Chapter 25

Plunging into the Sun

In This Chapter

- Yohkoh's successor will be even better
- STEREO will give a stereo view
- Everything's new over the Sun every day
- Probing the Sun

The images that we get hourly and daily of the Sun from a wide variety of telescopes on Earth and in space are fabulously beautiful and informative. But there is always room to do better. A series of spacecraft are planned for the next half-dozen years that should bring our understanding of solar processes to an even higher level.

B Follows A

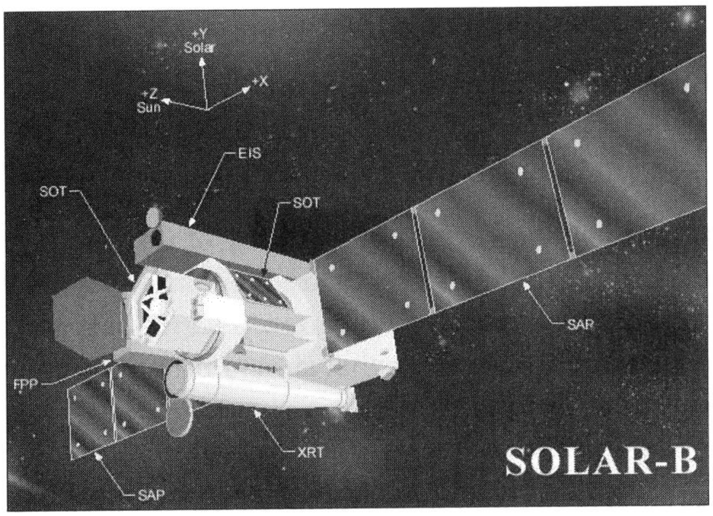
The Japanese Space Agency had great success in its almost 10 years of operating the Yohkoh mission. The x-ray movies and flare studies at high energy gave us a continuous view of solar violence that helped us understand the underlying mechanisms. But now it has been a dozen years since Yohkoh was launched. Before launch, Yohkoh was known as Solar-A. The Japanese and their collaborators in the United States and elsewhere are hard at work on Solar-B. Only after launch will we learn its new name.

The ostensible purpose of Solar-B is to study how the Sun's magnetic field links the photosphere, where we measure it directly, and the corona. At the higher levels, we see the magnetic field only indirectly, though the form of coronal loops and streamers certainly give the shape of the field away.

The Solar Scoop

Solar-B is a joint project of the Japanese Institute of Space and Astronautical Science (ISAS), NASA in the United States, and the United Kingdom. The spacecraft itself is Japanese, and it will be launched in Japan. We hope for a launch in 2007.

Solar-B will have higher spatial resolution than previous spacecraft and will do so at a high cadence. Its field of view will encompass a sunspot region. But the main point is that its high resolution should resolve and measure the 3D magnetic field of the actual tubes of flux that are thought to permeate the corona at a finer scale than the resolution of today's telescopes. Like TRACE, the spacecraft will be in a Sun-synchronous orbit around the Earth. Over the period of its operation, we hope to understand better how the variability of the Sun's magnetic field is linked to the solar effects on Earth.



An artist's conception of Solar-B.

(NASA)

B's Visual Views

One way that Solar-B will improve on Yohkoh is to have high-resolution imaging in visible light simultaneously with its extreme-ultraviolet and x-ray observations. After all, we all like to see what is going on. Of course, there are many scientific things to see. As Yogi Berra reportedly said, "You can see a lot just by looking." And with Solar-B, we should be able to see phenomena on the Sun as small as 0.2 arc seconds (about 150 km [about 100 miles]), twice the size of each pixel. This is at least as good as the best ground-based solar telescopes, and will be available without the ground-based variations in seeing.

Leon Golub at the Harvard-Smithsonian Center for Astrophysics, who built the TRACE telescope, is building the x-ray telescope for Solar-B. Alan Title of Lockheed Martin Advanced Technology Center in California, who is in charge of the TRACE mission, is building the Solar Optical Telescope. George Doschek of the U.S. Naval Research Laboratory and Len Culhane of the Mullard Space Science Laboratory in the United Kingdom are the Principal Investigators for the ultraviolet telescope. Preparing a spacecraft like this one requires commuting a good bit between the United States or the United Kingdom and Tokyo.

The 0.5-m (20-inch)–diameter visible light telescope will provide not only imaging, but also spectroscopy. Furthermore, instruments associated with it will be able to measure the three-dimensional magnetic field at the solar surface. The magnetic field measurements will see details 10 times smaller than previous measurements of this type.

B's X-Ray Views

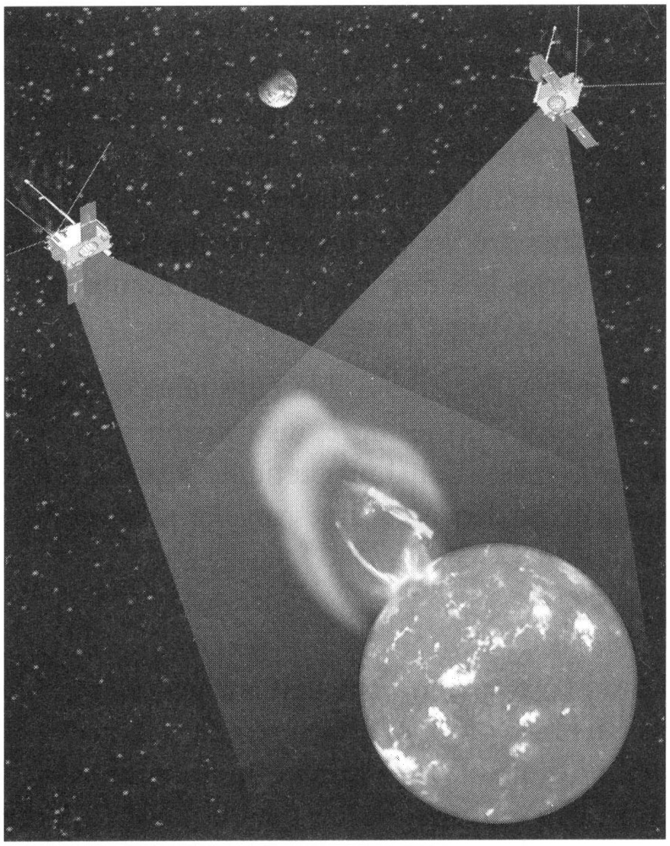
Solar-B will carry an x-ray telescope that is more sensitive and that has higher resolution than Yohkoh's. Its resolution of 2 arc seconds will match the best rocket images of x-rays and will be available on a minute-by-minute basis. To provide this resolution, its pixels will be half that size—1 arc second, about 2.5 times finer than Yohkoh's pixels. It will still view the whole Sun at the same time. One other improvement over Yohkoh is that it will be sensitive to the cooler, yet still million-degree coronal gas, whereas Yohkoh was optimized for the hottest gas from the corona or flares.

B's Ultraviolet

Solar-B will carry a spectrograph that works in the ultraviolet part of the spectrum. By scanning the spectrograph, the spacecraft will be able to make images of the Sun at any given ultraviolet wavelength in the covered range. It will also have a resolution of 2 arc seconds and should be able to see motions with speeds as low as 10 kilometers (6 miles) per second.

STEREO Views

We hope that Solar-B will be well situated in orbit when it comes time for NASA to launch its Solar-TErrestrial RElations Observatory, or STEREO. The mission got its name from the fact that it is actually a pair of spacecraft. Just as we humans get three-dimensional images because we have two eyes that look at an object from slightly different locations, the two STEREO spacecraft will look at the Sun from slightly different directions.



An artist's conception of the twin STEREO spacecraft viewing the Sun.

(JHUAPL)

Have you ever seen a 3D movie? Did you notice how there almost always is some time when an object appears to come quite far out of the screen toward you? The movie-makers' goal is to show off the 3D capabilities. Similarly to their methodology, the STEREO mission's pair of spacecraft are meant to observe things coming off the Sun toward us. The closer these things come to us, the more their angle will be different when viewed from the two spacecraft.

The ideal objects for such observations are coronal mass ejections, CMEs. We have said that SOHO has shown CMEs to erupt almost every day. With STEREO's sensitivity and good ability to measure distances, we should learn a lot more about CMEs and about how to predict their approach to Earth. We want to protect electrical lines, satellites, and other objects from the consequences of a massive CME hitting us, and STEREO should help us in this aim.

The general goals of STEREO are to figure out how CMEs form and what they can do to us and to the rest of interplanetary space. How do they move? How do they change over time? Coronal mass ejections are often preceded by extremely fast moving particles, which means that those particles have been given a lot of energy. How do the CMEs transfer energy to those particles?

STEREO consists of two spacecraft that will be launched on the same rocket. The spacecraft will be put in an orbit around the Sun at the same distance from the Sun as the Earth. But after a couple of months, engineers will use encounters with the Moon to put one of the spacecraft ahead of the Earth in its orbit and the other behind. Over months and years, the two spacecraft will drift farther apart. As they move farther from each other, their 3D visualization abilities will improve.

Each of the STEREO spacecraft will contain two coronagraphs for imaging the corona in visible light. Each will also be able to image the corona in front of the solar disk in the extreme ultraviolet. Additional instruments will study the space around the Sun, in part by making images and in part by directly measuring the particles that flash or drift by and the magnetic fields that the spacecraft encounter.

Activity Over Time

The Solar Dynamics Observatory, SDO, is another NASA mission that we hope for in the next half-dozen years. We hope that it will stay aloft in its Earth orbit for a good part of the solar-activity cycle. This cycle should reach its minimum in around 2005 or 2006 and its maximum in 2012 or so. It will monitor the magnetic field in particular detail, in the hope of finding the key to what triggers the changes in it that launch eruptions like flares and coronal mass ejections.

SDO's field of view will be broader than that of current spacecraft, so it will be able to image the entire visible disk in high detail at the same time. It will also often measure velocities over the entire disk as its helioseismological mission.

The spacecraft is also supposed to carry a wide variety of filters that will enable it to make high-resolution images showing all the levels of the solar atmosphere, an extension in wavelength availability and in resolution of the Extreme-ultraviolet Imaging Telescope that has been so successful on SOHO. It will also be able to take series of images at a very high cadence. SDO is scheduled to bear a coronagraph as well.

Furthermore, SDO will carry an instrument to monitor the total amount of radiation from the Sun in the extreme ultraviolet. We discuss such instruments that measure wide ranges or the totality of solar radiation in the Part 6 of this book.

Priority has been assigned, even at this early date, to getting a lot of data down from the spacecraft to Earth, given the high cadence of its very detailed imaging. It is thus planned for an Earth-synchronous orbit so that it will appear to hover over some point on Earth. To do so, it will be at an altitude of about 6½ Earth radii, the same altitude as all the Earth-synchronous satellites that bring us much of our television signals.

We hope that STEREO will be successfully sending back data from far to the sides of the Earth. So, SDO would add another observation point and help in making accurate 3D observations. At the same time, Solar-B should be providing the 3D magnetic field.

Solar Probe

To find out exactly what the Sun is doing, we want to get as close as we can. Of course, the Sun is very hot, so it is extremely difficult to get too close to it. Nonetheless, NASA has plans to do so. These plans have been canceled for financial reasons, reinstated, and then again put on hold. At this writing, I can't say whether Solar Probe will remain in the queue. It was originally supposed to be launched in 2007, travel via a gravity assist from Jupiter, and reach the Sun in 2010.

Plans are—or were—for Solar Probe to reach as close as 3 solar radii, or about 2,000 km (about 1,200 miles), above the solar photosphere. That is approximately 99 percent of the distance toward the Sun. The temperature there will be about 3,600°F (2,000°C).

By sampling the solar corona and the surrounding region as close to the Sun as possible, Solar Probe would obviously help understand the solar wind. In particular, some parts of the solar wind move away from the Sun much faster than other parts. The technical terms are the "fast wind" and the "slow wind." How does the solar corona that we see at eclipses and from spacecraft turn into the expanding solar wind? Solar Probe should also be able to see detail in the photosphere and in the corona that we just can't see from farther away. As with so many other experiments and observations of the Sun, a major goal is to figure out how the solar corona gets so hot.

A measuring instrument just can't go right up to the Sun because it would burn up or overload its sensors. The current design is to have a heavily shielded spacecraft, to keep the measuring instruments safe from the solar radiation. A mirror will move quickly out to the side of the spacecraft, in order to—one hopes—reflect a bit of bright sunlight into the instruments. Designing the survival of such a mission will be a major feat.

The Solar Scoop

Every 10 years, under the auspices of the U.S. National Academy of Sciences, a group of astronomers makes a prioritized list of the most important things to do to advance astronomy. This prioritization has proven to be an example to other sciences and has been well received by Congress and by the funding agencies. Although Solar Probe would be very expensive, the latest astronomy and astrophysics Decadal Survey has selected it as a high-priority "large" mission, given its mix of large and small missions.

Remote sensing—the technique of viewing from afar—is basically what astronomers do. But it is nice to get "ground truth" whenever we can. Comparing what we actually find in the Sun's lair with what we thought we saw from way back here on Earth should be very valuable.

The Longer Term

NASA's Sun-Earth Connection Program has a broad view of the various spacecraft above and has still more plans. Many are to investigate Earth's atmosphere and magnetosphere; we just choose not to go into them in this book. Others, more closely and directly linked to the Sun, are currently more interesting to us.

Solar Polar Imager

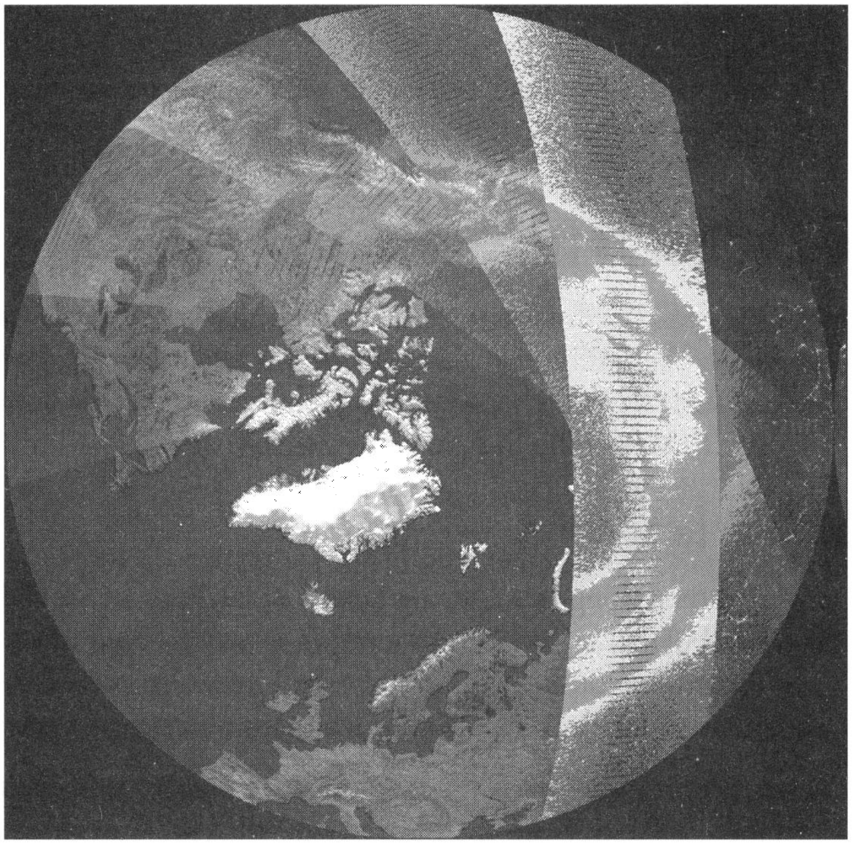
Even farther along the drawing board, or perhaps we should say the "dreaming board," is Solar Polar Imager. This spacecraft would go high out of the plane of Earth's orbit and look down on the poles. Only the Ulysses mission has sampled the regions above the poles so far, and that spacecraft doesn't carry any cameras.

The current plans for Solar Polar Imager is to have it orbit the Sun at about half the distance of Earth from the Sun. It will orbit the Sun three times each year—that is, its orbit will be to Earth's as 3:1. Its orbit will be very inclined, so from parts of its orbit it will be able to see the solar poles from a high angle. It is possible that Solar Polar Imager will be carried to its orbit by giant sails that pick up solar radiation rather than by the chemical rockets that we now use exclusively for spacecraft. The sails would have to be larger than a football field across, while still being very lightweight.

Though the final choice of instruments is years in the future, some ideas exist about what would be on such a spacecraft. In particular, we want to know better what the magnetic field is like near the poles and even just at a variety of relatively high latitudes on the Sun. Thus, a magnetograph is a priority for Solar Polar Imager. The spacecraft might also have instruments for helioseismology. Presumably, it would measure the velocities near the poles. Note that the Doppler effect allows us to measure only the part of the velocity of an object that is coming directly toward us or directly away from us. So up-down motions near the Sun's poles are perpendicular to our view, and we can't measure them. Solar Polar Imager would fill in that gap in our knowledge.

Not a Dodge in Your Future

Another spacecraft in the future is the Reconnection And Microscale (RAM) spacecraft. From its place in orbit around the Earth, it will take images of the solar photosphere and corona at very high resolution. The hope is that it can improve the imaging by a factor of 1,000.



The TIMED spacecraft, named for Thermosphere-Ionosphere-Mesosphere-Energetics and Dynamics. It is studying the region 60–180 km (40–110 miles) high, above the troposphere, where Earth's weather occurs, up to and including the lower ionosphere. It seeks to measure the variability of solar radiation and of Earth's response in this relatively unexplored region. TIMED was launched in 2001.

(NASA)

As of this writing, the hope is that RAM can image features as small as 10 km (6 miles) in the corona, compared with the 400-km (250-mile) or so lower limit of even TRACE. If it is 40 times better in each of two directions, that multiplies out to 1,600 times better overall, justifying the hoped-for factor of 1,000. It would reach 70 km (45 miles), about 1/10 of an arc second, for its spectroscopy in the extreme ultraviolet. It would measure the energy in individual x-ray photons to high accuracy, with a spatial resolution of about 700 km (450 miles), or about 1 arc second.

Of course, RAM will be useful only if there really are features that small. More theoretical work is necessary to find out the odds that details will continue to be seen as we get below features a few hundred kilometers in size. Current theory indicates that this size scale will indeed be useful to study the processes of magnetic reconnection.

Solar Orbiter

The European Space Agency eventually plans to launch a Solar Orbiter. At this early date, plans are for it to orbit about 80 percent closer to the Sun than Earth and to be launched by 2010. It would be at its closest to the Sun every five months. Its orbit would be inclined so that it could observe face-on the regions reasonably far out of the Sun's equator instead of seeing them at an angle.

Because of its location out of the plane of Earth's orbit, Solar Orbiter's visible and ultraviolet-sensitive cameras would contribute greatly to 3D observations of coronal mass ejections. Of course, its location would also make it a worthy successor to Ulysses in measuring particles as they go by as well as the magnetic field at high latitude.

Solar Orbiter will carry coronagraphs to work in both visible and ultraviolet light. It will also measure the solar magnetic field with a magnetograph. Another instrument will measure the Sun's total radiation from close up. It should receive about 25 times stronger solar radiation than we get on Earth.

If tests go well on ESA's earlier SMART-1 mission to the Moon in 2003, Solar Orbiter will use the same kind of electrical propulsion rather than chemical rockets.

Can We Do It?

All space exploration is very expensive, and NASA's priorities are not necessarily those of scientists. It is impossible to predict the funding situation a half-dozen years in the future. It is clear from recent years that bringing off missions within the assigned budgets is very important. Those treasuring the prospective science returns from the missions just discussed must hope that the budgets of the space agencies of the several countries involved are robust and diverse enough to include these solar missions along with their other priorities.

The Least You Need to Know

- Solar-B, from Japan, the United States, and the United Kingdom, is the next major solar mission.
- High-resolution imaging and 3D magnetic field measurements are key.
- Plans exist to go much closer to the Sun than spacecraft in orbit around the Earth or even 1.5 million km from it and to view from high solar latitudes.
- Learning about the processes and particles that most affect Earth is a priority.