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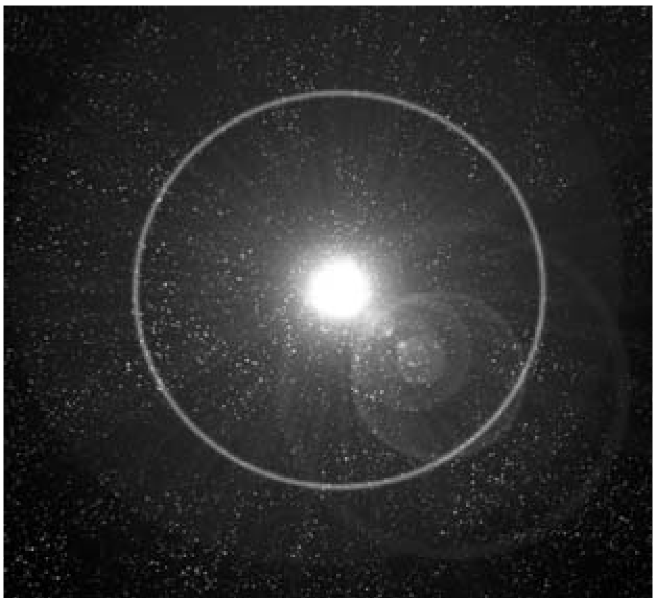
Gamma Ray Bursts: The Mystery of the Most Powerful Explosions in the Universe



Artist concept of a gamma ray burst

During the Cold War, the United Sates Air Force launched the Vela satellites to detect telltale gamma rays from clandestine nuclear bomb tests. In 1967, the Vela satellites instead discovered intense bursts of gamma rays coming from deep space. Since that time, the source of these powerful blasts has been one of astronomy's most baffling mysteries. Spacecraft, such as NASA's Compton Gamma Ray Observatory (de-orbited in June 2000), have detected about one burst a day. They differ greatly in duration, averaging just a few seconds, but some have gone on for more than 15 minutes; others wink out after one tenth of a second. They appear randomly from all directions in the sky and are not known to repeat.

Gamma rays are the highest energy form of electromagnetic radiation (light). All light travels in waves, and is classified according to its wavelength, the distance between the peaks of its waves. Electromagnetic radiation varies greatly in energy level, with only a fraction visible to the human eye. Radio waves have the longest wavelength and are therefore the least energetic. Somewhat higher on the energy scale are microwaves and infrared light, with shorter wavelengths and higher energies. Slightly higher still is the familiar rainbow of colors that makes up visible light. ultraviolet light carries even more energy, followed by X-rays, which are second only to gamma rays. Gamma rays have the shortest wavelengths and carry the most energy.

Gamma rays are created by the most violent events in the universe, such as when matter is fused inside exploding stars, shot to nearly the speed of light by the whirling magnetic field of a pulsar, or rubbed out in the intense gravity near a black hole. A typical gamma ray emitted by a gamma ray burst carries 100,000 times more energy than visible light.

Gamma rays are so powerful that they will penetrate any mirror (or pass through without being deflected by any lens) employed to focus them. Detectors must be used instead. The detectors are essentially plates of material that interact with incoming gamma rays and emit electric currents or lower energy light that may be processed electronically. Most gamma rays are absorbed by the Earth's atmosphere, so the detectors must be placed on satellites to be of any use in finding gamma ray bursts.

Many theories have been proposed to explain the distribution and origin of gamma ray bursts. Most astronomers believe the sources of the bursts are among the most distant objects in the known universe.

Most theories propose that the bursts emanate from the farthest reaches of the observable universe, perhaps from hypernovae - exceptionally fierce exploding stars more than 20 times the mass of our Sun that form a black hole in their cores; or from furious collisions between extremely dense celestial objects, such as neutron stars and black holes. These theories are called "cosmic origin" theories.

Astronomers expected to associate the locations of the bursts with known stars or galaxies. But despite many observations by numerous telescopes, no such identification was made until recently.

Launched on April 30, 1996, an Italian-Dutch satellite called BeppoSAX was able to locate gamma ray bursts with sufficient precision and speed to permit coordinated observations by other telescopes using different wavelengths. Analysis of the light at these other wavelengths revealed that a gamma ray burst creates a rapidly expanding fireball. As the fireball expands, it loses energy, emitting light that is progressively less energetic, from X-rays through visible light down to radio.

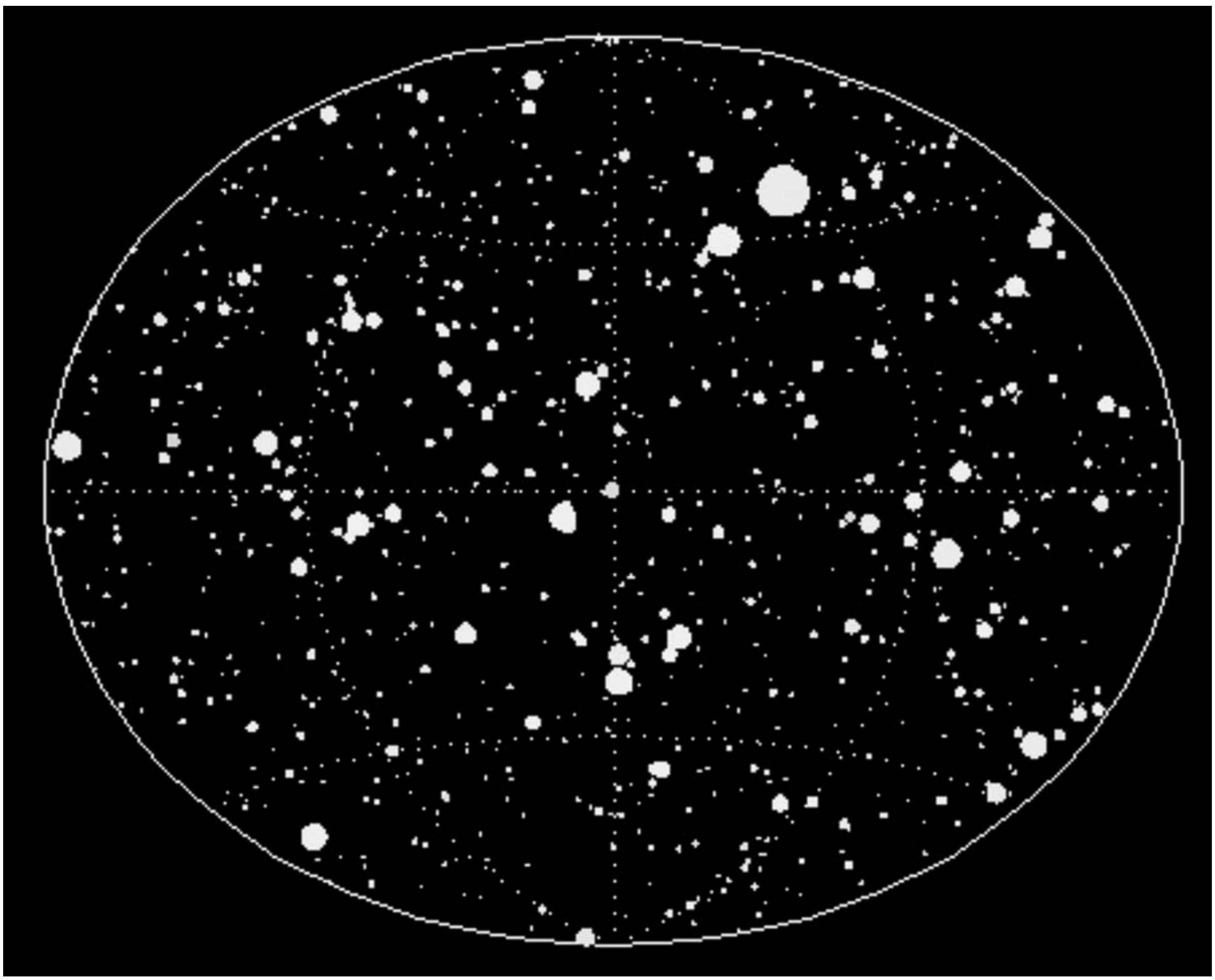
Scientists analyzed the visible light from a few of these bursts using spectrometers. A spectrometer separates light into its constituent wavelengths, or colors, much like a prism separates white light into a rainbow. Using the spectrometer, scientists discovered that the light was shifted from its normal wavelength to a longer, lower energy wavelength. This is called redshift, and it is similar to what is heard by a person stuck in a traffic jam as an ambulance approaches. As the ambulance passes by and moves away, the person hears the siren change pitch from high to low. The lower pitch corresponds to sound with a longer wavelength. Similarly, light from an object will be redshifted to a longer wavelength if the object is moving away from the observer.

Astronomers used redshift to determine distance to a certain class of gamma ray bursts, called long bursts, because they persist for two seconds or more. On the large scale, the expansion of the universe causes galaxies to move away from each other. The farther away an object is, the faster it is receding and the greater its redshift. All long burst spectra taken to date have high redshifts, indicating that such bursts are extremely distant, supporting the cosmic origin theories.

However, about 20 - 30 percent of gamma ray bursts are in the short burst category, those that last less than two seconds. Because they vanish so quickly, no one has yet been able to get an accurate position for follow-up observations by other telescopes, and their distances are still uncertain. It's possible that they may be produced by a different source, which might be consistent with local origin theories, but no one knows for sure.

Long gamma ray bursts shine relatively brightly in gamma rays, so if they are very remote, they must be extremely powerful. In fact, given their apparent brightness, the measured distances make long gamma ray bursts the most powerful explosions known. It is hard to comprehend how energetic the most potent long bursts are; it's best done in steps. Our Sun produces enough energy in one second to meet current United States demand for nine million years. Yet, in a few seconds, some long gamma ray bursts emit 100 times the energy that the Sun will produce over its entire 10 billion-year lifetime.

Some astronomers think that instead of shining equally in all directions, gamma ray bursts direct their radiation into beams. (Probably two oppositely-directed beams; one from each pole of the celestial object that is producing the burst. This is what is seen in other high-energy astronomical phenomena like black holes that are consuming large amounts of matter.) A flashlight can be



The positions of over 1,000 gamma-ray bursters are shown on this map of the entire sky. The bursters are evenly distributed around the sky. If they were in our Milky Way galaxy, we would expect to see more of them along the equator of our disk-shaped galaxy. The even distribution provides evidence that gamma-ray bursters are located outside our galaxy, probably in distant galaxies billions of light-years away.

seen from a great distance if someone turns its beam our way, but it appears to vanish when turned away. Similarly, we would only detect beamed gamma ray bursts from across the cosmos if they happened to have one of their powerful beams directed our way. If gamma ray bursts beam their radiation, their power output would be about 100 times less because they are bright only in narrow beams rather than in all directions. However, even assuming that their radiation was beamed, the most energetic long bursts still released as much energy as our Sun will produce over its lifetime.

Beaming also introduces a new mystery — if gamma ray bursts are beamed, then their unfathomable energy release is even more common than it appears. Since we would only see the bursts if their beams are directed our way, there must be many more that we don't see because their beams point in other directions.

The source of this enormous energy remains a mystery. Theories using known celestial objects have been proposed, but it's possible that gamma ray bursts represent undiscovered physical principles. In any event, gamma ray bursts are cosmic laboratories in which we can test our physical theories with energies impossible for us to produce, and deepen our understanding of the ultimate limits of energy production.