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COMMISSION 10 SOLAR ACTIVITY

ACTIVITE SOLAIRE

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TRIENNIAL REPORT 2009–2012

1. Introduction

Commission 10 of the International Astronomical Union has more than 650 members who study a wide range of activity phenomena produced by our nearest star, the Sun. Solar activity is intrinsically related to solar magnetic fields and encompasses events from the smallest energy releases (nano- or even picoflares) to the largest eruptions in the Solar System, coronal mass ejections (CMEs), which propagate into the Heliosphere reaching the Earth and beyond. Solar activity is manifested in the appearance of sunspot groups or active regions, which are the principal sources of activity phenomena from the emergence of their magnetic flux through their dispersion and decay. The period 2008–2009 saw an unanticipated extended solar cycle minimum and unprecedentedly weak polar-cap and heliospheric field. Associated with that was the 2009 historical maximum in galactic cosmic rays flux since measurements begun in the middle of the 20th Century. Since then Cycle 24 has re-started solar activity producing some spectacular eruptions observed with a fleet of spacecraft and ground-based facilities. In the last triennium major advances in our knowledge and understanding of solar activity were due to continuing success of space missions as SOHO, Hinode, RHESSI and the twin STEREO spacecraft, further enriched by the breathtaking images of the solar atmosphere produced by the Solar Dynamic Observatory (SDO) launched on 11 February 2010 in the framework of NASA's Living with a Star program. In August 2012, at the time of the IAU General Assembly in Beijing when the mandate of this Commission ends, we will be in the unique position to have for the first time a full 3-D view of the Sun and solar activity phenomena provided by the twin STEREO missions about 120 degrees behind and ahead of Earth and other spacecraft around the Earth and ground-based observatories. These new observational insights are continuously posing new questions, inspiring and advancing theoretical analysis and modelling, improving our understanding of the physics underlying magnetic activity phenomena. Commission 10 reports on a vigorously evolving field of research produced by a large community. The number of refereed publications containing 'Sun', 'heliosphere', or a synonym in their abstracts continued the steady growth seen over the preceding decades, reaching about 2000 in the years 2008–2010, with a total of close to 4000 unique authors. This report, however, has its limitations and it is inherently incomplete, as it was prepared jointly by the members of the Organising Committee of

Commission 10 (see the names of the primary contributors to the sections indicated in parentheses) reflecting their fields of expertise and interest. Nevertheless, we believe that it is a representative sample of significant new results obtained during the last triennium in the field of solar activity.

2. **Solar-cycle activity** (P. Charbonneau & H.S. Hudson)

This triennium witnessed the end of Hale Cycle 23 and the beginning of Cycle 24, and this seemingly routine evolution produced surprises. The Cycle 23/24 minimum itself, nominally at the very end of 2008, was exceptionally protracted, more so than any from the past century. This confounded almost all of the experts who dared to predict the onset time of the new cycle (e.g., Pesnell, 2008). At the same time various indices related to solar activity achieved record levels of – passivity. Finally, in fits and starts, activity resumed to the point where no less than seven GOES X-class flares have occurred in the first three quarters of 2011.

Several conferences have already been devoted to this anomalous minimum, including IAU Symposiums No. 273 (Ventura, California, 2010) and No. 286 (Mendoza, Argentina, 2011). A literature search for articles whose abstracts included the term "solar minimum" produced more than 300 hits in 2010, threefold of the average number of papers during Cycle 23. The minimum between Cycles 23 and 24 has caught our attention! One is reminded of Mark Twain's quote, "There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact." But the phenomena we are experiencing are not trifling at all, since life on Earth depends so intimately on the Sun, and we need to understand its behavior better than we presently do.

The indices of activity have behaved erratically. The sunspot number (SSN), the longest continuous record of sunspot activity, had correlated very well with the F10.7 radio index, introduced in 1947. But in this minimum, the correlation changed significantly (e.g. Svalgaard & Hudson 2010), suggesting either an altered Sun or else a new bias in the interpretations of these indices. Thanks to the excellent material now available for monitoring solar activity, we know that these signs relate to the behavior of the ever-fascinating solar magnetic field.

Numerous attempts have been made to understand the peculiar features of this extended minimum using various types of dynamo models. Attention has focused primarily on flux transport dynamos, in which the large-scale meridional flow in the convection zone regulates both the equatorward propagation of activity belts, as well as poleward transport of the surface magnetic field and reversal of the Sun's dipole moment. In such models, relatively modest, persistent variations of the meridional flow speed can lead to significant variations in overall cycle amplitudes (e.g. Lopes & Passos 2009). The challenge provided by the Cycle 23/24 minimum has led to more detailed and targeted analyses. The low polar field strength and long duration characterizing this minimum could be reproduced by a flux transport dynamo model, provided the meridional flow sped up in the rising phase of the cycle, and subsequently slowed down in the descending phase (Nandy *et al.* 2011). This proposed phasing is actually contrary to that inferred observationally (Hathaway & Rightmire 2011), but the discrepancy may hinge on the development of a high-latitude counterrotating flow cell, which in itself could yield weaker polar surface fields (Jiang *et al.* 2009) as well as a delayed start for Cycle 24 (Dikpati *et al.* 2010).

These dynamo-based "explanations" of the Cycle 23/24 minimum all rely on the kinematic approximation, where the magnetic back-reaction of the dynamo-generated magnetic field is altogether neglected, or at best subsumed in simple, *ad hoc* algebraic quenching nonlinearities. Significant progress has also taken place with fully dynamical magnetohydrodynamical simulation of dynamo action, particularly in the successful production of large-scale magnetic fields undergoing polarity reversals (Ghizaru *et al.* 2010; Käpylä *et al.* 2010; Brown *et al.* 2011). The Ghizaru *et al.* simulations are noteworthy in being solar-cycle-like in a number ways, including regular polarity reversals on a multi-decadal timescale, good cross-hemispheric coupling, torsional oscillations of a few nHz amplitude, and the buildup of a high-latitude counterrotating flow cell in the descending phase of the simulated cycles. Detailed analyses of such simulations may provide insight on what was dynamically peculiar –or not– in the transition from Cycle 23 to 24.

This was the third cycle for which stable total solar irradiance (TSI) measures were available, from a series of spacecraft. Within a precision expressed in tens of parts per million, the first two minima agreed well. During the Cycle 23/24 minimum, though, TSI dropped significantly below this level (Fröhlich 2009; Kopp & Lean 2011), confounding those experts who had expected solar minima to reflect a basal level of solar luminosity. Associated with this variation, which could be due either to a true luminosity variation or to superficial activity (Fröhlich 2009), apparently all measures of solar magnetic activity seem to have diminished. The EUV flux decreased relative to the previous minimum (Solomon *et al.* 2010). The solar polar fields, thought to supply the heliospheric field, decreased (Wang *et al.* 2009). A diminished interplanetary magnetic field suggested a lower "floor" than seen before (Owens *et al.* 2008). At the same time cosmic-ray fluxes achieved record high levels (Mewaldt *et al.* 2010), consistent with a magnetic deflation of the heliosphere resulting from the diminished magnetic activity.

During the maximum of Cycle 23, and continuing at present, Livingston and Penn have been tracking sunspot magnetic fields and brightnesses in a uniform and stable manner, and have surprisingly found a secular trend in field intensity: their magnetic fields are decreasing – and in umbral brightness: their darkness is also decreasing (Penn & Livingston 2010). Such long-term variations, centered now on the anomalous Cycle 23/24 minimum, have never before been observed.

On a separate subject, the absolute value of the solar luminosity may require revision. The new value of TSI at solar minimum, from improved measurements, turned out to be about 0.33% lower than previously thought (Kopp & Lean 2011).

3. The solar large-scale magnetic field (C.J. Schrijver)

Our understanding of the Sun's large-scale magnetic field was aided in the past few years by two unique events. First, there was the extended sunspot minimum which pushed the solar and heliospheric fields, and the associated galactic cosmic ray fluxes, to a state never before seen in the modern instrumental era. Second, the instrumentation available to study the Sun's magnetic field from the surface into the heliosphere was strengthened by a new capability: the achievement of the first full-sphere view of the Sun (in fact, of any star) from the STEREO spacecraft as they drifted past quadrature from the Sun-Earth line on 6 February 2011, in combination with unrivaled view of the front side offered by the Solar Dynamics Observatory (launched on 11 February 2010).

The unusually weak polar-cap and heliospheric fields appear to be a consequence of a mild but sustained increase in the poleward meridional advection, as demonstrated by surface flux transport modeling by Wang *et al.* (2009). That change in the meridional surface velocity was observationally confirmed by Hathaway & Rightmire (2011).

The full-sphere view brought the phenomenon of sympathetic activity back into focus. One set of events, studied by Schrijver & Title (2011) using SDO observations combined with STEREO coronal images, revealed that a series of flares and filament eruptions (evolving into CMEs) were all connected through a network of topological divides. This series of events was possibly initiated by the emergence of a new active region some 90 degrees away (visible only in the STEREO/B images). MHD modeling by Török *et al.* (2011) supports that hypothesis, by showing how the eruption of one flux rope can cause a neighboring one – until then marginally stable – to erupt, cascading from one eruption to another in the set of four model flux ropes. Jiang *et al.* (2011) discuss observations of such a nature, including the formation of transient coronal dimmings between the erupting structures.

Insights on the coupling of the Sun's surface to the heliospheric field also came from theory and modeling. Work by Yeates *et al.* (2010a), for example, shows that whereas the potential-field source-surface (PFSS) modeling works remarkably well in mapping the heliospheric field to its source regions, non-potential effects are significant: their magnetofrictional modeling reveals how the introduction of electrical currents by shearing of the field by differential rotation can almost double to Sun's open flux at maximum, adding in contrast only one quarter around cycle minimum relative to a purely potential PFSS model. Yeates *et al.* (2010b) discuss CME formation in the context of the shearing of large-scale field, stressing – as have other studies – that knowledge of the full-sphere magnetic field is important in both the study of the background heliospheric field as well as the eruptive phenomena that rock its foundations.

It appears that the pattern of overarching helmet structures is related to flaring activity: Svalgaard *et al.* (2011) report on a correlation of flaring with the Hale sector structure. But whether that reflects patterns in the sources of the flux or is related to the interaction of emerging flux with the pre-existing large-scale field remains to be established.

One of the outstanding problems in coronal-heliospheric studies is the origin of the slow solar wind, with a composition and ionization balance reminiscent of that of the closed-field active region environment. Antiochos *et al.* (2011) argue that the slow solar wind may in fact originate from the boundary region between open and closed fields which maps into a "web of separatrices" into the heliosphere; the nature of these narrow coronal channels appears to commonly be a singular line that is in fact a separatrix lying on the solar surface (Titov *et al.* 2011). Linker *et al.* (2011) discuss the implications of these studies for the evolution of the heliospheric field in an MHD model: they find that the open field evolves across the solar surface through reconnection with the closed field, remaining closed underneath the helmet streamers until field migrates out into open-field coronal holes again, thus arguing against the diffusive transport of open field through closed-field regions as proposed by, e.g., Fisk (2005).

4. **Simulation studies** (K. Kusano)

Numerical simulation is now an indispensable methodology for the study of various disciplines, and the rapid growth of supercomputers is further increasing its importance for the understanding of complex phenomena like solar dynamics. Radiative magnetohydrodynamic (MHD) simulations have improved rapidly over the past years. In particular, sunspot models were dramatically advanced by Rempel *et al.* (2009) and Rempel & Schlichenmaier (2011). These first-principles MHD models of a whole sunspot compare well with the high resolution observations. Our understanding of penumbral structure and Evershed flow were greatly improved recently by the comparison between simulations and observations, although the convective structure in penumbra is still under investigation.

Another new trend in simulation studies is the forward modelling of wave propagation through sunspots based on 3D MHD simulations (Cameron *et al.* 2008; Parchevsky &

Kosovichev 2009; Moradi *et al.* 2009). This type of study is important for the detailed assessments of the validity of helioseismic interpretations to constrain the subsurface models. Flux emergence is another central subject of the radiative 3D MHD simulations (Cheung *et al.* 2010), enabling calculations of the whole evolution from small-scale turbulence in the early stage of flux emergence to the formation of an active region. Simulations of flux emergence also help us understand the building-up process of free energy within an active region (Hood *et al.* 2011).

Data-driven simulation, in which the observed data are used for the initial and boundary conditions, is also a recent new challenge (Fan 2011; Wu *et al.* 2009), and it is promising as the new method of realistic simulations. However, it is still under development and how to evaluate its physical reality is also a future issue.

5. **Transition region** (H. Peter)

As the interface between the chromosphere and the corona, where the change from plasma-dominated to magnetic-field-dominated takes place, the transition region is of vital interest to understand the dynamics of the corona.

The redshifts in the transition region and the blueshifts in the low corona are well established. New evidence has been found that in the quiet Sun, for temperatures above 1 MK the line shifts tend to drop to zero (Dadashi *et al.* 2011). On the modeling side there are two new proposals to understand the transition-region line shifts. In their 3D MHD models Hansteen *et al.* (2010) find that plasma is heated low in the atmosphere to high temperatures and only then does it rise before it cools and falls down again. This process gives very small shifts at high temperatures (not quite the observed blueshifts). A similar model by Zacharias *et al.* (2011b) identifies up- and downflows in the legs of coronal loops, depending on the surface region they are connected to, which can change in time. They also find fingers of cool gas reaching high into the corona. It remains to be seen which of these processes (or both or different ones) govern the observed line shifts.

The interpretation through 3D MHD models of the transition region already hints at high spatial and temporal complexity. Based on spectroscopic observations McIntosh & De Pontieu (2009) analyzed SUMER data, showing the long-known transition-region line asymmetries re-interpreting them in terms of a background and a fast upflow component in the spectral profile. They show that the upflow component could carry enough energy and mass to power the solar corona. Later Tian *et al.* (2011) conducted a similar study for data from EIS where they also compared their interpretation to artificially created spectra, with similar results. Martínez-Sykora *et al.* (2011a) did a comprehensive study of the line asymmetries based on a 3D MHD model in order to better understand how to interpret the line asymmetries.

6. **Reconstruction of the 3D solar corona** (C.H. Mandrini)

Observational methods for reconstruction of the three dimensional (3D) structure of the solar corona can be divided in two broad categories: solar stereoscopy (SS), and solar rotational tomography (SRT). These complementary methods have different purposes, strengths, and limitations, and can provide great observational insight, as well as powerful constraints to MHD models. Both techniques have been boosted by the STEREO mission, and will greatly benefit from the expanded temperature coverage, and increased spatio-temporal resolution, provided by the SDO/AIA instrument. A very recent comprehensive review on coronal 3D reconstruction methods can be found in Aschwanden (2011).

Solar stereoscopy using images simultaneously taken from two different spacecraft has been applied to reconstruct (by triangulation) the geometry of coronal loops, and combined with multiple-band EUV DEM analysis to provide the electron density and temperature distribution along them (Aschwanden *et al.* 2008). Some recent works in which stereoscopic triangulations have been applied are Aschwanden (2009) to oscillating loops, Feng *et al.* (2009) to polar plumes, Liewer *et al.* (2009) and Bemporad *et al.* (2009) to an erupting filament/prominence, and Thompson (2011) to a strongly rotating, erupting, quiescent polar crown prominence.

White-light tomography allows determination of the 3D electron density distribution. Recent developments include a new approach called Qualitative SRT, which has been applied to LASCO/C2 data covering the complete Solar Cycle 23 (Morgan & Habbal 2010). This technique has been recently applied to STEREO/COR1 data (Kramar *et al.* 2009), and used with total brightness measurements for the first time (Frazin *et al.* 2010). Frazin *et al.* (2009a) discuss the possibility of using advanced image processing concepts to reconstruct CMEs from the view-points provided by SOHO and STEREO.

Tomography has been recently applied to EUV data for the first time, and combined with local DEM analysis to form a novel technique named differential emission measure tomography (DEMT; Frazin *et al.* 2009b). This allows construction of 3D electron density and temperature maps. DEMT has been applied to STEREO/EUVI data to analyze coronal cavities by Vásquez *et al.* (2009), and combined with magnetic extrapolations to study the large scale thermodynamic structure of the solar corona by Vásquez *et al.* (2011). Also, DEMT is currently being used to provide density and temperature constraints on the inner corona MHD component of the Space Weather Modeling Framework of the University of Michigan (Jin *et al.* 2011). The effects of dynamics in tomographic reconstructions can be mitigated by using time-dependent approaches, such as the Kalman-filtering method (Butala *et al.* 2010). Another recent effort concerning multi-instrumental tomography is the work by Barbey *et al.* (2011), who developed a parallelized open-source tomography software, able to handle different data sources such as STEREO/EUVI and STEREO/COR1, with the inclusion of both a static and a smoothly varying temporal evolution models.

7. **Solar flares** (L. Fletcher)

As is well known, solar flares are due to the release of magnetic energy. In the few days before a flare a distinct increase has recently been reported in both the subphotospheric kinetic helicity density (a measure of twist which can be imparted to the field) determined by local helioseismology and the photospheric helicity (Reinard *et al.* 2010; Komm *et al.* 2011; Magara & Tsuneta 2008; Park *et al.* 2008). This behavior reinforces our physical picture of active region energy loading. With vector fields now available from Hinode Solar Optical Telescope (SOT), and routinely from the Solar Dynamics Observatory (SDO), studies of magnetic free energy, and its evolution (Jing *et al.* 2009, 2010) are feasible, though still problematic. The active-region magnetic topology is also core to flare evolution. Combining MHD simulations and flare observations, Masson *et al.* (2009) suggest a coronal null topology supporting ‘slip-running’ flare reconnection. Topological studies by Des Jardins *et al.* (2009) indicate that the strongest flare energy release occurs near topological structures known as separators. As a flare is an essentially magnetic disturbance, it makes sense to try and understand how magnetic energy is transported through the corona and converted to other forms by magnetic perturbations (e.g. Birn *et al.* 2009; Longcope *et al.* 2009; Reeves *et al.* 2010).

Electron acceleration and the radiation of non-thermal X-rays are core to flare physics. New visibility-based approaches to RHESSI imaging (Kontar *et al.* 2008; Dennis & Pernak 2009) are being used to quantify the sizes and shapes of flare X-ray sources, and multi-wavelength observations constrain the number of non-thermal electrons required to produce the observed flare emission in the chromosphere (Watanabe *et al.* 2010a; Krucker *et al.* 2011) and the corona (Krucker *et al.* 2010). Recent work confirms that a large – some might say worryingly large – fraction of electrons needs to be accelerated, prompting investigations of 'reacceleration' models (Brown *et al.* 2009). Electron acceleration and propagation remain a focus of modelling, with recent investigations including wave-particle interactions in beam-generated turbulence (Hannah & Kontar 2011; Zharkova & Siversky 2011). Stochastic (Petrosian & Chen 2010; Bian *et al.* 2010), current-sheet (Gordovskyy *et al.* 2010; Karlický & Bárta 2011; Mann & Warmuth 2011) and shock acceleration models (Warmuth *et al.* 2009) all continue to compete.

Optical emission occurs in flares of all sizes (Jess *et al.* 2008; Kretzschmar 2011) but the emission mechanism is still unclear. Potts *et al.* (2010) find evidence for an optically thin chromospheric source, but other events look more photospheric in origin. The photosphere is clearly affected by flares: Fe I line profiles from the SDO Helioseismic Magnetic Imager (HMI) show blue-shifts at the time of the impulsive phase (Martínez Oliveros *et al.* 2011) simultaneous with a change in the line-of-sight photospheric magnetic field (see also Wang & Liu 2010). The excitation of flare-associated helioseismic disturbances may be related to this (Martínez Oliveros & Donea 2009; Matthews *et al.* 2011).

The Extreme ultraviolet Imaging Spectrometer (EIS) on Hinode has been used to probe flare chromospheric sources (Watanabe *et al.* 2010b; Graham *et al.* 2011; Milligan 2011) typically showing hot, dense, redshifted plasmas. However, the standard assumptions of EUV spectroscopy (ionization equilibrium, Maxwellian distribution of electron speeds) may be invalid during a flare, motivating investigations of out-of-equilibrium plasmas (e.g. Dzivčáková & Kulinová 2010; Kulinová *et al.* 2011). With the anticipated launch of the Interface Region Imaging Spectrometer (IRIS), large ground-based telescope projects such as the Atacama Large Millimeter Array (ALMA), the Advanced Technology Solar Telescope (ATST) and its possible European counterpart, and smaller ground-based instruments (e.g. ROSA, IBIS), chromospheric flare observations should prosper in the coming years. Given the rich physics of this layer, and its role as the source of the greater part of a flare's radiation, the flare community would do well to look to the chromosphere, and prepare to take advantage of these data.

8. Flux rope formation and CME initiation (L. van Driel-Gesztelyi)

Flux rope-like magnetic structures are commonly seen in coronal mass ejections (CMEs) as well as measured in situ in their related 'magnetic clouds' in the interplanetary medium. It has been an open question, however, whether a flux-rope is present prior to the CME eruption or forms from a sheared magnetic arcade through magnetic reconnection during the eruption. There has been significant progress in our understanding of the CME process from its initiation through its evolution and structure over the last three years. Here I show a few highlights.

We have known since long from vector magnetic field observations that magnetic flux emerges twisted. However, a sub-surface flux rope cannot directly cross the photosphere, but it must be destroyed and transformed by reconnection before it can enter the corona (Hood *et al.* 2009, and references therein). Nevertheless, signatures of a global twist are recognisable at a glance in emerging active regions (ARs) even in longitudinal magnetograms as large-scale yin yang pattern of the polarities due to contribution from the azimuthal vector component (Luoni *et al.* 2011). Flux rope formation continues as the active region decays and its field is getting dispersed due to its interaction with turbulent (super)granulation eddies. Flux dispersion towards the internal magnetic inversion line of an AR leads to magnetic cancellations there and gradually transforms a sheared arcade into a flux-rope, which may erupt in a CME. Key observational evidence was provided for this scenario by Green *et al.* (2011), in agreement with 3-D MHD simulations by Aulanier *et al.* (2010). With Hinode/EIS spectral measurements filament rotation ($v \leqslant 20$ km s^{-1}), consistent with the expansion of a twisted structure, was found *prior to* a CME eruption and X-class flare (Williams *et al.* 2009).

The twist is further increased during the eruption through a series of reconnections with the surrounding sheared arcade along a current sheet which forms *under* the departing flux rope (see Amari *et al.* 2010 for an MHD simulation and Liu *et al.* 2010 for observational evidence). The flux rope is very hot ($T \approx 10MK$), while at lower-T it appears as a void (a cavity), as evidenced by high-resolution multi-wavelength SDO observations (Cheng *et al.* 2011). Long, thin, straight, bright structures in the wake of CMEs have been interpreted as imaging evidence of current sheets (Ciaravella & Raymond 2008; Saint-Hilaire *et al.* 2009).

What is the cause of the eruption? Aulanier *et al.* (2010) has argued that the eruption is *not* caused by magnetic cancellations, nor coronal tether-cutting – these processes simply *build a flux-rope* and make it slowly rise to the critical height above the photosphere at which the torus instability can set in. The eruptive threshold is determined by the vertical gradient of the magnetic field in the low-β corona. Démoulin & Aulanier (2010) have shown that the *loss of equilibrium* is in fact equivalent with the *torus instability*, which is identified as the principal driver of CMEs. Kink instability, another ideal MHD instability, may simply raise the flux rope high enough for the torus instability to set in. On its own, kink instability leads to a confined eruption.

9. Coronal waves (B. Vršnak)

The past three years were very dynamic and fruitful in research on coronal large-scale large-amplitude propagating disturbances. About sixty peer-reviewed papers were published on EUV waves, coronal shocks and Moreton waves. In the majority of the papers the initiation, morphology, and kinematics of waves were analyzed, and the results were most often interpreted in terms of fast-mode MHD waves. However, in some events various non-wave or slow-mode-wave interpretations were proposed. Following this track, Warmuth & Mann (2011) provided evidence that there are physically different classes of propagating coronal disturbances, where a part of them are not really waves. Consequently, Long *et al.* (2011) proposed a new term, Coronal Bright Fronts, to avoid inconsistency in terminology. Considering the wave – driver relationship, all studies showed that initially it is difficult to resolve the wave and the eruption. Later on, the wave detaches from the eruption, and continues as a freely propagating wave. Furthermore, due to the high sensitivity of new instruments, it became possible to recognize the full EUV-wave dome around the eruption (e.g. Veronig *et al.* 2010), giving an insight into the 3-D kinematics and morphology of the disturbance. Studies of coronagraphic white-light signatures of the coronal shocks, as well as studies of the relationship between EUV waves, chromospheric Moreton waves, and radio type II bursts provided additional information about the shock formation and evolution. Several studies demonstrated that the wave is initiated during the temporary lateral acceleration of CME flanks, and that after the driven phase, it evolves as freely propagating blast.

Exceptionally important studies on EUV waves are those employing spectral analysis, since they provide detailed plasma diagnostics. The Hinode/EIS campaign HOP-180, targeted specifically to hunt EUV waves, provided a unique high-cadence spectroscopic data of an EUV wave, showing downflows of 20 km s^{-1} at the wavefront, analogous to that in Moreton waves (Harra *et al.* 2011). As a response to great advances in observations, several theoretical studies were published. The presented MHD simulations dealt with the relationship between the CME expansion and the resulting response of the ambient atmosphere, demonstrating very persuasively all the complexity of wave phenomena associated with coronal arcade eruption. It should be also noted that several review papers were published (Wills-Davey & Attrill 2009; Warmuth 2010; Gallagher & Long 2011; Zhukov 2011).

10. Solar radio bursts and particle acceleration (Y. Yan)

Solar radio emission provides important complementary diagnostics of activity events to optical, EUV, X-ray and γ-ray observations. Multi-wavelength analyses have advanced our knowledge on thermal and non-thermal phenomena in the solar atmosphere and interplanetary space (e.g. Cliver & Ling 2009; Kaufmann *et al.* 2009; Lee *et al.* 2009; Minoshima *et al.* 2009; Krucker *et al.* 2010; Klein *et al.* 2010; Reid *et al.* 2011).

Analysis of radio bursts with fine structures have attracted much attention so as to identify acceleration mechanisms of fast particles and their propagation in the flare area (e.g. Ning *et al.* 2009; Chernov *et al.* 2010; Kumar *et al.* 2010). For example, the coherent characteristics of the zebra pattern structures i.e. quasi-parallel narrow-band stripes in the microwave dynamic spectra can be applied to coronal magnetic field diagnostic in addition to that of other plasma parameters (e.g. Zlotnik *et al.* 2009; Chen *et al.* 2011).

Theoretical research on radio emission generated by electrons accelerated in solar flares/CMEs advanced as well. Li & Fleishman (2009) found that the radio emission produced by stochastic acceleration due to cascading MHD turbulence and regular acceleration in collapsing magnetic traps, are distinctly different. Li *et al.* (2011) presented simulations for decimetric type III radio bursts at twice the local electron plasma frequency, extending their previous model of metric-wave type III bursts to the lower corona.

Prototype studies on new-generation solar-dedicated imaging-spectroscopy facilities in decimetric and microwave ranges have started (Yan *et al.* 2009; Sawant *et al.* 2009; Wang *et al.* 2010). The analysis of the first interferometric observation of a zebra-pattern radio burst with simultaneous high spectral and temporal resolutions (Chen *et al.*2011) indicates that the different models can be examined with strict constraints. In the near future high-resolution true imaging-spectroscopy observations are expected to greatly advance our capability to measure and map coronal magnetic fields, to understand the physics of solar flares, and their influence on space weather.

11. Generation of hot plasma outflows from active regions - a potential source of the slow solar wind (L. van Driel-Gesztelyi)

One of the major discoveries in coronal physics made by Hinode/EIS was the presence of persistent high-temperature high-speed outflows from the periphery of ARs with line-of-sight velocities up to 50 km s^{-1} (Harra *et al.* 2008; Doschek *et al.* 2008) and spectral line asymmetries nearly 200 km s^{-1}, being suggestive of multiple components (Bryans *et al.* 2010; Peter 2010; Brooks & Warren 2011). Outflow locations are of low electron density and low radiance (Del Zanna 2008) and they originate over monopolar magnetic field concentrations (Doschek *et al.* 2008; Baker *et al.* 2009). Two main categories of mechanism have been proposed to be the driver of these outflows (i) magnetic reconnection-related (see Baker *et al.* 2009; Del Zanna *et al.* 2011 and references therein) and (ii) compression of surrounding fields by AR expansion (Murray *et al.* 2010). The blue-shifted plasma flows are believed to be a possible source of the slow solar wind

(Brooks & Warren 2011) when topological conditions in the large-scale solar magnetic fields are favourable (see the last paragraph in Section 3 and references therein).

12. Closing remarks

Studies of solar activity have produced far more exciting new results than we were able to cover and cite in this brief report – only the solar cycle was at minimum, solar activity studies have continued to increase both in volume and quality. The wealth of key findings indicates a vigorous, active community organised and supported by Commission 10.

Lidia van Driel-Gesztelyi
President of the Commission

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