all macroscopic time scales, the obvious next order of business is to look for the corresponding redshift in the energy spectra. If a gamma from a dim burst has been redshifted by $z = 1$, its energy will be half of what it started out with several billion years ago.

At the January meeting of the American Astronomical Society near Washington, Norris and company showed preliminary spectral data indicating that the energy distribution from the dimmest group of bursters is significantly "softer" (shifted toward lower gamma energies) than that of the brightest group. A detailed paper on the evidence for spectral redshifting consistent with $z = 1$ in the BATSE data is now in preparation.

So the evidence for cosmological time dilation in the dimmest gamma-ray bursters now extends all the way from minutes down to 10^{-20} seconds, the period of a 300-keV gamma. "When Paczynski predicted all this, I was skeptical," Norris told us. "My earlier work had been on models of what might be happening to neutron stars in the Galactic halo to make them emit gamma bursts. So my initial motivation for this work was to prove that gamma bursters are local by *not* finding cosmological time dilation."

Holdout

For University of Chicago theorist Don Lamb it was somewhat the other way around. Nowadays he holds out for gamma-ray bursters very close by—in the Galactic disk itself.[2] But when he and Chicago colleague Jean Quashnock set out last year to take a careful look at the publicly available BATSE data catalog, "we came at it from a decidedly cosmological perspective," Lamb recalls. "We had written a paper suggesting the use of bursters as probes of the large-scale structure of the universe. So it was a shocker for us to find that previously unnoticed correlations in the angular-distribution data indicated repeaters and that bursts of intermediate brightness favored the Galactic plane."

Both of these effects, if true, strongly support the idea that the bursters are local. But Meegan, a senior member of the BATSE team, tells us that a recently completed analysis of a much larger data sample finds no evidence of repeaters or excess events in the plane of the Galactic disk. Lamb, however, remains unconvinced. Disputes of this kind are not uncommon in big science when outsiders who, in the short run, have only limited access to the data find themselves in interpretive disagreement with those who took the data.

A 12 March astronomical telegram[3] from the group that runs the COMPTEL imaging gamma-ray telescope aboard the Compton Observatory adds new grist to the repeater question. The group reports that a burst COMPTEL recorded on 1 March has an angular position so close to that of a burst it recorded last 4 July that it could well be a repeater. COMPTEL is able to see only a small fraction of the gamma bursts BATSE finds, but it can measure with greater precision the positions of those it does see.

Models of what's causing the gamma-ray bursts range from chunks of antimatter invading the solar system's Oort Cloud to the sudden consumption of neutron stars by black holes in galaxies too far away to have been seen by telescopes. With so much freedom to speculate, Norris admits, one can of course imagine alternative explanations of the observed correlation between brightness and time structure—"and one of them might turn out to be right." Stirling Colgate and Peter Leonard at Los Alamos, for example, have recently proposed a model that attributes the gamma bursts to planetoids falling onto neutron stars in the Galaxy.[4] That scenario, Colgate told us, might account for what Norris and company have found in terms of a correlation between evolutionary effects and distance from us. But it's not easy, Norris argues, to find an alternative explanation that gives roughly the same dilation factor on all time scales and also reproduces the isotropy and brightness distribution of the BATSE data.

"Even if the bursters are at cosmological distances," Norris concedes, "it's entirely possible that what we're seeing is complicated by evolutionary effects." (Those would be on a significantly longer time scale than the local evolutionary effects Colgate is talking about.) Virginia Trimble (University of Maryland and University of California, Irvine) recently pointed out that previous attempts to observe the cosmological expansion of space–time have all foundered on the rocks of astrophysical evolutionary effects.[5] "So if they really have unearthed cosmological time dilation," she told us, "it would be a 'first,' with a significance well beyond the contentious issue of gamma-ray bursters." But aren't the Hubble redshifts of the distant galaxies long-standing evidence of cosmological time dilation? "That's certainly the standard explanation," Trimble answered. "But one could argue that the Hubble red shifts by themselves, uncorroborated by other evidence, are just some sort of 'tired light' effect."

—BERTRAM SCHWARZSCHILD

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THE VERY LONG BASELINE ARRAY OPENS ITS EYES

One might expect a compound eye 5000 miles wide to have extraordinary vision, but also to open rather slowly. So it is with the Very Long Baseline Array, a continent-wide interferometer completed last May.

Built and administered by the National Radio Astronomy Observatory, the VLBA is a collection of ten identical radio telescopes (see box) that took seven years to build and cost $85 million. The VLBA, a national facility available to astronomers worldwide, is capable of carrying out very long baseline interferometry in both spectral-line and continuum emissions. The VLBI technique, first applied in 1967,[1] combines recordings of simultaneous observations made at widely separated telescopes as though each observation came from a different part of the same telescope. This single "effective" telescope has an aperture equivalent to the largest separation (longest baseline) between any two of the telescopes. The longest baseline is most sensitive to the smallest structures in the radio source and thus determines the highest resolution for a given wavelength. With additional telescopes on different baselines, the effective telescope becomes sensitive to a range of size scales in the source, and the structure of the source can be determined and mapped. Such maps have been reliably made since about 1980.[2] The VLBA can make VLBI maps with 0.2

milliarcsecond angular resolution at a wavelength of 7 mm (43 GHz) and 24 milliarcseconds at 90 cm (330 MHz). The receivers also operate at 1.3, 2.0, 3.6, 6.2, 13, 20 and 50 cm.

Lessons from the past

The VLBA's older siblings are various *ad hoc* arrays of dissimilar radio telescopes scattered around the world. "The VLBI technique is extremely powerful," says Alan Marscher of Boston University, "but in the past we've had three shortcomings to work around: time coverage, wavelength coverage and nonuniformity"—that is, equipment and operating variations among the radio observatories. Marscher points out that while the observatories were always very cooperative, they could only dedicate about three weeks to VLBI every three months because of other research commitments. The sporadic time coverage made it difficult to follow the evolution of any particular radio source. The wavelength range for VLBI was confined between 1 and 90 cm, and so the shortest wavelengths, with the highest resolutions, were not available. Nonuniformity problems ranged from obvious differences in antennas and receivers, including the wavelengths at which they operate, to different methods of data collection and storage. This all means that "VLBI observations were usually not fully optimized," says Marscher.

The VLBA learned from its elders. The ten antennas, receivers, recorders, clocks, computers, even the control buildings' floorplans, are all identical. This uniformity allows an unprecedented optimization of the array, leading to tremendous gains in dynamic range—the ratio of the peak flux of radio source features in a map to the rms noise in a blank region of the map. "The VLBA is so well understood and calibrated," says Anthony Readhead of Caltech, "that we can achieve a dynamic range of 200–300:1 during 15-minute snapshots, allowing us to routinely map hundreds of sources in a year." For comparison, it took Timothy Pearson and Readhead five years to map 47 sources in the first "complete" VLBI survey, with a typical dynamic range of 100:1. R. Craig Walker of NRAO in Socorro, New Mexico, adds that for long exposures, comparable to those of the first survey, the dynamic range is now several thousand to one, which allows the detection of very weak features in radio sources.

State of the art

All facets of the VLBA are state of the art. Each station records data together with timing information from a hydrogen maser clock, accurate to better than one part in 10^{13}. The recorders' ultranarrow heads record 504 tracks across one-inch-wide tape, storing more than 3.5 megabytes per square inch of tape. After an observation is completed, all of the stations' tapes are sent to the VLBA headquarters in Socorro. There, a specially designed machine called a correlator, which performs 750 billion floating point operations per second, combines the tapes simultaneously (rather than sequentially) using the embedded timing information. The correlator can handle data from the VLBA and up to ten more VLBI stations around the world. The output from this device is a Fourier transform of the actual brightness distribution across the sky. This result can then be inverted into an image.

A facility with so many marvelously complex components has to endure some growing pains. Miller Goss, assistant director of NRAO for the VLBA and the Very Large Array—a 22-mile radio interferometer near Socorro—cites two teething problems that have now been resolved: bugs in the communications software for running the array remotely and some misalignments of antenna components. The biggest problem now is getting the correlator to function properly. "It's not very robust. When it works, it gives very good results, but there are problems that cause it to crash," says Jon Romney, the leader of the correlator group in Socorro. So far, the correlator has needed "hands-on experimenting" for each project. "For the near term," says Romney, "we need to make it more robust, more automated, and add the capability to include data from non-VLBA observatories."

"These technical problems are not insoluble, but the question is how long will the delays be and with what implied cost?" says Patrick Thaddeus of Harvard, the chairman of the NRAO visiting committee. "The VLBA has the potential to be a powerful device, making spectacular discoveries. But it isn't yet." Goss hopes that by the end of this year the VLBA will operate 24 hours a day and average ten major observing programs every week.

VLBA Observatory Sites

Mauna Kea, Hawaii
Brewster, Washington
Owens Valley, California
Kitt Peak, Arizona
Pie Town, New Mexico
Los Alamos, New Mexico
Fort Davis, Texas
North Liberty, Iowa
Hancock, New Hampshire
St. Croix, Virgin Islands

Early results

Despite the problems, says Goss, "the VLBA is now at the stage where we can get real science out of it." Indeed, two of the test objects have provided tantalizing views of the VLBA's abilities.

Using only five of the VLBA antennas in August 1992, Philip Diamond of NRAO in Socorro led a team that imaged SiO masers within 10 milliarcseconds of the surface of a highly evolved pulsating star. Diamond estimates that in our solar system, the star's surface would be between the orbits of Mars and Jupiter and the masers would be between Saturn and Uranus. Surprisingly, the masers were in a highly structured arc. "We always thought that the region near the star's surface was too turbulent to support this kind of structure," he says. The team consisted of Diamond, Athol Kemball, John Benson, Vivek Dhawan, William Junor and Anton Zensus.

In August 1993 Walker, Romney and John Benson observed the radio galaxy 3C84 at 3.6 cm with eight VLBA antennas and found evidence for a rare counterjet at milliarcsecond scales, as well as the expected core-jet structure. Analyzing a previous observation made in June 1991, Rene Vermeulen and Readhead of Caltech and Donald Backer of the University of California, Berkeley, also found the counterjet in 3C84. They used 14 VLBI antennas (eight of which were from the VLBA) at 1.3 cm. The counterjet is dimmer at the longer wavelength, so both groups think they might be seeing absorption by a foreground feature—possibly an accretion disk surrounding the galaxy's core.

Perhaps the most important aspect of Walker's observation of 3C84 is the detection of the counterjet using only eight antennas and a single (though not the first) pass of the data through the new correlator. "Our first observations—with the facility still in its growing stage—are at the state of the art," says Walker. Readhead goes further: "The VLBA is bringing a complete revolution to VLBI." Just how complete, only time will tell.

—Stephen G. Benka

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