ABSTRACT

(In Alphabetical Order of Author Names)

Strongly Blueshifted Phenomena Observed in a Flare with Hinode/EIS

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We present a detailed examination on strongly blueshifted phenomena observed with the Extreme-ultraviolet Imaging Spectrometer on board the Hinode satellite associated with an X3.4 flare that occurred on 13 December 2006. We discuss physical characteristics of the phenomena by comparing the Hinode SOT and XRT data.

A New View of Coronal Magnetic Topology From the Hinode XRT

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The combination of broad temperature sensitivity, high spatial resolution and large dynamic range allows the X-ray Telescope (XRT) on Hinode to observe the magnetic connectivity from the core of active regions to the quiet sun, and to follow the dynamic changes in that connectivity. For the first time we see the entire structure within an active region, not just the loop tops or footpoints. Relating the coronal structure and dynamics to the evolution of the photospheric magnetic field is a primary goal of the Hinode mission. We present X-ray observations in support of that goal.

Interaction between Non-Thermal Electrons and Plasma in the Chromosphere and Transition Region during Solar Flares: Energetic Balance of Solar Flares

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The main aim of our investigations is the interaction between non-thermal electrons and plasma in flaring loops and the energetic balance of solar flares. Taking into account the influence of the energy spectrum of non-thermal electrons speeding down the flaring loops, the geometry of the loops, properties of the plasma (density, temperature) we intend to explain the processes of plasma evaporation and the formation of the observed chromospheric emission in strong Fraunhofer lines (like Hα, calcium lines etc.).

In our investigations we plan to use: SXR images taken with XRT telescope on board the Hinode satellite, HXR data taken with RHESSI, narrow and broadband data taken with the Solar Optical Telescope (Hinode/SOT), high-temporal resolution optical spectra taken with ground-based telescopes (MSDP spectrograph with SECIS instrument of the Wroclaw Observatory and THEMIS telescope).

Using observational data we will investigate the total energy balance of flaring loops. Our goal is the explanation of how the energy spectrum of non-thermal electrons and the structure of flaring loops affect the processes of interaction of electrons with chromospheric and coronal plasma and the processes of evaporation. This analysis will use corresponding codes for numerical modeling of the chromospheric and corona emission.

The project is still under development and the collaboration with various scientific teams is kindly appreciated.

Microwave Enhancement in Coronal Holes

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The microwave enhancement in coronal holes is a unique radio signature different from what is observed at other wavelengths. In microwaves, coronal holes appear bright over a narrow frequency range above $\approx$ 15 GHz. The enhancements are readily imaged by the Nobeyama radioheliograph at 17 GHz both in the polar and equatorial holes. Compact brightpoints that are observed in the coronal holes are different from the coronal brightpoints and correspond to the network junctions. These bright points often show flare-like brightenings. It has been suggested that the radio enhancement reflects the dynamic nature of the chromosphere because the thermal radio emission at 17 GHz originates from the upper chromosphere where the temperature is around 10 000 K. The enhancement is seen as a few percent increase in the brightness temperature over the quiet chromospheric values. Combined 17 GHz and Hinode observations are likely to help make progress on this phenomenon. Since coronal holes are the seats of high speed solar wind, the coronal holes may provide some clue to the solar wind origin. High-speed streams are also important for causing geomagnetic storms if they are directed at Earth.

This paper is dedicated to the memory of Professor T. Kosugi

2006 Dec 17 Long-Duration Flare Observed with Hinode EIS

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Long-duration solar flares generally have a cusp apex at the loop top. The cusp shape reflects the topology of magnetic fields near the flare-loop top and it is one of the indirect pieces of evidence supporting the occurrence of the magnetic reconnection process above flare loops. The Hinode EUV Imaging Spectrometer (EIS) observed a long-duration flare that occurred on 2006 Dec 17. We present the first EIS spectroscopic observation of cusp-shaped flare loops. We also report velocity fields around the cusp structures and post-flare loops.

High-Velocity Nonthermal Plasma Motion Concentrated at the Footpoints of Coronal Loops

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Hinode EUV imaging spectrometer has observed large line widths in the EUV coronal emission lines near the footpoints of coronal loops. It is highly suggestive that the heating of coronal loops is taking place near the footpoints.

Coronal Dimming Observed with Hinode

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Coronal dimming has been a technique used to determine the source of plasma that forms part of a coronal mass ejection. Generally dimming is detected through imaging instruments such as SOHO EIT by taking difference images. In a few cases the SOHO-CDS has been used to determine outflowing material, and a decrease in density. Hinode tracked active region 10930 from which there were a series of flares. We combine dimming observations from EIT with Hinode data to show the impact of flares and coronal mass ejections on the region surrounding the flaring active region, and we discuss evidence that the eruption resulted in a prolonged steady outflow of material from the corona.

Temperature Diagnosis of Coronal Loop Oscillations Using Hinode EIS and Norikura NOGIS Coronagraph

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NOrikura Green-line Imaging System, "NOGIS" (Ichimoto et al. 1999), is a 10cm-aperture coronagraph developed at the Norikura Solar Observatory, NAOJ. Using a 5303 Å (Fe XIV) Lyot filter, NOGIS can provide both intensity and Doppler velocity images of 2 MK plasma from the coronal green-line emission. The Doppler images are constructed by subtracting a [$\lambda - 0.45$ Å] image from a [$\lambda + 0.45$ Å] image. The line-of-sight velocity up to ± 25 km s^{-1} can be obtained with an accuracy of about 0.6 km s^{-1}. NOGIS field of view is 2000×2000 pixels in a full frame mode. Spatial resolution is 1.84 arcseconds in a partial frame mode and time resolution is reduced to about 1 minute to increase signal-to-noise ratio.

Since July 1997, NOGIS has observed many coronal transients in the inner corona (up to 1.5 $R_{\odot}$), such as flares, plasma ejections, propagating waves and loop oscillations (Yamasaki 2001; Hori et al. 2005; Suzuki et al. 2005). Because the NOGIS observation is restricted to emission from 2 MK plasma, it is difficult to examine the heating/cooling processes in the individual events. We propose a NOGIS joint observation with Hinode EIS and XRT, especially for temperature diagnosis of coronal loop oscillations above the solar limb. The existence of temperature dependency in flare loop oscillations is already reported from SOHO/SUMER slit observations. We expect that combination of Hinode/EIS and NOGIS can detect loop oscillations even in "apparently" quiet loops. If such oscillations commonly exist through the corona, their damping energy can be counted as one of coronal heating sources. Detailed observation plan will be presented. (N.B. NOGIS observation will be resumed in the beginning of May in this year.)

Diagnosis of Fine Structures in Solar Radio Bursts as Manifestation of Magnetic Reconnection Processes

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Solar radio emission in cm and dm wave range plays an important role in understanding energy release, plasma heating, particle acceleration and particle transport during solar bursts. With the high time and temporal resolution (4 MHz in 1.25 ms) mode of Huairou Solar Broadband Radio Dynamic Spectrometer in 1.100 − 1.340 GHz, we have observed lots of new fine structures of solar radio bursts during the flares and other solar activities. We present the observations on 1 December 2004, which exhibit plenty of radio fine structures. Among them, a hand-shaped burst that occurred during the impulsive phase is interesting. This group of bursts showed a unique fine structure with mixed fast-and-slow frequency drift rate. We suppose that its fast, positive-frequency drift may be due to the fast downward flows from the reconnection site and its slow, negative-frequency drift may be due to the slow upward motion of flare loops.

Our radio spectrometer data give information on the core region of the reconnection site. Hinode will provide us with data of the Sun's three-dimensional magnetic fields, monochromatic images of various wavelengths, and the X-ray images. The Chinese Spectral Radioheliograph will give images of solar bursts at 500 MHz − 15GHz bands. All of them being combined, we will be able to obtain better understanding on the physics of solar radio bursts.

Flare Energy and Fast Electrons via Alfvén Waves

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The impulsive phase of a solar flare marks the epoch of rapid conversion of energy stored in the pre-flare coronal magnetic field. Hard X-ray observations imply that a substantial fraction of flare energy released during the impulsive phase is converted to the kinetic energy of mildly relativistic electrons (10 – 100 keV). We investigate a new scenario, intended to replace the "thick target model," in which shear Alfvén waves transport the energy from its coronal sources and at the same time generate fast electrons either directly, via inertial effects in the corona, or indirectly via a turbulent cascade developing in the chromosphere. This scenario offers solutions to some perplexing flare problems, such as the flare "number problem" of finding and resupplying sufficient electrons to explain the impulsive-phase hard X-ray emission.

Searching for Umbral Dots in Hinode Data

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We present an approach for finding and analysing observations taken by the Solar Optical Telescope (SOT) on Hinode by conducting a study of umbral dots. The observations consist of coordinated, multi-wavelength observing sequences spanning several hours for each spot considered. Typically these multi-wavelength observations include longitudinal magnetograms in 6302 Å, and filtergrams in Ca II H, G-band and blue continuum. Various tools and techniques will be presented that will be used as part of the investigation.

Fine Structures of the Evershed Flow Observed by SOT aboard Hinode

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Small scale structure of the Evershed effect was studied using the Spectropolarimeter (SP) and Broadband Filter Imager (BFI) of SOT aboard Hinode. SP maps and high cadence continuum images of BFI covering the entire sunspots are used to investigate the spatial distribution of the flow field, brightness and magnetic fields. It is revealed that the Evershed flow starts at the front edge of inwardly migrating penumbral grains with an upward velocity component and turns to nearly horizontal flow preferentially in dark lanes (or dark core of filaments) of the penumbra. Our results are in general agreement with the well known un-combed penumbral concept in which the Evershed flow takes place in nearly horizontal field channels. We discovered a number of tiny elongated regions in the deep photosphere in which there is an obvious upward motion of 1 – 1.5 km s^{-1} distributing over the penumbra. They could be identified as the 'foot points' of the individual Evershed flow channels. Cross-correlation among the flow speed, intensity, magnetic field strength and inclination, and distribution of strong down flows in and around the penumbra will also be discussed.

Temperature-Dependent Upflow in the Plage Associated with an X3.2 Flare on 13 December 2006

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We present Hinode/EIS raster scan observations of a plage region taken during the gradual phase of an X3.2 flare of 13 December 2006. The plage region is located 200 arcsec eastward from the flare arcade. The spectral observations with multi-wavelengths allow us to determine velocities from the Doppler shifts in various temperatures. EIS observed strong upflows in addition to a stationary plasma in the Fe XV line 284.2 Å (log $T = 6.3$) in the plage region. The strong upflows are almost 160 km s^{-1} which is calculated by two component Gaussian fitting. On the other hand, at the transition region temperature (He II 256.3 Å, log T=4.7), very weak upflows, almost motionless, were observed. Furthermore, we found that these upflow velocities clearly depend on the temperature, by comparing the upflow velocities among Fe XV, Fe XIV, Fe XIII, Fe XII, Fe XI, Fe X, Fe VIII, O V, and He II. The hottest line, Fe XV, shows the fastest upflow velocity and the second-highest line, Fe XIV, shows the second-highest upflow velocity (130 km s^{-1}). The upflow velocities of other Fe lines also follow the order of temperature. All velocities are below the sound speed, but the dependence of velocities on temperature is similar to the dependence of sound speed on temperature. To complement the global dynamics to EIS data, we use EIT data. In this talk, we discuss the characteristics of the plasma which shows the blue shift in the plage region.

Discovery of Small-Scale Horizontal Magnetic Structures in the Photosphere

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We discover two different types of episodes (hereafter referred to as type 1 and type 2) on the appearance of strong horizontal magnetic fields with solar optical telescope aboard Hinode. Type 1 is an emergence of strong thin horizontal magnetic fields associated with separating vertical components on both ends. Its size is a few granules. We also detect strong area asymmetry of the Stokes V profile about 8 minutes before the first emergence. One of the footpoints has very strong downflows (several km s^{-1}), while the region with strong linear polarization signal has small blue shift, indicating an upward-moving horizontal flux. Type 2 appears to be more ubiquitous. Strong linear polarization signals appear inside granules (not in inter-granules). Their size is smaller than granules, and lifetime is longer than several minutes. We cannot see the significant vertical magnetic components at the edges of the horizontal magnetic fields region. We find that horizontal magnetic fields for the type 1 emergence is larger than that for type 2, and interpret that type 2 is more subject to the convective motion due to its magnetic fields smaller than the equipartition field strength. We will summarize the nature of the two types, and discuss their origin.

Magnetoconvection, Chromospheric Reconnection and Coronal Heating: Implication from MHD Simulation

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Observations by Hinode provides unprecedented oppotunity to study the magneto-convection dynamics and its conseqnece in the upper atmosphere. In this paper we present the results of magnetohydrodynamic simulations of convection-zone – corona coupling, as well as some preliminary analyses of Hinode observations. The simulation setup is as follows: the domain includes the upper convection zone, photosphere, chromosphere and corona. Convection is driven by radiative cooling in the photoshere, which is treated by the Newton approximation. When convection is developed and reached to a quasi-steady state, a vertical magnetic field is imposed. We have run the simulation with various field strength.

As is well known, magnetic field is concentrated in the intergranular lanes. Moreover, we found that, when the imposed magnetic field is weaker than the equi-partition value with the kinetic energy of the convection flows (about 400 G), the magnetic field in the convection zone becomes highly turbulent and intermittent. As a consequence, fairly strong (400 G) horizontal magnetic field transiently appears in the photosphere, at the top of the granular cells. These horizontal field undergoes reconnection with the pre-existing "canopy" field in the chromosphere, and generates high-frequency Alfvén waves and jets (spicules). Generation of high-frequency Alfvén waves is of particular interest because they may have significant contributions to coronal heating and solar wind acceleration. Such transient emergence of granular-scale horizontal field has been found in the data taken by the spectropolarimeter of Solar Optical Telescope. Preliminary analyses of the data and proposal of further observation will be presented.

Takeo Kosugi and Indo-Japan Collaboration in Solar Physics

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The great Japanese solar astronomer Takeo Kosugi was indeed a true friend of India. He took initiative to begin collaborative scientific efforts between Japan and India in order to exchange the solar observing technology and to carry out investigations on the energetics and dynamics of solar flares in context to Solar X-ray Spectrometer (SOXS), Indian mission, and proposed Solar-B Japanese mission as well as ground-based optical and radio waveband observations through ISAS and PRL. We present a few reminiscences of our collaboration. Next, we present the results of our joint investigations based on multi-wavelength study of a very impulsive solar flare of 10 March 2001, observed by Yohkoh mission in simultaneous to optical observations made in India, and SOXS flare observations from India and simultaneous observations from ground based facilities in Japan. The 10 March 2001 flare was well covered with many space based and ground based observatories viz. Yohkoh, SOHO, WAVES/WIND, Nobeyama, and Hiraiso, Japan. The observations revealed that the flare was very impulsive with a very hard X-ray spectrum and γ-rays suggested that non-thermal emission was most dominant. On the other hand an unusual phenomenon of association of CME with highly impulsive flare was observed. We conclude from SOHO/MDI and Mitaka magnetograms that the energy build-up took place due to photospheric reconnection/ flux cancellation, and further emergence of positive flux increased the shear $> 80^\circ$ at the flare location, which seems the main cause for the trigging of the flare. The flare showed two bright compact sources in H-alpha. We co-aligned the Hα, SXR, HXR, MW and magnetogram images within the instrumental limit. The flare showed single HXR source, which is found spatially associated with one of the Hα kernels. We report the unusual feature of the rotation of HXR and Hα sources during the impulsive phase of the flare. From the spatial correlation of multi-wavelength images of the different sources, we conclude that this flare has a three-legged structure. We briefly discuss the X-ray and optical emission characteristics of microflares observed by SOXS in $4 - 25$ keV in simultaneous to Hα observations made at NAOJ, and explores the possibility of their candidature to heat the solar corona.

Plasma Properties of Penumbral Fine Structures

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We present a set of sunspot observations obtained with the Hinode spectropolarimeter at various positions on the disk. We are analyzing the limb-side parts of the penumbra using a one-component inversion technique. This choice is motivated by the high angular resolution of $0.3''$ attained by the observations. The dependence of the resulting stratifications on the position on the disc is analyzed and discussed. The retrieved stratifications of plasma parameters are compared with those predicted by current models of penumbral fine structure.

Velocity Structure of Jets in Coronal Holes

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Doppler velocity of jets in coronal holes was studied with the Extreme-ultraviolet Imaging Spectrometer (EIS) on board Hinode. The EIS is capable of obtaining EUV spectra and context images in two wavelength ranges, 17 – 21 nm and 25 – 29 nm. Its high resolution and efficiency are suitable for studying fine structures of the corona and the transition region.

An analysis of Doppler shifts in a coronal line (Fe XII) has indicated that loop-shaped bright points are red-shifted. Faint elongated jets above the bright points are blue-shifted by 30 km s^{-1}. The corresponding velocity features are not detected in transition region lines. It suggests that the observed jets are high-velocity flow with a coronal temperature. These characteristics are found in many bright points in coronal holes. On the other hand, bright points outside coronal holes do not indicate significant velocity.

Bright points in coronal holes can be explained as the line-of-sight velocity component of the reconnection jets, which are caused by magnetic flux emergence in pre-existing open fields. A smaller velocity associated with the bright points outside coronal holes implies difference in magnetic field structures in the corona.

Derivation of dB_z/dz from Stokes Profiles and its Application to Azimuth Ambiguity Resolution

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We derived the longitudinal gradient of magnetic field strength (dB_z/dz) from Stokes profiles by using Artificial Neural Networks (ANN) and used it for resolving the azimuth angle ambiguity of magnetic field with a simple algorithm. ANN can infer physical quantities from Stokes profiles with an exceptionally high speed compared to ordinary inversion codes. Carroll and Staude (2001) and Socas-Navarro (2005) demonstrated that ANN can obtain vector magnetic field components and Doppler velocities. We constructed an ANN to derive the sign of the dB_z/dz component from Stokes profiles by training it with a synthesized data set of 16000 profiles. Its evaluation with synthesized profiles indicates that three-layer ANN can determine the sign of dB_z/dz with 90 % accuracy, though simpler two-layer ANN failed to achieve that. High quality Stokes profiles obtained with the Spectro-Polarimeter (SP) on board Hinode were processed with the ANN.

Once the sign of dB_z/dz is determined from Stokes profiles, gradients of horizontal components can be estimated from the equation div $\boldsymbol{B} = 0$. We compare the results with that of potential field extrapolation method and discuss the advantages and disadvantages of this method.

Micro-Flares Observed with Hinode/XRT

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Micro-flares are tiny events, but the coordinated observation between photospheric magnetic fields and coronal activities for micro-flares will reveal the elementary processes of coronal heating. The X-Ray Telescope (XRT) on the Hinode satellite has many advantages for micro-flare observations. The first is its high spatial resolution (1 arcsec/pixel), of course. However, we would like to point out the flexibility of its exposure cadence. If we accept to restrict the observation duration, XRT can observe active regions in cadence as high as 3 s.

We used such high-cadence observation data for NOAA 10923 taken on November 14, 2006. Nine micro-flares occurred in 30 minutes. We found that the time variation of their intensities is more impulsive than Yohkoh/SXT observed. The duration of each impulsive peak is about 30 s. Some of the events accompanied jet structures. We will show magnetic features below the micro-flares, observed by the Hinode/SOT.

Chromospheric Micro-Jets Discovered above Sunspot Penumbrae

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The Solar Optical Telescope (SOT) aboard Hinode allows us to observe dynamical activities in the photosphere and the chromosphere with high and stable image quality of 0.2 arcseconds. This superior performance of SOT provides new findings of fine-scale transient activities occurring in the chromosphere. In this paper, we report the discovery of fine-scale jet-like phenomena ubiquitously observed above sunspot penumbrae. The jets are identified in image sequences of a sunspot taken through a Ca II H line filter at 3968 Å. Their length is typically between 3000 and 10000 km, and their width is smaller than 500 km. It is notable that their lifetime is shorter than 1 minute. Those small spatial and temporal scale possibly makes it difficult to identify the phenomena in existing ground-based observations. The jets are easily identified when a sunspot is located far from the disk center, and motion of the bright features suggests that mass is erupted from the lower chromosphere to the upper atmosphere. Velocities of the motion are estimated to be 50 to 100 km s^{-1} from their lateral motion of intensity patterns. The velocities are much faster than sound speeds in the chromosphere. A possible cause of such high-speed jets is magnetic reconnection at the lower chromosphere resulted from un-combed magnetic configuration in penumbrae which is suggested by vector magnetic field measurements in the photosphere.

Formation Process of a Light Bridge Observed with Hinode/SOT

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The formation of a light bridge is important in understanding the process of break-up of a sunspot. SOT on Hinode successfully observed evolution of a light bridge forming in the middle of a spot in AR 10923 from 12 to 17 November 2006. This observations was the first time ever for us to see the evolution of a light bridge longer than several days with high spatial resolution. Signatures of its formation was the intrusion of penumbral filaments into an umbra before the light bridge appeared. When the formation of the light bridge started, many umbral dots were observed emerging around the leading edge of penumbral filaments, and rushing into the umbra along a trail. Their inward velocities were about 1.5 km s^{-1} which were significantly faster than the velocities of penumbral intrusion, 0.7 km s^{-1}. The light bridge is found to be the consequence of continual emergence and inward motion of the umbral dots. This observation clearly indicates close relationship among penumbrae, umbral dots, and light bridges. The Spectro-Polarimeter (SP) in SOT provided physical conditions in the photosphere around the light bridge and the umbral dots rushing into the umbra. We found that the magnetic field strength was about 1 kG weaker than the surroundings in the light bridge and in the umbral dots, and the upflow velocities of about 0.5 km s^{-1} were associated. This suggests that there is a hot gas with weak field strength penetrating from the deep sub-photospheric layers to near the visible surface, and the inward motion of the umbral dots is not the motion of magnetic field lines, but the motion of the hot gas pushing through the surrounding magnetic fields.

Cooperative Observation of Umbral Dots between Hinode/SOT and Domeless Solar Telescope at Hida

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Hinode SOT will give us high spatial resolution images of solar fine structure. We can follow and track temporal evolution of fine features in the photosphere without any fear of seeing distortion of the images. Umbral dots are small and faint features in dark umbral regions, so it has been a very difficult observational task thus far to get their basic properties and their characteristics of temporal evolution. In this paper, we will propose to do cooperative observation between Hinode/SOT imaging and Domeless Solar Telescope spectroscopic observations. The science target is to get the chracteristics of umbral dots, such as (1) temperature from two-color imaging, (2) magnetic filed from spectropolarimeter, (3) Doppler velocity from spectroscopy, (4) identification of chromospheric counterparts from Hα imaging, and (5) proper motions. The derived properties of umbral dots will give us information on the convective energy flow in the umbral atmosphere and temporal evolution of sunspots, especially on the decaying mode of spots.

X-ray Bright Points Observed with Hinode/XRT

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X-ray bright points (XBPs) are small scale phenomena detected in soft X-rays everywhere in the quiet Sun. Understanding of their characteristics is very important because they might contribute to the required power to keep the corona at its high temperature. Although the physical processes in these phenomena may turn out to be the same physical processes as in big flares, the truth has not yet been known because of the difficulty in fabricating X-ray optics with high angular resolution compared to other wave lengths.

We observed XBPs with the X-Ray Telescope (XRT) aboard the Hinode satellite launched in September 2006. XRT has high angular resolution (1 arcsec) and covers wide temperatures (ranging from < 1 MK up to > 20 MK) ever achieved as a grazing-incidence imager for the Sun. The observed fine images suggest that XBPs have not only a simple loop or a cusp structure but more complicated morphologies. We report those results of observations with Hinode XRT.

Formation of Moving Magnetic Features and Penumbral Magnetic Fields with Hinode/SOT

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We investigate the formation process of Moving Magnetic Features (MMFs) observed with Hinode/SOT. Moving magnetic features are small magnetic elements moving outward in the moat region surrounding mature sunspots. We derive vector magnetic fields of MMFs around simple sunspots near the disk center. Most of MMFs whose polarity is opposite to the sunspot have large redshift around the penumbral outer boundary. We find that some of them have Doppler velocities of about 10 km s^{-1} and such large Doppler motion is observed only in the Stokes V profile. The Stokes Q and U profiles in the same pixel do not have any significant Doppler motions. Horizontal magnetic fields of the penumbra frequently extend to the moat region and the MMFs having horizontal fields with their polarity being the same as the sunspot are formed. The MMFs whose polarity is opposite to the sunspot appear around the outer edge of the extending penumbral fields. We also found penumbral spines, which have more vertical magnetic fields than the surroundings, branch off at their outer edge. MMFs having relatively vertical fields with their polarity being the same as the sunspot are detached from the outer edge of the branch. The branch of penumbral spine is formed where granular cells appear in the penumbra.

Evolution of Vector Magnetic Fields in a Flare Productive Active Region NOAA10930 with the Hinode/SOT

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We successfully observed the evolution of vector magnetic fields in an active region NOAA10930 with Hinode/SOT for one week (2006/12/8-2006/12/15). A lot of flares including four X-class flares occurred in this active region. It was very difficult to perform such continuous observation with a high spatial resolution and a constant measurement quality in the case of ground-based telescopes. An evolving sunspot with positive polarity moved around an opposite polarity old sunspot in contact with each other. Elongated magnetic structures with positive and negative polarities were alternately located along the polarity inversion line (PIL) in between the two sunspots before the X3.4 class flare. Such elongated magnetic structures were formed due to flux emergence around the following edge of the evolving sunspot, and then the PIL became very complicated. The flare ribbons were observed in Ca II H with Hinode/SOT and they appeared at the PIL. One of the two flare ribbons evolved along the PIL. After the X3.4 class flare, the PIL became smooth and a region with azimuth angle perpendicular to their surroundings disappeared. And then the elongated magnetic structures with negative polarity merged into the old sunspot with negative polarity and positive ones merged into the evolving sunspot with positive polarity. These elongated magnetic structures with alternating polarity disappeared during a day after the X3.4 class flare.

We will discuss photospheric magnetic activity responsible for large flares by using a time series of high spatial resolution vector magnetic fields observed with Hinode/SOT.

Three-Dimensional Coronal Magnetic Field Analysis Based on Hinode/SOT Vector Magnetograms

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The understanding of three-dimensional magnetic field structure on solar coronal active regions is crucially important to reveal the mechanism of solar activity, in particular the triggering mechanism of solar flares. However, since only photospheric magnetic field is observable, three-dimensional magnetic field in solar corona has to be reconstructed from photospheric magnetogram as a solution of boundary-value problem based on the force-free field approximation. For this purpose, Hinode/Solar Optical Telescope (SOT) is an ideal tool, because of its high resolution and the quality of continuity. In this paper, aiming to reveal the characteristic magnetic structure in the triggering region of solar flares, we have analyzed three-dimensional magnetic field of active region NOAA 10930, using vector magnetograms observed by Hinode/SOT Spectro-Polarimeter (SP). The extended magnetofrictional code has been developed for this study by adopting the multi-grid relaxation technique and the optimized searching procedure of initial trial function. The results indicated that magnetic field in the region, where GOES X3.4 flare occurred on 13 Dec. 2006, 02:20 UT, consisted of multiple flux systems of different magnetic shear. Furthermore, we have found that pre-flare brightening of X-shape, which was observed during a couple of hours prior to the onset of the flare, were located on the site where magnetic vector sharply changes the azimuth. The results are basically consistent with the so-called Reversed Shear Flare Model, which had predicted that solar flare should be triggered by the nonlinear development of resistive tearing mode instability growing on magnetic shear reversal (Kusano et al. 2004 ApJ, and Kusano 2005 ApJ). The comparison analyses between flare kernels observed by XRT and the three-dimensional field line structure was also performed.

Has Hinode Found the Missing Turbulent Magnetic Field of the Quiet Sun?

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Measurements with the Hinode Spectro-Polarimeter (SP) of the quiet Sun allow characterization of the weak, mixed-polarity magnetic flux at the highest angular resolution to date ($0.3''$), and with good polarimetric sensitivity (0.025 % relative to the continuum). The image stabilization of the Hinode spacecraft allows long integrations with degradation of the image quality only by the evolution of the solar granulation. From the Stokes V profile measurements we find an average solar "Apparent Flux Density" of 14 Mx cm^{-2}, with significant Stokes V signals at every position on the disk at all times. However, there are patches of meso-granular size ($5 - 15''$) where the flux is very weak. At this high sensitivity, transverse fields produce measurable Stokes Q, U linear polarization signals over a majority of the area, with apparent transverse flux densities in the internetwork significantly larger than the corresponding longitudinal flux densities. When viewed at the center of the solar disk, the Stokes V signals (longitudinal fields) show a preference for occurrence in the intergranular lanes, and the Q, U signals occur preferably over both granule interiors and lanes.

A Multi-Wavelength View of an Active Region Structure around a Filament Channel

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The combination of multi-wavelength, high resolution, high cadence data from the Hinode X-Ray Telescope (XRT) and the Transition Region And Coronal Explorer (TRACE) give an unprecedented view of solar active region dynamics and coronal topology. We focus on examples of filament structures observed by TRACE and XRT in December 2006 and February 2007. Co-alignment of observations in these two instruments yields a striking picture of the coronal structures, with loops lying both along and above the filament. Overlying loops exhibit remarkable dynamics while the filament lies dormant, and numerous X-point and triple-leg structures undergo repeated brightenings. We also employ magnetic field data from SOLIS to compare a non-linear force-free model of the coronal magnetic field with the observed loops.

Solar Flares Observed with Yohkoh/HXT

S. Masuda
Solar-Terrestrial Environment Laboratory, Nagoya University

Late professor Takeo Kosugi was a PI of the Hard X-ray Telescope (HXT) on board Yohkoh. Thanks to his strong leadership and his enlightening strategy, HXT succeeded in detecting more than 3,000 solar flares during its ten-year operational period and revealed a lot of new features in solar flares. This contributed much toward the realization of the RHESSI satellite. In this presentation, notable highlights among many scientific results obtained from HXT observations are reviewed.

First Discovery of Ellerman Bombs by Hinode/SOT with Hida/DST

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High resolution Ca II H broad band filter images obtained by Solar Optical Telescope (SOT) aboard Hinode reveals that there are many small scale (≈ 1 arcsec) bright points outside sunspots and inside emerging flux regions. We identified some of these bright points with Ellerman bombs by using Hα images taken by Domeless Solar Telescope at Hida observatory. The Ca bright points identified with Ellerman Bombs are usually associated with bipolar magnetic field structures. Moreover, Ca II H images show a series of arch-like filaments with a size of ≈ 5 arcsec whose foot points correspond to the locations of the Ca bright points. In this study, we will report the difference between Ellerman bombs and other Ca bright points without Hα features.

Classification of Phenomena Observed by EIS aboard Hinode

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EUV Imaging Spectrometer (EIS) aboard Hinode observes plasma in temperature range of several 10^4 K to several 10^6 K by detection of multiple spectral lines emitted in the wavelength of 170Å–210Å and 250Å–290Å. EIS can achieve observation with three times better spectral resolution ($R \approx 4000$) than previous EUV instruments and spatial resolution of $1''$. In this talk, spectral analysis of typical corona and transition region observed by EIS will be demonstrated. Distribution of line intensities of features observed in maps will be discussed.

Hinode/XRT Observations of a Coronal Sigmoid

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We present the first observations of an X-ray sigmoid made with the Hinode X-Ray Telescope, co-aligned with those of TRACE and SoHO/MDI. XRT's extraordinary angular resolution (1 arcsec/pixel) and the sigmoid's location near disk center combined to provide an unprecedented view of the formation and eruption of this phenomenon. XRT observed the sigmoid over a 23-hour period with a cadence of at least one image per 30 s, and with a much lower cadence for several days prior. The first motions associated with eruption of the sigmoid started at 0600 UT on 12 February 2007; the first brightening of the ensuing X-ray arcade was seen at 0740UT.

The images during the pre-eruptive phase, which ends with the onset of large-scale motions, show:

+ The overall S-shape of the sigmoid is not defined by any single X-ray loop. Rather, many individual loops collectively comprise an S-shaped pattern.

+ The S-shape is comprised of two separate J-shapes, whose straight sections lie anti-parallel to one another in the middle of the S, on opposite sides of the magnetic polarity inversion line.

+ During the several-day span of the XRT observation, the S-shape gradually becomes better defined.

The images during the eruptive phase show:

+ Approximately 100 minutes before any soft X-ray flaring begins, a diffuse linear structure, almost as long as the sigmoid, lifts off from the middle of the S. It shows slight clockwise rotation.

+ The X-ray flare begins with the appearance of a sheared arcade of short loops, in the area centered between the two J-shaped patterns of the sigmoid.

+ Within 16 hours of the start of the flare, no S-shape remains.

Taken together, these features provide strong support for the Bald-Patch Separatrix Surface model of sigmoids put forth by Titov and Demoulin (1999).

An Emerging Flux Region Observed with Hinode/SOT on 11 December 2006.

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We have studied an emerging flux region observed by Hinode/SOT on 11 December 2006. As the flux emerged, bright points often appeared and disappeared in both G-band and Ca II filter observations. Three patterns are found in the observations. The first is simultaneously observed bright points at the same location in both (G-band and Ca II) filter observations. The second is bright points observed only with the Ca II filter (not found in G-band at the same time and at the same location). The third is bright points observed only with the G-band filter (not found in Ca II at the same time and at the same location).

The size of this emerging flux region is about 15 000 km. On the other hand, the wavelength with the largest growth rate in the Parker instability at the photosphere is about 4000 km. Therefore we believe that two or three loops may have emerged side by side. Then they may have interacted with each other and resulted in bright points. Dark lanes were also observed as the flux emerged. We have investigated the relation of the observed dark lanes in G-band and Ca II filters. We found that the dark lane in the Ca II observation appeared later than in the G-band one.

Center-to-Limb Variation in Stokes Profiles of Magnetic Fluxtubes Observed with Hinode Spectropolarimeter

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It is very important to investigate the magnetic structure and evolution of pores, growing small sunspots without penumbra, in order to understand the formation of sunspots. We here present spectro-polarimetric measurements of several pores with the Solar Optical Telescope (SOT) aboard Hinode with various viewing angles. We analyzed the Stokes V amplitude and area asymmetries and confirmed that the asymmetries are depressed at the center of the pores while they show large positive values in the surrounding area; this is consistent with the previous report by Leka and Steiner (2001). In addition to this ring of positive asymmetry, we found another larger ring structure. The larger ring shows positive asymmetries at the disk-center side, whereas it shows negative asymmetries again at the limb side. In this presentation, we suggest that the center-to-limb-variation of the magnitude of the area asymmetry and its pattern indicate a systematic inflow into the pore from the surroundings.

Performance of Image Stabilizer of Hinode Solar Optical Telescope

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Solar Optical Telescope of Hinode has an image stabilizer system. The system consists of a tip-tilt mirror in the Optical Telescope Assembly (OTA) and a correlation tracker in the Focal Plane Package (FPP). The digital servo loop is operated at 580 Hz, and its designed crossover frequency is about 20 Hz. The system performance was investigated during the initial operation period, and the pointing was found to be stabilized about 0.01 arcsec for 10 s period. The stability of the pointing achieved with the image stabilizer enables the polarimetirc observations with high signal to noise ratio.

Dynamical Properties of Flux Tubes and its Relationship to Convective Collapse Revealed by Spectropolarimeter of Hinode/SOT

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We present the dynamical properties of photospheric fluxtubes observed with Spectro Polarimeter of Solar Optical Telescope (SOT) aboard Hinode. Based on the high time cadence observations with small FOV of 4×40 arcsec at disk center quiet sun, we found the merge of flux in the inter-granular lanes, and formation of bright point in the continuum. At the bright point, very strong red shift with about 6 km s^{-1} was observed. During the formation of bright point, the Stokes V-profile amplitude and its separation increased. We discuss the formation of kilo Gauss fluxtube formation based on the observations.

Coronal Temperature Diagnostics with Hinode X-ray Telescope

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An X-ray telescope (XRT) on board the Hinode satellite observes the Sun in X-rays with high special resolution (1 arcsec $\approx$ 730 km on solar the disk). This telescope has nine X-ray filters with different temperature responses. Using these filters, the XRT can detect the coronal plasma with a wide temperature range from less than 1 MK to more than 10 MK. Moreover, based on observations with more than two filters, we can estimate the coronal temperature. In this paper, we use the filter ratio method for coronal temperature diagnostics. Using this method, we can easily estimate the averaged temperature of the coronal plasma along the line-of-sight. This method has been used frequently in the past, but the high quality XRT data give us temperature maps with unprecedented accuracy and resolution. The XRT usually takes the full Sun images with two kinds of filters four times a day. Using this data and filter ratio method, we can obtain full Sun temperature maps with high special resolution. In our analysis, we can derive reliable temperatures not only in active regions but also in quiet regions and coronal holes. This map can be created with the data set of one synoptic observation. This means that we can obtain four maps a day. The result is a full Sun temperature movie that gives us an unprecedented view of the time evolution of solar temperature. In this meeting, we will show the full Sun temperature movie and our coronal temperature analysis results.

X-ray Waves Observed with Hinode X-ray Telescope

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When solar flares occur, wave-like disturbances and shock waves are sometimes observed in several kinds of wavelengths. In 1960, the coronal shock wave was indirectly detected in Hα, i.e., the intersections of the coronal shock waves and chromosphere are observed as the H-alpha wave-like disturbances called “Moreton waves”. In 2000’s, the soft X-ray telescope (SXT) on board Yohkoh discovered several wavelike disturbances (shock waves) in the solar corona associated with flares, which we call “X-ray waves”. The shock waves are very faint phenomena and propagate at a high speed (little faster than the Alfvén velocity $\approx$ 1,000 km s^{-1}). So, it is difficult to observe them. An X-ray telescope (XRT) on board Hinode was expected to detect such faint shock waves, because of its high spatial-resolution and high S/N. On 13 December 2006, the XRT detected the wavelike disturbance associated with an X-class flare. The speed of the wavelike disturbance is about 630 km s^{-1}. In this flare, a type II radio burst, which shows the existence of a shock wave, was also observed with the Hiraiso Radio Spectrograph (HiRAS). Moreover, EUV Imaging Spectrometer (EIS) on board Hinode scanned the region where the X-ray wavelike disturbance was propagated. We analyzed these data and examine whether the wavelike disturbance is shock wave or not. In this meeting, we will show the analysis results.

Discovery of Cool Cloud-Like Structures in the Corona with Hinode/SOT

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We observed an active region AR10921 near the west limb of the solar disk on 9 November 2006 with a Ca II broadband filter of Hinode/SOT. In addition to spectacular spicules, we found a large cloud-like structure located 10 000 – 20 000 km above the limb. The cloud had a very complex fine structure with dominant horizontal thread-like structure. Some features were moving horizontally and also showed clear vertical oscillatory motions. The periods and amplitudes of these oscillations were 130 − 250 s and 200 − 850 km, respectively. The vertical oscillatory motion sometimes had a coherence length as long as 16 000 km. We conclude from various observational features that this vertical oscillation is a signature of Alfvén waves propagating along the horizontal magnetic fields. We will discuss their origin and implications.

Hinode/SOT High Resolution Observation of Small Scale Magnetic Flux Emerging around a Sunspot

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We studied small-scale emerging flux regions outside of a sunspot penumbra with Hinode/SOT in the Ca II H line, G-band, and Fe 6302 Å magnetograms. We found that they have the following properties.
1. In the initial phase of flux emergence, these emerging flux regions are observed as filaments in the Ca II H line and as dark granular lanes in the G-band, respectively. The width of Ca filaments is about $2''$ ($\approx$ 1500 km) and wider then that of granular lanes, which is $1''$ ($\approx$ 700 km). The life time of the Ca filaments is about 20 minutes. It is not clear yet whether the granular lanes appear before the formation of the Ca filaments.
2. Ca bright points are seen at the footpoints of Ca filaments. G-band bright points are also observed at the same positions. These bright points correspond to the areas of strong magnetic fields. Initially, the distance between the two footpoints of a Ca filament is $\approx 2''$. The growth speed of the filaments is ≈ 4 km s^{-1} at the initial stage then it decreases to ≈ 1 km s^{-1}.

Many Faces of the Fine Structure of the Eclipse Corona

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The inner white-light corona (up to 2 solar radii) can only be observed during total solar eclipses. New mathematical methods of the corona image processing and digital photo cameras or CCD cameras allow us to detect very faint structures (of a few arcsec) in this part of the corona, even from images taken with relatively small telescopes (1–2 m in the focal length). In the present paper we will discuss such structures as observed during the last few solar eclipses, mainly those of 2002, 2005 and 2006. Obtained results show that the white-light corona is highly structured not only in the sense of a variety of different types of its classical “objects”, e.g., polar plumes, helmet streamers, threadlike streamers, etc, but also within these objects themselves. Voids, loops, radial and non-radial threads, and other yet-undefined dark structures (“empty space”?) are well visible especially inside helmet streamers. This strongly indicates that the classical picture of the corona characterized by a hydrostatic distribution of density and temperature is no longer a viable assumption, and it is rather magnetic forces that play a dominant role in shaping and structuring this part the corona. Given a remarkable similarity between the EUV corona as observed by SOHO and the white-light corona observed by us during the above-mentioned eclipses up to two solar radii, it is suggestive for modeling to approximate the “missing” observations of the white-light corona by those of the EUV one. Moreover, the last eclipse observations also indicate that the peaks of some prominences extend well into the white-light corona. So, the next total eclipses of the Sun, of 1 August 2008 and 22 July 2009, offer an excellent opportunity for preparing joint observations from Hinode and ground-based eclipse teams.

A New View of the Solar Corona with the X-Ray Telescope (XRT) aboard Hinode

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We present pieces of initial results made with the X-Ray Telescope aboard the Hinode satellite launched in September 2006. The XRT is a successor of the Soft X-ray Telescope (SXT) for Yohkoh, and employs Walter-I-like grazing incidence optics. Thanks to the increased effective area (larger mirror) as compared to the SXT with significant effort on high-precision polishment for the mirror surface, the XRT images the corona with the highest angular resolution (1 arcsec) ever achieved with solar X-ray telescopes while maintaining exposure times (i.e., cadence) similar to those with SXT. Furthermore, due to the use of a back-thinned CCD device coupled with an optimized set of focal-plane analysis filters, the XRT is capable of imaging coronal plasmas in a wide and continuous temperature range from 1 MK to above 10 MK.

Since the beginning of its observation in late October 2006, the XRT has been continuously taking images of the X-ray Sun at a rate exceeding 1000 images a day. The XRT has so far revealed many new aspects of coronal phenomena which include (1) transient brightening activities (microflares) in active regions, (2) temperature structure of the corona, (3) frequent X-ray jets in polar regions, (4) flares, and so on. Introductory overview on the XRT observations will be given together with scientific significance of the XRT.

Observations of Solar Flares with Hinode XRT

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Soft-X-ray imaging observations of the corona prior to the onset, and in the early phase of, solar flares are expected to provide us with key clues to understand magnetic field structure which leads to explosive energy release and subsequent particle acceleration that take place in flares. The X-Ray Telescope (XRT) aboard the Hinode mission is equipped with a unique capability in that it can image detailed structure of high-temperature (> 2 MK) coronal loops with the highest angular resolution (1 arcsec) ever achieved as a solar X-ray telescope.

We report XRT observations of X-class flares that commenced in December 2006 in NOAA AR10930, with emphasis on the X3.4 flare on December 13. The soft X-ray flare in this event was initiated in strongly-sheared bundles of fine loops along a magnetic neutral line about 10 minutes before the onset of the impulsive phase (identified by hard X-rays and microwaves with the HXD-WAM instrument aboard Suzaku satellite and Nobeyama Radio Polarimeter, respectively). Evolution of the flaring loop systems in the early phase of the flare towards the onset of the impulsive phase will be presented and their timing relationship with explosive energy release as indicated by impulsive emission of hard X-rays and microwaves discussed.

Initial Analysis of Hinode/SOT Helioseismology Data

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We present initial analysis of various helioseismology data acquired by Hinode/SOT. Hinode/SOT provides opportunity for studying solar wavefield in high resolution. One big goal would be to study active regions using tomographics means, but the data can also be used to investigate wave generation and propagation in turbulent magnetized plasma, including sunspot oscillations and flare-induced waves. We report on some initial analysis of G-band and H-line intensity oscillations.

Kosugi-san and Nobeyama Solar Radio Observatory

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Kosugi-san started his science career at Nobeyama Solar Radio Observatory as a post graduate student of University of Tokyo in 1972. From the beginning, he had been interested in particle acceleration process in solar flares and his life-long research was devoted to this problem. He started in the field of metric wavelength, then moved to microwave which is more directly related to high energy particles produced in solar flares. He also was interested in hard X-ray emission from accelerated particles. Yohkoh and Nobeyama Radioheliograph were realized almost simultaneously due to his great contribution. Still, we do not understand the particle acceleration mechanism in solar flares. With Hinode and Nobeyama Radioheliograph, we wish to solve this problem in near future and to report to Kosugi-san the answer.

Ca II H Anemone Jets Discovered outside Sunspots Observed with Hinode/SOT

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Solar Optical Telescope (SOT) aboard Hinode discovered tiny jets in the chromosphere outside sunspots with Ca II H broad band filter. The widths of the jets are less than 0.3 arcsec (i.e., < 200 km), and their velocities are 5 – 20 km s^{-1}. The life time of jets are a few minutes. The small bright points (or nanoflares) appeared near the footpoints of the jets. The shape of the jets and bright points is similar to those of the anemone jets observed with Yohkoh/SXT and Hinode/XRT. It is likely that these tiny Ca jets are small scale version of anemone jet, suggesting that these are produced by magnetic reconnection between small bipole (tiny emerging flux ?) and pre-existing (locally uniform) magnetic field.

Spatial Distribution of Stokes-V Area-Asymmetries with Hinode/SOT

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Rich information such as line-of-sight velocity gradient is extracted from Stokes-V profiles. We performed a simple investigation on the high-resolution spatial distribution of the normalized Stokes-V area-asymmetries. Stokes-V asymmetry maps show fine filamentary structure in penumbra. Milne-Eddington analysis indicates that such filaments have more horizontal, weaker magnetic fields with outward flow. Inner ends of such filaments are brighter in the continuum, and have higher temperature. This suggests anti (diamagnetic) flux tubes with outward cooling plasma flow. In addition to the well-known penumbral asymmetries, there are islands (one to a few arcsec) with higher area-asymmetry scattered in the moat region and neutrals sheet. Overview of these regions will be presented.

Calibration for Co-Alignment among Images from the Three Telescopes of Hinode with Sub-Arcsecond Accuracy: Mercury Transit, DC Offset, and Orbital Variations of Telescope Pointing

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Understanding of magnetic coupling from the photosphere to the corona is one of observational goals to be archived by the Hinode mission. Studies using coordinated data from three telescopes on Hinode are expected to provide major improvement in our understanding of heating and dynamics in the solar atmospheres. For such observational studies, precise spatial alignment of images from the three telescopes is required. Our goal is to establish co-alignment procedure with accuracy in order of 0.5 arcsec or better. This presentation will give an introduction of Hinode between-telescopes image co-alignment method and then discuss the latest status of calibration works for establishing the co-alignment procedure. For active region observations with sunspots, sunspots are used as fiducial to co-align XRT data on SOT data. Coronal and chromospheric features can be used for EIS vs XRT and EIS vs SOT, respectively. Satellite jitter in order of 1 arcsec or less is included with orbital variation of pointing in the series of XRT and EIS data, whereas image stabilization system (correlation tracker) removes the satellite jitter and orbital variation from the series of SOT images. The telescopes pointing is moved to track the region of interest in case of tracking mode. Telescope pointing show orbital variation in order of a few arcsec, which can be well predicted from Hinode orbit information. For SOT vs XRT, it is confirmed that orbital variation is well predicted with sub-arcsec accuracy. Using Mercury transit observed on November 8, 2006, the roll orientation of images from each telescope as well as the DC offset of pointing among the telescopes have been well determined. Modeling co-alignment is under development and it is the only method for quiet Sun observations.

Magnetic High-Speed Local Flows Revealed in Hinode Optical Stokes Observations

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The SOT spectro-polarimeter has, for the first time, been providing Stokes profiles of magnetic sensitive lines with 0.3 arcsec spatial resolution and 0.1 % photometric accuracy under seeing free condition. When we examine SOT Stokes profiles, we can easily recognize that remarkable Stokes V profiles with enhanced signal at the red wing side exist at various locations on the solar surface. The Stokes V profiles with enhancement on the red wing suggests that high speed downward flows with speed exceeding the sound velocity are formed in vertical oriented magnetic fields. The authors have found three types of such high-speed flows in umbra, penumbra, in moat region around sunspots, and also in quiet regions. The authors will discuss the nature of these flows.

Fine Structures of Solar X-ray Jets

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The X-ray telescope (XRT) aboard Hinode satellite has the great spatial/time resolution in X-ray range. And, the observations using XRT have revealed the fine structures of solar corona. From the observations, we found the fine thread structures in the X-ray jets and the structures move dynamically like wave. We also found that some X-ray jets start just after small loop expansion in the footpoint brightening. The observation results suggest that the reconnection process X-ray jets is very similar to that in large flares.

In-Orbit Optical Performance of Hinode/SOT in G-band (430 nm) Estimated with a Phase Diversity Method

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The Solar Optical Telescope (SOT) carried by Hinode was designed to perform a high-precision polarimetric observation of the Sun in visible light spectra with a spatial resolution of 0.2 – 0.3 arcsec. The SOT is a sophisticated instrument and consists of two separate optical parts; the Optical Telescope Assembly (OTA) which is 50 cm aperture Gregorian telescope feeding the light into following observing instruments which is called the focal plane package (FPP) made of two filtergraphs and a spectro-polarimeter. The performance of the OTA is important because a spatial resolution and its temporal stability is mainly determined by this component. The image of sub-arcsecond G-band (430.5 nm) bright points clearly indicates that the SOT achieves the diffraction-limit on orbit. We have studied the on-orbit optical performance of SOT using a phase diversity method. In this paper, we describe the method and result of the phase diversity and discuss on-orbit performance of the SOT.

High Resolution Observation of Spicules with Ca II H Filtergraph of Hinode/SOT

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High cadence observation with a Ca II H broadband filtergraph (passband of 0.25 nm) of the Solar Optical Telescope (SOT) aboard Hinode has revealed dynamical nature of limb spicules. Thanks to a diffraction-limited and low-scattered light property of the instrument, we can track the detailed evolution of individual spicules for the first time with a spatial resolution of 0.2 arcsec. The spicules in Ca II H are typically several arcsec tall and have multi-thread structure; each threads are a few tenth of arcsec wide. It should be stressed that most spicules do not show a simple up-and-down motion along a rigid path line. They start with bright structure emanating from Ca II H bright region, get widen and diffused with time and ascent, showing expansion with lateral or even helical motion in tall events. Small and short lived spicules tend to fade out after ascent. We will present new findings of spicule dynamics in different magnetic environments and discuss about long standing controversy of its motion and evolution.

Ubiquitous Alfvén Waves in the Chromosphere

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We see direct evidence of Alfvén waves in the middle to upper chromosphere as imaged in Ca II 3968 Å timeseries with Hinode/SOT. Our observations focus on spicules at the limb, and straw-like features associated with network and plage on the disk. The high spatial and temporal resolution of Hinode/SOT allows us to directly observe how these jet-like features undergo significant transverse motions (0.5–1 Mm) that are driven by Alfvén waves with strong amplitudes of 20–30 km s^{-1} and periods of 150–500 s. Preliminary estimates of the energy flux carried by these waves strongly suggests that they may play a significant role in the energy balance of the upper atmosphere, especially for the solar wind and quiet Sun corona. We study the generation and propagation of these waves by comparing our Hinode observations with advanced 3D radiative MHD simulations that encompass the convection zone up through the corona.

Rapid Changes in the Small Scale Magnetic Fields and the Chromosphere

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FPP magnetograms show examples of magnetic field evolution on the spatial and temporal scale of granulation. Individual features can appear and disappear on the time scale of 120 s. In Ca II H post flare cooling loops have structures at or near the diffraction limit of the telescope. The transverse velocity of the loops is on the order of 30 km s^{-1} and the repeat pattern in on the order of 10 s. This suggest that the pattern of loops is moving transversely. Surges at the limb are observed to repeat with a time separation of 30 to 40 s. The vertical velocity of the individual fronts is about 50 km s^{-1} initially slowing to 30 km s^{-1} 10 arcsec above their base. The transverse velocity of the events is 10 – 15 km s^{-1}.

High-Sensitivity Observations of Quiet-Sun Magnetic Fields by Using both Extreme-Limb and Sun-Center Spectro-Polarimetric Data

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Stokes V is much more sensitive to magnetic fields than Stokes Q and U, and extreme (80° or beyond) limb should be observed with Hinode spectro-polarimeter to reveal the static and dynamic properties of vector magnetic fields of the quiet Sun. (80° from sun center corresponds to 100 – 150 km above the nominal height.) We employ wide-FOV snapshot data as well as high-cadence small-FOV data for the north and south poles, east and west limb (all with similar equatorial distance from the center) as well as sun center for this purpose. Strong vertical fields are highly packed in the inter-granular lanes located in the sun-center, while in the limb region ubiquitous isolated Stokes V (i.e. fields horizontal to local surface) patches are seen. Larger (1–2 arcsec) magnetic patches seen in the poles show unipolar-Q with bipolar U and V. This suggests ice-cream-cone-like structure. There appears to be more such magnetic islands in the poles than in the equatorial limb (quiet Sun).

Attempt to Detect Alfvén Waves with SOT aboard Hinode

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Flux tube on the sun may carry linear and torsional Alfvén waves generated by photospheric motion. Photospheric motion of 2 km s^{-1} would provide magnetic fluctuation of 40 G for 1 kG tube with the Alfvén speed of 50 km s^{-1}. This may be close to the detection limit of the Stokes Q and U signals for flux tubes located in the sun center. However, for flux tubes located near the limb, the fluctuation would be seen in the Stokes V signal, and can be detectable. We also may be able to confirm the 90 degree phase shift between magnetic fluctuation and velocity fluctuation, which is easier to observe for flux tubes near the limb. Detection of waves with its spectra would be important in terms of coronal heating and solar wind acceleration. An attempt to detect waves along flux tubes will be reported.

On the Moat-Penumbra Relation

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Granular proper motions in solar active regions (AR) have been studied by using local correlation tracking techniques. Time series of high-resolution images are used to compute the horizontal flows for every AR. Large-scale radial outflows, the well-known sunspots moats, have been detected around the spots in all the AR. However, these outflows are only found in those umbral core sides without penumbra. These results evidence a relation between the moat flow and the penumbrae. Hinode will give us the opportunity to get into the details of this relation and establish the precise link we suggest between the moat and the well-known Evershed flow.

Evolution of Vector Magnetic Fields in Canceling Magnetic Features

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Magnetic flux cancellation was first described by Livi, Wang, Martin (1985) and Martin, Livi, Wang (1985) as the mutual flux disappearance in closely-spaced magnetic flux of opposite polarity. The two canceling components of opposite polarity were referred to as a canceling magnetic feature (Wang et al. 1988). Flux cancellation has been found to associate with most (if not all) types of magnetic activity, such as flares, filament eruptions, initiation of coronal mass ejections, and ubiquitous small-scale activity on the quiet Sun. Suggestions of the role of flux cancellation in chromospheric and coronal heating were also suggested by various authors (Sturrock et al. 1999; Longcope and Kankelborg 1999; von Rekowski et al. 2006). Therefore to diagnose the physical process underline the observed flux cancellation will lead to better understanding on the origin of solar activity. So far controversial interpretations, e.g., flux submergence (Parker 1987), flux emergence of U-loops (Spruit, van Ballegooijen, and Title 1987), magnetic reconnection in the lower solar atmosphere (Wang and Shi 1993), reconnection-submergence (Priest et al. 1994), flux emergence of O-loops (Lites et al. 1995) were proposed by different authors.

We propose observation campaigns on the nature of flux cancellation by observing the vector field evolution in canceling magnetic features. Three types of target regions are suggested to choose: (1) small- to middle-size active regions (ARs), (2) periphery of big ARs, and (3) quiet Sun region with either enhanced or quiet network. As flux cancellation and new emerging flux are intrinsically associated, the regions with newly emerging flux regions are of priority in the selection. The accurate vector magnetograms will require observations from the Spectro-polarimeter at the line-pair of Fe I 630.15 and 630.25 nm; The knowledge of the life-story of flux evolution will ask the observations from the Narrowband Filter Imager at the same Fe I line-pair for photosphere and the Mg b I 517.27 nm for chromosphere; The knowledge of temperature and dynamic structures will need the observations from Broadband Filter Imager from Ca II line, CH line and lines for temperature measurements. The average rate of flux cancellation in ARs is of the magnitude 10^{18-19} Mx/hour and on the quiet Sun, 10^{18} Mx/hour; while the total flux involved in an AR and an area of network field is in the orders of magnitude of 10^{21-22} Mx and 10^{20} Mx, respectively. Therefore for AR observations, 3–5 day duration of the observations is necessary when the AR located close to the central meridian; to the quiet Sun observations 2–3 day duration would be necessary. We would require the kind collaborations from the colleagues in SOT team to get training and knowledge in magnetic calibration and data analysis. The response of transition region and corona to the observed flux cancellation in the photosphere is extremely important to learn the physics of flux cancellation. We would ask the coordinative observations form EIS and X-ray telescope to study the coupling of flux cancellation and the heating of higher atmosphere.

Temperature and Density Structures of the Solar Corona
— A Test of Diagnostic Capability of the EIS Instrument on board Hinode —

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Increased diagnostic capability of the EIS instrument on board Hinode is tested with a set of iron emission lines located in the two EIS observing wavelengths (170 – 210 Å and 250 – 290 Å). First-light spectra of a small active region show iron emission lines at the ionization stages of Fe VIII (185.2 Å and 186.6 Å) through Fe XVII (204.7 Å, 254.9 Å, and 269.4 Å), showing emission measure distribution at upper transition-region, low and high coronal temperatures. Decay phase spectra of a C-class flare confirms the presence of Fe XVII at 254.9 Å, as well as those lines of flare temperatures; Fe XXIV (192.0 Å and 255.1 Å) and Fe XXIII (263.8 Å) reveal that the emission measure distribution extends above 10^7 K.

Milne-Eddington Model Fitting Program of the Hinode/SOT-SP Data

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The Hinode SOT/SP obtains line polarization profiles of magnetically sensitive Fe lines. By fitting these profiles under a given atmospheric model, we can measure the detailed magnetic and dynamic structure of the photosphere. We will report the status of the development of the fitting program and the initial results obtained by using it. This code is based on the Milne-Eddington model and is an extended version of the MELANIE and PIKAIA originally maintained by the HAO group in USA.

Study of Non-Potential Magnetic Field Inferred from Photospheric Vector Magnetograms and Soft X-ray Images

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The measurements of photospheric vector magnetic field and soft X-ray images provide some basic information on the development and relaxation of non-potential magnetic flux and the relationship with the solar eruptions. The following projects are proposed in the study of Hinode data:

(1) The formation of non-potential magnetic field and helicity in solar active regions inferred from the vector magnetograms and soft X-ray images.

(2) The large-scale topology of magnetic field inferred from local and full-disk photospheric vector magnetograms and soft X-ray images.

(3) The comparison between the vector magnetograms from Hinode and ground-base observations.