEs at a pace of 8 hours, but cannot produce two or more fast CMEs (>800 km·s^{-1}) within a time interval of 15 hours. This interesting phenomenon is particularly discussed.

Shen, Wang *et al*.[32] study the kinematic evolution of the 8 October 2007 CME in the corona based on observations from SECCHI onboard satellite B of STEREO. The observational results show that this CME obviously deflects to a lower latitude region of about 30° at the beginning. After this, the CME propagates radially. They also analyze the influence of the background magnetic field on the deflection of this CME. They find that the deflection of this CME at an early stage may be caused by a non-uniform distribution of the background magnetic-field energy density and that the CME tends to propagate to the region with lower magnetic-energy density. In addition, they find that the velocity profile of this gradual CME shows multi-phased evolution during its propagation in the COR1-B FOV. The CME velocity first remains constant: 23.1 km·s^{-1}. Then it accelerates continuously with a positive acceleration of about 7.6 m·s^{-2}.

Ten CME events viewed by the STEREO twin spacecraft are analyzed by Gui, Shen *et al*.[33] to study the deflections of CMEs during their propagation in the corona. Based on the three-dimensional information of the CMEs derived by the graduated cylindrical shell (GCS) model (Thernisien, Howard, and Vourlidas in Astrophys. J. 652, 1305, 2006), it is found that the propagation directions of eight CMEs changed. By applying the theoretical method proposed by Shen *et al*. (Solar Phys. 269, 389, 2011) to all the CMEs, they find that the deflections are consistent, in strength and direction, with the gradient of the magnetic energy density. There is a positive correlation between the deflection rate and the strength of the magnetic energy density gradient and a weak anti-correlation between the deflection rate and the CME speed. Their results suggest that the deflections of CMEs are mainly controlled by the background magnetic field and can be quantitatively described by the Magnetic Energy Density Gradient (MEDG) model.

The transition of the magnetic field from the ambient magnetic field to the ejecta in the sheath downstream of a Coronal Mass Ejection (CME) driven shock is analyzed by Liu, Opher *et al*.[34] in detail. The field rotation in the sheath occurs in a two-layer structure. In the first layer, Layer 1, the magnetic field rotates in the coplanarity plane (plane of shock normal and the upstream magnetic field), and in Layer 2 rotates off this plane. They investigate the evolution of the two layers as the sheath evolves away from the Sun. In situ observations have shown that the magnetic field in the sheath region in front of an Interplanetary Coronal Mass Ejection (ICME) form a planar magnetic structure, and the magnetic field lines drape around the flux tube. Their object is to investigate the magnetic configuration of the CME near the Sun. They use a 3D MHD simulation code, the Space Weather Modeling Framework (SWMF) to simulate the propagation of CMEs and the shock driven by it. Close to the Sun, Layer 2 dominates the width of the sheath, diminishing its importance as the sheath evolves away from the Sun, consistent with observations at 1 AU.

At which height is a prominence inclined to be unstable, or where is the most probable critical height for the prominence destabilization? This question is statistically studied by Liu, Wang *et al*.[35] based on 362 solar limb prominences well recognized by Solar Limb Prominence Catcher and Tracker from 2007 April to the end of 2009. They find that there are about 71% Disrupted Prominences (DPs), among which about 42% of them do not erupt successfully and about 89% of them experience a sudden destabilization process. After a comprehensive analysis of the DPs, they discover the following: (1) 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; (2) 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; (3) stable prominences are generally longer and heavier than DPs, and not higher than 0.4 R_s; (4) About 62% of the EPs were associated with Coronal Mass Ejections (CMEs); but there is no difference in apparent properties between EPs associated with CMEs and those that are not.

Halo Coronal Mass Ejections (CMEs) are significantly faster than normal CMEs, which is a long-standing puzzle. In order to solve the puzzle, Zhang, Guo *et al*.[36] first investigate the observed properties of 31 limb CMEs that clearly display loop shaped frontal loops. The observational results show a strong tendency that slower CMEs are weaker in white-light intensity. Then, they perform a Monte Carlo simulation of 20000 artificial limb CMEs that have an average velocity of about 523 km·s^{-1}. The Thomson scattering of these events is calculated when they are assumed to be observed as limb and halo events, respectively. It is found that the white-light intensity of many slow CMEs becomes remarkably reduced when they turn from being viewed as a limb event to being viewed as a halo event. When the intensity is below the background solar wind fluctuation, it is assumed that they would be missed by coronagraphs. The average velocity of "detectable" halo CMEs is about 922 km·s^{-1}, very close to the observed value. This also indicates that wider events are more likely to be recorded. The results soundly suggest that the higher average velocity of halo CMEs is due to that a majority of slow events and some of narrow fast events carrying less material are so faint that they are blended with the solar wind fluctuations, and therefore can not be observed.

Kinematic properties of Coronal Mass Ejections (CMEs) suffer from projection effects, and it is expected that the real velocity should be larger and the real angular width should be smaller than the apparent values. Several attempts have been taken to correct the projection effects, which however led to an inflated average velocity probably due to the biased choice of CME events. In order to estimate the overall influence of the projection effects on the kinematic properties of the CMEs, Wu and Chen[37] perform a forward modeling of real distributions of CME properties, such as the velocity, the angular width, and the latitude, by requiring their projected distributions to best match observations. Such a matching is conducted by Monte Carlo simulations. According to the derived real distributions, they found that (1) the average real velocity of all non-full-halo CMEs is about 514 km·s^{-1}, and the average real angular width is about 33°, in contrast to the corresponding apparent values of 418 km·s^{-1}and 42.7° in observations; (2) For the CMEs with the angular width in the range of 20°−120°, the average real velocity is 510 km·s^{-1} and the average real angular width is 43.4°, in contrast to the corresponding apparent values of 392 km·s^{-1}and 52° in observations.

EUV Imaging Telescope (EIT) waves are a wavelike phenomenon propagating outward from the coronal mass ejection source region, with expanding dimmings following behind. Chen, Ding, and Chen[38] present a spectroscopic study of an EIT wave/dimming event observed by the Hinode/Extreme-ultraviolet Imaging Spectrometer. Although the identification of the wave front is somewhat affected by the pre-existing loop structures, the expanding dimming is well defined. They investigate the line intensity, width, and Doppler velocity for four EUV lines. In addition to the significant blueshift implying plasma outflows in the dimming region as revealed in previous studies, they find that the widths of all four spectral lines increase at the outer edge of the dimmings. They illustrate that this feature can be well explained by the field line stretching model, which claims that EIT waves are apparently moving brightenings that are generated by the successive stretching of the closed field lines.

The nature of EIT wave is still elusive, with the debate on-going between fast-mode wave model and non-wave model. In order to distinguish between these models, Yang and Chen[39] investigate the relation between the EIT wave velocity and the local magnetic field in the corona. It is found that the two parameters show significant negative correlation in most of the EIT wave fronts, *i.e.*, the EIT wave propagates more slowly in the regions of stronger magnetic field. Such a result poses a big challenge to the fast-mode wave model, which would predict a strong positive correlation between the two parameters. However, it is demonstrated that such a result can be explained by the fieldline stretching model, *i.e.*, that "EIT waves" are the propagation of apparent brightenings, which are generated by successive stretching of closed magnetic field lines pushed by the erupting flux rope during Coronal Mass Ejections (CMEs).

Chen, Ding *et al*.[40] report a spectroscopic analysis of an EUV Imaging Telescope (EIT) wave event that occurred in active region 11081 on 12 June 2010 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. Using EUV Imaging Spectrometer raster observations for this region, they study the properties of plasma dynamics in the wave front, as well as the interaction between the wave and the upflow region. They find a weak blueshift for the Fe_{XII} λ195.12 and Fe_{XIII} λ 202.04 lines in the wave front. The local velocity along the solar surface, which is deduced from the line-of-sight velocity in the wave front and the projection effect, is much lower than the typical propagation speed of the wave. A more interesting finding is that the upflow and non-thermal velocities in the upflow region are suddenly diminished after the transit of the wave front. This implies a significant change of magnetic field orientation when the wave passed. As the lines in the upflow region are redirected, the velocity along the line of sight is diminished as a result. They suggest that this scenario is more in accordance with what is proposed in the field-line stretching model of EIT waves.

Chen and Wu[41] suggest that "EIT waves" are the apparent propagation of the plasma compression due to successive stretching of the magnetic field lines pushed by the erupting flux rope. According to this model, an EIT wave should be preceded by a fast-mode wave, which, however, had rarely been observed. With the unprecedented high cadence and sensitivity of the Solar Dynamics Observatory (SDO) observations, they discern a fast-moving wave front with a speed of 560 km·s^{-1} ahead of an EIT wave, which had a velocity of ~190 km·s^{-1}, in the "EIT wave" event on 27 July 2010. The results, suggesting that "EIT waves" are not fast-mode waves, confirm the prediction of their field-line stretching model for an EIT wave. In particular, it is found that the coronal Moreton wave was ~3 times faster than the EIT wave, as predicted.

The data from SOHO/EIT and SOHO/LASCO observations are used by Liu, Xia, *et al*.[42] to determine the relationship between coronal dimming and full halo CME. The events of full halo CME examined in their study are observed by LASCO coronagraph and taken from the CDAW CME catalogue from 1996 to 2008. Dimming events are identified by using difference images taken by EIT at the 195 Å passband. They find strong relationship between full halo CMEs and the coronal dimming events, with up to 93.3% of the front-side halo CMEs associated with the EIT 195 Å dimming events. Full halo CMEs that show no clear signatures of dimming usually have lower sky plane velocities (<700 km·s^{-1}) compared to the mean velocity of CMEs associated with dimming.

Between 2004 July 5 and July 7, two intriguing fast Coronal Mass Ejection (CME)-streamer interaction events are recorded by the Large Angle and Spectrometric Coronagraph. At the beginning of the events, the streamer is pushed aside from its equilibrium position upon the impact of the rapidly outgoing and expanding ejecta; then, the streamer structure, mainly the bright streamer belt, exhibits elegant large-scale sinusoidal wavelike motions. The motions are apparently driven by the restoring magnetic forces resulting from the CME impingement, suggestive of MHD kink mode propagating outward along the plasma sheet of the streamer. The mode is supported collectively by the streamer-plasma sheet structure and is therefore named "streamer wave" in the present study. With the white light coronagraph data, Chen, Song *et al*.[43] show that the streamer wave has a period of about 1 hr, a wavelength varying from 2 to 4 solar radii, an amplitude of about a few tens of solar radii, and a propagating phase speed in the range 300–500 km·s^{-1}. They also find that there is a tendency for the phase speed to decline with increasing heliocentric distance. These observations provide good examples of large-scale wave phenomena carried by coronal structures and have significance in developing seismological techniques for diagnosing plasma and magnetic parameters in the outer corona.

With a survey through the LASCO data from 1996 to 2009, Song, Kong *et al*.[44] present 11 events with plasma blobs flowing outwards sequentially along a bright coronal ray in the wake of a coronal mass ejection. The ray is believed to be associated with the current-sheet structure that formed as a result of solar eruption, and the blobs are products of magnetic reconnection occurring along the current sheet. The ray morphology and blob dynamics are investigated statistically. It is 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, based on the analysis of blob motions, that 58% (26) of the blobs are accelerated, 20% (9) are decelerated, and 22% (10) moved with a nearly constant speed. Comparing the dynamics of their blobs and those that are observed above the tip of a helmet streamer, they find that the speeds and accelerations of the blobs in these two cases differ significantly. It is suggested that these differences of the blob dynamics stem from the associated magnetic reconnection involving different magnetic field configurations and triggering processes.

3 Magnetic Reconnection in Interplanetary Space

Wang, Wei *et al*.[45] report in situ observation of energetic electrons (~100–500 keV) associated with magnetic reconnection in the solar wind by the ACE and Wind spacecraft. The properties of this magnetic cloud driving reconnection and the associated energetic electron acceleration problem are discussed. Further analyses indicate that the electric field acceleration and Fermi-type mechanism are two fundamental elements in the electron acceleration processes and the trapping effect of the specific magnetic field configuration maintains the acceleration status that increases the totally gained energy.

During 26–27 November 2000 a complex interplanetary coronal mass ejection, composed of four flux ropes, was detected by Wind and ACE at 1 AU. Xu, Wei and Feng[46] identify two Petschek-like exhaust events within the interiors of the second and third flux ropes, respectively. In the first event, Wind and ACE detected an exhaust at the same side from the reconnection site, which is associated with a large-scale bifurcated current sheet with a spatial width of ~10000 ion inertial lengths and the magnetic shear was 155°. In the second event, the two spacecraft observed the oppositely directed exhausts from a single reconnection X line. The exhausts are also related to a large-scale current sheet with a spatial width of ~3000 ion inertial lengths and a shear angle of about 135°. The two exhaust events result from fast and quasi-stationary reconnection. The related current sheets are both flat on the scale of a few hundred Earth radii and locate close to the centers of subflux ropes. The decrease of radial expansion speed of each flux rope might account for the formation of the two current sheets. Reconnections at the centers of flux ropes may change the entire topology of the flux ropes and may fragment them into smaller ones.

The interaction between interplanetary small-scale magnetic flux ropes and the magnetic field in the ambient solar wind is an important topic in the understanding of the evolution of magnetic structures in the heliosphere. Through a survey of 125 previously reported small flux ropes from 1995 to 2005, Tian, Yao *et al*.[47] find that 44 of them reveal clear signatures of Alfvénic fluctuations and thus classify them as Alfvén wave trains rather than flux ropes. Signatures of magnetic reconnection, generally including a plasma jet of ~30 km·s^{-1} within a magnetic field rotational region, are clearly present at boundaries of about 42% of the flux ropes and 14% of the wave trains. The reconnection exhausts are often observed to show a local increase in the proton temperature, density, and plasma beta. About 66% of the reconnection events at flux rope boundaries are associated with a magnetic field shear angle larger than 90° and 73% of them reveal a decrease of 20% or more in the magnetic field magnitude, suggesting a dominance of anti-parallel reconnection at flux rope boundaries. The occurrence rate of magnetic reconnection at flux rope boundaries through the years 1995–2005 is also investigated and they find that it is relatively low around the solar maximum and much higher when approaching solar minima. The average magnetic field depression and shear angle for reconnection events at flux rope boundaries also reveal a similar trend from 1995 to 2005. Their results demonstrate for the first time that boundaries of a substantial fraction of small-scale flux ropes have properties similar to those of magnetic clouds, in the sense that both of them exhibit signatures of magnetic reconnection. The observed reconnection signatures could be related either to the formation of small flux ropes or to the interaction between flux ropes and the interplanetary magnetic fields.

Coronal Bright Points (CBPs) are long-lived small-scale brightenings in the solar corona. They are generally explained by magnetic reconnection. However, the corresponding magnetic configurations are not well understood. Zhang, Chen *et al*.[48] carry out a detailed multi-wavelength analysis of two neighboring CBPs on 2007 March 16, 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. Although the EUV images at high-temperature lines resemble the SXR appearance, the 171 Å and 195 Å channels reveal that the blurry CBP in SXR consists of a cusp-shaped loop and several separate bright patches, which are explained to be due to the null-point reconnection and the separatrix reconnection, respectively.

Two-dimensional particle-in-cell simulations are performed by Huang, Lu, and Wang[49] to investigate electron dynamics in antiparallel and guide field (in the presence of a strong guide field) magnetic reconnection, and the mechanisms of electron acceleration are compared. In the antiparallel reconnection, the dominant acceleration occurs in the vicinity of the X line, where the magnetic field is weak. Most of these electrons come from the regions just outside of the separatrices, which move into the vicinity of the X line along the magnetic field lines. Electrons can also be non-adiabatically accelerated in the pileup region by the reconnection electric field, where the gyroradii of the electrons are comparable to the curvature radii of the magnetic field lines. Most of these electrons come from the regions inside of the separatrices, which move into the pileup region along the magnetic field lines. In the guide field reconnection, electrons are accelerated by the parallel electric field. They are firstly accelerated when moving toward the X line along the magnetic field lines, and then are further accelerated when they are funneled into the vicinity of the X line. Most of energetic electrons come from the region outside of the pair of the negative separatrices. The efficiency of such an acceleration mechanism is obviously higher than that in the antiparallel reconnection. In both the antiparallel and guide field reconnection, the mechanisms of electron acceleration favor the electrons with higher initial energy.

In collisionless magnetic reconnection, the in-plane Hall currents are carried mainly by the magnetized electrons.

The in-plane Hall currents are directed toward the X line along the magnetic field lines just inside the separatrices and away from the X line along the separatrices. Such a current system leads to the quadrupole out-of-plane magnetic field with the peaks between the regions carrying the in-plane currents. Simultaneously, the electron flow toward the X line along the separatrices causes electron density depletions along the separatrices. The features of separatrix regions in magnetic reconnection and the relations between the electron density depletions and the out-of-plane magnetic field are investigated by Lu, Huang *et al*.[50] with both two-dimensional particle-in-cell simulations and Cluster observations. They conclude that the electron density depletions are formed because of the magnetic mirror, and they are outside the peaks of the out-of-plane magnetic field. Such a theoretical prediction is confirmed by both simulations and observations.

Two-dimensional (2D) particle-in-cell simulations are performed by Lu *et al*.[51] to investigate the structures of the out-of-plane magnetic field in magnetic island, which is produced during anti-parallel collisionless magnetic reconnection. Regular structures with alternate positive and negative values of the out-of-plane magnetic field along the *x* direction are formed in magnetic island. The generation mechanism of such structures is also proposed in their paper, which is due to the Weibel instability excited by the temperature anisotropy in magnetic island.

Two-dimensional particle-in-cell simulations are performed by Lu *et al*.[52] to investigate the formation of electron density depletions in collisionless magnetic reconnection. In anti-parallel reconnection, the quadrupole structures of the out-of-plane magnetic field are formed, and four symmetric electron density depletion layers can be found along the separatrices due to the effects of magetic mirror. With the increase of the initial guide field, the symmetry of both the out-of-plane magnetic field and electron density depletion layers is distorted. When the initial guide field is sufficiently large, the electron density depletion layers along the lower left and upper right separatrices disappear. The parallel electric field in guide field reconnection is found to play an important role in forming such structures of the electron density depletion layers. The structures of the out-of-plane magnetic field B_y and electron depletion layers in anti-parallel and guide field reconnection are found to be related to electron flow or in-plane currents in the separatrix regions. In anti-parallel reconnection, electrons flow towards the X line along the separatrices, and are directed away from the X line along the magnetic field lines just inside the separatrices. In guide field reconnection, electrons can only flow towards the X line along the upper left and lower right separatrices due to the existence of the parallel electric field in these regions.

Two-dimensional (2-D) particle-in-cell (PIC) simulations are performed by Huang, Lu *et al*.[53] to investigate the evolution of the Electron Current Sheet (ECS) in guide field reconnection. The ECS is formed by electrons accelerated by the inductive electric field in the vicinity of the X line, which is then extended along the *x* direction due to the imbalance between the electric field force and Ampere force. The tearing instability is unstable when the ECS becomes sufficiently long and thin, and several seed islands are formed in the ECS. These tiny islands may coalesce and form a larger secondary island in the center of the diffusion region.

The evolutionary process of magnetic reconnection under solar coronal conditions is investigated by Zhang, Feng *et al*.[54] with their recently developed 2.5 D Adaptive Mesh Refinement (AMR) resistive Magneto Hydrodynamics (MHD) model. They reveal the successive fragmentation and mering of plasmoids in a long-thin current sheet with Lundquist number R_m=5.0×10^4. It is found that several big magnetic islands are formed eventually, with many slow-mode shocks bounding around the outflow regions. The multi-scale hierarchical-like structures of the magnetic reconnection are well resolved by the model and the AMR technique of the model can capture many fine pictures (*e.g.*, the near-singular diffusion regions) of the development and simultaneously it can save a great deal of computing resources.

4 Energetic Particles

Recently, Tan and coworkers study the September 24 2001 Solar Energetic Particle (SEP) event observed by the WIND spacecraft at 1 AU and found that there is a counter-streaming particle beam with a deep depression of flux at 90° pitch angle during the beginning of the event. They suggested that it is a result of a reflecting boundary at some distance outside of 1 AU. While this scenario could be true under some specific configuration of an interplanetary magnetic field, Qin, He and Zhang[55] offer another possible explanation. They simulated the SEP event by solving the five-dimensional focused transport equation numerically for 40 keV electrons with perpendicular diffusion. They find 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. It can happen when a significant number of observed particles come from adjacent field lines through parallel transport to large radial distance first, hopping across field lines through perpendicular diffusion, and then getting scattered back to 1 AU, where they combine with the particles directly coming from the Sun to form a counter-streaming beam.

A model of Solar Energetic Particle (SEP) propagation in the three-dimensional Parker interplanetary magnetic field is calculated numerically by He, Qin and Zhang[56]. They study the effects of the different aspects of particle source on the solar surface, which include the source location, coverage of latitude and longitude, and spatial distribution of source particle intensity, on propagation of SEPs with both parallel and perpendicular diffusion. They compute the particle flux and anisotropy profiles at different observation locations in the heliosphere. From their calculations, they find 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. They focus on the situations when a spacecraft is not connected to the particle sources on the solar surface. They find that when the magnetic footpoint of the spacecraft is farther away from the source, the observed particle flux is smaller and its onset and maximum intensity occur later. When the particle source covers a larger range of latitude and longitude, the observed particle flux is larger and appears earlier. There is east-west azimuthal asymmetry in SEP profiles even when the source distribution is east-west symmetric. However, the detail of particle spatial distribution inside the source does not affect the profile of the SEP flux very much. When the magnetic footpoint of the spacecraft is significantly far away from the particle source, the anisotropy of particles in the early stage of an SEP event points toward the Sun, which indicates that the first arriving particles come from outside of the observer through perpendicular diffusion at large radial distances.

To obtain the mean free path of Solar Energetic Particles (SEPs) for a solar event, one usually has to fit time profiles of both flux and anisotropy from spacecraft observations to numerical simulations of SEPs' transport processes. This method can be called a simulation method. But a reasonably good fitting needs a lot of simulations, which demand a large amount of calculation resources. Sometimes, it is necessary to find an easy way to obtain the mean free path of SEPs quickly, for example, in space weather practice. Recently, Shalchi *et al*. provided an approximate analytical formula of SEPs' anisotropy time profile as a function of particles' mean free path for impulsive events. He and Qin[57] determine SEPs' 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 obtain SEPs' mean free path with the traditional simulation methods. Finally, they compare the mean free path obtained with the simulation method to that of the analytical method to show that the analytical method, with some minor modifications, can give a good, quick approximation of SEPs' mean free path for impulsive events.

The analytical nonlinear theory of magnetic field line random walk predicts the existence of non-diffusive transport for certain forms of the turbulence spectrum. Shalchi and Qin[58] use computer simulations to test these predictions made for well-established one- and two-dimensional models of magnetic field fluctuations. For the first time it is shown by using simulations, that for a whole family of spectra a non-diffusive behavior of field line wandering can be found.

The Focused Transport Equation (FTE) includes all the necessary physics for modeling the shock acceleration of energetic particles with a unified description of first-order Fermi acceleration, shock drift acceleration, and shock surfing acceleration. It can treat the acceleration and transport of particles with an anisotropic distribution. The energy spectrum of pickup ions accelerated at shocks of various obliquities is investigated by Zuo, Zhang *et al*.[59] based on the FTE. They solve the FTE by using a stochastic approach. The shock acceleration leads to a two-component energy spectrum. The low-energy component of the spectrum is made up of particles that interact with shock one to a few times. For these particles, the pitch angle distribution is highly anisotropic, and the energy spectrum is variable depending on the momentum and pitch angle of injected particles. At high energies, the spectrum approaches a power law consistent with the standard Diffusive Shock Acceleration (DSA) theory. For a parallel shock, the high-energy component of the power-law spectrum, with the spectral index being the same as the prediction of DSA theory, starts just a few times the injection speed. For an oblique or quasi-perpendicular shock, the high-energy component of the spectrum exhibits a double power-law distribution: a harder power-law spectrum followed by another power-law spectrum with a slope the same as the spectral index of DSA. The shock acceleration will eventually go into the DSA regime at higher energies even if the anisotropy is not small. The intensity of the energy spectrum given by the FTE, in the high-energy range where particles get efficient acceleration in the DSA regime, is different from that given by the standard DSA theory for the same injection source. They define the injection efficiency η as the ratio between them. For a parallel shock, the injection efficiency is less than 1, but for an oblique shock or a quasi-perpendicular shock it could be greater.

The issue of the influence of Coronal Holes (CHs) on Coronal Mass Ejections (CMEs) in causing solar energetic particle (SEP) events is revisited by Shen, Yao *et al*.[60]. It is a continuation and extension of their previous work, in which no evident effects of CHs on CMEs in generating

SEPs are found by statistically investigating 56 CME events. They extrapolate the coronal magnetic field, define CHs as the regions consisting of only open magnetic field lines and perform a similar analysis on this issue for 76 events in total by extending the study interval to the end of 2008. Three key parameters, CH proximity, CH area and CH relative position, are involved in the analysis. The new result confirms the previous conclusion that CHs do not show any evident effect on CMEs in causing SEP events.

It is generally believed that gradual Solar Energetic Particles (SEPs) are accelerated by shocks associated with Coronal Mass Ejections (CMEs). Using an ice-cream cone model, the radial speed and angular width of 95 CMEs associated with SEP events during 1998–2002 are calculated by Pan, Wang *et al*.[61] from SOHO/LASCO observations. Then, they investigate 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. These characteristic times of SEP are (i) the onset time from the accompanying CME eruption at the Sun to the SEP arrival at 1 AU, (ii) the rise time from the SEP onset to the time when the SEP intensity is one-half of peak intensity, and (iii) the duration over which the SEP intensity is within a factor of two of the peak intensity. It is found that the onset time has neither significant correlation with the radial speed nor with the angular width of the accompanying CME. For events that are poorly connected to the Earth, the SEP rise time and duration have no significant correlation with the radial speed and angular width of the associated CMEs. However, for events which are magnetically well connected to the Earth, the SEP rise time and duration have significantly positive correlations with the radial speed and angular width of the associated CMEs. This indicates that a CME event with wider angular width and higher speed may more easily drive a strong and wide shock near the Earth-connected interplanetary magnetic field lines, may trap and accelerate particles for a longer time, and may lead to longer rise time and duration of the ensuing SEP event.

5 Space Plasma

A multidimensional electron phase-space hole (electron hole) is considered to be unstable to the transverse instability. Wu, Lu *et al*.[62] perform two-dimensional (2-D) Particle-in-Cell (PIC) simulations to study the evolution of electron holes at different plasma conditions; they find that the evolution is determined by combined actions between the transverse instability and the stabilization by the background magnetic field. In very weakly magnetized plasma ($\Omega_e \ll \omega_{pe}$, where Ω_e and ω_{pe} are the electron gyrofrequency and plasma frequency, respectively), the transverse instability dominates the evolution of the electron holes. The parallel cut of the perpendicular electric field ($E_\perp$) has bipolar structures, accompanied by the kinking of the electron holes. Such structures last for only tens of electron plasma periods. With the increase of the background magnetic field, the evolution of the electron holes becomes slower. The bipolar structures of the parallel cut of $E_\perp$ in the electron holes can evolve into unipolar structures. In very strongly magnetized plasma ($\Omega_e \gg \omega_{pe}$), the unipolar structures of the parallel cut of $E_\perp$ can last for thousands of electron plasma periods. At the same time, the perpendicular electric field ($E_\perp$) in the electron holes can also influence electron trajectories passing through the electron holes, which results in variations of charge density along the direction perpendicular to the background magnetic field outside of the electron holes. When the amplitude of the electron hole is sufficiently strong, streaked structures of $E_\perp$ can be formed outside of the electron holes, which then emit electrostatic whistler waves because of the interactions between the streaked structures of $E_\perp$ and vibrations of the kinked electron holes.

A multi-dimensional electron phase-space hole (electron hole) is considered to be unstable to the transverse instability. Wu, Wu *et al*.[63] perform two-dimensional (2-D) particle-in-cell (PIC) simulations to study the evolutions of electron holes in weakly magnetized plasma ($\Omega_e < \omega_{pe}$, where Ω_e and ω_{pe} are the electron gyrofrequency and plasma frequency, respectively), and the effects of perpendicular thermal velocities on the transverse instability are investigated. The transverse instability can cause decay of the electron holes. They find that with the increasing perpendicular thermal velocity tending to stabilize the transverse instability, the corresponding wave numbers decrease.

Observations have shown that electron phase-space holes (electron holes) possess regular magnetic structures. Wu, Lu *et al*.[64] perform two-dimensional (2-D) electromagnetic Particle-in-Cell (PIC) simulations in the (x, y) plane to study magnetic structures associated with electron holes under different plasma conditions. In the simulations, the background magnetic field ($B_0 = B_0 e_x$) is along the x direction. The combined actions between the transverse instability and stabilization by the background magnetic field lead to the generation of the electric field E_y. Then electrons suffer the electric field drift and produce the current in the z direction, which leads to the fluctuating magnetic field along the x and y directions. Meanwhile, the motion of the electron holes along the x direction and the existence of the electric field E_y generate the fluctuating magnetic field along the z direction. In very weakly magnetized plasma ($\Omega_e \ll \omega_{pe}$, where Ω_e and ω_{pe} are the electron gyrofrequency and electron plasma frequency, respectively), the transverse instability is very strong and the magnetic structures associated with electron holes disappear quickly. When Ω_e is comparable to ω_{pe}, the parallel cut of the fluctuating magnetic field δ_{Bx} and δ_{Bz} has unipolar structures in the electron holes, while the parallel cut of fluctuating magnetic field δ_{By} has bipolar structures. In strongly magnetized plasma ($\Omega_e>\omega_{pe}$), electrostatic whistler waves with streaked structures of E_y are excited. The fluctuating magnetic field δ_{Bx} and δ_{Bz} also have streaked structures. The relevance between their simulation results and the magnetic structures associated with electron holes observed in the plasma sheet is also discussed.

Previous particle-in-cell simulations have evidenced that supercritical, quasi-perpendicular shocks are non-stationary. By separating the incident ions into reflected (R) and Directly Transmitted (DT) parts, Yang, Lu and Wang[65] investigate the ion distributions in a non-stationary perpendicular shock. The upstream ion distributions have two parts corresponding to the *R* and incident ions respectively, while the *R* ions have higher energy. The downstream ions have a core-ring distribution. The core and ring parts correspond to the DT and R ions, respectively. The ion distributions depend largely on the non-stationary shock structure. The percentage of the reflected ions cyclically varies in time with a period equal to the shock self-reformation cycle, and the number of the R ions increases with the steepness of the shock ramp.

Both hybrid/full particle simulations and recent experimental results have clearly evidenced that the front of a supercritical quasi-perpendicular shock can be non-stationary. One responsible mechanism proposed for this non-stationarity is the self-reformation of the front itself being due to the accumulation of reflected ions. Important consequences of this non-stationarity are that not only the amplitude but also the spatial scales of fields components at the shock front (ramp and foot) are strongly varying within each cycle of the self-reformation. On the other hand, several studies have been made on the acceleration and heating of heavy ions but most have been restricted to a stationary shock profile only. Yang, Lembège, and Lu[66] perform one-dimensional test particle simulations based on shock profiles fields produced in PIC simulation in order to investigate the impact of the shock front non-stationarity on heavy ion acceleration (He, O, Fe). Reflection and acceleration mechanisms of heavy ions (with different initial thermal velocities and different charge-mass ratios) interacting with a non-stationary shock front (self-reformation) are analyzed in detail. Present preliminary results show that: (1) the heavy ions suffer both shock drift acceleration (SDA) and Shock Surfing Acceleration (SSA) mechanisms; (2) the fraction of reflected heavy ions increases with initial thermal velocity, charge-mass ratio and decreasing shock front width at both stationary shocks (situation equivalent to fixed shock cases) and non-stationary shocks (situation equivalent to continuously time-evolving shock cases); (3) the shock front non-stationarity (time-evolving shock case) facilitates the reflection of heavy ions; (4) a striking feature is the formation of an injected monoenergetic heavy ions population which persists in the shock front spectrum for different initial thermal velocities and ions species. The impact of the shock front non-stationarity on the heavy ions spectra within the shock front region and the downstream region are detailed separately. These results are compared with previous experimental analysis and theoretical models of Solar Energetic Particles (SEP) events. The variations of Fe/O spectra in high energy part have been retrieved, and the non-stationary effects of shock front strongly amplify these variations.

One-dimensional test particle simulations based on shock profiles issued from one-dimensional particle-incell simulation are performed by Yang, Lembège *et al*.[67] in order to investigate the impact of the shock front non-stationarity (self-reformation) on the acceleration processes and the resulting energy spectra of PIs (protons H^+) at a strictly perpendicular shock. PIs are represented by different shell distributions (variation of the shell velocity radius). The contribution of Shock Drift Acceleration (SDA), Shock Surfing Acceleration (SSA), and Directly Transmitted (DT) PI's components to the total energy spectra is analyzed. Their results show that (1) both SDA and SSA mechanisms can apply as preacceleration mechanisms for PIs, but their relative energization efficiency strongly differs; (2) SDA and SSA always work together at non-stationary shocks (equivalent to time-varying shock profiles) but SDA, and not SSA, is shown to dominate the formation of high-energy PIs in most cases; (3) the front non-stationarity reinforces the formation of SDA and SSA PIs in the sense that it increases both their maximum energy and their relative density, independently on the radius of PI's shell velocity; and (4) for high shell velocity around the shock velocity, the middle energy range of the total energy spectrum follows a power law $E_k^{-1.5}$. This power law is supported by both SDA and DT ions (within two separate contributing energy ranges) for a stationary shock and mainly by SDA ions for a non-stationary shock. In both cases, the contribution of SSA ions is comparatively weak.

Electron phase space holes (electron holes) are found to be unstable to the transverse instability. Two-dimensional (2-D) electromagnetic particle-in-cell simulations are performed by Du, Wu *et al*.[68] to investigate the structures of the fluctuating magnetic field associated with electron holes. The combined actions between the transverse instability and the stabilization by the background magnetic field (B_0=B_0e_x) lead a one-dimensional electron hole into several 2-D electron holes which are isolated in both the x and y directions. The electrons trapped in these 2D electron holes suffer the electric field drift v_E=E×B_0 /B_0^2 due to the existence of the perpendicular electric field E_y, which generates the current along the z direction. Then, the unipolar and bipolar structures are formed for the parallel cut of the fluctuating magnetic field along the x and y directions, respectively. At the same time, these 2-D electron holes move along the x direction, and the unipolar structures are formed for the parallel cut of the fluctuating magnetic field along the z direction.

A test particle code is employed by Gao, Lu, Wang[69] to explore the dynamics of charged particles and perpendicular diffusion in turbulent magnetic field, where a three-dimensional (3-D) isotropic turbulence model is used. The obtained perpendicular diffusion at different particle energies is compared with that of the Nonlinear Guiding Center (NLGC) theory. It is found that the NLGC theory is consistent with test particle simulations when the particle energies are small. However, the difference between the NLGC theory and test particle simulations tends to increase when the particle energy is sufficiently large, and the threshold is related to the turbulence bend-over length. In the NLGC theory, the gyrocenter of a charged particle is assumed to follow the magnetic field line. Therefore, when the particle has sufficiently large energy, its gyroradius will be larger than the turbulence bend-over length. Then the particle can cross the magnetic field lines, and the difference between the test particle simulations and NLGC theory occurs.

Wang, Wang *et al.*[70] address the stochastic heating of minor ions by obliquely-propagating low-frequency Alfvén waves in the solar wind. An important characteristic of the stochastic heating is unearthed by means of test particle simulation. That is, when the wave amplitude exceeds some threshold condition for stochasticity, the time-asymptotic kinetic temperature associated with the minor ions becomes independent of the wave amplitude, and it always approaches the value dictated by the Alfvén speed, to wit, $T_{kin}≈m_iv^2/2$. During the course of the heating process the minor ions gain a net average parallel speed, $v_{\parallel}≈v_A$ in the laboratory frame. These results are consistent with observations which find that minor heavy ions often move faster than the local protons with a speed roughly equal to the local Alfvén speed.

Satellite observations have revealed that superthermal electrons in space plasma generally possess a power law distribution. Lu, Shan *et al.*[71] utilize a power law function to model the omnidirectional differential fluxes of superthermal electrons observed by Cluster in the magnetosheath. By assuming an isotropic pitch angle distribution and performing a nonlinear least squares fitting, they can calculate the index a of the power law distribution of the superthermal electrons. They find that in the magnetosheath the indices a of the power law distributions decrease with the increase of ω_{pe}/Ω_e. It is consistent with the results of the recent particle-in-cell simulations, which described the electron distributions scattered by enhanced whistler waves. This is the first reported observation of this relation in space plasma.

6 Space Weather Numerical Modeling by 3-D SIP-CESE MHD Model

Feng, Yang *et al.*[72] explore the application of a six-component overset grid to solar wind simulation with a three-dimensional (3-D) Solar-InterPlanetary Conservation Element/Solution Element MHD (SIP-CESE MHD) model. The essential focus of their numerical model is devoted to dealing with: (1) the singularity and mesh convergence near the poles via the use of the six-component grid system, (2) the $\nabla\cdot\boldsymbol{B}$ constraint error via an easy-to-use cleaning procedure by a fast multigrid Poisson solver, (3) the Courant-Friedrichs-Levy number disparity via the Courant-number insensitive method, (4) the time integration by multiple time stepping, and (5) the time-dependent boundary condition at the subsonic region by limiting the mass flux escaping through the solar surface. In order to produce fast and slow plasma streams of the solar wind, they include the volumetric heating source terms and momentum addition by involving the topological effect of the magnetic field expansion factor f_s and the minimum angular distance θ_b (at the photosphere) between an open field foot point and its nearest coronal hole boundary. These considerations can help them easily code the existing program, conveniently carry out the parallel implementation, efficiently shorten the computation time, greatly enhance the accuracy of the numerical solution, and reasonably produce the structured solar wind. The numerical study for the 3-D steady-state background solar wind during Carrington rotation 1911 from the Sun to Earth is chosen to show the above-mentioned merits. Their numerical results have demonstrated overall good agreements in the solar corona with the Large Angle and Spectrometric Coronagraph on board the SOHO satellite and at 1 AU with WIND observations.

A hybrid three-dimensional (3-D) MHD model for solar wind study is proposed by Feng, Zhang *et al.*[73] with combined grid systems and solvers. The computational domain from the Sun to Earth space is decomposed into the near-Sun and off-Sun domains, which are respectively constructed with a Yin–Yang overset grid system and a Cartesian Adaptive Mesh Refinement (AMR) grid system and coupled with a domain connection interface in the overlapping region between the near-Sun and off-Sun domains. The space-time conservation element and solution element method is used in the near-Sun domain, while the Harten-Lax-Leer method is employed in the off-Sun domain. The Yin-Yang overset grid can avoid well-known singularity and polar grid convergence problems and its body-fitting property helps achieve high-quality resolution near the solar surface. The block structured AMR Cartesian grid can automatically capture far-field plasma flow features, such as heliospheric current sheets and shock waves, and at the same time, it can save significant computational resources compared to the uniformly structured Cartesian grid. A numerical study of the solar wind structure for Carrington rotation 2069 shows that the newly developed hybrid MHD solar wind model successfully produces many realistic features of the background solar wind, in both the solar corona and interplanetary space, by comparisons with multiple solar and interplanetary observations.

Feng, Yang *et al*.[74] carry out the Adaptive Mesh Refinement (AMR) implementation of the SIP-CESE MHD model using a six-component grid system. By transforming the governing MHD equations from the physical space (x, y, z) to the computational space (ξ, η, ζ) while retaining the form of conservation, the SIP-AMR-CESE MHD model is implemented in the reference coordinates with the aid of the parallel AMR package PARAMESH available at the website of http://sourceforge.net/projects/paramesh/. In the meantime, the same volumetric heating source terms as in Feng, Yang, *et al*.[71] are also included. The simulated the solar-wind background of different solar-activity phases show overall good agreements in the solar corona and in interplanetary space with these multiple-spacecraft observations.

Zhou, Feng *et al*.[75] present the evolution of the Sun-Earth connection event on 4 November, 1997 by using a 3-D SIP-CESE MHD simulation, in which a spherical high-speed, high-pressure, and high-density plasmoid at 14°S 34°W is used to mimic Coronal Mass Ejection (CME) disturbance. The results provide a relatively satisfactory comparison with the Wind spacecraft observations, such as southward interplanetary magnetic field and large-scale smooth rotation of the magnetic field associated with the CME.

Jiang, Feng *et al*.[76] present new extensions of the space-time Conservation Element and Solution Element (CESE) method for simulations of Magnetohydrodynamic (MHD) problems in general curvilinear coordinates by using an Adaptive Mesh Refinement (AMR) grid system. By transforming the governing MHD equations from the physical space (x, y, z) to the computational space (ξ, η, ζ) while retaining the form of conservation, the CESE method is established for MHD in the curvilinear coordinates. Utilizing the parallel AMR package PARAMESH, they present the first implementation of applying the AMR CESE method for MHD (AMR-CESE-MHD) in both Cartesian and curvilinear coordinates. To show the validity and capabilities of the AMR-CESE-MHD code, a suite of numerical tests in two and three dimensions including ideal MHD and resistive MHD are carried out, with two of them in both Cartesian and curvilinear coordinates. Numerical tests show that their results are highly consistent with those obtained previously by other authors, and the results under both coordinate systems confirm each other very well.

Jiang, Feng *et al*.[77] present a new implementation of the MHD relaxation method for reconstruction of the nearly force-free coronal magnetic field from a photospheric vector magnetogram according to a new version of the CESE scheme with the full MHD equations. The bottom boundary condition is prescribed in a similar way as in the stress-and-relax method, by changing the transverse field incrementally to match the magnetogram, and other boundaries of the computational box are set by the nonreflecting boundary conditions. Applications to the well-known benchmarks for nonlinear force-free-field reconstruction, the Low & Lou force-free equilibria, validate the method and confirm its capability for future practical application, with observed magnetograms as inputs. The same method has been further improved[78] recently.

The observations both near the Sun and in the heliosphere during the activity minimum between solar cycles 23 and 24 exhibit different phenomena from those typical of the previous solar minima. Yang, Feng *et al*.[79] have chosen Carrington rotation 2070 in 2008 to investigate the properties of the background solar wind by using the 3-D SIP-CESE MHD model. They also study 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 multiple satellites, such as the SOHO, Ulysses, STEREO, WIND and ACE. The comparison demonstrates that the first simulation with the observed magnetic fields reproduces some observed peculiarities near the Sun, such as relatively small polar coronal holes, the presence of mid- and low-latitude holes, a tilted and warped current sheet, and the broad multiple streamers. The numerical results also capture the inconsistency between the locus of the minimum wind speed and the location of the heliospheric current sheet, and predict slightly slower and cooler polar streams with a relatively smaller latitudinal width, broad low-latitude intermediate-speed streams, and globally weak magnetic field and low density in the heliosphere. The second simulation with strengthened polar fields indicates that the weak polar fields in the current minimum play a crucial role in determining the states of the corona and the solar wind.

Yang, Feng *et al*.[80] conduct simulations using the 3D SIP-CESE MHD model and magnetogram data from a Carrington Rotation (CR) 1897 to compare the three commonly used heating methods, *i.e*. the Wentzel-Kramers-Brillouin (WKB) Alfvén wave heating method, the turbulence heating method and the volumetric heating method. Their results show that all three heating models can basically reproduce the bimodal structure of the solar wind observed near the solar minimum. The results also demonstrate that the major acceleration interval terminates about 4 R_s for the turbulence heating method and 10 R_s for both the WKB Alfvén wave heating method and the volumetric heating method. The turbulence heating and the volumetric heating methods can capture the observed changing trends by the WIND satellite, while the WKB Alfvén wave heating method does not.

In summary, the SIP-CESE MHD model developed by Feng and his colleagues [72-80] has the following merits.

(i) The new implementation of volumetric heating source term taking the topological effect of magnetic field with the expansion factor (f_s) and the angular distance (θ_b) into consideration, to some extent, can effectively distinguish the high-speed solar wind from the low-speed solar wind.

(ii) The combination of the projected normal characteristic method and the mass flux limit enables the model to reproduce reasonable distributions of the plasma density, temperature and velocity on the solar surface and incorporation of the time-dependent magnetograms into the model is under development.

(iii) The model provides a unified treatment of flow evolution in space and time and keeps the local and global space-time flux conservation in a coherent and efficient manner.

(iv) The solution points in SIP-CESE MHD model[74] are explicitly given on the mesh nodes, while formerly these points have to be calculated after setting the grids and the projection of the CE onto the spatial space has been greatly simplified to a rectangular cuboid. Therefore, the fluxes at the interface of any pair of conservation elements (CEs) can be efficiently evaluated by means of non-staggered space-time grids without using Riemann solvers or other flux models, which significantly reduces the CPU time.

(v) The treatment of time iteration by integrating two half timesteps into one full timestep leads to low-storage and makes the scheme suitable for building blocks for adaptive mesh refinement calculations.

(vi) The introduction of six-component grid for the computational domain from the Sun to Earth or beyond enables us to fit the spherical surface boundary with an easy implementation of the inner boundary conditions, and meanwhile to avoid both coordinate singularities and polar grid convergence. Particularly, it will be easy to recognize the observation at the lower boundary.

(vii) Through the use of nonsingular transform from the physical space to the reference space, the quadrangular frustum pyramid cell for the spherical shell computational domain for solar wind modeling becomes the conventional rectangular box in the reference space (ξ, η, ζ), which can be seen as the usual Cartesian coordinate. Consequently, the AMR implementation of the code follows easily from PARAMESH in Cartesian coordinate. Thus, besides the CESE scheme, many other modern numerical schemes in Cartesian coordinate such as total variation diminishing (TVD) scheme and finite volume method (FVM) can be applied directly to the transformed system. This feature provides us many flexible alternatives of solving the transformed governing equations in (ξ, η, ζ) and then we recover the solution in the physical space through the transformation to obtain the solar wind solution.

(viii) It should be noted that the same CESE solver can apply to any coordinate system (such as Cartesian, spherical, cylindrical coordinates and any other curvilinear coordinates) with only the difference of the coordinate transformation, and consequently the solver is highly independent of the grid system.

(ix) Based on the CESE MHD model, the new implementation of the MHD relaxation method[76,77,78] for reconstruction of coronal magnetic field from a photospheric vector magnetogram will open a new way for the study of solar active region with the help of HMI/SDO or MDI/SOHO observations.

7 Space Weather Prediction Methods

Shen, Feng and Xiang[81] develop an improved model to build a self-consistent global structure on the source surface of 2.5 R_s covering four different phases of solar activity. This model takes into the consideration of the topological effect of f_s and θ_b. The model uses as input for 136 Carrington Rotations (CRs) covering four different phases of solar activity: (1) an empirical model of the magnetic field topology on the source surface using Line-of-Sight (LOS) photospheric field (B_{los}) measurements by Wilcox Solar Observatory (WSO); (2) an empirically derived global coronal density distribution using K coronal Polarized Brightness (PB) by MKIII in High Altitude Observator (HAO). The solar wind speed on the source surface is specified by the function of both f_s and θ_b. Then the coronal mass outputs are analyzed and the self-consistent global distribution on the source surface is numerically studied for the four different phases. Finally, the model estimates the solar wind speed at 1 AU as a simple function of the speed on the source surface. The results indicate reasonable semi-quantitative agreement with observations at different phases of solar activity.

A 1D-HD shock propagation model is established by Zhang, Chen and Feng[82] to predict the arrival time of interplanetary shocks at 1 AU. Applying this model to 68 solar events during the period of February 1997 to October 2000, it is found that their model could be practically equivalent to the STOA, ISPM and HAFv.2 models in forecasting the shock arrival time. The absolute error in the transit time from their model is not larger than those of the other three models for the same sample events. Also, the prediction test shows that the relative error of their model is ≤ 10% for 31% of all events, ≤30% for 75%, and ≤50% for 84%, which is comparable to the relative errors of the other models. These results might demonstrate a potential capability of their model in terms of real-time forecasting.

Using 141 CME-Interplanetary Shock (CME-IPS) events and f_0F_2 from eight ionosonde stations from January 2000 to September 2005, from the statistical results Li, Wei, Feng and Zhao[83] find that there is a "same side-opposite side effect" in ionospheric negative storms, *i.e.*, a large portion of ionospheric negative disturbances are induced by the same-side events (referring to the CMEs whose source located on the same side of the heliospheric current sheet (HCS) as the Earth), while only a small portion is associated with the opposite-side events (the CMEs source located on the opposite side of the HCS as the Earth); the ratio is 128 vs. 46, and it reaches 41 vs. 14 for the intense ionospheric negative storms. In addition, the ionospheric negative storms associated with the same-side events are often more intense. A comparison of the same-side event (4 April 2000) and the opposite-side event (2 April 2001) shows that the intensity of the ionospheric negative storm caused by the same-side event is higher than that by the opposite-side event, although their initial conditions are quite similar. Their preliminary results show that the HCS has an "impeding" effect to CMEIPS, which results in a shortage of energy injection in the auroral zone and restraining the development of ionospheric negative perturbations.

8 Proposed Missions

Coronal Mass Ejections (CMEs) represent a great concentration of mass and energy input into the lower corona. They have come to be recognized as the major driver of physical conditions change in the Sun-Earth system. Consequently, observations of CMEs are important for understanding and ultimately predicting space weather conditions. Wu, Sun *et al.*[84] discuss a proposed mission, the Solar Polar Orbit Radio Telescope (SPORT) mission, which will observe the propagation of interplanetary CMEs to distances of near 0.35 AU from the Sun. The orbit of SPORT is an elliptical solar polar orbit. The inclination angle between the orbit and ecliptic plane should be about 90°. The main payload on board SPORT will be an imaging radiometer working at the meter wavelength band (radio telescope), which can follow the propagation of interplanetary CMEs. The images that are obtained by the radio telescope embody the brightness temperature of the objectives. Due to the very large size required for the antenna aperture of the radio telescope, they adopt interferometric imaging technology to reduce it. Interferometric imaging technology is based on indirect spatial frequency domain measurements plus Fourier transformation. The SPORT spacecraft will also be equipped with a set of optical and in situ measurement instruments such as a EUV solar telescope, a solar wind ion instrument, an energetic particle detector, a magnetometer, a wave detector and a solar radio burst spectrometer.

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References

[1] He J S, Marsch E, Tu C Y, Guo L J, Tian H. Intermittent outflows at the edge of an active region-a possible source of the solar wind. A&A 2010, 516, A14, 10.1051/0004-6361/ 200913712

[2] He J S, Marsch E, Curdt W, Tian H, Tu C Y, Xia L D, Kamio S. Magnetic and spectroscopic properties of supergranular-scale coronal jets and erupting loops in a polar coronal hole. A&A 2010, 519, A49, doi:10.1051/0004 -6361/ 201014709

[3] Guo L J, Tian H, He J S. Quasi-periodic outflows observed by the X-Ray telescope onboard Hinode in the boundary of an active region. Res. Astron. Astrophys., 2010, 10(12): 1307-1314

[4] Tian H, Tu C Y, Marsch E, He J S, Kamio S. The nascent fast solar wind observed by the EUV imaging spectrometer on board Hinode. Astrophys. J., 2010, 709: L88-L93

[5] Tian H, Potts H E, Marsch E, Attie R, He J S. Horizontal supergranule-scale motions inferred from TRACE ultraviolet observations of the chromosphere. A&A, 2010, 519, A58, doi:10.1051/0004-6361/200913254

[6] He J S, Marsch E, Tu C Y, Yao S, Tian H. Possible evidence of Alfvén-cyclotron waves in the angle distribution of magnetic helicity of solar wind turbulence. Astrophys. J., 2011, 731, 85

[7] Yao S, He J S, Marsch E, Tu C Y, Pedersen A, Rème H, Trotignon J G. Multi-scale anti-correlation between electron density and magnetic field strength in the solar wind. Astrophys. J., 2011, 728, 146

[8] He J S, Tu C Y, Marsch E, Yao S. Do oblique alfvén/ion-cyclotron or fast-mode/whistler waves dominate the dissipation of solar wind turbulence near the proton inertial length. Astrophys. J., 2012, 745, L8

[9] Shen F, Feng X S, Xiang C Q, Song W B. The statistical and numerical study of the global distribution of coronal plasma and magnetic field near 2.5 R_s over a 10-year period. JASTP, 2010, 72: 1008-1018

[10] Song W B, Feng X S, Shen F. The heating of the solar transition region. Res. Astron. Astrophys., 2010, 10(6): 529-532

[11] Song W B, Feng X S, Shen F, Guo J P. Differential Rotation of strong magnetic flux during solar cycles 21–23. Solar Phys., 2011, doi:10.1007/s11207-011-9744-3

[12] Zhang J, Wang Y M, Liu Y. Statistical properties of solar active regions obtained from an automatic detection system and the computational biases. Astrophys. J., 2010, 723: 1006-1018

[13] Zhang M, Xia L D, Tian H, Chen Y. Signatures of transition region explosive events in hydrogen Lyβ profiles. A&A, 2010, 520, A37

[14] Xia C, Chen P F, Keppens R, van Marle A J. Formation of solar filaments by steady and nonsteady chromospheric heating. Astrophys. J., 2011, 737, 27

[15] Li X, Lu Q M, Chen Y, Li B, Xia L D. A kinetic alfvén wave and the proton distribution function in the fast solar wind. Astrophys. J., 2010, 719: L190-L193

[16] Xiao T, *et al*. Cluster-C1 observations on the geometrical structure of linear magnetic holes in the solar wind at 1 AU. Ann. Geophys., 2010, 28: 1695-1702

[17] Chen Y, Feng S W, Li B, Song H Q, Xia L D, Kong X L, Li X. A coronal seismological study with streamer waves. Astrophys. J., 2011, 728, 147

[18] Li B, Chen Y B, Li X. Standing shocks in the inner slow solar wind. Chin. Phys. Lett., 2011, 28, (5), 059601

[19] Li B, Xia L D, Chen Y. Solar winds along curved magnetic field lines. *A&A*, 2011, 529, A148, doi:10.1051/0004-6361/201116668.

[20] Feng S W, Chen Y, Li B, Song H Q, Kong X L, Xia L D, Feng X S. Streamer wave events observed in solar cycle 23. Solar Phys., 2011, 272: 119-136

[21] Zhao X H, Feng X S, Xiang C Q, Liu Y, Li Z, Zhang Y, Wu S T. Multi-spacecraft observations of the 2008 January 2 CME in the inner heliosphere. Astrophys. J., 2010, 714: 1133-1141

[22] Zhao X H, Wu S T, Wang A H, Vourlidas A, Feng X S, Jiang C W. Uncovering the wave nature of the EIT wave for the 2010 January 17 event through its correlation to the background magnetosonic speed. Astrophys. J., 2011, 742, 131

[23] Zhang Y Z, Feng X S, Song W B. Effects of physical features in the solar atmosphere on the coronal mass ejection evolution. Astrophys. J., 2011, 728, 21

[24] Shen F, Feng X S, Wang Y M, Wu S T, Song W B, Guo J P, Zhou Y F. Three-dimensional MHD simulation of two coronal mass ejections' propagation and interaction using a successive magnetized plasma blobs model. J. Geophys. *Res*., 2011, 116, A09103, doi:10. 1029/2011JA016584

[25] Shen F, Feng X S, Wu S T, Xiang C Q, Song W B. Three-dimensional MHD simulation of the evolution of the April 2000 CME event and its induced shocks using a magnetized plasma blob model. J. Geophys. Res., 2011, 116, A04102, doi:10.1029/2010JA015809

[26] Zuo P B, Wei F S, Feng X S, Xu X J, Song W B. Magnetic cloud boundary layer of 9 November 2004 and its associated space weather effects. J. Geophys. *Res*., 2010, 115, A10102, doi:10.1029/2009JA014815

[27] Guo J P, Feng X S, Zhang J, Zuo P B, Xiang C Q. Statistical properties and geoefficiency of interplanetary coronal mass ejections and their sheaths during intense geomagnetic storms. 2010, J. Geophys. Res., 115, A09107, doi:10.1029/2009JA015140

[28] Guo J P, Feng X S, Emery B A, Zhang J, Xiang C Q, Shen F, Song W B. Energy transfer during intense geomagnetic storms driven by interplanetary coronal mass ejections and their sheath regions. J. Geophys. Res., 2011, 116, A05106, doi:10.1029/2011JA016490

[29] Wang Y M, Cao H, Chen J H, Zhang T F, Yu S J, Zheng H N, Shen C L, Zhang J, Wang S. Solar limb prominence catcher and tracker (slipcat): an automated system and its preliminary statistical results. Astrophys. J., 2010, 717:973-986

[30] Wang Y M, Chen C X, Gui B, Shen C L, Ye P Z, Wang S. Statistical study of coronal mass ejection source locations: Understanding CMEs viewed in coronagraphs. *J.* Geophys. Res., 2011 116, A04104, doi:10.1029/2010 JA016101

[31] Chen C X, Wang Y M, Shen C L, Ye P Z, Zhang J, Wang S. Statistical study of coronal mass ejection source locations: 2. Role of active regions in CME production. J. Geophys. Res., 2011, 116, A12108, doi:10.1029/ 2011JA016844

[32] Shen C L, Wang Y M, Gui B, Ye P Z, Wang S. Kinematic evolution of a slow CME in corona viewed by STEREO-B on 8 October 2007. Solar Phys., 2011, 269: 389-400, doi:10.1007/s11207-011-9715-8

[33] Gui B, Shen C L, Wang Y M, Ye P Z, Liu J J, Wang S, Zhao X P. Quantitative analysis of CME deflections in the corona. Solar Phys., 2011, 271:111-139

[34] Liu Y C.-M., Opher M, Wang Y M, Gombosi T I. Downstream structure and evolution of a simulated CME-driven sheath in the solar corona. A&A, 2011, 527, A46

[35] Liu K, Wang Y M, Shen C L, Wang S. Critical height for the destabilization of solar prominences: statistical results from

STEREO observations. Astrophys. J., 2012, 744, 168

[36] Zhang Q M, Guo Y, Chen P F, Ding M D, Fang C. Why are halo coronal mass ejections faster. Res. Astron. Astrophys., 2010, 10(5): 461-472

[37] Wu Y, Chen P F. The inversion of the real kinematic properties of coronal mass ejections by forward modeling. Res. Astron. Astrophys., 2011, 11(2): 237-244

[38] Chen F, Ding M D, Chen P F. Spectroscopic analysis of an EIT wave/dimming observed by Hinode/EIS. Astrophys. J., 2010, 720: 1254-1261

[39] Yang H Q, Chen P F. The dependence of the EIT wave velocity on the magnetic field strength. Solar Phys., 2010, 266: 59-69

[40] Chen F, Ding M D, Chen P F, Harra L K. Spectroscopic analysis of interaction between an extreme-ultraviolet imaging telescope wave and a coronal upflow region. Astrophys. J., 2011, 740, 116

[41] Chen P F, Wu Y. First evidence of coexisting eit wave and coronal moreton wave from SDO/AIA observations. Astrophys. J., 2011, 732, L20

[42] Liu K, Xia L D, Chen Y, Song H Q. Statistical study on the relationship between halo CME and coronal dimming. Sci. China Tech. Sci., 2010, 53: 2020-2024

[43] Chen Y, Song H Q, Li B, Xia L D, Wu Z, Fu H, Li X. Streamer waves driven by coronal mass ejections. Astrophys. J., 2010, 714: 644-651

[44] Song H Q, Kong X L, Chen Y, Li B, Li G, Feng S W, Xia L D. A Statistical study on the morphology of rays and dynamics of blobs in the wake of coronal mass ejections. Solar Phys., 2012, 276: 261-276

[45] Wang Y, Wei F S, Feng X S, Zhang S H, Zuo P B, Sun T R. Energetic electrons associated with magnetic reconnection in the magnetic cloud boundary layer. Phy. Rev. Lett., 2010, 105, 195007

[46] Xu X J, Wei F S, Feng X S. Ob servations of reconnection exhausts associated with large- scale current sheets within a complex ICME at 1 AU. J. Geophys. Res., 2011, 116, A05105, doi:10.1029/2010JA016159

[47] Tian H, Yao S, Zong Q G, He J S, Qi Y. Signatures of magnetic reconnection at boundaries of interplanetary small-scale magnetic flux ropes. Astrophys. J., 2010, 720: 454-464

[48] Zhang Q M, Chen P F, Guo Y, Fang C, Ding M D. Two types of magnetic reconnection in coronal bright points and the corresponding magnetic configuration. Astrophys. J., 2012, 746, 19

[49] Huang C, Lu Q M, Wang S. The mechanisms of electron acceleration in antiparallel and guide field magnetic reconnection. Phys. Plasmas, 2010, 17, 072306

[50] Lu Q M, Huang C, Xie J L, Wang R S, Wu M Y, Vaivads A, Wang S. Features of separatrix regions in magnetic reconnection: Comparison of 2-D particle-in-cell simulations and Cluster observations, J. Geophys. Res., 115, A11208, doi:10.1029/2010JA015713

[51] Lu S, Lu Q M, Shao Y, Yoon P H, Wang S. Weibel instability and structures of magnetic island in anti-parallel collisionless magnetic reconnection. Phys. Plasmas, 2011, 18, 072105

[52] Lu S, Lu Q M, Cao Y, Huang C, Xie J L, Wang S. The effects of the guide field on the structures of electron density depletions in collisionless magnetic reconnection. Chin. Sci. Bull., 2011, 56(1): 48-52

[53] Huang C, Lu Q, Yang Z, Wu M, Dong Q, Wang S. The evolution of electron current sheet and formation of secondary islands in guide field reconnection. Nonlin. Proc. Geophys., 2011, 18: 727-733

[54] Zhang S H, Feng X S, Wang Y, Yang L P. Magnetic reconnection under solar coronal conditions with the 2.5D AMR resistive MHD model. Chin. Phys. Lett., 2011, 28(8), 089601

[55] Qin G, He H Q, Zhang M. An effect of perpendicular diffusion on the anisotropy of solar energetic particles from unconnected sources. Astrophys. J., 2011, 738, 28

[56] He H Q, Qin G, Zhang M. Propagation of solar energetic particles in three-dimensional interplanetary magnetic fields: in view of characteristics of sources. Astrophys. J., 2011, 734, 74

[57] He H Q, Qin G. A simple analytical method to determine solar energetic particles' mean free path. Astrophys. J., 2011, 730, 46

[58] Shalchi A, Qin G. Random walk of magnetic field lines: analytical theory versus simulations. Astrophys. Space Sci., 2010, doi:10.1007/s10509-010-0397-8

[59] Zuo P B, Zhang M, Gamayunov K, Rassoul H, Luo X. Energy spectrum of energetic particles accelerated by shock waves: from focused transport to diffusive acceleration. 2011, 738, 168

[60] Shen C L, Yao J, Wang Y M, Ye P Z, Zhao X P, Wang S. Influence of coronal holes on CMEs in causing SEP events. Res. Astron. Astrophys., 2010, 10(10): 1049-1060

[61] Pan Z H, Wang C B, Wang Y M, Xue X H. Correlation analyses between the characteristic times of gradual solar energetic particle events and the properties of associated coronal mass ejections. Solar Phys., 2011, doi:10.1007/s11207-011-9763-0

[62] Wu M Y, Lu Q M, Huang C, Wang S. Transverse instability and perpendicular electric field in two dimensional electron phase-space holes. J. Geophys. Res., 115, 2010, A10245, doi:10.1029/2009JA015235

[63] Wu M Y, Wu H, Lu Q M, Xue B S. Effects of perpendicular thermal velocities on the transverse instability in electron phase space holes. Chin. Phys. Lett., 2010, 27(9), 095201

[64] Wu M Y, Lu Q M, Du A M, Xie J L, Wang S. The evolution of the magnetic structures in electron phase-space holes: Two-dimensional particle-in-cell simulations. J. Geophys. Res., 2011, 116, A10208, doi:10.1029/ 2011JA016486

[65] Yang Z W, Lu Q M, Wang S. Ion velocity distributions in a non-stationary perpendicular shock. Chin. Phys. Lett., 2010, 27(1), 019601

[66] Yang Z W, Lembège B, Lu Q M. Acceleration of heavy ions by perpendicular collisionless shocks: Impact of the shock front non-stationarity. J. Geophys. Res., 2011, 116, A10202, doi:10.1029/2011JA016605

[67] Yang, Z W, Lembège B, Lu Q M. Impact of the non-stationarity of a supercritical perpendicular collisionless shock on the dynamics and energy spectra of pickup ions. J. Geophys. Res., 2011, 116, A08216, doi:10.1029/2010JA016360

[68] Du A M, Wu M Y, Lu Q M, Huang C, Wang S. Transverse instability and magnetic structures associated with electron phase space holes. Phys. Plasmas, 2011, 18, 032104

[69] Gao X L, Lu Q M, Wang S. Dynamics of charged particles and perpendicular diffusion in turbulent magnetic field. Astrophys. Space Sci., 2011, doi:10.1007/s10509-011-0758-y

[70] Wang B, Wang C B, Yoon P H, Wu C S. Stochastic heating and acceleration of minor ions by Alfvén waves. Geophys. Res. Lett., 2011, 38, L10103, doi:10.1029/ 2011GL047729

[71] Lu Q M, Shan L C, Shen C L, Zhang T L, Li Y R, Wang S. Velocity distributions of superthermal electrons fitted with a power law function in the magnetosheath: Cluster observations. J. Geophys. Res., 2011, 116, A03224, doi:10.1029/2010JA016118

[72] Feng X S, Yang L P, Xiang C Q, Wu S T, Zhou Y F, Zhong D K. Three-dimensional solar wind modeling from the Sun to Earth by a SIP-CESE MHD model with a six-component grid. Astrophys. J., 2010, 723: 300-319

[73] Feng X S, Zhang S H, Xiang C Q, Yang L P, Jiang C W, Wu S T. A hybrid solar wind model of the CESE+HLL method with a Yin-Yang overset grid and an AMR grid. Astrophys. J., 2011, 734, 50

[74] Feng X S, Yang L P, Xiang C Q, Jiang C W, Ma X P, Wu S T, Zhong D K, Zhou Y F. Validation of the 3D AMR SIP–CESE solar wind model for four Carrington rotations. Solar Phys., 2012, doi: 10.1007/s11207-012-9969-9

[75] Zhou Y F, Feng X S, Wu S T, Du D, Shen F, and Xiang C Q. Using a 3-D spherical plasmoid to interpret the Sun-to-Earth propagation of the 4 November 1997 coronal mass ejection event. J. Geophys. Res., 2012, 117, A01102, doi: 10.1029/2010JA016380

[76] Jiang C W, Feng X S, Zhang J, Zhong D K. AMR Simulations of magnetohydrodynamic problems by the CESE method in curvilinear coordinates. Solar Phys., 2010, 267: 463-491, doi:10.1007/s11207-010-9649-6

[77] Jiang C W, Feng X S, Fan Y L, Xiang C Q. Reconstruction of the coronal magnetic field using the CESE-MHD method. Astrophys. J., 2011, 727, 101

[78] Jiang C W, Feng X S. A new implementation of the magnetohydrodynamics-relaxation method for nonlinear force-free field extrapolation in the solar corona. Astrophys. J., 2012, 749, 135

[79] Yang L P, Feng X S, Xiang C Q, Zhang S H, Wu S T. Simulation of the unusual solar minimum with 3D SIP-CESE MHD model by comparison with multi-satellite observations. Solar Phys., 2011, 271: 91-110, doi:10.1007/s11207-011-9785-7

[80] Yang L P, Feng X S, Xiang C Q, Jiang C W. Numerical validation and comparison of three solar wind heating methods by the SIP-CESE MHD model. *Chin.* Phys. Lett., 2011, 28(3), 039601

[81] Shen F, Feng X S, Xiang C Q. Improvement to the global distribution of coronal plasma and magnetic field on the source surface using expansion factor fs and angular distance. J. Atmos. Solar Terr. Phys,. 2012, 77, 125–131

[82] Zhang Y, Chen J Y, Feng X S. Predicting the shock arrival time using 1D-HD solar wind model. Chin. Sci. Bull., 2010, 55(11): 1053-1058

[83] Li Z, Wei F S, Feng X S, Zhao X H. The "same side-opposite side effect" of the heliospheric current sheet in ionospheric negative storms. Solar Phys., 2010, 263: 263-273

[84] Wu J, Sun W Y, Zheng J H, Zhang C, Liu H, Yan J Y, Wang C, Wang C B, Wang S. Imaging interplane-tary CMEs at radio frequency from solar polar orbit. Adv. Space Res., 2011, 48: 943-954