Astrophysics

Robotic Telescopes Catch Up With Gamma Ray Bursts

Optical flashes spotted just minutes after two bursts portend a bright future for understanding the universe’s most violent explosions

Robots still can’t master the mundane—like mowing the lawn or washing your socks—but they can pull off some spectacular feats. Astronomers have trained robotic telescopes to sweep the skies in one of the field’s most glamorous pursuits: the hunt for gamma ray bursts (GRBs), brief but enormously powerful blasts of high-energy radiation from deep space. Now, after years of unrealized hopes, the automatons have come through—with surprising results.

Reports this week describe two GRBs spotted late last year by an x-ray satellite, which beamed the locations of the bursts to an Internet-based alert network on the ground. Within minutes, rapidly pivoting optical telescopes photographed fiery “afterglows” of lower energy visible light, created as shock waves from the bursts reverberated through space. The events—just the second and third ever seen so quickly—have thrilled experts by revealing one unusually persistent fireball and illuminating the brief life of another that otherwise would have passed unnoticed.

“These are about as different as you could possibly imagine two bursts being,” says astrophysicist George Ricker of the Massachusetts Institute of Technology (MIT) in Cambridge. “People now realize how much can be done in the first few minutes” to explore those differences, he says.

Theorists believe that so-called long GRBs—those lasting a few seconds to a few minutes—arise within ferocious beams of particles and energy spawned when a massive spinning star collapses to form a new black hole, which swallows most of the star. Models predict that such a “collapsar” spits out narrow jets that explode into space along the star’s axis. Gamma rays stream from turbulence within the jet itself, the theory holds. “These should be the fastest bulk motions in the universe,” says astrophysicist Bing Zhang of Pennsylvania State University (PSU), University Park. Only the small fraction of explosions with jets aimed directly at Earth would appear as GRBs; the rest might look like ordinary supernovas.

According to the currently reigning model, GRB afterglows arise when a jet hits gas or dust in space near the burst. A violent “reverse shock” cascades back into the jet itself and sparks a flash of optical light that quickly expires, says astrophysicist Peter Meszaros of PSU. The leading edge of the jet then keeps plowing forward, spewing x-rays and optical light as it gradually slows down during the next hours and days.

“Not fadeaway. An October burst (red curve) dimmed far more gradually than two other rapidly detected afterglows.”
but we have needed more detail about its initial evolution,” says astrophysicist Andrew MacFadyen of the California Institute of Technology (Caltech) in Pasadena, a creator of the collapsar scenario. That’s because the jet moves fastest during the earliest phases of the afterglow, opening the clearest window onto the central engine that powers it.

Not long ago, such early detections seemed set to become routine. Several groups of astronomers built small robotic telescopes to monitor wide swaths of the sky, often several times a night, in a quest for rapidly varying or moving objects. Programmers designed the systems to interrupt their scans if they received an Internet alert from NASA’s Compton Gamma-Ray Observatory (CGRO) or the Dutch-Italian BeppoSAX satellite. Most systems weren’t cheap—typically $250,000 in hardware costs and perhaps four times that for the complex software needed to control them. Still, astronomers knew there was no other way to ensure a rapid GRB follow-up on the ground, because big telescopes can’t whip to a random spot on the sky that quickly.

The first sighting was spectacular. On 23 January 1999, the Robotic Optical Transient Search Experiment (ROTSE), telephoto lenses on a swiveling platform near Los Alamos National Laboratory in New Mexico, caught the fantastically bright optical emission from the most powerful burst yet seen, GRB 990123 (Science, 26 March 1999, p. 2003). That image, snapped just 22 seconds after the explosion began, remains the only optical record of a burst in progress.

But the robots wouldn’t strike again for nearly 4 years. Burst alerts dwindled as CGRO and BeppoSAX expired in 2000 and early 2002, respectively. Meanwhile, on Earth, astronomers realized that their robot scopes needed bigger lenses or mirrors to catch typical GRB optical glows, which are less than 1% as bright as GRB 990123’s flash. Consequently, most GRB images on the ground were taken hours or days later by astronomers at larger telescopes, long after the crucial initial flash was gone.

The current GRB sentinel in orbit is the High-Energy Transient Explorer-2 (HETE-2), launched in October 2000. HETE-2 spent its first year beset by a degraded optical filter and funding woes (Science, 30 November 2001, p. 1817). But now, says mission leader Ricker of MIT, it’s all systems go as HETE-2 beams down sky positions for about 20 bursts per year. Even so, it takes a chain of good fortune—quick and accurate positions, bursts per year. Even so, it takes a chain of beams down sky positions for about 20

Two of HETE-2’s latest detections have set the field abuzz. On 4 October 2002, the satellite spotted a bright GRB about 10.7 billion light-years away. Although it was too low in the sky for U.S.-based robotic telescopes to see, an automated system in Wako, Japan, captured an image just 193 seconds after the explosion. The burst alert also jangled the cell phone of Caltech astronomer Derek Fox, who leapt out of bed to send a command to the upgraded 1.2-meter Oschin Telescope at Caltech’s Palomar Observatory, which ordinarily scans for near-Earth asteroids. That telescope took several images starting 9 minutes after the burst.

As Fox and his colleagues report this week in Nature, these and myriad other observations of GRB 021004 paint a fascinating portrait of a stubbornly bright afterglow. Its light subsided at a leisurely rate, in stark contrast to that of GRB 990123 and the other recent burst spotted by HETE-2 (see figure, p. 1833). “Our story is that something continuously refreshes the reverse shock,” says Caltech astrophysicist Shrinivas Kulkarni, who was scheduled to appear with Fox this week at a NASA press briefing in Washington, D.C. “The only way to do that is to keep adding energy.”

Fox and Kulkarni see two plausible explanations. First, the central explosive engine powering the jets could remain active for much longer than expected. If so, the collaspsar would be a sort of inferno rather than a single detonation, perhaps driven by material falling back onto a raging accretion disk around the newborn black hole. Second, the jets themselves might drag slower material along their edges, forming an extended spray of matter to feed the reverse shock.

No such behavior was evident in a much shorter burst seen by HETE-2 on 11 December 2002, for which robots played the critical role. First on the scene in 65 seconds was RAPTOR, an advanced telephoto-lens system based at Los Alamos. At that early phase, the afterglow was the second-brightest yet seen, says astronomer W. Thomas Vestrand, leader of the RAPTOR team. Vestrand’s group has fixed a software bug that prevented an even faster image, so he expects RAPTOR to take data as early as 10 seconds after future explosions.

The best records of GRB 021211 came from the Katzman Automatic Imaging Telescope (KAIT) at Lick Observatory near San Jose, California. KAIT, a 0.76-meter telescope designed to discover scores of supernovas per year, swung to the GRB less than 2 minutes after the blast. In the next 10 minutes, KAIT took 18 exposures, producing by far the most detailed tracing of a GRB’s early output.

GRB 021211 dimmed so fast that its afterglow might have escaped notice without the robots, says KAIT director Alex Filippenko of the University of California (UC), Berkeley. In earlier years, astronomers might have classified the event as a mysterious “dark” GRB with no visible afterglow. “Now, it seems that dark bursts may just fade very quickly and be faint to begin with,” says astronomer Weidong Li of UC Berkeley, lead author of a report on GRB 021211 in the 20 March Astrophysical Journal Letters.

It’s too soon to draw conclusions about early GRB behaviors with just three good samples in hand, Filippenko notes. That will soon change. A NASA satellite called Swift, set for launch in December, should spot and study about 100 bursts per year. A growing fleet of perhaps two dozen telescopic robots worldwide will respond obediently to Swift’s notices. Leading systems include SuperLOTIS at Kitt Peak National Observatory in Arizona and a Spanish collaboration called BOOTES. ROTSE, now an international program led by the University of Michigan, Ann Arbor, is installing four identical telescopes in Australia, Namibia, Texas, and Turkey. An Italian team has erected a new 0.6-meter Rapid Eye Mount automated telescope for GRB studies in Chile, and an older 1.5-meter telescope at Palomar Observatory will be fully roboticized later this year.

Even veterans of cosmic mayhem are bracing themselves for more surprises about GRBs from Swift and this robot army. “Ten years ago, I would have said that we understand how massive stars die,” says Kulkarni. “Now, I think there is a huge variety of ways, and gamma ray bursts are the tip of the iceberg.”

—ROBERT IRION