accepted as a standard by the International Astronomical Union. "It was a little bit of a shock to some people that the galaxy was 20% to 30% smaller than they had thought," says Reid. Now Reid and his colleagues plan to use the VLBA to measure the distance to the nearby galaxy M33 by observing masers consisting of water vapor.

Astronomers are also looking to the VLBA to open up areas even the most skilled VLBI exponents have considered daunting—tasks such as extracting data on the polarization of signals received by the VLBI arrays. David Roberts and John Wardle of Brandeis University in Waltham, Massachusetts, are among the few researchers who have the skill and patience to try this kind of analysis routinely, which is valuable because it reveals the structure of the magnetic fields running down radio jets shooting from distant active galaxies—which in turn sheds light on the fluid flows taking place. From the studies Roberts and Wardle have carried out so far, the structure of the magnetic fields suggests that the speeding blobs of plasma observed in radio jets aren't discrete "cannonballs being shot out," says Wardle, but areas of compression in a steadily flowing jet. Studies of this type should multiply rapidly in number over the next few years, he predicts, as the correlator and software designed for the VLBA have been set up to allow astronomers to conduct polarization studies with unprecedented ease.

The instrument should also incorporate a technique called phase referencing that will allow astronomers to observe faint radio sources over long periods—just as photographers use long exposures to take pictures in poor light. That's currently very difficult with VLBI because the atomic clocks used to synchronize the signals recorded at each telescope slip out of time with one another after a few minutes, and atmospheric conditions change—both of which cause errors in the phase of the recorded signals. But in phase-referenced observations, the array is pointed alternately at the target and then at a previously imaged nearby reference source. By tracking the errors that appear over time in the reference signal, it's possible to correct the target signal, and build up an image from several hours of data.

If, as NRAO's Walker hopes, phased referenced observations become routine at the VLBA by the end of the year, stellar astronomers will be able to bring its immense resolving power to bear on weakly radio-emitting stars in our own galaxy. Indeed, technical advances like phase referencing, together with the anticipated influx of new VLBI users, should make for a heady cocktail. "It's really going to have a major impact on astronomy," says Caltech's Readhead. "We're in the middle of a revolution." And perhaps the VLBA will start making headlines.

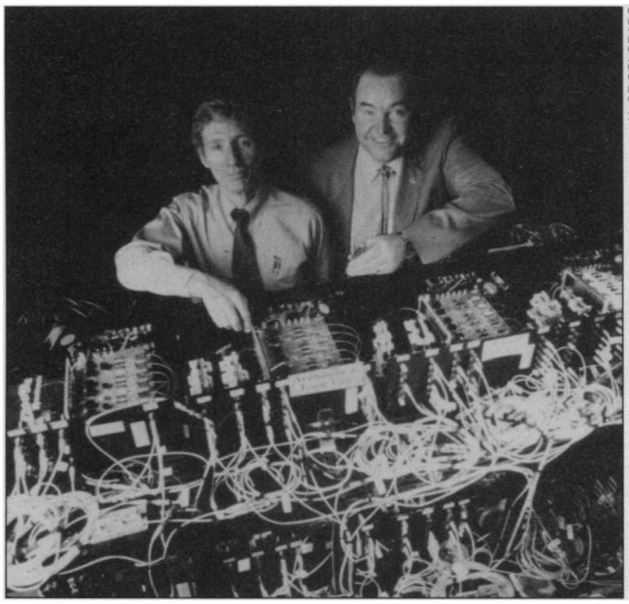
–Peter Aldhous

OPTOELECTRONICS

Computing at the Speed of Light

A University of Colorado research team provided a glimpse of the future on 12 January when it unveiled the world's first general-purpose optical computer: a machine that stores its programs and processes information by means of light rather than electrons. Although principal investigators Harry Jordan and Vincent Heuring compare the desktop-sized array of lasers, switches, and optical fibers to electronic technology in the days of vacuum tubes, their creation has the power of a small personal computer. And it points the way toward future optical computers that could function hundreds or thousands of times faster than conventional machines.

"This finally gets the computational aspect of optical computing off the ground," says Donald Chiarulli of the University of Pittsburgh, a long-time researcher in the field. "It's significant because it's gone so far beyond the conceptual stage," agrees William Rhodes of the Georgia Institute of Technology, editor of the journal *Applied Optics*.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No laptop. Vincent Heuring *(left)* and Harry Jordan with their prototype optical computer.

What distinguishes the Colorado computer from earlier optical devices is its ability to store and manipulate its own instructions internally, explains Jordan. Indeed, he says, "the idea of a stored program was the breakthrough in the 1940s that made computing what it is today." By contrast, an optical processor unveiled in 1990 by Bell Laboratories' Alan Huang was able to perform simple calculations using light beams, but could only respond to instructions and data fed to it by an electronic computer.

To accomplish their feat, Jordan and Heuring made use of a "bit-serial" architecture. The idea is to encode the computer's instructions and data as a linear string of infrared laser pulses circulating at the speed of light around a tightly spooled loop of optical fiber. Each 4-meter-long pulse, representing a single binary digit, circulates through the 4-kilometer loop some 50,000 times a second, which is the computer's fundamental clock speed. Other laser beams route these pulses through lithium niobate "optical switches" for processing. In fact, notes Heuring, since the light circulates through the computer at a known velocity—186,000 miles per second—the arrival time of any pulse can be predicted very precisely and used in the fundamental design of the circuitry. "In effect," he says, "we are storing information in space-time, which is a concept you only used to see in science fiction or relativity."

Unfortunately, Jordan and Heuring admit, this bit-serial architecture deliberately gives up on parallel computing, which many researchers regard as optical computing's greatest single advantage over electronics. Because photons (unlike electrons) can pass right through each other without hindrance, the Holy Grail of the field has always been an optical circuit that could carry out zillions of computations simultaneously in criss-crossing data channels. But the Colorado team felt the bit-serial approach was a better choice for the time being, because of cost—the design calls for only 66 lithium niobate switches, costing $3,000 apiece—and because it could be well suited for use in telecommunications, where transcontinental fiber optic cables already carry optical data pulses in bit-serial form.

The Colorado team has estimated that with the use of technologies already demonstrated in the laboratory, they could build a palm-sized bit-serial computer smaller by a factor of 400 than the current prototype. And since the velocity of light is constant, the speed of such a computer would rise by that same factor of 400, to 20 billion cycles per second—hundreds of times faster than the fastest personal computer today.

–M. Mitchell Waldrop