Hinode probes the Sun’s mysteries

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Investigating the interaction of the Sun’s magnetic field with its outer atmosphere, the Hinode spacecraft, with three telescopes on-board, is probing some of the Sun’s outstanding riddles; Why a hot corona exists and how it is heated? What drives explosive events such as solar flares and coronal mass ejections; What creates the Sun’s magnetic field? Hinode’s ‘detection of Alfvén waves’ opens a new era in unlocking the secrets of the Sun.

Solar-B, now named Hinode (or ‘sunrise’), launched from Japan’s Uchinoura Space Centre on 22 September 2006, has been providing unprecedented high-resolution images of our dynamic Sun (Figure 1). The defined goals of the Hinode spacecraft are to investigate the connection of the dynamics and heating in the corona with the magnetic field at the solar surface. The spacecraft is placed in a ‘Sun-synchronous’ orbit, which enables viewing of the Sun for 24 h a day for about 8 months of the year. There are three instruments on-board: the solar optical telescope (SOT), the X-ray telescope (XRT), and the extreme-ultraviolet imaging spectrometer (EIS). These instruments are uniquely designed to scrutinize mechanisms for coronal heating, magnetic field mapping from the photosphere to the coronal structures, and the energy budget in the solar atmosphere.

The SOT is the first space-borne (50-cm aperture) telescope to measure the strength and direction of the Sun’s magnetic field from space. It is capable of recording magnified views of the Sun’s surface, and thereby revealing solar convection. It has a spatial resolution of 0.2–0.3 arcsec in the 3880–6880 Å spectral range, which is approximately the size of photospheric magnetic flux tubes. The stability requirement of <0.09 arcsec in 3-sigma is achieved to acquire images by a combination of spacecraft structural design (body pointing control) and active image stabilization in the telescope. The combined SOT system is optimized to measure the vector magnetic field in the photosphere as well as in the chromosphere. Images from SOT show greatly magnified views of the Sun’s surface, which reveal new details about solar convection (Figure 2a). SOT images and magnetic maps clearly show the highly dynamic and intermittent nature of the Sun’s lower chromosphere (Figure 2b).

The XRT is a high-resolution grazing incidence telescope. It images the coronal

Figure 1. This image, from Hinode’s X-ray telescope shows details of bright points. The presence of ubiquitous small brightenings reveals magnetic activity all around the Sun (image credit: NAOJ).

Figure 2. a, SOT/Hinode is the largest solar telescope flown in space, which provides the best spatial resolution (0.2–0.3 arcsec in the 3880–6880 Å spectral range). Its microscopic observation allows the observation of fine structures in a sunspot (image credit: NAOJ). b, SOT/Hinode can simultaneously observe the photosphere and chromosphere. G-band bright points indicate strong magnetic fluxes. Bright structures in Ca II H imply heating in the chromosphere. These datasets provide a clue to chromospheric heating (image credit: NAOJ).
plasma in the wide temperature range \(1-30\) MK at 1 arcsec resolution\(^3\). This allows investigation of the temporal evolution of the spatial distribution of temperature and emission measure of different coronal structures. XRT also aims at investigating the generation, transport and emergence of solar magnetic field. Eventually, one can study the dissipation of magnetic energy in a variety of problems, such as flares, pico-flares, coronal heating and coronal mass ejections (CMEs). X-ray images exhibit evolving magnetic-field topology, providing clues to understanding the energy build-up, storage and release process in coronal transient events (Figure 3). Since XRT covers a wide range of temperature, it is a unique instrument capable of observing almost all coronal structures.

The EIS instrument utilizes an off-axis diffraction grating in a normal incidence optical layout with high level of Mo/Si multi-layer coatings\(^5\). The multi-layer coatings have high reflectance in two wavelength ranges, namely 170–210 Å and 250–290 Å (Figure 4). These wavelength ranges are observed simultaneously with two large, illuminated CCDs. These wavelength bands contain strong emission lines with their formation temperatures ranging from \(10^3\) to \(10^7\) K. Many of these EUV emission lines emanate from the transition region and the corona. EIS also measures spectral line profiles of several EUV lines. The observed line profiles carry the radiation signature of the emitting plasma, such as velocity, density and temperature. Thus EIS probes the chromosphere and chromosphere–corona transition region through these emission lines. Since it probes the layers which separate the photosphere from the corona, it is a crucial link between SOT and XRT.

In brief, three instruments on-board Hinode, cover a variety of problems\(^1\), such as (i) physics of thin flux tubes (formation, dynamics, group motion, fading, propagating waves, etc.); (ii) evolution of magnetic field (flux appearance and disappearance, development of active regions, magnetic field structure, current system, etc.); (iii) coronal heating (energy generation, propagation, dissipation, magnetic field structure, current system, plasma velocity field, etc.); (iv) physics of coronal dynamics (energy build-up, trigger, instability, etc.); and (v) physics of magnetic reconnection (plasma velocity field, magnetic field structure, current system, etc.).

The Hinode’s scientific goal of understanding the physics of the solar plasma from the photosphere to its outer solar atmosphere in its entirety is likely to be achieved from simultaneous observations of magnetic field and plasma dynamics. Coordinated measurements with the Hinode’s optical, EUV and X-ray telescopes, which are probing the Sun from the photosphere to the corona, have already provided new information on how changes in magnetic field at the Sun’s surface spread through the outer layers of the Sun’s atmosphere.

![Figure 3](image-url). Bright thread of loops depicts magnetic structure in coronal plasma which is frozen in the magnetic field. Study of these frequent brightenings and eruptions is crucial to understanding coronal heating (image credit: NAOJ).

![Figure 4](image-url). The EUV Imaging Spectrometer on-board Hinode has returned impressive images and spectra (image credit: NAOJ).
Detection of Alfvén waves

Erdélyi and Fedun\cite{1} describe the main discovery from Hinode spacecraft as: ‘Hinode’s main discoveries so far contribute to finding additional observational evidence of ubiquitous magnetic waves that may be the long-sought candidate for transporting the energy from the Sun’s subsurface energy reservoir to the solar atmosphere’. Existence of Alfvén waves in the solar atmosphere continues to be a ‘hot topic’, since Alfvén made its theoretical prediction in 1940. Since then, existence of these magnetic waves could not be proved beyond doubt from ground-based or space-borne experiments.

Making use of SOT’s high-resolution images, De Pontieu et al.\cite{2} have now shown that the chromosphere is permeated by Alfvén waves with strong amplitudes of 10–25 km/s and periods of 100–500 s. Estimating the energy flux of these waves and comparing it with MHD simulations, they find that Alfvén waves are capable of accelerating the solar wind and heating the corona. Okamoto et al.\cite{3} have suggested that fine-scale, thread-like structures oscillating with periods of several minutes are nothing but Alfvén waves which propagate on coronal magnetic field lines. Curtain et al.\cite{4} have provided evidence of Alfvén waves in solar X-ray jets (Figure 5). Direct observation of Alfvén waves without any ambiguity opens a new era in solar physics, probing almost all structures from sunspot penumbrae to coronal holes.

As Hanson and Voss\cite{5} conclude in the introduction to the special issue of Science: ‘Much more is expected to come from Hinode, yet it has already provided a new view of the Sun well-fitting its name’, and the enthralled Hinode’s team of scientists have only just started.


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