Astro 10: Comprehension 03

Friday, 08th May 2009

This comprehension test has 20 (twenty) multiple choice questions. Using **only** the text provided on the following pages, select the best answer to each question. Each question has only one answer. All the information you need to answer the questions is given in the text and this test is closed book.

Switch all cell phones off.

Around campus and in your Astro 10 lectures, you have repeatedly heard that astronomers at Penn State run a satellite called "Swift" which observes "Gamma Ray Bursts". In order to learn more about Swift and Gamma Ray Bursts, you look up Wikipedia and find the following information:

Gamma Ray Bursts

Gamma-ray bursts (GRBs) are the most luminous electromagnetic events in the universe since the Big Bang. They are flashes of gamma rays emanating at random from distant galaxies. The duration of a gamma-ray burst is typically a few seconds, but can range from a few milliseconds to several minutes. The characteristics of the light curve vary significantlly and are independent of the total duration of the burst. The initial burst is usually followed by a longer-lived "afterglow" emitting at longer wavelengths (X-ray, ultraviolet, optical, infrared, and radio).

Most observed GRBs appear to be collimated emissions caused by the collapse of the core of a rapidly rotating, high-mass star into a black hole. A subclass of GRBs (the "short" bursts) appear to originate from a different process, the leading theory being the merger of neutron stars orbiting in a binary system. All observed GRBs have originated from outside the Milky Way galaxy, though a related class of phenomena, soft gamma repeater flares, are associated with galactic magnetars. The sources of most GRBs have been billions of light years away.

GRBs were first detected in 1967 by the Vela satellites, a series of satellites designed to detect nuclear explosions in space. Since then, hundreds of theoretical models have been created in an attempt to explain these bursts, such as collisions between comets and neutron stars. Little information was available to support any of these models until the discovery of X-ray and optical afterglows and the determination of the redshift of GRB 970508. Where the scientific community had once been divided over how far away GRBs occur from Earth, there is now consensus that they occur in distant galaxies. It has been hypothesized that a gamma-ray burst in the Milky Way could cause mass extinctions on Earth.

There are several gamma-ray burst research missions currently in progress. *Swift*, launched in November 2004, features an extremely sensitive gamma ray detector and the ability to point on-board telescopes towards the direction of a new burst in less than one minute after the burst is detected.

History: The Cold War

Gamma-ray bursts were discovered in the late 1960s by the U.S. Vela nuclear test detection satellites. The Velas were built to detect gamma radiation pulses emitted by nuclear weapon tests in space. The United States suspected that the USSR might attempt to conduct secret nuclear tests after signing the Nuclear Test Ban Treaty in 1963. On July 2 1967, at 14:19 UTC, the Vela 4 and Vela 3 satellites detected a flash of gamma radiation that were unlike any known nuclear weapons signatures. Unclear on what had happened, but not considering the matter particularly urgent, the team at the Los Alamos Scientific Laboratory, lead by Ray Klebesadel, filed the data away for later investigation.

History: BATSE and CGRO

Little progress was made, however, until the 1991 launch of the Compton Gamma Ray Observatory (CGRO) and its Burst and Transient Source Explorer (BATSE) instrument, an extremely sensitive gamma-ray detector. This instrument provided crucial data indicating that GRBs are isotropic (not biased towards any particular direction in space, such as toward the galactic plane or the galactic center). Because the Milky Way galaxy has a very flat structure, if gamma-ray bursts were to originate from within the Milky Way, they would not be distributed isotropically across the sky, but instead concentrated in the plane of the Milky Way. Although the luminosity of the bursts suggested that they had to be originating within the Milky Way, the distribution provided very strong evidence to the contrary. The peak flux distribution was also inconsistent with a local population, indicating that cosmological redshift effects were taking place.

For decades after the discovery of GRBs, astronomers searched for a counterpart: any astronomical object in positional coincidence with a recently observed burst. Astronomers considered many distinct objects, including white dwarfs, pulsars, supernovae, globular clusters, quasars, Seyfert galaxies, and BL Lac objects. Researchers specifically looked for objects with unusual properties which might relate to gamma-ray bursts: high proper motion, polarization, orbital brightness modulation, fast time scale flickering, extreme colors, emission lines, or an unusual shape. The best hope seemed to lie in finding a fainter, fading, longer wavelength emission after the burst itself, the "afterglow" of a GRB.

History: BeppoSAX

BeppoSAX, an Italian and Dutch research satellite launched on April 30, 1996. Success for the BeppoSAX team came in February 1997. The satellite detected a gamma-ray burst (GRB 970228), and when the X-ray camera was pointed towards the direction from which the burst had originated, it detected a fading X-ray emission. Ground-based telescopes later identified a fading optical counterpart as well. The location of this event having been identified, once the GRB faded, deep imaging was able to identify a faint, very distant host galaxy in the GRB's location. Within only a few weeks the long controversy about the distance scale ended: GRBs were extragalactic events originating inside faint galaxies at enormous distances.

Two major breakthroughs occurred with the next event registered by BeppoSAX, GRB 970508. This event was localized within four hours of its discovery, allowing research teams to begin making observations much sooner than any previous burst. One variable object was found in the bursts's error boxa small area around the specific position to account for the error in the position. The spectrum of the object revealed a redshift of $z = 0.835$, placing the burst at a distance of roughly 6 billion light years from Earth. This was the first accurate determination of the distance to a GRB, and it further proved that GRBs occur in extremely distant galaxies. This was also the first burst with an observed radio frequency afterglow.

The next burst to have its redshift calculated was GRB 971214 with a redshift of 3.42, a distance of roughly 12 billion light years from Earth. Using the redshift and the accurate brightness measurements made by both BATSE and BeppoSAX, Shrinivas Kulkarni, who had recorded the redshift at the Keck Observatory, calculated the amount of energy released by the burst in half a minute to be 3×10^{53} ergs, several hundred times more energy than is released by the sun in 10 billion years. The burst was proclaimed to be the most energetic explosion to have ever occurred since the Big Bang, presenting a dilemma for GRB theoreticians: either this burst produced more energy than could possibly be explained by any of the existing models, or the burst did not emit energy in all directions, but instead in very narrow beams which happened to have been pointing directly at earth. While the beaming explanation would reduce the total energy output to a very small fraction of Kulkarni's calculation, it also implies that for every burst observed on earth, several hundred occur which are not observed because their beams are not pointed towards earth.

Current missions: The Swift Satellite

NASA's *Swift* satellite is a multi-wavelength space-based observatory dedicated to the study of gamma-ray burst (GRB) science. Its three instruments work together to observe GRBs and their afterglows in the gamma-ray, X-ray, ultraviolet, and optical wavebands.

Swift was launched in November 2004 and can point towards the direction of a new burst in less than one minute after the burst is detected. *Swift's* discoveries include the first observations of short burst afterglows and vast amounts of data on the behavior of GRB afterglows at early stages during their evolution, even before the GRB's gamma-ray emission has stopped. The mission has also discovered large X-ray flares appearing within minutes to days after the end of the GRB.

Based on continuous scans of the area of the sky which one of the instruments monitors, *Swift* uses momentum wheels to autonomously slew into the direction of possible GRBs. The mission name "Swift", which is not an acronym, refers to this rapid slew capability and the nimble bird of the same name. All discoveries of *Swift* are quickly sent to the ground and that data is available to other observatories which join *Swift* in observing the GRBs.

In the time between GRB events, *Swift* is available for other science and scientists can submit proposals for observations.

The *Swift* Mission Operation Center (MOC), where commanding of the satellite is performed, is located in State College, Pennsylvania and operated by the Pennsylvania State University and industry subcontractors. The *Swift* main ground station is located in Malindi on the coast of Eastern Kenya, Africa and is operated by the Italian Space Agency. The *Swift* Science Data Center (SDC) and archive are located at the Goddard Space Flight Center. The UK *Swift* Science Data Centre is located at the University of Leicester.

Types of bursts

Researchers generally consider two broad classes of GRBs. "Short" GRBs have an average duration of 0.3 seconds and range from a few milliseconds to 2 seconds. "Long" GRBs have an average duration of 30 seconds and range from 2 seconds to several minutes. Some theories suggest that short and long bursts are each caused by two distinct physical processes.

Gamma-ray burst spectra cover a fairly wide energy range, both from event to event and within the duration of a single burst. At the extremes, burst spectra have been measured with energies as low as 2 keV, whereas some were higher than 10 MeV. The energy emitted by gamma-ray bursts is divided into three segments: the low energy continuum, which ranges from 2 keV to 30 keV, the intermediate energy continuum, from 30 keV to 1 MeV, and the high energy continuum, which covers all energy levels greater than 1 MeV. The first two GRBs to be observed in the low energy range were GRB 720427, which was detected by the Apollo 16 gamma-ray spectrometer, and GRB 720514, which was observed by the UCSD Solar X-Ray Spectrometer and by Vela 5b.

Jets of collimated emissions

The prevailing theory to explain GRB emissions is that they are created by a rapidly rotating central engine, such as a dying star that collapses to form a black hole. The newly formed black hole absorbs infalling matter and releases enormous amounts of energy as relativistic jets along the axis of rotation to form collimated emissions, material and radiation traveling along parallel trajectories. As these jets drill through the layers of stellar material to reach the surface of the dying star, they are focused into narrow beams. Observations have confirmed the presence of dying stars at the source of long gamma-ray bursts. Evidence suggests the beams have an opening angle of only a few degrees and travel at more than 99.995% the speed of light.

Features suggestive of significant asymmetry have been observed in at least one nearby type Ic supernova - which may have the same progenitor stars as GRBs - and have been observed to accompany GRBs in some cases (see "Progenitors", below). The jet opening angle (degree of beaming), however, varies greatly, from 2 degrees to more than 20 degrees. There is some evidence which suggests that the jet angles and apparent energy released are correlated in such a way that the true energy release of long GRBs is approximately constant -about 1044 J, or the energy equivalent to 1/2000 of a solar mass. This is comparable to the energy released in a bright type Ib/c supernova (sometimes termed a "hypernova"). Bright hypernovae appear to accompany some GRBs, suggesting that hypernovae may be a source.

The fact that GRBs are jetted also suggests that there are far more events occurring in the Universe than those actually seen, even when factoring in the limited sensitivity of available detectors. Most jetted GRBs will "miss" the Earth and never be seen; only a small fraction happen to be pointed such that they can be detected. Still, even with these considerations, the rate of GRBs is very small - about once per galaxy per 100,000 years.

Short GRBs, while also extragalactic, appear to come from a lower-redshift population and are less luminous than long GRBs. They appear to be generally less beamed or possibly not beamed at all, intrinsically less energetic than their longer counterparts, and probably more frequent in the universe despite rarely being observed.

Progenitors

The immense distances of most gamma-ray burst sources from Earth have made investigation of the progenitors, the systems that produce these explosions, extremely difficult. Currently, the most widely-accepted model for the origin of long duration GRBs is called the collapsar model, in which the core of an extremely massive, low-metallicity, rapidly-rotating star collapses into a black hole. The collapsar model originally explained the formation of black holes and was later applied to GRBs.

While this model is popular today, various other models have been strongly supported throughout the history of GRB research. In 1974, less than a decade after GRBs had first been discovered, Marvin Ruderman of Columbia University presented a review listing dozens of proposed models. By the end of the 1970s, the number of models included on this list had grown to more than 100. These models varied by the type of energy converted into GRBs, including gravitational, thermonuclear, rotational, and magnetic. By the late 90s, consensus had been reached among the scientific community that GRB emissions were non-thermal. The list of models also varied by the types of objects involved (black holes, neutron stars, white dwarf stars, comets, etc.). In 1973, Martin Harwit and Edwin Salpeter of Cornell University first presented the idea that GRBs are produced by comets falling onto neutron stars. Because comets have a wide range of sizes and shapes and can collide with neutron stars at a wide range of angles, this model was flexible enough to account for the vast range of characteristics displayed by GRBs.

Stellar wind from highly magnetized, newly-formed neutron stars (proto-magnetars), accretion-induced collapse of older neutron stars, and the mergers of binary neutron stars have all been proposed as alternative models. The different models are not mutually exclusive, and it is possible that different types of bursts have different progenitors. For example, there is now good evidence that some short gamma-ray bursts (GRBs with a duration of less than about two seconds) occur in galaxies without massive stars, strongly suggesting that this subset of events is associated with a different progenitor population than longer bursts - for example, merging neutron stars. However, in 2007 the detection of 39 short gamma-ray bursts could not be associated with gravitational waves which are hypothesized to be observable in such compact mergers. This is not surprising as the current sensitivity of even the best gravitational waves detectors is not sufficient to detect such signals even from the nearest short GRBs detected so far.

Emission mechanisms

The means by which gamma-ray bursts convert energy into radiation remains poorly understood, and as of 2007 there is still no generally accepted model for how this process occurs. A successful model of GRBs must explain not only the energy source, but also the physical process for generating an emission of gamma-rays which matches the durations, light spectra, and other characteristics observed. The nature of the longer-wavelength afterglow emission ranging from X-ray through radio that follows gamma-ray bursts has been modeled much more successfully as synchrotron emission from a relativistic shock wave propagating through interstellar space, but this model has had difficulty explaining the observed features of some observed GRB afterglows (particularly at early times and in the X-ray band), and may be incomplete, or in some ways inaccurate.

Notable gamma-ray bursts

GRB 080319B

On March 19, 2008, NASA's *Swift* detected GRB 080319B, later referred to as the "naked-eye

GRB." It was the most luminous event observed in optical and infrared wavelengths, and the most distant event observed that would be theoretically visible to the naked eye (7.5 Gly). Additionally, its rotational axis was closely aligned with Earth, allowing more detailed observation of the jet. In September 2008, a team of astronomers announced the discovery of an "inner jet", previously unknown.

GRB 090423

GRB 090423 is a gamma-ray burst (GRB) discovered by the *Swift* Gamma-Ray Burst Mission on April 23, 2009 at 07:55:19 UTC. Located a few degrees west of eta leonis (in the constellation Leo), it is the current record-holder as the event/object most distant from Earth, occurring at a redshift of $z = 8.2$.. The event occurred roughly 600 million years after the Big Bang, confirming that massive stellar births (and deaths) did indeed occur in the very early universe.

Notes

1. GRBs are named after the date on which they are discovered: the first two digits being the year, followed by the two-digit month and two-digit day. If two or more GRBs occur on a given day, the name is appended with a letter 'A' for the first burst identified, 'B' for the second and so on.
2. For more on galaxies hosting GRBs, see the GHostS database `http://www.grbhosts.org`
3. 1 MeV (Mega electronvolt) $= 1 \times 10^6$ eV $\equiv 1.78 \times 10^{-30}$ kg.

References

An extensive reference list of peer-reviewed journal articles is provided on the Wikipedia website[1], but was not reproduced here due to space constraints.

Text taken from:
Wikipedia on 15 April 2009
Version of article:
`http://en.wikipedia.org/w/index.php?title=Gamma-ray_burst&oldid=283651746`
and
`http://en.wikipedia.org/w/index.php?title=Swift_Gamma-Ray_Burst_Mission&oldid=281913535`
Modified by: Dr. N. Ross.
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[1] `http://en.wikipedia.org/wiki/Gamma-ray_burst`