PROLOGUE

The Dog Years

They say that dogs age seven times faster than humans. No one is more aware of this than the men and women in charge of an aged electronic watchdog that fights a daily battle against decrepitude in the name of science. The Solar and Heliospheric Observatory, known universally as SOHO, is an electronic beast stationed 1.5 million miles away, in one of the most hostile environments any spacecraft has ever been expected to inhabit. Here, SOHO is perpetually bombarded, not just by light, heat, and X-rays from the Sun, but also by a wind of smashed atoms hurled outwards by the unpredictable solar forces.

Had this watchdog been a flesh-and-blood animal, the onslaught would long since have triggered the deathly creep of cancer. In the machine world, the equivalent is an inexorable degeneration as the subatomic bombardment gradually eats away at the spacecraft's electronic organs. By 2003, after nearly eight years in space, SOHO had lost the use of certain cameras and other electronic systems. Its antenna would not point straight anymore, and its ability to harvest sunlight for power was down nearly a fifth. Yet it soldiered on, constantly monitoring the Sun's boiling surface for clues that might one day solve a century-and-a-half-old mystery: why enormous explosions occasionally plague the Sun. And more importantly, how they affect us when the Earth accidentally gets in the way of the blast.

The Sun is the heart of our solar system. It is an enormous sphere of gas, over a hundred times the diameter of the Earth. Its surface temperature is 6,000 degrees Celsius; its center is at well over 10 million degrees. Its gravity guides Earth and the other planets through their orbits; its warmth provides the lifeblood of energy for plants and animals on Earth. Also like a heart, the Sun pulsates. This is not a visible movement but rather a gradual buildup in strength and subsequent weakening of the giant magnetic bubble that emanates from within the Sun and surrounds all the planets. As befits a celestial body of some 4.6 billion years in age, each one of these magnetic heartbeats takes a leisurely eleven years, or thereabouts, to complete.

So, in the average career of a scientist, he or she can expect to see this happen four times. This makes understanding the Sun as difficult as a biologist trying to deduce the life cycle of an unknown creature by observing it just long enough to witness four beats of its heart. As a result, solar astronomy is a multigenerational science. Each new cohort works to build a finer legacy of observations for those yet to come.

No one knows when that body of evidence will be rich enough to provide the necessary insight, or when technology will be mature enough to provide the final incisive observation. Each new generation of astronomers works with the same ambition that drove their scientific forebears: that they might be the ones who finally understand the Sun. When the Sun entered an intense bout of activity in 2003, SOHO's astronomers realized they had been given the chance of a lifetime—if their spacecraft could survive.

During October and November that year, the Sun was wracked by a succession of explosions known as solar flares, the most powerful events that can take place in the solar system. A solar flare dwarfs the power of an atomic bomb, and during the fourteen days spanning the Halloween period, some seventeen of them erupted across the Sun. Each one triggered a powerful "sunquake" and smothered SOHO with a burst of debilitating radiation. Some of them also triggered major eruptions that each spewed billions of tons of electrified gas into space, pummeling anything that got in the way, be it the tiny SOHO spacecraft or the entire planet Earth.

Scientists looked on, suffused with a cocktail of excitement, awe, and dread. No one knew how long SOHO could survive under normal circumstances; under these conditions it was anyone's guess. SOHO's masters could do little but hope for the best as they sat in their offices at NASA's Goddard Space Flight Center (GSFC) in Greenbelt and watched their spacecraft receive the worst punishment of its life.

Just a few weeks before, there had been no hint of such activity on the Sun's boiling surface. In fact, it was so quiet that scientists were beginning to think that it had settled into one of its periodic dormant phases. Then the Sun began to quake.

SOHO picked up this solar heart murmur in early October and scientists began searching for its cause. They could find nothing on the visible face and so concluded that something on the far side was hurling shock waves right around the Sun. They had no choice but to wait for the Sun's leisurely rotation to bring whatever it was into view.

On 18 October they spotted a darkened patch near the eastern edge of the Sun. It was barely visible at first, little more than a small blemish. Twenty-four hours later, it had swollen into an ugly bruise, seven times larger than the Earth. It was a giant sunspot. Sunspots appear from time to time, although they are usually much smaller than this monster. They are caused when knots of magnetism burst from the Sun's interior, cooling the surrounding gas and making it appear dark in comparison to the rest of the solar surface. Oriental astronomers made the first observations of sunspots thousands of years ago, spotting them with the naked eye when the Sun passed behind light cloud or fog banks.

Astronomers now know that flares often explode above sunspots, and it was not long before this particular sunspot let rip. The first Halloween flare took place above the engorging spot on 19 October. Its blast of radiation almost immediately blacked out radio communications for about an hour on the sunlit side of the Earth. Undiminished by the outburst, the sunspot continued to grow and the Sun continued to quake. Therein lay a puzzle. This particular sunspot had been almost negligible when the scientists had first seen it, yet the Sun had been quaking long beforehand. Could that mean another, already fully formed sunspot was on its way?

Suspicions were confirmed on 21 October when SOHO transmitted the next in its never-ending sequence of images that updates every fifteen minutes. To one side of the Sun, scientists could see the aftermath of a large eruption that had taken place just beyond view, over the Sun's eastern horizon. The eruption took the form of an expanding cloud of hot gas heading off into space. Subsequent images that day revealed a second outburst of seething gas from the same location. There had to be another huge sunspot edging round from the far side. The scientists estimated that the Sun's rotation would drag it into view within the next few days.

In the meantime, they still had the first giant to watch. On 22 October, it flared once again, and this time the explosion triggered its own eruption of solar gas. Larger than a planet, the gaseous eruption contained a hellish cocktail of particles, most of them electrically charged and all of them at a few million degrees Celsius, about ten thousand times hotter than the air in a kitchen oven. As scientists watched the expanding cloud of gas head off into space, they realized that some of it would touch the Earth.

Whereas light and X-rays from a flare cross the 93 million miles separating us from the Sun in just 8 minutes, each lumbering eruption of particles takes between eighteen and forty-eight hours to arrive. As the time of impact approached, astronauts Michael Foale and Alexander Kaleri hunkered down in the International Space Station's most heavily shielded module to escape the deadly storm. Airlines instructed their pilots to reduce altitude in the hope that the Earth's atmosphere would protect the passengers and crew from higher than usual doses of radiation. They also directed flights away from polar routes, which research suggests are the most vulnerable to high radiation doses during solar storms.

About half an hour before the storm struck Earth, it swept over SOHO, blinding the cameras and building up electrical charges that threatened to short-circuit the sensitive equipment. SOHO survived, but not every satellite was so fortunate. The first electronic casualty was the Japanese Space Agency's Midori 2 weather satellite, which fell silent during the bombardment and has not been heard from since. Other satellites temporarily malfunctioned or shut themselves down to await resuscitating messages from ground controllers.[1]

At the surface of the Earth, there were few reported problems although sky watchers noticed auroras glowing in the sky. These natural

[1] Often, this was because the solar storm temporarily blinded spacecraft navigation devices. These little cameras, called *star trackers*, watch the stars, allowing a spacecraft to know which way it is pointing. Cut off the star tracker and the spacecraft has no way of knowing which way is up. To protect it from firing thrusters in all directions to try and correct its perceived balance problems, the spacecraft renders itself unconscious and waits for a wake-up call from Earth when the danger has passed.

The two sunspot groups responsible for the Halloween flares of 2003. Each group is about ten times the diameter of the Earth. (Image: NSO/AURA/NSF/Bill Livingston)

light shows are caused by solar particles colliding with the molecules in our atmosphere. They usually take place close to the Earth's north and south poles, and their intensity is recognized as a barometer for measuring the activity of the Sun. During Halloween 2003, the phantom glow of the auroras lit the sky many times.

As the Sun rotated, the sunspot continued to pump out volley after volley of electrified matter. With each shot it came progressively closer to striking the Earth a direct blow. By 26 October, the sunspot had grown to more than ten times the diameter of the Earth, making it the largest for over a decade—and it wasn't alone anymore.

The second sunspot had finally slid into view around the Sun's eastern edge, and it more than equaled the first in size. To see one giant sunspot was awesome, to see two was frightening. To herald its arrival, the second twisted knot of magnetism let loose a massive flare, blacking out some radios. Not to be outdone, the original sunspot erupted as well.

And so it continued. Each new day brought a new flare and eruption. It was no longer a case of whether the Earth would be hit, merely how strong the blast would be.

On 28 October, scientists' worst fears were realized. As the original sunspot drew in line with the Earth, it exploded with the most powerful flare yet. Fifty billion times the energy of an atomic bomb was released, resulting in almost immediate communications failures across the world. The worldwide marine emergency call system became inoperable for forty minutes, contact was lost with expeditions on Mount Everest, and faltering radios hindered crews fighting forest fires in California. Ten times farther into space than the Earth, NASA's Cassini spacecraft was orbiting the ringed planet Saturn. It, too, received a blast of radio waves, let loose by the flare.

Not only this but the flare triggered an enormous solar eruption, sending a billion tons of million-degree gas careening into space, straight at SOHO and the Earth. This was too much even for the data-hungry scientists. They commanded SOHO to switch to a low-power "safe mode," turning off the vulnerable equipment. To continue operations in the face of this new eruption would be the scientific equivalent of flying a kite in a thunderstorm with piano wire instead of string to keep control. So they closed the spacecraft's eyes and concentrated instead on simply keeping it alive.

When the storm arrived at Earth, it was ferocious. The solar flare had rocketed the eruption into space at an amazing 2,300 km/sec. (1,440 miles/sec.) As a result, the electrified gases took just twelve minutes to collide with Earth after crashing past SOHO.

Again, Earth-orbiting satellites began to behave erratically. Airlines hastily rerouted flights, instructing all aircraft to drop below the line of latitude that runs from northern Scotland, across Hudson Bay to the lower tip of Alaska, and through Russia (57 degrees north). As air traffic controllers imposed these restrictions, delays began to mount up at airports. Flying altitudes were lowered to below 25,000 feet and the additional fuel needed to plough through the thicker atmosphere soon ran up a price tag of millions of dollars.

As the particles battered the Earth's natural cloak of magnetism, erratic currents surged along northern power lines, eventually damaging power stations and blacking out fifty thousand people in Sweden. In the United States of America, power was reduced at two New Jersey nuclear units for fear they would be damaged by the power surges. Magnetic compasses swung wildly back and forth as the electrified gases that had once been part of the Sun now assaulted our planet.

As the storm abated, the sunspot fired another similarly sized barrage at Earth. Indeed, as October became November, flares and eruptions repeatedly disrupted the Earth. During this time, radio communications simply could not be relied upon, satellite television reception became patchy, mobile phones ceased to work in some countries, and the Global Positioning System (GPS) gave inaccurate readings. It was the stuff of high-drama techno-thrillers, and, as word spread across the Goddard Space Flight Center, unrelated workers would daily pop into the SOHO offices to check on the progress, both of the spacecraft and the terrible assault on Earth.

Eventually, the situation began to quieten down as the first sunspot disappeared from view over the western edge of the Sun, leaving only the second spot in view. It was about now that cameraman Ed Harriman framed a picture of the setting Sun over war-torn Baghdad as part of a documentary about the eight-month-old war. His picture caught the Sun setting behind the palls of smoke and pollution drifting across the defeated city. When he played the tape back he saw something on the face of the Sun that he had failed to notice at the time. It was the second monstrous sunspot, clearly visible on the face of the Sun. SOHO continued to watch the remaining sunspot too, as it slid across the face of the Sun and headed back to the far side. But one big surprise was still in store.

On 4 November, spacecraft again saw a solar flare erupt from above this spot and throw a massive tract of solar material into space. The X-ray monitors on several spacecraft rose until eventually they overloaded. Although they could not put an immediate figure on the outburst, the waiting scientists were certain of one thing: this was the most powerful solar flare in the cycle yet, possibly the most powerful ever recorded. As they worked with the data collected before the instruments saturated, the numbers seemed too wild. After double and even triple checks, however, there was no escape from the fact that this flare was at least twice as powerful as the one that had caused such havoc the week before.

Astronomers tracked the eruption and held their breath. If it were to strike the Earth, untold damage could be done to satellites, power stations, and other forms of technology. Radiation levels inside high-altitude airliners could reach extreme levels.

Thankfully, taking place on the Sun's horizon, the explosion was not directed toward Earth, and the eruption hurtled into deep space. Earth was caught only in the side wash, with relatively minor disruption.

There could be no complacency about this good fortune. No one had done anything clever or heroic; it had simply been a lucky escape. In the ensuing weeks and months many wondered what would have happened if such a massive solar storm had directed its full force at Earth.

The answers lie buried in the historical records of around 150 years ago. . . .