stantial, even against the rule of thumb of 20 to 25% that paleontologists use for denoting different faunal ranges.

Koch notes, however, that the data set for the East Gulf area is four times the size of the Atlantic Coast data set, which difference warns of potential statistical traps. Using the appropriate curves, Koch calculates that, given this disparity in sample size, there would be an apparent difference of some 35 to 40% in species composition between the East Gulf region and the Atlantic Coast, even if the two had been ecologically identical. "I conclude that most of the measured faunal difference results from differences in the amount of data between the two areas," says Koch.

In another example, in which the data sets were of similar size, a species count showed a 31% difference between two locations. But Koch shows that under these circumstances a difference of 12 to 14% would be expected from sampling errors alone, even if the two areas were in fact ecologically identical. The 31% therefore falls to 17 to 19%, which is a real but much less marked difference. And so it goes.

Although Koch is not the first person to remove the statistical traps resulting from sample size effects, his technique is very straightforward and simple. Raup, who with Rex Crick developed in 1979 a "prohibitively expensive" computer program to address the problem, describes Koch's work as "a giant shortcut." Koch's method, says Raup, "produces a very good approximation and is therefore potentially very helpful."

Koch suggests that one way to avoid the sample size problem is simply to eliminate the rare species from the data sets. David Jablonski, of the University of Chicago, is not convinced. "Koch believes that our samples are hopelessly distorted," he says. "But if you look through a whole series of horizons you can reduce the problem and come close to getting a real biological signal out of the data." Jablonski does agree, however, that "There's no question that taking the fossil record at face value can be horribly misleading. Koch is right in saying that although ecologists are aware of the skewed distribution of species in ecosystems, paleontologists in general have not been. We have to be careful in evaluating fossil assemblages. You have to try to compare what you see in the fossil record with what you see in living ecosystems. When you get a good match you know you are looking at a real biological signal." ■ ROGER LEWIN

ADDITIONAL READING

C. F. Koch, "Prediction of sample size effects on the measured temporal and geographic distribution patterns of species," *Paleobiology* **13**, 100 (1987).

Supernova 1987A: Notes from All Over

As Supernova 1987A in the Large Magellanic Cloud continues on its inexorable course—it has currently reached magnitude 3.3, with perhaps another magnitude of brightening to go in the next few months before it begins its long, slow fade into oblivion—astronomers are following its every step with avid interest. Some recent developments:

A New Limit on the Mass of the Neutrino?

As the first reasonably close supernova in modern times, Supernova 1987A also has the distinction of being the first such outburst ever observed via neutrino radiation. The pulse of 11 neutrino events seen in Japan's Kamiokande II proton decay detector, together with the 8 events seen simultaneously in the IMB detector near Cleveland, have not only pinpointed the exact time of the explosion—7:35:41 a.m. Universal Time on 23 February 1987—but have gone a long way toward validating researchers' understanding of the physics of the explosion itself.

Just as important, as more than one theorist was quick to realize, the events can also be used to place an upper bound on the mass of the neutrino (or more precisely, the electron neutrino, which dominates the Kamiokande II and IMB signal). One such analysis was recently presented in *Nature* by John N. Bahcall of the Institute for Advanced Study in Princeton and Nobel laureate Sheldon L. Glashow of Harvard University.

If neutrinos actually have zero mass, they point out, then relativity theory says that the particles must move at precisely the speed of light, which means in turn that they will take a certain amount of time—about 170,000 years—to make the trip from the Large Magellanic Cloud. If neutrinos have a nonzero mass, however, then relativity says they must travel more slowly than light, which means that they will take somewhat longer to make the trip. For any given particle, the actual time delay depends on its ratio of mass to energy; thus, say Bahcall and Glashow, if one could assume that Supernova 1987A had emitted all its neutrinos at once, it would be a simple matter to determine the particles' mass: just plot the energy versus arrival time for all the detected events and read off the answer.

Intriguingly enough, the Kamiokande II and IMB events are spread out over several seconds, which is roughly what one would expect for a neutrino mass of a few electron volts (eV)—precisely the mass range that theorists have favored on the basis of cosmological arguments. Unfortunately, say Bahcall and Glashow, the neutrinos were most assuredly *not* emitted at the same instant. For one thing, the energies and arrival times of the observed events show no consistent pattern. For another, the best theoretical models of supernova explosions suggest that neutrinos were actually emitted over the course of several seconds, as the core of the supernova's massive progenitor star collapsed to form a neutron star.

So from a strictly logical standpoint, say the authors, there is no way to disentangle the effect of an unknown neutrino mass from the effect of an unknown spread in emission times. However, they argue that one can set an upper limit on the mass through a plausibility argument: unless we have been extremely unlucky, the various time delays have probably not conspired to make a very long neutrino pulse look like a very short pulse.

Consider the Kamiokande II record, in which the first eight events are tightly bunched within the first 2 seconds. (The remaining three come almost 10 seconds later.) If one assumes that the mass effect has not compressed this pulse during its flight by more than a factor of 2—a crude and admittedly arbitrary cutoff, but one that Bahcall and Glashow believe is conservative—then one can derive an upper bound for the neutrino mass: 11 eV, or considerably better than the best limits set in terrestrial laboratories (18 eV).

It should be said that not everyone agrees with this analysis. Well before 1987A, for example, University of Chicago physicist David Schramm and his colleagues had already done detailed calculations of supernova neutrino signals and had found that a neutrino mass would produce exactly the kind of pulse compression that Bahcall and Glashow reject. "You can set a reasonable limit of 30 eV," says Schramm. But he is reluctant to push the available data any further.

On the other hand, it is also worth noting that a mass limit as low as 11 eV, if true, would have large cosmological consequences. The universe is filled with a haze of primordial neutrinos left over from the Big Bang, in much the same way that it is filled with the photons of the 2.7 K microwave background radiation. If these neutrinos have any mass at all, then they must exert a large gravitational effect on the visible galaxies, and indeed on the universe as a whole. But if their mass is as small as 11 eV, then their gravitational pull cannot be sufficient to produce what cosmologists call a "flat" universe—one whose expansion will asymptotically slow to zero in the infinite future. Conversely, if the universe is indeed flat, as a number of theories now predict, then the so-called dark matter that controls its expansion must consist of something besides neutrinos.

The closest Supernova

Supernova 1987A (arrow) shines forth in the Large Magellanic Cloud.

National Optical Astronomy Observatories

Some Neutrino Facts

As every elementary astronomy text reminds us, a supernova can flare as brightly as an entire galaxy, briefly outshining billions of less profligate stars. However, as the results from the Kamiokande II and IMB detectors also remind us, a supernova emits more than light. From a global standpoint, in fact, the optical emissions are trivial. The vast bulk of a supernova's energy comes out in the form of neutrinos.

To dramatize that fact, University of Arizona theorist Adam Burrows offers a few numbers:

- The collapsing core of Supernova 1987A emitted some 10^{58} neutrinos in the space of a few seconds. That is about ten times the number of protons, neutrons, and electrons in the sun.
- The total energy carried off by those neutrinos was 3×10^{53} ergs, which is roughly equivalent to converting a tenth the mass of the sun into pure neutrino radiation.
- The total kinetic energy produced in the explosion, largely contained in a shell of matter blasted outward at some 17,000 kilometers per second, is smaller than the neutrino energy by a factor of 100. The energy of the emitted light is a factor of 100 smaller than *that*.
- Leaving aside other blast effects, 1987A's neutrino flux alone would have been deadly to an unprotected human out to a radius of nearly a billion kilometers, comparable to the orbit of Jupiter in our own solar system—even though neutrinos only interact via the weak interaction.
- To get a sense of how feeble the weak interaction really is, consider that 1987A sent some three thousand trillion (3×10^{16}) neutrinos through the 7000-cubic-meter IMB detector. Allowing for detection inefficiencies, the experimenters estimate that only about 22 neutrinos actually interacted in the detector.
- With some 4 billion human beings on Earth, the neutrino pulse from 1987A caused roughly 1 million of us to experience a neutrino interaction somewhere in our bodies.

Sanduleak −69 202: Guilty as Charged

For supernova watchers, the month of March 1987 brought more than its share of confusion. The observed position of Supernova 1987A corresponded almost exactly, to within 0.1 arc second, with a 12th-magnitude star known from an earlier survey as Sanduleak −69 202. The closest neighbor lay at a distance of 3 arc seconds, some 30 times farther away. Moreover, preexplosion spectra showed Sanduleak to be a supergiant star of spectral type B3, meaning that it was more or less the kind of very hot, very massive young star that astronomers would expect to become a supernova. The obvious conclusion was that star and supernova were one and the same: Sanduleak −69 202 had exploded.

Except that it apparently had not. Spectra from the International Ultraviolet Explorer (IUE) satellite, taken at wavelengths where the supernova was already fading rapidly, seemed to show both Sanduleak and its neighbor shining through unchanged. According to Robert Kirshner of the Harvard-Smithsonian Center for Astrophysics, principal investigator for supernova observations on the IUE, Sanduleak could not possibly have been the culprit—which left theorists in the awkward position of trying to explain how the unknown progenitor star could have simultaneously been too dim to be seen from Earth, and yet big enough to go supernova.

Now, however, the theorists are breathing easier: it was Sanduleak after all. "I haven't recanted," laughs Kirshner. "I've just examined the data more carefully."

The confusion, he says, lay in thinking that only two stars were involved. In fact, there were three. In early April, a group from the European Southern Observatory circulated a fresh analysis of the old photographs that included the coordinates of a third star lying some 4 arc seconds from the second.

"When I saw the circular I felt a little queasy," recalls Kirshner. "There was something going on we didn't understand." He and his colleagues accordingly made a painstaking reexamination of the IUE data, using software that has recently been developed for such tasks at the Goddard Space Flight Center, which operates IUE. In the end they found that the two IUE sources were separated by 4 arc seconds, not 3. Moreover, one of the spectra was clearly that of star 2—and the other spectrum, although noisy, was clearly *not* that of Sanduleak. In other words, the IUE spectra were almost certainly showing stars 2 and 3. Sanduleak has indeed blown up.

The theorists are thus off the hook, at least partially. Now all they have to do is explain why Supernova 1987A is about 50 to 100 times dimmer than similar supernovas seen in other galaxies—is it just that astronomers never noticed the dim ones before?—and why Sanduleak died while it was still a hot blue supergiant star when most of the existing supernova theories had called for a cooler, bigger, more highly evolved *red* supergiant. ■ M. MITCHELL WALDROP

ADDITIONAL READING

J. N. Bahcall and S. L. Glashow, "Upper limit on the mass of the electron neutrino," *Nature (London)* **326**, 476 (1987).