come back strong more than 5 million years later in the Carboniferous. The first clue came when Hou Hong-Fei of the Institute of Geological Sciences in Beijing sent Maples and Waters two well-preserved echinoderm fossils dating from just after the extinction.

When Maples and Waters journeyed to far northwest China to investigate, they struck it rich, uncovering more Famennian echinoderm fossils than have ever been collected before. Their finds quadruple the number of known Famennian echinoderm taxa, and together they bear a strong resemblance to the later Carboniferous fauna, said Maples. The evidence suggests that the seas covering that part of China could have been the long-sought echinoderm refuge. There, the creatures were somehow spared the anoxia sweeping other parts of the world and continued to diversify. When conditions elsewhere improved, the echinoderms reconquered their old territories in the rest of the world.

Sorting winners from losers

Identification of refuges can solve only one mystery of recovery periods, however. Another, deeper problem is what enables a group to flourish in the long run, as many Lazarus taxa do, while others bow out for good. As Erle Kauffman of the University of Colorado pointed out at the meeting, the key characteristics might depend on the nature of the extinction. If an extinction is abrupt, as a number of paleontologists believe the Cretaceous-Tertiary extinction was, the ability to evolve rapidly might be a boon. In the wake of the extinction, plenty of ecological niches would suddenly be vacant. The prize would go to the group able to diversify rapidly and fill those niches; more slowly evolving groups would be left in the dust.

Erwin thinks his bellerophonts may be a case in point. Their history until the mass extinction shows they never produced new species or genera very quickly; it took them hundreds of millions of years to diversify into species spread around the world in a variety of environments. That ubiquity helped them survive the extinction, says Erwin, but afterward, when so many new opportunities presented themselves, the bellerophonts couldn't evolve rapidly enough to exploit them. Perhaps as a result, they were eclipsed by other groups.

Still, the ability to diversify rapidly isn't in itself enough to guarantee success. Thor Hansen of Western Washington University noted that four of what he calls "bloom taxa" of mollusks greatly increased their numbers of species per family following the Cretaceous-Tertiary extinction but then, within 5 million years, fell back to the diversity levels at which they had started.

The failure of a quickly evolving species to take firm hold makes sense to Kauffman. For him, a quick evolutionary response may not always be as important as a running start—which is only possible if mass extinctions are gradual affairs. Kauffman thinks all extinctions—including the Cretaceous-Tertiary—were driven by environmental change spanning at least 1 million or 2 million years. Given that much time, some species will be able to adapt to environmental stresses such as changing climate, says Kauffman. As a result, they will have an edge over their rivals in the early recovery period, while those stresses still linger.

Kauffman has found that some seemingly abrupt "explosive radiations" that were assumed to have taken place during the recovery actually began earlier, during the extinction episode itself. The diversification of the bivalve mollusk *Mytiloides* after the Cenomanian-Turonian extinction 90 million years ago, for example, seems to have begun with a "progenitor taxon" that evolved under high environmental stresses late in the extinction.

But meeting attendees agreed that testing these ideas will take a much more detailed view of recoveries than paleontologists have usually had. One way to get the needed detail is to apply the same scrutiny to the fossil record of recoveries that paleontologists have lately given to the extinction episodes. Kauffman, for example, helped pioneer the technique of sampling outcrops every centimeter or so instead of at intervals of meters for studying deposits from extinction intervals; he's now applying it to recoveries. He and others are also attacking the record with geochemical and isotopic techniques for deciphering environmental change and correlating records at different sites. As these efforts start to yield results, paleontologists may finally learn what it takes for a survivor to become a winner.

–Richard A. Kerr

ASTRONOMY

Solar Farms May Reap Gamma Rays

The sun, leisurely crossing the sky each day above Barstow, California, shines its light down on 1800 mirrors belonging to the world's largest solar "farm." In response, the farm does—absolutely nothing. The $140-million experimental facility, designed to convert the sun's energy into electricity, was built during the Carter years when alternative energy was a hot topic. Officially known as the Solar One Solar Power Pilot Plant, it was eventually shut down in the late 1980s.

In an ironic twist, this facility built for the sun may be resurrected by operating at night. A small group of astronomers confirmed recently that Solar One's mirrors, or heliostats, can be used to detect the faint bursts of light produced when gamma rays from deep space crash into Earth's atmosphere. These researchers hope that, if more elaborate tests support this finding, Solar One could explore a part of the gamma ray spectrum to which present detectors are blind and which Iowa State University astronomer Richard Lamb calls "terra incognita." That ability, in turn, would allow astronomers to study some of the most energetic objects in the universe, such as the monstrous black holes thought to lie at the centers of galaxies.

Exploring this untouched territory with Solar One could be not only a productive journey but a relatively cheap one. O. Tümay Tümer of the University of California, Riverside, who first proposed the conversion in 1991, estimates that the solar plant could be turned into a gamma ray detector for the bargain price of $1 million. The only alternative may be to build a new detector at a cost of hundreds of millions. "The good thing about Solar One is it's $140 million lying on the ground there. You can't beat that," Tümer says. But skeptics argue that Solar One, among other limitations, is at a less-than-ideal site and has low-quality mirrors that would reduce its effectiveness.

Boosters and detractors agree, however, that something is sorely needed to fill in a blind spot marring the vision of gamma ray astronomers. In space, instruments such as the EGRET detector on the Compton Gamma Ray Observatory have been able to scan the sky for gamma rays with energies up to 30 gigaelectron volts (GeV). In contrast, ground-based detectors, such as a collecting mirror at Whipple Observatory in Arizona that's 10 meters in diameter, can only catch gamma rays with energies of 200 GeV and higher. "There's this window where we have no observations, and we know exciting physics occurs there," says Michael Salamon of the University of Utah.

O. TÜMAY TÜMER

Solar astronomy. This abandoned solar power plant might provide a new look at the gamma ray spectrum.

One reason astronomers believe something interesting is happening in that window is that phenomena tend to disappear within it. EGRET, out in space, has picked up low-energy gamma rays coming from a few dozen so-called active galactic nuclei (AGN), which are thought to be powered by the accretion of material around a massive black hole. But on the ground, facilities tuned to the higher end of the gamma ray spectrum, such as the Whipple Observatory, have only spotted one of these sources. In between the high and low energies, gamma rays from almost all of these objects are cut off. But at what level? "That's the big mystery," says Rene Ong, who heads a University of Chicago group collaborating with Tümer's team.

Knowing the cutoff level of AGNs could help illuminate a number of phenomena, including a fog of infrared photons that shrouds the universe. Some of the gamma rays from distant AGNs never even reach Earth, presumably because they are weakened by this fog. Determining the energies of these rays would give researchers their first probe of the density and nature of this mysterious infrared background, says Salamon. A complete gamma ray spectrum for AGNs might also resolve a debate about the nature of the huge jets of material commonly found shooting out from the centers of these nuclei. One camp of astrophysicists argues that the jets are largely made up of electrons and positrons; the other camp prefers protons and atomic nuclei. Each side makes slightly different predictions about what energy gamma rays the jets should emit, so observations in the unexplored part of the spectrum "might settle this important question," says Lamb.

Settling that and other questions, astronomers say, can be done with mirrors. Gamma rays themselves can't penetrate the atmosphere, but when one hits, it prompts a cascade of electron-positron pairs whose rapid movements generate shock waves. These shocks produce a cone of so-called Cerenkov light. Lower energy gamma rays produce less Cerenkov light than higher energy rays do, and so "to get to low energies, you need to collect as many Cerenkov photons as possible," says Salamon. Solar One's mirrors, each measuring 20 feet by 20 feet, could, if combined, provide a collecting area 750 times the size of Arizona's Whipple.

Those exploring this approach are starting small, however. In August, Tümer, Ong, and their colleagues showed that they were able to detect Cerenkov light with just 3 heliostats. Each mirror reflected light to its own photomultiplier tube, allowing the researchers to pick out of the background light nanosecond-length intense pulses that are typical of Cerenkov radiation. If further tests are successful, astronomers may then make a formal proposal to operate 50 to 300 heliostats at Barstow, says Ong. With 300 mirrors, Tümer estimates, Solar One could observe gamma rays ranging from 10 GeV to 500 GeV, bridging the gap between ground-based measurements and those made in space.

Solar One may face some friendly competition on another continent. In southern France, Patrick Fleury of Ecole Polytechnique heads a team investigating a solar power plant in Themis. Although Themis has many fewer mirrors than Barstow has, the site has a number of advantages, notes Fleury. It is at an elevation of 1500 meters, much higher than Barstow, and suffers less light pollution, both of which mean Cerenkov cones should be easier to see. By the end of the year, Fleury's group plans to conduct a test run with six heliostats; the eventual goal would be to bring all of the site's 160 heliostats on line, Fleury says, allowing astronomers to observe gamma rays as weak as 30 GeV.

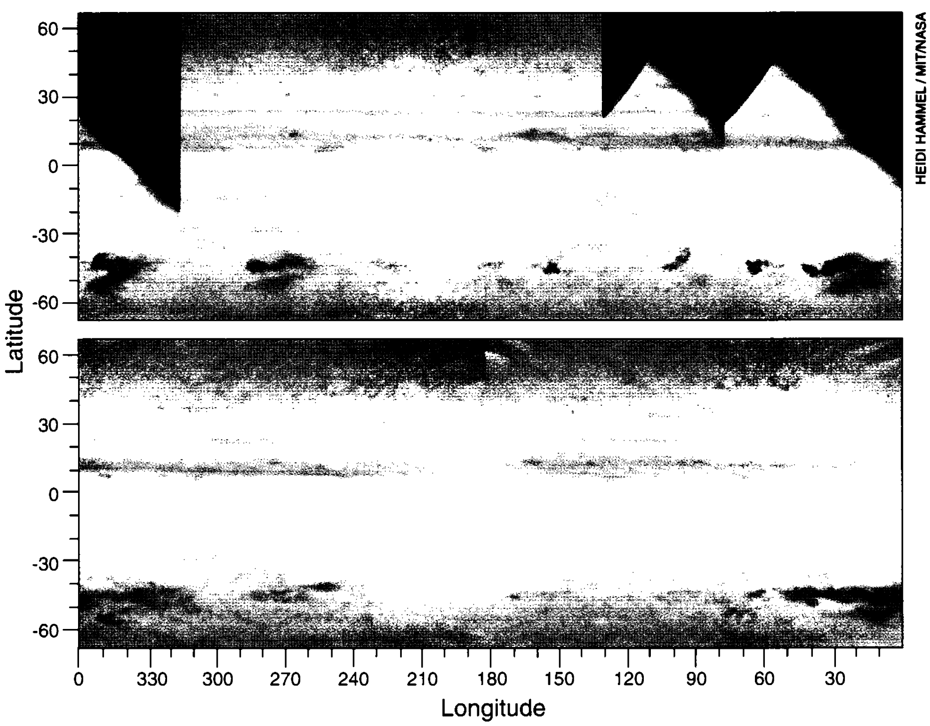
Not all gamma ray astronomers, however, are ready to embrace conversions of Solar One or Themis. They argue that filling the gamma ray gap demands a specialized new detector. "To think you can do it with petty cash and a solar farm is fanciful," says Trevor Weekes of Whipple Observatory. One concern, for instance, is that the Solar One and Themis plants may be able to collect the Cerenkov light from a broad spectrum of gamma rays, but are not well set up to inform astronomers exactly what energy gamma rays produced the light.

As a result, rather than retool solar power plants, some gamma ray astronomers are drawing up plans for next generation detectors such as the "Big Bowl," a 500-meter-diameter hole lined with custom-designed mirrors. But even Salamon, who originated the Big Bowl notion, warns that the $100 million to $150 million needed to construct such a telescope is not likely to be available anytime soon. "It might turn out, for the financial reasons alone, that the solar power plant is the way to go," he says.

–John Travis

PLANETARY SCIENCE

A Giant Licks Its Wounds



Jupiter won't be shaking off the effects of July's impacts by comet Shoemaker-Levy anytime soon—that's what the latest images from the Hubble Space Telescope show. Contrary to some early predictions, the dark splotches of high-altitude debris, shown in a view of the planet's entire surface on 23 July just after the last impact (*top*), were still visible a month later (*bottom*). But they are fading as the debris is stretched along latitude bands by Jupiter's fierce winds and drifts southward, where it encounters winds blowing in the opposite direction and forms swirls. Heidi Hammel of the Massachusetts Institute of Technology, who produced the images, guesses that the debris could be around for a year or two—plenty of time for astronomers to catch more of the healing process.

–Richard A. Kerr