Finally a Gamma Ray Burster Shows Optical and X-Ray Afterglows

We don't know whether the enigmatic gamma-ray bursters are near or very far away. But now, at long last, we're beginning to accumulate vital clues at other wavelengths.

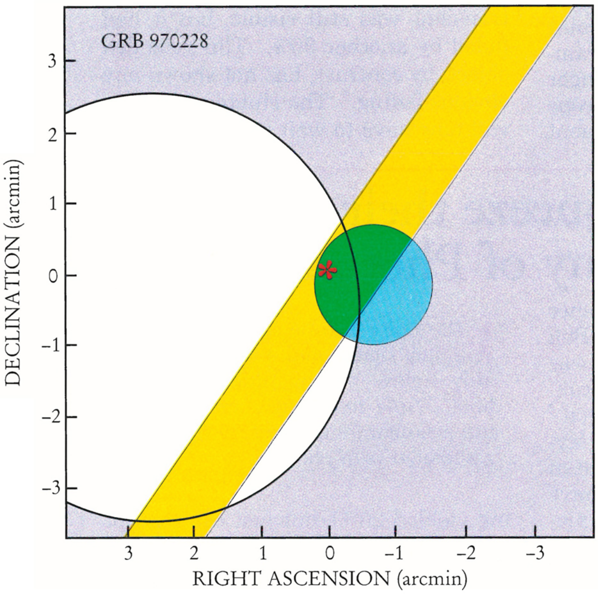
After decades of looking in vain, astronomers have finally found the optical and x-ray "afterglow" of a gamma-ray burster (GRB), together with a fuzzy object that may well be its parent galaxy. Of the several thousand GRBs that have been recorded by orbiting gamma detectors since the early 1970s, the one detected by the Italian–Dutch BeppoSAX satellite on 28 February is the first, and so far the only one, for which a transient or persistent counterpart has been identified at any other wavelength.

These exciting new observations[1] still don't solve the great mystery of the gamma-ray bursters: Do these brief, pointlike outbursts of very energetic photons come to us from uniquely powerful cataclysms halfway across the cosmos, or from much more modest happenings on the outskirts of our own Galaxy? We don't really know yet, but the 28 February BeppoSAX discovery, together with spectacular followups by powerful optical telescopes in March and April, bring the solution much closer. Gamma-ray astronomers expect that GRB 970228, as it is prosaically cataloged, is but the first of many GRBs that will soon be revealing much more of themselves than one can make out from an outburst of a few seconds or minutes.

BATSE and Beppo

Since its launch in 1991, the Burst and Transient Source Experiment (BATSE) aboard the Compton Gamma Ray Observatory has recorded almost 1800 GRBs, the lion's share of all those ever seen. (See PHYSICS TODAY, April 1994, page 17.) But when the 28 February GRB performed its 80-second outburst, BATSE was unfortunately on the wrong side of the Earth. BeppoSAX, however, which was launched just a year ago, had a clear view. As the Italian acronym for *Satellite per Astronomia X* implies, BeppoSAX is primarily an x-ray observatory. Beppo was the nickname of the eminent Italian physicist Giuseppe Occhialini, who died in 1993. The observatory's cosmic-ray-veto shield serves also as a GRB monitor, but with minimal directional sensitivity. Fortunately, one of the satellite's wide-field x-ray cameras was pointing in the right direction. Its 3-arcminute angular resolution is good enough to tell more sensitive x-ray telescopes and optical telescopes where to look for a faint afterglow.

The photon-energy spectrum of a GRB typically peaks at hundreds of keV. But it extends from GeV all the way down to soft x rays. So x-ray imaging can be a good way of pinpointing the direction of a GRB, once the alarm has been sounded by a gamma detector. One should not confuse the routine x-ray component of the fleeting gamma-ray burst with the newly discovered x-ray afterglow, which persists for many hours after the burst itself.



CELESTIAL POSITION of the optical afterglow (red asterisk) of the 28 February gamma-ray burster, shown relative to the error circles of the x ray observations by BeppoSAX's wide-field (large circle) and narrow-field (blue and green circle) cameras. The yellow swath indicates the constraint on the burster's position later determined with the help of timing data from the Interplanetary Network of satellites. (Adapted from ref. 1.)

To look for a faint x-ray afterglow of the 28 February GRB, the BeppoSAX team reoriented the satellite so that its narrow-field x-ray cameras could point in the direction indicated by the wide-field camera's burst image. The analysis and subsequent maneuver were accomplished in 8 hours, a *tour de force*. The narrow-field cameras are not only much more sensitive to faint images than the wide-field cameras; they also have subarcminute pointing resolution.

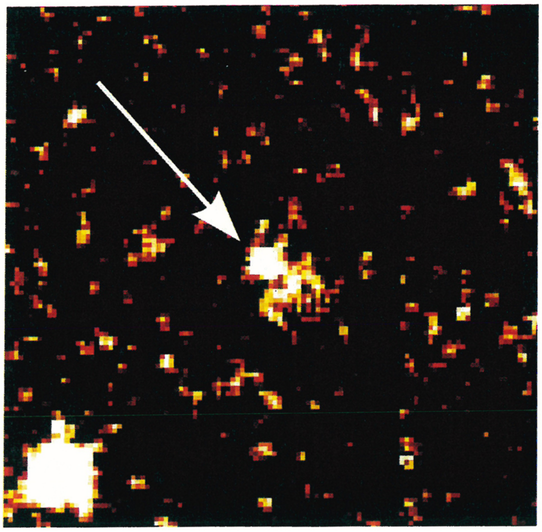
BATSE, with its eight gamma detectors on the corners of the Compton satellite, has the widest field of view of all. It can detect a GRB anywhere on the sky, so long as the Earth is not in the way. But its angular resolution (a few degrees) is not nearly good enough, by itself, to tell an optical or x-ray telescope where to look for a faint afterglow.

BeppoSAX's narrow-field cameras did indeed find a faint x-ray afterglow 8 hours after the burst. At a few keV, the afterglow was a hundred thousand times fainter than the burst itself. When they looked again a week later, the afterglow had waned by a further factor of 20.

Optical sightings

The University of Amsterdam's Jan van Paradijs, who collaborates with the BATSE and BeppoSAX teams, also does radio- and optical astronomy. As soon as he had the wide-field x-ray image of GRB 970228, he phoned from BATSE headquarters in Huntsville, Alabama, to ask one of his graduate students in Amsterdam to undertake a search for radio afterglow with the radiotelescope in nearby Westerbork. No radio source was found, but various theoretical conjectures about GRBs do predict afterglows at a great variety of wavelengths.

Fortunately another graduate student overheard the phone conversation and reminded van Paradijs that the group had an hour of observing time reserved on the 4.2-meter



HUBBLE SPACE TELESCOPE image of the optical afterglow of the 28 February gamma ray burster combines the observations of 26 March and 7 April. The arrow indicates the pointlike optical transient, which faded from magnitude 21.3 one day after the burst to magnitude 26.4 on 7 April. To the transient's immediate lower right is a persistent faint extended object that may be its parent galaxy. The bright foreground star in the lower left corner is 3 arcseconds away. (Image courtesy of K. Saha, Space Telescope Science Institute.)

William Herschel Telescope in the Canary Islands that very night, for a completely unrelated purpose. Sure enough, 21 hours after the first BeppoSAX observation, van Paradijs's group had an optical image of a faint point object, within the wide-field camera's error box, that was no longer visible when the Herschel telescope looked again on 8 March. Subsequent analysis confirmed that the image of the optical transient had been within the tight positional contraints imposed by the narrow-field x-ray image and long-baseline timing data from two other satellites. (See the figure on page 17.)

Now it was time to enlist more powerful eyes. A week after it had faded from view at the Herschel, the optical transient could no longer be seen as a point source by the New Technology Telescope in the Chilean Andes or the 10-meter Keck telescope in Hawaii. But those powerful telescopes did detect a faint extended object, perhaps a galaxy, just where the transient had been.

On 26 March the Hubble Space Telescope (HST) got into the act. Unencumbered by atmospheric blurring, it could still see the transient, now almost 100 times fainter than when the Herschel telescope had seen it. The HST image (see above) also made it clear that the pointlike transient was near the edge of the extended object and certainly not at its center. When the HST looked again on 7 April, the transient was still visible, but it had faded by another 30%. The extended object, by contrast, has not shown any obvious fading.[2] The Hubble telescope will now have to wait until August for the Sun to get out of the way, before it can look again.

If the fuzzy object turns out to be a faint galaxy, that will lend strong support to the majority opinion that GRBs are indeed at cosmological distances and are therefore the brightest phenomena in the universe. An independent analysis of the HST images by Patricia Caraveo and colleagues at the University of Milan concludes that the optical transient moved perceptibly from the one Hubble sighting to the next. That would, of course, mean that the object is well inside our own Galaxy. If that's true, it would be difficult to explain why the distribution of GRBs on the sky is so very isotropic. But the HST team strongly asserts that there is no evidence of such "proper motion." In any case, one cannot yet exclude the possibility that the fuzzball belongs to a class of previously unrecognized objects in the outskirts of our Galaxy.

Nowadays, BATSE leader Gerald Fishman and his colleagues eat and sleep with special beepers always at their sides. The purpose is to alert them as soon as the next bright GRB is sighted so that, with the help of the recently launched Rossi X-Ray Timing Explorer, they can provide a prompt and precise fix on its celestial coordinates to a long list of waiting optical, x-ray and radiotelescopes.

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References

1. J. van Paradijs *et al.*, Nature **386**, 686 (1997).
2. K. C. Sahu *et al.*, Nature, in press (1997).

Can Phonons Squeeze their Way Into the Company of Photons?

> The noise can be squeezed out of a light signal until it falls considerably below the quantum, or shot, limit. Now researchers are trying to use a similar trick to reduce the noise associated with phonons.

Twelve years ago, Richart Slusher and his colleagues at AT&T Bell Labs produced light whose noise was below the vacuum quantum fluctuations, at least in part of the signal.[1] Since then, researchers have been trying to squeeze the uncertainties out of other systems as well. So far they have succeeded in quieting a classical mechanical oscillator[2] and both classical[3] and nonclassical[4] states of a vibrating, trapped ion. Now comes a report of squeezed phonons: By striking a crystal with a femtosecond laser pulse, a group at the University of Michigan believes it has excited an acoustic mode whose variance falls below the standard quantum limit.[5] So far, the noise has been reduced by only 0.01% (the earliest experiments on optical squeezing yielded 20%), but just the concept of squeezed phonons has intrigued many observers.

Squeezing is a trade-off

If you squeeze a wad of putty in your hand, some of it will ooze out between your fingers. In the same way, reducing the noise in one variable of a quantum system makes the noise grow in the complementary variable. The two so-called quadrature variables are linked by the Heisenberg uncertainty principle, which places a lower limit on the product of uncertainties in them. For a mechanical system, the complementary variables may be position and momentum; for a light wave, they mey be the electric and magnetic field vectors.

The vibrating atoms in a solid follow the same rules: Even at absolute zero, the atoms undergo quantum oscillations about their equilibrium positions, with the motions obeying $\Delta x\, \Delta p \geq \hbar$. These oscillations are equivalent to the vacuum fluctuations of an electromagnetic field and constitute the fundamental limit to any measurement.

At the University of Michigan, Gregory Garrett, Alberto Rojo, John Whitaker and Roberto Merlin, together with Ajay Sood from the Indian Insti-