New avenues in solar physics science with Hinode

K. A. P. Singh and T. Van Doorsselaere

With its unprecedented high-resolution facility, Hinode is a very potential mission to unravel the intricacies of the Sun from space. It helps solving the long awaiting ‘coronal heating conundrum’ and understanding the mysterious solar corona by recent discoveries of ubiquitous waves, anemone jets and outflows. Hinode findings proved the presence of waves of sufficient strength to power the solar wind which buffets the Earth’s magnetic field and causes the space weather events.

Hinode (meaning ‘Sunrise’ in Japanese) is a recently launched space mission to observe and study the Sun in high temporal and spatial resolution and can be regarded as ‘Hubble of the Sun’. It is spearheaded by Japanese Aerospace Exploration Agency (JAXA) in collaboration with NASA, Science and Technology Facilities Council (STFC), and European Space Agency (ESA). Hinode carries three high-resolution instruments: Solar Optical Telescope (SOT), X-ray Telescope (XRT) and Extreme-Ultraviolet Imaging Spectrometer (EIS). SOT is the largest solar optical telescope ever flown in space and observes the cooler parts of the solar atmosphere: the photosphere (temperature 5000 K) and the chromosphere (temperature 10,000 K). The XRT is a grazing incidence telescope which observes the hottest parts of the solar corona, with temperatures over 2 MK. The EIS is an imaging spectrometer designed to observe solar plasma in the temperature range of 0.1–10 MK which corresponds to the upper transition region and the corona. With its three suites of telescopes, the mission probes the Sun from photosphere to corona (Figure 1). It therefore has the capabilities to address three burning issues in solar physics: (a) What creates the Sun’s dynamic magnetic field?, (b) Why does a hot solar corona exist above the cool photosphere?; (c) What drives solar explosive events e.g., flares, CMEs) and how do they affect space weather?

In order to understand these issues, one needs to investigate the interaction between the Sun’s magnetic field and the corona. Satellite observations of the Sun started from Skylab in 1970s, then Solar Maximum Mission (SMM), Yohkoh, SOHO, TRACE, RHESSI and STEREO. They all have revealed the solar atmosphere in multi-wavelengths, ranging from ultraviolet to even gamma rays. However, no space mission could unambiguously answer the above questions.

SOT onboard Hinode with its unprecedented high spatial (~150 km) and temporal (~5 s) resolution has shown clear evidence of the existence of waves in the solar atmosphere. It has shown that spicules (Figure 2) are swaying transversally all the time, confirming the earlier findings of Kukhianidze et al. This confirms the presence of ubiquitous wave power in the solar atmosphere that was first discovered by Tomczyk et al. using the Coronal Multi-Channel Polarimeter (CoMP) instrument at the National Solar Observatory (NSO), New Mexico. They found periodic line-of-sight motions with an amplitude under 1 km s⁻¹ and interpreted them as Alfvén waves. Recently, Van Doorsselaere et al. have challenged this interpretation and interpreted the observed oscillations as guided kink waves. A correct interpretation is important because kink and Alfvén waves are fundamentally different in many respects, e.g. their excitation and damping mechanisms, phase speeds, propagation, compressibility and nonlinear evolution are essentially different. The interpretation of Tomczyk et al. was based on the facts that the observed phase speeds are much larger than the sound speed, they propagate along the field lines and seem to be incompressible. Van Doorsselaere et al. on the other hand, have clearly shown that the structure effects play an important role and kink waves can also be incompressible.

The Hinode discoveries of waves in the corona by De Pontieu et al. have followed Tomczyk et al. in their interpretation of the waves as Alfvén waves. As stated above, De Pontieu et al. have shown that spicules show a lot of wave power and claim that the wave energy flux of 100 W m⁻² is sufficient to drive the solar wind. Okamoto et al., using SOT, found transverse oscillations in fine thread-like structures in solar prominences and interpreted them as Alfvén waves. In similar prominences, Ofman and Wang have found sufficient energy flux for coronal heating in kink waves in the presence of background flow. Using XRT, Cirtain et al. have found oscillations in X-ray jets. The observations altogether constitute an excellent development in solar physics. Waves are now considered as truly ubiquitous in the solar atmosphere. This enormous wave power could contribute to coronal heating. However, a consensus on their nature (kink or Alfvén) and energetics first has to be reached, before any conclusions can be drawn.

The XRT telescope detects a large number of polar jets showing high velocities of the apparent outflows. This indicates that the jets may contribute to the high-speed solar wind. These jets also shed light on magnetic reconnection, which is another possible contributor to solve the coronal heating problem. Magnetic reconnection is responsible for the explosive and transient events such as solar flares and CMEs. With SOT, Shibata et al. discovered tiny ubiquitous chromospheric anemone jets (upside down

Figure 1. An artist impression shows the layers of the Sun with its surface ‘photosphere’, and atmospheric layers ‘chromosphere’ and the mysterious ‘corona’. (Image credit: NASA.)
Y-shaped) outside sunspots in the active regions. Their smaller size and frequent occurrence is indicative of the direct evidence of small-scale reconnection in the solar atmosphere as conjectured by Parker\textsuperscript{10}. He proposed that nanoflares heat the corona and generate MHD waves, which eventually accelerate high-speed solar winds. Hinode’s finding of numerous jets in the low chromosphere with indirect evidence of reconnection is fairly consistent with these ideas.

SOT has all the capabilities to observe dynamic activities in the photosphere and chromosphere with high resolution and stable image quality. This has led to new observations of fine-scale jet-like features, called the penumbral microjets\textsuperscript{11}, in the chromospheric surroundings of a sunspot (penumbra). The energy associated with these jets is found to be comparable to the lowest energy of nanoflares observed in the corona. The complex magnetic configuration in penumbral regions can facilitate the magnetic reconnection. It therefore seems that the microjets have the potential\textsuperscript{11} to heat the atmospheric layers (e.g. transition region, corona) above the sunspots.

The chromosphere is a highly structured layer (Figure 2) above the solar photosphere. Most of the radiation that is generated in the chromosphere is because of a plethora of spiky features called spicules (Figure 3). At the limb, the dynamics of magnetized chromosphere is dominated by spicules. SOT has shown\textsuperscript{12} that there are two types of spicules (Type-I and II) which dominate the structure of the magnetic chromosphere. Type-I spicules are driven by shock waves and seem to form when global oscillations and convective flows leak into the upper atmosphere along magnetic field lines on 3–7 min time scale. Type-II spicules or straws, on the other hand, are much more dynamic and seem to be formed as a consequence of magnetic reconnection, typically in the vicinity of plage and network. The Type-II spicules are comparatively thinner and they are sufficient in sending the plasma to chromosphere at speeds of 50–150 km s\textsuperscript{-1}. Both types of spicules are observed to carry waves with amplitudes of up to 20 km s\textsuperscript{-1}. The energy flux associated with these waves is important\textsuperscript{12} for quiet sun heating in the corona and acceleration of the solar wind. These waves can be used to estimate the magnetic field strength in spicules. The magnetic field strength in spicules is estimated between 7 and 18 G, although magnetic field of 30 G is also possible.

Hinode data shows continuous mass loss from the sun in the form of slow (~300 km s\textsuperscript{-1}) and fast solar wind (~800 km s\textsuperscript{-1}). Hinode has clearly seen the presence of persistent outflows\textsuperscript{13} at the edges of the solar active regions. This has been confirmed both by the XRT and EIS instruments. The Doppler velocity obtained by EIS is found\textsuperscript{14} to be in the range between 20 and 50 km s\textsuperscript{-1}, and it is consistent with the XRT observations. These outflows may be indicative of one of the solar wind sources at the sun. The outflows observed, both by EIS and XRT, most likely forms part of the slow solar wind. The observed steady flows could have further implications for the general structure of the plasma and coronal heating models. It is still not clear where these outflows originate and what could be their acceleration mechanisms. In situ measurements of solar wind particles and magnetic field with the Advanced Composition Explorer (ACE) satellite shows\textsuperscript{15} that one of the sources of the slow solar wind resides in boundaries between coronal holes and active regions, a finding which is consistent with the new Hinode discoveries.

Hinode is designed to address the fundamental questions concerning the interaction of magnetic field with its atmosphere, solar variability and space weather. The three instruments SOT, XRT and EIS are made for observing the simultaneous response of chromosphere and corona to changes in the photospheric magnetic field. Apart from high resolution observations, the key factor that differentiates Hinode mission from the previous ones is measuring the properties of sun’s magnetic field. So far, Hinode discoveries provide information in solving all three key questions in solar physics. They have opened new avenues for more challenging observations and theories. Undoubtedly, more exciting results are to come in the near future.

Genome sequence of a fungus for the biofuel industry

Ramesh Maheshwari

Much hope is pinned on the production of ethanol from plant biomass – the only naturally renewable raw material to stem the fuel crisis due to fast-depleting reserves of fossil fuel. The spotlight has been on a fungus, *Trichoderma reesei* as the source of enzymes that are required to breakdown cellulose – the principal component of biomass – into fermentable sugars for the production of ethanol as a biofuel. This multicellular, multinucleate filamentous fungus has been awaiting its turn for genome sequencing “to better understand this fungus and expand its extraordinary biotechnological potential”.

*T. reesei* belongs to a class of fungi which commonly reproduce by asexual spores (conidia), but under certain conditions produce sexual stage known as *Hyphocrea jecorina*. Although rules of nomenclature recommend that the fungus be called by its sexual stage *Hyphocrea*, since the sexual stage is infrequent and the fungus is commonly recognized by its asexual (conidia-forming) stage (image: wikimedia.org/wiki-commons/thumb/4/4d/Trichoderma_harzianum.jpg/250px), the name *T. reesei* is in common usage. Actually, *T. reesei* is a mutant strain derived from *T. viride* QM6a isolated during the Second World War from rotting military tents and clothing in the warm and humid jungles in the Solomon Islands in the South Pacific. Microbiologists in the US Army Research and Development Laboratories in Natick, Massachusetts, selected this fungus from over thousand strain of microbes because this strain secreted higher levels of cellulase – a group of enzymes that split the β-1,4 glycosidic linkages in cellulose – the principal constituent of biomass. After a series of exposure to high energy electrons and ultraviolet irradiation that improved its cellulase productivity with concomitant alteration in its morphology, the high cellulase-producing mutant strain was renamed *T. reesei* in honour of Elwyn T. Reese (a biochemist in the Natick laboratories), who had envisaged exploiting this organism for enzymatic conversion of cellulose in plant biomass into ethanol using cellulases in a two-step process (Figure 1).

Certain strains of *T. reesei* secrete cellulase extracellularly in excess of 100 g/l, indicating that even unconcentrated culture broth containing cellulases could suffice for bioconversion of cellulose into glucose. It was hoped that genome sequencing will throw light on genes of *T. reesei* which encode components of the cellulase enzyme system and determine why this fungus is able to secrete an exceptional quantity of cellulases. This knowledge could help improve the productivity of other enzymes in other species of fungi. The genome sequence1 was determined through shotgun cloning and sequencing and is now published with the customary long list (45 in this instance) of authors. Among the sequences identified were the genes whose predicted gene products had similarity to known proteins.

The *T. reesei* genome (33.9 Mb) contains 9129 genes compared to 10,620 in the model filamentous fungus, *Neurospora crassa* (38.7 Mb). Surprisingly, *T. reesei* has only seven genes encoding endo- and exoglucanases (cellobiohydrolase) – crucial components of the cellulase system! This suggests that rather than the number of copies of the genes, it is their transcription2, innate characteristics of the gene products (folding), post-translational modifications (disulphide bond formation, glycosylation) of their gene products that are important in high enzyme productivity and stability. Orthologs (regions of DNA encoding genes with similar functions) of the yeast-secretory pathway are represented as single copies in the *T. reesei* genome. Thus, contrary to expectation,

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**Step I**

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(C_{6}H_{12}O_{5})_n + nH_2O \xrightarrow{\text{Cellulase}} nC_6H_{12}O_6 \xrightarrow{\text{Glucose}}
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**Step II**

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\text{Glucose} \xrightarrow{\text{Yeast}} 2C_2H_4OH + 2CO_2 \xrightarrow{\text{Ethanol}}
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Figure 1. A scheme for the use of *Trichoderma reesei* in the production of fuel ethanol.