netically dominated plasma that dissipates energy through plasma instabilities.

Any model for long GRBs must explain the large amount of ^{56}Ni inferred to have been produced in the supernovae SN2003dh and SN1998bw. The type Ib and Ic supernovae observed so far shine principally because of radioactive decay of this isotope. In the collapsar model, ^{56}Ni is thought to be produced from gas that is ejected in a wind from the accretion disk (*6*). This wind is separate from the relativistic jet and flows at large angles (30°) from the pole. The jet itself does not synthesize sufficient ^{56}Ni and does not contain much mass.

The main problem in observing GRBs has been their short duration. It is difficult to point many telescopes at them fast enough to measure their luminous output at all wavelengths when the burst is brightest. GRBs can only be detected from space, because gamma rays are absorbed by the atmosphere. Their position in the sky must be determined accurately and quickly so that other satellites and Earth-based telescopes can search for their emission. The HETE-II satellite is providing valuable localizations of GRBs, including GRB030329. The SWIFT satellite, scheduled for launch in spring 2004, promises to revolutionize the field by simultaneously observing GRBs in many wavelengths (gamma ray through optical) soon after it detects them.

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ASTRONOMY

Short Gamma-Ray Bursts

Stephan Rosswog

More than 35 years after their initial discovery, gamma-ray bursts (GRBs) remain one the most exciting and mysterious events in our universe. GRBs are flashes of energetic photons that outshine, for a short moment, the whole rest of the gamma-ray sky. They are classified as "short" or "long" depending on whether their duration is shorter or longer than 2 s. A wealth of information about long GRBs has been gathered, including afterglows at different wavelengths, redshifts, host galaxies, and indications that the bursts occur close to star-forming regions (*1*). In contrast, information about short GRBs is so far restricted to gamma rays alone.

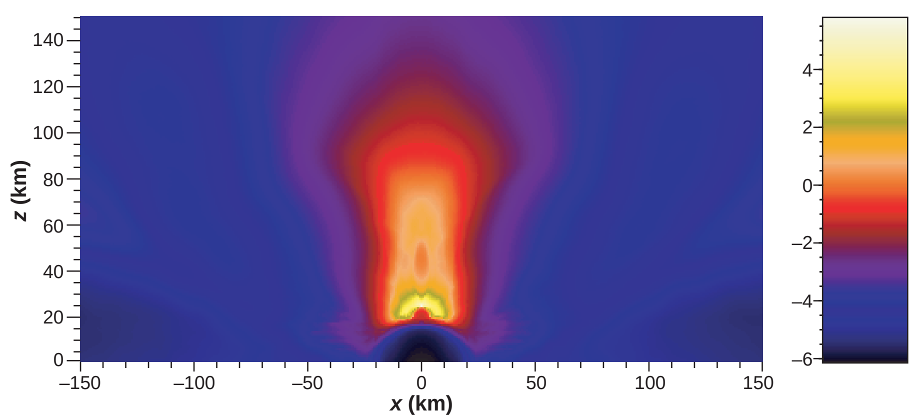
In principle, the two classes of GRBs could be caused by two different types of progenitors, or they could have the same kind of progenitor, which acts in two different ways depending on its initial conditions (such as its initial rotation). It is more likely that each class of GRB has a different kind of progenitor, because there are substantial differences apart from the duration of the burst. For example, the number of subpulses that constitute the light curve of a GRB is different for short and for long bursts (*2*). The spectra of short GRBs are harder (*3*); that is, they have a larger fraction of high-energy photons, their peak energy is larger (*4*), and they evolve differently in time (*2*). The peak energies of the spectra are influenced by the cosmological expansion—that is, for more remote bursts, one would expect lower peak energies—and by the speed with which the radiation-producing matter is ejected from the central engine. Therefore, a higher peak energy of the short bursts could mean either that their central engines produce higher outflow velocities or that they occur on average closer to Earth. Statistical arguments (*5*) also point to a relatively local origin of the short GRB class.

Compact binary mergers—the coalescence of either two neutron stars or of a neutron star and a low-mass black hole—have long been the standard model for the central engine of GRBs (*6*–*8*). Such mergers provide huge energy reservoirs of several 10^{53} ergs and would yield a natural explanation for the shortest time scales observed in GRBs. More recently, the association of long GRBs with supernovae has been substantiated (*9*). Compact binary mergers are now thought to power only short GRBs.

If the gamma-ray emission were beamed into a narrow jet, we could detect a short GRB only if it is by chance directed toward Earth, and we would miss most bursts that occur in the universe. This would mean that the "true" event rate is much higher than our observed one. The estimated compact binary merger rates are high enough to explain all short GRBs, even if the gamma-ray emission is strongly beamed. Because of the long time from the birth of the binary system to its death in the final coalescence, GRBs resulting from compact binary mergers are expected to occur relatively late in the life of the universe. Fryer *et al.* (*10*) estimate that they occur at 0.5 to 0.8 times the cosmological redshift of long GRBs, providing further support for a relatively local origin of short GRBs.

Generally, it is assumed that whatever the exact progenitor system, it will produce a "fireball" consisting of electron-positron pairs, photons, and some baryons. To explain the spectra of GRBs, the final fireball has to reach ultrarelativistic velocities. This is only possible if the fireball contains less than 10^{-5} solar masses of baryonic material; otherwise, only nonrelativistic outflow will result.

By which mechanism can the hot merger remnant deposit the required energy in a volume that is almost devoid of baryons? Candidates are the annihilation of neutrino-antineutrino pairs (*6*) and magnetic processes.



A possible mechanism for short GRBs. The annihilation of neutrino-antineutrino pairs above the remnant of a neutron star merger drives relativistic jets along the original binary rotation axis. Only the upper half-plane is shown; the *x* axis lies in the original binary orbital plane. The dark oval around the origin is the newly formed, probably unstable, supermassive neutron star formed in the coalescence.

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Detailed three-dimensional simulations of the hydrodynamics of the merger events (*11*) indicate that neutrino annihilation will drive two relativistic jets along the initial binary rotation axis (see the figure). The energy contained in the relativistic outflow can explain observations only if the outflow remains well collimated until the jets have reached large distances from the remnant (*11*, *12*). Such a collimation is indeed expected to occur (*11*).

Several magnetic mechanisms have also been proposed (*13*, *14*). Recent neutron star merger simulations (*11*) corroborate an idea originally suggested by Duncan and Thompson in 1992 (*15*). The merger of two neutron stars produces a (probably short-lived) supermassive neutron star in the center of the merger remnant. The star rotates rapidly, with different rotation periods for different parts of the star. It acts as a convective dynamo, amplifying the original seed magnetic fields to values of ~3×10^{17} G. As a kind of "superpulsar," this object will blow out a short ultrarelativistic wind of subsecond duration containing several 10^{52} ergs. If this picture is correct, short GRBs should contain two components: a relatively weak, well-collimated component from neutrino-antineutrino annihilation and a—possibly uncollimated—magnetic component that contains substantially more energy.

To get a better understanding of the central engine of short GRBs, we must detect them by a signature other than gamma rays. The first afterglow detections of long GRBs revolutionized our knowledge about them. Hopefully the SWIFT satellite, to be launched early next year, will detect afterglows of short GRBs. These data could show whether the short bursts indeed have a relatively local origin. They may also reveal whether short GRBs are, like their long-duration cousins, associated with star-forming regions or occur elsewhere, for example in the outskirts of galaxies, as expected for at least some compact binary mergers.

The ultimate proof for a binary origin of short GRBs could come from ground-based gravitational detectors such as LIGO or GEO600. A coalescing binary system emits a unique gravitational wave pattern that, if detected concurrent with a GRB, could be a Rosetta stone for GRB science.

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PHYSIOLOGY

Running a-Fowl of the Law

Norman C. Heglund

I came across a colleague searching the grass in a circle of light under a street lamp. "What are you looking for?" I asked. "Keys," he answered, at which point I started to help him in his search. But after a while it became apparent that we were not finding any keys, so I asked, "Are you sure they're here?" to which he replied "Oh, no, they're not here, they're out there someplace," gesturing off into the darkness, "but the light's better here!"

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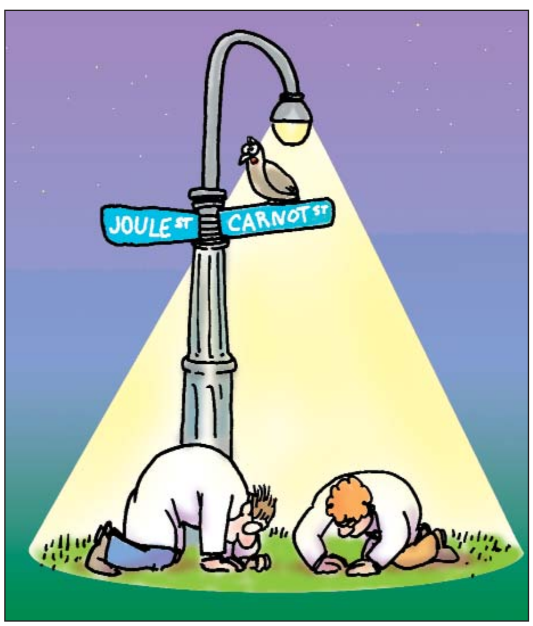
Research is often like that. We know specifically what we are looking for, but for one reason or another we are unable to search for it directly. The paper by Marsh *et al.* (*1*) on page 80 of this issue is a good example of approaching a scientific question indirectly. These authors wanted to measure the metabolic energy required to swing the legs during walking and running, and to compare it to the total metabolic energy requirement. But making this type of measurement in complex animals such as vertebrates is a daunting task. Moving the limbs involves many muscles—some working together, some working against each other—with each muscle group showing activity during different phases of the stride cycle. Lacking the means to make direct measurements, Marsh *et al.* have found a clever substitute.



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They used microspheres to measure the distribution of blood flow to the hindlimb muscles of guinea fowl while the birds were running. They injected a quantity of tiny spheres, each about twice the size of a red blood cell, into the arterial system of the birds, at the level of the heart. These spheres passed easily throughout the arterial system, but they became stuck in the capillaries (the concentration of spheres was low enough to ensure a negligible effect on blood flow). Because blood flow to muscle tissue is controlled locally according to oxygen demand, the density of spheres stuck in a capillary bed is proportional to the blood flow in that volume of muscle, and, by inference, to the oxygen consumption rate. Marsh and colleagues found that swinging the legs consumed a significant fraction of the total energy required for running.

What is the interest in measuring the energy required to swing the legs? It is just one part of a long-standing mystery in comparative physiology. Since the late 1970s, we have known that the mass-specific cost of locomotion—the metabolic cost (in joules) required to move 1 kg of body mass a distance of 1 m—generally increases with speed and decreases with increasing body size (*2*). By the early 1980s, we knew that the mass-specific work (in joules) done to move 1 kg of body mass a distance of 1 m also increases with speed even more rapidly than does the energy cost, but the work done appears to be independent of size. One consequence is that the efficiency—the work done divided by the metabolic

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