ASTRONOMY

No Backing Off From the Accelerating Universe

Intensive scrutiny of data from distant exploding stars has not shaken the conclusion that the universe contains a large-scale repulsive force

CHICAGO—Early this year, two international teams of astronomers came to an extraordinary conclusion about the nature of the universe: The unexpected dimness of distant, exploding stars called supernovae indicates that a large-scale repulsive force permeates the universe, accelerating its expansion and sweeping distant objects unexpectedly far away. Last week, a workshop* was held here to see how that conclusion is holding up in the face of new data and to give other astronomers a chance to challenge the results. But the wary posture first adopted by many researchers turned into an embrace: The teams' original conclusion not only withstood the intensive scrutiny, it actually gathered further support.

One by one, participants took up possible confounding factors that could be making the supernovae look farther away than they are, which would mimic the large-scale repulsion generated by a background energy called the cosmological constant, or lambda. None of the possible suspects—cosmic dust, weaker explosions in the distant, early universe, or other effects—could explain away the results. "I personally very much dislike the cosmological constant," said Mario Livio, an astrophysicist at the Space Telescope Science Institute in Baltimore. "But given the existing observations, there is a lambda."

While astronomers like Livio may accept the message of the supernovae reluctantly, some cosmologists welcome it, because it rounds out a consistent picture of the origin, contents, and fate of the universe (see p. 1247). But with so much riding on these stellar explosions, the pressure is on for theorists to understand just why the explosions are so uniform—and therefore why they are such apparently reliable beacons.

By studying nearby examples of the brilliant supernovae called type Ia's, observers long ago determined that they blow up with the same absolute brightness each time, so that their apparent brightness as seen from Earth can serve as a distance measure. More recently, observers found that they could correct for small, residual differences in the explosions, because intrinsically brighter supernovae, for example, signal their presence by taking longer to light up and fade than dimmer ones do. "This is a way to 'read the wattage of the light bulb,' " said Alexei Filippenko of the University of California (UC), Berkeley, and a member of the High-z Supernova Search Team, which is led by Brian Schmidt of the Mount Stromlo and Siding Spring Observatories in Australia.

Reassured by these local observations, Schmidt's team and the Supernova Cosmology Project, led by Saul Perlmutter of Lawrence Berkeley National Laboratory and UC Berkeley, have been pushing far out into the universe and back in time by finding supernovae in distant galaxies, then measuring their brightness and the rate at which cosmic expansion is carrying them away from Earth. The announcements early this year were among the first results of the quest, and at the meeting, Filippenko and Perlmutter gave separate talks on the teams' latest haul of data. Perlmutter's group has now fully analyzed 42 distant supernovae with more in the pipeline, while the High-z team is now adding about a dozen new events to the 16 it has already published. The newest measurements only reinforce the earlier conclusion: The expansion of the universe has sped up since the supernovae exploded billions of years ago, by an amount implying that 70% of the universe's energy is in the form of lambda.

Blasts from the past. Supernovae flare in distant galaxies.

"You will see that we are in remarkably violent agreement," joked Perlmutter about the two highly competitive groups. Both speakers then described how they have tried to rule out the possibility that they are being fooled by cosmic dust, which signals its presence by reddening the supernovae—just as dust reddens the setting sun. Whether the astronomers apply a correction to the brightness of the red supernovae or simply throw them out, said Perlmutter, the conclusions do not change. The teams are pressing the search for unknown forms of "gray" dust that might shroud only distant explosions and not redden them. So far, all tests have turned up negative.

The teams have also considered the possibility that type Ia supernovae were intrinsically dimmer in the past, perhaps because the raw materials that made up the parent star were less "polluted" with heavy elements—which gradually build up in galaxies as generations of stars are born and die. But in a joint study, the teams found that the spectra of nearby and distant supernovae match at virtually every bump and wiggle after the simple "wattage" correction, implying that the composition of near and distant supernovae is the same.

There are other reasons to doubt that different levels of heavy-element pollution in the host galaxies are throwing off the results, said Philip Pinto of the University of Arizona, Tucson, who is not a member of either team. "We have such a rich sample of galaxies to sample from nearby," said Pinto—some of them heavily polluted and some not. "And we don't see any differences among the local, really well-observed supernovae."

But theorists can't say exactly why the supernovae appear to work so beautifully as standard candles. "As the referee in this contest between the theorists and observers," said the University of Chicago's Donald Lamb, an astrophysicist who chaired a lengthy session on explosion mechanisms, "I hereby declare that the observers have won hands down."

Even so, initial work by the theorists suggests it's at least plausible that type Ia's explode with such predictable fury. The explosions are thought to originate from a particular type of white dwarf star—a dim, dense, stellar cinder made mostly of carbon and oxygen. In one explosion scenario, the dwarf's gravity steadily sucks material from an ordinary companion star. When the dwarf's mass passes a particular value called the Chandrasekhar limit, it begins to contract under its own weight, heating the carbon core and igniting thermonuclear fusion there.

That uniform mass threshold could help explain the regularity of the ensuing explosion. And other factors could push the ex-

* "Type Ia Supernovae: Theory and Cosmology," University of Chicago, 29–31 October.

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plosions even closer to uniformity, said Ken'ichi Nomoto, reporting on work he did with Izumi Hachisu at the University of Tokyo and Mariko Kato at Keio University in Japan. Their calculations suggest that a white dwarf can steal material from a companion star and blow up only if it has a specific composition. Material ripped from the companion, he explains, tends to form a huge gas cloud around the dwarf, which could disrupt the steady accretion. The accretion can proceed only if the white dwarf sweeps away the cloud with a strong wind.

Intense x-rays from the white dwarf drive material off the dwarf's surface and so create the wind. But the wind will be either too weak to disperse the cloud or so strong that it prevents all accretion unless the white dwarf is laced with just the right amount of x-ray–absorbing heavy elements—ensuring further uniformity. "If anything, it strengthens [the case] for a standard candle," says Livio.

The clinching evidence that the supernovae are telling the truth about cosmic expansion, however, could come from further observations. Both teams are reaching for more distant supernovae, which probe the expansion rate even earlier in cosmic history. In the young universe, when the same amount of matter was crammed into a smaller volume, gravity should have overwhelmed the unchanging boost of the cosmological constant, slowing the expansion. The earliest supernovae should appear relatively close and bright—an effect that no confounding factor suggested so far could create. Perlmutter's team took the lead last month, discovering what is probably the most distant supernova yet at the 10-meter Keck Telescope in Hawaii.

Named after the composer Tomaso Albinoni (Perlmutter's team now has so many supernovae to keep track of that they have taken to naming them after composers), this event is more than 8 billion light-years away. With many more like it, the team should be able to see the brightening. So far, the musical theme fits: As far off as the searchers can find them, the supernovae all keep playing the same tune.

–JAMES GLANZ

MARINE GEOPHYSICS

Ocean Drilling Floats Ambitious Plans for Growth

A proposed major expansion of the world's ocean drilling research program is taking the community into uncharted waters

For 15 years, a vessel that looks like a cross between a freighter and an oil derrick has been roaming the oceans, boring holes in seafloor sediments and crust. Its team of roughnecks and scientists has sampled ancient muds beneath the ice-infested waters of Antarctica and rocky crust off the Galápagos Islands. However, some of the most tempting scientific targets on the ocean floor, including unstable sediments, oil- and gas-rich regions, and the deepest reaches of the crust, have been off limits to the *JOIDES Resolution* and the Ocean Drilling Program (ODP), the 22-nation scientific consortium that operates it. Next year, Japan hopes to begin building a \$350 million drill ship that could open up these forbidden zones. But researchers don't know if their governments will be willing to spend the extra money needed to operate that country's generous gift to the ocean drilling community.

Japan's plans, expected to be approved early next year by the Diet, call for up to \$40 million to start construction of a ship equipped with a riser—a pipe enclosing the drill pipe—that extends from the ship to the sea floor. Risers, which are standard on deep-sea oil platforms, allow drillers to flush heavy debris from deep holes and shore up unstable sediments. They also help provide a safeguard against blowouts when the bit penetrates oil or gas deposits. Japan intends to pick up the entire tab for building the ship, which should be completed by 2003, just when the ODP's lease on the *JOIDES Resolution* will end. The timing seems perfect, and many ocean drillers would welcome the riser ship's capabilities. "We've come up against these technological barriers. … We need a riser drill ship," says ODP director Kathryn Moran.

The problem is that most people in the ocean drilling community believe the program also needs a second ship, to replace the *JOIDES Resolution*, that could drill less ambitious holes in rapid succession while the riser ship concentrated on more challenging projects. And they know that the annual cost of operating two ships—roughly \$130 million, or nearly three times the current \$44 million budget—is steep. "The [U.S.] National Science Foundation and we are aware there has to be new money if [a two-ship program is] going to fly," says Michael Arthur, a geochemist at Pennsylvania State University, University Park, and chair of the U.S. Science Advisory Committee to Joint Oceanographic Institutions Inc., which runs the ODP from Washington, D.C. Although no one can say how NSF and its counterparts in Europe will be able to find that new money, administrators and scientists have already set up the framework for a successor to the ODP, dubbed the Integrated Ocean Drilling Program (IODP), that assumes the use of two ships.

Clear sailing. JAMSTEC's Kinoshita says Japan is committed to a riser ship.

There is no question that the limitations of the *Resolution* are hindering scientific progress. For example, Arthur notes that a recent attempt to drill into a fault in the Woodlark Basin in the western Pacific had to be stopped after a rising hydrocarbon content indicated that drillers might be approaching an oil or gas deposit. The *Resolution*'s attempts to drill more than about 2 kilometers into the crust beneath the sediments, even in the absence of oil and gas deposits, have been foiled by jammed drill bits and poor core recovery. Nor has the ship had much luck drilling through the loose sands along continental margins, which provide a record of changing sea level.

DRILL SHIPS—PRESENT AND FUTURE

	JOIDES Resolution	Japanese vessel
Length	143 m	190 m
Annual cost	\$44 million	\$85 million, est.
Max. hole depth	2.1 km	5–7 km
Max. water depth	6 km	2.5 km, eventually to 4 km
Gross tonnage	9719 tons	~30,000 tons
Riser	none	2.5 km, eventually to 4 km

Outgunned. By any comparison, Japan's proposed drill ship is impressive, although the *JOIDES Resolution* can drill cheaper holes.

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