The most detailed X-ray images ever captured of our star are yielding clues to how the solar atmosphere twists and pops.

# Hinode Reveals the Sun

By Monica Bobra

AS DAWN BROKE over the Pacific Ocean on September 23, 2006, a rocket lifted off outside the coastal Japanese town of Kagoshima. It carried an international suite of Sun-watching instruments, aptly named Hinode ("hee-no-day"), Japanese for Sunrise.

The three instruments aboard the $300 million craft — a joint effort of institutions in Japan, the United States, England, and Europe — are designed to study the Sun's atmosphere in visible, ultraviolet, and X-ray light. Among their key targets are hot wellsprings of energy that spew particles into space, much like volcanoes on Earth. Yet while volcanoes are rigid, these so-called active regions roam across the face of the Sun, appearing and disappearing regularly.

Highly unpredictable and rapidly explosive, active regions have been enigmatic to scientists since their discovery. Yet Hinode has already unraveled some of this mystery from its home in polar orbit around Earth.

The Sun's atmosphere consists of plasma: gas so hot that the atoms break apart into a sea of naked nuclei and loose electrons. These charged particles stream within powerful solar magnetic fields and emit most of their light in X-rays. The X-Ray Telescope (XRT) aboard Hinode catches some of this light to make the highest-resolution X-ray views of the Sun to date. It captures active regions roiling at temperatures between 1 and around 25 million kelvins (upwards of 45 million degrees Fahrenheit).

#### An Unnerving Start

After Hinode's launch, scientists were looking forward to analyzing XRT's detailed images. But that didn't happen without a bit of turmoil. According to the mission plan, the satellite would take about a month to attain its proper orbit. Telemetry reported, however, that XRT's protective front door opened unexpectedly after just a few hours in space. This sent scientists into a swirl of worry that a speck of space debris in Earth's upper atmosphere might crash into the telescope's fragile filters and ruin the whole party.

Although the spacecraft indicated no damage, proof didn't come until October 23rd, when XRT took its first picture. The stunning image showed active regions as wispy interconnected loops of plasma resembling a seething gnarled ball of yarn — the ultimate Gordian knot.

Astronomers were taken by surprise. Earlier observations had shown little evidence of such complexity. Another space-based solar telescope, the ultraviolet-sensing Transition Region and Coronal Explorer (TRACE), occasionally sees twisted structures immediately before active regions erupt. And the smaller X-ray telescope aboard Hinode's older sibling, the now-defunct Yohkoh satellite, imaged active regions that looked like worms — fat S-shaped structures. But neither Yohkoh nor TRACE could discern twisted gossamer threads, each swirling in its own way to create an intertwined network of wires like the heap underneath a computer desk.

#### Answers Sought

Even a cursory look at the observations raises endless questions from the solar-research community. Why is the magnetic field acting this way? Does it bubble up from the

The Japanese Solar-B satellite was renamed Hinode (Sunrise) upon reaching space.

NAOJ

surface in an already complicated configuration, or does it tangle itself later? And how tangled is tangled *enough* to erupt as a solar flare?

But that's not the only puzzle. The XRT images also show that active regions are much larger than expected. We see thin loops spread across one-third of the solar disk. Previous active-region images in ultraviolet light, such as those from TRACE or the Extreme Ultraviolet Imaging Telescope aboard the Solar and Heliospheric Observatory (SOHO), show small, bright cores. Yohkoh's pictures exhibited haloes of dim fog surrounding the intense centers. The XRT's high-resolution images resolve that fog into long, thin loops connected to the active region's heart.

To see movies of Hinode's X-ray observations, visit SkyandTelescope.com/skytel

XRT also disproves the notion that active regions are isolated, a local mess in an otherwise smooth expanse of solar calm. In one particular series of X-ray images, loops from the sole active region in the Sun's northern hemisphere expel a fast-moving cascade across surprising distances — all the way to the south pole. In a matter of hours, the plasma flows some 800,000 kilometers (500,000 miles), about the diameter of the Moon's orbit around Earth.

**Selective X-ray Vision**

Capturing such detail is challenging because the solar atmosphere's brightest features are millions of times more intense than the dim ones. XRT's camera shoots through one of nine different filters; like a strainer, each allows only a narrow range of X-ray wavelengths to enter the telescope. In this manner, scientists can discriminate between hotter and cooler plasmas. As a result we can, for the first time, see the twisted, intertwined active regions during every step of a solar flare — as they brighten, erupt, and fade.

Many researchers suspect that tangled magnetic fields hold the energy required to heat the Sun's atmosphere to millions of degrees, much like a twisted rubber band stores energy. But understanding why the solar atmosphere is so much hotter than expected will take much more than X-ray observations to accomplish.

By coordinating XRT observations with those by the other two instruments aboard Hinode — the Solar Optical Telescope and the Extreme Ultraviolet Imaging Spectrometer — as well as the newly launched STEREO mission that is providing a three-dimensional view of the Sun, the solar-physics community will come closer to solving the problem. Furthermore, with 2007 designated by the United Nations as the International Heliophysical Year, the world's scientists will have plenty of opportunities to collaborate.

Hinode's nominal mission extends for the next three years. During this time the Sun will ramp up from its current state of solar minimum, when few active regions bubble up, toward solar maximum, when a pitted and pocked solar atmosphere sports multiple, concurrent active regions. Having provided plenty of food for thought during its first months in orbit, XRT will no doubt give solar astronomers lots more to chew on in the coming years. †

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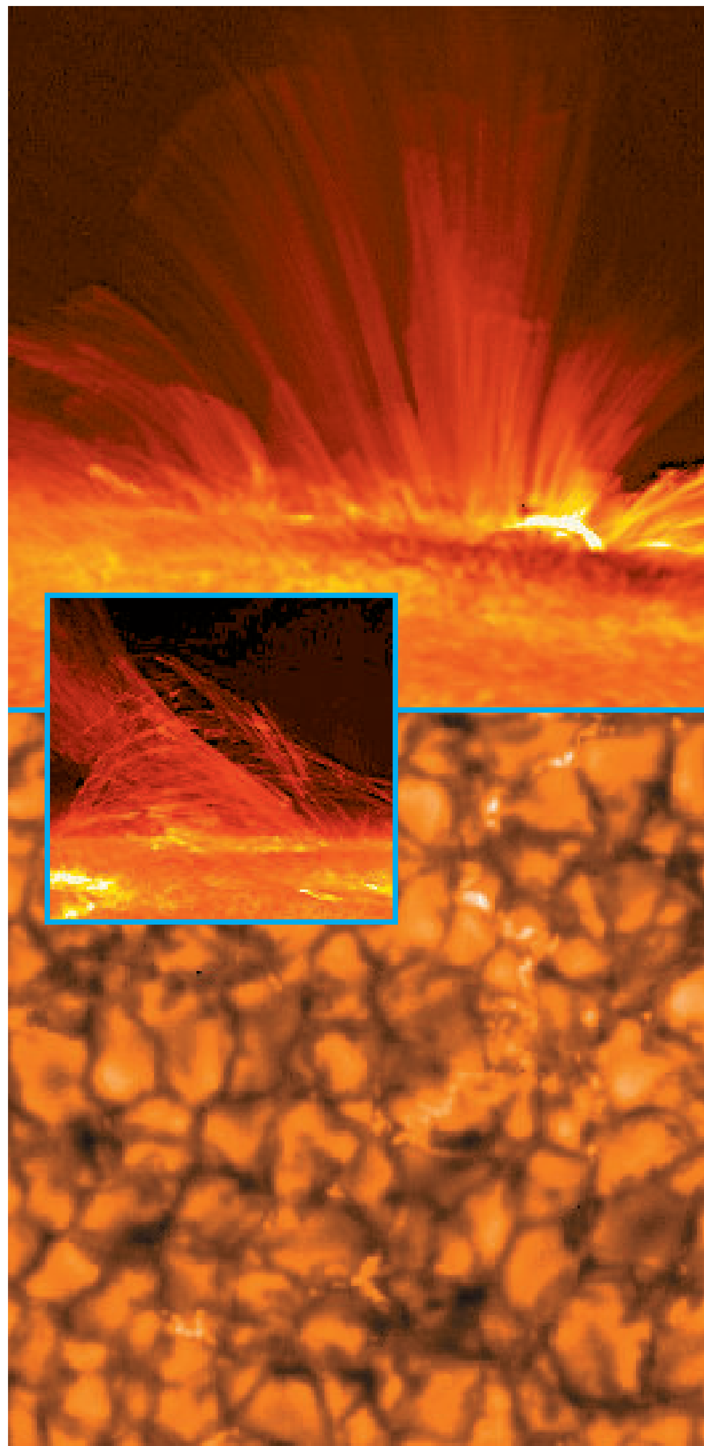
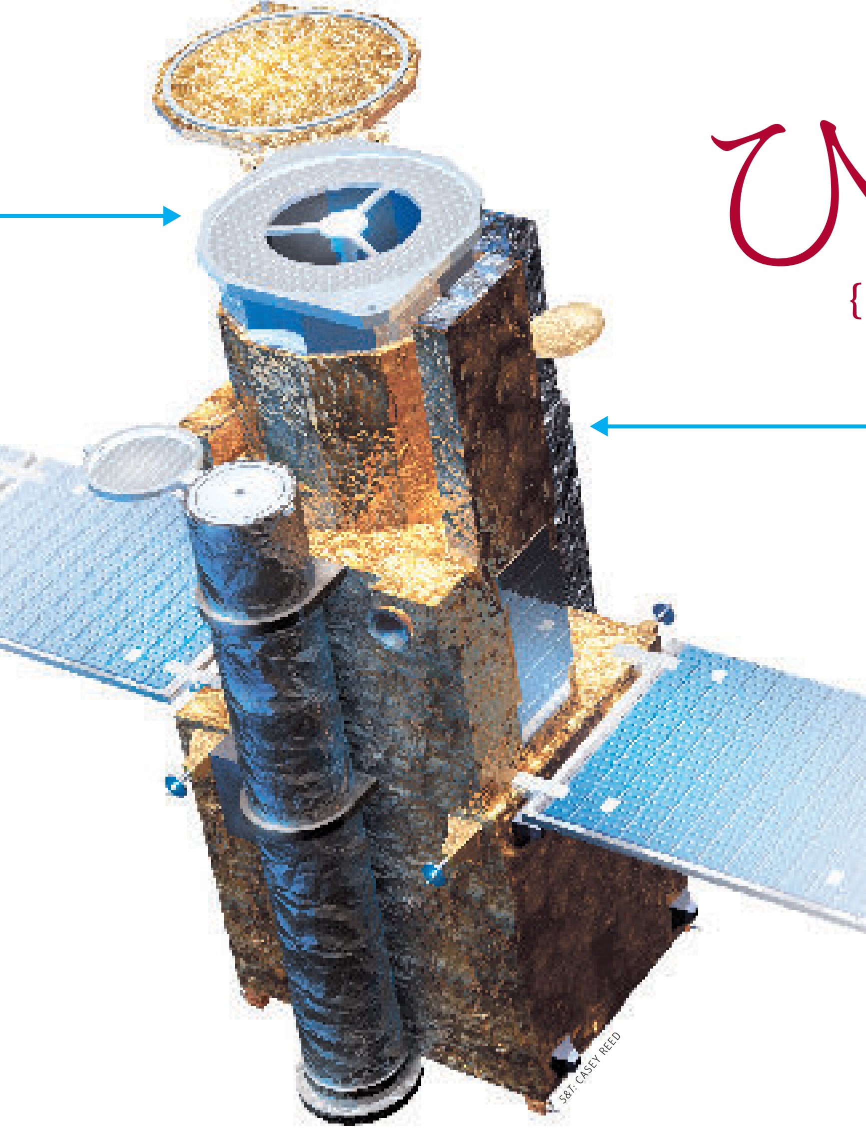
## Solar Optical Telescope (SOT)

Supporting Institutions:
High Altitude Observatory (HAO)
Lockheed Martin Solar and Astrophysics Laboratory (LMSAL)
National Astronomical Observatory of Japan (NAOJ)
Japan Aerospace Exploration Agency (JAXA)

Instrument Highlights:
The high-resolution, visible-light detector is producing stunning vistas of the Sun's roiling surface and is the first space-based instrument to map changes in the magnetic fields of the lower atmosphere. *Below and middle:* Oblique views of sunspots near the solar limb show thin streamers of plasma tracing magnetic-field lines. *Bottom:* Peering directly down onto the solar surface reveals mosaic-like mottling called granules, which are actually the tops of enormous convection cells of hot gas boiling to the surface. The 50-centimeter telescope utilizes image-stabilization techniques to achieve 0.09-arcsecond resolution.





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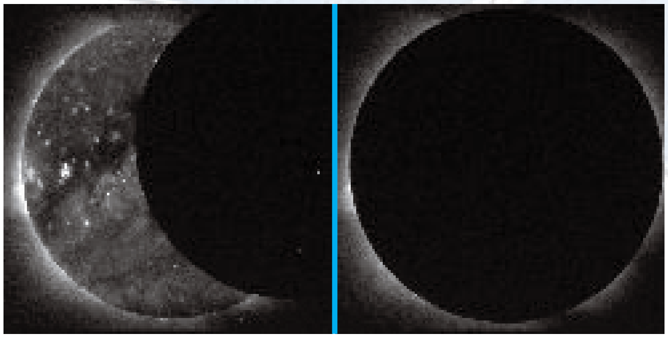
## Extreme-ultraviolet Imaging Spectrometer (EIS)

Supporting Institutions:
US Naval Research Laboratory (NRL)
UK Science & Technology Facilities Council (STFC)
NAOJ, JAXA

Instrument Highlights:
EIS has 10 times the sensitivity in ultraviolet light than previous solar satellites. Its best resolution is in the important wavelengths between 17 and 29 nanometers (170 to 290 angstroms).

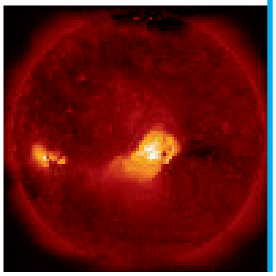
Perfect Placement
In an unusual coincidence of orbital geometry, Hinode passed through the perfect place to witness a total solar eclipse last March 19th. On Earth, the best that observers in eastern Asia could manage was just a partial eclipse. XRT is the only instrument that sees the full disk.



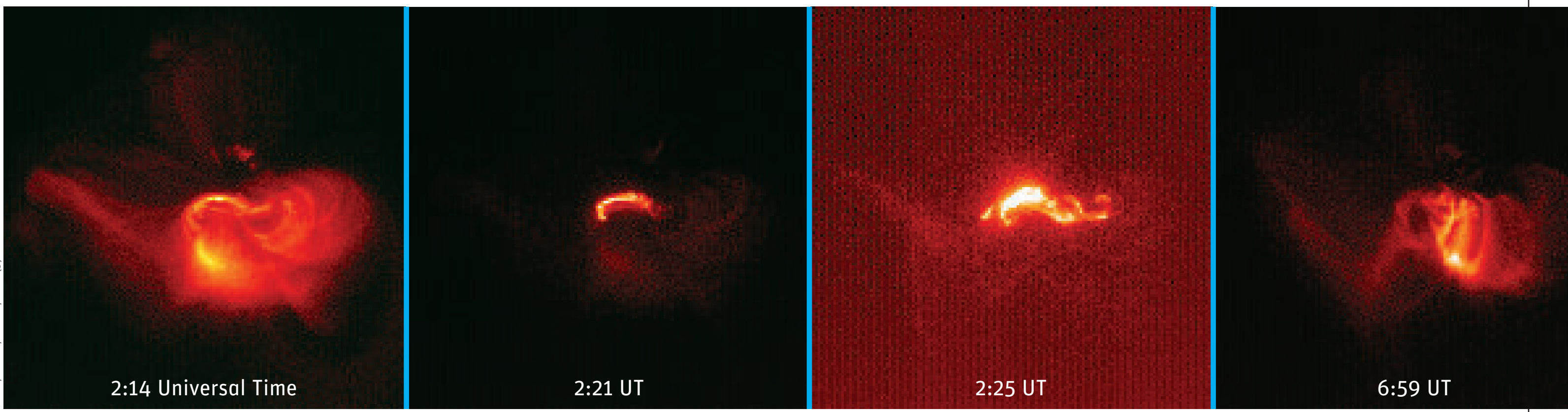
JAXA / NAOJ / NASA / SAO (2)

## X-Ray Telescope (XRT)

Supporting Institutions:
Smithsonian Astrophysical Observatory (SAO)
NASA, NAOJ, JAXA



Instrument Highlights:
*Left:* XRT reveals an active region on November 11, 2006, that extends over more than one-third of the solar disk. On Earth, this would be equivalent to spanning the entire Pacific Ocean. *Below:* By stringing together individual frames into a movie, scientists can watch the solar atmosphere evolve before their eyes. XRT can snap images every two seconds to pinpoint rapid changes, such as this flare erupting on December 13th. At first, multiple threads twist together to form a loop. Minutes later, the top of the loop brightens rapidly. The outburst causes XRT's automatic exposure control to take shorter exposures — long enough to capture the blazing loops, but too brief to record the surrounding plasma. During the next few hours, the structure cools and becomes a warping tunnel of loops.

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