

Gamma Ray Burst Educational Unit

An Educator's Guide with Activities in Science and Mathematics



National Aeronautics and
Space Administration

<http://swift.sonoma.edu>

Gamma-Ray Bursts and the Swift Education and Public Outreach Program

Busy educators sometimes have trouble finding ways to help their students feel the excitement of science in action. As a part of its educational effort, the NASA Education and Public Outreach group at Sonoma State University has put together a compact presentation based on the science of one of NASA's exciting space missions: The Swift Gamma-Ray Burst mission.

Since many children remember and understand better when they actively engage in manipulating the concepts about which they are learning, we have included several hands-on activities to help keep their interest and reinforce their comprehension and retention of the scientific concepts covered in the presentation of the mission. We have also included information about Swift, what kind of objects it will observe and why astronomers are interested in them. To help you determine when this project might be of most use to you in your science and/or math curriculum, we have included a matrix of the math and science standards covered. This introduction to the activities includes some frequently asked questions.

What is Swift?

Swift is a NASA satellite that is planned for launch in late 2004, and is part of NASA's Science Mission Directorate. Astronomical satellites in this division are designed to explore the structure of the Universe, examine its cycles of matter and energy, and peer into the ultimate limits of gravity: black holes. Swift's primary mission is to observe gamma-ray bursts, extraordinary explosions of matter and energy that astronomers think signal the births of black holes. These explosions, as huge as they are, fade very rapidly, so Swift must react quickly to study them. The satellite moves so quickly that astronomers decided to name it Swift, after a bird that can dive at high speed to catch its target. It is one of a very few NASA missions that has an actual name and not an acronym!

What instruments will Swift use?

There are three scientific instruments on board Swift: the Burst Alert Telescope (BAT), the X-ray Telescope (XRT), and the Ultraviolet/Optical Telescope (UVOT). The BAT is sensitive to X-rays, a very energetic form of light. Gamma-ray bursts emit X-rays when they explode, and the BAT will be the first instrument onboard Swift to detect them. Swift will then "swiftly" turn toward the burst and point the XRT and UVOT at the target. They will observe the burst in lower energy X-rays and in ultraviolet and optical light, respectively.

What will my students learn from these activities?

This series of activities uses gamma-ray bursts – distant explosions of incredible fury – as an engagement to teach basic concepts in physical science and mathematics. The mapping of the activities to the national science and math standards and a detailed listing of the science and mathematics learning objectives can be found in p. 48 through 51.

How are these activities organized?

Page 3 has a general introduction to gamma-ray bursts and their history. Depending on the age and ability of your students, you may need to tell them about this information, have them read it, or have a few advanced students give a presentation to the rest of the class based on this introduction and other sources they may find. With this introduction, try to convey the excitement of the scientists when they first discovered these enigmatic explosions and the decades-long pursuit to understanding them. You may find other useful educational materials available at:

<http://epo.sonoma.edu/orderforms/orderformpublic.html>

Each activity has the following components to help you make it an exciting learning experience for the students:

1. *Science concepts and estimated time* (note: time varies significantly for different age groups and levels of scientific understanding.)

2. *Background Information* specific to the activity (see the suggestions above for possible presentations of this background information.)

3. The “*essential question*” asked by the activity. Take the time to help students understand that scientists ask questions. Each activity states the essential question that this activity is designed to answer, or to help the student explore.

4. The *materials* needed to complete the activity.

5. There is a glossary defining words that may be unfamiliar; the first time those words are used they are printed in **bold**.

6. The specific *learning objectives* of the activity.

7. The *procedures* to be followed step-by-step for the most efficient and effective use of the activity.

8. The *assessment* for the activity. It is important that before you start an activity you have a clear understanding of what constitutes a successful activity. This assessment area of the activity gives some suggestions for ways to evaluate your students’ work in mastering the activities’ objectives.

9. *Transfer activities*: One of our goals in science is to help students see science and scientific concepts as tools to be used throughout their lives, not just as a small part of their education. Including transfer activities after the activity is completed will not only reinforce the specific objectives, but will also help your students learn to apply scientific concepts to their “real lives.”

10. (For some activities) suggested *extension and reflection activities*. These extras help the student follow up the activity with comprehension exercises so that they better assimilate the information, and use the concepts they have learned to better understand phenomena in everyday life.

11. *Lesson adaptations* that will help you cope with the special needs of students in your classroom.

12. An *answer key* which provides you with the answers to the mathematical questions given to the students, and helps you evaluate the products the students may produce as a part of the activity.

13. *Student handouts and worksheets* that contain the information and directions necessary for the student to complete the activities. NOTE: giving the students the worksheet without the appropriate background information and procedures will not only decrease the learning of the students, it may also cause frustration and feelings of inadequacy to master science principles.

14. *Specific standards* list that presents more detailed information about the national science and math standards covered in each activity, and at the end of the guide.

Who developed these activities?

The activities that describe gamma-ray bursts have been developed as part of the NASA Education and Public Outreach (E/PO) Program at Sonoma State University, under the direction of Professor Lynn Cominsky.

Contributors to this education unit also include Dr. Philip Plait, Tim Graves, Sarah Silva, Dr. Garrett Jernigan and Dr. Mary Garrett. We gratefully acknowledge the advice and assistance of the Swift Education Committee, the NASA SEU Educator Ambassador (EA) team, with extra thanks to EAs Dr. Tom Arnold, David Beier, Teena Della, Dee Duncan, Tom Estill, Mandy Frantti, Dr. Mary Garrett, Walter Glogowski, Bruce Hemp, Rae McEntyre, Janet Moore, Marie Pool, Dr. Christine Royce, and Rob Sparks.



Where can I get more information?

The last page of this booklet contains a list of resources for Swift and gamma-ray bursts.

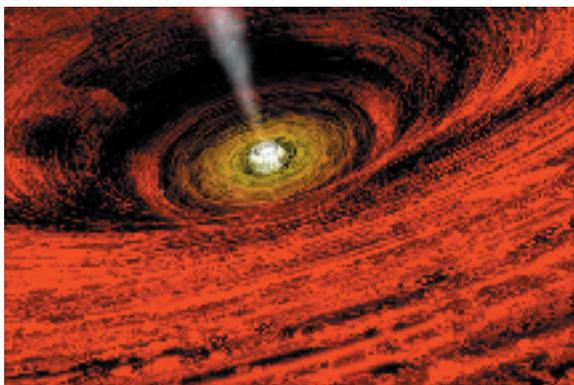
To learn more about Swift Education and Public Outreach, visit

<http://swift.sonoma.edu>

Introduction to Gamma Rays and Gamma Ray Bursts

The **electromagnetic spectrum** comes in many flavors, from the low-energy **radio** region, through **microwave**, **infrared**, **visible light** (the only part of the spectrum we can see with our unaided eyes), **ultraviolet**, **X-ray**, and up to extremely high-energy **gamma ray** end. Astronomical objects of different sorts emit some or all of these kinds of **radiation**, and we can only get a complete picture of these objects by studying them in all the different regions of the electromagnetic spectrum.

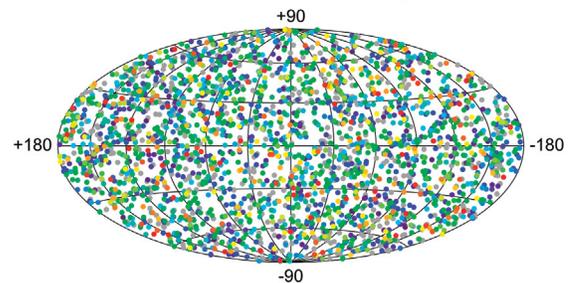
The type of radiation emitted by an object tells us quite a bit about it. Low energy or relatively cold objects like planets and dust clouds emit mostly radio or infrared waves, which are low-energy waves. Hotter, more energetic objects like stars and nebulae can emit higher energy waves in the visible and ultraviolet range. Even more energetic objects like **pulsars** (the collapsed cores of stars that exploded as **supernovae**), extremely hot gas, and **black holes** can emit X-rays. But to emit gamma rays you need something incredibly energetic, something that dwarfs the energy emitted by “cooler” objects. Some pulsars which have unusually intense magnetic fields can generate gamma rays. The fierce magnetic energy in a huge **solar flare** can (very briefly) generate gamma rays. Twisted magnetic fields from spinning supermassive black holes can channel particles and accelerate them to velocities near light speed, generating focused **jets** of gamma rays.



But even these pale in comparison to **gamma-ray bursts (GRBs)**. In the 1960s, the United States was concerned that other countries might test

nuclear weapons in near-Earth space, despite a treaty to ban such events. Nuclear detonations produce bursts of gamma rays, so the U.S. military launched a series of satellites designed to detect these high-energy explosions. To their surprise, scientists soon began detecting dozens of explosions, but discovered they were not coming from the vicinity of the Earth; these bursts were occurring in deep space.

2704 BATSE Gamma-Ray Bursts



The source of these bursts was a mystery (and to a large extent still is today). Some bursts lasted for only **milliseconds**, while some dragged on for seconds or minutes. At first astronomers assumed these must be “local” phenomena—somewhere in our own **Milky Way Galaxy**. Because of the energy involved in producing such a large number of gamma rays, a more distant object would have to be unimaginably powerful to account for a GRB.

As time went on, and astronomers began to use ever-more sophisticated instruments, it became clear that not only were GRBs not local, they were really not local—the more distant ones are billions of light years from the Earth! In the 1990s, the Burst And Transient Source Experiment (BATSE) instrument onboard NASA’s Compton Gamma Ray Observatory provided the initial evidence for this in the form of the distribution of GRBs: BATSE found that GRBs were scattered evenly across the sky (see diagram above). If GRBs were coming from inside our own Galaxy, we should see more of them toward the center (an analogy would be seeing more buildings when looking toward the center of a city when you live in a suburb). Since the GRBs were randomly distributed, this argued for sources well

outside our Galaxy. This means GRBs are at vast distances, which in turn means they are incredibly powerful events – in fact, they are the largest explosions seen in the Universe today, second only to the Big Bang itself in the release of energy.

The vast amounts of energy inferred from the distant locations of the GRBs puzzled scientists until they realized that the energy might be beamed, that is, concentrated into tight jets instead of being sprayed in all directions. Beaming the gamma rays dropped the total energy needed to produce GRBs into the range just barely understandable using the most catastrophic of all events: the birth of a black hole.

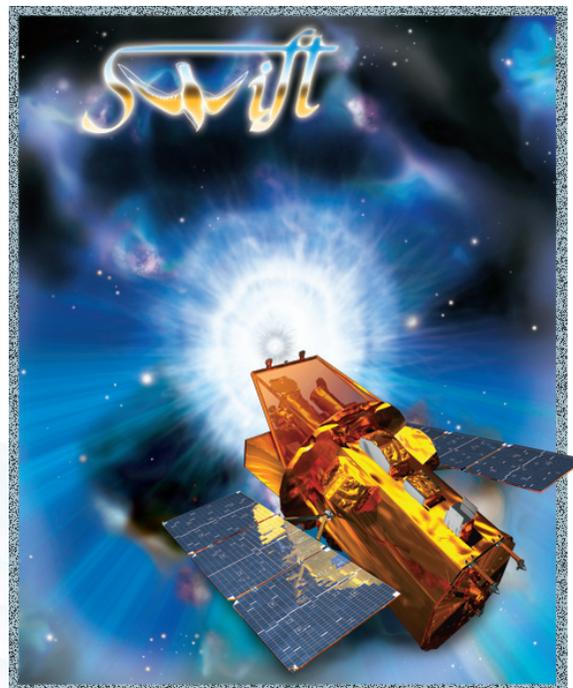


Currently, there are two (not necessarily competing) theories on how GRBs are produced. One is called a **hypernova**, or a super-supernova. When a star with about 10-40 times the mass of the Sun reaches the end of its life, it explodes, violently expelling matter and energy into space. These supernovae are very energetic events, but not powerful enough to make gamma rays in the quantities necessary for GRBs. But if a very massive star—one with 50–100 times the mass of the Sun—explodes, the energies involved may be enough to create a gamma-ray burst. Indeed, at least one GRB was seen at the site of a supernova in a relatively nearby galaxy, and there is indirect evidence the two are connected.

The other theory involves a **binary system** comprised of two **neutron stars**. These are the extremely dense and massive cores of stars that previously exploded as supernovae. As they orbit each other, the collapsed stars lose energy through gravitational radiation, a complicated process predicted by Einstein's Theory of General Relativity. As the system loses energy the stars slowly spiral inward. When they are close enough, their mutual gravitation rips the stars apart, and they coalesce. As they merge, they form a black hole with an extremely dense ring of material spinning madly around it. When

that matter falls into the black hole some time later, a burst of energy is released which could power a GRB. There are indications that at least some GRBs fit into this merging collapsed star category.

Whichever theory turns out to be correct, we know that GRBs appear without warning somewhere in the sky at least once every day, indicating that somewhere, far off in the Universe (we hope!) a black hole is born. NASA's Swift mission will allow scientists to study GRBs better than ever before. Also, some GRBs are followed by a fading **afterglow** of light which can be seen in X-rays, optical, infrared, and even radio wavelengths. Follow-up observations of this decay allow astronomers to better pinpoint the direction to the GRB and even look into its local environment. The Swift satellite will quickly lock on to GRBs, using the gamma ray-sensitive **Burst Alert Telescope** to get a rough location in seconds, and a more accurate one within minutes as its **X-ray** and **Ultraviolet/Optical Telescopes** image the target. The information on the location and strength of the GRB will be relayed to the ground to allow faster and more detailed follow-up observations of the rapidly fading catastrophe. Astronomers hope they will get enough data to finally solve the riddle of these explosions that are so vast that they equal the energy of a billion *billion* (10^{18}) Suns.



Stepping Into The Classroom!

Follow the Foot Steps:

Elicit Engage	The instructor assesses the learners' prior knowledge and helps them become engaged in a new concept by reading a vignette, posing questions, doing a demonstration that has a non-intuitive result (a discrepant event), showing a video clip, or conducting some other short activity that promotes curiosity and elicits prior knowledge.
Explore	Learners work in collaborative teams to complete activities that help them use prior knowledge to generate ideas, explore questions and possibilities, and design and conduct a preliminary inquiry.
Explain	Learners should have an opportunity to explain their current understanding of the main concept. They may explain their understanding of the concept by making presentations, sharing ideas with one another, reviewing current scientific explanations and comparing these to their own understandings, and/or listening to an explanation from the teacher that guides them toward a more in-depth understanding.
Elaborate Evaluate Extend	Learners elaborate their understanding of the concept by conducting additional activities. They may revisit an earlier activity, project, or idea and build on it, or conduct an activity that requires an application of the concept. The focus in this stage is on adding breadth and depth to current understanding. The evaluation phase helps both learners and instructors assess how well the learners understand the concept and whether they have met the learning outcomes. There should be opportunities for self assessment as well as formal assessment. Learners should also be given an opportunity to extend their new found knowledge.

Learn More:

Science Teacher: Expanding the 5E Model - by Arthur Eisenkraft, September 2003.

Designing Professional Development for Teachers of Science and Mathematics - Susan Loucks-Horsley, Nancy Love, Katherine E. Stiles, Susan Mundry, Peter W. Hewson - Corwin Press.



Duration:

Introduce concepts and
Perform activity: 45 min

Sorting Out The Cosmic Zoo

1



Essential Question:

How do astronomers differentiate one type of high-energy astronomical object from another?

Objectives - Students will:

- be able to list at least four observable properties of astronomical objects
- create their own categorization method based upon observable properties
- be able to categorize astronomical objects in scientifically accepted categories based upon observable properties

Science Concepts:

Astronomical objects can be categorized by such characteristics as position in the sky, duration of an event (like a flare), periodicity, and distance.

Background Information

Gamma-ray bursts (GRBs) were first detected in the late 1960s by U.S. satellites designed to look for space-based nuclear weapons testing. GRBs are characterized by a short burst of gamma rays (from milliseconds in duration to a few minutes), and rarely have an easily detectable glow more than a few minutes after the event. GRBs are flashes-in-the-pan: they explode once, never to return.

GRBs were a big mystery to astronomers when they were first seen (and in fact, they still are). The situation became worse when, on March 5th, 1979, intense flashes of gamma rays were detected coming from the direction of the **Large Magellanic Cloud**, a companion galaxy to the Milky Way. Then, over the next few months, more flashes of gamma rays were detected coming from the same region of the sky. For a while, the idea that GRBs only flashed once was in doubt, but then it was realized that the repeating sources were a totally different class of object. Dubbed **Soft Gamma Ray Repeaters (SGRs)**, because they peak at a slightly lower (also called “softer”) energy of gamma ray than GRBs, these were found to be neutron stars — incredibly dense remnants of supernova explosions — which have extremely strong magnetic fields, far stronger than typical neutron stars. For reasons still unknown, the super-magnetic field can cause the crust of the neutron star to slip, much like an earthquake. The intense gravity of the neutron star makes such a slip a dramatic event indeed; the energies can be enough to generate huge bursts of gamma rays which typically last for less than a second. Over time, the pressure builds up again, and another flash is seen. This is how gamma rays are seen from the same object more than once.

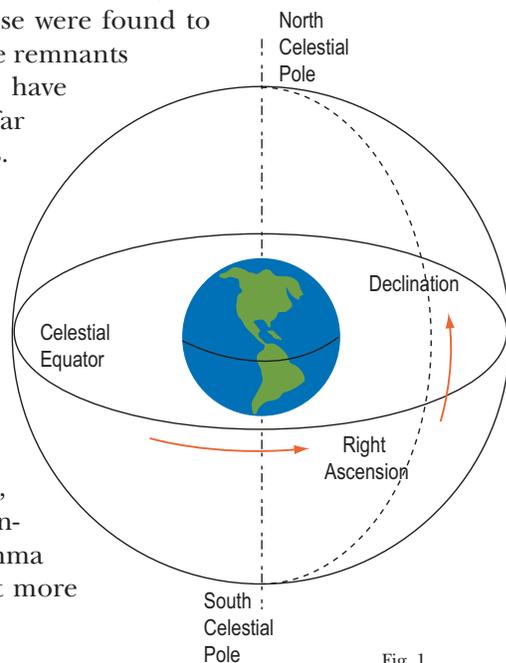


Fig. 1

Also in the mid-1970s, different kinds of high-energy events were starting to be identified. The so-called **X-Ray Bursters (XRBs)** were discovered. Like SGRs, they were neutron stars with repeating bursts, but their magnetic fields, while strong, were not at the level of the SGRs’ strength. And unlike SGRs, which are isolated, individual neutron stars, XRBs are caused by neutron stars in binary systems. The neutron star in such a system can **accrete**, or draw in, matter from a normal companion star. The matter builds up on the surface of the neutron star, and then suddenly explodes in a thermonuclear blast. It is this explosion which creates the burst of X-rays, which lasts for roughly 20 to 100 seconds. After the matter burns up in the blast, the accretion starts again and the pattern repeats. This causes repeated XRBs from the same object.

During the 1970s through the 1990s, much confusion arose because it was not clear at first that there were actually three different types of physical mechanisms that were producing the bursts of energy. Placing something in its correct category is half the battle in understanding it. It took 30 years for astronomers to sort out these different types of phenomena, and in fact they are still working on classifying and understanding them. Your students will do the same, but in just 45 minutes!

The Mystery Source Cards

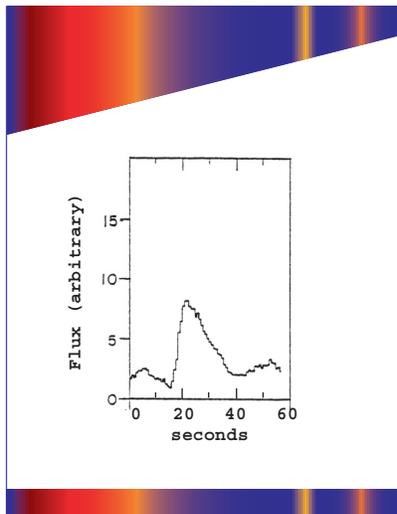
The cards in this activity contain real data determined from characteristics of actual astronomical objects that emit bursts of high-energy electromagnetic radiation, either as X-rays or gamma rays. In this activity, your students will sort the cards into different categories using just the information printed on them.

On the front of each card is the name of the object, and a graph showing the burst's energy ver-

sus time; what astronomers call the **light curve**. The back of each card has the name of the object, its coordinates using the Galactic coordinate system, the energy at which the spectrum of the object peaks, whatever object is seen at the source's position using optical light (if any), the distance to the object, whether the bursts repeat, and whether there is any periodicity associated with the object other than the bursts. These characteristics are detailed below.

On the front of the cards:

- **Object Name:** The name of the object is based on its coordinates on the sky. The sky is mapped by astronomers using a coordinate system similar to longitude and latitude, but the axes are called **Right Ascension** (or RA) and **declination** (Figure 1). RA is measured in the direction of East-West on the sky, and goes from 0 to 24 hours (each further divided into 60 minutes). Declination is measured in North-South on the sky, and goes from -90 to 90 **degrees**. card is its RA (a four first two digits are the minutes) and its including the plus or minus RA of 5 hours 30 minutes degrees would thus have name of the object using back of the cards.



- **Light curve:** This is the by an object plotted these objects have bursts have narrow profiles and take many seconds or the profiles and broad-also emit multiple peaks. amount of light emitted against time. Some of that are very short, so they sharp peaks, while others minutes, stretching out ening the peaks. Some Note that time scales (x-axis) on the light curves may be different on each card, and that the units of the **flux** are arbitrary; in other words, the y-axis units cannot be compared from card to card, but the x-axis can be compared if care is taken to note the units. Make sure the students understand that they cannot compare the heights of the peaks of different bursts, and instead should look at the widths. Tip: Most students will try to group the bursts using only the light curves, and may spend the majority of their time doing it that way instead of looking at the information on the back sides of the cards. If you see a group spending too much time (say, more than five minutes) on the light curves, gently urge them to look at the other physical characteristics of the bursts on the other side of the cards.



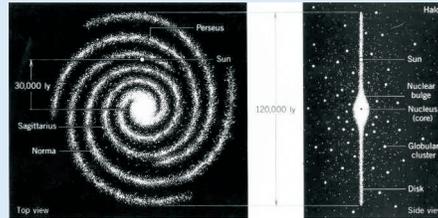
About:

The Vela satellites were launched to detect the blast of gamma rays generated by a nuclear bomb. Always launched in pairs, they could use the timing of the gamma-ray detections to locate the source of the explosion (see Activity 2, Angling for Gamma-Ray Bursts). They never detected a single nuclear bomb, but they did detect 73 GRBs.



Location (Galactic coordinates):

The galactic coordinate system is a way of measuring the position of an object in the sky using the Milky Way Galaxy as a base. Our Galaxy is a flat disk, and the Sun is in that disk about 30,000 light years from the center. Astronomers have defined the galactic coordinate system based on the center of the Milky Way and the plane of the disk. Galactic longitude (ℓ) is measured along the plane of the Milky Way, where the position of the center of the Galaxy on the sky is defined as 0 degrees. Galactic longitude goes from 0 to 360 degrees. Galactic latitude (b) is measured away from the plane of the Milky Way, in degrees. Galactic latitude goes from -90 degrees at the South Galactic Pole to +90 degrees at the North Galactic Pole, similar to latitude on the surface of the Earth.



Spin or Orbital Period:

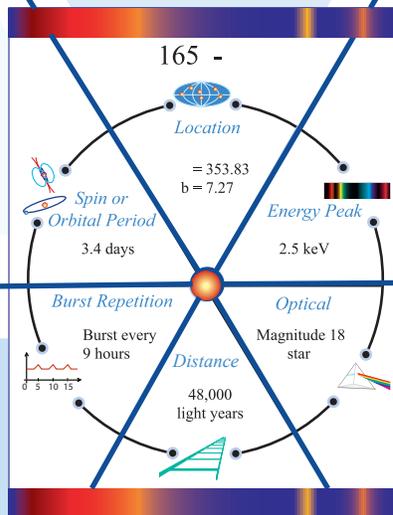
Any pattern of cycles seen in the object's light. This is different than repetition, which just notes if a given burst repeats. If the object that is bursting is spinning, or orbiting another object, then there might be a periodic pattern during the bursts, or a periodicity seen in different wavelengths. "None" means there is no **period**, and "N/A" means no information is available.

Galactic coordinates are usually plotted on an Aitoff projection, which is similar to familiar **Cartesian coordinates** except that the plot is oval in shape (see "Additional Information: **Aitoff Maps**" below). Over 2700 GRBs are plotted on an Aitoff map in the "Introduction to Gamma Rays and Gamma-Ray Bursts" section).



Energy Peak:

These objects are luminous at a variety of different energies. The peak energy is the **photon** energy at which the object emits the largest number of photons. As an example, an optical photon has an energy of about 1 **electron Volt** (eV). X-rays have an energy of about 1000 eV (or 1 **keV**; k = kilo) to about 50,000 eV (50 keV). "**Hard**" X-rays (which are sometimes also called soft gamma rays) range from about 50 keV to 1000 keV. Gamma rays go from about 1000 keV through a million keV range and beyond.



Burst Repetition:

This indicates whether the high-energy bursts are seen to repeat or not. "None" means that no repetition has been observed, and "N/A" means no information is available.



Optical:

The identification of the object seen at the position of the burst using optical light. Some objects appear to be associated with galaxies, some with stars, others with **supernova remnants** (the debris left over when a star reaches the end of its life and explodes in a supernova.)



Distance:

The distance from the Earth to the object in **light years**. Note that there is a large range of distances for the objects on the cards.

The students' task is to look at the data on the cards, try to find out how many categories of objects there are, and sort the objects into their respective groups. For example, they may sort them by distance, and find that they fall into, say, two groups, one near and one far. Or, they may sort them by peak energy into, say, two groups, and find out each energy group can be further divided into the object type, or by position on the sky.

In the end, you can take a survey or have the students vote on how many categories of objects there should be, and how they divided the objects into these groups. Remind them that the data they used were painstakingly determined over decades of time, and that astronomers from 1975 would have given anything to have a copy of these cards!

Additional Information: Aitoff Maps

In this exercise the students will be plotting the distribution of the mystery objects on the sky. Typically, when making all-sky plots, astronomers use an Aitoff projection, which is a method of mapping a sphere so that distortions are kept to a minimum. Most people are familiar with a map of the Earth projected onto a rectangle. While this is an intuitive way of mapping the Earth, it generates big distortions near the poles, making Greenland, for example, look much larger than it really is. An Aitoff projection (see figure 2) maintains the correct relative areas for all the continents.

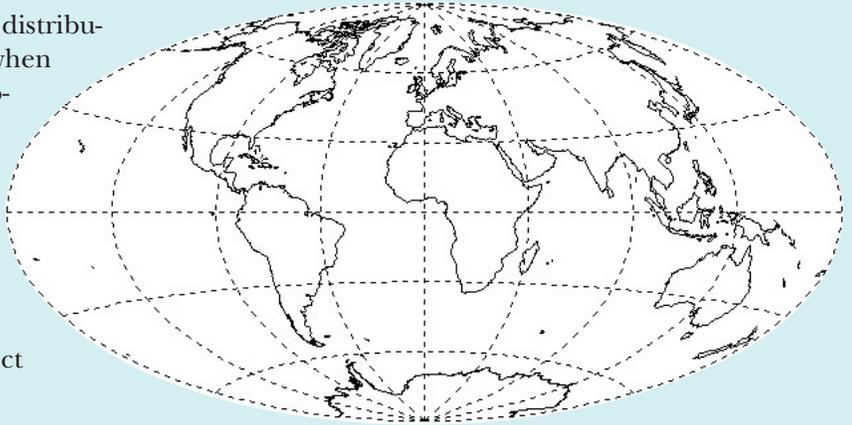


Fig. 2

In an Aitoff map of the sky, the center vertical line represents 0 degrees longitude, and longitude increases to the left to 180. Then it skips over to the right side (which is also 180) and continues increasing to the left, from 180, through 270, and finally to 360, which is the same as 0 (see the blank Aitoff map on page 14).

The center horizontal line is 0 degrees latitude, and latitude increases upwards to +90 degrees at the north pole, and decreases to -90 degrees at the south pole.

The sky map is the same! In that case, we call the coordinates “Galactic longitude” and “Galactic latitude” (see the description above for “Galactic coordinates”).

It may help to use an overhead to give examples of how to plot points on an Aitoff map.

Beware! Many people mistakenly think that their location is plotted on an Aitoff map of the sky. They may ask you “where they are” on the Aitoff map. Remind them that the Aitoff map is a map of the sky, as if the spherical sky were “unwrapped” and plotted on paper. Since the students are on the Earth, and not in the sky, they are not on the map.

Ask the students to compare the map of the World on the Aitoff map above, to the common views often shown (below).



Materials for each group of 2 or 3 students:

- 1 set of Mystery Object cards printed in the center of this booklet. (Also available online for downloading; see Resources and Web Links p.52)
- A set of six or seven different colored pencils or crayons for plotting (or small stickers)

Materials for each student:

- Student Worksheet
- Student Blank Aitoff projection sky map for plotting

Elicit and Engage!

Procedure step 3:

A good way to do this would be to first ask your students a series of leading questions. Questions like:

- What do we know about gamma rays?
- Are they light or particles?
- What types of objects emit gamma rays?
- How do we know these things?

Depending on their answers your questions may change.

This method is a really good method to intrigue your students and engage their minds. Also it is good as an assessment tool.



Engage and Explore!

Procedure step 7:

Keep reminding the students that there are no wrong or correct answers as long as they can explain their reasoning, as scientists do. Ask your students why they think others may have chosen to categorize their cards differently.

Procedure:

1. **Pre-class:** read through the entire activity, including the Worksheet. Make copies of the Student Worksheets, one per student.
2. As a possible warm-up exercise, perform the Extension Activity outlined below after the Procedure section.
3. **In class:** Introduce the activity to the students by reviewing information in the section “Introduction to Gamma Rays and Gamma-Ray Bursts” and in the activity overview. However, do NOT tell the students that there are three different groups of objects (gamma-ray bursts, soft gamma repeaters, and X-ray bursters).
4. Explain to the students that they will be given a series of cards with information about astronomical objects on them. These objects fall into different categories. They are to determine any trends in the objects, determine how many categories there are from those trends, and which objects belong to which categories.
5. They will also be plotting the positions of the objects on the sky maps (using the enclosed blank Aitoff projection map) to see if there are trends there as well. They can use colored pencils to represent the different types of objects, or you can use small stickers as a substitute.
6. The activity can be done individually or in teams of two or three students.
7. **Post-class:** After the activity is completed, discuss the results with the students. Ask them how much time they spent looking at each characteristic of the bursts, and which physical properties were useful and which weren't. Was there one best way to categorize the objects? How many burst groups did they find, and what was the key characteristic of each group? Engage them in thinking about what they did, and discussing their methods. Were they frustrated in any way, or did they find categorization to be easy? You can compare and contrast the methods of the different groups of students, and even make a table of the number of groups into which they sorted the objects (i.e., how many students sorted the objects into two different groups, how many into three, etc.).
8. When you are done, show them how astronomers categorize the objects using the information in the introduction to the activity, and compare these results to what the students found. Tell the students that the amount of information they had on the cards was very limited, and the current information about these objects has been gathered after decades of observations and analysis by hundreds of astronomers. Finally, remind them that the data on the cards represent everything astronomers knew about these objects for many years, and that astronomers are even today still frustrated by our limited understanding of gamma-ray bursts! That's why astronomers have built Swift: to help solve remaining mysteries about gamma-ray bursts.

Transfer Activities:

Different luminous objects can look very similar when they are at a large distance. For example, when driving at night, the headlights from a distant truck and a small car may look similar, and the difference may only be obvious as they get nearer. Students can try to identify different vehicles from

a distance, and devise ways to tell them apart. This also applies to birds, which can look very similar when high in the sky. How can you differentiate them? Color, shape, style of flight? Once you categorize them, can you determine anything else about them from these categories?

Extension Activities:

Categorization of different objects is essential in all fields of science. One obvious example is zoology. As a warm-up activity, choose four or five animals with widely different characteristics (for example, elephant, alligator, insect, bird). Divide the students into groups of three or four, and present them with pictures of the animals and ask them to describe them in as many ways as they can. After they are done, have them then categorize them into groups based on similarities (for example, the elephant

and alligator both have four legs). Compare the results of each group and have them discuss them as a class. If you want to challenge them, add in a bacterium or virus. This would also be a useful exercise to do in class before the main activity.

Sorting objects into various categories is also a major challenge in astronomy. There are several activities in which students can classify objects. An excellent one is the Galaxy Classification Activity located at:

<http://btc.montana.edu/ceres/html/gal1.html>

Lesson Adaptations:

Students who are visually impaired may have difficulty reading the light curves on the fronts of the cards. To aid them, glue yarn or string over the light curve, trying to follow the bumps and wiggles in the plot, or use “puffy paint” which becomes raised and puffy when it dries. (Many craft stores carry this type of paint.) The students can

run their fingers over the string/paint to literally feel the shape of the light curves. Be careful to tell them the time scale along the x-axis! A light curve may feel more sharply peaked than another, but if the timescale is much longer than the other the shape may be misleading.

Hint: A clear plastic globe like a hamster exercise ball can be used to better explain Right Ascension and declination. Use a dry erase marker to draw the lines while explaining them to the class.

Remember to ask your students a series of leading questions!



Evaluate:

Points	Student Categorization (reasoning)	Graph	Calculations	Scientifically Accurate Categorization
4	Reasoning for grouping is well-supported	Plotting is accurate	Calculations are all accurate	All objects are in the right categories
3	Reasoning is supported	Plotting is adequate	Most calculations are accurate	Most objects are in the correct categories
2	Reasoning is somewhat supported	Plotting is somewhat accurate	Some calculations are accurate	Many objects are in the wrong categories
1	Reasoning is not supported	Plotting is inaccurate	Calculations are inaccurate	Objects are almost all in wrong categories
0	None turned in	None turned in	None turned in	None turned in

Elaborate!

Answer Key for *Sorting Out The Cosmic Zoo*:

1. Astronomers have categorized the objects into three groups. The table below gives the name of the object in the correct grouping.

X-ray Bursters	Soft Gamma-Ray Repeaters	Gamma-ray bursts
0748-67	0526-66	0501+11
1636-53	1627-41	0656+79
1659-29	1806-20	1156+65
1728-34	1900+14	1338-80
1735-44		1525+44
1820-30		1935-52
1837+05		2232-73
1850-08		2359+08

Several of the properties are useful for categorizing the objects. Peak energy is perhaps the best. The first group has a low peak energy, around 2-3 keV. The second group peaks somewhat higher, at 30 keV, and the last group peaks much higher at 175-1500 keV, with a few at somewhat lower energies. (This is also the answer to Question 3.)

Another good property is the optical counterpart. The GRBs all have host galaxies. The counterparts to the XRBs are all stars, while the SGRs are all found in supernova remnants.

The GRBs are spread out over the whole sky in Galactic coordinates, while the two other groups tend to be more in the plane (at 0° Galactic latitude). An exception is that one of the SGRs is in our neighboring galaxy, the Large Magellanic Cloud (0526-66).

The SGR bursts and the XRBs repeat every few hours, while the GRBs are never seen to repeat.

The SGRs often have spin periods of seconds to minutes (reflecting the spin of the actual neutron star), the XRBs show orbital periods around their companion stars of minutes to hours, while the GRBs show no periodicities at all.

The distances to the XRBs and SGRs (with the one exception in the second group; 0526-66 which is located in the Large Magellanic Cloud) are the smallest, as the objects are located inside our Milky Way. The GRBs are all very distant (billions of light years).

2. Right is the Aitoff sky map with the objects plotted correctly. The GRBs are the Xs, the SGRs are the diamonds, and the XRBs are the stars.

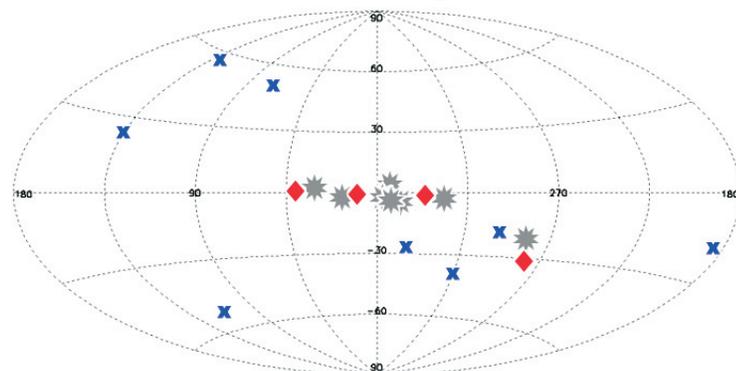
The GRBs are randomly distributed. The other two groups tend to be near the Galactic plane (except 0526-66).

3. The first group has a low peak energy around 2-3 keV. The second group peaks somewhat higher, at 25-30 keV, and the last group peaks much higher at 175-1500 keV, with a few at somewhat lower energies.

4. The distance to the first and second groups (with one exception in the second group; 0526-66) is the smallest, inside the Milky Way. The first group averages about 30,000 light years, and the second group about 70,000 light years. The GRBs are all very distant, ranging from 100 million to 10 billion light years, with an average of 6.5 billion light years.

5. See the answer to question 1.

6. The peak energies would be a big help, as this fairly cleanly separates the groups (see Question 3). The position on the sky helps (Question 2). Also, GRBs do not repeat, which separates them from the other two groups.



Sorting Out The Cosmic Zoo

Student Worksheet

Name _____

Date _____

With a partner or two, examine the collection of 20 cards - each shows real data from a burst that was detected by a space-based X-ray or gamma-ray detector. On the front of each card is a plot of the burst itself, showing the number of photons detected vs. time (pay careful attention to the time scale on the x-axis of each plot). Your goal is to sort the objects on the cards into different groups based on their similarities.

The back of each card gives information about the following properties for each burst:



• **Location** – latitude (b) and longitude (ℓ) in Galactic coordinates of the burst



• **Energy Peak** – the energy where the burst has the maximum number of photons



• **Optical Counterpart** – what is seen in visible light at the position of the burst



• **Distance** – the distance from the Earth to the burst in light years



• **Burst Repetition** – how often the bursts are seen to recur, if they do recur. “None” means that no repetition has been detected, and “N/A” means no information is available.



• **Spin or Orbital Period** – either the spin period of the burster, or its binary orbital period if it is in a binary system. “None” means there is no periodicity, and “N/A” means no information is available.

1. Sort the bursts into different groups based on common properties. How many groups do you think there are? What properties do you think are the most useful for separating the groups?

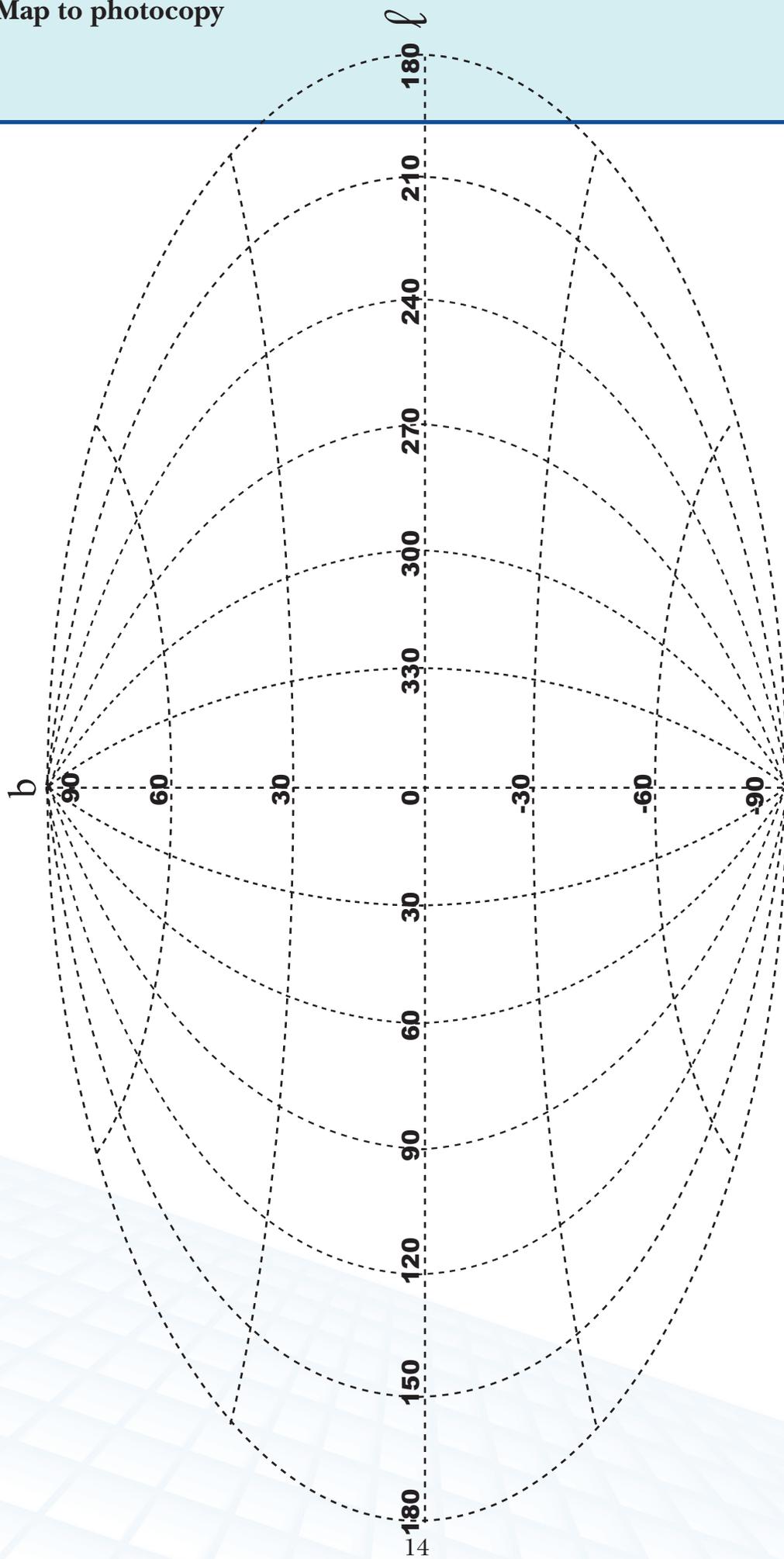
4. What is the average distance from the Earth of the bursts in each group? Is there a lot of variation in the distances of the objects in each group, or are they all at about the same distance?

2. Plot the bursts in each group on the galactic latitude and longitude Aitoff map. Use a different symbol or color for each group. What can you say about the distribution of each group? Are the bursts in each group randomly located, or do they fall into a pattern on the sky?

5. What other properties do the members of each group have in common?

3. What is the average peak energy of the bursts in each group?

6. Imagine you are an astronomer 20 years ago, and you have observed these objects. All you have are their locations in the sky, their peak energies, and the repetition rate. Do you think you could sort these objects into separate groups?



Angling For Gamma Ray Bursts

2

Duration:

Introduce concepts: 30 min

Perform activity: 1 hour

Background Information

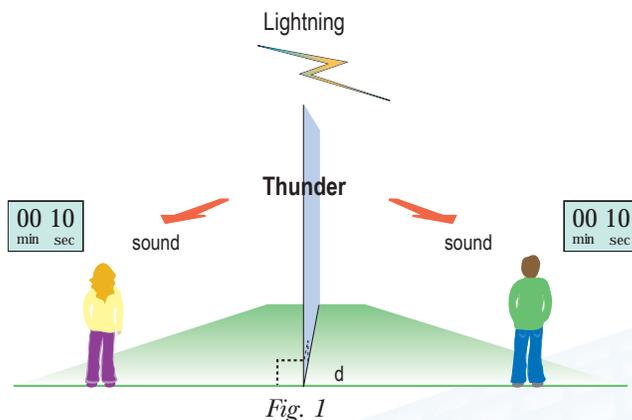
Note for the Teacher

[This information is split up into a section for you, and one for the students to read. You will of course need to read the student portion as well. It is included in the **Student Handout** section. The information provided to the student is sufficient to do the exercise, but the additional information given to you below will complement the student's understanding of how the direction to a GRB is triangulated. Going over this information with the students the day before they perform the exercise will increase their understanding of the activity and its concepts.

Remember to emphasize the point that the people in the following analogy are hearing sound waves, not light waves. Sound waves are transmitted through a medium (such as air) while light waves (also known as photons) are not, and can travel through the vacuum of space. Also, in this analogy, it is important to stress the difference in speed between sound and light waves, and that the lightning and thunder occur simultaneously.]

Imagine you are outside and a storm is approaching. There is a flash of lightning, and a few moments later — say, ten seconds — you hear the thunder. The flash of light traveled from the lightning bolt to you in less than a millisecond, since the speed of light is 300 million meters per second. But the sound waves are much slower, around 300 meters per second, so they take an appreciable amount of time to reach you, even though the lightning and thunder occurred at the same time.

If a friend stands a few hundred yards to your left *but the same distance to the lightning bolt as you*, she will hear the thunder at the same time you do. Since you are both the same distance from the lightning, it takes the same amount of time for the thunder to reach you. If you mark the time when you hear the thunder, then compare watches, you will see you heard it at the same time. That means the wave front of the thunder was traveling perpendicularly to the line between you and your friend (Figure 1).



If your friend now stands a few hundred meters away from you, *farther* from the lightning, she will hear the thunder *after* you do, because it takes time for the sound wave to pass you and reach her. When you compare watches, you can see that she heard it after you (Figure 2). So the minimum time delay (0 seconds) happens when a line between you and your friend is perpendicular to



Essential Question:

How can the directions to gamma-ray bursts be determined using the properties of light?

Objectives - Students will:

- be able to explain at least two properties of light and how it travels through space.
- be able to use time differences to determine directions to gamma-ray bursts.
- be able to explain how astronomers use multiple satellites to determine the direction to gamma-ray bursts.

Science Concepts

1. Satellites can be used to determine the time when a GRB occurs, and to get its direction.
2. It takes several satellites using time delays to accurately get the direction to the GRB.
3. Light travels in a straight line and at a constant speed in a vacuum. From a distant object, the light rays are parallel.

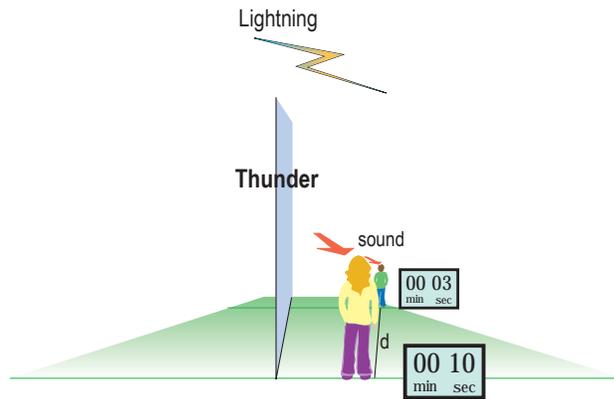


Fig. 2

the direction that the sound travels. The maximum delay (the distance between the two of you divided by the speed of sound) happens when the line between you is parallel to the direction the sound is traveling. If the line between you is at an angle to the sound direction, the time delay will be somewhere between the minimum and maximum (Figure 3). In fact, the time delay depends on that angle. So, if you know the distance between the two of you, the direction to your friend, the speed of sound, and the delay between the times you heard the thunder, you can calculate the direction to the lightning.

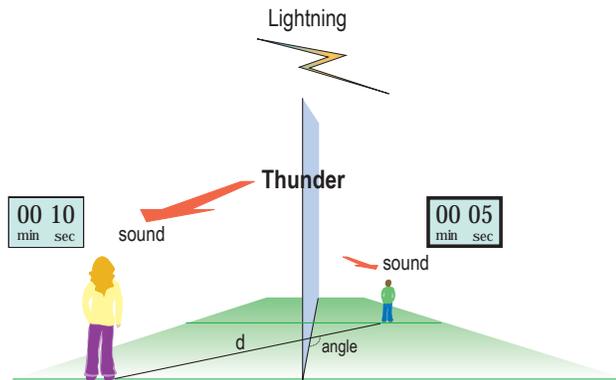


Fig. 3

In this activity, the locations in space of different satellites are analogous to the positions of you and your friend(s). Because the satellites are so widely separated, we can use the delay in the arrival times of the light rays to triangulate the direction to a cosmic gamma-ray burst, just as the direction to the lightning was triangulated in the analogy above using sound waves (thunder).

Materials for each group of 2 or 3 students:

- Ruler
- Scissors
- Pencil
- Protractor
- Light rulers (assembled in activity)
- Graph paper (preferably 0.5 cm/square)
- Calculator

Materials for each student:

- Student Worksheet
- Student Handout

Procedure:

1. **Pre-class:** make copies of the Handouts (which can be reused), and the Student Worksheets, one per student. Make copies of the light rulers on card stock (using regular paper makes it difficult to manipulate the light rulers). Make sure each group gets one or two extra light rulers in case they make a measuring or cutting mistake.

2. At least one day before the activity is performed in class, give the students the Student Handout. As homework, have them read it carefully and write out a paragraph describing the

At least one day before,
Engage your students !

procedures of the activity. You can also assign the Extension Activity (see below) as homework before the activity is done.

3. Explain to the students that they will be using the time delays between satellite detections of a gamma-ray burst to find the direction to the burst.
4. Go over the material in the introduction above. Use the thunder analogy (from the Background Information section) with diagrams to make sure they understand the concept. The illustration on the front of the poster will also be helpful. To print images on a transparency, see:

<http://swift.sonoma.edu/education/grb/transparency/>

5. **In-class:** Perform the activity. Note that at the end of the Student Handout is a Math Extension exercise. This is for students who are learning more advanced trigonometry, and can be considered “extra credit.” When your students get to step 2 and they are all trying to find the solutions, walk around the classroom and assist them with lining the light rulers up.
6. **Wrap up/reflection:** After the activity is completed, have the students break up into different groups of three and discuss their results. How are their individual results alike, and how are they different? What are possible sources of error, and what might be the biggest ones? After a few minutes, break up the groups so the students can have individual reflection time. Have them think of where else this activity might be useful. Some examples could be finding the direction to a thunderstorm, surveying, and earthquake measurements. How would your students set up an experiment to use this method in those cases?

Engage!



Procedure step 3:

Instead of just lecturing, try asking your students questions about time delays. Questions like you may have used in the first activity “Sorting Out The Cosmic Zoo” (revisiting these questions help the students to have a deeper understanding.) Other examples:

- What is a time delay?
- Why do scientists use this method to locate GRBs?
- How does Swift plan to locate bursts?
- Why are light rays parallel from very far distances?
- What is the big question for the scientists explained in the student handout p.19 ?

Transfer Activities:

A. Using the example of two people listening to a thunderstorm, have the class make a plot showing the time delays measured between the two people as the angle between them and the direction to the lightning changes from perpendicular to parallel. They can measure this directly by using scale drawings. Have them describe the plot. Does it look familiar to them? The delays should fall along (half of) a sine curve.



Elaborate!

B. Lead a discussion about how this activity could be modified to include the third dimension. Topics could include how many satellites would be needed (answer: 4), how the light rulers would need to be modified (or changed completely) to accommodate the new dimension, and how you would calculate the angle to the GRB from the Earth.

Extension Activities:

A. Have the students research GRBs and write a short (1 page) report on some aspect of them. This can include how they are discovered, what they are, a biography of a scientist involved in studying them, a paper about the interplanetary network of satellites and/or the satellites it uses, or some other aspect of GRB research.

B. Have the students go online and research a recent GRB. Where was it located, what satellite(s) observed it, what else is known about it? They could also write a report on the Gamma-Ray Burst Coordinates Network (or GCN; see <http://gcn.gsfc.nasa.gov/>), which reports new GRBs to the astronomical community.

Answer Key for Angling for Gamma-Ray Bursts:

Step 1: Plotting the Satellites and Calculating the Delay Times

- 1) This depends on the scale of the graph paper used. You will need to measure this yourself. The answers given below assume a grid scale of 0.5 centimeters per square.
- 2) 5 minutes; 13 minutes
- 3) 9×10^{10} meters; 2.3×10^{11} meters
- 4) 5 light minutes; 13 light minutes

Step 2: Plotting the Delay Times Using the Light Rulers

- 5) 2.5 cm; 6.5 cm (for 0.5 cm/square)
- 6) 19 minutes 24 seconds

Step 3: Adding a Third Satellite

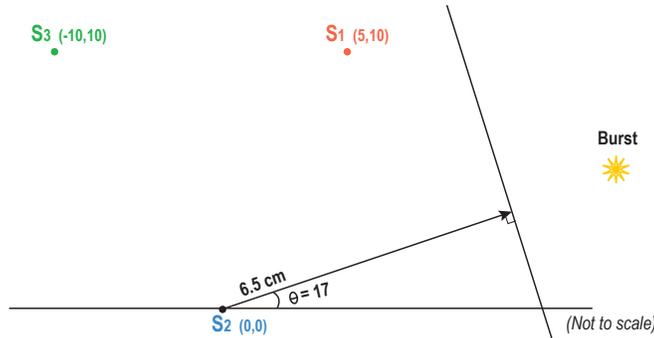
- 7) 19.4 minutes
- 8) 3.5×10^{11} meters
- 9) 19.4 light minutes
- 10) 9.7 cm (for 0.5 cm/square)

Step 4: Finding the Direction to the Gamma-Ray Burst

- 11) The angle should be close to 17° . Anything within about 5 degrees of this is acceptable.

Evaluate:

Points	Graph	Calculations	Reflections
4	Graph is accurate	Calculations are all accurate	Answers are complete, correct, and reflective
3	Graph is adequate	Most calculations are accurate	Answers are correct, but incomplete or not reflective
2	Graph is somewhat inaccurate	Some calculations are accurate	Some answers are incorrect, incomplete or not reflective
1	Graph is inaccurate	Calculations are inaccurate	Answers are incorrect
0	No graph turned in	No calculations completed	None turned in



Reflection Question

12. This will depend on the student. Some possible answers include: gamma rays are higher energy, shorter wavelength, and higher frequency than visible light; gamma rays travel at the speed of light, gamma rays and visible light travel in a straight line (unless

their path is bent by gravity), gamma rays and visible light from a very distant source travel in parallel lines, gamma rays and visible light can travel in a vacuum, gamma rays and visible light from an object can be used to measure the object's direction.

Math Extension

13 $\theta = \arcsin(\text{opposite}/\text{hypotenuse}) = \arccos(\text{adjacent}/\text{hypotenuse}) = \arctan(\text{opposite}/\text{adjacent})$

14. The three values should be close to 17°

15. The average should be close to 17°

16. The *measured* value may be different from the *calculated* value due to measurement errors in the light rulers, or in the angles determined by the light rulers. Let the students use their imagination here.

17. From the point-point slope formula:

$$\tan(\text{angle}) = (y_S - y_E) / (x_S - x_E)$$

18. $\theta_{E-S1} = 63^\circ$ and $\theta_{E-S3} = 135^\circ$

Angling For Gamma-ray Bursts

Student Handout

Introduction

Getting the direction to a GRB in the sky is tricky. The direction to a source that emits optical light is relatively easy to find using aluminum or glass mirrors to focus the light. But gamma rays have such high energies they pass right through glass and aluminum, so a regular lens or mirror is useless. In fact, the original satellites used to discover GRBs could only get a very rough position for them in the sky.

Modern satellites like Swift will be able to get much more accurate directions to GRBs using sophisticated detectors, but for decades this option was not available. What could astronomers do?

An alternative method was cleverly devised using the *timing* of a GRB. Many space probes sent out into the solar system are equipped with detectors that are sensitive to gamma rays. The direction cannot be determined from any given probe, but the exact time of the event can be recorded. When a GRB explodes billions of light years away, the light rays appear to come in as parallel rays to different detectors at widely spaced locations. This fact, together with the timing of the event from different satellites, can be used to determine the direction to the GRB.

In Figure 1 (top), two satellites WIND (S_1) and Swift (S_2) see the light rays from the GRB at different times, since they are at different distances from the burst source. Imagine a plane lying in front of the satellites at some arbitrary distance, perpendicular to the incoming gamma rays. Because the GRB is so far away, the gamma rays arrive at the plane at the same time. They then travel different distances d_1 and d_2 to reach the satellites. These distances depend on the direction to the burst, as can be seen in Figure 1 (bottom). Light takes

a finite time to travel those distances, and the delay between the detection of the burst by the two satellites can be used to determine the direction to the burst.

Note that d_1 and d_2 are parallel. This is because the two satellites see the burst coming from the same direction.

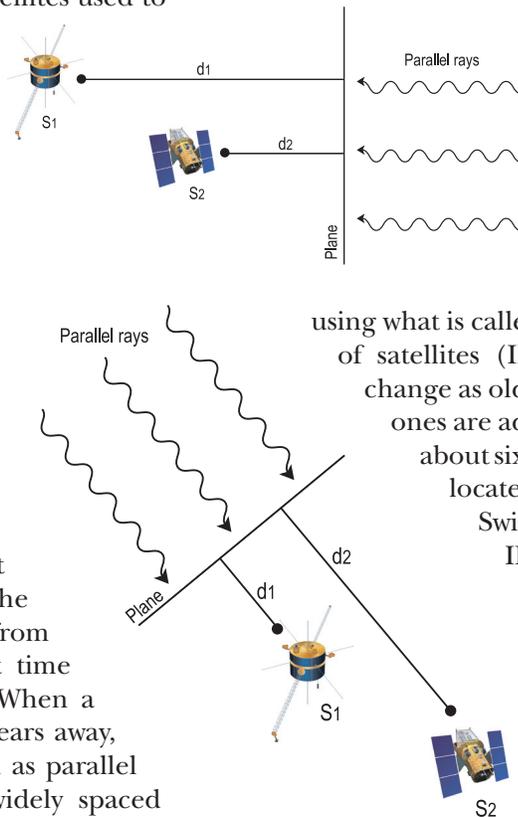


Figure 1

So, if each satellite records the time it receives a burst of gamma rays, then the direction to the GRB can be found knowing the relative positions of the satellites. In fact, since 1990, scientists have used this technique to locate many GRBs on the sky,

using what is called the interplanetary network of satellites (IPN). The member satellites change as old ones are shut down and new ones are added, but in general there are about six satellites in the IPN, and they locate about 150 GRBs per year.

Swift itself will be a part of the IPN; although it will directly determine the direction to a GRB, it's always nice to have an independent method as backup.

In this activity, you will determine the direction to a burst using the times it is detected by three different spacecraft located somewhere in the **solar system**. We are going to assume that all the spacecraft are in the plane of the Earth's orbit around the Sun; that is, there is no third dimension. We are only concerned with two dimensions, x and y . We will also assume the burst is billions of light years away, so the incoming gamma rays are traveling along parallel lines.

Scientists have used this technique to locate many GRBs on the sky.. Currently, about 150 GRBs every year!





1 light minute = 1.8×10^{10} meters
Remember, units are important!

Step 1: Plotting the Satellites and Calculating the Delay Times

You will use your graph paper to represent the Earth's neighborhood in space. Near or at the center of the graph paper, mark one point as the origin (0,0). This will be the location of the Earth. Now draw and label the x and y axes. Each square on the graph paper will have a length of one **light minute**. A light minute is a measure of distance, defined as the distance light travels in a vacuum in one minute, approximately 1.8×10^{10} meters (m).

1. Using a ruler, measure the length of a row of ten squares, then divide by ten to get the length of the side of one square in centimeters (cm). Repeat this procedure using different rows of squares, then calculate the average value. Round numbers to the nearest 0.1 cm. If the scale of the grid is given on your graph paper, compare your answer to that. This number is the scale of the grid in cm/light minutes.

Using the data listed below, plot the locations of the satellites on the grid. Label the satellites " S_1 " and " S_2 ". Note that Swift is in low Earth orbit, so on the scale of this grid it is about at the same place as Earth (at 0,0).

Satellite Name	Satellite Designation	Coordinates (light minutes)
WIND	S_1	(5,10)
Swift	S_2	(0,0)

Table 1

On May 16, 2000 at 9:23:00 UT (Universal time, sometimes called Greenwich time), gamma rays from a GRB passed the plane (see Table 1). At 9:28:00 UT satellite S_1 detected the gamma-ray burst. At 9:36:00 UT satellite S_2 detected the same GRB.

Questions:

- How long did it take (in minutes) for the light to reach each satellite after it passed the plane?
- Given that the speed of light is 3×10^8 m/s (be careful to note the units!), what distance did the light travel (in meters) to reach the two different satellites after it passed the plane?
- How many light minutes distance did the rays travel after they passed the plane? (Recall that one light minute is about 1.8×10^{10} meters.) Compare your answer to the answer to question 2. What does this imply?

Questions 5:

Using the grid scale you calculated for Question 1, convert the distances the light traveled in light minutes (Question 2) to centimeters on the graph paper. Round numbers to the nearest 0.1 cm.

Step 2: Plotting the Delay Times Using the Light Rulers

You have been provided with T-shaped "light rulers," each of which has a long arrow along the vertical leg, and a shorter arrow along the top crossbar. The crossbar will be considered the "top" of the light ruler, and the other end at the tip of the long vertical leg will be the "bottom." The arrows are perpendicular, and the long arrow intersects the short one at its middle. These will represent the different distances that light travels from the plane to the two satellites; hence the name "light rulers." The purpose of these next calculations is to find the lengths for the light rulers.

Step 2: Plotting the Delay Time - Easy Guide

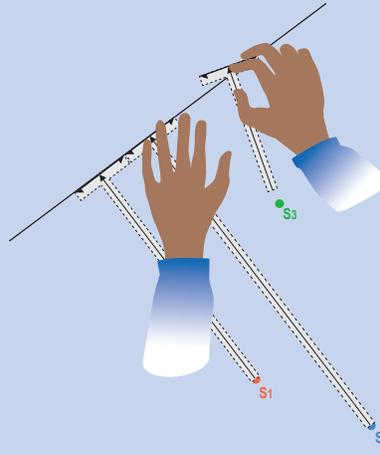
- Get one of the light rulers.
- Starting at the tip of the long arrow (where it meets the short one), measure along the long arrow and mark the point on that line such that the length is the length you found in Question 5 for Satellite 1. Cut the light ruler at this mark. **Label this ruler S_1 .** Repeat this procedure for the other ruler using the data for S_2 . Don't



Don't forget to label the second ruler

forget to label the second ruler! These rulers now represent the distances in grid units that the light traveled from the plane to each satellite.

- Now, put the bottom end (the cut end, opposite the long arrow's head) of each light ruler on the graph so that it is on the position of the satellite it represents.
- Rotate the rulers around until the short arrows are lined up. It may help to use a straight-edge to line them up (see figure 2).
- Align them as accurately as you can! The direction that the short arrows point defines



the plane, while the long arrows point in the direction to the gamma-ray burst.

- Once the rulers are aligned, lay down your straight-edge over the short arrows on the light rulers and draw the line representing the plane. If you want, you can leave gaps where the light rulers are. Remove the light rulers, then fill in the gaps using your straight-edge. Make sure you extend the line as far as you can on the graph paper.

- Once you have drawn the line, place the light rulers back on their satellites. Now, starting where you left off before, *continue to rotate the light rulers around*. Is there another position where the two light rulers align as they did before?
- When you find another position like the first one, mark it with your straight-edge as you did before.
- Extend it as far as you can on the graph paper. This line represents a second possible plane, and therefore a second possible direction to the gamma-ray burst. This is a problem: there are two possible solutions to the direction to the gamma-ray burst! We need a tie-breaker, and for that we need to use a third spacecraft.

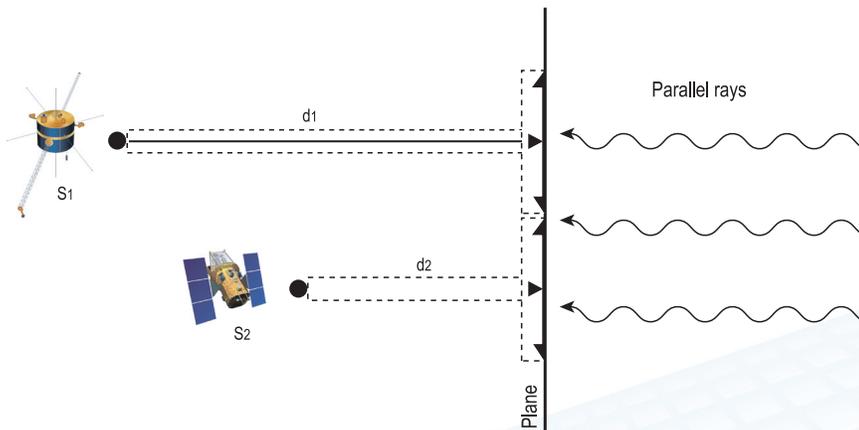


Figure 2

Step 3: Adding a Third Satellite

We'll use data from the Ulysses spacecraft (table 2) and proceed as before with S_1 and S_2 . Use the table below to add Ulysses to your graph. Call it S_3 .

On May 6, 2000, at 9:42:24 UT, satellite S_3 detected the same GRB as the other two spacecraft did.

Satellite Name	Satellite Designation	Coordinates (light minutes)
Ulysses	S_3	(-10, 10)

Table 2



Make sure you check your units!

Questions:

6. How long did it take (in minutes and seconds) for the light to reach satellite S_3 after it passed the parallel plane?
7. Convert to decimal minutes (for example, 1 minute 30 seconds = 1.5 minutes).
8. What distance (in meters) did the light travel to reach the satellite S_3 after it passed the plane?
9. How many light minutes distance did the rays travel after they passed the plane?
10. Use the grid scale to convert this distance to centimeters on the graph.

Question 11

Assuming the x-axis represents 0° and that the angle increases counter-clockwise, measure the angle from the x-axis to the line connecting the Earth and the plane.

Step 4: Finding the Direction to the Gamma-Ray Burst

As you did before, measure, mark, and cut the third light ruler so that its length represents the light travel distance you found in Question 9. Place the bottom of the light ruler on S_3 , and rotate it around. You should find that the short arrow aligns with only one of the two lines representing possible planes. Label this line as the correct one. That's the plane that is perpendicular to the direction of the GRB.

However, simply knowing the direction isn't good enough; astronomers will want a number representing the angle from the Earth to the gamma-ray burst. You'll need to measure that angle with a protractor. First, find a perpendicular line that connects the Earth to the plane. Hint: you have already done this with the light ruler! Draw the line.

Congratulations! Now astronomers back on Earth will know where to point their telescopes to follow-up on this burst.

Math Extension

(optional, for geometry and trigonometry students):

Reflection Question

12. Explain at least two properties of gamma-ray light (for example, how it is different or similar to visible light?).



What are some properties of light?

In reality, astronomers won't draw the lines and use a protractor. They use trigonometry to determine the angle. To determine the angle, first make sure the line representing the plane is extended so that it intersects the x-axis of your graph. You now have a right triangle, with one side whose length you have already calculated. From this, you can find the angle from the Earth to the GRB as measured from the x-axis.

13. Write down trigonometric formulae that show how to compute the value of the angle using sines, cosines, and tangents of the lengths of the different sides of the triangle.

14. Using each of those trigonometric formulae, calculate the value of the

angle from the Earth to the gamma-ray burst in degrees.

15. Average the three angles to get a predicted direction to the gamma-ray burst.

16. Compare this value to what you measured in question 11, and comment on any differences if there are any.

17. Write down a **general equation** for the angle from the Earth to satellites S_1 and S_3 with respect to the x-axis (Satellite 2, Swift, is orbiting the Earth so we have assumed it is at Earth's position.)

18. Calculate the value of the two angles.

Angling For Gamma-ray Bursts

Student Worksheet

Name _____

Date _____

Step 1: Plotting the Satellites and Calculating the Delay Times

1. a) Length of one square (1st measurement)
_____ (cm)
b) Length of one square (2nd measurement)
_____ (cm)
c) Average of two measurements
_____ (cm)
2. t_{S1} = _____ minutes
 t_{S2} = _____ minutes
3. d_{S1} = _____ meters
 d_{S2} = _____ meters
4. d_{S1} = _____ light minutes
 d_{S2} = _____ light minutes

Step 2: Plotting the Delay Times Using the Light Rulers

5. d_{S1} = _____ cm on the graph
 d_{S2} = _____ cm on the graph

Step 3: Adding a Third Satellite

6. t_{S3} = _____ minutes _____ seconds
7. t_{S3} = _____ minutes
8. d_{S3} = _____ meters
9. d_{S3} = _____ light minutes
10. d_{S3} = _____ cm on the graph

Step 4: Finding the Direction to the Gamma-Ray Burst

11. Angle from the x-axis to the gamma-ray burst
_____ (degrees)

Reflection Question

12. Use the space below and/or the back of this sheet to write your answer.

Math Extension:

13. Formulae for angle:
 $\sin \theta$ = _____
 $\cos \theta$ = _____
 $\tan \theta$ = _____
14. Direction to the gamma-ray burst
using $\sin \theta$ formula _____ (degrees)
using $\cos \theta$ formula _____ (degrees)
using $\tan \theta$ formula _____ (degrees)
15. Average of three numbers _____ (degrees)
16. Use the space below and/or the back of this sheet to write your answer.
17. Equation for angle = _____

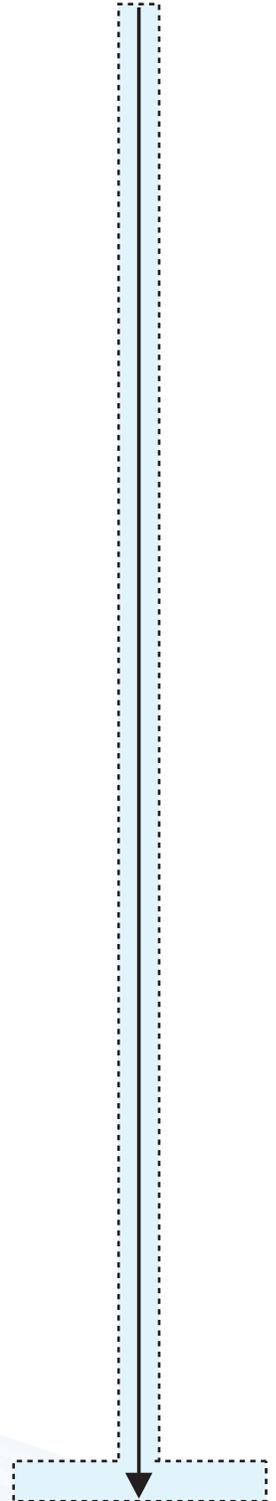
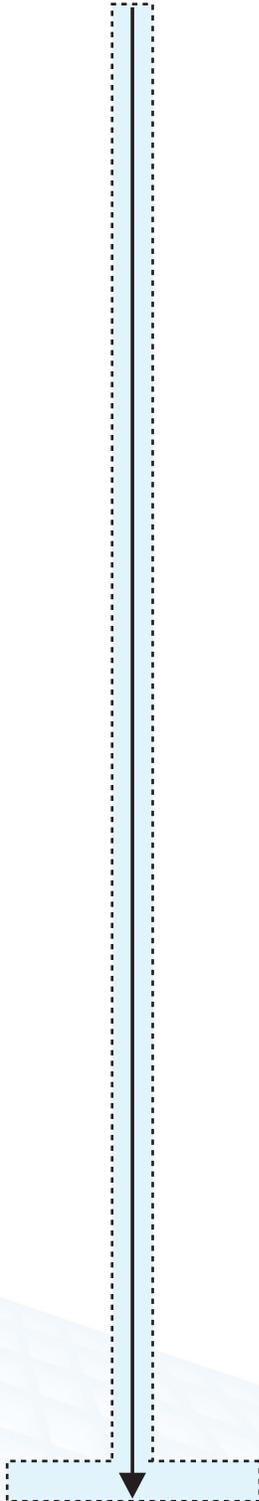
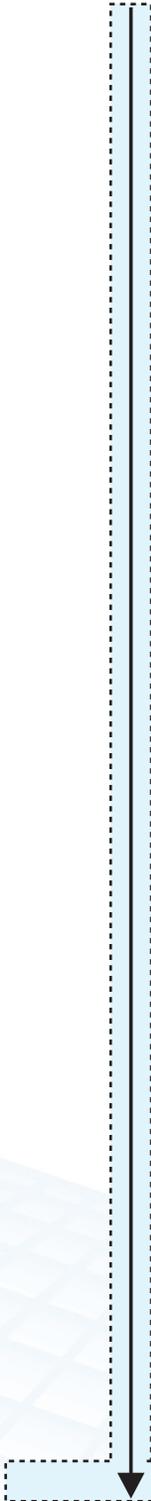
18. θ_{S1} = _____ degrees
 θ_{S3} = _____ degrees

Light rulers to photocopy on heavy paper

Top



Bottom



GRB Distribution on the Sky: The Plots Thicken

3

Duration:

Introduce concepts and
Perform activity: 1 hour

Background Information:

[Note: This information is split up into a section for you, and one for the students to read. You will of course need to read the student portion as well. It is included in the Student Handout section. Read that part first. The information provided to the student is sufficient to do the exercise, but the additional information given to you below will complement the student's understanding of how the GRBs are distributed in the sky, and what this tells us about them. Going over this information with the students the day before they perform the exercise will increase their understanding of the activity and its concepts. Be careful not to give away the answers, though!]

The distribution of positions of GRBs in the sky is one key to understanding their distance. As more and more were detected over the years, it became clear that they were distributed evenly across the sky. Even after careful examination

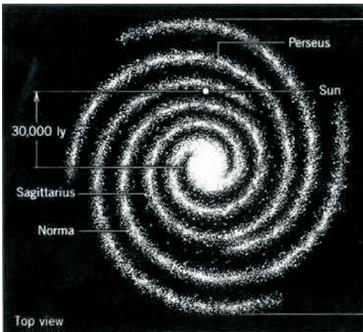
by astronomers who divided the sky into many different sections, there were no apparent clumps of GRBs or voids in any direction, meaning they were evenly spread out in every direction in the sky. This immediately tells us that they are either very close or very far. Why?

Let's assume for a moment that the GRBs are inside our own Milky Way Galaxy. We know the Galaxy is shaped like a disk about 100,000 light years in diameter, with a central "hub," a ball of stars roughly 10,000 light years in diameter. The Sun is located

about halfway to the edge of the disk, off to the side from the central region. If GRBs are some sort of phenomenon that occur in the disk, then we should see more toward the center, since in that case we are looking across the bulk of the Galaxy (as in the case discussed in the Student Handout when you are near the edge of the stadium). Since GRBs are not seen to be concentrated in any one direction, we can deduce immediately that they are not distributed across the Galaxy, even without knowing their exact distance.

Since they are not at intermediate distances, they must either be very close by or very far away. As it happens, astronomers have postulated that the Sun is surrounded by a large sphere of comets called the Oort cloud (named after the 20th century Dutch astronomer who first proposed it). It is perhaps a trillion kilometers across, and since it is so big and spherical, the Earth sits very near the center of it. If GRBs come from there, then the distribution on the sky would be very close to what is actually seen. The problem with this idea is that the comets are very cold, low energy objects, and there is no known way to make them generate bursts of high-energy gamma rays.

Perhaps we need to think bigger. A lot bigger. If we look at the Universe as a whole, we see that galaxies like the Milky Way are distributed throughout it. In every direction we look, we see galaxies, and there are hundreds of billions of them. If a GRB occurs in a particular galaxy only rarely (explaining why we have never seen one in our own Galaxy), then we should still see plenty when looking across the whole Universe. In that case, we would see them everywhere we look. That's just how they do appear! But that leaves a new problem: this means that GRBs would have to be phenomenally energetic, since galaxies are so far away.



Essential Question:

How does the perceived distribution of objects in the observable sky depend on their actual location in space?

Objectives - Students will:

- be able to compare their classroom plots with GRB distributions in the sky.
- be able to divide objects into bins, to count, plot, and describe distributions of objects.
- be able to explain how mapping the perceived distribution of GRBs gives insight into the real spatial distribution.

Science Concepts:

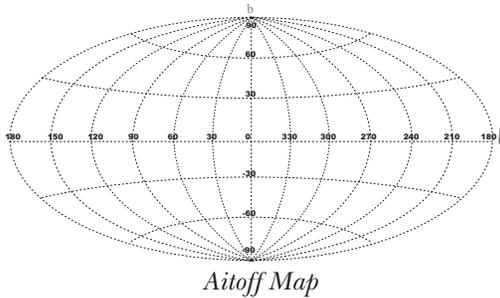
GRBs are distributed randomly across the sky. This means they are either very close or very far away. The pattern of objects we see in the sky can tell us about their location in the Universe.



The scientists know that GRBs must be very close or very far away.

This left astronomers with the riddle: are GRBs nearby, coming from objects with no known mechanism to generate gamma rays, or are they very far away, coming from objects generating fantastic energies that couldn't be explained?

That discovery had to wait until actual distances could be determined, and, in the end, it was found that GRBs were very far away, implying huge energies were involved (see Activity 4). But even without knowing the distances, astronomers were able to determine quite a bit about the location of GRBs. In the following activity, your students will follow the same logic used by the astronomers of that day, and figure out for themselves how the distribution of objects can tell us about where they are.



About Aitoff Maps:

GRB distributions in the sky are plotted using Aitoff maps (see Activity 1, “Additional Information: Aitoff Maps” for more about these). In the Student Handout, the first Aitoff maps (Figures 4 and 5) are simulated apparent distributions of GRBs (the way they appear in the sky), assuming different spatial distributions of GRBs (the way they are distributed throughout space). Figure 8 (in the Student Handout) shows the actual distribution as seen by an experiment onboard a NASA satellite.

Potential Pitfalls

1. In this activity, we will be distinguishing between the apparent distribution of objects in the sky versus their actual location in space. As an example, two stars in the sky may appear to be very close together in the sky, but one may be close by while the other is much farther away. Because we cannot directly perceive the difference in distances to astronomical objects, they all appear to be effectively infinitely far away. This makes the sky look like a bowl over our heads with the objects painted on it. So in this activity, when we refer to the distribution of objects “in the sky” we mean their two-dimensional distribution, without regard to their distance. When we refer to their location “in space” we also include the third-dimension. To apply this to the example above, the two stars appear near each other in the sky, but are actually located very far apart in space. You will need to be very clear about this when explaining this activity to your students.

2. The students will be comparing a one-dimensional distribution of foil balls along the circumference of a circle to a two-dimensional distribution of GRBs in the sky. Make sure they understand the analogy.

3. Some students may be confused about Aitoff maps, thinking that their location is somewhere in the map. Make sure you review the information about Aitoff maps from Activity 1, “Sorting Out the Cosmic Zoo”.

Procedure step 2:

To eliminate any misconceptions:

- Ask your students what they think these aluminum balls represent?
- How is this different than GRBs? Where are the pitfalls of this representation for GRB?
- How can this be compared to other distributions?
- What is the big question for the scientists explained in the student handout p.30 ?

(You could also continue to ask them these questions or similar questions when you get to procedure step 6.)

Procedure:

Pre-class:

1. The day before you plan to do the activity, introduce the activity by using the *Background Information* section. Give the students the example of the lighters in the concert, making sure you discuss the binning of directions to aid analysis. To help engage the students, have them do the extension activity on page 28.
2. Explain to the students that they will be investigating how the apparent distribution of objects yields clues to their distances and real spatial distribution. They will be counting the number of aluminum foil balls placed in a circle on the floor, then moving their point of reference and counting

them again. The results will be plotted, and compared to various simulated distributions of GRBs. In essence, they will be performing the same technique used by astronomers to understand GRBs before their distances were known. You will also need to explain Aitoff projection maps to them.

3. Give each student a copy of the Student Handout. As homework, have them read it carefully and write out a paragraph describing the procedures of the activity. You can also assign the Extension Activity (see below) as homework before the activity is done.

4. The day before the activity, create the “wedge assembly.”

a. Take 2 popsicle sticks and glue them together at their centers to form a plus-shape [diagram]. Repeat this with two more popsicle sticks. Glue the two pluses together to form an asterisk-shape with 8 arms, each 45 degrees apart. Pipe cleaners can be used instead; they do not need to be glued, but can instead be wrapped together at their centers.

b. Cut the yarn into 8 lengths of about 3 meters each.

c. Glue one end of each piece of yarn to the tip of each popsicle stick, so that when fully extended you have an asterisk-shape several meters across (Figure 2). If you are using pipe cleaners, tie the yarn to the ends of the pipe cleaners.

5. Crumple approximately 100 aluminum foil balls so they are about 3-4 cm in diameter. (We recommend handing out sheets of foil to the students to help.) Any type of ball will do, such as tennis balls or ping pong balls, but be aware they will roll around! Foil balls work best.



Engage!

In-class:

Explore!

6. Prepare the exercise.

a. In an open area at least 5 meters across (you may have to go outside), place the foil balls more-or-less evenly distributed along the circumference of a circle 4 meters in diameter. It is not critical that the balls be evenly distributed, but try to make the circle as close to 4 meters across as possible, since the diameter is used in the exercise. You can have a student measure the diameter and report it to the class. As long as everyone uses the same number it will work out.

b. Place the popsicle stick/pipe cleaner wedge assembly in the center of the circle, and extend the yarn out so that the circle is divided into 8 even pie-wedge-shaped bins. Try to make the wedges as equal in size as possible.

Materials for each class:

- Student Handout
- 1 sheet of graph paper for plotting aluminum ball distributions
- Aluminum foil (enough to make ~100 balls; one 75 foot roll)
- 4 popsicle sticks, meter sticks or pipe cleaners
- Glue (if using popsicle sticks)
- Yarn or string (about 24 meters in length)
- Scissors

Materials for each student:

- Student Worksheet

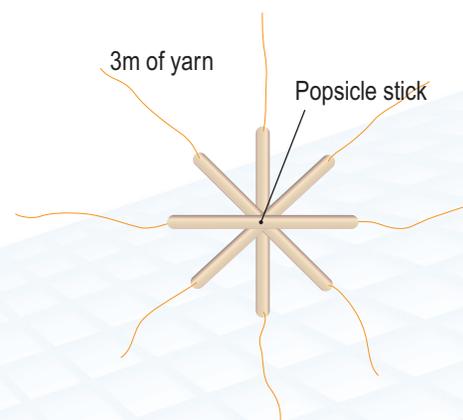


Fig. 2

7. Begin the exercise. After the students fill out the first table in the exercise, get some volunteers to move the wedge assembly as outlined in the student handout.

Post-activity:

8. Discuss the actual distribution of GRBs in the sky, and how they really are at vast distances. Astronomers' first step in figuring this out was to do what the students just did: plot GRB positions on the sky. Does the actual distribution really tell you anything about the distance to the GRBs? Imagine they are in a sphere surrounding the Sun just past Pluto, for example, and compare that to GRBs being at cosmological (very vast) distances.



Elaborate and Evaluate!

Revisit any questions you have asked them throughout the activity, especially those that are the most basic. This is a great assessment tool.

Transfer Activities:

Encourage the students to go outside on a clear night and look at the stars in the sky. Do they appear to be evenly distributed, or do they have a pattern? What does this imply about their spatial

distribution? (Stars are not randomly distributed; they appear to lie in groups called constellations, and more stars are seen along the plane of the Milky Way than outside of that plane.)

Extension Activities:

In the late 1700s, astronomer William Herschel tried to determine the size and shape of the Milky Way by counting up stars in different directions. Jacobus Kapteyn repeated this effort in the 1920s. Have the students research how astro-

nomers used this method, how well it worked, and what the failings are. They can compare this to the method used in the activity of finding the distribution of GRBs.

Lesson Adaptations:

Sight-impaired students can be encouraged to actually feel the balls with their hands as they move around the circle. They can feel where the yarn is, and can count the balls that way. It

might be helpful to put some distinguishing object such as a rock or a blackboard eraser where the yarn intersects the circle.

Evaluate:

	Comparison of Plots	Calculations
4	Comparisons are all complete and accurate	Calculations are all accurate
3	Comparisons are mostly complete and accurate	Most calculations are accurate.
2	Comparisons are somewhat complete and accurate	Some calculations are accurate.
1	Comparisons are not complete and accurate.	Calculations are inaccurate.
0	None turned in.	None turned in.

Answer Key for GRB Distribution on the Sky: The Plots Thicken:

• **Step 1: Having a Ball**

1. This will depend on how many foil balls are made. For the answer key, numbers will be given assuming 100 foil balls are used.
2. Assuming a diameter of 4 meters, the circumference of the circle is 12.6 meters, so the balls should be about $12.6/100 = .126$ meters (12.6 cm) apart.
3. 8 wedges
4. 45°
5. $100 \text{ balls} / 8 \text{ wedges} = 12.5$ balls per wedge (rounding up or down is acceptable)

• **Step 2: The Cutting Wedge**

6. No. Some wedges are now wider than others where they intersect the circle, so there will be more balls in the wider wedges, and fewer in the smaller ones.
7. The curve for Position 1 should be roughly flat, with some peaks and valleys due to the somewhat random distribution of the balls. The curve for Position 2 is more like a sine wave, also with random peaks and valleys. [Overall it should look like Figure 7 from the students handout.]
8. Some sources of deviation include: the balls may not be exactly evenly spaced, the wedges may not be perfectly straight, some balls will fall on a wedge boundary and be moved into one wedge or another.
9. Both tables should add up to the same number of balls.
10. This should not be surprising; the distribution changed but the total number of foil balls did not. This may catch a few students!

11. The average number of balls per wedge is $100 \text{ balls} / 8 \text{ wedges} = 12.5$, as before.

12. Again, this should not be surprising: the total number of balls and the number of wedges did not change. The average value does not change, only the actual number in each wedge changed.

• **Step 3: A Twist in the Plot**

13. Figure 4 has points distributed evenly throughout it. In Figure 5 the points cluster along the equator, with some vertical thickness. There is also a bulge in the center, which thins out at longitude 180° .

14. Figure 6 should most resemble the plot for Position 1, and Figure 7 should resemble Position 2.

15. In Figure 4, the GRBs are spread evenly across space in a spherical distribution, with us viewing them from the center. In Figure 5, they are distributed in a flat disk, with us viewing them from off-center.

• **Step 4: BATSE in the Belfry**

16. Figure 4 looks most like the real distribution, as does the collapsed plot.

17. GRBs must be distributed evenly throughout space, with us in the center of that distribution.

18. In general, although the actual distances cannot be found using this method, it can distinguish between whether the GRBs are located in the Milky Way or not. If they were, we would see an off-center distribution. So GRBs must be either very close or very far away.

GRB Distribution Across the Sky: The Plots Thicken

Student Handout

Introduction

The discovery of GRBs was quite a shock to astronomers. Gamma rays are very high-energy photons, and it takes extremely energetic events to generate them. After all, GRBs were discovered when satellites were used to look for nuclear bomb tests on Earth! For GRBs to come from astronomical objects means they have to be extraordinary events. What kind of objects could be at the heart of these phenomena?

One key to understanding GRBs is to know just how much energy they are emitting, and the only way to know that is to find their distances. The problem is, the flash of gamma rays lasts only seconds, and in the early years of GRB astronomy there was no known way to determine their distance. The only physical characteristics astronomers were able to ascertain were the number of gamma rays detected as a function of time (also called a “light curve”; see Activity 1), and the direction in the sky to the GRB (see Activity 2).

What kind of objects could be at the heart of these phenomena?

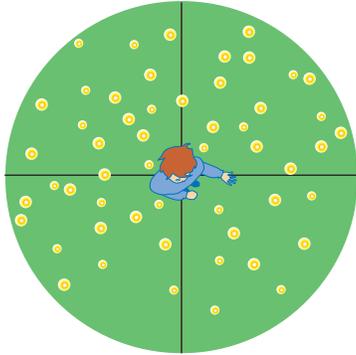


Fig. 1. The fans with lighters will be all around you

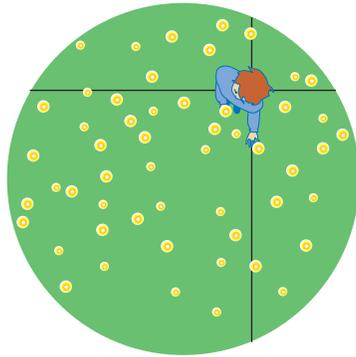


Fig. 2. Off-center pattern of lights

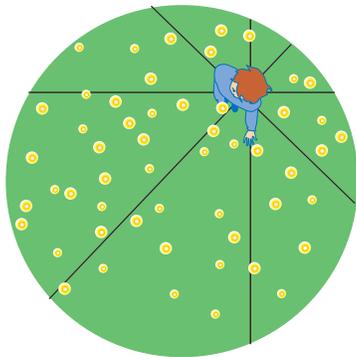


Fig. 3 It would help even more to divide up your view into regions

However, astronomers rapidly understood that the positions of the GRBs might give an important clue to understanding their physical nature. As a simple example, imagine you are attending a rock concert at a sports stadium. During a song, hundreds of fans pull out their lighters and flick them on. If you have bad seats, located in the middle of the crowd, the fans with lighters will be all around you, and by looking at how the lights are distributed you might correctly surmise you are in the middle of the crowd, even though you might not clearly see the far rows of seats (Figure 1). If, however, you have great seats near the front of the crowd, you will see more lighters in one direction (behind you, away from the stage) than the other (toward the stage). In the latter case, you can deduce that you are not in the center of the crowd because of the off-center pattern of lights (Figure 2).

It would help even more to divide up your view into regions to aid counting; for example, you could use four quadrants, (Figure 2) counting all the lighters that are in the region from due north to due west, then due west to due south, etc. You could further subdivide to look for more detail, dividing each quadrant into 2 smaller sections, for example, for a total of 8 pie-piece shaped slices. This would allow a quantitative analysis of the distribution (Figure 3).

Gamma-ray bursts are far enough away that we cannot measure their distances directly. When GRBs were discovered, astronomers weren't sure if they were nearby (like in our solar system), very far away (like billions of light years away), or at some intermediate distance (like inside or near our Milky Way Galaxy).

However, clever scientists realized that even if they couldn't measure the distance to GRBs, they could infer their distance, at least well enough to know if one of the choices above (near, middle, or far) was wrong. They did this by looking at the distribution of GRBs in the sky.

In this activity, you will model what astronomers did by investigating the distribution of aluminum foil balls arranged in a circle on the floor, and comparing them to the distribution of gamma-ray bursts on the sky.



Scientists realized they could infer gamma-ray burst distances.

Step 1: Having a Ball

Your teacher will have already set up the circle of foil balls. Note the wedges dividing the circle into evenly spaced bins.

Questions:

1. How many balls are there in total?
2. Given the diameter of the circle, what should the distance be between each ball (to the nearest 0.1 cm)?
3. How many wedges are there?
4. What is the angle covered by each pie wedge?
5. On average, how many balls do you expect to find in each pie wedge?

Step 2: The Cutting Wedge

The wedges are centered on the center of the circle. We'll call this "Position 1". Count the number of balls in each pie wedge, filling out the table in the student worksheet as you do so.

When everyone is done filling out the table, move the wedge assembly so that the center of the wedges is located about halfway between the center of the circle of balls and the edge. Call this "Position 2".

As before, count up the balls in each wedge, filling out the second table in the student worksheet.

On your graph paper, plot the number of balls you counted in each wedge versus the wedge number. Use dots for the first table (Position 1), and "x"s for the second (Position 2). Draw "the line of best fit", a freehand curve that roughly follows the points (in other words, don't just connect the dots).

Question 6:

Do you expect to see the same distribution of balls in the wedges as you found before? Describe what you expect.

Questions:

7. In your own words, describe the two curves. How are they similar, different?
8. The plot for Position 1 should ideally be perfectly flat, with the same number of balls in each wedge. However, your plot will not look like that. What is (are) the source(s) of deviation from a flat line?
9. Calculate the total number of balls for both tables by summing up the numbers in the second column.
10. Do these numbers surprise you? Why or why not?
11. Calculate the average number of balls per wedge for both tables.
12. Do these numbers surprise you? Why or why not? How do these numbers compare to what you calculated in Question 5?

Step 3: A Twist in the Plot

Now you will compare what you have found with real and simulated gamma-ray burst distributions in the sky. Figures 4 and 5 show computer-generated simulations of what the positions on the sky of gamma-ray bursts would look like if the GRBs had two different three-dimensional distributions.

Question 13:

In what ways are the plots similar? Different? Be specific.

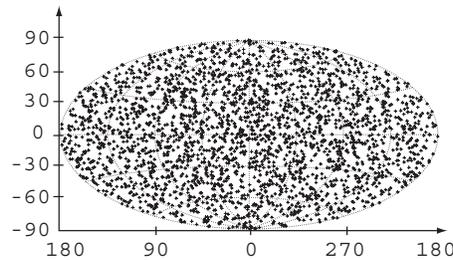


Fig. 4

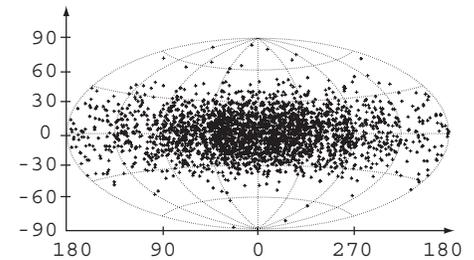


Fig. 5

Take a moment to examine them. Remember: these simulate the positions of the gamma-ray bursts on the sky, and show the entire sky.

These plots are different than what you did before with the aluminum foil balls in that they show the distribution of GRBs over the area of the sky, whereas the foil balls were restricted to the circumference of a circle. To make comparison more useful, Figure 6 is a plot of the totals of the distribution from Figure 4 collapsed down to a line along the equator of the plot. Figure 7 is the same, but using the distribution from Figure 5.

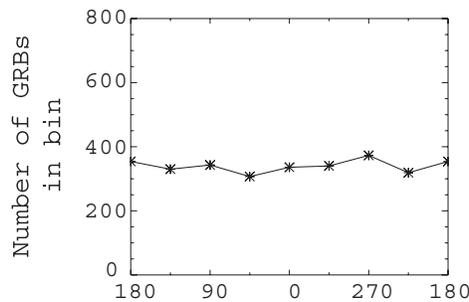


Fig. 6

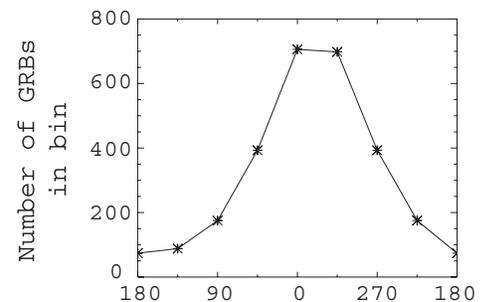


Fig. 7

Questions:

14. Compare the plots you made using the aluminum foil balls for Positions 1 and 2 with Figures 6 and 7. Which figure looks more like your plot for the dot grid at Position 1? Which looks like the plot for Position 2?

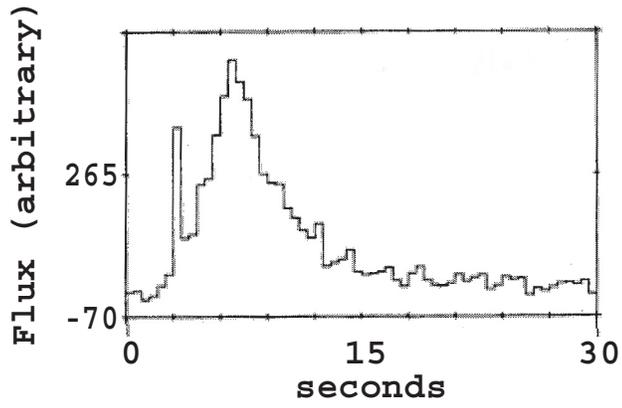
The maps of the GRB positions in Figures 4 and 5 were generated using computer simulations assuming the GRBs were distributed a certain way in space.

15. By comparing the plots to your own, describe in your own words how you think the GRBs were distributed in space for Figure 4 and Figure 5.

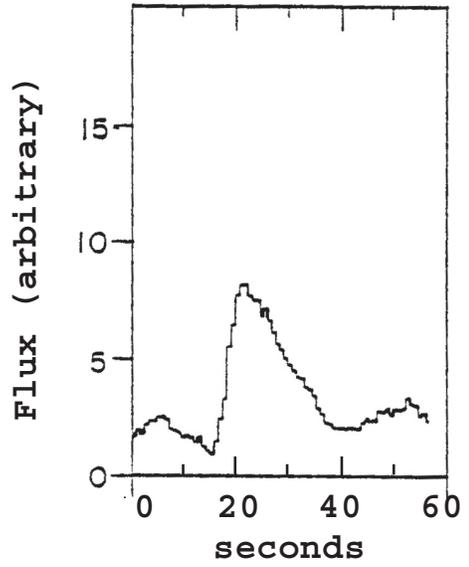


Explain and Elaborate!

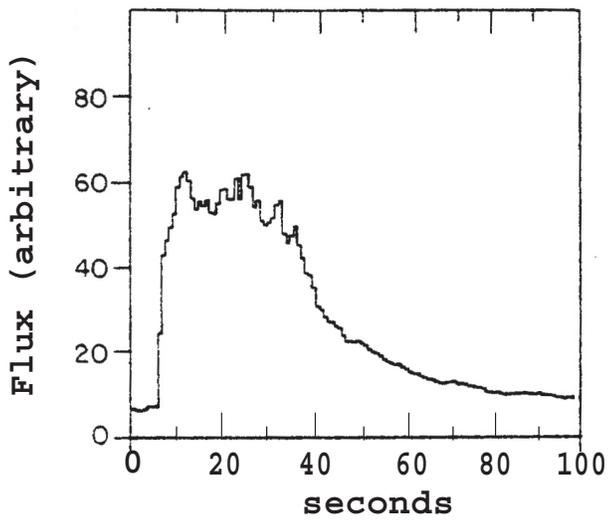
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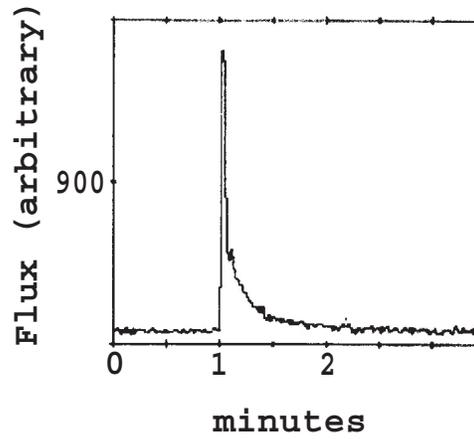
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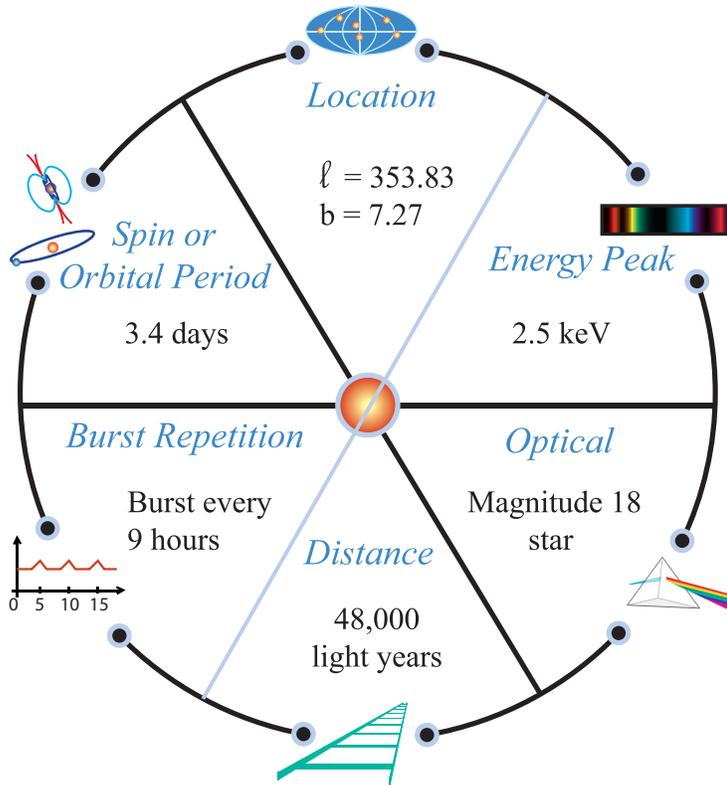
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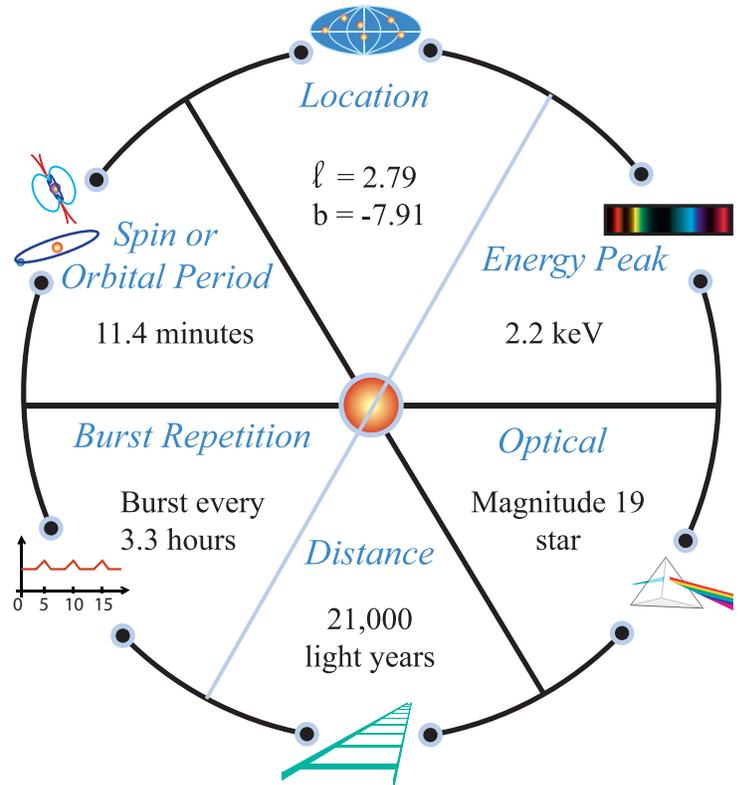
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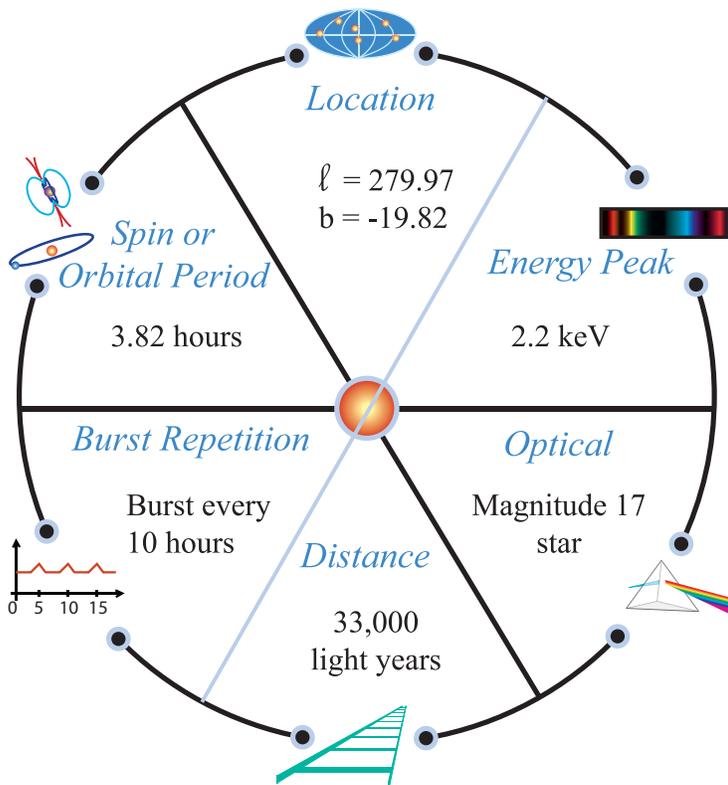
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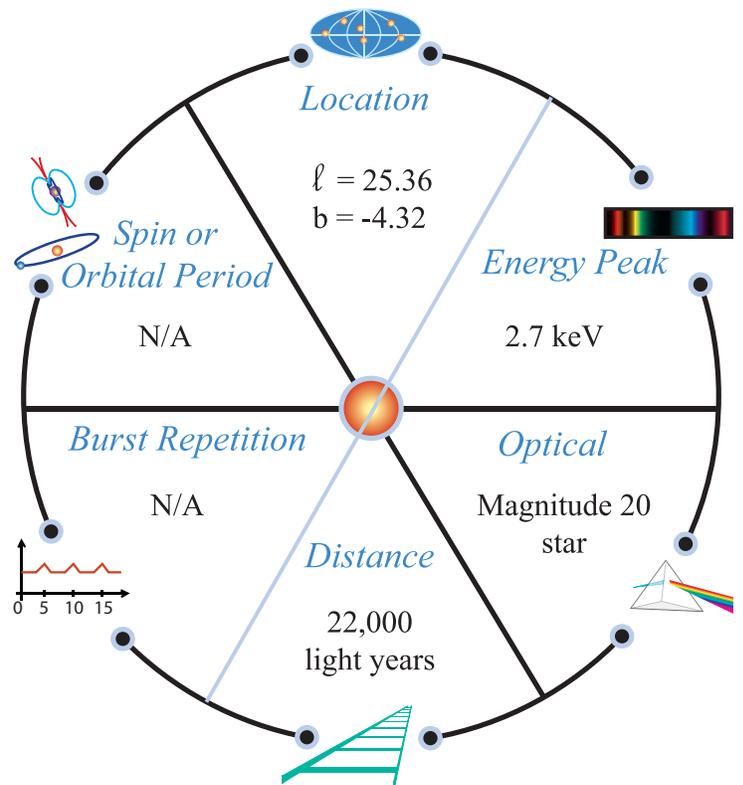
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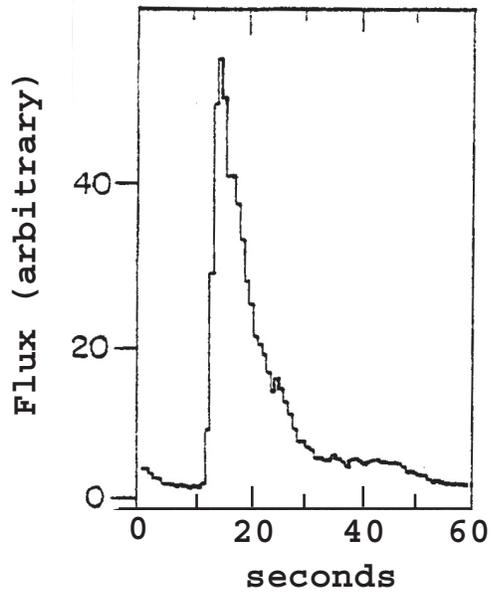
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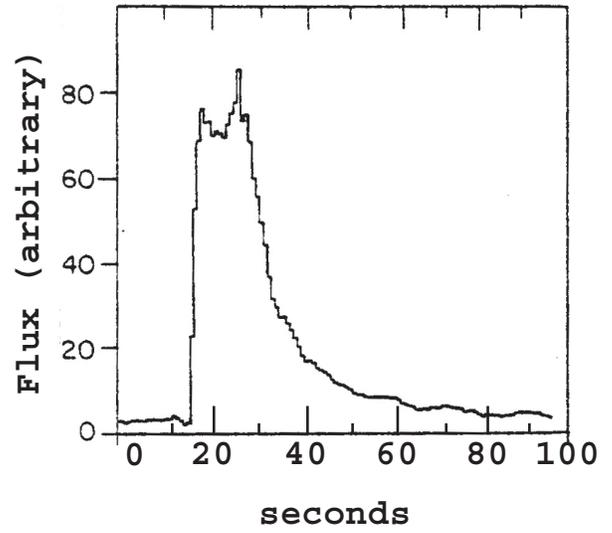
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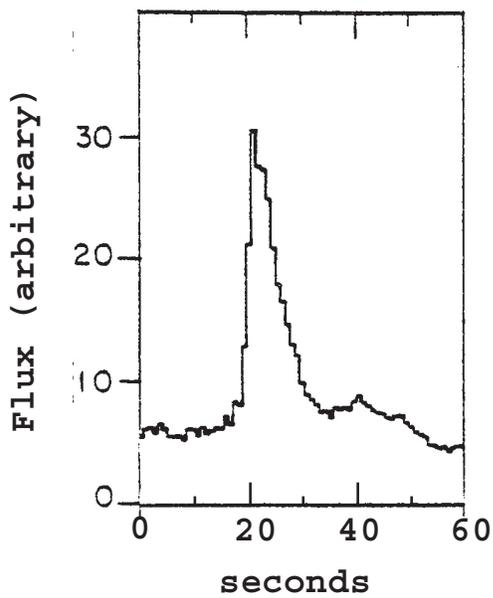
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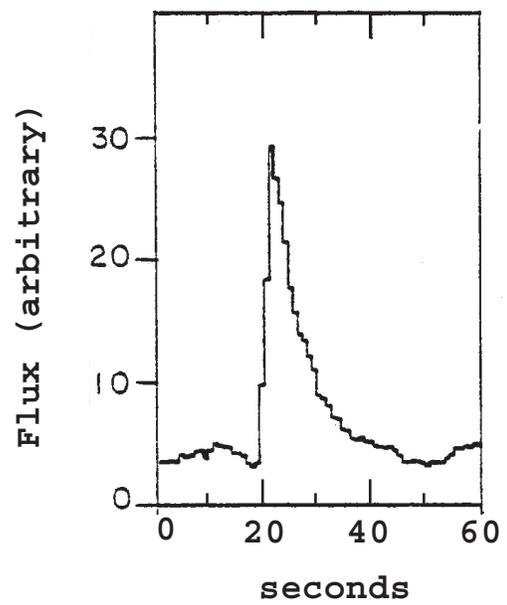
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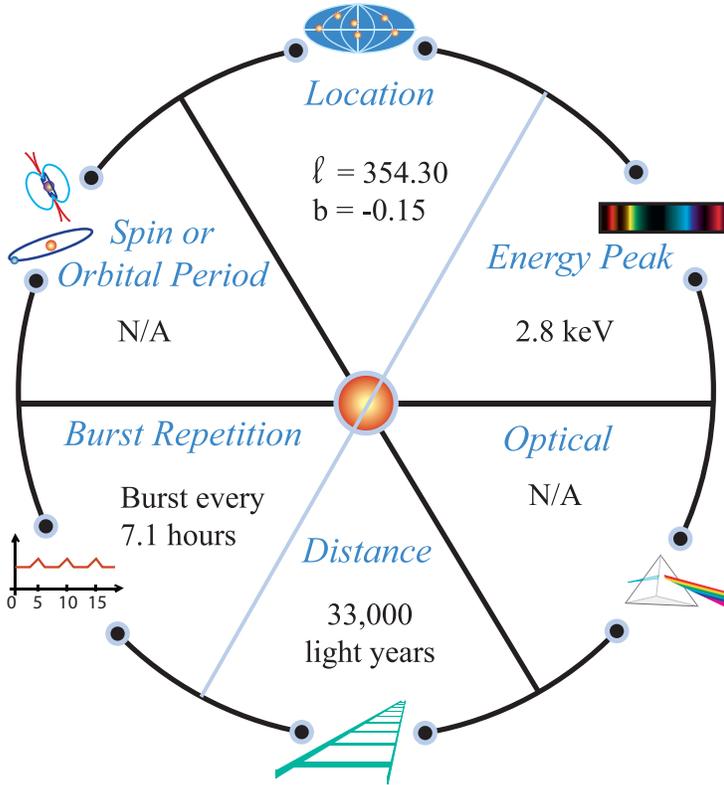
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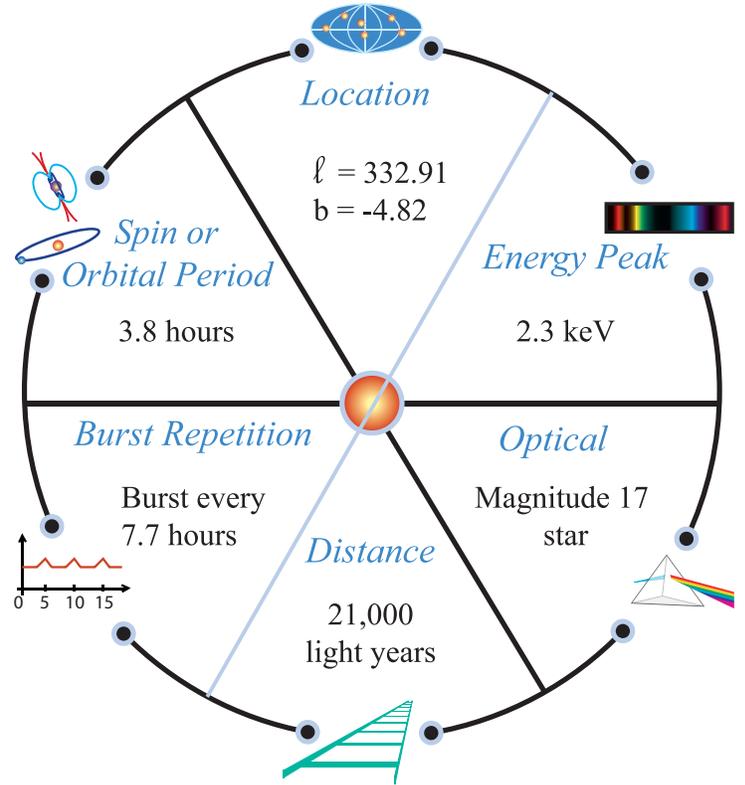
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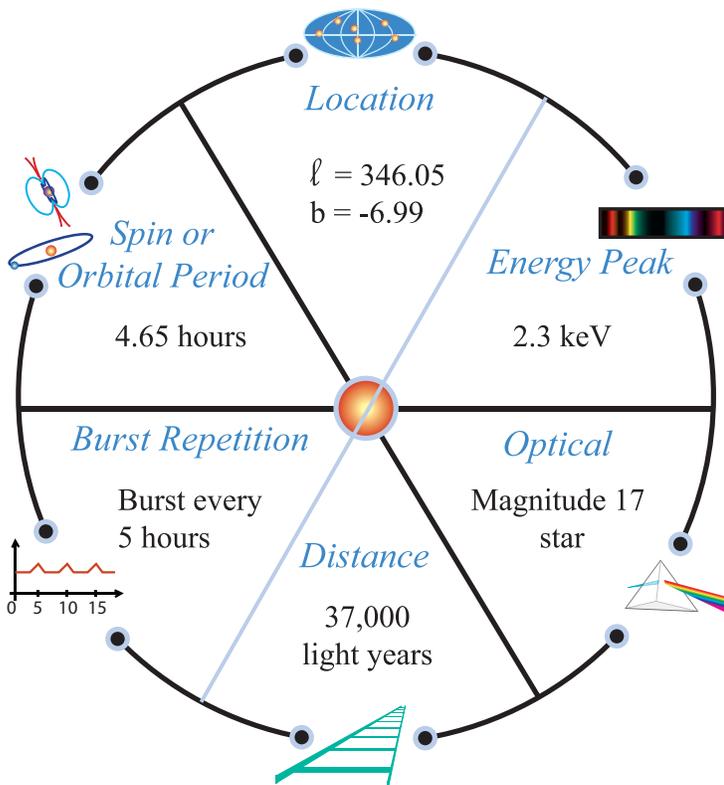
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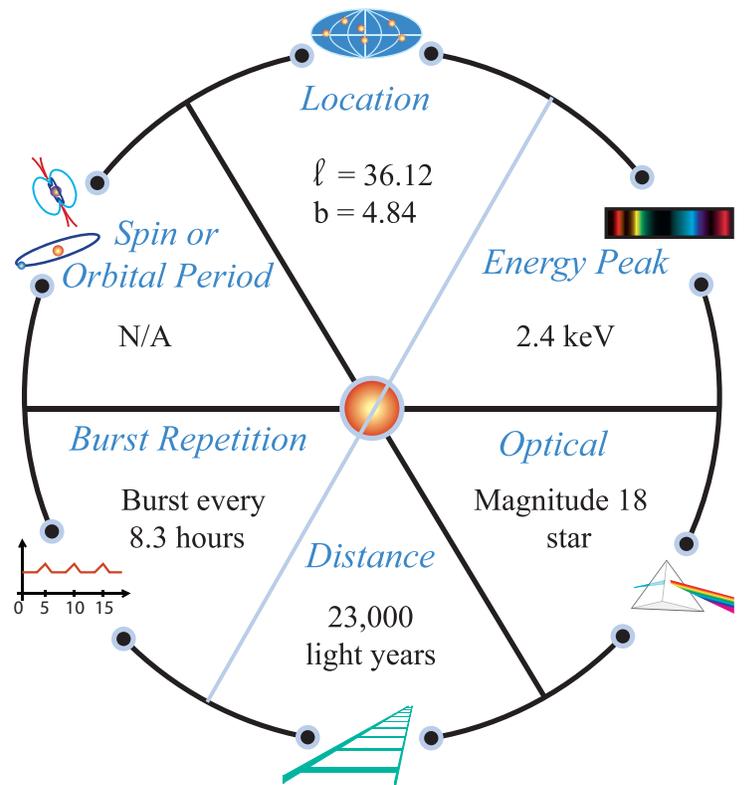
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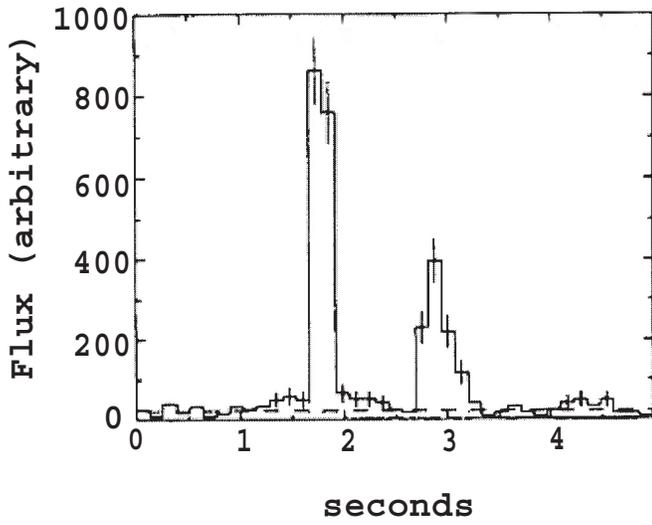
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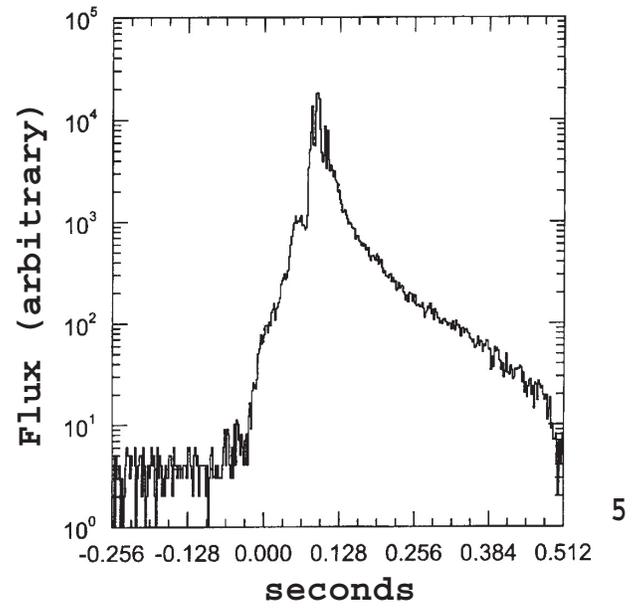
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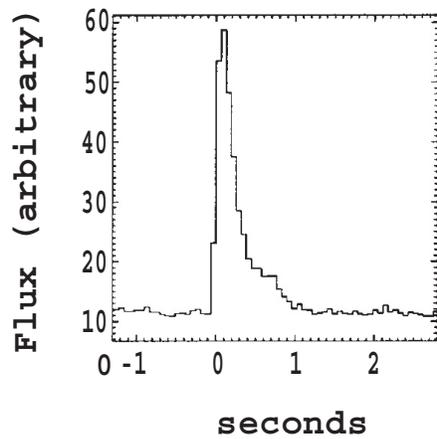
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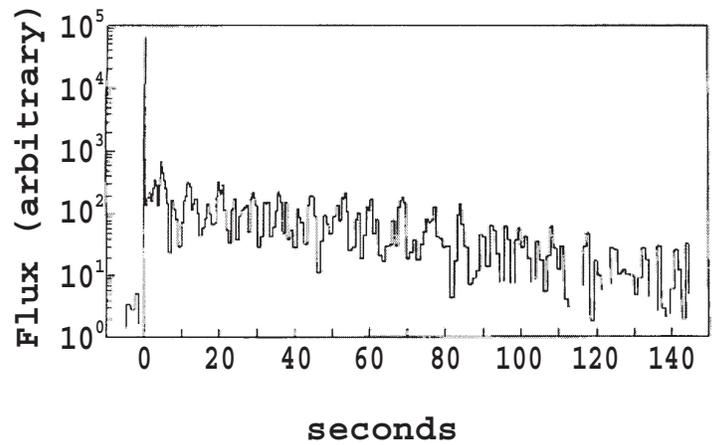
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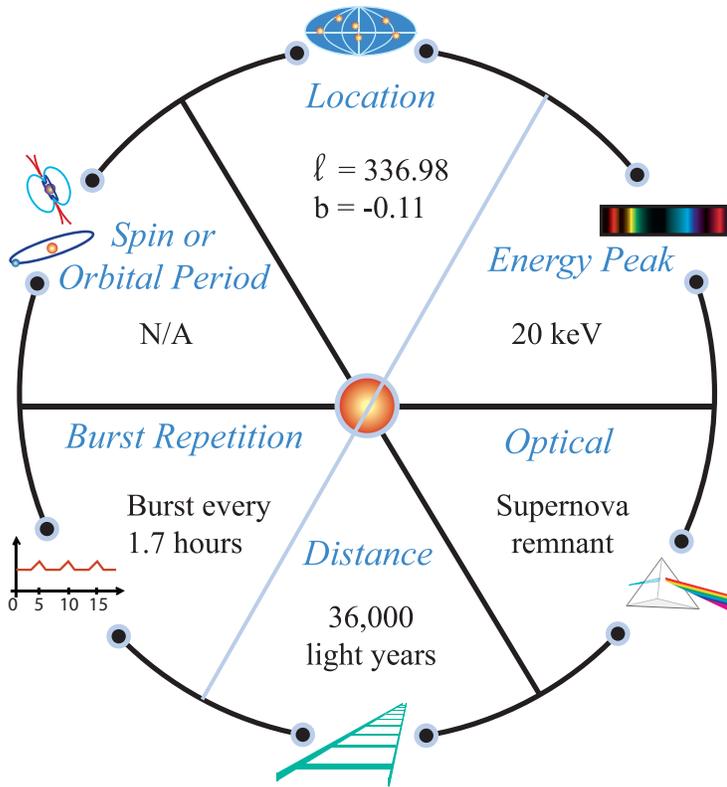
1900+14



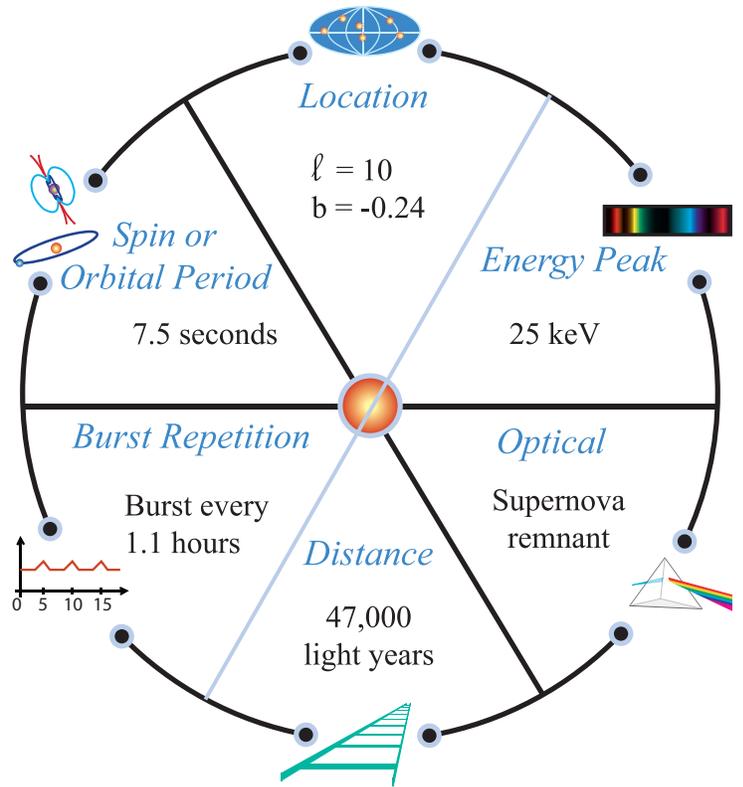
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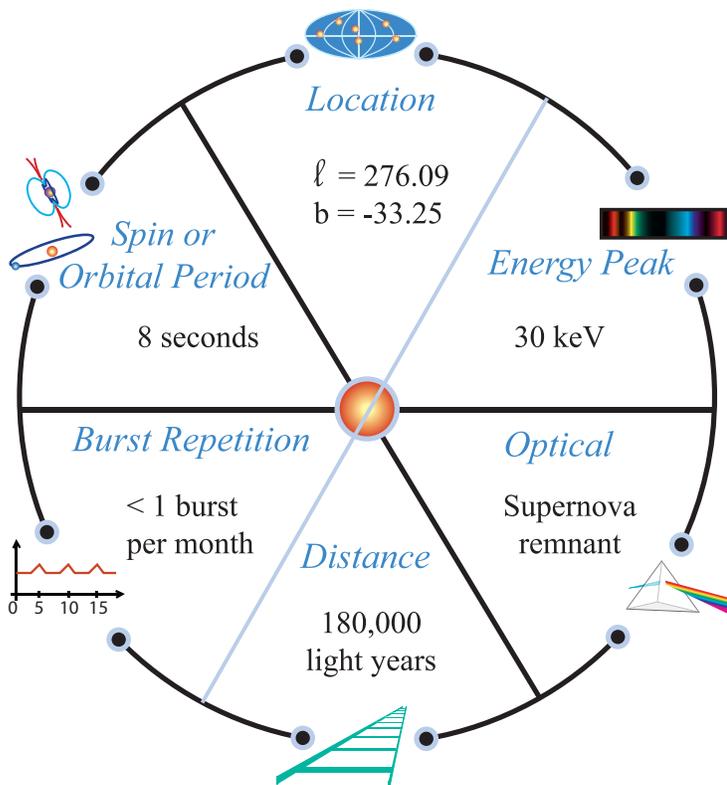
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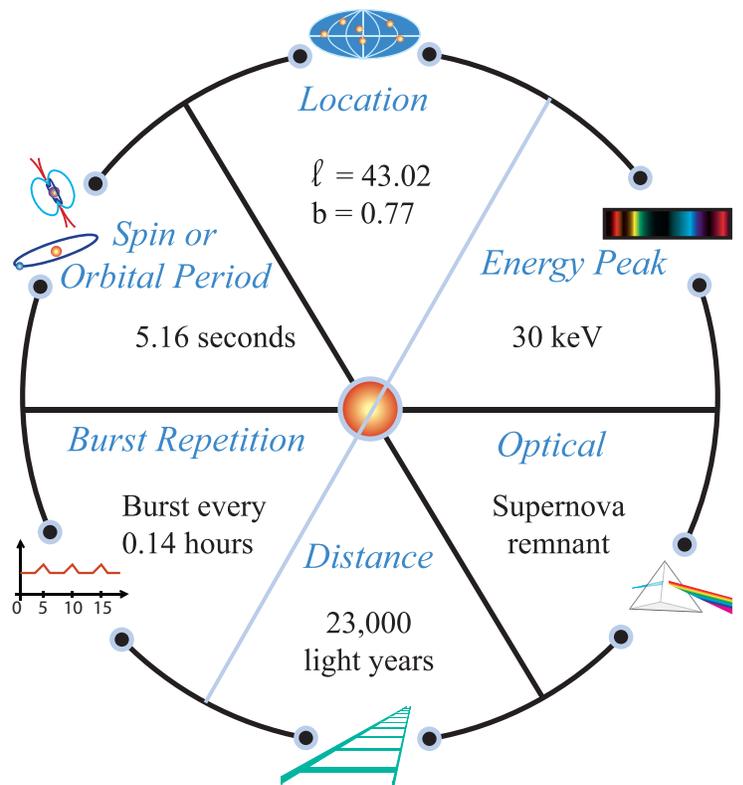
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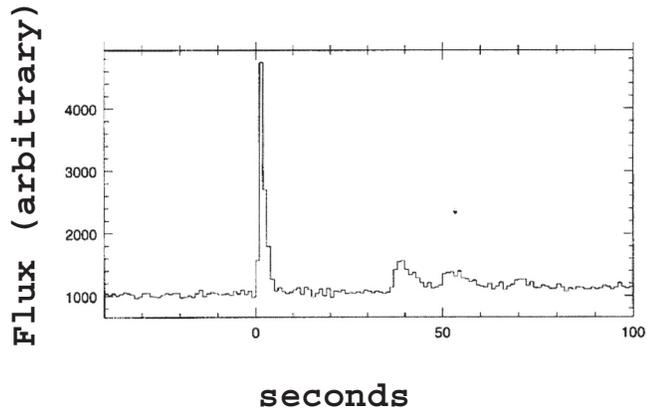
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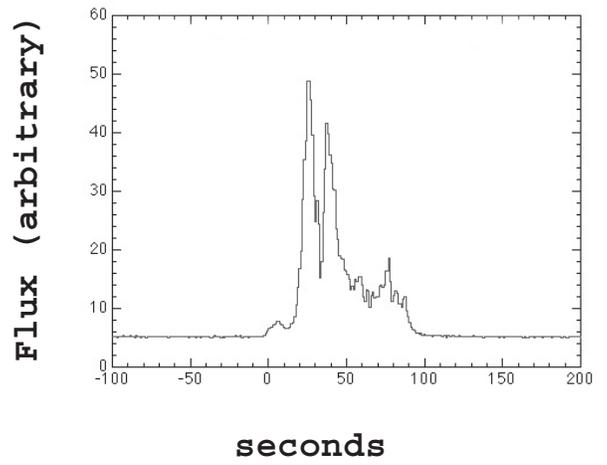
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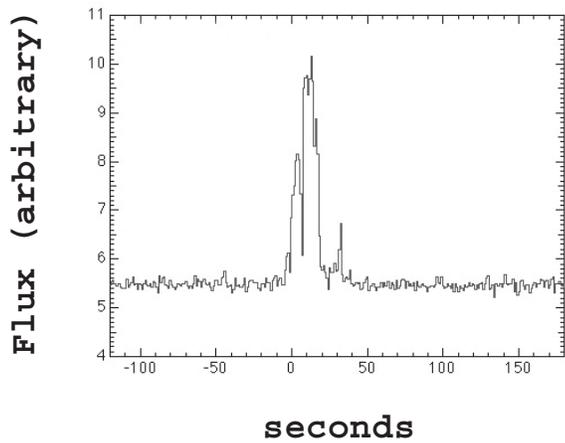
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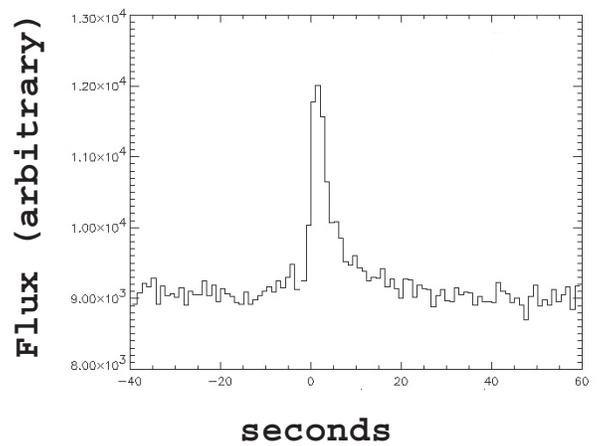
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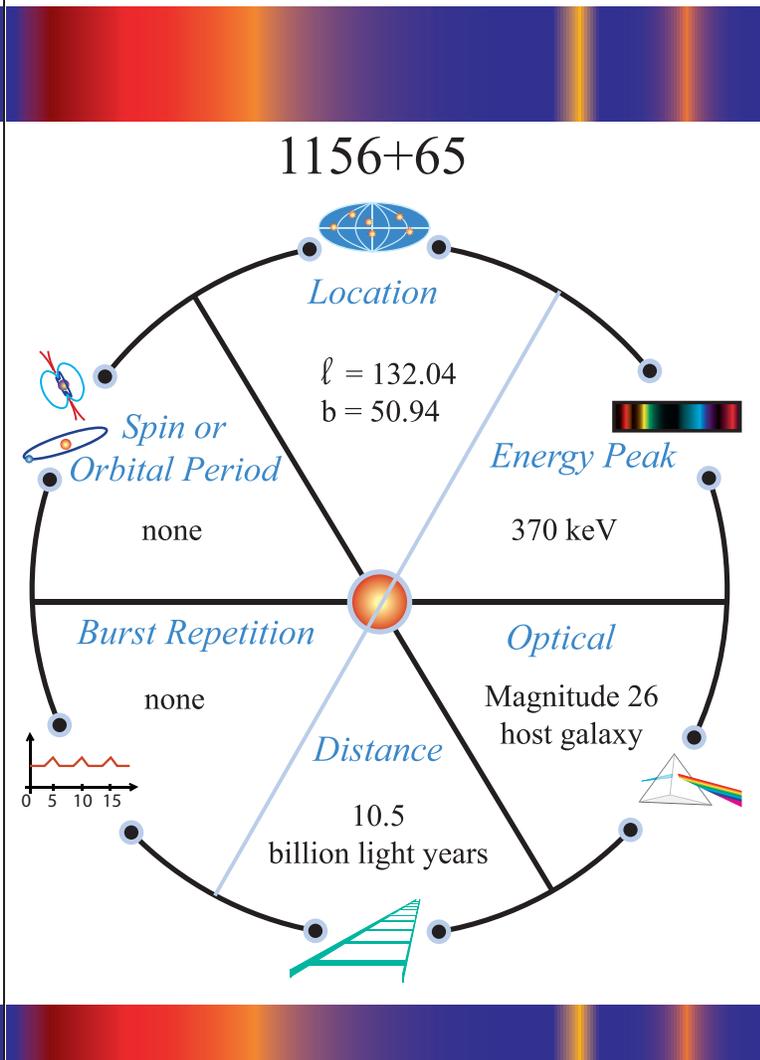
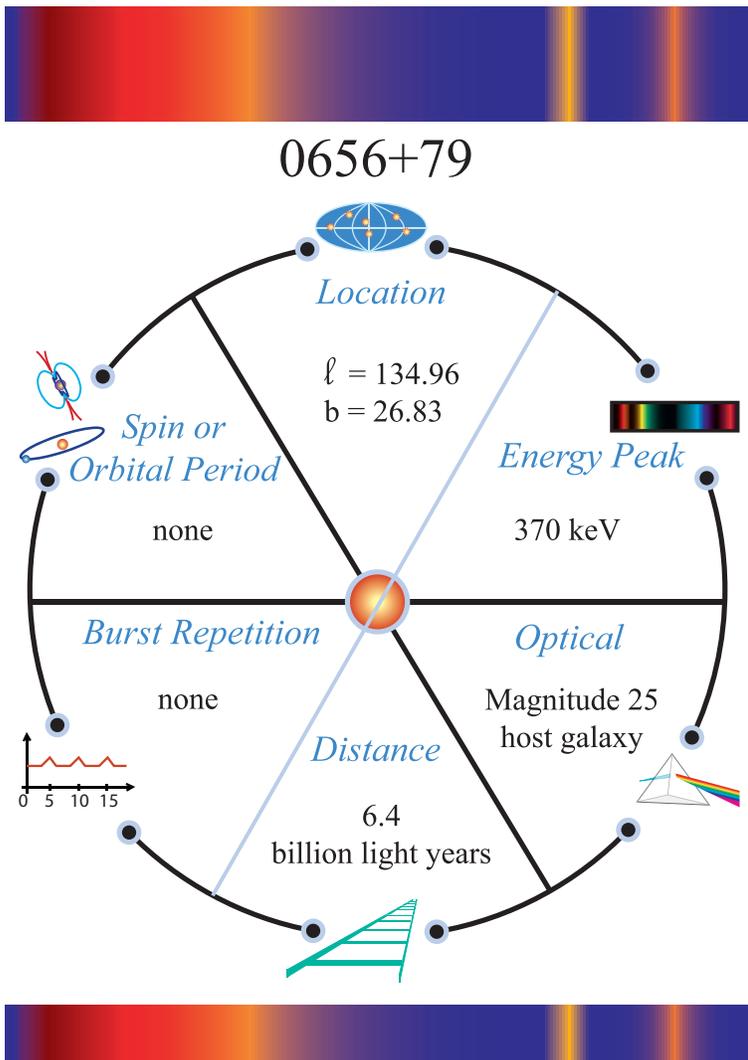
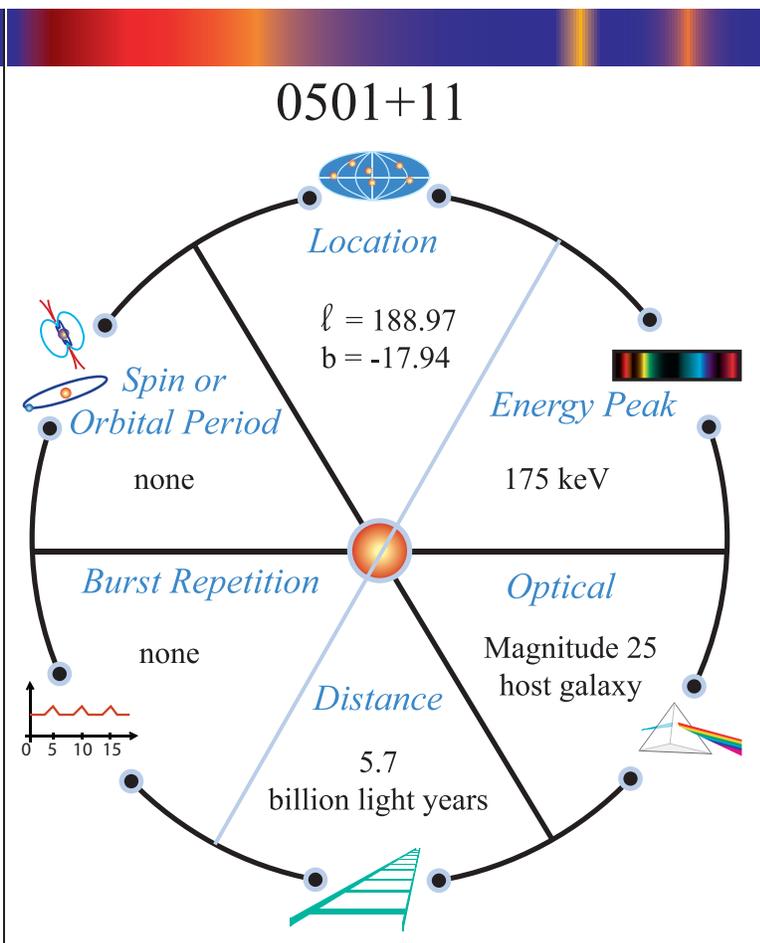
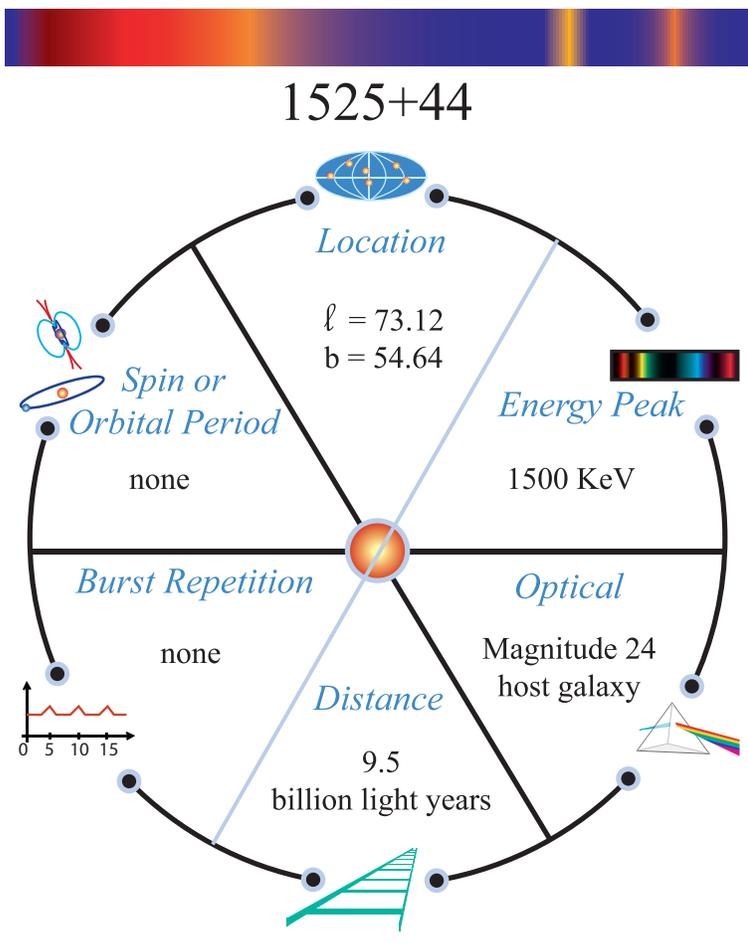


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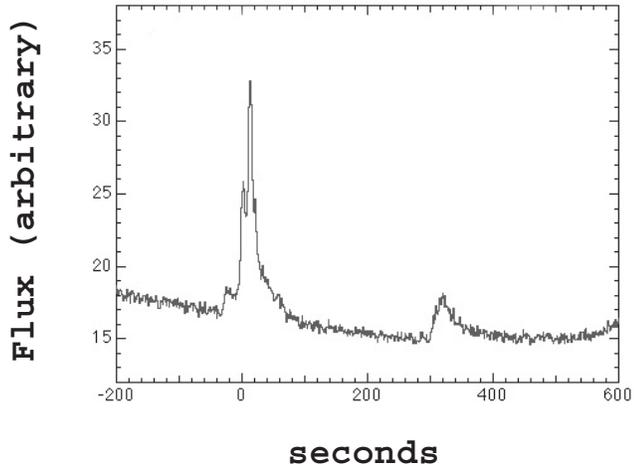


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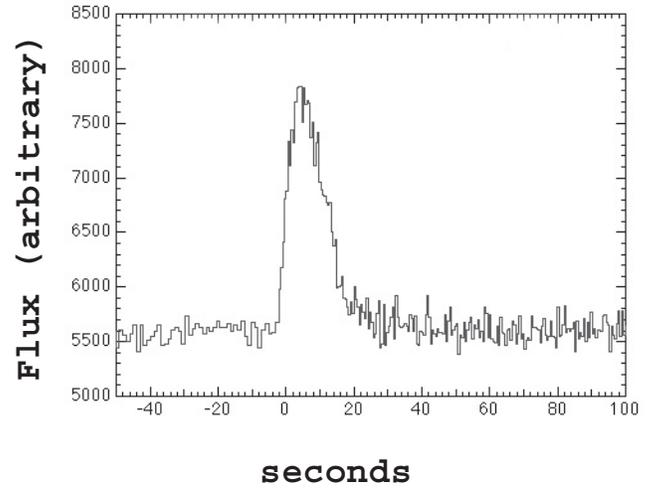




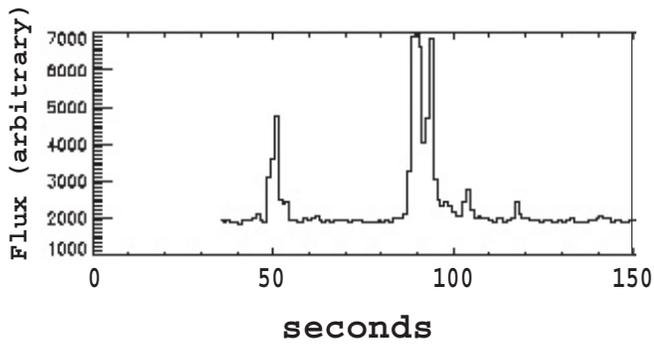
2359+08



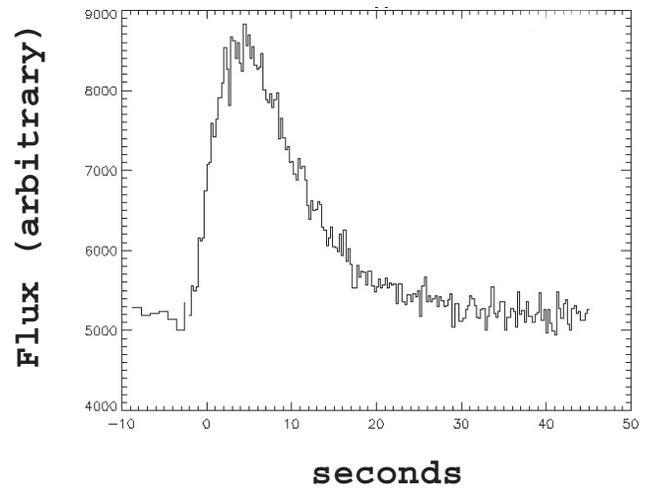
1935-52



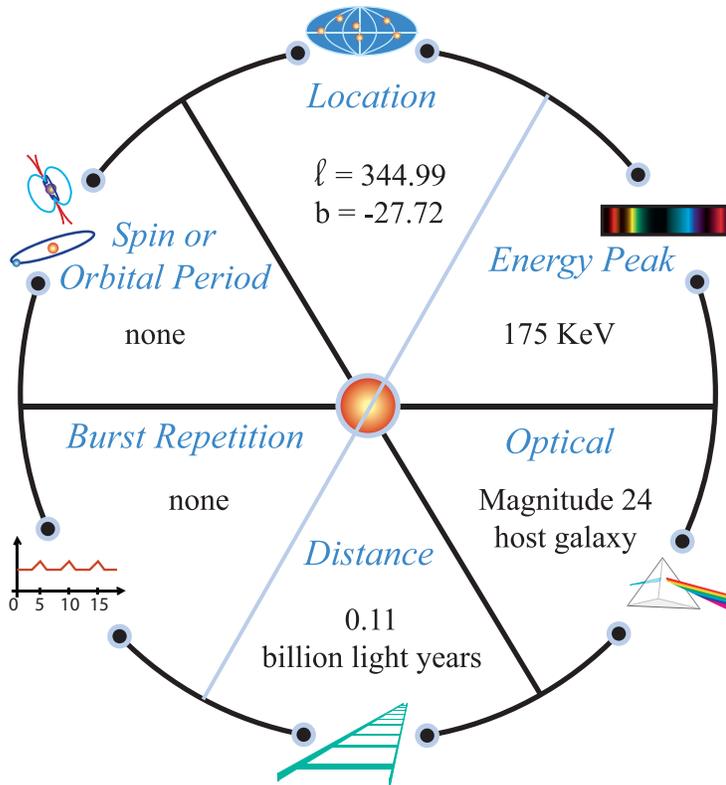
1338-80



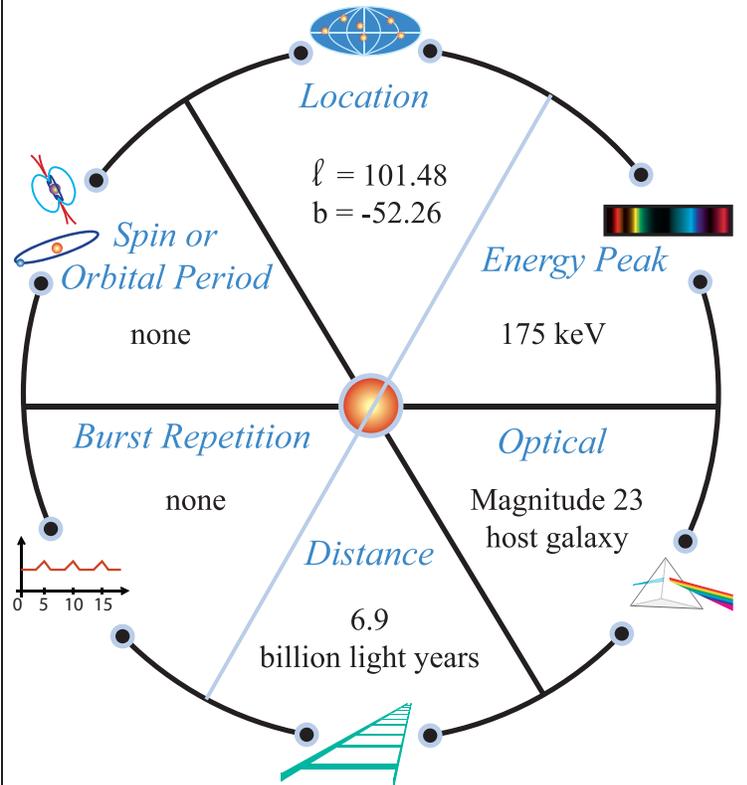
2232-73



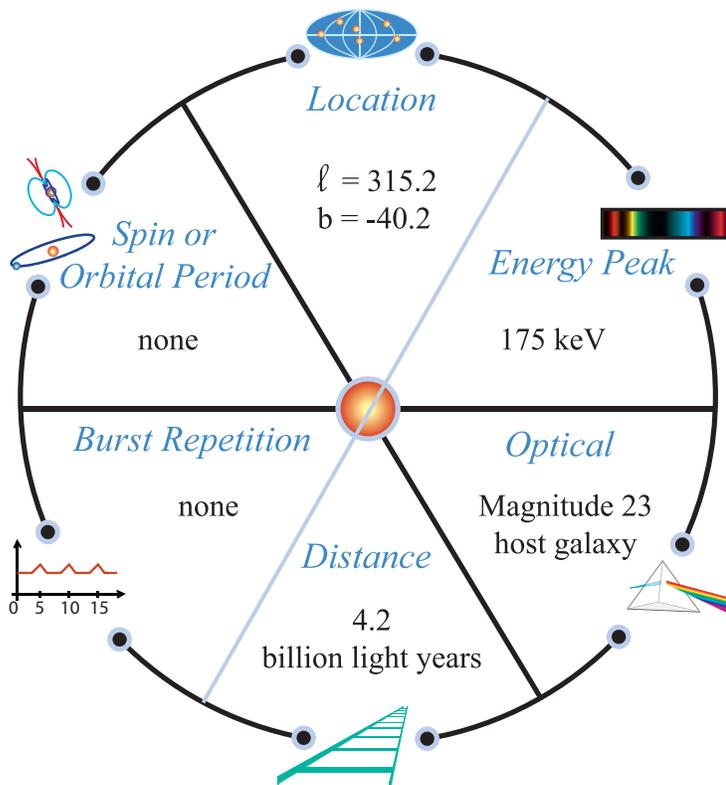
1935-52



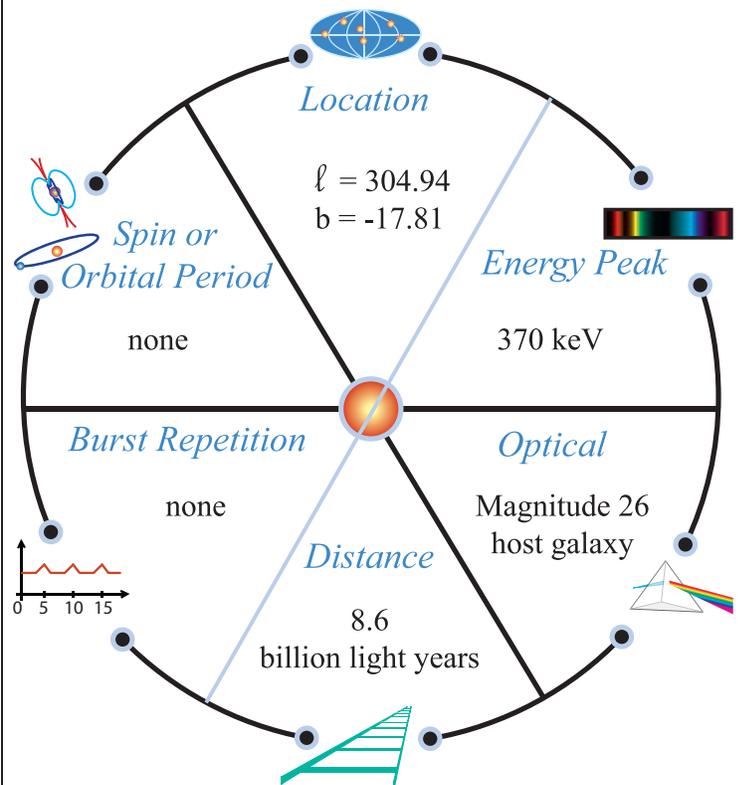
2359+08



2232-73



1338-80



Step 4: BATSE in the Belfry

Figure 8 shows the real gamma-ray burst distribution in the sky, taken by NASA's Burst Alert and Transient Source Experiment (BATSE) detector that orbited the Earth from 1991 to 2000. There are 2704 bursts plotted on the map. Figure 9 shows the same thing, but collapsed down to a plane like Figures 6 and 7.

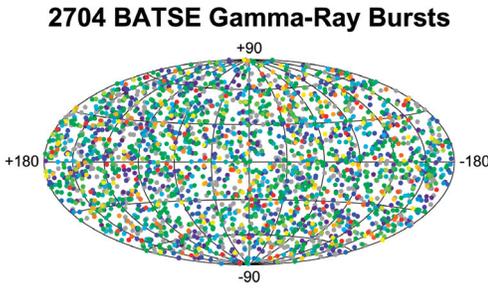


Fig. 8

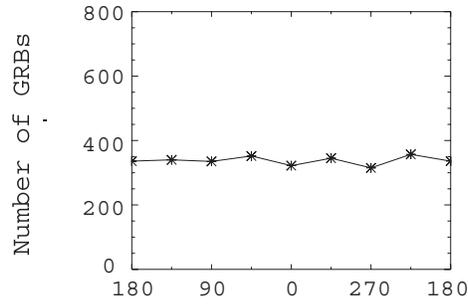


Fig. 9

Compare the real distribution in the BATSE map to Figures 4 and 5, and the plot in Figure 9 to those in Figures 6 and 7.

Questions:

16. Which simulated distribution looks most like the real one? Does the collapsed plot match as well?
17. What does this tell you about the real distribution of GRBs in space?
18. Describe what this exercise tells you about determining the distance to GRBs.

GRB Distribution Across the Sky: The Plots Thicken - Student Worksheet

Name _____

Date _____

Step 1: Having a Ball

1. _____

2. _____

3. _____

4. _____

5. _____

Step 2: The Cutting Wedge

TABLE 1: Number of balls in each pie wedge for Position 1

Wedge	# balls in wedge
1	
2	
3	
4	
5	
6	
7	
8	

6. _____

TABLE 2: Number of balls in each wedge for Position 2

Wedge	# balls in wedge
1	
2	
3	
4	
5	
6	
7	
8	

7. _____

8. _____

9. Total 1: _____

Total 2: _____

10. _____

11. Average 1: _____
Average 2: _____

12. _____

Step 3: A Twist in the Plot

13. _____

14. _____

15. _____

Step 4: BATSE in the Belfry

16. _____

17. _____

18. _____

Name _____

Date _____

Duration:

Introduce concepts and
Perform activity: 45 min

Beam Me Up!

4

**Essential Question:**

If an object emits light in a beam and not isotropically, how does this affect what we know about it?

Objectives - Students will:

- be able to explain the difference between beaming and isotropic emission
- model GRB observations using a flashlight beam
- use beam opening angle and number of observed GRBs to estimate the total number of GRBs
- model beaming energy by using a megaphone
- be able to explain why beaming means that GRBs have less energy than originally anticipated

Science Concepts

Many astronomical objects emit energy in narrow beams, which changes how we calculate the total energy they emit. The total calculated emitted energy of an object is much less than if we assume energy is emitted in all directions. Also, the number of objects we see depends on how tightly the beams are focused.

Background Information

[This information is split up into a section for you, and one for the students to read. You will of course need to read the student portion as well. It is included in the Student Handout section. The information provided to the student is sufficient to do the exercise, but the additional information given to you below will complement the student's understanding of how beaming affects the total energy of a GRB and how many of them we see. Going over this information with the students the day before they perform the exercise will increase their understanding of the activity and its concepts.]

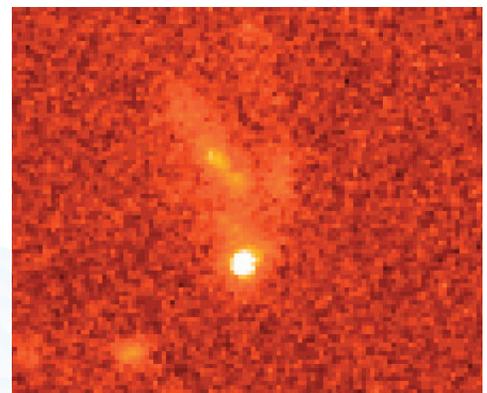
If GRBs **beam** their energy instead of emitting it **isotropically**, there can be a huge savings in energy. To see how, let's look first at an object that emits isotropically. To find the total light emitted by an object that emits this way, you take the amount of light you see falling on a given area (say, 1 square meter), and then find the ratio of that area to the area of the sphere defined by your distance to the object. For example, say you are 10 meters from a light bulb (the distance from a bulb you would be if you were across a large room), and you have a detector that is one square meter in area (a circle about 0.6 meters across). The total area of the sphere of light around the light bulb at your distance is

$$\text{Area} = 4\pi r^2 = 4\pi (10\text{ m})^2 = 1257\text{ m}^2$$

So the total light emitted by the light bulb is 1257 times what you see in your 1 square meter detector. And that's only if you're across a large room!

GRBs are a lot farther away than that. A GRB that was spotted on January 23, 1999 was nearly bright enough to be seen by the naked eye, but was 10 billion light years away. Assuming it emitted light isotropically, and using the formula above, astronomers found that the GRB must have had the energy of about 2 million billion (2×10^{15}) times that of the Sun! Even for astronomers familiar with big numbers, this energy was so vast that no one could imagine what could power such an explosion.

But if the GRB beamed its energy, we cannot use the equation above, because it will grossly overestimate the total amount of light emitted. To see this, imagine the beam from the GRB mentioned above was so incredibly narrowly focused that by the time the beam reached the Earth, it was only 0.6 meters across, so that the area of the beam were 1 square meter (in reality, no beam could ever possibly be this narrow). If that were the case, our 1 square meter detector will in fact see all the energy emitted by the object instead of some tiny fraction. But if the GRB emitted isotropically, given the distance of 10 billion light years, the light would be spread out over a sphere with an area of



GRB 990123 Host Galaxy Imaged
Credit: HST GRB Collaboration, STIS, HST, NASA

$$(4\pi r^2) = 4\pi (1 \times 10^{10} \text{ light years} \times 9.5 \times 10^{15} \text{ m/light year})^2$$

$$= 1.1 \times 10^{53} \text{ m}^2$$

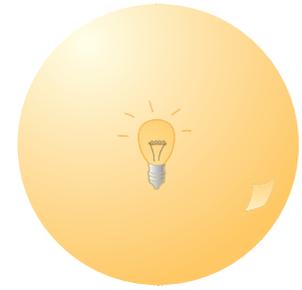
In that case, the 1 m² detector saw only a tiny fraction of the total light emitted by the GRB: 9 x 10⁻⁵⁴ of it, to be exact (1 square meter out of 1.1 x 10⁵³)!

So we see that beaming can, in principle, solve the energy problem. Even a moderately narrow beam can drop the total energy need by a factor of hundreds or thousands (in fact, a beam 1 degree across means a drop in energy of just about 50,000). If this is taken into account, then it becomes possible to have known energy sources for GRBs. In fact, this is one of the reasons why astronomers think that GRBs signal the births of black holes: the energy released in the formation of a black hole is similar to that of a GRB if beaming is taken into account.

There is another implication of beaming besides energy needs. Since the beam is narrow it means that we have to be in the path of that beam to see the GRB. If the beam misses us, we don't see it! Before the idea of beaming, astronomers assumed we were seeing every GRB that went off, but if the energy is beamed, we miss many – if not most– GRBs! This means that if we see, say, 100 per year, then there must be many more GRBs going off, perhaps thousands per year, that we do not see. The number we miss depends on how tightly the beam is focused; a broad beam means we don't miss many, while a narrow beam means we miss a lot. If the beam from a GRB is 1 degree across, the energy we calculate for it drops by 50,000, but it also means there are 49,999 of this kind for every 1 we see.

In this activity, your students will use flashlights and megaphones to represent the beam from a GRB. They will see that beaming means the GRB has lower energy, and also that there must be many more GRBs going off than we actually detect.

Isotropic: the emission of light equally in all directions.



Engage and Explore!



Additional Information:

Part A:

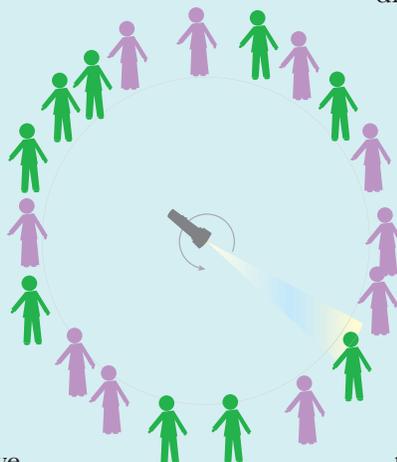
Students will be constructing crude megaphones out of paper and using them to project their voice. This may lead to some confusion if the students are placed too close together, so you'll need ample elbow room for this. Spread the students out across the classroom, in the hallway or even outside if necessary.

Part B:

For this activity, you will need to spin a flashlight around so that it rotates many times (more than three times) but stays in one place on the floor. This can usually be done with a standard flashlight, but takes practice. Try it several times until you feel comfortable with it. If you cannot get the flashlight to stay in one spot on the floor, you can attach it to a ruler using tape and spin that. If the ruler has a hole in it (for example, the kind that go in three-ring binders have

holes) then you can use a pencil or other narrow object as a spindle. Put it through the hole and spin it that way. (Note: this method makes it harder to spin the flashlight around more than once or twice.) A lazy Susan (a rotating plate used in restaurants for condiments) could also be used, as long as it doesn't take too long to slow to a stop!

The students will be sitting in a circle about 4 meters in diameter. You may need to adjust the diameter if you have too few or too many students to fit that size circle. Since the students will be observing the flashlight, it may help to cover any windows and dim the lights. You will be spinning the flashlight a number of times, the more the better, but it should be at least twice for every student in the classroom (if there are 20 students, spin it 40 times). You may want to have a student or two keep track of how many times you have spun it, or mark a piece of paper every time you spin it. Either way, you should keep track of the number of times you spin the flashlight yourself as a check.



Materials for each group of 2 or 3 students:

- Student Handout
- Construction paper and tape (Part A)
- Flashlight (one for the whole class in Part B) and an apparatus to spin it if needed
- A protractor (Part B)

Materials for each student:

- Student Worksheet
- Student Handout
- Calculator

Note: Student groups may want to find their own opening angle for #11. If so, they may need their own flashlight.

Procedure:

1. **Pre-class:** make copies of the Student Worksheet and Handout, one per student.
2. **In class:** Introduce the activity by reviewing information in the introduction to gamma ray bursts and in the activity overview.
3. Part A: Explain to the students that they will be constructing megaphones from paper, and comparing the loudness of their voices with and without the megaphone. They will then extrapolate this knowledge to GRBs. The activity is done in pairs.
4. Part B: Explain to the students that they will be observing a flashlight and noting when they can see the filament and when they can't. In the end, they will compare results.
5. You will need enough space for the students to sit in a circle about 4 meters in diameter, depending on the number of students in the class.

6. The activity is done individually, though the class will compare results at the end.

7. **Post-class:** In Part A, students may have the misconception that the megaphone is actually amplifying his or her voice. The megaphone does not amplify one's voice; the total energy in the sound waves remains the same. The megaphone focuses a person's voice so the sound waves all move in a narrower beam, rather than spreading out in all directions. By forcing the sound waves into a beam, the megaphone keeps the sound from getting fainter as quickly. Less total energy is needed to be heard with a megaphone.

8. Engage the students in discussing an extrapolation of the activity to much greater distances. Imagine Student A was located a kilometer away from Student B. If Student B were able to hear Student A's voice, he might be puzzled. It would be very difficult or impossible to shout loudly enough to be heard from such a distance. The total energy Student A could put into the sound waves of her voice would get diminished by the great distance, and Student B wouldn't hear her. But if the energy in the sound waves from Student A's voice were able to be focused into a beam, it could be heard across that distance. A megaphone beams the voice, so that sound waves with lower total energy can still be heard.

The gamma ray burst energy problem is like Student A's voice. GRBs are located at distances of billions of light years. If they emitted their light isotropically, like Student A's voice without the megaphone, the energy needed would be beyond that generated by any known process.

But if that energy is beamed, like Student A's voice when using a megaphone, the total energy needed is far less, well within the realm of known physics. This solves the energy problem! But as seen in Part A, it also means that GRBs are more common than previously thought. This is a tradeoff: the more the energy is beamed, the easier they are to detect if we see the beam, but the narrower the beam, the more likely it is to miss us.

9. When the students are done with Part B, collect the values each student got for question 7 and put them on the blackboard. Have the students compare the numbers and discuss any similarities or differences. Ask them what they think the results would have been like had the beam been much narrower, or much larger. Remind them that GRB beams are probably very narrow, only a few degrees across. Some astronomers estimate that we only see one out of every 100 GRBs.

Engage!



*Procedure step 2:
Instead of just sitting
and lecturing, try
asking your students
leading questions.*

Questions like:

- What is a GRB? (revisiting questions that you used in the first activity)
- What do we know about properties of light?
- Why do scientists care about GRBs and how they distribute their light?
- What is the big question for the scientists explained in the student handout (p.41) ?

Depending on their answers, your questions may change. This is a really good method to intrigue your students and engage their minds.

It is also good as an assessment tool!

Extension Activities:

As a way of explaining how beaming takes less energy than isotropic emission, have the students sit in a circle on the floor. Get 20 or so small objects such as pennies, erasers, or pens, but don't tell the students how many you have. Sit in the middle of the circle, and announce that you are a gamma-ray burst (or a penny burst, or whatever objects you have), and that you are emitting isotropically. Give one object to each student. Tell them to think about how many objects you must have started with to be able to give each one of them an object (they should guess that you have as many objects as there are students in the class). Collect the objects again, and then again announce you are a burst. Then give all the objects to a single student. Ask the class that if they were that student, and they thought that objects were distributed as before, how many would you have to start with (they should guess that it would

be the total number of students times the number of objects you gave that one student). But in reality, you had the same number both times. This shows that the total calculated energy of a GRB is much smaller if it is beamed than if it is emitted isotropically.

As an advanced math extension, the students can calculate the ratios of the areas of beams of varying opening angles compared to the whole sky. The area in square degrees of a beam of opening angle θ (in degrees) is

$$\text{Area} = 2\pi (1 - \cos \theta)$$

The area of the sky is 41,253 square degrees. They can then extrapolate how many GRBs are not seen depending on their beam opening angles as an extension to Step 4 of Part A ("Light Up My Life").

Elaborate!

Lesson Adaptations:

For Part A, if a student is visually impaired, they can be the one who does the speaking (Student A). If they have trouble speaking, they can blow a

whistle or use some other sound generator such as a radio. For Part B, choose them to spin the flashlight, or keep track of the number of spins.

Evaluate:

Points	Part A: Answer questions & explanation of beaming energy	Part B: Calculations	Part B: Explanation of beaming	Part B: Explanation of GRB numbers
4	Answers are complete and correct	Calculations are all accurate	Explanation is thorough and accurate	Calculations are all accurate
3	Answers are mostly correct and complete	Most calculations are accurate	Explanation is accurate, but not thorough	Most calculations are accurate
2	Answers are somewhat correct and complete	Some calculations are accurate	Explanation is somewhat accurate	Some calculations are accurate
1	Answers are incorrect and incomplete	Calculations are inaccurate	Explanation is inaccurate	Calculations are inaccurate
0	None turned in	None turned in	None turned in	None turned in

Answer Key for *Beam Me Up!*:

Part A

• Step 2: Shout Out

1. Student A's voice should have been *louder* with the megaphone.
2. Student A had to speak louder without the megaphone, so the energy was higher *without* the megaphone.
3. The energy in Student A's voice was not amplified by the megaphone. The megaphone prevents the energy from Student A's voice from expanding outward in all directions. Instead, the energy is focused into a beam, focusing more energy in one direction.

• Step 3: Gigaphone

4. The *unbeamed* GRB has more energy. The beamed GRB put all its energy into one direction, but the unbeamed GRB had to spread that energy out in every direction. To make the unbeamed GRB as bright as the beamed one, it would have to put out far more energy.

Part B

• Step 1: Setup

5. This depends on class size.

• Step 2: Won't You Beam Mine?

6. For the answer key, we will use 100 as the total number of spins. Scale your answers below to match the number of spins you actually used.

7. This answer will vary from student to student.

8. This will be the total number of spins minus the number of times they saw the filament.

9. This varies from student to student.

10. This will be $360^\circ / \text{number of students}$.

• Step 3: Opening Up

11. An opening of 90° is $\frac{1}{4}$ of a circle, so they should see the filament $\frac{1}{4}$ of the time, for a total of 25 times.

12. This depends on the opening angle measured. The answer is:
 $\text{opening angle} / 360^\circ$.

13. This depends on the opening angle measured and the number of spins. The answer is:
 $(\text{opening angle} / 360^\circ) \times \text{number of spins}$.

14. This will vary from student to student. In general, variations will depend mostly on the fact that you don't have many spins, so you have "small number statistics", and you should expect big variations. If you spun the flashlight 1000 times, for example, the variations would be much lower.

• Step 4: Light Up My Life

15. This is the same as question 9:
 $(\text{opening angle} / 360^\circ) \times \text{the number of gamma ray bursts} =$
 $(\text{opening angle} / 360^\circ) \times 100$.

16. This is $100 - \text{the answer to question 11}$:
 $100 - ((\text{opening angle} / 360^\circ) \times 100)$

Beam Me Up

Student Handout

Introduction

Once it was determined that GRBs were located at cosmological (very vast) distances, another problem was dropped into astronomers' laps: what could generate so much energy?

This problem was known before the distances were determined, and was actually used as a key argument against large distances for GRBs. The farther away an object is, the more energy it must emit to be seen. Think of it this way: the Sun is by far the most brilliant object in the sky to our eyes, ten billion times brighter than Sirius, the brightest nighttime star. Yet in reality Sirius is actually more luminous than the Sun; it gives off more total energy. But Sirius is 550,000 times farther away from us than the Sun is, and so the star's light is diminished by distance.

In fact, the brightness of an object decreases by the square of the distance. A 100 kW light bulb 1 meter away will actually appear 4 times brighter than one 2 meters away (the distance doubles, so the amount of light you see drops by a factor of 4). It will be 100 times brighter than one 10 meters away, and 10,000 times brighter than one 100 meters away.

This is called the "inverse square rule" of brightness. It occurs because a star (or a light bulb) emits light isotropically, in all directions. The light expands away from the star in the shape of a sphere. The area of that sphere is equal to $4\pi r^2$, where r is the distance to the light source. If the distance to the star is tripled, the area goes up by a factor of $3 \times 3 = 9$, and the light you see hitting your eye drops by $1/9$.

Now think what this means for GRBs. They are so far away that for us to receive any energy from them at all means they must be incredibly luminous. In fact, when astronomers calculated how much energy they must be emitting in total, the numbers were so big that no known source of energy could possibly power a burst of that size. This was a major puzzle.

But there was a way out. What if the light were not emitted isotropically? What if it were beamed?

Some objects do not emit light in all directions, but instead send out light in narrow beams, like the beams from a lighthouse. Beams are emitted from young stars, still circled by a disk of debris that may form planets. Neutron stars, ultra-dense cinders left over from supernova explosions, are known to emit their energy in very tightly-constrained beams. Even the giant black holes in the centers of active galaxies can emit narrow beams which can stretch for hundreds of thousands of light years. It is therefore logical to suppose that GRBs also might beam their emission.

In the following activities, you will investigate how beaming energy saved the day for astronomers, and the implications of beaming on the total number of GRBs in the Universe.

Think about it!



What could generate so much energy?

The sun is brighter than Sirius. But Sirius is 550,000 times farther away!

What if light were not emitted isotropically?

What if it were beamed?



From 10 meters away, 1 square meter covers only a small portion of the emitted light.



If the light is beamed, a detector sees all the light.

Remember you are producing sound waves not light waves like gamma-ray bursts.



Listen!

A. Megaphones and Gamma Ray Bursts

Step 1: Setup

In this activity you will compare the loudness of someone speaking with and without a megaphone.

First, split up into pairs. Then make a megaphone out of construction paper. Simply roll up the paper into a cone such that the narrow end has a small opening, but large enough to fit around your mouth. The large opening of the cone should be several times wider than the narrow end. When it has the right shape, tape the flap so it stays together.

Step 2: Shout Out

Pick roles for each student. Student A will be the one who will make the noises with and without the megaphone, while Student B will be the one listening.

Each pair of students should face each other and stand between 4 and 10 meters apart. Teams should be far enough apart from each other to minimize confusion. Follow the “Shout Out Easy Guide” on the left side to do the activity, and answer the questions below.

Step 2: Shout Out Easy Guide

Student A: Without using the megaphone, speak normally to Student B. It doesn't matter what you say, but it would be helpful if you use some sort of sequence that is easy to follow, like the alphabet, or counting upwards. As you speak, talk more and more quietly.

Student B: Listen carefully to Student A. When Student A's voice is no longer or just barely audible, let them know by raising your hand.

Student A: When Student B lets you know you are just barely audible, continue speaking at that level, and raise the megaphone up to your mouth. Make sure you keep your voice tone and volume at the same level. Continue to speak as you did before.

Student B: When Student A uses the megaphone, listen for their voice. Can you hear it better now? If so, let Student A know.

Student A: When Student B lets you know your voice is audible, once again begin to lower the volume.

Student B: Similar to before, listen carefully, and let Student A know when their voice is barely audible through the megaphone.

Questions:

1. Did Student A's voice get quieter, remain the same, or get louder when the megaphone was used?
2. When you speak, you generate sound waves. The loudness of the sound is related to the energy put into the sound waves. Given that, compare the amount of energy Student A put into his voice when it was barely audible without the megaphone to the energy at the end, when it was barely audible with the megaphone. Was the sound wave energy of the barely audible voice greater with the megaphone, or without it?
3. In your own words, describe what the megaphone did to Student A's voice.



Step 3: Gigaphone

Now apply what you have just experienced to the field of high-energy astronomy. At first, astronomers thought that gamma-ray bursts emitted their light isotropically (in all directions). Then they realized the GRB energy must be beamed.

Imagine two GRBs are at the same distance from Earth, but one is beaming its energy while the other one emits its light isotropically. Astronomers on Earth measure their apparent brightness and find them to be equal.

Question 4:

Why?

B. Spin the Flashlight

Step 1: Setup

In a clear space on the classroom floor, form a circle of sitting students. Don't crowd each other! Keep about 30 centimeters of space between you and the person on your right and left. Adjust your positions so that every student has an equal distance from the students on the left and right.

The teacher is going to spin a flashlight in the center of the circle several times, and will announce the number of that spin. When the flashlight stops, note whether you can see the filament of the bulb or not (not just the bulb, but the part actually making light). You may need to crouch down a bit to see the filament. Every time you see the filament, make a tally mark on the student worksheet (question 7).

When you are done spinning the flashlight return to your seats.

Question 5:

Write down how many students are sitting around the circle.

Watch closely to see how the flashlight is beamed.



Step 2: Won't You Beam Mine?

6. How many times was the flashlight spun?
7. How many times did you see the filament?
8. How many times did you not see the filament?
9. What is the ratio of how many times you saw the flashlight filament to the number of times the flashlight was spun?
10. Using the number of students sitting at the circle, determine approximately how many degrees apart you were from the student next to you.

Step 3: Opening Up

The beam from the flashlight has an opening angle; that is, the beam is not perfectly straight, but expands out from the bulb in a cone. The opening angle is defined as the angle from one side of the cone to the other, as measured from the vertex. Note that if you are anywhere inside that cone, you can see the flashlight filament. You can verify this: put the flashlight on a flat horizontal surface (a desk or table, for example), then put your head down on the table. By placing your eye along the edge of the opening cone, you can see the filament. If you are outside the cone, you cannot see the filament.

Now take the flashlight you used and lay it down on a piece of paper (or put it up against the blackboard). There will be a triangular or parabolic shape of bright light coming from the flashlight on the paper. The edges of this light should have fairly straight lines. Using a ruler, trace these lines. Remove the flashlight, and use the rulers to extend the lines so they connect at a point. Using a protractor, measure the angle between the lines. This is the opening angle.

Question 11:

Imagine a flashlight with an opening angle of 90° . If it were spun 100 times, how many times on average would you expect to see the filament?



Applying the theory: measuring the opening angle and determining its effects.

Questions:

12. Knowing the opening angle, what are the odds you will see the filament in any given spin?

13. Knowing the number of spins actually made, how many times would you expect to see the filament of the bulb?

14. Compare the ratio of the times you saw the filament (from question 5) to the expected ratio (question 9). In your own words describe the similarities or differences.

Step 4: Light up My Life

The Swift satellite is expected to see about 100 gamma-ray bursts per year. These bursts almost certainly emit their light in a beam.



Explain and Elaborate!

Questions:

15. If the opening angle of the GRB beam is the same as your flashlight, what is the actual number of GRB events per year?

16. How many do astronomers miss?

Beam Me Up!

Student worksheet

Name _____

Date _____

A. Megaphones and Gamma Ray Bursts

Step 2: Shout Out

- 1) _____
- 2) _____
- 3) _____
- _____
- _____
- _____
- _____
- _____

Step 2: Gigaphone

- 4) _____
- _____
- _____
- _____
- _____

B. Spin the Flashlight

Step 1: Setup

- 5) _____

Step 2: Won't You Beam Mine?

- 6) _____

- 7) _____

- 8) _____

- 9) _____

- 10) _____ degrees

Step 3: Opening Up

- 11) _____

- 12) _____

- 13) _____

- 14) _____

- _____
- _____
- _____
- _____
- _____

Step 4: You Light Up My Life

- 15) _____ GRBs per year

- 16) _____

Glossary

- A** **Accrete:** to gain mass by the accumulation of matter.
- Accretion Disk:** The flattened disk of matter swirling just outside a black hole.
- Afterglow:** the fading light from a gamma ray burst that can last for days or months.
- Aitoff Map:** a way of mapping a sphere two-dimensionally such that regions near the poles are not artificially stretched-out.
- B** **Beam:** to focus light into a narrow jet, instead of emitting light in an expanding sphere.
- Binary system:** a pair of stars which orbit each other due to their mutual gravity.
- Black Hole:** An object so small and dense that the escape velocity within the event horizon is faster than the speed of light.
- Burst Alert Telescope (BAT):** the instrument onboard Swift which initially detects gamma-ray bursts.
- C** **Cartesian coordinates:** a way of mapping an object's position using perpendicular x- and y-axes.
- D** **Declination:** a coordinate on the sky corresponding to latitude on the Earth.
- Degree:** 1/360th of the circumference of a circle.
- E** **Electromagnetic Spectrum:** the broad range of energies that characterizes light.
- Electron Volt (eV):** a unit of energy commonly used in astronomy. A typical gamma ray has an energy of about 100 million (10^8) electron Volts. A photon of visible light has about 1 eV of energy.
- F** **Flux:** the amount of energy passing through an area of one square meter every second.
- G** **Galaxy:** a collection of gas, dust, and billions of stars bound together by their own gravity.
- Gamma Ray:** range of electromagnetic energy with energies from about 1000 keV and up.
- Gamma Ray Burst:** a sudden blast of gamma rays coming from a random point on the sky.
- H** **Hard X-ray:** an X-ray within the upper end of the X-ray range. This overlaps with the soft gamma ray energy range.
- Hypernova:** an unusually energetic type of supernova.
- I** **Infrared:** the range of electromagnetic energy with energies from about 0.001 - 1 eV.
- Isotropic:** the emission of light equally in all directions.
- J** **Jet:** A thin, highly focused beam of matter and energy emitted from some black holes. Jets can range from a few light years in length to hundreds of thousands of light years long.
- Joule (J):** a unit of energy, equal to 6.3×10^{18} eV.
- K** **keV:** one thousand (10^3) electron Volts.
- L** **Large Magellanic Cloud (LMC):** a companion galaxy to our Milky Way.
- Light Curve:** a plot showing the change in brightness of an object versus time.
- Light Minute:** the distance light travels in a minute; approximately 18.1 billion meters (1.8×10^{10} meters).
- Light Year:** the distance light travels in one year; approximately 10 trillion kilometers (10^{13} kilometers).
- Luminosity:** the total energy emitted by an object per second.

M **Microwaves:** range of electromagnetic energy with energies from about 10^{-4} eV to 0.001 eV.

Milky Way: the name of our galaxy.

Millisecond: one-thousandth (10^{-3}) of a second.

N **NASA:** the National Aeronautics and Space Administration.

Neutron star: the ultra-dense core of an exploded star.

P **Period:** the amount of time it takes for a pattern to repeat.

Photon: an individual particle of light.

Pulsar: a rapidly rotating neutron star that emits energy in beams.

R **Radiation:** a type of energy emitted as waves or particles, generally known as light or electromagnetic radiation.

Radio: the range of electromagnetic energy with energies less than about 10^{-4} eV.

Right Ascension: a coordinate on the sky corresponding to longitude on the Earth.

S **Soft X-ray:** an X-ray within the lower end of the X-ray range.

Soft Gamma Ray: a gamma ray within the lower end of the gamma ray energy range. This overlaps with the hard X-ray energy range.

Soft Gamma-ray Repeater: an object that emits a blast of gamma rays in a semi-periodic manner. Astronomers think these are neutron stars undergoing “star quakes”.

Solar Flare: a huge burst of energy from the Sun.

Solar System: a collection of planets, moons, comets, etc. which orbits a star. Our solar system is roughly 10^{10} kilometers (10^{13} meters) across.

Supernova: a star which explodes at the end of its life.

Supernova Remnant (SNR): the expanding cloud of gas left over from an exploding star.

U **Ultraviolet:** range of electromagnetic energy with energies from about 3 eV to 100 eV.

Ultraviolet/Optical Telescope (UVOT): the telescope onboard Swift sensitive to ultraviolet and visible light.

V **Visible** (also called Optical): the range of electromagnetic energy with energies from about 1 eV to 3 eV.

X **X-ray:** the range of electromagnetic energy with energies from about 100 eV to 1000 keV

X-ray Burster: a neutron star that periodically emits a blast of X-rays. Astronomers think these are neutron stars accreting matter from a nearby companion star.

X-ray Telescope (XRT): the telescope onboard Swift sensitive to X-rays

National Science Standards

GRB Specific Standards Activity #1

Content Standard A: Science as Inquiry

Abilities necessary to do scientific inquiry

- Students conduct scientific investigations when they sort the cards.
- Students formulate explanations for how they sorted the cards.
- Students are encouraged to discuss reasoning and results with their peers.
- Students are asked to plot the data on cards and analyze their results.
- Students are asked to communicate and defend the results of their scientific inquiry.

Understanding about scientific inquiry

- Scientists used the same data to arrive at similar conclusions.
- Scientists rely on tools such as Swift to enhance the gathering and manipulation of data.

Content Standard B: Physical Science

Interactions of energy and matter

- Students are asked to compare high energy objects and sort the energy of the objects by magnitude.
- Students learn what type of EM waves are emitted by these objects.
- Students learn to appreciate the amount of energy emitted by a GRB.
- Energy is transferred by light waves from GRBs.

Content Standard D: Earth and Space Science

Origin and evolution of the universe

- One of the proposed progenitors of GRBs is the birth of a black hole.

Content Standard G: History and Nature of Science

Science as a human endeavor

- By sorting and defining categories with the data on the cards, students see how the individuals and teams have contributed and will continue to contribute to the scientific enterprise.

Nature of scientific knowledge

- Students see how science distinguishes itself from other methods of acquiring knowledge

through the use of real, observed data.

- Students will understand that as technology improves, scientific knowledge may change.

Historical perspectives

- Students can see how useful these scientific data were for scientists, and how they have changed the understanding of burst sources.

GRB Specific Standards Activity #2

Content Standard A: Science as Inquiry

Abilities necessary to do scientific inquiry

- Students use the light rulers and calculators as a tool in their scientific investigation.
- Students must determine the direction to the GRB, eliminating false leads.
- Students are asked to communicate and defend their results.

Understanding about scientific inquiry

- Students, like scientists, use alternate methods to arrive at same conclusion.

Content Standard B: Physical Science

Motion and forces

- Gamma rays travel at the speed of light.

Interactions of energy and matter

- Gamma rays are a high energy form of light.
- The amount of energy in a gamma ray is very high, and gamma rays are the most energetic form of light.

Content Standard D: Earth and Space Science

Origin and evolution of the universe

- One of the proposed progenitors of GRBs is the birth of a black hole.

Content Standard E: Science and Technology

Abilities of technological design

- Swift will do the same things as the IPN, i.e. locate bursts.

Content Standard G: History and Nature of Science

Science as a human endeavor

- Real teams of scientists use this method to locate GRBs.

Historical perspectives

- Students emulate older methods of determining the direction to a GRB, and learn that Swift will update this method.

GRB Specific Standards Activity #3

Content Standard A: Science as Inquiry

Abilities necessary to do scientific inquiry

- Students discover how objects like GRBs are distributed relative to the student's position.
- The students model the GRB distribution using an Aitoff projection.
- Students use real GRB plots (scientific criteria) to find the preferable explanations about the GRB distributions, and in doing so are prompted to recognize and analyze alternative explanations and models.
- Students are asked to communicate their results and formulate explanations when plotting the distribution.
- Students are asked to describe, using their own words, how they arrive at the GRB distribution conclusion.

Understanding about scientific inquiry

- Students learn that Swift will gather additional needed data about GRBs.
- Students get more familiar with the use of mathematics, technology, and evidence from their inquiry.

Content Standard D: Earth and Space Science

Origin and evolution of the universe

- Students discover that the mysterious GRBs can provide important clues about how the Universe has evolved over time.
- Students are able to get a grasp of how objects and events are distributed in the Universe.
- One of the proposed progenitors of GRBs is the birth of a black hole.

Content Standard E: Science and Technology

Understanding about science and technology

- Scientists studying GRBs ask different questions (for example, about different distributions of GRBs) than scientists studying different disciplines.

Content Standard G: History and Nature of Science

Science as a human endeavor

- The Swift team's goal is to determine the origins of and physical mechanisms behind the mysterious GRBs, which will contribute to the future of GRB science.
- Students will grasp the general idea of the methods scientists use to solve scientific mysteries.

GRB Specific Standards Activity #4

Content Standard A: Science as Inquiry

Abilities necessary to do scientific inquiry

- While experimenting with the megaphone, students see that scientists conduct scientific investigations for a variety of reasons.
- Students learn that the results of scientific inquiry have led to the belief that GRBs beam their energy.
- Students will also see that even scientists do not understand everything about beaming, and Swift will help to answer these questions.

Understanding scientific inquiry

- The energy emitted by a GRB is sometimes so great that even scientists have difficulty grasping it.

Content Standard B: Physical Science

Motion and forces

- Gamma rays travel at the speed of light.

Interactions of energy and matter

- Gamma rays are a high energy form of light.
- The amount of energy in a gamma ray is very high, and gamma rays are the highest energy form of light.
- Sound waves from the student's voice transmit energy through the air. GRB light waves also transmit energy, through the vacuum of space.
- Light waves in general transmit energy.

Content Standard D: Earth and Space Science

Origin and evolution of the universe

- Students are able to get a grasp on how objects and events are distributed in the Universe.
- One of the proposed progenitors of GRBs is the birth of a black hole.

Content Standard E: Science and Technology

Science as a human endeavor

- Scientists studying GRBs ask different questions (for example, about beaming) than scientists studying different disciplines.
- Scientists had to creatively answer the question about the total energy emitted in a GRB.

Mathematics Standards

Number and Operations

Understand numbers, ways of representing numbers, relationships among numbers, and number systems

- Students develop a deeper understanding of very large and very small numbers and of various representations of them; (#1 & 2)

Compute fluently and make reasonable estimates

- Students develop fluency in operations with real numbers, vectors, and matrices, using mental computation or paper-and-pencil calculations for simple cases and technology for more-complicated cases. (#2)
- Students judge the reasonableness of numerical computations and their results. (All four)

Algebra

Understand patterns, relations, and functions

- Students generalize patterns using explicitly defined and recursively defined functions; (#2 & 3)
- Students understand and perform transformations such as arithmetically combining, composing, and inverting commonly used functions, using technology to perform such operations on more-complicated symbolic expressions; (#2)

Geometry

Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships

- Students analyze properties and determine attributes of two- and three-dimensional objects; (All four)
- Students use trigonometric relationships to determine lengths and angle measures. (#2 & 4)

Specify locations and describe spatial relationships using coordinate geometry and other representational systems

- Students use Cartesian coordinates and other coordinate systems, such as navigational, polar, or spherical systems, to analyze geometric situations. (#2 & 3)
- Students investigate conjectures and solve problems involving two- and three-dimensional objects represented with Cartesian coordinates. (#2 & 3)

Apply transformations and use symmetry to analyze mathematical situations

- Students understand and represent translations, reflections, rotations, and dilations of objects in the plane by using sketches, coordinates, vectors, function notation, and matrices; (#2)

Use visualization, spatial reasoning, and geometric modeling to solve problems

- Students draw and construct representations of two- and three-dimensional geometric objects using a variety of tools; (#1,2 & 4)
- Students use geometric models to gain insights into, and answer questions in, other areas of mathematics; (All four)
- Students use geometric ideas to solve problems in, and gain insights into, other disciplines and other areas of interest such as art and architecture. (All four)

Measurement

Understand measurable attributes of objects and the units, systems, and processes of measurement

- Students make decisions about units and scales that are appropriate for problem situations involving measurement. (#1 & 2)

Apply appropriate techniques, tools, and formulas to determine measurements

- Students understand and use formulas for the area, surface area, and volume of geometric figures, including cones, spheres, and cylinders; (#3 & 4)
- Students apply informal concepts of successive approximation, upper and lower bounds, and limit in measurement situations; (#3 & 4)
- Students use unit analysis to check measurement computations (#2, 3 & 4).

Data Analysis and Probability

Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

- Students understand the differences among various kinds of studies and which types of inferences can legitimately be drawn from each; (#1)

- Students know the characteristics of well-designed studies, including the role of randomization in surveys and experiments; (#1, 2, & 3)
- Students understand histograms, parallel box plots, and scatterplots and use them to display data; (#1 & 3)

Develop and evaluate inferences and predictions that are based on data

- Students evaluate published reports that are based on data by examining the design of the study, the appropriateness of the data analysis, and the validity of conclusions; (#1 & 3)

Understand and apply basic concepts of probability

- Students understand the concepts of sample space and probability distribution and construct sample spaces and distributions in simple cases; (#3)
- Students use simulations to construct empirical probability distributions; (#3)



In all four activities the students are asked to perform the following standards: (unless otherwise noted)

Problem Solving

- Build new mathematical knowledge through problem solving
- Solve problems that arise in mathematics and in other contexts
- Apply and adapt a variety of appropriate strategies to solve problems
- Monitor and reflect on the process of mathematical problem solving

Reasoning and Proof

- Make and investigate mathematical conjectures (#3 & 4)

Communication

- Organize and consolidate their mathematical thinking through communication
- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others
- Analyze and evaluate the mathematical thinking and strategies of others
- Use the language of mathematics to express mathematical ideas precisely

Connections

- Recognize and use connections among mathematical ideas
- Understand how mathematical ideas interconnect and build on one another to produce a coherent whole
- Recognize and apply mathematics in contexts outside of mathematics

Representation

- Create and use representations to organize, record, and communicate mathematical ideas
- Select, apply, and translate among mathematical representations to solve problems
- Use representations to model and interpret physical, social, and mathematical phenomena

Resources and Web Links

- For more information on Swift, its instruments, and GRBs, see the Swift Education and Public Outreach web site:

<http://swift.sonoma.edu>

- This *GRB Educational Unit* as well as materials dealing with the electromagnetic spectrum can be found on the Swift E/PO web site at:

<http://swift.sonoma.edu/education/index.html>

- Imagine the Universe! has a nice introductory tutorial on gamma-ray bursts:

http://imagine.gsfc.nasa.gov/docs/science/known_11/history_gamma.html

... as well as supernovae (with a small amount of math):

http://imagine.gsfc.nasa.gov/docs/science/known_12/supernovae.html

- More information (with links) about gamma-ray astronomy is at the NASA Goddard Space Flight Center's website at

<http://www.gsfc.nasa.gov/gsfsc/spacesci/gamma/gamma.htm>

- A vast collection of (somewhat more technical) information on GRBs is

<http://www.mpe.mpg.de/~jcg/grb.html>

- An introduction to Galactic coordinates (as part of the Multi-wavelength Milky Way poster):

http://adc.gsfc.nasa.gov/mw/mmww_usemap.html

- A NASA tutorial on pulsars:

<http://science.nasa.gov/newhome/help/tutorials/pulsar.htm>

- The GRB Coordinates Network provides rapid-response information on the locations and follow up observations for GRBs detected by spacecraft, and can also provide automatic alerts to observers when GRBs are reported.

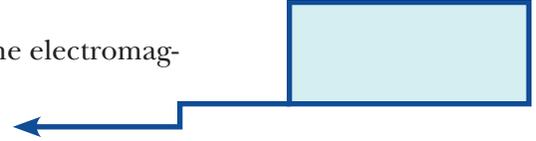
<http://gcn.gsfc.nasa.gov/>

- The Third Interplanetary Network maintains a list of GRBs that are detected by many spacecraft throughout the solar system. Information provided by spacecraft in this network are used to refine the GRB positions.

<http://ssl.berkeley.edu/ipn3/>

- The Swift E/PO team has also used GRBs as the centerpiece of a series of activities developed in partnership with the Great Explorations in Math and Science group at UC Berkeley's Lawrence Hall of Science. *The Invisible Universe: from Radio Waves to Gamma-rays* may be ordered through their web site at:

<http://www.lhs.berkeley.edu/GEMS/GEMS.html>



Questions, comments and concerns:
contact us at grb@swift.sonoma.edu