High-Redshift Absorption Lines Show Convincingly that Gamma-Ray Bursters Are Very Far Away

Last month in these pages we wrote, "Gamma-ray astronomers expect that [the 28 February gamma-ray burst] is but the first of many GRBs that will soon be revealing much more of themselves . . ." (page 17). "Soon" turned out to be an understatement. On 8 May, just as we were going to press, the new Italian–Dutch BeppoSAX satellite recorded another GRB, one that will surely make its way into the textbooks.

Gamma-ray bursters were discovered in the early 1970s, by US surveillance satellites monitoring for surreptitious nuclear weapons tests. But none of the several thousand GRBs recorded before 8 May 1997 provided the "smoking gun" that would reveal whether these brief high-energy gamma outbursts come to us over cosmological distances or merely from the outskirts of our own Galaxy. Not knowing the distances to within five orders of magnitude meant that our ignorance of their intrinsic luminosities spanned ten orders of magnitude.

> All of a sudden the long debate is over. Gamma-ray bursters really do live halfway across the cosmos. Now we know that they are, for brief moments, the most luminous objects in the universe.

Cosmological redshifts

Now we finally seem to have that smoking gun. Like its 28 February BeppoSAX predecessor, the 8 May burster left behind an optical afterglow that could still be seen weeks after the gamma burst. But this time, prompt spectroscopic observation of the optical transient while it was still bright enough has yielded telltale absorption lines with enormous, obviously cosmological, redshifts.

Using the 10-meter Keck II telescope on Hawaii's Mauna Kea, Mark Metzger and his Caltech colleagues measured the absorption spectrum[1] of the optical transient 56 hours after the gamma burst, not long after the transient had passed its peak luminosity and had just begun to fade.

The spectrum, reproduced on this page, exhibited ten clear magnesium and iron absorption lines with large redshifts. Eight of them appear to come from a single absorbing system with a redshift of $z \equiv \Delta\lambda/\lambda \approx 0.835$. That would mean that the optical afterglow of the burster passed through the absorber at a time when the cosmos was $1/(1+z) \approx 54\%$ of its present size. Translating large redshifts into distances from us depends somewhat on poorly known cosmological parameters; but we're certainly talking here about billions of light-years.

These iron and magnesium lines are quite typical of absorption features seen in quasar light that has traversed distant foreground galaxies along the line of sight. If the absorber in this case is the 8 May burster's home galaxy, then z is a direct measure of its distance. But in the more likely event that the absorber lies somewhere between us and the burster, 0.835 becomes a lower limit on the burster's cosmological redshift. The two remaining magnesium lines evident in the absorption spectrum both have a z of 0.767. Presumably they are due to additional absorption in a second distant galaxy along the way.

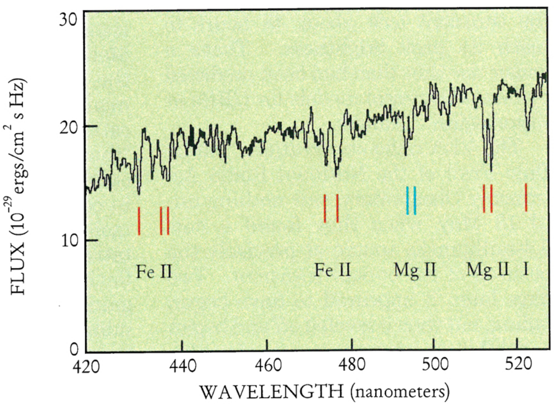
The data also provide an interesting *upper* limit on the burster's redshift. We know that light traveling over cosmological distances exhibits a "forest" of variously redshifted Lyman-α absorption lines due to hydrogen clouds all along the line of sight. In the laboratory the Lyman-α wavelength is 122 nm, deep in the ultraviolet. Only at high redshifts, therefore, does Lyman-α absorption impinge upon the visible spectrum. Metzger and company found no evidence of the Lyman-α forest in the spectrum of the optical transient. Thus the lower limit of their spectral range, which cuts out near 400 nm, translates into an upper limit of $z \approx 2.3$ for the redshift of the 8 May burster.

The spectroscopic evidence for bracketing the optical transient between redshifts of 0.835 and 2.3 is solid. But can we be sure it has anything to do with the 8 May GRB? BeppoSAX has one great advantage over the venerable BATSE gamma-burst detector aboard the orbiting Compton Gamma Ray Observatory. Although BeppoSAX's restricted field of view catches only a small fraction of the GRBs that BATSE sees at a rate of almost one a day, BeppoSAX can exploit its sophisticated x-ray cameras to quickly pinpoint the positions of those it does see.

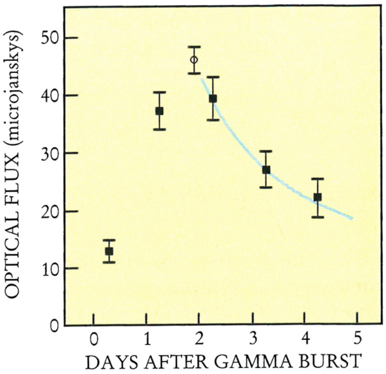
Within a few hours of a gamma-ray burst, the BeppoSAX team can analyze the wide-field x-ray camera images enough to tell optical and radio astronomers where to look for an afterglow within an error circle 5 arcminutes in diameter. Such a circle typically has dozens of steady optical or radio sources. The trick is to reimage the field later, to catch out the one that's waxing or waning. Meanwhile, BeppoSAX will have been reoriented to let its narrow-field cameras look for an x-ray afterglow and pinpoint it to within 1 arcminute.

Dress rehearsal

The 28 February burster, the first one for which any afterglow was detected, was a kind of dress rehearsal. The



HIGH-REDSHIFT ABSORPTION SPECTRUM of the optical afterglow of the 8 May gamma-ray burster reveal that this burster, and the galaxy that absorbed its light, were billions of light-years distant from us. The spectrum was recorded at the Keck II telescope 56 hours after the gamma burst. The magnesium and iron lines indicated in red all have redshifts of $z \approx 0.835$. Both of the others (blue), presumably from a second galaxy along the line of sight, have $z \approx 0.767$. Roman numerals indicate ionization state. (Adapted from ref. 1.)



LIGHT CURVE of the optical afterglow of the 8 May gamma-ray burster in the days following the burst. The solid squares are data from telescopes on Mount Palomar. The open circle indicates an observation at the 1.5-meter Loiano telescope in the Apennines. The drawn curve plots $1/t$ falloff, where t is the elapsed time since the gamma burst. (Adapted from ref. 2.)

first optical exposures were made at the 4.2-meter William Herschel Telescope 21 hours after the burst, but more than a week passed before the transient was identified and more powerful telecopes got into the act. By that time the optical image was too faint for adequate spectroscopy. But the observed optical and x-ray afterglows hinted at even greater rewards for rapid, concerted action next time.

Within 7 hours of the 8 May burst, BeppoSAX's wide field was under scrutiny by several optical telescopes and by the Very Large Array (VLA) of 27 radio dishes at Socorro, New Mexico. A day later, Howard Bond (Space Telescope Science Institute) announced that he had identified the optical transient with the Kitt Peak 0.9-meter telescope, and that this pointlike object was still getting brighter. Using two telescopes on Mount Palomar, Metzger's Caltech collaborator George Djorgovski and colleagues measured the light curve (see page **) of the optical transient's first five days.[2] The curve shows that the transient took about 48 hours to reach its peak brightness. That's a longer rise time than had been predicted by most theoretical models for GRBs at cosmological distances.

The VLA radio observations, led by Dale Frail of the National Radio Astronomy Observatory, saw nothing until 13 May, when they found a new 0.4-millijansky source at precisely the position of the optical transient. Two days later, it appeared to have begun fading, but then it leveled off and began to exhibit an erratic sequence of peaks. Frail and company are still trying to make sense of this peculiar behavior. Perhaps it's random scintillation due to multiple scattering off ionized gas in our Galaxy—the radio analog of star twinkling. In any case, the delayed onset of the radio transient relative to the optical transient is not a surprise. Most cosmological GRB scenarios do involve an early phase that is too dense for synchroton radiation at radio frequencies to escape.

"Able was I . . ."

At the end of May, observers and theorists gathered for a few days on the Mediterranean island of Elba, to digest the deluge of new data in recent months. "There were so many interesting theory talks," Metzger told us, "that we never got to see Bonaparte's exile villa." The theorists are now free to concentrate all their efforts on cosmological scenarios, that is to say, putative cataclysms capable of spewing forth something like 10^{52} ergs worth of gamma radiation in a fraction of a minute. Nothing much more modest than a black hole swallowing a neutron star in one gulp will do. Irrespective of the details of the initial event, the deposition of so much energy so fast into a small volume is expected to generate a fireball that expands at highly relativistic speed.

More optical and radio light curves will now be much in demand, to help choose from among the various speculations. Very-long-baseline radio interferometry is also getting into the fray. With antennae thousands of miles apart, it can achieve milliarcsecond resolution, which at $z \approx 1$ corresponds to only a few light-years.

As we go to press, we hear of two new developments: The good news is that an oxygen *emission* line, also at $z \approx 0.835$, has now been identified in the fading optical transient of the 8 May burster. The bad news is that another of BeppoSAX's guidance gyros has been misbehaving. That will limit the usefulness of the satellite for perhaps a month.

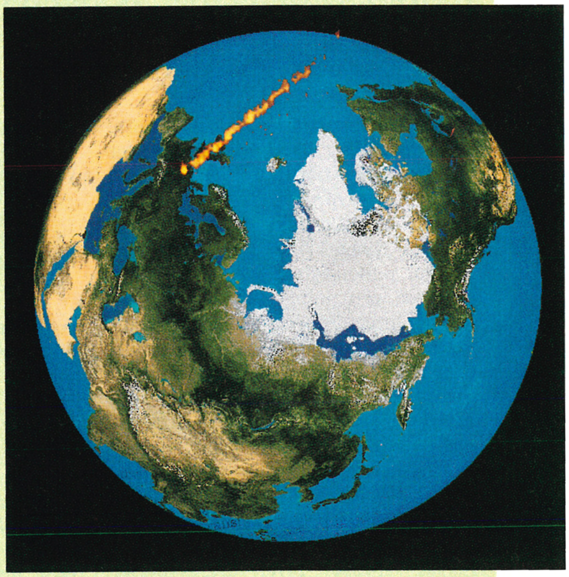
BERTRAM SCHWARZSCHILD

References

1. M. Metzger *et al.*, Nature **387**, 26 June 1997.
2. M. Djorgovski *et al.*, Nature **387**, 26 June 1997.

Polar Orbiter Shows Evidence of Minicomet Bombardment

This multiple-exposure ultraviolet image, taken last September by the Visible Imaging System (VIS) aboard NASA's Polar orbiter, shows a 500-km-long trail of something roughly 10 000 km above the Atlantic, coming in toward Europe and shining brightly at 130.4 nm, a prominent UV emission line of atomic oxygen. The VIS has also recorded many such trails at 308.5 nm, a characteristic wavelength of hydroxyl-radical fluorescence.



LOUIS FRANK AND NASA

In three papers recently submitted to *Geophysical Research Letters*, VIS developer Louis Frank and coauthor John Sigwarth (both at the University of Iowa) argue that these infalling objects are kiloton minicomets, consisting mostly of water ice and bombarding the Earth at a rate of 10 or 20 a minute. An important part of their evidence is a steady patter of large, transient dark spots in the Earth's ultraviolet dayglow, recorded from above by the Polar orbiter. The UV trails, they conjecture, are generated by photodissociation of water molecules in sunlight as the minicomets begin to break up in the vicinity of the Earth; and the dark splotches indicate the final deposition of the water in the upper atmosphere.

The bombardment rate is highest in October and lowest in January. The authors argue for a large, persistent population of these water minicomets in a highly eccentric orbital band whose perihelion is near Earth's orbit. If this population of orbiting "snowballs" has really been pelting the Earth for billions of years, it could account for much of the water in our oceans—and who knows what else.

BERTRAM SCHWARZSCHILD