GAMMA-RAY BURSTS

Long Afterglows Reveal the Secrets of Distant Fireballs

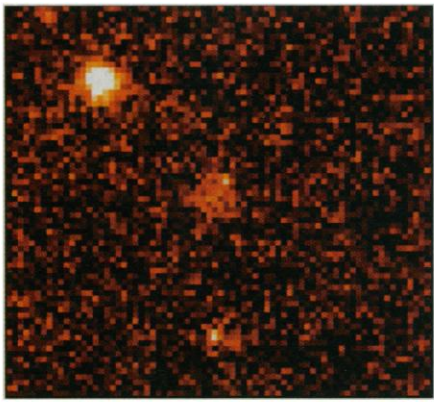
HUNTSVILLE, ALABAMA—If you light a bonfire on the beach, the embers will glow for hours after the party is over, and the ashes may smolder for days. For all their mystery and fury, the cosmic blasts that were the focus of the Fourth Huntsville Gamma-Ray Burst Symposium held here last week seem to obey much the same rule. The violent bursts are followed by fading "afterglows" in progressively longer, less energetic wavelengths: x-rays, visible light, and radio waves. Lasting for weeks or months, the afterglows transform the fleeting gamma-ray bursts (GRBs)—which erupt for fractions of a second to minutes in a hard-to-study corner of the spectrum—into a long-lasting phenomenon at easily accessible wavelengths. "Fading counterparts are where all the excitement has been," says Kevin Hurley of the University of California, Berkeley.

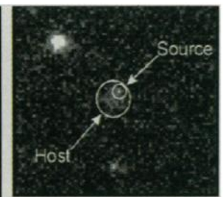
By now, as astronomers discussed here, study of a handful of afterglows has solidified a picture that, less than a year ago, was just one of several competing hypotheses. Clues ranging from the rate at which the afterglows fade to the "twinkling" of the radio signal all imply that GRBs emerge from shocks within gigantic fireballs billions of light-years from Earth. The small number of afterglows detected so far—just a half-dozen x-ray and two optical afterglows and one in the radio band, among thousands of GRBs—leaves some astronomers feeling cautious. But others think they are closing in on a portrait of these mysterious events. "I think we're beginning to see the light at the end of the tunnel," says Peter Mészáros of Pennsylvania State University in University Park, who originated the fireball shock theory with Martin Rees of Cambridge University.

The latest chapter in the GRB story began with last year's launch of the Italian-Dutch BeppoSAX satellite, which carries both x-ray cameras and a gamma-ray detector. BeppoSAX nabbed an x-ray afterglow following a GRB on 28 February, and because x-ray cameras can determine the position of an event much more accurately than a gamma-ray detector can, the x-ray observation in turn guided ground-based telescopes to a fading optical counterpart. It lay near the edge of a fuzzy patch of light, which many interpreted as the burst's distant "host" galaxy. The finding hinted that GRBs originate in the distant universe rather than in the neighborhood of our own galaxy, as a competing theory had it.

But controversy erupted when several groups suggested that the patch might be fading—which a galaxy wouldn't do—and another group concluded that the pointlike optical counterpart was whipping across the sky so quickly that it must be nearby (*Science*, 25 April, p. 529). Soon after, the counterpart of another GRB tipped the debate back toward distant sources: Optical spectra of material lying just in front of the x-ray afterglow of an 8 May GRB implied that the source lay billions of light-years away (*Science*, 23 May, p. 1194).

But a full resolution had to wait until Earth's motion brought the 28 February burst site from behind the sun again. On 4 September, the orbiting Hubble Space Telescope finally observed it again and found "no significant proper motion and no evidence of fading," as Andrew Fruchter of the Space Telescope Science Institute in Baltimore reported for his group. As a result, the apparent conflicts "have been reduced to rubble," says Charles Meegan of NASA's Marshall Space Flight Center here, who was the symposium's organizer. Moreover, the Hubble scientists found that the counterpart was still fading steadily after 6 months—another sign of a distant, energetic fireball rather than a weaker nearby event that would have run out of steam long ago.





ANDREW FRUCHTER, ELENA PIAN, AND NASA

Still smoldering. The afterglow of a 28 February gamma-ray burst is still visible on 5 September, near a hazy patch that may be a host galaxy.

The scale of these fireballs became clear when Dale Frail of the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico, described his team's follow-up of the 8 May GRB. Frail, Greg Taylor of NRAO, Shri Kulkarni of the California Institute of Technology, and Luciano Nicastro and Marco Feroci of the BeppoSAX GRB team had gone looking for the gradually fading radio emission predicted for a distant fireball. They found the radio signal, but it didn't match the smooth decline they had expected. "One day [the emission] was barely detectable; the next day it was a whopping bright source," says Frail.

The radio source was twinkling. As Jeremy Goodman of Princeton University had pointed out, natural striations in the ionized gases of the Milky Way should scatter the radio waves from a point source in a distant universe. The radio source should twinkle as Earth moves in its orbit, just as stars twinkle because of atmospheric motions. As the source grew in size, the twinkling should shut off—just as planets, with their larger apparent sizes, look steady.

When the twinkling began dying down a couple of weeks later, the apparent size Frail and his colleagues deduced for the radio source implied a fireball about a tenth of a light-year across, moving outward at close to the speed of light. That kind of violent expansion—"extreme, relativistic motion on a scale that is not seen in any other place," as Tsvi Piran of Hebrew University in Jerusalem puts it—is just what the cosmic fireball theory predicts.

Now, the afterglows are yielding hints about the settings in which GRBs take place. One clue came with the help of another orbiting sentinel capable of pinpointing some x-ray afterglows: the All Sky Monitor (ASM) on the orbiting Rossi X-ray Timing Explorer. After the ASM determined the position of a 28 August burst, the Japanese x-ray satellite ASCA slued to observe it and found that the x-rays were being absorbed or briefly boosted at some wavelengths, as if the fireball was expanding in a dense, lumpy region of a distant galaxy.

All of those data are fresh grist for the theorists. Piran and Re'em Sari of Hebrew University have compared the drastic flickering of the GRBs to the smoother behavior of the afterglows to conclude that dozens of shock waves collide within the fireball during its first few minutes, when the gamma-rays are emitted. Others considered what kinds of cataclysmic events could set off such a fireball in the first place. Candidates include the sudden merger of two neutron stars or the collapse of most of a single, rapidly spinning, massive star to form a black hole. The spinning black hole would act as a huge reservoir of energy, which powerful magnetic fields could transfer outward to the surviving material, explained Princeton University's Bohdan Paczyński.

Still, the meeting belonged to the observers, whose great successes have made such theorizing possible. "The way everybody's pulling together," said Don Smith, an ASM team member at the Massachusetts Institute of Technology, "it's been real exciting to be part of the chase."

–James Glanz