Bursts, Rays, and Jets

High-energy astrophysics focuses on understanding the origins of the most energetic radiation and particles observed or theoretically predicted in the universe. This area of research probes the most mysterious and most difficult-to-observe astrophysical phenomena. Understanding these phenomena is worth the effort, however, because they may be key to understanding the origin of the universe and the fundamentals of particle physics. Recent observations of extreme events such as ultrahigh-energy cosmic rays and gamma ray bursts have led to significant progress in determining their sources and modeling the mechanisms that produced them. Relativistic jets accelerated from massive compact objects, such as neutron stars or black holes, have been implicated as the primary culprits for producing high-energy events. Here we present three Reviews of the more rapidly advancing areas of research, ultrahigh-energy cosmic rays, gamma ray bursts, and relativistic jets.

The highest energy cosmic rays are thought to be extragalactic. However, their source remains a mystery, as discussed in a Review by Guenter Sigl (p. 73). About 12 events have been detected by large-area, ground-based detectors that sample the secondary particles of the cosmic rays. These observations, combined with theoretical models, suggest that ultrahigh-energy cosmic rays come from the earliest processes in the formation of the universe, nonstandard particle physics, or acceleration of particles by energetic processes such as gamma ray bursts.

Gamma ray bursts—which last for only a few seconds and generate about 10^{53} ergs per second of energy output, greater than any other astrophysical phenomenon—are now being detected at a rate of about one per day. Peter Mészáros (p. 79) reviews our current understanding of these curious events. The Italian-Dutch satellite BeppoSAX in particular has helped to locate gamma ray bursts, and accurate locations make it much easier to observe the afterglows with ground-based telescopes and satellites. These observations have led to a model that favors the collapse of a massive object into a neutron star or black hole, generating jets that create gamma ray bursts.

Relativistic jets, collimated flows of plasma that travel at almost the speed of light, may produce gamma ray bursts, ultrahigh-energy cosmic rays, and many other high-energy phenomena. David Meier, Shinji Koide, and Yutaka Uchida (p. 84) review the latest observations of jet structures, mainly from radio and x-ray wavelength observations, and focus on magnetohydrodynamic simulations of relativistic jets that reproduce these structures. A neutron star or black hole, in a binary system or in the act of formation, will accrete mass and angular momentum. Differential rotation of this mass and momentum may twist the magnetic field lines of the system, producing bipolar jets, and simulations can provide the appropriate conditions to accelerate particles to produce ultra high-energy cosmic rays or create gamma ray bursts in the jet stream.

Relativistic jets also make up the centerpiece of the first of three News stories. Mark Sincell (p. 66) describes how the jets of recently discovered objects known as microquasars may shed light on the mechanisms behind quasars—galaxy-spanning structures powered by supermassive black holes. Next, Govert Schilling (p. 68) tells of another attempt to link two similar-looking phenomena: faint high-energy blips known as soft gamma repeaters and anomalous x-ray pulsars. Finally, Richard Stone (p. 70) travels to Tatarstan to report on a project intended to rival much larger Western ground- and space-based attempts to detect gravitational waves from binary pulsars

Thus, the combination of numerical simulations, observations, and theory is improving our understanding of the origins of high-energy astrophysical phenomena. The future looks bright for resolving some of these great mysteries in the early 21st century.

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