Chapter 28

The Forecast Today Is Flares

In This Chapter

- The Sun flares up, linked with the sunspot cycle
- Solar flares are followed with telescopes on the ground and in space
- The corona burps regularly
- Solar telescopes often pick up comets near the Sun.
- Space weather affects the Earth

How's the temperature today? Will it rain? Will a rain of particles from the Sun make your radio go haywire? Should you bring your airplane down to lower altitude, or bring your astronauts back down quickly? In this twenty-first century, we must forecast not only weather near the Earth's surface, but also space weather.

How's the Space Up There?

Buck Rogers, Captain Video, and other early fictional astronauts moved easily around the solar system. But the solar system, outside the Earth's protective envelope, is a rough place. High-energy particles of light, including x-rays and gamma rays, and fast-moving particles of matter smack into whatever is up there. To function in space, we must be alert to *space weather.*

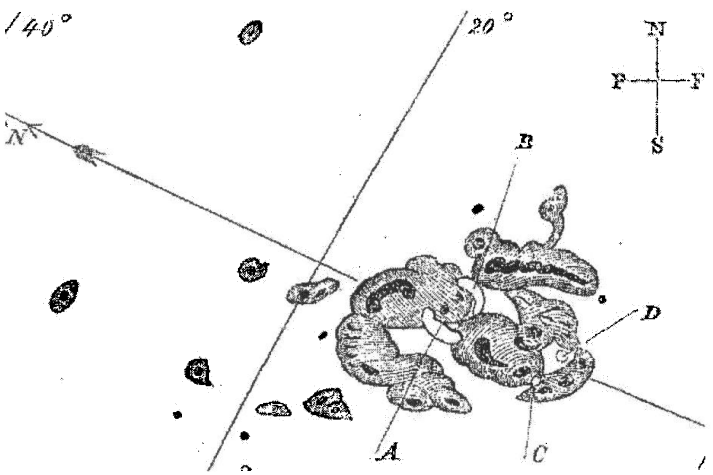
Sun Words

Space weather is the condition of space in the vicinity of the Earth as it is affected by particles and radiation from the Sun.

Sun Words

A **solar flare** is an abrupt brightening of part of the Sun within seconds, including the release of electromagnetic radiation and particles.

Our knowledge of space weather dates back to 1859. Then, the English amateur astronomer Richard Carrington noticed that a bit of the Sun's surface brightened abruptly. He was, in this way, the first person to see a *solar flare.* Carrington was observing in ordinary sunlight, with a projected image that cut down the overall intensity over direct observation. What he saw was a white light flare, and he reported that a large magnetic storm followed this flare. Scientists today still observe flares, but we mainly study them in other parts of the spectrum. They have long been monitored in hydrogen light in the visible part of the spectrum, and radio flares have also long been under study. In recent years, satellites have provided monitoring of solar flares in x-rays and gamma rays. Solar flares in white light are very rare; only about 50 have ever been seen.



Richard Carrington's 1859 observation of the first solar flare to be seen. He saw a brightening at points A and B that soon moved to points D and C.

(MNRAS)

Monitoring the Sun in hydrogen light, as has long been carried out at solar observatories, has provided movies of solar flares. In views looking downward at the solar disk, the brightening appears abruptly and spreads along magnetic field lines. The first brightening takes place in seconds, and the whole region may then remain bright for hours. When seen on the solar limb, flares explode outward into space. While some of its matter falls back, much of the matter is ejected from the Sun at high speed. The coronal mass ejections discussed in Chapter 23 used to be thought of as caused by flares, but the present view is that the ejection and the flare are both aspects of a large-scale rearrangement of the magnetic field in the corona.

A flare seen in hydrogen-alpha, the red line of hydrogen, from the Big Bear Solar Observatory. The material twisted as it rose, following the magnetic lines of force.

(BBSO/then Caltech/now NJIT)

Twisted Magnetism

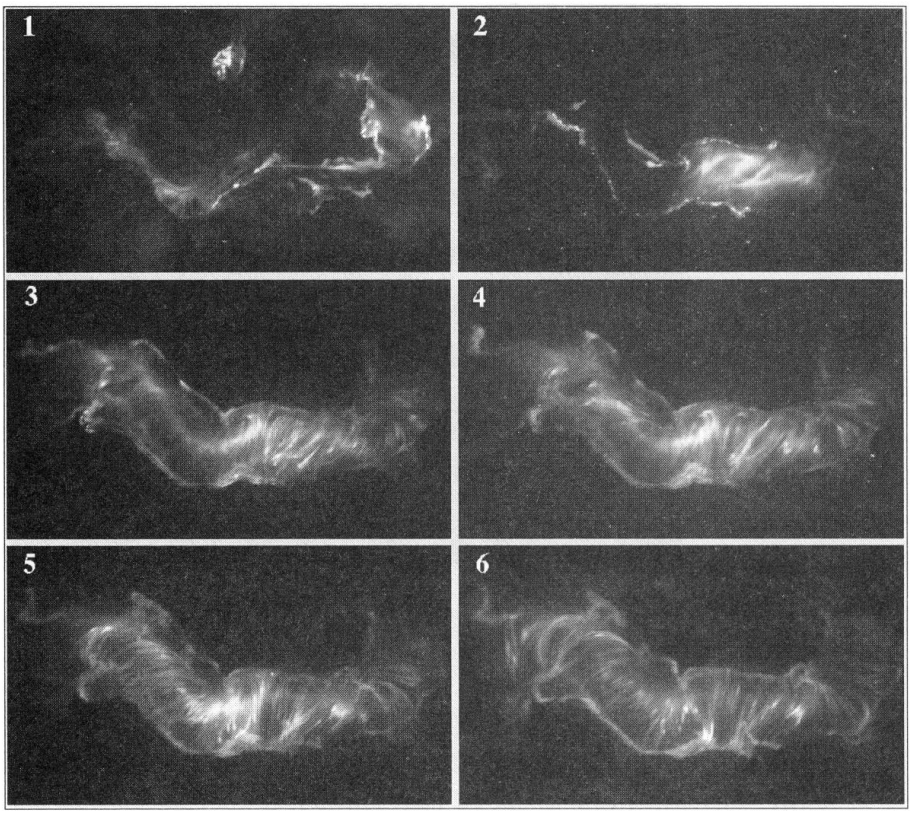
A single solar flare can brighten the solar output by as much as 0.1 percent within seconds. How does so much energy accumulate, and why is it released? More technically, astronomers speak of two things:

- The energy-storage mechanism
- The trigger

The frequency of flares varies along with the solar-activity cycle. Many more big flares occur at sunspot maximum.

Though the details of explaining flare activity are controversial, it is clear that the energy for a flare is stored in the Sun's magnetic field. The powerful magnetic field that is typical in sunspot regions keeps the matter restrained and allows the energy to build up. Then magnetic reconnection occurs. That is, the positive and negative polarities seek a new configuration with respect to each other. As they become connected in a different series, energy is abruptly generated and heats the corona to tens of millions of degrees.

We have already seen how scientists using the SOHO spacecraft discovered a magnetic carpet on the Sun of readily changing magnetic connections. The details of the flare changes can best be followed spatially with the TRACE spacecraft. TRACE observations show how the flaring begins at a particular location and then spreads over a wider region. The high resolution of TRACE, in particular, also shows how thin post-flare loops form.



The evolution of a flare as seen from TRACE, including the formation of postflare loops.

(Leon Golub, SAO, and Alan Title, LMSAL)

Particles ejected from the Sun in solar flares move so fast that they can reach Earth in hours. But x-rays and gamma rays formed as the flare begins travel even faster, since they move at the speed of light. They pass the 150,000,000 km (93,000,000 miles) in only eight minutes. On some spacecraft, such as Yohkoh, when an x-ray camera sensed a flare, it started other instruments recording at a higher cadence than normal.

X-ray observations are so important to flare studies that the current classification of flares depends on them.

- **X-class:** The flares with the strongest x-ray emission are X-class. They can lead to major geomagnetic storms and to massive disruptions of communications on Earth, especially when associated with coronal mass ejection directed toward the Earth.

- **M-class:** The medium-size flares, M-class, are less significant in general, though some particles from the Sun can arrive at the Earth, and minor geomagnetic storms or radio blackouts can occur.
- **C-class:** The smallest type of flares, C-class, doesn't affect us much on Earth.

These types are classified by the strength of emission in the range from 1 to 8 angstroms.

Flares are also classified by the area that they take up in H-alpha, from an importance of 4 for the largest flares in area down to an importance of 0. Optical flares are also classified by B for brilliant, N for normal, and F for faint. A huge flare, X-class in x-rays, might also be of importance 3B based on its optical appearance.

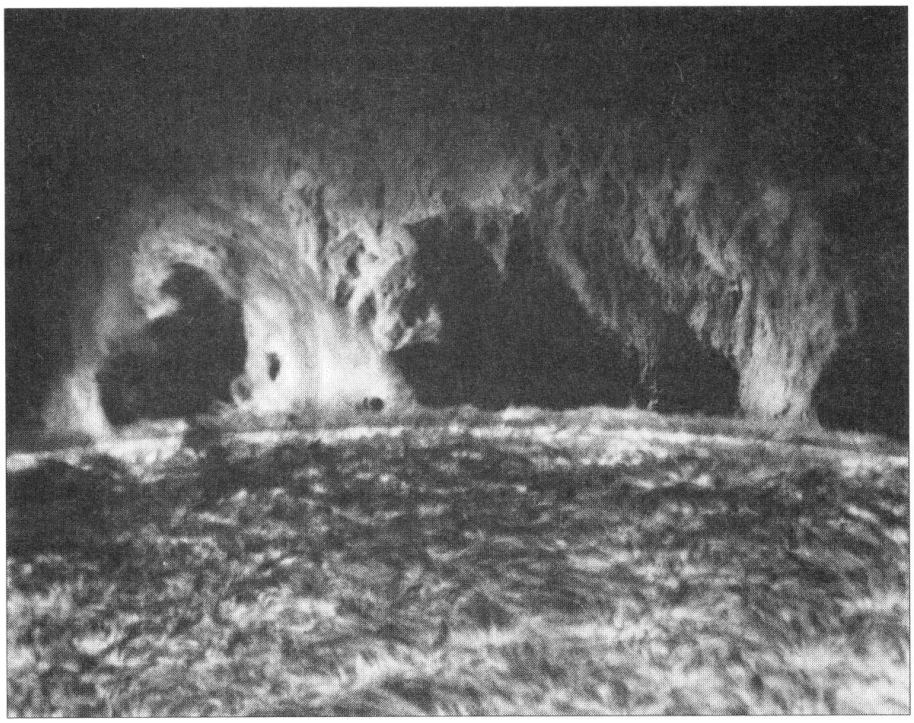
Flares are also monitored in the radio part of the spectrum. The radio comes through a window of transparency, so it can always be observed from Earth's surface. Links of radio telescopes like that at the Nobeyama Radio Observatory make images of the flares on the Sun. But a single flare makes so much radio energy compared with the radio background of the quiet Sun that flares can be monitored even without any resolution of details on the solar surface.

Flares and Other Eruptions

When you look at the limb of the Sun in the light of hydrogen-alpha, even without an eclipse, you usually see small regions sticking out. These are almost always prominences, gas at about the temperature of the solar chromosphere, approximately 20,000°F (10,000°C). Prominences look bright because we see them silhouetted against the dark sky. Likewise, when we look down on prominences, seeing them silhouetted against the solar photosphere, they look dark. These disk features are called filaments and run along the neutral line that separates opposite magnetic fields.

Prominences (and, therefore, filaments) can live for months. The longest lived of these quiescent prominences can be seen repeatedly each time the Sun rotates enough to bring them to the limb. But sometimes a prominence erupts. These eruptive prominences lift off the Sun, usually gently, and can extend millions of kilometers.

Just because you see something at the edge of the Sun, don't call it a flare. Too many people talk of the "flares on the Sun" when they really mean the prominences. Flares are much more explosive and powerful events than erupting prominences. Temperatures in flares reach millions and even tens of millions of degrees; they are much more impulsive than erupting prominences.



A large quiescent prominence at the limb of the Sun. Prominences can be seen with the eye as totality begins and ends at solar eclipses, or through hydrogen-alpha filters outside of totality.

(BBSO/Caltech, now NJIT)

Ejecting Matter

From time to time over the past 150 years, the corona at eclipses has seemed oddly asymmetric. Features appeared that didn't seem to extend radially outward. For a long time, these features were thought to be merely unusual and odd. Only since the launch of Solar Maximum Mission in 1980 was it realized that these coronal mass ejections (CMEs) are fundamental parts of the solar activity. Before this time, the ground-based coronagraphs didn't see out far enough above the Sun to realize that the ejections occasionally seen were so major or common.

Coronal mass ejections represent part of the corona drifting off into interplanetary space. They are carried by gently erupting magnetic field. Each coronal mass ejection carries perhaps 10 billion tons of matter into space at a speed that averages 400 km (250 miles) per second. The matter can reach Earth in days. The fact that the speed of the coronal mass ejection can increase as it gets farther from the Sun shows that it is controlled by the coronal magnetic field.

The Large Angle Spectroscopic Coronagraph (LASCO) set of telescopes on SOHO has proven especially valuable for studying coronal mass ejections. The telescopes show that at peak times of the solar-activity cycle, coronal mass ejections go off about every day.

LASCO on SOHO has discovered over 500 comets, which often appear in the same field of view as coronal mass ejections. One comet that hit the Sun was at first thought to lead to a splash of cometary material. It is currently thought that, given the common appearance of coronal mass ejections, a CME coincidentally occurred right after the comet hit. These coincidences were verified dramatically by the independent coronal mass ejection that occurred as a bright comet passed the Sun in the LASCO field of view in 2003.

For decades, scientists have assumed that solar flares—seen shining brightly on the Sun, at least in hydrogen light—caused the magnetic storms on Earth that we discuss in the following section. But in recent years, we have realized that coronal mass ejections are also major contributors to geomagnetic storms.

Indeed, a debate has raged over whether coronal mass ejections are begun by solar flares. The evidence is ambiguous, though I would bet that the resolution of the discussion is that the link is not always there. Sometimes CMEs can erupt without a specific flare occurring.

Usually, we notice coronal mass ejections when the gas sticks out to the side. That is, the eruption is in the plane of the sky, from our point of view. But occasionally, a halo event occurs. In these halo events, we see fairly uniform brightening around the space coronagraph's occulting disk. This symmetry tells us that the coronal mass ejection is pointed at us. Now, the magnetic field in interplanetary space curves around, so even coronal mass ejections that go off to the side can still hit us. But the halo events seem particularly relevant to magnetic storms on Earth.

Coronal mass ejections are important not only for where they are going, but also for where they have been. By carrying magnetic flux away from the Sun, they affect the underlying solar activity. They leave the lower levels of the Sun with a weaker magnetic field.

Space Weather

For thousands of years, people have looked up at the night sky and occasionally seen aurorae. The aurora borealis is the "northern lights," the patterns of glowing atmosphere caused by incoming particles from the Sun. The aurora australis is the similar phenomenon in the southern hemisphere. The aurorae are perhaps the best known type of space weather.

Space weather is the condition of space between the Earth and the Sun, with x-rays and gamma rays flashing by at the speed of light and high-energy particles from the Sun making their way more slowly. Just as people on Earth can skid off the road when

The Solar Scoop

Auroras have been seen on Jupiter and on Saturn, as well as on Earth. When an aurora occurs in one hemisphere, it occurs in the other hemisphere as well. Particles from the Sun are funneled down into the atmosphere symmetrically along magnetic lines of force to circles around both poles.

the weather on Earth is bad, satellites and people in space can be affected or harmed by space weather. The United States' National Oceanographic and Atmospheric Administration (NOAA) has stepped up its forecasting role and its study of the factors that go into space weather.

Some of space weather is the result of the normal solar wind. A correlation has been established between the presence of coronal holes on the Sun and geomagnetic storms, disruptions of the Earth's magnetic field. Since coronal holes represent open field lines at the Sun, the solar wind is relatively free to escape there.

But more violent actions take place with coronal mass ejections and solar flares. Flares have long been known to affect communications on the Earth. Static that occurs soon after flares can wipe out contacts. A lot of research, both military and nonmilitary, has focused on predicting the occurrences of flares. No definitive predictor has ever been found, though astronomers continue to look at some particular configurations of the magnetic field. Astronomers are better at predicting when there will be no flare. If the Sun looks quiet and the sunspot regions are docile and nicely arranged with one polarity on one side and the other polarity on the other side, a solar flare is unlikely. But if you see a jumble of polarities, reconnection and a flare are possible, even though we can't predict just when this would occur.

Coronal mass ejections are so substantial that they batter the Earth's magnetosphere and upper atmosphere. During the solar maximum of 1980, there were few satellites in space to be bothered by coronal mass ejections, but by 1990 there were dozens. And in the most recent solar maximum, around 2001, hundreds of space satellites were vulnerable to coronal mass ejections. Indeed, soon after one halo event occurred, one of the communication satellites went dead. Though nobody has been definitive about it, it sure looks as though there is a link between that dead satellite and the coronal mass ejection.

Even a few minutes' notice of the arrival of solar particles can allow safety measures to be taken. For example, high voltage on satellites can be diminished, making it less likely that the satellites would be disabled. Solar storms reaching the Earth can also cause fluctuations in power lines, sometimes tripping circuit breakers. A few minutes' notice to electric utilities can be helpful here, too.

Astronauts in space shuttles are vulnerable to high-energy radiation. Too much of it can lead to radiation sickness. Predicting when a storm of solar particles will arrive

might allow astronauts to retreat into the most ked regions of their spacecraft. The prediction of a major storm might even lead to the abortion of a crewed mission for the protection of the astronauts.

It has gotten easier to monitor space weather from your own home. Many people check www.spaceweather.com on the web. The site is controlled by NOAA, which also sponsors the Sun-Earth Connection (SEC) site at sec.noaa.gov. In addition to general astronomy news, spaceweather.com shows what the Sun looks like recently as seen through many different filters. It shows sunspots on both the near side of the Sun and, newly, the far side. It tells you about coronal holes, solar flares, and geomagnetic storms. And it often gives a prediction of the likelihood of an aurora. So you might add spaceweather.com to, perhaps, weather.com whenever you go outdoors—or if you are responsible for communications or television relay satellites.

Our Sun is our friend, but it can turn on us. We study the Sun both to love it and to fear it. A panoply of telescopes on the ground and in space—ranging in wavelength coverage from gamma rays to radio waves—is there to protect us and to help us learn about our nearest star and its relation to our home planet.

Solar Scribblings

Space weather may be a limiting factor in sending people to Mars. Though our Apollo astronauts reached the Moon in four days, the trip to Mars is much longer and will take years. Astronauts could be harmed by particles from flares or coronal mass ejections during that period.

The Least You Need to Know

- Solar flares are abrupt explosions on the Sun, often reaching tens of millions of degrees.
- Coronal mass ejections carry huge amounts of matter into interplanetary space.
- Coronal mass ejections can coincidentally occur when comets are seen near the Sun.
- Space weather can easily be followed online.