HIGH-ENERGY ASTROPHYSICS

Gamma Ray Bursts May Pack a One-Two Punch

Unexpected lines in x-ray spectra hint that the universe's most energetic explosions are triggered by a delayed-action fuse

Scientists have fingered a new suspect in a case of unimaginable cosmic violence. The mystery, which has haunted astrophysicists for 3 decades, is what causes gamma ray bursts—short, intense flashes of high-energy photons that occur about once a day somewhere on the sky. In early 1997, observations by the Italian-Dutch BeppoSAX satellite and follow-up studies with ground-based telescopes traced the flashes to cataclysmic explosions in distant reaches of the observable universe. But what could cause the explosions, which produce more energy in 1 second than the sun will emit in its entire 10-billion-year lifetime?

Most astrophysicists now agree that the answer is a hypernova, the blast of energy released when a supermassive star collapses into a black hole. A rival hypothesis—that the implosion occurs when two neutron stars collide—is less popular, although some astrophysicists invoke it to explain very short gamma ray bursts with a distinctive energy distribution (see sidebar).

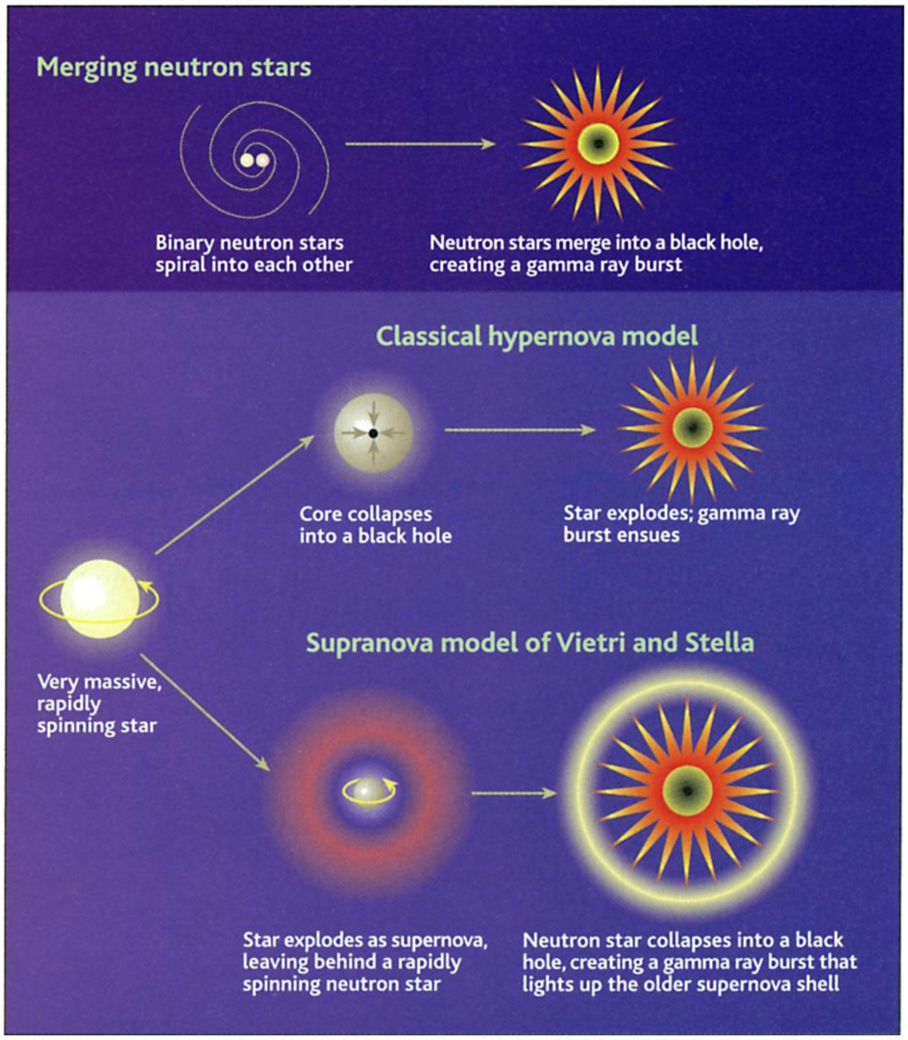
Two papers in this issue of *Science* (pp. 953 and 955), reporting on new x-ray observations of two gamma ray bursts, embrace a modified form of the hypernova model. On its way to becoming a black hole, the authors propose, the supermassive star actually collapses twice. "The classical hypernova model is dead," says Mario Vietri of the Third University of Rome, a co-author of both papers.

The new observations were the talk of the day at a recent workshop.* "This is the second most important BeppoSAX discovery" after the first bursts were pinpointed in 1997, says Filippo Frontera of the CNR Institute of Technology and Cosmic Ray Studies (TeSRE) in Bologna, Italy. "It's very exciting," adds theorist Peter Mészáros of Pennsylvania State University, University Park.

According to standard stellar evolution theory, a massive star ends its short life in a supernova explosion, blasting most of its mass into space. The star's core implodes into a small, compact neutron star, or, if it is massive enough, into a black hole. Although the details of black hole formation are unknown, astronomers believe that the final stages of the process may release huge amounts of energy, as trillions of tons of superheated gas are instantaneously sucked into the hole at almost the speed of light.

The hypernova or collapsar model was first proposed by Bohdan Paczyński of Princeton University and independently by Stan Woosley of the University of California, Santa Cruz. It describes how the core of a supermassive, rapidly rotating star collapses all the way into a black hole after it runs out of nuclear fuel, while two powerful jets of matter and energy shoot into space in opposite directions. Internal shocks in the jets and the interaction of the jets with circumstellar material create the gamma ray burst. The model helps to explain why many gamma ray bursts occur in star-forming regions, where massive stars still reside at the end of their relatively short lives. It won additional converts in April 1998, after a gamma ray burst was observed to coincide with a strange supernova (*Science*, 19 June 1998, p. 1836).

The new x-ray observations show further evidence of stellar explosions in the redshifted radiation from two bursts. On page 953, a team led by Lorenzo Amati of TeSRE reports BeppoSAX observations of iron-absorption features in the x-ray spectrum of GRB 990705 (the gamma ray burst of 5 July 1999). On page 955 Luigi Piro of the CNR Institute of Space Astrophysics in Rome and his colleagues report observations by NASA's Chandra X-ray Observatory of iron emission in the spectrum of GRB 991216.



SOURCE: G. SCHILLING

Third way. Neutron stars or supernovas? Iron detected millions of kilometers from ground zero suggests gamma ray bursts result from stars that explode twice.

* Gamma ray bursts in the afterglow era, 17–20 October, Rome.

X-ray Satellites Seek Clues to Bursts

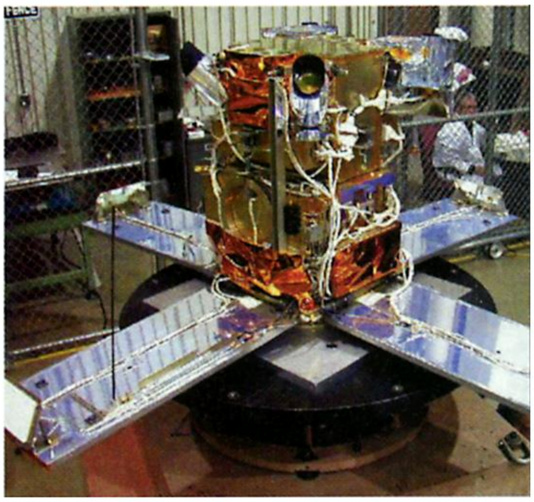
Scientists rejoiced last month when the High Energy Transient Explorer 2 (HETE-2), the first satellite dedicated to spotting gamma ray bursts, rocketed successfully into orbit from Kwajalein Missile Range in the Pacific Ocean. The new orbiting observatory bolsters a handful of x-ray satellites whose instruments are trained on the mysterious explosions. But researchers say setbacks to the fleet have left unfortunate gaps in coverage.

Launched on 9 October, HETE-2—built by the Massachusetts Institute of Technology in Cambridge, in collaboration with NASA and institutes in the United States, France, and Japan—is expected to be the field's workhorse for the next 4 years. It will provide precise positional information for about one burst per week. The data will reach ground-based observatories within seconds, through a continuous satellite link and a dedicated Internet service. Large optical and radio telescopes will then study the burst, which may still be in progress, as well as its afterglow and the distant galaxy in which it occurs.

Astronomers hope HETE-2 will solve the riddle of short bursts—a distinct group of explosions, each lasting less than a second, that have never been studied in detail. Because short bursts are much briefer than ordinary gamma ray bursts and have a different distribution of energies, many astronomers suspect that they result from a different explosion mechanism. "HETE-2 can give precise positions for these short bursts and enable counterpart identification to determine if they have the same properties as long bursts," says Neil Gehrels of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Because HETE-2 cannot detect x-ray spectra, it can play only a supporting role in such crucial work as scrutinizing gamma ray bursts and their afterglows for traces of iron (see main text). For studies like that, satellites such as NASA's Chandra X-ray Observatory and the Italian-Dutch BeppoSAX are the instruments of choice. What would have been an even better x-ray observatory, the Japanese ASTRO-E satellite, plunged to Earth in February after its launch rocket misfired (*Science*, 18 February, p. 1178).

Another potential burst-hunter is out of the lineup by fiat. According to Luigi Piro of the CNR Institute of Space Astrophysics in Rome, the European XMM-Newton x-ray satellite, launched in December 1999, is actually better equipped than Chandra to observe spectral features in gamma ray bursts. Unfortunately, he says, the European Space Agency doesn't accept "target of opportunity proposals" that let researchers respond rapidly to unexpected events such as gamma ray bursts. "They're missing a big opportunity here," Piro says. "I hope they will change their minds."



Good as gold. HETE-2 is set to be the workhorse of gamma ray–burst astronomy.

Meanwhile, BeppoSAX may get a new lease on life. Launched in April 1996, the mission was originally funded for 5 years. But according to Filippo Frontera of the CNR Institute of Technology and Cosmic Ray Studies in Bologna, Italy, a request to extend its life for 1 year has recently been presented to the Italian Space Agency ASI. A funding decision is expected early next year.

–G.S.

(Another group, led by Angelo Antonelli of the Astronomical Observatory of Rome, has since detected iron in the x-ray spectrum of a third gamma ray burst, GRB 000214.)

Astrophysicists believe that all the iron in nature forms in nuclear reactions inside stars and escapes when the stars explode. "You really need a supernova" to produce the large amounts of iron that Chandra detected, Piro says, a finding consistent with the hypernova model. The hitch, Vietri says, is that the observations by Amati's group show that dense, iron-rich material already appears to have traveled millions of kilometers from the center of the explosion by the time the burst takes place. "In the hypernova model, there's no time [for the iron] to cover these large distances," he says.

So Vietri, together with Luigi Stella of the Astronomical Observatory of Rome, has proposed a new scenario, the "supranova model." It assumes that a massive star first explodes as a supernova, shedding its iron into space and leaving a spinning neutron star behind. For a few months or years, the rapid rotation of this stellar remnant keeps it from collapsing into a black hole. Eventually, though, the neutron star slows down, probably because of magnetic braking. Then it implodes, touching off a gamma ray burst.

Not everyone is convinced. "The 'supranova model' is not a model but a wish," Woosley says. "There are no detailed dynamical calculations to back it up." Mészáros admits that the iron-absorption features may be difficult to explain in the original hypernova model, but he says that Vietri's model is only "a possibility. The case is not yet proven."

Martin Rees of Cambridge University is bothered by what he calls an "unnatural" long delay between the supernova and the gamma ray burst. "Most people would guess that the [final] collapse would happen after minutes, not months," he says. Rees and Mészáros say they have worked out a simpler explanation for the new x-ray observations, in a paper in press at *Astrophysical Journal Letters*.

Some critics even doubt whether the spectral lines themselves are real. Rees says it is curious that Chandra spotted the faint emission features at an energy to which its detector is most sensitive; it would be quite a coincidence, he says, if the spectrum were redshifted into just the right range. And Woosley wonders why the Japanese ASCA x-ray satellite hasn't detected similar spectral features.

Piro admits that his team needs to do more work, starting with a reanalysis of x-ray spectra of old gamma ray bursts. "We're basically in the same stage as when the first iron lines were observed in [the spectra of] active galactic nuclei," he says about disputed sightings that finally won acceptance.

The clues that crack the case may well come from a newcomer to the investigation. In December scientists at the Massachusetts Institute of Technology in Cambridge will start receiving observations from the HETE-2 orbiting gamma ray observatory, launched on 9 October. Its early-warning capability, Rees says, might enable astronomers to study the crucial first hour of a gamma ray burst's afterglow. "It's terribly important to see what the [iron] line does" at that time, he says. "If we discover line changes, that would be a very important clue."

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CREDIT: MIT