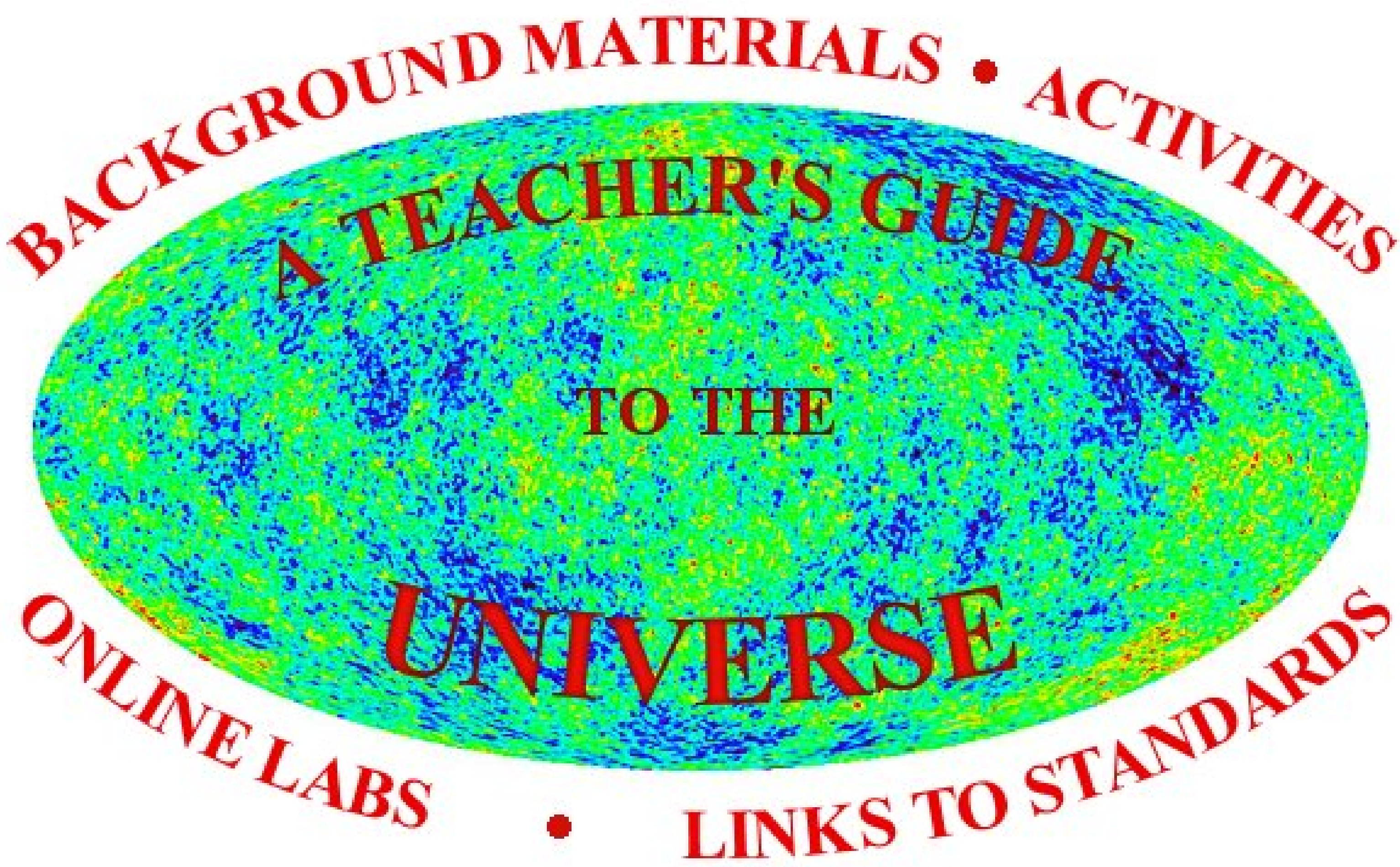
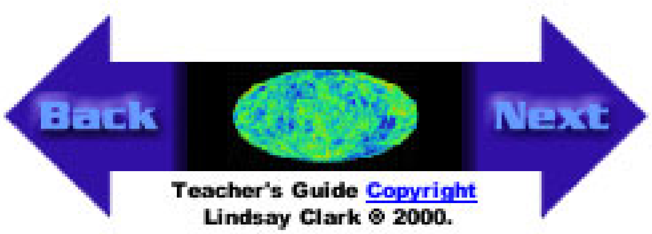
A Teacher's Guide to the Universe





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A Teacher's Guide To the Universe

An Introduction

This Web Page was designed for high school teachers, or educators of the same level, who are interested in teaching astronomy and cosmology to their students. The following lesson plans were designed over several months in collaboration with Professor David Spergel of the Department of Astrophysics of Princeton University and Dr. Margaret Fels, Center for Teaching and Learning at Princeton University, to enrich high school classrooms with astronomy lesson plans according to guidelines suggested by the Core Curriculum Content Standards of the State of New Jersey and by the National Science Education Standards.

This page is a work in progress and from time to time pages may be under construction. In addition, since the page is still under construction your comments are appreciated (To respond see below). Also, please note that credit has been given where appropriate on page footnote.html and can be viewed through links like this: #

The original motivation behind this site was the independent work of Lindsay Clark and was submitted to the Department of Astrophysics at Princeton University in partial fulfillment of the requirements for the degree of Bachelor of Arts. The full text of the thesis is available here, in pdf format. If you do not have Adobe Acrobat Reader, you can download it here.

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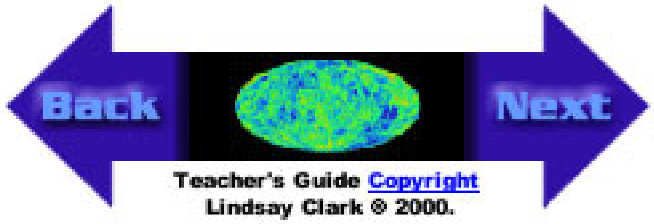

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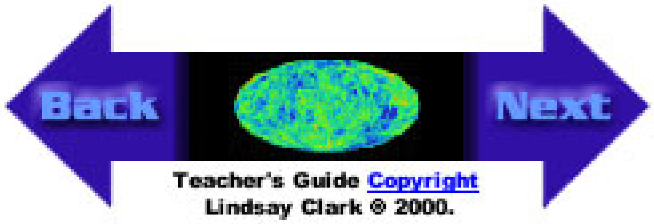

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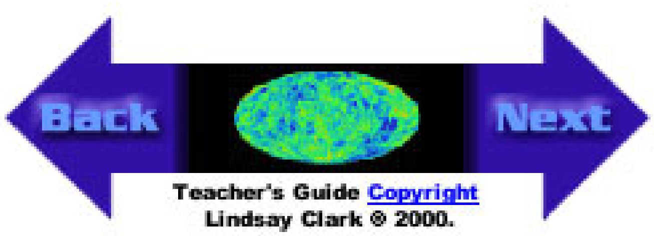
Introduction

The State Constitution of New Jersey stipulates that resident children receive a "Thorough and Efficient"[1] education. To that end, the state of New Jersey has created Core Curriculum Content Standards. The New Jersey Standards are meant to serve as guidelines for science education and to "define the results expected but do not limit district strategies for how to ensure that their students achieve these expectations" [2]. The Core Curriculum also defines an assessment standard which "will define the State high school's graduation requirements" [3]. This paper contains units designed to help teachers teach to their students the information required by the New Jersey Core Curriculum Content Standard 5.11: "All students will Gain an Understanding of the Origin, Evolution, and Structure of the Universe" [4] . The examples are written for high school teachers and therefore reference Progress Indicators 7-9 as a primary guidelines. The progress indicators for high school Astronomy as stated in the New Jersey Standards are : "7. Construct a model that accounts for the variation in the length of day and night. 8. Evaluate evidence that supports scientific theories of the origin of the universe. 9. Analyze benefits generated by the technology of space exploration" [5]. This paper concentrates on Indicator Eight, but many other Curriculum Content Standards can and will be incorporated into these exercises, according to the intention of the standards when they were created. Some examples of other standards that are used as guidelines are Cross-Content Workplace readiness standards 1-3, "1. All students will develop career planning and workplace readiness skills. 2. All students will use technology, information and other tools. 3. All students will use critical thinking, decision-making, and problem-solving skills" [6].

In addition to the Standards for education put in place by the State of New Jersey, National Science Education Standards describe a method of education based upon Scientific Inquiry, which is "more than 'science as process,' in which students learn such skills as observing, inferring, and experimenting. Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills" [7]. The units in this paper are written to promote this type of learning and teaching. They should not limit the activities of the teacher or student but should serve as a starting point for deeper scientific investigations according to the interest of the students.

Each of these units include Purpose, Backgrounds, and Activities. The Purpose section generally outlines the goals for several sequential lessons and indicates progress indicators used where appropriate. The Background sections include the basic information necessary to put the specific activity into context. These Background sections are not meant to serve as a complete resource for information for the student or teacher nor as the starting point for the lesson. For further information students should be encouraged to consult other resources including textbooks, web pages listed in the document and the informative sources listed in the Other Resources section which follow the units. The Activities themselves will appear in a box to offset them from the extra information.

This is a work in progress; some activities or background sections may refer to future lesson plans that are still under construction. In the future, activities which reference other web sites for information may be integrated into this text, along with figures and data needed for activities. In addition, the Other Resources section will be expanded to include more references in diverse media.



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The Size of the Universe

These activities are aligned with Indicators:

- National Science Education Standards
  - Teaching Standards A, B, C, D, E
  - Professional Development Standards A, B, D
  - Assessment Standards A, B, C, D, E
  - Content Standards, Unifying
  - Program Standards A, B, D
  - System Standard D
- New Jersey Core Curriculum Content Standard
  - Cross Content Workplace Readiness Standards 1, 2, 3, 4
  - Mathematics Standards 4.2, 4.4, 4.5, 4.6, 4.9, 4.10, 4.16
  - Science Standards 5.2, 5.5, 5.11

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Purpose

- To expand a comparison of the Earth and other planets in the solar system to larger building blocks of the universe including stars other than the Sun, galaxies and galaxy clusters, which builds on Indicator 4 of Science Standard 11.
- To improve the conception that the creation of units is arbitrary and should be used to suit the user's needs.

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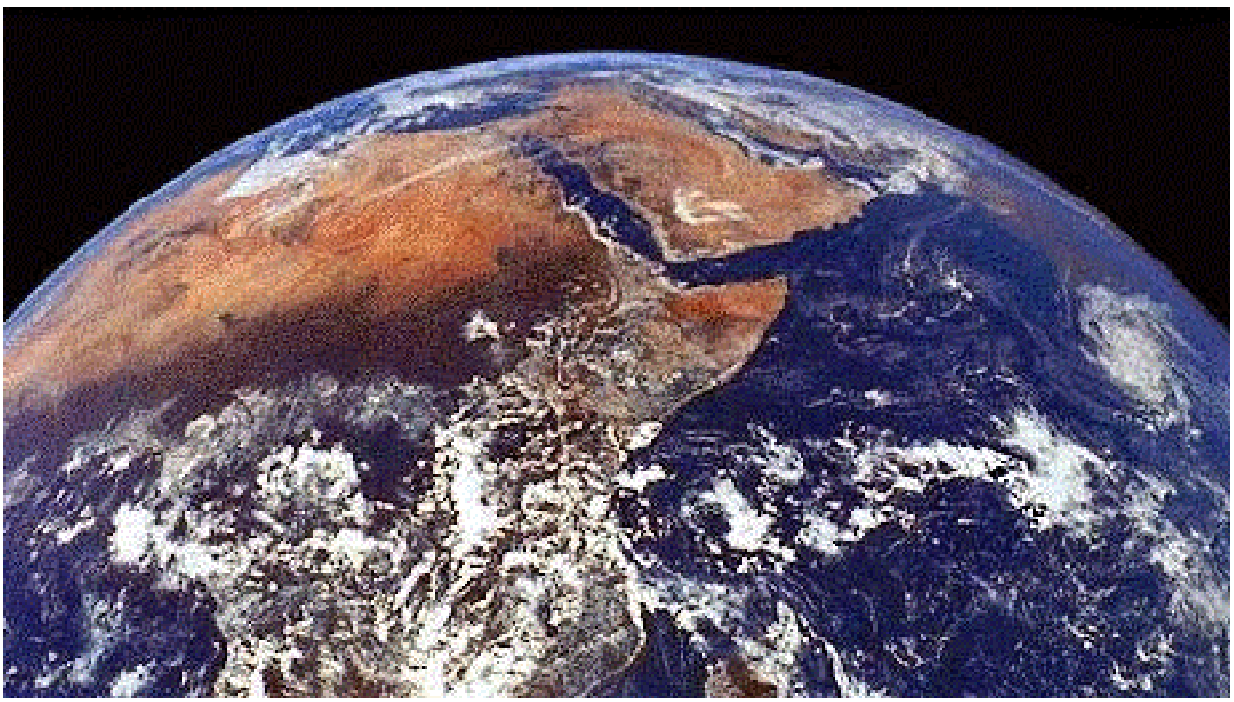
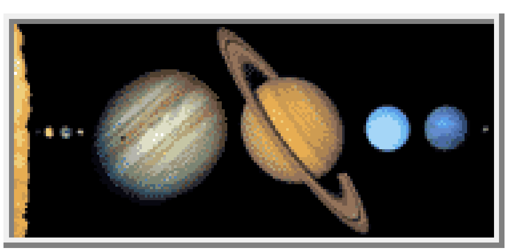
Introductory Background

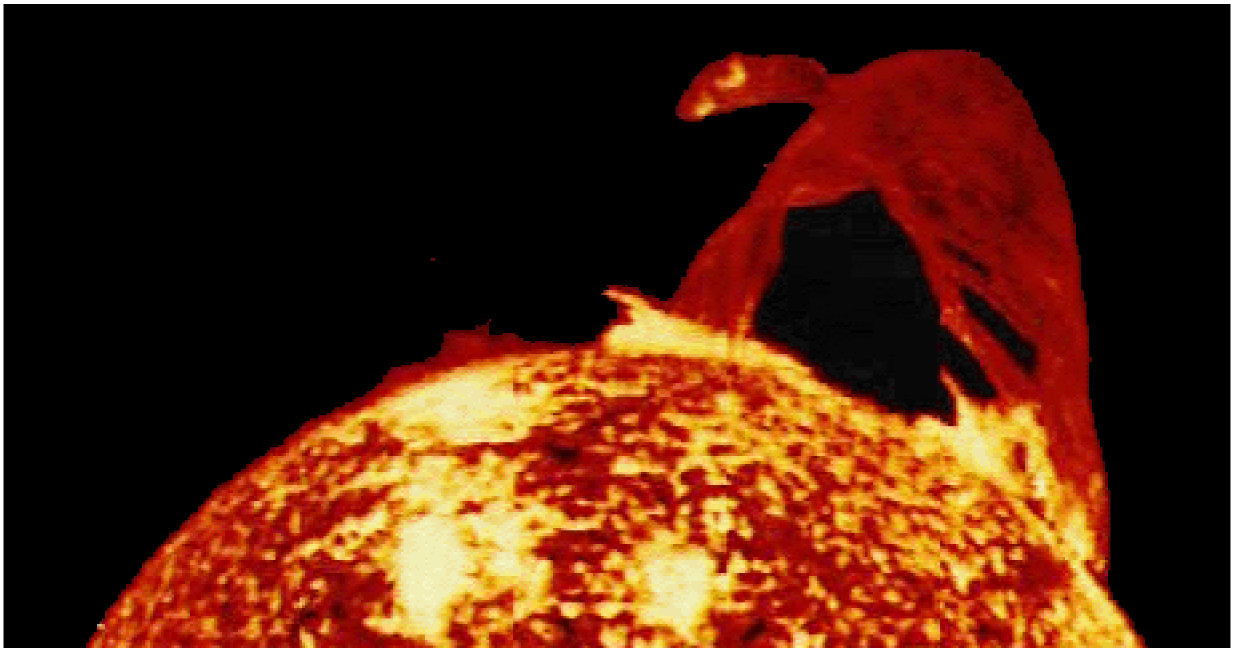
The Earth, our planet, 43



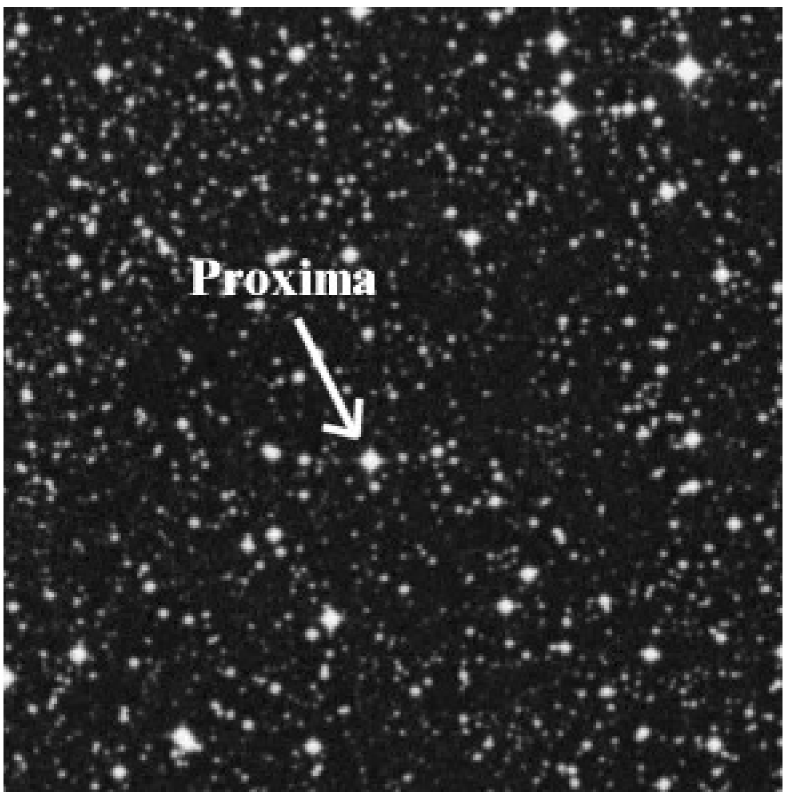
is part of the solar system that contains eight other planets 53



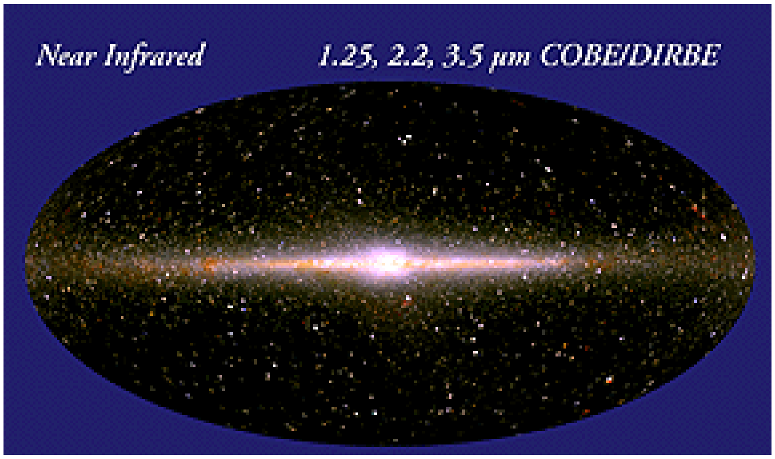
and the Sun 40.



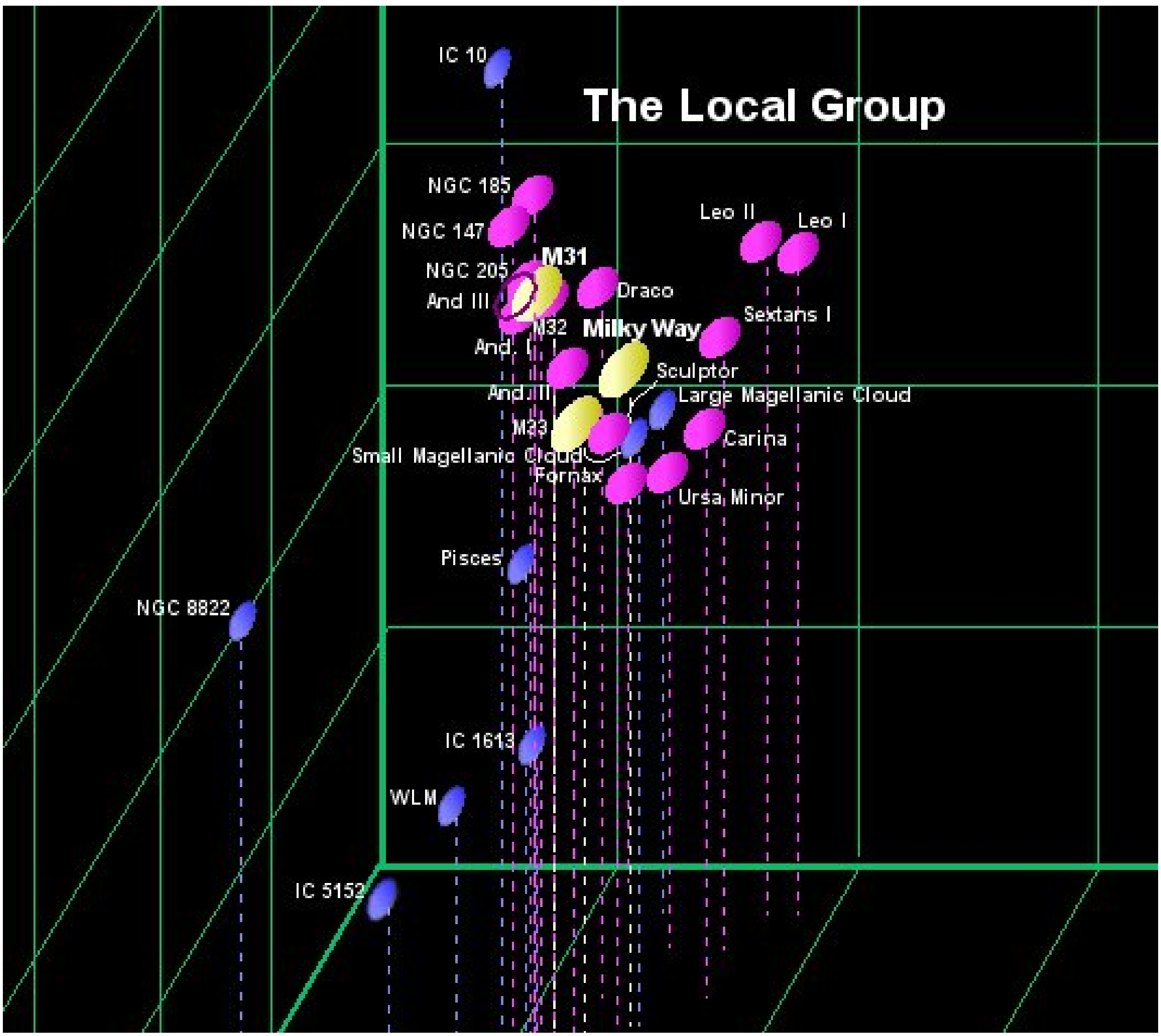
The Sun is a star and there are many others like it in the universe. The closest star to our own is called Proxima Centauri. 54

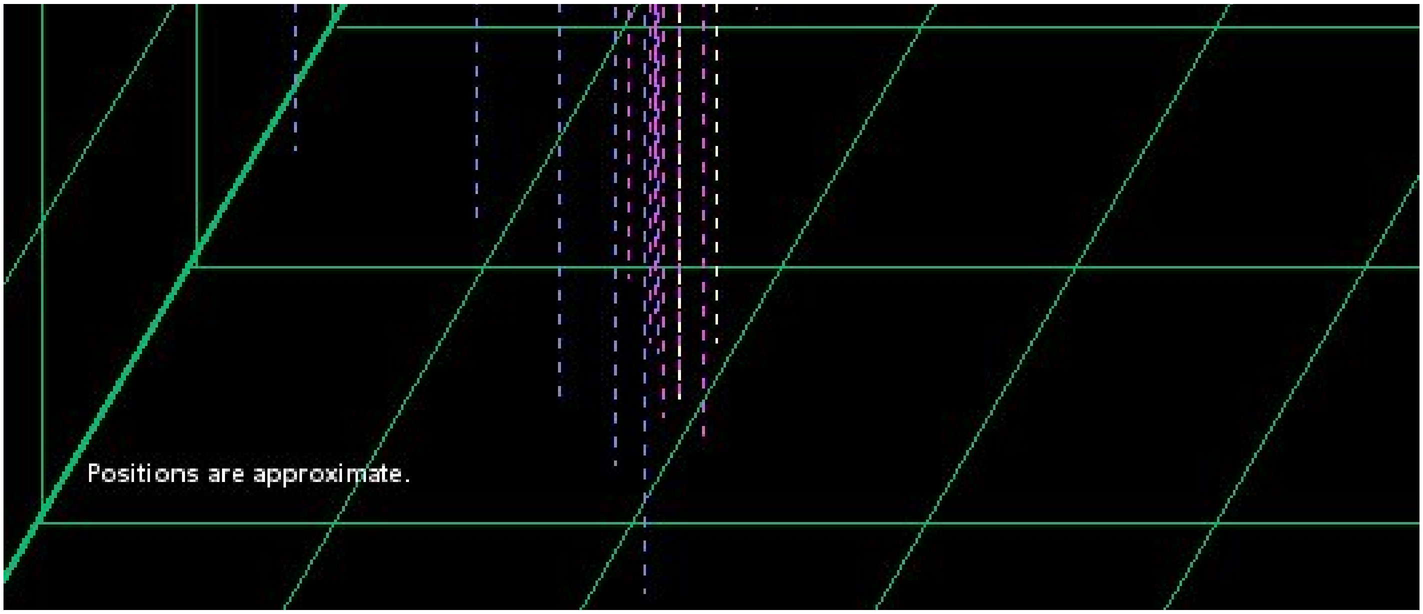


Together with approximately 10^{11} other stars they make up the Milky Way 52.



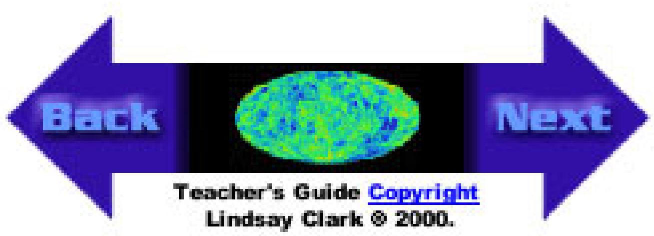
The Milky Way is one of about 10^9 galaxies in the visible universe. Galaxies cluster into groups; our group is labeled the Local Group and contains about 30 galaxies [8].





Clusters of galaxies also cluster forming Superclusters. The main force holding all of these systems together is gravity.

Each of these structures is formed out of smaller building blocks, so the higher the level of structure the bigger the structure gets. In other words, as you build a building out of bricks the building becomes bigger than the bricks. Cities become even bigger than the buildings that make it up. The size of astronomical building blocks is very large and sometimes becomes difficult to comprehend and measure with everyday units of measurement. Astronomers have created many more units of measurement for astronomical scaling. One of these units is called an Astronomical Unit (AU), the mean distance between the Earth and the Sun, 1.496×10^{11} km. Instead of using larger units like the AU, another way to make the size of the universe comprehensible is to scale the universe down to our everyday scientific units. Some models scale down to compare astronomical objects to the mass and radius of our Earth and Sun. Other models shrink the scale even further so that the diameter of our Sun is the size of a piece of fruit.



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Scaling Activity Introduction

We begin by creating a scaled-down map of the classroom to familiarize students with scaling and distance on a very familiar level. We continue by scaling the size of the solar system and continue this model out to the edge of the local group. Also, in another model the distance to the edge of the known universe is scaled to a comprehensible size by setting the distance between the Sun and the Earth to the thickness of a sheet of paper. It is presumed that students have some knowledge of the planets and workings of the solar system, and also a general idea of the scale of the solar system. This exercise builds on this knowledge and extends it to scale the universe including the nearest star to the Sun, the distance to the center of our galaxy, the diameter of the galaxy, the distance to the next galaxy, the diameter of the local group and the distance to the edge of the known universe.

Tables I, II & III, which are to be used in the activities which follow, show statistics of the planets in metric units, Earth units, and scaled units, respectively. The scaled units are calculated based upon scaling the diameter of the Sun to 3 inches. This convenient size is demonstratable in a large classroom, and also familiar to students as ordinary objects, like oranges or tennis balls. It also allows for conceivable scaled distances to astronomical objects. The first two tables are included mainly for reference and comparison, and to encourage familiarization with scientific units.

Table I. Astronomical Object Properties in metric units

	Mass (kg)	Equatorial Diameter (km)	Distance from Sun (10^6 km)	Rotation Period (days)	Orbital period (years)
Sun	1.99×10^{30}	1392000	0		
Mercury	3.30×10^{23}	4,878	58	59	0.241
Venus	4.87×10^{24}	12,100	108	243	0.615
Earth	5.98×10^{24}	12,756	150	1	1
Mars	6.42×10^{23}	6,786	228	1.03	1.88
Jupiter	1.90×10^{27}	142,984	778	0.4	11.86
Saturn	5.69×10^{26}	120,536	1427	0.4	29.46
Uranus	8.65×10^{25}	51,118	2871	0.7	84.01
Neptune	1.02×10^{26}	48,528	4497	0.6	164.79
Pluto	1.29×10^{22}	2,300	5914	6.4	247.69
Proxima Centauri			40500000		
Distance to Center of Galaxy			2.46717×10^{11}		
Diameter of Galaxy			9.25188×10^{11}		
Distance to Andromeda			2.15877×10^{13}		
Diameter of Local Group			3.08396×10^{13}		

Table II. Astronomical Object Properties in Earth Units (based on Earth mass and radius)

	Mass (M_e)	Equatorial Diameter (R_e)	Distance from Sun (AU)	Rotation Period (days)	Orbital period (years)
Sun	333333	10913	0		

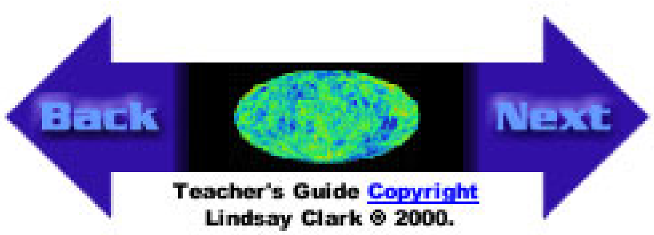
Mercury	0.06	0.38	0.39	59	0.241
Venus	0.81	0.95	0.72	243	0.615
Earth	1	1	1	1	1
Mars	0.11	0.53	1.52	1.03	1.88
Jupiter	317.94	11.21	5.2	0.4	11.86
Saturn	95.18	9.45	9.54	0.4	29.46
Uranus	14.53	4.01	19.19	0.7	84.01
Neptune	17.14	3.88	30.06	0.6	164.79
Pluto	0.002	0.18	39.53	6.4	247.69
Proxima Centauri			270000		
Distance to Center of Galaxy			1644.79		
Diameter of Galaxy			6167.92		
Distance to Andromeda			143918.13		
Diamter of Local Group			205597.33		

Table III. Astronomical Object Properties in Scaled Units (based upon scaling the radius of the Sun to 3 inches)

	Mass	Equatorial Diameter (Scaled Inches)	Distance from Sun (Scaled inches)	Rotation Period (days)	Orbital period (years)
				0	
Sun		3	0		
Mercury		0.01051	10.42ft.	59	0.241

Venus		0.02607	19.39ft.	243	0.615
Earth		0.02749	26.94ft.	1	1
Mars		0.01462	40.95ft.	1.03	1.88
Jupiter		0.30815	139.73ft.	0.4	11.86
Saturn		0.25977	256.28ft.	0.4	29.46
Uranus		0.11016	515.62ft.	0.7	84.01
Neptune		0.10458	807.65ft.	0.6	164.79
Pluto		0.00495	1062.14ft.	6.4	247.69
Proxima Centauri			1377.59 miles		
Distance to center of galaxy			8392001.92miles		
Diameter of galaxy			31470007.18miles		
Andromeda			734300167.6miles		
Diameter of Local Group			1049000239miles		

Because this exercise concentrates on distance scale, you may want to begin the lesson with an exercise demonstrating the relative masses and radii of the planets. For a good example of this comparison, consult the New Jersey Science Curriculum Framework in the list of learning activities for standard 11 under Planet Gravities. This exercise uses relative numbers of pennies in empty soda cans to represent the weight of a full soda can on other planets. The number of pennies in each can changes based upon how massive the particular planet is and how big its radius is.



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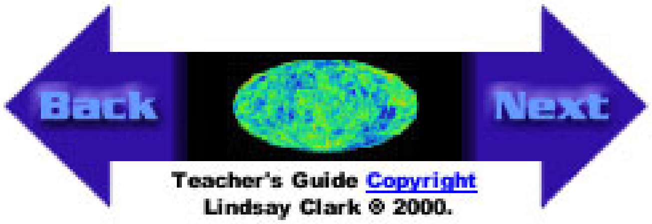
Activity: Mapping the Classroom

In order to gain a better understanding of the scale of the universe, it is helpful to begin by calculating the size and scale of something that is easily measurable. As a useful introductory exercise, map the classroom in two dimensions at different scales so that the skills of linear measurement, unit conversion and metric conversion are mastered before distances between objects become difficult to imagine. Divide the class into small groups. Give each group graph paper, rulers, pencils and construction paper. Ask each group to create a map of the room. Assign one or two people in each group to measure the dimensions of the room, the teacher's desk, the doorways and other objects in the classroom. Ask the students to pick a scale (as in one block on the graph paper equals one foot) and to draw the classroom on the paper. They should then create construction paper furniture and doors, also to their scale. It is sometimes useful to have two groups use the same scale so that they can compare the size of their "furniture." Ask the students whether the furniture in their map would "fit" in the maps of other students who have used the same scale. This question stresses the importance of consistency within scale. Then ask the students to create a smaller scale of their own maps. This project can be done in two ways: 1) by going back to the original measurements, or 2) by scaling down the current map scale. At this point, you can also ask the students to convert their scales from imperial (feet and inches) to metric (meters and centimeters) or vice versa. (The conversion factor is 2.54 centimeters to one inch.) This exercise will show the students that scaling is arbitrary, meaning that any scale can be chosen, but demonstrates that a convenient scale, such as 1 foot is equal for each graph paper block, will expedite their work. It also shows that scales can be changed at will, as long as they are changed consistently. If this activity is completed, the maps should be saved; as described in a later activity, they can be used to depict the expanding universe.



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Activity: Mapping the Earth-Moon System

To begin this activity, scale the Earth to 16 inches. Many globes come in this size, especially the inflatable beach ball kind sold in many Nature stores. Once students understand that the size of the Earth as represented by the globe requires the use of scale, ask a student to guess the size of the moon compared to a 16 inch globe. Blow up a balloon to that estimated size of the moon. Ask another student to guess the distance at which the moon orbits the Earth at this scale. Place this balloon at that estimated distance from the globe. Then, to show the correct scaling of the Earth-Moon system when the Earth is 16 inches in diameter, blow up another balloon to 4.4 inches and place it at a distance 40.2 feet. Students are usually amazed at this scaling and are amazed even further when the Sun is also scaled. The size of the Sun at this scaling is 145.5 feet and the scaled distance is 15,700 feet, nearly 3 miles. (It is usually helpful to pick a local landmark three miles away to illustrate this distance).

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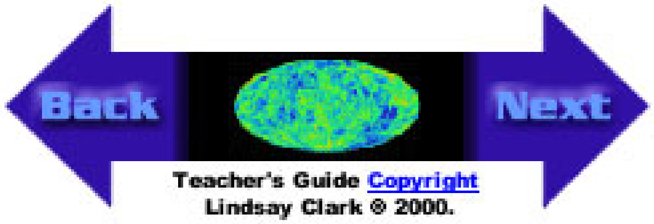
Mapping the Solar System and Nearest Star

Now impress the students further by shrinking the Sun's scaled size down to 3 inches, or about the size of an orange. Depending on the amount of time you want to spend on this activity, you may either present the students with the 3 inch model of the Sun and ask them to guess the size of each of the planets, or present objects that are the scaled sizes of Jupiter and Saturn and ask the students which planets they think these might represent. Objects that are good sizes for Jupiter and Saturn are popcorn kernels. (Saturn is about as big as Jupiter with its rings.) Other helpful sizes: .01 inches is about the size of a grain of sand; .1 inches is the thickness of a pencil point. Have the students calculate the scaled sizes of and distances to each of the planets. This can be done in small groups, with each group concentrating on one planet. Then have the students pace out the distance between the planets. (A football field is the best place to go.) Have the students spot inconsistencies in their calculations if mistakes are made. For example, demonstrate the problems that arise if they calculate Jupiter's orbit inside the Earth's. It is important to explain, however, that the planets do not always line up in a straight line, but orbit around the Sun. Use the Orbital and Rotation period data from Table III to explain the positions of the planets at any one time. Another remarkable concept to point out is that we can see the planets from Earth despite these distances. Once the distance to Pluto is discussed, mention (or have the students calculate) the distance to the nearest star. The distance in this scale to Proxima Centauri, the nearest star, is 1400 miles: about the distance from Trenton to Oklahoma City. Proxima Centauri is about one-tenth the size of the Sun, in this scale about .3 inches. Ask the students to imagine holding out a raisin to a friend in Oklahoma City and having them be able to see it. Explain that this extraordinary visibility is possible because stars are so incredibly bright.



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And Beyond!

Once we move past the nearest star, even the 3-inch Sun model becomes too large for us to conceive, so we choose a different scale. This time, imagine that the distance between the Sun and Earth is the thickness of a sheet of paper, instead of the 27 feet as in the last model. Have the students figure out the distances in this scale by measuring a ream of paper. They should conclude that the distance to the nearest star is scaled to a stack of paper 71 feet high, that the diameter of the Milky Way would be represented by a stack 310 miles high, and that the nearest galaxy would be scaled to over 6000 miles. The most astonishing calculation is that according to our best estimates of the edge of the known universe, the paper stack would reach 31 million miles high . . . or about one-third of the way to the Sun in real distance! [9]

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Introduction: Mapping in Time

Astronomers have another unique way of scaling the universe. Sometimes, distances get so large that even scaling based upon the distance between the Earth and Sun, or even Pluto and the Sun becomes inconceivable. Instead, astronomers use light to measure distance. They can do this because light travels at a finite speed, not instantaneously as it may seems to us as we turn on the light in a room. It appears to us that light hits everywhere in a room at the same time, but in reality, it hits the far corners slightly after the front corners. However, the light moves so quickly, and the difference in time is so small between the lighting of the front and back corners, that we do not notice the discrepancy. When you make the "room" big enough, the difference in time between lighting the front and back gets larger and it takes a conceivable amount of time to travel from one end of the room to the other. If you make this "room" big enough, the light would have to travel a whole year before it lit the back wall. Astronomers call the length of this "room" a light-year because it is the distance that light can travel in one year. This distance is 9.4608 x 10^{12}km. This distance provides a useful scale for an astronomer because not only is it large enough to measure the distances required by astronomers, but it also introduces time into the scale.

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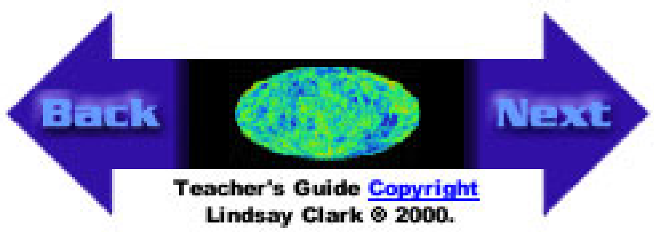
Activity: Finite Wave Speed

An easy and effective everyday way to experience the finite speed of light is in an analogy to sound. Sound is also a type of wave with finite speed. The speed that a sound wave travels is, however, much slower than the speed at which light waves travel. For this reason it is much more easily measured by humans. Take students to a large field with pencils, paper, stopwatches and walkie-talkies if available. The other important equipment includes something which makes a loud noise, some examples include air horns, starter pistol, or even a car horn. First have students measure out the distance between the noise-making item and their position on the field; they should try to be as far away as possible but 300 meters at least. While you stand at the far end of the field with the noise making device have the students stand at the far end of the field with stopwatches and recording devices. If you have walkie-talkies, give one to a student and keep one yourself. Turn on the walkie-talkies. If you don't have walkiee-talkies work out a system before hand with your students so that there is a visual signal which indicates that the sound wave has been started. Simultaneously, give the signal and make the sound. Students should start stop watches when the first signal is given and stop them when they hear the sound. If you have walkie-talkies the time between the sound over the walkie talkie and the sound through the air should be measured. The more times this is measured the less likely that individual differences in measurement will throw off the calculation. It also may take students a few practice measurements to get the hang of the stopwatch. From their data have the students calculate the speed of sound. The approximate speed of sound in air under "normal" conditions is about 340 m/s, but this is very dependant upon the temperature and humidity of the air. Discuss the variability of the speed with the students, but as with their scaling projects it is not so important that their answers be "right" so much as consistent. There is no measurement of the air on that field on that day at that temperature more accurate than their own. Therefore the answers they get, if they are confident in their measurements, are right. In addition, have them suggest ways that their measurements could be improved and in what ways the accuracy of their experiments are limited, for example the limitation of human reaction time.

The main source of information that astronomers can collect from the universe is electromagnetic radiation. Loosely speaking, this information is all light. All the information available to astronomers travels from distant galaxies and other objects at the speed of light, 3×10^8 meters/second, to Earth, where it is received. Because the objects studied by the astronomers study are so far away, the light these objects emit takes minutes, days or even years to reach the Earth. For example, the Sun is about eight light minutes away. That means that the light emitted by the Sun travels at 3×10^8 meters per second for eight minutes before it hits the Earth. When that light is collected on the Earth by astronomers with a telescope or in a photograph, they receive the light that the Sun emitted eight minutes ago. They are actually seeing the Sun as it was eight minutes in the past! If they wait eight more minutes, they will see the Sun as it was when they took the first photograph. With objects that are much farther away, the light takes longer to reach the Earth and therefore we can see further into the past.



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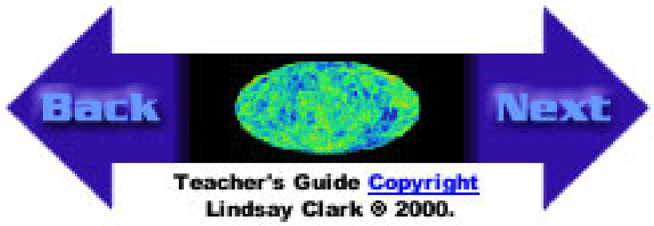
Activity: Mapping in Time

Have the students imagine that they are sitting on each of a few planets, the Sun, the nearest star, the edge of the galaxy, the Andromeda Galaxy, and the edge of the Local Group. Have them imagine that they are looking towards the Earth and can see into their classroom. Have them figure out what they would see. This involves calculating the distance in light years, understanding that in astronomy looking out in space also means looking back in time, and creativity to imagine the classroom as it was in the past. Table IV lists distances to the astronomical objects listed above, in light units.

Table IV. Astronomical Object Distances from Earth in Light Units.

	Distance from Earth in Light Units
Mars	4.3 light minutes
Jupiter	34.8 light minutes
Pluto	5.33 light hours
Sun	8.3 light minutes
Distance to Center of Galaxy	26065 light years
Proxima Centauri	4.28 light years
Andromeda Galaxy	2283105 light years
Edge of Local Group	3253424 light years

In order to imagine these time scales, it is helpful to have some chronological references: 3 million yeas ago "Lucy"- like bipedal beings roamed the Earth; 2 million years ago, human predecessors had begun using tools; 26,000 years ago, *Homo sapiens* were joined by *H. sapiens sapiens*, or modern man, anatomically indistinguishable from modern humans; four years ago, an older sibling of a student may have been in the class.



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Introduction: Scaling in Density

Once students have a sense of how far away things are in the universe in one dimension, as in the previous activities, it is useful to increase dimensional understanding to include three dimensions. The easiest way to do this is to examine volume and mass in the form of density in different locations and over different volumes throughout the universe.

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Activity: Scaling in Density

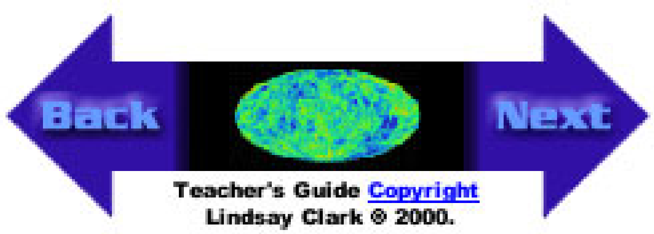
Begin with water, because it is a familiar substance and a useful metric for density. Table 5 lists various estimates for densities throughout the universe. To gain a better understanding of these densities, students can compare the number of water molecules in a cubic meter (or centimeter) for each density.

Table V. Average Densities of Objects in the Universe.

	Density	Number of Water Molecules per cubic metric unit
Water	1 gram/cm^3	3.345 x 10^{22} molecules per cm^3
Rock	2.67 gram/cm^3	8.9 x 10^{22} molecules per cm^3
Earth	5.5 gram/cm^3	1.8 x 10^{23} molecules per cm^3
Sun	1.4 gram/cm^3	4.683 x 10^{22} molecules per cm^3
Jupiter	1.33 gram/cm^3	4.45 x 10^{22} molecules per cm^3
Solar System	2 x 10^{-12} gram/cm^3	7 x 10^{10} molecules per cm^3
Molecular Clouds	2 x 10^{-22} gram/cm^3	10 molecules per cm^3
Milky Way Galaxy	6 x 10^{-23} gram/cm^3	2 molecules per cm^3
Local Group	7 x 10^{-37} gram/cm^3	24 molecules per **km^3**
Critical Density of the Universe	1 x 10^{-29} gram/cm^3	1/3 molecule per **m^3**

Certain calculations have been made using only lower limits for mass calculation, making the density calculations also lower limits. Other evidence has suggested that this is a lower limit for the mass calculation for most of the universe. However, astronomers to this day are uncertain of the explanation for this evidence that suggests the mass of the universe is ten times greater than the mass we can see in the form of stars and dust. For more information on this subject, called dark matter, see http://map.gsfc.nasa.gov/html/outreach.html.

Overall, students should begin to understand although we live in a place that is particularly dense, most of the universe is not like Earth. Matter tends to clump together, even on the largest scales of the universe that we know today. This leaves quite a bit of empty space in the universe. This empty space becomes notable once the jump is made from the solar system to molecular clouds. The molecular clouds are simply dust clouds which eventually break up and condense to form stars. The last line in the table is the Critical density of the Universe. What this means will become more clear after studying the Big Bang and expanding universe, but in a nut shell, the critical density is the density that is needed in the universe to make it stop expanding and collapse on itself due to gravity. With current data, it does not appear that the universe is dense enough on the whole to collapse. Astronomers, however, will still actively study the possibility of collapse until enough data is collected to accurately determine the density of the universe.



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Basis for Distance Measurement

Once students have a better understanding of the scale of the universe, they may begin to wonder how astronomers have measured the distances to such far away objects. Astronomers have built up a series of distance measures called a distance ladder, the first few steps of which are possible to demonstrate within the classroom.

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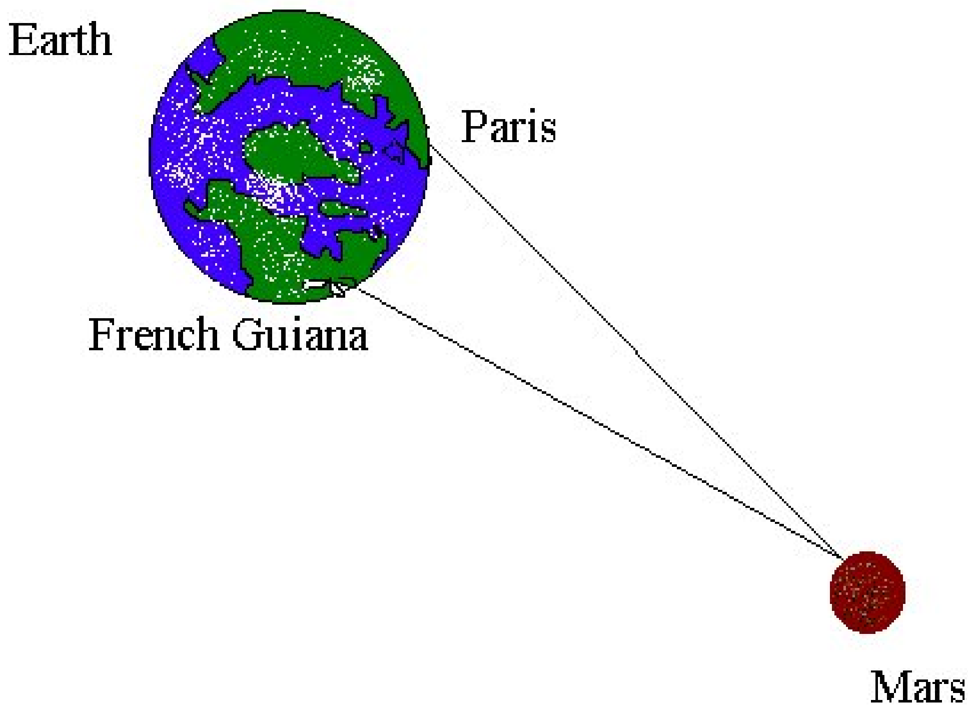
Background: Parallax

The first step on the distance ladder is called parallax. The easiest way to see parallax is to hold out your finger vertically in front of a background object, a door or wall for example. Shut your right eye and note where on the background object the image of your finger appears. Now open your right eye and close the left one without moving your finger. The image of your finger should appear to have jumped to a different spot on the background wall. It is possible to tell how far away your finger is from your eyes just by measuring the distance between your eyes and the distance that the image appeared to move in degrees of arc. Technically, the parallax of an object, measured in arc seconds, is the reciprocal of the distance measured in parsecs between that object and the observer. This can be converted into a distance measured in meters by the equivalence: 1 parsec = 3.086×10^{16} m. In other words, a star that is 2 parsecs away appears to shift 1/2 arc second on the sky.

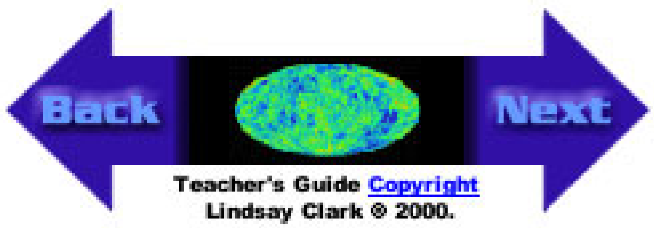
Historically, parallax has helped make some important astronomical measurements. When determining the distances between planets and their relative sizes, early astronomers had difficulty making precise measurements. It was easier for them to make relative measurements, basing the measurements on the distance between the earth and the sun which they called 1 Astronomical Unit. This relative measurement was helpful, but still needed to be calibrated so that actual distances could be calculated. This calibration was first done by astronomer Giovanni Cassini in 1673. Cassini knew that parallax was an effective means to calculate distance and he also knew how sensitive to the size of the baseline the measurement was. Using the previous example, Cassini knew that by increasing the distance between his two measurements (effectively increasing the space between his "eyes") he could get a larger parallax angle which is easier to measure. For this reason in order to measure the appearance of mars at its closest approach he sent his fellow astronomer, Jean Richer, to French

Guiana to make measurements while he stayed in Paris thereby increasing the distance between his "eyes" to several thousand kilometers. Using triangulation, Cassini was able to make a measurement of the distance to Mars. He calculated a distance of about 140 million kilometers which was only off by 7% of today's accepted value of 150 million kilometers.



Cassini was able to make his measurements against a background of stars which did not appear to move. This was fortunate for him, because otherwise he would not have been able to notice a change in position of mars. However, the fact that the "background" stars did not appear to move troubled earlier astronomers. The reason they did not appear to move is that their distance was so great that even increasing the distance between measurements to the diameter of the earths orbit (which is possible by making a measurement in June and December for instance) did not appear to change the stars position. To easily see this effect, try moving your finger from arms length in front of your face to right in front of you nose. The distance that your finger appears to jump should have increased dramatically when compared with the distance it appears to jump at arms length. Now imagine you could stretch your arm to twice its own length. Your finger would now appear to jump even less against the background. Now imagine stars that are very far away, even if you moved a great deal between measurements they would still seem to move very little, in fact perhaps so little that they wouldn't appear to move at all. Early astronomers, like Tycho Brahe for example, refused to accept that the earth travelled around the sun because they knew that the stars would show parallax as the earth orbited. What they did not yet understand was that the stars were so far away that they would be unable to measure the parallactic shift. 10

To see the effects of parallax in the classroom see the parallax activity on the next page.



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Activity: Parallax

For this activity you will need:

- A stick(a meter stick is best), protractor, safety pin and 2 coffee straws (preferably with red stripes on the sides) for every lab group.
- Masking tape
- 1 Additional Meter Stick
- Large Room with chalk board on at least 1 wall
- Some stiff clay

Directions for Teachers:

1. Have the students construct an astrolabe out of 1 protractor, two straws, a safety pin, some modeling clay and a (meter) stick. This is done by gently pressing the point of the safety pin through each of the two straws very close to one end of each straw making sure the pin enters and exits through the red lines if your straws have them. The pin should act as a pivot for the two straws. Aligning the straws on the red lines assures that the straw is centered and will help with measuring the small angles later on. Now have the students place a small (1cm diameter) ball of clay onto the underneath side of the origin hole of the protractor. Now push the open safety pin through the hole of the protractor and clay fastening it on the "wrong" side of the protractor. The two straws should move freely one on top of the other. Now attach securely with masking tape the protractor to the middle of the (meter) stick. The (meter) stick should extend the baseline of the protractor.

The (meter) stick will have to rest slightly to the curved side of the protractor since the safety pin will need to move slightly. The purpose of this attachment is so that the students can make sure their protractor aligns with their baseline for measurement.

2. Place a meter stick vertically from the floor about 5-10 ft from the chalk board so that the top is eye level. Taping it to a chair is an easy way to accomplish this. This is your "planet" and the chalkboard represents the background stars.

3. Have the students spread out around the room and create different sized base lines by placing tape on the floor. The baselines should be as close to parallel as possible to the chalk board without detailed measurement. Have them range in size from about a foot to a few meters.

4. Have the students record the relative positions and baseline sizes of the groups around them. This will be useful to determine relative accuracies.

5. Have the first partner stand in the middle of their taped baseline and have the second student record the length of the baseline and the distance between the first partner's eyes.

6. Have the first student close his or her right eye and direct the second student to mark a spot on the board where he or she sees the image of the meter stick with his or her left eye.

7. Now, have the student switch eyes so that the left eye is closed and the right eye is open. Have the first student direct the second student to make another mark on the board where he or she sees the image of the meter stick with the right eye.

8. Without moving, the first student should then measure the angle between the two marks on the board using the astrolabe. It is very important that the protractor is parallel to the board. For this reason, have the second partner make sure that the stick which extends the protractor is directly over the baseline as the first student makes their measurement.

9. Have the first student line up one mark in each of the pivoting straws with the right eye while making sure the protractor is parallel to the board. Once the straws are lined up hold the straws in place and turn the protractor over to read the position of each straw. If you have straws with red lines, read the position of each red line (this is the center of each straw.)

10. This first measurement is very difficult to make accurately, however, the measurement greatly improves once the baseline size is increased.

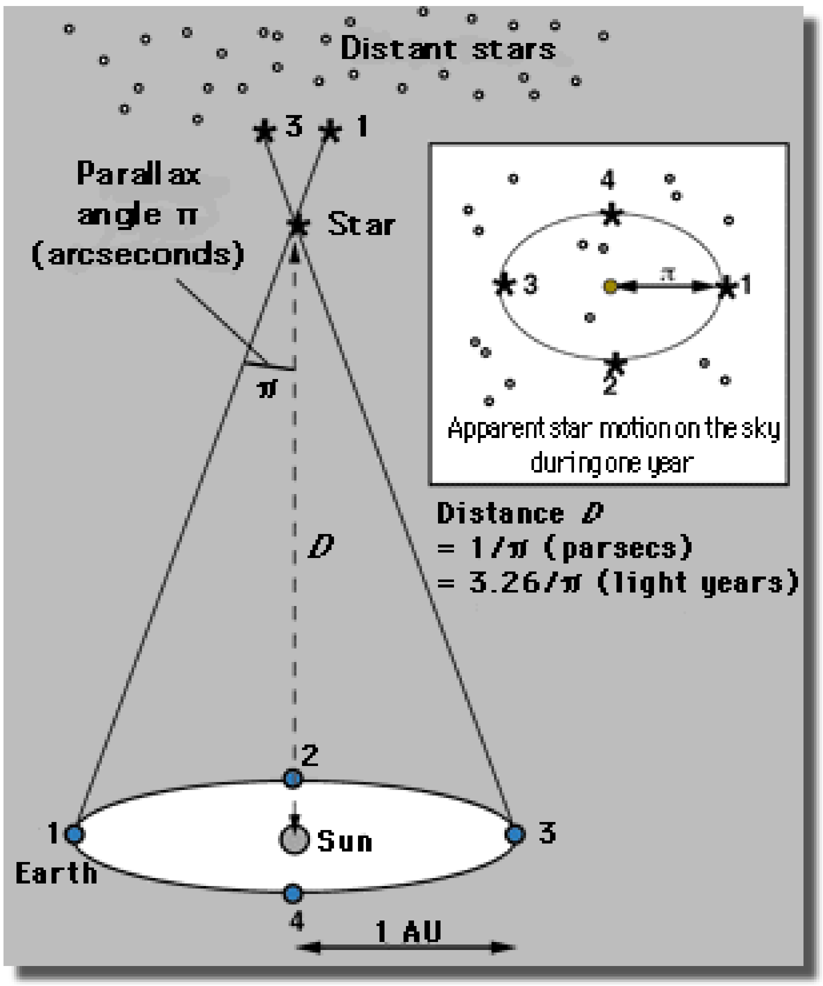
11. Repeat steps 5-9, Only this time increase the size of baseline from the distance between the eyes to the entire taped baseline. Partner roles may be switched at this time.

12. Have students calculate their distances from the meter stick using trigonometry.

Student& data should be recorded and presented in group format for two reasons; so that error analysis can be discussed and so that students notice that measurements can be made from any location. Students should also note that the further the observer from the meter stick the smaller the measured angle. In fact, some students may not notice any change in angle at all. This fact is also important as it shows the limits to parallax measurement. These students should be encouraged to find a way to measure the meter stick's parallax at that distance, i.e. allow the observer to make left and right eye observations a few feet right and left of their baseline. Students should not be allowed to directly measure the distance between their point of observation and the meter stick, since this is not possible for astronomers measuring the distance to stars. Instead, students should be encouraged to reason out the accuracy of their results, perhaps by comparing their results to those of students who observed farther away from and closer to the meter stick and making sure the results are consistent.

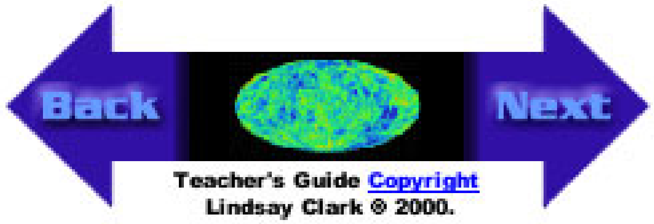
One might wonder why parallax measurement is useful since it is certainly easier to measure the distance to the meter stick directly than with parallax. Unfortunately, since the nearest star is 4.3 light-years away, astronomers cannot actually measure the distance to the star in the same way we can measure small distances and for this reason parallax becomes useful.

Parallax can be used to measure the distance to nearby stars since they can be measured against background stars, which do not appear to move as far, or in fact at all, due to parallax since they are so far away. This is because, as the students will have discovered during the activity, the farther from the "star" they are, the smaller the measured angle is on the background. After a star is far enough away, the angle is so small that even if telescopes were on opposite sides of the Earth they would not be able to measure the angle. In this case, the astronomers use the orbit of the Earth to increase the distance between right and left measurements. This is illustrated in the following diagram:



Parallax Diagram 11

This diagram shows three observations that are taken at three different times during Earth's orbit to measure the parallax of a nearby star against three background objects: a spiral galaxy 12, an elliptical galaxy 13 and a barred spiral galaxy 14.



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Another Parallax Activity

Have the students repeat parallax calculations using the data from the chart above so that they see how parallax measurement is usually used in astronomy. In actual measurements, the angles are measured on photographic plates taken at intervals along the Earth's orbit. Have the students assume the three measurements were taken each a quarter year apart, to facilitate measuring the distances between observations. For reference, 1 A.U., the distance from the Earth to the Sun, is 1.496×10^{11} m and one parsec = 3.086×10^{16} m.

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Other Resources for Measuring Parallax

Unfortunately, this technique is limited by the size of the Earth's orbit and also by the Earth's atmosphere which blurs any parallax less than 1/50 arc second [15]. So, for stars more than 50 parsecs away another method of distance measurement is needed.

Some Modern day experiments avoid these problems by sending satellites into space to measure parallax. This makes the orbit slightly larger and eliminates much of the atmospheric blurring. Two such projects are the HIPPARCOS satellite (http://astro.estec.esa.nl/SA-general/Projects/Hipparcos/hipparcos.html) and the SIM mission (http://huey.jpl.nasa.gov/sim/).

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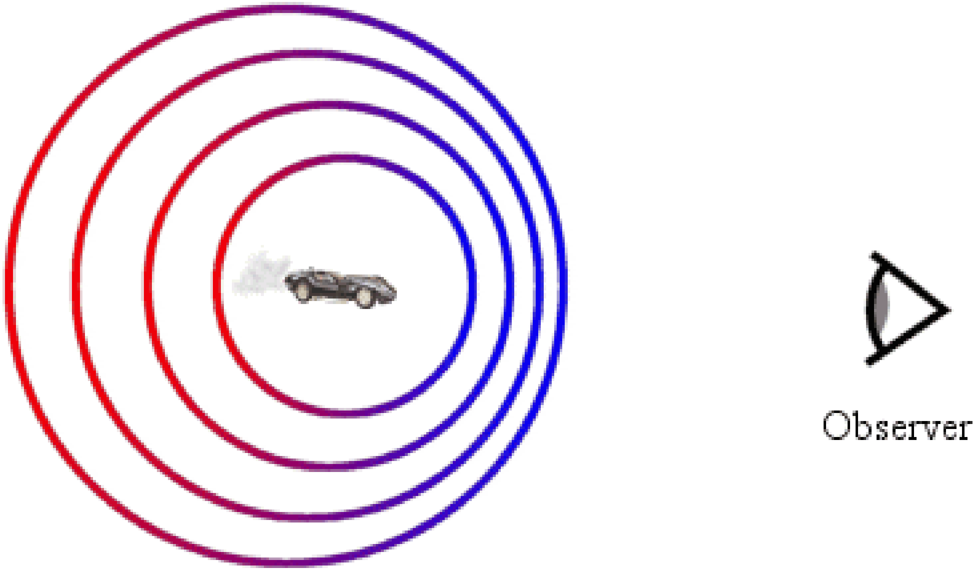
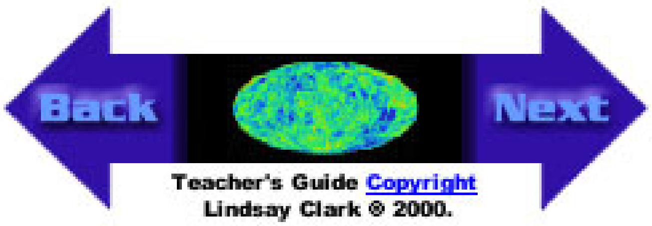
Background: Red Shift

A method of distance measurement which reaches much farther than parallax is red shift measurement. People can experience red shift everyday, not only as part of an astronomical phenomenon, but as a related effect called Doppler Shift. Doppler Shift occurs anytime a wave is created by a moving object. For example, when a car is moving down the road and honks its horn, a person standing on the side of the road hears a noise which starts out high pitched and grows lower in pitch as the car passes. Even children notice this effect and often make appropriate noises when playing with toy cars and planes (For an example of how this sounds see http://physics7.berkeley.edu/darkmat/dopplershift.html and click "vroom") The pitch changes because the sound waves pile up upon one another in the direction that the car is moving, causing the frequency of the wave to be higher. This is represented in the following diagram. As the car moves away from the observer the sound waves are stretched out which causes a lowering in pitch.

Doppler Shift


Observer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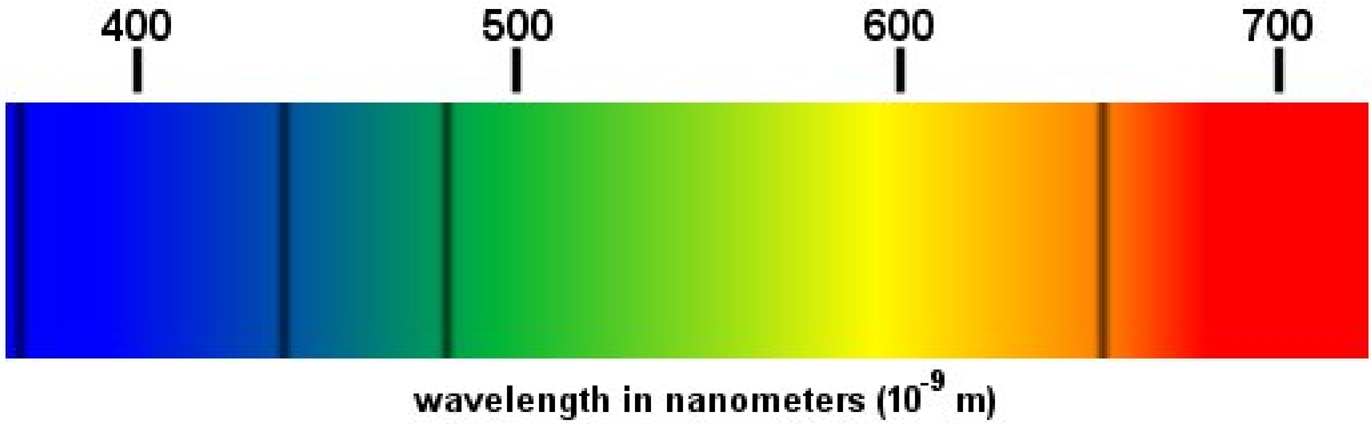
Activity: Everyday Doppler Shift

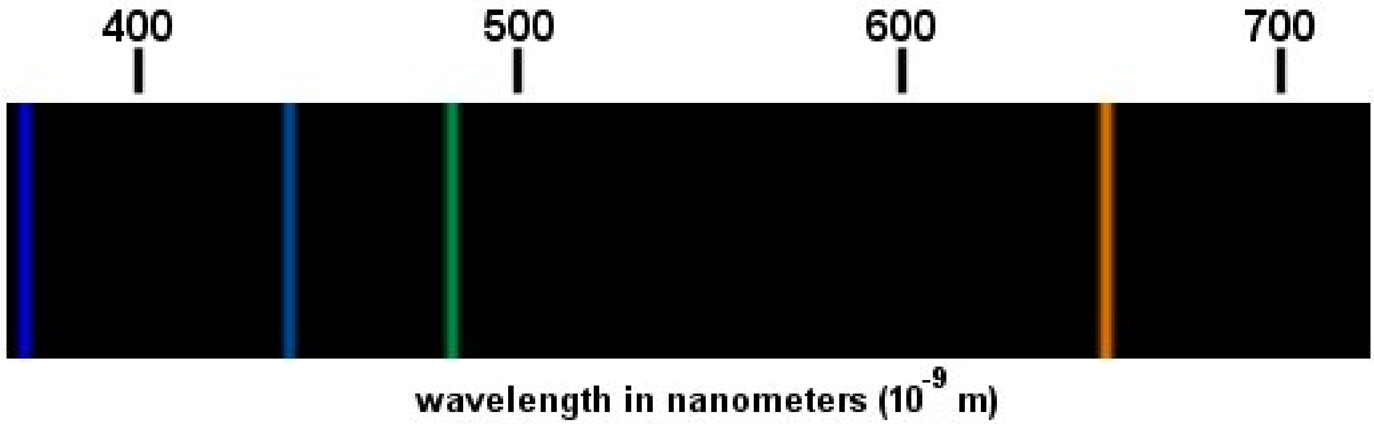
For a simple outdoor activity which analyzes everyday Doppler Shift devised by Kara C. Granger see **http://www2.smart.net/~ksmale/astrocappella/dopp_lp.html**.

Fortunately for astronomers, the information that they receive from stars in space is in the form of *electromagnetic radiation* [17], which is a fancy word for what people experience as light. Like sound, light changes "pitch" when the object that emits it moves towards the observer. This change in "pitch" is actually a change in color, so that as a star, moves towards an observer, the light it emits becomes bluer and as it moves away from the observer it becomes redder. This change in color is called a "shift": a "blue shift" when the object is moving towards the observer, a "red shift" when the object is moving away. In order to explain why this is called a shift, we must look at a spectrum. A common example of a spectrum is the rainbow that comes out of a prism, in which the white light spreads out into a rainbow so that we can see each color. Similarly, the light emitted by a star can be split into component colors so that we can examine each part. Each star has a specific set of features, like swirls or loops in finger prints, that occur at certain *wavelength* (colors). These features are unique to each star. When the spectrum is shifted, however, the features appear to the right or left of their expected location depending whether the shift is red or blue.

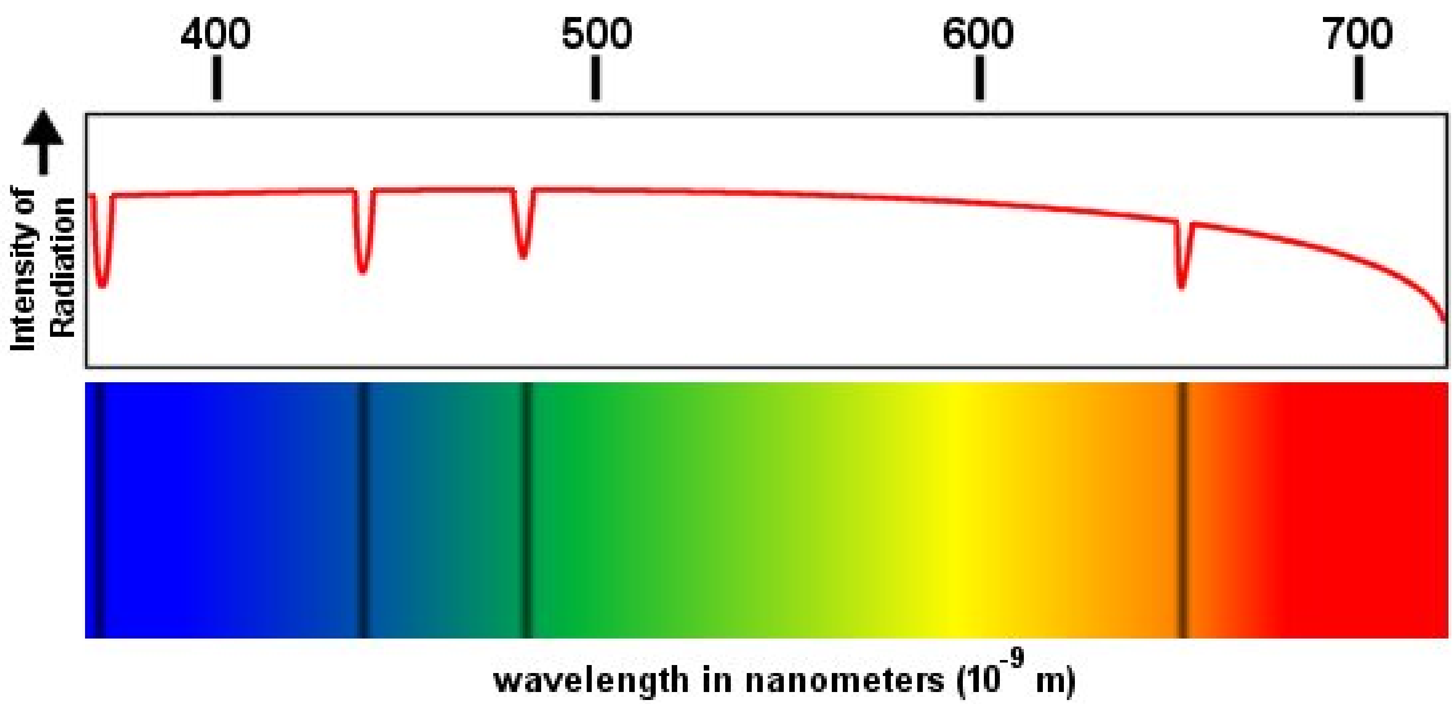
There are several different ways in which a spectrum can be represented. The Absorption Line Spectrum looks like a rainbow in which the "features" appear as black lines at certain frequencies. In the Emission Line Spectrum, the features appear in color and the rest is dark. The Spectral Line diagram is a sort of squiggly line that shows the amount of energy at each particular wavelength. Here are examples of each of these types of spectra:



Absorption lines



Emission Lines



Spectral Lines and how they correspond to Absorption lines

These spectral diagrams may be complicated but once a student understands electromagnetic radiation and the spectrum it produces, a red shift of this spectrum can easily be used to measure distances. For an online introduction to light and spectrum in astronomic measurement see http://violet.pha.jhu.edu/~wpb/spectroscopy/spec_home.html.

As mentioned above, the red shift occurs when the light emitting object is moving away from the observer; in this case, the star is moving away from Earth. A famous astronomer, Edwin Hubble (for whom the Hubble Space Telescope is named), discovered [21] that the red shift is related to the distance that the moving object is from the observer in the following way:

$$\frac{Red\ Shift \times Speed\ of\ Light}{Hubble\ Constant} = Distance$$ [22].

To calculate the red shift, one must measure the distance that the spectrum has been shifted. Usually this is done by comparing the observed spectrum to one a standard. The formula for red shift is:

$$Red\ Shift = \frac{The\ shift\ in\ wavelength}{The\ original\ wavelength}.$$

For example, if a feature on a spectrum is normally measured at 393.3 x 10^{-9} m and then that feature in a galaxy is measured at 401.8 x 10^{-9} m , the red shift of that galaxy would be:

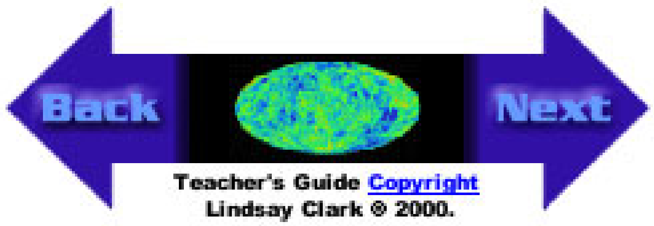
$$= \frac{401.8 \times 10^{-9} m - 393.3 \times 10^{-9} m}{393.2 \times 10^{-9} m} = 0.0216$$

and the speed at which the galaxy was moving away from Earth would be:

$$0.0216 \times 3.0 \times 10^{5}\ km \cdot s^{-1} = 6480\ km \cdot s^{-1}.$$

Then the distance to the galaxy would be:

$$\frac{0.0216 \times 3.0 \times 10^5\ km}{50\ km \cdot s^{-1} \cdot Mpc^{-1}} = 130\ Mpc.$$



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A Basic Red Shift Activity

To make students more familiar with the measurement of red shift and the relation Hubble found, try the activity at the following Web site:

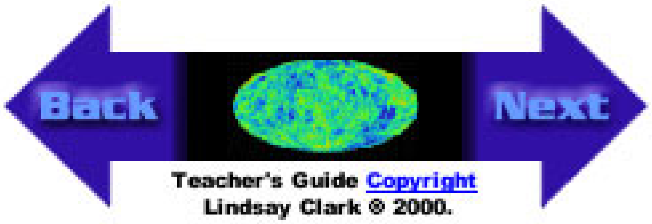
http://www.astro.washington.edu/astro101/hubble. This activity is very well explained and shows students how to measure galactic red shift with provided images and tools.

With the data they have collected from the web, have the students calculate their redshifts and velocities using the equations listed above. Then have the students make a plot of velocity versus distance. They may have to make use of their experience with scaling from previous exercises to fit the graphs on normal graph paper.

What your students should discover is that their plots form a straight line. Have your students calculate the slope of this line, and a possible equation to determine the velocity as a function of distance. Hubble found this equation to be:

Velocity = "constant" x distance.

This "constant" is now called the Hubble constant. As mentioned before the value of this "constant" is still being debated, for as your students may discover, the points fall very close but not exactly on a straight line, more data are needed before we are really sure. Therefore, the equation for velocity could actually be a slightly steeper line, or possibly not even a line at all. Today, typical values of the Hubble constant range from 50 to 100 km s^{-1} Mpc^{-1}.



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Background: Galactic Brightness

Because astronomers make so many measurements that are indirect, it is beneficial to have many different ways of measuring the same thing so that results can be compared to ensure accuracy. For this reason, astronomers have developed many different ways to measure distance to astronomical objects. Another important reason for creating different types of measures is that each of these measurements suffer limitations and are only accurate for objects within a certain distance from Earth. This is the case with parallax. Red shift combined with Hubble's relation is one of the farthest reaching measurement strategies known today and can reach beyond 100 million parsecs. Sometimes, however, it is useful to make more simple measurements that have smaller limits to determine distances to objects which are closer. Astronomers are frequently hindered by the limits of observation time and available funds. They are encouraged to be as efficient as possible and therefore it is useful to have many methods available to make the measurements they need. One common measurement for distance that does not reach as far as red shift, but is much simpler to carry out is Galactic Distance Brightness.

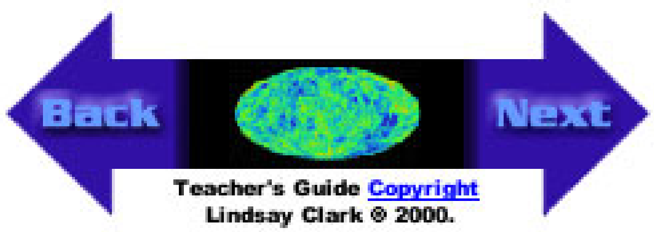
Brightness is a good measure for astronomers to use because of the simple way it relates to distance. Think of streetlights on dark nights: from far away it is possible to look at a street light with no discomfort. However, if you looked at that same streetlight close up, it would hurt your eyes. This is because light is related to distance in the following way:

$$\mathit{Apparent\ Brightness} = \frac{\mathit{Luminosity}}{4\pi \times \mathit{distance}^2}$$

which is called the "inverse-square relation."

This relationship means that the brightness of an object to an observer (apparent brightness) is equal to the amount of light the object emits per second (luminosity) divided by the distance the observer is from the source squared (distance^2) times a constant number (4π). In other words, as you move away from a light-emitting source, the more quickly it appears to grow dim. This is why the streetlight does not hurt your eyes from far away, but does from a small distance.

Astronomers have discovered that galaxies of a certain type have the same intrinsic brightness (luminosity), which is a measure of how bright the galaxy is at the source, or in a sense the "wattage" of the galaxy. Since a galaxy's "type" is based upon simple visual cues, it is possible to tell what type a galaxy is just by looking at it, almost as if light bulbs of different wattages were different shapes. Therefore, by looking at a galaxy and determining its type, we know its luminosity. Because light becomes dimmer the farther the viewer is from its source according to the inverse-square relation, we can figure out how far away the galaxy is, and roughly how far away all the other galaxies in its cluster are, simply by measuring how bright it appears to us.



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Activity: Galactic Brightness

Listed in several textbooks (including Kauffman 1994 p.482) there is a table which shows pictures of galaxies along with their spectra demonstrating their red shift. Have the students calculate the distances to these galaxies, as discussed above, and notice that the more distant the object is, the dimmer it appears. Making a graph of estimated Brightness versus Distance may help the students see and appreciate the relationship between apparent brightness and luminosity.

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Background: Supernovae

Another activity which uses standard candles to determine distance and combines this technique with red shift activities can be found at Supernova Background.

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The Expanding Universe

These activities are aligned with Indicators:

- National Science Education Standards
  - Teaching Standards A, B, C, D, E
  - Professional Development Standards A, B, D
  - Assessment Standards A, B, C, D, E
  - Content Standards, Unifying
  - Program Standards A, B, D
  - System Standard D
- New Jersey Core Curriculum Content Standard
  - Cross Content Workplace Readiness Standards 1, 2, 3, 4
  - Language Arts and Literacy Standard 3.1, 3.3
  - Mathematics Standards 4.1, 4.2, 4.4, 4.5, 4.6, 4.9, 4.10, 4.11, 4.12, 4.13, 4.16
  - Science Standards 5.2, 5.3, 5.5, 5.11

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Purpose

- To gain an understanding of the expansion of the universe in all directions from all points in preparation for studying the evolution of the universe as suggested by Indicator 8 of Science Standard 11.
- To build on previous scale units by "stretching" this scale to show expansion of the universe.

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Historical Background on Expansion

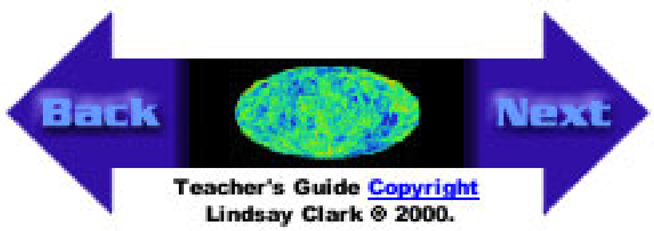
After a discussion of Red Shift used to determine the distance to an astronomical object, students may begin to wonder about the motions of these objects, because measuring the distances to these objects using their Red Shift requires that the objects have a motion (velocity with respect to the Earth). The objects, therefore, do not have a stationary position to measure. What is even more puzzling is that the farther an object is from the Earth, the faster it moves away. These ideas may still confuse the student and therefore they deserve more discussion.

When we discussed the Hubble relation, we used it as a way to measure distance to objects, as it is most commonly used today. However, when Hubble found this relation, it was useful as much more than a simple distance measure. It showed that most galaxies were expanding at very high rates away from the Earth. Until this point, in the 1920s, most astronomers still believed in a Newtonian universe which was more or less static, meaning that it was not getting bigger or smaller, but staying the same size as it was in the distant past or future. Einstein even changed his theory of relativity to make it agree with this static model of the universe. Later, when the theory of an expanding universe became generally accepted, Einstein called this change "the greatest blunder of [his] life" [25]. Even though most students won't know about the theory of relativity, you may want to share this example with them to show that even great scientists like Einstein make mistakes and are unsure of their work.

Actually, even before 1914 when V. M. Slipher took spectra of "spiral nebulae", some scientists and philosophers suspected that the universe was larger than the Milky Way, which until this point was considered the whole of the universe with other spiral and elliptical "clouds" in it. They thought that these clouds might be systems of "island universes" made of stars that were independent of the Milky Way, or as we know them today, other galaxies. Slipher found that 11 out of 15 of these spiral clouds showed red shift and were therefore moving away from the

Earth. They were entered as evidence in the famous Shapley-Curtis Debate in which the two noted astronomers discussed the ultimate size of the galaxy and which astronomical objects were to be considered part of the galaxy and which were extragalactic. Harlow Shapley had devised a model of the Milky Way that was very large and therefore could contain these objects. Heber Curtis disagreed with Shapley's assertions andd a debate was arranged between the two scientists in 1920. The three main points discussed concerning the "island universes" were:

1. What are the distances to the spirals?
2. Are the spirals composed of stars or gas?
3. Why do spirals avoid the plane of the Milky Way? [26]



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Activity: Debate

The Shapley-Curtis debate provides a unique opportunity for astronomical instruction. It combines for the students examples public speaking and the ability to explain what they have learned as well as the importance of historical context for scientific discovery. Have the students reenact the debate, perhaps having different actors play Shapley and Curtis for different points in the argument. Much of the information needed to research this debate, including lecture notes for undergraduate-level students, can be found at http://anctwrp.gsfc.nasa.gov/diamond_jubilee/debate20.html. Another useful resource is a paper by Virginia Trimble called "The 1920 Shapley-Curtis Discussion: Background, Issues, and Aftermath." [27]

It was Hubble who put an end to this debate in 1923 by finding a special type of star called a Cepheid variable star in the Andromeda galaxy. This special type of star changes brightness on very regular intervals and this interval is related to its luminosity. So by measuring the period (time difference) between the brightest moments of variability we can find its luminosity and calculate its distance just like the galaxies with known Luminosities. For more information and activities on finding distances using Cepheid Variable stars see http://www.itpa.lt/~astro/aol/market/experiments/middle/skills207.html and http://zebu.uoregon.edu/~soper/MilkyWay/cepheid.html. The distance that Hubble deduced in this manner placed the Andromeda galaxy far outside the confines of our own galaxy and determined it to be its own independent stellar system.

Hubble did make some mistakes however; here is some of his data:

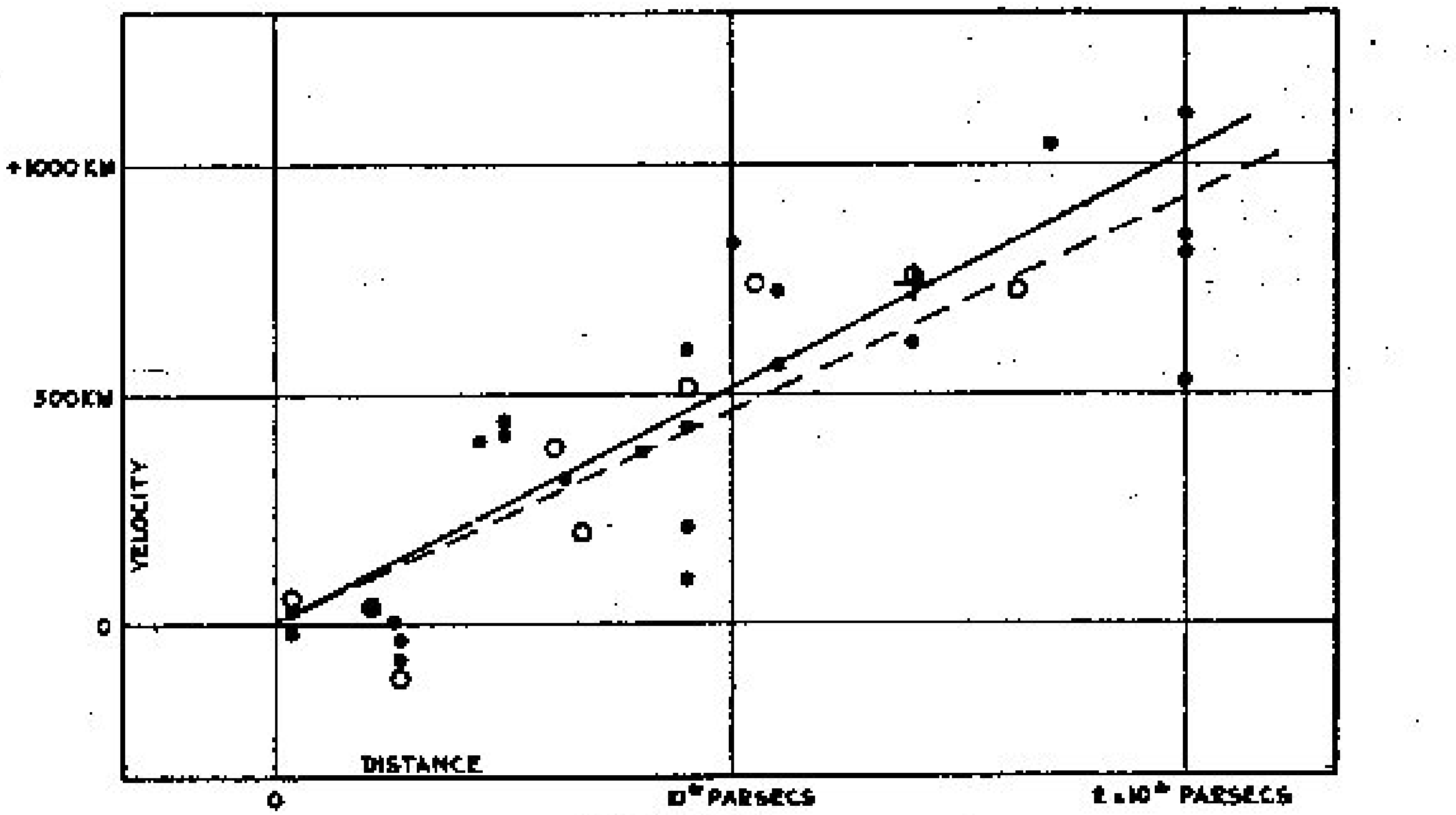
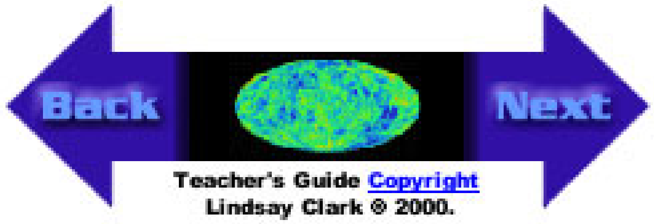


FIGURE 1

Hubble's Data 28

With this data he calculated that the distances to galaxies, including the nearest galaxy, Andromeda, were too small. There are actually two types of Cepheid stars each of which have a different relationship between their period and luminosity. Hubble chose the wrong type of star to do his calculations and therefore miscalculated his distances. This led to another miscalculation of the age of the universe. With Hubble's data the age of the universe was calculated to be 1,840 million years. Not too long after these calculations were made, the geologists discovered that with radioactive dating, the rocks on Earth were at least 3.6 billion years old. These discoveries were in conflict and needed to be reconciled since the Earth could not be older than the universe itself. Another astronomer named Baade found the misuse of Cepheid stars and began the correction of Hubble's data. He also calculated a much larger age and size for the universe. Even today we are still unsure of the actual amount of expansion, but are sure that the universe is expanding. Scientists must have many ways to check their answers, as the astronomers could check with the geologists, because they are never sure they have done everything right.



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Background: Contemporary Expansion

Today, astronomers have determined that the universe is not static, because we can see the red shifts of galaxies which show not just random motion from galaxy to galaxy, but huge expansions of the galaxies within the universe in all directions away from the Earth. Actually, since the galaxies that are farther away are expanding faster in all directions than the ones near Earth, the universe is expanding in all directions equally. In other words, since the time of Copernicus, who asserted that the Earth was not the center of the universe, astronomers have believed that the Earth is not an extraordinary place in the universe. There should be nothing special about the conditions surrounding the Earth or its location in space. For this reason, astronomers believe that the Earth is not at the center of the universe.

The notion of simultaneous expansion from all points is a difficult one to grasp, but a few simple demonstrations may help clarify this concept.

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Activity: Mapping Expansion

Have the students take their furniture models from one of the smallest scaled maps of the mapping the classroom activity and place them on the map. Then arrange some of the other classroom maps in order of increasing scale. This activity is most effective if you have three maps which increase linearly in size. Take the smallest map along with its furniture and explain that this is the size of the universe is at time t = 0. Then move the furniture to the second map and explain that as the universe stretches it is simply as if the scale of the map is stretching while the furniture stays the same size. This second map is t = 1 second, for example. Then, again move the furniture onto an even larger map. See if the students can find the expansion rate of this "stretching universe".

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Activity: Building the Expansion

While the previous example is a good beginning for imagining a stretching universe, it is only two dimensional and does not clarify the idea that all points are expanding simultaneously. A good and simple way to demonstrate that the universe expands from all points simultaneously and has no real center is to print out the pictures found here [29]

onto transparencies for use on an overhead projector or put one on regular paper for individual use.

These images of points which represent galaxies, when overlapped on a certain "galaxy" show expansion from that point but when overlapped on another "galaxy" seem to center around the new point. Thus no matter where in space the expansion is viewed, it appears that everything is moving away from that point [31].

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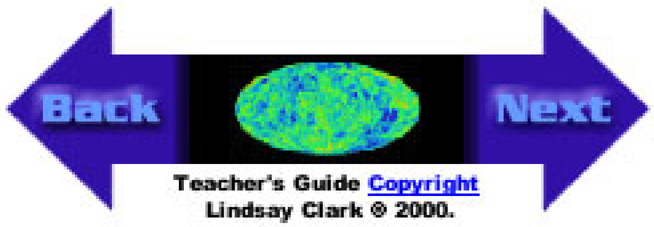
Activity: Building the Expansion II

This expansion can be seen easily in three dimensions if it is built with tinker toys. Using the round yellow blocks as galaxies, connect several together in a random three dimensional pattern using the shortest rods. Then expand, or have the students expand, the universe by connecting these same blocks (or different ones if you want to prepare the three models ahead of time) with the next shortest rods. Then expand again using the longest rods. This is a good model to show the expansion from all points in three dimensions, especially since the "galaxies" stay the same size during the expansion. This is because gravity and other forces hold planets, galaxies and clusters and objects within them together in spite of this universal expansion. For example, people do not stretch because of the expansion of the universe [32].

There are some things that do stretch, however. One important example of this is electromagnetic radiation, or light. Light occurs and is usually represented as waves like these which stretch, cool and grow more red:

A Stretching Light Wave

As you can see, as the wave stretches, the wavelength (the measurement of the length of the wave from peak to peak) increases. This is what happens to electromagnetic radiation in the expanding universe. Hot or High energy waves which occur on the blue end of the spectrum have shorter wavelengths which get stretched to cooler, redder, longer waves. There is an interesting example of this effect which astronomers have discovered and called the Cosmic Background Radiation. This is the very cool, stretched-out radiation left over from the beginning of the universe, or the Big Bang.



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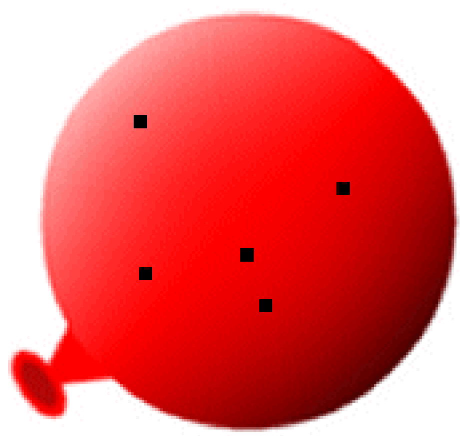
Activity: Stretching Radiation

As is shown in the pictures below it is easy to show students how radiation stretches on the surface of an inflating balloon.

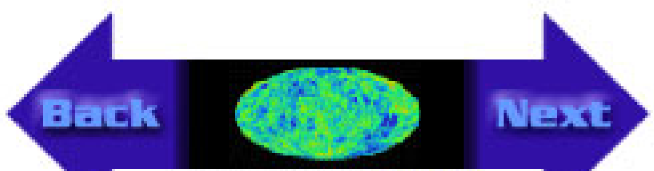


Stretching Wavelength

Simply have them draw wavelengths (simple sine curves) onto the balloons with markers along with tick marks showing scale measured in millimeters. As they inflate the balloon in stages they can re-measure the wave from peak to peak to find the expansion rate and use the tick marks to help calibrate their scale.

Sometimes this balloon model is used to show the expanding universe by painting galaxies on with markers and inflating the balloon. This model is problematic for two reasons. First, it may confuse students since it is only expanding along the surface of the balloon and not actually three-dimensionally, even though the object is three-dimensional. Second, the galaxies in this model stretch unlike real galaxies which are subject to the (stronger) forces of gravity which hold them together so they do not expand with universal expansion.

You may want to mention the stretched radiation from the Big Bang in the form of the Cosmic Background Radiation, both because many students have heard of these terms in popular media and are interested in finding out about them and in preparation for future lessons (following) which discuss these concepts more fully. For more information on this information and an animated version of the balloon stretching activity see http://www.sns.ias.edu/~whu/physics/physics.html.



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Background: Supernovae

Here is an activity which ties together both distance measurement and the expanding universe. It uses the spectrum of the supernovae, which are exploding old stars, to determine the rate of the expansion of the universe and the brightness of the supernovae as standard candles to determine distance. Like the galaxies whose "wattage" could be determine just by looking at them, supernovae type can be determined by looking at their spectrum, which is explained in the red shift section. A certain type of supernovae, type Ia, has a spectrum which shows that lots of hydrogen is present near the explosion. Astronomers have determined that this type of supernova has a maximum brightness. This maximum is calculated by using physics and the mass of the dying star. Although recent discoveries have shown that this maximum is not always the exact same number, it is a good approximation to use that all supernovae type Ia have a maximum absolute brightness of -19 magnitudes. This is the measurement of the brightness of the supernova as if you were 10 parsecs from it, measured according to an ancient system developed by Hipparcos.

In this system, Hipparcos divided up all the stars he could see into six categories, 1-6. He labeled the brightest stars "1" and the dimmest ones "6". However, he labeled these stars as he saw them (which is now called the apparent brightness), not as if he were 10 parsecs from them (which is now called absolute brightness). As we discussed in the Galactic Brightness Section, this difference in brightness is important because brightness falls off with distance according to the inverse square law

$$b = \frac{L}{4\pi d^2}.$$

Supernovae are so intrinsically bright that their magnitude ratings go all the way to an absolute magnitude of -19. This means a supernova which is 10 parsecs away would be $1.5*10^7$ times brighter than Sirius, the brightest star in the nighttime sky.

To find out why look here.

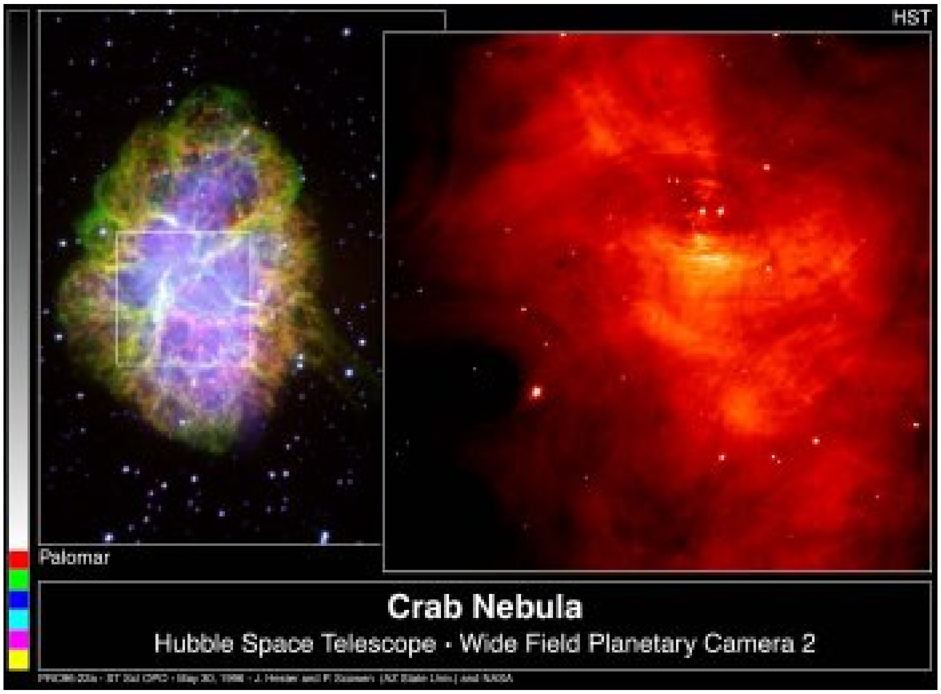
Since we now know how bright the supernova can possibly get, we can calculate the distance to it by making observations of how bright we perceive it, which is called the apparent brightness, and then using the formula:

$$D = 10^{(m - M + 5)/5}.$$

In this formula,

- D = the distance in parsecs to the supernova,
- m= the apparent brightness in magnitudes,
- M= the absolute magnitude.

In order to measure the maximum apparent brightness, astronomers must first discover a supernova, which is relatively easy because supernovae are so bright. A supernova which exploded in 1054 A.D. according to the accounts of an imperial astronomer from the Sung Dynasty, was visible even during the daytime and can be seen today in the crab nebula:

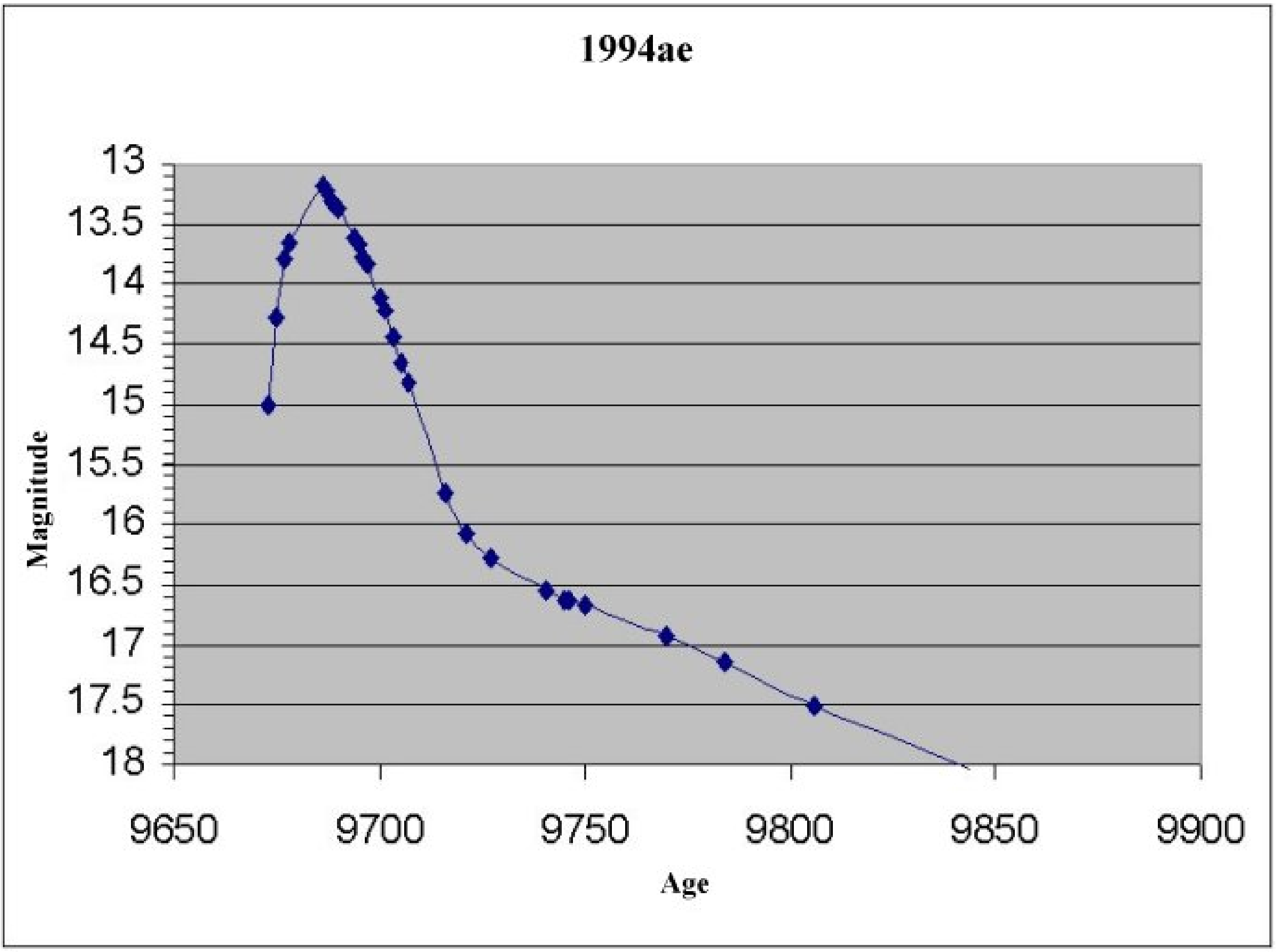


The Crab Nebula [23]

All the astronomers must do is observe many galaxies and watch for any bright patches to appear as seen in this picture:

Supernova 1987A [24]

Then they must take the spectrum of the supernova to confirm that it has the right "finger print", or spectrum to be a supernova. If astronomers wish to use the supernova for a distance measurement they then must observe the spectrum as often as they can for several days, preferably every day. They can then make a plot like this one:



The x axis is in units of days, but it is labelled according to a shortened form of Julian Dating. In this system, astronomers decided to start counting days on January 1, 4713 BC (Day 0) and then added one day for every day after that. This number is then shortened by subtracting 2440000, leaving the number around 9000 for dates near 1990 A.D. The y axis is in units of the observed brightness in magnitudes; remember, brighter supernova have lower magnitudes. The line connecting data points is drawn in for convenience and is merely a best fit line intended to give some idea of the usual shape for these sort of curves. As you can see from the graph, supernovae grow brighter until they reach a maximum brightness and then grow fainter. In absolute magnitudes, this brightness is about -19, however you will notice that they appear much dimmer because the supernovae are so far away.

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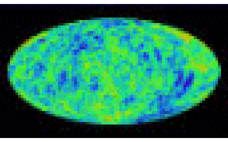


A Teacher's Guide to the Universe

Supernovae Lab

Activity

The following activity contains many graphs of supernova brightness as a function of time (The data contained in this activity is from BVI Light Curves for 22 Type Ia supernovae[35].

Purpose: To derive a relationship between supernovae distances and their redshifts.

Materials:

- Copies of directions, light curves, and spectra for each student
- graph paper
- straight edge
- calculators (optional)

Procedure (for teachers):

1. Complete an introduction with the students explaining the material from the Supernovae Background Section
2. Have the students complete calculations and make a graph (on graph paper) of the distance modulus versus red shift for the nine supernovae listed below using the directions for students also found below.
3. Have the students approximate or find a best fit line (a straight line!) on their graph. This graph is known as a Hubble diagram because it shows the relation between distances of astronomical objects and their red shift, or in other words that the farther away an object is the faster it is traveling away from you. It also shows that at some time in the distant past the world was much hotter and denser. In other words, if everything that we can see now is traveling away from us, then at some time in the past they must have been much closer to us. This concept is known as the Big Bang. See the activities in the Expanding Universe Section for further explanation of this concept.
4. Have the students find the slope of the best fit line. The slope is an estimation of Hubble's Constant. This constant can then be used to estimate the age of the universe Age=1/Hubble's constant. If students have completed the Red Shift Lab, this is the same type of graph that is made at the end and students should compare their values from the two experiments just as astronomers do to check their own answers.
5. If you wish to account for the force of gravity which works against the cosmological expansion which is described by Hubble's constant, the age of the universe can be calculated:

Age=2/(3*Hubble's constant).

(This is an approximation that is only correct if the universe is flat and matter dominated. See Curvature of the Universe Background to learn more about the Shape of the Universe.)

Students should compare the graphs and estimations of Hubble's constant that they calculated using supernova data with those they calculated using red shift. Since astronomers have no real way of "checking" their answers to see if they are right (for example by using a meter stick to measure the 'actual' distance to a supernova) they must rely on many different distance indicators and their estimation of error in those measurements to see how close they think their estimates are. Also students can notice the difficulties of using real data in the supernova lab. Some of the points will not fall on a straight line, this is because we are using a simple technique to estimate the distance to the supernovae. When the astronomers calculated this same table they got answers that fell much closer to a straight line because they used a more complicated technique. You can see their graph here on page 29. For comparison, here is a Hubble Diagram I made using the online version of this lab.

The materials needed for the lab can be found below or here in .pdf form, including detailed instructions I gave when teaching this lab in an advanced physics class. The red shift which is listed in the table is really a number which has been calculated (log (the speed of light*the red shift)) but shows the same relation when plotted against the distance modulus. You may want to use the red shifts listed in the table rather than having the students calculate the red shift by hand as the precision required might be too great for the error which is acquired by hand measure. You can pass out some of the spectra so that students can try to understand how the red shift measurement is made, and then use the tabulated data for their graphs.

Alternatively, instead of printing out all of these materials and completing the lab by hand, both the light curve measurements and the red shift measurements can be made online in the next section. This online activity does require some Java functions on the web browser so make sure that your school's computing facilities can handle the program before bringing the students to the computer lab.

Directions: Supernova Lab

1. Examine the light curves for each supernova to get a feel for how they all look.

2. For each supernova find the maximum brightness (m) on the curve. Remember the lower the number the brighter the supernova is.

3. Find and record the distance modulus for each supernova, the distance modulus is defined: D=m-M, where m=the observed maximum brightness and M is the absolute brightness for supernova -19.12.

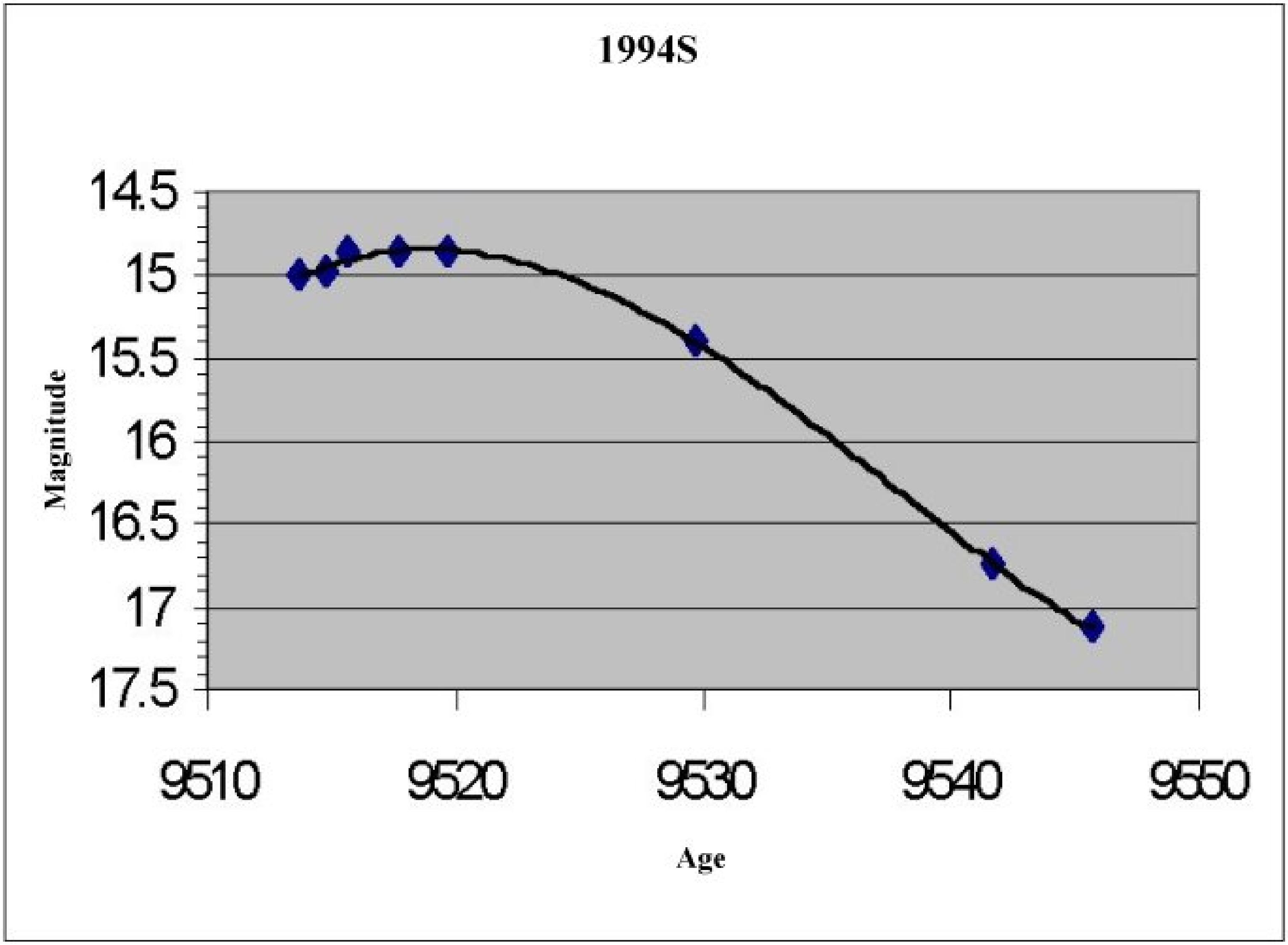
4. Use the Distance modulus (D) to find and record the actual distance in parsecs: d(distance in pc)=$10^{(D+5)/5}$ and in km 1pc=3.09×10^{13}km.

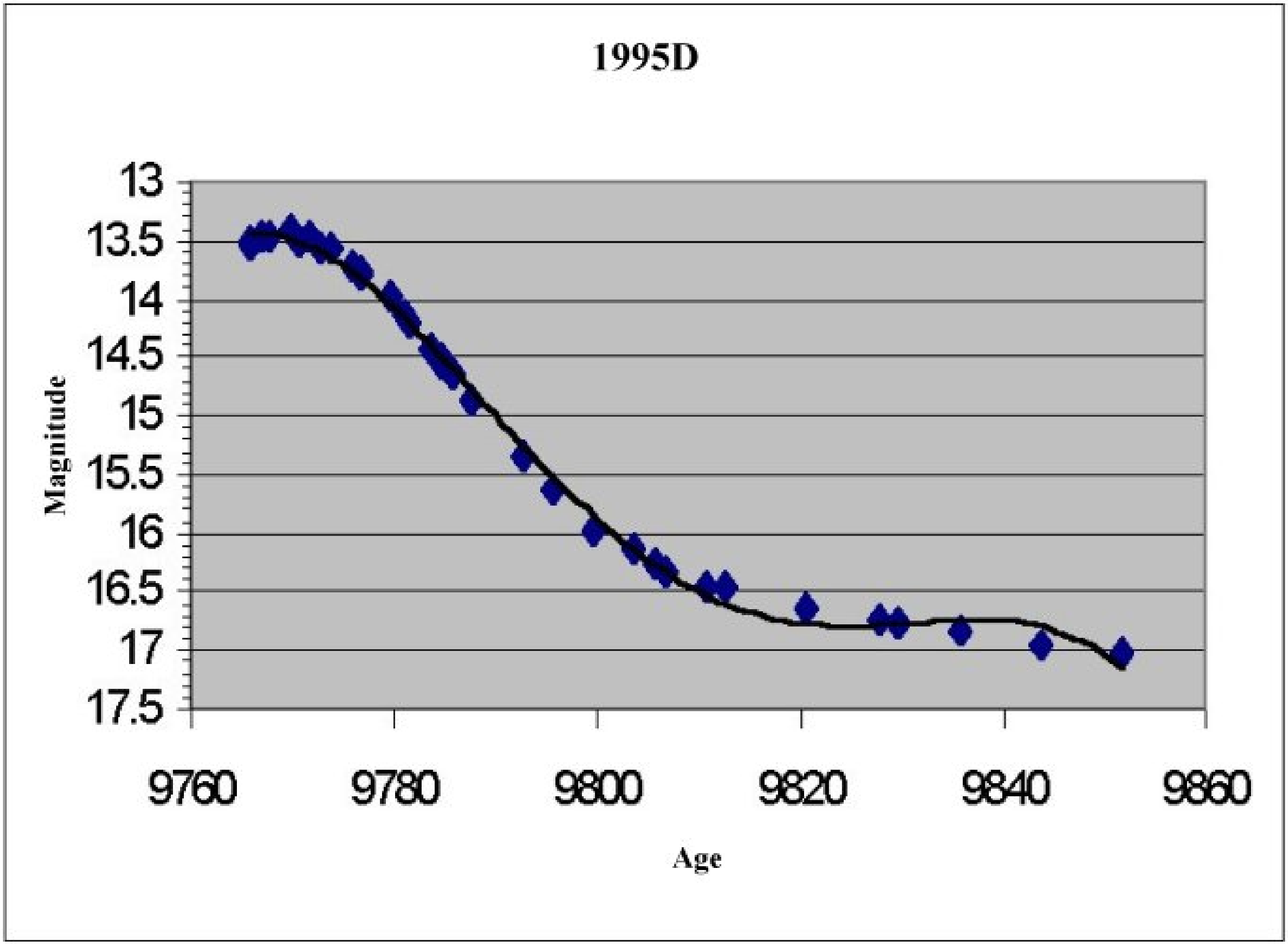
5. Make a plot of the distance modulus versus the red shift as listed in the table.

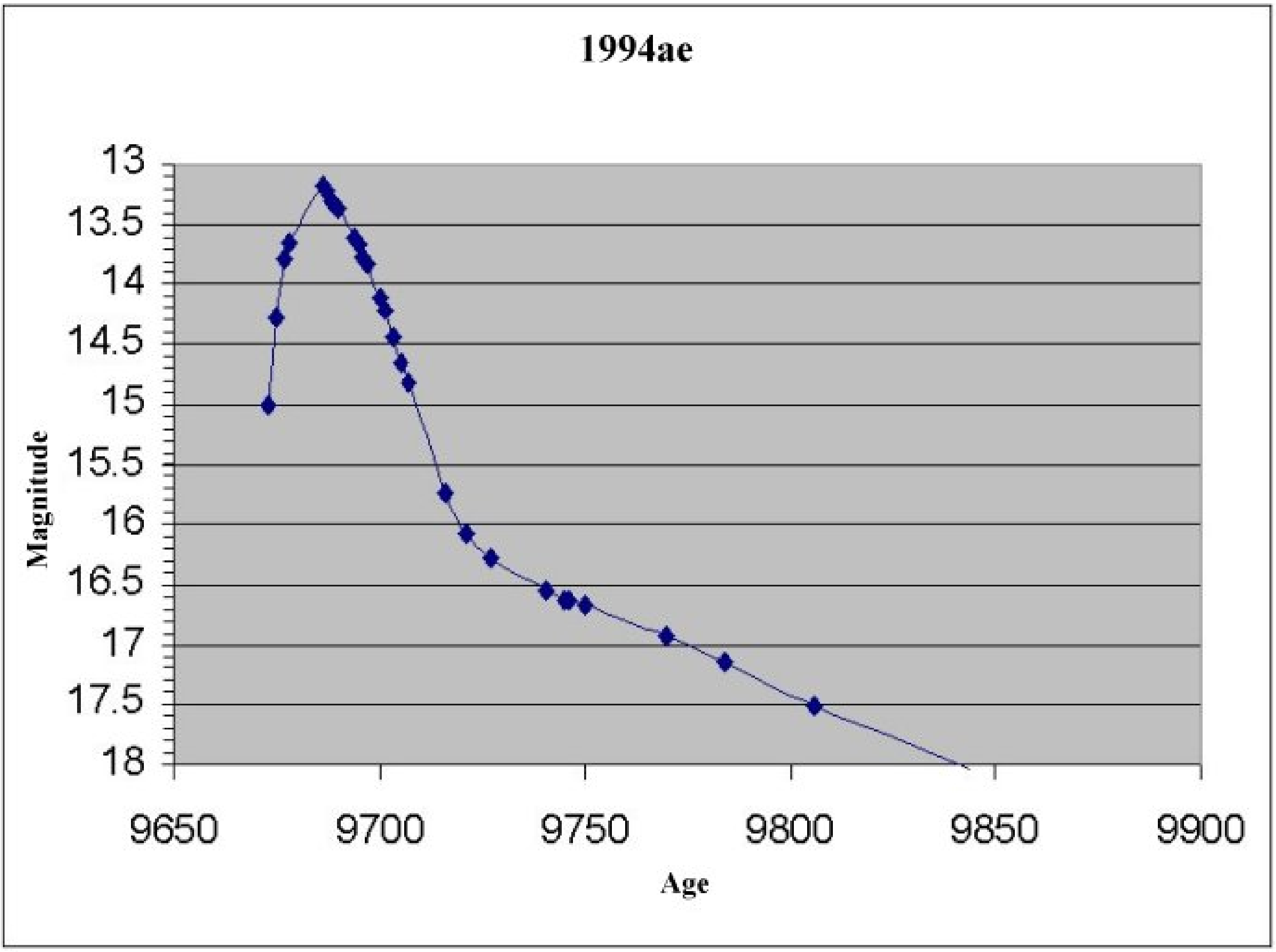
6. Draw a line on the graph which you think comes nearest to the most of your data points as possible.

7. Try to find a relationship between the red shift and the distance modulus. (How does one relate to the other, could you suggest a mathematical equation? Remember this is real data so there may be some error and the equation may not be exact.)

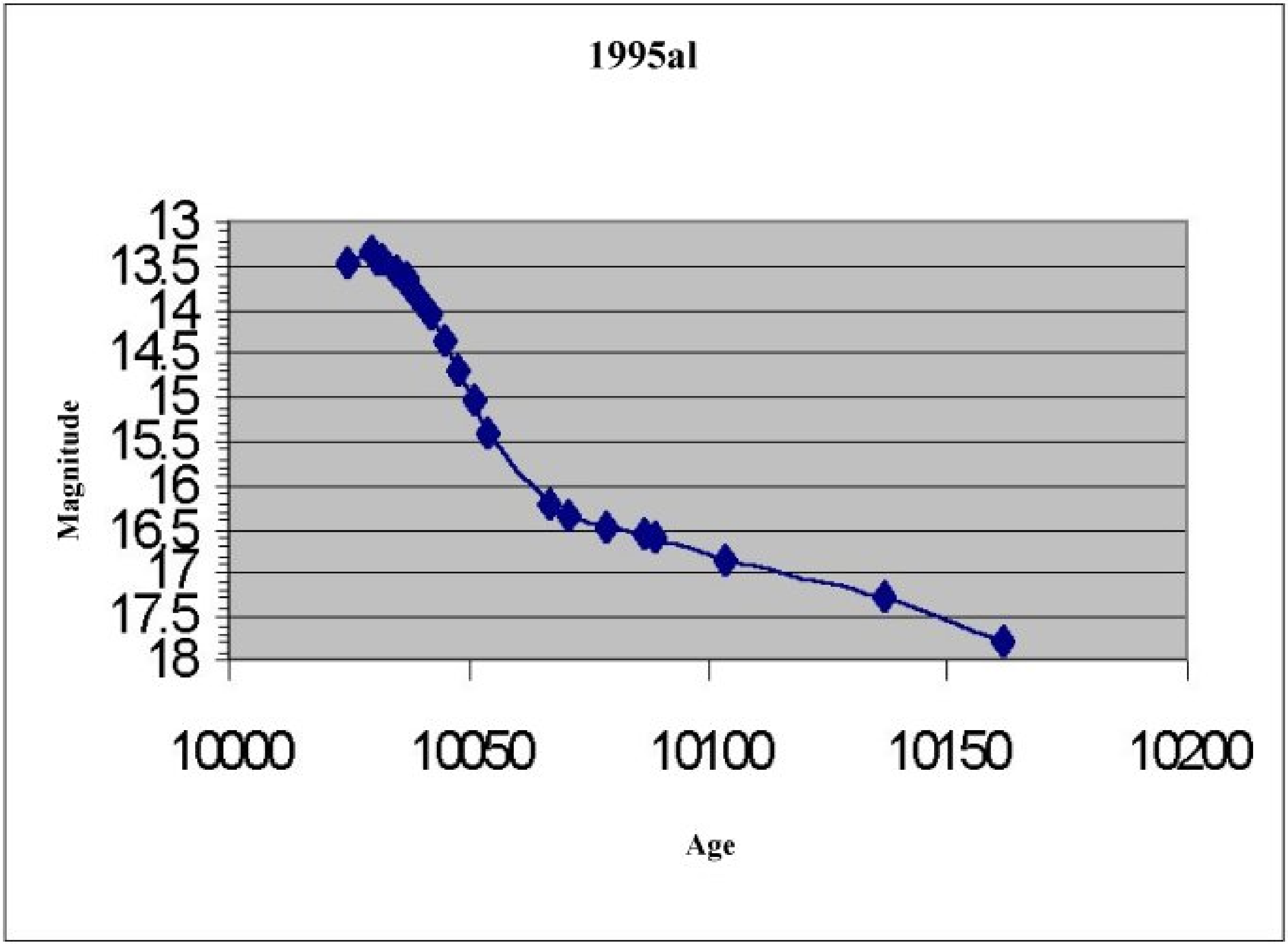
Light Curves

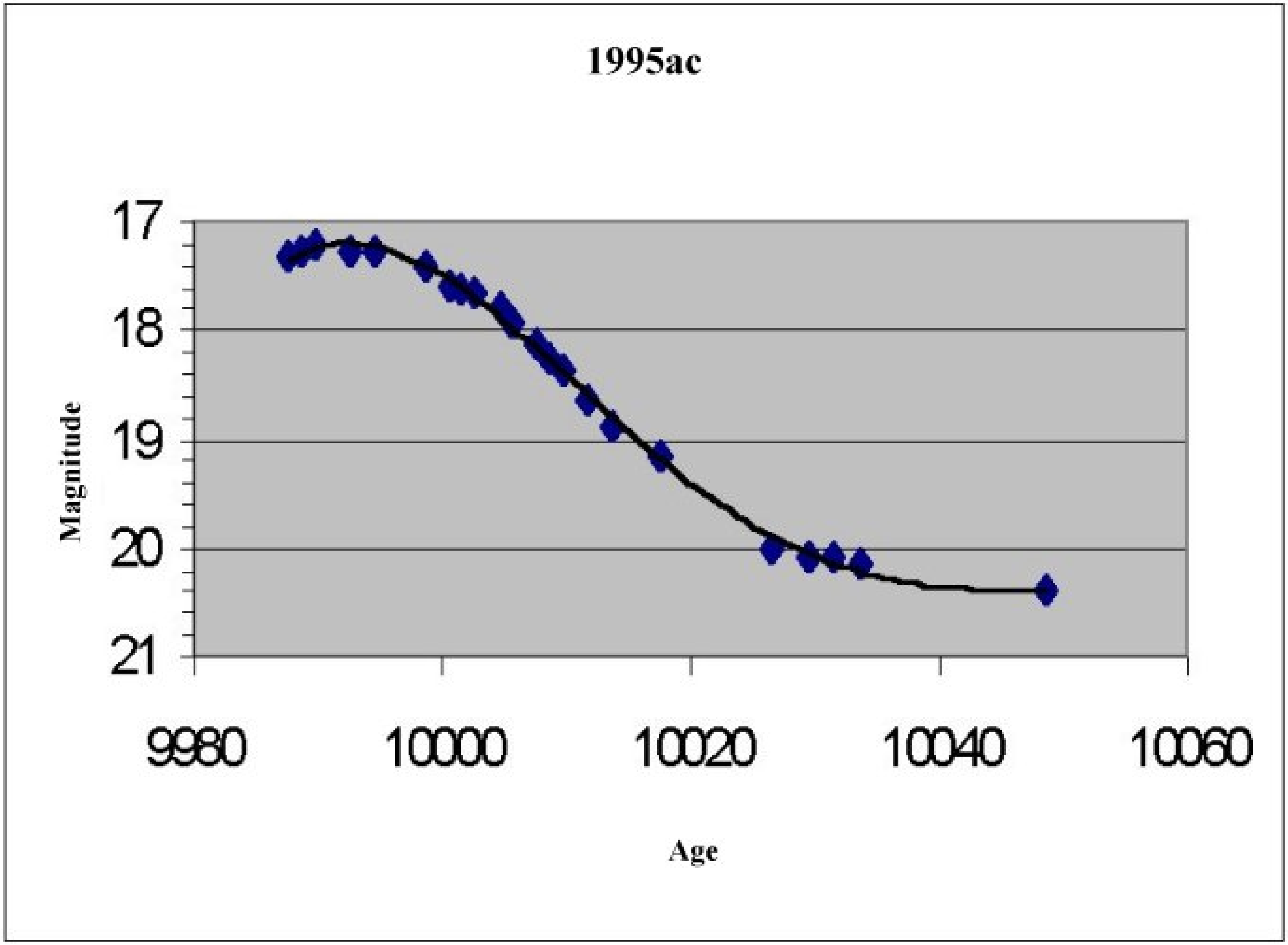

1994S
Magnitude
14.5
15
15.5
16
16.5
17
17.5
9510
9520
9530
9540
9550
Age

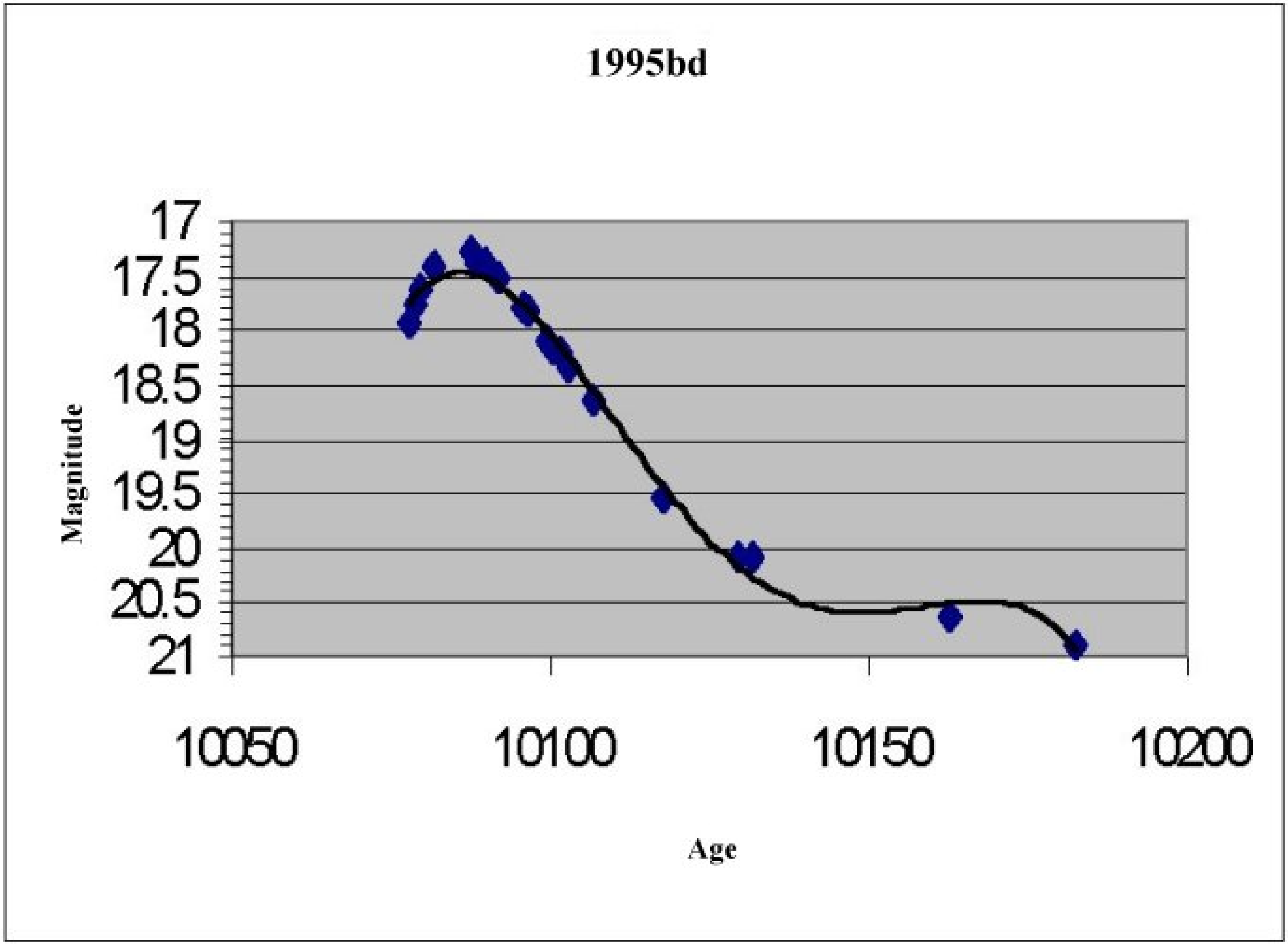

1995D
Magnitude
13
13.5
14
14.5
15
15.5
16
16.5
17
17.5
9760
9780
9800
9820
9840
9860
Age

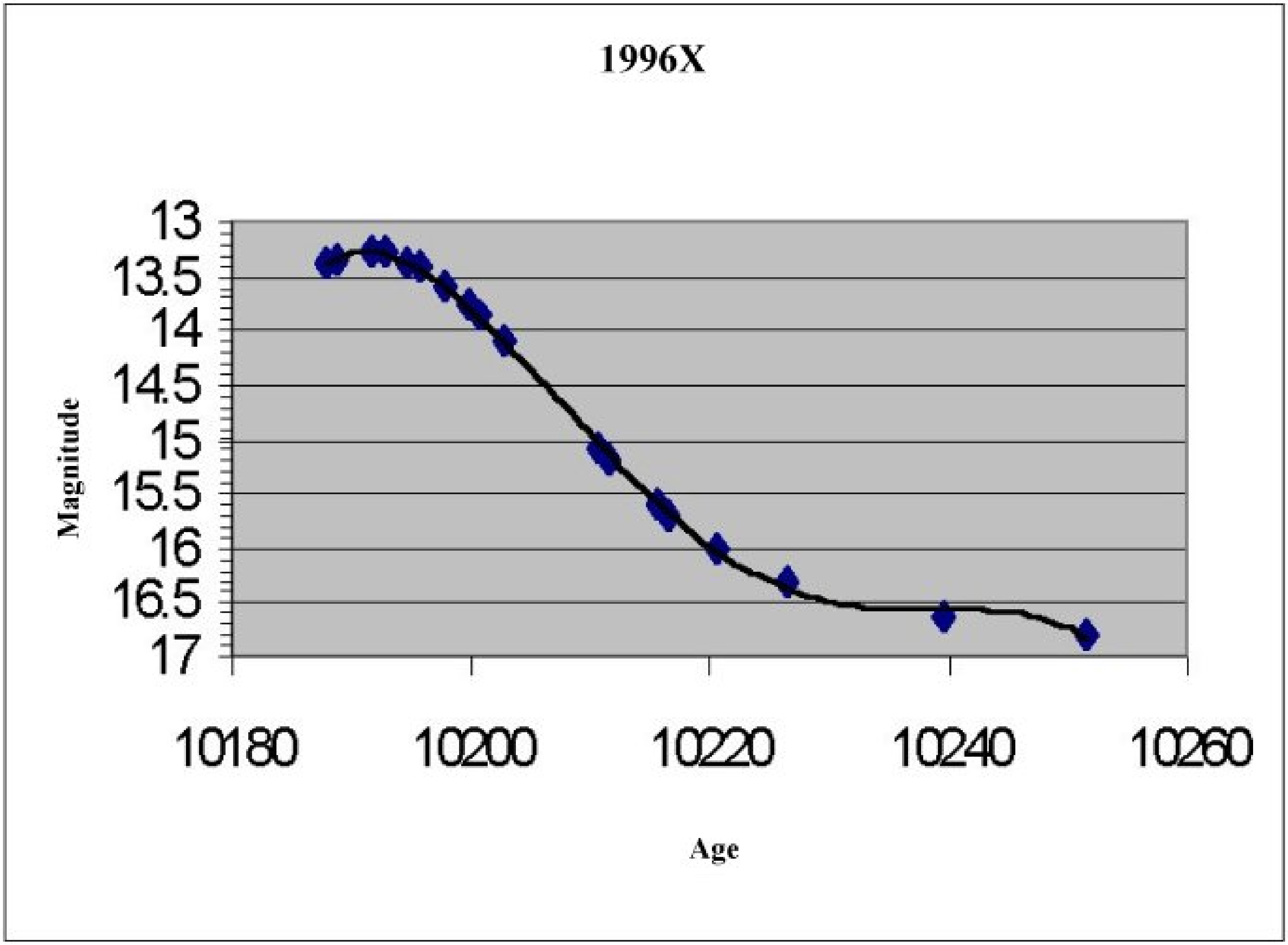


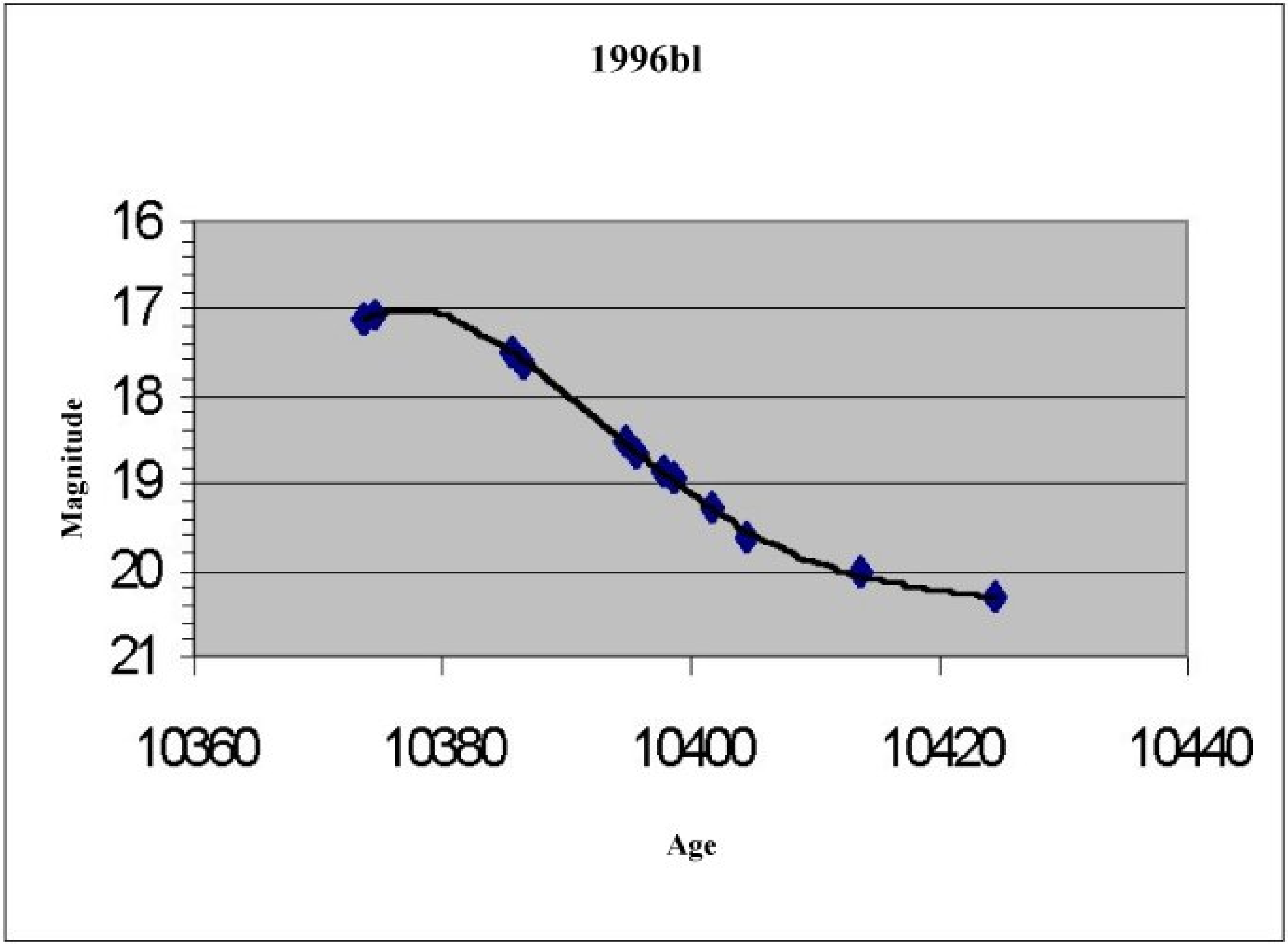
1994ae
Magnitude
13
13.5
14
14.5
15
15.5
16
16.5
17
17.5
18
9650
9700
9750
9800
9850
9900
Age

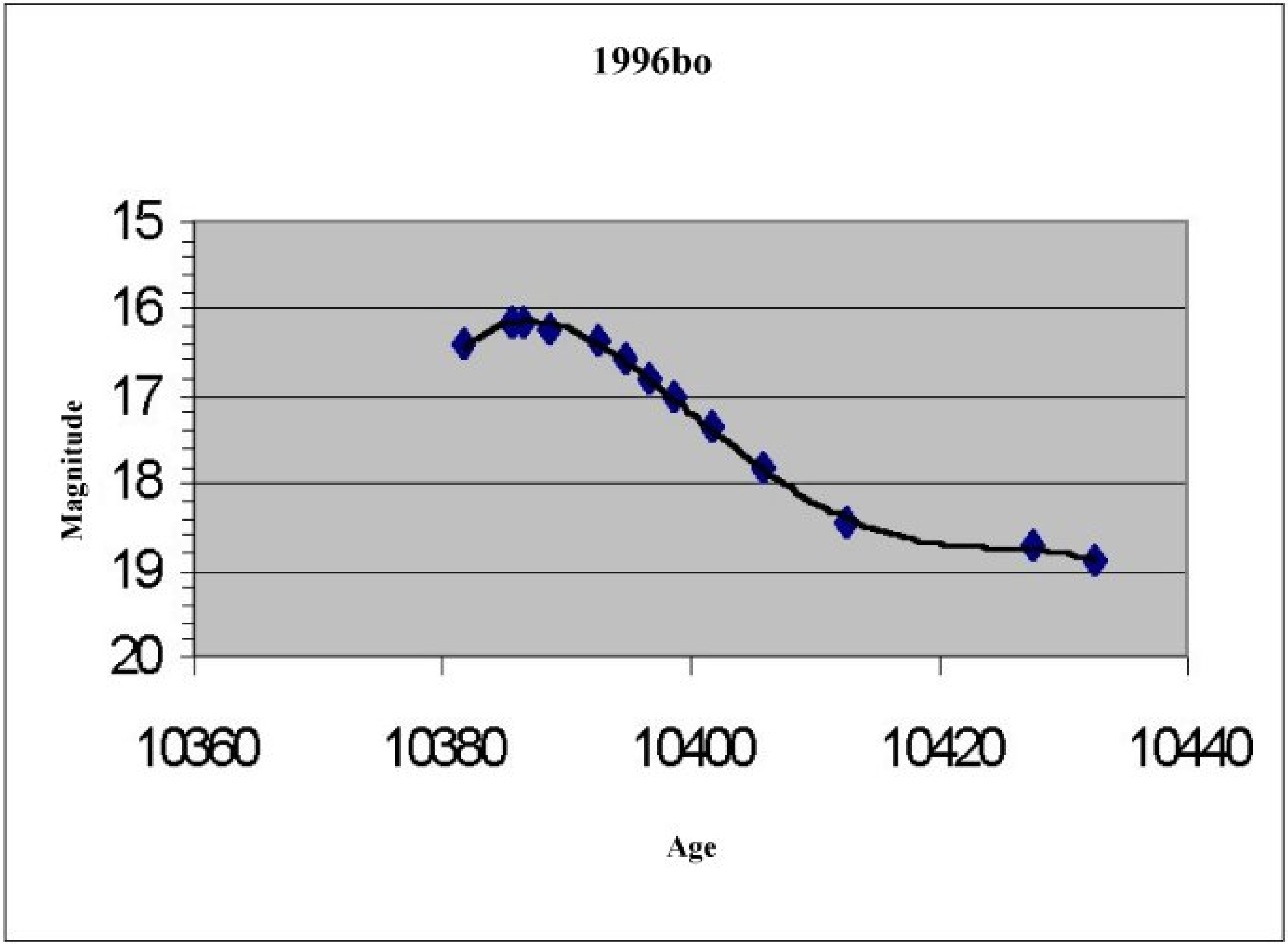

1995al
Magnitude
13
13.5
14
14.5
15
15.5
16
16.5
17
17.5
18
10000
10050
10100
10150
10200
Age


1995ac
17
18
19
20
21
Magnitude
9980
10000
10020
10040
10060
Age

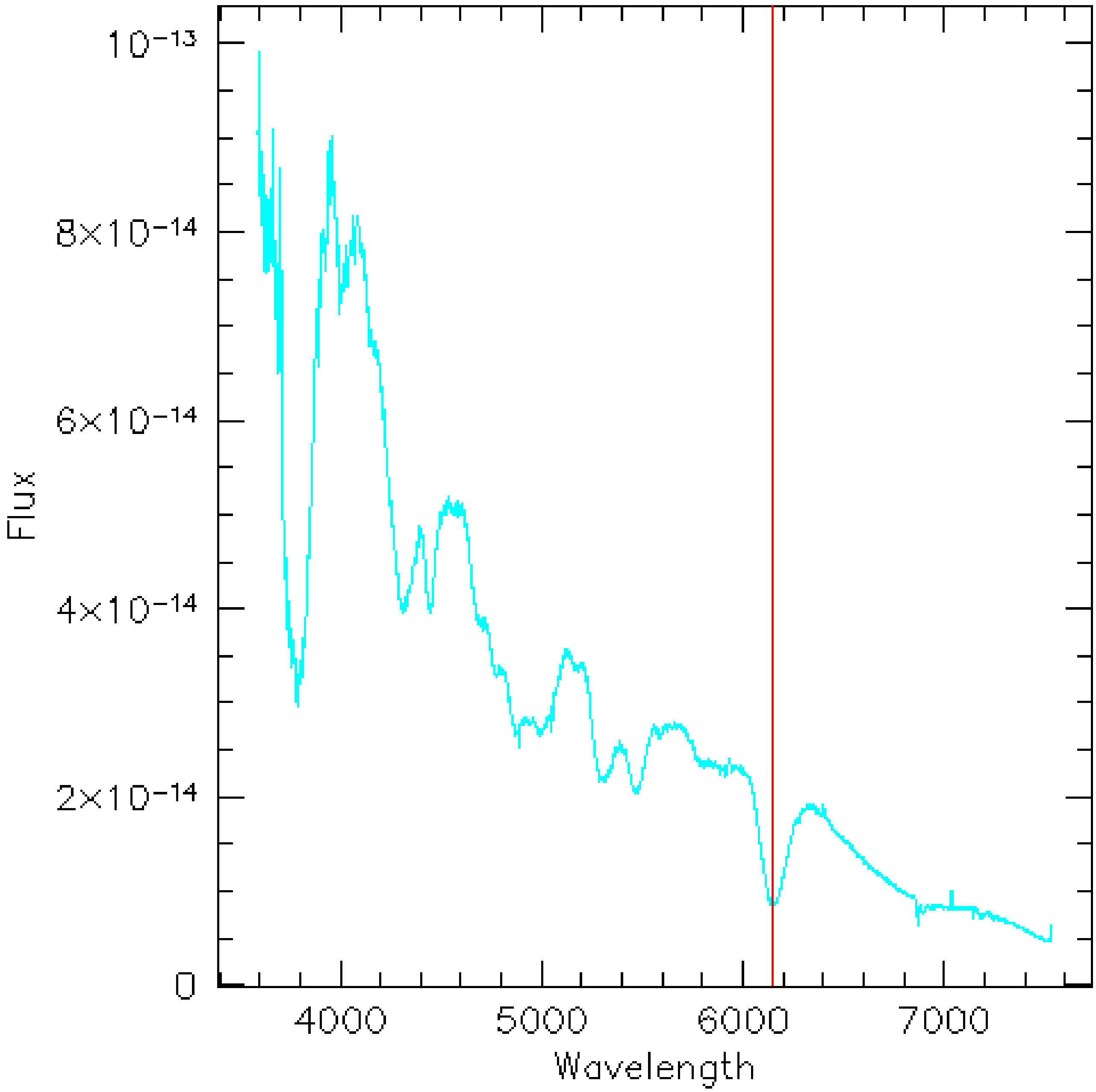

1995bd
Magnitude
17
17.5
18
18.5
19
19.5
20
20.5
21
10050
10100
10150
10200
Age


1996X
Magnitude
13
13.5
14
14.5
15
15.5
16
16.5
17
10180
10200
10220
10240
10260
Age

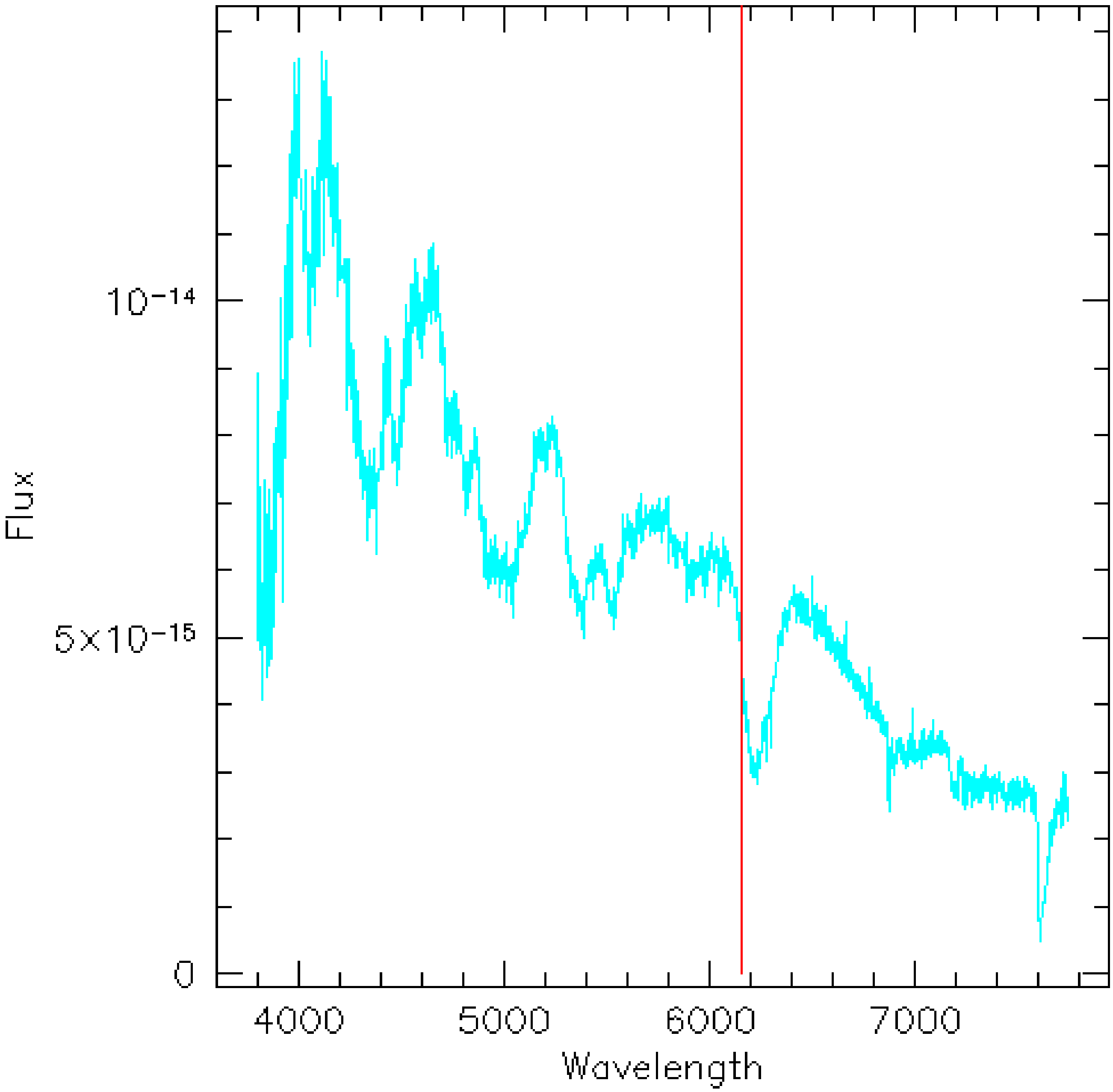

1996bl
16
17
18
19
20
21
Magnitude
10360
10380
10400
10420
10440
Age



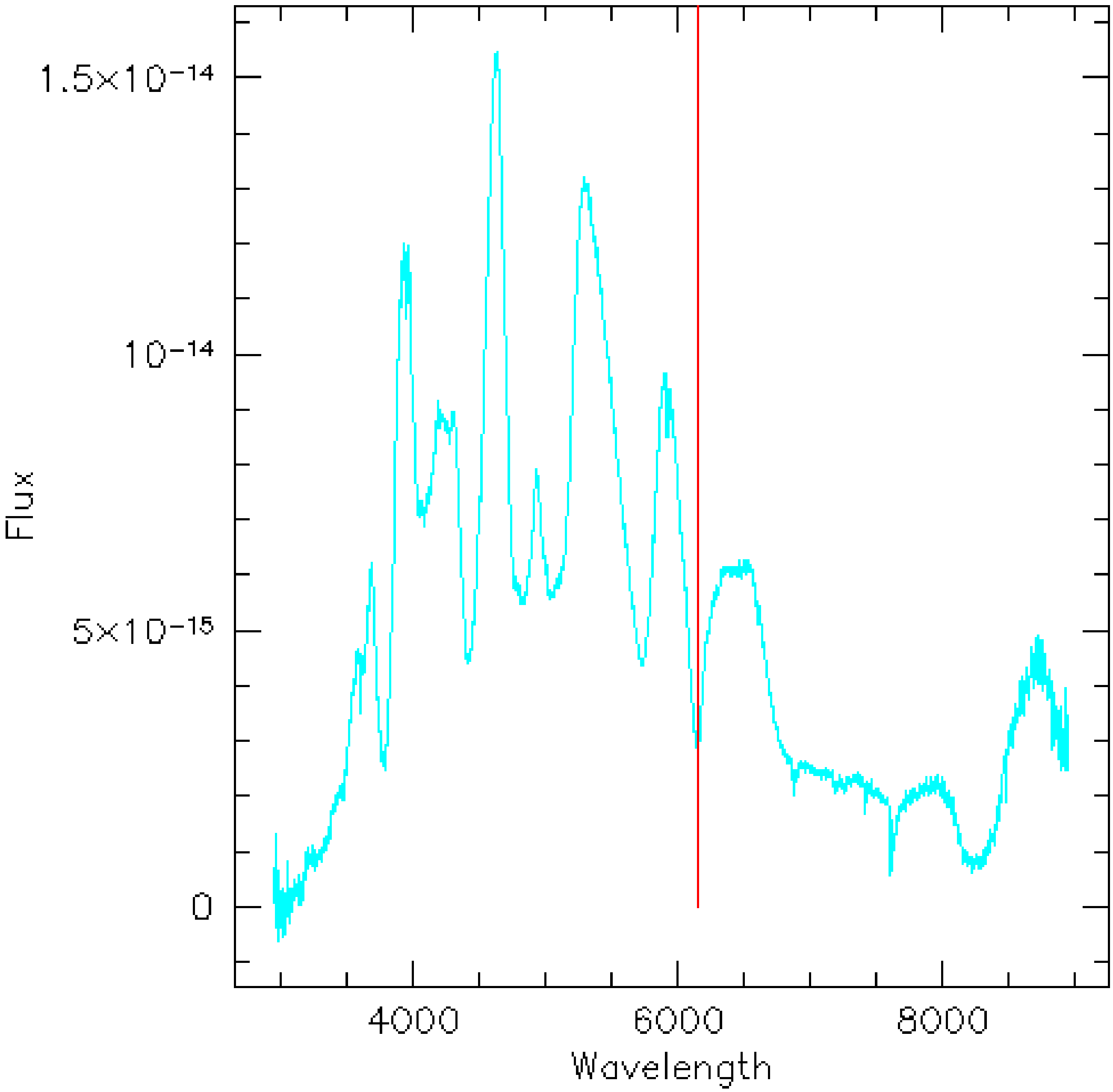
Supernovae Spectra
Supernova 1994S



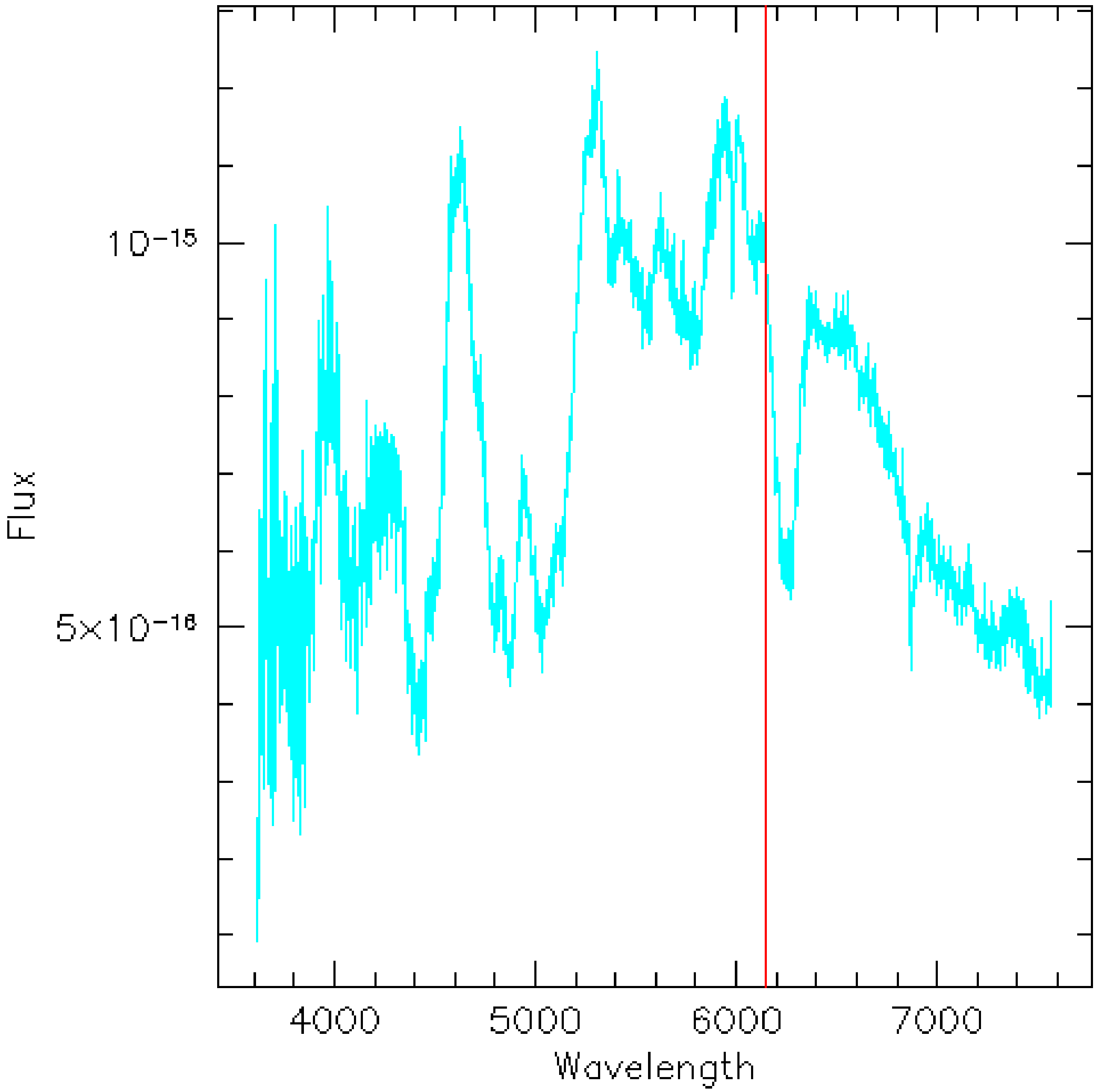
Supernova 1995D



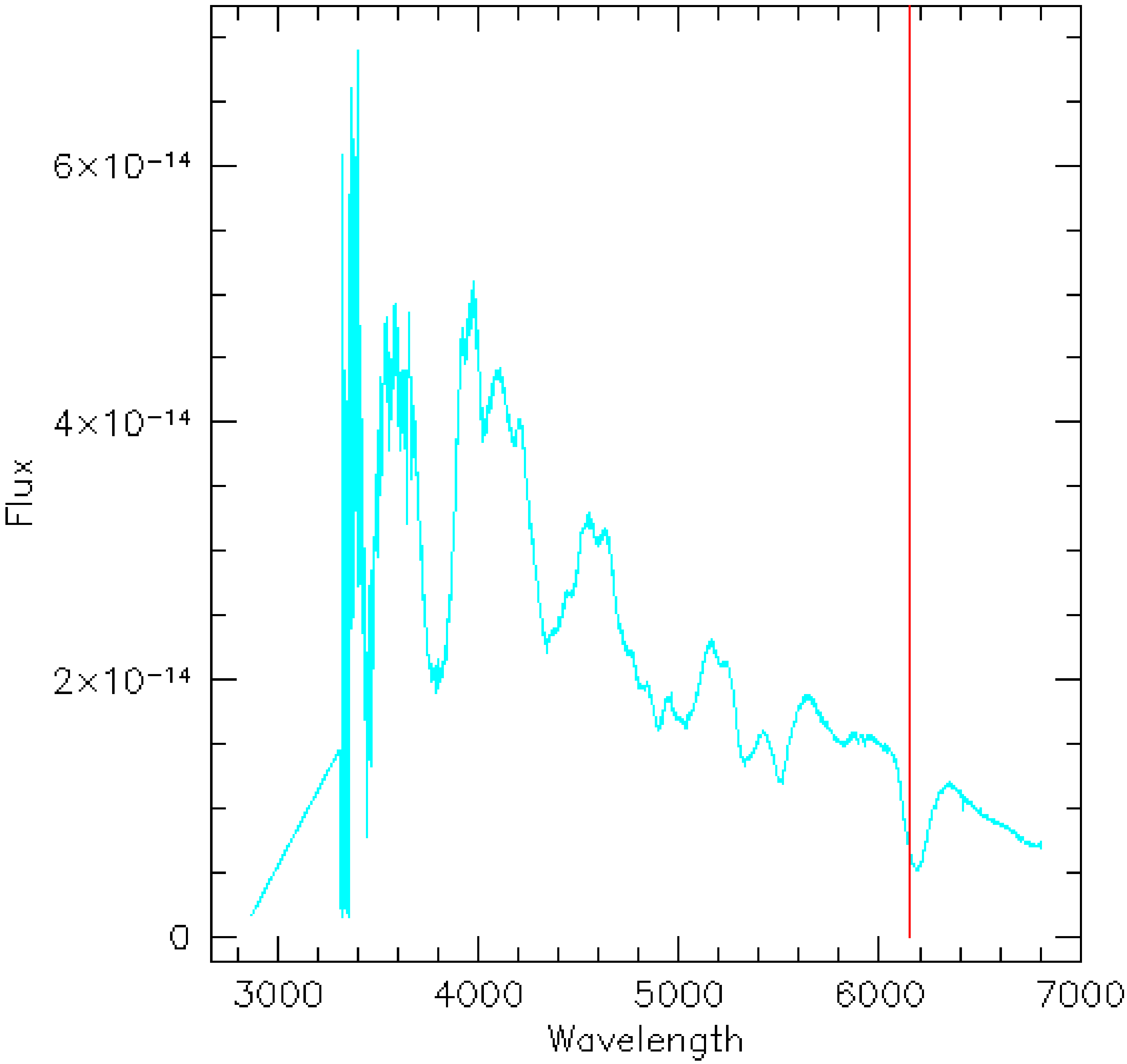
Supernova 1994ae



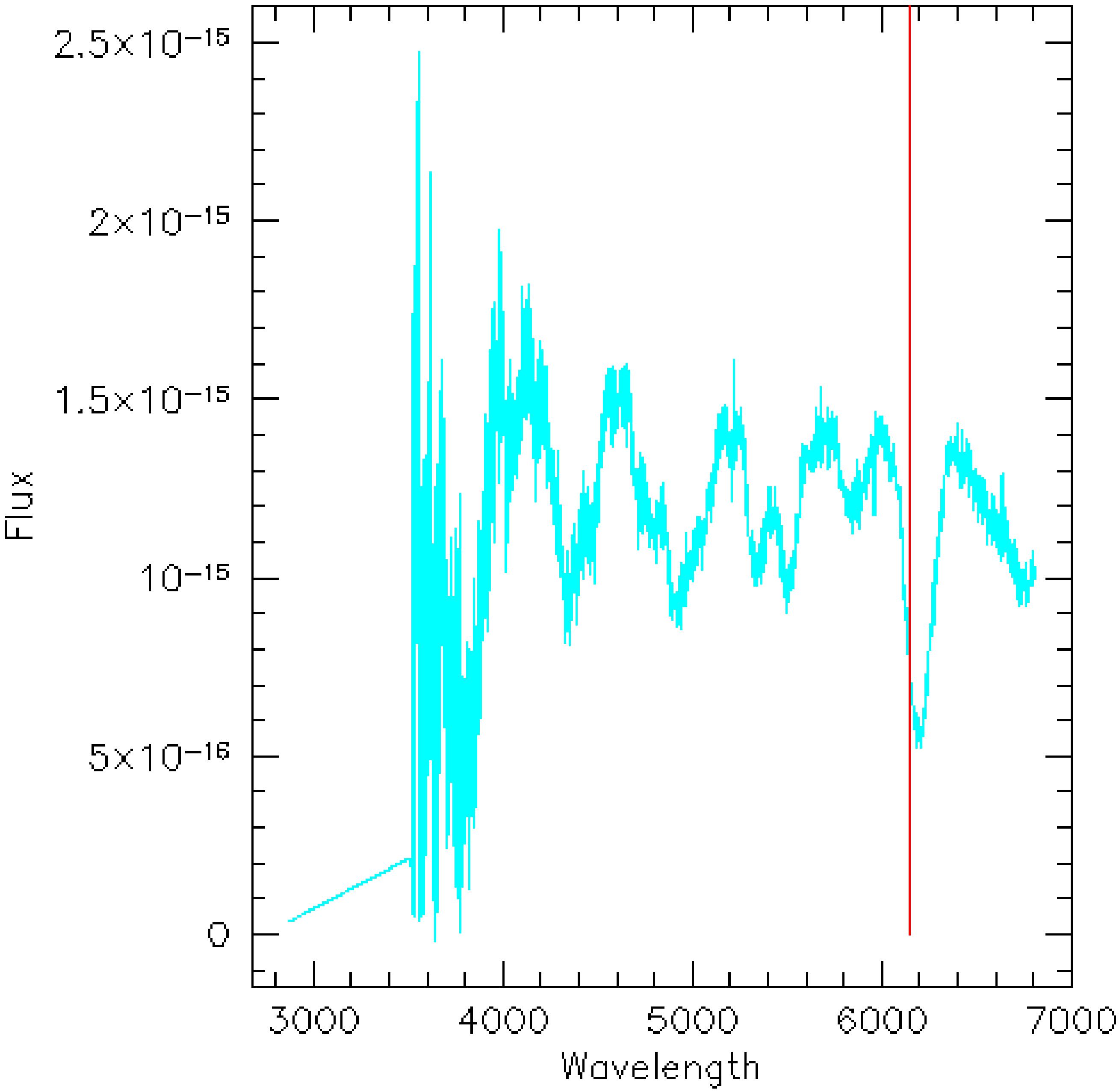
Supernova 1995al



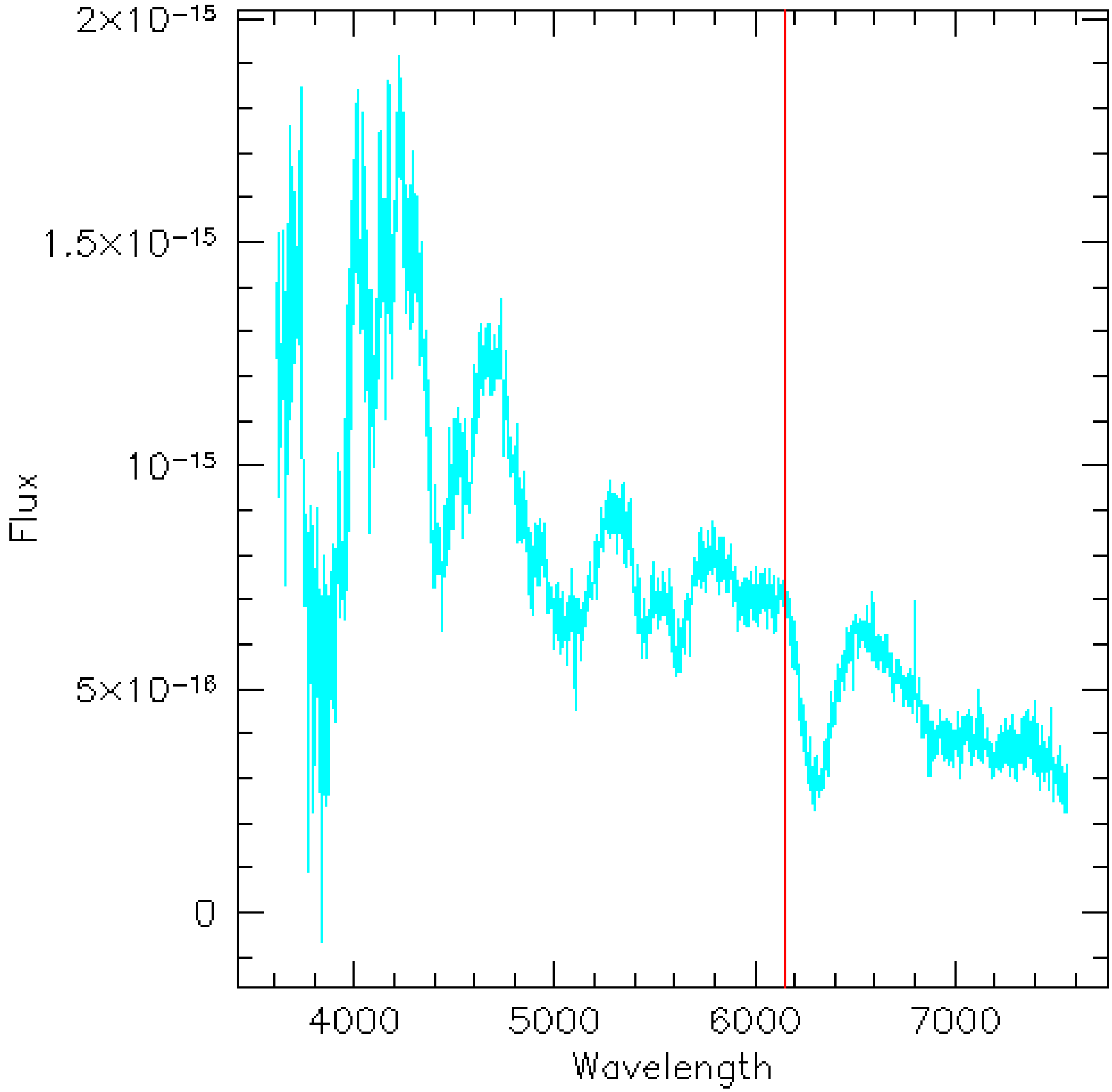
Supernova 1995ac



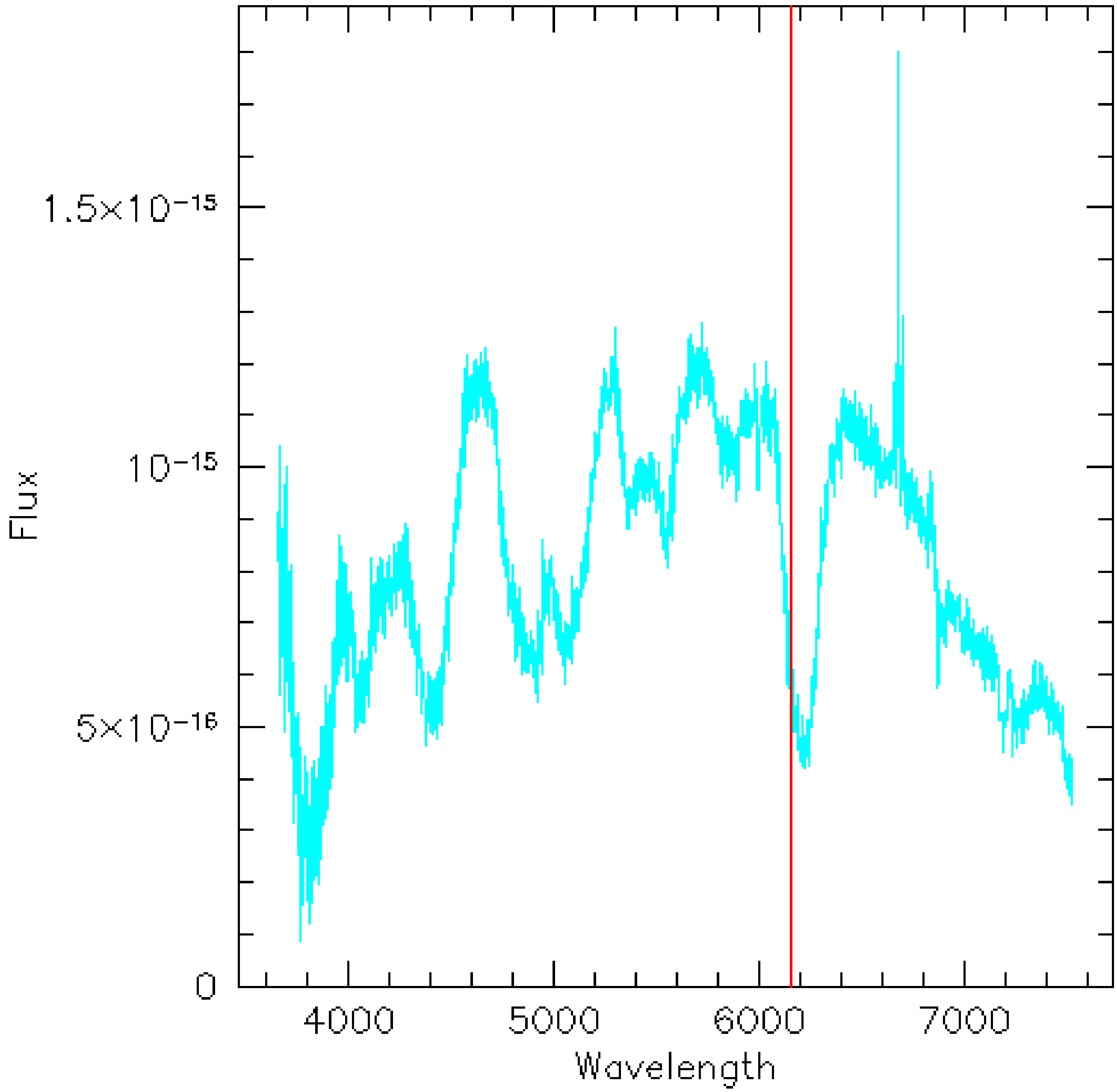
Supernova 1995bd



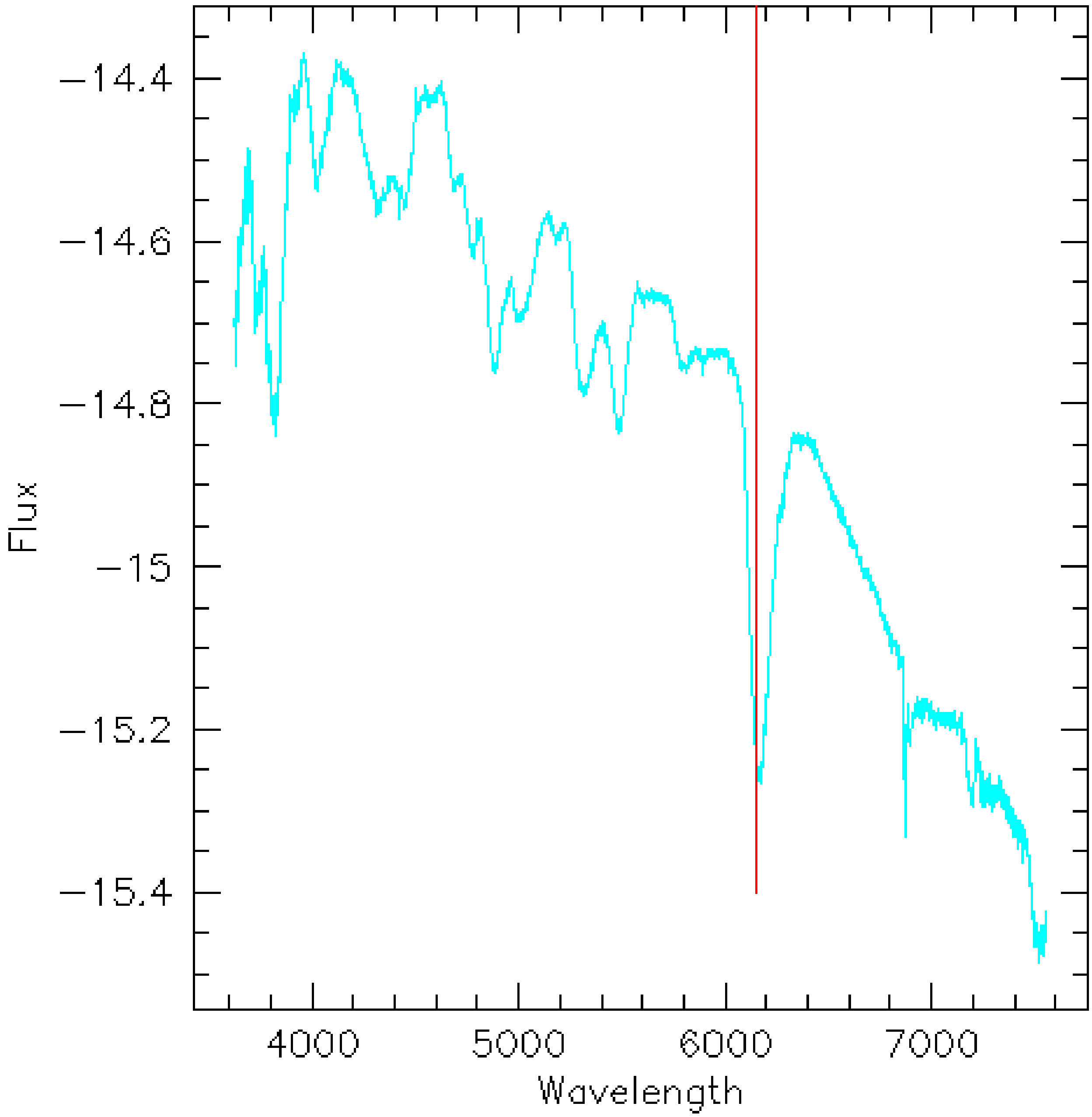
Supernova 1996X



Supernova 1996bl



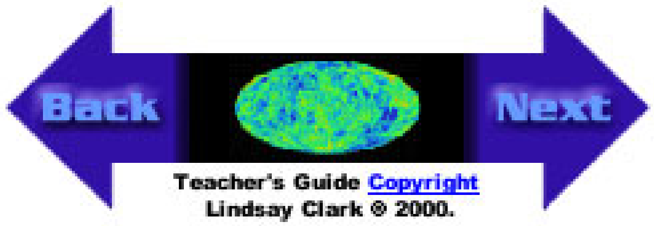
Supernova 1996bo



Supernovae Red shift Table

Supernova	Redshift
1994S	3.658
1995D	3.293
1994ae	3.107
1995al	3.188
1995ac	4.176

1995bd	3.681
1996X	3.308
1996bl	4.033
1996bo	3.714



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Supernovae Lab

Supernovae Activity - Online

Purpose: To derive a relationship between supernovae distances and their redshifts.

Directions:

1. For each supernova follow the link to its light curve, and find and click on the maximum brightness (m) on the curve. Remember the lower the number, the brighter the supernova is.
2. Find and record the distance modulus for each supernova, the distance modulus is defined: D=m-M, where m=the observed maximum brightness and M is the absolute brightness for supernovae: -19.12.
3. Use the Distance modulus (D) to find and record the actual distance in parsecs: d(distance in pc)=$10^{(D+5)/5}$ and in km 1pc=3.09×10^{13}km.
4. Return to this page using the link at the bottom of each light curve page.
5. Proceed to the red shift measurement section at the bottom of the page.
6. For each of the ten links measure the redshift as described in the next step.
7. When you click on the link you will see a graph of the spectrum of the supernova. The name of the supernova will appear at the top of the graph. This graph shows the amount of light (flux) for each color (wavelength of light) which reaches the spectrometer from the supernova. Specifically, this

spectrum is an absorption spectrum. The general hill shape of the graph shows the temperature of the supernova, and the bumps and wiggles show which elements have absorbed the light as it travelled from the supernova to the detector that took the spectrum. As you may remember the spectrum of the supernova is like its "finger print". For these supernovae, we will be measuring the Silicon II line. This is the dip in the graph that a doubly ionized atom of silicon would make when it absorbs the light from the supernova. If the supernova were not moving with respect to Earth, the Silicon II line would appear at 6150 Angstroms (6150 x 10^{-10}m), much as a car horn that is still remains at the same pitch. However, the Si II line is redshifted, indicating that the supernova is moving away from Earth similiar to the change in pitch that you experience as a car horn moves away from you which is known as the Doppler Shift. The red line on the graph indicates where 6150 Angstroms falls on the graph and the Si II "line" appears as the closest dip or trough to the right of the red line. Notice that because the Si II line moves to the right of the graph, its wavelength is longer. The light has been stretched out, which causes it to move towards the redder end of the electromagnetic spectrum which is why it is called, Red Shift.

1. Click on the graph as close as you can to the center bottom of the trough. The screen will flash and return with the flux and wavelength that you have measured listed at the top of the screen.

2. If you wish to remeasure simply click again on the graph.

3. Record the wavelength.

4. Calculate the redshift: (Your measured wavelength - 6150)/6150.

5. Scale the redshift by multiplying by the speed of light in kilometers (3x10^5 and then taking the logarithm of this product: log (speed of light*redshift). Record this number.

6. Return to this page by following the link at the top of each spectrum page or follow the link to the next spectrum.

Light Curve Links

Supernova 1994S

Supernova 1995D

Supernova 1995E

Supernova 1994ae

Supernova 1995al

Supernova 1995ac

Supernova 1995bd

Supernova 1996X

Supernova 1996bl

Supernova 1996bo

Red Shift Measurement Section

Supernova 1994S

Supernova 1995D

Supernova 1995E

Supernova 1994ae

Supernova 1995al

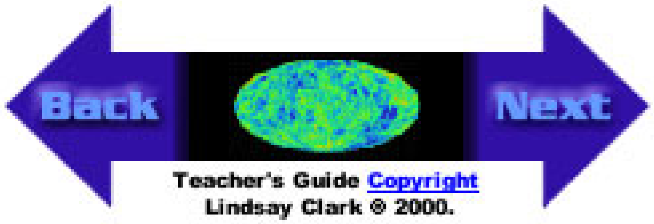
Supernova 1995ac

Supernova 1995bd

Supernova 1996X

[Supernova 1996bl]

[Supernova 1996bo]



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The Shape of the Universe

These activities are aligned with Indicators:

- National Science Education Standards
  - Teaching Standards A, B, C, D, E
  - Professional Development Standards A, B, D
  - Assessment Standards A, B, C, D, E
  - Content Standards, Unifying
  - Program Standards A, B, D
  - System Standard D
- New Jersey Core Curriculum Content Standard
  - Cross Content Workplace Readiness Standards 1, 2, 3, 4
  - Language Arts and Literacy Standard 3.3
  - Mathematics Standards 4.1, 4.2, 4.4, 4.5, 4.7 4.9, 4.10, 4.11, 4.13, 4.16
  - Science Standards 5.2, 5.5, 5.9, 5.10, 5.11

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A Teacher's Guide to the Universe

Purpose

Purpose:

- To help students begin to understand the shape of the universe the study of the curvature of the Earth.
- To help students learn about current astrophysical projects and the methods they will use to determine the curvature of the universe and its implications for the fate of the universe.

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A Teacher's Guide to the Universe

Introduction

Part of understanding Cosmology involves understanding the size of the universe. The Size of the Universe section discussed the vast expanses of the universe. Another important concept in Cosmology is the expansion of the universe that was discussed in the Expanding Universe section. After studying the expansion of the universe, students and teachers alike often wonder about its general shape. This section begins to explore the shape of the universe by discussing its curvature and the factors that ultimately control the fate of the universe.

Although the actual shape, called the topology, and the curvature of the universe are not yet known, scientists have several predictions for these interrelated characteristics of the universe. In order to begin to understand these predictions for the shape of the universe, it is simpler for students to start by studying the shape of the Earth.

These next few activities and background materials discuss the measurement of the curvature of the Earth in preparation for studying the curvature of the Universe.

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A Teacher's Guide to the Universe

Background: Measuring the Earth's Curvature

With increasing exposure to images of Earth from space, students are often very convinced of the fact that the Earth is spherical. They do not cry out in fear that their parents will fall off the "edge" of the Earth when they leave for business trips in China, because they know it is possible to fly around the Earth. Even weather maps on the evening news are beginning to show curvature due to images from weather satellites. Another idea students often are equally convinced of is that no one before Christopher Columbus' voyage knew that the Earth was round.

In order to help students begin to understand curvature of the universe by studying the shape of the Earth, students must rediscover the measurements of the Earth as were made by ancient astronomers from before Columbus' time, who did not know that the Earth is spherical as we do today. Students must forget their preconceptions of a spherical Earth and use only their scientific observations to prove that the Earth is spherical, as was done in ancient times. They must begin to observe with only what they immediately know from their surroundings. This approach to studying the universe is important because students often have misconceptions about the universe from popular media.

This activity will allow students to measure the circumference of the Earth. Begin this exercise with a discussion of how the Earth appears every day.

Perhaps have the students sit on a flat field and look around, or show them pictures of deserts or farming fields. According to our everyday experience, the Earth is flat, with small variations for hills or mountains. Ask the students if there are any places from which the Earth might not look flat. Students should come up with mountains, etc., but perhaps they have been to the beach and noticed a slight curvature, or maybe they have been on an airplane to visit faraway countries and have seen the Earth's curvature from the plane.

Next, ask the students to think about some ways of actually showing that the Earth is spherical. They should come up with ways that are obvious now but may have been either controversial or impossible in the days of early astronomy: pictures from space, or actually travelling around the Earth and ending up in the same spot. Before Columbus, some early astronomers had already figured out that the Earth is curved from observing a lunar eclipse. A lunar eclipse occurs when, in the course of their regular orbits, the Moon, Earth and Sun happen to line up in a nearly straight line. The Earth casts a shadow on the Moon, which darkens because the Earth blocks the light from the Sun.

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The Earth's shadow on the surface of the Moon is obviously curved during these eclipses, which gave ancient astronomers the idea that the Earth must be spherical.

Here is a picture taken by Fred Espenak that shows the Earth's curved shadow on the surface of the moon.

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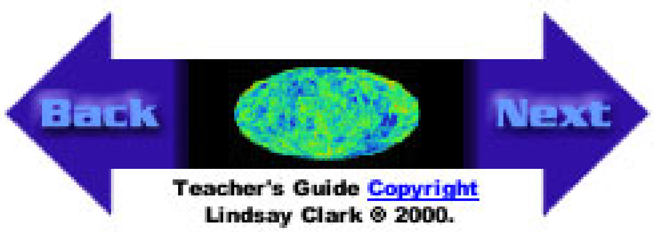
If you are interested in more images and facts about eclipses, check out: http://sunearth.gsfc.nasa.gov/eclipse/LEphoto/LEgallery.html.



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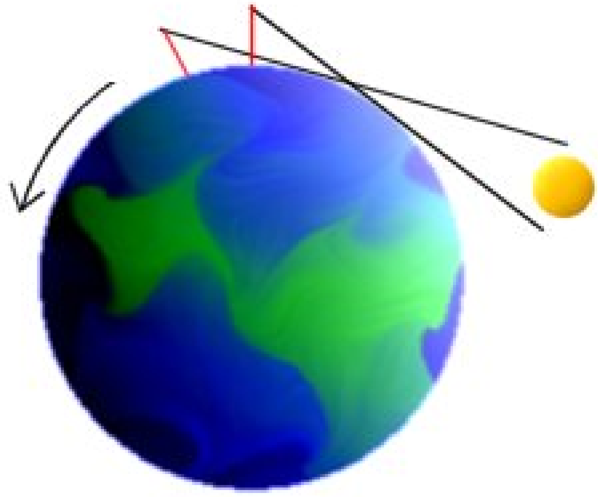
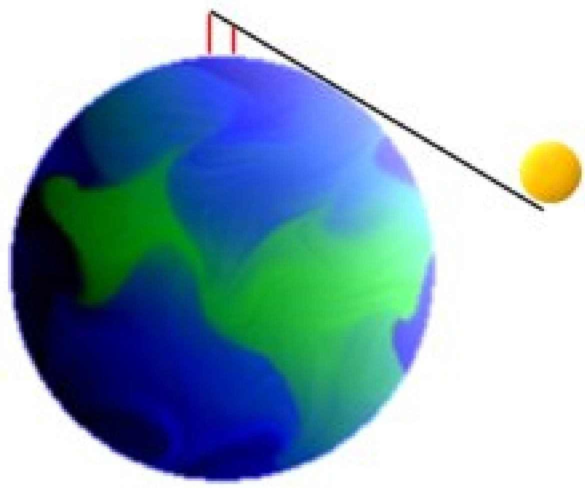
A Teacher's Guide to the Universe

Activity: Measuring the Earth's Curvature

Here is a quick experiment, designed to show that the earth is round and to calculate its circumference. It is easy to do if you are in the right location. Unfortunately, in order to do this experiment properly you must have a clear view of the sunset or sunrise over the ocean. The idea behind the experiment is this: if the Earth is round, then objects which travel away from you along the surface of the Earth will disappear from view at a certain distance. More interesting is that they disappear from the bottom up. Think of a friend walking over a hill. If you watch her from one side of the hill as she walks over the hill, her feet will disappear first and then her legs and body followed by her head. This is one way ancient sailors knew that the Earth must be rounded like a hill. They could see the tall masts of ships long after their hulls as the boats receded far away. To see why this effect occurs, look at the diagram below:



As the Earth rotates, the view from the top of the pink stick changes to reveal the sun or make the sun disappear depending upon which way the Earth is rotating. If the Earth rotates as shown the Sun will disappear. (Note: this diagram is NOT to scale.) Looking at the following diagram you can see that if you watched the sunset from a low point of view and then got up really quickly you might be able to witness the sunset twice in one day.



Based on this principle it is possible to calculate the circumference of the Earth:

Materials:

- A location where you can clearly view a sunrise or sunset over the ocean
- A friend to help you measure the height of your eyes while laying down and while standing.
- A measuring tape or meter stick
- A stopwatch
- Pen and paper to record times and heights

Directions:

1. Go to a place where you can easily view the sunset or sunrise over the ocean. Be sure to check local weather reports to know the time of day to expect the sunrise or set.

2. If viewing a sunset, make your first measurement lying down on the ground and your second measurement while standing. If viewing a sunrise, do the opposite. From now on I will explain only the directions for the sunset, please make the necessary adjustments for the sunrise experiment.

3. Before the sunset, get a friend to measure the height of your eyes while you are lying down and still able to see the horizon where you expect the sunset.

4. Prepare a stopwatch to begin counting.

5. Wait for the sunset.

6. When the last bit of sun has disappeared, start the stop watch and quickly get up and stand in a position that is directly above where your eyes were when you were laying down.

7. You should be able to see the Sun set again.

8. Stop the stopwatch when you see the last bit of sun disappear again.

9. Have your friend measure the height to your eyes in the standing position.

10. Calculate the circumference of the Earth using the following two equations:

    - Distance to the horizon

      $$D = \sqrt{2 \times Radius\ of\ Earth \times height\ of\ your\ eyes}$$

      To see where this equation came from go to : http://www-spof.gsfc.nasa.gov/stargaze/Shorizon.htm

    - $$\frac{\left(\sqrt{2Rh1} - \sqrt{2Rh2}\right)}{2\pi \times R} = \frac{s}{S}$$, Where R = The radius of the Earth

      $h1$ and $h2$= the height of your eyes during the two measurements ($h1$ should be the bigger of the two heights)

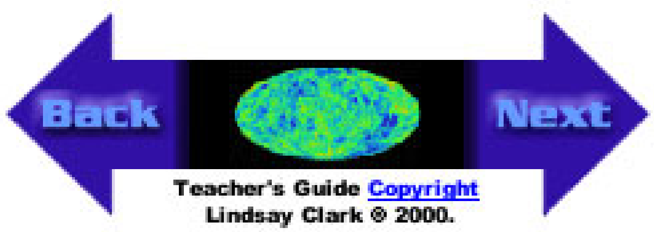
s=the number of seconds between sun sets

S=the number of seconds in one day, which is equal to 60 seconds*60 minutes*24 hours.

This equation is a proportion that assumes the Earth rotates once in 24 hours so that the difference between the distances to the horizon over the whole circumference of the Earth is equal to the ratio of the time between your measurements and a whole day.

- For example, if you measured 6 seconds in between the sunset when you were laying down with your eyes at a height of 10 cm off of the ground and the sunset when you were standing up at a height of 2m, then you would have to solve the two above equations for the radius of the Earth in terms of h_1 and h_2 (which are .10 m and 2 m) and the number of seconds in between sunsets:

$$\left(\frac{60\,s \times 60\,min \times 24\,hours \times \sqrt{2} \times \left(\sqrt{h1} - \sqrt{h2}\right)}{6\,s \times 2\pi}\right)^2 = Radius\ of\ the\ Earth$$



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A Teacher's Guide to the Universe

Activity: Measuring the Earth's Curvature II

One of the first people to make a very accurate measurement of the circumference of the Earth was Eratosthenes, a Greek philosopher who lived in Alexandria around 250B.C. He was told that on a certain day during the summer (June 21) in a town called Syene, which was 4900 stadia (1 stadia = 0.16 kilometers) to the south of Alexandria, the sunlight shown directly down the well shafts so that you could see all the way to the bottom. Eratosthenes knew that the sun was never quite high enough in the sky to see the bottom of wells in Alexandria and he was able to calculate that in fact it was about 7 degrees too low. Knowing that the sun was 7 degrees lower at its highpoint in Alexandria than in Syene and assuming that the sun's rays were parallel when they hit the Earth, Eratosthenes was able to calculate the circumference of the Earth using a simple proportion: C/4900 stadia = 360 degrees/ 7 degrees. This gives an answer of 252,000 stadia or 40,320 km, which is very close to today's measurements of 40,030 km.

With the help of another classroom and teacher who is located far (several hundred miles), to the North or South of you, your class can perform a similar experiment. Alternatively, one student or a group of students who travel for spring break could perform this experiment during their trip. Contact information for interested teachers can be submitted and received here:

Materials:

- One new wooden pencil, unsharpened, for each group of experimenters
- A flat board or surface upon which to balance the pencil and make marks

- Pencils for marking the length of shadows
- Large sheets of paper, small sheets of paper, scissors
- Geometric Compass (for drawing circles) and protractors
- Collaborating group to the North or South of you.

Directions:

1. Contact a group of students, or anyone else who is willing to help you out, at a location far (at least several hundred miles) to the North or South of you. This experiment achieves the best results if your locations are at approximately the same longitude. Arrange a day to simultaneously conduct this experiment. If the weather becomes cloudy in one location you can postpone that half of the experiment for a day or two.
2. 45 minutes or so before noon, set up the experiment outside at a flat location. Balance the new pencil on either end on the flat board. It might be difficult to balance the pencil on its end. If you cannot balance the pencil you may use a small bit of clay to hold the pencil in place. You may want to check that the pencil is completely vertical either by placing a carpenter's level on the board or by checking that both the top and bottom of the pencil are aligned with a weighted string or plumb bob. If you do not want to make marks on the board you may cover it with paper. Make sure the pencil's shadow is completely on the board. Mark on the board or paper the location of the bottom of the pencil.
3. Make a mark on the board where the end of the pencil's shadow falls. Make a mark every 5 or 10 minutes from 11:30 a.m. to 12:30 p.m.
4. Record the length of the shortest shadow and discard any other measurements.
5. Share your measurement of the shortest shadow with your collaborating experimenters. You could do this by writing and sending detailed journal articles similar to the ones found in scholarly journals (see The Astrophysical Journal Online for examples), by email, by telephone or even video conferencing (if your school has the capabilities.)

6. From a road atlas or online-directions service (http://www.Mapquest.com) determine the distance between the two locations of the experimenters.

7. Draw a circle of at least 10 inches in diameter on a large blank piece of paper. Also draw on this circle a radial line (from the center to the edge) which goes beyond the edge of the circle about 3 inches.

8. On a separate piece of paper, draw a scale diagram of each pencil and its shadow, choosing a scale in which the height of the pencil is about 4 times as large as its scaled height. Draw the pencil and its shadow so that they form a right angle.

9. Cut out the two right triangles of paper that you have just drawn.

10. Place one of the paper triangles so that its pencil side (you may want to label it P) continues the line you drew on the circle and its shadow side is lined up as closely as possible along the edge of the circle. See diagram below.

11. Draw a line on the large sheet of paper that extends the hypotenuse of this triangle. This represents the light from the sun coming in hitting the tip of the pencil and forming a shadow.

12. Now place the paper triangle on the edge of the circle so that its hypotenuse is parallel with the first triangle, its shadow side is aligned with the edge of the circle and the pencil side points directly out from the center of the circle. The hypotenuse of each triangle needs to be parallel with the hypotenuse of the other because the light rays from the Sun are assumed to be parallel since the Sun is so far away from the Earth. See diagram below.

13. Draw a line from this triangle's P side to the center of the circle.

14. Measure the angle created at the center of the circle between the two extensions of the P sides of the paper triangles. This will give you the difference in latitude between the locations of your two measurements. You could easily look up the latitudes of your locations online or in an atlas, but Eratosthenes didn't have an atlas, so we will pretend that we don't eeither.

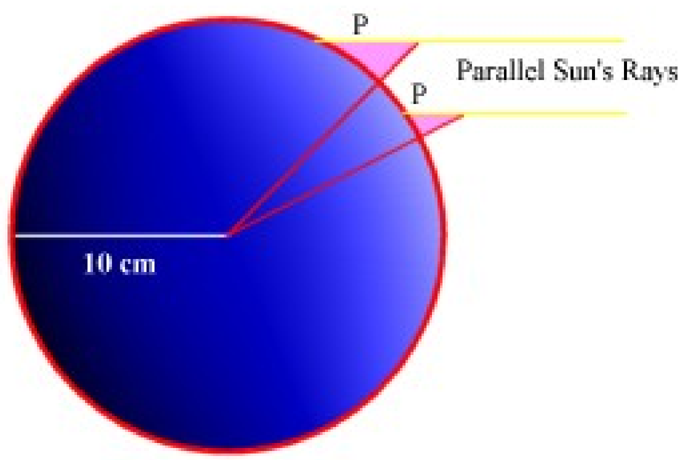
15. Now, perform calculations to get the circumference of the Earth.

    360 degrees/difference in Latitude in degrees = Earth's Circumference/ Distance between measurements

16. Use the formula Circumference = 2*pi*R to calculate the radius of the Earth

17. Look up the currently accepted value of the radius of the Earth and compare your answer.

18. Describe factors that might cause any difference you observe between values. Possible explanations include measurement error, a pencil which was placed on a slight hill, or the fact that the Earth is not a perfect sphere and is instead an ellipsoid which does not have a constant radius.



Oftentimes, schoolchildren are taught that Christopher Columbus met with opposition when planning his trip around the world because people believed the Earth was flat. Actually, many people knew at that time that the Earth was indeed round; the real confusion lay in determining exactly how big the Earth was and whether or not he should risk the trip. The reason for the confusion appears to be that an error was made converting the result of Eratosthenes' experiment (described above) into more modern units of distance measurement, which you can read about at http://www.youth.net/eratosthenes/welcome.html.

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A Teacher's Guide to the Universe

Background: Curvature of the Universe

We began our study of the shape of the universe by studying the shape of the Earth. Throughout these next few lessons it will sometimes be necessary to look to models or approximations to help us understand the characteristics of the universe we live in because many high school students have difficulty comprehending a space with more than three dimensions. We have been able to successfully measure the circumference and therefore the radius of the Earth. This demonstrates both how big, in comparison with our everyday lives and how small in comparison with the universe that the Earth really is. If we think more generally, the radius of the Earth also tells us something about its geometry. The Earth's radius is a length that best describes the rate of curvature of the surface of the Earth. For this reason, we can call it a radius of curvature. The radius is the important factor in the circumference, surface area and volume of the Earth. It is important to understand the role of the radius in an easily understandable situation since this concept will reappear when we study the curvature of the universe.

What causes the spherical shape of the Earth? One of the most obvious causes affects our daily lives and holds us to the Earth's surface; it is called Gravity. Gravity can be thought of as a force which pulls every object that has mass towards all the other masses. For this reason, every part of the Earth pulls every other part of the Earth towards itself. In addition, the force of Gravity is inversely proportional with distance, which means that the closer two masses are the harder they pull towards one another. Therefore if you add up all of these forces, which pull the parts of the Earth together, the net result is that all of the Earth's matter is pulled into a sphere. The shape of the Earth is not quite so simple, however. Other forces contribute to the shape of the Earth. Some obvious contributions to the imperfections of the Earth's spherical shape come from the plate tectonics of the Earth which form mountains. In comparison with the

Earth's siize, however, these "bumps" are truly insignificant. Less obvious is the bulge towards the Earth's Equator which is created by centrifugal force. As the Earth spins on its axis, the fastest moving parts, the parts at the equator, get pulled out away from the center of the Earth, making the slightly bulged or ellipsoidal shape. The two equations, which must balance against each other on every part of the Earth, are gravity which pulls inwards and centrifugal force which pulls outwards. Their equations are:

- Force of Gravity: $F = \frac{Gm_1m_2}{R_E}$

  Where G = a constant (6.67…)

  m_1, m_2 are masses which attract each other

  R_E is the Radius of the Earth

- And Centrifugal Force: $F = \frac{mv^2}{r}$

  Where m is the mass of the rotating body,

  V is the velocity the rotating part has

  R is the distance from the center of rotation.

How does this relate to the Universe? The shape of the observable universe, the part we can see, is a sphere. To understand why the observable universe is a sphere and exactly how big it is we need to go far back in the history of the universe.

In the Expanding Universe section, we discovered that at some time in the distant past the universe was much hotter and denser than it is now. The evidence for this description of the early universe came from the supernova data, which showed that the farther away an object was from our point of observation, the faster it was travelling away from us. This meant that if all of the objects we could see were travelling away from us at some speed, then at some point in the past they must have been closer to us, resulting in a hotter and more dense universe. We used this evidence to approximate the age of the universe. Knowing that the slope of the line created in our Hubble diagram was in units of 1/time and calling it the Hubble Constant, we took the reciprocal of h_0 to find the time that has elapsed since this hotter denser state. We decided that this represented the age of the Universe. We calculated this length of time to be approximately 15 billion years.

This length of time is important because it regulates the size of the observable universe. Imagine the Earth at the center of a very large sphere. Imagine lots of stars on the outside surface of this sphere and nothing in between the stars and the Earth. We know from studying the speed of light that the distance to the surface of the sphere could be calculated from the speed of light and the length of time it took the light to reach Earth from the stars. In a similar manner, if we knew that certain light sources we could see were 15 billion light years away, then we know that we are seeing them as they were 15 billion years ago and that it took the light that long to travel to us. Because this could happen in any direction, we know that there is a sphere 15 billion light years away which is the farthest distance we can see. This is known as the observable universe. The only reason that this sphere is not any bigger is that the light has not had enough time since the beginning of the universe to reach the Earth. This sphere is, of course, expanding all of the time since with each second the universe gets one second older and light can travel one light second farther. In reality, we cannot always see right to the earliest parts of the universe. Lots of things get in the way and block our view of the universe, such as giant dust clouds and lots of other galaxies.

The shape of the observable universe does not tell us the whole story, however. The universe as a whole could have many different shapes, each of which have different properties. One of the most important properties is called curvature. The Earth, which is a sphere-like shape, has positive curvature. There are also possibilities for the shape of the universe that have negative curvature. We will explore these shapes in the next activity, but first we must examine what might cause these different shapes.

The Earth's shape was determined primarily by the force of gravity, so it is reasonable to think that gravity may be the cause of the shape of the universe. Scientists have discovered that gravity is also responsible for holding together the powerful explosions that heat the stars and for holding together the galaxies of stars and clusters of galaxies. For this reason, perhaps we should examine gravity as the primary force which shapes the universe.

Since gravity is a force which is dependent both on mass and distance, we can easily study it by examining the density of the universe, which is a factor of mass/distance^3. Imagine there is a fixed amount of mass in the universe and a fixed volume. The density of the universe would therefore equal mass/volume. If gravity were the only force controlling this mass, then gravity would pull everything in this volume together and form a very dense ball of mass. So, why is the universe in which we live so spacious a place? There must be something which opposes this gravitational attraction.

To discover what opposes gravity, we must again look to the expansion that we uncovered from the supernova lab. Whatever is causing this expansion must be opposing gravity. We can think of the balancing of these factors in this way. Imagine that you are standing on Earth and throwing a ball in the air. You give the ball some kinetic energy and as it rises in the air this energy is converted to gravitational potential energy. Eventually all of the kinetic energy is converted and the ball has a velocity of zero and then the potential energy begins to convert back into kinetic energy and the ball returns to Earth. You could imagine a situation where this is not the case, however. Imagine that you threw the ball so hard that the Earth's gravity could not pull the ball back towards itself and instead the ball kept going into space. This is the situation that could happen if you threw a ball at the Earth's escape velocity. You could also imagine a situation in the middle of these two extremes: you threw the ball just hard enough that it will not escape the Earth's gravity and yet it will not return to the Earth's surface. This situation is called orbit. When a shuttle orbits the Earth, it has just enough energy to escape falling back to Earth, but not enough to completely escape the Earth's gravitational pull and therefore it remains balanced in orbit.

In the case of the universe, let's try to define the expansion and contraction factors that are opposing one another in terms of energy. First we have the kinetic energy from the expansion of the universe. If we assume that we are calculating the relationship of these energies in spherical shells then the kinetic energy from the expansion of one of these shells is: $\frac{1}{2}mv^2$ where m is the mass of the shell and v is the velocity due to the expansion. The gravitational potential energy due to one of these shells is –Gmm/r, where G is the gravitational constant as before, m is the mass of the shell as above, r is the distance from the center of the shell to the surface of the shell, and m is the mass of all the stuff inside the shell. This mass can be calculated from the density (d) inside the shell times the volume inside the shell: $\frac{4}{3}\pi r^3$. The total energy of the shell equals:

$$\frac{mv^2}{2} - \frac{Gm_1m_2}{r}$$

If we substitute in v=Hr which we learned from the Hubble diagram in the Supernovae Lab Activity and $m = d \times \frac{4}{3}\pi r^3$ from above this equation becomes:

$$M\left(\frac{H^2r^2}{2} - \frac{4}{3}G\pi d\frac{r^3}{r}\right)$$

Since the mass of this shell is constant and so is the energy we can divide out some of the constants and substitute k for (the total energy of the shell * (2/m)) to get the equation:

$$H^2 - \frac{8}{3}\pi Gd = \frac{k}{r^2}$$

This equation was discovered independently by Alexander Friedmann and Georges Lemaitre. What this equation tells us is exactly what we learned from the ball analogy: there is a balance between two types of energy and for differing values of d there will be very different outcomes. Remember the ball could fall back to Earth, fly far away from Earth or balance in between. For our equation of the universe, we will call the value of d which just balances the equation d(critical): $d_{critical} = \frac{3}{8} H^2 \pi G.$ In this case H equals the Hubble constant that we calculated using the Hubble Diagram. To date, scientists have tried many methods to calculate the actual value of the density of the universe without reaching a consensus. We are therefore unsure what will happen to the universe, but there are three possible scenarios:

- The density is more than d(critical): The universe will one day reverse direction and collapse back on itself,
- The density is exactly critical: The universe will just barely expand forever,
- The density is less than critical: The universe will continue to expand forever.

We began writing these equations to see how gravity affects the shape of the universe. So what does this equation mean in terms of the shape of the universe? In order to understand this we must look to one of the most well known and respected scientists, Albert Einstein. Einstein reinterpreted the constant k from the above equation. We had said that k was a value for energy. Einstein instead interpreted it as a measure of the curvature of space. In the simplest of terms Einstein rewrote this equation as : "Matter tells space how to curve, and space tells matter how to move," (this description of Einstein's interpretation comes from John Wheeler's Gravitation). In other words, the curvature of space, like the curvature of the Earth is directly linked to the gravity which tells matter how to move. We can also reinterpret our three scenarios to describe the curvature of the universe,

- Density is more than critical: The universe will eventually re-collapse, k=+1 and the curvature is considered positive. This means it is like the surface of the Earth.
- Density is exactly critical: The Universe is will just barely expand forever, k=0 and the curvature is considered flat. This means it is a plane just as in Euclidean geometry.
- Density is less than critical: The universe will expand forever, k=-1 and the curvature is considered negative. This means the surface is hyperbolic or

saddle shaped. You can most easily think of a hyperbolic space in two dimensions as a rubber sheet which has two opposing corners pulled up and the other two corners pulled down, or the basic shape of a horse saddle.

In the next activity we will examine more closely what it means for a surface to have negative or positive curvature; however, let's first consider the following example. Imagine two laser beams which are aligned completely parallel on a flat surface. If the beams continue forever without being interrupted, the beams will never intersect. This is one of the definitions students may learn in regular geometry class. Now if you put these beams on a spherical surface, like that of the Earth, and made the condition that the beams had to stay on the surface then the beams behave differently. On a spherical surface, beams (or straight lines) which start out parallel can intersect. Think of lines of longitude. They are parallel at the Equator and intersect at the poles. Now imagine a surface on which the parallel lines do not remain parallel and do not intersect but actually diverge from one another. One surface which has this property is called hyperbolic.

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A Teacher's Guide to the Universe

Activity: Curvature of the Universe

Materials:

- String cut into several different lengths, a few inches, a foot, three feet etc.
- Protractors
- A globe, or several if possible
- A horse's Saddle if possible or try making a hyperbolic sheet from paper or cloth as decribed here.

Directions:

1. Have students form small groups.
2. Give each group one of the lengths of string, spreading the different lengths around the room. Have a different length of string for each group.
3. Have the students first make a triangle on a flat piece of paper using the string as the perimeter.
4. Have them measure the angles of the triangle. They should discover that their angles add to 180 degrees.
5. Have them make new triangles on the paper until they are convinced that not matter what shape triangle they form the total angle summation will equal 180 degrees.
6. Now have them make a triangle on the globe using the string as the perimeter.

7. Have them stretch the string as tightly as they can on the surface of the globe.

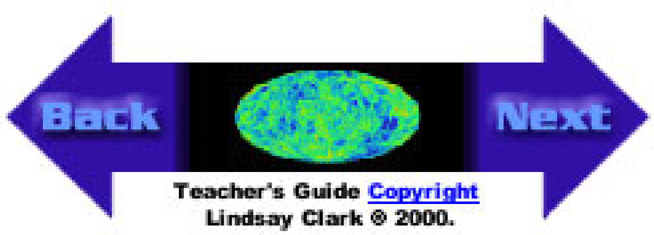
8. They may find that the sides of their triangle are not straight lines. This is because on the surface of a sphere the shortest distance along the surface is not a straight line. It is actually a portion of what is called a Great Circle. A Great Circle is a circle on the surface of a sphere which has the center of the sphere as its center. For example all of the lines of longitude are Great Circles, but the only line of latitude which is a Great Circle is the Equator. In general terms the shortest distance along any surface is called a geodesic.

9. Have them measure the angles of their triangle and record the sum of the angles.

10. If you have a saddle or hyperbolic sheet, try the same procedure. The geodesic for a hyperbolic surface is a hyperbola. This may not work as well as for the globe because the curvature is not smooth and may have imperfections. See 12.

11. Have the students tabulate their results on a chalkboard in the front of the room for each of the surfaces. See if they can find trends based upon the length of the string and the sum of the angles.

12. If a saddle or hyperbolic sheet are unavailable, have students complete the exercise on the globe and flat piece of paper. Explain that a hyperbolic surface has the opposite result from a sphere. The angles of a triangle on a hyperbolic surface add up to less than 180 degrees.



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Activity: Curvature of the Universe II

Astronomers have tried to look for evidence of curvature by studying the number of galaxies they can see in the distant universe. As they look out they expect that the number of galaxies that they can see should stay about the same as right near them, or in other words the galaxies should be evenly distributed throughout space. If the universe is positively or negatively curved, however, the evenly spread galaxies will either appear less or more dense far from the observer.

Purpose: To examine why evenly spread galaxies in the Universe would appear less or more dense in a positively or negatively curved universe

Materials:

- Rulers
- Paper
- A spherical surface which can be written on and cut up such as the domed top half of a 2 liter bottle, or ideally the plastic lid which is often placed on top of frozen yogurt or slushies.
- Stretchy material in square pieces about a foot per side or a hyperbolic sheet made as described here.
- Pens which can mark on the spherical surface and material.

Directions:

1. Have the students make evenly spaced marks on the domed surface using the rulers and pens.

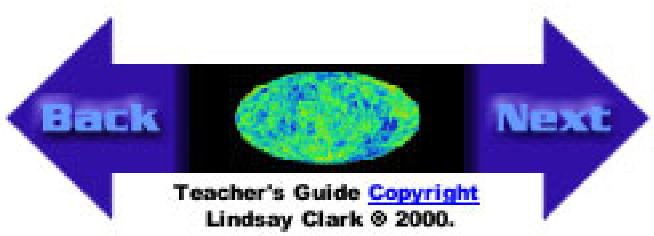
2. Also, have them make evenly spaced marks on the flat paper.

3. Have one student from each group hold two opposite sides of the stretchy material up and another student hold the other two sides down to form a surface which approximates a hyperbolic one. Have a third student mark evenly spaced marks over the surface of the stretched surface. If you have a hyperbolic sheet try making the marks as evenly as you can without destroying the surface.

4. Now, because these are representations of 2 dimensional surfaces in 3 dimensions we need to make flat maps of the locations of these evenly distributed particles. To do this, simply leave the flat paper map flat, let the lycra material go and lie flat on the table and take scissors and cut radial slits in the plastic lid so that it too can lie flat on the table. If you have a hyperbolic sheet simply observe the sheet from above. For further discussion of mapping between dimensions see below.

5. Have the students come up with a trend which describes the new location of the "evenly spread" dots. Starting from the center of each surface and moving out in rings describe the density of the dots. Students should find that the dots on the spherical surface now grow less dense as you move from the center, the dots on the plane surface remain at the same even density, and the dots on the "hyperbolic" surface grow more dense towards the edges.

6. Explain to the students that Princeton Physicists have tried to examine the curvature of the universe by plotting the concentration of galaxies which are assumed to be evenly spread throughout the universe. Their results seem to be closest to the flat paper model suggesting that the density of the universe is nearly critical.



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Additional Information and Activities

The MAP (Microwave Anisotropy Probe) satellite also hopes to measure the curvature of the Universe by using a technique similar to the angle measuring technique described above. While at first thought it might be easiest to use lasers and actually draw large triangles through space, this is not a very practical experiment. The actual technique, however, does something very similar. The MAP satellite, after it is launched in the Fall of 2000, will look at the cosmic microwave background, which is energy left over from when the universe was hot and dense and is now stretched out and cooled. The satellite will look specifically at very tiny fluctuations in the otherwise very uniform temperature of the cosmic microwave background. The scientists involved with MAP expect that the largest fluctuations will be 1 degree on the sky. They are the fluctuations that correspond to the distance a sound wave can travel from the hottest densest moment of the universe's history, sometimes called the big bang, to a moment when the energy had cooled down to 4000 kelvin (Temperature in kelvin = degrees Celsius - 273). This distance is called the sonic horizon. The reason this distance is easy to measure is because the soup of protons and electrons which made up the early universe was so hot that light could not easily get through it. Think of this soup as a rain cloud. The cloud is not transparent to light; the light has a hard time getting through the cloud. The water vapor right next to the cloud, however, is transparent to light and light can travel easily straight through it. If something, perhaps a giant explosion, made a big wave in the cloud we could see it on the surface of the cloud. If we knew some of the properties of the cloud, for example the density of the cloud, and what was causing the wave we should be able to predict how big the wave would be. The early universe was like this cloud and the wave on the surface, which in this case is called the surface of last scatter, is analogous to the sonic horizon. Now, what can we do with this sonic horizon? Think back to the triangle experiment. If we knew the length of one of the sides and the angle across from it on a flat surface, and then we measured that angle on another surface and it was smaller, then we would know that our triangle was on a hyperbolic or negatively curved space. Conversely, if we measured the angle and it was larger than the angle we expected on the flat triangle, then we would know our triangle would be on a spherical or positively curved space. The MAP scientists will look at the sonic horizon and measure the angle it covers on the sky. They expect this angle to be 1 degree, but if the curvature of the universe is something other than flat then the angle they measure will be different.

Students can think of this angle change as a remapping of the way light appears on the sky. To return to the example of the Earth, mapping the surface of the Earth, which is a two dimensional surface in three dimensions, to a flat sheet of paper is difficult to do well. Many different ways have been developed. They are known as Map Projections. Unfortunately many different maps distort either angles or distances and consequently distort our perceptions of things like relative continent size. Take the Mercator projection for example: It distorts the size of Greenland making it nearly as large as Africa.

There are several activities you can have students complete to understand the distortions maps create when modeling the surface of the Earth. Here is an activity which describes how to make a Mercator Projection map. I would suggest after creating the grid as described here you paste some paper shapes on the globe and have the students draw in the shapes using their coordinates in latitude and longitude. By using regular shapes that are the same size on different parts of the globe the istortion becomes very clear. There are also many web sites which describe many map projections. Here are a few.

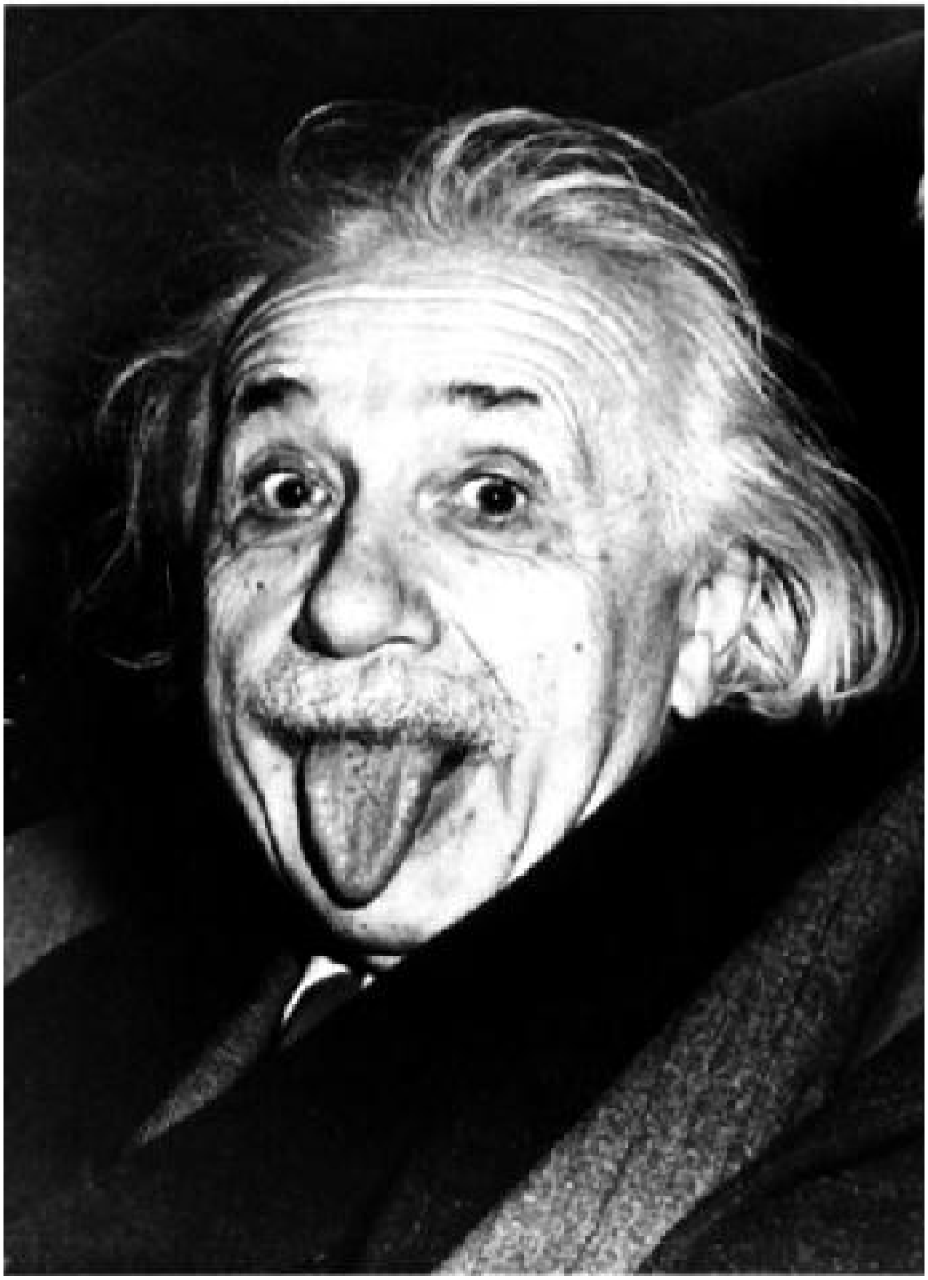
http://www.ahand.unicamp.br/~furuti/ST/Cart/CartProp/DistPres/distPres.html

http://tectonic.nationalgeographic.com/2000/exploration/projections/index.cfm

http://everest.hunter.cuny.edu/mp/

If you have the resources available you could have students look up many projections on the web and have them report to the class about the distortions of their particular map.

Another fun example which illustrates distortion is looking at a picture which has been mapped to a globe. Here is a 2-D picture of Albert Einstein.



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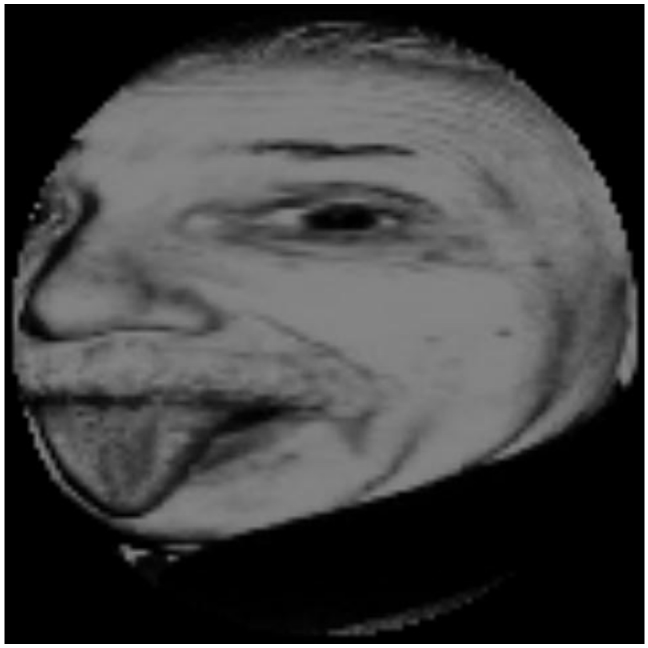
Here is how it looks mapped using an orthographic projection. An orthogrphic projection shows a 2 dimensional depiction of a three dimentional surface



Here is how it looks when many of these 2 dimensional images are put together to give the illusion of a three dimensional mapping of Einstein's Picture:

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Other Resources

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- Web Sites and Youth Books

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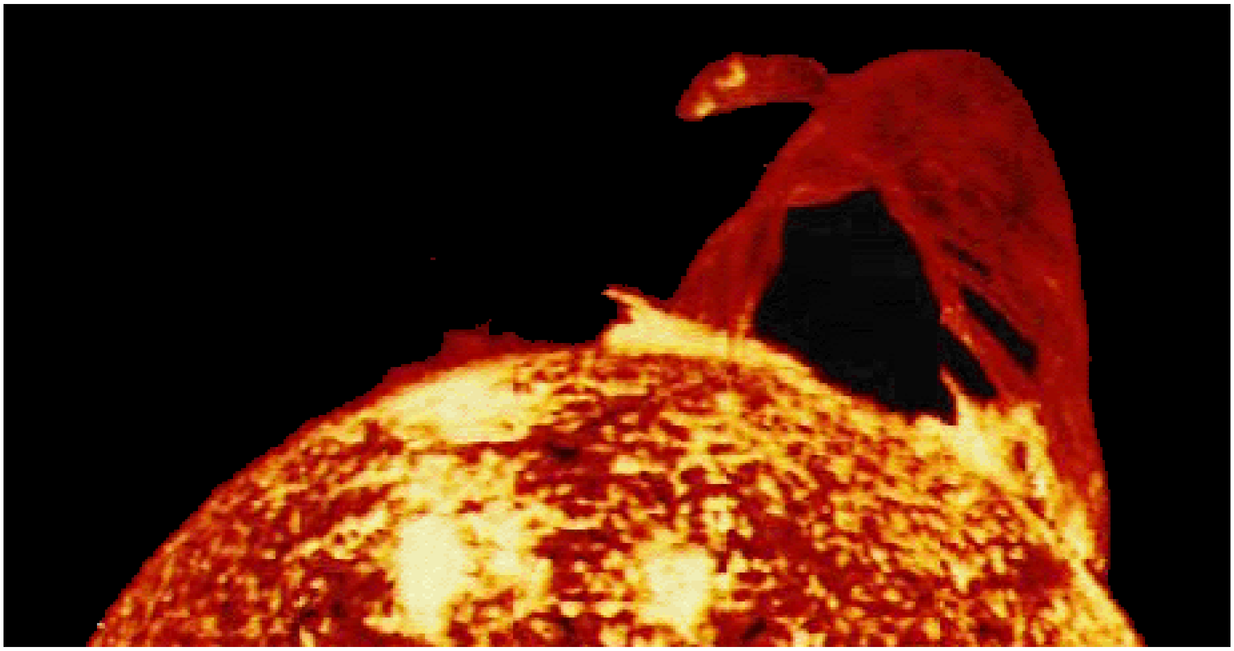
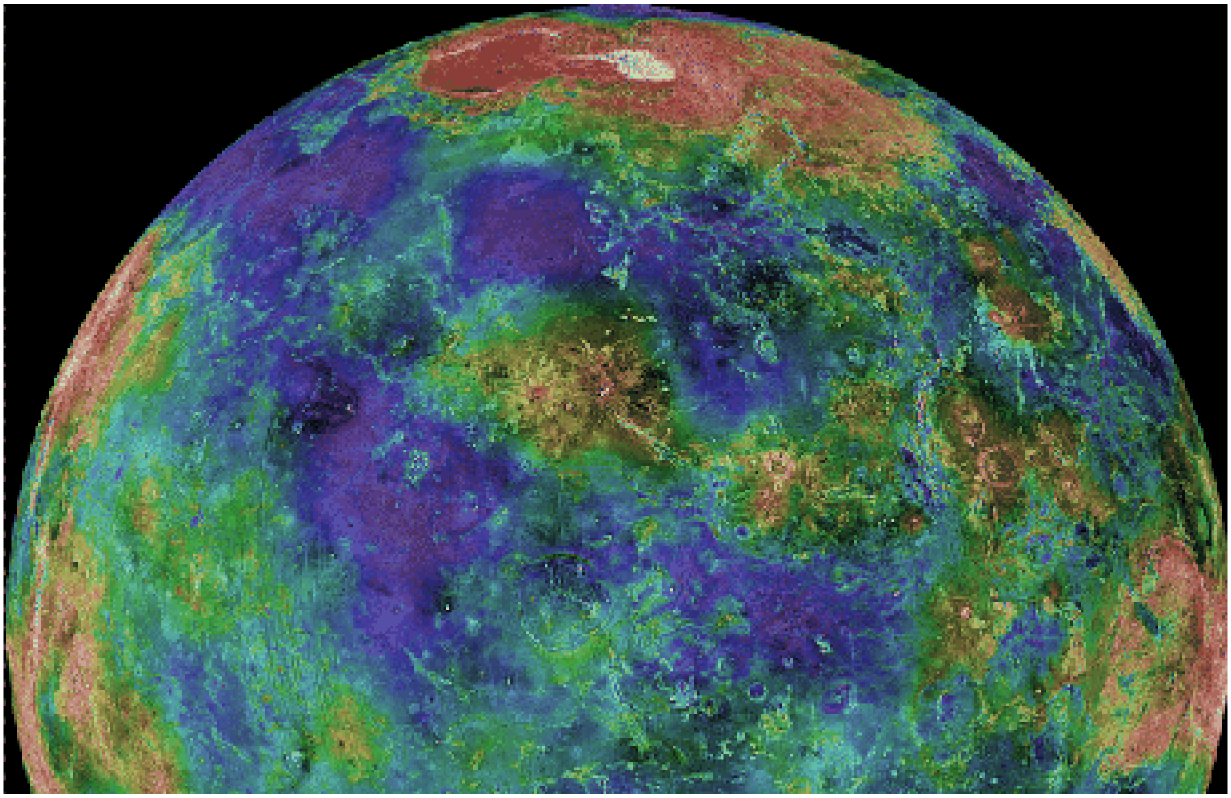
Pictures

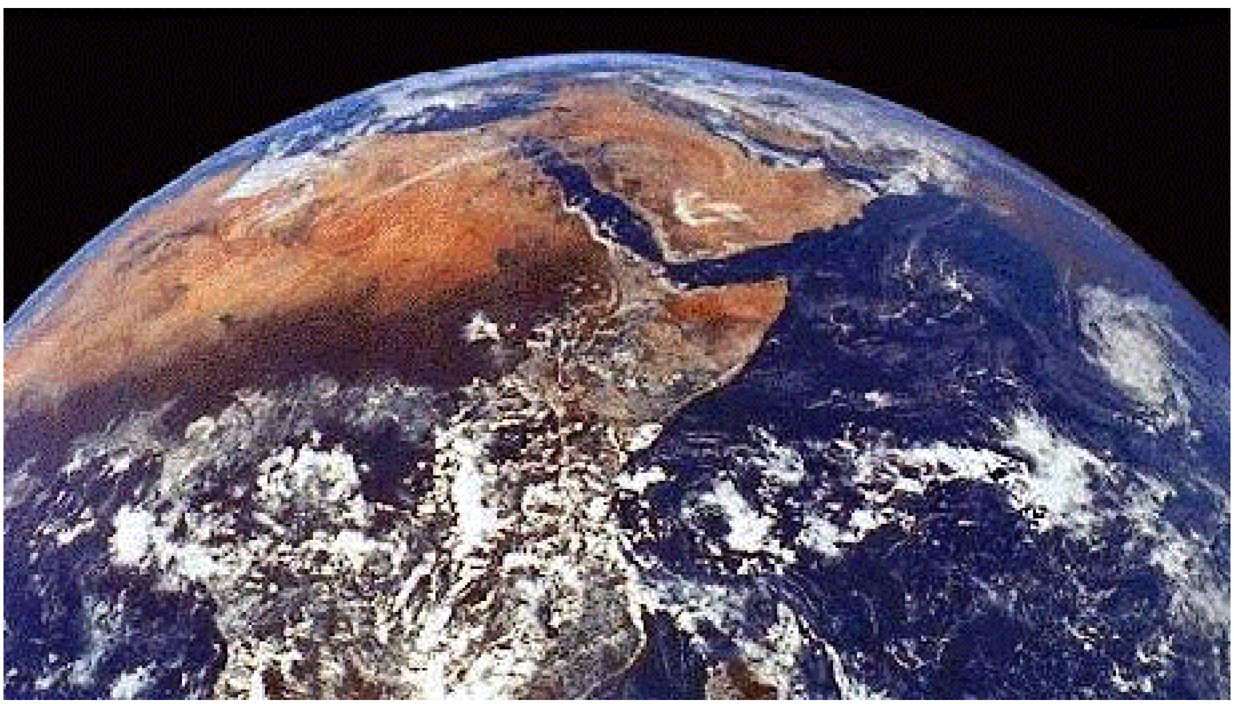


The Sun 40

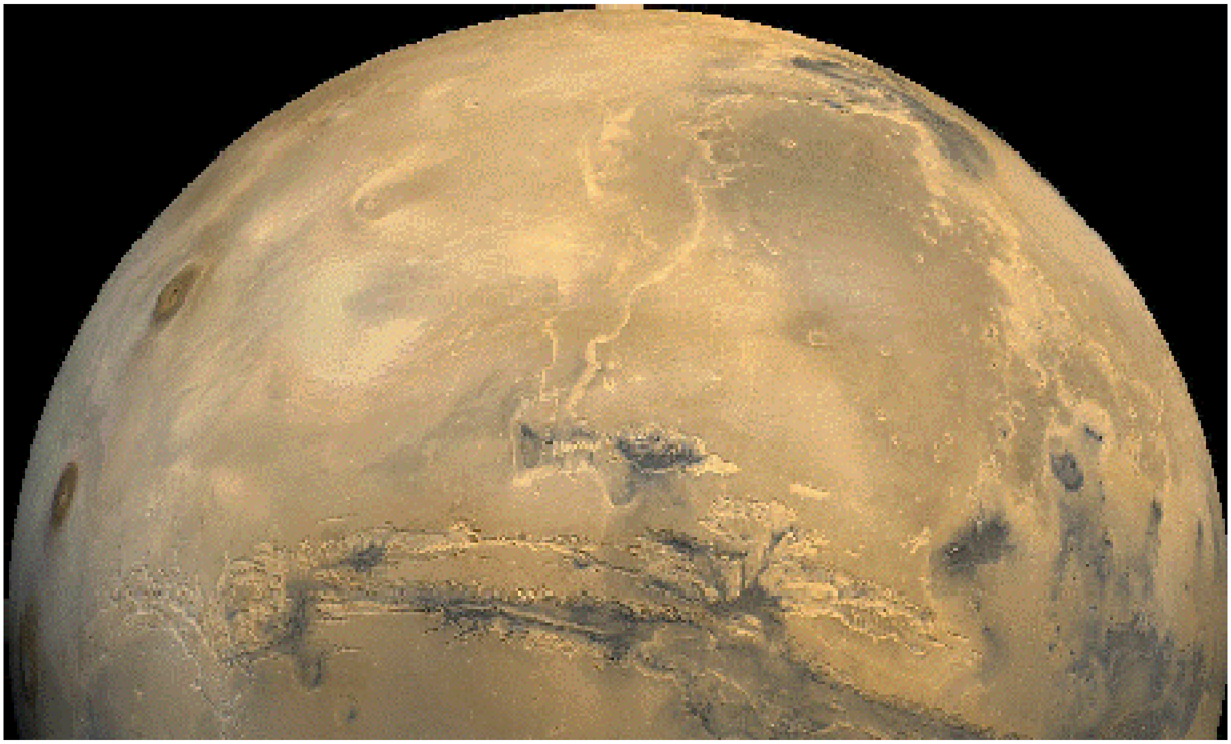
Mercury 41



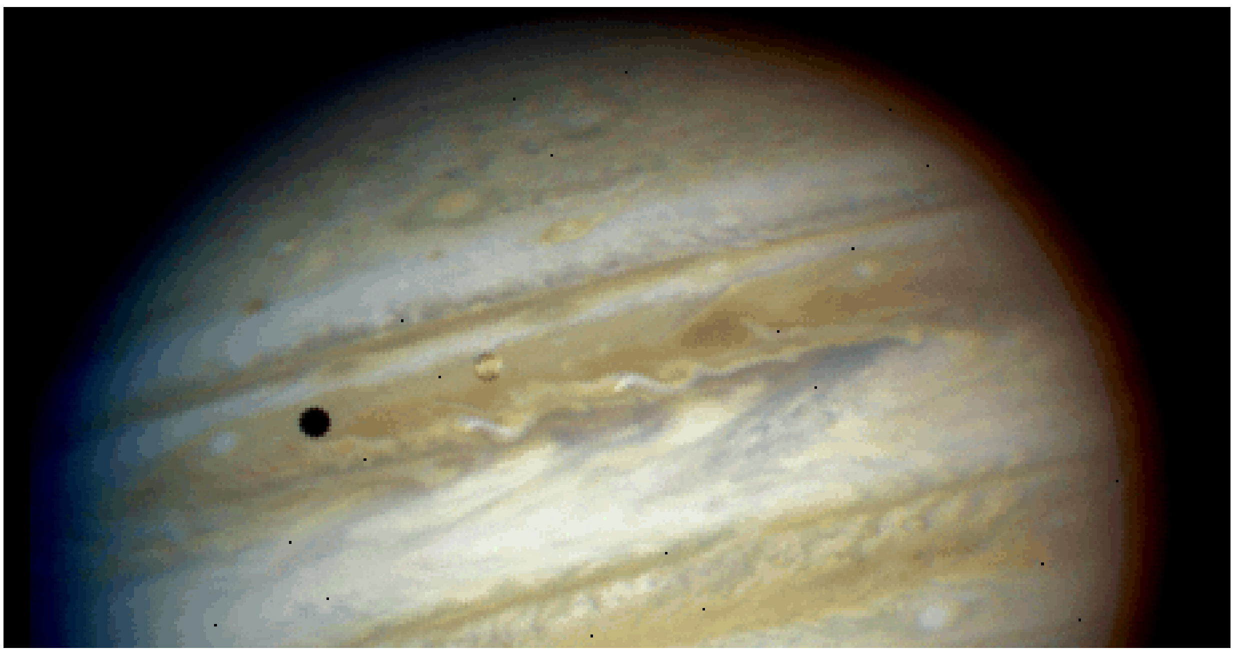
Venus 42



Earth 43

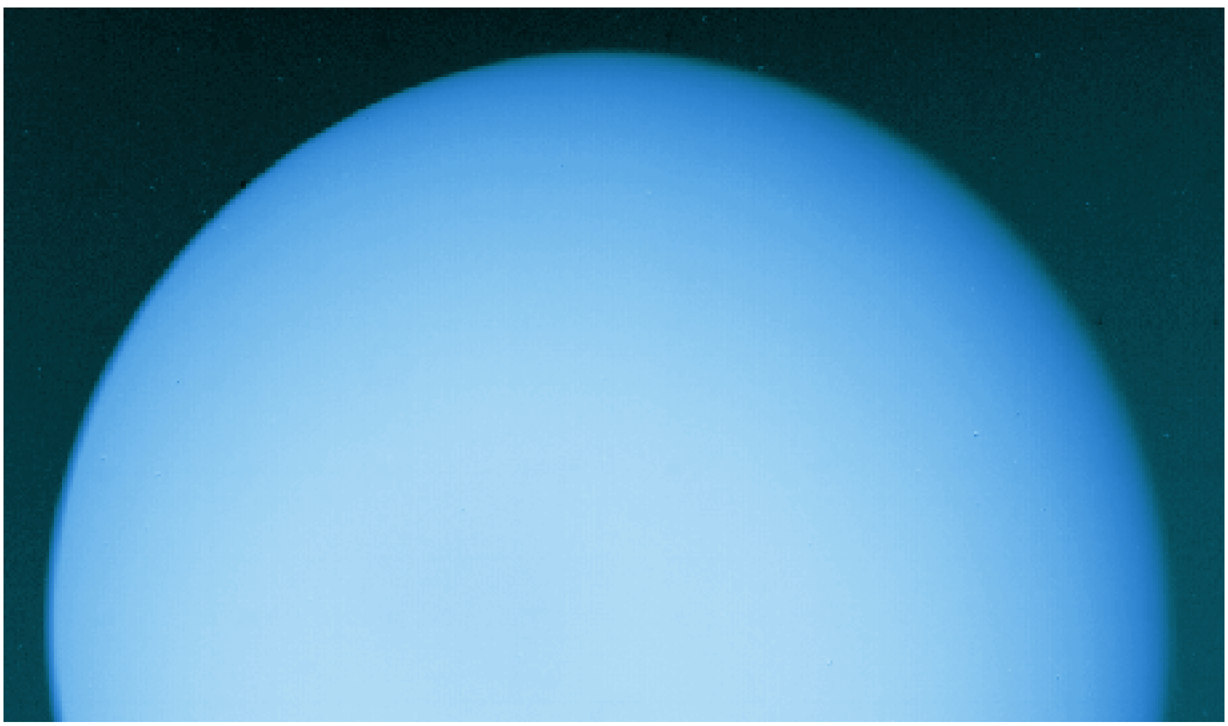


Mars 44

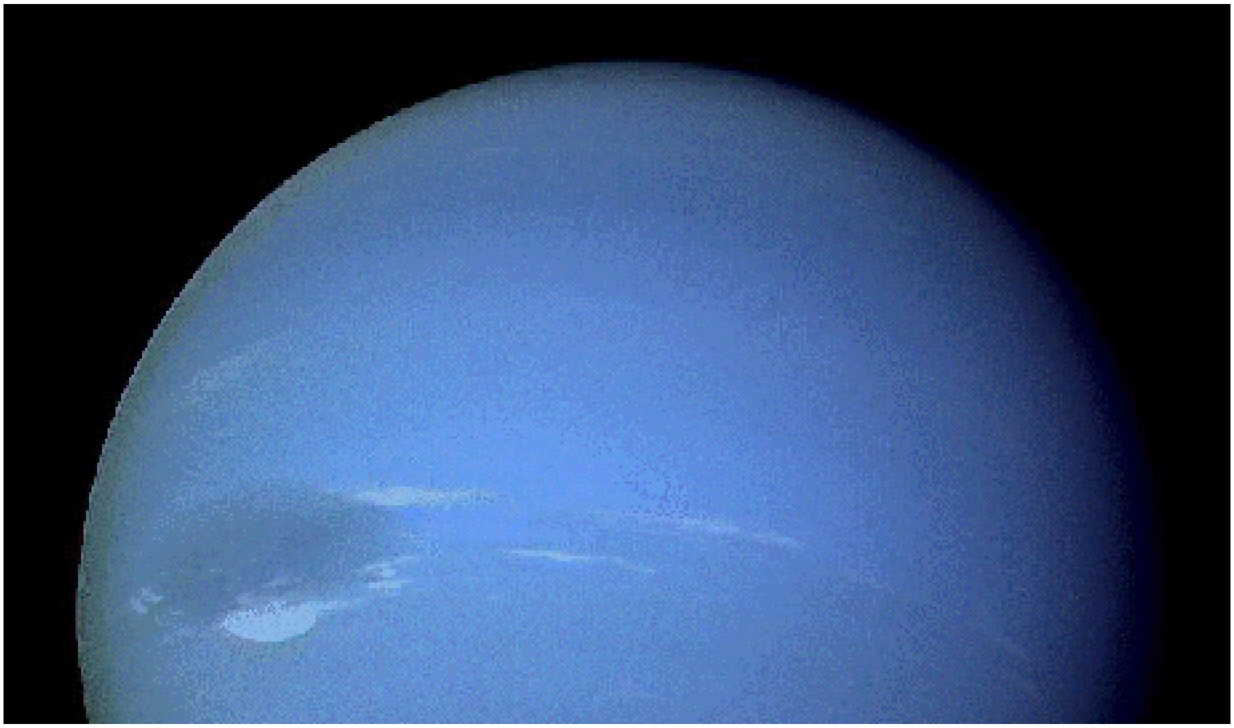


Jupiter 45

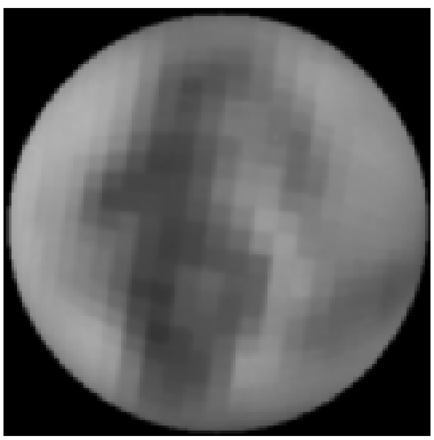
Saturn 46



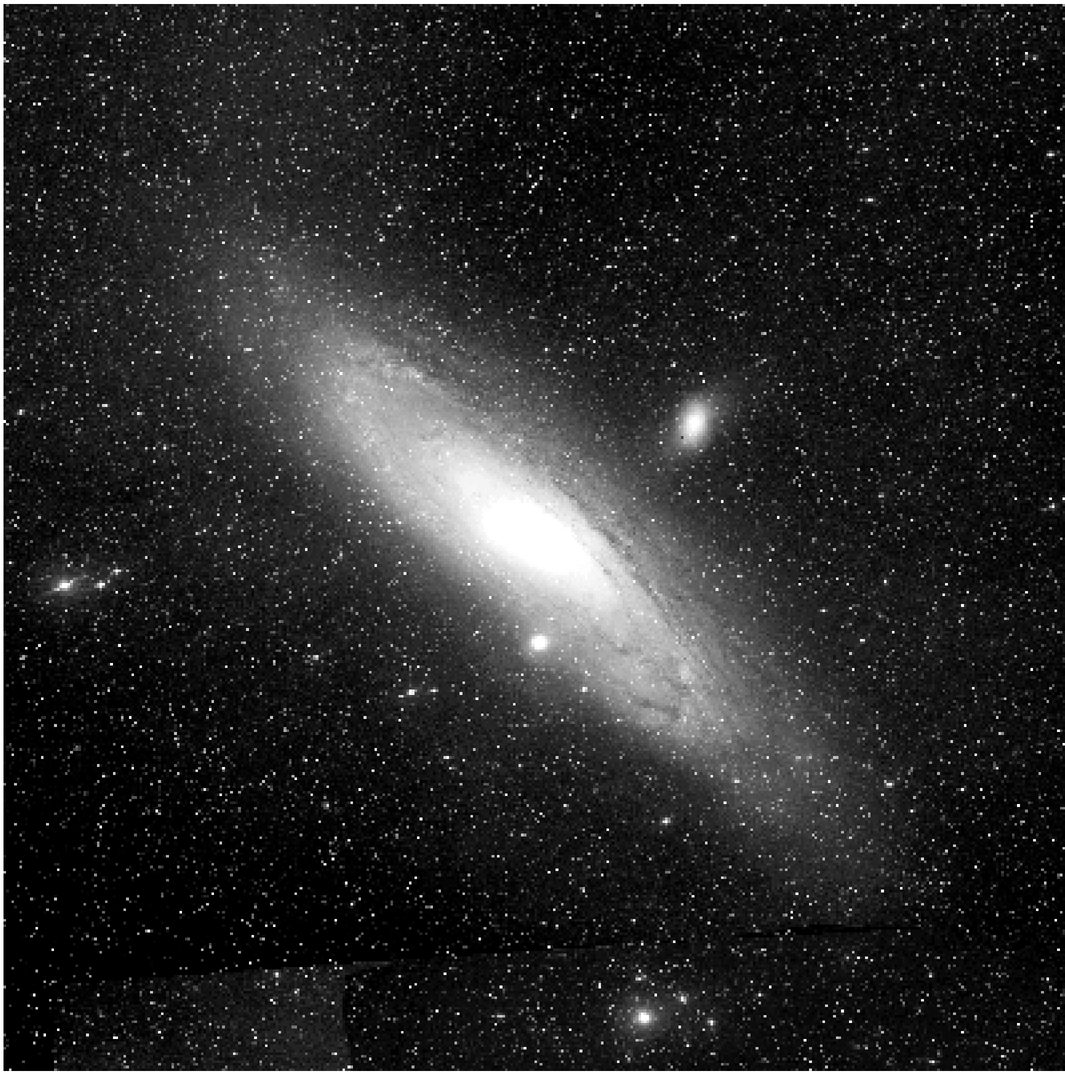
Uranus 47



Neptune 48

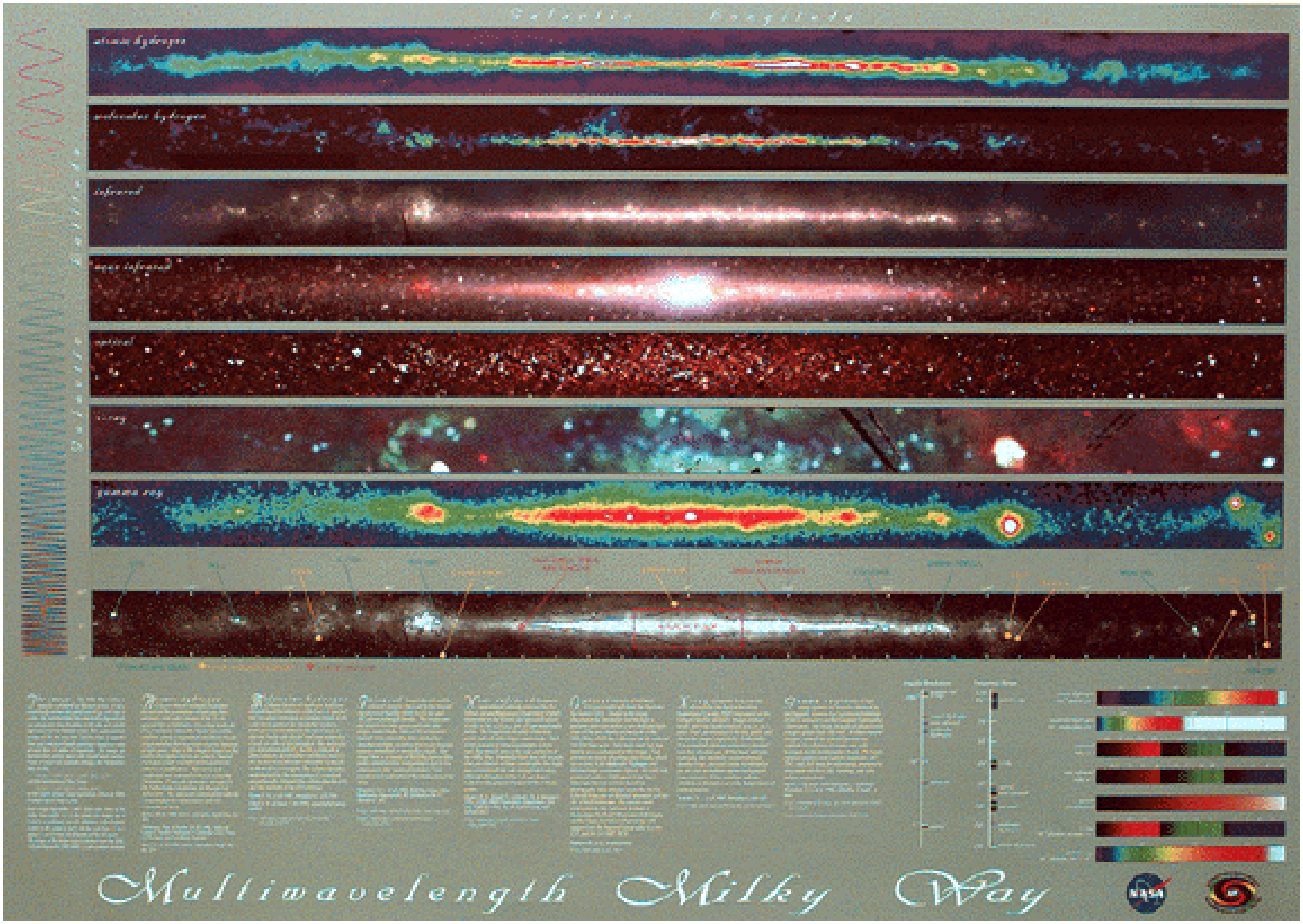


Pluto 49



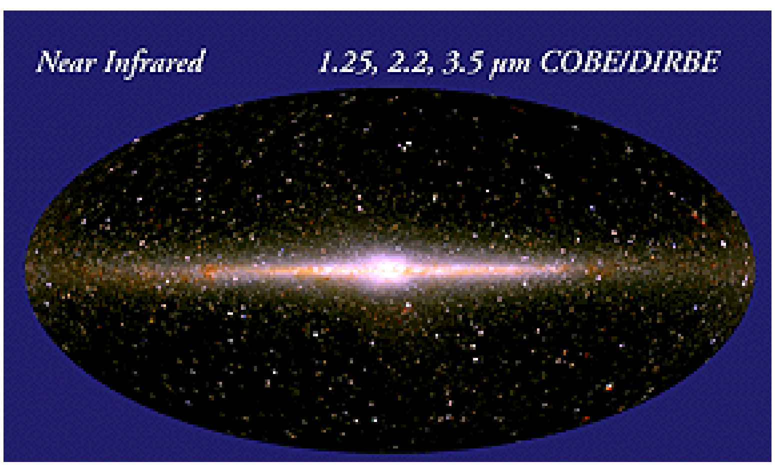
Andromeda 50

Andromeda and Satellite Galaxies M32 and M110 51



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

(Visit Web site to get a free copy of this poster of the Milky Way Galaxy in Multiwavelength)



Milky Way 52

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Web Sites

For more information about Scaling:

Powers of ten : a book about the relative size of things in the universe and the effect of adding another zero / by Philip and Phylis Morrison and the Office of Charles and Ray Eames PUBLICATION: [Redding, Conn.] : Scientific American Library ; N.Y Distributed by W.H. Freeman, c1982.

"Based on the film Powers of ten by the Office of Charles and Ray Eames."

Web Sites containing additional resources with descriptions

For excellent Planetary images:

1. http://spacelink.nasa.gov/Instructional.Materials/Curriculum.Support/Space.Science/.index.html
2. http://nssdc.gsfc.nasa.gov/imgcat/
3. http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Solar.System.Lithograph.Set/

An entire "Astonomy Magazine":

4. www.kalmbach.com/astro/astronomy.html

The Astronomical Society of the Pacific's Web Page:

5. www.aspsky.org

The Comet Halebopp's Home Page:

6. www.halebopp.com

A page where you can estimate Limiting Magnitude:

7. www.seds.org/billa/lm/rjm.html

An excellent page that discusses virtually every aspect of astronomy:

8. www.skypub.com

Excellent information about constellations and their stars:

9. www.astro.wisc.edu/~dolan/constellations/constellations.html

More information about Parallax:

10. http://sim.jpl.nasa.gov/science/parallax.html

A well-organized page of astrophysics links:

11. www.atm.dal.ca/~andromed

Some astrophysics links of interest:

12. www.maths.monash.edu.au/~johnl/Astro/astrolinks.html

    Los Angeles' Astronomical Society's library of astrophysics information:
13. www.laas.org/www.html

    Space Telescope Science Institute's Online Activities Page:
14. http://oposite.stsci.edu/pubinfo/education/amazing-space/light/welcome.html

    Online Astronomy Labs including a more techical SN Light Curve Lab:
15. http://www.deepspace.ucsb.edu/labs/pclabs/index.htm

    Free Downloadable Astronomy Software from Astronomy Today:
16. http://www.prenhall.com/cgi-bin/divisions/esm/chaisson/chaissonpick.pl

    PBS Online's Mysteries of Deep Space Classroom Activities:
17. http://www.pbs.org/deepspace/classroom/index.html

    PBS Online's Mysteries of Deep Space Interactive Timeline from Big Bang to 10^{100} years in the future:
18. http://www.pbs.org/deepspace/timeline/index.html

    Astronomy Today's Other Resources:
19. http://www.prenhall.com/cgi-bin/divisions/esm/chaisson/chaissonpick.pl

    Cosmos in a computer, Lots of movies and simulations:
20. http://www.ncsa.uiuc.edu/Cyberia/Cosmos/CosmosCompHome.html

    Lecture Notes for Stellar Spectra:
21. http://zebu.uoregon.edu/~imamura/208/jan18/jan18.html

    Lecture Notes for Kirchoff's Laws:
22. http://zebu.uoregon.edu/~imamura/208/jan18/kirchhoff.html

    A list of interesting downloadable Astronomy Programs:
23. http://www.fourmilab.ch/index.html

    Davison Soper's page on Luminosity:
24. http://zebu.uoregon.edu/~soper/Light/luminosity.html

    A Biography and other resources on Edwin Hubble:
25. http://www.astro.virginia.edu/~eww6n/bios/Hubble.html

    Another online lab for Hubble's Constant:
26. http://www.ucolick.org/~dennis/hubble.html

    Online Hertzsprung-Russell Diagram:

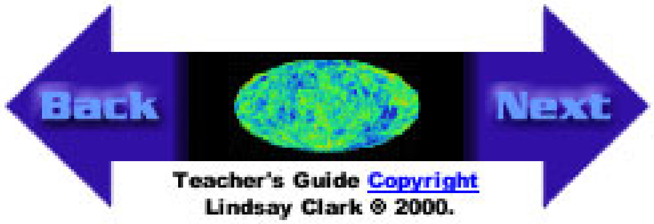
27. http://www.telescope.org/btl/lc4.html

    Downloadable programs forexcellent Astronomy Labs

28. http://www.gettysburg.edu/project/physics/clea/CLEAsoft.overview.html

Youth Books about the Big Bang

Asimov, Isaac. The Birth of the Universe. Milwakee, Wisc.:Gareth Stevens Publishing, 1995.
Couper, Heather. The Big Bang. NY, NY: DK Publishing, 1997.
Darling, David J. The Universe Past, Present and Future. Minneapolis, MN:Dillon Press, 1985.
Hawkes, Nigel. Mysteries of the Universe. Brookefield, Conn:Copper BeechBooks, 1995.
Ruiz, Andres Llamas. The Origin of the Universe. NY, NY:Sterling Publishing Co., 1996.



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Works Consulted

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Books and Articles

Abell, Geore O., Morrison, David, and Wolff, Sidney C.. Realm of the Universe. Saunders College Publishing, Fort Worth, TX:1994.

Berman, Louis and Evans, J. C.. Exploring the Cosmos. Little, Brown and Company, Boston:1986.

Chaisson, Eric and McMillan, Steve. Astronomy Today. Prentice Hall, Englewood Cliffs, NJ:1993.

De Vaucouleurs, G. The Cosmic Distance Scale and Hubble Constant. Australian National University, Canberra:1982.

Kauffman, William J. III. Universe. W. H. Freeman and Company, New York:1994.

Lemonick, Michael D.. The Light at the Edge of the Universe. Princeton University Press, Princeton, NJ:1993.

Pasachoff, Jay M.. Astronomy:From the Earth to the Universe. Saunders College Publishing, Philidelphia, Penn.:1991.

Peebles, P. J. E.. Principles of Physical Cosmology. Princeton University Press, Princeton, NJ:1993.

Riess, Adam G, Kirshner, Robert P., et all BVRI Light Curves for 22 Type Ia Supernovae. ApJ: 1998.

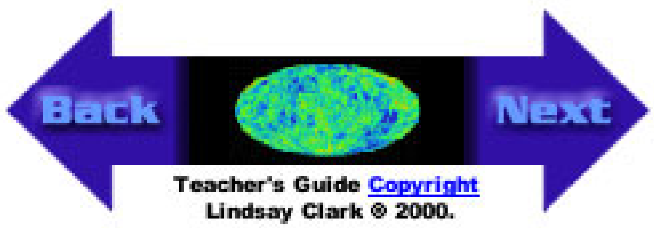
Shu, Frank H.. The Physical Universe An Introduction to Astronomy. University Science Books, Sausalito, CA:1982.

Silk, Joeseph. A Short History of the Universe. Scientific American Librairy, New York:1994.

Thurston, Wiiliam P. Three dimensional geometry and topology edited by Silvio Levy, Princeton University Press, Princeton, NJ: 1997.

Trimble, Virginia. "The 1920 Shapley-Curtis Discussion: Background, Issues, and Aftermath" Publications of the Astronomical Society of the Pacific 107: 1133-1144, 1995 December.

Wilson, Robert. Astronomy Through The Ages. Princeton University Press, Princeton, NJ:1997.



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Web Sites

Unless otherwise noted links on this page and throughout the document were verified 5/98.

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

http://antwrp.gsfc.nasa.gov/apod/lib/local_group.html

http://antwrp.gsfc.nasa.gov/apod/lib/local_group.html

http://beast.as.arizona.edu/cgi/figure.plx?CH=05&NUM=11

http://beast.as.arizona.edu/cgi/figure.plx?CH=26&NUM=07

http://cossc.gsfc.nasa.gov/diamond_jubilee/d_1996/hub_1929.html

http://einstein.uhh.hawaii.edu/spacegrant/lab2/measure.htm

http://imagine.gsfc.nasa.gov/docs/science/know_12/supernovae.html 5/3/99

http://hermes.astro.washington.edu/mirrors/nineplanets

http://oposite.stsci.edu/pubinfor/hrtemp/96-22a.jpg 5/3/99

http://physics7.berkeley.edu/darkmat/dopplershift.html

http://seds.lpl.arizona.edu/messier/m/m023.html

http://seds.lpl.arizona.edu/messier/m/m031.html

http://seds.lpl.arizona.edu/messier/m/m032.html

http://sunearth.gsfc.nasa.gov/eclipse/LEphoto/LEgallery.html 5/3/99

http://violet.pha.jhu.edu/~wpb/scale.html

http://violet.pha.jhu.edu/~wpb/spectroscopy/spec_home.html

http://www.astro.ucla.edu/~wright/doppler.htm

http://www.debsdomicile.com/eclipse.htm 5/3/99

http://www.eia.brad.ac.uk/btl/gy9.html

http://www.injersey.com/Education/NJDOE/

http://www.injersey.com/Education/NJDOE/01intro.html http://www.injersey.com/Education/NJDOE/10scistan5_11.html

http://www.nap.edu/readingroom/books/nses/htmlp.2

http://www.th.physik.uni-frankfurt.de/~jr/gif/phys/einstein_tongue 5/3/99

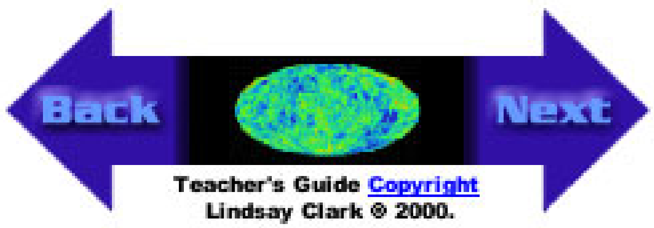
http://www.seds.org/billa/dssm/m31.html

http://www.seds.org/messier/large/m31.gif

http://www.seds.org/messier/more/local.html

http://zebu.uoregon.edu/~soper/Light/doppler.html

http://zebu.uoregon.edu/~soper/Light/doppler.html



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2. Ibid., -- Back

3. Ibid., -- Back

4. Ibid., -- Back

5. http://www.injersey.com/Education/NJDOE/10scistan5_11.html -- Back

6. http://www.injersey.com/Education/NJDOE/ -- Back

7. http://www.nap.edu/readingroom/books/nses/html p.2 -- Back

8. For more information and lots of photos of Local Group Members see http://www.seds.org/messier/more/local.html and http://antwrp.gsfc.nasa.gov/apod/lib/local_group.html -- Back

9. http://violet.pha.jhu.edu/~wpb/scale.html -- Back

10. Wilson, 1997 p.95 -- Back

11. http://sim.jpl.nasa.gov/science/parallax.html -- Back

12. For more information on a typical spiral galaxy see http://seds.lpl.arizona.edu/messier/m/m031.html -- Back

13. For more information on a typical elliptical galaxy see http://seds.lpl.arizona.edu/messier/m/m032.html -- Back

14. For more information on a typical barred spiral galaxy see http://www.eia.brad.ac.uk/btl/gy9.html -- Back

15. Kauffman, 1994 p.338 -- Back

17. For an excellent discussion of light as electromagnetic radiation and what we can learn from it see http://violet.pha.jhu.edu/~wpb/spectroscopy/spec_home.html -- Back

21. For further discussion, on how this discovery was made, see later lessons on the expanding universe. -- Back

22. The speed of light is 3 X 10^8 m/s, The value of the Hubble Constant however is still a topic of current debate, but for

the purposes of these exercises use the value 50 km s^{-1} Mpc^{-1} -- Back

23. http://oposite.stsci.edu/pubinfo/hrtemp/96-22a.jpg -- Back

24. http://imagine.gsfc.nasa.gov/docs/science/know_l2/supernovae.html -- Back

25. Kauffman, 1994 p.527 -- Back

26. Shu, 1982 p.286 -- Back

27. Trimble, Virginia. "The 1920 Shapley-Curtis Discussion: Background, Issues, and Aftermath" Publications of the Astronomical Society of the Pacific 107: 1133-1144, 1995 December -- Back

28. http://cossc.gsfc.nasa.gov/diamond_jubilee/d_1996/hub_1929.html -- Back

29. http://seds.lpl.arizona.edu/messier/m/m023.html -- Back

30. Ibid., -- Back

31. This idea was obtained through discussion with Neil Tyson, Visiting Lecturer of Astrophysics at Princeton University, who attributed the idea to Steve Soter at the American Museum of Natural History. -- Back

32. This idea was obtained through discussion with David Spergel, Professor of Astrophysics at Princeton University. -- Back

33. Thanks to Neil Cornish for hypertri.ps. -- Back

35. (Riess, Adam G., Kirshner, Robert P., et all ApJ, 1998) astro-ph 9810291 http://xxx.lanl.gov/format/astro-ph/9810291 -- Back

36. http://starchild.gsfc.nasa.gov/docs/StarChild/questions/question6.html -- Back

37. http://sunearth.gsfc.nasa.gov/eclipse/LEphoto/LEgallery.html -- Back

38. Thurston, 1997 p. 51 -- Back

39. http://www.th.physik.uni-frankfurt.de/~jr/gif/phs/einstein_tongue -- Back

40. http://hermes.astro.washington.edu/mirrors/nineplanets -- Back

41. Ibid., -- Back

42. Ibid., -- Back

43. Ibid., -- Back

44. Ibid., -- Back

45. Ibid., -- Back

46. Ibid., -- Back

47. Ibid., -- Back

48. Ibid., -- Back

49. Ibid., -- Back

50. http://www.seds.org/billa/dssm/m31.html -- Back

51. http://www.seds.org/messier/large/m31.gif -- Back

52. http://adc.gsfc.nasa.gov/mw/allsky.html -- Back

53. http://spaceart.com/solar/cap/misc/ss.htm -- Back

54. Image was modified from its original STScI Digitized Sky Survey format. -- Back

Lindsay M. Clark

Introduction Section:

I am currently an Educator in Formal Programs at Adler Planetarium & Astronomy Museum in Chicago, IL.

I am also the Education/Outreach Coordinator for the Microwave Anisotropy Probe (MAP), a NASA Satellite Mission.

I recently graduated with Honors from Princeton University with an A.B. in Astrophysical Sciences and a certificate in the Program of Teacher Preparation. I graduated in Spring of 1999, but finished my teaching certificate the following fall by student teaching for a semester.

Prior to my time here at Princeton, I spent the first 18 years of my life growing up in Baltimore, Md where I attended and graduated cum laude from The Bryn Mawr School in Baltimore.

As if all this isn't enough to keep me busy I spend a great deal of time dancing (ballet, jazz, modern and tap) and am currently dancing with a student run group called BodyHype at Princeton.
I also perform with student groups

- Princeton University Players
- The Princeton Triangle Club

and am a member of one of Princeton's oddly famous eating clubs,

- The Princeton Tower Club

If you want a more formal description of my life work I finally bit the bullet and wrote a RESUME!

Please visit the efforts of my most time consuming occupation:
A Teacher's Guide to the Universe:
Cosmology Lesson Plans for High School Teachers