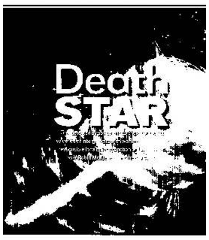
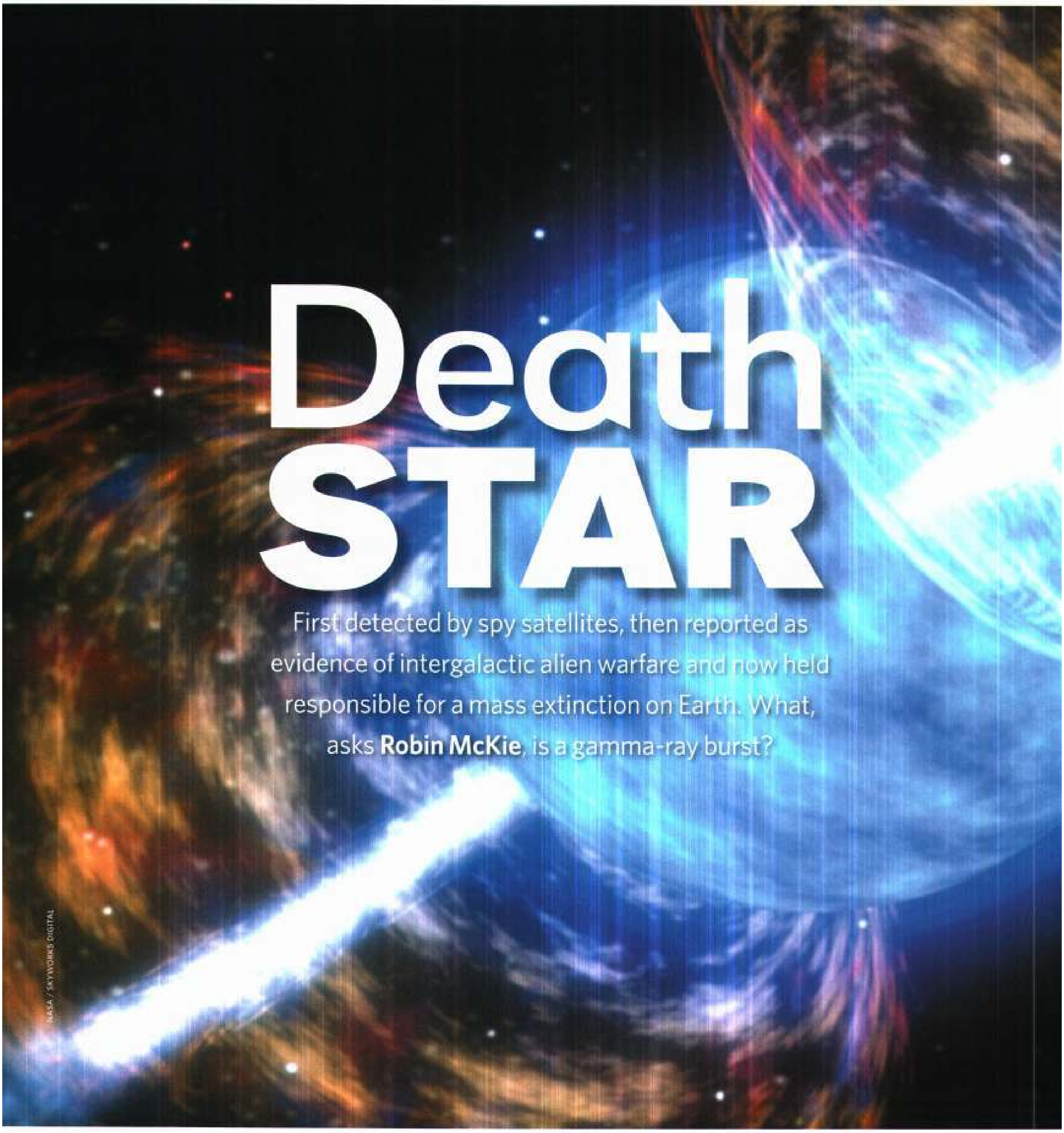
Cosmos
01/09/2009
Page: 70
Section: General News
Region: national Circulation: 25000
Type: Australian Magazines Science /Technology
Size: 3330.00 sq.cms
Frequency: Bi-monthly



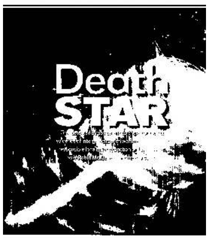


Death STAR

First detected by spy satellites, then reported as evidence of intergalactic alien warfare and now held responsible for a mass extinction on Earth. What, asks **Robin McKie**, is a gamma-ray burst?

NASA / SKYWORKS DIGITAL

MEDIA MONITORS



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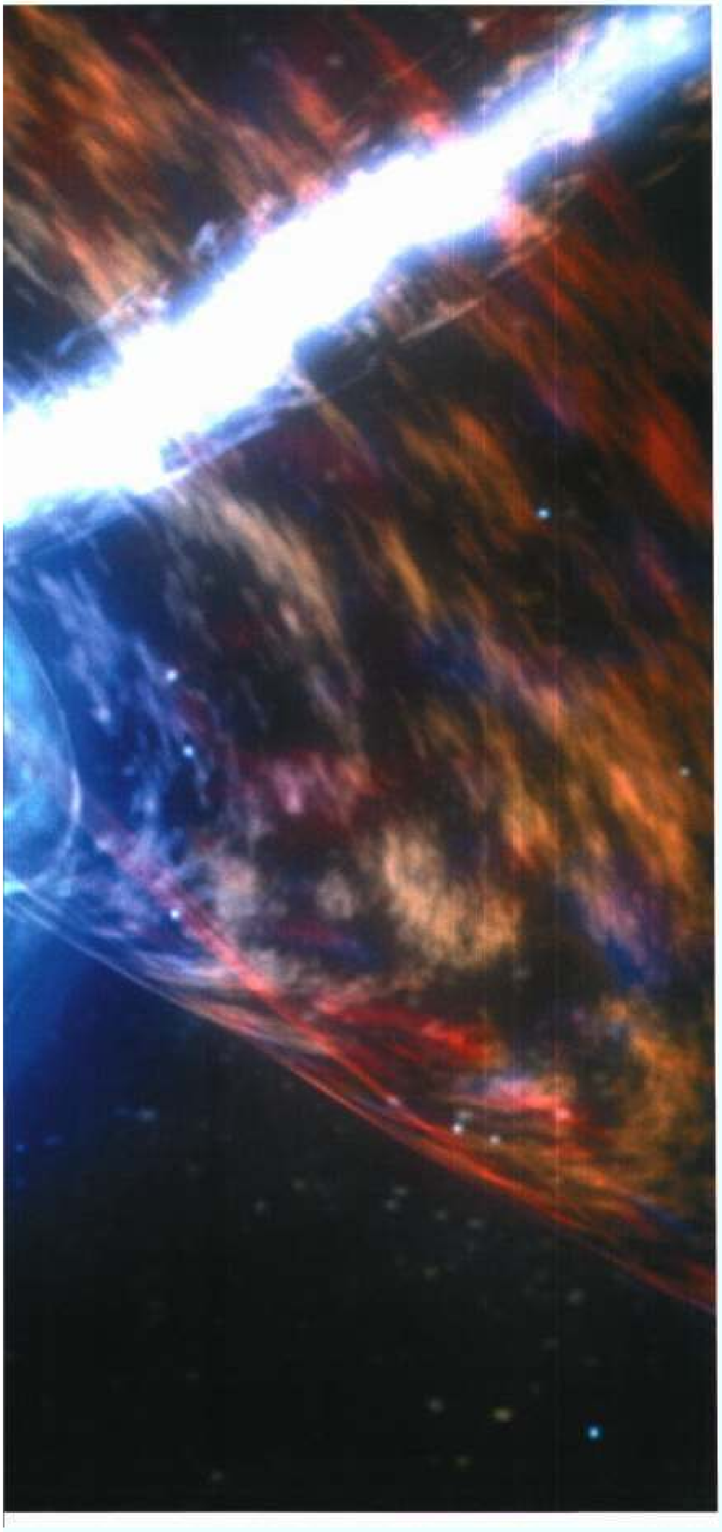


OBSERVERS OF THE northern night sky during the early hours of 19 March 2008, would have made little of the flicker of light that appeared briefly in the constellation Bootes. The display lasted a few minutes before fading and then disappearing. As far as astronomical shows go, this was a damp squib.

Yet the display was special. Indeed, it was one of the most remarkable celestial occurrences ever recorded by human beings. That light, which so briefly illuminated the heavens, had taken almost eight billion years to reach our world – but was still visible to the naked eye.

By a very large margin, the spectacle – produced by photons that had travelled half way across the universe – was a record-breaker. "If someone just happened to be looking at the right place at the right time, they saw the most distant object ever seen by human eyes without optical aid," says Stephen Holland of NASA's Goddard Space Flight Centre in Maryland, USA.

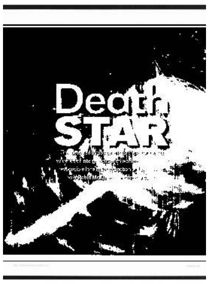
As to the cause, scientists are now certain that the light was associated with a gamma-ray burst, the most energetic event in the universe. Triggered when giant stars destroy themselves, these are the biggest bangs since the Big Bang itself.

"Gamma-ray bursts occur when a giant star uses up all its fuel, collapses, and turns a vast amount of its mass into hard radiation in a few seconds, leaving behind a massive black hole," says Neil Gehrels, another Goddard astrophysicist. The star emits a blast of gamma radiation, followed by a burst of X-rays and finally, a pulse of visible light: "the death throes of a great star and the birth cries of a black hole," as Gehrels describes it.

This is physics at its most extreme. Almost daily, one of these violent stellar paroxysms is detected by astronomers (see "The light fantastic", p73). Yet only a few decades ago, scientists had absolutely no idea of their existence. The story of their discovery is one of the most extraordinary scientific detective tales of modern times and takes us from the intrigues of the Cold War to the setting up, in the 21st century, of the slickest, most complex astronomical operation ever devised: a series of satellites that track these eruptions, alerting astronomers, on 24-hour duty, so they can then turn their huge, mountain-top telescopes to study the glowing leftovers.

Explaining the existence of gamma-ray bursts has also pushed scientists to the limits of their understanding of the laws of physics. And although many mysteries have been solved, some issues still perplex astronomers. A puzzling new class of bursts has been recently discovered, for example, while it has even been suggested that radiation from these objects could have changed the course of evolution here on Earth.

And there is more. Gamma rays are the most energetic and most dangerous type of electromagnetic radiation. Astronomical sources include the Sun, though its weak emissions are blocked by our atmosphere. But the radiation from a nearby gamma-ray burst would be a different matter. "If one went off in our galactic neighbourhood, we would be fried," says astronomer Julian Osborne, from the University of Leicester in England. "The radiation could wipe out life on Earth." »



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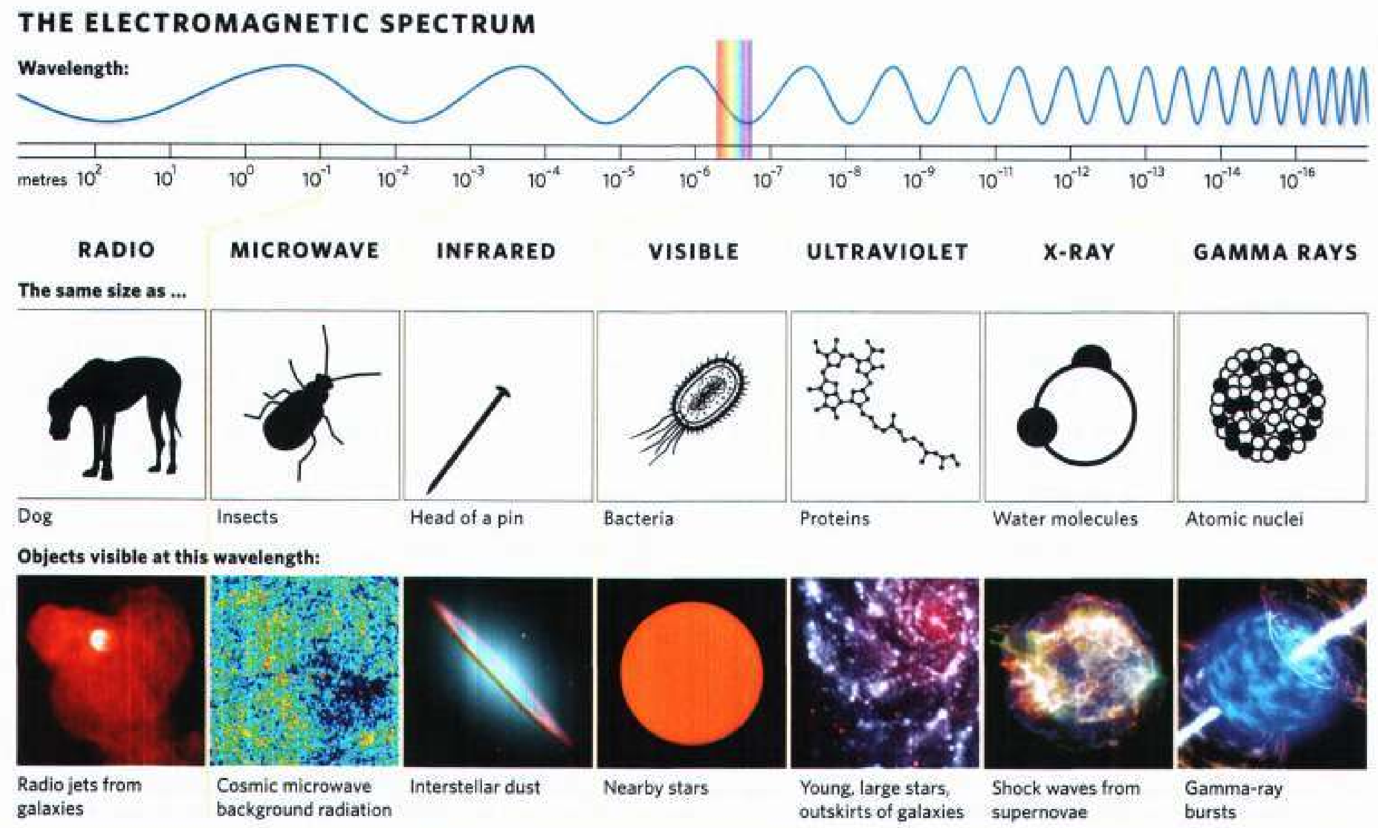


The electromagnetic spectrum classifies different types of radiation. The properties of the different types of radiation depend on wavelength, which can vary from hundreds of kilometres down to a fraction of the size of an atom. Human eyes can only detect radiation in the visible part of the spectrum, but many objects in the universe emit radiation outside these visible wavelengths. In fact, many objects can only be detected at very specific wavelengths. The giant lobes of energetic gas inflated by the jets from supermassive black holes can only be seen at radio wavelengths; microwave radiation provided astronomers with clues about the Big Bang; interstellar dust can only be seen in infrared; stars such our sun emit visible light; stars younger and larger than our Sun, often found in the outskirts of galaxies, emit more ultraviolet light; and X-rays are emitted from gas heated by recent supernovae. Gamma rays are the most energetic and dangerous of all types of radiation - yet gamma-ray bursts are invisible to us.

Clearly, gamma-ray bursts are remarkable events. So let us look in detail at their origins, their possible impact on Earth – and the intriguing story of their discovery.

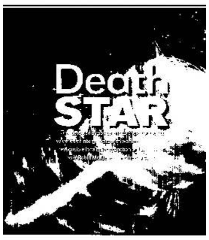
ON 2 JULY 1969, physicists Ray Klebesadel and Roy Olson sat down in a tiny office at the Los Alamos National Laboratory in New Mexico to examine data sent back by the U.S. Vela 4 spy satellites. At the time, the U.S. was afraid the Soviet Union was planning to test atomic bombs in space, far from prying Western eyes, in order to gain a lead in nuclear weapons development. So two Vela satellites were placed in orbits over 100,000 km high and fitted with instruments that could detect gamma rays released by an atomic blast.

For two years, the spacecraft operated perfectly, though no nuclear explosions were ever detected. However, the craft did pick up several mysterious bursts of gamma radiation of only a few seconds' duration (too brief to have come from a nuclear explosion). So Klebesadel and Olson decided to investigate. At first, they found no correlation between the two probes' signals – one would detect a burst but not the other – until they reached records for 2 July 1967 and discovered a powerful gamma-ray signal that both craft recorded. "It was reproduced very accurately between the records of the two spacecraft," Klebesadel later recalled. "It was clearly not the response to a nuclear detonation, but it was definitely something of interest."

Klebesadel and Olsen checked that day's solar flare activity but drew a blank. Nor could they link the burst to any other known astronomical event. So they continued collecting data, identifying another dozen similar bursts. They presented their findings at an American Astronomical Society conference in Columbus, Ohio, in 1973. Inexplicable eruptions of hard radiation – each lasting a few seconds and unrelated to any known body in the universe – had been discovered at completely random times, they announced.

The National Enquirer, the U.S. supermarket tabloid, was – remarkably – the only newspaper that covered the conference, and published what is likely to be the first story on gamma-ray bursts: "Mysterious explosions in space baffle top U.S. scientists". Five years later, with observations of gamma-ray bursts accumulating and plausible explanations remaining scarce, *The National Enquirer* found its own explanation: "Aliens in Outer Space Fighting Real-Life 'Star Wars'".

"That wasn't at all what I had said," stressed Klebesadel. For their part, scientists were mystified. "We didn't know



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Aliens in Outer Space Fighting Real-Life 'Star Wars'

. . . Say Leading Scientists

Real-life "Star Wars" are raging in outer space!

Top scientists believe that mysterious explosions in deep space — which resemble huge nuclear blasts — are the result of alien beings locked in a furious intergalactic war.

INTERGALACTIC WAR This is an artist's interpretation of what a war in deep space could look like.

The National Enquirer, p5 1979

> With observations of gamma-ray bursts accumulating and plausible explanations remaining scarce, *The National Enquirer* found its own explanation: "Aliens in Outer Space Fighting Real-Life 'Star Wars'".

whether these firecrackers were going off next door or at the edge of the universe," says Stan Woosley of the University of California at Santa Cruz. Most astronomers preferred simple, local explanations and argued that pulsars, white dwarf stars or globular clusters were involved. Most scientists dismissed extra-galactic sources because no known astronomical object could produce energies that could account for the brightness if they were so distant.

Then, in 1991, NASA launched the Compton Gamma-Ray Observatory, which was equipped with the most sensitive radiation detectors ever built. And again, scientists got a shock. "About once a day, the Compton would see a tremendous flash of gamma rays, and it would show up in three, four or sometimes more detectors," recalled mission scientist Jerry Fishman. Gamma-ray bursts were almost commonplace, it appeared. Indeed they were so frequent Fishman was able to make a map of their distribution in less than a year. This showed bursts were located randomly across the sky – another sensational finding, as Osborne explains.

"The Milky Way is a flattened rotating disc of stars that appears as a band of light across the night sky. If gamma-ray bursts were local to our galaxy, they would also have been distributed as a band. But the Compton observatory showed this was not the case ... they occur everywhere you look – suggesting they lie far outside our galaxy." Two decades after their discovery, gamma-ray bursts were proving to be more – not less – baffling.

The problem for astronomers was that the intense energy of gamma rays made it extremely difficult to focus them and to pinpoint their source. By contrast, visible light is easily focussed and its spectrum reveals precious information about the velocity and distance of its source. The more its spectrum is shifted to the red, the faster it is receding from us and the greater is its distance. Astronomers therefore needed an afterglow: the visible embers of the eruption that first generated those gamma rays, which would reveal its distance.

ON 28 FEBRUARY 1997, they got their wish. An Italian-Dutch satellite, BeppoSAX – built to study stellar radiation and carrying a powerful X-ray camera and a gamma-ray detector – picked up a burst of gamma rays followed by a longer-lasting pulse of X-rays from the same part of the sky. It was enough to provide a fix for ground-based telescopes which, within hours, pinpointed a source: a galaxy more than two billion light-years from Earth. A few weeks later, another two gamma-ray bursts were spotted: one was six billion light-years away while the other was a stunning 12 billion light-years away. Given that our universe is 13.7 billion years old, that eruption must have occurred while it was still in its infancy. "That is one reason why gamma-ray bursts are so important to astronomy," adds Osborne. "They illuminate the universe not long after the Big Bang and give us a way of probing some of its earliest events."

But in showing that gamma-ray bursts were immensely distant, astronomers were left with the headache of explaining

THE LIGHT FANTASTIC

The stars we see at night typically range in distance from four to 1,500 light-years away. (A light-year is the distance travelled by light in a vacuum in a year and is equivalent to 9,460 billion km.) Alpha Centauri, the closest star to Earth, is 4.35 light-years away; Sirius, the brightest star visible from Earth, is 8.6; while the red giant Antares, in the Scorpio constellation, is 604 light-years away. Only a handful of visible objects lie outside this range - such as the Large Magellanic Cloud which is 160,000 light-years away from Earth, while the Andromeda galaxy, which appears to the naked eye as a mere smudge in the constellation Andromeda, is around 2.5 million light-years distant. Until last year, Andromeda held the record as the most remote object visible to the naked eye, a claim now shattered by GBR-080319B: a gamma-ray burst which took place 7.6 billion light-years away.

The star Sirius, captured here with visible light that took 8.6 years to reach Earth.

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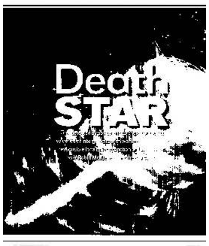

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An animation of a gamma-ray burst, which begins when the core of the star collapses, forming a black hole.

A jet of matter is formed and breaks through the outer shell of the star within about 10 seconds.

their causes. After considerable debate and argument, they concluded that only the collapse of a massive star could generate the kind of energy they were observing – though even this idea pushed physics to its limit. For radiation to be detectable billions of light-years away, a stunning amount of material – equivalent to the entire mass of the Sun – would have to be destroyed and turned into gamma rays within a few seconds of a star collapsing. The idea stretched credulity.

Then in 2003 Hungarian astrophysicist Peter Mészáros (now with Pennsylvania State University) and Martin Rees of the University of Cambridge suggested a solution: the energy from those collapsed stars was not being sprayed uniformly and dissipated across space but was actually being channelled in beams. In other words, gamma-ray bursts are more like searchlights than balls of radiation. That display was visible in Bootes because it was shining straight at Earth.

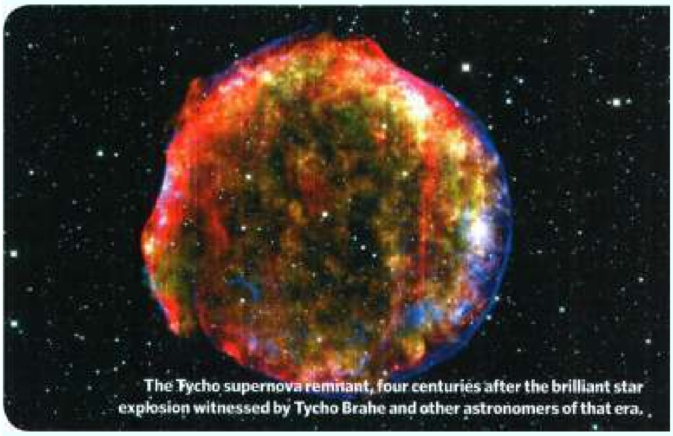
Such a mechanism means that the initial stellar eruption does not have to be as outrageously cataclysmic as was previously thought, though it still has to be highly energetic. But how could this channelling occur? What causes those gamma rays to be sent off in beams? The answer, says David Burrows of Pennsylvania State University, in the U.S., is simple. It is all a matter of spin.

Supernovae and gamma-ray bursts are both triggered when a giant star reaches the end of its life (see "Ka-boom!"). "The crucial difference in the case of a gamma-ray burst is that its progenitor is spinning," said Burrows. "As a result, the material falling towards its core is whipped round the star to create a doughnut-shaped layer of material. It forms a coat, in effect. Nothing can get through this blanket, and radiation can only emerge straight outwards, in a beam, at the star's poles where there is no blanket." Think of a torch bulb wrapped within a sushi roll. Its light will only escape upwards and downwards.

We only see those stellar 'sushi rolls' that are pointed in our direction, so there must be many more gamma-ray bursts, aimed at other parts of the sky that we never record. In other words, gamma-ray bursts may be far more common than previously suspected. "And they are not all remote," adds Burrows. "We have seen some erupt in nearby galaxies."

It is an intriguing picture that has since been confirmed by NASA's Swift telescope, the world's most powerful gamma-ray observatory. Launched in 2004, it has discovered more than 400 of these fantastic celestial events. Once a burst is detected, a radio message is flashed to Earth; triggering alarm calls on Swift scientists' mobile phones. At the same time, robot telescopes are directed towards the eruption while astronomers across the globe gather for teleconferences, usually within minutes of receiving their alarm call.

"If it is a big, important burst, we can direct a really large ground-based telescope, such as the Gemini or Keck observatories in Hawaii, towards it, often within a few tens of minutes," says Judith Racusin, of Pennsylvania State



The Tycho supernova remnant, four centuries after the brilliant star explosion witnessed by Tycho Brahe and other astronomers of that era.

KA-BOOM!

Both supernovae and gamma-ray bursts are produced by a stellar demise. In the core of stars, at extreme temperatures and pressures, nuclei of hydrogen atoms fuse to form helium nuclei, which produces large amounts of energy. The outward flow of energy balances the inward pressure of the star's own mass and gravity. In larger stars, fusion proceeds so quickly that it runs out of hydrogen fuel in a few million years. It then begins to burn its helium, forming carbon, nitrogen and oxygen nuclei. When helium runs out, these heavier elements combine to form silicon and finally the silicon to make iron. At this stage, nuclear fusion can go no further and the star can no long generate energy to balance its outer mass. Its core collapses and a shock wave rips through the star, blowing it apart. Supernovae spray energy evenly across space in the form of radiation and neutrinos. Gamma-ray bursts, however, channel energy in tight beams of gamma radiation. In both cases, the collapsed core becomes a black hole.

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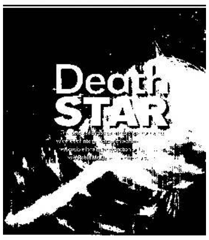

The star shatters, which in this case triggers a supernova event.

After most of the mass of the star spreads through space, a remnant black hole is left.

University. It's a hectic type of astronomy, Racusin observes. "In astronomy, events normally change on million or billion-year time-scales. With gamma-ray bursts, we get text messages that wake us in the night to react to something that ... will change in a few seconds."

Such coverage is frenetic but rigorous. Nevertheless, it took a slice of luck when it came to the burst in Bootes, officially known as GRB-080319B. "A gamma-ray burst had already gone off in that part of the sky and wide-field telescopes were already pointing in its general direction," adds Racusin. A robot telescope, called Pi of the Sky and based in Chile, caught visible light from 080319B before Swift had even alerted astronomers. Hence their special knowledge about the eruption.

Swift's results now show that the collapsar model of gamma-ray burst creation is correct, though the satellite's data has also revealed an unexpected anomaly: a small set of events, around 30 out of Swift's 400-plus total, that produce gamma-ray bursts of less than two seconds' duration and which cannot be explained in terms of an exploding star. "These brief bursts are far more difficult to explain," adds Osborne. "Most probably they are caused by two incredibly dense, neutron stars colliding and destroying themselves."

> The energies released by a gamma-ray burst are colossal ... if one were to go off in our neighbourhood of the galaxy – within 1,000 light-years – the consequences would be fatal.

EITHER WAY, THE ENERGIES released by a gamma-ray burst are colossal and that has key implications for Earth, for if one were to go off in our neighbourhood of the galaxy – within 1,000 light-years – the consequences would be fatal.

"The first thing you would see would be a big flash of light," says Arnon Dar of the Israel Institute of Technology in Haifa. "You would become blind in a very short time. Your skin would be completely burned and ... an enormous dosage of radioactive radiation would kill you in a very short time."

Fortunately, no star in our galactic neighbourhood looks ready to erupt in a way that threatens life here. The gamma-ray bursts that we observe are almost always the death throes of stars in the early universe, whose radiation travelled for billions of years before reaching Earth, says astrophysicist Peter Tuthill from the University of Sydney. The composition of stars has changed between the early universe and the modern era – gradually the concentration of metal ions has increased in the core of stars, which makes stars spin more slowly. Therefore young stars – such as the stars in our region of the universe – are less likely to end their life with a gamma-ray burst.

Despite the small chance of a local gamma-ray burst, astronomers are keeping a close eye on one star, known as WR104, only 8,000 light-years distant, that has the possibility of exploding as a gamma-ray burst one day. "If this system did emit a gamma-ray burst, we might be in the wrong place," says Tuthill, "though [the line of sight of its beams] might be inclined enough that it misses us."

There are clues that gamma-ray bursts have affected Earth in the past. "A gamma-ray burst probably erupts in a galaxy once every few hundred million years," says astronomer Adrian Melott, from the University of Kansas. "A relatively close one, a few thousand light-years away, would not have immediately devastated the planet but it would still have had a major impact." Melott calculates that its gamma rays would cause nitrogen in the atmosphere to react with oxygen and other elements to create chemicals that would erode Earth's protective ozone layer. As a result, the planet would be bathed in damaging ultraviolet radiation. Plankton, which sustains ocean life, would be destroyed, triggering a bout of extinctions.

As an example, Melott points to the Ordovician extinction event which occurred about 440 million years ago and led to massive eradication of sea life, including marine invertebrates and corals – then the most common life forms on the planet. "That extinction event is entirely consistent with gamma rays from a burst erupting over the South Pole and sweeping over the Southern Hemisphere," he adds. "Fortunately, gamma-ray bursts are not common events in our neighbourhood - but when they happen they certainly have an impact."

Robin McKie is a contributing editor of *Cosmos*, based in London. He is the science editor of Britain's *The Observer*.