rafts on their backs for a day's march, in order to drill a core in the 7-meter-deep lake. According to radiocarbon dating done on the core, the top 1.6 meters of sediment accumulated during the past 42,000 years. So layer by layer, Colinvaux's team identified and counted pollen grains from the present back into the last ice age.

According to the refugium hypothesis, during glacial times the Amazonian climate dried out, favoring grasses and herbs over trees. Isolation is a classic means of speciation, so the idea was that many species arose in the resulting fragments of forest —"moist islands in a sea of aridity," as Colinvaux calls them. Most maps of presumed ice-age refugia, inferred from present-day biodiversity hot spots, call for dry savannah around Lake Pata. So the theory predicts that in the lake's bottom muds more than 15,000 years old, there should be less pollen from rain-forest trees and more from grasses.

Instead, throughout the Lake Pata record, 70% to 90% of the total pollen was from trees, with only a few percent from grass; all herb pollens remained below 10%. "The refuge hypothesis was a good one in that it was testable," says Colinvaux. "It said the Amazon was dry in the last glacial maximum. We drilled a lake core from the Amazon lowland in the last glacial maximum to see if it was dry. The hypothesis fails that test."


J. E. MORENO

Glacial visitor. Pollen grain from a montane tree species denotes a 5° cooling.

Some of Colinvaux's colleagues agree. The refugium theory was once "a very strongly held dogma," says Kelts, but it has been challenged in recent years, as researchers questioned the reality of the biodiversity hot spots and offered alternative speciation mechanisms (*Science*, 13 September, p. 1496). Says ecologist Edward Connor of the University of Virginia: "This puts an additional, if not the final, nail in the coffin." Others, however, worry about overinterpreting this single pollen record. "The problem is they just don't have that many samples to answer this question," says ornithologist Joel Cracraft of the American Museum of Natural History. Indeed, illustrating the difficulties of locating a sample site, in 1994 Thomas van der Hammen of the University of Amsterdam in the Netherlands suggested on meteorological considerations that in glacial times the Lake Pata site was actually within a rain-forest refugium, not savannah—in which case you'd expect to find rain-forest tree pollen throughout the core.

To address the dearth of sample sites, palynologist Simon Haberle, a former postdoc of Colinvaux's who is now at Cambridge University, surveyed the pollen in sand and mud dumped off the coast by the Amazon River. By carrying in pollen from as far away as the Andes, the river "gives a very broad picture of the basin's vegetation," says Haberle. The data, soon to be published in a report of the Ocean Drilling Program, resemble those at the Lake Pata site, showing low and stable abundances of grasses and savannah trees back into the last ice age. But even such a broadly based sample is open to criticism, notes limnologist Barbara Leyden of the University of South Florida, because gallery forests confined to the river edges might overwhelm any grass pollen that blew in from a distance.

However the evolutionary debate ends, the new data will heat up another dispute: the issue of tropical temperatures during glacial times. Many oceanographers have remained wedded to microfossil evidence taken from marine sediments around the world, which indicates just 2°C or less of tropical cooling during glacial times (*Science*, 14 January 1994, p. 173). But in the ice-age Lake Pata record, tree pollen typical of today's rain forest was joined by that of trees now found only at elevations 800 to 1000 meters higher. And Haberle also sees a changing pollen pattern in the Amazon river fan, suggesting "expansion of cold-adapted [Andean] vegetation types down into the lowlands of the Amazon."

The vegetation's altitude change at Lake Pata translates to a cooling of 5° to 6°C—the same amount implied by other recent studies in South and Central America, which focused on noble gases in ground water, changes in ice-age snow lines on peaks, and other pollen records. Analyses of Caribbean coral chemistry have shown the same cooling. All this data is beginning to make a dent, says climate modeler David Rind of NASA's Goddard Institute for Space Studies in New York City. "I'd say the [oceanographic] community is moving more in the direction that it's at least possible there was considerable cooling in the tropics."

But there's no consensus yet. "There are just enough questions about the methodology of these data on land," says paleoceanographer Thomas Crowley of Texas A&M University, that "I by no means am willing to throw in the towel and say the [marine temperatures] are wrong." With that kind of skepticism abounding, Haberle believes "it will not be until we get 100, 200, or 300 sites in the Amazon basin that we get a clear idea of how vegetation changed." But even one good sample is a lot better than none.

–**Richard A. Kerr**

ASTRONOMY

All-in-One Detectors for The Faintest Objects

Peter Jakobsen was skeptical, and perhaps a bit rude, a few years ago when Michael Perryman—his colleague in the Astrophysics Division of the European Space Agency (ESA) in Noordwijk, the Netherlands—first proposed equipping optical telescopes with a new kind of detector called a superconducting tunnel junction. STJs, which consist of an insulator sandwiched between two thin films of superconducting metal, had been studied for nearly a decade as possible x-ray detectors, but few believed that they could be sensitive enough to detect the far less energetic photons of visible light. "Come back to me when you have something that works," Jakobsen recalls saying.

Perryman did just that, and now Jakobsen is a self-described "STJ evangelist." Last spring, Tone Peacock, Perryman, and other scientists at ESTEC, an ESA research center, announced in *Nature* (9 May, p. 135) that they had built an STJ able to detect individual photons across a wavelength range spanning the near-ultraviolet to visible spectrum. And, unlike conventional detectors, the device simultaneously measures the photons' energy. That first demonstration has now touched off a flurry of activity by raising hopes that an array of these devices could serve as a detector more versatile and sensitive than today's instruments, collecting images and spectra at the same time from the very faintest astronomical objects.

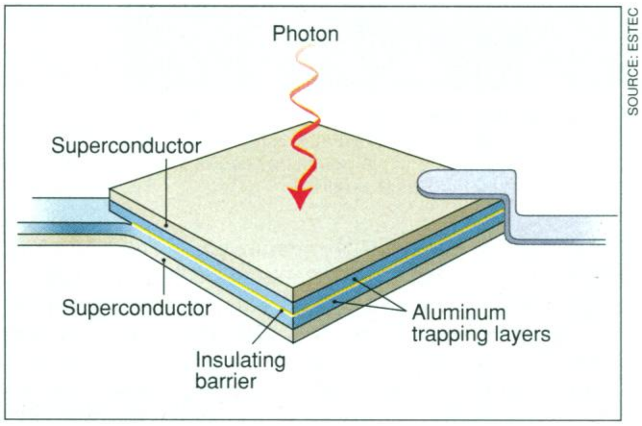
In laboratories from ESTEC to Lawrence Livermore National Laboratory in California to Yale University, researchers are scrambling to improve STJs and fashion them into arrays. Astronomers, meanwhile, are thinking about how they would exploit such detectors. Jakobsen himself would like to see such a device fitted to the Hubble Space Telescope. And Shrivinas Kulkarni, an astrophysicist at the California Institute of Technology (Caltech) who is helping to develop STJ detectors, says, "If these devices work as promised, they will revolutionize the search for faint galaxies, planets around other stars, and pulsars."

In themselves, STJs are nothing new. The arrangement of slightly separated superconducting layers, cooled to near absolute zero, is essentially a "Josephson junction"—a device invented by the physicist

Brian Josephson in the 1960s that is now used in technologies such as supersensitive magnetic field detectors. When a photon strikes an STJ, pairs of loosely bound electrons in the superconductor called Cooper pairs are split up. The freed electrons then "tunnel" through the insulating barrier, creating a current. Because the number of free electrons is proportional to the energy of the absorbed photons, an STJ device can not only detect individual photons, but also reveal their energy (or wavelength).

Scientists generally assumed that STJs would first make their mark in x-ray astronomy, because an x-ray photon should generate about 1000 times more free electrons than does an optical photon. But researchers have not been able to get x-ray devices to perform anywhere near their theoretical limit. The technical difficulties on the x-ray front prompted Peacock, Perryman, and Clare Foden (now at the Toshiba Cambridge Research Center in the United Kingdom) to try their luck with the lower energy photons of visible, ultraviolet, and near-infrared light. After choosing the right materials and designs and finding a way to hold down the electronic noise that would otherwise render the device useless, they discovered, to their delight, that STJs are adept at measuring ordinary light.

By this spring they were ready to publish the results of their first tests, showing that their niobium-based device could record the position and wavelength of individual photons, pinning down their arrival time to less than a millisecond. "Being able to do all these things with a single device," says Perryman, "is what makes STJs unique." It is beyond the reach of the current standard in astronomical detectors, charge-coupled devices (CCDs), which are remarkably efficient at counting photons but give no information about wavelength. That is because only one electron is dislodged when a photon hits this semiconductor device, regardless of the photon's energy. To get a spectrum, astronomers have to pass the light through various filters, diffraction gratings, or prisms before it reaches the detector, with inevitable losses in sensitivity and efficiency. But roughly a thousand electrons are released when an optical photon slams into an STJ, the exact number yielding an instant wavelength reading. What is more, STJs work well under conditions where CCDs falter: in very low light levels, and in the ultraviolet or infrared.

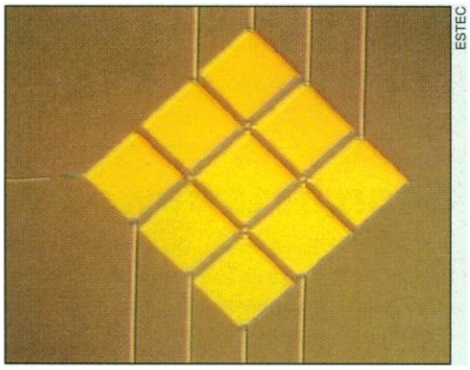


Superconducting sandwich. Twin layers of superconductor will spill electrons into a gap when struck by a photon.

But STJs will need a lot of refining before astronomers can exploit their apparent advantages. The niobium STJ described in *Nature*, for example, can distinguish between light of different colors, but not with the precision astronomers need. However, Peacock and his ESTEC colleagues Peter Verhoeve and Nicola Rando have since developed a more sensitive tantalum STJ. This device must be kept colder than niobium—at about 0.3 K versus 1 K—and at this lower operating temperature, each photon releases more electrons, sharpening the energy resolution of the detector. The result is an ability to distinguish wavelengths of light as little as 7 nanometers apart, compared to 45 nm for the niobium STJ. But even at 7 nm, "most spectral features in a galaxy would be washed out," notes Dan Fabricant, an astronomer at the Harvard-Smithsonian Center for Astrophysics. "If they could get that down to 1 nm, they'd be very competitive with some conventional spectrographs."

Another big challenge is scaling up STJ devices, from the 6-by-6 array ESTEC is currently working on to arrays of thousands or millions of elements that can act as the equivalent of a photographic plate to produce an image. "We've proved that a single junction works," Perryman explains. "But we still need to figure out how to manufacture vastly bigger arrays and wire them up." The problem now, Peacock adds, is that "every single device, every single junction, needs its own amplifier and related electronics." Apart from being expensive, these electronic devices give off heat—unwelcome in a superconducting device—and create "intrinsic" noise that could degrade the measurements.

Of these problems, the heat from the STJ itself should be easier to cope with, according to Yale physicist Dan Prober. The more difficult problem, the noise produced by large numbers of amplifiers, could impose limits on the ultimate array size, Prober says. To push back that limit, he and his colleagues are developing large STJ arrays that rely on fewer amplifiers per pixel. For example, they have taken a strip of tantalum with a tunnel junction at each end. When a photon hits the strip, it creates electrical excitation—in the form of broken-apart pairs of electrons—at the point of impact. These single electrons then diffuse to the junctions at both ends of the strip. By measuring the total excitation,



Modest beginnings. A 3-by-3 array of niobium detectors, each about 20 micrometers on a side.

as well as the amount of charge collected at each junction, the scientists can infer both the photon's energy and location. The Yale group has already tested a prototype x-ray detector that could distinguish 100 different locations on the strip (100 pixels, in other words) with just two junctions and two amplifiers.

Now they plan to extend the same strategy to two dimensions, creating a square of superconducting material with a junction at each corner. "If we can resolve 100 elements in the strip, we should be able to resolve thousands of positions in the square," Prober says. "And we'll need just four amplifiers rather than thousands."

Although plenty of obstacles remain, astronomers are eagerly anticipating putting these new devices to work. A practical STJ detector would be best suited to studying weak sources of visible photons, says Prober—objects that are very cold or very distant. "Anything strong enough to see by eye would overwhelm the detector." But that leaves plenty of possible targets.

Jakobsen, for example, is intrigued by the device's potential to capture ultraviolet photons from extremely faint galaxies. After spending several years trying to design an instrument that ESA could put on the Hubble Space Telescope during a servicing mission in 2002, Jakobsen is now convinced that STJs are the most promising technology, although cryogenic refrigeration in space will pose a challenge. "The Space Telescope's Wide Field Camera has identified thousands of faint galaxies," he explains, "and we want to follow up on those fuzzy blobs and get their redshifts" by measuring their spectra. The task is beyond current Space Telescope instruments but within reach, he thinks, of STJs operating in the ultraviolet range, where their spectral resolution should peak.

Caltech's Kulkarni, who is collaborating with the Yale group, has a different application in mind. As one of the world's premier hunters of pulsars—neutron stars that give off regular pulses of radio waves—he is eager to study these objects in optical wavelengths, where their signals are exceedingly faint. He hopes to have an STJ detector mounted on the 10-meter Keck Telescope in Hawaii within 2 years, and he has urged NASA to launch a "crash program" on STJs.

His colleague, Caltech astrophysicist Chris Martin, is already pondering other applications for STJs, such as examining the dim haze of background light from distant galaxies and other objects that pervade the night sky. "We could survey a big chunk of the sky and get spectral information about every object in the picture," Martin says.

Even so, STJ enthusiasts say the devices will probably be restricted to specialized niches in astronomy for some time, leaving most of the optical field to large CCD arrays. "CCDs are so cheap and reliable, it's going to be hard to knock them off their pedestal," Perryman concedes. Jakobsen—the former skeptic now turned STJ champion—agrees. "We're just adding another tool to the tool chest," he says. "Skepticism about STJs still persists, but there's a lot of excitement too."

–Steve Nadis

Steve Nadis is a science writer in Cambridge, MA.

ASTROPHYSICS

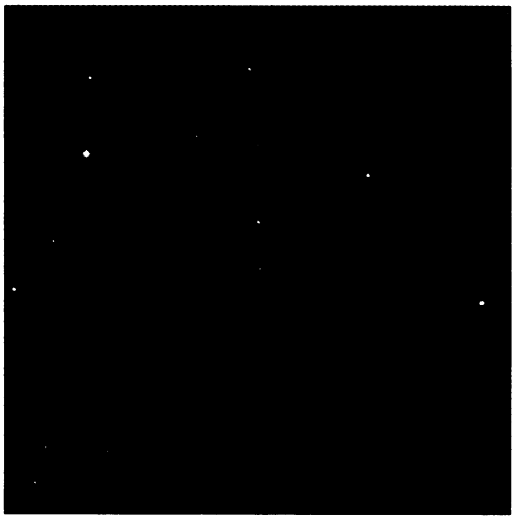
Search Narrows for Gamma-Ray Bursts

For more than 30 years, astronomers have been unable to explain the source of the mysterious bursts of gamma rays that occur approximately once a day in random positions across the sky. Gamma-ray cameras can't pin down the direction of a burst to less than a few degrees. As a result, astronomers haven't been able to link any burst to any known object, or even learn whether these explosive events occur in the neighborhood of our own galaxy or in the far reaches of the universe. But now a simultaneous sighting by an x-ray and a gamma-ray camera on board the Italian-Dutch Beppo-SAX satellite has narrowed the search.

Because x-ray cameras have much sharper angular resolution than do gamma-ray detectors, the 20 July double sighting pinned down the position of the burst to within arc minutes—a precision tens of times greater than before. Astronomers are now scouring the tiny patch of sky, hoping to find an optical or radio "counterpart." No definite candidate has yet been found, but astronomers hope that the double sighting, announced earlier this month in a circular of the International Astronomical Union (IAUC 6467) and described last week at the 82nd National Congress of the Italian Physical Society, will be the first of many that could finally crack the gamma-ray burst mystery.

What made the double sighting possible was the diverse instrument array aboard Beppo-SAX, which was launched last April and is named after Italian x-ray astronomer Giuseppe (Beppo) Occhialini. In addition to a gamma-ray detector, Beppo-SAX also carries an arsenal of x-ray detectors, including two wide-field cameras built by the Utrecht laboratory of the Space Research Organization Netherlands (SRON). On 20 July, one of these cameras happened to be looking in the right direction at the moment the gamma-ray burst occurred and saw a simultaneous burst of x-rays. The positional sensitivity of the x-ray camera enabled astronomers to trace the origin of the burst to a small part of the sky in the constellation Hercules, with a radius of only 10 arc minutes, much smaller than the apparent size of the full moon.

"Small error boxes make the search [for a source] much more meaningful," says University of Chicago astronomer Cole Miller. Astronomers promptly took up the hunt. The Beppo-SAX investigators themselves consulted catalogs of optical sources—stars and galaxies—but were unable to find a suspect counterpart within the error box. Early this month, the Beppo-SAX team enlisted the help of Dale Frail of the National Radio Astronomy Observatory in Socorro, New Mexico, and Shrivinas Kulkarni of the California Institute of Technology in Pasadena to observe the burst area with the NRAO's Very Large Array radio telescope in search of possible radio emissions from the debris of the explosive event. But once again the astronomers found nothing unusual, although "there are plenty of theories which predict a long-lasting radio counterpart after the burst," according to Frail.



DIGITAL SKY SURVEY

Mystery spot. Somewhere in this 15-by-15 arc-minute part of the sky is the source of the gamma-ray burst of 20 July. White circle marks position of x-ray source found by the Rosat satellite.

Thomas Boller and Wolfgang Voges of the Max Planck Institute for Extraterrestrial Physics in Munich, Germany, did find a weak x-ray point source within the SAX error box in 1993 observations by the German Rosat satellite, but Boller and Voges are not sure it has any connection to the gamma-ray burst. In the meantime, their colleague Jochen Greiner has used the high-resolution imager of Rosat to scrutinize the SAX error in detail, and other researchers are making similar observations with x-ray instruments on board the Japanese ASCA satellite and on Beppo-SAX. Results have not yet been disclosed.

SRON's John Heise, project scientist for the x-ray wide-field cameras on Beppo-SAX, believes that the satellite should be able to make such double detections as often as six times per year. Next time, astronomers looking for a counterpart could get lucky, says Jan van Paradijs of the University of Amsterdam in the Netherlands, "especially if the position could be passed on to radio and optical observers much more quickly."

Some astronomers doubt that observations such as those by Beppo-SAX will be accurate enough, however. Princeton University's Bohdan Paczyński says finding counterparts "will not be possible until the error boxes become much smaller still. There are lots of different objects even in a 1-by-1 arc minute part of the sky." That problem may be solved by the High-Energy Transient Experiment (HETE), a small international satellite that is due for launch by NASA in the next few weeks. HETE carries not only gamma-ray and x-ray detectors, but also four sensitive ultraviolet cameras, which can locate sources with even greater precision.

If gamma-ray bursts are accompanied by ultraviolet emission, HETE will be able to pinpoint their locations to within a couple of arc seconds. But if an even more focused hunt still doesn't yield a counterpart, the mystery of gamma-ray bursts will become that much deeper.

–Govert Schilling

Govert Schilling is an astronomy writer in Utrecht, the Netherlands.