Week 4 Review

Meszaros Paper
Hakkila Paper

Swift:

The Swift Gamma-Ray Burst Mission consists of a robotic spacecraft called ***Swift***, which was launched into orbit on November 20, 2004 at the NASA Goddard Space Flight Center. Collaboration between US, UK and Italy with additional scientific involvement in France, Japan, Germany, Denmark, Spain, and South Africa. The mission is operated by Pennsylvania State University. *Swift* is a first-of-its-kind multi-wavelength observatory dedicated to the study of gamma-ray burst (GRB) science. Its three instruments work together to observe GRBs and afterglows in the gamma-ray, *X*-ray, ultraviolet, and optical wavebands.

BAT:
The Burst Alert Telescope (BAT) is Swift's GRB watchdog. BAT searches in the gamma range.

XRT:
Swift's X-ray Telescope, which searches in the x-ray range.

UVOT:
Swift's Ultra-Violet/Optical Telescope that searches in the UV and optical range.

Afterglow:

Most of the GeV emission is produced in the afterglow phase. Swift observations reveal that long gamma-ray bursts come with and without supernovae, and with and without pronounced X-ray afterglows. Several models for the origin of gamma-ray bursts postulated that the initial burst of gamma rays should be followed by slowly fading emission at longer wavelengths created by collisions between the burst ejecta and interstellar gas. This fading emission would be called the "afterglow." Early searches for this afterglow were unsuccessful. The breakthrough came in February 1997, when the satellite BeppoSAX detected a gamma-ray burst (GRB 970228) when the X-ray camera was pointed towards the direction from which the burst had originated, it detected fading X-ray emission. Afterglows are thought to arise as a result of external shock waves.

Redshift:

In physics, **redshift** happens when light or other electromagnetic radiation from an object is increased in wavelength, or shifted to the red end of the spectrum. "Redder" means an increase in wavelength – equivalent to a lower frequency and a lower photon energy. A redshift occurs whenever a light source moves away from an observer. Mathematically, it is a numeric value obtained from measuring the difference in wavelengths of the emitted light and the detected light, then dividing that difference by the wavelength of the emitted light.

GRB Energy Range:
300 keV - 1 MeV

Gamma-Ray Bursts:

Gamma-ray bursts (GRBs) are the most powerful explosions the Universe has seen since the Big Bang. They occur approximately once per day and are brief, but intense, flashes of gamma radiation. They come from all different directions of the sky and last from a few milliseconds to a few hundred seconds. [NASA Swift] BATSE also found that GRBs can be classified into two duration classes, short and long GRBs, with a dividing line at approximately 2 seconds. [Meszaros] Bursts could have a single profile or oscillate wildly up and down in intensity, and their spectra are highly variable unlike other objects in space. There are at least two different types of progenitors (sources) of GRBs: one responsible for the long-duration, soft-spectrum bursts and one (or possibly more) responsible for short-duration, hard-spectrum bursts. The demarcation into two classes of bursts is however too simplistic to be the whole story. Some bursts fit neither category.

Collapsars:

The collapsar model is a type of hypernova that produces a gravitationally collapsed object, or black hole. When core collapse occurs in a star at least around fifteen times as massive as the sun—though chemical composition and rotational rate are also significant—the explosion energy is insufficient to expel the outer layers of the star, and it will collapse into a black hole without producing a visible supernova outburst. A star with a core mass slightly below this level—in the range of 5–15 times the sun—will undergo a supernova explosion, but so much of the ejected mass falls back onto the core remnant that it still collapses into a black hole. If such a star is rotating slowly, then it will produce a faint supernova, but if the star is rotating quickly enough, then the fallback to the black hole will produce relativistic jets. The energy that these jets transfer into the ejected shell renders the visible outburst substantially more luminous than a standard supernova. The jets also beam high energy particles and gamma rays directly outward and thereby produce x-ray or gamma-ray bursts; the jets can last for several seconds or longer and correspond to long-duration gamma-ray bursts, but they do not appear to explain short-duration gamma-ray bursts.

Long duration GRBs:

The long bursts were found to be associated with galaxies where active star formation was taking place, typically at redshifts z around $1 - 2$, and in some cases a supernova of type Ic was detected associated with the bursts, confirming the stellar origin of this class. Observations showed an unusually luminous core collapse supernova of type Ic associated with some GRBs; these supernovae have since been referred to as hypernovae. The core collapse model, referred to as a collapsar, is currently well established as the source of most long GRBs. Long GRBs (LGRBs) are found in galaxies where massive stars are forming, present over a large redshift range from $z = 0.0085$ to $z > 8$. Most LGRBs that occur near enough for supernova detection have an accompanying Type Ib or Ic supernovae, supporting the growing evidence that LGRBs are caused by “collapsars” where the central core of a massive star collapses to a compact object such as a black hole or possibly a magnetar. [Meszaros] LGRBs are the endpoints of the lives of massive stars .

Hypernovae:

A hypernova is a type of supernova explosion with an energy substantially higher than that of standard supernovae. An alternative term for most hypernovae is "superluminous supernovae".

Short Duration GRBs:

The host properties are substantially different than those of LGRBs, indicating that SGRBs have a different origin than LGRBs. The current interpretation is that SGRBs arise from an old population of stars, probably due to mergers of compact binaries such as double neutron star or neutron star-black holes. Short GRBs are found to have generally a lower luminosity and a lower total energy output, as well as a weaker afterglow. Additionally, the jet angle appears to be wider than for LGRBs. Recent observations contradict theory of neutron stars colliding (see p. 8, last paragraph of Meszaros) but a support a magnetar theory.

Discovery of GRBs:

It is interesting that gamma-ray bursts were detected serendipitously by the Vela satellites, which were built to detect covert nuclear weapon tests in space by the Soviet Union. The first detection of a GRB were made by the Vela 3 and Vela 4 satellites on July 2, 1967, at 14:19 UTC, but it was ignored because the operators at Los Alamos Scientific Laboratory were uncertain as to what had happened. Eventually, after the Los Alamos team continued to find inexplicable gamma-ray bursts in their data from additional satellites with better instruments, they determined that the sources of the GRBs had not been of terrestrial or solar origin. The discovery was then declassified and published in 1973 as an *Astrophysical Journal* article entitled “Observations of Gamma-Ray Bursts of Cosmic Origin”. [Ian Strong]

Gamma-ray Progenitors:

Gamma-ray burst progenitors are the types of celestial objects that can emit gamma-ray bursts (GRBs). There are at least two different types of progenitors (sources) of GRBs: one responsible for the long duration, soft-spectrum bursts and one (or possibly more) responsible for short-duration, hard-spectrum bursts. These are the potential sources.

GRB090429B:

The most distant known GRB. It is now the most distant known object in the universe. It was detected on April 29, 2009. But its distance was not announced until 2011. The burst had a redshift of z=9.4. It was a five-second-long burst of gamma rays from the constellation triggered the Burst Alert Telescope on NASA's Swift satellite. As with most gamma-ray bursts, this one, designated GRB 090429B, heralded the death of a star some 30 times the Sun's mass and the likely birth of a new black hole.

High Energy vs. Very High Energy Astrophysics:

The HAWC experiment is considered a high energy astrophysics project, which is also known as TeV astronomy. High energy astrophysics is concerned with the study of astrophysical sources of gamma-ray photons, with energies in the range between 30 GeV and 30 TeV. This field began in 1989, with the discovery of the first TeV astronomical source: the Crab Nebula. “High energy”, or “GeV”, astronomy refers to the energy range from 30 MeV to 30 GeV, while “very high energy”, or “TeV”, astronomy, refers to the range from 30 GeV to 30 TeV [J.Holder]

External Shock Model:

The external shock model is the favored interpretation for the long-term afterglows starting at high energies and phasing into gradually longer wavelengths over periods of days to months.

Internal Shock Model:
Internal shocks continue to be the model most widely used by observers to interpret the prompt MeV emission.

Tidal Radius:

Tidal forces overwhelm the gravity that might hold the satellite together within the Roche limit, no large satellite can gravitationally coalesce out of smaller particles within that limit. The Roche limit is reached when the gravitational force and the tidal force balance each other out. The distance within which a celestial body, held together only by its own gravity, will disintegrate due to a second celestial body's tidal forces exceeding the first body's gravitational self-attraction.[1] Inside the Roche limit, orbiting material disperses and forms rings whereas outside the limit material tends to coalesce. The term is named after Édouard Roche, who is the French astronomer who first calculated this theoretical limit in 1848.

AGN:
Active galactic nuclei

Fermi Satellite"

- Large Area Telescope (LAT)
  The LAT measures the spectra in the energy range from 20 MeV to 300 GeV, locating the source positions to an accuracy of < 1 degree. LAT detects bursts at a rate of ∼ 8 per year.
- Gamma-Ray Burst Monitor (GBM)
  The GBM measures the spectra of GRB in the energy range from 8 keV to 40 MeV, determining their position to ∼ 5o accuracy. The GBM detects GRBs at a rate of ∼ 250 per year, of which on average 20% are short bursts .

The great strength of this combination is to provide the large field of view and high detection rate of the GBM extending to energies as low as the BAT in Swift, with the very high energy window of the LAT, which opens up a whole new vista into the previously almost unexplored GeV to sub-TeV range of GRBs. Two unexpected features of the GeV emission of bursts were soon discovered by the Fermi-LAT. One is that the onset of the GeV emission is invariably delayed relative to the onset of the MeV emission (by a few seconds in LGRBs, and fractions of a second in SGRBs) . The other is that the GeV emission generally lasts for much longer then the MeV emission, decaying as a power law in time and lasting up to a 1000 s in some cases, i.e. well into the afterglow phase for both short and long GRBs. The fact that GeV emission has been detected from a number of SGRBs is, in itself, also new. Remarkably, the GeV behavior of LGRBs and SGRBs is quite similar.

Hikkila Paper Notes:

Research over the past three decades has revolutionized cosmology while supporting the standard cosmological model. However, the cosmological principle of Universal homogeneity and isotropy has always been in question. Gamma-ray bursts are the most energetic explosions in the Universe. As they are associated with the stellar endpoints of massive stars and are found in and near distant galaxies, they are viable indicators of the dense part of the Universe containing normal matter .
The spatial distribution of gamma-ray bursts can thus help expose the large scale structure of the Universe. As of July 2012, 283 GRB redshifts have been measured.

Subdividing this sample into nine radial parts, each containing 31 GRBs, indicates that the GRB sample having $1.6 < z < 2.1$ differs significantly from the others in that 14 of the 31 GRBs are concentrated in roughly 1/8 of the sky. A two-dimensional Kolmogorov-Smirnov test, a nearest-neighbour test, and a Bootstrap Point-Radius Method explore the significance of this clustering. This sample of GRBs can be subdivided by redshift, resulting in distance groupings for which angular information can also be obtained.

When the five groups are compared, following the method discussed in the next section, there is a weak suggestion of anisotropy in one group. When the six groups are compared, there is little sign of any differences between the sky distributions of the groups. This is also the case for the samples involving seven and eight groups, but this is not the case when considering the sample containing nine groups.

They acknowledge that the results could be tainted by the overexposure of Swift's detectors in certain parts of the sky. They have used redshifts to help guard against tainted results. (How?)

They have to prove their results are not tainted in the paper: “We test the hypothesis that Swift’s sky exposure and Galactic extinction might be responsible for the group4 burst clustering “.