A long-awaited satellite should find scores of gamma ray bursts, sparking a rapid response from telescopes that span the globe

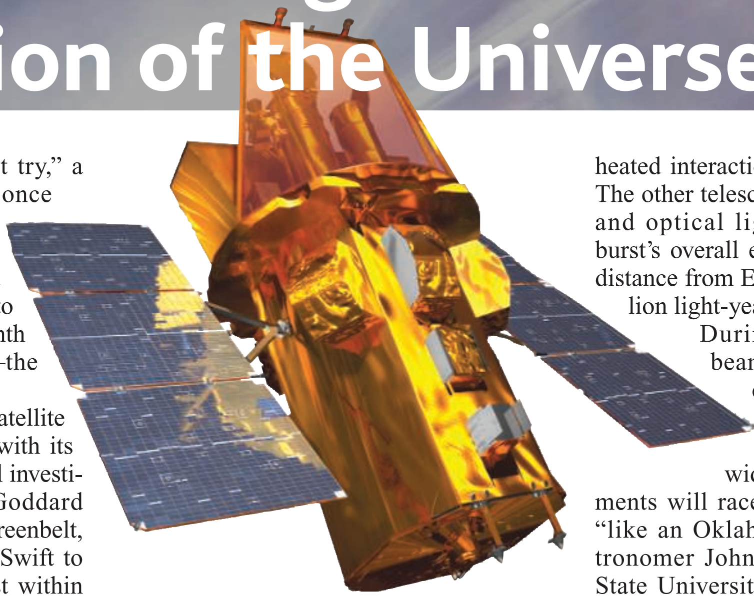
Astronomers Eager for a Swift New Vision of the Universe

"Swifts fly expertly on their first try," a writer for *National Geographic* once observed about the graceful, darting birds. Astronomers trust that those words will hold true for a satellite called Swift, which hopes to start flitting around space next month in search of gamma ray bursts—the biggest explosions in the universe.

"This is the first astronomical satellite that can rapidly change direction with its own onboard brains," says principal investigator Neil Gehrels of NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. That agility will allow Swift to swivel its "eyes" onto a new burst within minutes. What it "sees" should yield insights about the earliest incandescent moments of each explosion, thought to arise from especially violent supernovas that form black holes at their cores.

The satellite also will send notice of every burst to a fleet of telescopes on the ground, from robotic instruments that respond in seconds to the planet's most powerful telescopes. The unprecedented reach of this network promises to lift the veils on what drives the tightly beamed blast waves.

"Swift will take us from burst-by-burst science to very deep studies using hundreds of bursts," says astrophysicist Joshua Bloom of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. Bloom hopes that Swift's most distant bursts will let scientists peer back to the first few hundred million years of cosmic history: "The early universe may have been a ripe petri dish for making what we think were the first gamma ray bursts. They are our best hopes for probing this very hot era in cosmology."



Bird's eye. Swift will pivot in orbit to view evanescent gamma ray bursts.

BAT's eyes

The $250 million mission, a collaboration between NASA and institutions in Italy and the United Kingdom, was scheduled to take flight in December 2003 before several delays—most seriously, a 5-month overhaul of electronic components to make them more resistant to radiation. Recent damage to Florida's Kennedy Space Center from hurricanes Frances and Jeanne then pushed the launch from September to early November.

The mission features a compact assembly of three telescopes. Swift will catch gamma ray bursts with its Burst Alert Telescope (BAT), which Gehrels calls "the most sensitive gamma ray imager ever." Like someone staring upward to watch for meteors, BAT's gaze will encompass a large swath of the heavens (about 1/6) at any one time. An array of 32,768 cadmium-zinc-telluride detectors, covering a half-meter square, will register electronic blips from incoming gamma rays.

Because gamma rays are so energetic, they would pierce through the optics of a traditional telescope. Instead, BAT will interpret a geometrical pattern created by a "coded aperture mask": a screen above the detectors with randomly placed square lead tiles. "A burst from a particular point on the sky will cast a unique shadow [through the tile pattern] onto the detectors," says astrophysicist Craig Markwardt of GSFC. The satellite's software will calculate the location well enough for Swift to reorient itself toward the burst within about a minute.

After the adjustment, the satellite's two other telescopes will zero in on the burst's rapidly changing cascade of energy. One telescope will gather x-rays to scrutinize the burst's internal chaos and its super-heated interaction with material around it. The other telescope, sensitive to ultraviolet and optical light, will help gauge the burst's overall energy and its approximate distance from Earth—typically, several billion light-years.

During each step, Swift will beam the burst's location and characteristics to the ground for e-mail flashes to astronomers worldwide. With each alert, instruments will race to that parcel of the sky "like an Oklahoma land rush," says astronomer John Nousek of Pennsylvania State University, University Park, site of the mission control center. "All scientists will get all of the information as fast as is robotically possible."

The rush could happen often: Mission scientists estimate that Swift will spot 100 to 150 gamma ray bursts a year. But its two research telescopes aren't likely to observe the first critical seconds of many explosions. The sun, moon, or Earth could be too close for a safe view, and the satellite's pivot speed will be too slow to catch the initial flare for all but a few events.

Ground patrol

For the fastest response, the Swift team will rely on automated telescopes now deployed across the globe. Teams on six continents have built small new telescopes or have adapted larger existing telescopes to respond to Swift's electronic prompts—often within mere seconds. The web of ground teams, 39 and counting, will compose the most sweeping coordinated response to a satellite's observations. "It's become a cottage industry," says astronomer Kevin Hurley of the University of California, Berkeley, who coordinates the follow-up effort. "Everything is now in place to reap all of the benefits of studying bright new sources that last only a half-day or so."

One such ambitious project is the Robotic Optical Transient Search Experiment (ROTSE), which has identical autonomous telescopes in Australia, Namibia, Turkey, and Texas. At least one of the 0.45-meter telescopes should be able to zip to a Swift

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position in less than 10 seconds. That's an advantage because efforts to track a burst's optical or infrared emissions from the ground must take place at night. "With apologies to our British colleagues, the sun never rises on the ROTSE array," quips astronomer Donald Smith of the University of Michigan, Ann Arbor.

Similar efforts in California, Chile, Europe, Hawaii, Japan, and elsewhere will provide global coverage of any given burst as Earth rotates. Even well-equipped amateur astronomers could provide useful results, says Hurley. But everyone expects the squadron of automatons to have growing pains. "These robotic telescopes are incredibly hard to operate and to keep running," Smith says. "It's like Whack-a-Mole: As soon as you fix one thing, something else pops up."

Provided that some of the robots work as advertised, astronomers expect to see the first fires of gamma ray bursts more clearly than ever. That's critical for unraveling what happens at the heart of a titanic supernova, says astronomer Derek Fox of the California Institute of Technology in Pasadena. "At very early times, you observe the blast wave a short distance from the central engine," he says. "The later you look, the less memory it has of the initial explosion."

Although the robots will have the best shot to catch a burst's first sparks, the world's largest telescopes will join the act, too. Plans call for one of the 8.2-meter telescopes of the European Southern Observatory's Very Large Telescope array in Chile to swing to a new burst within 15 minutes or so, when feasible. One of the 10-meter Keck Telescopes in Hawaii will respond to some bursts as well. These mammoth mirrors gather so much more light than other instruments do that they will nail down the distances to the explosions—especially the faintest ones near the edge of the observable universe.

Gamma Ray Bursts: New Cosmic Rulers?

One class of stellar explosions, called type Ia supernovas, erupts with surprising uniformity. They probably arise from white dwarfs that explode when they exceed a well-known threshold of mass. By correcting for subtle variations, astrophysicists turned the supernovas into "standard candles": cosmic light bulbs of similar brightness (*Science*, 24 November 1995, p. 1295). That property has made type Ia supernovas the premier probes of the accelerating expansion of space, one of astronomy's landmark finds in recent years.

At first glance, it seems unlikely that gamma ray bursts could serve the same purpose. Gigantic spinning stars—the favored progenitors of gamma ray bursts—have wildly varying masses, spin rates, heavy elements, and other properties. When the stars die, those factors apparently spawn bursts whose energies vary as much as 100,000 times from one burst to the next.

But astrophysicists have found a physical pattern hidden within that drastic range. Each burst churns out light that peaks at a unique frequency. A spectral plot reveals that crescendo as a bump in the number of photons at that energy. Each burst also has a total output of energy: its "wattage." For the best-studied bursts, researchers can derive that output by accounting for whether the explosion channeled its emissions toward us along a needlelike cone or a wider spray (*Science*, 30 November 2001, p. 1816).

Those two quantities—peak frequencies of energy and total energy—are tightly correlated for gamma ray bursts, according to astronomer Giancarlo Ghirlanda of the Brera Observatory in Italy and his colleagues. "There is a very small scatter. It convinces us that something significant is going on," Ghirlanda says, although theorists have no idea why the relation exists.

Still, the correlation is so striking that just 15 gamma ray bursts already reveal the mass content of the universe and its expansion nearly as well as type Ia supernovas and other techniques, Ghirlanda says. His team confidently calls gamma ray bursts "new rulers to measure the universe" in the 20 September *Astrophysical Journal Letters*. A team from Nanjing University in China, led by Zigao Dai, reached a similar conclusion.

Other astrophysicists are wary. A couple of noteworthy bursts don't fit the correlation, and the overall statistics are still shaky, say CfA astrophysicist Joshua Bloom and graduate student Andrew Friedman. "The biggest problem is the small number of bursts so far," Friedman says. Swift's cornucopia of bursts should settle the debate, both sides agree.

–R.I.

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Coded pattern. A lead-tile mask will cast a unique gamma ray shadow on Swift's detector for each burst.

The deepest probes?

Indeed, the prospect of detecting such faint bursts is the stuff of dreams for astrophysicists. Currently, quasars—the active cores of galaxies, powered by supermassive black holes—are the brightest steady sources that astronomers can see in the young universe. These reach back to within about 1 billion years of the big bang. But in its first 20 minutes of raging energy, a gamma ray burst is 1000 times brighter than any quasar, says Bloom of CfA. "We may see when the first stars were dying," Bloom says. Such a burst, far earlier than the quasar era, would illuminate all other matter between it and Earth to give astronomers the deepest possible cosmic probe.

But it's not clear that the universe's earliest stars actually unleashed gamma ray bursts. Such stars were different beasts, with virtually no heavy elements and perhaps far more mass than later generations. If Swift sees no bursts within the first few hundred million years after the big bang, it will have revealed something fundamental about how those stars lived and died, Bloom notes.

Another profound riddle that Swift may address is the origin of the shortest gamma ray bursts. A whole class of bursts flashes for fractions of a second, then vanishes (*Science*, 30 November 2001, p. 1817). Astrophysicists speculate that these events might arise from something never before observed, such as two neutron stars crashing together. "We're all really curious about what these are," says Hurley. "No one has found a [glowing remnant] yet." If Swift can do that, it may open a new window on the violent universe.

With such rewards ahead, the Swift scientists are itching to fly. "It will be like waiting for the next firework to go off on the Fourth of July," says Nousek of Penn State. "It's going to be a treat."

–ROBERT IRION